Visible & Infrared Survey Telescope for Astronomy

Data Flow System

Document Title: VISTA Data Reduction Library Design

Document Number: VIS-SPE-IOA-20000-0010

Issue: 1.2

Date: 2005-08-12

Document Prepared by:	Jim Lewis Peter Bunclark Simon Hodgkin (CASU)	Signature and Date:	Jim Lewis Digitally signed by Jim Lewis DN: cn=Jim Lewis, c=GB, o=Institute of Astronomy, ou=CASU, email=jrl@ast.cam.ac.uk Reason: I am the author of this document Date: 2005.08.12 14:08:19 +01'00'
Document Approved by:	Mike Irwin (CASU Manager)	Signature and Date:	Mike Irwin Digitally signed by Mike Irwin DN: cn=Mike Irwin, c=GB, o=University of Cambridge, ou=Instutue of Astronomy, email=mike@ast.cam.ac.uk Reason: I am approving this document Date: 2005.08.12 14:08:48 +01'00'
Document Released by:	Malcolm Stewart (VDFS Manager)	Signature and Date:	

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

Notification List

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

IoA	Will Sutherland
RAL	Gavin Dalton
QMC	Jim Emerson

Contents

Change Record....2
Notification List....2
Figures....5
1 Introduction....7
1.1 Scope....7
1.2 Applicable Documents....7
1.3 Reference Documents....7
1.4 Abbreviations and Acronyms....8
1.5 Glossary....8
2 Mathematical Description....10
2.1 Reset Correction....10
2.2 Non-Linearity....10
2.3 Gain Correction....13
2.4 Measurement of Read Noise and Gain....13
2.5 Dark-correction, flat-fielding and sky-correction....14
2.6 Fringe Removal....15
2.7 Image persistence....16
2.8 Crosstalk....16
2.9 Astrometric Calibration....17
2.10 World Coordinate System....18
2.11 Effect of Scale Change on Photometry....18
2.12 Confidence Maps....18
2.13 Catalogue generation....19
2.14 Photometric Zeropoint....22
2.15 Illumination Correction....23
3 Functional Description....25
3.1 Recipes....27
4 Instrument Data Description....37
5 DRL Data Structures....44
5.1 Introduction to Data Products....44
5.2 Channel Table....45
5.3 Bad Pixel Mask....46
5.4 Linearity Channel Table....46
5.5 Crosstalk Matrix....47
5.6 Illumination Correction Table....47
5.7 Difference Image Statistics Table....47
5.8 Persistence Mask Table....48
5.9 Extracted Standards Table....48
5.10 Matched Standards Table....49
5.11 Object Catalogues....49
6 DRL Functions....52
6.1 vircam_crosstalk....52
6.2 vircam_darkcor....54
6.3 vircam_defringe....55
6.4 vircam_flatcor....57

6.5 vircam_genlincur 58
6.6 vircam_getstds 60
6.7 vircam_illum 61
6.8 vircam_imcombine 62
6.9 vircam_imcore 65
6.10 vircam_imstack 66
6.11 vircam_interleave 68
6.12 vircam_lincor 70
6.13 vircam_matchstds 72
6.14 vircam_matchxy 73
6.15 vircam_mkconf 74
6.16 vircam_persist 76
6.17 vircam_photcal 77
6.18 vircam_platesol 78
6.19 vircam_sky_flat_combine 81
7 Data Reduction CPL Plugins 83
7.1 vircam_reset_combine 83
7.2 vircam_dark_combine 84
7.3 vircam_dark_current 85
7.4 vircam_dome_flat_combine 86
7.5 vircam_detector_noise 86
7.6 vircam_linearity_analyse 87
7.7 vircam_twilight_combine 88
7.8 vircam_mesostep_analyse 89
7.9 vircam_persistence_analyse 90
7.10 vircam_crosstalk_analyse 91
7.11 vircam_jitter_microstep_process 92
7.12 vircam_standard_process 94
8 Validation tests 97
9 Development Plan 101
10 Appendix: QC1 Parameters 102
11 Appendix: DRS Dictionary 110
12 Appendix: Raw FITS Header 114

Figures

Figure 3-1 Relationship between recipes, calibration data and data products. 25
Figure 3-2 Association Map relating Calibration Observations, Recipes and Calibration Products..26
Figure 3-3 vircam_reset_combine 27
Figure 3-4 vircam_dark_combine 27
Figure 3-5 vircam_badpix_mask 28
Figure 3-6 vircam_dome_flat_combine 28
Figure 3-7 vircam_detector_noise 29
Figure 3-8 vircam_linearity_analyse 29
Figure 3-9 vircam_twilight_combine 30
Figure 3-10 vircam_illumination_analyse 31
Figure 3-11 vircam_mesotep_analyse 32
Figure 3-12 vircam_persistence_analyse 33
Figure 3-13 vircam_crosstalk_analyse 34
Figure 3-14 vircam_sky_flat_combine 35
Figure 3-15 vircam_jitter_microstep_process 36
Figure 4-1 A Simulated VIRCAM readout shown displayed in the ESO-VLT Real-Time Display Tool 37
Figure 4-2 Synthetic VISTA data shown organised by GASGANO 39

Spacing page

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 1.2, 2005-05-09.
[AD3] *VISTA Infra Red Camera DFS Calibration Plan*, VIS-SPE-IOA-20000-00002, issue 1.2, 2005-08-12.
[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

[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

	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.
DAS	Data Acquisition System
DIT	Digital Integrations mean that separate readouts are summed digitally.
Exposure	The stored product of many individual **integration**s that have been co-added in the DAS. The sum of the integration times is the exposure time.
Integration	A simple snapshot, within the **DAS**, of a specified elapsed time. This elapsed time is known as the integration time.
Jitter (pattern)	A pattern of **exposures** at positions each shifted by a small movement (<30 arcsec) from the reference position. Unlike a **microstep** the non-integral part of the shifts is any fractional number of pixels. Each position of a jitter pattern can contain a **microstep** pattern.
Mesostep	A sequence of **exposures** designed to completely sample across the face of the detectors in medium-sized steps, in order to monitor residual systematics in the photometry.
Microstep (pattern)	A pattern of **exposure**s at positions each shifted by a very small movement (<3 arcsec) from the reference position. Unlike a **jitter** the non-integral part of the shifts are 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 **jitter** pattern.
OB	Observation Block
Object	In the context of image analysis, an astronomical object.
Pawprint	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).
Preset	A telescope slew to a new position requiring a reconfiguration of various telescope systems.
Robust Estimate	A statistical estimator that is resilient to small perturbations on the assumed shape of the underlying distribution.
Tile	A filled area of sky fully sampled (filling in the gaps in a pawprint) by combining multiple **pawprint**s. Because of the detector spacing the minimum number of pointed observations (with fixed offsets) required for reasonably uniform coverage is 6, which would expose each piece of sky, away from the edges of the tile, to at least 2 camera pixels. The pipeline does not combine **pawprint**s into tiles.

2 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 2.13, 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

$$\Delta I' = I'_2 - I'_1 = f(I_2) - f(I_1) \qquad \textbf{(2-1)}$$

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

$$I = g(I') \textbf{ and } I_1 = g(I_1') \;\; I_2 = g(I_2') \qquad \textbf{(2-2)}$$

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 ΔI 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 ΔI such that,

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

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

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

The quantity we want ΔI 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 × 65k in size, or 4.3 × 2 Gbytes. Most likely we would need a different correction for each "channel" making a total of 256 × 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 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 nonlinearity 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

$$\Delta I_i' = \sum_m a_m (I_2{}^m - I_1{}^m) = \sum_m a_m \Delta I_i{}^m [(1+k_i)^m - k_i{}^m] \qquad \textbf{(2-5)}$$

where k_i are the exposure ratios under the constant illumination. In general $\Delta I_i = st_i$ where t_i is the exposure time of the ith 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

$$\Delta I_i' = \sum_m a_m (I_2{}^m - I_1{}^m) - \sum_m a_m s^m t_i{}^m [(1+k_i)^m - k_i{}^m] \qquad \textbf{(2-6)}$$

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.

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

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

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

$$a_m = b_m / s^m = b_m / b_1^m \qquad \textbf{(2-8)}$$

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:

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

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 σ_f^2. Doing the same for the two dark frames yields σ_d^2. If the background means of one of the flat and dark frames are locally: m_f and m_d the local gain in electrons per ADU is:

$$\varepsilon = (m_f - m_d)/(\sigma_f^2 - \sigma_d^2) \qquad \textbf{(2-10)}$$

and the readout noise in electrons is

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

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

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

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

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

therefore,

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

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.

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

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

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

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

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 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:

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

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

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:

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

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.

2.7 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

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

where k is the image sequence number, f is the fraction of the image persisting after frame reset(s), Δt is the time interval between frames, and τ 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.

2.8 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.

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,

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

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

2.9 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

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

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

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

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^3) 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

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

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/.

2.10 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 3rd order parameterisation (equation 2.22). The coefficients for this are encoded in the FITS header using the keywords `PV2_1` and `PV2_3`.

2.11 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 $2\pi s ds$ becomes $2\pi r' dr'$ on the detector, which using k to denote k_3 / k_1 leads to a relative area of

$$(1 + k \times r'^2).(1 + 3k \times r'^2) \approx (1 + 4k \times r'^2) \qquad \textbf{(2-24)}$$

or in other words roughly 4 × 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.

2.12 Confidence Maps

We define a confidence map c_{ij} as a normalised[1] 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 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.

[1] In practice we use a 16-bit integer map such that the median level is 100%

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, vignetted 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

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

where σ_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

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

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.

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

2.13 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.

2.13.1 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 × 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.

2.13.2 Image parameterisation

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

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

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

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. 1st moment

$$x_0 = \sum_i x_i.I(x_i, y_i) / \sum_i I(x_i, y_i) \quad \textbf{(2-29)}$$

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

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

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

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

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

The simplest way to derive the ellipse parameters from the 2nd moments is to equate them to an elliptical Gaussian function having the same 2nd 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, $ecc = \sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4.\sigma_{xy}^2} / \sigma_{rr}$; and the position angle, θ is defined by, $\tan(2\theta) = 2.\sigma_{xy} / (\sigma_{yy} - \sigma_{xx})$. 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

$$ArealProfile \rightarrow T + p_1, T + p_2, T + p_3, ...T + p_m \quad \textbf{(2-31)}$$

where $p_j; j = 1,...m$ 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

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

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

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

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

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.

2.13.3 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 2-3σ are generally flagged as stellar images, those below 3σ (i.e. sharper) as noise-like, and those above 2-3σ (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.

2.14 Photometric Zeropoint

For the purposes of quality control (e.g. sky transparency and system performance) a photometric zeropoint will be determined for each observation by direct comparison of instrumental magnitudes with the magnitudes of 2MASS stars. A more accurate 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" 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:

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

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 ($-2.5 \times \log_{10}[counts/sec]$), κ is the extinction coefficient, X is the airmass of the observation, ce^{std} is the colour term to convert to the instrumental system, and ε is an error term. This assumes that the second-order extinction term and colour-dependency of κ 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 κ should be constant in each passband. The extinction κ can be monitored through each night either by assuming the true instrumental zeropoint only varies slowly as a function of time or by making measurements over a range of airmass.

2.15 Illumination Correction

The two methods of determination of illumination correction differ in that the first described below requires a rich standard star field, but the second can be used before such a field is available.

2.15.1 Standard Star Field

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 medium rich photometric standard field into cells. For each cell we define a median zero point of all the stars in that cell:

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

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

$$ic_j = \langle zp \rangle - zp_j \qquad \textbf{(2-36)}$$

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:

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

2.15.2 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.

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

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

$$ZP(x_i, y_i) = a_{00} + a_{10}x_i + a_{01}y_i + a_{20}x_i^2 + a_{11}x_i y_i + a_{02}y_i^2 \tag{2-39}$$
$$ZP(x_j, y_j) = a_{00} + a_{10}x_j + a_{01}y_j + a_{20}x_j^2 + a_{11}x_j y_j + a_{02}y_j^2 \tag{2-40}$$

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

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

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 Δm_{ij} then:

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

In the simplest case, observing the same star in a number of different places would allow one to measure the Δm_{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.

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) to produce a photometric zeropoint. 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.

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

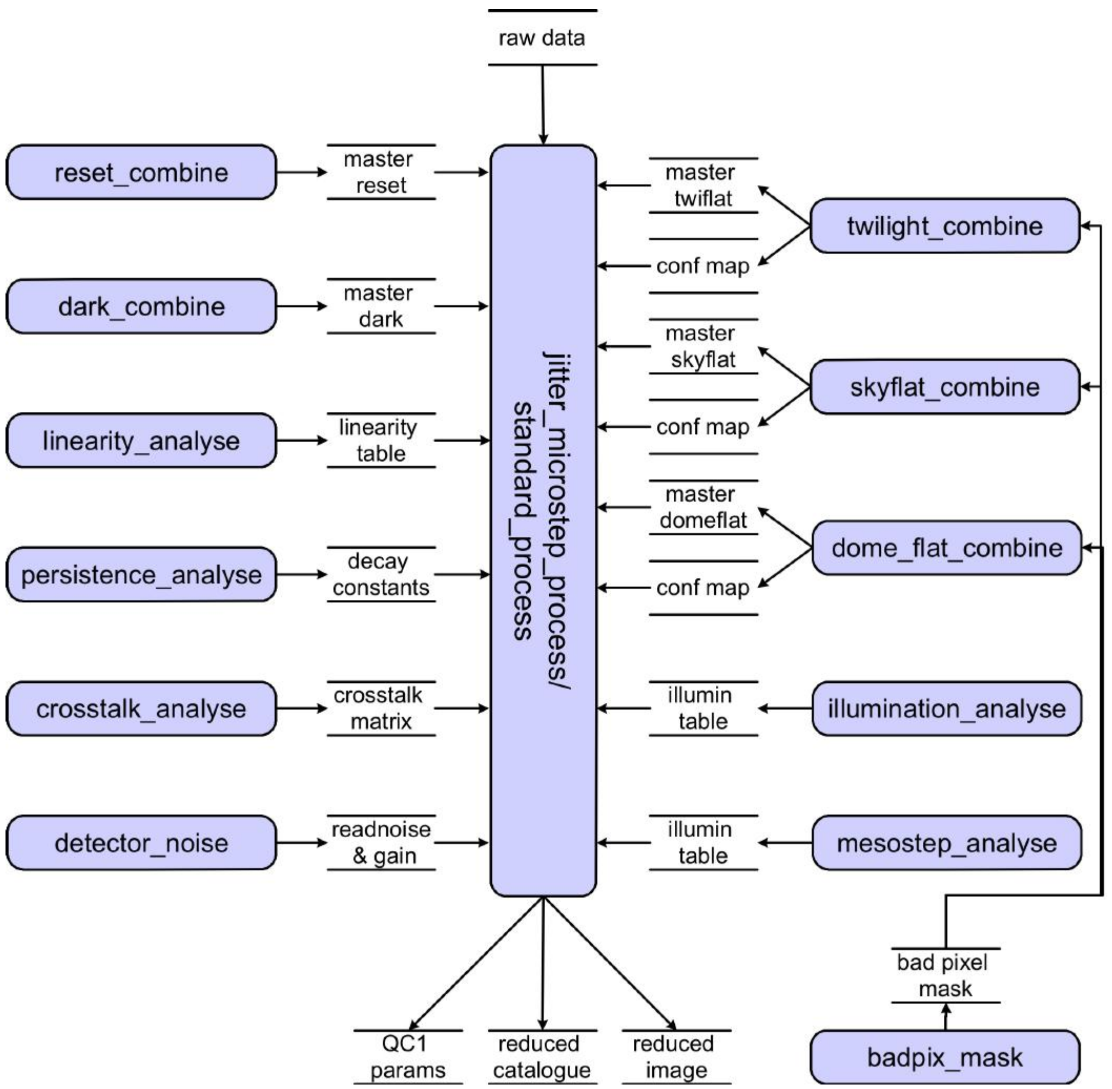

Figure 3-1 Relationship between recipes, calibration data and data products.

The relationship between calibration observations, and the recipes used to produce final calibration frames, is illustrated in the association map in Figure 3-2.

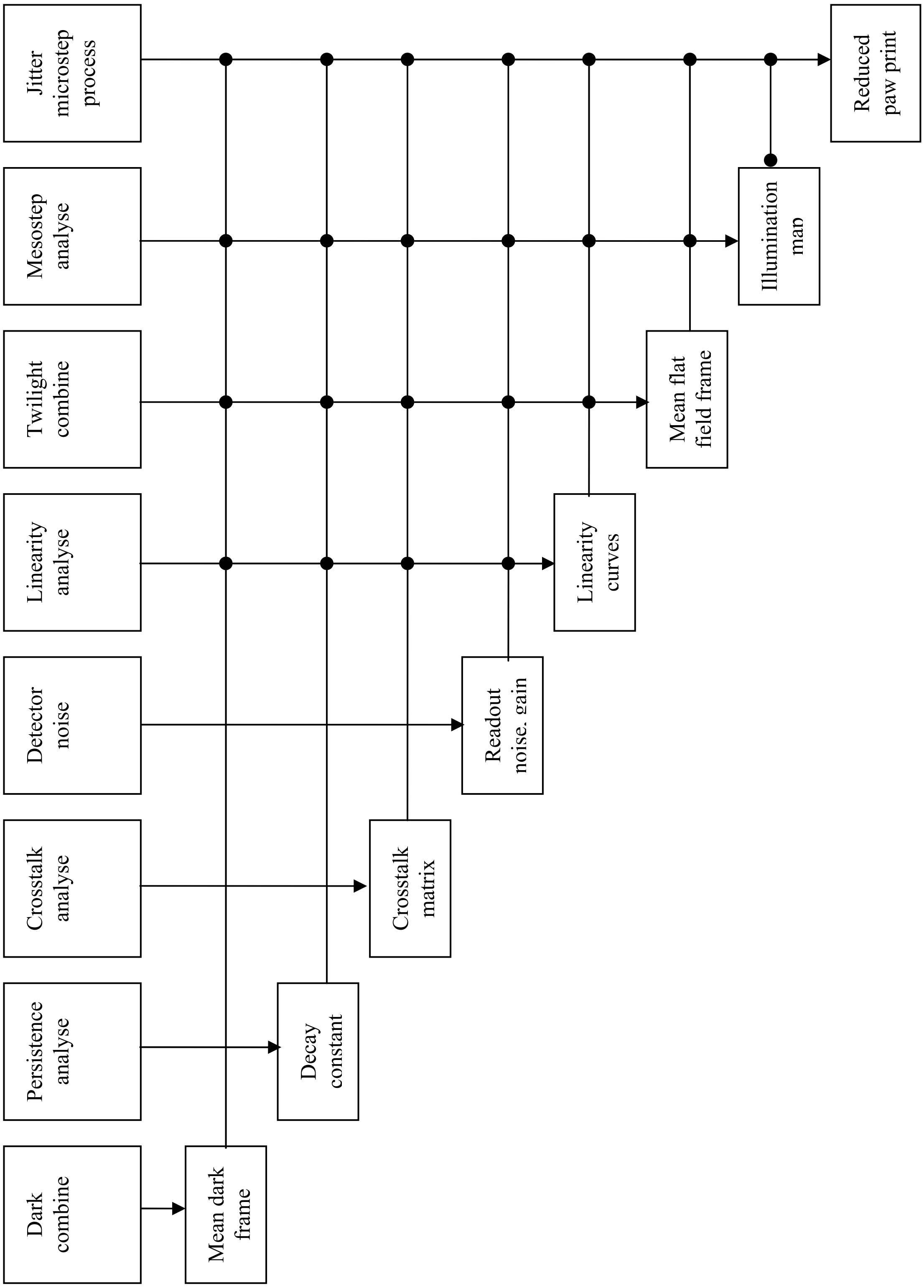

Figure 3-2 Association Map relating Calibration Observations, Recipes and Calibration Products.

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.

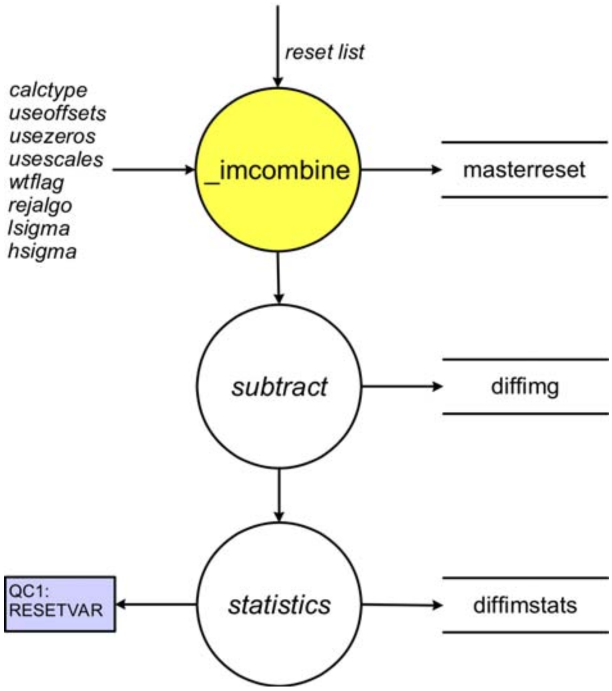

Figure 3-3 vircam_reset_combine

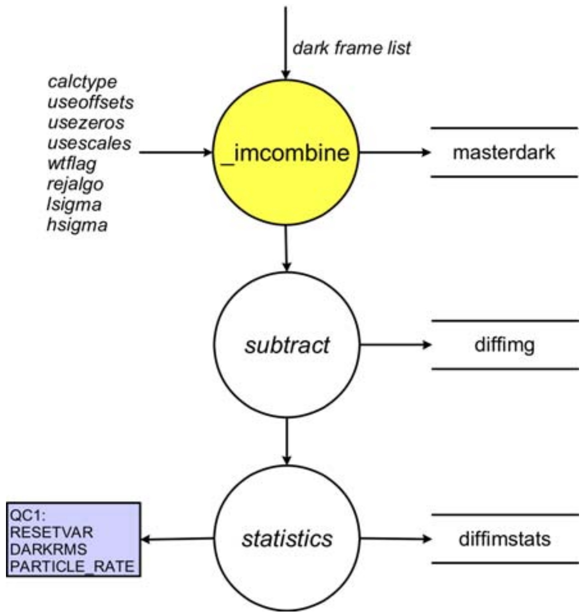

Figure 3-4 vircam_dark_combine

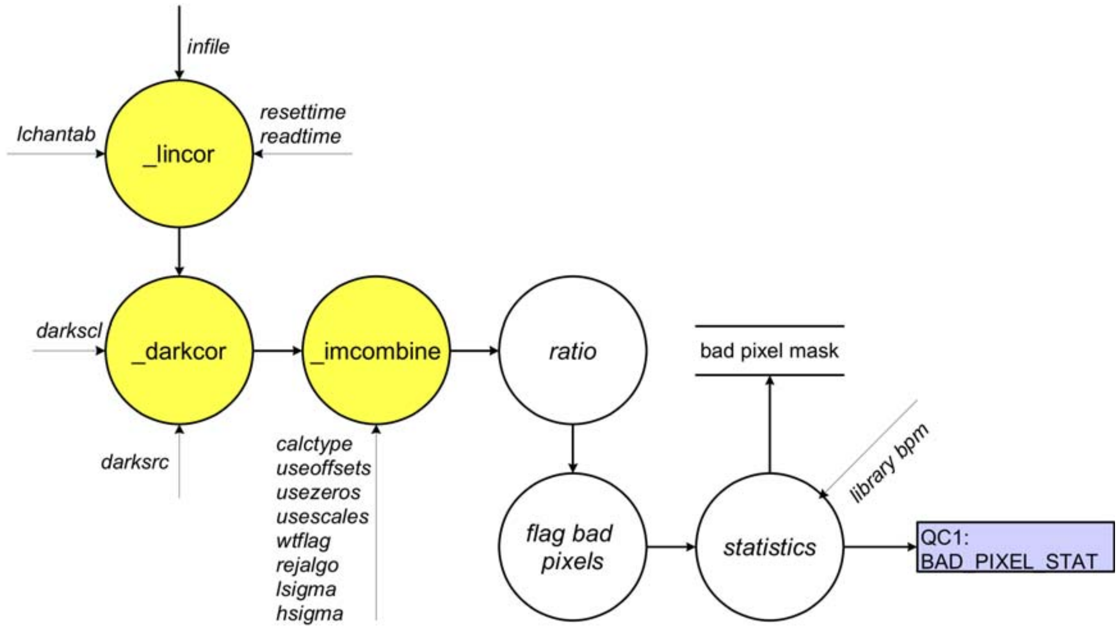

Figure 3-5 vircam_badpix_mask

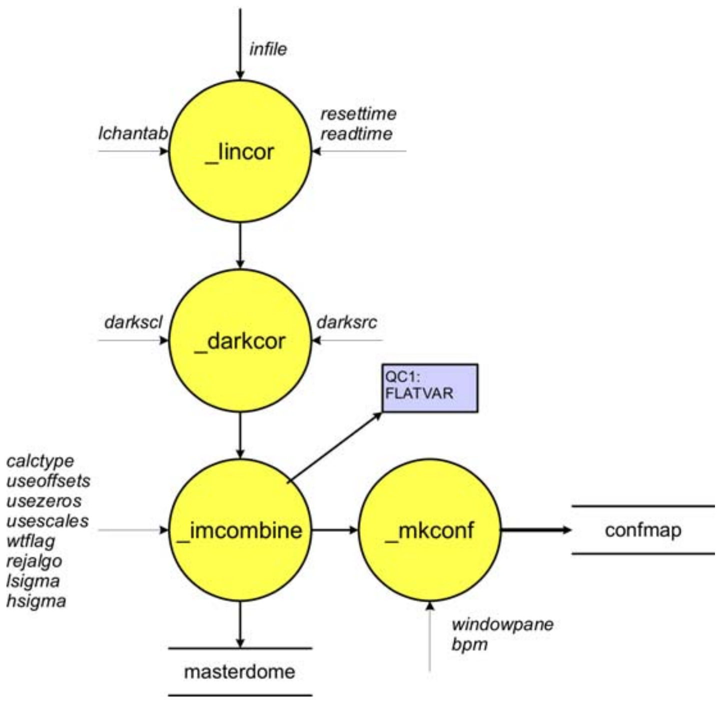

Figure 3-6 vircam_dome_flat_combine

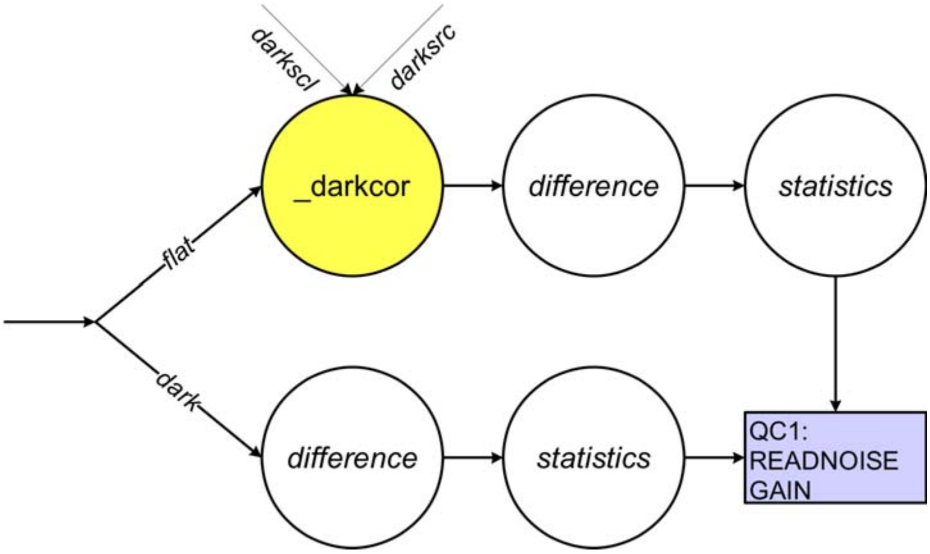

Figure 3-7 vircam_detector_noise

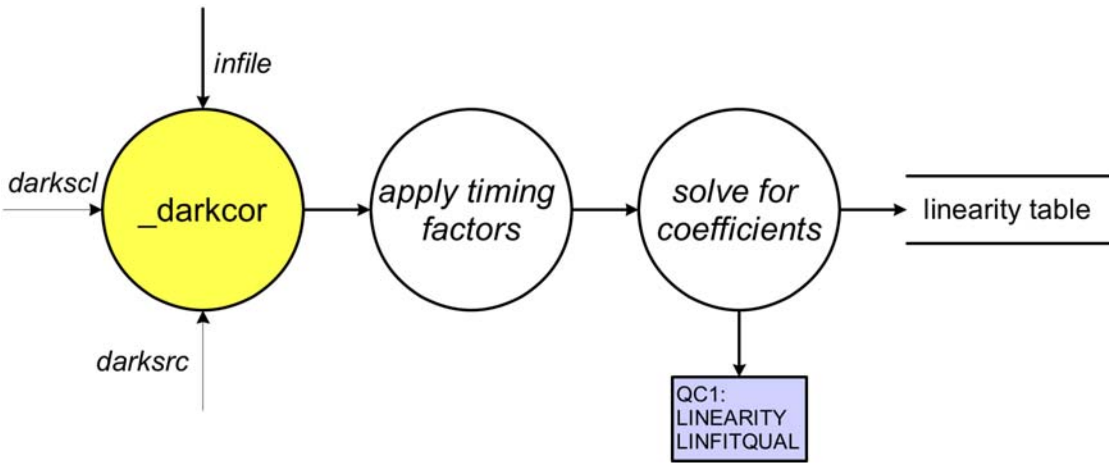

Figure 3-8 vircam_linearity_analyse

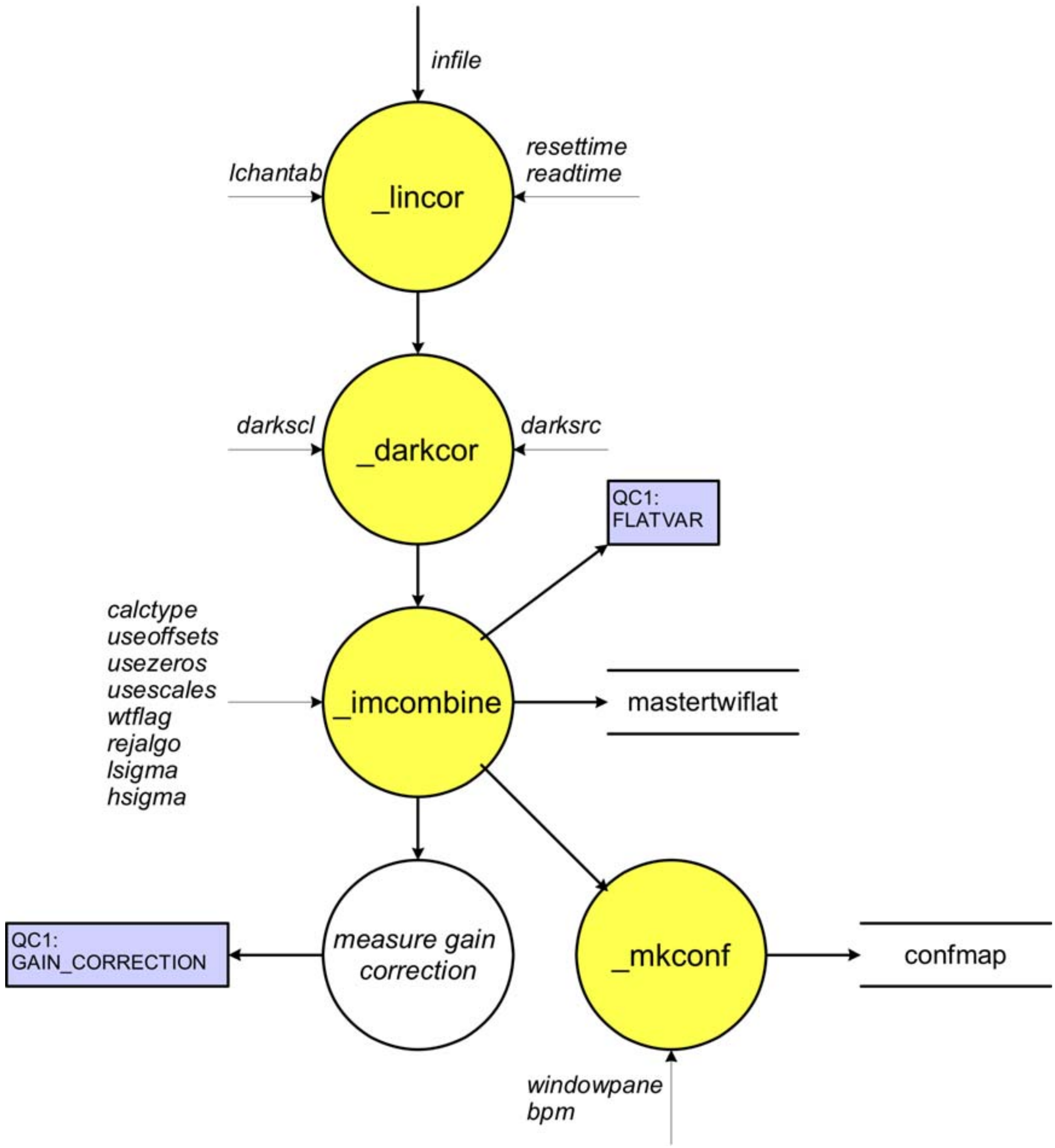

Figure 3-9 vircam_twilight_combine

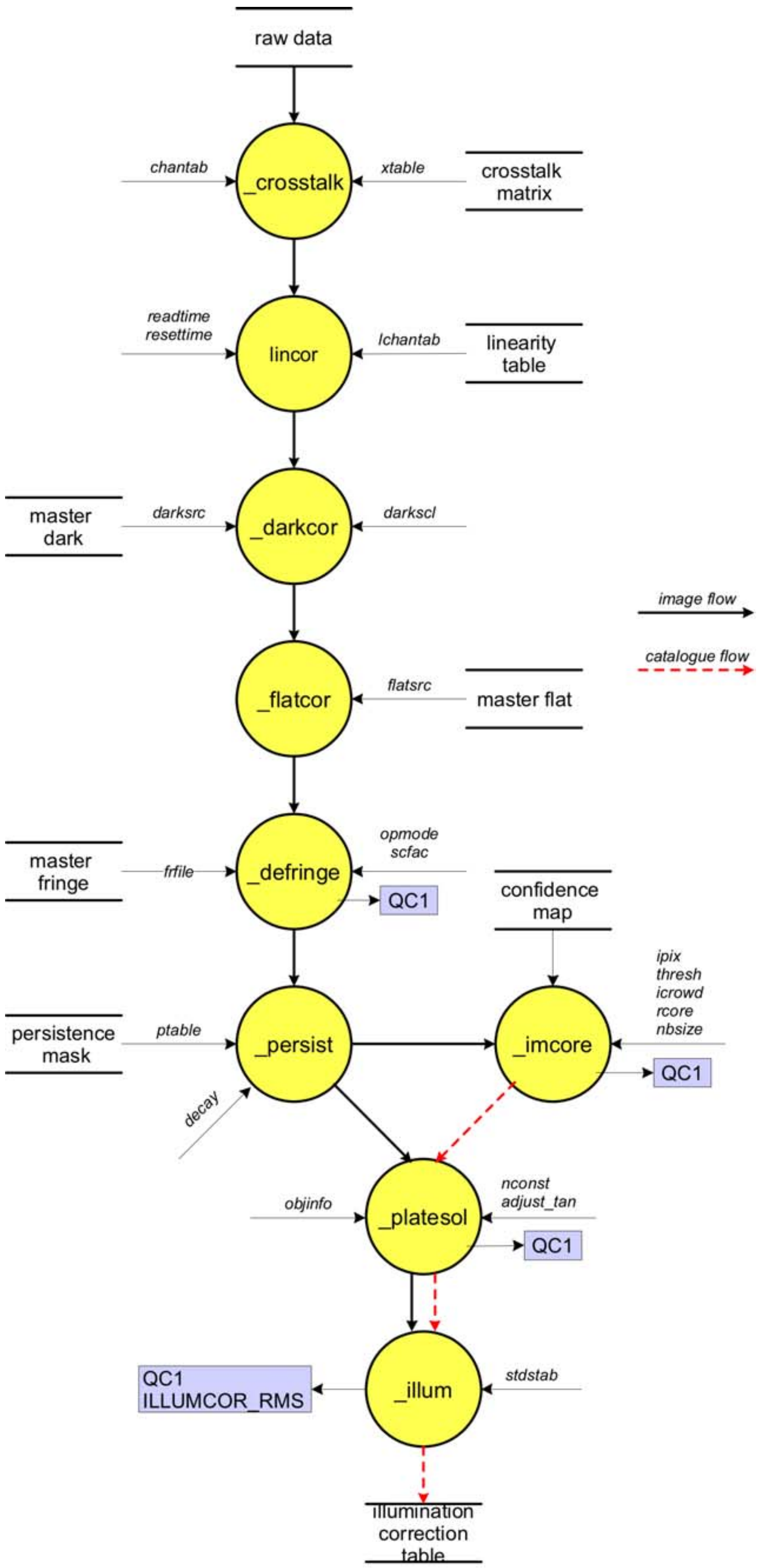

Figure 3-10 vircam_illumination_analyse

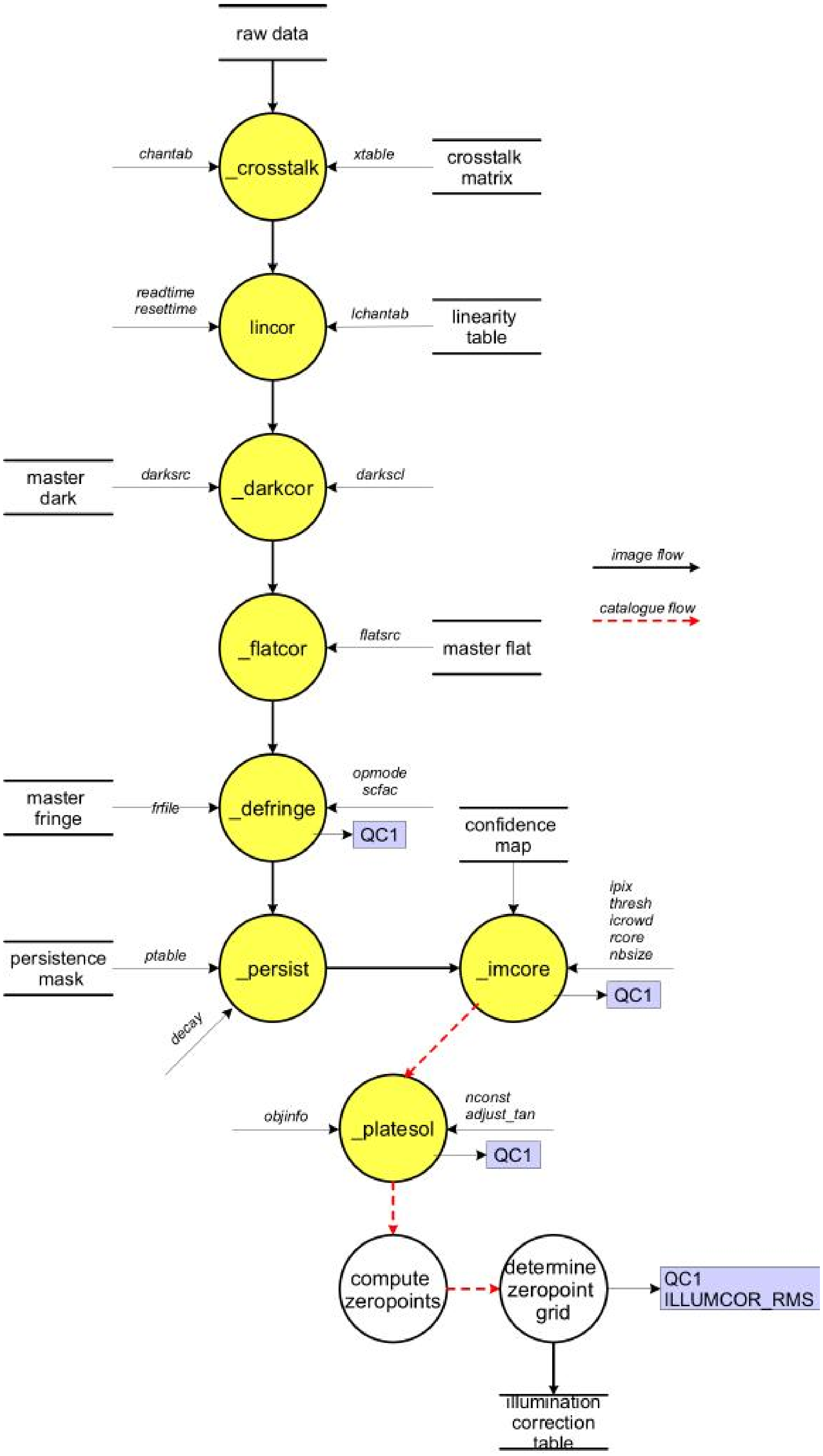

Figure 3-11 vircam_mesotep_analyse

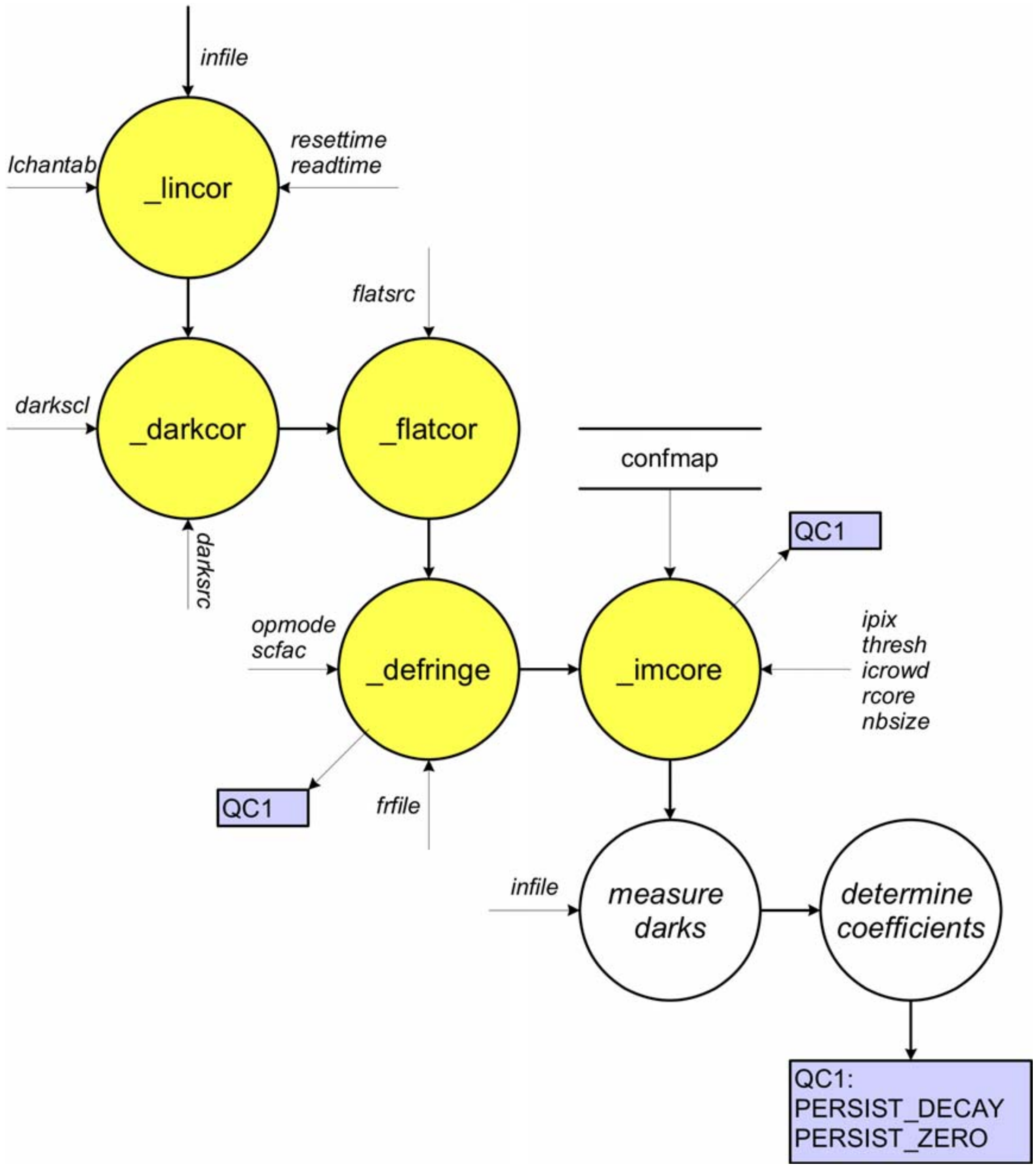

Figure 3-12 vircam_persistence_analyse

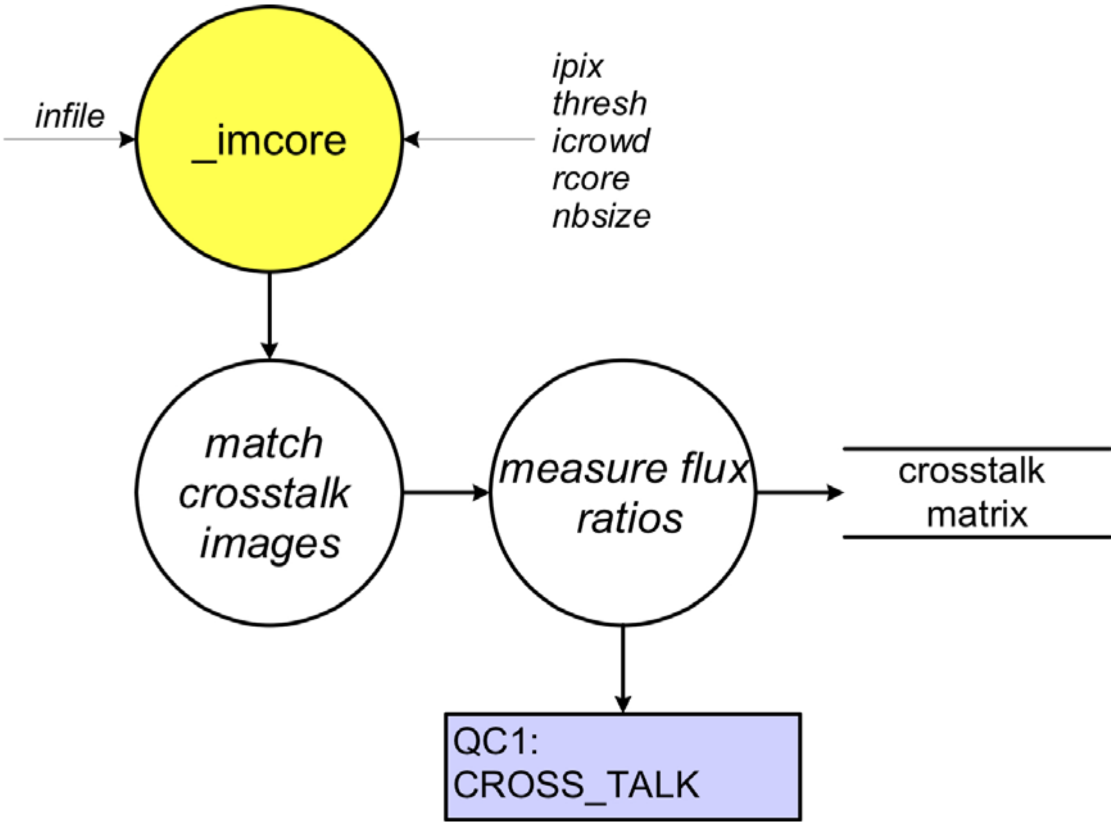

Figure 3-13 vircam_crosstalk_analyse

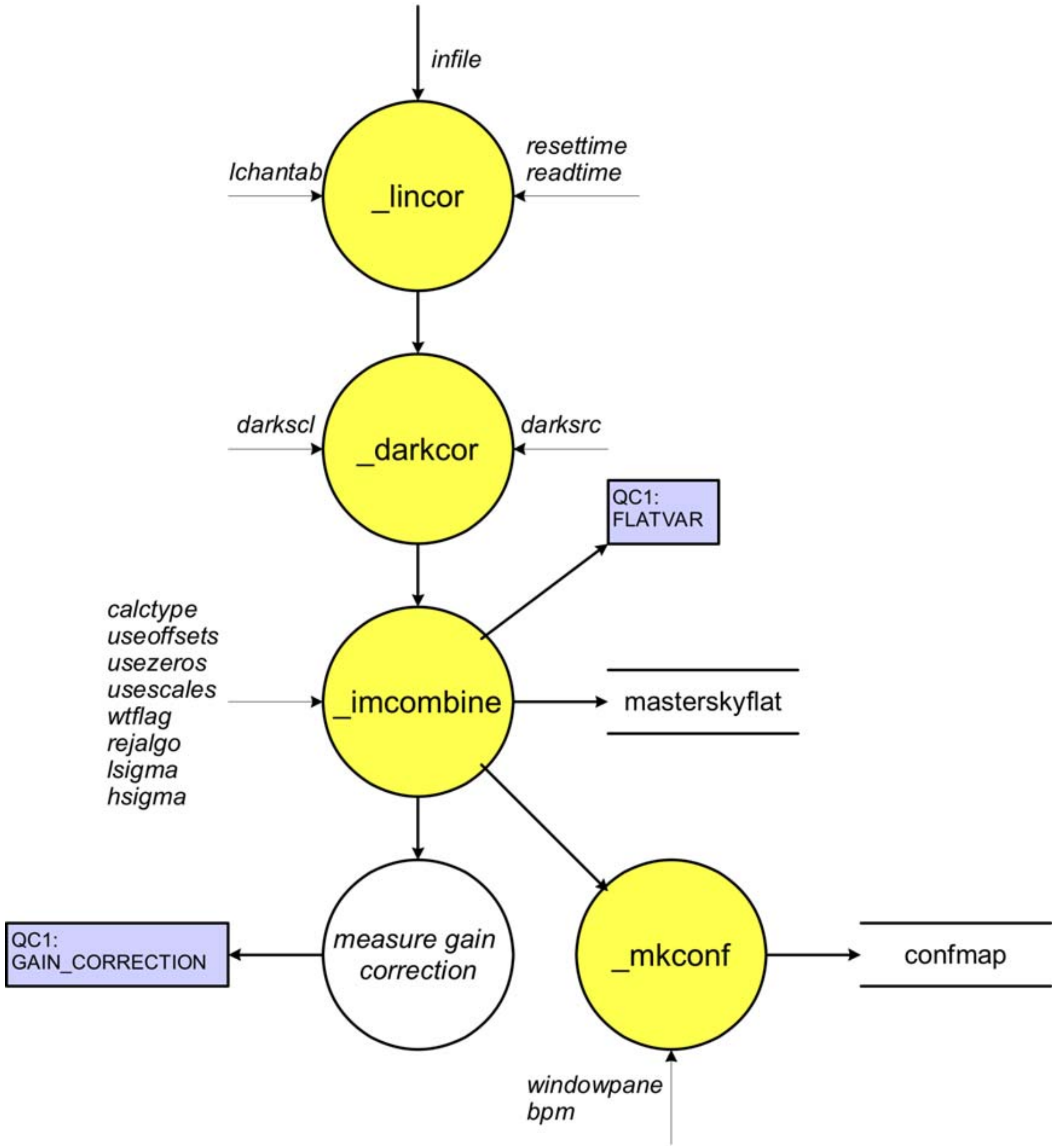

Figure 3-14 vircam_sky_flat_combine

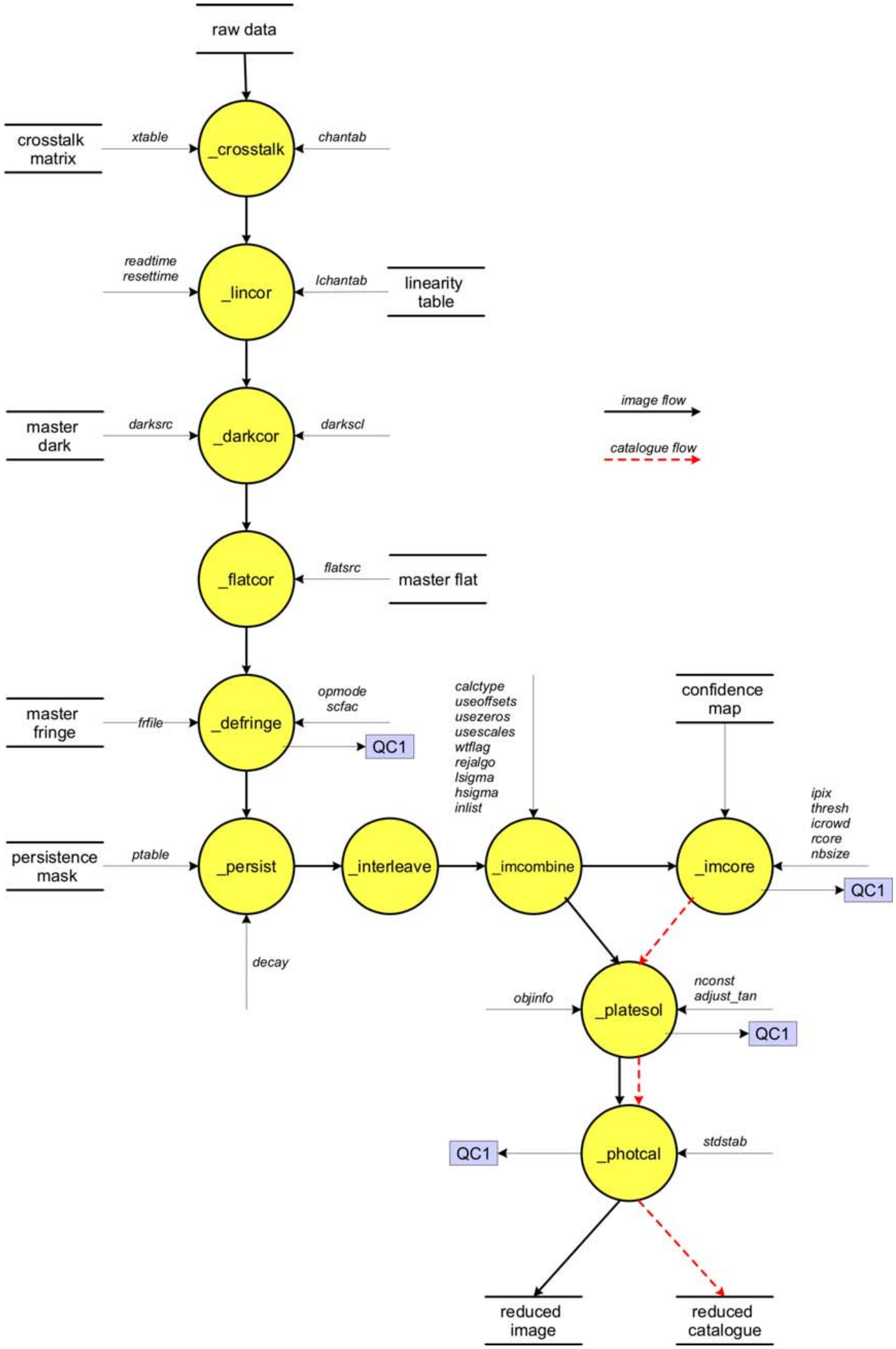

Figure 3-15 vircam_jitter_microstep_process

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.

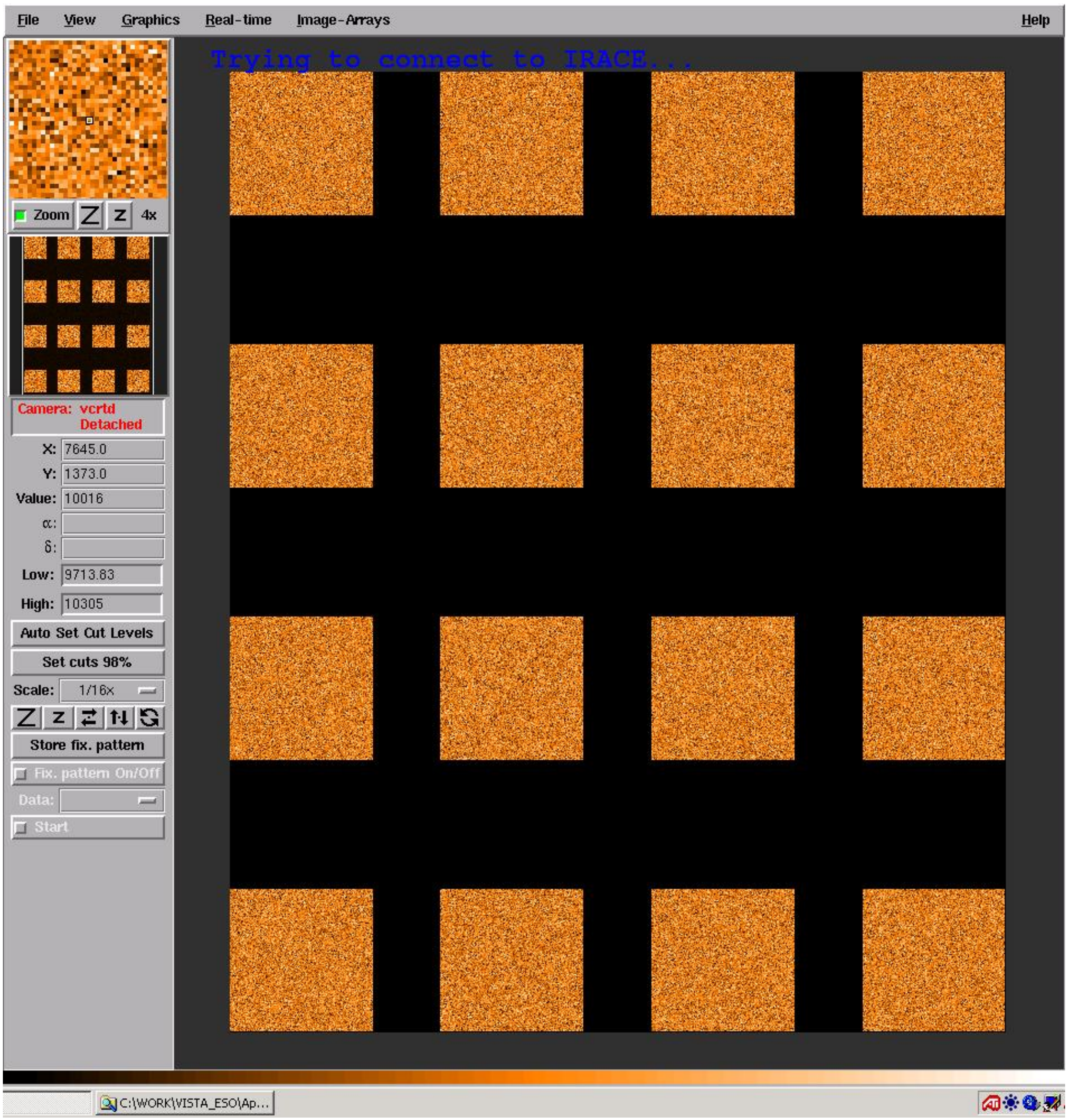

Figure 4-1 A Simulated VIRCAM readout shown displayed in the ESO-VLT Real-Time Display Tool

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).

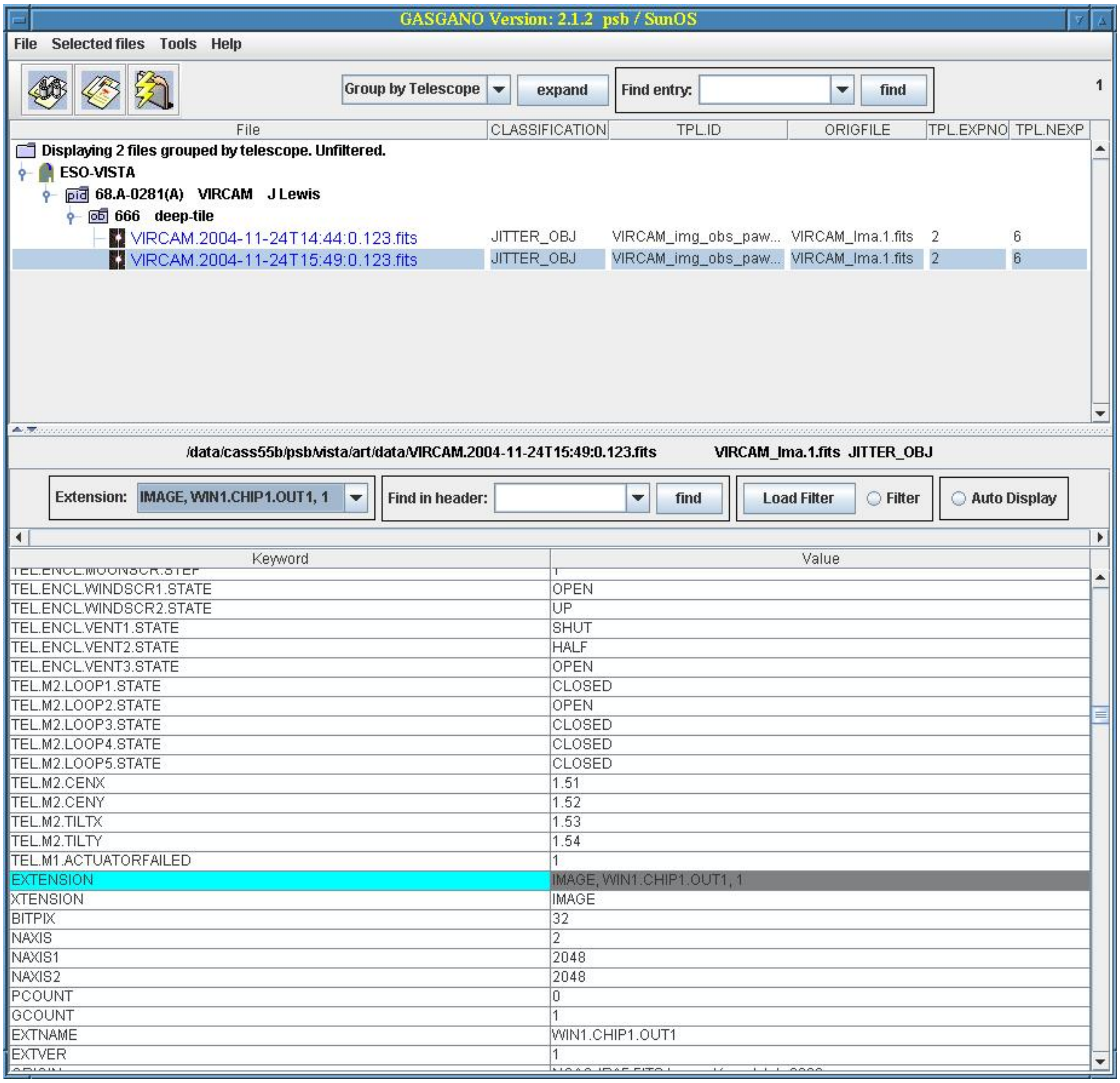

Figure 4-2 Synthetic VISTA data shown organised by GASGANO

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

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

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

Table 4-1 Data Processing Table

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.

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 5.11)

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 sky 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
- Local sky maps

Calibration Parameters:

- 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

The calibration parameters for illumination correction, nonlinearity, persistence and the crosstalk matrix will be stored in FITS tables as specified in the following sections.

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. This information will be provided by the 'channel table'. Strictly speaking this is neither an intermediate nor final data product, but rather a piece of static calibration information on which much of the rest of this section relies. The information will be stored in a single FITS binary table and will be identifiable with the PRO CATG keyword value CHANTAB. The table will contain the following columns:

Column	Name	Type	Units	Description
1	chanindex	int		Index of the data channel which is an integer from 1-256. This is a unique ID for the data channel in the context of the whole of the VIRCAM detector set.
2	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.
3	detnum	int		The number of the detector that this channel belongs to. This is just a numeric reference to the detector's position in the focal plane.
4	imextension	int		The FITS image extension where the data from this channel resides.
5	ixmin	int	pixels	The X coordinate of the lower left corner of the data channel
6	ixmax	int	pixels	The X coordinate of the upper right corner of the data channel
7	iymin	int	pixels	The Y coordinate of the lower left corner of the data channel
8	iymax	int	pixels	The Y coordinate of the upper right corner of the data channel
9	dcrpix1	int	pixels	The X coordinate of the location within the data channel where the first pixel is read out.
10	dcrpix2	int	pixels	The Y coordinate of the location with

				the data channel where the first pixel is read out.
11	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.
12	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.
13	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.
14	dcd2_2	int		Can take the values (-1,0,1). Gives the partial derivative of the slow readout axis to the Y axis.

5.3 Bad Pixel Mask

As we mentioned in section 2.12 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. The value of PRO CATG will be BPM.

5.4 Linearity Channel Table

As each data channel has its own electronics each channel will potentially require its own linearity curve. Using the timing and location information from the channel table (below) and the algorithm described in section 2.2.2 will lead to a set of coefficients, which will be combined with the channel table to form a 'linearity channel table'. This will again take the form of a FITS binary table, which will include all of the columns of the channel table as described in section 5.1 plus the following:

Column	Name	Type	Units	Description
15	norder	int		The polynomial order used.
16	coeff_1	double		The first order coefficient (because of the formalism described in section 2.2.2 no zeroth order coefficient will exist and this coefficient will always be 1.0).
17	coeff_2	double		The second order coefficient
15+n	coeff_n	double		The nth order coefficient, where n = norder

The value of PRO CATG will be LCHANTAB.

5.5 Crosstalk Matrix

Detector crosstalk is described in section 2.8. 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 a PRO CATG keyword value of XTALK and with the following columns:

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

5.6 Illumination Correction Table

The effect of large scale background variation in the flat field images (usually due to scattered light) are described in section 2.15. 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 value of PRO CATG equal to ILLCORTAB and 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

5.7 Difference Image Statistics Table

For recipes that monitor detector performance in particular, it is often worthwhile to keep statistical information on difference 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 image statistics table will be a FITS table with the PRO CATG keyword being DIFFIMSTATS and consisting of the following columns:

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.

5.8 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.

.
The PRO CATG keyword value will be set to PERSISTMASK.

5.9 Extracted 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 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

The PRO CATG keyword value will be set to STDTAB.

5.10 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 the following columns:

Column	Name	Type	Units	Description
1	xobj	float	pixels	The X position of the object on the image
2	yobj	float	pixels	The Y position of the object on the image.
3	xpredict	float	pixels	The X position of the matching standard as predicted from the image WCS and the object's equatorial coordinates.
4	ypredict	float	pixels	The Y position of the matching standard as predicted from the image WCS and the object's equatorial coordinates.
5	ra	float	degrees	The standard's RA
6	dec	float	degrees	The standard's Dec
7 – n	mags	float	mags	Any photometric information that might exist in the standard star catalogue

The PRO CATG keyword value will be set to MSTDTAB.

5.11 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 2.13 for more details).

The following columns are present:

column	name	description
1	No.	running number for ease of reference, in strict order of image detections
2	Isophotal_flux	standard definition of summed flux within detection isophote.
3	Total_flux	a total flux derived from a curve-of-grown technique and elliptical apertures
4	Core_flux	flux within a specified radius aperture, typically set such that $R_{aperture} = \langle FHWM \rangle$ where the quantity in angle brackets is the mean FWHM of all stellar images.
5	X_Coordinate	x,y coordinates in pixels with (1,1) defined to be the centre of the first active pixel in the array. See 2.13.2.
6	Y_Coordinate	
7	Gaussian_sigma	Second moment parameters. See 2.13.2
8	Ellipticity	
9	Position_angle	
10	Peak_height	Peak intensity in ADU relative to local value of sky
11	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
12	Areal_2_profile	
13	Areal_3_profile	
14	Areal_4_profile	
15	Areal_5_profile	
16	Areal_6_profile	
17	Areal_7_profile	
18	Areal_8_profile	
18	Core_1_flux	A series of different radii aperture measures similar to column 4. Together with the peak height (column 10) these give a simple curve-of-growth analysis from peak pixel, $0.5R_{core}$, R_{core}, $\sqrt{2}R_{core}$, $2R_{core}$, $2\sqrt{2}R_{core}$,
19	Core_2_flux	
21	Core_3_flux	
22	Core_4_flux	
23	RA	RA and Dec of each object in degrees. These are added during WCS refinement
24	Dec	
25	Classification	simple flag indicating most probably classification for object: **-2:** Object is compact (maybe stellar) **-1:** Object is stellar **0:** Object is noise **1:** Object is non-stellar

26	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.
27-32	blank	

The PRO CATG keyword value will be set to OBJCAT.

6 DRL Functions

In what follows we describe the low level functions that will be driven by the VIRCAM pipeline. The parameter lists included are based on the current level of functionality available with CPL version 2.0. Future versions of CPL may include high level structures and functions which will cause us to alter the way that information is passed to these routines when they are finally written. The reader must therefore not assume that the API for the DRL functions will be exactly as described here.

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. This is done so that the error status does not need to be tested after every call. 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.

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.
- Each image required as input or output by the function will be listed in bold under sub-subsections 3 and 5. In parenthesis afterwards will be the data type. If any FITS keywords are required in the input files or are written to the output files, then these will be included in a table after the file description.
- An int * parameter called 'status' will be included in the input and output parameter lists for each function. This is because the status is inherited as mentioned above. It is also the one returned value in all of these functions and is returned as an integer.
- 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.
- Very obvious error conditions such as corrupted input files, running out of disc space, etc have been omitted for brevity.

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 5.5). The latter consists of factors by which the data from one channel affects another.

Mathematical Description:

See section 2.8 for a full mathematic description of crosstalk removal.

6.1.2 Function Parameters

None

6.1.3 Input Images and Required FITS Header Information.

infiles (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 5.5)

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

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 vircam_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 factor such that it matches the scale of the reset anomaly in the target object frame. This is done by comparing regions of each quadrant where the reset anomaly is worst. Instrumental commissioning will determine which regions of the quadrants should be used in the scaling calculation. 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

float **darkscl**

An input scaling factor; a value that is less than or equal to zero, means that the scaling factor will be worked out automatically by this function. A positive value will be used as is.

6.2.3 Input Images and Required FITS Header Information

infile (float)

The input science image to be corrected.

darksrc (float)

The input mean dark image.

6.2.4 Input Tables

None

6.2.5 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 DARKCOR	char	The name of the flat field image specified in **darksrc**
DRS DARKSCL	float	The scale factor used in the subtraction

6.2.6 Output Tables

None

6.2.7 Other Output

int * **status**

Output status from function; a non-zero value indicates a failure at some level.

6.2.8 QC1 Outputs

None

6.2.9 Quality Assessment

Reset anomaly ramp removed

6.2.10 Error Conditions

- The following conditions will cause fatal errors
  - Mismatched data array dimensionality between the input images
- There are no non-fatal error conditions

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 2.6.

6.3.2 Function Parameters

int **opmode**

The operational mode of the algorithm; a value of 1 means that the scale factor will be determined automatically, a value of 2 means that the scale factor will be taken from the parameter **scfac.**

float **scfac**

If the value of **opmode** is such that we want to set the fringe scale manually, then this should have the value of the desired scale. Otherwise this parameter is ignored.

6.3.3 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

frfile (float)

The input mean fringe image.

keyword	**type**	**description**
EXPTIME	int	The exposure time of the fringe data

6.3.4 Input Tables

None.

6.3.5 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 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.

6.3.6 Output Tables

None

6.3.7 Other Output

None.

6.3.8 QC1 Outputs

FRINGE_RATIO

6.3.9 Quality Assessment

QC1 parameter FRINGE_RATIO shows significant improvement in sky noise

6.3.10 Error Conditions

- The following conditions will cause fatal errors
  - Zero or negative exposure times
  - Mismatched data array dimensionality
- The following conditions will cause non-fatal errors
  - Negative fringe-scale factor (e.g. as occasionally produced in conditions following a solar flare).

6.4 vircam_flatcor

6.4.1 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.

6.4.2 Function Parameters

None

6.4.3 Input Images and Required FITS Header Information

infile (float)

The input science image to be corrected.

flatsrc (float)

The input mean flat field image.

6.4.4 Input Tables

None

6.4.5 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 FLATCOR	char	The name of the flat field image specified in **flatsrc**

6.4.6 Output Tables
None

6.4.7 Other Output
None

6.4.8 QC1 Outputs
None

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

6.4.10 Error Conditions
- The following conditions will cause fatal errors
  - Mismatched data array dimensionality between the input images
  - A value of zero in the flat field data array
- There are no non-fatal error conditions

6.5 vircam_genlincur

6.5.1 General

Name:
vircam_genlincur

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

General Description:
A series of exposures of a stable dome light source with a range of exposure times should be given. From the known readout, reset 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 linearity channel table.

Mathematical Description:
This function implements the mathematical description in section 2.2.2

6.5.2 Function Parameters
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.

float **readtime**

The time it takes to read out each data channel in seconds.

float **resettime**

Time it takes to reset a data channel in seconds.

6.5.3 Input Images and Required FITS Header Information

infiles (float)

The input science images to be examined

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

6.5.4 Input Tables

chantab

The channel table as described in section 5.2.

6.5.5 Output Images

None

6.5.6 Output Tables

lchantab

The linearity channel table as described in section 5.4.

6.5.7 Other Output

None

6.5.8 QC1 Outputs

LINEARITY
LINFITQUAL

6.5.9 Quality Assessment

The value of LINEARITY is reasonable for all detectors. The value of LINFITQUAL shows a fractional error of less than a 2%.

6.5.10 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

6.6 *vircam_getstds*

6.6.1 General

Name:

vircam_getstds

Purpose:

Given an input image, extract a list of standard stars from a catalogue that should appear on that image. It is expected that the 2MASS catalogue (about 43Gbytes in FITS-table format) will be available through a CPL interface.

General Description:

The header of in 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 a requested standard star catalogue. Once the stars have been selected the information about them is written to an extracted standards table (5.9) along with their expected x,y positions based on the input WCS.

Mathematical Description:

N/A

6.6.2 Function Parameters

float **border**

A multiplicative factor defining the amount by which the coordinate coverage range should be widened. This can be used to add some padding around the edges to cover cases where the input WCS is poorly known.

char * **catsrc**

A specification of the source of the standard catalogue; this can be either a locally held file or a URL for a VizieR catalogue.

6.6.3 Input Images and Required FITS Header Information

infile (any)

The input image; the header of the image is all that will be required.

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
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	

6.6.4 Input Tables
None

6.6.5 Output Images
None

6.6.6 Output Tables
outtab

The table of extracted objects in the format described in section 5.9

6.6.7 Other Output
None

6.6.8 QC1 Outputs
None

6.6.9 Quality Assessment
N/A

6.6.10 Error Conditions
- The following conditions will cause fatal errors
  - Non-physical coordinate coverage
  - Inability to contact the catalogue source in the event that it has been done with an internet connection.
- The following conditions will lead to non-fatal errors
  - No objects found in the catalogue

6.7 vircam_illum

6.7.1 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 an image. 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 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 2.15

6.7.2 Function Parameters

int **nbsize**

The size of the cells in pixels to use when dividing up the input data.

6.7.3 Input Images and Required FITS Header Information

None

6.7.4 Input Tables

stdtab

The photometric standards table as defined in 5.9

objtab

The table of objects extracted from an image of a standard star field. This is described in section 5.11

6.7.5 Output Images

None

6.7.6 Output Tables

illcortab

The illumination correction table as defined in section 5.6.

6.7.7 Other Output

None

6.7.8 QC1 Outputs

ILLUMCOR_RMS

6.7.9 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** (6.17).

6.7.10 Error Conditions

- The following conditions will cause fatal errors
  - No matching objects
- There are no non-fatal error conditions

6.8 vircam_imcombine

6.8.1 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
- known bad pixels can be masked and rejected
- individual pixels can be weighted by confidence
- known Cartesian offsets can be applied to the input images

Mathematical Description:

None

6.8.2 Function Parameters

int **calctype**

A flag to determine whether the output should be a mean or a median of the input frames

int **useoffsets**

If set, then the images will be shifted in pixel space by amounts defined in the image headers

int **usezeros**

If set, then the images will be biased by an amount specified in the image headers

int **usescales**

If set, then the images will be multiplied by a factor specified in the image headers

int **wtflag**

A flag to determine how to weight the pixels; the options are:

- Ignore pixel weights altogether
- Weight bad pixels to 0 and all others to 1.
- Use weights implied by the input confidence maps

int **rejalgo**

A flag to specify the rejection algorithm used to flag outliers. This will include standard Poisson rejection based on the read-noise and gain as well as other popular algorithms.

float **lsigma**

The lower threshold for clipping outliers in units of sigma.

float **hsigma**

The upper threshold for clipping outliers in units of sigma.

6.8.3 Input Images and Required FITS Header Information

inlist (float)

The list of input files to be combined.

keyword	type	description
DRS VIRXOFF	float	The number of pixels in X by which to shift the current input image relative to the output grid. Ignored unless **useoffsets** has been set.
DRS VIRYOFF	float	The number of pixels in Y by which to shift the current input image relative to the output grid. Ignored unless **useoffsets** has been set

6.8.4 Input Tables

None

6.8.5 Output Images

outfile (float)

The output file; depending upon whether **useoffsets** has been set this may or may not have the same physical dimensions as the input list.

keyword	type	description
DRS VXXXX	char	A set of FITS keywords that list the files that were combined to form this output file. This establishes the provenance of the output file.

outconf (short int)

The output confidence map.

6.8.6 Output Tables

None

6.8.7 Other Output

None

6.8.8 QC1 Outputs

None

6.8.9 Quality Assessment

N/A

6.8.10 Error Conditions

- The following conditions will cause fatal errors
  - **useoffsets** set but no offset information exists in the header
- There are no non-fatal error conditions

6.9 vircam_imcore

6.9.1 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 5.11.

Mathematical Description:
This function implements the mathematical description in section 2.13

6.9.2 Function Parameters

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 the default profile fit.

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

6.9.3 Input Images and Required FITS Header Information

infile (float)
The input image from which to extract the objects

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

6.9.4 Input Tables

None

6.9.5 Output Images

None

6.9.6 Output Tables

objtab
The table of extracted objects as described in section 5.11.

6.9.7 Other Output

The following keywords are written back to the input file (**infile**)

keyword	type	description
DRS SKYLEVEL	float	The mean sky level in the image
DRS SKYNOISE	float	The mean sky noise in the image

6.9.8 QC1 Outputs

SATURATION
MEAN_SKY
SKY_NOISE
SKY_RESET_ANOMALY
NOISE_OBJ
IMAGE_SIZE
APPERTURE_CORR
ELLIPTICITY

6.9.9 Quality Assessment

N/A

6.9.10 Error Conditions

- The following conditions will cause fatal errors
  - Negative threshold value
  - Zero or negative sky noise estimate
- The following conditions will lead to non-fatal errors
  - No objects found

6.10 vircam_imstack

6.10.1 General

Name:

vircam_imstack

Purpose:

Stack a list of images into an output by mapping the input WCSs onto an output grid.

General Description:

A list of images is combined to form an output image. The full range of equatorial coordinates in the input file list is used to define an output grid. Each of the input pixels is mapped onto an appropriate pixel on the output grid. The resulting stacks can be either averaged or medianed to an output value. 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
- known bad pixels can be masked and rejected
- individual pixels can be weighted by confidence

Mathematical Description:

None

6.10.2 Function Parameters

int **calctype**

A flag to determine whether the output should be a mean or a median of the input frames

int **usezeros**

If set, then the images will be biased by an amount specified in the image headers

int **usescales**

If set, then the images will be multiplied by a factor specified in the image headers

int **wtflag**

A flag to determine how to weight the pixels; the options are:

- Ignore pixel weights altogether
- Weight bad pixels to 0 and all others to 1.
- Use weights implied by the input confidence maps

int **rejalgo**

A flag to specify the rejection algorithm used to flag outliers. This will include standard Poisson rejection based on the read noise and gain as well as other popular algorithms.

float **lsigma**

The lower threshold for clipping outliers in units of sigma.

float **hsigma**

The upper threshold for clipping outliers in units of sigma.

6.10.3 Input Images and Required FITS Header Information

inlist (float)

The list of input files to be stacked.

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.
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	

6.10.4 Input Tables

None

6.10.5 Output Images

outfile (float)
The output file.

keyword	type	description
DRS VXXXX	char	A set of FITS keywords that list the files that were combined to form this output file. This establishes the provenance of the output file.

outconf (short int)
The output confidence map.

6.10.6 Output Tables

None

6.10.7 Other Output

None

6.10.8 QC1 Outputs

None

6.10.9 Quality Assessment

N/A

6.10.10 Error Conditions

- The following conditions will cause a fatal error
  - No or incomplete WCS defined in an input file header
- There are no non-fatal error conditions.

6.11 vircam_interleave

6.11.1 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:

- 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

6.11.2 Function Parameters

int **usezeros**

If set, then the images will be biased by an amount specified in the image headers

int **usescales**

If set, then the images will be multiplied by a factor specified in the image headers.

6.11.3 Input Images and Required FITS Header Information

inlist (float)

The list of input files to be combined.

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.
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	

6.11.4 Input Tables

None

6.11.5 Output Images

outfile (float)
The output file.

keyword	type	description
DRS VXXXX	char	A set of FITS keywords that list the files that were combined to form this output file. This establishes the provenance of the output file.

outconf (short int)
The output confidence map.

6.11.6 Output Tables

None

6.11.7 Other Output

None

6.11.8 QC1 Outputs

None

6.11.9 Quality Assessment

N/A

6.11.10 Error Conditions

- The following conditions will lead to a fatal error.
  - No or incomplete WCS in an input file header
- The following conditions will lead to a non-fatal error
  - The non-integral part of the offset substantially different from 0.5 pixel

---

6.12 vircam_lincor

6.12.1 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 linearized 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.

6.12.2 Function Parameters

float **readtime**

The time it takes to read out each data channel in seconds.

float **resettime**

Time it takes to reset a data channel in seconds.

6.12.3 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

6.12.4 Input Tables

lchantab

The linearity channel table for the detector represented in the input image (**infile**). See section 5.4 for a full description of the table and its contents.

6.12.5 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 LINCOR	char	The name of the linearity channel table specified in **lchantab**

6.12.6 Output Tables

None

6.12.7 Other Output

None

6.12.8 QC1 Outputs

None

6.12.9 Quality Assessment

N/A

6.12.10 Error Conditions

- The following conditions will cause fatal errors
  - Negative exposure, readout or reset time.

- There are no non-fatal error conditions

6.13 *vircam_matchstds*

6.13.1 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 (5.10).

Mathematical Description:

N/A

6.13.2 Function Parameters

float **srad**

A search radius in pixels; this is used as a limit to define if a match is valid.

6.13.3 Input Images and Required FITS Header Information

None

6.13.4 Input Tables

objtab

The table of extracted objects from an image; this should be in the format of an object catalogue described in section 5.11

stdstab

The table of stars taken from the standard catalogue; this should be in the format of an extracted standards table (5.9)

6.13.5 Output Images

None

6.13.6 Output Tables

outtab

The table of objects that matched between the two input tables; this will be in the format of a matched standards table (5.10)

6.13.7 Other Output

int * **nmatch**

The number of stars that matched between the two input tables

6.13.8 QC1 Outputs

None.

6.13.9 Quality Assessment

N/A

6.13.10 Error Conditions

- There are no fatal error conditions.
- The following conditions will lead to non-fatal errors
  - No objects in one or both catalogues
  - No objects match between the catalogues

6.14 vircam_matchxy

6.14.1 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:

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

Mathematical Description:

None

6.14.2 Function Parameters

float **srad**

The search radius in pixels used to define a threshold radius for matching.

6.14.3 Input Images and Required FITS Header Information

None

6.14.4 Input Tables

progtab

The table of objects appearing on the 'programme' frame; this should be in the format of an object catalogue (see section 5.11).

temptab

The table of objects appearing on the 'template' frame; this should be in the format of an object catalogue (see section 5.11).

6.14.5 Output Images

None

6.14.6 Output Tables

None

6.14.7 Other Output

float * **xoffset**

The Cartesian offset in X

float * **yoffset**

The Cartesian offset in Y.

int * **nmatch**

The number of objects that matched to form the offset estimate.

6.14.8 QC1 Outputs

None

6.14.9 Quality Assessment

N/A

6.14.10 Error Conditions

- There are no fatal error conditions.
- The following conditions will lead to non-fatal errors
  - No objects matched. Offsets of zero will be returned.

6.15 vircam_mkconf

6.15.1 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. A four quadrant windowpane of bad pixels can be added (IR arrays sometimes have these).

Mathematical Description:

'Good' pixels will be given a confidence of:

$$C_i = 100 Q_i / \langle Q \rangle$$

where Q_i is the pixel's value in the quotient map, and $\langle Q \rangle$ is the mean value in the quotient map.

Quality Assessment:

N/A

6.15.2 Function Parameters

int **windowpane**

If set, then a simple cross denoting the edges of the quadrants will be marked as a list of bad pixels.

6.15.3 Input Images and Required FITS Header Information

inflat (float)

The input flat field

bpm (byte)

The bad pixel mask

6.15.4 Input Tables

None

6.15.5 Output Images

outconf (short int)

The output confidence map.

keyword	type	description
DRS FLATIN	char	The name of the mean flat field frame that was used to create this confidence map
DRS BPMIN	char	The name of the bad pixel mask image that was used to create this confidence map

6.15.6 Output Tables

None

6.15.7 Other Output

None.

6.15.8 QC1 Outputs

None

6.15.9 Quality Assessment

N/A

6.15.10 Error Conditions

- There are no fatal error conditions.
- The following conditions will lead to non-fatal errors:

- Missing library bad pixel mask.

6.16 *vircam_persist*

6.16.1 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 5.8. 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 2.7.

6.16.2 Function Parameters

float **decay**

The decay constant in seconds as described in section 2.7.

float **fract**

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

6.16.3 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

6.16.4 Input Tables

ptable

The persistence mask. See section 5.8.

6.16.5 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

6.16.6 Output Tables

None

6.16.7 Other Output

None.

6.16.8 QC1 Outputs

None

6.16.9 Quality Assessment

Persistent images removed to with the image mean sky noise.

6.16.10 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

6.17 vircam_photcal

6.17.1 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 2.14

6.17.2 Function Parameters

None.

6.17.3 Input Images and Required FITS Header Information.

infile (any)

The input image; needed so that the header can be updated.

6.17.4 Input Tables

stdstab

A matched standards table (see 5.10) with the photometric standard stars that have matched the objects on the image

objtab

An object catalogue (see 5.11) generated from the input frame.

illcortab

An illumination correction table (see 5.6)

6.17.5 Output Images

None

6.17.6 Output Tables

None

6.17.7 Other Output

Both **infile** and **objtab** have the following added to their FITS headers:

keyword	**type**	**description**
DRS MAGZPT	float	The calculated photometric zero point for the image
DRS MAGZERR	float	The RMS of the photometric zero point for the image
DRS MAGNZPT	int	The number of stars used in the zero point calculation

6.17.8 QC1 Outputs

ZPT_2MASS
ZPT_STDS
LIMITING_MAG

6.17.9 Quality Assessment

DRS MAGZERR is within the expected internal consistency of the photometric source catalogue.

6.17.10 Error Conditions

- There are no fatal error conditions
- The following conditions will lead to non-fatal errors
  - No matching photometric standards

6.18 vircam_platesol

6.18.1 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 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:

$$\xi = ax + by + c \qquad \textbf{(6-1)}$$

$$\eta = dx + ey + f \qquad \textbf{(6-2)}$$

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 2.9 for information on how the expected projection geometry will be incorporated.

6.18.2 Function Parameters

int **nconst**

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

int **adjust_tan**

If set, then the tangent point will be moved before the fit to take into account any Cartesian offset between the frame as defined by the current WCS, and the frame defined by the standards.

6.18.3 Input Images and Required FITS Header Information

infile (any)

The input file; only the header is used in this function.

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_1	double	
PV2_3	double	

6.18.4 Input Tables

objinfo

The table of objects with Cartesian pixel coordinates and equatorial coordinates. This will be in the format of a matched standards table (5.10)

objtab

Full object catalogue extracted from **infile**. This is only needed so that the routine can update the coordinates for each object.

6.18.5 Output Images

infile (any)

The input file; the WCS structure in the header will be modified to include the new parameters found in this function.

keyword	**type**	**description**
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)

6.18.6 Output Tables

None

6.18.7 Other Output

None

6.18.8 QC1 Outputs

WCS_DCRVAL1
WCS_DCRVAL2
WCS_DTHETA
WCS_SCALE
WCS_SHEAR (6-constant model)
WCS_RMS

6.18.9 Quality Assessment

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

6.18.10 Error Conditions

- There are no fatal error conditions.

- The following conditions will lead to non-fatal errors
  - No objects in one or both catalogues
  - No objects match between the catalogues

6.19 vircam_sky_flat_combine

6.19.1 General

Name:

vircam_sky_flat_combine

Purpose:

Combine sky or object observations to create a mean sky flat and confidence map.

General Description:

- Process the images to linearize and remove dark current
- Combine the images with biasing and rejection.
- Normalise each detector's flat-field by the ensemble median level over all the detectors' flat-fields. The normalised level in each image is the detector gain correction.
- Create the confidence map from the mean flat field and the master bad pixel mask

Mathematical Description:

None

6.19.2 Function Parameters

float **low**

The lower limit to define an under exposed flat field image

float **high**

The upper limit to define a saturated flat field image

6.19.3 Input Images and Required FITS header information

Input Data:

- A series of exposures of a sparse patch of sky. These can either be target images of offset sky images.
- Library mean dark frame for the given exposure and integration time.
- Linearity channel table
- Library bad pixel mask

Parameters:

6.19.4 Input Tables

None

6.19.5 Output Images

Outputs:

- Mean sky flat field for the given passband (MASTERSKYFLAT)
- Confidence map for the given passband (CONFMAP)

6.19.6 Output Tables

None

6.19.7 Other Output

None

6.19.8 QC1 Outputs

GAIN_CORRECTION
FLATVAR

6.19.9 Quality Assessment

N/A

6.19.10 Error Conditions

Fatal Error Conditions:

- Missing library master images
- Missing library master tables
- All flat images either under or over exposed

Non-fatal Error Conditions:

- Missing library bad pixel mask (No pixels flagged as bad)

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 is used to produce calibration frames. Each plugin is documented below. Where a calibration product is created by the recipe, the value in parenthesis after the file specifies the value of the PRO CATG keyword in the output file header.

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. Error conditions will also occur within the plugin, but outside of one of the VIRCAM functions. These will be documented here under the banner of *additional* error conditions. Very obvious fatal errors such as failure to specify any files to reduce or running out of disc space are not included in the list.

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

Type:

Detector calibration

Input Data:

- List of reset frames
- Library mean reset frame
- Channel table

Parameters:

int **ncells**

The number of cells into which we can divide each data channel

Algorithm:

- Combine the sequence of reset frames into a single mean with rejection.
- Subtract the library reset frame
- Calculate the global difference level and at the level of each data channel
- Split each data channel of the difference frame into cells and do a robust median estimate in each.

Outputs:

- New master reset frame (MASTERRESET)
- Difference image (DIFFIMG)
- Reset difference image statistics table (DIFFIMSTATS)

QC1 Parameters:

RESETVAR

Vircam Functions Used:

vircam_imcombine

Additional Fatal Error Conditions:

None

Additional Non-fatal Error Conditions:

- Missing calibDB reset frame (No comparison with previous frame done)
- Missing channel table (No comparison with previous frame done)
- Library mean reset frame data array dimensionality mismatch with new mean reset frame. (No comparison with previous frame done)

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. Estimate dark counts in the new frame.

Type:

Detector calibration

Input Data:

- List of dark frames
- Library mean dark frame
- Library confidence mask
- Channel table

Parameters:

int **ncells**

The number of cells into which we can divide each data channel

Algorithm:

- Combine the sequence of dark frames with rejection.
- In conjunction with confidence map, assess the number of rejected pixels 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.
- Subtract this frame from a calibDB dark frame.
- Calculate global difference level and the level in each data channel
- Divide each data channel in the difference map into cells and do a robust-background estimate in each.

Outputs:

- New master dark frame (MASTERDARK)
- Dark frame difference image (DIFFIMG)
- Dark difference image statistics table (DIFFIMSTATS)

QC1 Parameters:

DARKRMS
PARTICLE_RATE

Vircam Functions Used:

vircam_imcombine

Additional Fatal Error Conditions:

None

Additional Non-fatal Error Conditions:

- Missing calibDB mean dark frame. (No comparison with previous frame done)
- Missing calibDB confidence map (All pixels assumed to be good)
- Missing channel table (No comparison with previous frame done)
- Library mean dark frame data array dimensionality mismatch with new mean dark frame. (No comparison with previous frame done)

7.3 vircam_dark_current

Name:

vircam_darkcurrent

Purpose:

Analyse a series of dark exposures for slope, i.e. dark-current per second.

Type:

Detector Calibration

Input Data:

- A series of DARK exposures at a variety of different exposure times
- Linearity channel table
- Library bad pixel mask

Parameters:

float **thresh**

The threshold in units of background sigma above or below the local mean value which defines whether a pixel is bad or not

Algorithm:

- Perform robust iterative linear fit across all exposures at each pixel position

Outputs:

- Dark current map

QC1 Parameters:

DARKCURRENT

Vircam Functions Used:

None

Additional Fatal Error Conditions:

None

Additional Non-fatal Error Conditions:

None

7.4 vircam_dome_flat_combine

Name:

vircam_dome_flat_combine

Purpose:

Combine a series of dome flat exposures and create confidence maps.

Type:

Detector calibration

Input Data:

- List of dome flat exposures
- Master dark frames of the appropriate exposure time
- Linearity channel mask
- Master bad pixel mask

Parameters:

float **low**

The lower image flux limit to define an under-exposed flat field image

float **high**

The upper image flux limit to define a saturated (over-exposed) flat field image.

Algorithm:

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

Outputs:

- New master dome flat (MASTERDOME)
- New master dome flat confidence map (CONFMAP)

QC1 Parameters:

FLATVAR

Vircam Functions Used:

vircam_imcombine, vircam_mkconf, vircam_darkcor, vircam_lincor

Additional Fatal Error Conditions:

- All images saturated
- Missing calibDB mean dark frame
- Missing linearity channel mask

Additional Non-fatal Error Conditions:

- Missing bad pixel mask (No pixels flagged as bad)

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
- Two dark frames

Parameters:

None

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

QC1 Parameters:

READNOISE

GAIN

Vircam Functions Used:

vircam_darkcor

Additional Fatal Error Conditions:

- Non-physical result

Additional Non-fatal Error Conditions:

None

7.6 *vircam_linearity_analyse*

Name:

vircam_linearity_analyse

Purpose:

Create linearity curves for each detector channel and bad-pixel maps

Type:

Detector calibration

Input Data:

- A series of dome flat exposures taken under constant illumination with varying integration times.
- Channel map
- A master dark frame for each integration time used in the dome series

Parameters:

int **nord**

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

Algorithm:

- Process each flat exposure by removing the reset anomaly with the appropriate dark frame
- 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 linearity channel table.
- Combine the 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 and in the calibDB bad-pixel mask. Compute the difference.

Outputs:

- Linearity channel table (LCHANTAB)

QC1 Parameters:

LINEARITY
LINFITQUAL
BAD_PIXEL_STAT

Vircam Functions Used:

vircam_darkcor, vircam_genlincur

Additional Fatal Error Conditions:

- Missing channel map
- Missing dark frames

Additional Non-fatal Error Conditions:

None

7.7 vircam_twilight_combine

Name:

vircam_twilight_combine

Purpose:

Create a master twilight flat field and initial confidence map

Type:

Detector calibration

Input Data:

- A series of twilight flat exposures taken in a single passband
- A master dark frame for each integration time used in the flat field series.
- Linearity channel table
- A master bad pixel mask

Parameters:

float **low**

The lower image flux limit to define an under-exposed flat field image

float **high**

The upper image flux limit to define a saturated (over-exposed) flat field image.

Algorithm:

- Examine a list of twilight flat-field exposures and reject all those that are over or under exposed.
- Linearize and remove the dark current from the remaining flat frames.
- Combine the flat frames with rejection.
- Normalise each detector’s flat-field by the ensemble median level over all the detectors’ flat-fields. The normalised level in each image is the detector gain correction.

- Create the confidence map from the mean flat field and the calibDB bad pixel mask

Outputs:

- Mean flat field and gain corrections for the input data passband (MASTERTWIFLAT)
- Initial confidence map for the input data passband (CONFMAP)

QC1 Parameters:

GAIN_CORRECTION
FLATVAR

Vircam Functions Used:

vircam_darkcor, vircam_lincor, vircam_imcombine, vircam_mkconf

Additional Fatal Error Conditions:

- Failure to include a master dark frame for each exposure time used in the twilight flat exposures
- Missing linearity channel table
- All input flats over or under exposed

Additional Non-fatal Error Conditions:

- Missing calibDB bad pixel mask (No pixels flagged as bad)

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:

- A series of exposures of a sparse secondary standard field that has been offset in a regular raster
- 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
- Persistence mask
- Crosstalk table
- Photometric standard catalogue

Parameters:

float **thresh**

Detection threshold for object extraction.

Algorithm:

- Process the observations by linearising, dark correction and flat fielding
- Compute the zero-point of standard stars on a grid of each of a series of meso-stepped exposures.

- Work out the residual zero-point at each position on the detector relative to the zero-point at the centre.
- Write the illumination correction table.

Outputs:

- Illumination correction table (see 5.6) (ILLCORTAB)

QC1 Parameters:

ILLUMCOR_RMS

Vircam Functions Used:

vircam_darkcor, vircam_lincor, vircam_flatcor, vircam_defringe, vircam_persist, vircam_crosstalk, vircam_imcore, vircam_getstds, vircam_platesol, vircam_matchstds

Additional Fatal Error Conditions:

- Missing master calibration frames
- Missing master calibration tables
- Missing photometric standard catalogue

Additional Non-fatal Error Conditions:

None

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:

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. Δt curve to an exponential to work out the characteristic decay constant, τ_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_defringe, vircam_imcore

Additional Fatal Error Conditions:

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

Additional 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:

- 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 5.5 (XTALK)

QC1 Parameters:

CROSS_TALK

Vircam Functions Used:

vircam_imcore

Additional Fatal Error Conditions:

- Missing channel table or confidence map

Additional 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. If sufficient qualifying data were taken, combine into a mean sky map.

Type:

Science

Input Data:

- A jittered and/or microstepped sequence of exposures of a target region.
- Library mean dark frame for the given exposure and integration time.
- Library mean flat field frame for the given passband
- Library confidence map for the given passband
- Library fringe frame
- Linearity channel table
- Crosstalk matrix
- Persistence mask
- Astrometric standard data (through CPL interface to 2MASS)
- Photometric standard data (through CPL interface to 2MASS)

Parameters:

float **persist**

Persistence time constant for the detector

float **thresh**

Detection threshold in units of background sigma for object extraction

Algorithm:

- Remove crosstalk images
- Process the images by linearising and removing dark current and flat fielding
- De-fringe
- Remove persistent images
- 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

Sky map algorithm:

- Process the images to linearize and remove dark current
- Combine the images with biasing and rejection.
- Normalise each detector's flat-field by the ensemble median level over all the detectors' flat-fields. The normalised level in each image is the detector gain correction.
- Create the confidence map from the mean flat field and the master bad pixel mask

Outputs:

- Single exposure images that corrected for linearity, dark current, flat field, sky, image persistence and crosstalk. A full WCS will appear in the header
- Interleaved super-frame images from the above.
- Stacked jitter images from the super-frames. Full WCS and photometric zero point will appear in the FITS header.
- Associated confidence maps for each output image (CONFMAP)
- Object catalogue in the form of a FITS table (OBJCAT)

QC1 Parameters:

WCS_DCRVAL1
WCS_DCRVAL2
WCS_DTHETA
WCS_DSCALE
WCS_SHEAR
WCS_RMS
MEAN_SKY
SKY_NOISE
SKY_RESET_ANOMALY
FRINGE_RATIO
NOISE_OBJ
IMAGE_SIZE
APERTURE_CORR
ELLIPTICITY
ZPT_2MASS
LIMITING_MAG

Vircam Functions Used:

vircam_darkcor, vircam_lincor, vircam_flatcor, vircam_defringe, vircam_persist, vircam_matchxy, vircam_crosstalk, vircam_imcore, vircam_getstds, vircam_platesol, vircam_matchstds, vircam_imstack, vircam_sky_flat

Additional Fatal Error Conditions:
- Missing master calibration frames
- Missing master calibration tables
- Object catalogues don't match – unable to work out jitter offsets
- Microstep non-integral offsets deviate too much from 0.5 pixel

Additional Non-fatal Error Conditions:
- Failure to match object catalogue entries to astrometric standards. (Recipe will proceed with WCS as defined in the raw telescope header)
- Failure to match object catalogue entries to photometric standards. (Recipe will proceed to the end without a photometric zeropoint.)

7.12 *vircam_standard_process*

Name:

vircam_standard_process

Purpose:

Process sequence of photometric standard data that may have been both jittered and microstepped; if sufficient standards are present, also compute an illumination map.

Type:

Science

Input Data:
- A jittered and microstepped sequence of exposures of a standard star region.
- Library mean dark frame for the given exposure and integration time.
- Library mean flat field frame for the given passband
- Library confidence map for the given passband
- Library fringe frame
- Linearity channel table
- Crosstalk matrix
- Persistence mask
- Astrometric standard data
- Photometric standard data

Parameters:

float **persist**

Persistence time constant for the detector

float **thresh**

Detection threshold in units of background sigma for object extraction

Algorithm:
- Process the images by linearising and removing dark current and flat fielding
- De-fringe
- Remove persistent images
- Remove crosstalk images
- 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 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 and magnitudes of photometric standards.
- Apply illumination correction to catalogue

Outputs:

- Single exposure images that corrected for linearity, dark current, flat field, sky, image persistence and crosstalk. A full WCS will appear in the header
- Interleaved super-frame images from the above.
- Stacked jitter images from the super-frames. Full WCS and photometric zero point will appear in the FITS header.
- Associated confidence maps for each output image (CONFMAP)
- Object catalogue in the form of a FITS table (OBJCAT)

QC1 Parameters:

WCS_DCRVAL1
WCS_DCRVAL2
WCS_DTHETA
WCS_DSCALE
WCS_SHEAR
WCS_RMS
SATURATION
MEAN_SKY
SKY_NOISE
SKY_RESET_ANOMALY
FRINGE_RATIO
NOISE_OBJ
IMAGE_SIZE
APERTURE_CORR
ELLIPTICITY
ZPT_STDS
LIMITING_MAG
ILLUMCOR_RMST

Vircam Functions Used:

vircam_darkcor, vircam_lincor, vircam_flatcor, vircam_defringe, vircam_persist, vircam_matchxy, vircam_crosstalk, vircam_imcore, vircam_getstds, vircam_platesol, vircam_matchstds, vircam_imstack, vircam_illum

Additional Fatal Error Conditions:

- Missing master calibration frames

- Missing master calibration tables
- Object catalogues don't match – unable to work out jitter offsets
- Microstep non-integral offsets deviate too much from 0.5 pixel

Additional Non-fatal Error Conditions:

- Failure to match object catalogue entries to astrometric standards. (Recipe will proceed with WCS as defined in the raw telescope header)
- Failure to match object catalogue entries to photometric standards. (Recipe will proceed to the end without a photometric zero point.)

8 Validation tests

Validation procedures shall be developed along with the software for the different function levels:

- Unitary test for each low-level Data Reduction Library function
- Reduction tests based on the generic CPL plugin application

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. In others, data from other instruments, namely WFCAM will be made to look like VISTA data. Where nothing else is available, simulated data will be generated and wrapped to look like VISTA data files. In the table below we give a list of the test data files that will be available for use in the validation procedures. Each FITS file will contain data for all sixteen detectors. The 'rich_field' files will consist of observations of a medium rich stellar field, which can be used for many of the validation tests we require. The series will be a 5 point jitter series, where each jitter point is also a 4 point microstep sequence.

Included in the test suite will be files that can be used in comparison with output from test procedures on functions and plugins. 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.

datafile	**comment**
bpm.fits	A bad pixel mask
chantab.fits	The channel table (5.2)
dark_after_richXX.fits	A series of dark frames taken after the last rich_fieldXX frame.
darkXX.fits	A list of dark frames with the same exposure time as rich_fieldXX
darkXX_exp.fits	A series of dark frames with exposure times the same as those for domeflatXX_raw.fits
domeflatXX.fits	A series of dome flat exposures done with a series of exposure times with constant illumination. These have been dark corrected.
domeflatXX_raw.fits	A series of dome flat exposures done with a series of exposure times with constant illumination. These have **not** been dark corrected.
fringe.fits	A mean fringe frame
illumtab.fits	An illumination correction table for rich_field01.fits
lchantab.fits	The linearity channel table
match_stds.fits	Matched standards table of objtab01.fits matched to stds_2mass.fits
meanconf.fits	A confidence map arising from twiflatXX.fits.
meandark.fits	A mean dark frame formed from the list darkXX.fits

meandomeflat.fits	A mean dome flat formed from domeflatXX.fits
meanreset.fits	A mean reset frame formed from the list resetXX.fits
meantwiflat.fits	A mean twilight flat field frame formed from twiflatXX.fits
objtab01.fits objtab02.fits	The object tables for rich_field01_sig.fits and rich_field02_sig.fits for a given set of extraction parameters
persistmask.fits	A persistence mask for the rich_fieldXX series
resetXX.fits	A list of reset frames
rich_comb.fits	The rich_field_sig series combined with no coordinate offsets
rich_comb_conf.fits	The confidence map formed from combining rich_field_sig files with no coordinate offsets.
rich_field01_dark.fits	The first rich_field file – dark corrected using meandark.fits
rich_field01_flat.fits	The first rich_field file – flat fielded using meantwiflat.fits
rich_field01_lin.fits	The first rich field file – linearised using lchantab.fits
rich_field01_sigf.fits	The first rich field file with linearity, dark, and flat corrections applied
rich_fieldXX.fits	A raw microstep and jitter sequence of a rich photometric standard field
rich_fieldXX_meso.fits	A raw meso-stepped series of the rich_field region.
rich_fieldXX_sig.fits	The rich field series with linearity, dark, flat and fringe corrections applied
rich_stack.fits	A stack of rich_fieldXX_sig.fits series.
rich_stack_conf.fits	A confidence map formed from stacking the rich_fieldXX_sig.fits series
rich_super.fits	A super frame of the first microstep sequence in the rich_fieldXX_sig series.
rich_super_conf.fits	The confidence map formed from interleaving the first microstep sequence in the rich_fieldXX_sig series.
stds_2mass.fits	A list of 2mass standards that appear on rich_field01.fits
twiflatXX.fits	A list of twilight flat field frames in one colour. These have been linearity and dark corrected
twiflatXX_raw.fits	A list of raw twilight flat field frames in one colour
xtalk.fits	A full crosstalk matrix

Table 8-1 A list of data files to be made available for testing vircam functions and plugins

In the tables below we give a list of each of the VIRCAM functions and plugins from chapters 6 and 7 and the input files required from the test data suite. The files in the column 'output test files' will be used in to test consistency of result with the output of each function or plugin.

function	input test files	output test files
vircam_crosstalk	rich_field01.fits	xtalk.fits
vircam_darkcor	rich_field01.fits meandark.fits	rich_field01_dark.fits
vircam_defringe	rich_field01_sigf.fits fringe.fits	rich_field01_sig.fits

vircam_flatcor	rich_field01.fits meantwiflat.fits	rich_field01_flat.fits
vircam_genlincur	domeflatXX.fits chantab.fits	lchantab.fits
vircam_getstds	rich_field01.fits	stds_2mass.fits
vircam_illum	rich_field01_sig.fits	illumtab.fits
vircam_imcombine	rich_fieldXX_sig.fits meanconf.fits	rich_comb.fits rich_comb_conf.fits
vircam_imcore	rich_field01_sig.fits meanconf.fits	objtab01.fits
vircam_imstack	rich_fieldXX_sig.fits	rich_stack.fits rich_stack_conf.fits
vircam_interleave	rich_fieldXX_sig.fits	rich_super.fits rich_super_conf.fits
vircam_lincor	rich_field01.fits lchantab.fits	rich_field01_lin.fits
vircam_matchstds	objtab01.fits stds_2mass.fits	match_stds.fits
vircam_matchxy	objtab01.fits objtab02.fits	
vircam_mkconf	twiflatXX.fits	meanconf.fits
vircam_persist	rich_fieldXX_sig.fits dark_after_richXX.fits	
vircam_photcal	rich_stack.fits stds_2mass.fits	
vircam_platesol	rich_field01_sig.fits match_stds.fits	

Table 8-2 Files to be used to test each vircam function

plugin	input test files	output test files
vircam_reset_combine	resetXX.fits	meanreset.fits
vircam_dark_combine	darkXX.fits	meandark.fits
vircam_dome_flat_combine	domeflatXX.fits	meandomeflat.fits
vircam_detector_noise	domeflatXX.fits darkXX.fits	
vircam_linearity_analyse	domeflatXX_raw.fits darkXX_exp.fits chantab.fits	lchantab.fits bpm.fits
vircam_twilight_combine	twiflatXX_raw.fits meandark.fits lchantab.fits bpm.fits	meantwiflat.fits meanconf.fits

vircam_mesostep_analyse	rich_fieldXX_meso.fits meandark.fits meantwiflat.fits lchantab.fits fringe.fits	illumtab.fits
vircam_persistence_analyse	rich_fieldXX.fits meandark.fits meantwiflat.fits lchantab.fits meanconf.fits	
vircam_crosstalk_analyse	rich_fieldXX.fits meandark.fits meantwiflat.fits lchantab.fits meanconf.fits	xtalk.fits
vircam_sky_flat_combine	rich_fieldXX.fits meandark.fits meantwiflat.fits fringe.fits lchantab.fits meanconf.fits bpm.fits	rich_comb.fits rich_comb_conf.fits
vircam_jitter_microstep_process	rich_fieldXX.fits meandark.fits meantwiflat.fits fringe.fits lchantab.fits meanconf.fits xtalk.fits persistmask.fits	rich_stack.fits rich_stack_conf.fits
vircam_standard_process	rich_fieldXX.fits meandark.fits meantwiflat.fits fringe.fits lchantab.fits meanconf.fits xtalk.fits persistmask.fits	rich_stack.fits rich_stack_conf.fits illumtab.fits

Table 8-3 Files to use in testing each vircam plugin

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

10 Appendix: QC1 Parameters

```
#******************************************************************************
# E.S.O. VISTA project
#
#  "@(#) $Id: dicVIRCAM_QC.txt,v 0.7 2004/07/29 12:05:28 vltsccm 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
# jrl          2004-12-08     add FRINGE_RATIO, ILLUMCOR_RMS
# jrl          2004-12-13     change FRINGE_RATIO to FRINGE_RATIO,
#                             add LINFITQUAL
#
#      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: 0.7 $
Revision:          $Revision: 0.2 $
Date:              2004-12-13
Status:            Development
Description:       VIRCAM Quality-Control

Parameter Name:    QC DID
Class:             header|qc-log
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 DARKCURRENT
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              adu/sec
Comment Format:    average dark current on frame [adu/sec].
Description:       measured using the median of the pixel values,
                   can later be compared with similar darks for trends

Parameter Name:    QC DARKRMS
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              adu
Comment Format:    measure of rms noise of dark frame [adu].
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 PARTICLE_RATE
Class:             ext-header|header|qc-log
```

```
Context:            process
Type:               double
Value Format:       %f
Unit:               count/sec
Comment Format:     cosmic ray/spurion rate [count/sec].
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 RESETVAR
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               percentage
Comment Format:     percentage variation in current reset frame [percentage].
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 READNOISE
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               electron
Comment Format:     readnoise [electron].
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 FLATVAR
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               percentage
Comment Format:     rms variation of flatfield pixel sensitivity per detector
[percentage].
Description:        rms is defined here as the Gaussian equivalent MAD ie.
                    1.48*median-of-absolute-deviation from unity after
                    normalising by median level ie. measuring the rms
                    sensitivity variation.
                    The rms can later be compared with library values
                    for troubleshooting problems.

Parameter Name:     QC GAIN
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               e/ADU
Comment Format:     gain [e/ADU].
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 BAD_PIXEL_STAT
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               scalar
```

```
Comment Format:    fraction of bad pixels per detector [scalar].
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 significantly with time.

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

Parameter Name:    QC LINFITQUAL
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              scalar
Comment Format:    the RMS fractional error in linearity fit [scalar]
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 SATURATION
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              ADU
Comment Format:    saturation level of bright stars [ADU].
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 PERSIST_DECAY
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              s
Comment Format:    mean exponential time decay constant [s].
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:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              scalar
Comment Format:    fractional persistence at zero time (extrapolated) [scalar].
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:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              scalar
Comment Format:    average values for cross-talk component matrix [scalar].
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 WCS_DCRVAL1
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %e
Unit:              deg
Comment Format:    actual WCS zero point X - raw header value [deg].
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:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %e
Unit:              deg
Comment Format:    actual WCS zero point Y - raw header value [deg].
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:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %e
Unit:              deg
Comment Format:    actual WCS rotation PA - raw PA header value [deg].
Description:       measure of difference between dead-reckoning
                   PA and true position angle of the detector.
                   Derived from current polynomial distortion model
                   and 6-constant detector model effective rotation term.

Parameter Name:    QC WCS_SCALE
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %e
Unit:              deg/pixel
Comment Format:    measured WCS plate scale per detector [deg/pixel].
```

```
Description:        measure of the average on-sky pixel scale of detector
                    after correcting using current polynomial distortion model

Parameter Name:     QC WCS_SHEAR
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %e
Unit:               deg
Comment Format:     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:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %e
Unit:               arcsec
Comment Format:     robust rms of WCS solution for each detector [arcsec].
Description:        robust average of residuals from WCS solution for each
                    detector. Measure of integrity of WCS solution.

Parameter Name:     QC MEAN_SKY
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               ADU
Comment Format:     mean sky level [ADU].
Description:        computed using a clipped median for each detector
                    Sky levels should vary smoothly over the night.
                    Strange changes in values may indicate a
                    hardware fault.

Parameter Name:     QC SKY_NOISE
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               ADU
Comment Format:     rms sky noise [ADU].
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 SKY_RESET_ANOMALY
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               ADU
Comment Format:     systematic variation in sky across detector [ADU].
Description:        robust average variation in background level for each
                    detector, computed by measuring the large scale variation
                    from a filtered 64x64 pixel background grid, where each
                    background pixel is a clipped median estimate of the
                    local sky level. Effectively generates an 32x32 sky
                    level map and computes the MAD [TBC] of these values with
                    respect to the global detector median.  Monitoring
                    the non-flatness of this gives a measure of reset-anomaly
                    problems.

Parameter Name:     QC NOISE_OBJ
Class:              ext-header|header|qc-log
Context:            process
Type:               integer
Value Format:       %d
```

```
Unit:               number
Comment Format:     number of classified noise objects per frame [number].
Description:        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:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               arcsec
Comment Format:     mean stellar image FWHM [arcsec].
Description:        measured from the average FHWM of stellar-classified
                    images of suitable signal:to:noise.  The seeing will
                    obviously vary over the night with time and wavelength
                    (filter). This variation should be predictable given
                    local site seeing measures.  A comparison with the
                    expected value can be used as an indication of poor
                    guiding, poor focus or instrument malfunction.

Parameter Name:     QC APERTURE_CORR
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               mag
Comment Format:     2 arcsec [mag] 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:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               scalar
Comment Format:     mean stellar ellipticity [scalar].
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 ZPT_2MASS
Class:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
Unit:               mag
Comment Format:     1st-pass photometric zeropoint [mag].
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:              ext-header|header|qc-log
Context:            process
Type:               double
Value Format:       %f
```

```
Unit:              mag
Comment Format:    photometric zeropoint [mag].
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 undoutbedly vary (slowly)
                   over time as a result of the cleaning of optical surfaces
                   etc.

Parameter Name:    QC LIMITING_MAG
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              mag
Comment Format:    limiting mag ie. depth of exposure [mag].
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 FRINGE_RATIO
Class:             ext-header|header|qc-log
Context:           process
Type:              double
Value Format:      %f
Unit:              scalar
Comment Format:    [scalar] Ratio of sky noise before to 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:             ext-header|header|qc-log
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:

```
HIERARCH ESO QC DID          = 'ESO-VLT-DIC.VIRCAM_QC         ' / Data dictionar
HIERARCH ESO QC DARKCURRENT  = 200.000000      / average dark current on frame [
HIERARCH ESO QC DARKRMS      = 3.456000        / measure of rms noise of dark fr
HIERARCH ESO QC PARTICLE_RATE= 20.500000       / cosmic ray/spurion rate [count/
HIERARCH ESO QC RESETVAR     = 4.500000        / percentage variation in current
HIERARCH ESO QC READNOISE    = 150.000000      / readnoise [electron].
HIERARCH ESO QC FLATVAR      = 234.560000      / rms variation of flatfield pixe
HIERARCH ESO QC GAIN         = 1.600000        / gain [e/ADU].
HIERARCH ESO QC BAD_PIXEL_STAT= 0.006000       / fraction of bad pixels per dete
HIERARCH ESO QC GAIN_CORRECTION= 0.950000      / ratio of detector median flatfi
HIERARCH ESO QC LINEARITY    = 0.030000        / the percentage average non-line
HIERARCH ESO QC LINFITQUAL   = 0.000000        / the RMS fractional error in lin
HIERARCH ESO QC SATURATION   = 65535.000000    / saturation level of bright star
HIERARCH ESO QC PERSIST_DECAY= 40.000000       / mean exponential time decay con
HIERARCH ESO QC PERSIST_ZERO = 0.800000        / fractional persistence at zero
HIERARCH ESO QC CROSS_TALK   = 1.000000        / average values for cross-talk c
HIERARCH ESO QC WCS_DCRVAL1  = 5.555550e-04    / actual WCS zero point X - raw h
HIERARCH ESO QC WCS_DCRVAL2  = -5.555500e-04   / actual WCS zero point Y - raw h
```

```
HIERARCH ESO QC WCS_DTHETA   = 1.000000e-02    / actual WCS rotation PA - raw PA
HIERARCH ESO QC WCS_SCALE    = 9.444400e-05    / measured WCS plate scale per de
HIERARCH ESO QC WCS_SHEAR    = 1.000000e-04    / power of cross-terms in WCS sol
HIERARCH ESO QC WCS_RMS      = 9.444400e-06    / robust rms of WCS solution for
HIERARCH ESO QC MEAN_SKY     = 12345.120000    / mean sky level [ADU].
HIERARCH ESO QC SKY_NOISE    = 2000.000000     / rms sky noise [ADU].
HIERARCH ESO QC SKY_RESET_ANOMALY= 123.450000  / systematic variation in sky acr
HIERARCH ESO QC NOISE_OBJ    =          150    / number of classified noise obje
HIERARCH ESO QC IMAGE_SIZE   = 0.500000        / mean stellar image FWHM [arcsec
HIERARCH ESO QC APERTURE_CORR= 0.456000        / 2 arcsec [mag] diam aperture fl
HIERARCH ESO QC ELLIPTICITY  = 0.021100        / mean stellar ellipticity [scala
HIERARCH ESO QC ZPT_2MASS    = 26.500000       / 1st-pass photometric zeropoint
HIERARCH ESO QC ZPT_STDS     = 26.400000       / photometric zeropoint [mag].
HIERARCH ESO QC LIMITING_MAG = 24.567000       / limiting mag ie. depth of expos
HIERARCH ESO QC FRINGE_RATIO = 0.000000        / [scalar] Ratio of sky noise bef
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_STAT		linearity_analyze
CROSS_TALK		crosstalk_analyse
DARKCURRENT		dark_combine
DARKRMS		dark_current
ELLIPTICITY	imcore	jitter_microstep_process standard_process
FLATVAR		dome_flat_combine twilight_combine sky_flat_combine
FRINGE_RATIO	defringe	jitter_microstep_process standard_process
GAIN		detector_noise
GAIN_CORRECTION		twilight_combine sky_flat_combine
ILLUMCOR_RMS	illum	mesostep_analyse standard_process
IMAGE_SIZE	imcore	jitter_microstep_process standard_process
LIMITING_MAG	photcal	jitter_microstep_process standard_process
LINEARITY	genlincur	linearity_analyse
LINFITQUAL	genlincur	linearity_analyse
MEAN_SKY	imcore	jitter_microstep_process standard_process
NOISE_OBJ	imcore	jitter_microstep_process standard_process
PARTICLE_RATE		dark_combine

PERSIST_DECAY		persistence_analyse
PERSIST_ZERO		persistence_analyse
READNOISE		detector_noise
RESETVAR		reset_combine
SATURATION	imcore	standard_process
SKY_NOISE	imcore	jitter_microstep_process standard_process
SKY_RESET_ANOMALY	imcore	jitter_microstep_process standard_process
WCS_DCRVAL1	platesol	jitter_microstep_process standard_process
WCS_DCRVAL2	platesol	jitter_microstep_process standard_process
WCS_DTHETA	platesol	jitter_microstep_process standard_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	photcal	jitter_microstep_process
ZPT_STDS	photcal	standard_process

11 Appendix: DRS Dictionary

```
################################################################################
# E.S.O. VISTA project
#
#  "@(#) $Id: ESO-VLT-DIC.VIMOS_DRS,v 0.1 2005/04/04  vltsccm Exp $"
#
#
# VIRCAM_QC dictionary
#
# who           when            what
#--------       -------             ------------------------------------------------
# pbunclark     2005-04-04      Original
# jrl          2005-04-15     various tidyups

Dictionary Name:   ESO-VLT-DIC.VIRCAM_DRS
Scope:             DFS
Source:            ESO VLT
Version Control:   @(#) $Id: 0.1 $
Revision:          0.1
Date:              2005-04-15
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 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 DARKCOR
Class:            header
Context:          PROCESS
Type:             string
Value Format:     %s
Unit:
Comment Format:   flat field 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 FRINGEi
Class:            header
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

Parameter Name:   DRS FLATCOR
Class:            header
Context:          PROCESS
Type:             string
Value Format:     %s
Unit:
Comment Format:   flat field image
Description:      The name of the flat field image specified in
                  flatsrc

Parameter Name:   DRS MAGZPT
Class:            header
Context:          PROCESS
Type:             double
Value Format:     %f
Unit:             mag
Comment Format:   [mag] photometric zero point
```

```
Description:        The calculated photometric zero point for the
                    image

Parameter Name:     DRS MAGZERR
Class:              header
Context:            PROCESS
Type:               double
Value Format:       %f
Unit:               mag
Comment Format:     [mag] RMS of photometric zero point
Description:        The RMS error in the calculated photometric
                    zero point of the image

Parameter Name:     DRS MAGNZPT
Class:              header
Context:            PROCESS
Type:               integer
Value Format:       %d
Unit:
Comment Format:     No. stars in ZPT calc
Description:        The number of stars used in the photometric
                    zero-point calculation

Parameter Name:     DRS VIRXOFF
Class:              header
Context:            PROCESS
Type:               double
Value Format:       %f
Unit:
Comment Format:     X-pixels to shift input image
Description:        The number of pixels in X by which to shift
                    the current input image relative to the
                    output grid. Ignored unless useoffsets has
                    been set

Parameter Name:     DRS VIRYOFF
Class:              header
Context:            PROCESS
Type:               double
Value Format:       %f
Unit:
Comment Format:     Y-pixels to shift input image
Description:        The number of pixels in Y by which to shift
                    the current input image relative to the
                    output grid. Ignored unless useoffsets has
                    been set

Parameter Name:     DRS VXXXXX
Class:              header
Context:            PROCESS
Type:               string
Value Format:       %s
Unit:
Comment Format:     one input of this combination
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 LINCOR
Class:            header
Context:          PROCESS
Type:             string
Value Format:     %s
Unit:
Comment Format:   linearity channel table
Description:      The name of the linearity channel table specified
                  in lchntab

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 BPMIN
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 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

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).
```

12 Appendix: Raw FITS Header

```
SIMPLE  =                    T / Standard FITS (NOST-100-2.0)
NAXIS   =                    0 / number of axes of data array
BITPIX  =                    8 / number of bits per pixel value
EXTEND  =                    T / FITS file extension may be present
RA      =           123.123457 / 00:00:00.123 RA of telescope
DEC     =           -12.123457 / -00:00:00.12 Dec of telescope
RADECSYS= 'ICRS    '           / Name of celestial reference frame
EQUINOX =               2000.0 / Equinox of celestial reference frame.
ORIGIN  = 'ESO     '           / European Southern Observatory
TELESCOP= 'ESO-VISTA'          / ESO <TEL>
INSTRUME= 'VIRCAM  '           / Instrument used
OBJECT  = 'Sirius  '           / Target description
IMAGETYP= 'OBJECT  '           / Exposure type
AIRMASS =              1.12346 / Averaged airmass
DATE    = '2004-12-13T12:31:46.000' / Date this file was written
DATE-OBS= '2004-12-25T09:00:00.123' / UTC date at start of exposure.
UTC     =            86399.123 / 00:00:00.123 UTC s at start since midnight
REQTIME =                5.000 / Requested integration time
EXPTIME =                5.123 / Actual integration time
LST     =            80000.123 / 00:00:00.123 LST seconds since midnight
MJD-OBS =       54321.12345678 / Modified Julian Date at start
OBSERVER= 'SERVICE '           / Name of observer
PI-COI  = 'J Lewis '           / Name(s) of proposer(s)
COMMENT General comment
HISTORY Historical Fact
ESO-LOG
ORIGFILE= 'VIRCAM_Ima.1.fits'  / Original File Name
ARCFILE = 'VIRCAM.2006-03-05T07:25:0.000.fits      ' / Archive File name
CHECKSUM= 'Pd3jPc3hPc3h'       / ASCII 1s-complement checksum
RECIPE  = 'QUICK_LOOK'         / Data-reduction recipe to be used
OFFSTNUM=                 1234 / Value of first OBSNUM in current tile sequence
OBSNUM  =             12345678 / Observation Number
GRPNUM  =                  666 / Group number applied to all members
GRPMEM  =                    T / Group membership
STANDARD=                    F / Standard-star observation
NOFFSETS=                    6 / Number of offset positions in a field
OFFSET_I=                    2 / Serial Number of offset
NJITTER =                    6 / Number of positions in a tel jitter pattern
JITTRNUM=                 1236 / Value of first OBSNUM in current jitter sequenc
JITTER_I=                    3 / Serial number of this tel jitter pattern
JITTER_X=                3.330 / X offset in jitter pattern
JITTER_Y=                0.000 / Y offset in jitter pattern
NUSTEP  =                    4 / Number of positions in microstep pattern
USTEPNUM=                 1237 / Value of first OBSNUM in current microstep sequ
USTEP_I =                    1 / Serial number of microstep pattern
USTEP_X =                1.123 / X offset in microstep pattern
USTEP_Y =                1.123 / Y offset in microstep pattern
HIERARCH ESO DPR DID         = 'ESO-VLT-DIC.DPR-1.8' / DPR Dictionary
HIERARCH ESO DPR CATG        = 'SCIENCE                         ' / Observation ca
HIERARCH ESO DPR TYPE        = 'OBJECT                          ' / Observation ty
HIERARCH ESO DPR TECH        = 'IMAGE                           ' / Observation te
```

```
HIERARCH ESO OBS DID         = 'ESO-VLT-DIC.OBS' / OBS Dictionary
HIERARCH ESO OBS ID          =          666    / Observation block ID
HIERARCH ESO OBS NAME        = 'deep-tile                       ' / OB name
HIERARCH ESO OBS GRP         = 'ABCD    '      / linked blocks
HIERARCH ESO OBS OBSERVER    = 'Bunclark                        ' / Observer Nam
HIERARCH ESO OBS PI-COI ID   =          162    / ESO internal PI-COI ID
HIERARCH ESO OBS PI-COI NAME = 'Lewis                           ' / PI-COI name
HIERARCH ESO OBS PROG ID     = '68.A-0281(A)        ' / ESO program identificati
HIERARCH ESO OBS TPLNO       =            2    / Template number within OB
HIERARCH ESO OBS TARG NAME   = 'South Pole                      ' / OB target na
HIERARCH ESO OBS START       = '2006-03-05T07:20:00.123' / OB start time
HIERARCH ESO OBS EXECTIME    =            0    / Expected execution time
HIERARCH ESO TPL PRESEQ      = 'VIRCAM_img_obs_paw.seq' / Sequencer script
HIERARCH ESO TPL START       = '2006-03-05T07:20:00.123' / TPL start time
HIERARCH ESO TPL DID         = 'ESO-VLT-DIC.TPL-1.9           ' / Data dictionar
HIERARCH ESO TPL ID          = 'VIRCAM_img_obs_paw                          '
HIERARCH ESO TPL NAME        = 'VIRCAM Jittered pawprint sequence           '
HIERARCH ESO TPL NEXP        =            6    / Number of exposures within temp
HIERARCH ESO TPL EXPNO       =            2    / Exposure number within template
HIERARCH ESO TPL VERSION     = '@(#) $Revision: 1.5 $' / Version of the template
HIERARCH ESO TEL FOCU LEN       =        4.120 / Focal length (m)
HIERARCH ESO TEL FOCU SCALE     =       24.000 / Focal scale (arcsec/mm)
HIERARCH ESO TEL FOCU VALUE     =    12345.120 / M2 setting (mm)
HIERARCH ESO TEL PARANG END     =       45.000 / Parallactic angle at end (deg)
HIERARCH ESO TEL PARANG START   =       47.000 / Parallactic angle at start (deg
HIERARCH ESO TEL AIRM END       =        1.001 / Airmass at end
HIERARCH ESO TEL AIRM START     =        1.002 / Airmass at start
HIERARCH ESO TEL TRAK STATUS    = 'ON       ' / Tracking status
HIERARCH ESO TEL TRAK RATEA     =     0.000000 / Tracking rate in RA (arcsec/sec
HIERARCH ESO TEL TRAK RATED     =     0.000000 / Tracking rate in DEC (arcsec/se
HIERARCH ESO TEL DOME STATUS    = 'FULLY-OPEN' / Dome status
HIERARCH ESO ADA GUID STATUS    = 'ON       ' / Status of autoguider
HIERARCH ESO ADA GUID RA        =   180.000000 / 00:00:00.123 Guide star RA J200
HIERARCH ESO ADA GUID DEC       =    -45.00000 / %DEGREE Guide star DEC J2000
HIERARCH ESO ADA POSANG         =     33.00000 / Position angle at start
HIERARCH ESO ADA ABSROT START   =      2.00000 / Abs rot angle at exp start (deg
HIERARCH ESO TEL ID             = 'v 3.45                          ' / TCS version
HIERARCH ESO TEL DID            = 'ESO-VLT-DIC.TCS-1.33            ' / Data dictio
HIERARCH ESO TEL DATE           = '2006-05-03' / TCS installation date
HIERARCH ESO ADA ABSROT END     =      3.00000 / Abs rot angle at exp end (deg)
HIERARCH ESO ADA ABSROT PPOS    = 'posit'      / sign of probe position
HIERARCH ESO ADA WFS1 RA        =    12.123457 / RA of WFS star 1
HIERARCH ESO ADA WFS1 DEC       =   -75.987654 / Dec of WFS star 1
HIERARCH ESO ADA WFS2 RA        =    12.123457 / RA of WFS star 2
HIERARCH ESO ADA WFS2 DEC       =   -75.987654 / Dec of WFS star 2
HIERARCH ESO TEL ALT            =       80.000 / Alt angle at start (deg)
HIERARCH ESO TEL AZ             =       10.000 / Az angle at start (deg) S=0,W=9
HIERARCH ESO TEL GEOELEV        =         2335 / Elevation above sea level (m)
HIERARCH ESO TEL GEOLAT         =     -29.2543 / Tel geo latitute (+=North) (deg
HIERARCH ESO TEL GEOLON         =     -70.7346 / Tel geo longitude (+=East) (deg
HIERARCH ESO TEL OPER           = 'Senor Operador                  ' / Telescope O
HIERARCH ESO TEL FOCU ID        = 'CA       ' / Telescope focus station ID
HIERARCH ESO TEL TH M1 TEMP     =         8.12 / M1 superficial temperature
HIERARCH ESO TEL MOON RA        =    10.000000 / 00:00:00.123 RA (J2000) (deg)
HIERARCH ESO TEL AMBI FWHM START=         0.50 / Observatory Seeing queried from
HIERARCH ESO TEL AMBI FWHM END  =         0.70 / Observatory Seeing queried from
HIERARCH ESO TEL AMBI TEMP      =         4.20 / Observatory ambient temperature
HIERARCH ESO TEL AMBI RHUM      =            5 / Observatory ambient relative hu
HIERARCH ESO TEL AMBI WINDDIR   =          340 / Observatory ambient wind direct
HIERARCH ESO TEL AMBI WINDSP    =        15.00 / Observatory ambient wind speed
HIERARCH ESO TEL MOON DEC       =     20.00000 / %DEGREE DEC (J2000) (deg)
HIERARCH ESO TEL ENCL MOONSCR STEP=            1 / Moonscreen positions step
HIERARCH ESO TEL ENCL WINDSCR1 STATE= 'OPEN    ' / Louvre state
HIERARCH ESO TEL ENCL WINDSCR2 STATE= 'UP      ' / up/down slide state
HIERARCH ESO TEL ENCL VENT1 STATE= 'SHUT    '  / Vent 1 door state
HIERARCH ESO TEL ENCL VENT2 STATE= 'HALF    '  / Vent 2 door state
HIERARCH ESO TEL ENCL VENT3 STATE= 'OPEN    '  / Vent 3 door state
HIERARCH ESO TEL M2 LOOP1 STATE = 'CLOSED  '   / Focus-loop switch state
HIERARCH ESO TEL M2 LOOP2 STATE = 'OPEN    '   / Centroiding-loop switch state
HIERARCH ESO TEL M2 LOOP3 STATE = 'CLOSED  '   / Tilt-loop switch state
HIERARCH ESO TEL M2 LOOP4 STATE = 'CLOSED  '   / Astigmatic-loop switch state
HIERARCH ESO TEL M2 LOOP5 STATE = 'CLOSED  '   / Trefoil-loop switch state
HIERARCH ESO TEL M2 CENX        = 1.510000     / X-Centre reading 1
```

```
HIERARCH ESO TEL M2 CENY        = 1.520000     / Y-Centre reading 2
HIERARCH ESO TEL M2 TILTX       = 1.530000     / X-tilt reading 3
HIERARCH ESO TEL M2 TILTY       = 1.540000     / Y-tilt reading 4
HIERARCH ESO TEL M1 ACTUATORFAILED=            1 / Number of failed actuator
HIERARCH ESO TEL ENCL FFLAMP1 ID= '123     '   / Dim tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP1 NAME= 'VIS_DOM_DIM' / Dim tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP1 STATE= 'OFF     ' / ON/OFF state of flat lamp 1
HIERARCH ESO TEL ENCL FFLAMP2 ID= '234     '   / Bright tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP2 NAME= 'VIS_DOM_BRIGHT' / Bright tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP2 STATE= 'ON      ' / ON/OFF state of flat lamp 2
HIERARCH ESO TEL ENCL FFLAMP3 ID= '345     '   / Halogen lamp pair
HIERARCH ESO TEL ENCL FFLAMP3 NAME= 'VIS_DOM_HALOGEN' / Dim tungsten lamp pair
HIERARCH ESO TEL ENCL FFLAMP3 STATE= 'OFF     ' / ON/OFF state of flat lamp 3
HIERARCH ESO INS THERMAL ENABLE=            T  / If T, enable thermal control lo
HIERARCH ESO INS THERMAL DET TARGET=       130.00 / Detector target temperature
HIERARCH ESO INS THERMAL WIN DELTA=          0.0 / Window target temp wrt ambien
HIERARCH ESO INS THERMAL TUB DELTA=          0.0 / Tube target temp wrt ambient
HIERARCH ESO INS ID          = 'VIRCAM                        ' / Instrument ID
HIERARCH ESO INS DID         = 'ESO-VLT-DIC.VIRCAM_ICS        ' / Data dictionar
HIERARCH ESO INS OPER        = '                              ' / Instrument ope
HIERARCH ESO INS SWSIM       = 'UNKNOWN        ' / Software simulation
HIERARCH ESO INS MODE        = 'IMAGE     '    / Instrument mode
HIERARCH ESO INS PATH        = 'UNKNOWN   '    / Optical path
HIERARCH ESO INS FILT SWSIM =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS FILT STOFF =            0    / Offset [steps] to be applied
HIERARCH ESO INS FILT USESW =      UNKNOWN    / If T, in-position switch is use
HIERARCH ESO INS FILT IDi   = 'UNKNOWN   '    / Filter unique id
HIERARCH ESO INS FILT NAMEi = 'UNKNOWN        ' / Filter name
HIERARCH ESO INS FILT FOCUSi=        1.235    / Filter focus offset [m]
HIERARCH ESO INS FILT DENSITYi=          1.2  / Filter optical density
HIERARCH ESO INS FILT NO    =            0    / Filter wheel position index
HIERARCH ESO INS FILT DATE  = 'UNKNOWN '      / Filter index time
HIERARCH ESO INS FILT ERROR =            0    / Last filter wheel error [Enc]
HIERARCH ESO INS HB DEVNAME = 'UNKNOWN            ' / Name of the ICS device.
HIERARCH ESO INS HB DEVDESC = 'UNKNOWN            ' / Description of the ICS de
HIERARCH ESO INS HB LCUID   =            0    / ID of the LCU managing the devi
HIERARCH ESO INS HB SWSIM   =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS HB FREQUENCY=          1.2   / Square wave frequency.
HIERARCH ESO INS HB PIN     =            0    / Output pin.
HIERARCH ESO INS SENSORi SWSIM=                / If T, function software simulat
HIERARCH ESO INS LSMi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS LSMi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS LSCi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS LSCi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS LSCi SETPi  =         1.23    / Set-point.
HIERARCH ESO INS VACi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS VACi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS CCCi SWSIM  =      UNKNOWN    / If T, function software simulat
HIERARCH ESO INS CCCi OK     =      UNKNOWN    / If T, controller was operationa
HIERARCH ESO INS SENSi ID    = 'UNKNOWN   '    / Sensor type
HIERARCH ESO INS SENSi NAME  = 'UNKNOWN        ' / Sensor name
HIERARCH ESO INS SENSi VAL   =        1.235    / Sensor value
HIERARCH ESO INS SENSi STAT  = 'UNKNOWN '      / Sensor string value
HIERARCH ESO INS SENSi MIN   =        1.235    / Minimum value
HIERARCH ESO INS SENSi MAX   =        1.235    / Maximum value
HIERARCH ESO INS SENSi MEAN  =        1.235    / Average value
HIERARCH ESO INS SENSi RMS   =        1.235    / RMS of samples over exposure
HIERARCH ESO INS SENSi TMMEAN=        0.000    / Time weighted average
HIERARCH ESO INS SENSi GRAD  =        1.235    / Linear regression slope
HIERARCH ESO INS SENSi LRCONST=        0.000   / Linear regression constant
HIERARCH ESO INS SENSi LRRMS =        1.235    / Linear regression RMS
HIERARCH ESO INS SENSi DETCOEF=        0.000   / Lin. reg. determination coeff.
HIERARCH ESO INS SENSi UNITi = UNKNOWN         / Sensor unit
HIERARCH ESO INS PRESi ID    = 'UNKNOWN   '    / Pressure sensor type.
HIERARCH ESO INS PRESi NAME  = 'UNKNOWN        ' / Pressure sensor name.
HIERARCH ESO INS PRESi VAL   =        1.235    / Pressure.
HIERARCH ESO INS PRESi MIN   =        1.235    / Minimum pressure.
HIERARCH ESO INS PRESi MAX   =        1.235    / Maximum pressure.
HIERARCH ESO INS PRESi MEAN  =        1.235    / Average pressure.
HIERARCH ESO INS PRESi RMS   =        1.235    / RMS of samples over exposure.
HIERARCH ESO INS PRESi TMMEAN=        0.000    / Time weighted average.
HIERARCH ESO INS PRESi GRAD  =        1.235    / Linear regression slope.
HIERARCH ESO INS PRESi LRCONST=        0.000   / Linear regression constant.
```

```
HIERARCH ESO INS PRESi LRRMS =        1.235    / Linear regression RMS.
HIERARCH ESO INS PRESi DETCOEF=        0.000   / Lin. reg. determination coeff..
HIERARCH ESO INS PRESi UNITi = UNKNOWN         / Pressure unit.
HIERARCH ESO INS SW1 ID      =    'UNKNOWN'    / Switch ID
HIERARCH ESO INS SW1 NAME    = 'Filter in-position switch' / Switch name
HIERARCH ESO INS SW1 STATUS  =     'CLOSED'    / Switch status
HIERARCH ESO INS TEMP1 ID       = 'ID1     '   / ID of sensor 1
HIERARCH ESO INS TEMP1 NAME     = 'Ambient temperature' / Location of sensor 1
HIERARCH ESO INS TEMP1 VAL      =      260.100 / Temperature sensor 1 reading
HIERARCH ESO INS TEMP1 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP1 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP1 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP1 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP1 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP1 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP1 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP1 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP1 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP1 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP2 ID       = 'ID2     '   / ID of sensor 2
HIERARCH ESO INS TEMP2 NAME     = 'Cryostat window temperature' / Location of se
HIERARCH ESO INS TEMP2 VAL      =      260.100 / Temperature sensor 2 reading
HIERARCH ESO INS TEMP2 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP2 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP2 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP2 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP2 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP2 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP2 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP2 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP2 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP2 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP3 ID       = 'ID3     '   / ID of sensor 3
HIERARCH ESO INS TEMP3 NAME     = 'Cryostat tube temperature' / Location of sens
HIERARCH ESO INS TEMP3 VAL      =      260.100 / Temperature sensor 3 reading
HIERARCH ESO INS TEMP3 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP3 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP3 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP3 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP3 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP3 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP3 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP3 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP3 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP3 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP4 ID       = 'ID4     '   / ID of sensor 4
HIERARCH ESO INS TEMP4 NAME     = 'Liquid Nitrogen tank temperature' / Location
HIERARCH ESO INS TEMP4 VAL      =      260.100 / Temperature sensor 4 reading
HIERARCH ESO INS TEMP4 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP4 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP4 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP4 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP4 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP4 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP4 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP4 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP4 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP4 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP5 ID       = 'ID5     '   / ID of sensor 5
HIERARCH ESO INS TEMP5 NAME     = 'Baffle temperature' / Location of sensor 5
HIERARCH ESO INS TEMP5 VAL      =      260.100 / Temperature sensor 5 reading
HIERARCH ESO INS TEMP5 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP5 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP5 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP5 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP5 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP5 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP5 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP5 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP5 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP5 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP6 ID       = 'ID6     '   / ID of sensor 6
HIERARCH ESO INS TEMP6 NAME     = 'Lens barrel temperature' / Location of sensor
```

```
HIERARCH ESO INS TEMP6 VAL      =      260.100 / Temperature sensor 6 reading
HIERARCH ESO INS TEMP6 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP6 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP6 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP6 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP6 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP6 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP6 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP6 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP6 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP6 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP7 ID       = 'ID7     '   / ID of sensor 7
HIERARCH ESO INS TEMP7 NAME     = 'Filter wheel shield temperature' / Location o
HIERARCH ESO INS TEMP7 VAL      =      260.100 / Temperature sensor 7 reading
HIERARCH ESO INS TEMP7 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP7 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP7 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP7 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP7 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP7 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP7 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP7 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP7 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP7 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP8 ID       = 'ID8     '   / ID of sensor 8
HIERARCH ESO INS TEMP8 NAME     = 'Filter wheel hub temperature' / Location of s
HIERARCH ESO INS TEMP8 VAL      =      260.100 / Temperature sensor 8 reading
HIERARCH ESO INS TEMP8 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP8 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP8 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP8 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP8 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP8 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP8 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP8 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP8 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP8 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP9 ID       = 'ID9     '   / ID of sensor 9
HIERARCH ESO INS TEMP9 NAME     = 'Closed cycle cooler 1 1st stage' / Location o
HIERARCH ESO INS TEMP9 VAL      =      260.100 / Temperature sensor 9 reading
HIERARCH ESO INS TEMP9 MIN      =      260.100 / Minimum value
HIERARCH ESO INS TEMP9 MAX      =      260.100 / Maximum value
HIERARCH ESO INS TEMP9 MEAN     =      260.100 / Average value
HIERARCH ESO INS TEMP9 RMS      =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP9 TMMEAN   =      260.100 / Time weighted average
HIERARCH ESO INS TEMP9 GRAD     =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP9 LRCONST  =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP9 LRRMS    =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP9 DETCOEF  =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP9 UNIT     = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP10 ID      = 'ID10    '   / ID of sensor 10
HIERARCH ESO INS TEMP10 NAME    = 'Closed cycle cooler 1 2nd stage' / Location o
HIERARCH ESO INS TEMP10 VAL     =      260.100 / Temperature sensor 10 reading
HIERARCH ESO INS TEMP10 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP10 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP10 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP10 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP10 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP10 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP10 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP10 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP10 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP10 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP11 ID      = 'ID11    '   / ID of sensor 11
HIERARCH ESO INS TEMP11 NAME    = 'Closed cycle cooler 2 1st stage' / Location o
HIERARCH ESO INS TEMP11 VAL     =      260.100 / Temperature sensor 11 reading
HIERARCH ESO INS TEMP11 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP11 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP11 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP11 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP11 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP11 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP11 LRCONST =      120.120 / Linear regression constant
```

```
HIERARCH ESO INS TEMP11 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP11 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP11 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP12 ID      = 'ID12    '   / ID of sensor 12
HIERARCH ESO INS TEMP12 NAME    = 'Closed cycle cooler 2 2nd stage' / Location o
HIERARCH ESO INS TEMP12 VAL     =      260.100 / Temperature sensor 12 reading
HIERARCH ESO INS TEMP12 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP12 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP12 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP12 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP12 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP12 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP12 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP12 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP12 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP12 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP13 ID      = 'ID13    '   / ID of sensor 13
HIERARCH ESO INS TEMP13 NAME    = 'Closed cycle cooler 3 1st stage' / Location o
HIERARCH ESO INS TEMP13 VAL     =      260.100 / Temperature sensor 13 reading
HIERARCH ESO INS TEMP13 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP13 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP13 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP13 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP13 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP13 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP13 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP13 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP13 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP13 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP14 ID      = 'ID14    '   / ID of sensor 14
HIERARCH ESO INS TEMP14 NAME    = 'Closed cycle cooler 3 2nd stage' / Location o
HIERARCH ESO INS TEMP14 VAL     =      260.100 / Temperature sensor 14 reading
HIERARCH ESO INS TEMP14 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP14 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP14 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP14 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP14 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP14 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP14 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP14 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP14 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP14 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP15 ID      = 'ID15    '   / ID of sensor 15
HIERARCH ESO INS TEMP15 NAME    = 'Wavefront sensor PY CCD assembly' / Location
HIERARCH ESO INS TEMP15 VAL     =      260.100 / Temperature sensor 15 reading
HIERARCH ESO INS TEMP15 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP15 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP15 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP15 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP15 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP15 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP15 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP15 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP15 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP15 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP16 ID      = 'ID16    '   / ID of sensor 16
HIERARCH ESO INS TEMP16 NAME    = 'Wavefront sensor NY CCD assembly' / Location
HIERARCH ESO INS TEMP16 VAL     =      260.100 / Temperature sensor 16 reading
HIERARCH ESO INS TEMP16 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP16 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP16 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP16 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP16 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP16 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP16 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP16 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP16 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP16 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP17 ID      = 'ID17    '   / ID of sensor 17
HIERARCH ESO INS TEMP17 NAME    = 'Science detector 1AB' / Location of sensor 17
HIERARCH ESO INS TEMP17 VAL     =      260.100 / Temperature sensor 17 reading
HIERARCH ESO INS TEMP17 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP17 MAX     =      260.100 / Maximum value
```

```
HIERARCH ESO INS TEMP17 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP17 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP17 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP17 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP17 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP17 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP17 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP17 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP18 ID      = 'ID18    '   / ID of sensor 18
HIERARCH ESO INS TEMP18 NAME    = 'Science detector 1CD' / Location of sensor 18
HIERARCH ESO INS TEMP18 VAL     =      260.100 / Temperature sensor 18 reading
HIERARCH ESO INS TEMP18 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP18 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP18 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP18 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP18 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP18 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP18 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP18 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP18 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP18 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP19 ID      = 'ID19    '   / ID of sensor 19
HIERARCH ESO INS TEMP19 NAME    = 'Science detector 2BA' / Location of sensor 19
HIERARCH ESO INS TEMP19 VAL     =      260.100 / Temperature sensor 19 reading
HIERARCH ESO INS TEMP19 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP19 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP19 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP19 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP19 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP19 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP19 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP19 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP19 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP19 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP20 ID      = 'ID20    '   / ID of sensor 20
HIERARCH ESO INS TEMP20 NAME    = 'Science detector 2DC' / Location of sensor 20
HIERARCH ESO INS TEMP20 VAL     =      260.100 / Temperature sensor 20 reading
HIERARCH ESO INS TEMP20 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP20 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP20 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP20 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP20 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP20 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP20 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP20 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP20 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP20 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP21 ID      = 'ID21    '   / ID of sensor 21
HIERARCH ESO INS TEMP21 NAME    = 'Science detector 3AB' / Location of sensor 21
HIERARCH ESO INS TEMP21 VAL     =      260.100 / Temperature sensor 21 reading
HIERARCH ESO INS TEMP21 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP21 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP21 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP21 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP21 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP21 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP21 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP21 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP21 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP21 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP22 ID      = 'ID22    '   / ID of sensor 22
HIERARCH ESO INS TEMP22 NAME    = 'Science detector 3CD' / Location of sensor 22
HIERARCH ESO INS TEMP22 VAL     =      260.100 / Temperature sensor 22 reading
HIERARCH ESO INS TEMP22 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP22 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP22 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP22 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP22 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP22 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP22 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP22 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP22 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP22 UNIT    = 'KELVIN'     / Temperature unit
```

```
HIERARCH ESO INS TEMP23 ID      = 'ID23    '   / ID of sensor 23
HIERARCH ESO INS TEMP23 NAME    = 'Science detector 4BA' / Location of sensor 23
HIERARCH ESO INS TEMP23 VAL     =      260.100 / Temperature sensor 23 reading
HIERARCH ESO INS TEMP23 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP23 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP23 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP23 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP23 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP23 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP23 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP23 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP23 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP23 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP24 ID      = 'ID24    '   / ID of sensor 24
HIERARCH ESO INS TEMP24 NAME    = 'Science detector 4DC' / Location of sensor 24
HIERARCH ESO INS TEMP24 VAL     =      260.100 / Temperature sensor 24 reading
HIERARCH ESO INS TEMP24 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP24 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP24 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP24 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP24 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP24 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP24 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP24 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP24 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP24 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP25 ID      = 'ID25    '   / ID of sensor 25
HIERARCH ESO INS TEMP25 NAME    = 'FPA thermal plate' / Location of sensor 25
HIERARCH ESO INS TEMP25 VAL     =      260.100 / Temperature sensor 25 reading
HIERARCH ESO INS TEMP25 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP25 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP25 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP25 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP25 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP25 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP25 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP25 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP25 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP25 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS TEMP26 ID      = 'ID26    '   / ID of sensor 26
HIERARCH ESO INS TEMP26 NAME    = 'WFS plate'  / Location of sensor 26
HIERARCH ESO INS TEMP26 VAL     =      260.100 / Temperature sensor 26 reading
HIERARCH ESO INS TEMP26 MIN     =      260.100 / Minimum value
HIERARCH ESO INS TEMP26 MAX     =      260.100 / Maximum value
HIERARCH ESO INS TEMP26 MEAN    =      260.100 / Average value
HIERARCH ESO INS TEMP26 RMS     =      260.100 / RMS of amples over exposure
HIERARCH ESO INS TEMP26 TMMEAN  =      260.100 / Time weighted average
HIERARCH ESO INS TEMP26 GRAD    =        0.010 / Linear regression slope
HIERARCH ESO INS TEMP26 LRCONST =      120.120 / Linear regression constant
HIERARCH ESO INS TEMP26 LRRMS   =      260.100 / Linear regression RMS
HIERARCH ESO INS TEMP26 DETCOEF =      260.100 / Lin. reg. determination coeff
HIERARCH ESO INS TEMP26 UNIT    = 'KELVIN'     / Temperature unit
HIERARCH ESO INS HOWFS DATE     = '2006-03-05T01:02:03.123' / Time of new coefs
END
XTENSION= 'IMAGE   '           / Extension first keyword
NAXIS   =                    2 / number of axes of data array
NAXIS1  =                 2048 / Size of first axis
NAXIS2  =                 2048 / Size of second axis
BITPIX  =                   32 / number of bits per pixel value
EXTNAME = 'WIN1.CHIP1.OUT1'    / FITS extension name
EXTVER  =                    1 / Detector index
INHERIT =                    T / Extension inherits primary header
DET_LIVE=                    T / This detector is alive
RADECSYS= 'ICRS    '           / Name of celestial reference frame
EQUINOX =               2000.0 / Equinox of celestial reference frame.
CTYPE1  = 'RA---ZPN'           / Type of celestial axis 1
CTYPE2  = 'DEC--ZPN'           / Type of celestial axis 2
CRPIX1  =              6860.80 / Pixel coordinate of reference in axis 1
CRPIX2  =             -3507.20 / Pixel coordinate of reference in axis 2
CRVAL1  =     270.000000000000 / RA of reference point
CRVAL2  =     -75.000000000000 / Dec of reference point
CD1_1   = -9.444444E-05        / Transformation matrix element
CD1_2   = 0.000000E+00         / Transformation matrix element
```

```
CD2_1   = 0.000000E+00         / Transformation matrix element
CD2_2   = 9.444444E-05         / Transformation matrix element
PV2_1   = 1.000000E+00         / linear term in ZPN
PV2_2   = 0.000000E+00         / quadratic term in ZPN
PV2_3   = 4.200000E+01         / cubic term in ZPN
PV2_4   = 0.000000E+00         / forth-order term in ZPN
PV2_5   = 0.000000E+00         / fifth-order term in ZPN
HIERARCH ESO DET MINDIT      =    1.7726000    / Minimum DIT
HIERARCH ESO DET MODE NAME   = '        '      / DCS Detector Mode
HIERARCH ESO DET MODEi NAME  = '        '      / DCS Detector Mode
HIERARCH ESO DET NC IDIV     =            1    / # of Sub-Divs for R-O
HIERARCH ESO DET NC NSAMPPIX =            1    / # of Samples/Pixel
HIERARCH ESO DET NCORRS      =            0    / Read-Out Mode
HIERARCH ESO DET RSPEED      =            1    / Read-Speed Factor
HIERARCH ESO DET IRACE ADCi NAME= 'VIRGO   '   / Name for ADC Board
HIERARCH ESO DET IRACE ADCi HEADER=            1 / Header of ADC Board
HIERARCH ESO DET IRACE ADCi ENABLE=            1 / Enable ADC Board (0/1)
HIERARCH ESO DET IRACE ADCi FILTERi=            1 / ADC Filter Adjustment
HIERARCH ESO DET IRACE ADCi DELAY=           15 / ADC Delay Adjustment
HIERARCH ESO DET NCORRS NAME = 'DblCor  '      / Read-Out Mode Name
HIERARCH ESO DET NDIT        =           10    / # of Sub-Integrations
HIERARCH ESO DET NDITSKIP    =            0    / DITs skipped at 1st.INT
HIERARCH ESO DET NDSAMPLES   =            0    / # of Non-Dest. Samples
HIERARCH ESO DET NDSKIP      =            0    / Samples skipped per DIT
HIERARCH ESO DET RSPEEDADD   =            0    / Read-Speed Add
HIERARCH ESO DET VOLTi CLKHINMi= '3.3     '    / Name of High Clock
HIERARCH ESO DET VOLTi CLKHITi=       0.0000   / Tel Value High Clock
HIERARCH ESO DET VOLTi CLKHIi=       0.0000    / Set Value High Clock
HIERARCH ESO DET VOLTi CLKLONMi= '        '    / Name of Low Clock
HIERARCH ESO DET IRACE SEQCONT=            F   / Sequencer Cont. Mode
HIERARCH ESO DET IRACE SEQINT=                 / Sequencer Intr. at Stop
HIERARCH ESO DET VOLTi CLKLOTi=       0.0000   / Tel Value Low Clock
HIERARCH ESO DET VOLTi DCNMi = 'FRED    '      / Name of DC Voltage
HIERARCH ESO DET VOLTi DCTAi =       4.9000    / Tel Value 1 for DC
HIERARCH ESO DET VOLTi CLKLOi=       0.1000    / Set Value Low Clock
HIERARCH ESO DET VOLTi DCi   =       0.0000    / Set Value DC Voltage
HIERARCH ESO DET CHIP TYPE   = 'RAYTHEON'      / The Type of Det Chip
HIERARCH ESO DET CON OPMODE  = 'SIMULATION'    / Operational Mode
HIERARCH ESO DET FRAM TYPE   = 'DIT     '      / Frame type
EXPTIME =           20.1234500 / Integration time
ORIGFILE= '                                    ' / Original File Name
HIERARCH ESO DET CHOP CYCSKIP=            0    / # of Chop Cycles to Skip
HIERARCH ESO DET CHOP NCYCLES=            0    / # of Chop Cycles
HIERARCH ESO DET CHOP ST     =                 / Chopping On/Off
HIERARCH ESO DET CHOP FREQ   = 0.000000        / Chopping Frequency
HIERARCH ESO DET CHIP ID     = 'VM301-S/N-022' / Detector ID
HIERARCH ESO DET CHIP NAME   = 'VIRGO   '      / Detector name
HIERARCH ESO DET CHIP NX     =         2048    / Pixels in X
HIERARCH ESO DET CHIP NY     =         2048    / Pixels in Y
HIERARCH ESO DET CHIP PXSPACE= 2.000e-05       / Pixel-Pixel Spacing
HIERARCH ESO DET EXP NO      =         9876    / Exposure Number
HIERARCH ESO DET FRAM UTC    = '2006-03-05T10:11:12' / Time Recv Frame
HIERARCH ESO DET FRAM NO     =            2    / Frame number
HIERARCH ESO DET VOLTi DCTBi =       0.0000    / Tel Value 2 for DC
HIERARCH ESO DET WIN NX      =         2048    / # of Pixels in X
HIERARCH ESO DET DID         = '        '      / Dictionary Name and Revision
HIERARCH ESO DET DIT         =    0.0000000    / Integration Time
HIERARCH ESO DET DITDELAY    =        0.000    / Pause Between DITs
HIERARCH ESO DET EXP UTC     = '2006-03-05T10:11:12' / File Creation Time
HIERARCH ESO DET EXP NAME    = '        '      / Exposure Name
HIERARCH ESO DET WIN NY      =         2048    / # of Pixels in Y
HIERARCH ESO DET WIN STARTX  = 1.000000        / Lower Left X Ref
HIERARCH ESO DET WIN STARTY  = 1.000000        / Lower left Y Ref
HIERARCH ESO DET WIN TYPE    =            0    / Win-Type
END
```

_o☺o_