The Detector Monitoring Project

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Abstract. Many detectors, optical CCDs and IR arrays, are currently in operation onboard ESO instruments at the La Silla Paranal Observatory. A unified scheme for optical detector characterization has been adopted since several years in La Silla, and it is used by the Science Operation team to monitor the 18 CCDs belonging to the eight instruments operated by ESO at the Observatory. This scheme has been proven successful in ensuring a high quality performance of the detectors along the years. In Paranal the science operation team and QC Garching monitor the performance of the detectors using instrument-specific data reduction pipelines.

Understanding the performance limits and the calibration requirements of an instrument is fundamental in the operational scheme followed at the observatory and crucially depends on our knowledge of the nature of the detector arrays, their key performance parameters and the way these are defined and measured. Recently two issues were addressed: (1) despite the many commonalities among detectors, different ways to check their performance are in use and (2) the characterization matrix is often incomplete, i.e. not all crucial parameters are measured for all detector systems.

The detector monitoring project arises from the desire to improve the efficiency of the data flow, simplify Quality Control (QC) operations and promote standardization of testing procedures among detectors in use at ESO. The goals of the project are: (a) designing a detector monitoring plan that covers all the detectors in use; (b) reviewing the current reduction procedures and associated pipeline recipes; (c) standardizing the test procedures whenever applicable; (d) merging the test procedures for IR and optical detectors when possible and describe the differences in all the other cases; (e) consolidate the measurement procedures and the use of data reduction recipe and algorithms. The ultimate goal is to provide the observatory and the instrument operation teams (IOTs) with a complete and homogeneous detector-monitoring scheme.

1 Introduction

Modern detectors for astronomy are almost perfect devices when compared to the expectations of astronomers:

1. The ability to detect 100% of the incident light is achieved with detectors with quantum efficiency up to 99%.

2. The availability of progressively larger focal plane arrays is accomplished in modern instruments with few hundred million of pixels (e.g. Megacam at CFHT, Omegacam at ESO).
3. Very low noise performance for faint object astronomy is reached by modern detectors with noise as low as $2\,e^-$ rms at reasonable readout speed (e.g. 255 kbps)

On the other hand, when dealing with performance of modern detectors in detail, the astronomers are confronted with many issues that can significantly affect their science projects. For example, when looking at the signal in a detector, it is important to know the signal gain variation and stability, the QE spatial variations (intrinsic or as a result of external contamination), the effects of flux, bias voltages and temperature on linearity, the conditions under which signal persistence becomes significant, just to name a few. When looking at the noise, possible sources include the bias spatial variations, the dark current, the amplifier glow, electronic ghosts, readout noise, microphonic noise, pickup-up noise, odd-even column effects, etc. All of these effects have to be recognized, characterized and measured routinely for monitoring purposes.

At ESO, a lot of attention is given to detector systems: in Garching the Infra-Red [1] and Optical detector groups [2] use state-of-the-art facilities [3] to characterize in great details the qualities and the weaknesses of detectors to be used onboard ESO instruments and to set parameters for best performance on sky. At the Observatories, engineers and astronomers (Instrument Scientists in particular) monitor the behaviour of detector systems and characterize the quantities that may depend on the changing ambient conditions (e.g. electric interferences).

The current scheme is among the most advanced in the astronomical world and serves well the ESO scientific community. Is it possible to improve it? Is there something missing?

This chapter describes an effort initiated recently at ESO to implement a more thorough and modern plan of performance monitoring for those detectors that are being used onboard scientific instruments and relevant auxiliary systems (e.g. wave-front sensors) at the La Silla Paranal Observatory (LPO). Sections 2 and 3 describe the *status quo* at the Observatories, Sect. 4 explains the rationale of the project, and gives some details of the new monitoring plan and its current status. Section 5 gives some details on the Common Pipeline Library, which provides the basic set of tools for the practical implementation of the plan.

2 Status at the La Silla Observatory

The optical instruments in La Silla make use of a total of 1 IR array and 18 CCD detectors, of several types (EEV, MIT/LL, LLes/UV flooded, TK1024)

Table 1. Summary of available detector in La Silla

Instrument	Detector	Size	Pixel (μm)	Format	Wavelength Range (nm)
SUSI2	E2V 44-82	2048×4096	15	M of 2	300–1000
EMMI blue	Tektronix 1024 AB	1024×1024	24	S	300–500
EMMi red	MIT/LL CID-20	2048×4096	15	M of 2	400–1000
WFI	E2V 44-82	2046×4098	15	M of 4x2	350–1100
FEROS	E2V 44-82	2048×4102	15	S	350–920
HARPS	E2V 44-82	2048×4096	15	M of 2	380–530 530–690
EFOSC2	Loral/Lesser MPP Thin	2048×2048	15	S	300–1100
CES	E2V 44-82	2048×4096	15	S	350–1000
SOFI	Rockwell Hawaii HgCdTe	1024×1024	18	S	900–2500

Note: Format: S – single detector, M – Mosaic

and with different characteristics, covering an integrated wavelength range from 340 to 1000 nm. Table 1 lists the detectors currently in use at the observatory.

To monitor and characterize (if needed) all these detectors in a comprehensive and uniform way, common test procedures had to be developed over the years. CCD tests are performed weekly by personnel of the Science Operations department, and generally involve use of the "beta-light". The beta-light consists of a tritium radioactive pellet encapsulated inside a glass whose interior is covered by fluorescent material. The electrons from the decay of the tritium excite the fluorescent material generating a steady glow. The flux emitted by these sources is extremely stable since it follows a known law of decay with time with a time scale set by the half life of the tritium (12.4 years).

A different source, but the same strategy, is used for both HARPS and FEROS. The HARPS CCD is not accessible, and beta light tests are therefore not feasible. Similarly, for FEROS, insertion of the beta light is inconvenient, as it has an impact on the instrument stability. Instead LEDs, placed just above the CCDs, are used. This technique is proven to be fully satisfactory comparing the data from the FEROS LEDs (high stability power source, no feedback) with the beta light data purposely acquired for the comparison. This is achieved thanks to the use of a mechanical shutter so that the LED can be let to stabilise before the images are taken [4].

The tests are performed via graphic user interfaces (GUI) with a similar "look and feel" for the several detectors. The test strategy and the reduction algorithm are the same for all detectors. While the test is running, feedback is displayed on the screen. Once (If) certified, the test results are automatically saved in the database and published on the web.

The extracted values are: bias level, average count rate, gain, readout noise, linearity and shutter delay. The analysis method used is the traditional photon transfer method, documented, among others, by [5]. The final result is a homogeneous database spanning over several years to be used for trending, troubleshooting and health checks of the detectors.

3 Status at the Paranal Observatory

The instruments in operation at the Paranal Observatory include both optical CCDs and infrared arrays. Table 2 and 3 list all the optical and infrared detectors currently in use plus the one foreseen for future instruments.

The monitoring of the performance of these detectors is a collaboration of the Science Operations and Engineering/Instrumentation departments of the Paranal observatory and the Quality Control Group in Garching: test data are routinely acquired at the observatory, primarily during the day by means of calibration technical templates and the main detector parameters are checked and trend analysis is performed offline. According to the calibration plan of the observatory, all instruments and detectors should be

Table 2. Optical detectors datasheet for present and (near) future instruments at the LPO

Instrument	**Detector**	**Size**	**Pixel (μm)**	**Format**	**Wavelength Range (nm)**
FORS1	Tek 2048EB4-1	2048×2048	24	S	330–1100
FORS2	MIT/LL CCID-20	2048×4096	15	M of 2	330–1100
FLAMES (Giraffe)	E2V 44-82	2048×4102	15	S	370–950
UVES Blue	E2V 44-82	2048×4096	15	S	300–500
UVES Red	E2V 44-82 MIT/LL CCID-20	2048×4096	15	M of 2	420–1100
VIMOS	E2V 44-82	2048×2048	15	M of 4	360–1100
NAOS OPT	E2V CCD50	128×128	24	S	450–1100
Future Instruments					
OMEGACAM	E2V 44-82	2048×4096	15	M of 32	330–1000
GALACSI/ GRAAL	E2V L3 CCD220	240×240		M of 5	450–950
MAD	E2V CCD 39	80×80	24	S	450–950
VISTA OPT	E2V CCD 42-40	2048×2048	15	M of 4	850–1100
X-Shooter UVB	E2V 44-82	2048×4096	15	S	320–500
X-Shooter VIS	MIT/LL CID-20	2048×4096	15	S	500–1100

Table 3. Near-IR detectors datasheet for present and (near) future instruments at the LPO

Instrument	**Detector**	**Size**	**Pixel (μm)**	**Format**	**Wavelength Range (μm)**
ISAAC	Rockwell Hawaii	1024×1024	18	S	0.9–2.5
	HgCdTe	1024×1024	27	S	1–5
	SBRC Aladdin				
VISIR	DRS BIB Si:As	256×256	50	M of 2	5–25
CONICA	SBRC Aladdin 3 InSb	1024×1024	27	S	1–5
NAOS	Rockwell Hawaii HgCdTe	1024×1024	18	S	0.9–2.5
SPIFFI	Rockwell Hawaii HgCdTe	2040×2048	18	S	0.9–2.5
MIDI	Raytheon IBC SI:As	320×240	50	S	5.0–25
AMBER	Rockwell Hawaii HgCdTe	1024×1024	18	S	0.9–2.5
CRIRES science	Raytheon Aladdin III	1024×1024	27	M of 4	0.95–5.2
CRIRES SV	Raytheon Aladdin III	1024×1024	27	S	1–2.2 (5)
Future Instruments					
X-Shooter NIR	Rockwell Hawaii 2RG	2048×2048	18	S	1.1–2.4
Hawk-I	Rockwell Hawaii 2RG	2048×2048	18	M of 4	1.1–2.4

monitored in the same way, but still some differences exist among instruments: for example, for most instruments, basic parameters such as bias level and noise are measured daily but the conversion factor is not monitored for all and other important measurements (e.g. linearity, fringing, contamination, etc) are not yet monitored. Additionally, measurements of the same parameter are made differently for different instruments, typically because they have different data reduction pipelines and recipe implementation. One example of this is the readout noise: we find cases in which it is measured as the sigma value in one raw file within a specific X×Y pixels window, corrected for fixed-pattern contribution but also measured on each whole single raw frame, with no corrections. Although both methods are acceptable and give consistent results, more uniformity would be desirable. This situation is exemplified in Table 4, which shows for various instruments in Paranal which measurements are checked and/or monitored for longterm variability (trend analysis).

The quality control web pages in Garching [6] provide links to the data measured for each instrument, and also allow queries to the parameters database (trending plot archive) for specific periods of time, which is a powerful tool for troubleshooting and for use of archival data mining.

Table 4. Detector parameters currently monitored

Optical Instrument	**RON**	**Bias Level**	**Inverse Gain**	**Linearity**	**Bad Pixels**
FORS1/2	Ch/Tr	Ch/Tr	Ch/Tr	–	–
UVES	Ch/Tr	Ch/Tr	–	–	–
VIMOS	Ch/Tr	Ch/Tr	Tr	Ch/Tr	–
GIRAFFE	Ch/Tr	Ch/Tr	Tr	Tr	–

IR Instrument	**RON**	**Dark Current**	**Inverse Gain**	**Linearity**	**Bad Pixels**
ISAAC	Ch	Ch	–	Tr	Tr
CONICA	Ch	Ch	Tr	–	Tr
SINFONI	Ch	Ch	Tr	Tr	Tr
CRIRES	–	–	–	–	–
AMBER	–	–	–	–	–
MIDI	Ch/Tr	–	–	Ch/Tr	–
VISIR	Ch	Ch	–	–	Tr

Note: Format: Ch – checked, Tr – Trend analysis

4 The Detector Monitoring Plan

The establishment of a monitoring plan for IR and optical detectors at the Observatory comes from the need to expand and unify as much as possible the detector testing strategy, with the aim of gaining in efficiency and quality of the measurements. The monitoring plan is mostly complementary and does not supersede the characterization and testing plans implemented in Garching by the infrared and optical detector teams (IDG and ODT): as such, it is limited at considering those parameters that can be measured at the telescope by means of day-time and night-time calibrations. All other parameters are already characterized before the instrument is commissioned at the observatory or are included in the manufacturers' specifications documents. It is however possible that, as a result of an upgrade (e.g. the implementation of a new read-out mode), or some other structural change (e.g. change of the operating temperature of a camera) a new characterization has to be performed at the observatory. Additional testing procedures are also designed and carried out by the instrumentation group at the observatory, like for example the measurement and monitoring of variable environmental effects such as electrical interferences. In the interest of economy of efforts and of ESO-wide standardization, the plan includes the relevant test procedures devised in the labs in Garching and tries to make use of proven recipes, algorithms and procedures already in place, for example at the La Silla Observatory. For the same reasons, the Common Pipeline Library [7] was the chosen tool for the practical implementation (data reduction recipes, see Sect. 4 for details). This plan is meant to achieve the following broad goals:

- Standardize test procedures whenever applicable (e.g. define a unique way to measure linearity).
- Unify test procedures for IR and Optical detectors whenever applicable and describe the differences in all the other cases (e.g. define unique ways to acquire data sets).
- Unify the measurement procedures and the use of data reduction recipes and algorithms.
- Utilize available resources, such as data taking OBs, pipeline recipes, existing reporting tools (e.g. QC web pages).

Some additional specific goals:

- Generate a list of all the parameters, the required accuracy and their measurement frequencies (Table 4).
- Provide a description of each parameter, its impact on science and its dependencies on operating conditions, as provided at the observatory.
- Set the requirements for data acquisition and the operating conditions for measurements.
- Give a description of the algorithms for measuring each parameter and the methods for data analysis.

The monitoring plan also provides useful by-products: (1) a higher level implementation roadmap to serve as guide for the pipeline developers who have the task of providing the data reduction recipes, (2) quantitative measurements to plan for interventions and to monitor the health of the instruments for the instrument scientist and the engineers. In this way, the detector monitoring plan interests a broader audience:

- The night astronomer, who operates the instruments and is interested in optimizing their scientific output.
- The day astronomer who needs guidelines to validate the calibration data.
- The user support astronomer, who needs the nitty-gritty specifics of the detectors to advise the users when setting their observational tactics and techniques.
- The quality control scientist, who is in charge of the back-end instrument health checks.
- The astronomer (user), who is interested in planning a strategy for his observations and achieving specific scientific goals.

Not all of the parameters listed in Table 5 affect performance at a system level. Therefore the monitoring plan also lists the parameters, their importance at a system level and their dependencies on operating conditions. It is important to understand the dependencies on operating conditions in order to set test frequencies and to use predictive tools.

For example, the readout noise has high importance, since it affects all aspects of astronomical applications and it is a good indicator of instrument

Table 5. Detector parameters in alphabetical order and IR/OPT compatibility

Parameters	**OPT**	**IR**	**MIR**	**Accuracy (unit)**	**Method**	**F**	**P**
Amplifier Glow	X	X	X	Signal (ADU)	Statistics: Bias/Dark	N	14
Bias Level	X X			<1 1 digit (ADUs)	Bias Statistics	D	1
Bad pixels, Cosmetic Quality	X	X	X	N/A	Bias Frames (OPT) Dark Frames (IR) Flat frames (ALL)	Y	2
Contamination	X				UV Flats analysis	Y	16
Conversion Factor	X	X	X	2 digits [e^-/ADU]	Transfer Curve TDI images	BA M	3
Cosmic Ray Sensitivity	X				Long darks statistics	N	17
Crosstalk (multiple ports)	X	X	X	1/300,000	Bright star sequence	Y	8
CTE (V/H)	X			10^{-6}	EPER (overscan); Signal variance;	O	6
Dark Current	X	X	X	2 digits [e^-/px/s] –[e^-/px/hr]	Dark Frames Statistics	D	1
Dark Signal Non uniformity variable fixed (DSNU +FPN)	X			<10%		BA	5
Full Well Capacity	X			1%	Linearity curve	BA	4
Linearity	X	X	X	<1%	Transfer Function	BA	3
Persistence (Remanence)	X	X	X	% of original	Dark current measurements after illumination	Y	13
Readout Noise (RON)	X	X	X	2 digits [e- RMS]	Bias Frames (OPT) Dark Frames (IR)	D	1
50Hz Pick up Noise	X	X	X	2 digits (ADU)	FFT analysis	Y/N	7
Microphonic Noise			X			BA	8
N-pixel correlated Noise			X			M	9
Odd-Even column effect		X				D	2
Shutter Pattern/Error	X			% of maximum signal	Linearity curve Shutter procedure	Y/N	11
Spatial Uniformity, Response non-Uniformity (PRNU) - Fringing	X	X	X	<2%	Analysis of flats	M/N	10
Stability		X	X	N/A	Visual inspection bias frames	D	15
Stray light	X				Flat frames	W	18
Temperature stabilization	X	X	X		% error	Y	12

Notes: **F**=Frequency, **P**=Priority, D=Daily, W=weekly, M=monthly, BA=biannual, Y=yearly, O=once, N=when needed.

electronic problems. It can change with temperature, it may be influenced by detector electronics and by external electromagnetic interference (pick up noise). The crosstalk has medium importance, since it affects spatial resolution. It is important at design level and it is usually stable, independent of pixel location, normally proportional to signal. The pick up noise is considered of low importance, it depends on the detector integration time, readout speed, environment conditions, detector mounting and dismounting and other nearby equipment that is altered.

The monitoring plan is being developed in phases, currently in different stages of completion:

1. Requirement analysis and definitions: completed and recorded in [8].
2. Analysis of current status of detector monitoring at ESO: completed.
3. Implementation of pipeline recipes: on-going.
4. Implementation of observing templates for data collection: to be initiated.

The plan will become gradually operative, following the development status of the pipeline recipes and the observing templates. After an initial phase of testing and cross checks with independent tools it will become part of the routine operations at the LPO.

5 The Common Pipeline Library

The ESO Common Pipeline Library (CPL, [7]) has been developed to unify, share and centralize the pipelines code, reduce their maintenance costs. The CPL is a self-contained ISO-C library, designed for use in a C/C++ environment. CPL is used for the development of all ESO pipelines, both for internal developments and for developments by the external consortia.

The CPL itself is split into four major components, reflecting the algorithmic level of the software contained therein (Fig. 1):

- The CPLCORE library provides the fundamental CPL data types (to support/define images, tables, vectors, matrix) the operations defined on these data types, and elementary utility functions.
- The CPLUI (UI for User Interface) provides services defining the standard interface for recipes and provides more complex data reduction related utilities and services. In particular, it contains the necessary types to handle the plugin interface, the parameters used to handle command-line options and the (set of) frames used to store the input list of files.
- The CPLDRS (DRS for Data Reduction System) uses the CPLCORE data types and functions to implement higher level data processing algorithms. CPLDRS is itself organized in sub-modules corresponding to different stages of data reduction: detector calibration, geometrical calibration, aperture definition, and photometry.

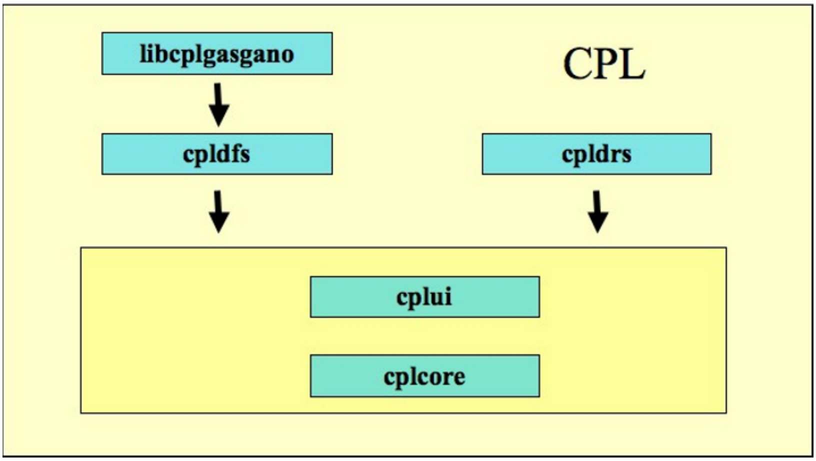

Fig. 1. Software layers of the ESO Common Pipeline Library

– Finally, the most recent addition to CPL, the CPLDFS module (DFS for Data Flow System) provides DFS related utilities for the creation of DFS compliant data products, or quality control logs.

The routines of the detector monitor project will be provided as part of the detector correction module in the CPLDRS layer. All pipelines will be able to invoke the same function, e.g. the detector linearity algorithm. Each pipeline will call these functions from the instrument specific recipes, thus providing the flexibility required to cope with instrument-specific features, keywords, or data structures.

Acknowledgement. The authors would like to thank Nicolas Haddad, Pedro Mardones, Emanuela Pompei and Martin Roth for the fruitful discussions and comments. James Brewer and Thomas Agustejin for having pioneered the work for a common algorithm for detector monitoring in La Silla. Emilio Barrios and Paul Le Saux who developed the GUI and are maintaining the whole software.

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Discussion

D. Baade: This looks like a very meritorious project. But how comes that the two detector departments, which have provided nearly all of the detector systems, do not know about it?
D. Baade: Were the many scary anonymous examples of defective detectors taken from present ESO detector systems?
P. Amico: The examples are not specific to ESO's systems.
P. Bonifacio: I would like to know with detail the effects of cosmic rays on detectors. Therefore, I would like its monitoring to be put at least at a medium importance level. Long exposures, necessary to beat the RON on very faint objects. The experience gained can be very important for the design and construction of future instruments.
P. Amico: The cosmic rays rate is mainly dependent on the detector's environment (typically the surrounding material and the location/altitude). This quantity is characterized in Garching. It is checked for stability at the Observatory, typically during commissioning. We plan to monitor the cosmic rays rate, but since it is not expected to vary significantly, this measurement has lower priority than others.
D. Osip: How many CCDs do you operate with a Nod & Shuffle mode? Do you have different characterization and monitoring plans for this mode?
P. Amico: There are no instruments at the Observatory, which offer Nod & Shuffle.