The PACS photometer status

M. Sauvage for the PACS ICC

Performance Verification – What for?

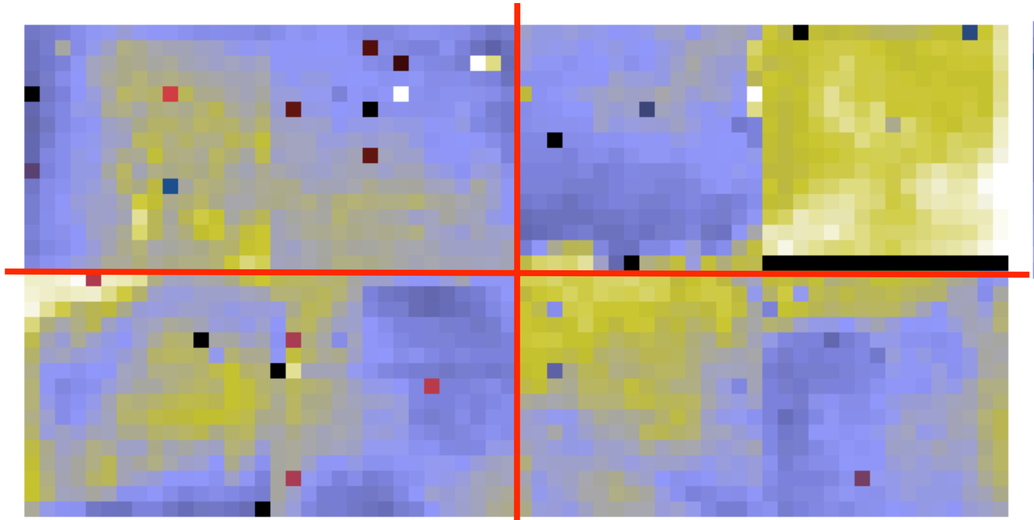
- End of PV phase ≠ we understand everything of the photometer and all issues are fixed.
- End of PV phase = we understand enough of it to start science operations, but issues remain.

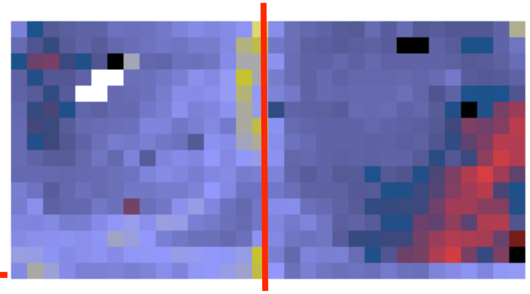
- What will be shown here?
  - Understanding the signal
  - Dealing with cosmic rays
  - Finite time constants
  - Noise characteristics and variability
  - Gain stability and drifts
  - Foreground illumination levels
  - Optical performance
  - Photometric accuracy
  - Recommended observing modes
  - Effective sensitivity

General message: there are very few signs that the detectors have changed w.r.t. ground-based tests, but real life is more complex than simulations.

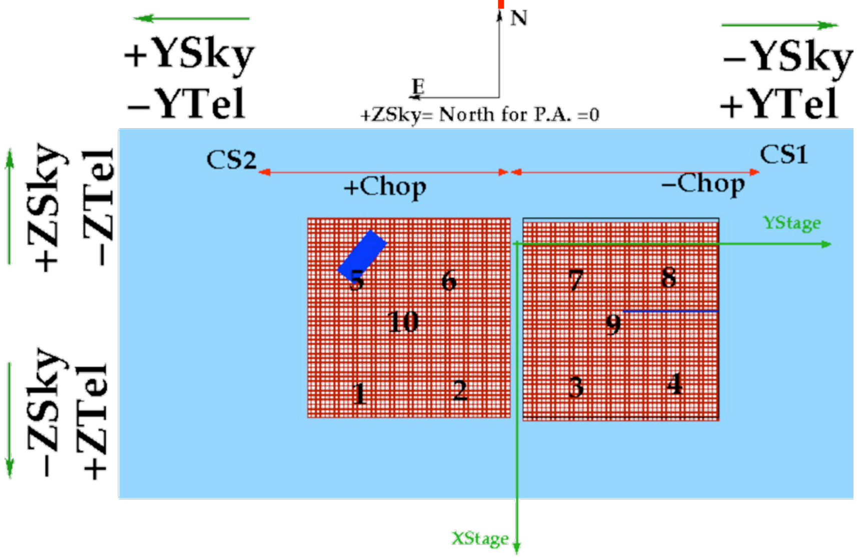
Preliminary: understanding the signal

- The dominant part of the signal comes from the pixel offset.
  - Its variability is the source of most of the 1/f noise.





Standard representation of the PACS arrays



- The arrays are composite:
  - 16x16 pixels matrices
  - ~1 pixel spacing
- Blue matrices are electrically coupled by pairs in a group.
  - 1+2, 3+4, 5+6, 7+8
- Red matrices are not coupled.

Preliminary: understanding the signal

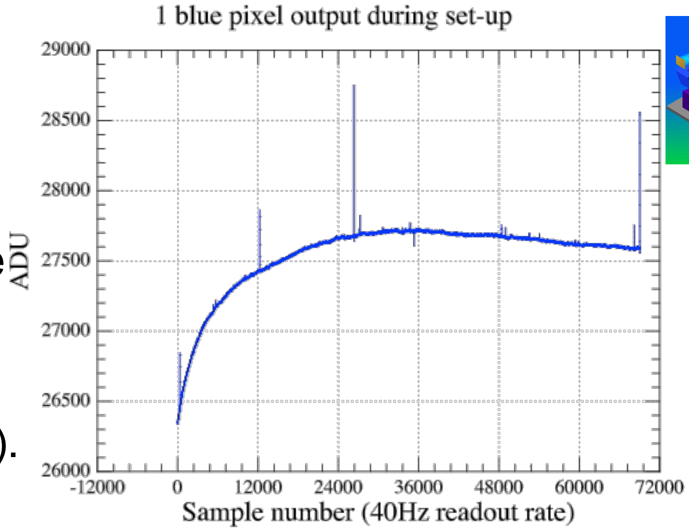
- The detectors are read on board at a rate of 40Hz.
  - Multiplexing occurs along the lines of the individual matrices.
  - All columns of index # of all matrices are read simultaneously.
    - Column readout rate is 40*16 = 640 Hz.

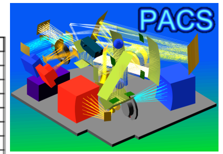
- Data rate:
  - To fit within the bandpass
    - In prime mode, individual readouts are averaged by groups of 4.
    - In parallel mode, the blue readouts are averaged by groups of 8 (the red stays at 4).

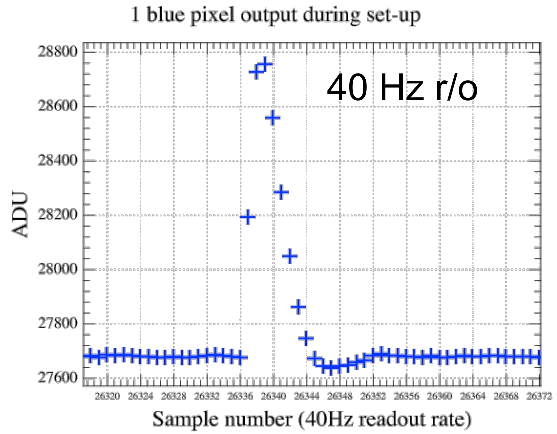
  - When this is insufficient to reduce the data rate, we sacrifice some of the lowest significance bits in the average (in a clever way).
    - Prime scan mode: bit rounding = 1 but moving to 0, except for calibration block.
    - Prime point source mode: bit rounding = 1
    - Parallel scan mode: bit rounding = 2
    - Bit rounding of n, means digitization step (in ADU) is 2^n.

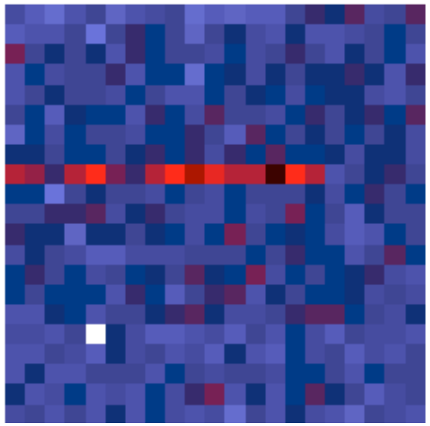
Cosmic rays

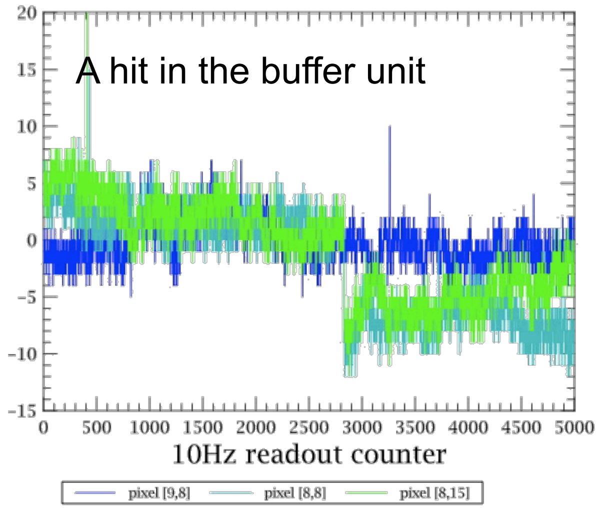
- Thanks to the small cross-section, CR rate is low (less than 1% of the data is affected by an impact).
  - Most are short-lived.
  - They can be negative (wall impact).
- Removal strategies
  - Multi-resolution approach valid at small scan speed in the absence of high-contrast sources.
  - Sigma-clipping on dither positions.
  - Outlier filtering at the map creation stage (available in *dp.pacs*).

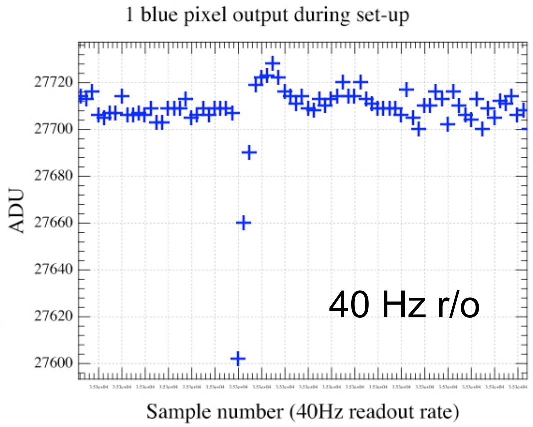










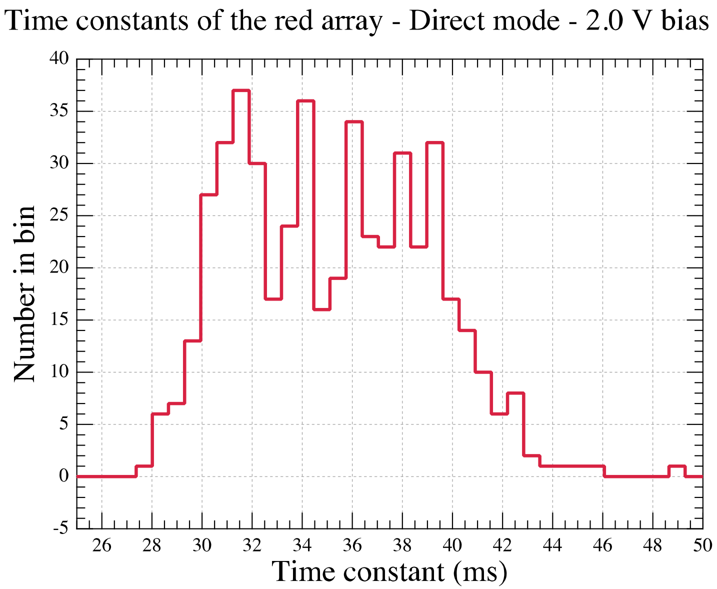


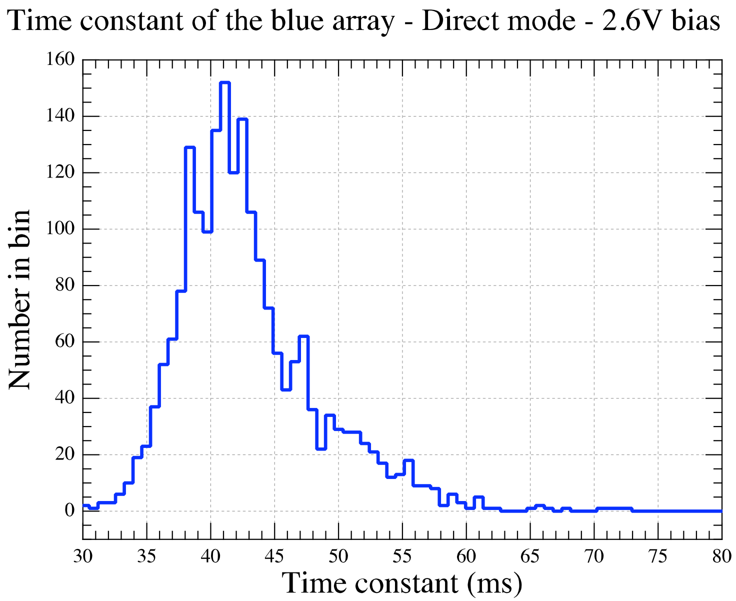
Time constants

- Bolometers have a thermal time constant.
- The readout circuit also introduces a time constant.

- Zero-order representation: the signal is low-pass filtered.

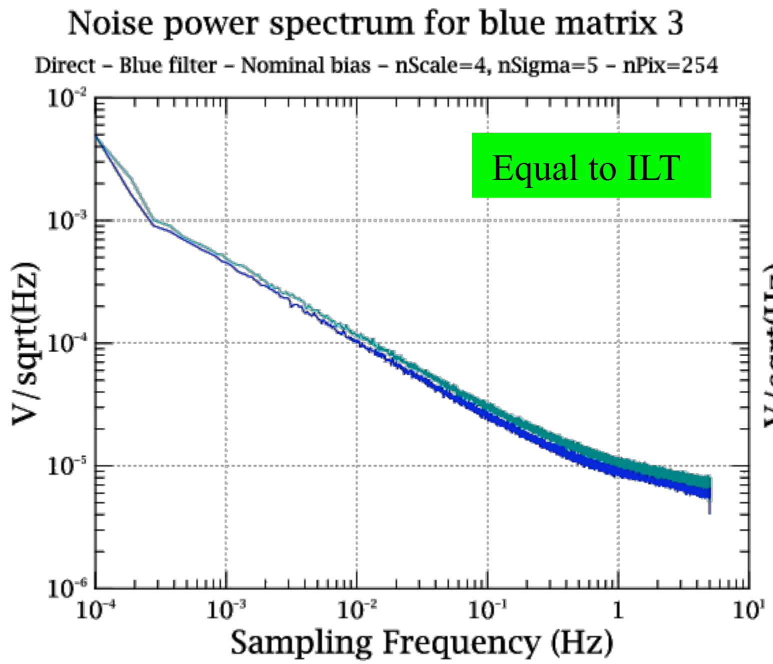
- This has an impact on the instantaneous "gain". In chopped observation, the first image (4 readouts) is affected by the transition.
  - At 40 Hz, one sample every 25ms.

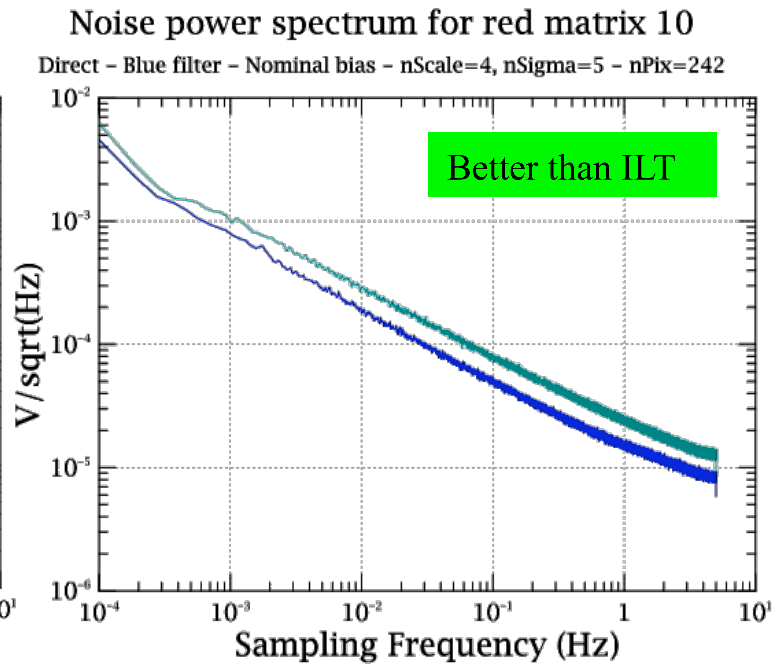




Noise Charateristics

- Noise in the PACS bolometers is essentially $1/f^{1/2}$ over the whole bandpass
  - closure of the bandpass at high frequencies.
- Almost 100% of this noise is additive, i.e. offset drifts.

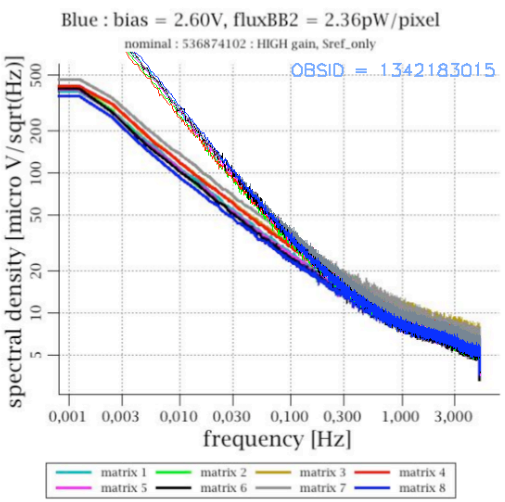


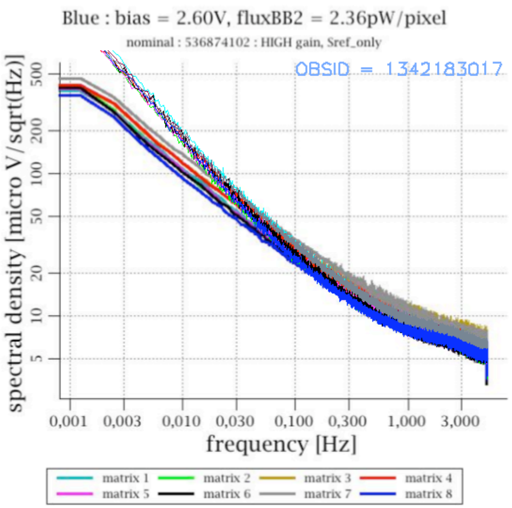


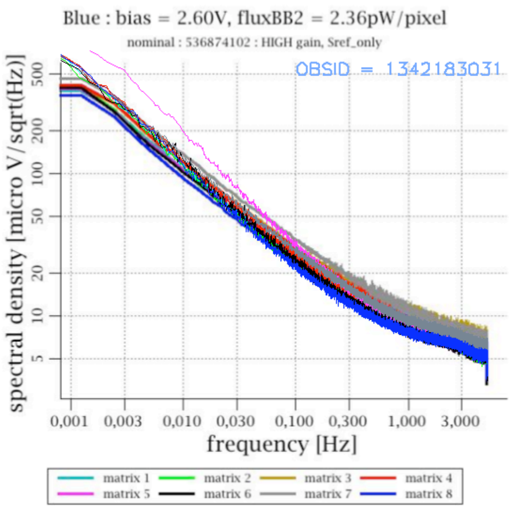
- A fraction of this noise is correlated:
  - Very slow global trend (could be related to the temperature).
  - Group-to-group trends.
- Chopping efficiently leaves only white noise but at a higher level than the original 3Hz level.

Noise characteristics

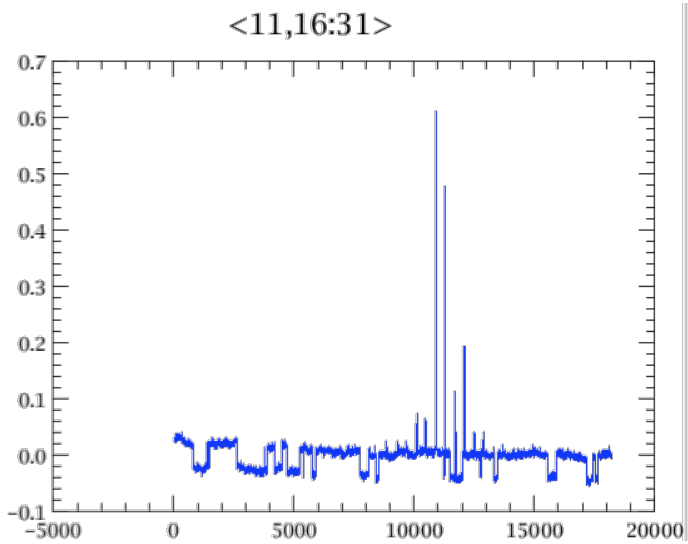
- The power in the low-density part of the spectrum is a function of the time elapsed since recycling (indication of a temperature/relaxation effect).





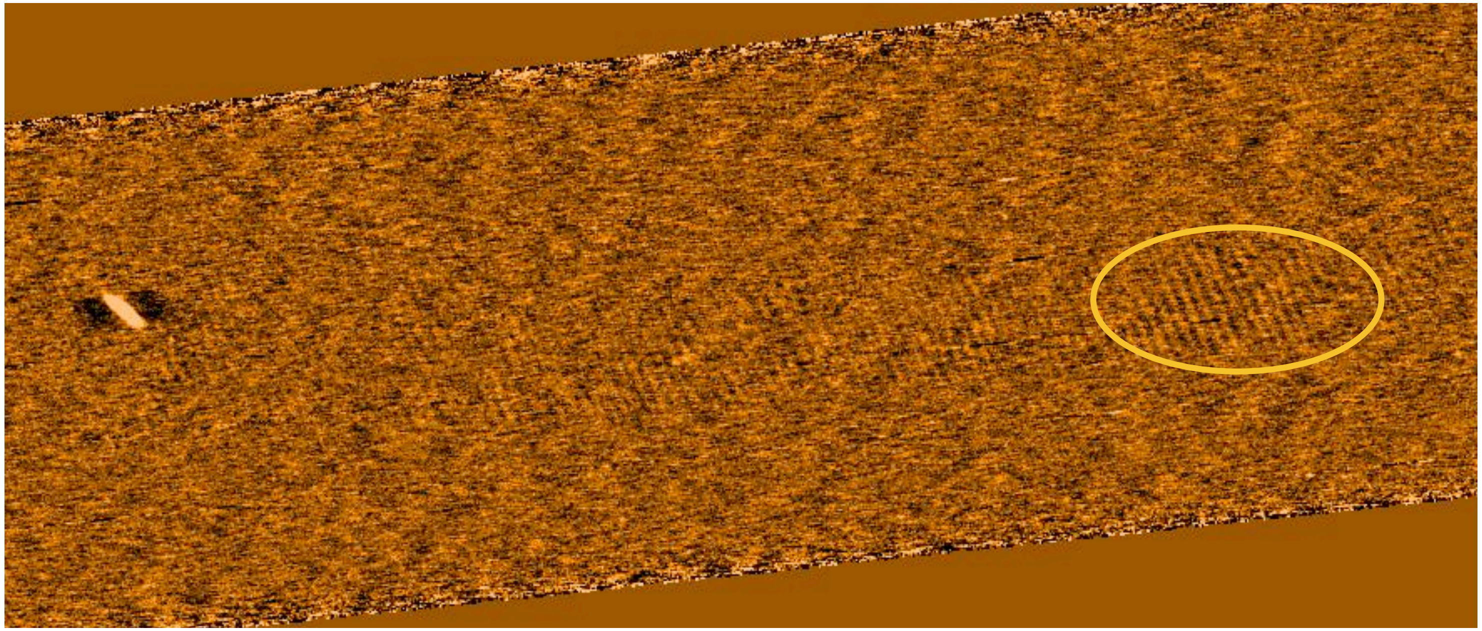


- Some erratic behaviors (possibly linked to the current in the readout circuit) are under investigation.
  - Affecting line 11 of matrix 6.



Interferences

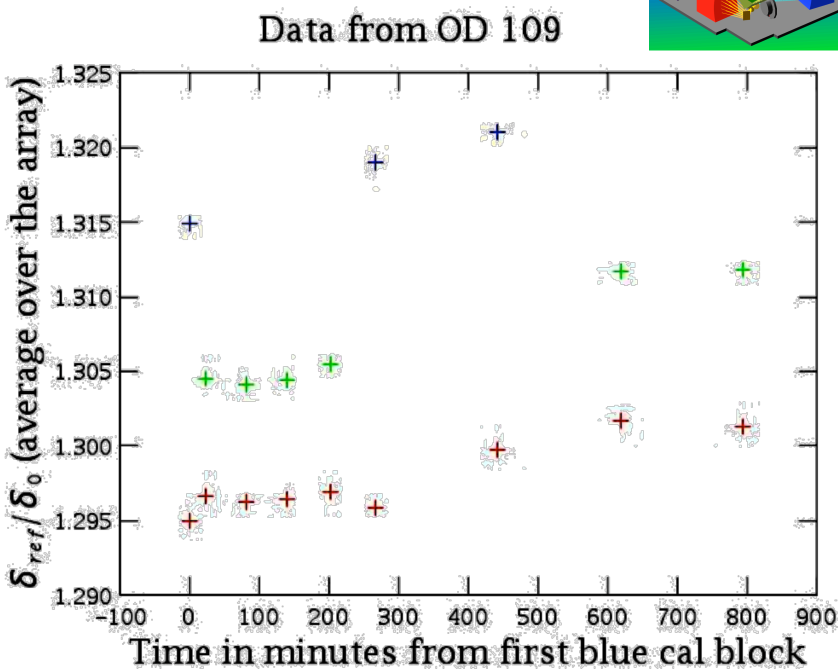
- Since the first integrated tests on the satellite in a space simulator (SOVT), we have observed erratic interferences on the data



  - They affect only the blue photometer.
  - Amplitude is variable (from faint to severe).
  - They are intermittent (i.e. a large fraction of the observations is unaffected).
  - The root cause has not yet been found.
  - They obviously degrade the performance of the affected observation.

Gain stability and drifts

- The gain calibration of the photometer rests on the following recipe:
  - A responsivity figure (scalar) that converts Volts into Jy/pixel.
  - A flat-field that takes into account pixel-to-pixel responsivity variations.
  - A gain drift correction
    - *not operational yet.*

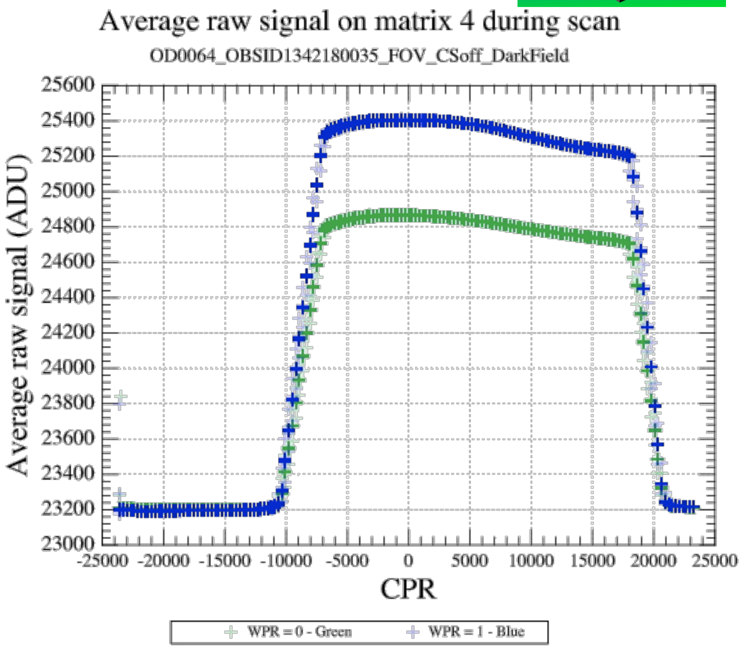


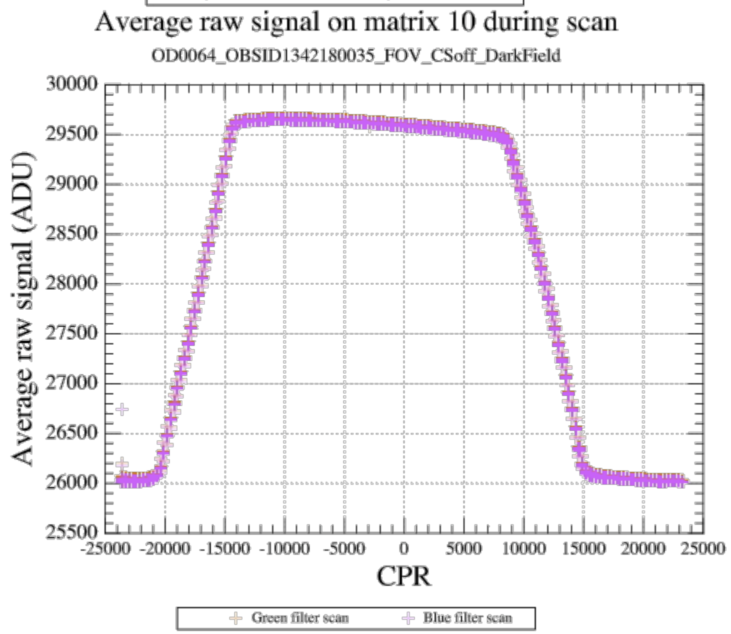
- Gain drifts are measured by comparing the difference between the two calibration source images obtained at the start of an observation, to a reference measurement compatible with the responsivity and flat field value.

- Gain drifts are on average below 1% inside the orbit or from one orbit to another.
- Pixel gains can show larger variations (a few %).
- Larger variations can be observed at the start of the orbit.

Foreground flux level

- The illumination by the telescope plays an important role on the bolometer response (and sensitivity): the larger the flux, the smaller the response.
- Measurement are consistent with very low emissivity of the surface, and stray light within specification.
  - Foreground in the blue and green filters is lower than expected.
- A strong illumination gradient exist in the field of view
  - Chopping implies nodding.
- An unidentified source is introducing extra light on the red photometer
  - Equivalent to the telescope contribution
  - Homogenous over the whole field of view
  - Not variable in time



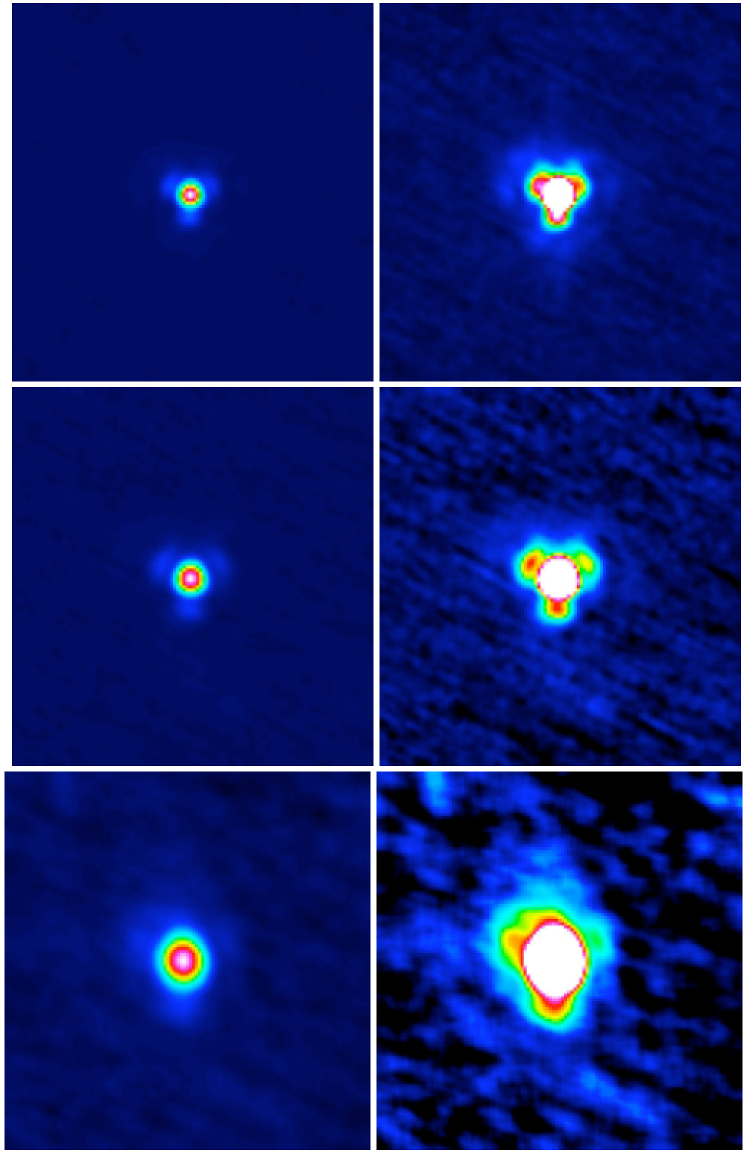


Optical performance

- The core of the PSF is in line with the specification (diffraction limited down to 90µm).

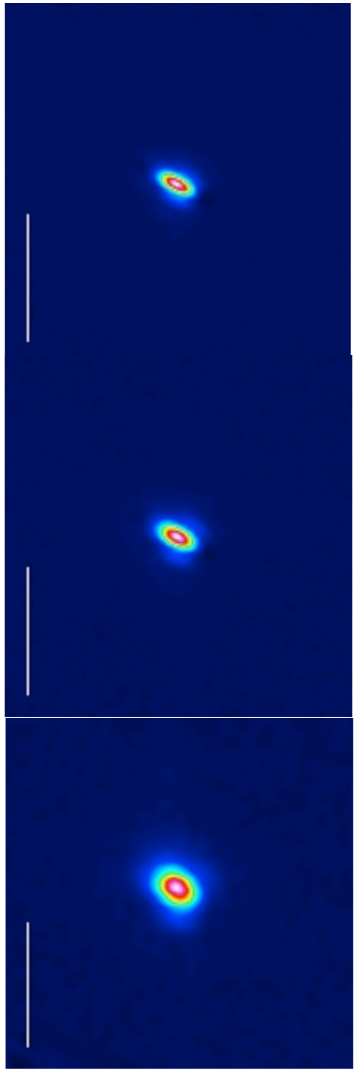
- The PSF is measured in ideal conditions:
  - Individual readouts can be re-registered.
- In normal conditions, the PSF is enlarged by the different contributions of the pointing uncertainty.
  - This can reach 2" increase of the FWHM.

- The structure in the PSF is due to the primary mirror supports.

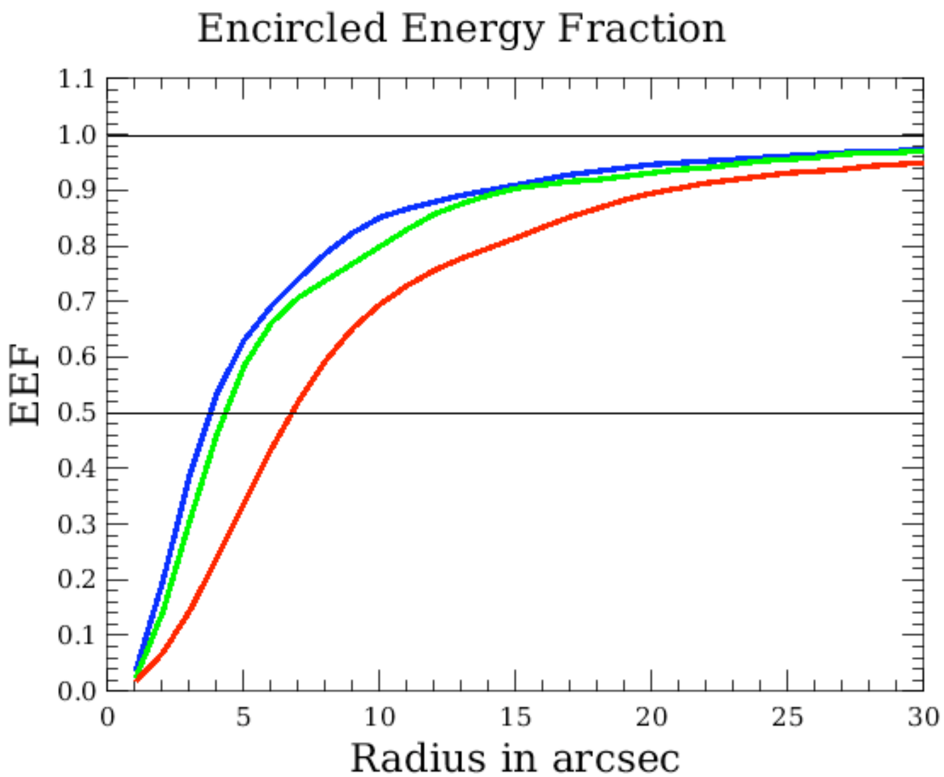


Optical performance

- Scanning and averaging on board enlarge the PSF



- A significant fraction (more than assumed) of the PSF energy is at large radius.



60"/s,
8 frames averaging on the blue,
4 frames on the red

Photometric calibration and accuracy

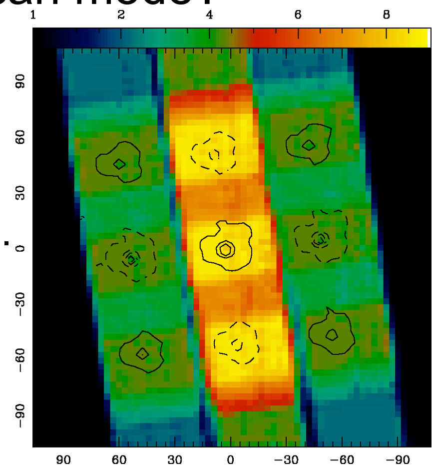
- Prime calibrators for the PACS photometer are stars.
- Secondary calibrators used: more stars and asteroids.
- Spectral convention is νf_ν = cte.
- Reference wavelength for the PACS filters: 70, 100 and 160 μm.
  - Chosen to minimize the color corrections.
  - All transmission curves available in *hipe*.

- As of the current release of HIPE, the photometric accuracy in all filters is estimated (from inter-comparison of calibration observations) at 10%.

- First comparisons also suggest a good photometric match for extended source with MIPS (e.g. within 20% at 70 and 160 μm).

Final observing modes

- Why do we only keep the point source mode and the scan mode?



  - Chopping transforms the $1/f^{1/2}$ noise into white noise but:
    - Chopping fast is best to beat the noise.
    - Chopping slow is best to maximize efficiency (time constants).
    - The available field of view is small.
    - Flat-field errors and bad-pixels location become important.
    - Coverage is very heterogeneous.
  - Comparative tests show that relative performances between chopped and scanned observations is favorable to the scan mode.
    - We recommend the 20"/s scan speed to exploit the shape of the noise power spectrum

- The scan mode is the standard mode for the photometer.
- The point source mode should only be used for point sources (no faint extension), with well known position (1 pixel uncertainty), with a clean environment (no companion object).
- This will simplify the calibration and data reduction strategies.

Sensitivity

- In short: sensitivity is not as good as predicted in HSPOT.
  - Lower response in red band due to higher flux.
  - Non-optimal $1/f^{1/2}$ noise rejection compared to assumptions.
  - Actual PSF vs. assumed one.
  - Effect of the finite time constants in point source mode.

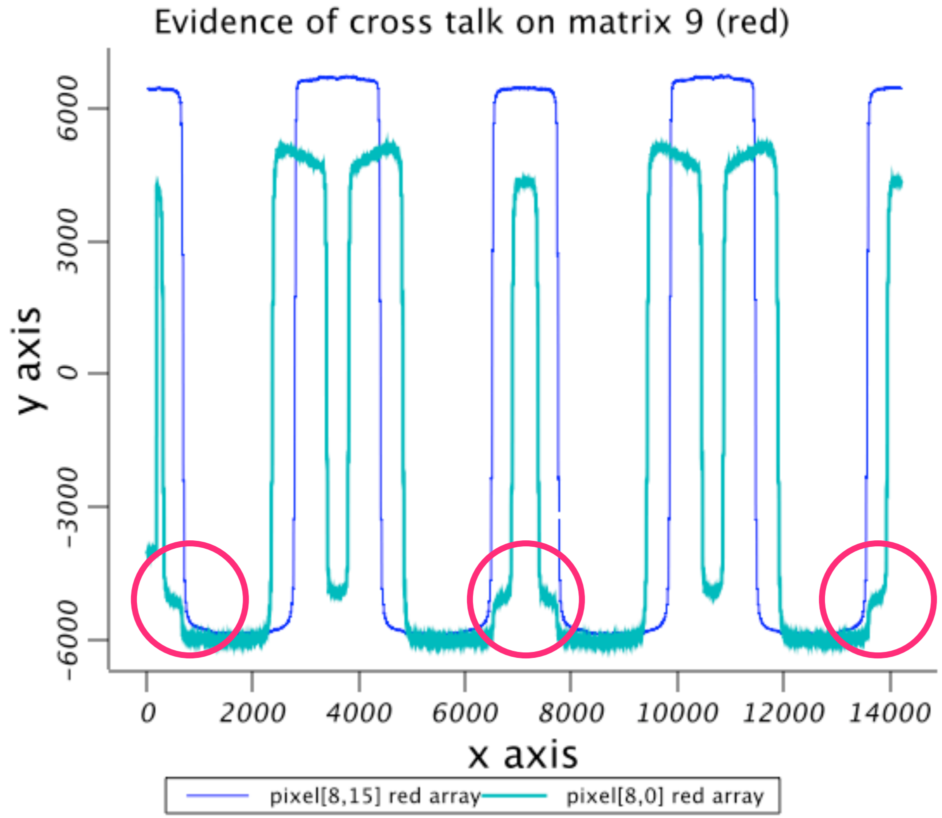
- Quoting a number is extremely dependent on the type of source observed, the observing mode, and the data reduction strategy.

- In cosmological surveys (fields of point sources, high-pass filtered):
  - Blue & Green band: 25-30% degradation w.r.t. HSPOT.
  - Red band: 60% degradation w.r.t. HSPOT.

- In point source mode observations:
  - For sources above 10 mJy, 50% degradation w.r.t. HSPOT.

Still ahead of us - Crosstalk

- As pixels are read in sequence along the line, the signal from pixel i can influence the signal from pixel i+1.
- This is not noticeable except for some pixels located to the right of a dead pixel, or for pixels 0, located to the "right" of pixel 15.



Mostly noticeable on the red side but affects also the blue side

- We are testing if it can be fixed by the electrical setup, or if it can be handled by the analysis. Otherwise, better mask column 0.

Still ahead of us

- Pinpoint the source of interferences.

- Drift correction:
  - Calibration blocks are taken at the start of each observation
  - They can be used to monitor gain variation
  - This can in theory improve the photometric accuracy of the calibration.

- Establish calibration and sensitivity on extended sources.

- Implement different strategies to deal with $1/f^{1/2}$ noise.
  - Interfacing *hipe* data structures with other software is not a problem.

- Deblurring:
  - Map reconstruction is currently made assuming one (average) astrometry per readout.
  - We can use the information that each readout is the sum of 4/8 in the map reconstruction.