

Report on Status of ESO Public Surveys and Current Activities

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This report on the status of the ESO Public Surveys includes a brief overview of their legacy value and scientific impact. Their legacy is ensured by their homogeneity, sensitivity, large sky coverage in multiple filters, large number of targets, wavelength coverage and spectral resolution, which make them useful for the community at large, extending beyond the scientific goals identified by the survey teams. In May 2019, as almost all first-generation imaging and spectroscopic surveys completed their observations and second-generation imaging surveys got well underway, the Public Survey Panel reviewed the scientific impact of these projects. The review was based on a quantitative assessment of the number of refereed publications from the survey teams and archive users. It included the number of citations, the number of data releases and statistics on access to archive data by the user community. The ESO Users Committee also discussed the availability and usage of ESO Public Survey data by the community during their yearly meeting in April 2019. We describe the status of these projects with respect to their observing plans, highlight the most recent data releases and provide links to the resulting science data products.

ESO Public Surveys: overview of engagement rules and status

By design, the ESO Public Surveys cover a variety of research areas, from the detection of planets via micro-lensing, through stellar variability and evolution, the Milky Way and Local Group galaxies, to extragalactic astronomy, galaxy evolution, the high-redshift Universe and cosmology. Differently from Large Programmes, these projects are planned to span more than four semesters and last for many years. For example, the latest call for the Cycle 2 survey projects for the Visible and Infrared Survey Telescope for Astronomy (VISTA) required them to span a time interval of more than three years. These survey projects all have a legacy value for the community at large in addition to the science goals identified by the proposing teams.

ESO science policies for Public Surveys

The selection of ESO Public Surveys is a two-step process which starts with the submission of letters of intent. On the basis of these letters, the Public Survey Panel (PSP) formulates a coherent, well-balanced scientific programme that takes into account any synergies among teams in the community and the international survey projects. The PSP then provides recommendations to ESO including a list of the teams that should be invited to submit full proposals on the basis of the ranking of the descriptions of their science projects as provided in the letters of intent. In so doing, the PSP fosters active collaborations within the community by asking independent teams to join, encouraging them to optimise science goals and observing strategies, and sharing resources.

Once the proposals have been recommended for approval by the PSP and the Observing Programmes Committee, data acquisition for each ESO Public Survey starts. This involves the review and assessment of each survey management plan by the ESO Survey Team. The survey management plan is an essential tool for the survey team, as well as for operations at ESO; it details the data acquisition plan, and the allocated resources for data processing and analy-

sis, including the timeline for the delivery of science data products over the entire duration of the survey project. The approval of the survey management plan is further confirmed by the agreement signed between ESO's Director General (DG) and the Principal Investigator (PI) of each survey.

The agreement between the DG and the PI specifies the milestones for the data releases and their content and responsibility for the scientific quality and accuracy of the data products, which is to be warranted by the Public Survey team under the leadership of the PI. The agreement states that a final release which includes the reprocessing of the entire data set is expected upon completion of data acquisition for each survey. This final data release should take place within one year of completion of the data acquisition for any survey. The PSP was set up to periodically review the progress of the surveys and to assess compliance with the specification of the survey products. In May 2019, a PSP review took place to evaluate the scientific impact of the active Public Surveys.

Operations for ESO Public Surveys

The ESO Public Survey observations — whether in service mode or visitor mode — are carried out according to the process defined by the ESO Data Flow System. The raw data acquired for ESO Public Surveys are immediately public. Once the Public Survey teams have carried out data reduction to remove instrumental signatures, calibrate the data and complete the measurements defined by their scientific goals, ESO assists the survey teams to define and package their data products in a manner consistent with the ESO Science Archive and Virtual Observatory standards and in agreement with the specifications in the survey management plans. The goal is to integrate science data products from the Public Surveys into the ESO Archive, together with the entire archive content from the La Silla Paranal Observatory. This is done via the Phase 3 process, which is an audit process that certifies the integrity, consistency and data quality of the products available from the ESO Archive and ensures a homogeneous

user experience once the data are published through the Archive.

ESO Public Survey status

A total of twenty Public Surveys¹ have been carried out by consortia in the community and are actively supported by ESO. The majority have completed data acquisition using ESO facilities and are in the process of publishing science data products via the ESO archive.

ESO Public Surveys were launched in 2005 with an initial call for the optical imaging surveys at the VLT Survey Telescope (VST; Capaccioli & Schipani, 2011), followed by a call for the near-infrared surveys (Cycle 1) in 2007 (Arnaboldi et al., 2007) at VISTA (Sutherland et al., 2015). Once the imaging surveys were under way, ESO opened a first call for Public Spectroscopic Surveys in 2011, followed by a second call for the VIMOS Public Spectroscopic Surveys in 2015. The call for Cycle 2 VISTA imaging Public Surveys was opened in 2015 and the selected surveys began in April 2017 (Arnaboldi et al., 2017). Four of the seven Cycle 2 VISTA surveys exploit the time domain: for example, following up exotic transients like the optical-near-infrared echo of gravitational wave (GW) events (VinRouge); studying the 3D shape of the Milky Way bulge (VVVX) via astrometry — to test stellar evolution models and microlensing, and to obtain proper motion membership (VVVX, VISIONS); or detecting high-*z* supernovae (SN) in cosmological deep fields (VEILS). Two of the seven Cycle 2 surveys, VVVX and the Continuing UltraVISTA, follow up the successful Cycle 1 surveys, very much in the spirit of other surveys such as the Sloan Digital Sky Survey (SDSS).

In the optical, the VST Public Surveys completed their data acquisition in Period 104. The V-ATLAS survey was granted an extension by the PSP to acquire the *u'g'r'*-band imaging of chosen sub-areas. The data acquisition for this extension is ongoing and completion is expected in Period 105. In Figure 1 we show the cumulative curves of data acquisition for the VST surveys. The data acquisition for the Cycle 1 VISTA imaging surveys was completed between 2015

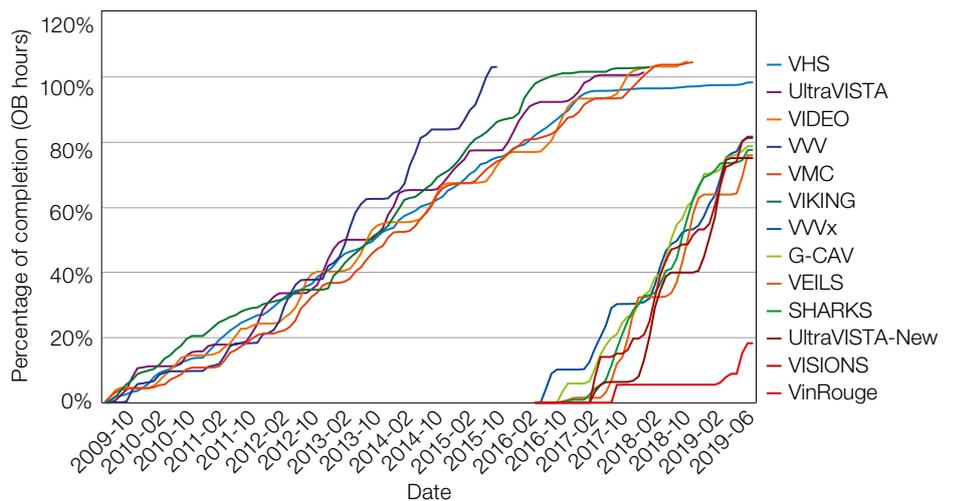
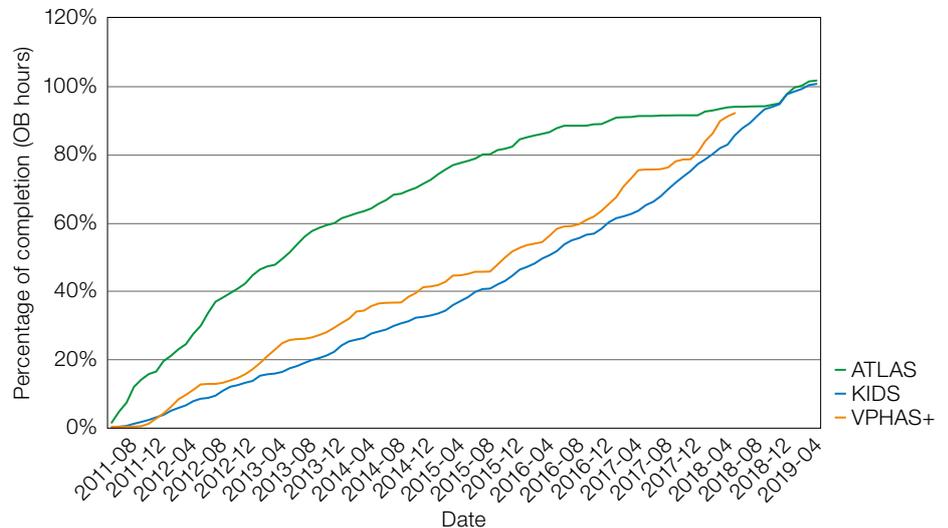


Figure 1. (Upper) Cumulative curves for the completion of the VST surveys. The VST ATLAS survey was extended after the completion of the observing plan to allow further coverage in the *u'g'r'*-bands (as outlined in its Survey Management Plan). The VPHAS+ curve is below 100% because the PI requested that it be terminated early.

Figure 2. (Lower) Cumulative curves of completion for Cycle 1 and 2 VISTA Surveys. The cumulative curves of completion can reach values over 100% for Public Surveys that were compensated for time corresponding to low-quality observations (OBs with a D grade). Public Survey teams can ask for compensation via reports submitted to the OPC.

and 2018, except for the VHS South Pole fields. The data acquisition for the Cycle 2 VISTA imaging surveys is two-thirds complete. In Figure 2 we show the cumulative curves of data acquisition for all VISTA surveys. The data acquisition for the four spectroscopic surveys, including the two that were carried out with the VIMOS spectrograph, has also been completed.

In Tables 1 and 2 we provide a summary of the observational parameters for the twenty ESO Public Surveys and the total

observing time — in hours for the imaging surveys and in nights for the spectroscopic surveys.

Scientific impact of ESO Public Surveys

A standard reference metric for the assessment of scientific impact is given by the number of refereed publications from the Public Survey teams. Given the legacy value of these projects and the science data products readily available for download via the ESO Archive, other

VST Survey ID	Science	Area (square degrees)	Filters	Magnitude limits	Total time (hours)
KIDS — Kilo-Degree Survey http://kids.strw.leidenuniv.nl/ (de Jong et al., 2013)	Extragalactic	1350 ^b	$u' g' r' i'$	24.1 24.6 24.4 23.4	3421
ATLAS http://astro.dur.ac.uk/Cosmology/vstatlas/ (Shanks et al., 2013)	Wide area/baryon acoustic oscillations	4700 ^c	$u' g' r' i' z$	22.0 22.2 22.2 21.3 20.5	1585
VPHAS+ — VST Photometric H α Survey of the Southern Galactic Plane http://www.vphas.eu (Drew et al., 2013)	Stellar astrophysics	1800 ^d	$u' g' H\alpha r' i'$	21.8 22.5 21.6 22.5 21.8	1200
VISTA Cycle 1	Science	Area (square degrees)	Filters	Magnitude limits	Total time (hours)
UltraVISTA http://home.strw.leidenuniv.nl/~ultravista/ (McCracken et al., 2013)	Deep high-z	1.7 Deep 0.73 Ultra deep	$Y J H Ks$ NB118	25.7 25.5 25.1 24.5 26.7 26.6 26.1 25.6 26.0	1832
VHS — VISTA Hemisphere Survey http://www.ast.cam.ac.uk/~rgm/vhs/ (McMahon et al., 2013)	Southern sky	17 800	$Y J H Ks$	21.2 21.1 20.6 20.0	4623
VIDEO — VISTA Deep Extragalactic Observations Survey https://www.eso.org/sci/observing/PublicSurveys/sciencePublicSurveys.html (Jarvis et al., 2013)	Deep high-z	12	$Z Y J H Ks$	25.7 24.6 24.5 24.0 23.5	2073
VVV — VISTA Variables in the Via Lactea http://vvvsurvey.org/ (Hempel et al., 2014)	Milky Way	560	$Z Y J H Ks$	21.9 21.1 20.2 18.2 18.1	2205
VIKING — VISTA Kilo-Degree Infrared Galaxy Survey http://www.astro-wise.org/ (Edge et al., 2013)	Extragalactic	1500	$Z Y J H Ks$	23.1 22.3 22.1 21.5 21.2	2424
VMC — VISTA Magellanic Clouds Survey http://star.herts.ac.uk/~mcioni/vmc/ (Cioni et al., 2013)	Resolved star formation history	180	$Y J Ks$	21.9 21.4 20.3	2047
VISTA Cycle 2	Science	Area (square degrees)	Filters	Magnitude limits	Total time (hours)
VINROUGE* — Kilonova counterparts to gravitational wave sources http://www.star.le.ac.uk/nrt3/VINROUGE/ (Tanvir et al., 2017)	Kilonova counterparts to GW sources	300	$Y J Ks$	21.0 21.0 20.1	77
Cont. UltraVISTA — Completing the legacy of UltraVISTA http://home.strw.leidenuniv.nl/~ultravista/	High-z	0.75	$J H Ks$	26.0 25.7 25.3	567
VVVX* — Extending VVV to higher Galactic latitudes http://vvvsurvey.org/	Milky Way	1700	$J H Ks$	$Ks = 17.5$	1631
VEILS* — VISTA Extragalactic Infrared Legacy Survey http://www.ast.cam.ac.uk/~mbanerji/VEILS/veils_index.html	Galaxy evolution, AGN, SN	9	$J Ks$	$J < 23.5$ $Ks < 22.5$	847
G-CAV — Galaxy Clusters At VIRCAM http://www.oats.inaf.it/index.php/en/2014-09-12-12-59-22/tematiche-di-ricerca/macroarea-1-en/670-galaxy_cluster.html	Galaxy clusters	30	$Y J Ks$	24.5 24 23	440
VISIONS* — VISTA star formation atlas https://visions.univie.ac.at	Star formation atlas	550	$J H Ks$	21.5 20.5 19.5	449
SHARKS — Southern Herschel-Atlas Regions Ks-band survey https://www.iac.es/sharks/	Near-infrared counterparts for radio sources	300	Ks	22.7	929

Table 1. (Upper) VLT Survey Telescope Public Surveys. These projects began operations in October 2011 and data acquisition is now completed according to their survey management plans. The total number of completed hours is reported to the 30 September 2019 date.

Table 2. (Centre) Cycle 1 VISTA Public Surveys; these projects began operations in April 2010 and are now all completed but for the VHS subareas close to the South Galactic Pole. The total number of completed hours is reported to the 30 September 2019 date.

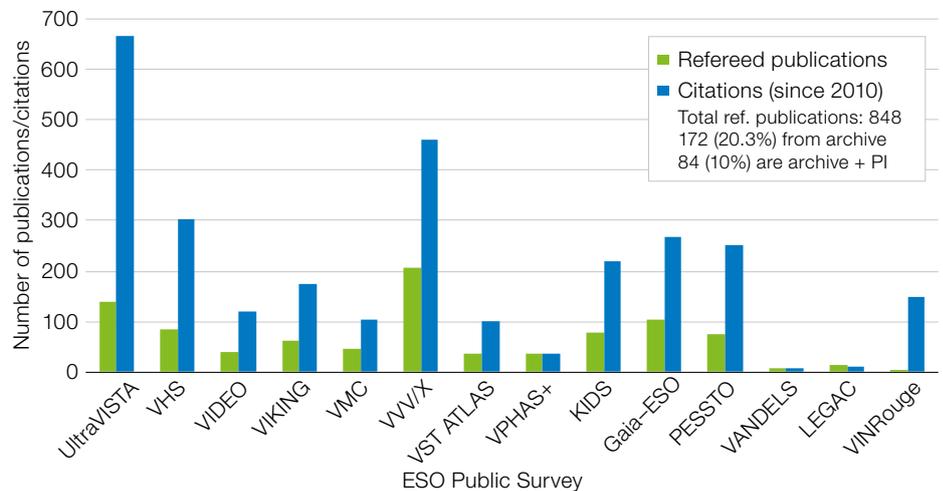
Table 3. (Lower) Cycle 2 VISTA Public Surveys began operations in April 2017. The four Cycle 2 VISTA surveys that explore the time domain are indicated by an asterisk in the table. The total number of completed hours by 30 September 2019 is shown in the last column.

Public Spectroscopic Survey ID and homepage	Science topic	Number of targets/spectra	Spectral resolution	Total time (nights)
Gaia-ESO http://www.gaia-eso.eu/ (Randich et al., 2013)	Milky Way, stellar populations	200 000	20 000	282.5
PESSTO — Public ESO Spectroscopic Survey of Transient Objects http://www.pessto.org/ (Smartt et al., 2013)	Transient, SN progenitors	150	~ 2500	384.0
VANDELS http://vandel.inaf.it (McLure et al., 2017)	Physics of galaxies in the early universe CANDELS, UDS & CDFS fields	2700	~ 1500	142.7
LEGA-C — Large Early Galaxy Astrophysics Census http://www.mpia.de/home/legac/index.html (van der Wel et al., 2016)	Dynamics of galaxies at $z = 0.6-1.0$	3100	~ 1500	99.8

Table 4. Public Spectroscopic Surveys. PESSTO and Gaia-ESO began operations in 2012 and were completed in 2017. The surveys using the Visible Multi Object Spectrograph (VIMOS), called VANDELS and LEGA-C, began operations in 2015 and were completed in March 2018, before the decommissioning of the VIMOS spectrograph.

independent archives (for example, the VISTA science archive, Vizier) or the Public Survey webpages have also been made available to those in the community interested in accessing data products for their independent scientific explorations.

The ESO library routinely monitors refereed publications, based on data acquired from ESO approved observing programmes. This includes papers published by PIs/co-investigators (Cols) as well as archive papers. Archive papers come in two flavours: *archive only* and *archive plus PI* publications. In *archive only* papers, none of the authors of these refereed publications are listed as PIs or Cols of the approved Public Survey proposals. In the case of *archive plus PI* publications, science data products from the ESO Public Surveys are used together with data owned by a PI or Col of an ESO programme to achieve their scientific published results. In the case of ESO Public Surveys, the total number of refereed publications by teams and archive users was 848 by 30 September 2019. Of these refereed publications, 172 (20.3%) are *archive only* and 84 (10%) are *archive plus PI* since 2010 (from ESO telbib²). The total number of citations from ESO Public Survey refereed publications is 26 266. In Figure 3 we provide the histogram of the cumulative number of refereed publications and citations per survey project.



Published data releases

Because of the extensive amount of time allocated using ESO facilities, the science policies for ESO Public Surveys entail the submission and publication of the science data products from these projects into the ESO Archive. The publication process for science data products extends well after the completion of the data acquisition. This additional time is used by the Public Survey teams to execute global calibrations of the entire data volume and to carry out the relevant measurements required to achieve their scientific goals. The ultimate publication of the results of these steps is contained in the final catalogue release. All twenty ESO Public Surveys are currently involved in the publication of their science data products via the ESO Archive.

The Public Survey teams adopted a range of strategies to deal with the data volumes from their respective surveys. Some rely on the support of data centres while others have developed their own

Figure 3. Histogram of the cumulative number of refereed publications and citations (divided by 10) for each ESO Public Survey.

specific infrastructures. Five out of six Cycle 1 VISTA surveys and two out of three VST surveys received extensive support from the dedicated data centres, CASU³ and WFAU⁴. The deep UltraVISTA and Continuing UltraVISTA surveys relied on dedicated support from CASU, TERAPIX⁵ and CALET⁶ centre at the IAP in Paris, while the KIDS survey is supported by Astro-WISE⁷. The Cycle 2 VISTA surveys have adopted different strategies compared to the first generation, with a larger number receiving tailored support to their data processing from their respective science institutes.

For the Public Spectroscopic Surveys, Gaia-ESO, PESSTO, LEGA-C and VANDELS, the teams built their data reduction infrastructure based on previous experience they had acquired through managing large programmes at ESO and

scientific networks (for example, PESSTO–WISeREP).

All survey teams have successfully published several data releases for some of their science data through the Phase 3 process (Arnaboldi et al., 2014); an overview of these releases is available via this webpage⁸. Since January 2019, the total volume of science data products released from the ESO Public Surveys amounts to 27.4 Tb, including ancillary files. The data releases published this year include: the fourth data release of KIDS (> 1000 square degrees) and UltraVISTA (deep stacked images of the COSMOS field from observations acquired between December 2009 and June 2016); the proper motion of selected stars in the Milky Way disc and bulge from the VVV near-infrared Astrometric Catalogue (VIRAC); accurate PSF-fitting photometry of the 300 square degrees around the Galactic centre; and the fifth data release of VMC with full coverage

of the Small Magellanic Cloud. All data releases were promptly advertised via the Archive/Phase 3 web pages, followed up with specific announcements on the ESO science page, the Science Newsletter⁹ and the ESO archive community forum¹⁰.

The most recent data releases join a large number of data collections from the ESO Public Surveys that can be browsed using the Archive Science Portal¹¹. The science data products from the ESO Public Surveys amount to a total volume of 68.6 Tb (nearly 8.5×10^5 files) which are currently accessible via the ESO Archive. The science data products that can be actively queried and downloaded amount to nearly 320 000 catalogue files, half a million astrometrically and photometrically calibrated images, and 56 000 1D extracted spectra. In Figure 4 we show a collection of on-sky footprints of the data releases published during the last year by the ESO Public Survey teams.

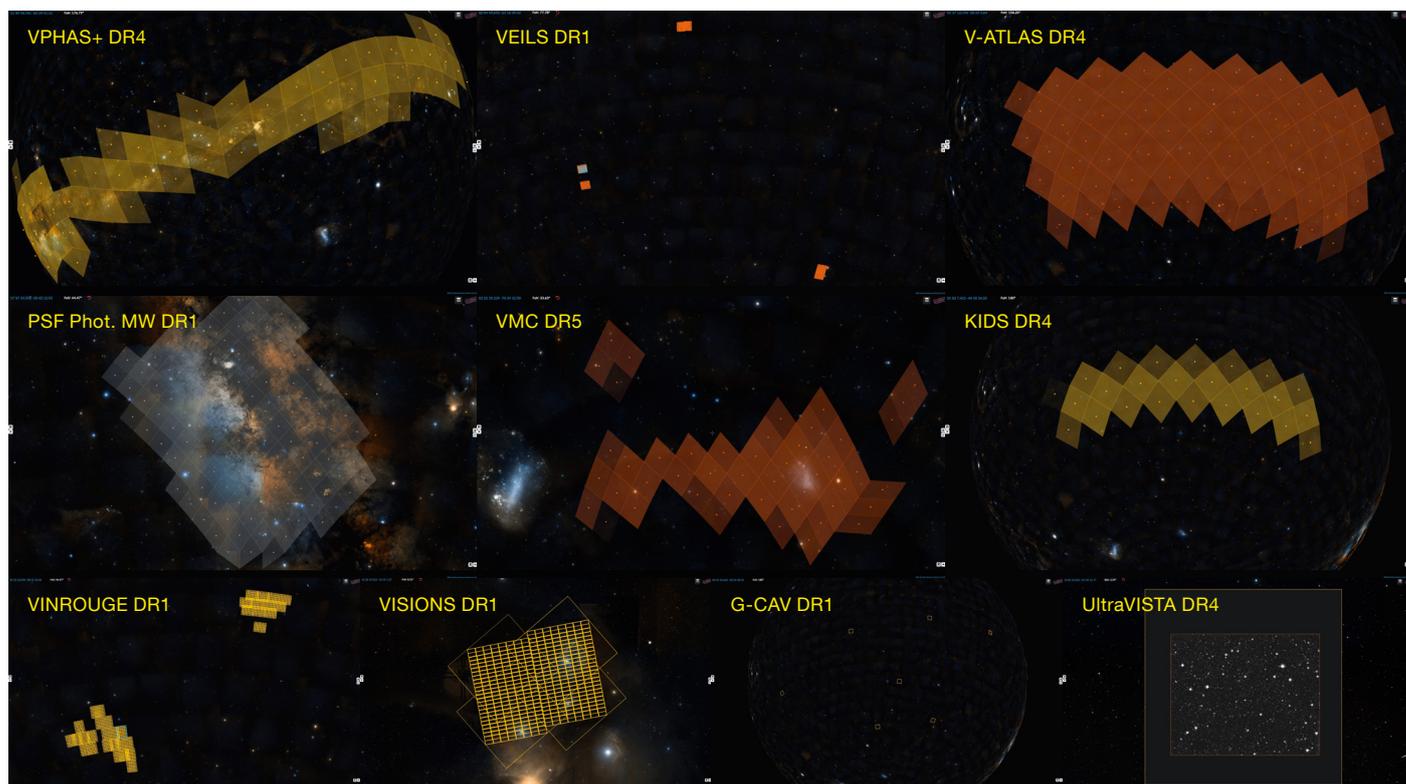
Data download statistics

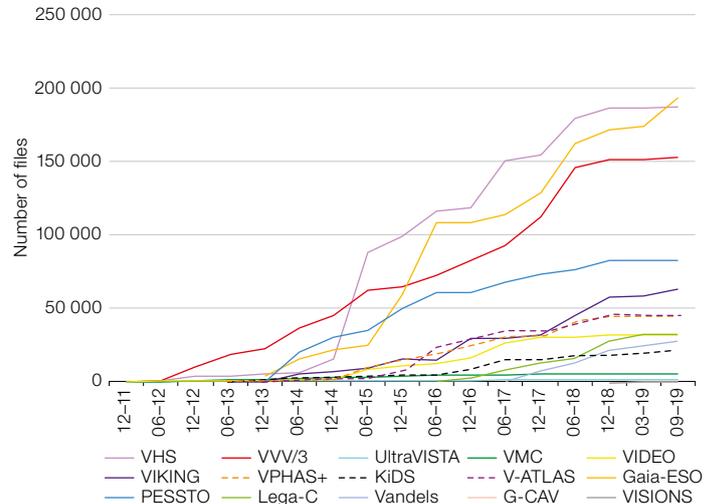
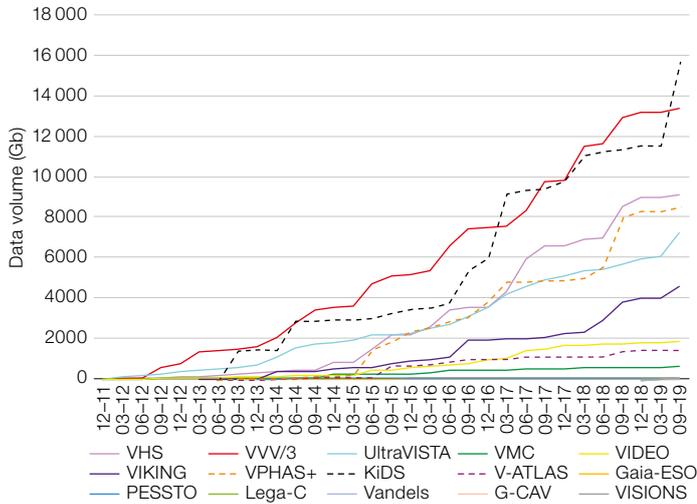
In Figure 5 we show the cumulative curves of the data volume (Gb) and the number

of files downloaded by the community for each ESO Public Survey. The lower chart shows the numbers of catalogues, the numbers of distinct users and the numbers of queries carried out using the ESO catalogue query interface¹² to access ESO Public Survey catalogues. On average, users of the ESO catalogue query interface carry out at least 21 independent queries to access catalogue records.

An enhanced archive capability allowing programmatic access¹³ results in anonymous exploration and retrieval of catalogue records (and other products) via Virtual Observatory tools, for example, Aladin and Topcat. This new service allows users to repeat queries in an automated fashion, in order to perform more complex queries by combining data from different surveys or other content of the ESO Science Archive, thereby enhancing the scientific use of the catalogue content of the ESO Archive. One interesting statistic is the number of distinct users — 1583 users from 77 different countries — who have downloaded ESO Public Survey science products published via the ESO Archive. To place this in context, the fraction of distinct users who access

Figure 4. Montage of the footprints of the data releases from the ESO Public Surveys published by 2019, as shown on the ESO Archive Science Portal interactive interface.





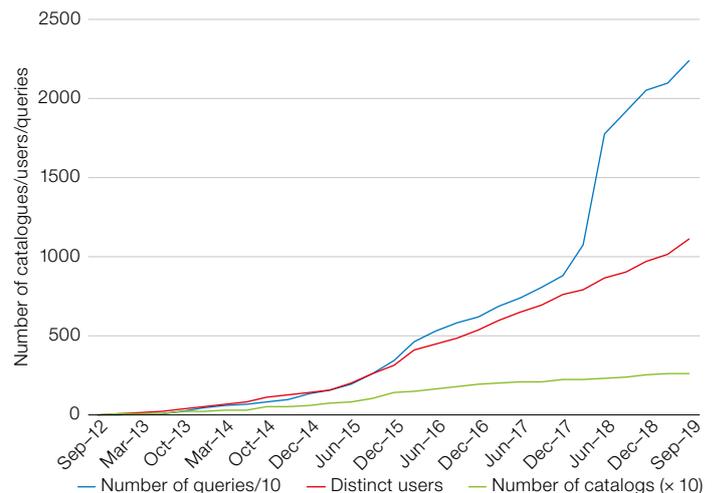
data products from ESO Public Surveys is 46% of the total number of users (3457) who have downloaded science data products from the ESO Archive.

How ESO promotes Public Survey science

ESO promotes science results from Public Surveys via science/photo press releases and community workshops. The most recent photo release of the new image of the Large Magellanic Cloud¹⁴ celebrated the 500th anniversary of its first being seen by Europeans (during the voyage of the explorer Ferdinand Magellan). Among the science press releases, we particularly note those on the 3D structure of the bulge of the Milky Way¹⁵, the constraints on the clumpiness of the dark matter distribution in the Universe¹⁶, and the first light from a gravitational wave source¹⁷.

Three community workshops were organised by ESO in 2012, 2015 and 2019 to support survey science and operations at ESO. The most recent was the 4MOST community workshop (see also The Messenger 175¹⁸, and Liske & Mainieri, 2019). A workshop focused on the next-generation galaxy evolution surveys is currently being organised in Perth, Australia in February 2020. This second Australia-ESO conference will discuss the future coordination of these surveys with multi-wavelength facilities in the southern hemisphere.

Figure 5. Charts showing the cumulative data volume (upper left) and numbers of files downloaded (upper right) for each ESO Public Survey. The lower chart shows the cumulative curves for the number of catalogues (x 10), the number of distinct users, and number of queries (x 0.1) related to the ESO Public Surveys downloaded using the ESO catalogue query interface.



Community awareness of ESO Public Surveys: feedback from the User Community poll

In April 2019 the ESO Public Surveys were identified as the special topic for the User Community (UC) poll. The results of this UC poll showed that more than 60% of the ESO users who responded were aware of the ESO Public Surveys. About 25% of UC poll participants (excluding all Survey Pls/Cols) had used archive data from Public Surveys to complement other datasets. This was the most frequent usage of these data products according to the results of the poll.

The science data products from ESO Public Surveys were retrieved from the

ESO Archive in the vast majority of cases. The UC poll participants who had used science data products from Public Surveys for their own science reported that they had published between one and three peer-reviewed papers based on these data. Finally, most users who had participated in the surveys or used Public Survey data provided a positive assessment of their utility, scheduling, rate of progress/publication, and the effectiveness of communication with ESO. Regarding the services provided by ESO, i.e., archive interfaces and Phase 3, the vast majority of the users were “satisfied” or “very satisfied”, with the ESO Archive being the preferred site for data retrieval. The release description published together with an active release was considered

the most reliable/useful documentation to support the scientific use of the available data products.

The Public Survey Panel review

Membership and evolution of the Public Survey Panel

In 2005, the Public Survey Panel (PSP) was set up as a subpanel to the Observing Programmes Committee, its role being later extended to include monitoring of the progress of the Public Survey projects. Four chairs organised the work of the panel: Duccio Macchetto, Simon White, Danny Lennon, and Miguel Mas Hesse (the current chair). From 2005 to 2012, ESO set up three separate panels: the VISTA, VST imaging, and Spectroscopic Public Survey Panels; the VISTA and VST Panels were later merged. Since 2018 there has been only one panel for all ESO Public Surveys, whether imaging or spectroscopy. In the near future, the PSP will advise ESO on the selection of 4MOST surveys (see de Jong et al., 2019).

The PSP review in May 2019

As most of the Public Surveys completed their data acquisition in 2019, the goal and objectives of the PSP review held in May at the ESO headquarters were to assess the scientific success of the Public Surveys using criteria that included published results in refereed journals, the progress of the analysis, potential scientific extensions, complementarity with other telescopes, activities to promote the surveys, and the use of survey data products for independent projects in the community. The PIs of the twenty active Public Surveys were invited to the review and asked to address the above criteria during their presentations. All PIs but one attended the review and contributed to a lively and constructive discussion. The PSP report was presented to the Scientific Technical Committee at its meeting in October 2019.

Outlook and Conclusions

While work on the scientific analysis continues for the twenty Public Surveys, ESO

announced 2019 a call for letters of intent for 4MOST Community Surveys on 26 November 2019. The community surveys will access up to 30% of the available time on the 4MOST spectrograph on VISTA over a period of five years. These projects will complement the GTO surveys that were presented during the 4MOST workshop at ESO in May and are described in the special issue of the Messenger in March 2019⁷.

Large surveys are considered a key tool in observational astronomy because they allow explorations that go beyond individual targeted observations. They are characterised by large investments that comprise dedicated telescopes and instruments, a wide community of astronomers involved in the science projects and extended networks for the data distribution and analysis. The scientific success of such survey projects includes the legacy value of science products that are made available through the archives for further scientific exploration by the community. ESO Public Surveys are an example of an effective implementation of this strategy, with the goal of supporting the scientific advancement of its community.

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Links

- 1 ESO Public Surveys Project webpage: <http://www.eso.org/sci/observing/PublicSurveys/sciencePublicSurveys.html>
- 2 ESO Telescope Bibliography telbib: <http://telbib.eso.org>
- 3 The Cambridge Astronomy Survey Unit: <http://casu.ast.cam.ac.uk/>
- 4 The Wide Field Astronomy Unit: <http://www.roe.ac.uk/ifa/wfau/>
- 5 TERAPIX: <http://terapix.iap.fr/>
- 6 CALET: <https://calet.org/>
- 7 Astro-WISE: <http://www.astro-wise.org/>
- 8 ESO Phase 3 Data Releases: <http://eso.org/rm/publicAccess#/dataReleases>
- 9 ESO Science Newsletter: <http://www.eso.org/sci/publications/newsletter/>
- 10 ESO Archive Community Forum: <https://esocommunity.userecho.com/>
- 11 ESO Archive Science Portal: <https://archive.eso.org/scienceportal/>
- 12 ESO catalogue query interface: <https://www.eso.org/qj/>
- 13 ESO Archive Programmatic Access webpage: <http://archive.eso.org/programmatic/>
- 14 VISTA image of LMC: <https://www.eso.org/public/news/eso1914/>
- 15 VISTA image of Milky Way bulge: <https://www.eso.org/public/news/eso1339/>
- 16 VISTA image from KIDS survey: <https://www.eso.org/public/news/eso1642/>
- 17 First Light from Gravitational Wave Source: <https://www.eso.org/public/news/eso1733/>
- 18 Messenger issue dedicated to 4MOST GTO surveys: <https://www.eso.org/sci/publications/messenger/archive/no.175-mar19/messenger-no175.pdf>

Notes

- ^a Astrofit2 Marie Skłodowska-Curie Fellow
^b The survey area was reduced from the original approved coverage to coincide with the VIKING footprint.
^c The survey area was increased to 4700 square degrees after approval by the PSP; data-taking is currently active.
^d The survey area was reduced from that approved by the PSP following a request by the PI to end the survey early.