

Public Surveys at ESO

Magda Arnaboldi^{*1a}, Nausicaa Delmotte^a, Michael Hilker^a, Gaitee Hussain^a, Laura Mascetti^b,
Alberto Micol^a, Monika Petr-Gotzens^a, Marina Rejkuba^a, Jörg Retzlaff^a,
and

Steffen Mieske^a, Thomas Szeifert^a, Rob Ivison^a, Bruno Leibundgut^a, Martino Romaniello^a

^a ESO, K. Schwarzschild str. 2, 85748 Garching, Germany; ^b TERMA GmbH, Europahaus,
Europaplatz 5, 64293 Darmstadt, Germany

ABSTRACT

ESO has a strong mandate to survey the Southern Sky. In this article, we describe the ESO telescopes and instruments that are currently used for ESO Public Surveys, and the future plans of the community with the new wide-field-spectroscopic instruments. We summarize the ESO policies governing the management of these projects on behalf of the community. The on-going ESO Public Surveys and their science goals, their status of completion, and the new projects selected during the second ESO VISTA call in 2015/2016 are discussed. We then present the impact of these projects in terms of current numbers of refereed publications and the scientific data products published through the ESO Science Archive Facility by the survey teams, including the independent access and scientific use of the published survey data products by the astronomical community.

Keywords: Public Surveys, science data products, astronomical archives, surveys, data management, observatory operations, ESO, Phase 3

1. INTRODUCTION

ESO has a strong background in Survey projects, starting with the ESO/SERC Southern Sky survey in the years 1974-1987, and the EIS survey from 1997 to 2004. Since 2010, ESO operates two telescopes fully dedicated to surveys: the 4 meter Visible and Infrared Survey Telescope for Astronomy (VISTA)[1] in the near infrared, and the 2.6 meter VLT-Survey telescope (VST)[2,3] in the optical bands, hence providing a wavelength coverage from the optical UV (0.33 micron) to the Ks band (2.15 micron). The Public Spectroscopic Surveys were also added to ESO's portfolio of observing programs in 2012. The spectrographs used for the Public Spectroscopic Surveys at ESO provide multiplexing capabilities over Field-of-view (FoV) of tens of arcmin diameter (FLAMES@UT2, VIMOS@UT3), to single slits (UVES@UT2, EFOSC/SOFI@NTT). The spectral resolution ranges from ten of thousand (UVES/FLAMES) to a few thousand (VIMOS/EFOSC/SOFI), depending on the science goals, with a wavelength coverage from optical to near infrared. The immediate and future outlook of ESO's commitments to surveys is bright. The array of fully robotic telescopes employed by the Next-Generation Transit Survey (NGTS) achieved first light at ESO's Paranal Observatory in northern Chile on January 14, 2015 and started science operations on April 1st 2016. This project will search for transiting exoplanets — planets that pass in front of their parent star and hence produce a slight dimming of the star's light that can be detected by sensitive instruments. The goal of this facility is to discover Neptune-sized and smaller planets, with diameters between two and eight times that of Earth. As a result of this collaboration, their data products, in particular the light curves of their most likely candidates, will become available to the community through the ESO Science Archive Facility (SAF). The first data release is expected two years after the start of science operations.

Future developments include the construction and deployment of two wide field spectrographs – the Multi Object Optical and Near Infrared Spectrograph (MOONS) – and the 4 meter Multi Object Spectroscopic Telescope (4MOST). MOONS is a wide field fiber-fed spectrograph consisting of ~1000 fibers deployable over a field of view of ~500 square arcmin, the largest patrol field offered by the Nasmyth focus at the VLT. The total wavelength coverage is 0.6 -1.8 micron, with two resolution modes: medium (few thousands) and high resolution (up to ten thousand). 4MOST is a very large field (goal > 4 square degrees) multi-object spectrograph with up to 2200 fibers and spectral resolutions of 5000 and 20 000 in

¹ marnabol@eso.org

the wavelength range 0.42-0.9 micron. Clearly, these two wide-field spectrographs are built for the effective follow-up of the interesting candidates identified via their colors or morphological properties provided by the Public Imaging Surveys and/or space missions, like Gaia and eROSITA among others.

In this contribution to the Proceedings of the SPIE conference ``*Astronomical Telescopes + Instrumentation*'', we shall describe the policies governing the thirteen Public Surveys just completed or ongoing at the ESO facilities, their science goals and current completion rates, and the second call for VISTA surveys, whose proposal selection was discussed at the ESO OPC in May 2016. We conclude by presenting the scientific impacts of these surveys in terms of number of refereed publications, dedicated scientific workshops, an expanding community and download of products from the ESO SAF.

2. POLICIES FOR PUBLIC SURVEYS AT ESO

The current implementation of the ESO policies for Public Surveys is such that the community carries out all the activities that go beyond those enlisted in the ESO mission statement [4]. In this scheme, ESO supports the Public Survey teams for standard telescope operations at the La Silla Paranal Observatory (Service Mode and support for Visitor Mode observations), the delivery of the raw data, the management of the archive and reduced products, plus the organization of the high level peer reviews. These activities are planned and coordinated by the ESO Survey team, whose members come from the Directorate for Science and Data Management and Operations Division at ESO. The Public Survey teams are responsible for the definition of the observing strategy, the final quality control of the scientific data and for the data reduction.

The legacy value, including the coordination and scientific excellence of the ESO survey program are assessed periodically during peer reviews organized by ESO. The selection of ESO Public Surveys is carried out by two Public Survey Panels (PSPs): the Joint VISTA/VST PSP for the imaging surveys, and the Public Spectroscopic Survey Panel (PSSP) for the spectroscopic surveys. The selection of the Public Surveys is a three-step process: (1) submission of the Letter of Intent evaluated by survey panels, (2) invitation and submission of the survey proposals to the OPC, (3) approval of the survey management plan by the ESO DG, with report to the OPC. Once the three-step selection process is complete, survey teams access telescope time, either in Service Mode (imaging), or Visitor Mode (spectroscopy). The raw data from Public Surveys are public immediately, and the survey teams agree to return science data products and high level science data, i.e. catalogues, in yearly releases. Because the ESO public surveys are managed within the framework of the VLT/VLTI science policies (ESO Council meeting 104, 17-18 December 2004), the primary point of publication of the reduced products from the ESO Public Surveys is the ESO SAF (<http://archive.eso.org/cms.html>).

The progress of the Public Surveys and their compliance with ESO policies and delivery of the agreed products is monitored via the extended reports submitted by the teams to the November OPCs, and the agreed reviews with the relevant Public Survey Panel. In this way, ESO does comply with the mandate of supporting the community and fostering new collaborations within the context of astronomical surveys.

3. ON-GOING ESO PUBLIC SURVEY PROJECTS

The ESO Public Surveys projects are very large observing programmes that require a total observing time at the telescope that lasts longer than two years, with typical requests of observing time totaling a few hundreds to thousand hours. Their observing strategies range from pencil beam deep surveys on cosmological fields, to wide area surveys covering from a few hundred to thousands of square degrees, and up to the whole Southern Hemisphere. They have a legacy value for the astronomical community at large because they cover a broad range of research topics: from the study of the Milky Way and the Local group, stellar astrophysics, to galaxy evolution, cosmology and high redshift universe. They support synergies among each other and are complementary either in wavelengths (optical vs. near-infrared) or in observing modes, e.g. spectroscopic follow-up of interesting candidates, selected on the basis of their physical properties, i.e. spectral energy distribution or morphology.

More information on ESO Public Surveys is available at <http://www.eso.org/sci/observing/PublicSurveys.html>.

3.1 VISTA Surveys and the second VISTA call

The first cycle of approved VISTA Public Surveys includes six imaging surveys that started scientific operations in April 2010. A summary of the general observing parameters of the six VISTA imaging survey is given in Table 1. These imaging

surveys are currently either completed (VVV in 2015) or expected to be completed in 2016/2017 (VIKING, VMC and VHS, see Figure 1).

Table 1. General observational parameters for the six VISTA public surveys. The columns illustrate the Public Survey (col.1), the main scientific classification of the surveys' scientific goal (col.2.), the targeted total area (col. 3), the filters (col.4), the magnitude limits (10σ AB for VMC, otherwise 5σ AB) in the different filters (col.5) and the observing hours completed up to April 1st, 2016 (col.6).

| Survey ID and home page | Science topic | Area (deg ²) | Filters | Magnitude limits | Observing time completed (hrs) to April 1 st 2016 |
|--|---------------|-----------------------------|-------------------|--|--|
| Ultra-VISTA http://home.strw.leidenuniv.nl/~ultravista/ | 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 | 1598 |
| VHS http://www.ast.cam.ac.uk/~rgm/vhs/ | Whole sky | 17800 | Y J H Ks | 21.2 21.1 20.6 20.0 | 3730 |
| VIDEO http://www-astro.physics.ox.ac.uk/~video | Deep high-z | 12 | Z Y J H Ks | 25.7 24.6 24.5 24.0 23.5 | 1483 |
| VVV http://vvvsurvey.org/ | Galactic MW | 560 | Z Y J H Ks | 21.9 21.1 20.2 18.2 18.1 | 2157/Completed |
| VIKING http://www.astro-wise.org/projects/VIKING/ | Extragalactic | 1500 | Z Y J H Ks | 23.1 22.3 22.1 21.5 21.2 | 2194 |
| VMC http://star.herts.ac.uk/~mcioni/vmc/ | Resolved SFH | 180 | Y J Ks | 21.9 21.4 20.3 | 1529 |

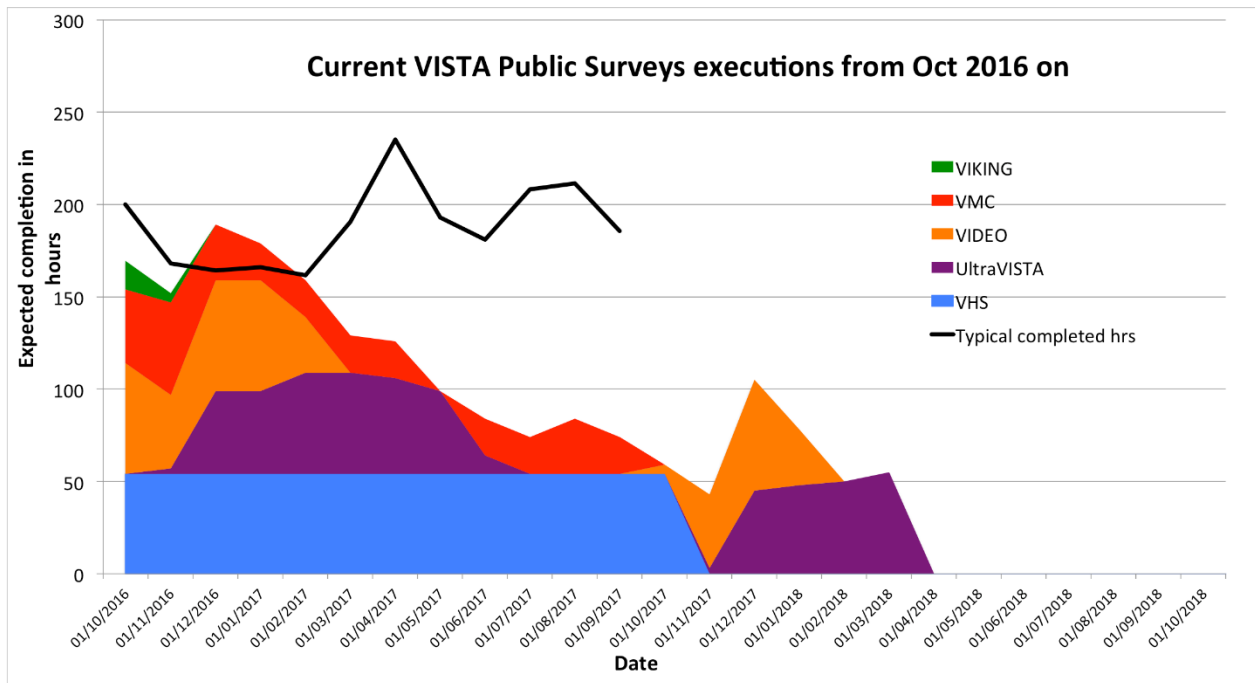


Figure 1. Histogram of expected hours of observations for the five VISTA surveys in period Oct 2016 till April 2018. The areas are color coded according to the VISTA surveys. Full line indicates the typical completed hours per month based on VISTA executions in the previous 4.5 years. The available time between the colored areas and the black line will be taken on by the survey projects selected during the second VISTA Call.

A second VISTA call was opened in 2015, for observations up to the 4MOST commissioning in 2020. Thirteen letters of intent were submitted by interested teams, with the participation of 13 PIs and 517 co-Is, with an over subscription of a factor larger than two of the available observing time. Seven projects were invited to submit their proposals that were discussed during the OPC meeting in May 2016. These projects will be announced to the community when their survey management plans are approved and published on the ESO Public Survey web pages [5] at the end of 2016, with the first observations to be scheduled starting from 2017.

3.2 VST Surveys

The Public Surveys on VST started operations in October 2011. These are three imaging surveys whose observing parameters and total number of executed hours are listed in Table 2. In contrast to VISTA, a number of GTO projects are carried out on VST, and hence the observing time is shared with the Public Survey projects. Of the three VST Public Survey, one (V-ATLAS) will be completed end of 2016, see cumulative completion rates for the VST imaging surveys in Figure 2.

Table 2. General observational parameters for the three VST public surveys. The columns illustrate the Public Survey (col.1), the main scientific classification of the surveys' main scientific goal (col.2.), the targeted total area (col. 3), the filters (col.4), the magnitude limits (10σ AB) in the different filters (col.5) and the observing hours completed up to April 1st, 2016 (col.6) .

| Survey ID and home page | Science topic | Area deg ² | Filters | Magnitude limits | Observing time completed (hrs) to April 1 st 2016 |
|--|----------------------|-----------------------|------------------------|--------------------------|--|
| KIDS http://kids.strw.leidenuniv.nl/ | Extragalactic | 1500 | u' g' r' I' | 24.1 24.6 24.4 23.4 | 1635 |
| ATLAS http://astro.dur.ac.uk/Cosmology/vstatlas/ | Wide area/BAO | 4000 | u' g' r' I' z | 22.0 22.2 22.2 21.3 20.5 | 1316 |
| VPHAS+ http://www.vphas.eu | Stellar astrophysics | 2000 | U' g' H α r' I' | 21.8 22.5 21.6 22.5 21.8 | 688 |

An overview of the ESO VISTA and VST public imaging surveys was the focus of The Messenger, Volume 154, (<http://www.eso.org/sci/publications/messenger/archive/no.154-dec13/messenger-no154.pdf>) with the presentation of the scientific goals of the surveys by each team.

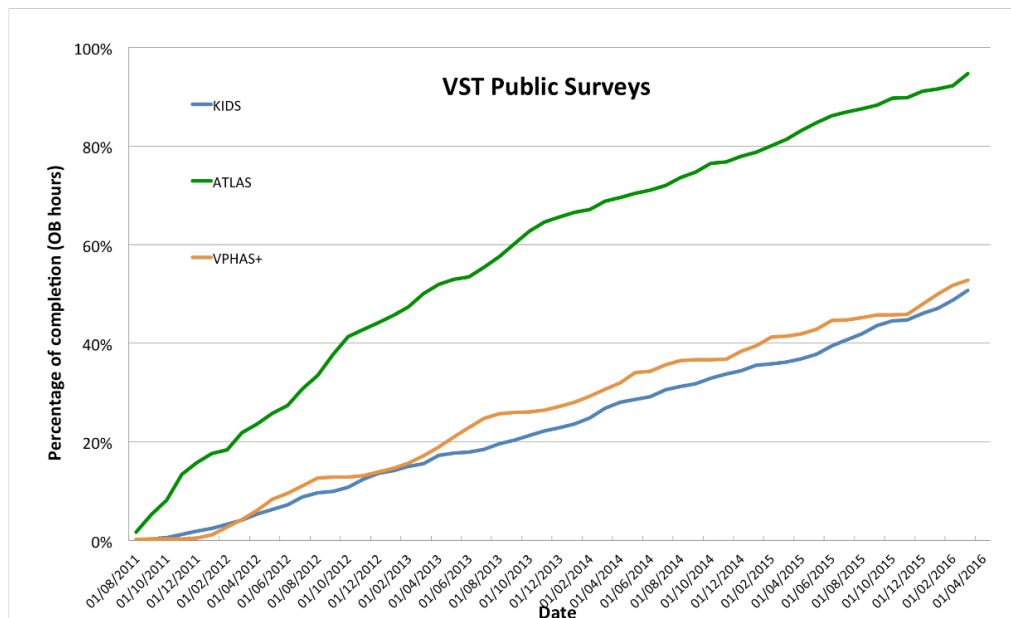


Figure 2. Cumulative curves of completion fractions as function of time for the VST imaging surveys

3.3 Public Spectroscopic Surveys

There are four Public Spectroscopic Surveys currently on going at the ESO facilities. The initial call for spectroscopic surveys selected two projects, Gaia ESO and PESSTO that started in January 2012. Following the review of the Public Spectroscopic Panel in October 2015, these survey projects were awarded the fifth year of telescope time. The second call for Public Spectroscopic Surveys selected two additional surveys for the VIMOS spectrograph on UT3 in 2014: LEGA-C and VANDELs. Their observations started in October 2014 and are to be completed by the end of Q1/2018, when VIMOS will be decommissioned to make room for CRIFES+. Hence ESO is currently managing thirteen Public Surveys on ESO telescopes of the La Silla-Paranal Observatory.

Gaia ESO: this survey targets 10^5 stars distributed among the major components of the Milky Way (MW) galaxy and in 100 open clusters. It has a strong synergy with the Gaia satellite survey and will provide the phase space structure and abundances for the stellar population in the MW. Spectra are obtained with the FLAMES/ UVES spectrographs on VLT UT2. Target selection comes from the imaging surveys VHS and VVV, among others. (Survey home page: <http://www.gaia-eso.eu/>).

PESSTO: the goal of this survey is to carry out the spectroscopic follow-up of about 150 transient objects in an unbiased sample of nearby galaxies to understand the physics of supernovae explosion, and achieve a statistical sample of SN progenitors in the nearby universe. Observing time is allocated at the NTT with EFOSC2 and SOFI. (Survey home page: <http://www.pessto.org/>).

VANDELs: this Public Spectroscopic Survey with VIMOS targets star forming galaxies in the redshift range $2.5 < z < 7.0$ and passive galaxies in the redshift range $1.5 < z < 2.5$, in the two CANDELs fields CDF South and UDS. The goals are to measure metallicities and kinematics of the ionized gas in these systems. A total of 914 hours are allocated with VIMOS on VLT UT3. (Survey home page: <http://vandel.s.inaf.it>).

LEGA-C: this Public Spectroscopic Survey with VIMOS targets 3000 early-type galaxies in the COSMOS field in the redshift range $0.6 < z < 1.0$. The goals are to understand how galaxies grow in mass through measurements of their dynamical masses, stellar ages and metallicities. A total of 1010 hours are allocated to this project with VIMOS on VLT UT3. (Survey home page: <http://www.mpia.de/home/legac/index.html>).

3.4 Impact of ESO Public Surveys

Among the merit parameters that quantify the scientific impact of ESO Public Surveys there are the number of refereed publications by ESO survey teams and archive users. Other useful parameters to quantify the legacy values of these projects are the number of ESO press releases and the cumulative data download of data products from the ESO archive, that are illustrated in the following section.

There are now 337 refereed publications from the ESO Public Surveys, according to the ESO telbib census (<http://telbib.eso.org>) on April 2016. The refereed publications are thus distributed: VHS 28, Ultra-VISTA 53, VVV 92, VIDEO 22, VIKING 19, VMC 25, KIDS 9, VST-ATLAS 7, VPHAS+ 10, Gaia-ESO 40, PESSTO 31, LEGA-C 1. 55 of these refereed publications (16% of the total) are based on archival data (raw or reduced), and none of the authors are listed as PIs/Co-Is in the Public Survey proposals.

The science carried out by ESO Public Surveys was the focus of two workshops held at ESO in 2012 and 2015. A highlight of the latter workshop was the healthy attendance by young astronomers presenting the results from the large team efforts — a new generation of European scientists is clearly taking on a more prominent role.

4. RETURNS FOR THE ASTRONOMICAL COMMUNITY: ACCESS TO SCIENCE PRODUCTS

4.1 Phase 3 for ESO Public Surveys

The ESO Public Surveys generate a very large data volume, of the order of tens of terabytes of raw data each year, whose science quality is ensured by the constant monitoring of the instrument stability and standard calibrations. Because these large data volumes are very homogenous and stable, a standard pipeline processing is capable of removing the instrumental

signature and producing reduced data in physical units for further scientific analysis and processing. In this context, “physical units” signify that images are astrometrically and photometrically calibrated, and one-dimensional (1D) spectra are uniquely associated with the RA, Dec position of the target object, they are wavelength calibrated and have physical flux units.

To support the ESO Public Surveys, a process was developed including the preparation, submission, validation and publication of reduced data through the ESO SAF, which is identified as “Phase 3” [6,7]. Within the Phase 3 process, the data provider, i.e. the survey PI or his/her delegates, is responsible for the data generation, their scientific quality and the documentation of the released data. ESO is responsible for the definition of the data format and the metadata information, which jointly are referred to as the “Phase 3 standard”. ESO also provides the Phase 3 tools to automatically validate [8], upload and manage data submissions [7], to carry out the user support to the data providers, and the audit process for the content validation of the released data [9]. The Phase 3 process was launched in 2011 and more than 52 terabytes of reduced data were either validated, ingested or published through the ESO SAF. Through the Phase 3 process in 2014/2015, more than 35 TB of data products have been published, see Figure 3, and the list of available data releases can be accessed at this URL: http://www.eso.org/sci/observing/phase3/data_releases.html

An even larger volume of science data products will be released during the second half of 2016, from the VISTA submission #4, VST submission #3 and the Spectroscopic Survey submission #3.

4.2 Accessing science data products for independent science and enlarging the ESO community

The metadata of the reduced products are key information for their publications through the query forms of the ESO SAF (http://archive.eso.org/wdb/wdb/adp/phase3_main/form) and a prerequisite for their further dissemination through the VO network. The metadata encode the level of calibration and support the archive exploration and queries by high level quality parameters, e.g. the limiting magnitude and the FWHM of the point-spread-function for imaging data, or the signal-to-noise ratio and the spectral resolution for 1D spectra [10].

By adopting the Phase 3 standard, the reduced products from ESO Public Surveys, but also Large Programmes and ESO in-house pipeline processed data, can be served co-jointly through the same ESO SAF query forms. In Figure 3 we show the sky coverage of the survey image products currently available at the ESO SAF and released via the Phase 3 process. Since the first Public Survey data release in December 2011, more than 25 TB and a million files were retrieved from the ESO SAF. By accessing the science data products through the ESO SAF, the community benefits from the joint efforts by ESO, the PI's of the ESO Public Survey projects and their collaborators, including the data centres at CASU[11], WFAU[12], and TERAPIX[13]. In Figure 4 we show the cumulative curves for each survey project that describe the download of products in terms of volume and number of files, as function of time.

Complementary to the archive download of the survey science data products, it is of importance to assess the impact of survey projects in terms of usage of the ESO archive and in enlarging the community that access ESO services for their own scientific research.

The availability of science data products from ESO Public Surveys, Large programmes and ESO in-house reprocessed data has triggered a steady growth of users that access the ESO SAF and download data. Since 2011, a total of 1600 unique users have returned, on average, seven times to download science products from the ESO SAF. 30% of these archive users are new members to the ESO community, as they have not submitted proposals before. Furthermore, on average the access to the ESO archive services brings a steady inflow of new registrations to the ESO user-portal [14].

5. CONCLUSIONS

Observational astronomy is in the era of surveys. Projects such as these are characterized by large investments in “survey systems” that include dedicated telescopes and instruments, a large community of astronomers involved in the science projects and large networks for the data distribution. ESO Public Surveys are examples of effective implementations of such systems, and empower the wider community to discover the Universe in the spirit of the IAU statement “The Universe: yours to discover”.

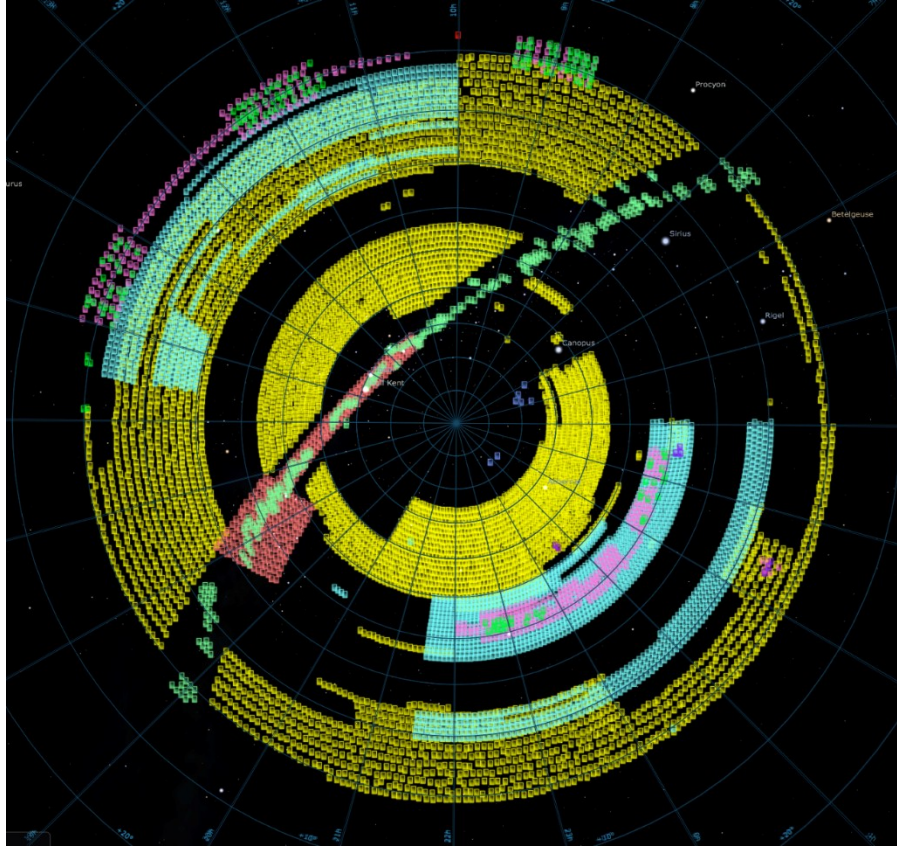


Figure 3. The Southern Hemisphere (pole view) with footprints of imaging products from the VISTA & VST public survey released through the Phase 3 process in 2014/2015. The sky area covered is almost **11500 square degrees** of the Southern Hemisphere. The optical/NIR images cover 4336 / 9445 square degrees of sky area.

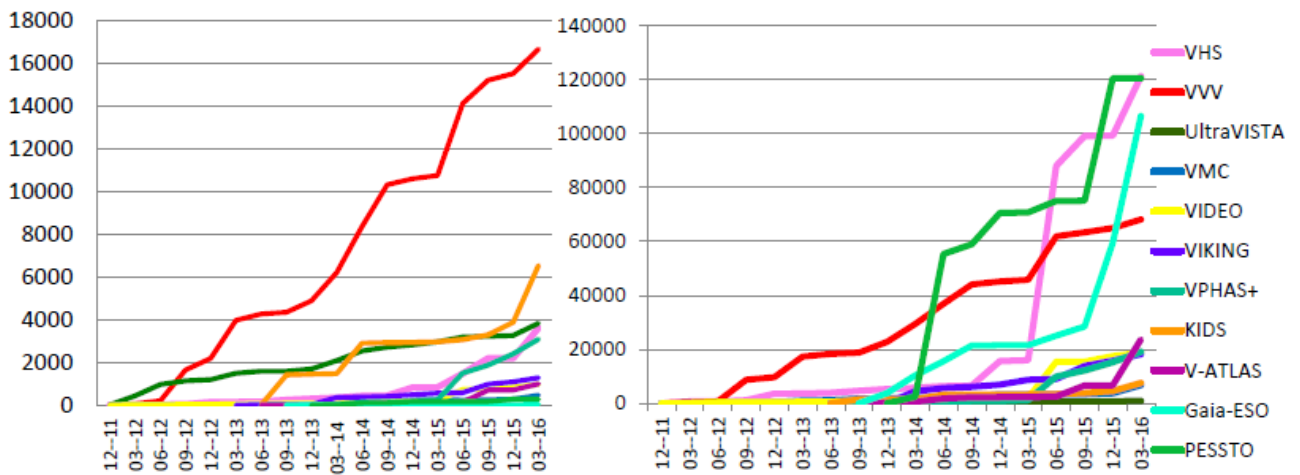


Figure 4. Cumulative curves for volume (Gigabytes, left) and number of files (right) downloads for the ESO Public Surveys, with published Phase 3 releases. The cumulative curve for each survey project includes all science data product types (images, 1D spectra, source lists, catalogues) and the ancillary FITs files (images, two-dimensional spectra) downloaded by the archive users. As the two VIMOS Public Surveys will carry out their first Phase 3 submission the second half of 2016, they do not appear in the plots.

ACKNOWLEDGMENTS

We would like to thank our La Silla Paranal colleagues, for their work and support to the science operations of the ESO Public Surveys. We wish to acknowledge our colleagues from the Department of Engineering for their support in developing the tools required for carrying out Phase 1, Phase 2 and Phase 3 for the ESO Public Surveys, and the ESO library team for the careful monitoring of the refereed publications. Finally, we wish to thank the PIs of the Public Surveys and their collaborators, including the data centers at CASU, WFAU and TERAPIX, for their hard work and support to ESO mission.

REFERENCES

- [1] Sutherland, W. et al. 2015, A&A, 575, 27
- [2] Arnaboldi, M., Capaccioli, M., Mancini, D. et al. 1998, The Messenger, 93, 30
- [3] Capaccioli, M., Schipani, P. 2011, The Messenger, 146, 2
- [4] <http://www.eso.org/public/about-eso/>
- [5] <http://www.eso.org/sci/observing/PublicSurveys/sciencePublicSurveys.html>
- [6] Arnaboldi, M. et al. 2014, The Messenger, 156, 24
- [7] Retzlaff, J. et al. Paper 9910-8, this volume
- [8] Mascetti L. et al. Paper 9910-87, this volume
- [9] Delmotte N. et al. Paper 9910-7, this volume
- [10] Micol, A. et al. Paper 9910-121, this volume
- [11] <http://casu.ast.cam.ac.uk/>
- [12] <http://www.roe.ac.uk/ifa/wfau/>
- [13] <http://terapix.iap.fr/>
- [14] Romaniello M. et al. 2016, The Messenger, 163, 5