Quality Control of VLT FLAMES/GIRAFFE data

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ABSTRACT

GIRAFFE is a medium to high resolution spectrograph forming part of the complex multi-element fibre spectrograph FLAMES on the 8.2m VLT-UT2 telescope which also has a fibre link to the high-resolution spectrograph UVES. It has been operational since March 2003. GIRAFFE has been designed to be very stable and efficient. Here, first results concerning the Quality Control process are presented.

Keywords: Multi-object spectroscopy, fibre spectroscopy, quality control, trending, data reduction pipelines, instrument performance, FLAMES, GIRAFFE

1. INTRODUCTION: FLAMES AND GIRAFFE

FLAMES is the **F**ibre **L**arge **A**rray **M**ulti-**E**lement **S**pectrograph mounted at the Nasmyth A platform of the 8.2m Kueyen (UT2) telescope, which is part of the Very Large Telescope (VLT) of the European Southern Observatory (ESO) situated on Cerro Paranal. It has been operational since March 2003, and is described by [1].

As a complex multi-instrument, FLAMES has three main components:

- a Fibre Positioner (called OzPoz) hosting two plates with fibre systems (while one plate is observing, the other one can be configured for the next observation);
- a fibre link to the red arm of the high-resolution UVES spectrograph (UVES can also be used as a stand-alone echelle spectrograph);
- a medium to high resolution optical spectrograph, GIRAFFE, fed by 3 types of fibre systems (see below).

The GIRAFFE spectrograph operates at resolution R = 6,000…48,000 across the entire visible range, 370-940 nm. It is equipped with two gratings, high (H) and low (L) resolution. GIRAFFE has a single 2Kx4K EEV CCD (15 µm pixels). Find more information about GIRAFFE at its home page[a].

The fibre system feeding GIRAFFE consists of the following components:

- 2 Medusa slits (one per positioner plate); up to 130 separate objects (including sky fibres) can be observed simultaneously in the Medusa mode, with 5 additional fibres each for simultaneous calibration ("SIMCAL" fibres). One Medusa fibre has a diameter of 1.2 arcsec.
- 2 IFU slits; each IFU is deployable and consists of an array of 20 square microlenses. 15 such IFUs form an IFU slit, with a total of 300 object fibres plus 15 dedicated sky fibres plus 5 SIMCAL fibres. One IFU covers 2 by 3 arcsec.
- 1 Argus slit; the Argus array is a single rectangular IFU of 22 by 14 microlenses. Again, there are 300 object fibres plus 15 sky fibres plus 5 SIMCAL fibres. The Argus array spans up to 7.3 by 11.5 arcsec on the sky.

The GIRAFFE fibre system has a total of 1230 fibres (object plus sky plus SIMCAL fibres). Results about the first year of operations are given by [7]. The UVES-FIBRE data and their Quality Control process are described here [2].

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[a] http://www.eso.org/instruments/flames/Giraffe.html

2. GIRAFFE DATA AND DATA REDUCTION

2.1. Calibration data

GIRAFFE has in both high and low resolution modes a number of fixed standard settings identified by their central wavelength. Presently there are 31 settings in HR mode and 8 settings in LR mode. With 39 standard settings and 5 fibre systems, the total number of possible configurations is 195, far too high for a preventive calibration strategy. Hence, the calibration plan for GIRAFFE is driven by the SCIENCE observations of the previous night. To these, a number of predefined calibrations are added to support instrument health checks.

The standard set of calibrations consists of:

- a set of three fibre flats per configuration (obtained with a flat field lamp attached to the OzPoz robot arm, so-called 'robotic' flats)
- one ThAr arc-lamp exposure.

In ARGUS mode, a set of screen flats is added, using the Nasmyth screen which provides a better illumination. There is also an observation of a flux standard star. If defined by the observer, it is also possible to obtain nighttime flats in exactly the same instrument setup and position as the science data, but these nighttime calibrations are an exception.

An important feature of GIRAFFE is the option to illuminate 5 fibres (per fibre system) with an arc-lamp simultaneously with the SCIENCE exposure, to obtain highest possible accuracy of the wavelength calibration.

The set of health check calibrations presently consists of:

- 5 bias frames to check for detector health
- 5 arc-lamp exposures with the simultaneous calibration lamp (one per fibre system), to check the grating stability
- 5 robotic flats (one per fibre system) to check for fibre availability and throughput.

To these daily calibrations a set of technical calibrations is added about once per month which consist of a series of dark exposures and CCD illuminations without the fibre system, to check for CCD linearity, gain, dark current, and noise parameters.

2.2. Calibration and reduction cascade

The data processing scheme is rather simple. It follows the scheme of the calibration cascade in Figure 1:

1. A set of raw bias frames is combined to obtain a master bias.
2. A set of raw fibre flats (Figure 2) is combined and processed to obtain fibre localization information ("where is the signal from fibre #317?") and width/PSF information ("how far extends the signal of that fibre?"). The extracted signal per fibre is also used to flatten the science data (spectral response per fibre).
3. The arc-lamp exposure (Figure 3) is extracted per fibre, using the localization and width information from the flats; emission lines are found and identified; the dispersion solution is obtained per fibre.

The reduction of science data uses the calibration solutions:

4. SCIENCE data are debiased, localized, extracted, flatfield-corrected and rebinned.
5. For IFU and Argus data, spectral images are reconstructed.
6. A flux-calibration of the Argus data is foreseen.

2.3. Data reduction and pipeline

The data reduction pipeline is based on code provided by the Observatoire de Genève[3,4] and has been integrated into the ESO Dataflow System using the Common Pipeline Library (CPL) developed to provide a uniform platform for all ESO pipelines[5]. It has been installed on Paranal and at Data Flow Operations Group (DFO) in Garching in March 2004. Eventually it will be released to the public. The GIRAFFE pipeline has built-in QC functions.

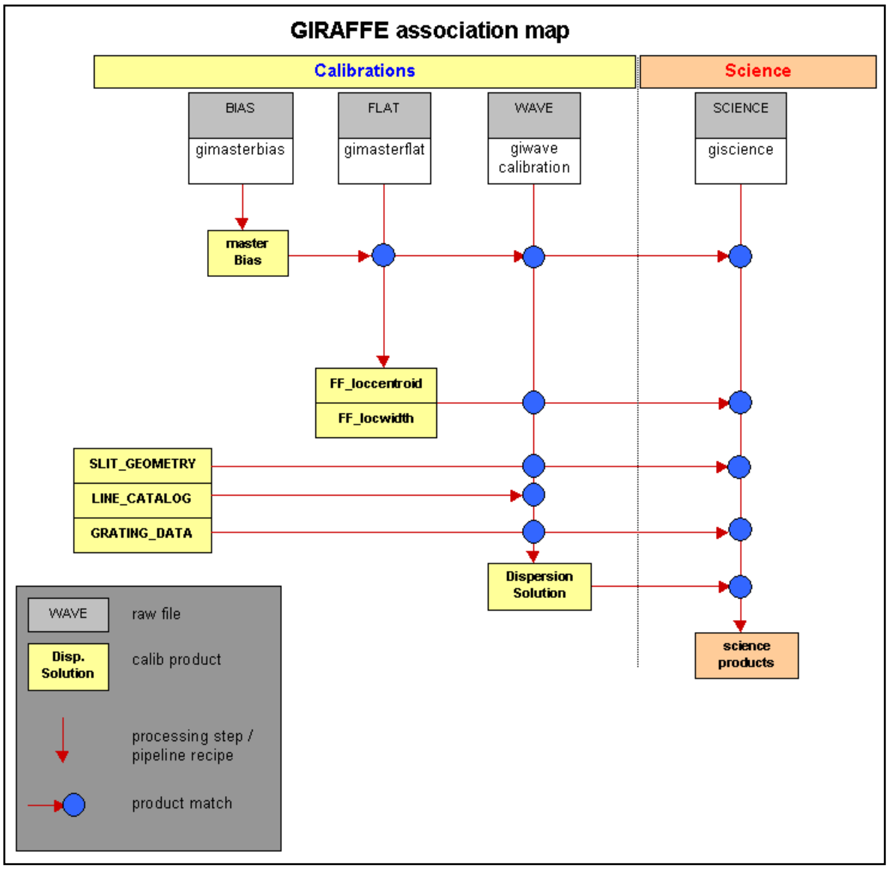


Figure 1. The Giraffe calibration map.

It has presently the following recipes: `gimasterbias`, `gimasterflat`, `giwavecalibration`, `giscience`. The pipeline has been used to process all calibration data since April 2003 up to now, while science data have been processed since April 2004. The processed data are now included in all data packages delivered by DFO to the Service Mode users. The pipeline is furthermore crucial to extract QC information and perform the health checks.

2.4. Examples

Flat field. Figure 2a shows a raw flat field in a Medusa setup. The 2k x 4k data are displayed here compressed vertically, to enhance the curvature of the fibre signal. The pipeline uses the continuous signal per fibre to find its location. In a second step, the signal is traced, a Gaussian with variable width and height is fitted and the signal is extracted. The final pipeline version will use an algorithm to determine the PSF more precisely, and to use optimal extraction. Pipeline products are the extracted signal, its location and its FWHM values (Figure 2b).

Arc-lamp. Figure 3a shows a raw arc-lamp exposure, displayed to scale. The close-up displays two emission lines in four adjacent fibres. The spectral format is such that the lines of constant wavelengths are slightly curved. Figure 3b shows the arc-lamp exposure extracted by the pipeline. The format of this product corresponds to the extracted flat field in Figure 2b. Finally, Figure 3c displays the rebinned arc-lamp exposure, with the curvature removed. This product is created for QC purposes. It represents the dispersion solution for all fibres. All emission lines can easily be checked to form an exactly horizontal line. The quality of that line corresponds to the quality of the wavelength calibration for the science data.

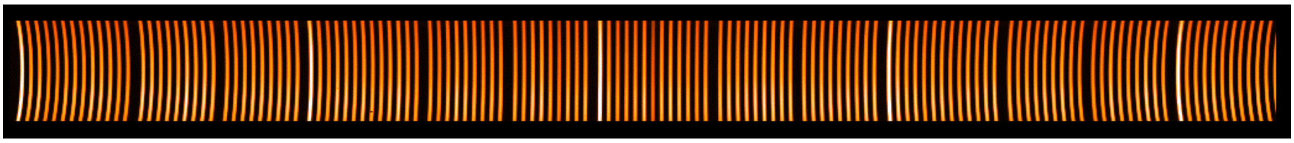
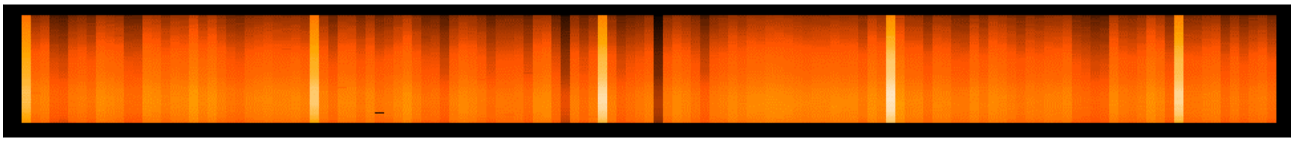


Figure 2. GIRAFFE Flat field data. a. Raw flat field. The five bright fibres are the SIMCAL fibres. The vertical scale is highly compressed.



b. Pipeline-processed flat field. As above, the vertical scale is highly compressed.

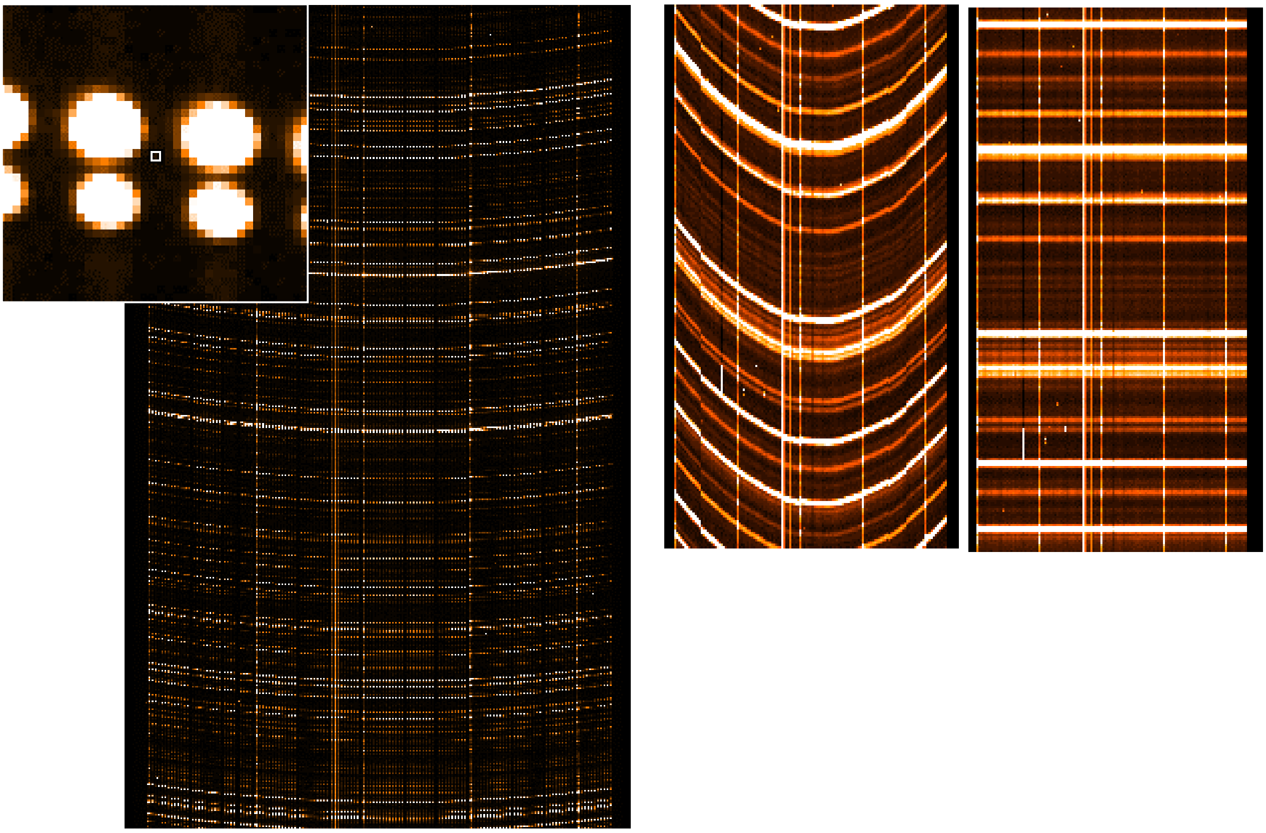


Figure 3. a. Raw arc-lamp exposure (Medusa mode), with curved spectral format. b. Product after extraction (the curvature is still present). c. Rebinned arc-lamp spectrum, with strictly horizontal emission lines.

Science. After pipeline processing, the fibre signal comes extracted and binned to wavelength space (Figure 4). All sky emission lines show up as a straight line. The final pipeline version will also include sky correction, flattening (with partial correction for the instrument response curve), and correction for fibre-to-fibre efficiency.

Science, image reconstruction. The IFU and Argus modes with their microlenses have combined imaging and spectroscopy capabilities. A (partial or full) collapse of the spectra can be rearranged into narrow-band images of the sources. Figure 5 shows an example for the Argus IFU. The signal for the whole set of 300 object fibres in the left frame is used to reconstruct the narrow-band image on the right side. The broken lines mark the extraction range in wavelength.

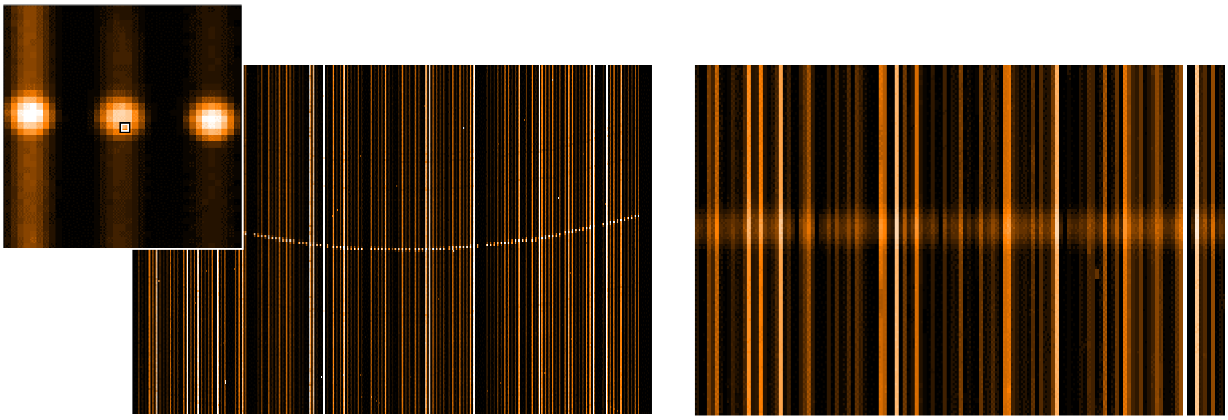


Figure 4. GIRAFFE science frame. a. Raw science frame in a Medusa mode. The dotted line is the OI 6300 Å emission line. The close-up shows that line in three adjacent fibres. b. Reduced science frame, in the region of the OI line. Each column represents a science spectrum, with wavelength increasing upwards.

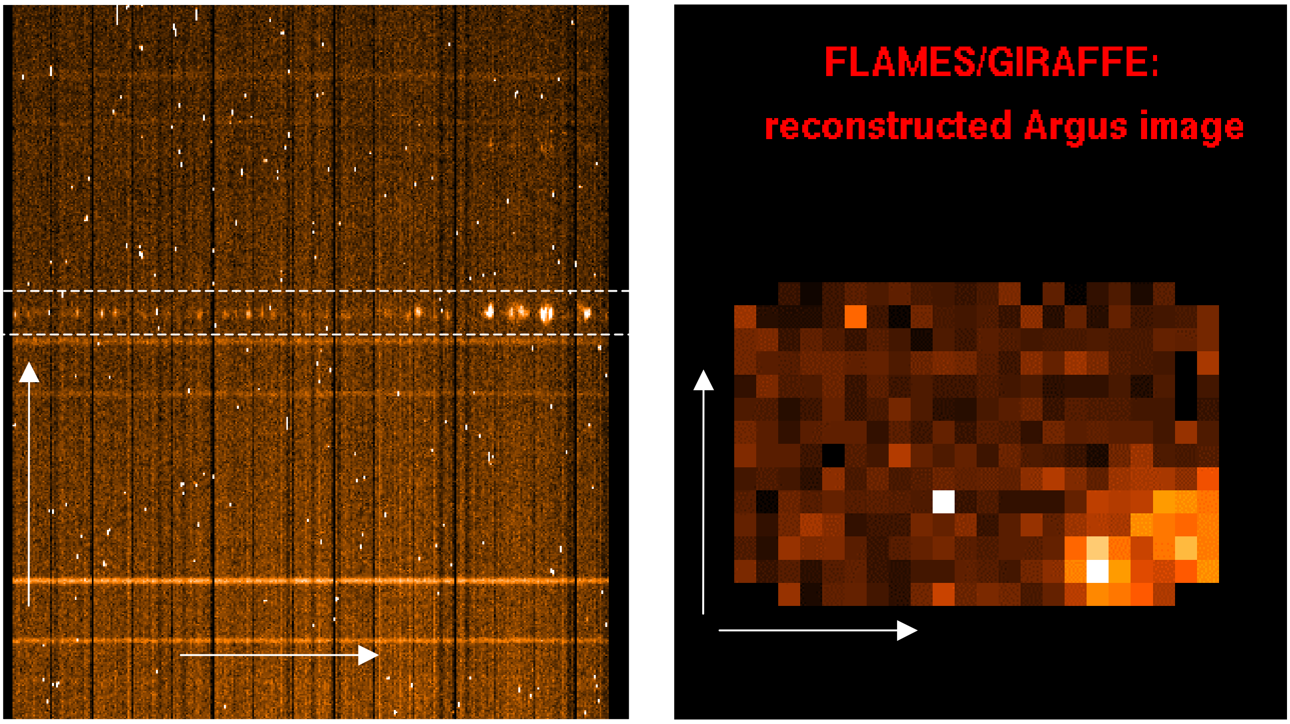


Figure 5. Image reconstruction of GIRAFFE Argus spectra. a. The reduced Argus spectrum, same format as Figure 4b. The two white lines mark a spectral range which defines the extraction limits for the reconstructed image. b. Reconstructed Argus image in the wavelength range defined in a. The extracted signal is rearranged in (arbitrary) X and Y coordinates on the sky.

3. QUALITY CONTROL AND TRENDING

3.1. Shared QC

The Quality Control (QC) process for GIRAFFE has been designed along the proven principles for other VLT instruments[6]. It is a shared process between on-site staff and off-line Data Flow Operations Group (DFO) at ESO headquarters. On-site staff have the expertise about instrument operations and are able to interact directly and in real time with the instrument. On the other hand, available manpower and time is limited. Hence the focus here is on safe operations (to avoid problems) and on routine checks of the vital instrument functions (health check).

Off-line DFO processing is always delayed in time, due to the data transfer from the Observatory to Garching headquarters. The transfer is done on media which are shipped by courier mail twice a week, the typical transfer time (point-to-point) being 5 days. All calibration data are processed in Garching, QC checked and certified. Any problem with the instrument, which leaves a fingerprint in the data, can be analyzed here, on a data set basically as extended as the instrument history is.

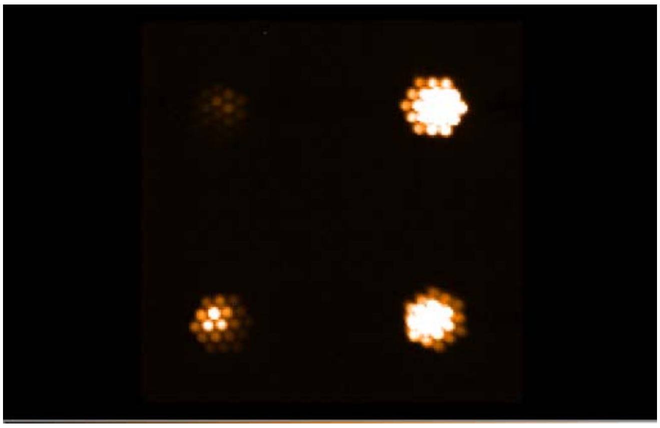


Figure 6. FACB view

3.2. QC on Paranal

Nighttime. The nighttime astronomer is the first chain in the QC process:

- During acquisition, the astrometric accuracy is checked by the Fibre Acquisition Control Bundles (FACBs). These are pointed on a set of fiducial stars in the field and are used to calculate offsets between targets and fibres which would result in efficiency losses (Figure 6). In cases of non-tolerable offsets, the User Support Group in Garching is informed to contact the PI about improved coordinates.
- In Service Mode, each science exposure is graded by checking the user-specified constraints (about seeing, moon properties, transparency, and others) against the runtime conditions. Bad grading gives an OB another chance to be executed (if possible).
- If feasible, the night astronomer checks count levels against prediction, to avoid saturation, to estimate the SNR, and to check if all fibres are receiving light.
- There are also occasional checks that the pipeline produces output. If it fails to do so, this could indicate a problem with the instrument (like a bad positioning of the grating).

Daytime. The daytime astronomer focuses on the daytime calibrations. To this belongs:
- a completeness check;
- a check against reference frames if available;
- a check of the Health Check monitor[b];

[b] maintained by DFO Garching under the URL http://www.eso.org/qc/ALL/daily_qc1.html

– a check of pipeline products.

By these procedures, it should be possible to detect major instrument failures immediately, like grating misplacement, CCD failure, fibre unit failures, or calibration lamp degrading.

3.3. QC in Garching

The GIRAFFE QC scientist is responsible for processing of all GIRAFFE calibration data, extracting QC information, and processing GIRAFFE science data taken in Service Mode. As the most extensive pipeline user, he is also monitoring the pipeline performance and responsible for initiating upgrades, in co-ordination with PSO. Finally he is responsible for creating the data packages sent out to the SM users, and he has to maintain documentation of all this on the web. The GIRAFFE QC home page is under the URL www.eso.org/qc/index_giraffe.html.

From the continuous calibration and science data stream, the quality of the data is measured using so-called QC parameters. A set of QC reports assists the QC scientist in the review and certification process. Each calibration product is reviewed. If certified, it is ingested into the calibration database for further usage.

3.4. IOT

From the beginning of VLT operations, the Instrument Operating Teams (IOT) played a major role in the shared process of instrument operations. This is also the case for GIRAFFE. From each key group, one member is part of the GIRAFFE IOT: the Paranal instrument scientist and the control software responsible; from Garching, the User Support Group delegate, the QC scientist, the pipeline software developer, and other key people. Any major new development is first discussed within the IOT before it is implemented.

3.5. Health Check monitor

For some instrument components, it is crucial to have the information about their health in (almost) real time. In practice this means they should be available when the Paranal daytime astronomer starts his review process. This service is provided by the Health Check (HC) Monitor which has been developed by DFO Garching.

For GIRAFFE, this process is based on the set of daily HC calibrations. These are processed on-line. The extracted QC information is logged, the logs are ftp'ed to Garching where an automatic procedure picks them up and compares them to pre-existing values in the QC database[c]. The evaluation is fed back onto the web.

4. TRENDING

Trending is defined as combining QC information over time. It helps detecting variations, degradation and trends and is important to assess the long-term performance of the instrument. The trending process for GIRAFFE is still in a development phase. Presently covered are:

- CCD parameters (bias, dark, RON, fixed-pattern noise, linearity, contamination, gain)
- grating stability
- fibre efficiency variations, fibre availability
- calibration lamp monitoring

The following properties are planned to be included in the long-term trending:

- resolution, quality of dispersion solution
- instrument throughput

The gateway to the trending results[d] links to trending plots, downloads and tutorial pages. A few examples in the following sections show results for the first year of GIRAFFE operations.

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[c] Access to the QC database is provided at the URL http://archive/bin/qc1_cgi
[d] under http://www.eso.org/qc/GIRAFFE/qc/qc1.html

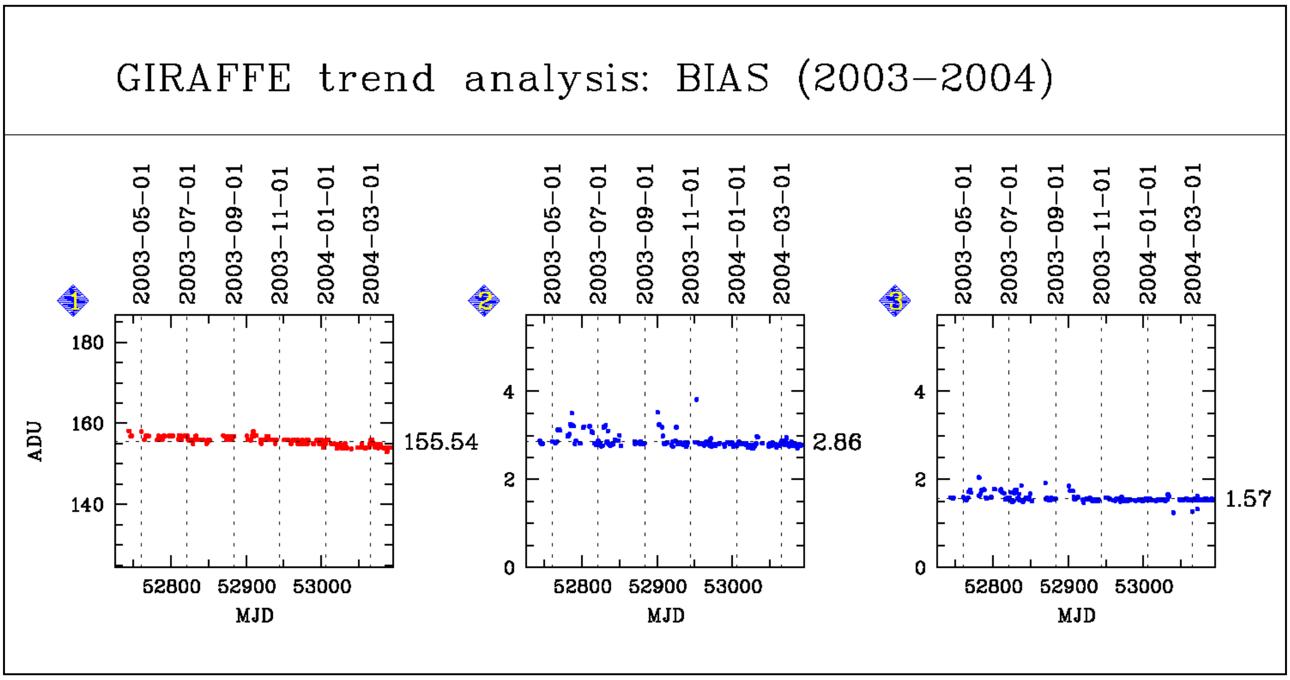

Figure 7. The behaviour of GIRAFFE bias level (item 1), RON (raw frame; item 2) and RON (master frame, item 3) during the first year of operation. The master bias is usually made of 5 input raw frames. Numbers at the right side are mean values over the range of time.

4.1. GIRAFFE CCD

The GIRAFFE CCD has shown a very stable bias and read noise level (Figure 7). The only problem with the CCD occurred during October/November 2003 when a few columns showed a failure (periodic memory effect) which degraded the cosmetics.

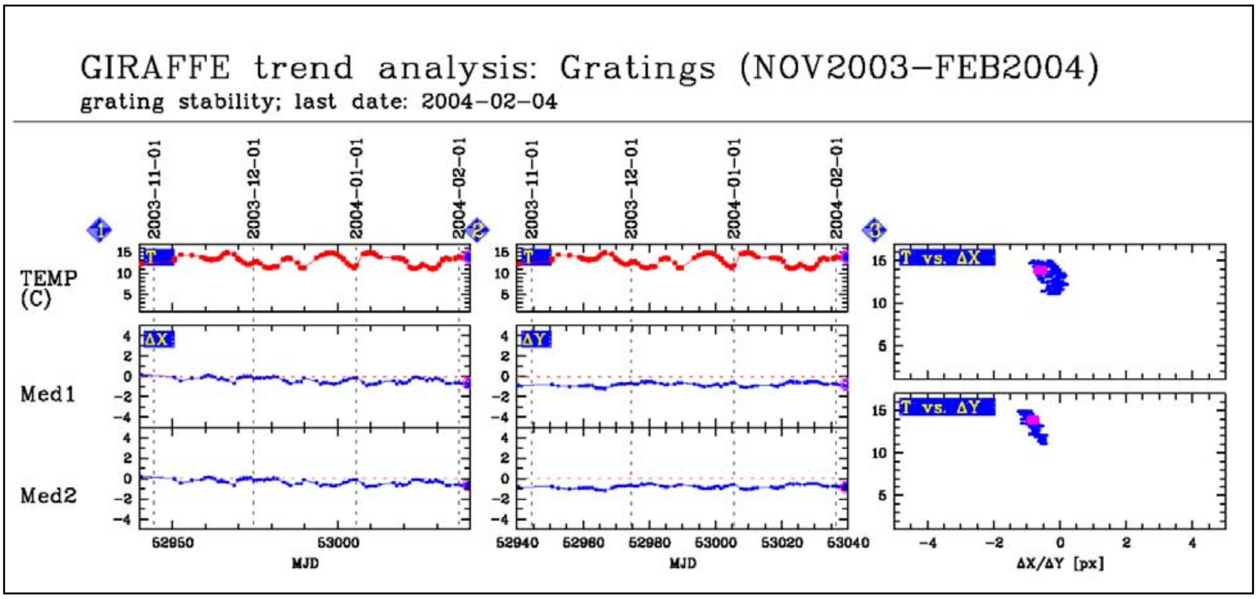

Figure 8. Grating stability and temperature sensitivity.

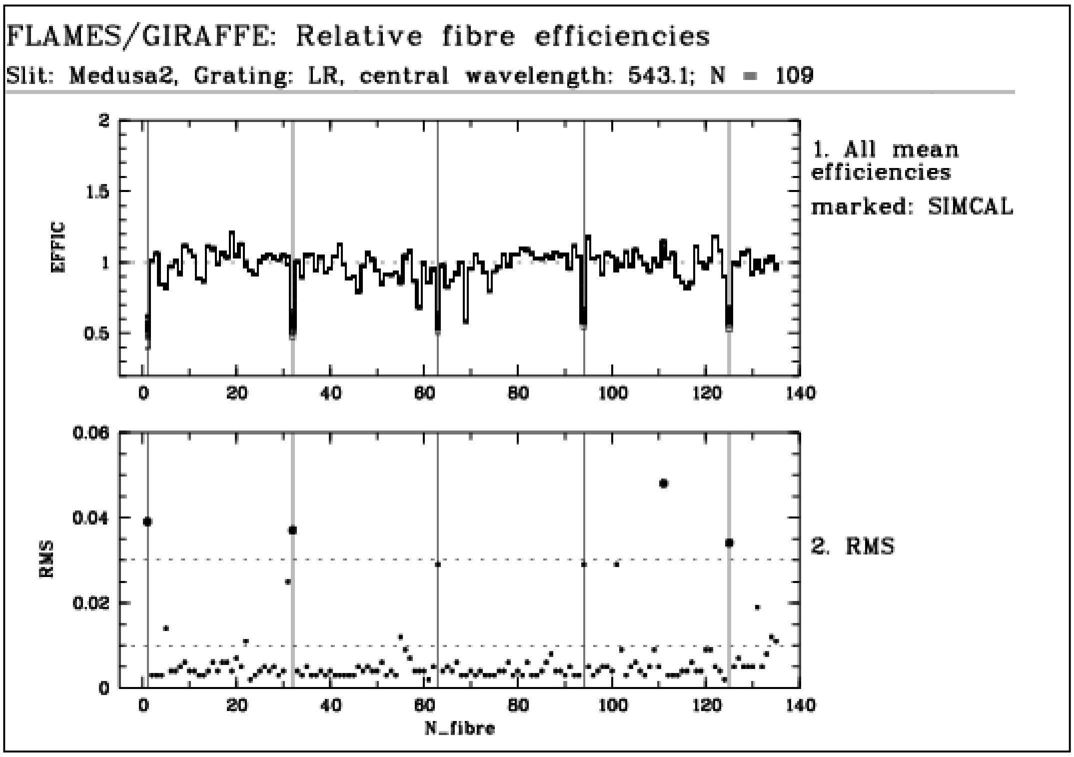

Figure 9. Top: mean efficiencies, normalized to one. The fibres are illuminated by the robotic calibration lamp, except for the SIMCAL fibres which are lit by a dedicated lamp with intrinsically more unstable signal. A total of 109 measurements are plotted here on top of each other. Bottom: the rms of the variations against the mean value from top. Most fibres are stable within 0.3 %. Apart from the SIMCAL fibres, only one object fibres shows rms variations of more than 3% (upper broken line).

4.2. Grating stability

The two GIRAFFE gratings are mounted side by side. Their stability is monitored through daily arc-lamp exposures in all five slit systems, using the SIMCAL calibration lamp only. Crucial for monitoring are sudden shifts (e.g. by an earthquake) and slow thermal drifts. As the trending data show in Figure 8, the thermal drift in dispersion direction is about 1 pixel.

4.3. Relative fibre efficiency

In Medusa mode, any fibre can be used as a SKY fibre, while IFU and Argus have dedicated SKY fibres. In either case, the signal measured in these SKY fibres is used to subtract the sky blindly from the science fibres*. With the fibre throughput inevitably varying from fibre to fibre, the stability of the fibre-to-fibre efficiency is crucial for the accuracy achievable for the sky subtraction.

With the daily HC flats in Medusa modes, this stability can be assessed easily. All flats are pipeline-processed. Their extracted signal is collapsed and referenced against a fixed flat from October 2003. The specific variations from fibre to fibre are visible in Figure 9. The rms scatter of most fibres over a period of more than four months is of the order of 0.3%. This means that the sky measured in any of these fibres can be scaled to any other of the ‘good’ fibres with that accuracy. Obviously you may want to de-select the ‘bad’ fibres from sky measurement.

These measurements also play an important role to monitor the fibre availability: if any of the fibres gets broken, its rms will increase immediately.

*After the text went to print, it was realized that this sentence might be misleading. We mean "… is used by the astronomer to subtract the sky signal from the science fibres". The GIRAFFE pipeline does **not** subtract any sky signal.

5. CONCLUSIONS

Despite its complexity, the GIRAFFE spectrograph has been very successful in operations since it started duty in March 2003. The general ESO concepts of Quality Control and Trending have been smoothly extended to GIRAFFE. Despite the lack of pipeline support in its first year, the most fundamental QC data, procedures and parameters could be established from the beginning which helped to assess the performance and maintain the quality of the instrument. This process will be extended and further improved to include e.g. resolution monitoring and end-to-end system throughput measurements.

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