Payload on-ground calibration

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## Overall approach

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*FPM : Focal plane module*
Calibration bench @ UNIBE
Context

• CHEOPS does not have an on-board calibration source nor a shutter

• All the key measurements already done during CCD characterization campaign

• Most of these results have to be measured again during payload calibration
  – change of electronics
  – payload optics
  – but gain sensitivities are measured for good

• Some of these results will be updated in-flight during the Monitoring & Characterization phase (M&C)

See R. Alonso’s talk (talk n°6.2)
Inputs for DRP

See S. Hoyer’s talk (talk n°8)
Inputs for DRP

- Bias & Read-out noise
- System gain
- Dark
- Flat fields

**CALIBRATION**
- Bias and RON estimation
- ADU to photon conversion
- Dark Current correction
- Flat field correction

**CORRECTION**
- Bad Pixel Flagging
- Jitter Estimation
- Pixel to Physical Coordinate Conversion
- Image Correction
- Light-Curve Quality Analysis

**Photometric Extraction**
- Aperture Photometry
- Contamination Estimation

**U** will be updated during in-flight M&C
Inputs for DRP

- Instrumental Effects
- Environment Effects

**CALIBRATION**
- Reference Files
- L0.5 Raw Data
- Housekeeping Information

**CORRECTION**
- L1 Calibrated Data
- L1 Corrected Data

### Photometric Extraction
- Data Reduction Reports
- L2 Light Curves

### Correction Steps
- Bias and RON
- ADU to photon conversion
- Dark Current correction
- Flat field correction
- Bad Pixel Correction
- Jitter Estimation
- Pixel to Physical Coordinates
- Smearing Correction
- Background correction

### Notes
- Hot pixels (dark)
- Dead pixels (FF)
- will be updated during in-flight M&C
Inputs for DRP

- Bias image
- System gain
- Dark image
- Flat fields
- Non linearity

Error budget will be updated during in-flight M&C
Bias & Read-out noise

- CCD characterization:
  - 0s exposures in the dark
  - Bias level = 1735 ± 1 ADU
  - RON = 4.02 ± 0.01 ADU

from FM2 test report
(CHEOPS-UGE-SYS-120_1.2)
Bias & Read-out noise

- CCD characterization:
  - 0s exposures in the dark
  - Bias level = 1735 ± 1 ADU
  - RON = 4.02 ± 0.01 ADU

- Measurements during payload calibration
  - dependence on electronic chain
  - small RON variations with $V_{\text{bias}}$ (less than 0.2 ADU/V, from CCD characterization)
Dark current

- CCD characterization:
  - Various exposures in the dark at different temperature (-40..20 °C)
  - Dark @ -40°C = 0.0016 ADU/s (10 times better than specs)
  - Hot pixels coordinates

from FM2 test report (CHEOPS-UGE-SYS-120_1.2)
Dark current

• CCD characterization:
  – Various exposures in the dark at different temperature (-40..20 °C)
  – Dark @ -40°C = 0.0016 ADU/s (10 times better than specs)
  – Hot pixels coordinates

• Measurements during payload calibration
  – only at 0°C and 10°C to identify/locate hot pixels
System gain

- CCD characterization:
  - Different exposures in white light up to saturation
  - Slope at (0,0) of a 2D-polynomial fit
  - Gain = 0.4410 ADU/e^-

from FM2 test report
(CHEOPS-UGE-SYS-120_1.2)
System gain

- **CCD characterization:**
  - Different exposures in white light up to saturation
  - Slope at (0,0) of a 2D-polynomial fit
  - Gain = 0.4410 ADU/e⁻

- **Measurements during payload calibration**
  - Dependence on electronic chain
  - Gain variations with respect to $V_{bias}$ will be extrapolated from CCD characterization measurements
System gain

- Gain sensitivity from CCD characterization (not repeated during payload calibration campaign)

- Voltages stability from DLR (nov. 2016)
  - Very high $V_{\text{bias}}$ stability (less than 1 mV over tens of hours)

from FM2 test report (CHEOPS-UGE-SYS-120_1.2)
Full-well capacity

- CCD characterization:
  - Different exposures in white light up to saturation
  - Full-well capacity is defined as the point where CCD response is 3% away from linear fit
  - FWC = 58823 ADU

- Conservative definition
  - when reaching FWC, the CCD is not fully saturated (still signal beyond FW)
Non-linearity

• CCD characterization:
  – Different exposures in white light up to saturation
  – Non-linearity is the difference between CCD response and a linear fit
  – Nominal non-lin. ≤ 0.088 % in the 10-to-70% \( F_{WC} \) range

from FM2 test report

\( (CHEOPS-UGE-SYS-120_1.2) \)
Non-linearity

- CCD characterization:
  - Different exposures in white light up to saturation
  - Non-linearity is the difference between CCD response and a linear fit
  - Nominal non-lin. $\leq 0.088\%$ in the 10-to-70\%$_{\text{FWC}}$ range

- Measurements during payload calibration
  - Should show no dependence on electronic chain (dominated by CCD)
  - Nominal case only (expect very small $V_{\text{bias}}$ variations during mission compared to the range explored)
Flat fields

- CCD characterization:
  - Various exposures in monochromatic light at different $\lambda$
  - Wavelength bands of 30 nm
  - Blue diamond and “tree-ring” effects

from FM2 test report
(CHEOPS-UGE-SYS-120_1.2)
Flat fields

- CCD characterization:
  - Various exposures in monochromatic light at different $\lambda$
  - Wavelength bands of 30 nm
  - Blue diamond and “tree-ring” effects

- Measurements during payload calibration
  - Additional vignetting due to optics
  - Denser wavelength sampling (FF combination)
Quantum efficiency

- CCD characterization:
  - Various exposures in monochromatic light at different $\lambda$
  - Wavelength bands of 30 nm
  - $QE = \frac{N_{\text{electrons}}}{N_{\text{photons}}}$ from CCD
  - Measurements during payload calibration to include transmission of the whole optical system

from FM2 test report (CHEOPS-UGE-SYS-120_1.2)
Other tests of the CCD characterization

- Saturation
  - No memory effect

(No new measurement planned during calibration)
Other tests
during payload calibration campaign

PSF shape

• Functional test
  – check alignment and any optical issue
  – identify PSF for tracking
  – over FoV and λ

• No delivery of in-flight PSF
  – non-uniform illumination of the pupil
  – gravity effect

⚠ For illustration purposes only!
Final lab PSF not yet measured.
In-flight PSF expected to be different.
Other tests
during payload calibration campaign

Photometric performances

- This is not a calibration

- Performance test 1: stability
  - nothing moves + tracking loop
  - stability measurement

- Performance test 2: flat field
  - with jitter

- Performance test 3: full
  - with temperature variations (survival heaters)
Payload on-ground calibration

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