Data Flow System

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Notification List

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Contents

1 Introduction....................4
2 System Properties....................4
3 Monitoring....................5
4 Astrometry....................6
5 Photometry....................12

1 Introduction

On-sky data has been taken with VIRCAM from September 2008 to January 2009. All of this was shipped to Cambridge via disk and ingested into the VIRCAM raw data archive here. Although much of the data was of marginal quality for use in system characterisation, all nights of genuine on-sky data from December 2008 to January 2009 and a further seven nights from late September to early October 2008 have been reduced through the science pipeline. This involved following as closely as possible the usual steps of non-linearity correction, dark-correction, flat fielding based on twilight flats, sky subtraction, dither stacking and catalogue generation.

It should be borne in mind that during this time frame the performance of VISTA was being constantly developed and tuned. Various known problems existed at various times and subsequent changes have improved things such as tracking, optical image quality, filter cleanliness, observing overheads and observing procedures. It should also be understood that this report from CASU has no formal status in the process of the verification of VISTA. Any formal reports on verification of VISTA performance are not the responsibility of CASU.

2 System Properties

The data from VIRCAM received so far indicate that the detectors are generally functioning well and that given the right type of calibration good scientific results can be extracted from them. The main results from a preliminary analysis are:

- **crosstalk** -- appears to be negligible. There is no measurable crosstalk, even from very bright objects. Our current expectation is that correcting for crosstalk will be unnecessary.
- **persistence** -- this is also appears quite minimal. Observations of the η Carina region containing large numbers of bright stars on jittered observation frames, where the delay between exposures is minimal, have no visible persistence. It therefore looks like persistence correction will also be unnecessary.
- **linearity** -- all of the detectors show a distinct non-linearity of generally between 2-4% at the 10000 ADU level. In the case of detector #13 the non-linearity at 10000 ADU is more like 9%. The linearity error estimate is very good with the exception of detector #5 which probably requires a higher order polynomial to better describe it.
- **saturation levels** -- TBD
- **sky brightness levels** -- TBD
- **night sky fringing** -- there is no evidence in the data to hand for any significant fringing in any filter used in observations, though further analysis is required to put a quantitative limit on this
- **geometry** -- the pixel-arrays on the chips (but not necessarily their physical mountings) are mutually misaligned by a maximum rotation of 0.15 degrees, derived from inspection of WCS solutions. There is no evidence so far of non-

coplanarity, but final judgment is reserved pending data with full tuning applied to the instrument and telescope.

3 Monitoring

Some example data monitoring statistics for data taken in several 2MASS touchstone fields on 20081011.

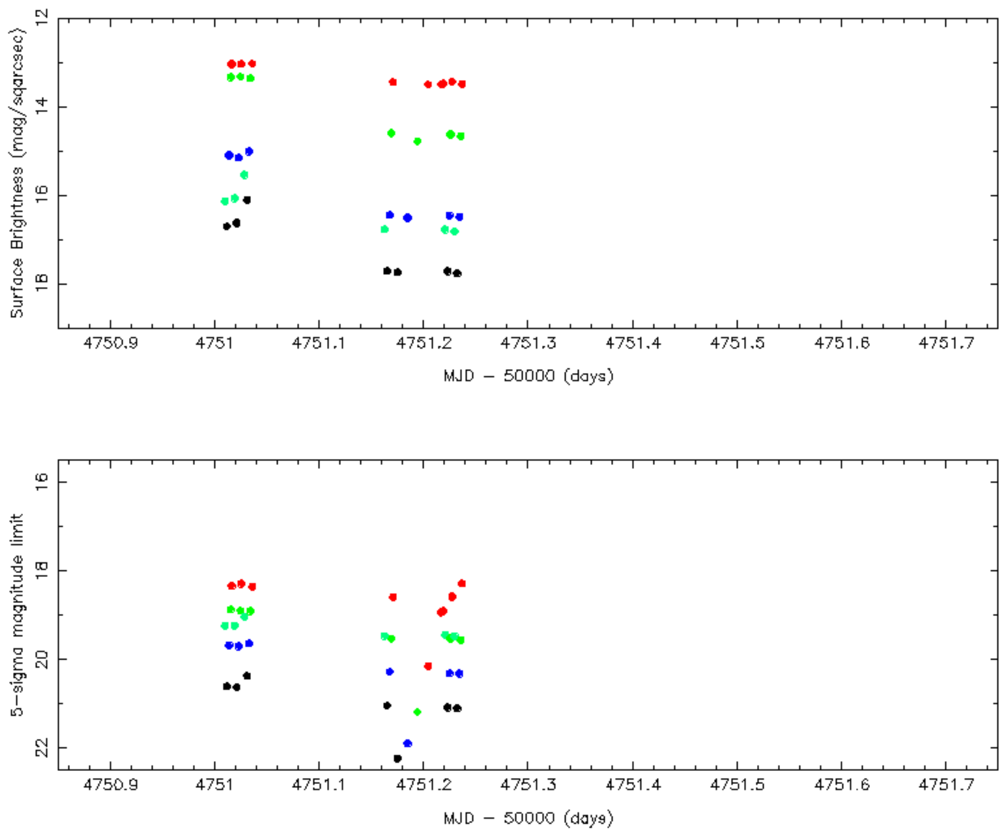


Figure 3-1 The observed sky brightness levels and limiting magnitudes: J - blue; H - green; Ks - red; NB118 - light green; Y - black

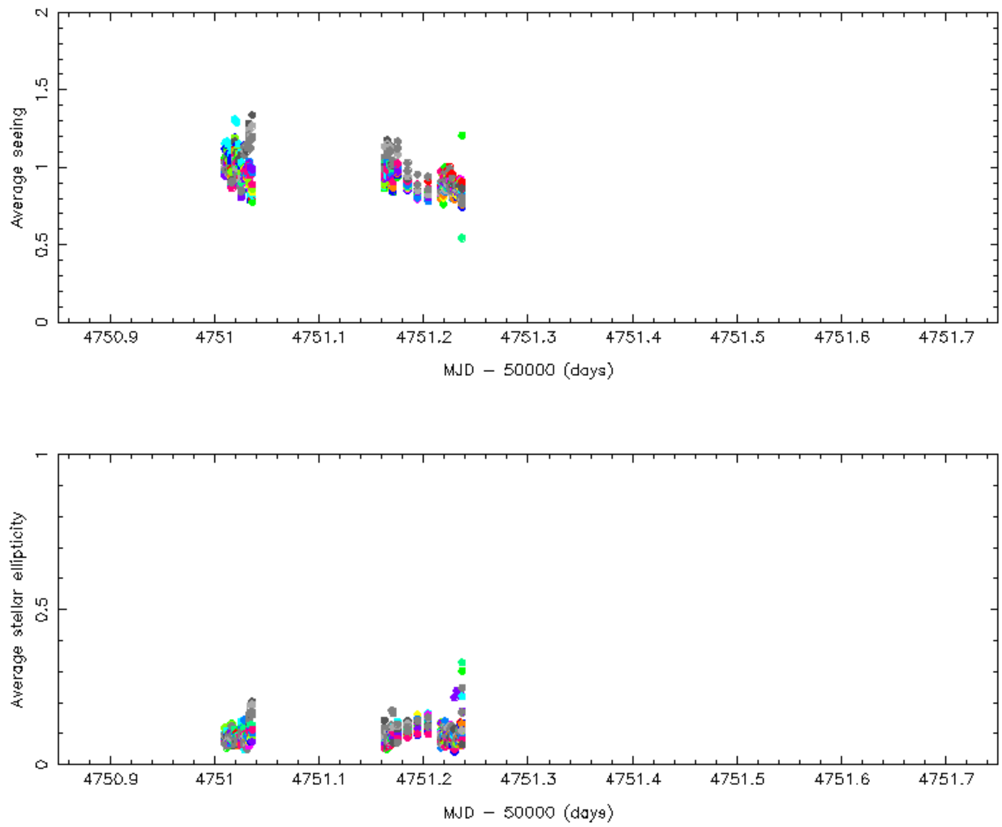


Figure 3-2 Average seeing and ellipticity of stellar objects on each detector.

4 Astrometry

For general information on the size of the expected field distortion and its effects on photometry for VISTA see http://www.ast.cam.ac.uk/vdfs/docs/reports/astrom.

In the following tests we have used the 2MASS PSC as the basis for all the astrometric calibration. The results are very promising and we intend to use 2MASS for all astrometric calibration in much the same way as we have done for WFCAM. Note that 2MASS astrometry is based on Tycho 2 and is in the International Celestial Reference System (ICRS). This does not require an Equinox to be specified. For most practical purposes this is (almost) equivalent to Equinox 2000 in FK5, but for purists the astrometry CASU will be producing for VIRCAM will be in the ICRS and will have keyword/value RADECSYS = 'ICRS' set. EQUINOX = 2000.0 will be left as is for backwards compatibility with existing software.

From earlier ray-tracing data provided by the VPO we expected VIRCAM to have an astrometric radial distortion of the form

$$r_{true} = k_1 r + k_3 r^3 + k_5 r^5$$

where r_{true} is an idealised angular distance from the optical axis and *r* is the measured distance. k_1 is the scale at the centre of the field, which for VISTA is nominally xx.y arcsec/mm.

This can be rewritten in a more useful form as

$$r_{true} = r' + k'_3\, r'^3 + k'_5\, r'^5$$

where *r'* is the measured angular distance from the optical axis using the k_1 scale and $k'_3 = k_3 / k_1$, $k'_5 = k_5 / k_1$. If we convert all units to radians the r^3 coefficient is conveniently scaled (in units of radians/radian^3) and was expected to be +42.0 in all bands for VIRCAM. The r^5 term was unmeasurable from the provided data but was expected to be small.

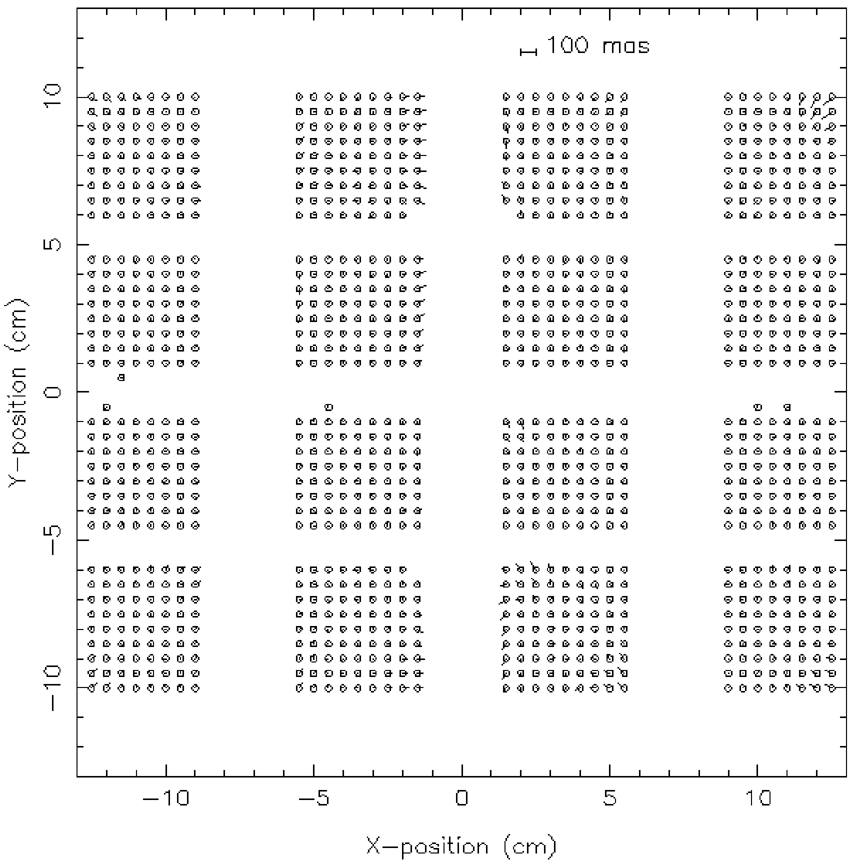
The pipeline processing essentially corrects for the radial distortion and then solves for the following linear transformation from (distorted) standard coordinates with respect to the optical axis

$$\xi' = ax + by + c$$

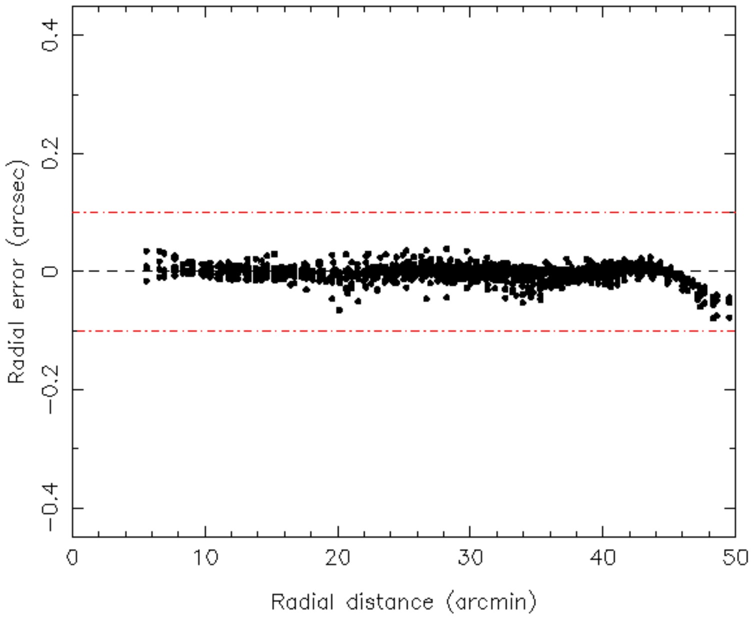
$$\eta' = dx + ey + f$$

where a, e, b, d encode for scale(s), rotation and shear, and *c* and *f* are offsets.

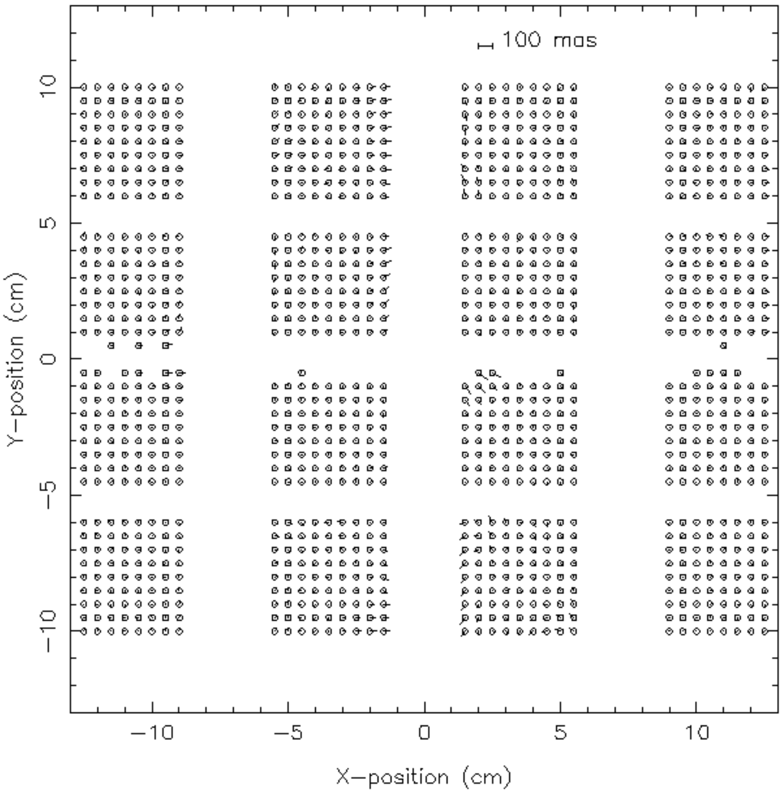
First results are very promising and shown below. The first plot shows the residual stacked distortion from several pointings over the entire array using the default optical axis location with respect to each detector and the expected r^3 distortion term in the astrometric model.



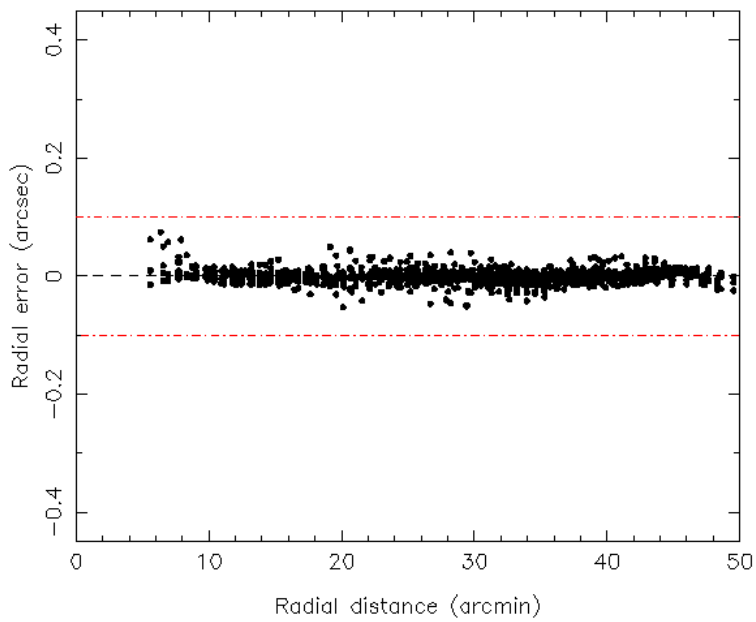
There is a small apparent radial trend in the data which is better revealed in the next figure showing the residuals as a function of radius and highlighting the need for a further radial distortion term in the model.



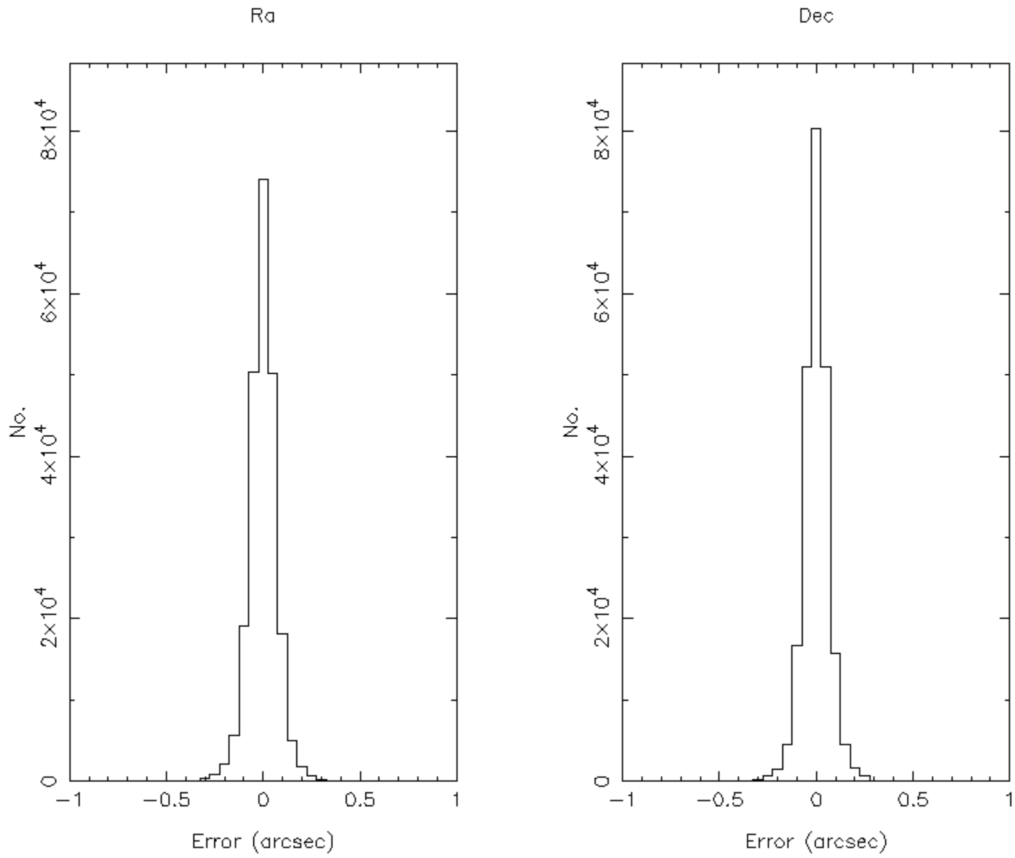
After a few trial and error iterations an r^5 term of -10000.0 was found to correct the remaining distortions rather well (more detailed fitting is not warranted until the final alignments and adjustments to VISTA have been made) as the corresponding pair of updated residual figures demonstrate.



100 mas
Y–position (cm)
X–position (cm)



The only requirement on using a 2MASS star in the astrometry was that it had to have a photometric s:n ratio > 10:1 in all of J,H,K. This ensures that the 2MASS astrometry errors are around 100 mas or less for the majority of the point sources used. Note that even in high latitude fields there are still around 50 suitable 2MASS stars per detector to use for the astrometric refinement. The individual fit residuals for each 2MASS star used in the these tests are shown in the histograms below and are around 50-60 mas on both axes (using a robust rms estimator).



Note that the residual systematics are already well below the 100mas threshold over the entire field, and therefore already meet the astrometric requirements. It is also apparent that the WCS is well described by a ZPN projection. Indeed our measured k_3 distortion coefficient is within +/-1 of the predicted value of 42 radian/radian^3 optical distortion.

Until the final VISTA adjustments are made during the next phase of commissioning there is no point in pursuing this further at this stage since systematic subtleties in the residual maps will undoubtedly change things at the few micron level.

5 Photometry

As for WFCAM we will be using the 2MASS PSC to provide an accurate photometric calibration for every science product frame. An example of this is a detailed analysis of some J-band Eta Carina data carried out by photometrically calibrating it against 2MASS using, at the time, WFCAM proxies for the colour equations to get an overall idea of the throughput and the relative detector sensitivities. Coupled with provisional gain estimates, these suggested that the overall throughput of VISTA is some 0.5 magnitudes better than that of WFCAM, at least in the J-band (see table for details).

Det #	**Gaincor**	**Gain #1**	**Gain #2**	**Magzpt**	**RMS**	**# Stds**	**Seeing**	**Ellipt**
	(ADU)	**(e-/ADU)**					**(arcsec)**	
1	0.8369	3.997	3.700	23.653	0.070	580	0.99	0.13
2	1.3219	4.383	4.294	23.610	0.053	1094	1.00	0.16
3	1.2213	4.123	4.156	23.405	0.050	491	0.98	0.14
4	1.0017	4.741	4.398	23.386	0.042	781	1.02	0.16
5	0.9634	6.039	4.282	23.638	0.059	930	1.00	0.14
6	0.8785	4.387	4.162	23.570	0.059	841	0.94	0.18
7	0.8273	4.356	3.978	23.556	0.062	1127	1.01	0.16
8	1.0231	4.629	4.329	23.529	0.050	829	0.98	0.16
9	0.9926	5.049	4.695	23.511	0.055	676	0.94	0.13
10	0.9214	4.578	3.997	23.582	0.071	167	0.94	0.16
11	1.0336	5.117	4.760	23.569	0.049	378	0.94	0.17
12	0.9236	4.357	3.932	23.523	0.053	479	0.98	0.15
13	1.3584	6.704	5.871	23.613	0.053	851	0.96	0.13
14	1.0026	5.164	4.763	23.581	0.049	622	0.98	0.13
15	0.8915	4.296	4.041	23.579	0.041	456	0.98	0.16
16	1.1480	5.602	5.535	23.567	0.107	446	1.04	0.15
Average				23.565	0.088	10748	0.98	0.15

Figure 5-1 J band data of η Carina region from 20080714 at airmass of 2.13. Gain correction is computed from twilight flats, giving the relative gain. Gain #1 and #2 are two different attempts at measuring real detector gain. **Magzpt** is the brightness of a star that gives 1 ADU per second on a detector. **RMS** is the scatter of the photometric solution per detector (2MASS contributes the most). **# Stds** is the number of 2MASS stars included in the photometric solution. **Seeing** and **Ellipticity** are the average FWHM and ellipticity of stellar images on the detector. For comparison WFCAM average J Magzpt = 23.0 and the average gain is 4.5 e-/ADU.

Subsequent analysis of some VIRCAM data taken on several 2MASS touchstone fields showed that this throughput advantage persists over all the bands analysed to date as the following provisional magzpts illustrate:

Filter	**Magzpt**
Y	23.56
J	23.78
H	23.85
K	23.05
NB118	20.84

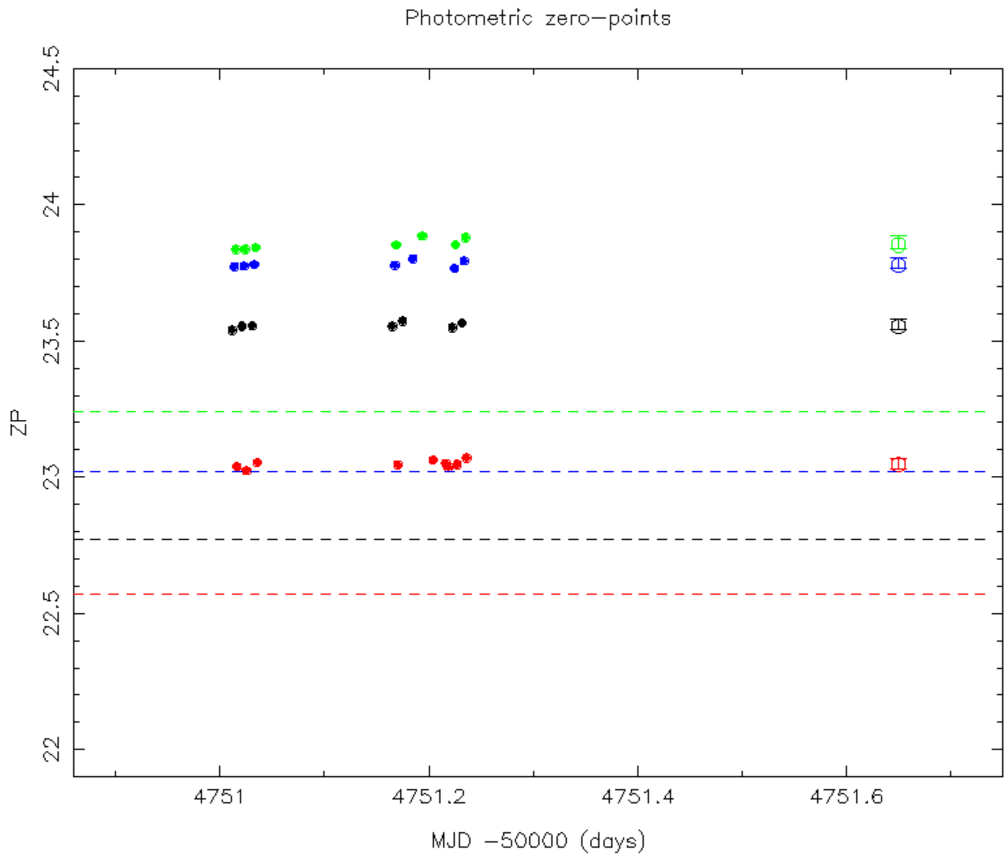


Figure 5-2 Magnitude zeropoints as a function of time during a single observing session: J - blue; H - green; Ks - red; Y - black

Note that these are "average magnitude zeropoints for the entire array and that this analysis needs repeating when more accurate colour equations have been derived and further checks on the non-linearity corrections have been made. The following figures illustrate the first steps in this process.

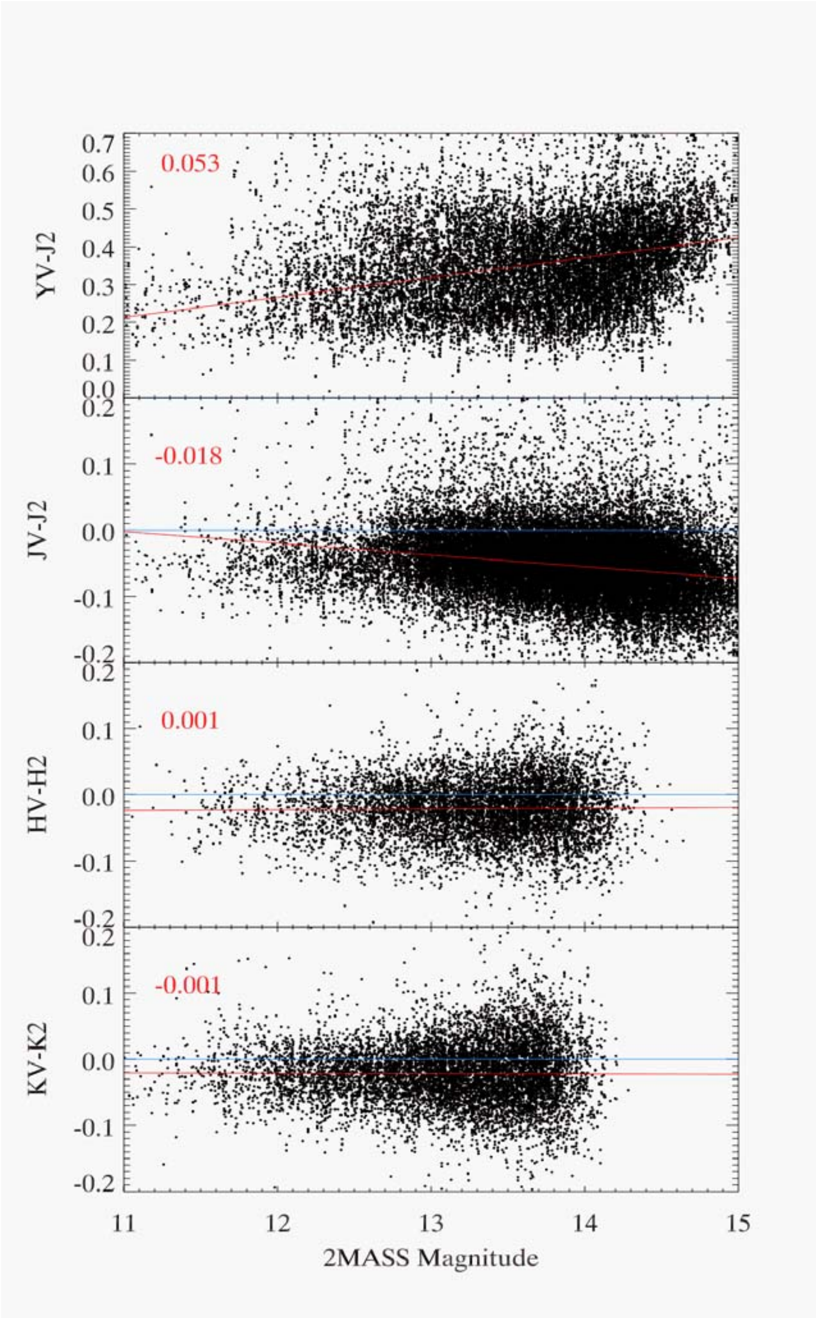


Figure 5-3 Raw magnitude offset vs. 2MASS magnitude. The red numbers indicate the slope of the fitted red line.

Figure 5-3 shows the raw magnitude offset as a function of 2MASS magnitude after solving for a global array zero-point but without using any colour terms at this stage (slopes on the plots are per unit magnitude). The mix of stellar populations between f,g and k,m stars varies strongly with magnitude and this most likely highlights colour-dependent residuals rather than any residual non-linearity in the VIRCAM magnitudes. As is demonstrated in the following plots.

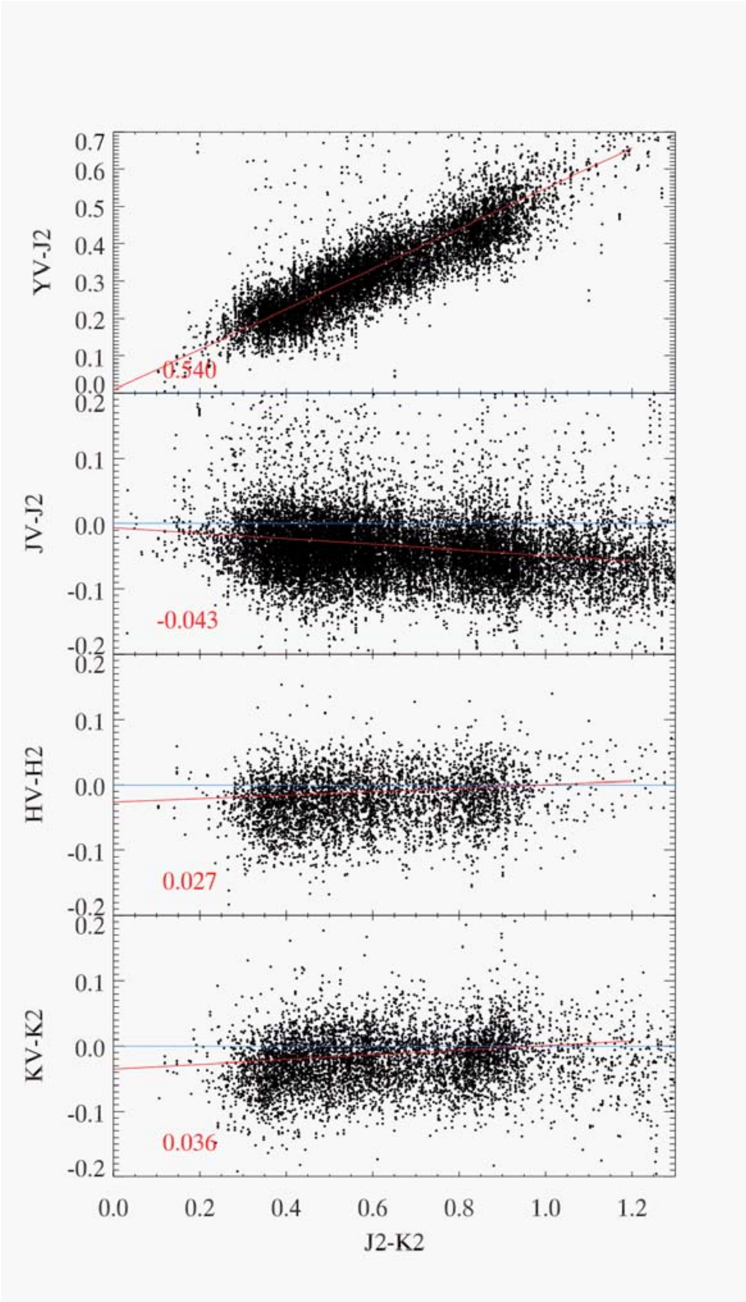


Figure 5-4 VISTA/2MASS magnitude difference vs. 2MASS (J-K) colour.

Figure 5-4 shows the linear colour term fits to the residuals as a function of 2MASS (J-K) colour. This could be cleaned up by selecting a slightly brighter 2MASS limit and also by checking observing conditions a bit more stringently. However, it does highlight the expected significant colour terms in the Y-band and also demonstrates measurable small colour terms in the J,H,K passbands (colour terms as a function of J-K are highlighted on the plots).

Now if this interpretation is correct then the residual magnitude difference between 2MASS and VIRCAM as a function of 2MASS magnitude should be much improved after applying the colour terms as shown in Figure 5-5 below.

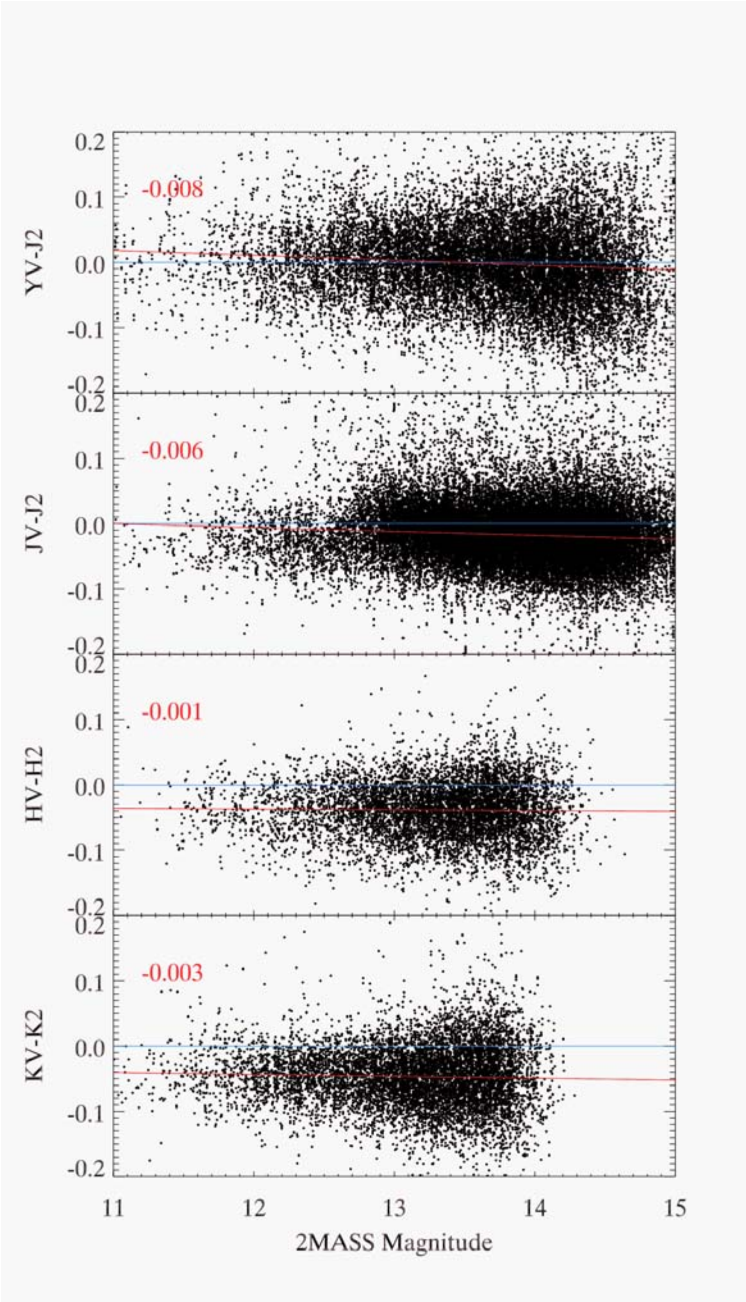


Figure 5-5 Magnitude offset vs. 2MASS magnitude after application of colour terms.

Application of the first pass colour terms derived from the 2MASS photometry vastly improves the apparent non-linearity. Y and J are appreciably more linear than before. There are still residual effect at the 1% per magnitude level but we suspect these will disappear after a more thorough analysis of the colour-equations, which in turn may also lead to minor zeropoint corrections to make once these colour terms are more accurately known.

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