Visible & Infrared Survey Telescope for Astronomy

Data Flow System

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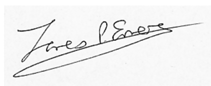
Document Released by:	**Jim Emerson** (VDFS Project leader)	**Signature And date:**	
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1 Introduction

1.1 Purpose

This document forms part of the package of documents for the Preliminary Design Review of 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" and at PDR consists of a "draft version of the Calibration Plan including a list of all planned templates." It will be developed from an incomplete form at PDR to a complete form at the FDR.

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 User Requirements [AD2]. The major reduction recipes and algorithms to be applied to the data are described in the VISTA DFS Data Reduction Specification [RD1].

Each camera exposure will produce a 'pawprint' consisting of 16 non-contiguous images of the sky, one from each detector. The VISTA DFS 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. [An exception is VIRCAM_howfs_obs_exp which is included here as it uses the science detectors.] 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 instruments requirements specification,* VLT-SPE-ESO-19000-1618, issue 1.0, 1999-04-21.

[AD2] *VISTA Infra Red Camera DFS User Requirements,* VIS-SPE-IOA-20000-00001, issue 0.5, 2004-04-08.

1.4 Reference Documents

The following documents are referenced in this document.

[RD1] *VISTA Infra Red Camera Data Reduction Specifications*, VIS-SPE-IOA-20000-00003, issue 0.5, 2004-04-08.
[RD2] *Data Interface Control Document*, GEN-SPE-ESO-19940-794, issue 2.0, 2002-05-21.
[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 2.0, 2004-04.
[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

CDS	Correlated Double Sampling
DAS	Data Acquisition System
DFS	Data Flow System
IMPEX	Import Export (P2PP ASCII files)
HOWFS	High Order Wave-Front Sensor
ICRF	International Coordinate Reference Frame
IWS	Instrument Workstation
FITS	Flexible Image Transport System
LOWFS	Low Order Wave-Front Sensor
OB	Observation Block
OT	Observing Tool

QC-0	Quality Control, level zero
QC-1	Quality Control, level one
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
WFCAM	Wide Field Camera (on UKIRT)
WCS	World Coordinate System
2MASS	2 Micron All Sky Survey

1.6 Glossary

To aid the understanding of the concepts in logical order the glossary is not alphabetical.

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. 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.
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**.
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.
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.
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	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).
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

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 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 DFS receives no data from these CCDs. The CCDs therefore do not impact on the VISTA DFS, 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.

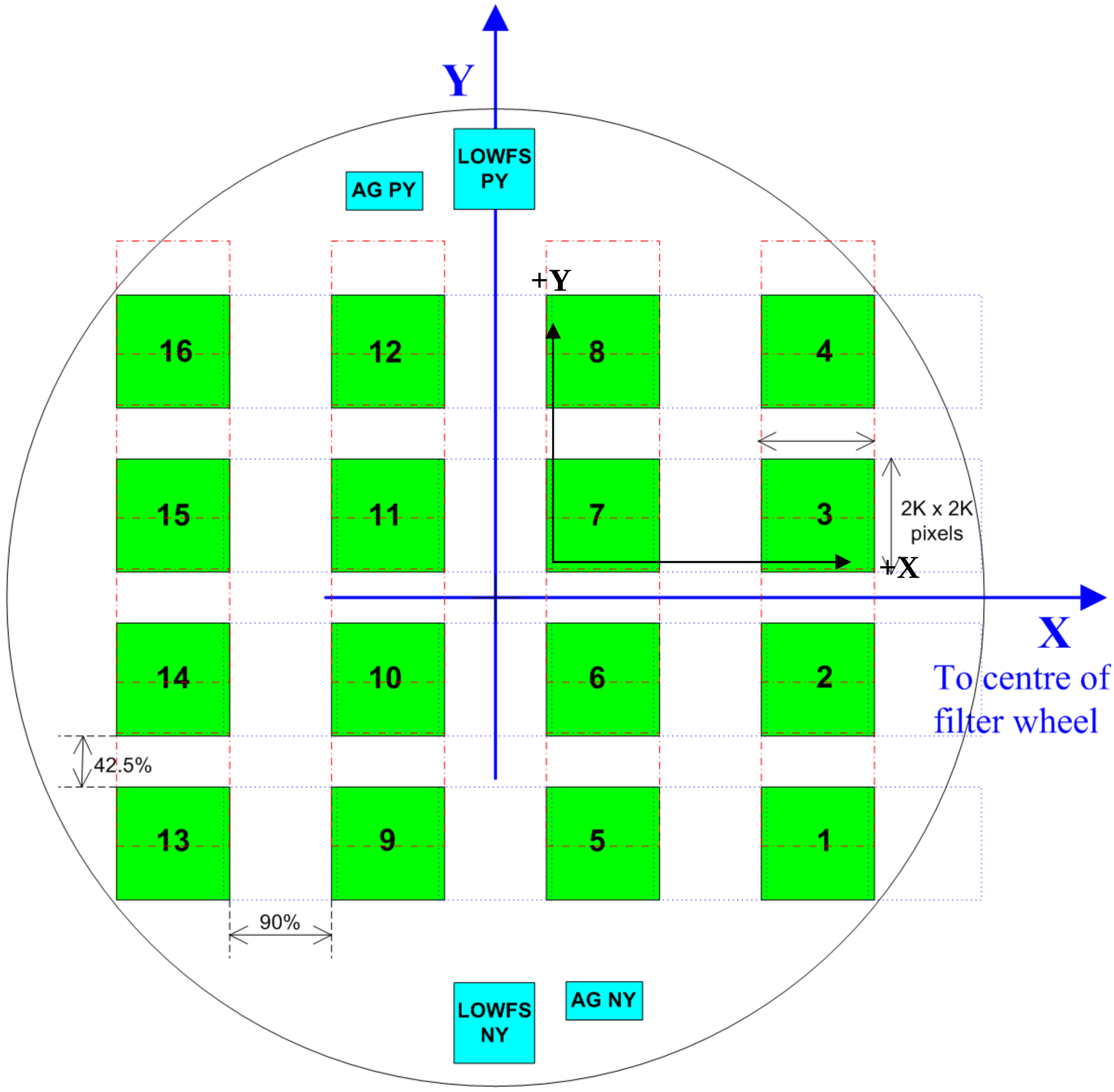

Figure 2-1 VISTA Focal plane: Each of the 4 groups of detectors in the Y direction (e.g. #s 1-4, 5-8, 9-12, 13-16) is read out by a separate IRACE controller.

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.

The VISTA DFS 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 DFS will calibrate the resulting six pawprints individually. The further step of combining these into a contiguous map is left to the science user.

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.

Section 3 defines the observing modes, 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 DFS pipeline will be triggered by the 'arrival' of each exposure, and by the completion of a template (when one might want to operate on many of the exposures gathered during the template). The content of the FITS headers, for example OB identifiers, can allow the DFS pipeline to handle the set of observed files from the OB as an ensemble, and to choose appropriate processing based on the header information.

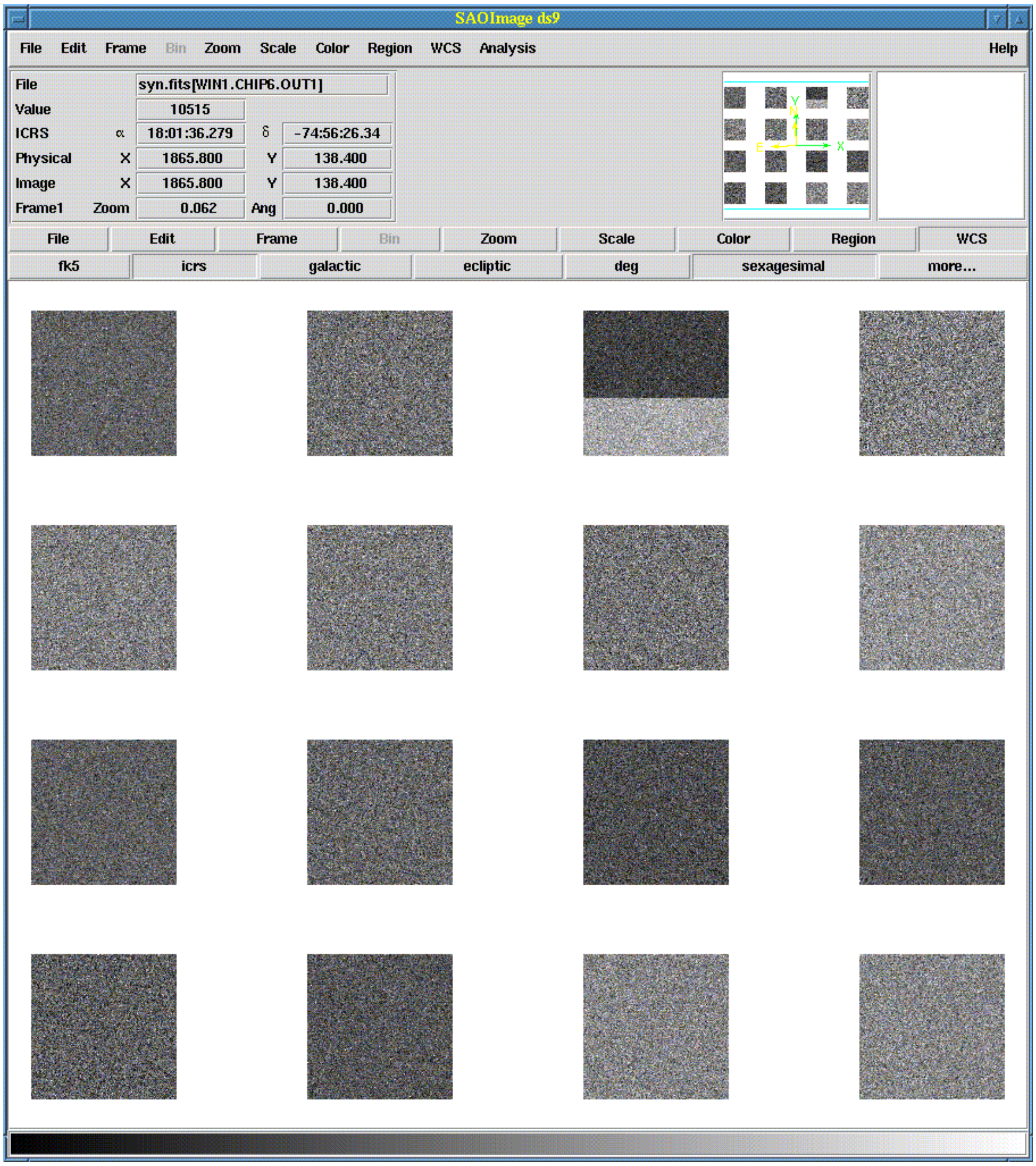

Figure 2-2 Synthesized VISTA Pawprint.

3 Observing Modes

3.1 IMAGING Mode

IMAGING is the only mode in which science data will be acquired.

3.1.1 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 DFS to create a single pawprint, in which the jitters from all detectors are included.

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.

3.1.2 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 Data Quality measures.

3.2 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 is passed to the archive, it is considered as a separate observing mode for VISTA DFS purposes.

3.2.1 Description

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.

3.2.2 Calibrations

The HOWFS uses some of the science mode IR detectors, but has a special beam splitting filter. Thus its flat-field needs to be calibrated separately from the science mode IR detectors.

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 (number of FITS files by FDR)
- **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]. The exact specification of each recipe, and its subcomponents, will appear in later issues of [RD1] as only the list itself is required for PDR
- **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 (time to process the raw output in DFS pipeline will be added by FDR)
- **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 reproduction, 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.

4.2 Reset Frames

Responsible:	Science Operations
Phase:	Daytime
Frequency:	Daily
Purpose:	A Reset frame is a Reset-Read sequence with minimum exposure (1 sec is the minimum VISTA can produce) taken with the cold blank in. 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:	1 s
Prerequisites:	
See Also:	

4.3 Dark Frames

Responsible: Science Operations

Phase: Daytime

Frequency: Daily

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

- the accumulated counts that results from thermal noise (dark counts). 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 counts 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 count correction is consistent. The Dark template will not move 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
Template:	VIRCAM_img_cal_dark.tsf
OT queue:	VIRCAM.Daytime.Calibration
Pipeline Recipe:	vircam_dark_combine
Duration:	One for each integration and exposure setting for the science observations made on the same night
Pipeline Outputs:	Master Dark Dark + reset anomaly stability trend (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 high-accuracy bad pixel mapping. 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.
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 Bad pixel maps Bad pixel statistics (QC)
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 ambient light; nor can they be taken in conditions of excessive ambient light.
See Also:	Dome flat observations are also employed in linearization measurements described in 4.6.

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 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
Prepared OBs:	VIRCAM_img_det_noise.obx
OT queue:	VIRCAM.Daytime.Calibration
Pipeline Recipe:	vircam_detector_noise
Pipeline Outputs:	Readout noise and gain estimate for each sector 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 to generate a look-up table of observed-to-true data values which can be applied to the images in the pipeline. [Linearization within the DAS, which is an alternative, is not included in its 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 Trend of non-linearity function(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 ambient light; nor can they be taken in conditions of 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 read out channels.) Mean flat-fields also are the data source for the initial 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. A new confidence map is formed each time some sort of image combination is done. 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 DFS 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. There will still be a very small

	residual error in gain correction as the twilight sky has a slightly different colour to the night time sky. Dusk and dawn twilight flats will be combined to 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:	Master twilight flats Initial confidence maps Trend in mean gain correction between detectors (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_illumination_analyse, vircam_mesostep_analyse
Pipeline Output: Correction map
Duration: 30 min
Prerequisites:
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: Decay constant
Trend of decay constant and possible adjacency effects (QC)
Duration: 10 min
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 changes to the electrical environment a routine procedure to check it is planned.
Procedure: The 16 detectors are read out in 16 sectors, making a total of 256 sectors in the camera. Cross-Talk calibration consists of placing a saturated star on a sector and measuring any effect on the other

	255 sectors. 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 sectors 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. Trend of off-diagonal components (QC)
Duration:	10 min
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*),

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

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. Therefore, some must be chosen to pass close to the zenith of VISTA (for airmass unity), and such that 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 be not 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.

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

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.

Procedure: Suitable fields from this network will be observed over a range of airmass each night to determine the Zero Points (*ZP*) and to monitor the extinction coefficients (κ) for all broad-band filters.
Outputs: FITS files
Prepared OBs: VIRCAM_standard
OT queue: Science
Pipeline Recipe: vircam_photcal_fit
Pipeline Output: Zero Point (*ZP*)
Zero Point trend (QC)
Extinction coefficient (κ)
Extinction coefficient trend (QC)
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_photcal_apply
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 Flats

Responsible: Science Operations
Phase: Night
Frequency: Throughout night
Purpose: In the situation where the detector flat-field is not stable over the course of a night, we will use night-sky flats. 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 over twilight flats is the identical colour match between the sky observations and the targets, which means that there is no colour variation in the gain correction. 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 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_sky_flat_combine
Pipeline Output: Night sky Flats
Trend with respect to master flat (QC)
Initial confidence map
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.
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_offset_sky_combine
Pipeline Output:	Local sky estimate Fringe 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_pattern.tsf
OT queue:	Science
Pipeline Recipe:	vircam_jitter_combine
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 microstep appropriately in the template, microsteps can be nested within each jitter position.
Raw Outputs: FITS Files
Template: VIRCAM_img_obs_pattern.tsf
OT queue: Science
Pipeline Recipe: vircam_microstep_interleave
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:	vircam_distortion_update
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 (with accuracy better than 2″, dependent on the guide star accuracy, and the determined geometry of the camera) into the FITS headers of each data frame. 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_wcs_fit
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_gen_catalogue
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 VISTA control software for VIRCAM. Therefore, the procedures described in this document are assured that they have been fed data which has passed QC-0.

7.3 Trend Analysis (QC-1)

Effect	Section	Description
Mean reset frame variation	4.2	The current mean reset frame is compared with the most recent library frame. Subtracting one from the other should leave neither significant residuals nor any structure in the residuals map.
Reset anomaly variation	4.3	The current mean dark frame is compared with the most recent library frame that was taken with matching integration and exposure times. The difference of the two should yield neither significant residuals nor any structure in the residuals map.
Dark current trend	4.2	Comparing the current estimate with recent values for the same chip should show any systematic trends in dark current.
Particle Event Rate	4.3	Pixels rejected during the combination of dark frames will give an estimate of the rate of cosmic ray hits for each detector. This can be compared with previous estimates and monitored.
Bad pixel statistics	4.4	The fraction of bad pixels (either hot or cold) should not change significantly with time on a detector.
Detector readout noise and gain	4.5	The noise properties of each detector should remain stable so long as the electronics have not been modified.
Trend in non-linearity	4.6	Although all infrared detectors are non-linear to some degree, the shape and scale of the linearity curve for each detector should remain constant. New linearity curves should show no significant change from other recent estimates unless the electronics of the system have been modified.
Trend in mean gain correction	4.7	The ratio of median counts in a mean flat exposure for a given detector relative to that for another detector specifies the mean gain correction between those two detectors. The mean gain corrections for the ensemble should be very stable with time.
Trend in persistence decay time and adjacency effects	4.9	The image persistence decay constant for each detector should be monitored.
Trend in cross-talk matrix	4.10	Values in the cross-talk matrix should be very

Effect	Section	Description
Mean reset frame variation	4.2	The current mean reset frame is compared with the most recent library frame. Subtracting one from the other should leave neither significant residuals nor any structure in the residuals map.
values		stable with time, not withstanding an update of the driving electronics.
Variation in photometric zero point and extinction coefficient.	5.2	The photometric zeropoint will probably vary over time as a result of the cleaning of optical surfaces. Extinction will vary over a night, but wildly varying extinction coefficients are an indication of bad photometric conditions.
Depth of exposure	5.2	This can be compared with a target input value to see if the image has been exposed for long enough.
Variation of master flats	6.1.1	Dividing the current flat-field by a recent library flat-field for the same filter should leave neither significant residuals nor large scale variations.
Pointing accuracy	6.2.2	The equatorial coordinates of a location in the focal plane computed from the fitted WCS and computed from the raw file WCS should agree to < 2 arcseconds.
Trend in mean sky and sky noise	7.1.1	These will vary over the night, but should do so smoothly. If this is not the case, then we are observing in non-photometric conditions. A strange value here may also indicate a serious electronic fault.
Number of noise objects	7.1.1	The number of noise objects from frame to frame should be reasonably constant.
Mean seeing	7.1.1	The seeing will obviously vary over the night with time and wavelength (filter). This variation should be smooth. Wild variation could be an indication of non-photometric seeing.
Mean stellar ellipticity	7.1.1	Mean stellar ellipticity can be affected by failures in the tracking and autoguiding.

8 Templates

8.1 Calibration Templates

8.1.1 IMAGING mode exposures

8.1.1.1 Reset

Name: Reset
Identifier: VIRCAM_img_cal_reset.tsf
Description: Make Reset frame (reset-read only) with cold blank,
Parameters: number of reset frames
Raw Frames: FITS
Pipeline recipes: vircam_reset_combine

8.1.1.2 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

8.1.1.3 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
Raw Frames: Sequence of FITS files
Pipeline recipes: vircam_dark_combine

8.1.1.4 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.
Parameters: Filter, illumination combination
Raw Frames: None
Pipeline recipes: None

8.1.1.5 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.
Parameters:	Filter, list of integration times and corresponding numbers of integrations
Raw Frames:	FITS files
Pipeline recipes:	vircam_dome_flat_combine

8.1.1.6 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

8.1.1.7 Acquire Twilight Field

Name:	Twilight
Identifier:	VIRCAM_img_acq_twilight.tsf
Description:	Select a dusk or dawn twilight field. Track (no autoguiding). Includes procedure to wait until sky brightness is appropriate.
Parameters:	Azimuth, Altitude, filter
Raw Frames:	None
Pipeline recipes:	None

8.1.1.8 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. Must give exposure time before repeating.
Raw Frames:	FITS files
Pipeline recipes:	vircam_twilight_combine

8.1.1.9 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.

8.1.1.10 Photometric Calibration Standard Fields

All of the science modes 8.2.1.1 to 8.2.1.3 below may also be used to observe photometric standard fields for calibration.

8.1.2 HOWFS mode exposures

Below IWS refers to the Instrument Workstation on which HOWFS processing is done.

8.1.2.1 HOWFS Dome Screen

Name:	HOWFS 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

8.1.2.2 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
Raw Frames:	FITS
IWS Procedures:	Yes
Pipeline recipes:	None

8.2 Science Templates

8.2.1 IMAGING mode exposures

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.

8.2.1.1 Observe single Pawprint

8.2.1.1.1 Acquire

Name: **Acquire**

Identifier: VIRCAM_img_acq_paw.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.

i.e. nest
Preset to tile ‘centre’ position
Check/Set IMAGING mode in parallel
Check/Set camera PA in parallel [default +X axis to +RA]
Check/Set first filter in parallel
For first pawprint
    Check/Offset telescope to pawprint position
    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 P2PP, LOWFS required flag, if set (default) 1 pair LOWFS stars found by P2PP.
Raw Frames: None
Pipeline recipes: None

8.2.1.1.2 Observe_ (FJM)

Name: Observe_(FJM)
Identifier: VIRCAM_img_obs_paw_fjm.tsf
Description: The camera is already in IMAGING mode, position angle is set, first filter position is set, pointing at a target pawprint with autoguider and LOWFS on or off, (having been put in this state by the **Acquire** template).

For each filter specified make a series of exposures at the positions specified by the patterns of jitter and microstep exposures, without changing guide star. The order of positions is determined to optimize speed.

i.e. nest **FJME**
For each demanded filter position (1 to F)
    Check/set demanded filter in
    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 filter

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_microstep_interleave
vircam_jitter_combine

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

8.2.1.2 Observe set of Pawprints (e.g. to fill a tile)

8.2.1.2.1 Acquire Tile

Name: Acquire tile

Identifier: VIRCAM_img_acq_tile.tsf

Description: Acquire pawprint positions and parameters for a tile. The pattern of pawprint offsets is designed to fill in the gaps between the detectors to make an (almost) evenly sampled contiguous sky image – a tile.

Check/Set camera to IMAGING mode, check/set camera position angle, check/select first science filter, obtain parameters specifying offsets required for a tiled exposure pattern, all in parallel with a preset of telescope to the "central null target" (defined to be the centre of the tile that will result), optionally (and usually) guide, optionally (and usually) activate LOWFS.

This is similar to the **Acquire Target** template, but in addition obtains all the offsets (default 6) for the pawprints of the tile, and all the associated guide stars, and the jitter and microsteps at each pawprint position.

Parameters: Coordinates of central null target, camera position angle (E of N on sky, defaults to give +X to +RA), filter list, tile ID (defaults to 2x3 giving offsets of 2 X steps of 95% detector width, 3 Y steps of 47.5% detector height), autoguiding required flag if set (default) list of guide stars found by P2PP (defaults to 6); LOWFS required flag, if set (default) list of LOWFS star pairs found by P2PP (defaults to 6 pairs).

Keyword to show which of the **Observe_( )** procedures is required. The selected Observe template parameters, LOWFS required flags, optional non-sidereal drift parameters.

Raw Frames: None

Pipeline recipes: None

8.2.1.2.2 Observe_(PJM)

Name: Observe_(PJM)

Identifier: VIRCAM_img_obs_tile_pjm.tsf

Description: A template which cycles through all the pawprints of a tile (or set of offsets) to complete the tile (or set of offsets), with required jitters and microsteps at a fixed filter position.

The camera is already in IMAGING mode, position angle is set, and filter position is set, pointing at first target pawprint with autoguider and LOWFS on or off, (having been put in this state by the **Acquire Tile** or **Acquire Offsets** template).

Make a series of exposures at the positions specified by the pawprint positions and patterns of jitter and microstep exposures. The order of positions is determined to optimize speed.

i.e. nest **PJME**

```
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
```

Parameters: Are passed from VIRCAM_img_acq_tile.tsf or from VIRCAM_img_acq_offsets.tsf: Tile-pattern ID defining number

	and location of the pawprints [defaults to 6 locations], or list of offsets.
	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_microstep_interleave vircam_microstep_calibrate vircam_jitter_combine vircam_jitter_calibrate
Note	The pipeline handles microstepped and jittered exposures in a different way.

8.2.1.2.3 Observe_(JPM)

Name:	Observe_(JPM)
Identifier:	VIRCAM_img_obs_tile_jpm.tsf

Description:	At a fixed filter position, this template cycles through all the jitter positions (relative to the pawprint positions of a tile - or set of offsets), to complete the tile (or offsets), with required pawprints and microsteps e.g. at (0,0) jitter position observe all 6 pawprints, followed by at (10,10) jitter positions observe all 6 pawprints, etc. etc. This template has its jitter loop outside the pawprint loop, and is potentially useful if it is very important to minimize the variation of the final co-added point-spread function across the entire tile. However it increases the overheads by ~4 seconds per exposure due to the larger offsets and associated change of guide star with each offset.
	
	The camera is already in IMAGING mode, position angle is set, filter position is set, pointing at first target jitter position relative to pawprint position with autoguider and LOWFS on or off, (having been put in this state by the **Acquire Tile** or **Acquire Offsets** template).
	
	Make a series of exposures at the positions specified by the jitter positions, pawprint pattern and pattern of microstep exposures.
	
	i.e. nest **JPME**
	For each jitter position relative to each pawprint (1 to J)
	    For each pawprint position (1 to P)
	        Check/offset telescope (steps 5-10′) to tile ‘centre’+ pawprint
	            offset+ jitter position

Acquire guide and LOWFS stars
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 pawprint
Next jitter

Parameters: Are passed from either VIRCAM_img_acq_tile.tsf or from VIRCAM_img_acq_tile.tsf : Tile-pattern ID defining number and location of the pawprints [defaults to 6 locations], or list of offsets;
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_microstep_interleave
vircam_microstep_calibrate
vircam_jitter_combine
vircam_jitter_calibrate

Note: The pipeline handles microstepped and jittered exposures in a different way.

8.2.1.2.4 Observe Tile

Name: **Observe Tile**

Identifier: VIRCAM_img_obs_tile.tsf

Description: Carry out the pattern of pawprint offsets to fill in the gaps between the detectors to make an (almost) evenly sampled contiguous sky image – a tile.

The camera is already in IMAGING mode, position angle is set, first filter position is set, pointing at first target pawprint with autoguider and LOWFS on or off, (having been put in this state by the **Acquire Tile** template).

Go to a series of pawprints at the offset pattern previously specified using the **Acquire Tile** template, changing guide star. At each pawprint execute, depending on a keyword, either the **Observe_(FJM)** procedure, or the **Observe_(PJM)** procedure.

Or execute **Observe_(JPM)** procedure. The parameters of the selected **Observe_( )** procedure must have been previously specified using the **Acquire Tile** template.

For each pawprint (steps 5-10′) (1 to P)
  Check/Offset telescope to pawprint central position
  Acquire guide star
  LOWFS on two stars in parallel
    either Observe_(FJM)
    or Observe_(PJM)
Next pawprint

Or **Observe_(JPM)**

Parameters: Are passed from VIRCAM_img_acq_tile.tsf: Tile-pattern ID defining number and locations of the pawprints [defaults to 6 locations];
keyword to show which **Observe_( )** procedure is required; all the parameters accepted by the **Observe_( )** templates.

Raw Frames: (Number of pawprint locations [6] x number of exposure in each pawprint) FITS files

Pipeline recipes: as for pawprints as tile is not formed by pipeline

Note: Pipeline produces pawprints, these are not tiled together.

8.2.1.2.5 Acquire Offsets

Name: Acquire offsets

Identifier: VIRCAM_img_acq_offsets.tsf

Description: Acquire pawprint positions and parameters for any set of offset exposures. This is similar to the **Acquire Tile** template, but instead of acquiring the offsets from a selection of specific tile IDs they are provided explicitly to the template. This template is to allow versatility and can be used to produce offset patterns not contained within the set of Tile IDs, and to produce an arbitrary pattern.

Check/Set camera to IMAGING mode, check/set camera position angle, check/select first science filter, obtain parameters specifying offsets required for an offset exposure pattern, all in parallel with a preset of telescope to the "central null target" (defined to be the centre of the region that will result), optionally (and usually) guide, optionally (and usually) activate LOWFS.

Parameters: Coordinates of first target, camera position angle (E of N on sky, defaults to give +X to +RA), filter list, number of offsets P (defaults to 1), list of offset steps, autoguiding required flag (default set), if flag set list of guide stars (1 per offset position) found by P2PP, LOWFS required flag (default set), if set list of

LOWFS star pairs (1 pair per position found by P2PP); keyword to show which **Observe_( )** procedure is required; the selected Observe template parameters, LOWFS required flags, optional non-sidereal drift parameters.

Raw Frames: None

Pipeline recipes: None

8.2.1.2.6 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.

Carry out the pattern of pawprint offsets to fill in the gaps between the detectors to make an (almost) evenly sampled contiguous sky image, i.e. a tile.

The camera is already in IMAGING mode, position angle is set, first filter position is set, pointing at first target pawprint with autoguider and LOWFS on or off, (having been put in this state by the **Acquire Offsets** template). The list of offsets must have been defined in the **Acquire Offsets** template.

Go to a series of pawprints at the P offsets previously specified using the **Acquire Offsets** template, changing guide star. At each pawprint execute, depending on a keyword, either the **Observe_(FJM)** procedure, or the **Observe_(PJM)** procedure. Or execute **Observe_(JPM)** procedure. The parameters of the selected **Observe_( )** procedure must have been previously specified using the **Acquire Offsets** template.

For each offset pawprint (unknown steps) (1 to P)
  Check/Offset telescope to pawprint central position
  Acquire guide star
  LOWFS on two stars in parallel
    either Observe_(FJM)
    or Observe_(PJM)
Next pawprint

Or **Observe_(JPM)**

Parameters: Are passed from VIRCAM_img_acq_offsets.tsf: Number of offset locations and associated data; keyword to show which **Observe_( )** procedure is required; all the parameters accepted by the **Observe_( )** templates.

Raw Frames:	(Number of pawprint locations x number of exposure in each pawprint) FITS files
Pipeline recipes:	as for pawprints
Note	Pipeline produces pawprints, these are not merged.

8.2.1.3 Observe set of Tiles

Three templates (FTPJME, TFPJME and TPFJME) that observe more than one tile were outlined in the URD [AD2]. However as explained there, no templates that observe multiple tiles have been defined for PDR. This is because the pipeline concentrates on individual tiles. The FTPJME nesting can nevertheless be achieved with multiple copies of the Observe Tile template within an OB – each specifying a different, single filter.

8.2.2 HOWFS mode exposures

Below IWS refers to the Instrument Workstation on which HOWFS processing is done.

8.2.2.1 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:	Target Coordinates, detector window, optionally guide and 2 LOWFS coordinates.
Raw frames:	None
IWS Procedures:	None
Pipeline recipes:	None

8.2.2.2 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:	Filter, detector window, integration time, number of integrations
Raw Frames:	FITS
IWS Procedures:	Trigger HOWFS analysis system, forward coefficient residuals to TCS
Pipeline recipes:	None

8.2.2.3 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:	Filter, detector window, integration time, number of integrations
Raw Frames:	FITS
IWS Procedures:	Trigger HOWFS analysis system, produce look up table.
Pipeline recipes:	None

8.3 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 regularity 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 DFS 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.

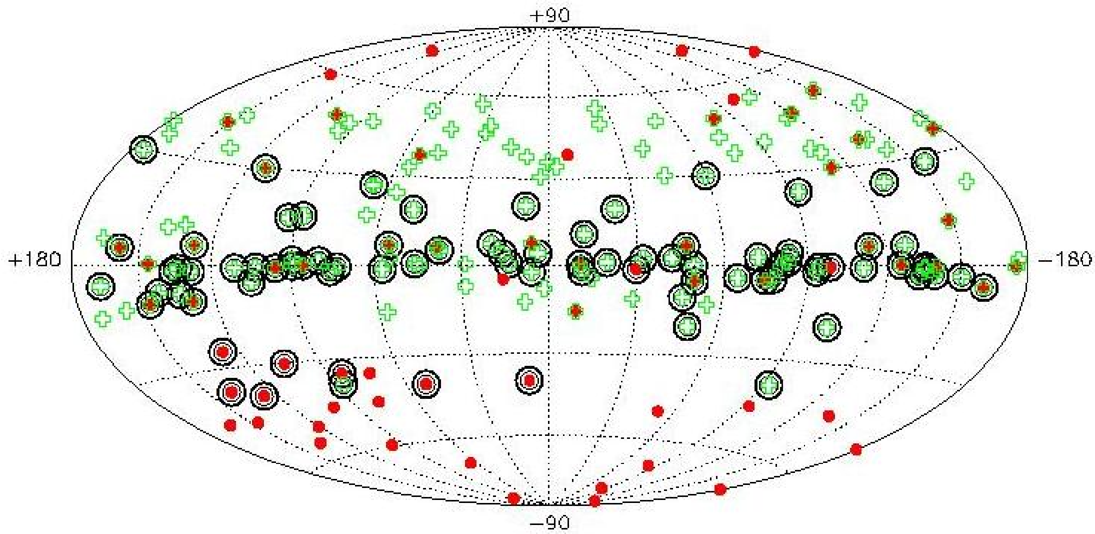

Figure 9-1 VISTA/WFCAM Standard Fields

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. Table10-1 will be superseded by the formal issue of the VISTA DFS Data Interface Dictionary ([RD13] is in effect a preliminary version of this).

```
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    = '2004-03-29T13:37:57.000' / 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= 'P Bunclark'         / 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'         / CASU Data-reduction recipe
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
NDITHER =                    6 / Number of positions in a tel dither pattern
DITHRNUM=                 1236 / Value of first OBSNUM in current dither sequenc
DITHER_I=                    3 / Serial number of this tel dither pattern
DITHER_X=                3.330 / X offset in dither pattern
DITHER_Y=                0.000 / Y offset in dither 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 INS FILT1 ID       = 'J       '   / Filter identification device co
HIERARCH ESO INS FILT NAME1     = 'VIS#J/04_ESO843' / Filter Name
HIERARCH ESO INS FILT1 NO       =            2 / Filter wheel slot number
HIERARCH ESO INS FILT1 ENC      =         1234 / Filter wheel encoder position
HIERARCH ESO INS PRES1 ID       = 'P1      '   / ID of pressure sensor 1
HIERARCH ESO INS PRES1 NAME     = 'Cryostat'   / Location of pressure sensor 1
HIERARCH ESO INS PRES1 VAL      = 1.000000E-04 / Pressure sensor 1 reading
HIERARCH ESO INS PRES2 NAME     = 'Ambient '   / Location of pressure sensor 2
HIERARCH ESO INS PRES2 VAL      = 1.000100E+00 / Pressure sensor 2 reading
HIERARCH ESO INS PRES2 ID       = 'P2      '   / ID of pressure sensor 2
HIERARCH ESO INS FILT INPOS     =            T / filter in-position switch state
HIERARCH ESO INS FILT TIME      = '2006-03-05T16:17:18.123' / Last filt wheel in
HIERARCH ESO INS FILT ERROR     =           -6 / Last fil wheel index error
HIERARCH ESO INS TEMP29 TARGET  =       160.00 / Sensor 29 target
HIERARCH ESO INS TEMP30 TARGET  =       160.00 / Sensor 2 target
HIERARCH ESO INS TEMP1 ID       = 'ID1     '   / ID of sensor 1
HIERARCH ESO INS TEMP1 NAME     = 'Cryostat window cell ' / Location of sensor 1
HIERARCH ESO INS TEMP1 VAL      =       260.10 / Temperature sensor 1 reading
HIERARCH ESO INS TEMP2 ID       = 'ID2     '   / ID of sensor 2
HIERARCH ESO INS TEMP2 NAME     = 'Ambient air temperature ' / Location of senso
HIERARCH ESO INS TEMP2 VAL      =       260.10 / Temperature sensor 2 reading
HIERARCH ESO INS TEMP3 ID       = 'ID3     '   / ID of sensor 3
HIERARCH ESO INS TEMP3 NAME     = 'Baffle 7 '  / Location of sensor 3
HIERARCH ESO INS TEMP3 VAL      =       260.10 / Temperature sensor 3 reading
HIERARCH ESO INS TEMP4 ID       = 'ID4     '   / ID of sensor 4
HIERARCH ESO INS TEMP4 NAME     = 'Lens Barrel ' / Location of sensor 4
HIERARCH ESO INS TEMP4 VAL      =       260.10 / Temperature sensor 4 reading
HIERARCH ESO INS TEMP5 ID       = 'ID5     '   / ID of sensor 5
HIERARCH ESO INS TEMP5 NAME     = 'Liquid Nitrogen Tank ' / Location of sensor 5
HIERARCH ESO INS TEMP5 VAL      =       260.10 / Temperature sensor 5 reading
HIERARCH ESO INS TEMP6 ID       = 'ID6     '   / ID of sensor 6
HIERARCH ESO INS TEMP6 NAME     = 'Cold head 1 1st stage ' / Location of sensor
HIERARCH ESO INS TEMP6 VAL      =       260.10 / Temperature sensor 6 reading
HIERARCH ESO INS TEMP7 ID       = 'ID7     '   / ID of sensor 7
HIERARCH ESO INS TEMP7 NAME     = 'Cold head 1 2st stage ' / Location of sensor
HIERARCH ESO INS TEMP7 VAL      =       260.10 / Temperature sensor 7 reading
HIERARCH ESO INS TEMP8 ID       = 'ID8     '   / ID of sensor 8
HIERARCH ESO INS TEMP8 NAME     = 'Cold head 2 1st stage ' / Location of sensor
HIERARCH ESO INS TEMP8 VAL      =       260.10 / Temperature sensor 8 reading
HIERARCH ESO INS TEMP9 ID       = 'ID9     '   / ID of sensor 9
HIERARCH ESO INS TEMP9 NAME     = 'Cold head 2 2st stage ' / Location of sensor
HIERARCH ESO INS TEMP9 VAL      =       260.10 / Temperature sensor 9 reading
HIERARCH ESO INS TEMP10 ID      = 'ID10    '   / ID of sensor 10
HIERARCH ESO INS TEMP10 NAME    = 'Cold head 3 1st stage ' / Location of sensor
HIERARCH ESO INS TEMP10 VAL     =       260.10 / Temperature sensor 10 reading
HIERARCH ESO INS TEMP11 ID      = 'ID11    '   / ID of sensor 11
HIERARCH ESO INS TEMP11 NAME    = 'Cold head 3 2st stage ' / Location of sensor
HIERARCH ESO INS TEMP11 VAL     =       260.10 / Temperature sensor 11 reading
HIERARCH ESO INS TEMP12 ID      = 'ID12    '   / ID of sensor 12
HIERARCH ESO INS TEMP12 NAME    = 'Cryopump 1 ' / Location of sensor 12
```

```
HIERARCH ESO INS TEMP12 VAL     =       260.10 / Temperature sensor 12 reading
HIERARCH ESO INS TEMP13 ID      = 'ID13    '   / ID of sensor 13
HIERARCH ESO INS TEMP13 NAME    = 'Cryopump 2 ' / Location of sensor 13
HIERARCH ESO INS TEMP13 VAL     =       260.10 / Temperature sensor 13 reading
HIERARCH ESO INS TEMP14 ID      = 'ID14    '   / ID of sensor 14
HIERARCH ESO INS TEMP14 NAME    = 'WFS Plate ' / Location of sensor 14
HIERARCH ESO INS TEMP14 VAL     =       260.10 / Temperature sensor 14 reading
HIERARCH ESO INS TEMP15 ID      = 'ID15    '   / ID of sensor 15
HIERARCH ESO INS TEMP15 NAME    = 'WFS CCD 1 ' / Location of sensor 15
HIERARCH ESO INS TEMP15 VAL     =       260.10 / Temperature sensor 15 reading
HIERARCH ESO INS TEMP16 ID      = 'ID16    '   / ID of sensor 16
HIERARCH ESO INS TEMP16 NAME    = 'WFS CCD 2 ' / Location of sensor 16
HIERARCH ESO INS TEMP16 VAL     =       260.10 / Temperature sensor 16 reading
HIERARCH ESO INS TEMP17 ID      = 'ID17    '   / ID of sensor 17
HIERARCH ESO INS TEMP17 NAME    = 'WFS CCD 3 ' / Location of sensor 17
HIERARCH ESO INS TEMP17 VAL     =       260.10 / Temperature sensor 17 reading
HIERARCH ESO INS TEMP18 ID      = 'ID18    '   / ID of sensor 18
HIERARCH ESO INS TEMP18 NAME    = 'WFS CCD 4 ' / Location of sensor 18
HIERARCH ESO INS TEMP18 VAL     =       260.10 / Temperature sensor 18 reading
HIERARCH ESO INS TEMP19 ID      = 'ID19    '   / ID of sensor 19
HIERARCH ESO INS TEMP19 NAME    = 'Filter wheel shield ' / Location of sensor 19
HIERARCH ESO INS TEMP19 VAL     =       260.10 / Temperature sensor 19 reading
HIERARCH ESO INS TEMP20 ID      = 'ID20    '   / ID of sensor 20
HIERARCH ESO INS TEMP20 NAME    = 'Filter wheel hub ' / Location of sensor 20
HIERARCH ESO INS TEMP20 VAL     =       260.10 / Temperature sensor 20 reading
HIERARCH ESO INS TEMP21 ID      = 'ID21    '   / ID of sensor 21
HIERARCH ESO INS TEMP21 NAME    = 'Science detector 1 ' / Location of sensor 21
HIERARCH ESO INS TEMP21 VAL     =       260.10 / Temperature sensor 21 reading
HIERARCH ESO INS TEMP22 ID      = 'ID22    '   / ID of sensor 22
HIERARCH ESO INS TEMP22 NAME    = 'Science detector 2 ' / Location of sensor 22
HIERARCH ESO INS TEMP22 VAL     =       260.10 / Temperature sensor 22 reading
HIERARCH ESO INS TEMP23 ID      = 'ID23    '   / ID of sensor 23
HIERARCH ESO INS TEMP23 NAME    = 'Science detector 3 ' / Location of sensor 23
HIERARCH ESO INS TEMP23 VAL     =       260.10 / Temperature sensor 23 reading
HIERARCH ESO INS TEMP24 ID      = 'ID24    '   / ID of sensor 24
HIERARCH ESO INS TEMP24 NAME    = 'Science detector 4 ' / Location of sensor 24
HIERARCH ESO INS TEMP24 VAL     =       260.10 / Temperature sensor 24 reading
HIERARCH ESO INS TEMP25 ID      = 'ID25    '   / ID of sensor 25
HIERARCH ESO INS TEMP25 NAME    = 'Science detector 5 ' / Location of sensor 25
HIERARCH ESO INS TEMP25 VAL     =       260.10 / Temperature sensor 25 reading
HIERARCH ESO INS TEMP26 ID      = 'ID26    '   / ID of sensor 26
HIERARCH ESO INS TEMP26 NAME    = 'Science detector 6 ' / Location of sensor 26
HIERARCH ESO INS TEMP26 VAL     =       260.10 / Temperature sensor 26 reading
HIERARCH ESO INS TEMP27 ID      = 'ID27    '   / ID of sensor 27
HIERARCH ESO INS TEMP27 NAME    = 'Science detector 7 ' / Location of sensor 27
HIERARCH ESO INS TEMP27 VAL     =       260.10 / Temperature sensor 27 reading
HIERARCH ESO INS TEMP28 ID      = 'ID28    '   / ID of sensor 28
HIERARCH ESO INS TEMP28 NAME    = 'Science detector 8 ' / Location of sensor 28
HIERARCH ESO INS TEMP28 VAL     =       260.10 / Temperature sensor 28 reading
HIERARCH ESO INS TEMP29 ID      = 'ID29    '   / ID of sensor 29
HIERARCH ESO INS TEMP29 NAME    = 'FPA thermal plate (actual) ' / Location of se
HIERARCH ESO INS TEMP29 VAL     =       260.10 / Temperature sensor 29 reading
HIERARCH ESO INS TEMP30 ID      = 'ID30    '   / ID of sensor 30
HIERARCH ESO INS TEMP30 NAME    = 'Cryostat tube outside (actual) ' / Location o
HIERARCH ESO INS TEMP30 VAL     =       260.10 / Temperature sensor 30 reading
HIERARCH ESO INS TEMP31 ID      = 'ID31    '   / ID of sensor 31
HIERARCH ESO INS TEMP31 NAME    = 'undecided temperature sensor ' / Location of
HIERARCH ESO INS TEMP31 VAL     =       260.10 / Temperature sensor 31 reading
HIERARCH ESO INS TEMP32 ID      = 'ID32    '   / ID of sensor 32
HIERARCH ESO INS TEMP32 NAME    = 'undecided temperature sensor ' / Location of
HIERARCH ESO INS TEMP32 VAL     =       260.10 / Temperature sensor 32 reading
HIERARCH ESO INS HOWFS DATE     = '2006-03-05T01:02:03.123' / Time of new coefs
HIERARCH ESO OBS DID         = 'ESO-VLT-DIC.OBS' / OBS Dictionary
HIERARCH ESO OBS ID          =              666 / Observation block ID
HIERARCH ESO OBS NAME        = 'DITHER                      ' / 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_Dither.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_Dither                          '
HIERARCH ESO TPL NAME        = 'VIRCAM Dithered mode sequence                  '
HIERARCH ESO TPL NEXP        =                  6 / Number of exposures within tem
HIERARCH ESO TPL EXPNO       =                  2 / Exposure number within templat
HIERARCH ESO TPL VERSION     = '@(#) $Revision: 1.5 $' / Version of the template
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 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 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 TEL ENCL MOONSCR STEP=            1 / Moonscreen positions step
HIERARCH ESO TEL ENCL WINDSCR1 STATE= 'OPEN     ' / Louvre state
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
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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
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      =        1.2345678 / Minimum DIT
HIERARCH ESO DET MODE NAME   = 'UNKNOWN '      / DCS Detector Mode
HIERARCH ESO DET MODEi NAME  = 'UNKNOWN '      / DCS Detector Mode
HIERARCH ESO DET NC IDIV     =                0 / # of Sub-Divs for R-O
HIERARCH ESO DET NC NSAMPPIX =                0 / # of Samples/Pixel
HIERARCH ESO DET NCORRS      =                0 / Read-Out Mode
HIERARCH ESO DET RSPEED      =                0 / Read-Speed Factor
HIERARCH ESO DET IRACE ADCi NAME= 'UNKNOWN '   / Name for ADC Board
HIERARCH ESO DET IRACE ADCi HEADER=                0 / Header of ADC Board
HIERARCH ESO DET IRACE ADCi ENABLE=                0 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADCi FILTERi=                0 / ADC Filter Adjustment
HIERARCH ESO DET IRACE ADCi DELAY=                0 / ADC Delay Adjustment
HIERARCH ESO DET NCORRS NAME = 'UNKNOWN '      / Read-Out Mode Name
HIERARCH ESO DET NDIT        =                0 / # 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= 'UNKNOWN '    / Name of High Clock
HIERARCH ESO DET VOLTi CLKHITi=           1.2346 / Tel Value High Clock
HIERARCH ESO DET VOLTi CLKHIi=           1.2346 / Set Value High Clock
HIERARCH ESO DET VOLTi CLKLONMi= 'UNKNOWN '    / Name of Low Clock
HIERARCH ESO DET IRACE SEQCONT=          UNKNOWN / Sequencer Cont. Mode
HIERARCH ESO DET IRACE SEQINT=          UNKNOWN / Sequencer Intr. at Stop
HIERARCH ESO DET VOLTi CLKLOTi=           1.2346 / Tel Value Low Clock
HIERARCH ESO DET VOLTi DCNMi = 'UNKNOWN '      / Name of DC Voltage
HIERARCH ESO DET VOLTi DCTAi =           1.2346 / Tel Value 1 for DC
HIERARCH ESO DET VOLTi CLKLOi=           1.2346 / Set Value Low Clock
HIERARCH ESO DET VOLTi DCi   =           1.2346 / Set Value DC Voltage
HIERARCH ESO DET CHIP TYPE   = 'UNKNOWN '      / The Type of Det Chip
HIERARCH ESO DET CON OPMODE  = 'UNKNOWN '      / Operational Mode
HIERARCH ESO DET FRAM TYPE   = 'UNKNOWN '      / Frame type
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     =          UNKNOWN / Chopping On/Off
HIERARCH ESO DET CHOP FREQ   = 0.000000        / Chopping Frequency
HIERARCH ESO DET CHIP ID     = 'UNKNOWN '      / Detector ID
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HIERARCH ESO DET CHIP NAME   = 'UNKNOWN '       / Detector name
HIERARCH ESO DET CHIP NX     =                0 / Pixels in X
HIERARCH ESO DET CHIP NY     =                0 / Pixels in Y
HIERARCH ESO DET CHIP PXSPACE= 0.000e+00        / Pixel-Pixel Spacing
HIERARCH ESO DET EXP NO      =                0 / Exposure Number
HIERARCH ESO DET FRAM UTC    = 'UNKNOWN '       / Time Recv Frame
HIERARCH ESO DET FRAM NO     =                0 / Frame number
HIERARCH ESO DET VOLTi DCTBi =           1.2346 / Tel Value 2 for DC
HIERARCH ESO DET WIN NX      =                0 / # of Pixels in X
HIERARCH ESO DET DID         = 'UNKNOWN '       / Dictionary Name and Revision
HIERARCH ESO DET DIT         =        1.2345678 / Integration Time
HIERARCH ESO DET DITDELAY    =            1.235 / Pause Between DITs
HIERARCH ESO DET EXP UTC     = 'UNKNOWN '       / File Creation Time
HIERARCH ESO DET EXP NAME    = 'UNKNOWN '       / Exposure Name
HIERARCH ESO DET WIN NY      =                0 / # of Pixels in Y
HIERARCH ESO DET WIN STARTX  = 0.000000         / Lower Left X Ref
HIERARCH ESO DET WIN STARTY  = 0.000000         / 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

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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