The ESO Imaging Survey: Status Report and Preliminary Results

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1. Introduction

The ESO Imaging Survey (EIS) presented in earlier issues of *The Messenger* [7, 2], and with up-to-date information on the ongoing observations available on the web (http://www.eso.org/eis), is a concerted effort by ESO and the Member State community to provide targets for the first year of operation of the VLT. It consists of two parts: a relatively wide-angle survey (EIS-WIDE) to cover four pre-selected patches of sky, 6 square degrees each, spread in right ascension to search for distant clusters and quasars and a deep, multicolour survey in four optical (SUSI-2) and two infrared bands (SOFI) covering the HST/Hubble Deep Field South (HDFS) and its flanking fields (EIS-DEEP). From the start, the main challenge has been to carry out a public survey in a limited amount of time requiring observations, software development and data reduction with the goal of distributing the survey data products before the call for proposals for the VLT. To cope with this one-year timetable, a novel type of collaboration between ESO and the community has been established which has allowed EIS to combine the scientific and technical expertise of the community with in-house know-how and infrastructure. In spite of adverse weather conditions in some of the earlier runs, EIS has already proved to be a successful experiment achieving most of its scientific technical goals, thereby laying the ground work for future imaging surveys.

2. Observations

Observations for EIS-WIDE are being carried out with EMMI on the NTT. They started July 1997, and so far 36 out of 42.5 half and full-nights (360 hours) have been used, with data being accumulated in four patches over eight runs. All observing runs have been carried out, in standard visitor mode, by members of the EIS team. In contrast to most earlier work, the EIS mosaic consists of frames with significant overlaps (a quarter of an EMMI frame). The easiest way of visualising the geometry of the EIS mosaic is to picture two independent sets of frames, each forming a contiguous grid (normally referred to as odd and even), superposed and shifted in right ascension and declination by half the length of an EMMI frame. In this way, each position on the sky, except at the edges of the patch, is sampled by at least two independent frames for a total integration time of 300 sec. To ensure continuous coverage, adjacent odd/even frames have a small overlap at the edges (∼ 20 arcsec). Therefore, a small fraction of the surveyed area is covered by more than two frames. Such a mosaic ensures good astrometry, relative pho-

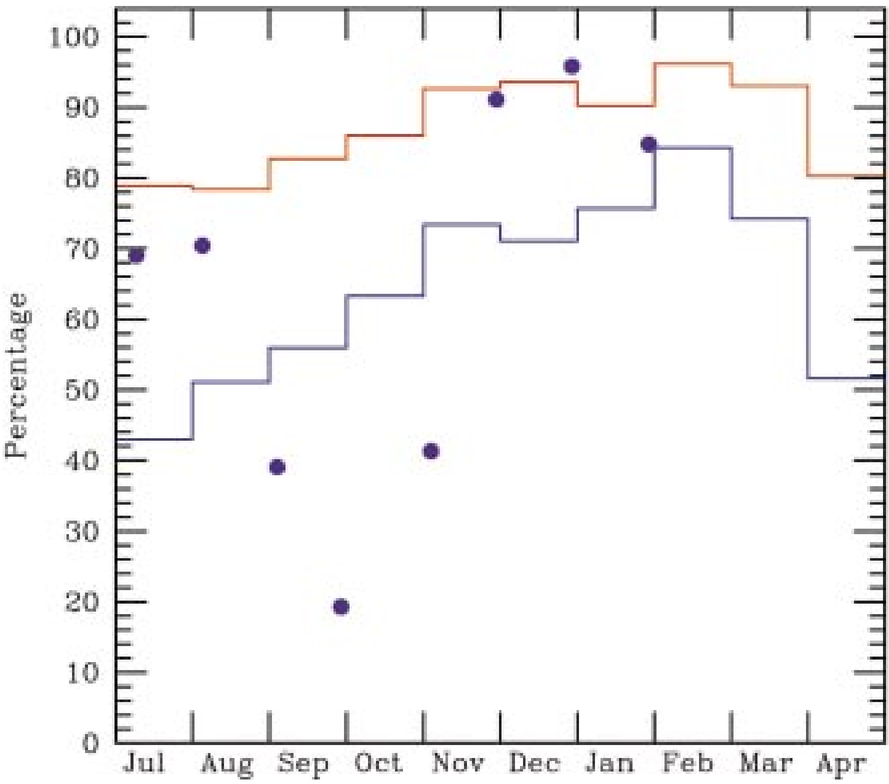

Figure 1: Fraction of allocated time used for observations (filled circles) as a function of EIS run in the period July 1997 to January 1998, compared to the average (over the past five years) number of clear nights (upper line) and photometric nights (lower line) per month at La Silla. Note that runs 1 and 2 were half-nights.

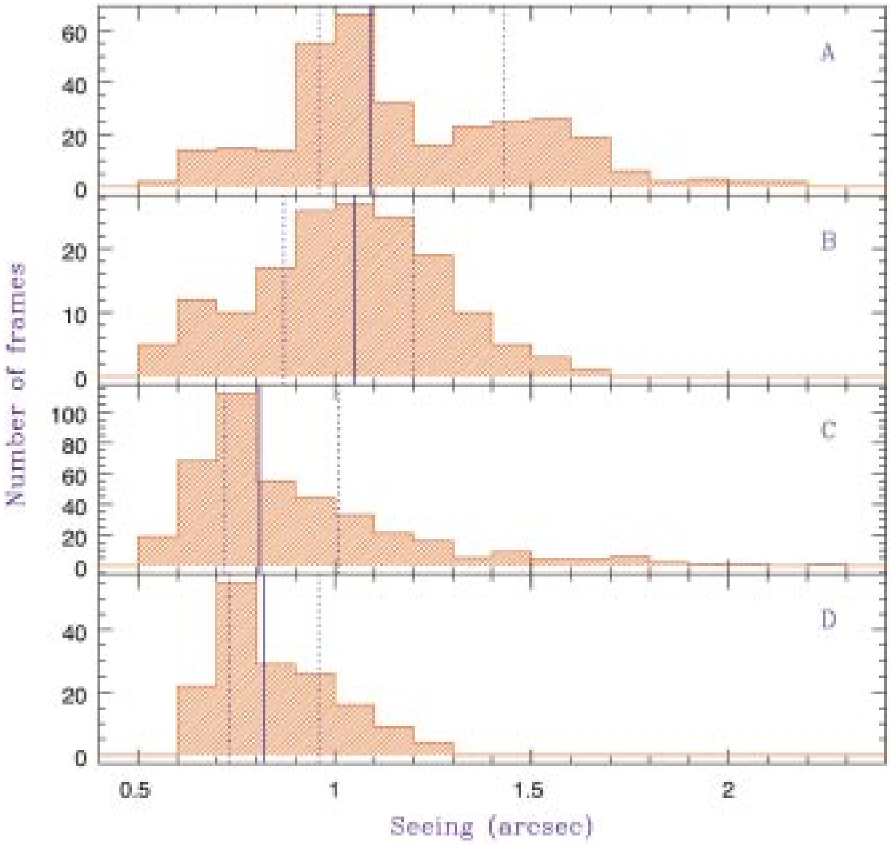

Figure 2: Seeing distribution, as measured from the I-band images in all four EIS patches. The large-seeing tail in the distribution of patch A are frames for which no new observations were possible due to the lack of time.

tometry and the satisfactory removal of cosmic hits and other artefacts.

EIS was one of the first programmes to use the upgraded NTT and as expected had to overcome some problems both on and off the telescope. These included: some limitations of the current version of the Phase-2 Proposal Preparation software (P2PP) for large programmes; unexpected overheads from the new data flow system (DFS) and VLT control system (VCS); failures of the EMMI controller (CAMAC); problems with the pointing model and difficulties in retrieving data from the ESO Archive. The pointing model was particularly relevant to EIS because of the mosaic pattern adopted. Thanks to the dedication of people in the NTT team, the User Support Group, the Archive Group and the EIS team, these issues have been largely overcome. As expected, EIS has proved to be a useful test case for supporting the smooth transition between the first releases of software engineering products and routine science operations at the NTT.

These problems and the need for calibration of the new filters have led to some time losses. However, the impact that these time losses have had on the overall performance of the survey has been relatively minor as compared to the losses due to bad weather. This is illustrated in Figure 1, which shows for each EIS run the percentage of time used for observations. The figure does not tell the whole story as dismal full-night runs such as runs 4 and 5 had a considerably larger impact on the sky coverage than earlier half-night runs. Furthermore, the quality of nights has also varied considerably within a run and from run to run. These difficulties were brought to the attention of the EIS Working Group (WG) which recommended several adjustments in the scope of the observations, such as giving priority to the I-band observations and limiting the scope of the B-band coverage of patch B. However, the changes will not severely affect the primary science goals of the survey as originally proposed, with the exception of the search for high-redshift ($z \gtrsim 3$) QSOs.

So far a total of about 2000 science frames, roughly equivalent to 20 square degrees, have been taken. In Table 1, we list the position of the centres (J 2000) of the various patches and the current sky coverage, in square degrees, for the different passbands. In order to maintain some degree of uniformity of contiguous regions, most regions observed under poor conditions have been re-observed. In Figure 2, we show the seeing distribution for all the I-band frames that have been accepted for co-addition up to run 7. Even though these re-observations have limited the sky coverage, some 3 square degrees have been re-observed, they have been worthwhile since currently the median seeing in the different patches is in the range 0.8–1.1 arcsec. We should emphasise that since EIS is being carried out over a fixed amount of time, a trade-off between area and data quality is unavoidable.

3. EIS Pipeline

By far the most demanding task of the EIS team has been the development of a fully automated pipeline to handle the large data volume generated by EIS. A major aim of the EIS software is to handle the generic problem posed by building up a mosaic of overlapping images, with varying characteristics, and extraction of information from the resulting inhomogeneous co-added frames. The long-term goal has been to develop a "portable" system, which may eventually be installed in other European institutes.

Due to time constraints, it was decided early on that the development of the pipeline should take advantage, as much as possible, of pre-existing software elements such as: (1) standard IRAF tools for the initial processing of each input image; (2) the Leiden Observatory Data Analysis Center (LDAC) software, developed for DENIS[3], to perform photometric and astrometric calibrations; (3) the SExtractor object detection and classification code[1]; (4) the "drizzle" image co-addition software[4, 5], originally developed for HST, to create coadded output images from the many, overlapping, input frames.

However, handling mosaic data taken on different nights under varying conditions has required significant changes in the pre-existing software and the need for new concepts and intermediate products to provide the necessary information for the source extraction and data quality control of the co-added superimage, from which the final object catalogues are created. In order to illustrate the power of the tool being developed, a brief description of the architecture of

Table 1. Current Sky Coverage

Patch	α	δ	B	V	I
A	22:42:54	–39:57:32	—	1.2	3.2
B	00:49:25	–29:35:34	1.5	1.5	1.6
C	05:38:24	–23:51:00	—	—	5.6
D	09:51:36	–21:00:00	—	—	2.8
	—	—	1.5	2.7	13.2

the pipeline is necessary. For each input frame a weight map, which contains information about the noise properties of each pixel in the frame, and a flag map, which contains information about the pixels that should be masked, such as bad pixels and likely cosmic hits, are produced. After background subtraction and astrometric and relative photometry calibration, each input frame is mapped to a flux-preserving conical equal area projection grid, chosen to minimise distortion in area and shape of objects across the relatively large EIS patch. The flux of each pixel of the input frame is redistributed in the superimage and co-added according to weights of the input frames contributing to the same region of the co-added image.

In the process of co-addition, combined weight and context maps are created. The combined weight map provides the information necessary for the object detection algorithm to adapt the threshold of source extraction to the noise properties of the context being analysed. SExtractor has been modified to incorporate this adaptive thresholding. The context map characterises the origin of each pixel of the superimage and provides information which relates each detected object to the set of input frames that have contributed to its final flux. A context should be viewed as a virtual frame with its depth and seeing being almost uniform and determined by the combination of a unique set of input frames. For a survey such as EIS, being carried out in visitor mode with varying seeing conditions, the context information is essential as it may not be possible to easily characterise the PSF in the final co-added image, which can compromise the reliability of the galaxy/star classification algorithm. More importantly, the contexts represent regions of uniform noise, seeing and depth. Therefore, using the information available for each context, one may *a posteriori* define “uniform” regions with well-defined limiting magnitudes from which object and derived catalogues (e.g. the candidate cluster catalogue) may be extracted.

The pipeline works equally well for stacking dithered images and, in this case, the context map can be used to easily carve out the deepest part of the co-added image. Images from EMMI, SUSI and DENIS have been used for tests providing excellent results.

Another area, common to all large programmes, that has demanded considerable attention is the bookkeeping and monitoring of the progress of the observations, the data reduction and data quality. This has required interfacing the pipeline to a database, with calls installed in the various modules of the pipeline, which allows the status of a particular frame or a set of frames (corresponding to ten EMMI exposures that make up an EIS observational block) to be tracked throughout its lifetime in the pipeline and archive. In addition, logs of the observations and the reductions, reports (monitoring the progress of the observations, down time, survey efficiency, etc.) and diagnostics produced by the different modules of the pipeline (monitoring the pointing, seeing, astrometry and relative photometry) are created and posted on the web automatically for easy access by all team members.

In order to allow full control of the data flow, from the preparation of the observations to the final archiving of the data, it is essential to have a suitable data-acquisition system which can be interfaced to the data reduction pipeline, such as the DFS/VCS implemented on the NTT. Even though some additional features are still required, most of the basic tools are already in place. There are areas where improvements can be made such as the mass production of observational blocks (OBs), essential for large programmes with well-defined observing protocol, and the automatic generation of the observed schedule, which would allow the automatic updating of the status of the OBs resident in the re-

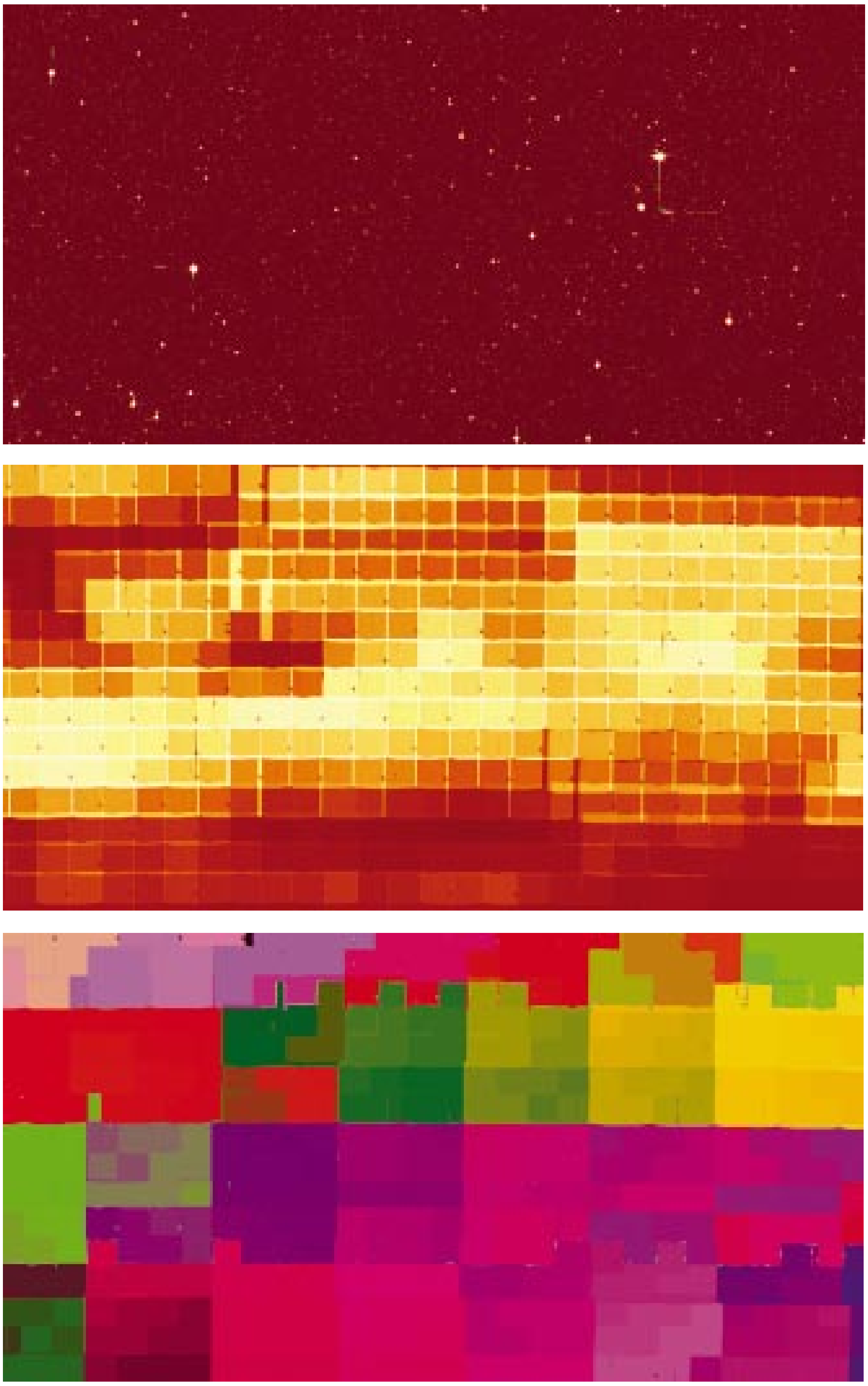

Figure 3: Co-added I-band image of patch A (top panel) showing a region approximately $2° \times 1°$ and the corresponding weight (middle panel) and context maps (bottom panel). In the weight map, dark colours represent regions of higher noise.

Figure 4: Colour composite obtained from a selected region 13′ × 7.5′ of the co-added B, V and I images of patch B. Note the presence of ghost images around bright stars present in the B and V filters. In the region a nearby cluster (z ~ 0.1) is seen as well as a concentration of red galaxies at the lower-left of the figure.

pository. The DFS has been a remarkable undertaking that will have an enormous impact on the efficiency with which large programmes will be conducted at the VLT. Similar systems, even if simpler versions, should be considered for other telescopes dedicated to survey work.

Even though considerable work lies ahead and several tests of the performance and fine-tuning of different modules of the pipeline remain to be carried out, it has been possible to streamline the pipeline to only a few scripts that control the entire process of data reduction. Under normal conditions, the data reduction requires four commands to go from raw frames residing in the Archive to co-added frames to object catalogues back into the Archive. The typical data flow rate is of 0.032 MB/sec on a 250 MHz UltraSparc2, which means that the reduction of a 6-square-degree patch requires about 70 hours. We should point out that at this stage no attempt has yet been made to multiplex operations, and the flow rate given above should be considered as a very conservative lower limit.

The pipeline is being developed in close collaboration with the ESO Archive group. The ESO Archive is the entry point of the raw data into the EIS pipeline and the distribution point of the final products to the community. Furthermore, we are using the EIS data to prototype general-purpose tools which will be required by the Science Archive Research Environment. This collaboration has been mutually beneficial yielding: (1) a general server to support EIS catalogues (fits binary tables) and the display of conical equal area co-added image sections; (2) the installation of a server to display the superimage, stored in 4k × 4k sections; (3) the implementation of additional features in SKYCAT; (4) The implementation of the EIS database; (5) the development of algorithms to cross-correlate the EIS catalogues with other available databases.

4. Preliminary Results

In order to illustrate the final products of the pipeline, Figure 3 shows a low-resolution (3 arcsec/pixel) representation of the I-band co-added image of patch A. This low-resolution image is created automatically by the pipeline and serves as a preliminary check of the co-addition. Also shown are the associated weight and context maps. In patch A, there are over 3500 contexts for 300 input frames, spanning a wide range of scales. About 520 are "big" contexts where there are two overlapping images. The average size of these is roughly 3.7′ × 3.7′. While most patches have been observed primarily in I-band, 1.5 square degrees of patch B have been covered in B, V and I, and, as an illustration, Figure 4 shows a true-colour composite image of a small area with multi-colour information.

The final catalogue of objects extracted from the co-added image uses the weight map to adapt the threshold of the source extraction algorithm and for each detected object identifies the context in which it has been found. The characterisation of each context is critical to control of the completeness and uniformity of the object catalogues derived from the co-added image. This is currently the main area of software development.

One of the major concerns has been whether the observations would be deep enough to search for distant clusters of galaxies. To address this and other questions posed by the WG and OPC, the EIS team has also developed basic tools for the scientific evaluation of the data, which allow for the comparison of star and galaxy counts with those of other authors and for the search of clusters using the matched-filter algorithm. A preliminary comparison of EIS galaxy counts with those obtained by the Palomar Distant Cluster Survey (PDCS)[6] shows that the EIS galaxy counts extend beyond those of the PDCS. Preliminary tests with EIS I-band data also indicate that about 15–20 candidate clusters per square degree can been found in the estimated redshift range $0.2 < z < 1.2$, which will yield over 300 candidate clusters after the completion of EIS-WIDE. Tests have also shown that "complete" cluster samples will be able to be produced by an adequate selection of "uniform" areas within the survey region using the context information. The astrometry of the EIS catalogues has an internal accuracy of about 0.03 arcsec, more than adequate for multi-slit spectroscopy at the VLT. The relative photometric accuracy is estimated to be of the order of 0.05 mag. However, the absolute calibration of patch A is still uncertain as it relies to a large extent on data not yet available from other telescopes.

5. Data Release: Catalogues and Images

EIS will produce a wide range of data products including the following catalogues:

1. Single-frame catalogues
2. Object catalogues extracted from the co-added images
3. Colour catalogues
4. Derived catalogues (e.g. candidate clusters).

The object catalogues will include positions, magnitude, major and minor-axis, position angle, stellarity index, SExtractor flags, and in the case of the catalogues extracted from the co-added image, the context and the characteristics of the context such as noise, a measure of the seeing, the 1σ limiting isophote and the limiting magnitude for point sources in that context.

The following pixel maps will also be available in the ESO Archive:

1. Astrometrically and photometrically calibrated frames
2. Co-added images, weight and context maps at both full resolution and in compressed form
3. Cut-outs of selected regions.

Currently, the EIS team and the ESO Archive group are studying the ways and means of making the EIS data accessible to the community. The target date of July 31, 1998 has been proposed to the OPC for the full release of the data from calibrated frames to co-added images to object catalogues and derived catalogues. The date is a compromise that takes into account the workload of the EIS team and the call for proposals for the VLT, expected to be issued on August 1, 1998. Given the large amount of data involved, a questionnaire is available on the EIS home page to survey the type of data products the astronomical community is most likely to request in the final release. The results of this survey will help evaluate the demand and the definition of a general policy that optimises the distribution of the data to the largest possible number of astronomers in the community.

However, recognising the value that a preview of the data would have, even if in a preliminary form, it has been decided that some products will be distributed earlier. A tentative schedule for the release of these products is available on the EIS home page (http://www.eso.org/eis), with the first release expected to be in March, soon after the publication of the present issue of *The Messenger*. In this first release we expect to make available reduced single frames with astrometric and photometric calibration, and corresponding catalogues. In addition, the compressed co-added image, weight and context maps of patch A and the corresponding preliminary catalogue will be available on-line. This release will also be accompanied by a complete description of the observations, data reduction and the contents of the catalogues as well as other information characterising the quality of the data and catalogues, prepared by the EIS team. A catalogue of cluster candidates will also be produced for distribution together with image cut-outs to serve as finding charts.

The hope is that this preliminary release will trigger valuable feedback from the community and will already provide useful data for the preparation of VLT projects. These preliminary releases will also serve as a test case for the final delivery, allowing the EIS team and the Archive group evaluate the amount and type of requests, the performance of the on-line server and the requirements posed by the distribution of large amounts of data in the form of pixel maps. Since several applications may not require the data at full resolution, the EIS team is currently analysing the performance of various compression algorithms, and their impact on the astrometry and photometry. This information is available on the EIS home page and, whenever possible, this option should be considered as it would greatly facilitate the distribution of large volumes of data.

Finally, it is important to emphasise the enormous workload of the EIS team. It includes observations, software development, tests of the pipeline, data reduction of survey frames as well as from other telescopes for the photometric calibration of the survey. Moreover, the team is also involved in the preparation for EIS-DEEP and the upgrade of the software to handle data from the wide-field imager at the 2.2-m telescope. Therefore, the team will not be able to provide support to the users until the final release of the data. For the time being, technical inquiries should be addressed to the ESO Archive Group (awicenec@eso.org with copies to eisweb@eso.org). Time allowing, answers to the most frequently asked questions will be made available on the EIS home page.

6. EIS Software and By-Products

Besides the astronomical data, the EIS team is committed to make publicly available to the ESO community all the software that has been developed for EIS. Our ultimate goal is to make, as much as possible, the EIS pipeline portable to other institutes. By July 1998, a detailed description of the various algorithms used in the different modules of the EIS pipeline should become available. Full documentation and in-depth discussion is also envisioned by the end of 1998, if the necessary resources are available. For that purpose, an effort is being made to keep the complete history of EIS on the web for future reference documentation, summaries of meetings, results of tests, error reports, software upgrades, and relevant communication between team members. Although time consuming, this activity has been considered an integral part of the development phase in view of the long-term prospects of the EIS pipeline and the expected turnover of the members of the EIS team.

In addition to these more tangible products, EIS has also provided other important by-products including valuable information on the performance of the NTT and the DFS/VCS. It has been used to prototype several developments in the ESO Science Archive Research Environment (SARE) and has created some useful new interfaces between ESO and the community, such as the EIS WG and the EIS team.

This shows the usefulness of public surveys not only for finding astronomical targets for the VLT but also from the operational point of view. It has also shown the agility of ESO in responding to a challenge, attracting talent spread throughout the ESO community and coordinating an effort such as EIS at short notice. Without all of these elements it would have been impossible to keep to the ambitious timetable of EIS.

7. The EIS Team and the Involvement of the ESO Community

The community has played an active role in the survey by participating in the EIS Working Group, which met three times during 1997 to decide on the modifications of the survey strategy as they became necessary. The ESO Member State community is also broadly represented in the EIS team, which is composed primarily of visitors and represent over 80% of the 4.5 FTEs allocated to the project in 1997.

Equally important has been the contribution given by the Geneva Observatory, which has monitored the extinction measurements during the EIS observations, and the Leiden Observatory, which has provided time for observations of standard stars and several pointings of the fields being observed, as well as DENIS data to be used for external calibration. H. Boehnhardt and collaborators also supplied observations taken at the 2.2-m telescope. All of these efforts have been extremely helpful in order to recover from the time losses caused by El Niño, providing essential data for the calibration of the photometric zero-point of the different patches.

EIS has also captured the interest of the astronomical community with the EIS home page being accessed about

3500 times during the month of January 1998 and averaging 4000 hits per month in 1997.

8. Conclusions

Even though the weather was not very co-operative at the beginning of the survey, it is fair to say that EIS is achieving most of its originally planned goals. A detailed account of the ongoing work has been presented to the EIS WG and to the OPC. As a result, the OPC has given the go ahead for the continuation of EIS-WIDE and has allocated time for EIS-DEEP. It should be mentioned that since SOFI will only be available in June, the EIS WG has recommended that the goals of the original DEEP-I and II[7] be combined to cover the HDFS region and its flanking fields, with the observations scheduled to start in July 1998.

Observations for EIS-WIDE with EMMI will be completed in March 1998, to be followed by U-band observations with SUSI-2 in the fall of 1998 over about 1.5 square degrees of patch B. already covered in B, V and I. At the same time the preparations have started for the EIS-DEEP observations. Trial reductions with single frames, taken with EMMI and SUSI, have shown that the EIS pipeline can adequately handle dithered optical images. Attention will now turn to interfacing EIS with the SOFI data reduction pipeline.

The EIS pipeline is already a reality, taking raw data and producing co-added images, object catalogues and derived catalogues, largely unsupervised. Most of the remaining work is to implement and verify the production of final object catalogues with the required "context" information for data-quality control, essential in the preparation of complete samples for statistical studies. The pipeline has been developed with one eye on short-term needs and the other on the long-term, which should facilitate its upgrade to handle the data from the wide-field camera at the ESO/MPIA 2.2-m telescope.

Preliminary results clearly indicate that the EIS data meet the requirements for the primary science goals of the project which, in conjunction with the various by-products outlined above, make this pilot programme a success. One of the important remaining challenges is to make the data reach the community in a timely and easy-to-use manner. Hopefully, by doing so, EIS will pave the way for gradually more ambitious public surveys.

Acknowledgements

We would like to thank the members of the EIS Working Group, for their scientific input in the definition of the survey, and the OPC for their support of this pilot programme. We would also like to acknowledge the support of DMD, in particular M. Albrecht, the NTT team, the ECF, in particular R. Albrecht, and Jim Beletic for innumerable discussions. We would like to express our thanks to A. Baker, D. Clements, S. Coté, E. Huizinga and J. Rönnback for their contribution in the early phases of the EIS project and C. Lidman for providing data from his survey. We are also grateful to Yannick Mellier, Marc Postman and Steve Kent for their help on several fronts and for providing some test data, and D. Koo for valuable comments during his visit to ESO.

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Après EIS

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1999 will be the first year of the VLT scientific operations, yet this will not be the only novelty brought by the new year. In 1999 the flow of scientific data from the old La Silla Observatory will be several times higher than in 1998. Indeed, with the full dedication of the ESO/MPIA 2.2-m telescope to wide-field imaging, the ESO community will have for the first time an efficient survey instrument: the 8k × 8k camera covering a 0.54° × 0.54° field of view. In the meantime, the construction is about to start of a new 2.5-m telescope to be placed on Paranal by 2001, which will have a four times bigger field of view (and data flow rate). This sudden expansion of ESO wide-field imaging and survey capabilities requires a major effort by both ESO and its community, in order to take full advantage of these new facilities that are primarily designed to support and foster the science to be done with the VLT.

1. Providing Targets for the VLT

With the advent of the VLT, European astronomy has – perhaps for the first time in this century – a real chance to successfully compete in ground-based, optical-IR astronomy. In the early years of next century there will be twelve 8-m-class telescopes in operation. Competition will be fierce, and leading or lagging behind others in critical areas of astronomical research will not just depend on the performance of the big telescopes and their instrumentation, but also on the ability to *timely* feed them with the appropriate targets. For this very reason, imaging surveys as a continuous, long-term need for the full scientific exploitation of the VLT are now widely endorsed within the ESO community.

For such surveys, 2–4-m-class telescopes are much more cost-effective than the VLT in finding objects of special interest for the deep imaging and spectroscopic study at the VLT itself. For this to be true, such targets have to be relatively rare, and the imager must have a substantially larger field of view compared to VLT imagers. Instead, if the potential targets are very numerous per field of view of the VLT imagers (e.g. FORS, VIMOS, NIRMOS), then the VLT itself may offer a competitive, or even more appropriate alternative. Classes of such "rare" objects that are scientifically attractive targets for the VLT are listed in Table 1.

While these potential targets will certainly not exhaust the capabilities of the VLT, it seems fair to say that all together they are likely to take a major share of the VLT observing time. This is exemplified in Table 2, instrument by instrument, following the order of instrument implementation at the VLT. The list is probably