Chapter 3
Public Surveys at ESO

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Abstract We provide an overview of the ESO public survey projects being carried out at the ESO survey telescopes, VISTA and VST, on the VLT instruments, UVES, FLAMES and VIMOS, and on the NTT, with SOFI and EFOSC, at the La Silla-Paranal Observatory. We outline the motivations behind these extensive projects, the policies and the facilities supporting these programmes. We illustrate how their data products are validated and published through the ESO Science Archive Facility, in order to make them accessible to the astronomical community. We conclude with an outlook on the future of public surveys at ESO.

3.1 Motivation

Observational astronomy is in an era of surveys. Projects like SDSS, Pan-STARRS, SkyMapper and LSST are characterised by large investments in "survey-systems", which include dedicated telescopes and instruments, a large community of astronomers involved in the science projects and large networks for the data distribution. The goals of these "survey-systems" are to enable new science in a variety of fields and serve broad communities. ESO has a strong background in survey projects ESO/SERC Southern Sky survey (1974–1987), and the EIS survey (1997–2004): this avenue has now received more impetus. ESO currently operates two dedicated survey telescopes, VISTA [5] and VST [1, 3], and organises survey projects that include the use of the available instrumentations at the La Silla-Paranal Observatory. The legacy value and the scientific excellence of the survey program are reviewed periodically during peer reviews organised by 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. Because the ESO public surveys are managed within the framework of the VLT/VLTI science policies (ESO council meeting 104, 17–18

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December 2004), the primary point of publication of the reduced products from the ESO public surveys is the ESO Science Archive Facility (SAF).

3.2 What the ESO Public Surveys Projects Are and What Their Status Is

3.2.1 Public Imaging Surveys

The ESO public surveys projects are very large programmes that require observing time at the telescope that last longer than 2 years. Their observing strategies include pencil beam deep surveys on cosmological fields, to wide area surveys covering from few hundreds to thousands of squared 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 terms of observing modes, for example spectroscopic follow-up of interesting candidates identified via their colors or morphological properties. Important rules that apply to all these projects are that public imaging surveys are carried out in service mode, all raw data become immediately public and the survey teams commit to deliver reduced data, images and catalogues, within yearly release.

We summarize the general observational parameters of the nine imaging surveys, currently being carried out at the survey telescopes, VISTA and VST, in Tables 3.1 and 3.2 respectively. The six VISTA surveys started in April 2010 and have now completed their fifth year of science operations. The three VST public surveys started in October 2011 and are in their fourth year of science operations. A more detailed description of the survey goals of the imaging public surveys is available from the Public Surveys web pages: http://www.eso.org/sci/observing/PublicSurveys.html.

All the nine imaging surveys are either approaching or nearing completion of the initial allocated time defined on the basis of their approved survey management plans. The fraction of completion ranges from more than 80 % (VHS) to 60 % (UltraVISTA), with values in between for the other VISTA imaging surveys. For the VST surveys, the fraction of completeness varies from more than 72 % (ATLAS), 50 % (VPHAS+) and down to 30 % (KIDs). Two of the VISTA surveys (VVV, VIKING) and two of the VST surveys (ATLAS and VPHAS+) will complete the execution of their allocated time by 2017.

Table 3.1 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, 2015 (col.6)

Survey ID	Science topic	Area (deg^2)	Filters	Magnitude limits (mag)	Obs. time (h)
Ultra-VISTA	Deep high-z	1.7 deep	YJ HKs	25.7 25.5 25.1 24.5	1,315
Ultra-VISTA	Deep high-z	0.73 ultra deep	NB118	26.7 26.6 26.1 25.6 26.0	1,315
VHS	Whole sky	17,800	YJ HKs	21.2 21.1 20.6 20.0	3,174
VIDEO	Deep high-z	12	ZYJ HKs	25.7 24.6 24.5 24.0 23.5	1,298
VVV	Galactic MW	560	ZYJ HKs	21.9 21.1 20.2 18.2 18.1	1,815
VIKING	Extragalactic	1,500	ZYJ HKs	23.1 22.3 22.1 21.5 21.2	1,748
VMC	Resolved SFH	180	YJ Ks	21.9 21.4 20.3	1,284

Table 3.2 General observational parameters for the three VST public surveys. The columns illustrates 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, 2015 (col.6)

Survey ID	Science topic	Area (deg^2)	Filters	Magnitude limits (mag)	Obs. time (h)
KIDs	Extragalactic	1,500	u g r I	24.1 24.6 24.4 23.4	1,213
ATLAS	Wide area	4,000	u g r I z	22.0 22.2 22.2 21.3 20.5	1,134
VPHAS+	Stellar astrophysics	2,000	u g H|*alpha* r I z	21.8 22.5 21.6 22.5 21.8	540

3.2.2 Public Spectroscopic Surveys

There are four public spectroscopic surveys being carried out at the ESO facilities now. The first two projects, Gaia ESO and PESSTO, started in January 2012 and are now in their third year of visitor mode operations. Following the call for VIMOS public surveys in 2014, two additional surveys were approved: they are LEGA-C and VANDELS. Their observations started in October 2014. Hence ESO is currently managing 13 Public Surveys on ESO telescopes of the La Silla-Paranal Observatory. Here we describe concisely the science goals of the Public Spectroscopic Surveys. Gaia ESO: this survey targets 100000 stars distributed among the major component of the Milky Way (MW) galaxy and in 100 open clusters. It has a strong synergy with the Gaia survey and will provide the phase space structure and abundances for the stellar population in the MW. Spectra are obtained with FLAMES and FLAMES/UVES spectrographs on VLT UT2. Target selection comes from the imaging surveys VHS, VVV etc. The current allocation entails 240 nights over 4 years, with a possible extension to a fifth year pending a review of the project.

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. Three hundred and sixty nights are allocated to this survey over 4 years at the NTT, with EFOSC2 and SOFI. As for Gaia ESO, this survey may be extended for another year after a successful review.

VANDELS: this 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 CANDELS and CDF South ultra-deep fields. The goals are to measure metallicities and kinematics of the ionized gas in these systems. A total of 914 h are allocated at VIMOS on VLT UT3. The survey is expected to be completed in 4 years.

LEGA-C: this spectroscopic survey with VIMOS targets 3,000 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 1,010 h are allocated to this project with VIMOS on VLT UT3, with expected completion in 4 years. More information on ESO public surveys is available at http://www.eso.org/sci/observing/PublicSurveys.html. Similarly to the imaging surveys, all raw data from the spectroscopic surveys become immediately public and the survey teams commit to deliver reduced data, extracted spectra and catalogues, within yearly release.

3.3 Management of Public Surveys at ESO

Public surveys at ESO are projects executed within the framework of the VLT/VLTI policies for science operations. In this scheme, ESO supports the public survey teams for standard telescope operations (service mode and support for visitor mode observations), the delivery of the raw data, the management of the archive and of the reduced products, plus the organization of the high level peer reviews to monitor the surveys progress and ensure the excellence and coordination of the overall program. The public survey teams are responsible for the definition of the observing strategy, the final quality control of scientific data and for the data reduction. They deliver the reduced data for publication through the ESO SAF (http://archive.eso.org/cms.html). These reduced data are delivered in yearly incremental releases, and a final release including publication of the catalogs is planned at the end of each survey project. Observations for the ESO public surveys are carried out at the survey telescopes, VISTA and VST, at the spectrographs UVES/FLAMES, VIMOS, and at the NTT with SOFI and EFOSC. In Table 3.3 we report technical data and efficiency parameters for survey telescopes at different observatories. VISTA and VST have singularly an "on-average" efficiency, when compared with other wide field telescopes. Together they make ESO the only Observatory that provides wide field capabilities with a wavelength coverage from the UV (0.33 μm) to the Ks band (2.15 μm). The ESO spectrographs supporting the spectroscopic surveys provide multiplexing capabilities over FoV of tens arcmin diameter (FLAMES/VIMOS) to single slits (UVES/EFOSC/SOFI). Spectral resolution ranges from ten thousands

Table 3.3 Survey facilities with their technical parameters (telescope diameter, field of view (FoV), pixel size, wavelength range) and figure of merit (Entendue) for optical and NIR survey telescopes

Facility	Telescope diameter (m)	FoV (deg^2)	Pixel size (arcsec $pixel^{-1}$)	Wavelength range (μm)	Entendue ($m^2\,deg^2$)
SkyMapper	1.4	5.7	0.5	0.32–0.95	6.6
Pan-STARRS1	1.8	9.0	0.3	0.4–1.15	16.3
SDSS	2.5	2.4	0.4	0.33–1.0	6.0
MegaCAM	3.6	1.0	0.2	0.34–0.95	7.6
CTIO(Deacm)	4.0	4.0	0.2	0.6–1.0	16.0
VISTA	4.0	1.65	0.34	0.88–2.15	5.2
SuprimeCAM	8.0	0.25	0.2	0.36–1.0	13.5
VLT HAWKI	8.2	0.016	0.1	1.0–2.2	0.81
VLT VIMOS	8.2	0.06	0.2	0.36–1.0	3.2
LBC LBT	8.4	0.15	0.23	0.32–1.0	8.1
VST	2.6	1.0	0.21	0.33–1.0	5.5
Subaru Hyper-SuprimeCAM	8.0	1.5	0.17	0.36–1.0	94
LSST	8.4	3.5	0.2	0.33–1.1	319

(UVES/FLAMES) to few thousands (VIMOS/EFOSC/SOFI) depending on the science goals, with wavelength coverage from the optical to the near-infrared.

3.4 Legacy Value of ESO Public Survey Projects and Community Engagement

The entire ESO public surveys generate a very large data volume, of the order of 10 TB 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" signifies 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 unit. Thanks to the ESO public surveys, ESO set up a process of preparation, submission, validation and publication of reduced data through the ESO SAF, which is identified as "Phase 3" [2]. 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 refereed to as the "Phase

3 standard". ESO also provides the Phase 3 tools to validate, upload and manage data submissions, the user support to the data providers, and carries out an audit process for the content validation of the released data [4]. The Phase 3 process was launched in 2011 and more than 30 TB of reduced data were ingested and published through the ESO SAF since the last year (2014). The metadata of the reduced products are key information for their publications through the query forms of the ESO SAF 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, like for example the limiting magnitude and the FWHM of the point-spread-function for imaging data, or the signal-to-noise ratio and the spectra resolution for 1D spectra. By adopting the Phase 3 standard, the reduced products from ESO public surveys, but also large programs and ESO-in-house pipeline processed data, can be served co-jointly through the same ESO SAF query form, which is available at http://archive.eso.org/wdb/wdb/adp/phase3_main/form. Since the first data release in December 2011, more than 15 TB and more than half a million files were retrieved from the ESO SAF! In Fig. 3.1 we show the sky coverage of the survey image products available at the ESO SAF and released via the Phase 3 process.

In addition to images and spectra, the ESO SAF published the scientific catalogues at the ESO catalogue query interface (http://www.eso.org/qi/). The catalogues from ESO public surveys come into three flavors: source lists, multi epoch photometry (light curves) and high level catalogues:

1. Source-lists are fits tables containing a list of sources with their photometric parameters in a single band. A source list inherits the metadata information from

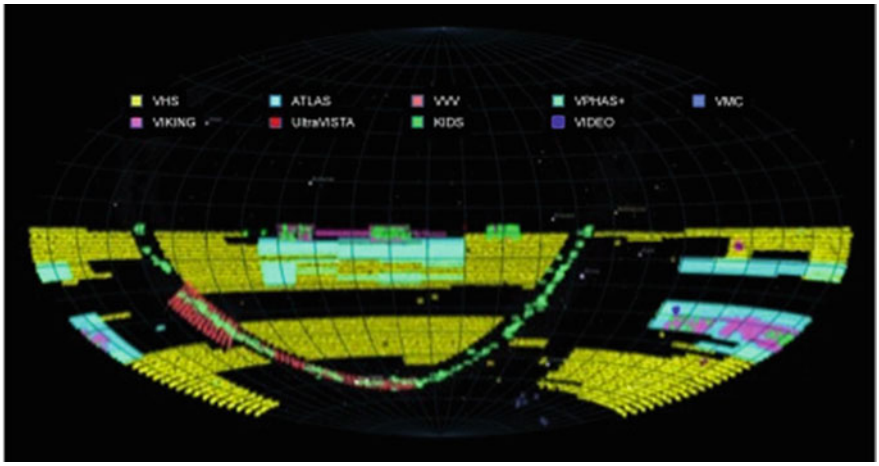

Fig. 3.1 Sky coverage of the ESO public survey products available at the ESO SAF and published through the Phase 3 process – Full sky (Hammer-Aitoff projection). The total area covered amounts to almost 10,000 deg^2 in the Southern Hemisphere. These products included all VISTA and VST data acquired before Oct 1st, 2013

the image it is extracted from and these products are delivered mostly by imaging surveys.
2. The multi epoch photometry or light curves contain the photometric parameters measured at different epochs for all sources.
3. The high-level catalogues contain either the multi-band aperture matched photometric measurements for sources in the whole area or sub-areas of the imaging surveys, or the physical parameters (i.e. EWs, abundances, redshifts, etc.) measured from spectra of individual objects, completed at a given date. One of the attribute that qualifies the science quality of a high-level catalog is the uniqueness of the source identifier. Having unique entries is very important for all those science goals addressing star/galaxy counts, the luminosity functions of stars/galaxies on large areas on the sky and galaxy evolution studies.

Further dissemination of catalog products via the Virtual Observatory is implemented by the on-going collaboration with the Centre de Donnes astronomiquées de Strasbourg (CDS). Such collaboration adds science content to the catalogs from ESO public surveys by cross-matching them with those coming from other projects, like for example X-rays and Gamma-ray experiments.

The community is informed of any new data releases via publication of dedicated announcements on the ESO science newsletter and on the ESO SAF website. The public surveys projects are also advertised by articles published on the Messenger by the ESO survey team and the PIs of the surveys (e.g. the Messenger volume n.154). ESO Press releases are also important channels to advertise the scientific results from the ESO public surveys and their data. The public surveys were the focus of an ESO workshop in 2012; the scientific results of these surveys will be discussed next at the workshop "Rainbows on the Southern Sky: legacy value of ESO Public Surveys and Large Programmes" (http://www.eso.org/sci/meetings/2015/Rainbows2015.html) in October 2015 at the ESO headquarters in Garching. Scientific workshops and the periodic reviews organised by ESO with the public survey panels are important occasions to foster scientific debate and identify the way forward to ensure the continuing scientific excellence of the survey program.

3.5 Future Outlook

The Next-Generation Transit Survey (NGTS) achieved first light at ESO's Paranal Observatory in northern Chile on January 14, 2015. 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. Their data products, in particular the light curves of their most likely candidates, will be ingested through Phase 3 in the ESO SAF and become available to the community. The first data release is expected 2 years after the start of science operations. In

March 2015, ESO published the announcement of a call for new surveys with the Arizona Radio Telescope. These projects will be selected and added to the currently on-going survey program in 2015. The horizon of the public surveys at ESO includes also a new call for imaging surveys with VISTA in 2016, and, on a longer timescale 4MOST (4-m Multi-Object Spectroscopic Telescope) from 2020. 4MOST is a very large field (goal $> 5\,\mathrm{deg}^2$) multi-object spectrograph with up to 3,000 fibres and spectral resolutions of 5,000 and 20,000 for VISTA. The science cases will cover the Gaia follow-up for chemistry and kinematics of the Galaxy and the redshift surveys of targets from the eROSITA X-ray mission. The future of Public Surveys at ESO is bright!

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