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EUROPEAN ORGANISATION FOR ASTRONOMICAL RESEARCH IN THE SOUTHERN HEMISPHERE

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Paranal Instrumentation Programme Plan
and 6 Monthly Report, September 2021

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Scientific Technical Committee is invited to note this document.

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Please note that much of the detailed planning in this document is done while the pandemic of coronavirus across Europe and Chile persists. Many of the milestones and objectives for 2020 and 2021 had to be revisited and the plans are continuously updated.

1. Executive Summary

The Paranal Instrumentation Programme (PIP) provides new instrumentation and infrastructures, or upgrades to the existing ones, to fulfil the mandate: "*The VLT ... to stay at the forefront of image quality through novel adaptive optics concepts – and efficient new instrumentation in order to maintain its world-leading position*" (ESO Long Term Perspectives document [ESO/Cou-1689 rev, 2016]).

This plan and report is updated biannually. The current plan includes (in *italics* the projects already in operation or integration/commissioning at Paranal):

- the VLT/I second generation instruments (*GRAVITY*, *ESPRESSO* and *MATISSE*) and the upgraded *CRIRES*$^{+}$ – all offered for observations to the community;
- the imager and spectrometer ERIS;
- *the upgrade of the VLTI infrastructure to accommodate the second generation VLTI instruments*;
- two multi-object spectrographs (MOONS for VLT and 4MOST for VISTA);
- two new instruments (NIRPS and SOXS) for La Silla, fully funded by the community;
- *development of an upgrade and replacement plan for the VLT workhorse instruments*;
- the upgrade of the *GALACSI Infrared Sensor (IRLOS)*;
- a visible MCAO instrument for UT4/AOF (MAVIS);
- the upgrade of FORS;
- CUBES, a new UV spectrograph (to be recommended for design and construction); and
- the enhanced GRAVITY+ system at VLTI (to be recommended for design and construction).

Initiating approximately one new instrument and one instrument upgrade every two years, the programme planned to reach a quasi-steady state in ~2021, with eight to nine projects running at any time. The COVID-19 pandemic has delayed the completion of several projects since 2020, so the number of projects presently running is higher than foreseen. In principle, increase in scope, delay or overspend is accommodated within the total resources available by either rephasing or de-scoping the existing projects, or by shifting the start of new ones. The recent delays made the start date of the two Phase A studies, recommended by the VLT2030 process, GRAVITY+ and BlueMUSE, problematic. The resources allocation to PIP in 2021 exceeded what was originally established in the BFL, and this has allowed the Phase A study of GRAVITY+ to run, and which is now proposed for recommendation to start the design and construction phase. Given that GRAVITY+ is a rather demanding project for the PIP programme, its development will have an impact on projects that are either recently started or must still be deployed such as FORS+, CUBES and BlueMUSE. As for BlueMUSE, ESO plans to start the Phase A study early 2023, if no further crisis occurs. Based on the very successful MUSE, the project is considered a low technological risk and it will be initially followed up by a reduced team (project manager, scientist and engineer), the same follow-up scheme will be used for CUBES.

Recent commissioning runs (CRIRES+, IRLOS) have been carried out by Paranal staff with remote support from Garching. They have been extremely successful, thanks to the dedication of all people involved.

ERIS went through the PAE process, but is still in Europe, where the high vibrations induced by the NIX camera are being addressed.

A risk policy and a cost-to-completion (CtC) policy have been implemented. Since October 2018, the non-contracted funds have been indexed for inflation in order to preserve the long-term spending power of the PIP budget. A lessons learned report on the second generation instruments is available in the Messenger (Vol. 166, p. 29, 2016). A new lessons learned exercise, expected at the end of 2020, has been moved to 2022 and will include in-house and consortium-led projects.

2. <u>Introduction</u>

The fundamental goals for the Paranal Instrumentation Programme are summarised in several strategic ESO documents (Cou-994, 2004; Cou-1689 rev., 2016), and were confirmed in the recent article dedicated to the decadal ESO strategy (The Messenger 183, p.3, 2021): "*Ensure that the current facilities remain at the forefront of astronomical investigations, by e.g. Ensuring, in partnership with the community, that VLT, VLTI, ALMA (with ESO's partners), including their instrumentation, continue to be state-of-the-art*".

As far as the VLT/I instruments are concerned, this strategy is implemented following the guidelines discussed in the "Science Prioritisation Report" document (STC-551, 2015) and the guidelines for decommissioning the VLT instruments and upgrades (STC-569 and STC-570, 2016, STC-587, 2017). A new roadmap for the VLT/I has been presented to STC (STC-658, 2020) that includes the outcome of the VLT2030 process (STC-646, 2020).

The instrumentation development plan provides a framework for the implementation of new instrumentation and upgrades, and proposes an implementation that allows a renewal of the Paranal instrumentation consistent with the available resources, while maintaining the commitments taken for the running VLT and VLTI projects. The plan does not include obsolescence management or maintenance of ageing instruments; these are the responsibility of the Paranal Observatory, although they are implemented within the PIP projects in case of instrument upgrades.

The complement of VLT/I instruments in operations or approved (see figures 1 & 2 and the tables in Appendix A) cover most options in imaging (including Adaptive Optics (AO) and VLTI diffraction limit) and spectroscopy in the 300-24,000 nm range.

The wavelength/resolution coverage is not the only relevant parameter space; the Paranal instrumentation set includes five Integral Field Unit instruments (three AO-assisted) and at least four multi-object spectrographs. The Paranal Observatory provides polarimetry, high contrast imaging and coronography, fast photometry and superb astrometry, as well as the finest instruments for precise Doppler shifts determination.

The strategy for the VLT in the era of full ELT operations has been developed through discussions with the community at large and a dedicated workshop which took place in June 2019. The workshop is summarised in STC-639 (2019), STC-646 (2020) and a Messenger article (Messenger Vol. 177, p. 51, 2019). The STC, in its 95th meeting, recommended starting the Phase A study of GRAVITY+ immediately, and BlueMUSE not later than 2022. An additional call, that will include a high resolution MOS, will follow later, after these projects have started.

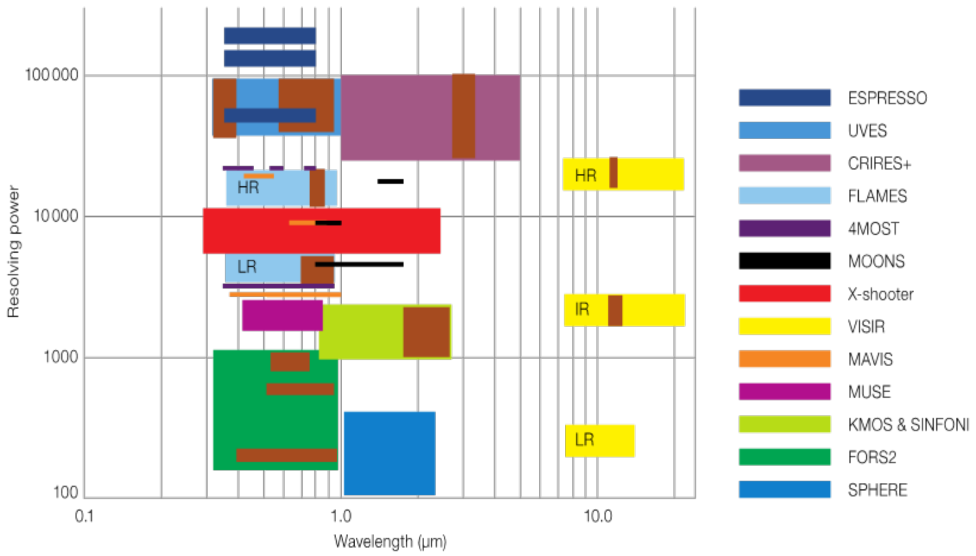


Figure 1: Wavelength - Resolving Power diagram for the VLT instruments, including those under design and construction.

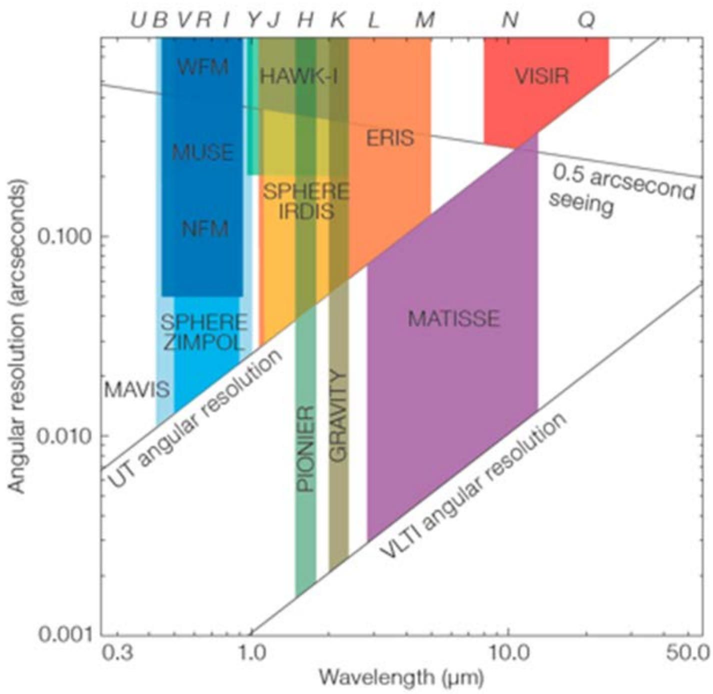


Figure 2: Wavelength - Angular Resolution diagram for the VLT and VLTI instruments, including those under design and construction. MAVIS will replace HAWK-I at UT4.

3. Current Programme

Table 1 summarises the status of the projects under PIP governance. It contains projects in all phases, from design to commissioning. MAVIS started the design phase in early 2021. CUBES and GRAVITY+ are expected to start the design and construction phases in early 2022.

Project Name	Description	Status
1. MATISSE	VLTI mid IR imager	Operations/PAC pending
2. ESPRESSO	High Resolution 1UT & 4UT	Operations/PAC
3. ERIS	AOF Imager and Spectrograph	PAE
4. CRIRES+	Upgrade, X-disperser, new detectors	Operations/PAC pending
5. MOONS	IR Multi-Object Spectrograph for VLT	Integration Europe
6. 4MOST	Optical Multi-Object Spectrograph for VISTA	Integration Europe
7. IRLOS Upgrade	Low noise Detector for IRLOS	Operations/PAC pending
8. FORS Upgrade	New Detector electronics SW	Design & Construction
9. MAVIS	Visible MCAO for UT4	Design & Construction
VLTI Facility		
10. PR5	GRA4MAT Fringe Tracker	Commissioning
LA SILLA		
11. SOXS @ NTT	X-Shooter – for NTT	Integration Europe
12. NIRPS @ NTT	IR Planet RV and atmospheres	Integration/PAE
PHASE A Studies		
13. CUBES	UV Spectrograph	For recommendation
14. GRAVITY+	GRAVITY Expansion	For recommendation

Table 1: List and summary description of running Paranal Instrumentation projects. VLTI infrastructure has been split into its main subsystems. Delivery dates are given in table 2. Phase A studies are also listed, but they are not approved projects.

3.1 Recent Instruments at Paranal

Several instruments and projects have been offered for observing incrementally, for several years, even though they have not yet formally reached Provisional Acceptance Chile (PAC). PAC has been awarded for ESPRESSO and is expected soon for MATISSE. CRIRES+ has just finished commissioning and it will be offered for operations in all its modes. IRLOS has also been fully commissioned, actually performing better than predicted.

Several PIP interventions planned at Paranal and at La Silla in 2020 were postponed to 2022. Some have taken place thanks to the support of Paranal staff and to the use of the renewed G-RAF remote facility, such as the commissioning of CRIRES+, the Front End of NIRPS and the IRLOS installation and commissioning. Others had to be postponed to 2022.

In general, COVID-19 generated delays are in the range of ~9 to ~18 months for projects that are in construction or in an advanced phase, with an average delay of 10-12 months. Projects in early phases have been much less affected by the pandemic. The situation is far from being normalised, in particular regarding travelling to the observatories, and to the laboratories and facilities in many institutes. Nevertheless, a great deal of work has been accomplished in all projects. FORS has finally been shipped from La Silla to Garching and then to Trieste. The 4MOST review for the VISTA modifications took place, and the ERIS PAE has been completed, though the instrument could not yet be shipped because of high vibrations. Many major sub-systems have been delivered to all projects in the integration phase.

3.1.1 MATISSE

Principle Investigator	B. Lopez, OCA
Consortium Institutes	Observatoire de la Côte d’Azur (OCA), Nice (lead) Institut National des Sciences de l’Univers, Paris University of Nice Sophia-Antipolis, Nice Max-Planck-Institut für Astronomie, Heidelberg Max-Planck-Institut für Radioastronomie, Bonn Netherlands Research School for Astronomy, Leiden Institut für Theoretische Physik und Astrophysik, Kiel University of Vienna
ESO Project Team	A. Glindemann (PM), M. Schöller (PS), P. Bristow (PE)
Installation Location/Date	VLTI/February 2018
Status	In operations
Guaranteed Nights	150 single UT nights; 7.2% (173 nights) of VISA for eight years

3.1.1.1 *Overview/Description*

MATISSE (Multi-Aperture mid-Infrared SpectroScopic Experiment) is a 4-way beam combiner second generation instrument for the ESO VLTI, designed to be sensitive from the L to the N band. MATISSE’s multi-way combination will provide a capability to create simple images with interferometric resolution of a wide range of targets, including young stellar objects (T Tauri stars, Herbig Ae/Be stars, β Pic objects), AGN cores, and asteroids, following the STC and Council recommendations of 2007. The re-integration of MATISSE at Paranal started in Q4 2017 and First Fringes were achieved on 18 February 2018. Science operations started in April 2019.

3.1.1.2 *Highlights of period*

The Commissioning Report was released as well as the PAC report and the punch list. One action in the punch list concerns an intervention for the cold motors in the L-band cryostat. The proposed modification has been approved, and the intervention is planned to start on 26 December, the pandemic situation permitting. It was decided to wait for the results of the intervention before granting PAC.

3.1.1.3 *Technical activities*

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
Kick-off	November 2008	November 2008	0
PDR	October 2009	November 2009 (to be repeated in December 2010)	0
PDR (2)	-	December 2010	0
Optical&Cryo FDR	-	September 2011	0
FDR	January 2011	April 2012	15
PAE	May 2014	September 2017	40

Brief bullet summary of upcoming activities for next period
• PAC to be awarded after successful intervention in December/January.

3.1.2 ESPRESSO

Principle Investigator	F. Pepe; Observatoire de Genève
Consortium Institutes	Observatoire de Genève, University of Bern Instituto Nazionale di Astrofisica (INAF), Trieste and Brera Instituto de Astrofísica de Canarias Universidade do Porto e Lisboa Instituto Nacional de Engenharia (INETI), Lisbon
ESO Project Team	A. Manescau (PM/PE), G. Lo Curto (PM/PS)
Installation Location/Date	VLT Combined Coudé Laboratory / Q1 2018
Status	Commissioning
Guaranteed Nights	273 (1 UT)

3.1.2.1 *Overview/Description*

The Echelle Spectrograph for Rocky Exoplanet and Stable Spectroscopic Observations, ESPRESSO, is a super-stable Optical High-Resolution fibre-fed Spectrograph for the combined coudé focus of the VLT. It can be operated by either one of the UTs or collecting the light from up to four UTs simultaneously. The light path that relays the light from the telescopes to the combined coudé laboratory, 60m away, has been equipped within the scope of the project.

ESO participates in ESPRESSO with several Work Packages (WPs): detector, cryogenics, grating and cameras, calibration system and coudé interfaces, and it is integrated in the project structure as an associated partner.

3.1.2.2 *Highlights of period*

- With the release of the ESPRESSO PAC Report and the ESPRESSO Post-PAC Punch List, a PAC review meeting took place and PAC was granted on 26 April 2021.
- Front End lenses were installed by Paranal staff, with remote support from the consortium. Activity was executed during shift T from 17 – 28 May 2021, addressing one action item from the post-PAC punch list report with the tests and characterisation of the system after the replacement had been drafted. The preliminary conclusion is that the gain in efficiency with the new lenses is as expected (10 - 12% in the extreme blue, 2 - 5% in the first 30 orders).
- The new release of the ESPRESSO pipeline includes the recipes for cosmic ray detection, addressing one action item from the post-PAC punch list.
- COVID-19 is affecting the progress of all remaining activities (the ones listed in the post-PAC punch list and the ones identified in the PAC review meeting).
- There is little progress on the investigation of the detector cryostat instability due to the pandemic and conflicts with other projects. The spare cryostat is being refurbished, including new cabling, temperature sensors and connectors. Some technical problems have been found (vacuum leak, and cable installation in the cryostat) which are been resolved to continue with the cryostat characterisation.
- The progress of the activities on the ESPRESSO detector system is limited due to many operations requirements and limited staff at the observatory. Nevertheless, Paranal staff is highly committed to complete these tasks.

3.1.2.3 *Technical activities*

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
Kick-off Meeting	4 - 5 October 2010	4 - 5 October 2010	0
Technical Kick-off Meeting	17 - 18 January 2011	17 - 18 January 2011	0
PDR	October 2011	29 - 30 November 2011	1
Advanced FDR (LLI)	July 2012	18 June 2012	-1
FDR	April 2013	14 - 16 May 2013	1
Coudé PAE	June 2015	April 2016	10
PAE	October 2015	June 2017	20
PAC	December 2016	26 April 2021	46

Current main risks	
Risks	Planned action
COVID-19	The pandemic is slowing down technical activities and asks for reschedule technical missions.
High accuracy calibrations: 1. Lack of high purity ThAr lamps; and 2. LFC unavailability.	Temporary mitigation using a mix of FP & ThAr; in the longer term, the blue LFC is under development and will be installed asap.

Current main risks	
Risks	Planned action
RV stability: Blue detector oscillating up to 4m/s PTV.	The investigation is ongoing, new test cryostat is prepared and under test. An intervention is planned as soon as Paranal becomes accessible for the team.

Brief bullet summary of upcoming activities for next period
• Continue the tests with the spare cryostat for the understanding and fixing of the RV stability issue (from previous period). Prepare the cryostat repair mission. • Resubmit the change request for the refurbishment of the cooling of the LFC room (from previous period). • Implementation and validation of faster readout mode (from previous period). • Continue with the progress on the actions included ESPRESSO Post-PAC Punch List (ESO-385649).

3.1.3 CRIRES$^+$

Principle Investigator	A. Hatzes, Thüringer Landessternwarte Tautenburg
Consortium Institutes	European Southern Observatory Thüringer Landessternwarte Tautenburg Georg-August-Universität Göttingen (IAG) Instituto Nazionale di Astrofisica (INAF) Osservatorio Astrofisico di Arcetri Uppsala University, Department of Physics & Astronomy
ESO Project Team	R. Dorn (PM), J. Vernet (PS), P. Bristow (PE)
Installation Location/Date	Nasmyth B UT3 / Q4 2019
Status	PAE phase
Guaranteed Nights	62

3.1.3.1 Overview/Description

The CRIRES Upgrade project (CRIRES$^+$) transformed CRIRES into a cross-dispersed spectrograph. The simultaneous wavelength coverage is increased by a factor of at least ten with respect to the previous configuration. In addition, a mosaic of three HAWAII 2RG detectors has been installed and new gas cells are used to calibrate the instrument and to obtain precise (a few ms^{-1}) radial velocities. Finally, a polarimetric unit has been added to measure accurately the magnetic fields of low-mass stars and stars in their early stages of formation.

3.1.3.2 Highlights of period

Two months after the second commissioning run was completed, one of the three closed cycle coolers of the CRIRES$^+$ instrument failed, and the instrument had to be warmed up to service the CCC heads which is usually scheduled every 18 months. This preventive maintenance could not be performed due to the reduction of Instrumentation staff following the COVID-19 measures in place on Paranal. Because of the failure of one cold head, this maintenance was rescheduled, and all three closed cycle coolers were serviced with new displacers and seals.

The instrument was cooled down again, tested and COMM3 (Commissioning 3) took place from 9 to 13 June 2021 and COMM4 (Commissioning 4) from 13 to 18 August 2021. Jonathan Smoker, the newly appointed ESO project scientist of CRIRES+, led the activities from Paranal.

COMM3 and COMM4 were "distributed" with contributors in eight different locations simultaneously (Berlin, Garching, Uppsala, Moscow, Munich, Paranal, Santiago, Vienna). COMM3 and COMM4 were focused on pending instrument characterisation (RV standards, AO off-axis vignetting etc.) and template testing, as well as commissioning of the spectro-polarimetry mode of CRIRES+. For the latter, the AO acquisition and observation templates have been tested and optimised and throughput data were taken in J, H and K-band to be included in the Exposure Time Calculator (ETC). A polarimetric signal was detected on gamma Equ and found to be very similar to the spectra obtained by SPIRou at CFHT. Additional RV standards data have been taken in COMM4, but bad weather conditions limited data quality. Currently the best RV attainable using the gas cell is only around 20 m/s. More data will need to be taken in technical time to optimise the RV precision.

Testing and debugging of templates of all differential tracking cases has been completed and are working fine (NGS=Target, NGS !=Target, NoAO SVGS=Target, NoAO != Target).

For the ETC all settings have now been observed in AO mode. The automatic pipeline works well on Paranal, and the quality of reduction is being checked with ongoing work. The Calibration Checker has been tested and is working, the Health Checker is still pending, waiting for final requirements and coding of quality control parameters.

The Ne-lamp used for the metrology died and was replaced by a lamp from the Paranal spare pool. The new lamp seems to have less flux than the original lamp which caused the metrology to fail for some settings. The light loss is being investigated and it is planned to change the lamp before Science Verification. A new set of spare lamps has been sent to Paranal. A workaround has also been implemented for the metrology, removing the use of some of the weaker neon lines and reducing the analysis threshold for those that remain.

DRS development has continued with significant progress related to wavelength calibration and spectro-polarimetry and support for QC, while substantial modification has been made to the templates to be ready to support operations. Regular daytime G-RAF sessions were organised throughout the period.

The Commissioning phase of CRIRES$^+$ is now completed and the remaining actions will be investigated by technical time requests in the next months. The call for proposals for CRIRES$^+$ SV projects was issued on 17 June 2021 and the SV run is scheduled from 15 to 19 September 2021. The instrument is then offered in October 2021.

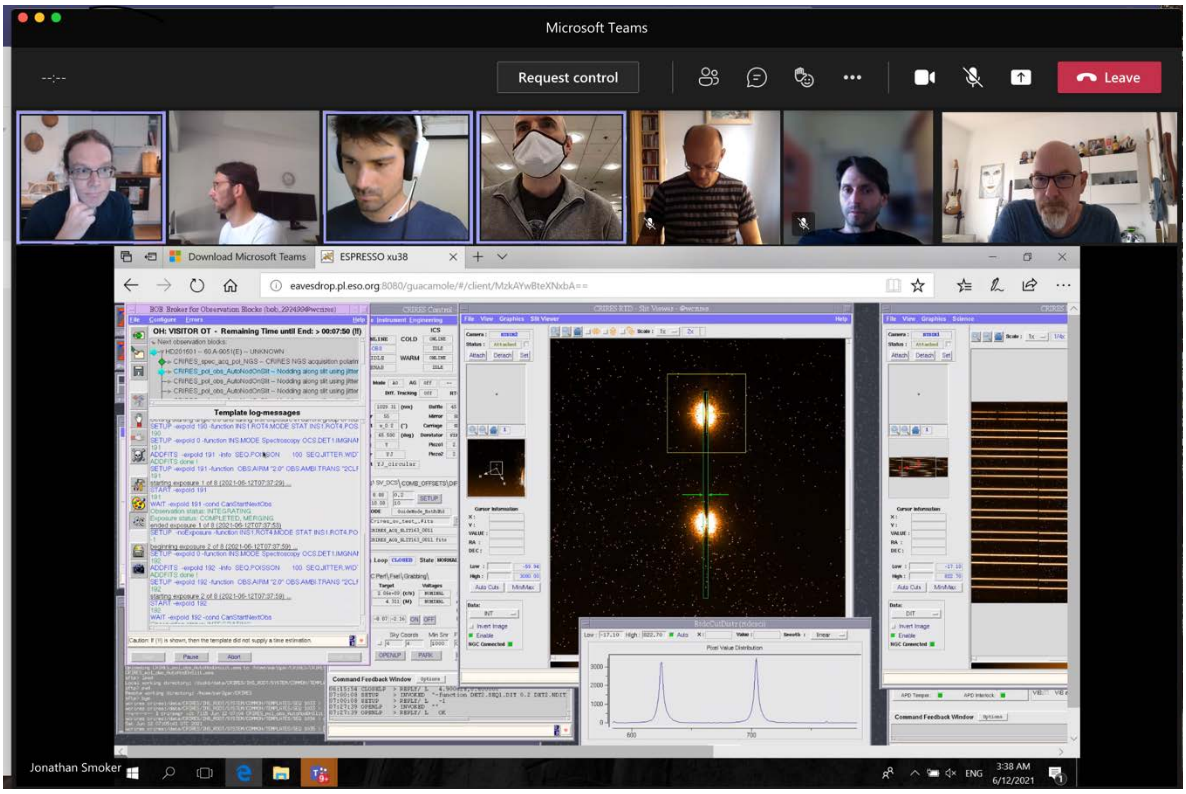


Figure 3: The CRIRES+ team during Commissioning 3 with contributors in eight different locations simultaneously (Berlin, Garching, Uppsala, Moscow, Munich, Paranal, Santiago, and Vienna).

3.1.3.3 *Technical activities*

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
PDR	April 2015	April 2015	0
Optical FDR	April 2015	April 2015	0
FDR	December 2015	April 2016	4
PAE	December 2016	September 2019	34
PAC	November 2017	March 2022	52

Current main risks	
Risks	Planned action
Electronics obsolescence not complete by PAC.	Monitor progress, upgrade at later stage on Paranal.
HCL calibration source not optimised for operations.	Have Paranal engineers adjust the lamp and verify the effect by operating the instrument via remote access from Garching.

Brief bullet summary of upcoming activities for next period
• Science Verification; • Start Instrument operations in October 2021; and • Technical time requests to solve remaining issues on RV precision, instrument spectral resolution and optimization of wavelength calibration.

3.1.4 VLTI Facility Project

Principle Investigator	None
Consortium Institutes	NAOMI: IPAG, Grenoble, France
ESO Project Team	F. Gonté (PM), J. Woillez (PE/PS)
Installation Location/Date	VLTI, over period Q2 2014 to Q4 2020
Status	In operation: • Service Station I2; • Interferometric and combined Coudé laboratory; • Inner and outer Coudé rooms of Unit Telescopes; • Star separators for Auxiliary and Unit Telescopes; • NAOMI; and • VIBMET. In integration phase: • GRA4MAT.
Guaranteed Nights	28 GTO nights with NAOMI and the VLTI-AT for IPAG

3.1.4.1 Overview/Description

Since 2014, the VLTI Facility Project covers the following sub-projects/activities:

- The construction of a new service station for the Auxiliary Telescopes which helped with the installation of the star separators and NAOMI inside the telescopes.;
- The upgrade of the VLTI hardware and software infrastructure to prepare the arrival of the GRAVITY and MATISSE instruments. This activity includes the installation of the star separators in the ATs and UTs, the upgrade of the VLTI laboratory, VLTI combined coudé room, UT inner and outer coudé rooms, and control software;
- The improvement of the VLTI infrastructure performance, by means of an investigation programme, with the objective of achieving the performance specifications of the second generation instruments MATISSE and GRAVITY. This activity includes the development of VIBMET, a daytime vibration metrology for the maintenance of the UTs;
- The development of NAOMI, a visible AO system for the ATs, designed to improve the overall performance of VLTI in median and poor seeing conditions, and enable robust fringe tracking; and
- The use of the GRAVITY fringe tracker to support MATISSE (GRA4MAT), as a cost-effective replacement of a second generation fringe tracker.

The VLTI facility project was expected to be closed by the end of 2020; COVID-19 has delayed this to mid-2021. The issue with the L-band dispersion wheel of MATISSE is now pushing the completion even further, to a date not possible to determine at the moment.

3.1.4.2 *Highlights of period*

NAOMI: Adaptive Optics for the ATs.

NAOMI PAC was granted. This work package is now closed.

GRA4MAT: GRAVITY Fringe Tracker for MATISSE.

The issue with the MATISSE L-band dispersion wheel severely impacted the continuation of the commissioning of GRA4MAT in L-band. Observations with the UTs have shown that GRA4MAT is significantly impacted in L-band by fringe jumps, a consequence of the poorer AO correction. A mitigation involving changes to the group delay control loop of the GRAVITY fringe tracker could not be implemented due to the COVID19-induced shutdown of VLTI operations with ATs (modifying and testing the GRAVITY fringe tracker is not the best use of UT time). The recent UT commissioning run was completely weathered out.

Due to the L-band issue and the COVID-19 situation, it is still not possible to determine when the commissioning of GRA4MAT on the UTs can be completed. There is again an additional delay of at least +6 months.

Milestone schedule			
Major Milestones	Planned date at kick-off/ Stated in agreement	Actual date, or current best estimate	Slip (months)
VLTI-Infrastructure			
VLTI operational with AT-STS	01.09.2015	01.10.2015	1
PAC AT-STS	01.04.2016	01.11.2016	7
VLTI operational with UT-STS	01.04.2016	01.04.2016	0
PAC UT-STS	01.10.2016	01.11.2016	1
PAC UT coudé Room	01.10.2016	01.11.2016	1
PAC VLTI lab& CCL	01.04.2016	01.07.2016	3
PAC AT upgrade	01.04.2016	01.11.2016	7
Closeout Differential DL	26.01.2014	01.10.2017	45
PAC ISS for Gravity	01.12.2016	01.11.2017	11
VLTI-Performance			
AT coudé train recoating	15.02.2017	15.08.2017	6
VibMET deployment	15.12.2017	15.10.2019	23
NAOMI			
PDR	21.05.2015	21.05.2015	0
FDR (delta-FDR required)	15.02.2016	28.04.2017	14
1st Corrective Optics delivery	01.02.2017	01.06.2017	4
PAE	15.02.2017	10.07.2018	17
PAC	15.12.2018	16.04.2021	28 (-2)
GRA4MAT			
Kick-off meeting	15.03.2016	15.12.2016	9
Technical review	22.04.2016	26.08.2019	40
PAC (delay: COVID-19 & MATISSE issue)	15.12.2017	31.06.2022	57 (+6)

Completed Milestones – Pending Milestones – (+XX) slip variance since last STC.

3.1.4.3 *Technical activities*

Current main risks	
Risks	Planned action
Further GRA4MAT delays due to combined COVID-19 and MATISSE L-band issues.	Continue relying on the remote observing room (G-RAF). But there is no easy fix to the MATISSE L-band hardware failure.

Brief bullet summary of upcoming activities for next period
GRA4MAT • Continue the UT commissioning despite the MATISSE L-band failure. • Wait for the MATISSE L-band fix to complete the commissioning. • Improve the group delay control loop of the GRAVITY fringe tracker.

3.1.5 IRLOS Upgrade

Principle Investigator	None
Consortium Institutes	None
ESO Project Team	S. Oberti (PM & PE), F. Selman (PS)
Installation Location/Date	UT4 / 2021
Status	The AIV and commissioning has been successfully completed. The new capabilities are available for operation.
Guaranteed Nights	None

3.1.5.1 *Overview/Description*

The former InfraRed Low Order Sensor (IRLOS) of the MUSE Narrow Field Mode has a limiting magnitude of H=14.5, which is a major limitation for the exploitation of MUSE NFM for faint targets. The main project scope is to replace the former Hawaii I detector with a Read-Out Noise (RON) of 11e- by a Saphira detector. The expected gain from using a detector with a sub-electron RON is of ~ 2 magnitudes, which has been set as a performance goal.

3.1.5.2 *Highlights of period*

The following key milestones were achieved during this reporting period:

- AIV and COMM1 during shift N between 10 and 24 March 2021;
- Resolution of action items from COMM1 and preparation of COMM2; and
- COMM2 during shift Y between 12 and 18 July 2021.

3.1.5.3 *Detailed activities*

After a careful preparation, the AIV and COMM1 took place between 10 and 24 March 2021. As nobody could travel from Europe, Paranal staff took over all hardware related activities with the remote support from Europe via G-RAF and MS Teams. The cryostat swap, cool-down and fine centring in X, Y, Z were carried out efficiently, as planned. Nevertheless, significant issues were encountered in the following areas:

- The Saphira detector and NGC picked up a large amplitude 50 Hz noise. After long investigations, the chain of causes could be narrowed down to the grounding design of the preamplifier cable shield. A work around was found, which allowed to proceed with commissioning activities. A long term solution is still under investigation;
- The image of the pupil on the lenslet arrays was found to be misaligned. So Paranal staff had to undertake a delicate realignment of the warm optics upstream IRLOS, with remote guidance from Garching. A good alignment could be reached, with a flux imbalance less than 10% between subapertures;
- A list of SPARTA issues to be resolved before proceeding with the commissioning of the faint end mode was identified; and
- Difficulties have been encountered for the acquisition of faint targets in full pupil mode. Some improvements were defined to implement a robust acquisition strategy. The corresponding OS code was then developed and tested during daytime.

After solving the main technical issues there were three nights with good to median atmospheric conditions and a lower humidity rate, permitting the following:

- Reaching the performance specification with the workhorse modes for extended targets (large scale) and unresolved targets (small scale). With the latter, it was possible to run automatic operations in a robust fashion at 17th J magnitude, i.e. beyond expectations;
- The Tip/Tilt residual jitter has been reduced by sampling the wavefront at 500 Hz instead of 200 Hz previously, which extends the range of high performance as a function of magnitude and turbulence conditions (seeing and coherence time);
- By alignment and system configuration tuning, the off axis guiding capabilities were maximized for offsetting purpose and to increase the sky coverage; and
- Even though not fully optimized, the two workhorse modes have been verified and delivered back for operation with a version controlled and archived Software. As a matter of fact, MUSE was running observations in Narrow Field Mode the night after the first commissioning ended, and has been running regularly since then.

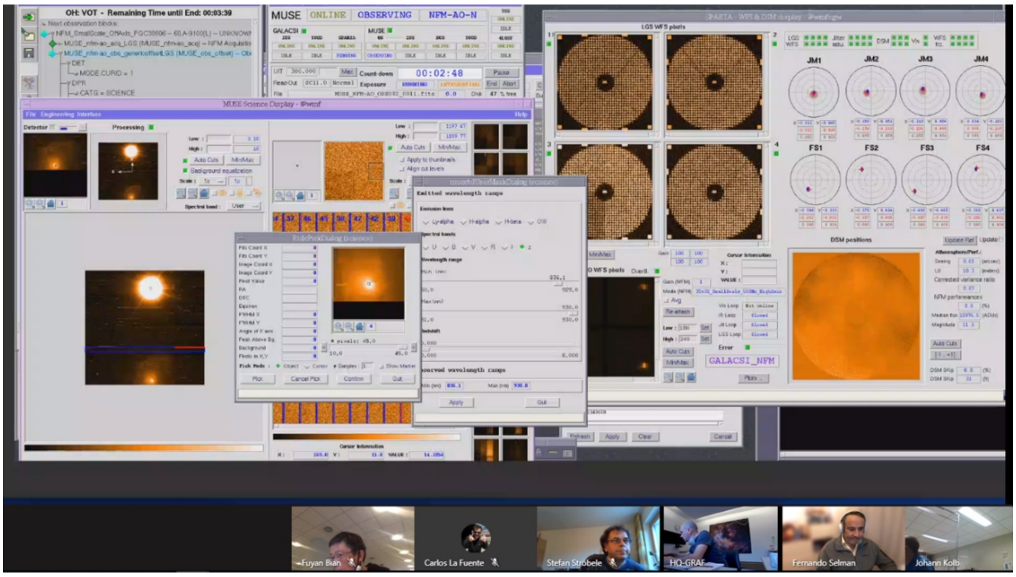


Figure 4: A typical Teams screen shot during a commissioning night [Left] MUSE observing PGC 33606 while IRLOS was alternating guiding on the off axis star and on the Galaxy nucleus [Right] SPARTA panel showing the LGS 40x40 WFS focal planes, the DSM's 1156 actuators positions fitting the turbulence and the four IRLOS spots [Bottom] The team located at the UT4 console (Fuyan Bian and Carlos La Fuente), the VLTI control room (Johann Kolb), Santiago (Fernando Selman), HQ G-RAF (Sylvain Oberti) and from home in Garching (Stefan Ströbele)

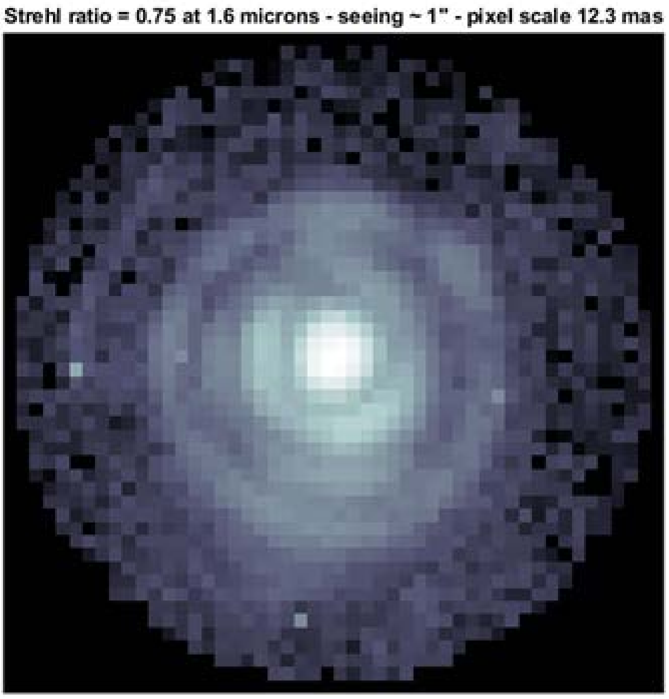


Figure 5: LTAO closed loop - H band PSF on IRLOS in full pupil mode with Tip/Tilt correction at 200 Hz and defocus truth sensing from the active optics guide probe. The image is raw, without any processing (log scale display only). Performance was stable for about one hour with a Strehl ratio of ~ 0.75 at 1600nm under a seeing of ~ 1" according to the DIMM. Scaled to the blue, it corresponds to a Strehl ratio of 0.18 at 650 nm which is ~4 times higher than the specified performance of GALACSI NFM and twice higher than the goal performance under a seeing of 0.6".

During the second commissioning, the team's ambition was to deliver a faint mode extending the limiting magnitude beyond the original project's goal. All operational modes were also fine-tuned. Given the bootstrap and acquisition difficulties encountered with the full pupil mode and the good performance achieved in 2x2 small scale at 500Hz, it was decided to implement a 2x2 small scale mode running at 200 Hz. Despite the challenge of working remotely and encountering unfriendly weather conditions, the new goal was achieved. Indeed, the limiting magnitude could be extended by two additional magnitudes in J, enabling observations down to J=18.5 in **turbulence categories 10% to 50%**, and down to J=19.0 for turbulence category of 10% and airmasses smaller than 1.2. The current IRLOS is thus able to go fully four magnitudes fainter than the original one. At the same time, the capabilities to observe brighter targets were enhanced to automate the process of inserting filters and widening the laser constellation. In principle, it is now possible to do observations in the range of magnitudes between 0.5 and 19.3, although the system is offered only for low-order reference objects in the range 5.5 to 19.0.

Preliminary results show that the performance is better than the best achieved performance prior to commissioning IRLOS+. Under all conditions of coherence time and seeing higher Strehl ratios and a smaller core PSF FWHM are obtained. Now it will be possible to even extend the operational range from coherence times of 3.1 ms, down to 2.5 ms, at least for low airmasses.

The accompanying figure below shows an observation of the Einstein cross using one of the lensed quasar images, with J=15.9, for low-order sensing. This target which was impossible with the original IRLOS is now in the easy, bright range of IRLOS+.

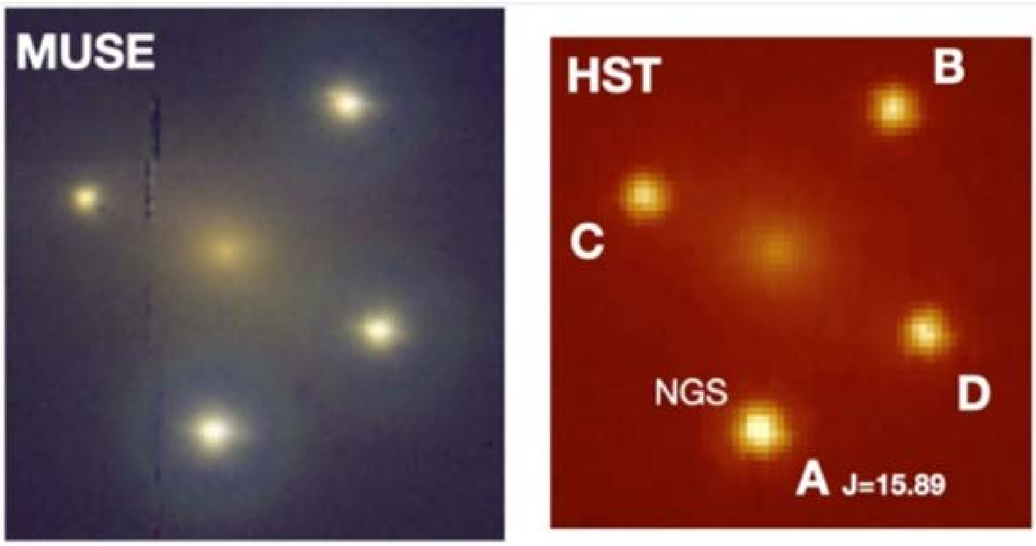


Figure 6: Einstein cross observed with MUSE NFM and IRLOS+ - 600 seconds total integration time - DIMM seeing of 1.03", coherence time 3.6 ms, at airmass 1.14 – spaxels of 25 mas [Left] and with HST [Right].

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
Kick-off meeting	19 March 2019	19 March 2019	0
Design review	Q2 2019	12 July 2019	0
PAE	Q2 2020	30 October 2020	4
PAC	Q4 2020	Q4 2021	12

Current main risks	
Risks	Planned action
Unstable grounding problem on the preamplifier cable. The work around solution consists in insulating the cable shield from the NGS chassis but appears to be mechanically unstable. A sustainable solution shall be implemented.	A non-metallic connector locking ring is being investigated. An alternative solution consists in powering the preamplifier through the video cable. It would require a modification of an NGC board located outside the cryostat.

Brief bullet summary of upcoming activities for next period
• Commissioning data reduction. • Commissioning report. • PAC process

3.2 Projects Currently Under Development

A number of projects are being developed in collaboration with consortia in ESO Member States. ERIS, MOONS and 4MOST are in AIT Phase. All these projects have been affected by the pandemic in a rather heavy way, and since 2020 they have announced delays ranging from 9 to 18 months and the situation is not yet normalised. The Paranal Instrumentation Programme is also responsible for the development of the infrastructure upgrades, enabling the instruments to deliver their best performance, and 4MOST is of this nature. After a successful Phase A review, the visible MCAO imager and spectrograph MAVIS is in design phase.

3.2.1 MOONS

Principle Investigator	M. Cirasuolo, C. Evans, UK ATC (Astronomy Technology Centre)
Consortium Institutes	CAAUL, GEPI, INAF, AIUC, ETH, ESO, University of Cambridge, University of Geneva
ESO Project Team	P. Hammersley (PM), J. Vernet (PS), F. Delplancke (PE)
Installation Location/Date	Nasmyth platform of a UT, Q3 2023
Status	Integration Phase
Guaranteed Nights	298

3.2.1.1 *Overview/Description*

MOONS is a 0.8 to 1.8 microns multi-object spectrometer for the Nasmyth focus of the VLT. The instrument is fibre fed, has a multiplex of at least 500 with a goal of 1000 and covers a total field of 25 arc minutes in diameter. There are two spectral resolving powers, ~4000 spanning the full wavelength range and a higher resolution mode which gives ~9000 in the I window and ~20000 in a region in H windows. The instrument itself has two main parts:

- The rotating front-end which is at the focal plane and houses the fibre positioners, acquisition system, metrology system for the fibres, etc.; and
- The cryogenic spectrograph which houses the spectrograph optics, VPH gratings and detectors.

3.2.1.2 *Highlights of period*

The MOONS FDR was granted in February 2018. The main contracts have been signed and the components are now being delivered. The Integration Readiness Meeting was held successfully in July 2020 and both the spectrometer and front end are currently being integrated.

The rescheduling of MOONS to assess the impact of COVID-19 and the latest developments in delivery of externally sourced items (FPUs, Optics, detector cabling), and the progress at institutes is now complete. This indicates that the best case scenario for the Spectrograph would be PAE in Q2 2023.

The cryostat has performed well in the initial cold test. The optical bench has been installed, as well as the cryogenic systems and cabling. Currently, the cryostat is being prepared for the first cool down with the optics and a detector. This has required a considerable effort and has been delayed by COVID-19 due to staff being forced to self-isolate.

The science grade Hawaii 4RG detectors were delivered and initial tests have been made on the Hawaii 4RG engineering array. There was an issue with detector glow with one of the science arrays, but this has been replaced. The cables for the final cryostat are now on order. The visible CCDs have also been delivered and the controller is currently being modified to work with these CCDs.

The collimators and the six cameras have been delivered to the Consortium. Three cameras have been integrated, aligned and derived to the UK ATC. The remaining camera should be delivered by the end of the year. The dichroic and the first of the gratings have been delivered. There has been, however, a delay on the high resolution H grating. This is a mosaic, and it has been difficult to obtain the required quality. The manufactures are making progress and are promising delivery by the end of the year.

The production units of focal plane fibre positioners are being delivered in instalments, as are production fibres. The measured transmission of the fibres meets the transmission budget. Installation has begun, but with 1000 fibres to be mounted this will take many months to complete. Acquisition cameras have now been fully delivered and this is the first subsystem to have delivered the full hardware. The field corrector has been completed and is ready for shipping to Paranal.

The OPS software, particularly that for source selection optimisation and trajectory, has functioning prototypes and work in improving its performance is progressing.

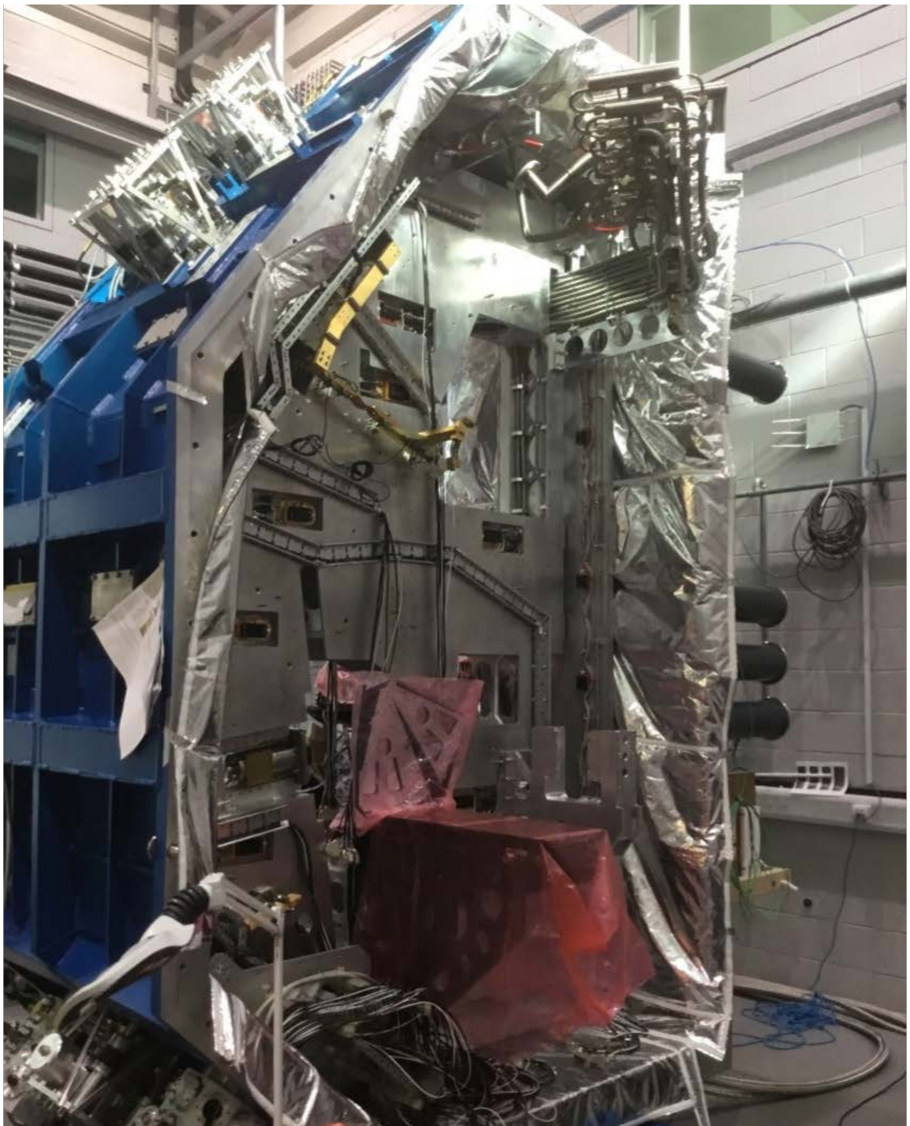


Figure 7: The inside of the MOONS Cryostat at the UK ATC.

3.2.1.3 *Technical activities*

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
Kick-off meeting	October 2014		
PDR	September 2015	22 October 2015	1
FDR	Q4 2016	Q1 2017	3
PAE	Q3 2019	Q2 2023	45
PAC	Q2 2020	Q1 2024	45

Current main risks	
Risks	Planned action
Delays during AIV.	
Brexit.	ESO is waiting for clear guidelines.
COVID-19 and further lockdowns.	

Brief bullet summary of upcoming activities for next period
• First full cold optical tests of the spectrograph.

3.2.2 ERIS

Principle Investigator	R. Davies, MPE
Consortium Institutes	MPE Garching (lead) INAF/Arcetri Astrophysical Observatory, Firenze UK ATC, Edinburgh ETH Zürich NOVA Leiden ESO (associated)
ESO Project Team	A. Glindemann (PM), H. Kuntschner (PS), A. Cortés (PE)
Installation Location/Date	Cassegrain UT4/2020
Status	Integration Phase
Guaranteed Nights	210

3.2.2.1 *Overview/Description*

ERIS is a new instrument for the Cassegrain focus of UT4, comprising:

- A new diffraction limited IR imaging camera (“NIX”);
- A modified version of SPIFFI to adapt it to the new AO module (“ERIS-SPIFFI”); and
- An AO WFS module (visible NGS, LGS) which will use any one of the four AOF lasers (one at a time).

ERIS with its IR imaging camera replaces the functionality of the most important NACO modes in imaging (1-5 μm) with enhanced AO performance, using the AOF’s deformable secondary mirror for AO correction. These improvements will also be transferred to SPIFFI, resulting in better AO performance compared to SINFONI, including increased sky coverage.

3.2.2.2 *Highlights of period*

The PAE review took place on 16 July, two weeks later than planned. The conclusion was that ERIS fulfils most of the technical specifications except for the level of vibrations induced by the closed-cycle cooler.

Further non-compliances concerned the reliability of the NIX filter wheel – modifications of the operational parameters and further intensive tests after the PAE review removed this concern – and the overall mass and the overheads when using templates. For the latter, Requests for Waiver were issued and accepted.

The vibrations caused serious concerns since they were clearly in excess of the acceptable level for telescope (and VLTI) operations. After intensive analysis it was found that modifications of the anti-vibration mount of the closed-cycle cooler caused the springs, supposedly reducing the transfer of vibrations, to be compressed solidly so that they became excellent transmitters of vibrations. When the springs were removed the vibration level was in spec. However, the closed-cycle cooler was then only supported by some sturdy rubber bellow and now (at the time of writing this report, on 6 September) it has to be analysed if the proper mounting of a reduced number of springs, in order to ensure operations under varying gravity vectors, still provides the required damping of the vibrations.

A second PAE review is planned for the middle of September under the mandatory condition that ERIS is compliant with the vibration specifications, and its result will be reported at the STC meeting.

The planned AIV activities starting in November remains a big concern. It is currently completely unclear if anybody who is not a Chilean resident is allowed enter the country. Even if the Chilean borders reopen, it is unclear if the usual schedule for Paranal AIV activities can be maintained, i.e. 14 days on the mountain, three days in Antofagasta and then another 14 days on the mountain. If not, the AIV will last three months instead of six weeks and commissioning will have to be shifted to March 2022 or later.

A few points that were reported at the last STC meeting related to the delivery of the dichroic, the cooling hoses of the WFS camera, the handling tool repair, and the SPIFFI pipeline.

The dichroic was delivered in time before the PAE and has been tested and accepted. The final AO tests were done with the new dichroic.

The cooling hoses underwent several hour tests and proved to be tight.

The replacement of the main carrier plate of the handling tool is still outstanding but does not block its usage.

The SPIFFI pipeline is no longer a concern. The statement in the Board Report was that "*ERIS is one if the few instruments to have working pipelines at PAE*". However, this does not mean that everything is perfect, more work needs to be done to finalise the pipelines, in particular an optimal dither pattern needs to be defined in order to minimise the effect of clustered bad pixels on NIX.

3.2.2.3 *Technical activities*

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
ERIS PDR	Q1 2016	Q1 2016	0
ERIS FDR	Q1 2017	May 2017	2
ERIS PAE	Q4 2019	Q3 2021	20
ERIS PAC	TBD		

Current main risks	
Risks	Planned action
AIV and commissioning at Paranal.	The currently uncertain situation makes it impossible to do a proper planning.

Brief bullet summary of upcoming activities for next period
• Finalise preparatory work at Paranal (BFL extension, floor upgrade) in time for ERIS delivery; and • AIV and commissioning at Paranal.

3.2.3 4MOST

Principle Investigator	Dr. Roelof de Jong, AIP
Consortium Institutes	Leibniz Institut für Astrophysik Potsdam (AIP) Australian Astronomical Observatory (AAO) Centre de Recherche Astrophysique de Lyon (CRAL) Zentrum für Astronomie der Universität Heidelberg (ZAH) Institute of Astronomy, Cambridge (IoA) Max-Planck-Institut für extraterrestrische Physik (MPE) Max-Planck-Institut für Astronomie (MPIA) Nederlandse Onderzoekschool Voor Astronomie (NOVA)
ESO Project Team	J.-F. Pirard (PM/PE), V. Mainieri (PS)
Installation Location/Date	VISTA Telescope/2022-2023
Status	MAIT Phase
Guaranteed Nights	70% for five years' operation (more than 2200 multiplex); options up to 10 to 15 years' operation, with respectively 20% and 15% fibres hours.

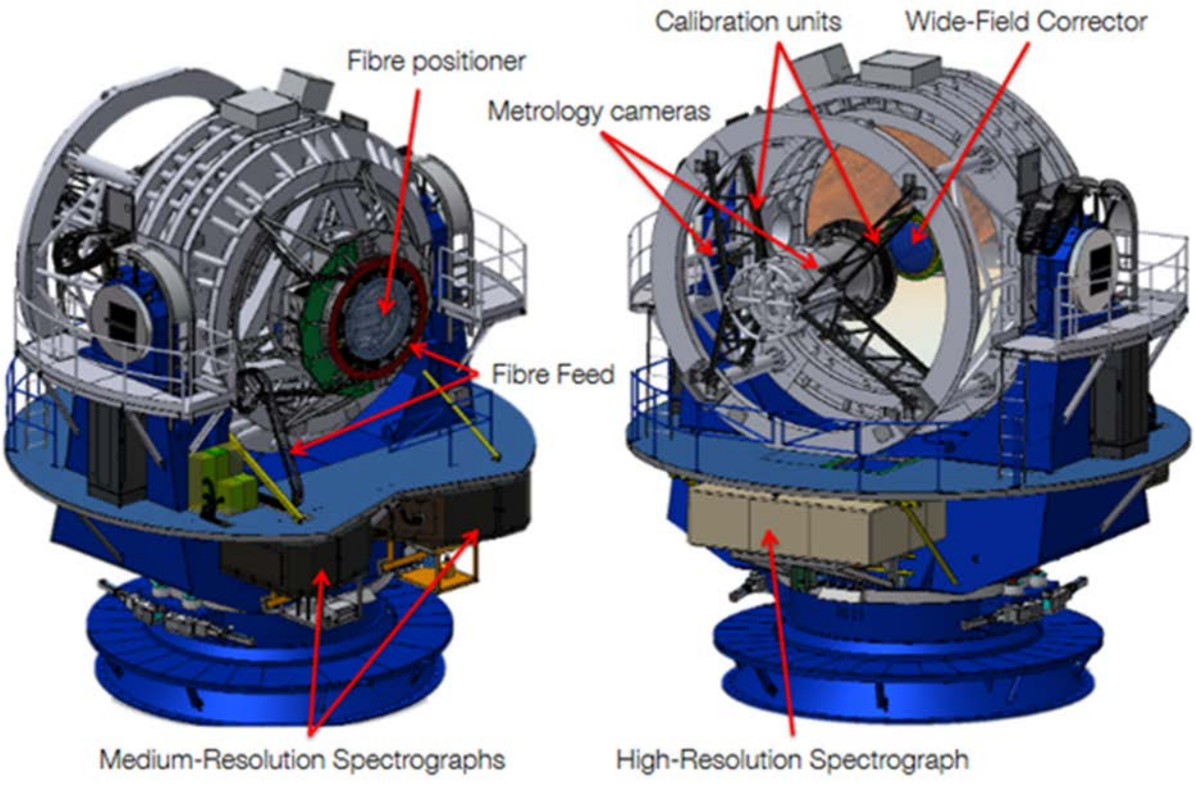
3.2.3.1 *Overview/Description*

4MOST will provide the ESO community with a world-class optical spectroscopic survey facility that will make major contributions to many of the science areas: from the Extreme Universe (Dark Energy & Dark Matter, Black Holes), to Galaxy Formation & Evolution, to the Origin of Stars and Planets. The unique capabilities of the 4MOST facility are enabled by its large field-of-view, high multiplex, its broad optical spectral wavelength coverage, and a dedicated telescope at a first-class astronomical site: VISTA at Paranal.

As a spectroscopic survey facility, operations of 4MOST will be different from normal operations. To efficiently fill all fibres and to make low target density surveys possible, all 4MOST surveys will be merged into one survey and observed simultaneously.

4MOST's unique capabilities result from:

- Large field of view (>4 deg2);
- Spectral resolutions (LRM: R>5,000, HRM: R>18,000) for both galactic and extragalactic applications;
- High multiplex (>700 in LRM, >700 in HRM);
- Minimum broad wavelength coverage in LRM (400-885 nm);
- Minimum broad wavelength coverage in HRM (393-435, 516-573, 610-679 nm); and
- Implementation at the Cassegrain focus of the VISTA telescope (Paranal).



Overview of 4MOST Facility Design.

3.2.3.2 *Highlights of period*

- AESOP (Fibre Positioner) delivery to Potsdam.
- Local Acceptance Review of the Calibration System has started.
- ADC delivered to UCL for integration in the WFC.
- All Hands Meeting (virtual) taking place 13-18 September.
- VISTA Modification FDR took place in May 2021.

3.2.3.3 *Technical activities*

The 4MOST facility project is presently progressing with the MAIT phase and experiencing a dynamic manufacturing phase. Several components have been successfully completed and tested according to the WP plan. The first subsystems and test setup are being delivered to Potsdam:

- All lenses and mechanical components of Wide Field Corrector (WFC) system have been delivered to UCL including the ADC. WFC assembly at UCL has started.
- Two Auto-guiding and Wavefront Sensor cameras have already been accepted.
- Secondary Guider system components manufacture is completed, and the assembly is ongoing.
- The metrology system got successful “first light” in the lab.
- The fibre positioner AESOP has been delivered to AIP.
- LRS-A is now close to its final configuration. The three arms have been successfully assembled and aligned. The performance tests of the three arms have been achieved and data has been provided to the DRS. Results are globally very good and in specification.

3.2.3.4 *Scientific/Operations activities*

In terms of science & operations, the highlights are the following:

- The Project has continued their preparations for the Onboarding of Community Surveys once they join the Science Team early 2022;
- After the experience from OpR2 with the distributed operations model, DMS has proposed to centralise several data reduction and analysis tasks in a new 4MOST Data Processing Center (4DPC);
- The Operational Rehearsal planned for fall 2021 has been rebranded into OpR2.5. The main purposes of OpR2.5 are to provide a first test of the 4DPC and to produce more data for the development of the pipelines. This yet again highlights the extraordinary value of the OpR’s in preparing for a successful start of science operations; and
- The new ETC has been rolled out and it works well, with significant speed increases.

3.2.3.5 *Vista Modification*

The FDR of the VISTA Telescope modification took place in May 2021. Several action items have been highlighted concerning the wavefront sensor upgrade, the cooling, and the mechanical design.

The actions are presently being fulfilled and the requested modifications implemented:

- The performance of the new WFC algorithm has been evaluated and the conversion of the algorithm into software compatible with the TCS has started;
- The cooling and mechanical design are being modified to take into account remarks highlighted at the FDR;

- The installation and commissioning activities of the telescope are being detailed; and
- Extra manpower is moved to the project in prevision of the arrival of 4MOST at the beginning of 2023.

3.2.3.6 *4MOST Project*

The 4MOST All Hands Meeting 2021 (AHM2021) is a fully virtual meeting taking place during the week of 13 - 18 September.

The Project is developing a Code of Conduct for all its members. The draft was discussed with ESO and an agreement was reached on the escalation path for Community Survey participants in the Project.

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
Kick-Off	August 2016	June 2016 (Letter of Intent)	-3
PDR	June 2016	June 2016	0
FDR1	February 2018	May 2018	3
FDR2	February 2018	March 2019	13
TRR	June 2021	May 2022	11
PAE	December 2021	October 2022	10
PAC	September 2022	August 2023	11

Current main risks	
Risks	Planned action
Delays of subsystem delivery and system AIT.	Rescheduling of project.
Lack of human resource availability.	Replacement of leaving persons.
Coronavirus	The pandemic evolution is not known, but an impact, mainly on the schedule, is real. A careful monitoring of the impact is being performed.

Brief bullet summary of upcoming activities for next period
• Local Acceptance Reviews (LAR) of the Calibration System, 1st Fibre Feed, AG&WFS Cameras. • Operational Rehearsal 2.5.

3.2.4 MAVIS

Principle Investigator	François Rigaut
Consortium institutes	Australian Astronomical Observatory, ANU & Macquarrie, INAF (Arcetri, Padua, Milano, Capodimonte) Laboratoire d'Astrophysique de Marseille
ESO Project Team	R. Arsenault (PM), H. Kuntschner (PS), U. Seemann (PE)
Installation Location/Date	UT4 Nasmyth A, ~2027
Status	Preliminary Design
Guaranteed Nights	150

3.2.4.1 *Overview/Description*

MAVIS is the Multi-Conjugate Adaptive Optics system in the visible for the VLT. This system will replace GRAAL/Hawk-I on UT4 towards 2027. The target specifications require a Strehl ratio larger than 10% at 500 nm in a 30" field of view. Science cases have been developed around such concept and showed that an Integral Field Unit would benefit many of these (~50% or more). Thus, a spectroscopic mode is being developed as well; the IFU would have a 3.6x2.5" with wavelength coverage of 370-950 nm for a resolution >5000 (possibly >10000; 25mas or 50mas sampling respectively).

3.2.4.2 *Highlights of period*

- Agreement with Consortium, Statement of Work and Technical Req. Specification all finalized and contract signed.
- Kick-Off Meeting for Phase B took place on 1 June 2021 (Technical KO meeting 11 May).
- MAVIS PI managed to raise additional funds (960 kEUR) to cover part of the extra cost of the spectrograph.
- Milestones for Phase B and following have been maintained despite delay for Kick-Off (progress made by project before start of Phase B).
- RTC design for AO module now fully conform to new ELT-standard architecture for and using the ESO RTC toolkit (was not the baseline of Phase A).

3.2.4.3 *Technical activities*

Milestone schedule			
Major Milestones	Planned date at kick-off/ Stated in agreement	Actual date, or current best estimate	Slip (months)
KO Design and construction	June 2021	June 2021	0
PDR	July 2022	July 2022	0
FDR Long Lead Item	January 2023	January 2023	0
FDR	September 2023	September 2023	0
Assembly Read. Rev.	April 2025	April 2025	0
Test Read. Rev.	January 2027	January 2027	0
PAE	March 2027	March 2027	0
PAC	July 2027	July 2027	0

Current main risks	
Risks	Planned action
Applicable Document Situation not solved. Important ELT standards not yet adapted for VLT. Required by SoW and TRS. May have impact if project baseline not in line with these new standards (increase cost, effort, delay).	Work closely with PIP Eng. to follow-up progress and get information about ESCB conclusions and scope of new ADs. Keep consortium aware of changes and status. 1 July 2021: nine out of nine AD's still in draft. 2 September 2021: five out of nine AD's still in draft.
Cost of MAVIS above the allocated ESO funds. Risk is that not enough are available for building the intended spectroscopic mode. More than 50% of science cases require this mode.	Promote consortium search for new partners. Take part of risk with ESO led Work Packages. 1 July 2021: MAVIS identified additional funds (960 kEUR)
ESO deliverables dates not well defined nor consolidated. Risk that ESO may cause delay for the MAVIS consortium.	Get more information about internal constraints. Schedule deliveries relative to MAVIS milestones. Find compromise between require dates and possible delivery dates.

Brief bullet summary of upcoming activities for next period
• Take decision on DM procurement within Tech. Dev. Contract (deadline November 2021). • Iterate with consortium on AD's now released and whether they impact consortium. • Conduct TTR on laser splitting scheme. • Conduct September progress meeting (16 – 17 September 2021). • Follow up start of Phase B: progress meetings, reports, etc. • Monitor situation for release of AD's still in Draft (5).

3.3 Upgrade and Refurbishments

The programme is involved in several upgrade and refurbishment projects, which are led by ESO. They include major obsolescence avoidance, for which support is asked to the Directorate of Operations. In collaboration with the STC, the VLT/I programme scientists have developed a strategic view that identifies the 'workhorse' instruments for the VLT, i.e. instruments that will have a substantially longer lifetime and will stay many more years at the telescope (STC-570 and STC-587). These are the instruments subject to upgrade and refurbishment.

3.3.1 FORS upgrade

Principle Investigator	ESO
Consortium institutes	INAF Observatory of Trieste, PS M. Nonino
ESO Project Team	F. Derie (PM), A. Manescau (PE), R. Siebenmorgen (PS)
Installation Location/Date	End 2024
Status	Final Design (phase C)
Guaranteed Nights	None

3.3.1.1 *Overview/Description*

FORS2 is a highly demanded workhorse that shall remain operative at VLT for the next 15 years (STC-588). FORS control electronics and software, as well as whole operations and data flow software, shall be upgraded with the latest standards. The full ELT Framework and standards will be deployed on FORS-Up for test and validation of the ELT ICS on a real and representative instrument. Since years, the Instrument Operation Team is requesting the upgrade of FORS2 with a 4K x 4K broadband detector to improve the operations of the instrument, eliminating the need for exchange of the RED or BLUE detector systems, with direct impact on instrument maintainability and reduction of risk. An additional requirement is to minimise the absence of FORS2 from operations. The project plans to upgrade first FORS1 in Garching, to be on the VLT for 2024 with a beta version of ELT Framework.

Due to the ELT Framework development plan, the expected planning is four years from authorisation to proceed till PAC of FORS1+MOS-MXU on UT1. There will be no downtime of FORS2 until FORS1 is retrofitted with MOS only. The retrofit of the MOS-MXU will take about one period in 2024. At that time, the ELT Framework shall be advanced enough for its deployment on FORS1 on UT1.

3.3.1.2 *Highlights of period*

Phase C started on 1 September 2020 with a clear technical baseline definition and the required resources.

COVID-19 lockdown impacts the project both in Europe and in Chile. The actual delay on the design activities is about ten months. Consequently, the FDR must be shifted to 25 October 2021. The other milestones are also affected. Transport of FORS1 from La Silla to Garching delayed due to COVID-19, was done in July. Unfortunately there are corrosion damages caused by humidity in the transport boxes that were not properly packed by the transport company in Chile. A claim to the insurance company is being prepared.

3.3.1.3 *Technical activities*

- Update of Schedule and budgets required due to COVID-19.
- Release of project documents (TLR, SPE, SOW) and preparation of FDR data package.
- Follow-up of the broadband CCD231-84 procurement with E2V.
- Follow-up of INAF-OATs Trieste technical and scientific collaboration.
- Transport of FORS1 from La Silla to Garching (one year delay due to COVID-19).
- Breadboarding test of the new calibration unit diffusor.
- Ongoing Pipeline and QC upgrade for the new broadband CCD.
- FDR review plan as per ESO-408005.
- Preparation of budget and resources for 2022.

Milestone schedule			
Major Milestones	Planned date at kick-off	Actual date, or current best estimate	Slip (months)
Phase C (Kick Off)	01.09.2020	01.09.2020	0
Phase C (FDR)	23.12.2020	25.10.2021	10
Phase D (TRR)	01.07.2022	01.05.2023	10
Phase D (PAE)	03.01.2023	03.06.2023	5
Phase E (PAC)	01.04.2024	01.04.2024	0

Current main risks	
Risks	Planned action
FORS1 corrosion after transport from Chile.	Immediate repair and Insurance claim.
FORS1 carriage safety certification.	Investigation by manufacturer in September 2021, repair in Q4 2021.

Brief bullet summary of upcoming activities for next period
• Transport of FORS1 to INAF Trieste for control system retrofitting in 2022. • Follow-up of main orders (CCD) and INAF-OATS collaboration. • Kick off of three Phase Holographic GRISM (600B Na line and K line) with INAF Brera. • Finalise conceptual design of the New Calibration Unit (ESO internal). • Perform safety inspection of FORS1 carriage. • FDR 25.10.2021 and post review actions.

3.4 Phase A studies

Two projects, CUBES and GRAVITY+ recently passed the Phase A review and are going for recommendation to STC in October 2021 to move to the design and construction phases, and to the December 2021 Council for the award of the GTO time.

3.4.1 UV Spectrograph (CUBES)

Following the recommendations of the 90th STC meeting, ESO issued a CfP for a competitive Phase A study in January 2020. In agreement with the STC recommendations, the CfP clearly states that the scope of the project must be limited in aim and costs.

One consortium, that includes INAF (PI S. Cristiani), STFC-UKATC and Durham, LSW Heidelberg, NCAC Warsaw, IAG-USP and LNA (Brazil), answered positively to the call. The proposal was found fully compliant, and the Phase A study agreement signed. During the development of Phase A, AAO-MQ joined the team. The CUBES consortium completed Phase A on schedule and the review took place in June 2021.

The most challenging requirement and innovative aspect of CUBES is to deliver a spectrograph with an increased efficiency in the UV. CUBES (Cassegrain U-Band Efficient Spectrograph) has the goal of covering with a high efficiency the UV ground-based region (300 - 400 nm) with intermediate resolution (about 20K).

The current baseline design includes:

- A foreoptics sub-system that includes an Atmospheric Dispersion Corrector and an Acquisition and Guiding system;
- Two image slicers (to enable different spectral resolutions: ~22 K and ~6.5 K); and
- Two arms, both equipped with transmission gratings and cameras (and cooled detectors). The current baseline design assumes 9K CCDs. The two arm design is the result of a trade-off study (efficiency, resolution, mass and volume) developed during Phase A.

The instrument is standalone, but a fibre port has been studied to combine it with UVES. Several science cases would benefit from the simultaneous observations, which would represent an optimisation of the VLT observing time. The full control system to operate UVES+CUBES simultaneously needs to be studied but several examples have been developed already at ESO. This option is at present left open, to be further evaluated. CUBES has two spectral configurations (R > 20k and > 6k), which are enabled in the baseline design by exchanging two independent image slicers.

High-resolution spectroscopy of the near-UV regime provides access to a tremendous diversity of iron-peak and heavy elements in stellar spectra, as well as some lighter elements (notably Beryllium) and light-element molecules (CO, CN, OH). The near-UV range is also critical in extragalactic observations, such as studies of the circumgalactic medium (CGM) of distant galaxies and in measuring the contribution of different types of galaxies/AGN to the cosmic UV background.

Motivated by these topics, CUBES will open-up exciting new scientific opportunities for ESO's Paranal Observatory, providing the ultimate UV spectrograph at the VLT, a world-leading capability well into the 2030s. Looking ahead to the start of ELT operations, it is noted that the VLT cannot be competitive for observations shortwards of ~400 nm. This is because of the protected silver coatings of four of the five ELT mirrors, that limits the performance in the UV compared to Al-coated mirrors. CUBES will exploit this unique part of parameter space.

The design is primarily motivated by the cases detailed in the science cases by the consortium, but CUBES is envisaged as an exciting chance to provide the VLT with a new capability, enabling a broader range of scientific applications and serving a diverse user community.

The COVID-19 crisis did not cause delays to the project thanks to the consortium's efficient organisation (who established early remote collaboration tools). The PI is pro-active and managed to put together an impressive pool of talents for the project.

The Phase A Review was held by video-conference and proceeded successfully. Two half-days were scheduled to take into account the time difference between Australia, Europe and Chile. A traceable RIX process was conducted. The review board was composed of senior ESO experts including the VLT Scientist, two external reviewers, and chaired by E. Emsellem. The board report praised the quality of the consortium work: "*The instrument concept is mature, trade-offs were performed during the Phase A, and feasibility is not questioned. A reliable cost estimation exercise took place and leads to a realistic total cost for the instrument*."

No technical show-stoppers were identified during the review and the concept elaborated is sound and well advanced for a Phase A.

As far as costs, the review board did not find any problems: "*The cost estimate were reasonable, and reported the issue in the board report."*

Given the intermediate size of the project and its low risk, the ESO follow-up team will be limited to the project office with the occasional support of experts, when needed. The plan is to have Kick-Off for the preliminary design phase in early 2022. Approximately 12 months are projected to PDR, 30 months for the FDR plus three years of manufacturing and integration. Thus, the project is expected to be ready for commissioning toward 2027.

3.4.2 GRAVITY+

GRAVITY+ aims to upgrade the VLTI system and significantly enhance its capabilities towards faint science, all sky, high contrast, milli-arcsecond optical interferometric imaging with an emphasis on the UTs. In particular, GRAVITY+ aims at opening up the extragalactic sky for milli-arcsecond resolution interferometric imaging, obtaining high quality spectra for exoplanets, and refining tests of general relativity in the Galactic Centre. These goals require an upgrade of the GRAVITY instrument and of the VLTI infrastructure including a new high order adaptive optics system at the coudé of the UTs, new laser guide stars on the not-yet-equipped telescopes, completion of the latent wide dual-field capability, and the improvement of the fringe tracking performance. There are no doubts that GRAVITY+ will be transformational for optical interferometry and for the VLT/I as a whole.

The large GRAVITY+ Consortium, led by MPE (PI: F. Eisenhauer) is aiming at a very fast track project; Phase A lasted six months and the original plan foresaw a full implementation within four years. The design is well advanced, and is largely based, for the AO modules, on the

ERIS concept and experience. A number of important work packages are developed at ESO, and the project is quite demanding for the limited resources of the programme.

The Phase A review meeting was held on-line on 9 July 2021; the board included a number of senior ESO experts and two external ones, and was chaired by F. Derie. The board has been positively impressed by the quality of the documentation, the design concept, the preliminary analysis performed, the development and management plan and it has clearly recommended that GRAVITY+ is well positioned to begin Phase B. The documents were well laid out, easy to understand, and detailed beyond the level expected for a Phase A review. The team's technical plans were also well justified in the context of scientific goals.

Noticing the huge amount of work compressed in a few years and the budget at the limit of the resources available, the board also recommended that the project should not enlarge the scope of the work with potential 'adds on'. Amongst other recommendations, the board also suggested to expand the duration of the project by one year. ESO is preparing an agreement with the consortium along these lines. ESO will provide the framework SW and follow up the development of the new Real Time Computer, that will be done by the consortium. ESO will be responsible for the launch telescopes and laser units and for the telescopes' modifications. The estimate of the overall costs to ESO for the project are higher than planned at the beginning of Phase A, both in terms of staff resources and funds, and a way has been negotiated with the consortium to remain within the initial limits. The design and construction phase of GRAVITY+ should start at the beginning of 2022 and the implementation will happen in different steps, starting with the AO system first. The last laser unit will be installed at the end of 2025.

3.5 La Silla Instrumentation

The Paranal Instrumentation Programme also covers projects for La Silla. These projects are only contemplated because they are at a minimal cost to ESO. Following the STC recommendations, ESO launched a Call for Ideas for scientific projects at the NTT for a new instrument to be provided by the community.

SOXS (Son Of X-Shooter) for the NTT and NIRPS for the 3.6m telescope were selected.

The strategic view is to dedicate the NTT for the follow-up of transient events, and the 3.6m telescope for exo-planet studies to support future exo-planet space missions. The timeline of the two projects extends the La Silla lifetime beyond 2025. As for the other projects in a similar development stage, both NIRPS and SOXS have reported not negligible delays in 2020, but advance now to a more regular pace. The major limitations are imposed by the difficulty or impossibility of teams to travel from one country to another.

3.5.1 SOXS for NTT

Principle Investigator	S. Campana
Consortium Institutes	INAF-Brera, Italy INAF-OACN, Capodimonte INAF-OAPD, Padua INAF-OACT, Catania INAF-TNG, Trieste INAF-OAR, Roma INAF-OATO, Torino Universidad Andrés Bello, Chile Finnish Centre for Astronomy with ESO (FINCA) Weizmann Institute, Israel
ESO Project Team	L. Pasquini (PM/PE), M. Schöller (PS)
Installation Location/Date	3.5m NTT, 2021
Status	MAIT
Guaranteed Nights	900

3.5.1.1 *Overview/Description*

The SOXS is a new state-of-the-art instrument for the NTT on La Silla. SOXS will be a high-efficiency spectrograph with a Resolution-Slit product of 4500” over the entire band capable of simultaneously observing the complete spectral range 350 – 2000 nm. SOXS will have a 12” slit and will be specifically suited for rapid response observations of transient objects. The Consortium will also contribute to the operation of the telescope.

3.5.1.2 *Highlights of Period*

SOXS is developed by 12 institutes, and limited access to the laboratories, limited traveling from one site to the main integration site (Padua), delays in the delivery of components by the manufacturer because of COVID-19 restriction is affecting this AIT phase. The situation has however evolved positively in the past six months and all subsystems are expected to reach the integration site in Q1 2022, after Local Readiness Reviews.

The calibration unit is the first subsystem that passed LRR and has been shipped to Padua (6 September) for integration with the rest of the instrument. All other subsystems are proceeding towards LRR.

3.5.1.3 *Technical activities*

Mechanical structure & common path: The Common Path is undergoing integration in Padua. The alignment activities are ongoing, as well as the tests with the control system including software and electronics. The Common Path includes most of the controlled devices, so the development of this subsystem allows for the parallel tuning of software and control loops.

The main issue for the Common Path subsystem is still the delay for the ADC procurement. Its delivery has been continuously delayed for many months, because of an issue in the production of a CaF_2 lens. Now this issue has been solved and all the lenses of the two ADC quadruplets are produced. It is expected to be shipped in September, after alignment.

UV-Visible spectrograph: The UV-VIS spectrograph opto-mechanics are almost ready. In the last months, two out of three optical elements of the UV-VIS camera have been delivered and all the optics are available but (again) one CaF_2 lens in the camera (different company than the ADCs) had an issue. Assuming it is delivered soon, the system is expected to be shipped from Israel to Italy in early December.

NIR spectrograph: The last optical element, the collimator lens of the NIR spectrograph, has been delivered in July so the integration activities are ongoing in Merate. In parallel the vacuum and cryogenics control system are being developed in Catania. The spectrograph is expected to be shipped to Padua in January 2022 and this subsystem is now on the critical path.

Guide camera & calibration box: The AGC camera optics have been completed by INAOE (Mexico). They had suffered big delays as well, because the optics vendor could only work very sporadically. Finally, in July, the optics have been completed and sent to the coating company. Afterwards the system will be shipped to Italy. The plan is to complete the integration of the AGC camera in Padua within November. As mentioned above, the calibration box is complete, and after internal acceptance, has been shipped from Finland to Italy on 6 September.

Electronics: Everything is basically ready except for the parts that need the real system for tuning. The team has been working on these parts efficiently, even if remotely in some cases.

Software & operations: The development of the pipeline is continuously progressing, and a first version will be ready at PAE time. The ETC has been reviewed and updated and contacts have been established with ESO experts for advice on Quality Control development.

The overall schedule sees an additional shift of three months of PAE to accommodate the delays in the procurement and the limitations of the past months.

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip (months)
Official kick-off/MoU for Phase A	n/a	3 March 2017	n/a
PDR	n/a	20 - 21 July 2017	n/a
FDR	n/a	19 - 20 July 2018	n/a
MoU for construction	n/a	10 October 2018	n/a
PAE	July 2020	July 2022	24
PAC	March 2021	March 2023	24

Current main risks	
Risks	Planned action
SOXS may exceed the weight limit of the NTT building crane.	To keep intensive contact with the Consortium in order to keep the weight under control.

Brief bullet summary of upcoming activities for next period
• Local tests of all subsystems and integration in Padua. • Start of system tests.

3.5.2 NIRPS for the 3.6m

Principle Investigator	R. Doyon; University of Montreal F. Bouchy, Observatoire de Genève
Consortium Institutes	*PI Institutes:* Université de Montréal (“UdeM”) Université de Genève (“UniGe”), Observatoire Astronomique *Other participating institutes:* Instituto de Astrofísica e Ciências do Espaço (“IA-P”), Porto Instituto de Astrofísica de Canarias (“IAC”), La Laguna, Tenerife Université de Grenoble – Alpes (“UGA”), Saint-Martin-d'Hères, France Universidade Federal do Rio Grande do Norte (“UFRN”), Natal, Brazil NRC Herzberg Astronomy
ESO Project Team	N. Hubin (PM/PE), C. Péroux (PS), G. Lo Curto (LPO scientist)
Installation Location/Date	First light of NIRPS Front-End Q4 2019 First light of NIRPS Back-End Q4 2022
Status	Integration Phase
Guaranteed Nights	725 nights

3.5.2.1 <u>*Overview/Description*</u>

NIRPS is a fibre-fed high spectral stability and high-resolution spectrograph for the 3.6m telescope to be operated in tandem with HARPS. NIRPS will cover the 973-1800 nm spectral range. The NIRPS RV precision (after calibration and data reduction) must be better than 1 m/s over short- and long-time scales (years), in order to execute coherent and long-lasting programmes. None of the HARPS modes, polarimetry included, shall be compromised. NIRPS will have two fibre modes: a high efficiency mode with R = 80,000 and a high precision mode with R = 100,000.

To allow the parallel operation of NIRPS and HARPS, a new fibre adaptor has been built. This also encompasses, beyond a tip-tilt stage, a low order adaptive optics system for the IR. This fibre adaptor shall allow to mount piggy-back a separate K-band spectrograph.

To be competitive with various other activities in the field of extrasolar planets, NIRPS must be executed on the fastest feasible timescale.

3.5.2.2 *Highlights of period*

- **NIRPS-BE**: PAE documentation have been submitted and reviewed with identified corrective actions being implemented at the time of this writing. NIRPS-BE PAE system tests were also done remotely as much as possible. The instrument is in good shape, but spectrograph stability issues have been identified and need to be corrected by the Consortium. The fibre link gluing has shown deficiencies in Canada and needs to be resolved by the Consortium as soon as the Canadian borders are open again.
- **NIRPS-FE**: Due to the COVID-19 lockdown and travel restrictions from/to Chile and from/to La Silla Observatory, the postponed NIRPS-FE Adaptive Optics commissioning finally took place in May and will continue in late September.

3.5.2.3 *Technical Activities*

- **Front-End**: Due to the COVID-19 lockdown and travel restrictions from/to Chile and from/to La Silla Observatory, the postponed NIRPS-FE Adaptive Optics commissioning finally took place in May (with some bad weather limitations and IT communication issues) and will continue in late September again (Chilean borders closed to non-Chileans) in G-RAF remotely from Garching with ESO local support at La Silla. The May commissioning of the FE has shown that the functionality of the adaptive optics have been significantly improved from the initial commissioning in 2019. The September commissioning will focus on the AO performance of NIRPS-FE. The limitations of the IT infrastructure and standardisation of the NIRPS-FE equipment identified in May were resolved thanks to the support of the LPO IT and Garching SW team in August. Data transfer from the 3.6m Telescope to the control room is now reliable and should permit an efficient commissioning of the NIRPS-FE.
- **Back-End**: Activities in Montreal and University Laval are still impacted by COVID-19 and closure of the Canadian border to Europeans. PAE documentation has been submitted and has been reviewed with identified corrective actions being implemented at the time of writing. NIRPS-BE PAE system tests were also done remotely as much as possible. The instrument is in good shape and meets all specifications (with a R=80000 minimum specification) apart from the spectrograph stability issues which were identified during the PAE tests conducted by ESO and are being investigated by the Consortium. The fibre link gluing has shown deficiencies in Canada and needs to be resolved by the Consortium. Unfortunately, this requires the IAC/Geneva team members to fly to Canada which has not been possible so far due to the closure of Canadian borders; hopefully this will be possible in September (TBC). The pipeline has also made good progress and should be completed by end of September. Currently two major critical actions hold the PAE of NIRPS-BE: spectrograph stability and FL issue. When these are resolved, ESO will need to perform the final system test with spectrograph and FL remotely and validated end-to-end dataflow with the delivered pipeline. Based on the current situation, we do not expect to be able to ship the instrument before end of 2021 (COVID-19 permitting).

Milestone schedule			
Major Milestones	Planned date at kick-off/Stated in agreement	Actual date, or current best estimate	Slip[1] (months)
Official kick-off	n/a	January 2016	n/a
PDR	n/a	October 2016	n/a
FDR	n/a	May 2017	n/a
Front-End PAE	November 2018	September 2019	10
Front-End Comm	March 2019	Started December 2019 September 2021	24
Back-End PAE	March 2019	November 2021	32
Back-End Comm	September 2019	February and April 2022 (TBC)	28
PAC	December 2019	October 2022	34

Current main risks	
Risks	Planned action
FE Adaptive Optics operation robustness without on-site expert for operation.	FE Adaptive Optics operation robustness without on-site expert for operation.
Readiness of the NIRPS Pipeline compliant with ESO DFS requirements.	Readiness of the NIRPS Pipeline compliant with ESO DFS requirements.
NIRPS-BE stability non-compliance.	Special attention from the Quebec team is invested to investigate this issue with monitoring from the ESO scientists.

Brief bullet summary of upcoming activities for next period
• NIRPS FE COMM3 in September. • Repaired (gluing) of the Fibre Links in Quebec as soon as Canadian borders are open again and shipping to La Silla. • NIRPS-FE + FL commissioning as soon as the FL are repaired (February 2022?). • Complete NIRPS BE PAE and organise shipping to La Silla (COVID-19 permitting). • Secure documentation in the ESO PDM system.

4. The Future

The new VLT instruments will start operations after the first light of the ELT. The VLT in the era of mature ELT operations has been studied with the ESO community and a strategic view has been developed using dedicated workshops and user surveys, in consultation with the STC and in harmony with the Strategy Working Group (SWG) and ESO's science prioritisation working group. The VLT and VLTI scientists have prepared, in collaboration with community

1 The value for "slip" is a bit arbitrary, as the MoU states the dates for milestones in months after kick-off, while the fact sheet uses the dates planned at FDR. The FDR happened to coincide with the final signature of the MoU.

representatives, a roadmap document for the VLT/I (STC-658, 2020), whose main strategic points are analysed in the next sections (see also The Messenger 177, 67, and STC-639, 2019).

4.1 Strategic View

The VLT/I will continue to serve a large community and provide unique data in the JWST and ELT era. In particular, it is recognised that the Paranal Observatory and the ESO community have some clear strengths, the most notable being:

- Flexibility of operations, small/large programmes, reactivity, monitoring;
- Diversity and quality of instruments; unique workhorses such as X-Shooter and MUSE; and
- Uniqueness and world leadership in some areas:
  - High resolution spectroscopy;
  - Integral field spectroscopy;
  - High contrast imaging with AO;
  - Interferometry; and
  - Access to blue in the era of JWST and ELTs.

The main strategic choices are to:

1) **Focus on unique VLT/I strengths and exploit the uniqueness of the VLT/I**;
2) The VLT/I shall continue to host a mix of workhorse and dedicated instruments; and
3) PIP should commit no more than 50% of all the available resources until 2030 in these first projects, leaving margin for future ideas and proposals.

Of the potential new projects presented at the VLT in 2030 workshop, STC recommended to immediately start with the Phase A study of GRAVITY+, followed, not later than 2022, by the Phase A of BlueMUSE.

GRAVITY+ went through a Phase A study and has been described above.

BlueMUSE is a seeing-limited, blue-optimised, medium spectral resolution, panoramic integral field spectrograph. It has a similar architecture and many systems similar to the very successful MUSE instrument, but with a new and distinct science case enabled by its main characteristics: (1) a wavelength coverage 350 – 580 nm; (2) an average spectral resolution R=4000; (3) up to 2 $arcmin^2$ field-of-view. Among the science goals, it will survey large samples of massive stars in our galaxy and the Local Group, study ionized nebulae, starburst and low surface-brightness galaxies. At high redshift, it would allow for the first time to detect the intergalactic medium unambiguously in emission, as well as to study the evolution of the circumgalactic medium properties near the peak of the Cosmic Star formation history. While ESO has completed the Phase A study of GRAVITY+ as soon as possible, the impossibility to close many pending projects and interventions suggest a careful and patient approach. Plans are discussed in more details in section 4.6 and the following pages.

As part of the VLT2030 process, ESO plans to have a second round for VLT/I instruments. The call has to be issued not before the new projects have started and potentially will include an HR-MOS, for which a strong science case was presented at the VLT2030 workshop.

4.2 VLTI

With the completion of NAOMI and (soon) GRA4MAT, STC-658, which is based on the current VLTI Roadmap (STC-599, The Messenger 171,14,2018), the VLTI is now entering in Epoch 2. The VLTI roadmap foresees:

Epoch 2: 2020-2025

- Exploit fully the existing infrastructure by upgrading the existing instrumentation. GRAVITY+ has been selected in the VLT2030 process and represents a major upgrade of the VLT/I infrastructure.
- Increase the sky coverage and angular resolution capability by doubling the delay line optical path. This has been studied and is under implementation since 2020 under Paranal governance.
- Host visiting instruments pushing the technique in new directions. One project at least is funded (“SCIFY” ERC) and had its kick-off in late 2020. Several other projects seek funds (e.g. VICKING).

Epoch 3: beyond 2025

- VLTI imaging capability might be expanded by adding more telescopes and building a 6-to-8T beam combiner. There are some projects in the community to fibre-link VLTI telescopes, at the exploratory level.
- VLTI might be used as a development platform for a next generation optical interferometer**.** GRAVITY+ is a step into that direction by pushing AO+LGS on 8-m class interferometers.

4.3 Visitor Focus

Visitor instruments are usually designed for a specific science case and do not have the reach of a facility instrument. They have a minimal interface with the telescope, and ESO has no specific requirements about HW and SW standards other than safety and that visitor instruments are operated by the Consortium. The data products of visitor instruments do not necessarily have to be compliant with the ESO archive.

The availability of a free focal station to host visitor instruments has been advocated in several instances and at the VLT2030 workshop, several potential visitor instruments were presented for VLT and VLTI: ASGARD for VLTI: FT + J-band spectro + L-band nuller; RISTRETTO: AO+spectro for spectrum of one planet; HIRiSE: link between SPHERE and CRIRES$^+$; PIU: polarimetric bonnette for UVES.

Instruments at Cassegrain focus are, in general, easier to remove and a pragmatic approach is to provide regular access to a Cassegrain focus shared with an instrument built explicitly to be easily removed, such as CUBES. As for Nasmyth instruments, they cannot be exchanged, and it does not seem appropriate to leave one focus permanently unused at present. The time between the decommissioning of one instrument and the installation of a new one could be used for hosting visitor instruments. Since October 2019, the Nasmyth focus on UT1 occupied by NACO has been free, waiting for the arrival of MOONS, that is now expected in 2023. According to STC-569, FLAMES should be decommissioned in the long term and its focus could be made free until a new instrument is built. VLTI Visitor focus is officially open as of P104, and two instruments can be accommodated, one on the AMBER table and one on the FINITO table.

4.4 Instrument decommissioning

ISAAC was decommissioned to make way for SPHERE, and MIDI was decommissioned to be replaced by GRAVITY. AMBER was decommissioned after P101 and VIMOS after P100. The decommissioning of VLT/I instruments follows a discussion with the STC (see STC-569). CRIRES$^+$ has replaced VIMOS, NACO was decommissioned in October 2019 (to be replaced by MOONS), possibly followed by FLAMES. HAWK-I will be decommissioned and replaced by MAVIS (~2026).

Each time a new instrument is accepted, the instrument to be decommissioned is identified (at the time of the new project Final Design Review at the latest), on the basis of a grid of criteria that includes scientific potential, complementary with new instruments (and therefore coverage of the parameter space), instrument status and future perspectives, as explained in STC-569.

4.5 Upgrades

The documents STC-587 and the roadmap VLT/I instrumentation STC-656 identify which instruments will be operated in the long term, and will therefore require an upgrade or a refurbishment to maintain them at the forefront for the next ~15 years, In addition to the on-going GRAVITY+ and FORS upgrades, two additional potential upgrades have been discussed:

- **UVES:** The case for keeping UVES has been emphasised in STC-570 and STC-587. In the long term, a general refurbishment of this instrument is necessary in order to guarantee its life and to improve its efficiency. The complementarity with the UV spectrograph shall be considered, as well as the scientific overlap with ESPRESSO. The number of observing proposals for UVES remains constantly high, the operations of the instrument do not pose urgent challenges. The roadmap document confirms that UVES should be kept in the long term. A UVES-20 years workshop took place in October 2020, showing a wide interest for this instrument, and indicating some priorities for a potential upgrade. A summary paper of the UVES workshop has been published (Messenger 183, p. 37, 2021). It is TBD whether the upgrade should be mainly limited to obsolescence, or should include a much wider intervention.
- **SPHERE:** The possibility of enhancing the XAO capabilities of SPHERE by coupling high contrast imaging and high resolution spectroscopy has been advocated and a link from SPHERE to CRIRES$^+$ (HIRISE) and a SPHERE upgrade were proposed at the VLT in 2030 workshop (SPHERE+). HIRISE has been proposed as a visitor instrument. While

the SPHERE+ case was not considered compelling by STC, the technology development programme at ESO is collaborating with the project as pathfinder for the ELT PCS. The SPHERE HODM has several faulty actuators. Even if no further losses occurred in the last years of operations in Paranal, this status is risky in the long term and any SPHERE upgrade shall evaluate the procurement of a new HODM.

All instruments foreseen to be operated in the long term are either new or have recently been upgraded. FLAMES, HAWK-I and VISIR will move into a ‘maintenance only’ status. This means that no upgrade is foreseen, no obsolescence fight planned and if a major failure occurs, it will not be repaired. No urgency for other upgrades has been identified at present.

All major upgrades are treated as new projects and compared to running or planned instruments in order to decide on priorities.

4.6 Development Plan

The development plan laid out in Table 2 and Table 3 show the projects under construction and the ones planned. It is based on the present planning and on the ESO resource allocations for the running projects. For future projects, projections are made using typical effort figures expended on previous VLT instruments. So far, the FTE requests for the PIP programme exceeded what was established in the ESO Long Range Plan for the years 2015 – 2026. The reasons are delays in major projects and an underestimation of the effort needed. The ESO staff effort should have reached a steady state of 26 FTEs/year after 2020, but is instead showing a smooth decline, partially caused by the delays induced by COVID-19. Starting in 2017, staff effort contingency has been included at programme level to cover potential delays in the projects and unforeseen extra scope. However, in order to cover the need of expertise in some areas, hiring temporary support or agreements with institutes are needed, that may need to use up to ~0.3 MEUR/year of the capital investments budget in order to pay for the additional staff effort.

GRAVITY+ is a very ambitious project, that requires a considerable fraction of the PIP overall resources. ESO is making an effort to accommodate it into the programme, with a rather fast schedule (the project is planned to finish early 2026), this will come to the price of stretching the PIP resources beyond the planned BFL amount in the next year, and will have an impact on the development of those projects (FORS+, CUBES, BlueMUSE) recently started or about to start.

Table 2 shows the development timetable. ESO plans to start the BlueMUSE Phase A study in early 2023, assuming no new major impediment in the advance status and completion of the other projects.

Year	Phase A	Design & Construction	Delivered (PAE)
2013		CRIRES+ MOONS	MUSE
2014	NTT Call for Ideas	4MOST	SPHERE PRIMA Astrometry (discontinued)
2015		NIRPS NACO Survival	LFC for HARPS VLTI PR1 GRAVITY BCI
2016		SOXS X-Shooter ADC	GRAVITY CIAO VISIR Upgrade VLTI PR4 NACO Survival
2017	MCAO for UT4 (Pre-Phase A)		ESPRESSO X-Shooter ADC MATISSE
2018	FORS Upgrade		AOF VLTI PR3 (NAOMI)
2019	MAVIS	IRLOS Upgrade	CRIRES+ NIRPS FE
2020	CUBES	FORS Upgrade	
2021	GRAVITY+	MAVIS	ERIS IRLOS Upgrade
2022		CUBES GRAVITY+	NIRPS BE VLTI PR5 (GRA4MA) SOXS 4MOST
2023	BlueMUSE		MOONS
2024	New VII/upgrade	BlueMUSE	FORS Upgrade
2025		New VII/upgrade	
2026			GRAVITY+
2027			MAVIS, CUBES

Table 2: Development plan for the Paranal Instrumentation Programme. Column "Delivered" refers to shipping to Paranal for instruments and to the end of the integration for infrastructure projects (AOF, VLTI).

Effort has been allocated for 2022 and beyond to the new initiatives. In case of conflicts of critical expertise, projects close to completion usually have the highest priority.

ESO goals for 2020 included PAC for MATISSE, and to complete the commissioning of GRA4MAT and of ERIS. They were transferred to 2021, and will now move to 2022.

Based on previous experience, the 26 FTEs allocated to PIP can support up to eight projects in a semi steady state. When considering CUBES and GRAVITY+, the open projects are now

14 (see Table 1) and, even if several (four to five) are not very demanding in effort, the programme must focus on finishing the pending ones, and is extremely careful in embarking on new projects, and this is done only after a detailed scrutiny of the allocated resources is completed. Figure 7 shows the status of the Paranal instrumentation in 2023, according to the present programme plan.

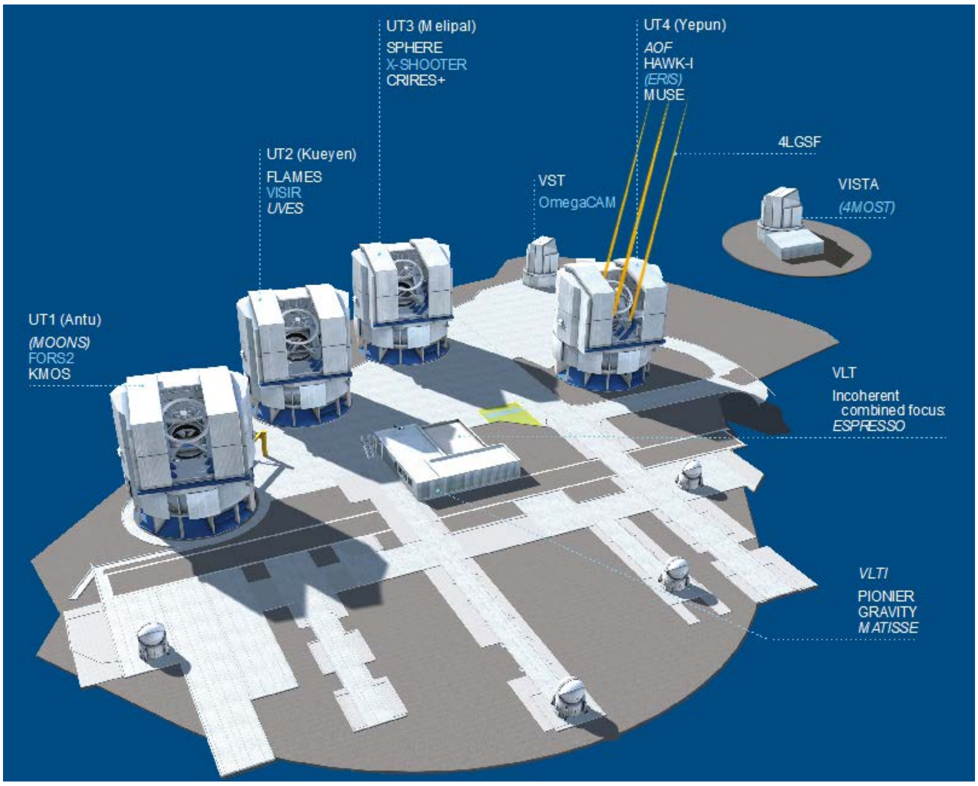


Figure 7: Paranal Instrumentation configuration in 2023, according to the present plan. Instruments in *italics* are presently in design or construction phase.

4.7 Milestones for the coming projects

The following table summarises the approval and definition milestones for the next periods. The next project after BlueMUSE will be selected in 2023 and will start the Phase A study in 2024.

Date	CUBES	MAVIS	GRAVITY+	BlueMUSE
Q1 2018		CfT Phase A		
Q3 2018		Deadline CfT		
Q4 2018		Phase A KO		
Q1 2019				
Q1 2020	Phase A CfP			
Q2 2020	Phase A KO	Phase A Review		
Q1 2021			Phase A KO	
Q2 2021	Phase A Review	Start Design		
Q3 2021			Phase A review	
Q1 2022	Start design		Start Design	
Q1 2023				Phase A KO

Table 3: Upcoming milestones for new projects.

The table below shows in more detail the upcoming milestones for the major projects:

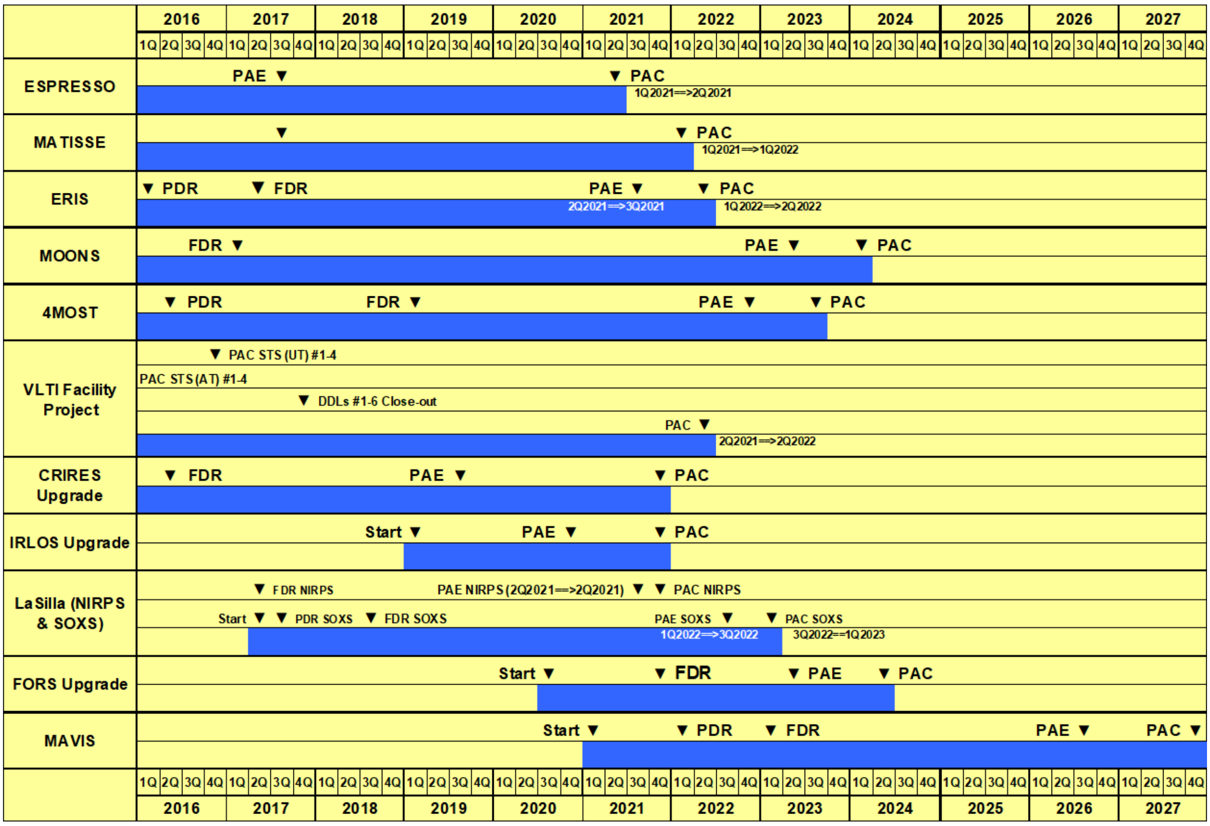


Table 4: Detailed Milestones for the running (approved) projects.

5. <u>Managing the Programme</u>

The Paranal Instrumentation Programme is managed according to the approved ESO internal project management procedures. One programme manager and one programme engineer run the programme, guided by two programme scientists, one dedicated to the VLT, Survey Telescopes and La Silla, and one to the VLTI, and a programme controller. In 2022 the programme control will move to the new Programme Planning and Control Office of the Directorate of Programs.

5.1 Procurement Procedure

Input for the selection of new instruments is provided via normal routes such as the STC and its subcommittees, scientific conferences, or directly from the community.

The procedure leading to instrument construction follows the normal VLT model: Top-Level Requirements are prepared and issued with a Call for Proposals. One or more Phase A studies can be funded to develop concepts, draft technical specifications, cost-to-completion and schedule. Following the Phase A reviews, a decision is made on construction of the instrument. All steps are done in consultation with the STC. In case the procurement model is an ESO-led consortium, a competitive process is normally used to select external institutes as partners. For upgrades or smaller projects (or in case of urgency), this competitive process may be waived.

When possible, R&D or prototyping is carried out and funded within the instrument projects themselves. Areas of general development, which are essential for instrumentation and cannot be allocated to a single instrument, or have development times that go beyond the construction period of one instrument, are carried out by the Technology Development Programme.

The programme must retain flexibility to react to the evolving scientific and technological landscape and to re-assign priorities. New proposals are evaluated in collaboration with the STC against the existing plan. Acceptance of a new project may result either in cancelling/de-scoping or re-phasing planned projects. A similar evaluation is made if one of the running projects requests a substantial increase in the allocated resources. In planning resources for new projects (which have not yet been fully defined), figures derived from past experience are used. The governing bodies are kept fully appraised of the evolution of the planning as well as of the status of the approved programme through this document and presentations to the STC and its La Silla - Paranal subpanel.

5.2 Resources

Resources (cash and effort) are allocated to the programme according to the Budget and Forward Look document. Each project has an allocated budget and cash expenditure profile and a cost-to-completion, that includes cash and staff effort. Project managers request resources from the ESO matrix through the standard ESO process.

A table summarising costs-to-completion for all PIP projects is given in Table 5. This is updated in each issue of this document.

A limited contingency is included, but not assigned to each project, and held by the programme manager who has to contain all costs within the approved value of the total programme. Unexpected costs beyond this, due to technical problems, delays, or enlarged scope, need to be paid from the future programme resources, requiring delays or cancellation of future instruments. Similarly, major requests for staff effort in areas of high priority will cause delay in other running projects or a strategic change in their organisation, for instance by increased outsourcing to institute partners. The risk of delays to one project impacting other projects is mitigated by allocating staff effort contingency beyond the currently planned completion dates of each major project.

The plan is based on the planning for BFL 2022. The overall effort and expenditure profile is shown in Figure 8 and Figure 9. Overall funding has reached an average value of approximately 3.8 (2018) MEUR/year cash and in the long term will level at 26 FTEs/year of staff effort. The programme aims to reach a quasi-steady state of around eight to nine approved projects running at any time. So far the Programme has required more staff effort than planned, and some capital is being used to hire temporary effort in order to finish the running projects.

The staff effort for future projects is requested by the programme, and kept in one job, until, after a successful Phase A review and acceptance of the project proposal, the project is approved. At this point, a separate job is created and the project becomes autonomous.

The evolution of the allocated staff effort with time for the whole Paranal Instrumentation Programme is shown in Figure 8. Different projects are indicated with different colours, and the green edge on top shows the FTEs available for the future projects and contingency. The details of these allocations (as at present) for the two projects proposed for recommendation: CUBES & GRAVITY+ are also given in the same figure.

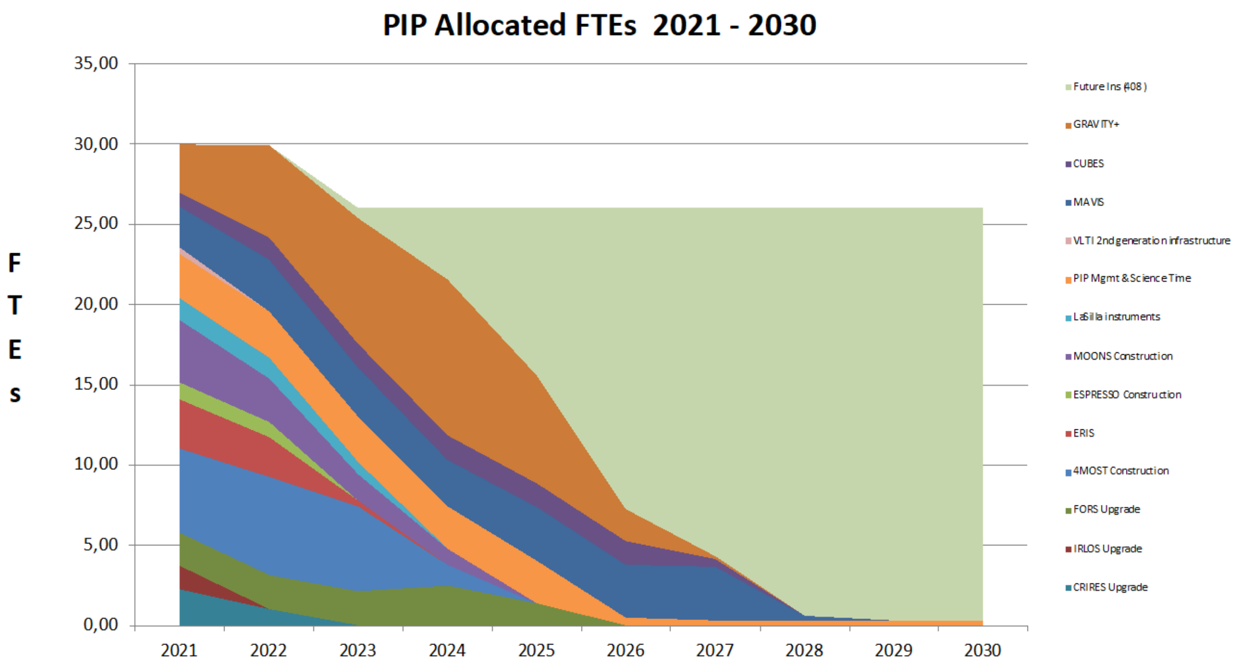


Figure 8: **Distribution of the ESO allocated human resources to the programme for the different projects (September 2021). The green slice on top (JOB408) is available for new projects. The resources allocated for GRAVITY+ and CUBES (to be approved for design and construction phase) are also provided.**

5.3 Resource indexation

Since 2019, the Paranal Instrumentation Programme benefits from indexation, adjusting the resources to the official ESO inflation index, as for the rest of the ESO budget. The indexation is implemented in two ways: as far as staff effort is concerned, this is kept at a constant level after 2022, irrespective of the increase in the staff cost, so it is allocated in FTEs and not in Euros. As far as capital is concerned, the non-committed capital is indexed, and the cash evolution is shown in Figure 9, in which the committed and uncommitted expenditures are separately given. The reason for indexing the uncommitted fraction only is based on the fact that PIP agreements, MoU and contracts are all fixed price values, not indexed, and they will continue to be so. The committed component of the budget is therefore not influenced by the cost increase.

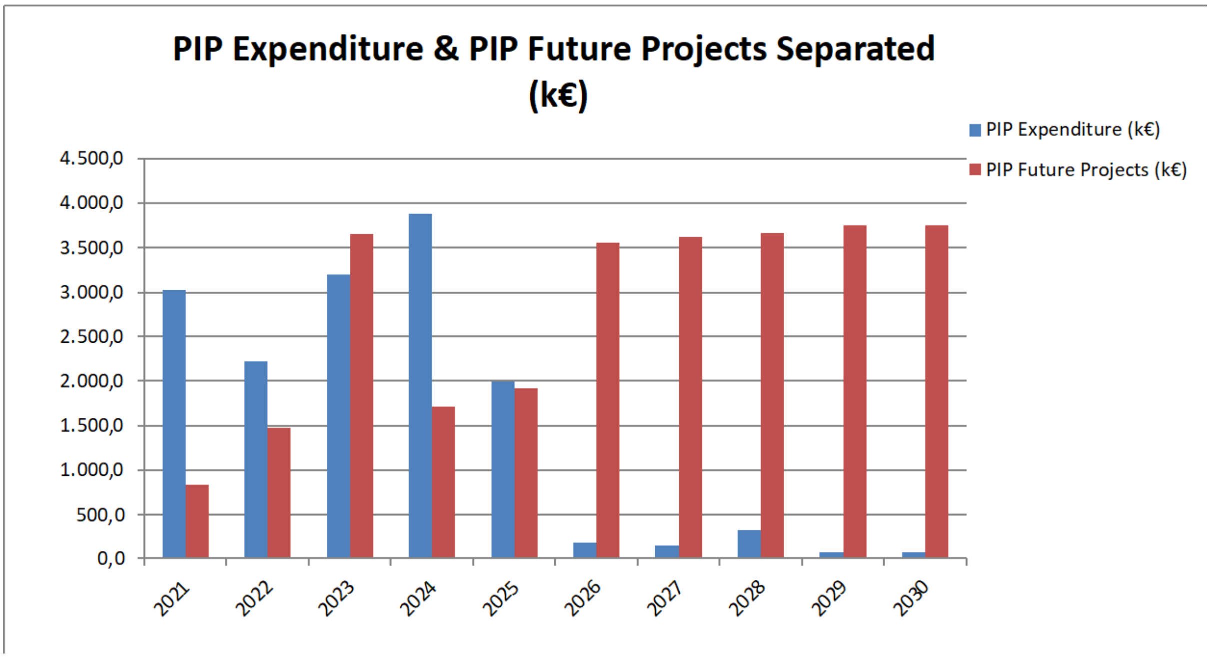


Figure 9: Paranal Instrumentation Programme capital expenditure profile (staff effort not included), according to past real expenditures and actual projections. In red the funds not yet committed to approved projects (it includes also CUBES and GRAVITY+), to which indexation is applied.

5.3.1 Planning

The Paranal Instrumentation Programme covers 19 foci and 21 instruments (14 foci and 16 instruments for the VLT/I only). With one new project (instrument or upgrade) starting every year, the average life of an instrument in operations on the VLT will, in the steady state, be some 16 years. By interspersing the programme with upgrades, the instrument suite can be maintained and will remain world leading.

The table below summarises cost-to-completion for running PIP projects. It also provides figures for GTO nights and consortia furnished equipment. The material costs in the first column indicate costs to ESO. The invoiced amounts refer to September 2021. ESO FTE (planned) refer to what was foreseen for each project at the approval of the project. When comparing the numbers with FTE (cost-to-completion), it is clear that most projects have substantially underestimated the need of ESO effort in the past, as well as the total time, by a factor ~1.5.

Instrument	Cost to Completion (k€)	Invoiced (k€)	ESO FTEs (Planned)	Cost of ESO FTEs (Planned) (k€)	ESO FTEs (cost to completion)	ESO FTEs (Actual)	Cost of ESO FTEs (Actual) (k€)	Guaranteed Time Observing (Observing Nights) UT/VISA/4m/3.6m &NTT	Consortium Furnished Equipment (k€)
ESPRESSO	4 029	4 402	21.15	2 672	30.76	47.05	5 988	273/0/0/0	4 776
MATISSE	1 349	1 850	20.77	2 338	22.95	26.81	3 528	150/173/0/0	3 125
ERIS	3 341	3 795	25.60	3 447	25.60	32.11	4 147	210/0/0/0	2 700
MOONS *	6 912	7 010	9.30	1 269	11.48	19.80	2 720	298/0/0/0	3 700
4MOST	5 200	3 172	23.45	3 248	27.38	32.14	4 191	0/0/1278/0	14 766
VLTI Facility Project	18 713	21 791	260.80	25 766	319.65	329.34	34 052	120/0/0/0	1 620
CRIRES Upgrade **	1 069	1 484	15.30	2 061	18.23	40.40	4 962	62/0/0/0	1 700
LaSilla (NIRPS & SOXS)	100	81	5.50	771	5.60	4.17	551	0/0/0/1625	5 895
IRLOS Upgrade	300	142	3.00	431	3.00	3.58	488	n/a	n/a
FORS Upgrade	1 350	97	15.50	2 239	15.50	2.76	396	n/a	n/a
MAVIS	8 400	345	23.80	3 437	23.80	1.95	280	150/0/0/0	n/a
GRAND TOTAL	**50 763**	**44 168**	**424.17**	**47 678**	**503.95**	**540.11**	**61 303**	**1263/173/1278/1625**	**38 282**

Table 5: Cost-to-completion table for all running Paranal Instrumentation Projects. Cost-to-completion are costs to ESO, i.e. do not include external funding when present. * MOONS has received a financial contribution from the Consortium of 600 kUSD, assumed 1 EUR=1.10 USD . ** CRIRES Upgrade: The Thüringer Landessternwarte Tautenburg (TLS) transferred the amount of 380 kEUR to ESO.

5.4 Risk Register

A document describing the risk policy for the whole programme and which is applicable to all projects has been released. It is in line with the one adopted ESO–wide, and similar to the one for the ELT. The programme risk register is regularly reviewed and updated. It contains five active risks at present. A description of the top programme active risks is given below.

Risk	Description	Impact	Mitigation
Availability of engineering capabilities for future instruments.	FTE availability for new projects uncertain. Mostly in the areas of software and electronics.	Non implementing or delaying new projects, loss of reputation.	Delay start of new projects, allocate higher staff complement, finance the resources through collaborations with community/ outsource.
The delays related to COVID-19 will impact the development of new projects and the development of the approved ones.	All projects in AIT phase suffered and announced between ~9 and 18 months' delay.	The number of FTEs/yr is fixed, and all 2020 activities and goals need to be moved to 2021. This has increased the quest for extra effort in 2021 and 2022	Carefully analyse the allocated resources. Increase the FTE complement, delay start of BlueMUSE to when affordable.
Over costs	Some projects close to end incur over-spending and ask ESO for extra funds	For the cost-cap programme, the impact is that less funds will be available for new projects.	A limited contingency is kept at programme level. Delay start of payments, allow to access funds from next year.

Table 6: Main active programme risks.

The highest risks at present are:

- The combination of possible resource (both human and cash) overrun by on-going projects close to completion, especially in critical areas, that may delay the start of the new projects or the completion of lower priority ones. In a couple of areas, the non-availability of staff for new projects may be critical for their start. This risk became reality after the COVID-19 outburst (Observatories not operational and not accessible): many activities planned to be executed in 2020 were postponed to 2021, and some need to me moved to 2022. This created an over-request of effort from PIP, that was mitigated by an allocation of human resources higher than planned in the BFL. The work to start GRAVITY+ has made the over-request from the programme even larger for 2022.

5.5 Schedule and Coordination

A higher level of schedule coordination for the Programme is needed, especially to better manage the many interventions at Paranal and the use of common resources and facilities (telescope, integration hall, etc.). A link to each schedule is available through the PIP project summary in the PIP intranet and a programme-wide planning is maintained and updated.

In addition to the main milestones, it is essential to prepare and follow-up the schedule of the activities in Paranal. This includes not only the telescopes and instruments, but also the use of the integration facilities and other resources. The coordination of these activities is one of the main tasks of the programme engineer. A schematic example of the coming activities in Paranal and La Silla is provided in the table below for Q3 2021 and Q1 2022. All the activities have been scrutinised in order to separate those which do not require travel of large crews from Europe to the Observatory. Activities which could be performed remotely, or by Paranal staff with remote support, are scheduled in 2021. Those requiring large external teams have been moved to 2022. The schedule below is only tentative, and it reflects the situation as known at the beginning of September 2021. The present travel restrictions to Chile make many interventions very uncertain. The most endangered activities are marked with (TBC?), meaning they are COVID-19 permitting.

	UT3	UT4	VLTI-AT-UT	NIH	CCL/ La Silla
September	SV CRIRES+ (remote)				NIRPS AO comm2 (remote)
October		4LGS split tests (MAVIS)	GRAVITY metrology upgrade		
November		Back Focal Length extension for ERIS		ERIS AIV (TBC?)	NIRPS-FL test with AO (TBC?) LFC refurbishment (TBC?)
December		ERIS installation & 1st light (TBC?)	MATISSE wheel intervention (TBC?) GRAVITY wide		
January		ERIS COMM1 (TBC?)	MATISSE wheel intervention (TBC?) GRA4MAT final COMM		NTT Active Optics upgrade (TBC?) NIRPS-BE AIV (TBC?)
February		ERIS COMM2 (TBC?)	MATISSE final COMM UT		NIRPS-BE AIV & COMM1 (TBC?)
March					ESPRESSO cryostat repair & detector
April		ERIS COMM3 (TBC?)			NIRPS-BE Comm2 (TBC?)

Table 7: Planned Paranal and La Silla activities for Q4 2021 and Q1 2022

6. APPENDIX A: Characteristics tables of Paranal instruments in operation and in construction

VST + ΩCAM	(0.3-1 μm 1x1 Degree)
VISTA	(0.8-2.5 μm eq. 46x46 arcmin)
FORS2	(0.3-1 μm, 6.8x6.8 arcmin)
WIFI, SOFI, EFOSC	
AO assisted	
HAWK-I + AOF (GLAO)	(0.8-2.4 μm 7x7 arcmin)
Diffraction limit (1 UT)	
VISIR	(0.8-24 μm 32x32 arcsec)
ERIS	(1-5 μm 2x2 arcmin)
SPHERE	(0.6-2.3 μm 11x11 arcsec)
MAVIS	(0.4-1 μm 30x30 arcsec)
Diffraction limit (VLTI)	
MATISSE	(3.5-12 μm, ~1 arcsec)
GRAVITY	(2-2.4 μm, 2 arcsec)
PIONIER	(1.5-2.4 μm)

Table 8: Imagers

IFUs	
MUSE	(1x1 arcmin) (7.5x7.5 arcsec **AO assisted**)
FLAMES	(7x7 arcsec, 15*2.4x3 arcsec)
ERIS (SPIFFI)	(0.8x0.8, 3.3x3.3 arcsec) **AO assisted**
KMOS	(24* 2.8x2.8 arcsec on 7 arcmin Ø field)
X-Shooter	(1.8x4 arcsec)
SPHERE	(1.73x1.73 R=50)
MAVIS	(2.5x3.7 arcsec R=~5900 or 11-14000) **AO Assisted**
MOS	
FORS2	19
KMOS	24 mini-ifus
FLAMES	< 130 or 15 mini-ifus + 7 to UVES-RED
MOONS	1000
4MOST (VISTA)	2400
No MOS AO assisted	

Table 9: IFUs and MOS

GRAVITY	2-2.4 µm R=22 & 500 & 4,000
VISIR	8-13 µm R~500
FORS2	0.3-1 µm R=300-3,000
MUSE	0.46-0.93 µm R~3,000
ERIS	1.1-2.45 µm R=2-4,000
KMOS	0.8-2.5 µm R~3,600
SPHERE	1-2.3 µm R-100-700
4MOST/MOONS	0.4-0.92/0.8-1.6 µm R~6,000 and ~20,000 (both)
X-Shooter	0.3-2.4 µm R=6-10,000
FLAMES	0.37-0.9 µm R=6-20,000
VISIR	10 µm R=3,200 & 25,000
CRIRES$^+$	0.95-5 µm R=40-100,000
UVES	0.3-1 µm R=40-120,000
ESPRESSO	0.38-0.8 µm R=130-210,000 *4UT R=70,000
HARPS (3.6m La Silla)	0.38-0.68 µm R=115,000
NIRPS (3.6m La Silla)	0.98-1.4 µm R=100,000
SOXS (NTT La Silla)	0.35-1.8 µm R=4-5000

Table 10: Spectrographs

Polarimetry: FORS2 (Circ.and Lin.), HARPS, SPHERE, CRIRES$^+$
High Contrast/Coronography: SPHERE, VISIR
RV Precision: ESPRESSO (<0.1 m/s), HARPS (<0.3 m/s), CRIRES$^+$ (<3 m/s), NIRPS
FAST Photometry: VISIR (5ms), HAWK-I Bust mode (2ms), FORS2 (2ms)
Astrometry: Gravity (30 µarcsec, goal 10), ERIS (300 µarcsec)

Table 11: Summary of some of the special modes