The ESO Public Imaging Survey

A. RENZINI and L. DA COSTA, ESO

1. Background

In the era of 4-m-class telescopes it was common to select targets and/or prepare observations using deep Schmidt plates for which full sky coverage was available down to *m* ~ 23. Now, in the blossoming era of 8-m-class telescopes one needs much deeper survey data to feed high-throughput, high-multiplex spectrographs able to reach at least two magnitudes deeper, or to find relatively rare objects such as clusters of galaxies, brown dwarfs, or trans-neptunian objects (for an extensive list of such potential targets see Renzini 1998, *The Messenger*, 91, 4). To a large extent, the scientific outcome of an 8-m-class telescope critically depends on the availability of preparatory imaging surveys, and the demand for deep and wide surveys will intensify as other large-aperture telescopes become operational world-wide and the competition becomes more and more fierce.

CCD and computer technology have evolved at a rapid pace over the last two decades, and multi-colour, digital imaging surveys of appropriate area and depth are within reach. Even though there are a number of ongoing optical/infrared digital all-sky surveys (DENIS, SDSS, 2MASS), none of them are particularly suitable for feeding targets for large telescopes (for most possible targets they are not deep enough) nor will they be publicly available in the near future. Surveys more suitable to large telescopes are being conducted at several observatories (e.g., CFHT, CTIO, La Palma, Kitt Peak) with the products becoming public within their respective communities. Groups with specific science goals are also conducting ambitious surveys, but again these data are unlikely to become accessible to general ESO users in a short-time scale.

To meet this challenge, in 1996, ESO took the initiative of proposing to carry out a public survey to fulfill at least some of the short-term needs of the ESO community in view of the first scientific runs of the VLT. Without hampering the possibility of groups to conduct their own surveys, a public survey offers a number of advantages. In particular, data can be used for a broad range of scientific applications, thus resulting in a substantial saving of telescope time (that can be as high as a factor of 10!), compared to the case in which each individual science group has to secure its own survey data. Moreover, public survey data can be easily complemented by "privately" acquired data for specific applications, such as in the case of second-epoch or narrow-band filter observations.

A Working Group (WG) was therefore appointed in 1996 to design the survey and to supervise the work of the Survey Team charged to carry out the observations, data reduction and distribution of survey products. Both the WG and the Survey Team were assembled from the community itself, with ESO providing the coordination and the required facilities and resources.

The main objectives of the resulting ESO Imaging Survey (EIS) were to conduct a public optical-IR imaging survey at the NTT, to reduce the data, construct object catalogues, and select from them special classes of objects of potential interest for VLT programmes. All this within a short time scale, before the start of operation of the first Unit Telescope of the VLT. In addition, EIS was seen as a first step towards developing an appropriate environment for carrying out future surveys, public as well as private. Indeed, the software tools developed by the programme were regarded as an integral part of the survey products, to be disseminated throughout the ESO community to facilitate the reduction and analysis of wide-area imaging data. The dissemination of such tools was seen as essential for the community to take full advantage of dedicated imaging telescopes such as the MPG/ESO 2.2-m telescope, now already in operation, and the VLT Survey Telescope (VST, Arnaboldi et al. 1998, *The Messenger*, 93, 30) to be installed on Paranal.

2. The EIS Project and the WFI Pilot Survey

In practice, to combine as far as possible wide-area coverage and depth, EIS consisted of two complementary projects: EIS-WIDE and EIS-DEEP. The goal of EIS-WIDE was to cover with EMMI@NTT four patches in the sky, 6 square degrees each, providing *V* and *I* data to a limiting magnitude of V_{AB} ~ 24.5 and I_{AB} ~ 24. This part of the survey was optimised to detect candidate clusters of galaxies at moderate to high redshift ($z \lesssim 1$). A ~ 2-square-degree fraction of one of the patches was also to be observed in U and B to allow for the identification of QSOs, metal-poor stars, etc.

The goals of EIS-DEEP were to cover with SUSI2 and SOFI three adjacent pointings in the Hubble Deep Field South including the fields covered by the various HST cameras, and four adjacent pointings in the AXAF deep field. In both cases the multicolour *UBVRIJHK* data should have been deep enough to provide accurate photometric redshifts and to select Lyman-break galaxies. In practice, this required limiting magnitudes in the range 26–27 in the optical passbands and 23–24 in the infrared.

The one-year period (July 1997–July 1998) available to achieve the primary goals of EIS-WIDE represented a formidable task, as no consolidated experience existed at ESO or in the community. Apart from the limitations due to the weather, the goals were only met thanks to the enthusiastic response of many scientists from the community who brought their specific experience to ESO and to the resources made available at ESO to support the temporary relocation of these scientists. The contribution of ESO and ECF staff was also critical for several aspects of data processing, archiving, and distribution.

With the advent of the Wide Field Imager (WFI) at the 2.2-m telescope (Baade et al 1999, The Messenger, 95, 15) a "WFI Pilot Survey" was designed by the WG and recommended by the OPC to be conducted by the EIS Team. The scientific goal of the Pilot Survey was essentially to complete that part of the EIS-WIDE project that could not be done due to bad weather during the allocated nights (it is worth recalling the impact of El Niño in 1997–98). The "pilot" designation was meant to reflect the development period required for the major upgrade of the survey software to enable it to pass from one-CCD (EMMI) or two-CCD camera data to the eight 2k × 4k CCDs of WFI.

The companion article by da Costa et al. in this issue of The Messenger describes in some detail what was achieved by these surveys, with emphasis on the survey products. All the data from EIS-WIDE, EIS-DEEP and the WFI Pilot Survey were delivered to the community in due time. Over the last three Calls for Proposals (P63–P65), over 100 proposals for four different Panels, were based on the EIS data, or referred to EIS. Follow-up observations were conducted using ESO telescopes as well as other facilities to prune samples in preparation of VLT proposals. Targets selected from the EIS data were also used during Science Verification of UT1/Antu as well as of FORS1 Commissioning and Science Verification.

3. The Public Survey, Period 64 to 67

The usefulness of Public Surveys in support of VLT programmes being generally recognised, the WG at its meeting in September 1998 recommended ESO to issue a "Call for Ideas" for future public surveys to be conducted with the 2.2-m and NTT telescopes (The Messenger 94, 31). The resulting "ideas" were discussed in depth by the WG in March 1999, and two optimised proposals emerged. A small short-term proposal to complete the EIS-WIDE survey reaching the goals as originally stated, and a two-year Public Survey programme. The latter consists of three parts: (1) a deep multi-band (UBVRI) optical survey with the WFI over three fields of one square degree each; (2) a deep near IR survey with SOFI, covering two 450 square arcmin fields selected within the area observed in the optical; and (3) a shallower set of WFI observations in *V* and *I* of selected stellar fields in preparation for FLAMES at UT2/Kueyen (hereafter the "Pre-FLAMES Survey").

The selected fields for the deep optical/IR survey (hereafter Deep Public Survey, DPS) are given in Table 1. The main scientific drivers for this part of the Public Survey are the search for high-redshift objects: galaxies (e.g. Lyman-break galaxies), clusters and QSOs, as well as the possibility to derive photometric redshifts from such a large, homogeneous, multicolour database. The goals and requirements in terms of limiting magnitudes are similar to those of EIS-DEEP described above except that DPS is meant to cover a much larger area. The same database will also provide a unique and urgently needed tool for studies of Galactic structure and stellar populations. The DPS is therefore designed to provide targets for several of the first-generation VLT instruments, with emphasis on FORS1 and FORS2, ISAAC, UVES, VIMOS, and NIRMOS.

On the other hand, the Pre-FLAMES Survey is of crucial importance for stellar astronomy studies with the FLAMES System on UT2/Kueyen, where the OzPoz fibre positioner can pick up ~ 130 targets over a field of 25 diameter (well matched by the field of view of WFI) and feed the MEDUSA mode of GIRAFFE. Alternatively, 8 fibres from OzPoz could send the light of as many targets to UVES, over to the other Nasmyth platform of the same telescope (see Renzini 1999, *The Messenger*, 96, 13). The accuracy of fibre positioning, which requires accurate target coordinates to start with, is critical. Existing stellar catalogues fail to give the information that is necessary to operate FLAMES, i.e., coordinates with the required astrometric accuracy $\lesssim 0\farcs1$ rms) combined with multicolour information. The tentatively selected fields for the Pre-FLAMES Survey are listed on the EIS web pages. Interested scientists are welcome to give suggestions to complement and/or improve the list.

The Public Survey proposal was submitted as a Large Programme in response to the Call for Proposals for Period 64, applying for a total of 81 nights: for the DPS 54 nights at the 2.2-m telescope and 15 nights at NTT for its IR part, plus 12 nights at the 2.2-m telescope for the Pre-FLAMES Survey. This Large Programme was proposed for a two-year period, hence being distributed over ESO Periods 64 through 67. Details of the Public Survey, including the original proposal, can be found at http://http.hq.eso.org/science/eis/public-surveys/

This Public Survey "large proposal" was approved and recommended by the OPC, and 18 nights with WFI@2.2 and 8 nights with SOFI@NTT have been scheduled in Period 64. To increase the participation of the community in the Public Survey, an Announcement of Opportunity was also issued for groups in the community to carry out the observations and data reduction of the infrared part of the DPS, following the same guidelines of the EIS Team. Following an examination of the proposals, the WG has already selected the Team that will be in charge of this part of the survey (PI H. Jørgensen, Copenhagen).

The Public Survey in periods 64–67 will provide the ESO community with a competitive edge in the realm of the high-redshift universe as well as in stellar studies. Furthermore, it will allow the continuation of the development effort of EIS that will guarantee a smooth transition between the WFI@2.2 and the VST that will be equipped with ΩCam, four times larger than WFI in both field of view and number of pixels.

Table 1: Deep Public Survey Selected Fields.

Field	α(J2000.0)	δ(J2000.0)
Deep 1	22 43 00	–39 58 00
Deep 2	03 32 28	–27 48 00
Deep 3	11 22 00	–21 35 00

4. The Public Survey Products and Distribution

Among the many requirements of a Public Survey, the most important is perhaps that the data products be easily retrievable by external users. While this may seem trivial, practice has shown that it is not always simple to reconcile the needs of different users – with the implied large variety and size of the products – with other practical constraints such as efficiency and resources. In addition, data from ground-based optical observations are subject to atmospheric conditions and thus require more information to be properly characterised, relative to radio or space-based data.

The EIS/Pilot Survey project made available four kinds of data products: astrometrically and photometrically calibrated images, filtered and verified object catalogues drawn from single-colour coadded frames, derived catalogues such as colour catalogues, and target lists. Each release was also accompanied by papers describing the observations, data reduction, the different types of catalogues available and the target lists produced. The object catalogues were also essential to validate the data by computing simple statistics such as the number counts of stars and galaxies, colour-colour diagrams for point-sources and the two-point angular correlation function for galaxies. This allowed the photometric zero-points, star/galaxy classification, and uniformity of the data to be tested.

The primary reason for adopting this data release model was the strong desire to have verified data publicly available in the shortest possible time to meet the stringent deadlines imposed by the imminent start of the VLT regular operations, which began with the submission of the proposals for Period 63 (deadline October 1, 1998). However, this model is not the most suitable for long-term projects such as the Public Survey described in the previous section. The time baseline for the completion of the project is much longer, and intermediate products may be valuable for different applications. While it is obviously highly desirable to cut to the minimum the time lag between the collection of the survey data and the VLT follow-up, the sheer volume of the data expected from WFI@2.2m requires more time for detailed verification of the data products. In addition, users may have their own ideas on how to best extract catalogues for their specific scientific purposes, while final results for a given sky area can only be produced after all the observations are completed.

One solution to accommodate these various constraints is to provide both a prompt release, soon after an observation run is completed, and a more complete release on a time table synchronised with the ESO observing periods. In this framework one provides rapid access to reduced – but still unverified – data, thus allowing users to extract objects directly from the images. Meanwhile, the Survey Team will work to prepare complete and fully verified data releases. The aim is to strike a balance both between the needs of the community and the operational requirements, and between speed and quality. Following this approach, the distribution of data accumulated from the Public Survey will consist of prompt and final releases, which will occur on different time scales, as described below.

4.1. Prompt releases

The prompt releases will consist of products that are generated directly by the EIS-WFI pipeline. These will provide the opportunity for users to have a "quick-look" at the data soon after they have been acquired. These releases will consist of:

• Astrometrically and photometrically calibrated coadded images of dithered, single-pointing exposures and associated weight maps. The astrometric and photometric accuracy shall be better than 0.″05 and 0.1 mag,

• Catalogues of objects extracted from these images using SExtractor, in the form of FITS binary tables.

Such releases are expected to start as soon as the ongoing work of upgrading the EIS-WFI pipeline is completed and the new version properly tested, which should occur by the end of 1999.

These data together with SExtractor, LDAC and Drizzle softwares, which are publicly available and can be retrieved from the EIS home page, or directly from their respective authors, will enable users to work in parallel to the Survey Team, starting from the same basic data and at the same time. Users will, therefore, be able to evaluate the data and prepare, if they so desire, their own customised catalogues without having to rely solely on those derived by the Survey Team. Moreover, new tools are in the process of being installed which will further enhance the scope of work that can be done outside ESO without the need for distributing large amounts of raw or processed data.

4.2. Complete releases

Complementing these prompt releases, complete releases of verified data including all the data accumulated during all previous observing periods will occur every 6 months, namely on February 15 for odd periods and August 15 for even periods. These will include not only images but also a host of derived products which require more time for their proper preparation and verification. These releases will include:

• Tools to allow the extraction of image sections (cut-outs) from image mosaics and associated weight maps

• Co-added, mosaiced images of individual patches and associated weight maps

• Colour catalogues for multi-passband observations

with all image products being photometrically and astrometrically calibrated as specified above.

Each release will be followed by an update of the web and will be accompanied by papers prepared by the Survey Team. These papers are an integral part of the data distribution as they describe in detail the observations, the quality of the data, the data reduction and verification procedures, and the description of the content of the derived catalogues and of the methodology used in their preparation. These papers are also important as a reference, thereby recognising the commitment of ESO in producing the data and in making them available to the ESO community. While no direct scientific exploitation of the data will be done in these papers, they would still represent a reasonable reward for the members of the Survey Team for their effort in conducting such a survey of public utility.

5. Data Distribution Logistics

A daunting task for public wide-field imaging surveys is finding the ways and means of exporting the data to outside users. To give an indication of the scale of the problem it suffices to mention that the Pilot Survey alone has produced over 0.5 Terrabytes of data in roughly 11 nights of WFI observing, while 66 nights have been assigned for the Public Survey at the WFI@2.2. Even after co-addition of all dithered images, a single-passband 6-square-degree mosaic consists of 6.5 Gigabytes, and a complete data set for the recently observed EIS patches (combining data from EMMI and WFI) comprises 64 Gb of images and weight maps, and 32 Gb of context maps. The stellar fields comprise another 63 Gb of images. Therefore, with the presently available technology it is unrealistic to consider the distribution of pixel maps for an undetermined number of requests. To make the distribution possible, with the resources currently available at ESO for this task, a certain number of constraints are unavoidable. The distribution of bulk data must be limited to well-defined packages of reduced data, produced semi-automatically; distribution of large volumes of data must be limited to certain media, e.g. DLT model 7000 which store 35 Gb and are produced in about 2 hours (5 Mb/s). Large volumes of data cannot be requested by a simple click on the web page, but will have to be requested by submitting a statement of purpose which should include a scientific justification and demonstrate that resources are available at the home institute to handle the requested amount of data.

Note that even a single WFI frame (267 Mb) cannot be transferred by FTP in a reasonable time, under normal conditions. Major improvements will have to await the development of new storage media and of broadband technology. This also raises the issue of how rapidly and widely new storage media become available throughout European institutes. By now it should be clear that the rate at which images can currently be disseminated lags far behind the rate at which they are acquired.

In order to overcome this problem, the community is urged to consider using compressed images, which can lead to a significant reduction (as much as a factor of 500) in the size of the images. However, such compression schemes inevitably involve some loss of information and the scientific value of the resulting products depends on the specific application. Experiments conducted by the Survey Team indicate that for astrometric applications very little is lost, even for very large compression factors. In fact, the loss in accuracy is $\lesssim$ 0.5 of pixel size, comparable to the estimated internal error of the astrometric solution. Examples of compressed images have been made available in the most recent data release. With the advent of the WFI it seems that the combination of compressed images for large fields and full resolution cut-outs for small regions should be seriously considered.

In summary, to a large extent the scope of the Survey Team work and the range of data products have been dictated by the recognition of the difficulties in exporting full-resolution images, as resulting from the direct experience with the EIS project, and the expected trend with the WFI@2.2 and the ΩCam at the VLT Survey Telescope. One needs to efficiently translate terabytes of imaging data into megabytes of useful information in the form of the various data products made available by the Survey Team (single and multi-band object catalogues, target lists, cut-outs, postage stamps). In this context it is important to emphasise once more that the primary goal of the ESO public surveys has been to support VLT observations and not to be an end in itself.

6. Future Plans

The Survey Team and the ESO Archive Group continue to explore other ways to provide external users with more flexibility in their use of the survey data. In the short term it will be possible to use the SKYCAT interface to run SExtractor on image cut-outs extracted from WFI mosaics, of sufficient size ($12' \times 12'$) to include the field-of-view of the FORSes and of individual VIMOS and NIRMOS cameras, regardless of their respective orientations on the sky. In the long term, efforts will be made to implement an object-oriented database which will allow users to fully explore the multi-dimensional position, magnitude and colour space defined by the objects extracted from the imaging surveys. The development of such a database, where astronomical objects extracted from survey data can be stored, updated and associated with all the information available from internal and external sources, and of tools for searching special categories of objects is an essential element for the efficient use of public survey data, as well as of all other imaging data that will also become publicly available after the proprietary period.

7. Conclusion

Besides the data, arguably one of the most important contributions of the EIS project has been to foster a collaboration between different European groups to develop a comprehensive imaging data analysis pipeline for the timely and full exploitation of the data that will become available from wide-field imagers. EIS has both benefited from and contributed to this ongoing effort, by capitalising on the available expertise and by providing data and a realistic framework and time-table to test concepts, designs and implementations of pipelines, database architecture and data archiving and distribution schemes. Since the first feasibility study carried out in 1995, over 30 people have contributed to the EIS effort among EIS visitors, WG members and ESO staff and fellows.

EIS has also provided a stimulating environment for the introduction of students to modern techniques of data reduction and analysis and the means to disseminate their experience throughout the community. This has been achieved by the EIS Visitor Programme which has sponsored long-term visits, ranging from 6 months to over 2 years, of 15 people over the past two years as well as short-term visits of leading experts acting as consultants. While about half of the long-term visitors have already returned to their home institutes, a large fraction continues to contribute to EIS in different ways.

As stated over two years ago, EIS was conceived as an experimental project not only to provide targets for the first year of VLT (see da Costa et al. in this issue of *The Messenger*) but also to explore the feasibility of conducting public surveys using dedicated wide-field imaging telescopes. Indeed, with its 9×9 arcmin field of view, EMMI@NTT was far from being the ideal instrument for wide area surveys. Yet, without the experience gained with EIS it would now be much more difficult to efficiently deal with the WFI@2.2 data, and in the medium term perspective with the almost 10 times larger data flow from the ΩCam@VST. EIS has served to prototype and build a framework for this type of long-range programme, essential for the whole ESO community to benefit from such telescopes, and to do so to the largest possible extent independently of the effective resources available at the individual institutes.

The new policy outlined here is meant to bring the data promptly to the users, while allowing the Survey Team more time to deliver the final products. Budget constraints obviously limit the size of the Survey Team, which cannot grow at the same pace as the data flow. Hopefully, this new model will stimulate new uses and checks of the data. Experience has shown that, regardless of the care taken, handling large volumes of data is a difficult task and only by the exhaustive use of the data in different applications can problems be detected. Therefore, the participation and the feedback from the users is essential to ensure the quality of the data. Users are also encouraged to periodically visit the EIS home page to monitor any new version of the various releases, and report any possible error.

8. Acknowledgements

We would like to thank the EIS Team and the ESO Archive Group for their continuing efforts to explore ways of improving the accessibility of the data by external users, as well as the NTT and 2.2-m Telescope Teams for their cooperation.

E-mail: arenzini@eso.org

ESO IMAGING SURVEY: Past Activities and Future Prospects

L. DA COSTA[1], S. ARNOUTS[1], C. BENOIST[1], E. DEUL[1,2], R. HOOK[3], Y. -S. KIM[1], M. NONINO[1,4], E. PANCINO[1,5], R. RENGELINK[1,2], R. SLIJKHUIS[1], A. WICENEC[1], S. ZAGGIA[1]

[1]*European Southern Observatory, Garching b. München, Germany*
[2]*Leiden Observatory, Leiden, The Netherlands*
[3]*Space Telescope – European Coordinating Facility, Garching b. München, Germany*
[4]*Osservatorio Astronomico di Trieste, Italy*
[5]*Dipartimento di Astronomia, Universtà di Padova, Italy*

1. Introduction

The ESO Imaging Survey (EIS) project is an ongoing effort to carry out public imaging surveys in support of VLT programmes. Background information on the original and future goals of the programme can be found in Renzini & da Costa (1997) and in a companion article by Renzini & da Costa in this issue of *The Messenger*.

The first phase of the project, which started in July 1997, consisted of a moderately deep, large-area survey (EIS-WIDE) and a deep optical/infrared survey (EIS-DEEP), with the observations being conducted at the NTT. EIS has recently reached another milestone with the completion of a Pilot Survey using the Wide-Field Imager (WFI) mounted on the MPG/ESO 2.2-m telescope at La Silla.

The purpose of this contribution is to briefly review the results of the original EIS and to give an update of the results obtained from the observations carried out as part of the Pilot Survey. The ongoing work to develop an advanced pipeline for handling data from large CCD mosaics and of facilities to make access to the data products easier to external users are also discussed.

2. EIS-WIDE

This part of the survey consisted of a mosaic of overlapping EMMI-NTT frames (9×9 arcmin) with each position on the sky being sampled twice for a total integration time of 300 sec. The observations were carried out in the period July 97–March 98 and covered four patches of the sky south of $\delta = -20°$ and in the right ascension range $22^h < \alpha < 10^h$, thus producing targets suitable for the VLT almost year-round. The locations of these fields are shown in Figure 1 and their approximate centres are given in Table 1, which also lists the area covered in each passband. The typical depth of the survey, as measured from the co-added mosaics and with the magnitudes expressed in the AB system, is given in Table 2 which lists: in column (1) the passband; in column (2) the median seeing; in column (3) the 1σ limiting isophote; in column (4) the 80% completeness magnitude (e.g., Nonino et al. 1999); in