Monitoring and Characterisation Program

R. Alonso (IAC / ULL)
Core Science Team member
Coordinator of Working Group B1 "Characterisation of the photometric performances"

Approach and working definitions

- There is no hardware to perform calibration of the instrument on fly (e.g. shutter or LEDs illuminating the detector).
- Instead, a Monitoring and Characterisation (M&C) program is envisaged, defining particular targets and observing modes that allow to monitor the performance of the instrument.
- **Monitoring**: "To keep track of systematically with a view to collecting information."
- **Characterisation**: "The act of describing distinctive characteristics or essential features."
- The M&C **procedures** (observations + data analysis + updates of reference files) are under responsibility of Project Science Office (PSO) with support from the Science Team.
- **Calibration**: "the act of checking or adjusting (by comparison with a standard) the accuracy of a measuring instrument"

M&C Procedures:

- Flat-field
- Dark current
- Maps: Dead pixels, bright pixels.
- Straylight.
- Point-Spread Function (PSF)
- Detector gain and Charge-transfer inefficiency (CTI) (*in progress*)

Some of the measurements aim to monitor the evolution of parameters measured **on-ground** (e.g. Flat-field, pixel maps, see previous talk by Adrien Deline), others aim to monitor the evolution of parameters measured during **In-Orbit-Commissioning** (e.g. Straylight, PSF, see previous talk by Andrea Fortier)

Flat field

M&C: Goal

Monitor the temporal evolution of the flat-field at different parts of the focal plane, and verify the validity of the default flat-field (on-ground)

Procedure

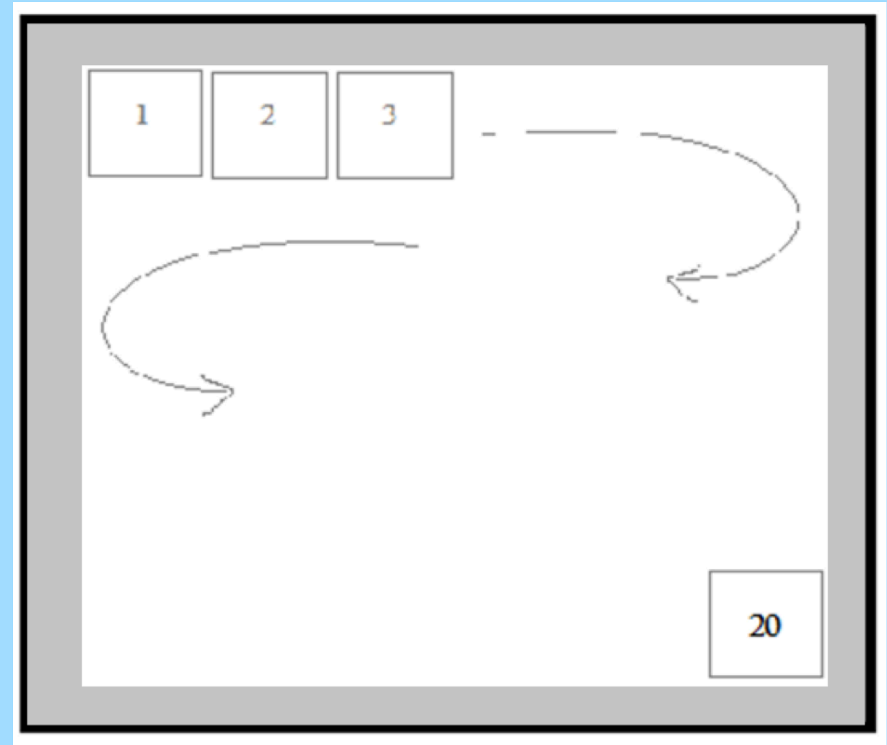
150 CCD window images (200x200 px), spatially displaced thanks to jitter, at ~25 different positions of focal plane, taken with short exposure times. *Kuhn, Lin & Loranz (1991) algorithm*

Targets

Bright stellar clusters

Cadence & expected duration

Every 3-6 months, visit duration ~120 min



Schematic representation of the sampling of the full frame CCD using 200x200 window frames and scanning the focal plane.

Output

Flat-field images (lower precision as the ground-based data is expected)

Dark current

M&C: Goals

Monitor the temporal evolution of the dark current, expected non-detectable at beginning of mission.

Locate and characterise new hot pixels in the nominal CCD window.

Procedure

During commissioning: exposures before opening the telescope cover.

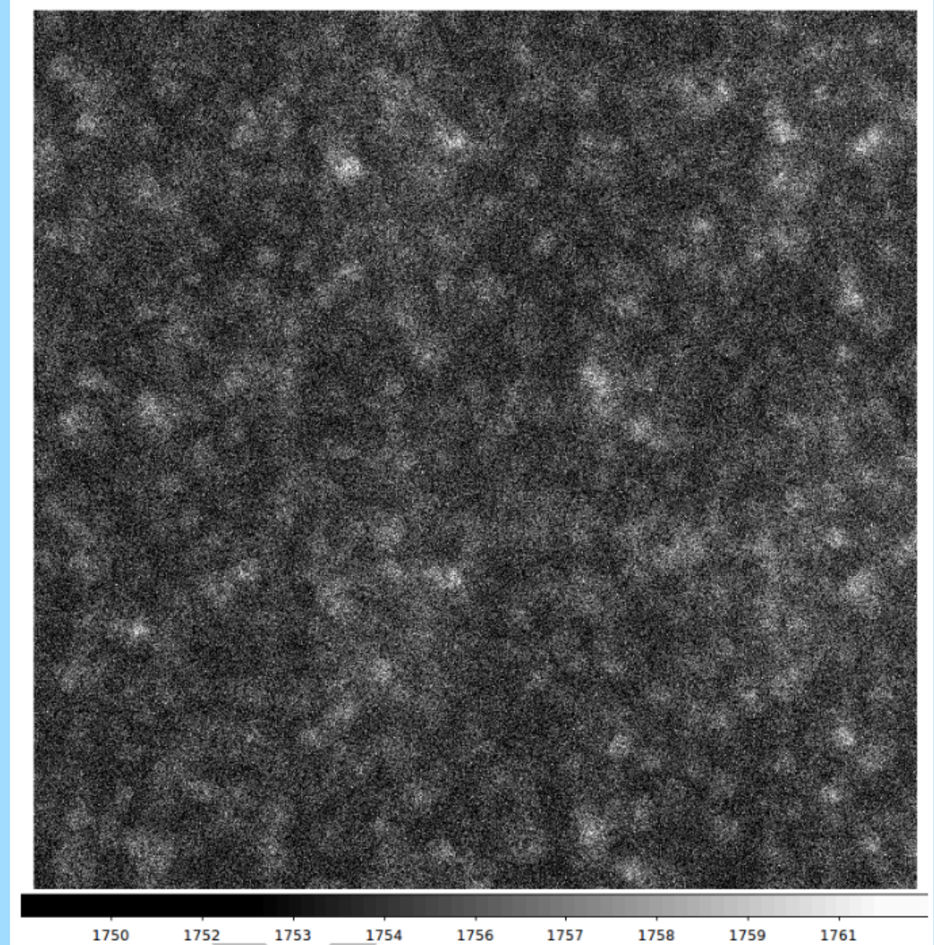
After commissioning: short and long exposure times of regions of the sky void of stars, dithering in 12 positions

Targets

Dark regions of the sky ("empty" fields)

Cadence & expected duration

CCD monitored every week.



Simulated full frame image (1024x1024 px) obtained by median-stacking of 12 images shifted spatially. The bottom bar reports the count rate in ADU.

Output

Full-frame dark current map.

Straylight

M&C: Goals

Monitor and characterise the straylight at different angular distances.

Used to update the scheduling constraints due to the limiting factors —> affects visibility constraints.

Procedure

Observe targets getting close to illuminated sources.

Targets

1) Stars approaching the Moon (see Figure)

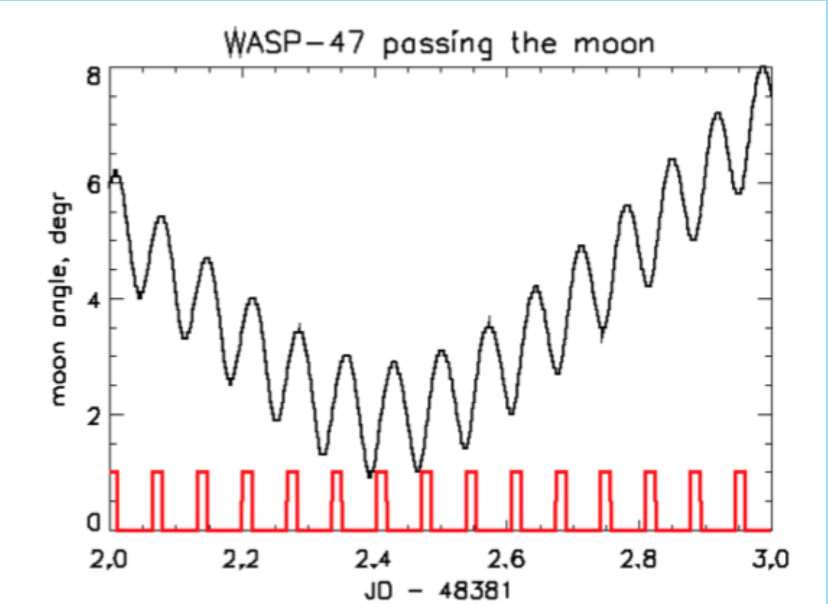
2) Stars with Line Of Sight perpendicular to CHEOPS' orbital plane.

3) Stars getting close to illuminated Earth

Cadence & expected duration

Target 1) during commissioning, and every ~6 months.

Targets 2) during commissioning, targets 3) monitored during nominal observations



Monitoring a target while the Moon passes nearby. The black line plots the distance of the target to the Moon, showing the parallax effect due to the polar orbit. The red bars mark Earth occultations. In aprox. 12h of observations, it is possible to monitor distances from 1 to 8 degrees from the target.

Output

Measurements of the PST (Point Source Transmission). Updates on scheduling constraints.

Dead/bright pixels map

M&C: Goals

Update the positions of dead and bright pixels, notably in the nominal CCD window, for use in Data Reduction Pipeline (*see talk on DRP by S. Hoyer*).

Procedure

Dead pixels: response significantly lower than nominal. Obtained as byproduct of the straylight images. Also from images of the nominal targets right before/after Earth occultation.

Bright pixels map: dark level significantly higher than nominal. Obtained as byproduct of dark current monitoring. Images of the nominal targets to study the temporal evolution of hot pixels and identify RTS (Random Telegraphic Signal) pixels*.

Targets

Byproducts of dark monitoring, straylight monitoring, and nominal science observations

Cadence & expected duration

CCD monitored every week.

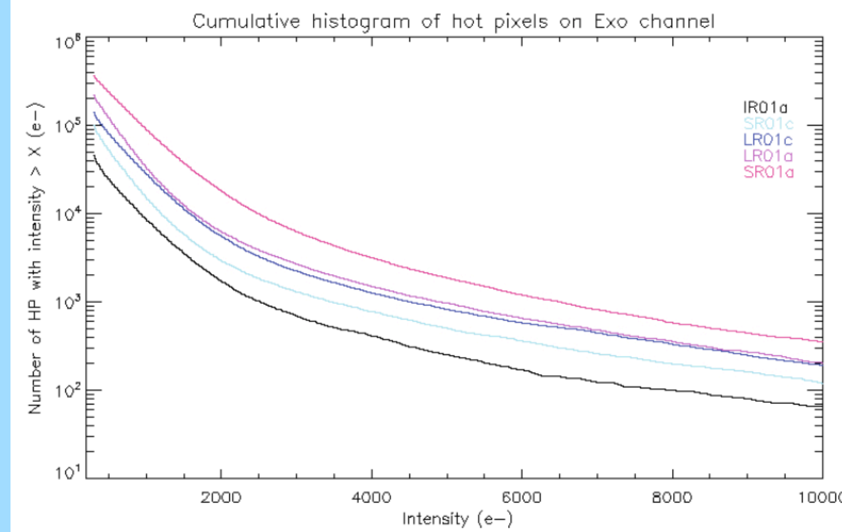


Fig. 6. Number of hot pixels having an intensity higher than x electrons at the beginning of the five first runs on the PF CCDs.

Data from CoRoT showing the increase with time of the number of hot pixels (Auvergne et al. 2009, A&A, 506, 411). The weekly dark current maps in CHEOPS will be used to perform similar statistics of hot pixels.

Output

Updated maps of malfunctioning pixels

* : Pixels with apparently chaotic behaviour switching between two or more intensity levels. See e.g. https://en.wikipedia.org/wiki/Burst_noise

CHEOPS

PSF monitoring

esa

M&C: Goals

Locate the region of the CCD that provides the most symmetrical PSF.

Notice that the PSF in the CCD nominal window will be best known through the nominal observations.

Procedure

Short exposures of single bright targets, scanned over different positions of the focal plane.

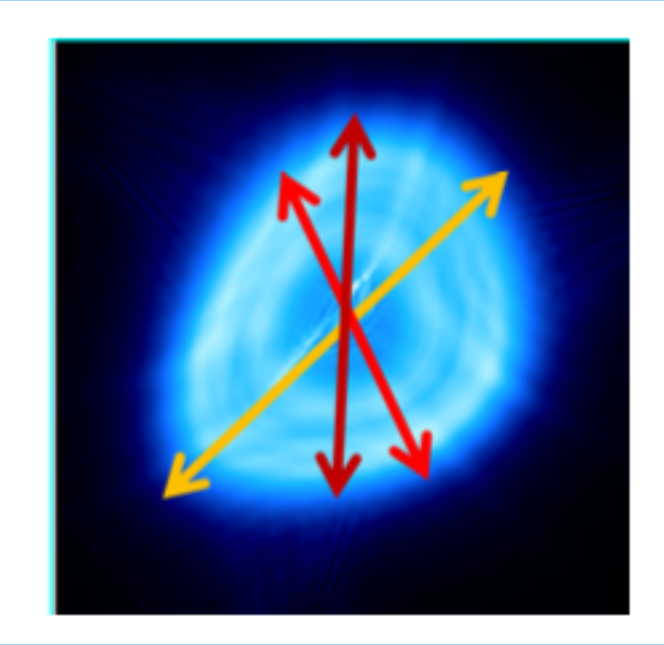
Different parameters to quantify the PSF shape.

Targets

Isolated very bright stars (V~6)

Cadence & expected duration

Every ~6 months, a full scan takes 1-14h depending on the number of positions being scanned



A simulated PSF and different parameters (size of the PSF at different angles) to be measured for the selection of the best CCD position for the nominal 200x200 px observing window.

Output

Parameters of the PSF at different CCD positions.

Gain and CTI monitoring

M&C: Goals

Monitor the evolution of the detector gain and of the Charge Transfer Inefficiency (CTI).

If CTI starts to be significant, the results from the CTI monitoring will be used to inform the DRP in order to perform a CTI correction.

Procedure

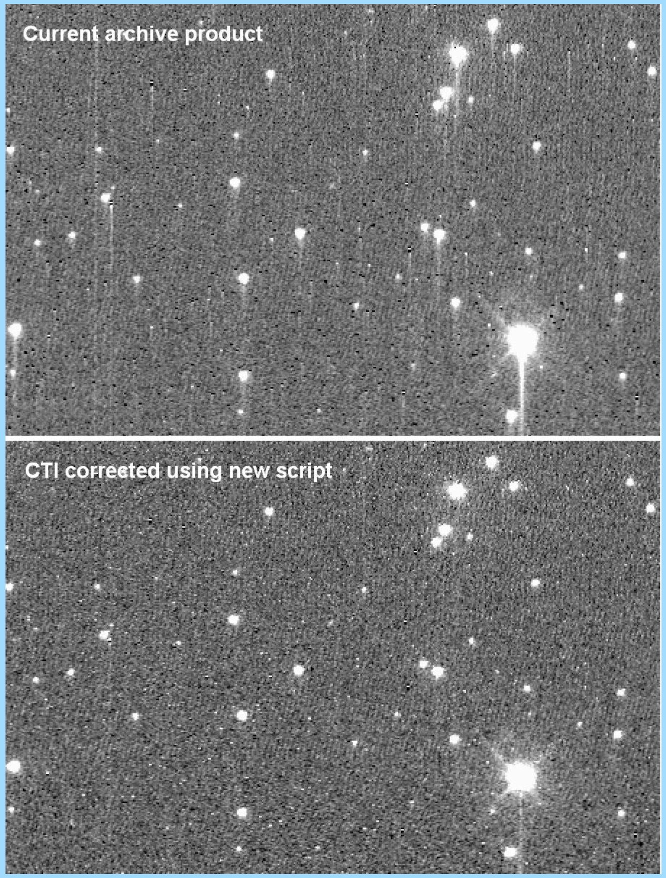
In progress. Will be fed from the the nominal observations, and thus no individual M&C observation needed.

Targets

Nominal targets.

Cadence & expected duration

N/A



HST archive images affected from the CTI , and the results after its correction. From http://www.stsci.edu/hst/stis/software/analyzing/scripts/pixel_based_CTI

Output

Evaluation of the CTI; if above a given threshold, inform the DRP to plug-in the CTI correction modules.

M&C using nominal observations

M&C: Goals

Monitor the global performance of the instrument + Data Reduction Pipeline (DRP).

Procedure

Observations in the nominal mode, potentially of selected targets (a reference transit, or a stellar candle).

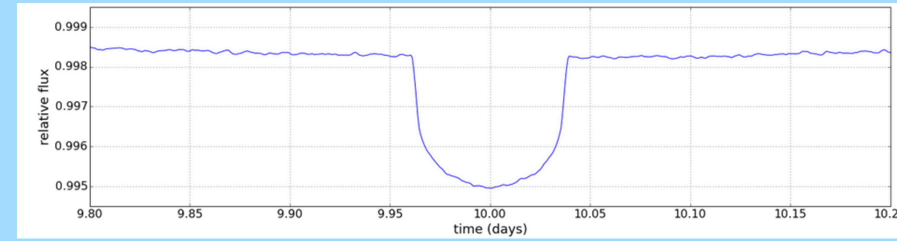
Evaluation of the output of DRP using different indicators.

Targets

Science visits, selected reference transits and stellar candles.

Cadence & expected duration

Every few months for reference transit or stellar candle observations. Duration about 5-6h for targets that are not already in the GTO program.



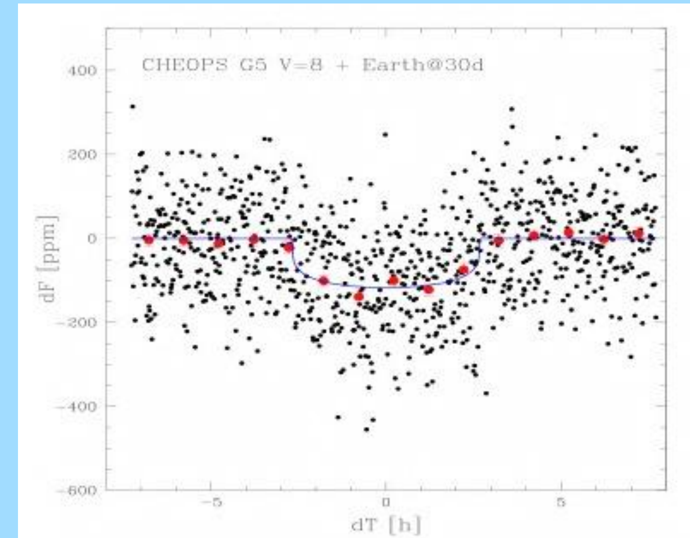


Fig 5: Simulation of a transiting Earth size-sized planet of 60 day period orbiting a G5 star of 8th V-magnitude as observed by CHEOPS. Sampling time is 1 minute and photon noise 100 ppm/minute. The red dots indicate 1h-averaged photometry. This light curve illustrates a transit detection with a S/Ntransit=10.

Output

Global performance indicators. Potential updates to observation planning tools (ETC, SnR estimations).

M&C reports

- M&C programmes will allow analysing CHEOPS performance evolution over time.
- Results from the analysis will be made available to the Community as Instrument Science Reports (ISRs).
- ISRs will consist of:
  - Reference number, title, list of authors, issue date
  - Abstract, introduction setting the context of the work reported
  - Log of observations used
  - Data analysis description
  - Discussion
  - Conclusions summarising the findings and describing the next steps
  - Reference list

Thank you!

CHEOPS esa

Appendix: Details on the Kuhn, Lin & Loranz 1991 algorithm

Taken from Xu et al. 2016, ApJ, 827, 137

2. KLL FORMALISM

The basic steps of KLL's method are as follows. Consider an image that is shifted by a vector $\boldsymbol{a}_i$ from an invariant source s,

$$s_i(\boldsymbol{x}) = s(\boldsymbol{x} - \boldsymbol{a}_i), \quad (2)$$

where $\boldsymbol{x}$ represents a pixel in the CCD frame and i represents the ith frame in a series $i = 1, \ldots, N$. After subtracting the dark current and amplifier bias at each pixel, we have

$$d_i(\boldsymbol{x}) = g(\boldsymbol{x}) s_i(\boldsymbol{x}), \quad (3)$$

where d_i and g are the observed image and pixel gain at $\boldsymbol{x}$ on the CCD. Thus, we assume that the source image does not change between observations. So

$$\frac{d_i(\boldsymbol{x} + \boldsymbol{a}_i)}{d_j(\boldsymbol{x} + \boldsymbol{a}_j)} = \frac{g(\boldsymbol{x} + \boldsymbol{a}_i)}{g(\boldsymbol{x} + \boldsymbol{a}_j)}. \quad (4)$$

The logarithmic form of the above equation is

$$D_i(\boldsymbol{x} + \boldsymbol{a}_i) - D_j(\boldsymbol{x} + \boldsymbol{a}_j) - G(\boldsymbol{x} + \boldsymbol{a}_i) + G(\boldsymbol{x} + \boldsymbol{a}_j) = 0, \quad (5)$$

where $\log d_i \equiv D_i$ and $\log g \equiv G$. Then a solution for $G(x)$ is to minimize

$$\sum_{i<j,x} [D_i(\boldsymbol{x} + \boldsymbol{a}_i) - D_j(\boldsymbol{x} + \boldsymbol{a}_j) - G(\boldsymbol{x} + \boldsymbol{a}_i) + G(\boldsymbol{x} + \boldsymbol{a}_j)]^2. \quad (6)$$

Since the function G is independent of the observation, the problem is that there is no exact solution. But we can seek a least-squares solution for the gain function G, that is

$$\sum_{i<j} [G(\boldsymbol{x}) - G(\boldsymbol{x} - \delta_{ij}) - D_i(\boldsymbol{x}) + D_j(\boldsymbol{x} - \delta_{ij})] + \sum_{i<j} [G(\boldsymbol{x}) - G(\boldsymbol{x} + \delta_{ij}) - D_j(\boldsymbol{x}) + D_i(\boldsymbol{x} + \delta_{ij})] = 0, \quad (7)$$

where $\delta_{ij} = \boldsymbol{a}_i - \boldsymbol{a}_j$ and the first sum on the left-hand side of the above equation is over all distinct i and j. Since finding an exact solution to Equation (7) is difficult, we construct solutions by iterating from an initial guess $G^0(\boldsymbol{x}) = 0$. The solution at iteration $r + 1$ is given by

$$G^{r+1}(\boldsymbol{x}) = K(\boldsymbol{x}) + \frac{1}{n(\boldsymbol{x})} \sum_{i<j} [G^r(\boldsymbol{x} - \delta_{ij}) + G^r(\boldsymbol{x} + \delta_{ij})]. \quad (8)$$

where

$$K(\boldsymbol{x}) = \frac{1}{n(\boldsymbol{x})} \left\{ \sum_{i<j} [D_i(\boldsymbol{x}) - D_j(\boldsymbol{x} - \delta_{ij})] + \sum_{i<j} [D_j(\boldsymbol{x}) - D_i(\boldsymbol{x} + \delta_{ij})] \right\} \quad (9)$$

and $n(\boldsymbol{x})$ is the total number of terms. This has the form of a relaxation solution to Poisson's equation. The average of surrounding pixels from the previous iteration determined the iterated solution at a given pixel. This is the basis of KLL's method (Kuhn et al. 1991).