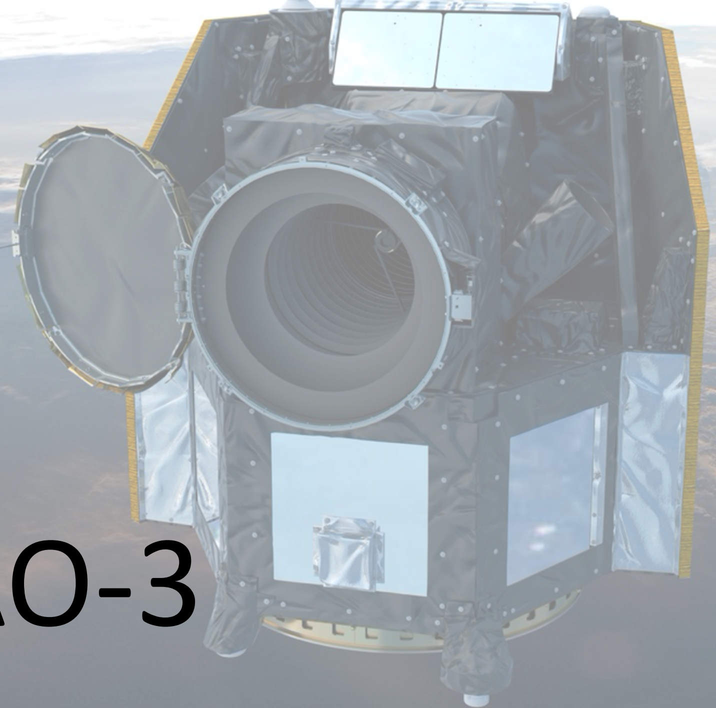
CHEOPS SCIENCE TEAM

CHEOPS T&S WORKING GROUP 2 – DATA ANALYSIS



CHEOPS AO-3

Long-term photometric stability and transit stacking

Motivation

- This slide set illustrates the current state of knowledge of the CHEOPS Data-Analysis working group concerning the long-term inter-visit stability of CHEOPS.
- Much of what we know is based on the single study of WASP-76 illustrated in the slides that follow.

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The “Ramp”

- The shape of the defocussed CHEOPS PSF affects the extracted flux.
- The PSF shape varies with the temperature of the telescope tube assembly, measured with the *thermfront2* temperature sensor in the tube.
- This variation is rapid after a pointing change, and has an orbital modulation component.
- For a given target there is also a slow annual variation with Sun angle.
- The following slides illustrate the single-visit and annual effects for WASP-76 (magnitude G = 9.4).

Long-term inter-visit stability of CHEOPS using WASP-76

Alexis Brandeker

and CHEOPS data-analysis working group

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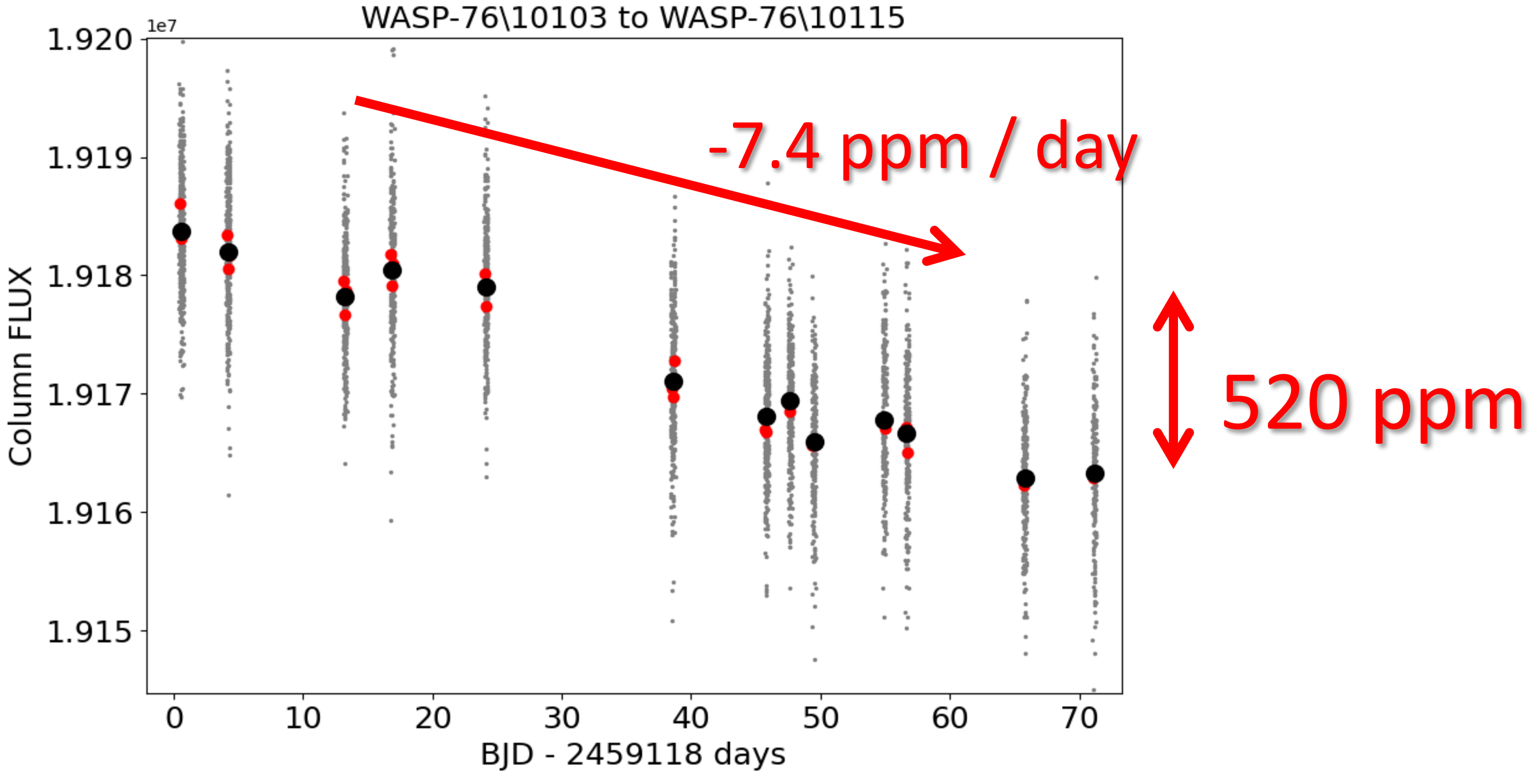
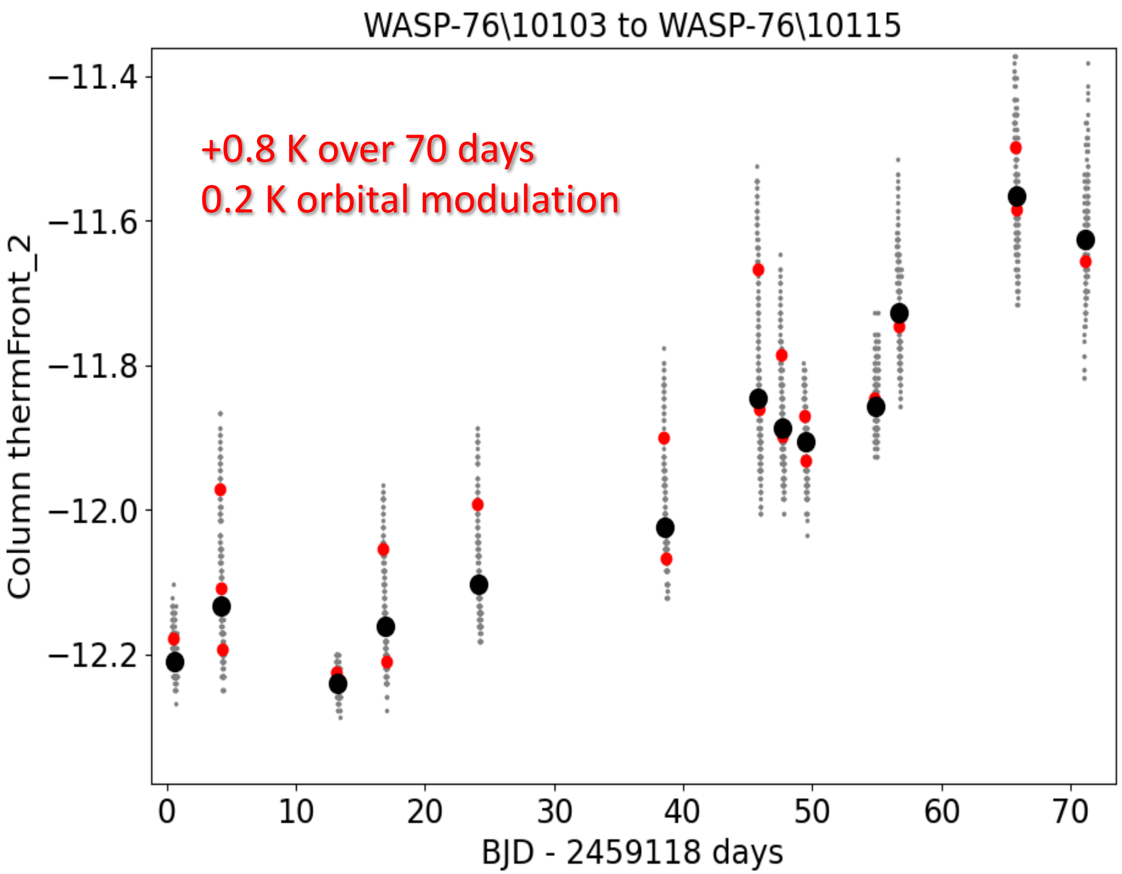
WASP-76: long-term flux trend

- Key:
  - Small grey dots:flux for each extracted frame,
  - Red discs: flux averaged per orbit, and
  - Black discs: flux averaged per visit.
- There is a clear negative trend with time.



WASP-76: *thermfront2* sensor trend

- Key:
  - Small grey dots:flux for each extracted frame,
  - Red discs: flux averaged per orbit, and
  - Black discs: flux averaged per visit.
- There is a clear positive trend of tube temperature with time.



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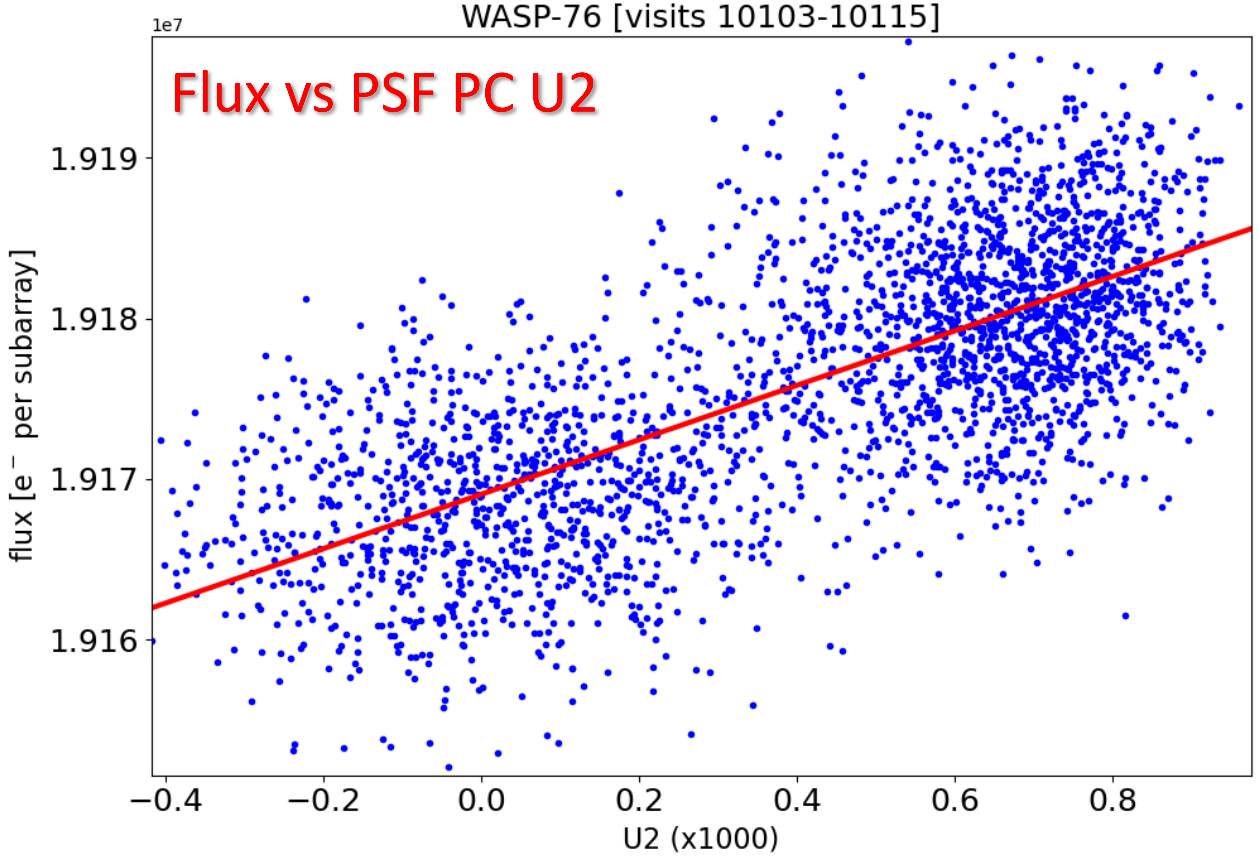
“Ramp” decorrelation

- With no decorrelation the RMS is unlikely to exceed 1 part per thousand (1000 ppm) at a single location at G = 9.4.
- Decorrelation against the thermfront2 temperature sensor reading is effective and is implemented in pyCHEOPS.
  - https://ui.adsabs.harvard.edu/abs/2021MNRAS.tmp.3057M/abstract
- Decorrelation against the U2 basis vector in PIPE* data products is equally effective.
- Using this methodology, 100 ppm RMS has been achieved at G = 9.4 over 70 days at single location.
- The following slides illustrate the linear dependence and the long-term photometric stability for WASP-76 after decorrelation.

* PIPE is a PSF photometric extraction package that models the PSF shape using principal component analysis. The PSF shape correlates with temperature, so the basis vector coefficients U1, U2, … can be used for decorrelation.



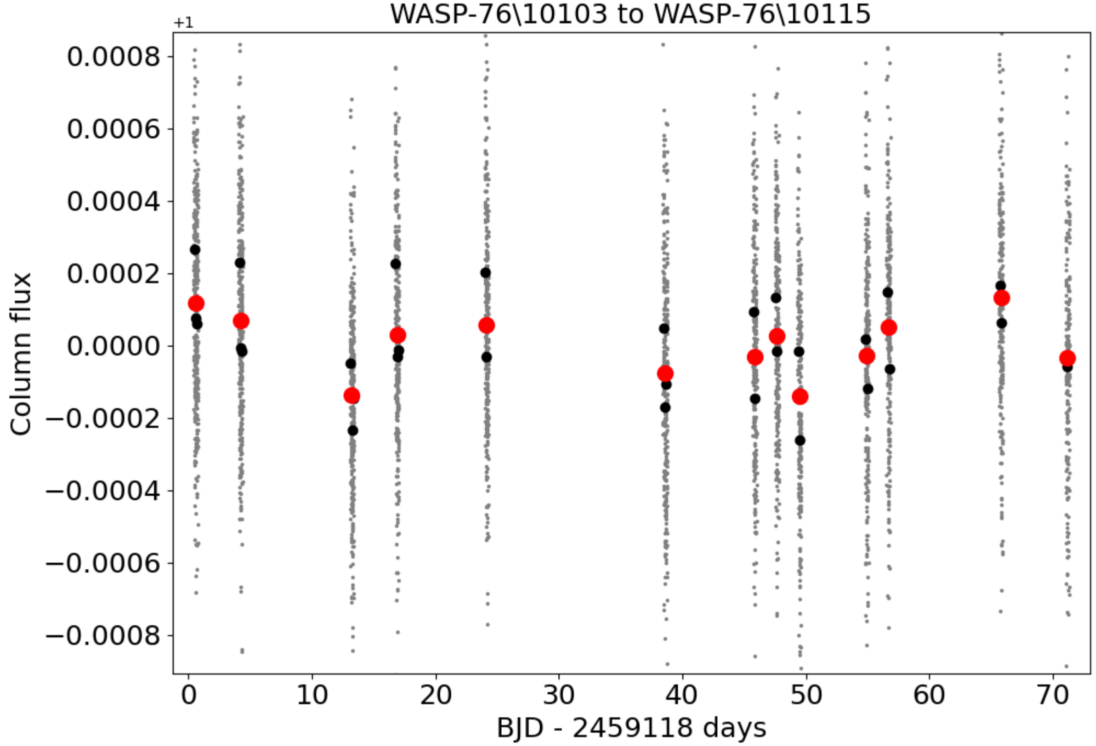
The plot shows the PSF U2 PC coefficient vs. extracted flux for every data point of all visits. There is a clear correlation.

WASP-76 long-term data de-trended

Decorrelated with U2:

84 ppm scatter over 70 days

No systematic trend

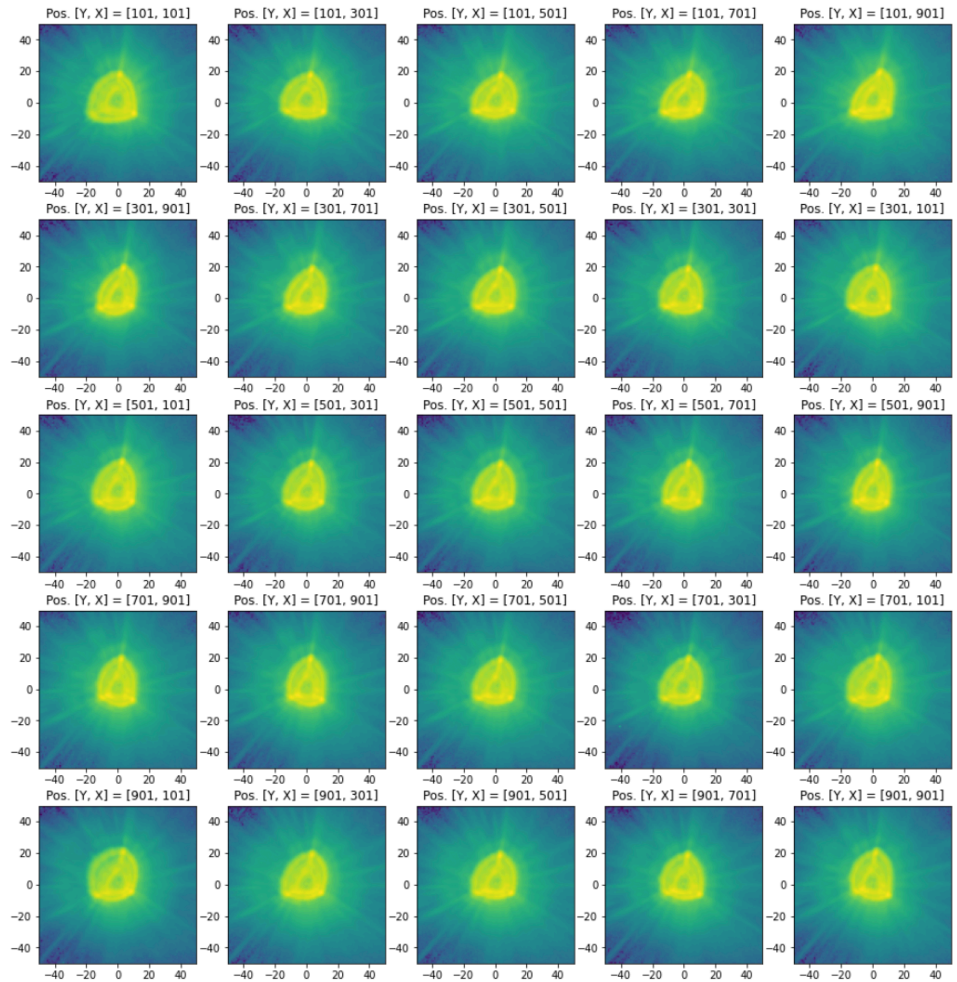


The WASP-76 photometry de-trended with U2. No systematic trend is present. The scatter is reduced to 84 ppm over 70 days.

NB: The colour coding for the red and black discs is reversed compared to previous plots; red is here the visit average and black the orbit average.

Caveats

- Long-term photometric stability has never been part of the CHEOPS mission specification.
- The conclusions in this slide set are based on a single long-term study of one target, at a single PSF location on the CCD.
- The PSF location can be changed at any time for operational reasons. *This is not under user control.*
- The shape of the PSF, and hence the photometric zero point, varies strongly over the CCD area.



SNR advantages of transit stacking

CHEOPS data-analysis working group

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Stacking multiple transits

- How does the SNR of the transit-depth measurement depend on the number of transits combined from multiple visits?
- The answer depends on
  - Interruptions
  - Target brightness
  - Correlated noise

pyCHEOPS multi-visit mode

- Resources:
  - Documentation in the pyCHEOPS Cookbook
    - Section 5.5: Fitting your Data - Multiple Visits
  - Tutorial demonstrations in pyCHEOPS tutorial examples
    - WASP-189.ipynb: secondary-eclipse stacking with MultiVisit.

PYCHEOPS Cookbook v1.0

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Note: For the construction of this cookbook PYCHEOPS was successfully installed and run using Ubuntu 18 and Python 3.6.

Abstract

The purpose of this document is to provide users of *CHEOPS* data with information on the PYCHEOPS Python module. This cookbook details PYCHEOPS dependencies and installation, how to download *CHEOPS* data, and several data analysis recipes. Therefore, this document can be used as a walk-through of obtaining and analysing *CHEOPS* data, or as a reference guide of PYCHEOPS.

Contents

“Rules-of-thumb”

- Improved coverage of ingress and egress across multiple visits => SNR of transit depth will increase faster than sqrt(N) initially.
  - Significant advantages from stacking, particularly for low-efficiency observations.
- If observations are photon-limited, SNR will tend to sqrt(N) subsequently.
- For bright targets, SNR will eventually be dominated by correlated (astrophysical) noise
  - No advantage in further stacking beyond gap-filling.
  - Multiple visits allow better detrending of spacecraft systematics.

Summary of recommendations

- Long-term monitoring can be undertaken entirely at the applicants' risk.
- With no decorrelation the RMS is unlikely to exceed 1 part per thousand (1000 ppm) at a single CCD location at G = 9.4.
- Decorrelation against *thermfront2* in pyCHEOPS or U2 in PIPE can achieve 100 ppm RMS at G = 9.4 over 70 days at single PSF location.
- If a change of PSF location is made during a sequence of long-term monitoring visits, we recommend modelling the light curve with a floating zero point for each PSF location.
- Stacking of multiple transits over 2 to 4 visits is generally a good idea.
  - For lower-efficiency observations more visits could be needed to reach the sqrt(N) regime
  - For higher efficiency visits this might be obtained in only a couple of light curves.