# OmegaCAM Secondary Standards preparatory programme - progress report

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## 1 Introduction

The photometric calibration of OmegaCAM depends on standard star catalogs with fields that cover the complete FoV of the instrument. For the year-round calibration of the instrument, a catalog fullfilling this requirement needs to include the following standard fields: a polar field unique for OmegaCAM, and extensions of the Landolt[6] equatorial fields SA92, SA95, SA98, SA101, SA104, SA107, SA110, and SA113. These catalogs must be built for the $u'$, $g'$, $r'$ and $i'$ bands (known as the **key bands**).

The OmegaCAM calibration plan foresees in constructing these standard star catalogs during Commissioning and during the first year of operations using OmegaCAM itself (see req. 569, Valentijn et al. [10]). However, a preliminary first version of such a catalog is needed at Commissioning for the early verification of the presence of illumination variations (see req. 548, Valentijn et al. [10]). The initial catalog will also be used for calibrating the Exposure Time Calculator (see req. 568, Valentijn et al. [10]).

### 1.1 Scope of this document

For the construction of a preliminary standard star catalog, two preparatory programmes are conducted by the Consortium. These programmes are caried out with the WideField-Imager (WFI) at the ESO-2.2m, and with the INT/WFC at La Palma. The latter programme was initiated because no Sloan filters are available on WFI@ESO-2.2m. This report gives the status of these preparatory programmes.

This report was also written at the request of ESO in order to demonstrate the accuracy of the DFS pipeline. The data reduction of the photometric standards obtained from La Palma (Sect. 3) is being carried out using this software. The results thus serve as a (necessarily only partial) demonstration that the specifications of the DFS software can be met on a real dataset.

During OmegaCAM operations the task of the DFS software will be to determine a photometric zeropoint from observations of a calibrated standard star field. The La Palma and WFI programmes discussed here, on the other hand, started from a few calibration stars which needed to be propagated to the standard star fields. Thus only the scatter in the derived, individual zeropoints on a single CCD can be used as a check on the S/W at present.

The WFI data (Sect. 2) turned out to be unsuitable for establishing photometric standards, particularly because the filter set differs from the OmegaCAM set, but also because of the bad photometric conditions during the observations. The work on the WFI data has, therefore, been discontinued. The WFI data is neither used in establishing photometric standards, nor in evaluating the quality of the OmegaCAM pipeline.

Table 1: The central pointings used in the WFI@ESO-2.2m observing run.

| STD FIELD | $\alpha$(2000.0) | $\delta$(2000.0) |
|---|---|---|
| SA 101 | 09 55 57 | −00 23 14 |
| SA 104 | 12 42 31 | −00 38 36 |
| SA 107 | 15 39 36 | −00 12 36 |
| SA 110 | 18 42 21 | +00 14 52 |
| NGC 5904 | 15 18 33 | +02 04 58 |
| SA113 | 21 40 35 | +00 41 45 |
| SA98 | 06 51 52 | −00 19 54 |

# 2 The WFI@ESO-2.2m preparatory programme

The discussion in the following sections has been adapted from the unpublished work of Navasardyan et al. [8]. We empasize that the WFI data set and the results derived therefrom are not used. The discussion below is added for completeness only.

## 2.1 Observing runs at the WFI@ESO-2.2m

Observations have been done using the WFI mosaic camera at the ESO 2.2m telescope. Observing time was allocated in three separate runs, for a total of 11 nights (April 20-26, 2000; July 9-13; February 3-7, 2001). Only 6 of these were photometric. The strategy was to cover $60 \times 60$ $arcmin^2$ standard fields in the B, V, R, I broad-band filters. This required at least 4 pointings for covering the necessary field with WFI. In order to secure a wide range of magnitudes, images with both a short and a long exposure time have been taken. A fifth, central pointing with a short exposure time has also been taken of every field for cross checking the photometric accuracy. The overall covering scheme was as follows: one central and 4 lateral pointings dithered by 15 arcmin in both the RA and DEC directions. The exposure times were about 8 sec (B, V, I) and 5 sec (R) for the short exposure time images, and 2×600 sec (B), 2×250 sec (V), 2×200 sec (R) and 2×300 sec (I) for the deep images. The fields observed are given in Table 1.

For the photometric calibration of the data, we made additional obeservations of the PG1323 field (21 April 2000) and the Rub149 field (5 February 2001). Both fields are from the catalog of Landolt[6]. The purpose was to require a proper color baseline for the calibration equation, and a better mapping of the chip-to-chip variations of the photometric zero point.

## 2.2 Data reduction : pre-reduction and astrometric calibration

Only the data collected during the first and last runs have been reduced as no useful data were obtained throughout July 9-13. The priority has been given to the more covered standards fields and the fields which also contain Stetson standard stars.

Pre-reductions were carried out using the MSCRED package in IRAF. Mean combined bias and twilightflat frames have been created for each run. The WFI images observed in the I band show a very strong fringing pattern which has been removed using the average fringing pattern as provided by the ESO2.2m telescope team [1]. This average pattern has been scaled to the actual value of the fringing in the image and removed. The astrometric calibration was performed for

[1] http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/

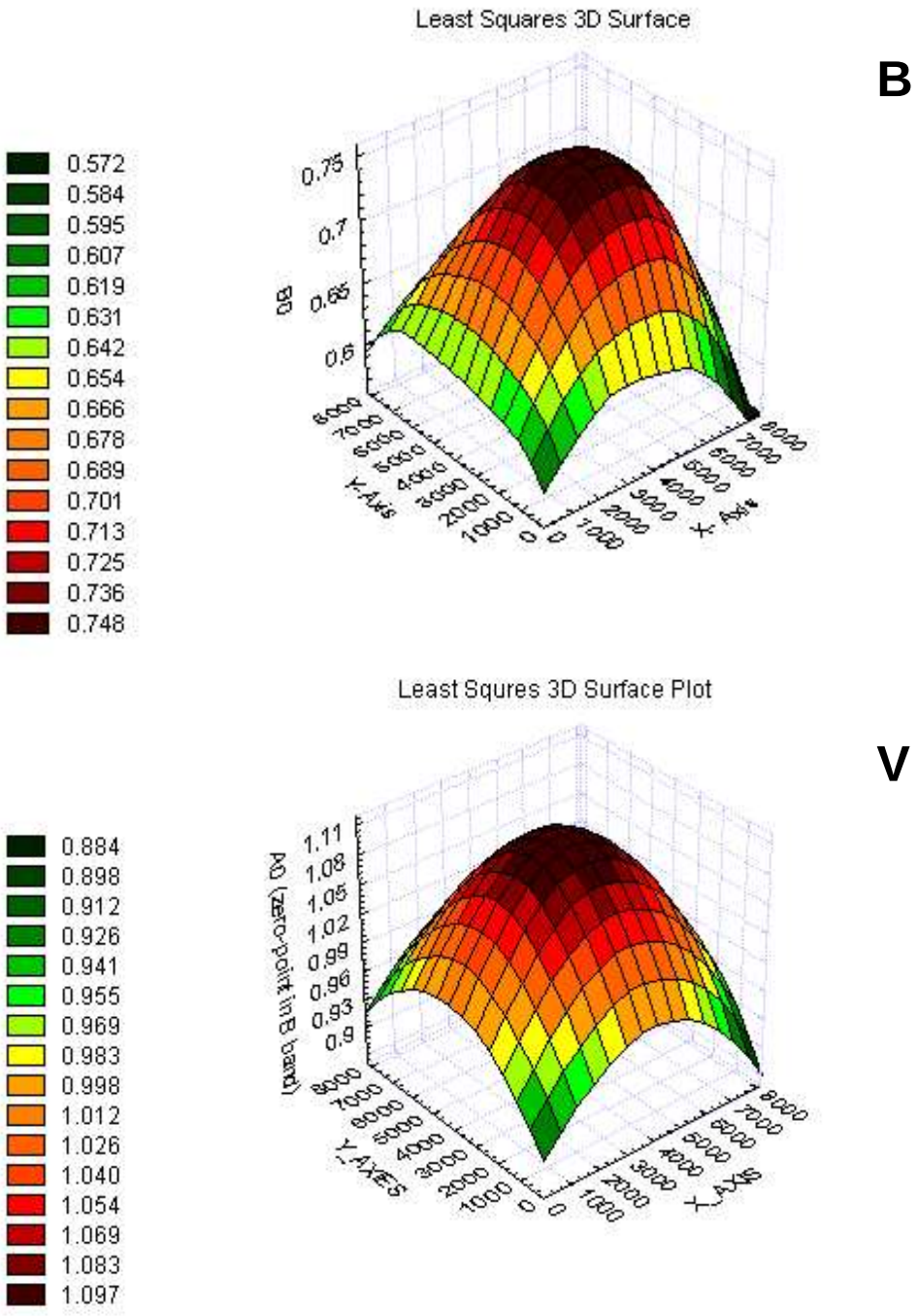


Figure 1: The zeropoint as a function of the X and Y positions in the B and the V bands, as fitted by a 3D least-squares surface. The figure is from Navasardyan et al. [8].

each CCD of the mosaic separately using USNO A2 catalogue entries. The astrometric solution was computed only for the V band, the B, R and I bands are simply matched with the V band images. The astrometric errors are less than 1 arcsecond. An illumination correction has been applied to the data using the assumption that the low-order structure variation seen in the flatfields was the result of illumination variations; a fit was made to this low-order variation and the flatfield was corrected for it. See Sect. 2.3.1 for some more discussion on this topic.

## 2.3 Data reduction : photometric calibration

The photometry has been done using the packages daophot and daogrow written by Stetson[12]. The instrumental magnitudes are based entirely on synthetic aperture photometry (bright isolated stars), or profile-fitting photometry with aperture curve-of-growth correction (fainter stars, or those with neighbors less than a few arcseconds away). Star selection is done using parameters like sharpness and roundness of the profile. The zeropoints and color terms were calculated for each CCD of the mosaic using both Landolt and Stetson standard stars. As the data were not sufficient to derive also the extinction correction, the average extinction coefficients $k_i$ adopted were $k_B = 0.22$, $k_V = 0.12$, $k_R = 0.09$, and $k_I = 0.05$.

### 2.3.1 Illumination correction

It is already known from the work of various authors that, in general, wide field cameras suffer from photometric inhomogeneities. This is also true for the WFI at the ESO 2.2m telescope; Alcala et al. [1] stress the photometric inhomogeneity among different CCDs. Accurate photometry requires that these inhomogeneities are characterized and corrected for.

The photometric inhomogeneity is unfortunately not a simple offset among CCDs; a significant photometric gradient is evident even across one single chip (Manfroid et al. [7], Koch et al. [5]). This non-uniform illumination is usually attributed to an additional light-pattern caused by internal reflections off the telescope corrector which cannot be corrected by the standard flatfielding procedures. In order to correct for the effect, one must know the spatial distribution of this pattern. Manfroid et al. [7] describe some strategies for dealing with these calibration errors, but these require special observations. The correction coefficients provided by Koch et al. [5] are only for the V and R bands.

For studying the photometric inhomogeneity across the mosaic area in this work, Landolt[6] standard stars have been combined from SA98, SA101 and Rubin 149. In order to enlarge the set of standard stars for SA98 also Stetson standards have been included [2]. Assuming that the color term is constant over the whole mosaic area and using the averaged value over all the chips, the zero points have been calculated for each standard star. Only brighter stars (those with magnitude less than 15) are used for this purpose. Least-squares 3D surfaces have been fit for the V and B filters. The results are shown in Fig. 1. Both fits show that there is a radial structure.

## 2.4 WFI results

Standard star catalogs have been extracted from the data for SA110 and for NGC5904. Excerpts from both these catalogs are given in Tables 7 and 8. The complete catalog for NGC5904 lists 4614 stars, and for SA110 3506 stars. A comparision between our magnitude estimates and the magnitudes from the Stetson stars that were included in our catalogs is shown in Figs. 2 and 3. While the results for the NGC5904 field appears to be acceptable, the dispersion in the SA110 field appears definitely larger than our goal. We believe that this is entirely related to

[2] *Stetson Photometric Standards*, web site : http://cadcwww.hia.nrc.ca /standards/

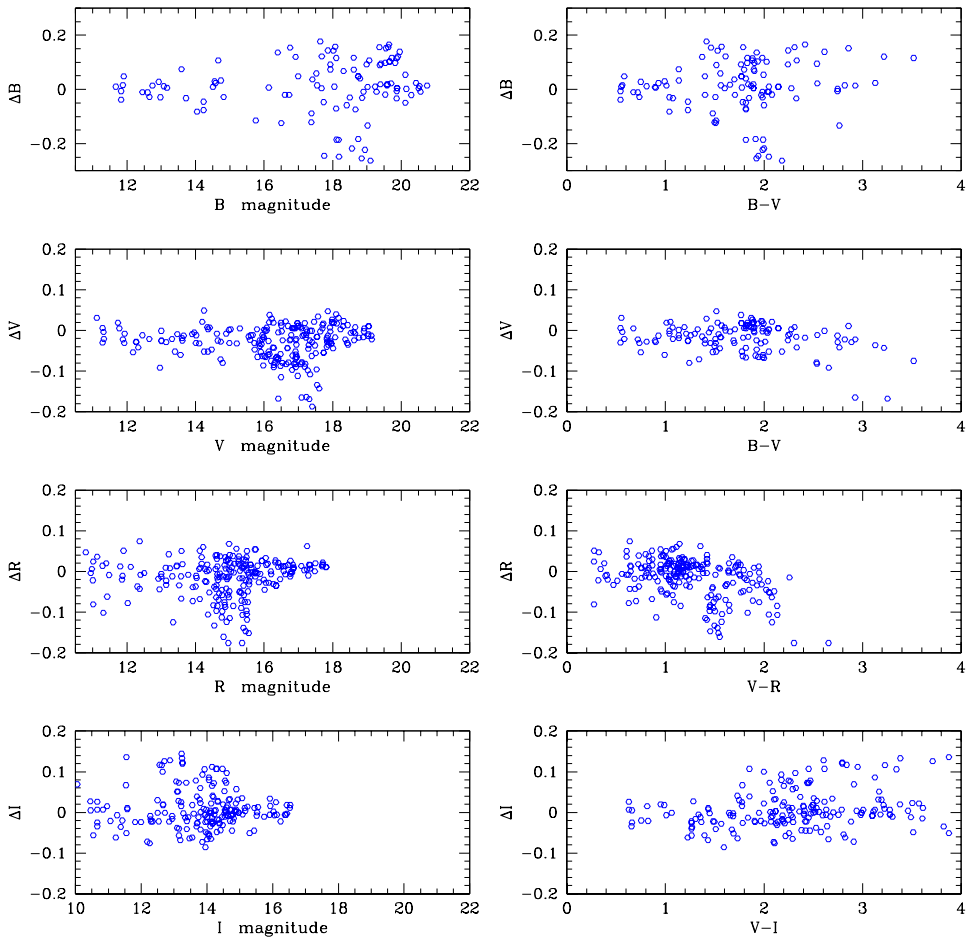


Figure 2: The difference between our photometry of SA110 in the B, V, R, I band-passes and that of Stetson. In each of the panels, the ordinate shows $M_{Stetson} - M_{present\ work}$, and the abscissa $M_{Stetson}$. The figure is from Navasardyan et al. [8].

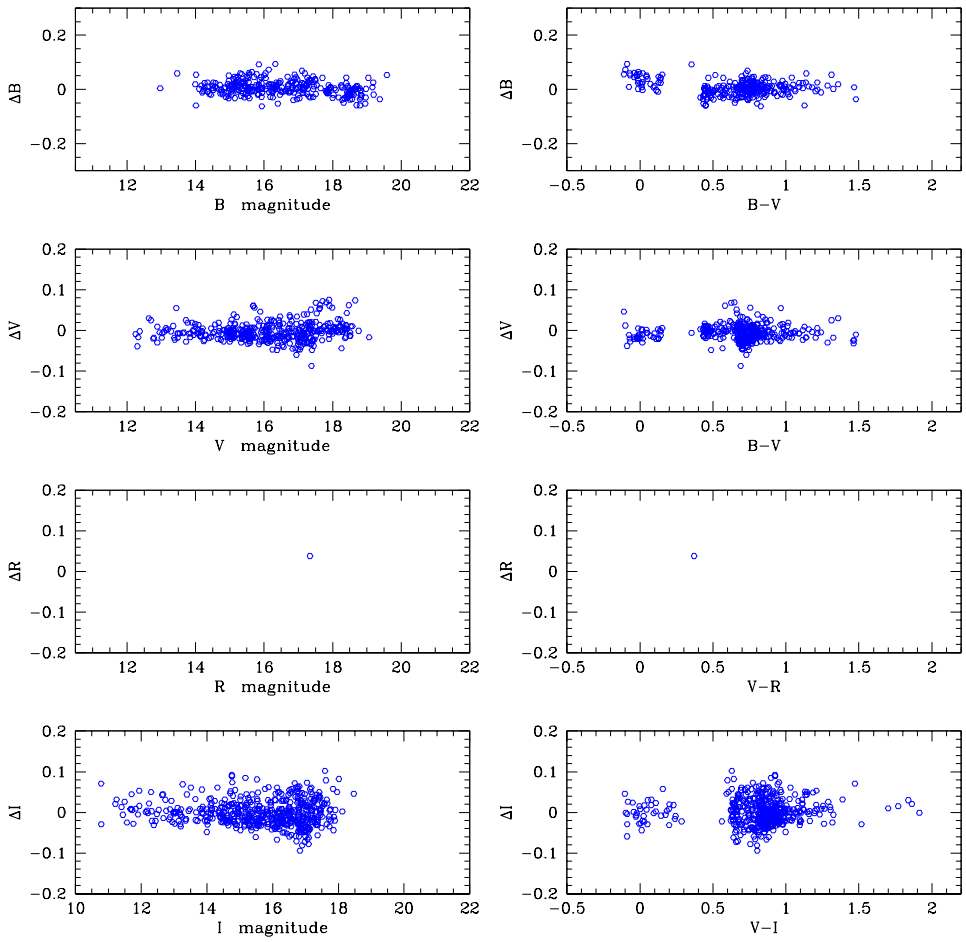


Figure 3: The difference between our photometry of NGC5904 in the B, V, R, I band-passes and that of Stetson. In each of the panels, the ordinate shows $M_{Stetson} - M_{present\ work}$, and the abscissa $M_{Stetson}$. The figure is from Navasardyan et al. [8].

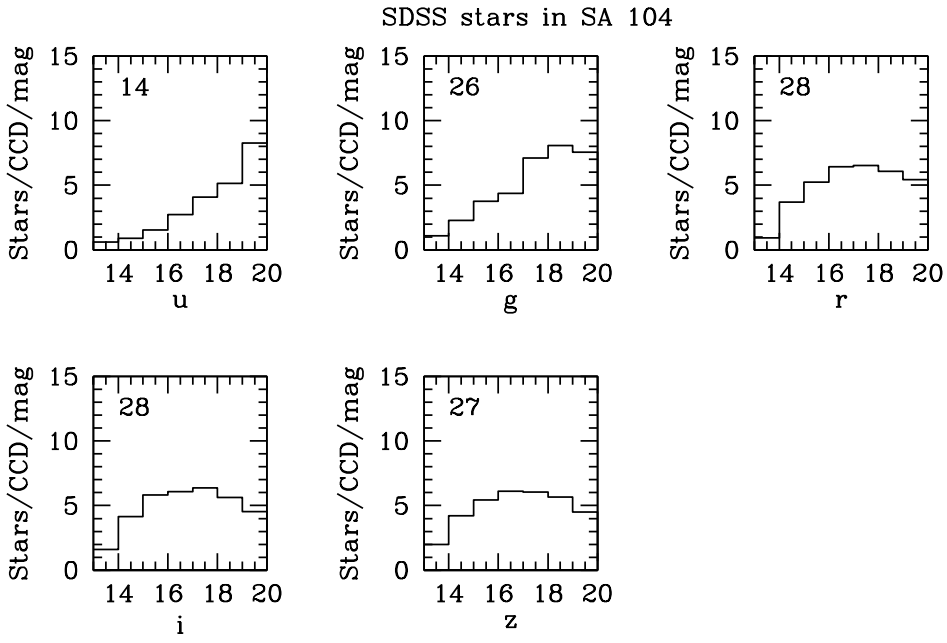


Figure 4: The magnitude distribution of the standard stars in SA104, taken from SDSS Data Release 3. SA104 is the standard field with the highest galactic latitude. The average number of stars per CCD between 14th and 19th magnitude in each filter is printed in each panel.

the limitations of the observational material for SA110. The catalog for SA110 is, therefore, limited in its usefulness.

# 3 The La Palma - INT/WFC preparatory programme

## 3.1 Observing runs at the INT/WFC

The La Palma preparatory programme is based on data from three observing runs using the WideField-Camera (WFC) on the 2.5m Isaac Newton Telescope. Like WFI, the WFC is a CCD mosaic camera covering an area of about $0.5^\circ \times 0.5^\circ$, but it uses fewer CCDs than WFI (4) with a larger pixel scale ($0.333''$). The runs were performed in February 2002, June 2002 and February 2003, respectively. The first of these runs suffered from bad weather, and of the total of 15 nights allocated to the programme approximately half were photometric. The Landolt fields observed are given in Table 2. Every Landolt field was observed in a 5-point dither covering $\sim 1.1 \times 1.1$ square degree on the sky. To cover an adequate range of magnitudes, of every pointing both a short ($\sim$ 10s) and a long exposure ($\sim$ 300s) were made. All the observations were done in the $u'$, $g'$, $r'$ and $i'$ bands. Of all the equatorial Landolt fields needed for OmegaCAM only SA95 has not been observed. The total volume of raw data generated over the three runs combined is $\sim$ 200 Gb.

Stars between 14th and 19th magnitude can be used for calibration. The equatorial fields have average surface densities of between 20 and 80 such stars per $7.5' \times 15'$ OmegaCAM CCD, depending on the passband and the galactic latitude (see Figure 4).

Table 2: The central pointings used in the La Palma INT observing runs. The level of completion for the data reduction is given in the penultimate column. Fields identified with a * are covered by the SDSS DR3. SA95 could not be observed.

| STD FIELD | $\alpha$(2000.0) | $\delta$(2000.0) | $l^{II}$ | $b^{II}$ | Completion | Run |
|---|---|---|---|---|---|---|
| SA 92* | 00 55 47 | +00 56 57 | 125 | -61 | 0% | June 2002 |
| SA 98 | 06 52 05 | −00 19 41 | 213 | 0 | 100% | February 2003 |
| SA 101* | 09 56 27 | −00 23 09 | 238 | 40 | 100% | February 2003 |
| SA 104* | 12 42 22 | −00 33 09 | 298 | 62 | 100% | February 2003 |
| SA 107* | 15 39 35 | −00 15 07 | 6 | 41 | 100% | June 2002/Feb 2003 |
| SA 110 | 18 42 43 | +00 20 53 | 32 | 2 | 100% | June 2002 |
| SA 113* | 21 42 08 | +00 29 36 | 56 | -36 | 50% | June 2002 |

### 3.2 Data reduction

All data has been reduced with the OmegaCAM pipeline. The data reduction consisted of the usual steps of de-biasing, flatfielding and astrometric calibration. The masterflat was constructed from domeflats and twilightflats. For the $i'$ band some fringing was present, but the pattern was not pronounced enough to derive a reliable fringeflat; no de-fringing has therefore been applied. One issue impacting on the quality of the final reduction that has not been addressed yet is the non-linearity of two of the chips of the INT/WFC (in one case, up to 10%!). This issue is under investigation. The progress made so far in the data reduction of the La Palma data is given in Table 2. Analysis of the measurements continues.

### 3.3 Color terms

Color terms for the $u'$, $g'$, $r'$ and $i'$ bands have been determined for our data. The analysis was based on catalogs derived from the data of all the five pointings in the fields SA101 and SA107 using the secondary standard stars from SDSS DR3. The catalogs were derived using the standard photometric pipeline recipe (**Recipe- PhotCal_Extract_Resulttable** - req. 562), and analyzed interactively.

The color terms were all found to be small or even non-existent. This is not surprising, because the Sloan filters at the INT/WFC closely match the original ones. The color terms for $g'$ and $i'$ are $0.14 \pm 0.01$ and $0.07 \pm 0.01$, respectively, using ($g'$-$r'$) and ($r'$-$i'$) as the colors. No evidence for any color term was found for the $u'$ and $r'$ bands. Figure 5 shows some of the data on which the results are based. Further analysis will improve on the uncertainty on the results.

### 3.4 Illumination correction

No illumination gradients across the detector block of the INT/WFC are known to exist (M. Irwin, private communication). Nevertheless, the possible presence of these gradients has been verified (**Recipe- Illumination_Correction_Verify** - req. 548). These checks are done by plotting the zeropoints of the individual standard stars against their x and y position in the focal plane of the INT/WFC. The verification did not reveal any appreciable illumination variations. The results for the $g'$ band are shown in Fig. 6. The data points from the different chips have been corrected for chip-to-chip differences in the gain, and the color term for the $g'$ band has been applied (see Sect. 3.3). The figure shows that if any illumination variation is present, that it is below 0.03 mag across the whole FoV.

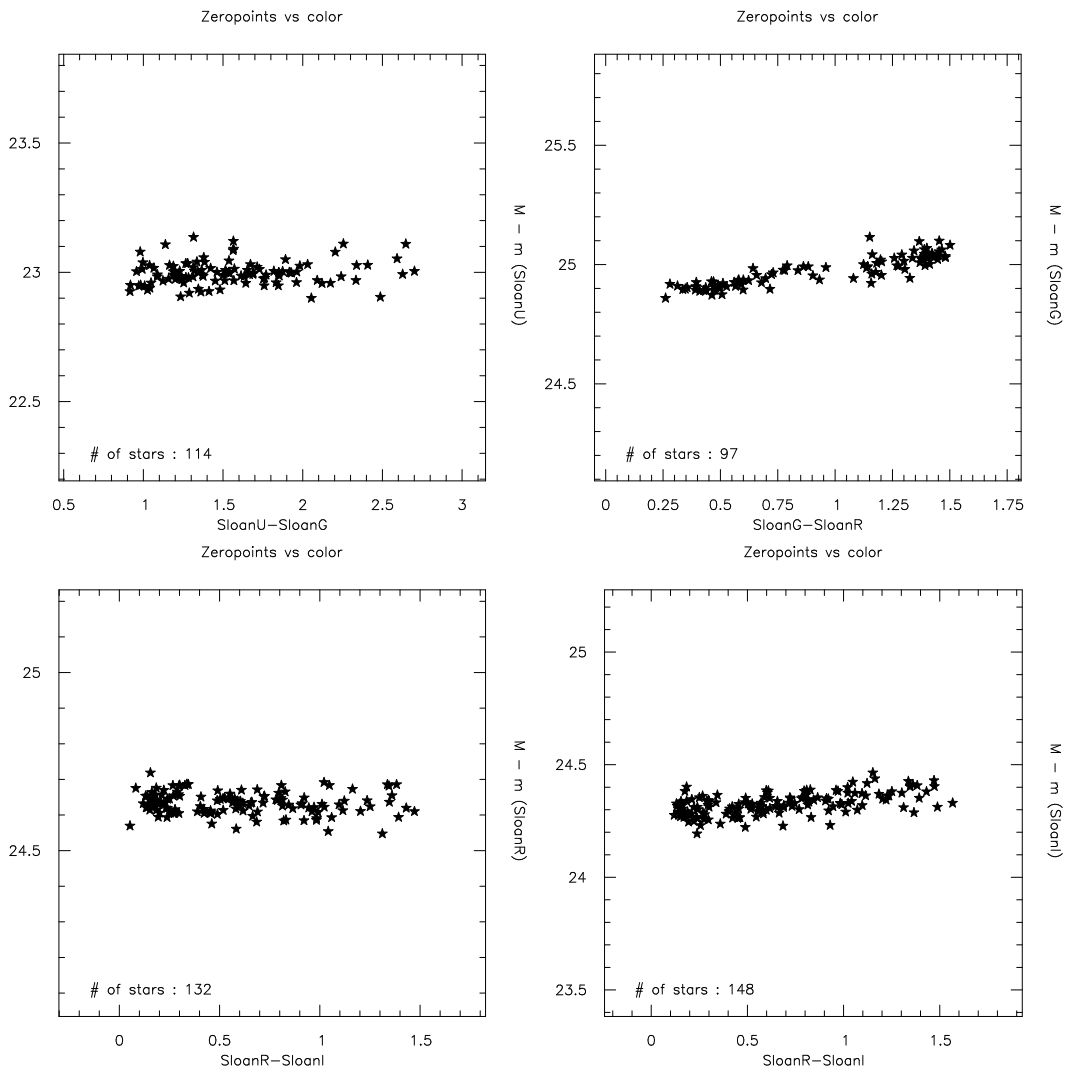


Figure 5: Zeropoint-vs-color plots for the $u'$, $g'$, $r'$ and $i'$ bands. The data for the standards used in the analysis is obtained from SDSS DR3. In each panel, the x-axis shows the color as catalogued in SDSS DR3, and the y-axis shows the difference between the SDSS DR3 magnitudes of the stars and our measurements.

### 3.5 Preliminary results - a typical table

Source catalogs have been derived from the data. To give an example of the large quantity of suitable standard stars that can be found on just one chip, a catalog that has been derived for one extension (chip) of the central pointing of SA98 is presented here. The measured fluxes from the stars on this extension were compared with the measured flux of the standard stars 98-1124 and 98-634 also present on this extension. These two standards were put on the Sloan system by applying the transformation equations from Smith et al. [11]. The resulting catalogs contain each $\sim 880$ candidate sources in the $14 < m < 19$ range. Excerpts of these catalogs are shown in Tables 9 and 10 for the $g'$ and $r'$ bands, respectively.

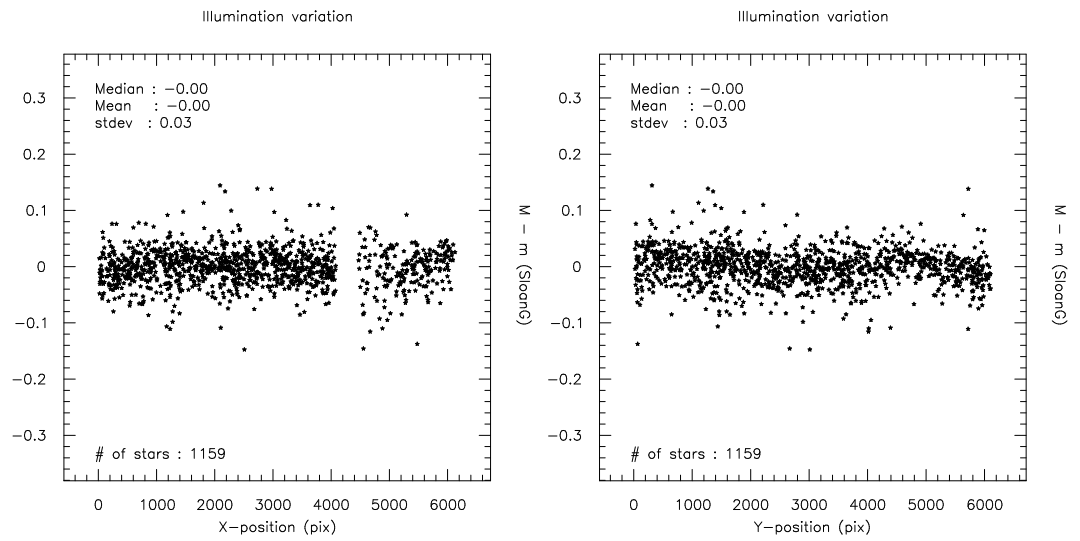


Figure 6: Zeropoint-vs-position plot for the $g'$ band. The data for the standards used in the analysis is obtained from SDSS DR3. In both panels, the x-axis shows the pixel positions of the individual standard stars in the focal plane of INT/WFC. The y-axis shows the difference between the SDSS DR 3 magnitude of a star and the one measured by us. The data points from the different chips have been corrected for chip-to-chip differences in the gain, and the color term for the $g'$ band has been applied to our measurements (see Sect. 3.3).

# 4 Error budget - error propagation

A break-down of all the sources of error in the OmegaCAM pipeline is presented in Table 3. The table gives the accuracy of the separate steps as required by ESO-DFS (when applicable), and a reference to the relevant requirements as described in Valentijn et al. [10] and Rengelink et al. [9]. Also given in this table is the achieved accuracy. The items in this table are briefly discussed in this section. The photometric part of the pipeline uses fully reduced images as input, so any errors propagating through the image processing part of the pipeline also play a role here. The quality of the photometry is, therefore, a good measure of the quality of the processing system as a whole.

## 4.1 Flat-fielding

The flatfielding in the OmegaCAM pipeline is done using a master flatfield (**Recipe- Master Flat** - req. 546) that is derived from a suitable combination of master domeflat, master twilight-flat and (if available) master nightskyflat frames. After flatfielding the science data, the flatness of the background should be accurate within 2%.

Tests of the quality of the flat-fielding have been performed on WFI data observed in the U, B, V, R and I bands (Héraudeau[4]). For most of these, the quality of the flat-fielding meets this criterium (especially I). For the U band, the results are inconclusive (see also Table 3).

## 4.2 Illumination correction

The OmegaCAM system treats the illumination correction as a multi-step process. First, a quick verification is done to ascertain whether illumination variations are actually present (**Recipe-**

Table 3: Summary of sources of error in the OmegaCAM pipeline. The second column gives the accuracy as stated in the requirements (also required by ESO-DFS). The third column gives the achieved accuracy. The entries in the last column refer to the applicable requirements as described in Valentijn et al. [10] and Rengelink et al. [9].

| Source of error | Required acc. | Achieved acc. | Note | Ref. |
|---|---|---|---|---|
| bias | $(\mathrm{RON}/\sqrt{10})^{\dagger}$ | $\sim 0.1\%$ | 1 | req. 541 |
| flat-field | $< 2\%$ | $\sim 0.5\%$ | 2 | reqs. 542-547 |
| illumination correction | $< 1\%$ | N.A. | | req. 548 |
| astrometric calibration | $0.1''$ rms | $0.17''$ rms ($\alpha$)<br>$0.10''$ rms ($\delta$) | | seq. 634 |
| measured standard star magnitudes | $< 0.03$ mag | $\leq 0.02$ mag | 3 | |
| catalogued standard star magnitudes | $< 0.02$ mag | $\sim 0.09$ mag | 4 | req. 569 |
| color terms | $< 2\%$ | N.A. | | req. 565 |
| atmospheric extinction | $< 5\%$ | N.A. | | req. 562 |
| zeropoint | $< 5\%$ | $\simeq 1\%$ | 5 | reqs. 563-564 |

† : the accuracy of the master bias is described in terms of the readout noise (RON).

Note 1:
Two master biases, derived from data of two different observations, were divided to get the result. Both were made from 10 raw bias images and the readout noise was 2.0 ADU.

Note 2:
Two master flat fields, derived from data of two different observations, for the same filter and chip were divided to get the result.

Note 3:
Tests of the quality of the aperture photometry are described in Section 5.2. There it was concluded that, for apertures in the range of 3 to 5 times the PSF_FWHM, the difference between MAG_ISO and MAG_APER were less than a few hundreds of a magnitude. The adopted MAG_ISO (and thus the algorithm used to the determine the total flux), has internal uncertainties smaller than 0.02 mag.

Note 4:
This number represents the accuracy of the secondary standards at present, not taking into account any color terms or illumination correction (to be determined for La Palma). But see Note 5.

Note 5:
Averaging the zeropoints derived from 20 stars (most CCDs will have at least this many standard stars on them) gives an accuracy improvement of a factor 4.5. Fig. 7 shows that this can be realized: it shows a comparison between the zeropoints derived for 26 Landolt stars on a single CCD. Landolt's magnitudes [6] were transformed to the SDSS system using the color equations of [11], which should be accurate to 0.01 magnitude. The results are shown in the left panel of Fig. 7. No color terms for the WFC filters were applied. The r.m.s. of the set of zeropoints is $\sim$ 0.09 mag, resulting in a mean zeropoint for the CCD determined to an accuracy of 0.02 mag. The three outliers are removed from the input data through $\sigma$-clipping. The sigma-clipping removes stars from the sample that have mistakenly been identified as a standard star, or that suffer from irregularities in their aperture photometry (e.g. includes a cosmic ray). The right panel of Fig. 7 shows the same stars plotted against their $g'-r'$ color. The r.m.s. scatter seen in the left panel is clearly dominated by color terms (see also Sect. 3.3). Removing a linear color term results in a scatter of only 0.03 mag (see also Fig. 6), allowing the mean to be determined to better than 0.01 mag.

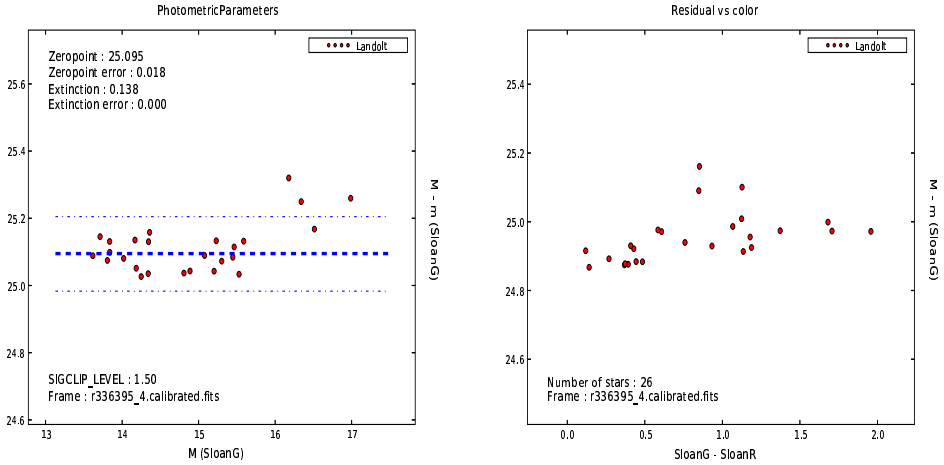


Figure 7: The result of using **Recipe- PhotCal_Extract_Zeropoint** (req. 563) on a single-CCD image observed in the $g'$ band for 26 standard stars from the Landolt [6] catalog (left panel). In the left panel, the x-axis shows the $g'$ magnitudes of the standard stars as derived from their catalogued B and V magnitudes and using the transformation equations of Smith et al. [11]. The right panel shows the same stars plotted against their $g'-r'$ color. Both the $g'$ and $r'$ magnitudes of the standard stars were derived from the catalogued B and V magnitudes using the transformation equations of Smith et al. [11]. In both panels, the y-axis shows the difference between the transformed magnitudes and the ones measured by us.

**Illumination_Correction_Verify** - req. 548). The results from Sect. 3.4 show that the catalogs produced by the photometric pipeline are accurate enough to do such a quick verification. Second, if any illumination variation is present, it is characterized by fitting the variation of the raw zeropoints of the standard stars as a function of position on the CCD in an interactive analysis (req. 548). This fit is then used to derive an illumination correction frame (**Recipe-Illumination_Correction** - req. 548). This frame is applied to the science data in the image reducing part of the pipeline. The accuracy of the correction to be applied should be good enough to make sure that the 'photometric flatness' across the CCD is better than 1% ($< 0.01$ mag variation in the raw zeropoints across the CCD).

In the case of OmegaCAM, we have the advantage that the focal plane is covered by many CCDs, and of each of these the zeropoint is determined separately and independently. The variation of the illumination across a particular CCD will be a small fraction of the peak-to-peak variation over the full field.

### 4.2.1 Verifying the presence of illumination variations

The **Illumination_Correction_Verify** recipe creates two sets of products that are used in the verification process: a set of photometric catalogs (the same kind as is produced by **Recipe-PhotCal_Extract_Resulttable**), and a set of zeroth-order illumination correction frames. To show the effectiveness of the recipe, the results of running it on a particular WFI image are shown here. Details of the image used are given in Table 4. The WFI image has been fully reduced with the OmegaCAM pipeline (no illumination correction applied), and the secondary standards used by the recipe were those of SDSS DR3. To derive the R magnitude from the Sloan ones, the transformation equations of Smith et al. [11] were used.

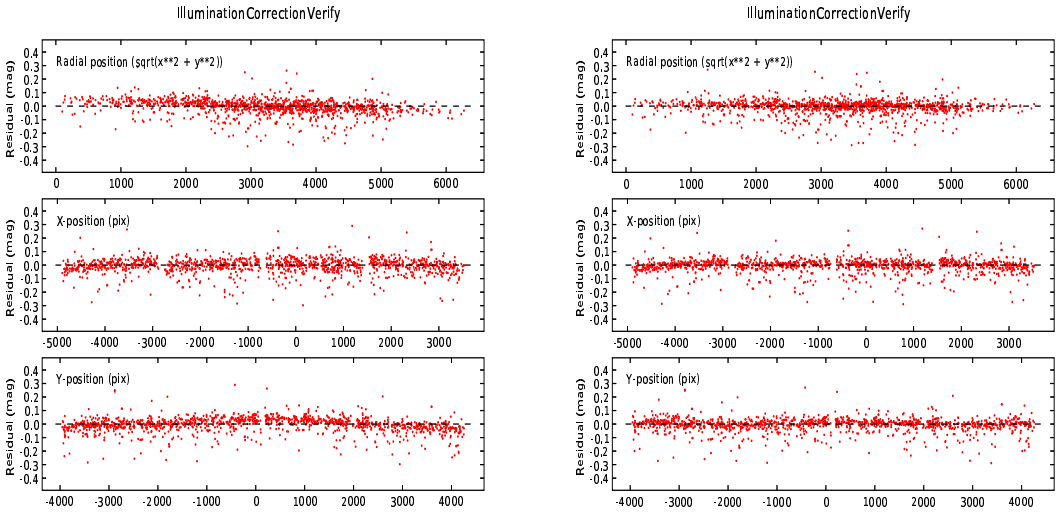


Figure 8: The raw zeropoints of the standard stars on the test WFI image (see Table 4) versus their y-position (bottom), x-position (center) and radial position (top) in the WFI focal plane. The left panel shows the zeropoints *before* applying a rough correction for the illumination variation, the right panel shows the same data *after* applying this correction in the image processing part of the OmegaCAM pipeline. The raw zeropoints from the different chips have been corrected for chip-to-chip differences in the gain. The data for the standards is taken from SDSS DR3. The R magnitudes have been derived from the catalogued $g'$ and $r'$ magnitudes using the transformation equations of Smith et al. [11].

The measured zeropoints of the standard stars on the image as processed by the recipe are plotted in the left panel of Fig. 8 versus their position in the focal plane of WFI. Every single CCD of the image contained approximately 150 suitable standard stars. It is clear from this figure that large variations in the zeropoint across the focal plane do exist. The amplitude and rough shape of the variation in both the x- and y-direction are comparable to those found by Koch et al. [5] (see their Fig. 4).

The illumination correction frames produced by the recipe are shown in Fig. 9 as a multi-extension FITS file. The top-left frame belongs to CCD50, and the bottom-right one to CCD54. The pixel values have linear units so that for image processing purposes the frames can be treated as a flatfield. The pixel values in this image vary from 1.02 in the center to 0.94 in the corners (this corresponds to a variation of 0.08 mag).

To get a feeling for the minimum requirements a given image should meet for the recipe to produce meaningful results several more WFI images were processed by the same recipe. It turned out that in order to get meaningful results, at least 100 or more suitable standard stars should be present on every CCD.

### 4.2.2 Applying the illumination correction

To show that the OmegaCAM pipeline is capable of applying a correction for illumination variations, the WFI image used in Sect. 4.2.1 has been re-processed by the standard OmegaCAM pipeline using the illumination correction frames displayed in Fig. 9. Photometric catalogs have

then been derived from the image. The measured zeropoints in these catalogs are plotted in the right panel of Fig. 8.

The right panel of this figure shows a clear improvement in the photometric flatness of the image when compared to the left panel. Especially in the y-direction, the variation of the zeropoint has almost vanished and is well below 0.1 magnitude. The scatter in the zeropoints also seems to have been decreased. The case for the x-direction is less clear, but also here a reduction in the scatter is visible. Any residual variation in the zeropoint is possibly due to the 'rough' nature of the illumination correction frames that are automatically generated by the **Illumination_Correction_Verify** recipe. A more thorough, interactive characterization of the illumination variation that also takes into account small-scale variations will remedy this.

## 4.3 Astrometric calibration

The astrometric calibration in the OmegaCAM pipeline is a separate step in the image processing part of the pipeline. The accuracy of the astrometric calibration is required to be better than $0.1''$ rms. This is important for accurate co-addition of science data. The photometric part of the pipeline depends on good astrometric calibration to properly identify the photometric standard stars (see Sect. 5.1).

The input reference catalog for the astrometric calibration is the USNO A2.0 catalog of which the sources have a positional accuracy of $0.3''$ rms. The results of testing the astrometric calibration with the OmegaCAM pipeline on WFI data are presented in Fig. 10. The tests show that the accuracy of the astrometric calibration is $0.10''$ for the declination and $0.17''$ for the right ascension. The uncertainty on the astrometric calibration is dominated by the positional accuracy of the sources in the USNO catalog.

## 4.4 Measuring the standard star magnitudes

Sufficiently accurate aperture photometry on the standard stars in a field is crucial for the quality of the photometric calibration. With a required accuracy of 5% on the overall photometric calibration in the **key bands**, this means that the accuracy on the measured magnitudes should be better than $\sim 0.03$ mag; this amounts to approximately 97% of the flux inside the aperture or better. In the photometric pipeline, the aperture photometry is delegated to SExtractor[2] (**Recipe- PhotCal_Extract_Resulttable** - req. 562). Some results on testing the performance of the automated aperture photometry are discussed in Sect. 5.2.

## 4.5 Standard star magnitudes and color terms

The **key band** magnitudes of the stars in the Secondary Standard Star Catalog are required to have an accuracy better than 0.02 magnitude. The required accuracy of the color transformation terms used in the photometric calibration is 2% for the calibration of the **user bands**, and 1% for the transformation between the **key band** monolithic filters and the **composite filter** (req. 565 - to be determined interactively). Color transformations, if needed, are performed on the *catalogued* magnitudes of the standard stars.

## 4.6 Atmospheric extinction coefficient and zeropoints

The uncertainty on the parameters derived by the photometric part of the pipeline is tied up with all of the errors described in the sections above. The accuracy of the atmospheric extincion coefficient and the zeropoints is required to be better than 5% for the **key bands**. To obtain such an accurate value for both these parameters, a large number of standard stars are needed per CCD (the results plotted in Fig. 6 show that a zeropoint more accurate than 0.01 mag can

Table 4: The WFI image used in the test for the illumination verification.

| | | |
|---|---|---|
| Image | : | wfi26628 |
| Field observed | : | SA 113 |
| Observing date | : | 18 June 1999 |
| Exposure time | : | 420 sec |
| Filter | : | #844 (R) |
| Airmass | : | 1.47 |

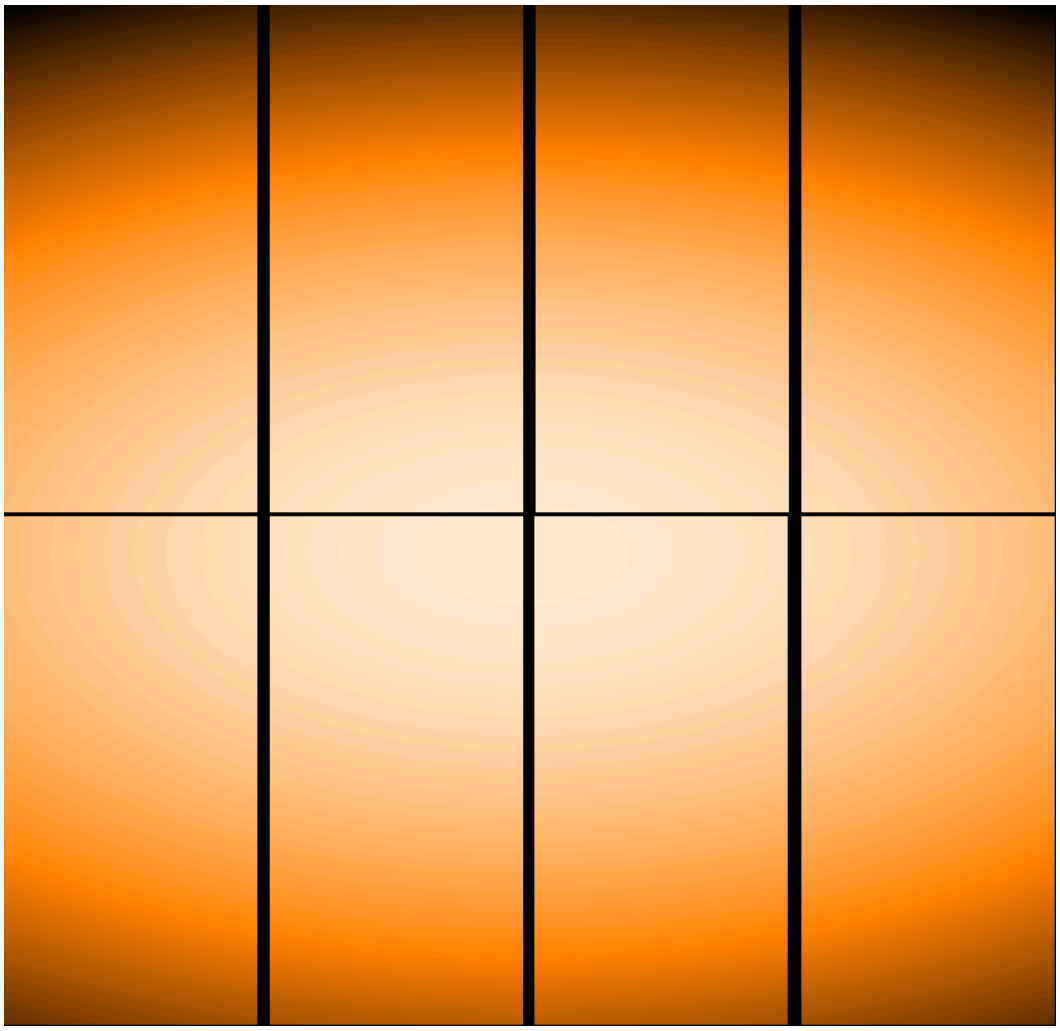

Figure 9: The eight illumination correction frames as produced by **Recipe- Illumination_Correction_Verify** from the test WFI image (Table 4). The pixel values in this image vary from 1.02 in the center to 0.94 in the corners. The top-left frame belongs to CCD50, the bottom-right one to CCD54. The figure was obtained from *skycat* at a scale factor of 1/10.

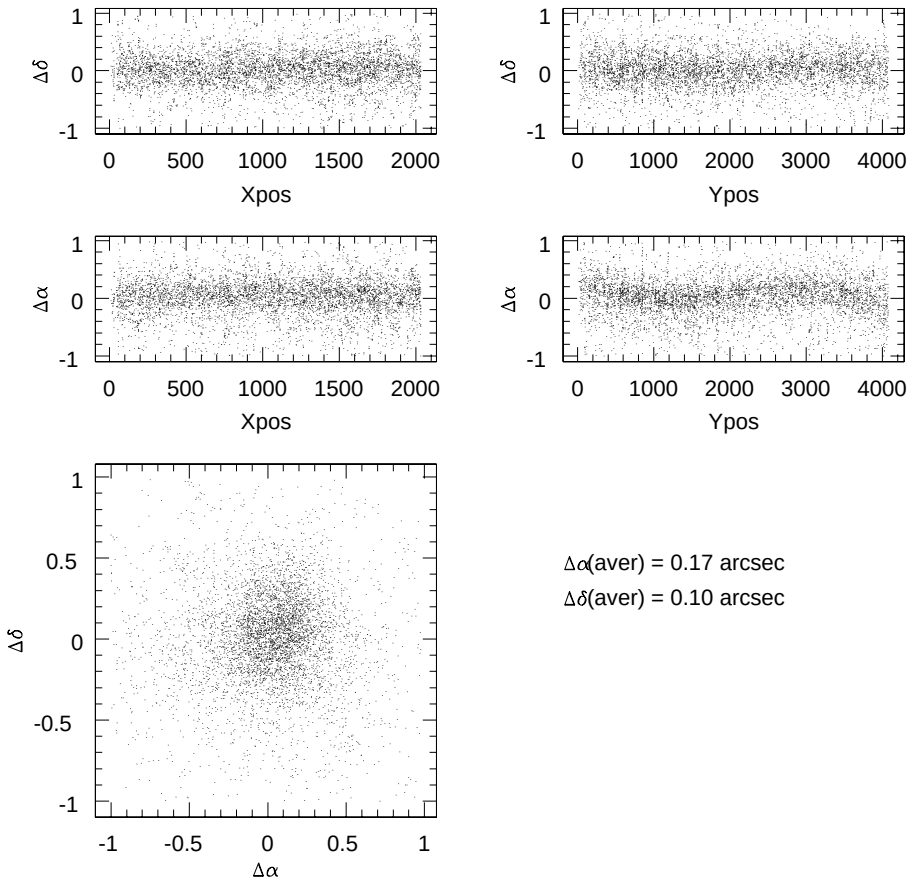


Figure 10: The residuals in the $\alpha$ and $\delta$ values after astrometrically calibrating WFI data with the OmegaCAM pipeline. The top panels show the residuals as a function of pixel postion on the CCD.

be derived). In Figure 4, the magnitude distribution for the worst-case, highest-latitude field (SA104) is given: in each band there are at least 20 stars per CCD in the 14–19 magnitude range (17 in $u'$).

## 4.7 Error budget - residuals

The source catalogs for SA98 presented in Tables 9 and 10 contain $\sim$ 20 standard stars from the original Landolt[6] catalog. A comparison between the known magnitudes of these stars, and the values found here (the residuals $\Delta g'$ and $\Delta r'$) provides a handle on the quality of the image processing part of the pipeline. The results of the comparison are shown in Fig. 11. The scatter on the results is $\sim$ 0.06 mag. The only 'photometric' sources of this scatter could be the lack of an illumination correction and not taking into account possible color terms. The transformation equations of Smith et al. [11] were used to put the stars from the Landolt [6] catalog on the Sloan system.

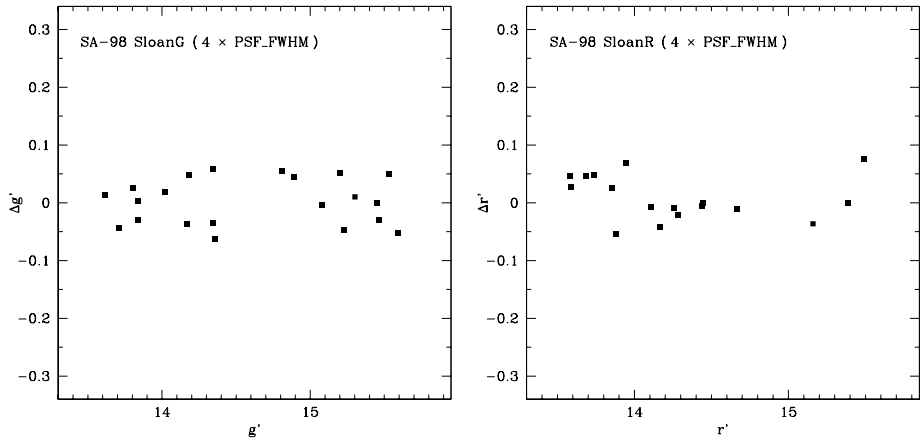


Figure 11: Residual-versus-Sloan magnitudes for the SA 98 catalog given in Tables 9 and 10. The $\sim$ 20 stars from these tables plotted in the figure are standard stars also present in the Landolt [6] catalog. The transformation equations of Smith et al. [11] were used to derive the $g'$ and $r'$ magnitudes from their B and V magnitudes. The x-axis shows these transformed $g'$ and $r'$ magnitudes. The residuals $\Delta g'$ and $\Delta r'$ shown on the y-axis are the difference between the transformed magnitudes of the standard stars and the ones found here. The residuals provide a handle on the quality of the image processing part of the pipeline. The scatter is a (conservative) upper limit on the uncertainty that propagates into the photometric part of the pipeline.

# 5 Comments on specific software tasks

The photometric software for the OmegaCAM pipeline makes heavy use of source catalogs. These are either catalogs extracted from images of standard fields, or standard star catalogs. The extraction of source catalogs from the input science images is delegated to a dedicated part of the OmegaCAM photometric pipeline (**Recipe- PhotCal_Extract_Resulttable** - req. 562). Two aspects of the catalog extraction that are of particular importance are the robust and correct identification of standard stars, and the quality of the aperture photometry performed on these stars. Both issues will briefly be discussed in this section. Also given is a break-down of the processing time needed for running the full photometric pipeline.

## 5.1 Standard star identification

Standard star identification is currently done by the *prephotom* tool from LDAC[3]. Although less elaborate than the LDAC *associate* machinery, the performance is found to be good. The robustness of the standard star identification is enhanced by carefully cleaning the source catalogs before association with the standard star catalog. The photometric software removes sources from the catalog that have been flagged by SExtractor[2] as being saturated or having clipped apertures (these sources, therefore, can not negatively influence the further processing in the photometric part of the pipeline). Also removed from the catalog are hot pixels.

The robustness of the standard star identification is found to be high, but some mis-identifications can still occur. However, any mis-identified or multiply identified standard star will clearly show up as an outlier; the *correctly* identified and measured standard stars all have values for the raw zeropoint that cluster tightly around one particular value. Such outliers are removed during processing.

To give an example of the ability of the software to find the standard stars in a given field, catalogs have been derived from a deep exposure of one of the La Palma programme fields using the standard photometric pipeline recipe (**Recipe- PhotCal_Extract_Resulttable** - req. 562). Details of the image used are given in Table 5. Being a deep exposure, the field will be crowded with stars, both standards and *non*-standards. This image, therefore, provides a good test of the robustness of the standard star identification. The image was fully reduced with the OmegaCAM pipeline, and the secondary standards used were those of SDSS DR3.

In this example, approximately 280 standard stars per CCD were identified by **Recipe-PhotCal_Extract_Resulttable**. In Fig.12, the results for the central part of chip A5383-17-7 are shown. The total number of standard stars on this particular chip was 356, of which 283 were found to be *suitable* for photometric purposes. The rejected standard stars were for the most part saturated, or were too close to 'bleeding' bright stars.

### 5.1.1 Standard star identification at high airmass

For the photometric calibration of OmegaCAM, images of the south celestial pole will be taken on a daily basis. As seen from Paranal, the south celestial pole is at a large airmass of $\sim 2.40$. It is, therefore, important that the photometric software is capable of finding standard stars at such values of the airmass.

To check the correctness and robustness of the standard star identification on images obtained at high airmasses, catalogs have been derived from one WFI image using the standard photometric pipeline recipe (**Recipe- PhotCal_Extract_Resulttable** - req. 562). Details of the image used are given in Table 6. The airmass of this image (2.30) is comparable with that of the south celestial pole as seen from Paranal. The image was fully reduced with the OmegaCAM pipeline, and the secondary standards used were those of SDSS DR3.

On average, approximately 65 standard stars per CCD were identified as suitable by **Recipe-PhotCal_Extract_Resulttable**. In Fig. 13, the results for the central part of CCD51 are shown. The total number of standard stars on this particular chip was 186, of which 73 were found to be *suitable* for photometric purposes. Many of the rejected standard stars were below the default DETECTION_THRESHOLD used by the recipe ($\sim 11$).

This test shows that it is possible to positively identify enough standard stars for a proper photometric calibration at an airmass comparable to that of the southern celestial pole as seen from Paranal.

## 5.2 Aperture photometry

The aperture photometry is done in an automated fashion by SExtractor[2]. The default measured magnitude used by the photometric pipeline is MAG_ISO. To check on the validity of the MAG_ISO output of SExtractor when compared with its MAG_APER output, three tests were performed on a fully-reduced single-CCD frame of SA110 from the La Palma preparatory programme. The results are shown in Figure 14. The MAG_ISO values were produced by setting the DETECTION_THRESHOLD configuration parameter for SExtractor on a fixed 5.0 for all three tests. The aperture size used to extract MAG_APER was set at 3.0, 4.0, and 5.0 times the FWHM of the overall fitted PSF model. The PSF model was derived from the frame using PSFEx. Hot pixels, saturated sources, and sources with an ELONGATION $> 1.2$ were removed from the SExtractor catalog. The total number of legitimate sources plotted in either of the three panels of Figure 14 is approximately 840.

The panels in Fig. 14 show a good agreement between the MAG_ISO and MAG_APER values in the for OmegaCAM relevant range ($14 < m_{g'} < 19$); the difference between the two is in the order of a few hundreds of a magnitude. However, it is clear from this figure that the 'correct' choice of aperture size is very important; too small an aperture and some of the flux of the

Table 5: The INT/WFC image used in the example for standard star identification at deep exposures.

| | | |
|---|---|---|
| Image | : | r336602 |
| Field observed | : | SA 107 |
| Observing date | : | 11 February 2003 |
| Exposure time | : | 300 sec |
| Filter | : | 214 ($r'$) |
| Airmass | : | 1.25 |

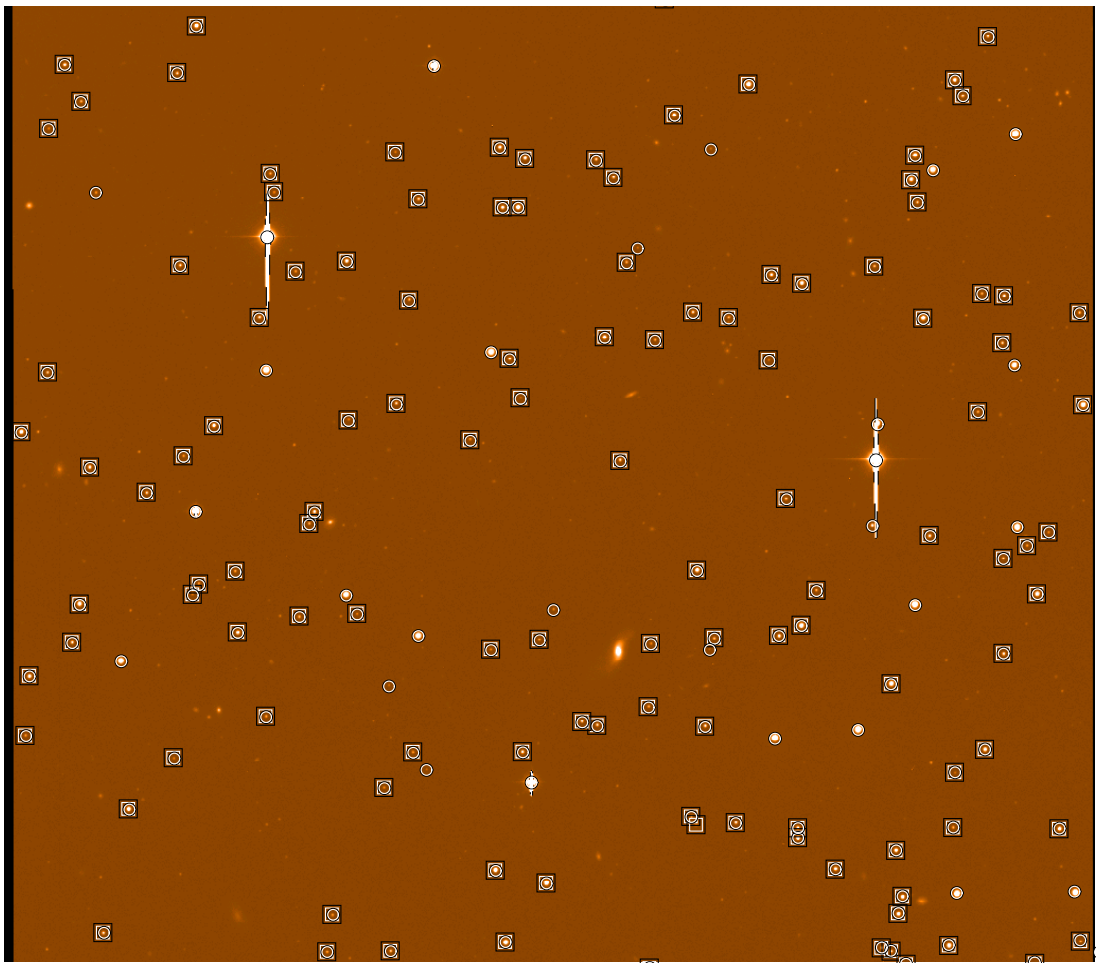

Figure 12: The results from running **Recipe- PhotCal_Extract_Resulttable** on a deep La Palma programme image observed with an exposure time of 300 seconds. Shown is the central part of chip A5383-17-7. The circles denote the sources in the standard star catalog, and the squares show the sources that have been identified by the recipe as suitable standard stars. The secondary standards used are those from SDSS DR3. The figure was obtained from *skycat* at a scale factor of 1/2.

Table 6: The WFI image used in the test for standard star identification at higher airmass.

| | | |
|---|---|---|
| Image | : | wfi60622 |
| Field observed | : | SA 107 |
| Observing date | : | 27 April 2000 |
| Exposure time | : | 10 sec |
| Filter | : | #844 (R) |
| Airmass | : | 2.30 |

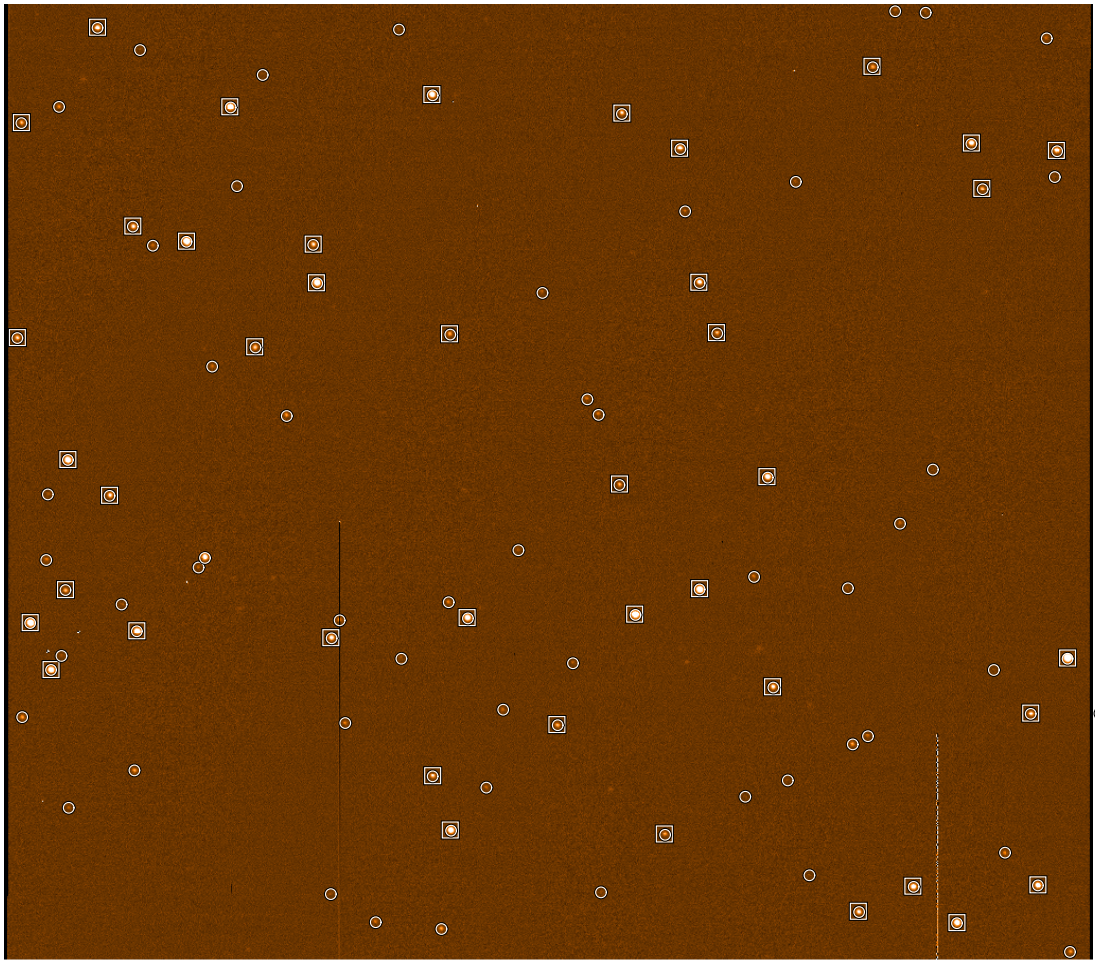

Figure 13: The results from running **Recipe- PhotCal_Extract_Resulttable** on a WFI image observed at airmass 2.3. Shown is the central part of CCD51. The circles denote the sources in the standard star catalog, and the squares show the sources that have been identified by the recipe as suitable standard stars. The secondary standards used are those from SDSS DR3. The figure was obtained from *skycat* at a scale factor of 1/2.

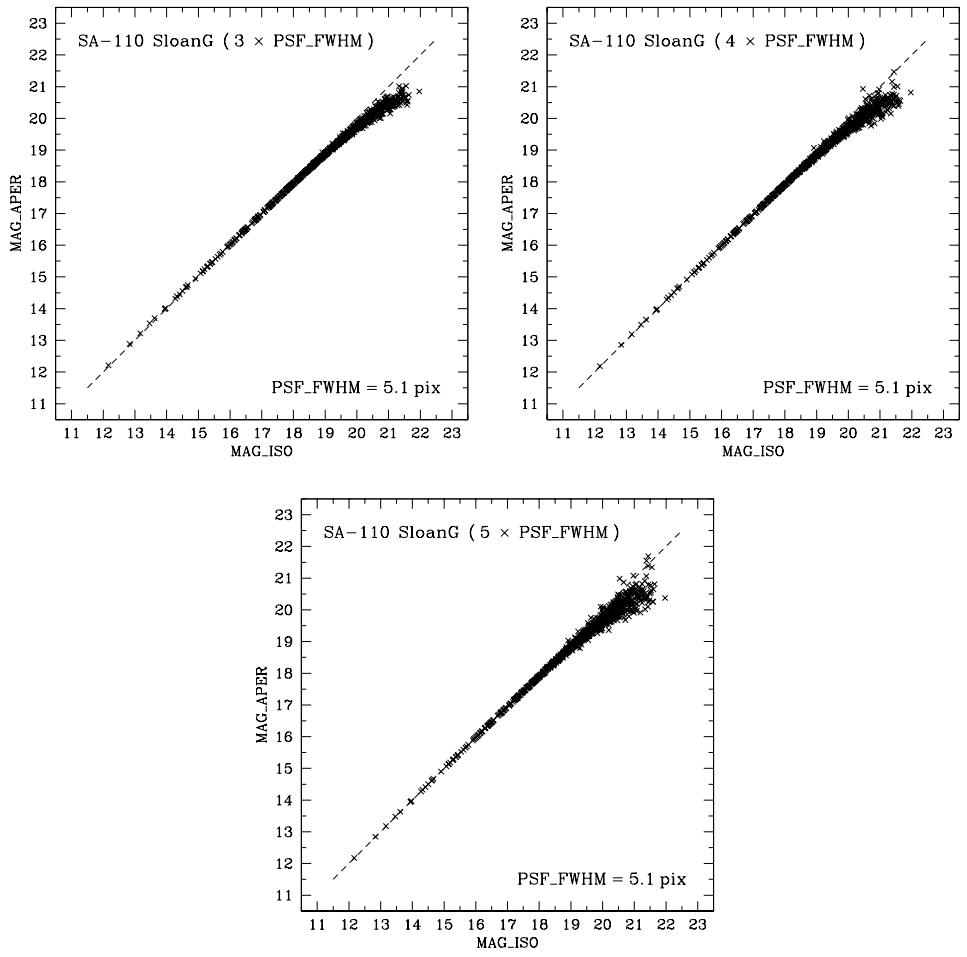


Figure 14: The measured MAG_APER versus MAG_ISO for apertures 3.0, 4.0, and 5.0 times the PSF_FWHM in pixels.

brighter stars will be lost, too large an aperture and the uncertainty on the measured flux will not only increase but will also start to affect the measured fluxes of the brighter stars.

Experience has shown that MAG_APER is the best type of flux to use, because this flux measurement uses a fixed, circular aperture that can be fully controlled through the configuration of SExtractor (and thus be tailored to suit the seeing conditions). The size of this aperture is set by the PHOT_APERTURES SExtractor configuration parameter. The typical aperture used has a diameter of 30-40 pixels which roughly translates to $8''$-$12''$.

### 5.3 Processing time of the photometric pipeline

The time budget for processing the data from the stage of the raw images all the way to the wanted extinction coefficient and zeropoint is divided between the image processing part of the pipeline and the photometric part of the pipeline. The largest part of the total processing time is spend in processing the raw images (de-biasing, flatfielding, astrometric calibration, de-fringing and applying an illumination correction). This process takes $\sim 2.5$ min for data of a *single* chip. Extracting a source catalog from this chip and associating this with the standard star catalog is found to take $\sim 15$ secs. This number depends on how crowded the standard field under consideration is, and on the detection threshold limit set for the source extraction software (SExtractor[2]).

The processing time of the catalogs produced from the standard field data depends on the task performed by the photometric part of the pipeline. For deriving the monitoring report (req. 562 in Valentijn et al. [10]), the catalogs from all the pointings of the **standard polar field** must be combined. This will be at least $32 \times 3$ catalogs. For deriving the zeropoints (reqs. 563/564 in Valentijn et al. [10]), the 32 catalogs derived from one of the standard equatorial fields are used. The time required for deriving the monitoring report is estimated to be $\sim 3$ minutes. For deriving the zeropoints for the night, the processing time is $\sim 1$ minute for one of the **key bands**. The total processing time for the photometric part of the pipeline, therefore, amounts to $\sim 7$ minutes. Note, that these time estimates are less certain than the ones given in the previous paragraph, because they are mainly based on 'artificial' catalogs.

The hardware configuration used in these tests had an Intel P4 1700 MHz CPU and 512 Mb internal memory (see Section 2 of Rengelink et al. [9]). A more detailed breakdown of the estimated processing time can be found in Sections 5 and 6 of Rengelink et al. [9].

## 6 Summary

Using the results of the La Palma Preparatory programme in particular, we have been able to show that the OmegaCAM DFS pipeline performs to the level needed to allow derivation of photometric zero points with 5% accuracy. Based on real data we have been able to track the errors on photometry that arise from the basis image processing steps (better than 0.5%), and from source magnitude measurements (2%). Comparison with Landolt stars, transformed to the SDSS system (accuracy 1%), shows a scatter of 9%, but this is dominated by a color term in the WFC. Correcting for this term results in an achieved scatter in zeropoint determination from individual standard stars of 3%, which is within the specified 5%. With at least 20 stars per CCD, assuming all errors are random and uncorrelated, this should result in a zero point determination of accuracy around 1%. It is not yet possible to test the size of the errors contributed by the correction for sky concentration, or by color term determinations. We expect these to be dominated by the quality of the calibration data.

Table 7: Excerpt from the standard star list for SA110 as produced by the WFI preparatory programme. The total number of calibrated sources in this list is 3508.

| ID | RA | DEC | B | $\delta$B | V | $\delta$V | R | $\delta$R | I | $\delta$I |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 18:40:06.8 | 0:27:40.2 | 16.579 | 0.007 | 15.361 | 0.009 | 99.999 | 9.999 | 99.999 | 9.999 |
| 2 | 18:40:07.2 | 0:29:58.3 | 21.048 | 0.040 | 18.496 | 0.023 | 99.999 | 9.999 | 15.103 | 0.013 |
| 3 | 18:40:09.6 | 0:35:47.4 | 20.658 | 0.034 | 18.450 | 0.020 | 17.038 | 0.014 | 99.999 | 9.999 |
| 4 | 18:40:11.5 | 0:32:54.4 | 19.418 | 0.024 | 17.185 | 0.011 | 15.666 | 0.015 | 99.999 | 9.999 |
| 5 | 18:40:12.8 | 0:27:36.5 | 15.154 | 0.009 | 14.015 | 0.010 | 13.218 | 0.021 | 12.631 | 0.019 |
| 6 | 18:40:15.4 | 0:29:15.2 | 21.326 | 0.047 | 18.875 | 0.035 | 17.105 | 0.018 | 15.584 | 0.018 |
| 7 | 18:40:15.9 | 0:22:40.2 | 20.432 | 0.020 | 18.543 | 0.035 | 17.445 | 0.017 | 16.094 | 0.013 |
| 8 | 18:40:16.6 | 0:25:17.8 | 15.687 | 0.036 | 14.683 | 0.011 | 13.986 | 0.021 | 13.378 | 0.018 |
| 9 | 18:40:17.4 | 0:32:54.6 | 20.747 | 0.041 | 17.622 | 0.017 | 15.556 | 0.016 | 99.999 | 9.999 |
| 10 | 18:40:18.7 | 0:35:47.3 | 99.999 | 9.999 | 18.925 | 0.029 | 17.513 | 0.006 | 99.999 | 9.999 |
| 11 | 18:40:18.8 | 0:24:40.2 | 15.805 | 0.012 | 14.709 | 0.011 | 14.022 | 0.021 | 13.400 | 0.018 |
| 12 | 18:40:20.5 | 0:32:34.1 | 21.272 | 0.030 | 18.548 | 0.019 | 16.667 | 0.016 | 14.997 | 0.012 |
| 13 | 18:40:20.8 | 0:32:59.3 | 20.308 | 0.016 | 18.033 | 0.015 | 16.418 | 0.016 | 14.987 | 0.013 |
| 14 | 18:40:21.9 | 0:24:21.7 | 21.296 | 0.045 | 18.842 | 0.024 | 17.134 | 0.017 | 15.594 | 0.013 |
| 15 | 18:40:21.9 | 0:32:30.8 | 21.655 | 0.049 | 18.502 | 0.019 | 16.371 | 0.016 | 99.999 | 9.999 |
| 16 | 18:40:22.2 | 0:24:50.6 | 21.619 | 0.030 | 17.975 | 0.014 | 15.661 | 0.015 | 99.999 | 9.999 |
| 17 | 18:40:26.8 | 0:26:39.8 | 20.648 | 0.018 | 17.333 | 0.011 | 15.148 | 0.016 | 99.999 | 9.999 |
| 18 | 18:40:27.0 | 0:26:06.1 | 16.502 | 0.008 | 14.928 | 0.010 | 13.869 | 0.022 | 12.607 | 0.019 |
| 19 | 18:40:27.3 | 0:33:34.9 | 21.566 | 0.033 | 18.126 | 0.015 | 15.834 | 0.016 | 99.999 | 9.999 |
| 20 | 18:40:27.4 | 0:33:49.4 | 19.603 | 0.015 | 17.287 | 0.010 | 15.758 | 0.022 | 99.999 | 9.999 |
| 21 | 18:40:27.6 | 0:25:51.1 | 20.819 | 0.028 | 18.323 | 0.018 | 16.577 | 0.017 | 15.009 | 0.012 |
| 22 | 18:40:27.7 | 0:25:40.1 | 13.296 | 0.005 | 12.241 | 0.009 | 11.619 | 0.022 | 10.962 | 0.018 |
| 23 | 18:40:28.0 | 0:34:00.0 | 21.274 | 0.040 | 18.135 | 0.016 | 16.032 | 0.022 | 99.999 | 9.999 |
| 24 | 18:40:28.6 | 0:36:33.8 | 20.576 | 0.030 | 18.142 | 0.026 | 16.593 | 0.005 | 99.999 | 9.999 |
| 25 | 18:40:29.4 | 0:36:06.7 | 20.614 | 0.045 | 18.621 | 0.041 | 17.262 | 0.007 | 99.999 | 9.999 |
| 26 | 18:40:29.9 | 0:21:42.9 | 21.231 | 0.029 | 18.569 | 0.019 | 16.856 | 0.016 | 15.219 | 0.019 |
| 27 | 18:40:30.5 | 0:21:02.6 | 21.030 | 0.049 | 18.705 | 0.025 | 17.172 | 0.017 | 15.755 | 0.018 |
| 28 | 18:40:30.5 | 0:22:13.4 | 20.622 | 0.022 | 17.641 | 0.017 | 15.751 | 0.018 | 99.999 | 9.999 |
| 29 | 18:40:30.7 | 0:21:49.9 | 19.356 | 0.017 | 17.679 | 0.014 | 16.524 | 0.016 | 99.999 | 9.999 |
| 30 | 18:40:30.7 | 0:23:18.0 | 19.717 | 0.018 | 99.999 | 9.999 | 16.113 | 0.028 | 99.999 | 9.999 |
| 31 | 18:40:31.1 | 0:31:26.1 | 20.188 | 0.026 | 17.833 | 0.017 | 16.191 | 0.016 | 99.999 | 9.999 |
| 32 | 18:40:31.5 | 0:22:29.1 | 20.103 | 0.018 | 17.055 | 0.011 | 15.160 | 0.015 | 99.999 | 9.999 |
| 33 | 18:40:34.0 | 0:41:45.6 | 20.852 | 0.049 | 17.707 | 0.015 | 15.693 | 0.012 | 14.077 | 0.022 |
| 34 | 18:40:34.1 | 0:38:55.7 | 19.905 | 0.027 | 17.114 | 0.012 | 15.191 | 0.012 | 99.999 | 9.999 |
| 35 | 18:40:34.3 | 0:24:47.3 | 19.341 | 0.031 | 17.108 | 0.015 | 15.936 | 0.014 | 99.999 | 9.999 |
| 36 | 18:40:34.8 | 0:24:30.0 | 20.046 | 0.034 | 17.856 | 0.021 | 16.659 | 0.015 | 15.372 | 0.017 |
| 37 | 18:40:35.3 | 0:46:01.2 | 19.827 | 0.017 | 16.719 | 0.008 | 14.679 | 0.008 | 13.004 | 0.020 |
| 38 | 18:40:35.4 | 0:38:13.8 | 18.528 | 0.013 | 17.001 | 0.009 | 15.967 | 0.011 | 14.659 | 0.012 |
| 39 | 18:40:35.5 | 0:21:15.0 | 15.886 | 0.020 | 14.578 | 0.015 | 13.755 | 0.014 | 12.987 | 0.026 |
| 40 | 18:40:35.6 | 0:41:23.9 | 14.297 | 0.011 | 13.308 | 0.011 | 12.803 | 0.012 | 12.147 | 0.013 |
| 41 | 18:40:35.8 | 0:24:47.3 | 19.271 | 0.012 | 17.103 | 0.011 | 15.960 | 0.011 | 14.677 | 0.017 |
| 42 | 18:40:36.2 | 0:22:46.7 | 19.920 | 0.019 | 18.192 | 0.022 | 17.175 | 0.016 | 15.787 | 0.018 |
| 43 | 18:40:36.9 | 0:29:36.1 | 18.467 | 0.010 | 16.900 | 0.016 | 15.909 | 0.010 | 14.944 | 0.017 |
| 44 | 18:40:37.1 | 0:31:15.1 | 15.510 | 0.010 | 14.154 | 0.013 | 13.345 | 0.018 | 12.517 | 0.024 |
| 45 | 18:40:37.3 | 0:23:43.4 | 18.742 | 0.011 | 15.244 | 0.012 | 13.269 | 0.018 | 11.148 | 0.024 |
| 46 | 18:40:37.5 | 0:25:46.5 | 20.966 | 0.029 | 18.499 | 0.021 | 17.169 | 0.011 | 15.718 | 0.017 |
| 47 | 18:40:37.9 | 0:47:32.8 | 20.243 | 0.027 | 18.547 | 0.017 | 17.458 | 0.010 | 16.235 | 0.012 |
| 48 | 18:40:38.5 | 0:43:22.9 | 19.579 | 0.037 | 18.018 | 0.012 | 16.973 | 0.009 | 15.548 | 0.012 |
| 49 | 18:40:39.6 | 0:29:29.8 | 18.471 | 0.010 | 15.795 | 0.013 | 14.164 | 0.020 | 12.533 | 0.024 |
| 50 | 18:40:39.6 | 0:34:33.6 | 19.550 | 0.021 | 16.537 | 0.010 | 14.753 | 0.013 | 99.999 | 9.999 |
| 51 | 18:40:40.2 | 0:36:13.0 | 18.719 | 0.013 | 17.187 | 0.008 | 16.136 | 0.008 | 15.099 | 0.012 |
| 52 | 18:40:40.3 | 0:29:09.0 | 20.826 | 0.040 | 18.241 | 0.017 | 16.746 | 0.011 | 15.207 | 0.017 |
| 53 | 18:40:40.4 | 0:37:34.5 | 20.010 | 0.019 | 17.648 | 0.010 | 16.076 | 0.008 | 14.749 | 0.012 |
| 54 | 18:40:40.6 | 0:25:29.9 | 20.718 | 0.025 | 18.382 | 0.019 | 17.150 | 0.011 | 15.796 | 0.017 |
| 55 | 18:40:40.9 | 0:28:02.1 | 20.969 | 0.024 | 17.632 | 0.013 | 15.625 | 0.010 | 99.999 | 9.999 |
| 56 | 18:40:41.2 | 0:32:24.1 | 19.726 | 0.015 | 18.014 | 0.015 | 16.987 | 0.011 | 15.767 | 0.017 |
| 57 | 18:40:41.5 | 0:30:46.3 | 19.284 | 0.012 | 17.035 | 0.011 | 15.762 | 0.011 | 99.999 | 9.999 |
| 58 | 18:40:41.5 | 0:40:41.8 | 18.800 | 0.013 | 17.078 | 0.008 | 15.843 | 0.008 | 14.772 | 0.012 |
| 59 | 18:40:41.6 | 0:37:04.7 | 11.659 | 0.010 | 10.801 | 0.010 | 99.999 | 9.999 | 99.999 | 9.999 |
| 60 | 18:40:41.7 | 0:42:46.2 | 20.416 | 0.024 | 17.483 | 0.010 | 15.264 | 0.011 | 99.999 | 9.999 |

Table 8: Excerpt from the standard star list for NGC5904 as produced by the WFI preparatory programme. The total number of calibrated sources in this list is 4614.

| ID | RA | DEC | B | $\delta$B | V | $\delta$V | R | $\delta$R | I | $\delta$I |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15:16:14.6 | 2:00:14.0 | 99.999 | 9.999 | 17.238 | 0.023 | 16.814 | 0.017 | 16.350 | 0.041 |
| 2 | 15:16:15.0 | 1:48:56.8 | 17.204 | 0.014 | 16.597 | 0.028 | 16.294 | 0.013 | 15.932 | 0.029 |
| 3 | 15:16:15.6 | 1:56:35.9 | 18.536 | 0.014 | 17.547 | 0.012 | 16.892 | 0.013 | 16.293 | 0.036 |
| 4 | 15:16:15.6 | 1:57:43.8 | 17.746 | 0.014 | 16.724 | 0.015 | 16.087 | 0.008 | 15.514 | 0.034 |
| 5 | 15:16:15.8 | 2:00:52.9 | 99.999 | 9.999 | 99.999 | 9.999 | 17.463 | 0.005 | 16.896 | 0.034 |
| 6 | 15:16:16.3 | 1:42:23.3 | 18.021 | 0.003 | 17.304 | 0.029 | 16.929 | 0.013 | 16.489 | 0.030 |
| 7 | 15:16:16.6 | 1:52:52.7 | 99.999 | 9.999 | 99.999 | 9.999 | 99.999 | 9.999 | 16.417 | 0.033 |
| 8 | 15:16:16.6 | 2:05:06.7 | 99.999 | 9.999 | 99.999 | 9.999 | 17.409 | 0.027 | 16.963 | 0.044 |
| 9 | 15:16:17.0 | 1:39:09.2 | 16.408 | 0.009 | 15.397 | 0.029 | 14.916 | 0.008 | 14.351 | 0.031 |
| 10 | 15:16:17.6 | 1:49:12.4 | 18.664 | 0.004 | 17.714 | 0.018 | 17.160 | 0.011 | 16.600 | 0.025 |
| 11 | 15:16:17.8 | 2:00:57.5 | 17.027 | 0.019 | 16.102 | 0.012 | 15.602 | 0.009 | 15.108 | 0.029 |
| 12 | 15:16:18.2 | 1:43:36.2 | 16.625 | 0.010 | 15.582 | 0.025 | 14.991 | 0.007 | 14.432 | 0.026 |
| 13 | 15:16:18.3 | 1:59:26.2 | 17.658 | 0.014 | 16.923 | 0.013 | 16.501 | 0.009 | 16.007 | 0.030 |
| 14 | 15:16:18.3 | 2:20:29.2 | 99.999 | 9.999 | 99.999 | 9.999 | 99.999 | 9.999 | 17.095 | 0.019 |
| 15 | 15:16:18.6 | 1:50:05.3 | 16.837 | 0.010 | 16.059 | 0.022 | 15.621 | 0.006 | 15.149 | 0.023 |
| 16 | 15:16:18.9 | 1:42:45.6 | 19.002 | 0.006 | 18.129 | 0.018 | 17.685 | 0.003 | 17.232 | 0.029 |
| 17 | 15:16:18.9 | 2:12:59.2 | 18.204 | 0.012 | 17.477 | 0.018 | 17.063 | 0.012 | 16.700 | 0.028 |
| 18 | 15:16:18.9 | 2:29:56.8 | 16.198 | 0.018 | 15.773 | 0.011 | 15.412 | 0.010 | 15.131 | 0.029 |
| 19 | 15:16:19.2 | 1:56:03.6 | 14.944 | 0.021 | 14.274 | 0.011 | 13.836 | 0.007 | 13.470 | 0.033 |
| 20 | 15:16:19.3 | 1:42:57.4 | 16.517 | 0.009 | 15.771 | 0.027 | 15.375 | 0.009 | 14.977 | 0.027 |
| 21 | 15:16:19.3 | 1:55:28.9 | 16.949 | 0.019 | 16.404 | 0.012 | 16.025 | 0.007 | 15.680 | 0.029 |
| 22 | 15:16:19.3 | 2:23:44.0 | 14.668 | 0.006 | 13.977 | 0.026 | 13.594 | 0.004 | 13.173 | 0.026 |
| 23 | 15:16:19.5 | 2:35:09.9 | 17.105 | 0.027 | 16.296 | 0.019 | 15.940 | 0.013 | 15.903 | 0.037 |
| 24 | 15:16:19.8 | 1:51:19.0 | 18.972 | 0.006 | 18.431 | 0.018 | 18.099 | 0.007 | 17.695 | 0.027 |
| 25 | 15:16:19.8 | 2:12:37.5 | 18.612 | 0.006 | 18.024 | 0.019 | 17.631 | 0.005 | 17.304 | 0.030 |
| 26 | 15:16:19.8 | 2:18:39.7 | 14.212 | 0.004 | 13.787 | 0.026 | 13.518 | 0.006 | 13.276 | 0.025 |
| 27 | 15:16:19.9 | 2:30:05.2 | 16.566 | 0.018 | 15.977 | 0.012 | 15.578 | 0.012 | 15.272 | 0.029 |
| 28 | 15:16:20.2 | 1:38:10.5 | 19.234 | 0.005 | 17.985 | 0.018 | 17.346 | 0.017 | 16.654 | 0.027 |
| 29 | 15:16:20.3 | 1:40:27.9 | 18.168 | 0.003 | 16.960 | 0.024 | 16.279 | 0.009 | 15.640 | 0.023 |
| 30 | 15:16:20.3 | 2:36:02.2 | 99.999 | 9.999 | 99.999 | 9.999 | 17.476 | 0.032 | 17.099 | 0.048 |
| 31 | 15:16:20.4 | 2:12:13.4 | 18.461 | 0.007 | 17.791 | 0.019 | 17.358 | 0.014 | 16.996 | 0.028 |
| 32 | 15:16:20.5 | 2:31:00.3 | 99.999 | 9.999 | 99.999 | 9.999 | 99.999 | 9.999 | 17.237 | 0.024 |
| 33 | 15:16:20.6 | 2:01:39.3 | 99.999 | 9.999 | 99.999 | 9.999 | 17.306 | 0.003 | 16.342 | 0.023 |
| 34 | 15:16:20.7 | 1:50:20.0 | 16.355 | 0.009 | 15.714 | 0.026 | 15.347 | 0.008 | 14.888 | 0.027 |
| 35 | 15:16:20.7 | 1:55:12.5 | 17.843 | 0.014 | 17.447 | 0.016 | 17.114 | 0.012 | 16.831 | 0.034 |
| 36 | 15:16:20.9 | 1:41:10.5 | 19.277 | 0.006 | 17.984 | 0.018 | 17.297 | 0.020 | 16.590 | 0.027 |
| 37 | 15:16:20.9 | 2:18:02.8 | 99.999 | 9.999 | 99.999 | 9.999 | 99.999 | 9.999 | 17.334 | 0.019 |
| 38 | 15:16:21.0 | 1:38:34.9 | 21.385 | 0.024 | 20.719 | 0.029 | 20.440 | 0.020 | 99.999 | 9.999 |
| 39 | 15:16:21.2 | 2:30:30.7 | 17.591 | 0.014 | 17.063 | 0.016 | 16.681 | 0.017 | 16.375 | 0.032 |
| 40 | 15:16:21.3 | 1:45:38.3 | 17.798 | 0.003 | 17.288 | 0.025 | 16.965 | 0.011 | 16.608 | 0.025 |
| 41 | 15:16:21.6 | 1:52:40.8 | 18.419 | 0.014 | 17.946 | 0.008 | 17.580 | 0.004 | 17.208 | 0.034 |
| 42 | 15:16:21.7 | 1:56:36.6 | 99.999 | 9.999 | 99.999 | 9.999 | 99.999 | 9.999 | 17.328 | 0.024 |
| 43 | 15:16:21.8 | 2:11:07.7 | 18.672 | 0.006 | 17.857 | 0.026 | 17.389 | 0.018 | 16.937 | 0.030 |
| 44 | 15:16:21.9 | 1:51:30.0 | 12.665 | 0.005 | 11.937 | 0.025 | 99.999 | 9.999 | 11.306 | 0.029 |
| 45 | 15:16:21.9 | 2:03:28.4 | 17.374 | 0.022 | 16.102 | 0.012 | 15.342 | 0.008 | 14.612 | 0.029 |
| 46 | 15:16:22.0 | 1:41:59.8 | 18.065 | 0.006 | 17.512 | 0.017 | 17.186 | 0.011 | 16.843 | 0.027 |
| 47 | 15:16:22.0 | 1:49:26.3 | 13.788 | 0.004 | 12.569 | 0.024 | 12.002 | 0.003 | 11.364 | 0.025 |
| 48 | 15:16:22.4 | 1:48:10.3 | 13.959 | 0.004 | 13.066 | 0.024 | 12.630 | 0.006 | 12.112 | 0.025 |
| 49 | 15:16:22.5 | 1:42:29.5 | 99.999 | 9.999 | 99.999 | 9.999 | 99.999 | 9.999 | 17.061 | 0.019 |
| 50 | 15:16:22.5 | 1:49:37.7 | 14.820 | 0.005 | 14.576 | 0.025 | 14.370 | 0.006 | 14.152 | 0.026 |
| 51 | 15:16:22.5 | 2:29:14.7 | 18.300 | 0.014 | 17.279 | 0.016 | 16.528 | 0.018 | 15.985 | 0.030 |
| 52 | 15:16:22.8 | 1:57:16.0 | 15.216 | 0.020 | 14.391 | 0.011 | 13.903 | 0.009 | 13.425 | 0.033 |
| 53 | 15:16:22.9 | 1:53:27.3 | 99.999 | 9.999 | 99.999 | 9.999 | 99.999 | 9.999 | 16.858 | 0.024 |
| 54 | 15:16:23.0 | 1:54:54.7 | 17.093 | 0.019 | 15.960 | 0.011 | 15.203 | 0.006 | 14.550 | 0.028 |
| 55 | 15:16:23.2 | 2:20:41.0 | 17.927 | 0.009 | 16.803 | 0.024 | 16.127 | 0.012 | 15.497 | 0.023 |
| 56 | 15:16:23.5 | 1:51:31.4 | 19.146 | 0.007 | 18.461 | 0.018 | 18.054 | 0.007 | 99.999 | 9.999 |
| 57 | 15:16:23.6 | 2:14:42.4 | 16.425 | 0.014 | 15.733 | 0.022 | 15.357 | 0.007 | 15.021 | 0.023 |
| 58 | 15:16:23.6 | 2:18:14.6 | 14.750 | 0.005 | 13.868 | 0.026 | 13.391 | 0.004 | 12.944 | 0.025 |
| 59 | 15:16:23.9 | 2:20:43.4 | 18.780 | 0.010 | 18.126 | 0.019 | 17.728 | 0.011 | 17.352 | 0.033 |
| 60 | 15:16:24.1 | 1:59:41.0 | 17.777 | 0.014 | 17.087 | 0.014 | 16.660 | 0.010 | 16.229 | 0.031 |

Table 9: Excerpt from the preliminary standard star list for SA98 as produced by the La Palma preparatory programme. The results shown are those for the $g'$ band ($14 < m_{g'} < 19$). The total number of candidate sources in this list is 880.

| ID | RA (deg) | DEC (deg) | $g'$ | $\delta g'$ | ID | RA (deg) | DEC (deg) | $g'$ | $\delta g'$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 103.2038 | -0.28448550 | 16.401 | 0.046 | 61 | 103.1812 | -0.26978090 | 18.897 | 0.068 |
| 2 | 103.2033 | -0.31607590 | 17.793 | 0.050 | 62 | 103.1786 | -0.38325690 | 16.667 | 0.047 |
| 3 | 103.2013 | -0.28949510 | 15.499 | 0.046 | 63 | 103.1773 | -0.40950880 | 16.653 | 0.047 |
| 4 | 103.2033 | -0.31707800 | 18.959 | 0.070 | 64 | 103.1782 | -0.25995320 | 15.387 | 0.046 |
| 5 | 103.2035 | -0.25146700 | 18.860 | 0.067 | 65 | 103.1786 | -0.39463110 | 18.652 | 0.062 |
| 6 | 103.2013 | -0.36643120 | 18.106 | 0.053 | 66 | 103.1782 | -0.27155320 | 16.601 | 0.047 |
| 7 | 103.1985 | -0.36916830 | 14.693 | 0.046 | 67 | 103.1781 | -0.37431270 | 18.524 | 0.059 |
| 8 | 103.1998 | -0.40374560 | 18.566 | 0.060 | 68 | 103.1748 | -0.38470530 | 14.690 | 0.046 |
| 9 | 103.1996 | -0.42162720 | 18.144 | 0.053 | 69 | 103.1784 | -0.32486670 | 18.235 | 0.054 |
| 10 | 103.1977 | -0.39257710 | 16.095 | 0.046 | 70 | 103.1760 | -0.37536510 | 16.371 | 0.046 |
| 11 | 103.2005 | -0.27205190 | 17.503 | 0.049 | 71 | 103.1781 | -0.26702490 | 17.220 | 0.048 |
| 12 | 103.1942 | -0.41066050 | 14.514 | 0.046 | 72 | 103.1783 | -0.24745000 | 17.802 | 0.050 |
| 13 | 103.1962 | -0.31838880 | 15.868 | 0.046 | 73 | 103.1760 | -0.30301160 | 16.690 | 0.047 |
| 14 | 103.1954 | -0.26815300 | 15.164 | 0.046 | 74 | 103.1766 | -0.30873440 | 16.966 | 0.047 |
| 15 | 103.1961 | -0.33418000 | 18.665 | 0.062 | 75 | 103.1760 | -0.37784690 | 17.913 | 0.051 |
| 16 | 103.1932 | -0.32835250 | 15.826 | 0.046 | 76 | 103.1752 | -0.36415550 | 17.327 | 0.048 |
| 17 | 103.1928 | -0.27342610 | 14.923 | 0.046 | 77 | 103.1746 | -0.33380710 | 16.172 | 0.046 |
| 18 | 103.1930 | -0.40630360 | 17.725 | 0.050 | 78 | 103.1749 | -0.38018660 | 18.699 | 0.063 |
| 19 | 103.1928 | -0.24642800 | 15.977 | 0.046 | 79 | 103.1718 | -0.36247550 | 15.261 | 0.046 |
| 20 | 103.1926 | -0.32154020 | 16.754 | 0.047 | 80 | 103.1739 | -0.36008860 | 17.465 | 0.049 |
| 21 | 103.1931 | -0.33681920 | 17.501 | 0.049 | 81 | 103.1735 | -0.31702460 | 16.705 | 0.047 |
| 22 | 103.1933 | -0.32408730 | 17.925 | 0.051 | 82 | 103.1724 | -0.41766840 | 17.714 | 0.050 |
| 23 | 103.1921 | -0.26894250 | 16.007 | 0.046 | 83 | 103.1737 | -0.32869060 | 18.026 | 0.052 |
| 24 | 103.1921 | -0.27529010 | 16.937 | 0.047 | 84 | 103.1745 | -0.29026280 | 18.616 | 0.061 |
| 25 | 103.1921 | -0.29914580 | 17.926 | 0.051 | 85 | 103.1728 | -0.24985690 | 16.607 | 0.047 |
| 26 | 103.1910 | -0.34045350 | 17.705 | 0.050 | 86 | 103.1731 | -0.30895600 | 18.215 | 0.054 |
| 27 | 103.1875 | -0.38624670 | 14.470 | 0.046 | 87 | 103.1712 | -0.42434780 | 18.621 | 0.061 |
| 28 | 103.1899 | -0.40937500 | 18.050 | 0.052 | 88 | 103.1695 | -0.27665380 | 15.158 | 0.046 |
| 29 | 103.1911 | -0.25592810 | 17.721 | 0.050 | 89 | 103.1703 | -0.37393930 | 17.497 | 0.049 |
| 30 | 103.1906 | -0.31011390 | 18.156 | 0.053 | 90 | 103.1708 | -0.36905760 | 18.468 | 0.058 |
| 31 | 103.1888 | -0.24327270 | 16.940 | 0.047 | 91 | 103.1685 | -0.34456050 | 14.574 | 0.046 |
| 32 | 103.1869 | -0.31861840 | 16.412 | 0.046 | 92 | 103.1688 | -0.42534330 | 16.652 | 0.047 |
| 33 | 103.1868 | -0.39917840 | 17.728 | 0.050 | 93 | 103.1701 | -0.36007030 | 18.114 | 0.053 |
| 34 | 103.1877 | -0.32026650 | 17.971 | 0.052 | 94 | 103.1719 | -0.24704760 | 18.870 | 0.067 |
| 35 | 103.1879 | -0.27174180 | 18.021 | 0.052 | 95 | 103.1709 | -0.26807740 | 18.055 | 0.052 |
| 36 | 103.1862 | -0.30237130 | 16.945 | 0.047 | 96 | 103.1698 | -0.30686230 | 18.393 | 0.057 |
| 37 | 103.1863 | -0.34347250 | 18.596 | 0.060 | 97 | 103.1684 | -0.41131430 | 18.789 | 0.065 |
| 38 | 103.1851 | -0.34368480 | 16.351 | 0.046 | 98 | 103.1679 | -0.41330660 | 18.649 | 0.061 |
| 39 | 103.1860 | -0.29830630 | 17.753 | 0.050 | 99 | 103.1672 | -0.40293970 | 18.695 | 0.063 |
| 40 | 103.1849 | -0.29456910 | 16.581 | 0.047 | 100 | 103.1657 | -0.27061960 | 16.665 | 0.047 |
| 41 | 103.1841 | -0.42638900 | 18.650 | 0.061 | 101 | 103.1635 | -0.42003010 | 18.372 | 0.056 |
| 42 | 103.1849 | -0.33827940 | 17.909 | 0.051 | 102 | 103.1624 | -0.41469710 | 17.096 | 0.047 |
| 43 | 103.1830 | -0.38698930 | 16.486 | 0.046 | 103 | 103.1626 | -0.42291800 | 18.689 | 0.062 |
| 44 | 103.1832 | -0.39177660 | 18.280 | 0.055 | 104 | 103.1608 | -0.42023340 | 15.745 | 0.046 |
| 45 | 103.1836 | -0.36252940 | 18.765 | 0.064 | 105 | 103.1612 | -0.35510960 | 16.405 | 0.046 |
| 46 | 103.1834 | -0.35197290 | 18.671 | 0.062 | 106 | 103.1641 | -0.24232070 | 18.566 | 0.060 |
| 47 | 103.1828 | -0.30540680 | 16.921 | 0.047 | 107 | 103.1616 | -0.36953730 | 18.725 | 0.063 |
| 48 | 103.1821 | -0.39457240 | 18.043 | 0.052 | 108 | 103.1598 | -0.33117640 | 16.285 | 0.046 |
| 49 | 103.1832 | -0.29175980 | 18.569 | 0.060 | 109 | 103.1599 | -0.40075870 | 17.434 | 0.048 |
| 50 | 103.1794 | -0.24346320 | 14.032 | 0.046 | 110 | 103.1600 | -0.41108380 | 17.951 | 0.051 |
| 51 | 103.1819 | -0.36496820 | 18.209 | 0.054 | 111 | 103.1602 | -0.40638600 | 18.640 | 0.061 |
| 52 | 103.1827 | -0.28152590 | 18.802 | 0.065 | 112 | 103.1603 | -0.36011020 | 18.000 | 0.052 |
| 53 | 103.1792 | -0.35857360 | 15.128 | 0.046 | 113 | 103.1597 | -0.40275480 | 18.631 | 0.061 |
| 54 | 103.1800 | -0.37249050 | 16.156 | 0.046 | 114 | 103.1564 | -0.28429640 | 14.374 | 0.046 |
| 55 | 103.1799 | -0.41313270 | 17.655 | 0.049 | 115 | 103.1603 | -0.27872130 | 18.788 | 0.065 |
| 56 | 103.1798 | -0.27646400 | 17.594 | 0.049 | 116 | 103.1595 | -0.29008470 | 18.015 | 0.052 |
| 57 | 103.1779 | -0.30043060 | 14.783 | 0.046 | 117 | 103.1553 | -0.40724190 | 15.340 | 0.046 |
| 58 | 103.1793 | -0.30255620 | 16.088 | 0.046 | 118 | 103.1561 | -0.38755990 | 16.096 | 0.046 |
| 59 | 103.1805 | -0.35718880 | 18.439 | 0.057 | 119 | 103.1574 | -0.36146000 | 17.620 | 0.049 |
| 60 | 103.1799 | -0.35058080 | 18.417 | 0.057 | 120 | 103.1577 | -0.36958520 | 18.533 | 0.059 |

Table 10: Excerpt from the preliminary standard star list for SA98 as produced by the La Palma preparatory programme. The results shown are those for the $r'$ band ($14 < m_{r'} < 19$). The total number of candidate sources in this list is 880.

| ID | RA (deg) | DEC (deg) | $r'$ | $\delta r'$ | ID | RA (deg) | DEC (deg) | $r'$ | $\delta r'$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 103.2046 | -0.41366900 | 18.986 | 0.089 | 61 | 103.1849 | -0.33827900 | 17.022 | 0.059 |
| 2 | 103.2038 | -0.28447110 | 15.483 | 0.057 | 62 | 103.1830 | -0.38699380 | 15.782 | 0.057 |
| 3 | 103.2039 | -0.40050030 | 18.535 | 0.074 | 63 | 103.1832 | -0.39178530 | 16.963 | 0.059 |
| 4 | 103.2042 | -0.33114100 | 18.216 | 0.067 | 64 | 103.1840 | -0.37561550 | 18.937 | 0.087 |
| 5 | 103.2037 | -0.35169890 | 18.973 | 0.088 | 65 | 103.1836 | -0.36250450 | 17.933 | 0.064 |
| 6 | 103.2046 | -0.25020830 | 18.868 | 0.084 | 66 | 103.1834 | -0.35196340 | 17.880 | 0.063 |
| 7 | 103.2013 | -0.28949030 | 14.923 | 0.057 | 67 | 103.1828 | -0.30540470 | 16.102 | 0.058 |
| 8 | 103.2035 | -0.25143940 | 17.527 | 0.061 | 68 | 103.1821 | -0.39457050 | 16.803 | 0.058 |
| 9 | 103.2032 | -0.29322030 | 18.570 | 0.074 | 69 | 103.1832 | -0.34822040 | 18.374 | 0.070 |
| 10 | 103.2023 | -0.35324700 | 18.321 | 0.069 | 70 | 103.1832 | -0.29175110 | 17.626 | 0.061 |
| 11 | 103.1985 | -0.36916870 | 14.076 | 0.057 | 71 | 103.1819 | -0.36495260 | 17.517 | 0.061 |
| 12 | 103.2011 | -0.40250700 | 18.486 | 0.072 | 72 | 103.1792 | -0.35856450 | 14.607 | 0.057 |
| 13 | 103.2013 | -0.36642350 | 17.401 | 0.060 | 73 | 103.1827 | -0.28152570 | 17.810 | 0.063 |
| 14 | 103.2021 | -0.27369750 | 18.250 | 0.068 | 74 | 103.1800 | -0.37248370 | 15.472 | 0.057 |
| 15 | 103.1996 | -0.42163460 | 17.200 | 0.059 | 75 | 103.1799 | -0.41314300 | 16.757 | 0.058 |
| 16 | 103.1998 | -0.40375810 | 17.382 | 0.060 | 76 | 103.1810 | -0.36334940 | 18.389 | 0.070 |
| 17 | 103.2005 | -0.27203940 | 16.747 | 0.058 | 77 | 103.1794 | -0.30255590 | 15.429 | 0.057 |
| 18 | 103.1978 | -0.39258880 | 15.521 | 0.057 | 78 | 103.1805 | -0.35718680 | 17.677 | 0.062 |
| 19 | 103.1993 | -0.33611410 | 18.726 | 0.079 | 79 | 103.1799 | -0.35056780 | 17.534 | 0.061 |
| 20 | 103.1983 | -0.39729690 | 18.962 | 0.088 | 80 | 103.1807 | -0.32346150 | 18.138 | 0.066 |
| 21 | 103.1988 | -0.29191900 | 18.226 | 0.067 | 81 | 103.1812 | -0.26975840 | 17.984 | 0.064 |
| 22 | 103.1985 | -0.32366600 | 18.948 | 0.087 | 82 | 103.1779 | -0.30042890 | 14.268 | 0.057 |
| 23 | 103.1963 | -0.31838090 | 15.111 | 0.057 | 83 | 103.1786 | -0.38325680 | 15.980 | 0.057 |
| 24 | 103.1955 | -0.26814250 | 14.698 | 0.057 | 84 | 103.1798 | -0.27645570 | 16.822 | 0.058 |
| 25 | 103.1964 | -0.38419510 | 18.427 | 0.071 | 85 | 103.1782 | -0.25994870 | 14.863 | 0.057 |
| 26 | 103.1961 | -0.33418720 | 17.755 | 0.062 | 86 | 103.1773 | -0.40952090 | 16.185 | 0.058 |
| 27 | 103.1929 | -0.27341240 | 14.435 | 0.057 | 87 | 103.1791 | -0.30884660 | 18.901 | 0.085 |
| 28 | 103.1932 | -0.32834640 | 15.208 | 0.057 | 88 | 103.1781 | -0.37430320 | 17.853 | 0.063 |
| 29 | 103.1930 | -0.40630800 | 17.014 | 0.059 | 89 | 103.1748 | -0.38470960 | 14.176 | 0.057 |
| 30 | 103.1935 | -0.38046390 | 18.109 | 0.066 | 90 | 103.1782 | -0.27154000 | 15.796 | 0.057 |
| 31 | 103.1934 | -0.32408510 | 17.142 | 0.059 | 91 | 103.1784 | -0.32485950 | 17.407 | 0.060 |
| 32 | 103.1931 | -0.33682210 | 16.316 | 0.058 | 92 | 103.1781 | -0.26701260 | 15.739 | 0.057 |
| 33 | 103.1926 | -0.32153840 | 16.108 | 0.058 | 93 | 103.1761 | -0.37535860 | 15.817 | 0.057 |
| 34 | 103.1921 | -0.26892390 | 15.270 | 0.057 | 94 | 103.1783 | -0.24743130 | 16.824 | 0.058 |
| 35 | 103.1921 | -0.27528040 | 16.165 | 0.058 | 95 | 103.1769 | -0.40505820 | 18.651 | 0.077 |
| 36 | 103.1928 | -0.34951230 | 18.935 | 0.087 | 96 | 103.1760 | -0.37784050 | 16.015 | 0.057 |
| 37 | 103.1921 | -0.29913460 | 17.102 | 0.059 | 97 | 103.1766 | -0.30873050 | 15.819 | 0.057 |
| 38 | 103.1910 | -0.34045330 | 16.957 | 0.059 | 98 | 103.1766 | -0.38551240 | 18.531 | 0.073 |
| 39 | 103.1875 | -0.38625560 | 14.177 | 0.057 | 99 | 103.1760 | -0.30301460 | 15.960 | 0.057 |
| 40 | 103.1899 | -0.40937590 | 17.267 | 0.060 | 100 | 103.1752 | -0.36414180 | 16.660 | 0.058 |
| 41 | 103.1879 | -0.27172720 | 17.081 | 0.059 | 101 | 103.1746 | -0.33380560 | 15.740 | 0.057 |
| 42 | 103.1911 | -0.25592000 | 16.990 | 0.059 | 102 | 103.1749 | -0.38019040 | 17.873 | 0.063 |
| 43 | 103.1906 | -0.31010720 | 17.362 | 0.060 | 103 | 103.1739 | -0.36007930 | 16.668 | 0.058 |
| 44 | 103.1887 | -0.29794950 | 16.443 | 0.058 | 104 | 103.1736 | -0.31701280 | 15.717 | 0.057 |
| 45 | 103.1889 | -0.24325520 | 16.189 | 0.058 | 105 | 103.1740 | -0.39525660 | 18.406 | 0.071 |
| 46 | 103.1891 | -0.29703050 | 18.021 | 0.065 | 106 | 103.1737 | -0.32867720 | 16.706 | 0.058 |
| 47 | 103.1868 | -0.39917220 | 16.591 | 0.058 | 107 | 103.1745 | -0.29025060 | 17.677 | 0.062 |
| 48 | 103.1888 | -0.26525720 | 18.227 | 0.067 | 108 | 103.1750 | -0.26058680 | 18.654 | 0.077 |
| 49 | 103.1877 | -0.32026560 | 17.033 | 0.059 | 109 | 103.1725 | -0.41767360 | 16.913 | 0.059 |
| 50 | 103.1869 | -0.31861310 | 15.760 | 0.057 | 110 | 103.1728 | -0.24984500 | 15.158 | 0.057 |
| 51 | 103.1863 | -0.30236460 | 15.413 | 0.057 | 111 | 103.1731 | -0.30894640 | 16.681 | 0.058 |
| 52 | 103.1865 | -0.34967040 | 18.493 | 0.073 | 112 | 103.1742 | -0.28921130 | 18.492 | 0.072 |
| 53 | 103.1874 | -0.30977690 | 18.670 | 0.077 | 113 | 103.1732 | -0.33898680 | 18.533 | 0.073 |
| 54 | 103.1851 | -0.34368200 | 15.676 | 0.057 | 114 | 103.1712 | -0.42436860 | 17.814 | 0.063 |
| 55 | 103.1849 | -0.29456820 | 15.965 | 0.057 | 115 | 103.1735 | -0.24142670 | 18.387 | 0.070 |
| 56 | 103.1863 | -0.34345840 | 18.048 | 0.065 | 116 | 103.1723 | -0.30439930 | 18.044 | 0.065 |
| 57 | 103.1860 | -0.29829980 | 16.963 | 0.059 | 117 | 103.1697 | -0.34339440 | 18.350 | 0.070 |
| 58 | 103.1862 | -0.30580880 | 18.373 | 0.070 | 118 | 103.1685 | -0.34456290 | 14.107 | 0.057 |
| 59 | 103.1842 | -0.42639630 | 17.871 | 0.063 | 119 | 103.1703 | -0.37393610 | 16.713 | 0.058 |
| 60 | 103.1865 | -0.24697320 | 18.303 | 0.069 | 120 | 103.1708 | -0.36904830 | 17.691 | 0.062 |

Table 11: Cross-references between relevant RIX items from VST-TRE-ESO-23100-0033 Issue 1.0 and the sections in this document where these are discussed.

| RIX | Description | Reference |
|---|---|---|
| 28 | Execution time pipeline | Section 5.3 |
| 29 | Error budget breakdown | Section 4 and subsections |
| 39 | Aperture photometry | Section 4.4, Section 5.2 |
| 132 | Standard star distribution | Section 4.6 |
| 144 | Aperture photometry | Section 4.4, Section 5.2 |
| 147 | Standard star distribution | Section 4.6 |

# A Cross-reference table

Table 11 gives cross-references between the for this report relevant RIX items from VST-TRE-ESO-23100-0033 Issue 1.0 (*OmegaCAM Data Flow Software - Preliminary Acceptance Europe Conclusions of the Board*), and the various sections in this document.

# B Glossary

This glossary explains the OmegaCAM specific terms used throughout the text.

**Standard polar field** : standard field centered at the south celestial pole.
**Composite filter** : filter divided into four kwadrants, one for each **key band**.
**Key bands** : the four Sloan bands in which OmegaCAM will be maintained continuously. These are the $u'$, $g'$, $r'$ and $i'$ bands.
**User bands** : any other band than one of the **key bands**.

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