Report on the ESO Workshop

Rainbows on the Southern Sky: Science and Legacy Value of the ESO Public Surveys and Large Programmes

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This was the third ESO workshop on the science from Large Programmes and the second on Public Surveys. By design, this workshop covered all areas of research in observational astronomy, providing a forum for the presentation of the most recent scientific results from these programmes and fostering discussions on the planned developments enabled by large and coherent time allocations on ESO telescopes. Several aspects of the legacy value of such programmes – technological, archival content, access to data, time domain and sociological — were evaluated and set a reference for future developments of ESO services to the community.

Introduction: Large Programmes and Public Surveys at ESO

The ESO Large Programmes were introduced in 1996, following the recommendation of a working group nominated by the Observing Programmes Committee (OPC), with the aim of focusing on specific science goals that require large time allocations, typically more than ten nights (100 hours) and/or observations that span up to four observing periods. Since then, about 13 % of the total available science time on ESO telescopes has been allocated to Large Programmes and more than 150 such programmes have been scheduled at the La Silla Paranal Observatory. A Large Programme is selected after a dedicated discussion that involves the whole OPC (in addition to the panels), and these programmes are expected to target scientific projects that are not possible within the regular time allocation and are relevant for a large fraction of the astronomical community.

Since 2010, ESO Public Surveys, on the Visible and Infrared Survey Telescope for Astronomy (VISTA), the VLT Survey Telescope (VST), the Very Large Telescope (VLT) and the New Technology Telescope (NTT), were added to the portfolio of programmes enlarging the observational perspectives available to the community. The Public Surveys lead to an increase in the legacy value of data from ESO telescopes on account of their homogeneity and uniformity for the sky area covered and often include a time-domain component. In 2010 and 2011, the nine imaging Public Surveys started on VISTA and the VST, and were soon followed by the spectroscopic Public Surveys: PESSTO (Public ESO Spectroscopic Survey of Transient Objects) on the NTT; and Gaia-ESO, LEGA-C (Large Early Galaxy Astrophysics Census) and VANDELS (A deep VIMOS survey of the CANDELS Fields), all on the VLT. The raw data from all Public Surveys are immediately public. In addition, these programmes produce science data products, reduced images and spectra, as well as catalogues of astrophysical measurements extracted from the science data. The science data products delivered by the Public Surveys, and published via the ESO Science Archive Facility (SAF), support new ways of conducting research and effectively enlarge the scientific community using ESO services.

ESO regularly organises workshops that present an overview of the scientific advances enabled by the use of its facilities and provide a forum for input by the community on promising new projects and programmes. The assessment of the scientific return from the Large Programmes was the goal of two workshops in 2003 (Wagner & Leibundgut, 2004) and in 2008 (Mathys & Leibundgut, 2009); the presentation of, and the first results from, the imaging Public Surveys were discussed in 2012 (Arnaboldi & Rejkuba, 2012). The first Large Programmes workshop in 2004 included a discussion with the community on surveys, which ultimately led to the establishment of ESO Public Surveys. The 13 ongoing ESO Public Surveys and a representative set of recently completed Large Programmes were now the focus of the workshop referred to as the Rainbows2015 workshop[1] and reported here.

The workshop covered all areas of observational astronomy and the presentations were organised in seven sessions: planets; stars; the Milky Way and Local Group; extragalactic astronomy; galaxy evolution; the high-redshift Universe and cosmology; and the legacy value of Public Surveys and Large Programmes. Keynote speakers provided an overview of the recent advances and open questions when introducing their topic; the overviews were followed by invited talks from the Large Programme and Public Survey principal investigators (PIs) and by additional oral contributions. A concise summary of the content of the workshop is presented.

Legacy of Large Programmes and Public Surveys

The workshop was opened by Bruno Leibundgut, starting with a session on the legacy value of Large Programmes and Public Surveys. The session focused on the interplay between the research topics in observational astronomy and the feedback from the concept of the legacy value of Large Programmes/Surveys. The legacy of an observing programme starts with the curation and archiving of its data and Alex Szalay covered these aspects in his keynote talk on the Sloan Digital Sky Survey (SDSS) projects. As the workshop progressed, it became clear that the legacy can provide a variety of different metrics for the assessment of the success of these projects. Building on well-known parameters, like the number of publications and citations, other measures are the number of public releases, training of young researchers, engagement of the wider population, as, for example, via the citizen science projects such as the Galaxy Zoo, enlarging the network of scientific collaborations, as well as independent archive science and serendipitous discoveries that open new fields. Alex Szalay made the point that the way the science is done in astronomy research is changing. Fast progress is now coming from multiwavelength and time-domain analysis of data, thereby shifting the focus from smaller programmes driven by hypothesis to projects managing terabytes of data. Szalay argued that the equivalent of “microscopes” and “telescopes” for managing large volumes of data are the new instruments that are needed.

Guinevere Kauffmann elucidated very interesting points about some further

changes in how research is being done and emphasised the need to coordinate efforts, transparency and the sharing of data and tools. The contributed talk by Sara Ellison further explored the use of neural networks for data mining of the SDSS archive, while Marc Moniez emphasised the impact of the upcoming Large Synoptic Survey telescope.

Cosmology, galaxy evolution and extragalactic astronomy

The first half of the workshop focused on cosmology, galaxy evolution and extragalactic astronomy. Three keynote speakers introduced the main areas: Richard Ellis (cosmology and the high-redshift Universe), Natascha Foerster-Schreiber (galaxy evolution) and Guinevere Kauffmann (extragalactic astronomy and the local Universe). These fields are rapidly developing thanks to the modern facilities, and even more progress is anticipated from ongoing and future surveys. Many recent advances were enabled by ESO telescopes and featured in the invited talks that covered, among other topics: the search for high-redshift quasars (talk by Bram Venemans); the first objects that reionised the Universe (Laura Pentericci, Bo Milvang-Jensen); surveys of samples of quasars which allow the intergalactic and circumgalactic medium to be probed (talks by Trystyn Berg, Sebastian Lopez, Valentina D’Odorico and Tom Shanks); surveys of galaxies establishing galaxy growth, luminosity function evolution and star formation history across a range of redshifts (Storm Dunlop, Adriano Fontana, Rebecca Bowler and Lidia Tasca); and cosmology constraints from the mapping of the large-scale structure at $z \sim 1$ (Luigi Guzzo). Synergies with upcoming surveys, such as Euclid, were also mentioned.

At lower redshift and in the local Universe, results were presented on dark matter–baryon connections via gravitational lensing (Alastair Edge, Hendrik Hildebrandt and Piero Rosati), on the kinematics of the outer halos of early-type galaxies (Claudia Pulsoni), and the diversity of dusty molecular tori in active galactic nuclei (Klaus Meisenheimer). In general, the focus appears to be shifting from large-area redshift surveys towards the need for high quality, deeper observations targeting the physics of galaxies (Ross McLure and Arjen van der Wel) and cosmology.

Figure 1. Participants of the Rainbows2015 workshop in the entrance hall of ESO Headquarters.

Dissecting galaxies into stars, planets and … black holes

The Milky Way, the Local Group and the physics of stars and planets were covered during the central part of the workshop. Hans-Walter Rix reviewed the composition and dynamics of the Milky Way disc around the Solar Neighbourhood and to large radii. Maurizio Salaris described the recent advances and challenges in stellar astrophysics: he pointed out that specific details of the models have large uncertainties and their predictions can only be constrained by observations. The surveys of the Milky Way (Vista Variables in the *Via Láctea* [VVV], the VST Photometric Hα Survey [VPHAS+] and Gaia–ESO) are providing large samples that enable star formation (Philipp Lucas), stellar evolution and Galactic chemical evolution (Rodolfo Smiljanic) to be addressed, in addition to providing a first complete view of the Milky Way Bulge (Dante Minniti, Manuela Zoccali, Chris Wegg and Matthieu Portail), and Disc (Sofia Randich, Boris Gaensicke). Variable stars were investigated as distance indicators (Wolfgang Gieren), as well as population tracers in the Milky Way (Dante Minniti) and its satellites — the Magellanic Clouds (Vincenzo Ripepi). The search for the most metal-poor stars in the halo (Piercarlo Bonifacio), the chemical enrichment of ultra-faint dwarf spheroidal galaxies (Georges Kordopatis), and the census of circumstellar discs in nearby star-forming regions (Giacomo Beccari) were also covered. Mariya Lyubenova presented a new stellar spectral library, based on X-shooter observations.

Reinhard Genzel presented the results from the Galactic Centre Legacy Programme. This is actually a series of many programmes that together comprise a long-term coherent monitoring experiment, which has unambiguously established that there is a Schwarzschild–Kerr black hole at the centre of the Milky Way, if general relativity is applicable. This programme continues to test the physical processes in the vicinity of the Milky Way black hole and will enter a new phase in the coming years when the star S2 will again pass very close to the black hole, in 2018. Several instruments will measure this event, including the newest addition to the Paranal suite, aptly called GRAVITY.

The last session of the workshop covered time domain astrophysics, such as supernovae (Stephen Smartt, Stefano

Benetti and Cosimo Inserra) as well as proper motion and parallaxes (Radostin Kurtev), and ending with a review of results on the characterisation and formation of planets. Didier Queloz gave an exciting overview of the field, highlighting how far we have come from the first discoveries of planets around other stars, to the physical characterisation of the most extreme planetary systems. The High Accuracy Radial velocity Planet Searcher (HARPS) on the ESO 3.6-metre is leading this field and has provided a census of the super-Earth and Neptune-mass planet population around Solar-type stars (Francisco Pepe), while the VLT Interferometer provides exquisite resolution to zoom into the early stages of planet formation and protoplanetary disc physics (Jean-Philippe Berger).

Closing the loop: Legacy of Large Programmes/Public Surveys and archives

The closing session returned to data archiving and access as one aspect of the contribution to the legacy value of Large Programmes and Public Surveys. The SAF is the collection point for Large Programme and Public Survey products and the primary point of publication/availability of these products to the ESO community as laid down by ESO Council resolution #104 from 17–18 December 2004. Phase 3 — the process of preparation, validation and ingestion of science data products for storage in the SAF, and subsequent data publication to the scientific community (Arnaboldi et al., 2014) — ensures the coherent legacy and data return via the ESO SAF.

Following the publication of the first data release from ESO Public Surveys in December 2011, the survey science data products in the ESO SAF cover more than 11 500 square degrees (Optical/near-infrared: 4336 / 9445 square degrees) with more than 35 TB of data consisting of 2.7×10^5 files, with more than 2.6×10^6 spectra (Jörg Retzlaff). The data releases from ESO Public Surveys include high-level science catalogues. Statistics on the data access and download from the SAF were shown, including the cumulative number of archive users of these products, amounting to twice the number of PIs and Co-Is listed in the ESO Public Survey teams. Currently archive papers contribute about 25 % to the total number of refereed papers from ESO facilities each year.

The support to the community is further enhanced by the availability of science data products from the science archives at the Wide Field Astronomy Unit at the Institute for Astronomy, University of Edinburgh (Nicholas Cross) which provides extensive programmatic access via SQL queries to their data assets. The requirements on survey project design that must include not only new instrumentation, but also dedicated services for data processing, storage, effective publication and retrieval, was highlighted in the case of the next generation spectroscopic surveys planned for the 4-Metre Multi-Object Spectroscopic Telescope (4MOST; talk by Eduardo Gonzalez-Solares).

Clearly the wealth of data available through Public Surveys and Large Programmes transforms our view of the Universe into an *N*-dimensional space where correlations and information can be mined, and extracted to test and formulate new theories. On account of the web and fast-evolving archive tools, a large pool of users can now share the scientific method and join the astronomical community. Diversity, openness, curiosity and the unexpected are concepts that can change our way of doing astronomical research, and become attributes of what is meant by "legacy value".

Concluding remarks

Scientific discoveries are driven by strongly motivated, highly interested individuals supported by leading-edge technology developments. The community shares these discoveries and benefits via technology advances in archiving and data transfer. At the workshop we celebrated the achievements of the successful PIs and their teams who pursue important questions in observational astrophysics with ESO facilities.

The large variety of programmes and progress in different science fields generated a vibrant atmosphere and led to vigorous discussions during lunches and coffee breaks. The programme was dense and diverse, with many excellent presentations. The talks from the Rainbow2015 workshops can be found on the workshop page[1]. The photograph of the workshop participants is shown in Figure 1.

Several sociological aspects distinguished this workshop from those in the past:

- A number of Large Programme/Public Survey PIs could not attend the workshop and delegated the invited talks to younger members of their teams. Hence there was a healthy attendance by young astronomers presenting the results from the large team efforts — a new generation of European scientists is clearly taking up a more prominent role.
- The selection of Large Programme presentations invited by the Scientific Organising Committee triggered some healthy responses from the Large Programmes community. In addition to the inevitably limited selection of invited talks, several other Large Programme teams submitted requests for a contributed talk and participated in the scientific discussions.
- There was a strong representation of the Public Survey panels (Joint VISTA/VST and the Spectroscopic panel) and their members took part in the discussions and interacted with the PIs of the Public Surveys.
- Surveys and Large Programmes empower the wider community to discover the Universe. In this sense they are the effective implementation of the IAU statement "The Universe: yours to discover".

References

Arnaboldi, M. & Rejkuba, M. 2012, The Messenger, 150, 67

Arnaboldi, M. et al. 2014, The Messenger, 156, 24

Mathys, G. & Leibundgut, B. 2009, The Messenger, 135, 53

Wagner, S. & Leibundgut, B. 2004, The Messenger, 115, 41

Links

[1] Workshop programme: http://www.eso.org/sci/meetings/2015/Rainbows2015/program.html