EIS - An Imaging Survey for VLT Science

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Abstract. The imaging data assembled by the recently completed ESO Imaging Survey (EIS) are reviewed and their scientific value briefly assessed. Among the various applications, the imaging data has been used to build a large sample of candidate distant clusters of galaxies in the Southern Hemisphere to be used for follow-up observations with the VLT as well as other space and ground-based facilities. Preliminary results from ongoing work to confirm these candidates are reported and the future prospects discussed.

1 Introduction

The ESO Imaging Survey (EIS) was a joint effort of ESO and its community to carry out a public imaging survey and to prepare target lists for different scientific applications in preparation for the beginning of regular operation of the VLT. The primary scientific goals were conceived by a Working Group (WG) composed of experts selected from the community at large and the survey was conducted by a team formed primarily by astronomers from the community. Among the different goals of EIS, one of the top priorities was the construction of a catalog of distant cluster of galaxies candidates over an extended redshift baseline from which targets could be drawn for subsequent follow-up work. Such a sample was constructed by the EIS team and it is the main focus of this presentation.

The importance of a large sample of confirmed distant clusters is vast, as emphasized throughout this meeting, ranging from the study of galaxy and large-scale structure formation and evolution to estimates of cosmological parameters. This has motivated several recent attempts to find and investigate intermediate and high-redshift clusters using X–ray, optically- and infrared-selected samples. Even though X–ray samples are in many respects superior to those selected in optical or infrared, the number of confirmed distant clusters in the Southern Hemisphere is still quite small. Currently, the best samples of distant X–ray clusters are all based on deep pointings of the ROSAT PSPC [11]. In particular, the RDCS [10] includes about 30 $z > 0.5$ spectroscopically confirmed clusters, the majority in the Northern Hemisphere. Moreover, considering the currently foreseen timetable of future X-ray missions it is clear that no new X-ray based high-redshift cluster sample will be available in the next few years. Clearly, if VLT is to play a role in the study of the distant clusters it will have to rely on optically- or infrared–selected cluster samples, at least in the near future. It is worth pointing out that while some investigations require well-defined complete samples, usually difficult to asses from optically-selected ones, others can benefit solely by a statistically large sample.

The need for cluster targets was foreseen by the EIS WG which recommended a moderately deep, wide-angle I-band survey to search for distant clusters, despite the inadequacy of the available detectors for wide-field imaging at the beginning of the survey. Still, EIS is currently the largest imaging survey available (17 square degrees) in the Southern Hemisphere to a depth ($I \lesssim 23$) suitable for blind searches of distant clusters.

2 General Results from EIS

EIS was conceived as an attempt to optimize the use of the NTT by carrying out a coordinated imaging survey in the one-year period between the re-commissioning of the NTT and the commissioning of the first unit of the VLT project. The main objectives of EIS were: 1) to conduct a public optical-IR imaging survey in preparation for VLT; 2) to produce target lists for VLT before the start of the Science Verification period. The survey was designed to satisfy the requirements of a broad range of applications. Following the recommendations of the EIS WG the survey consisted of two parts: **1)** An optical, moderately deep, multi-passband, wide-angle survey (EIS-WIDE) covering four patches distributed in the right ascension range $22^h < \alpha < 10^h$ to produce targets almost year-round. The survey consisted of a mosaic of overlapping EMMI-NTT frames 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, with all of the data, including pixel maps and derived catalogs, being publicly released in March and July 1998; **2)** Deep optical/infrared observations of the HDF-S and AXAF Deep Field (EIS-DEEP). These observations were obtained using SUSI2 and SOFI at the NTT in the period August-November 1998, with all of the data, including derived catalogs, being publicly released December 10-12 1998 [3] [9].

The accumulated imaging data provided the following data sets: **1)** ~ 17 square degrees in I-band ($I_{AB} \sim 23.5$); **2)** ~ 3 square degrees in VI; **3)** $\sim$ 2 square degrees in BVI; **4)** ~ 125 square arcmin in JKs ($K_{AB} \sim 23.5$); **5)** ~ 80 square arcmin in $UBVRI$ ($I_{AB} \sim 26$). In addition, combined, the optical/infrared deep observations provide a coverage of 15 and 25 square arcmin in eight and seven passbands, respectively [3] [9]. Similar data will soon become available for the HDF-S STIS field.

From the available photometric data several target lists were extracted for immediate use in follow-up observations at different facilities and for Science Verification observations. Among them are candidate galaxy clusters, quasars, high-redshift galaxies as well as galactic objects such as white dwarf and brown dwarf candidates [17]. Some of these targets have already been used for follow-up observations. Quasar candidates identified in patch B have been observed with 2dF at AAT, leading to the confirmation of about 50% of the candidates. Distant EIS cluster candidates and high-redshift galaxies, identified using dropout and photometric redshift techniques, have been successfully confirmed from VLT observations using the VLT test camera [2] and FORS (see ESO PR 12/99), respectively, as part of the Science Verification of UT1.

3 EIS Cluster of Galaxies Candidates

As part of the main effort of the EIS team, the galaxy catalogs derived from the I-band images were used to search for candidate clusters using the matched–filter algorithm [7] to detect clusters and to estimate redshifts. The final EIS candidate clusters sample consists of 304 objects in the redshift range $0.2 \lesssim z \lesssim 1.3$ [5] [6] [14], with a median redshift of $z \sim 0.5$. This EIS cluster sample is the largest such a catalog presently available in the Southern Hemisphere and it is arguably one of the main results of the EIS-WIDE effort.

An extensive effort is now underway to validate these candidates at different redshift intervals either by direct spectroscopy, using 4-m class telescopes for the low-redshift ($z \lesssim 0.5$) cluster candidates, or by using optical/infrared color-magnitude relations to identify the red-sequence of early-type cluster galaxies known to exist over the redshift range considered. The latter has been carried out by complementing the I-band EIS data with suitably deep optical data ($z \lesssim 0.7$) and by infrared observations of high-redshift candidates ($z > 0.7$). The identification of the red-sequence is a necessary step for a preliminary "confirmation" and for the selection of targets for subsequent spectroscopic observations with 8-m class telescopes.

These follow-up observations include: **1)** 2dF@AAT test runs of EIS cluster candidates in patch B and D [13]; **2)** EFOSC2@3.6m observations of seven $z \sim 0.5$ clusters [8]; **3)** JKs SOFI@NTT observations of fifteen clusters with $z > 0.6$ [4] [8]; **4)** deep optical observations of two high-z candidates with the VLT-TC [2]; **5)** deep optical observations (VI) of four clusters with the Danish 1.5m telescope [4]; and **6)** deep optical observations (V) of thirteen clusters with the Nordic Optical Telescope [4]. In addition, deep $I-$band imaging of $\sim$ 10 clusters with $z \lesssim 0.5$ will be carried out in the near future for weak lensing studies [15]. Altogether this implies that about one-third of the EIS cluster candidates will have already been followed-up by the end of 1999.

Gathering the information already available from the various groups, the results from these preliminary confirmation efforts can be summarized as follows: **1)** the combination of new spectroscopic measurements, redshift data from the literature, and the presence of color-magnitude relations [6] provide either direct or indirect evidence that most EIS clusters with $z < 0.3$ are likely to be real. Particularly promising are the preliminary results of the 2dF observations for candidates with $z < 0.5$. Test observations (3 hours long), conducted under poor seeing conditions, showed that at least 50% of the observed candidates have two or more concordant redshifts and are very likely real associations; **2)** new imaging and spectroscopic data for ten candidates with $0.4 < z < 0.6$ provide strong evidence that nine of them are real associations; **3)** optical and infrared color information for fifteen candidate clusters with $z > 0.6$ suggest that twelve of them are real, including five at $z \gtrsim 0.9$.

These preliminary results are extremely encouraging, suggesting that a confirmation rate of about 70% can be achieved. This clearly justifies vigorously pursuing the confirmation effort. The data already obtained have also shown ways to improve the confirmation process.

4 Future Prospects

4.1 Clusters

The work on the EIS clusters is expected to proceed in several fronts which include imaging and spectroscopic confirmation, velocity dispersion measurements, deep imaging for weak lensing studies, and $X-$ray observations with XMM. Such a program requires a variety of observations that can be conducted at different facilities. For instance, the detection of the early-type red sequence of intermediate redshift candidates ($z \lesssim 0.7$) is possible from optical observations with 2-m class telescopes, while for candidates at higher redshifts infrared imaging is needed. Spectroscopic confirmation of low-redshift EIS candidates ($z \lesssim 0.5$) can be successfully carried out using 2dF@AAT. In fact, by the appropriate selection of galaxies using color information, or whenever possible photometric redshifts, as well as further constraints on the positioning of fibers will certainly increase the success rate of confirmation, and can lead not only to accurate redshift measurements but may also provide a robust determination of the velocity dispersion.

Beyond $z > 0.5$ 8-m class telescopes are required if one expects to build a large sample of confirmed clusters in a timely fashion. To confirm the reality of these candidates requires the observation of at least a few galaxies and the best candidates are those lying along the red-sequence. Even though FORS1 is not the ideal spectrograph, given the geometry of the slits, the observations can be made more efficient by using photometric redshift techniques. Using the optical/infrared data accumulated in the process of determining the red-sequence and those available from the public surveys one can select galaxies over the field-of-view of FORS1 within a small estimated redshift interval about the nominal cluster redshift. The effectiveness of the method has been demonstrated for the two high-redshift candidates observed with the VLT-TC for which $BVIJKs$ color catalogs are available [1]. By selecting galaxies in a photometric redshift bin of 0.2 around the nominal cluster redshift the surface density of galaxies in the field is reduced by a factor of more than five, thereby significantly increasing the chances of targeting other cluster members well-beyond the cluster core and with different SEDs. It remains to be seen in practice how large the success rate of measuring redshifts for cluster members will be using this method. However, these observations should provide enough data to confirm the reality of the cluster and, perhaps, to obtain a first estimate of the velocity dispersion. More accurate velocity dispersion measurements will require the next generation of VLT instruments (FORS2 and especially the integral field unit of VIMOS), which would greatly benefit from having already a sample of confirmed clusters. It is worth mentioning that the infrared data used to detect red-sequences will also be used to search for higher redshift clusters. Preliminary analysis of the JKs data available, covering about 500 square arcmin, have led to the discovery of at least seven concentrations of red objects with estimated redshifts $1.1 < z < 1.7$, reminiscent of recently confirmed clusters at $z \sim 1.2$ [12] [16]. Finally, deep I-band imaging is required to estimate weak lensing masses. For low-redshift clusters this will require observations with the WFI@2.2, while at higher redshift VLT observations are needed.

If the program outlined above is successful it will naturally provide a unique data set of confirmed high-z clusters, with virial and weak lensing masses, for follow-up observations with XMM in time for the second announcement of opportunities. This concerted study of clusters over such an extended look-back time will provide a unique database to investigate the evolution of clusters and their galaxy population.

4.2 Public Surveys

Recently, the WG for public surveys endorsed the continuation of such programs using the recently commissioned wide-field imager (WFI@2.2) and the NTT for infrared observations. These surveys are expected to be conducted by both the EIS team and outside groups under the same general guidelines adopted for EIS. The two-year plan recommended by the WG envisions a deep five-passband multicolor survey of three square-degrees, complemented by deep infrared observations (JKs) of an area of 1000 square arcmin. It also calls for shallower observation of selected stellar fields in preparation for follow-up observations with the FLAMES spectrograph. In the short-term the WG has also reaffirmed its support for completing the EIS-wide survey in two additional passbands (BV) of the 17 square degrees area covered in $I-$band by EIS.

5 Summary

The initiative taken by ESO and the Member States to carry out a coordinated public imaging survey in a one-year time-scale has been successful providing a vast set of imaging data, for a wide-range of applications, in time for the Science Verification period of UT1 and for the first year of VLT operation. As a by-product the EIS experiment has led to the development of a powerful data reduction pipeline prototype and a survey environment, both essential ingredients for the continuation of other Public Surveys using the WFI@2.2 imager. The target lists prepared by EIS have already been used in a number of follow-up works, in preparation for VLT programs, and for the Science Verification period, thus meeting the primary requirement of the survey. In particular, a significant effort has been made by different groups to investigate the EIS candidate cluster catalog leading to encouraging results which, if vigorously pursued, could lead to the construction of a large sample of high-redshift clusters for observations with the VLT as well as other facilities such as HST and XMM.

The response of the community to EIS has been good, judging by the interest manifested by the number of accesses to the EIS web pages, the amount of data retrieved, the number of follow-up programs undertaken over the past six months and the desire of the WG to continue public surveys. However, a significant effort must still be made to cope with the large volume of data expected from the wide-field imager.

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