Visible & Infrared Survey Telescope for Astronomy

Data Flow System

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Notification List

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1 Introduction

1.1 Purpose

This document forms part of the package of documents describing the Data Flow System for VISTA, the Visible and Infrared Telescope for Astronomy. As stated in [AD1] "The Calibration Plan is the prime document which describes the different instrument-specific components of the Data Flow System".

1.2 Scope

This document describes the VISTA DFS calibration plan for the output from the 16 Raytheon VIRGO IR detectors in the (Infra Red) camera for VISTA. The baseline requirements for calibration are included in the VISTA DFS Impact Document [AD2]. The major reduction recipes and algorithms to be applied to the data are described in the VISTA DFS Data Reduction Library Design [RD1].

Each camera exposure will produce a 'pawprint' consisting of 16 non-contiguous images of the sky, one from each detector. The VISTA pipeline will remove instrumental artefacts, combine the pawprint component exposures offset by small jitters, and photometrically and astrometrically calibrate each pawprint. It will also provide Quality Control measures. It will not combine multiple adjacent pawprints into contiguous filled images, nor stack multiple pawprints at the same sky position.

This document does not describe any calibrations or procedures relating to the CCD detectors that are also located within the camera and which interact with the Telescope Control System.

This document covers only the Routine Phase of operations of VISTA's IR Camera. In particular it does not describe any calibrations or procedures that form part of the Commissioning Plan for VISTA, nor any procedures needed during routine Engineering Maintenance. [Except for HOWFS observations, which are made using the science detectors, and passed to the science archive.] Arrangements for processing any calibrations or procedures carried out under such categories are the responsibility of the VISTA Project Office.

1.3 Applicable Documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered as a superseding requirement.

[AD1] *Data Flow for the VLT/VLTI Instruments Deliverables Specification,* VLT-SPE-ESO-19000-1618, issue 2.0, 2004-05-22.
[AD2] *VISTA Infra Red Camera DFS Impact,* VIS-SPE-IOA-20000-00001, issue 1.1, 2005-02-08.
[AD3] *VISTA Infrared Camera Data Flow System PDR RID Responses with PDR Panel Disposition,* VIS-TRE-IOA-20000-0006 issue 1.0

[AD4] *VISTA Infrared Camera Data Flow System FDR RID Responses* VIS-TRE-IOA-20000-0013 issue 0.4 2005-01-26

1.4 Reference Documents

The following documents are referenced in this document.

[RD1] *VISTA Infra Red Camera Data Reduction Library Design*, VIS-SPE-IOA-20000-00010, issue 1.1, 2005-04-28.
[RD2] *Data Interface Control Document*, GEN-SPE-ESO-19940-794, issue 3, 2005-02-01.
[RD3] *VISTA Operational Concept Definition Document,* VIS-SPE-VSC-00000-0002 issue 1.0, 2001-03-28
[RD4] *VISTA Infrared Camera Technical Specification,* VIS-SPE-ATC-06000-0004, issue 2.0, 2003-11-20
[RD5] *VISTA IR Camera Software Functional Specification*, VIS-DES-ATC-06081-00001, issue 2.0, 2003-11-12.
[RD6] *IR Camera Observation Software Design Description*, VIS-DES-ATC-06084-0001, issue 3.2, 2005-02-24.
[RD7] *VISTA Science Requirements Document*, VIS-SPE-VSC-00000-0001, issue 2.0, 2000-10-26
[RD8] *A New System of Faint Near-Infrared Standard Stars*, Persson et al., Astrophys. J. **116**, 2475-2488, 1998
[RD9] *JHK standard stars for large telescopes: the UKIRT Fundamental and Extended lists*, Hawarden et al., Mon.Not.R.Soc. **325**, 563-574,2001
[RD10] *The FITS image extension*, Ponz et al, Astron. Astrophys. Suppl. Ser. **105**, 53-55, 1994
[RD11] *Representations of world coordinates in FITS*, Griesen, & Calabretta, A&A, **395**, 1061.2002
[RD12] *Representations of celestial coordinates in FITS*, Calabretta & Griesen, A&A, **395**, 1077, 2002
[RD13] *Overview of VISTA IR Camera Data Interface Dictionaries,* VIS-SPE-IOA-20000-0004, 0.1, 2003-11-13
[RD14] *Northern JHK Standard Stars fro Array Detectors,* Hunt et al Astr.J 115, 2594, 1998

1.5 Abbreviations and Acronyms

2MASS	2 Micron All Sky Survey
CDS	Correlated Double Sampling
DAS	Data Acquisition System
DFS	Data Flow System
FITS	Flexible Image Transport System
HOWFS	High Order Wave-Front Sensor
ICRF	International Coordinate Reference Frame
IMPEX	Import Export (P2PP ASCII files)
IR	Infra Red
IWS	Instrument Workstation
LOWFS	Low Order Wave-Front Sensor

OB	Observation Block
OS	Observing System
OT	Observing Tool
PI	Principal Investigator
QC-0	Quality Control, level zero
QC-1	Quality Control, level one
SDT	Survey Definition Tool
TCS	Telescope Control System
URD	User Requirements Document
VDFS	VISTA Data Flow System
VIRCAM	VISTA Infra Red Camera
VISTA	Visible and Infrared Survey Telescope for Astronomy
VPO	VISTA Project Office
WCS	World Coordinate System
WFCAM	Wide Field Camera (on UKIRT)
ZPN	Zenithal Polynomial

1.6 Glossary

Confidence Map An integer array, normalized to a median of 100% which is associated with an image. Combined with an estimate of the sky background variance of the image it assigns a relative weight to each pixel in the image and automatically factors in an exposure map. Bad pixels are assigned a value of 0, 100% has the value 100, and the maximum possible is 32767 (negative values are reserved for future upgrades). The background variance value is stored in the FITS header. It is especially important in image filtering, mosaicing and stacking.

Exposure The stored product of many individual **integration**s that have been co-added in the DAS. Each exposure is associated with an exposure time.

Integration A simple snapshot, within the DAS, of a specified elapsed time. This elapsed time is known as the integration time.

Jitter (pattern) A pattern of **exposures** at positions each shifted by a small **movement** (<30 arcsec) from the reference position. Unlike a **microstep** the non-integral part of the shifts is any fractional number of pixels. Each position of a jitter pattern can contain a **microstep** pattern.

Mesostep A sequence of **exposures** designed to completely sample across the face of the detectors in medium-sized steps to monitor residual systematics in the photometry.

Microstep (pattern) A pattern of **exposure**s at positions each shifted by a very small **movement** (<3 arcsec) from the reference position. Unlike a **jitter** the non-integral part of the shifts are specified as 0.5 of a pixel, which allows the pixels in the series to be interleaved in an effort to increase resolution. A microstep pattern can be contained within each position of a **jitter** pattern.

Movement A change of position of the telescope that is not large enough to require a new guide star.

Offset A change of position of the telescope that is not large enough to require a telescope **preset**, but is large enough to require a new guide star.

Pawprint The 16 non-contiguous images of the sky produced by the VISTA IR camera, with its 16 non-contiguous chips (see Figure 2-2). The name is from the similarity to the prints made by the padded paw of an animal (the analogy suits earlier 4-chip cameras better).

Preset A telescope slew to a new position involving a reconfiguration of the telescope control system and extra housekeeping operations that are not necessary for a **movement** or an **offset**.

Tile A filled area of sky fully sampled (filling in the gaps in a pawprint) by combining multiple **pawprint**s. Because of the detector spacing the minimum number of pointed observations (with fixed offsets) required for reasonably uniform coverage is 6, which would expose each piece of sky, away from the edges of the tile, to at least 2 camera pixels. The pipeline does not combine **pawprint**s into tiles.

2 Overview

2.1 Hardware

VISTA is a wide field alt-az telescope designed for a single purpose, surveys, and which does not have a conventional focus. It can only be used with a purpose built camera, and is delivered with an IR camera. Thus it is the performance and pointing of the telescope-camera system that is important.

The telescope by itself has no capability to lock onto a guide star or carry out wave front sensing. The IR Camera therefore contains, as well as 16 IR detectors, two Autoguider CCDs and two low order wave front sensor (LOWFS) units, each with two CCDs, operating in the I band, as shown in Fig 2-1. Two autoguiders, on opposite

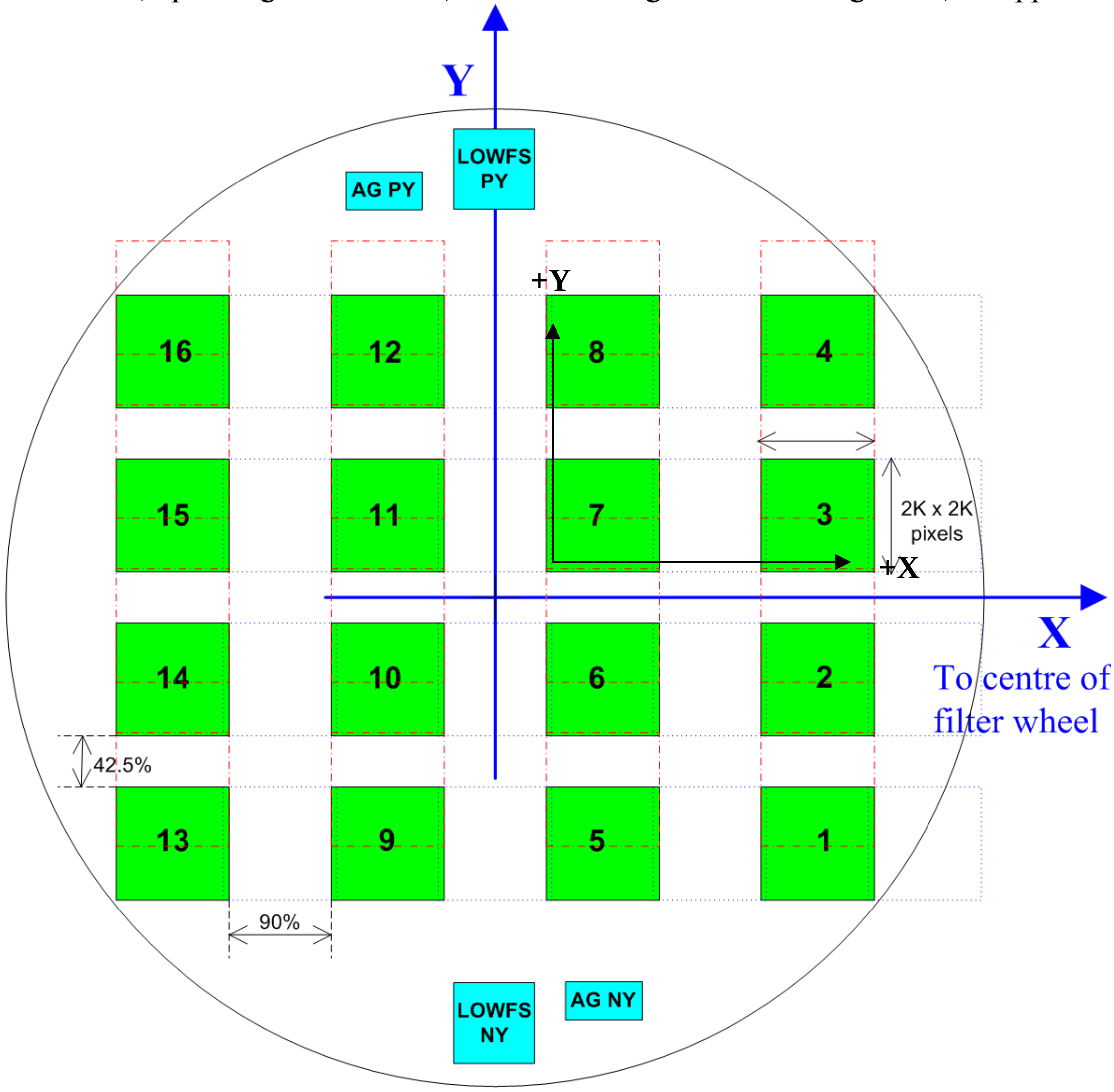

Figure 2-1 VISTA Focal plane: Each of the 4 groups of detectors in the Y direction (e.g. #s 1-4, 5-8, 9-12, 13-16) is read out by a separate IRACE controller.

edges of the focal plane, are used in order to meet the sky coverage requirements, although only one is allowed to apply corrections to the telescope axes at any given time. The LOWFSs measure aberrations that are used by the external active optics control process to adjust the position of the 5 axis (x, y, z, tip, tilt) secondary mirror support system and some aspects of the M1 surface to maintain image quality. The LOWFS operates roughly every 1 minute during tracking and needs exposures of ~40 sec to average out seeing effects. Although the Autoguiders and LOWFSs are physically located within the IR camera, both are considered part of the TCS from a software point of view. This is primarily to maintain consistency with existing VLT software and standards. The VISTA pipeline receives no data from these CCDs. The CCDs therefore do not impact on the VISTA pipeline, except in so far as the pointing and image quality of the camera are dependent on their proper operation.

A high order wave front (curvature) sensor (HOWFS) uses some of the science detectors to determine occasional adjustments to the primary mirror support system. (This is done perhaps once at the start of the night and once around midnight.) Processing the signals from the HOWFS is done within the Instrument Workstation, and so the pipeline will not have to deal with the HOWFS at all. However all data from the IR detectors, including HOWFS data, is passed to the science archive, so the necessary calibration templates for the HOWFS are covered here.

Within the IR Camera are 16 Raytheon 2048x2048 VIRGO detectors arranged in a sparse array. Each camera exposure produces a pawprint consisting of 16 non-contiguous images of the sky. An example display of a complete FITS file consisting of a (synthesized) VISTA “pawprint” is shown in Figure 2-2.

The VISTA IR camera has only one moving part, the filter wheel which has 8 filter holders, each filter holder containing 16 filters, one for each IR detector. There are further auxiliary (beam splitting) filters for use with the high order wave front sensor.

One of the filter holders contains a set of 16 cold blanks (metal units which completely block the detectors from incoming sky radiation, and produce negligible thermal emission) which are used for taking dark frames. The instrument will be delivered with 4 filter sets (Y, J, H, K_S) and a further three sets of cold blanks, which can be replaced with other filters in due course. The position angle of the camera axis can be controlled by the instrument rotator. Single integrations are taken by a Reset-Read-Read procedure with the difference of the two Reads being performed within the DAS.

2.2 Observing Modes

IMAGING is the only mode in which science data will be acquired, but the science array is used to acquire data for internal wave-front analysis.

2.2.1 Imaging Mode Description

The sky target position is acquired and tracked and in parallel (for observing efficiency) the required filter set is placed in the beam. The LOWFS provides the necessary updates to the M2 and M1 support units. A set of exposures, each of which may consist of a number of integrations, are taken and are usually jittered by small offsets, to remove bad pixels and determine sky background. The set of exposures produced is combined in the pipeline to create a single pawprint, in which the jitters from all detectors are included.

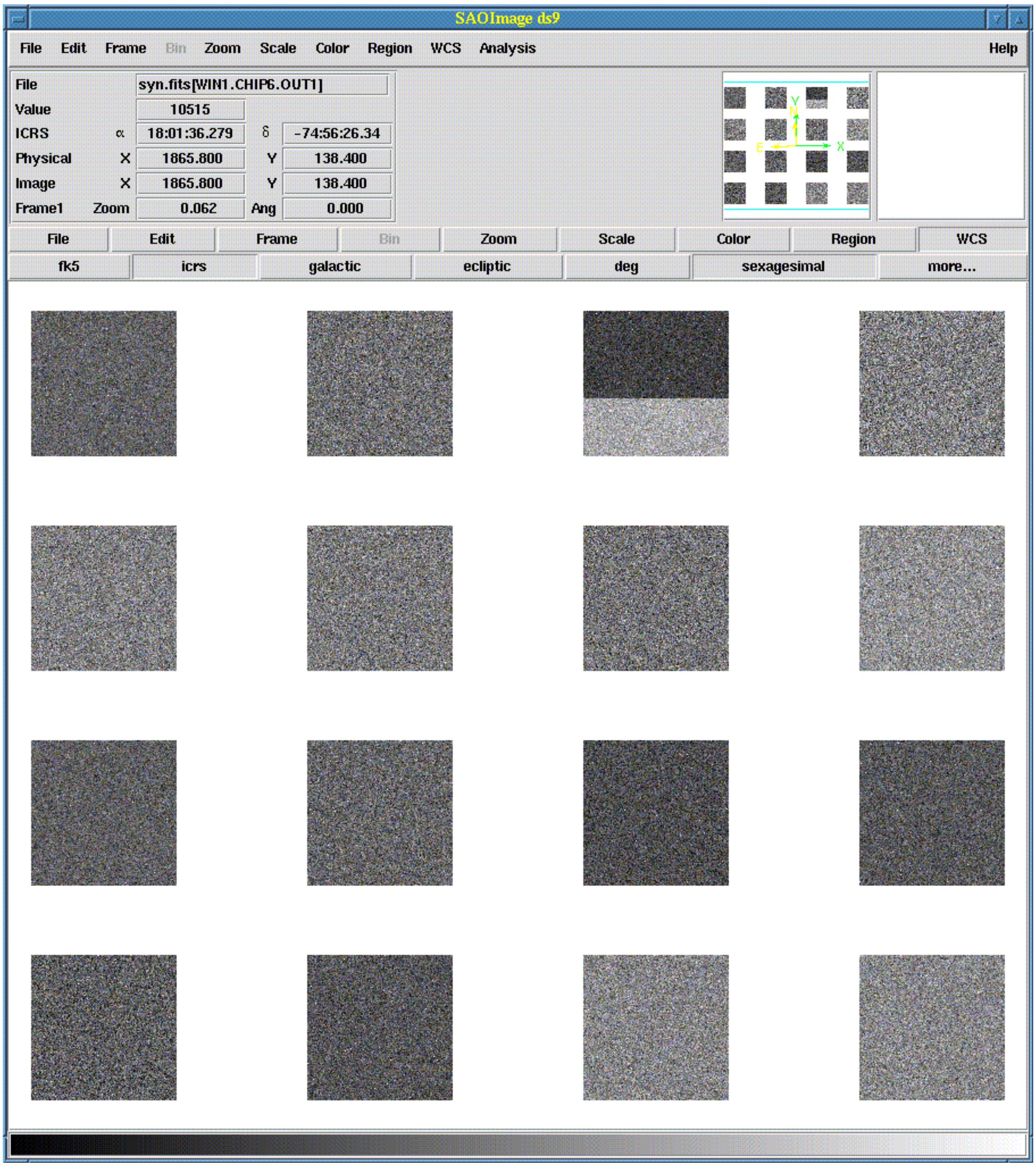

Figure 2-2 Synthesized VISTA Pawprint.

Six such pawprints, taken at appropriate offsets, can be combined to produce an almost uniformly sampled image of a contiguous region, each bit of sky, except at the edges, having been observed by at least two pixels. The individual exposures making up each pawprint may be made on a jitter or a microstep pattern. Microstep patterns are interleaved rather than combined, so the calibration procedures are unchanged, though the data volume increases.

2.2.2 Calibrations

The calibrations are of four sorts:

i. those that characterize the properties of the transfer function (image in, electrons out) of the end-to-end system (telescope, camera, IR detector system including associated controllers, etc.) so that instrumental effects can be removed from the data. As VISTA has a wide field of view, particular attention must be paid to variations across the field;
ii. those that characterize the astrometric distortions of the images;
iii. those that characterize the photometric zero points and extinction coefficients corresponding to the images;
iv. those that generate Quality-Control measures.

2.2.3 High Order Wave Front Sensor (HOWFS) Mode

The HOWFS mode is processed in the Instrument Workstation and is logically part of the TCS. However, as it uses the IR detectors, all of whose data are passed to the archive, it is considered as a separate observing mode for VISTA pipeline purposes.

In HOWFS mode a special beam-splitting filter is used to make a curvature sensor in which two images (above and below focus) of a reference star are formed and used to generate corrections to the forces in the M1 support unit, ensuring the mirror figure is maintained. This mode will typically be used of order twice a night (start and around midnight), or less often if the repeatability of the lookup table is good.

2.2.4 Calibrations

The HOWFS uses some of the science mode IR detectors, but has a special beam splitting filter whose unique signature needs to be removed from the HOWFS data before it can be analysed. However, this flat-fielding is carried out within the HOWFS image-analysis software (which is part of the Camera Software) and not by the pipeline, and is noted here for completeness.

2.3 Pipeline

The VISTA pipeline will produce photometrically and astrometrically calibrated pawprints, with instrumental artefacts removed. In order to achieve almost uniform coverage of a full contiguous area of sky, a six point offset pattern is used by default. A template that implements this pattern is defined and the pipeline will calibrate the resulting six pawprints individually. The further step of combining these into a contiguous map is left to the science user.

For certain science programs the OS will allow distinct OBs for eventual “PI” processing; the main example of this would be observing offset sky frames to calibrate the sky in extended-object science frames. The QC pipeline is not required to associate such observations, but will perform routine reductions on such data.

Other processes which are not calibration issues, but which may nevertheless relate to achievable data quality, are not discussed here. Such (excluded) processes include:

- *co-addition of individual integrations* of a pawprint into a single exposure within the data-acquisition system;
- *combination of many pawprints* to cover contiguous areas of sky;
- *co-addition of many pawprints* to go deeper.

2.4 Operation

This section defines the observing modes, Section 3 contains an error discussion, Section 4 describes the calibration data required for instrumental signature removal, Section 5 describes the calibration data required for photometric calibration. Section 6 describes the calibration data to be derived from science data, including astrometric calibration. Section 7 discusses Quality Control measures based on regularly measured selected sets of calibrations for the purpose of instrument "health checks". Section 8 describes all templates and Section 9 the Technical Programs. Finally Section 10 details the Format of Data Frames.

The philosophy throughout is that the VISTA pipeline will be triggered by the completion of each template. In the case of a template aborting, the pipeline will process as far as possible with the available data. The content of the FITS headers allow the VISTA pipeline to handle the set of observed files as an ensemble and to choose appropriate processing based on the header information.

3 Calibration Accuracy

3.1 Overview

The error budgets for the astrometric, photometric and flat-fielding requirements have two generic components, systematic and random, that contribute to the overall errors.

We discuss each in turn and indicate how the requirements will be met by the strategy adopted.

3.2 Astrometric Error

The astrometric calibration will be based on the 2MASS PSC. 2MASS astrometry is derived from direct calibration to TYCHO 2 and is in the ICRS system. [Note that this requires `RADECSYS = 'ICRS'` in the FITS headers]. It is known to have average systematic errors better than ~100mas and RMS errors better than ~100mas, for all point sources with S:N > ~10:1 [AD2]. We will be using 2MASS as the primary astrometry calibrator and in tests on similar mosaic instruments we have shown that our suggested ZPN distortion model, combined with a linear plate solution for each detector, achieves astrometric calibration at the 100mas or better level.

The initial WCS will be based on the known detector characteristics (scale, orientation, focal plane position) and telescope pointing information (tangent point of optical axis on sky). The astrometric refinement algorithm will be based on a standard proven method we have developed for optical mosaic cameras and as such will be capable of automatically converging from starting points as far off as an arcmin. However, after commissioning updates we do not anticipate the initial WCS to be this inaccurate, since this level of accuracy is significantly larger than the combined error budget for the alignment of the various system components [RD4].

Further reduction in the internal astrometric systematics beyond 100mas may be possible by monitoring generic trends in the astrometric solution residuals, but this is out-with the scope of this document.

3.3 Photometric Error

3.3.1 RMS

The error budget for photometry of astronomical sources requires photon noise to be the dominant noise source. For this to be the case, integration times should be chosen such that observations are general sky noise limited, i.e. sky noise should be much greater than RMS readout noise and dark current contributions. Clearly, this places a comparable requirement on the RMS contribution from flat fielding. However, providing the master flats used for this are combined from multiple observations with at least a total of 100,000 detected electrons this is easily achievable. In practice a goal of 0.1% RMS flat field noise due to photon noise contribution is the aim.

3.3.2 Additive systematics

More difficult problems to quantify are the systematics present in the various correction stages due to, for example, changing flat-field characteristics, reset anomalies, unexpected background variation and so on. The additive components of these systematics can be dealt with using a background tracking algorithm which effectively monitors and removes background variations to the level of 0.1% of sky, prior to performing object photometry. This will be part of the catalogue generation software. Subsequent derived object catalogues are therefore relatively insensitive to variations in any additive component provided such variations smoothly change over the image with typical scale length ~ 20 arcsec or greater. Abrupt jumps in background level within a single detector frame usually indicate either a processing problem (e.g. the sector non-linearity correction is incorrect) or a hardware problem.

Experience with other NIR mosaics (e.g. WFCAM) suggest that other additive systematic contributions such as fringing, will probably only occur at a relatively low level (~ 1% of sky) and the current defringing scheme will reduce these to a level (~ 0.1% of sky) where their impact is negligible.

The main unknown here is the stability of the reset anomaly. This will be characterised through laboratory tests during camera assembly and acceptance and further quantified during commissioning.

3.3.3 Multiplicative systematics

External differences between the detectors, the differential detector gains, will be calibrated from master twilight flat fields for each passband. In practice the main limitations here are those due to colour equation differences between the detectors, and to residual errors in the nonlinearity corrections rather than the properties of master flat field frames. Intra-detector systematics are taken care of by conventional flat fielding. However, both types of global multiplicative systematics typically can be controlled at the 1-2% level and can be externally monitored and further corrected by the “illumination” measurement correction stage described next. The final photometry correction stage is to use the illumination correction measurements to reduce the effects of uneven illumination e.g. scattered light in the flat fielding, residual detector differences and so on, to below the 2% level. This is a master calibration processing task that is probably best done as either a post main pipeline processing stage or at the science database extraction point.

3.3.4 Extinction monitoring

We also anticipate using 2MASS to monitor systematic variations in extinction for each camera exposure. Tests on WFCAM using 2MASS photometry suggest that this is achievable at the few % level per exposure, since even in high Galactic latitude fields there will be hundreds of unsaturated 2MASS stars per VISTA exposure. Offline nightly trend analysis of these measures combined with regular observations of secondary photometric standard fields, set up in the VISTA instrumental system, will enable calibration of most nights to the level of 1% to 2% global.

4 Calibration Data for Instrumental Signature Removal

4.1 Purpose

Section 4 describes what calibration data has to be collected with what frequency to allow one to remove instrumental signatures.

For each piece of calibration data required this section defines:

- **Responsible:** responsibility for obtaining the calibration data
- **Phase**: when the calibration data has to be acquired (day or night time)
- **Frequency**: how often calibration data need to be acquired.
- **Purpose:** reason for needing the calibration data
- **Procedure**: the procedure for acquiring the calibration data
- **Raw Outputs**: the output of the procedure
- **Prepared OBs/Templates**: the pre-prepared observation blocks or templates to acquire the calibration data
- **OT queue**: the corresponding Observing Tool queue for the Observation Blocks.
- **Pipeline Recipe**: The name (if any) of the processing recipe applied by the data flow system pipeline. Recipes may contain algorithms and procedures as subcomponents. Each such recipe corresponds to one listed in [RD1].
- **Pipeline Output**: the Pipeline output products, appended with (QC) for those also used as Quality Control parameters
- **Duration**: an estimate of the required time to execute the calibration procedure including overheads.
- **Prerequisites**: possible dependencies on instrumental or sky conditions or other calibration procedures are given
- **See also**: any further information.

The calibration data is used for instrumental signature removal. The aim is to provide pawprints as though taken with a perfect camera, which produces a photometrically linear, defect-free, evenly-illuminated, though sparsely sampled, reproduction of the sky. This will have no additional systematic, random noise or other artefacts, and will be on an arbitrary photometric and astrometric scale.
Off-sky calibrations and quality control measures will be made routinely, before and after observing, using the in-dome illuminated screen.

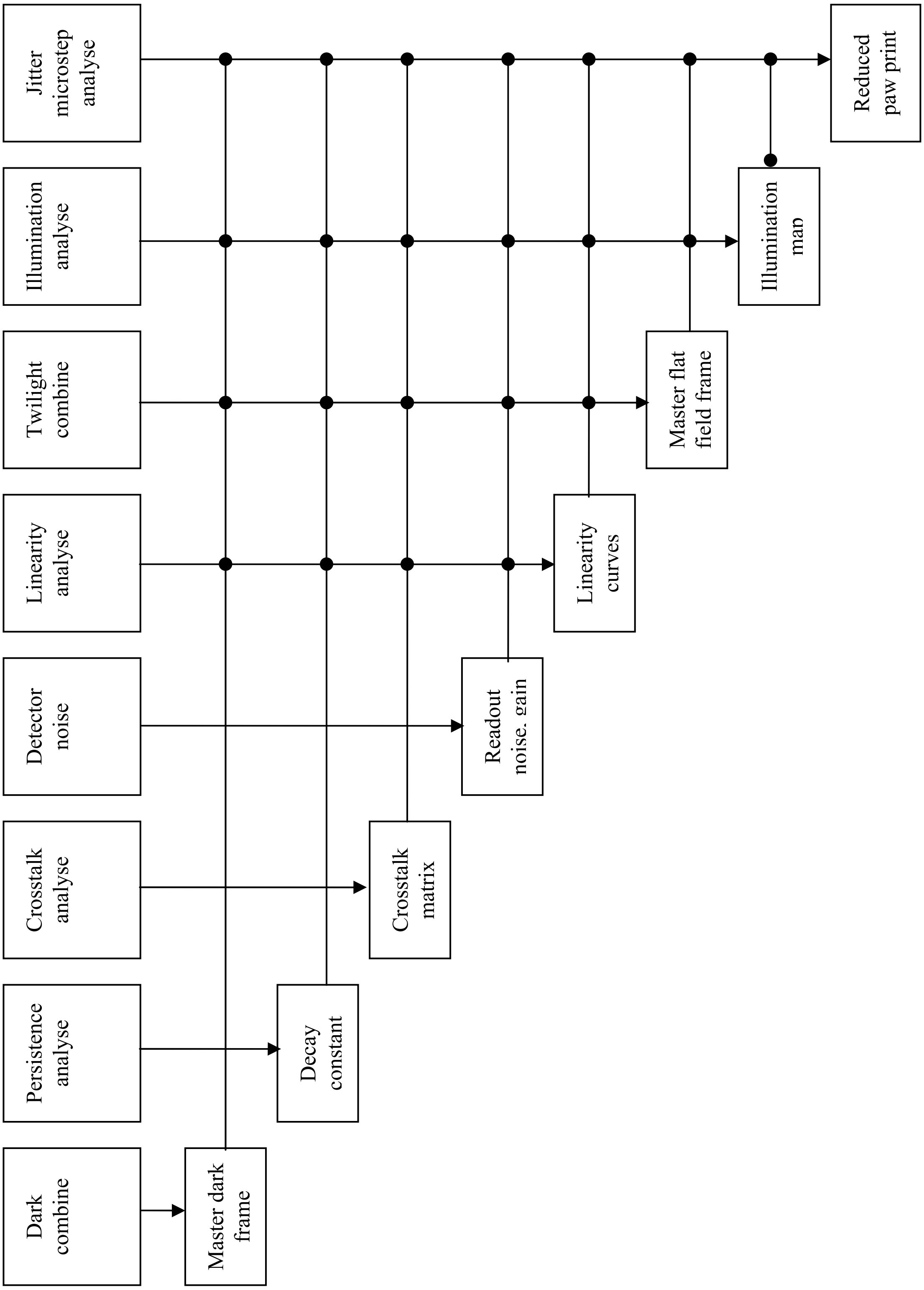

Figure 4-1 Cascade Diagram for producing Calibration Frames

4.2 Reset Frames

Responsible:	Science Operations
Phase:	Daytime
Frequency:	Daily
Purpose:	A Reset frame is a Reset-Read sequence with minimum exposure taken with the cold blank in (1 sec is the minimum VISTA can produce, but 10s would be a more realistic estimate for the duration for a single exposure including overheads as the IRACE system is specified to process an exposure within 5s and to allow the next exposure to start within 10s). It differs from a dark frame, which consists of a Reset-Read-Read sequence where the output is the difference of the two reads. The aim is to map the effect of the reset. Sequences of Reset frames will be taken off-sky and analysed to estimate the stability of the reset pedestal and pixel to pixel variation.
Procedure:	Read out frame, compare with library reset frame.
Raw Outputs:	FITS files
Template:	VIRCAM_img_cal_reset.tsf
OT queue:	VIRCAM.Daytime.Calibration
Pipeline Recipe:	vircam_reset_combine
Pipeline Outputs:	Variance with respect to standard frame (QC)
Duration:	10 s
Prerequisites:	
See Also:	

4.3 Dark Frames

Responsible: Science Operations

Phase: Daytime

Frequency: Daily

Purpose: Dark Frames are used to calibrate out and measure two separate additive effects.

- the accumulated counts that result from thermal noise (dark current). This is generally a small, but not negligible effect.
- an effect, here called ‘reset anomaly’, in which a significant residual structure is left in the image after the reset is removed in the DAS, when it does a correlated double sample (CDS, Reset-Read-Read).

Both dark current and reset anomaly are additive and can be removed together, using dark frames (exposures with cold blank filters completely blocking the detectors from incoming radiation) taken with the same integration time as the target observation. In order to minimize contamination from transient events, a dark frame would be a combination of many frames with rejection.

If the spatial structure of the reset anomaly is not stable with time

	it could leave a challenging background variation over the detector, which may need to be removed with a background filter. This latter scenario is best avoided as real astronomical signal will inevitably be removed. (In general, for other instruments examined where the reset anomaly structure is repeatable and stable, the integration time seems to determine the spatial structure of the residuals, while the ambient flux seems to determine its intensity.)
Procedure:	A series of dark frames will be taken with each integration and exposure time combination used for target observations so that the structure of the reset anomaly can be modelled correctly and the dark correction is consistent. The Dark template, which does not require the telescope, will insert the cold blank and perform a timed exposure. If the requested time is less than the array minimum read-out cycle time of ~1s (e.g. zero) the controller will deliver, and report, the minimum detector integration time of ~1s.
Raw Outputs:	FITS Files
Templates:	VIRCAM_img_cal_dark.tsf; vircam_img_cal_darkcurrent.tsf
OT queue:	VIRCAM.Daytime.Calibration
Pipeline Recipes:	vircam_dark_combine; vircam_dark_current
Duration:	One set of observations for each integration and exposure setting for the science observations made on the same night
Pipeline Outputs:	Mean Dark Dark + reset anomaly stability measure (QC) Detector dark current (QC) Detector Particle Event rate (QC)
Prerequisites:	
See Also:	

4.4 Dome flats

Responsible:	Science Operations
Phase:	Daytime or non-observing nights.
Frequency:	Daily
Purpose:	Monitoring instrument performance, image structure, and confidence maps. They will not be used for gain correction (flat-fielding) due to non-uniform illumination over the whole of the focal plane and the different colour of the illumination compared to the night sky. Note that dome flats may have a spectral energy distribution closer to that of some objects of interest and thus be more adequate for gain correction, but for pipeline processing whole fields in a consistent way an average gain/flat-field correction for typical objects is the usual method.
Procedure:	The Dome template will acquire the dome screen (constant illumination); a series of timed exposures are made through a given filter.
Raw Outputs:	FITS files

Prepared OBs:	VIRCAM_img_cal_domeflat.obx
OT queue:	VIRCAM.Daytime.Calibration
Pipeline Recipe:	vircam_dome_flat_combine
Pipeline Outputs	Updated Master dome flats Updated confidence maps Bad pixel statistics (QC) Number of saturated pixels Lamp efficiency
Duration:	10 min
Prerequisites:	The need for constant illumination of the dome screen implies that the dome flats cannot be taken in conditions of variable or excessive ambient light.
See Also:	Dome flat observations are also employed in linearization measurements described in 4.6 and in generating bad pixel maps.

4.5 Detector Noise

Responsible:	Science Operations
Phase:	Daytime
Frequency:	Daily
Purpose:	In order to understand the noise properties of the detectors, it is important to measure the readout noise and gain of each chip. This is a vital piece of information, not only as large changes in either property could signal a detector health issue, but also as further down the pipeline the issue of pixel rejection algorithms becomes important (for example, during jittering).
Procedure:	Both of these properties can be measured from a pair of dark exposure frames and a pair of dome flat frames. The dark exposures should have matching integration and exposure times to the dome flats, and both dome flat frames should be observed with the same dome illumination. Care should be taken to ensure that the flats are exposed in a region of the response curve where the detectors are reasonably linear.
Raw Outputs:	FITS files
Template:	VIRCAM_img_cal_noisgain.tsf
OT queue:	VIRCAM.Daytime.Calibration
Pipeline Recipe:	vircam_detector_noise
Pipeline Outputs:	Readout noise and gain estimate for each read-out channel of each detector (QC)
Duration:	1 minute
Prerequisites:	
See Also:	

4.6 Linearization Measurements

Responsible:	Science Operations
Phase:	Daytime or cloudy nights (better)

Frequency:	Monthly
Purpose:	Infrared detectors can be strongly non-linear. The linearity curve of each detector can be determined through a series of differently timed dome screen observations under constant illumination. These curves are used in conjunction with the pixel timing information to obtain a true linear value for each pixel and to generate high-accuracy bad-pixel maps (linearization in the DAS would be an alternative but is not included in the Technical Specification).
Procedure:	On a series of specified dates (monthly) take series of dome flats under constant illumination at varying exposures up to full counts.
Raw Outputs:	FITS files
Prepared OBs:	VIRCAM_img_cal_linearity.obx
OT queue:	VIRCAM.Daytime.Calibration
Pipeline Recipe:	vircam_linearity_analyse
Pipeline Output:	Linearization curve and lookup tables updated bad-pixel maps Measure of non-linearity function (QC) Bad pixel statistics (QC)
Duration:	[30] min
Prerequisites:	The need for constant illumination of the dome screen implies that the dome flats cannot be taken in conditions of variable or excessive ambient light.
See Also:	Dome flat measures in 4.4

4.7 Twilight Flats

Responsible:	Science Operations
Phase:	Twilight
Frequency:	Evening/Morning
Purpose:	Flat-fielding removes multiplicative instrumental signatures from the data. This includes pixel-to-pixel gain variations and the instrumental vignetting profile. It also provides a global gain correction between detectors and individual read out channels within each detector. (Each of the 16 detectors has 16 read out channels, giving a total of 256.) Mean flat-fields also are the data source for the science-level confidence map for each detector and filter combination. This is similar to a weight/bad-pixel map where the mean level is normalized to a value of 100% and bad pixels are flagged with a value of zero. It is used in conjunction with an estimate of the sky background variance in each frame to propagate the weight of each individual pixel. Although this is especially important for later manipulation of the pawprints outside the VISTA pipeline for doing deep stacking and tiling, it is also vital for the object

detection part of the pipeline which is used, *inter alia*, in astrometric and photometric corrections.

Mean flat-fields can be derived from a variety of sources (each with their own advantages and disadvantages). Sky flats taken at twilight have a good (but not perfect) colour match to the night sky observations we wish to correct, and can be taken under conditions where the contribution from night sky fringing, emission from dust (on the optical surfaces) and other spatial effects are most negligible. The slightly imperfect colour match between the twilight and night sky will cause a very small residual error in the gain correction. Dusk and dawn twilight flats can be combined (outside of the pipeline), to update the master flats, and thereby moderate effects caused by the significant variation in the illumination caused by the reset and read times.

Procedure: The sky level must be such that any emission from fringing or dust on the optical surface will be negligible in comparison, and this means that there is only a short time in which to acquire the twilight flats. It will not always be possible to get a complete set of twilight flats every night for schedules involving many filters or on nights with changeable weather. If, however, the detector flat-fields are sufficiently stable, then it is possible to use master flats taken over several nights, which is the method of choice.

Raw Outputs: FITS Files

Prepared OBs: VIRCAM_img_cal_twiflat.obx

OT queue: VIRCAM.Daytime.Calibration

Pipeline Recipe: vircam_twilight_combine

Pipeline Output: Mean twilight flats
Confidence maps
Change (vs calibDb) in mean gain correction coefficients between detectors and channels (QC)

Duration: 10 min evening twilight, 10 min morning twilight.

Prerequisites:

See Also:

4.8 Illumination Correction Measurement

Responsible: Science Operations

Phase: Night

Frequency: Monthly

Purpose: The gain correction as modelled by 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. However, scattered light within the camera may lead to large-scale background variations which cannot be modelled and removed, as its level depends critically on the ambient flux. Dividing a target frame by a flat-field frame that is affected by

	this will cause systematic errors in the photometry across the detector. It is necessary to map out the spatial systematic effects across each detector so that a correction map can be factored into the final photometry measured from each detector.
Procedure:	The illumination correction can be measured in two ways. In the event that observations of a secondary photometric standard field with a density of 100-200 objects per detector are available, then the illumination correction can be measured by looking at the spatial variation of the photometric zero-point across each detector. If such a field is not available, then a mesostep sequence is taken consisting of a series of exposures of a sparse field of relatively bright stars on a regular grid of offsets that cover one detector. Measuring a flux on each exposure allows the definition of a position-dependent scale factor (this must be done for each filter and each detector).
Raw Outputs:	FITS files
Prepared OBs:	VIRCAM_img_cal_illumination.obx
OT queue:	VIRCAM.Nighttime.Calibration
Pipeline Recipe:	vircam_mesostep_analyse
Pipeline Output:	Correction map
Duration:	30 min
Prerequisites:	Photometric conditions
See Also:	

4.9 *Image Persistence Measurements*

Responsible:	Science operations
Phase:	Night
Frequency:	Monthly and on detector/controller change
Purpose:	Image persistence (sometimes also called ‘remanence’) is the effect where residual impressions of images from a preceding exposure are visible on the current image.
Procedure:	On a sequence of (monthly) dates choose a fairly empty field with a nearly saturated star. Take an exposure and then a sequence of dark frames to measure the characteristic decay time. This must be done for each detector.
Raw Outputs:	FITS files
Prepared OBs:	VIRCAM_img_cal_persistence.obx
OT queue:	VIRCAM.Nighttime.Calibration
Pipeline Recipe:	vircam_persistence_analyse
Pipeline Output:	Persistence constants
Duration:	10 min (although if the decay time constant turns out to be significantly more than about half a minute, then this may be something of an underestimate).
Prerequisites:	
See Also:	

4.10 Electrical Cross-Talk Measurements

Responsible:	Science operations
Phase:	Night
Frequency:	Monthly
Purpose:	Electrical cross-talk will be measured in the laboratory and during commissioning, and is expected to be negligible. As cross-talk might change with any alterations to the electrical environment, a routine procedure to check it is planned.
Procedure:	The 16 detectors are read out in 16 channels, making a total of 256 channels in the camera. Cross-talk calibration consists of placing a saturated star on a channel and measuring any effect on the other 255 channels. This results in a 256x256 matrix, the majority of whose elements will hopefully be zero. Any electrical cross talk between different detectors is anticipated to be smaller than between channels within a detector. No specific template is necessary, as a suitably crafted observation block will be used.
Raw Outputs:	FITS Files
Prepared OBs:	VIRCAM_gen_tec_crosstalk.obx
OT queue:	VIRCAM.Nighttime.Calibration
Pipeline Recipe:	vircam_crosstalk_analyse
Pipeline Output:	Cross-talk matrix. Average measure of off-diagonal components (QC)
Duration:	10 min for all detectors, assuming a decay time-constant < 30s
Prerequisites:	
See Also:	

5 Data for Photometric Calibration

5.1 Introduction

The camera will be on the telescope semi-permanently, in a survey mode, providing a stable configuration which enables a long-term approach to photometric calibration to be taken. The strategy is to define routine calibration procedures, so that the accuracy, and hence the scientific value, of the archive, will be maximized. Magnitudes will be calibrated on the Vega scale.

At any time (*t*) on any night (*n*) for any star (*i*) in any filter waveband (*b*),

$$m^{cal}{}_{ib} = m^{inst}{}_{ibtn} + ZP_{btn} - \kappa_{btn}(X-1) \quad \textbf{Equation 1}$$

where *ZP* is the Zero Point (i.e. the magnitude at airmass unity which gives 1 count/second at the detector), m^{cal} is the calibrated instrumental magnitude, m^{inst} is the measured instrumental magnitude ($-2.5 \times log_{10}[counts/sec]$), κ is the extinction coefficient and *X* is the airmass of the observation. This assumes that the second-order extinction term and colour-dependency of κ are both negligible.

Typically, the Zero Point of the instrument + telescope system should be stable throughout the night. Long-term decreases in the sensitivity of the instrument, and hence a decreasing *ZP*, could be caused by for example the accumulation of dust on the primary mirror.

On photometric nights the extinction coefficient κ should be constant in each filter. The extinction κ will be monitored through each night assuming a fixed zero point and making measurements over a range of airmass. Although 2MASS found their extinction coefficients to vary seasonally any effect should be much less for VISTA since it has narrower filter profiles especially at J, and is at a much drier site.

A network of Secondary Standard photometric fields will be set up so that routine photometric standard observations can be made with the telescope in focus *every hour*. Frequent time-sampling is required to ensure accurate measurement of extinction and Zero Point, and so that the photometricity of a night can be monitored and derived from the data. Many of these standard fields (the equatorial ones) will have been observed and calibrated in advance by WFCAM. The secondary fields will meet the following criteria:

- Extend over the area of the IR camera pawprint
- Span 24 hours in RA, with a target spacing of 2 hours.
- Enable observations over a range of airmass. Some must be chosen to pass close to the zenith of VISTA (for airmass unity). Some fields will be available to the North and South of the zenith to optimize telescope azimuth slewing. The remainder will be near-equatorial.

- Have a density of sources sufficient to characterize the systematic position-dependent photometric effects in VISTA, but not be too crowded. The target is of order 100 stars per detector with magnitudes no fainter than J=18, K_s=16 to avoid prohibitively long exposures.
- They should encompass as broad a spread as possible in colour in order to derive colour terms robustly and facilitate transformations from and to other filter systems and e.g. the AB magnitude system. i.e.

$$M^{std} = m_b^{cal} + C(M_x^{std} - M_y^{std})$$ **Equation 2**

where M^{std} is the magnitude in a defined standard system, m_b^{cal} is the calibrated magnitude in the instrumental system, and C is the colour term for the appropriate standard colour index $(M_x^{std} - M_y^{std})$.

- Each field should be centred on a primary standard: either a UKIRT Faint Standard [RD9] and www.jach.hawaii.edu/JACpublic/UKIRT/astronomy] or a LCO/Palomar NICMOS (Persson) standard [RD8], or a standard from [RD14], enabling direct calibration of the secondary standards. There are sufficient of these faint primary standards so that we can select primary standards which will not saturate the detector in a short (seconds) in-focus exposure.
- Technical Program TP-VIS1 describes the observations needed to set up the secondary standard fields.

5.2 Photometric Standards

Responsible: Science Operations

Phase: Night

Frequency: Hourly

Purpose: Determine *ZP* and κ to allow application of

$$m^{cal}{}_{ib} = m^{inst}{}_{ibtn} + ZP_{btn} - \kappa_{btn}(X-1)$$

to photometrically calibrate all objects seen.

In the event that observations of a secondary photometric standard field with a density of 100-200 objects per detector are available, then the illumination correction can be measured by looking at the spatial variation of the photometric zero-point across each detector.

Procedure: Suitable fields from this network will be observed over a range of airmass each night to determine the Zero Points (*ZP*) to monitor the extinction coefficients (κ) for all broad-band filters, and if sufficiently high density of standards, to measure the illumination correction.

Outputs: FITS files

Template:	VIRCAM_img_cal_std.tsf
OT queue:	Science
Pipeline Recipe:	vircam_standard_process
Pipeline Output:	Zero Point (*ZP*) Extinction coefficient (κ) Illumination correction map Colour terms (*C*) Illumination correction Global gain correction (check)
Duration:	5 min 10 times per night
Prerequisites:	
See Also:	

5.3 Apply Photometric Calibration

Responsible:	Science Operations
Phase:	Night
Frequency:	All on sky data
Purpose:	Apply Photometric Calibration
Procedure:	Apply $m^{cal}{}_{ib} = m^{inst}{}_{ibtn} + ZP_{btn} - \kappa_{btn}(X-1)$ using *ZP* and κ found from photometric calibration fields to calibrate frames photometrically.
Outputs:	Photometry FITS headers
Prepared OBs:	None
OT queue:	
Pipeline Recipe:	vircam_jitter_microstep_process
Pipeline Output:	Calibrated frames Depth of Exposure (QC)
Duration:	
Prerequisites:	
See Also:	

6 Calibration Data Derived from Science Data

6.1 For Instrument Signature Removal

6.1.1 Night-Sky Maps

Responsible:	Science Operations
Phase:	Night
Frequency:	Throughout night
Purpose:	If experience shows that the detector flats are not reliably stable over the timescale of a night, then night-sky flats will have to be used instead. These are formed either from the target frames or from any special offset sky frames that might have been taken (for example where there is a large extended object in the field). All such frames over an appropriate time range are combined with rejection to form a normalized night sky flat-field. The advantage of dark flats over twilight flats is the better colour match to the average astronomical object. This minimises the sensitivity of the gain and flat-field correction to differential colour terms with respect to astronomical objects. However, fringing and thermal emission from dust particles on the optical surfaces can be high enough to affect the background significantly in some passbands. Dividing the target frames by a sky flat without correcting for these two additive effects could lead to significant systematic errors in photometry. In the Garching pipeline, master flats will be determined from as many observations as possible, but if it is determined that the flats vary rapidly, then only flats taken close in time may be useable.
Procedure:	Use normal science exposures.
Raw Outputs:	FITS Files
Prepared OBs:	None
OT queue:	science
Pipeline Recipe:	vircam_jitter_microstep_process
Pipeline Output:	Night sky maps
Duration:	Occurs in parallel with all night observing
Prerequisites:	Determine the characteristics of fringing and thermal emission from dust on the optical surfaces during commissioning.
See Also:	6.1.2

6.1.2 Sky Subtraction and Fringe Removal

Responsible:	Science operations
Phase:	Night
Frequency:	Throughout night
Purpose:	The sky background varies over large scales in the infrared. In some wavebands, fringing and thermal emission from any local dust (on optical surfaces) will also be present. All of these

	effects can be removed using the sky-subtraction algorithm. The source of the sky background estimate is usually the science data frames themselves. In cases where large extended or very bright objects might be present, it may be necessary to use 'offset sky' exposures in the observation template.
Procedure:	Preset or offset to, uncrowded, regions taken near or adjacent to the region of interest. Observe in the same way as the corresponding science field.
Raw Outputs:	FITS Files
Prepared OBs:	None
OT queue:	science
Pipeline Recipe:	vircam_jitter_microstep_process
Pipeline Output:	Local sky estimate Fringe and dust maps
Duration:	Same as science field.
Prerequisites:	
See Also:	

6.1.3 Jittering

Responsible:	Science Operations
Phase:	Night
Frequency:	Nearly all the time
Purpose:	Removal of bad pixels and other cosmetic effects, as well as cosmic rays, and determining the sky background. Typically a long exposure is split into several shorter exposures, which, rather than being repeated with each pixel looking at exactly the same sky position, are carried out at a series of different (jittered) positions. This is similar to microstepping (same template), but with less fine sampling, and the pipeline combines the jittered exposures using a rejection algorithm.
Procedure:	Perform a specified pattern of exposures at each position of a jitter pattern. Predefined patterns and movement size in pixels may be selected. Microsteps can be nested within each jitter position by setting the number of microsteps appropriately in the template.
Raw Outputs:	FITS Files
Template:	VIRCAM_img_obs_paw.tsf, VIRCAM_img_obs_tile.tsf, VIRCAM_img_obs_offsets.tsf
OT queue:	Science
Pipeline Recipe:	vircam_jitter_microstep_process
Pipeline Output:	Combined frames of pawprint Confidence map for pawprint
Duration:	Variable
Prerequisites:	
See Also:	6.1.4

6.1.4 Microstepping

Responsible:	Science operations
Phase:	Night
Frequency:	As required
Purpose:	Improved sampling. This is most likely to be employed in times of excellent seeing, when the point-spread function is under-sampled. It can also be used if there are strong intra-pixel sensitivity (QE) variations. It may not be commonly used. It is similar to jittering (same template) but with improved sampling through finer pattern spacing, and the pipeline interleaves the exposures without further rejection.
Procedure:	Perform a specified pattern of exposures at each position of a microstep pattern. Predefined patterns and movement size in pixels may be selected, and there is a default pattern/size [2×2 pattern, modulo a 0.5 pixel shift]. By setting the number of microsteps appropriately in the template, microsteps can be nested within each jitter position.
Raw Outputs:	FITS Files
Template:	VIRCAM_img_obs_paw.tsf
OT queue:	Science
Pipeline Recipe:	vircam_jitter_microstep_process
Pipeline Output:	Interleaved science frames with corresponding confidence maps
Duration:	Variable
Prerequisites:	
See Also:	6.1.3

6.2 *For Astrometric Calibration*

Astrometric calibration will take the instrument signature free pawprints and provide the transformation between pixel coordinates and celestial coordinates for each of the 16 constituent images, though still leaving the pawprints on an arbitrary photometric scale. The transformations are manifested in a Flexible-Image Transport System (FITS) [RD10] World-Coordinate System (WCS) [RD12]. The projection used will be Zenithal Polynomial (ZPN), based on the predicted properties from the optical design.

Quantifying the distortion terms used in the WCS will be done from on-sky observations. An initial astrometric distortion is available from the optical design, and an updated early empirical value will be derived from commissioning data. Following that, an increasingly accurate value will be derived from the astrometry of all target frames.

6.2.1 Optical Distortion Effects

Responsible:	Science Operations
Phase:	Night
Frequency:	All science frames
Purpose:	The strongest term in the optical-distortion model is the cubic radial term, but this and all distortions will be slightly colour (i.e. filter) dependent and must be determined on sky. The expected

power of the distortion means that no practically useful jitter is possible without non-linear resampling. The 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. It is thus crucial to determine it accurately.

Procedure:	Astrometric stars in the science fields are used to map the distortion, an increasingly accurate description of which builds up from the astrometry of all target frames.
Raw Outputs:	FITS files
Prepared OBs:	None
OT queue:	Science
Pipeline Recipe:	This is not part of the pipeline.
Pipeline Output:	Refined optical distortion model
Duration:	No overhead
Prerequisites:	Initial value from optical design, an early empirical value from commissioning data,
See Also:	

6.2.2 Final WCS Fit

Responsible:	DFS calibration pipeline
Phase:	Night
Frequency:	All imaging frames on sky
Purpose:	The camera software writes an initial WCS based on the given position of the guide star into the FITS headers of each data frame. The accuracy will be better than 2″, dependent on the guide star accuracy, and the determined geometry of the camera. This provides a close starting point for orientation of the data frames and location of astrometric stars for a full WCS solution that will provide refined scientific quality astrometry. After instrumental-signature removal astrometric stars are centroided in the data frames to typically 0.1 pixels accuracy. An astrometric solution is carried out using reference catalogues based on the International Coordinate Reference Frame (ICRF) [e.g. 2MASS catalogue]. Accuracy is dependent on the reference catalogue accuracy, but the final uncertainty estimate comes from the RMS of the fit and the known systematics of the reference catalogue.
Procedure:	None
Raw Outputs:	None
Prepared OBs:	None
OT queue:	-
Pipeline Recipe:	vircam_jitter_microstep_process
Pipeline Output:	Refined WCS FITS header for all frames Pointing accuracy (QC) [Calculated from equatorial coordinates computed at particular location using the fitted WCS and the initial WCS that was written to the raw header]

Duration:	Zero overhead
Prerequisites:	Commissioning to determine initial WCS
See Also:	

7 Quality Control

7.1 *Further Quality Control Data Derived from Science Frames*

7.1.1 Object Extraction

Responsible:	Science Operations
Phase:	Night
Frequency:	Nearly all the time
Purpose:	Object extraction is vital for various steps in the pipeline, including astrometric and photometric calibration, where the position and/or photometric measures of real objects are required. It is also needed in order to assess the quality of the data in terms of the observing conditions and the depth of exposure.
Procedure:	Extract objects from each frame using the object extraction algorithm. Classify objects as stellar, non-stellar and noise using the classification scheme. Use the stellar objects to work out the average properties of the images on the frame.
Raw Outputs:	FITS Files
Template:	-
OT queue:	Science
Pipeline Recipe:	vircam_jitter_microstep_process
Pipeline Output:	Mean sky background (QC) Mean sky noise (QC) Number of noise objects (QC) Mean seeing (QC) Mean stellar ellipticity (QC)
Duration:	Variable
Prerequisites:	
See Also:	

7.2 *On line quality control (QC-0)*

QC-0 is generic for all VLT-compliant instruments and is provided by the Data-Flow Operations group. All image-mode data produced by the instrument is fed into the pipeline to produce QC-1 parameters.

7.3 Quality Control Parameters

Quality-control parameters are generated during pipeline processing. These may be used at a later time for trend analysis.

Parameter	**Description**
QC.DARKCURRENT average dark current on frame [adu/sec].	measured using the median of the pixel values, can later be compared with similar darks for trends
QC.DARKRMS measure of rms noise of dark frame [adu].	rms is defined here as the Gaussian equivalent MAD ie. 1.48*median-of-absolute-deviation from median The rms can later be compared with library values for darks of the same integration and exposure times.
QC.PARTICLE_RATE cosmic ray/spurion rate [count/sec].	average no. of pixels rejected during combination of dark frames, used to give an estimate of the rate of cosmic ray hits for each detector. This can later be compared with previous estimates and monitored.
QC.RESETVAR percentage variation in current reset frame [percentage].	variation is defined here as the Gaussian equivalent MAD ie. 1.48*median-of-absolute-deviation from unity after normalising by median level ie. measuring the rms reset level variation. The rms can later be compared with library values for troubleshooting problems.
QC.READNOISE readnoise [electron].	measured from the noise properties of the difference in two consecutive dark frames, using a MAD estimator as above for robustness against spurions. The noise properties of each detector should remain stable so long as the electronics/micro-code have not been modified.
QC.FLATVAR rms variation of flatfield pixel sensitivity per detector [percentage].	rms is defined here as the Gaussian equivalent MAD ie. 1.48*median-of-absolute-deviation from unity after normalising by median level ie. measuring the rms sensitivity variation. The rms can later be compared with library values for troubleshooting problems.
QC.GAIN gain [e/ADU].	determined from pairs of darks and flatfields of the same exposure/integration time and illumination by comparing the measured noise properties with the expected photon noise contribution. The gain of each detector should remain stable so long as the electronics/micro-code have not been modified.
QC.BAD_PIXEL_STAT fraction of bad pixels per detector [scalar].	determined from the statistics of the pixel distribution from the ratio of two flatfield sequences of significantly different average count levels. The fraction of bad pixels per detector (either hot or cold) should not change significantly with time.

QC.GAIN_CORRECTION ratio of detector median flatfield counts to global median [scalar].	the ratio of median counts in a mean flat exposure for a given detector relative to the ensemble defines the internal gain correction for the detector These internal relative detector gain corrections should be stable with time.
QC.LINEARITY the percentage average non-linearity [percentage].	derived from measured non-linearity curves for each detector interpolated to 20k counts (ADUs) level. Although all infrared systems are non-linear to some degree, the shape and scale of the linearity curve for each detector should remain constant. A single measure at 20k counts can be used to monitor this although the full linearity curves will need to be examined quarterly [TBC] to look for more subtle changes.
QC.LINFITQUAL the RMS fractional error in linearity fit [scalar]	Derived by applying the linearity coefficients to the image data that were used to measure them. This is the RMS of the residuals of the linearised data normalised by the expected linear value
QC.SATURATION saturation level of bright stars [ADU].	determined from maximum peak flux of detected stars from exposures in a standard bright star field. The saturation level*gain is a check on the full-well characteristics of each detector.
QC.PERSIST_DECAY mean exponential time decay constant [s].	the decay rate of the persistence of bright images on subsequent exposures will be modelled using an exponential decay function with time constant tau. Requires an exposure on a bright star field followed a series of darks.
QC.PERSIST_ZERO fractional persistence at zero time (extrapolated) [scalar].	determined from the persistence decay behaviour from exponential model fitting. Requires an exposure on a bright star field followed a series of darks (as above)
QC.CROSS_TALK average values for cross-talk component matrix [scalar].	determined from presence of +ve or -ve ghost images on other channels/detectors using exposures in bright star fields. Potentially a fully populated 256x256 matrix but likely to be sparsely populated with a small number of non-zero values of band-diagonal form. This QC summary parameter is the average value of the modulus of the off-diagonal terms. Values for the cross-talk matrix should be very stable with time, hardware modifications notwithstanding.
QC.WCS_DCRVAL1 actual WCS zero point X - raw header value [deg].	measure of difference between dead-reckoning pointing and true position of the detector on sky. Derived from current polynomial distortion model and 6-constant detector model offset.
QC.WCS_DCRVAL2 actual WCS zero point Y - raw header value [deg].	measure of difference between dead-reckoning pointing and true position of the detector on sky. Derived from current polynomial distortion model and 6-constant detector model offset.

QC.WCS_DTHETA actual WCS rotation PA - raw PA header value [deg].	measure of difference between dead-reckoning PA and true position angle of the detector. Derived from current polynomial distortion model and 6-constant detector model effective rotation term.
QC.WCS_SCALE measured WCS plate scale per detector [deg/pixel].	measure of the average on-sky pixel scale of detector after correcting using current polynomial distortion model
QC.WCS_SHEAR power of cross-terms in WCS solution [deg].	measure of WCS shear after normalising by plate scale and rotation, expressed as an equivalent distortion angle. Gives a simple measure of distortion problems in WCS solution.
QC.WCS_RMS robust rms of WCS solution for each detector [arcsec].	robust average of residuals from WCS solution for each detector. Measure of integrity of WCS solution.
QC.MEAN_SKY mean sky level [ADU].	computed using a clipped median for each detector Sky levels should vary smoothly over the night. Strange changes in values may indicate a hardware fault.
QC.SKY_NOISE rms sky noise [ADU].	computed using a MAD estimator with respect to median sky after removing large scale gradients. The sky noise should be a combination of readout-noise, photon-noise and detector quirks. Monitoring the ratio of expected noise to measured provides a system diagnostic at the detector level.
QC.SKY_RESET_ANOMALY systematic variation in sky across detector [ADU].	robust average variation in background level for each detector, computed by measuring the large scale variation from a filtered 64x64 pixel background grid, where each background pixel is a clipped median estimate of the local sky level. Effectively generates an 32x32 sky level map and computes the MAD [TBC] of these values with respect to the global detector median. Monitoring the non-flatness of this gives a measure of reset-anomaly problems.
QC.NOISE_OBJ number of classified noise objects per frame [number].	measured using an object cataloguer combined with a morphological classifier. The number of objects classified as noise from frame-to-frame should be reasonably constant; excessive numbers indicate a problem.
QC.IMAGE_SIZE mean stellar image FWHM [arcsec].	measured from the average FHWM of stellar-classified images of suitable signal:to:noise. The seeing will obviously vary over the night with time and wavelength (filter). This variation should be predictable given local site seeing measures. A comparison with the expected value can be used as an indication of poor guiding, poor focus or instrument malfunction.

QC.APERTURE_CORR 2 arcsec [mag] diam aperture flux correction.	the aperture flux correction for stellar images due to flux falling outside the aperture. Determined using a curve-of-growth of a series of fixed-size apertures. Alternative simple measure of image profile properties, particularly the presence of extended PSF wings, as such monitors optical properties of system; also required for limiting magnitude computations.
QC.ELLIPTICITY mean stellar ellipticity [scalar].	the detected image intensity-weighted second moments will be used to compute the average ellipticity of suitable signal:to:noise stellar images. Shot-noise causes even perfectly circular stellar images to have non-zero ellipticity but more significant values are indicative of one of: optical, tracking and autoguiding, or detector hardware problems.
QC.ZPT_2MASS 1st-pass photometric zeropoint [mag].	the magnitude of a star that gives 1 detected ADU/s (or e-/s) for each detector, derived using 2MASS comparison stars for every science observation. This is a first pass zero-point to monitor gross changes in throughput. Extinction will vary over a night, but detector to detector variations are an indication of a fault.
QC.ZPT_STDS photometric zeropoint [mag].	the magnitude of a star that gives 1 detected ADU/s (or e-/s) for each detector, derived from observations of VISTA standard star fields. Combined with the trend in long-term system zero-point properties, the ensemble "average" zero-point directly monitors extinction variations (faults/mods in the system notwithstanding) The photometric zeropoints will undoutbedly vary (slowly) over time as a result of the cleaning of optical surfaces etc.
QC.LIMITING_MAG limiting mag ie. depth of exposure [mag].	estimate of 5-sigma limiting mag for stellar-like objects for each science observation, derived from QCs ZPT_2MASS, SKY_NOISE, APERTURE_CORR. Can later be compared with a target value to see if main survey requirements (ie. usually depth) are met.
QC.FRINGE_RATIO [scalar] Ratio of sky noise before to after fringe fit	A robust estimate of the background noise is done before the first fringe fitting pass. Once the last fringe fit is done a final background noise estimate is done. This parameter is the ratio of the value before fringe fitting to the final value after defringing.

8 Templates

The hierarchy of the templates defined for VIRCAM are shown in Figure 8-1 below. There are a series of templates for each of the operating modes described in section 3. Note: the template definitions are refined from those presented in early drafts of this document to reflect enhancements in the final design of the camera observation software [RD6].

- Acquisition templates *(shown in blue italic)*, which define the operating mode and telescope target parameters. Each Observation Block begins with an acquisition template defining the primary target to which that Observation Block refers. Acquisition templates do not generate exposures.
- Calibration templates (shown in red), which obtain exposures necessary for calibrating observations in a particular instrument mode. A calibration template can result in one or more exposures being made.
- Observation templates (shown in black), which obtain the exposures necessary to make science observations. An observation template can result in one or more exposures being made.

HOWFS mode

- *VIRCAM_howfs_acq*
- *VIRCAM_howfs_acq_domescreen*
- VIRCAM_howfs_cal_reset
- VIRCAM_howfs_cal_dark
- VIRCAM_howfs_cal_domeflat
- VIRCAM_howfs_obs_exp
- VIRCAM_howfs_obs_wfront

IMAGING mode

- *VIRCAM_img_acq*
- *VIRCAM_img_acq_twighlight*
- *VIRCAM_img_acq_domescreen*
- VIRCAM_img_cal_reset
- VIRCAM_img_cal_dark
  - VIRCAM_img_cal_darkcurrent
- VIRCAM_img_cal_domeflat
  - VIRCAM_img_cal_linearity
  - VIRCAM_img_cal_noisgain
- VIRCAM_img_cal_twiflat
- VIRCAM_img_cal_persistence
- VIRCAM_img_cal_std
- VIRCAM_img_obs_exp
  - VIRCAM_img_cal_crosstalk
  - VIRCAM_img_cal_illumination
- VIRCAM_img_obs_paw
  - VIRCAM_img_obs_tile
  - VIRCAM_img_obs_offsets

Figure 8-1 Hierarchy of VISTA IR Camera Templates

The relationship between the templates, the data they produce and the pipeline recipes which will be used is displayed in Table 8-1.

DATA FILE	VIRCAM_ TEMPLATE	DRP CATG	DRP TYPE	DPR TECH	RECIPE	HEADER INPUTS	CALIB DB	PRODUCTS
HOWFS reset frame	howfs_cal_reset	TECHNICAL	BIAS	IMAGE	HOWFS data is processed on the instrument workstation			
HOWFS Dark Frame	howfs_cal_dark	TECHNICAL	DARK	IMAGE				
HOWFS dome flat	howfs_cal_domeflat	TECHNICAL	FLAT,LAMP	IMAGE				
HOWFS wavefront	howfs_obs_exp	ACQUISITION	PSF-CALIBRATOR	IMAGE				
HOWFS wavefont	howfs_obs_wfront	ACQUISITION	PSF-CALIBRATOR	IMAGE				
Test observation	img_obs_exp	TEST	OBJECT	IMAGE	Test not processed			None
Reset Frame	img_cal_reset	CALIB	BIAS	IMAGE	reset_combine	Exposure parameters	library reset frame	Mean reset
Dark Frame	img_cal_dark	CALIB	DARK	IMAGE	dark_combine	Exposure parameters	library dark frame	Mean dark
Dark Current	img_cal_darkcurrent	CALIB	DARK, DARKCURRENT	IMAGE	dark_current	Exposure parameters		Dark Current map
Persistence sky measure	img_cal_persistence	CALIB	OBJECT, PERSISTENCE	IMAGE	persistence_analyse	Exposure parameters WCS set	linearity channel table library dark frame library flat field	Persistence constants
Persistence dark measure		CALIB	DARK, PERSISTENCE	IMAGE		Exposure parameters		
Dome Flat	img_cal_domeflat	CALIB	FLAT, LAMP	IMAGE	dome_flat_combine	Exposure parameters	library bad-pixel map library dark frame linearity channel table	Mean Dome Flat Dome confidence map
Linearity Measure	img_cal_linearity	CALIB	FLAT, LAMP, LINEARITY	IMAGE	linearity_analyse	Exposure parameters	library dark frame channel map	Linearity channel table Bad pixel map

DATA FILE	VIRCAM_ TEMPLATE	DRP CATG	DRP TYPE	DPR TECH	RECIPE	HEADER INPUTS	CALIB DB	PRODUCTS
Noise & Gain	img_cal_noisgain	CALIB	FLAT, LAMP, GAIN	IMAGE	detector_noise	Exposure parameters	linearity channel table	Noise and gain values
Twilight Flat	img_cal_twiflat	CALIB	FLAT, TWILIGHT	IMAGE	twilight_combine	Exposure parameters	library bad-pixel map library dark frame linearity channel table	Mean twilight flat Sky confidence map Gain correction
Cross-Talk obs	img_cal_crosstalk	CALIB	OBJECT, CROSSTALK	IMAGE	crosstalk_analyse	Exposure parameters	library dark frame linearity channel table library flat field library confidence map persistence constants	cross-talk matrix
Mesostep sequence	img_cal_illumination	CALIB	STD, ILLUMINATION	IMAGE	mesostep_analyse	Exposure parameters WCS set	library dark frame linearity channel table library flat field library confidence map persistence constant crosstalk matrix library fringe map photometric catalogue	illumination map
Standard star field	img_cal_std	CALIB	STD, FLUX	IMAGE, JITTER	standard_process	Exposure parameters WCS set	library dark frame linearity channel table library flat field library confidence map persistence constants crosstalk matrix library fringe map photometric catalogue	photometric coefficients

DATA FILE	VIRCAM_ TEMPLATE	DRP CATG	DRP TYPE	DPR TECH	RECIPE	HEADER INPUTS	CALIB DB	PRODUCTS
Pawprint	img_obs_paw	SCIENCE	OBJECT	IMAGE, JITTER	jitter_microstep_process	Exposure parameters WCS set	library dark frame linearity channel table library flat field library confidence map persistence constants library fringe map crosstalk matrix photometric catalogue	Reduced Paw Prints Associated confidence maps Object catalogues Sky map (e.g. for de-fringing, when input criteria met)
Pawprint Extd object		SCIENCE	OBJECT, EXTENDED	IMAGE, JITTER				
Tile	img_obs_tile	SCIENCE	OBJECT	IMAGE, JITTER	jitter_microstep_process			
Tile extended		SCIENCE	OBJECT, EXTENDED	IMAGE, JITTER				
non-standard tile pattern	img_obs_offsets	SCIENCE	OBJECT	IMAGE, JITTER	jitter_microstep_process			
non-standard tile of extended source		SCIENCE	OBJECT, EXTENDED	IMAGE, JITTER				

Table 8-1 Relationship between Data Types, Observation Templates and Pipeline Recipes

8.1 Imaging Calibration Templates

8.1.1 Reset

Name:	Reset
Identifier:	VIRCAM_img_cal_reset.tsf
Description:	Make Reset frame (reset-read only) with cold blank (a single reset/read sequence). Used with HOWFS and IMAGING mode.
Parameters:	number of reset frames
Raw Frames:	FITS
Pipeline recipes:	vircam_reset_combine

8.1.2 Dark

Name:	Dark
Identifier:	VIRCAM_img_cal_dark.tsf
Description:	Make dark exposure (reset-read-read) with cold blank
Parameters:	integration time, number of integrations
Raw Frames:	FITS
Pipeline recipes:	vircam_dark_combine

8.1.3 Dark Current

Name:	Dark Current
Identifier:	VIRCAM_img_cal_darkcurrent.tsf
Description:	Make a series of dark exposures at a variety of different exposure times
Parameters:	List of integration times, and corresponding numbers of integrations for determination of detector dark current.
Raw Frames:	Sequence of FITS files
Pipeline recipes:	vircam_dark_combine

8.1.4 Acquire Dome Screen

Name:	Dome Screen
Identifier:	VIRCAM_img_acq_domescreen.tsf
Description:	Set instrument into IMAGING mode and select science filter. Move telescope to point at illuminated screen and switch on lamps.
Parameters:	Filter, illumination combination
Raw Frames:	None
Pipeline recipes:	None

8.1.5 Dome Flat

Name:	Dome Flat

Identifier:	VIRCAM_img_cal_domeflat.tsf
Description:	Make a dome flat exposure (or sequence of exposures) suitable for calibrating IMAGING mode observations. The flat-field lamps may be switched off when exposure is complete.
Parameters:	Filter, list of integration times and corresponding numbers of integrations, switch calibration source off flag.
Raw Frames:	FITS files
Pipeline recipes:	vircam_dome_flat_combine

8.1.6 Detector Linearity

Name:	Linearity
Identifier:	VIRCAM_img_cal_linearity.tsf
Description:	Make series of dome flat exposures at a variety of exposure times.
Parameters:	Filter, List of integration times and corresponding numbers of integrations
Raw Frames:	FITS files
Pipeline recipes:	vircam_linearity_analyse

8.1.7 Noise and Gain

Name:	Noisegain
Identifier:	VIRCAM_img_cal_noisgain.tsf
Description:	Make a series of dark exposures followed by the same number of flat-field exposures with matched integration times and number of integrations.
Parameters:	filter, optional: detector controller mode, list of integration times and corresponding number of integrations, optional “switch off calibration source when finished”.
Raw Frames:	FITS Files
Pipeline recipes:	vircam_detector_noise

8.1.8 Acquire Twilight Field

Name:	Twilight
Identifier:	VIRCAM_img_acq_twilight.tsf
Description:	Select a dusk or dawn twilight field. Track (no autoguiding).
Parameters:	filter, optional: Azimuth, Altitude
Raw Frames:	None
Pipeline recipes:	None

8.1.9 Twilight Flat

Name:	Twilight Flat
Identifier:	VIRCAM_img_cal_twiflat.tsf

Description:	Take a series of exposures sufficient to make a twilight sky flat-field
Parameters:	List of integration times and corresponding numbers of integrations, or illumination level, depending on level of automation. Includes procedure to wait until sky brightness is appropriate, or abort if the time is too late (dusk and dawn).
Raw Frames:	FITS files
Pipeline recipes:	vircam_twilight_combine

8.1.10 Persistence

Name:	Persistence
Identifier:	VIRCAM_img_cal_persistence.tsf
Description:	Take one exposure with a selected science filter, followed by a series of dark exposures. All exposures have the same integration time and number of integrations. The field should contain a nearly-saturated star.
Parameters:	science filter, number of dark exposures, number of exposures, integration time, number of integrations.
Raw Frames:	FITS files
Pipeline recipes:	vircam_persistence_analyse

8.1.11 Astrometric Calibration

No specific astrometric calibration templates are required as all science frames will be calibrated according to the procedure described in 6.2.2.

8.1.12 Photometric Calibration Standard Fields

Name:	Calibrate
Identifier:	VIRCAM_img_cal_std.tsf
Description:	This template is identical to VIRCAM_img_obs_paw.tsf (see 8.3.2 for full operational description) except for the insertion of FITS information indicating a photometric standard field (STANDARD = T). It is only necessary to observe a pawprint for calibration, a full tile is unnecessary.
Parameters:	Number of filter positions F, and (if F>1) filter IDs; Number of jitter positions J, Number of microstep positions M nested at each jitter position; (if J >1) jitter pattern ID, jitter scale factor, and (if M=1) at each jitter position integration time, number of integrations; (if M>1) microstep pattern ID, microstep scale factor, and at each microstep position the integration time, number of integrations.
Raw Frames:	As many FITS files as there are exposures
Pipeline recipes:	vircam_standard_process

8.1.13 Quick look

Name:	quick look
Identifier:	VIRCAM_img_obs_exp.tsf
Description:	Make a series of exposures at the same target position with a single filter, with no jittering or microstepping.
Parameters:	science filter, number of exposures, integration time, number of integrations.
Raw Frames:	FITS files
Pipeline recipes:	None.

8.1.14 Cross-talk

Name:	Cross-talk
Identifier:	VIRCAM_img_cal_crosstalk.tsf
Description:	Make a series of exposures, with each exposure offset from the previous one by a sequence of meso-steps designed to place a bright star on each of the 16 readout channels on each detector.
Parameters:	science filter, optional list of meso-step offsets, optional detector mode, number of exposures, integration time, number of integrations.
Raw Frames:	FITS files
Pipeline recipes:	vircam_crosstalk_analyse

8.1.15 Illumination

Name:	Illumination
Identifier:	VIRCAM_img_cal_illumination.tsf
Description:	make a series of exposures, with each exposure offset from the previous one by a sequence of meso-steps designed to place a bright star at a regular grid of offset positions across each detector.
Parameters:	List of science filters, list of mesostep offsets, list of [guide star plus two aO stars] for each mesostep in the sequence, optional detector mode, number of exposures, integration time, number of integrations.
Raw Frames:	FITS files
Pipeline recipes:	vircam_mesosteop_analyse

8.2 HOWFS mode calibration

HOWFS processing is carried out on the Instrument Workstation, and data is not passed on to the pipeline.

8.2.1 HOWFS Acquire Dome Screen

Name:	HOWFS Acquire Dome Screen

Identifier:	VIRCAM_howfs_acq_domescreen.tsf
Description:	Set camera into HOWFS mode and select HOWFS intermediate filter. Move telescope to dome illuminated screen, set tracking off and set illumination level.
Parameters:	Filter, screen illumination lamp combination.
Raw Frames:	None
IWS Procedures:	No
Pipeline recipes:	None

8.2.2 HOWFS Reset

Name:	HOWFS Reset
Identifier:	VIRCAM_howfs_cal_reset.tsf
Description:	Make a series of reset exposures suitable for calibrating HOWFS observations.
Parameters:	Filter (Dark), number of frames.
Raw Frames:	FITS
IWS Procedures:	Yes
Pipeline recipes:	None

8.2.3 HOWFS Dark

Name:	HOWFS Dark
Identifier:	VIRCAM_howfs_cal_dark.tsf
Description:	Make several dark exposures suitable for calibrating HOWFS observations.
Parameters:	Filter, integration time, number of integrations.
Raw Frames:	FITS
IWS Procedures:	Yes
Pipeline recipes:	None

8.2.4 HOWFS Dome Flat

Name:	HOWFS Dome Flat
Identifier:	VIRCAM_howfs_cal_domeflat.tsf
Description:	Make a flat-field exposure (or exposures) suitable for calibrating HOWFS observations.
Parameters:	Filter & illumination combination, integration time, number of integrations, focal plane X, Y, and detector window size.
Raw Frames:	FITS
IWS Procedures:	Yes
Pipeline recipes:	None

8.3 Imaging Mode Science Templates

The nesting of the observing loops is described in the same way as in the URD [AD2] using a shorthand based on the order of nesting of the loops for the 6 components, (F for filter, T for tile, P for pawprint, J for jitter, M for microstep, E for exposure), with the order of the letters indicating increasing nesting of the loop as one reads to the right.

8.3.1 Acquire

Name:	**Acquire**
Identifier:	VIRCAM_img_acq.tsf

Description:	Acquire single target.
	Check/Set camera to IMAGING mode, check/set camera position angle, check/select first science filter, all in parallel with a preset of telescope to new target, optionally (and usually) guide, optionally (and usually) activate LOWFS. The flat-field lamp is checked and automatically switched off when the telescope presets to a new celestial target.
	
	i.e. nest
	Preset to defined position
	Check/Set IMAGING mode in parallel
	Check/Set camera PA in parallel [default +X axis to +RA]
	Check/Set first filter in parallel
	If guiding required
	    Acquire guide star
	    LOWFS on two stars in parallel

Parameters:	Target coordinates, focal plane position to be at target position [e.g. centre of camera (default), or specified offset from centre of camera, or centre of a specified detector], camera position angle (E of N on sky, defaults to give +X to +RA), first filter, autoguiding required flag, if set (default) coordinates for 1 guide star from the SDT, LOWFS required flag, if set (default) 1 pair LOWFS stars found by the SDT.
Raw Frames:	None
Pipeline recipes:	None

8.3.2 Observe Paw

Name:	Observe
Identifier:	VIRCAM_img_obs_paw.tsf
Description:	This template makes one “pawprint” observation using a selection of filter changes, jittering and microstep movements. It is assumed the telescope has already been positioned at the target using the acquisition template. The detector controller is configured with the required readout and exposure times and the following sequence executed: **FJME --** step through science filters in outer loop. At each science filter execute a jitter pattern (if specified), and within each jitter pattern execute a microstep pattern (if specified)

Parameters:	List of science filters Number of jitter positions, [optional: jitter pattern ID, jitter scale factor] Number of microstep patterns, [optional: microstep pattern ID, microstep scale factor] Number of exposures Integration time Number of integrations [optional: New camera-position angle]
Raw Frames:	As many FITS files as there are exposures
Pipeline recipes:	vircam_jitter_microstep_process
Note:	The pipeline handles microstepped and jittered exposures differently. To just perform exposures at a fixed position set J=1 and M=1 To just perform a jitter pattern with no microsteps set M=1 To just perform a microstep pattern with no jitters set J=1

8.3.3 Observe Tile

Name:	Observe Tile
Identifier:	VIRCAM_img_obs_tile.tsf
Description:	This template makes sufficient observations to generate a contiguous “tile”, using a selection of pawprints, filter changes, jittering and microstep movements. It is assumed the telescope has already been pointed to the null target with the acquisition template. The detector controller is configured with the required readout and exposure time parameters and one of the following sequences executed: **FPJME** – Construct the tile from a series of pawprints, repeating each pawprint with a different science filter. Within each pawprint execute a jitter pattern (if specified), and within each jitter pattern execute a microstep pattern (if specified). **PFJME** – Construct the tile from a series of pawprints. Within each pawprint execute a jitter pattern, except, this time repeat each jitter with a different science filter before moving on to the next. Within each jitter, execute a microstep pattern (if specified). **FJPME** – Construct the tile from a pawprint and jitter pattern such that one jitter observation is made from each pawprint in turn. Within each jitter pattern there can be a microstep pattern. The whole sequence may be repeated with different science filters. Each time a new pawprint is selected, the TCS is provided with a new guide star and a new pair of LOWFS stars, taken from the list provided by the template. i.e. nest **FPJME**

For each Filter
  For each pawprint position (1 to P)
    Check/offset telescope (steps 5-10′)
    Acquire new guide and LOWFS stars
    For each jitter position (1 to J)
      Check/Move telescope (steps <30″, same guide star)
      For each microstep (1 to M)
        Check/Move telescope (steps <3″, same guide star)
        For each exposure (1 to E)
          Make exposure
        Next exposure
      Next microstep
    Next jitter
  Next pawprint
Next Filter

Parameters:	Nesting pattern (FPJME, PFJME or FJPME as above) List of science filters Tile pattern ID, tile scale factor List of [guide star plus two HOWFS stars] for each pawprint in the tile pattern Number of jitter positions, [optional: jitter pattern ID, jitter scale factor], Number of microstep positions, [optional: microstep pattern ID, microstep scale factor] Number of exposures Integration time Number of integrations
Raw Frames:	As many FITS files as there are exposures
Pipeline Recipes:	vircam_jitter_microstep_process
Note	The pipeline handles microstepped and jittered exposures in a different way.

8.3.4 Observe Offsets

Name:	**Observe Offsets**
Identifier:	VIRCAM_img_obs_offsets.tsf
Description:	Similar to **Observe Tile** except the offsets are not limited to a set of pre-defined offset patterns. The purpose is to allow the versatility of more general sets of offsets, rather than those offset pattern that have been predefined for produce a simple tile.
Parameters:	List of science filters Tile pattern ID Tile scale factor List of [guide star plus two LOWFS stars] for each offset List of RA, Dec offsets

	Number of exposures Integration time Number of integrations [optional: list of position-angle offsets]
Raw Frames:	(Number of pawprint locations × number of exposure in each pawprint) FITS files
Pipeline recipes:	vircam_jitter_microstep_process
Note	Pipeline produces pawprints, these are not merged.

8.3.5 Observing a set of Tiles

Three templates (FTPJME, TFPJME and TPFJME) that observe more than one tile were outlined in the URD [AD2]. The template design has now been considerably streamlined such that the required behaviour can be realised with the observe-tile template, or with multiple templates within an OB.

8.4 HOWFS mode data

HOWFS processing is carried out on the Instrument Workstation, and data is not passed on to the pipeline.

8.4.1 HOWFS Acquire

Name:	HOWFS Acquire
Identifier:	VIRCAM_howfs_acq.tsf
Description:	Acquire a HOWFS (High-Order Wave Front Sensor) source. Set instrument into HOWFS mode which selects HOWFS intermediate filter. If guiding and LOWFS are required, set guide star and two LOWFS coordinate sets.
Parameters:	HOWFS filter Target coordinates and camera position angle [optionally: guide star, two LOWFS stars] focal plane X,Y
Raw frames:	None
IWS Procedures:	None
Pipeline recipes:	None

8.4.2 HOWFS Wave front

Name:	HOWFS wave front
Identifier:	VIRCAM_howfs_obs_wfront.tsf
Description:	Make a HOWFS wave front measurement for measuring the current residual from the active optics lookup table. This will typically be done only ~ twice per night, once at the start of the night, and once around midnight if necessary.
Parameters:	HOWFS filter focal plane X,Y and detector window size integration time number of integrations [optional: max iterations, number of coefficients, name of file]
Raw Frames:	FITS
IWS Procedures:	Trigger HOWFS analysis system, forward coefficient residuals to TCS
Pipeline recipes:	None

8.4.3 HOWFS Expose

Name:	HOWFS Expose
Identifier:	VIRCAM_howfs_obs_exp.tsf

Description:	Make a HOWFS wave front measurement suitable for populating the active optics lookup tables in the TCS. This will be done only very occasionally [~quarterly] in engineering time and does not form part of the routine operations.
Parameters:	HOWFS filter focal plane X,Y and detector window size integration time number of integrations [optional: max iterations, number of coefficients, name of file]
Raw Frames:	FITS
IWS Procedures:	Trigger HOWFS analysis system, produce look up table.
Pipeline recipes:	None

8.5 Instrument Health Templates

Instrument health monitoring templates are defined in [RD5] and are run on a regular basis. For example the instrument filter wheel is tested regularly for position repeatability, and this may determine how often to repeat a flat-field calibration with a particular science filter. The templates in [RD5] are not repeated here, since these monitoring outputs are not processed by the VISTA pipeline and hence are not described in this Calibration Plan.

9 Technical Programs

9.1 TP-VIS1: Establishment of Secondary Standard Fields

This section outlines the procedures required to establish a network of secondary standard fields early in the operation of VIRCAM.

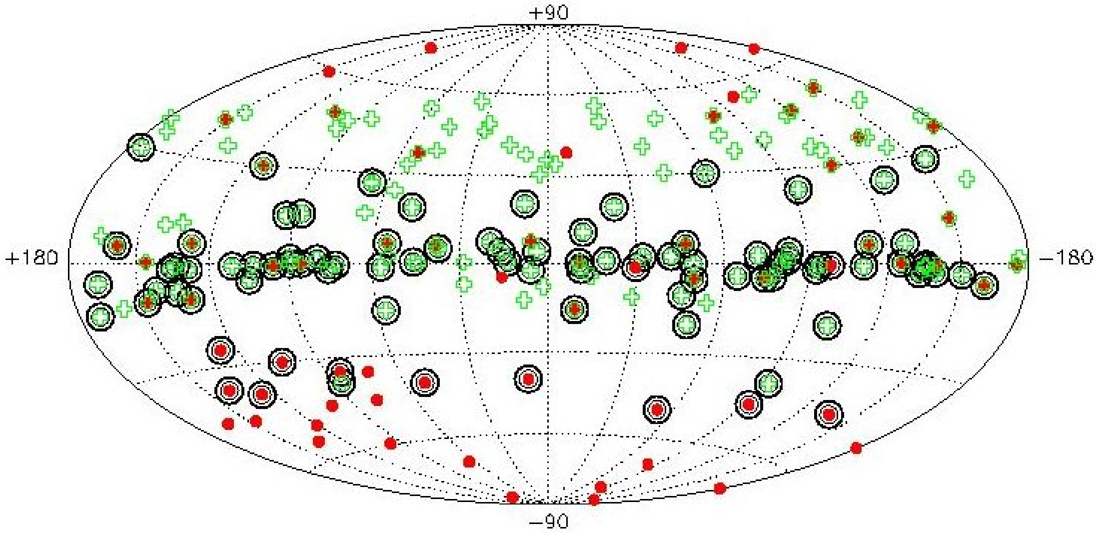

Figure 9-1 VISTA/WFCAM Standard Fields

Name:	Secondary Standard Fields
Program Identifier:	TP-VIS1-IMA-PHO-0001
Purpose:	Provide secondary standards for VISTA for routine calibrations (see Section 5)
Description:	A programme of observations around the primary standards is required to make direct measurements of all the secondary standards in the VIRCAM filter system. These observations will be repeated throughout the year to minimize the errors in the secondary star measurements, to identify variables, and to make full coverage in Right Ascension. The secondary standard fields selected are shown in Figure 9-1 which is a Hammer-Aitoff projection of targets selected from [RD8] and [RD9], and tabulated in Appendix A. For the equator, there are 63 fields with > 60 stars in one detector, with declination roughly in the range -10 to 10 degrees (Table A-2). (Restricting this to >100 stars per detector would restrict the RA coverage due to limiting fields to the galactic plane). Further fields are selected to be within 10° of the zeniths at VISTA (-24.67, Table A-1) and UKIRT (+19.82, Table A-3).

Observing Conditions:	Photometric
Frequency:	Complete night at quarterly intervals over first 2 years of VIRCAM operations to ensure the photometric pedigree and accuracy of the standard fields
Special Conditions:	None
Analysis procedure:	A master catalogue of standard stars will be derived for each field with photometry in each of the VIRCAM filters. Photometry will be measured using standard VFDS pipeline procedures [RD1].
Products:	Y, J, H, Ks magnitudes of ~1500 secondary standards in each field
Accuracies:	The target is 0.005 magnitude *rms* for secondary standards in each waveband after two years of repeated observations.
Responsible Person:	TBD

10 Format of Data Frames

10.1 Principle

There is only one data format, used in both IMAGING and HOWFS modes. Data frames will be in ESO modified standard FITS format [RD10], the ESO modifications being limited to the *hierarchical header* proposal. The headers are compliant with the final World Coordinate System (WCS) specification [RD11]. Data from the full set of chips is stored in Multi Extension Format (MEF) as 32-bit signed integers [RD10]. Offset 16-bit format is not used because data will be co-added in the data acquisition system before output. Though not a requirement, the integer format enables the use of highly efficient lossless compression.

10.2 Model FITS header

A model FITS header for raw data is presented in
Table 10-1. In addition to the header shown in the model, standard pipeline-processing keywords will be inserted into the data products.

```
SIMPLE  =                    T / Standard FITS (NOST-100-2.0)
NAXIS   =                    0 / number of axes of data array
BITPIX  =                    8 / number of bits per pixel value
EXTEND  =                    T / FITS file extension may be present
RA      =           123.123457 / 00:00:00.123 RA of telescope
DEC     =           -12.123457 / -00:00:00.12 Dec of telescope
RADECSYS= 'ICRS    '           / Name of celestial reference frame
EQUINOX =               2000.0 / Equinox of celestial reference frame.
ORIGIN  = 'ESO     '           / European Southern Observatory
TELESCOP= 'ESO-VISTA'          / ESO <TEL>
INSTRUME= 'VIRCAM  '           / Instrument used
OBJECT  = 'Sirius  '           / Target description
IMAGETYP= 'OBJECT  '           / Exposure type
AIRMASS =              1.12346 / Averaged airmass
DATE    = '2004-12-13T12:31:46.000' / Date this file was written
DATE-OBS= '2004-12-25T09:00:00.123' / UTC date at start of exposure.
UTC     =            86399.123 / 00:00:00.123 UTC s at start since midnight
REQTIME =                5.000 / Requested integration time
EXPTIME =                5.123 / Actual integration time
LST     =            80000.123 / 00:00:00.123 LST seconds since midnight
MJD-OBS =       54321.12345678 / Modified Julian Date at start
OBSERVER= 'SERVICE '           / Name of observer
PI-COI  = 'J Lewis '           / Name(s) of proposer(s)
COMMENT General comment
HISTORY Historical Fact
ESO-LOG
ORIGFILE= 'VIRCAM_Ima.1.fits'  / Original File Name
ARCFILE = 'VIRCAM.2006-03-05T07:25:0.000.fits      ' / Archive File name
CHECKSUM= 'Pd3jPc3hPc3h'       / ASCII 1s-complement checksum
RECIPE  = 'QUICK_LOOK'         / Data-reduction recipe to be used
OFFSTNUM=                 1234 / Value of first OBSNUM in current tile sequence
OBSNUM  =             12345678 / Observation Number
GRPNUM  =                  666 / Group number applied to all members
GRPMEM  =                    T / Group membership
STANDARD=                    F / Standard-star observation
NOFFSETS=                    6 / Number of offset positions in a field
OFFSET_I=                    2 / Serial Number of offset
NJITTER =                    6 / Number of positions in a tel jitter pattern
JITTRNUM=                 1236 / Value of first OBSNUM in current jitter sequenc
JITTER_I=                    3 / Serial number of this tel jitter pattern
JITTER_X=                3.330 / X offset in jitter pattern
JITTER_Y=                0.000 / Y offset in jitter pattern
```

```
NUSTEP  =                    4 / Number of positions in microstep pattern
USTEPNUM=                 1237 / Value of first OBSNUM in current microstep sequ
USTEP_I =                    1 / Serial number of microstep pattern
USTEP_X =                1.123 / X offset in microstep pattern
USTEP_Y =                1.123 / Y offset in microstep pattern
HIERARCH ESO DPR DID         = 'ESO-VLT-DIC.DPR-1.8' / DPR Dictionary
HIERARCH ESO DPR CATG        = 'SCIENCE                       ' / Observation ca
HIERARCH ESO DPR TYPE        = 'OBJECT                        ' / Observation ty
HIERARCH ESO DPR TECH        = 'IMAGE                         ' / Observation te
HIERARCH ESO OBS DID         = 'ESO-VLT-DIC.OBS' / OBS Dictionary
HIERARCH ESO OBS ID          =          666    / Observation block ID
HIERARCH ESO OBS NAME        = 'deep-tile                       ' / OB name
HIERARCH ESO OBS GRP         = 'ABCD    '      / linked blocks
HIERARCH ESO OBS OBSERVER    = 'Bunclark                        ' / Observer Nam
HIERARCH ESO OBS PI-COI ID   =          162    / ESO internal PI-COI ID
HIERARCH ESO OBS PI-COI NAME = 'Lewis                           ' / PI-COI name
HIERARCH ESO OBS PROG ID     = '68.A-0281(A)        ' / ESO program identificati
HIERARCH ESO OBS TPLNO       =            2    / Template number within OB
HIERARCH ESO OBS TARG NAME   = 'South Pole                      ' / OB target na
HIERARCH ESO OBS START       = '2006-03-05T07:20:00.123' / OB start time
HIERARCH ESO OBS EXECTIME    =            0    / Expected execution time
HIERARCH ESO TPL PRESEQ      = 'VIRCAM_img_obs_paw.seq' / Sequencer script
HIERARCH ESO TPL START       = '2006-03-05T07:20:00.123' / TPL start time
HIERARCH ESO TPL DID         = 'ESO-VLT-DIC.TPL-1.9           ' / Data dictionar
HIERARCH ESO TPL ID          = 'VIRCAM_img_obs_paw                             '
HIERARCH ESO TPL NAME        = 'VIRCAM Jittered pawprint sequence              '
HIERARCH ESO TPL NEXP        =            6    / Number of exposures within temp
HIERARCH ESO TPL EXPNO       =            2    / Exposure number within template
HIERARCH ESO TPL VERSION     = '@(#) $Revision: 1.5 $' / Version of the template
HIERARCH ESO TEL FOCU LEN       =        4.120 / Focal length (m)
HIERARCH ESO TEL FOCU SCALE     =       24.000 / Focal scale (arcsec/mm)
HIERARCH ESO TEL FOCU VALUE     =    12345.120 / M2 setting (mm)
HIERARCH ESO TEL PARANG END     =       45.000 / Parallactic angle at end (deg)
HIERARCH ESO TEL PARANG START   =       47.000 / Parallactic angle at start (deg
HIERARCH ESO TEL AIRM END       =        1.001 / Airmass at end
HIERARCH ESO TEL AIRM START     =        1.002 / Airmass at start
HIERARCH ESO TEL TRAK STATUS    = 'ON       ' / Tracking status
HIERARCH ESO TEL TRAK RATEA     =     0.000000 / Tracking rate in RA (arcsec/sec
HIERARCH ESO TEL TRAK RATED     =     0.000000 / Tracking rate in DEC (arcsec/se
HIERARCH ESO TEL DOME STATUS    = 'FULLY-OPEN' / Dome status
HIERARCH ESO ADA GUID STATUS    = 'ON       ' / Status of autoguider
HIERARCH ESO ADA GUID RA        =   180.000000 / 00:00:00.123 Guide star RA J200
HIERARCH ESO ADA GUID DEC       =    -45.00000 / %DEGREE Guide star DEC J2000
HIERARCH ESO ADA POSANG         =     33.00000 / Position angle at start
HIERARCH ESO ADA ABSROT START   =      2.00000 / Abs rot angle at exp start (deg
HIERARCH ESO TEL ID             = 'v 3.45                        ' / TCS version
HIERARCH ESO TEL DID            = 'ESO-VLT-DIC.TCS-1.33          ' / Data dictio
HIERARCH ESO TEL DATE           = '2006-05-03' / TCS installation date
HIERARCH ESO ADA ABSROT END     =      3.00000 / Abs rot angle at exp end (deg)
HIERARCH ESO ADA ABSROT PPOS    = 'posit'      / sign of probe position
HIERARCH ESO ADA WFS1 RA        =    12.123457 / RA of WFS star 1
HIERARCH ESO ADA WFS1 DEC       =   -75.987654 / Dec of WFS star 1
HIERARCH ESO ADA WFS2 RA        =    12.123457 / RA of WFS star 2
HIERARCH ESO ADA WFS2 DEC       =   -75.987654 / Dec of WFS star 2
HIERARCH ESO TEL ALT            =       80.000 / Alt angle at start (deg)
HIERARCH ESO TEL AZ             =       10.000 / Az angle at start (deg) S=0,W=9
HIERARCH ESO TEL GEOELEV        =         2335 / Elevation above sea level (m)
HIERARCH ESO TEL GEOLAT         =     -29.2543 / Tel geo latitute (+=North) (deg
HIERARCH ESO TEL GEOLON         =     -70.7346 / Tel geo longitude (+=East) (deg
HIERARCH ESO TEL OPER           = 'Senor Operador                ' / Telescope O
HIERARCH ESO TEL FOCU ID        = 'CA       ' / Telescope focus station ID
HIERARCH ESO TEL TH M1 TEMP     =         8.12 / M1 superficial temperature
HIERARCH ESO TEL MOON RA        =    10.000000 / 00:00:00.123 RA (J2000) (deg)
HIERARCH ESO TEL AMBI FWHM START=         0.50 / Observatory Seeing queried from
HIERARCH ESO TEL AMBI FWHM END  =         0.70 / Observatory Seeing queried from
HIERARCH ESO TEL AMBI TEMP      =         4.20 / Observatory ambient temperature
HIERARCH ESO TEL AMBI RHUM      =            5 / Observatory ambient relative hu
HIERARCH ESO TEL AMBI WINDDIR   =          340 / Observatory ambient wind direct
HIERARCH ESO TEL AMBI WINDSP    =        15.00 / Observatory ambient wind speed
HIERARCH ESO TEL MOON DEC       =     20.00000 / %DEGREE DEC (J2000) (deg)
HIERARCH ESO TEL ENCL MOONSCR STEP=          1 / Moonscreen positions step
HIERARCH ESO TEL ENCL WINDSCR1 STATE= 'OPEN    ' / Louvre state
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HIERARCH ESO TEL ENCL WINDSCR2 STATE= 'UP      ' / up/down slide state
HIERARCH ESO TEL ENCL VENT1 STATE= 'SHUT    '  / Vent 1 door state
HIERARCH ESO TEL ENCL VENT2 STATE= 'HALF    '  / Vent 2 door state
HIERARCH ESO TEL ENCL VENT3 STATE= 'OPEN    '  / Vent 3 door state
HIERARCH ESO TEL M2 LOOP1 STATE = 'CLOSED  '   / Focus-loop switch state
HIERARCH ESO TEL M2 LOOP2 STATE = 'OPEN    '   / Centroiding-loop switch state
HIERARCH ESO TEL M2 LOOP3 STATE = 'CLOSED  '   / Tilt-loop switch state
HIERARCH ESO TEL M2 LOOP4 STATE = 'CLOSED  '   / Astigmatic-loop switch state
HIERARCH ESO TEL M2 LOOP5 STATE = 'CLOSED  '   / Trefoil-loop switch state
HIERARCH ESO TEL M2 CENX        = 1.510000     / X-Centre reading 1
HIERARCH ESO TEL M2 CENY        = 1.520000     / Y-Centre reading 2
HIERARCH ESO TEL M2 TILTX       = 1.530000     / X-tilt reading 3
HIERARCH ESO TEL M2 TILTY       = 1.540000     / Y-tilt reading 4
HIERARCH ESO TEL M1 ACTUATORFAILED=            1 / Number of failed actuator
HIERARCH ESO TEL ENCL FFLAMP1 ID= '123     '   / Dim tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP1 NAME= 'VIS_DOM_DIM' / Dim tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP1 STATE= 'OFF     ' / ON/OFF state of flat lamp 1
HIERARCH ESO TEL ENCL FFLAMP2 ID= '234     '   / Bright tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP2 NAME= 'VIS_DOM_BRIGHT' / Bright tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP2 STATE= 'ON      ' / ON/OFF state of flat lamp 2
HIERARCH ESO TEL ENCL FFLAMP3 ID= '345     '   / Halogen lamp pair
HIERARCH ESO TEL ENCL FFLAMP3 NAME= 'VIS_DOM_HALOGEN' / Dim tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP3 STATE= 'OFF     ' / ON/OFF state of flat lamp 3
HIERARCH ESO INS THERMAL ENABLE=           T  / If T, enable thermal control lo
HIERARCH ESO INS THERMAL DET TARGET=       130.00 / Detector target temperature
HIERARCH ESO INS THERMAL WIN DELTA=          0.0 / Window target temp wrt ambien
HIERARCH ESO INS THERMAL TUB DELTA=          0.0 / Tube target temp wrt ambient
HIERARCH ESO INS ID          = 'VIRCAM                      ' / Instrument ID
HIERARCH ESO INS DID         = 'ESO-VLT-DIC.VIRCAM_ICS      ' / Data dictionar
HIERARCH ESO INS OPER        = '                            ' / Instrument ope
HIERARCH ESO INS SWSIM       = 'UNKNOWN        ' / Software simulation
HIERARCH ESO INS MODE        = 'IMAGE     '    / Instrument mode
HIERARCH ESO INS PATH        = 'UNKNOWN   '    / Optical path
HIERARCH ESO INS FILT SWSIM =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS FILT STOFF =            0    / Offset [steps] to be applied
HIERARCH ESO INS FILT USESW =      UNKNOWN    / If T, in-position switch is use
HIERARCH ESO INS FILT IDi   = 'UNKNOWN   '    / Filter unique id
HIERARCH ESO INS FILT NAMEi = 'UNKNOWN        ' / Filter name
HIERARCH ESO INS FILT FOCUSi=        1.235    / Filter focus offset [m]
HIERARCH ESO INS FILT DENSITYi=          1.2  / Filter optical density
HIERARCH ESO INS FILT NO    =            0    / Filter wheel position index
HIERARCH ESO INS FILT DATE  = 'UNKNOWN '      / Filter index time
HIERARCH ESO INS FILT ERROR =            0    / Last filter wheel error [Enc]
HIERARCH ESO INS HB DEVNAME = 'UNKNOWN            ' / Name of the ICS device.
HIERARCH ESO INS HB DEVDESC = 'UNKNOWN            ' / Description of the ICS de
HIERARCH ESO INS HB LCUID   =            0    / ID of the LCU managing the devi
HIERARCH ESO INS HB SWSIM   =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS HB FREQUENCY=          1.2   / Square wave frequency.
HIERARCH ESO INS HB PIN     =            0    / Output pin.
HIERARCH ESO INS SENSORi SWSIM=                / If T, function software simulat
HIERARCH ESO INS LSMi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS LSMi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS LSCi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS LSCi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS LSCi SETPi  =         1.23    / Set-point.
HIERARCH ESO INS VACi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS VACi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS CCCi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS CCCi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS SENSi ID    = 'UNKNOWN   '    / Sensor type
HIERARCH ESO INS SENSi NAME  = 'UNKNOWN        ' / Sensor name
HIERARCH ESO INS SENSi VAL   =        1.235    / Sensor value
HIERARCH ESO INS SENSi STAT  = 'UNKNOWN '      / Sensor string value
HIERARCH ESO INS SENSi MIN   =        1.235    / Minimum value
HIERARCH ESO INS SENSi MAX   =        1.235    / Maximum value
HIERARCH ESO INS SENSi MEAN  =        1.235    / Average value
HIERARCH ESO INS SENSi RMS   =        1.235    / RMS of samples over exposure
HIERARCH ESO INS SENSi TMMEAN=        0.000    / Time weighted average
HIERARCH ESO INS SENSi GRAD  =        1.235    / Linear regression slope
HIERARCH ESO INS SENSi LRCONST=        0.000   / Linear regression constant
HIERARCH ESO INS SENSi LRRMS =        1.235    / Linear regression RMS
HIERARCH ESO INS SENSi DETCOEF=        0.000   / Lin. reg. determination coeff.
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HIERARCH ESO INS SENSi UNITi = UNKNOWN         / Sensor unit
HIERARCH ESO INS PRESi ID    = 'UNKNOWN   '    / Pressure sensor type.
HIERARCH ESO INS PRESi NAME  = 'UNKNOWN        ' / Pressure sensor name.
HIERARCH ESO INS PRESi VAL   =        1.235    / Pressure.
HIERARCH ESO INS PRESi MIN   =        1.235    / Minimum pressure.
HIERARCH ESO INS PRESi MAX   =        1.235    / Maximum pressure.
HIERARCH ESO INS PRESi MEAN  =        1.235    / Average pressure.
HIERARCH ESO INS PRESi RMS   =        1.235    / RMS of samples over exposure.
HIERARCH ESO INS PRESi TMMEAN=        0.000    / Time weighted average.
HIERARCH ESO INS PRESi GRAD  =        1.235    / Linear regression slope.
HIERARCH ESO INS PRESi LRCONST=        0.000   / Linear regression constant.
HIERARCH ESO INS PRESi LRRMS =        1.235    / Linear regression RMS.
HIERARCH ESO INS PRESi DETCOEF=        0.000   / Lin. reg. determination coeff..
HIERARCH ESO INS PRESi UNITi = UNKNOWN         / Pressure unit.
HIERARCH ESO INS SW1 ID      =    'UNKNOWN'    / Switch ID
HIERARCH ESO INS SW1 NAME    = 'Filter in-position switch' / Switch name
HIERARCH ESO INS SW1 STATUS  =     'CLOSED'    / Switch status
HIERARCH ESO INS TEMP1 ID       = 'ID1     '   / ID of sensor 1
HIERARCH ESO INS TEMP1 NAME     = 'Ambient temperature' / Location of sensor 1
HIERARCH ESO INS TEMP1 VAL      =      260.100 / Temperature sensor 1 reading
HIERARCH ESO INS TEMP1 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP1 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP1 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP1 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP1 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP1 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP1 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP1 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP1 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP1 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP2 ID       = 'ID2     '   / ID of sensor 2
HIERARCH ESO INS TEMP2 NAME     = 'Cryostat window temperature' / Location of se
HIERARCH ESO INS TEMP2 VAL      =      260.100 / Temperature sensor 2 reading
HIERARCH ESO INS TEMP2 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP2 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP2 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP2 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP2 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP2 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP2 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP2 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP2 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP2 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP3 ID       = 'ID3     '   / ID of sensor 3
HIERARCH ESO INS TEMP3 NAME     = 'Cryostat tube temperature' / Location of sens
HIERARCH ESO INS TEMP3 VAL      =      260.100 / Temperature sensor 3 reading
HIERARCH ESO INS TEMP3 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP3 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP3 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP3 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP3 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP3 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP3 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP3 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP3 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP3 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP4 ID       = 'ID4     '   / ID of sensor 4
HIERARCH ESO INS TEMP4 NAME     = 'Liquid Nitrogen tank temperature' / Location
HIERARCH ESO INS TEMP4 VAL      =      260.100 / Temperature sensor 4 reading
HIERARCH ESO INS TEMP4 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP4 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP4 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP4 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP4 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP4 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP4 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP4 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP4 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP4 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP5 ID       = 'ID5     '   / ID of sensor 5
HIERARCH ESO INS TEMP5 NAME     = 'Baffle temperature' / Location of sensor 5
HIERARCH ESO INS TEMP5 VAL      =      260.100 / Temperature sensor 5 reading
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HIERARCH ESO INS TEMP5 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP5 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP5 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP5 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP5 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP5 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP5 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP5 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP5 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP5 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP6 ID       = 'ID6     '   / ID of sensor 6
HIERARCH ESO INS TEMP6 NAME     = 'Lens barrel temperature' / Location of sensor
HIERARCH ESO INS TEMP6 VAL      =      260.100 / Temperature sensor 6 reading
HIERARCH ESO INS TEMP6 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP6 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP6 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP6 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP6 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP6 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP6 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP6 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP6 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP6 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP7 ID       = 'ID7     '   / ID of sensor 7
HIERARCH ESO INS TEMP7 NAME     = 'Filter wheel shield temperature' / Location o
HIERARCH ESO INS TEMP7 VAL      =      260.100 / Temperature sensor 7 reading
HIERARCH ESO INS TEMP7 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP7 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP7 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP7 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP7 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP7 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP7 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP7 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP7 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP7 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP8 ID       = 'ID8     '   / ID of sensor 8
HIERARCH ESO INS TEMP8 NAME     = 'Filter wheel hub temperature' / Location of s
HIERARCH ESO INS TEMP8 VAL      =      260.100 / Temperature sensor 8 reading
HIERARCH ESO INS TEMP8 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP8 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP8 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP8 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP8 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP8 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP8 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP8 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP8 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP8 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP9 ID       = 'ID9     '   / ID of sensor 9
HIERARCH ESO INS TEMP9 NAME     = 'Closed cycle cooler 1 1st stage' / Location o
HIERARCH ESO INS TEMP9 VAL      =      260.100 / Temperature sensor 9 reading
HIERARCH ESO INS TEMP9 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP9 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP9 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP9 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP9 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP9 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP9 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP9 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP9 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP9 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP10 ID      = 'ID10    '   / ID of sensor 10
HIERARCH ESO INS TEMP10 NAME    = 'Closed cycle cooler 1 2nd stage' / Location o
HIERARCH ESO INS TEMP10 VAL     =      260.100 / Temperature sensor 10 reading
HIERARCH ESO INS TEMP10 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP10 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP10 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP10 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP10 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP10 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP10 LRCONST =      120.120 / Linear regression constant
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HIERARCH ESO INS TEMP10 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP10 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP10 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP11 ID      = 'ID11    '   / ID of sensor 11
HIERARCH ESO INS TEMP11 NAME    = 'Closed cycle cooler 2 1st stage' / Location o
HIERARCH ESO INS TEMP11 VAL     =      260.100 / Temperature sensor 11 reading
HIERARCH ESO INS TEMP11 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP11 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP11 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP11 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP11 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP11 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP11 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP11 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP11 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP11 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP12 ID      = 'ID12    '   / ID of sensor 12
HIERARCH ESO INS TEMP12 NAME    = 'Closed cycle cooler 2 2nd stage' / Location o
HIERARCH ESO INS TEMP12 VAL     =      260.100 / Temperature sensor 12 reading
HIERARCH ESO INS TEMP12 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP12 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP12 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP12 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP12 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP12 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP12 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP12 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP12 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP12 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP13 ID      = 'ID13    '   / ID of sensor 13
HIERARCH ESO INS TEMP13 NAME    = 'Closed cycle cooler 3 1st stage' / Location o
HIERARCH ESO INS TEMP13 VAL     =      260.100 / Temperature sensor 13 reading
HIERARCH ESO INS TEMP13 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP13 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP13 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP13 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP13 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP13 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP13 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP13 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP13 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP13 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP14 ID      = 'ID14    '   / ID of sensor 14
HIERARCH ESO INS TEMP14 NAME    = 'Closed cycle cooler 3 2nd stage' / Location o
HIERARCH ESO INS TEMP14 VAL     =      260.100 / Temperature sensor 14 reading
HIERARCH ESO INS TEMP14 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP14 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP14 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP14 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP14 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP14 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP14 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP14 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP14 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP14 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP15 ID      = 'ID15    '   / ID of sensor 15
HIERARCH ESO INS TEMP15 NAME    = 'Wavefront sensor PY CCD assembly' / Location
HIERARCH ESO INS TEMP15 VAL     =      260.100 / Temperature sensor 15 reading
HIERARCH ESO INS TEMP15 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP15 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP15 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP15 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP15 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP15 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP15 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP15 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP15 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP15 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP16 ID      = 'ID16    '   / ID of sensor 16
HIERARCH ESO INS TEMP16 NAME    = 'Wavefront sensor NY CCD assembly' / Location
HIERARCH ESO INS TEMP16 VAL     =      260.100 / Temperature sensor 16 reading
HIERARCH ESO INS TEMP16 MIN     =      260.100 / Minimum value
```

```
HIERARCH ESO INS TEMP16 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP16 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP16 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP16 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP16 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP16 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP16 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP16 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP16 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP17 ID      = 'ID17    '   / ID of sensor 17
HIERARCH ESO INS TEMP17 NAME    = 'Science detector 1AB' / Location of sensor 17
HIERARCH ESO INS TEMP17 VAL     =      260.100 / Temperature sensor 17 reading
HIERARCH ESO INS TEMP17 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP17 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP17 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP17 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP17 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP17 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP17 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP17 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP17 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP17 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP18 ID      = 'ID18    '   / ID of sensor 18
HIERARCH ESO INS TEMP18 NAME    = 'Science detector 1CD' / Location of sensor 18
HIERARCH ESO INS TEMP18 VAL     =      260.100 / Temperature sensor 18 reading
HIERARCH ESO INS TEMP18 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP18 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP18 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP18 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP18 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP18 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP18 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP18 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP18 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP18 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP19 ID      = 'ID19    '   / ID of sensor 19
HIERARCH ESO INS TEMP19 NAME    = 'Science detector 2BA' / Location of sensor 19
HIERARCH ESO INS TEMP19 VAL     =      260.100 / Temperature sensor 19 reading
HIERARCH ESO INS TEMP19 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP19 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP19 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP19 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP19 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP19 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP19 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP19 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP19 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP19 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP20 ID      = 'ID20    '   / ID of sensor 20
HIERARCH ESO INS TEMP20 NAME    = 'Science detector 2DC' / Location of sensor 20
HIERARCH ESO INS TEMP20 VAL     =      260.100 / Temperature sensor 20 reading
HIERARCH ESO INS TEMP20 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP20 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP20 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP20 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP20 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP20 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP20 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP20 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP20 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP20 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP21 ID      = 'ID21    '   / ID of sensor 21
HIERARCH ESO INS TEMP21 NAME    = 'Science detector 3AB' / Location of sensor 21
HIERARCH ESO INS TEMP21 VAL     =      260.100 / Temperature sensor 21 reading
HIERARCH ESO INS TEMP21 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP21 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP21 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP21 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP21 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP21 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP21 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP21 LRRMS   =      260.100 / Linear regression RMS
```

```
HIERARCH ESO INS TEMP21 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP21 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP22 ID      = 'ID22    '   / ID of sensor 22
HIERARCH ESO INS TEMP22 NAME    = 'Science detector 3CD' / Location of sensor 22
HIERARCH ESO INS TEMP22 VAL     =      260.100 / Temperature sensor 22 reading
HIERARCH ESO INS TEMP22 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP22 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP22 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP22 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP22 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP22 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP22 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP22 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP22 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP22 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP23 ID      = 'ID23    '   / ID of sensor 23
HIERARCH ESO INS TEMP23 NAME    = 'Science detector 4BA' / Location of sensor 23
HIERARCH ESO INS TEMP23 VAL     =      260.100 / Temperature sensor 23 reading
HIERARCH ESO INS TEMP23 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP23 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP23 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP23 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP23 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP23 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP23 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP23 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP23 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP23 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP24 ID      = 'ID24    '   / ID of sensor 24
HIERARCH ESO INS TEMP24 NAME    = 'Science detector 4DC' / Location of sensor 24
HIERARCH ESO INS TEMP24 VAL     =      260.100 / Temperature sensor 24 reading
HIERARCH ESO INS TEMP24 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP24 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP24 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP24 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP24 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP24 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP24 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP24 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP24 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP24 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP25 ID      = 'ID25    '   / ID of sensor 25
HIERARCH ESO INS TEMP25 NAME    = 'FPA thermal plate' / Location of sensor 25
HIERARCH ESO INS TEMP25 VAL     =      260.100 / Temperature sensor 25 reading
HIERARCH ESO INS TEMP25 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP25 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP25 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP25 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP25 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP25 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP25 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP25 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP25 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP25 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP26 ID      = 'ID26    '   / ID of sensor 26
HIERARCH ESO INS TEMP26 NAME    = 'WFS plate'  / Location of sensor 26
HIERARCH ESO INS TEMP26 VAL     =      260.100 / Temperature sensor 26 reading
HIERARCH ESO INS TEMP26 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP26 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP26 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP26 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP26 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP26 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP26 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP26 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP26 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP26 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS HOWFS DATE     = '2006-03-05T01:02:03.123' / Time of new coefs
END
XTENSION= 'IMAGE   '           / Extension first keyword
NAXIS   =                    2 / number of axes of data array
NAXIS1  =                 2048 / Size of first axis
```

```
NAXIS2  =                 2048 / Size of second axis
BITPIX  =                   32 / number of bits per pixel value
EXTNAME = 'WIN1.CHIP1.OUT1'    / FITS extension name
EXTVER  =                    1 / Detector index
INHERIT =                    T / Extension inherits primary header
DET_LIVE=                    T / This detector is alive
RADECSYS= 'ICRS    '           / Name of celestial reference frame
EQUINOX =               2000.0 / Equinox of celestial reference frame.
CTYPE1  = 'RA---ZPN'           / Type of celestial axis 1
CTYPE2  = 'DEC--ZPN'           / Type of celestial axis 2
CRPIX1  =              6860.80 / Pixel coordinate of reference in axis 1
CRPIX2  =             -3507.20 / Pixel coordinate of reference in axis 2
CRVAL1  =     270.000000000000 / RA of reference point
CRVAL2  =     -75.000000000000 / Dec of reference point
CD1_1   = -9.444444E-05        / Transformation matrix element
CD1_2   = 0.000000E+00         / Transformation matrix element
CD2_1   = 0.000000E+00         / Transformation matrix element
CD2_2   = 9.444444E-05         / Transformation matrix element
PV2_1   = 1.000000E+00         / linear term in ZPN
PV2_2   = 0.000000E+00         / quadratic term in ZPN
PV2_3   = 4.200000E+01         / cubic term in ZPN
PV2_4   = 0.000000E+00         / forth-order term in ZPN
PV2_5   = 0.000000E+00         / fifth-order term in ZPN
HIERARCH ESO DET MINDIT      =    1.7726000    / Minimum DIT
HIERARCH ESO DET MODE NAME   = '        '      / DCS Detector Mode
HIERARCH ESO DET MODEi NAME  = '        '      / DCS Detector Mode
HIERARCH ESO DET NC IDIV     =            1    / # of Sub-Divs for R-O
HIERARCH ESO DET NC NSAMPPIX =            1    / # of Samples/Pixel
HIERARCH ESO DET NCORRS      =            0    / Read-Out Mode
HIERARCH ESO DET RSPEED      =            1    / Read-Speed Factor
HIERARCH ESO DET IRACE ADCi NAME= 'VIRGO   '   / Name for ADC Board
HIERARCH ESO DET IRACE ADCi HEADER=            1 / Header of ADC Board
HIERARCH ESO DET IRACE ADCi ENABLE=            1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADCi FILTERi=            1 / ADC Filter Adjustment
HIERARCH ESO DET IRACE ADCi DELAY=          15 / ADC Delay Adjustment
HIERARCH ESO DET NCORRS NAME = 'DblCor  '      / Read-Out Mode Name
HIERARCH ESO DET NDIT        =           10    / # of Sub-Integrations
HIERARCH ESO DET NDITSKIP    =            0    / DITs skipped at 1st.INT
HIERARCH ESO DET NDSAMPLES   =            0    / # of Non-Dest. Samples
HIERARCH ESO DET NDSKIP      =            0    / Samples skipped per DIT
HIERARCH ESO DET RSPEEDADD   =            0    / Read-Speed Add
HIERARCH ESO DET VOLTi CLKHINMi= '3.3     '    / Name of High Clock
HIERARCH ESO DET VOLTi CLKHITi=       0.0000   / Tel Value High Clock
HIERARCH ESO DET VOLTi CLKHIi=       0.0000    / Set Value High Clock
HIERARCH ESO DET VOLTi CLKLONMi= '        '    / Name of Low Clock
HIERARCH ESO DET IRACE SEQCONT=             F  / Sequencer Cont. Mode
HIERARCH ESO DET IRACE SEQINT=                 / Sequencer Intr. at Stop
HIERARCH ESO DET VOLTi CLKLOTi=       0.0000   / Tel Value Low Clock
HIERARCH ESO DET VOLTi DCNMi = 'FRED    '      / Name of DC Voltage
HIERARCH ESO DET VOLTi DCTAi =       4.9000    / Tel Value 1 for DC
HIERARCH ESO DET VOLTi CLKLOi=       0.1000    / Set Value Low Clock
HIERARCH ESO DET VOLTi DCi   =       0.0000    / Set Value DC Voltage
HIERARCH ESO DET CHIP TYPE   = 'RAYTHEON'      / The Type of Det Chip
HIERARCH ESO DET CON OPMODE  = 'SIMULATION'    / Operational Mode
HIERARCH ESO DET FRAM TYPE   = 'DIT     '      / Frame type
EXPTIME =           20.1234500 / Integration time
ORIGFILE= '                                        ' / Original File Name
HIERARCH ESO DET CHOP CYCSKIP=            0    / # of Chop Cycles to Skip
HIERARCH ESO DET CHOP NCYCLES=            0    / # of Chop Cycles
HIERARCH ESO DET CHOP ST     =                 / Chopping On/Off
HIERARCH ESO DET CHOP FREQ   = 0.000000        / Chopping Frequency
HIERARCH ESO DET CHIP ID     = 'VM301-S/N-022' / Detector ID
HIERARCH ESO DET CHIP NAME   = 'VIRGO   '      / Detector name
HIERARCH ESO DET CHIP NX     =         2048    / Pixels in X
HIERARCH ESO DET CHIP NY     =         2048    / Pixels in Y
HIERARCH ESO DET CHIP PXSPACE= 2.000e-05       / Pixel-Pixel Spacing
HIERARCH ESO DET EXP NO      =         9876    / Exposure Number
HIERARCH ESO DET FRAM UTC    = '2006-03-05T10:11:12' / Time Recv Frame
HIERARCH ESO DET FRAM NO     =            2    / Frame number
HIERARCH ESO DET VOLTi DCTBi =       0.0000    / Tel Value 2 for DC
HIERARCH ESO DET WIN NX      =         2048    / # of Pixels in X
HIERARCH ESO DET DID         = '        '      / Dictionary Name and Revision
```

```
HIERARCH ESO DET DIT         =    0.0000000    / Integration Time
HIERARCH ESO DET DITDELAY    =        0.000    / Pause Between DITs
HIERARCH ESO DET EXP UTC     = '2006-03-05T10:11:12' / File Creation Time
HIERARCH ESO DET EXP NAME    = '        '      / Exposure Name
HIERARCH ESO DET WIN NY      =         2048    / # of Pixels in Y
HIERARCH ESO DET WIN STARTX  = 1.000000        / Lower Left X Ref
HIERARCH ESO DET WIN STARTY  = 1.000000        / Lower left Y Ref
HIERARCH ESO DET WIN TYPE    =            0    / Win-Type
END
```

The section between the two ENDs repeating as appropriate for the next 15 extensions.

Table 10-1 FITS Example Header

Appendix A. All-Sky IR Survey Fields

Name	RA	DEC	Num
9103	00 33 15.2	-39 24 10	59
9106	03 26 53.9	-39 50 38	65
9115	05 36 44.8	-34 46 39	133
HD38921	05 47 22.19	-38 13 51.3	125
9123	06 59 45.6	-30 13 44	530
9132	08 25 36.1	-39 05 59	1434
9133	08 27 12.5	-25 08 01	577
9137	09 15 50.5	-36 32 34	639
FS140	17 13 22.65	-18 53 33.8	1061
HD161743	17 48 57.93	-38 07 07.5	3223
FS34	20 42 34.73	-20 04 34.8	221
9172	17 48 22.6	-45 25 45	
9181	20 31 20.4	-49 38 58	
9187	23 23 34.4	-15 21 07	
FS112	03 47 40.70	-15 13 14.4	
FS129	11 21 48.95	-13 13 07.9	
9157	14 56 51.9	-44 49 14	

Table A-1 Southern Standards

Name	RA	DEC	Num
HD1160	00 15 57.30	+04 15 04.0	82
BRI0021	00 24 24.60	-01 58 22.0	72
FS2	00 55 09.93	+00 43 13.1	78
FS3	01 04 21.63	+04 13 36.0	79
FS105	01 19 08.19	+07 34 11.5	79
FS6	02 30 16.64	+05 15 51.1	82
T832-38078	03 04 02.00	+00 45 52.0	94
FS110	03 41 02.22	+06 56 15.9	73
FS10	03 48 50.20	-00 58 31.2	74
FS11	04 52 58.92	-00 14 41.6	128
FS119	05 02 57.44	-01 46 42.6	173
SAO112626	05 19 17.16	+01 42 16.1	176
S840-F	05 42 32.10	+00 09 04.0	293
FS13	05 57 07.59	+00 01 11.4	375
HD40335	05 58 13.52	+01 51 23.0	342
9118	06 22 43.7	-00 36 30	593
S842-E	06 22 43.70	-00 36 30.0	593
SA98-653	06 52 04.95	-00 18 18.3	958
FS121	06 59 46.82	-04 54 33.2	928
FS14	07 24 14.40	-00 33 04.1	507
RU149D	07 24 15.36	-00 32 47.9	514
P545-C	08 29 25.10	+05 56 08.0	158
LHS2026	08 32 30.50	-01 34 37.0	162
S705-D	08 36 12.50	-10 13 39.0	262
FS18	08 53 35.51	-00 36 41.7	121
FS124	08 54 12.60	-08 05 03.0	173
HD77281	09 01 38.01	-01 28 34.8	122
GL347A	09 28 53.50	-07 22 15.0	122
S708-D	09 48 56.40	-10 30 32.0	108
P550-C	10 33 51.80	+04 49 05.0	71
FS20	11 07 59.93	-05 09 26.1	79

HD121968	13 58 51.17	-02 54 52.3	65
S791-C	13 17 29.60	-05 32 37.0	65
HD129655	14 43 46.44	-02 30 20.0	93
FS136	14 59 32.05	-00 06 17.0	74
T868-53850	15 00 26.40	-00 39 29.0	81
T868-110639	15 10 17.00	-02 41 05.0	100
PG1528+062B	15 30 39.00	+06 01 13.0	119
S870-T	15 39 03.50	+00 14 54.0	135
FS137	16 26 42.72	+05 52 20.3	170
SA108-475	16 37 00.00	-00 34 39.0	241
9170	17 27 22.2	-00 19 25	394
SA109-381	17 44 12.00	-00 20 33.0	574
HD161903	17 48 19.22	-01 48 29.7	811
FS35	18 27 13.52	+04 03 09.4	1502
FS143	18 29 53.79	+01 13 29.9	787
FS144	18 29 56.90	+01 12 47.1	814
SA110-232	18 40 52.00	+00 01 55.0	3177
L547	18 51 15.60	-04 16 02.0	3773
S808-C	19 01 55.40	-04 29 12.0	3043
GL748	19 12 14.60	+02 53 11.1	3007
FS148	19 41 23.52	-03 50 56.1	856
S813-D	20 41 05.10	-05 03 43.0	261
SA112-822	20 42 54.00	+00 15 02.0	289
P576-F	20 52 47.30	+06 40 05	288
GL811.1	20 56 46.60	-10 26 54.6	178
HD201941	21 12 45.32	+02 38 33.9	226
FS29	21 52 25.36	+02 23 20.7	138
9185	22 02 05.7	-01 06 02	114
FS30	22 41 44.72	+01 12 36.5	104
FS31	23 12 21.60	+10 47 04.1	80
FS32	23 16 12.37	-01 50 34.6	85
FS154	23 18 10.08	+00 32 55.6	85

Table A-2 Equatorial Standards

Name	RA	DEC	Num
HD3029	00 33 39.53	+20 26 01.7	58
FS109	03 13 24.16	+18 49 38.4	103
FS115	04 23 18.17	+26 41 16.4	182
FS12	05 52 27.66	+15 53 14.3	689
FS120	06 14 01.44	+15 09 58.3	774
P309-U	07 30 34.50	+29 51 12.0	187
FS21	11 37 05.15	+29 47 58.4	52
FS23	13 41 43.57	+28 29 49.5	283
HD136754	15 21 34.53	+24 20 36.1	99
FS141	17 48 58.87	+23 17 43.7	245
FS149	20 00 39.25	+29 58 40.0	3317
FS152	22 27 16.12	+19 16 59.2	146

Table A-3 Northern Standards

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