Quality Control of the 3D spectrograph SINFONI

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Abstract

SINFONI is composed of an adaptive optics module and an integral field spectrograph based on image slicers, working in the near infra-red. SINFONI is mounted on UT4 of the VLT and is offered since April 2005 in service mode. As all other VLT data, SINFONI science and calibration data are processed, archived and quality checked. The SINFONI pipeline, installed on Paranal Observatory for quick-look purpose and used in ESO headquarters in expert mode extracts quality characteristics in terms of QC parameters, that are trended and archived. The new challenge was the design and implementation of QC parameters related to the cube reconstruction, that differs from reconstruction methods used for fiber fed integral field spectrographs.

Key words: integral field spectroscopy, image slicers, image reconstruction

1. Introduction

The integral field spectrograph SINFONI [1] is operated by ESO Paranal Observatory since April 2005 in service mode. It is composed by an adaptive optics module [2] and the spectrograph providing diffraction limited spectra in three IR wavelength bands (J, H, K, H+K) in three image scales (250 mas/pixel, 100 mas/pixel, 25 mas/pixel). The image slicers projects the image in 32 sliced side by side on the detector. The SINFONI data reduction pipeline [3] calibrates the spectra and transforms the data into a data cube, where the first two dimensions are the sky coordinates and the third axis is the calibrated wavelength.

SINFONI is operated, as all other VLT/VLTI instruments, within the common VLT data flow system [5], meaning raw data are transfered to ESO headquarters for reasons of archiving, processing and quality control.

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In this article we focus on the quality control of the optical distortion of the instrument and the related cube reconstruction, that is applied to all science frames and selected calibration frames.

2. Quality Control Concepts

Quality control (QC) is a shared process between Paranal Science Operations (PSO) and the QC group at ESO headquarters in Garching (`www.eso.org/qc`). PSO verify as part of their daily check list the completeness of the calibration plan and perform a quick check using reference calibrations. QC group in Garching process calibrations and service mode science observations. The processing of calibrations and science data takes into account the closest in time acquired calibrations; furthermore only certified master calibrations are used for the association within the data reduction cascade too. The pipeline calculates quality control characteristics from the raw and processed calibrations. Certified master calibration products and extracted quality control parameters are ingested into dedicated databases accessible via web interfaces (e.g. `archive.eso.org/bin/qc1_cgi`).

A further task of the QC group at ESO headquarters includes the composition of service mode data packages for the PIs. They contain raw and processed calibration and science frames, log files and information on the data quality and the data reduction cascade.

One particular component of QC is the Health Check. The log files of the on-line data reduction pipeline on Paranal, in particular those of the daily or regular acquired health check calibration sequences are sent several times a day to ESO headquarters, since the pixel data take much longer ($\simeq$ 8-14 days) to be available in Garching. These short-term delivered log files contain QC parameters extracted from the on-line pipeline; they are compared with QC values derived from the off-line pipeline at ESO headquarters (see Fig. 1). The health check plots are provided to PSO via a web interface to close the quality control loop between Paranal Observatory and the QC group at ESO headquarters within 1-2 hours.

3. Optical distortion

One difference between integral field unit (IFU) instruments based on fibers (like GIRAFFE and VIMOS) and IFU instruments based on slicers (like SINFONI) is the different handling of the cube reconstruction. The SINFONI pipeline must correct for the optical image distortion as a function of wavelength, as a pre-requisite for re-sampling the individual slices into a single data-cube. Optical distortion is one of the first data reduction steps after the usual SKY subtraction or subtraction of the off-lamp frame. The optical distortion is measured via 75 frames of fiber spectra at different positions in the field of view. Figure 2 shows a reconstructed median image of a combination of a few of these fiber calibration frames. Flats and arc frames are taken within the same calibration observation block for reasons of coherence and for logistic reasons within the calibration cascade [4]. The pipeline recipe derives polynomial coefficients of the distortion model that are monitored as QC parameters. Figure 3 shows a region of the difference between a raw fiber frame and the fiber frame corrected by optical distortion to demonstrate the

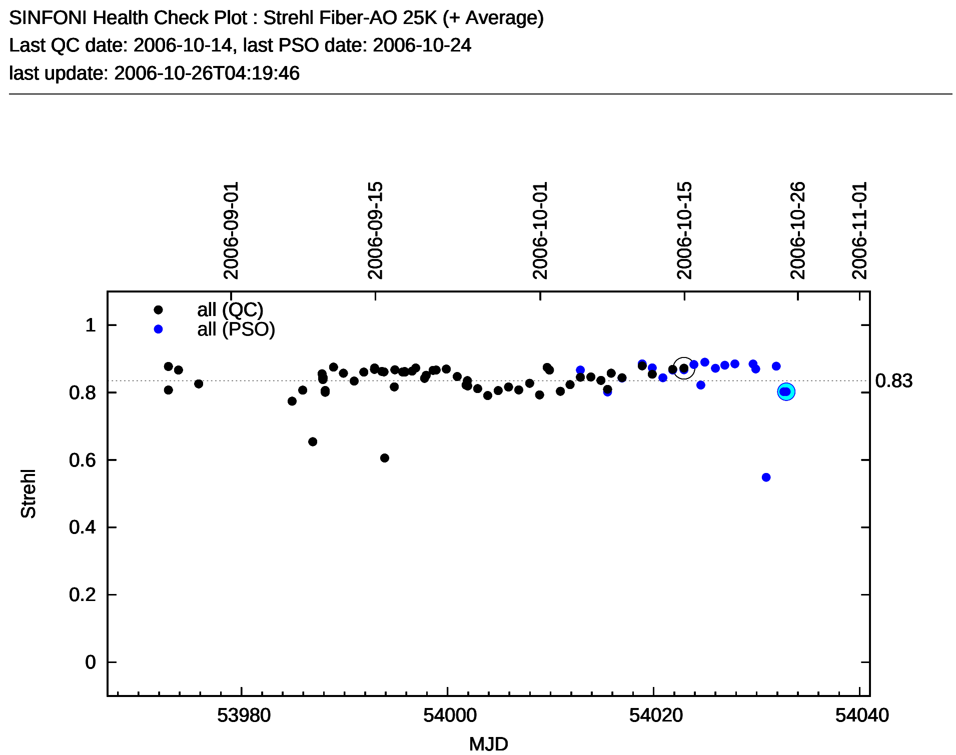

Fig. 1. SINFONI health check plot. The performance of AO facility is tested on an internal fiber. The Strehl ratio is monitored. The plot shows the QC parameters derived from the off-pipeline in Garching (up to 2006-10-14) and the most recent QC parameters extracted from the logs of the on-line pipeline. to compensate the lag of pixel data delivery

degree of applied image alignment. Optical distortion calibrations are updated once a month according to the SINFONI calibration plan.

4. Cube Reconstruction

The cube reconstruction step is an image transformation, to convert the detector read-out format with 32 stripes into a data cube, where each plane is the image at a certain wavelength [3]. The cube reconstruction is an integral part of the data reduction pipeline; it is applied to all science frames, calibration frames containing stars (telluric standard stars or PSF calibration stars) for reasons of the data recution. It is also applied to internal calibration fiber spectra, sky observations and flat field calibrations mostly for the purpose of quality control. For the transformation it is assumed that all slices have a common pixel scale (arcsec/pixel) in spatial x and y direction, but the starting position is allowed to vary. Cube reconstruction parameters are therefore the start position and the width of each of the 32 slitlets. An enhanced method taking the pixel scales in x and y of each slitlet into account is expected to be implemented in the near future. Two data products, the DISTORTION and the SLITLETS_DISTANCE master calibrations contain numerical values like the polynomial coefficients and the distances respectively.

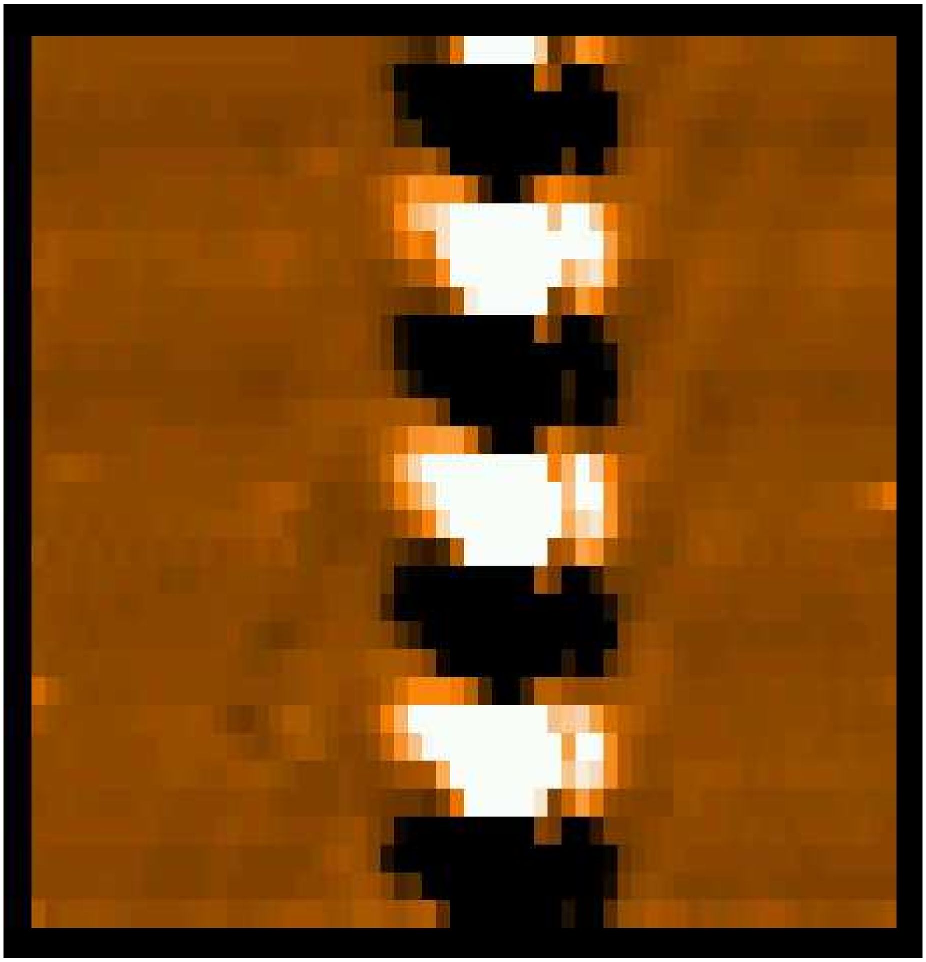

Fig. 2. Cube reconstructed and median collapsed fiber images. Of the 75 fiber frames, only every tenth is shown; they are added and subtracted in alternating into the co-added image for reasons of better contrast. Each fiber exposure is offset from the previous one by a sub-pixel step to scan the whole field y-range of the FOV.

They are used in subsequent data reduction steps of the calibration cascade.

The third calibration product relevant for cube reconstruction is the SLIT_POS product, containing the 32 starting positions of each slitlet. This property is derived from the discontinuities of the dispersion solutions. The dispersion solution is derived from arc line frames that are taken nearly daily.

5. Monitoring

Monitoring within the VLT dataflow means that QC parameters are downloaded from databases to be used for a variety of analysis. So far monitoring is not part of the pipeline itself but part of the assessment of the pipeline products.

Fig. 3. Difference between a raw fiber exposure and the same fiber exposure corrected for optical distortion. Note that the fiber image is chopped in 32 slitlets and projected side by side on the detector by the image slicer.

5.1. *Optical Distortion*

The monitoring of the individual polynomial coefficients of the distortion model is rather academic. It is more practical to apply the distortion model to selected pixels on the detector and monitor the resulting correction offsets in pixels for these detetcor positions. As shown in Fig. 4 the optical distortion correction is applied to 5 selected points of the detector (the central pixel and the pixel central to each quadrant) for the K-band grating. The results for the H+K grating are given in Fig. 5.

For the low-dispersion H+K grating no significant long-term trend can be derived, but the high-dispersion K grating shows a small but significant trend of 1 pixel in 10 months. These long term trending plots show the high degree of stability of the instrument optics and demonstrate the importance of quality control tools for the operation of complex astronomical instrumentation.

5.2. *Slit Positions*

For the cube reconstruction of intermediate pipeline products like raw observations corrected for dark current, optical distortion and flat field, the 32 sliced have to be identified, extracted and re-aligned [3]. For the extraction of the slitlets the discontinuities of the wavelength dispersion solution, derived from arc lamp exposures (Fig 6) is used. The arc lamp frames are acquired daily, hence the SLIT_POS product that contains the left and right rim positions of all slices can be applied in the data reduction cascade taking

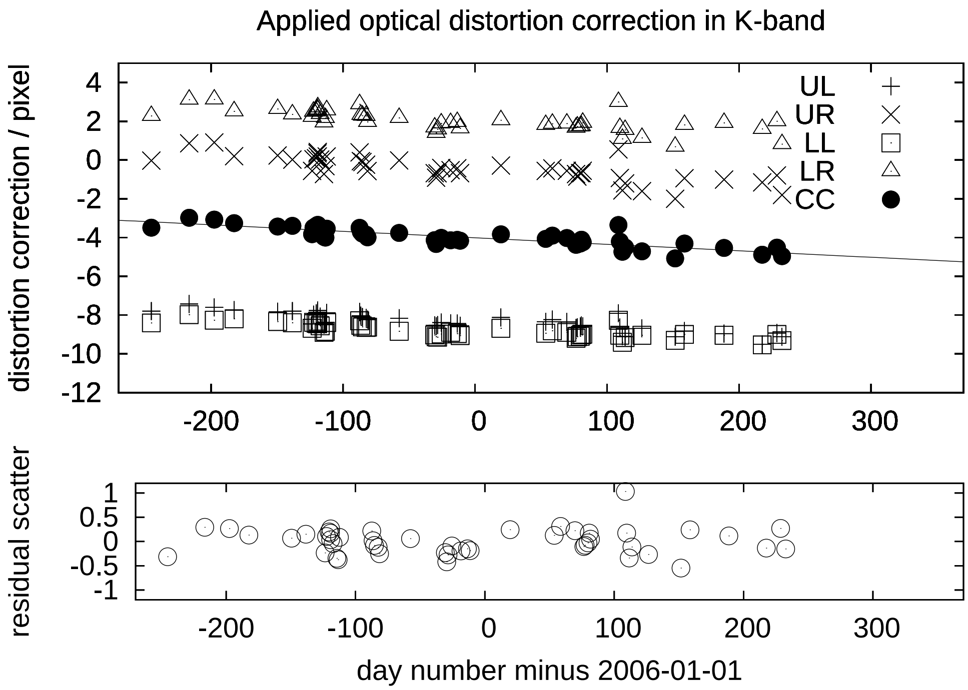

Fig. 4. Long-term trend of the optical distortion correction applied to the central pixel (CC=1024,1024) of the 2048×2048 pixel detector and the central pixels of each quadrant (UL=512,1536; UR=1536,1536; LL=512,512; LR=1536,512). The long-term trend of the CC position is fit by a linear function $f(t) = -3.4 * 10^{-3}\text{t} - 4.01$. The residual scatter ($\sigma$=0.26 pixel) is shown in the lower box.

into account variations of the optics of a shorter time scale. The long-term monitor of e.g. slitlet #17 for the two gratings and the 0.025 camera is shown in Fig. 7 for the first 20 months of operations. Discontinuities in the long term trend are due to instrumental interventions. Sporadic offsets of about 4 pixel are due to the columns with undefined spectroscopic signal between two consecutive slitlets.

6. Operational aspects

In the first year of SINFONI operations 700 Giga byte of service mode raw data have been processed of which 16% are science data. The SINFONI pipeline running in Garching generated 42 400 master calibrations, of which about 18 000 of the certified ones are archived and publicly available. About 10-20% of pipeline processing time is for quality control purpose and does not directly serve for data reduction purpose. The SINFONI QC parameter database contains about 23 000 quality control characteristics derived from calibrations frames.

Upcoming operational events in the near future include the extension of the QC1 parameter database for calibration stars, the commissioning of the laser guide star facility, the sky spider mode and the support of pre-imaging.

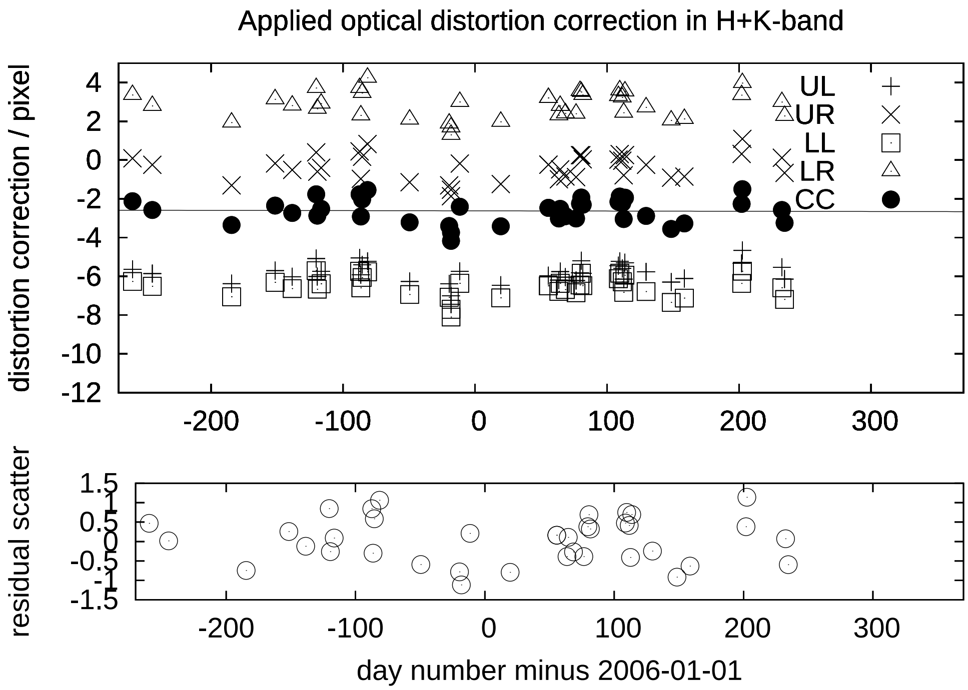

Fig. 5. As Fig. 4, but for the H+K grating. The long-term trend of the CC position is fit by a linear function $f(t) = -1.1 * 10^{-4}\mathrm{t} - 2.62$ and is found to be negligible. The residual scatter (σ=0.63 pixel) is shown in the lower box.

References

[1] Eisenhauer, F. et al. 2003, The ESO Messenger 113, 17
[2] Bonnet, H. et al., 2004, The ESO Messenger 117, 17
[3] Modigliani, A. et al. 2006, these proceedings
[4] Hummel, W. et al. 2006, New Astronomy Reviews 50, 412
[5] Quinn, P. et al., 2002, SPIE 4844, 1

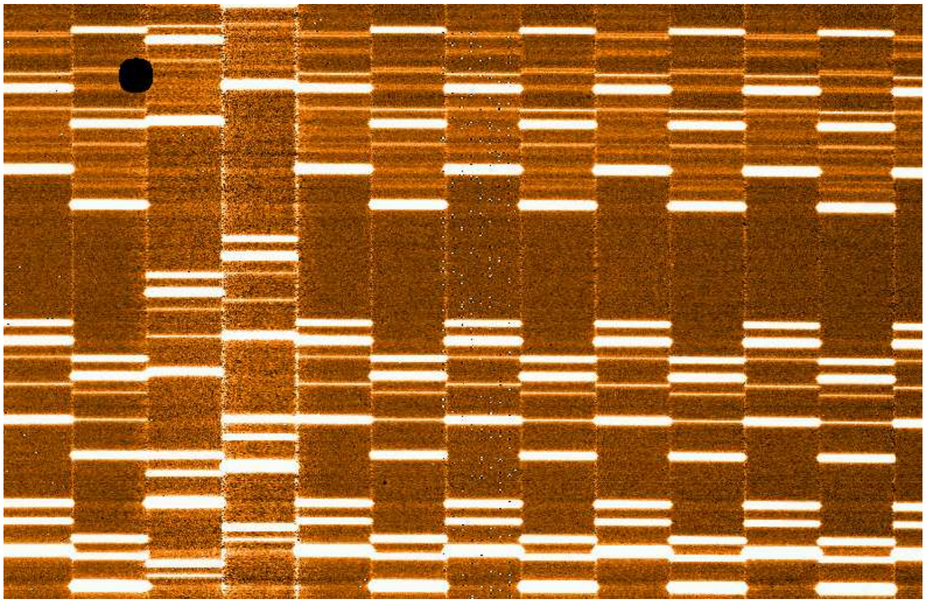

Fig. 6. Wavelength calibration frame, corrected for dark current, optical distortion and flat fielded.

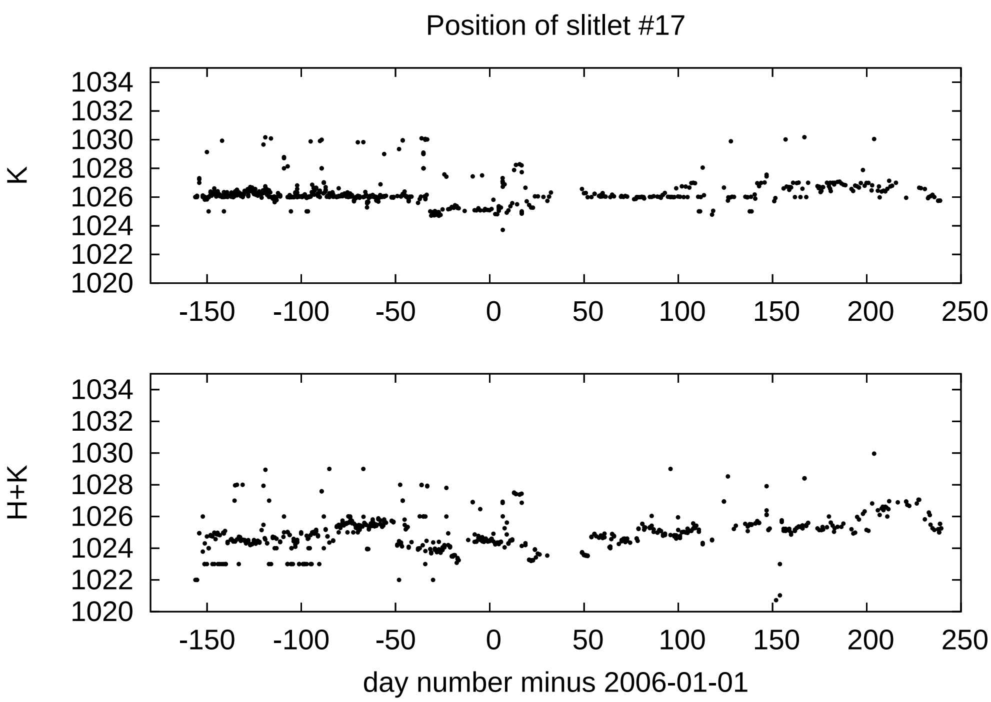

Fig. 7. Left edge of slitlet #17 as derived from daily arc lamp calibrations.