ESO Phase 3 Data Release Description

Data Collection	VIMOS Archive Reprocessing Release
Data Provider	Wolfram Freudling, James Lewis and Mark Neeser
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Document Author	Mark Neeser

Abstract

This is the release of reduced data from the VIMOS imager from the beginning of regular operation (April 2003) until the instrument decommissioning (March 2018). As part of the UK in-kind project the full VIMOS archived dataset has been reduced using new calibration and science recipes by ESO, as internal data products (IDP's).

Overview of Observations

This data set contains all science observations done using the VIMOS instrument in imaging mode. These are not part of a single self-contained project or survey. Rather they contain observations from many different projects and surveys, using various filters and observing methods. The distribution of fields is obviously governed by the time of year in which the observations were taken.

Release Content

This data release contains all of the observations done with the VIMOS imager starting from April 2003 until the end of VIMOS operations in March 2018. The last image was taken in November 2017. For science observations the following data products are available:

- Stacked jittered images of the individual exposures at the detector level
- Variance arrays for the stacks
- Confidence maps for the stacks
- Source catalogues for the stacks

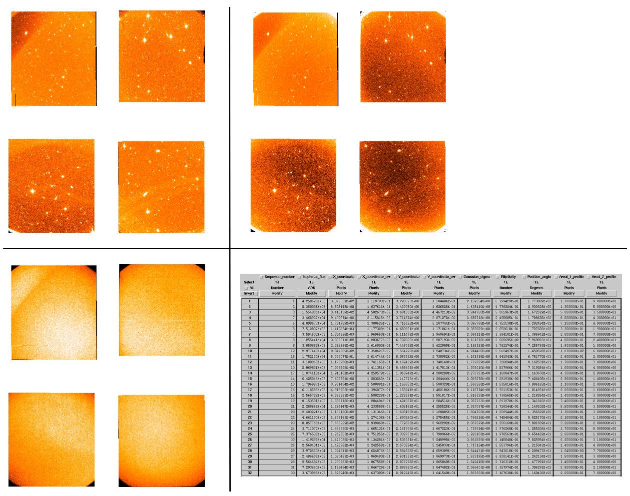

Figure 1: an example of the science image data products provided in this release. Clockwise from the top left are the stacked jittered images, the associated variance map, the source catalogue, and the confidence map.

All reduction has been done at the OB level and no attempt has been made to stack data between OBs. No attempt is made to create full tiled images of science data.

The full VIMOS imaging distribution of science data products consists of 38,100 frames with a total size of 1.9 Tb.

The following observations have been omitted from this release:

- Observations done under any technical programme having an OBS.PROG.ID like "60" and "060" (including any standard star observations).
- The processed single observations that are combined into the stacks.

Release Notes

The data from April 2003 up to August 2015 was processed by the Cambridge Astronomy Survey Unit (CASU) using recently written science recipes that run within the ESO CPL environment. The data from April 2016 was processed by ESO using the VIMOS imaging pipeline version 4.0.2. The main processing steps are described in the following section.

Data Reduction and Calibration

For all observations the following data reduction steps are performed:

- Bias correction using a master bias frame.
- Dark correction using a master dark frame that has been scaled to the exposure time of the science/standard observation.
- Flat fielding using a master twilight flat field for the matching filter. Twilight flat fields are changed roughly every three months during the reduction. This is so that there will be three months of data that can be stacked together in order to work out the illumination correction.
- A gain correction is applied to each detector. This is done to compensate for slight gain variations between the detectors.
- Images science OBs are trimmed to remove parts that are badly affected by shadowing. This is not done in standard star images, as these will not ultimately be stacked.
- A source catalogue is extracted for each exposure and this is used to fit a world coordinate system (WCS). The ZPN projection is used in conjunction with known projection coefficients. In general the WCS is done relative to the 2MASS point-source catalogue.
- The individual exposures for a single OB and a given detector are stacked using the WCS solutions defined above. The stacks are formed using a bi-linear interpolation algorithm to resample the input pixels onto the output grid. This leads to an OB stack for each detector. The stack is averaged by the number of input images. Therefore, all magnitude computations should be done using the effective exposure time header **EFF_EXPT**.
- A source catalogue is extracted from the stacked images (one for each detector).
- The source catalogue is used to redefine the WCS for the stack.
- The photometric calibration is done using VIMOS standard star exposures. A detailed description of this is given in Appendix A (pg. 10).
  In the event that no suitable standard star exposure exists (i.e. if no STD image exists within the same night as the associated science image), the zeropoint of the science exposure is defined using the zeropoint average (as measured over more than five years of standard star data) for that VIMOS filter. If such an estimate of the zeropoint has been made, it will be reflected in the data product headers:
  ZPFUDGED = True
  PHOTZPER = 0.30 (a large zeropoint error equivalent to the σ of the filter average)
  HIERARCH ESO PRO REC1 CAL8 CATG ≠ OBJECT_CATALOGUE_STD

- The spatial resolution quality keywords PSF_FWHM and PSF_FERR are computed using stellar sources in each image. If the data is a multi-extension stack and there are an insufficient number of stars in the field of view of any single detector, then the average value of the other detectors is used for this keyword. Otherwise, the Paranal seeing monitor (DIMM) is used by converting its value to the different telescope size, the different waveband, and an average over the duration of the exposure. The keyword comments describe the method used.

All image products are accompanied by a variance map that has been propagated through the complete reduction cycle. Stacks also have a confidence map. Source catalogues are generated at a threshold of 1.5 times the background noise, with a minimum area of 10 pixels. The reductions were done with version 4.0.2 of the pipeline suite.

Data Quality

For all of the VIMOS object catalogues a source-by-source match was made to the 2MASS catalogue to determine the overall astrometric quality of the images. The astrometric solutions are generally good to 300 milli-arcseconds, with no discernable systematic residuals, however, individual images can be slightly worse with very slight residual image distortions.

The VIMOS standard star fields are photometrically calibrated using the APASS catalogue. The original intent was to calibrate the science fields in the same way. However, with a magnitude limit of about 16.5 – 17.0, even the faintest APASS stars will be saturated in VIMOS images with exposure times greater than about 130 seconds (in the U-band) and about 20 seconds (in all other filters). Since VIMOS science exposures are typically much longer, most of the APASS field stars will be saturated.

Since there was no suitably deep standard star catalogue during the time of our reprocessing, we have used the zeropoints from matched VIMOS standard star fields to photometrically calibrate the science stacks. To assess the photometric quality we first measure the global photometric quality of the standard star fields. A comparison was made between the sources in the VIMOS standard star catalogues and the APASS catalogue. This comparison was done including all of the six available VIMOS filters (*U, B, V, R, I, and z*) and was applied to 29,591 VIMOS standard star images and more than 1.14×10^6 matched sources. We find that the median APASS—VIMOS magnitude difference $\Delta mag = 0.03 \pm 0.1$, as measured for all VIMOS filters. 66% of sources have magnitude differences of less than 0.1 magnitudes (73% have $|\Delta m| < 0.2$ magnitudes). (see Figures 2 & 3 and Table 1).

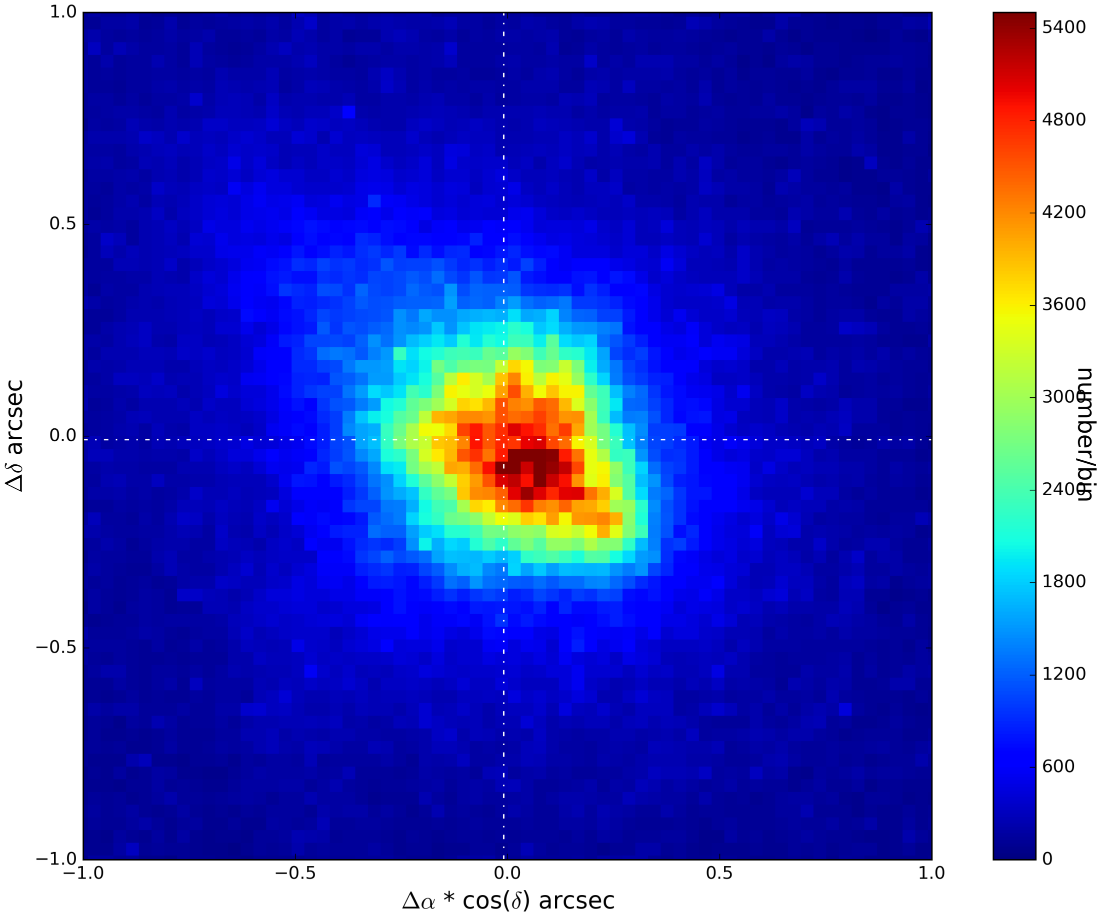

Figure 2: the astrometric quality of the VIMOS reprocessed science stacks as measured by comparing the VIMOS source lists with the 2MASS catalogue. The standard deviation of the Δα*cos(δ) and Δδ distribution is 0.3 arcsec. This is close to the accuracies of the 2MASS point source catalogue.

Astrometric and Photometric Accuracies	
median Δα * cos(δ)	0.02 +/- 0.3 arcsec (science images)
median Δδ	-0.04 +/- 0.3 arcsec (science images)
median Δmag	0.03 +/- 0.1 magnitudes (standard images)

Table 1: a summary of the results that match the VIMOS science stack source lists and standard star catalogues with the 2MASS (astrometry) and APASS catalogues (photometry). The very slight (Δα, Δδ) offsets correspond to less than 1/10 and 1/5 of a pixel, but are likely due to the fact that the centroids are computed on saturated stars, or that there is a small residual distortion in the VIMOS images.

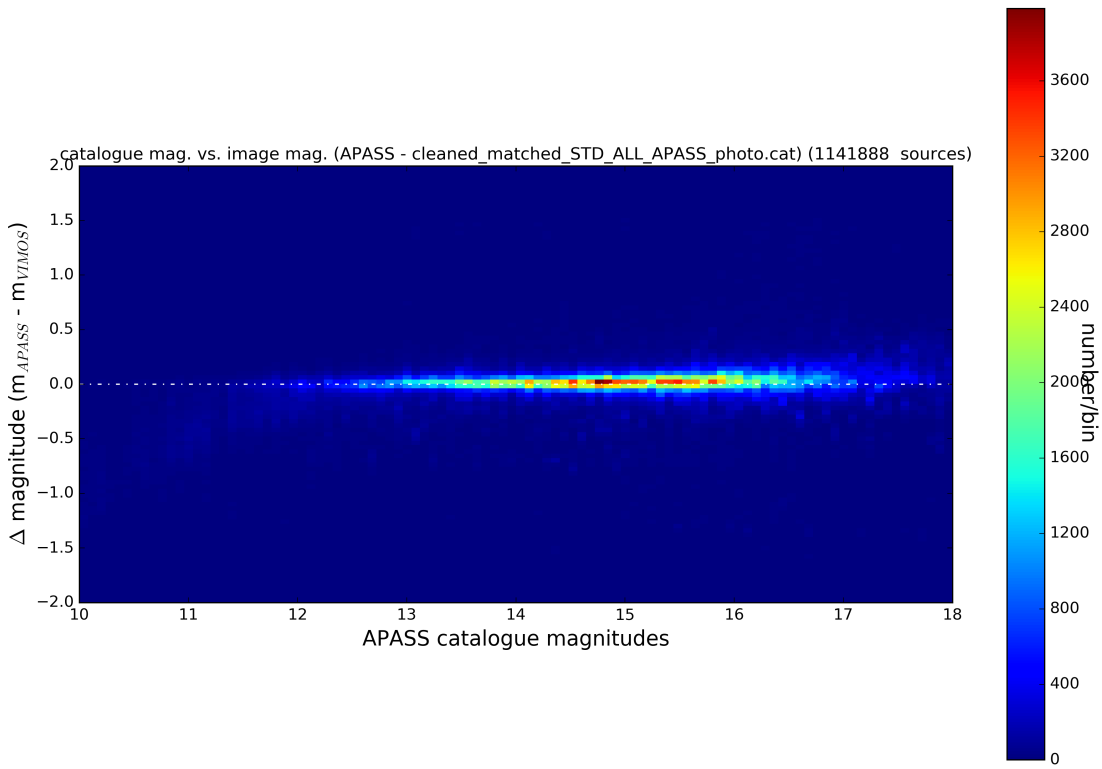

Figure 3: A magnitude – Δmagnitude density plot showing the photometric quality of the VIMOS standard star source catalogues. The data is derived from sources in all six filters from reprocessed VIMOS standard star fields matched with APASS catalogue stars. The standard deviation of the magnitude difference distribution is 0.13 magnitudes, with 66.3 % of sources having |Δm| < 0.1 magnitudes.

Two further photometric comparisons were made to assess the quality of the VIMOS science image photometry. The first used the shortest exposure science images and the second used previously published data available for the GOODs fields. In each case, these VIMOS science images are photometrically calibrated using standard stars, as described in Appendix A.

For the B, V, R, and I filters exposure times of ≦ 5 seconds ensure that APASS sources are unsaturated down to about two magnitudes brighter than the catalogue limit. For the U and z-bands this is 30 and 10 seconds, respectively. In the VIMOS image archive 799 images satisfy these short exposure time limits. For each image a source-by-source match was made between the APASS catalogue and the VIMOS source catalogues. The magnitude difference between APASS and VIMOS was done using the colour terms listed in Appendix B. The median APASS—VIMOS magnitude difference Δmag is summarized for each filter in Table 2.

Photometric Accuracies of Short Exposure VIMOS Science Images		
Filter	**Number of Images**	**Δmag (APASS – VIMOS)**
U	171	0.12 +/- 0.24
B	146	0.20 +/- 0.16
V	75	0.15 +/- 0.13
R	306	0.01 +/- 0.19
I	64	0.12 +/- 0.16
z	37	0.17 +/- 0.16

Table 2: a summary of the results that match the shortest VIMOS science exposure source lists with the APASS catalogues.

Finally, a comparison was made between VIMOS data published for the GOODS field and the same images processed in this data release. This data distribution contains 57 and 77 individual VIMOS stacks that cover the GOODS field in the U- and R-bands, respectively. VIMOS imaging of the GOODS field has been released as a phase 3 data product (cite: GOODS field Release Description) with a photometric calibration based on secondary standards adapted from images obtained with the Wide-Field Imager (WFI) (Nonino et al. 2009).

To compare the GOODS photometry to that derived for the stacks using fits to the VIMOS standard stars, a SExtractor (Bertin & Arnouts 1996) source detection was done independently on each of the two GOODS fields (U- and R-bands) and on the individual VIMOS image stacks.

For this comparison we have accounted for the difference in photometric systems used (AB for the phase 3 GOODS data and VEGA for the CASU-processed stacks), have removed all sources with SExtractor FLAGS > 0 (to remove saturated stars), used a 3 sigma detection threshold, and a spherical source matching within 1.5 arcsec.

The magnitude offsets in the GOODS field differ from those of the standard stars and short exposures. This is due to the fact that the vast majority of GOODS sources are galaxies, which differ in colour to the predominantly stellar detections of the standard and short exposure fields.

Photometric Accuracies of VIMOS Science Stacks in the GOODS field		
Filter	**Number of VIMOS stacks**	**Δmag (GOODS – VIMOS)**
U	57	-0.31 +/- 0.12
R	77	-0.12 +/- 0.13

Table 3: a summary of the results that match the CASU-processed VIMOS science exposures with the GOODS field available from the phase 3 archive.

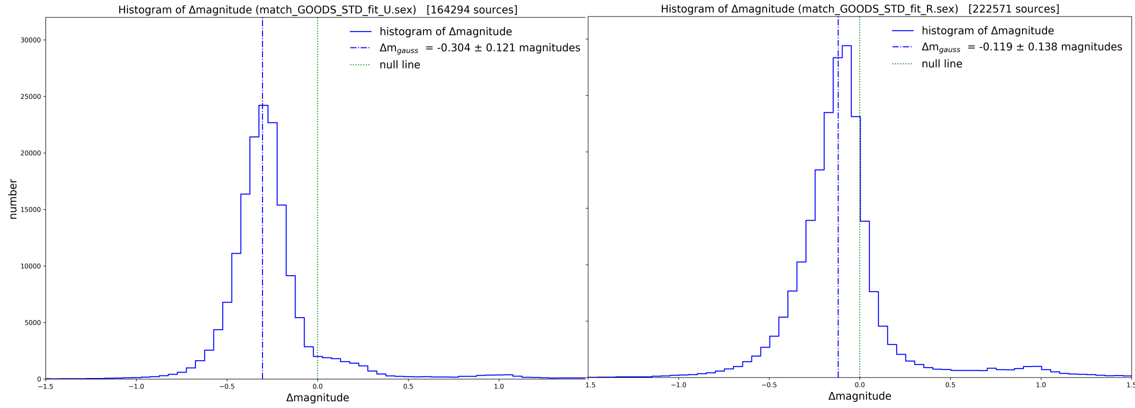

Figure 4: Δmagnitude histograms comparing the GOODS – VIMOS source detections in the U-band (left panel) and R-band (right panel) images.

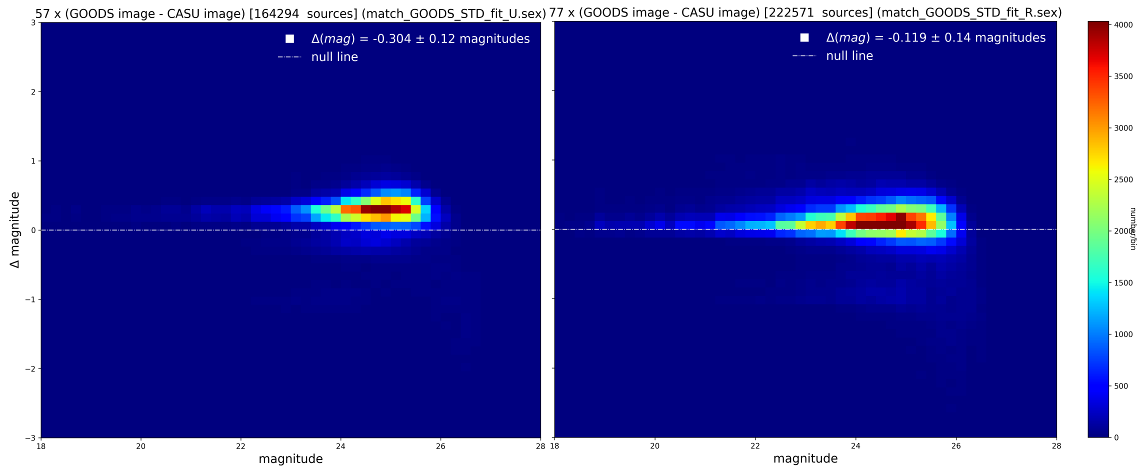

Figure 5: A magnitude – Δmagnitude density plot comparing the GOODS – VIMOS source detections in the U-band (left panel) and R-band (right panel) images.

Known issues

Clearly, the weakest attribute of this data release of VIMOS images lies in its photometry. Both the necessity and disadvantage of photometrically calibrating the science images using standard star exposures is obvious. With differences in observing date and sky pointing between the standard star frames and the science images, we cannot guarantee that the zeropoints assigned to each science file are as accurate as if they were determined in situ. Therefore, we recommend that the user treat the VIMOS photometry with caution, or consider refining our zeropoint estimates with further catalogue comparisons (i.e. GAIA, VHS, etc.) if a higher level of photometric accuracy is required.

Previous Releases

None

Data Format

Files Types

The files are generally named after the raw files they are derived from. In their raw form VIMOS observations occupy four separate FITS files. The timestamp is altered slightly so that all four files have unique names. The processed data are stored in multi-extension FITS files with the information for each detector being held in a separate image/table extension. The ordering of the detectors is always the same (BRIAN, Keith, Tom, DAVID). The original product file name (as stored in the image header as PIPEFILE) is derived from the first raw BRIAN file included in the combined stack. The primary header unit has just header information that is relevant to the exposure or the stack as a whole. Below are examples of the file names that may be created from a given OB.

The first raw BRIAN file in this OB was called VIMOS.2012-01-17T02:41:00.878.fits:

- VIMOS.2012-01-17T02:41:00.878_st.fits – the stacked exposures from the whole OB
- VIMOS.2012-01-17T02:41:00.878_st _var.fits – the variance map for the stack
- VIMOS.2012-01-17T02:41:00.878_st _conf.fits – the confidence map for the stack
- VIMOS.2012-01-17T02:41:00.878_st _cat.fits – the source catalogue for the stack

When the data is downloaded from the phase 3 archive, all files will have names of the form: ADP.<submission_timestamp>.fits.

Catalogue Columns

Col #	Name	Description
1	Sequence_number	Running number for ease of reference, in strict order of image detections
2	Isophotal_flux	Standard definition of summed flux within detection isophote.
3	X_coordinate	The *x*, *y* coordinates and errors with (1, 1) defined to be the centre of the first active pixel in the image array.
4	X_coordinate_err	
5	Y_coordinate	
6	Y_coordinate_err	
7	Gaussian_sigma	Second moment parameters
8	Ellipticity	
9	Position_angle	
10	Areal_1_profile	The number of pixels above a series of threshold levels, relative to local sky. The levels are set at T, 2T, 4T, 8T, 16T, 32T, 64T and 128T where T is the analysis threshold
11	Areal_2_profile	
12	Areal_3_profile	
13	Areal_4_profile	
14	Areal_5_profile	
15	Areal_6_profile	
16	Areal_7_profile	
17	Areal_8_profile	
18	Peak_height	Peak intensity and its error in ADU relative to local value of sky
19	Peak_height_err	
20	Aper_flux_1	Flux and error within a specified radius aperture, typically set so that $R_{aperture} = \langle FWHM \rangle$ where the quantity in angle brackets is the mean FWHM of all stellar images. This is also known as the "core radius". The apertures here correspond to (0.5,1/$\sqrt{2}$, 1, $\sqrt{2}$, 2, 2$\sqrt{2}$, 4, 5, 6, 7, 8, 10, and 12) times the core radius.
21	Aper_flux_1_err	
22	Aper_flux_2	
23	Aper_flux_2_err	
24	Aper_flux_3	
25	Aper_flux_3_err	
26	Aper_flux_4	
27	Aper_flux_4_err	
28	Aper_flux_5	
29	Aper_flux_5_err	
30	Aper_flux_6	
31	Aper_flux_6_err	
32	Aper_flux_7	
33	Aper_flux_7_err	
34	Aper_flux_8	
35	Aper_flux_8_err	
36	Aper_flux_9	
37	Aper_flux_9_err	
38	Aper_flux_10	
39	Aper_flux_10_err	
40	Aper_flux_11	
41	Aper_flux_11_err	
42	Aper_flux_12	

43	Aper_flux_12_err	
44	Aper_flux_13	
45	Aper_flux_13_err	
46	Petr_radius	Petrosian radius, r_p in pixels as defined in Yasuda, et al. 2001, AJ, 112, 1104.
47	Kron_radius	Kron radius, r_k in pixels as defined by Bertin and Arnouts 1996, A & A Supp, 117, 393.
48	Hall_radius	Hall radius, r_h in pixels as defined by Hall and Mackay 1984, MNRAS, 210, 979.
49	Petr_flux	Petrosian flux and error to $2r_p$
50	Petr_flux_err	
51	Kron_flux	Kron flux and error to $2r_k$
52	Kron_flux_err	
53	Hall_flux	Hall flux and error to $5r_h$. Alternative total flux
54	Hall_flux_err	
55	Error_bit_flag	Bit pattern listing various processing error flags. Currently this is the number of bad pixels included in the aperture flux (Aper_flux_3)
56	Sky_level	Local interpolated sky level from background tracker
57	Sky_rms	Local estimate of variation in sky level around images
58	Parent_or_child	Flag for parent or part of de-blended deconstruct
59	RA	RA and Dec of each object in degrees
60	Dec	
61	Classification	simple flag indicating most probable classification for object: **-2:** Object is compact (maybe stellar) **-1:** Object is stellar **0:** Object is noise **1:** Object is non-stellar
62	Statistic	an equivalent N(0,1) measure of how stellar-like an image is. It is used in deriving the classification in a "necessary but not sufficient" sense. This statistic is computed from a discrete curve-of-growth analysis from the peak and aperture fluxes and also factors in ellipticity information. The stellar locus is used to define the "mean" and "sigma" as a function of magnitude such that the "statistic" can be normalised to an approximate N(0,1) distribution.
63-80	blank	

Converting the source catalogue fluxes (here, using any of the 13 aperture flux values: *Aper_flux_1* to *Aper_flux_13*) to magnitudes can be done with the following relation:

magnitude = PHOTZP - 2.5*log$_{10}$(Aper_flux_i) - APCORi (for i = 1 . . . 13)

where uppercase parameters indicate header keywords:

PHOTZP = the photometric zeropoint [magnitude]
APCORi = the stellar aperture correction for the ith aperture flux [magnitude]

Note that, since the VIMOS image stacks have been averaged to the number of input exposures, all magnitude computations should be done using the effective exposure time keyword, **EFF_EXPT**.

Appendix

A. VIMOS Photometry Using Standard Stars

Our original intent was to use APASS stars in the science field to photometrically calibrate these images. However, with a magnitude limit of about 16.5 – 17.0, even the faintest APASS stars will be saturated in VIMOS images with exposure times greater than about 130 seconds (in the U-band) and about 20 seconds (in all other filters). Since VIMOS science exposures are typically much longer, most of the APASS field stars will be saturated. The median exposure time of VIMOS standard star fields is ~14 seconds (in the U-band) and ~2 seconds (in all other filters), well-below APASS saturation levels. Therefore, we have used the APASS standard star catalogues to calibrate the VIMOS standard stars, which in turn, have been used to define the associated science image zeropoints.

If a standard star image existed on the same night and in the same filter as the science exposure, the standard star zeropoint (ZP_{std}) was converted to a science image zeropoint (ZP_{sci}) using:

$$ZP_{sci} = ZP_{std} + ext\_coef*(AM_{sci} - AM_{std}) + (APcor_{sci} - Apcor_{std})$$

where:
ext_coef is the filter-specific extinction coefficient (HIERARCH ESO DRS EXTCOEF)
AM_{sci} & AM_{std} are the airmass values of the science and standard images.
$APcor_{sci}$ & $Apcor_{std}$ are the aperture correction values (from the APCOR3 keywords) for the science and standard star images, respectively.

In the event that no suitable standard star exposure existed, the zeropoint of the science exposure was defined using the zeropoint median (as measured over several years of standard star data) for that VIMOS filter. These "default" zeropoints were measured for each of the six filters and for each of the two detector sets, in the following way:

- zeropoints were filtered if they deviated by more than +/- 1σ from the median zeropoint.
- a linear regression fit was made to the remaining zeropoints.
- zeropoints were again filtered if outside of +/- 1σ of the linear fit.
- a final linear regression fit was made to the remaining zeropoints.

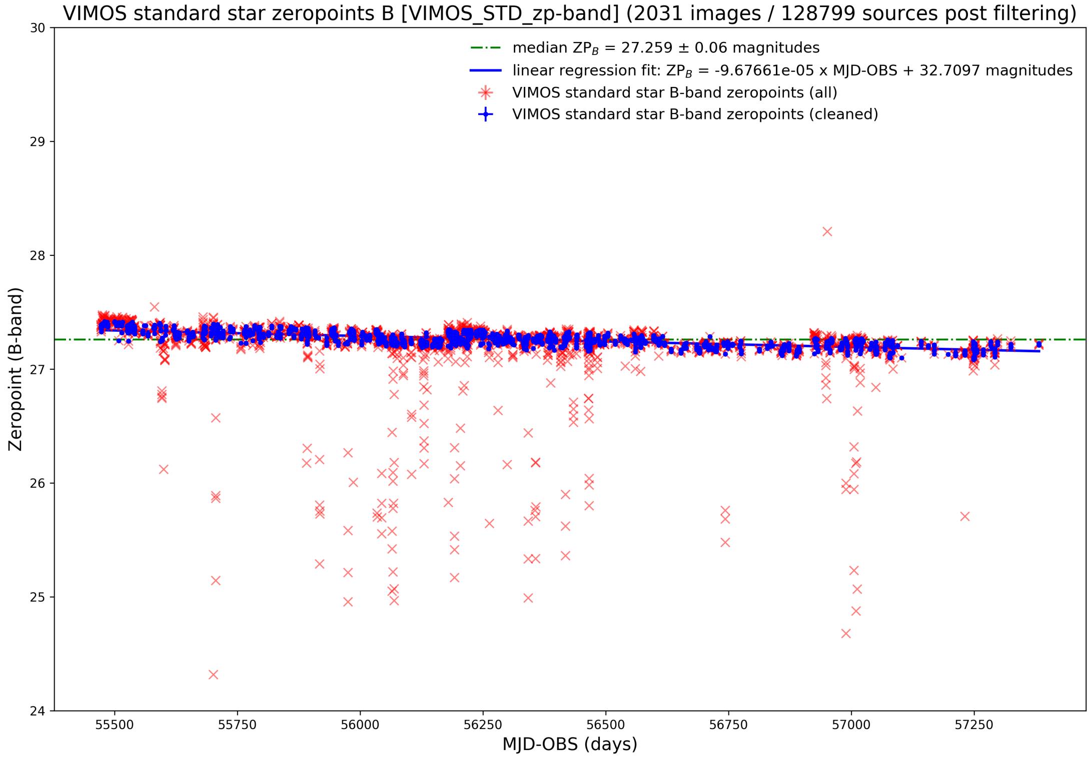

Figure 6: The full zeropoint history of VIMOS standard stars in the B-band filter and the new detectors. All standard star zeropoints are shown as red crosses. The blue points are those zeropoints used to define the zeropoint fit.

This results in a zeropoint fit of the form: ZP = m * MJD-OBS + b (for each filter and detector). The values of this fit are summarized in Table 4.

VIMOS Standard Star Zeropoint Fits (old detectors)			**ZP_{std} = m * MJD-OBS + b**		
Filter	**m**	**b**	**median ZP**	**<AM_{std}>**	**<$Apcor_{std}$>**
U	1.2067×10^{-5}	25.226	25.870 +/- 0.10	1.133	0.301
B	1.9609×10^{-5}	26.248	27.310 +/- 0.05	1.129	0.264
V	1.2079×10^{-5}	26.398	27.049 +/- 0.04	1.127	0.228
R	1.2866×10^{-5}	26.603	27.300 +/- 0.06	1.129	0.210
I	1.2998×10^{-5}	26.016	26.722 +/- 0.07	1.141	0.186
z	5.3127×10^{-5}	22.743	25.622 +/- 0.08	1.110	0.212
VIMOS Standard Star Zeropoint Fits (new detectors)					
U	-9.6630×10^{-5}	31.054	25.596 +/- 0.12	1.126	0.265
B	-9.6766×10^{-5}	32.710	27.259 +/- 0.06	1.124	0.223
V	-5.1644×10^{-5}	29.923	27.013 +/- 0.04	1.132	0.205
R	-4.8654×10^{-5}	30.123	27.383 +/- 0.05	1.128	0.183
I	-3.8051×10^{-5}	29.501	27.359 +/- 0.06	1.139	0.170
z	-1.4330×10^{-4}	34.654	26.601 +/- 0.10	1.102	0.138

Table 4: a summary of the fits to the cleaned VIMOS standard star zeropoints.

B. Colour Transformations

The colour transformations used for the conversion between the VIMOS-IMG photometric system and the system used for photometric calibration (e.g. APASS) can be found in the fits tables included in this distribution (HIERARCH ESO PRO CATG = PHOTCAL_TAB), and are divided into two tables defining the transformations for the old VIMOS detector set and the current VIMOS detector set.

For the old VIMOS detectors (data prior to August 1, 2010) the transformations are:

$U_{vimos} = 3.2 * g_{APASS} – 2.2 * r_{APASS}$

$B_{vimos} = 1.0 * B_{APASS} + 0.05 * g_{APASS} - 0.05 * r_{APASS}$

$V_{vimos} = 1.0 * V_{APASS}$

$R_{vimos} = 1.05 * r_{APASS} – 0.05 * g_{APASS}$

$I_{vimos} = 1.16 * i_{APASS} – 0.16 * r_{APASS}$

$z_{vimos} = 1.65 * i_{APASS} – 0.65 * r_{APASS}$

For the current VIMOS detectors (data post August 1, 2010) the transformations are:

$U_{vimos} = 3.2 * g_{APASS} – 2.2 * r_{APASS}$

$B_{vimos} = 1.0 * B_{APASS} + 0.05 * g_{APASS} - 0.05 * r_{APASS}$

$V_{vimos} = 1.0 * V_{APASS}$

$R_{vimos} = 1.08 * r_{APASS} – 0.08 * g_{APASS}$

$I_{vimos} = 0.96 * i_{APASS} – 0.04 * r_{APASS}$

$z_{vimos} = 1.65 * i_{APASS} – 0.65 * r_{APASS}$

References

1. APASS catalogue: https://www.aavso.org/apass
2. GOODS field phase 3 Release Description version 1.0, 24.04.2009: https://www.eso.org/sci/observing/phase3/data_releases/goods_vimos_im_dr1.pdf
3. Nonino, M., Dickinson, M., Rosati, P., Grazian, A., Reddy, N., Cristiani, S., Giavalisco M., Kuntschner, H., Vanzella, E., Daddi, E., Fosbury, R., & Cesarsky, C. 2009, ApJS, 183, 244.
4. Bertin, E., & Arnouts, S. 1996, A&AS, 117, 393

Acknowledgements

According to the ESO data access policy, all users of ESO data are required to acknowledge the source of the data with an appropriate citation in their publications. Since processed data downloaded from the ESO Archive are assigned a Digital Object Identifier (DOI), the following statement must be included in any publications making use of them:
Based on data obtained from the ESO Science Archive Facility with DOI(s) :
https://doi.eso.org/10.18727/archive/60

All users are kindly reminded to notify Mrs. Grothkopf (esodata at eso.org) upon acceptance or publication of a paper based on ESO data, including bibliographic references (title, authors, journal, volume, year, page numbers) and the observing programme ID(s) of the data used in the paper.