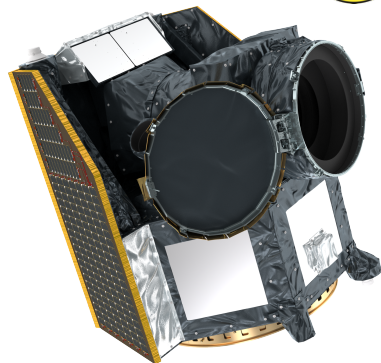




Systematics in the light curves



Systematics in the light curves

In general, CHEOPS does not have many instrument systematics to be worried about. The most important to consider are:

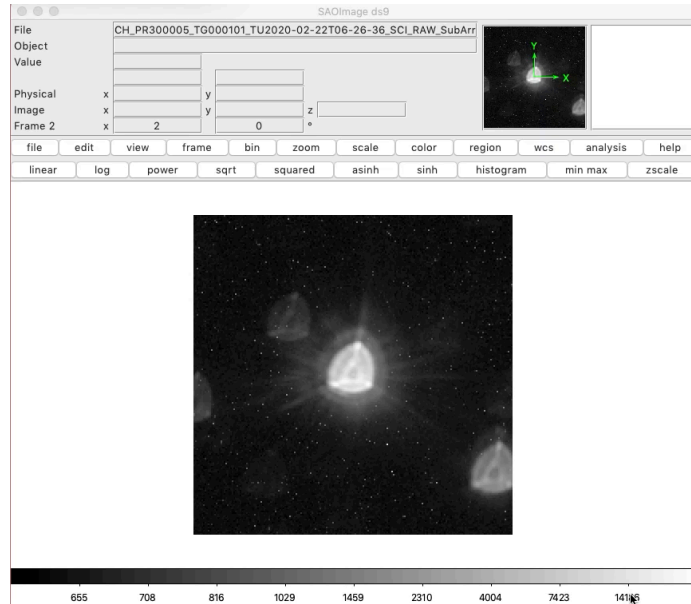
- ❖ Correlations with the roll angle:
 - Stars in the field of view
 - Smearing trails from (bright) stars in the FoV
 - Earth stray-light
- ❖ Correlations with the pointing jitter
- ❖ Internal reflections (optical reflections within the telescope)
- ❖ Correlations with the telescope tube temperature (flux ramp)
- ❖ (Potential) correlations with bad pixels

Most of these systematics are corrected by the Data Reduction Pipeline (DRP, Hoyer et al. 2020) and `pycheops` (Maxted et al. 2021, MNRAS, <https://github.com/pmaxted/pycheops>).



Correlations with the roll angle

Movie



¹PSF large size is responsible for the contamination level, while PSF asymmetry is responsible of the roll dependency with the stars in the FoV.

❖ Stars in the field of view:

As shown in the movie on the left, neighbouring stars rotate around the line of sight. This is because CHEOPS is in a nadir-locked orbit. Due to the large size and asymmetrical shape of the PSF¹, background stars will contaminate with their flux the photometric aperture. Therefore, the measured flux will depend on the position of the satellite in the orbit. That is, the photometric extraction will show a correlation with the roll angle. The background contamination is simulated by the DRP, which provides the background LC that can be used to correct the target's LC. Pycheops can be used to improve the precision by decorrelating against roll angle.

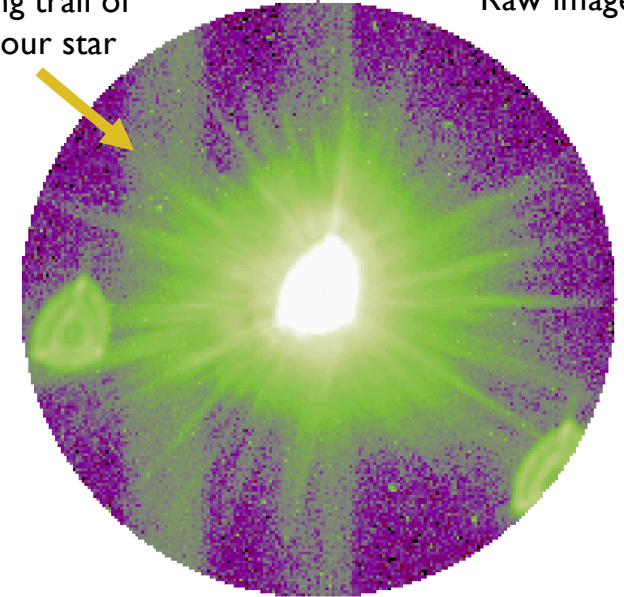
Correlations with the roll angle

❖ Smearing trails from (bright) stars in the FoV:

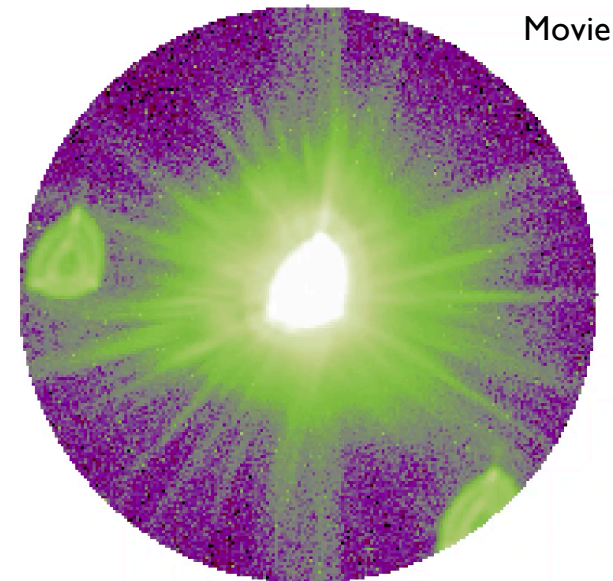
CHEOPS has no shutter. After an image is acquired in the exposed section of the CCD, it is fast transferred to the covered section for read-out. This transfer takes 25 milliseconds. During this time, the pixels of the CCD continue collecting photons. This causes all the stars in the Field of View to leave smearing trails in the image. Very bright stars will leave stronger smearing trails that move horizontally inside and outside the aperture (see movie), correlating with the roll angle. Smearing trails are corrected by the DRP and residuals are corrected by `pycheops` using the decorrelation against the roll angle.

Smearing trail of neighbour star

Raw image



Movie

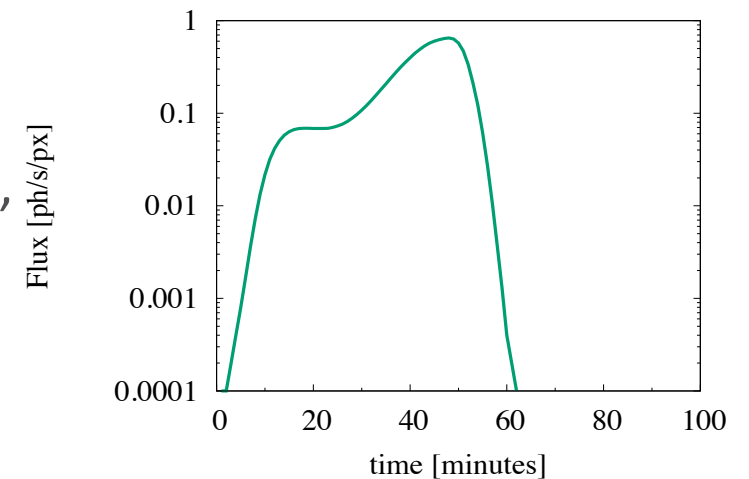
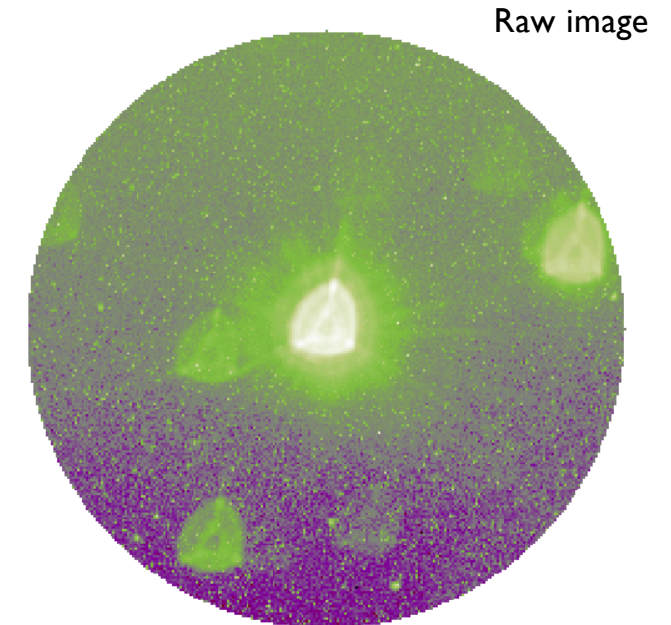


Correlations with the roll angle

❖ Earth stray-light

When the line of sight is close to the illuminated Earth limb, the background of the images can become very bright (and maybe also inhomogeneous). The image on the right represents a rather extreme example of this case. The stray light contamination follows the periodicity of the orbit during which it goes from ~ 0 to the maximum value (as in the figure on the bottom right).

The DRP performs homogeneous background correction. However, if there are gradients in the image, this correction will not eliminate them. Our recommendation is to exclude images with high background contamination or corresponding data points from the LC analysis.



Example of Earth SL variation in one orbit

Correlations with pointing jitter

- ❖ CHEOPS pointing is not stable within a pixel. It generally jitters around with an amplitude of 2-3 pixels depending on the pointing direction. If the star is fainter than $G = 11$, the pointing can also drift in time (NOPITL). A linear decorrelation against x and y will compensate for this. Such a decorrelation is available in `pycheops`.

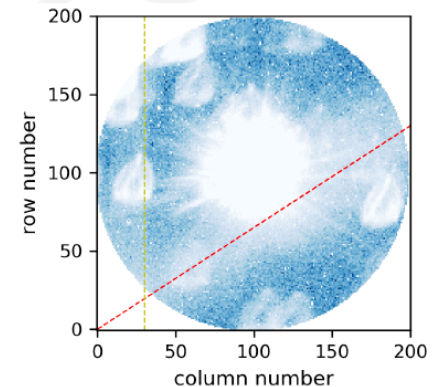
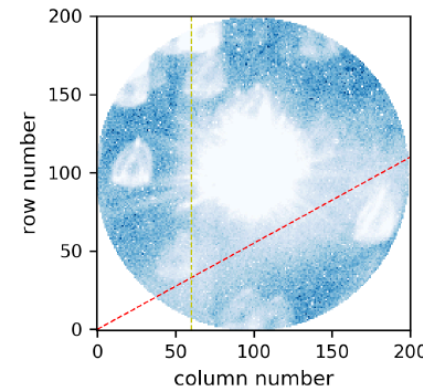
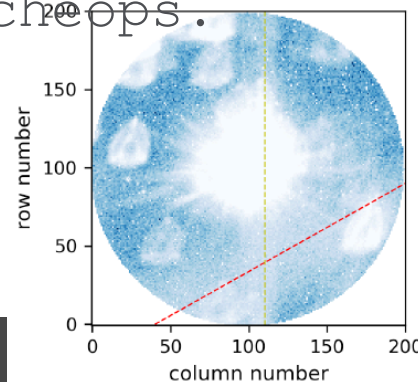
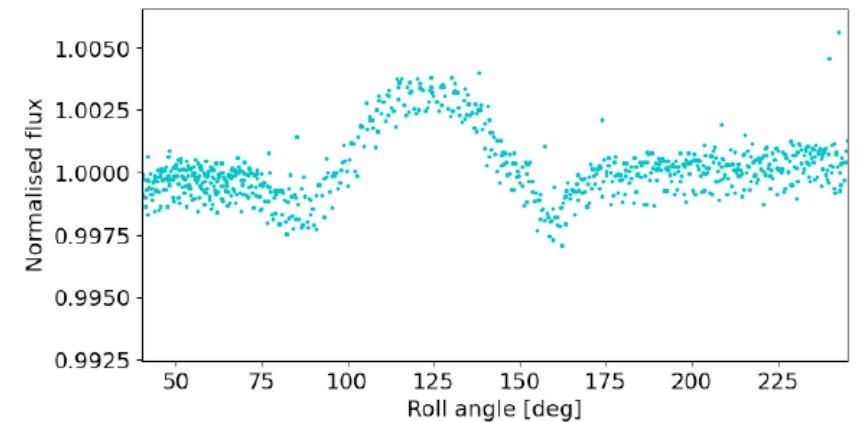
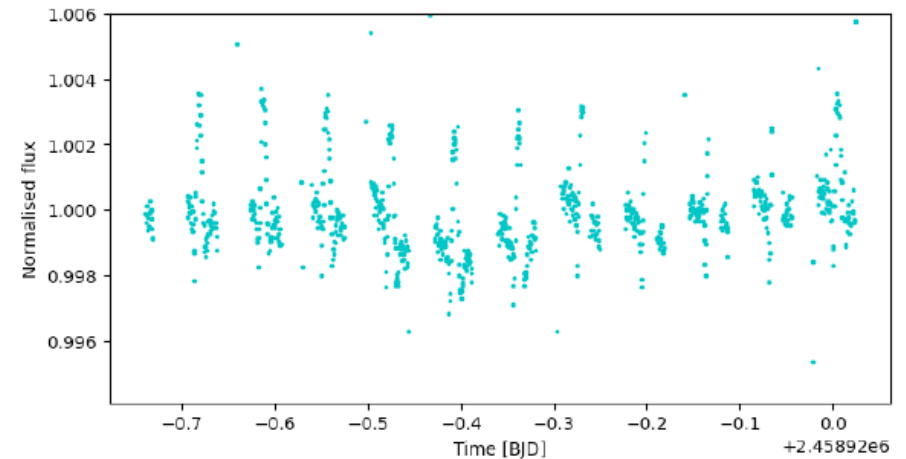
 CHEOPS

Internal reflections

Bright objects (stars, planets, the Moon, etc.) within 24° of the line of sight can reflect in the mounting of the secondary mirror (spiders).

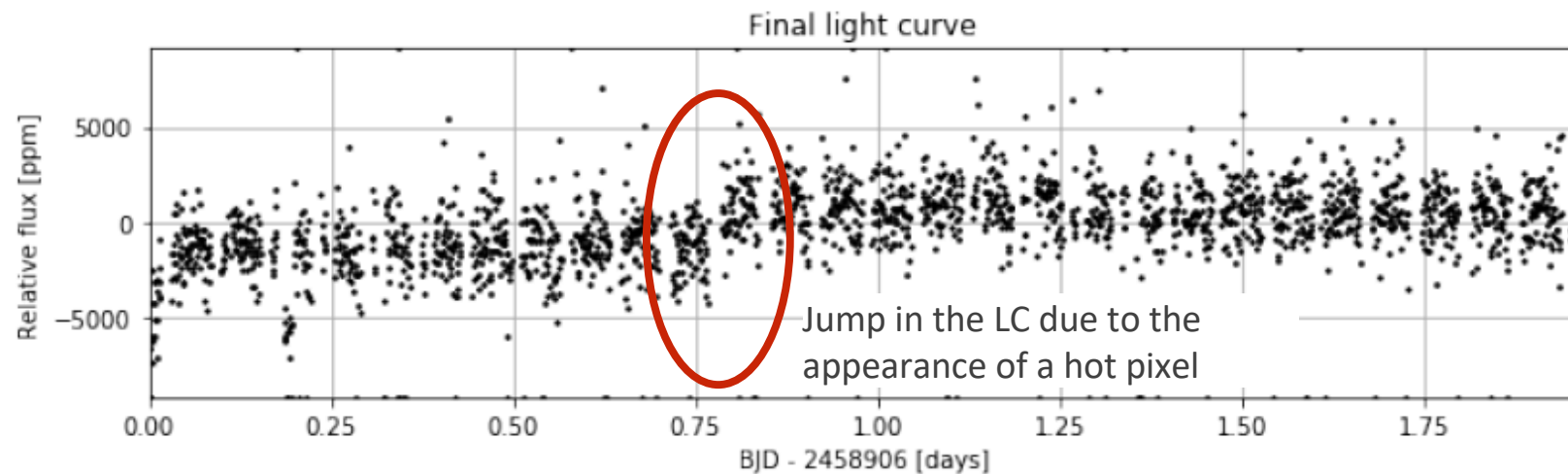
Example from Bonfanti et al 2021: the patterns in the LC correspond to the bump seen when the flux is plotted against the roll angle. The cause: a bright star in the FoV (but outside the window) that generates a smearing trail (yellow vertical line) and a bar (red line) due to internal reflections.

Corrections can be made using the `add_glint` function in `pycheops`.



(Potential) correlations with bad pixels

It can happen that during a visit a hot pixel appears inside the aperture.

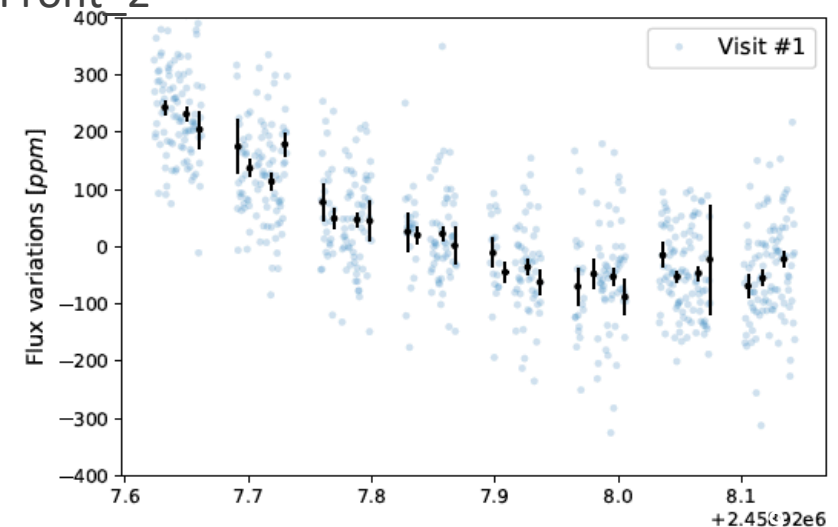


We recommend to detect where the hot pixel is located in order to determine what is the best approach to correct for it.

Correlations with the telescope tube temperature

❖ Ramp effect

- If present, the ramp is always seen at the beginning of the visit
- The ramp is due to a “PSF breathing” which is connected to temperature changes in the telescope tube at the beginning of a new visit (due to the change in the pointing direction) → **note however that not all visits present a ramp!!!**
- It’s hard to define a typical duration: between 2.5 and 12 hours
- The slope and amplitude of the ramp depends on the aperture size
- Amplitude: O(100-1000) ppm depending on the aperture (small for apertures of 30-40 px)
- Hint to detect the ramp: check the HK parameter thermFront_2



Correlations with the telescope tube temperature

❖ Ramp effect

Two independent ways for correcting for the ramp have been proposed and seem to work very well:

- Autocorrelation + Principal Components Analysis of the images (PSF)
- Linear decorrelation. The linear decorrelation has been implemented in `pycheops`

$$\text{Flux}_{\text{corrected}} = \text{Flux}_{\text{measured}} (1 + \beta \Delta T)$$

$$\Delta T = T_{\text{thermFront}_2} + 12$$

β = constant that depends on the aperture size,

$$\beta = 0.0004 \text{ for } R_{\text{ap}} = 40 \text{ px;}$$

$$\beta = 0.00033 \text{ for } R_{\text{ap}} = 30 \text{ px;}$$

$$\beta = 0.0002 \text{ for } R_{\text{ap}} = 25 \text{ px;}$$

$$\beta = 0.00014 \text{ for } R_{\text{ap}} = 22.5 \text{ px}$$

