Planck-HFI photometric calibration

G. Lagache

On behalf of the Planck collaboration

arXiv:1303.5069

Herschel Calibration workshop March 2013

1) Planck and HFI: basic characteristics

2) Pipeline for map production

3) Calibration of the low-frequency channels (100-353 GHz)

4) Calibration of the high-frequency channels (545-857 GHz)

5) Setting the zero levels

6) Comparison to SPIRE

1) Planck and HFI: basic characteristics

2) Pipeline for map production

3) Calibration of the low-frequency channels (100-353 GHz)

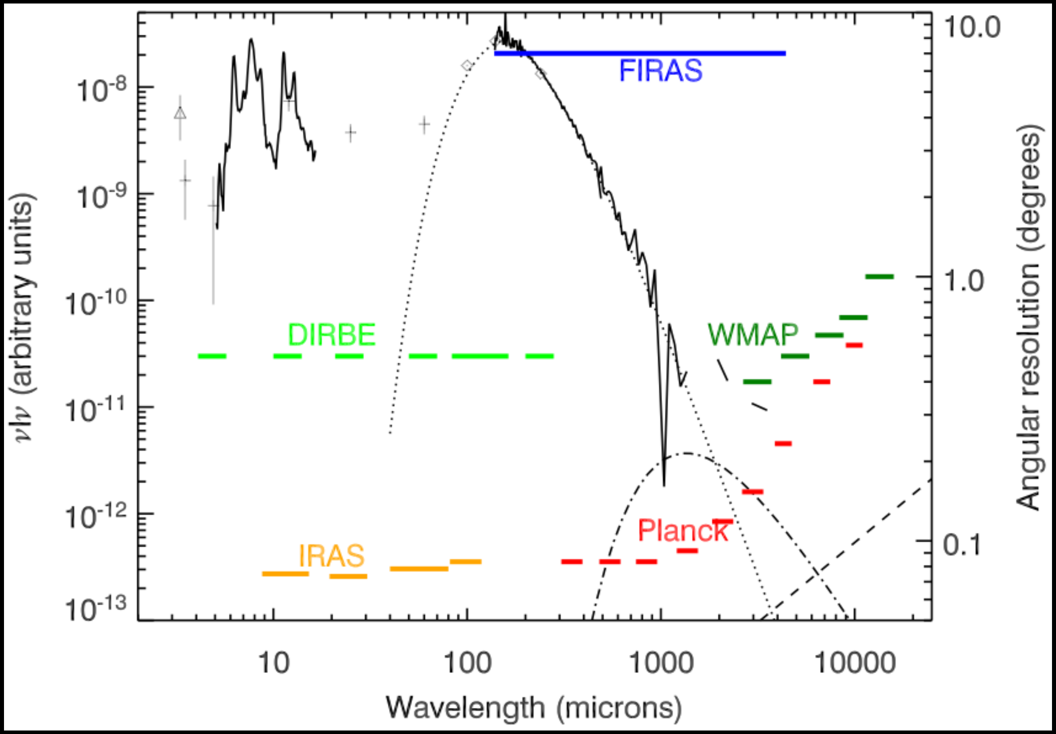
4) Calibration of the high-frequency channels (545-857 GHz)

5) Setting the zero levels

6) Comparison to SPIRE

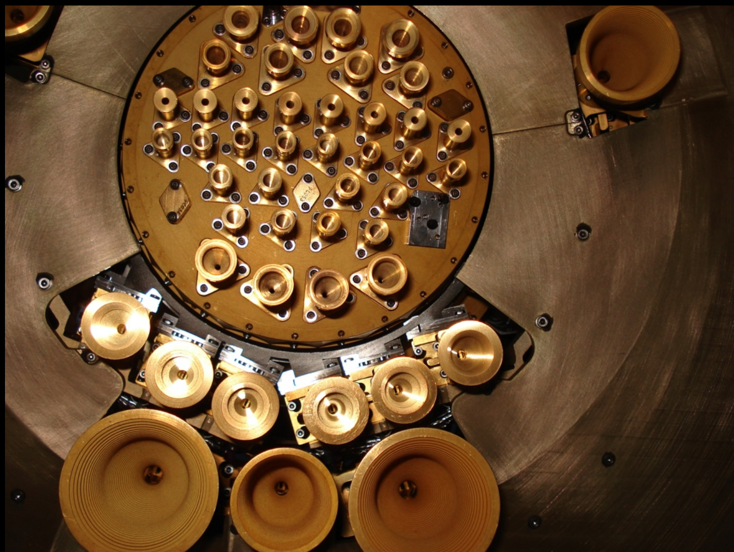
Planck fact sheet

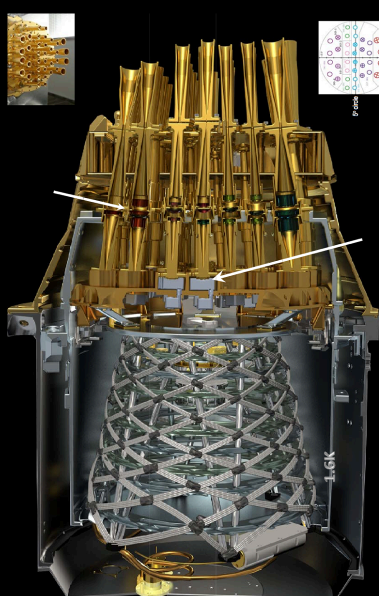
- ESA's satellite mission, launched on May the 14th 2009
- 1.5 m off-axis Gregorian telescope
- Two instruments:
  - LFI: radiometers cooled to 20K at 30, 44 and 70 GHz
  - HFI: bolometers cooled to 100mK at 100, 143, 217, 353, 545 and 857 GHz
  - Unprecedent frequency coverage
- Angular resolution:
  - 30 to 13 arcmin for LFI
  - 10 to 4.5 arcmin for HFI



HFI: PI: J.-L. Puget (IAS, France)
LFI: PI: R. Mandolesi (INAF/IASF)

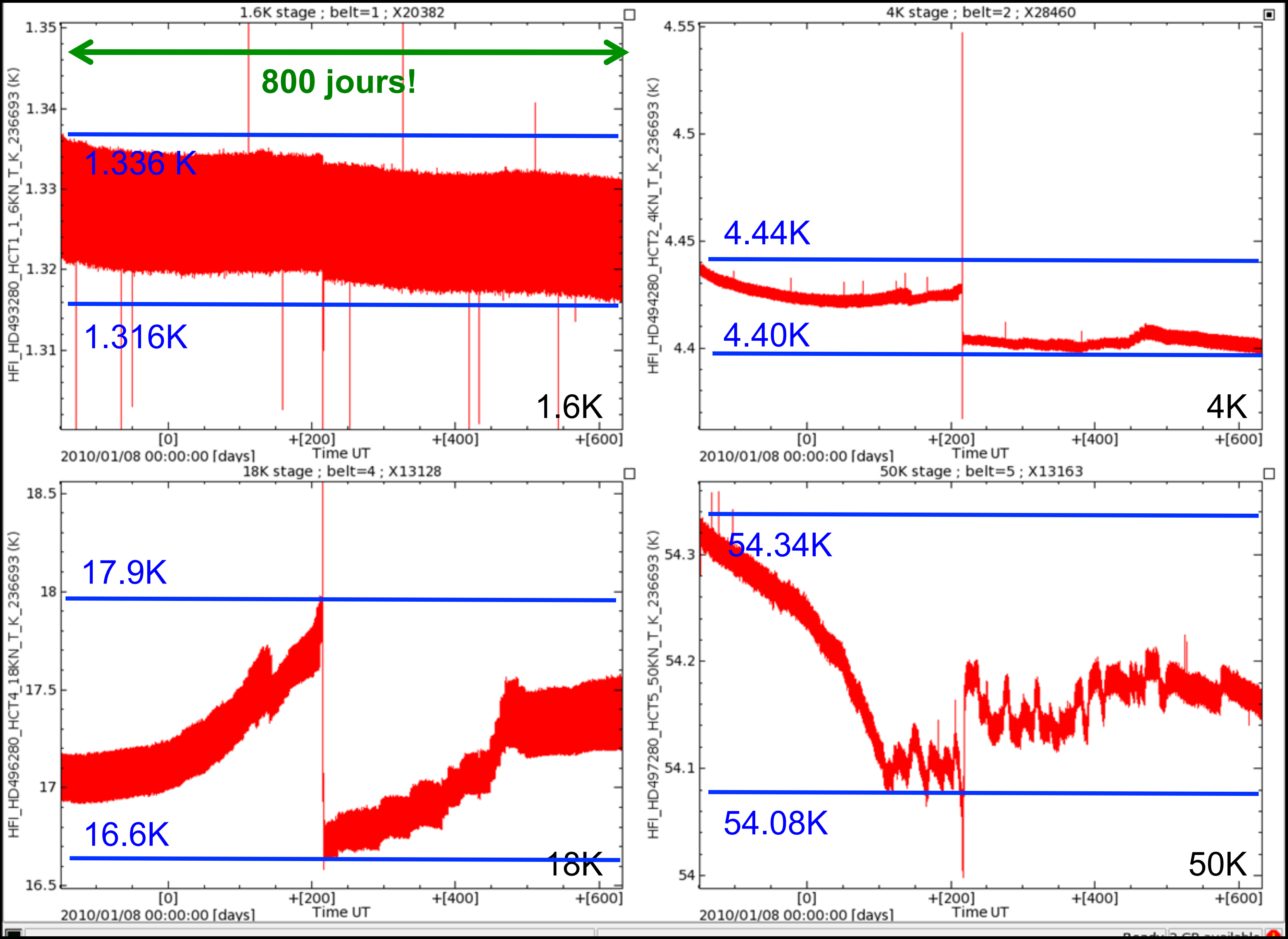
Planck-HFI






Cornets «dos à dos» à 4 K
Filtres à 1,6 K
Bolomètres, cornets et filtres à 0,1 K
0,1 K
Échangeur de chaleur
1,6 K - 0,1 K
1,6 K
4 K
Éclaté de l'instrument HFI

Temperature stability



From L. Vibert

HFI Data

- One circle per minute (repeated ~50 times)

- 200 measures per second and per detector, continuously during 30 months

- ~1000 Billions of « samples » (72 channels, 30 months) – several Billions of telemetry packets

- Raw data from one detector (TOI)
    - 50 Go (NB1 we have 52 detectors, NB2 several versions!)

- Add ancillary data: pointing, thermometry,...

- 1 release = 1 month of processing, 2200 maps

- Sky maps: 50 Millions of pixels (6 frequencies for HFI + 3 LFI)

- CMB Power spectrum: 1000 values

HFI Data

- One circle per minute (repeated ~50 times)

- 200 measures per second and per detector, continuously during 30 months

- ~1000 Billions of « samples » (72 channels, 30 months) – several Billions of telemetry packets

- Raw data from one detector (TOI)
  - 50 Go (NB1 we have 52 detectors, NB2 several versions!)

- Add ancillary data: pointing, thermometry,...

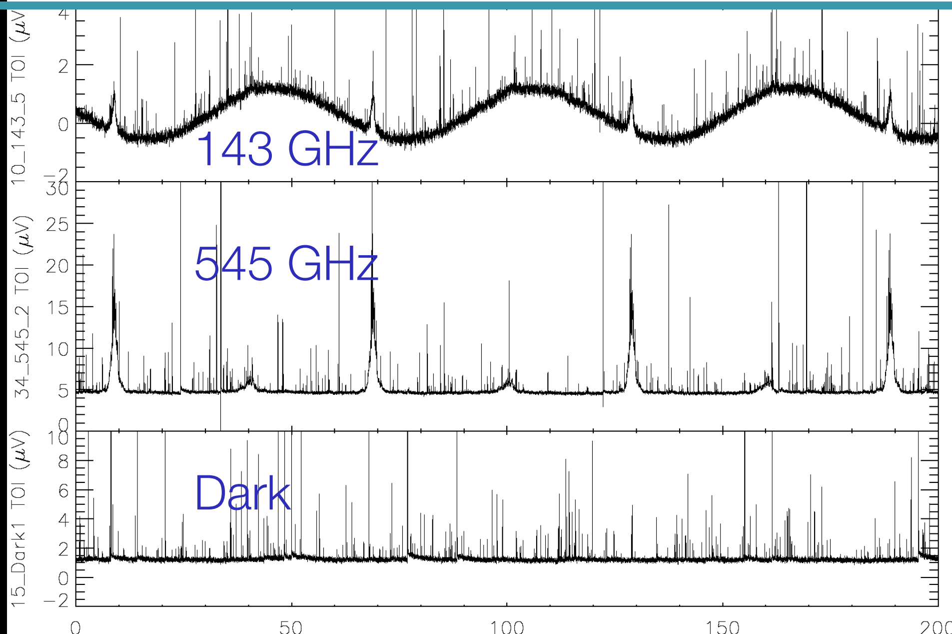
- 1 release = 1 month of processing, 2200 maps

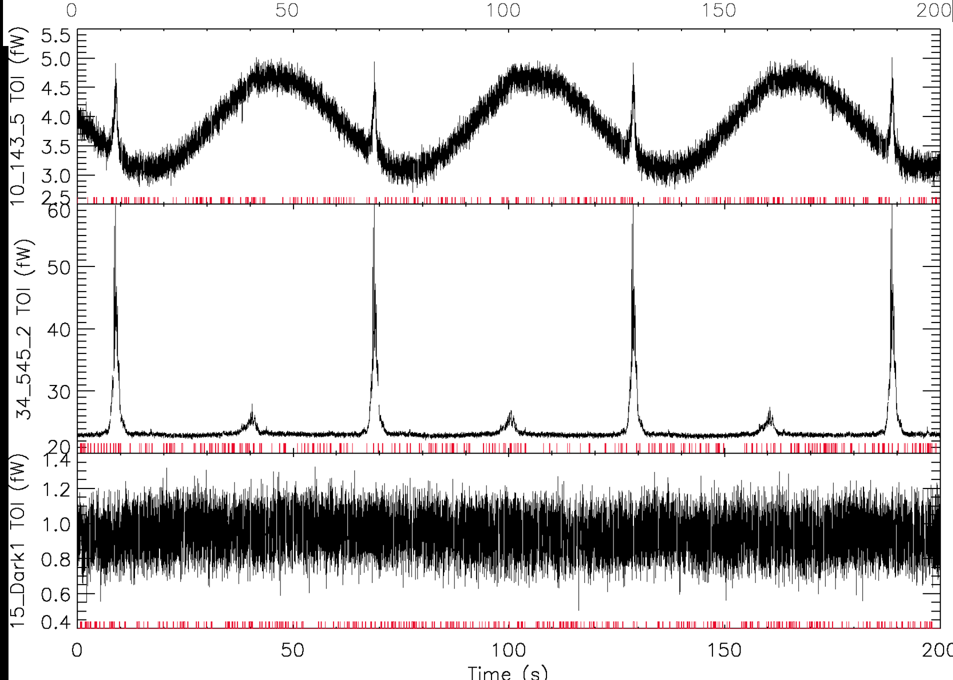
- Sky maps: 50 Millions of pixels (6 frequencies for HFI + 3 LFI)

- CMB Power spectrum: 1000 values

- ….. 10 cosmological parameters!!

Time ordered Informations





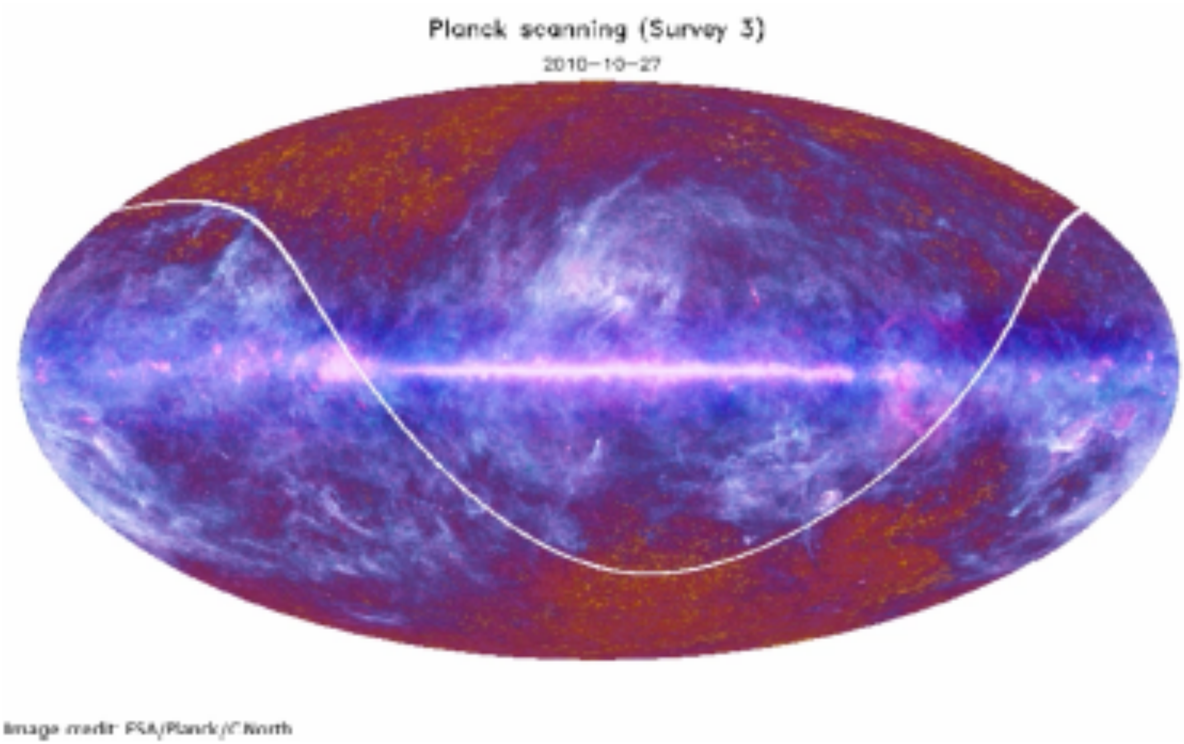
- 3 min of raw signal (1 bolo)

- After some treatments:
  - Cosmic rays (between 40 and 120 /minutes/bolo – 10-15% data lost)
  - Bolo time constant deconvolution
  - Themometer decorrelation
  - etc

Planck collab, arXiv:1303.5067

Map construction

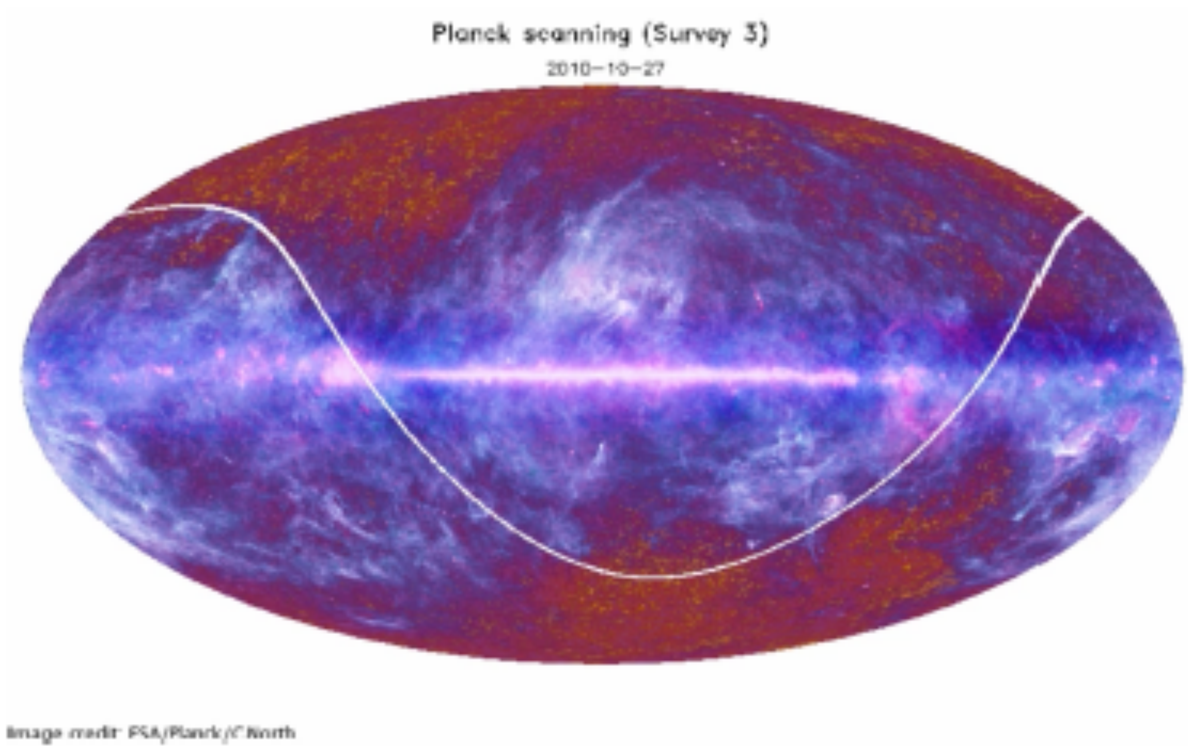
Data from several detectors (~100 To) are used simultaneously



From O. Perdereau

Map construction

Data from several detectors (~100 To) are used simultaneously



From O. Perdereau

1) Planck and HFI: basic characteristics

2) Pipeline for map production

3) Calibration of the low-frequency channels (100-353 GHz)

4) Calibration of the high-frequency channels (545-857 GHz)

5) Setting the zero levels

6) Comparison to SPIRE

Map production and calibration

- In rings: 1/f noise and time varying components (zodi, FSL, dipoles)
    - Calibration and map-making are interleaved

- A four-step process

  1) Average the measurements in each HEALPix pixel visited during a stable pointing period (a *ring*)

  2) Calibration:
     - Solar dipole (100-353 GHz)
     - Planets (545-857 GHz)
     - Relative gain time variation (100-217 GHz)

  3) Destriping (Polkapix, Tristram et al. 2011) and projection (Healpix map, Nside=2048, pixel size of 1.7')

     - Iterate 2 and 3

  4) Setting the map zero levels

1) Planck and HFI: basic characteristics

2) Pipeline for map production

3) Calibration of the low-frequency channels (100-353 GHz)

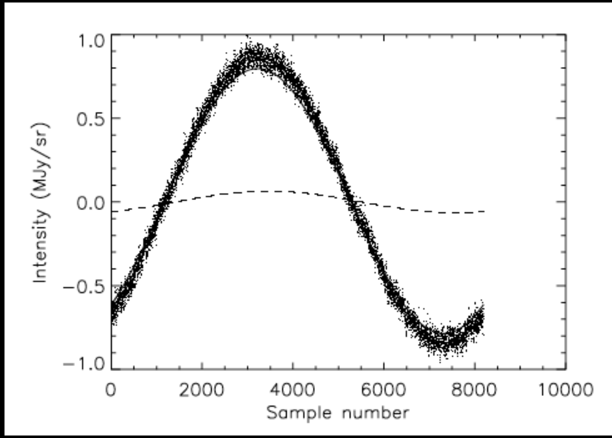
4) Calibration of the high-frequency channels (545-857 GHz)

5) Setting the zero levels

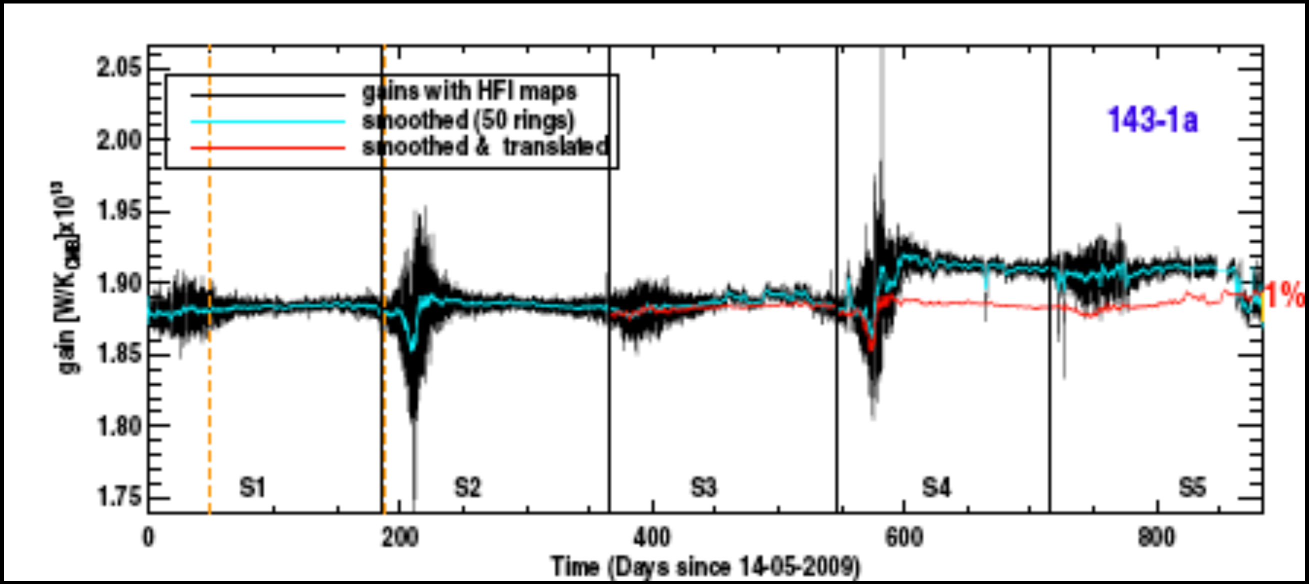
6) Comparison to SPIRE

Dipole calibration at low frequencies

• A ring calibration



• Unexpected gain time variation (due to imperfections in the linearity of the analog-to-digital converters (ADC) used in the bolometers read-out units).



From O. Perdereau, M. Tristram

Dipole calibration at low frequencies

- Mapping the ADC response in the warm phase (4K)
  - Corrections are being made

- For the 2013 data release:
  - time variation « breaks » the absolute calibration using the orbital dipole => fit of Solar dipole determined by WMAP and FIRAS
  - Effective correction for relative gain variation for the 100-217 GHz channels (using Bogopix)

Frequency [GHz]	Time stability (a) [%]	Relative (b) [%]	Absolute (c) [%]	Model [%]
100	0.3	0.2	0.54	0.24
143	0.3	0.2	0.54	0.24
217	0.3	0.2	0.54	0.24
353	1.	1.	1.24	0.24

1) Planck and HFI: basic characteristics

2) Pipeline for map production

3) Calibration of the low-frequency channels (100-353 GHz)

4) Calibration of the high-frequency channels (545-857 GHz)

5) Setting the zero levels

6) Comparison to SPIRE

From a FIRAS to a planet-based calibration

- FIRAS 7-deg beam, all sky, one « dust » spectrum per pixel, diffuse emission

- FIRAS gain error at high frequency: 3%

- FIRAS calibration was first adopted but

    - A systematic effect in the calibration coefficients was observed for a long time

    - Cannot be: FIRAS beam, pixelisation effect, « pipeline » effect, zodical light, far-side lobes, color corrections, time gain variations

    - Converging evidences for an overestimate of the HFI brightness at high ν, when calibrating using FIRAS
        - Relative calibration of CMB anisotropies at 545 GHz, IS dust SED, planet flux from models, dipole calibration at 545 GHz, CIB measurements

=> We abandonned the FIRAS calibration (both the gain and the offset) to the profit of a planet calibration (and an « Astrophysical » zero level).

Calibration on planets

- Use Neptune and Uranus

- Do a first photometric calibration using FIRAS at 545 and 857 GHz (and the dipole at 100-353 GHz)

- Create small maps around the planets position by projecting the destriped and calibrated timelines

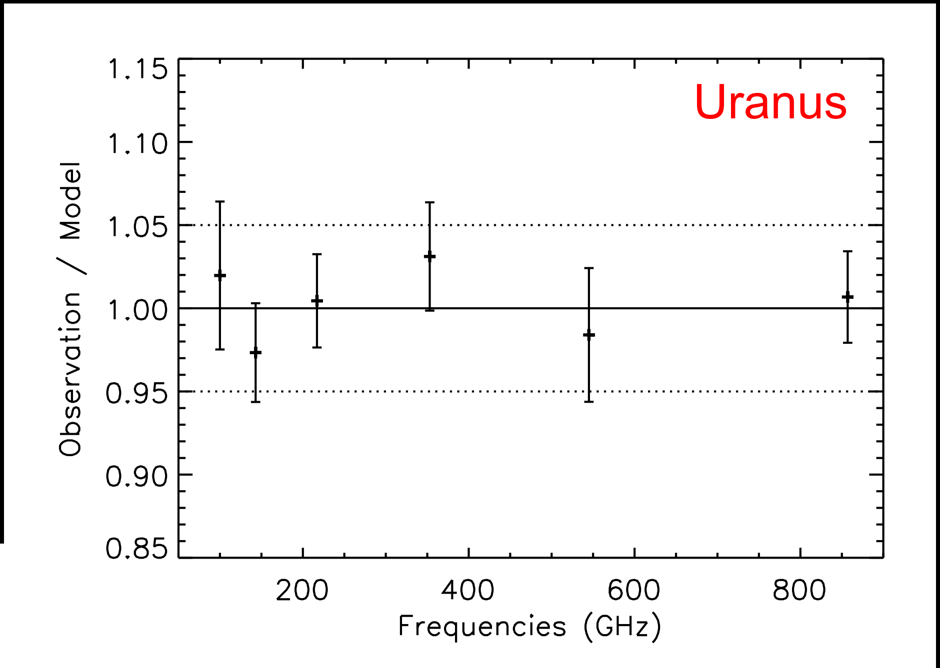
- Simultaneously built maps of the « background »

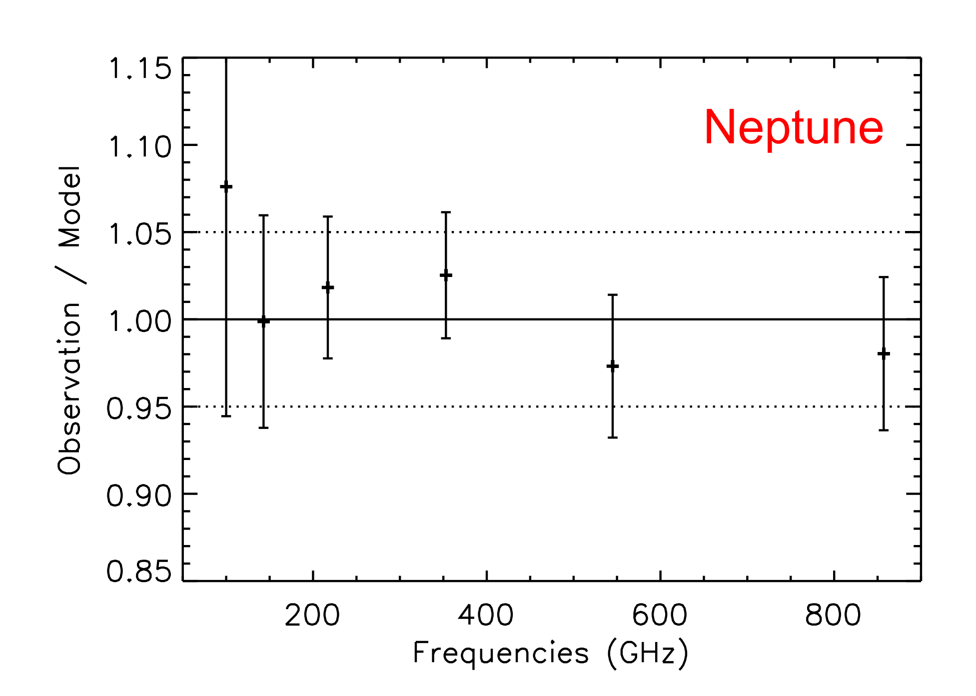
- Measure the planet flux densities using aperture photometry: integrate the flux up to 3FWHM and correct for the beam solid angle difference between 3FWHM and the full solid angle (0.8% at 545 GHz and 1.5% at 857 GHz).

- At 545 and 857 GHz, apply a correction factor to the FIRAS calibration to match the Uranus and Neptune flux densities given by the models
    - Factors are 1.07 at 857 GHz and 1.15 at 545 GHz
    - ESA2 for Uranus and ESA3 for Neptune

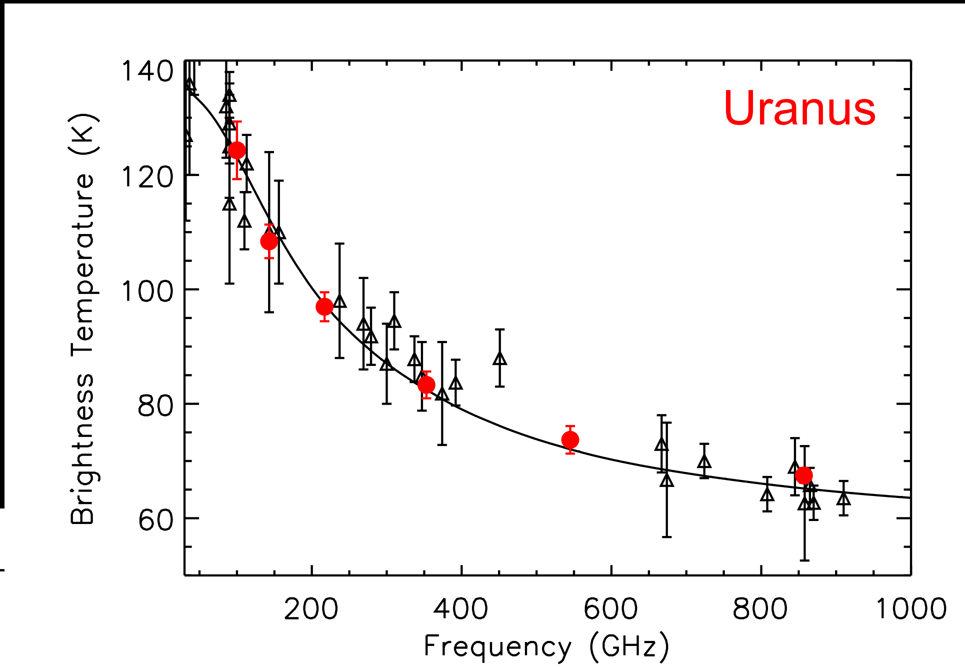
- Apply color corrections and unit conversions

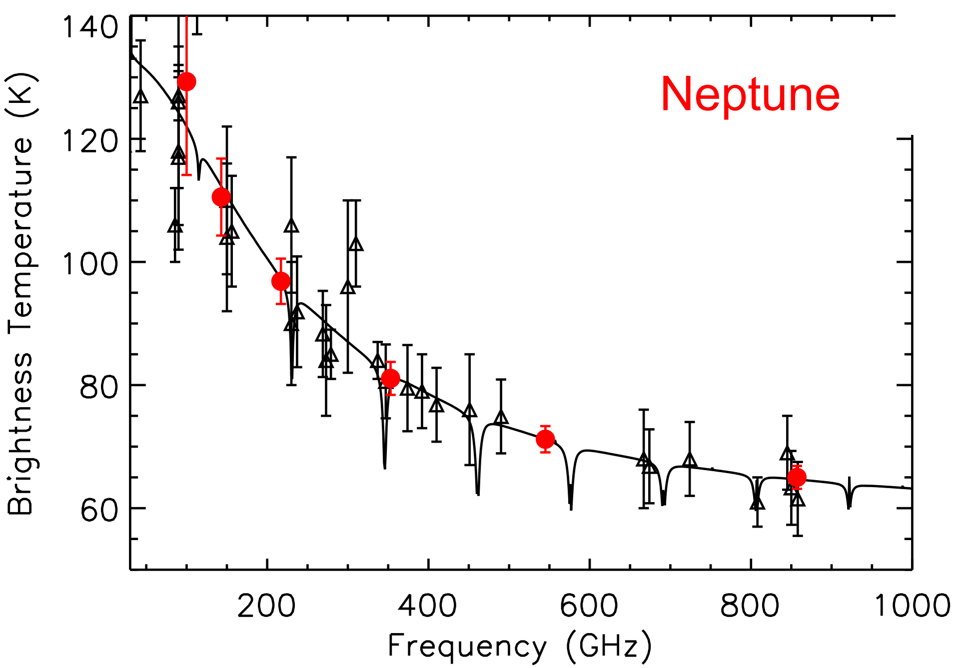
Calibration on planets: flux densities





Calibration on planets: Tb





Calibration on planets

- 5% uncertainty on the flux measurements, 5% on the model

Frequency [GHz]	Time stability (a) [%]	Relative (b) [%]	Absolute (c) [%]	Model [%]
100	0.3	0.2	0.54	0.24
143	0.3	0.2	0.54	0.24
217	0.3	0.2	0.54	0.24
353	1.	1.	1.24	0.24
545	1.	5.	10.	5.
857	1.	5.	10.	5.

- Will be more precise for the next Planck data release:
    - Use Mars measurement and relative calibration using the low-frequency channels, calibrated on the dipole and the two high-frequency channels

1) Planck and HFI: basic characteristics

2) Pipeline for map production

3) Calibration of the low-frequency channels (100-353 GHz)

4) Calibration of the high-frequency channels (545-857 GHz)

5) Setting the zero levels

6) Comparison to SPIRE

Zero Levels

- An « Astrophysical » zero level (from 100 to 857 GHz)

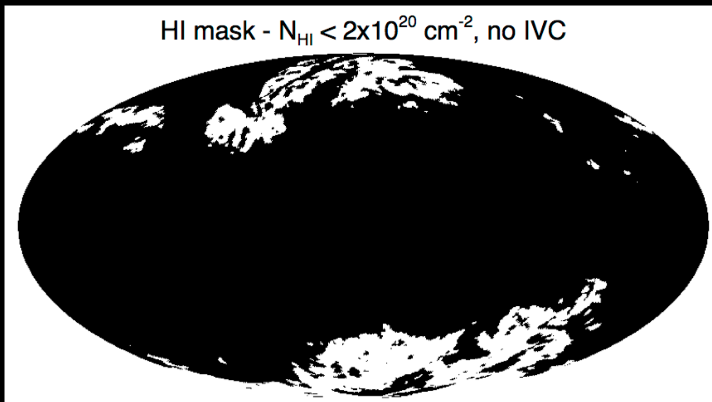
- An extragalactic zero level
  - The CIB monopole
  - Set using a galaxy evolution model (not FIRAS measurements!)
    - In agreement with galaxy number counts, luminosity functions, etc
    - Béthermin et al. 2012, error of ~20%

Table 4. CIB monopole that has to be added to the maps.

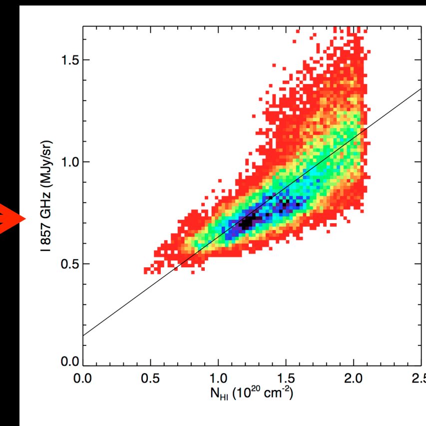
Frequencies [GHz]	CIB [MJy sr^{-1}] (νI_ν = cst)
100	3.0×10^{-3}
143	7.9×10^{-3}
217	3.3×10^{-2}
353	1.3×10^{-1}
545	3.5×10^{-1}
857	6.4×10^{-1}

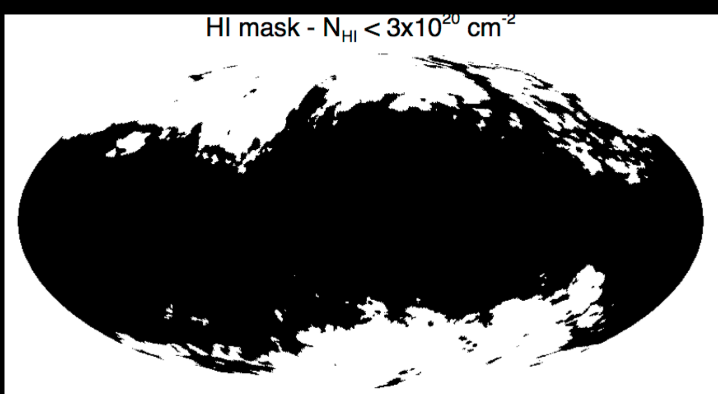
- A Galactic zero level
  - Set at 857 GHz using the correlation with N(HI)
  - Set at the other frequencies using the correlation with the 857 GHz

Galactic zero Levels

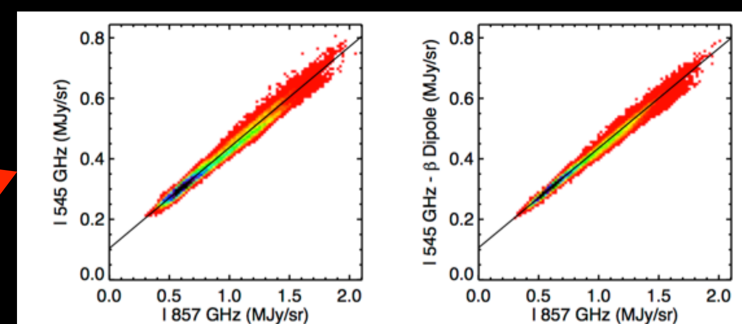


857- N(HI) correlation

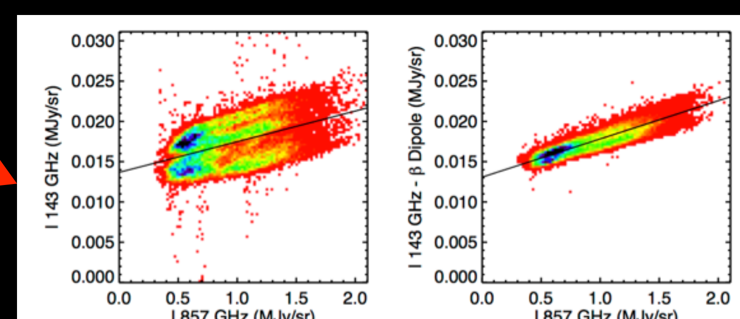




857-545 correlation



857-143 correlation



From M.-A. Miville-Deschênes

Galactic zero Levels

Table 5. Table giving the offsets that have to be removed at each frequency to set the Galactic zero level. The offsets have been computed assuming zero Galactic dust emission for zero gas column density.

Frequencies [GHz]	DX9 maps [MJy sr^{-1}] (νI_ν = cst)	zodi-removed DX9 maps [MJy sr^{-1}] (νI_ν = cst)
100	0.0047±0.0008	0.0044±0.0009
143	0.0136±0.0010	0.0139±0.0010
217	0.0384±0.0024	0.0392±0.0023
353	0.0885±0.0067	0.0851±0.0058
545	0.1065±0.0165	0.0947±0.0140
857	0.1470±0.0147	0.0929±0.0093

- Zero level recipe:
  - Total emission analysis: map = map + CIB – Galactic zeros
  - Galactic studies: map = map – Galactic zeros

1) Planck and HFI: basic characteristics

2) Pipeline for map production

3) Calibration of the low-frequency channels (100-353 GHz)

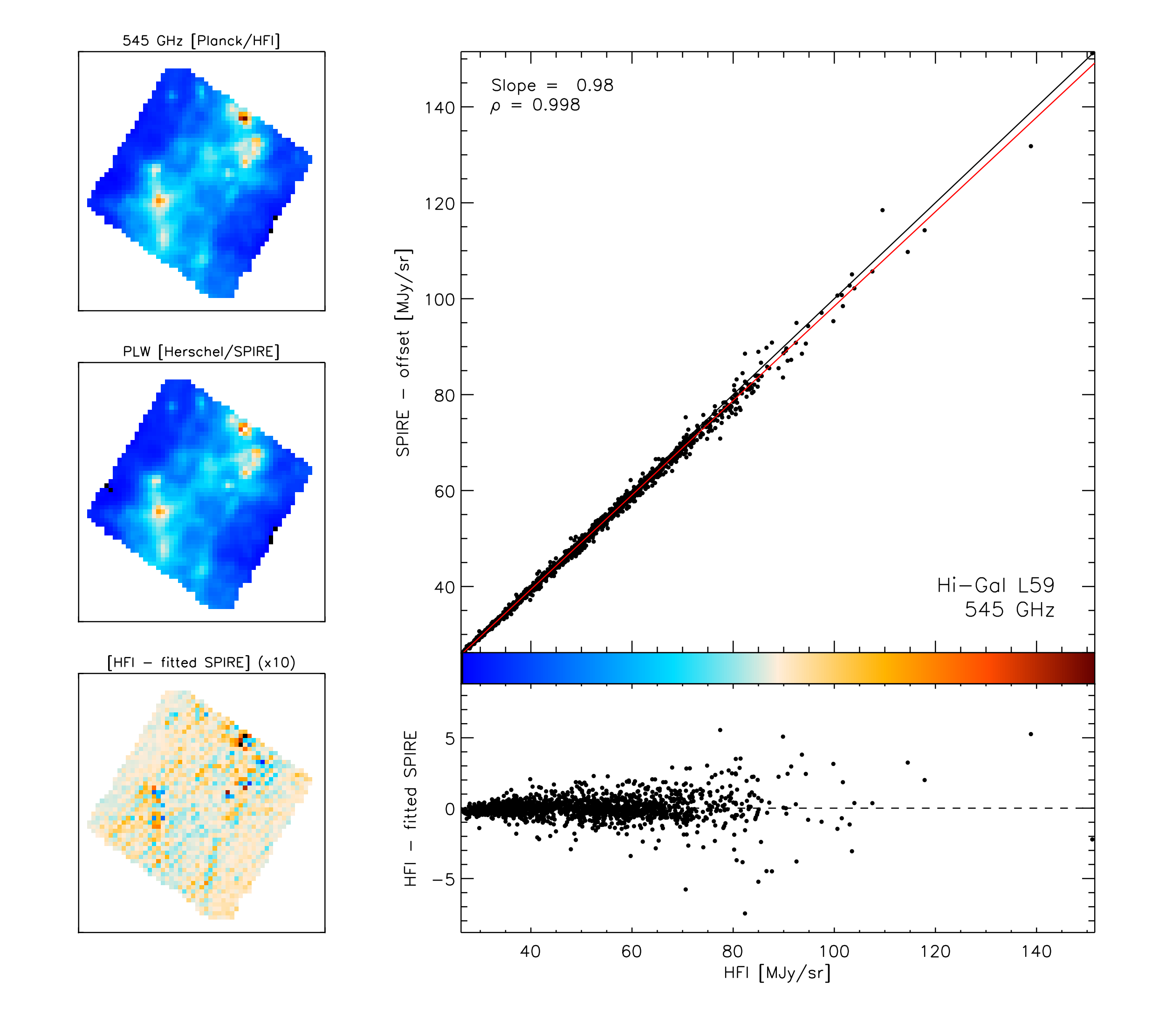
4) Calibration of the high-frequency channels (545-857 GHz)

5) Setting the zero levels

6) Comparison to SPIRE

Comparison with SPIRE (work in progress)

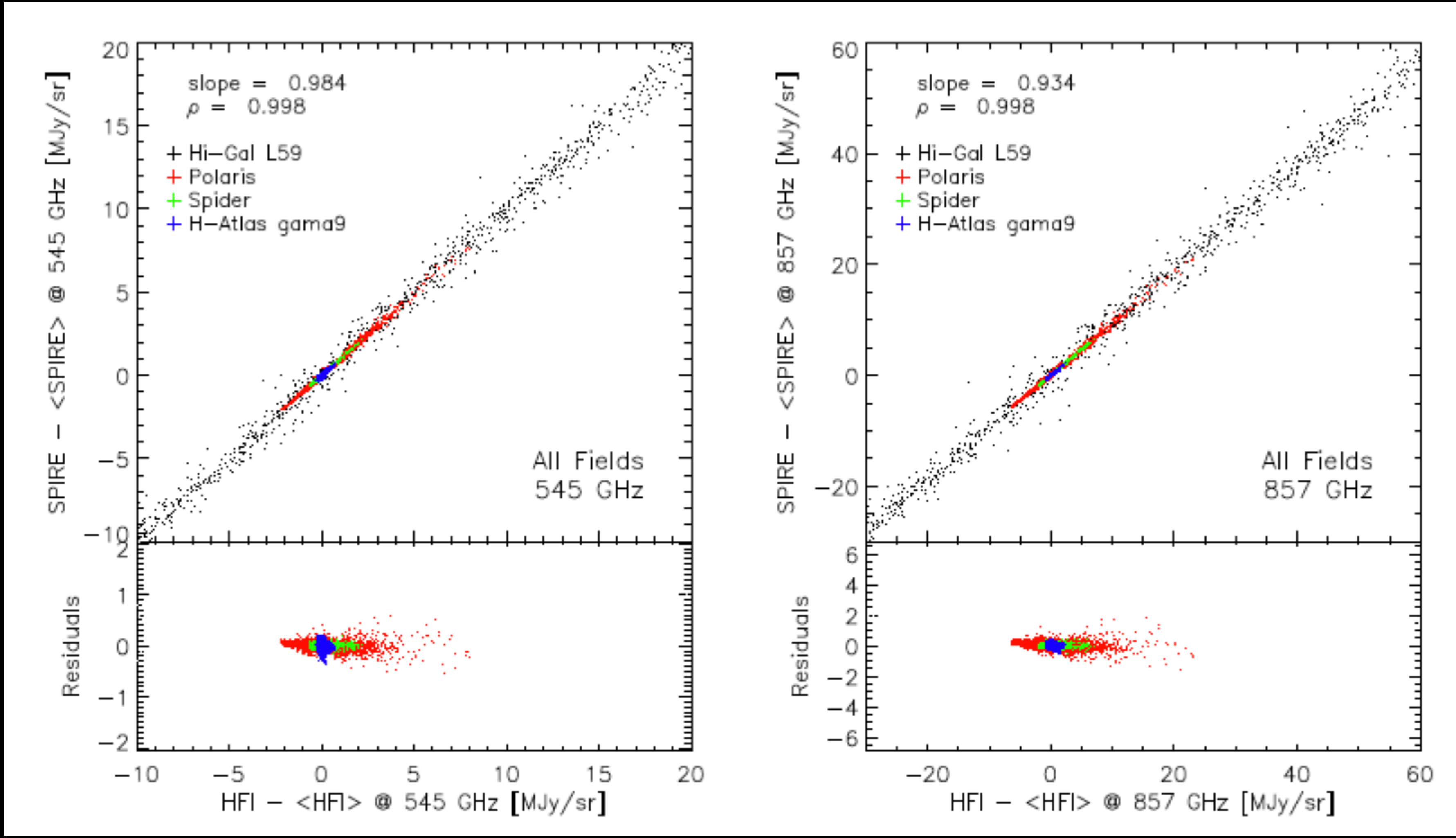
Pixel-to-pixel comparison (one field)



From B. Bertincourt

Comparison with SPIRE

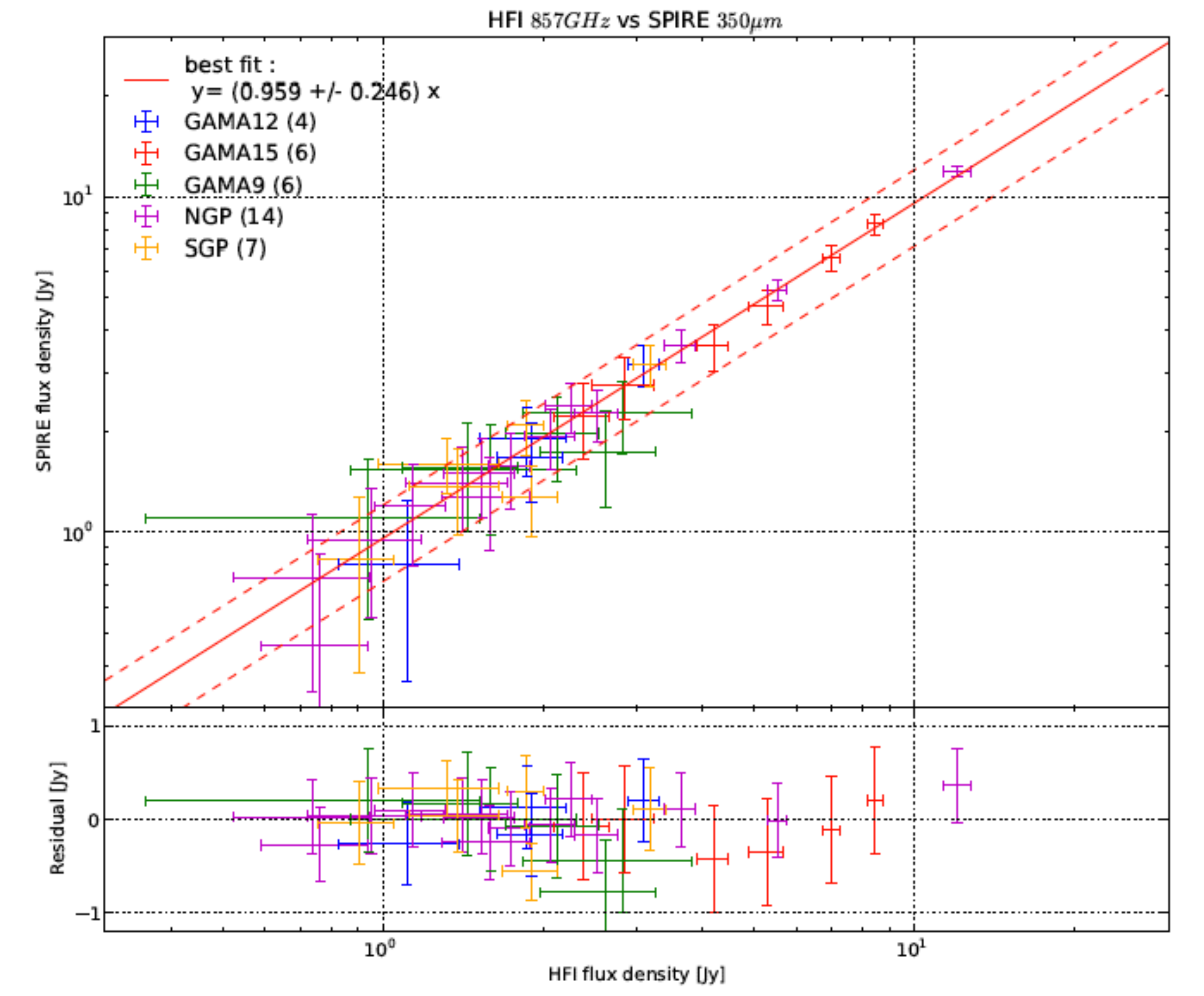
Pixel-to-pixel comparison (all fields)



From B. Bertincourt

Comparison with SPIRE

Point sources



From L. Maurin, S. Eales

Conclusion

- Low-frequency channels:
  - Correction for gain time variation
  - Absolute calibration: 0.3% accuracy for 100-217 GHz, 1% at 353 GHz
  - Additional 0.24% from the « model » (WMAP)

- At 545 and 857 GHz: 10% absolute calibration uncertainties
  - 5% from the measurements, 5% for the models

- The future:
  - Correct for « ADC non-linearity»
  - Calibration using the orbital dipole (rather than the Solar dipole)

  - Work more on the systematics on planet flux measurements (simulations)

  - Develop the pipeline for calibration on Mars
    - plan is to intercalibrate the high-freq channels on the low-freq ones using the Mars relative frequency variation as given by the model