Plan

Survey Management Plan: Individual Surveys

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Change Record

Issue	Date	Page, Section, Paragraph Affected	Reason, Remarks
0.01	2023-08-23	All	New document
0.02	2023-10-02	All	Input from all Surveys using Google Doc version
0.03	2023-10-14	All	Final checks by PSs and dPSs, cleaned formatting, updated acronym list
1.00	2023-10-16	Formatted for release	Released version
1.01	2024-07-19	All	Addressing RIXes of review panel
1.02	2024-07-22		All changes accepted to get rid of cross-reference errors. Prepared for release.
2.00	2024-07-22	S17 updates	Released version
3.00	2024-10-17	Many small edits throughout, updates to DL2-SURV status and updated table in Section 7.	Released version
3.01	2025-05-09	Sect. 6.4, 6.8, 6.9, 6.11, 6.12	Updates reflecting the new baseline simulations.
4.00	2025-05-19	Small edits to refer to correct web sites, edit some contributor roles	Released version

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1 Scope

This document describes the detailed Survey Management Plans of the individual Surveys that will be conducted during the first five years of operations of 4MOST. It describes in more detail the management aspects of the individual Surveys in the 4MOST Project, highlighting in particular those aspects where a Survey deviates from the general plan in terms of target scheduling, data analysis and data products, and/or data publication schedule. A summary is provided in Section 7 at the end of the document of all Survey deliverable L2 data products (DL2-SURV). This document should be read in conjunction with the accompanying Survey Management Plan documents on the Organisation, the Front-end Operations and the Back-end Operations. The figures and tables in this document should be considered representative of the intention of the different Surveys, but the actual implementation may change in particular details up to the last moment before the start of the survey based on further optimisation of the survey strategy and experience gained on the actual performance of the 4MOST instrument during Commissioning and Science Programme Verification phases before the start of the survey.

2 Applicable Documents (AD)

The following applicable documents (AD) of the exact issue shown form a part of this document to the extent described herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document are the superseding requirement.

AD ID	Document Title	Document Number	Issue	Date
[AD1]				
[AD2]				
[AD3]				

3 Reference Documents (RD)

The following reference documents (RD) contain useful information relevant to the subject of the present document.

RD ID	Document Title	Document Number	Issue	Date
[RD1]	Data Release Plan	VIS-PLA-4MOST-47110-9210-0003	3.00	2024-10-17
[RD2]	4MOST Survey Management Plan – Organisation	VIS-PLA-4MOST-47110-9220-0001	3.00	2024-10-17
[RD3]	4MOST Survey Management Plan – Front-end Operations	VIS-PLA-4MOST-47110-9220-0002	3.00	2024-10-08
[RD4]	4MOST Survey Management Plan – Back-end Operations	VIS-PLA-4MOST-47110-9220-0003	3.00	2024-10-15
[RD5]	Science Team Policies	VIS-POL-4MOST-47110-9213-0001	7.00	2024-10-13
[RD6]	Operations Plan	VIS-PLA-4MOST-47110-9720-0001	5.00	2019-09-24

RD ID	Document Title	Document Number	Issue	Date
[RD7]	4MOST Science Management Plan	VIS-PLA-4MOST-47110-9210-0001	3.00	2024-07-03
[RD8]	Science Policy ICD	ESO-287481	1.00	2018-11-12
[RD9]	ESO Science Data Product Standard	ESO-044286	8	2022-03-15
[RD10]	4MOST SMP: Survey Simulation Prediction	https://www.eso.org/sci/observing/PublicSurveys/4MOSTsmp.html	1.00	2025-05-12

4 Definitions

- **Data levels**:
  - Level 0: Raw data with associated meta-data
  - Level 1: Calibrated 1D spectra, catalogue of targeted objects
  - Level 2: Derived scientific parameters, e.g., elemental abundances, redshifts, selection functions, etc.
- **L2 Data Release Products**
  - DL2 or DL2-IWG: ESO Deliverable-L2 products generated by the common 4MOST pipelines of the IWGs on the agreed schedule in the Data Release Plan .
  - DL2-SURV: ESO Deliverable-L2 products generated by a dedicated pipeline developed by a Survey to be delivered to ESO Science Archive Facility (SAF) on a previously agreed schedule.
  - AL2-IWG: Additional Data Product that will be generated by an IWG on a best effort basis and will only be delivered to the 4PA on a flexible schedule.
  - AL2-SURV: Additional Data Product that will be generated by a Survey on a best effort basis and will only be delivered to the 4PA on a flexible schedule.

5 Pre-amble

An efficient use of 4MOST is maximal if the Consortium's surveys and all other approved Participating Community Surveys are executed in parallel observing mode (ESO-287481, [RD8]). Parallel observing mode means that targets from several surveys (Consortium and Participating Community Surveys) with clearly different target classes and science aims are targeted simultaneously by different fibres of the 4MOST instrument.

Consortium and Participating Community Surveys will join a common Science Team and this document is part of a series of documents that together provide a coherent and unique Survey Management Plan (SMP). The other documents are:

- *4MOST SMP: Organisation* [RD2] containing the organisational structure of the project including conflict resolution pathways, the work-flow and data-flow concepts, the work breakdown structure, and the schedule including data releases.
- *4MOST SMP: Front-end Operations* [RD3] describing the survey strategy concept, the front-end operations plan including the feedback loop, special survey strategy considerations like deep fields and poor observing conditions program, and the calibration plan.

- *4MOST SMP: Back-end Operations* [RD4] describing the back-end process with an overview of the hardware required, the creation and quality control of L0, L1, L2 data, and the overall quality control and data delivery, archiving, and publishing process.
- *4MOST SMP: Survey Simulation Prediction* [RD10] a restricted access web site showing the input catalogues and simulation predictions for both the overall survey as well as for the individual (sub-)Surveys. The web site is available here: https://www.eso.org/sci/observing/PublicSurveys/4MOSTsmp.html
  Even though this current document below contains plots showing sky distributions and calculated exposure time plots of the input catalogues, please refer to the web site to see the latest status of the catalogues.

Please note that the FTEs contributions of Surveys to the IWGs listed in this document are the same as the ones listed in the Front-end [RD3] and Back-end documents [RD4] and should not be considered additional resources.

In agreement with the Science Team Policies ([RD5], ESO-286592), the 4MOST PI will represent the full Science Team towards ESO and is responsible for the delivery of the 4MOST survey programme. The joint SMP documents should capture the full details of the delivery of one dimensional, calibrated, science-ready spectra extracted from the raw data, which are in common to all surveys (Level-1 data), as well the delivery of the additional science products that may differ from survey to survey, including further processed Level-1, aka stacked 1D spectra to different depth/sensitivities, and the Level-2 data, aka catalogues of physical measurements for the targeted objects/science aims.

Both Level-1 and Level-2 data will be ingested into the ESO Archive and shall adhere to the ESO Science Data Product Standard (ESO-044286, [RD9]).

The 4MOST Survey Management Plan will be made public via the ESO Public surveys web pages.

6 Individual surveys

6.1 Survey 1 – The Milky Way Halo Low-Resolution Survey

Survey PIs: Else Starkenburg, C. Clare Worley

6.1.1 Science Summary

The goal of the Milky Way halo low-resolution survey is to study the formation and evolution of the Galactic halo to deduce its assembly history and the 3D distribution of mass in the Galaxy. The combination of multi-band photometry, Gaia proper motion (and parallax) data, together with radial velocities and overall metallicity and abundance information, obtained from low spectral resolution data of halo giants with 4MOST, will yield an unprecedented characterization of the Galactic Halo and its interface with the Galactic thick disk. The survey will produce a (volume and magnitude) complete sample of halo giants covering at least 10,000 square degrees of high latitude sky, and measure their line-of-sight velocities with a precision of 1-2 km/s as well as their metallicities to better than 0.2 dex precision. Not only will this allow us to retrieve the history and dynamical evolution of this component of our Galaxy, but will also lead to strong constraints on cosmological models from, for example, the lumpiness of the dark matter halo and a detailed assessment of the amount and type of mergers the Galaxy has experienced. As a by-product of determining the metallicity distribution function across the halo, a significant sample of extremely metal-poor stars will also be identified for further more detailed follow up.

This science case is covered in SubSurvey(s):

- S0101 – HaloLR_giants

Expanded science description: messenger-no175-23-25.pdf

Merged Science Programme:

4GRoundS will measure the radial velocities and metallicities of southern RR Lyrae detected by Gaia DR3. These stars have excellent photometric distances, allowing the exquisite Gaia proper motions to be converted into physically-useful transverse velocities. Armed with the missing radial velocity, 4GRoundS will provide the community a dataset that will enable studies of the orbital structure of the halo and outer disk, and allow realistic modelling of these components. It will also enable the identification of coherent dynamically-cold streams. Together, these analyses will map the mass of the Milky Way out to 100 kpc and test models of the dark sector.

This science case is covered in SubSurvey(s):

- S0102 – RRLyrae_LR

Expanded science description: messenger-no190-10-12.pdf

6.1.2 Target Catalogues

S0101 – HaloLR_giants

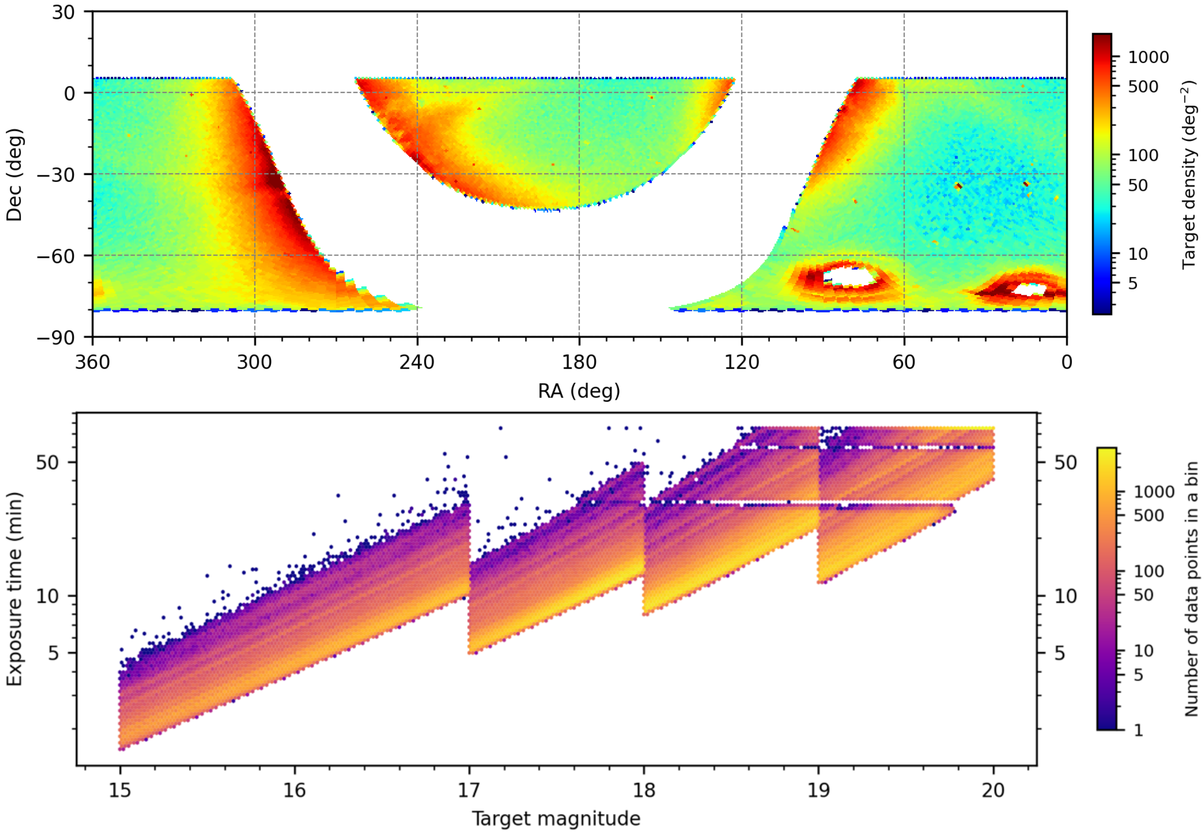


Figure 1: Top) Input target distribution of the S0101 Halo LR Giants subsurvey. Bottom) The exposure time estimates as function of target G-mag (S1 plots as of upload 2023-05-15)

The input targets' sky coverage of S0101 is displayed in Figure 1, for which the selection covers -80º<Dec<+5º and is avoiding the Galactic disk and inner Magellanic Clouds regions. The requested completeness value for this subsurvey is 60% and the required area to be observed is 15,000 deg^2. S/N requirements are >10, 15, 20, 30 (depending on target magnitude) in both 5125.0–5225.0 Å and 8475.0–8675.0 Å wavelength regions, with resulting exposure time estimates also displayed in Figure 1. S0101 has no cadencing requirements, but will use any cadencing obtained "for free" to detect radial velocity binaries. The Scientific FoM tracks the LSM x SSM of targets.

S0102 – RRLyrae_LR

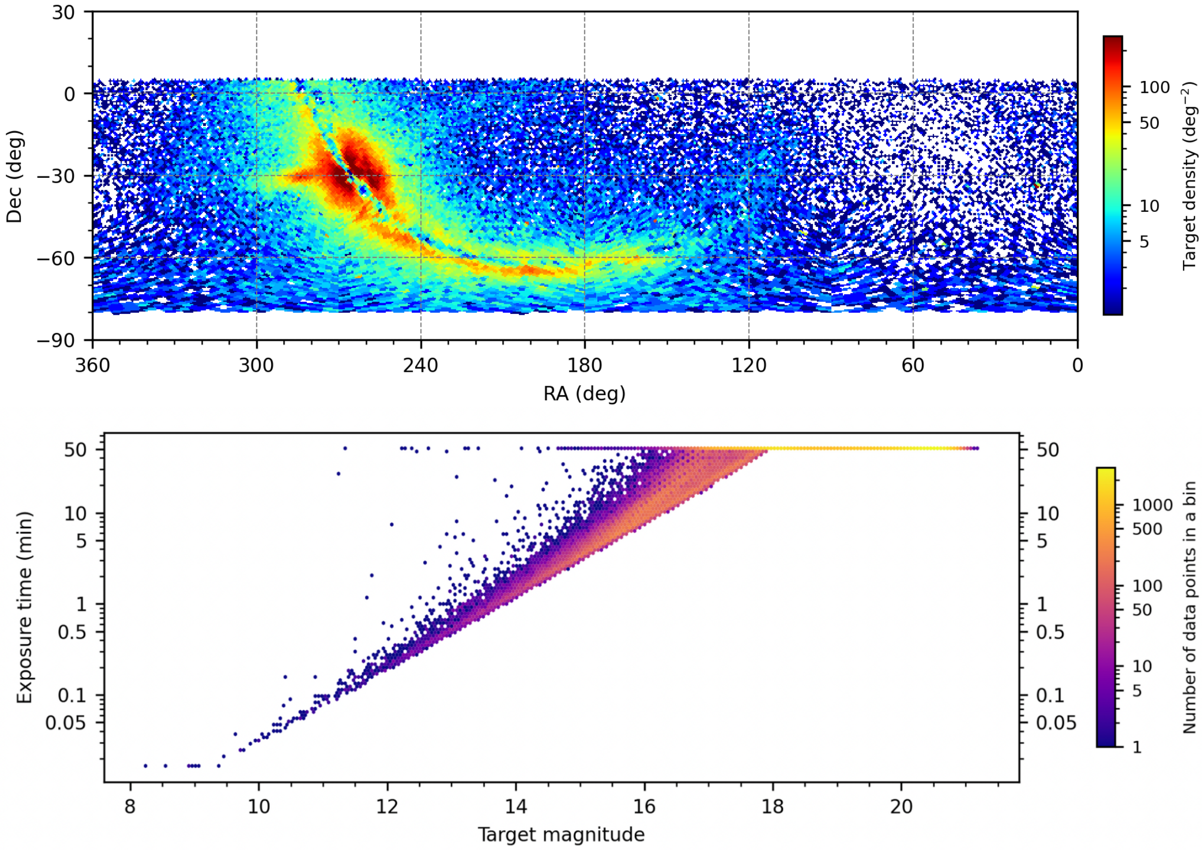


Figure 2: Top) Input target distribution of the S0102 RR Lyrae LR subsurvey. Bottom) The exposure time estimates as function of target G-mag

The input target sky coverage of S0102 is displayed in Figure 2, essentially -80º<Dec<+5º all sky coverage with a concentration towards the Milky Way bulge and the Sagittarius Dwarf. The requested completeness for this subsurvey of 60% and the required area to be observed 20,000 deg^2. S/N requirements are >=50 in the 4200.0–5000.0Å wavelength region, with resulting exposure time estimates also displayed in Figure 2. As RR Lyrae have a significant short timescale radial velocity variation depending on their pulsation phase, we are placing no constraints on the cadence of the observations for ease of scheduling. The Scientific FoM tracks the LSM x SSM of targets.

S1 Summary

Table 1: Key parameters of the input target catalogue of the S1 Survey

N	Sub	Name	Res	Cadence	Date earliest Date latest	RA range DEC range	Epoch	TMAX [min]	AREQ [deg^2]	Fcom	FH_D [kH]	FH_G [kH]	FH_B [kH]	FH_S [kH]	N targets
1	S0101	HaloLR_giants	LR	(0, 0, 0, 0)	59945.5 – 59945.5 62501.5 – 62501.5	0.0 – 360.0 -80.0 – 5.0	2016.0	120 (G)	15000	0.598	538	591	1073	1996	2399311
2	S0102	RRLyrae_LR	LR	(0, 0, 0, 0)	59945.5 – 59945.5 62501.5 – 62501.5	0.0 – 360.0 -80.0 – 5.0	2016.0	60 (G)	20000	0.598	98.3	99.5	98.6	99.1	183159

The S1 Survey aims to observe red halo giant stars and RR Lyrae stars over a large fraction of the sky, which does not necessarily need to be in contiguous areas. Being a large area Survey with a moderately low completeness requirement, weather variations over the 5-year period will have no significant impact. The key input parameters of the S1 target catalogue are listed in Table 1.

6.1.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.1.4 Management Structure

The overall management of S1 is provided by the Survey PIs. The MW Halo Giants section of the Survey is also managed by the Survey PIs (Starkenburg, Worley), while the RR Lyrae section of the Survey is managed by the RR Lyrae subsurvey Lead (Ibata).

A description of the different WGs within S1 is described in Section 6.1.5 with the FTE contributions to the different internal WGs listed in Section 6.1.9 and the contributions to the 4MOST common IWGs listed in Section 6.1.6. More specifically, the full effort in WP 2.2.1.5 (Calibration Samples) and WP 2.2.1.6 (Quality Control) is directed towards the IWGs (4,3,6,7,9), while half of the effort in WP 2.2.1.4 (Cross-Survey Science), WP 2.2.1.1.0 (Milky Way Halo Survey) and WP 2.2.1.1.1 (4GRoundS) is directed towards those IWGs.

The contributions to the IWGs includes effort on (~2 FTE/yr):

- defining calibration samples
- defining test samples for OpRs
- inspecting the L1 and L2 data as part of quality control
- working with the IWGs on key analyses (e.g. ages, distances, RV precision, viability of processing RR Lyrae through standard pipeline).

For S1 internally, the full effort in WP 2.2.1.2 (Management) and WP 2.2.1.3 (Catalogue Creation) is directed towards the S1 specific work, while half of the effort in WP 2.2.1.4 (Cross-Survey Science), WP 2.2.1.1.0 (Milky Way Halo Survey) and WP 2.2.1.1.1 (4GRoundS) is also directed towards the S1 specific work. This effort includes (~2 FTE/yr):

- Management of team meetings and monitoring of work in WPs
- Catalogue preparation and submission
- 4FS simulation inspection to understand fibre hours, cross-survey effects and sky coverage.
- Development and implementation of code for classification of MW halo members
- working with the other surveys on in-common analyses (e.g. ages, distances, halo membership, RV precision).
- Development and implementation of the machine learning procedure to provide radial velocities as well as chemistry for the RR Lyrae where possible

For the MW Halo Giants section of the Survey, S1 is planning to use the tools, procedures, and available hardware of the common IWGs.

For the 4GRoundS RR Lyrae section of the Survey, the plan is that the stars will be processed through the standard pipeline of 4GP, but specialist software will also be developed that will result in DL2-SURV measurements to be delivered to ESO via 4PA for the final 4MOST data release. The results from the standard pipeline of 4GP will be AL2-SURV measurements that will be delivered to 4PA only and also only for the final 4MOST data release.

6.1.5 Work-breakdown structure

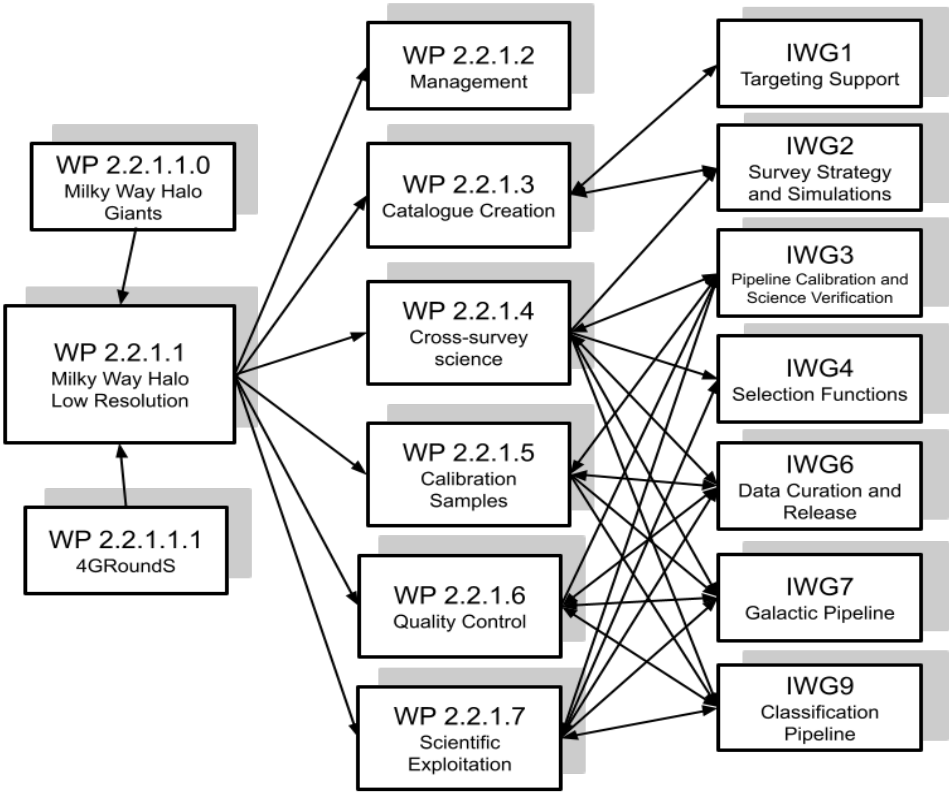


Figure 3: Work Breakdown Structure for Survey S1

S1 consists of two main sub-surveys and - because of the way these two were merged as community and consortium surveys - two sub-teams. These two are described in the work packages 2.2.1.0 and 2.2.1.1 as these are real entities. However, for the purpose of communication and interfaces with the IWGs, as well as the final coordination of our science goals, our survey works as one team, and this is reflected in the WBS above.

WP 2.2.1.1.0: Coordination of the halo survey of giants (mainly, the survey does include some other target types as well, but they are selected in the same way). The goal of this WP is to identify streams and substructures using giants to study the Milky Way, its history, and constrain the dark matter properties.

WP 2.2.1.1.1: Coordination of the 4GRoundS - RR Lyrae Survey. The goal of this WP is to identify streams using RR Lyrae to constrain dark matter properties inside the Milky Way. This specific target type brings accurate distances to large distances, something that is missing for other target types.

WP 2.2.1.2: This WP provides the management and direction of S1 as follows:

- ensuring the team meets regularly (see minutes at https://ds-web.aip.de/docushare/dsweb/View/Collection-4835)
- providing representation on the SCB
- ensuring S1 representation on IWGs, at AHM etc
- ensuring the membership list is kept up to date (https://www.4most.eu/4mostauth/survey_detail/1/)
- ensuring text relating to S1 on the 4MOST webpage is kept up to date (https://www.4most.eu/cms/science/galactic-consortium-surveys/)

- overseeing the definition of S1 policies regarding membership and contribution for co-authorship – this cannot conflict with SCB policies.
- overseeing the definition and progress of the scientific projects

This is led by the Co-PIs of S1.

WP 2.2.1.3: The WP is responsible for the creation of the S1 catalogue including the targets from WP 2.2.1.4 and making the catalogues available to the S1 members. In particular, it provides representation on IWG1 and IWG2.

It is responsible for

- ensuring catalogue is on Gaia reference frame (currently DR3)
- preparing and submitting the catalogue to 4FS
  - main survey S0101
  - RR Lyrae/4GRoundS S0102
- review and analysis of simulations from IWG2 including
  - monitoring the fibre-hour allocation outcomes
  - impact of shared targets
  - impact of downsampling
- Reviewing and implementing catalogue updates
  - integration of community survey targets (i.e. WP 2.2.1.4)
  - consideration of HR and LR targets
  - refinement/cleaning of target selection (e.g. removing non-RR Lyrae stars from WP 2.2.1.4 target list)
  - cadencing:
    - No requirements, a "goal" to have multiple observations of the same field at least a year apart - if possible - for the main survey and for the RRLyrae survey

WP 2.2.1.4: Coordinating collaboration with the other Surveys with overlapping science goals (e.g. S3-11 LR disk and bulge survey, low metallicity targets sub-survey, S9 - Magellanic Clouds). This includes work in IWG7 that is focussed on specific targets only relevant to us and a few other surveys (examples are A- and M- type targets across some of the Galactic surveys).

WP 2.2.1.5: Defining S1 requirements on calibrations samples and coordinating feedback from S1 on Calibration Samples proposed and their output products via IWG3 and IWG7.

WP 2.2.1.6: Defining S1 requirements on Quality Control of S1 data, reviewing data distributed by the QCS/IWG6, providing feedback to QCS/IWG6.

WP 2.2.1.7: Scientific Exploration of the 4MOST data for the purpose of the scientific goals as outlined in the White Papers (see [RD1] and [RD2]).

6.1.6 Contribution to the Infrastructure Working Groups

IWG1

S1 takes an active role in S1, currently we lead the working group on sky fibre placement (by Tadafumi Matsuno).

IWG2

The representative for S1, currently Mike Irwin, is responsible for the upload of the S1 catalogues and so attends the IWG2 meetings and gives feedback on simulations and the upload process. He is involved in several IWG2 work packages.

Rodrigo Ibata (PI of 4GRoundS) is also a member, specifically to represent the 4GRoundS sub-survey.

The S1 PIs are also members of the working group, not generally attending all meetings, but monitoring emails and results, and providing S1 feedback when requested.

IWG3

For S1, we provide feedback and selection criteria for the definition of the target lists for the various testing phases during commissioning. This includes requirements on measurements for the experiments in the SPV phase and targets for OpR4. The main S1 requested targets are also covered by requests from other main surveys. However, the RR Lyrae are a special case and S1, directed by 4GRoundS PI Rodrigo Ibata and in collaboration with the Bulge RR Lyrae survey must provide useful target lists for the OpR4 and SPV phases.
Marica Valentini (co-lead of this work package) and Guillaume Guiglion are currently representatives of our survey.

IWG4

S1 provides a good and active representation in this working group. S1 is contributing to the work as to how to define the object selection function and how it will be usefully used by the surveys. Currently, Sarah Martell, Else Starkenburg, Nicolas Martin, Sofia Feltzing and Diane Feuillet are all representatives for our survey. Sarah Martell used to lead the object selection function effort; this is now taken over by Sanjib Sharma.

IWG5

Many S1 members have expressed their interests in this work package, but at the moment not much activity has been taking place in this IWG.

IWG6

S1 is contributing to the definition of quality control tests for the L2 quality control pipeline (4QCP). S1 has quality criteria for the measurement of the radial velocities and the chemical abundances, so is contributing to the development of tests relating to the accuracy and precision of those values. Currently, Tadafumi Matsuno and Eduardo Balbinot represent S1 in IWG6.

IWG7

IWG7 is well staffed with S1 survey members: 15 S1 members are members of IWG7 as well, although not all as actively and some are representing multiple surveys. Most notably, Georges Kordopatis is co-lead of this IWG and a large effort is done from S1 on the assembly of an improved 4MOST line list for FGK stars (led by Martin Montelius).

IWG8

No S1 representatives are needed for this IWG, as we are a Galactic survey.

IWG9

We have active S1 representation in IWG9, currently Sergey Khoperskov is our representative.

6.1.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.1.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

All targets of Survey 1 will be processed by the 4GP/4CP/4SP pipelines and quality-controlled products will be delivered to 4PA and the ESO SAF.
In addition, the data products described in the following subsections will be provided.

6.1.8.1 Deliverable L2 Survey data: reduction processing

S0101 – HaloLR_giants

No extra DL2-SURV processing is required by this sub-survey within S1.

S0102 – RRLyrae_LR

This sub-survey will provide DL2-SURV data products of the following measurements

- Phase-corrected radial velocities
- stellar parameters (Teff, logg, [Fe/H])
- distance

These will be provided to ESO as a catalogue with all objects in the survey in the ESO-compliant DXU data format, though the Survey cannot commit to a delivery before DR3 due to the nature of the specialist survey analysis.
The specialist processing and analysis of the RR Lyrae will require the full supporting data that will be unlikely to be available before DR3, which will include LSST, Gaia DR4, Euclid, as well as overlaps with WEAVE. When the dataset becomes sufficiently large to allow a machine learning analysis (with 3 epochs of observation for >10,000 sources) it will be possible to develop the optimal strategy to correct the measurements given the spectra and the photometric variability information.
The machine learning algorithm will be designed to determine radial velocities and chemistry of the RR Lyrae, building on previous work by the team (Tenachi, Ibata, & Diakogiannis, 2023, arXiv230303192T). The spectra and associated meta-data of each target will be ingested, and the algorithm will be required to predict the stellar parameters, with RR Lyrae in common with the WEAVE survey serving as the training sample.
The Gaia DR3 identifiers will be stored at all steps of the analysis as an identifier that is complementary to the official unique identifier assigned by 4MOST, ensuring that there is no confusion among RR Lyrae targets and observations.
The RR Lyrae spectra will be also processed through the standard pipeline of 4GP. They will be delivered to ESO from DR1 onwards as DL2-IWG data products by IWG7, but will need to have additional uncertainty flags due to their RR Lyrae nature. The results from the standard pipeline will be used to inform on and compare to the specialist processing as it is developed.
The specialist processing will result in AL2-SURV and DL2-SURV data products. For delivery details see the relevant sections below.

6.1.8.2 Deliverable L2 Survey data: quality assessment

S0101 – HaloLR_giants

No extra DL2-SURV processing is required by this Survey.

S0102 – RRLyrae_LR

Since all RR Lyrae are targeted, many of the observed stars will belong to known structures (e.g. stellar streams) and will be used to test the efficacy of the software. The AL2-SURV products will be compared to literature values.
A further quality assessment will be possible using the results of the standard pipeline: thanks to the overlap with WEAVE, we will be able to measure the typical errors between the standard pipeline's results and the final WEAVE values. Thus, deviations in the final 4MOST parameters from the standard pipeline results will be used to identify possible analysis problems.

As there will be only one release of data, the quality control will be carried out as part of the software development to ensure the accuracy of the final release results.

6.1.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

S0101 – HaloLR_giants

No extra DL2-SURV processing is required by this Survey.

S0102 – RRLyrae_LR

DL2-SURV products will be derived by a specialist pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines which are developed to be ESO compliant. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.

Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.1.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

S0101 – HaloLR_giants

No extra DL2-SURV processing is required by this Survey.

S0102 – RRLyrae_LR

The results from the standard IWG7 pipeline of the S0102 targets will be delivered as part of the DL2-IWG data products from DR1.

The results from the RRLyrae specialist processing are aimed to be delivered to 4PA as AL2-SURV data products for DR2, but the Survey cannot commit to a DL2-SURV product until DR3, because the machine learning nature of the pipeline that requires large datasets with repeat observations. We will release the data products associated with a scientific publication at the next DR.

6.1.8.5 Deliverable L2 Survey data: Required hardware and staff

S0101 – HaloLR_giants

No extra DL2-SURV processing is required by this Survey.

S0102 – RRLyrae_LR

The hardware for the processing and analysis of the RR Lyrae is already available, as the 4GRoundS PI has a mini-cluster of 4 NVIDIA A100s GPUs and a mini-cluster of 16x48 core normal servers installed at his university's HPC. However, it is not expected that the processing will be computationally expensive by the standards of these machines.

It is expected that a minimum of 1FTE/year of effort is required, which will increase as the data are taken and become available to analyse.

Prior to the specialist processing being available, the RR Lyrae spectra will be processed using the standard pipeline of IWG7. 4GP will draw on the expertise of the RR Lyrae survey in the processing of these stars.

6.1.8.6 Additional L2 data: reduction processing

S0101 – HaloLR_giants

Currently, Rotational Velocity (vsini), stellar age and spectro-photometric distance are not yet implemented in the 4GP described in 4MOST Survey Management Plan – Back-end Operations [RD4]. S1 notes that the techniques to derive these parameters are still in rapid development and that S1 expects to collaborate with other Surveys to implement these parameters. These parameters are therefore currently AL2 products.
If joint software with other Surveys is developed, it will be in the 4GP framework, including delivery to ESO. They are not expected to be implemented for DR1, only later data releases.
If the software modules are not developed in the 4GP framework but are sufficiently developed otherwise, then these parameters will be delivered as DL2-SURV data products though not before DR2. We will release the data products associated with a scientific publication at the next DR.

S0102 – RRLyrae_LR

4GRoundS will carry out further specialised analysis of their RR Lyrae targets to measure specifically **[X/H], mass, age, radius** of the RR Lyrae. It will follow on from the process referenced above to produce the DL2-SURV products.
The AL2-SURV will only be delivered if they are determined to the required quality and accuracy, as depends on the precision of the DL2 parameters.
The RR Lyrae analysis is in principle very complicated due to the spectral dependence on phase. As described above in Section 6.1.8.1 for the DL2-SURV products, a machine learning algorithm will be built to determine radial velocities and chemistry of the RR Lyrae, using the WEAVE results as a reference. We will release the data products associated with a scientific publication at the next DR.

6.1.8.7 Additional L2 data: quality assessment

S0101 – HaloLR_giants

As described in the previous section, S1 aims to place the development of the extra parameters to be delivered in the 4GP framework, including quality assessment.

S0102 – RRLyrae_LR

The data quality assessment will be carried out as described in Section 6.2.8.2 as for the DL2-SURV data products. As there will be only one release of data, the quality control will be carried out as part of the software development to ensure the accuracy of the final release results.

6.1.8.8 Additional L2 data: data delivery and Phase 3 compliance

S0101 – HaloLR_giants

All data products are expected to be delivered through the 4GP workflow according to the schedule described in Section 6.12.

S0102 – RRLyrae_LR

Any AL2-SURV data productwill be delivered directly to 4PA and will be published by 4PA only. It will not be delivered via the 4OR.The data will be delivered as a FITS catalogue and meet the data product requirements of 4PA.
Each measurement shall have associated uncertainty, limit, and flag columns as appropriate.

6.1.8.9 Additional L2 data: product delivery schedule to the 4PA archive

S0101 – HaloLR_giants

All data products are expected to be delivered through the 4GP workflow according to the schedule described in Section 6.12.

S0102 – RRLyrae_LR

The AL2-SURV data products described here aim to be delivered to 4PA for DR2.

6.1.8.10 Additional L2 data: Required hardware and staff

The below outline the available hardware and staff effort to deal with the additional L2 data flow of S1.

S0101 – HaloLR_giants

All data products are expected to be delivered through the 4GP workflow according to the schedule described in Section 6.12.

S0102 – RRLyrae_LR

As for Section 6.2.8.5, the hardware for the processing and analysis of the RR Lyrae is already available as the 4GRoundS PI has a mini-cluster of 4 NVIDIA A100s GPUs and a mini-cluster of 16x48core normal servers installed at his university's HPC. However, it is not expected that the processing will be computationally expensive by the standards of these machines.
It is expected that a minimum of 1FTE/year of effort is required, which will increase as the data are taken and become available to analyse.

6.1.9 Team

Table 2: Survey S1 team members with their affiliation, role in S1, and total expected FTE contributions next to science exploitation. For WP descriptions see Section 6.1.5.

Name	Affiliation	Roles	FTE/yr
Alessia Garofalo	OAS	4GRoundS Co-I, target selection, WP 2.2.1.1.1, WP 2.2.1.3	0.1
Alessio Mucciarelli	UniBo	4GRoundS Co-I, WP 2.2.1.1.1	0.1
Alis Deason	Durham	Mock halo sample, IWG5, WP 2.2.1.5, WP 2.2.1.3	0.05
Amina Helmi	RuG	Milky Way halo membership, target selection, WP 2.2.1.3, WP 2.2.1.4	0.1
Andreas Koch-Hansen	ARI	Milky Way Halo, WP 2.2.1.1.0	0.05
Anke Arentsen	IoA	Multiplicity WG, WP 2.2.1.1.1, WP 2.2.1.4	0.025
Anna Barbara de Andrade Queiroz	AIP	IWG2, bulge WG, WP 2.2.1.4	0.05

Name	Affiliation	Roles	FTE/yr
Arnaud Siebert	ObAS	4GroundS co-I, WP 2.2.1.1.1	0.05
Ása Skúladóttir	UNIFI	4GroundS co-I,WP 2.2.1.1.1	0.02
Azadeh Fattahi	Durham	IWG5,WP 2.2.1.3	0.05
Benoit Famaey	ObAS	4GroundS co-I,WP 2.2.1.1.1	0.05
C. Clare Worley	Canterbury	Co-PI of S1, DRM, WP 2.2.1.2, WP 2.2.1.5, WP 2.2.1.6	0.2
Camilla Juul Hansen	GUF	IWG7, S14, S1+2, WP 2.2.1.1.0, WP 2.2.1.4	0.05
Cristina Chiappini	AIP	IWG2, S3 Co-PI, WP 2.2.1.4	0.05
Daniel Zucker	AAO-MQ	IWG3, WP 2.2.1.5	0.05
Denis Erkal	Surrey	IWG5, WP 2.2.1.3	0.05
Diane Feuillet	LU	IWG4,7 PCWG, WP 2.2.1.1.0. WP 2.2.1.6	0.1
Eduardo Balbinot	RuG/Leiden	IWG6 (S1 rep), IWG2-MC (S1/3 rep), WP 2.2.1.3, WP 2.2.1.5	0.1
Eline Tolstoy	RuG	Inter-Survey (WEAVE), WP 2.2.1.4	0.05
Else Starkenburg	RuG	Co-PI of S1, IWG2, Cross-Survey, WP 2.2.1.2, WP 2.2.1.3, WP 2.2.1.4	0.2
Eva Grebel	ARI	SPB rep, MW halo membership, WP 2.2.1.4, WP 2.2.1.6	0.05
Georges Kordopatis	OCA	IWG7 co-lead, WP 2.2.1.5, WP 2.2.1.6	0.1
Giacomo Monari	ObAS	S1-4GRoundS Co-I, Disk RR Lyrae, WP 2.2.1.1.1	0.05
Gisella Clementini	OAS	S1-4GRoundS Co-I, target selection, WP 2.2.1.1.1, WP 2.2.1.3	0.1
Giuseppina Battaglia	IAC	S1-4GRoundS Co-I, WP 2.2.1.1.1	0.05
Guillaume Guiglion	MPIA	IWG2, 3, 7, WP 2.2.1.4, WP 2.2.1.5	0.1
Guillaume Thomas	IAC	S1-4GRoundS Co-I	0.05
Hans-Walter Rix	MPIA	Gaia XP cross-validation	0.05
Ivan Minchev	AIP	IWG2, S3 Co-PI	0.05
Joss Bland-Hawthorn	SIFA	S1-4GRoundS Co-I, Milky Way Halo, WP 2.2.1.1.0, WP 2.2.1.1.1	0.05

Name	Affiliation	Roles	FTE/yr
Khyati Malhan	MPIA	S1-4GRoundS Co-I, WP 2.2.1.1.1	0.05
Lorenzo Posti	ObAS	S1-4GRoundS Co-I, WP 2.2.1.1.1	0.05
Manuel Bayer	RuG	Milky Way Halo, WP 2.2.1.1.0	0.05
Marica Valentini	AIP	IWG3, WP 2.2.1.5	0.1
Martin Montelius	RuG	IWG7, WP 2.2.1.5	0.1
Matthias Steinmetz	AIP	Inter-Survey, WP 2.2.1.4	0.05
Michael Hayden	SIFA	Deputy PS - Galactic, WP 2.2.1.4	0.05
Michele Bellazzini	OAS	4GRoundS Co-I, WP 2.2.1.1.1	0.1
Mike Irwin	IoA	Target selection S1 halo, IWG2, WP 2.2.1.3, WP 2.2.1.4	0.1
Nicholas Walton	IoA	Milky Way Halo, WP 2.2.1.1.0	0.05
Nicolas Martin	ObAS	4GRoundS Co-I, WP 2.2.1.1.1	0.05
Norbert Christlieb	LSW	Cross-Survey, WP 2.2.1.4	0.1
Paolo Bianchini	ObAS	4GRoundS Co-I, WP 2.2.1.1.1	0.05
Pascale Jablonka	EPFL	S9 representative in SPB, WP 2.2.1.4	0.05
Rodrigo Ibata	ObAS	4GRoundS lead, WP 2.2.1.1.1, WP 2.2.1.3	0.2
Sarah Martell	UNSW/SoP	IWG4, WP 2.2.1.4	0.1
Sergey Khoperskov	AIP	S1 rep in IWG9, WP 2.2.1.1.0	0.05
Sergey Koposov	IfA	Milky Way Halo, WP 2.2.1.1.0	0.05
Shoko Jin	RuG	Inter-Survey (WEAVE), WP 2.2.1.4	0.05
Sofia Feltzing	LU	IWG4, S1 selection function, WP 2.2.1.4	0.15
Stephan Geier	Potsdam	Cross-Survey, WP 2.2.1.4	0.05
Tadafumi Matsuno	RuG	IWG1, IWG6, WP 2.2.1.3, WP 2.2.1.6	0.1
Vanessa Hill	OCA	Inter-Survey (WEAVE), WP 2.2.1.4	0.05
Yuan-Sen Ting	ANU	Milky Way Halo, WP 2.2.1.1.0	0.05
Zhen Yuan	ObAS	S1-4GRoundS Co-I, WP 2.2.1.1.1	0.05
Karin Lind	SU	Galactic PS	0.05

6.2 Survey 2 – The Milky Way Halo High-Resolution Survey

Survey PI: Norbert Christlieb

6.2.1 Science Summary

The goal of the Milky Way halo high-resolution survey is to study the formation and evolution of the Galactic halo to deduce its assembly history. We will study the formation history of the Milky Way, and the earliest phases of its chemical enrichment, with a sample of 1.3 million stars at high galactic latitude. Elemental abundances of up to 20 elements with a precision of better than 0.2 dex will be derived for these stars. The sample will include members of kinematically coherent substructures, which we will associate with their possible birthplaces by means of their abundance signatures and kinematics, allowing us to test models of galaxy formation. Our target catalogue is also expected to contain 30,000 stars at a metallicity of less than one hundredth of that of the Sun. This sample will therefore be almost a factor of 100 larger than currently existing samples of metal-poor stars for which precise elemental abundances determined from high-resolution spectroscopy are available, hence enabling us to study the early chemical evolution of the Milky Way in unprecedented detail.

This science case is covered in SubSurvey(s):

- S0201 – Bright Subsurvey
- S0202 – Faint Subsurvey
- S0203 – Deep Subsurvey

Expanded science description: messenger-no175-26-29.pdf

Merged Science Programme:

The goal of S0204 is to study the Sagittarius dwarf galaxy with high-resolution spectroscopy in order to deduce its formation history. This subsurvey is run in conjunction with S14, to ensure adequate coverage of the Sagittarius dwarf galaxy, and targets are selected from the S14 Sagittarius catalogue.

This science case is covered in SubSurvey(s):

- S0204 – SGR Subsurvey

Expanded science description: messenger-no190-19-21.pdf

6.2.2 Target Catalogue

The targets for Subsurveys S0201-S0203 have been selected from Gaia DR3. Metallicities have been determined using synthetic narrow-band photometry in the system of the Pristine survey (Starkenburg et al. 2017) derived from Gaia BP/RP spectra (Martin et al. 2023, arXiv:2308.01344). The selection criteria are summarised in Table 3.

The selection criteria for S0204 are the same as that listed for S1401, as is the completion, area covered and SNR requirements.

Table 3: Target selection criteria for S0201-S0203. The criteria 5 and 6 select dwarf/subgiant, and giant stars, respectively. The logical combination of the criteria is "1 and 2 and 3 and 4 and (5 or 6)".

<table>
<tr><th>Criterion #</th><th>Bright survey (Suburvey 1)</th><th>Faint survey (Suburvey 2)</th><th>Deep survey (Subsurvey 3)</th></tr>
<tr><td>1</td><td colspan="2">$+5° > \delta > -80°$</td><td rowspan="2">Selected areas</td></tr>
<tr><td>2</td><td colspan="2">$|b| > 20°$</td></tr>
<tr><td>3</td><td colspan="3">[Fe/H] < −0.4</td></tr>
</table>

4	$12.0 \leq G \leq 15.0$	$15.0 < G \leq 16.0$	$16.0 < G \leq 17.0$
5	$0.15 \leq (G_{BP}\text{-}G_{RP})_0 \leq 1.10$		
6	$[1.10 < (G_{BP}\text{-}G_{RP})_0 \leq 1.60]$ & $[M_G < 3.5]$		
Number of targets	**1,310,000**	**1,380,000**	**74,000**

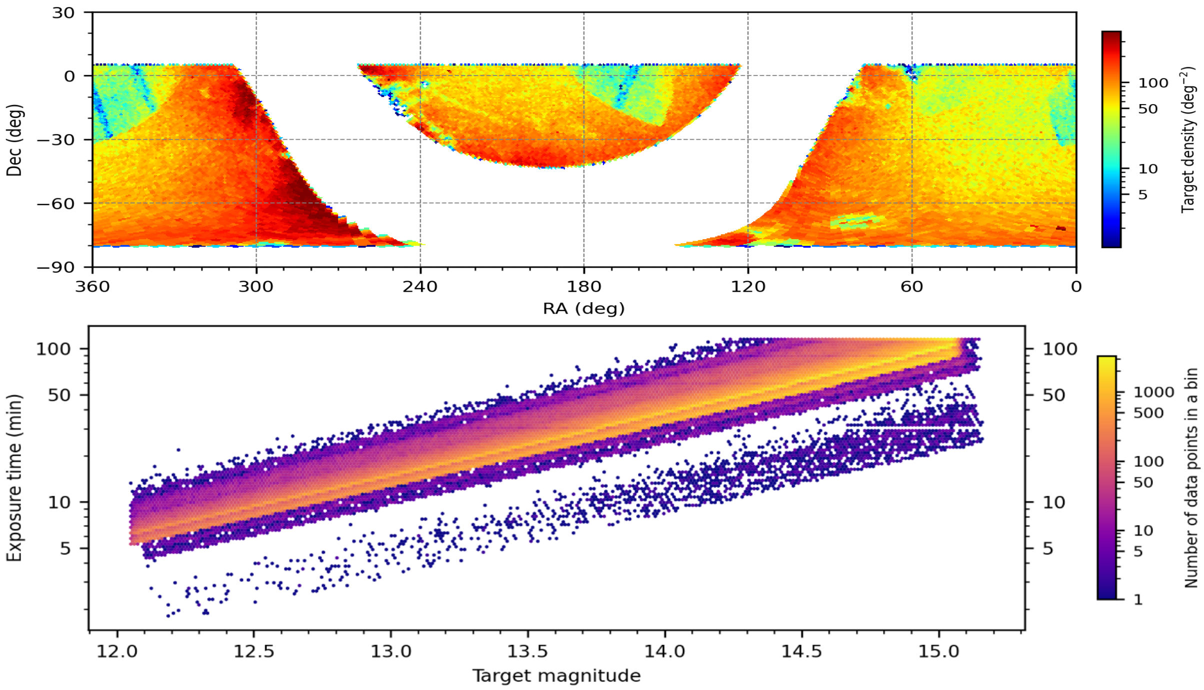


Figure 4: Top) Input target distribution of the S0201 Bright subsurvey. Bottom) The exposure time estimates as a function of target G-mag. (S2 plots as of upload 2023-05-15)

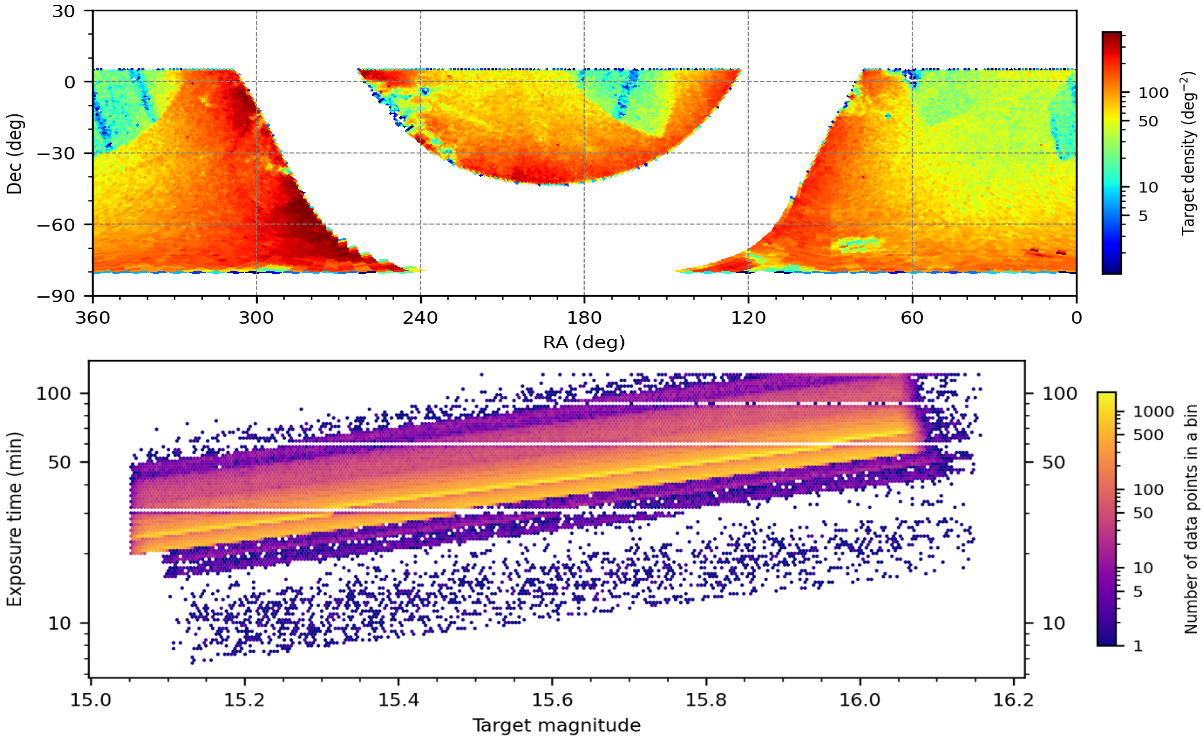


Figure 5: Top) Input target distribution of the S0202 Faint subsurvey. Bottom) The exposure time estimates as a function of target G-mag.

The input targets sky coverage of S0201-S0202 are displayed in the top panels of Figure 4 and Figure 5. These subsurveys cover the areas between -80º<Dec<+5º while avoiding the Galactic disk and inner Magellanic Clouds regions. These subsurveys cover 1.31 million (S0201 Bright), 1.37 million (S0202 Faint) targets. The S/N requirements vary for each subsurvey and on the stellar types. For S0201 (Bright), they are SNR > 50 per pixel for dwarfs and SNR > 30 per pixel for giants at the continuum in the wavelength region 415.0-416.5 nm. For S0202 (Faint), the requirements are SNR > 25 per pixel for dwarfs and SNR > 15 per pixel for giants in the same wavelength region as mentioned above (the spectral success criteria are summarised in Table 4). The resulting exposure time estimates for these requirements are displayed in the bottom panels of Figure 4 and Figure 5. The Scientific FoM is based on the number of successfully observed targets relative to the input target catalogues, with additional weights based on subsurvey priorities (derived from science priorities).

Table 4: Spectral success criteria of S0201-S0203. The SNR is measured in the continuum in the wavelength region 415.0-416.5 nm.

Star type	SNR per pixel/per Å in survey		
	Bright	Faint	Deep
Dwarfs and subgiants	50/170	25/80	25/80
Giants	30/100	15/50	15/50

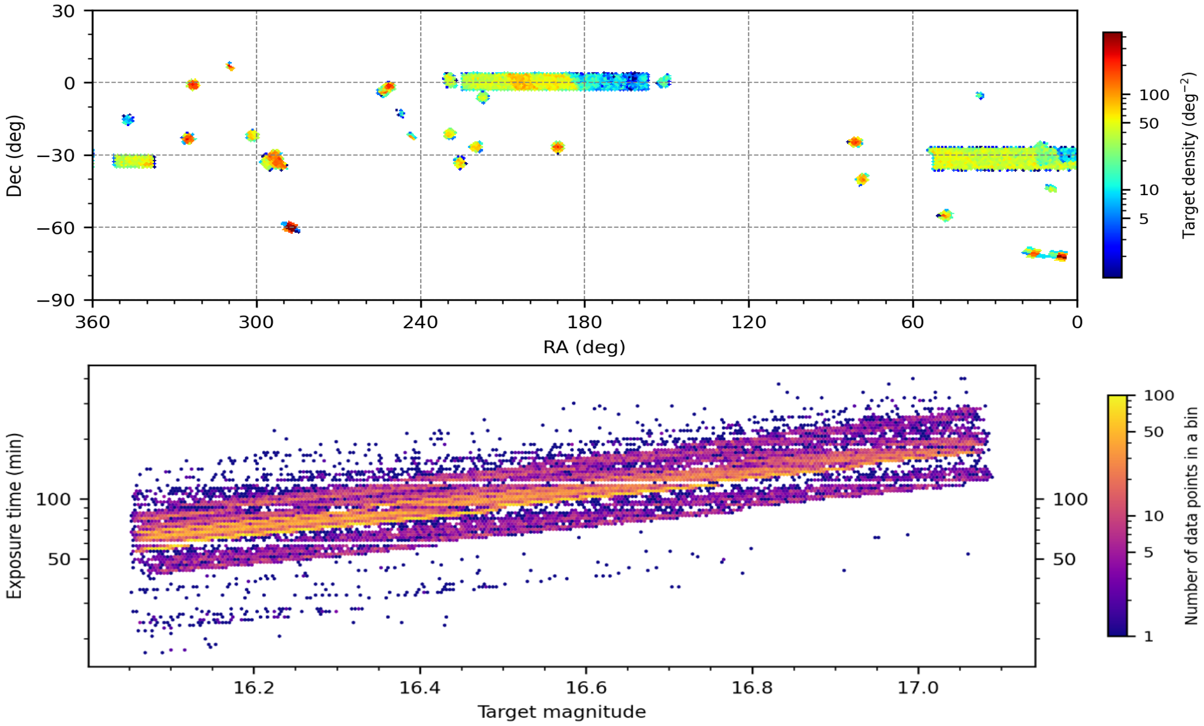


Figure 6: Top) Input target distribution of the S0203 Deep subsurvey. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of S0203 is displayed in the top panel of Figure 6. This subsurvey covers the areas between -80º<Dec<+5º while avoiding the Galactic disk in a few targeted regions with deep observations. This subsurvey covers 62k targets. The SNR requirements vary based on stellar types, where SNR > 25 per pixel is required for dwarfs, and SNR > 15 per pixel for giants, as measured in the continuum in the wavelength region 415.0-416.0 nm. The resulting exposure time estimates for these requirements are displayed in the bottom panel of Figure 6. The Scientific FoM is based on the number of successfully observed targets relative to the input target catalogues, with additional weights based on survey priority.

S0204 – Sgr Dwarf

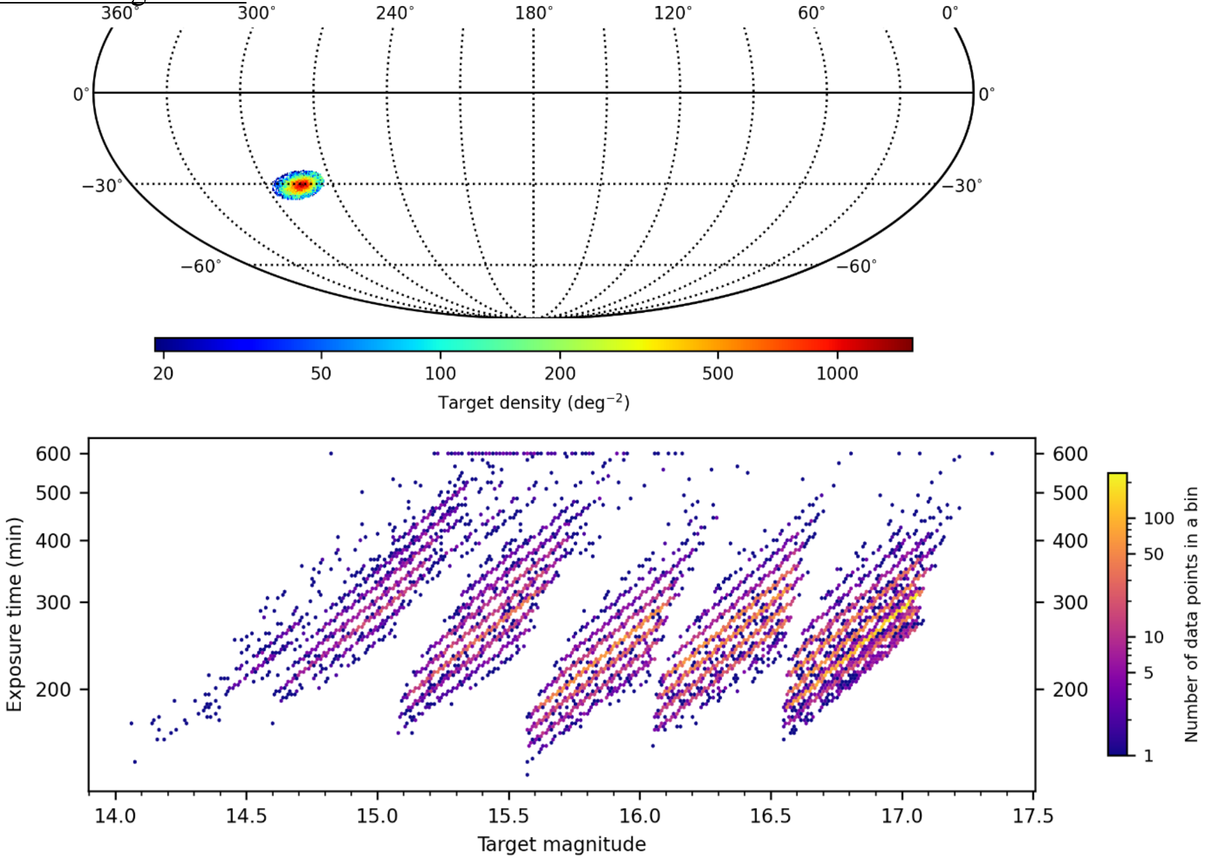


Figure 7: Top) Input target distribution of the S0204 SGR subsurvey. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of S0204 SGR is displayed in the top panel of Figure 7. This subsurvey covers the core of the Sagittarius dwarf. This subsurvey covers 38k targets, selected from the S1401 Sagittarius catalogue. The SNR requirements depend on the magnitude of the target, but range from 80 to 250@520nm. The resulting exposure time estimates for these requirements are displayed in the bottom panel of Figure 7. The Scientific FoM is based on the number of targets observed relative to the input target catalogues, with additional weights based on survey priority.

S2 Summary

Table 5: Key parameters of the input target catalogue of the S2 Survey

N	Sub	Name	Res	Cadence	Date earliest Date latest	RA range DEC range	Epoch	TMAX [min]	AREQ [deg^2]	Fcom	FH_D [kH]	FH_G [kH]	FH_B [kH]	FH_S [kH]	N targets	Rule WL range [A]
3	S0201	MW_halo_HRS_bright	HR	(0, 0, 0, 0)	0	0.0 – 360.0 -80.0 – 5.0	2016.0	120 (G)	14000	0.797	946	950	1016	1207	1306150	4150.0 -- 4165.0
4	S0202	MW_halo_HRS_faint	HR	(0, 0, 0, 0)	0	0.0 – 360.0 -80.0 – 5.0	2016.0	120 (D)	14000	0.797	878	915	1097	1557	1375940	4150.0 -- 4165.0
5	S0203	MW_halo_HRS_deep	HR	(0, 0, 0, 0)	0	0.0 – 360.0 -74.0 – 8.2	2016.0	400 (D)	1800	0.797	98.4	105	139	226	73771	4150.0 -- 4165.0
6	S0204	MW_halo_HRS_Sgr	HR	(0, 0, 0, 0)	0	273.1 -- 298.5 -35.6 -- -25.4	2016.0	600 (D)	150	0.797	123	129	155	218	38195	5244.2 -- 5245.4

The S2 Survey aims to observe halo stars over a large fraction of the sky, which does not necessarily need to be in contiguous areas. Being a large area Survey with a moderately low completeness requirement, weather variations over the 5-year period will have no significant impact. The key input parameters of the S2 target catalogue are listed in Table 5.

6.2.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.2.4 Management Structure

The top-level management of S2 consists of the PI, deputy PI, and the administrative assistants.
N. Christlieb (PI of S2, permanent position): Overall leadership of the survey project.
P. Bonifacio (permanent position in Paris): Will help the survey PI leading the project.
B. Wright (administrative assistant, permanent position): Well help with administrative issues, such as organising meetings; preparing meeting meetings; making travel arrangements for collaborative visits; taking care of guests.
N.N. (administrative assistant, to be hired for a fixed term of 6 years through an ERC Synergy Grant, provided that grant application will be approved): Well help with administrative issues, such as organising meetings; preparing meeting meetings; making travel arrangements for collaborative visits; taking care of guests.A description of the different WG within S2 is described in Section 7.1.10 with the FTE contributions to the different internal WGs listed in Section 7.1.11 and the contributions to the 4MOST common IWGs listed in Section 7.1.12. The full effort of WP-HALO-01, and half effort of WP-HALO-02 and WP-HALO-03 are primarily directed towards IWG1, 2, 4, 6, and 7. The contributions to these IWGs includes effort on (~1.5 FTE/yr):

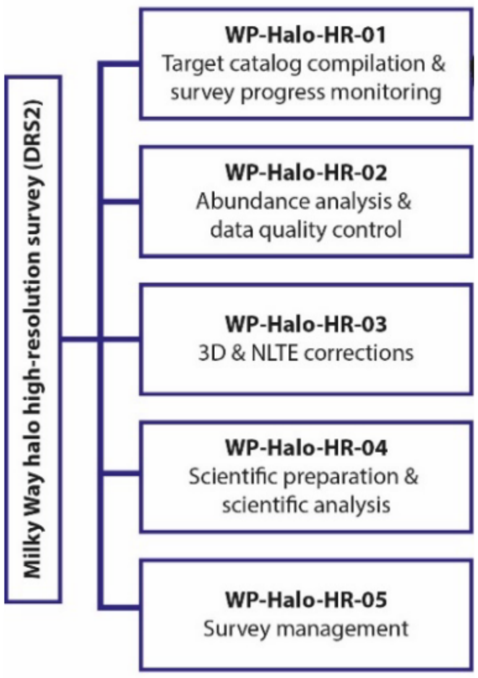
- Contributing to analysis modules in 4GP, particularly with NLTE analysis
- Quality control of data products, such as inspecting L1, L2 pipeline outputs
- defining calibration samples

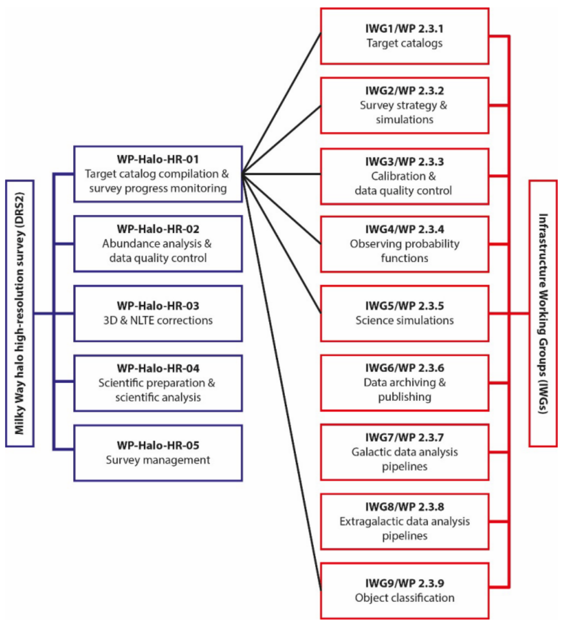
For S2 internally, the effort in WP-HALO-04 and WP-HALO-05 is mainly directed towards S2 specific work, while WP-HALO-02, WP-HALO-03, are roughly half effort towards S2 specific tasks. This effort includes (at least 1.5 FTE/yr, likely more):

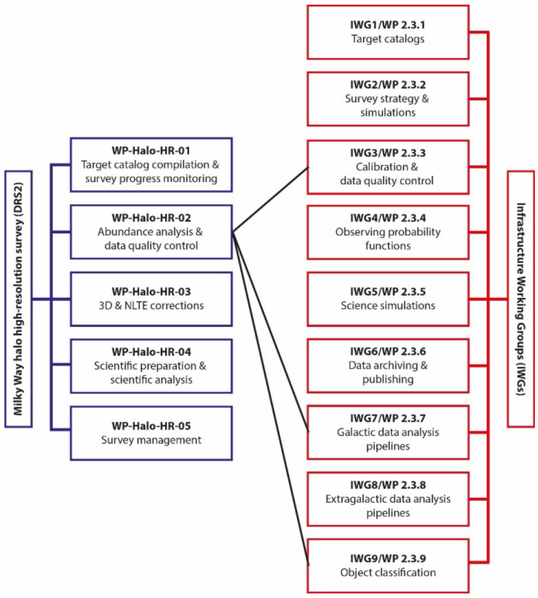
- Management of team meetings and monitoring of work in WPs
- Catalogue preparation and submission
- 4FS simulation inspection and FoM definition
- Scientific and analysis synergies with other surveys

S2 is planning to use the tools, procedures, and available hardware of the common IWGs.

6.2.5 Work-breakdown structure







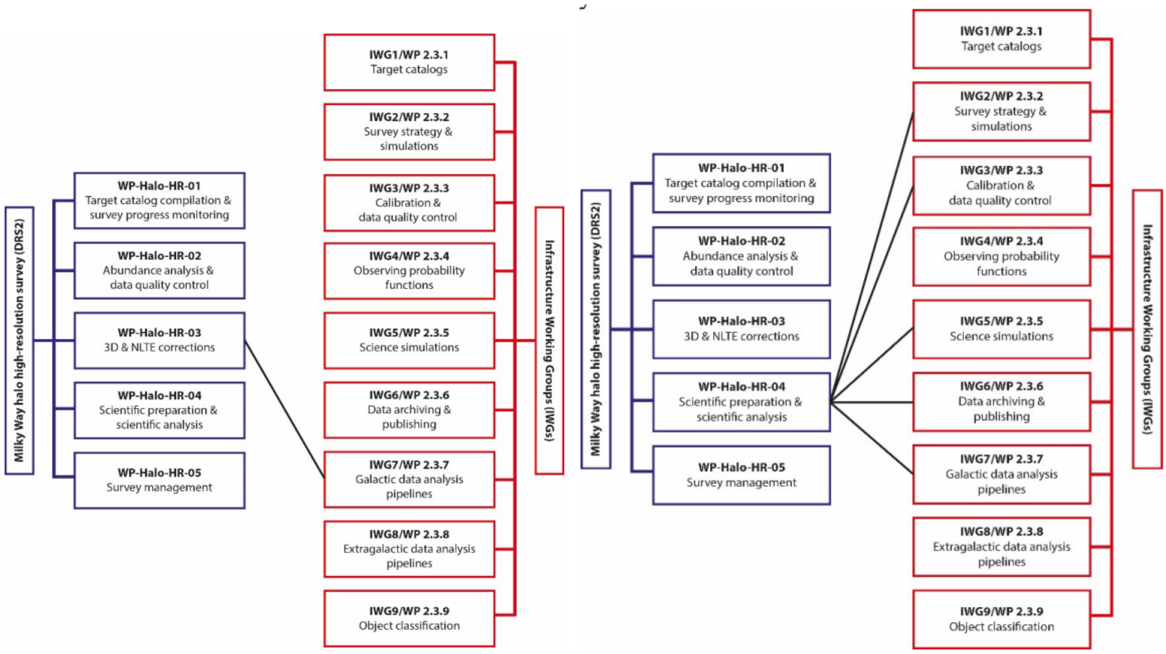


Figure 8: Work Breakdown Structure for Survey S2

S2 consists of three main sub-surveys and an additional survey to ensure sufficient coverage of the Sagittarius dwarf.

WP-Halo-HR-01: *Target catalogue compilation and survey progress*

Tasks: In this work package, the target catalogue shall be compiled, using publicly available data (e.g., Gaia DR3, SkyMapper, S-PLUS). The second task of this work package is survey progress monitoring. I.e., in regular time intervals (monthly), it shall be checked which of the objects listed in the target catalogue have been successfully observed. This requires some data quality control, and hence there must be a close link to the work package WP-Halo-HR-02 described below. Information on the status of the survey will be distributed to the survey team. Any problems will be reported to IWG2.

The links between this work package and the IWGs are shown in the top left panel of Figure 8.

Deliverables and Timescales: Target catalogue (January 2023 – final version); survey status reports (every 6 months after the start of regular 4MOST observations)

Resources: 3.0 FTE over 7 years

WP-Halo-HR-02: *Abundance analysis and data quality control*

Tasks: It is important that abundance analysis and data quality control are closely linked, and preferentially carried out by the same person, because data quality issues can best be recognized during the abundance analysis. This work package has strong links to IWG3 as well as IWG7, as shown in the top right panel of Figure 8.

Deliverables and Timescales: Stellar parameters and chemical abundances of the targets (provided by 4GP); data quality reports (in synchronisation with WP-Halo-HR-01). These deliverables will be distributed to IWG6, IWG9, and IWG7.

Resources: 3.0 FTE over 7 years

WP-Halo-HR-03: *3D and NLTE corrections*

Tasks: The output of the Galactic Abundance Analysis Pipeline will be abundances computed with hydrostatic, plane-parallel or spherically-symmetric model atmospheres and hybrid LTE/NLTE line formation calculations, but it is desirable to determine 3D NLTE abundances at least for the elements that are most important for Galactic chemical evolution (e.g., C, N, and

the α- elements), and for studying nucleosynthesis processes in the early Universe (e.g., Li, or the neutron-capture elements Sr, Ba, and Eu). Strong links with IWG7 (as shown in the bottom left panel of Figure 14), and this data will be provided through IWG7/4GP (i.e., it will not be additional data products).
Deliverables: 3D model atmosphere grid covering the relevant regions of the HR diagram; NLTE corrections for selected elements.
Resources: 3.0 FTE over 7 years
WP-Halo-HR-04: *Scientific preparation and science analysis*
Tasks: In this work package, we summarise the scientific preparation during the Survey Program Validation (SPV) phase, and the efforts of using the stellar abundances derived from 4MOST data into scientific results to be published in refereed journals during and after the Science Operations Phases. The latter requires combination with complementary data (e.g., Gaia parallaxes and proper motions), and close interaction with theoretical groups providing models and simulations for proper interpretation of the results. Some preparatory work needs to be done already a long time before the start of the 4MOST science operations; for example, compilation of the complementary data.
Deliverables and Timescales: Observation preparation (2015-2024) and science results (2024-2029). First results derived from the regular survey data are expected to be published about 1 year after beginning of Survey Operations; i.e., mid-2025. Results from SPV data will be published immediately.
Resources: 6.0 FTE over 7 years
WP-Halo-HR-05: *Survey management*
Tasks and Deliverables: Plans; organisation; management of resources and funding; communication; reports
Resources: 3.0 FTE over 7 years

6.2.6 Contribution to the Infrastructure Working Groups

The contributions of S2 to the IWGs are summarised in Table 6. In particular, Hans-Günter Ludwig and Anish Amarsi are working on 3D/NLTE corrections (IWG7); Paul Barklem, Sven Buder, Elisabetta Caffau, Guillaume Guiglion, Tadafumi Matsuno and Stephanie Monty are contributing to the development and testing of the Galactic Pipeline (4GP/IWG7).

6.2.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.2.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey 2 will be processed by the 4GP/4CP/4SP pipelines and quality-controlled products will be delivered to 4PA and the ESO SAF.

6.2.8.1 Deliverable L2 Survey data: reduction processing

No extra DL2-SURV processing is required by this Survey.

6.2.8.2 Deliverable L2 Survey data: quality assessment

No extra DL2-SURV processing is required by this Survey.

6.2.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

No extra DL2-SURV processing is required by this Survey.

6.2.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

No extra DL2-SURV processing is required by this Survey.

6.2.8.5 Deliverable L2 Survey data: Required hardware and staff

No extra DL2-SURV processing is required by this Survey.

6.2.8.6 Additional L2 data: reduction processing

No extra AL2-SURV processing is required by this Survey.

6.2.8.7 Additional L2 data: quality assessment

No extra AL2-SURV processing is required by this Survey.

6.2.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2-SURV processing is required by this Survey.

6.2.8.9 Additional L2 data: product delivery schedule to the 4PA archive

No extra AL2-SURV processing is required by this Survey.

6.2.8.10 Additional L2 data: Required hardware and staff

No extra AL2-SURV processing is required by this Survey.

6.2.9 Team

Table 6: Survey S2 team members with their affiliation, role in S2, and total expected FTE/year contributions.

Name	Affiliation	WP-01	WP-02	WP-03	WP-04	WP-05	Remarks
Amarsi	Uppsala			0.1	0.1		IWG7
Barklem	Uppsala		0.1				IWG7
Buder	ANU		0.1				IWG7
Christlieb	ZAH-LSW				0.3	0.2	
Korn	Uppsala				0.1		
Ludwig	ZAH-LSW	0.1		0.2			
Bonifacio	GEPI	0.1				0.1	IWG2
Caffau	GEPI		0.2				IWG7
Guiglion	ZAH-LSW		0.1		0.1		
Lagae	Stockholm				0.1		
Lind	Stockholm			0.1			Galactic PS
Matsuno	Groningen	0.2					IWG6, 7
Monty	Cambridge		0.1				IWG7
Nordlander	ANU	0.1					IWG1,7
Quirrenbach	ZAH-LSW					0.1	
Sbordone	ESO	0.1					IWG6, 7
Wright	ZAH-LSW					0.5	

Antony	ZAH-LSW				1.0		
N.N.	ZAH-LSW		0.2				DFG funding pending
N.N.	ZAH-LSW			0.3			DFG funding pending
N.N.	ZAH-LSW	0.5	0.5				DFG funding pending
N.N.	ZAH-LSW			1.0			DFG funding pending
N.N.	ZAH-LSW				1.0		DFG funding pending
N.N.	ZAH-LSW					0.5	DFG funding pending
Sum		**1.1**	**1.3**	**1.6**	**2.7**	**1.4**	

6.3 Survey 3 – Milky Way Disk and Bulge Low-Resolution Survey (4MIDABLE-LR)

Survey PIs: Cristina Chiappini, Ivan Minchev

6.3.1 Science Summary

4MIDABLE-LR (S3) main goal is to study kinematic and chemical substructures in the Milky Way disc and bulge region with samples of unprecedented size (with spectra for over 10 million stars, with enough SNR to extract also chemical information for around 5 million stars) out to larger distances and greater precision than conceivable with Gaia alone or any other ongoing or planned survey. Gaia gives us the unique opportunity for target selection based almost entirely on parallax and magnitude range, hence increasing the efficiency in sampling larger Milky Way volumes with well-defined and effective selection functions. S3 shall provide a detailed and extended chrono-chemo-kinematical map of our Galaxy. For a detailed description of the Survey Science and Requirements see RD2 and RD3.

Immediate Objective is to produce comprehensive chemo-kinematical maps, which will be used to:

• Better understand the current Milky Way disk structure and dynamics (the central bar, spiral arms, vertical structure, effects of recent and ongoing mergers)

• Better constrain the formation of the Milky Way bulge/bar using both chemical and kinematical information, as well as spectroscopic stellar distances and ages using machine learning methods supported by high-quality training samples (seismic giants – Miglio et al. 2021, Montalban et al. 2021 and clusters – Gruner & Barnes 2020, Cantat-Gaudin et al. 2020)

• Study the inner disk/bulge and disk/halo interfaces by simultaneously covering a large volume, and ensuring high-quality chemical and kinematical information

• Quantify the impact of secular processes, stellar radial migration, as well as the merger history on our Galaxy's assembly and recover the evolutionary history of the disk and bulge

• Further expand the legacy of Gaia with complementary radial velocity and chemical information.

Given the different target densities, extinction regimes, and spectral types, S3 has been organised in sub-surveys in order to effectively provide a large Gaia follow-up and still stay within the boundaries of the 4MOST project. Therefore, the following catalogues now form our 4MIDABLE-LR (S3) survey (for more details on these catalogues see Section 6.4.1) :

1. **Main sub-surveys:**
   - S0301 - ESN – Extended Solar Neighbourhood
   - S0302 - Dyn – Dynamical disk
   - S0303 - Chem – Chemo-dynamical disk
   - S0304 - BIG – Chemo-dynamical Bulge/Inner Galaxy

2. **Additional Science and Science Calibration sub-surveys (in same order as simulations):**
   - S0305 - BD – Bulge Deep
   - S0306 - VMP – Very metal-poor stars candidates from SH XGboost using Gaia DR3 XP
   - S0307 - VMP_PIGS - Very metal-poor candidates from PIGS (Pristine Inner Galaxy)
   - S0308 - Ceph – Cepheids
   - S0309 - HSD – Hot Subdwarf

- S0310 and S0311 - WD – White Dwarfs(WD and WD100 - within 100 pc)
- S0312 - CWDB – Compact White Dwarf Binaries(eRosita follow-up)
- S0313 and S0314 - Planetary Nebulae(PN_CS for Central star and PN_NEB)
- S0315 - A100pc – stars within 100 pc from the Sun
- S0316 - OBstars – O and B stars
- S0317 to S0322 - Seismic Giantsfrom K2, CoRoT and TESS (in both LR and HR in this order: SeisK2_LR, SeisK2_HR, SeisCo_LR, SeisCo_HR, SeisTE_LR, SeisTE_HR)
- S0323 - Seismic Giant calibrators to be observed by Plato - SeisPL_HR
- S0324 and S0325 OCs – Clusters (in both LR and HR – OCsHR and OCsLR)

Expanded science description: messenger-no175-30-34.pdf

6.3.2 Target Catalogue

The main sub-surveys' (S0301-S0304) source catalogue is Gaia DR3. Other subsurveys are also based on Gaia DR3 advanced catalogues, i.e., using Gaia DR3 plus complementary information. The goals of the main catalogues are summarised in section 6.4.1. More information on the magnitude ranges, as well as the spectral success criteria, can be found in Table 7 below. The area covered by each catalogue can be seen in the IWG2 pages, which summarise the main properties of all our submitted catalogues [RD10]. S3 has a complex structure, with 4 main sub-surveys in LR (ESN, Dyn, Chem, BIG), two science calibration sub-surveys both in HR and LR (Seismic – divided by mission, i.e., CoRoT, K2 and TESS - and OCs - a total of 8 catalogues), as well as ancillary sub-surveys (13 in total: BD, VMP, VMP_PIGS, Ceph, HSD, WD, WD100, CWDB, HSD, PN_NEB, PN_CS, A100pc, OBstars). Ancillary surveys are scientifically complementary to S3 main science goals, but are composed of sparse samples, with low fibre-hour consumption. These are observed in a way not to compromise the selection function of the main four sub-surveys. Finally, we have the PLATO giants catalogue. These are science calibrators in PLATO to be observed in the first two year-long PLATO observing campaign. The goal is to cover all the relevant mass (age) and metallicity range. Spectroscopic observations prior to launch would be fundamental to define this sample, especially not to be dominated by solar-metallicity, of which plenty of data already exist in Kepler. In total, our survey has 25 sub-catalogues.

The target selection pipeline for the main S3 sub-surveys was designed to be parallel and efficient on HPC clusters with the objective of analyzing extensive datasets for upcoming surveys and models. This selection is model-independent (selections based on Gaia magnitde range intervals (Table) and parallax probability distributions). While the ESN catalogue takes advantage of the best-of Gaia volume (exquisite parallaxes), Dyn and Chem cover large portions of the MW disk (these two surveys are in the same footprint but have different requirements of SNR). This is because the capability of CNN to derive precise and accurate abundances relies on the precision and accuracy of the training sample labels as well as the level of noise in the spectra used in the training.Within S3, we aim at measuring a large number of abundances. CNN will learn from labels originally measured by standard spectroscopy; hence high-S/N is required for standard spectroscopy to measure precise and accurate enough numerous abundances.This defines the SNR being required for the CHEM (and BIG catalogues). and it is necessary for achieving standard spectroscopy and learning phase of CNN. A brief summary of the catalogue selection and goals of the additional sub-surveys and science calibration sub-surveys is provided below (see also Table 7).

- S0305 - BD – Bulge Deep survey. Currently, the most complete sample in the inner Galaxy is provided by the APOGEE DR17 survey in the infrared. The bulge-box defined by Queiroz et al. (2021) using APOGEE contains approximately 30,000 stars within the inner 5 kpc. The Bulge Deep (BD) sample will expand this number by a factor of five, enabling the exploration of critical questions about the inner Galaxy. The requirements for BD sample are very similar to the ones defined for the Bulge Inner Galaxy, with a precision of 0.2 dex in Fe, Ba, and C. BD is a selection of faint (17<G<18) stars in a rectangular patch in the bulge region to make a chemo-dynamical characterization of the Galactic bar, bulge, and inner disk. The BD region contains the BDBS survey region. This survey is coordinated with the S0403 counterpart, and now also included one field that overlaps with Roman: |l| < 10°, –11° < |b| < –3° (plus Roman field -0.5° < l < 1.6° and -3° < b < -1.25°)

- S0306 - VMP – The goal of this catalogue is to create a massive census and characterise very metal-poor stars in the disc and bulge taking advantage of VMP candidates from Gaia + SH XGBoost ([Fe/H] < -1.8 and 4MOST footprint sky cut + ZGal < 5 kpc - using distance and extinction estimated from StarHorse2021, Anders et al. 2022) and metallicities form SHBoost (selected from a catalogue of more than 200 million objects that will be made public soon - Khalatyan et al. 2024, submitted).
- S0307 - VMP_PIGS – The goal is to follow-up with 4MOST the very metal-poor candidates from the Pristine Inner Galaxy (PIGS; [Fe/H] < -1.8) survey. PIGS is a narrow-band CaHK photometric survey (non public - see Arentsen et al. 2020).
- S0308 - Ceph – Cepheids - This catalogue was created from all literature catalogues with time-domain capabilities and then cross-matched against Gaia DR3. The classification of variable stars has been verified using statistical methods and the catalogue contains classical/type II Cepheids.
- S0309 - HSD – Hot Subdwarf - The goal of this sub-survey is to obtain spectra for hot subdwarf candidates in order to i) confirm their nature as hot subdwarfs; ii) obtain their physical parameters (effective temperature, surface gravity, atmosphere composition), and, to a lesser extent, iii) probe their binarity. The targets are selected from Gaia DR3. For targets with good astrometry (parallax error smaller than 20%) a colour and absolute magnitude cut was applied to select hot sub-luminous stars. For stars with more uncertain parallaxes, the colour as well as reduced proper motion were used as further selection criteria (see Culpan et al. 2022 A&A 662A..40C).
- S0310 and S0311 - WD and WD100 are our white dwarfs sub-surveys (WD100 - within 100 pc) - The goal of WD100 catalogue is to obtain a complete spectroscopic census of all white dwarfs identified by Gaia within the 100pc solar neighbourhood in the southern hemisphere. This sample will have multiple scientific applications from studying stellar formation history to determining the incidence and properties of various white dwarf populations. Targets come from Gentile Fusillo et al. (2021 - Gaia EDR3). Beyond 100pc the WD (S0311) sub-survey will target all southern white dwarfs brighter than G=20.2. These complementary observations will have, among others, the additional goals of mapping the different Galactic populations of white dwarfs and tracing rare white dwarf subtypes.
- S0312 - CWDB – Compact White Dwarf Binaries Survey (eRosita follow-up) uses Gaia DR3 counterpart to the X-ray sources (stacked eRASS:4 catalogue, combining the first 3 sky surveys, and selected all Gaia DR3 entries within 30" of each eRASS source).
- S0313 and S0314 - Planetary Nebulae Surveys (PN_CS for Central star and PN_NEB) – The targets came from Chornay & Walton (2021) and the HASH PN catalogue (http://hashpn.space/). For PN_NEB, target coordinates are determined from ground-

based imaging catalogues, which are typically calibrated to the Gaia reference frame. They are designed to sample the nebulae and as such are not always the brightest features.

- S0315 - A100pc – The goal of this sub-survey is to obtain a volume complete survey of the 100 pc Gaia DR3. Selection criteria were based on two steps. Step 1 defines the dense and non-dense regions, namely: a) dense regions include the Galactic Plane and exclude the LMC and SMC regions (l <= 180 && b <- 0.139l + 25 && b > 0.139l - 25) || (l > 180 && b >- 0.139 l + 25 && b < 0.139*l – 25); SMC: sqrt(pow(l-303.2,2) + 2*pow(b+44.4,2)) < 5; LMC: sqrt(pow(l-280.3,2) + 2*pow(b+33.0,2)) < 8); b) non dense regions exclude the Galactic Plane and the LMC and SMC: !(Galactic Plane || SMC || LMC). In step 2 additional criteria based on parallax and astrometric excess noise are used in order to avoid spurious detections. The cut on parallax differs between dense and non-dense regions, namely: a) for dense regions: parallax - parallax_error > 10 && astrometric_excess_noise < 2; b) for not dense regions: parallax - parallax_error > 10. Moreover, a cut on bright stars (G < 10) is implemented in order to avoid saturation issues. Effectively this cut eliminates a large number of contaminants (~150,000 sources) at the expense of eliminating a small fraction of true 100 pc members.
- S0316 - OBstars – The goal of this survey is to obtain a large survey of OBstars in the MW disk, complementing efforts being made in WEAVE, as with 4MIDABLE-LR is possible to cover the inner parts of the Galaxy. The catalogue was built from: (1) The Alma Luminous Star catalogue; (2) The WEAVE-SCIP catalogue of OB stars; (3) The Starhorse catalogue; (4) In future optimizations: the VPHAS+ catalogue. Gaia DR3 photometry (G, BP, and RP) was also used. Empirical calibrations were used to compute B, I and (B-V). B and I allow us to estimate saturation limits, colour excess and required SNR in the blue and red region. (B-V) allows us to obtain Av considering a typical (B-V)0 value of -0.8 for OB stars.
- S0317 to S0322 - Seismic Giants Survey from K2, CoRoT and TESS (in both LR and HR in this order: SeisK2_LR, SeisK2_HR, SeisCo_LR, SeisCo_HR, SeisTE_LR, SeisTE_HR). Targets were selected based on their global measured seismic parameters (Δν and ν_max) or the high probability of detecting seismic parameters from their light curves obtained by the CoRoT, K2, and TESS space missions. Our collaboration has published seismic parameters adopted in the construction of this sample over the past years, and will continue to do so in the coming years (e.g. Miglio, Chiappini et al. 2021, Mackereth, Miglio et al 2021, Willet, Miglio et al. 2023). These targets are considered key science calibrators for which we will be able to obtain independent distances, stellar parameters and model-dependent ages.
- S0323 -- Seismic Giant calibrators to be observed by PLATO - SeisPL_HR. The survey sample consists of 60,000 red giants located in the PLATO field of view. For the area in the sky, we used the internal circle that describe the PLATO LOPS2 Field of view, i.e. (in galactic coordinates): l=256.9375, b=-24.62432, radius=24.4º (Nascimbeni, V. private comm.). In this filed we select stars with G <= 15.5, G > 6, parallax > 0, Gbp_Grp > 0.8; ruwe <1 .4. A crossmatch with StarHorse was also considered. The catalogue consists of two groups of targets: **Bright Sample**. This includes targets for which individual frequencies can be measured from PLATO light curves. It is designed to cover the evolutionary stages and mass ranges of stars located in the red giant locus. This sample has been designed for refining stellar tracks and therefore improve the age determination for all PLATO targets. This requires the following properties: 200 red

giants per mass and per Y /Z bin, covering the red giant branch, red clump, and secondary clump, for backtracking those with (rotationally split) mixed modes to the main sequence phase to quantify rotation and mixing profiles. This means we require 200 × 12 × 10 = 24 000 red giants with proper calibration capacity covering M ∈ [0.8, 1.9] M⊙ in steps of 0.05 M⊙, τ ∈ [0.8, 13] Gyr in steps of 1 Gyr, and covering 10 combinations of Y /Z such that Z ∈ [0.005, 0.04] is covered. We selected all Gaia targets falling in the PLATO area, then apply the following cuts: G <=13,5, G > 6; (5*LOG10(1000/parallax)-5) <5; parallax >0; Gbp_Grp>0.8; ruwe<1.4; 10<ν_max<150 (from SH and scaling relations). In order to guarantee a sufficient coverage of a large metallicity range, we kept in the sample all the red giant stars at G<15.5 with StarHorse [M/H]<1 dex. We rounded up the number of targets to 30,000 to optimise the observability by PLATO, e.g. targets may fall in between CCDs. Random selection was based on Gaia DR3 random_index. **Faint Sample**. This catalogue, of the same size of the bright one, includes targets for which at least the global seismic parameters, Δν and ν_max, can be measured. It is also designed to refine stellar tracks, but its main focus is to sample the metallicity range. Because metal-poor stars are further away, targets with fainter magnitudes were chosen, complementary to the bright sample, up to G= 15.5. For this reason, this sample has a significant value for Galactic Archaeology as well, since it is probing further distances. In this case the selection function is also simpler. We select Gaia targets falling in the PLATO area with 13<G < 15.5 mag, parallax > 0, Gbp_Grp > 0.8, ruwe < 1.4. Targets were randomly selected using the same algorithm adopted for the main S03 surveys.

-
- S0324 and S0325 OCs – Clusters (in both LR and HR – OCsHR and OCsLR). Science goal for S0324 and S0325 is to provide cluster calibrators for S3. Measuring multiple stars in the same clusters will allow the S3 results to be cross-calibrated against other surveys while also permitting an understanding of uncertainties. Therefore, similarly to the seismic sub-surveys, the OCs surveys are the backbone of our main surveys (science calibrators).

Table 7: S3 main 4 sub-surveys with their target brightness ranges and the key wavelength ranges where the indicated SNR shall be reached

Subsurvey ID	mag range Gaia Gmag	Wavelength range			Success Criteria SNR per Angstrom
		a	b	c	
S0301 ESN	14-16.5	4500-4700	5260 - 6450	6670 - 6740	SNRa >40 SNRb >50 SNRc >20
S0302 Dyn	14-18	4500-4700	8350 - 8850		SNRa >25 SNRb >25
S0303 Chem	14-18	4500-4700	5140 - 5200	6670 - 6740	SNRa >40 SNRb >50 SNRb >20
S0304 BIG	16-17	4500-4700	5140 - 5200	6670 - 6740	SNRa>20 SNRb>50 SNRc>20

Table 8: S3 additional sub-surveys with their target brightness ranges and the key wavelength ranges where the indicated SNR shall be reached

Subsurvey ID	mag range Gaia Gmag	Wavelength range		Success Criteria SNR per Angstrom
		a	b	
S0305 BD	17-18	same as BIG	same as BIG	same as BIG
S0306 VMP	<17	4500-5200	6670-6740	SNRa>40 or 50 SNRb>20
S0307 VMP_PIGS	14-17	same as Chem	same as Chem	same as Chem
S0308 Ceph	13-19.5	5140-5200	8350-8850	SNRa between 20 and 100, depending on magnitude

S0309 HSD	10-20.5	4500-4700		SNRa>10 or 30 depending on magnitude (faint or bright, respectively)
S0310 WD100	< 20.5	4000-5000	6000-7000	SNRa,b between 10 and 30, depending on magnitude, estimated effective temperature, and available fibre hours in the area.
S0311 WD	< 20.2	4000-5000	6000-7000	SNRa,b between 10 and 30, depending on magnitude, estimated effective temperature, and available fibre hours in the area.
S0312 CWDB	16-22	4210-5545	7410-8135	SNRa,b>3
S0313 PN_CS	10-20.5	4000-5000		SNRa>20 to 200, depending on magnitude
S0314 PN_NEB	14-29	4362-4364		SNRa>20 to 200, depending on magnitude
S0315 A100pc	10-21	6000-6600		SNRa>15 or 30, depending on magnitude (faint or bright, respectively)
S0316 OBstars	10-16	4500-4600	7400-7500	SNRa,b between 80 and 630, depending on magnitude
S0317 SeisK2_LR	<14.5	5140-5200		SNRa>100
	14.5-16.5			SNRa>75
	>16.5			SNRa>25
S0318 SeisK2_HR	<8	5345-5365		SNRa>250
	8<12			SNRa>175
	G>12			SNRa>100

S0319 SeisCo_LR	G<14.5	5140-5200		SNRa>100
	14.5-16.5			SNRa>75
	>16.5			SNRa>25
S0320 SeisCo_HR	<8	5345-5365		SNRa>250
	8-12			SNRa>175
	>12			SNRa>100
S0321 SeisTE_LR	<14.5	5140-5200		SNRa>100
	14.5-16.5			SNRa>75
	>16.5			SNRa>25
S0322 SeisTE_HR	<8	5345-5365		SNRa>250
	8-12			SNRa>175
	>12			SNRa>100
S0323 SeisPL_HR	<8	5345-5365		SNRa>250
	8-12			SNRa>175
	>12			SNRa>100
S0324 OCsLR	12-18	5160-5190	8480-8680	SNRa,b between 50 and 400, depending on magnitude
S0325 OCsHR	<17	3950-3990	5165-5186	SNRa,b between 100 and 800, depending on magnitude

We calculate our Figure of Merit (FoM) in 2 steps. First, we take the individual sub-survey FoMs (input as 'subsurvey_foms'; an array of 25 FoMs) and calculate their weighted sum (below as 'fom_all'). Finally, we take the minimum value among the 'fom_all' and the FoMs for the first four sub-surveys (viz. ESN, Dyn, Chem and BIG): this is the final FoM for the whole S3 survey. This comes from the criteria that for S3 to be considered a success, each of these 4 sub-surveys (viz. ESN, Dyn, Chem and BIG) should have FoM > 0.5.
We adopt the following code:

```
Parameters
    ----------
    subsurvey_foms : array
        FoMs of the subsurveys
    **kwargs: dictionary
        Empty dictionary
    """
# 'weights' array contains weights for each of the 25 sub-surveys.
# Subsurveys: [ESN, Dyn, Chem, BIG, BD, VMP, VMP_PIGS, Ceph, HSD, WD, WD100, CWDB, PN_CS,
PN_NEB, A100pc, OBStars, SeisK2_LR, SeisK2_HR, SeisCo_LR, SeisCo_HR, SeisTE_LR, SeisTE_HR,
SeisPL_HR, OCsLR, OCsHR]
# IDs: [301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321,
322, 323, 324, 325]
weights = np.array([1, 1, 3, 3, 1, 3, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 3, 1, 3, 1, 3, 3, 3, 3])
# 'fom_all' is the FoM for all the sub-surveys combined according to their weight.
# From FoM definition: fom_all = Sum_{i=1,17}((w_i/28)*FoM_i)
fom_all = np.dot(weights/np.sum(weights), subsurvey_foms.T)
# 'result' is the final FoM for the whole S3 survey. Here we assume the array subsurvey_foms has the same
# order as the subsurvey name list above. This has to be correct!
# From FoM definition: result = min(min{FoM_k}, fom_all) ; k = 1..4
result = np.min(np.asarray([np.min(subsurvey_foms[:, :4], axis=1), fom_all]).T, axis=1)
return result
```

6.3.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.3.4 Management Structure

Given the complexity of S3, we have named SSLs (sub-survey leaders). These are responsible for the preparation of the target catalogues and are encouraged to contribute to other work packages inside the project. The PIs together with the SH and the whole team are responsible for the preparation of the main catalogues. The SSLs are part of the management team and are listed in Table 1a. In Figure 1 we summarise the main milestones of our survey since 2018 (Gaia DR2). Currently, we are in the final optimisation phase for which the IWG2 simulations have been essential. This comprises the use of XP-spectra (which came out with Gaia DR3 - June 2022) to improve the metal poor candidates and exploration of cadence requirements (as also indicated in the Figure below).

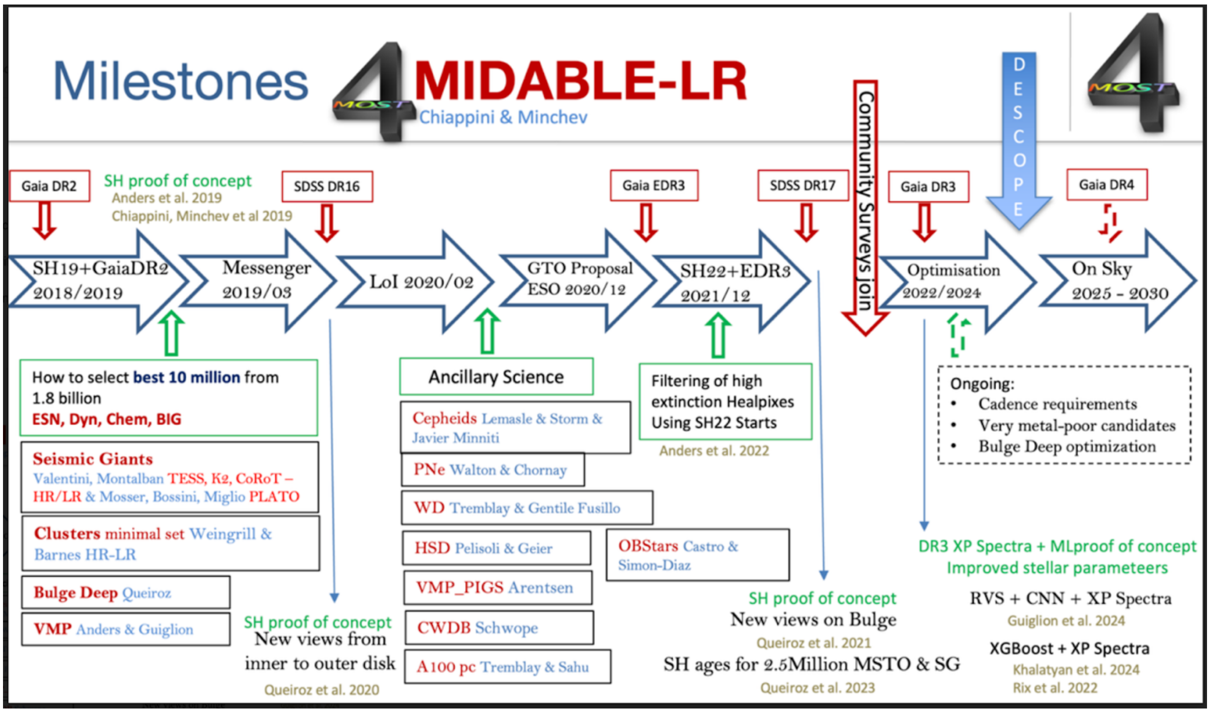


Figure 9: S3 Milestones and organisation

The decision-making process in 4MIDABLE-LR is always via discussions with the whole team. Most of the decisions are taken during the team telecons (once a month, for which the whole team is invited). There is a core team (PIs, SSLs and WP managers) but these are more operational, while important decisions are taken by the whole group. For the large catalogues the whole preparation steps are made transparent using the colab.aip.de system. The survey, even though complex, has a simple, inclusive and diverse management structure. More details on publication policies and outreach activities will be clarified soon.

During the steep learning curve since Gaia DR2, the work devoted to understanding the Gaia Data, and using the SH (a spectrophotometric Bayesian code - Queiroz et al. 2018) to provide primarily distance and extinctions (but also stellar parameters such as temperature, gravities and metallicities) has been crucial to define our survey strategy. While SH is not used for the target selection of the MSs, derived SH stellar parameters are used in the template assignment for the simulations, as well as for a posteriori check of our target selections. The SH extinctions (which have improved since Gaia EDR3) also play an important role in masking heavily extinct healpixes). The VMP survey target catalogue (a key catalogue since the beginning of S3), could now be optimised thanks to the XP-spectra of Gaia DR3, and that is ongoing. SH has also demonstrated that precise distances can be obtained once spectroscopic data are available. The support from the SH team as well as the AIP Infrastructure (e.g., required computer power, infrastructure for the SH releases – data.aip.de – and support from the eScience AIP session) has been critical for the target selection preparation of the largest catalogues, and are greatly acknowledged.

6.3.5 Work-breakdown structure

Figure 10 shows the S3 survey WBS (blue boxes). White lines connecting the blue and red boxes indicate the major interfaces of S3 with a corresponding IWG, where the activities for this survey will be merged and connected with similar activities in other surveys. Black lines connecting the blue and white boxes indicate the major interfaces of S3 with the SH Team and AIP Infrastructure. Not all interfaces are shown in the figure.

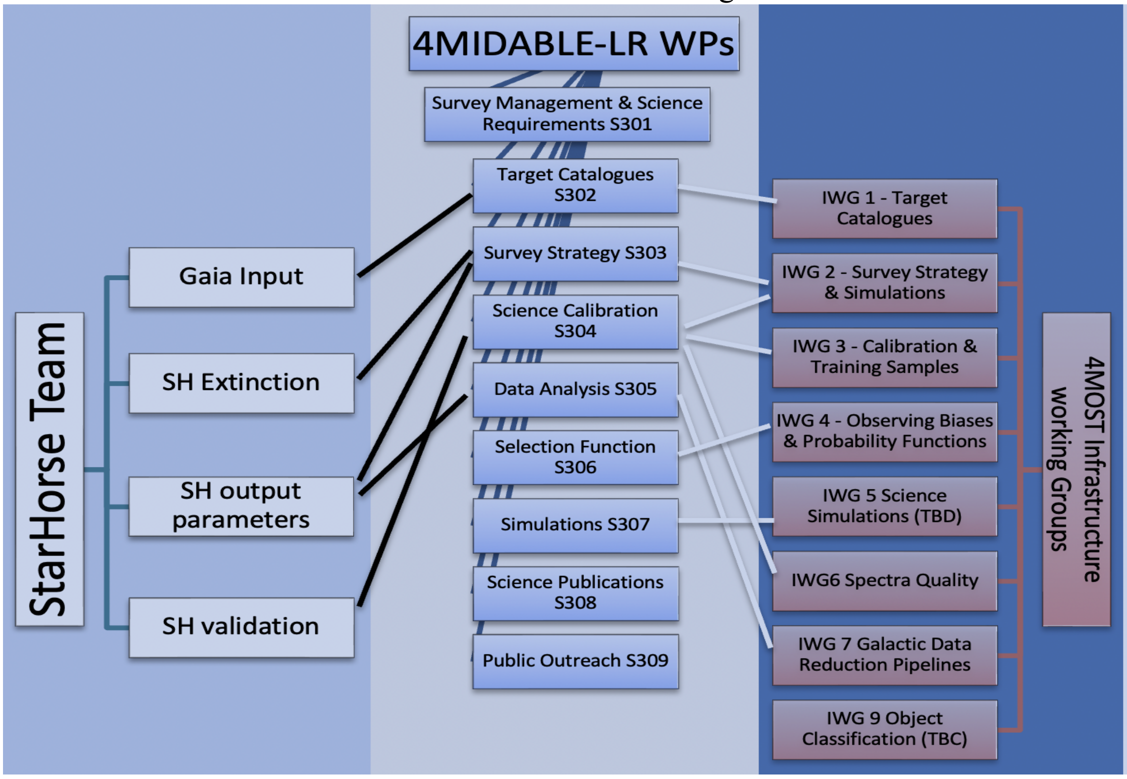


Figure 10: S3 Work Packages and Interfaces

Short description of 4MIDABLE-LR S3 Work Packages:

WP_S301: Survey Management, Science Requirements, Interface with other Surveys in 4MOST - The co-PIs Chiappini and Minchev lead the development of survey strategy, the construction and compilation of the main survey target catalogues, define the figures of merit and monitor the survey progress. The co-PIs are furthermore responsible for overall team leadership and coordinating the use and scientific exploitation of the survey data. In particular, one of the main activities of this WP during the last years has been to include the AC science, as well as organise the infrastructure needed for the Gaia exploitation and preparation of the largest S3 catalogues. Resources: ~0.4 FTE/year.

WP_S302: Target Catalogues. This WP involves a 2-step preparation of target catalogues: a) the science input catalogues are created, b) catalogues are put in the format required for ingestion in 4FS, together with the required auxiliary files. All SSLs are part of this WP. This WP is strongly connected to the SH Team. Several ST members have been working to bring the catalogues to the latest format requests by IWG2, assigning templates and concatenating the main catalogue (out of the sub-survey catalogues). Resources: ~0.3 FTE/year.

WP_S303: Survey Strategy – Analysis of the simulations. This goes beyond the analysis of IWG2 plots, but involves the analysis of the output simulation files. Currently this task is done by SSLs for the smaller catalogues and by dedicated ST members (not necessarily SSLs). Resources: ~0.1 FTE/year.

WP_S304: Science Calibration – Here our main science calibrators are analysed, OCs and Seismic Giants. These will provide validation targets for the SH products. This WP might be split in two (one for clusters and one for seismic giants). This WP shall be responsible for the delivering of DL2-SURV products. Moreover, this WP is strongly connected to the work of the

SH Team. Part of this WP became the current IWG3 (along the past years a large effort was made by S3 towards science calibration for the survey by considering the need for special targets, observations to optimise calibration strategies, and preparing cross-survey calibrations, including asteroseismology targets). We will coordinate with the S13 calibration open clusters. Resources: ~0.2 FTE/year.
WP_S305: Data Analysis – Spectroscopic pipeline run and quality control of the deliverables. Different machine-learning and classical pipelines are being explored (Cannon, Payne, CNN). It is not clear at this point if these will be all added to the main 4MOST pipeline. This WP within S3 is tackling this question among others. S3 members of the OBstars, PN, WD and Ceph surveys plan to contribute to the 4GP pipeline and are part of IWG7. One of the tasks of this WP is to produce a clear overview of what the DL2-SURV products need to be, beyond what will be included in the DL2-IWG. Currently, this WP is also analyzing OPR spectra (and is also connected to IWG6). Resources: ~0.3 FTE/year.
WP_S306: Selection Function – In this WP the full selection function of the survey will be computed. This includes the work done in IWG4, but also the target selection used to create the catalogues. For the main catalogues the Target Selection is entirely based on parallax and magnitude range, providing an efficient and traceable selection function. Resources: ~0.2 FTE/year.
WP_S307: Simulations – All SSLs should also take part in activities involved in this WP. Resources: ~0.2 FTE/year.
WP_S308: Science Publications and Data Releases. Preparing release files of S3. Mirror at www.aip.de, Resources: ~0.3 FTE/year.
WP_S309: Outreach. We will have one responsible for a 4MIDABLE-LR website. Resources: ~0.1 FTE/year.

6.3.6 Contribution to the Infrastructure Working Groups

As a consortium survey, we expect to contribute to and benefit from the centralised 4MOST Consortium data-flow system and participate in the 4MOST Infrastructure Working Groups. In the IWGs we will contribute our expertise to developing the survey strategy, the data reduction and analysis pipelines, the selection function analysis, and data quality control, archiving and publishing. Below there is a list of current S3 members assigned to IWGs (notice that this does not include S3 members assigned to these IWGs by other surveys). Moreover, one of our team members (N. Walton) contributes to DMS. Currently, S3 members are the co-leads of IWG2, IWG3, IWG4 and IWG7, devoting a large fraction of their FTEs to the project as a whole, therefore benefiting several surveys. The drawback of this is that these members have very little FTEs to dedicate to survey specific tasks.

IWG1
B. Ratcliffe .
C. Chiappini – PI, and member of SH team (acts as deputy in IWG1 for now – need one more S3 member)).
- Resources: ~0.1 FTE/year.

IWG2
S3 provides a large contribution to IWG2. The Galactic co-chair is an S3 member. Other members have provided different contributions along these years (as described briefly below):
C. Chiappini (PI) – overall feedback on simulations and strategy
I. Minchev (PI) – interface of our catalogues with 4FS, feedback on simulations and strategy

A. B. Queiroz – IWG2 co-chair of Bulgeand disk WG
S. Khoperskov – IWG2 co-chair Bulge- and Disk WG
G. Guiglion – IWG2 member (focus on spectral quality and Templates)
G. Traven – IWG2 Multiplicity WG
A. Arentsen – IWG2 Multiplicity WG
M. Dorsch - IWG2 Multiplicity WG
E. Balbinot – IWG2 S3 member of WG Magellanic Clouds
N. Walton – link to DMS
J. Storm – IWG2 co-chair

- Resources: ~0.4 FTE/year.

IWG3

S3 has not only the Galactic lead in this IWG but is also making a large contribution to ensure the best calibration outcome to the whole 4MOST survey.

M. Valentini (IWG3 Galactic Lead)
J. Montalban – Seismo expert
A. Miglio – Seismo expert
S. Barnes – Clusters expert
J. Weingrill – Clusters expert
N. Castro – OB stars expert
G. Guiglion – Machine Learning Training samples
Š. Mikolaitis – Pipeline calibration/science verification
G. Cescutti – pipeline calibration – metal-poor

- Resources: ~0.5 FTE/year.

IWG4

Currently there are no specific roles assigned to the S3 members in IWG4.

S. Sharma
C. Chiappini
P.E. Tremblay
E. Starkenburg
L. Casagrande

- Resources: ~0.2 FTE/year.

IWG6

G. Guiglion
M. Valentini
S. Simon-Diaz
E. Balbinot
I. Pelisoli

- Resources: ~0.2 FTE/year.

IWG7

S3 has an important contribution to IWG7. In particular, S3 contributed to the pipeline modulus for White Dwarfs, FGK stars payne/CNN/Cannon, HSD and PNe. In particular, S3 is contributing to the OBA module in 4GP, developed by Joachim Bestelehner for the analysis of OB stars in S9, but which is also being adapted for S3. In the case of OB stars the deliverables are Teff, log g, radial velocities, He abundances, rough Vsini. Moreover, two of the S3 members are IWG7 leaders.

G. Guiglion – Pipeline CNN

M. Valentini – Analysis pipeline – Seismic calibrations
W. Sun – Pipeline Payne
G. Traven – Pipeline Cannon
G. Kordopatis (IWG7 co-leader)
R. Church (IWG7 co-leader)
N. Gentile Fusillo – WDs expert
P.E. Tremblay - WDs expert
E. Grebel – Variable stars expert
N. Walton - PN
M. Bergemann - NLTE
M. Dorsch - Hot sub-dwarfs pipeline
S. Simon Diaz - OB stars expert
N. Castro - OB stars expert
- Resources: ~0.5 FTE/year.

6.3.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.3.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of S3 Survey will be processed by the 4GP pipeline and quality-controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
Further to the standard data products from the common 4MOST pipelines, a Survey may have extra Deliverable L2 Survey products (DL2-SURV) that will go to both the ESO Science Archive Facility (SAF) and the 4MOST Public Archive (4PA). They may furthermore elect to produce Additional L2 data products (AL2) that will only be made available through 4PA. Such data products are described in the following subsections.
In addition, the data products described in the following subsections will be provided.

6.3.8.1 Deliverable L2 Survey data: reduction processing

Below is a list of DL2-SURV data products to be delivered by S3.
All data to be delivered during Phase 3 will comply with the data standards (ESO-044286).

- Star Horse deliverables - *StarHorse* (software description in Queiroz et al. 2018) deliverables are considered L2 Data products of S3. These will be coming from the SH Team (see Figure 2). The deliverables here are similar to the ones produced by Queiroz et al. (2020, 2023) for SDSS data releases and will include distances and extinction (primary deliverables), as well as secondary parameters such as Teff_SH, logg_SH, and Ages_SH stellar. Stellar ages shall be delivered only for part of the dataset, MSTO and subgiants for which isochrone-ages are credible – as the ones produced by Queiroz et al. 2023).
- Seismic Red giants - distances, radii, mass, reddening, which serve as science calibrators for S3

6.3.8.2 Deliverable L2 Survey data: quality assessment

For all the DL2-SURV data described above, the quality control will be taken care of by their sub-survey leaders of the above sub-surveys and by the StarHorse Team. These are going to be also part of scientific publications (just as the SH Team did in the case of SDSS). These quality control procedures will run for the entire duration of the survey. Quality control will curate data that are demonstrably wrong (systematic error far outside formal error, e.g. wavelengths outside arm range or negative temperature for stars) and will add flags to create warnings for possibly unreliable data.

6.3.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.3.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

The vast majority of L2 data products for S3 targets, including spectroscopic stellar parameters and chemical abundances, will be delivered as DL2-IWG products following the agreed DR schedule. The smaller set of DL2-SURV products we plan to produce are secondary in nature, in the sense that they depend on having DL2-IWG parameters available. We therefore commit to releasing our DL2-SURV products at the closest DR following journal publication, with the aim to start publications with DR2.

6.3.8.5 Deliverable L2 Survey data: Required hardware and staff

- SH Team - 1 PhD, 1 Postdoc and 3 staff (all in partial time) - Software ready.
- Seismic Red Giants - Team members (5) - software ready.

6.3.8.6 Additional L2 data: reduction processing

- Seismic Red giants - Individual ages
- OBstars - Wind strength Q and ionising fluxes logQ(H0) and logQ(He0) - the wind strength Q-parameter will not be a deliverable product because only upper limits can be provided for many stars with weak winds.
- In addition to the L2 pipeline output the S0310 and S0311 surveys of white dwarfs will also produce mass and cooling age estimates for all their targets. As these additional stellar parameters are not directly measured from the spectra and their derivation requires some underlying assumptions, they will only be included as additional data products. Dedicated python scripts will be used to ingest the L2 pipeline products (Teff

and logg) and calculate the additional stellar parameters for each white dwarf target. We will adopt the most recent white dwarf mass-radius relation and use pre-computed grids of masses and cooling ages corresponding to the atmospheric composition of the target white dwarf. The specific mass and cooling age of each target will be obtained by interpolating the grid points at the Teff and logg values calculated by the pipeline.

6.3.8.7 Additional L2 data: quality assessment

- WDs S3010 and S3011: White dwarf Masses and cooling ages will be calculated from pre-computed grids starting from the already quality-assessed Teff and logg outputs of the pipeline. By definitions these values will be within the physical range expected for white dwarfs. Output values that correspond to the edge of the grids will be flagged as potentially unreliability. All Mass and cooling age outputs will be compared to the values in Gentile Fusillo et al. 2021 calculated using Gaia photometry and parallaxes. This comparison will be used to assess the potential biases, trends and evaluate the overall reliability of the uncertainties. Dedicated python scripts will be used to carry out all quality assurance steps. These procedures are not computationally expensive nor time consuming and can be carried out for each Data Release.

6.3.8.8 Additional L2 data: data delivery and Phase 3 compliance

All data to be delivered during Phase 3 must comply with the ESO science data standards (ESO-044286).

- WDs S3010 and S3011: The additional stellar parameters (Teff and cooling ages) will be provided as part of catalogues of 4MOST white dwarfs produced for each Data Release. All data will be handled directly by the sub-survey leads Nicola Gentile Fusillo and Pier-Emmanuel Tremblay.

6.3.8.9 Additional L2 data: product delivery schedule to the 4PA archive

- WDs S3010 and S3011: For each planned Data Release we will prepare a catalogue of 4MOST white dwarfs that will also contain the additional stellar parameter. Therefore, these AL2 products will be delivered to the 4PA archive in Data Release instalments (i.e., for all white dwarfs which will be included in the Data Release) ahead of each scheduled Data Release date. We will release the data products associated with a scientific publication at the next DR.

6.3.8.10 Additional L2 data: Required hardware and staff

- WDs S3010 and S3011: The computation of the additional data products is not computationally expensive. All necessary hardware is already available and the all effort will be carried out by Nicola Gentile Fusillo and Pier-Emmanuel Tremblay.

6.3.9 Team

The current management Team structure is described in Table 8. Sub-survey Leaders should contribute a minimum of 0.1 FTE. We expect to increase our resources (either by encouraging more members to effectively participate with at least 0.1 FTE, and/or by having more external members, or upon grant applications - our current 65 survey members are listed in Table 9).

Table 8: Survey S3 sub-survey leaders, with their affiliation, and expected FTE/yr contributions

	Leaders	+SH Team	+all	FTEs/yr
ESN	PIs	Chiappini/Minchev	+all	0.3/0.3
Dyn	PIs	Chiappini/Minchev	+all	
Chem	PIs	Chiappini/Minchev	+all	
BIG	PIs	Chiappini/Minchev	+all	

Seismo	Valentini/Montalban	AIP/UniBo	0.1/0.1
OCs	Weingrill/Barnes	AIP/AIP	0.1/0.1
VMP	Anders/Guiglion	ICCUB/ZAH/LSW, MPIA	0.1/0.1
BD	Queiroz	IAC	0.1
Cepheids	Storm/Lemasle/Minniti	AIP/Heildelberg Univ.	0.1/0.1/0.1
PN	Walton/Chornay	IoA/IoA	0.1/0.1
WDs	Tremblay/Gentile Fusillo	Warwick/Trieste Univ.	0.1/0.1
HSD	Geier/Pelisoli	UniPotsdam/ Warwick	0.1/0.1
VMP_PIGS	Andern-Arentsen	IoA	0.1
CWDB	Schwope	AIP	0.1
A100pc	Tremblay/Sahu	Warwick	0.1/0.1
OBstars	Castro/Simon-Diaz	AIP/IAC	0.1/0.1
Plato giants	Mosser/Bossini/Miglio	GEPI/IA/UniBo	0.1/0.1/0.1

Table 9: Survey S3 members with their affiliation, roles, and total expected FTE/yr contributions next to science exploitation

Name	Affiliation	Function	FTE
Friedrich Anders	ICCUB	StarHorse Interface Leader, VMP sub-survey leader Management Team,	0.1
Anke Andern-Arentsen	IoA	VMP_PIGS sub-survey leader Management Team, IWG2-multiplicity WG	0.1
Coryn Bailer-Jones	MPIA		0.05
Eduardo Balbinot	RuG	IWG6, IWG2	0.05
Sydney Barnes	AIP	OC sub-survey leader Management Team	0.1
Thomas Bensby	LU		0.05
Maria Bergemann	MPIA	IWG7	0.05

Name	Affiliation	Function	FTE
Joachim Bestenlehner	Sheffield	IWG6, IWG7	0.05
Diego Bossini	IA	Seismic Plato sub-survey leader, Management Team	0.1
Luca Casagrande	ANU	IWG4	0.1
Andrew Casey	Monash		TBD
Norberto Castro	AIP	OBstars sub-survey leader Management Team, IWG3, IWG7	0.1
Gabriele Cescutti	OATS	IWG3, WP_S304	0.1
Cristina Chiappini	AIP	PI, SCB, STSC, Membership manager, WP_S301 leader Management Team	0.3
Nick Chornay	IoA	PN sub-survey leader Management Team	0.1
Ross Church	LU	IWG7	0.15
Anna Barbara de Andrade Queiroz	IAC	StarHorse Interface Leader BD sub-survey leader Management Team, IWG2	0.1
Matti Dorsch	Potsdam	IWG2-Multiplicity WG	0.1
Jay Farihi	UCL		TBD
Sofia Feltzing	LU		0.15
Morgan Fouesneau	MPIA		TBD
Francesca Fragkoudi	Durham		0.1
Stephan Geier	Potsdam	HSD sub-survey leader Management Team	0.1
Nicola Gentile Fusillo	Trieste Univ.	WD sub-survey leader Management Team, IWG7	0.1
Ortwin Gerhard	MPE		0.05
Eva Grebel	Heildelberg Univ.		0.05
David Gruner	AIP		0.05
Amina Helmi	RuG		TBD
David Hobbs	LU	Executive Board	0.1
Arman Khalatyan	AIP	StarHorseTeam / AIP e-Science	0.1
Sergey Khoperskov	AIP	WP_S302 leader Management Team, IWG2	0.2
Georges Kordopatis	OCA	IWG7	0.15
SungWon Kwak	AIP		0.1

Name	Affiliation	Function	FTE
Andrea Miglio	UniBo	Seismic Plato sub-survey leader, Management Team	0.1
Šarūnas Mikolaitis	TFAI	IWG3, WP_S304	0.1
Ivan Minchev	AIP	PI, SCB, SSLs Interface, Membership manager, WP_S301 leader Management Team	0.3
Javier Minniti	John Hopkins	Cepheids	0.1
Josefina Montalban	UniBo	Seismo sub-survey leader Management Team	0.1
Benoit Mosser	GEPI	Seismic Plato sub-survey leader, Management Team	0.1
Samir Nepal	AIP	WP_S303, SH Team	0.1
Ingrid Pelisoli	Warwick	HSD sub-survey leader Management Team	0.1
Bridget Ratcliffe	AIP	IWG1, WP_S304	0.1
Hans-Walter Rix	MPIA		0.1
Nils Ryde	LU	SPB, Management Team	0.1
Andreas Sandler	Heildelberg Univ.	OBstars	0.1
Christian Schneider	UHH		TBD
Axel Schwope	AIP	CWDB sub-survey leader Management Team	0.1
Sanjib Sharma	SIFA	IWG4	0.1
Sergio Simón-Díaz	IAC	OBstars sub-survey leader Management Team, IWG7, IWG6	0.1
Else Starkenburg	RuG	IWG4	0.05
Matthias Steinmetz	AIP	Executive Board	0.1
Jesper Storm	AIP	WP_S303 leader Cepheid sub-survey leader Management Team	0.2
Weijia Sun	AIP	WP_S305, IWG7	0.2
Gregor Traven	UNILJ	WP_S305, IWG7, IWG2-multiplicity WG	0.05
Pier-Emmanuel Tremblay	Warwick	WD sub-survey leader A100pc sub-survey leader Management Team , IWG4	0.1
Marica Valentini	AIP	WP_S304 leader Management Team, IWG3 Leader	0.2

Name	**Affiliation**	**Function**	**FTE**
Nicholas Walton	IoA	PN sub-survey leader Management Team	0.1
Jörg Weingrill	AIP	OC sub-survey leader Management Team	0.1
Daniel Zucker	AAO-MQ		0.05

6.4 Survey 4 – Milky Way Disk and Bulge High-Resolution Survey (4MIDABLE-HR)

Survey PIs: Thomas Bensby, Maria Bergemann

6.4.1 Science Summary

The signatures of the formation and evolution of a galaxy are imprinted in its stars. Their velocities, ages, and chemical compositions present major constraints on models of galaxy formation, and on various processes such as the gas inflows and outflows, the accretion of cold gas, radial migration, and the variability of star formation activity. Understanding the evolution of the Milky Way requires large observational datasets of stars via which these quantities can be determined accurately. This is the science driver of the 4MOST MIlky way Disc And BuLgE High-Resolution (4MIDABLE-HR) survey: to obtain high-resolution spectra at R=20 000 and to provide detailed elemental abundances for large samples of stars in the Galactic disc and bulge. These data will allow us to obtain precise spectroscopic diagnostics of more than three million stars: precise radial velocities; rotation; abundances of many elements, including those that are currently only accessible in the optical, such as Li, s-, and r-process; and multi-epoch spectra for a sub-sample of stars. Synergies with complementary missions like Gaia and TESS will provide masses, stellar ages and multiplicity, forming a multi-dimensional dataset that will allow us to explore and constrain the origin, chemical evolution, and structure of the Milky Way.

This science case is covered in eleven SubSurveys:

- S0401 – 4MIDABLEHR_DISK
- S0402 – 4MIDABLEHR_ZDISK
- S0403 – 4MIDABLEHR_DEEPBULGE
- S0404 – 4MIDABLEHR_CEPHEIDS
- S0405 – 4MIDABLEHR_EROSITA
- S0406 – 4MIDABLEHR_SEISMIC
- S0407 – 4MIDABLEHR_CLUSTERS
- S0408 – 4MIDABLEHR_PLANETS
- S0409 – 4MIDABLEHR_LOWMETALLICITY
- S0410 – 4MIDABLEHR_PLATO
- S0411 - 4MIDABLE_K2
- S0412 - 4MIDABLE_TESSPRIOR

Expanded science description: messenger-no175-35-38.pdf

6.4.2 Target Catalogue

Plots have been updated according to the catalogue upload dated 2025-03-28. Further details are available at *4MOST SMP: Survey Simulation Prediction [RD10]* web site.

S0401 – 4MIDABLEHR_DISK

S0402 – 4MIDABLEHR_ZDISK

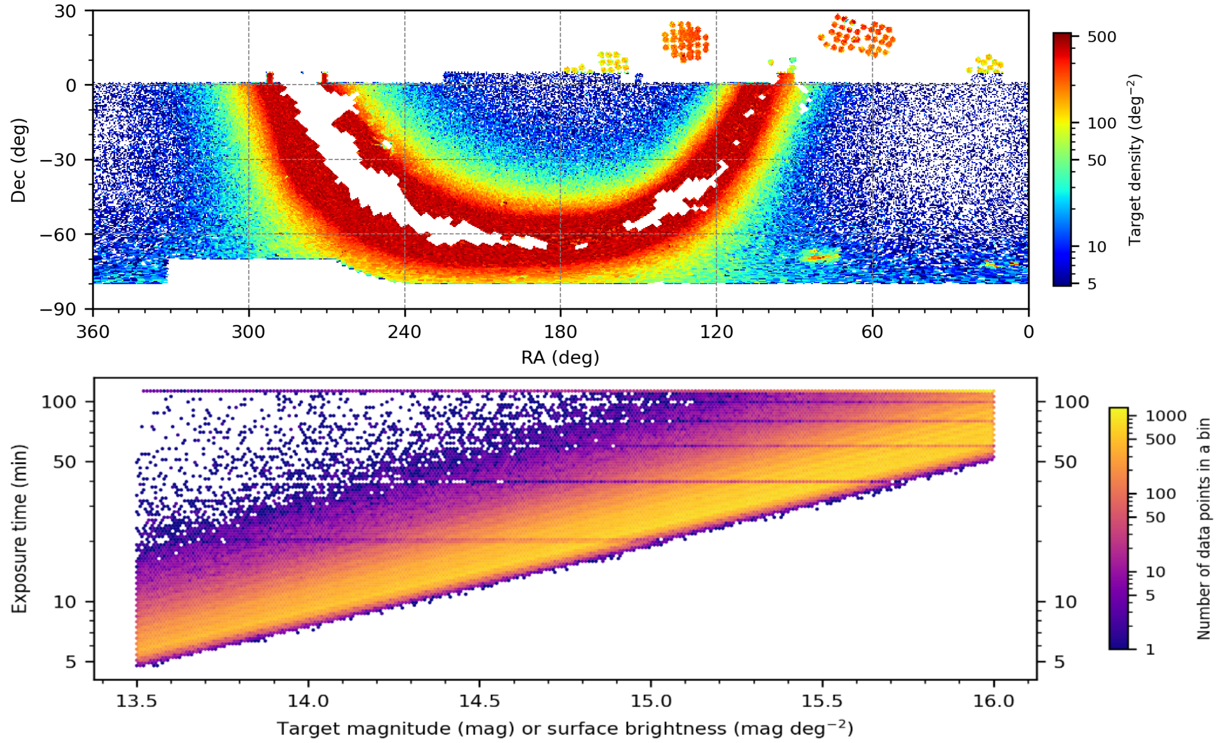


Figure 11: Top) Input target distribution of the subsurvey S0401 4MIDABLEHR_DISK. Bottom) The exposure time estimates as function of target G-mag.

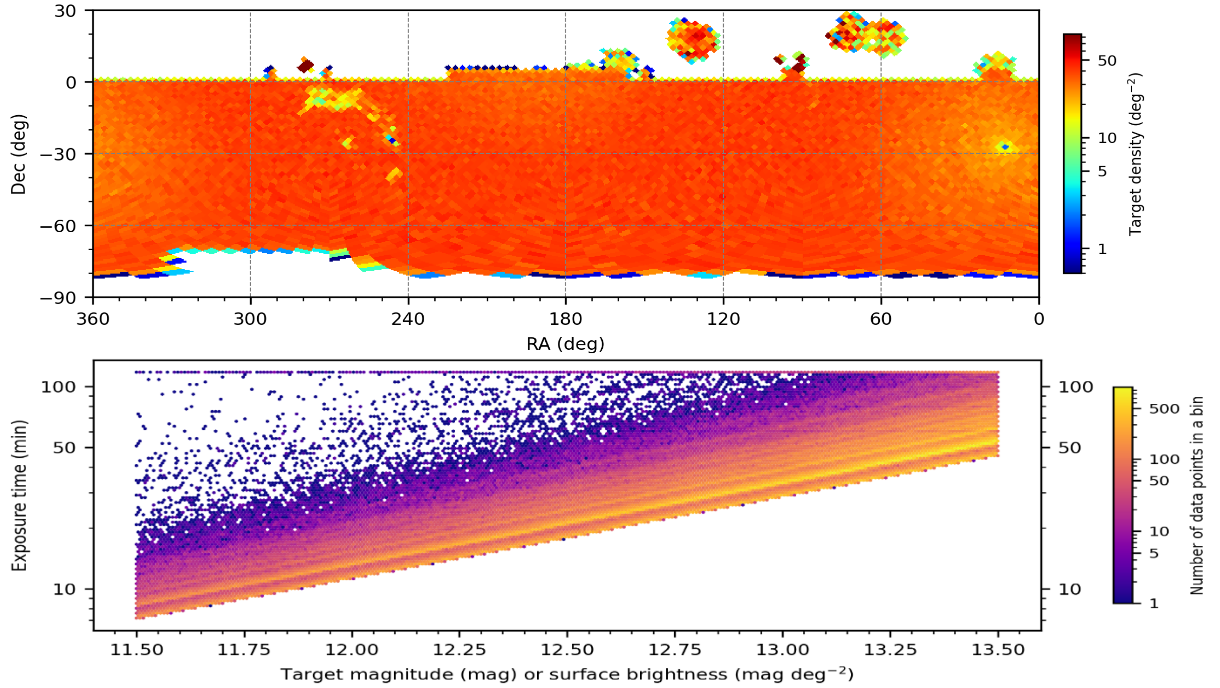


Figure 12: Top) Input target distribution of the subsurvey S0402 4MIDABLEHR_ZDISK. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the two subsurveys S0401 and S0402 is displayed in the top panels of Figure 11 and Figure 12 covering in total 5.87M and 770k targets in the Galactic disk, respectively. The completeness limit is 50% and the required area to be observed is ~18,000 deg^2 for both subsurveys (see Table 9). S0401 selects within $13.5 < G < 16$ and the target S/N is 100/Å in the green, while S0402 selects within $11.5 < G < 13.5$ and the target S/N is 250/Å in the blue. Targets are selected directly, without any restriction based on parallax. For S0401 there is an absolute magnitude cut at M_G < 2 in order to have a homogeneous sample of red giant stars throughout the MW disk. For S0402 there is an absolute magnitude cut of 2 < M_G < 6 to avoid red giants and main sequence KM dwarfs.. Resulting exposure time estimates are displayed in the bottom panels of the figures. Additional targets at b>+5 have been added to aid observations of seismic fields. S0401 and S0402 science greatly benefits from being able to detect multiplicity of targets by radial velocity variation between exposures. The cadence flag is therefore set to (1, 0, 0, 340), for all targets except those with exposure time in dark conditions exceeding 60 min. Multiplicity information aids the scientific exploitation of the surveys, as it enables more detailed analysis of the relevance of binaries (low-, and high-mass) in the Galactic chemical evolution, but also the data will help to constrain the accuracy of abundances and possible effects of secular stellar evolution. This means that targets are removed from the target pool after each observation and only re-entered after 340 days. Due to seasonal constraints on optimally repeating visits to targets, slightly less than 1 year was chosen in order to allow the algorithm more flexibility.

S0403 – 4MIDABLEHR_DEEPBULGE

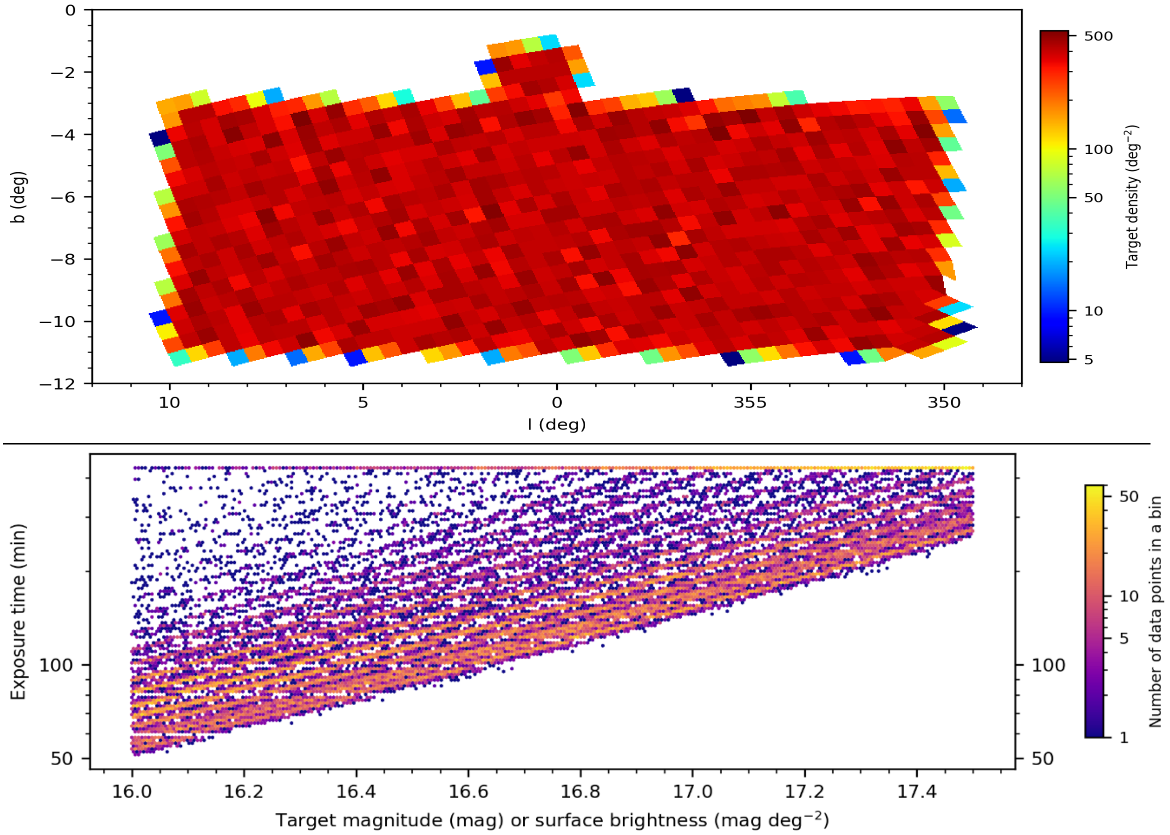


Figure 13: Input target distribution of the subsurvey S0403 4MIDABLEHR_DEEPBULGE. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the S0403 subsurvey is displayed in Figure 13, covering in total 68k targets in the bulge region (220 deg^2). The completeness limit is 50%. S0403 (deep bulge) selects within $16 < G < 17.5$ and the target S/N is 100/Å in the green. Resulting exposure time estimates are displayed in the bottom panels of the figures. S0403 has no cadence requirements.

S0404 – 4MIDABLEHR_CEPHEIDS

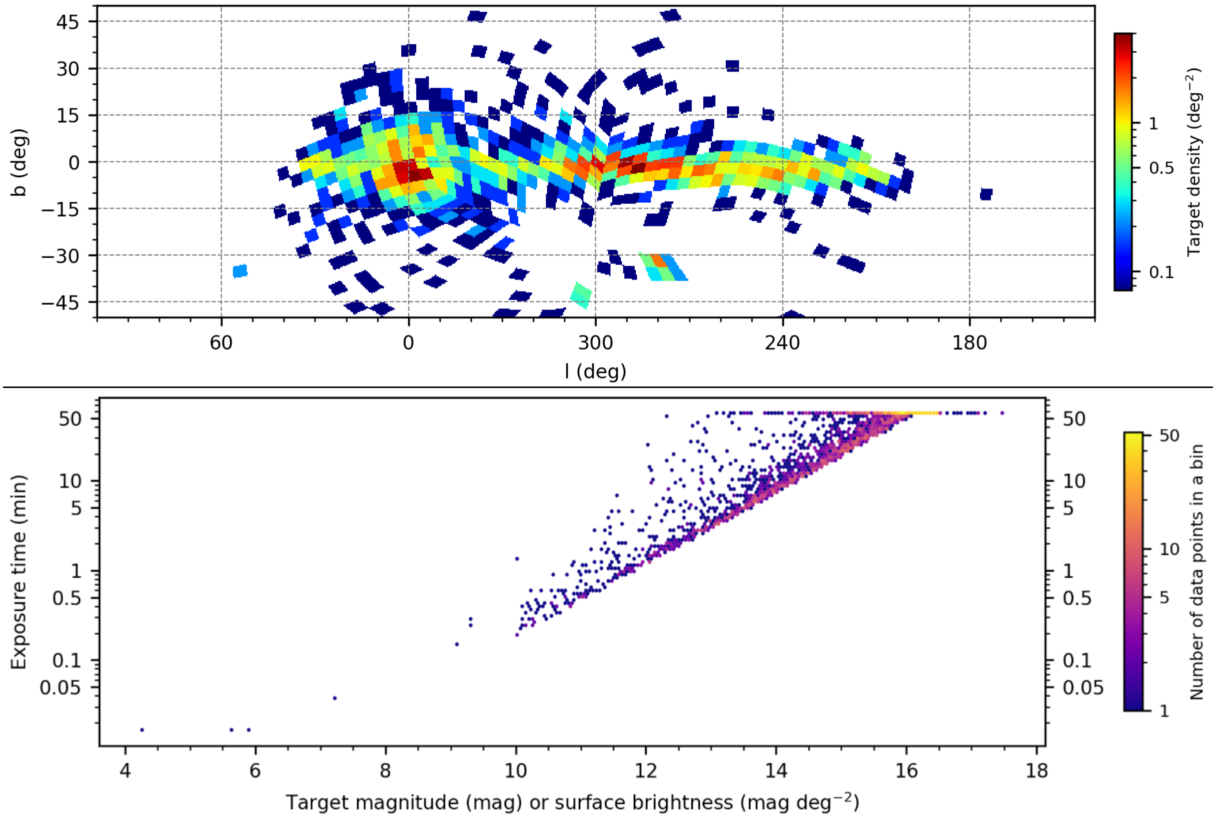


Figure 14: Input target distribution of the subsurvey S0404 4MIDABLEHR_CEPHEIDS. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of S0404 is displayed in the top panel of Figure 14 covering in total about 3,000 Cepheids over 3500 deg^2 distributed over the Galactic midplane. The completeness limit is 50%. S0404 selects within $10 < G < 16.5$ and the target S/N is 100/Å in the green. Resulting exposure time estimates are displayed in the bottom panels of the figures. The cadence flag is set to (1,1,9,60) to represent that targets should be observed 9 times with a cadence of at least 60 days. Each time, observations should be completed within a single OB because the intrinsic variability of these targets does not allow stacking.

S0405 – 4MIDABLEHR_EROSITA

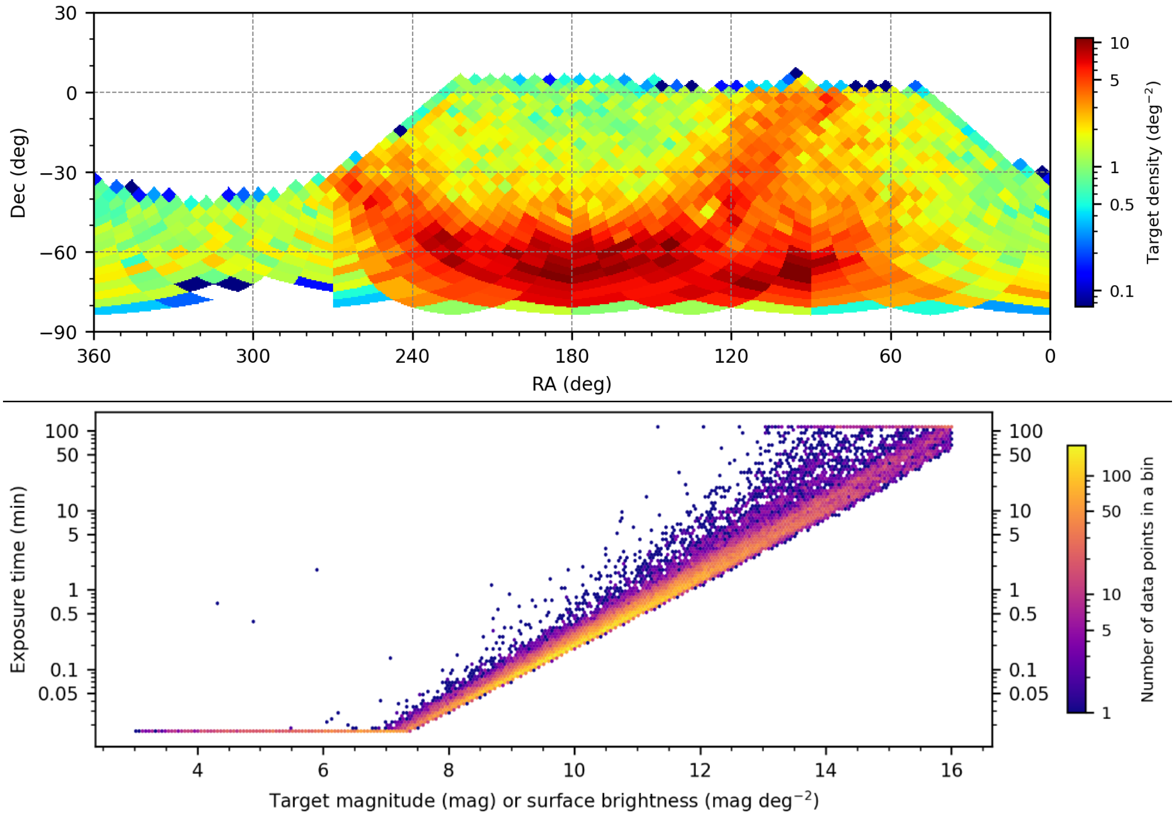


Figure 15: Top) Input target distribution of the subsurvey S0406 4MIDABLEHR_EROSITA. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of S0405 is displayed in the top panel of Figure 15 covering 45.7k HR targets identified as stars in the eROSITA catalogue. The completeness limit is 95% and the required area to be observed is 14,000 deg^2 (see Table 10). The target S/N is 100/Å in the green, with resulting exposure time estimates displayed in the bottom panels of the figures. No cadence is required for eROSITA targets.

S0406 – 4MIDABLEHR_SEISMIC

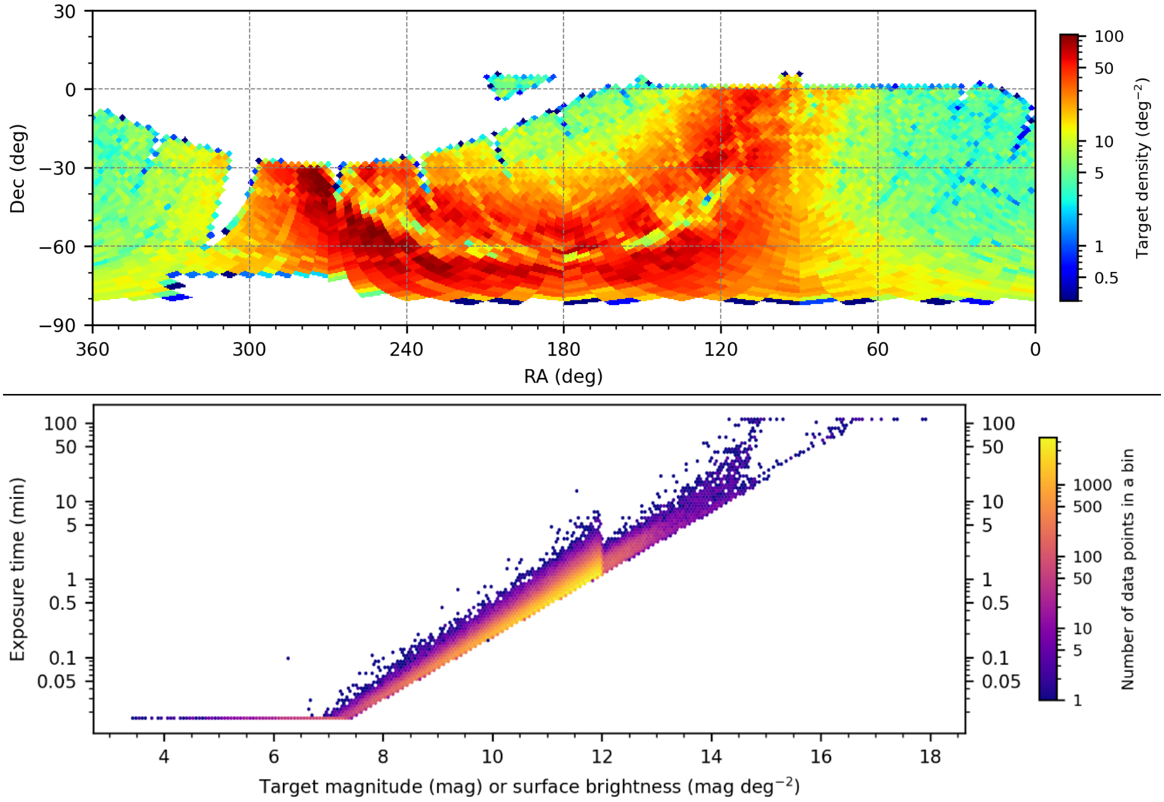


Figure 16: Top) Input target distribution of the subsurvey S0407 4MIDABLEHR_SEISMIC. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the subsurvey S0406 (SEISMIC) (is displayed in the top panel of Figure 16) includes 353k targets observed with TESS and with seismic detection or G < 12. The completeness limit is 50% and the required area to be observed is 14,533 deg2. The target S/N is 100/A in the green. There are cadence requirements for this subsurvey (0, 0, 0, 0), (0, 1, 0, 0).

S0407 – 4MIDABLEHR_CLUSTERS

This subsurvey contains about 1000 additional TESS targets that are located in open clusters, while S0407 targets are field stars. The completeness limit is 95% and the required area 57 deg^2. The science exploitation of open cluster targets is coordinated with S13. The target S/N is 250/Å for G<13.5 and 100/Å for G>13.5. Plots omitted because of the very small number of clusters.

S0408 – 4MIDABLEHR_PLANETS

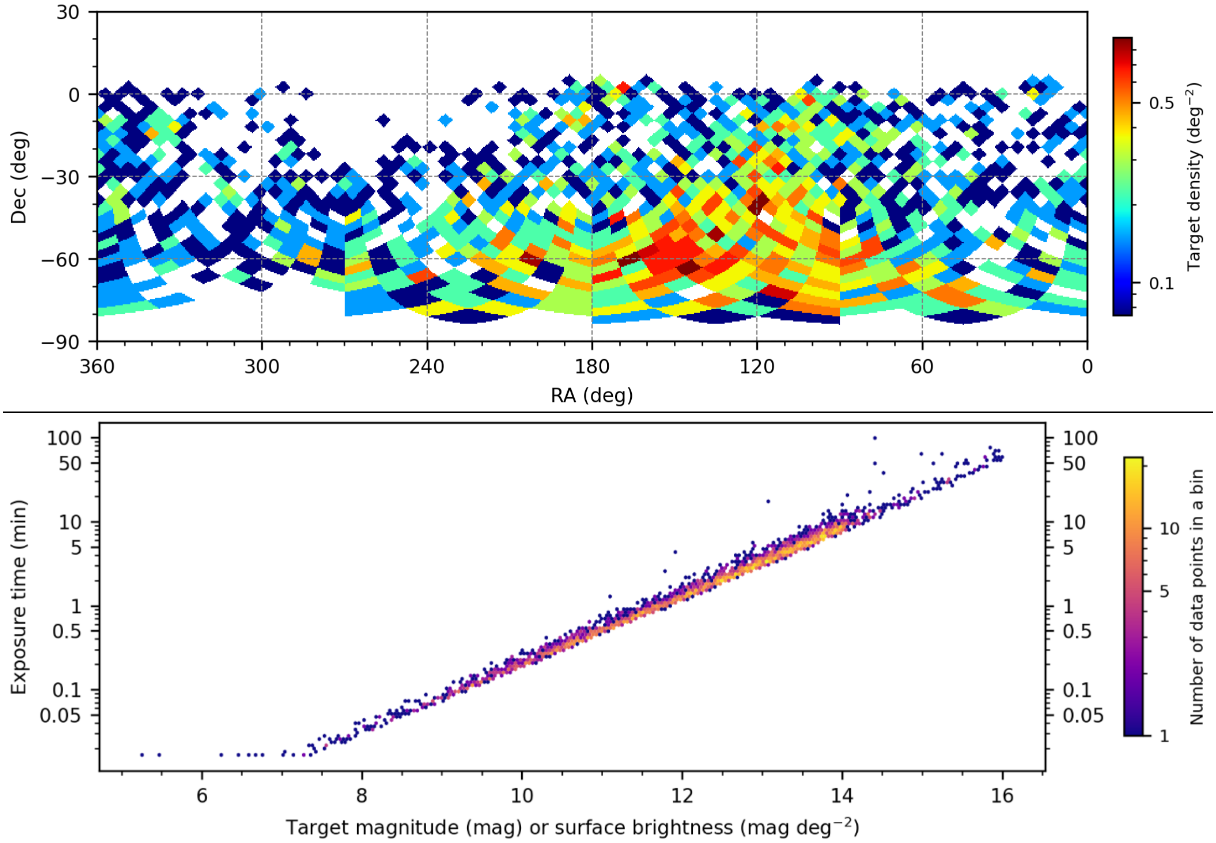


Figure 17: Top) Input target distribution of the subsurvey S0409 4MIDABLEHR_PLANETS. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the subsurvey S0409 is displayed in the top panel of Figure 17 covering 3200 (confirmed or candidate) exo-planet host stars and from NASA and TESS, as well as detections with ground-based facilities. The completeness limit is 95% and the required area to be observed is 6,000 deg2 (see Table 10). The target S/N is 250/Å in the blue for G<13.5 and 100/Å in the green for G>13.5, with resulting exposure time estimates displayed in the bottom panels of the figures. There are no cadence requirements for this subsurvey.

S0409 – 4MIDABLEHR_METALPOOR

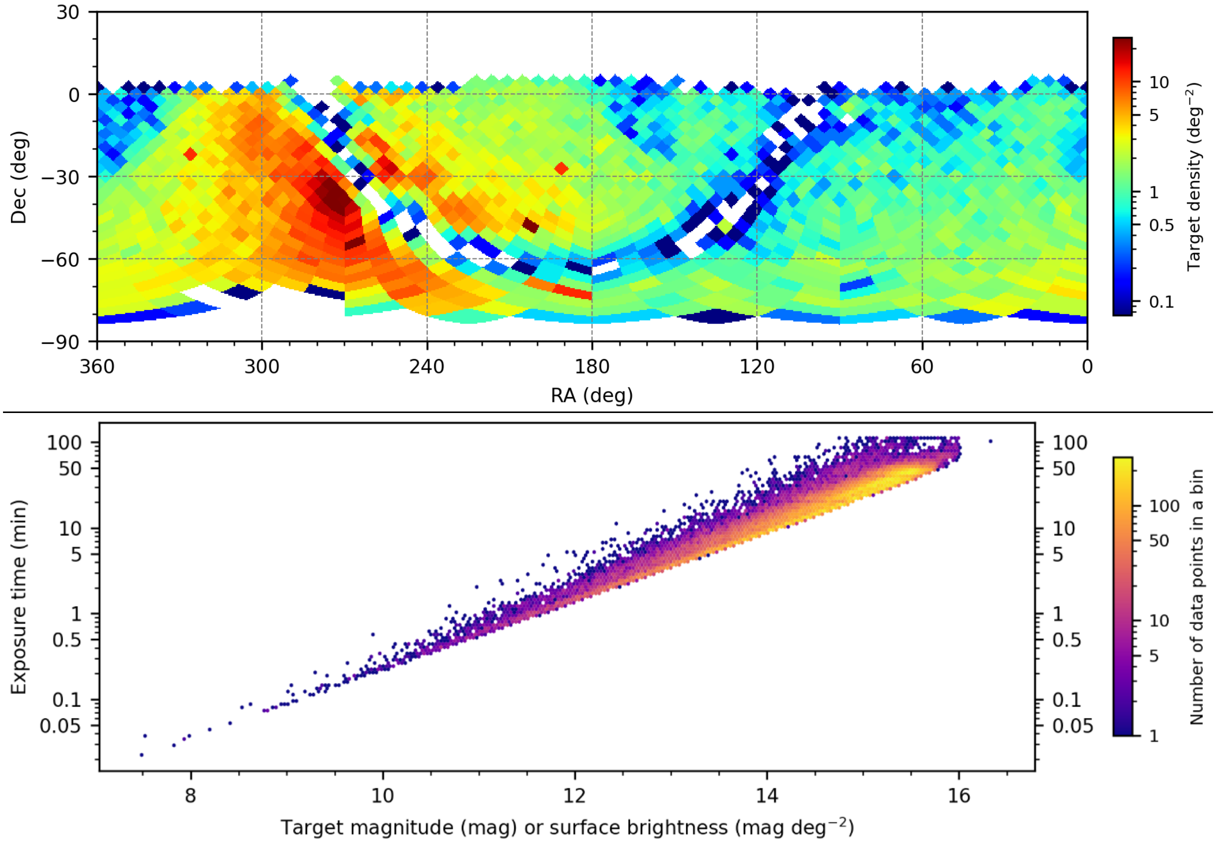


Figure 18: Top) Input target distribution of the subsurvey S0410 4MIDABLEHR_METALPOOR. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the subsurvey S0409 is displayed in the top panel of Figure 18 covering 51k candidate metal-poor stars, with [Fe/H] <= −1.5 from Gaia DR3 BP/RP-analysis. The completeness limit is 50% and the required area to be observed is 15,000 deg^2 (see Table 10). The target S/N is 100/Å in the green, with resulting exposure time estimates displayed in the bottom panels of the figures. There are no cadence requirements for this subsurvey.

S4010 – 4MIDABLEHR_PLATO

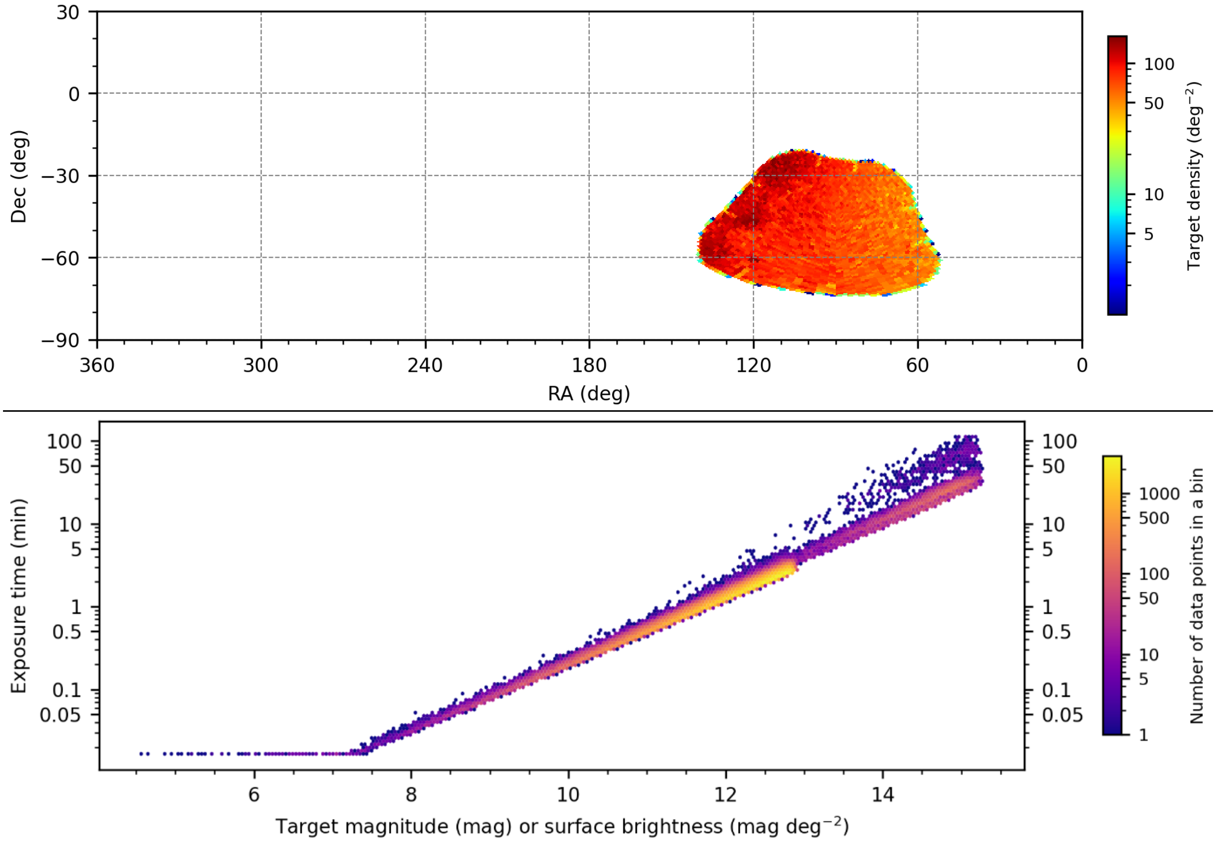


Figure 19: Top) Input target distribution of the subsurvey S4010 4MIDABLEHR_PLATO. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the subsurvey S0410 is displayed in the top panel of Figure 19 covering 178k PLATO targets. This is a separate subsurvey, because the target selection (all stars in the core sample of the PIC are dwarfs and subgiants) and the types of targets are entirely different from the S4:7 selection (mostly red giants). The PLATO field position is defined in agreement with the PLATO collaboration, as per the 4MOST-PLATO consortium wide agreement. The completeness limit is 95% and the required area to be observed is 2,100 deg^2 (see Table 10). The target S/N is 100/Å in the green, with resulting exposure time estimates displayed in the bottom panels of the figures. There are no cadence requirements for this subsurvey.

S4011 – 4MIDABLEHR_K2

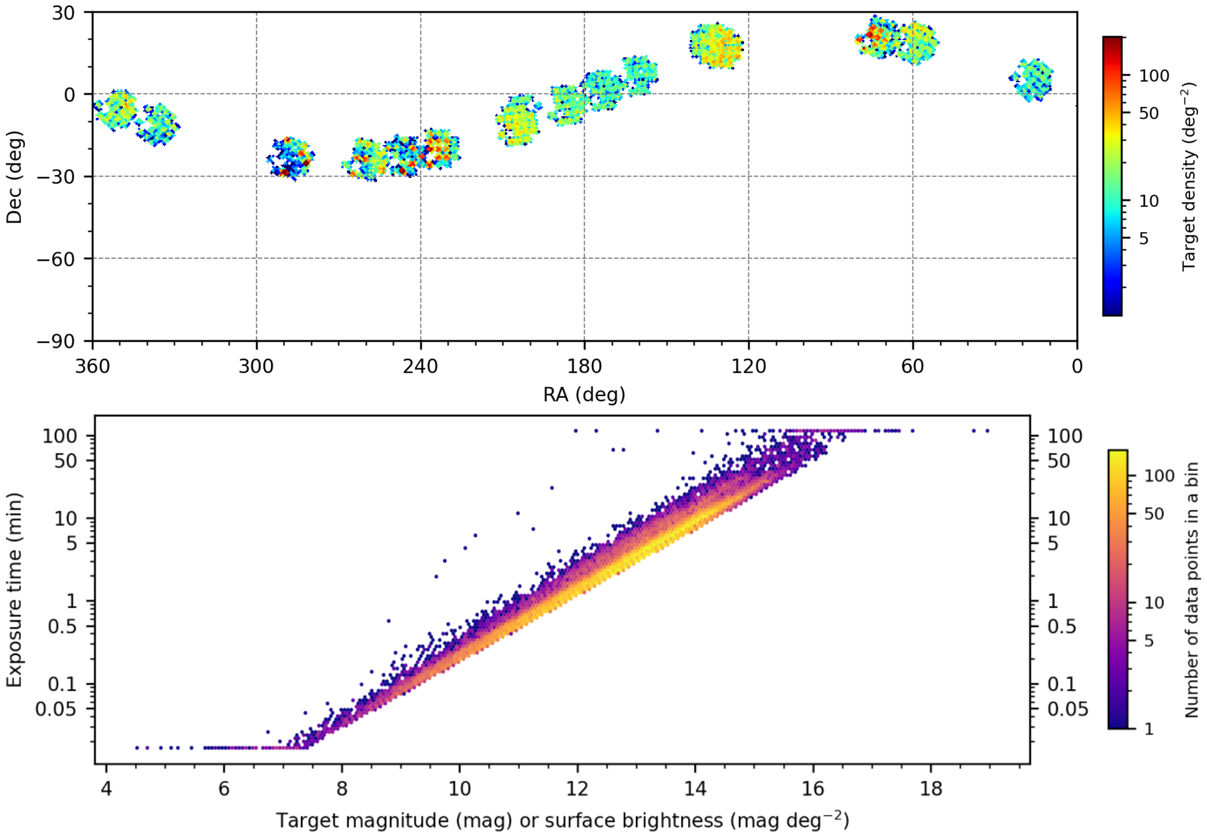


Figure 20: Top) Input target distribution of the subsurvey S4011 4MIDABLEHR_K2. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the subsurvey S0411 (K2) (is displayed in the top panel of Figure 20) includes 42k targets observed with K2 and with reliable detection of oscillations. The completeness limit is 95% and the required area to be observed is 2867 deg^2. The target S/N is 100/A in the green. There are cadence requirements for this subsurvey (0, 1, 0, 0), (1, 1, 1, 650).

S4012 – 4MIDABLEHR_TESSPRIOR

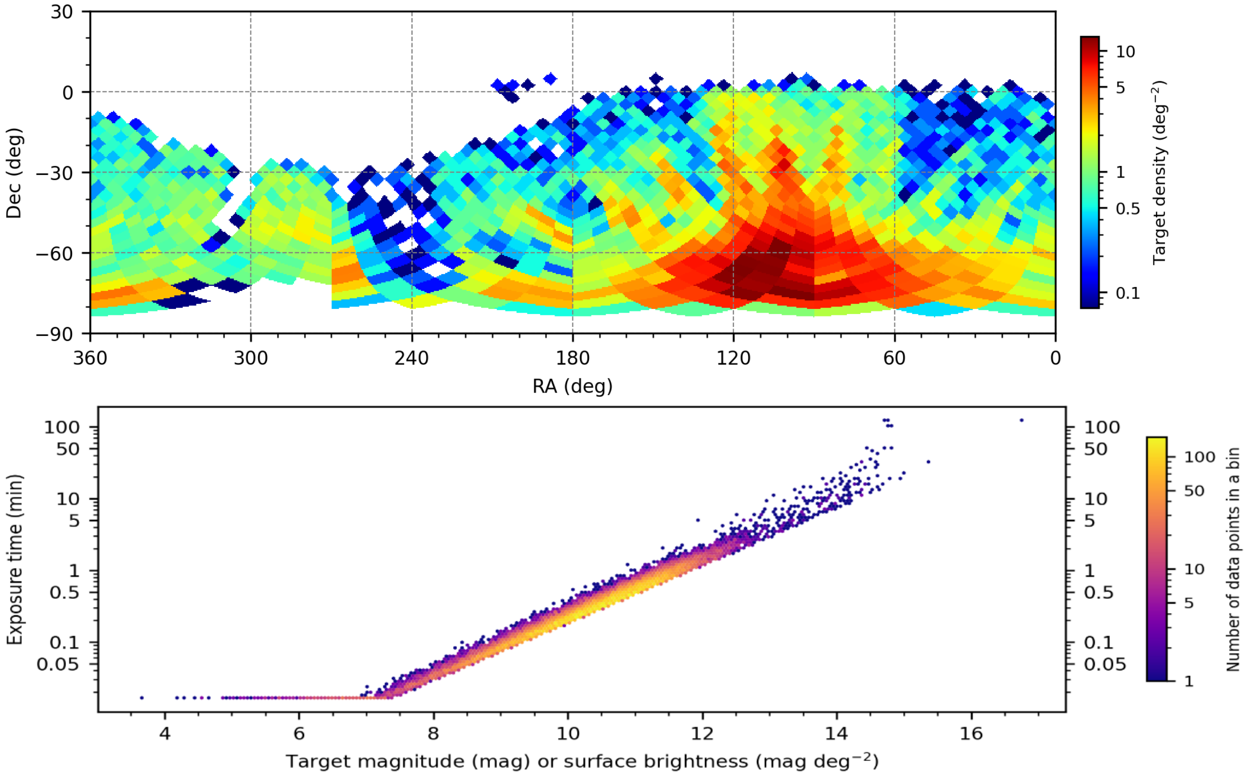


Figure 21: Top) Input target distribution of the subsurvey S4012 4MIDABLEHR_TESSPRIOR. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the subsurvey S0412 (TESSPRIOR), is displayed in the top panel of Figure 21) includes 25k targets observed with TESS, with seismic detection and evolutionary state determination. The completeness limit is 95% and the required area to be observed is 11733 deg^2. The target S/N is 100/A in the green. There are cadence requirements for this subsurvey (1, 1, 1, 650).

Table 10: Key parameters of the input target catalogue of the S4 Survey

Sub	Name	Res	Cadence	Date earliest Date latest	RA range DEC range	Epoch	TMAX [min]	AREQ [deg^2]	Fcom	FH_D [kH]	FH_G [kH]	FH_B [kH]	FH_S [kH]	N targets	Rule WL range [A]
S0401	4MIDABLEHR_DISK	HR	Multiple (4)	0	0.0 -- 360.0 -80.0 -- 28.7	2016.0	120 (G)	18061	0.500	513	506	550	685	1927268	5354.0 -- 5361.0
S0402	4MIDABLEHR_ZDISK	HR	Multiple (4)	0	0.0 -- 360.0 -80.0 -- 28.7	2016.0	120 (G)	19273	0.500	219	214	216	229	792606	4315.3 -- 4320.0
S0403	4MIDABLEHR_DEEPBULGE	HR	(0, 0, 0, 0) (0, 1, 0, 0)	0	263.1 – 282.5 -43.0 -- -21.7	2016.0	480 (G)	228	0.500	98.6	106	139	216	66468	5354.0 -- 5361.0
S0404	4MIDABLEHR_CEPHEIDS	HR	(0, 1, 0, 0) (1, 1, 9, 60)	0	0.1 -- 359.8 -79.8 -- 26.2	2016.0	60 (G)	2854	0.500	1.12	1.08	1.11	1.35	2636	4315.3 -- 5361.0
S0405	4MIDABLEHR_EROSITA	HR	Multiple (3)	0	0.0 -- 359.9 -80.0 -- 5.0	2016.0	120 (G)	13616	0.950	14.2	11.3	7.16	6.49	44370	5354.0 -- 5361.0
S0406	4MIDABLEHR_SEISMIC	HR	(0, 0, 0, 0) (0, 1, 0, 0)	0	0.0 -- 360.0 -80.0 -- 5.0	2016.0	120 (G)	14533	0.500	51.6	38.7	18.2	10.5	353990	5354.0 -- 5361.0
S0407	4MIDABLEHR_CLUSTERS	HR	(0, 0, 0, 0)	0	101.7 – 255.9 -63.5 -- 1.0	2016.0	120 (G)	77	0.950	0.348	0.316	0.297	0.351	1038	5354.0 -- 5361.0
S0408	4MIDABLEHR_PLANETS	HR	(0, 0, 0, 0)	0	0.1 -- 360.0 -80.0 -- 4.9	2016.0	120 (G)	5908	0.950	1.10	0.836	0.437	0.327	3076	5354.0 -- 5361.0
S0409	4MIDABLEHR_LOWMETALLICIT	HR	Multiple (3)	0	0.0 -- 360.0 -80.0 -- 5.0	2016.0	120 (G)	16312	0.500	9.98	9.36	9.27	10.8	49193	5354.0 -- 5361.0
S0410	4MIDABLEHR_PLATO	HR	Multiple (3)	0	52.3 -- 140.0 -73.7 -- -20.9	2016.0	120 (G)	1890	0.950	93.6	71.6	37.2	25.4	178382	5354.0 -- 5361.0
S0411	4MIDABLEHR_K2	HR	(0, 1, 0, 0) (1, 1, 1, 650)	0	9.3 -- 359.5 -31.3 -- 28.5	2016.0	120 (G)	2867	0.950	26.8	20.8	12.5	10.9	42136	5354.0 -- 5361.0
S0412	4MIDABLEHR_TESSPRIOR	HR	(1, 1, 1, 650)	0	0.0 -- 360.0 -80.0 -- 4.8	2016.0	120 (G)	11733	0.950	11.7	8.81	4.15	2.42	25080	5354.0 -- 5361.0

The key input parameters of the S4 target catalogue are listed in Table 10. The FoM of the subsurveys reflect the $SSM \times LSM$, while the total survey FoM is a weighted mean of the subsurvey FoM. Largest weight is given to the first three subsurveys that together account for 73%.

We are working on reducing the size of the S0401 target catalogue, in order to be less biased toward nearby stars and to reduce the overconsumption of fibre hours, both requested and unwanted.

6.4.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.4.4 Management Structure

Maria Bergemann and Thomas Bensby jointly lead the survey. Together with all 4MIDABLE-HR team members the decisions concerning the content and direction of the survey and its subsurveys are taken after discussions during regular team telecons (often bi-weekly, or at least once a month)

A description of the different WP within S4 is described in Section 7.3.10 with the FTE contributions of the survey members listed in Section 7.3.11 and the contributions to the 4MOST common IWGs listed in Section 7.3.12. In summary, S4 contributes substantially (~3 FTE/year) to IWG2, 3, 4 and 7; approximately half the efforts may count as survey-internal and the other half as beneficial to all Galactic surveys. Another ~1.5FTE is devoted to internal survey management, catalogue preparation, synergies with other surveys and survey-specific analysis outside 4GP.

S4 is planning to use the tools, procedures, and available hardware of the common IWGs, except for the AL2 products outlined in Sect. 7.3.6.

6.4.5 Work Breakdown Structure

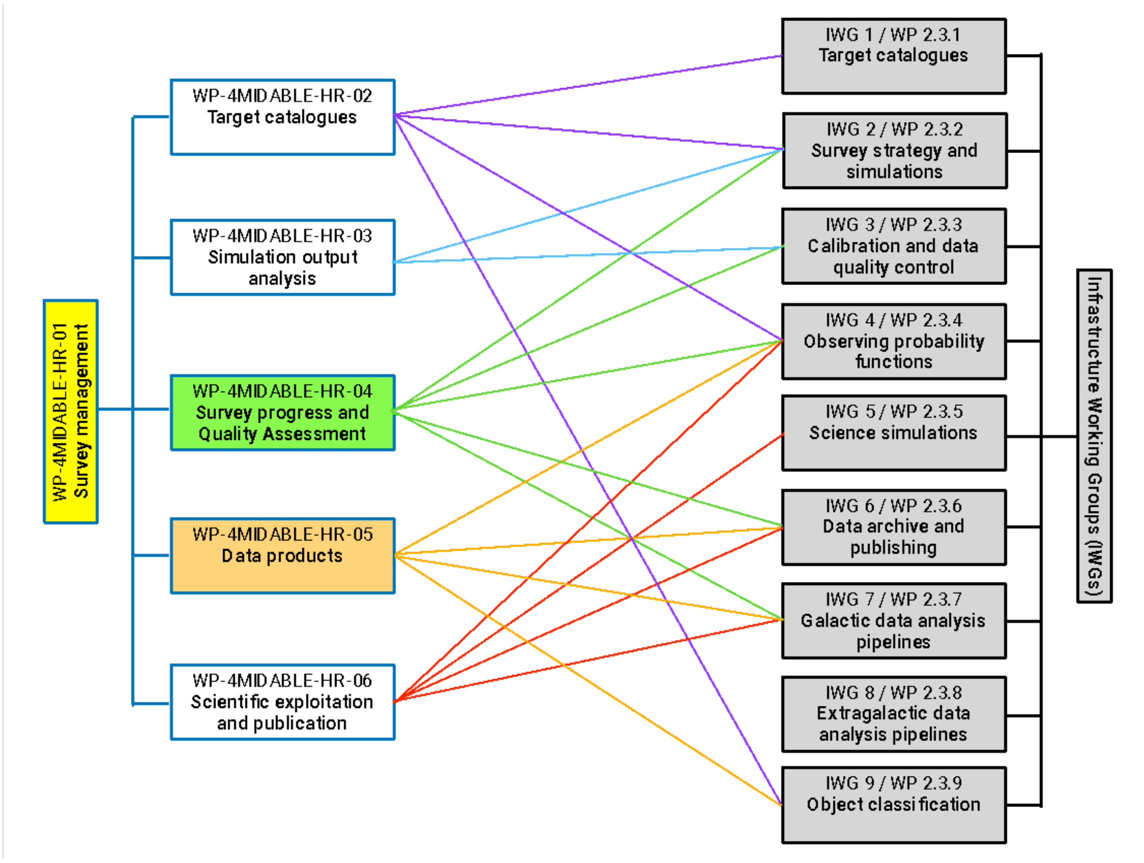


Figure 22: Work Breakdown Structure for Survey S4

WP-4MIDABLE-HR-01: Survey Management
Leads: Thomas Bensby and Maria Bergemann
This work package provides the management of 4MIDABLE-HR. It is led by the 4MIDABLE-HR co-PIs and ensures, e.g., that regular telecons are organised, the membership-list and SMP is up-to-date, the survey has representatives in the SCB, SPB, the IWGs, and oversees the work of the survey WPs.

WP-4MIDABLE-HR-02: Target catalogue
Lead: Jeff Gerber
Contributors: Christian Schneider, Aldo Serenelli
This work package has the overall responsibility to create the joint target catalogue with input from the subsurvey contributors providing target lists for each of the subsurveys (see below). This WP then makes sure that the catalogue is uploaded to the 4FS for exposure time calculations and selected as preferred catalogue for the next round of simulations (or eventually observations).
S0401 - DISK: Main disk and bulge catalogue (Gerber)
S0402 - ZDISK: Nearby disk catalogue (Gerber)
S0403 - DEEPBULGE: Deep bulge catalogue (Gerber)
S0404 - CEPHEIDS (Bono, D’Orazi)
S0405 - EROSITA (Schneider)
S0406 - SEISMIC (Serenelli)

S0407 - CLUSTERS (Ernandes)
S0408 - PLANETS (Bergemann)
S0409 - METALPOORDISK (Youakim, Hoppe)
S0410 - PLATO (Serenelli)
S0411 - K2 (Serenelli)
S0412 – TESSPRIOR (Serenelli)

WP-4MIDABLE-HR-03: Simulation output analysis
Lead: Gregor Traven
This work package looks at the simulation output and summarises what is good and what needs to be improved upon. These results are usually communicated during the 4MIDABLE-HR team telecons. Close communication and collaboration with WP-4MIDABLE-HR-02 is crucial to ensure that issues related to the target catalogue are addressed in subsequent target catalogue uploads to the survey simulator.

WP-4MIDABLE-HR-04: Survey progress and quality assessment
Lead: PIs, all members contributing

WP-4MIDABLE-HR-05: Data products
Lead: PIs, all members contributing

WP-4MIDABLE-HR-06: Scientific exploitation and publication
Lead: PIs, all members contributing

6.4.6 Contribution to the Infrastructure Working Groups

<u>IWG1</u>
Our survey contributes to IWG1 by production of a catalogue for selection of targets for Galactic surveys (F. Anders, C, Chiappini).

<u>IWG2</u>
Our survey contributes to IWG2 in the following ways:
- DISC WG (from September 2022, G. Guiglion)
- BULGE WG (N. Ryde, until September G. Traven)
- coordination of HR survey overlap (S2, S4) (T. Bensby, M. Bergemann)
- calibration and S/N ETC validation for HR and LR (S. Martell, D. Feuillet, D. Zucker)
- contribution to discussions, analysis of 4FS simulations and inputs (T. Bensby, C. Chiappini, G. Traven, M. Valentini, D. Feuillet)
- analysis of stellar multiplicity requirements, strategy and implementation for Galactic surveys (G. Traven, also lead of the SWG, T. Merle)
- feedback loop WG (J. Lian)

<u>IWG3</u>
Our survey contributes to IWG3 in the following ways:
- co-leadership of IWG3 (M. Valentini)
- A. Serenelli, G. Traven, N. Storm are contributing to the cross-calibration survey 4MOST/SDSS-V/WEAVE (from September 2022, as part of IWG3)
- G. Guigion has held the position of the deputy of the cross-calibration survey 4MOST/SDSS-V/WEAVE (from September 2022, as part of IWG3)

<u>IWG4</u>
Our survey contributes to IWG4 in the following ways:
- co-leadership of IWG4 (S. Martell)

- discussion and analysis of HR selection (S. Feltzing, D. Feuillet)
- liaison to DMS and ODG (C. Worley)

IWG5

There are no imminent plans to activate IWG5 (joint Galactic and extragalactic "universe" simulations), but this may change during survey operations. Currently this is handled by each Survey individually.

IWG6

IWG6 was reactivated during the previous year, in the sense that its scope was redefined and new leads appointed. IWG6 is fully active and described in reference document (SMP - Back-end Operations). S4 now has a new representative on IWG6 (Martina Baratella).

IWG7

Our survey contributes to IWG7 in the following ways:

- co-leadership of IWG7 (G. Kordopatis, R. Church)
- Development of the SAPP pipeline for 4MOST (M. Gent, J. Gerber, M. Bergemann)
- Development of the CNN pipeline for 4MOST LR and HR (G. Guiglion)
- Calculation of synthetic spectral grids and templates for OpRs and for Galactic surveys (N. Storm, J. Gerber)
- Development of spectral normalisation procedures for 4GP (M. Kovalev, until 2021)
- Extinction and reddening procedures for spectral templates (M. Bergemann, until 2020)
- Calculation, assembly, and analysis of atomic data and input linelists to 4GP Galactic pipeline (M. Bergemann, P. Barklem, U. Heiter, H. Hartmann)
- QC of L0/L1 HR and LR data, OpR analysis (G. Guiglion, M. Gent, M. Bergemann)
- calibration and validation targets in IWG7 (M. Valentini)
- pipeline for the analysis of binaries and triples in 4MOST (T. Merle, G. Traven)
- pipeline for the analysis of Cepheids in Galactic surveys (B. Lemasle)

IWG8

Our survey does not contribute to this WP.

IWG9

Contribution of our survey to this WP is currently TBD.

6.4.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.4.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey. We will provide stellar parameters and detailed elemental abundances, as well masses, ages, and radii as determined by the SAPP integrated into 4GP (L2PR summary document) with auxiliary information based on asteroseismic and/or photometric/astrometric constraints.

All targets of Survey S4 will be processed by the 4GP pipeline and quality-controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.

Additional data products (AL2) that will be determined by S4 include stellar mass, age and radius determined with alternative approaches to that implemented in 4GP, e.g., chemical clocks, rotation-activity-relations, and /or other evolutionary models and complementary data. Further, stellar parameters and abundances based on 3D atmospheric models and NLTE may be determined, as well as binary parameters beyond the standard.

6.4.8.1 Deliverable L2 Survey data: reduction processing

No extra DL2-SURV processing is required by this Survey.

6.4.8.2 Deliverable L2 Survey data: quality assessment

No extra DL2-SURV processing is required by this Survey.

6.4.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

No extra DL2-SURV processing is required by this Survey.

6.4.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

No extra DL2-SURV processing is required by this Survey.

6.4.8.5 Deliverable L2 Survey data: Required hardware and staff

No extra DL2-SURV processing is required by this Survey.

6.4.8.6 Additional L2 data: reduction processing

For targets with higher priority and/or more comprehensive information available at the time of data 4MOST L1 availability, the following additional L2 products will be produced:

- S4:7, S4:9, S4:10 seismic data: analysis of spectra using multiple sources of global oscillation parameters (from different code/mode analysis methods) and/or individual frequencies, contingent upon availability of improved parameters from asteroseismology. Aim to provide improved stellar parameters, as well as masses and ages. Software to be used: SAPP
- Selected targets of S4, especially S4:10: 3D NLTE parameters and chemical abundances where possible and required according to the amplitude of the effects of convection and NLTE, as documented in the literature. Owing to increased computational resources required, this analysis will not be attempted at the survey level, but only for the high-priority / ToI targets. Software to be used: Dispatch and other codes as defined by survey members.
- S4:10 Multiplicity, granulation, and variability analysis from time-domain space photometry: stellar parameters and selected abundances (e.g. Si, Mg, C, O) contingent upon release of PLATO parameters (scheduled for launch in 2026). Software to be used: different codes as defined by survey members.
- S4:5 Stellar parameters and abundances for Cepheids based on refined line ratio techniques. Software to be used: TBC
- S4:6 Analysis of 4MOST spectra (Ca H & K), for a subsample TESS information on spottedness for stellar activity studies. Software to be used: different codes as defined by survey members.The analysis of 4MOST data for eROSITA targets will follow the standard IWG7 codes, as according to the MoU between 4MOST and eROSITA the X-ray fluxes will remain proprietary to eROSITA consortium. If the data become available to the S4 team for the science exploitation (following the submission of the request in

future and pending upon the decision of eROSITA consortium on approval or rejection), then these will be used as value-added information for the closest DR accommpanying a journal publication.

- S4:8 Joint analysis of spectra and photometry for clusters with/without CMD priors and kinematics from Gaia. Aim to check and validate effects on atomic diffusion through the intracluster abundance variations. Software to be used: different codes as defined by survey members, including stellar evolution models that can account for the physical effects (e.g. CESTAM).

Most of these products (asteroseismic data, NLTE, photometry analysis of clusters with/without priors, multiplicity) are being implemented into the IWG7 pipeline through contributed grids and modules. Therefore, the corresponding L2 data products for these targets will become standard DL2. *These products are foreseen to be implemented by DR2 but they will be released at the latest with the closest DR accompanying the journal publication.*

6.4.8.7 Additional L2 data: quality assessment

QC will be defined for each subsample and will include well-studied calibration samples with parameters from the literature. Documented published software will be used. The time-line is dependent on the availability of data from auxiliary facilities, e.g., TESS data are continuously improved as more sectors are progressively being released to the community.

6.4.8.8 Additional L2 data: data delivery and Phase 3 compliance

Data flow chart will be defined. All data to be delivered during Phase 3 must comply with the ESO science data standards (ESO-044286).

6.4.8.9 Additional L2 data: product delivery schedule to the 4PA archive

Product delivery timeline will be defined, if possible. This may not be possible, however, owing to dependencies on supplementary external datasets, which do not depend on internal survey planning strategy. All targets will be analysed using the IWG7 pipeline, also using the contributed (dedicated) modules. The corresponding L2 data products will be delivered to ESO as agreed upon via the DR release schedule. For eROSITA, we cannot provide a timeline, as according to the new MoU between 4MOST and eROSITA, the X-ray fluxes will remain proprietary to the eROSITA consortium and any use of these datasets by S4 members will require an approval from the eROSITA consortium, which we cannot count on at the stage of this SMP submission.

6.4.8.10 Additional L2 data: Required hardware and staff

Computer clusters, currently partly available through the MPG.
Staff: 2 Postdocs, 2 PhD students, 1 software developer

6.4.9 Team

Table 11: Survey S4 team members with their affiliation, role in S4, and expected FTE contribution.

Name	Affiliation	Function	FTE / year
Richard Anderson	EPFL	TBD	0.05
Martina Baratella	AIP	TBD	0.1

Name	Affiliation	Function	FTE / year
Thomas Bensby	LU	S4 co-PI	0.2
Maria Bergemann	MPIA	S4 co-PI	0.2
Bertram Bitsch	MPIA	advice on stellar abundances and planet occurence rates	0.05
Lisa Bugnet	ISTA	Seismic analysis for S4 stars	0.1
Tristan Cantat-Gaudin	MPIA	selection of cluster targets	0.01
Gabriele Cescutti	OATS	neutron capture elements, GCE	0.2
Cristina Chiappini	AIP	S3 co-PI, target selection StarHorse/Bulge deep/ IWG2	0.1
Ross Church	LU	IWG7 co-lead	0.3
Sofia Feltzing	LU	IWG4	0.1-0.2
Diane Feuillet	LU	IWG4, IWG7, Project culture	0.1
Rafael A. Garcia	CEA	Seismic analysis for S4 stars	0.1
Jeffrey Gerber	MPIA	S4 Catalogue creator, IWG1, IWG2	0.3
Guillaume Guiglion	MPIA	IWG2 rep., IWG7 (CNN pipeline), training set, IWG3 deputy	0.4
Henrik Hartman	LU	spectral line list for IWG7	0.05
Heitor Hernandes	LU	IWG2 Deep bulge WG	0.1
Georges Kordopatis	OCA	IWG7 co-lead	0.2
Karin Lind	SU	Galactic PS	0.05
Sarah Martell	UNSW-SoP	IWG4 co-lead, ODG member	0.1
Savita Mathur	IAC	asteroseismic constraints	0.1
Thibault Merle	ULB	IWG7, Multiplicity working group,	0.2
Ivan Minchev	AIP	S3 co-PI	0.1
Christian Schneider	UHH	EROSITA subsurvey	0.2
Aldo Serenelli	ICE-CSIC	SEISMIC/PLATO subsurveys, cross-calibration WG, IWG3	0.3
Nick Storm	MPIA	S4 SV catalogue, grid calculations for IWG7	0.1
Gregor Traven	UNILJ	IWG7, IWG2 rep, IWG3 rep, multiplicity WG	0.05
Marica Valentini	AIP	IWG3 co-lead, calibrations, science verifications, seismic targets and red giants	0.1
C. Clare Worley	IoA	S1 co-PI, DRM	0.2
Giuseppe Bono	Univ. Roma	selection of Cepheid targets	0.1
Valentina D’Orazi	INAF Padova	selection of Cepheid targets	0.1
Andrea Perdomo Garcia	MPIA	PLANETS subsurvey	0.05

Name	Affiliation	Function	FTE / year
Richard Hoppe	MPIA	METALPOOR subsurvey, 3D NLTE	0.05
Total			4.76

6.5 Survey 5 – Galaxy Clusters

Survey PI: Johan Comparat

6.5.1 Science Summary

Galaxy clusters constitute an important probe for cosmological studies. They trace the highest density peaks of the matter distribution of the Universe and thus allow unique cosmological tests e.g. the cluster counts as a function of their mass. The eROSITA X-ray telescope on board the Spectrum Roentgen Gamma observatory was launched in July 2019 and has completed four scans of the full sky used for targeting. The experiment detected about 100,000 groups and clusters of galaxies over the full sky through X-ray emission from the hot intergalactic medium. Provided accurate redshifts for each cluster and group, the halo mass function deduced should yield the tightest constraint ever on the cosmological model. The purpose of the 4MOST eROSITA Galaxy Cluster Redshift Survey is to measure spectroscopic redshifts of optically selected galaxies that are counterparts to the cluster X-ray emission over 13,500 square degrees. The measured redshifts will provide an accurate third dimension to the two-dimensional X-ray cluster map. It will allow detailed studies of the evolution of clusters and their galaxies over the last 8 Gyr (z<1). The final eROSITA cluster sample will be 20 times larger than in previous experiments. We will measure [σ_8, Ω_m] to the [2, 3] percent level via the abundance and the clustering of eROSITA clusters and their galaxies.
Expanded science description: messenger-no175-39-41.pdf

6.5.2 Target catalogues

The German eROSITA consortium has access to the Western galactic hemisphere (half the sky). It contains 13,500 square degrees of extra-galactic sky. Out of these, only 9,250 square degrees are reached by the VISTA/4MOST infrastructure at Declination smaller than 0 degrees. This reduces the total number of X-ray selected clusters and groups from 100k (on ~27k deg2 of extra-galactic sky) to about 34k (on ~9 k deg2).
Provided accurate redshift for each of these clusters and groups, the halo mass function deduced should yield the tightest constrain ever on the cosmological model (Pillepich et al. 2012, 2018, Ghirardini et al. 2024, Artis et al. 2024, Seppi et al. 2024). The purpose of the 4MOST eROSITA Galaxy Cluster Redshift Survey is to measure spectroscopic redshifts of optically selected galaxies that are counterpart to the X-ray emission (Finoguenov et al. 2019). At the depth of the final eROSITA survey, the redshift range subtended by X-ray selected clusters is $0 < z < 1.2$ (Clerc et al. 2018, Bubul et al. 2024, Liu et al. 2024, Kluge et al. 2024). At the highest redshifts, only very massive clusters will be observed while at low redshift groups will be detected. The goal is to add an accurate third dimension to the group and cluster catalog using spectroscopy. To best follow up the variety of groups and clusters, we divide this survey into six sub surveys (components) ordered by importance.

1. S0501. cluster_BCG. 34,418 targets. The brightest cluster galaxies sub survey. It aims to obtain high signal to noise spectra of the brightest cluster galaxy for each X-ray detection (BCG as identified by redmapper). This will provide a redshift for every cluster and group detected by eROSITA. Furthermore, it will allow outstanding galaxy evolution studies. A similar survey is described in Furnell et al. (2018), Erfanianfar et al., (2019), Kluge et al. 2024.
2. S0502. cluster_specz. 221,280 targets. It aims to measure accurate spectroscopic redshifts for a subset (~30k) of the full cluster catalog using at least three confirmed members per cluster.

3. S0503. cluster_vdisp. 379,211 targets. It aims to measure accurate velocity dispersions for a subset (~20k) of the full cluster catalog using at least ten confirmed members per cluster.
4. S0504. cluster_mdyn. 3,363 targets. It aims to measure dynamical masses for a small subset (~50) of the full cluster catalog using at least hundred confirmed members per cluster.
5. S0505. cluster_fillMem. 919,760 targets. All members targets around the BGCs targeted. Every additional member for which we can obtain a spectroscopic redshift will enhance the goals of the previous sub surveys.
6. S0506. filament_GAL. 1,541,270 targets. The filaments sub survey aims to measure galaxy redshifts in the filaments between groups and clusters at low redshift z < 0.2. It is a magnitude limited sample selected from the legacy survey imaging.

The S5 Survey aims to observe about ~34,000 galaxy groups and clusters on 9,250 deg2 in the Western galactic hemisphere and its extra-galactic sky covered by the legacy surveys. It requires 9,000 deg^2 of sky to be observed, the goal is to cover the full area: 9,250 deg2. Being a large area Survey, weather variations over the 5-year period will have no significant impact as long as the scheduler has a preference to complete contiguous areas. Of importance is sufficient galaxy sampling in the crowded, dense cluster areas, which requires several configurations to be observed, but simulations predict this is reasonably feasible with 4MOST.

The distribution on the sky of the targets is shown on Figures provided by IWG2. For S0501, S0502, S0505 the density follows the depth of the X-ray observations used to draw targets. eROSITA is deeper at the ecliptic poles and thus provides a higher number density of targets there. For S0503, the selection is intended to be homogeneous throughout the sky. The mean target density per square degree is 3.5, 130, 170 for S0501, 05, 03.

The subsurveys S0501, 02, 03, 06 require coverage 9,000 square degrees within the eROSITA DE footprint (western Galactic Hemisphere) with a goal to cover the full footprint of 9,250 square degrees. The area is in the western galactic hemisphere (eROSITA German half of the sky) and avoids the galactic disk |b|>20 and the Magellanic clouds or regions with high extinction. It is contained within 4MOST reach in Declination (-80<Dec.<+5). Sub survey S0504 contains only a few clusters covering ~50 deg2. S0505 with the all members does not have an area requirement (set to 1 deg2).

For each target selected and in each subsurvey, the required dark time exposures as a function of magnitude are shown on IWG2 webpages. The signal to noise requirement (S/N) is set in the red arm spectrograph: 720nm-900nm. It ranges between 3 (faint end) and 10 (bright end) depending on the target magnitude and fibre-magnitude. At the faint end, a target is deemed successful if the redshift was measured. At the bright end, we aim to measure in addition to redshift parameters of the stellar population(s) and of the gas phase, signal to noise permitting. For targets with a z band fibre magnitude brighter than 18, we request a S/N of 10. For targets with a z band fibre magnitude in the range 18-19 (19-20, fainter than 20), we request a S/N of 5 (4, 3).

Subsurvey S0501, BCGs have typical total z-band magnitude between 16 and 20 (z band fibre magnitudes in the range 18-21.7) and reach the required signal to noise (that varies with fibre magnitude, see before) in less than 20 minutes.

Subsurvey S0506 selects sources brighter than z mag<18 (most of them are between 17 and 18 and have fibre magnitudes between 18 and 19.3) and most reach the signal to noise required within 10 minutes. These targets are good targets for grey and bright times.

S0502, 03, 04, 05 have the faintest targets of all with z band magnitudes between 19 and 21.5 (fibre magnitudes between 19.1 and 22), which typically require 40-60 minutes to be successful.

The requested completeness values for the subsurveys is 70%, except for the S0505 cluster_fillMem that has a 30% completeness requirement. S5 has no cadencing requirements. The Scientific FoM of all three sub surveys tracks the LSM x SSM of targets.
The key input parameters of the S5 target catalogue are listed in Table 12.

Table 12: Key parameters of the input target catalogue of the S5 Survey

N	Sub	Name	Res	Cadence	Date earliest Date latest	RA range DEC range	Epoch	TMAX [min]	AREQ [deg^2]	Fcom	FH_D [kH]	FH_G [kH]	FH_B [kH]	FH_S [kH]	N targets	Rule WL range [A]
44	S0501	cluster_BCG	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -80.0 -- 0.1	2016.0	100 (D)	9000	0.707	11.3	11.7	17.0	28.3	34418	7200.0 -- 9000.0
45	S0502	cluster_specz	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -80.0 -- 0.1	2016.0	40 (D)	9000	0.707	63.5	64.7	95.8	162	221280	7200.0 -- 9000.0
46	S0503	cluster_vdisp	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -79.9 -- 0.1	2016.0	40 (D)	9000	0.707	120	132	214	367	379211	7200.0 -- 9000.0
47	S0504	cluster_mdyn	LR	(0, 0, 0, 0)	0	43.4 -- 351.4 -79.4 -- -1.2	2016.0	40 (D)	50	0.707	0.803	0.890	1.46	2.49	3363	7200.0 -- 9000.0
48	S0505	cluster_fillMem	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -80.0 -- 0.1	2016.0	40 (D)	1	0.315	0.017	0.020	0.033	0.057	919760	7200.0 -- 9000.0
49	S0506	filament_GAL	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -75.0 -- 0.0	2016.0	40 (D)	9000	0.707	364	277	190	269	1541270	7200.0 -- 9000.0

6.5.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.5.4 Management Structure

J. Comparat manages the survey, which entails:

- Coordination between the 4MOST and the eROSITA consortia and its two relevant working groups: clusters & follow-up.
- Organize a monthly discussion with S5 members
  - Ongoing technical and scientific activities
  - Application for funding to support S5 survey science
  - Foster scientific projects with S5's unique targets
- Targeting coordination with
  - S6 for high redshift clusters that appear point-like in X-ray
  - S15 for the clusters that are jointly targeted
  - S16 for the S0506 filament subsurvey

6.5.5 Work-breakdown structure

S5 will use the structure already in place for SDSS-IV (Clerc et al. 2020, Kirkpatrick et al. 2020, Ider Chitham et al. 2020) and now for SDSS-V (Aydar et al. in preparation). The workflow will be similar for 4MOST and in parts externally handled within the eROSITA cluster working group.

- The X-ray cluster candidate catalogue is created (X-ray only) by the eROSITA cluster working group and in its catalogue work package (E. Bulbul, A. Liu, et al. in 2024, Merloni et al. 2024).
- Photometric redshifts are estimated and probable galaxy members are identified using the legacy survey DR10. Prepared by M. Kluge and J. Comparat with eromapper software (Ider Chitham et al. 2020, Kluge, Comparat et al. 2024).
- Such galaxies are fed into spectroscopic follow-up projects (SDSS-V, 4MOST, etc). Selection function QC by R. Schmidt & A. Edge (IWG1).
- Probabilities of observation are derived using simulations by J. Sorce (IWG4).
- After galaxy spectroscopic redshifts are measured, they are fed into the eromapper software to refine cluster redshifts and properties (dynamical properties) with

eromapper software (Ider Chitham et al. 2020). Task of M. Kluge (currently run every 6 months by adding newly acquired spectroscopic redshifts).

- The catalogues are then shared via MoU with the eROSITA cluster working group. At the new spectroscopic redshift, they re-analyze the X-ray data (E. Bulbul, A. Liu) and then shared back with 4MOST S5 members.
- Scientific exploitation from the X-ray perspective: Astrophysics WP (J. Sanders, MPE) & Cosmology WP (V. Ghirardini, A. Artis, MPE).
- Scientific exploitation from the optical perspective (in depth analysis of spectra) to be done with a 4MOST leadership, to be defined.

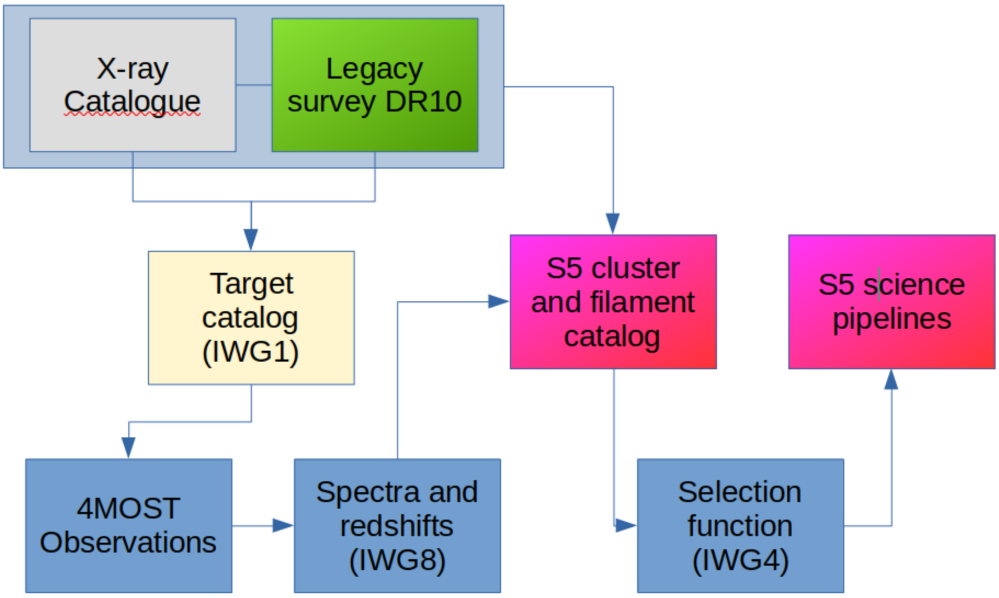


Figure 23: Work Breakdown Structure for Survey S5

6.5.6 Contribution to the Infrastructure Working Groups

IWG1

R. Schmidt contributes to IWG1 by providing change tracking of all 4MOST input catalogue packages.

All members contribute to creating the target catalogue. The responsible person for the target catalogue is the PI J. Compara) and a post-doc at MPE M. Kluge. The targeting work is, as of June 2024, finished.

IWG2

J. Comparat contributes to IWG2.

IWG4, 5

J. Sorce will contribute to IWG4 and 5 with simulation analysis.

IWG8

M. Kluge participates in IWG8. A PhD student to be hired in Sept 2024 will join.

6.5.7 Level-1 data reduction re-process and ancillary products

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by S5.

6.5.7.1 Level-1 data quality assessment

The standard L1 QC described in in Survey Management Plan: Back-end Operations [RD4] will be used by S5.

6.5.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.5.8.1 Deliverable L2 Survey data: reduction processing

The eRASS:5 catalogues will be in the public domain (Q1 2026, planned) at the time of 4MOST DR1. The 4MOST DR1 will release a targeting catalogue based on eRASS:5 (BCG, cluster members).

Corresponding to each following 4MOST DR, i.e. the ones with spectroscopy, S5 will deliver an ESO phase-3 product that contains the list of updated spectroscopic redshifts and dispersions of clusters limited to the eRASS:5 clusters for which the observations are completed (requirement achieved). While reliable cluster detection and characterisation will not be possible until observations of each cluster are essentially complete, we will release the data products associated with a scientific publication at the next DR.

6.5.8.2 Deliverable L2 Survey data: quality assessment

The two members part of IWG8 will participate in the QC of the redshifts measured and galaxy properties. Cluster redshifts and dispersions will be compared to previous measurements on these clusters.

6.5.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met.

6.5.8.4 Deliverable L2 Survey data: product delivery schedule to ESO

Further characterization beyond the standard 4XP will require re-analysis of the eROSITA X-ray data. It is therefore not feasible to publish cluster properties on the same timeline as the DL2-SURV products for individual galaxy spectra. This analysis is also model dependent and therefore closely tied to a publication. Cluster catalogues with properties recomputed at their spcetroscopic redshift will therefore be published as DL2-SURV data products associated with publication(s). The data release will occur at the next PDR following the article publication.

6.5.8.5 Deliverable L2 Survey data: required hardware and staff

The software to handle 4MOST cluster observations is at hand and up and running on MPE computers.

6.5.8.6 Additional L2 Survey data: reduction processing

No extra AL2 processing is planned by this Survey

6.5.8.7 Additional L2 Survey data: quality assessment

No extra AL2 processing is planned by this Survey

6.5.8.8 Additional L2 Survey data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey

6.5.8.9 Additional L2 Survey data: product delivery schedule to the 4PA archive

No extra AL2 processing is planned by this Survey

6.5.8.10 Additional L2 Survey data: required hardware and staff

No extra AL2 processing is planned by this Survey

6.5.9 Team

Table 13: Survey S5 team members with their role in S5, affiliation, and expected FTE contributions.

Name	Function	Affiliation and Country	FTE /yr
PI J. Comparat	Principle Investigator (IWG2)	MPE	0.3/yr
M. Kluge, Post-Doc	Target selection, redshift measurement (IWG1, 8)	MPE	0.7/yr
J. Sorce	IWG4-5 simulation and selection function	CRAL	0.1/yr
PhD student (TBD in Sept 2024)	Redshift measurement (IWG 8) and exploitation	MPE	0.1/yr
R. Schmidt	Target selection QC (IWG1)	Heidelberg	0.1/yr
M. Salvato, A. Merloni, K. Nandra, A. Schwope	Targets coordination with S6	MPE	0.05/yr
A. Edge	Target validation	Durham	0.05/yr
E. Bulbul, V. Ghirardini, E. artis, J. Sanders, N. Malavasi	Scientific exploitation	MPE	0.5/yr

6.6 Survey 6 – Active Galactic Nuclei

Survey PI: Andrea Merloni

6.6.1 Science Summary

The presence of super-massive black holes (SMBHs) in the nuclei of virtually all massive galaxies in the Universe has driven huge interest of a broad community of astrophysicists in establishing a close link between AGN activity and galaxy evolution. Despite strong observational evidence that the formation and growth of SMBHs and their host galaxies are related processes, it is still unclear which physical mechanisms are responsible for their coupling. In order to discriminate among the many different model predictions proposed in the past years, sizable samples of AGN over a large range of large-scale environments and different periods/phases of their evolution are needed. To this end, X-ray, mid-IR or astrometric AGN searches provide a solid foundation for the most comprehensive SMBH evolution studies since they are less biased by obscuration effects than searches at optical wavelengths. X-ray-selected AGN are also more complete at the faint end of the AGN luminosity function, due to minimal host-galaxy dilution when compared to optical and mid-IR selection approaches while the mid-IR is least biased against the effects of obscuration. The advent of Gaia, on the other hand, allows for astrometric QSO selection free from colour biases, simplifying the selection function characterization of optical QSO samples across a wide redshift range.

Unfortunately, until now the samples of X-ray and mid-IR selected, spectroscopically identified AGN were relatively small with respect to the optically selected AGN available from large area surveys like the SDSS, mainly due to the small fields of view of sensitive X-ray imaging telescopes, and to the difficulty of obtaining spectroscopic redshift for large number of mid-IR selected AGN with the previous generation of fiber-fed spectroscopic systems. Consequently, the modest source statistics of X-ray and mid-IR selected AGN hamper our understanding of how the relationship between AGN and their host galaxies evolves as a function of redshift, AGN luminosity, nuclear obscuration, host galaxy mass, star-formation properties, and large-scale environment. A complete AGN sample of hundreds of thousands of sources with spectroscopic redshifts and classifications is required to fully sample this multi-dimensional parameter space. The synergy between eROSITA and Gaia, complemented with VISTA near-IR and WISE mid-IR AGN selection approaches, and 4MOST will allow this to become reality.

The 4MOST AGN survey will provide spectroscopic identification for up-to one and half million AGN out to redshift of $z \sim 6$ over an area of about 10,000 deg2. The well understood X-ray, mid-IR and Gaia astrometric AGN identification approaches, combined with the uniform and well characterised selection functions of the eROSITA, WISE and Gaia all-sky surveys, will ensure a highly complete AGN selection. We will aim at a high spectroscopic completeness for the 4MOST AGN survey, to keep systematic uncertainties to a minimal level. The WISE-selected AGN will include a sample of luminous dust-obscured quasars, which may be responsible for powerful AGN-driven feedback and may escape detection by eROSITA due to its predominantly soft X-ray response. Such a highly complete 4MOST AGN sample will serve as a benchmark to test competing models of SMBH formation, growth, and their connection to galaxies and large-scale structure in the Universe. The unbiased selections will allow us to quantify the effect of dust-bias in intervening absorption systems at $2<z<3$ and will provide the first large-scale and systematic analysis of quasar feedback through BAL outflows up to redshift 4.

The survey is complemented by four smaller sub-surveys focusing, respectively, on (i) a bright, high-SNR sample for detailed physical investigation of the AGN-host galaxy interaction (AGN feedback through predominantly emission line kinematics, S602 and S607), (ii) a deeper IR selected sample in the WAVES-WIDE area (S606),and (iii) a high-z QSO search and confirmation survey focusing on quasars at $z > 4.5$ and extending previous searches of high-redshift quasars to more complete populations including dust-obscured quasars, weak-lined quasars and broad absorption line quasars (S604).

The 4MOST low-resolution spectra will be used to measure the redshift of the AGN and the detailed properties of the emission and absorption (both intrinsic and intervening) lines.

Expanded science case:

Expanded science description: messenger-no175-42-45.pdf (S6 Consortium)

Expanded science description: messenger-no190-38-41.pdf (PAQS, Community)

6.6.2 Target Catalogues

The S6 AGN survey is composed of 5 different subsurveys:

S0601 – AGN_WIDE: (eROSITA X-ray selected AGN, wide area)

S0602 – AGN_DEEP: (eROSITA X-ray selected AGN, high-SNR, deep area)

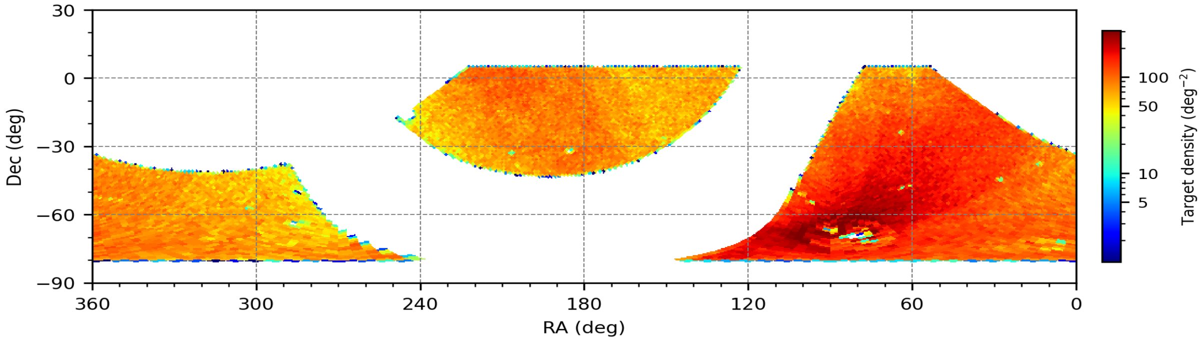
S0603 – AGN_IR, (IR color selected AGN sample, wide area)

S0604 – AGN_HIGHZ, (High-redshift QSO selection, wide area)

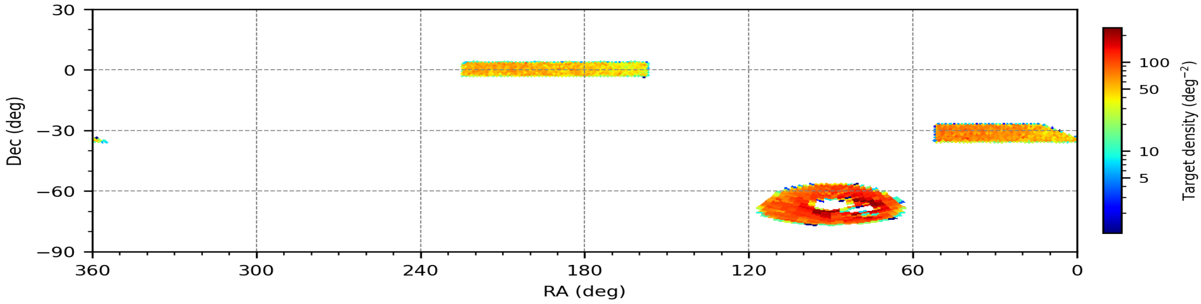
S0605 – PAQS, (Purely astrometric Gaia-based QSO selection, South Galactic Cap region)

S0606 - AGN_IR_DEEP, (IR color selected AGN sample, deep area)

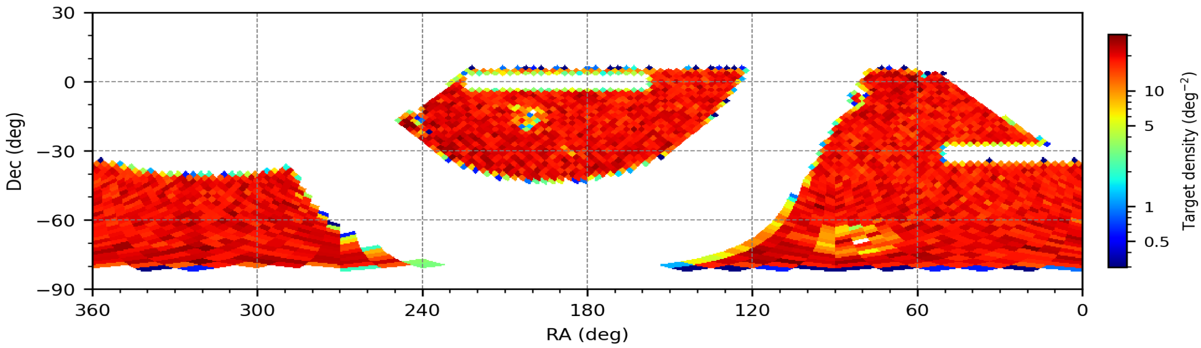
S0607 - DEEP_SEP: (eROSITA X-ray selected AGN, high-SNR, deep area near the SEP)



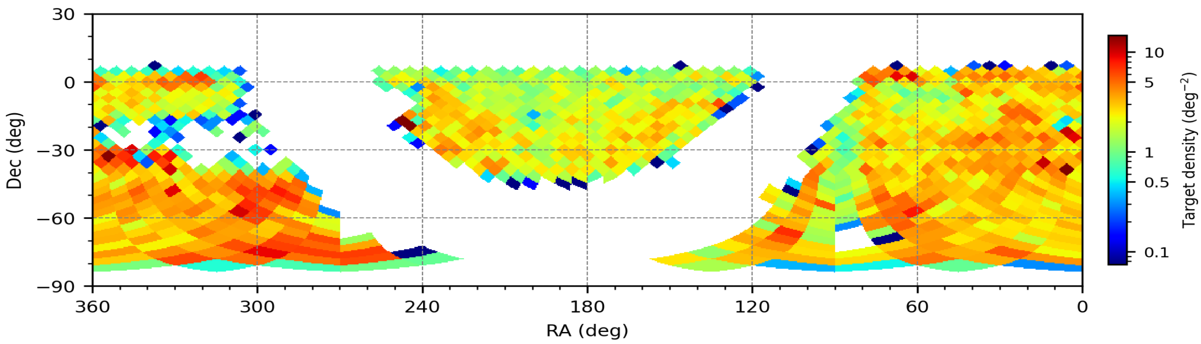
Dec (deg)
RA (deg)
Target density (deg^{-2})



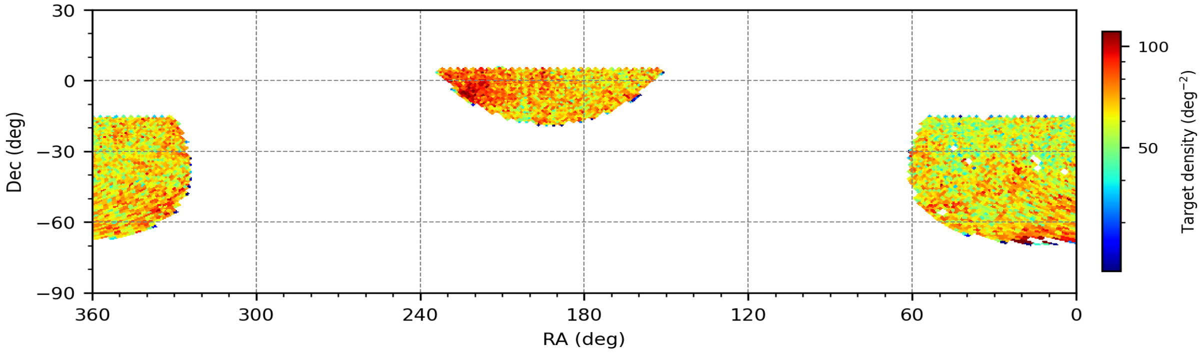
Dec (deg)
RA (deg)
Target density (deg^{-2})



Dec (deg)
RA (deg)
Target density (deg^{-2})



Dec (deg)
RA (deg)
Target density (deg^{-2})



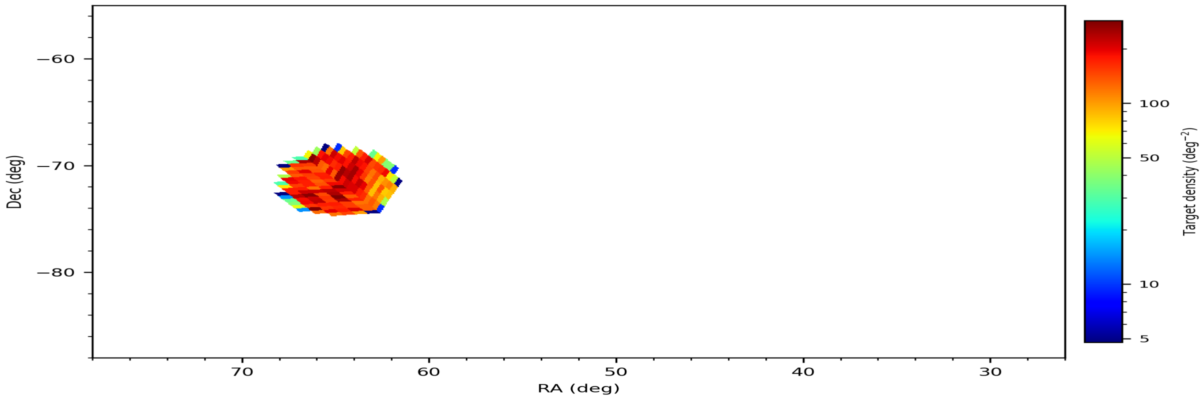
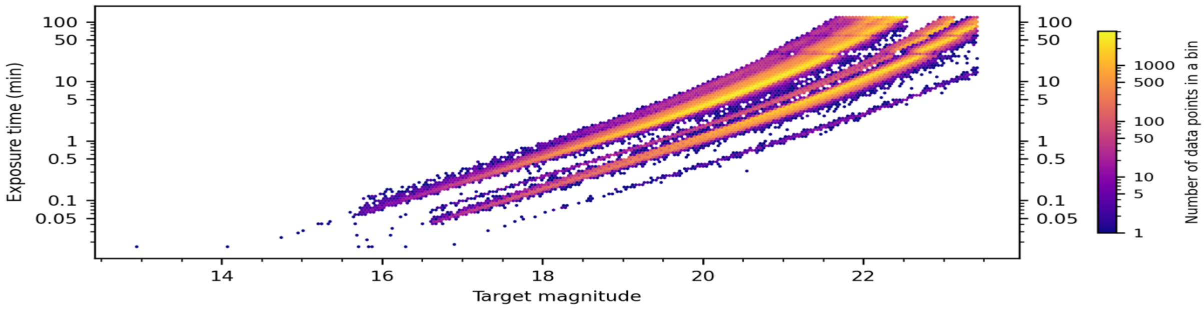
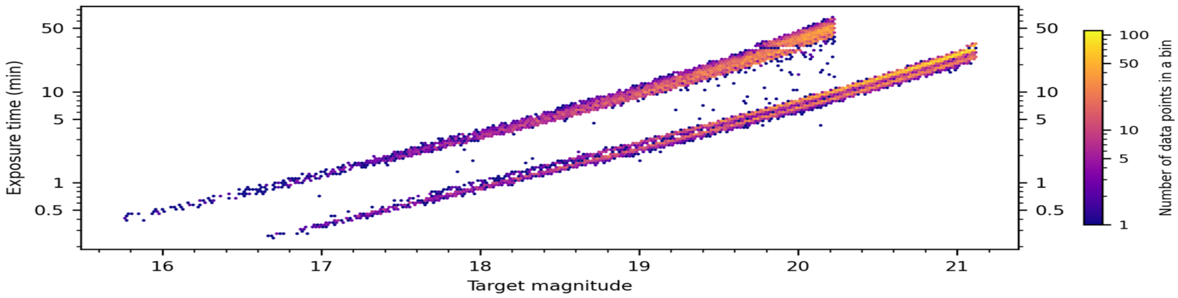


Figure 24: Input target distribution of the S0601 -- AGN_WIDE, S0602 – AGN_DEEP, S0603 -- AGN_IR, S0604 -- AGN_HIGHZ, S0605 -- PAQS, S0606 AGN_IR_DEEP, S0607 DEEP_SEP — subsurveys from top to bottom.





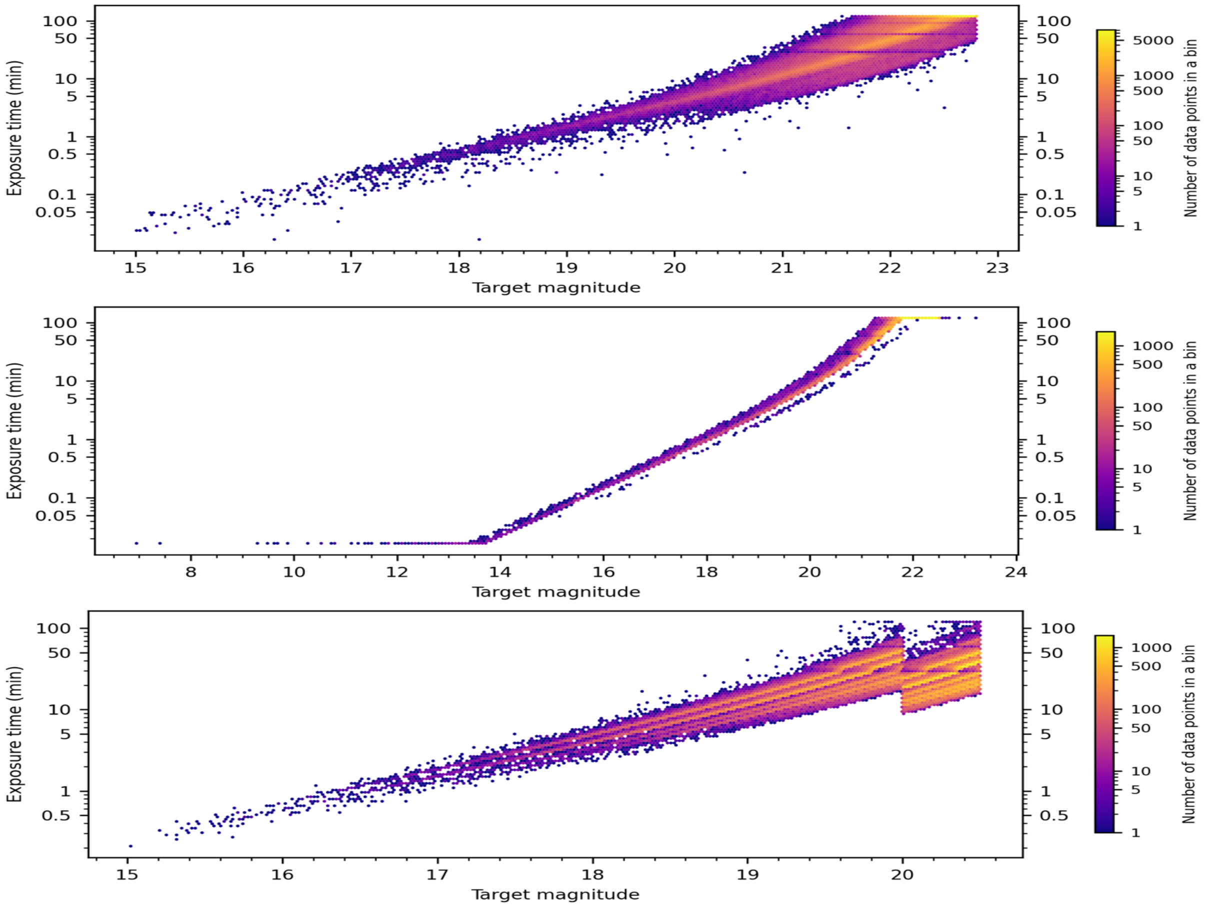


Figure 25: The exposure time estimates as function of target r-mag for the S0601 AGN_WIDE, S0602 AGN_DEEP, S0603 AGN_IR, S0604 AGN_HIGHZ, S0605 PAQS subsurveys from top to bottom. Please note the different x- and y-scales

The input targets sky coverage of the 7 AGN sub-surveys S0601-S0607 is displayed in Figure 24, with exposure time estimates displayed in Figure 25.

The sub surveys for S06 are split across four footprints:

Wide-area Sub surveys require at least 10,000 deg^2 fully contained within the eROSITA-DE extragalactic area. This requirement ensures science goals related to estimates of luminosity functions and spatial clustering of AGN will be achieved. Targets will be selected from the DESI Legacy Imaging Survey DR10 optical counterparts to eROSITA X-ray point sources (down to a magnitude of about r~22.8) and/or WISE IR-AGN selection criteria following the Assef et al. (2018) and Hickox et al. (2007) approaches to identify obscured quasars from a combination of W1, W2, and the r-band, down to r~22.8. For the High-z search, deep DECam imaging will be combined with VISTA (VHS/VIKING) and WISE IR imaging to select a highly complete sample of z > 4.5 QSO candidates. The target S/N is approximately >2-3/AA for S0601, >10 for S0602, >1.5-2 for S0603, >1 for S0604 and >8-12 for S0605.

The Gaia Purely Astrometric Quasar Survey will cover 3000 deg^2 centred on the south galactic cap (only partially, ~50%, overlapping with the other Wide Subsurveys) targeting optical sources with no proper motion from Gaia DR3 down to G<20.5.

The Deep Tiers will cover a total of ~1000 deg^2 in two separate patches, fully overlapping with the WAVES WIDE and LMC surveys. The survey will target bright (r<20) X-ray to high SNR (>10) and faint (r<22.8) mid-IR selected AGN and will require longer integration time over multiple visits.

Finally, the SEP-DEEP X-ray survey covers a small area of approximately 30 deg^2 around the SEP, where the large eROSITA X-ray exposure and source crowding requires an ad-hoc data reduction.

S6 Summary

Table 14: Key parameters of the input target catalogue of the S6 Survey

50	S0601	AGN_WIDE	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -80.0 -- 5.0	2016.0	120 (D)	10000	0.800	480	626	1137	2027	1060883	4200.0 -- 9000.0
51	S0602	AGN_DEEP	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -76.6 -- 4.0	2016.0	240 (D)	1000	0.794	45.5	58.2	100	173	76431	4200.0 -- 9000.0
52	S0603	AGN_IR	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -80.0 -- 5.0	2015.5	120 (D)	9100	0.800	50.5	61.6	129	260	182694	5700.0 -- 7100.0
53	S0604	AGN_HIGHZ	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -80.0 -- 5.4	2015.5	120 (D)	5000	0.899	7.04	8.53	15.9	28.9	39743	4200.0 -- 9000.0
54	S0605	PAQS	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -69.1 -- 6.0	2016.0	120 (D)	3367	0.699	76.9	87.8	139	233	314739	7700.0 -- 8500.0
55	S0606	AGN_IR_DEEP	LR	(0, 0, 0, 0)	0	0.0 -- 360.0 -35.6 -- 4.0	2015.5	240 (D)	900	0.800	15.5	23.5	55.0	113	29798	5700.0 -- 7100.0
56	S0607	DEEP_SEP	LR	(0, 0, 0, 0)	0	82.5 -- 97.5 -69.5 -- -63.6	2016.0	240 (D)	25	0.794	3.38	4.32	7.66	13.4	4967	4200.0 -- 9000.0

6.6.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.6.4 Management Structure

The managerial role in the survey is taken by an "Executive Group" and follows the main scientific themes of the Survey. The members of the Executive Group consult regularly and take decisions on all scientific and organisational matters. Below the list of the Executive Group members:

- D. Alexander
- M. Banerji
- J.-K. Krogager
- A. Merloni

Each of these 4 members is responsible for at least one specific sub-survey. The role of the EG is to take decisions regarding the joint S6 strategy and to coordinate catalogue creation for the respective sub-surveys. The EG meets once per month. Additional meetings are called when needed.

EG membership is held for the duration of the survey. Should one EG member, for whatever reason, be incapable of fulfilling their role within the EG, a deputy may be nominated among the S6 members.

In addition, members of the S6 survey team have taken leadership roles in the 4MOST IWG that are most relevant for the scientific success of the survey, in detail:

- D. Alexander is co-lead of IWG1 (Targeting support) and an IWG2 member
- S. Croom is co-lead of IWG8 (Extra-galactic pipeline)
- D. Gadotti is co-lead of IWG3 (Pipeline calibration and science verification)
- J.-K. Krogager is co-lead of IWG8 (Extra-galactic pipeline).

Other members of the S6 survey have joined all the other IWGs in the project providing the needed liaison and workforce to the common activities.

The members of the S6 executive group commit to devote the necessary time for regular (monthly) exec and monthly team-wide meetings, and join the key science and all-hands yearly in- person events. IWG co-leads will also provide resources at the level of 0.2 FTE/year. Altogether, the S6 contribution to IWGs, SPB and other project-level tasks sums up to more than 2 FTE/yr.

6.6.5 Work-breakdown structure

WP1: Survey planning, strategy, trade-offs
Scope: Definition of the survey design, scope, figures of merit, trade-offs
IWG liaison(s): IWG2, IWG4
Leadership: Executive Group, PI
Milestones: 1- In place by May 2024 (final catalogue upload); 2- Possible revisions to be worked after SPV in late 2025

WP2: Targeting Catalogs
Scope: Preparation, curation and ingestion of targeting catalogue(s)
IWG liaison(s): IWG1, IWG3, IWG9
Leadership: according to sub-packages (See below)
WP2.1: Collation, curation of (external) multi-wavelength catalogues
WP2.2: X-ray Wide and deep surveys
WP2.3: Mid-IR Wide and Deep survey
WP2.4: High-z Survey
WP2.5: Gaia PAQS survey
WP2.6: Homogenization, SED, Photo-z, Classification
Since the approval of the Community survey and the final definiton of the 4MOST survey program, there is now a significant amount of synergy with other surveys and sub-surveys. The S6 executive group has taken a leding role in the so-called AGN coordintion group, where all matter related to AGN target selction, target overlap and scientific synergy and technical coordination are discussed.
Milestones: Final Catalogues to be prepared by May 2024.

WP3: Pipeline, Data Analysis and Validation
Scope: Development, testing and validation of the L2 pipeline tailored to the need of the survey (see Section 6.6.8 below); Development, testing and validation of additional S6-specific L2 products.
IWG liaison(s): IWG8, IWG9
Leadership: IWG8 co-leads; indivdual "Internal Work Packages" (IWP) will focus on a particular data product each. The IWP leads (see section 6.6.8) will be responsible for the Quality Control of each of the specific products. Bo Milvang-Jensen will provide the overall survey-level oversight on the QC work for S6.
Milestones: See section 6.6.8 for more details. In summary, in the first data release (late 2027), we plan to release: absorption lines identified, their redshifts and uncertainties; rest-frame quasar continuum luminosity near the broad line used for black-hole mass estimates, a Gaussian fit to obtain line-width and flux; and lastly synthetic broad band magnitudes and their uncertainties.
By the final data release (2032), we plan to release all the described data products, that is, what is mentioned above plus the following: absorption line equivalent widths and uncertainties, black hole mass estimates and quasar continuum extinction E(B-V) or A(V) from full spectral modelling as well as the balnicity index of broad absorption lines in quasars with these features.

WP4: Archiving, Databases, Publication
Scope: Maintaining the interface with the 4PA and internal archives for S6-specific products.
IWG liaison(s): IWG6
Leadership: TBD
Milestones: TBD (will be set in IWG6)

WP5: Team Organization, Communication

Scope: Maintaining a healthy and efficient level of internal communication; meeting planning and organization; Wiki curation.
IWG liaison(s): N/A
Leadership: EG

WP6: Science policies
Scope: Define and implement the internal rules for science project definition, collaborations, etc.
IWG liaison(s): N/A
Leadership: TBD
Milestones: Internal survey policy, including project approval and coordination, and external collaborations to be finalized in March 2025

6.6.6 Contribution to the Infrastructure Working Groups

IWG1
D. Alexander is co-lead of IWG1. In addition, two more members of the survey are active in IWG1: J. Comparat and M. Salvato. Their tasks include: astrometric verification of input targets, validation of imaging catalogues.

IWG2
D. Alexander, J. Comparat, A. Merloni, G. Worseck, S. Wuyts are members of IWG2. Within IWG2, A. Merloni is a member of the "wide-area" WP, responsible for assessing the survey strategy and optimising the coverage of the wide-area components.

IWG3
D. Gadotti is co-lead of IWG3. In addition, N. Gupta is also a member of IWG3. J.-K. Krogager represents IWG8 for L2 pipeline validation.

IWG4
G. Worseck, M. Krumpe are members of IWG4.

IWG5
N/A

IWG6
Christina Konstantopoulou and Kasper Heintz

IWG7
N/A

IWG8
Two out of the three IWG8 leaders are from S6 (S. Croom and J.-K. Krogager). Moreover, 4 members of S6 also contribute to IWG8 (M. Salvato, T. Shanks, T. Terndrup, S. Wuyts). The main contributions of our survey members are: IWG8 management, testing and development of the redshifting pipeline optimized for quasars, infrastructure development (4DPC integration), and adaptation of visual inspection tools (MARZ).

IWG9
H. Choi, K. Leighly, M. Salvato and A. Merloni are members of IWG9. Our survey contributes to IWG9 in the following ways: Generation of training and test data for machine learning

algorithms, classification of broad absorption line quasars

6.6.7 Level-1 data reduction re-process and ancillary products

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4]] will be used by this Survey.

6.6.7.1 Level-1 data quality assessment

The standard L1 QC described in in Survey Management Plan: Back-end Operations [RD4] will be used by S6.

6.6.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey S6 will be processed by the 4XP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.

6.6.8.1 Deliverable L2 Survey data: reduction processing

In agreement with the submitted proposal, the PAQS sub survey (S0605) will provide data products that are not currently incorporated in the L2 pipeline. These data products are: absorption line identifications, quasar emission line widths and fluxes, continuum luminosities, black hole mass estimates, quasar continuum extinction measurements, BAL identifications and a multi-wavelength catalog of photometry cross-matches. The DXU of these data products is documented separately (https://gitlab.4most.eu/jkrogager/paqs-dxu).
The data products are being produced by 5 internal work packages (IWP), mostly driven by the requirements of the PAQS sub-survey. Below we provide a short summary of each work package and the algorithms used to obtain these measurements.
Absorption line identifications (led by-L. Christensen and S. Balashev): This IWP will provide the absorption line redshifts and equivalent widths for HI, H2 and metal-lines of intervening absorbers detected in the quasar spectra of PAQS. The main algorithms rely on cross-correlation with line templates and have been used extensively by our team (Noterdaeme et al. 2009, Balashev et al. 2014, Ledoux et al. 2015). We are furthermore investigating machine-learning algorithms (Balashev et al. in prep.) to assist the traditional algorithms and for internal quality control (i.e., inspection of sources with inconsistent values between both approaches). When possible, we will further provide column densities of the absorbing species.
Quasar emission lines (led by M. Vestergaard): This IWP will provide measurements of broad emission line fluxes and line-widths as well as continuum luminosities in order to estimate so-called single-epoch black hole mass estimates (Vestergaard 2002) for all broad line objects in the S6 survey.
Quasar extinction measurements (led by E. Glikman): This IWP will provide synthetic broad band magnitudes to provide spectral slopes that can be compared to photometric colors for improved flux calibration checks. We will also provide a parametrized continuum extinction either E(B-V) or A(V) based on template fitting (Krogager et al. 2015, Glikman et al 2018).
Quasar Broad Absorption Lines (led by K. Leighly and H. Choi): This IWP will identify broad absorption lines associated to the quasars themselves and classify these into high-ionisation (HiBALs) and low-ionisation (LoBALs) systems. The core algorithm is a convolutional neural

network (Leighly, Choi et al. in prep). The WP will also provide an estimate of the absorption strength (either balnicity or absorption index) as well as a continuum model.
Cross-match catalog (led by N. Gupta and J. Fynbo): This IWP will provide a cross-matched source catalog to identify matches with public photometric surveys (optical, near-infrared, WISE, radio, X-ray). The catalog will only contain the cross-match IDs and matching criteria. The source photometry can then easily be retrieved by the various public surveys.
All data products will be subject to a strict DXU definition.-Each measurement will be tied to a-unique spectrum (SPECUID) and target (OBJ_UID) ID together with the unique target name (OBJ_NME following IAU coordinate conventions) and provenance of the ESO SAF filename used for the analysis, in compliance with ESO Phase 3 data standards.

6.6.8.2 Deliverable L2 Survey data: quality assessment

Quality assessment will be ensured by each of the WPs described above following similar procedures as the L2 pipeline. That is, quality control metrics will be calculated for each class of measurements, such as reduced chi^2 for fitting methods, cross-correlation robustness or classification probabilities in case of machine learning algorithms. These, together with the L1 QC parameters, will serve as a basis for visual inspection of outliers.
As the calculations will not be performed on a nightly basis, like the L2 pipeline, the QC will be done after each run of the analysis leading up to a public data release.

6.6.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

All data products will be delivered as a single, multi-extension FITS file with a PRODCATG = SCIENCE.CATALOG in a Binary Table format. The detailed content of this file and its metadata will be explained in the DXU document.
A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.6.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

The data delivery schedule will be tied to the overall 4MOST scheme. Initial data releases will provide only a subset of the full products to ensure proper time to analyse the more complex higher-level data products, such as equivalent width and column density measurements since lines might be blended, black hole mass estimates and continuum extinction parameterization.
In the first data releases (DR1), the PAQS survey team therefore plan to release: absorption lines identified, their redshifts and uncertainties; rest-frame quasar continuum luminosity near the broad line used for black-hole mass estimates, a non-parametric line-width and line flux and

their uncertainties; synthetic broad-band magnitudes and their uncertainties; BAL identifications and their probabilities; cross-match IDs of observed targets in the data release.
By the final data release, the PAQS team plan to release all the described data products, that is, what is mentioned above plus the following: absorption line equivalent widths, column densities and uncertainties, attempted black hole mass estimates (when possible) and quasar continuum extinction E(B-V) from full spectral modelling as well as the balnicity index of broad absorption lines in quasars with these features. For the other S6 sub-surveys, attempted black hole mass estimates (when possible) and quasar continuum extinction E(B-V) from full spectral modelling will also be released then. We note that any of these data products will be released earlier if they are included in the analysis leading to a refereed journal article.
Finally, the collection of observed S6 target catalogues will be published and included in Public Data Releases starting at DR1.

6.6.8.5 Deliverable L2 Survey data: Required hardware and staff

The aim of our survey is to deliver these data products as part of the L2 pipeline in order to minimise data transfers. In the meantime, we have organised a processing centre with local resources at CRAL and the Observatory of Lyon. This will require regular transfers of internally released L1 data and subsequent processing at the dedicated machine in Lyon. J-K Krogager and the local IT staff at CRAL are responsible for the maintenance and operations.
The algorithms used to obtain the data products, as explained in the three WPs, will be delivered by the WP responsibles and executed on the machine in Lyon.

6.6.8.6 Additional L2 data: reduction processing

No extra AL2 processing is planned by this Survey.

6.6.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.6.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey.

6.6.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 processing is planned by this Survey.

6.6.8.10 Additional L2 data: Required hardware and staff

No extra AL2 processing is planned by this Survey.

6.6.9 Team

Table 15 lists all the key members of the survey, defined as executive group members, IWG co-leads and active IWG members. The full list of S6 team members is available on the 4most.eu website.

Table 15: Person-power and FTE allocation for the Survey 6 in the period 2023-2029. Only Currently active members in exec or IWG roles are listed. The FTE contribution is explicitly restricted to managerial and/or IWG-related tasks.

Name	Main Function	Affiliation and Country	FTE
A. Merloni	Principle Investigator, X-ray survey lead, IWG2 member	MPE, Germany	0.2/year
D. Alexander	Exec. Member, mid-IR survey lead; IWG1 co-lead (Targeting support), IWG2 member	Durham Univ., UK	0.2/year
M. Banerji	Exec. Member, High-z survey lead	Univ. of Southampton, UK	0.1/year
J.-K. Krogager	Exec. Member, PAQS survey lead; IWG8 co-lead (Extra-galactic pipeline)	Univ. of Lyon, France	0.2/year
S. Croom	IWG8 co-lead (Extra-galactic pipeline)	Univ. of Sydney, Australia	0.2/year
D. Gadotti	IWG3 co-lead (Pipeline calibration and science verification)	Durham Univ., UK	0.2/year
H. Choi	IWG9 member (Classification)	Oklahoma Univ., USA	0.1/year
J. Comparat	IWG1, IWG2 member (Catalogue; Survey strategy)	MPE, Germany	0.1/year
N. Gupta	IWG3 member (Science verification)	IUCAA, India	0.1/year
K. Heintz	IWG6 member (Quality Control)	NBI, Denmark	0.1/year
C. Konstantopoulou	IWG6 member (Quality Control)	Uni. Geneva, Switzerland	0.1/year
M. Krumpe	IWG4 member (Selection function)	AIP, Germany	0.1/year
K. Leighly	IWG9 member (Classification)	Oklahoma Univ., USA	0.1/year

Name	Main Function	Affiliation and Country	FTE
M. Salvato	IWG1, IWG9 member (Target catalogue; Classification)	MPE, Germany	0.1/year
T. Shanks	IWG8 member (Extra-galactic pipeline)	Durham Univ., UK	0.1/year
D. Terndrup	IWG8 member (Extra-galactic pipeline)	Ohio State Univ., USA	0.1/year
S. Wuyts	IWG2, IWG8 member (Survey strategy; Extra-galactic pipeline)	Univ. of Bath, UK	0.1/year

6.7 Survey 7 – Wide Area VISTA Extragalactic Survey (WAVES)

Survey PIs: Simon Driver, Joe Liske

6.7.1 Science Summary

WAVES is the combination of four tightly intertwined galaxy surveys: the original WAVES Consortium Survey and the three Community Surveys ORCHIDSS, 4MOST-StePS and 4C3R2.

WAVES is designed to study the growth of structure and mass on scales of ~1 kpc to ~10 Mpc over a 7 Gyr timeline. On the largest length scales (1–10 Mpc) WAVES will compare the emergence of large-scale structure in the form of groups, filaments and voids with the Cold Dark Matter paradigm. At inter-mediate scales (10 kpc–1 Mpc) WAVES will probe the size and mass distribution of galaxy groups, as well as the galaxy merger rates, directly witnessing the assembly of dark matter halos and stellar mass. On the smallest scales (1–10 kpc) WAVES will provide accurate environmental measurements to complement high-resolution space-based imaging to study the mass and size evolution of galaxy bulges, discs and bars. WAVES will provide a panchromatic legacy dataset of ~1.6 million galaxies, firmly linking the very low ($z < 0.1$) and intermediate ($z \sim 0.8$) redshift Universe.

4MOST-StePS represents the high-signal-to-noise component of WAVES. For a small sample of ~3300 galaxies, StePS will collect high-quality (median SNR of ~30 $Å^{-1}$) spectra, thus affording access to the wealth of information on galaxy physics, mass assembly and chemical enrichment history that is encoded in the galaxies' continuum and absorption/emission features. This sample will provide a precise empirical description of the evolutionary path of massive galaxies in the intermediate redshift range ($0.3 < z < 0.7$) between LEGA-C and SDSS.

ORCHIDSS will focus on the continuous cycle of gas accretion, consumption and feedback which regulates galaxy evolution. Using the powerful combination of 4MOST spectroscopy and sensitive radio observations from the MeerKAT deep extragalactic surveys, ORCHIDSS will trace the evolution of neutral gas and its lifecycle within galaxies across the bulk of cosmic history.

Finally, 4C3R2 will support future Euclid and Rubin weak lensing experiments to deliver precision tests of our cosmological model by providing an accurate calibration of the colour-redshift relation. This will be achieved by collecting redshifts for ~100,000 galaxies selected to systematically cover a KiDS-VIKING colour space in which there is little variation in redshift at any point, and which is not already covered by other components of WAVES.

Expanded science descriptions:

- Original WAVES Consortium Survey: messenger-no175-46-49.pdf
- 4MOST-StePS Community Survey: messenger-no190-22-24.pdf
- ORCHIDSS Community Survey: messenger-no190-25-27.pdf
- 4C3R2 Community Survey: messenger-no190-28-30.pdf

6.7.2 Target Catalogue

Sub-surveys

The original WAVES Consortium Survey, ORCHIDSS and 4C3R2 all have a wide and deep component. Thus, WAVES consists of a total of 9 sub-surveys:

S0701 WAVESwide
S0702 WAVESdeepG23
S0703 WAVESdeepDDF

S0704 StePS
S0705 ORCHIDSSwideMFS
S0706 ORCHIDSSwideDDF
S0707 ORCHIDSSdeep
S0708 4C3R2wide
S0709 4C3R2deep

Note that WAVESdeepG23 and WAVESdeepDDF were separated into two sub-surveys for technical reasons. They cover different survey regions (see below) but are otherwise identical.

Survey regions

The following table lists the WAVES survey regions. Note that the Deep Drill Fields (DDFs) are single 4MOST pointings.

Table 16: Survey S7 survey regions.

Survey region	RA (deg)	Dec (deg)	Area (deg^2)	Sub-surveys targeting this region
WAVESwide N	157.25 – 225.0	-3.95 – 3.95	542	S0701, S0708
WAVESwide S	330.0 – 51.6	-35.6 – -27.0	626	S0701, S0708
WAVESdeep G23	339.0 – 351.0	-35.0 – -30.0	50	S0702, S0704, S0708
WAVESdeep DDF1 ELAIS-S1	9.5	-43.95	4	S0703, S0704, S0708
WAVESdeep DDF2 XMMLSS	35.875	-5.025	4	S0703, S0704, S0706[1], S0707, S0709
WAVESdeep DDF3 ECDFS	53.125	-28.1	4	S0703, S0704, S0706[1], S0707, S0709
WAVESdeep DDF4 COSMOS	150.125	2.2	4	S0703, S0704, S0706, S0707, S0709
ORCHIDSSwide MFS	49.35295 – 57.92002[2]	-38.46243 – -33.42806[2]	16	S0705

[1]DDF2, DDF3 and DDF4 are targeted by S0706 ORCHIDSSwideDDF over a somewhat larger area than the nominal single 4MOST pointing. These larger areas currently have a complex geometry because they are based on the overlap between HI surveys and the available optical/NIR data.
[2]The S0705 ORCHIDSSwideMFS region has a complex shape dictated by the MeerKAT Fornax Survey (MFS). The RA and Dec ranges given here are the minimum-maximum ranges.

Master source catalogue

The optical/NIR master source catalogue, which is used by all sub-surveys except S0705 ORCHIDSSwideMFS and S0706 ORCHIDSSwideDDF, was derived from ugri VST imaging from the KiDS survey and ZYJHK VISTA imaging from the VIKING survey in the case of the WAVESwide N and S and WAVESdeepG23 regions. For the DDF regions, the master source catalogue was derived from an assortment of equivalent-quality VST and VISTA imaging. The source detection and multi-band photometry was performed using our own ProFound code and associated procedures.
For the S0705 ORCHIDSSwideMFS and S0706 ORCHIDSSwideDDF, the master source catalogue is LS DR8.

Target selection

S0701 WAVESwide: Z < 21.1 AND z_{phot} < 0.2 AND source_type = galaxy OR ambiguous. Required completeness = 90%.

S0702 WAVESdeepG23: Z < 21.25 AND z_{phot} < 0.8 AND source_type = galaxy OR ambiguous. Required completeness = 90%.

S0703 WAVESdeepDDF: Same as for S0702.

S0704 StePS: I < 20.5 AND 0.3 < z_{phot} < 0.7 AND source_type = galaxy OR ambiguous; randomly down-sample to achieve a target density of 60 deg^2. Required completeness = 85%.

S0705 ORCHIDSSwideMFS: initial selection: 80% of photo-z posterior < 0.57 and photo-z FLAG_CLEAN = 1. An optical selection is then applied that matches the source density and population properties of radio continuum sources as follows: Rest-frame colours and magnitudes are estimated for each source with Eazy fixed at the photo-z. Sources are then selected if they are either: 1. "Star-forming galaxies" based on UVJ colour classification, and with rest-frame B-band magnitude brighter then M*+0.7; or 2. Total magnitude r < 19.5. Required completeness = 75%.

S0706 ORCHIDSSwideDDF: initial selection: 80% of photo-z posterior < 0.57 and photo-z FLAG_CLEAN = 1. Radio selection: MIGHTEE 1.3 GHz continuum flux density > 15 μJy. Required completeness = 75%.

S0707 ORCHIDSSdeep: initial selection: Z < 23 AND 80% of photo-z posterior < 1.4. Radio selection: MIGHTEE 1.3 GHz continuum flux density > 15 μJy. Required completeness = 75%.

S07078 4C3R2wide: Galaxies with complete KiDS and VIKING ugriZYJHKs photometry are assigned by colour to the Masters et al. (2017) Self Organised Map (SOM) in order to group them by phenotype and redshift. Each galaxy is thus assigned to a unique SOM cell. We apply a magnitude cut of Z < 21.5. We assign a completeness requirement on a per cell basis, such that 45 galaxies are asked for per cell, where galaxies in cells with fewer than 45 objects have a completeness requirement of unity. As we aim to cover as many cells as possible we eliminate shared targets from high completeness surveys (WAVESwide / S5 / S8 / S18) and existing spectroscopy (GAMA/SDSS/DESI) in our footprint. For cells with completeness < 0.2 we down-sample with fixed random seeds to force the per-cell completeness requirement back up to 0.2.

S07089 4C3R2deep: Galaxies with complete KiDS and VIKING ugriZYJHKs photometry are assigned by colour to the Masters et al. (2017) SOM in order to group them by phenotype and redshift. Each galaxy is thus assigned to a unique SOM cell. We apply a magnitude cut of Z < 22.0. We assign a completeness requirement on a per cell basis, such that 10 galaxies are asked for per cell, where galaxies in cells with fewer than 10 objects have a completeness requirement of unity. As we aim to cover as many cells as possible we eliminate shared targets from high completeness surveys (WAVESdeep / S5 / S8 / S18) and existing spectroscopy (GAMA/SDSS/DESI) in our footprint. Note that this. For cells with completeness < 0.2 we down-sample with fixed random seeds to force our per-target completeness requirement back up to 0.2.

Spectral success criteria

For all sub-surveys except S0704 StePS, the true spectral success criterion is the successful measurement of a redshift, where "successful" is defined as $p > 0.9$, where p is the probability that the redshift is correct. Since the formal spectral success criterion cannot be defined in terms of redshift success, we have used simulations to determine the SNR required for a successful redshift measurement as a function of spectral template and redshift, where SNR refers to the

median SNR per Å in the range 8100 – 8900 Å. The formal spectral success criterion associated with each target is this SNR, given the target's z_{phot} and assigned template.
The formal spectral success criterion above is associated with a fair amount of "noise", in the sense the true SNR required for a successful redshift measurement of a given target may be significantly larger or smaller than the one derived by the simulations. The reason is the spectral template assignment uncertainty, i.e. our limited a priori knowledge (from optical and NIR photometry) of the target's true spectrum. To cope with this, in operations we will use the feedback loop to continue observing a target until its redshift has been measured with $p > 0.9$.
For S0704 StePS, the formal spectral success criterion is to obtain a median SNR per Å in the range 7250 – 7750 Å of 80. This translates into a request of 30 hours of observation for almost all targets. The feedback loop will be used to exclude targets that turn out to lie outside our redshift range of interest from further observations.

<u>Figure of Merit</u>
The scientific Figures of Merit for the individual sub-surveys are defined as follows, where $c = n_{completed} / n_{all}$ is the spectroscopic completeness, i.e. the ratio of the number of successfully observed targets (those with a successfully measured redshift) and the number of all targets:
<u>S0701 WAVESwide, S0702 WAVESdeepG23, S0703 WAVESdeepDDF:</u>
$FoM = 0.55 * c^2 + 1.4 * c^6 / (1.0 + \exp(-(c - 0.95) / 0.02))$
With this definition, the FoM scales as c^2 for $c < 0.9$ and as c^6 for $c > 0.9$, and the constants are chosen such that FoM(0.9) = 0.5 and FoM(0.95) = 1.0, which correspond to the requirement and goal for the spectroscopic completeness of these sub-surveys.
<u>S0704 StePS:</u>
$FoM = 0.25 * c * (0.25 + 3.75 * c^{3.5})$
This definition leads to FoM(0.85) = 0.5 and FoM(1.0) = 1.0 which correspond to the requirement and goal for the spectroscopic completeness of StePS.
<u>S0705 ORCHIDSSwideMFS, S0706 ORCHIDSSwideDDF, S0707 ORCHIDSSdeep:</u>
$FoM = 1.165 * c^3$
This definition leads to FoM(0.75) = 0.5 and FoM(0.95) = 1.0 which correspond to the requirement and goal for the spectroscopic completeness of these sub-surveys.
<u>S0708 4C3R2wide:</u>
$FoM = 0.5 * \mathrm{sqrt}(c / 0.0165)$
This definition leads to FoM(0.0165) = 0.5 and FoM(0.066) = 1.0 which correspond to the requirement and goal for the *average* spectroscopic completeness of 4C3R2wide across all SOM cells.
<u>S0709 4C3R2deep:</u>
$FoM = 0.5 * \mathrm{sqrt}(c / 0.0516)$
This definition leads to FoM(0.0516) = 0.5 and FoM(0.21) = 1.0 which correspond to the requirement and goal for the *average* spectroscopic completeness of 4C3R2deep across all SOM cells.
<u>S07 WAVES</u>
The overall WAVES scientific FoM is defined as the minimum of the sub-survey FoMs:
$FoM_{WAVES} = \min\{FoM_i\}$

6.7.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.7.4 Management Structure

The WAVES team structure is still evolving somewhat in parallel with the development of the WAVES policies. Here we describe the current status.

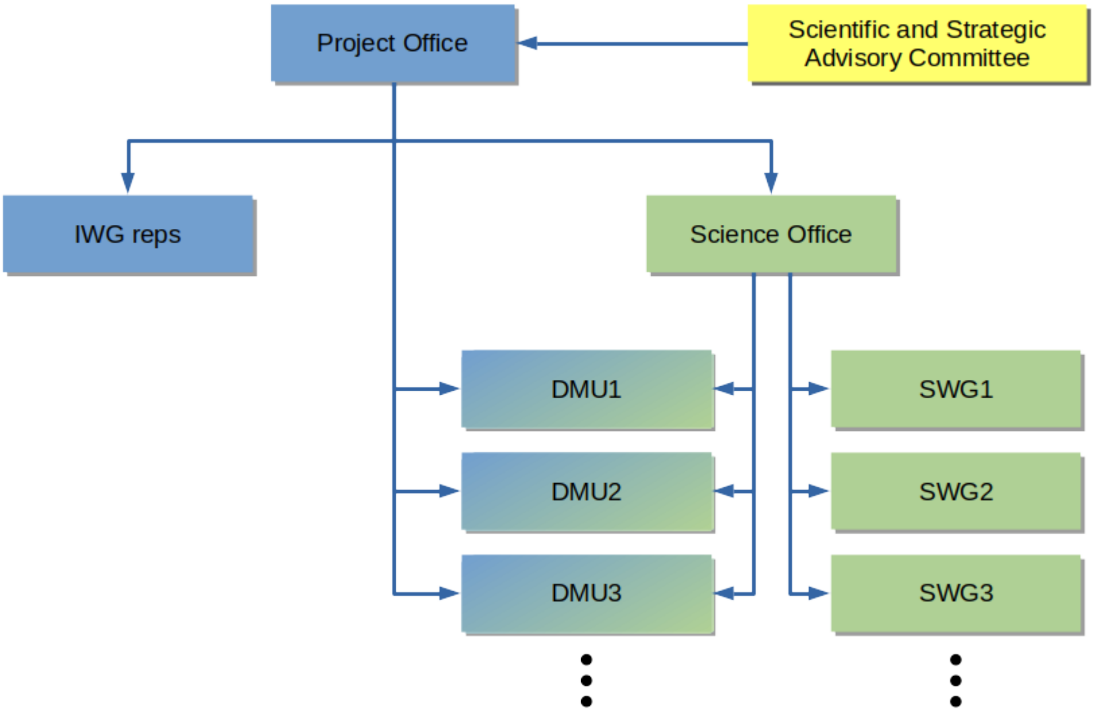


Figure 26: Survey S7 Management Structure.

Principal Investigators
WAVES is led by two PIs (Simon Driver and Joe Liske) who provide overall leadership and oversight of the project. They represent the project to the outside world and to 4MOST, in particular on the Science Coordination Board. They take a leading role in (MoU) negotiations with other collaborations. They appoint the Project Scientists for the three sub-surveys of the original WAVES Consortium Survey. They are members of the Project Office.
Disagreements between the PIs are mediated by the other members of the Project Office.
Project Scientists
Each WAVES sub-survey is led by a PS. The PSs of the StePS, ORCHIDSSwide and deep, and 4C3R2wide and deep sub-surveys are the PIs of the 4MOST-StePS, ORCHIDSS and 4C3R2 Community Survey proposals. The PSs of the three sub-surveys of the original WAVES Consortium Survey are appointed by the PIs for an indefinite period. The PSs are responsible for the day-to-day management of their sub-survey. They provide scientific leadership for the exploitation of their sub-survey data. The PSs are members of the Project Office and of the Science Office.
Project Office
The PO is the governing body of WAVES. It consists of the WAVES PIs and the sub-survey PSs. Other leading members of the team are (temporarily) added to the PO, as required by the issues of the day.
The PO exercises control over the definition of the sub-surveys. It analyses the output of the simulations and monitors the progress of the survey during operations. It appoints the members of the Scientific and Strategic Advisory Committee and receives their advice. It appoints the

WAVES representative on the 4MOST Science Policy Board and the 4MOST IWGs. It approves the WAVES policies.

The PO meets at least every two weeks.

Scientific and Strategic Advisory Committee

The SSAC is a high-level advisory body consisting of five senior, experienced members of the team. The members of SSAC are appointed by the PO for a renewable term of two years.

The SSAC is charged with maintaining a bird's eye view of WAVES in the context of its science goals in order to help ensure the scientific impact and legacy value of WAVES. It monitors the scientific output of WAVES and assesses its impact. The SSAC provides advice to the PO accordingly.

The SSAC meets every two months.

Science Office

The SO is in charge of delivering the WAVES scientific output. It consists of the PSs.

The SO establishes Science Working Groups on the core scientific topics of WAVES, and oversees their activities. It ensures that the necessary Data Management Units are established and monitors their progress.

Team communication

Communication among the WAVES team happens primarily through the WAVES workspace on Slack. The PIs regularly inform the team of ongoing developments using the WAVES team email list.

Team meetings will be organised around the time of the start of operations and every 1.5 years following that.

6.7.5 Work Breakdown Structure

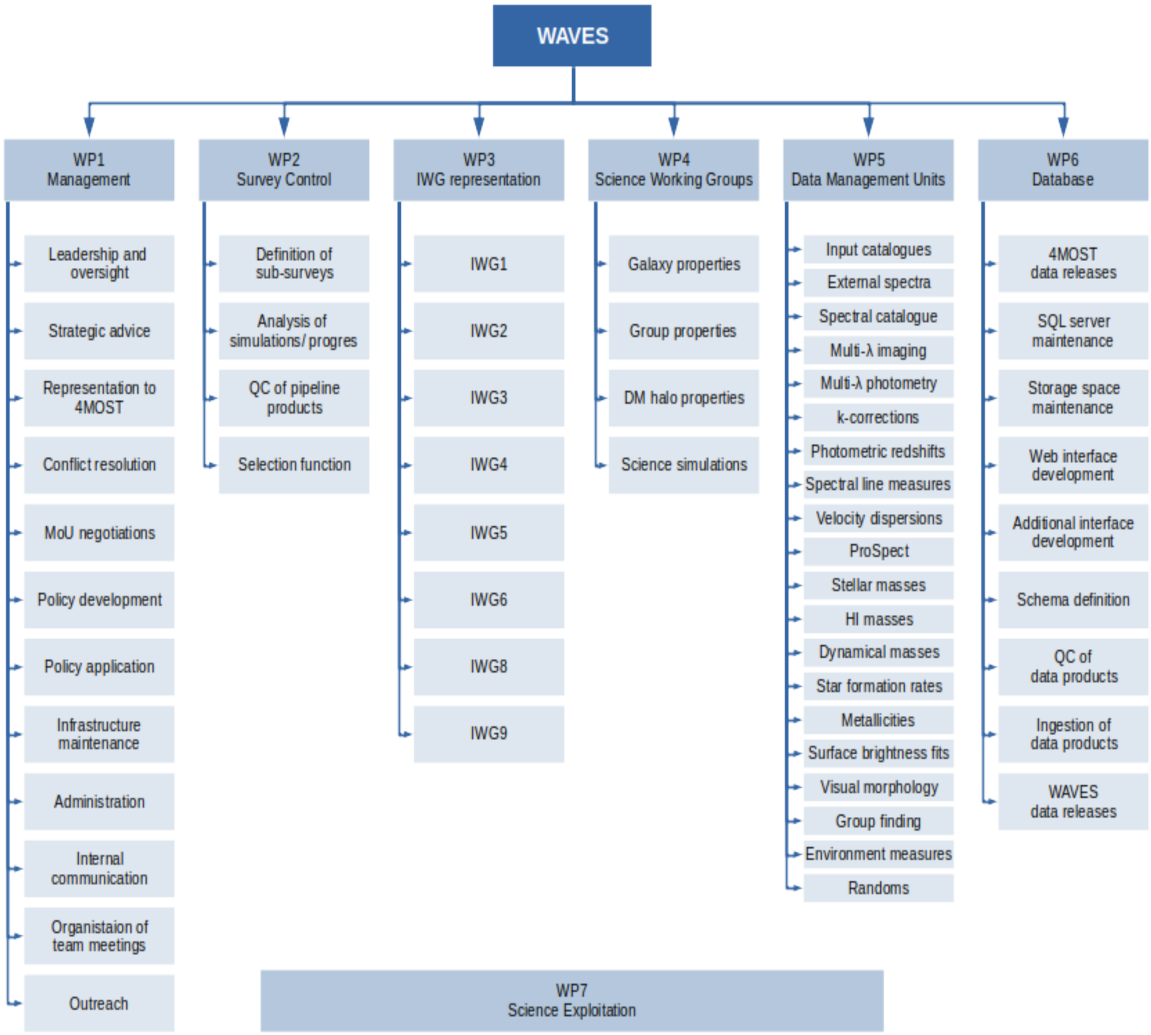


Figure 27: Survey S7 Work Breakdown Structure.

1. WP1: Management
    1.1. Overall project leadership and oversight
    1.2. Provision of strategic advice
    1.3. High-level representation to 4MOST
        1.3.1. Science Coordination Board
        1.3.2. Science Policy Board
    1.4. Conflict resolution
    1.5. MoU negotiations
    1.6. Policy development
        Development of WAVES-specific policies augmenting the 4MOST Science Team Policies.
    1.7. Policy application
        Development and application of the procedures to implement both the 4MOST Science Team Policies as well as the WAVES-specific policies.
        1.7.1. Scientific project approval

Internal review and approval of scientific projects (including collaboration projects) before their registration with 4MOST.

1.7.2. Invited memberships

1.7.3. Implementation of rules from MoUs

1.8. Maintenance of infrastructure

1.8.1. Website

1.8.2. Wiki

1.8.3. Slack

1.8.4. Internal admin database

The sub-WP is a placeholder in case the 4MOST Management System (4MS) does not fully meet the needs of WAVES.

1.9. Administration (4MS)

Administration of users (i.e. team members), science projects and publications. Science projects and publication records are expected to be largely self-administered by science project leaders.

1.10. Internal communication

Communication with the entire WAVES team via email and slack.

1.11. Organisation of WAVES team meetings

1.12. Outreach

2. WP2: Survey control

Each sub-WP below contains one sub-sub-WP per WAVES sub-survey which, however, has been omitted here for brevity.

2.1. Definition of sub-survey parameters

Definition of the survey regions, target selection, spectral templates, spectral template-to-target association, rules, rulesets, feedback loop parameters, LSM, SSM (i.e. completeness requirement), scientific FoM for each sub-survey.

2.2. Analysis of simulation outputs / observing progress

WAVES-specific analysis of the simulation output and (beginning with the Science Programme Verification phase) and real data and observing progress. The results are reported to IWG2 by WP 3.2.

2.3. QC of pipeline products

WAVES-specific QC analysis of the calibrated 1D spectra. Related to the work done in IWG3 (WP 3.3).

2.4. Selection function

Analysis of the WAVES selection function. Related to the work done in IWG4 (WP 3.4).

3. WP3: Representation on and contribution to 4MOST IWGs

This WP only contains the WAVES representation on the IWGs and the work related to contributions to the 4MOST infrastructure. It does not contain the actual WAVES-related analysis work.

3.1. IWG1

3.2. IWG2

3.3. IWG3

3.4. IWG4

3.5. IWG5

3.6. IWG6

3.7. IWG8

3.8. IWG9

4. WP4: Science Working Groups
   4.1. Galaxy properties
   4.2. Group properties
   4.3. DM halo properties
   4.4. Science simulations
5. WP5: Data Management Units

   The WAVES data flow will be broken up into individual tasks which are referred to as Data Management Units (DMUs). Each DMU performs a specific data analysis step on some input data, and as a result produces some output. A DMU's input may be either the output of another DMU or come from an external source. All DMU outputs (also called DMU products) are stored in the WAVES database. Most DMU products are advanced (L3) data products.

   5.1. Input catalogues
   5.2. External spectra and redshifts
   5.3. Spectral catalogue
   5.4. Multi-wavelength imaging data
   5.5. Multi-wavelength photometry
   5.6. k-corrections
   5.7. Photometric redshifts
   5.8. Spectral line measurements

        Only required to the extent that this is not already done by 4XP.

   5.9. Velocity dispersions

        Only required to the extent that this is not already done by 4XP.

   5.10. ProSpect
   5.11. Stellar masses
   5.12. HI masses
   5.13. Dynamical masses
   5.14. Star formation rates
   5.15. Metallicities
   5.16. Surface brightness fitting
   5.17. Visual morphology
   5.18. Group finding
   5.19. Environment measures
   5.20. Randoms
6. WP6: Database

   WAVES will maintain its own database on its own hardware in order to host and to distribute (both internally and to the public) DMU products (mostly advanced L3 data products). It will consist of an SQL server, a file server and several APIs, including a web interface accessible via the WAVES website.

   6.1. 4MOST Data Releases

        This sub-WP is a placeholder in case any work is required from Surveys in the preparation of 4MOST DRs.

   6.2. Installation and maintenance of SQL server
   6.3. Installation and maintenance of storage space
   6.4. Web interface development and maintenance
   6.5. Additional interface development and maintenance

Possible interfaces: AstroQuery, VO

6.6. Schema definition

6.7. Quality control of data products

6.8. Ingestion of data products

6.9. WAVES Data Releases

Definition of DRs of WAVES L3 products and their implementation in the WAVES database.

7. WP7: Science Exploitation

Scientific analyses and writing of papers. Each registered science project will represent a sub-WP here.

6.7.6 Contribution to the Infrastructure Working Groups

IWG1

S7 representative: Sabine Bellstedt

Other members: Peder Norberg

Bellstedt leads the effort on shared targets and contributes towards the development of the shared targets processing tool. Norberg represents IWG2 in IWG1.

IWG2

S7 representative: Joe Liske

Other members: Matteo Bianconi, Peder Norberg, Elmo Tempel, Taavi Tuvikene

Liske developed and maintains the observing time accounting code, and supports the port from C to python. Norberg is an IWG2 co-leader. Tempel leads the simulation effort. Tuvikene heavily supports the simulation effort. Bianconi leads the IWG2 sub-WG on the deep fields.

IWG3

S7 representative: Amata Mercurio

Other members: Jon Loveday

Mercurio contributed to defining the extragalactic SPV experiments for WAVES and to the preparation of extragalactic cross-calibration catalogues by contributing a catalogue of 4MOST targets in common with WEAVE.

IWG4

S7 representative: Jon Loveday

Other members: Behnood Bandi, Moorits Muru, Shishir Sankhyayan, Elmo Tempel, Taavi Tuvikene

Loveday and Bandi test the geometric selection function using simulated surveys. Tempel is a co-leader of IWG4 and the main developer of the geometric selection function. Tuvikene, Muru, and Sankhyayan all contribute to the development of the geometric selection function.

IWG5

This IWG is currently not active. But future contributors will include Power, Norberg, Lagos, Vulcani, de Lucia, and Fontanot.

IWG6

S7 representative: Jon Loveday

Meeting attendance and survey representation only.

IWG7
S7 does not contribute to this IWG since we have no Galactic targets.

IWG8
S7 representative: Luke Davies
Other members: Sabine Bellstedt, Marcella Longhetti, Matt Owers
Davies is a co-leader of IWG2 and leads the development of the galaxy redshifting code. He also develops a standard simulated test sample of spectra. Bellstedt, Owers, and Longhetti contribute to the development of the spectral fitting code. Longhetti contributes to the definition of the XGAL-L2 DXU.

IWG9
S7 representative: Caroline Heneka
Other members: Maciej Bilicki, Nicola Napolitano, Michelle Cluver
Heneka is a co-leader of IWG9. Heneka and Napolitano contribute to the development of the pipeline, in particular the pipeline infrastructure and the main classifier, with a focus on the joint classification and uncertainty estimation.

6.7.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.7.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of S7 will be processed by the 4XP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
In addition, S7 WAVES will deliver the following DL2-SURV products: optical and NIR photometry, spectral lines and indices, stellar masses, radio data, and environment measures.

6.7.8.1 Deliverable L2 Survey data: reduction processing

Optical and NIR photometry (S. Bellstedt): We will provide ugriZYJHK$_s$ photometry with associated uncertainties for all sources with Z < 22 (i.e. deeper than our spectroscopic target catalogue) in the WAVES survey regions (except the ORCHIDSSwideMFS region) derived from VST and VISTA imaging data using our own ProFound code. For the ORCHIDSSwideMFS region we will provide the LS DR8 photometry.
Spectral lines and indices (A. Iovino): In addition to the spectral modeling provided by 4XP, we will provide the results of our own spectral analysis of all spectra with SNR per Å > 80 (i.e. for S0704 StePS targets), including line strengths, indices, emission line fluxes, velocity dispersions, and associated uncertainties. We will also provide derived physical quantities, including star formation rates, stellar and dynamical masses, luminosity-weighted stellar population ages, as well as stellar population and gas metallicities, and their associated uncertainties.
Stellar masses (A. Robotham and L. Tortorelli): We will provide stellar masses and associated uncertainties for all targets with a successfully measured redshift estimated from the optical and NIR photometry using our own ProSpect code.

Radio data (K. Duncan): For all S0705 ORCHIDSSwideMFS, S0706 ORCHIDSSwideDDF and S0707 ORCHIDSSdeep targets with a successfully measured redshift we will provide MeerKAT L-band (1.3 GHz) radio continuum flux density and luminosity with associated uncertainties, as well as probabilistic source classifications (star-forming galaxy/radiative AGN/radio excess AGN) derived from 4XP/4CP/4SP pipeline products in combination with the radio continuum information.
Environment measures (E. Tempel and T. Lambert): We will provide lists of galaxy groups, pairs, filaments and voids, including their properties, with appropriate links to the galaxies that are members of these structures. For all WAVES targets with a successfully measured redshift we will provide environmental classifications relative to these structures.

6.7.8.2 Deliverable L2 Survey data: quality assessment

All DL2-SURV data products will be subject to an internal Quality Control process prior to their release. This process includes the formatting, the metadata as well as basic scientific checks. The internal QC WP is led by J. Liske.

6.7.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

All data products will be delivered as a single, multi-extension FITS file with a PRODCATG = SCIENCE.CATALOG in a Binary Table format. The detailed content of this file and its metadata will be described in a DXU. This DXU will be reviewed by the 4MOST Data Model Curator (DMC) to ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with S7 WAVES, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, our DL2-SURV products will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV products will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.7.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

All DL2-SURV products will be delivered for the first time at DR2, and updated at each DR thereafter, except the environment measures. This data product depends on the availability of a highly complete (sub-)sample. Since we cannot reliably predict when such a sample might be available, no commitment to a particular delivery date can be made. The environment measures will therefore be delivered at the next DR following the availability of this data product and the associated scientific paper.

6.7.8.5 Deliverable L2 Survey data: Required hardware and staff

All hardware required to produce our DL2-SURV data products are already available at the relevant institutes. The leaders of the WAVES Data Management Units that will produce the DL2-SURV products are listed above.

6.7.8.6 Additional L2 data: reduction processing

No extra AL2 processing is planned by this Survey.

6.7.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.7.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey.

6.7.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 processing is planned by this Survey.

6.7.8.10 Additional L2 data: Required hardware and staff

No extra AL2 processing is planned by this Survey.

6.7.9 Team

Table 17: Survey S7 team members with their affiliation, role in S7, and total expected FTE contributions next to science exploitation. Only key members are listed here.

Name	Function	Affiliation	FTE / yr
S. Driver	co-PI, multi-λ imaging	UWA	0.5
J. Liske	co-PI, SCB rep, IWG2 rep, user manager	UHH	0.5
A. Robotham	WAVESwide PS, group finding, ProSpect	UWA	0.5
L. Davies	WAVESdeepG23 PS, IWG8 rep and co-leader	UWA	0.5
S. Bellstedt	WAVESdeepDDF PS, target catalogue construction, IWG1 rep, IWG8 member, multi-λ photometry	UWA	0.5
A. Iovino	StePS PS, target catalogue construction	INAF OA Brera	0.5
K. Duncan	ORCHIDSS PS, target catalogue construction, radio data, HI masses	IfA	0.5
D. Gruen	4C3R2 co-PS, target catalogue construction	LMU	0.5
J. McCullough	3C3R2 co-PS, target catalogue construction, photo-z development	LMU	0.5
A. Mercurio	IWG3 rep, extragalactic calibration targets	U Salerno	0.2
J. Loveday	IWG4 rep, IWG6 rep, IWG3 member, QC, k-corrections	U Sussex	0.2
C. Heneka	IWG9 rep	ITP Heidelberg	0.1
M. Bilicki	SPB rep, IWG9 member, photo-z development	CFT	0.2
I. Baldry	Photo-z lead, external spectroscopy	LJMU	0.2
P. Norberg	IWG2 co-leader, science simulations	U Durham	0.5
M. Cluver	IWG9 member	UT Swinburne	0.1

Name	Function	Affiliation	FTE / yr
S. Croom	IWG8 co-leader	SIFA	0.8
M. Longhetti	IWG8 member	INAF OA Brera	0.4
M. Bianconi	IWG2 member	U Nottingham	0.15
E. Tempel	IWG4 co-leader, group finding	U Tartu	0.2
B. Bandi	IWG4 member	U Sussex	0.3
E. Taylor	Stellar masses, velocity dispersions	UT Swinburne	0.1
L. Costantin	Stellar and dynamical masses	CAB	0.1
C. Tortora	Stellar and dynamical masses	INAF OA Capodimonte	0.1
M. Owers	Spectral line measurements, SFRs	Macquarie U	0.1
F. Mannucci	Spectral line measurements	INAF OA Arcetri	0.1
C. Blake	Science simulations	UT Swinburne	0.1
C. Lagos	Science simulations	UWA	0.1
B. Vulcani	Science simulations	INAF OA Padua	0.1
G. de Lucia	Science simulations	INAF OA Trieste	0.15
J. Knoche	Database development, maintenance	UHH	0.1
F. D'Eugenio	Stellar and dynamical masses	Cambridge	0.15
A. Galazzi	Stellar continuum	INAF OA Arcetri	0.1
S. Zibetti	Stellar continuum	INAF OA Arcetri	0.1
L. Morelli	Stellar continuum	U de Atacama	0.1
F. LaBarbere	U and near-UV spectral range	INAF OA Capodimonte	0.1
P. Sanchez Balzquez	U and near-UV spectral range	UAM	0.1
A. Pasquali	Emission lines	ARI	0.1
F. Fontanot	Science simulations	INAF OA Trieste	0.1

6.8 Survey 8 – Cosmology Redshift Survey (CRS)

Survey PIs: Johan Richard, Jean-Paul Kneib

6.8.1 Science Summary

The 4MOST Cosmology Redshift Survey (CRS) will perform stringent cosmological tests via spectroscopic clustering measurements that will complement the best lensing, cosmic microwave background (CMB) and radio surveys in the southern hemisphere. The combination of carefully selected samples of bright galaxies, luminous red galaxies, and quasars, totalling ~5 million objects over the redshift range z = 0.15 to 3.5, will allow distance measurements as well as definitive tests of gravitational physics. Many key science questions will be addressed by combining CRS spectra of these targets with data from current DES, Planck, MeerKat, MWA, or future facilities such as LSST, Euclid and SKA. For example, overlapping lensing and spectroscopic datasets over a large area (>7500 deg^2) will allow improvements by a factor of 4 on the gravitational slip test. This very rich dataset will also improve the redshift calibration of all lensing imaging data used in the Southern hemisphere, significantly reducing the systematics on weak or galaxy-galaxy lensing estimates, and also provide growth rate measurements by allowing cross-correlation of spectroscopically-confirmed targets with CMB experiments.

Expanded science description: messenger-no175-50-53.pdf

6.8.2 Target Catalogue

For 4MOST CRS, we will conduct 4 sub-surveys:

S0801 – BG (Bright Galaxies), S0802 – LRG (Luminous Red Galaxies), S0803 – QSO (quasars) selected from ATLAS and S0804 – QSO selected from Legacy Surveys.

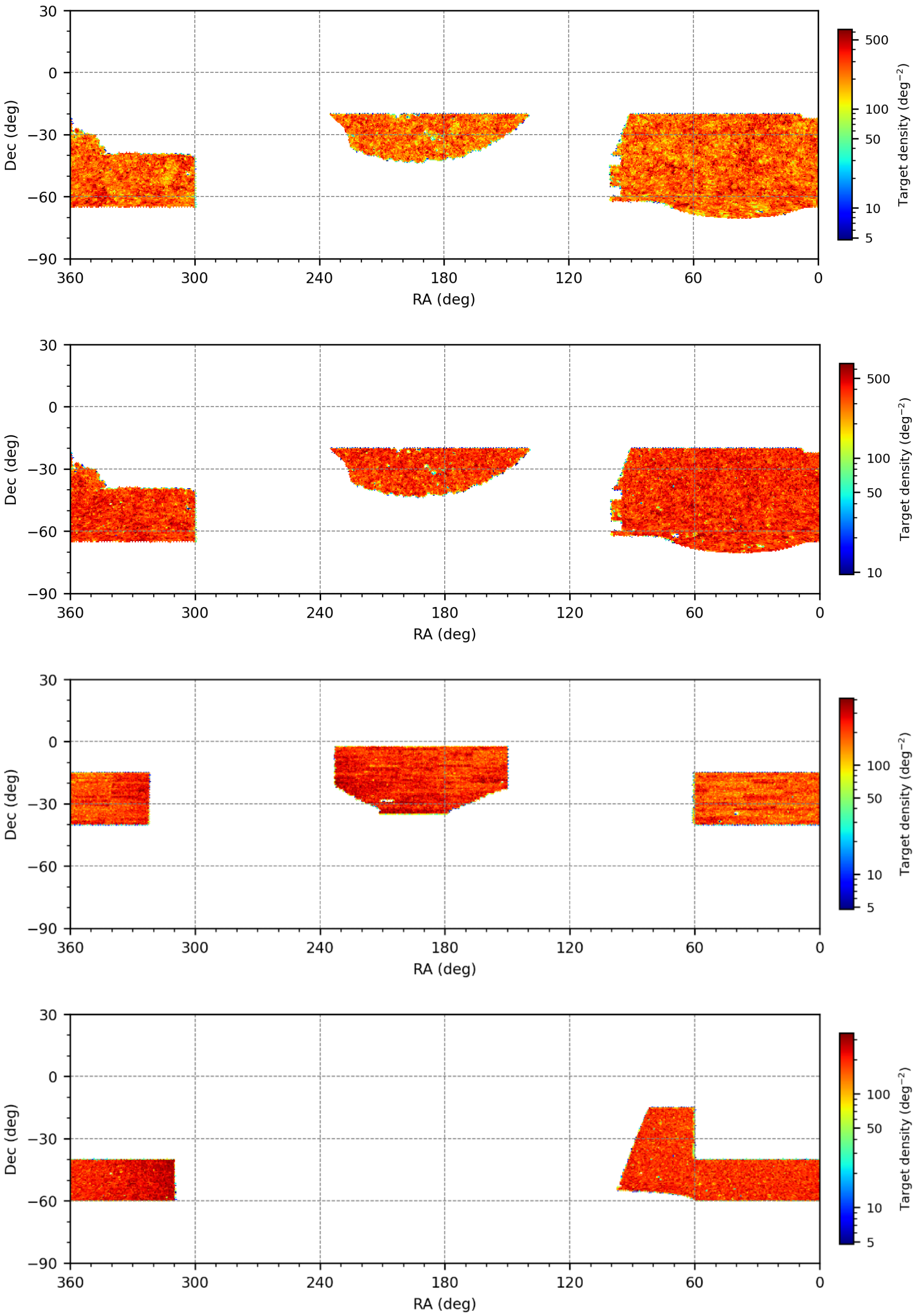


Figure 28: Input target distribution of the S0801 – BG, S0802 – LRG, S0803 – ATLAS QSO, S0804 – LS QSO subsurveys from top to bottom.

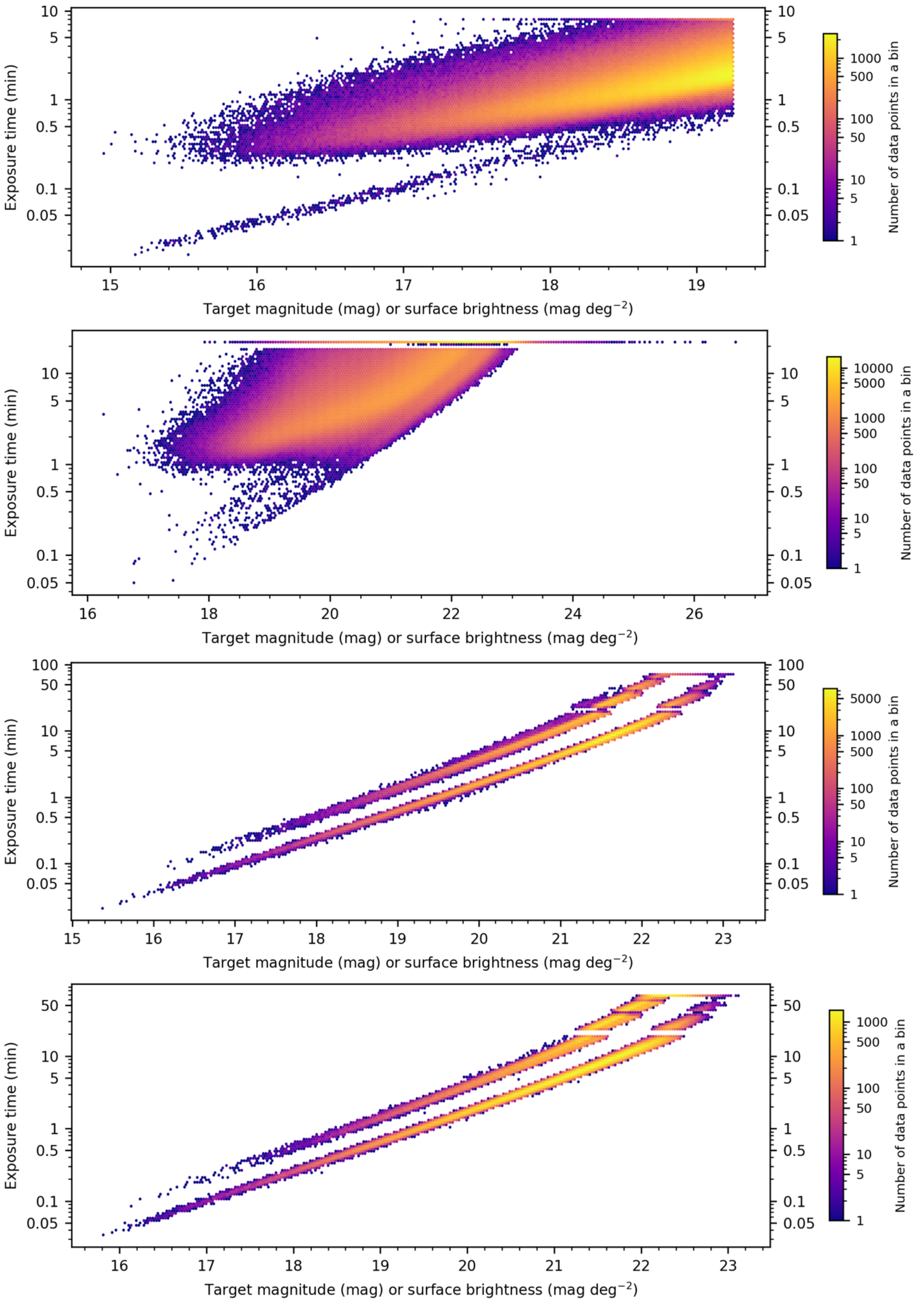
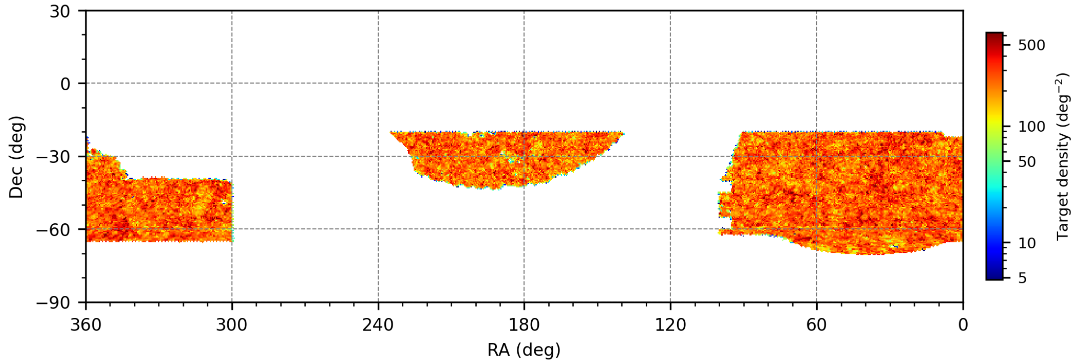


Figure 29: The exposure time estimates as a function of target r-mag for the S0801 – BG, S0802 – LRG, S0803 – ATLAS QSO, S0804 – DR10 QSO subsurveys from top to bottom. Please note the different x- and y-scales

The input targets sky coverage of S0801, S0802, S0803, and S0804 subsurveys are displayed



in

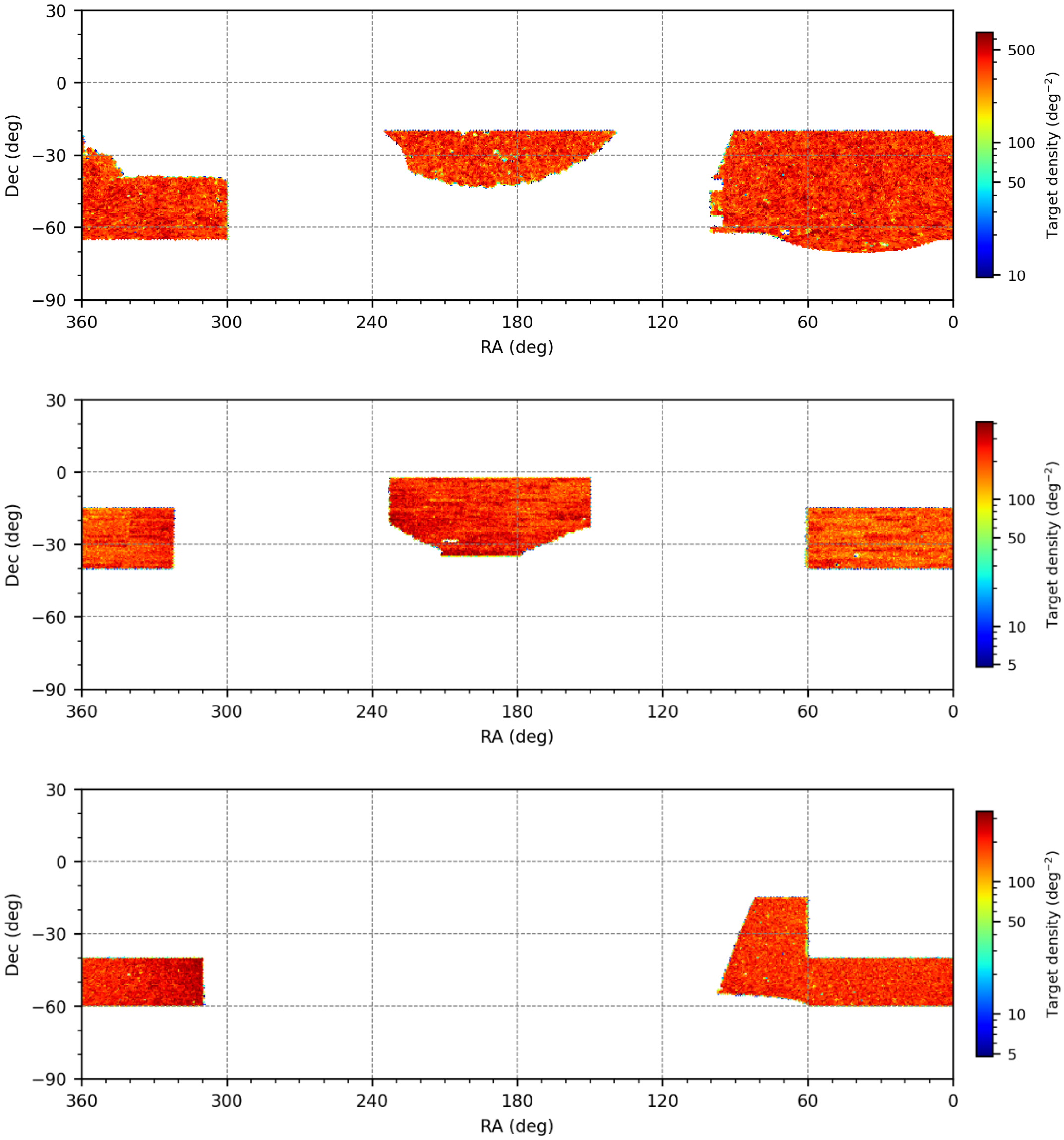
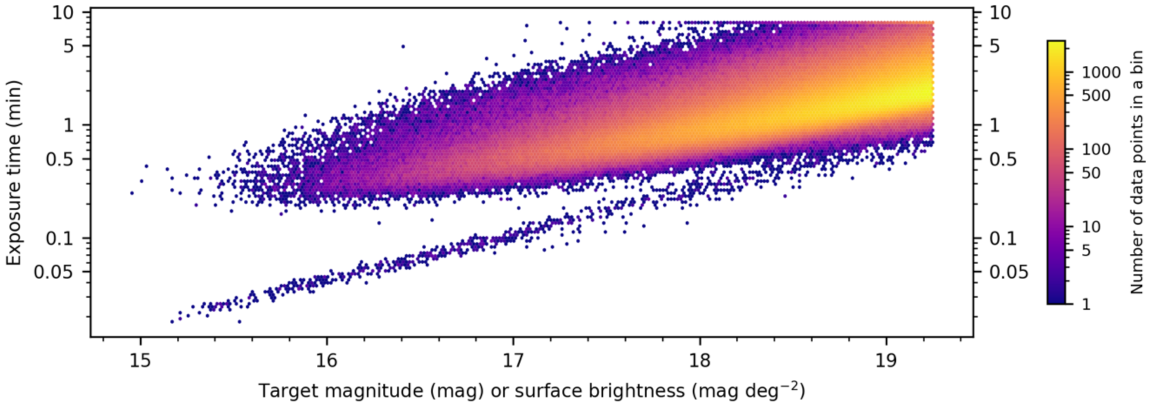
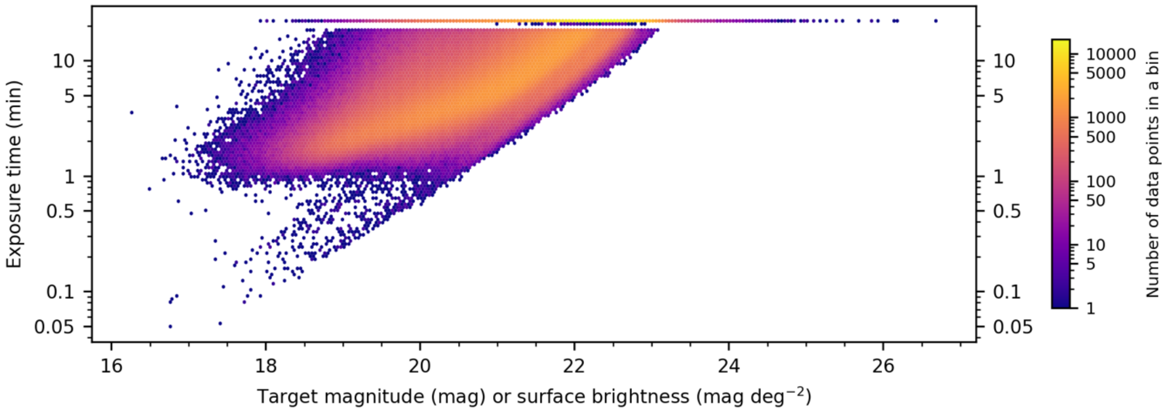


Figure 28, choosing areas that overlap with the DES+KIDS and ATLAS survey areas but only complementing the DESI footprint area. The area should be covered contiguously. The requested completeness values for these subsurveys are 65%, 65%, 65% and 50%, respectively. Median S/N requirements are >1.0–2.4 in the 4200–5000Å, 5500–6700Å, or 7200–9000Å wavelength regions, with resulting exposure time estimates displayed in





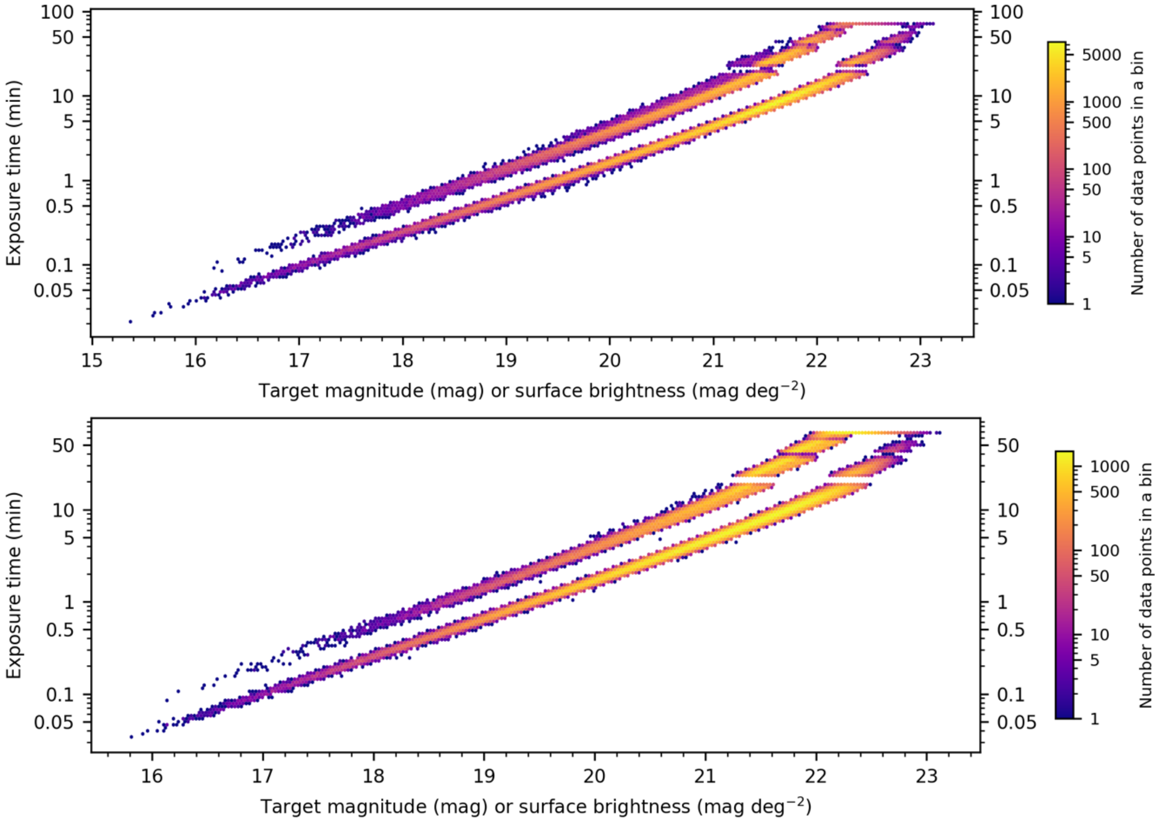


Figure 29. S8 has no cadencing requirements. The Scientific FoM of all four subsurveys tracks the LSM x SSM of targets.

<u>S8 Summary</u>

Table 18: Key parameters of the input target catalogue of the S8 Survey

66	S0801	BG	LR	(0, 0, 0, 0)	59946.0 -- 59946.0 88068.0 -- 88068.0	0.0 -- 360.0 -70.9 -- -20.0	2000.0	10 (D)	6000	0.650	132	156	110	71.9	1438802	7200.0 -- 9000.0
67	S0802	LRG	LR	(0, 0, 0, 0)	59946.0 -- 59946.0 88068.0 -- 88068.0	0.0 -- 360.0 -70.9 -- -20.0	2000.0	47 (B)	7000	0.650	473	423	508	819	2133759	7200.0 -- 9000.0
68	S0803	ATLAS	LR	(0, 0, 0, 0)	59946.0 -- 59946.0 88068.0 -- 88068.0	0.0 -- 360.0 -40.0 -- -2.1	2000.0	120 (G)	4900	0.650	224	215	313	548	962669	4200.0 -- 9000.0
69	S0804	DR10	LR	(0, 0, 0, 0)	59946.0 -- 59946.0 88068.0 -- 88068.0	0.0 -- 360.0 -60.0 -- -15.0	2000.0	120 (G)	2700	0.650	127	148	255	454	467971	4200.0 -- 9000.0

The S8 Survey aims to observe about 5 million galaxies and QSOs in two large areas and requires 7500 deg^2 of sky to be observed, in large contiguous areas. Being a large area Survey, weather variations over the 5-year period will have no significant impact as long as the scheduler can ensure meeting completeness requirements and aims to complete contiguous areas. The key input parameters of the S8 target catalogue are listed in Table 18.

6.8.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.8.4 Management structure

We describe below the management structure and the responsibilities of the team members related to the WG organisation of the survey.

PI: The two co-PIs are responsible for providing the resources to each WP of the survey and support for the 4MOST IWGs, for following up the overall progress of the tasks required and for keeping the membership registry up to date. They will lead the discussion with the survey team regarding invitation of external members shall extra resources be needed. They will be responsible for monitoring the progress of the survey and of the use of the data for cosmological analysis.

WP and sub-WP responsibles:

The lead of WP and sub-WP, as highlighted in the subsequent sections, are appointed by consensus during Survey Team meetings upon suggestion by the co-PIs, and with rotation or reconduction every 2-year during the length of the survey and the final analysis period. Should the WP lead not be able to carry out their duties the co-PIs will propose a replacement, or if in case of temporary absence, the WP responsible can nominate a deputy to cover the WG tasks.

IWG representative:

IWG representatives are nominated during survey team meetings upon suggestion by the co-PIs, with tacit renewal over the survey. Should the IWG representative not be able to carry out their duties the co-PIs will propose a replacement, or if for a temporary period the IWG representative can nominate a deputy to help cover the IWG tasks.

Communication Strategy The two co-PIs are in charge of communicating the survey members the evolution of the project. This is primarily done by the following online meetings:

- *Management meeting*: the 2 co-PIs and any other key person of the survey invited to the meeting. Frequency: as necessary, or at minimum on a monthly basis.
- *Target Catalogue meeting*: the 2 co-PIs, the target and simulation WG teams and their lead (link with IWG1 and IWG2). Frequency: monthly basis, or more often if needed.

Minutes and actions will be distributed by email. An online repository will compile the different documents.

Other communication means include a dedicated workspace on Slack for direct interactions between survey team members or specific sub-groups.

Conflict resolution will go through the co-PIs if they are not involved in the conflict. In the case the conflict involves one of the co-PIs, the conflict should be handled by the 4MOST ombudsperson.

6.8.5 Work Breakdown Structure

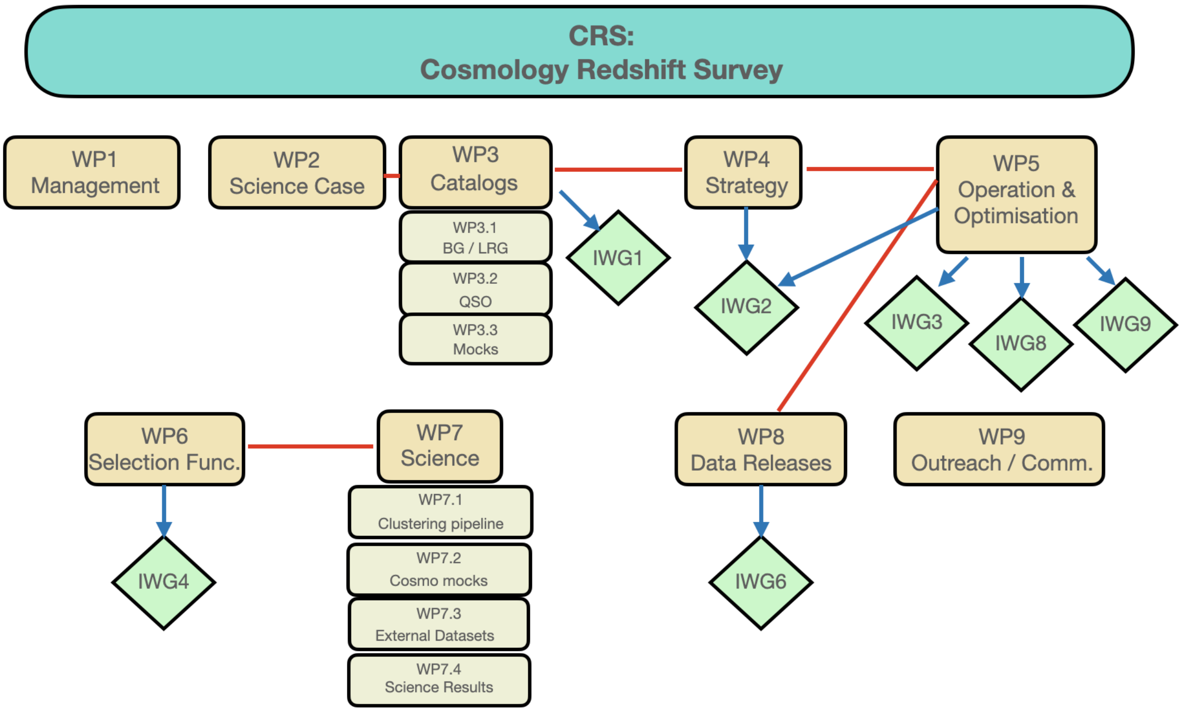


Figure 30: Work Breakdown Structure for Survey S8, , where the main WPs and sub-WPs are summarised, as well as external communication and contribution to the relevant IWGs (blue arrows). The main internal links between WPs are highlighted in red

<u>**WP1: Survey Management**</u>

Key roles: PI; IWG representatives.

Tasks: The task of this WP is:

1) to organise the survey at the high/science level,

2) to coordinate the work of all the different WPs,

3) to coordinate interactions with other surveys and the rest of the 4MOST consortium.

Under the PI responsibility:

- Managing the list of survey members and the inclusion of external members
- Representing the survey interests at the SCB
- Responsible for writing and updating the SSP, SMP and the ESO proposal for the survey.

Under the IWG survey representatives' responsibility:

- Contribute to the IWG by bringing their technical expertise
- Represent the survey interests within the IWG

Timescale: 2022-2028

Resources: 0.3 FTE per year on average = 2.1 FTE total

Deliverables: Survey science and management plans. Survey strategy.

WP2: Science Case development (including forecasts)

Key roles: *1 person responsible for forecasts*

Tasks: The task of this WP is to produce forecasts for cosmology measurements according to the characteristics of the survey (n(z) and sky distribution). These forecasts are used to prioritize sky areas in the survey. The main science cases to be forecasted are the following:

- cross-correlation with other surveys (lensing, CMB, radio)
- BAO & RSD clustering measurements
- cosmology with voids

Timescale: 2022-2025 (up to first data release)

Resources: 0.1 FTE per year on average = 0.4 FTE total

Deliverables: Fisher matrix forecasts

WP3: Preparation of mock and real target catalogues (link with IWG1)

Key Roles: at minimum **one person responsible per sub-WP, plus one person responsible for overall catalog format check (the same for all sub-WP).**

Tasks: production of all master input catalogues used as input for 4FS simulations, either from mock or real targets. Optimisation of the color / magnitude selections depending on the sub-survey, as described below.

WP3.1 - BG and LRG real targets (current responsible: A. Verdier)

The task is to make use of all available public photometric catalogs to produce BG and LRG target catalogs over the largest available area by cross-matching photometric, morphological and photometric redshift information, and applying the relevant color cuts as defined in [RD1] or similar.

Timescale: 2022-2024 (up to start of science operations)

Resources: 0.25 FTE per year during Phase 2 and 0.05 FTE per year during Phase 3 (average) = 0.4 FTE total

Deliverables: master target catalog for BGs and LRGs, containing the target properties (densities, redshift distribution) required for the science case of the survey and compatible with the input format for 4FS ingestion.

WP3.2 QSO real targets (current responsible: T. Shanks)

The task is to make use of all available public photometric catalogs to produce QSO target catalogs over the largest available area by cross-matching photometric, morphological and photometric redshift information, and applying the relevant color cuts as defined in [RD1] or similar.

Timescale: 2022-2028

Resources: 0.25 FTE per year during Phase 2 and 0.1 FTE per year during Phase 3 (average) = 1 FTE total

Deliverables: master target catalog for QSOs, containing the target properties (densities, redshift distribution) required for the science case of the survey and compatible with the input format for 4FS ingestion.

WP3.3 Mock targets (current responsible: J. Comparat)

The task is to make use of a full sky dark matter simulation and populate haloes according to the expected properties of the real targets (BGs, LRGs, QSOs).

Timescale: 2022-2024

Resources: 0.05 FTE per year on average during Phase 2 only = 0.1 FTE total

Deliverables: mock target catalogs for all 3 target categories (BGs, LRGs, QSOs), containing the target properties (densities, redshift distribution, sky area) required for the science case of the survey (mimicking the real targets catalogs) and compatible with the input format for 4FS ingestion.

<u>WP4: Observing Strategy</u>

Key roles: **PIs and IWG2 representatives + all**

Tasks:

The main task of this work package is to interact with IWG2 to perform simulations of the input target catalogues (either real targets or mocks) with 4FS and obtain feedback on the overall survey strategy. More precisely the following sub-tasks are performed:

- ingest the survey target catalogues into the interface
- run the ETC from the input catalogues and check the survey scope, then validate the catalogues for 4FS simulations
- checks output from 4FS simulations, including target duplicates with other surveys and homogeneity of the output
- refine the survey parameters according to IWG2 simulation
    - restrict the input catalogue to a specific magnitude limit or sky region
    - optimise the Large Scale Merit, Small Scale Merit and the Science FoM of the survey
    - aim to have a wide homogeneous survey

Timescale: 2022-2024

Resources: 0.3 FTE over the Phase 2 - 0.6 FTE total

Deliverables: the deliverables of this WP are an optimised set of survey parameters (survey area, LSM, SSM, and science FoM) at start of science operations, together with an optimised target catalogue for 4FS simulations ready for science operation.

WP5: Survey operations and optimisation (incl. quality check)

Key Roles: PIs, IWG2, IWG3, IWG8 and IWG9 survey representatives.

Responsibility for quality check will be rolling from a pool of trained survey members, for each planned data-release.

Tasks: the tasks of this work-package are to follow the progress of the survey and the quality of the measurements during science operations. This includes the monitoring of several indicators such as:

- monitor the L2 products after data reduction, in relation with IWG8.
- evaluation of percentage of targets with acceptable redshift measurement
- cross-checks on source classification (quasar, galaxy, star, …) in relation with IWG9.
- evaluation of redshift measurement quality using duplicate targets or by cross-matching a few number of targets with independent surveys like DESI.
- check on overall survey validation
- progress of the survey as a function time. Adjust weights / survey parameters if / when possible.

This work is performed in relation with IWG8 for data analysis, as well as IWG3 for calibrations and IWG2 for any updates required on the survey.

Timescale: 2024-2028

Resources: 0.6 FTE per year averaged over Phase 3 = 3 FTE total

Deliverables: set of tables / plots / statistical measurements allowing all survey members to follow the progress of the survey and its quality.

WP6: Selection functions (link with IWG4)

Key Roles: IWG4 representative

Tasks: Test the selection effects due to observation constraints (observation depth, fiber collision, gaps, bright stars, stellar density, Galactic dust extinction, seeing variations …) and competition with other 4MOST surveys, which affect the homogeneity of the output catalogues. We will compute from the various effects some corrections factors that will enter in the correlation measurements.

Timescale: 2022-2028

Resources: 0.4 FTE per year averaged over Phase 2 and Phase 3 - 2.8 FTE total.

Deliverables: weight calculations as a function of sky position and observational constraints.

WP7: Science

Key Roles: all science project leads + everyone invited to contribute

This work package contains tasks specific to the cosmology science case.

WP7.1: Clustering pipeline (current responsible: A. Verdier)

Tasks: The task of this work package is to develop (if not existing) and run the clustering pipelines on the observed target catalogues, either in redshift space, in configuration space.

Timescale: 2022-2028

Resources: 0.3 FTE average per year during Phase 2, then 0.1 FTE average per year during Phase 3 = 1.5 FTE.

Deliverables: set of analysis pipelines and clustering measurements for science.

WP7.2: Cosmology mocks (1 person responsible by subsurvey).

Tasks: replicate target catalogues and analysis performed in WP7.1 to estimate error bars on measurements.

Timescale: 2022-2028, to be tested prior to the first science observations and then run whenever needed.

Resources: 0.15 FTE per year averaged over Phase 2 and Phase 3 ~ 1 FTE total.

Deliverables: set of target catalogues over which the analysis pipelines can be run automatically.

WP7.3: External datasets

Tasks: provide a cross-match of targets covered with multiple probes (overlap with CMB experiments or weak-lensing measurements). At minimum the measurements should use public data releases from existing surveys (DES, KIDS, and in the future LSST and Euclid, …). These external datasets are used as input for the science analysis of the survey.

Weak-lensing catalogues: person responsible = TBD

CMB measurements: person responsible = TBD

Timescale: 2022-2028

Resources: 0.3 FTE per year averaged over Phase 2 and Phase 3 = 2.1 FTE total.

Deliverables: cross-matched catalogue between 4MOST redshifts and weak-lensing / 4MOST redshifts and CMB measurements.

WP7.4: Science results

Tasks: perform the final measurements based on the analysis pipelines (WP7.1) and outputs from WP7.2 and WP7.3. More specifically:

- Compute error bars on measurements based on cosmology mocks
- BAO fitting
- Develop and run pipeline to compute clustering measurement for voids

- Cross-correlations between CRS and Lensing
- Cross-correlations between CRS and CMB
- Discuss results and write science publications

Timescale: 2024-2028

Resources: 2 FTE per year average over Phase 3 - 10 FTE total.

Deliverables: Scientific publications

WP8: Preparation of Data Releases

- *after 1 year*
- *after 3 year*
- *at the end of survey*

Tasks: Preparation of DR in relation with IWG6

Timescale: 2024-2028

Resources: 0.2 FTE average over Phase 3 - 1 FTE total.

Deliverables: Scientific publications

WP9: Communication and Outreach

Key Roles: PIs, IWG2, IWG3, IWG8 and IWG9 survey representatives.

Responsibility for communication and outreach.

Tasks: the tasks of this work-package are to produce, text, visuals and movies (also in virtual reality) describing the measurements and results of the survey.

Timescale: 2024-2028

Resources: 0.2 FTE per year averaged over Phase 3 = 1 FTE total

Deliverables: Press releases, and participation in public events.

6.8.6 Contribution to the Infrastructure Working Groups

IWG1

The survey contributes to IWG1 in the following ways: survey representation as part of the IWG1 meetings and discussions, as well as contributions to the Sky Fibers Work Package. More precisely, the work on sky fibers involve estimating the surface brightness for extended targets using the morphological and photometric information of Legacy Survey DR9. This information is crucial to optimise the locations of sky fibers in empty regions devoid of any extended source flux. In addition, tests are performed on the impact of galaxy ellipticity in the estimation of the sky surface brightness. This work is performed as part of WP4 of IWG1 [RD2].

IWG2

The survey contributes to this IWG2 through discussions on the simulation outputs and feedback to the IWG2 representatives. Depending on the expertise needed for specific developments some survey members could contribute further to this crucial IWG.

IWG3

As IWG3 has only just started, the survey members only contribute through survey representation at the meeting, but there is likely to be a specific contribution by providing sets of targets to be used for calibration and commissioning. In particular it is of great importance that we observe a set of spectroscopically confirmed galaxies and quasars in order to cross-calibrate and verify the redshift measurements. This work will be carried out in close collaboration with IWG8.

IWG4

The survey is only contributing to IWG4 at the level of survey representation. Considering the importance of target selection to cosmology science, it is likely that the people involved in survey WP6 (described above) will interact closely and contribute more significantly to IWG4.

IWG6

As IWG6 has only just started, the survey members only contribute through survey representation at the meeting.

IWG8

The survey is contributing to this IWG8 the following way: IWG management as co-lead of the IWG and performing specific developments / tests with multiple codes for AGN redshift measurements and identifications. Additional contributions include leading the efforts to generate simplified but realistic simulated spectra for pipeline testing outside the OpR framework. These on-the-fly simulations provide more flexibility in terms of what sources are generated and can be run independently of the OpRs.

IWG9

Our survey does not contribute to IWG9 currently. With a new appointed survey representative to this IWG, the right expertise to be able to contribute to IWG9.

6.8.7 Level-1 data reduction re-process

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.8.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of S7 will be processed by the 4XP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
In addition to the data products provided by 4XP/4CP/4SP, S8 will produce clustering measurements as appearing in scientific publications in the form of machine-readable DL2-SURV product.

6.8.8.1 Deliverable L2 Survey data: reduction processing

Clustering measurements (Behnood Bandi and Aurélien Verdier): we will provide for each set of targets and contiguous sky region measurements of the 2D and 3D correlation function as a function of redshift. These measurements will be corrected for systematics from selection and observational effects using a weighting scheme.

6.8.8.2 Delivery L2 Survey data: quality assessment

All DL2-SURV data products will be subject to an internal Quality Control process prior to their release (WP8). This process includes the formatting, the metadata as well as a basic scientific checks.

6.8.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

All data products will be delivered as a single, multi-extension FITS file with a PRODCATG = SCIENCE.CATALOG in a Binary Table format. The detailed content of this file and its metadata will be described in a DXU. This DXU will be reviewed by the 4MOST Data Model Curator (DMC) to ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with S8 CRS, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.

Once the data model has been finalized, our DL2-SURV products will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV products will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.8.8.4 Deliverable L2 Survey Data: product delivery schedule to ESO archive

All DL2-SURV products will be delivered for the first time at DR2, and updated at each DR thereafter, except the environment measures. This data product depends on the availability of a highly complete (sub-)sample. Since we cannot reliably predict when such a sample might be available, no commitment to a particular delivery date can be made. The environment measures will therefore be delivered at the next DR following the availability of this data product and the associated scientific paper.

6.8.8.5 Deliverable L2 Survey Data: Required Hardware and Staff

All hardware required to produce our DL2-SURV data products are already available at the relevant institutes. In terms of effort, we estimate a total of ~ 1.0 FTE to produce the relevant DL2-SURV data products.

6.8.8.6 Additional L2 data: reduction processing

No extra AL2 processing is planned by this Survey.

6.8.8.7 Additional L2 data: quality assesment

No extra AL2 processing is planned by this Survey.

6.8.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey.

6.8.8.9 Additonal L2 data: product delivery schedule to the ESO archive

No extra AL2 processing is planned by this Survey.

6.8.8.10 Additional L2 data: Required hardware and staff

No extra AL2 processing is planned by this Survey.

6.8.9 Team

Table 19: Survey S8 team members with their role in S8, affiliation, and expected FTE contributions until Sept 2024.

Name	Affiliation	Function	FTE
Behnood Bandi	US	IWG3 representative	0.3
Felipe Barrientos	PUC	WP3.2 contributor	0.1
Nicolas Bouché	CRAL	IWG9 rep.	0.2
Johan Comparat	MPE	WP3.3 responsible	0.1
Alice Eltvedt	Durham	PhD student, WP3.2 contributor	0.3
Jean-Paul Kneib	EPFL	CoPI	0.3
Jens-Kristian Krogager	CRAL	IWG3 and IWG8 rep.	0.5
Jon Loveday	US	WP6 responsible, IWG4 and IWG6 rep.	0.4
Mamta Pommier	LUPM	WP7.3 contributor	0.1
Johan Richard	CRAL	CoPI, WP4 responsible, IWG2 rep.	0.5
Antoine Rocher	EPFL	TBD (postdoc start Jan. 2024)	0.2
Martin Sahlén	UU	WP2 contributor	0.1
Tom Shanks	Durham	WP3.2 responsible, IWG2 rep.	0.4
Jenny Sorce	AIP	IWG2 contributor	0.1
Aurélien Verdier	EPFL	PhD student, WP7.1 responsible	0.3
Cheng Zhao	Tsinghua University	WP2 responsible	0.2

6.9 Survey 9 – One Thousand and One Magellanic Fields (1001MC)

Survey PIs: Maria-Rosa Cioni, Lara Cullinane

This section provides the Survey Management Plan for the One Thousand and One Magellanic Fields Survey (1001MC), a Survey of the 4MOST Consortium, which includes among its subsurveys the Dormant Black Holes Community survey (referred to as Binary Compact companions or BCC). The Survey team currently has 41 members with the expectation to increase to 50—60 during the course of the project. This plan provides an organisational view of the work within the survey team and in connection with work that takes place within the 4MOST IWGs, as well as information on the expected data products from the Survey, the resource efforts and the policies that guide our enterprise.

6.9.1 Science Summary

The Magellanic Clouds are the largest and most massive satellite galaxies of the Milky Way. Their proximity makes them an excellent laboratory for the study of stellar populations and galaxy interactions. The 1001MC survey aims to measure the kinematics and elemental abundances of many different stellar populations that sample the history of formation and evolution of the Clouds. The survey will collect spectra for about a million sources with G<20 mag (Vega) distributed over an area of about 1000 deg^2. This sample includes young massive stars, intermediate-age giant stars and old red giant and horizontal branch stars, as well as different types of pulsating variable stars. These sources trace the spatial extent of the main structures and substructures throughout the galaxies; and the 4MOST spectra will, for example, allow the linking of kinematical and chemical patterns to these structures to establish the dynamical and chemical evolution of the system. Together with existing and future near-infrared spectra of comparable sensitivity and photometric observations, 1001MC will provide the community with an invaluable dataset for a wide range of scientific applications. The 1001MC survey will also target background galaxies with the aim to infer the dust attenuation along the line of sight.

Furthermore, the survey will perform a spectroscopic follow-up of ellipsoidal binary stars from the Optical Gravitational Lensing Experiment (OGLE) in order to study the short-period binary population with periods less than 10 days, and discover dormant black holes and neutron stars in non-interacting systems. A sample of about 1000 stars, including ellipsoidal variables and Wolf-Rayet (WR) stars, will be observed in order to obtain multiple radial velocity measurements on scales of months. The radial velocities, combined with the OGLE photometry will allow for determination of the binary secondary-component mass and therefore identify the compact companions.

Expanded science descriptions: messenger-no175-54-57.pdf and messenger-no190-17-18.pdf.

6.9.2 Target catalogue

The 1001MC footprint covers an area of about 1000 deg^2 (from about 0h to 6h in Right Ascension – RA and from –60 to –80 deg in Declination – Dec) in order to target objects that best trace the extent of the stellar populations and describe the substructure information throughout the Magellanic system (Figure 31). It consists of two overlapping circles centred on the Large and Small Magellanic Cloud (LMC and SMC), respectively. The coordinates of the centres are (RA = 80.21 deg, Dec = –69.58 deg) for the LMC and (RA = 13.05 deg, Dec = –72.83 deg) for the SMC. The radii of the circles are 15.6 deg and 11.3 deg for the LMC and SMC, respectively, with a sharp cut at declinations below –80 deg. We adopt the methodology described in Gaia Collaboration, Luri et al. (2021) to create a sample of stars that belong to the

Clouds based on their position, parallax and proper motion. The 1001MC survey area includes two deep fields corresponding to two single 4MOST pointings at the centres of the LMC and the SMC. The 1001MC survey has nine subsurveys (eight stellar and one extragalactic). There can be self-shared targets among subsurveys, because each subsurvey has a different observing strategy.

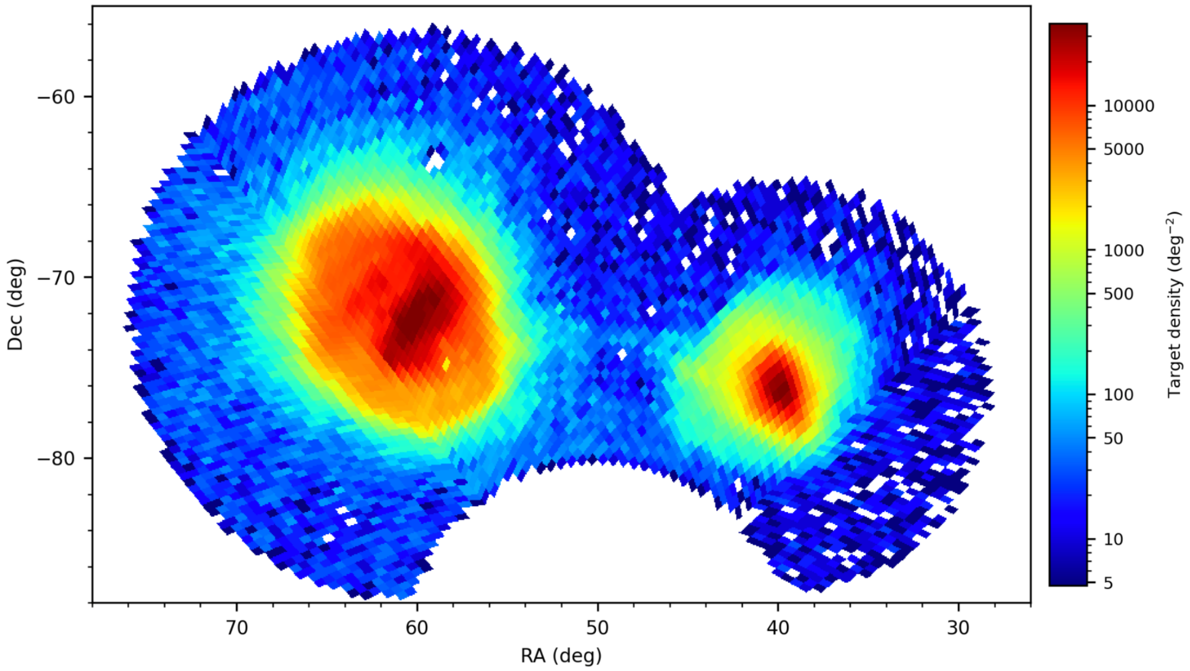


Figure 31: Distribution of targets from the 1001MC_LR subsurvey. The typical substructures of the Magellanic Clouds are clearly visible: the LMC bar and spiral arms, the SMC core, the LMC disc with its stellar density gradient, the SMC elongated structure with the wing, and mantles revealing the Bridge and other protuberances depicting the interaction between the galaxies, their star formation history and evolution. The plot is in Cartesian projection with the centre rotated to RA = 50 deg and Dec = –71.5 deg.

6.9.2.1 Subsurveys

The **1001MC_HRcomp** (S0901) is a high completeness high-resolution stellar subsurvey which consists of less numerous, bright Magellanic stellar populations such as Cepheids, yellow and blue supergiants, massive stars, asymptotic giant branch (AGB) stars, carbon stars, and mixed targets. It has a relatively low number of targets but requires a completeness of 80%.

The **1001MC_HRdeep** (S0902) is a deep-field high-resolution stellar subsurvey of the central regions of the Clouds which consists of a subset of all stellar population types already targeted by other high-resolution subsurveys, but with a cadencing observing strategy and multiple visits. The requested completeness is 80%.

The **1001MC_HR** (S0903) is a general high-resolution stellar subsurvey which consists of the most numerous stellar populations, such as giant stars close to the tip of the red giant branch (RGB), red supergiants and main-sequence stars. The requested completeness is 50%.

The **1001MC_LRcomp** (S0904) is a low-resolution, high-completeness stellar subsurvey which consists of less numerous stellar populations such as Cepheids, massive stars, yellow supergiants and stars that populate regions of the colour-magnitude diagram dominated by Milky Way stars. It has a relatively low number of targets but requires a completeness of 80%.

The **1001MC_LRdeep** (S0905) is a deep-field low-resolution stellar subsurvey of the central regions of the Magellanic Clouds which consists of a subset of all stellar population types already targeted by other low-resolution subsurveys, but with a cadencing strategy and multiple visits. The requested completeness is 80%.

The **100MC_LR** (S0906) is a general low-resolution stellar subsurvey which consists of the most numerous stellar populations such as main-sequence stars, red supergiants, RGB stars, red clump stars, subgiants and mixed targets. The requested completeness is 50%.

The **1001MC_RRLyr** (S0907) is a low-resolution subsurvey of RR Lyrae stars aiming to capture the stellar properties of the variables at different stages of their pulsation period for accurate radial velocity and metallicity measurements. The requested completeness is 50%.

The **1001MC_GAL** (S0908) is a low-resolution subsurvey of galaxies behind the Magellanic Clouds for which we require a completeness of 50%.

The **1001MC_BCC** (S0909) is a low-resolution subsurvey of binary stars with compact companions, possibly dormant black holes, for which we require a completeness of 80%.

6.9.2.2 Target selection

The majority of stellar sources in 1001MC are selected from a cross-match of the publicly available VMC survey and VHS data with data from Gaia DR3. We adopt VMC or VHS depending on position in the sky and we prefer VMC if both are available. Due to saturation at bright magnitudes in the VISTA data, we use 2MASS to select the brightest targets and then adopt VISTA at fainter magnitudes. The targets are selected from regions in the near-infrared (J–Ks, Ks) colour-magnitude-diagram, as described in Cioni et al. (2019). In addition, evolved massive stars are selected from the catalogues of Yang et al. (2019, 2020, 2021), Cepheids and RR Lyrae stars from the OGLE survey. All of them are matched with Gaia DR3. Sources with parameters ruwe exceeding 1.4, photometric uncertainties exceeding 0.2 mag in any Gaia band, or a corrected flux excess more than 5 times the magnitude average (per Riello et al. 2021) are excluded. Note that for Cepheids and RR Lyrae stars we do not apply the membership criteria from Gaia Collaboration, Luri et al. (2021). The other stellar sources, that are targets in the 1001MC_BCC subsurvey, come from the OGLE-IV catalogue of binary stars in the Clouds (Pawlak et al. 2016). All of these objects that are classified as 'ellipsoidal' and have orbital periods shorter than 2.5 days are selected for the target list. In addition, WR stars are selected from the catalogue by Neugent et al. (2018). The target list is then cross-matched with Gaia DR3.

The resulting Gaia magnitude (Vega) range is G=11–17 mag in HR and G=7–21 mag in LR subsurveys. The Milky Way extinction towards the Clouds is very small and we do not account for it. Stellar spectral templates are predominantly taken from the AMBRE project (de Larvery et al. 2012). The spectral resolution is significantly higher than that required by 4FS, so these templates have been re-sampled (wavelength spacing of 0.1 Angstrom) and re-scaled such that they fully cover the Gaia G-band response and have a magnitude in that band of 15 mag. The metallicity of the AMBRE templates lies between that of the LMC and the SMC. These templates cover FGKM-type stars, thus they need to be supplemented by other templates that cover the remaining stellar populations in the input catalogue. The templates for the massive stars (WR and OBA) are based on CMFGEN models (Hillier et al. 1998, ApJ, 496, 407). The final stellar spectrum in our current suite is for the carbon stars and is based on the COMARCS models (Aringer et al. 2019, MNRAS, 487, 2133). The majority of the templates are not reddened, but some of them have applied reddening of E(B–V)=0.15 mag to account for circumstellar dust. We prioritise candidate metal-poor ([Fe/H]<–2) stars – including these in the high-completeness 1001MC_HRcomp and 1001MC_LRcomp subsurveys – which we select from three sources each crossmatched with Gaia DR3: a) SkyMapper DR4 per the criteria in Oh et al. (2023, MNRAS, 524, 577); b) the Gaia XGBoost public catalogue of Andrae et al. (2023, A&A, 674, 27); c) the StarHorse public catalogue of Anders et al. (2022, A&A, 658, 91).

The targets in the extragalactic subsurvey are derived from a crossmatch of SkyMapper DR4 and the VISTA VMC and VHS surveys. Additional targets are added from Bell et al. (2020) for the LMC and Bell et al. (2022) for the SMC central regions, based on SMASH and VISTA photometry. We select targets with class_star<0.7 and flags+0 from the SkyMapper DR4 catalogue and we include only targets with J–Ks>0.8 and J<19 mag from the VISTA catalogues. We used Petrosian magnitudes from SkyMapper and point-spread-function magnitudes from VISTA to obtain the reddening corrected galaxies' spectral energy distributions (SEDs). We provide a theoretical R-band magnitude based on the best-fit spectral template. We used the software LePhare to fit galaxy and stellar templates to the reddening corrected SEDs, inferring the galaxy types and redshifts. LePhare works with "AVEROI_NEW" templates, which are based on the empirical templates of Coleman et al. (1980) and Kinney et al. (1996) and have been linearly interpolated to better sample the colour-redshift space (Ilbert et al. 1998). To obtain reddening corrected SEDs we used the Schlegel, Finkbeiner and Davis (1998) reddening map in the outer regions of the Clouds adopting a constant reddening of E(B–V)=0.037 mag up to 3 deg from the centre of the SMC and E(B–V) =0.075 mag up to 4.5 deg from the centre of the LMC. However, in our input catalogue and 4FS templates we ignore the reddening. We provide four galaxy templates from Mannucci et al. (2001) at rest frame (z=0) and not reddened. We remapped the best fit templates from LePhare on the Mannucci templates. The latter provide a much better spectral resolution in the optical domain. The four Mannucci templates differentiate different morphologies (two for early-type and two for late-type galaxies). We additionally restrict the galaxy selection to z<0.58 for early-type and z<0.4 for late-type galaxies.

The contents of the deep-field subsurveys are selected randomly from amongst all the stellar populations we observe. For 1001MC_HRdeep, we selected 114 targets in each galaxy (LMC and SMC) for each of the following stellar types: massive stars, main-sequence stars, blue supergiants, Cepheids, AGB stars, carbon stars and RGB stars. Similarly, for 1001MC_LRdeep we selected 228 targets per galaxy for each of the following stellar types: Cepheids, main-sequence stars, RGB stars, red clump stars, yellow and red supergiants, and RR Lyrae stars. We also included about 2000 massive stars in the 1001MC_LRdeep subsurvey.

We reduced the sample for the 1001MC_LR subsurvey by applying a random selection, using exponential weights to sample the magnitude length of the RGB without obvious over and under densities. We include: 15% of the main sequence stars, 15% of the red clump stars, 15% of the RGB stars, 50% of the subgiant stars, and 100% of the other included stellar types. We also reduce the sample of RGB stars in the 1001MC_HR subsurvey by 50%, using the same exponential weighting scheme. For the 1001MC_GAL subsurvey, we selected randomly only one third of the total SkyMapper sample, exponentially weighted on magnitude to select predominantly brighter targets. There was no downsampling performed on the available targets for the other subsurveys.

6.9.2.3 Spectral success criteria and Figure of Merit

The spectral success criteria are a function of magnitude, stellar type and spectrograph, and are quantified in terms of signal-to-noise ratio (SNR). The SNR is measured within either 514–520 nm (including the Mg b triplet at 516.7, 517.2 and 518.3 nm) or 534.5–536.5 nm for the low- and high-resolution stellar targets respectively; the two intervals differ because of the different response functions of the spectrographs. In low resolution we also use 835–885 nm (including the Ca II triplet at 849.8, 854.2 and 866.2 nm) for red sources. For background galaxies we use 720-900 nm. The SNRs are averages over the spectral ranges (including spectral lines).

For sources targeted in high resolution, we request a minimum SNR of 50–250 per Å, in steps of 25 Å, in nine 0.5-magnitude intervals from G=17 to G<13. For low resolution targets using the Mg spectral range, we have instead eighteen 0.5-magnitude intervals from G>20 to G<13. We request a minimum SNR of 5 per Å for G>20, and 10–170 per Å in steps of 10 Å for increasing brightness intervals. For red targets using the Ca spectral range, we define eight 0.5-magnitude intervals from G<17 to G>20. We request a minimum SNR of 5 per Å for sources with G>20, and 10–70 per Å also increasing in steps of 10 Å for brighter magnitude intervals. The SNR for any given source is evaluated only in one range. The minimum SNR for RR Lyrae stars varies from 5 to 20 per Å in steps of 5 Å, and is only defined for four intervals, which correspond to G magnitudes >19, 19<G<19.5, 19.5<G<20, and G>20 . In the deep fields, where the targets are bound to a cadence strategy, we use a minimum SNR of 50 per Å for all stellar type targets in high resolution, except for massive stars where we use 75 per Å. In the low resolution deep fields, we use the lowest minimum SNR to complete the observation of each stellar target in one visit. They are SNR=20 per Å in the range of the Ca II triplet and SNR=5, 20 and 50 per Å in the range of the Mg b triplet, where the latter is only for the massive stars. The minimum SNR for all targets in the 1001MC_BCC subsurvey is 30 per Å calculated in the range of the Mg b triplet.

The survey Figure of Merit (FoM) is defined as the product between the Small Scale Merit (SSM) and the Large Scale Merit (LSM) for all but subsurveys that have a cadence strategy. In those cases, the FoM is equal to the SSM. The SSM corresponds to a fractional ratio of the completed over the total number of targets. To reach a high level of completeness on the 1001MC_HRcomp, 1001MCLRcomp, 1001MC_HRdeep, 1001MC_LRdeep and 1001MC_BCC we adopt an SSM which is a bi-linear function, where the intercept between the two lines at SSM=0.5 corresponds to 80% completeness. For the other subsurveys, we adopt instead a linear SSM where a value of 0.5 corresponds to a completeness of 50%. A target is considered as completed if the fractional ratio of the observed over the requested time is at least 1. However, for surveys requiring a cadence strategy we request that this ratio divided by the total number of requested visits is larger than 0.8. The LSM prioritises areas with the highest legacy value, where the area overlap is large among other external projects. These regions encompass the disc-like structures of the galaxies and correspond approximately to two circular areas with radii of 8.5 deg for the LMC and 6 deg for the SMC, while the low priority regions correspond to the remaining area around the galaxies. The FoM for the survey as a whole is currently given by the FoM of the lowest performing subsurvey, excluding the subsurveys that request a cadence strategy. This is because cadence is an aspect of 4MOST on a best effort basis, and is still not fully implemented within the system; therefore subsurveys driven by a cadence strategy should not drive the overall performance of the survey.

Scheduling requirements

The 1001MC targets include pulsating variable stars (with periods from 8h to a few hundred days) which change temperature and velocity as a function of time. Thus, we cannot simply average spectra obtained at different epochs. Instead, we have to rely on the spectra from a single visit. Furthermore, to obtain systemic velocities of pulsating stars we need data from different phases which we can fit to a radial velocity template. For this reason, we need repeated observations but without a strict cadence. The 1001MC survey aims to collect several spectra

for targets within the deep fields and the BCC subsurveys several times and would prefer observations spanning a few years to increase the chance of detecting radial velocity shifts of wide (long period) double stars and to obtain a good sampling across the light-curve of variable stars. Deep observations will also serve to calibrate results derived from shallower spectra. The cadence strategy is as follows.
All targets in the 1001MC_BCC subsurvey require to reach a given SNR in one visit. A total of 6 and 8 visits is requested for ellipsoidal and WR targets with a minimum time separation of 1 and 30 days, respectively. For all targets in the 1001MC_HRdeep and 1001MC_LRdeep subsurveys we require to reach a given SNR in one visit. We request 5 visits in total for the massive stars in the 1001MC_LRdeep subsurvey and 20 visits in total for all other targets with a minimum time separation between visits of 30 days.

6.9.3 Management structure

Since 2024, the 1001MC survey has two PIs. There is no ending to their appointment unless circumstances change and replacements become necessary. The PIs together with the Deputy PI represent the main decisional body of the survey; in particular, for matters that appear controversial within the core team. In any other instance, decisions are taken in a transparent manner together with the core team.
The core team is made of active staff scientists or permanent members who, because of their long-term position, provide stability to the survey team. It also includes the two PIs of the BCC survey. Postdocs and students may also become members of the core team depending on the progress of their career and level of commitment. There are senior scientists interested in specific aspects of the survey, but that because of external commitments have only a limited time to dedicate to it; they also can become members of the core team if their activity increases.
The survey team is organised by science themes which are to a large extent reflected by the nature of the science targets, i.e., the WPs on specific sources, in line with the expertise of the members. The science themes are coordinated by the PIs. There is no specific leader for each science theme. Members of a theme work together assigning tasks to each other as needed and are encouraged to keep regular contacts with the other members of the theme.

6.9.3.1 Survey Team Policies

In addition to the 4MOST-wide Science Team Policies the 1001MC survey has the following team policies:

(i) a member who continues to actively participate to survey activities after leaving a 4MOST Consortium institute will be supported to obtain independent membership to the survey team, provided enough free places are available and permanent memberships cannot be justified based on 4MOST-wide activities,

(ii) survey team memberships are revised on a yearly basis,

(iii) a member who does not actively participate to survey activities for a period of one year, including not replying to emails, will be removed from the survey team,

(iv) admission of new members to the core team shall be decided by the PIs in consultation with the other core members,

(v) support for independent membership to the survey team shall be decided by the PIs in consultation with the other core members, and

(vi) the role, contribution and activity of any new member joining the survey team will be agreed with the core team.

(vii) candidate members to the survey (either from the consortium or external) are requested to send to the PIs an abstract indicating their interest, expertise and planned contribution to the survey. The PIs forward this material to the core team for furher decision.

(viii) candidate members are welcome to contact the PIs or any other member of the core team and survey team at large to explore the possibility to join and to learn about the existing/planned activities within the team.

Publications resulting from the survey data usually appear in a survey numeral paper. The exception to following a numeral series is when the survey data are ancillary to other studies or when the survey data are already publicly available to the astronomical community. The BCC survey will have its independent papers (or a separate series) to guarantee external visibility to the Community-based project and in line with ESO policies.

Scientific publications emerging from the survey will be led by the person doing most of the work and writing most of the text being it a student, a Postdoc or a staff member. Students are however encouraged to communicate with their supervisor and follow any other publication policy at their host institute. Authors (effective or potential) of survey papers should comply with the following basic rules:

(i) in response to the distribution of team papers be always polite in providing feedback, avoid sending comments in a hurry,

(ii) take sufficient time to read the work of others, consider that any paper is the result of the work of at least several months by one or more people,

(iii) ask for clarifications before judging,

(iv) provide quantitative comments to the extent possible, avoid vague comments but do not refrain from asking questions (support them with references),

(v) it is not sufficient to be part of the survey team to claim co-authorships of papers,

(vi) only projects for which communication and agreement with the core team and members working within the same theme has occurred are endorsed to proceed to registration in 4MS. A google sheet collecting project ideas will be maintained and reviewed at telecons to facilitate their visibility to the team at large, encourage collaboration and avoid conflicts.

(vii) a minimum period of two weeks shall be given to the team to assess the first version of a paper before uploading it to the ST internal publication database, the main author should also allow for a longer time in case of members having valid reasons not to be able to meet the two-weeks deadline,

(viii) a period of one week should be given to the co-authors to assess multiple versions of papers if major comments were received before uploading a revised version to the ST internal publication database, for minor comments a period of two days would be sufficient, but in both cases the main author should allow for a longer time in case of members requesting more time,

(ix) accompany the distribution of a revised paper with a short description of the major comments implemented or not implemented with a reason for the latter,

(x) you are encouraged to publish survey paper in A&A, and

(xi) in the acknowledgements include statements specific to the usage of data and software outside of the 4MOST project, or funding as provided by the co-authors.

(xi) when referring to the BCC survey in a 1001MC consortium-based publication use either its full name (the Dormant Black Hole survey) or refer to it as a 4MOST Community survey carried out within the 1001MC programme. Do not refer to it as a 1001MC subsurvey.

(xii) make tables and data products presented in publications publicly available with them and through the ESO archive in line with the public survey nature of the project,

In addition, survey members must follow the general 4MOST publication policies.

6.9.3.2 Communication pathways

The communication between the survey and the 4MOST wide WPs shall take place via the PIs, or the deputy PI if the PIs are not available, who will re-direct any query, if necessary to the most appropriate person(s) within the survey team.

The survey representatives in the IWGs, SPB, and communications group provide their report to the survey team at the monthly meetings and, if necessary, directly to the PIs at any time before or after these meetings.

The survey members working on a specific science aspect of the survey will communicate with each other at the regular online (monthly telecons)/ in-person (survey team) meetings, but are also encouraged to communicate among themselves at any time.

One internal survey meeting per year preferably in person would ideally take place each time at a different member institute. This will have the double purpose to advertise the survey and encourage other individuals to join. The annual meetings will focus on the progress of the scientific exploitation of the survey data and will feature scientific presentations from each survey member. They will also include a report on the status of the survey operations and data reduction as well as address any aspect for which the survey input will be needed. The location of the meetings will be chosen about six months ahead and the agenda will be set about one month in advance. Survey members will be encouraged to distribute drafts of their manuscripts ahead of the meetings to foster discussions. On the other hand, the annual meetings will give the opportunity to gather feedback on work that has not yet been written onto a journal paper. In addition, the annual meetings will provide platforms for young researchers to train their presentation skills.

Monthly zoom-based meetings are used to provide updates on the progress of the 4MOST facility, to address the survey preparation steps and also to report about the work taking place within the IWGs and other 4MOST boards. These meetings will allow those regularly working with the 4MOST data to exchange views about possible issues and report about progress on their investigations. They will also allow the PIs to identify if follow-up meetings, perhaps involving only a subset of the team members, are needed to address specific aspects of the analysis of the data. For example, at the stage of survey preparations additional meetings were scheduled among those contributing to the construction of the input catalogue or those preparing software to analyse the variable stars. Minutes of these meetings are posted on the survey dedicated space on the 4MOST wiki.

Survey members, especially those directly involved with any of the IWGs, are encouraged to attend the 4MOST Science Meetings where information is distributed and exchanged among the members of the project. Those attending the meetings will however report to the survey team about any important aspect for the survey and about tasks or collaborations to explore.

In the 1001MC survey we communicate via email, at the monthly meetings, at the general 4MOST meetings and with minutes posted at the wiki. Additional zoom-based meetings take place among a subset of the members as needed. A summary/decision is then reported before (via email) or at the monthly meetings.

6.9.4 Work-breakdown structure

The organigram shown below (Figure 32) is to be read such that by selecting any of the specific outer elliptical regions information flows to any of the tessellations encrypted in the circles. More than one of the outer regions can be selected together and the flow of information can touch upon many tessellations. The concentric circles can also be viewed as rotating wheels to form a specific combination of target, method, and science exploitation.

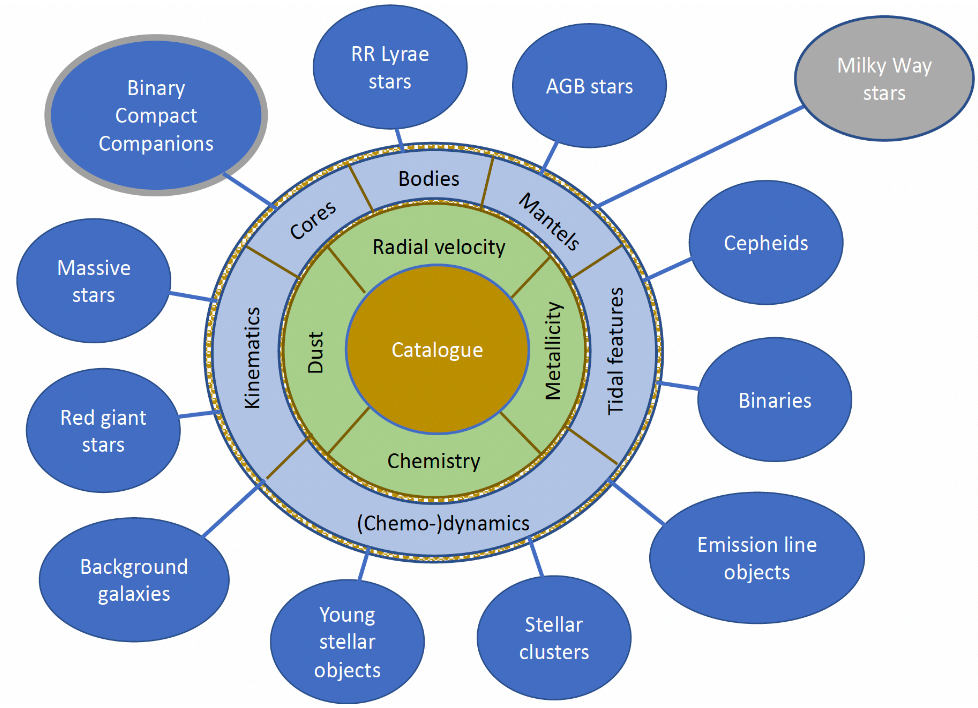


Figure 32: Work Breakdown Structure for Survey 1001MC

There are 11 general WPs that utilise the information obtained from one or more types of targets to address the formation and evolution of the host galaxies. These studies make use of complementary data that are not explicitly mentioned, such as multi-wavelength photometry and proper motions from VISTA and Gaia. These WPs are:

Catalogue: this represents the construction of a list of targets which cover a range of spatial structures, stellar types, parameters and include background galaxies. These sources will be re-classified using the spectra acquired by the survey.

Radial velocity: this refers to measuring the radial velocity of all stellar targets, including pulsating variable stars, and redshifts for background galaxies.

Metallicity: this refers to measuring the metallicity of the targets, for which it will be possible, using predominantly the Mg b or Ca II triplets and maps across the survey area.

Chemistry: this refers to measuring stellar atmospheric parameters and elemental abundances, depending on the type of targets and quality of the spectra, studying individual sources, patterns across the survey area, the chemical and accretion history of the system.

Dust: this refers to measuring the extinction towards the targets, and more specifically within the Magellanic Clouds system, using background galaxies as well as other stellar indicators.

Cores: this is on the study of the nature of the innermost regions of the LMC and SMC.

Bodies: this comprises the study of the stellar populations within the disc of the LMC and the elongated structure of the SMC, their formation and evolution as well as spatial extent.

Mantels: this is about the study of the outermost regions of the Magellanic Clouds, i.e., their halo as traced for example by metal-poor stars and sub-structures via multiple tracers.

Tidal features: this is about tracing and characterising features that result from the dynamical interaction between the LMC and the SMC as well as with the Milky Way and other galaxies. This includes protuberances emerging from the main bodies and large-scale tidal features such as the Magellanic Bridge(s) and the Magellanic Stream.

Kinematics: this is on the analysis of the radial velocity measurements across the survey area to identify and discover kinematical patterns.

(Chemo)dynamics: this is on the combined analysis of chemistry, metallicity and radial velocity to trace and explain variations across the survey area due to dynamical changes.

There are 11 WPs for specific sources on which information is used to also characterise the nature of the sources as well as their capabilities to provide information on the host galaxies. These WPs also make use of complementary data. They are:

Massive stars: this encompasses a large systematic study of the evolution of the stars in their native compact clusters in both cores and outer regions, the determination of the physical properties like the effective temperature, and as tracers of the young stellar populations. This WP also includes WR stars.

Binary Compact Companions: this originates from a community survey proposal which targets ellipsoidal binary stars discovered by OGLE to obtain multiple radial-velocity measurements and discover dormant black holes or neutron stars in non-interacting systems.

Red giant stars: this represents the bulk of the stellar population in the Magellanic Clouds with giants ascending the giant branch to the tip of the RGB and populating the red clump. They are therefore excellent tracers of distances and substructures from the multitude of diagnostics obtained with 4MOST spectra, which cover a range of metallicities, other elemental abundances and radial velocities.

Cepheids: this refers to the determination of predominantly temperature, surface gravity and iron abundance taking into account the variability of the stars (phases and features). It includes also estimating the metallicity dependence of the period-luminosity relations to measure distances to trace (mostly) young populations.

AGB stars: this includes the determination of radial velocities, stellar parameters, metallicities, abundances of alpha-elements and of the CNO cycle as well as the stellar luminosity which provide, together with the star formation history, important information to develop chemical evolution models. They trace (mostly) the intermediate-age population.

RR Lyrae stars: this refers to the determination of metallicity using both the DeltaS method and spectral synthesis. Spectra obtained at several phases will further support the analysis and the deep fields serve as calibration for stars elsewhere. They trace the oldest populations.

Young stellar objects: here the goal is to confirm the nature and characterise the properties of the massive sources in the low metallicity environment offered by the Magellanic Clouds.

Binaries: this is about searching for and studying spectroscopic binaries, determining the binary fraction as a function of spectral type and mass-ratio distribution, and on amplifying the study of radial velocity variability in connection with Gaia data on red supergiant stars.

Stellar clusters: this is about identifying and using stars associated to the stellar clusters to derive the star formation history of the Magellanic Clouds and possibly explain metallicity variations at a given age as well as to relate star formation to cluster formation.

Background galaxies: this is on the analysis of the rest-frame spectra of the galaxies to quantify the dust content along the line of sight.

Emission-line objects: this includes the study of emission-line sources which do not clearly fit in the categories above; for example, planetary nebulae, Be-type stars and quasars as tracers of galaxy properties, as probes of stellar evolution or of the intervening matter along the line of sight.

The WP on the **Milky Way** encompasses the sources that do not obviously belong to the Magellanic Clouds and need to be singled-out from our survey analysis. They are however of interest for members of other 4MOST surveys. For example, there are RR Lyrae stars and other Milky Way halo stars of interest to S1.

The synergies offered by surveys also targeting a fraction of the targets in our survey are, at this stage, dealt with within each WP. For example, the stars that we find in the outer regions of stellar clusters (of interest to S13) or the brightest stars (of interest to both S2 and S4). There are also a number of background galaxies and quasars that in our survey are observed as probes of the intrinsic properties of the Magellanic Clouds, but for which direct scientific investigations are dealt within, e.g., the S5, S6, S8 and S17 surveys.
Note that we refrain from assigning numbers and leads to the WPs. The contribution of team members to the WPs directly mirrors their scientific interest and most WPs have one or multiple connections to the IWGs.

6.9.5 Contribution to Infrastructure Working Groups

There is at least one member contributing to each IWG with more members, as expected, in IWG3 and IWG7 which reflects the need to calibrate and process a variety of stellar targets. In addition, there is one member (Niederhofer) acting as a point of contact in the communications group. Since 202, the co-PI (Cullinane) also contributes significantly to commissioning efforts, including coding procedures which will be used to verify instrument requirements. The current resources are at present sufficient, but we plan to eventually increase the number of contributors as the project and the survey activities progress. It is likely that the FTE of some team members will also increase once the 4MOST spectra become available.

<u>IWG1</u>
This working group was co-led by a member of our survey (Kacharov) from 2020 until 2023. This job involved overseeing and contributing to all IWG1 work packages: target catalogue repository, astrometry verification which he specifically led, shared targets, sky fibre allocation, and overall catalogue verification. He also organised and chaired weekly IWG1 telecons, edited and distributed the minutes, wrote 4MOST software and documents, managed the IWG1 gitlab and the wiki accounts as well as provided input on multiple JIRA tickets. In addition, he was responsible for the 4CAB process together with the other board members. Recently, the co-PI (Cullinane) took over representation of the 1001MC survey in this working group; her main activity is the revision of the input target catalogue and testing catalogue validation tools developed in the working group.

<u>IWG2</u>
This working group is co-lead by a member of our survey (Storm) who serves the purpose of the working group, which is to develop a survey plan for the five-year survey based on the target catalogues and supporting information provided by the individual surveys. This involves developing the algorithms to be used both for the simulator and for the actual observing system, to run simulations and discuss the outcomes with the various stakeholders, and to agree on how to proceed to converge on a common survey plan. The work is partly managerial, to make sure that issues are identified and dealt with, and it is part interacting with the surveys, to understand their needs and propose ways forward to resolve conflicting interests. Most of the practical work is done by OpSys and in close collaboration with the other IWGs, the 4MOST PI, the PSs and the IS under the umbrella of the ODG. There are also a number of ad-hoc working groups dedicated to particular aspects and the IWG2 leaders join these because they touch on the survey strategy. The work is expected to be intense up to the start of survey observations as the IWG2 has to provide a full survey plan for the entire five-year period. There will also be significant work to feed back into the survey plan the data and experience gained during the commissioning and the SPV phases. The IWG2 work is expected to decrease during regular survey operations,

but there will still be the need to monitor the performance of the observations and be ready to take action with the stakeholders involved when things do not develop as expected or unforeseen issues arise.
Our members have contributed also to the multiplicity working group (Bestenlehener, Lee, Mazeh, Pawlak, van der Swaelmen) by providing input to documents related to cadence and binary/multiplicity star analysis as well as by crossmatching the 4MOST input catalogue with the known catalogues of binary stars from, for example, OGLE and Gaia. The role of member Shenar is to test radial velocity measurements methods and potentially implement techniques of spectral disentangling on spectroscopic binaries.

IWG3

The 1001MC survey has one representative in this working group (Ripepi) who helps us design the observations, preceding the beginning of survey operations, to calibrate and validate the scientific output of the survey. He acts as a liaison between IWG3 and our survey and his main tasks are: participation to weekly IWG3 telecons, contribution to design the calibration, training and validation sample for the Galactic pipeline by provision of the missing/incomplete catalogues of interest for our survey (e.g., of Cepheids and RR Lyrae stars) in the format required by IWG3, contribution to design the science verification survey to be run during the SPV phase, which involves provision of the catalogues of interest for our survey, preparation of the OBs, execution of the observations and validation of the analysis pipeline results. He also contributes to the discussions and document writing in the context of IWG3 work. Other members (Castro Rodriguez and Oliveira) help with the preparation of the catalogue for commissioning, validations and science verifications for the massive stars as well as establishing whether templates and calibrations need to be modified to better suit the properties of young massive stellar objects. Some of these requirements may be met by Galactic surveys that target star formation, however those surveys will primarily target low-mass pre-main sequence stars. Validation targets for the multiplicity working group are provided by the respective members (e.g. Pawlak).

IWG4

The 1001MC representative in this working group has recently changed (from Cioni to Subramanian), with activity expected to increase moving forward. Most of the activity so far has been in the hands of a few persons and there has not been yet an overall participation by the group members.

IWG5

None. This working group is not active.

IWG6

Our survey is contributing to this working group with members checking the spectra obtained from the operational rehearsal stages (Bestenlehner and van der Swaelmen). They specifically address the stellar types within their expertise contributing to basic quality control routines and in the future, if time permits, also to further code development for both quality control and data release aspects. Member Patrick has contributed to the execution of the quality control tests and has provided feedback to other IWGs and the survey. The working group is led by member Carrera and his activities are more general to benefit all surveys.

IWG7

Several team members have contributed to the IWG7 activities. Survey member Bestenlehner developed a module to process O-, B- and A-type (OBA) stars and WR stars. The main aspects are: the integration and full automated analysis into 4GP, which requires fully non-LTE, spherical symmetric expanding stellar atmosphere (co-moving frame) models; stellar atmosphere grid calculation from 10,000 to 60,000 K for SMC and LMC baseline metallicities; and provision of new templates for the radial velocity. The line-list was updated and extended to make use of the entire wavelength range and a simple weighting scheme was introduced so that strong lines (e.g. Balmer lines) do not dominate over weaker metal lines. In the future the following aspects will also be included: luminosity and extinction parameter determination for which photometric data and distances are required (the workflow is still under discussion in IWG7), a decision module to select the right stars for processing via the module and group similar stars to derive meaningful stellar model uncertainties.
Zdenek developed a module for RR Lyrae stars to obtain [Fe/H] estimates from LRS spectra which is now complete and included in the GitLab for the Galactic pipeline. There are also plans to produce additional modules to derive radial velocities and elemental abundances, to the extent possible, on pulsating variable stars (e.g., Cepheids and evolved giant stars) and to detect spectroscopic binaries using the TODCOR algorithm (Zucker and Mazeh 1994, ApJ, 420, 806). The work on M-type stars will proceed taking into account the ongoing efforts to treat these objects within the IWG, that resulted from the inclusion of members from Community surveys. In addition, we plan to develop a pipeline module to derive orbital parameters of binary systems and another module on spectra disentangling which will allow us to analyse photometric eclipsing binaries.

IWG8
Our survey has one representative in this working group (Maitra) who informs us about the status of the extragalactic pipeline to process also the spectra of background galaxies that will be obtained within our survey. She is also crucial to inform the pipeline developers about the usage that our survey will make of the galaxy spectra which may require minor adjustments to the way the processing will develop, for example on the way the galaxy intrinsic reddening is taken into account to measure redshift. In particular, her tasks involve the familiarisation with the IWG8 pipeline and the fitting of SEDs, testing the pipeline for our survey.

IWG9
The current representatives of our survey in this working group (Ardern and Shenar) will contribute to the target classification using machine learning techniques, in particular in the preliminary definition of the classification classes. They will pay specific attention to the inclusion of variable and massive stars which are targeted in large numbers by our survey. Shenar will relay on his expertise in spectral classification of massive stars at low metallcity and on the ESO large programme he is leading (BLOeM) which will obtain multi-epoch spectroscopy of about 1000 massive stars in the SMC.

6.9.6 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.9.7 Level-2 data production

The 1001MC survey requires radial velocities, stellar parameters and elemental abundances for as many stars as possible which cover a range of spectral types and metallicities. Assuming our requested SNR is reached for all observed targets and based on current pipeline performance estimates, we expect to derive useful radial velocities for the entirety of our stellar target catalogue. We predict basic stellar parameters (effective temperature, surface gravity, and [Fe/H]) will be available for ~90% of our stellar targets - including all but the faintest targets, and some cool, molecule-rich AGB stars observed at lower SNR. A larger suite of abundances will be available for ~70% of the catalogue, including all high-resolution targets excepting the aforementioned cool AGB stars, and most of the brighter targets observed in low-resolution. We are also able to bin spectra in order to increase the SNR, and therefore can potentially expand the sample of stars for which we derive parameters.

We require information derived on single exposures as well as information obtained from stacked exposures. Stacks are at the level of single OBs, single visits and including all spectra on a given target. In the case of pulsating variable stars, we expect to make use of products from single observations. We also require redshifts and galaxy types, as far as possible, for the background galaxies.

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey. All targets of the 1001MC survey will be processed by the 4GP/4XP pipelines and quality-controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.

The 1001MC Survey team expects to deliver several other products beyond what is provided by the common pipelines as described below.

6.9.7.1 Deliverable L2 Survey data: reduction processing

We plan to provide additional data products beyond those coming from the common 4MOST pipelines. These include alternative methods to identify stars whose spectra are composed of two stellar components, and the derivation of stellar parameters and abundances that will not be implemented into the pipeline because of time constraints and availability of resources. These include, for example, quantities obtained for pulsating variable stars that take into account the periodic light-curve variation or quantities that refer to a complex phase of stellar evolution, like carbon stars, and quantities for emission-line stars. The production of these data products may also require external data. The systemic velocity of RR Lyrae stars, for example, will be obtained using OGLE/Gaia photometric information, line-of-sight velocity templates, and scaling relations.

6.9.7.2 Delivery L2 Survey data: quality assessment

The quality assessment will be performed by the survey team during the production and use of the data products for scientific applications.

6.9.7.3 Delivery L2 Survey data: data delivery and Phase 3 compliance

The additional data will be delivered as soon as they are sufficiently mature and are associated to a journal publication. In this case, they will be delivered at the nearest data release. For example, the data (stacked spectra by phase) that result from the analysis of a partial number of epochs for variable stars that is inferior to the one to be obtained at the end of the survey. The data will be made Phase 3 compliant using support from 4PA and/or ESO SAF staff.

6.9.7.4 Delivery L2 Survey data: product delivery schedule to the ESO archive

The additional data products will be made available as soon as they are sufficiently mature and are associated to a journal publication. In this case, they will be delivered at the nearest data release. For example, the data products that result from the analysis of a partial number of epochs for variable stars that is inferior to the one to be obtained at the end of the survey.

6.9.7.5 Delivery L2 Survey data: required hardware and staff

At present, we foresee that team members will have the necessary hardware to produce the additional data products and resources in terms of, for example, junior members, to perform their analysis. Student assistants at the AIP will be paid to support the survey to make the legacy products compliant with the ESO format and fit for delivery to the ESO archive.

6.9.7.6 Additional L2 data: reduction processing

6.9.7.7 Additional L2 data: quality assessment

6.9.7.8 Additional L2 data: data delivery and Phase 3 compliance

6.9.7.9 Additional L2 data: product delivery schedule to the 4PA archive

6.9.7.10 Additional L2 data: required hardware and staff

6.9.9 Team

The text and tables that follow summarise the key resources available over the first five years of survey operations. The core team members provide 3.4 FTE/yr whereas the other members (5.9 FTE/yr) as well as the collective minor contribution (0.2 FTE/yr) and potential new hires (1.8 FTE/yr), provide 7.9 FTE/yr, which results in a total of 11.3 FTE/yr for the 1001MC survey. Taking into account that only 7 of the 30 (for both survey programmes combined) available positions for invited members are currently filled, we expect an overall higher FTE during the course of the project.
Several team members are already engaged in activities to secure their position or to hire researchers who would contribute to the scientific exploitation of the survey. These activities are expected to also increase with the time approaching the availability of the first 4MOST data. In addition, the survey team will be enriched with independent members and external collaborators (for specific projects=papers) as needed.

Table 20: S9 Core team members

Name	Affiliation	Function	FTE/year
Maria-Rosa Cioni	AIP	co-PI	0.4
Lara Cullinane	AIP	co-PI, IWG1 and SITCOM	0.7
Jesper Storm	AIP	Deputy PI and IWG2	0.5
Kenji Bekki	ICRAR		0.1
Vanessa Hill	OCA	IWG7	0.1
Pascale Jablonka	EPFL	SPB	0.2
Andreas Koch-Hansen	ARI		0.1
Tsevi Maseh	TAU		0.3
Joana Oliveira (External)	Keele		0.1
Lee Patrick (External)	CAB CSIC-INTA	IWG6	0.2
Michał Pawlak	LU-Phys		0.5
Vincenzo Ripepi (External)	OAC	IWG3	0.2

Table 21: S9 Members including PhD students

Name	Affiliation	Function	FTE/year
Richard Anderson	EPFL		0.1
Steve Ardern (PhD)	Bath	IWG9	0.3
Dolev Bashi	Cam-TCL		0.1
Joachim Bestenlehner	Sheffield	IWG7	0.1
Ricardo Carrera	OAPD	IWG6	0.2
Norberto Castro Rodriguez	AIP	IWG3 and IWG7	0.2
Simon Faigler	TAU		0.2
Elad Goldberg (PhD)	TAU		0.5
Óscar Jiménez Arranz	LU-Phys		0.1
Nikolay Kacharov	AIP		0.1
Chandreyee Maitra	MPE	IWG8	0.2
Florian Niederhofer	AIP	Communications	0.2
Zdenek Prudil	ESO	IWG7	0.2
Abhinna Samantaray (PhD)	ARI		0.3
Tomer Shenar	TAU	IWG9	0.1
Teresa Sicignano (PhD)	OAC		0.3
Smitha Subramanian	IIA	IWG4	0.2
Salvatore Taibi	EPFL		0.1
Mathieu van der Swaelmen (External)	OAA	IWG6	0.2
Giordano Viviani (PhD)	EPFL		0.1
Mathias Schultheis	OCA	IWG7	0.2
Gil Nachmani (PhD)	TAU		0.5
Ross Church	LU-Phys	IWG7	0.1
Sreepriya Vijayasree (PhD)	AIP		0.3
Kriti Sharma (PhD; from October 2025)	AIP		0.5
PhD student (to work on RC stars; starting October 2025)	IIA		0.5

In addition, there are members who contribute to the project with an individual FTE below 0.1, but that collectively adds up to 0.2. These are: Andrew Cole (UTAS), Eva Grebel (ARI), David Hobbs (LU-Phys), Hugues Sana (KUL) and Matthias Steinmetz (AIP).
During the course of the survey several team members plan and are already in the process to apply for funding to hire new PhD students. A conservative estimate indicates that six PhD students are likely to join the project in addition to those listed above. Assuming each new student will give a 0.3 FTE we obtain an overall FTE of 1.8. Students who will work solely on 4MOST exploitation will have a higher FTE.

The 1001MC team will also be enriched with invited members to provide enough resources for working on specific topics or to maintain the collaboration with existing members moving to an institute outside of the consortium. This will result into additional FTEs to the project.

Team members are grouped with respect to their expected science exploitation and primary effort (underlined) as follows.
Catalogue: Anderson, Bestenlehner, Carrera, Castro Rodriguez, Cioni, Cullinane, Hobbs, Kacharov, Niederhofer, Patrick, Prudil, Ripepi, Shenar, Storm, Subramanian, van der Swaelemen, Vijayasree, Viviani
Radial velocity: Anderson, Bestenlehner, Carrera, Castro Rodriguez, Cioni, Cullinane, Hobbs, Kacharov, Niederhofer, Patrick, Prudil, Ripepi, Shenar, Storm, Subramanian, van der Swaelemen, Viviani, Vijayasree
Metallicity: Anderson, Ardern, Cioni, Cole, Cullinane, Grebel, Jablonka, Kacharov, Patrick, Prudil, Ripepi, Scowcroft, Steinmetz, Storm, Taibi, van der Swaelemen, Viviani
Chemistry: Carrera, Castro Rodriguez, Cioni, Cole, Cullinane, Grebel, Hill, Jablonka, Kacharov, Patrick, Schultheis, Sharma, Steinmetz, Storm, Taibi, van der Swaelmen
Dust: Cioni, Hobbs, Oliveira
Cores: Cioni, Niederhofer, Storm, Vijayasree
Bodies: Cioni, Cole, Ripepi, Storm, Subramanian
Mantles: Cioni, Cullinane, Hill, Jablonka, Prudil, Ripepi, Storm, Taibi
Tidal features: Cioni, Cullinane, Grebel, Prudil, Ripepi, Steinmetz, Storm
Kinematics: Cioni, Cole, Cullinane, Hobbs, Kacharov, Niederhofer, Patrick, Prudil, Steinmetz, Storm, van der Swaelemen, Vijayasree
(Chemo-)dynamics: Bekki, Grebel, Jiménez Arranz, Kacharov, Niederhofer, Steinmetz
Massive stars: Bestenlehner, Castro Rodriguez, Maitra, Patrick, Pawlak, Sana, Shenar
Binary Compact Companions: Bashi, Castro Rodriguez, Faigler, Church, Goldberg, Maitra, Mazeh, Nachmani, Pawlak, Sana, Shenar
Red giant stars: Anderson, Carrera, Cioni, Cole, Cullinane, Kacharov, Subramanian, van der Swaelmen, Viviani
Cepheids: Anderson, Ardern, Grebel, Patrick, Ripepi, Scowcroft, Sicignano, Storm, Viviani
AGB stars: Anderson, Castro Rodriguez, Cioni, Cole, Cullinane, Kacharov, Patrick, Pawlak, Schultheis, Sharma, Viviani
RR Lyrae stars: Anderson, Ardern, Grebel, Prudil, Ripepi, Scowcroft, Storm
Young stellar objects: Oliveira
Binaries: Bestenlehner, Castro Rodriguez, Church, Goldberg, Nachmani, Patrick, Pawlak, Sana, Shenar, Tsevi, van der Swaelemen
Stellar clusters: Carrera, Hobbs, Kacharov, Koch-Hansen, Grebel, Niederhofer, Ripepi, Storm, van der Swaelemen
Background galaxies: Cioni, Maitra
Emission-line objects : Castro Rodriguez, Cioni, Grebel, Ripepi, Samantaray
Milky Way: Hobbs, Jablonka, Steinmetz, Taibi

6.10 Survey 10 – Time-Domain Extragalactic Survey (TiDES)

Survey PI: Isobel Hook until 17/6/24, then Kate Maguire

6.10.1 Science Summary

The 4MOST Time-Domain Extragalactic Survey (TiDES) is focused on the industrialisation of spectroscopic follow-up of extragalactic optical transients selected from forthcoming large sky surveys. TiDES will conduct: (i) spectroscopic observations of 35,000 live transients, (ii) comprehensive follow-up of 70,000 transient host galaxies to obtain redshift measurements for photometric classification and cosmological applications, and (iii) repeat spectroscopic observations to enable the reverberation mapping of Active Galactic Nuclei (AGN). We will use our 35,000 live spectra to map out the full range of luminosity and timescale of explosive transients, assembling the largest samples of exotic transients to understand their diversity and physics. We will also use this sample of live supernovae to train and improve photometric classifiers, thus exploiting the larger sample of supernovae with only host galaxy redshifts to assemble the largest-ever sample of 70,000 type Ia supernovae, making a sub-2% measurement of the equation-of-state of dark energy. Finally, we will extend our Hubble diagram to z~2.5 using reverberation mapping of 700-1000 AGN.

Expanded science description: messenger-no175-58-61.pdf

Merged Science Programme: 4SLSLS: The 4MOST Strong Lens Spectroscopic Legacy Survey

Strong gravitational lensing is on the cusp of a revolution, with Euclid and LSST each forecast to discover over 100,000 strong lenses. Strong gravitational lenses are powerful probes of both galaxy formation and cosmology. However, without spectroscopic redshifts, only minimal science can be done despite the huge new samples that will be discovered in the current decade. Therefore, we propose to observe Euclid and LSST lens candidates with a source magnitude R<24 and a source photometric redshift below z_phot < 1.8, yielding 10000 spectroscopic source redshifts. We also propose to obtain lens velocity dispersions for the 5000 brightest of these lenses. This data will enable a range of legacy science including: the stellar Initial Mass Function, constraining dark energy, testing general relativity, and highly magnified source studies. We request 35,000 fibre hours spread roughly uniformly over the Euclid and LSST footprints i.e. the Southern extragalactic sky. The cost is therefore a very small fraction of 4MOST, but the scientific payoff and legacy value are very large.

Expanded science description: messenger-no190-49-52.pdf

After merging of the community survey, the science of S10 consists of four sub surveys:

- S1001 – TiDES-Live
- S1002 – TiDES-Hosts
- S1003 – TiDES-RM
- S1004 - TiDES-SL

The first three subsurveys cover the science described in the first abstract above, and the fourth was incorporated from the community programme 4SLSLS.

6.10.2 Target Catalogue

The area for S1001 and S1002 is determined by the LSST footprint and the survey does require the entire area to be observed. Additionally, the targets for S1001, S1002, S1004 are currently based on mock catalogues as these targets will be discovered by future surveys, LSST and Euclid. Selection criteria are summarised below.

TiDES-Live:

LSST transients alerts will be provided to S10 through community data brokers. Starting from the Rubin data stream, we will select a primary target list based on the following criteria
(i) We only consider data points in g,r,i,z bands, regardless of additional observations in u and Y bands.
(ii) the transient must be detected with > 5 sigma (on the image subtraction) in at least three bands
(iii) the detections with > 5 sigma must occur on at least two distinct nights
(iv) the object must reach 22.5 mag (or brighter) in any filter
In addition, smaller numbers of suitably bright targets may be included from other Rubin transient brokers, and transient searches on other facilities. Additionally, alert pipelines for specific science cases will be deployed e.g. young, local, and bright Supernovae (SNe) discovered hours after explosion, and Tidal Disruption Events (TDEs). These pipelines/surveys that discover our transients will form distinct labels so that the selection function can be reproduced.
TiDES-Hosts: Target selection will be based on a search of LSST catalogues near the position of known transients. At a later stage, the catalogue search will be replaced by analysis of images. In deep fields (with repeat 4MOST visits) we will observe multiple host candidates.
Timescale for availability of targets: Rubin/LSST is currently expected to ramp up from system first light in November 2024 to full survey operations in March 2025, with the full transient stream (which relies on reference images being available) in late 2025. For the early phase of 4MOST operation, we are investigating other sources of targets (from existing and upcoming transient surveys) for the TiDES-Live and TiDES-Hosts sub surveys.
TiDES-RM: Around 900 AGN have been selected over the redshift range $0.1 < z < 2.5$, in fields that will have regular repeat visits with 4MOST.
TiDES-SL: Targets will be selected from LSST & Euclid lens target catalogues. Euclid was successfully launched in July 2023 and the first public data release (Q1) is due around the end of 2024. An MoU is being discussed that would enable 4MOST observations of strong lens sources prior to the public Euclid data releases. Furthermore, in the early years when LSST photometry is not available, DES, DELVE and DeCALS data will be used for photometric redshifts.
The S/N requirements are >5 per 15A for S1001 and S1003, >3 per 1A for S1002 and TiDES-SL (for redshifts). To measure velocity dispersion in TiDES-SL galaxy spectra, a S/N of >20 per A is needed. The Scientific FoM uses the SSM*LSM.

6.10.3 Scheduling requirements

The S1001 sub survey will observe recently discovered transients and is time-domain sensitive, although it will not drive the 4MOST schedule. This sub-survey would benefit greatly from some coordination between the 4MOST schedule and that of Rubin Observatory.
The S1003 sub survey requires regular visits to the 4MOST deep fields to observe the variability of their AGN targets.

6.10.4 Management Structure

The key roles in management of the survey are shown in Table 22, and the roles are described below.

Table 22: S10 TiDES key management roles

Position	Name	FTE per year	Institute
PI	Isobel Hook	0.2	Lancaster University
Team membership manager	Kate Maguire		Trinity College, Dublin
EXB representative	Mark Sullivan		Southampton University
STSC representative	Patricia Shady	0.01	Bath University
TiDES Steering Group member	Stephen Smartt		Oxford University
TiDES Steering Group member	Seb Hoenig	0.1	Southampton university
TiDES Steering Group member and PI of TiDES-SL	Tom Collett	0.1	Portsmouth University

PI:
- The PI is responsible for coordinating the survey work, and for liaising with the 4MOST project through the SCB.
- The PI of S10 rotates every 2-3 years. About 6 months prior to rotation, volunteers are sought and a new PI is proposed to the TiDES membership.
- TiDES-SL has its own PI (T. Collett), being the leader of the 4SLSLS community survey proposal that was merged into S10. The TiDES-SL PI acts as deputy PI for attendance at SCB meetings if needed.

EXB representative:
- The EXB representative is responsible for representing S10 interests at the 4MOST EXB meetings and reporting back to S10 team members on relevant issues.
- The EXB representative rotates every 2-3 years at the time when the PI rotates. About 6 months prior to rotation, volunteers are sought and a new PI is proposed to the TiDES membership.

STSC representative:
- The STSC representative is responsible for representing S10 interests at the 4MOST STSC meetings and reporting back to S10 team members on relevant issues.
- The STSC representative rotates every 2-3 years at the time when the PI rotates. About 6 months prior to rotation, volunteers are sought and a new PI is proposed to the TiDES membership.

Team Membership Manager:
- The TM is in charge of keeping the membership registry (4MS) up to date. The TM shall ensure that the members of the Survey Team keep their affiliation and contact information up to date in the system.
- Should the TM not be able to carry out their duties the PI will step in until a stable solution can be found.

Steering Group members:
- A small Steering Group has been created to discuss and agree on practical matters. The group is selected to have the minimum number of people satisfying the following criteria:
    - Survey PI
    - EXB member

- ○ SPB member
- ○ One person from each sub-survey
- ○ One person from each TiDES founding institute (U. Southampton, U. Portsmouth, QUB and U. Lancaster)

WP managers:

- WP managers are selected from volunteers among the S10 membership. The current WP leaders are listed in Section 6.10.5.

6.10.5 Work Breakdown structure

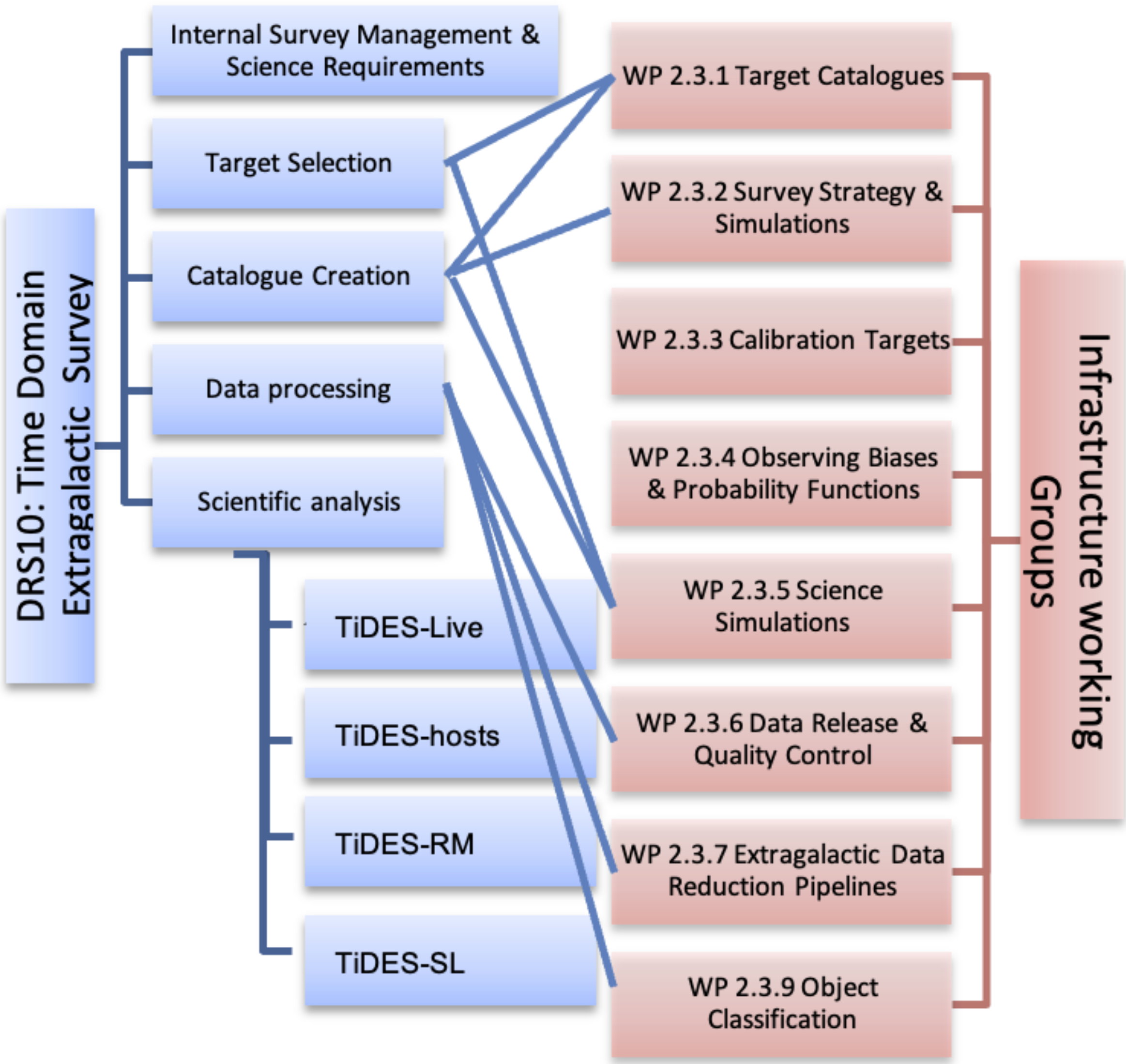


Figure 33: Illustration of S10 WBS (blue). Blue lines connecting the blue and red boxes indicate the major interfaces with a corresponding IWG where the activities for this survey will be merged and connected with similar activities in other surveys.

The survey work is divided into the following Work Packages (WPs). A brief description is provided for each.

- WP1 Management.

  - Tasks: Overall coordination of work, led by the PI and TiDES Steering group. This WP also provides the interface with the 4MOST project.
  - Current WP manager: I.Hook (rotates with PI).
- **WP2 Target selection**.
  - Tasks: Definition of target selection criteria for all sub-surveys.
  - WP manager: P. Schady
- **WP3 Catalogue creation**.
  - Tasks: Real-time creation of target lists and creation of Observing Blocks
  - Current WP manager: C. Frohmaier
- **WP4 Data processing**.
  - Tasks: definition and creation of S10-specific pipeline (including classification of live transients) and interface with IWG8 (extragalactic pipeline)
  - WP manager: P. Wiseman
- **WP5 Scientific Analysis.**
  - Tasks: Scientific exploitation for all sub-surveys is included in one WP. This WP will be subdivided at a later date (e.g. sub-WPs for each of the sub-surveys: SN, Hosts, RM, SL).
  - Current WP manager: I. Hook (rotates with PI). WP managers for the sub-WPs will be selected at a later date.

In each case the WP manager's role is to coordinate the work and report to the TiDES overall management. Interfaces with 4MOST IWGs are provided by some of the same individuals, but also by other TiDES representatives on the IWGs and other 4MOST groups. These are listed in section 6 below.

6.10.6 Contribution to the Infrastructure Working Groups

Several members of S10 have joined the IWGs in order to receive email updates, and a subset of these are actively contributing. Below we describe the contributions to each IWG.

IWG1

Currently 3 members of S10 are members of IWG1. The main S10 contact for IWG1 is C. Frohmaier. He attends the weekly meeting and is part of the Shared Targets Work Package.

IWG2

Currently 5 members of S10 are members of IWG2. We provide input to simulations (updated target lists) when required and analyse results of the simulations, providing feedback to those running the simulations.

C. Frohmaier attends the weekly IWG2 meetings as the S10 representative. He also works with members of the OpSys team to find solutions to the unique time-domain components. Specifically, he has worked with Jake Laas on the Transient API. He has also worked with Jesper Sollerman on the cadence flags in the catalogue uploads, and with Elmo Temple on various simulation design strategies.

IWG3

Currently two members of S10 are members of IWG3. The S10 contact is P. Schady, who attends fortnightly meetings via telecon and is part of the Extragalactic Pipeline Validation and Science Verification Work Packages.

IWG4
Currently 1 member of S10 is a member of IWG4 as a contact (I. Hook). However, they are not active in this IWG. This is because S10 target numbers are relatively low, and this survey does not have a significant impact on the selection function of other surveys.

IWG6
The current co-lead of IWG6 ("Quality Control and Data Curation") is a member of the survey (P. Wiseman). He devotes approximately 0.2-0.3 FTE to IWG6 work.

IWG8
Currently 4 members of S10 are members of IWG8, of which one is active (Y.-L. Kim). He participates in weekly video calls and contributes by testing pipeline software on simulated spectra that emerge from the operations rehearsals (e.g. OpR2.5). TiDES-SL will send a representative (A. Sonnenfeld, TBD) to IWG8 to work on deblending of spectra where multiple sources are present in the fibre.

IWG9
Currently 3 members of S10 are members of IWG9. IWG9 meets weekly alternating general and technical discussions. For TiDES-Live, there is on-going discussion within TiDES about how best to do the classification of live transients and as discussed below in Section 7.2 this will be done outside the 4MOST framework for operational reasons.

6.10.7 Level-1 data reduction re-process and ancillary products

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.10.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey S10 will be processed by the 4XP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.

6.10.8.1 Deliverable L2 Survey data: reduction processing

TiDES-SL will provide deblended lens and source redshifts and lens velocity dispersions for strong lens systems where the source and lens light are present in the same 4MOST fibre. (Note that TiDES-SL committed to public release of data products in the ESO proposal for 4SLSLS).

6.10.8.2 Deliverable L2 Survey data: quality assessment

The DL2-SURV data products will be subject to an internal Quality Control process prior to their release. This process includes the formatting, the metadata as well as visual inspections and basic scientific checks.

6.10.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop

their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.10.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

TiDES-SL products will be delivered to the 4PA archive in Data Release instalments ahead of each scheduled Data Release date with the aim to start from DR2 or otherwise the first DR after a refereed publication.

6.10.8.5 Deliverable L2 Survey data: Required hardware and staff

The required hardware is minimal (20k spectra should be manageable on a laptop). In terms of effort, we estimate 0.5 FTE years of development and maybe 0.1 FTE ongoing throughout the survey to check performance is as expected, and do the bulk uploads for each data release.

6.10.8.6 Additional L2 data: reduction processing

For TiDES-Live, S10 will determine classification and redshifts of live transients based on their own processing (i.e. outside the main 4MOST processing pipeline). The results will be provided to the Rubin community through the Lasair broker (agreed as part of the UK in-kind contribution to Rubin observatory) and to the Transient Name Server (https://www.wis-tns.org/). In addition, the results will be archived periodically in the ESO archive.
The reasons for needing a separate pipeline are as follows. Firstly, it is common practice in the transient astronomy community to make basic information about new transients available to the community as soon as possible, to enable rapid follow up (which can enable a different level of scientific analysis, especially for rare objects). The usual 4MOST data release schedule would be too slow to enable real-time follow-up before the transients fade. Therefore, a fast pipeline is required. However, since this is a requirement of S10 only, the resources for such a pipeline should not come out of the main 4MOST project.
The plan is that S10 will receive the L1 spectra of the live-transients within 12 hours of end-of-night from the CASU reduction pipeline. These data will be used to perform quick classifications of transients. Their classifications and redshifts will be publicly released through a data broker within 24 hours of the end-of-night. The redshift will come with an uncertainty and possibly a probability density function. The classification will come with a confidence flag. The classification and redshifting process will be largely automated. The rapid analysis pipeline will flag a subset of spectra for visual inspection. A rotating team of 5 people drawn from the TiDES team will visually inspect a subset of the spectra every day after the previous night's observations.

6.10.8.7 Additional L2 data: quality assessment

The TiDES-Live classification pipeline will be tested during the SPV phase by visually classifying the spectra and by 'manually' classifying the spectra using existing software tools such as Next Generation Superfit and SNID. During the main survey, quality assessment will be via classification success metrics that accompany the individual classifications and redshifts, as well as by visual inspection and 'manual' classification of a sub-set of spectra each night.

6.10.8.8 Additional L2 data: data delivery and Phase 3 compliance

For releasing the results, we use a dynamic platform such as Lasair and TNS so that results, especially classification, can be easily updated in real time as we or others obtain further information (for example a follow-up spectrum or further photometry from LSST). The initial results from the rapid analysis pipeline will be stored in the ESO archive periodically. A possible link could be explored so that users of the ESO archive could be directed to the latest dynamic results.
Final 1-d calibrated spectra of the transients and their host galaxies (TiDES-hosts) will be released following the ESO 4MOST data release plan.

6.10.8.9 Additional L2 data: product delivery schedule to the 4PA archive

For each planned Data Release we will prepare a catalogue of TiDES-Live classifications and redshifts that were derived from the rapid analysis pipeline. These AL2 products will be delivered to the 4PA archive in Data Release instalments (i.e. for all transients that will be included in the Data Release) ahead of each scheduled Data Release date.

6.10.8.10 Additional L2 data: Required hardware and staff

The additional processing will be carried out by members of the TiDES team (see next section). Computing resources have been identified at CASU for this process.
A rotating team of 5 people drawn from the TiDES team will visually inspect a subset of the spectra every day after the previous night's observations.

6.10.9 Team

Table 23: S10 TiDES members, affiliations, roles, and expected FTE/yr contributions

Name	Affiliation	Function	FTE/yr
Harry Addison	Surrey	PhD Student	
Thomas Collett	ICG	PI of TiDES-SL, TiDES Steering Group member, WPs 1 & 2	0.2
Jamie Dumayne	Lancaster	PhD Student	
Christopher Frohmaier	Southampton	WPs 2 & 3, IWGs 1 rep., IWG 2 rep., TiDES WP3 Lead	0.65
Sebastian Hoenig	Southampton	TiDES Steering Group member, WPs 2 & 3	0.1
Isobel Hook	Lancaster	PI, WPs 1 & 4, SCB rep.	0.26
Young-Lo Kim	Lancaster	WP 4, IWG 8 rep., IWG 9	0.75
Kate Maguire	TCD	Team membership manager, WP 2, SPB	0.12
Andrew Milligan	Lancaster	PhD Student	0.5

Name	**Affiliation**	**Function**	**FTE/yr**
Matt Nicholl	Birmingham	WP 2	0.05
Patricia Schady	Bath	STSC rep., IWG3 rep. TiDES WP2 Lead	0.1
Stephen Smartt	Oxford and QUB	TiDES Steering Group member	
Mark Sullivan	Southampton	EXB rep., WPs 1 & 2	0.08
Aprajita Verma	Oxford		0.05
Philip Wiseman	Southampton	IWG 6 rep, Project Culture WG member, TiDES WP 4 Lead	0.27

6.11 Survey 11 – The White Dwarf Binary (WDB) survey

Survey PIs: Odette Toloza, Alberto Rebassa-Mansergas

6.11.1 Science Summary

White dwarf binaries are relevant across a wide range of astrophysics since they comprise the most common fate of the majority of main sequence pairs. Thanks to the ESA Gaia mission we have identified the first statistically significant and unbiased sample of ~150,000 white dwarf binary candidates. It comprises systems that never interacted and that are part of common proper motion pairs (CPMPs) and systems that evolved through mass transfer episodes and that are now part of close white dwarf binaries (CWDBs). On the one hand, the white dwarfs in CPMPs can be used as reliable cosmo-chronometers to independently constrain key properties of the Milky Way and its stars. On the other hand, full characterization of the many different flavours of CWDB holds the potential to observationally constrain a wide variety of key ingredients that currently hamper the validity of the theoretical models.
Expanded science description: messenger-no190-4-6.pdf

6.11.2 Target Catalogue

The scientific organisation of S11 consists of three separated surveys, each having targets to be observed with the HRS and the LRS. Therefore, S11 is composed of six sub-surveys (see Figure S11-1 for a schematic representation). We use the following definitions for each sub-survey:
S1101: Compact white dwarf binary (CWDB) survey with LRS.
S1102: Compact white dwarf binary (CWDB) survey with HRS.
S1103: Common proper motion pair (CPMP) survey with LRS.
S1104: Common proper motion pair (CPMP) survey with HRS.
S1105: Central star planetary nebula (CSPN) survey with LRS.
S1106: Central star planetary nebula (CSPN) survey with HRS.

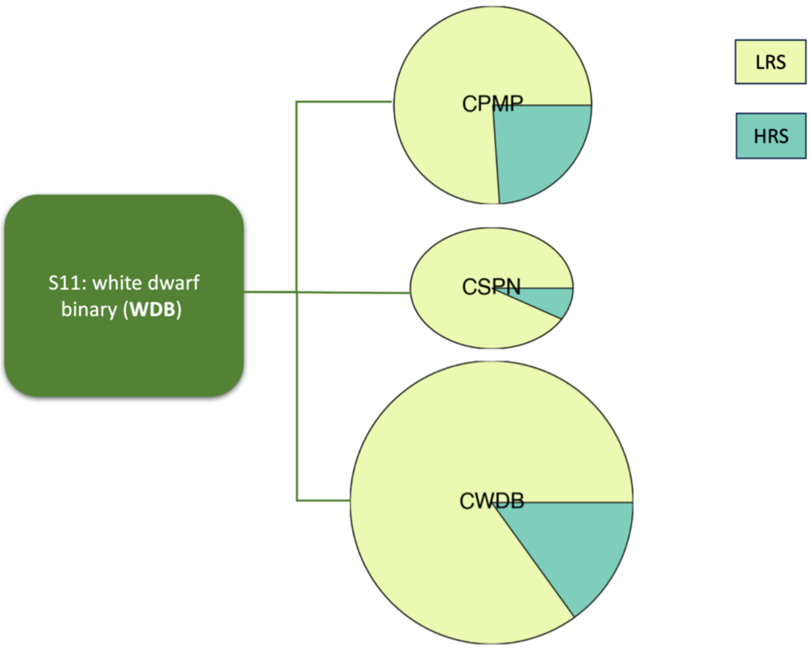


Figure 34: Sub-surveys within S11. The size of the blue ovals represents the size of the sub-surveys in logarithmic scale. The ratio of the oval (i.e width/height) represents the fraction of LRS/HRS targets.

S1101 and S1102 subsurveys

S1101 and S1102 aim to obtain LR and HR spectra respectively to reveal the type of close binary among the selected candidates (cataclysmic variable, detached white dwarf main sequence, Am CVn binary, etc). The spectra of sufficiently high SNR will be fitted to measure stellar parameters (Teff, logg, masses, radii).

The parent catalogue is the Gaia EDR3 astrometry and photometry database, which is crossmatched with the ultraviolet survey GALEX data release 7 source dataset. In summary, from the EDR3 x GALEX catalogue we select those targets with 15 < Gaia_G < 20, and with FUV_error < 0.3 & FUV > 0. This results in ~118,000 targets (see Figure 35), homogeneously distributed in the sky. Of these, ~22,000 targets have Gaia_G < 15, and are intended for HRS; ~96,000 have Gaia_G > 15, and are intended for LRS. Additionally, within S1101 there is a sub-sample of objects built by the crossmatch (IPHAS OR UVEX) x (EDR3). A cut on UVEX-based colours U-g vs M_U provides ~27,000 extra candidates in the Galactic plane.

Since white dwarfs will be observed as part of S3 (including those white dwarfs in binaries with another white dwarf or with a considerably less luminous companion) they are excluded from the S1101 and S1102 samples. Subdwarfs will also be observed within S3, therefore they are removed too.

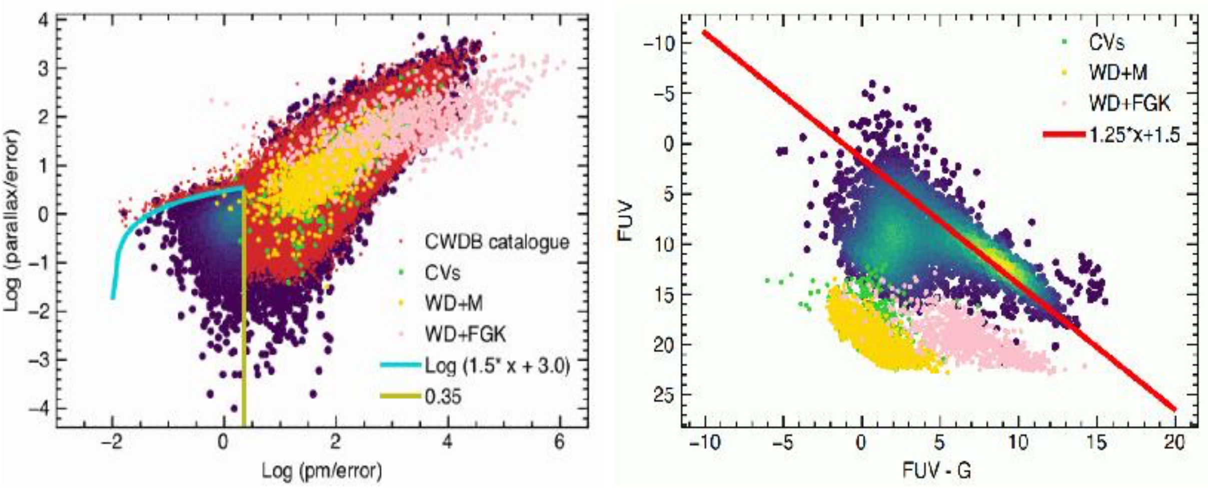


Figure 35: The selection of S1101 and S1102 targets. The left panel shows all Gaia EDR data with GALEX DR7 available magnitudes and fulfilling 15 < Gaia_G < 20, FUV_error < 0.3 and FUV > 0; in red the selected targets (CWDB catalogue), which are obtained from applying the cut to the GALEX FUV vs. FUV-G diagram in the rigt panel (objects under the red line). Known white dwarf binaries of different spectral classes are also illustrated, clearly showing that our selection comprises the vast majority of objects and, at the same time, is able to exclude quasars. Quasars are mainly represented by the bulk of objects with log(parallax/error) = log(pm/error) = 0 and are excluded using the following two equations: log(pm/error) < 0.35 (yellow solid vertical line) and log(parallax/error) < log[1.5*log(pm/error)+3] (cyan solid line; valid for log(pm/err)>-2).

We aim to achieve a SNR of at least 10 per Å for objects as faint as Gaia_G = 20. The required SNR gradually increases from 10 to 100 until Gaia_G = 17, and this value is set to a lower limit for brighter objects. We require continuation criteria such that at least 90% of the required SNR is achieved with one or multiple exposures.

The individual FoMs follow LSM*SSM, where SSM is defined so that a completeness of 40% and 90% are achieved for the S1101 and S1102 samples, respectively. The overall FoM of the survey is the weighted average of the 6 individual subsurveys, where S1101 and S1102 contribute with a weight of 0.45 and 0.35, respectively.

<u>S1103 and S1104 subsurveys</u>

S1103 and S1104 aim to observe respectively M dwarf and F, G, K dwarf main sequence companions of white dwarfs in common proper motions pairs to derive their metallicities (mainly Fe/H abundances), effective temperatures, surface gravities and activity indices (through the presence/absence of Hα or Ca II K&K emission).

The parent catalogue is Gaia DR3 astrometry and photometry. We have developed a routine that identifies white dwarfs within the parent catalogue and their common proper motion non-degenerate companions, i.e. targets with similar proper motions and parallaxes. The magnitude ranges are the following: Gaia_G >= 13, Gaia_BP <= 20.5 and Gaia_RP <= 20. This results in 3,400 targets (see Figure 36), of which ~2,800 are M dwarfs intended for LRS observations and ~900 are FGK stars intended for HRS. The samples are homogeneously distributed in the sky.

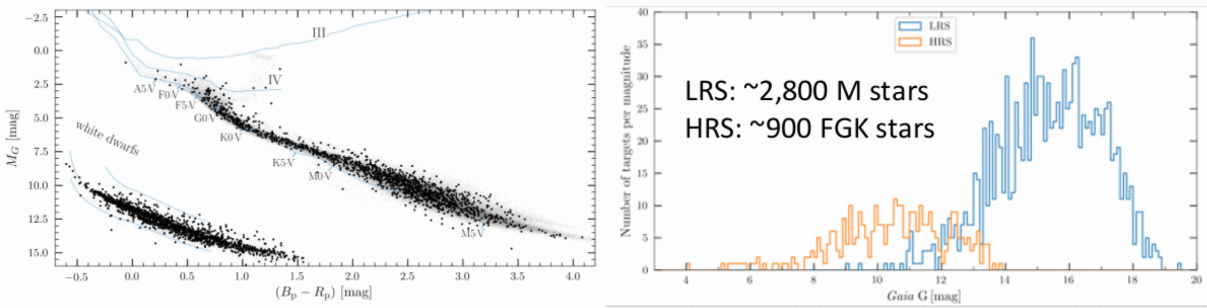


Figure 36: Left) The Gaia G vs. Bp-Rp diagram illustrating the selected targets, i.e. main sequence stars that are common proper motions pairs to white dwarfs. The blue solid lines represent evolutionary sequences. Right) Distribution of the targets according to their Gaia_G magnitudes and the intended observations.

We aim to achieve a SNR of at least 20 per Å for objects as faint as Gaia_G = 20/15 for LRS/HRS. The required SNR gradually increases from 20/15 to 150/250 until Gaia_G = 13/11 for LRS/HRS. We require continuation criteria such that at least 90% of the required SNR is achieved.

The individual FoMs are based on the SSMs, which are defined so that a completeness of 70% is achieved for both the S1103 and S1104 samples. The overall FoM of the survey is the weighted average of the 6 individual subsurveys, where S1103 and S1104 contribute with a weight of 0.05 and 0.05, respectively.

It is worth noting that the white dwarf companions to these main sequence stars will be observed by a subsurvey of S3.

<u>S1105 and S1106 subsurveys</u>

The CSPN subsurveys aim at a classification and spectral analysis of ~650 central stars of planetary nebulae with LRS and ~60 with HRS. We also wish to search for signs of binarity in the spectra.

The targets were selected from the catalogues of Gonzalez-Santamaria et al. 2021 (A&A, 656, A51) and Chornay & Walton 2021 (A&A, 656, A110), and they are homogeneously distributed in the sky. Both works used the HASH Planetary Nebula (PN) database (which lists all known PNe, mainly identified in Hα emission lines surveys or imaging) and the Gaia EDR3 to identify the most likely central star (CS) of each PN. We restricted ourselves to CS which have a high reliability (i.e. probability that a given candidate star is the correct CS). In the case of the targets from Chornay & Walton 2021 we only used targets with a reliability of match > 0.5, in the case of the Gonzalez-Santamaria 2021 catalogue, we only used targets from their groups A and B. Furthermore, we restricted ourselves to targets with 13<= Gaia_G <=18, and objects that lie within the 4MOST survey region. Although there are many shared targets with the S0316 PN survey the science goals and exposure times are different.

We aim to achieve a SNR of at least 50/250 per Å for objects as faint as Gaia_G = 18/13 for LRS/HRS. The required SNR gradually increases from 50/250 to 300/450 until Gaia_G = 11/13 for LRS/HRS. We require continuation criteria such that at least 90% of the required SNR is achieved.

The individual FoMs are based on the SSMs, which are defined so that a completeness of 70% and 80% are achieved for the S1105 and S1106 samples. The overall FoM of the survey is the weighted average of the 6 individual subsurveys, where S1105 and S1106 contribute with a weight of 0.05 and 0.05, respectively.

6.11.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.11.4 Management Structure

The two PIs of S11 (Dr. Odette Toloza and Dr. Alberto Rebassa-Mansergas) are in charge of the internal management of the survey and they are the team manager representatives. They are closely assisted by Dr. Roberto Raddi, Dr. Nicole Reindl and Dr. Anna Pala (who is the Science Policy Board representative of S11 as well as the SPB co-chair). Different WPs include creating and updating the target catalogues of the 6 different sub-surveys, defining the scientific exploitation rules, organising the internal meetings of the survey, appointing members to the different IWGs, and ensuring that all S11 members are well informed about the different developments (e.g. catalogue updates and submissions, IWG activities, etc). Details are given below.

Team Managers: the PIs

- The TMs are in charge of keeping the membership registry (4MS) up to date. The TMs shall ensure that the members of the Survey Team keep their affiliation and contact information up to date in the system.
- The TMs are appointed indefinitely.
- Should one of the TMs not be able to carry out their duties, the other TM will step in until a stable solution can be found. For example, the duties will be shared with the SPB representative.

Lead of Catalogue Creating WP: Dr. Roberto Raddi

- The lead is appointed by the Survey Team meeting upon suggestion by the PIs.
- The WP lead is renewed once per year, and can be renewed an indefinite number of times.
- Should the WP lead not be able to carry out their duties the PI/s will step up and take over until a stable solution can be found.

Lead of Scientific Exploitation WP: the PIs

- Decisions on both project leadership and co-authorship are discussed.
- Should one of the PIs not be able to carry out their duties, the SPB representative will step in until a stable solution can be found.

Lead of Communication with IWGs: the PIs

- The PIs and IWG representatives exchange information via email, which is summarised and shared with the other members of S11 each month during our internal meetings.
- Should one of the PIs not be able to carry out their duties, the SPB representative will step in until a stable solution can be found.

The internal meeting scheme of S11 is the following:

Name of the meeting: WDB internal meeting
Frequency of the meeting: Every second Friday of each month.

The meeting will be called: 1 week before the meeting date, the call will be made on email. A remainder will be sent a day before.
Agenda and supporting material will be available: 1 week before the meeting date.
The meeting is documented by: Minutes taken by one of the PIs, to be approved by circulating to the survey team.
Who participates: All members of the survey team are invited to the meeting.
Additional information: The main aim of this meeting is to exchange information between all WPs in the Survey Team and to share the activities performed at the IWGs. There will also be an agenda item dedicated to our science exploitation with presentations.

6.11.5 Work Breakdown Structure

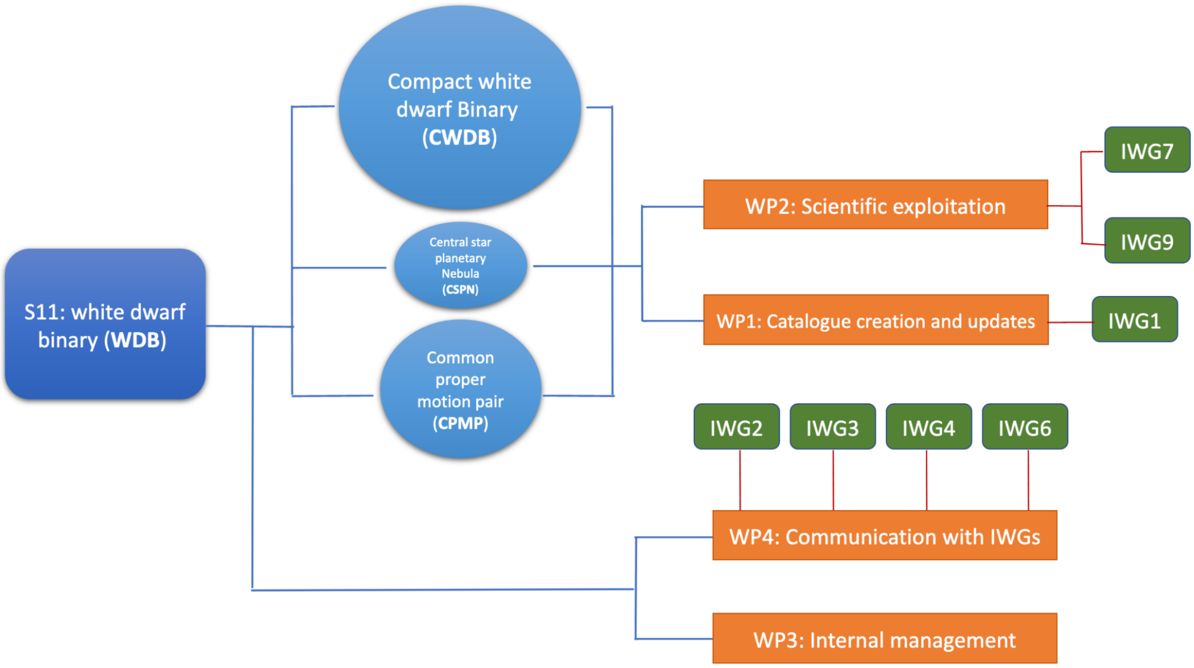


Figure 37: Work-breakdown organisation of the S11 survey.

S11 is divided into the following four different WPs (see also Figure 37):

1) **WP1: Catalogue creation and updates**. This WP deals with creating and, most important, updating the catalogues according to the IWG1 requirements, as well as creating the documentation of our different sub-surveys. Each sub-survey assembles the catalogue independently and all of them are merged when delivered to the 4FS. The target selection differs among the sub-surveys. For the S1101 and S1102 sub-surveys, the main tasks are to use Gaia eDR3, cross-matched with GALEX DR6/7 FUV photometry. Quality cuts are applied to ensure that the selected targets have the fewest number of contaminants possible. The S1103 and S1104 sub-surveys are based solely on the Gaia DR3 parallaxes and proper motions to select a list of reliable common proper motion pairs. For the S1105 and S1106 subsurveys, the targets are based on Chornay & Walton (2021) as well as Gonzalez-Santamaria et al (2021), who developed automated techniques that allowed them to identify the most likely central star. Based on the samples provided by these works, we restricted ourselves to objects that have a high likelihood that the Gaia source is indeed the central star.

2) **WP2: Scientific Exploitation**. Within this WP, we decide the core science papers. In addition, we evaluate who will lead the efforts on the different core science papers and what the authorship rules are. We foresee that each of the three main sub-surveys will have the following core-science publications:
CWDB:
   - Catalogue of CWDB (S1101 and S1102) survey.
   - All cataclysmic variables i.e. white dwarfs accreting from non-degenerate companions which include known and new systems from 4MOST.
   - Evolved cataclysmic variables from 4MOST.
   - (if any) AM CVn stars, i.e. white dwarfs accreting from helium companions, which include known and new systems from 4MOST.
   - Post common envelope binaries with M-stars as white dwarf's companions.
   - Post common envelope binaries with FGK-stars as white dwarf's companions.

   CPMP:
   - The catalogue of CPMPs (subsurveys S1103 and S1104).
   - The age-metallicity relation as revealed by white dwarf plus main sequence CPMPs.
   - The age-velocity dispersion relation as revealed by white dwarf plus main sequence CPMPs.
   - The age-rotation-activity relation of low-mass stars as revealed by white dwarf plus main sequence CPMPs.
   - The white dwarf mass-radius relation as revealed by white dwarf plus main sequence CPMPs.

   CSPN:
   - Catalogue of the 4MOST CSPNe (S1105 and S1106) subsurveys.
   - Atmospheric parameters of the 4MOST CSPNe.
3) **WP3: Management**. This WP deals with the internal management within our survey and encompasses the following tasks: sending regular emails to all members to keep them informed about the different developments, taking minutes during our internal meetings, helping in coordinating the information received from IWGs and other members. In addition, this WP manages the internal repository in the microsoft cloud i.e. presentations, documents, and keeps a copy of each catalogue uploaded to the 4FS, their ETC results, and a report of the scope of the survey.
4) **WP 4: Communication with IWGs**. We have survey representatives in all the IWGs except the extragalactic IWG8, which has a different scope. This WP involves all our survey representatives and deals with the different communication levels, both internally (to keep a good track of our tasks to be performed on each IWG) and externally (to ensure the different IWGs are aware of our specific tasks).

6.11.6 Contribution to the Infrastructure Working Groups

S11 contributes 1.75 FTEs to the IWGs. 1 FTE is survey-work specific, whilst 0.75 benefit also other surveys.

IWG1
Dr. Roberto Raddi is the S11 representative in the IWG1. He is co-lead of the WG and he is also contributing as a member of the WP3, Shared Targets. Dr. Raddi has reported bugs encountered with the first version of the local Exposure Time Calculator.

IWG2

Dr. Alberto Rebassa-Mansergas is the representative of S11 in the IWG2, as well as for the WP Simulations (WIDE group).

IWG3

At this stage, IWG3's activities focus mainly on producing catalogues for science verification observations and planning for the survey science. S11 has two representatives on IWG3, Dr. Odette Toloza and Dr. Elme Breedt. They are the communication links between the IWG and S11. They ensure that S11 stays informed about the latest catalogue requirements and that these are produced for the survey. In the future Elme will also contribute to the bad weather and twilight programmes or help where otherwise required.

IWG4

Dr. Alessandro Ederoclite is the S11 IWG4 representative.

IWG5

There is no active IWG5.

IWG6

Our survey contributes to IWG6 in two ways. Firstly, Dr. Ingrid Pelisoli, who is a member of both S11 and S3, was one of the IWG6 leads. She helps in defining and overseeing the IWG6's activities, which are focussed on guaranteeing that any data released by 4MOST, both internally and externally, are complete, usable and show the expected quality. Secondly, S11 has one representative in IWG6, Dr. Linda Schmidtobreick, who is responsible for analysing the completion and quality of data specific to S11, thus guaranteeing that any survey-specific expectations are met.

IWG7

IWG7 has a working sub-group led by Francesco Damiani from S12 focussed on developing pipelines for characterising (e.g. activity indicators, radial velocities) and measuring the stellar parameters (effective temperatures, surface gravities and metallicities) of M dwarf stars. Dr. Jesús Maldonado and Dr. Alberto Rebassa-Mansergas are part of this sub-group, and will actively participate in these tasks.

Dr. Nicola Gentile-Fusillo is the IWG7 representative of S11 (he is also a member of S3). He has developed the pipeline for classifying white dwarf subclasses and, for some of these, measuring their stellar parameters. Currently, he is implementing the pre-domain that will flag a target likely to be a binary, which will be sent to the internal classification pipeline of binaries.

IWG8

Our survey is not contributing to this IWG because the pipeline developed within this group is targeting extragalactic sources.

IWG9

Dr. Scaringi. Simone from S11 was one of the co-leads of IWG9. Tasks as a lead to IWG9 are described in Document: VIS-MAN-4MOST-47110-9230-0001. These included managing the IWG (e.g. registering work done by other IWG9 members, preparing documents, attending and leading weekly telecoms) and attending and contributing to the ODG meetings. More importantly the leads are ultimately responsible for delivering robust and operational classifiers that will be used to assign class labels to all spectra obtained during 4MOST operations. The class labels provided are then used by other IWG pipelines. Specifically, IWG9 is tasked to deliver basic target classification probabilities for each spectrum within the classes of QSO, AGN, GALAXY (Extragalactic sources) and STAR (all types of Galactic sources). IWG9 is also tasked to deliver probabilities of Galactic source sub-classes.

6.11.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.11.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey #11.3 and 11.4 (i.e. CPMP-LRS and CPMP-HRS) will be processed by the 4GP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
In addition, the data products described in the following subsections will be provided.

6.11.8.1 Deliverable L2 Survey data: reduction processing

S1101 and S1102 sub-surveys: the white dwarf effective temperatures, surface gravities, masses, radii and luminosities and the main sequence companion effective temperatures, masses and radii of a subset of the binary systems (known as unresolved white dwarf-main sequence binaries, some of which will be post-common envelope binaries) will be calculated using our proprietary fitting scripts. The spectra of these binaries usually display the white dwarf features in the blue and the main sequence (typically M or late K) star features in the red. As a consequence, they present a challenge for currently developed 4GP pipelines for single white dwarf and main sequence stars. Our routine will first fit the 4MOST spectra with a combination of white dwarf model spectra and main sequence star templates. From the fit, the spectral type (or effective temperature, hence mass and radius adopting the appropriate models) of the main sequence star will be recorded and the best-fit main sequence star template will be subtracted from the 4MOST spectra. The residual white dwarf spectra will be then fitted with a grid of model atmosphere spectra to derive the white dwarf effective temperatures and surface gravities. These values will be finally interpolated in the appropriate white dwarf cooling sequences of the La Plata group to get the mass, radius, cooling age and luminosity of each white dwarf.
S1103 and S1104 sub-surveys: we will derive total ages for the white dwarfs in common proper motions pairs. Given that the binaries are coeval, the white dwarf ages are the same as the ages of the main sequence companions. In order to determine the total age of a white dwarf, defined as the sum of its cooling age and its main sequence progenitor lifetime, two processes are required. First, a prescription for evolutionary cooling sequences provides a measure of the white dwarf cooling age from observed determinations of effective temperature and surface gravity (which will be derived from the available Gaia Gabs/Bp-Rp photometry/astrometry and/or from fitting the available 4MOST spectra of the white dwarfs observed by S3). To that end we adopt the widely-used sequences of the La Plata group, which encompass the full range of white dwarf masses and the most updated prescriptions in the treatment of physical processes. Second, a relationship between the mass of the white dwarf and the mass of its

progenitor is required to obtain a main sequence lifetime estimate. This initial-to-final mass relation enables the estimation of main sequence star masses from measures of the current day white dwarf masses, which in turn, can be used to determine the time spent on the main sequence from evolutionary sequences, provided the metallicity be known from the spectra of the main sequence companions (this parameter, [Fe/H] will be directly provided by 4GP). Once we know the main sequence lifetimes and the cooling times, the total ages will be determined as the sum of these two ages.

S1105 and S1106 sub-surveys: we will provide spectral types of the central star of the planetary nebula and their stellar parameters (i.e. effective temperatures and surface gravities). It has to be noted that the spectra of central stars are very diverse and a detailed, individual system analysis is unavoidable in most cases. The photospheric spectrum of the central star may be overgrown by nebular lines, show additional emission lines from a strongly irradiated companion, or may be littered by diffuse interstellar bands. Furthermore, the atmosphere of central stars may be H-, He-, or C-dominated - depending on the evolutionary history of the central star. A pipeline approach is therefore not appropriate to measure the atmospheric parameters, although similar techniques will be adopted. Consequently, we decided not to provide the pipeline to L2 since only a few hundred objects will be analysed with this pipeline for the entirety of the 4MOST targets.

The format and target names we will provide will follow the same structure as the 4GP output to ensure consistency and all data will comply with the data standards (ESO-044286).

6.11.8.2 Deliverable L2 Survey data: quality assessment

S1101 and S1102 sub-surveys: the spectra obtained by the Sloan Digital Sky Survey (SDSS) for unresolved white dwarf-main sequence systems offer a valuable means of ascertaining the effective temperature and surface gravity of the white dwarf, as well as determining the spectral type of its white dwarf's companion since these parameters are already derived from the SDSS spectra using the same fitting routine as outlined above. Consequently, the sample collected from the SDSS spectroscopy will be observed by 4MOST during the SVP phase. The primary objective of this endeavour is to gauge the effective temperature and surface gravity of the white dwarf as well as the subtype of the companion by analysing the spectra obtained from 4MOST, with the aim of attaining results that align with the values computed from the SDSS spectra.

S1105 and S1106 sub-surveys: the aim of these subsurveys is to determine the parameters for the central stars of planetary nebulae, CSPNe. To accomplish this, we have chosen a subset of our CSPNe bright (G<15 mag) sample of 11 targets that already possess atmospheric parameters obtained from existing literature that will be observed during the SPV phase. Utilising the model grids calculated from our team, we will derive the atmospheric parameters from the 4MOST spectra and compare them with the values reported in the literature. Furthermore, our investigation will involve searching for photospheric metal lines and indications of companions (such as the CNO emission line.complex around 4650A). The presence of these features can provide additional insights into the characterization of these CSPNe.

Once the fitting routines are adapted to be directly applied to the 4MOST spectra (a process that should take no longer than a couple of weeks once these spectra are available), the timescale for deriving the DL2 products is rather fast. They can be acquired within days after the spectra are obtained.

6.11.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.11.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

The data will be delivered with DR2 and following releases.

6.11.8.5 Deliverable L2 Survey data: Required hardware and staff

S1101 and S1102 sub-surveys: Alberto Rebassa-Mansergas will be in charge of adapting the fitting routine to be applied to the 4MOST spectra of unresolved white dwarf-main sequence binaries.
S1103 and S1104 sub-surveys: Alberto Rebassa-Mansergas will be in charge of deriving the white dwarf ages.
S1105 and S1106 sub-surveys: Nicole Reindl will be in charge of adapting the fitting routine to the 4MOST spectra of CSPNe.

6.11.8.6 Additional L2 data: reduction processing

No extra AL2 processing is planned by this Survey.

6.11.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.11.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey.

6.11.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 processing is planned by this Survey.

6.11.8.10 Additional L2 data: Required hardware and staff

No extra AL2 processing is planned by this Survey.

6.11.9 Team

Table 24: Survey S11 team members with their affiliation, role in S11, and total expected FTE contributions next to science exploitation.

Name	Affiliation	Function	FTE
Odette Toloza	USM	co-PI WP2, WP3, WP4 co-lead WP1 active member IWG3 representative	0.3
Alberto Rebassa-Mansergas	UPC	co-PI WP2, WP3, WP4 co-lead, WP1 active member, IWG7 member of M dwarf sub-group IWG2 representative	0.3
Simone Scaringi	Durham	IWG9 representative	0.1
Linda Schmidtobreick	ESO	IWG6 representative	0.1
Roberto Raddi	UPC	IWG1 representative, potential IWG1 co-lead WP1 lead	0.2
Ingrid Pelisoli	Warwick	IWG6 representative	0.1
Anna Francesca Pala	ESO	SPB representative and SPB co-chair	0.1
Elme Breedt	IoA	IWG3 representative	0.1
Nicola Gentile Fusillo	U. Trieste	IWG7 active member	0.2
Jesús Corral Santana	ESO	Instrument Scientist	0.25
Alessandro Ederoclite	CEFCA	IWG4 representative	0.1
Nicole Reindl	LSW Heidelgerb	WP1 and WP2 active member, external	0.05
Domitilla de Martino	OAC	IWG9 active member	0.05

6.12 Survey 12 – The 4MOST Survey of Young Stars (4SYS)

Survey PIs: Giuseppe Germano Sacco

6.12.1 Science Summary

Most young stars (<100 Myr) in the Galactic disc no longer reside in their dense, clustered birthplaces; they are found all around us. The 4MOST Survey of Young Stars (4SYS) will identify a representative sample of $\sim 10^5$ young stars within 500 pc of the Sun, a scale that increases the number of identified young field stars and the volume explored by two orders of magnitude. 4SYS will measure stellar chemistry, 3D kinematics and ages, and use these to: trace the spatial and dynamical evolution of star forming structures as they disperse; quantify the local disk star forming rate and chemical inhomogeneity at a range of spatial scales; vastly expand the numbers of identified young stars for exoplanetary studies; and provide huge coeval samples to improve young stellar evolutionary models. This is of fundamental importance in understanding the physical processes that drive star formation, the origins of the Galactic field population and the early evolution of stars, their discs and planetary systems.
The Science case is covered in three SubSurveys:

- S1201 - TS1_LR
- S1202 - TS1_HR
- S1203 - TS2_HR

Expanded science description: messenger-no190-7-9.pdf

6.12.2 Target Catalogue

4SYS aims to select a large sample of young stars, with excellent astrometry and photometry, that has a well understood selection function and which is as complete as possible, but with low contamination by older objects. We select targets within 500 pc, because this volume contains a full section of the thin disc, including stars inside and outside the local arm, and it reaches the scale of recently discovered grand star forming structures. This volume is also ideally suited for synergistic studies with TESS and eROSITA which will obtain good data for young stars over a similar volume. We include stars with ages from 1-100 Myr, covering the main epochs over which star forming clusters dynamically evolve and disperse, planetary systems form, discs disperse, and Pre-Main Sequence (PMS) stars with $0.5 < M/M_\odot < 1.0$ reach the ZAMS. To obtain the necessary resolution in time and space, the volume needs to be sampled by many stars. Thus, we choose low mass targets with spectral type G7-M6 that are at or near the peak of the initial mass function.
Targets for all three SubSurveys are selected from an initial parent sample created from the Gaia Archive selecting all the stars with parallax > 2 mas (d < 500 pc), -70 < DEC <5 deg and G < 17.3 mag and removing objects with low quality photometry according according to the criterium described in Sect. 9.4 of Riello et al. (2021, A&A, 649, A3). The Color-absolute Magnitude Diagram (CMD) of the parent sample used for the selection of targets of all three SubSurveys is shown in Figure 38. Magnitudes have been de-reddened using dustmaps python modules with the Leike et al. (2020, A&A, 639, 238) 3D extinction maps to calculate E(B-V) and extinction correction provided in the *Gaia* archive website.
Later type stars younger than 40 Myr are well separated from the main sequence, in particular they are high enough above the ZAMS to avoid heavy contamination by unresolved binaries. Older/hotter stars are closer to the ZAMS and we cannot rely on CMDs alone to select these targets. Therefore, we defined two main samples:

Target Sample 1 (TS1). Comprises stars that lie above the 40 Myr isochrone in the CMD (blue continuous line in Figure 38), with $M_G > 4$ mag (to exclude turn-off stars and subgiants) and between the two blue dashed lines that delimit spectral types K7-M6. It includes a total of about 91000 stars in the magnitude range 10 < G < 17.3 mag.

All stars in this sample have been included in the target catalogue but divided in two Subsurveys:

- S1201 - TS1_LR (~73000 stars with 15.2<G < 17.3 mag observed at LR)
- S1202 - TS1_LR (~18000 stars with 10<G < 15.2 mag observed at HR)

Target Sample 2 (TS2). Comprises of stars in the magnitude range 10 < G < 15.2 mag, that lie above the 120 Myr isochrone (blue continuous line in Figure 38), with M_G >4 (to exclude turn-off stars and subgiants) and within colour ranges shown by the green dashed lines in Figure 38 (spectral types G7-K7). Since young stars are fast rotators and strong X-ray emitters, we are using rotational periods derived from the TESS archive and X-ray fluxes from the e-ROSITA to complement the CMD-based selection, which otherwise will be affected by severe contamination. We select those stars that have either a rotation period smaller than the upper envelope of the rotation-color relation defined by members of the 120 Myr Pleiades cluster and/or a ratio between X-ray flux and flux in the G band above a threshold that has been defined using a sample of young clusters. All the stars in this sample are part of the SubSurvey:

- S1203 - TS2_HR (~52000 stars with 10<G < 15.5 mag observed at HR)

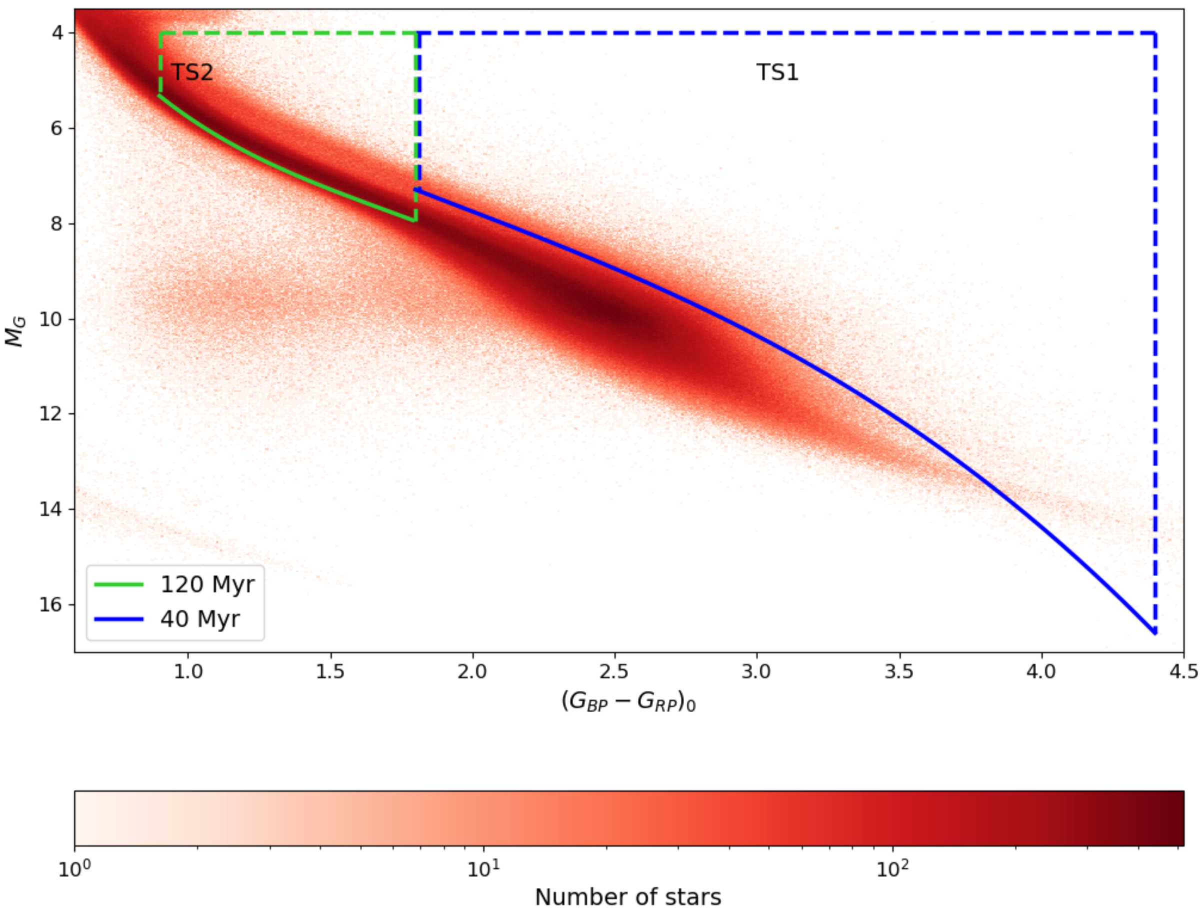


Figure 38: Color-absolute magnitude diagram of the initial sample used for the selection of targets of all the subsurveys. The area enclosed within the blue lines (note that the blue dashed line on the left is shifted of

0.01 mag for graphical purposes) includes stars in the target sample 1 (TS1), which are divided in the two SubSurvey S1201 (TS1_LR) and S1202 (TS1_HR) depending on the resolution used for the observations. The stars within the area enclosed within the green lines (Target Sample 2 - TS2) are used as input sample for the creation of the catalogue of the SubSurvey S1203 (TS2_HR).

Figure of Merit

The scientific Figure of Merit (FoM) is defined to reach a minimum level of completeness across the whole area of the sky covered by the survey and in three key regions (Upper Scorpius, Vela an Orion). Specifically, the FOM is the minumum of four Scope of Survey calculated for each of these four areas using a flat Large Scale Merit and a Small Scale Merit that goes as the square root of the completeness. Our choices led to a completeness level of 70% of the targets in each areas when the FoM = 0.5

Spectral Success Criteria

- SubSurvey S1201 (TS1_LR): Spectral success criteria have been set to fulfil the requirements of the low resolution survey, which are the determination of radial velocities, main stellar parameters (Teff and Log g) and the identification of the Li line at 607.8 nm, that is used with the surface gravity to distinguish young stars from contaminants. The required SNR then depends on spectral type, since there is a bigger dynamic range of gravity and lithium line strength between cooler stars at young ages and their main sequence counterparts than there is for warmer stars. In particular,
  - For stars with G > 16.2 mag, the required SNR per Å between 6600 and 6800 Å ranges between 25 and 45 (depending on color)
  - For stars brighter than G < 16.2, the SNR per Å between 6600 and 6800 Å range shall be between 50 and 60 to allow us a better determination of stellar ages based on Li abundances, activity and other indicators.
- SubSurvey S1202 (TS1_HR): The requirement for this SubSurvey is to derive the same parameters as for the brightest stars in S1201 with a higher precision thanks to the better spectral resolution. The minimum SNR per Å between 6650 and 6750 Å is between 80 and 120 depending on the stellar magnitude;
- Subsurvey S1203 (TS2_HR): The requirement for this SubSurvey is to derive chemical abundance of iron peak, alpha elements, CNO and neutron capture elements. The minimum SNR per Å between 5400 and 5600 Å ranges between 80 and 160 depending on the stellar magnitude. Spectra with the highest SNR will be used to derive the most complex elements, which require very high-quality spectra.

6.12.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.12.4 Management Structure

The survey is led by the PI (G.Sacco) in collaboration with a core team that is composed of the WP leads (see next section) and other survey members that can be nominated by the PI. This group is responsible for coordinating all the activities in preparation of the observations, representing the survey in the SCB and SPB, nominating the coordinators of the various WPs and the survey representatives in the IWGs. This leading group is in charge of communicating to the rest of the team the evolution of the project and coordinating the scientific exploitation of the data.

In addition to the policies defined in the Science team policies document [AD3], the survey S12 will follow these additional rules concerning the team membership, the definition of the scientific projects and the paper authorship.

Team membership:

- Applications to be a member of S12 from ST, the 4MOST consortium institutes and ESO are evaluated by the PI.
- Applications to be a member of S12 that need to be examined by the SPB (defined as invited members in the Science Team policies), are evaluated by the PI and the core team.

Scientific projects: The PI supported by the core team should coordinate the scientific exploitation of the data. In particular, they should ensure that all the scientific goals described in the survey are fulfilled, that results are timely published and that everyone contributing to the success of the survey is properly rewarded.

Scientific projects submitted to the SPB are divided in two categories:

- *Key projects*: They will be proposed by the PI and the core team and discussed during general telecons. The PI will try to reach a consensus among the survey members on the project goal and the leading author (potentially any survey member). In case of disagreement a decision will be taken by the PI in consultation with the core team.
- *Other projects*: They are proposed by all survey members and do not need (but they can) be discussed in general telecons. The leading author should communicate their intention to submit the project to the PIs and the survey representative in the SPB, at least, three weeks before the submission. The PI and SPB representative should timely inform all the other survey members of the incoming project, so they can express their intention to join the project.

Paper authorship. The PI, the member of the core team and other survey members that gave an important contribution to the activities for preparing the observations and running the survey or to the whole 4MOST project will be included in a list of *builders* that will be updated every year and prepared by the PI and the core team. *Builders* have the right to be co-authors of any paper produced by the survey. However, to exercise this right they have to explicitly ask for co-authorship and confirm that they have read the paper and agree to its publication before submission.

Communication Strategy The PI is in charge of communicating the survey members the evolution of the project. This is primarily done by the following online meeting:

- **Name of the meeting:** 4SYS General telecon
  Frequency of the meeting: Roughly every month
  Date of the meeting: It is communicated during the previous meeting and included in the minutes. With some exceptions these telecons are held on Friday at 15:30 CEST. Dates of these meetings are reported in the survey google calendar that is distributed to the survey members.
  Agenda: It is circulated a couple of days before the meeting.
  Minutes: A draft of the minutes is circulated within a week and stored in Docushare together with presentations held during the telecon. Final minutes are normally uploaded after the following meeting.
  Who participates: All the co-Is of the survey.
  Aim: The main aim of this meeting is to update all the co-Is on the evolution of the project and discuss main strategic choices and key scientific projects.
- **Name of the meeting:** Core team telecon

Frequency of the meeting: Roughly every month
Date of the meeting: It is agreed by the core team members.
Agenda: It is circulated a couple of days before the meeting.
Minutes: Informal minutes of the meeting are prepared by the PIs and circulated among the team members.
Who participates: All core team members.
Aim: The main aim of this meeting is to discuss the recent evolution of the project and plan future steps.

- **Name of the meeting:** WPs and sub-WP telecons
  Frequency of the meeting: Irregular
  Date of the meeting: It is agreed among the participants.
  Agenda: It is circulated a couple of days before the meeting.
  Who participates: Members of the WP or subWP the, in some cases the PI.
  Aim: The main aim is to discuss the evolution of the activities of the WP.

6.12.5 Work Breakdown Structure

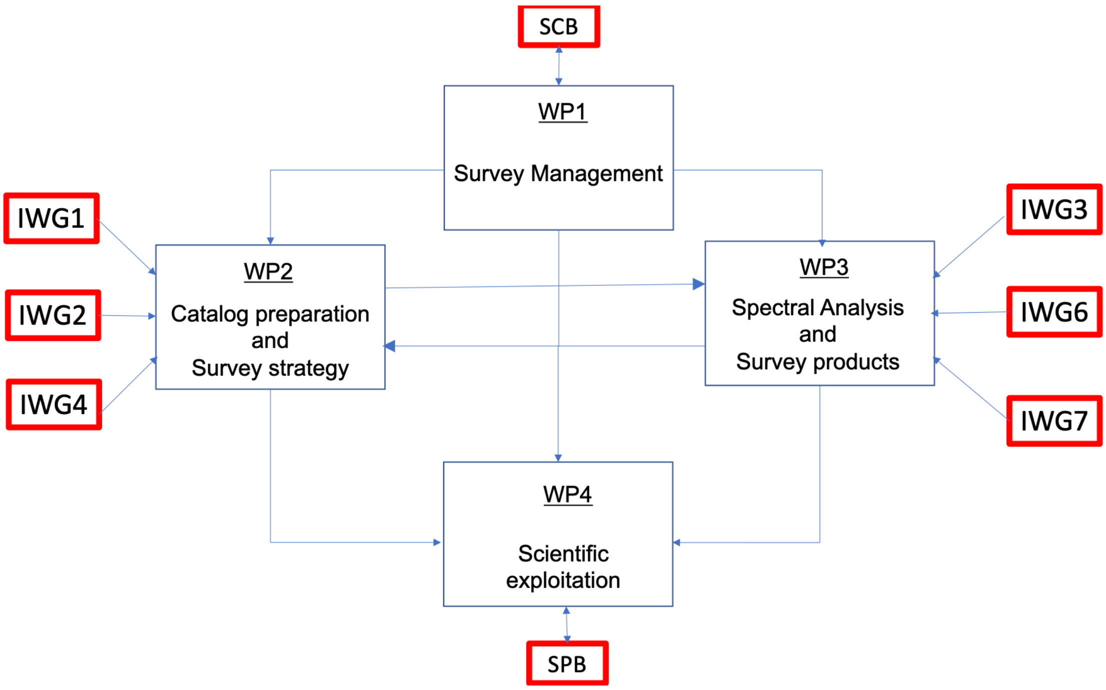


Figure 39: WBS of the survey S12 with the main WPs. We report in the red boxes the boards and the IWGs within the 4MOST context that will interact with the different WPs.

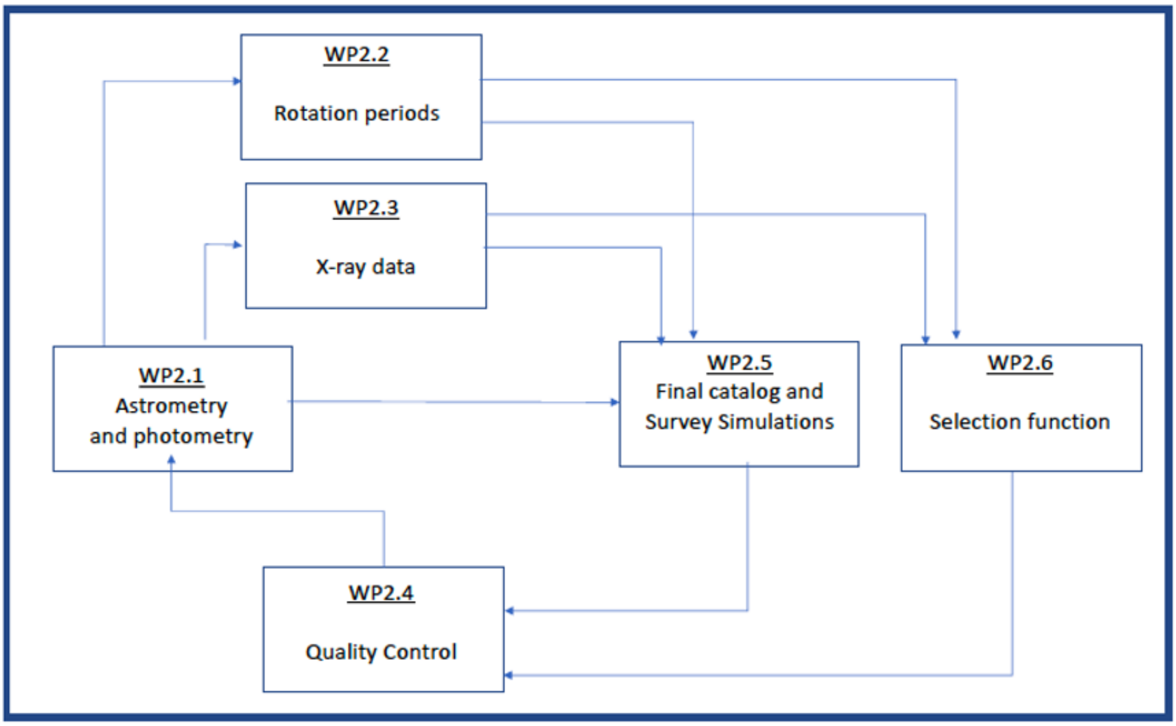


Figure 40: WBS for the WP2.

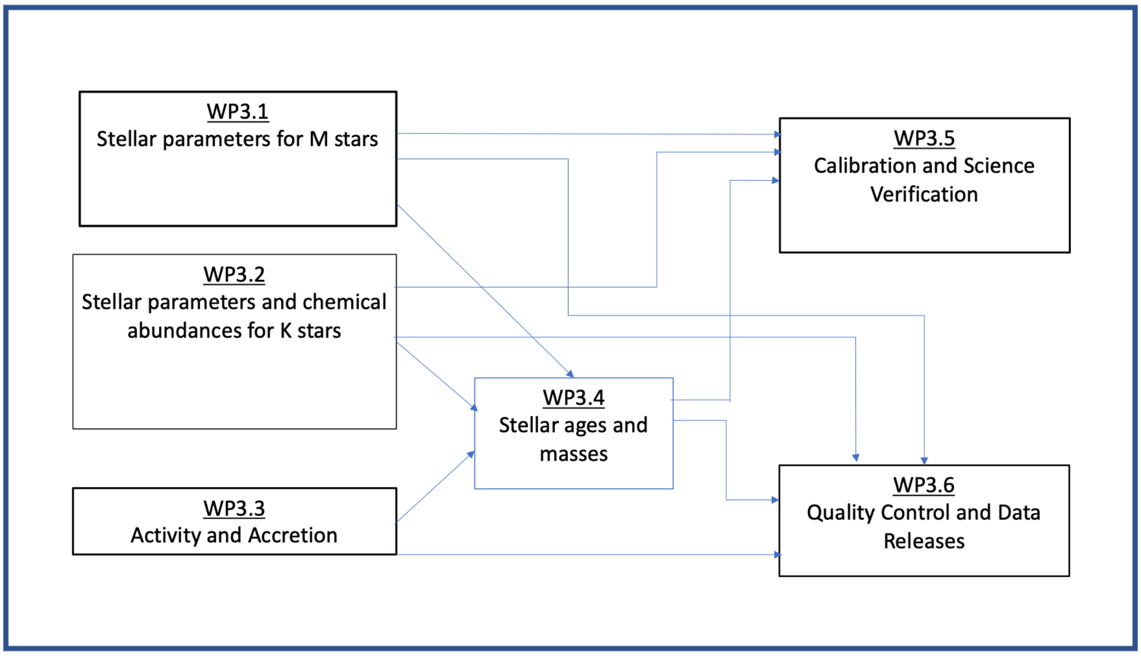


Figure 41: WBS for the WP3.

WP1-Management

This WP coordinates all the activities carried out by others WPs, defines the policies of the surveys and makes sure that all the co-Is are kept updated on the evolution of the project.

WP Lead: G. Sacco
WP Members: R. Jeffries, L. Magrini
Tasks:

1. Defining the whole survey organisation and coordinating the activities of the other WPs
2. Representing the survey in the SCB and the SPB
3. Writing the SMP and the Survey Policies;
4. Managing the Survey pages in the wiki and Docushare.
5. Organising telecons and ensuring a smooth flux of information between the consortium and 4SYS co-Is and within the survey.
6. Writing main release papers

WP2-Catalog Preparation and survey strategy

The overall goal of this WP is to carry out all the tasks from the creation of input catalogue to the definition of the selection function of the survey. The WP is divided into 6 sub-WPs represented in Figure 40. Below, we report the main tasks and the subWPs

WP leads: **R. Jeffries and A. Binks, N. Wright**
WP members: G. Beccari, L. Prisinzano, G. Sacco, C. Schneider
Tasks

1. Prepare the input catalogue and Figures of Merit
2. Prepare the description of the input catalogue
3. Represent the survey in IWG1, IWG2 and IWG4
4. Define the survey selection function;

Sub-WPs

- **WP2.1 Astrometry and photometry** (**G. Sacco**, A. Binks and R. Jeffries)
  Tasks: Define the input catalogue for the TS1 and pre-select candidates for TS2, using color-magnitude diagrams;
- **WP2.2 Rotation periods** (**A. Binks**)
  Tasks: Using TESS data to calculate rotation periods of the stars pre-selected by the WP2.1 for the TS2 and identify fast rotators;
- **WP2.3 X-ray data** (**C. Schneider**)
  Tasks: Identify X-ray bright stars in the catalogue pre-selected by the WP2.1 for the TS2;
- **WP2.4 Quality Control** (**G. Beccari**, L. Prisinzano, N. Wright)
  Tasks: Check the target selection carried out by the first sub-WP by cross-matching the catalogue of selected targets with catalogues of known young stars;
- **WP2.5 Final Catalogue and Survey simulations** (**N. Wright**, L. Prisinzano)
  Tasks: Prepare and submit the input catalogue, the Figures of Merits and the documentation, represents the survey in the IWG1, IWG2, analyse the results of the simulations;
- **WP2.6 Selection function** (**R. Jeffries**, G. Sacco)
  Tasks: Derive the survey selection function, represent the survey in IWG4;

WP3-Spectral analysis and Survey products

To fulfil its scientific goals 4SYS need to derive a series of astrophysical parameters. Some of the parameters are derived by the pipeline developed from the consortium, (the 4GP), but given the properties of young stars, we may need to develop new specific modules or tasks for the pipeline and new independent pipelines.

This WP carries out all the tasks from the development of new software for deriving astrophysical parameters to the quality control of the final products. The WP is divided into 6 sub-WPs represented in Figure 41. Below, we report the list of the persons involved and the main tasks of the subWPs.

WP leads: F. Damiani and L. Magrini

WP members: S. Antoniucci, R. Bonito, K. Biazzo, V. D'Orazi, E. Franciosini, R. Jeffries, B. Nisini, G. Weaver, N. Wright, M. Van der Swaelmen, E. Zari

MainTasks

1. Develop and test all the required software for L2 products required by 4SYS
2. Define the catalogue of targets for calibration and science verification;
3. Perform the quality control of the products;
4. Represent the survey in IWG3, IWG6, IWG7.

Sub-WPs

- **WP3.1 Stellar parameters for M stars (F. Damiani)**
  Tasks: Develop and tests a new module for the 4GP to derive stellar parameters for cool stars;
- **WP3.2 Stellar parameters and chemical abundances for K stars (L. Magrini,** V. D'Orazi, E. Franciosini, K. Biazzo)
  Tasks: Test the performance of the 4GP with young stars and eventually develop a task (or a module) for the 4GP to derive abundances for active stars;
- **WP3.3 Activity and accretion (G. Weaver,** R. Jeffries, R. Bonito, Biazzo, B. Nisini, S. Antoniucci)
  Tasks: Develop a task that will be included in the 4GP to derive spectral indices to quantify stellar activity and measure equivalent widths of the emission lines. This WP will be also in charge to estimate accretion rates from the emission lines.
- **WP3.4 Stellar Ages and Masses (R. Jeffries**, G.Weaver, E. Franciosini, L. Prisinzano)
  Tasks Develop a tool to distinguish young stars from contaminants and estimate their ages and masses;
- **WP3.5 Calibration and Science Verification (E. Zari**, F. Damiani , L. Magrini, N. Wright)
  Tasks: Define the sample for calibration and science verification, represent the survey in the IWG3 and contribute to the overall 4MOST science verification;
- **WP3.6 Quality control and data releases (K. Biazzo, S. Antoniucci)**
  Tasks: Perform the quality control of the 4SYS L2 products, define metadata for 4SYS L2 products, select products for data releases;

WP4-Scientific exploitation

This WP will lead the scientific exploitation of the data and the dissemination of the results.

WP lead: G. Sacco

WP members: All survey co-Is

MainTasks

1. Define scientific projects of the survey
2. Analyse and interpret L2 products
3. Write scientific articles;

6.12.6 Contribution to the Infrastructure Working Groups

IWG1

Two co-Is of the survey (L. Prisinzano and G. Sacco) are current members of this IWG. L. Prisinzano is the survey representative and a core member of the IWG. In particular she is a member of the WP1 (target catalogue repository) and the WP5 (catalogue verification checks). Total FTE/yr = 0.1

IWG2

Two co-Is of the survey (N. Wright and G. Sacco) are current members of this IWG. N. Wright is the survey representative and is participating in the WP for optimising the simulations in the different areas of the sky. G. Sacco is in charge of submitting the catalogue into the 4FS. Total FTE/yr = 0.2

IWG3

Three co-Is of the survey (E. Zari, F. Damiani and L. Magrini, N. Wright) are currently members of this IWG. E. Zari is the survey representative and, together with N. Wright, will focus on the cross-calibration with other surveys (SDSS V, WEAVE etc…). The whole team is working on the target sample for calibration and science verification. Total FTE/yr = 0.2

IWG4

Two co-Is of the survey (R. Jeffries and G. Sacco) are currently members of this IWG. They will work on the definition of the selection function of the survey. Total FTE/yr =0.1

IWG5

This IWG is currently not active.

IWG6

Two co-Is of the survey (K. Biazzo and S. Antoniucci) are members of this IWG. K. Biazzo is the survey representative. Total FTE/yr =0.1

IWG7

This is the IWG, with the largest contribution from 4SYS. 8 co-Is of 4SYS (L. Magrini, F. Damiani, G. Sacco, G. Weaver, M. Van der Swaelmen, K. Biazzo, B. Nisini, S. Antoniucci) are members of this IWG and others will likely join in the near future. The 4SYS co-Is will lead several projects for the development of new software that will be included in the 4GP. Specifically,

- F. Damiani is leading the task force for the development of a module for the analysis of spectra of M stars. The surveys S9, S11, S12, S13 and probably other surveys will include M stars in their input catalogues and are participating in the development of this module.
- G. Weaver and R. Jeffries are developing a task to calculate stellar activity indices for stars. This module is very relevant for a sub survey of S3 that focuses on activity and for S13 that will target some young clusters. However, it may be relevant for all the Galactic surveys.
- M. Van der Swaelmen is collaborating on the preparation of the set of templates for training and testing the 4GP pipeline. In particular, he is in charge of the preparation of templates for rotating stars.

Total FTE/yr =0.5

IWG8
This IWG is not relevant for 4SYS, because we do not have extragalactic targets.

IWG9
One co-I (F. Damiani) is representing the survey in this IWG. Total FTE/yr =0.1

6.12.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.12.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey S12 will be processed by the 4GP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
Further to the standard data products from the common 4MOST pipelines, S12 will have extra Deliverable L2 Survey products (DL2-SURV) that will go to both the ESO Science Archive Facility (SAF) and the 4MOST Public Archive (4PA).
In addition, the data products described in the following subsections will be provided.

6.12.8.1 Deliverable L2 Survey data: reduction processing

Survey S12 will deliver the following DL2_SURV products:
Accretion: Very young stars are characterised by the presence of circumstellar disc accreting material onto the stars. S12 will measure a series of parameters to identify stars that accreting and quantify the accretion rates.

- Flag indicating that a star is accreting;
- Equivalent widths and fluxes of emission lines that are tracers of accretion (Hα, Hβ, Ca II triplet, only when observed) with errors
- Width of Hα at zero intensity with error;
- Mass accretion rates with errors;

All the parameters will be derived with automatic pipelines developed and tested on other spectroscopic surveys. Specifically, this software will follow these basic steps:

1. Identification of stars with strong emission lines that can be identified as accretors (<5-10% of the sample);
2. Measurements of the line equivalent widths and the width of Hα at zero intensity;
3. Measurements of line fluxes and luminosity using flux calibrated spectra (when available) and other ancillary data (photometry, parallaxes)
4. Measurements of accretion luminosities and mass accretion rates using ancillary data (stellar masses)

Youth flag and stellar properties: S12 will provide an initial classification of stars to distinguish bona-fide young stars from contaminants and derive main physical parameters of stars classified as young (mass, age and radius). Specifically, we will follow the following approach:

1. Using Li line at 607.8 nm and surface gravity measured by the 4GP all bona-fide young stars will be identified;
2. We will derive stellar ages and masses using a combination of parameters (equivalent width of Li line at 607,8 nm, surface gravity, activity index, photometry, parallaxes). In

particular, we will train a neural network to derive ages from these large set of parameters using star clusters and associations with robust ages and then use the model for the 4SYS targets. This approach will allow us to reach a precision of ~10% on a large range.

3. Theoretical evolutionary models developed for Pre-Main Sequence stars will be used to estimates stellar radii

The same target names, formats and data standard of the 4GP output parameters will be used by our pipelines and will be all compliant with data standard (ESO-044286).

6.12.8.2 Deliverable L2 Survey data: quality assessment

Quality control and validation will be performed in three steps.

- A first check will be performed by an automatic pipeline that will analyse the distributions of the data products and their errors. Anomalous values will be identified automatically and, then a quality control scientist will check plot of the distributions;
- A second step of the quality control will be carried out by re-analysing a random subsample using a non-automatic approach and comparing measured products with what available in the literature;
- Finally, the products will be validated by the Survey PI before being uploaded on the 4PA.

Quality control and validation will be carried out in about one month.

6.12.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.

Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.12.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

All S12 DL2-SURV products are second level parameters that can be estimated after the main parameters derived by the 4GP are delivered. In particular, the parameters that characterise the accretion can be estimated only after a star is definitively classified as young and parameters like mass and age are not derived directly from spectra, but from the DL2-IWG products (e.g. log g, li abundance). Therefore, all DL2-SURV of S12 will be delivered starting from the DR2.

Table 25: S12 schedule and milestones as related to the 4MOST Project schedule

Survey Milestone	S12 Milestone

End of SPV	Software for data analysis ready
After two years observations+3 months	Two years data fully analysed
DR2	DL2-SURV parameters released

6.12.8.5 Deliverable L2 Survey data: Required hardware and staff

S12 DL2-SURV parameters will be delivered by two different independent teams:
Accretion: Accretion parameters will be delivered by a team currently composed of four Astronomers (K. Biazzo, S. Bonito, S. Antoniucci and B. Nisini) based in Italy at the INAF - Osservatorio Astronomico di Roma and at INAF-Osservatorio Astronomico di Palermo. Part of the team has already worked in the context of the Gaia-ESO survey and have a long experience in the analysis of large samples of spectra of young stars and all the required hardware for processing the dataset.

Youth flag and stellar properties: Youth flags and stellar parameters will be derived by a group based at the University of Keele and currently composed of R. Jeffries and G. Weaver. The Keele group has a long experience in the spectral analysis of young stars and, in particular, in age studies and have all the required hardware to process the data.

The Survey PI will be in charge of uploading the data in the 4PA in the correct format. He was the PHASE 3 manager for the last public data release of the Gaia-ESO survey.

6.12.8.6 Additional L2 data: reduction processing

No extra AL2 processing is planned by this Survey.

6.12.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.12.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey.

6.12.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 processing is planned by this Survey.

6.12.8.10 Additional L2 data: Required hardware and staff

No extra AL2 processing is planned by this Survey.

6.12.9 Team

Table 26: Survey S12 team members with their affiliation, role in S12, and total expected FTE contributions next to science exploitation.

Name	Affiliation	Function	FTE/yr
Giuseppe Germano Sacco	OAA	PI, WP1,2	0.4
Simone Antoniucci	OA-Roma	WP3	0.1
Giacomo Beccari	ESO	WP2	0.1
Henri Boffin	ESO	4MOST Communication & Outreach lead	0.3
Katia Biazzo	OA-Roma	WP3 (IWG6 rep.)	0.1
Alexander Binks	MIT	WP2 core team	0.25
Sara Bonito	OAPa	WP3	0.1
Valentina D'Orazi	OAPd	WP3	0.1
Francesco Damiani	OAPa	WP3, core team (IWG9 rep.)	0.3
Elena Franciosini	OAA	WP3	0.15
Robin Jeffries	Keele	WP1,2 core team, (IWG4 rep.)	0.2
Laura Magrini	OAA	WP1,3 core team (IWG7 rep.)	0.3
Brunella Nisini	OA-Roma	WP3	0.1
Loredana Prisinzano	OAPa	WP2 (IWG1 rep.)	0.1
Christian Schneider	UHH	WP2	0.1
George Weaver	Keele	WP3 (PhD)	0.3
Nicholas Wright	Keele	WP2, core team (IWG2 rep.)	0.25
Mathieu Van der Swaelmen	OAA	WP3	0.2
Eleonora Zari	MPIA	WP3 (IWG3 rep.)	0.15

6.13 Survey 13 – Stellar Clusters in 4MOST

Survey PIs: Sara Lucatello, Angela Bragaglia, Antonella Vallenari

6.13.1 Science Summary

We are a high legacy value Participating Survey targeting resolved Stellar Clusters in the Milky Way and Magellanic Clouds. The sample includes 148 Globulars in the Milky Way (MW) and three in the Magellanic Clouds and essentially all MW Open Clusters and Star Forming Regions visible in the 4MOST footprint, filling the metallicity/age distribution from the [Fe/H] = −2.5 dex of GCs to super-solar OCs, from a few Myr to 13.5 Gyr. The clusters will be studied both with LR and HR. We will coordinate with the planned Consortium surveys whenever they also target stars in clusters, both intentionally, as with calibration clusters, or as an effect of the selection functions, as will happen for instance in the MCs. We will ultimately be able to: understand how clusters form, evolve, dissolve, and populate the MW; calibrate complex physics that affect stellar evolution, on which our ability to measure ages ultimately stands; measure the contribution of star clusters to the formation and evolution of the individual Galactic components with unequalled precision, accuracy and statistics. The survey, targeting ~120K stars in LRS and ~90K in HRS, complements the planned Galactic and MC Consortium Surveys (CSs), allowing to derive a thorough and homogeneous chemo-dynamical picture of unprecedented accuracy and size, thereby setting precious constraints on models of Galaxy formation.

This science case is covered in eleven SubSurveys:

- S1301 – GC_HR_HC (high completeness)
- S1302 – GC_HR_LC (low completeness)
- S1303 – GC_HR_MC (medium completeness)
- S1304 – GC_LR_HC (high completeness)
- S1305 – GC_LR_LC (low completeness)
- S1306 – GC_LR_MC (medium completeness)
- S1307 – GC_LR_VHC (very high completeness)
- S1308 – OC_HR
- S1309 – OC_LR
- S1310 – VYC_HR
- S1311 – VYC_LR

Expanded science description: messenger-no190-13-16.pdf

6.13.2 Target Catalogue

S1301 – GC_HR_HC

S1302 – GC_HR_LC

S1303 – GC_HR_MC

S1304 – GC_LR_HC

S1305 – GC_LR_LC

S1306 – GC_LR_MC

S1307 – GC_LR_VHC

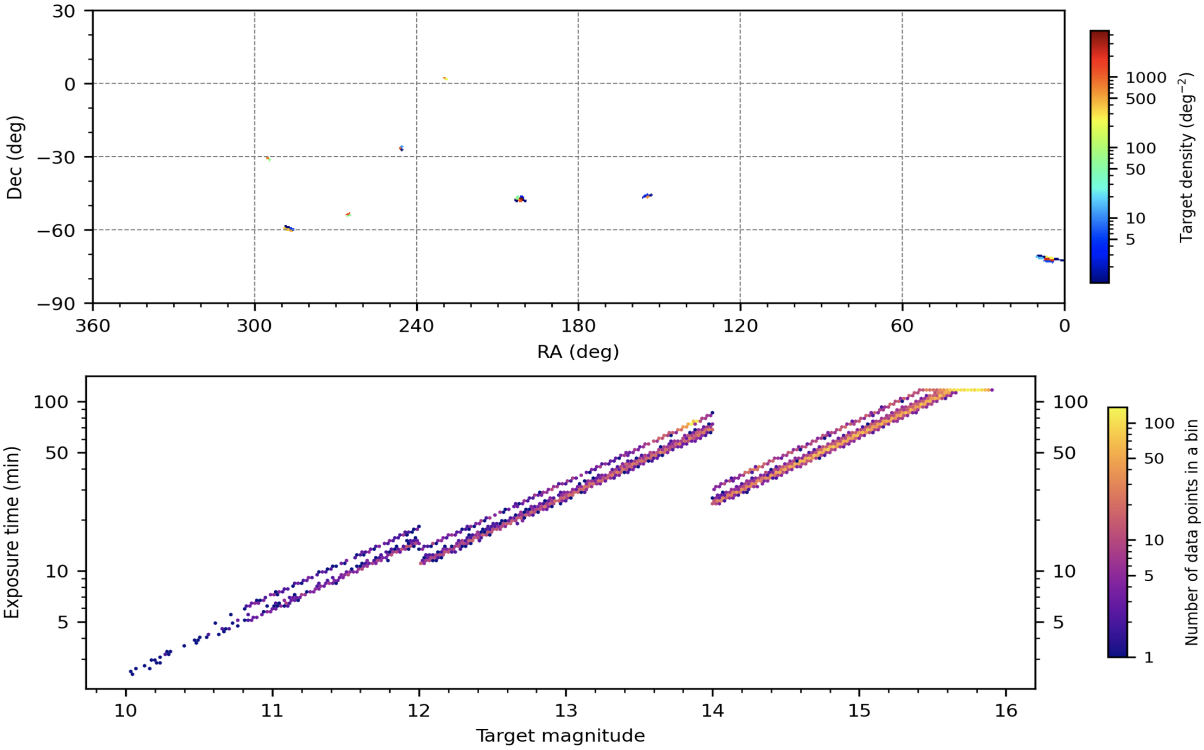


Figure 52: Top) Input target distribution of the subsurvey S1302 GC_HR_LC. Bottom) The exposure time estimates as function of target G-mag.

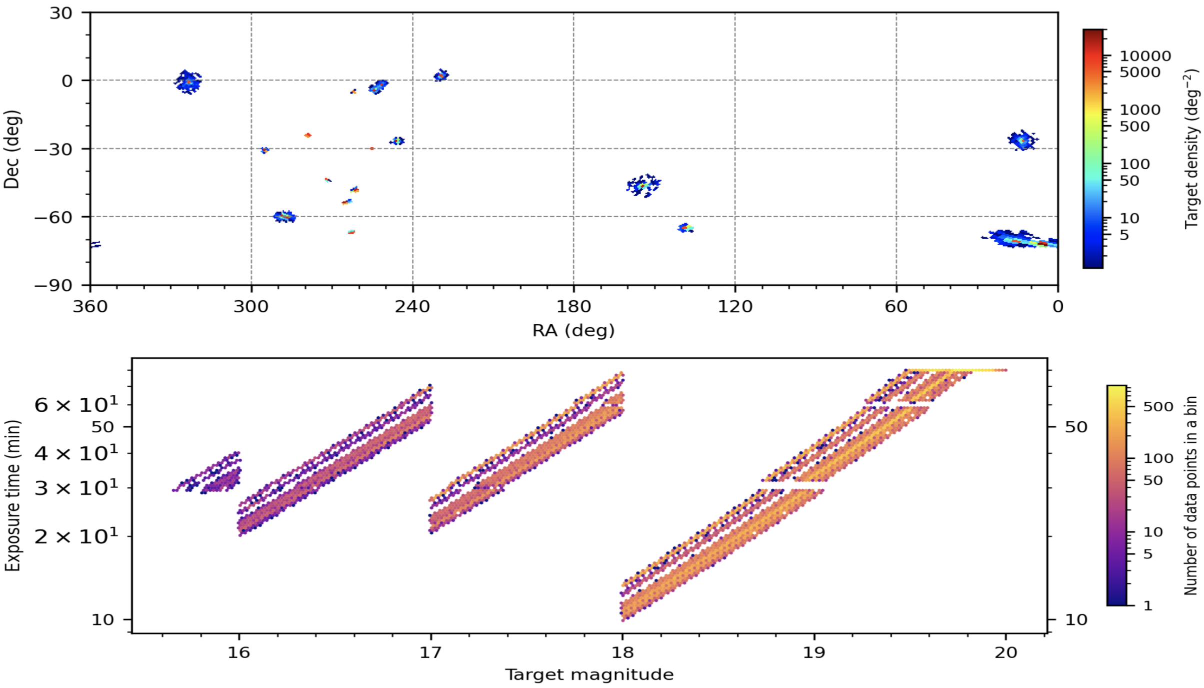


Figure 53: Top) Input target distribution of the subsurvey S1305 GC_LR_LC. Bottom) The exposure time estimates as function of target G-mag.

Targets for the survey have been selected based on Gaia DR3. Globular cluster targets have been split into seven subsurveys, three in HR and two in LR. This approach has been taken to allow varying degrees of required completeness, with larger clusters (with more targets) being assigned to lower completeness subsurveys.

Examples of input targets for two of the seven GC subsurveys are provided in Figs 52 and 53. In total they amount to 24k HR and 456k LR targets in 151 clusters in the Milky Way and the Magellanic Clouds. The GC targets are split into groups for which various levels of completeness are required, as to ensure that a statistically significant sample is collected for small/distant clusters while avoiding to use a large amount of time on close/large clusters. Subsurveys are: LC for low completeness = 10%, MC for medium completeness = 20%, HC for high completeness = 30%, and VHC for very high completeness = 40%. The required area to be observed is small and in the range 60-600 deg^2 for each subsurvey (see Table 27). The target S/N is set as a function of magnitude, with a minimum value of 120 in the red arm for the HR and 20 in the LR for the faintest targets respectively, calculated per Å. The resulting exposure time estimates displayed in the bottom panels of the figures.

<u>S1308 – OC_HR</u>

<u>S1309 – OC_LR</u>

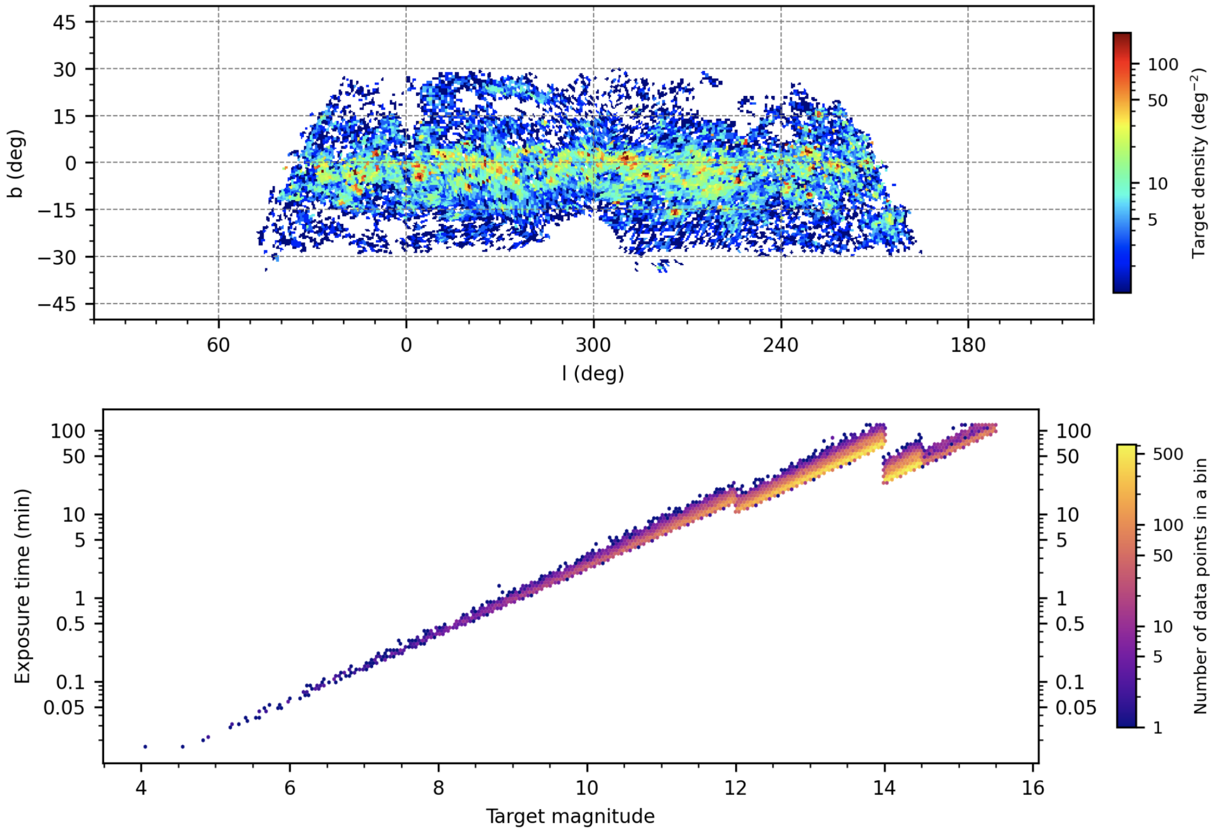


Figure 42: Top) Input target distribution of the subsurvey S1308 OC_HR. Bottom) The exposure time estimates as function of target G-mag.

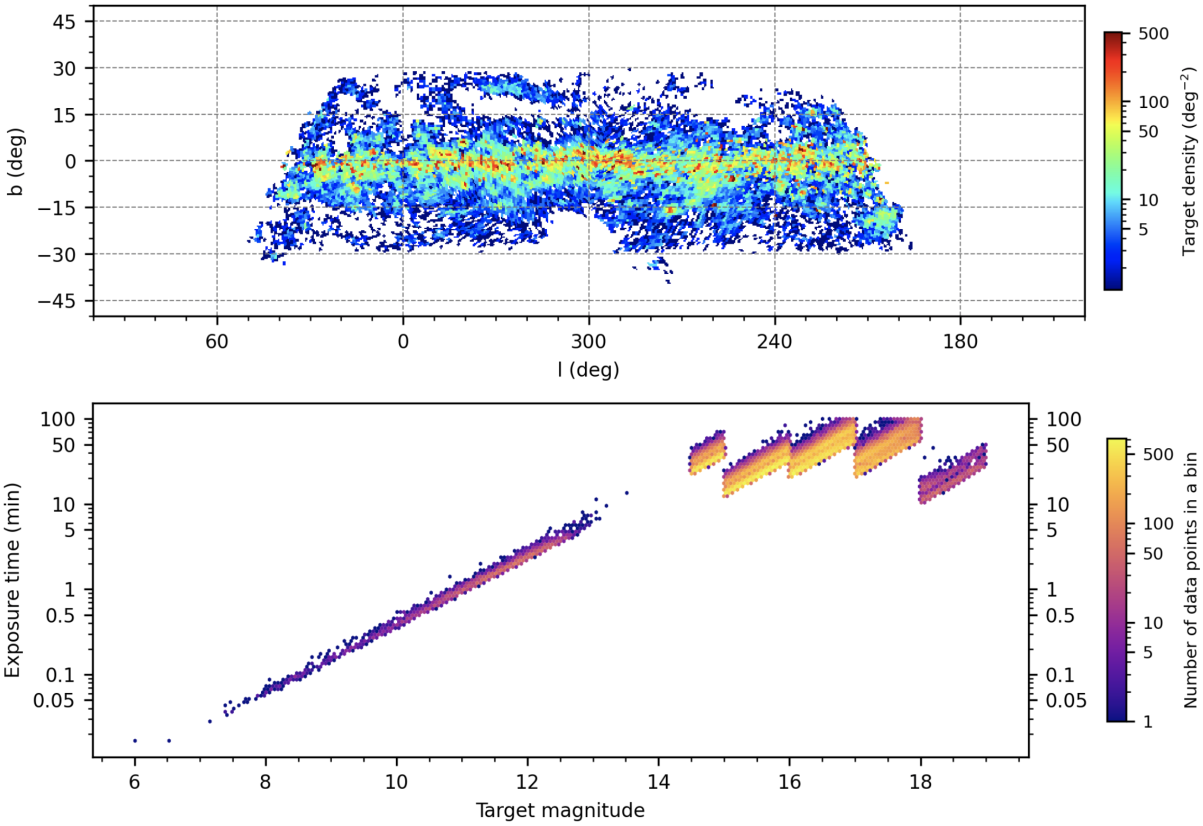


Figure 43: Top) Input target distribution of the subsurvey S1309 OC_LR. Bottom) The exposure time estimates as function of target G-mag.

Figure 42 and Figure 43 show the target distribution and exposure time required for the targets in OC_HR and OC_LR, respectively, a total 57k HR and 130k LR targets in 2022 clusters in the Milky Way. The completeness limit is 50% and the required area to be observed is approximately 7300 deg^2 for both subsurveys (see Table 27). The target S/N is 100 in the red for the faintest targets in HR and 20 in LR. with resulting exposure time estimates displayed in the bottom panels of the figures.

S1310 – VYC_HR
S1311 – VYC_LR

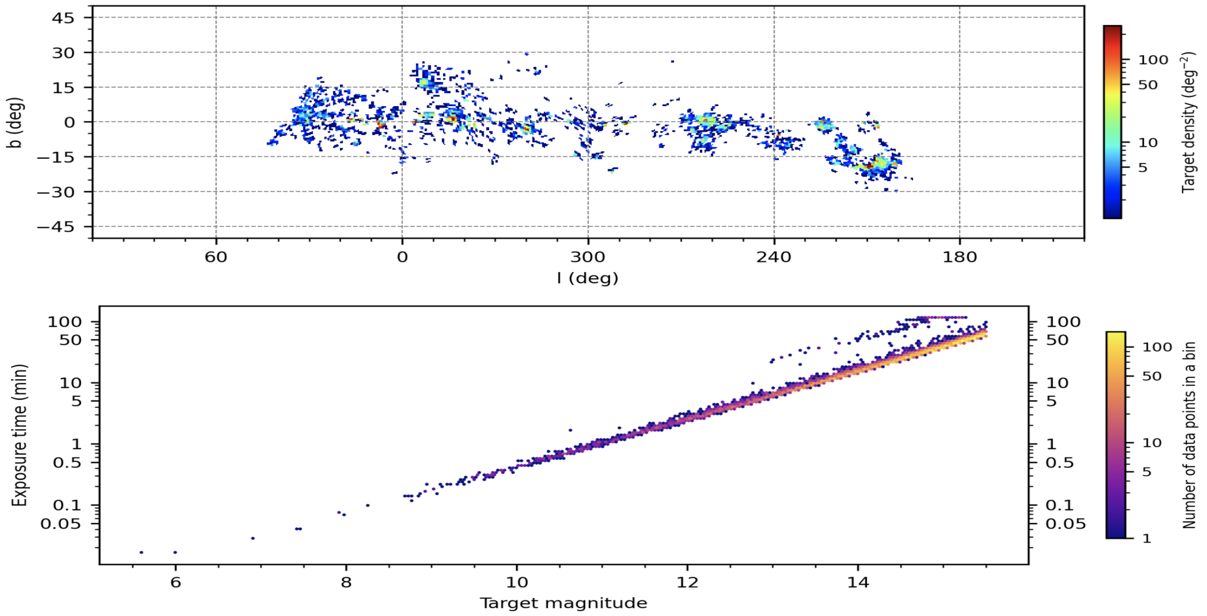


Figure 44: Top) Input target distribution of the subsurvey S1310 VYC_HR. Bottom) The exposure time estimates as function of target G-mag.

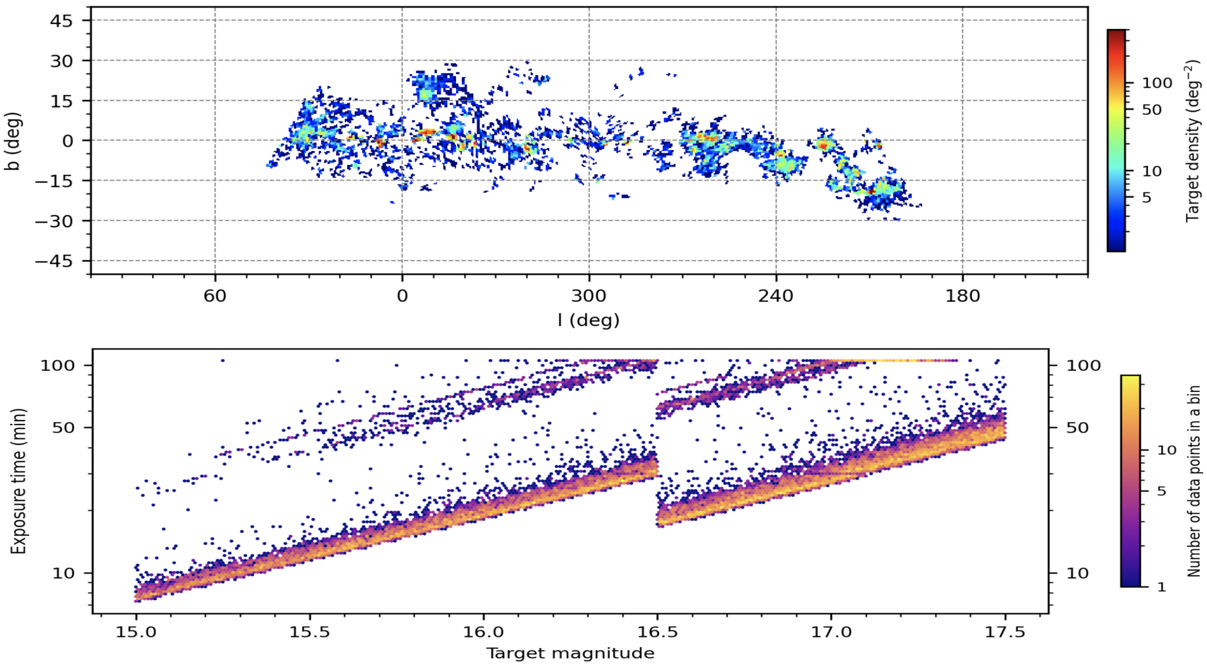


Figure 45: Top) Input target distribution of the subsurvey S1311 VYC_LR. Bottom) The exposure time estimates as function of target G-mag.

The input targets sky coverage of the two very young clusters surveys S1310 and S1311 is displayed in the top panels of Figure 44 and Figure 49, respectively, covering in total 9k HR and 23k LR targets in 87 very young clusters in the Milky Way. The completeness limit is 30% and the required area to be observed is approximately 1900 deg^2 (HR) and 2700 deg^2 (LR) (see

Table 27). The target S/N is 150 in the red arm for the HR and 60 in the LR, with resulting exposure time estimates displayed in the bottom panels of the figures.

Table 27: Key parameters of the input target catalogue of the S13 Survey

N	Sub	Name	Res	Cadence	Date earliest Date latest	RA range DEC range	Epoch	TMAX [min]	AREQ [deg^2]	Fcom	FH_D [kH]	FH_G [kH]	FH_B [kH]	FH_S [kH]	N targets
87	S1301	GC_HR_HC	HR	(0, 0, 0, 0)	0	69.0 – 347.1 -70.5 – 3.2	2016.0	120 (G)	235	0.300	0.678	0.688	0.718	0.767	1441
88	S1302	GC_HR_LC	HR	(0, 0, 0, 0)	0	3.4 – 295.2 -72.7 – 2.4	2016.0	120 (G)	60	0.100	2.52	2.53	2.62	2.78	11505
89	S1303	GC_HR_MC	HR	(0, 0, 0, 0)	0	13.1 – 325.3 -71.0 – 7.5	2016.0	120 (G)	228	0.200	3.18	3.21	3.35	3.57	10711
90	S1304	GC_LR_HC	LR	(0, 0, 0, 0)	0	6.6 – 348.4 -71.6 – 3.4	2016.0	120 (G)	204	0.300	8.15	10.3	17.7	30.0	24447
91	S1305	GC_LR_LC	LR	(0, 0, 0, 0)	0	0.2 – 359.6 -73.6 – 4.9	2016.0	120 (G)	405	0.100	97.5	123	218	375	255914
92	S1306	GC_LR_MC	LR	(0, 0, 0, 0)	0	39.3 – 328.8 -71.9 – 7.8	2016.0	120 (G)	598	0.200	99.1	125	222	381	171858
93	S1307	GC_LR_VHC	LR	(0, 0, 0, 0)	0	30.7 – 327.0 -71.7 – 0.1	2016.0	120 (G)	112	0.400	1.33	1.63	2.70	4.46	3509
94	S1308	OC_HR	HR	(0, 0, 0, 0)	0	0.2 – 359.9 -79.9 – 5.0	2016.0	120 (G)	7353	0.500	27.3	26.6	26.6	27.2	57302
95	S1309	OC_LR	LR	(0, 0, 0, 0)	0	0.2 – 359.9 -80.0 – 5.0	2016.0	120 (G)	7211	0.500	46.5	48.7	58.4	74.7	130298
96	S1310	VYC_HR	HR	(0, 0, 0, 0)	0	71.4 – 295.9 -79.2 – 5.0	2016.0	120 (G)	1910	0.300	1.03	0.967	0.950	0.979	8982
97	S1311	VYC_LR	LR	(0, 0, 0, 0)	0	71.4 – 296.0 -79.3 – 5.0	2016.0	120 (G)	2669	0.300	2.77	2.84	3.44	4.47	22542

The key input parameters of the S13 target catalogue are listed in Table 27. S13 has no cadencing requirements but will use any cadencing obtained "for free" to detect radial velocity binaries. The Scientific FoM has tracked the SoS until September 2023. It has been changed starting with the Sep 13th ingestion (simulations not available at the time of the writing of the present document). For the OC_HR, OC_LR, VYC_HR and VYC_LR we have maintained SoS. For the GC surveys, we have implemented a Scientific FoM that requires different degrees of completeness depending on which area of the sky (cluster) is observed. The Scientific FoM for the GC subsurveys calculated with the new algorithm and the latest available set of simulations, yielded values between 0.35 and 0.5 at 5-year. The total FoM is defined as the minimum for the subsurveys, and thus currently amounts to 0.35.

6.13.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.13.4 Management Structure

The top-level management of S13 consists of the three co-PIs, in consultation with the S13 Steering Committee on strategic decisions. In addition, the roles of survey manager, team manager, working group manager and lead of the catalogue creation WP are defined below.

co-PIs (Lucatello, Bragaglia, Vallenari):

- In charge of overall management (including internal policies).
- Supervise the contribution of survey members to IWGs.
- Coordinate and promote the scientific exploitation of the data (including scientific synergies with other surveys).
- Represent S13 in SCB and SPB.

Survey Manager (Lucatello):

- The SM is in charge of supervising the progress of the WPs and facilitate the interactions with IWGs.
- The SM helps reviewing the deliverables for the science team at each milestone and maintaining the schedule to produce internal deliverables.

- The SM is appointed for 2 years by the co-PIs. The position can be renewed indefinitely.
- Should the SM not be able to carry out their duties one of the (other) co-PIs will step in until a stable solution can be found.

Team Manager (Bragaglia):

- The TM is in charge of keeping the membership registry (4MS) up to date. The TM shall ensure that the members of the Survey Team keep their affiliation and contact information up to date in the system.
- The TM is in charge of setting the calendar for and organizing the internal meetings, after consulting with the co-PIs.
- Keeps track of the personnel effort internally and within the project. This includes being responsible for maintaining the builder list.
- The TM is appointed for 2 years by the co-PI. The position can be renewed indefinitely.
- Should the TM not be able to carry out their duties one of the (other) co-PIs will step in until a stable solution can be found.

Working Group Manager (Vallenari):

- The WGM is in charge of promoting the activities of the scientific WGs and facilitate their mutual interactions and with WPs.
- Coordinate interactions with other surveys.
- The WGM is appointed for 2 years by the co-PIs. The position can be renewed indefinitely.
- Should the WGM not be able to carry out their duties one of the (other) co-PIs will step in until a stable solution can be found.

Lead of the Catalogue Creating Work Package (Cantat-Gaudin):

- The lead and deputy are appointed by the co-PIs, after consulting with the Steering Committee.
- The Catalog WP lead is renewed every two years, and can be renewed an indefinite number of times.
- Should the WP lead not be able to carry out their duties the deputy WP lead will step up and take over until a stable solution can be found.

A description of the different WP within S13 is described in Section 7.3.10 with the FTE contributions to the different internal WGs listed in Section 7.3.11 and the contributions to the 4MOST common IWGs listed in Section 7.3.12. In summary, most of the work in WP_1304, WP_1305 and WP_1306, is directed towards IWG3, 6, 7 and 9. The contributions to these IWGs includes effort on (~1 FTE/yr):

- Cross-survey calibration
- Quality control of data products, for which clusters are particularly useful
- Contributing to analysis modules in 4GP

For S13 internally, the effort in WP_1301 (Management), WP_1302 (Survey Strategy), WP_1303 (Catalogue creation), WP_1308 (Synergies), and WP_1309 (Science exploitation) is mainly directed towards S13 specific work. This effort includes (at least 1 FTE/yr, likely more):

- Management of team meetings and monitoring of work in WPs
- Catalogue preparation and submission
- 4FS simulation inspection and FoM definition
- Scientific synergies with other surveys on targets of common interest
- Using data to meet science goals

S13 is planning to use the tools, procedures, and available hardware of the common IWGs, except for age and membership determination, which is not expected to be computationally demanding.

6.13.5 Work Breakdown Structure

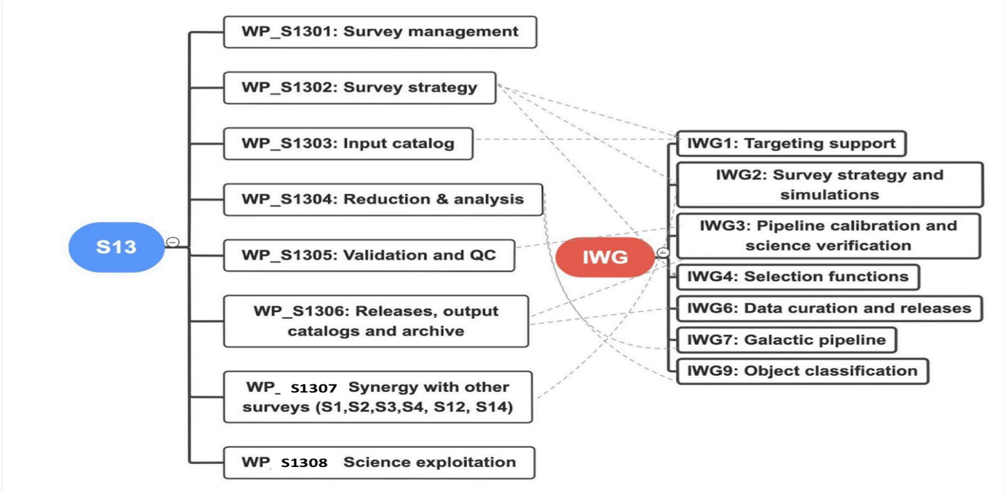


Figure 46: Work Breakdown Structure for Survey S13

A description of the different WGs within S13 is provided later in this section, with an estimate of the FTE contributions, that for efforts dedicated to IWG work is in section 6.14.11.
Overall, the total expected contribution to infrastructural work and to work that benefits more survey (including e.g. effort in developing synergy with other surveys) is of 1.5 FTE/yr. For what concerns S13 internal work, the total estimated effort is of at least 1.6 FTE/yr

WP_S1301: Management

This WP deals with the overall coordination of the survey.

- Tasks: coordinate all aspects of the survey. Coordinates the collaboration of different scientific WPs, Interfaces with the consortium, oversees the integration of Survey WPs with IWGs;
- Deliverables: Successful survey; Progress report, Management Plan
- Timescale: 7 years;
- Resources: 0.3 FTE/yr;

WP_S1302: Survey strategy:

This WP will work in close collaboration with IWG2

- Tasks: Through the use of the simulations, devises the most favourable strategy in terms of target distribution (spatial and in magnitude) for both HR and LR settings. Defines FoM to monitor survey advancement. Provides input for catalogue input as survey progresses.
- Deliverables: FoM and input on tiling
- Timescale: Mid 2023 for initial strategy, plus possible refinements during survey
- Resources: total 0.5 FTE (~0.1/yr), more for refinements during survey

WP_S1303: Input catalogue

This WP will work in close collaboration with IWG1

- Tasks**:** Selecting the appropriate targets for the survey scientific aims. The survey has three separate general classes of objects that are to be targeted, OCs, GCs and VYCs (each in HR and LR). Selections are performed separately for the three classes, relying on Gaia DR3 data combined with ancillary information (more details are given in the catalogue documentation).

- Deliverables: input catalogue in the required 4MOST format;
- Timescale: Final catalogue to be delivered in mid 2023, with updates implemented as foreseen in the 4MOST plan.
- Resources: total of 0.1 FTE/yr, plus that for the updates if applicable

WP_S1304: Reduction & analysis

This WP includes the contribution to the software for reduction and analysis (pipeline). This WP will contribute to IWG7

- Tasks:
  - Devise and implement a sky-subtraction approach suitable for young stars and highly and patchy reddened regions
  - Design and develop software suitable for the analysis of young, rotating stars
  - Develop an approach to analyze active objects
- Deliverables:
  - Pipeline module that will analyze young objects (including those with fast rotation) determining key parameters
  - Synthetic spectral grid for active stars
- Timescale:
  - Sky subtraction: ~Q3 2023
  - Pipeline module and grid ~Q2 2024
- Resources: Total foreseen is 0.3 FTE/yr, plus possible efforts for updates on the codes

WP_S1305: Validation and QC

This WP will work in close collaboration with IWG3 and IWG6

- Tasks: Validate the output of the pipeline, checking consistency and accuracy. Derive, if necessary, corrections and offsets to be applied to ensure uniform scale across the S13 sub-surveys, stellar types (parameter space), setups, SNR and throughout the progress of the survey. Deliverables: offsets and corrections (if applicable)
- Timescale: first delivery 6 months from beginning of survey operations, updates expected every ~6mo
- Resources: Total foreseen is 0.2 FTE/yr

WP_S1306: Releases, output catalogues and archive

This WP will work in close collaboration with IWG6

- Tasks: Define the content for what concerns S13, and contribute to internal and public releases efforts.
- Deliverable: S13 specific catalogue content definition
- Timescale: Q3 2023
- Resources: 0.2 FTE/yr

WP_S1307: Synergy with other surveys (S1,S2,S3,S4,S9,S12,S14)

- Tasks: Interface with other surveys, in particular those with considerable target overlap to maximize science returns.
- Deliverables: Lists of objects of common interests

- Timescale: Several of such lists are anticipated, starting in Q4 2022, with work extending into at least the second year of the survey operations.
- Resources: 0.15 FTE/yr

WP_1308: Science exploitation:

- Tasks: Use data to meet scientific goals
- Deliverables: scientific peer reviewed papers
- Timescales: throughout the survey and beyond
- Resources: not quantifiable at this stage, at least 3 FTEs in total, on average 0.6FTE/yr

6.13.6 Contribution to the Infrastructure Working Groups

IWG1

S13 members participate in IWG1, in particular working on efforts related to catalog repository, to the validation of ingested ones and to the definition of observations necessary for sky subtraction for young stellar objects. Estimate of required effort with IWG1: 1 FTE in total for the whole duration of survey, divided over members Cantat-Gaudin, Gran, Kuzma, Guarcello, Prisinzano and Bragaglia.

IWG2

Contribution is in the form of work on input in the optimization of the tiling for the disk and the Magellanic Clouds. Estimate of effort within IWG2 is 0.3FTE, cumulative for the whole duration of the survey, divided over members Lucatello, Spina and Valenti.

IWG3

S13 is contributing to IWG3 through the cross-survey WG (that includes scientists from WEAVE - to which key S13 people are full members-, DESI, SDSSV). Will heavily contribute to target selection for calibration clusters, will help with assessment of pipeline products accuracy, assessment of offsets and trends. Estimate of effort within IWG3: 0.75 FTE, cumulative for the whole duration of the survey divided over survey members D'Orazi, Carrera, Lucatello, and Vallenari.

IWG4

Currently contribution is just in the form of general inputs to the efforts. Estimate of effort within IWG4: >0.2 FTE, cumulative for the whole duration of the survey, divided over the PIs Vallenari, Bragaglia and Lucatello.

IWG6

Activities have just started; we expect to contribute to the quality assurance efforts. Estimated efforts within IWG6: 1.0 FTE, cumulative for the whole duration of the survey. Current S13 representative is Carrera, who is the Galactic lead for IWG6.

IWG7

Multiple contributions are planned by S13.

- Pipeline module to analyze young and rotating stellar objects
- Synthetic spectra grid of active stars
- Support to pipeline benchmarking and validation

Estimated effort within IWG7: >2.5 FTE, cumulative for the whole duration of the survey, divided over S13 members Aguado, Damiani, D'Orazi, Korn, Spina and Jian.

IWG8

IWG8 is not relevant to our survey.

IWG9

S13 will support the code development efforts. Estimated effort within IWG9: 0.6 FTE, cumulative for the whole duration of the survey. The current S13 representative is Castro-Ginard.

6.13.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.13.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey S13 will be processed by the 4GP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
Further to the standard data products from the common 4MOST pipelines, S13 will have extra Deliverable L2 Survey products (DL2-SURV) that will go to both the ESO Science Archive Facility (SAF) and the 4MOST Public Archive (4PA).
In addition, the data products described in the following subsections will be provided.

6.13.8.1 Deliverable L2 Survey data: reduction processing

S13 will use stellar parameters (Teff, logg, [Fe/H]), elemental abundances, and radial velocities determined by 4GP. In addition, S13 members are developing a module for 4GP to determine rotational velocities, particularly for objects in the VYC_* subsurveys.
By jointly exploiting 4MOST data, presently available or planned precision photometry and astrometry (e.g. Gaia, LSST etc), S13 will measure ages and membership probabilities for the entire sample.

6.13.8.2 Deliverable L2 Survey data: quality assessment

The quality assessment procedure is under development.

6.13.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with

all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.13.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

Cluster ages and memberships will be delivered, starting from DR2, for clusters for which the following conditions are met: 1) at least 1 year has passed since required completeness for such cluster has been achieved, both in HR and LR; 2) at least 1 year has passed since the Gaia DR4.

6.13.8.5 Deliverable L2 Survey data: Required hardware and staff

The calculation of ages and memberships is not computationally expensive and will involve several members from the team.

6.13.8.6 Additional L2 data: reduction processing

No extra AL2 processing is planned by this Survey.

6.13.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.13.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey.

6.13.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 processing is planned by this Survey.

6.13.8.10 Additional L2 data: Required hardware and staff

No extra AL2 processing is planned by this Survey.

6.13.9 Team

Table 28: Survey S13 team members with their affiliation, role in S13, and expected FTE contribution per year. Only commitments at the 0.05 FTE/yr level or more are included.

Name	Affiliation	Function	FTE
David Aguado	UNIFI	Pipeline contributor, IWG7	0.1
Angela Bragaglia	OAS	Co-PI, TM	0.2
Tristan Cantat-Gaudin	MPIA	Catalog master, IWG1 catalog validation	0.2
Ricardo Carrera	OAPd	Data assurance, IWG6 co-lead	0.2
Alfred Castro-Ginard	Leiden	Classification, IWG9	0.1
Valentina D'Orazi	OAPd	Calibrations IWG3 and pipeline contribution	0.1
Francesco Damiani	OAPa	Pipeline IWG7	0.3
Felipe Gran	OCA	Catalog contributor	0.1
Mario Giuseppe Guarcello	OAPa	Catalog contributor	0.1
Mingjie Jian	SU	Pipeline contributor	0.4

Name	Affiliation	Function	FTE
Pete Kuzma	IfA	Catalog contributor	0.1
Sara Lucatello	OAPd	co-PI, SM	0.3
Andre Moitinho	FCUL	Catalog contributor	0.1
Loredana Prisinzano	OAPa	Catalog contributor IWG1	0.1
Lorenzo Spina	UniPd	Selection function and simulations, IWG2	0.1
Antonella Vallenari	OAPd	Co-PI, WGM	0.2
Nicholas Wright	Keele	Simulations, Calibrations IWG2 and 3	0.05
Total			2.55

6.14 Survey 14 – The 4MOST Survey of Dwarf Galaxies and their Stellar Streams (4DWARFS)

Survey PI: Ása Skúladóttir

6.14.1 Science Summary

Dwarf galaxies are ideal laboratories to study the earliest chemical evolution, different nucleosynthetic channels, dark matter structure, and hierarchical galaxy formation. Thus, 4DWARFS is a key and highly complementary survey to further our understanding of Galactic evolution. 4DWARFS will target all the dwarf galaxies in the 4MOST footprint, in particular the main bodies of three large dwarf spheroidal galaxies, Sagittarius, Fornax and Sculptor. In addition, the survey will focus on the Sagittarius stream, which is a major constituent of the Galactic halo, and presents our best opportunity to observe a galaxy currently being disrupted, along with other identified stellar streams from Gaia DR3. 4DWARFS will address open scientific questions that can be uniquely answered through chemical abundance measurements in the dwarf galaxies and their streams. This survey will thus give new and valuable insights into: 1) the properties of the first stars; 2) various nucleosynthetic channels, such as SN type Ia, AGB stars and the r-process; 3) hierarchical galaxy formation, e.g. by quantifying the number of previous mergers in the Milky Way, and within the dwarf galaxies themselves. The 4DWARFS survey will provide stellar ages, radial velocities and chemical abundances for ~130,000 stars, and will thus increase the number of stars in dwarf galaxies and streams with detailed abundance information (>10 elements) by several orders of magnitude, ensuring the far-reaching and long- lasting legacy of this survey.
Expanded science description is in [messenger-no190-19-21.pdf]

6.14.2 Target Catalogues

4DWARFS will target stars in close to 50 individual dwarf galaxies, and stellar streams. The target selection and success criteria are therefore relatively complex, and 13 subsurveys are required to optimise the survey:

- S1401 – SGR_HR (Sagittarius)
- S1402 – SGR_LR (Sagittarius)
- S1403 – FNX_HR (Fornax)
- S1404 – FNX_LRb (Fornax)
- S1405 – SCL_HR (Sculptor)
- S1406 – SCL_LRb (Sculptor)
- S1407 – FD_LR (Faint dwarfs)
- S1408 – STR_HR (Streams)
- S1409 – STR_LR (Streams)
- S1410 – DEEP_HR (WAVES field)
- S1411 – DEEP_LR (WAVES field and faint end)
- S1412 – MP_HR (Metal-poor stars)
- S1413 – MP_LR (Metal-poor stars)

The three largest dwarf spheroidal galaxies (Sagittarius, Fornax and Sculptor) are covered in the first six subsurveys (HR and LR for each), while smaller galaxies will only be observed with LR in S1407. Subsurveys S1408 (HR) and S1409 (LR) include all stream stars, including those of Sagittarius. The last 4 subsurveys can be seen as complementary to the first 9 main subsurveys. The subsurveys S1410 (HR) and S1411 take advantage of the deep S7 WAVES field to go deeper and reach higher S/N. In addition, in S1411 the fainter end of dwarf galaxy and stream stars are included with lower priority, for optimal fibre use. Finally, the last two surveys S1312 (HR) and S1413 (LR) contain stars from dwarf galaxies and stellar streams which are likely to be metal-poor. These surveys contain no new stars, but are to ensure that this very important population of stars is adequately observed with high priority.

The target catalogue for the dwarf galaxies other than Sagittarius is based on the published catalogue of Battaglia et al. 2022, which is based on Gaia eDR3. The Sagittarius catalogue is based on Gaia DR3, selecting on the proper motion and other astrometry and photometry of Sagittarus. The target catalogue of the stellar streams will be published in an upcoming paper Ibata et al. in prep, and is based on the well-established STREAMFINDER algorithm (e.g. Malhan & Ibata 2018). Other details are listed here below. In all subsurveys the SNR success criteria is dependent on the magnitude of the star in question. Overview of the properties of different subsurveys can be seen in Table 29 below.

Table 29: Properties of the subsurveys of 4DWARFS.

Subsurvey ID	Number of targets	mag range Gaia Gmag	λ (nm)	Success S/N per Å
S1401 SGR_HR	45k	14-17	520	100-350
S1402 SGR_LR	109k	17-18	680	120-170
1403 FNX_HR	0.5k	16-18	520	100-200
1404 FNX_LR	1.6k	18-18.7	680	110-150
1405 SCL_HR	0.2k	15-17.5	520	140-180
1406 SCL_LR	0.8k	17.5-19	680	100-160
1407 FD_LR	9.5k	16-20.5	680	12-130
1408 STR_HR	16k	12.5-16.7	520	80-250
1409 STR_LR	38k	16.7-19.5	680	35-110
1410 DEEP_HR	1.3k	13-17	520	100-350
1411 DEEP_LR	17k	17-20.5	680	12-170
1412 MP_HR	8.8k	13.8-17	520	100-350
1413 MP_LR	8.3k	17-20	680	30-60

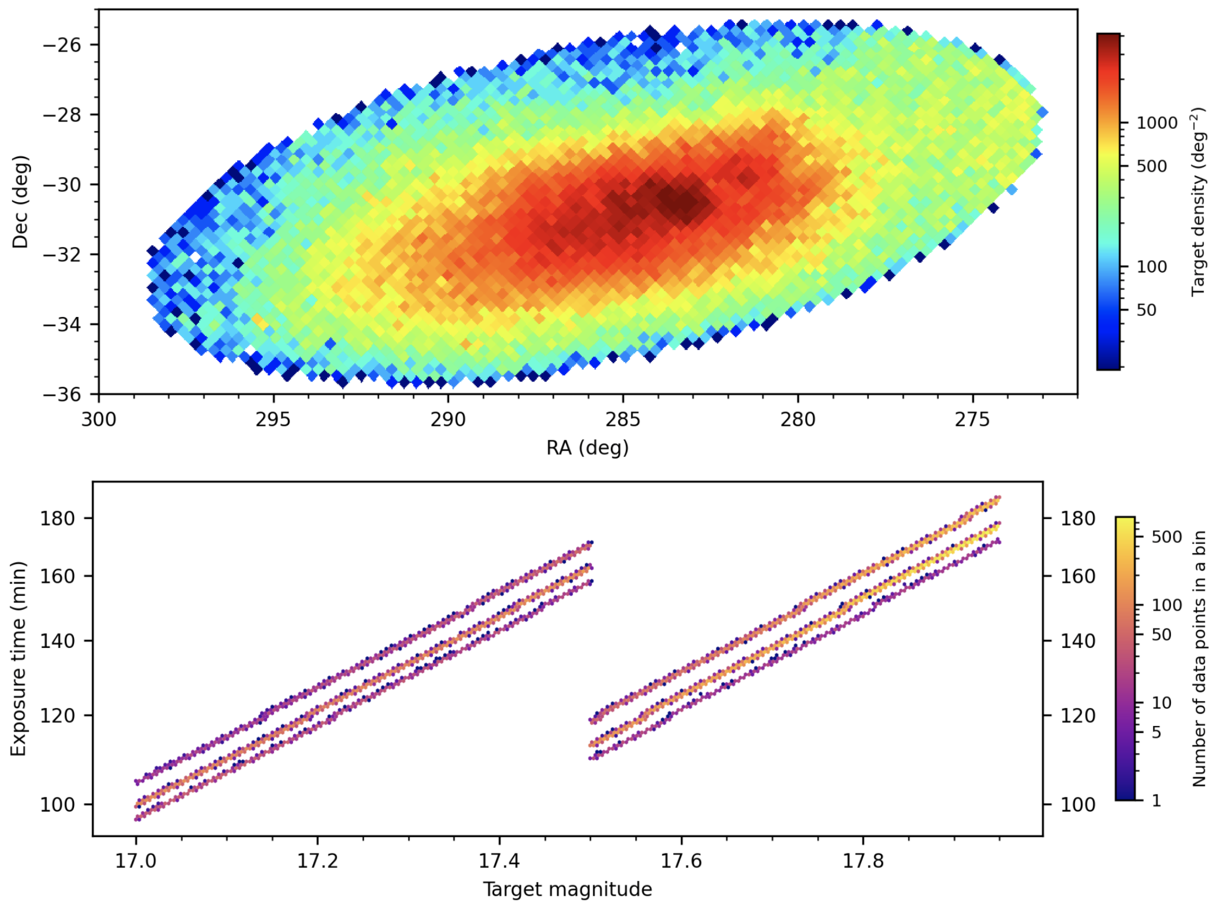


Figure 47: Top) Input target distribution of the subsurvey S1402 SGR_LR. Bottom) The exposure time estimates as function of target G-mag.

Sagittarius (S1401-1402)

The input targets sky coverage of the two subsurveys S1401 and S1402 is the same, and is displayed for SGR_LR in the above figures, covering in total 45k HR and 109k LR targets in the main body of the Sagittarius dwarf spheroidal galaxy. The completeness limit is 60% and the required area to be observed is ~700 deg^2 for both subsurveys (see Table 30). The target S/N depends on the magnitude of the stars and is from 100 to 350@520nm for SGR_HR, and from 120 to 170@680nm for SGR_LR, with resulting exposure time estimates displayed in the bottom panels of the figures.

Fornax, Sculptor and Faint dwarfs (S1403-1407)

The Fornax and Sculptor dwarf spheroidal galaxies are important targets for 4DWARFS that cover small regions of the sky (<20 deg^2 each). An example is shown in Figure 48 below, for S1404 FNX_LR. The FNX field includes 500 HR and 1600 LR targets with a completeness limit of 30% and the required area to be observed is 10-16 deg^2 (see Table 30). The target S/N is dependent on the magnitude, 100-200@520nm for FNX_HR, and 110-150@680nm for FNX_LR, with resulting exposure time estimates displayed in the bottom panels of the figures. The two subsurveys S1405 and S1406 cover 200 HR and 800 LR targets in the Sculptor dwarf spheroidal galaxy. The completeness limit is 30% and the required area to be observed is 13 deg^2. The target S/N depends on the magnitude of the target, ranging from 140 to 180@520nm for SCL_HR, and 100-160@680nm for SCL_LR. For the smaller dwarf galaxies, the completeness limit is 50%, and the required area is 350 deg^2. However, this is not a continuous area, like shown in Figure 49 below. The S/N depends on the magnitude of the stars, and ranges from 12 to 130@680nm.

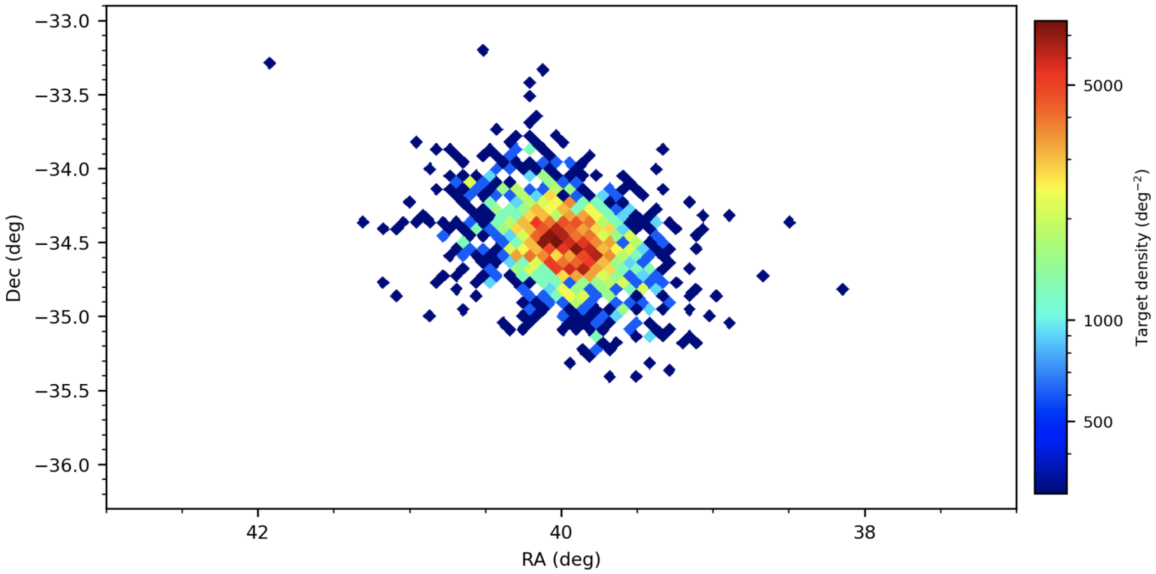


Figure 48: Input target distribution of the subsurvey S1404 FNX_LRb.

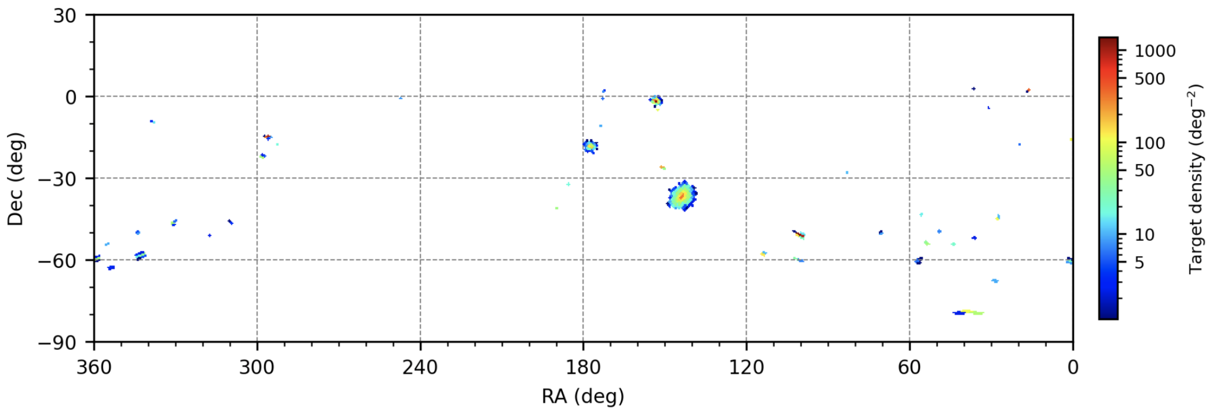


Figure 49: Input target distribution of the subsurvey S1407 FD (faint dwarfs).

The Stellar Streams (S1408-1409)

The subsurveys S1408 and S1409 cover 17k HR and 38k LR targets in known Milky-Way streams. The completeness limit is 50% and the required area to be observed is 5200-7600 deg^2 (see Table 30). The target S/N depends on the magnitude, with the range 80 to 250@520nm for the STR_HR, and 35 to 110@680nm for the STR_LR. The spatial coverage is shown in Figure 50 below for STR_LR.

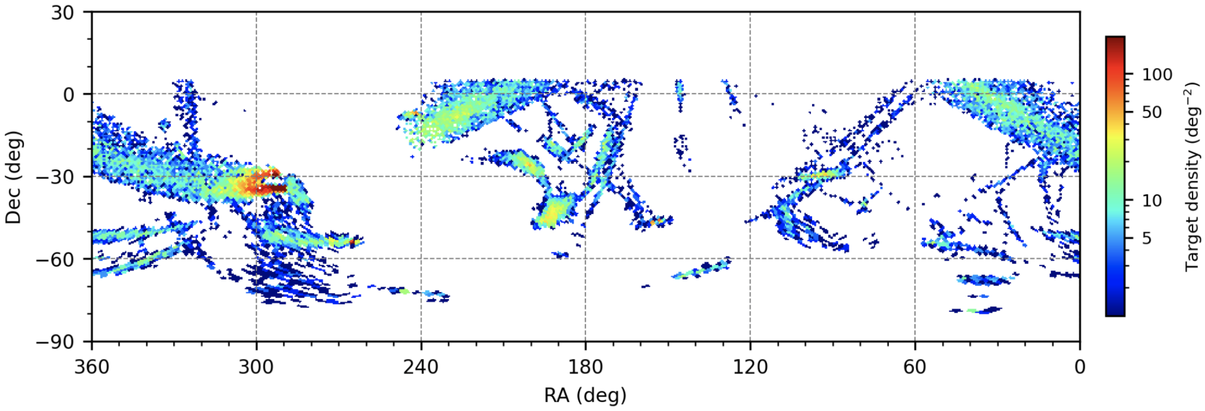


Figure 50: Input target distribution of the subsurvey S1409 STR_LR.

The complementary subsurveys (S1410-1413)

The last 4 subsurveys of 4DWARFS (S1410-1413) are complementary to the main subsurveys (S1401-S1409). The DEEP survey covers 1.4k HR and 17k LR targets in the WAVES deep fields. The LR subsurvey also covers faint targets in Fornax, Sculptor and the stellar streams. The completeness limit is 30% and the required area to be observed is 660 deg^2 in HR and 2310 deg^2 in LR (see Table 30). The target S/N depends on magnitude, and ranges from 100 to 350@520nm for DEEP_HR, and from 12 to 170@680nm for the DEEP_HR.

The subsurveys S1412 and S1413 only include targets that are already a part of other subsurveys, namely the blue end of the RGB (where metal-poor stars are expected to lie) in the dwarf spheroidal galaxies Sagittarius, Fornax and Sculptor. The completeness limit is 60% and the required area to be observed is 170-250 deg^2 (see Table 30). The target S/N depends on the magnitude, and ranges from 100 to 350@520nm in the MP_HR, and from 30 to 60@620nm in the MP_LR.

Table 30: Key parameters of the input target catalogue of the S14 Survey.

N	Sub	Name	Res	Cadence	Date earliest Date latest	RA range DEC range	Epoch	TMAX [min]	AREQ [deg^2]	Fcom	FH_D [kH]	FH_G [kH]	FH_B [kH]	FH_S [kH]	N targets
98	S1401	SGR_HR	HR	(0, 0, 0, 0)	0	273.1 – 298.5 -35.6 – -25.4	2016.0	360 (G)	167	0.600	117	123	145	183	44680
99	S1402	SGR_LR	LR	(0, 0, 0, 0)	0	273.1 – 298.6 -35.6 – -25.4	2016.0	360 (G)	170	0.600	161	174	217	288	108694
100	S1403	FNX_HR	HR	(0, 0, 0, 0)	0	38.5 – 41.0 -35.4 – -33.1	2016.0	1440 (G)	10	0.300	1.45	1.66	2.39	3.68	506
101	S1404	FNX_LRb	LR	(0, 0, 0, 0)	0	38.2 – 41.9 -35.4 – -32.8	2016.0	960 (G)	16	0.300	4.14	4.70	6.65	9.79	1645
102	S1405	SCL_HR	HR	(0, 0, 0, 0)	0	14.0 – 16.0 -34.9 – -33.0	2016.0	780 (G)	13	0.300	0.554	0.606	0.788	1.11	222
103	S1406	SCL_LRb	LR	(0, 0, 0, 0)	0	12.7 – 16.9 -34.7 – -32.8	2016.0	780 (G)	13	0.300	2.13	2.46	3.57	5.34	838
104	S1407	FD_LR	LR	(0, 0, 0, 0)	0	0.3 – 359.9 -79.8 – 3.1	2016.0	120 (G)	349	0.500	5.18	7.19	14.1	25.4	9525
105	S1408	STR_HR	HR	(0, 0, 0, 0)	0	0.0 – 360.0 -79.4 – 5.0	2016.0	120 (B)	5200	0.500	10.5	10.8	11.9	13.7	16942
106	S1409	STR_LR	LR	(0, 0, 0, 0)	0	0.0 – 360.0 -79.4 – 5.0	2016.0	120 (B)	7600	0.500	23.3	25.6	32.7	43.8	37948
107	S1410	DEEP_HR	HR	(0, 0, 0, 0)	0	0.5 – 360.0 -35.9 – 4.0	2016.0	420 (G)	660	0.300	0.992	1.04	1.21	1.51	1374
108	S1411	DEEP_LR	LR	(0, 0, 0, 0)	0	0.0 – 360.0 -79.8 – 5.0	2016.0	420 (G)	2310	0.300	5.54	7.35	13.7	23.7	17194
109	S1412	MP_HR	HR	(0, 0, 0, 0)	0	273.2 – 298.3 -35.6 – -25.5	2016.0	360 (B)	170	0.600	16.6	17.3	19.5	23.5	8776
110	S1413	MP_LR	LR	(0, 0, 0, 0)	0	12.7 – 298.3 -36.3 – -25.5	2016.0	360 (B)	250	0.600	10.7	11.7	15.2	21.0	8277

The above table shows the key parameters of 4DWARFS. There are no cadence requirements but the survey will benefit from the natural cadencing coming from the 4MOST survey strategy.

6.14.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.14.4 Management structure

PI: Ása Skúladóttir.

The PI can add another co-PI or dPI of the entire survey, if that becomes necessary.

If the PI steps down from her duties as PI, she will appoint another PI, or suggest an internal 4DWARFS vote on the matter.

In the case of death and/or disappearance of the PI, a new PI will be voted on by surviving 4DWARFS members.

Team Manager: Ása Skúladóttir

The TM is in charge of keeping the membership registry (4MS) up to date. The TM shall ensure that the members of the Survey Team keep their affiliation and contact information up to date in the system.

The TM is appointed by the PI. The position can be renewed indefinitely. Should the TM not be able to carry out their duties the PI will step in until a stable solution can be found.

Together with other 4DWARFS members, the PI will take decisions regarding the planning, execution and exploitation of the survey, and its subsurvey. Discussion and decision making will happen at regular team telecons (at least once a month).

The detailed structure of S14 is listed in the following subsections, where S14 will use the infrastructure of the common 4MOST IWGs, and accordingly contribute to said infrastructure.

6.14.5 Work-breakdown structure

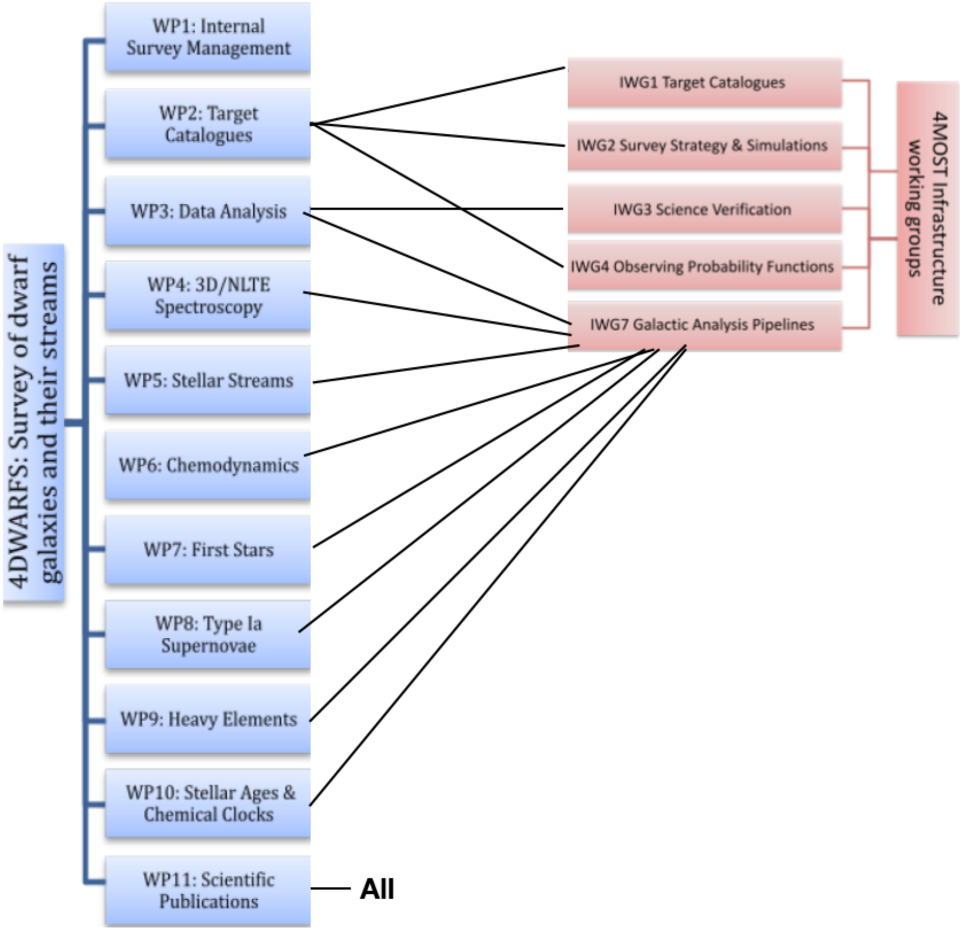


Figure 51: Work Breakdown Structure for Survey S14.

WP1: Internal Survey Management

The Internal Survey Management WP is led by the survey PI: Ása Skúladóttir. Dr. Skúladóttir is a member of the 4MOST Science Coordination Board (SCB) and IGW2 (Strategy & Simulations). WP1 is responsible for the management of the 4DWARFS survey, in particular the coordination of the Work Packages (WPs) listed below

WP2: Target Catalogues (WP2)

Leads: Ása Skúladóttir, Davide Massari, Rodrigo Ibata

Other key members: Eline Tolstoy, Giuseppina Battaglia and Pascale Jablonka (target selection); Moritz Reichert (IWG1), Salvador Cardona-Barrero (IWG1), and Romain Lucchesi. This WP involves building the target catalogues for the 4DWARFS survey. There are 3 types of target catalogues for the different classes of objects which 4DWARFS aims to observe. There are listed below, along with the people that will design and compile them:

1. dSphs (from Gaia DR3) - Ása Skúladóttir
2. UFDs (from Gaia DR3) - Davide Massari
3. Streams (from Gaia DR3) - Rodrigo Ibata

This WP will naturally be closely involved with IWG2, as well as liaising with IWG1 and IGW4.

WP3: Data Analysis

Lead: Ása Skúladóttir, and to-be-hired (funding secured)

Other key members: Kris Youakim (IWG7), Anish Amarsi, Thomas Nordlander, Karin Lind, Andrew Gallagher, Sven Buder, Diane Feuillet (IWG4), Romain Lucchesi (IWG3).
The Data Analysis WP will liaise with, and contribute to, the Galactic Pipelines IWG (IWG7). 4DWARFS will primarily rely on the 4MOST pipelines for data reduction and analysis. Where 3D/NLTE analysis is needed, WP3 will liaise with WP4. It will also be connected to IWG3 and IWG7.

WP4: 3D/NLTE Spectroscopy

Lead: Anish Amarsi
Other key members: Karin Lind, Thomas Nordlander, Andrew Gallagher.
The focus of WP4 is on next-generation stellar atmospheres and abundance analysis. This group will provide 3D and/or NLTE corrections for the derived chemical abundances, based on detailed modelling. WP4 will liaise and contribute to IGW7, providing 4MOST with options for 3D and/or NLTE abundance analysis.

WP5: Stellar Streams

Lead: Rodrigo Ibata
Other key members: Nicolas Martin, Ása Skúladóttir (S1,S2,S13 communication), Davide Massari (S13 connection)
WP5 focuses on the stellar stream science. Since stream targets are a significant part of 4DWARFS, they will liaise with WP2 (Target Selection), advising on the science to drive optimal target selection. This WP will also be connected to WP3 and WP4 since the main deliverable will be the > 15 elemental abundances for each star in each stream. Furthermore, this working package will be in close contact with surveys S1, S2, S13, to ensure that the synergies of all surveys are optimised, and agreement is reached on possible shared science goals.

WP6: Chemodynamics (WP6)

Lead: Giuseppina Battaglia
Other key members: Salvador Cardona-Barrero, Eline Tolstoy, Davide Massari, Ása Skúladóttir, Nicolas Martin.
WP6 focuses on chemodynamics, linking dynamics with chemical abundance tracers, which can help deduce the formation histories of the dwarf galaxies. This WP will make use of the chemical abundance and radial velocity results from WP3 (and possibly 3D/NLTE results from WP4). It will also interface with WP10, for stellar ages.

WP7: First Stars

Lead: Stefania Salvadori
Other key members: Ása Skúladóttir, Viola Gelli, Martina Rossi, Norbert Christlieb, Pascale Jablonka, Tadafumi Matsuno, Stephanie Monty.
The First Stars WP will analyse the abundance results from WP3 and WP4, with the aim of tracing the oldest chemical abundance patterns. This will require analysing the most metal-poor stars in the samples, utilising stellar ages from WP10, and also comparing to theoretical predictions from stellar models. This will enable us to characterise the mass range of the first stars, for example. Since 3D/NLTE effects can be very strong at low [Fe/H], this WP will interact with WP4. Furthermore, this package will include interpretation of the results through theoretical chemical evolution models.

WP8: Type Ia Supernovae

Leads: Ashley Ruiter, Ivo Seitenzahl
Other key members: Ása Skúladóttir

This WP focuses on understanding the nature of Type Ia supernovae. It will search for the chemical signatures of these supernovae in the data products of WP3, and compare them to theoretical models.

WP9: Heavy Elements

Lead: Camilla J. Hansen

Other Key members: Ása Skúladóttir, Simon Campbell, Amanda Karakas, Moritz Reichert

WP9 will use the data products from WP3 and WP4 to enhance our understanding of the distribution of heavy elements in the observed stars.

WP10: Stellar Ages & Chemical Clocks

Lead: Diane Feuillet

Other key members: Ása Skúladóttir, Camilla Hansen.

WP10 will use various methods to determine stellar ages. It will interact with and use the data products of WP3 and WP4, as well as rely on outputs from IWG7.

WP11: Scientific Publications

Lead: Ása Skúladóttir (PI), plus TBD

Key members: Linda Lombardo (IWG6), all of 4DWARFS

Scientific publications (including catalogues) will be the main output of the 4DWARFS Survey. This will be coordinated by the PI and other leads (yet to be determined). All projects will be discussed in regular 4DWARFS meetings before publication.

6.14.6 Contribution to the Infrastructure Working Groups

IWG1

Lead representative: Moritz Reichert.

Other key S14 members: Nikolay Kacharov, Salvador Cardona-Barrero, Tadafumi Matsuno.

S14 has a significant contribution to IWG1, as one of the co-leads is a S14 member. In addition, S14 provides manpower for the general work of IWG1, e.g. to ensure that the documentation of the submitted catalogues is adequate.

IWG2

Lead representative: Ása Skúladóttir

Other key members: Romain Lucchesi, Eline Tolstoy, Rodrigo Ibata, José María Arroyo-Polonio, Giuseppina Battaglia, Davide Massari.

The S14 representatives do the target selection for S14, and are responsible for uploading new and improved catalogues. Ása and Romain attend the IWG2 meetings, follow minutes and emails, and give feedback on simulations and the upload process. Eline participates in discussion for IWG2 work packages regarding the optimization of specific areas. Finally, José María contributes to the cadence working group within IWG2.

IWG3

Key members: Romain Lucchesi, another member to be hired (funding secured).

S14 contributes to the general work of IWG3, as needed.

IWG4

Lead representative: Diane Feuillet.

Other key members: Nicolas Martin.

S14 provides active representation, working on the definition of the object selection function, and how to effectively use it.

IWG6
Lead representative: Linda Lombardo.
Other key members: Tadafumi Matsuno.
S14 contributes to the tests of quality control, regarding accuracy and precision.

IWG7
Lead representative: Kris Youakim, another member to be hired (funding secured).
Other key members: Tadafumi Matsuno, Anish Amarsi, Sven Buder, Diane Feuillet, Camilla Juul Hansen, Andreas Koch Hansen, Karin Lind, Stephanie Monty, Thomas Nordlander, Ása Skúladóttir.
S14 has active representation in IWG7. Most notably, S14 contributes significantly by having extensive experience in large surveys (e.g. Sven and Karin), and with accurate 3D/NLTE abundances (e.g. Anish, Camilla, Thomas). Furthermore Ása was the chair of the pipeline panel review and continues to coordinate meetings between IWG7 leads and survey PIs.

IWG9
Lead representative: Arthur Alencastro Puls
The S14 member contributes to developing the algorithm intended to categorise object based on machine learning.

IWG - Project Culture
Lead representative: Anish Amarsi.
Other key members: Diane Feuillet
Both Anish and Diane contribute significantly to this IWG, e.g. in defining its goals in trying to secure a healthy environment, designing and executing polls for wellbeing among 4MOST members etc.

SCB
Lead representative: Ása Skúladóttir
Attending meetings, following emails and contributing to discussions and decisions as needed.

SPB
Lead representative: Andreas Koch Hansen
The S14 representative in this board participates as needed. The role of this board will become more significant after the start of operations.

6.14.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.14.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey S14 will be processed by the 4GP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.

Further to the standard data products from the common 4MOST pipelines, S14 will have extra Deliverable L2 Survey products (DL2-SURV) that will go to both the ESO Science Archive Facility (SAF) and the 4MOST Public Archive (4PA).
In addition, the data products described in the following subsections will be provided.

6.14.8.1 Deliverable L2 Survey data: reduction processing

By jointly exploiting 4MOST data, presently available or planned precision photometry and astrometry (e.g. Gaia, VRO/LSST, etc.) S14 will measure ages and galaxy/stream membership probabilities for the entire sample. These will become available in the DR2 release as DL2-SURV products, for those targets meeting quality control of radial velocities (membership); as well as [Fe/H] and [alpha/Fe] for stellar ages.

6.14.8.2 Deliverable L2 Survey data: quality assessment

The quality assessment procedure is under development.

6.14.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.14.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

Ages and Galaxy/stream memberships will start to be delivered in the DR2 release for those objects with sufficient data to meet quality checks as defined above.

6.14.8.5 Deliverable L2 Survey data: Required hardware and staff

The calculation of ages and Galaxy/stream memberships is not computationally expensive and will involve several members from the team.

6.14.8.6 Additional L2 data: reduction processing

No extra AL2 processing is planned by this Survey.

6.14.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.14.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 processing is planned by this Survey.

6.14.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 processing is planned by this Survey.

6.14.8.10 Additional L2 data: Required hardware and staff

No extra AL2 processing is planned by this Survey.

6.14.9 Team

The total FTEs of the current team, including postdocs and PhD students for which funding has been secured, is 3.61FTEs. Thereof 2.2 FTEs are expected for work directly provided to the IWGs and other work that benefits 4MOST as a whole.

In summary, most of the work in WP1-WP11 is survey-internal work on analysis and science exploitation. The contributions to IWG7 includes mainly work on implementing 3D/NLTE analysis in 4GP and/or post-correcting L2-products for such effects. It is not straightforward to estimate the total size of the FTE-contribution for this work to 4MOST specifically, since theory development benefits the entire community. For example, the generation of a single new NLTE grid for an element can easily take 2 FTE-years. Funds have been applied for (and some received) to provide more contributions to the IWGs, particularly for spectrum analysis.

For S14 internally, the effort includes (at least 2 FTE/yr):

- Management of team meetings and coordination of work in WPs
- Catalogue preparation and submission
- 4FS simulation inspection and FoM definition
- Scientific synergies with other surveys on targets of common interest
- Preparing data and data analysis.

S14 is planning to use the tools, procedures, and available hardware of the common IWGs, except for age and membership determination, which is not expected to be computationally demanding.

Table 31: Survey S14 team members with their affiliation, role in S14, and expected FTE contribution per year. Only commitments at the 0.03 FTE/yr level or more are included.

Name	Affiliation	Function	FTE/yr
David Aguado	IAC	IWG	0.10
Giuseppina Battaglia	IAC	Target selection	0.07
Sven Buder	ANU	IWG7	0.05
Sema Caliskan	UU	PhD student	0.03
Simon Campbell	Monash		0.03
Salvador Cardona-Barrero	IAC	IWG1	0.15
Norbert Christlieb	LSW	S2/S14 interface	0.02
Diane Feuillet	LU	IWG4, PCWG	0.15
Andrew Gallagher	AIP		
Viola Gelli	UNIFI	PhD student	0.03
Camilla Juul Hansen	MPIA	IWG7	0.03
Vanessa Hill	OCA	Science Verification	0.03
Rodrigo Ibata	ObAS	Stellar streams	0.07

Name	Affiliation	Function	FTE/yr
Pascale Jablonka	EPFL	Dwarf galaxies	0.03
Nikolay Kacharov	AIP	IWG1	0.05
Amanda Karakas	Monash		0.03
Andreas Koch-Hansen	ARI	SPB, IWG7	0.10
Iryna Kushniruk	SU	IWG7	0.10
Karin Lind	SU	IWG7, Management	0.05
Linda Lombardo	GEPI	IWG6	0.15
Romain Lucchesi	AU	IWG3, IWG2 support	0.25
Maria Lugaro	CSI CSFK	IWG3 support	0.05
Nicolas Martin	AU	Target selection	0.03
Davide Massari	OAS	Target selection	0.07
Stephanie Monty	IoA		0.03
Thomas Nordlander	ANU	IWG7	0.05
Moritz Reichert	UV	IWG1	0.15
Martina Rossi	UNIFI	PhD student	0.03
Ashley Ruiter	UNSW - SoS		0.03
Stefania Salvadori	UNIFI		0.03
Ivo Seitenzahl	UNSW - SoS		0.03
Ása Skúladóttir	UNIFI		0.40
Eline Tolstoy	RuG	Target selection, IWG2	0.08
Theodora Xylakis-Dornbusch	LSW	PhD student	0.03
Kris Youakim	SU	IWG7	0.15
Raghubar Singh	UNIFI	IWG7 (Recently hired, expected starting date 01.12.2024)	0.40
Shejeelammal Jameela	UNIFI	IWG3/IWG7 (Recently hired, expected starting date 01.01.2025)	0.40
Ioanna Koutsouridou	UNIFI	Recently hired, expected starting date: 01.11.2024.	0.10
PhD student 1 (funding secured)	UNIFI	Currently being hired (expected starting date: 01.11.2024)	0.20
Post Doc 4 (funding secured)	ANU		0.25
Total			**4.43**

6.15 Survey 15 – CHANCES: CHileAN Cluster galaxy Evolution Survey

Survey PIs: Christopher Haines and Yara Jaffé

6.15.1 Science Summary

Galaxies evolve within a dynamic web-like structure of large-scale filaments, groups and clusters. Galaxy formation and evolution studies must therefore measure observational signatures of galaxy properties against a wide range of local and global environments. The CHileAN Cluster galaxy Evolution Survey (CHANCES) as a 4MOST public survey to study the evolution of galaxies in and around ~150 clusters over the last 4 Gyr of cosmic time (z<0.45). By providing legacy spectroscopic support for the eROSITA X-ray mission, it will uniquely complement and benefit from the 4MOST-eROSITA consortium survey. CHANCES will provide comprehensive spectroscopic coverage of massive clusters in the local Universe, pushing well beyond the virial radius to cover the surrounding infall regions as far out as $5r_{200}$ from the cluster. This is needed to understand the effects of pre-processing on galaxies within infalling X-ray groups and filaments in a large sample of clusters and to unprecedented detail. The survey will push cluster galaxy evolution studies to the dwarf galaxy regime (10^8 -10^9 Msun) where environment is expected to play a major role, and at the same time will harness background QSO sight lines in order to probe the effect of clusters on the gaseous content of galaxies at z>0.35. Together, the three sub-surveys of CHANCES will go fainter (dwarfs), further in redshift space (evolution) and with a more holistic approach (gas and stars) than ever before in cluster science.

Expanded science description: messenger-no190-31-33.pdf

6.15.2 Target Catalogue

The S15 CHANCES survey is composed of 6 different subsurveys split into 3 science cases:

CHANCES LOW-Z: S1501, S1505 and S1506 - The low-redshift galaxy cluster sub-surveys. Galaxies are selected within $5r_{200}$ of 50 nearby galaxy clusters at z<0.07 as well as over the entirety of two superclusters.

CHANCES EVOLUTION: S1502 - The Evolution sub-survey. Galaxies are selected within $5r_{200}$ of 50 massive galaxy clusters evenly distributed over the redshift range 0.07<z<0.45, selected from the second Planck catalogue of Sunyaev-Zeldovich sources (PSZ2) which provides a homogenous all-sky sample of massive clusters over this redshift range. At 0.2<z<0.45, clusters are selected as having $M_{500,SZ}>7\times10^{14}$ Msun, while at lower redshifts, the mass limit is progressively reduced to account for the smaller volume available.

CHANCES CGM: S1503 and S1504 - The circumgalactic medium (CGM) subsurveys. QSO (including QSO candidates)are selected to lie behind (within 6 Mpc) massive galaxy clusters at z>0.35, such that any MgII absorption systems associated with cluster (and its surroundings) galaxies are redshifted into the 4MOST wavelength range. We then target galaxies within 1 arcmin of each QSO (covering CGM scales) with the aim to identify the host galaxy (or host halo) of the MgII absorption system and/or place upper limits on the presence of MgII absorbing gas.

The fundamental global properties of each of the main clusters being targetted in both the CHANCES LOW-Z and CHANCES EVOLUTION sub-surveys have been determined by previous X-ray (based on ROSAT data) and Sunyaev-Zel'dovich (Planck, ACT) surveys, and their redshifts are already known, permitting us to derive robust estimates of the mass (m200) and virial radius (r200) of each cluster in the survey. These are required for us to define the regions within which to target candidate cluster galaxies within 5r200 of each cluster. Details of the fundamental global properties, redshifts and how they have been compiled, confirmed and calibrated, will be published in the main survey paper (Haines et al. in preparation) and the CHANCES cluster sample paper (Sifón et al. in preparation).

Target galaxies for all sub-surveys will be extracted from the DESI Legacy Survey DR10 optical catalogues. The low-z and evolution sub-surveys are specifically designed to target likely member galaxies around each massive galaxy cluster, and hence require accurate photometric redshift estimates to efficiently target galaxies within a narrow redshift range around each cluster ($|z_{galaxy}-z_{cluster}|<0.02$), and efficiently exclude clearly foreground or background galaxies who lie at quite different redshifts ($|z_{galaxy}-z_{cluster}|>0.1$). The CGM survey (S1504) will target all galaxies within 1 arcmin of their corresponding QSOs (S1503) brighter than a given magnitude (magnitude limited survey; see below).

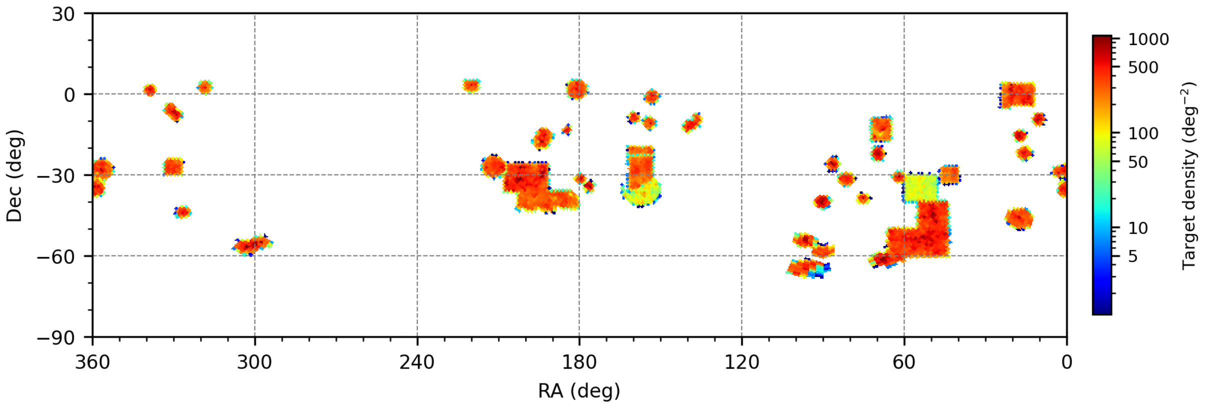
For each galaxy cluster in the CHANCES low-z sub-surveys (S1501, S1505 and S1506), 4MOST targets are first selected from the LSDR10 as galaxies brighter than r_{AB}=20.5 and within $5r_{200}$ of the cluster centre. We then use a combination of photometric redshifts as well as colour.magnitude information to assign cluster membership. In particular, we use publicly available phoeomtetric redshifts from Legacy Survey, or own photometric redshift estimtions using the same data, and photometric redshifts derived from the Southern Photometric Local Universe Survey (S-PLUS), which is imaging 8000deg^2 of the Southern sky in 12 optical bands to r_{AB}~21 using the T80-South 0.8m telescope at the Cerro Tololo Inter-American Observatory in Chile. The S-PLUS photometric system has been shown to deliver much more accurate photometric redshifts than standard broadband surveys. Additionally, we have been carrying out our own T80 observing program to cover those z~0.05 clusters outside the S-PLUS main survey footprint, including the entirety of the Shapley supercluster.

S1501 focuses on galaxies brighter than r_{AB}=18.5, where photometric redshifts are most reliable. this is also the regime where we aim to obtain a higher S/N (>10-20) which allows us to study several galaxy properties such as star formation rates in addition to the redshift. We target galaxies which are consider mambers by any of the photometric redshifts available. S1505 selects photometric members as in S1501 but in the range $18.5 < r_{AB} < 20.5$. In this magnitude range the photometric redshifts are naturally less accurate and the selection is less complete. Also, for S1505 we will reach a lower S/N, enough to measure a redshift. Given the difficulty of selecting all cluster members with photometric redshifts at these fainter magnitudes, we add an additional sub-survey S1506, which contains the same targets as S1505 plus an additional selection of galaxies inside the red sequence at $18.5 < r_{AB} < 20.5$.

For each galaxy cluster in S1502, 4MOST targets are first selected from the LSDR10 as galaxies within $5r_{200}$ of the cluster centre. To select galaxies most likely to be cluster members we use photometric redshift estimates from the LS DR9/10 photometric redshift catalogues from the Legacy Survey database. These are based on LS DR9/10 gr(i)z photometry (i-band only in DR10) combined with forced photometry of the WISE W1 and W2 images. Where available we also use deep VIRCAM J- and K-band photometry from two programs that targeted massive clusters observable from Paranal, taking advantage of the empirical finding that galaxies at a single redshift (e.g. cluster members) lie along a single tight linear relation in the (J-K)/K colour-magnitude diagram, independent of their star-formation history (i.e. star-forming galaxies lie on the same relation as quiescent ones). Additionally, over the redshift range of CHANCES (0<z<0.5), this linear relation shifts steadily to redder J-K colours with increasing redshift, rendering the (J-K)/K plane an effective spectral-type-independent photometric redshift proxy over 0<z<0.5.

The CHANCES CGM targets are selected as follow. First, a sample of background QSOs (S1503) are selected to lie at specific impact parameters from foreground clusters and within Declinations within -60 deg< Dec.<+4.5 deg. The majority of our QSO targets (blind sample) are drawn from the 4MOST S0601 targets as parent sample (and thus are technically QSO candidates), and are selected to be brighter than g<20.5 mag and to lie at impact parameters < 6 Mpc from galaxy clusters at 0.35< z<0.7 identified in the optical. Some of our QSOs are confirmed QSOs from the SDSS survey selected to be brighter than g<21 mag with (targeted sample) and without (control sample 1) MgII absorbers at the foreground cluster's redshifts plus another sample corresponding to QSOs with MgII at impact parameters > 6 Mpc of foreground clusters (control sample 2). Control sample 1 is selected to have a similar impact parameter distribution as our targeted sample, while both our control samples are selected to have a similar distribution of cluster richnesses (masses) and redshifts as our targeted sample. We also include a small sample of QSOs selected to be brighter than g<22 mag and at < 6 Mpc from clusters our CHANCES evolution sample (S1502) at z >0.35. In all our QSO targets we require that the best redshift estimate of the QSO (z_qso) satisfies z_qso > z_cl + Delta_v, with z_cl being the best estimate of the corresponding cluster redshift and Delta_v=5000 km/s at the cluster redshift frame. The combination of all these QSOs and QSO candidates targets correspond to our CHANCES QSO sample (S1503).

Finally, a sample of galaxies (including galaxy candidates) are selected to be all those targets brighter than r<21 mag lying within 1 arcmin of all our CHANCES QSO targets. We do not impose any morphological criteria for these but do exclude objects with positive absolute proper motions (PM) and parallaxes (Par) as measured from the Gaia DR3 survey. Specifically, we exclude those with PM/PM_err>3 or Par/Par_err>3. All these galaxy candidate targets correspond to our CHANCES CGM sample (S1504).



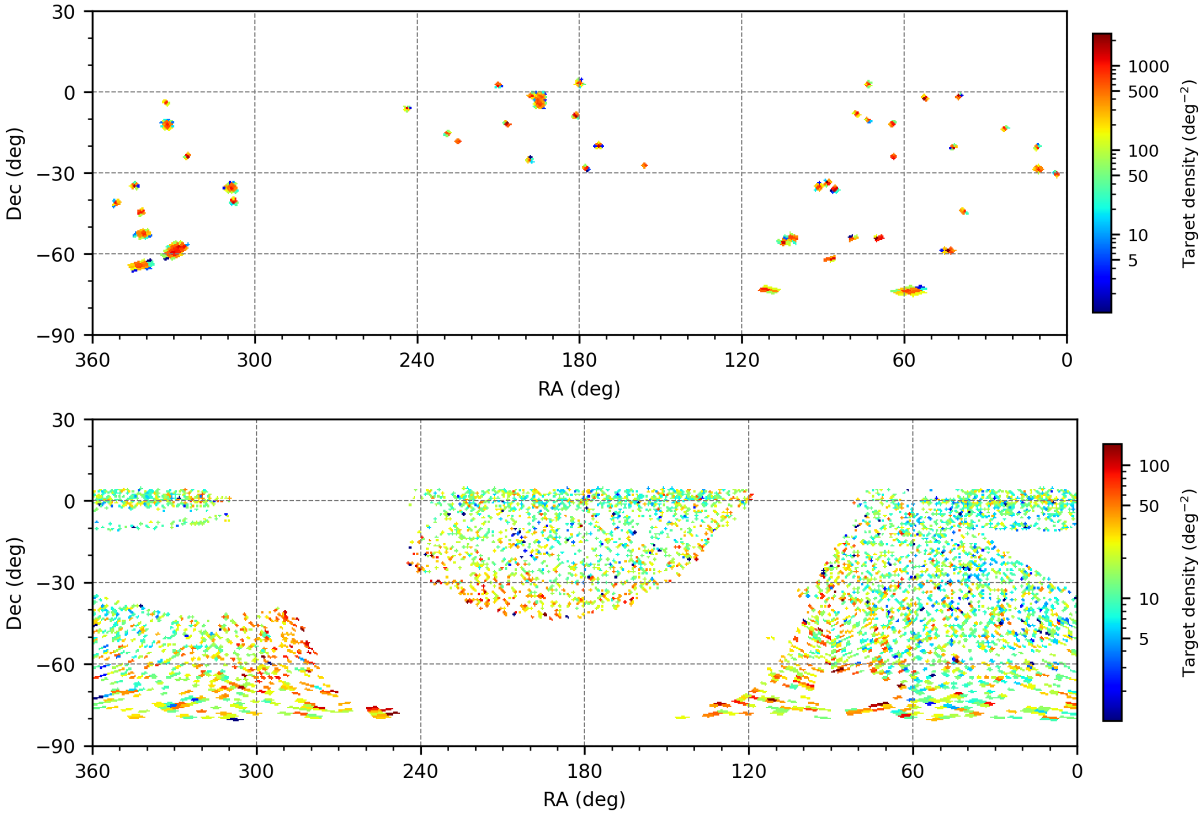
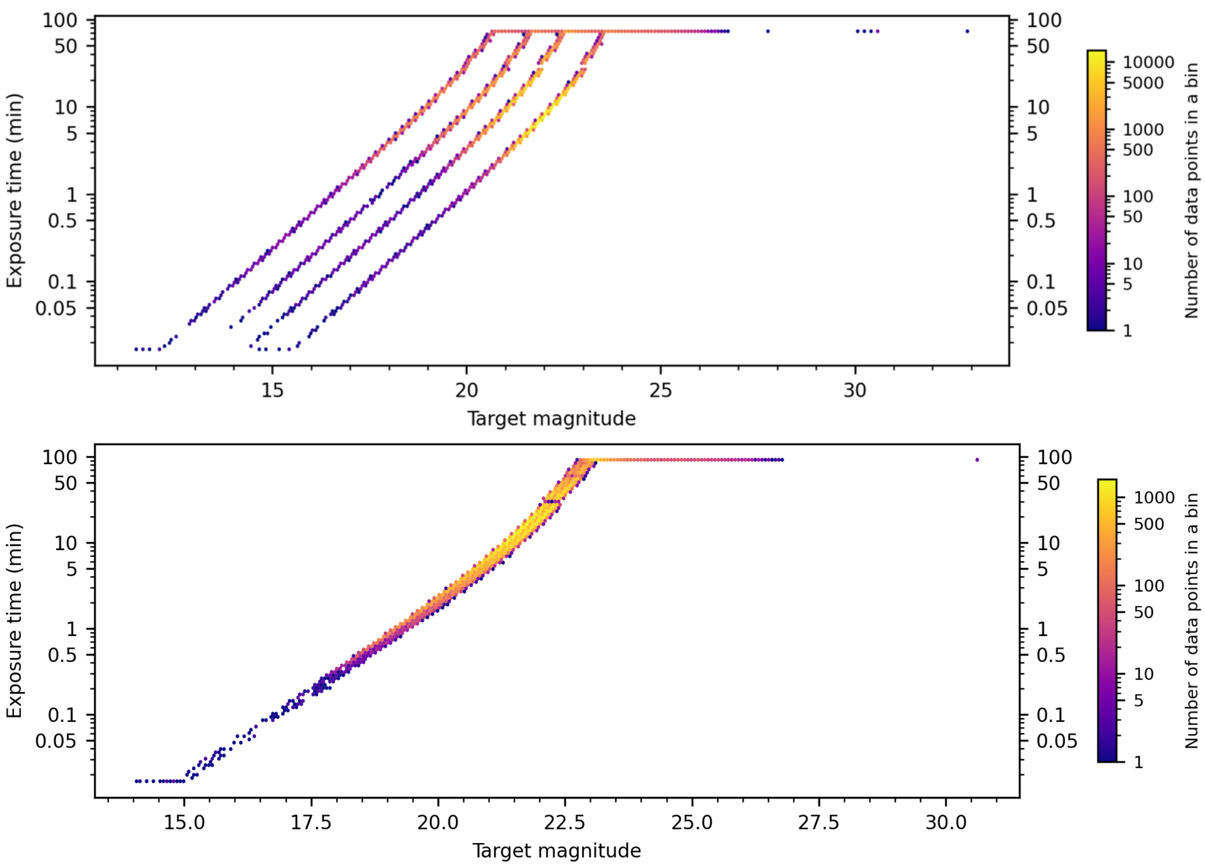


Figure 52: Input target distribution of the S15 sub surveys LowZ, Evolution, QSO, from top to bottom.



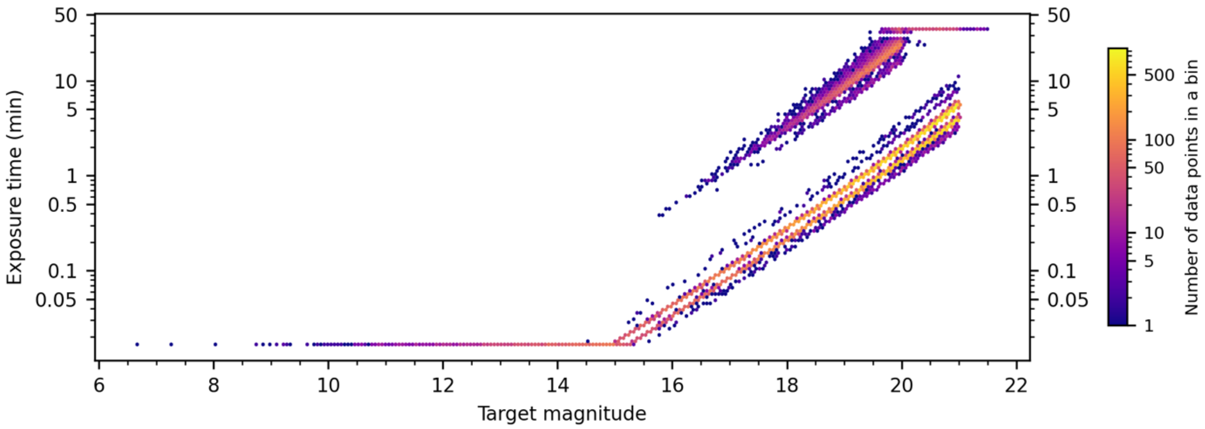


Figure 53: Exposure time estimates as a function of target magnitude for the LowZ, Evolution, and QSO sub surveys from top to bottom.

The input target sky density is shown in Figure 52. The S15 survey aims to cover the German half of the eROSITA sky with a footprint that matches the S5 survey. The LowZ sub survey requires S/N > 20 per A for targets with r<17.2. The Evolution sub survey requires S/N>5 per A and the QSO sub survey requires SNR>10 per A. The exposure times to reach these S/N is shown in Figure 53.

<u>S15 Summary</u>

Table 32: Key parameters of the input target catalogue of the S15 Survey.

N	Sub	Name	Res	Cadence	Date earliest Date latest	RA range DEC range	Epoch	TMAX [min]	AREQ [deg²]	Fcom	FH_D [kH]	FH_G [kH]	FH_B [kH]	FH_S [kH]	N targets	Rule WL range [A]
111	S1501	LowZ	LR	(0, 0, 0, 0)	59945.5 – 59945.5 62501.5 – 62501.5	0.0 – 360.0 -68.1 – 5.0	2000.0	120 (G)	2086	0.841	321	352	691	1315	570804	6000.0 – 6700.0
112	S1502	Evolution	LR	(0, 0, 0, 0)	59945.5 – 59945.5 62501.5 – 62501.5	2.7 – 352.3 -75.3 – 4.5	2000.0	120 (G)	564	0.794	108	118	187	306	142435	7200.0 – 9000.0
113	S1503	QSO	LR	(0, 0, 0, 0)	59945.5 – 59945.5 62501.5 – 62501.5	0.0 – 360.0 -80.0 – 4.5	2000.0	60 (G)	10000	0.794	31.9	23.7	18.7	21.4	83964	4200.0 – 9000.0

S15 uses the Scope-of-Survey FoM definition. The key input parameters for S15 are listed in Table 32. The S15 Low-z sub surveys needs a completeness of ~90% to reach its FoM requirement. The Evolution and QSO sub surveys reach their FoM requirement with a completeness of 87%.

6.15.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.15.4 Management structure

S15 has a management team (Table 33) led by the two PIs, and composed of five additional people representing different areas of expertise and the 3 subsurveys: Chris Haines is the coPI and also represents the S1502 subsurvey along with Ricardo Demarco. Yara Jaffé is the CoPI and also represents the S1501, S1505 and S1506 subsurvey along with Antonela Monachesi, and Paola Merluzzi. Nicolas Tejos represents S15.03 and S1504, and Alexis Finoguenov brings expertise on the 4FS, selection and characterisation of the galaxy clusters to be targeted by CHANCES, and synergies with other surveys. The CHANCES management team meets weekly over zoom and also organises separate in-person or virtual meetings with the working groups and the general team regularly to make sure each group is working smoothly and everyone is up to date with the survey progress and next pending tasks.

A description of the different WP within S15 is described in Section 6.15.5 with the FTE contributions of the survey members listed in Table 34 and the contributions to the 4MOST IWGs listed in Section 5.15.6.

S15 data products are expected to be delivered through the 4XP workflow and the survey is planning to use the tools, procedures, and available hardware of the IWGs.

Table 33: The S15 management team

Position	Name	FTE/yr	Institute
CoPI	Christopher Haines	0.6	Universidad de Atacama, Chile
CoPI	Yara Jaffé	0.65	Universidad de ValparaísoTécnica Federico Santa María, Chile
	Ricardo Demarco	0.2	Universidad de Concepción, Chile
	Alexis Finoguenov	0.3	Helsinki University, Finland
	Paola Merluzzi	0.25	INAF - Osservatorio Astronomico di Capodimonte, Naples, Italy
	Antonela Monachesi	0.35	Universidad de La Serena, Chile
	Nicolás Tejos	0.2	Pontificia Universidad Católica de Valparaíso, Chile

6.15.5 Work-breakdown structure

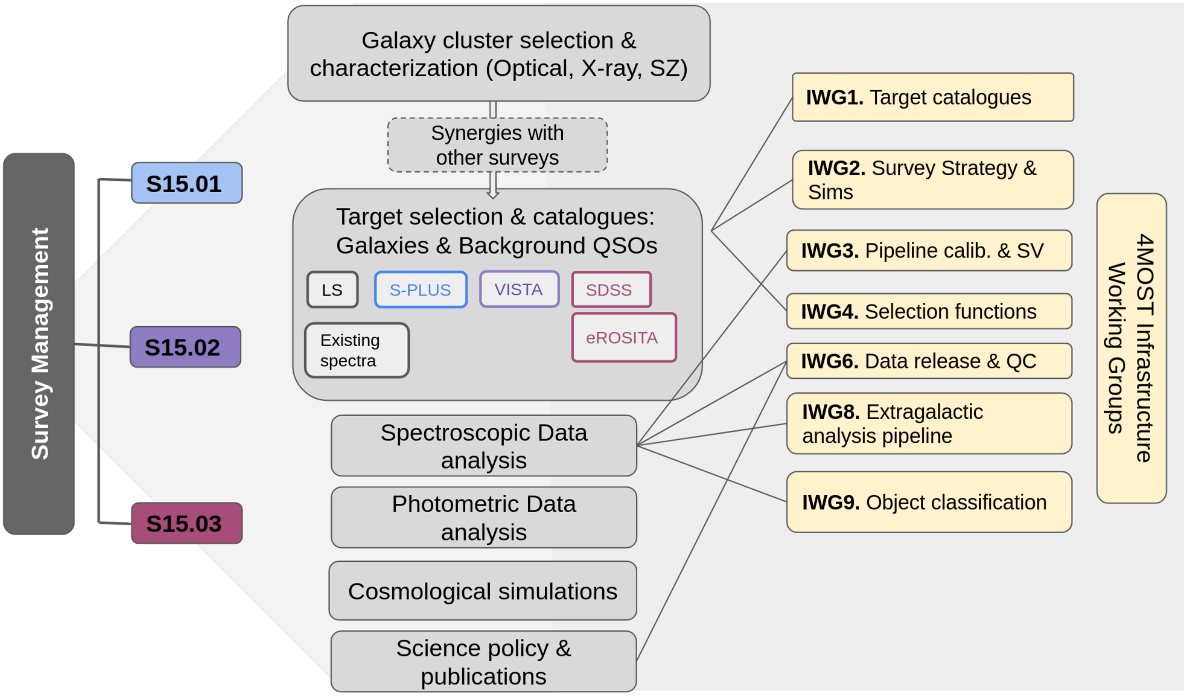


Figure 54: Work Breakdown structure for S15.

S15 has three sub-surveys, S15.01, S15.02, and S15.03, with different observational requirements. For S15.01, S15.02 the overall strategy and data for cluster and target selections are very similar and much of the working data are shared between the two.

Here, each WP and its connections to other WPs and IWGs is described in detail:

WP1. Survey management: S15 has a management team composed of 7 people representing the 3 sub-surveys and which supervises and defines all the WPs. The management team meets weekly and is led by the survey PIs. The different members of the management team are also leaders of several WPs and participate in IWGs.

WP2. Cluster selection & Characterisation: This group deals with the cluster selection function for S15.01,S1505, S1506 and S15.02 using the best available optical, X-rays and SZ data, as well as considering overlap with other 4MOST and external multi-wavelength surveys (WP **Synergies with other surveys**). This group's work is split into several smaller tasks:

WP2.1. X-ray data compilation: identification of extended ROSAT All Sky Survey (RASS) sources for the CHANCES LOW-Z (S1501, S1505, S1506) using 2MRS survey. Identification of all RASS sources using redMaPPer and legacy survey imaging data from DR10. Analysis of XMM-Newton data on CHANCES Evolution (S1502) survey and selecting a redshift-Lx range where this coverage is complete. Completing the cluster selection using information from S5 on eROSITA cluster detection and identification in DR10. Characterization of clusters using public data: XMM-Newton, Chandra, eROSITA (upon public availability). Leading XMM-Newton proposals on completion of the deep X-ray coverage of the CHANCES Evolution survey. Detecting X-ray AGN in the cluster fields and providing them to CHANCES QSO (S15-03) survey.

WP2.2. Optical data compilation, which includes cluster richness measurements using redMapper with LS imaging data DR10. Area selection for 15.01, based on the availability of S-PLUS data, and synergies with other optical surveys.

WP2.3. Compiling and maintaining the thermal SZ cluster catalogues from Planck, SPT and ACT.

WP2.4. Cluster selection function, data homogenization and cluster characterization. Within this group we also generate homogeneous cluster characterization quantities such as cluster virial radius.

WP3. Target Selection & Catalogues: This group coordinates all the efforts dedicated to constructing the catalogues and performing careful target selection (galaxies and background QSOs). This WP will work together with the IWG2 Survey Strategy and simulations that will define, based on the scientific goal of each sub-survey, the S/N, limiting magnitude and exposure times needed for each target. It also interacts with IWG4 (selection functions) and of course IWG1 (Target catalogues).

The work of WP3 is split into several smaller tasks:
At the early stage of the survey mocks were used as target inputs, and these are gradually being replaced by real targets. The baseline for real target catalogues are optical photometric catalogues extracted from LS DR10 (which includes a star-galaxy separation), and a compilation of all available spectroscopic redshifts in the areas of interest. In summary this is split into the following sub-groups:

WP3.01: Mock catalogues

WP3.02: Base LS catalogue construction
WP3.03: Compilation of redshifts from the literature.
WP3.04. Target selection for S1501, S1505, S1506. Combines the LS catalogues with S-PLUS to select galaxies via (accurate multi-band) photometric redshifts that place them inside the clusters and surrounding structures.
WP3.05 Target selection for S1502. Combines the LS catalogues with IR data from VISTA.
WP3.06 Target selection for S1503 and S1504. Has 3 different target selection strategies.

WP4. Spectroscopic data analysis: this group oversees managing the spectroscopic work of the survey by defining the different strategies, establishing criteria, and overseeing all the technical and scientific activities of the different sub teams in charge of processing, analysing and interpreting the data according to the needs and goals of each sub survey.

WP5. Photometric data analysis: this group is in charge of extracting and/or compiling photometric parameters from complementary surveys (e.g. LS, SPLUS, VISTA, and HI surveys) including galaxy structural parameters, stellar mass and sizes.

WP6. Cosmological simulations: S15 has a group of external and internal collaborators with access to state-of-the-art cosmological simulations which will be used for scientific exploitation of the data.

WP7. Science policy and publications: will manage all new science projects advertised and papers written by the team, including PhD projects, master student projects and postdoc research plans, making sure there are no conflicts and we follow our internal science policy and that of 4MOST.

6.15.6 Contribution to the Infrastructure Working Groups

IWG1
Emanuela Pompei is the CHANCES representative in IWG1. She collaborates with IWG1 i) attending the meetings; ii) informing the survey team about the IWG1 activities and decisions; iii) making possible requests from CHANCES about the input catalogues validation; iv) ensuring that the survey requirements for the input catalogue meet those of 4MOST; iv) contributing to assemble the suitable documentation for the input catalogues description.

IWG2
Alexis Finoguenov is the CHANCES representative in IWG2. He participates in the meetings and thus is in charge of updating the survey team about the activities of IWG2. His main tasks is i) to analyse the simulations related to CHANCES; ii) to investigate how to improve the results enhancing the success of the survey and iii) to accommodate IWG2 requirements for catalogue preparation.

IWG3
Emanuela Pompei is the CHANCES representative in IWG3. In particular, we would like to participate in IWG3: design the calibrations, training and validation sample for the extragalactic pipeline.

IWG4
Sean McGee is the CHANCES representative in IWG4. Beyond the needed information exchange between the IWG and the survey team, his tasks include i) to analyse the trends of the selection functions for the survey and ii) to suggest possible strategies to improve the success of the survey enhancing the probability to observe CHANCES targets.

IWG6

Maria Argudo Fernandez recently joined the IWG6 as CHANCES representative.

IWG8

Giuseppe D'Ago and Alessia Moretti are part of IWG8. By attending the meetings they ensure that the survey team is fully updated about the progress of IWG8. They participate in the discussion on the extragalactic pipeline. Giuseppe D'Ago has developed a wrapper for the automatic redshift measurements and spectral analysis. This could be applied to the reduced 4MOST spectra which will be observed for CHANCES and possibly generally applied to 4MOST data.

6.15.7 Level-1 data reduction reprocessing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.15.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey S15 will be processed by the 4XP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
Further to the standard data products from the common 4MOST pipelines, S15 will provide a Survey-derived data product (DL2-SURV). This data product is described in the following subsections.

6.15.8.1 Deliverable L2 Survey data: reduction processing

S15 will provide cluster memberships after 50% completeness has been reached for any given cluster, when averaged over the full infall regions to 5 x R_{200}. This completeness requirement is needed to prevent cases with very non-uniform coverage over the infall regions such that the surrounding large-scale structure cannot be reliably mapped. Cluster catalogues with properties computed from their memberships lists will be published as DR2-SURV data products associated with publication(s). The data release will occur at the next PDR following the article publication. S15 is requesting that the long-term scheduler prioritises completing cluster observations before new clusters are observed, but of course there are many competing requirements, and so we cannot yet predict in advance how many clusters will be included in each DR.

6.15.8.2 Deliverable L2 Survey data: quality assessment

Quality control will curate data that are demonstrably wrong (systematic error far outside formal error, e.g. wavelengths outside arm range) and will add flags to create warnings for possibly unreliable data.

6.15.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

S15 will release the cluster memberships though ESO phase 3 after they have been released in dedicated publications where the methodology is described in detail.

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for

DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.

Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.15.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

The DL2-SURV product of this Survey will be delivered in the first DR after publication.

6.15.8.5 Deliverable L2 Survey data: Required hardware and staff

The required hardware for creating the DL2-SURV product can be handled by existing hardware and a dedicated post-doc.

6.15.8.6 Additional L2 data: reduction processing

No extra AL2 reduction is planned by this Survey.

6.15.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.15.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 data are planned by this Survey.

6.15.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 products are planned by this Survey.

6.15.8.10 Additional L2 data: Required hardware and staff

No extra AL2 hardware and staff is planned by this Survey.

6.15.9 Team

Table 34: S15 Team members

Name	Function	Institute	FTEs/yr
Chris Haines	CoPI,WP1,WP3,WP5, WP7	UdA	0.65
Yara Jaffé	CoPI,WP1,WP3,WP7, WP5	USMV	0.65
Ricardo Demarco	WP1, WP4	UdeC	0.2

Name	Function	Institute	FTEs/yr
Alexis Finoguenov	WP1, WP2, IWG2	Univ. Helsinki	0.3
Paola Merluzzi	WP1, WP3, WP7, SPB	OAC	0.25
Antonela Monachesi	WP1, WP3, WP7, WP5	ULS	0.35
Nicolas Tejos	WP1, WP3, WP7	PUCV	0.2
Cristobal Sifon	WP2, WP7	PUCV	0.2
Laerte Sodre	WP3, WP5, WP7	USP	0.2
PhD Student 1 (Erik Vinicius Lima)	WP3	USP	0.6
PhD Student 2 (Amrutha Belwadi)	WP3	UdA	0.8
PhD Student 3 (Simon Véliz)	WP5	ULS	0.7
PhD Student 4 (Raul Baier)	WP3, WP5	USM	0.7
PhD Student (Franco Piraino)	WP3, WP5	USM	0.7
Master Student 1 (Elismar Lösch)	WP3	USP	0.7
Master Student 2 (Rodrigo Cuellar*)	WP3	UC	0.2
Master Student 3 (to start in 2023)	WP5	UV	0.7
Postdoc 1 (Giuseppe D'Ago)	WP3, WP5, IWG8	PUC/CATA	0.2
Postdoc 2 (Lawrence Bilton)	WP3, WP5	UV/PUCV	0.3
Postdoc 3 (Ciria Lima Dias, started April 2023)	WP3, WP5	ULS	0.8

Name	Function	Institute	FTEs/yr
Postdoc 4 (Hugo Mendez, started April 2023)	WP3, WP5	ULS	0.8
Postdoc 5 (Diego Pallero, To start soon)	WP6	UV	0.2
Postdoc 6 (Jacob Crossett)	WP5	UV/Birmingham	0.05
Analía Smith-Castelli	WP3	IALP	0.2
Sergio Torres Flores	WP3	ULS	0.1
Emanuela Pompei	IWG1, WP4, IWG3, WP2	ESO	0.1
Lorenzo Morelli	WP4	UdA	0.1
Bianca Poggianti	IWG8, WP4	INAF	0.075
Alessia Moretti	WP4	Univ. Padova	0.1
Sean McGee	IWG4, WP7	Univ. Birmingham	0.05
Ivan Lacerna	WP4	UdA	0.05
Maria Argudo Fernandez	WP4, IWG6, WP5	IAA, Granada	0.1
Raphael Gobat	WP4	PUCV	0.05
Ulrike Kuchner	WP5, WP6	Univ. Nottingham	0.05
Veronica Motta	WP4	UV	0.05
Julie Nantais	WP4	UNAB	0.01
Giovanni Busarello	WP3	INAF	0.05
Lucas Gabriel Silva	WP3	USP	0.05
Sebastian Lopez	WP3	UC	0.05
Edo Ibar	WP2, WP4	UV	0.01

Name	**Function**	**Institute**	**FTEs/yr**
Arianna Cortesi	WP5, WP3	Observatory of Valongo	0.05
Claudia Mendes de Oliveira	WP3, WP5	USP	0.05
Graham P. Smith	WP3	Univ. Birmingham	0.01
Marco Gullieuszik	WP5	INAF	0.01
Matteo Bianconi	WP5	Univ. Birmingham	0.01
Paul Eigenthaler	WP5	PUC	0.01
Alfredo Zenteno	WP3	NOIRLab	0.01
Johan Comparat	WP3	MPE	0.1
Pascale Jablonka	WP5	EPFL	0.01

In addition to the team members listed above, the CHANCES team is also hiring two postdocs who should start in the next few months, and at least one of them will devote most of their time to WP4 and spectroscopic analysis.

6.16 Survey 16 – Chilean AGN/Galaxy Evolution (ChANGES)

Survey PIs: Franz Erik Bauer, Paulina Lira

6.16.1 Science Summary

ChANGES will target a legacy sample of active galactic nuclei (AGN), based on optical continuum variability and spectral energy distribution (SED) selection from several existing surveys, and ultimately complemented by VRO/LSST to: 1) constrain the low-MBH, low-L/LEdd end of the accretion and black hole (BH) density functions to z~1, and, by extension, BH seed models; 2) investigate correlations among AGN (MBH, L/LEdd, UV slope, outflows, variability) and host properties (stellar age, metallicity, kinematics); 3) confirm/characterize rare BH subsamples (extreme variability, tidal disruption events, lensed, intervening absorption line systems) for detailed multi-wavelength follow-up studies.

Expanded science description: [messenger-no190-34-37.pdf]

6.16.2 Target Catalogue

S16 is divided into 12 subsurveys based on a handful of detailed science goals and distinct associated selection criteria. Two general selection criteria dominate the statistics, with 59% of targets found in the main variability selection subsurveys (W_VARZ/S1601, W_VARL/S1602, W_VARG/S1603, W_MUL/S1605, T_LST/S1609) and 40% in the main SED selection surveys (W_SED/S1604, W_HIZ/S1606, T_LST/S1609, T_LEN/S1610, D_ALL/S1611, M_SED/S1612). The total number of proposed unique candidate targets considering all subsurveys is ~3e6, of which we aim to observe at least ~1.2e6.

In particular, subsurveys S1601, S1602, S1603, and S1609 seek to characterize the variable AGN population in the optical, which is complementary to the classical selection methods of blue colors and/or X-ray detections. Selection has been carried out using optical time domain surveys ZTF (rAB < 21.5, 5 > δ > -30°, Ar < 0.5; S1601), LSQ (rAB < 22.5, 5 > δ > -80°, Ar < 0.5; S1602), and GAIA (rAB < 22.5, 5 > δ > -80°, Ar < 0.5; S1603), based on a balanced random forest classifier as described in Sánchez-Sáez+2021. These are built upon precursor imaging surveys, and will be supplemented by target-of-opportunity observations of variable AGN selected from LSST (rAB < 22, 5 > δ > -80°, Ar < 0.5; S1609) light curves. Finally, a subset of bright targets (rAB < 20) from S1601, S1602, and S1603 will be targeted for multiple epochs, separated by >6 months to characterize spectral variability.

Subsurveys S1604 and S1612 broadly target AGN selected by their optical-NIR-MIR SEDs, as characterized using DELVE+VHS+WISE photometry. Due to their scientific importance but relative rarity, we split out SED-selected AGN which are likely to lie at high redshift as S1606 (zAB < 23, 5 > δ > -80°, Ar < 0.5, SED-fitting, zphot>4.5, numerous redshift-dependent color dropout and interloper cuts) and candidate lensed AGN selected from multi-filter DECam, HSC and eventually LSST imaging as S1610 (rAB < 22, 5 > δ > -80°, Ar < 0.5), respectively. We additionally target all known AGN (selection on X-ray, radio, optical-NIR-MIR SED, and variability) in the central portions of four LSST Deep Drilling Fields (single 4MOST pointings for CDF-S, XMM-LSS, ELAIS-S1 and COSMOS), in order to make obscuration and bias corrections.

Finally, subsurvey S1607 (T_TDE) selects as targets-of-opportunity any active tidal disruption events involving stars and massive black holes with rAB < 21.5, 5 > δ > -80°, and Ar < 0.5, arising from the alert streams of all time domain surveys (e.g., ZTF, ATLAS, LS4, BlackGEM, Gaia, and eventually LSST), selecting using a balanced random forest classifier, as described in Sánchez-Sáez+2021, or similar. Subsurvey S1608 (T_TDEHOST) targets the host galaxies (rAB < 21.5, 5 > δ > -80°, and Ar < 0.5) for a larger set of past TDEs, aiming for redshifts and host galaxy properties.

Not all of this area needs to be observed, but having such a wide distribution of potential targets allows for maximum observing flexibility. The requested completeness values for these subsurveys range from 10% (T_TDE) to 80% (D_ALL). Median S/N requirements range from ~2-3 (redshift only) up to 10 (physical constraints on stellar populations and SMBHs), with resulting exposure time estimates ranging from minutes to a few hours.

S16 will greatly benefit from or be enhanced by synergistic cadencing with the Vera Rubin Observatory's Legacy Survey of Space and Time (LSST).

Individual Subsurvey Scientific FoMs are based on linear functions of the number of completed targets to number required, while the overall Scientific FoMs is a weighted average of each subsurvey, weighting more strongly the FoMs of the surveys which perform worse than the best ones.

6.16.3 Scheduling requirements

Subsurveys W_MUL, T_TDE, T_TDEHOST, T_LST, T_LEN have special scheduling requirements in order to observe the AGN and SMBH-related transients in desired states of variability. Specifically, W_MUL aims to observe a subset of brighter (rAB < 20) targets multiple times, separated by at least 6 months. T_TDE aims to observe live tidal disruption events, while T_LST, aims to observe on-going AGN variability events. T_TDEHOST and T_LEN require identification from LSST alerts and imaging products, respectively.

6.16.4 Management Structure

The overall management of S16 is provided by the two Survey PIs, F. Bauer and P. Lira. Subsurveys have their own leaders which are specified in the presentation of the WP3, in Section 6.17.5. (A description of all different WPs within S16 is found in the same Section, including the FTE contributions and the contributions to the 4MOST common IWGs). Currently we have identified leads for all WPs presented in Section 6.17.5

Meetings between the PIs and the subsurveys leads are scheduled as needed to decide on strategies and action items. Meetings of the full S16 members are scheduled monthly. The leaders of the subsurveys will become science leads of each subsurvey as data start flowing, under the general management of the PIs.

6.16.5 Work Breakdown Structure

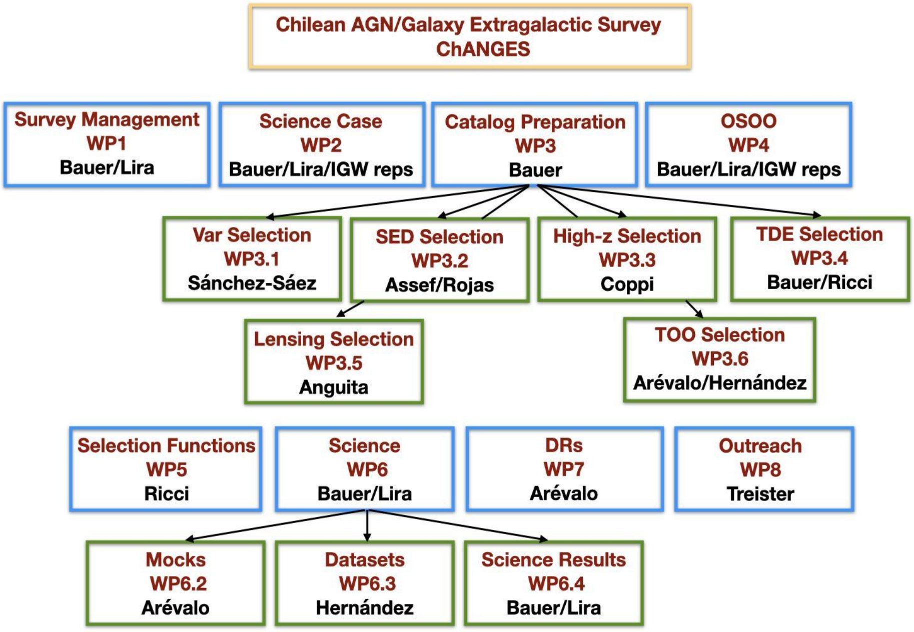


Figure 55: Work Breakdown Structure of S16

WP1: Survey Management

Key roles: PIs, WG leads, IWG representatives
Tasks:

- Organise survey at the high/science level [0.001 FTE - telecons, 0.001 FTE - emails]
- Coordinate work of different WPs [0.05 FTE - telecons, 0.05 FTE - emails]
- Coordinate interactions with 4MOST consortium and other surveys [0.025 FTE - telecons, emails]

Under PIs responsibility:

- Manage survey member list and inclusion of external members
- Represent survey interests on SCB [0.00625 FTE - telecons, 0.0125 FTE - emails]
- Write and update the SSP, SRP, SMP and ESO survey proposal [0.01 FTE]

Under IWG survey representatives' responsibility:

- Contribute to IWGs, bringing their technical expertise [0.01 FTE - telecon, outside work; x ~12 reps]
- Represent survey interests within IWGs [0.025 FTE - telecons, 0.025 FTE - emails; x ~12 reps]

Under the WG leads responsibility:

- Manage/organize individual WG efforts [0.025 FTE - telecons, 0.025 FTE - emails; x ~10 leads]

Timescale: 2022-2029
Resources: 0.66 FTE/yr, on average = 4.62 FTE total
Deliverables: Survey science and management plans. Survey strategy.

WP2: Science Case Development (including forecasts)

Key roles: PIs, WG members
Tasks: Produce forecasts for science measurements according to the characteristics of the survey [n(z) and sky distribution]. The main science cases to be forecasted are:

- AGN variability
- AGN evolution
- AGN demographics
- AGN outlier populations
- TDE populations and hosts

Timescale: 2022-2029
Resources: 0.125 FTE/yr on average = 0.875 FTE total
Deliverables: forecasts, catalogue selection functions and codes. These products are expected to feed into WP5, WP6 and WP7.

WP3: Preparation of mock and real target catalogues (link with IWG1)

Key Roles: at least one person responsible per WP3.X, plus one person responsible for overall catalog format check (the same for all sub-WP3): Bauer.
Tasks: production of all master input catalogues used as input for 4FS simulations, either from mock or real targets. Optimisation of the color / magnitude selections depending on the sub-survey, as described below.

WP3.0 Mock targets (current responsible: Bauer)

The task is to generate realistic target expectations, in collaboration with various team members.

Timescale: 2022-2023
Resources: 0.1 FTE per year on average x ~10 members during Phase 2 only = 1 FTE total
Deliverables: mock target catalogues for all target categories, containing the target properties (densities, redshift distribution, sky area) required for the science case of the survey (mimicking the real targets catalogues) and compatible with the input format for 4FS ingestion.

WP3.1 - Variable AGN real targets (current responsible: Sánchez-Sáez)

The task is to make use of all available public photometric datasets to produce Variable AGN target catalogues over the largest available area by cross-matching photometric, morphological and photometric redshift information, and applying the relevant variability selection and colour cuts as defined in [RD1] or similar.
Timescale: 2022-2029
Resources: 1 FTE in 2022, 0.4 FTE per year during rest of Phase 2 and Phase 3 (average) = 3.4 FTE total
Deliverables: master target catalog for variable AGN, containing the target properties (densities, redshift distribution) required for the science case of the survey and compatible with the input format for 4FS ingestion.

WP3.2 SED AGN real targets (current responsibles: Assef / Rojas)

The task is to make use of all available public photometric datasets to produce SED AGN target catalogues over the largest available area by cross-matching photometric, morphological and photometric redshift information, and applying the relevant colour cuts as defined in [RD1] or similar.

Timescale: 2022-2029
Resources: 1 FTE in 2022, 0.4 FTE per year during rest of Phase 2 and Phase 3 (average) = 3.4 FTE total
Deliverables: master target catalog for SED AGN, containing the target properties (densities, redshift distribution) required for the science case of the survey and compatible with the input format for 4FS ingestion.

WP3.3 High-z AGN real targets (current responsible: Bauer / Mazzucchelli)

The task is to make use of all available public photometric datasets to produce high-z AGN target catalogs over the largest available area by cross-matching photometric, morphological and photometric redshift information, and applying the relevant variability selection and color cuts as defined in [RD1] or similar.
Timescale: 2022-2029
Resources: 0.25 FTE per year during Phase 2 and 0.1 FTE per year during Phase 3 (average) = 1 FTE total
Deliverables: master target catalogue for high-z AGN, containing the target properties (densities, redshift distribution) required for the science case of the survey and compatible with the input format for 4FS ingestion.

WP3.4 TDE and host real targets (current responsibles: Bauer / Ricci)

The task is to develop TDE selection criteria, predictions, and targeting infrastructure (including ToO trigger criteria).
Timescale: 2022-2029
Resources: 0.25 FTE per year during Phase 2 and 0.3 FTE per year during Phase 3 (average) = 2 FTE total
Deliverables: master target catalog for TDEs, containing the target properties (densities, redshift distribution) required for the science case of the survey and compatible with the input format for 4FS ingestion. Management of transient API ingest and timeout/removal.

WP3.5 Lensing real targets (current responsible: Anguita)

The task is to develop lensed quasar selection criteria, predictions, and targeting infrastructure.
Timescale: 2022-2029
Resources: 0.1 FTE per year during Phase 2 and 0.25 FTE per year during Phase 3 (average) = 1.5 FTE total
Deliverables: master target catalog for lensed quasars, containing the target properties (densities, redshift distribution) required for the science case of the survey and compatible with the input format for 4FS ingestion.

WP3.6 TOO real targets (current responsibles: Bauer / Ricci / Hernandez)

The task is to develop selection and triggering criteria, predictions, and targeting infrastructure (including ToO trigger criteria) for nuclear transients and flares.
Timescale: 2022-2029
Resources: 0.1 FTE per year during Phase 2 and 0.25 FTE per year during Phase 3 (average) = 1.5 FTE total
Deliverables: master target catalog for nuclear transients and flares containing key target properties and triggering criteria required for the science case of the survey and compatible with the input format for 4FS ingestion.

WP4: Observing Strategy, Operations, Optimisation, and Quality Control

WP4.1 Observing Strategy (current responsible: Bauer)

Key roles: PIs and IWG2 representatives + all

Tasks:

The main task of this work package is to interact with IWG2 to perform simulations of the input target catalogues (either real targets or mocks) with 4FS and obtain feedback on the overall survey strategy. More precisely, the following sub-tasks are performed:

- ingest the survey target catalogues into the interface
- run the ETC from the input catalogues and check the survey scope, then validate the catalogues for 4FS simulations
- checks output from 4FS simulations, including target duplicates with other surveys and homogeneity of the output
- refine the survey parameters according to IWG2 simulation
    - restrict the input catalogue to a specific magnitude limit or sky region
    - define and optimise the Large Scale Merit, Small Scale Merit and the Science FoM of the survey
    - aim to achieve a homogeneous wide-area survey, complemented by deeper narrow-area surveys.

Timescale: 2022-2024
Resources: 0.3 FTE over the Phase 2 - 0.6 FTE total
Deliverables: the deliverables of this WP are an optimised set of survey parameters (survey area, LSM, SSM, and science FoM) at start of science operations, together with an optimised target catalogue for 4FS simulations ready for science operation.

WP4.2 Operations, Optimisation, Quality Control (current responsible: Lira)

Key Roles: PIs, IWG2, IWG3, IWG6, IWG8 and IWG9 survey representatives. Responsibility for quality checking will rotate from a pool of trained survey members, for each planned data-release.
Tasks: the tasks of this work-package are to follow the progress of the survey and the quality of the measurements during science operations. This includes the monitoring of several indicators such as:

- monitor the L2 products after data reduction, in relation with IWG6 and IWG8.
- evaluation of percentage of targets with acceptable redshift measurement
- cross-checks on source classification (quasar, galaxy, star, …) in relation with IWG9.
- evaluation of redshift measurement quality using duplicate targets or by cross-matching a small number of targets with independent surveys like DESI.
- progress of the survey as a function time. Adjust weights / survey parameters if / when possible.

This work is performed in relation with IWG8 for data analysis, as well as IWG3 for calibrations and IWG2 for any updates required on the survey.
Timescale: 2024-2029
Resources: 0.6 FTE per year averaged over Phase 3 = 3.6 FTE total

Deliverables: set of tables / plots / statistical measurements allowing all survey members to follow the progress of the survey and its quality.

WP5: Selection functions (link with IWG4; current responsible: Motta)

Key Roles: PIs and IWG4 survey representatives

Tasks: Test the selection effects due to observation constraints (observation depth, fiber collision, gaps, bright stars, stellar density, Galactic dust extinction, seeing variations …) and competition with other 4MOST surveys, which affect the homogeneity of the output catalogues. We will compute from the various effects some corrections factors that will enter in the correlation measurements.
Timescale: 2022-2029
Resources: 0.4 FTE per year averaged over Phase 2 and Phase 3 - 3 FTE total.
Deliverables: weight calculations as a function of sky position and observational constraints.

WP6: Science (current responsibles: Bauer / Lira)

Key Roles: all science project leads + everyone invited to contribute

WP6.1: AGN mocks

Tasks: replicate target catalogues and analysis performed in §7.1 to estimate error bars on measurements.

Timescale: 2022-2029, to be tested prior to the first science observations and then run whenever needed.
Resources: 0.15 FTE per year averaged over Phase 2 and Phase 3 ~ 1.1 FTE total.
Deliverables: set of target catalogues over which the analysis pipelines can be run automatically.

WP6.2: External datasets

Tasks: Cross-match targets covered with multiple probes. At minimum the measurements should use public data releases from existing imaging (DELVE, ZTF, LSQ, Gaia, VHS, WISE, LSST and Euclid) and spectroscopic (SDSS, LAMOST, DESI) surveys.

Timescale: 2022-2029
Resources: 0.3 FTE per year averaged over Phase 2 and Phase 3 = 2.4 FTE total.
Deliverables: cross-matched catalogue between 4MOST redshifts and external datasets.

WP6.3: Science results

Tasks: perform the final measurements based on the analysis pipelines (§7.1) and outputs from §7.2 and §7.3.

Timescale: 2024-2029
Resources: 2 FTE per year average over Phase 3 - 12 FTE total.
Deliverables: Scientific publications

WP7: Preparation of Data Releases (current responsible: P. Arévalo)

Tasks: Preparation of DRs in relation with IWG6

Timescale: 2024-2029
Resources: 0.2 FTE per year average over Phase 3 - 1.2 FTE total.
Deliverables: DRs after year 1, year 3 and at the end of the survey.

WP8: Communication and Outreach (current responsible: E. Treister)

Key Roles: PIs, IWG2, IWG3, IWG8 and IWG9 survey representatives.

Responsibility for communication and outreach.

Tasks: the tasks of this work-package are to produce, text, visuals and movies describing the measurements and results of the survey.

Timescale: 2024-2029
Resources: 0.02 FTE per year averaged over Phase 3 = 0.12 FTE total
Deliverables: Press releases, and participation in public events.

6.16.6 Contribution to the Infrastructure Working Groups

IWG1
The survey contributes to this IWG1 through discussions on the validation of the ETC and the limits on declination for the survey footprint. Depending on the expertise needed for specific developments some survey members could contribute further to this crucial IWG.
Ivan Katkov: 0.025FTE telecon participation, 0.025FTE correspondence, 0.0125FTE work
Franz Bauer: 0.005FTE telecon participation, 0.025FTE correspondence

IWG2
The survey contributes to this IWG2 through discussions on the simulation outputs and feedback to the IWG2 representatives. Depending on the expertise needed for specific developments some survey members could contribute further to this crucial IWG.
Fabio Vito: 0.025FTE telecon participation, 0.025FTE correspondence, 0.025FTE work
Franz Bauer: 0.013FTE telecon participation, 0.050FTE correspondence, 0.025FTE work

IWG3
The survey contributes to this IWG2 through general discussions, as well as specific contributions such as providing sets of targets to be used for calibration and commissioning. In particular it is of great importance that we observe a set of spectroscopically confirmed galaxies and quasars in order to cross-calibrate and verify the redshift measurements. This work will be carried out in close collaboration with IWG8.
Franz Bauer: 0.013FTE telecon participation, 0.025FTE correspondence, 0.05FTE work

IWG4
The survey is not currently contributing to IWG4. Based on the information found in the wiki it also seems that this IWG is not actively working since April 2022.
Paulina Lira: 0.000FTE telecon participation, 0.050FTE correspondence

IWG6
As IWG6 has only just started, the survey members only contribute through survey representation at the meeting so far.
Paulina Lira: 0.013FTE telecon participation, 0.050FTE correspondence

IWG7
S16 does not participate in this IWG.

IWG8
The survey is contributing to this IWG8 the following way:

Igor Chilingarian's spectral fitting code currently in IDL, will be converted to python to be accepted by 4MOST.

Igor Chilingarian: 0.013FTE telecons, 0.025FTE correspondence, 0.05FTE work
Kirill Grishin: 0.013FTE telecons, 0.025FTE correspondence, 0.05FTE work
Claudio Ricci: 0.000FTE telecons, 0.025FTE correspondence
Darshan Kakkad: 0.000FTE telecons, 0.025FTE correspondence
Franz Bauer: 0.000FTE telecons, 0.025FTE correspondence

IWG9

The survey is contributing to this IWG9 the following way:
Paula Sanchez-Saez: 0.025FTE telecon participation, 0.025FTE correspondence, 0.25FTE work
Paulina Lira: 0.000FTE telecon participation, 0.025FTE correspondence

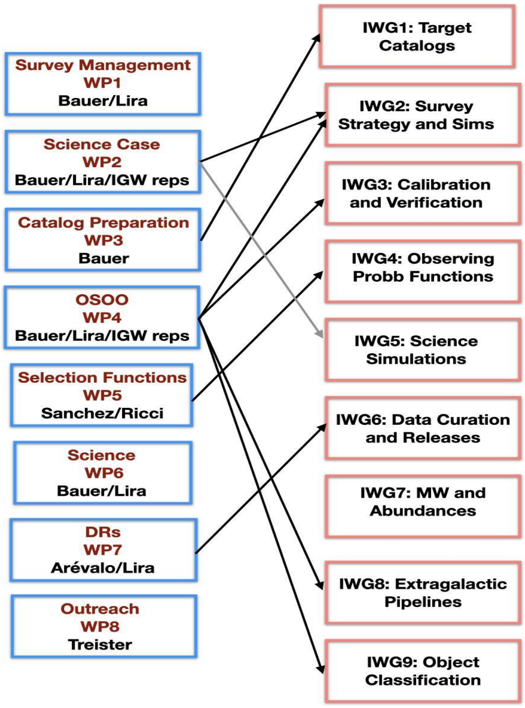


Figure 56: S16 WP to IWG interfaces

The organisational structure of S16 follows the WBS hierarchy presented in Section 6.16.5, where also the personal contributions are highlighted. A summary of the key personnel and their WP assignments can be found in Table 35.

All data products are expected to be delivered through the 4XP workflow and hence no extra tools, procedures, or hardware are needed beyond the normal tools available to scientists.

6.16.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.16.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

All targets of Survey S16 will be processed by the 4XP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
Further to the standard data products from the common 4MOST pipelines, S16 will provide Survey-derived data products (beyond L2, DL2-SURV) to be uploaded to both 4PA and ESO SAF for the data release immediately following the first publication using that data product. Such data products are described in the following subsections.

6.16.8.1 Deliverable L2 Survey data: reduction processing

Beyond what is provided by 4XP, S16 plans to create derived data product catalogues that include model-dependent estimates of: host galaxy parameters such as stellar age, metallicity, kinematics, SFR, stellar mass; AGN parameters such as AGN continuum slope, M_{BH}, L/L_{Edd} and BH-driven outflow velocity and mass when broad line(s) are present.

6.16.8.2 Deliverable L2 Survey data: quality assessment

Quality control will curate data that are demonstrably wrong (systematic error far outside formal error, e.g. wavelengths outside arm range) and will add flags to create warnings for possibly unreliable data.

6.16.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

DL2-SURV products will be derived by a custom pipeline. The output data model will follow the standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.
Once the data model has been finalized, the DL2-SURV product will follow a standard data flow. After production by the Survey's own pipeline, it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point. The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be packaged together with all other L2 data products and submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.16.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

These DL2-SURV products will be delivered to both 4PA and ESO SAF for the data release immediately following the first publication using that data product.

6.16.8.5 Deliverable L2 Survey data: Required hardware and staff

The Survey has sufficient computer hardware to process the relatively small data flow.

6.16.8.6 Additional L2 data: reduction processing

No extra AL2 reduction is planned by this Survey.

6.16.8.7 Additional L2 data: quality assessment

No extra AL2 processing is planned by this Survey.

6.16.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2 data are planned by this Survey.

6.16.8.9 Additional L2 data: product delivery schedule to the ESO archive

No extra AL2 products are planned by this Survey.

6.16.8.10 Additional L2 data: Required hardware and staff

No extra AL2 hardware and staff is planned by this Survey.

6.16.8.11 Survey-derived data products (beyond L2)

6.16.9 Team

Table 35: Survey S16 team members with their affiliation, role in S16, and total expected FTE contributions next to science exploitation.

Name	Affiliation	Function	FTE/yr
Timo Anguita	UNAB	Lead: WP 3.5 - Contrib: WP 1+2+3.0+6.3	0.25
Patricia Arevalo	UV	Lead: WP 3.6+6.2+7 - Contrib: WP 1+2+3.1+6.3	0.43
Roberto Assef	UDP	Lead: WP 3.2 - Contrib: WP 2+3.2+6.3	0.43
Franz Bauer	PUC	co-PI - SCB - membership manager - Lead: IWG3 rep, WP 1+2+3.0-3.6+4+6.0-6.4 - Contrib: IWG1, IWG2, IWG8	1.08
Igor Chilingarian	CfA	Lead: IWG8 rep - Contrib: WP 1+2+3.2+6.3	0.43
Paolo Coppi	Yale	Lead: WP 3.3 - Contrib: WP 1+2+3.1+6.3	0.43
Demetra De Cicco	NAP	Contrib: WP 2+3.0+6.3	0.10
Kirill Grishin (PhD)	APC	Contrib: IWG8, WP 6.3	0.10
Lorena Hernández-García	UV	Lead: WP3.6+6.3 - Contrib: WP 1+2+6.3	0.16
Darshan Kakkad	STScI	Contrib: IWG8, WP 6.3	0.05
Ivan Katkov	NYUAD	Lead: IWG1 rep - Contrib: WP 1+6.3	0.07
Paulina Lira	DAS	co-PI - Lead: IWG6 rep - Contrib: WP 1+2+3.1+4+6.0-6.4	0.80
Chiara Mazzucchelli	UDP	Contrib: WP 2+3.3+6.3	0.23
Veronica Motta	UV	Lead: IWG4 rep, WP5 - Contrib: WP 6.3	0.20
Federica Ricci	Rm3	Contrib: WP 6.3, General	0.03
Claudio Ricci	UDP	Lead: WP 5 - Contrib: WP 1+2+3.4+3.6+6.3	0.25
Alejandra Rojas	UDP/UA	Lead: WP 3.2 - Contrib: WP 1+2+3.2+6.3	0.43
Paula Sánchez-Sáez	ESO	Lead: IWG9 rep, WP 3.1 - Contrib: WP1+2+3.0+4+6.3	0.90
Victoria Toptun (PhD)	LMSU	Contrib: WP3.2+6.3	0.20

Name	Affiliation	Function	FTE/yr
Ezequiel Treister	PUC	Lead: WP 8 - Contrib: WP 1+2+6.3	0.05
Fabio Vito	OAS	Lead: IWG2 rep - Contrib: WP 1+2+6.3	0.08

6.17 Survey 17 – Understanding the Baryon Cycle with High-Resolution QSO Spectroscopy (ByCycle)

Survey PI: Celine Peroux

6.17.1 Science Summary

The Circumgalactic Medium (CGM) is central to our understanding of the baryon cycle including the connection between gas, stars and metals. Absorption lines detected against background quasars offer a compelling way to study this CGM. Given that absorption measurements are limited to pencil-beams along the sightline, only a large sample of quasar absorbers will enable a major breakthrough. Here, we propose to use the powerful synergy of absorption and emission diagnostics by observing a sizable sample of background quasars and foreground galaxies in the same fields. We propose to cross-correlate 4MOST HRS observations of the quasars with GTO LRS galaxy surveys (including WAVES Deep, CRS Luminous Red Galaxies and Emission Lines Galaxies) over the same area. We will measure the radial profile, covering fraction and optical depth of the neutral hydrogen and metals in their CGM. At high-redshift, we will build an unprecedented catalogue of Lya absorbers (DLA and LLS), measure their dust-free and ionisation-corrected metallicity to reappraise the missing metals problem. Together, these results will redefine our view of the CGM and provide a definite census of the cosmic metals. This long-lasting legacy dataset will bring high-resolution quasar spectroscopy to a new level by providing 249,000 intervening quasar absorber systems to be correlated with 1 million foreground galaxies & a grand total of 925,000 R=20,000 high-redshift background quasar spectra - a 3 orders of magnitude increase over currently available samples.

Expanded science description: [messenger-no190-42-45.pdf]

6.17.2 Target Catalogue

The ByCycle survey strategy requires an a priori knowledge that the quasar's redshift is greater than z = 0.55 to ensure the detection of intervening absorbers along its line of sight within the 4MOST wavelength coverage. To assess both the nature and redshift of a large sample of targets we revert to a prior, likelihood, and posterior probability in a Bayesian analysis (see Yang & Shen, 2023). The selection algorithm assigns probabilities for quasars, galaxies and stars, and simultaneously calculates photometric redshifts (Salvato, Ilbert & Hoyle, 2019) for all extragalactic sources. We make use of the latest Gaia release (DR3) to classify known stars as well as the most recent DESI Legacy Imaging Survey4 (DR10) in concert to estimate photometric redshifts. The comparison of the results with available quasar spectroscopic redshifts confirms that the resulting sample has both high completeness and high purity, securing the requirement of z > 0.55. This computation results in a total of 3.2 million quasars within the 4MOST project footprint (for example, with declination < +5 deg).

The ByCycle survey comprises both a deep and a wide component. The former is driven by the deep observations that will be carried out by other low-resolution galaxy surveys in five distinct cosmological fields (essentially S7). The wide component extends to an area designed in synergy with other low-resolution extragalactic survey efforts (including S5, S6, S7, S8, S9 and S16) to cover > 15 000 deg2.

6.17.3 Scheduling requirements

This Survey has no special scheduling requirements. In fact, it does not drive pointing at all, as it essentially 'piggy-backs' on other surveys.

6.17.4 Management Structure

PI: The PI
The PI of S17 is responsible for the internal activities of the survey, as well as its interface with the larger project. She ensures the overall leadership and oversight of the project. She takes decisions in consultation with the full S17 team.
• She is appointed indefinitely.
• Should she be unable to carry out her duties, appropriate replacement will be identified within the team (i.e. senior members from original proposing team).
• She is granted core authorship.

6.17.5 Work-breakdown structure

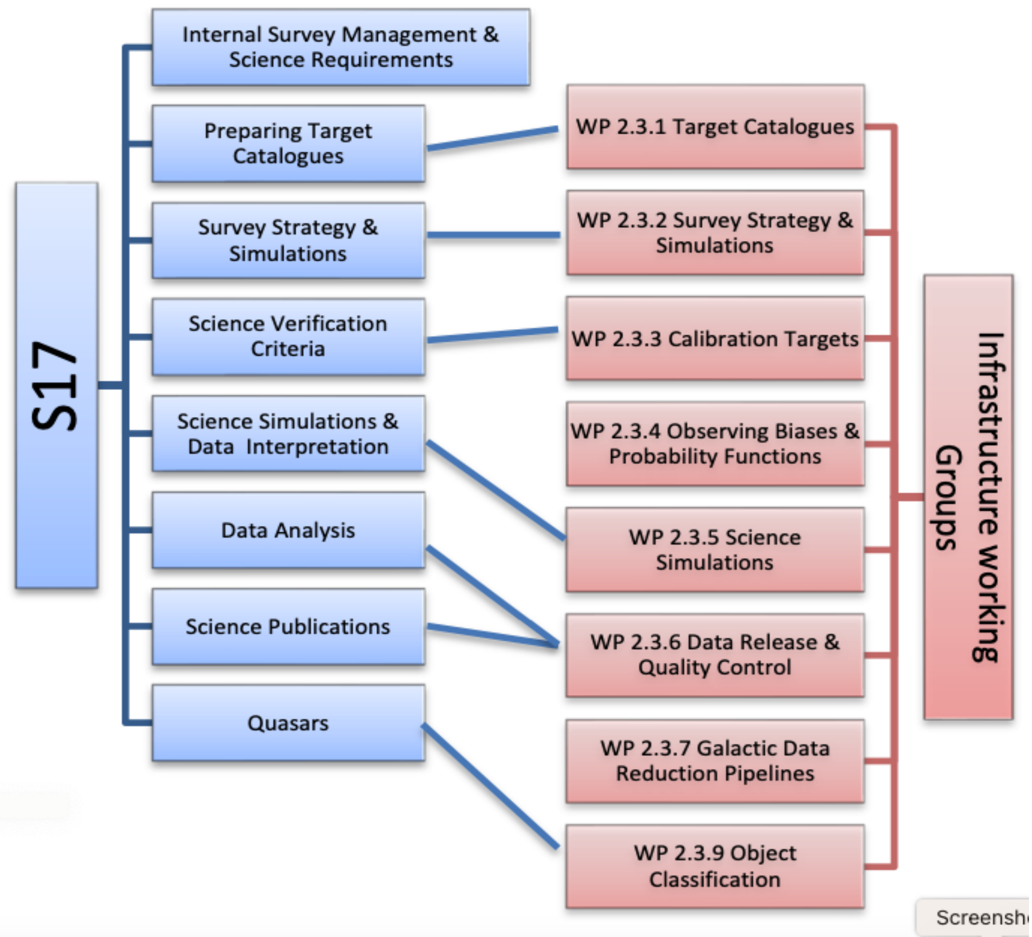


Figure 57: Work Breakdown Structure for Survey S17.

Ground-based Technical Work Packages

Technical Work Package 1: create mock VISTA/4MOST quasar spectra with absorbers - we will use available packages to generate synthetic quasar spectra with a variety of redshifts, magnitudes, colours, extinction properties, Lyman-α absorption forest decrements and SNR.

To generate the continuum of these quasars, we will use the publicly available *simqso* package as implemented in *desisim* code (McGreer+13). The basic procedure is to generate an unabsorbed continuum for each quasar by adding a set of emission lines on top of a broken power law continuum model. For high-redshift quasars, we will use the Lyman-α forest generator *CoLoRe* code (Farr+20). The unique next step will be to simulate mock quasar absorbers (metals and HI) with well-constrained physical properties. We will make use of TNG50 of the IllustrisTNG project (Marinacci+18; Springel+18; Naiman+18; Nelson+18; Pillepich+18). TNG50 is the box with the highest spatial resolution of three large cosmological volumes, simulated with gravo-magnetohydrodynamics (MHD) and incorporating a comprehensive model for galaxy formation physics. All data from TNG has been publicly released (Nelson+19a). By generating fake absorption lines going through the circumgalactic medium of TNG50 foreground galaxies (Nelson+ in prep.), we will create a controlled training set of mock VISTA/4MOST spectra.

Technical Work Package 2: operation, monitor the survey figure-of-merit, manage fibre conflict - our team will monitor the early data, making a continuous control of speed (number of objects) at which the survey progresses to its completeness goals as defined by the function-of-merit. While low and high- resolution fibres of the same astrophysical objects carry different scientific values, it is in practice not possible to simultaneously observe the same target with two fibres. For this reason, we anticipate a need for a careful monitoring of target overlaps with other extragalactic surveys.

Technical Work Package 3: retrieved data for foreground objects, data management - once recorded, the spectra of each objects will be stored in a local database at European Southern Observatory near Munich. An important component of the S17 project is a detailed knowledge of the foreground objects observed with VISTA/4MOST low-resolution fibres. We will put in place a constant monitoring of the acquisition of these various galaxy, active galactic nuclei, group and cluster spectra. We stress that all VISTA/4MOST data are freely available to anyone within the consortium.

Technical Work Package 4: quality control, monitor combined exposures, signal-to-noise - we will monitor the quality (photometric redshift accuracy, wavelength coverage and signal-to-noise). In addition, the same target can be observed multiple times at different dates to increase the quality of signal-to-noise ratio of the spectrum. We will put in place a constant monitoring of these progresses in order to ensure we are working with the highest quality data.

Technical Work Package 5: identify astronomical objects, fit continuum of quasars - all the targets are selected through their X-ray and optical properties. A portion of the objects have available spectra recorded and for the remaining, the selection was based on photometric redshift techniques to select the quasars with $z>0.55$. We calculated that 10% of the quasars will have $z<0.55$ instead and that an even smaller fraction will not be quasars but stars or galaxies. An important step of the S17 project will be to identify these objects early on. Additionally, the spectral features of the quasars will be fitted through an adaptive continuum. A number of tools exist to perform this analysis, often relying on principal component analysis (PCA) or Monte Carlo approaches (such as PyQSOfit, Guo+18). Bosman+20 have successfully trained Machine Learning algorithms on PCA. Recently, Liu&Bordoloi21 have proposed a novel intelligent quasar continuum neural network (iQNet) based on deep asymmetric autoencoder and decoder trained using Keras with Tensorflow backend (Abadi+15, Chollet+15), predicting the intrinsic continuum of any quasar. Building on these results, we will use autoencoding and decoding (e.g. de-noising) techniques to perform quasar continuum fit. We will use the quasar spectra produced in Technical Work Package 1 as a training data set.

By dividing the observed quasar spectrum with the fitted continuum, we will get a normalised quasar spectrum optimised for the search of absorbers (see Technical Work Package 7).

Technical Work Package 6: measure spectroscopic redshifts combined with photometric information - while spectra will be available to use, we will revert to innovative techniques to accurately determine redshifts of even the noisier data. To this end, we will combine the spectroscopic information with photometric data points as well as the morphology of the object as recorded in the eROSITA, WISE and Gaia images (Shu+19). Bovy+11 used extreme deconvolution technique to perform efficient, consistent, and fast quasar classification and photometric redshift estimation. Recently, Pasquet+19 have demonstrated that deep convolutional neural networks, a special type of multilayered neural network, can be used to successfully estimate redshifts based on the photometry images (see also Wu&Peek20). Their method exploits all the information present in the images without any feature extraction. We will use a similar approach to accurately measure the redshift of the background quasars, an important information to ensure the search of the absorbers is down at a lower redshift and for the legacy aspect of the surveys. In addition, the quasar spectra themselves will prove invaluable for many additional studies, including quasar outflows and black hole masses projects.

Technical Work Package 7: search and identify quasar absorbers with convolutional neural network - the products of Technical Work Package 5 will be normalised quasar spectra. These will constitute the input for the search and identifications of various types of quasar absorbers. This will include the high- column density neutral hydrogen systems (the so-called Damped Lyman-α Systems), the partially ionised absorbers (or Lyman-Limit Systems) and the many metal lines (including MgII, CIV, FeII, SiII, SII, MnII, ZnII, CrII, etc). Automated techniques using Gaussian Process was already applied to detect Damped Lyman-α Systems along quasar sightlines (Garnett+17; Ho+20). In Parks+18, a Convolutional Neural Networks (CNN) model was designed to detect and characterize Damped Lyman-α Systems in the quasar spectra of the SDSS and BOSS survey. This algorithm yields a classification accuracy of 99% on spectra with SNR above five. The classification accuracy is defined as the proportion of results with correct predictions. Recently, Wang+22 improves the CNN model from Parks+18, updating the framework to TensorFlow2.0 and successfully trained it on DESI mock spectra. Similarly, Zhao+22 used deep neural network with feed-forward calculation and error back propagation (using Keras and Tensorflow) trained on both synthetic and real data to successfully detect MgII absorbers with an accuracy of ~94%. Follow a similar approach, we will initially train the algorithm on the simulated spectra produced as part of Technical Work Package 1. Progressively, we will use real data as they become available to further optimise the architecture (kernel properties, number of layers and max polling parameters) of the algorithm through the analysis of the loss functions.

Technical Work Package 8: measure absorbers properties - in a simultaneous step, once the absorbers are identified and classified, we will be able to characterise their physical properties. In previous works using DESI mock spectra, Wang+22 indicated that a Convolutional Neural Network model provides estimations for redshift and HI column density with standard deviations of 0.002 and 0.17 dex for spectra with SNR above 3 per pixel. Also, their Damped Lyman-α Systems finder is able to identify overlapping high and lower column density systems (sub-DLAs). We will measure the absorbers' redshift, optical depth, equivalent width, column density and velocity width using a separate convolution neural network. We will make use of multiple lines in the same absorbers to test wavelength separation, equivalent width ratios and other fundamental properties of these absorbers.

Technical Work Package 9: build catalogues including ancillary data - we will build catalogues of value-added products from Technical Work Package 8. Key to this step will be to connect the properties of the quasar absorbers with the foreground objects observed in the same fields. We will cross-correlate the sky and redshift positions of the absorbers with the foreground objects observed with the low- resolution fibres. We will calculate the angular separation in 3D space. This important effort will also include a list of the physical properties of the foreground galaxies and active galactic nuclei such as systemic redshift, stellar mass, star-formation rate, metallicity as well as number of members and velocity dispersion for groups and clusters. These multiple physical properties will prove invaluable in performing the subsequent scientific analysis.

Key Goal I (early Universe) - Reach a definitive census of the cosmic metals

The high-redshift part of the S17 focuses on 20,0000 strong Lyman-α absorbers tracing both neutral and ionized gas observed over a large area. In Key Goal I, we will use the S17 high-redshift quasars to probe the Lyman-α absorbers tracing the neutral gas phase and its metal content. We will build a homogeneous compendium of Lyman-α absorbers towards a sub-sample of 100,000 SRG/eROSITA X-ray and optically-selected high-redshift quasar spectra. These datasets will transform our view of the Universe by providing a definitive metal census.
Work Package I.1: Neutral gas metallicity - We will assess the metal content, Z, of neutral gas traced by Damped Lyman-α Absorbers by modelling the column density of metal ions through Voigt profile fitting (Peroux+07), including ions of NI (4MOST blue arm), AlII, CIV, FeII (green arm), SiII, ZnII, CrII, AlIII (red arm). We will determine the ionized gas metallicity in Lyman Limit Systems by
performing a full photoionization modelling (Hamanowicz, Peroux+20) of the gas informed by presence of elements with varying degree of ionisation including NI, MgI, CIV and SiIV (red arm).
Work Package I.2: Cosmic evolution of baryons - We will provide the most robust estimate of the number density per unit redshift of Lyman Limit Systems, dn/dz, which is critical for estimates of the meta-galactic ultra-violet background used in radiative transfer models of the high-redshift Universe (Kollmeier+14, Fumagalli+17). The number densities of both Damped Lyman-α Absorbers and Lyman Limit Systems will allow us to calculate their gas mass content, Ωgas.
Work Package I.3: Cosmic metal census - Together, these measurements will enable a definitive census of the metals, Ωmetals =Ωgas x <Z>, in the Universe at intermediate redshifts taking into account both neutral and ionised phases of the gas, thus providing a new perspective on at the missing metals problem (Peroux&Howk20).

Key Goal II (late times) - Redefine our view of the Circumgalactic Medium

With the low-redshift part of the S17 project, we will cross-correlate quasar absorbers with galaxies detected in emission in the same fields. The primary targets are magnesium MgII quasar absorbers, which trace 10^4K cooler gas, and whose doublet nature makes their signature in quasar spectra unambiguous. In Key Goal II, we will use the powerful synergy of absorption and emission diagnostics to characterize the low density gas which remains the last puzzle piece to our understanding of galaxy formation and evolution. We will gather a sample of 1 million z>0.55 quasar spectra, exploring the low- density gas traced by 250,000 MgII down to equivalent width EW>0.002. The physical properties of the metal absorbers will be cross-correlated with up to 1 million foreground galaxies spectra observed in the same fields

(Driver+19, Richard+19). An additional 600,000 active galactic nuclei and 20,000 groups and clusters are ideally suited to probe the rarer denser foreground objects (Merloni+19, Finoguenov+19).

Work Package II.1: Circumgalactic medium metal enrichment – we will measure the radial profile of the neutral hydrogen and metals as a function of galactocentric radii (Adelberger+05; Crighton+11). Specifically, we will quantify the covering fraction of both neutral gas and numerous ions species (including MgII and CIV) as a function of impact parameter from the center of the foreground galaxy. The datasets are also optimal to compute the number density, dn/dz, of metal absorbers including MgII and CIV, down to unprecedented rest equivalent width (EW>0.002 Ang) thus probing the most diffuse gas. Together, these measurements will put direct limits on the clumpiness of the medium provide new constraints on the scales of metal mixing in the circumgalactic medium (Schaye+07). Furthermore, these findings will be confronted to state-of-the-art cosmological zoom hydrodynamic simulations with increased resolution in circumgalactic medium regions to characterize the physical properties of the gas (van de Voort+19, Peeples+19, Nelson+20). Fig. 7 displays early efforts undertaken with Illustris TNG50 which indicate the leap forward in the detection of the extended emission signal enabled by increase spectral resolution of the background quasar spectra.

Work Package II.2: Baryon budget – we will assess the strength of the absorbers by computing the optical depth of the metal doublets for different phases of the gas from cold at T=10^4K (MgII) to warm at T=10^5K (CIV). We will locate the gas spatially and in velocity space with respect to the associated galaxies (Rudie+12; Turner+14, Chen+21). We will use ionization models to identify whether the gas is enriched and photoionized or sufficiently hot to be collisionally ionized. We will thus constrain the source of ionization, the dynamical state of the circumgalactic medium gas and hence the total baryonic content of galaxy haloes. We stress that the nature of this baryonic physics impacts the matter power spectrum and thus the inference of cosmological parameters from weak lensing measurements from surveys like KIDS, DES and future missions. The proposed observations will provide a 1000-fold increase in the numbers of metal-absorber/galaxy pairs available for such studies with respect to previous works.

Work Package II.3: Impact of galaxy properties – thanks to the sizeable datasets, we will slice the samples by galaxy types to assess the impact of galaxy properties on their circumgalactic medium. In particular, we will look for evolution with cosmic times as traced by redshifts, as well as stellar mass, star-formation rate and metallicity.

Work Package II.4: Active galactic nuclei feedback - we will study the impact of active galactic nuclei feedback on the circumgalactic medium metal enrichment by correlating absorbers with 600,000 active galactic nuclei ("quasars probing quasars"; Hennawi&Prochaska13) as part of the VISTA/4MOST active galactic nuclei survey (Merloni+19). These datasets will be optimal to study the launch of star- forming, starbursting or active galactic nuclei-driven galactic winds, and hence the mechanism of mass loading, one of the major outstanding issue in today's galaxy formation and evolution studies.

Work Package II.5: Universe overdensities - we will put new constraints on the metal enrichment of denser environment (Lopez+18; Peroux+18) by measuring the neutral gas and metal absorbers properties in the immediate surrounding of 20,000 foreground groups and clusters observed as part of the Cluster survey (Finoguenov+19).

6.17.6 Contribution to the Infrastructure Working Groups

<u>IWG1: Targeting Support</u>

Our survey contributes to IWG1 by two team members, Fabian Balzer (University of Hamburg, now MPE, DE) and Celine Peroux (ESO, DE) attending and contributing to the meetings.

IWG2: Survey Strategy and Simulations
Our survey contributes to IWG2 by two team members, Celine Peroux (ESO, DE) regularly attending and contributing to the meetings. Joe Liske (University of Hamburg, DE) is assisting in representing S17 at IWG2. Additional one-to-one meetings with IWG2 key players to solve S17-specifics have been organised.

Joe Liske also represents S17 in Deep Field sub-group. Johan Comparat (MPE, DE) is representing S17 in the Work Package (WP) "Simulations" within IWG2.

IWG3: Pipeline Calibration and Science Verification
Patricia Schady (University of Bath, UK) represents S17 in IWG3 drafting a document providing science verification criteria for S17.

IWG4: Selection Functions
S17 is not contributing to IWG4 because it is not relevant on our science goals which aim optimising scheduling and number of background quasars/foreground objects pairs by relaxing criteria on the selection of the targets.

IWG5: Science Simulations
This working group is currently inactive.

IWG6: Data Curation and Data Release
Patricia Schady (University of Bath, UK) represents S17 in IWG6. Work is only beginning in that Working Group.

IWG7: Galactic Pipeline
S17 is not contributing to IWG7 which is a Galactic Working Group.

IWG8: Extragalactic Pipeline
Roland Szakacs and Celine Peroux (both ESO, DE) are contributing to IWG8's meetings. S17 particularly focus on the high spectral-resolution extragalactic pipeline. We have designed, developed and tested on Illustris TNG50 simulated data, a Machine Learning algorithm to detect and localise MgII absorbers in normalised quasar spectra. A paper presenting these results has been submitted. (Szakacs, Peroux et al.). In addition, Roland is contributing to IWG8 by generating mock quasar spectra from simqso two tests the tools developed by the working group.

Jens-Kristian Krogager (Lyon, FR) is additionally a member of S17 and one of the chair of IWG8. Jens-Kristian Krogager is currently co-leading the IWG and performing specific developments / tests with multiple codes for AGN redshift measurements and identifications.

JK Krogager is also leading the efforts to generate simplified but realistic simulated spectra for pipeline testing outside the OpR framework. These on-the-fly simulations provide more flexibility in terms of what sources are generated and can be run independently of the OpRs.

IWG9: Object Classification
S17 is closely following progress on object classification performed by IWG9. As discussed on several occasions, there is potentially important overlap with our own Machine Learning development described in section above for IWG8.

6.17.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.17.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.17.8.1 Deliverable L2 Survey data: reduction processing

This survey plans to fit quasar continuum including emission lines, as well as find and model absorption line properties (e.g. equivalent widths). A paper presenting early results has been recently accepted in MNRAS (Szakacs, Peroux et al. 2023).

6.17.8.2 Deliverable L2 Survey data: quality assessment

Quality assessment will be done by running the Machine Learning (Convolution Neural Network) algorithm on test data coming from simulated quasar absorbers from the TNG-50 hydrodynamical cosmological simulations tuned to mock 4MOST HRS quasar spectra (see also e.g. Nayak et al. 2024).

6.17.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

Given the specific nature of the information focussed on the quasar absorbers properties, S17 will provide DL2-SURV to 4MOST 4PA.

6.17.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

The DL2-SURV products of this Survey will be delivered in the first DR after publication.

6.17.8.5 Deliverable L2 Survey data: Required hardware and staff

This survey plans to fit quasar continuum including emission lines, as well as find and model absorption line properties (e.g. equivalent widths). A paper presenting early results has been recently accepted in MNRAS (Szakacs, Peroux et al. 2023). The data processing will make use of hardware facilities available at the Garching institutes (ESO and MPE). S17 will provide DL2-SURV (to be ingested into ESO archives) quasar absorbers-related products from DR2 onwards.

6.17.8.6 Additional L2 data: reduction processing

No extra AL2-SURV processing is planned by this Survey.

6.17.8.7 Additional L2 data: quality assessment

No extra AL2-SURV processing is planned by this Survey.

6.17.8.8 Additional L2 data: data delivery and Phase 3 compliance

No extra AL2-SURV processing is planned by this Survey.

6.17.8.9 Additional L2 data: Required hardware and staff

No extra AL2-SURV processing is planned by this Survey.

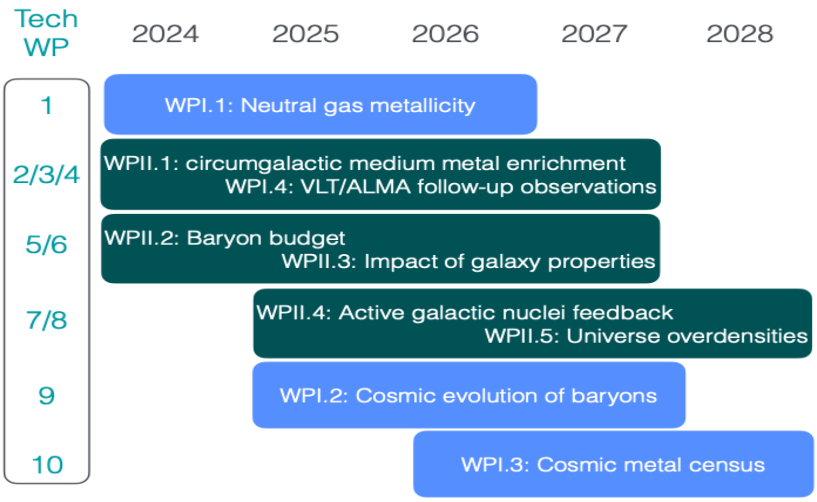


Figure 58: Gantt diagram illustrating the timeline and the relevant milestones of the Survey 17. The milestones are the science products described by the Work Packages. These will typically lead to one or more scientific publications. These milestones will be delivered at the date illustrated by the right-most edge of the boxes on the Gantt diagram. In Figure 57, the "infrastructure" milestones are indicated in the right most boxes in red colour. The corresponding timeline for these is shown on the left-side of this figure with label "Tech WP" standing for technical Work Package. They indicate the various steps for the analysis of the data.

6.17.9 Team

Table 28: Survey S17 team members with their affiliation, role in S17, and total expected FTE contributions next to science exploitation. For WP descriptions see Section 6.17.5.

Name	Main Function	Affiliation and Country	FTE
Celine Peroux	Principle Investigator, IWG1, IWG2, IWG8, SCB member	ESO, Germany	0.3/year
Nicolas Guerra-Varas	IWG1, IWG2, IWG8	ESO, Germany	1.0/year
Ramona Augustin	Co-I	AIP, Germany	
Fabian Balzer	Co-I	MPE, Germany	
Maria-Rosa Cioni	S9 PI	AIP, Germany	
Johan Comparat	IWG2, SCB	MPE, Germany	0.02/year
Simon Driver	Co-I	ICRAR, Australia	
Alejandra Fresco	Co-I	MPE, Germany	

Name	Main Function	Affiliation and Country	FTE
Antonella Garzilli	Co-I	EPFL, Switzerland	
Aleksandra Hamanowicz	Co-I	STScI, USA	
Anne Klitsch	Co-I	Copenhagen, DK	
Jean-Paul Kneib	Co-I	EPFL, Switzerland	
Jean-Kristian Krogager	IWG8 co-chair	Lyon, France	
Joe Liske	IWG2, SCB	Hamburg, Germant	0.05/year
Andrea Merloni	IWG2, SCB	MPE, Germany	0.05/year
Dylan Nelson	Co-I	Heidelberg, Germany	
Johan Richard	IWG2, SCB	Lyon, France	
Mara Salvato	IWG1, IWG9	MPE, Germany	0.05/year
Patricia Schady	IWG3, IWG6	Bath, UK	0.05/year
Yue Shen	Co-I	Illinois, USA	
Roland Szakacs	Co-I	ESO, Germany	
Simon Weng	Co-I	ESO, Germany	0.05/year
Qian Yang	Co-I	CfA Harvard, USA	

6.18 Survey 18 – 4MOST Hemisphere Survey (4HS)

Survey PIs: Edward Taylor, Michelle Cluver

6.18.1 Science Summary

The 4MOST Hemisphere Survey (4HS) is designed to deliver the best possible description of galaxies in the $z < 0.15$ Universe, focusing on science applications that absolutely require spectroscopic (as opposed to photometric) redshifts. The 4HS galaxy sample is NIR-flux limited ($J^{AB} < 18$) as a close approximation to a stellar mass selection (volume limited for log $M_{star} > 9.3/10.0/10.3$ and $z < 0.05/0.10/0.15$), and NIR colour-selected ($(J - K)^{AB} < 0.45$) to preselect galaxies to $z \sim 0.3$ and with near-total completeness for >2.5 million galaxies in the $z < 0.15$ interval. Our mean target density is ~325 / deg^2 and, for the reasons given below, we aim to survey the widest possible area: our goal is ~5.8 Million galaxies over 17.000+ deg^2. As a participating survey within 4MOST, 4HS can obtain high spectroscopic completeness with minimal bias as a function of local target density (i.e. minimising effects like 'fibre collisions' in SDSS; DESI). The overarching goal of 4HS is to produce a comprehensive census of galaxies in the local Universe, with broad and lasting scientific impact for the fields of both cosmology and galaxy evolution, strong synergies with the broader 4MOST project, and exceptional legacy value for science with flagship Southern and European facilities — particularly LSST, Euclid, and SKA.
This science case is covered in SubSurvey(s):

- S1801 qhsmain — the main sample, including for galaxy and environment science;
- S1802 qhspv — a subsample geared to PV cosmology, with extended footprint;
- S1803 qhswaves — the main sample selection applied to the WAVES input catalogue;
- S1804 qhs2mass — the 2MASS Extended Source Catalog as a supplemental sample.
- S1805 qhswide —- currently included as an exact copy of S1801-qhsmain, but with the option of independently changing the requested completeness and/or footprint.

Expanded science description: messenger-no190-46-48.pdf

6.18.2 Target Catalogue

- S1801 qhsmain

We have fully reprocessed the entire wide-field imaging content of the VISTA science archive DR6. We work with the reduced, calibrated and stacked 'paw' images as produced by the CASU VISTA pipeline v1.5 and re-derive the zeropoints (using the 2MASS PSC) and astrometry (using Gaia) to produce the original photometry that we use for selection. Our pipeline is optimised to derive high quality extended source photometry (thanks to the source separation framework, SCARLET, Melchior et al. 2018), including consistent optical-to-infrared magnitudes/colours.

The base selection for this sample is J < 18 and (J-K) < 0.45, where J and K are understood to be total, foreground-corrected AB magnitudes, as measured from the VISTA imaging. The maximal survey footprint is bounded by the availability of VISTA imaging and E(B-V) < 0.3 in the Planck foreground dust map. Star/galaxy separation is done based on a combination of (J-K) colour and a resolution metric (viz. model minus PSF-corrected-fixed aperture photometry), and then supplemented by excluding anything with a significant (> 8 sigma) proper motion measurement from Gaia.

We apply a simple star mask to exclude artefacts and/or badly contaminated photometry around bright stars. The star mask is based on the 2MASS Point Source Catalogue. Further, we include a J-band fibre magnitude exclusion, $J_{fibre} < 14.5$, to exclude some bright stars, and to ensure against saturation in the 4MOST data. Star/galaxy separation has been done using a combination of (J-K) colour and a J-band resolution metric.

We do not use either a peak position (which would be noisy on the scale of the 0.25arcsec pixels) or a centre-of-light (which can be strongly influenced by extended asymmetries, which SCARLET is particularly good at picking up). Instead, we find the position where the 1.45arcsec diameter 4MOST fibres will see the most flux. This has the advantage of 1.) giving optimal S/N and 2.) being close to the dynamical centre of the galaxy.

We use the same spectral success condition for all subsurveys, which is intended to deliver approximately uniform spectral data quality across the sample. The condition is framed in terms of the BG_NOISE_FLUX parameter, which quantifies the combination of read and sky noise (but not shot noise from the target itself) in the final coadded spectrum. The target value of BG_NOISE_FLUX < 6.5e-19 erg/cm2/sec is equivalent to ~18 minutes' integration in nominal gray conditions at airmass ~1. Recognising that we do not have the basis to meaningfully predict per-target observing requirements in advance, and cannot rely on repeat observations to build S/N, this is the strategy necessary for us to ensure near-total redshift success (> 99%), which in turn is necessary to deliver our science requirement of high *and unbiased* redshift completeness (93–99%). This also delivers the high spectral S/N for the bright, nearby, and massive galaxies that are the focus of our Peculiar Velocity (PV) cosmology science.

For real operations, our continuation condition will be based on redshift success: we will not continue on partially observed targets once we have a secure redshift determination. Current simulations include an approximate treatment of this feedback implemented as fobs > 0.6 (i.e. 75% of the nominal S/N request). This continuation condition is used for all subsurveys except S1802-qhspv, below.

Our survey Figure of Merit (FoM) is calculated following the "SSMLSM" prescription. Our Large Scale Merit (LSM) is broadly uniform across the survey footprint. Our Small Scale Merit (SSM) is defined as a strong function of completeness, reflecting our science requirement of high and unbiased completeness, and defined such that SSM = 0.5 (i.e. success) for a completeness of 93%. Using the SSMLSM prescription means that the FoM approximately tracks the total area over which we have met our completeness goals. In the most recent simulations, we see the overall FoM increase approximately linearly over the 5 year period, consistent with expectations.

- S1802 qhspv

The selection for this sample is J < 16.5 and (J-K) < 0.30. In view of our goal of obtaining sufficient S/N to support velocity dispersions for Fundamental Plane galaxies, the J magnitude selection is applied using the total magnitude as observed; i.e. no foreground extinction correction. In order to preselect early type galaxies at z < 0.12 without bias as a function of foreground or stellar population, the colour selection is still done using foreground-corrected colours. This means that, across the footprint of the S1801-qhsmain survey, this subsurvey is a wholly contained subset of S1801-qhsmain.

In order to probe the largest possible area/volume, the footprint of this subsurvey is expanded relative to S1801. The footprint is primarily limited by the availability of VISTA imaging, and secondarily limited by dust attenuation, as described above. The mean target density for S1802 is approximately 85 / deg2, compared to 325 / deg2 for S1801.

Foreground-corrected colours are used for star/galaxy separation, as described for S1801 Similarly target positions are selected in an identical fashion to S1801-qhsmain.
This survey uses a distinct continuation condition, which we are developing within IWG2. The motivation for this continuation condition is to obtain additional and/or repeat velocity dispersion measurements in pursuit of our PV cosmology gains. We do not continue on targets beyond the redshift range of interest; viz. z > 0.15. Then, there are three S/N ranges. for low S/N in a first measurement, we stop observing, because we know that we will not quickly get sufficient S/N for a good velocity dispersion measurement; we are better observing another target instead. At intermediate S/N, we know that a little bit more data will get us to the S/N ~ 10 threshold for a useful velocity dispersion measurement, so we definitely do want one more observation. Then at high S/N, we would like to get repeat observations for some small fraction of the sample to constrain and calibrate random and systematic errors, so we want to reobserve, but at low probability/completeness. This is the behaviour that our continuation criterion delivers.

Apart from this different continuation criterion, S1802 uses the same spectral success, SSM, LSM, and FoM as S1801 and other subsurveys.

- S1803 qhswaves

This subsurvey comprises our 4HS main sample over the footprint of the WAVES-Wide regions. Where our S1801-qhsmain sample is selected from wide VISTA imaging over the hemisphere, this does not include the deep/wide VISTA-VIKING area. However, the WAVES-produced catalogue includes VISTA-VIKING imaging/photometry and so fills that gap and enables us to complete the southern extragalactic sky.

The most recent imaging from the VIKING and KiDS surveys is used to construct the photometric input catalogue, with u/g/r/i imaging from VST, and Z/Y/J/H/Ks imaging from VISTA. The source-extraction software ProFound (Robotham et al. 2018) was used to identify objects and to measure their photometry in each of the above bands, following the method used for GAMA by Bellstedt et al. (2020).

S1803 is selected from the WAVES catalogues by applying the same selection as for S1801-qhsmain; namely J < 18 and (J-K) < 0.45, where J and K are understood to be total, foreground-corrected AB magnitudes. The target densities for S1801 and S1803 are similar; i.e. approximately 325 / deg^2, with approximately 75% of S1803 targets in common with S7/WAVES. Note that we do not enforce the WAVES-wide area selections for this subsurvey, in order to ensure continuity across the WAVES boundaries. This means that there is some significant overlap between S1801 and S1803 around the edges of the WAVES fields, which has the advantage of helping to explore our JK and star/galaxy selection boundaries.

We adopt the same coordinates as WAVES for this subsurvey. Specifically: brightest pixel coordinates, including a small per-square-degree correction derived by the WAVES team to match Gaia astrometry. Star/galaxy separation for this subsurvey is done in the same way as for WAVES, which is the combination of optical–NIR colour and observed size criteria.

S1803 uses the same spectral success, continuation condition, SSM, LSM, and FoM as S1801 and other subsurveys.

- S1804 qhs2mass

Like S1802, this subsample is geared towards our 4HS cosmology science goals: using Fundamental Plane-derived distances and peculiar velocities to map the cosmic velocity field, including bulk flows and the gravitational growth of large scale structure. Over most of the sky, this 2MASS-defined sample should almost completely overlap with our main sample, modulo a few very bright galaxies and/or different deblend solutions. The primary motivation for this sample is to extend the useful area for PV science beyond the limits of the archival VISTA imaging; especially at very low Galactic latitudes in the direction of the Galactic anticentre, into the Magellanic Clouds, and into the northern hemisphere.

The starting point for this subsample is the 2MASS XSC, and the pre-computed Gaia-to-2MASS cross-match from Gaia DR3. While some of these targets have existing redshifts from 6dFGS, SDSS, etc., we reobserve all targets 1) to obtain sufficient S/N to support a new velocity dispersion measurement, and/or 2) to enable cross-survey calibration of velocity dispersion measurements between 4HS and others. The XSC is defined via a S/N cut based on large aperture JHKs photometry, where S/N > 7 in any one band is sufficient for inclusion. We make the Gaia match, which is one-to-many symmetric by selecting the Gaia match with the smallest angular separation to each 2MASS source, and we use Gaia information to exclude a non-negligible fraction of stars on the basis of proper motion and/or resolved-ness in the Gaia imaging.

Since the observational focus for this subsample is velocity dispersion measurements to support PV cosmology science goals, the precision of target positions is potentially a limiting factor in the usefulness of these observations. This is our primary motivation for the match to Gaia; we also match to our VISTA and to the WAVES parent catalogues. Then, we have a hierarchy of data sources for target positions: we prefer our VISTA positions if available; if not, then we prefer a Gaia if available; if not, then we revert to the 'super' positions from the XSC, which are centroid positions as measured on the JHKs 'super' coadds (see Jarrett et al., 2000).
S1804 uses the same spectral success, continuation condition, SSM, LSM, and FoM as S1801 and other subsurveys.

- S1805 qhswide

Our survey package currently includes a fifth subsurvey, S1805-qhswide, which is best understood as an accounting tool. In close coordination with IWG2, S1805 is currently included as an exact copy of S1801-qhsmain, but with the option of independently changing the requested completeness and/or footprint (based on the LSM map) of either or both subsurveys, without the need for a full ingest. The motivation for this is to find the optimal balance of competing requirements (namely, area, completeness, and efficiency) within the larger 4MOST project. The inclusion of S1805 could provide additional redshifts (at low completeness) close to the plane to enable reconstruction of the cosmic density field in support of our PV cosmology goals. That said, our current intention is to drop this survey in advance of final operations once it has fulfilled its purpose of helping to identify the optimal area/completeness goals for S1801-qhsmain.

6.18.3 Scheduling requirements

This Survey has no special scheduling requirements.

6.18.4 Management Structure

The 4HS Management Structure consists of PIs, the Exec, and the Science Coordination Team (see organogram below) who collectively oversee Survey Management. Science Management falls within the Science Working Groups (SWGs), as listed below. Key roles are as follows:

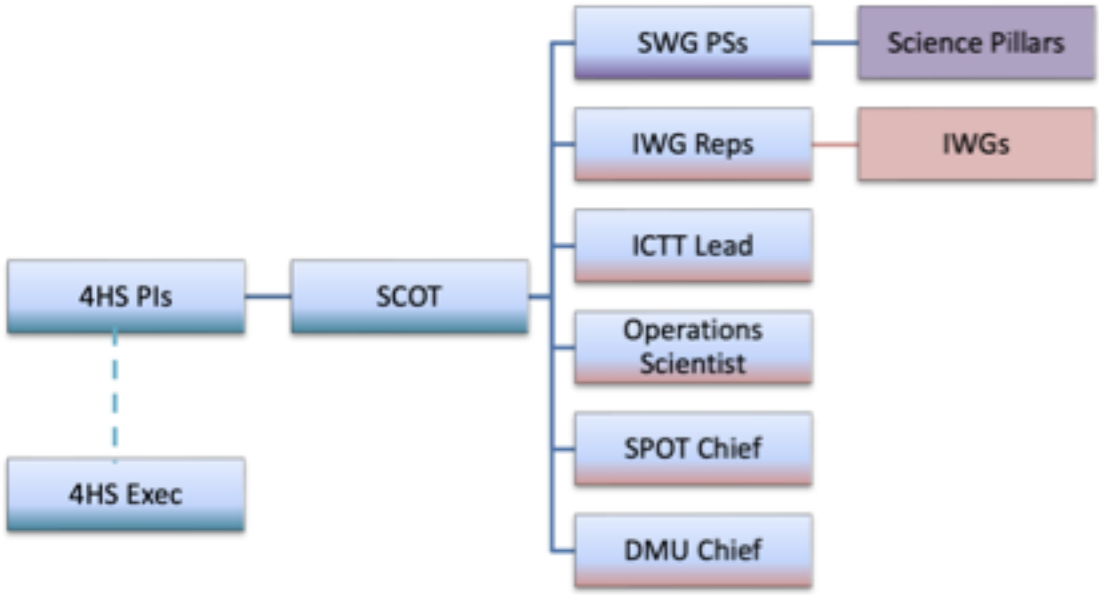


Figure 59: Management Structure for Survey S18, including high level survey management (teal shading), scientific management (purple shading) and operations management (salmon shading).

Principal Investigators:

- As PIs of 4HS they are responsible for the internal activities of the survey, as well as its interface with the larger project. Their prime directive is ensuring the delivery of the science and data products aligned to the core science of 4HS. Although they represent the main decision-making body, to ensure transparency, decisions are taken as recommendations to the Executive body for approval.
- They are appointed indefinitely.
- Should one or both be unable to carry out their duties, appropriate replacements will be identified in consultation with the 4HS Exec.
- The PIs of 4HS meet weekly.

The Exec:

- The Executive of 4HS acts as an Advisory Board to the PIs; they provide oversight and recommendations on matters put to them by the PIs and the SCOT. They retain oversight of decision-making across the survey and on all scientific, strategic, and technical matters. They can unanimously decide to remove one or both PIs if the best interests of the survey are no longer being met.
- Membership of the Exec is indefinite, but will be evaluated every two years to consider rotation on and off this group, while retaining continuity and a critical mass of collective knowledge.
- Members of the Exec meet once a month in alternating timezones to accommodate European and US participation.

Team Manager:

- The TM oversees the membership registry (4MS) and keeps it up to date. The TM shall ensure that the members of the Survey Team keep their affiliation and contact information up to date in the system.
- The TM is responsible for the organisation of roles within the survey
- The TM, co-PI Cluver is (currently) appointed indefinitely.
- Should the TM not be able to carry out their duties, co-PI Taylor will assume this role.

The SCOT (Science Coordination Team):

- The SCOT is the science and survey oversight and planning body that considers the scientific, strategic and technical aspects of the survey.
- Membership of this leadership body is determined by the key WPs of 4HS, including the PIs, IWG and SWG representatives. The appointment term therefore corresponds to that of their specific role.
- The SCOT meet every two weeks with communication largely occurring on Slack and Mattermost.

Peculiar Velocity/Cosmology SWG (WP2):

- The Project Scientist and Deputies for WP2 are appointed for a period of 3 or 2 years (by the PIs in consultation with the Exec), which can be renewed. However, rotation and fresh membership of the leadership team is encouraged on a 2-year timescale.
- Should the PS not be able to carry out their duties, one of the deputies will take on this role until a suitable outcome is finalised.
- Meetings of the members of this SWG are organised as needed by the leads with communication largely occurring on Slack and Mattermost.

Galaxy Environment SWG (WP3):

- The Project Scientist and Deputies for WP3 are appointed for a period of 3 or 2 years (by the PIs in consultation with the Exec), which can be renewed. However, rotation and fresh membership of the leadership team is encouraged on a 2-year timescale.
- Should the PS not be able to carry out their duties, one of the deputies will take on this role until a suitable outcome is finalised.
- Meetings of the members of this SWG are organised as needed by the leads with communication largely occurring on Slack and Mattermost.

Galaxy Properties SWG (WP4):

- The Project Scientist and Deputies for WP4 are appointed for a period of 3 or 2 years (by the PIs in consultation with the Exec), which can be renewed. However, rotation and fresh membership of the leadership team is encouraged on a 2-year timescale.
- Should the PS not be able to carry out their duties, one of the deputies will take on this role until a suitable outcome is finalised.
- Meetings of the members of this SWG are organised as needed by the leads with communication largely occurring on Slack and Mattermost.

Science Simulations/Mocks SWG (WP5):

- The Project Scientist and Deputies for WP5 are appointed for a period of 3 or 2 years (by the PIs in consultation with the Exec), which can be renewed. However, rotation and fresh membership of the leadership team is encouraged on a 2-year timescale.
- Should the PS not be able to carry out their duties, one of the deputies will take on this role until a suitable outcome is finalised.
- Meetings of the members of this SWG are organised as needed by the leads with communication largely occurring on Slack and Mattermost.

Input Catalogue Tiger Team Lead (Leading WP5):

- The ICTT Lead is appointed for a period of 2 years (by the PIs) and is tasked with overseeing the creation of the final 4HS input catalogue. This includes testing, QC
- Should the Lead be unable to fulfil their duties, a replacement Lead will be identified from the ICTT.
- Meetings of the members of this group are organised as needed, with communication largely occurring on Slack and Mattermost.

Operations Scientist (Leading WP7):

- The 4HS Operations Scientist is appointed by the PIs and provides insight and advice with respect to survey simulations and survey planning within the larger 4MOST project.

SPOT (Science Policy Team) Chief (Leading WP 8):

- The lead of WP8 is appointed by the PIs and Exec.
- The WP lead is appointed for a period of two years, which can be renewed indefinitely.
- Should the WP lead not be able to carry out their duties the deputy WP lead will assume the role and associated duties until a suitable outcome is finalised.

DMU (Data Management Unit) Chief (Leading WP 9):

- The lead of WP is appointed by the PIs and Exec.
- The WP lead is appointed for a period of two years, which can be renewed indefinitely.
- Should the WP lead not be able to carry out their duties the deputy WP lead will assume the role and associated duties until a suitable outcome is finalised.

Team communication:

- PIs communicate with the rest of the Team largely over email, Slack and Mattermost. In addition, pre-recorded video presentations are used to provide period updates (cadence once a quarter to once a month).
- Internal team communication is chiefly over Slack and Mattermost, where the latter, due to its permanence, is used exclusively for discussion and dissemination of plots, files and diagnostic results.

6.18.5 Work Breakdown Structure

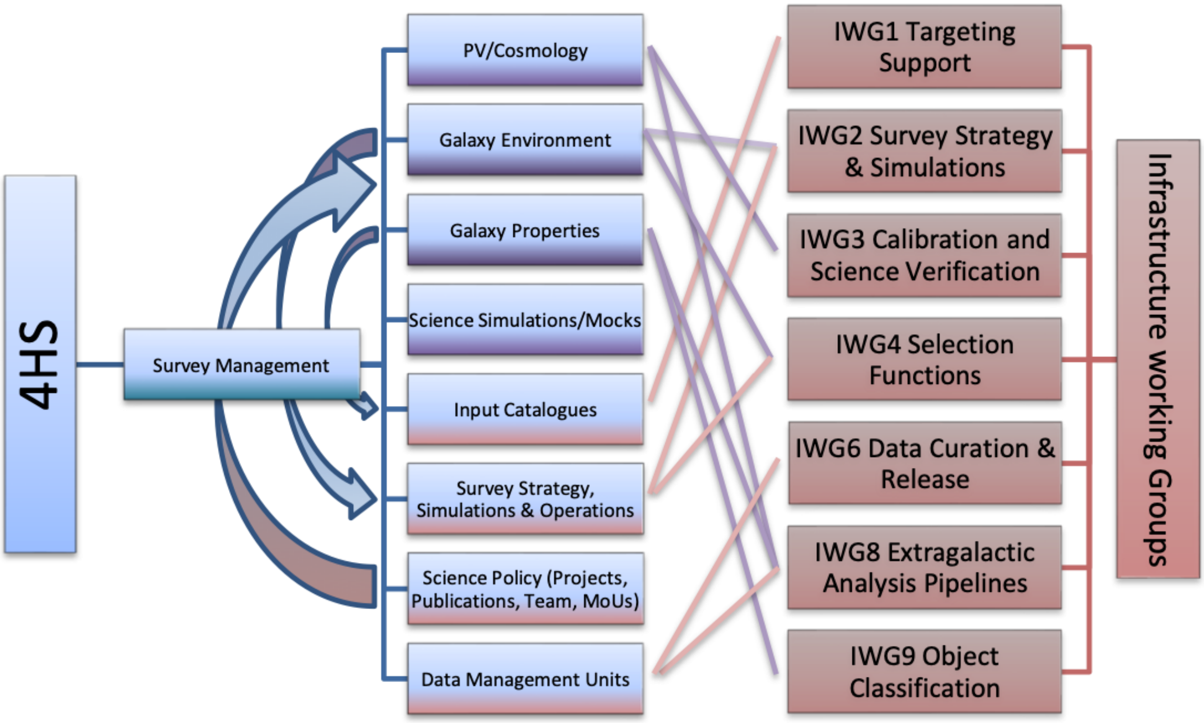


Figure 60: Work Breakdown Structure for Survey S18, where the main WPs and sub-WPs are summarised, as well as external communication and contribution to the relevant IWGs (blue arrows). The main internal links between WPs are highlighted in purple and salmon.

In the following section we outline the management structure of 4HS. Please refer to (Table 37) for FTE contributions to the Work Packages and Infrastructure Working Groups.

WP1: Survey Management

This WP is responsible for the internal survey management of 4HS and consists of several bodies that oversee the running and execution of 4HS, namely the 4HS PIs, the 4HS Exec and the 4HS SCOT (Survey Co-Ordination Team). See previous section for details.

WP2: Peculiar Velocity/Cosmology SWG

This WP considers all 4HS matters that pertain to our PV/Cosmology science, including survey strategy and scientific exploitation. Accurate measurement of velocity dispersions for the PV sub-sample (expected to be at least ~450 000 early-type galaxies) is crucial to this science; this links directly to outcomes from IWG8 and IWG3 and these representatives communicate closely with the activities within this WP. This SWG will coordinate the core science papers within this science pillar, as well as oversee the creation of the following key DMUs:

- Velocity dispersion measurements for Early-Type galaxies
- Fundamental Plane Distances and subsequent Peculiar Velocities
- Reconstructed maps of the density and velocity fields in the local Universe
- Random unclustered catalogues matching the selection function of the PV subsample

WP3: Galaxy Environment SWG

This WP considers all 4HS matters that pertain to our Galaxy Environment science pillar, including survey strategy and scientific exploitation. The high completeness requirements of

4HS are the foundation of being able to execute science that relies on multiple metrics and definitions of environment. This SWG is therefore tasked with testing survey simulations and developing scenarios that will optimise the observing strategy of 4HS to best achieve a high and unbiased completeness across the survey area (working closely with the IWG2 Representative, the IWG4 Representative, and the 4HS Operations Scientist). This SWG will coordinate the core science papers within this science pillar, as well as oversee the creation of the following DMUs:

- Group Catalogue and Halo Mass Estimates (and associated measures like group velocity dispersions, physical extent, BCG identifications, group centres, completeness-corrected luminosity/stellar mass estimates)
- Large-scale structure environment identification (filaments, nodes, voids, etc.)
- 'Non-parametric' environment measures (e.g., 5th nearest neighbour distances)

WP4: Galaxy Properties SWG

This WP considers all 4HS matters that pertain to our Galaxy Properties science pillar, including survey strategy and scientific exploitation. As the local universe benchmark survey, the targeting strategy of 4HS should include an assessment of expected galaxy demographics and whether the representation of especially rare systems (e.g., compact stellar systems) can/should be improved. This SWG is therefore responsible for assessing the input target catalogues' effectiveness and making recommendations with respect to target selection. This WP therefore works closely with the IWG1 representative and WP6 (Input Catalogues). This SWG will coordinate the core science papers within this science pillar, as well as oversee the creation of the following planned DMUs:

- Any ancillary datasets (including imaging, multiband photometry and SEDs as they become available)
- Stellar mass estimates and stellar populations (from SED fitting)
- Star formation rates (e.g., multiband photometry)
- Size, shape/structure, and morphology metrics

WP5: Science Simulations/Mocks SWG

This WP is tasked with providing the 4HS survey with light cones and mock catalogues that can be used to model the 4HS survey, reproducing its geometry and selection effects and thus enabling the extraction of robust astrophysical results. Similarly, the survey data can be used to validate and test the latest simulations. The first phase will be to generate a 4HS-like lightcone using SHARK and P-Millennium (or MillenniumTNG DM only) but with the view of expanding to new simulations as they become available (notably large volume cosmological hydro-simulations with suitable resolution, expected in the next year). The work in this WP includes:

- Creating mock catalogues matching the distributions and clustering of the 4HS redshift and peculiar velocity samples (in collaboration with WP2).
- Creating mock catalogues matched to the 'main sample' for use with group catalogue and cosmic web finder calibration (in collaboration with WP3)
- Mock spectra will be produced to understand any biases that affect the measurement of velocity dispersions of galaxies, which is important for the PV science, as well as simulated SEDs in the bands 4HS will have available to understand how well intrinsic galaxy properties (stellar masses, SFRs, SFHs, etc.) and morphological decomposition can be recovered.

4HS has been awarded 15 million CPU hours on the LUMI European Supercomputer to create state-of-the-art simulations and mocks in support of 4HS activities.

WP6: Input Catalogues

4HS has undertaken to reprocess all VHS imaging; this allows for bespoke input target selection, whilst providing a valuable resource to the 4MOST and wider astronomy community. The activities of WP6 include:

- Photometry pipeline development (with software support provided by an ADACS Merit Allocation)
- Data processing on the OzSTAR Supercomputer (supported by an ASTAC Time Allocation)
- Vetting of astrometry and photometric reproducibility (and calibrating zeropoint drift corrections using 2MASS)
- Testing of deblending and resolved source handling scenarios (e.g., shredding)
- Testing of target selection strategy (using Gaia, Pan-STARRS, and WISE)
- Providing concentrations, magnitudes, colours, and eccentricities to WP2 for PV Target Selection
- Development of a fast, interactive image viewer based on Aladin Lite Reprocessed VHS imaging and photometry will be made available to other 4MOST surveys, as well as the community, via Data Central (https://datacentral.org.au/) by mid-2025.

WP6 delivered the 4HS input catalogues derived from VHS photometry for the November 2023 upload. Aside from minor improvements to the photometry and additional quality control done via the image viewer, this WP is largely completed.

WP7: Survey Strategy, Simulations and Operations

This work package is tasked with developing the final survey strategy for 4HS (including the creation of sub-surveys, optimised target handling etc.). This entails overseeing survey simulations, evaluating the scientific implications of the current survey strategy and success criterion, and optimising these as part of a feedback loop. This work package includes the necessary comprehension of survey operations and how these may impact the survey. This WP is led by the Operations Scientist, working closely with the IWG2 Representative.

WP8: Science Policy (Projects, Publications, Team Membership, MoUs)

The novel nature of the 4MOST Project necessitates a Science Policy work package that is both inward (facilitating science within 4HS) and outward facing (integrating with the activities of the 4MOST Science Policy Board). WP8 (the SPOT) is tasked with managing the science and publication process across the key science pillars. In addition, they coordinate new membership (full member, affiliate member, etc.) approval (by the Exec and PIs) and act as liaisons for the brokering and creation of MoUs within and external to 4MOST. A detailed description of 4HS Science Policy, and how it interfaces with 4MOST Science Policy, can be found in the 4HS Science Policy Document (available upon request). The Science Policy Lead sits on the 4MOST SPB.

WP9: Data Management Units (Catalogue Creation)

4HS will make use of Data Management Units for its catalogues and value-added products. The management and oversight of these (including key source identifier, consistency, data standards, quality control, testing and verification etc.) is conducted within this WP. The deliverable survey data products (and brief description) is included as part of the next section. This WP is also responsible for overseeing the data release schedule and Data Release Manager will be appointed at the start of survey operations.

We expect to add 0.5-1 FTE of effort dedicated to this WP at the start of survey operations.

WP10: Science Exploitation

We list below the 4HS Team Members who will collaborate on the scientific exploitation of 4HS data and/or production of the Data Management Units.

Work Package 2 (PV/Cosmology SWG)	Key Personnel	Expected FTE/yr
Velocity dispersion measurements for Early-Type galaxies	Khaled Said, Anna de Graaff, John Lucey, Matthew Colless	1
Redshift-independent distance measurements, Peculiar Velocities	Wojciech Hellwing, Mike Hudson, Maciej Bilicki, Jenny Sorce, Cullan Howlett, John Lucey, Edward Taylor, Ryan Turner	3
	Additional resourcing via PhD and Postdocs (Helene Courtois)	5

Work Package 3 (Galaxy Environment SWG)	Key Personnel	Expected FTE/yr
Local density/n-nearest neighbour, other environment measures	Shadab Alam, Elmo Tempel, Cristóbal Sifón, Wojciech Hellwing, Sean McGee, S. Kannappan	2
Cosmic web, filament locations, distances to filament	Elmo Tempel, Ulrike Kuchner, Ros Skelton, Sean McGee, Wojciech Hellwing, S. Kannappan	2
Group catalogues, halo masses, group membership, central and satellite tagging	Sean McGee, Elmo Tempel, Sheila Kannappan, Aaron Robotham, Claudia Lagos, Ulrike Kuchner, Shadab Alam, Kelley Hess, Simon Driver, Cristóbal Sifón	2
	Additional resourcing via PhD and Postdocs (Simon Driver, Cristóbal Sifón, Michelle Cluver, Benedetta Vulcani, Elmo Tempel, Shadab Alam, Ros Skelton)	5

Work Package 4 (Galaxy Properties SWG)	Key Personnel	Expected FTE/yr
Emission and absorption line measurements from the 4XP outputs	Ilani Loubser, Anne Ferre Mateu, Andrew Battisti, Madusha Gunawardhana, Eric Bell, Leslie Hunt, Michael Maseda, Andrew Battisti, Leslie Hunt, Jarle Brinchman, Sheila Kannappan, Andrew Hopkins, Mark Norris, Caroline Foster, Mamta Pommier, Chris Lidman, Michael Brown	4
AGN identification	David Alexander, Michael Maseda, Sheila Kannappan	2
SFRs (from imaging)	Michelle Cluver, Tom Jarrett, Edward Taylor, Michael Brown	2
Stellar masses (from imaging)	Eric Bell, Tom Jarrett, Ros Skelton, Leslie Hunt, Edward Taylor	2
	Additional resourcing via PhD and Postdocs (Michael Maseda, Maciej Bilicki, Edward Taylor)	3

6.18.6 Contribution to the Infrastructure Working Groups

IWG1: Targeting Support

Within IWG1, 4HS is mainly contributing by running and testing the astrometry verification tool (IWG1-WP2), particularly aimed at the extragalactic surveys with no explicit connection to the Gaia DR3 astrometric reference frame. This Python tool, written by Nikolay Karachov (IWG1 co-lead), compares Gaia astrometry with the astrometric calibration of the surveys, and is a necessary component for all catalogue uploads. 4HS also actively participates in the weekly IWG1 telecons (including advocating for changes such as cross-match radius), as well as in the assessment of 4CAB change requests. The current IWG1 Representative is Leslie Hunt.

IWG2: Survey Strategy and Simulations

4HS leads the IWG2-Wide sub-group within IWG2. It has the role of collecting feedback on the simulations from the wide field surveys within 4MOST and providing that feedback to IWG2. It meets twice every fortnight, alternating between a Europe-friendly time zone and South/North American-friendly time zone. The current IWG2 Representative is Chris Lidman.

4HS members Elmo Tempel and Peder Norberg provide additional advice and recommendations.

IWG3: Pipeline Calibration and Science Verification
Pipeline Calibration and Science Verification is of particular importance to WP2 (PV/Cosmology) since this science is virtually unique to 4HS. We are therefore active participants in designing the necessary extragalactic pipeline tests, selecting suitable SV fields and overseeing the validation of the pipeline outputs. Currently 4HS leads the Abell Cluster 85 SPV testing. The current IWG3 Representative is John Lucey.

IWG4: Selection Functions
Our survey plans to actively contribute to IWG4 as they start testing the survey simulation for science analysis. This entails setting up a pipeline to take the survey simulation input and compute several measurements relevant for 4HS science such as local density, clustering statistics, cosmic web characterization. All these tools will eventually improve the survey simulation outputs ensuring delivery of the science and should be available to everyone within the 4MOST consortium (these should work for other surveys with possibly minor survey specific tweaks). The current IWG4 Representative is Shadab Alam who co-leads this IWG.

IWG5: Science Simulations
Inactive.

IWG6: Data Curation and Data Release
Our representative in IWG6 is also the lead of WP9 and is tasked with coordinating data products to and within 4HS. They are a key liaison between particularly IWG8 and IWG3. The current IWG6 Representative is Lucia Marchetti.

IWG7: Galactic Pipeline
Our Survey does not contribute to IWG7 because we consider extragalactic targets only.

IWG8: Extragalactic Pipeline
Within IWG8, 4HS will be testing the implementation pPXF in the pipeline, to measure velocity dispersions (and associated uncertainties), as well as spectra signal-to-noise for all early-type galaxies. We are also exploring the use of outputs from the spectral fitting package, PyParadise, which will additionally form part of the pipeline. The current IWG8 Representatives are Khaled Said and Matthew Colless.

IWG9: Object Classification
Our survey contributes to IWG9 by providing expertise on Machine Learning and template-fitting techniques for galaxies. Currently the focus is on QSOs and galactic sources, but we plan to contribute more substantially when more general galaxies are being considered. The current IWG9 Representative is Maciek Bilicki.

Additional Contributions to the 4MOST Project
Here we list the members of 4HS who have roles within the project, but not as representatives of 4HS.

- Michelle Cluver (SCB Chair, 4CAB Member)
- Jochen Liske (SCB Deputy Chair)
- David Alexander (IWG1 co-Lead, 4CAB co-Chair)

- Sabine Bellstedt (IWG co-Lead, 4CAB co-Chair)
- Peder Norberg (IWG2 co-Lead, OpSys, 4CAB Member)
- Elmo Tempel (IWG4 co-Lead, OpSys and OpSim)
- Scott Croom (IWG8 co-Lead)
- Luke Davies (IWG8 co-Lead)

6.18.7 Level-1 data reduction re-processing

The standard L1 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.

6.18.8 Level-2 data production

The standard L2 pipeline, data products, quality control, and deliveries described in Survey Management Plan: Back-end Operations [RD4] will be used by this Survey.
All targets of Survey #18 will be processed by the 4XP/4CP/4SP pipelines and quality controlled products will be delivered to 4PA and the ESO SAF according to the schedule described in the Survey Management Plan: Organisation [RD2] document.
Further to the standard data products from the common 4MOST pipelines, a Survey may have extra Deliverable L2 Survey products (DL2-SURV) that will go to both the ESO Science Archive Facility (SAF) and the 4MOST Public Archive (4PA). They may furthermore elect to produce Additional L2 data products (AL2) that will only be made available through 4PA. Such data products are described in the following subsections.
The key science goals of S18 require redshifts and line measurements (including velocity dispersions), which are output from 4XP. S18 is not currently planning to re-analyse or re-reduce any 4MOST spectra to achieve its core science goals, i.e. the outputs provided by 4XP are sufficient.

6.18.8.1 Deliverable L2 Survey data: reduction processing

The data products derived from the spectral outputs do not require reprocessing of the L1 spectra, and the normal tools and data resources available to our Team is sufficient for any additional analysis required. Imaging data products (VHS and WISE) are produced by the pipeline discussed in WP6: Input Catalogues running on the OzSTAR/Ngarrgu Tindebeek Supercomputer (Swinburne) with allocations from the Australian Supercomputer Time Allocation Committee.

6.18.8.2 Deliverable L2 Survey data: quality assessment

DL2-SURV products will start as 4HS Data Management Units delivered in fits format (including appropriate metadata, e.g. UCDs following IVOA standards) delivered to 4PA as AL2 products having gone through internal quality checks as detailed in 6.18.7.

6.18.8.3 Deliverable L2 Survey data: data delivery and Phase 3 compliance

Having been made available to the Team as AL2 DMUs, these data products will be converted to DXU products following standard DXU conventions also applied to the standard project pipelines. A template for DXU format is in use in the project, which will provide the guidance for the survey to develop their own DXU definition. The 4MOST Data Model Curator (DMC) will review such DXUs and ensure all ESO requirements have been met. Nevertheless, ESO will have to engage with the respective survey, through mediation of the DMC, such that any remaining inconsistencies between SAF requirements and the DL2-SURV product data model can be remedied.

Once the data model has been finalized, the DL2-SURV product will follow a standard data flow, i.e. it will be uploaded to a dedicated staging area at AIP within the 4MOST pre-release access point (4PRAP). The DMC can then and there verify the data model consistency. The DL2-SURV product will be published internally at an appropriate internal data release in advance of the public data release. It will then be submitted by the 4PA to the SAF through the same channels as the DL2 products from the common IWG L2 pipelines.

6.18.8.4 Deliverable L2 Survey data: product delivery schedule to the ESO archive

Please refer to the table below (Table 36) for expected delivery timeframes for DL2-SURV products. For Environment metrics and Group Catalogues we can and do commit to releasing best-effort interim catalogues internally to 4MOST via 4PA for testing and validation as AL2 data products and we commit to delivering the final data products as DL2-SURV for DR4. In the absence of a clear picture of how completeness and area will be realised over the 5-year survey, we commit to publicly releasing interim versions of the key data products described here through ESO as DL2-SURV with the next 4MOST PDR following the publication that describes that data product. In other words, environment metrics and group catalogues that are of sufficient scientific quality to be the subject of a journal publication will be released to the 4MOST Team via 4PA and be included in the next ESO DR as a DL2-SURV product.

6.18.8.5 Deliverable L2 Survey data: Required hardware and staff

Photometry data products are being constructed using the OzSTAR supercomputer and a time allocation from the Australian Supercomputing Time Allocation Committee. The normal tools and data resources available to our Team is sufficient for any additional analysis. Team members contributing effort are listed in WP10 and the process is overseen by WP9. Additional data products are derived from the spectral outputs and do not require reprocessing of the L1 spectra hence there are no hardware requirements beyond what the Team has access to via their home institutions.

6.18.8.6 Additional L2 data: reduction processing

These data products are derived from the spectral outputs (i.e. in catalogue space) and do not require reprocessing of the L1 spectra. The normal tools and data resources available to our Team is sufficient for this purpose.

6.18.8.7 Additional L2 data: quality assessment

4HS will make use of Data Management Units for its catalogues and value-added products, delivered in fits format including appropriate metadata, e.g. UCDs following IVOA standards. The management and oversight of these (including key source identifier, consistency, data standards, quality control, testing and verification etc.) is conducted by the WP9 Lead (DMU Chief) and Deputy. QC will be undertaken within the QC Team (6+ members) who will test and check draft DMU products. These will be released to the 4HS and 4MOST Team once they have passed QC. This procedure follows the highly successful model deployed by the GAMA Team (see Driver S.P. et al. 2022).

We note that products can pass QC but due to limitations of the data itself may not be of suitable quality for public release.

6.18.8.8 Additional L2 data: data delivery and Phase 3 compliance

Data will be delivered to 4PA following the instructions and compliance requirements set by the 4MOST Project and Data Release Manager.

6.18.8.9 Additional L2 data: product delivery schedule

For planned DL2-SURV products we commit to releasing best-effort interim catalogues internally to 4MOST via 4PA for testing and validation as AL2 data products according to the data timeline below. Additional data products created by the Team that have passed QC will be released to 4PA (providing access to the larger 4MOST Team) before any associated publications are submitted to a journal. The quality of these products will determine the timing of their public release via PA and on a best effort basis whether they can be delivered to ESO as DL2-SURV.

6.18.8.10 Additional L2 data: Required hardware and staff

These data products are derived from the spectral outputs and do not require reprocessing of the L1 spectra. Photometry data products are being constructed using the OzSTAR supercomputer and a time allocation from the Australian Supercomputing Time Allocation Committee. The normal tools and data resources available to our Team is sufficient for any additional analysis. Team members contributing effort are listed in WP10 and the process is overseen by WP9. We list here the key deliverable catalogues that will be created and the planned release dates (where DR1, DR2 etc. correspond to the 4MOST Data Delivery dates).

Table 36: Schedule for the Data Releases of the S18 data products

Data Management Unit	Requirements	Content	4PA Release (AL2)	ESO Release (DL2-SURV)
VHS and WISE Photometry (including sizes)	4HS Input Catalogue	4HS Input Catalogue	DR1	DR1
Fundamental Plane derived distances and Peculiar Velocities	Velocity Dispersions (Subset drawn from 4XP DXU) + VHS Imaging	DR1 DR2 DR3 DR4	DR1 DR2 DR3 <DR4	DR2 DR3 DR4 DR4
Stellar Masses	Redshifts + VHS Imaging + WISE Imaging	DR1 DR2 DR3 DR4	DR1 DR2 DR3 <DR4	DR2 DR3 DR4 DR4
Star Formation Rates	Redshifts + WISE Imaging	DR1 DR2 DR3 DR4	DR1 DR2 DR3 <DR4	DR2 DR3 DR4 DR4
Environment Metrics (cosmic web and 5th nearest neighbour)	Redshifts + VHS Imaging + Mock Lightcones	DR4	<DR4	<DR4
Group Catalogues	Redshifts + VHS Imaging + Mock Lightcones	DR4	<DR4	<DR4

6.18.9 Team

Table 37: Survey S18 team members with their affiliation, role in S18, and total expected survey management FTE contributions (i.e. excluding science exploitation). Contributions of 0.05 and less are not reflected.

Name	Affiliation	Function	FTE/yr
Shadab Alam	IfA	IWG4 Rep	0.2
Stefania Barsanti	ANU	WP4 Lead, WP8	0.3
Eric Bell	UMich	Exec Member, WP4, WP6	0.1
Maciej Bilicki	CFT	IWG9 Rep	0.15
Jarle Brinchmann	IA	Exec Member	

Name	**Affiliation**	**Function**	**FTE/yr**
Michelle Cluver	CAS	Co-PI, Team Manager, WP6, WP9	0.35
Matthew Colless	ANU	Exec Member, IWG8	0.1
Helene Courtois	IP2I	Exec Member	
Anna de Graaff	Leiden	WP5	0.1
Madusha Gunawardhana	SIFA	WP7	0.15
Wojciech Hellwing	CFT	WP5	0.2
Henk Hoekstra	Leiden	Exec Member	
Cullan Howlett	UQ	WP2 Lead, WP8	0.2
Leslie Hunt	OAA	IWG1 Rep, WP6, WP7	0.2
Sheila Kannappan	UNC	Exec Member	
Claudia Lagos	ICRAR	Exec Member, WP5 Lead, WP8	0.2
Chris Lidman	ANU	IWG2 Rep, WP2, WP7	0.15
Joe Liske	UHH	Exec Member	
Ilani Loubser	CSR	WP3	0.15
John Lucey	Durham	IWG3 Rep, WP2, WP6	0.35
Lucia Marchetti	UCT	IWG6 Rep, WP9 Lead	0.15
Michael Maseda	UW-Madison	WP4	0.15
Sean McGee	Birmingham	WP3 Lead, WP8	0.2
Moses Mogotsi	SAAO	WP3	0.15
Peder Norberg	Durham	WP8	
Khaled Said	UQ	IWG8 Rep	0.15
Matthieu Schaller	Leiden	WP5	0.2
Alessandro Sonnenfeld	Shanghai Jiao Tong University	WP4 lead, WP8	0.2
Jenny G. Sorce	AIP	WP2	0.1
Edward Taylor	CAS	Co-PI, WP6 Lead, WP7	0.4
Elmo Tempel	UT	WP7 Lead, WP9	0.15
Ryan Turner	Swinburne	WP2	0.2
Mattia Vaccari	UCT	WP9 Deputy	0.1

7 Summary DL2-SURV products

In Table 38 we provide a short overview of all expected data products to be released by individual Surveys on top of the data products released by the common pipelines as described in the Science Management Plan: Back-end Operations [RD4] document. In general, these products are requiring considerable extra development effort and large samples for validation beyond standard data production.

Table 38: Summary table of DL2-SURV data products deliveries from the different Surveys and their first anticipated 4MOST Data Release number. Updates of these catalogues may in general be expected in all following Data Releases.

Survey	Target type	DL2-SURV	First DL2 DR	Comment
S1-S0101	FGK stars	vsini, age, distance	DR2	Not provided if DL2-IWG exists
S1-S0102	RR Lyrae	Phase-corrected RV, Teff, log(g), [Fe/H], Distance	DR3	Requires large samples and sufficient repeats for ML statistics
S3	All FGK stars for which StarHorse method is applicable	Age, distance, extinction, Teff, log(g)		Released in closest DR following publication
S3	Stars with useful seismic constraints	Distance, mass, radii, extinction		Released in closest DR following publication
S4	Aim that AL2 products described become DL2-IWG		Aim DR2	Released in closest DR following publication
S5	Galaxy clusters	Clusters redshift	DR2	For clusters with sufficient redshifts
S5	Galaxy clusters	Cluster properties catalogue	As available	Released in closest DR following publication
S6	Target catalogues of observed targets	RA, Dec, selection data	DR1	Incremental updates with each DR, full parent sample with final DR
S6	PAQS QSOs	Absorption line identifications, QSO emission lines, extinction measurements, cross identifications	As available	Released in closest DR following publication
S6	Other sub-surveys	Black hole mass estimates (when possible) and quasar continuum extinction E(B-V) from full spectral modelling	As available	Released in closest DR following publication

Survey	Target type	DL2-SURV	First DL2 DR	Comment
S7	Galaxies	ugriZYJHK photometry	DR2	
S7	StePS galaxies	Spectral lines and indices	DR2	
S7	Galaxies	Stellar masses for galaxies with redshift	DR2	Possibly provided with DL2-IWG
S7	Radio galaxies	Radio continuum flux densities, source classifications	DR2	
S7	Galaxies	Environment measures for completed areas		Released in closest DR following publication
S8	Galaxies	Clustering measurements for sufficient completed areas		Released in closest DR following publication
S9	Binaries, variable stars, evolved giants	Phase-corrected RV, stellar parameters, abundances		Released in closest DR following publication
S9-S0909	Neutron star and black hole companions	Classification flag		Released in closest DR following full-cadence availability and/or publication
S10-S1004	Strong galaxy lens systems	Deblended lens and source redshifts and lens velocity dispersions	DR2	
S11	Unresolved white dwarf - main sequence binaries and planetary nebula central stars	Teff, log(g)	DR2	
S11	White dwarfs in common proper motion pairs	Age	DR2	

Survey	Target type	DL2-SURV	First DL2 DR	Comment
S12	Young stars	Classification flags Age, mass, radius Mass accretion rate Accretion line flux Halpha line width (Rotation periods)	DR2	At least 1 yr after Gaia DR4 and required completeness for cluster achieved.
S13	Stars in clusters	Membership flag Cluster age	DR2	
S14	Stars in dwarf galaxies and stellar streams	Membership flag Age	DR2	
S15	Galaxy clusters	Cluster membership catalogues		Once ≥50% completeness has been achieved
S16	AGN	Host galaxy parameters: stellar age, metallicity, kinematics, SFR, stellar mass; AGN parameters: AGN continuum slope, MBH, L/LEdd and BH-driven outflow velocity and mass when broad line(s) are present		Released in closest DR following publication
S17	QSOs	Absorption system measurements	DR2	Or closest DR following first publication
S18	Galaxies	Optical and IR Photometry of observed targets	DR1	
S18	Galaxies	Fundamental Plane derived distances and Peculiar Velocities, stellar masses, star formation rates	DR2	Or closest DR after first publication
S18	Galaxies	Environment metrics, group catalogues	<DR4	Requires full completeness in area

Appendix A List of Acronyms

List of Acronyms	
4MOST	4-metre Multi-Object Spectroscopic Telescope
4CP	4MOST Classification Pipeline
4DAP	4MOST Data Access Point
4DPC	4MOST Data Processing Centre
4GP	4MOST Galactic Pipeline
4OR	4MOST Operational Repository
4PA	4MOST Public Archive
4PRAP	4MOST Pre-Release Access Point
4SP	4MOST Selection Function Pipeline
4XP	4MOST eXtragalactic Pipeline
AD	Applicable Document
AGB	Asymptotic Giant Branch
AGN	Active Galactic Nucleus
AL2	Additional Level 2 (Data Product)
CCD	Charge Coupled Device
CCF	Cross-correlation Function
CNN	Convolutional Neural Network
DL2	Deliverable Level 2 (Data Product)
DL2-SURV	Deliverable Level 2 - Survey (data product not delivered by an IWG, but by a 4MOST Survey)
DMS	Data Management System
DOE	Detection Of Extrema

List of Acronyms	
DR	Data Release
DRC	Data Release Candidate
DRM	Data Release Manager
DRP	Data Release Plan
DRPD	Design Report Pipeline Description
dVM	designated Visitor Mode
DXU	Data eXchange Unit
ETC	Exposure Time Calculator
FITS	Flexible Image Transport System
FoM	Figure of Merit
FP	Fabry-Pérot
FTE	Full Time Equivalent
HB/RC	Helium Burning/Red Clump
HR	High Resolution
HRS	High Resolution Spectrograph
ICD	Interface Control Document
IDR	Internal Data Release
IWG	Infrastructure Working Group
JOG	Joint Operations Group
L1	Level 1
L2	Level 2
LR	Low Resolution
LRS	Low Resolution Spectrograph

List of Acronyms	
LSST	Legacy Survey of Space and Time (of the Vera Rubin Observatory)
MS	Main Sequence
OB	Observation Block
ODG	Operations Development Group
OpSys	Operations System
OSP	Operations Start-up Phase
PCA	Principal Component Analysis
PDR	Public Data Release
PI	Principal Investigator
PN	Planetary Nebulae
QA	Quality Assurance
QC	Quality Control
QE	Quantum Efficiency
RD	Reference Document
RGB	Red Giant Branch
RV	Radial Velocities
S/N	Sign-to-Noise ratio
SAF	Science Archive Facility
SB1	Single Lined Binary stars
SCB	Science Coordination Board (of 4MOST)
SED	Spectral Energy Distribution
simulcal	Simultaneous Calibration
SMBH	Super Massive Black Hole

List of Acronyms	
SMP	Survey Management Plan
SN	Supernova
SNR	Sign-to-Noise ratio
SPV	Survey Programme Validation
ST	Science Team
TBC	To Be Confirmed
TBD	To Be Determined
TDE	Tidal Disruption Event
ThAr	Thorium Argon
TO	Turn-Off
VALD	Vienna Atomic Line Database
VRO/LSST	Vera Rubin Observatory / Legacy Survey of Space and Time
WD	White Dwarf
WG	Working Group
WP	Work Package
WR	Wolf Rayet