

## Data Flow System

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## Change Record

Issue	Date	Sections Affected	Reason/Initiation/Documents/Remarks
1.0	2004-12-17	All	New Document
1.1	2005-05-03	All	post-FDR revision
1.2	2005-08-12	4	post DICB comments
1.3	2005-12-25	All	Consistency with DRL v0.1, JRL, MJJ, PSB updates
1.4	2006-06-15	All	Many changes to all sections to help bring the document into line with DRL 0.3
1.5	2006-09-28	0,5,6,7	Explanations of dummy products expanded. Expanded list of fatal and non-fatal errors for recipes. Many other smaller changes
1.6	2006-12-20	2,6,8	Added vircam_destripe + description Added parameters to jitter_microstep_process. Many other smaller changes, including touch-ups to table 10-1 update QC & DRS dictionaries Update vircam_standard_process, modify vircam_jitter_microstep_process, and modify entries in table 10-1. Modified vircam_illum entry in chapter 6. Modified vircam_mesostep_analyse and vircam_defringe Spell check and added QC STRIPERMS
1.7	2007-03-13	all	Changes throughout to meet requirements of v0.5 DRL release and all ESO feedback to 2007-03-01 arising from v0.4
1.8	2007-06-05	All	Undated all references to dfs tags. Expanded descriptions of test recipes to include output data. Put back some earlier lost detail changes. Added values of hard coded output file names and pafs as well as brief description in intro. Fixed a few typos spotted by SC. Added DRS EXTINGT to vircam_photcal outputs. Added vircam_gaincor and lots of references to it. New versions of jmp type routine figures to include gaincor. Update DRS dictionary (& spellcheck)

## Notification List

The following people should be notified by email that a new issue of this document is available.

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## 1 Introduction

This document forms part of the package of documents for the design of the Data Flow System for VISTA, the Visible and Infra-Red Survey Telescope for Astronomy.

### 1.1 Scope

This document describes the VISTA Infra-Red Camera Data Reduction Library Design for the output from the 16 Raytheon VIRGO IR detectors in the Infra Red-Camera for VISTA (VIRCAM). The baseline requirements for calibration are included in the VISTA Infra-Red Camera Data Flow System User Requirements [AD2], and the Calibration Plan is described in [AD3].

### 1.2 Applicable Documents

- [AD1] *Data Flow for the VLT/VLTI Instruments Deliverables Specification*, VLT-SPE-ESO-19000-1618, issue 2.0, 2004-05-22.
- [AD2] *VISTA Infra Red Camera DFS Impact*, VIS-SPE-IOA-20000-00001, issue 1.3, 2005-12-25.
- [AD3] *VISTA Infra Red Camera DFS Calibration Plan*, VIS-SPE-IOA-20000-00002, issue 1.3, 2005-12-25.
- [AD4] *VISTA Infra Red Camera DFS Data Reduction Library Specification*, VIS-SPE-IOA-20000-00003, issue 1.0, 2005-02-08.
- [AD5] *Data Interface Control Document*, GEN-SPE-ESO-19940-0794, issue 3, 2005-02-01.
- [AD6] *Common Pipeline Library User Manual*, VLT-MAN-ESO-19500-2720, issue 2.0.1, 2005-04-14
- [AD7] *Common Pipeline Library Reference Manual*, VLT-MAN-ESO-19500-2721, issue 2.0, 2005-04-08

### 1.3 Reference Documents

- [RD 1] *VISTA IR Camera Software Functional Specification*, VIS-DES-ATC-06081-00001, issue 2.0, 2003-11-12.
- [RD 2] *IR Camera Observation Software Design Description*, VIS-DES-ATC-06084-0001, issue 3.2 2005-02-24.
- [RD 3] *VISTA Science Requirements Document*, VIS-SPE-VSC-00000-0001, issue 2.0, 2000-10-26
- [RD 4] *Overview of VISTA IR Camera Data Interface Dictionaries*, VIS-SPE-IOA-20000-0004, 0.1, 2003-11-13
- [RD 5] *Definition of the Flexible Image Transport System (FITS)*, NOST 100-2.0
- [RD 6] *The FITS image extension*, Ponz et al, Astron. Astrophys. Suppl. Ser. **105**, 53-55, 1994
- [RD 7] *Representations of world coordinates in FITS*, Griesen, & Calabretta, A&A, **395**, 1061.2002
- [RD 8] *Representations of celestial coordinates in FITS*, Calabretta & Griesen, A&A, **395**, 1077, 2002

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- [RD 9] *Detectors and Data Analysis Techniques for Wide Field Optical Imaging*, Irwin M.J., 1996, Instrumentation for Large Telescopes, VII Canary Islands Winter School, eds. J.M. Rodríguez Espinosa, A. Herrero, F. Sánchez, p35. Also available from <http://www.ast.cam.ac.uk/~mike/processing.ps.gz>
- [RD 10] *INT WFS pipeline processing*, Irwin M and Lewis J, New Astronomy Reviews, **45**, Issue 1-2, p105, 2001.
- [RD 11] *VISTA Data Flow System: pipeline processing for WFCAM and VISTA*, Irwin et al, Ground-based telescopes, ed. Oschmann, proc SPIE, **5493**, p411, 2004
- [RD 12] *Automatic analysis of crowded fields*, Irwin M. 1985 MNRAS 214,575
- [RD 13] *Understanding Robust and Exploratory Data Analysis*, Hoaglin, Mosteller & Tukey 1983, Wiley.
- [RD 14] *Analysis of astronomical images using moments*, Stobie R, British Interplanetary Journal (Image Processing), **33**, p323, 1980

## 1.4 Abbreviations and Acronyms

2MASS	2 Micron All Sky Survey
ADU	Analogue to Digital Unit
CDS	Correlated Double Sampling
DFS	Data Flow System
DIT	Digital Integration
FITS	Flexible Image Transport System
FWHM	Full Width at Half Maximum
HOWFS	High-Order Wavefront Sensor
LUT	Look Up Table
MAD	Median Absolute Deviation from median
MEF	Multi-Extension FITS
NDR	Non-Destructive Read
RHS	Right Hand Side
RRR	Reset-Read-Read mode
VDFS	VISTA Data Flow System
VIRCAM	VISTA Infra Red Camera
VISTA	Visible and Infrared Survey Telescope for Astronomy
WCS	World Coordinate System
WFCAM	Wide Field Camera (on UKIRT)

## 1.5 Glossary

**CDS** Correlated-Double Sampling; before the charge of each pixel is transferred to the output node of the detector, the output node is reset to a reference value. The pixel charge is then transferred to the output node. The final value of the charge assigned to this pixel is the difference between the reference value and the transferred charge.

**Confidence Map** An integer array, normalised to a median of 100%, which is associated with an image. Combined with an estimate of the



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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.

<b>DAS</b>	Data Acquisition System
<b>DIT</b>	Digital Integration Time means that separate readouts are summed digitally.
<b>Exposure</b>	The stored product of many individual <b>integrations</b> that have been co-added in the DAS. The sum of the integration times is the exposure time.
<b>Integration</b>	A simple snapshot, within the <b>DAS</b> , of a specified elapsed time ( <b>DIT</b> seconds). This elapsed time is known as the integration time.
<b>Jitter (pattern)</b>	A pattern of <b>exposures</b> at positions each shifted by a small movement (<30 arcsec) from the reference position. Unlike a <b>microstep</b> the non-integral part of the shifts is any fractional number of pixels. Each position of a jitter pattern can contain a <b>microstep</b> pattern.
<b>Mesostep</b>	A sequence of <b>exposures</b> designed to completely sample across the face of the detectors in medium-sized steps, in order to monitor residual systematics in the photometry.
<b>Microstep (pattern)</b>	A pattern of <b>exposures</b> at positions each shifted by a very small movement (<3 arcsec) from the reference position. Unlike a <b>jitter</b> the non-integral part of the shifts are exact fractions of a pixel, which allows the pixels in the series to be interlaced in an effort to increase resolution. A microstep pattern can be contained within each position of a <b>jitter</b> pattern.
<b>OB</b>	Observation Block
<b>Object</b>	In the context of image analysis, an astronomical object.
<b>Pawprint</b>	16 non-contiguous images of the sky produced by VIRCAM with its 16 non-contiguous chips (see Fig 2-2 of [AD3]). The name is from the similarity to the prints made by the padded paw of an animal (the terminology was more appropriate to 4-chip cameras).
<b>Preset</b>	A telescope slew to a new position requiring a reconfiguration of various telescope systems.
<b>Robust Estimate</b>	A statistical estimator that is resilient to small perturbations on the assumed shape of the underlying distribution.
<b>Tile</b>	A filled area of sky fully sampled (filling in the gaps in a pawprint) by combining multiple <b>pawprints</b> . 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 <b>pawprints</b> into tiles.

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## 2 Mathematical Description

In this section we include a mathematic description of some of the methods we will use to calibrate and correct data from VIRCAM. The main technical challenges in processing VISTA data stem from the fact that: IR detectors are currently inherently more unstable than their optical counterparts; the sky emission, roughly 100 times brighter than most objects of interest, varies in a complex spatial and temporal manner; and the large data volume that arises from NIR mosaic cameras. To minimise the subsequent data volume several basic pre-processing steps will be carried out in the VISTA data-acquisition system, including reset-correction and co-addition of successive DITs from the same exposure.

The first stage of the VDFS pipeline will be to apply a linearity correction as outlined in section 2.2. Subsequent processing steps including: dark and reset-anomaly correction; flat-fielding and inter-channel gain correction; and sky artefact removal (e.g. fringe patterns), are designed to remove the instrumental and residual sky signatures from the images.

The algorithms used in the VIRCAM pipeline are the result of 25 years development in the analysis of digital images. An excellent and detailed review of the mathematical techniques involved in wide-field image analysis is given in [RD 9]. In particular, the robust estimator is detailed and an in-depth description of image detection and parameterization, as used in section 2.14, is given. Several of the effects included in this section may not even exist in VIRCAM data; it is prudent however to make arrangements for dealing with such issues if early experience with the data shows the effects to be present.

We outline in the following sections the salient points of the mathematical operations to be performed, for further detail see [AD2], [AD3] and [AD4].

### 2.1 Reset Correction

As with most electronic detectors infrared detectors are given a pedestal bias level by the driving electronics. As such the first step in any reduction of such data is to remove that bias. For VIRCAM this will be done in the DAS. This removes the need for explicit bias removal in the pipeline.

### 2.2 Non-Linearity

The Calibration Plan [AD3] lays out the necessity and the methodology for calibrating and correcting for the expected non-linearity in the response of the detector system to incident radiation.

#### 2.2.1 Correcting for non-linearity

In default CDS reset-read-read (RRR) mode, downstream of the data acquisition system (DAS) the output that we see is

$$\Delta I' = I'_2 - I'_1 = f(I_2) - f(I_1) \quad (2-1)$$

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where  $I'_1$  and  $I'_2$  denote the non-linear first (i.e. the reset-frame) and second readouts respectively and  $I_1$  and  $I_2$  the desired linear quantities. The non-linear function  $f(I)$  maps the distortion of the desired linear counts to the non-linear system  $I'$ . If we define the inverse transform  $g(I')$  that maps measured counts  $I'$  to linearized counts  $I$  as the inverse operator  $g() = f^{-1}()$  then

$$I = g(I') \text{ and } I_1 = g(I'_1) \quad I_2 = g(I'_2) \quad (2-2)$$

If  $I'_1$  and  $I'_2$  were directly available this is a one-to-one mapping and can be done efficiently and accurately using Look Up Tables (LUT). This is the conventional way of implementing the correction prior to other image manipulation operations. However, if  $I'_1$  and  $I'_2$  are not separately available and all we have to work from is the difference  $\Delta I'$  then a simple LUT transformation is not possible.

For example, taking the simplest case where the illumination level across the detector has not changed during the course of the RRR and no on-board co-addition is happening then, in principle given only  $\Delta I$  and knowledge of the timing of the RRR operations we can deduce  $I_1$  and  $I_2$  by using the effective integration time for each to estimate their scaling to the measured difference  $\Delta I$  such that,

$$I_1 = k\Delta I \text{ and } I_2 = (1+k)\Delta I \quad (2-3)$$

Unfortunately, the ratio  $k$  will not be constant for the non-linear quantities  $I'_1$  and  $I'_2$  forcing us to adopt a scheme along the following lines.

Given  $\Delta I'$  and defining the non-linear operator  $f()$  as a polynomial with coefficients  $a_m$  (typically up to quartic) we have

$$\Delta I' = \sum_m a_m (I_2^m - I_1^m) = \sum_m a_m [(1+k)^m \Delta I^m - k^m \Delta I^m] \quad (2-4)$$

The quantity we want  $\Delta I$  is buried in the non-linearity of the RHS and we have to solve an equation like this for every pixel. This is possible, and relatively simple to program using something like a Gauss-Seidel iterative scheme, but is more inefficient than a direct mapping.

If we wanted to use a completely general LUT approach we would require a 2D LUT for all possible values of  $I_1$  and  $I_2$  i.e.  $65k \times 65k$  in size, or  $4.3 \times 2$  Gbytes. Most likely we would need a different correction for each "channel" making a total of  $256 \times 8.6$  Gbytes = 2.2 Tbytes of LUT for the VIRCAM! Of course if the range of values of  $k$  is limited via exposure time quantisation this decreases the size of the total number

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of LUTs required considerably for the constant illumination case, but would be an ugly and possibly impractical solution.

Practical considerations (e.g. data volume), suggest two alternative solutions for non-linearity correction: either correct the individual frames directly in the DAS by measuring and downloading the appropriate LUTs, or polynomial coefficients, to the DAS; or use a non-linear inversion on the reset-corrected frames as outlined here. This methodology is not generally applicable, e.g. to multi-NDR/gradient fitting readouts, but is directly applicable to co-added (or co-averaged) frames of the same exposure times, assuming constant illumination over the series.

For reset-corrected data, the non-linear inversion is competitive with complex operations on LUTs and much simpler to implement. It also has the added advantage of removing all aspects of the non-linearity correction from the DAS. The main disadvantages are the method is restricted to CDS RRR mode, and if the illumination level is rapidly varying (e.g. twilight) the effective scale factors  $k_i$  may be hard to compute accurately - although for all realistic practical situations the knock-on effect is likely to be negligible.

## 2.2.2 Measuring non-linearity

If all that is available are reset-corrected data from say a time series of dome flats, it is still feasible to directly compute the non-linearity coefficients.

Given a series of measurements  $\{i\}$  of  $\Delta I'_i$  and using the previous notation and polynomial model

$$\Delta I'_i = \sum_m a_m (I_2^m - I_1^m) = \sum_m a_m \Delta I_i^m [(1 + k_i)^m - k_i^m] \quad (2-5)$$

where  $k_i$  are the exposure ratios under the constant illumination. In general  $\Delta I_i = s t_i$  where  $t_i$  is the exposure time of the  $i$ th reset-corrected frame in the series and  $s$  is a fixed (for the series) unknown scale factor. The  $k_i$  are computable from a knowledge of the exposure times and the reset-read overhead,  $t_i$  and  $\Delta I'_i$  are measured quantities leaving the polynomial coefficients  $a_m$  and the scaling  $s$  to be determined. Thus the model is defined by

$$\Delta I'_i = \sum_m a_m (I_2^m - I_1^m) - \sum_m a_m s^m t_i^m [(1 + k_i)^m - k_i^m] \quad (2-6)$$

and can be readily solved by standard linear least-squares methods using the following sleight-of-hand. Since the scaling  $s$  and hence the polynomial solution  $a_m$  are coupled, by simply (and logically) requiring in the final solution  $a_1 = 1$ , computation of  $s$  can be completely avoided.

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Rewriting the previous equation in the following form makes this more apparent

$$\Delta I'_i = \sum_m (a_m s^m) t_i^m [(1 + k_i)^m - k_i^m] = \sum_m b_m t_i^m [(1 + k_i)^m - k_i^m] \quad (2-7)$$

where now  $b_m$  are the coefficients to be solved for. The final step is to note that

$$a_m = b_m / s^m = b_m / b_1^m \quad (2-8)$$

since by definition  $a_1 = 1$ .

### 2.3 Gain Correction

In the case of a single detector camera the mean flat field image is normalised to a value of 1. This ensures that when the flat field correction is done the average counts in the output image is the same as in the input. For multi-detector instruments, we normalise the mean flat field image for each detector by:

$$V = \frac{\sum_{i=1}^n \langle I \rangle_i}{N} \quad (2-9)$$

where  $\langle I \rangle_i$  is a robust estimate of the average flux in the combined flat field image for the  $i$ th detector. Normalising in this way ensures that when doing flat field correction we also include a factor that removes the differences in mean gain of each detector.

### 2.4 Measurement of Read Noise and Gain

The read noise and gain can be measured using two dome flat frames of similar illumination and two similarly observed (in terms of exposure and integration times) dark frames. Forming the difference of the two flat frames gives a variance for the difference frame  $\sigma_f^2$ . Doing the same for the two dark frames yields  $\sigma_d^2$ . If the background means of the flat and dark frames are:  $m_{f1}$ ,  $m_{f2}$  and  $m_{d1}$ ,  $m_{d2}$  the local gain in electrons per ADU is:

$$\varepsilon = ((m_{f1} + m_{f2}) - (m_{d1} + m_{d2})) / (\sigma_f^2 - \sigma_d^2) \quad (2-10)$$

and the readout noise in electrons is

$$\sigma_{ro} = \varepsilon \sigma_d / \sqrt{2} \quad (2-11)$$

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## **2.5 Dark-correction, flat-fielding and sky-correction**

If the fringe spatial pattern is stable and if flat fields can be generated without fringing present, it is possible to decouple sky correction and fringe correction and apply a de-fringing method similar to the one we have developed for optical imaging [RD 11]. This involves creating a series of master fringe frames which are scaled by a suitable factor for each object frame. The scale factors are adjusted to minimise the fringe pattern in the processed frame.

Standard NIR processing recipes often subtract sky first and then flat-field. We can see why this can be advantageous compared with dark-correcting, flat-fielding and sky-correcting by considering the following encapsulation of the problem

$$D(x, y) = ff(x, y)[S(x, y) + F(x, y) + O(x, y) + T(x, y)] + dc(x, y) \quad (2-12)$$

where  $D(x, y)$  is observed,  $ff(x, y)$  is the flat-field function,  $S(x, y)$  is the sky illumination,  $F(x, y)$  is the fringe contribution,  $O(x, y)$  is the object contribution,  $T(x, y)$  is the thermal contribution,  $dc(x, y)$  is the dark current, and without loss of generality we have excluded any explicit wavelength and time-dependence for clarity.

Stacking a series of dithered object frames with rejection produces an estimate of the terms

$$\hat{I}(x, y) = ff(x, y)[S(x, y) + F(x, y) + T(x, y)] + dc(x, y) \quad (2-13)$$

therefore,

$$D(x, y) - \hat{I}(x, y) = ff(x, y)O(x, y) \quad (2-14)$$

obviating the need for dark-correcting and fringe removal as both separate data gathering requirements and as separate data processing steps; and minimising the effect of systematic and random errors in the flat-field function by removing the largest potential error terms.

In the event that the dark correction stage fails to remove the reset anomaly completely, the residual background variation is analogous to the problem of dealing with short-term variations in sky structure and can be dealt with using the methodology above.

The caveats here of course are that this method may well remove parts of large extended objects, large area nebulosity, and large low surface brightness objects and so on, unless suitable offset skies are used in the sky frame construction. Unfortunately this then opens the door for spatial and temporal variability of the sky background, leaving residual patterns.

The optimal strategy to use depends on the stability of the flat-fields, and the time constants for sky fringe pattern variations, and will be dealt with by assessing these characteristics during commissioning and then invoking suitable processing recipes.

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The alternative is to treat the dark correction  $dc(x, y)$ , flat field  $ff(x, y)$ , and fringe pattern  $F(x, y)$ , as accurately known master library frames, in which case data processing involves solving the following variant of the problem

$$D(x, y) = ff(x, y) [S(x, y) + k.F(x, y) + O(x, y) + T(x, y)] + dc(x, y) \quad (2-15)$$

where  $k$  is a scale factor to be determined by the fringe-removing algorithm. In this case applying the master frames leads to

$$D'(x, y) = S(x, y) + O(x, y) + T(x, y) \quad (2-16)$$

reducing the problem to one of detecting astronomical objects on an additive, slowly spatially varying, background. This could be the method of choice for analysing large scale astronomical surface brightness variations.

## 2.6 Stripe Removal

AIT data from the VIRCAM detectors has shown a low level medium frequency stripe pattern. The stripes are perpendicular to the readout direction and are the same for all channels in a detector. This means that they can be modelled out by calculating the median of each row (ignoring any bad or object pixels) to form a one dimensional stripe profile. The stripe profile is normalised to zero median. This ensures that once the stripes are subtracted the median background level will remain the same. Each point in the normalised stripe profile is used to correct the relevant row in the input data.

## 2.7 Fringe Removal

Atmospheric emission lines may cause interference fringes to be present in the sky background at the level of a few percent of sky. Since the fringes can have complex spatial structures on a range of physical scales on the detector, removing them successfully is a multi-stage process.

First we note that fringing is an additive effect, so if removed as part of a procedure that used night sky data as a flat field source, this would introduce a systematic error in the photometry. To perform sky fringe removal effectively requires the flat fielding to be decoupled from the defringing by, for example, using twilight sky exposures to construct the flat-field frames, where the contribution from sky emission lines is negligible.

Consequently, the first stage of the process is to flat-field the dark sky science data correctly and to use a sequence of offset sky exposures to construct a fringe frame. These input frames are combined after suitable scaling to match the background levels and sigma-clipping to remove astronomical objects.

The defringing process then requires solving for the fringe scale factor  $k$  in the following equation:

$$D(x, y) = S(x, y) + kF(x, y) + O(x, y) + T(x, y) \quad (2-17)$$

where  $S$  is the sky contribution,  $O$  is the astronomical object contribution and  $T$  is the contribution from the thermal background.



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Since the fringe pattern is characterised by more rapidly varying spatial structure than the sky and thermal contributions, the overall background variation on the target and fringe frame is temporarily removed by use of a robust low-pass filter such that:

$$D'(x, y) \approx kF(x, y) + O(x, y) \quad (2-18)$$

The objects are localised, therefore a simple robust background noise estimator based on the Median of the Absolute Deviation (MAD) from the median can be used iteratively to find the scale factor  $k$  that minimises the background noise in  $D'(x, y)$ . Allowing the scale factor to vary ensures that the relative contribution of the sky emission lines, which may vary in strength, is correctly dealt with.

More complex options involving decomposing the seasonal fringe patterns into eigen-fringe maps may be required at later stages in the processing but this is outside of the scope of the standard calibration pipeline.

The success, or otherwise, of fringe removal is monitored by the computed fringe map scale factor and also by a robust measure of the change (ratio) of the global background noise/variation after fringing. This is encoded in the FRINGE\_RATIO QC1 parameter.

## 2.8 Image persistence

Astronomical images, and artefacts from preceding frames, can persist and be present on the current image. Strategies for dealing with this involve assessing the time decay characteristics and adjacency effects (i.e. image spreading) if present. In the case of no image adjacency effects, correcting for image persistence will either involve updating and maintaining a persistence mask (for combination with the confidence map), or accumulating with suitable temporal decay, a persistence map, running over a night if necessary, to subtract from the current image. For example, in the simplest case

$$I_k^{obs}(x, y, t) = I_k^{true} + f \times I_{k-1}^{obs}(x, y, t - \Delta t) \times e^{-\Delta t / \tau} \quad (2-19)$$

where  $k$  is the image sequence number,  $f$  is the fraction of the image persisting after frame reset(s),  $\Delta t$  is the time interval between frames, and  $\tau$  is the persistence decay constant which may be different for each detector.

It is possible that image persistence may include some sort of adjacency effects. These will have to be characterised at commissioning.

## 2.9 Crosstalk

Images from one detector channel may produce secondary images (ghosts) on other channels either positive or negative in sign and may also even cross from one detector to another. In a stable environment, it is feasible to measure the contribution of crosstalk from one channel to another by using bright point-like sources, and thereby define a comprehensive crosstalk matrix  $C_{j,k}$ . Since this is environment specific, determining the final form of this matrix will be one of the commissioning tasks, although earlier laboratory-based measurements will be used to characterise its likely impact and to investigate ways of minimising the effect.

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Providing the cross-talk terms are small (i.e. <1%, the most likely scenario), then the following simple single-pass additive correction scheme will be used to correct for this problem,

$$I'_j = I_j - \sum_{k \neq j} I_j C_{j,k} \quad (2-20)$$

where  $I_j$  is the observed frame and  $I'_j$  the corrected version. The typical error in making a single pass correction is approximately  $\langle C_{j,k} \rangle_{j \neq k}^2$ , which governs the requirement on the magnitude of the cross-talk terms. Note also that the matrix  $C$  will in general not be symmetric.

## 2.10 Astrometric Calibration

From the optical design studies of VISTA we know that, to a good approximation, the astrometric distortion shows negligible variation with wavelength and is well described by a radially symmetric polynomial distortion model of the form

$$r_{true} = k_1 \times r + k_3 \times r^3 + k_5 \times r^5 + \dots \quad (2-21)$$

where  $r_{true}$  is an idealised angular distance from the optical axis,  $r$  is the measured distance, and  $k_1$  is the scale at the centre of the field, usually quoted in arcsec/mm. VISTA will have a central field scale, i.e.  $k_1$  value of roughly 17.09 arcsec/mm. The term due to  $k_5$  is usually negligible and, until real sky data is available, is not worth pursuing, since other similarly sized distortions may be present. Dropping this term and rearranging the preceding equation to a more convenient form gives

$$r_{true} = r' \times \left(1 + \frac{k_3}{k_1^3} \times r'^2\right) = r' + k \times r'^3 \quad (2-22)$$

where  $r'$  is the measured distance from the optical axis in arcsec using the  $k_1$  scale. If we convert all units to radians the “r-cubed” coefficient is conveniently scaled (in units of radians/radian<sup>3</sup>) and has a theoretical value of around 42 for VISTA, but will have a slight wavelength dependence.

Although this type of distortion generally presents no problem for accurate calibration of individual pointings, it can lead to various complications when stacking data taken at various locations, e.g. dither sequences. This is caused by the differential non-linear distortions across individual detectors being comparable to, or larger than, the pixel size of the detector. In these cases stacking involves resampling and interpolation of some form. While these are inevitable in combining pointings to form contiguous tiled regions, they may be avoided at earlier stages, such as stacking individual detector dither sequences, by suitably limiting dither offsets and thereby both simplify and speed up the data processing.

The effective scale due to the radial distortion is given by

$$dr_{true} / dr' = 1 + 3k \times r'^2 \quad (2-23)$$

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which describes the local change in relative pixel scale as a function of radial distance. For example, for VISTA at 0.8 degree radius, the differential distortion term is about 2.5%. This means that a 10 arcsec shift in the centre corresponds to a 10.25 arcsec shift at the outer corners of the arrays. For the outer detectors a large fraction of this distortion occurs across individual detectors.

In anticipation of this problem, we will implement a range of interpolation schemes that offer a trade off between maintaining independent pixel noise and resolution degradation.

For further information see the report at

<http://www.ast.cam.ac.uk/vdfs/docs/reports/astrom/>.

## 2.11 World Coordinate System

We intend, at least initially, to characterise the WCS using the ZPN projection [RD 7] and [RD 8], i.e. ARC + polynomial distortion, using a 3<sup>rd</sup> order parameterisation (equation 2.22). The coefficients for this are encoded in the FITS header using the keywords PV2\_1 and PV2\_3.

## 2.12 Effect of Scale Change on Photometry

In addition to astrometric effects the change in scale as a function of radius also has photometric implications. The aim of conventional flat fielding is to create a flat background by normalising out perceived variations from (assumed) uniformly illuminated frames. If the sky area per pixel changes then this is reflected in a systematic error in the derived photometry.

However, since it much simpler to deal with “flat” backgrounds, this problem is either usually ignored or corrected during later processing stages, together with other systematic photometry effects. The effect is simplest to envisage by considering what happens to the area of an annulus on sky when projected onto the detector focal plane. The sky annulus of  $2\pi r ds$  becomes  $2\pi r' dr'$  on the detector, which using  $k$  to denote  $k_3/k_1$  leads to a relative area of

$$(1 + k \times r'^2) \cdot (1 + 3k \times r'^2) \approx (1 + 4k \times r'^2) \quad (2-24)$$

or in other words roughly  $4 \times$  the linear scale distortion.

However, since other more unpredictable factors, such as scattered light, will also play a significant role, it is simpler procedurally to bundle all the effects together and correct all the photometric systematics in one operation. The VDFS calibration plan [AD3] describes a procedure for achieving this as an illumination correction.

## 2.13 Confidence Maps

We define a confidence map  $c_{ij}$  as a normalised<sup>1</sup> i.e.  $\langle c_{i,j} \rangle_j = 1$  inverse variance weight map denoting the “confidence” associated with the flux value in each pixel  $j$  of

<sup>1</sup> In practice we use a 16-bit integer map such that the median level is 100%

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frame  $i$ . This has the advantage that the map is always finite and can also be used to encode for hot, bad or dead pixels, by assigning zero confidence. Furthermore, after image stacking the confidence map also encodes the effective relative exposure time for each pixel, thereby preserving all the relevant intra-pixel information for further optimal weighting.

The initial confidence map for each frame is derived from regular analysis of the master calibration flat-field and dark frames and is unique for each filter/detector combination due to the normalisation. As such it also encodes individual pixel sensitivities and also allows, for example, vignettted regions to be correctly weighted when combining frames. To use the confidence maps for weighted co-addition of frames then simply requires an overall estimate of the average noise properties of the frame. This can readily be derived from the measured sky noise, in the Poisson noise-limited case, or from a combination of this and the known system characteristics (e.g. gain and readout noise).

All processed frames (stacked individual detectors, tiled mosaiced regions) have an associated derived confidence map which is propagated through the processing chain in the following manner.

Defining the signal  $s_i$  in frame  $i$  with respect to some reference signal level  $s_{ref}$  as  $s_i = f_i s_{ref}$ , where  $f_i$  denotes the relative throughput (which in photometric conditions would be  $\propto$  exposure time), the optimum weight to use for combining the  $j$ th pixel of (suitably aligned) frames  $i$  in order to maximise the signal:to:noise of sky-limited objects is defined by

$$x'_j = \frac{\sum_i w_{ij} x_{ij}}{\sum_i w_{ij}} \quad w_{ij} = c_{ij} f_i / \sigma_i^2 \quad (2-25)$$

where  $\sigma_i^2$  is the average noise variance in frame  $i$ ,  $x_{ij}$  is the flux in pixel  $j$  on the  $i$ th frame and  $x'_j$  is the combined output flux. The effective exposure time is that of  $s_{ref}$ .

The output confidence map, which is  $\propto outputnoise_j^{-2}$ , is therefore given by

$$c'_j = \frac{(\sum_i c_{ij} f_i / \sigma_i^2)^2}{\sum_i c_{ij} f_i^2 / \sigma_i^2} \quad (2-26)$$

Special cases of this occur when  $f_i = 1$ , e.g. equal length exposures in stable photometric conditions, or the more general Poisson noise limited case, when  $f_i / \sigma_i^2 = 1$ , and the special variant of this when  $f_i = 1$ . These cases are given below, prior to renormalisation.

$$c'_j = \sum_i c_{ij} / \sigma_i^2 \quad c'_j = \frac{(\sum_i c_{ij})^2}{\sum_i c_{ij} f_i} \quad c'_j = \sum_i c_{ij} \quad (2-27)$$

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## **2.14 Catalogue generation**

In order to provide quality control, and astrometric and photometric calibration information, it is necessary to generate detected object (i.e. stars, galaxies) catalogues for each target frame.

The catalogue generation software (e.g. [RD 12], [RD 9]) will make direct use of the confidence maps for object detection and parameterisation, and will produce the requisite information via the use of standard object descriptors. For completeness we give here a brief description of how this will be accomplished by use of the following steps:

- estimate the local sky background over the field and track any variations at adequate resolution to eventually remove them;
- detect objects/blends of objects and keep a list of pixels belonging to each blend for further analysis;
- parameterise the detected objects, i.e. perform astrometry, photometry and some sort of shape analysis.

### **2.14.1 Background analysis and object detection**

The possibly-varying sky background is estimated automatically, prior to object detection, using a combination of robust iteratively-clipped estimators.

Any variation in sky level over the frame will be dealt with by forming a coarsely sampled background map grid. Within each background grid pixel, typically equal to  $64 \times 64$  image pixels, an iteratively k-sigma clipped median value of “sky” will be computed based on the histogram of flux values within the grid pixel zone. A robust estimate of sigma can be computed using the Median of the Absolute Deviation (MAD) from the median (e.g. [RD 13]). This will then be further processed to form the frame background map (e.g. [RD 9]).

After removing the, possibly, varying background component, a similar robust estimate of the average sky level and sky noise per pixel can be made. This forms part of the quality control measures and also helps to robustly determine the detection threshold for object analysis.

Individual objects will be detected using a standard matched filter approach (e.g. [RD 12]). Since the only images difficult to locate are those marginally above the sky noise, assuming constant noise is a good approximation (after factoring in the confidence map information) and the majority of these objects will have a shape dominated by the point spread function (PSF), which thereby defines the filter to use.

### **2.14.2 Image parameterisation**

The following image parameters can be computed efficiently and are directly used as part of the image quality control and calibration analysis.

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Isophotal Intensity - the integrated flux within the boundary defined by the threshold level; i.e. the 0<sup>th</sup> object moment

$$I_{iso} = \sum_i I(x_i, y_i) \quad (2-28)$$

For Gaussian images, this is related to the total intensity by the factor  $(1 - I_t / I_p)^{-1}$ , where  $I_p$  is the peak flux and  $I_t$  the threshold level (all relative to sky).

Position - computed as an intensity-weighted centre of gravity; i.e. 1<sup>st</sup> moment

$$x_0 = \sum_i x_i \cdot I(x_i, y_i) / \sum_i I(x_i, y_i) \quad (2-29)$$

$$y_0 = \sum_i y_i \cdot I(x_i, y_i) / \sum_i I(x_i, y_i)$$

Covariance Matrix - the triad of intensity-weighted 2<sup>nd</sup> moments is used to estimate the eccentricity/ellipticity, position angle and intensity-weighted size of an image

$$\sigma_{xx} = \sum_i (x_i - x_0)^2 \cdot I(x_i, y_i) / \sum_i I(x_i, y_i) \quad (2-30)$$

$$\sigma_{xy} = \sum_i (x_i - x_0) \cdot (y_i - y_0) \cdot I(x_i, y_i) / \sum_i I(x_i, y_i)$$

$$\sigma_{yy} = \sum_i (y_i - y_0)^2 \cdot I(x_i, y_i) / \sum_i I(x_i, y_i)$$

The simplest way to derive the ellipse parameters from the 2<sup>nd</sup> moments is to equate them to an elliptical Gaussian function having the same 2<sup>nd</sup> moments. It is then straightforward to show (e.g. [RD 14]) that the scale size,  $\sqrt{\sigma_{rr}}$ , is given by  $\sigma_{rr} = \sigma_{xx} + \sigma_{yy}$ ; the eccentricity,  $ecc = \sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4 \cdot \sigma_{xy}^2} / \sigma_{rr}$ ; and the position angle,  $\theta$  is defined by,  $\tan(2\theta) = 2 \cdot \sigma_{xy} / (\sigma_{yy} - \sigma_{xx})$ . The ellipticity,  $e$ , which is simpler to interpret for estimating potential image distortions (e.g. trailing), is related to the eccentricity by  $e = 1 - \sqrt{(1 - ecc) / (1 + ecc)}$

Areal Profile - a variant on the radial profile, which measures the area of an image at various intensity levels. Unlike a radial profile, which needs a prior estimate of the image centre, the areal profile provides a single pass estimate of the profile

$$ArealProfile \rightarrow T + p_1, T + p_2, T + p_3, \dots, T + p_m \quad (2-31)$$

where  $p_j; j = 1, \dots, m$  are intensity levels relative to the threshold,  $T$ , usually spaced logarithmically to give even sampling.

The peak height,  $I_p$ , is a useful related addition to the areal profile information and is defined as

$$I_p = \max[I(x_i, y_i)]_i \quad (2-32)$$

or alternatively measured by extrapolation from the areal profile if the image is saturated. The areal profile provides a direct method to estimate the seeing of objects

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in an image by enabling the average area of stellar images (point sources) at half the peak height,  $\langle A \rangle$ , to be estimated. The seeing, or FWHM, is then given by  $FWHM = 2\sqrt{\langle A \rangle / \pi}$ .

Finally a series of aperture fluxes are required for object morphological classification (see below).

Aperture flux is defined as the integrated flux within some radius  $r$  of the object centre

$$I_{ap}(r) = \sum_{i \in r}^N I_i - N \times sky \quad (2-33)$$

Where boundary pixels are weighted pro-rata (soft-edged aperture photometry). A series of these is used to define the curve-of-growth,  $I_{ap}(r)$  -v-  $r$ , for each object.

### 2.14.3 Morphological Classification

The object detection software will produce a series of background-corrected flux measures for each object in a set of “soft-edged” apertures of radius  $r/2$ ,  $r/\sqrt{2}$ ,  $r$ ,  $\sqrt{2}r$ ,  $2r$  .....  $32r$ , where  $r$  is typically fixed as the median seeing for the site+telescope+camera. The average curve-of-growth for stellar images is used to define automatically an aperture correction for each aperture used and also forms the basis for object morphological classification (required for isolating stellar images for seeing and trailing quality control).

The curve-of-growth of the flux for each object is compared with that derived from the (self-defining) locus of stellar objects, and combined with information on the ellipticity of each object, to generate the classification statistic. This statistic is designed to preserve information on the “sharpness” of the object profile and is re-normalised, as a function of magnitude, to produce the equivalent of an  $N(0,1)$  measure, i.e. a normalised Gaussian of zero-mean and unit variance. Objects lying within  $2-3\sigma$  are generally flagged as stellar images, those below  $3\sigma$  (i.e. sharper) as noise-like, and those above  $2-3\sigma$  (i.e. more diffuse) as non-stellar.

A by-product of the curve-of-growth analysis is the estimate of the average PSF aperture correction for each detector.

### 2.15 Photometric Zeropoint

For the purposes of quality control (e.g. sky transparency and system performance) a primary photometric zeropoint will be determined for each observation by direct comparison of instrumental magnitudes with the magnitudes of 2MASS stars. An alternative cross-check on the photometric calibration will be applied retrospectively given a complete night of observations including regular exposures in VISTA photometric standard fields.

The internal gain-correction, applied at the flat-fielding stage, should place all the detectors on a common zeropoint system (at least to first order i.e. ignoring colour equation variations between the detectors), and given a stable instrumental setup, the apparent variation of zeropoint then directly measures the change in “extinction”

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without the need to rely solely on extensive standard field coverage over a range in airmass. Therefore for any given observation of a star in a particular passband:

$$m^{cal} = m^{inst} + ZP - \kappa (X - 1) = m^{std} + ce^{std} + \varepsilon \quad (2-34)$$

where  $ZP$  is the zeropoint in that passband (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 ( $-2.5 \times \log_{10}[\text{counts/sec}]$ ),  $\kappa$  is the extinction coefficient,  $X$  is the airmass of the observation,  $ce^{std}$  is the colour term to convert to the instrumental system, and  $\varepsilon$  is an error term. This assumes that the second-order extinction term and colour-dependency of  $\kappa$  are both negligible. By robustly averaging the zeropoints for all the matching stars on the frame an overall zeropoint for the observation can be obtained.

Typically, the zeropoint 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  $\kappa$  should be constant in each passband. The extinction  $\kappa$  can be monitored through each night either by assuming the true instrumental zeropoint only varies slowly as a function of time (and using the individual 2MASS calibrations to monitor it) or by making measurements over a range of airmass.

## 2.16 Illumination Correction

The two methods of determination of illumination correction differ in that the first described below requires either a rich standard star field or a series of fields with known photometry, but the second can be used before such information is available.

### 2.16.1 Standard Star Fields

Errors in the large scale structure of the illumination of the flat fields used in signature removal can cause position dependent systematic errors in photometry. This can be a result of a varying scattered light profile between twilight (nominally when the flat field exposures would have been made) and the time when the observation was done. We can map this out by first dividing an observation of a rich photometric standard field into cells or by dividing a series of calibrator fields from, for example, 2MASS into cells. For each cell we define a median zero point of all the stars in that cell:

$$zp_j = \langle m^{cal} - m^{inst} \rangle \quad (2-35)$$

(It is safe to ignore the extinction term for this exercise.) The illumination correction is then defined for each cell as:



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$$ic_j = \langle zp \rangle - zp_j \quad (2-36)$$

where  $\langle zp \rangle$  is the median value of  $zp_j$  over all the cells. This is defined such that a star in the  $j$ th cell is calibrated by:

$$m^{cal} = m^{inst} + ZP - \kappa (X - 1) - ic_j \quad (2-37)$$

### 2.16.2 Mesostep Analysis

We assume that the spatial sensitivity of each detector can be approximated by a polynomial surface, i.e. a magnitude offset as a function of  $(x, y)$  measured from the centre of the detector, e.g.

$$ZP(x, y) = \sum_{hk} a_{hk} x^h y^k \quad (2-38)$$

For example, in quadratic form, at positions  $i$  and  $j$ :

$$ZP(x_i, y_i) = a_{00} + a_{10}x_i + a_{01}y_i + a_{20}x_i^2 + a_{11}x_i y_i + a_{02}y_i^2 \quad (2-39)$$

$$ZP(x_j, y_j) = a_{00} + a_{10}x_j + a_{01}y_j + a_{20}x_j^2 + a_{11}x_j y_j + a_{02}y_j^2 \quad (2-40)$$

The difference in sensitivity/zeropoint between two positions  $i$  and  $j$  is then:

$$\begin{aligned} \Delta ZP(x_i, x_j, y_i, y_j) = & a_{10}(x_i - x_j) + (a_{01}(y_i - y_j) + a_{20}(x_i^2 - x_j^2) \\ & + a_{11}(x_i y_i - x_j y_j) + a_{02}(y_i^2 - y_j^2) \end{aligned} \quad (2-41)$$

If we make two observations of the same star at offset positions  $i$  ( $x_i, y_i$ ) and  $j$  ( $x_j, y_j$ ), we sample this function such that the difference in magnitude measured is  $\Delta m_{ij}$  then:

$$\Delta m_{ij} = \Delta ZP(x_i, x_j, y_i, y_j) \quad (2-42)$$

In the simplest case, observing the same star in a number of different places would allow one to measure the  $\Delta m_{ij}$  as a function of  $(x_i, y_i)$  and  $(x_j, y_j)$ . One could then fit a polynomial using least-squares and solve for the  $a_{hk}$ . The multiple observations of multiple stars in a grid across the array ensure we can solve for the polynomial coefficients accurately.

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### 3 Functional Description

Science data from VIRCAM is processed by a single recipe, namely `vircam_jitter_microstep_process`. Various other recipes are provided to generate the calibration data essential for instrumental-signature removal. A variation of the science recipe, `vircam_standard_process`, is used on observations of standard fields (which will contain many standard stars). The recipes will work for both the Paranal and Garching pipeline environments, but it is expected that higher-quality results will be obtained at Garching where complete nights of data will be analysed and more recent calibration data will be available.

An overview of the whole VIRCAM pipeline is illustrated in Figure 3-1.

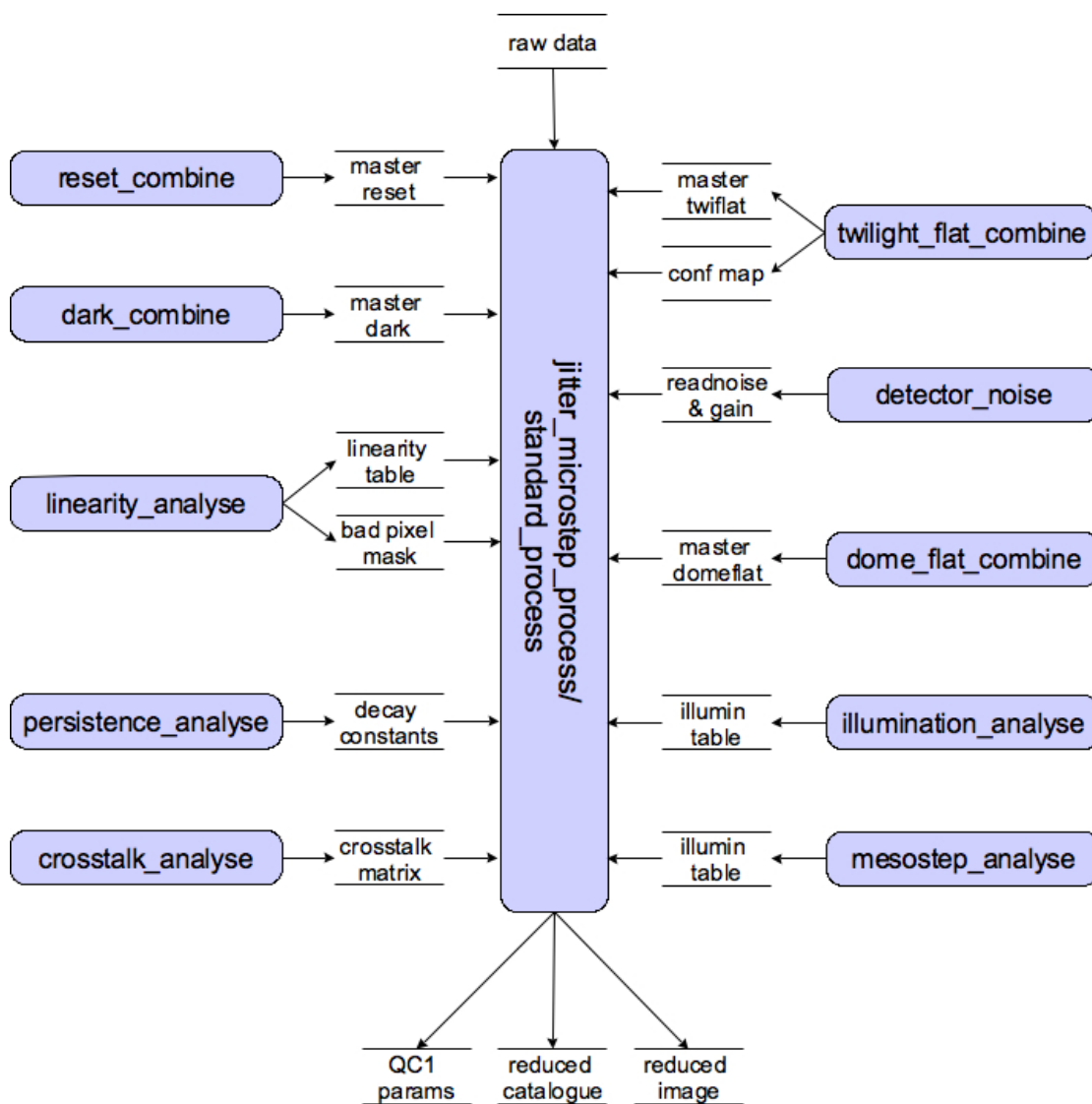


Figure 3-1 Relationship between recipes, calibration data and data products.

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There will initially be no calibration data, and so the pipeline must be “bootstrapped” by executing the recipes in the order shown in Figure 3-2. After this, there should be the minimum set of library calibration data to run the whole pipeline in production mode.

recipe:	linearity	dark	dome flat	dark current	detector noise	reset combine	twilight	meso step	persistence	cross talk
data:	domes, darks	darks	domes	darks	flats darks	resets	twilights			
static:	channel table									
products	channel table + linearity	←	←			←	←			
	Master BPM		←		←	←	←			
		Master Dark	←							
			Master dome flat							
				Master dark current						
					read/gain file					
						Master reset				
							Master twilight flat Master confidence Map			

**Figure 3-2 Bootstrapping table relating Calibration Observations, Recipes and Calibration Products.**

### 3.1 Recipes

The following figures illustrate the decomposition of the processing recipes into their component functions, shown in shaded yellow circles and with the leading “vircam” stripped for clarity. Open circles show further processing carried out within the recipe and shaded mauve rectangles the QC outputs.

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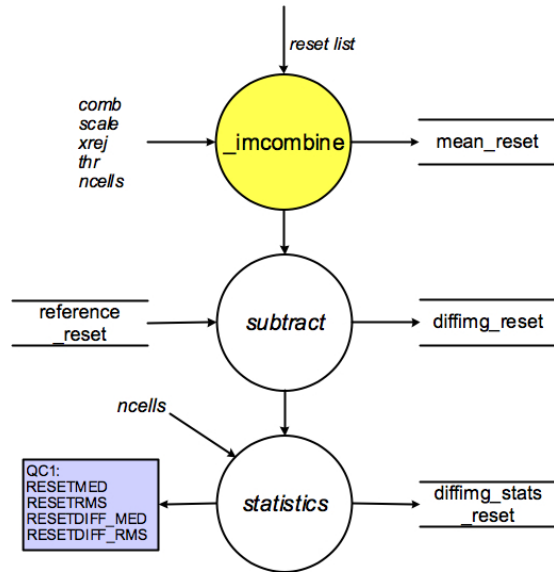


Figure 3-3 vircam\_reset\_combine

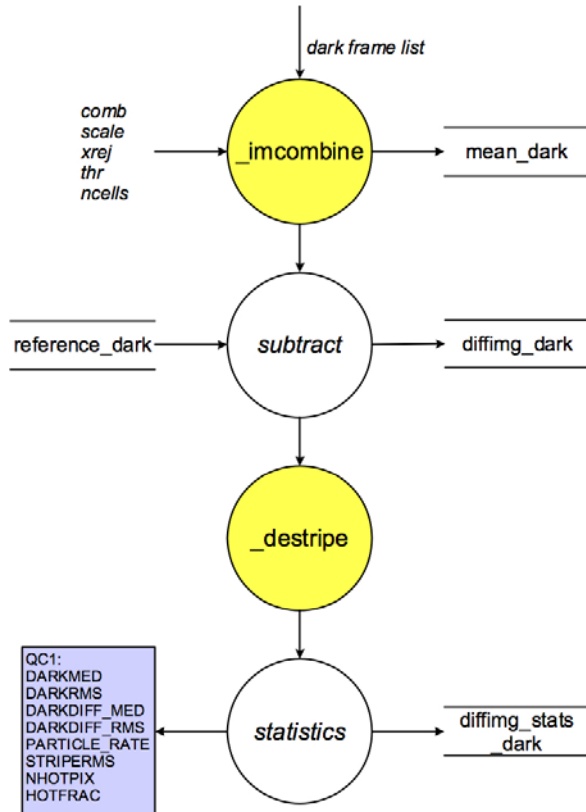


Figure 3-4 vircam\_dark\_combine

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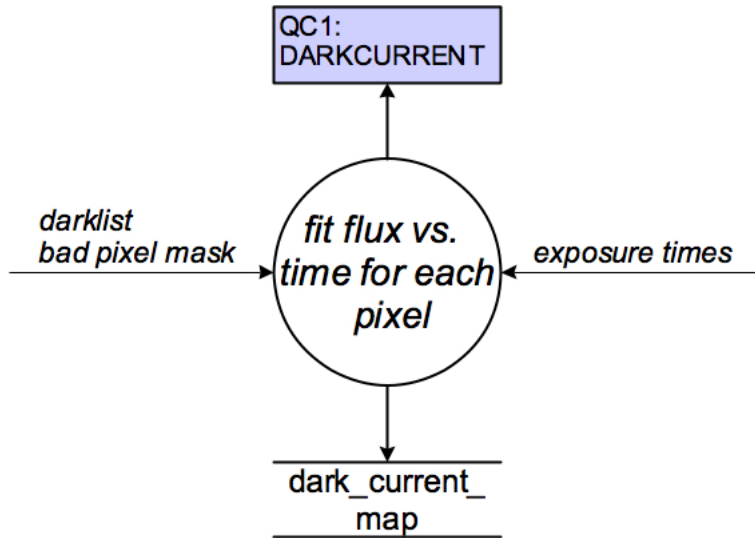


Figure 3-5 vircam\_dark\_current

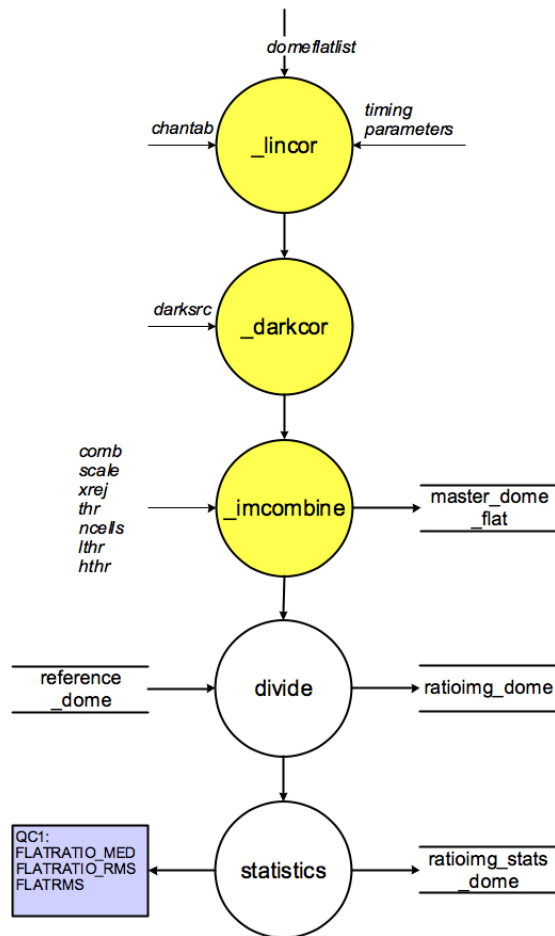


Figure 3-6 vircam\_dome\_flat\_combine

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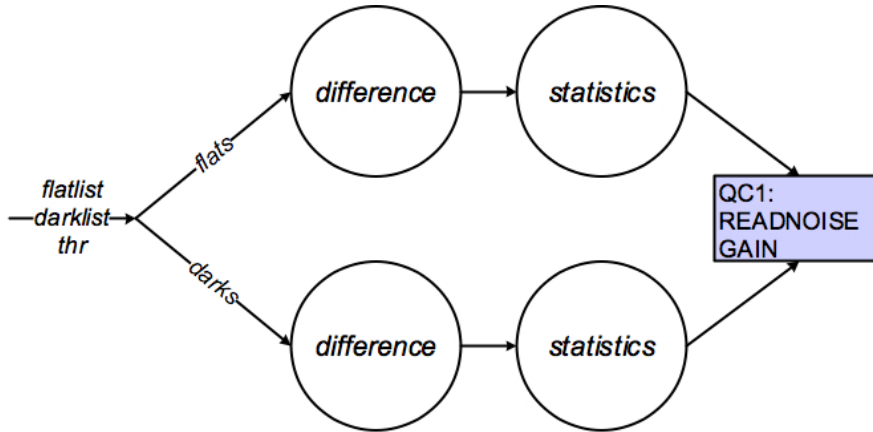


Figure 3-7 vircam\_detector\_noise

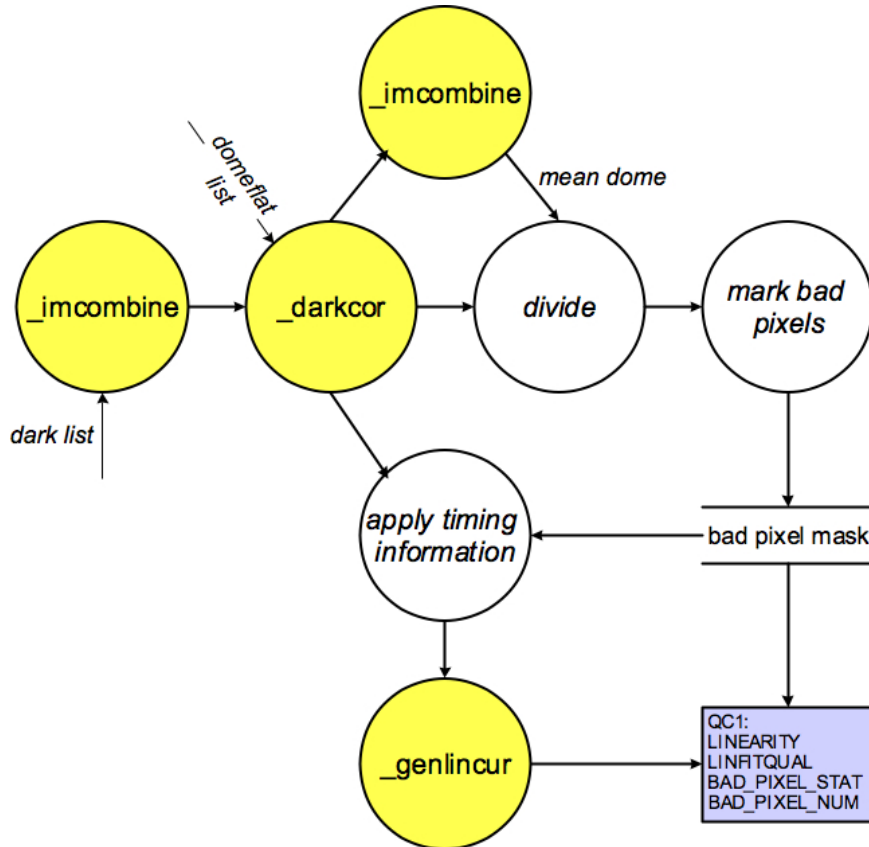


Figure 3-8 vircam\_linearity\_analyse

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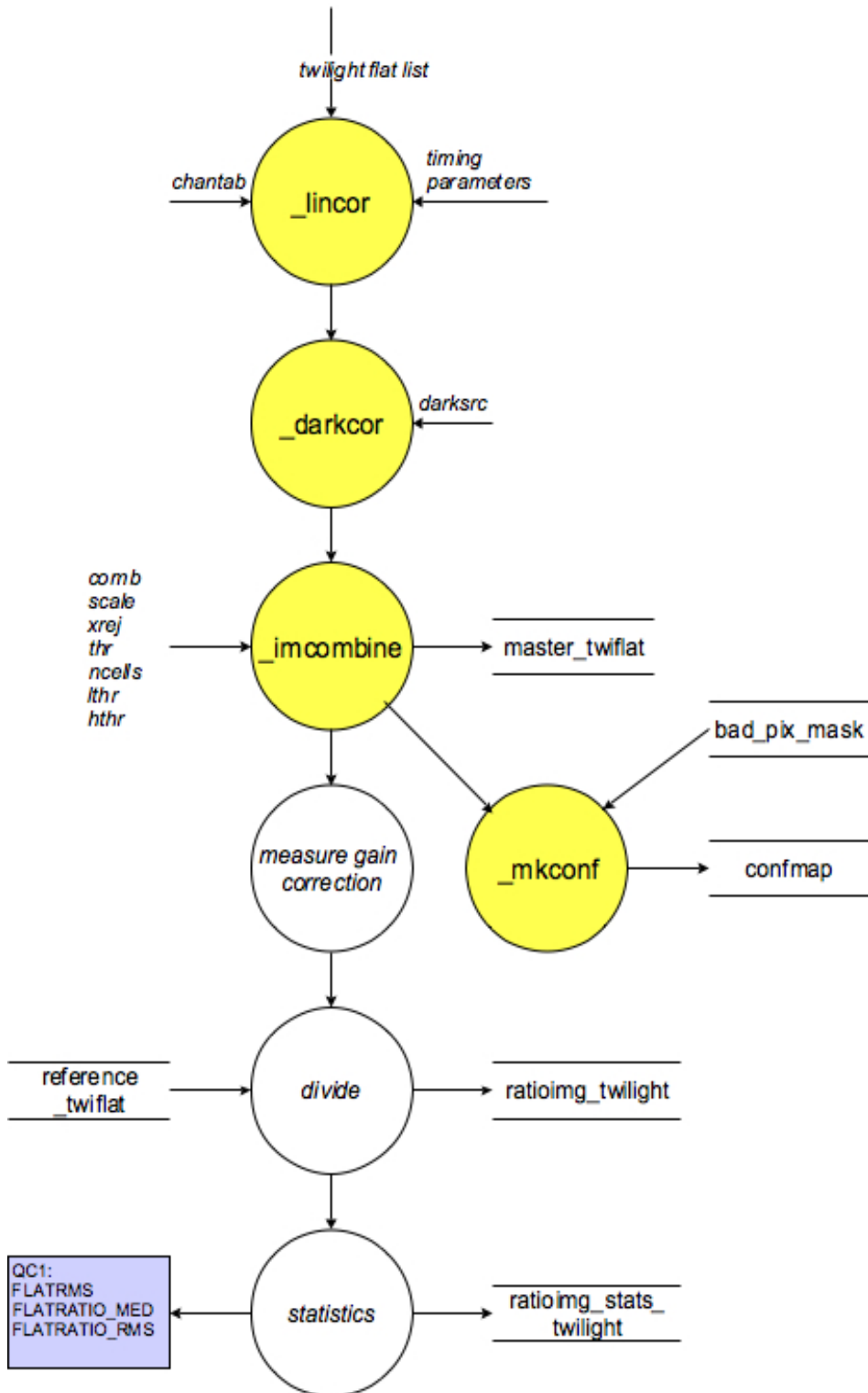


Figure 3-9 vircam\_twilight\_combine

<b>VISTA Data Flow System</b>	<b>Data Reduction Library Design</b>	Doc:	VIS-SPE-IOA-20000-0010
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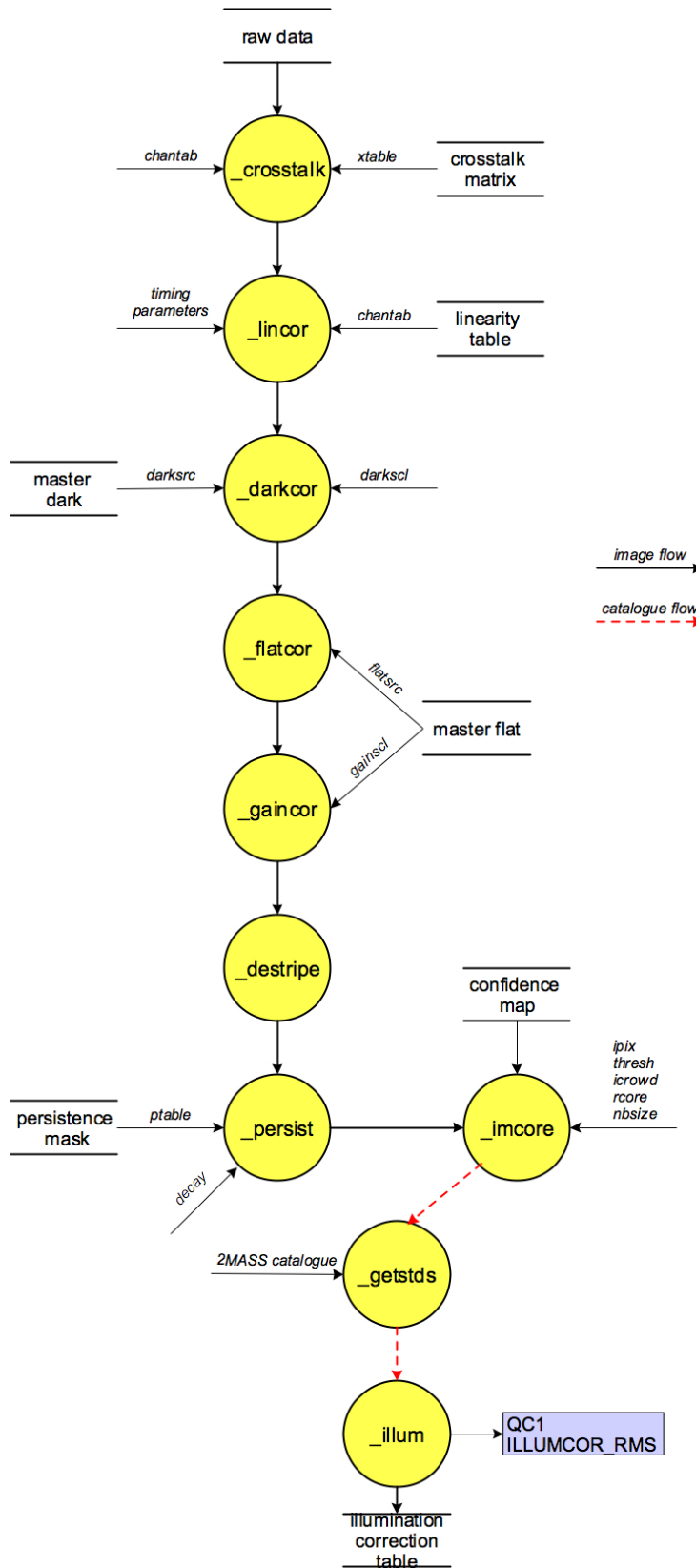


Figure 3-10 vircam\_mesostep\_analyse



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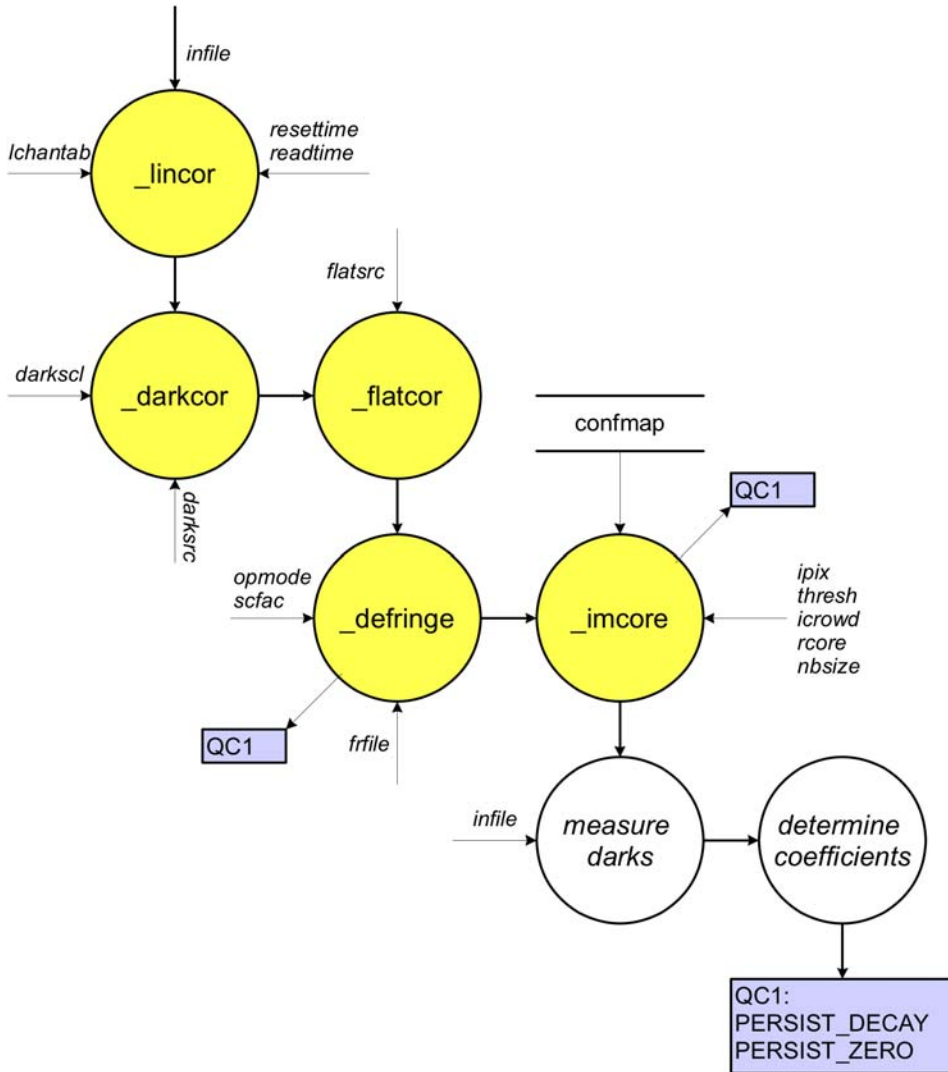


Figure 3-11 vircam\_persistence\_analyse

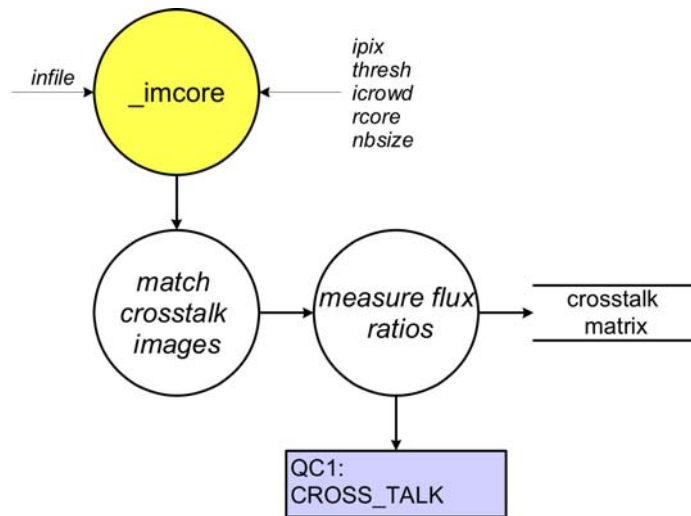


Figure 3-12 vircam\_crosstalk\_analyse

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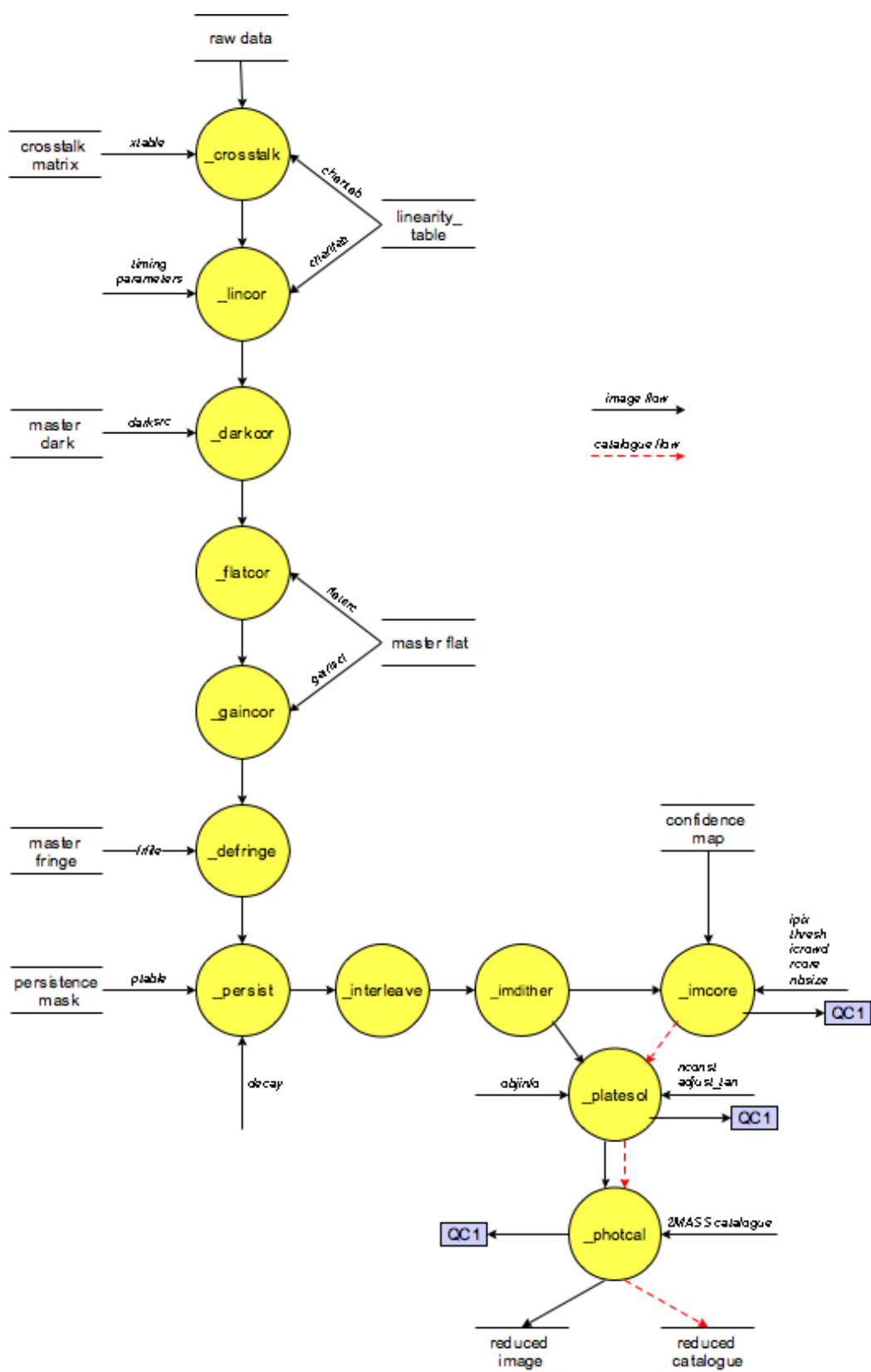


Figure 3-13 vircam\_jitter\_microstep\_process

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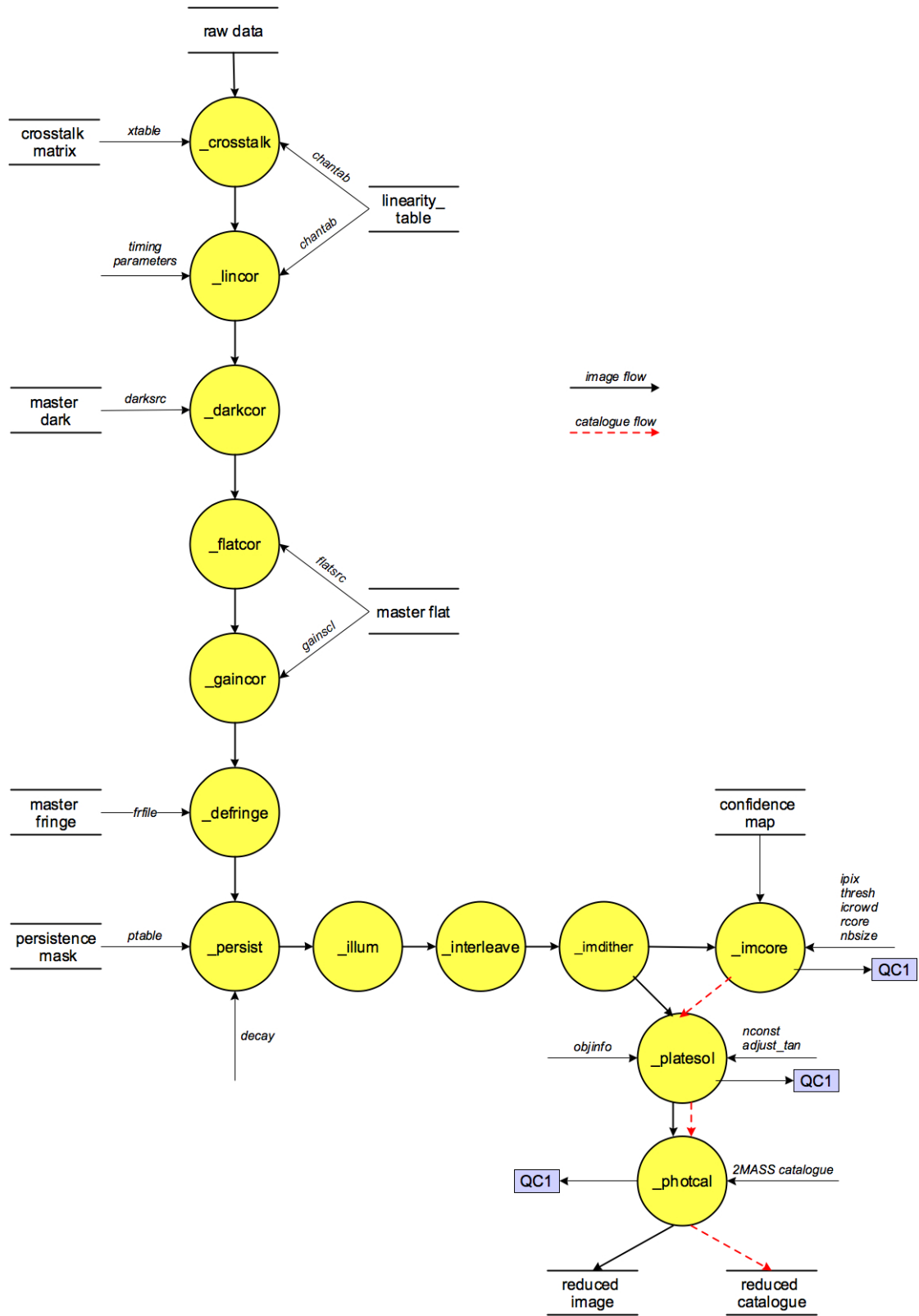


Figure 3-14 `vircam_standard_process`

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## 4 Instrument Data Description

There is only one data format, used in both IMAGING and HOWFS modes; but note, however, HOWFS data is analysed in real time on the instrument workstation and is not passed to the pipeline, and so will not be further considered here. Data frames will be in ESO modified standard FITS format [RD 5], the ESO modifications being limited to the hierarchical header proposal, and compliant with DICB standards [AD5]. The headers are also compliant with the final World Coordinate System (WCS) specification [RD 8]. Data from the full set of chips are stored in Multi Extension Format (MEF) as 32-bit signed integers [RD 6]. 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.

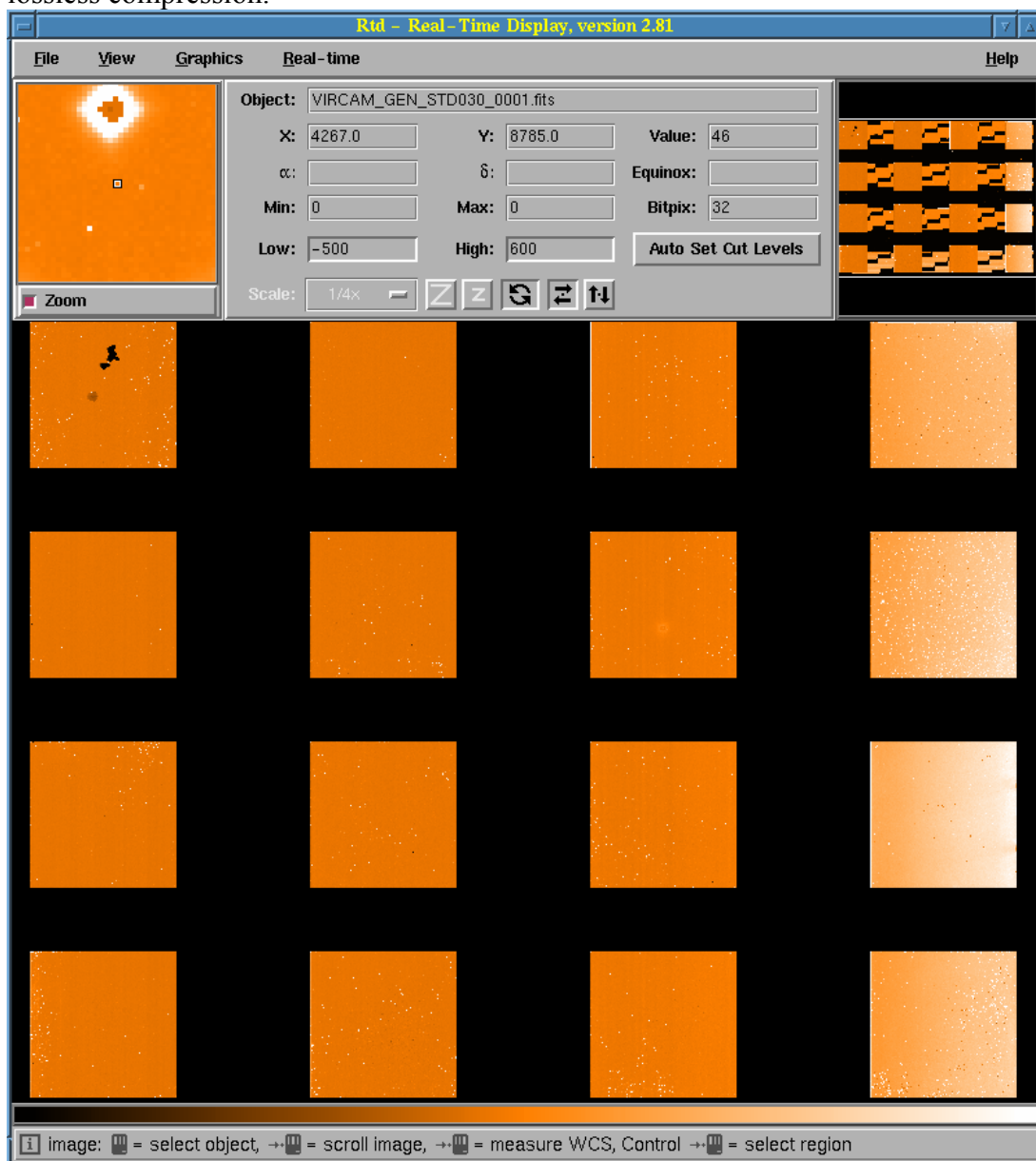


Figure 4-1 A VIRCAM engineering readout shown displayed in the ESO-VLT Real-Time Display Tool

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Raw VIRCAM data will contain headers from ESO standard DPR, OBS, TPL dictionaries and at least the following set of data dictionaries (and see [RD 2]):

- ESO-VLT-DIC.VIRCAM\_CFG
- ESO-VLT-DIC.VIRCAM\_HOWFS
- ESO-VLT-DIC.VIRCAM\_ICS
- ESO-VLT-DIC.VIRCAM\_OS
- ESO-VLT-DIC.VTCS
- ESO-VLT-DIC.IRACE

A full simulated FITS header is illustrated in the appendix (section 11).

A full 256MByte VIRCAM exposure simulation is shown in Figure 4-1, and two examples shown organised by GASGANO in Figure 4-2 demonstrate the compliance of the data format design with ESO data-interface standards.

The flow from raw data types and the templates which generate them, through the processing recipes and required calibration data, to final data products is shown in the data-processing table (Table 4-1, below).

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GASGANO Version: 2.1.2 psb / SunOS

File Selected files Tools Help

Group by Telescope expand Find entry: find

Displaying 2 files grouped by telescope. Unfiltered.

ESO-VISTA

68.A-0291(A) VIRCAM J Lewis

666 deep-tile

File	CLASSIFICATION	TPL.ID	ORIGFILE	TPL.EXPNO	TPL.NEXP
VIRCAM.2004-11-24T14:44:0.123.fits	JITTER_OBJ	VIRCAM_img_obs_paw...	VIRCAM_Ima.1.fits	2	6
VIRCAM.2004-11-24T15:49:0.123.fits	JITTER_OBJ	VIRCAM_img_obs_paw...	VIRCAM_Ima.1.fits	2	6

/data/cass55b/psb/vista/art/data/VIRCAM.2004-11-24T15:49:0.123.fits VIRCAM\_Ima.1.fits JITTER\_OBJ

Extension: IMAGE, WIN1.CHIP1.OUT1, 1 Find in header: find Load Filter Filter Auto Display

Keyword	Value
TELENCLMOONSCR.STATE	1
TELENCLWINDSCR1.STATE	OPEN
TELENCLWINDSCR2.STATE	UP
TELENCLVENT1.STATE	SHUT
TELENCLVENT2.STATE	HALF
TELENCLVENT3.STATE	OPEN
TEL.M2.LOOP1.STATE	CLOSED
TEL.M2.LOOP2.STATE	OPEN
TEL.M2.LOOP3.STATE	CLOSED
TEL.M2.LOOP4.STATE	CLOSED
TEL.M2.LOOP5.STATE	CLOSED
TEL.M2.CENX	1.51
TEL.M2.CENY	1.52
TEL.M2.TILTX	1.53
TEL.M2.TILTY	1.54
TEL.M1.ACTUATORFAILED	1
EXTENSION	IMAGE, WIN1.CHIP1.OUT1, 1
XTENSION	IMAGE
BITPIX	32
NAXIS	2
NAXIS1	2048
NAXIS2	2048
PCOUNT	0
GCOUNT	1
EXTNAME	WIN1.CHIP1.OUT1
EXTVER	1

Figure 4-2 Synthetic VISTA data shown organised by GASGANO

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

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



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

**Table 4-1 Data Processing Table**

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## 5 DRL Data Structures

### 5.1 Introduction to Data Products

The main pipeline products will be images stored as image extensions in multi-extension FITS files, and derived parameters from the processing stored as FITS keyword/value pairs in the appropriate FITS header units.

All science frames will be corrected for the standard instrumental signatures such as flat fielding and dark current, and for other possible electronic artefacts, such as crosstalk, persistence and reset anomalies. In addition all pawprint images will be astrometrically and photometrically calibrated, with the calibration information being stored as FITS header keywords in each image extension. A header keyword that associates each FITS image file with its confidence map file will also be included in the primary header unit. This keyword is in the form of a timestamp and is stored in the key ESO DRS VIR\_TIME.

The pipeline will also generate detected object catalogues for each science image which will be used in deriving much of the QC and calibration information. These will be stored as multi-extension FITS binary tables with a copy of the FITS header information from the FITS image files and a one-to-one correspondence of table and image extensions. Derived QC and calibration information will be added to these FITS catalogue files and also propagated to the FITS image files as described in [AD5]. In general the pipeline products fall into one of the following classes:

#### Science Images:

- images of single exposures
- pawprints arising from combining (stacking) jitter and microstep sequences

#### Object Catalogues:

- lists of detected parameterised objects for each science image (see 5.12)

#### Derived On-sky Calibration Information:

- Photometric zero points
- WCS coefficients
- other QC parameters (see Appendix for full specification)

#### Confidence Maps:

- Bad pixel masks derived from dome flat sequences
- Single image confidence maps derived from twilight flats and bad pixel masks
- Stacked/interleaved image confidence maps which also include effective exposure maps

#### Calibration Maps:

- Master combined dark frames
- Master combined flat field images
- Master eigen-fringe frames

#### Other Calibration Products:

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- Non-linearity coefficients for each data channel of each detector
- Persistence coefficients for each detector
- A 256x256 crosstalk matrix for the entire focal plane
- Illumination correction tables

Products from these lists that require extra explanation are discussed in the rest of this chapter. Table 5-1 lists all of the data products that are generated and their respective PRO.CATG keyword values. Table 5-2 and Table 5-3 give the DO.CATG keywords for the raw and calibration data required for each recipe. For the sake of completeness these tables include entries for the test procedures described in Chapter 8, but it is important to note that output data arising from the test procedures are not to be considered proper science products as described in this chapter.

<b>Product</b>	<b>PRO.CATG</b>
<b><i>Crosstalk products</i></b>	
Crosstalk matrix	XTALK_TABLE
<b><i>Master dark frame products</i></b>	
Master dark frame	MASTER_DARK
Master dark frame difference image	DIFFIMG_DARK
Master dark frame difference image stats table	DIFFIMG_STATS_DARK
<b><i>Master dark current products</i></b>	
Master dark current frame	MASTER_DARK_CURRENT
<b><i>Detector noise products</i></b>	
Detector noise table	READGAIN_TABLE
<b><i>Dome flat products</i></b>	
Master dome flat frame	MASTER_DOME_FLAT
Master dome flat frame ratio image	RATIOIMG_DOME_FLAT
Master dome flat frame ratio image stats table	RATIOIMG_STATS_DOME_FLAT
<b><i>Jitter/Microstep products</i></b>	
Single image	SIMPLE_IMAGE_SCI
Interleaved image	INTERLEAVED_IMAGE_SCI
Jittered image	JITTERED_IMAGE_SCI
Confidence map	CONFIDENCE_MAP_SCI
Object catalogue	OBJECT_CATALOGUE_SCI
<b><i>Linearity analysis products</i></b>	
Master channel table	MASTER_CHANNEL_TABLE
Master bad pixel mask	MASTER_BPM
<b><i>Mesostep analysis products</i></b>	
Illumination correction table	ILLCOR_TAB_MES
<b><i>Persistence Analysis products</i></b>	
Persistence mask table	PERSIST_MASK
<b><i>Master reset frame products</i></b>	
Master reset frame	MASTER_RESET
Master reset frame difference image	DIFFIMG_RESET
Master reset frame difference image stats table	DIFFIMG_STATS_RESET
<b><i>Standard star analysis products</i></b>	
Single image	SIMPLE_IMAGE_STD
Interleaved image	INTERLEAVED_IMAGE_STD
Jittered image	JITTERED_IMAGE_STD

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<b>Product</b>	<b>PRO.CATG</b>
<i>Crosstalk products</i>	
Crosstalk matrix	XTALK_TABLE
Confidence map	CONFIDENCE_MAP_STD
Object catalogue	OBJECT_CATALOGUE_STD
Illumination correction table	ILLCOR_TAB_STD
<i>Master twilight flat products</i>	
Master twilight flat frame	MASTER_TWILIGHT_FLAT
Master twilight flat frame ratio image	RATIOIMG_TWILIGHT_FLAT
Master twilight flat frame ratio image stats table	RATIOIMG_STATS_TWILIGHT_FLAT
Master confidence map	MASTER_CONF
<i>Products from test procedures</i>	
Single image	SIMPLE_IMAGE_TEST
Standards table	STANDARDS_TABLE
Matched standards table	MATCHED_STANDARDS_TABLE
Object catalogues	OBJECT_CATALOGUE_TEST
Jittered image	JITTERED_IMAGE_TEST
Confidence map	CONFIDENCE_MAP_TEST
Interleaved image	INTERLEAVED_IMAGE_TEST

**Table 5-1 PRO categories for data products**

<b>Input Data</b>	<b>DO.CATG</b>
<i>Crosstalk raw input</i>	
Crosstalk images	OBJECT,CROSSTALK
<i>Dark combine raw input</i>	
Dark images	DARK
<i>Dark current raw input</i>	
Dark current images	DARK,DARKCURRENT
<i>Detector noise raw input</i>	
Dome flat images	FLAT,LAMP,GAIN
Dark images	DARK,GAIN
<i>Dome flat raw input</i>	
Dome flat images	FLAT,LAMP
<i>Jitter/Microstep raw input</i>	
Science images	OBJECT
Science images (extended objects)	OBJECT,EXTENDED
<i>Linearity analysis raw input</i>	
Dome flat images	FLAT,LAMP,LINEARITY
Dark images	DARK,LINEARITY
<i>Mesostep analysis raw input</i>	
Standard images	STD,ILLUMINATION
<i>Persistence Analysis raw input</i>	
Object images	OBJECT,PERSISTENCE
Dark frames	DARK,PERSISTENCE
<i>Reset combination raw input</i>	
Reset frame	BIAS
<i>Standard star analysis raw input</i>	
Standard star image	STD,FLUX
<i>Twilight flat combination raw input</i>	

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<b>Input Data</b>	<b>DO.CATG</b>
<i>Crosstalk raw input</i>	
Crosstalk images	OBJECT,CROSSTALK
Twilight flat frame	FLAT,TWILIGHT
<i>Test procedure raw input</i>	
Test science image	SCIENCE_IMAGE

**Table 5-2 DO categories for raw input to recipes**

<b>Input Data</b>	<b>DO.CATG</b>
<i>Reference calibration data</i>	
Reference reset image	REFERENCE_RESET
Reference dark image	REFERENCE_DARK
Reference dome flat image	REFERENCE_DOME
Reference twilight flat image	REFERENCE_TWILIGHT_FLAT
<i>Master calibration frames</i>	
Master reset frame	MASTER_RESET
Master dark frame	MASTER_DARK
Master dome flat frame	MASTER_DOME_FLAT
Master twilight flat frame	MASTER_TWILIGHT_FLAT
Master confidence map	MASTER_CONF
Master bad pixel mask	MASTER_BPM
Master fringe frame	MASTER_FRINGE
Master channel table	MASTER_CHANNEL_TABLE
Master read/gain file	MASTER_READGAIN_TABLE
<i>Static calibration data</i>	
Initial channel table	CHANNEL_TABLE_INIT
Photometric calibration table	PHOTCAL_TAB
<i>Calibration for test procedures</i>	
Standards table	STANDARDS_TABLE
Matched standards table	MATCHED_STANDARDS_TABLE
Object catalogue	OBJECT_CATALOGUE

**Table 5-3 DO categories for recipe calibration data**

It is imperative that a recipe continue on as best it can until all frames in the input frameset are processed. Thus in the event of some sort of failure, the recipe may have to generate 'dummy' data products. These are images, tables etc. that are written to a FITS extension in the place of the data product that you would have normally expected from the given recipe. Dummy products are necessary in the event that you are processing many/all of the available extensions in one go. The dummy frames hold a position in the output data product FITS file where the real product should have gone, had there not been a failure. The types of failure that will generate dummy products are: the headers of the input frames indicate that detector was dead during the observation; an inability to load the necessary FITS image extensions for a particular detector; missing header information etc. A dummy product will be flagged with the Boolean header item ESO DRS IMADUMMY.

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## 5.2 Channel Table

Each VIRCAM detector will be split into 16 different data channels, each with its own electronics. This means that some reduction tasks will rely on knowing the location and readout timing information for each data channel. The location and linearity information will be provided by the 'channel table'. The information will be stored in a multi-extension FITS file with each extension being a FITS binary table (one for each detector). Each of the tables will contain the columns listed in below (although perhaps not in this order). The extension name should match the extension names for the input images. It is worth remembering here that there is no zeroth order coefficient, so the number of coefficient columns is the same as the polynomial order.

Two types of channel tables will be employed as shown in Table 5-1 and Table 5-3. A recipe which requests a table of type CHANNEL\_TABLE\_INIT will only make use of the positional information for the channels. Any information about the linearity and the readout parameters will be ignored. If a MASTER\_CHANNEL\_TABLE is requested, then the recipe will need the linearity information.

Column	Name	Type	Units	Description
1	channum	int		Number of the data channel, which is an integer from 1-16. This is a unique ID for the data channel in the context of the detector of which it is a part.
2	ixmin	int	pixels	The X coordinate of the lower left corner of the data channel
3	ixmax	int	pixels	The X coordinate of the upper right corner of the data channel
4	iymin	int	pixels	The Y coordinate of the lower left corner of the data channel
5	iymax	int	pixels	The Y coordinate of the upper right corner of the data channel
6	dcrpix1	int	pixels	The X coordinate of the location within the data channel where the first pixel is read out.
7	dcrpix2	int	pixels	The Y coordinate of the location with the data channel where the first pixel is read out.
8	dcd1_1	int		Can take the values (-1,0,1). Gives the partial derivative of the fast readout axis with respect to the X axis.
9	dcd1_2	int		Can take the values (-1,0,1). Gives the partial derivative of the fast readout axis with respect to the Y axis.
10	dcd2_1	int		Can take the values (-1,0,1). Gives the partial derivative of the slow readout axis with respect to the X axis.
11	dcd2_2	int		Can take the values (-1,0,1). Gives the partial derivative of the slow readout

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				axis to the Y axis.
12	qualfit	double		The quality of the linearity fit for this channel
13	lin_10000	double		The percentage non-linearity for the current channel at a level of 10000 ADU
14	norder	int		The order of the polynomial used in the fit.
15	coeff_1	double		The first coefficient in the fit. This must be set to 1 always
.				
.				
.				
14+n	coeff_n	double		The nth order coefficient, where n=norder

### **5.3 Bad Pixel Mask**

As we mentioned in section 2.13 on confidence maps, it is essential for many of the operations of the pipeline to know exactly which pixels in each image are always likely to be bad. This is done initially using a bad pixel mask. This will take the form of a FITS container file with an image extension of type byte for each detector. The values in the data array will be set to one for bad pixels and zero for good ones.

### **5.4 Confidence Maps**

Confidence maps combine bad pixel information with variance information in composite images, as described fully in 2.13. The maps are kept as FITS MEF files in short integer format in which zero equates to completely bad pixel and 100 to completely good pixel.

### **5.5 Dark Current Image**

Dark current is calculated by a looking at the time rate of change of the data in a series of dark frames taken with a variety of exposure times on a pixel by pixel basis. The result is a map with an estimate of the dark current (in ADU/sec) for each pixel.

### **5.6 Crosstalk Matrix**

Detector crosstalk is described in section 2.9. In order to correct for this effect we need a factor that defines the effect of one channel on a second one, i.e. a crosstalk matrix. This will be generated on an occasional basis and will be stored in the form of a FITS binary table with the following columns:

Column	Name	Type	Units	Description
1	source	int		The channel index of the crosstalk source

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2	victim	int		The channel index of the victim of the crosstalk
3	coef	float		The scaling factor required to remove the source crosstalk from the victim.

The information in this table will be used by the crosstalk correction routine in conjunction with the channel table (5.1).

### **5.7 Illumination Correction Table**

The effect of large scale background variation in the flat field images (usually due to scattered light) are described in section 2.16. An illumination correction table is generated by dividing the image plane into a number of boxes, using the systematic photometric zeropoint changes across the image to define the correction for each box. This is used to correct the instrumental magnitudes of subsequent observations for positional biases. This will be stored in the form of a series of binary FITS tables (one per detector) in a single MEF container with the following columns:

Column	Name	Type	Units	Description
1	xmin	int	pixels	The X position of lower left corner of the box
2	xmax	int	pixels	The X position of upper right corner of the box
3	ymin	int	pixels	The Y position of lower left corner of the box
4	ymax	int	pixels	The Y position of upper right corner of the box
5	illcor	float	mag	The illumination correction for the box

### **5.8 Difference/Ratio Images**

Some of the recipes will attempt to monitor performance of the detectors by comparing current images with library versions (e.g. dark frames). For additive effects like reset and dark current this can most easily be achieved with a difference image. This is simply the difference of two images in the sense of the master subtracted from the current image. Similarly for multiplicative effects like flat fielding this is most easily achieved with a ratio image which is the current image divided into the master image.

### **5.9 Difference/Ratio Image Statistics Tables**

For recipes that monitor detector performance in particular, it is often worthwhile to keep statistical information on difference/ratio images. This is because frames are often compared to library frame either by forming a difference or a ratio and the statistics in cells or subsections across the output image can be a useful diagnostic to detector performance. A difference/ratio image statistics table will be a FITS table with the following columns defined:



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Column	Name	Type	Units	Description
1	xmin	int	pixels	The X position of lower left corner of the cell
2	xmax	int	pixels	The X position of upper right corner of the cell
3	ymin	int	pixels	The Y position of lower left corner of the cell
4	ymax	int	pixels	The Y position of upper right corner of the cell
5	chan	int		The data channel to which this cell belongs. This is only useful if the whole cell fits into a data channel.
5	mean	float	adu	The mean value in the cell
6	median	float	adu	The median value in the cell
7	variance	float	adu	The variance of the values in the cell
8	mad	float	adu	The median absolute deviation from the median of the values in the cell.

### **5.10 Persistence Mask Table**

Dealing with image persistence properly requires knowledge of observations that were done previous to the current one. In the on-line pipeline this can be approximately accomplished by processing the observations from a particular template with respect to the times that they were done. This sort of information then can be used in conjunction with the persistence decay time constant and the end time of the current exposure to decide which frames will have affected the current image and how to scale them to correct the problem. The columns for the persistence mask table are:

Column	Name	Type	Units	Description
1	srcimage	char		The name of the source image
2	srctime	int	seconds	The end time of the source observation in seconds from 1 Jan 2000.

### **5.11 Standards Table**

During the course of the pipeline reductions it will be necessary to extract information from standard astrometric and photometric catalogues. The results of this extraction will be in an Extracted Standards Table and will contain the following columns:

Column	Name	Type	Units	Description
1	xpredict	float	pixels	The X position of the matching standard

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				as predicted from the image WCS and the object's equatorial coordinates.
2	ypredict	float	pixels	The Y position of the matching standard as predicted from the image WCS and the object's equatorial coordinates.
3	RA	float	degrees	The standard's RA
4	Dec	float	degrees	The standard's Dec
5 – n	mags	float	mags	Any photometric information that might exist in the standard star catalogue

## 5.12 Object Catalogues

The derived object catalogues are stored in multi-extension FITS files as binary tables, one for each image extension. Each detected object has an attached set of descriptors, forming the columns of the binary table, and summarising derived position, shape and intensity information (see section 2.14 for more details).

The following columns are present:

Column	Name	Description
1	Sequence number	Running number for ease of reference, in strict order of image detections
2	Isophotal_flux	Standard definition of summed flux within detection isophote.
3	X_coordinate	The $x$ , $y$ coordinates and errors with (1, 1) defined to be the centre of the first active pixel in the image array. See 2.14.2.
4	X_coordinate_err	
5	Y_coordinate	
6	Y_coorindate_err	
7	Gaussian_sigma	Second moment parameters. See 2.14.2
8	Ellipticity	
9	Position_angle	
10	Areal_1_profile	The number of pixels above a series of threshold levels, relative to local sky. The levels are set at T, 2T, 4T, 8T, 16T, 32T, 64T and 128T where T is the analysis threshold
11	Areal_2_profile	
12	Areal_3_profile	
13	Areal_4_profile	
14	Areal_5_profile	
15	Areal_6_profile	
16	Areal_7_profile	
17	Areal_8_profile	
18	Peak_height	Peak intensity and its error in ADU relative to local value of sky
19	Peak_height_err	
20	Aper_flux_1	Flux and error within a specified radius aperture, typically set so that $R_{aperture} = \langle FWHM \rangle$ where the
21	Aper_flux_1_err	
22	Aper_flux_2	

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23	Aper_flux_2_err	quantity in angle brackets is the mean FWHM of all stellar images. This is also known as the “core radius”. The apertures here correspond to $(0.5, 1/\sqrt{2}, 1, \sqrt{2}, 2, 2\sqrt{2}, 4, 5, 6, 7, 8, 10, \text{ and } 12)$ times the core radius.
24	Aper_flux_3	
25	Aper_flux_3_err	
26	Aper_flux_4	
27	Aper_flux_4_err	
28	Aper_flux_5	
29	Aper_flux_5_err	
30	Aper_flux_6	
31	Aper_flux_6_err	
32	Aper_flux_7	
33	Aper_flux_7_err	
34	Aper_flux_8	
35	Aper_flux_8_err	
36	Aper_flux_9	
37	Aper_flux_9_err	
38	Aper_flux_10	
39	Aper_flux_10_err	
40	Aper_flux_11	Petrosian radius $r_p$ in pixels as defined in Yasuda, et al. 2001, AJ, 112, 1104.
41	Aper_flux_11_err	
42	Aper_flux_12	Kron radius $r_k$ in pixels as defined by Bertin and Arnouts 1996, A & A Supp, 117, 393.
43	Aper_flux_12_err	
44	Aper_flux_13	Hall radius $r_h$ in pixels as defined by Hall and Mackay 1984, MNRAS, 210, 979.
45	Aper_flux_13_err	
46	Petr_radius	Petrosian flux and error to $2r_p$
47	Kron_radius	
48	Hall_radius	Kron flux and error to $2r_k$
49	Petr_flux	
50	Petr_flux_err	Hall flux and error to $5r_h$ . Alternative total flux.
51	Kron_flux	
52	Kron_flux_err	Bit pattern listing various processing error flags. Currently this is the number of bad pixels included in the aperture flux (Aper_flux_3)
53	Hall_flux	
54	Hall_flux_err	Local interpolated sky level from background tracker
55	Error_bit_flag	
56	Sky_level	Local estimate of variation in sky level around images
57	Sky_rms	
58	Parent_or_child	Flag for parent or part of de-blended deconstruct.
59	RA	
60	Dec	RA and Dec of each object in degrees. These are added during WCS refinement

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61	Classification	simple flag indicating most probable classification for object: <b>-2:</b> Object is compact (maybe stellar) <b>-1:</b> Object is stellar <b>0:</b> Object is noise <b>1:</b> Object is non-stellar
	Statistic	an equivalent $N(0,1)$ measure of how stellar-like an image is. It is used in deriving the classification (25) in a “necessary but not sufficient” sense. This statistic is computed from a discrete curve-of-growth analysis from the peak and aperture fluxes and also factors in ellipticity information. The stellar locus is used to define the “mean” and “sigma” as a function of magnitude such that the “statistic” can be normalised to an approximate $N(0,1)$ distribution.
63-80	blank	

### 5.13 Matched Standards Table

When doing astrometric and/or photometric reduction it is necessary to match astronomical objects that appear on an image with objects from a standard catalogue. The output from such a matching algorithm is called a Matched Standards Table and will contain all the columns from both input tables (cf. 5.11 and 5.12).

### 5.14 Readnoise/Gain Table

This is a multi-extension FITS file where each extension is a FITS table with a single row. Each extension will have ESO QC READNOISE and ESO QC GAIN in its header with the read noise and gain estimate. The table replicates these results with the following columns:

Column	Name	Type	Description
1	extname	char	The name of the chip to for the current noise values
2	readnoise	float	The readout noise of the chip in units of electrons.
3	gain	float	The gain of the chip in units of electrons per ADU

### 5.15 Photometric Calibration Table

This is a table used to define the transformation from instrumental to standard magnitudes.

Column	Name	Type	Description
1	filter	char	The name of the filter
2	extinction	float	The extinction coefficient for airmass of unity for the given filter.
3	offset	float	A pedestal value to be added to the instrumental magnitude once the colour equation has been applied.

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4	columns	char	The standard magnitude columns from the matched standards catalogue to be used. This is the names of the columns separated by a comma.
5	coeq	char	The colour equation coefficients. There should be one coefficient for each of the columns mentioned in the columns field. This should be formatted as a series of floating point numbers separated by commas.

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## 6 DRL Functions

In what follows we describe the low level functions that will be driven by the VIRCAM pipeline. The parameter list describes the full API for each function. Many of the functions make use of the following structures:

- **vir\_fits:** This is a convenience structure that binds the **cpl\_image** object for a particular image with the name of the originating FITS file, the image extension number, the primary header propertylist and the propertylist for the extension header.
- **vir\_tfits:** In a similar way, functions that get information from an existing FITS table will have parameters declared **vir\_tfits**. This wraps a **cpl\_table** object with the same ancillary information as above for **vir\_fits**.
- **vir\_mask:** This is provided as a means to load and manipulate stand-alone bad pixel masks. These can come from a bad pixel mask FITS file or a confidence map.

A feature of the DRL functions is an inherited status parameter. This is always the last in the parameter list and it is also the return value from each function. Each function will test the status value as its first action and return immediately if the status is bad. The error messages will be passed through the CPL error structure and hence information on the origin and cause of any error will not be lost by using inherited status.

CPL currently has no facility for generating or manipulating the information required for a full World Coordinate System. As this is a vital piece of information for any astronomical observation we have sought to rectify this situation by importing a WCS package into the VIRCAM software. This package is called **wcslib** and was written by Mark Calabretta, who is one of the leading authorities on the representation of world coordinate systems in astronomy. The VIRCAM pipeline accesses the functions in **wcslib** through a simple set of wrapper routines. These were written in anticipation that CPL itself would eventually provide this kind of functionality. When it does, then just the internals of the wrapper routines will need rewriting.

In this chapter we have simplified the descriptions of the functions by omitting both very obvious and repetitive features. A list of these shortcuts is included below.

- We have not enumerated very obvious keywords in the input or output header lists. These include things like the data array size, data type and data dimensionality.
- Inherited bad status will cause each function to return immediately without updating the CPL error message.
- A fatal error condition in a function will cause an appropriate CPL error message to be set and will cause the function to return to the calling routine immediately where the pipeline can take the necessary steps to terminate gracefully. We do not include segmentation violations, arithmetic exceptions and the like in the definition of a fatal error.

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- Very obvious error conditions such as corrupted input files, running out of disc space, etc have been omitted for brevity.
- Any function parameters that refer to image data will have the expected data type in square brackets next to the parameter name.

## 6.1 *vircam\_crosstalk*

### 6.1.1 General

**Name:**

vircam\_crosstalk

**Purpose:**

Remove electronic crosstalk from an image

**General Description**

Electrical crosstalk is removed from each data channel in the input images by means of a crosstalk matrix (see section 5.6). The latter consists of factors by which the data from one channel affects another. The applicability is to be decided during laboratory and on-sky tests.

**Mathematical Description:**

See section 2.9 for a full mathematic description of crosstalk removal.

### 6.1.2 Function Parameters

None

### 6.1.3 Input Images and Required FITS Header Information.

**infile** (float)

The input science container-file to be corrected; this must contain a full list of all the source and victim images.

### 6.1.4 Input Tables

**xtable**

The crosstalk matrix (see 5.6)

**chantab**

The channel table (see 5.2)

### 6.1.5 Output Images

**outfile** (float)

The output science image; if this is the same as the value for **infile** or is blank, then the output will overwrite the input.

keyword	type	description
DRS XTCOR	char	The name of crosstalk matrix table used

### 6.1.6 Output Tables

None

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### 6.1.7 Other Output

None

### 6.1.8 QC1 Outputs

None

### 6.1.9 Quality Assessment

Crosstalk artefacts are removed to with the expected sky noise

### 6.1.10 Error Conditions

- There are no fatal error conditions.
- There are no non-fatal error conditions

## 6.2 *vir*cam\_ darkcor

### 6.2.1 General

**Name:**

vircam\_ darkcor

**Purpose:**

Remove reset anomaly and dark current using a library mean dark frame of matching exposure/integration time if available.

**General Description**

The data array of the input dark frame is multiplied by a predetermined factor such that it matches the scale of the reset anomaly in the target object frame. The scaled dark frame is then subtracted from the target frame.

**Mathematical Description:**

$$I_i^{out} = I_i^{in} - kD_i$$

where  $I$  is the input data,  $D$  is the mean dark frame data and  $k$  is the scaling factor.

### 6.2.2 Function Parameters

vir\_fits \*infile [float]

The input science image to be corrected. This will be overwritten by the corrected image

vir\_fits \*darksrc [float]

The input mean dark image

float darkscl

An input scaling factor. This corresponds to the value of  $k$  in the mathematical description above.

int \*status

Input/output status from function.

### 6.2.3 Required Input FITS Header Information

None



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### 6.2.4 Output FITS Header Information

The following will be appended to the extension header for **infile**.

<b>keyword</b>	<b>type</b>	<b>description</b>
DRS DARKCOR	char	The name of the master dark file specified in <b>darksrc</b>
DRS DARKSCL	float	The scale factor used in the subtraction

### 6.2.5 QC1 Outputs

None

### 6.2.6 Quality Assessment

Reset anomaly ramp removed

### 6.2.7 Fatal Error Conditions

- Mismatched data array dimensionality between the input images
- The image data fails to load

### 6.2.8 Non-Fatal Error Conditions

None

## 6.3 *vircam\_defringe*

### 6.3.1 General

**Name:**

*vircam\_defringe*

**Purpose:**

Remove fringe patterns from an image using a mean fringe frame and a scaling algorithm

**General Description**

Large scale variations are removed from the input frame by dividing the image into squares over which a background median can be determined and then constructing an interpolated background correction. The fringe image is scaled by a value and subtracted from the input image. Statistics of the image show whether the scale factor used was too high or too low. The scale factor is adjusted and the fit is attempted again. This is repeated to convergence. Once convergence is achieved, then the fringes are removed with the correct scale factor. The background map variation is then added back in.

**Mathematical Description:**

$I_i = I_i - k * Fr_i$  where  $I$  is the input image data,  $k$  is the fringe scaling factor and  $Fr$  is the fringe data. For a full description of how the scale factor and the fringe data are computed see section 2.7.

### 6.3.2 Function Parameters

*vir\_fits* **\*\*infile** [float]

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The input science images to be corrected. These gets overwritten by the corrected images

int **nfiles**

The number of science images in the infiles list

vir\_fits **\*\*fringes** [float]

The list of fringe images

int **nfringes**

The number of fringe images in the input list

vir\_mask **\*mask**

The input bad pixel mask

int **nbsize**

The size of the cell for background modelling

int **\*status**

Input/output status from function

### 6.3.3 Required Input FITS Header Information

None

### 6.3.4 Output FITS Header Information

The following will be appended to the extension header for each input image

keyword	type	description
DRS FRINGEn	char	The name of the fringe file used in the nth defringing pass
DRS FRNGSCn	float	The scale factor for the nth defringing pass.

### 6.3.5 QC1 Outputs

FRINGE\_RATIO

### 6.3.6 Quality Assessment

The FRINGE\_RATIO indicates that the background variation has decreased significantly

### 6.3.7 Fatal Error Conditions

None

### 6.3.8 Non-Fatal Error Conditions

None

---

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## 6.4 *vircam\_destripe*

### 6.4.1 General

**Name:**

vircam\_destripe

**Purpose:**

Remove background stripes

**General Description**

The stripes in the background of an image are modelled by doing a block median of each row. This gives a 1d profile which is normalised to zero median. Each point on the profile is subtracted from a row in the input image. Bad pixels or object pixels can be removed with a bad pixel mask or a confidence map.

**Mathematical Description:**

None

### 6.4.2 Function Parameters

vir\_fits \*in [float]

The input science image to be corrected. This gets overwritten by the corrected image

vir\_mask \*inbpm

The input mask

int \*status

Input/output status from function

### 6.4.3 Required Input FITS Header Information

None

### 6.4.4 Output FITS Header Information

The following will be appended to the extension header for **in**.

keyword	type	description
DRS STRIPECOR	bool	Set if the stripe correction has been done
DRS STRIPERMS	float	The RMS of the stripe pattern removed from the image

### 6.4.5 QC1 Outputs

None

### 6.4.6 Quality Assessment

None

### 6.4.7 Fatal Error Conditions

- The image data fails to load

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#### 6.4.8 Non-Fatal Error Conditions

None

---

### 6.5 *vircam\_flatcor*

#### 6.5.1 General

**Name:**

*vircam\_flatcor*

**Purpose:**

Remove large and small scale gain variations by dividing science frames by a mean flat field frame.

**General Description**

The data array of the input image is divided by that from a mean flat field image. The mean flat field should have been normalised in the manner described in section 2.3. This ensures that during this reduction step we perform both for the flat field correction and the detector gain correction.

**Mathematical Description:**

$$I_i^{out} = I_i^{in} / F_i$$

where  $I$  is the input data and  $F$  is the mean flat field data.

#### 6.5.2 Function Parameters

*vir\_fits* \*infile [float]

The input science image to be corrected. This gets overwritten by the corrected image

*vir\_fits* \*flatsrc [float]

The input mean flat field image

int \*status

Input/output status from function

#### 6.5.3 Required Input FITS Header Information

None

#### 6.5.4 Output FITS Header Information

The following will be appended to the extension header for **infile**.

keyword	type	description
DRS FLATCOR	char	The name of the flat field image specified in <b>flatsrc</b>

#### 6.5.5 QC1 Outputs

None

#### 6.5.6 Quality Assessment

Robust estimates of the background of each detector image agree c.f. to expected sky noise.

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### 6.5.7 Fatal Error Conditions

- Mismatched data array dimensionality between the input images
- The image data fails to load

### 6.5.8 Non-Fatal Error Conditions

None

---

## 6.6 *vircam\_gaincor*

### 6.6.1 General

**Name:**

*vircam\_gaincor*

**Purpose:**

Correct input detector for inter-detector pedestal gain difference

**General Description**

An input image is scaled by a constant value so that all the images for a particular observation will effectively have the same gain. The constant will be derived in the manner described in section 2.3

**Mathematical Description:**

$$I_i^{out} = kI_i^{in}$$

where  $I$  is the input data and  $k$  is the scale factor for the given image.

### 6.6.2 Function Parameters

`vir_fits *infile` [float]

The input science image to be corrected. This gets overwritten by the corrected image

float `gainscl`

The multiplicative scale factor  $k$  described above.

int `*status`

Input/output status from function

### 6.6.3 Required Input FITS Header Information

None

### 6.6.4 Output FITS Header Information

The following will be appended to the extension header for `infile`.

keyword	type	description
DRS GAINCOR	float	The value of the gain correction applied to the current image

### 6.6.5 QC1 Outputs

None

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### 6.6.6 Quality Assessment

Robust estimates of the background of each detector image agree c.f. to expected sky noise.

### 6.6.7 Fatal Error Conditions

- The image data fails to load

### 6.6.8 Non-Fatal Error Conditions

None

## 6.7 *vircam\_genlincur*

### 6.7.1 General

**Name:**

*vircam\_genlincur*

**Purpose:**

Generate linearity coefficients given a list of dome flat field exposures.

**General Description:**

A series of dark corrected exposures of a stable dome light source with a range of exposure times should be given. From the known readout, reset, dit-delay and exposure times a timing map is constructed for each pixel according to the algorithm outlined in section 2.2.2. The results are written to a new channel table.

**Mathematical Description:**

This function implements the mathematical description in section 2.2.2

### 6.7.2 Function Parameters

*vir\_fits* **\*\*imlist** [float]

The list of input dark corrected dome flat images

int **nimages**

The number of images in the list

*vir\_tfits* **\*chantab**

The input channel table for the detector represented in the input image list.

This is described in section 5.2.

unsigned char **\*bpm**

A bad pixel mask.

int **norder**

The order of the polynomial to use in the expansion; note that because the zeroth term is defined to be zero, then the number of coefficients this routine will derive is the same as the polynomial order

int **kconst**

A flag, which, if set, signals that the value of  $k$  defined in section 2.2.2 is constant for all pixels in a given image

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cpl\_table \*lchantab

The output channel table.

int \*status

Input/output status from function

### 6.7.3 Required Input FITS Header Information

The following values need to be included in the extension headers of each of the files in **imlist**.

keyword	type	description
EXPTIME	float	The exposure time for the image
ESO DET MINDIT	float	The minimum DIT time
ESO DET DITDELAY	float	A delay between the reset and the first read

### 6.7.4 Output FITS Header Information

None

### 6.7.5 QC1 Outputs

None

### 6.7.6 Quality Assessment

The value of the **qualfit** and **lin\_10000** columns are reasonable for all channels.

### 6.7.7 Fatal Error Conditions

- Invalid channel table.
- Inability to map the data arrays of input images

### 6.7.8 Non-Fatal Error Conditions

- Failed fit for a channel

## 6.8 *vircam\_getstds*

### 6.8.1 General

**Name:**

*vircam\_getstds*

**Purpose:**

Given an input FITS header, extract a list of standard stars from a catalogue that should appear on the relevant image.

**General Description:**

The header of an input image is parsed to locate and read the standard WCS FITS header keywords. The WCS is used to define the coverage of the image in equatorial coordinates. The coverage is used to select objects from the 2MASS point source catalogue. (The catalogue is expected to be made

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available in FITS table form.) Once the stars have been selected the information about them is written to an extracted standards table (5.11) along with their expected  $x,y$  positions based on the input WCS.

**Mathematical Description:**

N/A

**6.8.2 Function Parameters**

**cpl\_propertylist \*plist**

The propertylist representing the FITS header of an input image. This header must have all of the keywords listed in the FITS header section below.

**int cache**

A flag, which, if set, indicates that a local cache should be set up to store catalogues that you have extracted. If used, this can significantly reduce the amount of searching that is required of the whole 2MASS catalogue and hence cut down the amount of time this routine takes. This is especially important when many exposures are being done in the same part of the sky.

**char \*path**

The full path to the directory where the 2MASS FITS tables are held.

**char \*catname**

The name of the catalogue being used

**cpl\_table \*index**

An index table for the catalogue FITS files – this parameter must be NULL on entry for the first time this routine is called and must be deleted explicitly after the last time this routine is called.

**cpl\_table \*\*stds**

The output table of standards

**int \*status**

Input/output status from function

**6.8.3 Required Input FITS Header Information**

The following must be available in the input propertylist **plist**.

<b>keyword</b>	<b>type</b>	<b>description</b>
CRPIX1	double	All of the standard FITS WCS keywords that are relevant for the projection model to be used with VIRCAM (nominally ZPN). See [RD 8] for more specific information
CRPIX2	double	
CTYPE1	char	
CTYPE2	char	
CRVAL1	double	
CRVAL2	double	
CD1_1	double	
CD1_2	double	
CD2_1	double	
CD2_2	double	
PV2_1	double	
PV2_3	double	



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#### 6.8.4 Output FITS Header Information

None

#### 6.8.5 QC1 Outputs

None

#### 6.8.6 Quality Assessment

N/A

#### 6.8.7 Fatal Error Conditions

- Inability to read the index table.
- Inability to read the catalogue tables.

#### 6.8.8 Non-Fatal Error Conditions

- No objects found in the catalogue

### 6.9 *vircam\_illum*

#### 6.9.1 General

**Name:**

*vircam\_illum*

**Purpose:**

Work out the spatial corrections in the photometric zero point.

**General Description:**

This function takes a table of photometric standards and a table of objects extracted from a list of images. The objects in both of the input tables are matched up. The pixel space of the original image is divided up into cells of **nbsize** pixels on a side. The mean zero point for each cell is calculated. Next the ensemble-mean zero point is calculated for all the cells. The illumination correction is then defined for each cell as the residual photometric zero point from that mean. The sense of the illumination correction for a cell is such that it must be subtracted from the mean frame zero point for objects in that cell.

**Mathematical Description:**

This function implements the mathematical description in section 2.16

#### 6.9.2 Function Parameters

`vir_fits` **\*\*images**

The input list of images

`cpl_table` **\*\*mstds**

The list of matched standards tables (section 5.13), one for each input image

`cpl_propertylist` **\*\*pl**

An array of propertylists representing the headers of the object catalogues that were derived from the input images.

`int` **nimages**

The number of images, matched standards catalogues and propertylists.

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char **\*filt**

The name of the filter for these observations.

cpl\_table **\*phottab**

The photometric calibration table (section 5.15)

int **nbsize**

The size of the side of a cell

cpl\_table **\*illcor**

The illumination correction table (section 5.7)

float **\*illcor\_rms**

The RMS of the illumination correction map

int **\*status**

The input/output function status

### 6.9.3 Required FITS Header Information

The following information is required in the extension header of the catalogues (see the parameter **pl**)

keyword	type	description
APCOR3	float	The aperture correction for an aperture of 1x the core radius as calculated by <b>vircam_imcore</b>
ESO QC SATURATION	float	The saturation level in counts

The following information is required from the primary header of the images

keyword	type	description
ESO TEL AIRM START	float	The airmass at the start of the observation.
EXPTIME	float	The exposure time in seconds

### 6.9.4 Output FITS Header Information

None

### 6.9.5 QC1 Outputs

None

### 6.9.6 Quality Assessment

Applying the correction table to the input file should result in a magnitude zero point with an RMS consistent with the mean RMS of the source photometric catalogue. This can be seen with the keyword **DRS MAGZERR** which is generated by **vircam\_photcal** (6.19).

### 6.9.7 Fatal Error Conditions

- Photometric calibration table is incomplete
- No input images
- No rows in matched standards catalogue
- Missing header information in standards catalogue or image

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### 6.9.8 Non-Fatal Error conditions

- No zeropoints can be calculated

## 6.10 *vircam\_imcombine*

### 6.10.1 General

**Name:**

vircam\_imcombine

**Purpose:**

Combine a list of images into an output image. Allow for  $x,y$  shifting, intensity biasing, intensity scaling, image weighting and bad pixel rejection.

**General Description:**

A list of images is combined to form an output image. The output image can be either a mean of the input pixels or a median. The images can have the following done to them before combination:

- the input data values for a given output pixel can be scaled by a preset amount for each input image
- the input data values for a given output pixel can be biased by a preset amount for each input image
- outliers can be masked and rejected

**Mathematical Description:**

None

### 6.10.2 Function Parameters

vir\_fits **\*\*fset** [float]

The input list of images to be combined.

int **nfits**

The number of input images

int **combtype**

A flag to determine whether the output should be a mean or a median of the input frames. 1 == median, 2 == mean

int **scaletype**

A flag to determine how the input will be scaled or biased before combining.

0: No scaling or biasing

1: Input files are biased additively to a common background median

2: Input files are scaled multiplicatively to a common background median

3: Input files are first scaled by exposure time and then biased to a common background.

int **xrej**

If set, then an extra rejection cycle will be performed. This is quite useful doing combinations in the region of bright objects.

float **thresh**

The rejection threshold in units of the background noise.

cpl\_image **\*\*outimage** [float]

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The output combined image  
unsigned char **\*\*rejmask**

The output rejection mask. The value for each pixel tells how many input pixels were rejected at that position.

unsigned char **\*\*rejplus**

The output positive residual rejection mask. The value for each pixel tells how many input pixels were rejected for having residuals that were positive. This is good for determining the number of cosmic ray hits there were on the input images.

cpl\_propertylist **\*\*drs**

An output propertylist for the provenance keywords to go in the DRS extension of the output file header.

int **\*status**

Input/output status from function

### 6.10.3 Required Input FITS Header Information

The following is required to be in the extension header for each image in **fset**.

keyword	type	description
EXPTIME	float	The exposure time for each input image. This is used when doing multiplicative scaling

### 6.10.4 Output FITS Header Information

The following will appear in the extension header of **outimage**.

keyword	type	description
DRS PROVXXXX	char	A set of keywords that describes the provenance of the output file.

### 6.10.5 QC1 Outputs

None

### 6.10.6 Quality Assessment

N/A

### 6.10.7 Fatal Error Conditions

- Unable to map input data arrays
- Unable to create output data arrays

### 6.10.8 Non-Fatal Error Conditions

- Input frame set is empty

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## 6.11 *vircam\_imcore*

### 6.11.1 General

**Name:**

*vircam\_imcore*

**Purpose:**

Generate a catalogue of objects on an image.

**General Description:**

This function is the main object extraction routine. It generates object catalogues for the purposes of astrometric and photometric calibration, generating catalogues of the form described in section 5.12. As a final step each object is given a stellar/non-stellar classification.

**Mathematical Description:**

This function implements the mathematical description in section 2.14

### 6.11.2 Function Parameters

*vir\_fits* **\*infile** [float]

The input frame from which to extract the objects

*vir\_fits* **\*conf** [int]

The input confidence map

int **ipix**

The minimum size of an object in pixels in order for that object not to be considered spurious.

float **thresh**

The detection threshold measured in units of the mean background noise

int **icrowd**

If set, then the function will attempt to de-blend merged objects

float **rcore**

The core radius in pixels for default photometric aperture.

int **nbsize**

The size in pixels of the grid squares used for background estimation.

int **cattype**

The output catalogue type. This can be:

1. The 32 column INT Wide Field Camera format
2. The 80 column WFCAM format
3. A very minimal format which is just fine if only positions are required.
4. An object mask

NB: option 1 corresponds to the catalogues described in section 5.12.

float **filtfwhm**

The FWHM of the smoothing kernel used in the detection algorithm

cpl\_table **\*\*outtab**

The output table of all the detected objects

cpl\_propertylist **\*\*extra**

A propertylist with QC information that one can append to a FITS header

int **\*status**

Input/output status from function

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### 6.11.3 Required FITS Header Information

The following information is required from the extension header of **infile**.

keyword	type	Description
EXPTIME	int	The exposure time of the input data in seconds

### 6.11.4 Output FITS Header Information

The following will be written to the extension propertylist of the input image

keyword	type	Description
DRS SKYLEVEL	float	The mean sky level in the image
DRS SKYNOISE	float	The mean sky noise in the image
DRS THRESHOL	float	The threshold in ADUs for the image detection
DRS RCORE	float	The core radius in pixels as specified in the parameter list
DRS FILTFWHM	float	The FWHM of the smoothing kernel in the detection algorithm
DRS SEEING	float	The derived seeing in pixels
DRS CLASSIFD	int	If set, then this catalogue has been classified
DRS MINPIX	int	The minimum number of pixels an object should cover
DRS CROWDED	int	If set, then the deblending software has been run on this catalogue

### 6.11.5 QC1 Outputs

SATURATION  
MEAN\_SKY  
SKY\_NOISE  
NOISE\_OBJ  
IMAGE\_SIZE  
APERTURE\_CORR  
ELLIPTICITY  
APCORPK  
APCOR1  
APCOR2  
APCOR3  
APCOR4  
APCOR5  
APCOR6  
APCOR7

### 6.11.6 Quality Assessment

N/A

### 6.11.7 Fatal Error Conditions

- Negative threshold value
- Zero or negative sky noise estimate

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- Unable to map input data arrays

### 6.11.8 Non-fatal Error Conditions

- No objects found

## 6.12 *vircam\_imdither*

### 6.12.1 General

**Name:**

vircam\_imdither

**Purpose:**

Dither all the images in a jitter sequence into a single output image

**General Description:**

This function takes all the images and their associated confidence maps from a jitter sequence and dithers them into a single output image and confidence map.

**Mathematical Description:**

None

### 6.12.2 Function Parameters

vir\_fits **\*\*in** [float]

The input images to dither

vir\_fits **\*\*inconf** [int]

The associated input confidence maps

int **nimages**

The number of input images in the jitter sequence

int **nconfs**

The number of input confidence maps. If this is the same as **ninputs** then it is assumed that each confidence map in the input list is associated with the image located in the same place of the input image list. If this is less than **ninputs** then the first confidence map in the list will be used for all of the input images.

int **lthr**

The lower rejection threshold expressed in units of the background dispersion

int **hthr**

The upper rejection threshold expressed in units of the background dispersion

cpl\_propertylist **\*p**

An output property list which can be used for the extension header for the output image. This will be the extension header for the first image in the list, but with appropriate modifications to the WCS.

cpl\_image **\*\*out**

The output dithered image.

cpl\_image **\*\*outc**

The output confidence map for the dithered image

int **\*status**

Input/output status from function

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### 6.12.3 Required FITS Header Information

The following information is required from the extension header of **infile**.

keyword	type	Description
EXPTIME	int	The exposure time of the input data in seconds
DRS XOFFDITHER	float	The jitter offset in <i>x</i>
DRS YOFFDITHER	float	The jitter offset in <i>y</i>

### 6.12.4 Output FITS Header Information

The following will be written to the extension propertylist of the input image

keyword	type	Description
DRS PROVXXXX	char	A set of keywords that describes the provenance of the output file.

### 6.12.5 QC1 Outputs

None

### 6.12.6 Quality Assessment

N/A

### 6.12.7 Fatal Error Conditions

- No images to combine.
- Confidence map dimensions don't match image dimensions

### 6.12.8 Non-fatal Error Conditions

- None

## 6.13 *vircam\_interleave*

### 6.13.1 General

**Name:**

vircam\_interleave

**Purpose:**

Interleave the pixels from a microstepped sequence to form an output frame and confidence map.

**General Description:**

The fractional microstep and offsets defined by the WCS in the input file headers are used to define the size and scale of the output grid. The input data is then mapped directly onto the output grid using known offsets. The result is a frame where the input pixels have been interwoven to form a finer grid. The images can have the following done to them before combination:



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- the input data values for a given output pixel can be scaled by a preset amount for each input image
- the input data values for a given output pixel can be biased by a preset amount for each input image

No pixel rejection is possible

**Mathematical Description:**

None

**Quality Assessment:**

N/A

**6.13.2 Function Parameters**

vir\_fits **\*\*infiles**

The list of input microstepped observation images

int **ninputs**

The number of input files in **infiles**.

vir\_fits **\*\*inconf**s

The list of input confidence maps. If the list is NULL or has a size of zero, then no output confidence map will be created. If the list has a size that is less than the size of the input file list (**infiles**), then only the first one will be used (i.e. each input image has the same confidence map). If the list has the same number of maps as the input images, then all the listed confidence maps will be used to form the output confidence map.

int **nconf**s

The number of confidence maps in **inconf**s.

int **nsteps**

The number of steps in the microstep pattern, e.g. for a 3x3 microstep pattern, this should be set to 3.

cpl\_propertylist **\*\*p**

A propertylist that will be used for the output image. This will be the header for the first image in the input image frameset (**infiles**), with the appropriate modifications to the WCS.

cpl\_image **\*\*outimage**

The output interleaved image

cpl\_image **\*\*outconf**

The output confidence map (if any)

int **\*status**

Input/output status from function

**6.13.3 Required Input FITS Header Information**

The following information is required from the extension header of the first file in the **infiles** list.

<b>keyword</b>	<b>type</b>	<b>description</b>
CRPIX1	double	All of the standard FITS WCS keywords that are relevant for the projection model to be used with VIRCAM (nominally ZPN). See [RD 8] for more specific information.
CRPIX2	double	
CTYPE1	char	
CTYPE2	char	

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CRVAL1	double	
CRVAL2	double	
CD1_1	double	
CD1_2	double	
CD2_1	double	
CD2_2	double	
PV2_1	double	
PV2_3	double	

The following information is required from the extension header from each of the files in the **infile** list.

<b>keyword</b>	<b>type</b>	<b>description</b>
DRS XOFFMICRO	float	The X offset in pixels of the current image relative to the first image in the microstep sequence.
DRS YOFFMICRO	float	The Y offset in pixels of the current image relative to the first image in the microstep sequence.
DRS BACKMED	float	The median value of the background

#### 6.13.4 Output FITS Header Information

WCS keywords as above modified for the new sampling. These are written to the output propertylist **p**. The following will also appear in **p**.

<b>keyword</b>	<b>type</b>	<b>description</b>
DRS PROVXXXX	char	A set of keywords that describes the provenance of the output file.

#### 6.13.5 QC1 Outputs

None

#### 6.13.6 Quality Assessment

N/A

#### 6.13.7 Fatal Error Conditions

- Failure to access input data
- Input frame list has no entries

#### 6.13.8 Non-Fatal Error Conditions

None

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## 6.14 *vircam\_lincor*

### 6.14.1 General

**Name:**

*vircam\_lincor*

**Purpose:**

Use linearity coefficients and timing information to put input data onto a linear scale.

**General Description**

The linearity coefficients for each data channel are combined with readout timing information in the manner described in section 2.2.1 to create a linearised data array for the input file.

**Mathematical Description:**

This function implements the mathematical description given in section 2.2.1. See that section for a full description.

### 6.14.2 Function Parameters

*vir\_fits* **\*infile**

The input image to be linearised

*vir\_tfits* **\*lchantab**

The channel table which is appropriate for this image.

int **kconst**

If set, then the value of  $k$  in section 2.2 is constant for all pixels in the image.

int **\*status**

Input/output status from function

### 6.14.3 Required Input FITS Header Information

The following items are required from the extension header of **infile**.

keyword	type	description
EXPTIME	float	The exposure time for the image
ESO DET MINDIT	float	The minimum DIT time
ESO DET DITDELAY	float	A delay between the reset and the first read

### 6.14.4 Output FITS Header Information

The following items will appear in the extension header of **infile**:

keyword	type	description
DRS LINCOR	char	The name of the FITS file of the channel table used to linearise the data

### 6.14.5 QC1 Outputs

None

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### 6.14.6 Quality Assessment

N/A

### 6.14.7 Fatal Error Conditions

- Inability to map input data.
- Channel table has incorrect information

### 6.14.8 Non-Fatal Error Conditions

None

## 6.15 *vircam\_matchstds*

### 6.15.1 General

**Name:**

*vircam\_matchstds*

**Purpose:**

Match a list of standard stars (from *vircam\_getstds*) to the  $(x,y)$  positions of objects on an image.

**General Description:**

This routine matches the objects found on an image with a list of objects that have been extracted from a standard catalogue. The  $(x,y)$  coordinates in both lists are compared and Cartesian offsets are found which cause the maximum number of objects to match. Output will be to a matched standards table (5.13).

**Mathematical Description:**

N/A

### 6.15.2 Function Parameters

**cpl\_table \*objtab**

The input table with the programme objects. Must have columns called **X\_coordinate** and **Y\_coordinate** (as one gets from *vircam\_imcore*).

**cpl\_table \*stdstab**

The input table with the template objects. Must have columns called **xpredict** and **ypredict** (as one gets from *vircam\_getstds*)

**float srad**

A search radius in pixels. This helps to define the number of points used in the grid search

**cpl\_table \*\*outtab**

The output table with both sets of Cartesian coordinates plus any extra information that appears in **stdstab**.

**int \*status**

Input/output status from function

### 6.15.3 Required FITS Header Information

None

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#### 6.15.4 Output FITS Header Information

None

#### 6.15.5 QC1 Outputs

None.

#### 6.15.6 Quality Assessment

N/A

#### 6.15.7 Fatal Error Conditions

- Input tables do not have the required columns

#### 6.15.8 Non-Fatal Error Conditions

- One of the input catalogues has no objects

### 6.16 *vircam\_matchxy*

#### 6.16.1 General

**Name:**

*vircam\_matchxy*

**Purpose:**

Work out relative jitter offsets by cross-correlating the locations of objects on a set of frames.

**General Description:**

Two catalogues of objects derived from two images (a programme image and a template image) are given. A search algorithm is used to try and maximise the number of objects that match between the two lists, by varying the Cartesian offsets. No axis flipping or rotation is allowed. The output is the *x,y* offsets. These can be applied to a whole group of files by the calling routine in order to define the relative offsets for a complete jitter sequence. The offsets are defined in the sense:

$$\Delta X = X_{template} - X_{programme}$$

In order to minimise the effect of the astrometric distortion on the offset solution, it is generally advisable that the input coordinates of the programme table should be biased by offsets that have been calculated from the initial WCS in the input images.

**Mathematical Description:**

None

#### 6.16.2 Function Parameters

*cpl\_table* \***progtab**

The table of objects appearing on the 'programme' frame. Must have columns **X\_coordinate** and **Y\_coordinate**.

*cpl\_table* \***temptab**

The table of objects appearing on the 'template' frame. Must have columns

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**X\_coordinate** and **Y\_coordinate**.

float **srad**

The search radius in pixels. This is used to define the number of points for the grid search.

float **\*xoffset**

The returned value of the  $x$  Cartesian offset

float **\*yoffset**

The returned value of the  $y$  Cartesian offset

int **\*nm**

The number of objects that matched between the two input lists

int **\*status**

Input/output status from function

### 6.16.3 Required FITS Header Information

None

### 6.16.4 Output FITS Header Information

None

### 6.16.5 QC1 Outputs

None

### 6.16.6 Quality Assessment

N/A

### 6.16.7 Fatal Error Conditions

- The input tables do not have the required columns.

### 6.16.8 Non-Fatal Error Conditions

- One of the tables has no objects.

## 6.17 *vircam\_mkconf*

### 6.17.1 General

**Name:**

vircam\_mkconf

**Purpose:**

Make an initial confidence map from two flat field images

**General Description:**

A mean flat field image and a bad pixel mask are given. The good pixels are given a confidence value as described below and the bad ones are assigned a value of zero.

**Mathematical Description:**

‘Good’ pixels will be given a confidence of:

$$C_i = 100F_i / \langle F \rangle$$

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where  $F_i$  is the pixel's value in the input flat field map, and  $\langle F \rangle$  is the mean value in the flat field map. A maximum confidence of 110 is allowed.

**Quality Assessment:**

N/A

**6.17.2 Function Parameters**

cpl\_image \*flat

The input flat field image

char \*flatfile

The file from which flat originated

vir\_mask \*bpm

The input bad pixel mask image

cpl\_image \*\*outconf

The output confidence map image

cpl\_propertylist \*\*drs

A propertylist to be used to store the output DRS keywords

int \*status

The input/output function status

**6.17.3 Required FITS Header Information**

None

**6.17.4 Output FITS Header Information**

keyword	type	description
DRS FLATIN	char	The name of the FITS file from which the flat data originated.
DRS BPMIN	char	The name of the FITS file from which the bad pixel map data originated

**6.17.5 QC1 Outputs**

None

**6.17.6 Quality Assessment**

N/A

**6.17.7 Fatal Error Conditions**

- One or other of the input images is unreadable.

**6.17.8 Non-Fatal Error Conditions**

None

---

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## 6.18 *vircam\_persist*

### 6.18.1 General

**Name:**

vircam\_persist

**Purpose:**

Remove effects of image persistence

**General Description:**

Images can persist on an IR detector after it has been read and reset. This persistence can be characterised by an exponential decay time. To correct this, a list of all the images that have been taken before the current image should be passed into this routine, along with their respective observational end times (in seconds from some zero point). This is the persistence mask defined in section 5.10. Using this information, an appropriate decay model and the ending time of the current exposure, a persistence map is built up. This map is then subtracted from the input image.

**Mathematical Description:**

This function implements the mathematical description in section 2.8.

### 6.18.2 Function Parameters

float **decay**

The decay constant in seconds as described in section 2.8.

float **fract**

The fraction of the ambient intensity that persists right after reset (i.e. no decay time).

### 6.18.3 Input Images and Required FITS Header Information

**infile** (float)

The input science image to be corrected.

keyword	type	description
EXPTIME	int	The exposure time of the input data
DATE-OBS	char	The UTC date of the start of the exposure

### 6.18.4 Input Tables

**ptable**

The persistence mask. See section 5.10.

### 6.18.5 Output Images

**outfile** (float)

The output science image; if this is the same as the value for **infile** or is blank, then the output will overwrite the input.

keyword	type	description
DRS PERMASK	char	The name of the persistence mask used



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### 6.18.6 Output Tables

None

### 6.18.7 Other Output

None.

### 6.18.8 QC1 Outputs

None

### 6.18.9 Quality Assessment

Persistent images removed to within the mean sky noise.

### 6.18.10 Error Conditions

- The following conditions will cause fatal errors
  - Negative or zero exposure time.
  - Mismatched dimensionality of data arrays.
- There are no non-fatal error conditions

## 6.19 *vircam\_photcal*

### 6.19.1 General

**Name:**

*vircam\_photcal*

**Purpose:**

Work out the photometric zero point for stars in an image

**General Description:**

The instrumental and standard magnitudes of objects on a frame are compared and a photometric zero point is calculated.

**Mathematical Description:**

This function implements the mathematical description in section 2.15

### 6.19.2 Function Parameters

*vir\_fits* **\*\*images**

The input list of images

*cpl\_table* **\*\*mstds**

The list of matched standards tables (section 5.13), one for each input image

*cpl\_propertylist* **\*\*pl**

An array of propertylists representing the headers of the object catalogues that were derived from the input images.

**int nimages**

The number of images, matched standards catalogues and propertylists.

**char \*filt**

The name of the filter for these observations.

*cpl\_table* **\*photcal**

The photometric calibration table (section 5.15)

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int \*status

The input/output function status

### 6.19.3 Required FITS Header Information

The following information is required in the extension header of the catalogues (see the parameter **pl**)

keyword	type	description
EXPTIME	float	The exposure time in seconds
APCOR3	float	The aperture correction for an aperture of 1x the core radius as calculated by <b>vircam_imcore</b>
APCOR5	float	The aperture correction for an aperture of 2x the core radius as calculated by <b>vircam_imcore</b>
ESO QC SATURATION	float	The saturation level in counts
ESO DRS RCORE	float	The core radius used in the object detection

The following information is required from the primary header of the images

keyword	type	description
ESO TEL AIRM START	float	The airmass at the start of the observation.

### 6.19.4 Output FITS Header Information

This routine calculates a zeropoint for two different apertures. It calculates these for each individual image and calculates a collective zeropoint for all the images in the list. In the table below the suffix “im” refers to results on an image by image basis and ‘all’ refers to the collective solution.

keyword	type	description
DRS ZPIM1	float	The calculated photometric zero point for the image in an aperture of radius 1x the core radius
DRS ZPSIGIM1	float	The RMS of the photometric zero point for the image in an aperture of radius 1x the core radius
DRS ZPIM2	float	The calculated photometric zero point for the image in an aperture of radius 2x the core radius
DRS ZPSIGIM2	float	The RMS of the photometric zero point for the image in an aperture of radius 2x the core radius
DRS LIMIT_MAG1	float	The 5 sigma limiting magnitude for this image in an aperture of radius 1x the core radius
DRS LIMIT_MAG2	float	The 5 sigma limiting magnitude for this image in an aperture of radius 2x the core radius
DRS MAGNZPTIM	int	The number of stars used in the zero point calculation in this image
DRS ZPALL1	float	The calculated photometric zero point for all images in an aperture of radius 1x the core radius
DRS ZPSIGALL1	float	The RMS of the photometric zero point for all images

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		in an aperture of radius 1x the core radius
DRS ZPALL2	float	The calculated photometric zero point for all images in an aperture of radius 2x the core radius
DRS ZPSIGALL2	float	The RMS of the photometric zero point for all images in an aperture of radius 2x the core radius
DRS MAGNZPTALL	int	The number of stars used in the zero point calculation in all images
DRS EXTINGT	float	The extinction in magnitudes used in the calculation of the zeropoint

### 6.19.5 QC1 Outputs

MAGZPT  
MAGZERR  
MAGNZPT  
LIMITING\_MAG

### 6.19.6 Quality Assessment

The RMS of the zeropoint is within the expected limits of the 2MASS catalogue, notwithstanding the quality of the observing conditions.

### 6.19.7 Fatal Error Conditions

- Photometric calibration table is incomplete
- No input images
- No rows in matched standards catalogue
- Missing header information in standards catalogue or image

### 6.19.8 Non-Fatal Error conditions

None

---

## 6.20 *vircam\_platesol*

### 6.20.1 General

**Name:**

vircam\_platesol

**Purpose:**

Work out a plate solution for an image given the RA, Dec,  $x$ ,  $y$  values for objects on that image.

**General Description:**

Cartesian and equatorial coordinates are fitted to standard plate solution models of either 4 or 6 constants (4-constant model being more robust but at the cost of assuming zero shear and no scale difference. The default therefore is 6). If so desired, the difference in the predicted  $x,y$  coordinates and the true  $x,y$  coordinates can be used to adjust the tangent point first to block correct for telescope pointing error. The median difference of the equatorial coordinates

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between that implied from the two sets of Cartesian coordinates is used to update the tangent point. A full least-squares solution is performed and the results are written back to the given FITS WCS header structure.

#### Mathematical Description:

For a 6 constant model, fits are done with the input standards for the equations:

$$\xi = ax + by + c \quad (6-1)$$

$$\eta = dx + ey + f \quad (6-2)$$

(where  $\zeta, \eta$  are standard coordinates with respect to the tangent point, distorted onto the detector system), to find values of  $a, b, c, e, d$  and  $f$ . For a 4-constant model the same equations are used, but with the constraint that  $a = e$  and  $b = d$ . See section 2.10 for information on how the expected projection geometry will be incorporated.

### 6.20.2 Function Parameters

`cpl_propertylist *plist`

The propertylist which represents the FITS header for an input image. It must have a rough FITS WCS already if the tangent point is going to be repositioned.

`cpl_table *matchedstds`

A matched standards table containing at least the following columns:

**X\_coordinate, Y\_coordinate, xpredict, ypredict, ra, dec.**

`int nconst`

The number of plate constants to be used. This can be either 6 (default) or 4.

`int shiftan`

If set, then the difference between the predicted and the true cartesian coordinates of the objects in the matched standards catalogue will be used to redefine the equatorial coordinates of the reference point of the WCS.

`int *status`

The input/output function status.

### 6.20.3 Required FITS Header Information

keyword	type	description
CRPIX1	double	All of the standard FITS WCS keywords that are relevant for the projection model to be used with VIRCAM (nominally ZPN). See [RD 8] for more specific information. NB: These will all be modified by this function on output.
CRPIX2	double	
CTYPE1	char	
CTYPE2	char	
CRVAL1	double	
CRVAL2	double	
CD1_1	double	
CD1_2	double	
CD2_1	double	
CD2_2	double	
PV2_i,	double	

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i=1~5		
NAXIS1	int	The X size of the data array from which the catalogue was generated
NAXIS2	int	The Y size of the data array from which the catalogue was generated

### 6.20.4 Output FITS Header Information

As above, but modified by the fit done in this routine, also:

<b>keyword</b>	<b>type</b>	<b>description</b>
DRS STDCRMS	float	The RMS of the WCS fit.
DRS NUMBRMS	int	The number of stars used in the WCS fit
DRS WCSRAOFF	float	The equatorial coordinates of the central pixel of the image is calculated both before and after the plate solution is found. This is the difference in the RA (in arcseconds)
DRS WCSDECOFF	float	The equatorial coordinates of the central pixel of the image is calculated both before and after the plate solution is found. This is the difference in the DEC (in arcseconds)

### 6.20.5 QC1 Outputs

WCS\_DCRVAL1  
WCS\_DCRVAL2  
WCS\_DTHETA  
WCS\_SCALE  
WCS\_SHEAR (6-constant model)  
WCS\_RMS

### 6.20.6 Quality Assessment

DRS STDCRMS is within the expected internal consistency of the input astrometric data convolved with a centring error.

### 6.20.7 Fatal Error Conditions

- Unsupported value of **nconst**.
- Too few standards for the fit.
- Required columns don't exist in input matched standards table.

### 6.20.8 Non-Fatal Error conditions

None

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## 7 Data Reduction CPL Plugins

Each recipe has a direct correspondence to a CPL plugin; but the correspondence between raw data-types and recipes is not one-to-one because, in some cases, science data are used to produce calibration frames. Each plugin is documented below. Where a calibration product is created by the recipe, the first value in parenthesis after the file description specifies the value of the PRO CATG keyword in the output file header. The actual names of the output files are hard coded as required by the CPL standard. If need be, then **esorex** can be used to change the name. For reference, the hard coded file name is included in bold next to the PRO CATG. Any occurrence of **??** in the file name means that the recipe may produce several of these files and the question marks denote a serial number starting with 0. The recipes will also produce PAF files with QC and setup information that can be used by the summit quality control system. The hard coded names of these are also given in the output list. A separate PAF file is created for each FITS extension that is processed. The parenthesis after the input data specifications indicate whether the data are required or optional and the DO CATG keyword that must appear in the sof file.

The plugins may receive error messages from the functions that they call. If these are considered by the function to be fatal, then the plugin will exit gracefully. If the errors are considered to be just a warning the plugin may choose to proceed with caution, to get the information it needs from another source or fail gracefully. As in the previous section we do not include conditions such as segmentation violations and arithmetic exceptions in the list of fatal errors. Only error conditions that occur within the plugin, and outside of the VIRCAM functions documented in section 6, will be documented here. In addition, all error conditions which would lead to the writing of a dummy product will be documented here. All recipes will fail if they are unable to identify RAW and CALIB frames or if they cannot make sense of the DO CATG values specified in the sof file.

All of the parameters that can be changed on the command line are listed for each recipe. It is worth noting that **esorex** allows the user to change parameters in a semi-permanent way using environment variables. Full details on the names of these environment variables can be found by using the **-man-page** switch with **esorex**. Finally all recipes have a parameter that is in addition to the ones documented below. This is **ext** and it defines the FITS extension number for the input files that are to be processed by the recipe. This allows the recipe to either process a single extension or all extensions (**ext** = 0).

### 7.1 *vircam\_reset\_combine*

**Name:**

vircam\_reset\_combine

**Purpose:**

Combine a sequence of reset frames to form a mean frame. Compare to a library reset frame to provide information on the stability of the pedestal and reset structure

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**Type:**

Detector calibration

**Input Data:**

- List of reset frames (required, BIAS)
- Library mean reset frame (optional, REFERENCE\_RESET)
- Channel table (optional, MASTER\_CHANNEL\_TABLE or CHANNEL\_TABLE\_INIT)
- Library bad pixel map (optional, MASTER\_BPM) or library confidence map (optional, MASTER\_CONF)

**Parameters:****int combtype**

Determines the type of combination that is done to form the output map. Can take the following values

1. The output pixels are medians of the input pixels
2. The output pixels are means of the input pixels

**int scaletype**

Determines how the input data are scaled or offset before they are combined. Can take the following values:

0. No scaling or biasing
1. All input frames are biased additively to bring their backgrounds to a common median level.
2. All input frames are biased multiplicatively to bring their backgrounds to a common median level.
3. All input frames are scaled to a uniform exposure time and then additively corrected to bring their backgrounds to a common median level.

**int xrej**

If set, then an extra rejection cycle will be run.

**int thresh**

The rejection threshold in numbers of background sigmas.

**int ncells**

If a difference image statistics table is being done, then this is the number of cells in which to divide each readout channel. The value must be a power of 2, up to 64

**Algorithm:**

- Combine the sequence of reset frames into a single mean with rejection.
- Calculate RMS of mean reset frame.
- If a library master reset frame is given, then subtract it from the mean frame created here to form a difference image. Calculate a mean and RMS of the difference image.
- If a channel map is included, then this is used to split each data channel of the difference image into cells and do a robust median and RMS estimate in each. The results of this analysis are written to a difference image statistics table.
- If a master bad pixel mask or a master confidence map is included these are used to mask out bad pixels in the above statistical analyses.

**Outputs:**

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- New master reset frame (MASTER\_RESET, **resetcomb.fits**)
- Difference image (DIFFIMG\_RESET, **resetdiff.fits**)
- Reset difference image statistics table (DIFFIMG\_STATS\_RESET, **resetdiffstab.fits**)
- **resetcomb\_???.paf**
- **resetdiff\_???.paf**

**QC1 Parameters:**

RESETMED  
 RESETRMS  
 RESETDIFF\_MED  
 RESETDIFF\_RMS

**VIRCAM Functions Used:**

vircam\_imcombine

**Fatal Error Conditions:**

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No reset frames in the input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

- Missing calibDB reset frame (No comparison with master frame done and no output difference image)
- Missing or invalid channel table (No difference image statistics table made)
- Missing bad pixel map or missing confidence map (No bad pixel rejection during statistical analysis)

**Conditions Leading To Dummy Products:**

- Reset frame image extensions won't load
- The detector for the current image extension has been disabled
- Failure in combination routine
- Master reset frame image extension won't load or is a dummy
- Channel table FITS extension won't load, is invalid or is a dummy

## **7.2 *vircam\_dark\_combine***

**Name:**

vircam\_dark\_combine

**Purpose:**

Combine a series of dark frames taken with a particular integration and exposure time combination. Compare with a similarly observed master dark frame. Calculate variation in the reset anomaly structure and scale.

**Type:**

Detector calibration

**Input Data:**



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- List of dark frames (required, DARK)
- Library mean dark frame (optional, REFERENCE\_DARK)
- Library bad pixel mask (optional, MASTER\_BPM) or library confidence map (optional, MASTER\_CONF)
- Channel table (optional, MASTER\_CHANNEL\_TABLE or CHANNEL\_TABLE\_INIT)

**Parameters:**

**int combtype**

Determines the type of combination that is done to form the output map. Can take the following values

1. The output pixels are medians of the input pixels
2. The output pixels are means of the input pixels

**int scaletype**

Determines how the input data are scaled or offset before they are combined. Can take the following values:

0. No scaling or biasing
1. All input frames are biased additively to bring their backgrounds to a common median level.
2. All input frames are biased multiplicatively to bring their backgrounds to a common median level.
3. All input frames are scaled to a uniform exposure time and then additively corrected to bring their backgrounds to a common median level.

**int xrej**

If set, then an extra rejection cycle will be run.

**int thresh**

The rejection threshold in numbers of background sigmas.

**int ncells**

If a difference image statistics table is being done, then this is the number of cells in which to divide each readout channel. The value must be a power of 2, up to 64

**Algorithm:**

- Combine the sequence of dark frames with rejection.
- In conjunction with bad pixel map or confidence map, assess the number of rejected pixels with positive residuals to give an indication of the rate of cosmic ray hits and their properties.
- Work out a robust median in a region that is unaffected by reset anomaly.
- Work out the number of hot pixels
- If a library master dark frame is given, then subtract it from the mean frame created here to form a difference image. Calculate a mean and RMS of the difference image.
- If a channel map is included, then this is used to split each data channel of the difference image into cells and do a robust median and RMS estimate in each. The results of this analysis are written to a difference image statistics table.
- If a master bad pixel mask or a master confidence map is included these are used to mask out bad pixels in the above statistical analyses

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**Outputs:**

- New mean dark frame (MASTER\_DARK, **darkcomb.fits**)
- Dark frame difference image (DIFFIMG\_DARK, **darkdiff.fits**)
- Dark difference image statistics table (DIFFIMG\_STATS\_DARK, **darkdifftab.fits**)
- **darkcomb\_?? .paf**
- **darkdiff\_?? .paf**

**QC1 Parameters:**

DARKMED  
DARKRMS  
DARKDIFF\_MED  
DARKDIFF\_RMS  
PARTICLE\_RATE  
STRIPERMS  
NHOTPIX  
HOTFRAC

**VIRCAM Functions Used:**

vircam\_imcombine, vircam\_destripe

**Fatal Error Conditions:**

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No dark frames in the input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

- Missing calibDB dark frame (No comparison with master frame done and no output difference image)
- Missing or invalid channel table (No difference image statistics table made)
- Missing bad pixel map or missing confidence map (No bad pixel rejection during statistical analysis)

**Conditions Leading To Dummy Products:**

- Dark frame image extensions won't load
- The detector for the current image extension has been disabled
- Failure in combination routine
- Master dark frame image extension won't load or is a dummy
- Channel table FITS extension won't load, is invalid or is a dummy

### **7.3 *vircam\_dark\_current***

**Name:**

vircam\_darkcurrent

**Purpose:**

Calculate the dark current of a detector using a series of dark exposures with varying exposure times.

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**Type:**

Detector Calibration

**Input Data:**

- A series of dark exposures at a variety of different exposure times (required, DARK, DARKCURRENT)
- Library bad pixel mask (optional, MASTER\_BPM) or library confidence map (optional, MASTER\_CONF)

**Parameters:**

float **thresh**

The threshold in units of background sigma above or below the local mean value. This defines whether a data point in the fit is bad or not.

**Algorithm:**

- Perform robust iterative linear fit across all exposures at each pixel position
- At each pixel position, the slope of the fit represents the dark current expressed in units of ADUs per second.
- Where the bad pixel mask is set the output value is set to zero.

**Outputs:**

- Dark current map (MASTER\_DARK\_CURRENT, **darkcurrent.fits**)
- **darkcurrent\_???.paf**

**QC1 Parameters:**

DARKCURRENT

**VIRCAM Functions Used:**

None

**Fatal Error Conditions:**

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- Not enough dark frames in the input frameset
- Missing exposure times in input headers
- Inability to save output products

**Non-fatal Error Conditions:**

- Missing bad pixel map or missing confidence map (No bad pixel rejection during statistical analysis)

**Conditions Leading To Dummy Products:**

- Dark frame image extensions won't load
- The detector for the current image extension has been disabled

**7.4 *vircam\_dome\_flat\_combine*****Name:**

vircam\_dome\_flat\_combine

**Purpose:**

Combine a series of dome flat images to create a mean dome flat. Compare with a similarly observed master dome flat frame.

**Type:**

Detector calibration

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**Input Data:**

- List of dome flat exposures all taken with the same exposure parameters (required, FLAT,LAMP)
- Master dark frame of the same exposure parameters as above (required, MASTER\_DARK)
- Master mean dome flat (optional, REFERENCE\_DOME\_FLAT)
- Channel map (optional, MASTER\_CHANNEL\_TABLE or CHANNEL\_TABLE\_INIT)
- Master bad pixel mask (optional, MASTER\_BPM) or master confidence map (optional, MASTER\_CONF)

**Parameters:**

float **lthr**

Any input flat with a mean value of less than this will be excluded as being underexposed.

float **hthr**

Any input flat with a mean value of more than this will be excluded as being overexposed.

int **combtype**

Determines the type of combination that is done to form the output map. Can take the following values

1. The output pixels are medians of the input pixels
2. The output pixels are means of the input pixels

int **scaletype**

Determines how the input data are scaled or offset before they are combined. Can take the following values:

0. No scaling or biasing
1. All input frames are biased additively to bring their backgrounds to a common median level.
2. All input frames are biased multiplicatively to bring their backgrounds to a common median level.
3. All input frames are scaled to a uniform exposure time and then additively corrected to bring their backgrounds to a common median level.

int **xrej**

If set, then an extra rejection cycle will be run.

int **thresh**

The rejection threshold in numbers of background sigmas.

int **ncells**

If a ratio image statistics table is being done, then this is the number of cells in which to divide each readout channel. The value must be a power of 2, up to 64

**Algorithm:**

- Remove any images that are saturated or underexposed.
- Process remaining images to linearise and remove dark current.
- Combine the dome flat exposures with rejection.

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- If a library master dome flat frame is given, then divide the mean frame created here into the master to form a ratio image. Calculate a mean and RMS of the ratio image.
- If a channel map is included, then this is used to split each data channel of the ratio image into cells and do a robust median and RMS estimate in each. The results of this analysis are written to a ratio image statistics table.
- If a master bad pixel mask or a master confidence map is included these are used to mask out bad pixels in the above statistical analyses

**Outputs:**

- New master dome flat (MASTER\_DOME\_FLAT, **domecomb.fits**)
- Ratio image (RATIOIMG\_DOME\_FLAT, **domeratio.fits**)
- Ratio image statistics table (RATIOIMG\_STATS\_DOME\_FLAT, **domeratiotab.fits**)
- **domecomb\_?.paf**
- **domeratio\_?.paf**

**QC1 Parameters:**

FLATRMS  
FLATRATIO\_MED  
FLATRATIO\_RMS

**VIRCAM Functions Used:**

vircam\_imcombine, vircam\_darkcor, vircam\_lincor

**Fatal Error Conditions:**

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No dome flat frames in the input frameset
- No master dark frame in input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

- Missing calibDB dome frame (No comparison with master frame done and no output ratio image)
- Missing or invalid channel table (No ratio image statistics table made)
- Missing bad pixel map or missing confidence map (No bad pixel rejection during statistical analysis and no linearisation done)

**Conditions Leading To Dummy Products:**

- Dome frame image extensions won't load
  - The detector for the current image extension has been disabled
  - All the dark corrected images are either below the under-exposure threshold or above the over-exposure threshold.
  - Master dark frame image extension won't load or is a dummy
  - Failure in combination routine
  - Channel table FITS extension won't load, is invalid or is a dummy
-

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## 7.5 *vircam\_detector\_noise*

### Name:

vircam\_detector\_noise

### Purpose:

Measure the detector readout noise and gain

### Type:

Detector calibration

### Input Data

- Two dome flat frames taken with the same exposure parameters (required, FLAT,LAMP,GAIN)
- Two dark frames taken with the same exposure parameters as the dome flats (required, DARK,GAIN)
- A master bad pixel mask (optional, MASTER\_BPM) or master confidence map (MASTER\_CONF)

### Parameters:

float **thresh**

The threshold in units of background sigma above or below the local mean value. This is used during the statistical analyses of the input images and difference images.

### Algorithm:

- Form difference images of the two dome flats and the two dark frames
- Do statistics as outlined in section 2.4 to give an estimate of read noise and gain

### Outputs:

- Read noise and gain estimates for each extension written to a detector noise table (READGAIN\_TABLE, **detector\_noise.fits**)
- **vircam\_detector\_noise\_?.paf**

### QC1 Parameters:

READNOISE

GAIN

### VIRCAM Functions Used:

None

### Fatal Error Conditions:

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- Insufficient dark or flat exposures
- Inability to save output products

### Non-fatal Error Conditions:

- Missing bad pixel map or missing confidence map (No bad pixel rejection during statistical analysis and no linearisation done) No stats are calculated.

### Conditions Leading To Dummy Products:

- The image extensions won't load
- Unphysical statistical result
- The detector for the current image extension is flagged dead.

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## 7.6 *vircam\_linearity\_analyse*

### Name:

*vircam\_linearity\_analyse*

### Purpose:

Create detector channel linearity curves and bad-pixel maps

### Type:

Detector calibration

### Input Data:

- A series of dome flat exposures taken under constant illumination with varying integration times (required, FLAT,LAMP,LINEARITY).
- Channel map (required, CHANNEL\_TABLE\_INIT)
- A list of raw dark frames containing a series of dark exposures with the same exposure parameters for each of the input dome flat exposures (required, DARK,LINEARITY)

### Parameters:

int **nord**

The order of the polynomial to be fit to the linearity curve of each channel

float **lthr**

The lower threshold in the ratio maps to define a pixel as bad. Units are in background sigma of the ratio map.

float **hthr**

The upper threshold in the ratio maps to define a pixel as bad. Units are in background sigma of the ratio map

float **overexp**

The maximum number of ADUs a dome flat image may have on average before it is considered to be over-exposed.

### Algorithm:

- Combine all sets of raw dark images into mean dark images
- Process each flat exposure by removing the reset anomaly with the appropriate dark frame
- Combine the dome series with rejection into a normalised mean flat field
- Divide the series by the mean frame
- Find pixels in the ratio maps whose values are over or under the input threshold value and flag them as bad
- Compute the number of bad pixels in this new bad pixel mask.
- Combine timing information from channel map and known read and reset times to derive the  $k$  factors needed as indicated in section 2.2.2.
- Solve for coefficients and store them in a new channel table.

### Outputs:

- Output channel table with new linearity information (MASTER\_CHANNEL\_TABLE, **lchantab.fits**)
- Output bad pixel mask (MASTER\_BPM, **bpm.fits**)
- **lchantab\_?.paf**

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- **bpm\_???.paf**

**QC1 Parameters:**

LINEARITY  
LINFITQUAL  
BAD\_PIXEL\_STAT  
BAD\_PIXEL\_NUM

**VIRCAM Functions Used:**

vircam\_darkcor, vircam\_genlincur

**Fatal Error Conditions:**

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No dark or dome flat frames in input frameset
- No channel table in input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

- Not enough dome flats in the series for the requested order of fit. Order is adjusted downwards.

**Conditions Leading To Dummy Products:**

- The dark/dome image extensions won't load
- Channel table fits extension won't load, won't verify or is flagged as a dummy.
- The detector for the current image extension is flagged dead.
- vircam\_genlincur failed

## ***7.7 vircam\_twilight\_flat\_combine***

**Name:**

vircam\_twilight\_flat\_combine

**Purpose:**

Combine a series of twilight flat images to create a mean twilight flat and initial confidence map. Compare with a similarly observed master twilight flat frame.

**Type:**

Detector calibration

**Input Data:**

- List of twilight flat exposures all taken with the same exposure parameters (required, FLAT,TWILIGHT)
- Master dark frame of the same exposure parameters as above (required, MASTER\_DARK)
- Master mean twilight flat (optional, REFERENCE\_TWILIGHT\_FLAT)
- Channel map (optional, MASTER\_CHANNEL\_TABLE or CHANNEL\_TABLE\_INIT)
- Master bad pixel mask (optional, MASTER\_BPM) or master confidence map (optional, MASTER\_CONF)

**Parameters:**



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**float lthr**

Any input flat with a mean value of less than this will be excluded as being underexposed.

**float hthr**

Any input flat with a mean value of more than this will be excluded as being overexposed.

**int combtype**

Determines the type of combination that is done to form the output map. Can take the following values

1. The output pixels are medians of the input pixels
2. The output pixels are means of the input pixels

**int scaletype**

Determines how the input data are scaled or offset before they are combined. Can take the following values:

0. No scaling or biasing
1. All input frames are biased additively to bring their backgrounds to a common median level.
2. All input frames are biased multiplicatively to bring their backgrounds to a common median level.
3. All input frames are scaled to a uniform exposure time and then additively corrected to bring their backgrounds to a common median level.

**int xrej**

If set, then an extra rejection cycle will be run.

**int thresh**

The rejection threshold in numbers of background sigmas.

**int ncells**

If a ratio image statistics table is being done, then this is the number of cells in which to divide each readout channel. The value must be a power of 2, up to 64

**Algorithm:**

- Remove any images that are saturated or underexposed.
- Process remaining images to linearise and remove dark current.
- Combine the twilight flat exposures with rejection. Normalise by its median.
- If a library master twilight flat frame is given, then divide the mean frame created here into the master to form a ratio image. Calculate a mean and RMS of the ratio image.
- If a channel map is included, then this is used to split each data channel of the ratio image into cells and do a robust median and RMS estimate in each. The results of this analysis are written to a ratio image statistics table.
- If a master bad pixel mask or a master confidence map is included these are used to mask out bad pixels in the above statistical analyses
- Use the mean flat and bad pixel map to create an initial confidence map.

**Outputs:**

- Master twilight flat (MASTER\_TWILIGHT\_FLAT, **twilightcomb.fits**)

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- Ratio image (RATIOIMG\_TWILIGHT\_FLAT, **twilightratio.fits**)
- Ratio image statistics table (RATIOIMG\_STATS\_TWILIGHT\_FLAT, **twilightratiotab.fits**)
- New master confidence map (MASTER\_CONF, **twilightconf.fits**)
- **twilightcomb\_?.paf**
- **twilightratio\_?.paf**

**QC1 Parameters:**

FLATRMS  
 FLATRATIO\_MED  
 FLATRATIO\_RMS  
**GAIN\_CORRECTION**

**VIRCAM Functions Used:**

vircam\_imcombine, vircam\_mkconf, vircam\_darkcor, vircam\_lincor

**Fatal Error Conditions:**

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No twilight flat frames in input frameset
- No master dark frame in input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

- No master twilight flat. No ratio image formed
- No master bad pixel map or confidence map. All pixels considered to be good.
- No channel table in input frameset. No ratio image stats table or linearisation will be done.

**Conditions Leading To Dummy Products:**

- The twilight frame image extensions won't load
- The detector for the current image extension is flagged dead.
- All the dark corrected images are either above the over exposure threshold or just below the under exposure threshold.
- Master dark extension won't load or is flagged as a dummy
- vircam\_imcombine failed
- Master twilight flat image failed to load or flagged as a dummy
- Channel table fits extension failed to load or flagged as a dummy

## **7.8 vircam\_mesostep\_analyse**

**Name:**

vircam\_mesostep\_analyse

**Purpose:**

Create a map of illumination corrections using a mesostep sequence of a standard stars

**Type:**

Detector calibration

**Input Data:**

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- A series of exposures of a sparse secondary standard field that has been offset in a regular raster (STD,ILLUMINATION)
- Library master dark frame for the given exposure and integration time (MASTER\_DARK)
- Library master flat field for the given passband (MASTER\_TWILIGHT\_FLAT)
- Library confidence map for the given passband (MASTER\_CONF) *or* a library bad pixel mask (MASTER\_BPM)
- Library fringe frame (MASTER\_FRINGE)
- Channel table (MASTER\_CHANNEL\_TABLE)
- Photometric calibration table (PHOTCAL\_TAB)
- Persistence mask
- Crosstalk table
- Photometric standard data (through VIRCAM interface to 2MASS)

**Parameters:**

int **ipix**

The minimum size of an object in pixels in order for that object not to be considered spurious.

float **thr**

The detection threshold measured in units of the mean background noise

int **icrowd**

If set, then the function will attempt to de-blend merged objects

float **rcore**

The core radius in pixels for the default profile fit.

int **nb**

The size in pixels of the grid squares used for background estimation

char **\*path2mass**

The full path to the 2MASS catalogue FITS files

int **destripe**

If this is set, then the input images will be de-striped. Not recommended for images that are likely to contain very large extended objects.

int **skycor**

If this is set, then the input images are stacked with rejection to form a mean background map. This is normalised to zero median and subtracted off the input images. This is not recommended for images that are likely to contain extended sources.

int **nord\_**

The order of the polynomial surface to be fit

**Algorithm:**

- Process the observations by linearising, doing dark correction, flat fielding and gain correction
- Compute the zero-point of standard stars on of each of the exposures.
- Divide the area of the detector into cells and bin each of the zeropoint calculations into these cells.
- Work out a median zero point for each cell

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- Fit the zeropoint solutions to a 2d polynomial.
- Evaluate the polynomial at the central grid points of each cell.
- Write the illumination correction table.

**Outputs:**

- Illumination correction table (see 5.7) (ILLCOR\_TAB\_MES, **illum.fits**)
- **illum\_???.paf**

**QC1 Parameters:**

ILLUMCOR\_RMS

**VIRCAM Functions Used:**

vircam\_darkcor, vircam\_lincor, vircam\_flatcor, vircam\_gaincor,  
vircam\_defringe, **vircam\_persist**, **vircam\_crosstalk**, vircam\_imcore,  
vircam\_getstds, vircam\_matchstds

**Fatal Error Conditions:**

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No science frames in input frameset
- Missing master calibration frames or unreadable extensions in input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

None

**Conditions Leading To Dummy Products:**

- Missing calibration images, calibration images that won't load or are flagged as dummy.
- A detector has been signalled dead.
- Processing routines fail.

## **7.9 vircam\_persistence\_analyse**

**Name:**

vircam\_persistence\_analyse

**Purpose:**

Analyse an image of bright stars and subsequent dark exposures to compute the persistence decay rate

**Type:**

Detector calibration

**Input Data:**

- An observation of bright stars taken close to saturation
- A master dark frame for the given integration time
- A master flat field for the given passband
- A master confidence map for the given passband
- Linearity channel table
- A series of dark exposures taken at regular time intervals afterwards

**Parameters:**

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float **thresh**

Detection threshold for object extraction

**Algorithm:**

- Process the observation by linearising, dark correction and flat fielding
- Compute the flux and position of bright stars on an image.
- Look on subsequent dark exposures at the same location and compute the flux.
- Fit the flux vs.  $\Delta t$  curve to an exponential to work out the characteristic decay constant,  $\tau_0$  and the flux a zero time.

**Outputs:**

- Persistence decay time constant
- Persistence fraction at zero time

**QC1 Parameters:**

PERSIST\_DECAY  
PERSIST\_ZERO

**VIRCAM Functions Used:**

vircam\_darkcor, vircam\_lincor, vircam\_flatcor, vircam\_gaincor,  
vircam\_defringe, vircam\_imcore

**Fatal Error Conditions:**

- Missing master calibration frames
- Missing master calibration tables
- No dark frames available after star observation.

**Non-fatal Error Conditions:**

None

---

## **7.10 vircam\_crosstalk\_analyse**

**Name:**

vircam\_crosstalk\_analyse

**Purpose:**

Analyse a series of images to work out the crosstalk matrix for all detector sections

**Type:**

Detector calibration

**Input Data:**

- A series of exposures of a bright star. The star should be centred in each of the instrument's data channels.
- Master flat and confidence map for the given passband
- Master dark frame for the given exposure time
- Channel table

**Parameters:**

float **thresh**

Detection threshold for object extraction

**Algorithm:**

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- Locate objects on each exposure.
- Use channel table to predict location of crosstalk images of the bright star and locate the crosstalk image in the object catalogue.
- Create crosstalk matrix from the ratio of the fluxes for a given channel combination.

**Outputs:**

- Crosstalk matrix as described in 5.6 (XTALK)

**QC1 Parameters:**

CROSS\_TALK

**VIRCAM Functions Used:**

vircam\_imcore

**Fatal Error Conditions:**

- Missing channel table or confidence map

**Non-fatal Error Conditions:**

None

## 7.11 *vircam\_jitter\_microstep\_process*

**Name:**

vircam\_jitter\_microstep\_process

**Purpose:**

Process a sequence of target data that may have been both jittered and microstepped.

**Type:**

Science

**Input Data:**

- A jittered and/or microstepped sequence of exposures of a target region (OBJECT) *or* (OBJECT,EXTENDED)
- Library mean dark frame for the given exposure and integration time. (MASTER\_DARK)
- Library mean flat field frame for the given passband (MASTER\_TWILIGHT\_FLAT)
- Library confidence map for the given passband (MASTER\_CONF) *or* a library bad pixel mask (MASTER\_BPM)
- Library fringe frame (MASTER\_FRINGE)
- Channel table (MASTER\_CHANNEL\_TABLE)
- Readnoise/gain file (MASTER\_READGAIN\_TABLE)
- Photometric calibration table (PHOTCAL\_TAB)
- Crosstalk matrix
- Persistence mask
- Astrometric standard data (through VIRCAM interface to 2MASS)
- Photometric standard data (through VIRCAM interface to 2MASS)

**Parameters:**

int **ipix**

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The minimum size of an object in pixels in order for that object not to be considered spurious.

float **thr**

The detection threshold measured in units of the mean background noise

int **icrowd**

If set, then the function will attempt to de-blend merged objects

float **rcore**

The core radius in pixels for the default profile fit.

int **nb**

The size in pixels of the grid squares used for background estimation

char **path2mass**

The full path to the 2MASS catalogue FITS files

int **destripe**

If this is set, then the input images will be de-stripped. Not recommended for images that are likely to contain very large extended objects.

int **skycor**

If this is set, then the input images are stacked with rejection to form a mean background map. This is normalised to zero median and subtracted off the input images. This is not recommended for images that are likely to contain extended sources.

int **savecat**

If set, then the catalogue generated during the astrometric and photometric calibration will be saved.

#### Algorithm:

- Process the images by linearising and removing dark current, flat fielding, destripping and gain correcting
- Remove crosstalk images
- De-fringe
- Remove persistent images
- Correct for sky background
- Work out microstep offsets using header information
- Combine the images into super-frames by interleaving using the microstep offsets
- Work out jitter offsets by cross-correlating stellar object positions on super-frame images
- Combine the super-frame images with offsets into a single stacked image
- Generate a catalogue of objects on the stacked image and do a morphological classification
- Fit a WCS using astrometric standards that appear in the stacked image catalogue. Update the FITS headers of the stacked image as well as those of the super-frames and the single exposure images.
- Calculate photometric zero point using instrumental magnitudes, magnitudes of photometric standards, and illumination corrections.
- Apply illumination correction to catalogue

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#### Outputs:

- Single exposure images that corrected for linearity, dark current, flat field, stripes, sky, **image persistence and crosstalk**. **A full WCS will appear in the header** (SIMPLE\_IMAGE\_SCI, **simple\_?.fits**)
- Interleaved super-frame images from the above if microstepping has been done as part of the observing sequence. (INTERLEAVED\_IMAGE\_SCI, **super\_?.fits**)
- Stacked jitter images from the super-frames. Full WCS and photometric zero point will appear in the FITS header. (JITTERED\_IMAGE\_SCI, **stack\_?.fits**)
- Associated confidence maps for each of the above output images. (CONFIDENCE\_MAP\_SCI, **superc\_?.fits, stackc\_?.fits**)
- Object catalogue in the form of a FITS table if the **savecat** parameter has been set (OBJECT\_CATALOGUE\_SCI, **catalogue\_?.fits**)
- **stack\_?.paf**
- **catalogue\_?.paf**
- **illum\_?.paf**

#### QC1 Parameters:

**FRINGE\_RATIO**  
SATURATION  
MEAN\_SKY  
SKY\_NOISE  
NOISE\_OBJ  
IMAGE\_SIZE  
APERTURE\_CORR  
ELLIPTICITY  
MAGZPT  
MAGZERR  
MAGNZPT  
LIMITING\_MAG  
WCS\_DCRVAL1  
WCS\_DCRVAL2  
WCS\_DTHETA  
WCS\_SCALE  
WCS\_SHEAR  
WCS\_RMS

#### VIRCAM Functions Used:

vircam\_darkcor, vircam\_lincor, vircam\_flatcor, vircam\_gaincor,  
**vircam\_defringe, vircam\_persist**, vircam\_matchxy, **vircam\_crosstalk**,  
vircam\_imcore, vircam\_getstds, vircam\_platesol, vircam\_matchstds,  
vircam\_imdither, vircam\_photcal

#### Fatal Error Conditions:

- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No science frames in input frameset



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- Missing master calibration frames or unreadable extensions in input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

None

**Conditions Leading To Dummy Products:**

- Missing calibration images, calibration images that won't load or are flagged as dummy.
- A detector has been signalled dead.
- Processing routines fail.

## 7.12 *vircam\_standard\_process*

**Name:**

vircam\_standard\_process

**Purpose:**

Process a sequence of photometric standard data that may have been both jittered and microstepped.

**Type:**

Science

**Input Data:**

- A jittered and/or microstepped sequence of exposures of a target region (SIMPLE\_IMAGE\_STD)
- Library mean dark frame for the given exposure and integration time (MASTER\_DARK)
- Library mean flat field frame for the given passband (MASTER\_TWILIGHT\_FLAT)
- Library confidence map for the given passband (MASTER\_CONF) *or* a library bad pixel mask (MASTER\_BPM)
- Library fringe frame (MASTER\_FRINGE)
- Channel table (MASTER\_CHANNEL\_TABLE)
- Readnoise/gain file (MASTER\_READGAIN\_TABLE)
- Photometric calibration table (PHOTCAL\_TAB)
- Crosstalk matrix
- Persistence mask
- Astrometric standard data (through VIRCAM interface to 2MASS)
- Photometric standard data (through VIRCAM interface to 2MASS and a second source if requested)

**Parameters:**

int **ipix**

The minimum size of an object in pixels in order for that object not to be considered spurious.

float **thr**

The detection threshold measured in units of the mean background noise

int **icrowd**

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- If set, then the function will attempt to de-blend merged objects
- float **rcore**  
The core radius in pixels for the default profile fit.
- int **nb**  
The size in pixels of the grid squares used for background estimation
- char **\*path2mass**  
The full path to the 2MASS catalogue FITS files
- char **\*catpath**  
The full path to a second photometric catalogue
- char **\*catname**  
The name of the second photometric catalogue
- int **destripe**  
If this is set, then the input images will be de-stripped. Not recommended for images that are likely to contain very large extended objects.
- int **skycor**  
If this is set, then the input images are stacked with rejection to form a mean background map. This is normalised to zero median and subtracted off the input images. This is not recommended for images that are likely to contain extended sources.
- int **savecat**  
If set, then the catalogue generated during the astrometric and photometric calibration will be saved.

**Algorithm:**

- Process the images by linearising and removing dark current, flat fielding, destripping and gain correcting.
- Remove crosstalk images
- De-fringe
- Remove persistent images
- Correct for sky background
- Work out microstep offsets using header information
- Combine the images into super-frames by interleaving using the microstep offsets
- Work out jitter offsets by cross-correlating stellar object positions on super-frame images
- Combine the super-frame images with offsets into a single stacked image
- Generate a catalogue of objects on the stacked image and do a morphological classification
- Fit a WCS using astrometric standards that appear in the stacked image catalogue. Update the FITS headers of the stacked image as well as those of the super-frames and the single exposure images.
- Calculate photometric zero point using instrumental magnitudes, magnitudes of photometric standards, and illumination corrections.
- If a second photometric catalogue is specified, then redo the photometric zero point.
- Apply illumination correction to catalogue

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#### Outputs:

- Single exposure images that corrected for linearity, dark current, flat field, stripes, sky, **image persistence and crosstalk**. **A full WCS will appear in the header** (SIMPLE\_IMAGE\_STD, **simple\_??fits**)
- Illumination correction table (ILLCOR\_TAB\_STD, **illum.fits**)
- Interleaved super-frame images from the above if microstepping has been done as part of the observing sequence. (INTERLEAVED\_IMAGE\_STD, **super\_??fits**)
- Stacked jitter images from the super-frames. Full WCS and photometric zero point will appear in the FITS header. (JITTERED\_IMAGE\_STD, **stack\_??fits**)
- Associated confidence maps for each of the above output images. (CONFIDENCE\_MAP\_STD, **superc\_??fits, stackc\_??fits**)
- Object catalogue in the form of a FITS table if the **savecat** parameter has been set (OBJECT\_CATALOGUE\_STD, **catalogue\_??fits**)
- **stack\_??paf**
- **catalogue\_??paf**
- **illum\_??paf**

#### QC1 Parameters:

**FRINGE\_RATIO**  
 SATURATION  
 MEAN\_SKY  
 SKY\_NOISE  
 NOISE\_OBJ  
 IMAGE\_SIZE  
 APERTURE\_CORR  
 ELLIPTICITY  
 MAGZPT  
 MAGZERR  
 MAGNZPT  
 LIMITING\_MAG  
 ILLUMCOR\_RMS  
 WCS\_DCRVAL1  
 WCS\_DCRVAL2  
 WCS\_DTHETA  
 WCS\_SCALE  
 WCS\_SHEAR  
 WCS\_RMS  
 ZPT\_2MASS  
 ZPT\_STDS  
 ZPT\_STDS\_CAT

#### VIRCAM Functions Used:

vircam\_darkcor, vircam\_lincor, vircam\_flatcor, vircam\_gaincor,  
**vircam\_defringe**, **vircam\_persist**, vircam\_matchxy, **vircam\_crosstalk**,  
 vircam\_imcore, vircam\_getstds, vircam\_platesol, vircam\_matchstds,  
 vircam\_imdither, vircam\_photcal, vircam\_illum

#### Fatal Error Conditions:

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- Null input frameset
- Input frameset headers incorrect meaning that RAW and CALIB frames cannot be distinguished
- No science frames in input frameset
- Missing master calibration frames or unreadable extensions in input frameset
- Inability to save output products

**Non-fatal Error Conditions:**

None

**Conditions Leading To Dummy Products:**

- Missing calibration images, calibration images that won't load or are flagged as dummy.
- A detector has been signalled dead.
- Processing routines fail.

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## 8 Validation tests

Validation procedures will be developed for each function defined in chapter 6 and every recipe defined in chapter 7. In the case of the former, recipe plugins have been written to test each function individually. As these recipes may prove useful in themselves, these will be installed in the same tree as the reduction recipes (under the `tests` sub-directory). A brief discussion of each test recipe is included in the next section. As in previous recipe descriptions, each recipe has a parameter **ext** which is used to tell the recipe which of the FITS extensions you want to process. This parameter has been left off the parameter list for each recipe for the sake of brevity.

### 8.1 Unitary Tests

Tests are included for modules listed in chapter 6. Test data will be provided for all of these validation procedures. In some cases this will consist of laboratory test data using the real VISTA focal plane detectors, and in others, simulated data will be generated to look like VISTA data files.

Included in the test suite will be files that can be used in comparison with output from the test procedures. These will be monitored to ensure that:

- the image data arrays and table columns all contain exactly the same data
- a selection of relevant FITS header keywords have been created and are consistent with the test output files.
- output QC1 parameters match the known values from the test suite.

A selection of SOF files will also be included to ensure that the tests are always done in a consistent manner.

#### 8.1.1 `vircam_darkcor`

**Name:**

`vircam_darkcor`

**Purpose:**

Test the function **`vircam_darkcor`** (section 6.2) by subtracting a dark frame from an input science frame.

**Input Data:**

- A raw science frame (required, `SCIENCE_IMAGE`)
- Master dark frame of the same exposure parameters as above (required, `MASTER_DARK`)

**Output Data:**

- A dark corrected science frame (`SIMPLE_IMAGE_TEST`)

**Parameters:**

float **`darkscf`**

The factor by which to scale the dark frame before subtracting.

#### 8.1.2 `vircam_defringe`

**Name:**

`vircam_defringe`

**Purpose:**

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Test the function **vircam\_defringe** (section 6.3) iteratively fitting a fringe pattern and subtracting it out.

**Input Data:**

- A raw science frame (required, SCIENCE\_IMAGE)
- A master fringe frame (required, MASTER\_FRINGE)
- Master mask in the form of a confidence map or a bad pixel mask (optional, MASTER\_CONF or MASTER\_BPM)

**Output Data:**

- A fringe corrected science frame (SIMPLE\_IMAGE\_TEST)

**Parameters:**

int **nbsize**

The size of the smoothing cells used in the large scale background removal algorithm

### 8.1.3 **vircam\_destripe**

**Name:**

vircam\_destripe

**Purpose:**

Test the function **vircam\_destripe** (section 6.4) by modelling the background stripes in an input image and subtracting it out.

**Input Data:**

- A raw science frame (required, SCIENCE\_IMAGE)
- Master mask in the form of a confidence map or a bad pixel mask (optional, MASTER\_CONF or MASTER\_BPM)

**Output Data:**

- A stripe corrected science frame (SIMPLE\_IMAGE\_TEST)

**Parameters:**

None

### 8.1.4 **vircam\_flatcor**

**Name:**

vircam\_flatcor

**Purpose:**

Test the function **vircam\_flatcor** (section 6.5) by dividing a flat field image into an input science frame.

**Input Data:**

- A science frame (required, SCIENCE\_IMAGE). For best results, this should have been previously dark corrected.
- Master twilight flat frame (required, MASTER\_TWILIGHT\_FLAT)

**Output Data:**

- A flat field corrected science frame (SIMPLE\_IMAGE\_TEST)

**Parameters:**

None

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### 8.1.5 **vircam\_gaincor**

**Name:**

vircam\_gaincor

**Purpose:**

Test the function **vircam\_gaincor** (section 6.6) by applying the gain correction implied from an input flat field.

**Input Data:**

- A science frame (required, SCIENCE\_IMAGE). For best results, this should have been previously dark corrected and flat fielded.
- Master twilight flat frame (required, MASTER\_TWILIGHT\_FLAT)

**Output Data:**

- A gain corrected science frame (SIMPLE\_IMAGE\_TEST)

**Parameters:**

None

### 8.1.6 **vircam\_getstds**

**Name:**

vircam\_getstds

**Purpose:**

Test the function **vircam\_getstds** (section 6.8) by extracting standard stars from the 2MASS catalogue that should appear on an input image.

**Input Data:**

- A science frame (required, SCIENCE\_IMAGE).

**Output Data:**

- A standards table (STANDARDS\_TABLE)

**Parameters:**

char \***catpath**

The full path to the 2MASS PSC FITS tables.

### 8.1.7 **vircam\_imcombine**

**Name:**

vircam\_imcombine

**Purpose:**

Test the function **vircam\_imcombine** (section 6.10) by combining a list of input images into a single output image.

**Input Data:**

- A list of science frames (required, SCIENCE\_IMAGE).

**Output Data:**

- An output combined image (SIMPLE\_IMAGE\_TEST)

**Parameters:**

int **comb**

Determines the type of combination that is done to form the output map. Can take the following values

1. The output pixels are medians of the input pixels
2. The output pixels are means of the input pixels

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**int scale**

Determines how the input data are scaled or offset before they are combined. Can take the following values:

0. No scaling or biasing
1. All input frames are biased additively to bring their backgrounds to a common median level.
2. All input frames are biased multiplicatively to bring their backgrounds to a common median level.
3. All input frames are scaled to a uniform exposure time and then additively corrected to bring their backgrounds to a common median level.

**int xrej**

If set, then an extra rejection cycle will be run.

**int thr**

The rejection threshold in numbers of background sigmas.

### 8.1.8 **vircam\_imcore**

**Name:**

vircam\_imcore

**Purpose:**

Test the function **vircam\_imcore** (section 6.11) by extracting objects from a science frame and writing them to a FITS table.

**Input Data:**

- A science frame (required, SCIENCE\_IMAGE).
- An appropriate confidence map (required, CONFIDENCE\_MAP or MASTER\_CONF)

**Output Data:**

- An object catalogue (OBJECT\_CATALOGUE\_TEST)

**Parameters:**

**int ipix**

The minimum size of an object in pixels in order for that object not to be considered spurious.

**float thr**

The detection threshold measured in units of the mean background noise

**int icrowd**

If set, then the function will attempt to de-blend merged objects

**float rcore**

The core radius in pixels for the default profile fit.

**int nb**

The size in pixels of the grid squares used for background estimation.

**int cattype**

The output catalogue type. This can be:

1. The 32 column INT Wide Field Camera format
2. The 80 column WFCAM format
3. A very minimal format which is just fine if all you want is positions



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4. An object mask

NB: option 2 corresponds to the catalogues described in section 5.12.

### 8.1.9 **vircam\_imdither**

**Name:**

vircam\_imdither

**Purpose:**

Test the function **vircam\_imdither** (section 6.12) by dithering a list of input files and their associated confidence maps into a single output map

**Input Data:**

- A list of science frames (required, SCIENCE\_IMAGE).
- A list of confidence maps (required, CONFIDENCE\_MAP or MASTER\_CONF)

**Output Data:**

- An output dithered image (JITTERED\_IMAGE\_TEST)

**Parameters:**

None

### 8.1.10 **vircam\_interleave**

**Name:**

vircam\_interleave

**Purpose:**

Test the function **vircam\_interleave** (section 6.13) by interleaving a set of input science frames

**Input Data:**

- A set of science frame (required, SCIENCE\_IMAGE)
- An appropriate set of confidence maps (required, MASTER\_CONF)

**Output Data:**

- An output interleaved image (INTERLEAVED\_IMAGE\_TEST)

**Parameters:**

None

### 8.1.11 **vircam\_lincor**

**Name:**

vircam\_lincor

**Purpose:**

Test the function **vircam\_lincor** (section 6.14) by linearising a science frame.

**Input Data:**

- A science frame (required, SCIENCE\_IMAGE). For best results, this should have been previously dark corrected and flat field.
- A channel table (required, CHANNEL\_TABLE)

**Output Data:**

- A linearly corrected image (SIMPLE\_IMAGE\_TEST)

**Parameters:**

None

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### 8.1.12 vircam\_matchstds

**Name:**

vircam\_matchstds

**Purpose:**

Test the function **vircam\_matchstds** (section 6.15) by matching an object catalogue with a standards table.

**Input Data:**

- An object catalogue (required, OBJECT\_CATALOGUE).
- An extracted standards catalogue (required, STANDARDS\_TABLE)

**Output Data:**

- A matched standards table (MATCHED\_STANDARDS\_TABLE)

**Parameters:**

None

### 8.1.13 vircam\_matchxy

**Name:**

vircam\_matchxy

**Purpose:**

Test the function **vircam\_matchxy** (section 6.16) by matching two object catalogues and working out the Cartesian positional difference.

**Input Data:**

- Two object catalogues (required, OBJECT\_CATALOGUE).

**Output Data:**

- A PAF with the  $x,y$  offsets written to it

**Parameters:**

None

### 8.1.14 vircam\_mkconf

**Name:**

vircam\_mkconf

**Purpose:**

Test the function **vircam\_mkconf** (section 6.17) by creating a confidence map from a master flat and a master bad pixel mask.

**Input Data:**

- A master flat field (required, MASTER\_TWILIGHT\_FLAT).
- A master bad pixel mask or master confidence map (required, MASTER\_BPM or MASTER\_CONF)

**Output Data:**

- An output confidence map (CONFIDENCE\_MAP\_TEST)

**Parameters:**

None

### 8.1.15 vircam\_platesol

**Name:**

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vircam\_platesol

**Purpose:**

Test the function **vircam\_platesol** (section 6.20) by fitting a plate constant model to a matched standards catalogue.

**Input Data:**

- A science frame with an initial WCS (required, SCIENCE\_IMAGE)
- A matched standards table of objects on the science frame (required, MATCHED\_STANDARDS\_TABLE).

**Output Data:**

- A PAF with the plate solution written to it

**Parameters:**

int **nconst**

The number of plate constants to fit. This must be either 4 or 6.

int **shiftan**

If this is set, then the position of the tangent point will be moved to take poor telescope pointing into account.

## **8.2 Recipe (plugin) Tests**

Each software release is accompanied by a set of simulated data sufficient to generate initial MASTER and REFERENCE calibration frames, and to exercise all of the plugin recipes in chapter 7 (often they will be carried over from previous releases, occasionally new files need to be generated to test new functionality). Increasingly, real vircam data will be provided as it becomes available through camera static testing and commissioning. “SOF” files will be provided to drive the recipes (but which may require modification depending on the test environment path names etc.).

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## 9 Development Plan

Following [AD1] the DRL development is summarised in Table 9-1. In keeping with the fact that VISTA will (initially) be a single-instrument telescope, and so will essentially have a single commissioning period (no COM2), milestone 5 is omitted in order to keep the numbering consistent with general VLT planning.

Act ID	Milestone	Timeline	Deliv. ID	Deliverables
M-02	FDR	-4w	DR2	This document
	PAE	-6m	-	Data Reduction Library prototype with some basic dome-flat capability; will test instrument simulation data-interface compatibility.
M-03	PAE	-4w	DR3	Data Reduction Library v0.1 Including: all basic planned functionality such that laboratory data from the instrument may be pipelined.
M-04	COM1	-4w	DR4	Data Reduction Library v0.5 Including: bug fixes found at PAE plus any new (previously unplanned) functionality required as a result of PAE detector characterisation.
M-06	PAC	-4w	DR6	Data Reduction Library v1.0 Including: more bug fixes and any refinements and additions to analysis required as a result of experience gained with real commissioning data.
M-09	SO1	+8w	DR11	Data Reduction Library v1.y Including: more of above, and feedback from early science users.
		+8w	DR11	Final version this document

**Table 9-1 Development Schedule**

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## 10 Appendix: QC1 Parameters

```

*****
# E.S.O. VISTA project
#
# "@(#) $Id: dicVIRCAM_QC.txt,v 0.8 2004/07/29 12:05:28 vltscm Exp $"
#
# VIRCAM_QC dictionary
#
# who          when          what
#-----
# pbunclark    2004-10-05    Original
# pbunclark    2004-11-19    Many clarifications
#              DID parameter added
#              POINTING -> WCS set
#              SEEING -> IMAGE SIZE
# mji          2004-11-22    Updated comments and descriptions
#              and rationalized order
# jr1          2004-12-08    add FRINGE_RMS, ILLUMCOR_RMS
# jr1          2004-12-13    change FRINGE_RMS to FRINGE_RATIO,
#              add LINFITQUAL
# psb          2005-12-13    RESETVAR changed to RESETRMS, improved
#              comments on DARKRMS, PARTICLE_RATE & RESETRMS
# jr1          2005-12-19    add RESETDIFF_RMS DARKDIFF_RMS
# jpe          2006-02-03    improve couple of descriptions.
# jr1          2006-03-24    add RESETDIFF_MED, DARKDIFF_MED,
#              FLATRATIO_MED, FLATRATIO_RMS
# jr1          2006-06-05    add MAGZPT, MAGZERR and MAGNZPT
# psb          2006-06-06    add QC.RESET_MED & QC.DARKMED
# jr1          2006-11-10    fixed a few typos and changed entries to a more
#              logical order. Removed SKY_RESET_ANOMALY.
# jr1          2007-02-27    Added STRIPERMS, NHOTPIX, HOTFRAC, BAD_PIXEL_NUM,
#              ZPT_STDS_CAT. Fixed units on some entries
#
# NAME
# ESO-DFS-DIC.VIRCAM_QC - Data Interface Dictionary for VIRCAM Quality
# control (level 1) parameters.
#-----
Dictionary Name:  ESO-VLT-DIC.VIRCAM_QC
Scope:            ESO VISTA VIRCAM
Source:           ESO VLT
Version Control:  @(#) $Id: 0.8 $
Revision:         $Revision: 0.9 $
Date:            2007-02-27
Status:           Development
Description:      VIRCAM Quality-Control

Parameter Name:   QC DID
Class:            header
Context:          process
Type:             string
Value Format:     %30s
Unit:
Comment Format:   Data dictionary for VIRCAM QC.
Description:     Name/version of ESO DID to which QC keywords comply.

Parameter Name:   QC RESETMED
Class:            header
Context:          process
Type:             double
Value Format:     %f
Unit:            adu
Comment Format:   [adu] Median reset level
Description:     Median reset level

Parameter Name:   QC RESETRMS
Class:            header
Context:          process

```

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Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] RMS noise in combined reset frame.  
Description: Variation is defined here as the Gaussian equivalent MAD ie. 1.48\*median-of-absolute-deviation from unity after normalising by median level ie. measuring the RMS reset level variation. The RMS can later be compared with library values for troubleshooting problems.

Parameter Name: QC RESETDIFF\_MED  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Median new-library reset frame.  
Description: Measure the median of the difference of a new mean reset frame and a library reset frame.

Parameter Name: QC RESETDIFF\_RMS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] RMS new-library reset frame  
Description: Measure the RMS of the difference of a new mean reset frame and a library reset frame.

Parameter Name: QC DARKMED  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Median dark counts  
Description: Median counts in a dark frame.

Parameter Name: QC DARKRMS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] RMS noise of combined dark frame.  
Description: RMS is defined here as the Gaussian equivalent MAD ie. 1.48\*median-of-absolute-deviation from median. The RMS can later be compared with library values for darks of the same integration and exposure times.

Parameter Name: QC DARKDIFF\_MED  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Median new-library dark frame.  
Description: Measure the median of the difference of a new mean dark frame and a library reset frame.

Parameter Name: QC DARKDIFF\_RMS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] RMS new-library dark frame  
Description: Measure the RMS of the difference of a new mean dark frame and a library dark frame.

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Parameter Name: QC PARTICLE\_RATE  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: count/s/detector  
Comment Format: [count/s/detector] Cosmic ray/spurion rate.  
Description: Average no. of pixels rejected during combination of dark frames, used to give an estimate of the rate of cosmic ray hits for each detector. This can later be compared with previous estimates and monitored.

Parameter Name: QC STRIPERMS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] RMS stripe pattern  
Description: The RMS of the stripe pattern removed from an image

Parameter Name: QC NHOTPIX  
Class: header  
Context: process  
Type: integer  
Value Format: %d  
Unit:  
Comment Format: Number of hot pixels  
Description: The number of detected hot pixels on an image

Parameter Name: QC HOTFRAC  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Fraction of hot pixels  
Description: The fraction of the pixels on an image that are estimated to be hot.

Parameter Name: QC DARKCURRENT  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu/sec  
Comment Format: [adu/sec] Average dark current on frame.  
Description: Measured using the median of the pixel values, can later be compared similar darks for trends

Parameter Name: QC FLATRMS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: RMS flatfield pixel sens per detector.  
Description: RMS is defined here as the Gaussian equivalent MAD ie.  $1.48 * \text{median-of-absolute-deviation from unity after normalising by median level ie. measuring the RMS sensitivity variation. The RMS can later be compared with library values for troubleshooting problems. significantly with time.}$

Parameter Name: QC FLATRATIO\_MED  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Median new/library flat frame.  
Description: Measure the median of the ratio of a new

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mean flat frame and a library flat frame.

Parameter Name: QC FLATRATIO\_RMS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: RMS new/library flat frame.  
Description: Measure the RMS of the ratio of a new mean flat frame and a library flat frame.

Parameter Name: QC GAIN\_CORRECTION  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Detector median flatfield/global median.  
Description: The ratio of median counts in a mean flat exposure for a given detector relative to the ensemble defines the internal gain correction for the detector. These internal relative detector gain corrections should be stable with time.

Parameter Name: QC READNOISE  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: e-  
Comment Format: [e-] Readnoise.  
Description: Measured from the noise properties of the difference in two consecutive dark frames, using a MAD estimator as above for robustness against spurions. The noise properties of each detector should remain stable so long as the electronics/micro-code have not been modified.

Parameter Name: QC GAIN  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: e-/adu  
Comment Format: [e-/adu] Gain.  
Description: Determined from pairs of darks and flatfields of the same exposure/integration time and illumination by comparing the measured noise properties with the expected photon noise contribution. The gain of each detector should remain stable so long as the electronics/micro-code have not been modified.

Parameter Name: QC LINEARITY  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Percentage average non-linearity.  
Description: Derived from measured non-linearity curves for each detector interpolated to 10k counts (ADUs) level. Although all infrared systems are non-linear to some degree, the shape and scale of the linearity curve for each detector should remain constant. A single measure at 20k counts can be used to monitor this although the full linearity curves will need to be examined quarterly [TBC] to look for more subtle changes.

Parameter Name: QC LINFITQUAL  
Class: header



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Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: RMS fractional error in linearity fit  
Description: Derived by applying the linearity coefficients to the image data that were used to measure them. This is the RMS of the residuals of the linearised data normalised by the expected linear value

Parameter Name: QC\_BAD\_PIXEL\_STAT  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Fraction of bad pixels/detector.  
Description: Determined from the statistics of the pixel distribution from the ratio of two flatfield sequences of significantly different average count levels. The fraction of bad pixels per detector (either hot or cold) should not change

Parameter Name: QC\_BAD\_PIXEL\_NUM  
Class: header  
Context: process  
Type: integer  
Value Format: %d  
Unit:  
Comment Format: Number of bad pixels/detector.  
Description: Determined from the statistics of the pixel distribution from the ratio of two flatfield sequences of significantly different average count levels. The number of bad pixels per detector (either hot or cold) should not change

Parameter Name: QC\_WCS\_DCRVAL1  
Class: header  
Context: process  
Type: double  
Value Format: %e  
Unit: deg  
Comment Format: [deg] Actual WCS zero point X - raw header value.  
Description: Measure of difference between dead-reckoning pointing and true position of the detector on sky. Derived from current polynomial distortion model and 6-constant detector model offset.

Parameter Name: QC\_WCS\_DCRVAL2  
Class: header  
Context: process  
Type: double  
Value Format: %e  
Unit: deg  
Comment Format: [deg] Actual WCS zero point Y - raw header value.  
Description: Measure of difference between dead-reckoning pointing and true position of the detector on sky. Derived from current polynomial distortion model and 6-constant detector model offset.

Parameter Name: QC\_WCS\_DTHETA  
Class: header  
Context: process  
Type: double  
Value Format: %e  
Unit: deg  
Comment Format: [deg] Actual WCS rotation PA - raw PA header value(h).  
Description: Measure of difference between dead-reckoning PA and true position angle of the detector. Derived from current polynomial distortion model

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and 6-constant detector model effective rotation term.

Parameter Name: QC WCS\_SCALE  
Class: header  
Context: process  
Type: double  
Value Format: %e  
Unit: deg/pixel  
Comment Format: [deg/pixel] Measured WCS plate scale per detector.  
Description: Measure of the average on-sky pixel scale of detector after correcting using current polynomial distortion model

Parameter Name: QC WCS\_SHEAR  
Class: header  
Context: process  
Type: double  
Value Format: %e  
Unit: [deg] Power of cross-terms in WCS solution [deg  
Comment Format: [deg] Power of cross-terms in WCS solution [deg].  
Description: Measure of WCS shear after normalising by plate scale and rotation, expressed as an equivalent distortion angle. Gives a simple measure of distortion problems in WCS solution.

Parameter Name: QC WCS\_RMS  
Class: header  
Context: process  
Type: double  
Value Format: %e  
Unit: arcsec  
Comment Format: [arcsec] Robust RMS of WCS solution for each detector.  
Description: Robust average of residuals from WCS solution for each detector. Measure of integrity of WCS solution.

Parameter Name: QC MEAN\_SKY  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Mean sky level.  
Description: Computed using a clipped median for each detector Sky levels (perhaps not at Ks) should vary smoothly over the night. Strange changes in values may indicate a hardware fault.

Parameter Name: QC SKY\_NOISE  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] RMS sky noise.  
Description: computed using a MAD estimator with respect to median sky after removing large scale gradients. The sky noise should be a combination of readout-noise, photon-noise and detector quirks. Monitoring the ratio of expected noise to measured provides a system diagnostic at the detector level.

Parameter Name: QC SATURATION  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Saturation level of bright stars.  
Description: Determined from maximum peak flux of detected stars from exposures in a standard bright star field. The saturation level\*gain is a check on the full-well characteristics of each detector.

Parameter Name: QC NOISE\_OBJ

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Class: header  
Context: process  
Type: integer  
Value Format: %d  
Unit:  
Comment Format:  
Description: Number of classified noise objects per frame. Measured using an object cataloguer combined with a morphological classifier. The number of objects classified as noise from frame-to-frame should be reasonably constant; excessive numbers indicate a problem.

Parameter Name: QC IMAGE\_SIZE  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: arcsec  
Comment Format: [arcsec] Mean stellar image FWHM.  
Description: Measured from the average FWHM of stellar-classified images of suitable signal:to:noise. The seeing will obviously vary over the night with time, wavelength (filter) and as airmass<sup>0.6</sup>. This variation should be predictable given local site seeing measures. A comparison with the expected value can be used as an indication of poor guiding, poor focus or instrument malfunction.

Parameter Name: QC APERTURE\_CORR  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] 2 arcsec diam aperture flux correction.  
Description: The aperture flux correction for stellar images due to flux falling outside the aperture. Determined using a curve-of-growth of a series of fixed-size apertures. Alternative simple measure of image profile properties, particularly the presence of extended PSF wings, as such monitors optical properties of system; also required for limiting magnitude computations.

Parameter Name: QC ELLIPTICITY  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Mean stellar ellipticity.  
Description: The detected image intensity-weighted second moments will be used to compute the average ellipticity of suitable signal:to:noise stellar images. Shot-noise causes even perfectly circular stellar images to have non-zero ellipticity but more significant values are indicative of one of: optical, tracking and autoguiding, or detector hardware problems.

Parameter Name: QC MAGZPT  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Photometric zero point.  
Description: A measure of the photometric zero point using an aperture of 1\* the core radius.

Parameter Name: QC MAGZERR  
Class: header  
Context: process  
Type: double  
Value Format: %f

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Unit: mag  
Comment Format: [mag] Photometric zero point error.  
Description: A measure of the RMS photometric zero point error using an aperture of 1\* the core radius.

Parameter Name: QC MAGNZPT  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: Number of stars in zero point calc.  
Description: The number of stars on this image used to calculate the photometric zeropoint.

Parameter Name: QC ZPT\_2MASS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] 1st-pass photometric zeropoint.  
Description: The magnitude of a star that gives 1 detected ADU/s (or e-/s) for each detector, derived using 2MASS comparison stars for every science observation. This is a first pass zero-point to monitor gross changes in throughput. Extinction will vary over a night, but detector to detector variations are an indication of a fault.

Parameter Name: QC ZPT\_STDS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] 2nd-pass photometric zeropoint.  
Description: The magnitude of a star that gives 1 detected ADU/s (or e-/s) for each detector, derived from observations of VISTA standard star fields. Combined with the trend in long-term system zero-point properties, the ensemble "average" zero-point directly monitors extinction variations (faults/mods in the system notwithstanding) The photometric zeropoints will undoubtedly vary (slowly) over time as a result of the cleaning of optical surfaces etc.

Parameter Name: QC ZPT\_STDS\_CAT  
Class: header  
Context: process  
Type: string  
Value Format: %s  
Unit: mag  
Comment Format: Standard catalogue for photometric zeropoint.  
Description: This is a label for the standard star catalogue used to calculate the photometric zeropoint.

Parameter Name: QC LIMITING\_MAG  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Limiting mag ie. depth of exposure.  
Description: Estimate of 5-sigma limiting mag for stellar-like objects for each science observation, derived from QCs ZPT\_2MASS, SKY\_NOISE, APERTURE\_CORR. Can later be compared with a target value to see if main survey requirements (ie. usually depth) are met.

Parameter Name: QC PERSIST\_DECAY  
Class: header  
Context: process

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Type: double  
Value Format: %f  
Unit: s  
Comment Format: [s] Mean exponential time decay constant.  
Description: The decay rate of the persistence of bright images on subsequent exposures will be modelled using an exponential decay function with time constant tau. Requires an exposure on a bright star field followed a series of darks.

Parameter Name: QC PERSIST\_ZERO  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Fractional persistence at T0 (extrapolated).  
Description: Determined from the persistence decay behaviour from exponential model fitting. Requires an exposure on a bright star field followed a series of darks (as above)

Parameter Name: QC CROSS\_TALK  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Average values for cross-talk component matrix.  
Description: determined from presence of +ve or -ve ghost images on other channels/detectors using exposures in bright star fields. Potentially a fully populated 256x256 matrix but likely to be sparsely populated with a small number of non-zero values of band-diagonal form. This QC summary parameter is the average value of the modulus of the off-diagonal terms. Values for the cross-talk matrix should be very stable with time, hardware modifications notwithstanding.

Parameter Name: QC FRINGE\_RATIO  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Ratio of sky noise before/after fringe fit  
Description: A robust estimate of the background noise is done before the first fringe fitting pass. Once the last fringe fit is done a final background noise estimate is done. This parameter is the ratio of the value before fringe fitting to the final value after defringing.

Parameter Name: QC ILLUMCOR\_RMS  
Class: header  
Context: process  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] RMS in illumination correction  
Description: The RMS of the illumination correction over all of the frame.

The above dictionary is illustrated as a FITS header extract as it will appear in the per-detector extension header:

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```

HIERARCH ESO QC DID = 'ESO-VLT-DIC.VIRCAM_QC' / Data dictionar
HIERARCH ESO QC RESETMED = 0.000000 / [adu] Median reset level
HIERARCH ESO QC RESETRMS = 0.000000 / [adu] RMS noise in combined res
HIERARCH ESO QC RESETDIFF_MED= 0.000000 / [adu] Median new-library reset
HIERARCH ESO QC RESETDIFF_RMS= 0.000000 / [adu] RMS new-library reset fra
HIERARCH ESO QC DARKMED = 0.000000 / [adu] Median dark counts
HIERARCH ESO QC DARKRMS = 3.456000 / [adu] RMS noise of combined dar
HIERARCH ESO QC DARKDIFF_MED = 0.000000 / [adu] Median new-library dark f
HIERARCH ESO QC DARKDIFF_RMS = 0.000000 / [adu] RMS new-library dark fram
HIERARCH ESO QC PARTICLE_RATE= 20.500000 / [count/s/detector] Cosmic ray/s
HIERARCH ESO QC STRIPERMS = 0.000000 / [adu] RMS stripe pattern
HIERARCH ESO QC NHOTPIX = 0 / Number of hot pixels
HIERARCH ESO QC HOTFRAC = 0.000000 / Fraction of hot pixels
HIERARCH ESO QC DARKCURRENT = 200.000000 / [adu/sec] Average dark current
HIERARCH ESO QC FLATRMS = 0.000000 / RMS flatfield pixel sens per de
HIERARCH ESO QC FLATRATIO_MED= 0.000000 / Median new/library flat frame.
HIERARCH ESO QC FLATRATIO_RMS= 0.000000 / RMS new/library flat frame.
HIERARCH ESO QC GAIN_CORRECTION= 0.950000 / Detector median flatfield/globa
HIERARCH ESO QC READNOISE = 150.000000 / [e-] Readnoise.
HIERARCH ESO QC GAIN = 1.600000 / [e-/adu] Gain.
HIERARCH ESO QC LINEARITY = 0.030000 / Percentage average non-linearity
HIERARCH ESO QC LINFITQUAL = 0.000000 / RMS fractional error in lineari
HIERARCH ESO QC BAD_PIXEL_STAT= 0.006000 / Fraction of bad pixels/detector
HIERARCH ESO QC BAD_PIXEL_NUM= 0 / Number of bad pixels/detector.
HIERARCH ESO QC WCS_DCRVAL1 = 5.555550e-04 / [deg] Actual WCS zero point X -
HIERARCH ESO QC WCS_DCRVAL2 = -5.555550e-04 / [deg] Actual WCS zero point Y -
HIERARCH ESO QC WCS_DTHETA = 1.000000e-02 / [deg] Actual WCS rotation PA
HIERARCH ESO QC WCS_SCALE = 9.444400e-05 / [deg/pixel] Measured WCS plate
HIERARCH ESO QC WCS_SHEAR = 1.000000e-04 / [deg] Power of cross-terms in W
HIERARCH ESO QC WCS_RMS = 9.444400e-06 / [arcsec] Robust RMS of WCS solu
HIERARCH ESO QC MEAN_SKY = 12345.120000 / [adu] Mean sky level.
HIERARCH ESO QC SKY_NOISE = 2000.000000 / [adu] RMS sky noise.
HIERARCH ESO QC SATURATION = 65535.000000 / [adu] Saturation level of brigh
HIERARCH ESO QC NOISE_OBJ = 150 / Number of classified noise obje
HIERARCH ESO QC IMAGE_SIZE = 0.500000 / [arcsec] Mean stellar image FWH
HIERARCH ESO QC APERTURE_CORR= 0.456000 / [mag] 2 arcsec diam aperture fl
HIERARCH ESO QC ELLIPTICITY = 0.021100 / Mean stellar ellipticity.
HIERARCH ESO QC MAGZPT = 0.000000 / [mag] Photometric zero point.
HIERARCH ESO QC MAGZERR = 0.000000 / [mag] Photometric zero point er
HIERARCH ESO QC MAGNZPT = 0.000000 / Number of stars in zero point c
HIERARCH ESO QC ZPT_2MASS = 26.500000 / [mag] 1st-pass photometric zero
HIERARCH ESO QC ZPT_STDS = 26.400000 / [mag] 2nd-pass photometric zero
HIERARCH ESO QC ZPT_STDS_CAT = 'UNKNOWN' / Standard catalogue for photomet
HIERARCH ESO QC LIMITING_MAG = 24.567000 / [mag] Limiting mag ie. depth of
HIERARCH ESO QC PERSIST_DECAY= 40.000000 / [s] Mean exponential time decay
HIERARCH ESO QC PERSIST_ZERO = 0.800000 / Fractional persistence at T0 (e
HIERARCH ESO QC CROSS_TALK = 1.000000 / Average values for cross-talk c
HIERARCH ESO QC FRINGE_RATIO = 0.000000 / Ratio of sky noise before/after
HIERARCH ESO QC ILLUMCOR_RMS = 0.000000 / [mag] RMS in illumination corre

```

The following table references the QC parameters with the functions and recipes where they are generated:

QC PARAMETER	FUNCTION	RECIPE
APERTURE_CORR	imcore	jitter_microstep_process standard_process
BAD_PIXEL_NUM		linearity_analyse
BAD_PIXEL_STAT		linearity_analyse
CROSS_TALK		crosstalk_analyse
DARKCURRENT		dark_current
DARKDIFF_MED		dark_combine
DARKDIFF_RMS		dark_combine

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DARKMED		dark_combine
DARKRMS		dark_combine
ELLIPTICITY	imcore	jitter_microstep_process standard_process
FLATRATIO_MED		dome_flat_combine twilight_combine
FLATRATIO_RMS		dome_flat_combine twilight_combine
FLATRMS		dome_flat_combine twilight_combine
FRINGE_RATIO	defringe	jitter_microstep_process standard_process
GAIN		detector_noise
GAIN_CORRECTION		twilight_combine
HOTFRAC		dark_combine
ILLUMCOR_RMS		mesostep_analyse standard_process
IMAGE_SIZE	imcore	jitter_microstep_process standard_process
LIMITING_MAG	photcal	jitter_microstep_process standard_process
LINEARITY		linearity_analyse
LINFITQUAL		linearity_analyse
MAGNZPT	photcal	jitter_microstep_process standard_process
MAGZERR	photcal	jitter_microstep_process standard_process
MAGZPT	photcal	jitter_microstep_process standard_process
MEAN_SKY	imcore	jitter_microstep_process standard_process
NHOTPIX		dark_combine
NOISE_OBJ	imcore	jitter_microstep_process standard_process
PARTICLE_RATE		dark_combine
PERSIST_DECAY		persistence_analyse
PERSIST_ZERO		persistence_analyse
READNOISE		detector_noise
RESETDIFF_MED		reset_combine
RESETDIFF_RMS		reset_combine
RESETMED		reset_combine
RESETRMS		reset_combine
SATURATION	imcore	jitter_microstep_process standard_process
SKY_NOISE	imcore	jitter_microstep_process standard_process

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STRIPERMS		dark_combine
WCS_DCRVAL1	platesol	jitter_microstep_process standard_process
WCS_DCRVAL2	platesol	jitter_microstep_process standard_process
WCS_DTHETA	platesol	jitter_microstep_process standard_process
WCS_RMS	platesol	jitter_microstep_process standard_process
WCS_SCALE	platesol	jitter_microstep_process standard_process
WCS_SHEAR	platesol	jitter_microstep_process standard_process
ZPT_2MASS	platesol	standard_process
ZPT_STDS	photcal	standard_process
ZPT_STDS_CAT	photcal	standard_process

**Table 10-1 The origin of QC Parameters**



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## 11 Appendix: DRS Dictionary

```
#####
# E.S.O. VISTA project
#
#  "@(#) $Id: ESO-VLT-DIC.VIRCAM_DRS,v 0.1 2005/04/04  vltscm Exp $"
#
#
# VIRCAM_DRS dictionary
#
# who          when          what
#-----
# pbunclark    2005-04-04    Original
# jrl          2005-04-15    various tidyups
# jrl          2006-03-23    add BACKMED, corrections
# jrl          2006-04-28    added CLASSIFD, THRESHOL, MINPIX and CROWDED
# jrl          2006-06-05    modified photometric zeropoint entries and
#                          added XOFFDITHER and YOFFDITHER.
# jrl          2006-11-10    added FILTFWHM, STRIPECOR, STRIPERMS, NDITCOR,
#                          SKYCOR, IMADUMMY. Rearranged entries into a
#                          more logical order.
# jrl          2007-02-27    removed NDITCOR. Small tidy-up
# jrl          2007-05-15    Added EXTINCT and GAINCOR

Dictionary Name:  ESO-VLT-DIC.VIRCAM_DRS
Scope:           DFS
Source:          ESO VLT
Version Control:  "@(#) $Id: 0.1 $"
Revision:        0.3
Date:            2007-05-30
Status:          Development
Description:     VIRCAM Processing keywords
#-----
# General keywords
#

Parameter Name:  DRS DID
Class:           header
Context:         PROCESS
Type:            string
Value Format:    %30s
Unit:
Comment Format:   Data dictionary for VIRCAM DRS
Description:     Name/version of ESO DID to which DRS
                  keywords comply.

Parameter Name:  DRS DARKCOR
Class:           header
Context:         PROCESS
Type:            string
Value Format:    %s
Unit:
Comment Format:   Dark image
Description:     The name of the dark image specified in
                  darksrc

Parameter Name:  DRS DARKSCL
Class:           header
Context:         PROCESS
Type:            double
Value Format:    %f
Unit:
Comment Format:   Dark scale factor
Description:     The scale factor used in the dark subtractionon

Parameter Name:  DRS FLATCOR
Class:           header
Context:         PROCESS
Type:            string
```

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Value Format: %s  
Unit:  
Comment Format: Flat field image  
Description: The name of the flat field image specified in flatsrc

Parameter Name: DRS LINCOR  
Class: header  
Context: PROCESS  
Type: string  
Value Format: %s  
Unit:  
Comment Format: Channel table  
Description: The name of the channel table used in the linearisation

Parameter Name: DRS GAINCOR  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Gain correction factor  
Description: The multiplicative gain correction for the current detector

Parameter Name: DRS SKYCOR  
Class: header  
Context: PROCESS  
Type: unknown  
Value Format: %b  
Unit:  
Comment Format: Flag for sky correction  
Description: If set, then a sky background subtraction has been done on this image.

Parameter Name: DRS STRIPECOR  
Class: header  
Context: PROCESS  
Type: unknown  
Value Format: %b  
Unit:  
Comment Format: Flag from stripe correction  
Description: If set, then this image has been destriped.

Parameter Name: DRS STRIPERMS  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] RMS of removed stripes  
Description: If destriping is done, then this is the RMS of the stripe pattern that was removed from the image

Parameter Name: DRS XOFFMICRO  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit:  
Comment Format: X-pixels to microstep input image  
Description: The number of pixels in X by which to microstep the current input image relative to the output grid.

Parameter Name: DRS YOFFMICRO  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Y-pixels to microstep input image

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Description: The number of pixels in Y by which to microstep the current input image relative to the output grid.

Parameter Name: DRS XOFFDITHER  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit:  
Comment Format: X-pixels to jitter input image  
Description: The number of pixels in X by which to jitter the current input image relative to the output grid.

Parameter Name: DRS YOFFDITHER  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Y-pixels to jitter input image  
Description: The number of pixels in Y by which to jitter the current input image relative to the output grid.

Parameter Name: DRS PROVXXXX  
Class: header  
Context: PROCESS  
Type: string  
Value Format: %s  
Unit:  
Comment Format: Input file #  
Description: A set of FITS keywords that lists the files that were combined to form this output file. This establishes the provenance of the output file.

Parameter Name: DRS SKYLEVEL  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Mean sky level  
Description: The mean sky level in the image

Parameter Name: DRS SKYNOISE  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Mean sky noise  
Description: The mean sky noise in the image

Parameter Name: DRS STDCRMS  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: arcsec  
Comment Format: [arcsec] RMS of the WCS fit  
Description: The RMS of the WCS fit

Parameter Name: DRS NUMBRMS  
Class: header  
Context: PROCESS  
Type: integer  
Value Format: %d  
Unit:  
Comment Format: No. of stars in WCS fit  
Description: Number of stars in the WCS fit

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Parameter Name: DRS WCSRAOFF  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: arcsec  
Comment Format: [arcsec] Diff in RA after proc.  
Description: The equatorial coordinates of the central pixel of the image is calculated both before and after the plate solution is found. This is the difference in the RA (in arcseconds).

Parameter Name: DRS WCSDECOFF  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: arcsec  
Comment Format: [arcsec] Diff in DEC after proc.  
Description: The equatorial coordinates of the central pixel of the image is calculated both before and after the plate solution is found. This is the difference in the DEC (in arcseconds).

Parameter Name: DRS BACKMED  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Background median value  
Description: The most recent estimate of the background

Parameter Name: DRS CLASSIFD  
Class: header  
Context: PROCESS  
Type: integer  
Value Format: %d  
Unit:  
Comment Format: Catalogue has been classified.  
Description: Set if the classification software has been run on this catalogue.

Parameter Name: DRS THRESHOL  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: adu  
Comment Format: [adu] Isophotal analysis threshold  
Description: Isophotal analysis used in object detection.

Parameter Name: DRS MINPIX  
Class: header  
Context: PROCESS  
Type: integer  
Value Format: %d  
Unit: pixels  
Comment Format: [pixels] Minimum size for images  
Description: Minimum number of pixels for an object to cover

Parameter Name: DRS CROWDED  
Class: header  
Context: PROCESS  
Type: integer  
Value Format: %d  
Unit:  
Comment Format: Crowded field analysis flag  
Description: If set, then the deblending software has been used to extract the objects in this catalogue.

Parameter Name: DRS RCORE

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Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: pixels  
Comment Format: [pixels] Core radius  
Description: The core radius. This is set to the approximate expected FWHM of all the stellar images

Parameter Name: DRS SEEING  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: pixels  
Comment Format: [pixels] The estimated seeing  
Description: The seeing esimated from the stellar images on the current frame.

Parameter Name: DRS FILTFWHM  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: pixels  
Comment Format: [pixels] Smoothing kernel FWHM  
Description: The FWHM of the smoothing kernel used in the object detection algorithm.

Parameter Name: DRS ZPIM1  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Photometric zeropoint  
Description: The calculated photometric zeropoint for stars on the current image only through an aperture of 1\* the core radius.

Parameter Name: DRS ZPSIGIM1  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] RMS in photometric zeropoint  
Description: The calculated RMS in photometric zeropoint for stars on the current image only through an aperture of 1\* the core radius.

Parameter Name: DRS ZPIM2  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Photometric zeropoint  
Description: The calculated photometric zeropoint for stars on the current image only through an aperture of 2\* the core radius.

Parameter Name: DRS ZPSIGIM2  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] RMS in photometric zeropoint  
Description: The calculated RMS in photometric zeropoint for stars on the current image only through an aperture of 2\* the core radius.

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Parameter Name: DRS LIMIT\_MAG1  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Limiting magnitude 1\*core radius  
Description: The calculated 5 sigma limiting magnitude through an aperture of 1\* the core radius

Parameter Name: DRS LIMIT\_MAG2  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Limiting magnitude 2\*core radius  
Description: The calculated 5 sigma limiting magnitude through an aperture of 2\* the core radius

Parameter Name: DRS MAGNZPTIM  
Class: header  
Context: PROCESS  
Type: integer  
Value Format: %d  
Unit:  
Comment Format: Number of stars used photometric zeropoint calc.(h)  
Description: The number of stars used to calculate the photometric zeropoint for this image only.

Parameter Name: DRS ZPALL1  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Photometric zeropoint  
Description: The calculated photometric zeropoint for stars on all the images reduced together through an aperture of 1\* the core radius.

Parameter Name: DRS ZPSIGALL1  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] RMS in photometric zeropoint  
Description: The calculated RMS in photometric zeropoint for stars on all the images reduced together through an aperture of 1\* the core radius.

Parameter Name: DRS ZPALL2  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Photometric zeropoint  
Description: The calculated photometric zeropoint for stars on all the images reduced together through an aperture of 2\* the core radius.

Parameter Name: DRS ZPSIGALL2  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] RMS in photometric zeropoint  
Description: The calculated RMS in photometric zeropoint for stars on all the images reduced together through an aperture of 2\* the core radius.

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Parameter Name: DRS MAGNZPTALL  
Class: header  
Context: PROCESS  
Type: integer  
Value Format: %d  
Unit:  
Comment Format: Number of stars used photometric zeropoint calc.(h)  
Description: The number of stars used to calculate the photometric zeropoint for all the images reduced together.

Parameter Name: DRS EXTINGT  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit: mag  
Comment Format: [mag] Assumed extinction  
Description: The extinction assumed when working out the magnitude zeropoint.

Parameter Name: DRS IMADUMMY  
Class: header  
Context: PROCESS  
Type: unknown  
Value Format: %b  
Unit:  
Comment Format: Flag for dummy image/table  
Description: If this is set, then the image/table contained in this particular HDU is a dummy product.

Parameter Name: DRS FLATIN  
Class: header  
Context: PROCESS  
Type: string  
Value Format: %s  
Unit:  
Comment Format: Flat field used  
Description: The name of the flat field frame that was used to create this confidence map

Parameter Name: DRS BPPMIN  
Class: header  
Context: PROCESS  
Type: string  
Value Format: %s  
Unit:  
Comment Format: Bad pixel map used  
Description: The name of the bad pixel mask image that was used to create this confidence map

Parameter Name: DRS PERMASK  
Class: header  
Context: PROCESS  
Type: string  
Value Format: %s  
Unit:  
Comment Format: Persistence mask used  
Description: The name of the persistence mask image that was used to create this confidence map

Parameter Name: DRS XTCOR  
Class: header  
Context: PROCESS  
Type: string  
Value Format: %s  
Unit:  
Comment Format: Crosstalk matrix table  
Description: Name of the crosstalk matrix table used to process this image

Parameter Name: DRS FRINGEi  
Class: header

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Context: PROCESS  
Type: string  
Value Format: %s  
Unit:  
Comment Format: Fringe file of nth pass  
Description: The name of the fringe file used in the nth defringing pass

Parameter Name: DRS FRNGSCi  
Class: header  
Context: PROCESS  
Type: double  
Value Format: %f  
Unit:  
Comment Format: Scale factor nth defringe pass  
Description: The scale factor for the nth defringing pass

## 12 Appendix: Raw FITS Header

```

SIMPLE = T / Standard FITS format (NOST-100.0)
BITPIX = 8 / # of bits storing pix values
NAXIS = 0 / # of axes in frame
EXTEND = T / Extension may be present
ORIGIN = 'ESO ' / European Southern Observatory
DATE = '2006-03-21T15:06:48' / Date this file was written
TELESCOP= 'VISTA ' / ESO Telescope Name
INSTRUME= 'VIRCAM ' / Instrument used.
OBJECT = 'OBJECT ' / Original target.
RA = 318.346792 / 21:13:23.2 RA (J2000) pointing (deg)
DEC = -88.93761 / -88:56:15.3 DEC (J2000) pointing (deg)
EQUINOX = 2000. / Standard FK5 (years)
RADECSYS= 'FK5 ' / Coordinate reference frame
EXPTIME = 10.0000000 / Integration time
MJD-OBS = 53815.62973579 / Obs start
DATE-OBS= '2006-03-21T15:06:49.1726' / Observing date
UTC = 54270.829 / 15:04:30.829 UTC at start (sec)
LST = 80333.420 / 22:18:53.420 LST at start (sec)
PI-COI = 'J.Lewis-P.Bunclark' / PI-COI name.
OBSERVER= 'Peter Bunclark' / Name of observer.
ORIGFILE= 'VIRCAM_IMG_OBS080_0001.fits' / Original File Name
COMMENT VISTA IR Camera OS $Revision: 0.21 $
HIERARCH ESO ADA ABSROT END = 0.00000 / Abs rot angle at exp end (deg)
HIERARCH ESO DPR CATG = 'TEST ' / Observation category
HIERARCH ESO DPR TECH = 'IMAGE,FILTOFFSET' / Observation technique
HIERARCH ESO DPR TYPE = 'STD,STRAYLIGHT' / Observation type
HIERARCH ESO INS DATE = '2005-12-14' / Instrument release date (yyyy-mm-d)
HIERARCH ESO INS FILT1 DATE = '2006-01-27T10:02:27' / Filter index time
HIERARCH ESO INS FILT1 FOCUS = 0.000 / Filter focus offset [mm]
HIERARCH ESO INS FILT1 ID = 'SLOT8 ' / Filter unique id
HIERARCH ESO INS FILT1 NAME = 'Y ' / Filter name
HIERARCH ESO INS FILT1 NO = 25 / Filter wheel position index
HIERARCH ESO INS FILT1 WLEN = 0.000 / Filter effective wavelength [nm]
HIERARCH ESO INS HB1 SWSIM = F / If T, heart beat device simulated
HIERARCH ESO INS ID = 'VIRCAM/1.56' / Instrument ID
HIERARCH ESO INS LSC1 OK = T / If T, controller is operational
HIERARCH ESO INS LSC1 SWSIM = F / If T, lakeshore ctrllr simulated
HIERARCH ESO INS LSM1 OK = T / If T, controller is operational
HIERARCH ESO INS LSM1 SWSIM = F / If T, lakeshore monitor simulated
HIERARCH ESO INS LSM2 OK = T / If T, controller is operational
HIERARCH ESO INS LSM2 SWSIM = F / If T, lakeshore monitor simulated
HIERARCH ESO INS LSM3 OK = T / If T, controller is operational
HIERARCH ESO INS LSM3 SWSIM = F / If T, lakeshore monitor simulated
HIERARCH ESO INS PRES1 ID = 'Vac1 ' / Pressure sensor type
HIERARCH ESO INS PRES1 NAME = 'Vacuum gauge 1' / Pressure sensor name
HIERARCH ESO INS PRES1 UNIT = 'mbar ' / Pressure unit
HIERARCH ESO INS PRES1 VAL = 0.000 / Pressure [mbar]
HIERARCH ESO INS SW1 ID = 'INPOS ' / Switch ID
HIERARCH ESO INS SW1 NAME = 'Filter In-position Switch' / Switch name
HIERARCH ESO INS SW1 STATUS = 'INACTIVE' / Switch status

```



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HIERARCH ESO INS SW2 ID      = 'REFSW   ' / Switch ID
HIERARCH ESO INS SW2 NAME    = 'Filter Reference Select' / Switch name
HIERARCH ESO INS SW2 STATUS  = 'PRIMARY   ' / Switch status
HIERARCH ESO INS SW3 ID      = 'HOME     ' / Switch ID
HIERARCH ESO INS SW3 NAME    = 'Filter Reference Switch' / Switch name
HIERARCH ESO INS SW3 STATUS  = 'INACTIVE  ' / Switch status
HIERARCH ESO INS TEMP1 ID    = 'Amb      ' / Temperature sensor type
HIERARCH ESO INS TEMP1 NAME  = 'Ambient temperature' / Temperature sensor name
HIERARCH ESO INS TEMP1 UNIT  = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP1 VAL   =          302.580 / Temperature [K]
HIERARCH ESO INS TEMP10 ID   = 'CC1_2    ' / Temperature sensor type
HIERARCH ESO INS TEMP10 NAME = 'Cryo cooler 1 2nd' / Temperature sensor name
HIERARCH ESO INS TEMP10 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP10 VAL  =          24.105 / Temperature [K]
HIERARCH ESO INS TEMP12 ID   = 'CC2_2    ' / Temperature sensor type
HIERARCH ESO INS TEMP12 NAME = 'Cryo cooler 2 2nd' / Temperature sensor name
HIERARCH ESO INS TEMP12 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP12 VAL  =          27.791 / Temperature [K]
HIERARCH ESO INS TEMP14 ID   = 'CC3_2    ' / Temperature sensor type
HIERARCH ESO INS TEMP14 NAME = 'Cryo cooler 3 2nd' / Temperature sensor name
HIERARCH ESO INS TEMP14 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP14 VAL  =          22.735 / Temperature [K]
HIERARCH ESO INS TEMP15 ID   = 'WFSN     ' / Temperature sensor type
HIERARCH ESO INS TEMP15 NAME = 'WFS CCD assembly PY' / Temperature sensor name
HIERARCH ESO INS TEMP15 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP15 VAL  =           1.000 / Temperature [K]
HIERARCH ESO INS TEMP16 ID   = 'WFSS     ' / Temperature sensor type
HIERARCH ESO INS TEMP16 NAME = 'WFS CCD assembly NY' / Temperature sensor name
HIERARCH ESO INS TEMP16 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP16 VAL  =          123.550 / Temperature [K]
HIERARCH ESO INS TEMP17 ID   = 'Dt1LAB   ' / Temperature sensor type
HIERARCH ESO INS TEMP17 NAME = 'Science detector 1AB' / Temperature sensor name
HIERARCH ESO INS TEMP17 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP17 VAL  =           73.583 / Temperature [K]
HIERARCH ESO INS TEMP18 ID   = 'Dt1CD    ' / Temperature sensor type
HIERARCH ESO INS TEMP18 NAME = 'Science detector 1CD' / Temperature sensor name
HIERARCH ESO INS TEMP18 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP18 VAL  =           73.002 / Temperature [K]
HIERARCH ESO INS TEMP19 ID   = 'Dt2BA   ' / Temperature sensor type
HIERARCH ESO INS TEMP19 NAME = 'Science detector 2BA' / Temperature sensor name
HIERARCH ESO INS TEMP19 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP19 VAL  =           74.668 / Temperature [K]
HIERARCH ESO INS TEMP2 ID    = 'Win      ' / Temperature sensor type
HIERARCH ESO INS TEMP2 NAME  = 'Cryostat window cell' / Temperature sensor name
HIERARCH ESO INS TEMP2 UNIT  = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP2 VAL   =          176.710 / Temperature [K]
HIERARCH ESO INS TEMP20 ID   = 'Dt2DC   ' / Temperature sensor type
HIERARCH ESO INS TEMP20 NAME = 'Science detector 2DC' / Temperature sensor name
HIERARCH ESO INS TEMP20 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP20 VAL  =           74.106 / Temperature [K]
HIERARCH ESO INS TEMP21 ID   = 'Dt3AB   ' / Temperature sensor type
HIERARCH ESO INS TEMP21 NAME = 'Science detector 3AB' / Temperature sensor name
HIERARCH ESO INS TEMP21 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP21 VAL  =           74.677 / Temperature [K]
HIERARCH ESO INS TEMP22 ID   = 'Dt3CD   ' / Temperature sensor type
HIERARCH ESO INS TEMP22 NAME = 'Science detector 3CD' / Temperature sensor name
HIERARCH ESO INS TEMP22 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP22 VAL  =           75.485 / Temperature [K]
HIERARCH ESO INS TEMP23 ID   = 'Dt4BA   ' / Temperature sensor type
HIERARCH ESO INS TEMP23 NAME = 'Science detector 4BA' / Temperature sensor name
HIERARCH ESO INS TEMP23 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP23 VAL  =           74.778 / Temperature [K]
HIERARCH ESO INS TEMP24 ID   = 'Dt4DC   ' / Temperature sensor type
HIERARCH ESO INS TEMP24 NAME = 'Science detector 4DC' / Temperature sensor name
HIERARCH ESO INS TEMP24 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP24 VAL  =           74.544 / Temperature [K]
HIERARCH ESO INS TEMP25 ID   = 'FPA     ' / Temperature sensor type
HIERARCH ESO INS TEMP25 NAME = 'FPA thermal plate' / Temperature sensor name
HIERARCH ESO INS TEMP25 UNIT = 'K         ' / Temperature unit
HIERARCH ESO INS TEMP25 VAL  =           69.997 / Temperature [K]
HIERARCH ESO INS TEMP26 ID   = 'WFSpl   ' / Temperature sensor type
HIERARCH ESO INS TEMP26 NAME = 'WFS plate' / Temperature sensor name
HIERARCH ESO INS TEMP26 UNIT = 'K         ' / Temperature unit

```

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HIERARCH ESO INS TEMP26 VAL = 108.360 / Temperature [K]
HIERARCH ESO INS TEMP3 ID = 'Tube ' / Temperature sensor type
HIERARCH ESO INS TEMP3 NAME = 'Cryostat tube' / Temperature sensor name
HIERARCH ESO INS TEMP3 UNIT = 'K ' / Temperature unit
HIERARCH ESO INS TEMP3 VAL = 33.256 / Temperature [K]
HIERARCH ESO INS TEMP4 ID = 'LNtnk ' / Temperature sensor type
HIERARCH ESO INS TEMP4 NAME = 'Liquid nitrogen tank' / Temperature sensor name
HIERARCH ESO INS TEMP4 UNIT = 'K ' / Temperature unit
HIERARCH ESO INS TEMP4 VAL = 103.180 / Temperature [K]
HIERARCH ESO INS TEMP5 ID = 'Baff ' / Temperature sensor type
HIERARCH ESO INS TEMP5 NAME = 'Baffle ' / Temperature sensor name
HIERARCH ESO INS TEMP5 UNIT = 'K ' / Temperature unit
HIERARCH ESO INS TEMP5 VAL = 21.332 / Temperature [K]
HIERARCH ESO INS TEMP6 ID = 'Lens ' / Temperature sensor type
HIERARCH ESO INS TEMP6 NAME = 'Lens barrel' / Temperature sensor name
HIERARCH ESO INS TEMP6 UNIT = 'K ' / Temperature unit
HIERARCH ESO INS TEMP6 VAL = 100.570 / Temperature [K]
HIERARCH ESO INS TEMP7 ID = 'FwShd ' / Temperature sensor type
HIERARCH ESO INS TEMP7 NAME = 'Filter wheel shield' / Temperature sensor name
HIERARCH ESO INS TEMP7 UNIT = 'K ' / Temperature unit
HIERARCH ESO INS TEMP7 VAL = 124.420 / Temperature [K]
HIERARCH ESO INS TEMP8 ID = 'FwHub ' / Temperature sensor type
HIERARCH ESO INS TEMP8 NAME = 'Filter wheel hub' / Temperature sensor name
HIERARCH ESO INS TEMP8 UNIT = 'K ' / Temperature unit
HIERARCH ESO INS TEMP8 VAL = 109.570 / Temperature [K]
HIERARCH ESO INS THERMAL DET MEAN= 0.00 / Detector mean temperature [K]
HIERARCH ESO INS THERMAL DET TARGET= 70.00 / Detector target temperature [K]
HIERARCH ESO INS THERMAL ENABLE= F / If T, enable thermal control
HIERARCH ESO INS VAC1 OK = T / If T, controller is operational
HIERARCH ESO INS VAC1 SWSIM = F / If T, vacuum sensor simulated
HIERARCH ESO OBS OBS = 'ESO-VLT-DIC.OBS-1.11' / OBS Dictionary
HIERARCH ESO OBS GRP = '0 ' / linked blocks
HIERARCH ESO OBS ID = -1 / Observation block ID
HIERARCH ESO OBS NAME = 'Maintenance' / OB name
HIERARCH ESO OBS PI-COI ID = 0 / ESO internal PI-COI ID
HIERARCH ESO OBS PI-COI NAME = 'M.Caldwell-A.Born' / PI-COI name
HIERARCH ESO OBS PROG ID = 'Maintenance' / ESO program identification
HIERARCH ESO OBS START = '2006-01-30T13:54:10' / OB start time
HIERARCH ESO OBS TPLNO = 1 / Template number within OB
HIERARCH ESO OCS DET1 IMGNAME= 'VIRCAM_GEN_STD' / Data File Name.
HIERARCH ESO OCS RECIPE = 'DEFAULT ' / Data reduction recipe to be used
HIERARCH ESO OCS REQTIME = 10.000 / Requested integration time [s]
HIERARCH ESO TEL ABSROT START= 0.000 / Abs rotator angle at start
HIERARCH ESO TEL AIRM END = 0.000 / Airmass at end
HIERARCH ESO TEL AIRM START = 0.000 / Airmass at start
HIERARCH ESO TEL ALT = 25.691 / Alt angle at start (deg)
HIERARCH ESO TEL AMBI FWHM END= -1.00 / Observatory Seeing queried from AS
HIERARCH ESO TEL AMBI FWHM START= -1.00 / Observatory Seeing queried from AS
HIERARCH ESO TEL AMBI PRES END= 750.00 / Observatory ambient air pressure q
HIERARCH ESO TEL AMBI PRES START= 750.00 / Observatory ambient air pressure q
HIERARCH ESO TEL AMBI RHUM = 12. / Observatory ambient relative humi
HIERARCH ESO TEL AMBI TAU0 = 0.000000 / Average coherence time
HIERARCH ESO TEL AMBI TEMP = 10.00 / Observatory ambient temperature qu
HIERARCH ESO TEL AMBI WINDDIR= 0. / Observatory ambient wind directio
HIERARCH ESO TEL AMBI WINDSP = 10.00 / Observatory ambient wind speed que
HIERARCH ESO TEL AO ALT = 0.000000 / Altitude of last closed loop aO
HIERARCH ESO TEL AO DATE = ' ' / Last closed loop aO
HIERARCH ESO TEL AO M1 DATE = '2006-03-21T15:06:47' / Last M1 update
HIERARCH ESO TEL AO M2 DATE = '2006-03-21T15:06:46' / Last M2 update
HIERARCH ESO TEL AO MODES = 0 / Which aO modes corrected closed lo
HIERARCH ESO TEL AZ = 0.317 / Az angle at start (deg) S=0,W=90
HIERARCH ESO TEL DATE = 'not set ' / TCS installation date
HIERARCH ESO TEL DID = 'ESO-VLT-DIC.TCS-01.00' / Data dictionary for TEL
HIERARCH ESO TEL DID1 = 'ESO-VLT-DIC.VTCS-0.2' / Additional data dict. fo
HIERARCH ESO TEL DOME STATUS = 'FULLY-OPEN' / Dome status
HIERARCH ESO TEL ECS FLATFIELD= 0 / Flat field level
HIERARCH ESO TEL ECS MOONSCR = 0.00 / Moon screen position
HIERARCH ESO TEL ECS VENT1 = 0.00 / State of vent i
HIERARCH ESO TEL ECS VENT2 = 0.00 / State of vent i
HIERARCH ESO TEL ECS VENT3 = 0.00 / State of vent i
HIERARCH ESO TEL ECS WINDSCR = 0.00 / Wind screen position
HIERARCH ESO TEL FOCU ID = 'CA ' / Telescope focus station ID
HIERARCH ESO TEL FOCU VALUE = 0.000 / M2 setting (mm)

```

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HIERARCH ESO TEL GEOELEV = 2530. / Elevation above sea level (m)
HIERARCH ESO TEL GEOLAT = -24.6157 / Tel geo latitude (+North) (deg)
HIERARCH ESO TEL GEOLON = -70.3976 / Tel geo longitude (+East) (deg)
HIERARCH ESO TEL GUID FWHM = 0.00 / Seeing measured by autoguider
HIERARCH ESO TEL GUID STATUS = 'OFF' / Status of autoguider
HIERARCH ESO TEL ID = 'v 0.44' / TCS version number
HIERARCH ESO TEL M2 ACENTRE = 0.00 / M2 centring alpha
HIERARCH ESO TEL M2 ATILT = 0.00 / M2 tilt alpha
HIERARCH ESO TEL M2 BCENTRE = 0.00 / M2 centring beta
HIERARCH ESO TEL M2 BTILT = 0.00 / M2 tilt beta
HIERARCH ESO TEL M2 Z = 0.00000 / Focussing position of M2 in Z coord
HIERARCH ESO TEL MOON DEC = -27.46744 / -27:28:02.7 DEC (J2000) (deg)
HIERARCH ESO TEL MOON RA = 253.667459 / 16:54:40.1 RA (J2000) (deg)
HIERARCH ESO TEL OPER = 'Operator name not set' / Telescope Operator
HIERARCH ESO TEL PARANG END = 0.000 / Parallax angle at end (deg)
HIERARCH ESO TEL PARANG START = 0.000 / Parallax angle at start (deg)
HIERARCH ESO TEL POSANG = 0.000 / Rot position angle at start
HIERARCH ESO TEL TARG ALPHA = 211323.230 / Alpha coordinate for the target
HIERARCH ESO TEL TARG COORDTYPE = 'M' / Coordinate type (M=mean A=apparent)
HIERARCH ESO TEL TARG DELTA = -885615.400 / Delta coordinate for the target
HIERARCH ESO TEL TARG EPOCH = 2000.000 / Epoch
HIERARCH ESO TEL TARG EPOCHSYSTEM = 'J' / Epoch system (default J=Julian)
HIERARCH ESO TEL TARG EQUINOX = 2000.000 / Equinox
HIERARCH ESO TEL TARG PARALLAX = 0.000 / Parallax
HIERARCH ESO TEL TARG PMA = 0.000000 / Proper Motion Alpha
HIERARCH ESO TEL TARG PMD = 0.000000 / Proper motion Delta
HIERARCH ESO TEL TARG RADVEL = 0.000 / Radial velocity
HIERARCH ESO TEL TH M1 TEMP = 0.00 / M1 superficial temperature
HIERARCH ESO TEL TH STR TEMP = 0.00 / Telescope structure temperature
HIERARCH ESO TEL TRAK STATUS = 'NORMAL' / Tracking status
HIERARCH ESO TPL DID = 'ESO-VLT-DIC.TPL-1.9' / Data dictionary for TPL
HIERARCH ESO TPL EXPNO = 1 / Exposure number within template
HIERARCH ESO TPL ID = 'VIRCAM_gen_tec_StrayLight' / Template signature
HIERARCH ESO TPL NAME = 'VIRCAM stray light investigation' / Template name
HIERARCH ESO TPL NEXP = 6 / Number of exposures within template
HIERARCH ESO TPL PRESEQ = 'VIRCAM_gen_tec_StrayLight.seq' / Sequencer script
HIERARCH ESO TPL START = '2006-01-30T13:54:10' / TPL start time
HIERARCH ESO TPL VERSION = '$Revision: 0.13 $' / Version of the template
NJITTER = 0 / Number of jitter positions
NOFFSETS = 0 / Number of offset positions
NUSTEP = 0 / Number of microstep positions
OBSNUM = 1 / Observation number
REQTIME = 10.000 / Requested integration time [s]
END

```

```

XTENSION = 'IMAGE' / IMAGE extension
BITPIX = 32 / # of bits per pixel value
NAXIS = 2 / # of axes in data array
NAXIS1 = 2048 / # of pixels in axis1
NAXIS2 = 2048 / # of pixels in axis2
PCOUNT = 0 / number of random group parameters
GCOUNT = 1 / number of random groups
EXTNAME = 'DET1.CHIP9' / Extension name
EXTVER = 1 / Extension version
ORIGIN = 'ESO' / European Southern Observatory
DATE = '2006-01-30T13:54:47.7333' / Date the file was written
EXPTIME = 10.000000 / Integration time
MJD-OBS = 53765.57956362 / Obs start 2006-01-30T13:54:34.297
DATE-OBS = '2006-01-30T13:54:34.2967' / Observing date
CTYPE1 = 'RA---ZPN' / Coord type of celestial axis 1
CTYPE2 = 'DEC--ZPN' / Coord type of celestial axis 2
CRVAL1 = 318.346791667 / RA at reference pixel
CRVAL2 = -88.9376111111 / Dec at reference pixel
CRPIX1 = 5401.6 / Pixel coordinate at ref point
CRPIX2 = 6860.8 / Pixel coordinate at ref point
CDELTA1 = 9.494444444444444E-05 / Coordinate increment
CDELTA2 = -9.494444444444444E-05 / Coordinate increment
CD1_1 = 5.81347849634012E-21 / WCS transform matrix element
CD1_2 = 9.494444444444444E-05 / WCS transform matrix element
CD2_1 = -9.494444444444444E-05 / WCS transform matrix element
CD2_2 = -5.81347849634012E-21 / WCS transform matrix element
HIERARCH ESO DET CHIP ID = 'ESO-Virgo45' / Detector ID
HIERARCH ESO DET CHIP LIVE = T / Detector live or broken

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HIERARCH ESO DET CHIP NAME = 'Virgo' / Detector name  
 HIERARCH ESO DET CHIP NO = 9 / Unique Detector Number  
 HIERARCH ESO DET CHIP NX = 2048 / Pixels in X  
 HIERARCH ESO DET CHIP NY = 2048 / Pixels in Y  
 HIERARCH ESO DET CHIP PXSPACE= 2.000e-05 / Pixel-Pixel Spacing  
 HIERARCH ESO DET CHIP TYPE = 'IR' / The Type of Det Chip  
 HIERARCH ESO DET CHIP VIGNETD = F / Detector chip vignetted?  
 HIERARCH ESO DET CHIP X = 3 / Detector position x-axis  
 HIERARCH ESO DET CHIP Y = 4 / Detector position y-axis  
 HIERARCH ESO DET CHOP FREQ = 0 / Chopping Frequency  
 HIERARCH ESO DET CON OPMODE = 'NORMAL' / Operational Mode  
 HIERARCH ESO DET DID = 'ESO-VLT-DIC.IRACE-1.34' / Dictionary Name and Re  
 HIERARCH ESO DET DIT = 10.000000 / Integration Time  
 HIERARCH ESO DET DITDELAY = 0.000 / Pause Between DITs  
 HIERARCH ESO DET EXP NAME = 'VIRCAM\_GEN\_STD030\_0001' / Exposure Name  
 HIERARCH ESO DET EXP NO = 3 / Exposure number  
 HIERARCH ESO DET EXP UTC = '2006-01-30T13:54:47.7333' / File Creation Time  
 HIERARCH ESO DET FRAM NO = 1 / Frame number  
 HIERARCH ESO DET FRAM TYPE = 'INT' / Frame type  
 HIERARCH ESO DET FRAM UTC = '2006-01-30T13:54:46.7037' / Time Recv Frame  
 HIERARCH ESO DET IRACE ADC1 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC1 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC1 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC1 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC1 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC1 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC10 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC10 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC10 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC10 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC10 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC10 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC11 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC11 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC11 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC11 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC11 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC11 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC12 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC12 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC12 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC12 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC12 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC12 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC13 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC13 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC13 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC13 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC13 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC13 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC14 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC14 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC14 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC14 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC14 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC14 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC15 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC15 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC15 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC15 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC15 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC15 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC16 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC16 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC16 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC16 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC16 HEADER= 1 / Header of ADC Board  
 HIERARCH ESO DET IRACE ADC16 NAME= 'VISTA-AQ-GRP' / Name for ADC Board  
 HIERARCH ESO DET IRACE ADC2 DELAY= 7 / ADC Delay Adjustment  
 HIERARCH ESO DET IRACE ADC2 ENABLE= 1 / Enable ADC Board (0/1)  
 HIERARCH ESO DET IRACE ADC2 FILTER1= 0 / ADC Filter1 Adjustment  
 HIERARCH ESO DET IRACE ADC2 FILTER2= 0 / ADC Filter2 Adjustment  
 HIERARCH ESO DET IRACE ADC2 HEADER= 1 / Header of ADC Board

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HIERARCH ESO DET IRACE ADC2 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE ADC3 DELAY= 7 / ADC Delay Adjustment
HIERARCH ESO DET IRACE ADC3 ENABLE= 1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADC3 FILTER1= 0 / ADC Filter1 Adjustment
HIERARCH ESO DET IRACE ADC3 FILTER2= 0 / ADC Filter2 Adjustment
HIERARCH ESO DET IRACE ADC3 HEADER= 1 / Header of ADC Board
HIERARCH ESO DET IRACE ADC3 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE ADC4 DELAY= 7 / ADC Delay Adjustment
HIERARCH ESO DET IRACE ADC4 ENABLE= 1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADC4 FILTER1= 0 / ADC Filter1 Adjustment
HIERARCH ESO DET IRACE ADC4 FILTER2= 0 / ADC Filter2 Adjustment
HIERARCH ESO DET IRACE ADC4 HEADER= 1 / Header of ADC Board
HIERARCH ESO DET IRACE ADC4 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE ADC5 DELAY= 7 / ADC Delay Adjustment
HIERARCH ESO DET IRACE ADC5 ENABLE= 1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADC5 FILTER1= 0 / ADC Filter1 Adjustment
HIERARCH ESO DET IRACE ADC5 FILTER2= 0 / ADC Filter2 Adjustment
HIERARCH ESO DET IRACE ADC5 HEADER= 1 / Header of ADC Board
HIERARCH ESO DET IRACE ADC5 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE ADC6 DELAY= 7 / ADC Delay Adjustment
HIERARCH ESO DET IRACE ADC6 ENABLE= 1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADC6 FILTER1= 0 / ADC Filter1 Adjustment
HIERARCH ESO DET IRACE ADC6 FILTER2= 0 / ADC Filter2 Adjustment
HIERARCH ESO DET IRACE ADC6 HEADER= 1 / Header of ADC Board
HIERARCH ESO DET IRACE ADC6 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE ADC7 DELAY= 7 / ADC Delay Adjustment
HIERARCH ESO DET IRACE ADC7 ENABLE= 1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADC7 FILTER1= 0 / ADC Filter1 Adjustment
HIERARCH ESO DET IRACE ADC7 FILTER2= 0 / ADC Filter2 Adjustment
HIERARCH ESO DET IRACE ADC7 HEADER= 1 / Header of ADC Board
HIERARCH ESO DET IRACE ADC7 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE ADC8 DELAY= 7 / ADC Delay Adjustment
HIERARCH ESO DET IRACE ADC8 ENABLE= 1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADC8 FILTER1= 0 / ADC Filter1 Adjustment
HIERARCH ESO DET IRACE ADC8 FILTER2= 0 / ADC Filter2 Adjustment
HIERARCH ESO DET IRACE ADC8 HEADER= 1 / Header of ADC Board
HIERARCH ESO DET IRACE ADC8 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE ADC9 DELAY= 7 / ADC Delay Adjustment
HIERARCH ESO DET IRACE ADC9 ENABLE= 1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADC9 FILTER1= 0 / ADC Filter1 Adjustment
HIERARCH ESO DET IRACE ADC9 FILTER2= 0 / ADC Filter2 Adjustment
HIERARCH ESO DET IRACE ADC9 HEADER= 1 / Header of ADC Board
HIERARCH ESO DET IRACE ADC9 NAME= 'VISTA-AQ-GRP' / Name for ADC Board
HIERARCH ESO DET IRACE SEQCONT= 'F' / Sequencer Continuous Mode
HIERARCH ESO DET MINDIT = 1.0011000 / Minimum DIT
HIERARCH ESO DET MODE NAME = '' / DCS Detector Mode
HIERARCH ESO DET NCORRS = 2 / Read-Out Mode
HIERARCH ESO DET NCORRS NAME = 'Double' / Read-Out Mode Name
HIERARCH ESO DET NDIT = 1 / # of Sub-Integrations
HIERARCH ESO DET NDITSKIP = 0 / DITs skipped at 1st.INT
HIERARCH ESO DET RSPEED = 1 / Read-Speed Factor
HIERARCH ESO DET RSPEEDADD = 0 / Read-Speed Add
HIERARCH ESO DET VOLT1 CLKHI1= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI10= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI11= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI12= 5.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI13= 1.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI14= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI15= 0.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI16= 2.5000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI2= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI3= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI4= 5.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI5= 1.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI6= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI7= 0.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI8= 2.5000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHI9= 4.0000 / Set Value High-Clock
HIERARCH ESO DET VOLT1 CLKHINM1= 'clk1Hi pmc' / Name of High-Clock
HIERARCH ESO DET VOLT1 CLKHINM10= 'clk10Hi FrameStart' / Name of High-Clock
HIERARCH ESO DET VOLT1 CLKHINM11= 'clk11Hi UcResetEnable' / Name of High-Clock
HIERARCH ESO DET VOLT1 CLKHINM12= 'clk12Hi VHiRowEnable' / Name of High-Clock
HIERARCH ESO DET VOLT1 CLKHINM13= 'clk13Hi VLORowEnable' / Name of High-Clock

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HIERARCH ESO DET VOLT1 CLKHINM14= 'clk14Hi VHiReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM15= 'clk15Hi VLoReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM16= 'clk16Hi VpOut' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM2= 'clk2Hi FrameStart' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM3= 'clk3Hi UcResetEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM4= 'clk4Hi VHiRowEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM5= 'clk5Hi VLoRowEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM6= 'clk6Hi VHiReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM7= 'clk7Hi VLoReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM8= 'clk8Hi VpOut' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHINM9= 'clk9Hi pmc' / Name of High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT1= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT10= 4.0234 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT11= 4.0234 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT12= 5.0244 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT13= 1.0352 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT14= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT15= 0.0439 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT16= 2.5293 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT2= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT3= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT4= 5.0195 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT5= 1.0352 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT6= 4.0332 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT7= 0.0439 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT8= 2.5293 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKHIT9= 4.0430 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT1 CLKLO1= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO10= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO11= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO12= 5.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO13= 1.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO14= 4.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO15= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO16= 9.7500 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO2= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO3= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO4= 5.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO5= 1.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO6= 4.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO7= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO8= 9.7500 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLO9= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM1= 'clk1Lo pmc' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM10= 'clk10Lo FrameStart' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM11= 'clk11Lo UcResetEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM12= 'clk12Lo VHiRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM13= 'clk13Lo VLoRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM14= 'clk14Lo VHiReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM15= 'clk15Lo VLoReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM16= 'clk16Lo VpOut' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM2= 'clk2Lo FrameStart' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM3= 'clk3Lo UcResetEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM4= 'clk4Lo VHiRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM5= 'clk5Lo VLoRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM6= 'clk6Lo VHiReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM7= 'clk7Lo VLoReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM8= 'clk8Lo VpOut' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLONM9= 'clk9Lo pmc' / Name of Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT1= 0.0391 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT10= 0.0391 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT11= 0.0439 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT12= 4.9609 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT13= 1.0254 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT14= 4.0283 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT15= 0.0342 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT16= 9.4824 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT2= 0.0391 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT3= 0.0293 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT4= 4.9609 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT5= 1.0303 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT6= 4.0234 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT7= 0.0342 / Tel Value Low-Clock

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HIERARCH ESO DET VOLT1 CLKLOT8= 9.4775 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 CLKLOT9= 0.0439 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT1 DC1 = -2.3600 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC10 = -3.3500 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC11 = 0.0000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC12 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC13 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC14 = 3.5000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC15 = 2.2000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC16 = 3.3000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC2 = -3.3500 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC3 = 0.0000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC4 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC5 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC6 = 3.5000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC7 = 2.2000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC8 = 3.3000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DC9 = -2.3600 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT1 DCNM1 = 'DC1 VIdle' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM10= 'DC10 VSlew' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM11= 'DC11 VRstUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM12= 'DC12 VDetCom' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM13= 'DC13 VnUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM14= 'DC14 VpUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM15= 'DC15 VnOut' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM16= 'DC16 RefBias' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM2 = 'DC2 VSlew' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM3 = 'DC3 VRstUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM4 = 'DC4 VDetCom' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM5 = 'DC5 VnUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM6 = 'DC6 VpUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM7 = 'DC7 VnOut' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM8 = 'DC8 RefBias' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCNM9 = 'DC9 VIdle' / Name of DC-voltage  
 HIERARCH ESO DET VOLT1 DCTA1 = -2.3633 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA10= -3.3594 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA11= 0.0000 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA12= 0.7031 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA13= 0.7031 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA14= 3.5010 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA15= 2.1973 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA16= 3.3008 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA2 = -3.3545 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA3 = 0.0049 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA4 = 0.6982 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA5 = 0.6982 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA6 = 3.5010 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA7 = 2.1973 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA8 = 3.2959 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTA9 = -2.3682 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT1 DCTB1 = -2.3535 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB10= -3.3203 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB11= 0.0000 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB12= 0.6982 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB13= 0.7031 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB14= 3.5010 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB15= 2.1826 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB16= 3.2959 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB2 = -3.3154 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB3 = 0.0000 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB4 = 0.6982 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB5 = 0.6982 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB6 = 3.4961 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB7 = 2.1826 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB8 = 3.2959 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT1 DCTB9 = -2.3584 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 CLKHI1= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI10= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI11= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI12= 5.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI13= 1.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI14= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI15= 0.0000 / Set Value High-Clock

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HIERARCH ESO DET VOLT2 CLKHI16= 2.5000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI2= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI3= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI4= 5.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI5= 1.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI6= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI7= 0.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI8= 2.5000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHI9= 4.0000 / Set Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM1= 'clk1Hi pmc' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM10= 'clk10Hi FrameStart' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM11= 'clk11Hi UcResetEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM12= 'clk12Hi VHiRowEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM13= 'clk13Hi VLoRowEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM14= 'clk14Hi VHiReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM15= 'clk15Hi VLoReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM16= 'clk16Hi VpOut' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM2= 'clk2Hi FrameStart' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM3= 'clk3Hi UcResetEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM4= 'clk4Hi VHiRowEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM5= 'clk5Hi VLoRowEnable' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM6= 'clk6Hi VHiReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM7= 'clk7Hi VLoReset' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM8= 'clk8Hi VpOut' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHINM9= 'clk9Hi pmc' / Name of High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT1= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT10= 4.0234 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT11= 4.0186 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT12= 5.0098 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT13= 1.0400 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT14= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT15= 0.0488 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT16= 2.5342 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT2= 4.0234 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT3= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT4= 5.0195 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT5= 1.0352 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT6= 4.0283 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT7= 0.0488 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT8= 2.5342 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKHIT9= 4.0430 / Tel Value High-Clock  
 HIERARCH ESO DET VOLT2 CLKLO1= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO10= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO11= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO12= 5.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO13= 1.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO14= 4.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO15= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO16= 9.7500 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO2= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO3= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO4= 5.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO5= 1.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO6= 4.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO7= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO8= 9.7500 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLO9= 0.0000 / Set value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM1= 'clk1Lo pmc' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM10= 'clk10Lo FrameStart' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM11= 'clk11Lo UcResetEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM12= 'clk12Lo VHiRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM13= 'clk13Lo VLoRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM14= 'clk14Lo VHiReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM15= 'clk15Lo VLoReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM16= 'clk16Lo VpOut' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM2= 'clk2Lo FrameStart' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM3= 'clk3Lo UcResetEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM4= 'clk4Lo VHiRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM5= 'clk5Lo VLoRowEnable' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM6= 'clk6Lo VHiReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM7= 'clk7Lo VLoReset' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM8= 'clk8Lo VpOut' / Name of Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLONM9= 'clk9Lo pmc' / Name of Low-Clock



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HIERARCH ESO DET VOLT2 CLKLOT1= 0.0537 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT10= 0.0488 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT11= 0.0439 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT12= 4.9512 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT13= 1.0352 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT14= 4.0234 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT15= 0.0439 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT16= 9.4678 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT2= 0.0488 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT3= 0.0488 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT4= 4.9609 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT5= 1.0449 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT6= 4.0283 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT7= 0.0488 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT8= 9.4678 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 CLKLOT9= 0.0586 / Tel Value Low-Clock  
 HIERARCH ESO DET VOLT2 DC1 = -2.3600 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC10 = -3.3500 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC11 = 0.0000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC12 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC13 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC14 = 3.5000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC15 = 2.2000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC16 = 3.3000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC2 = -3.3500 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC3 = 0.0000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC4 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC5 = 0.7000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC6 = 3.5000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC7 = 2.2000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC8 = 3.3000 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DC9 = -2.3600 / Set value DC-Voltage  
 HIERARCH ESO DET VOLT2 DCNM1 = 'DC1 VIdle' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM10= 'DC10 VSlew' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM11= 'DC11 VRstUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM12= 'DC12 VDetCom' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM13= 'DC13 VnUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM14= 'DC14 VpUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM15= 'DC15 VnOut' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM16= 'DC16 RefBias' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM2 = 'DC2 VSlew' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM3 = 'DC3 VRstUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM4 = 'DC4 VDetCom' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM5 = 'DC5 VnUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM6 = 'DC6 VpUc' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM7 = 'DC7 VnOut' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM8 = 'DC8 RefBias' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCNM9 = 'DC9 VIdle' / Name of DC-voltage  
 HIERARCH ESO DET VOLT2 DCTA1 = -2.3535 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA10= -3.3447 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA11= 0.0049 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA12= 0.7031 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA13= 0.7031 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA14= 3.4961 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA15= 2.1973 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA16= 3.2959 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA2 = -3.3447 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA3 = 0.0049 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA4 = 0.6982 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA5 = 0.6982 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA6 = 3.4961 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA7 = 2.1973 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA8 = 3.2959 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTA9 = -2.3535 / Tel Value 1 for DC  
 HIERARCH ESO DET VOLT2 DCTB1 = -2.3438 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB10= -3.3057 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB11= 0.0049 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB12= 0.6982 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB13= 0.7031 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB14= 3.4912 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB15= 2.1826 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB16= 3.2910 / Tel Value 2 for DC  
 HIERARCH ESO DET VOLT2 DCTB2 = -3.3057 / Tel Value 2 for DC

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HIERARCH ESO DET VOLT2 DCTB3 = 0.0049 / Tel Value 2 for DC
HIERARCH ESO DET VOLT2 DCTB4 = 0.6982 / Tel Value 2 for DC
HIERARCH ESO DET VOLT2 DCTB5 = 0.6982 / Tel Value 2 for DC
HIERARCH ESO DET VOLT2 DCTB6 = 3.4912 / Tel Value 2 for DC
HIERARCH ESO DET VOLT2 DCTB7 = 2.1777 / Tel Value 2 for DC
HIERARCH ESO DET VOLT2 DCTB8 = 3.2910 / Tel Value 2 for DC
HIERARCH ESO DET VOLT2 DCTB9 = -2.3438 / Tel Value 2 for DC
HIERARCH ESO DET WIN NX      = 2048 / # of Pixels in X
HIERARCH ESO DET WIN NY      = 2048 / # of Pixels in Y
HIERARCH ESO DET WIN STARTX  = 1 / Lower left X ref
HIERARCH ESO DET WIN STARTY  = 1 / Lower left Y ref
HIERARCH ESO DET WIN TYPE    = 0 / Win-Type: 0=SW/1=HW
INHERIT = T / Extension inherits primary header
PV2_1   =                1. / WCS parameter value term
PV2_2   =                0. / WCS parameter value term
PV2_3   =               42. / WCS parameter value term
PV2_4   =                0. / WCS parameter value term
PV2_5   =                0. / WCS parameter value term
END

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