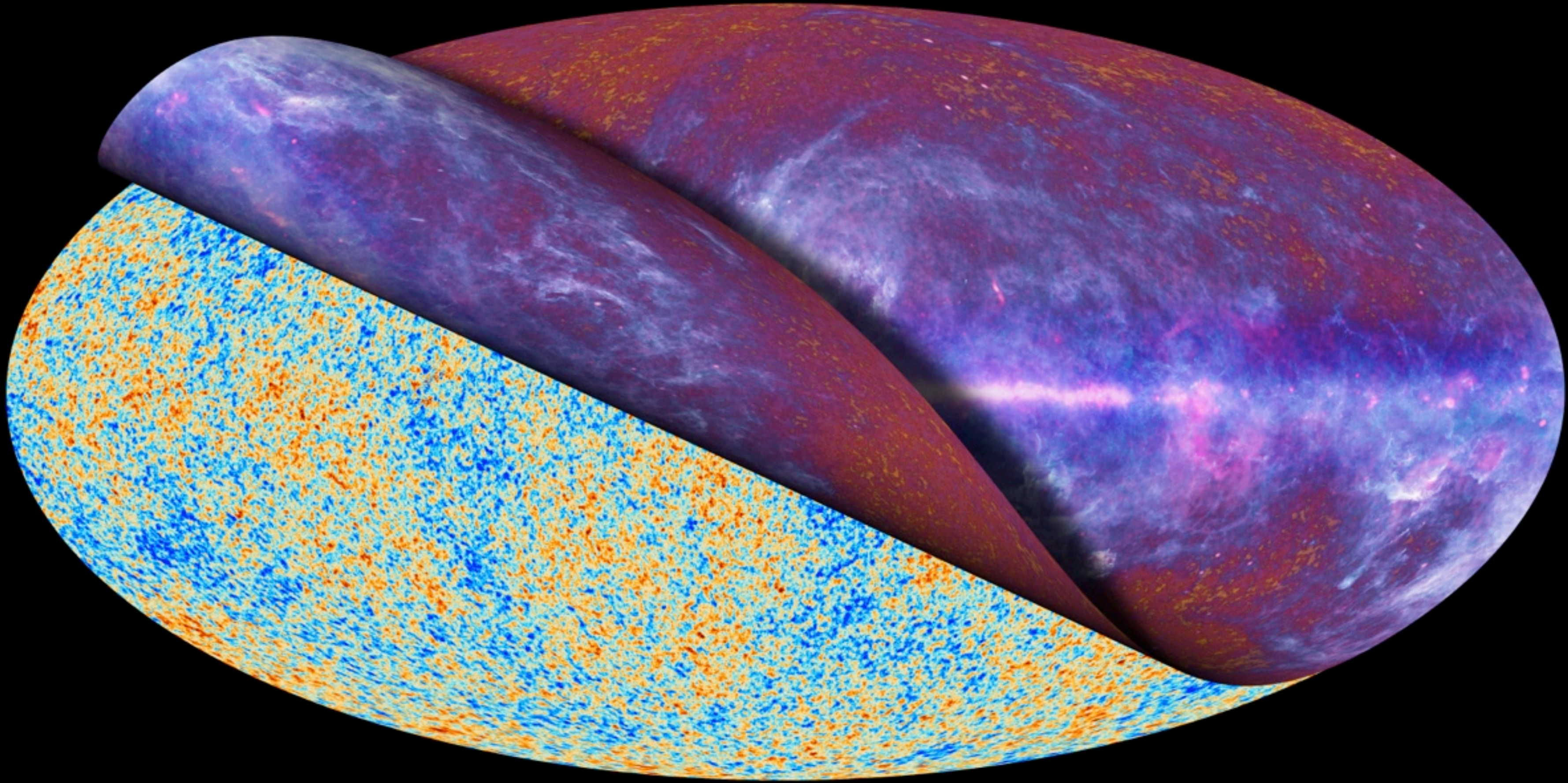


Planck unveils the Cosmic Microwave Background

Technical lessons learned from Planck for future space experiments

Lamarre, J.-M, with the help of many

LERMA – Observatoire de Paris (FRANCE)

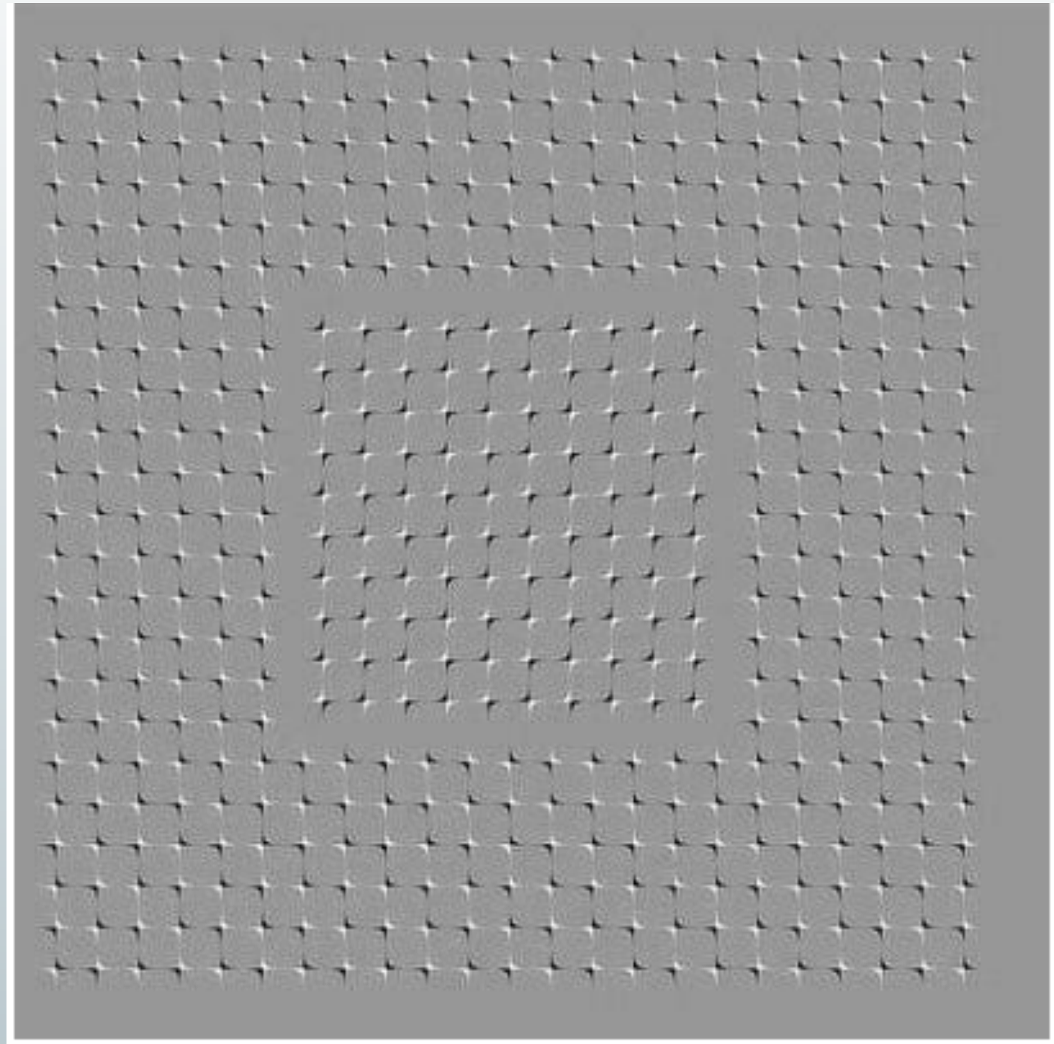
On behalf of the Planck collaboration

Noise and systematic effects

- Planck sensitivity is near to the fundamental limits, i.e. the photon noise of the source itself. Obtaining a better sensitivity means:
  - *increasing the duration of the mission.*
  - *increasing the number of detectors.*
- Due to its extreme sensitivity, Planck is in a regime in which systematic effects contribute significantly to the uncertainty.

Systematic effects

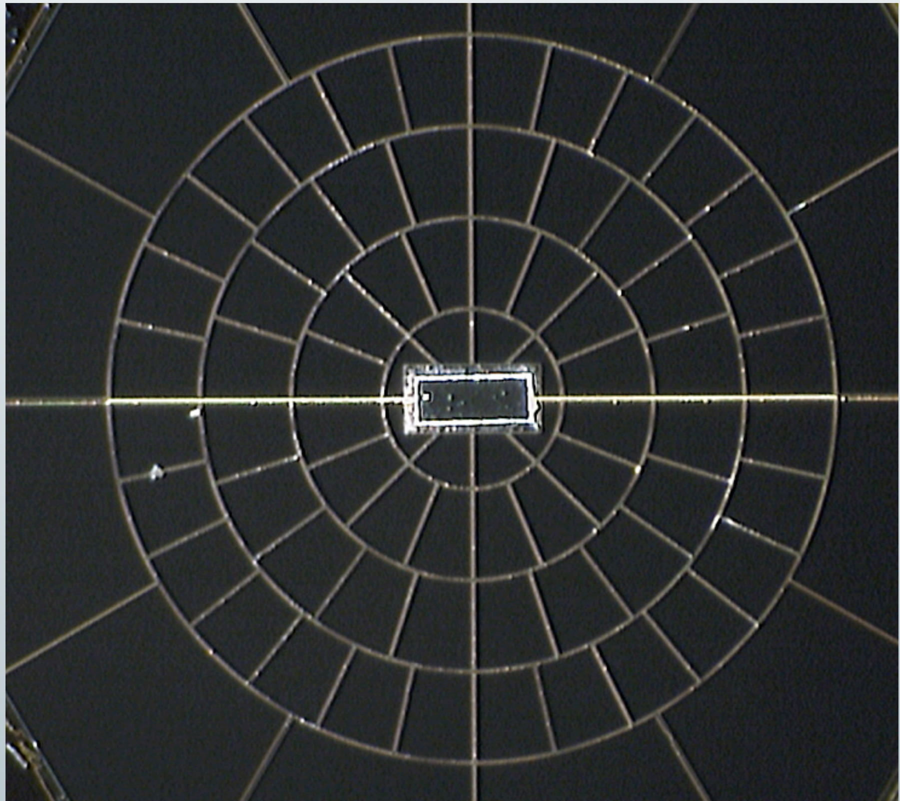
- Additive systematic effects
  - *Glitches (produced by cosmic rays)*
  - *Microphonics (produced by the Compressor of the HFI 4K cooler)*
  - *Electrical interference with internal/external signal*
- Uncertainty on the instrument properties that lead to a wrong inversion of the signal
  - *beam shape (impacts window function)*
  - *Spectral Response of channels*
  - *Defects of some electronic device*
  - *...*
- Distortions produced by the Data processing



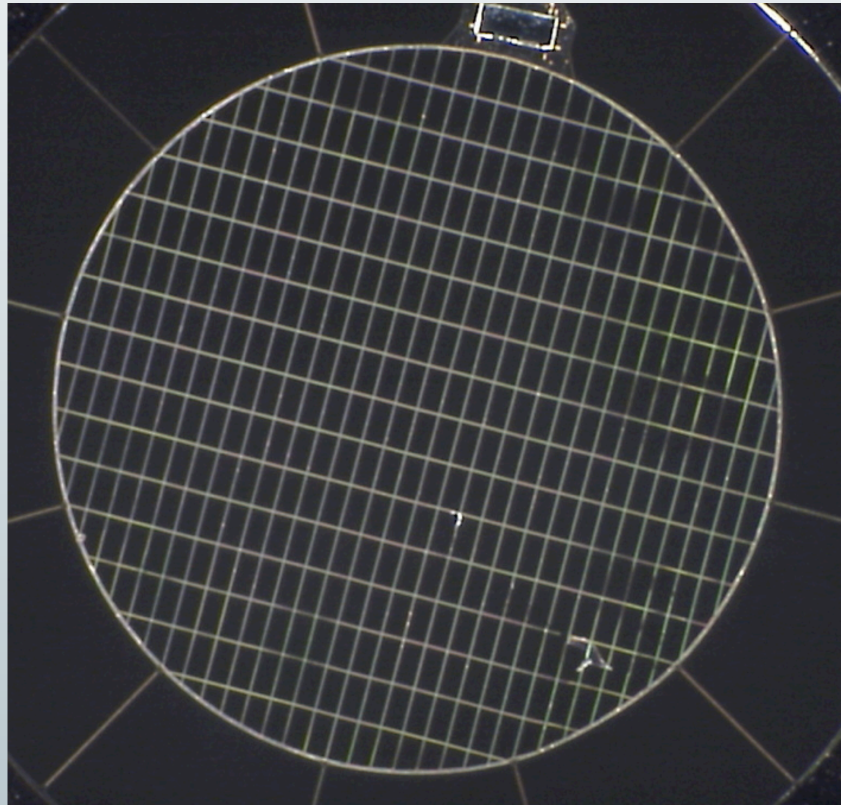
Glitches from cosmic rays

Bolometers were disigned with a grid absorber, efficient for photon absorption but offering a small cross section to particles

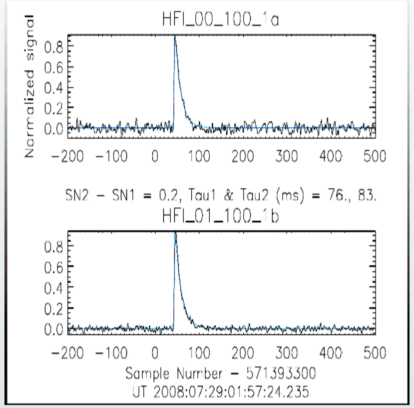
Spider Web Bolometer



Polarization Sensitive Bolometer



Glitches



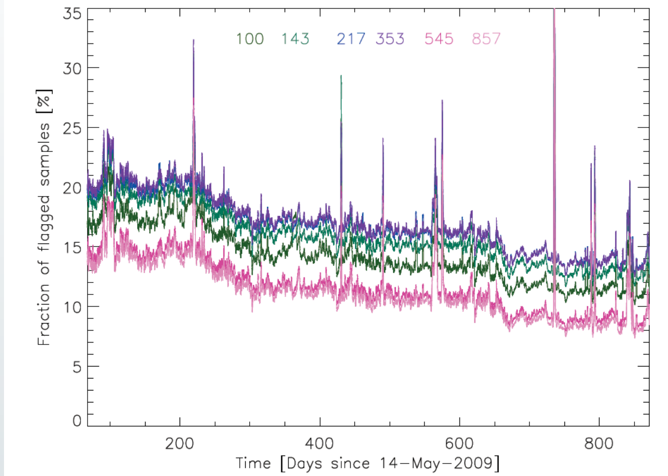


Figure 3. Evolution of the fraction of the flagged data per bolometer averaged over a channel for the six HFI channels. A running average over 31 pointing periods (approximately a day) is shown. The peak around day 455 comes from the sorption cooler exchange, while the peaks after day 500 are due to solar flares.

Planck - 2013-VI

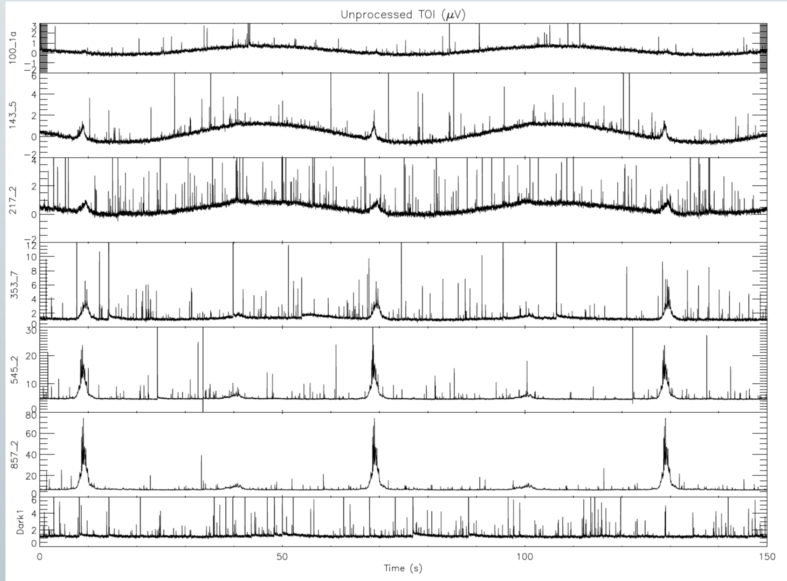
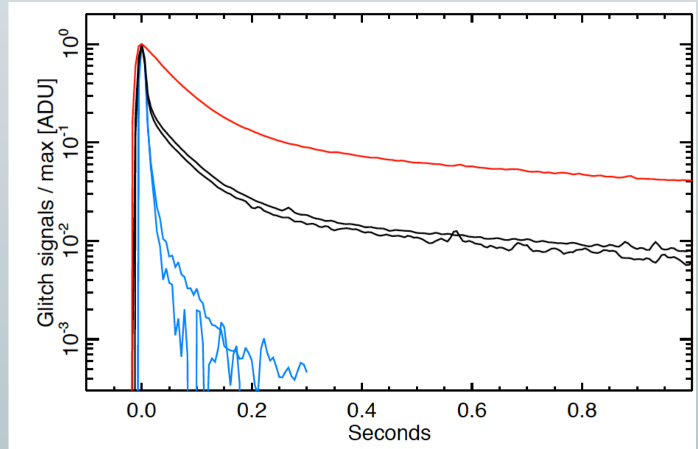
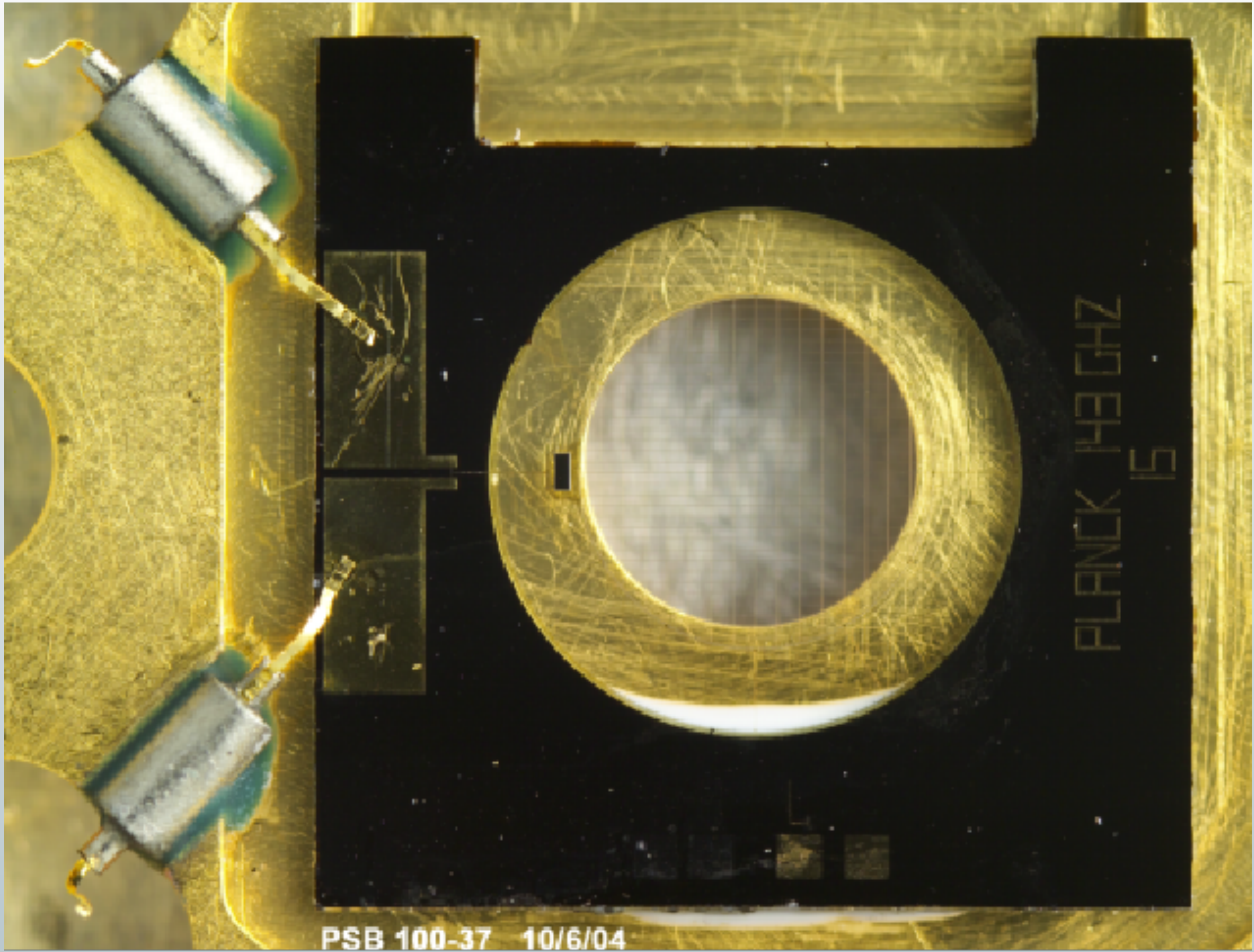


Figure 13. Examples of raw (unprocessed) TOI for one bolometer at each of six HFI frequencies and one dark bolometer. Slightly more than two scan circles are shown. The TOI is dominated by the CMB dipole, the Galactic dust emission, point sources, and glitches. The relative part of glitches is over represented on these plots due to the thickness of the lines that is larger than the real glitch duration.



Planck 2013-X


PLANCK 143 GHZ
15
PSB 100-37 10/6/04

Learned Lesson

- The bolometers (or any detector sensitive to particles) AND their environment have to be DESIGNED to minimize the effect of cosmic rays
- We should be prepared to remove a large quantity of glitches and to verify that this process does not introduce systematics.
- Early tests on the ground would have revealed the excess rate and permitted actions. Even late tests would have better prepared us for data reduction.

Instrument knowledge: We need a calibration strategy

- ➢ What must be calibrated on the ground
- ➢ what can be calibrated better in flight (a lot)

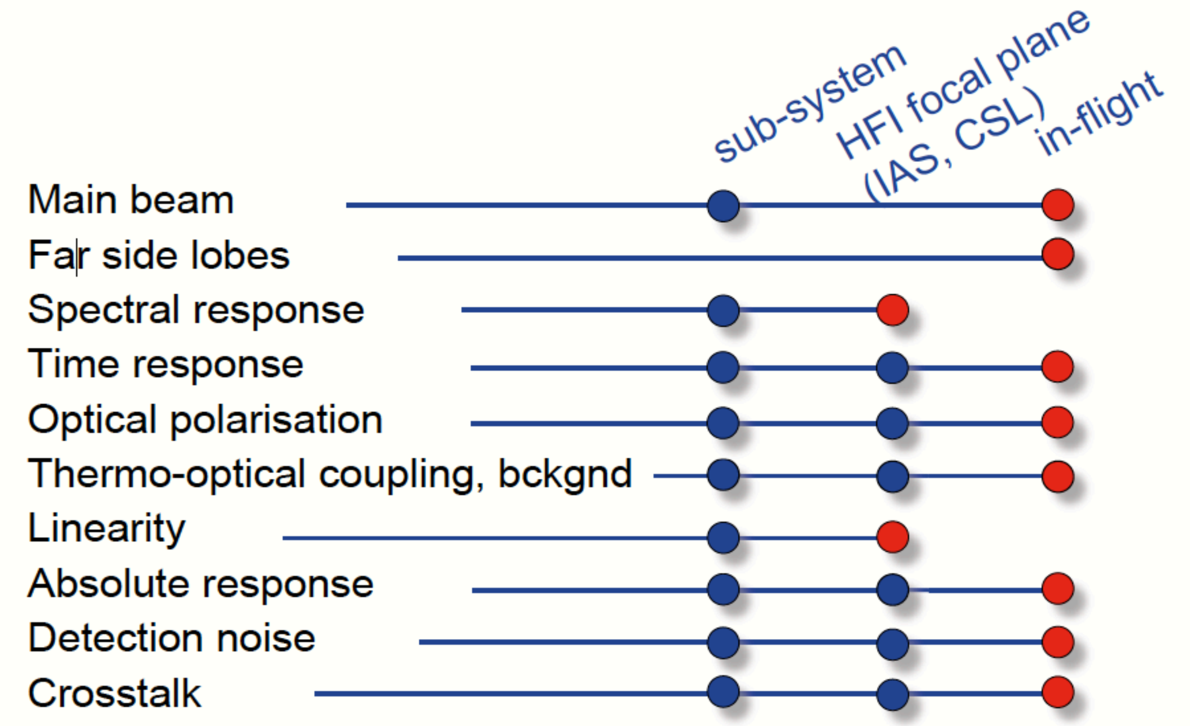


Fig. 1. Calibration philosophy. Blue dots indicate preliminary determinations, red dots indicate final determination.

Spectral transmission

- Spectral response can be measured on the ground only.
- Spectral response must be measured accurately to inter-calibrate channels. Essential for polarization and to pass calibration between sources with different spectra.
- This is not an easy task

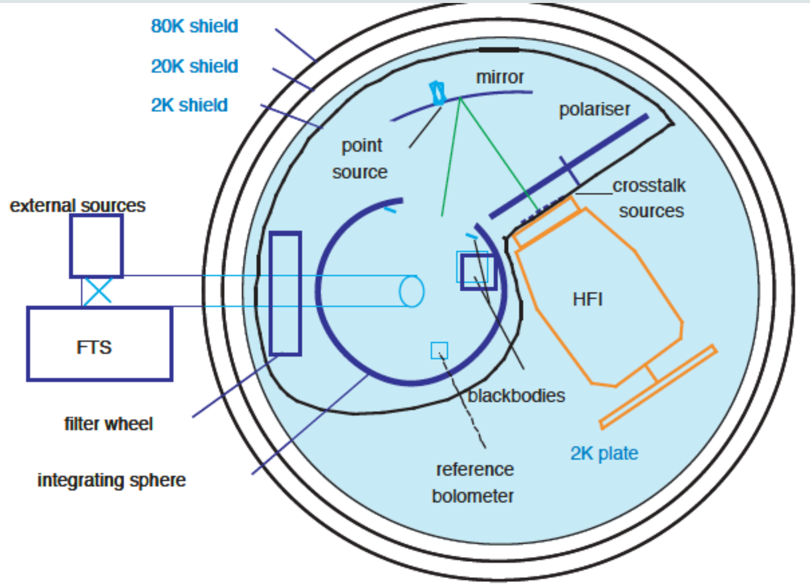


Fig. 3. Optical diagram of the HFI FPU calibration setup in the Saturne cryostat

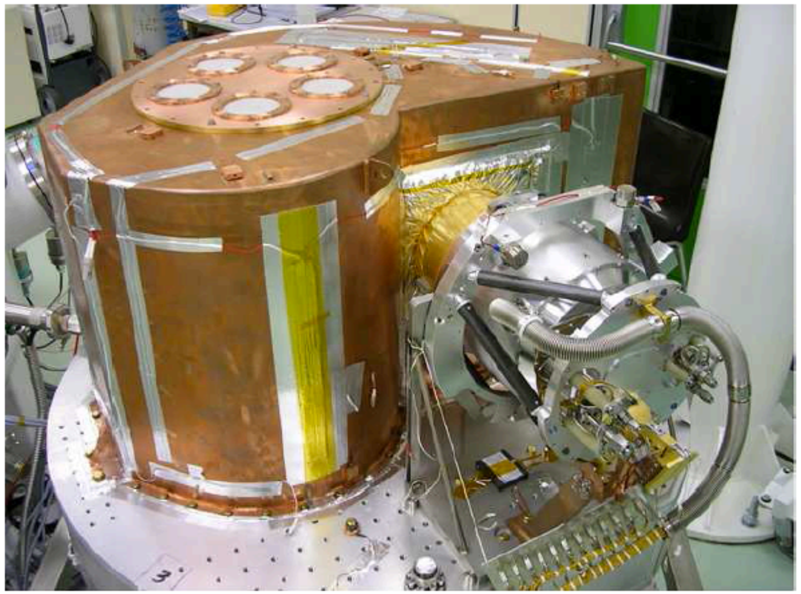


Fig. 5. Optical setup after integration of the 2 K optical baffle. The HFI detectors are looking into the 2 K enclosure. Only the back of the HFI PFM is visible, with its 4K and 18K interfaces.

How a problem becomes an achievement

- The CO lines are strong and « contaminate » dust measurements.
- Accurate measurements of the spectral response facilitated the production of CO maps, an unexpected outcome of Planck.

Planck Collaboration: HFI data processing

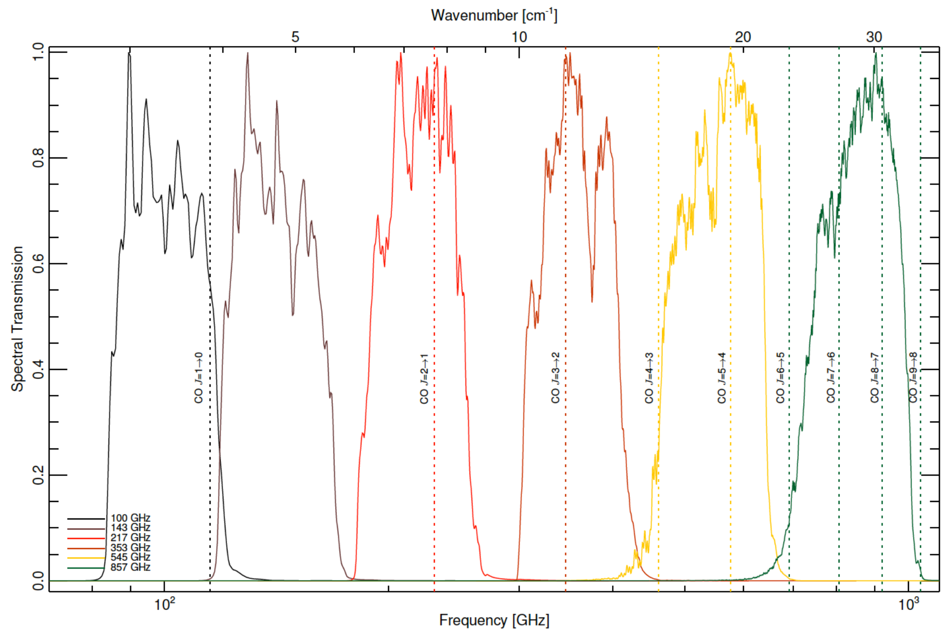
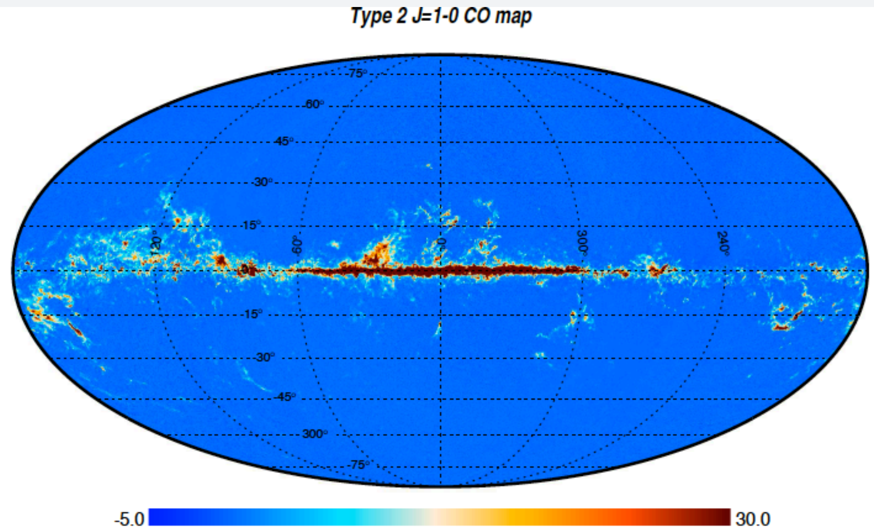
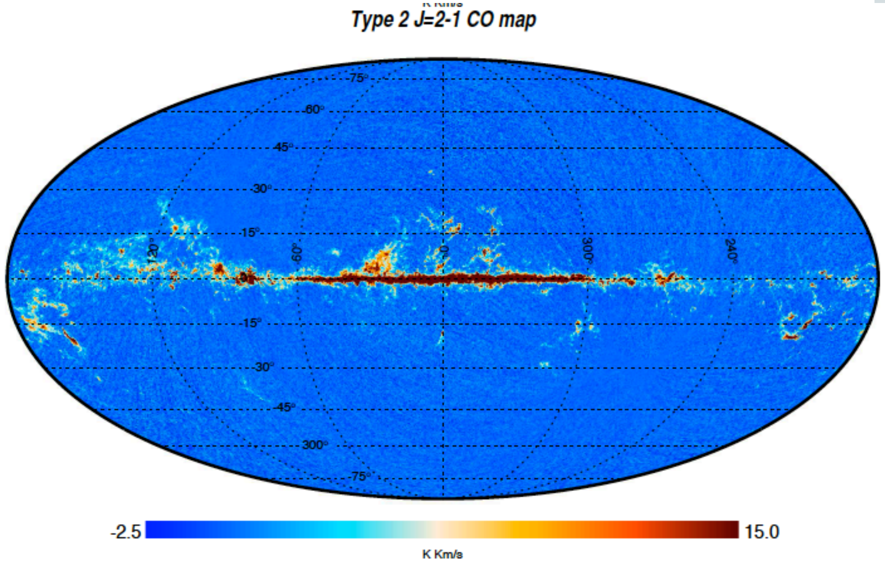


Figure 26. The band-averaged transmission spectra for all HFI frequency bands. The locations of the various relevant CO transitions are marked with vertical lines.



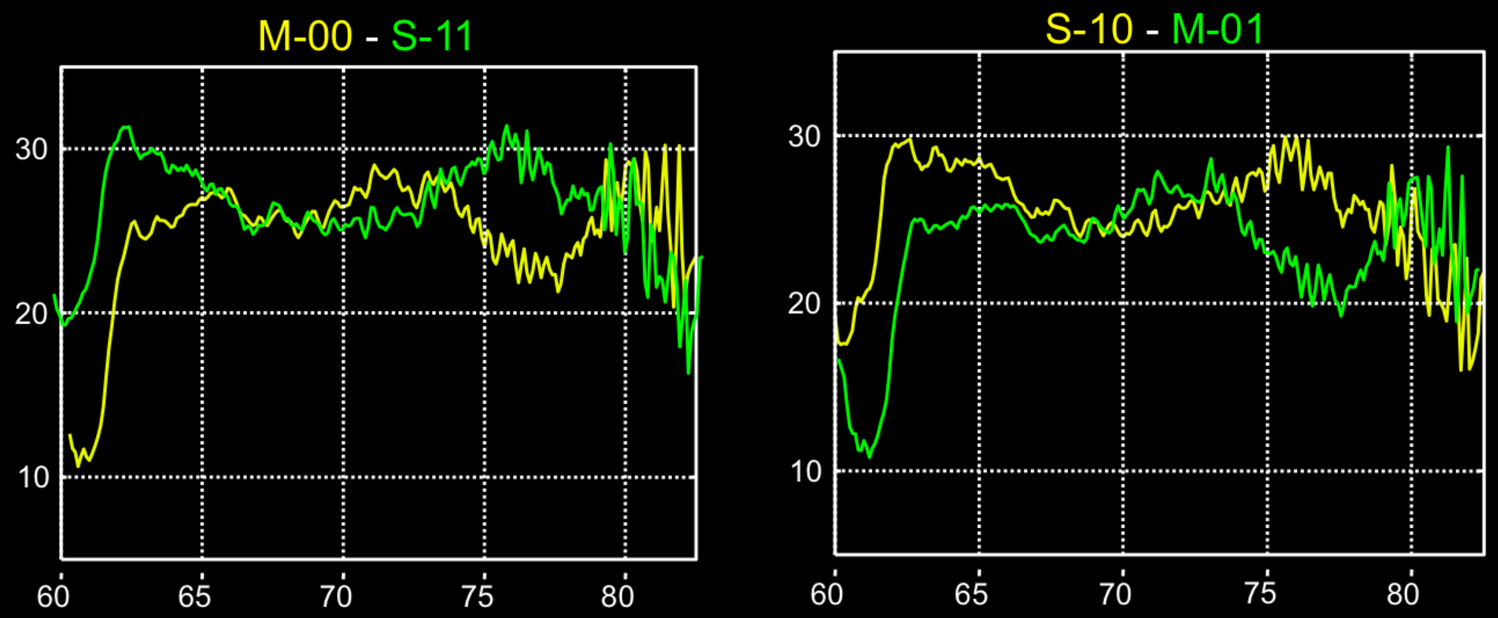


LFI bandpass mismatch

Real bandpasses

A. Zonca et al, JINST, 4, 2009

Frequency response is asymmetric on the two OMT arms



Effect expected on polarisation measurements that depend on the difference between the two OMT arms. Can be corrected if bandshape known within ~ 0.2% accuracy

Are the mirrors good enough?

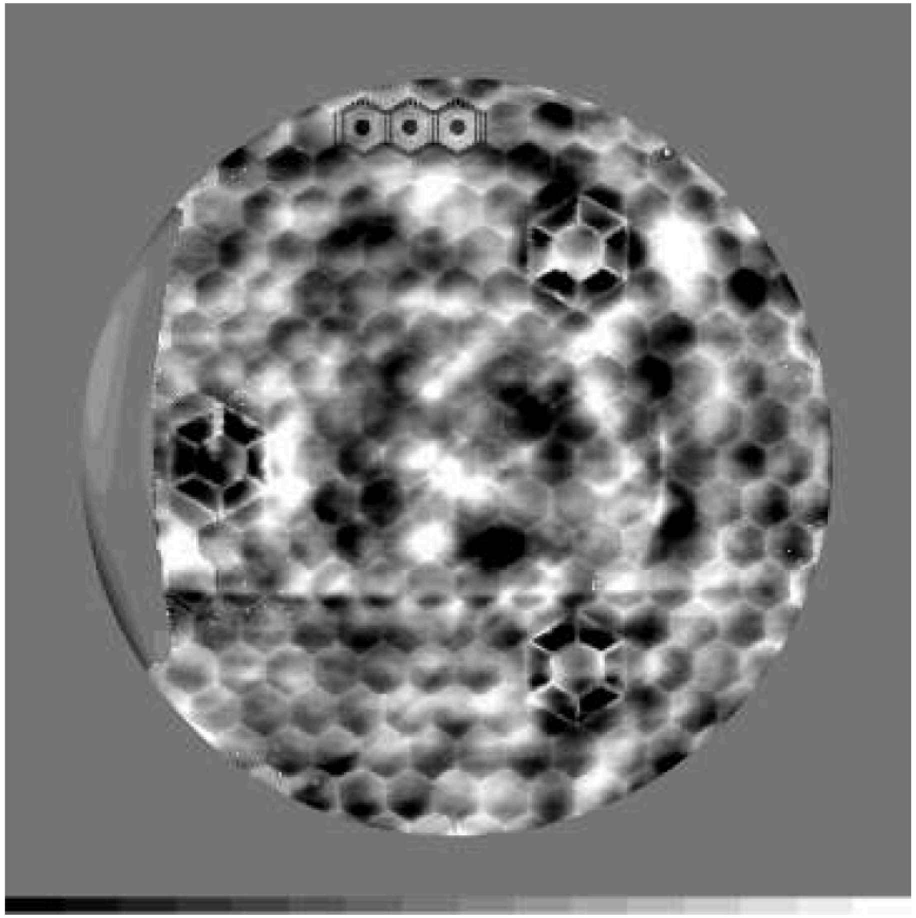
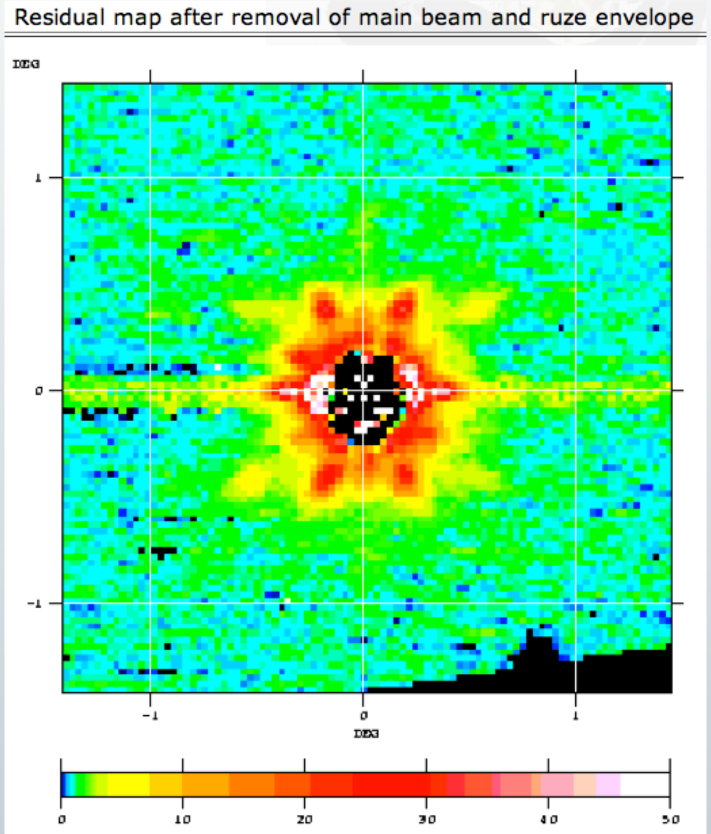
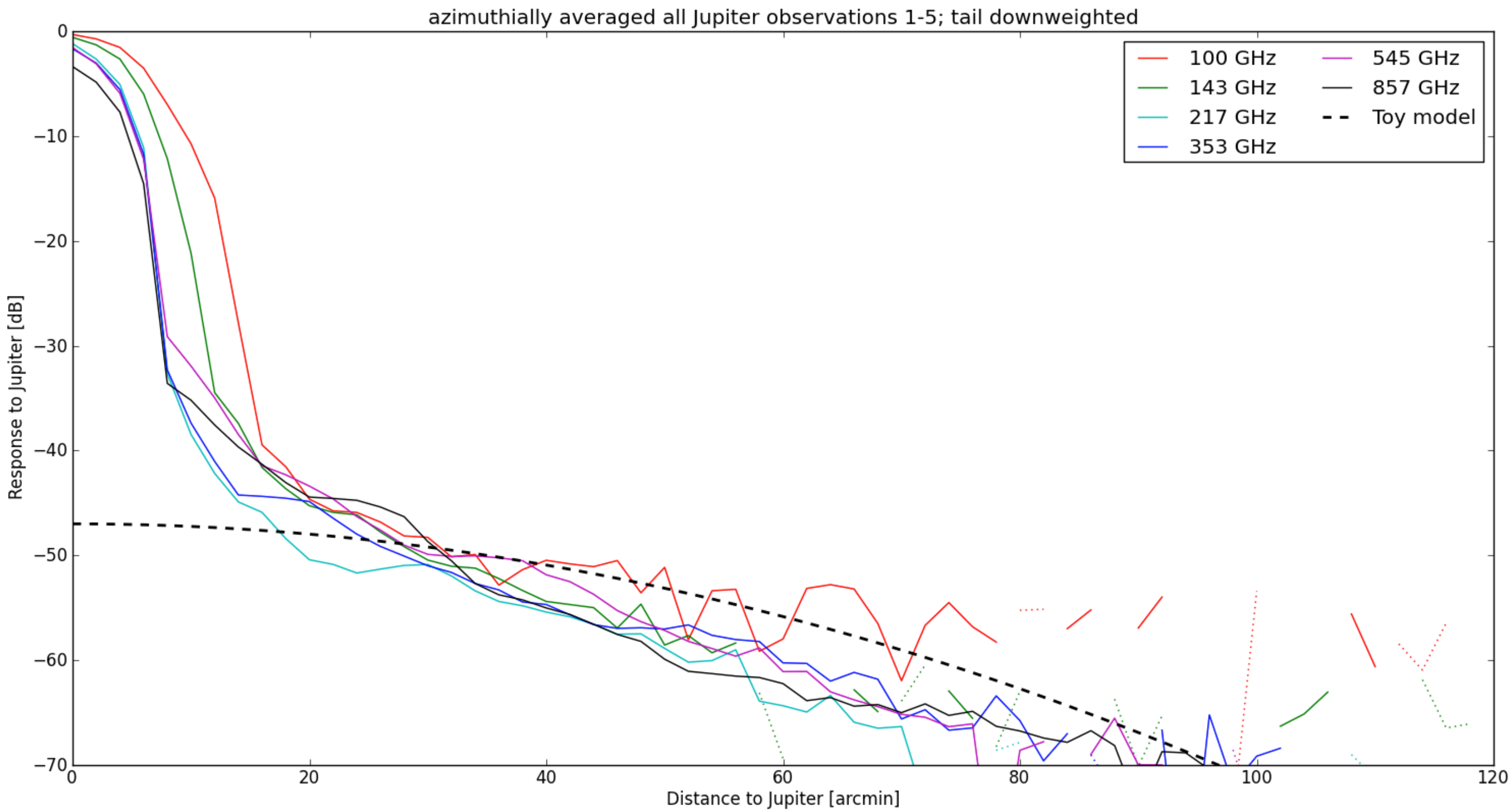


Fig. 8. The deformations at small scales of the SRFM at about 50 K as measured with $\lambda 10\ \mu m$ interferometry (the indentation at left is caused by vignetting in the interferometer optics). The colour scale is $\pm 10\ \mu m$.



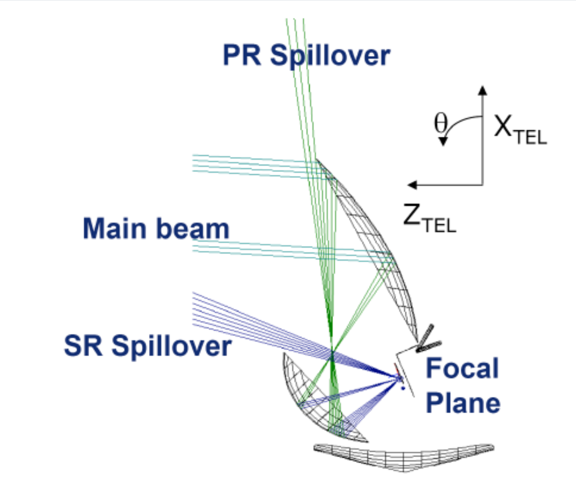
Are the beams known well enough?

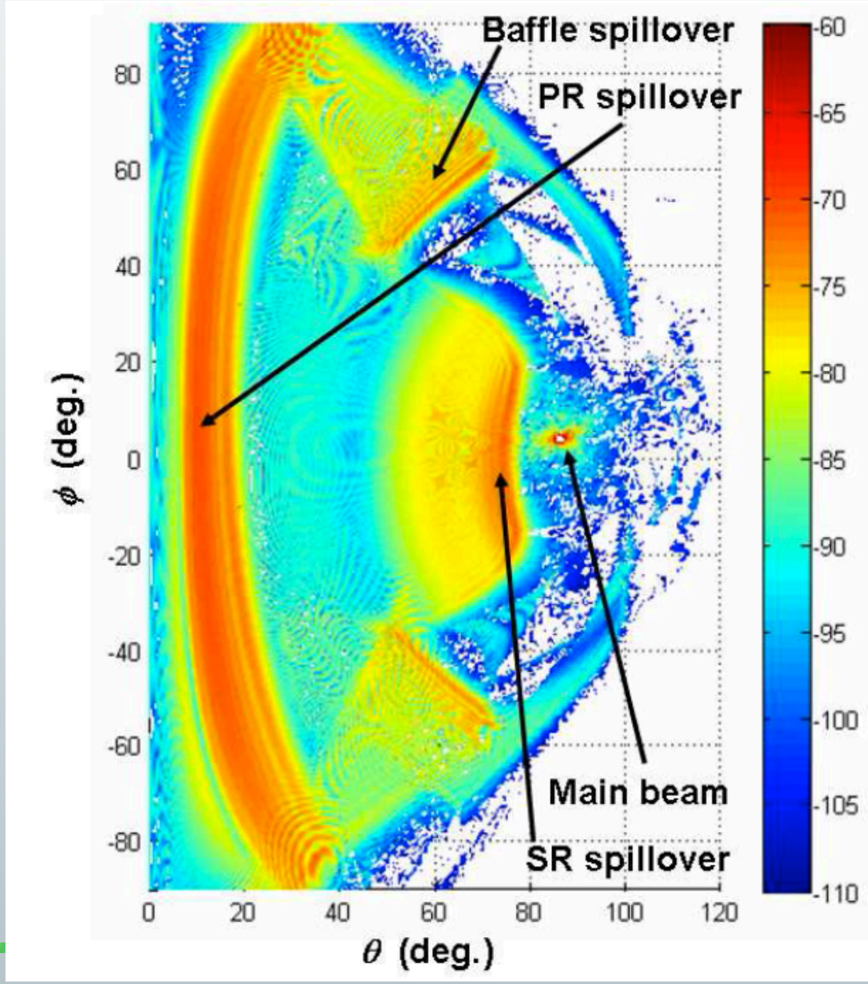
➢ Beam profiles on Jupiter



Far side lobes ?

- ➢ What about securing an in-flight measure of the FSLs (for future projects). On the moon ?





LESSONS ON SYSTEMATICS

- Anticipate and minimize systematics at the design level.
- A global and detailed calibration strategy must be defined in advance, which means anticipating on the data processing
- You must not miss the opportunity to characterize your instrument on the ground (calibrations), as well as possible.
- Systematics discovered in flight.
  - *Origin may be masked. ex: non linearity vs. gain variation*
  - *The most dangerous ones are changing with time (ex: 4K cooler lines)*
- Methods to correct systematics:
  - *Redundancy of data at different scales (scanning strategy, redundant design).*
  - *Templates from other experiments (ex: ...)*
  - *Access to raw data: on-board data compression hides real processes.*
  - *Numerical and physical models of instrumental parts*
  - *Sensitivity: if the good methods can be found, the level of residual systematics should be comparable to the noise*

Conclusions

- Planck was a high risk mission, very ambitious and using a lot of new technology.
- HEMT and bolometers are co-existing, which was a risk and is a help to identify systematics.
- It was successfully developed, tested, and operated.
- Many systematics were anticipated and technical solutions were found and implemented at the design level
- Ground calibrations were essential to understand the instrument.
- A large part of the calibration is made with flight data
- Telemetry: don't underestimate your needs. On board compression hides the details of systematics.
- Beware "easy" parts (e.g. ADCs) and watch out for interactions between systematics and with data processing.
- The technical achievements of Planck must be recognized:
  - *Measurement chains with unprecedented sensitivity*
  - *Entirely new cryogenic chain down to 0.1K*
  - *A flawless design and operation of the satellite*

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

- POLARIZATION SYSTEMATICS
  - *Gain variation*
  - *bandpass mismatch*
  - *calibration variation and mismatch (They dominate at large scales)*
  - *Far side lobes and foregrounds at low l*