Calibrating VISTA Data

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Summary. When VISTA is operating with its 16 detector 2048 × 2048 camera it will produce some 300GB of data each operational night. Calibration plans are outlined, making much use of the 2MASS catalogue, and build on experience with WFCAM on UKIRT.

1 Introduction

VISTA, the Visible & Infrared Survey Telescope for Astronomy [5], is a 4-m Survey Telescope equipped with a single instrument, a 1.65 degree diameter field of view near-infrared camera with only one moving part, the filter wheel, which is equipped with broad-band filters for Z, Y, J, H, & K_s (0.9-2.5 micron), and two spaces for other filter sets. VISTA is located on a peak $\sim$ 1500-m from the VLTs at the Cerro Paranal Observatory in Chile, and is being provided to ESO by the UK.

The VISTA camera's focal plane consists of 16 Raytheon 2048 × 2048 VIRGO near-IR detectors with 0.34 arcsec pixels arranged in a sparse 4 × 4 array with spacings of 90% & 42% of detector. A single exposure with VISTA produces a sparsely filled 0.6 sq degree detector 'pawprint'. These pawprints can be most efficiently turned into filled 'tiles' by taking a 3x2 set of suitably offset pawprints which when combined provide an area of 1.5 sq degrees covered by (at least) two exposures.

VISTA has a wide field of view, so particular attention must be paid to variations across the field, and VISTA's calibration observations are designed to characterize the transfer function of the end-to-end system (image in, data number out) and in particular:

1. the instrument characteristics
2. the astrometric distortions of the images
3. the photometric zero points, distortion (illumination correction) and extinction coefficients.

Using calibration observations and the data itself the VISTA calibration pipeline [6], [2] removes instrumental artefacts, combines the component exposures offset by small jitters into a pawprint, calibrates each pawprint photometrically and astrometrically, and finally provides Quality Control measures [4].

With its sixteen detectors and the relatively short integration times typical of infrared detectors, VISTA will on average (i.e. including weather factors) produce $\sim$ 250GB of data each night which far exceeds the data volumes produced by the instruments on all the VLTs. The need to handle a continuous high volume data stream implies that VISTA calibration must be a highly automated process, and here we describe our plans to cope with this.

2 Strategy: Prepare for VISTA with WFCAM

Given that we will not have real images with VISTA until it is commissioned later in 2007, we wanted to mitigate the risks in learning to properly handle VISTA data (and its large volume), to ensure data processing will keep up with the incoming data flood. The strategy we adopted has been to first design a data flow system (running in the UK) to handle data from UKIRT's wide-field infrared camera WFCAM, with upgrading to handle VISTA data and volumes in mind, and then to build on this and the experience gained to produce the system for VISTA. The comparison between WFCAM and VISTA is shown in Table 1.

Table 1. Similarities between WFCAM and VISTA

	WFCAM	VISTA
Telescope	4-m (UKIRT)	4-m
Camera pixel size	0.4 arcsec	0.34 arcsec
2kx2k Detectors	4 x Hawaii (Rockwell)	16 x VIRGO (Raytheon)
Time camera on	$\sim$ 50%	100%

Of course the two systems differ in many details, but setting up a system (the VISTA Data Flow System - VDFS) that is demonstrated to handle WFCAM data well provides the best way to prepare for VISTA data, and we believe that debugging of VISTA processing, including calibration, will be speeded up and de-risked through the WFCAM experience. The examples of data shown in this paper are based on WFCAM data. There are three other talks at this workshop which touch on the VDFS work [2], [4] and [1].

3 Instrument Characteristics

3.1 Cross-Talk & Persistence

The WFCAM camera on UKIRT suffers from cross-talk from saturated images. The cross-talk gives 'bumps' symmetrically above and below saturated stars (left hand side of Fig 1). For WFCAM these are mostly (but not perfectly) correctable (right hand side of Fig 1). Whilst there is no evidence so far that VISTA will suffer from any cross-talk, if it does then a similar strategy to that used for WFCAM should largely remove it.

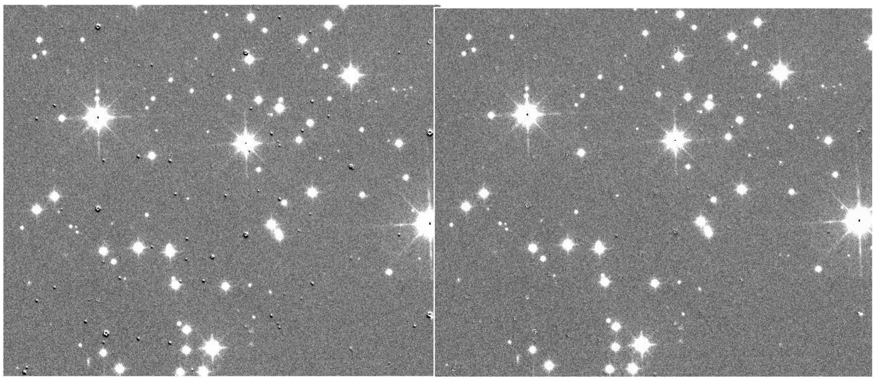

Fig. 1. Cross Talk from saturated stars in WFCAM observations (of the open cluster M67) before (left) and after (right) artefact cleaning.

Fig. 2. Persistence effect (pattern of 9 decaying artefacts in the middle and upper middle) for a WFCAM frame following on after frames on M67.

WFCAM also suffers from persistence/ remanence effects after observing bright objects. Fig 2 shows the persistence artefacts from a previous 9-point jitter sequence (9 closely spaced decaying images) of the Open Cluster field shown in Fig 1.

Persistence has proved much harder to completely correct, presumably because the characteristics of the persistence are not constant enough with time. It is not known if VISTA will show similar effects (the detectors and controllers are different) but we plan to take calibrations in case this effect needs to be corrected.

To characterize any persistence effects for VISTA we will choose a fairly empty field containing a star which saturates the VISTA detector. On a sequence of (monthly) dates we will take an exposure of the saturated star and then a sequence of dark frames to measure the characteristic decay time, which we hope will prove stable.

3.2 Linearity, Flat Fielding & Illumination Correction

Although VISTA has a Dome 'Flat screen' this will not be used for flatfielding but rather for monitoring instrument performance, image structure and generating confidence maps, and measuring system linearity.

To determine any non-linearity we will take a series of differently timed dome flat screen observations under constant illumination, which, with the pixel timing, will give the true linear value for each pixel & bad-pixel maps for each detector.

Twilight (flat) fields, will be used to remove multiplicative instrumental signatures and determine: pixel-to-pixel gain variations; the instrumental vignetting profile; the gain correction between the 16 detectors; and the gain correction between the 16 read out channels of each detector.

The Flat-field should remove all pixel-to-pixel gain differences as well as any large-scale variations due (generally) to vignetting within the focal plane, but any scattered light within the camera may lead to large scale background variations (requiring illumination correction) which cannot easily be modeled and removed, as the level depends critically on the ambient flux.

The illumination correction will be measured in three ways:

1. Observe secondary photometric standard fields (100-200 objects per detector) & the variation of zero-point across each detector gives a map of the spatial systematics across each detector
2. Carry out 'mesostep' sequence of exposures of a sparse field of relatively bright stars on a regular grid of offsets, to completely sample across the face of the detectors in medium-sized steps to monitor residual systematics in photometry
3. Use the stacked zero point differences from 2MASS objects in each pawprint (see Sec 5).

4 Astrometric Calibration

Astrometric calibration is based on the 2MASS point source catalog which is calibrated globally to ~ 100 milliarcsec and internally to $<\sim 50$ milliarcsec and tied to the TYCHO-2 catalogue and is in International Coordinate Reference System (ICRS).

The wide field of view means that the effects of distortion across the field of view need to be handled particularly carefully. The strongest term in the optical-distortion model is a cubic radial term and the actual distortion will be determined for VISTA from on-sky observations of 2MASS stars. This radial scale distortion also has an impact on photometric measurements, inducing an error up to 3.5% in the corners of the field, compared to the centre, if uncorrected.

5 Photometric Calibration

To achieve the 2% accuracy goal in the photometric calibration two independent methods are used to derive zero-points for each image.

Method 1: from the 2MASS all-sky point source catalogue

Method 2: from routine observations of standard star fields

Together these allow monitoring of effective zero-points at the $\sim$ few % level. Subsequent inter-detector comparisons enable residual errors in the gain correction to be detected and calibrated. Off-line analysis gives a measure of median zero-point for the night, and associated error (and scatter) which is indicative of photometric quality.

5.1 2MASS magnitudes

The initial photometric calibration for all filters will be based on the 2MASS photometric system which is globally consistent to $\sim$ 1% [3]. We will use colour equations (with some colour and signal-to-noise cuts) to convert 2MASS magnitudes to the VISTA instrumental system which enables each detector image to be calibrated directly from 2MASS stars that fall within field of view. Analysis of WFCAM data with respect to UKIRT standards shows that using 2MASS stars for WFCAM calibration delivers good frame-by-frame photometric zero-points at the +/-2% level (with factored-in extinction tracking). VISTA should be calibrated at least as well.

5.2 Network of standard star fields

We will also setup a network of Secondary Standard photometric fields, spaced every $\sim$ 2 hours in RA. These will be 2MASS 'Touchstone' fields and/or UKIRT faint standard fields which will provide $\sim$ 100 stars per detector $J < 18$, $K_s < 16$ to avoid long exposures which will characterize systematic position dependent photometric effects. These will encompass a broad spread in colour to derive colour terms robustly, and will be observed every two hours elapsed time throughout each night enabling an independent calibration to be made on a nightly basis. The Touchstone fields will also provide information on the stability and can be used to measure the illumination correction.

5.3 Extinction Coefficients

The extinction will be monitored through each (photometric) night assuming a fixed zero point and measuring the touchstone fields over a range of airmass. We then use the 2MASS stars in each pawprint to determine the extinction.

During nights which are less photometric we will assume a fixed zero point and use the 2MASS stars in each pawprint to determine the extinction coefficients as a function of time.

6 Conclusion

We have prepared our calibration plan for VISTA with the benefit of experience of handling and calibrating data from UKIRT's WFCAM, the closest operational analogue to VISTA. The astrometric and photometric calibrations will benefit greatly from the availability of the well-calibrated 2MASS survey. When VISTA is operational and we have characterized its performance we expect to be able to get well calibrated without much delay.

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References

1. M. Irwin: this conference proceedings (2007)
2. J. Lewis, M. Irwin, P. Bunclark, S. Hodgkin: this conference proceedings (2007)
3. S. Nikolaev, M.D. Weinberg, M.F. Skrutskie, R.M. Cutri, S.L. Wheelock & J.E. Giziz: Astrophys. J **120**, 3340 (2000)
4. M. Riello: this conference proceedings (2007)
5. www.vista.ac.uk
6. VISTA Infra Red Camera Calibration Plan, VIS-SPE-IOA-20000-0002 v1.4 (2007)