Ultrastable operation of CCDs for high resolution spectrographs

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ABSTRACT

High resolution spectroscopy demands CCD and spectrograph operation in an ultrastable positional and temperature environment, which will avoid shift of the spectral lines on the detector over long term observations. The poster describes the results obtained in the characterization of the HARPS detector system and the plans for the development of a test setup to further improve stability performances.

1. INTRODUCTION

Key long-term scientific goals of the E-ELT, such as indirect detection of Earth-like exo-planets and direct measurement of the expansion of the Universe, require measuring Doppler shifts of astronomical objects with wavelength accuracy significantly beyond the current state of the art (~1 cm/s vs. 100 cm/s). **The initial phase** of ESO's activities in this project therefore tries to understand the performance of a current high-performance system: HARPS at the ESO 3.6m telescope at La Silla. **In a second phase** this system is replicated for lab use together with special metrology to assess and isolate stability parameters. **In a third phase** both sets of results enter into possible stability improvements of the latter system and future generations of detector systems for ESPRESSO (VLT) & CODEX (E-ELT). The currently known ideas for potential improvement of the ultrastable cryostat design for high thermal, mechanical and positional stability are presented.

2. INITIAL PHASE: IN-SITU HARPS STABILITY TESTS

The HARPS detector system has been selected as baseline for first in-situ stability performance measurements with its Th-Ar calibration system. HARPS achieves overall radial velocity accuracy of astronomical objects of 100 cm/s after calibration and removal of systematic effects.

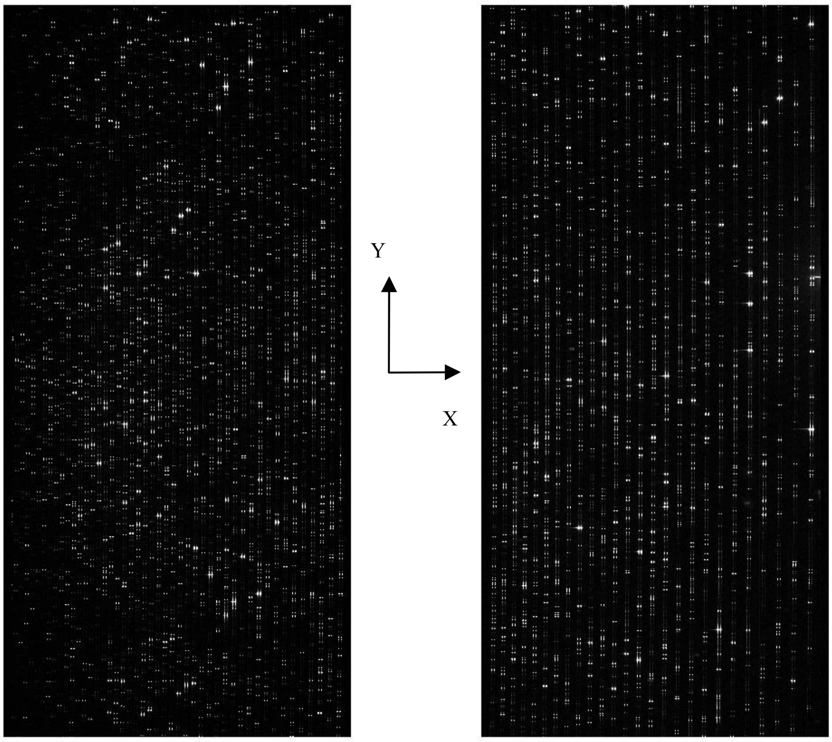

Figure 1: Example of spectra, recorded with the Th-Ar calibration system at the HARPS focal plane, using a mosaic of two 2k x 4k e2v CCD 44-82 detectors with 15 µm pixelsize (blue chip / red chip)

Different sequences of images have been obtained to:

- Measure intrinsic stability using currently valid parameters of the cooling control loop and detector readout parameters
- Look for possible drift due to a ΔT in the temperature set point (pix/ºC)
- Look for possible drift due to a change in the power dissipation of the chips

The following exposure sequences were carried out and analysed:

- Sequence A (6 hours): exposures spaced at ~ 1.5-min intervals (as short as possible, using slow readout at 104 Kpixel/s per CCD) to determine drifts possibly related to the temperature control loop and other short-term effects. Usage of original settings of control loop parameters.
- Sequence B (4 days): exposures spaced at 15 min intervals, to determine possible drifts due to environmental effects and/or drifts in the rest of the spectrograph (due to e.g. diurnal cycle, atmospheric pressure, LN2 tank exchange, etc). No chip activity, except for one dummy dark – a dark exposure not needed for the data set, but required to space the exposures.
- Sequence C (6 hours): Immediately after sequence B with low chip dissipation, start a period with high chip activity between individual exposures instead of the dummy dark (say N 1-sec dummy darks at high readout speed), to look at the effect of chip dissipation on drift.
- Sequence D (9 hours): After a stabilization period of 24 hours with no activity, start sequence type A (1.5 minutes between exposures). After 3 hours increase the temperature set point of the detector chip by + 0.5K while the sequence is going on, after again 3 hours change set point temperature back to nominal.

3. INITIAL PHASE: MAIN RESULTS SUMMARY

Sample results of sequences A and D are shown in Figure 2 & 3:

The spectral lines measured in each exposure are centroided. The difference of these centroid positions with respect to their centroid position from the first reference frame per sequence yields the shifts (x-x0) [pix], (y-y0) [pix].
Tccd is the measured temperature of the detector baseplate.

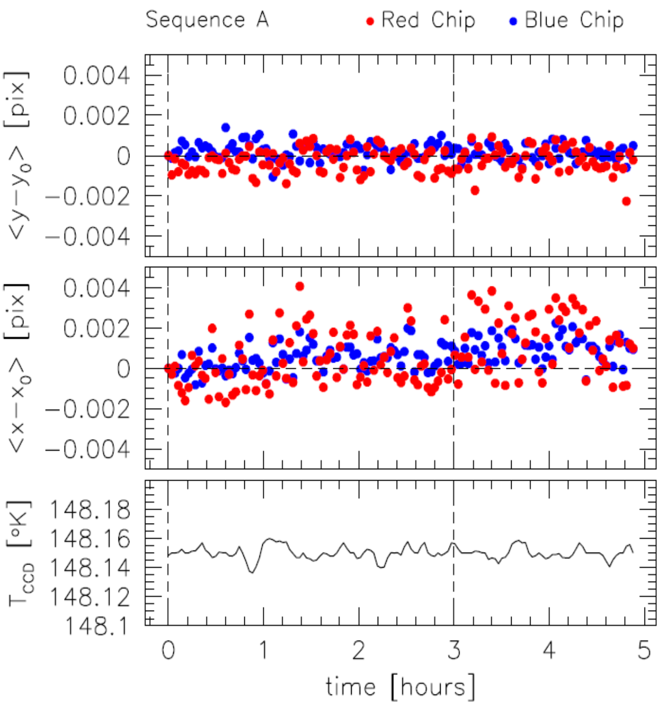

Figure 2: Mean shifts for all observations in Sequence A

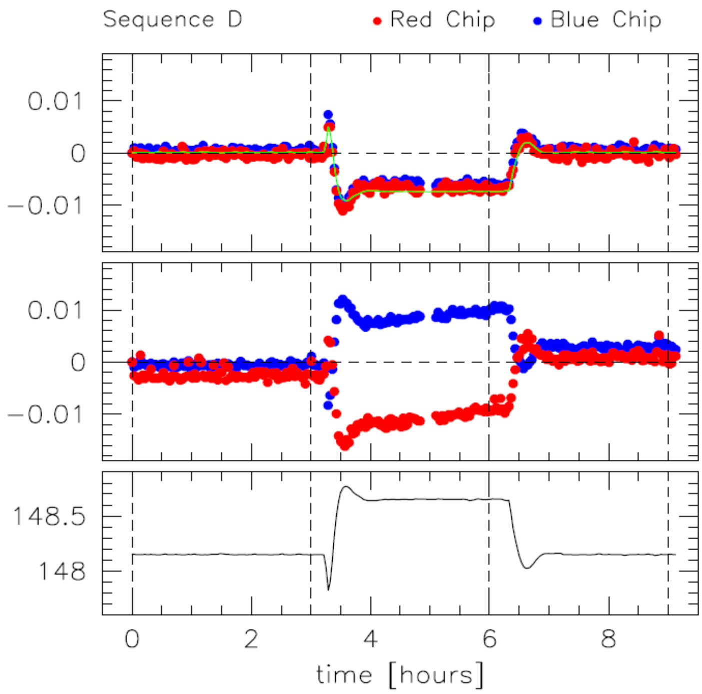

Figure 3: Mean shifts in Sequence D

Figure 2 shows the mean shifts for all observations in Sequence A:
A linear fit of "blue" sequence in the central plot shows a slope of $2.16 \pm 0.36\times10^{-4}$ pix/h. The RMS of the fit residual is 5.93×10^{-4} pixels, while the dispersion of the blue points in the upper plot is 3.95×10^{-4} pixels. Both numbers are very close to the error associated to any single image, which is $\sim5\times10^{-4}$ pixels. Temperature is recorded in the bottom plot, but no real correlation can be found. The computed shift is in the order of $\sim10^{-4}$ pixels, corresponding to 1.5 nm or a radial velocity drift of ~ 0.1 m/sec.
Figure 3 shows the mean shifts for all observations in Sequence D:
Opposite movements of blue and red chip after deliberate temperature setpoint changes can be seen, which indicates an expansion of the CCD mosaic table in x direction (cf. Figure 1).

4. SECOND PHASE: PLANS FOR THE LAB TEST FACILITY 'ULTRASTABLE CRYOSTAT'

Due to the limited availability and the necessity to leave the operational HARPS configuration unchanged as a stable instrument, it is planned to replicate the HARPS cryostat in the lab test facility 'ultrastable cryostat' with the following changes:

Improved thermal control and monitoring system: A Lakeshore temperature controller 340 will operate up to four Cernox sensors CX1080 at a stability of ~ 2 mK at 140K. Usage of CCD engineering grades enables for the first time to glue a temperature sensor directly to the light sensitive operative CCD silicon. Its relative temperature change can be assessed and correlated to a positional pixel instability.

Motion measurement systems:

a.) Capacitive position sensors: The primary motion sensor is a capacitive sensor glued with one electrode to one of the CCD light sensitive surfaces. The expected resolution is in the sub nm-range.

b.) Multispot projector: An independent direct validation system, which is mimicking in the lab the functionality of the calibration system of the HARPS spectrograph, without the optical and data analysis complexity of the latter (see figure 4).

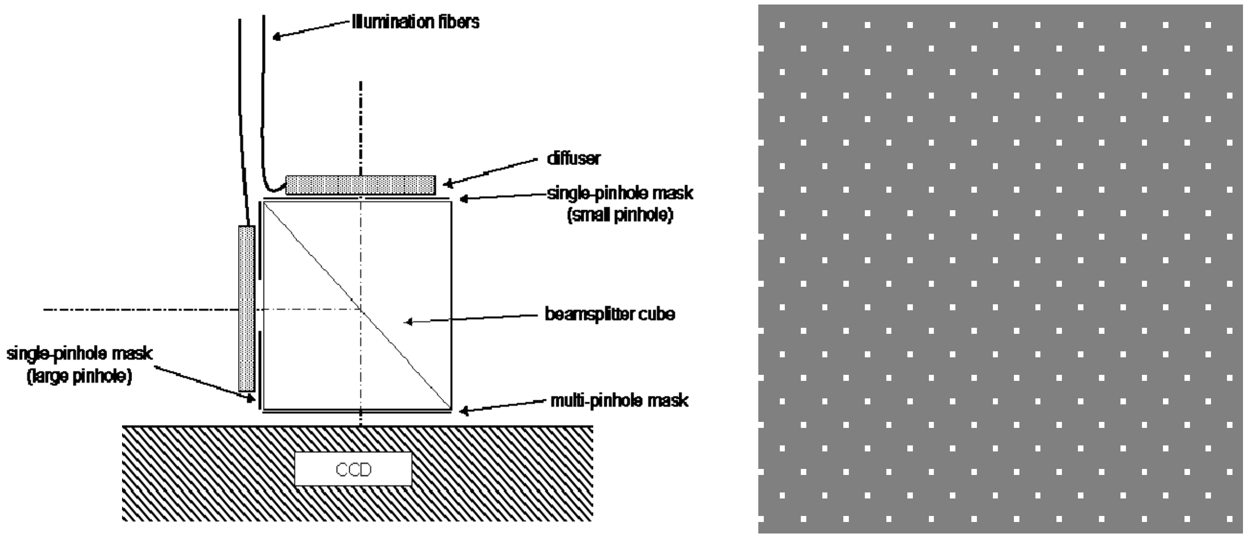

Figure 4: Principle of the multispot projector (left) and projected multi-spot pattern on the detector (right). With a spot spacing of 300 µm, a 10 x 10 mm field will contain 1000 spots. Assuming a centroiding accuracy of 1/100 of a pixel (150 nm), the average accuracy is about 5 nm RMS for a single exposure.

The fibre fed projector consists of a multi-pinhole mask producing an array of small spots. The illumination wavelength can be varied according to the needs. For flatfielding (overcoming CCD PRNU) a second, larger flatfield pinhole is mounted on the side of the beamsplitter cube producing a pattern of larger spots, complementing the small spots. The true (relative) intensities are found by subtracting a dark frame from the multi-pinhole image and dividing this by the flatfield frame.

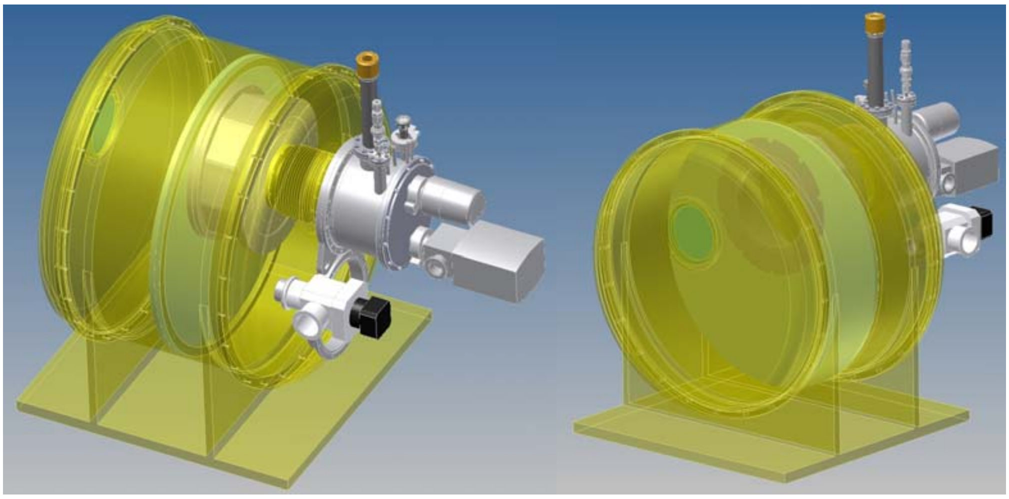

Figure 5: Detector cryostat integrated into the vacuum chamber for test at ESO Garching

5. THIRD PHASE: POSSIBLE IMPROVEMENTS IN THE NEXT GENERATION OF DETECTORS / CRYOSTATS FOR ESPRESSO / CODEX

ESPRESSO and CODEX aim for radial velocity accuracy of 10 cm/sec RMS, respectively 1 cm/sec RMS over 20-30 years. Both require a detector format of at least (90 mm x 90 mm) for each blue and red channel. A subset of the following improvements can be tested inside the ultrastable cryostat:

a.) Mechanics: Reduce thermal conductance between cold heat exchanger and cold bench; improve radial stabilisation of cold bench; increase thermal inertia of cryostat cold bench.
b.) Materials: CCD package and (mosaic) baseplate made of sintered silicon carbide, see Figure 6

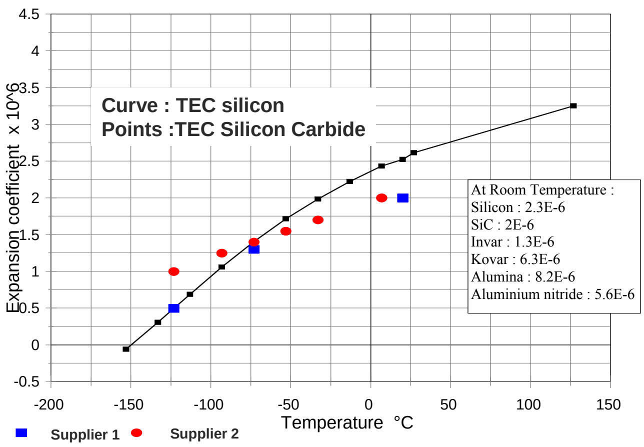

Figure 6: Thermal expansion coefficient of silicon versus silicon carbide at CCD operating temperature and room temperature (Reproduced by permission from authors.)

c.) Electrical operation: Operate CCDs with dummy serial clocking also during integration for constant power consumption.
d.) Temperature Control: Improve relative accuracy of thermal control through not measuring the absolute temperature with the 'correct' look-up table for the respective sensor, but using a steeper part of the curve for relative temperature information. This way only relative changes are considered and the temperature control loop is more sensitive to those.

6. ACKNOWLEDGMENT

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