Quality Control and Data Flow Operations of the survey instrument VIRCAM

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ABSTRACT

VIRCAM is the wide field infrared camera of the VISTA survey telescope on Paranal. VIRCAM, operated by ESO since Oct. 2009, is equipped with 16 detectors and produces on average 150 Gigabytes of data per night. In the following article we describe the back-end data flow operations and in particular the quality control procedures which are applied to ESO VIRCAM data.

Keywords: surveys, calibrations, quality control, scoring

1. INTRODUCTION

VISTA[1] (Visible and Infrared Survey Telescope for Astronomy) is a 4-m class wide-field survey telescope equipped with the IR camera VIRCAM and located at ESO's Cerro Paranal Observatory in Chile. It is dedicated to public surveys. VIRCAM started early-science operations in October 2009. The official start of operations was in April 2010. For the next five years it is primarily dedicated to six near infrared imaging surveys. VIRCAM is equipped with sixteen 2048×2048 pixel (67 Mpixels) Raytheon detectors covering about 0.6 deg^2 of the sky per single pointing. VIRCAM produces on average about 600 calibration and science frames per night, corresponding to 150 GB of (uncompressed) data. The Data Processing and Quality Control Group (QC Garching) is in charge of processing all calibration data from VIRCAM, using the VIRCAM data reduction pipeline.[2] For quality control purpose and for later reference, a certain fraction of science data (10% or more) is also processed at ESO. VIRCAM is fully integrated in the VLT dataflow operations. In the following we describe the system infrastructure, the quality control procedures and the scoring based of the derived quality control parameters. Finally we demonstrate some examples of the powerful QC concepts for diagnostic monitoring and scoring.

2. DATA FLOW OPERATIONS

The VLT dataflow is an integrated concept to operate the Paranal observatory which includes all processes from the observation proposal handling on the front end to the data archiving and science data processing on the back end side. The backend of this process is composed of several components such as the transfer of the data to ESO headquarters, the archiving, the generation of master calibrations data, and the processing of science data to calibrated data products. Furthermore it includes the quality control of the raw and reduced data and

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the delivery of the certified products to the end users. VIRCAM is almost fully integrated in the VLT data flow. All VIRCAM data are handled, as far as possible, in the same manner as data of VLT/I instruments.

The main differences with respect to operations of the other VLT/I instruments are:

- The unprocessed VLT data are transferred online to Garching within hours, while the VIRCAM data are shipped by airmail on USB disks to Garching HQ. The data arrive with a typical delay of 4-11 days. VIRCAM fits data headers and the log files with the quality control parameters as written by the on-line data reduction pipeline are transferred immediately to Garching. As a consequence the QC group at ESO headquarters has to support two different delivery and processing channels: near-realtime mode for VLT/I instruments, and bulk mode for VISTA.
- The VIRCAM data production rate ($\sim$150 GB/night) is the highest among the Paranal instruments. A new dedicated high performance processing facility has been put in operations.
- The sixteen detectors introduce a higher level of data complexity in terms of a high multiplex in the quality control information. New ways to manage the quality control data have been designed and implemented.
- The observing program is composed of six public surveys. This distribution has no direct impact on operations, but the expected homogeneity of the data for the next five years makes it easier to perform quality control, e.g. no support for unusual setups has to be implemented.

3. VIRCAM PROCESSING AND DATAFLOW INFRASTRUCTURE

3.1 Hardware and Software

The VIRCAM data are processed on a dedicated computer cluster[3] composed of twenty dual-core blades and a fiber-channel linked shared file system operated under *Global File System*[*]. The batch job queuing is performed by *CONDOR*[†], while the management of job dependencies, job ranking, including distributed data downloads is managed by ESO software tools. The blade cluster is designed to process the VIRCAM data as well as the data of the upcoming OmegaCAM optical survey instrument.

3.2 Overview of the Data Flow

All VIRCAM science and calibration data are immediately processed after acquisition by a data reduction pipeline[2] on Paranal. This on-line pipeline has limited accuracy and is tuned for quick-look purpose. The reduced data and the derived quality control parameters are used by the Paranal staff to verify if the data are compliant with the user-defined constraint sets. The pipeline logs containing quality control parameters are delivered once per hour to the ESO HQ in Garching for the scoring and trending analysis. The fits data headers of the VIRCAM frames are available immediately in the ESO archive in Garching. The raw pixel data are sent once a week from Paranal to Garching on USB disks, where they are ingested into the ESO archive with about a delay of 4-11 days.

In case of the public surveys with VIRCAM the final production of survey products (science images and catalogs) is delegated to the public survey teams. For the further steps all raw data are forwarded to the Cambridge Astronomy Survey Unit (CASU) to reduce frames to the paw print level. In a further step the Wide Field Astronomy Unit (WFAU) in Edinburgh generates mosaics and provides survey specific data reduction and analysis steps. WFAU provides then these products to the corresponding survey teams which analyze the images and catalogs related to the scientific content. Final products consisting of calibrated catalogs and images will be ingested into the ESO archive.

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[*] `http://sources.redhat.com/cluster/gfs/`

[†] `http://www.cs.wisc.edu/condor/`

4. VIRCAM QUALITY CONTROL SERVICES

The main Quality Control services in Garching can be divided into three areas:

- checking the completeness of calibrations according to the calibration plan
- processing raw calibration and, (a selected subset of) science frames to generate master calibrations and science products
- quality control of the data reduction pipeline products, scoring, and trending of extracted quality characteristics

4.1 Calibration Completeness

The calibration completeness check for all VLT/I instruments is performed by QC Garching according to the respective instrument calibration plans. VIRCAM is included in this scheme. The completeness checks include darks, twilight flats, and photometric standard star observations within a configurable time range. The results of the completeness checks are provided online via the calChecker tool[‡].

4.2 Data Processing at ESO HQ

Typically once a week the pixel data of about seven nights worth of VIRCAM observations arrive at ESO HQ and are ingested into the archive. As soon as all the frames of an observing night are ingested, frames are processed using the VIRCAM data reduction pipeline.[2] Thereafter, the products are analyzed by the QC jobs, which generate QC reports in graphical form, calculate and store additional QC parameters not provided by the pipeline, and perform the scoring.

The processing and analysis covers all VIRCAM calibrations. About 5-20% of the VIRCAM science observations are selected for processing to perform spot checks. The science product images and catalogs are ingested into the archive. They serve as reference products to be compared with the final science products delivered by the public survey teams to the ESO archive.

The processing environment forks sixteen processing jobs, one job per detector, and submits them to the batch queuing system. After the sixteen products are generated, they are merged to a single product frame.

The processing of calibration data, including download time, takes about 3 hours for a single night worth of data. The processing of all calibrations acquired within the time range of seven days, typically covered by a delivered disk, is performed within a 12-18 hours. The processing of a single observing night of science data, including download time, corresponding to 200 submitted jobs, takes about 8 hours.

4.3 Extracting Quality Control Parameters

The QC jobs triggered for each processing job extract quality information from the raw and processed frames. In the case that a required algorithm has not yet been implemented in the data reduction pipeline the QC job computes them from the raw or product frames. QC parameters are derived individually for each detector. The sixteen instances of the QC parameters are ingested into the QC database[§].

5. SCORING

All QC parameters measuring critical subsystems of VIRCAM are compared against thresholds to check for outliers. This process is called scoring[4,5]. The currently scored QC parameters are given in Table 1. The scoring flags are stored in a database.

For instruments with one detector, or with one detector per instrument mode, trending and scoring is performed by Health Check plots that monitor a single QC parameter. The next step of complexity, in terms of

‡ http://www.eso.org/qc/VIRCAM/reports/CAL/calChecker_VIRCAM.html

§ http://archive.eso.org/bin/qc1_cgi

Table 1. Scored QC parameters for VIRCAM.

detector	RON, dark level, dark current, RMS of stripes, reset values
detector	gain, linearity, lamp stability, number of bad pixel
twilight flats	RMS, flux levels, flux sequence
standard stars	photometric zeropoint, image quality, point source ellipticity, relative image quality
science	image quality, point source ellipticity

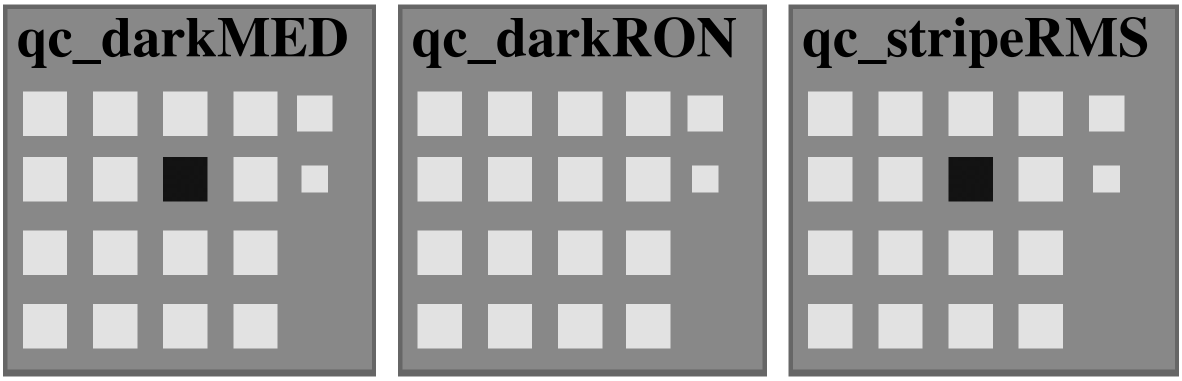

Figure 1. Score report of a master dark. Three QC parameters are scored for each detector individually: the dark median level (qc_darkMED), the read-out-noise (qc_darkRON), and the noise due to the horizontal stripe pattern (qc_stripeRMS). The layout of the 4×4 score matrix corresponds to the arrangement of the sixteen chips. The particular example shows the dark median level parameter and the stripe parameter of detector #11 (counted from lower left to upper right) beyond thresholds. The two additional small squares on the right hand side of each 4×4 score matrix shows the scoring of the aggregate AVERAGE and RMS.

managing QC, occurs for instruments with a detector mosaic detector. In addition of monitoring the QC parameters for each detector separately, aggregate QC parameters, as the average and the RMS of the QC parameter over the detectors have been introduced and put into operations since several years for instruments with up to four detectors. The underlying assumption is:

- Variations that occur in all N detectors in phase can be monitored by aggregate parameter AVERAGE/(average of N detector values).
- Variations of one or several individual detectors can be monitored by the detector RMS values.

For VIRCAM, hosting 16 detectors, the scoring of aggregate values alone is not sufficient, in particular when variations in aggregate RMS values show up and the originating detector(s) have to be identified. For this reason two levels of scoring have been implemented. Only the detector average and detector RMS QC parameters are scored within the hierarchical scoring system. This means that these scores contribute to the scoring value of the data raw type, and propagate to the total score of the instrument. The QC parameters of the individual detectors are scored as well, with each detector having its own threshold. The individual scoring flags do not contribute to the total instrument score; instead they are available as information on demand to the QC scientist in case further investigation is required (see Fig. 1) and they are displayed on the Health Check plots.

Due to this complexity, the Health Check plot for any VIRCAM QC parameter is composed of several plots, displayed in Figs. 2, 3, and 4. The aggregate AVERAGE is monitored in Fig. 2 that shows also the thresholds

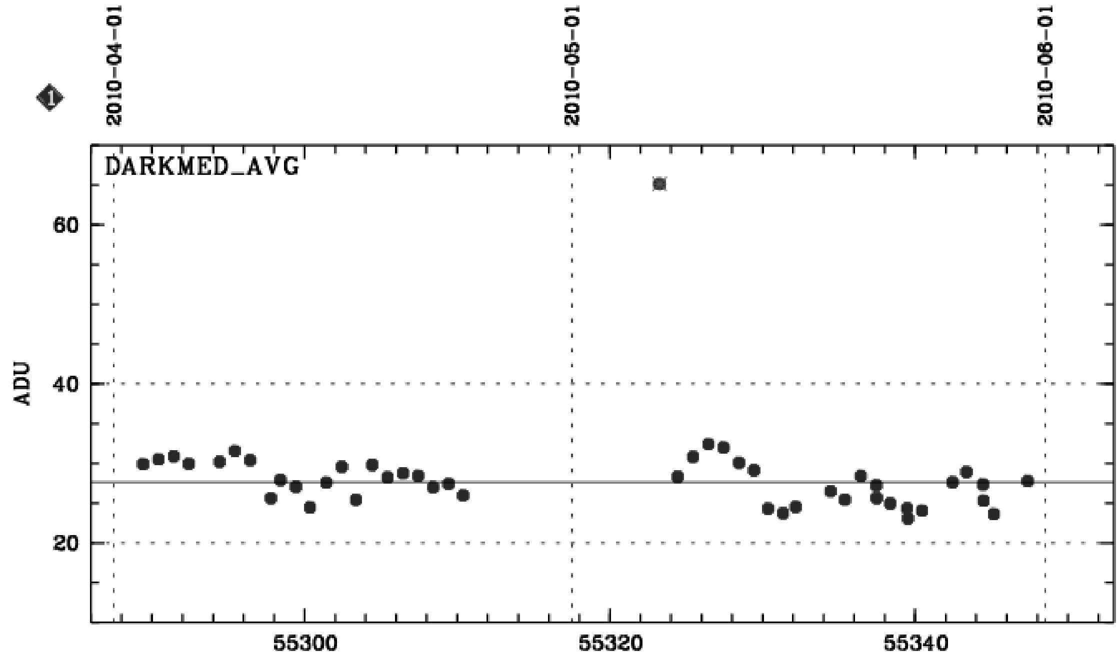

Figure 2. Health Check report for the dark median QC parameter with setup DIT=120 sec. The aggregate AVERAGE over sixteen detector values covering two months is shown. The plots show the situation three weeks after an intervention, (the gap in data points before and after MJD =55320). The first set of darks after the intervention was taken during the cool-down period of the instrument and produced a prominent outlier. The broken lines mark the configured thresholds against which the QC parameters are scored.

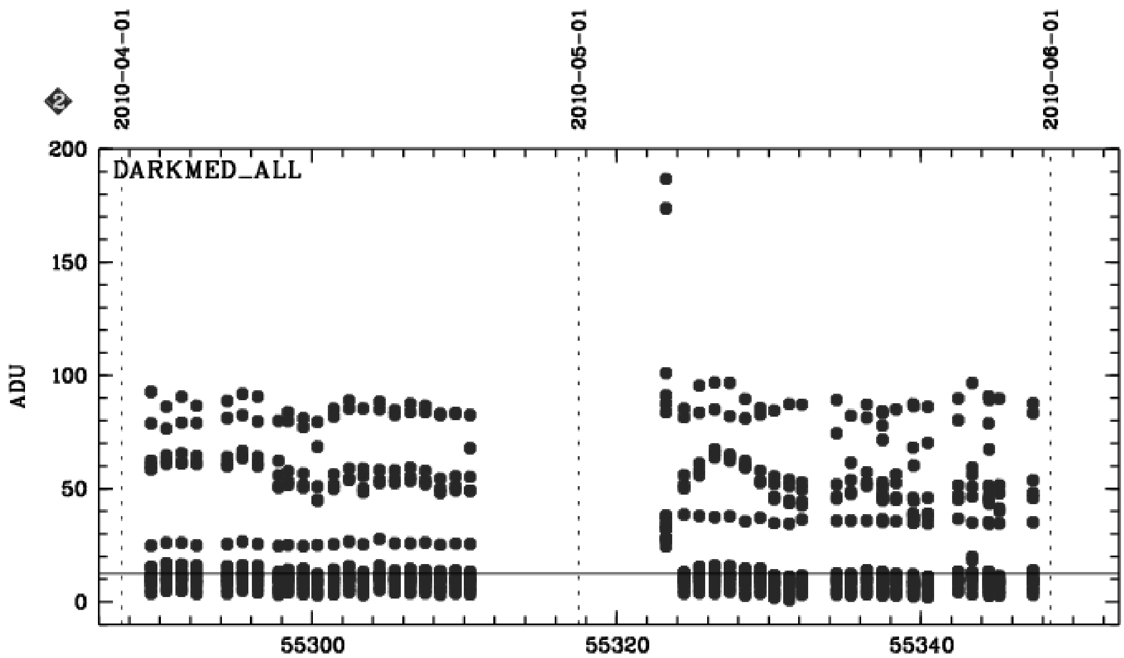

Figure 3. Health Check report for the dark median QC parameter with setup DIT=120 sec. The sixteen individual detector values are shown.

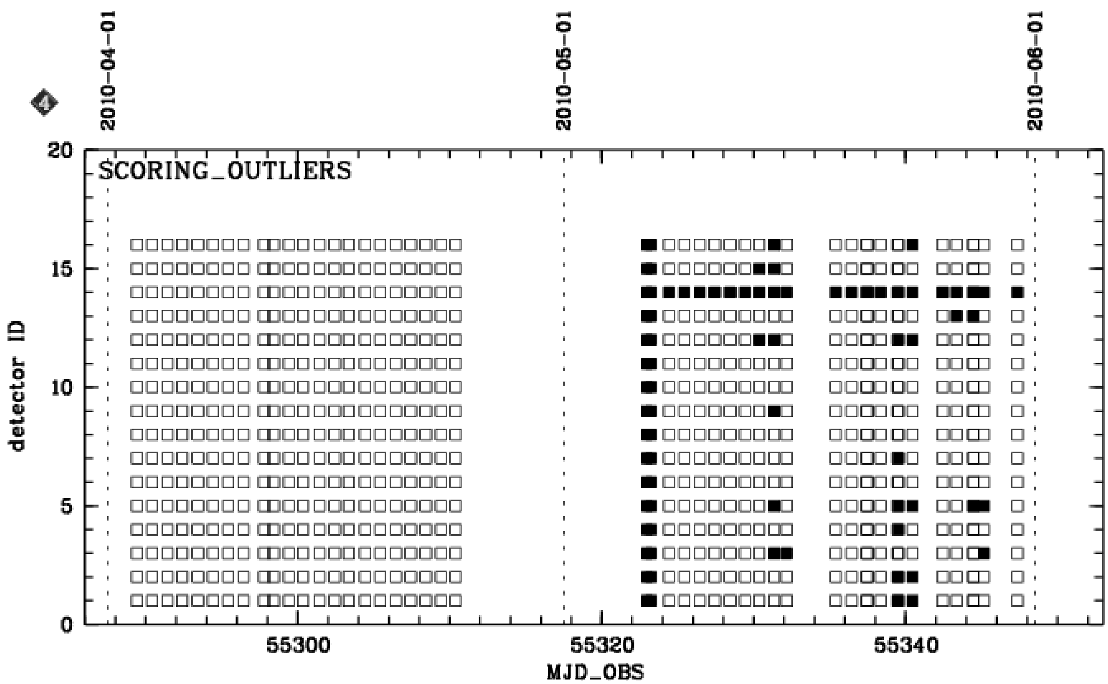

Figure 4. Health Check report for the dark median QC parameter with setup DIT=120 sec. Scoring values of all sixteen QC parameters. Empty boxes mark values within the thresholds. Outliers are marked by filled symbols. Note that all detectors have individual thresholds based on the long term individual trend of the dark median value. Indeed, in the lower figure one can appreciate that their scores are all out of thresholds on that day (MJD 55323). The plot furthermore shows that after the intervention, the dark level of detector #14 has constantly been beyond the thresholds valid before the intervention.

and the long-term median value. Outliers in this plot contribute to the total score of the instrument. Thresholds are either defined through statistics or through specifications.

The behavior of the sixteen single detector values is displayed in two additional plots, each one showing a different aspect. The first of them (see Fig. 3, for a complement example of Fig. 2), shows the trending of the sixteen single parameters to provide an overview on their individual behavior.

The second plot shows the scores of the individual QC parameters in Fig. 4. Each column shows the sixteen score values, either black symbols for outliers or empty symbols for values within thresholds. Note that all detectors have individual thresholds based on the long term individual trend of the dark median value. The example in Fig. 4 shows the situation about three weeks after an intervention. The first dark after the intervention was taken during the cooling of the instrument, hence all sixteen instances are flagged black. After the intervention most detectors show a new dark median level, sporadically exceeding the pre-intervention thresholds and resulting in a black score. The example identifies the dark median value of detector #14 constantly being beyond the limits adjusted before the intervention.

All Health Check plots are updated at least once a day for every scored QC parameter. The delivery of new QC parameters from the online pipeline on Paranal or the ingestion of newly extracted QC parameters from the processed products in Garching both trigger an update of the Health Check plots. Life examples for VIRCAM Health Check plots are available online¶.

As a general rule, scoring is only applied to final QC parameters derived with the instrument pipeline at ESO HQ, not to the preliminary QC parameters derived on-site. This is optimal for the data of VLT/I arriving within

¶http://www.eso.org/observing/dfo/quality/VIRCAM/reports/HEALTH

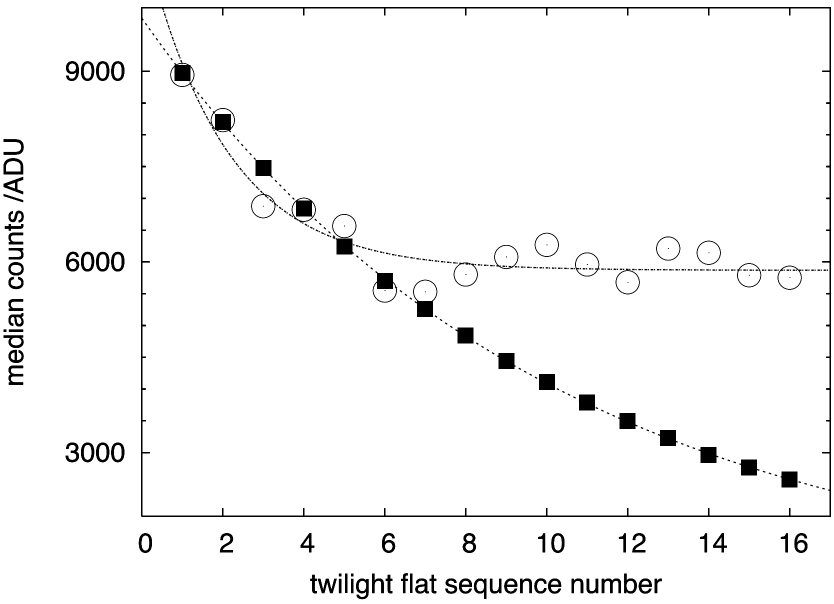

Figure 5. Raw frame fluxes of two twilight flat sequences showing the darkening of the evening sky and the exponential fit. The sequence with the black symbols is well fit by an exponential law. The raw flux sequence marked with open circles is contaminated by thin cirrus. The sequence can still be fit by an exponential law, but with larger residuals.

hours in Garching. For VIRCAM, with its own delivery scheme based on physically shipped data disks, scoring of 4-11 day old calibrations is not very useful. Therefore, a limited set of QC parameters delivered hourly by the Paranal pipeline are included in the scoring scheme in Garching, to allow near-realtime instrument monitoring.

6. QUALITY CONTROL EXAMPLES

6.1 Differential QC Parameters

The pipeline recipes for the master dark, reset, twilight flat and dome flat make use of reference calibrations that allow for the creation of difference or ratio products and the extraction of differential QC parameters. Reference calibrations are archived and updated for the processing in Garching and for the on-line pipeline on Paranal. Their purpose is that small changes in the structure of the master products are easily detectable, since the dominating structural noise (fixed pattern noise) is canceled out. Possible causes for changes are the displacements of the filter wheel, dust grains with variable position in the optical path, and sporadic changes in the detector reset pattern.

6.2 Twilight flat sequence parameters

From the operational point of view the acquisition of twilight flats requires the closest monitoring of all types of calibration frames. The VIRCAM twilight flat recipe requires a minimum number of raw twilight flat frames within a low flux range and a single observing sequence. The mean flux levels per chip have a significant chip-to-chip variation of 20% due to the different individual detector responses. Furthermore, each detector has its own linearity range and saturation level such that the intersection of all sixteen acceptable flux ranges result in a rather narrow overall allowed flux range for the flat field acquisition.

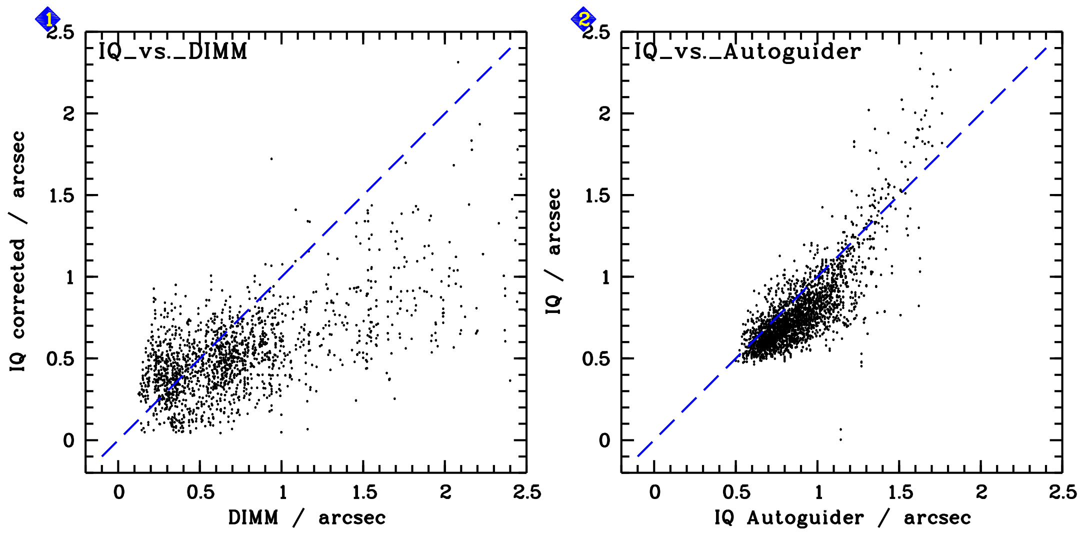

Figure 6. Left: Relation between VIRCAM K-band image quality and the Paranal seeing monitor (DIMM). The dashed line is the equivalence line. Right: Relation between VIRCAM K-band image quality and image quality reported by the autoguider CCD, located on the detector head. Again, the dashed line is the equivalence line.

For this reason a number of different flux range parameters has been introduced and is scored for each flat field sequence. This includes the overall range, and the maximum, mean and minimum flux. In addition to this, the number of raw frames accepted by the pipeline recipe to generate the master flats is monitored.

Atmospheric effects like cirrus result in an inhomogeneous illumination of the twilight flats. The impact of atmospheric disturbance is easier to detect in the raw frame sequence than in the final master twilight flat. Therefore, as further improvement, the shape of the flux sequence is monitored. The observed sequence of twilight flux values is fitted as an exponential decay, and the residuals between the fit and raw flux sequence are used as a measure of disturbances in the atmosphere (Fig. 5). The residual QC parameter can be used in the analysis of variations in the overall structure of the master twilight flats, usually monitored by the rms of the above mentioned ratio twilight flats. Small residuals indicate the variation is caused by contamination in the optical path of the instrument. In this case, the master twilight flat contains, as intended, all instrumental features to be corrected for. Large residuals are likely due to atmospheric effects. The master twilight flat can be discarded in this case, because it is contaminated by a transient atmospheric effect.

6.3 Normalized Image Quality

The image quality extracted from photometric standard star fields and from science exposures is a convolution of the intrinsic PSF of the instrument and the telescope and the atmospheric seeing. Separation of both components provides a potentially valuable and sensitive monitoring of the telescope's active optics and the instrument. For this reason the seeing values of the Paranal seeing monitor, DIMM, acquired at zenith at λ = 500 nm, are transformed to the wavelength and the air mass of the VIRCAM observation, and the measured image quality is corrected for the known intrinsic resolution of 0.51 arcsec FWHM (Fig. 6). The VIRCAM image quality is – as expected – well correlated with the image quality reported by the autoguider CCD, which is located on the same detector head. However, the DIMM values – which are truly independent on the VIRCAM intrinsic resolution – are not well correlated with the image quality extracted from the VIRCAM science detectors, likely because the DIMM operated on the Paranal summit, 1.5 km away from the VISTA dome. Therefore, the deviations between measured VIRCAM IQ and DIMM cannot be used as a measure of the telescope's active optics and instrument performance.

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