# The EIS Pre-FLAMES Survey: Observations of Selected Stellar Fields

*S. ZAGGIA, INAF/Osservatorio Astronomico di Trieste and European Southern Observatory (szaggia@eso.org) and*
*Y. MOMANY, B. VANDAME, R.P. MIGNANI, L. DA COSTA, S. ARNOUTS, M.A.T. GROENEWEGEN, E. HATZIMINAOGLOU, R. MADEJSKY, C. RITÉ, M. SCHIRMER, and R. SLIJKHUIS, European Southern Observatory*

## 1. Introduction

The primary goal of the ESO Imaging Survey (EIS) project is to produce data sets matching the foreseen scientific goals and requirements of different VLT instruments (e.g. Renzini and da Costa 1997) and to publicly release them prior to the commissioning and first year of operation of these instruments. With this goal in mind, for the past two years EIS has been carrying out the Deep Public Survey (DPS), an optical/infrared deep survey of high-galactic latitude fields, and the Pre-Flames (PF) Survey, a *B V I* survey of selected stellar fields, to provide suitable samples for VIMOS and FLAMES (Fibre Large Array Multi-Element Spectrograph, Pasquini et al. 2000), respectively.

FLAMES, which will be installed on the A Nasmyth platform of the VLT Kueyen telescope, consists of a fibre positioner, covering a corrected field of view of ≃ 25 arcmin in diameter, a dedicated fibre-fed spectrograph (GIRAFFE) and a fibre link to the UVES spectrograph located on the B Nasmyth platform. An important feature of the FLAMES set-up is that it will allow for simultaneous observations with both GIRAFFE and UVES. More details about FLAMES can be found in Pasquini et al. (2000) (see also the URL "http://www.eso.org/instruments/flames"). In the Medusa mode, GIRAFFE will be fed by 130 fibres 1.2 arcsec in diameter. The relatively small diameter of the fibres together with the lack of an imaging mode in FLAMES, make the preparation of target lists with accurate astrometry ($\lesssim$ 0.2 arcsec) essential in order to minimise off-centre light losses. For instance, under seeing conditions typical of Paranal (~ 0.7 arcsec), as much as ≃ 50% of the flux of an object can be lost by misplacing a fibre by ~ 0.5 arcsec. In addition, to take full advantage of GIRAFFE, multi-colour source catalogues with reliable photometry (e.g. ~ 0.03 mag at V = 20) over the large field-of-view of FLAMES are required for an adequate selection of targets for spectroscopic observations and for their subsequent analysis.

Foreseeing the need for building suitable data sets for FLAMES, ESO's Working Group for public surveys recommended the EIS project to carry out an imaging survey of selected dense stellar fields, the so-called Pre-Flames (PF) Survey. The survey is being conducted with the wide-field imager (WFI) at the MPG/ESO 2.2-m telescope, with a field of view (34 × 33 arcmin) comparable to that of FLAMES (≃ 25 arcmin in diameter). As in the case of other public surveys carried out by EIS, the ultimate goal has been not only to gather the imaging data, but develop and test procedures to produce science grade products in the form of fully calibrated images and multi-colour stellar catalogues, from which samples for observations with FLAMES can be extracted. The survey was designed to observe a suitable number of fields for commissioning and first year of operation of FLAMES. The selected fields have surface densities > 1000 objects per square degree at the magnitude limit of FLAMES. Such fields will provide enough targets for the 130 fibres available in the Medusa mode. Considering that in a typical night the MEDUSA mode can produce around 1000 stellar spectra in five to ten different fields (Pasquini 2000), this implies that approximately 500 stellar fields per year can be observed with FLAMES. While some teams will be able to gather their own preparatory imaging data, others may have to rely on public data. To meet this potential need, a total of 160 fields were selected for observations. These were assembled from suggestions of potential users as compiled by the FLAMES team. Table 1 gives: in column (1) the type of target; in column (2) the number of fields originally selected; in column (3) the number of observed fields of each type at the time of writing; and in column (4) the completeness by type. As can be seen, the survey is nearly completed, except for Local Group galaxies and the Magellanic Clouds.

In this contribution, we present a progress report of the Pre-Flames survey reviewing the main characteristics of the first set of data recently released. A more comprehensive discussion of the reduction techniques and of the results can be found in Momany et al. (2001). The released catalogues and images can be retrieved at the URL: "http://www.eso.org/eis/".

## 2. Survey Strategy

The observations for the PF Survey have been carried out using the WFI camera at the Cassegrain focus of the MPG/ESO 2.2-m telescope at the La Silla observatory. WFI is a focal reducer-type mosaic camera with 4 × 2 CCD chips of 2048 × 4098 pixels. The pixel size is 0.238 arcsec and the full field of view of the camera is 34 × 33 arcmin, with a filling factor of 95.9%. Test runs were conducted during the first semester of 1999, as part of the EIS Pilot Survey. These earlier data helped defining the observing strategy subsequently adopted in the PF survey,

*Table 1: Pre-FLAMES targets.*

| Target (1) | Fields (2) | Observed (3) | Completion (%) (4) |
|---|---|---|---|
| Globular Clusters | 32 | 29 | 90.6 |
| Open Clusters | 33 | 28 | 85.2 |
| Milky Way Bulge/Halo | 18 | 18 | 100.0 |
| Local Group Galaxies | 18 | 4 | 22.2 |
| Sagittarius | 17 | 17 | 100.0 |
| Large Magellanic Cloud | 34 | 15 | 44.1 |
| Small Magellanic Cloud | 8 | 3 | 37.5 |
| Total | 160 | 103 | 64.6 |

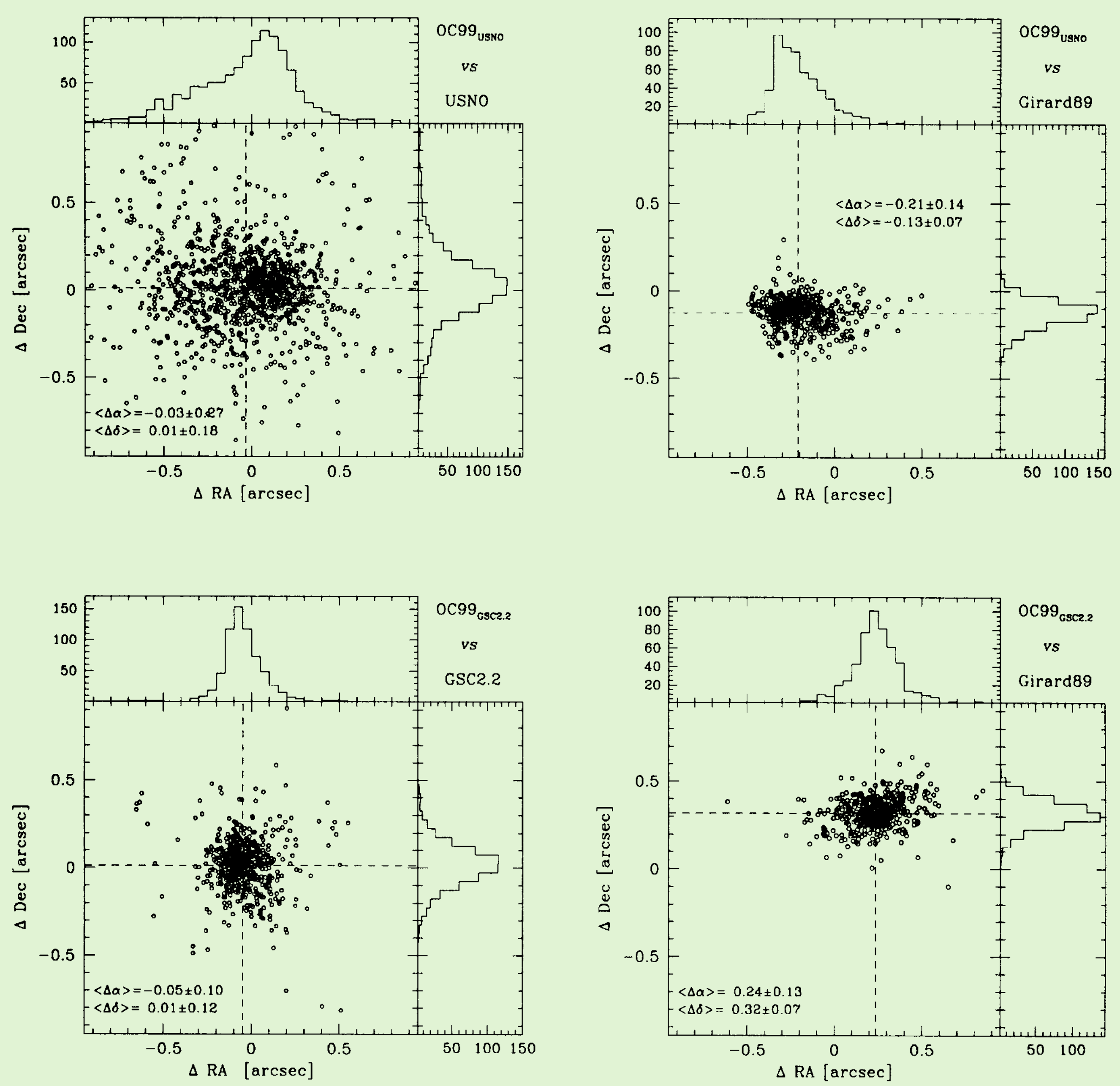



*Figure 1: The two-dimensional (RA, Dec) distribution of positional residuals relative to the reference catalogue used (left panels) and the astrometric catalogue of Girard et al. (1989) (right panels) for the USNO 2.0 (top panels) and GSC 2.2 (lower panels). The vertical and horizontal dashed lines mark the mean residuals in RA and Dec after applying a 3a clipping to the data. The mean values with the final 1-σ rms are given in the figure. Also shown are the histograms of the residuals as a function of RA (top) and Dec (right).*

which started in October 1999. The PF observations have been conducted in B, V and I to provide colour information for the selection of targets. The exposures were split into a short-exposure of 30 seconds (SHALLOW), to avoid saturating bright objects, and two deep exposures of four minutes each (DEEP). These are dithered by 30 arcsec both in right ascension and declination. The long exposures are sufficiently deep to reach the required signal-to-noise at the spectroscopic limit of FLAMES, while the short exposures allow one to recover saturated bright stars (a gain of ~ 4 mag). This is important because bright stars will be used as guide stars and should be in the same astrometric system as that of the target list.

*Table 2: Released Fields.*

| EIS ID (1) | Name (2) | RA (3) | Dec (4) | Filter (5) | Seeing (6) | Detected Objects (7) |
|---|---|---|---|---|---|---|
| OC 3 | Berkeley 20 | 05 32 58 | +00 13 04 | *B,V* | 1.0 | 7190 |
| OC14 | NGC 2506 | 08 00 11 | –10 47 17 | *B,V* | 0.9 | 18,900 |
| OC12 | NGC2477 | 07 52 17 | –38 32 48 | *B,V* | 1.1 | 38,800 |
| OC99 | M 67 | 08 51 22 | +11 49 00 | *B,V* | 1.1 | 4290 |
| SMC 5 | SMC | 00 56 45 | –72 19 00 | *B,V* | 1.3 | 280,000 |
| SMC 6 | SMC | 01 03 35 | – 72 19 00 | *B,V* | 1.3 | 246,000 |

## 3. Data Reduction

The WFI images are being processed using the new EIS pipeline described in more detail by Vandame et al. (2001) (see also Arnouts et al. 2001). The astrometric calibration performed by the pipeline makes extensive use of the method developed by Djamdji et al. (1993) based on the multi-resolution decomposition of images using wavelet transforms. As described in Arnouts et al. (2001), this package is used both to obtain a crude first estimate of a suitable reference pixel for the WFI images of each run, and an accurate determination of the astrometric solution for each image. Once an astrometric solution is found for each CCD in the mosaic, the images are corrected for the distortions and stacked. In its first implementation, the image warping was done using a *nearest neighbour* criterion to relocate the flux. More recently, the algorithm has been generalised and it is currently being tested (see below). Another issue not addressed in the first release of the PF data was the strong and variable fringing visible in the I-band images. Since the strategy adopted in the reduction of deep I-band images requires several consecutive frames, it could not be used to reduce the PF data. Therefore, the release of the PF I-band images was postponed (see below).

The source extraction and stellar photometry (PSF fitting technique) are being carried out using the DAOPHOT/ALLSTAR packages (Stetson 1987). Catalogues extracted from the SHALLOW and DEEP images are then combined to produce single-passband catalogues covering a wider range of magnitudes. Finally, these catalogues are associated to produce colour catalogues for each of the observed fields. Comparison with data available in the literature shows that a typical scatter of $\simeq$ 0.07 mag at V ~ 20 is reached in both magnitude and colours. The measured colours are in excellent agreement with those measured by other authors in spite of the large colour term required to transform WFI instrumental magnitudes into the Johnson-Cousins system.

## 4. Astrometry

Considering the importance of an accurate astrometric solution in the preparation of target lists for any fibre system, such as FLAMES, several tests were performed in order to evaluate and fine-tune the new pipeline algorithms. A detailed discussion of the results can be found in Momany et al. (2001). One of the issues addressed was the impact that the choice of the astrometric reference catalogue may have on the final results.

To assess the accuracy of the astrometric calibration, the M 67 field was used to investigate the distribution of the positional residuals relative to the reference catalogue used and to the astrometry obtained by Girard et al. (1989), properly accounting for proper motion. Figure 1 shows these distributions for the catalogues extracted from the images calibrated using the USNO 2.0 (top panels) and the GSC 2.2 (bottom panels) as references, respectively. The left panels show the residuals of the astrometric solution, while the right panels show the comparison with the Girard et al. data.

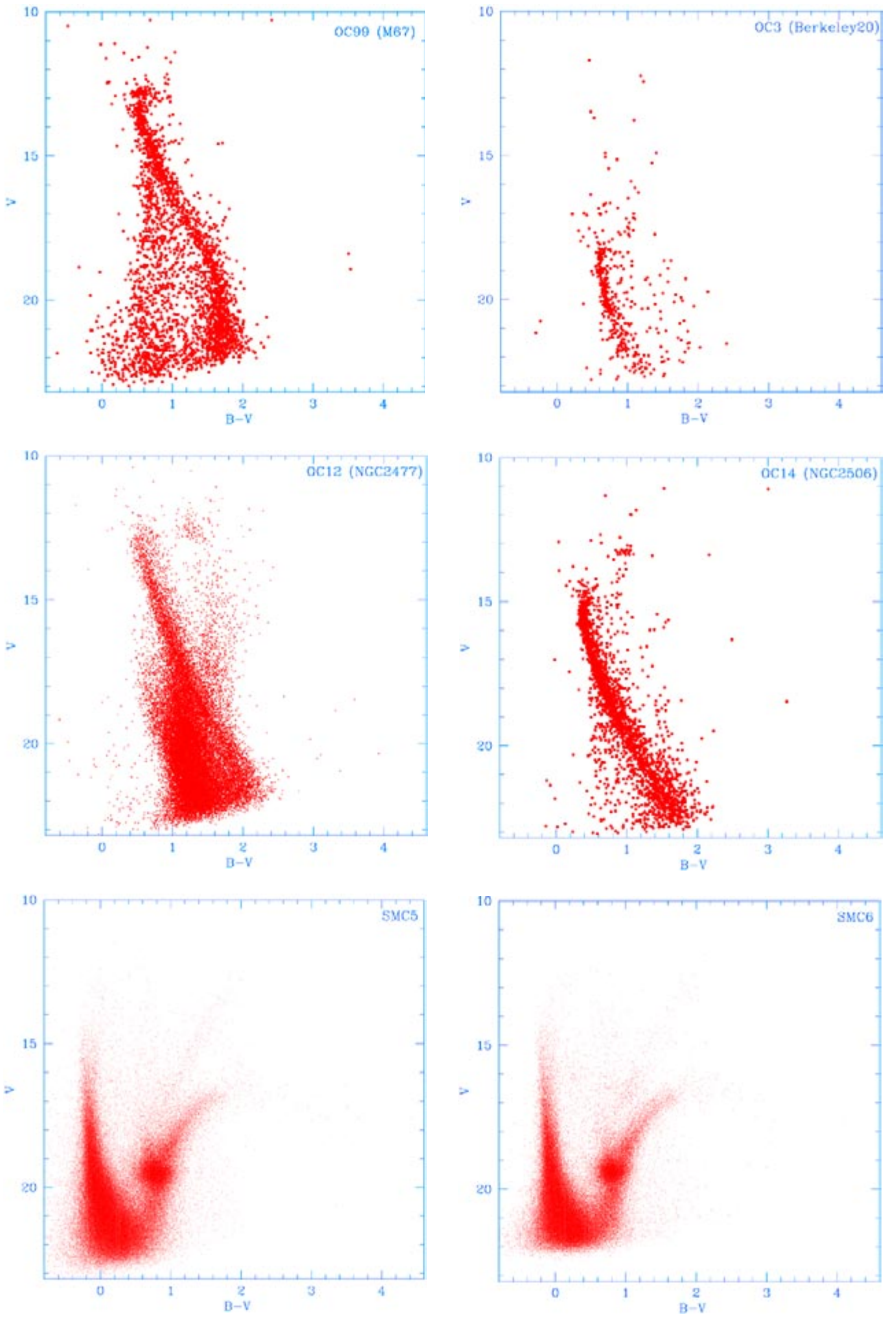



*Figure 2: The CMD for the six fields presented in this paper. The CMDs have been obtained from the combination of the catalogues extracted from the SHALLOW and DEEP images, as described in the text. To minimise foreground contamination the CMDs of Berkeley 20 and NGC 2506 correspond to circular regions of 3 and 5 arcmin in radius, respectively, around the nominal centre of the cluster.*

From this figure it is easy to see that while both reference catalogues yield comparable values of the *rms*, GSC 2.2 is far superior showing no systematic effects and residual distributions in both coordinates which are well represented by a Gaussian. From the comparison with the Girard et al. data, one finds that the astrometric solution has an accuracy of $\lesssim$ 0.15 arcsec, well below the 0.2 arcsec limit imposed by FLAMES and that the internal error of the astrometric calibration is better than ~ 0.1 arcsec. Note that the mean offsets are not relevant for the preparation of target lists for FLAMES since its fibre positioner is allowed to move within a 2 arcsec window (Pasquini, private communication). It is important to emphasise that these results were obtained by re-sampling the image to avoid the discreteness effects imposed by the nearest-neighbour approach adopted in warping the image. As discussed below, this limitation has now been overcome by introducing a suite of kernels in the warping algorithm.

While the recently released GSC 2.2 catalogue yields by far the best results,

*Figure 3: Colour composite Image of the* B V I *exposures of the SMC 5 field covering a field of view of 34 × 33 arcmin. This image is the combination of the DEEP dithered Images. In this field the following systems are present: NGC 346 (the brightest HII region in the SMC, see Fig. 6), NGC 330 (see Fig. 7), IC 1611, NGC 306, NGC 299, OGLE 109, OGLE 119, OGLE 99.*

at the time of the data reduction it did not cover all the fields of interest. Therefore, the USNO 2.0 reference catalogue was used instead. It is worth pointing out that the astrometric accuracy obtained using the latter is still within the requirements set by the FLAMES team.

## 5. Survey Products

Table 2 lists the fields for which fully calibrated images and catalogues have been released. These fields were all observed during a single run in the period November 27–29, 2000. The table gives: in column (1) the EIS target identification; in column (2) the name of the primary object being observed; in columns (3) and (4) the J2000 right ascension and declination; in column (5) the filters; in column (6) the mean seeing during the exposures; and in column (7) the number of detected objects in each field.

The images already released include the combined deep *B* and *V* exposures of each field. All images are normalised to 1 second exposure, and are presented in the TAN projection. In the data release, the science images have been combined with their corresponding weight-maps into a single fits file containing two image extensions. In addition to the pixel maps, the following catalogues are also available: (1) three catalogues for each pass-band: the SHALLOW, the DEEP and the combined catalogues, listing instrumental magnitudes, all in ASCII format; (2) a calibrated *B V* colour catalogue available in three different formats: a FLAMES input file, a SKYCAT input file and a normal ASCII file.

In order to illustrate the scientific potentiality of the data, Figure 2 shows the colour-magnitude diagram (CMD) for each of the observed fields. The CMDs include all the detected objects within the area covered by WFI, except for Berkeley 20 and NGC 2506. For these two cases the CMDs were computed using objects within a circular region of 3 and 5 arcmin in radius, respectively, around the nominal cluster centre in order to minimise foreground/background contamination. Figure 2 shows systems with well-defined main-sequences, probable binary sequences, blue straggler populations, red clump stars, potential white dwarf candidates, very red objects and systems with composite stellar populations, including very young stellar associations. The different pointings also provide valuable data for galactic structure studies.

*Figure 4: Same as in Figure 3 for the open cluster OC 26 (NGC 6253).*

Even though still a small sample, the examples presented here show the large variety of stellar systems being observed by the PF survey in terms of age, metallicity, size, distance and environment. The wide-area and the extended magnitude coverage (~ 13 mag) down to V ~ 23 provide an invaluable data set to extract samples suitable for the scientific drivers of FLAMES which include, among others, studies of: chemical abundances of stars in clusters and selected galactic components (bulge, disk, and halo); stellar kinematics and structure of stellar clusters; chemical composition and dynamics of nearby dwarf spheroidal galaxies; circumstellar activity in young stellar objects; very low mass stars and brown dwarfs in star-forming regions. In addition, the PF survey data can be combined to other publicly available data sets (e.g. 2MASS) which can greatly enhance the scientific value of the survey (see Momany et al. 2001). Moreover, combining the optical and infrared data may also allow for the spectral classification of objects by matching the photometric measurements against template spectra (Hatziminaoglou et al. 2001, submitted). This may help further disentangle different populations and search for particular types of stars.

## 7. Recent Developments

As mentioned above, at the time of the first release of the PF data there were two problems which had not been adequately addressed: a more general warping algorithm, to overcome the discreteness effects of the nearest-neighbour approach, and the fringing correction of the I-band images. In addition, the performance of the astrometric algorithm for very dense globular clusters had not been tested. These problems have now been addressed and the new algorithms are currently being tested. To illustrate the results of these tests, Figures 3–5 show colour images, covering 34 × 33 arcmin, of fields of different stellar density: a SMC field, an open cluster and one of the closest globular clusters. These images are the combination of the *B V I* DEEP images produced using the new warping algorithm. It is interesting to note the large number of stellar systems seen in the SMC field, among them: NGC 346, NGC 330, IC 1611, NGC 306, NGC 299, OGLE 109, OGLE 119, OGLE 99 (e.g. Bica & Dutra 2000 for an updated census of star clusters in the SMC). Figures 6–7 show cutouts around two of these systems. Note the absence of any detectable colour gradient in the images of the objects over the entire field of view. This result shows that the images in different passbands are accurately registered, attesting to the internal accuracy of the astrometric solution.

*Figure 5: Same as in Figure 3 for the globular cluster GC 10 (NGC 6121).*

The algorithms developed to deal with the PF survey data are currently being incorporated into the EIS survey system framework. This should allow the efficient reduction of all of the remaining data gathered by this survey. Current estimates of the pipeline throughput indicate that the image reduction part of a PF field takes about 23 minutes, not including overheads, well matched to the observing data rate. Once incorporated into the EIS data flow, it will be possible to reduce the images for the entire survey in ~ 40 hours.

Recently, new data from the PF survey as well as data publicly available in the archive have been used to further test the performance of the algorithms for a broader range of stellar densities, different observing strategies and filter combination. Some of these fields are shown in Figure 8, to illustrate the variety of systems considered so far. The ongoing tests have shown that the algorithms being implemented are robust and fast.

## 8. Summary

Based on the results presented so far and from the progress of the observations, the following goals of the survey have been met: (1) an astrometric accuracy better than ~ 0.10 arcsec; (2) a photometric accuracy below ~ 0.10 mag at the magnitude limit of FLAMES; (3) a completion level above 80% for the galactic fields; (4) a sufficient number of fields for commissioning, science verification and first year of operation. Equally important is that the new algorithms developed have proven to be robust, general and efficient, properly handling crowded stellar fields.

The PF survey has already covered 103 fields, corresponding to a total area of ~ 30 square degrees, surveying a variety of stellar systems and different directions of the Galaxy. The accumulated *B V I* data represent a valuable homogeneous dataset, with the final colour catalogues spanning almost 13 magnitudes. These data provide a wealth of information which can be used not only for the selection of FLAMES targets but also for a variety of other studies. It is important to emphasise that even though the filters being used are not standard for galactic work, the colour transformations seem to be adequate for most purposes. Finally, it is worth reminding that all the PF data will be publicly available before

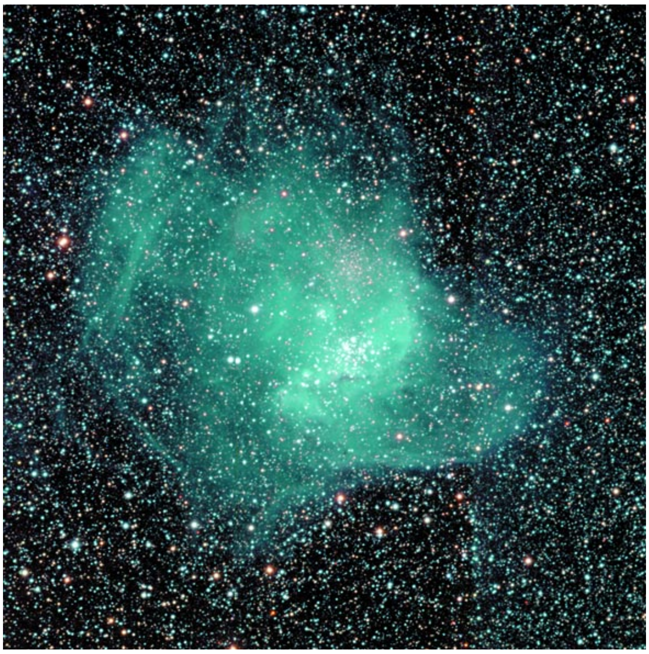
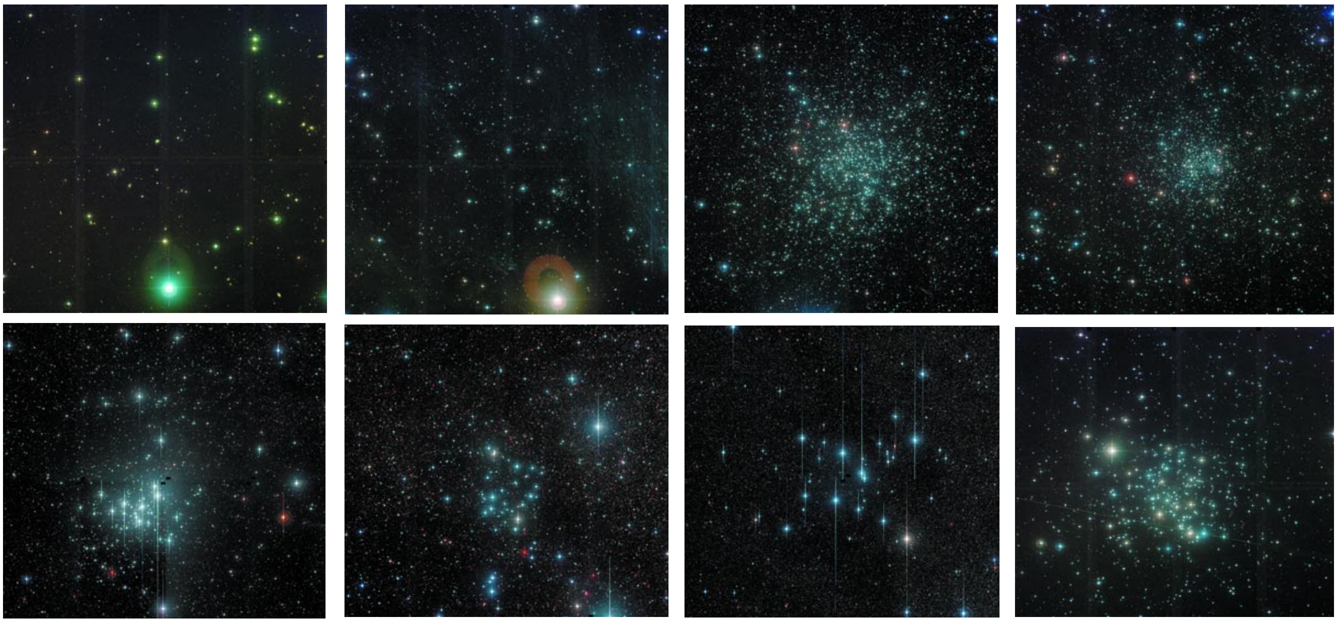


*Figure 6: Expanded view of NGC 346, the brightest HII region in SMC, extracted from the colour image shown in Figure 3. The figure shows a 8 × 8 arcmin region.*

*Figure 7: Expanded view of the globular cluster NGC 330 extracted from the colour image shown in Figure 3. The figure shows a 4 × 4 arcmin region. The seeing is ~ 1.3 arcsec.*



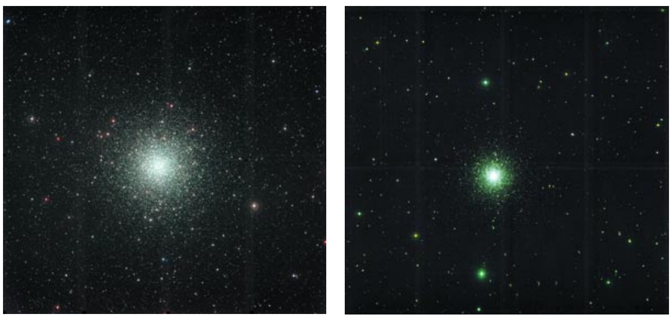


*Figure 8: Colour composite images, for a representative set of stellar systems, combining the* B V I *Pre-Flames images and the* U B V *images of the globular cluster NGC 1904 taken from the ESO Science Archive. The following fields are shown from the top left to the bottom right corners: OC 01 (Blanco 1); OC 03 (Berkeley 20); OC 12 (NGC 2477); OC 14 (NGC 2502); OC 25 (NGC6231); OC 27 (NGC 6281); OC 30 (NGC 6475); OC 99 (M 67); GC13 (NGC 6254); and NGC 1904. Each panel shows the full field of view of WFI.*

the beginning of operations of the FLAMES facility.

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