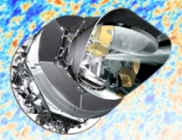


Planck 2013:
Measuring the Cosmic Microwave Background with the High Frequency Instrument

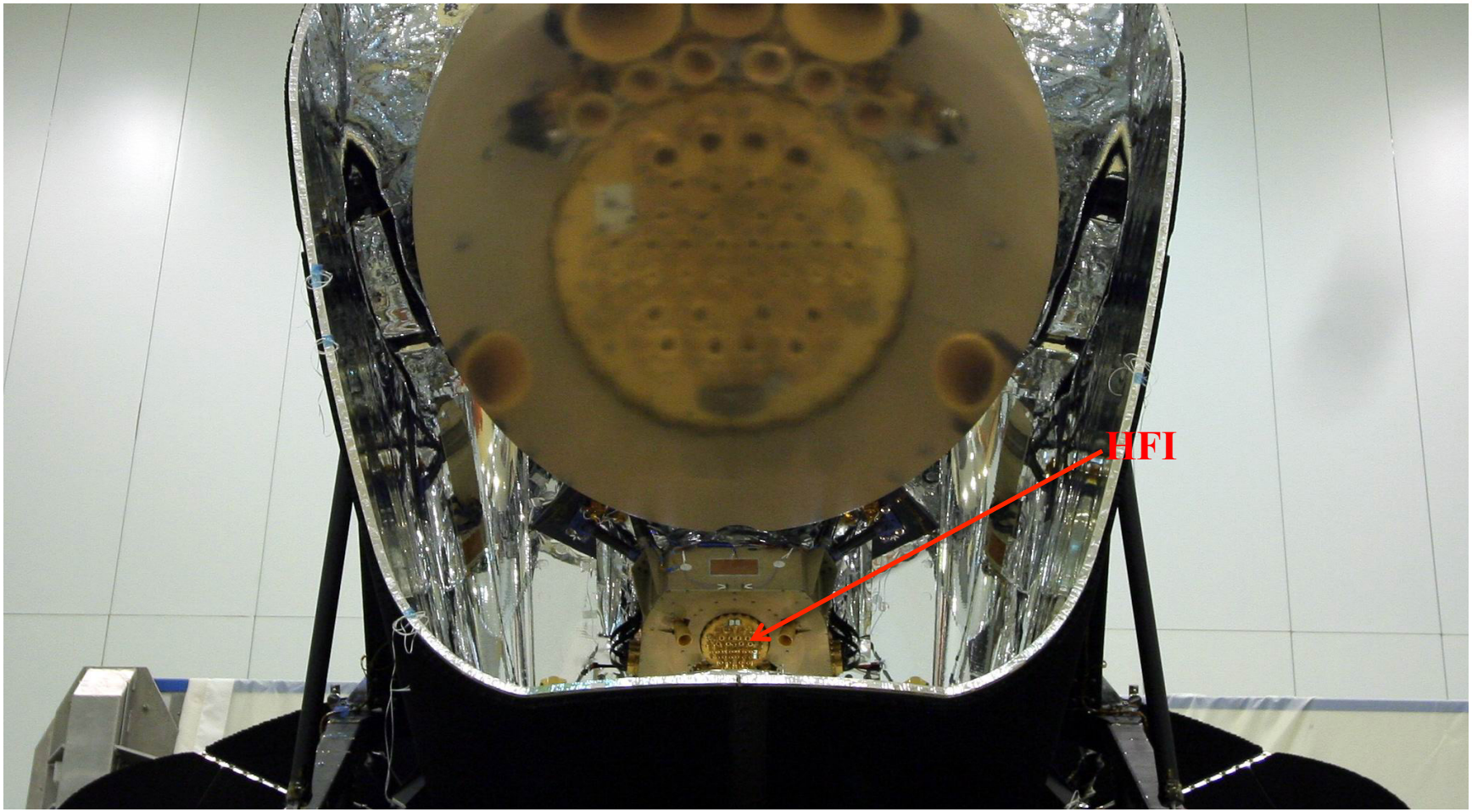
Brendan Crill

JPL/Caltech

For the Planck team

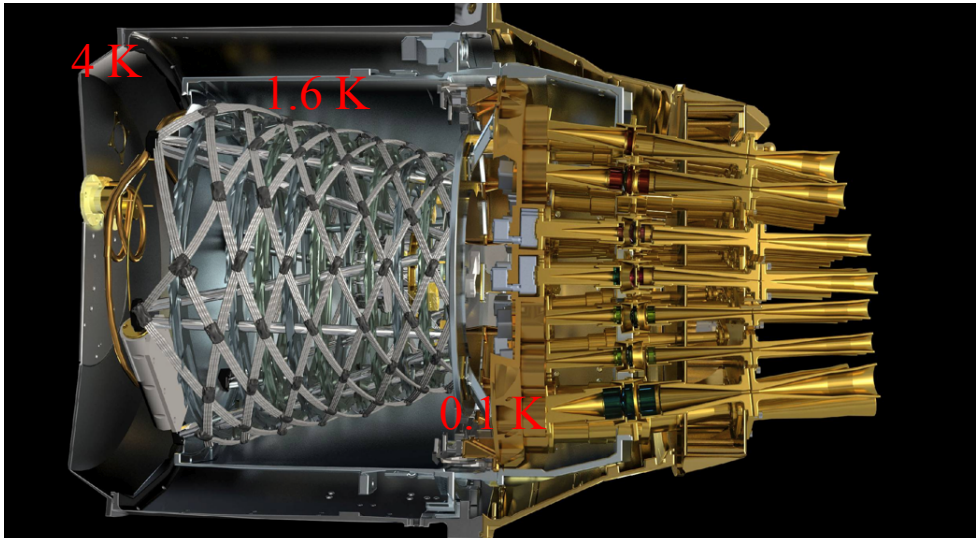
22 April 2013

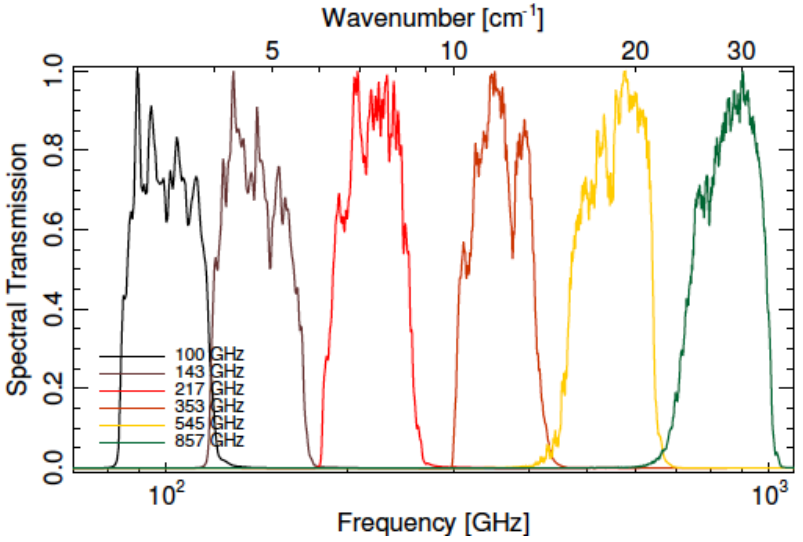
HFI on the Planck spacecraft



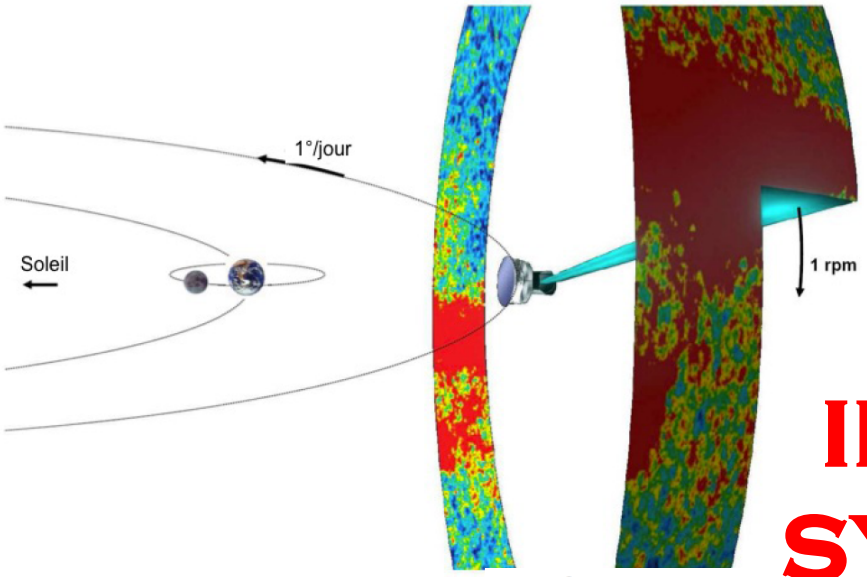
HFI in numbers

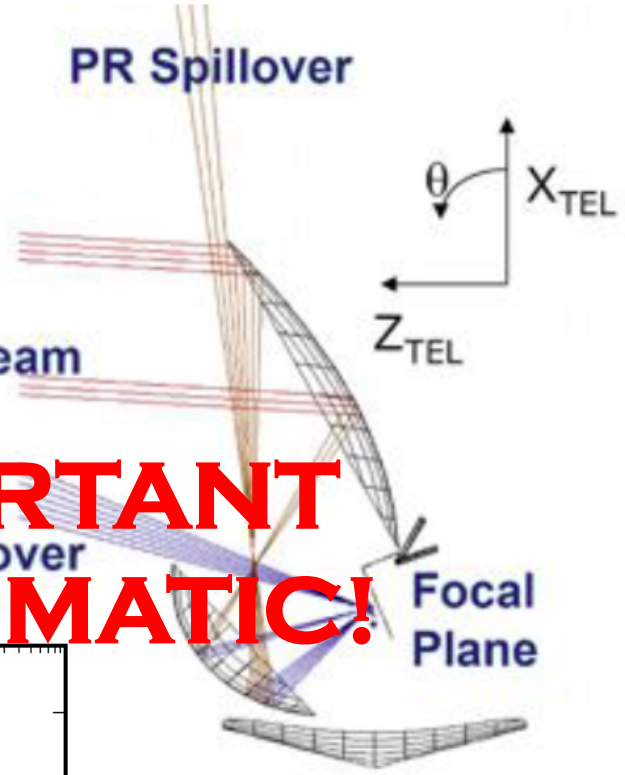
Quantity	Units						
Reference frequency ν	[GHz]	100	143	217	353	545	857
Number of bolometers		8	11	12	12	3	4
Effective beam solid angle Ω	[arcmin^2]	105.78	59.95	28.45	26.71	26.53	24.24
Error in solid angle σ_Ω	[arcmin^2]	0.55	0.08	0.03	0.02	0.03	0.03
Spatial variation (*rms*) $\Delta\Omega$	[arcmin^2]	0.31	0.25	0.27	0.25	0.34	0.19
Effective beam FWHM$_1$	[arcmin]	9.66	7.27	5.01	4.86	4.84	4.63
Effective beam FWHM$_2$	[arcmin]	9.65	7.25	4.99	4.82	4.68	4.33
Effective beam ellipticity ϵ		1.186	1.036	1.177	1.147	1.161	1.393
Variation (*rms*) of the ellipticity $\Delta\epsilon$		0.023	0.009	0.030	0.028	0.036	0.076
Sensitivity per beam solid angle	[μK]	10	6	12	39		
	[kJy sr^{-1}]					13	14
Sensitivity	[μK deg]	1.8	0.8	1.0	3.5		
	[kJy sr^{-1} deg]					1.1	1.1
Relative calibration accuracy	[%]	$\lesssim 0.2$	-	$\lesssim 0.2$	$\lesssim 1$	$\lesssim 5$	$\lesssim 5$
Absolute calibration accuracy	[%]	$\lesssim 0.5$	$\lesssim 0.5$	$\lesssim 0.5$	$\lesssim 1.2$	$\lesssim 10$	$\lesssim 10$



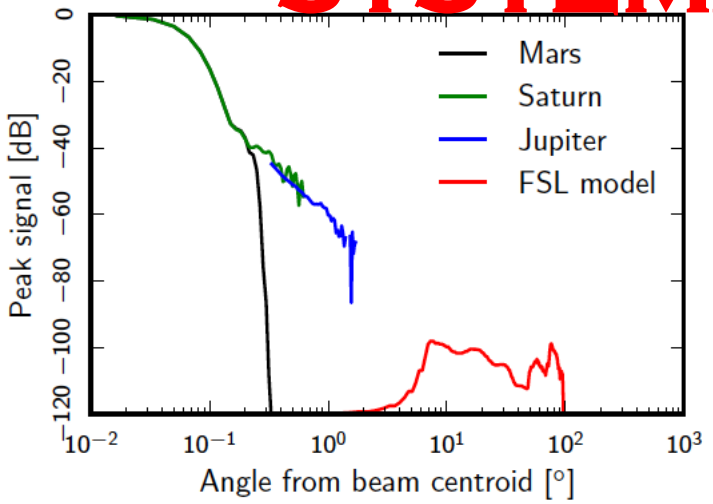


How HFI sees the sky



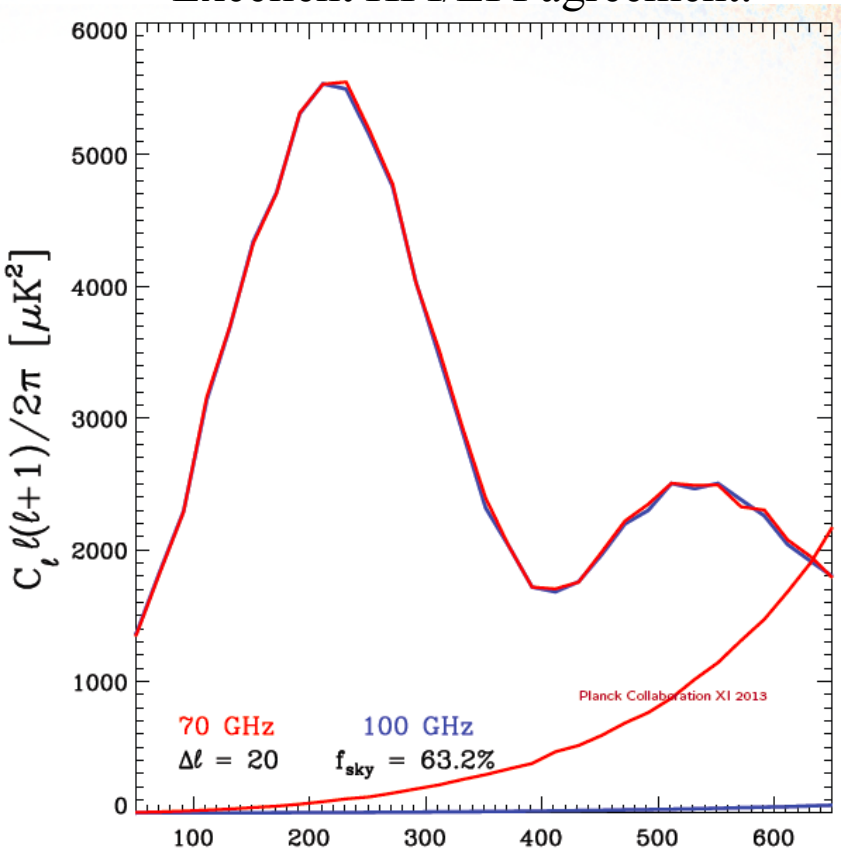


IMPORTANT SYSTEMATIC!

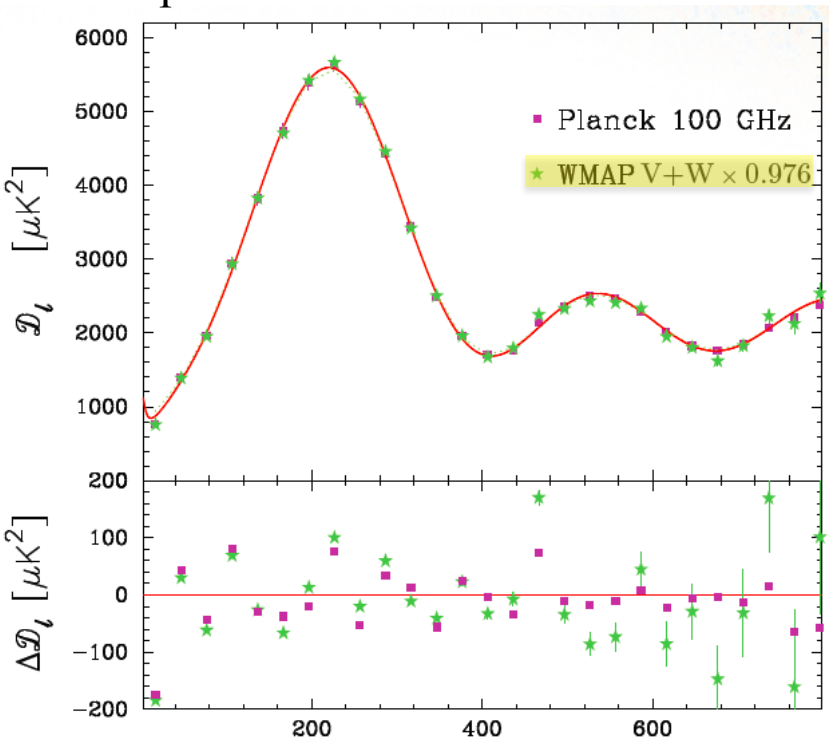


Discrepancy with WMAP

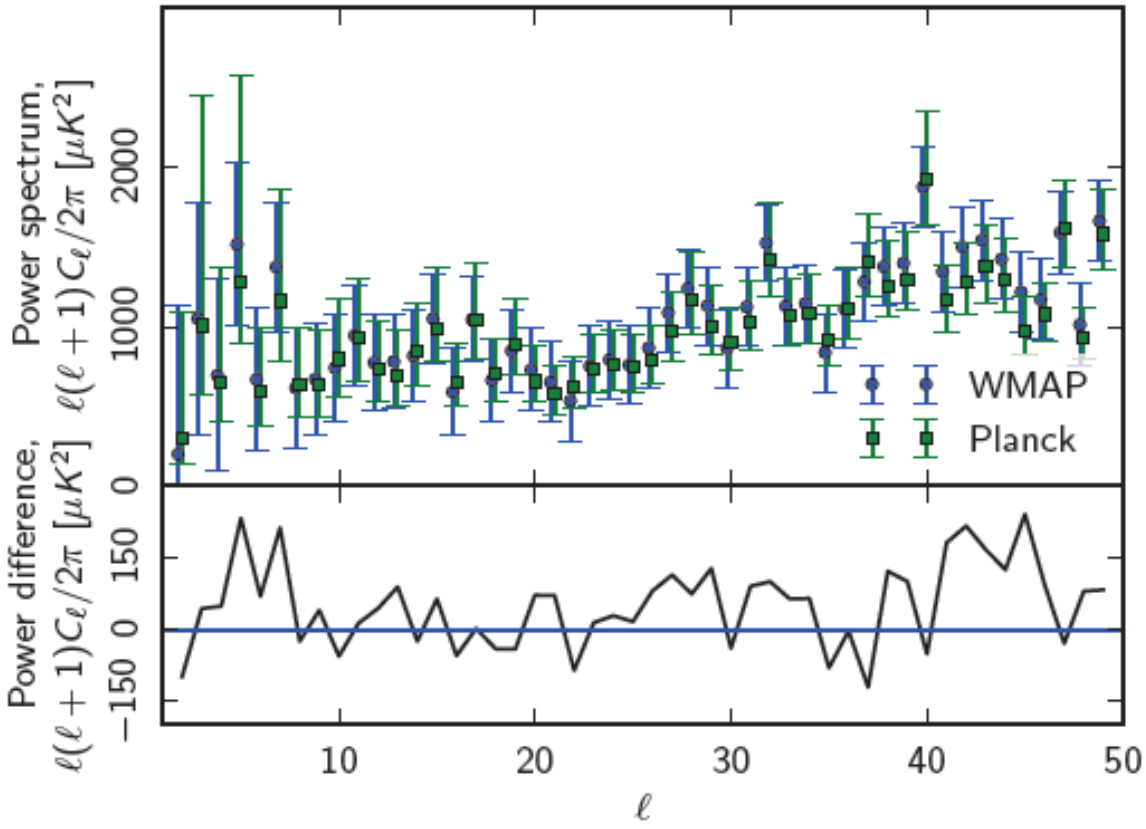
Excellent HFI/LFI agreement:



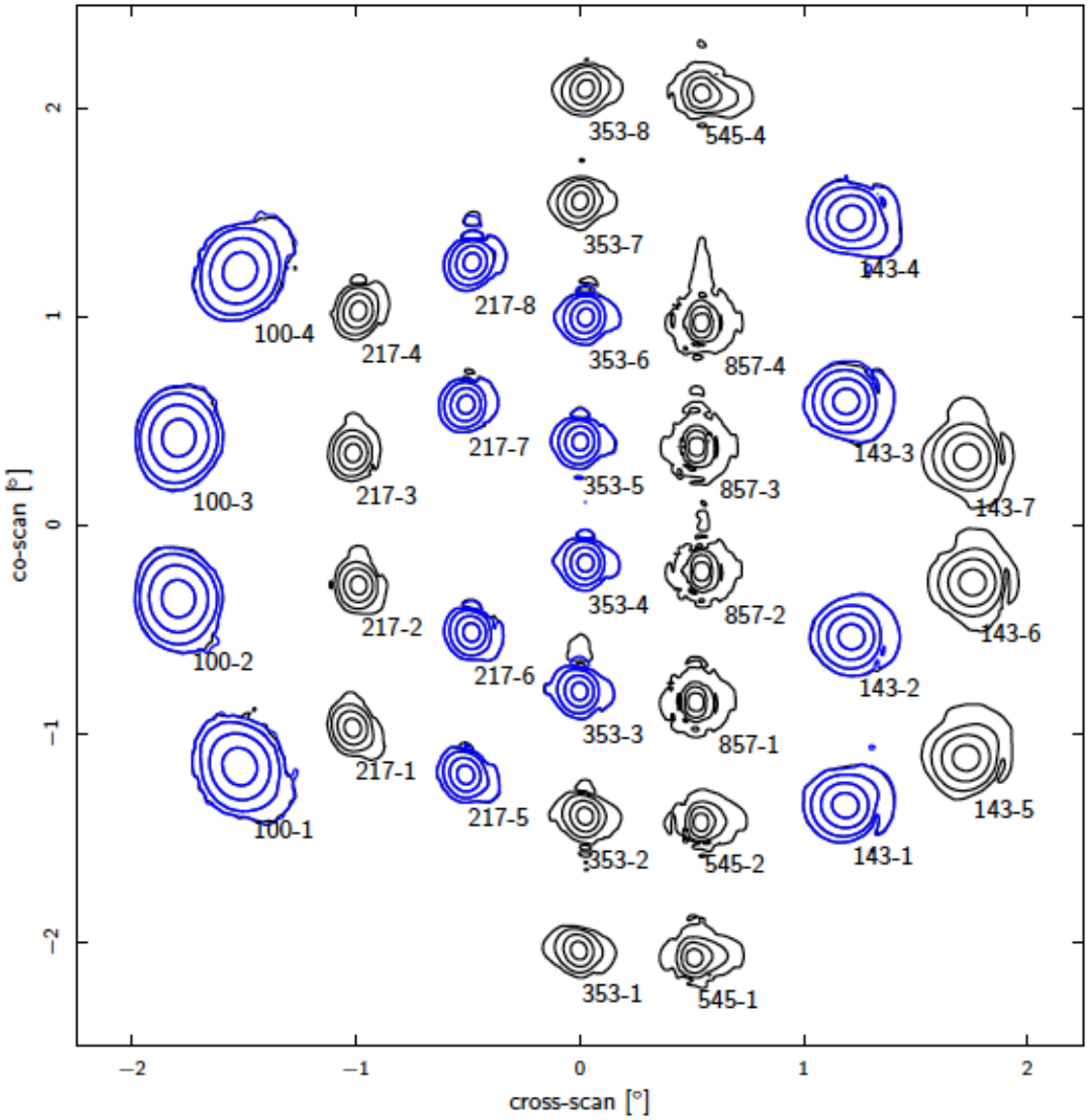
Planck measures different CMB power



at low multipole…



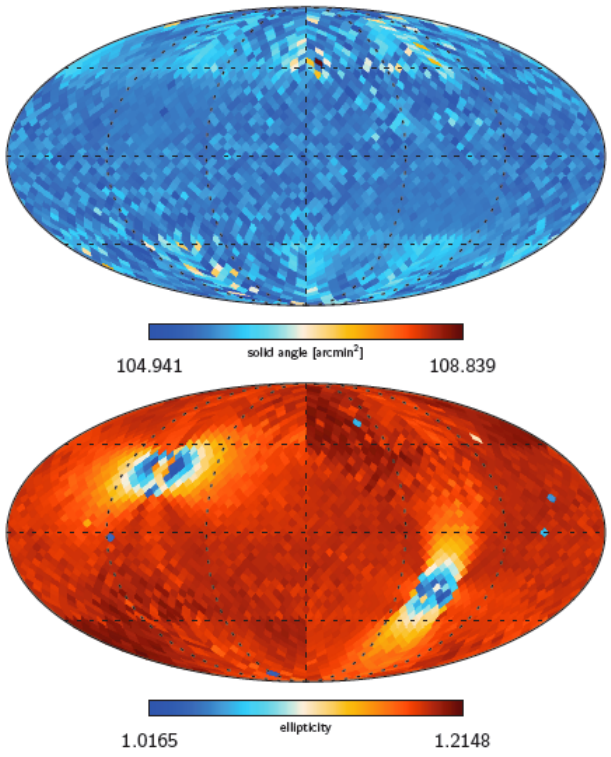
HFI beam maps



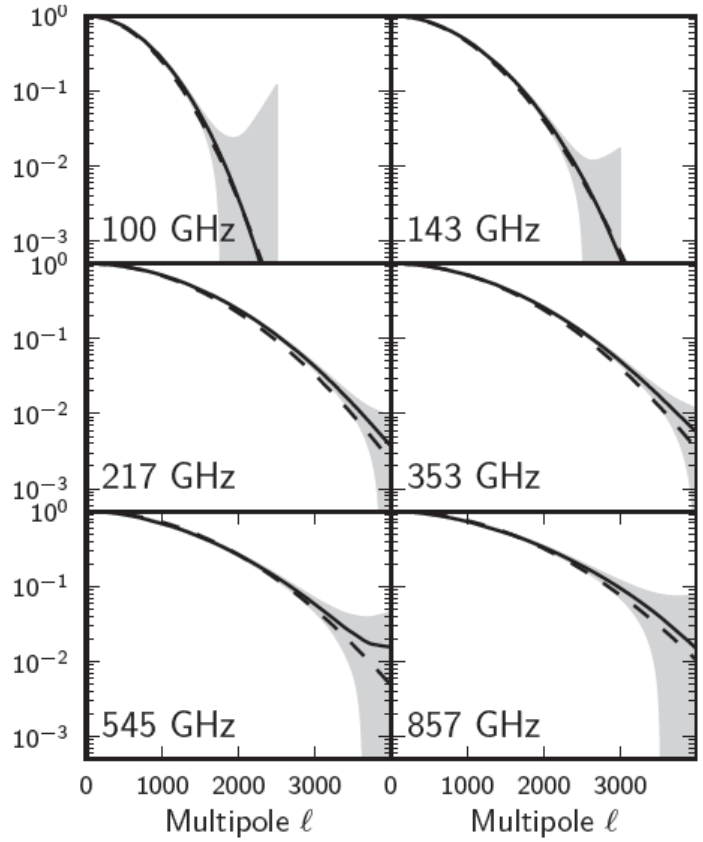
Effective beams and window function

- Angular response for a given pixel in the map comes from combination of scanning beam and scan history of Planck
  - Calculated using real space method (FEBECOP) and harmonic space methods (Quickbeam and Ficsbell)

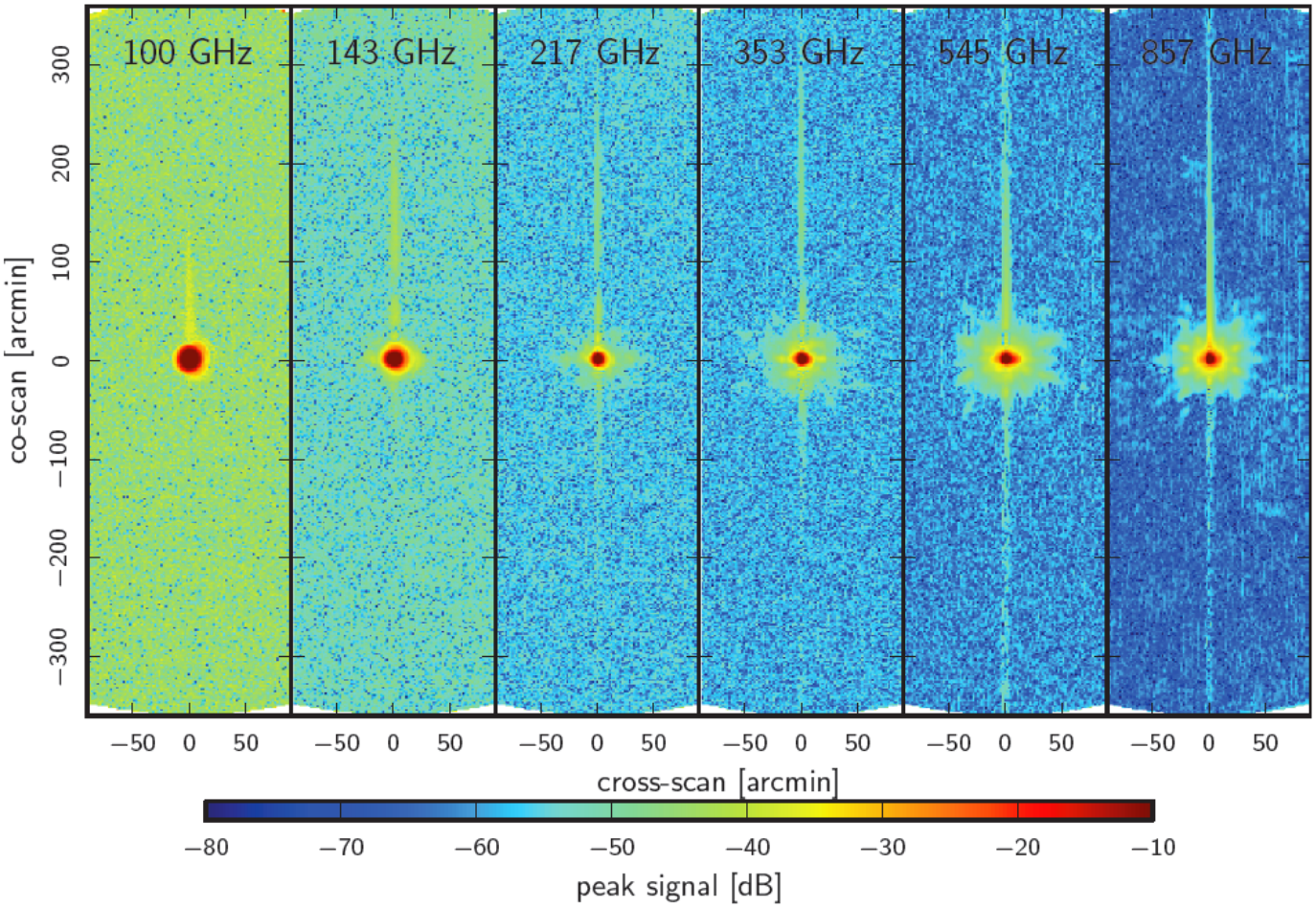
Effective beam parameters for 100 GHz



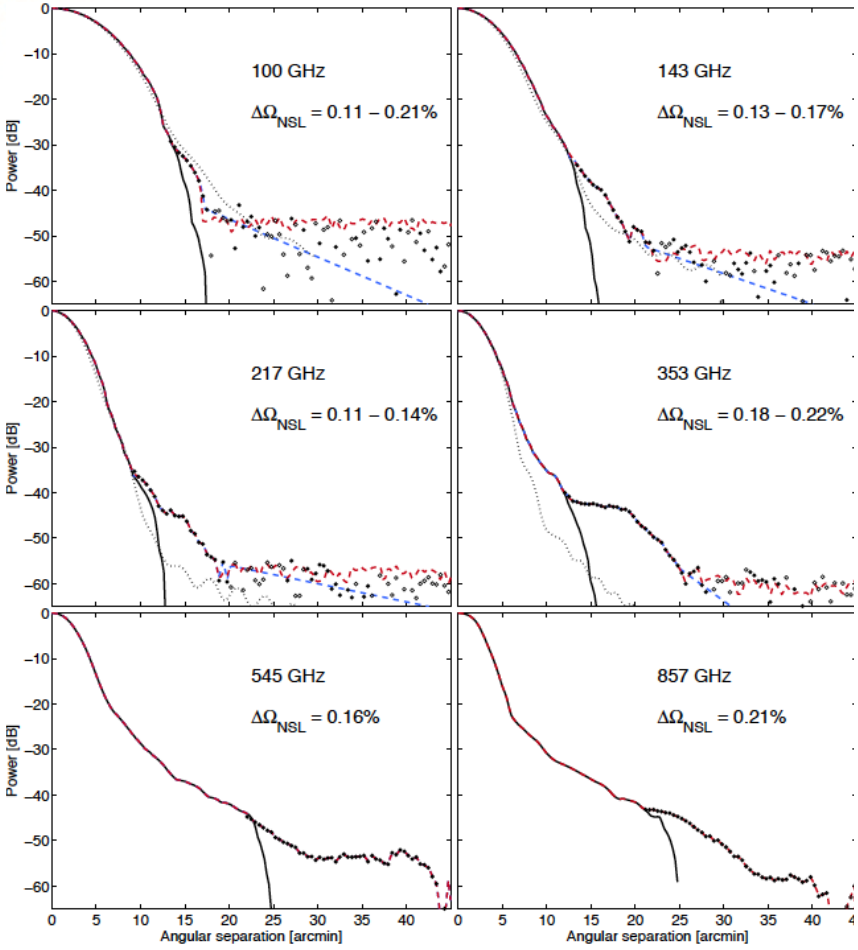
Effective beam window functions B_ℓ^2



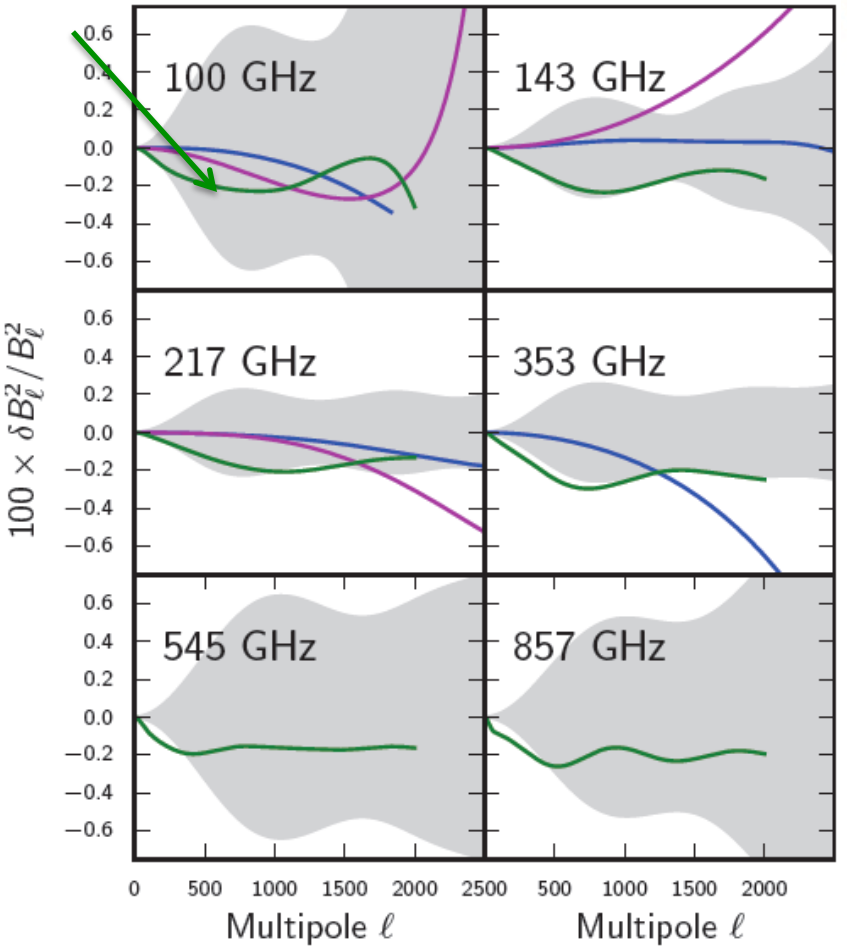
Near Sidelobes Measured on Jupiter



HFI beam radial profiles



Window function bias due to near sidelobes

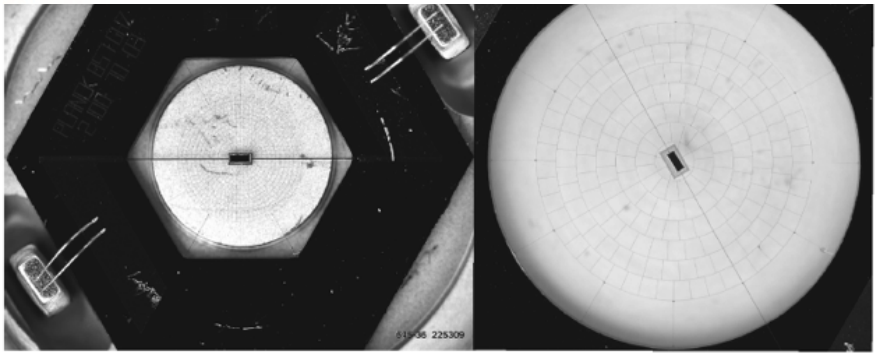


Planck / WMAP discrepancy

- As of now, still a mystery
- Discrepancy has angular scale dependence, not fully described by a single 2.5% number
- Suborbital missions use WMAP to calibrate..

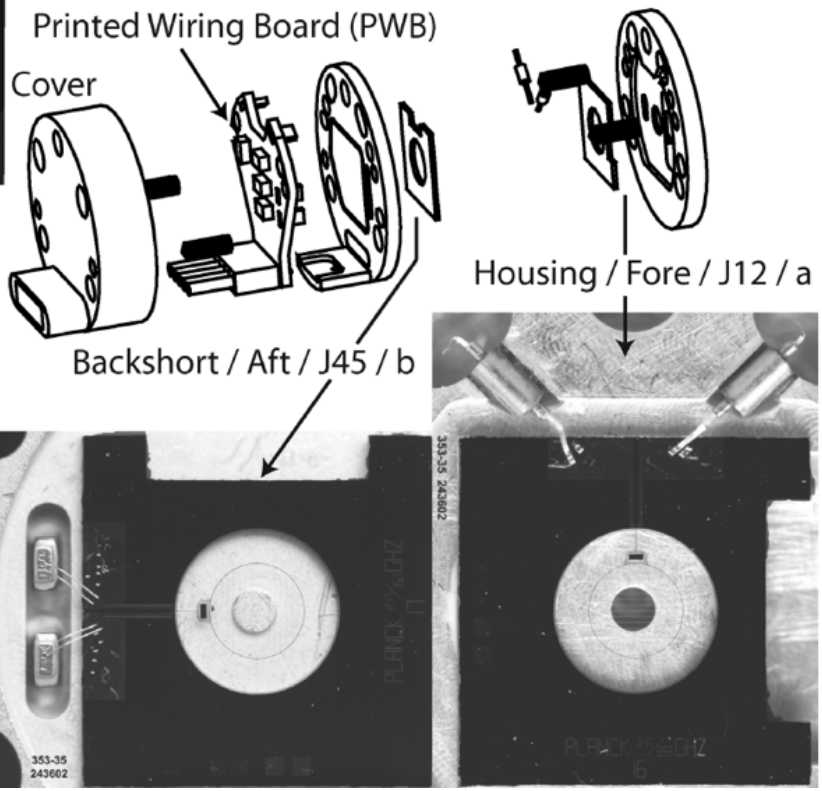
JPL Bolometers in HFI

Spider-web bolometer



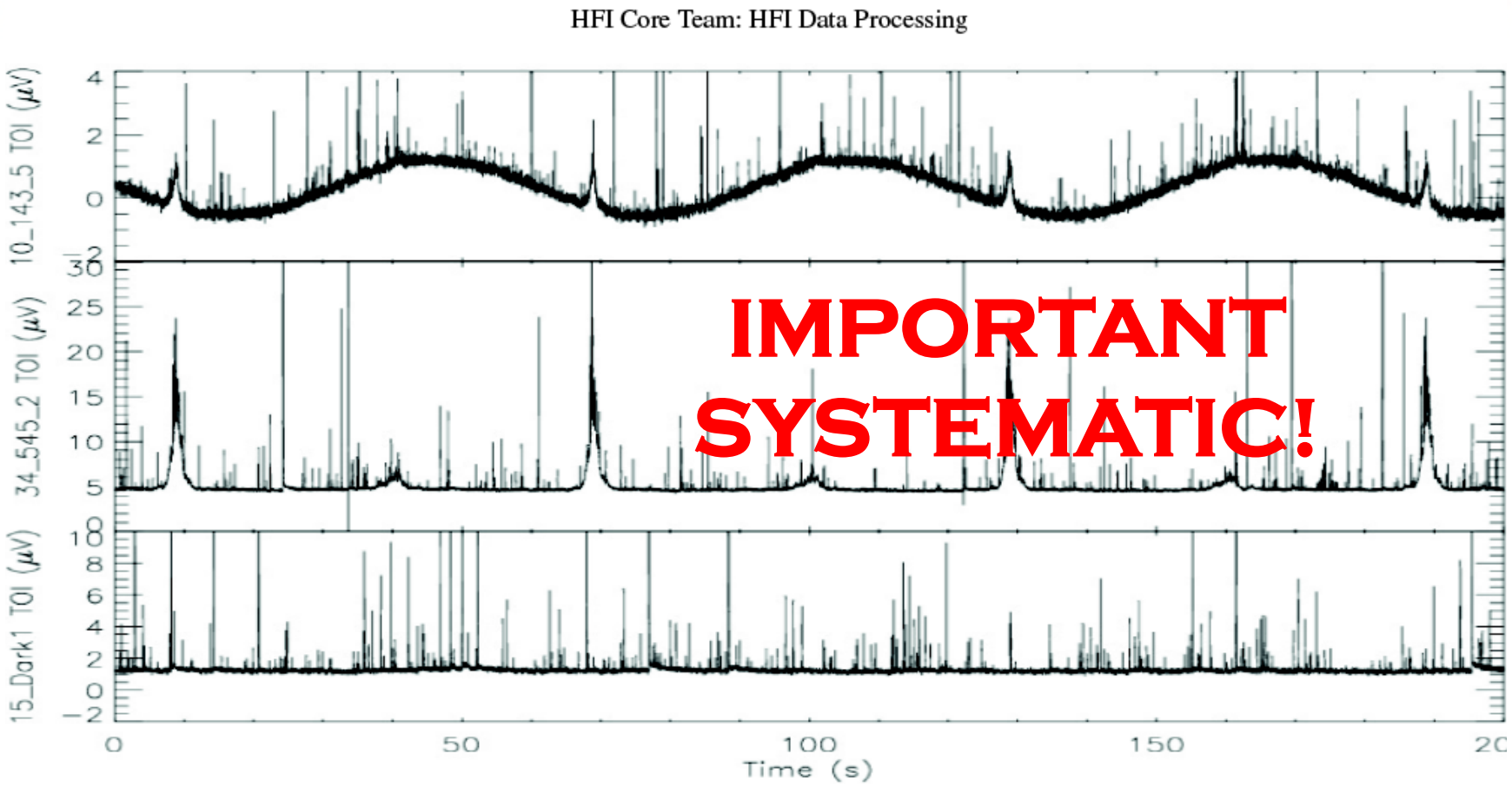
Holmes et al (2008)

Polarization-sensitive bolometer pair



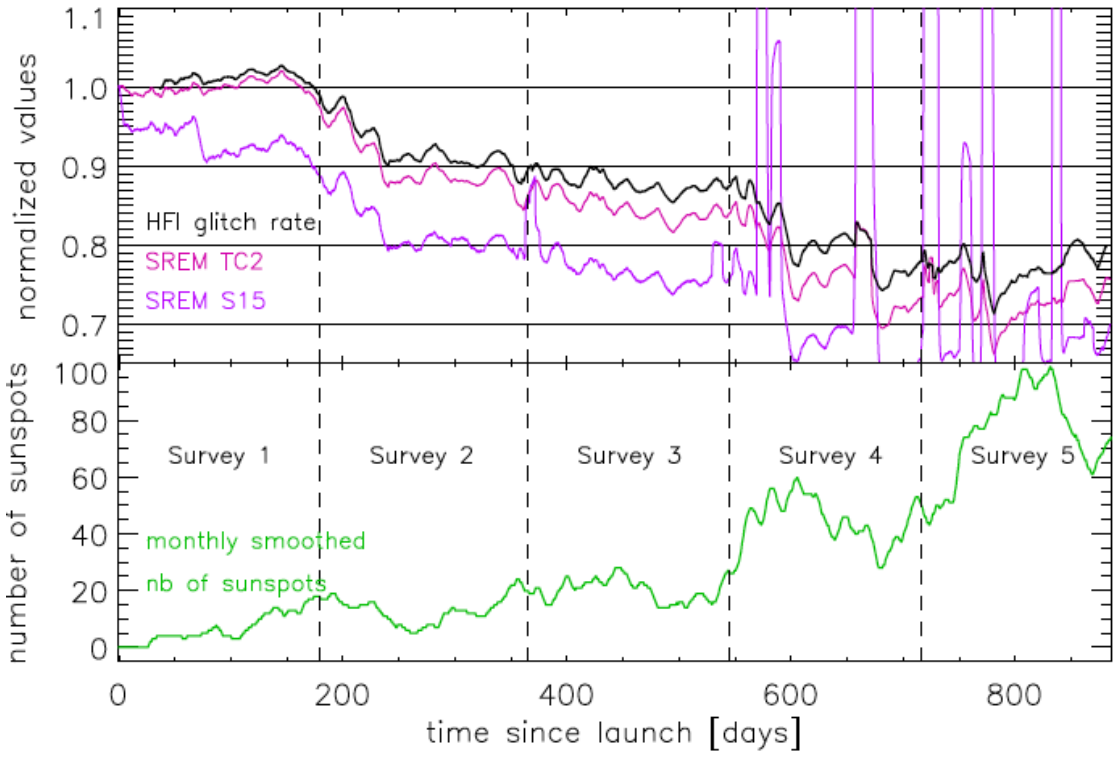
* Semiconductor thermistors
* Operate at 100 mK
* A long heritage from suborbital missions (Boomerang, Maxima, Archeops, Bicep, Acbar, etc…).

A chunk of time ordered data



Bolometers detect anything that deposits heat: cosmic rays

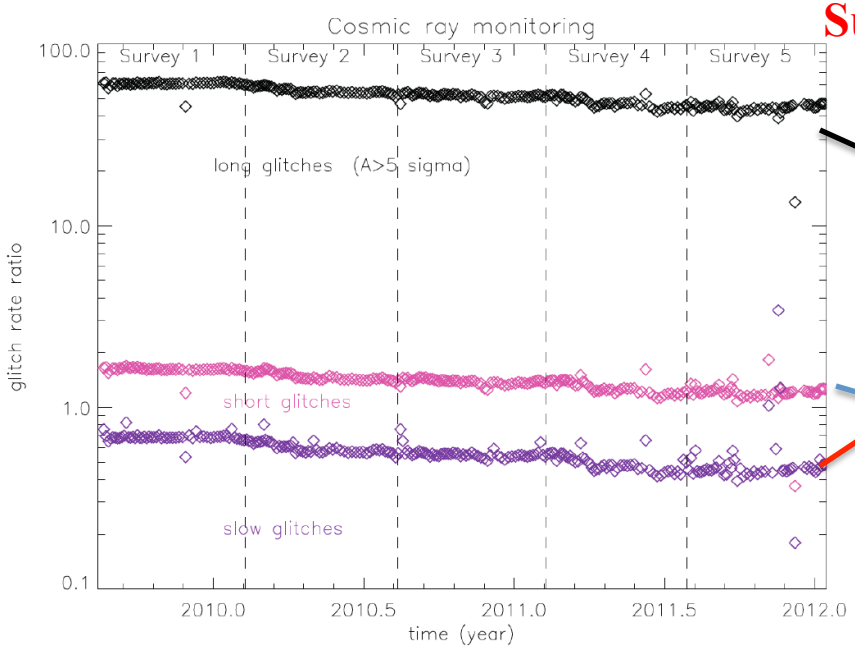
- Galactic cosmic ray hits: 1-2 per second in each bolometer: much higher rate than expected

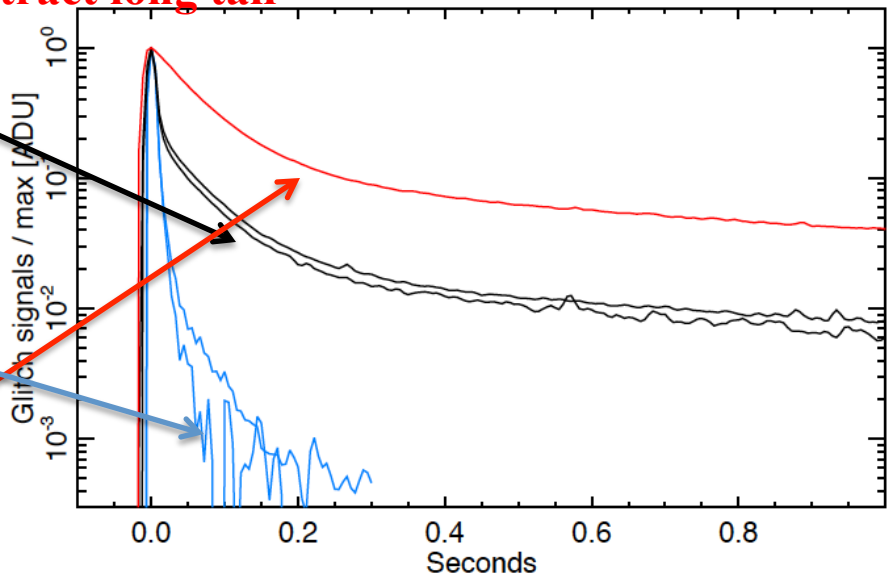


Cosmic Ray glitch families

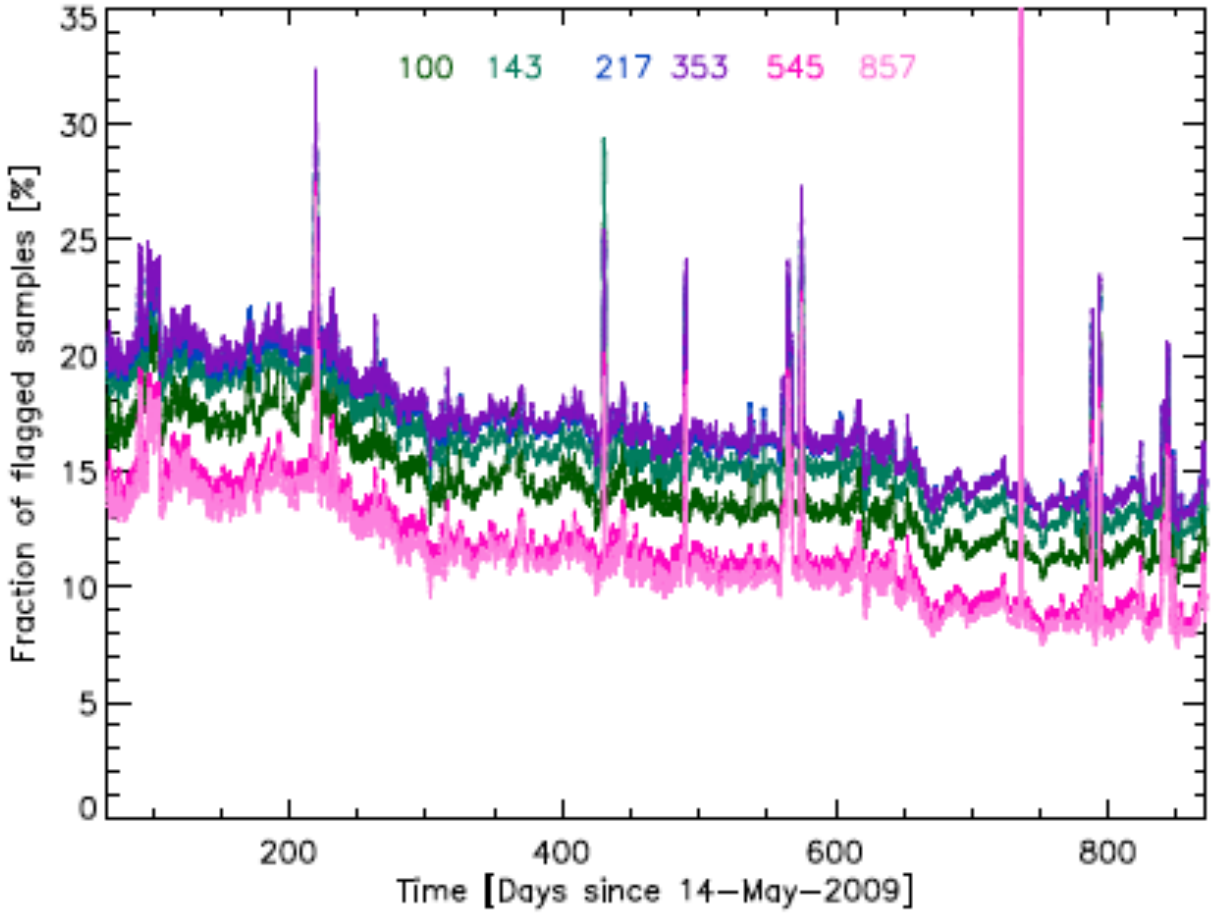
- Called “glitches” because they create unusable transients in the data
- Short glitches: particles directly impact bolometers [expected]
- Long glitches: particles impact Si wafer support structure [most common]
- Slow glitches: ??? [rare]

Solution: Flag transient peak; template fit and Subtract long tail

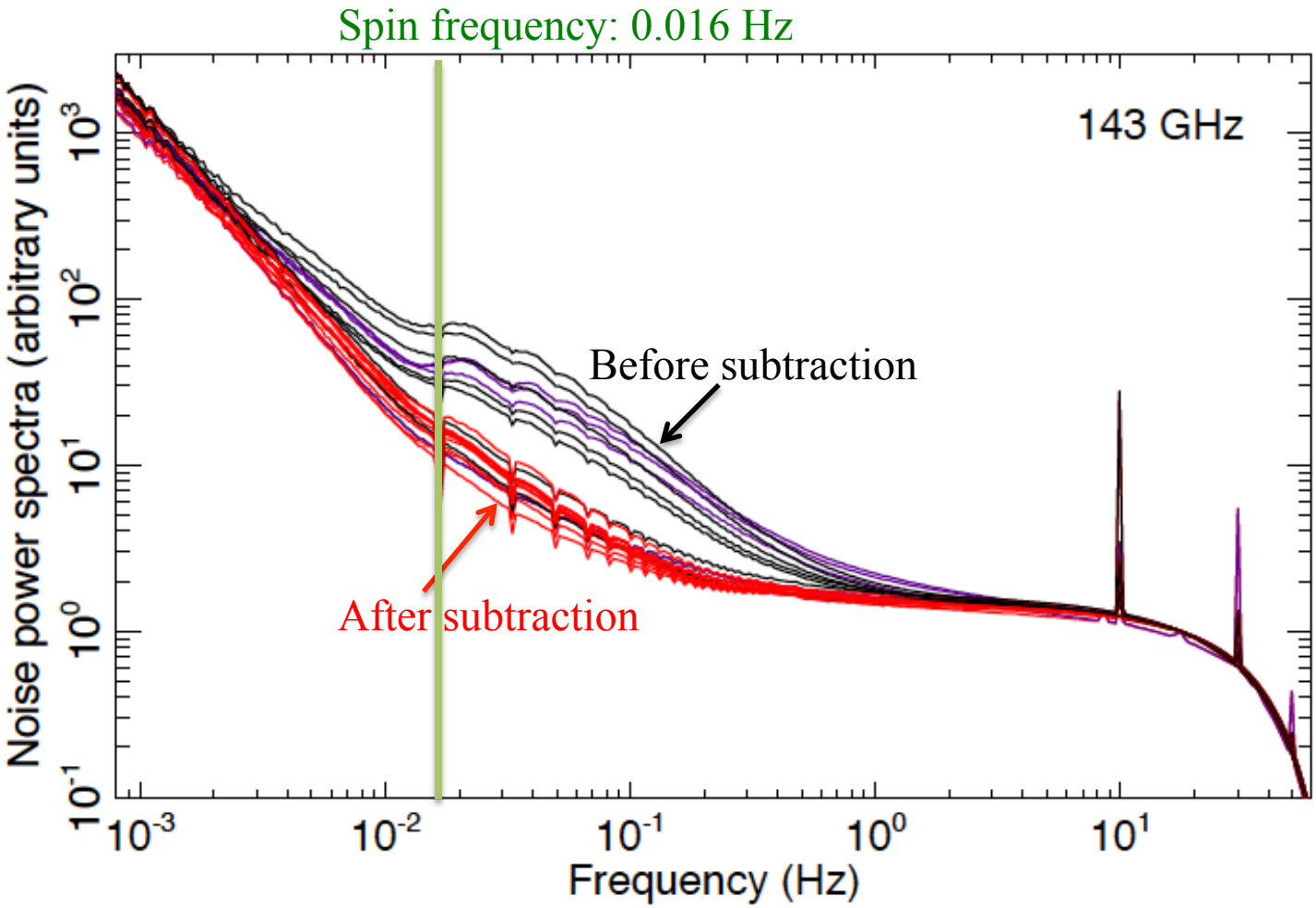




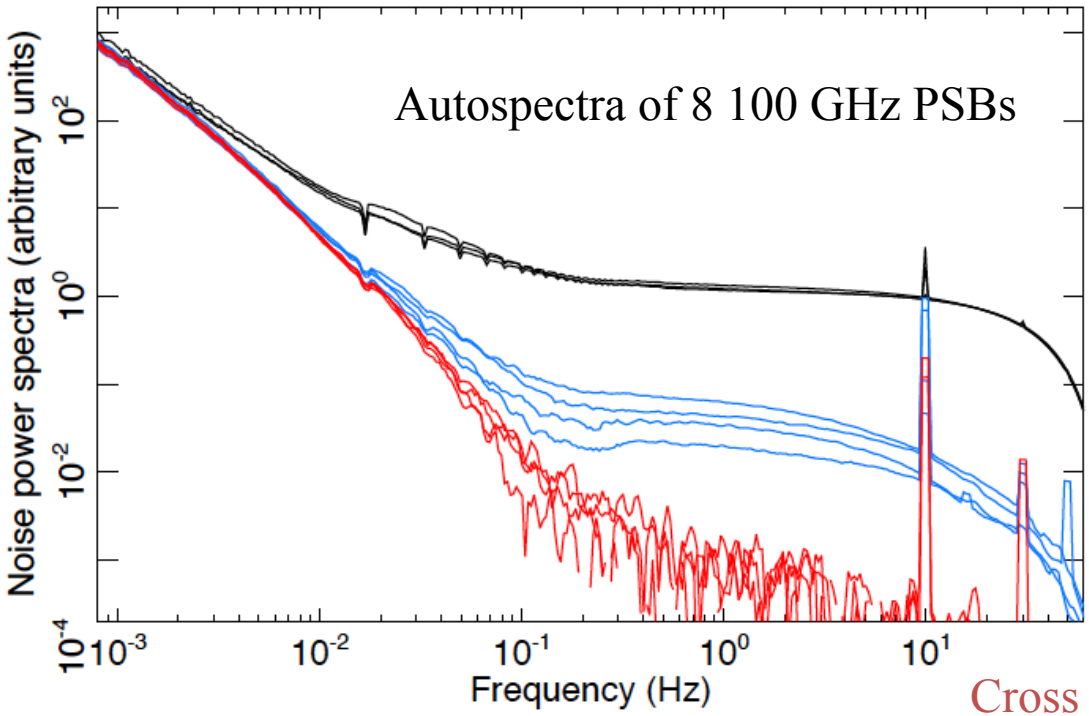
Fraction of flagged data



Noise improvement with glitch tail subtraction



Remaining correlated noise in polarization sensitive bolometers: unflagged correlated glitch tails

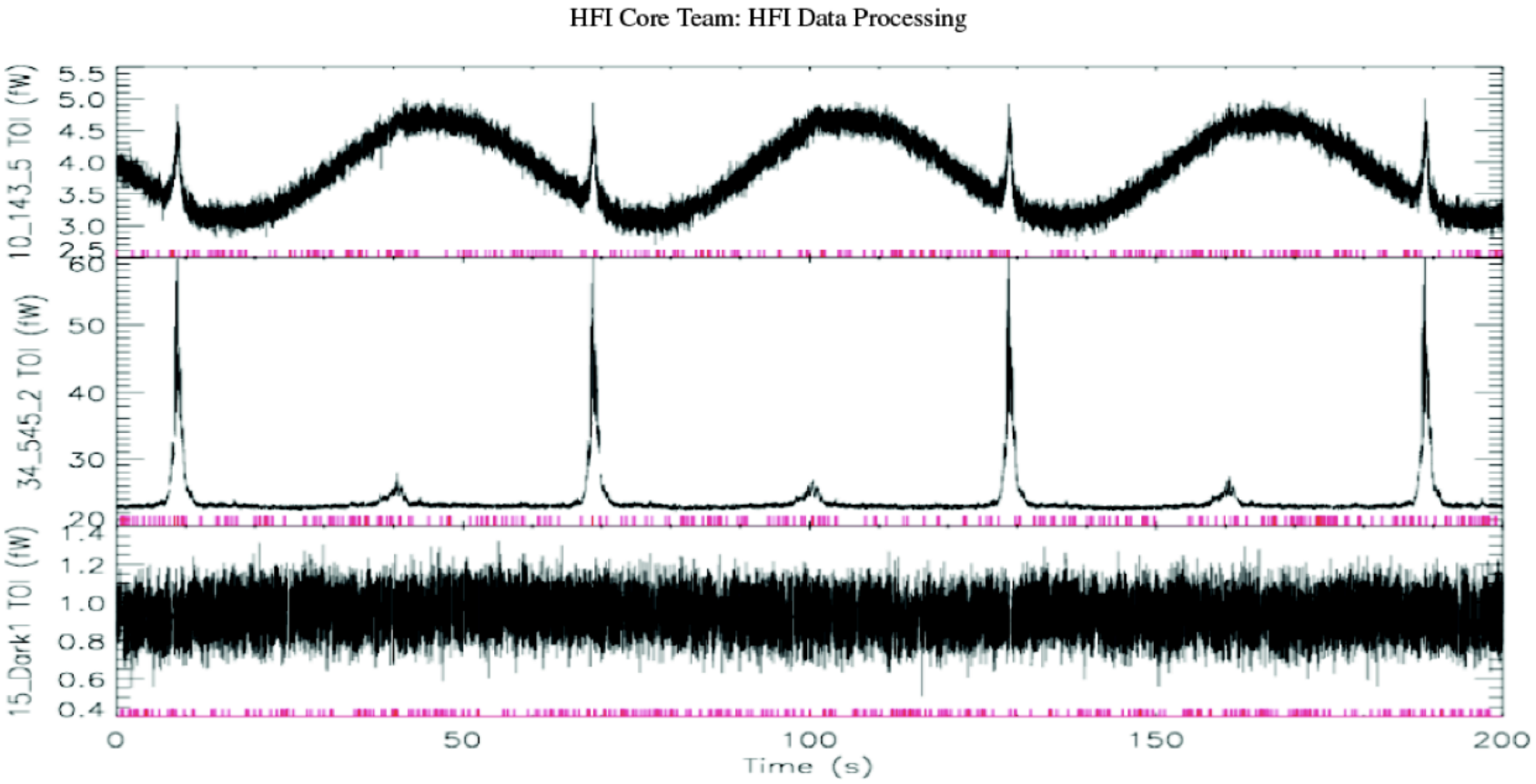


Cross spectra of PSB pairs in same horn

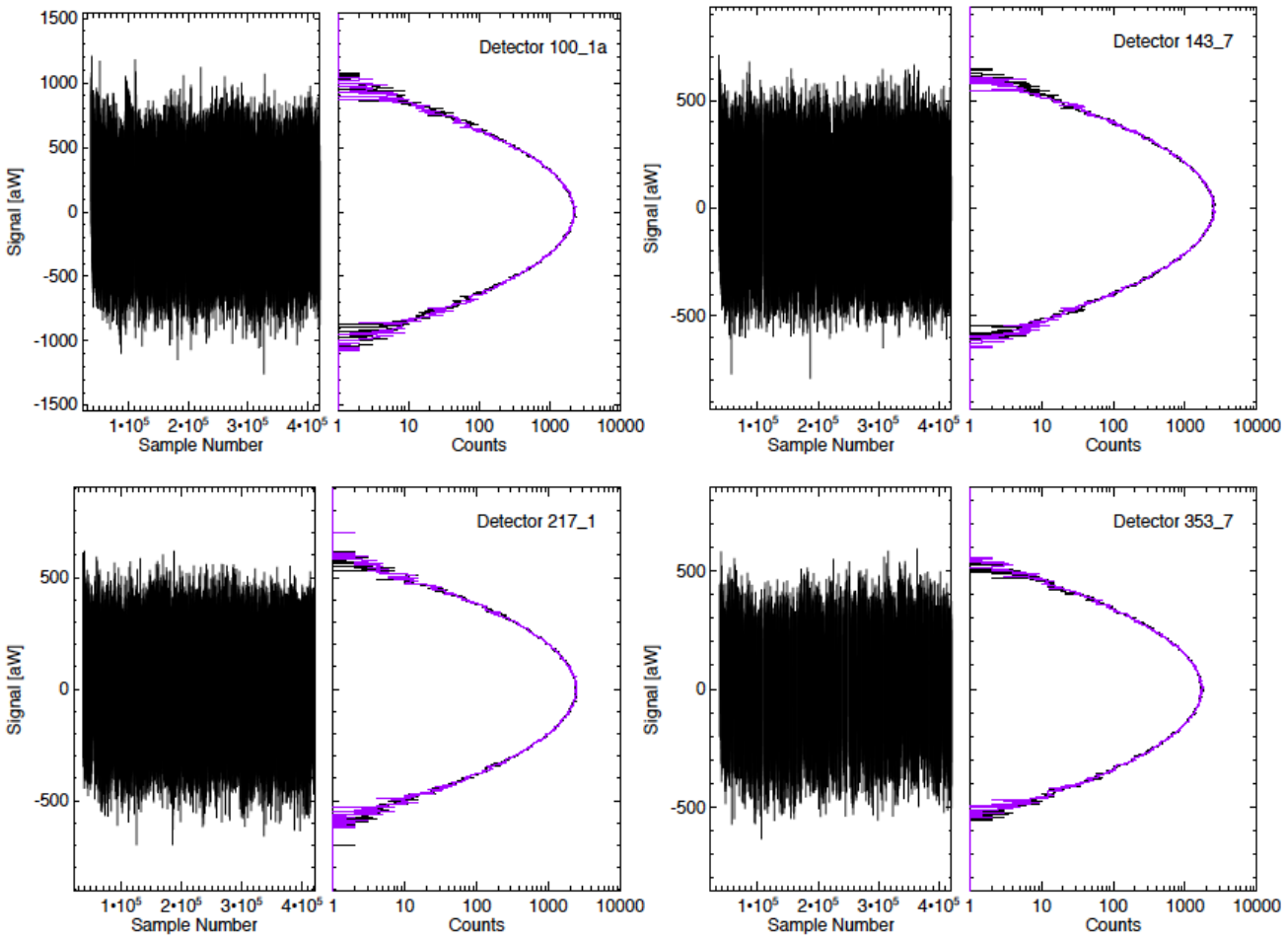
Cross spectra of PSBs in different horns

Time ordered data after deglitching

Nearly every data sample is touched: but signal bias $<5\times10^{-4}$ on all scales

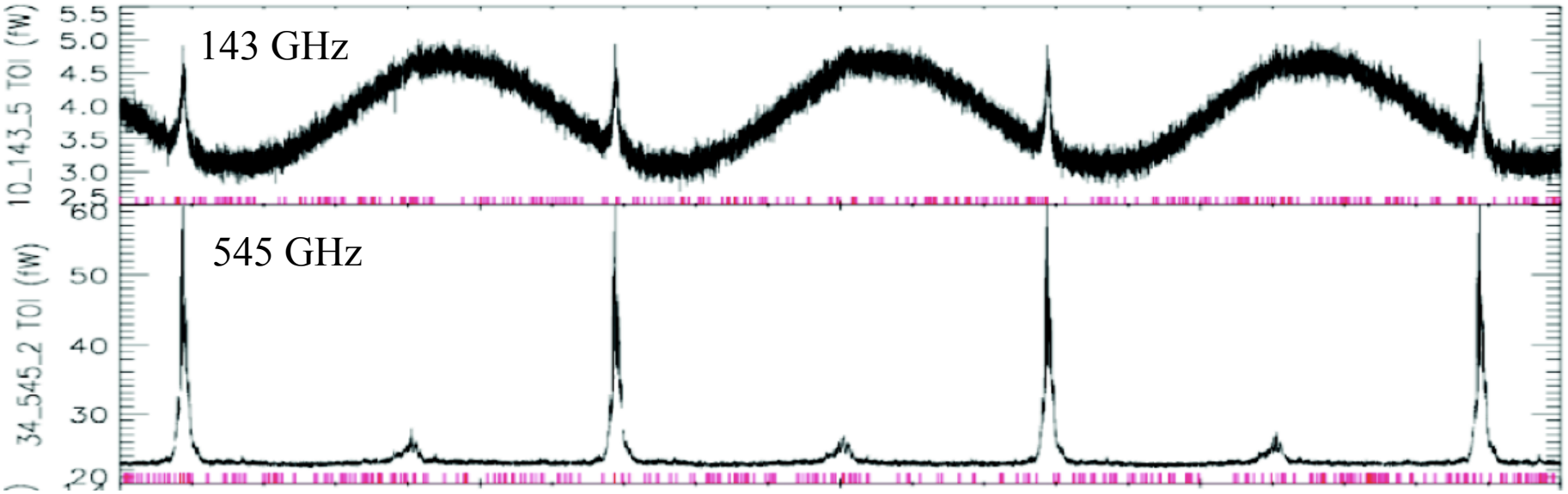


Noise after deglitching

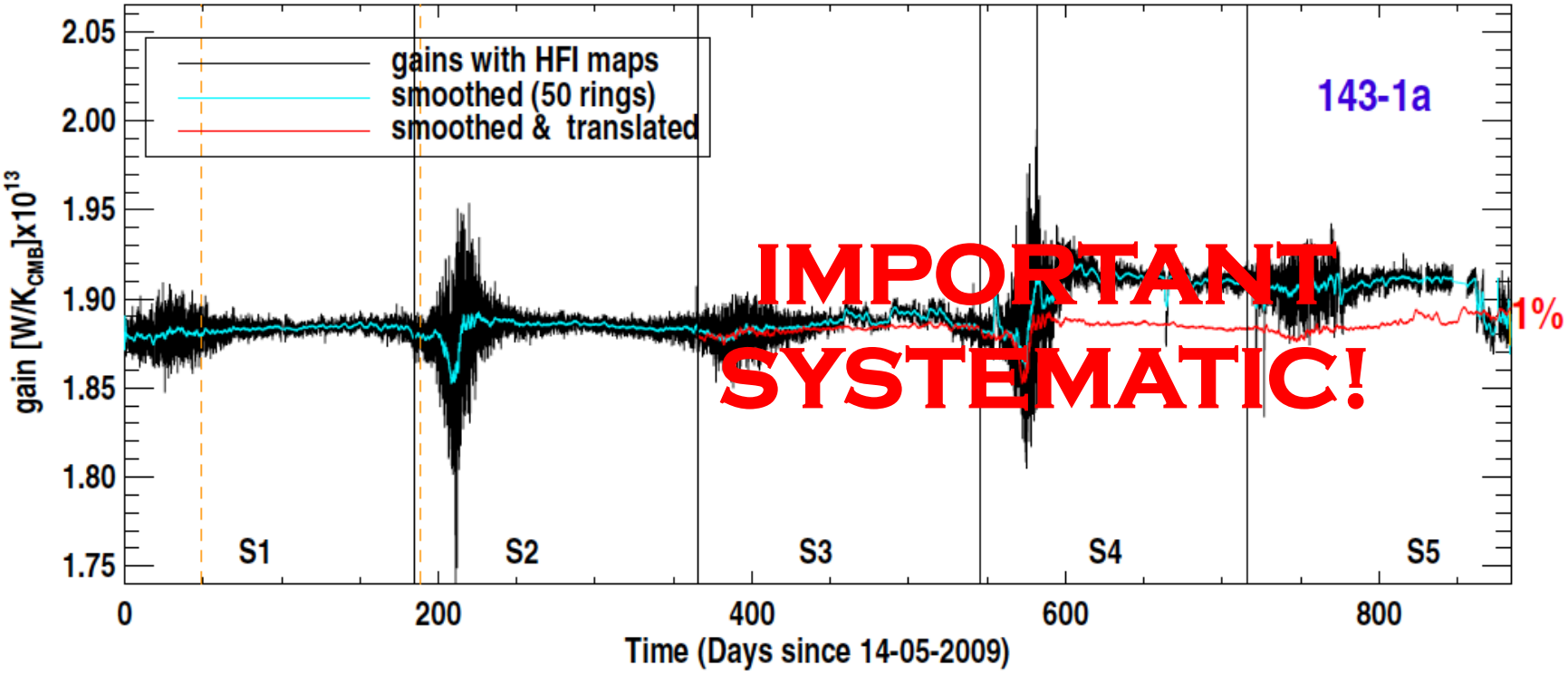


Calibration of HFI

- For 100-353 GHz we use WMAP 7 solar dipole [due to sun's motion relative to CMB]; 545-857 use Uranus + Neptune
- We see the orbital dipole with high S/N [modulation of solar dipole by Planck's orbit around the sun] but for now don't use it to calibrate
- Simultaneously fit for galactic template [from Planck maps] as well as dipole

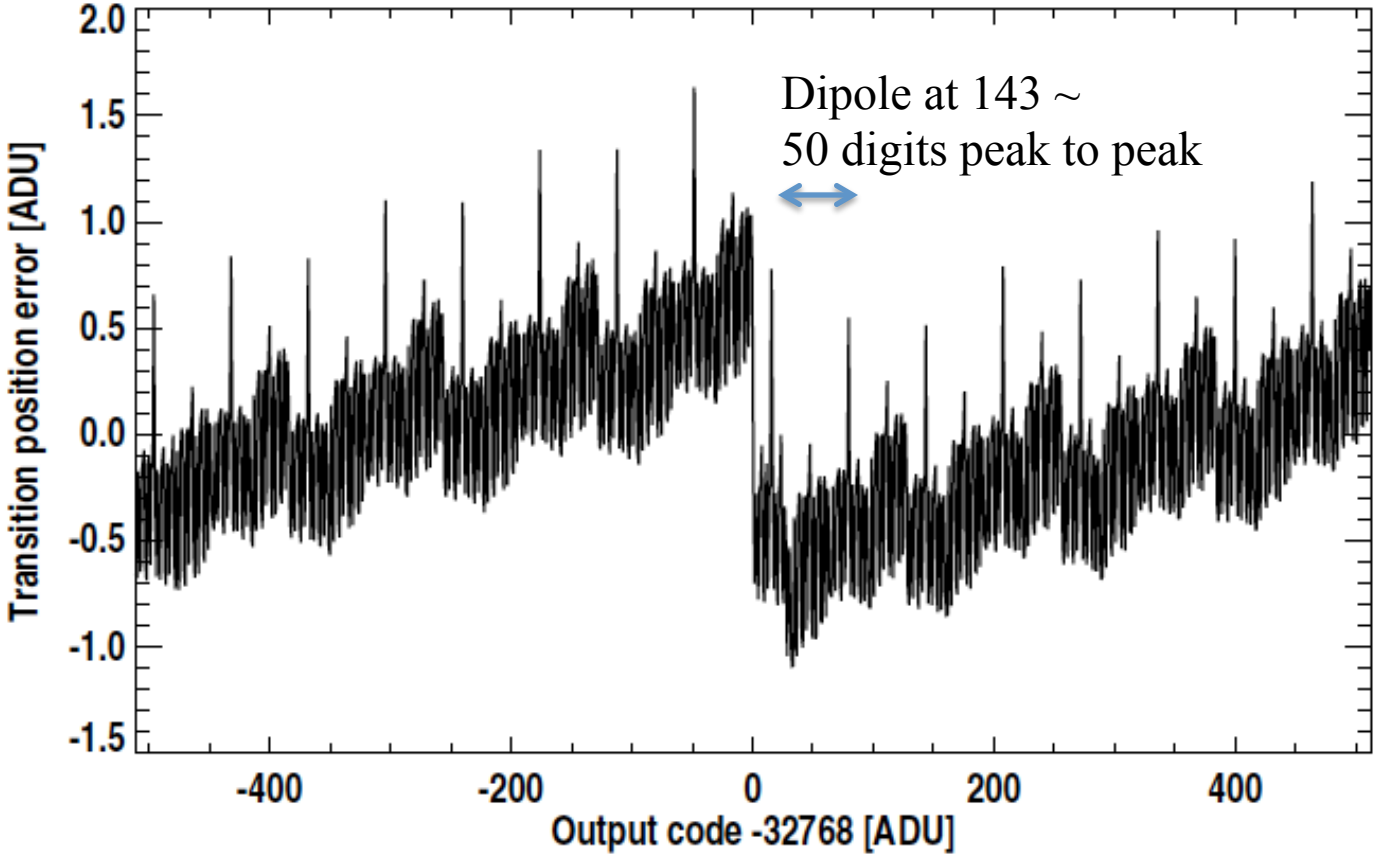


Fit to the dipole vs. time

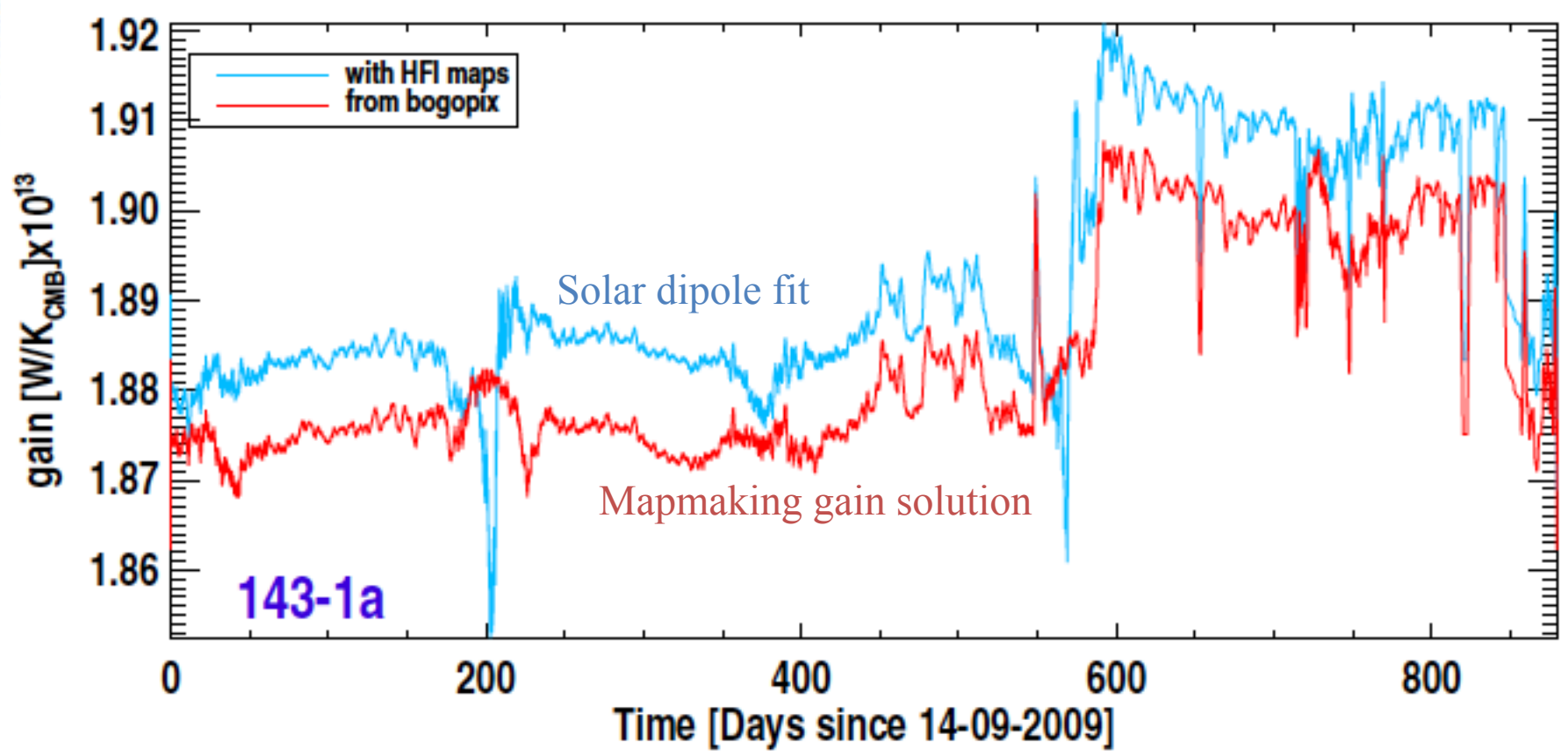


ADC nonlinearity!

- Bolometer voltage digitized by an analog-to-digital converter
- Nonlinearity measured on-orbit for each bolometer, now working to correct this



2013 solution: solve for time varying gain in mapmaking



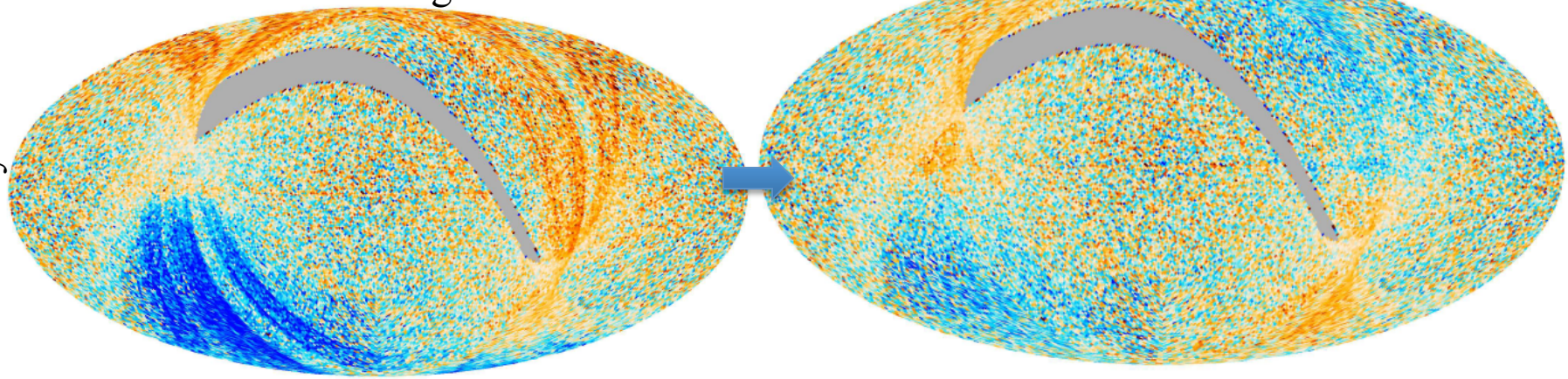
Map quality improves greatly

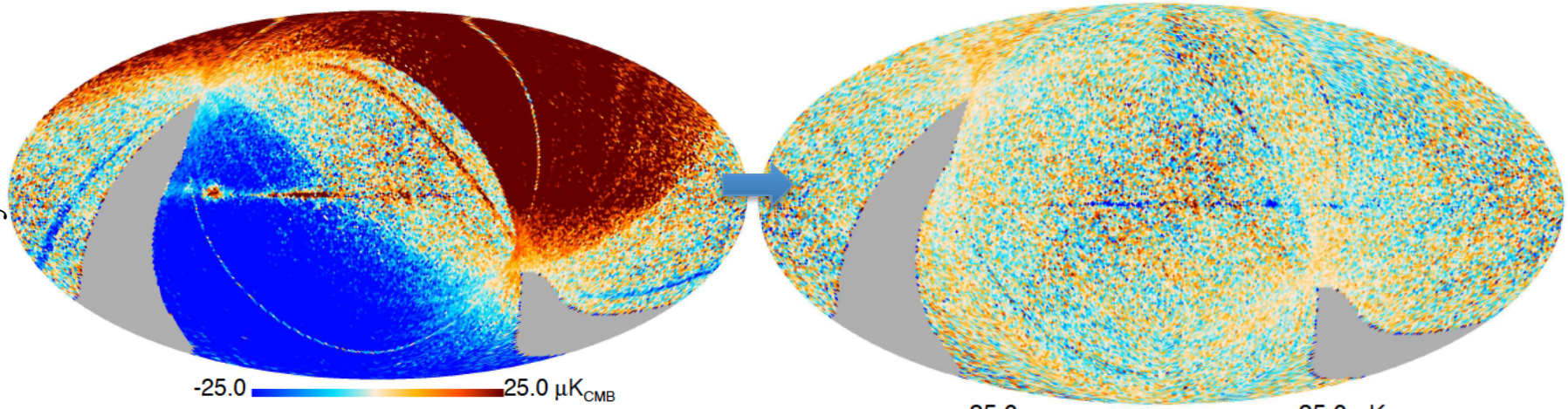
No time variable gain fit

Delivered maps include time variable gain fit

Survey 1 minus Survey 3

Survey 2 minus Survey 4

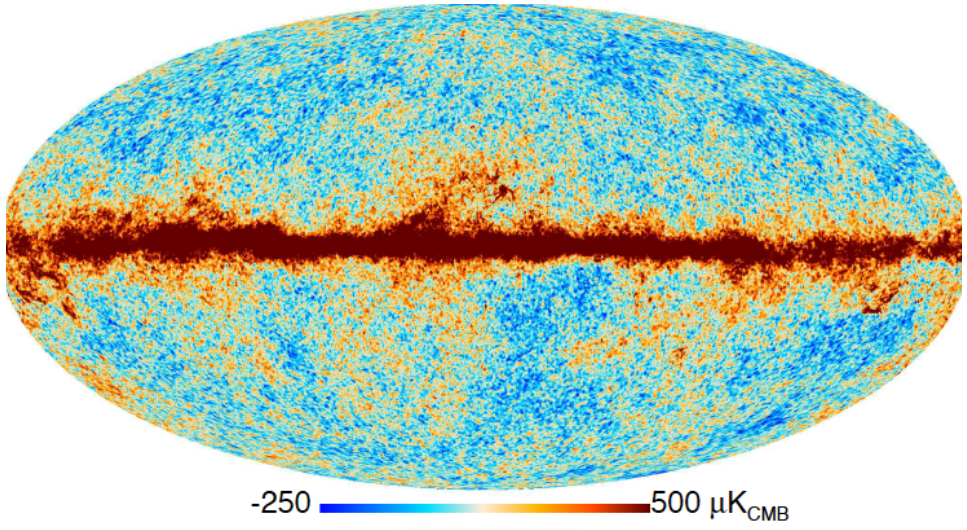




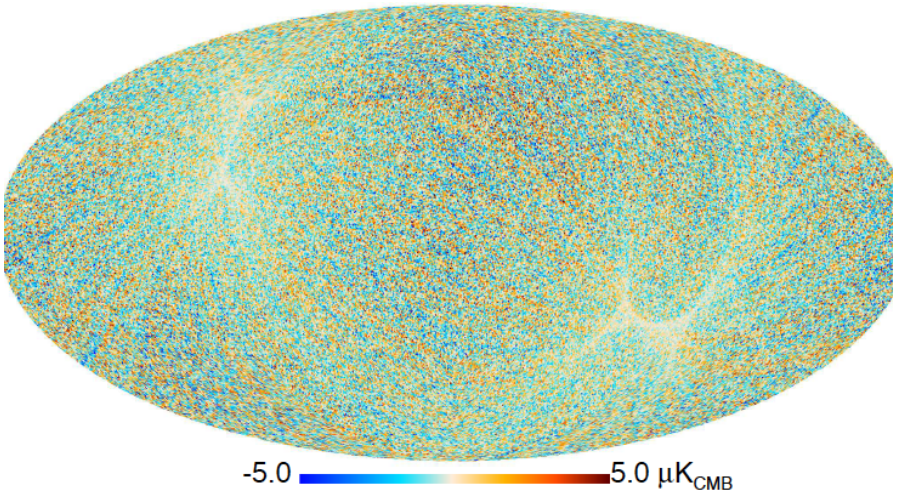
Null tests to check data quality

- The Planck Legacy Archive contains two types of data splits:
  - Single survey maps: 6 month timescales; different scan angle, different integration time; spacecraft on opposite side of solar system
  - Half-ring maps: ~20 minute timescales; nearly identical integration time & sky
- These maps should show identical sky structure to within the noise

143 GHz FIRST+LAST

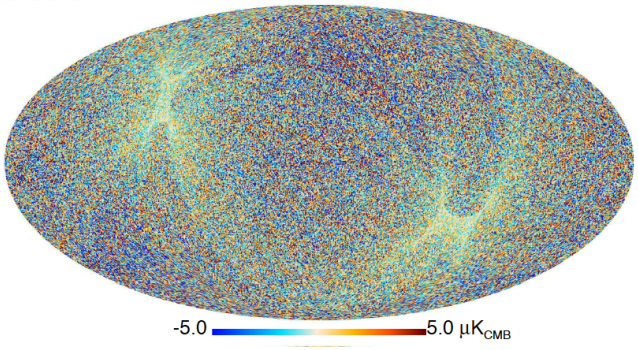


143 GHz FIRST-LAST

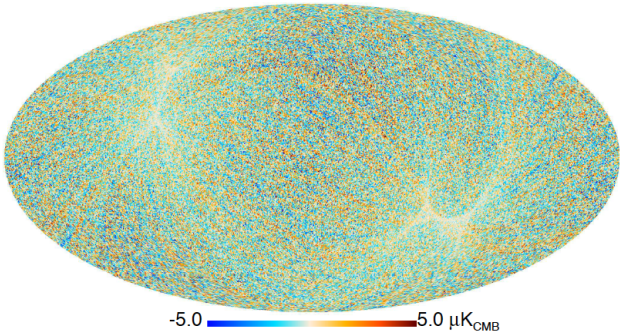


Half-ring differences

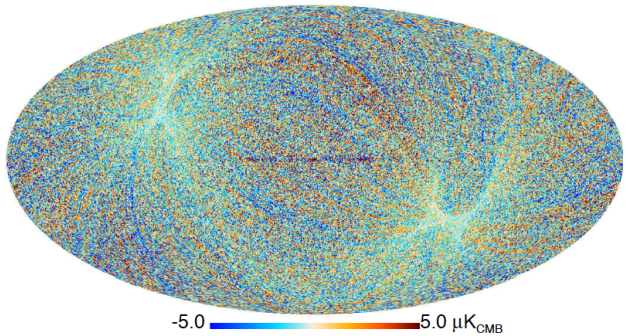
100 GHz



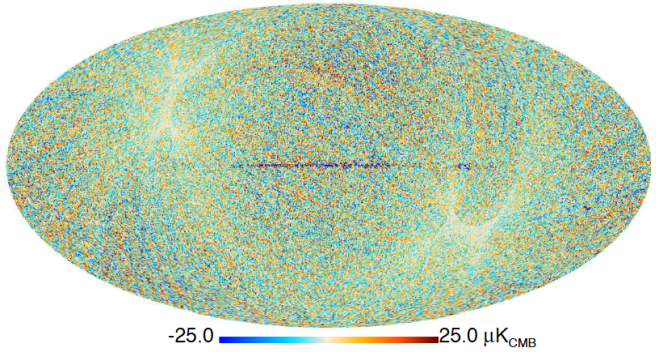
143 GHz



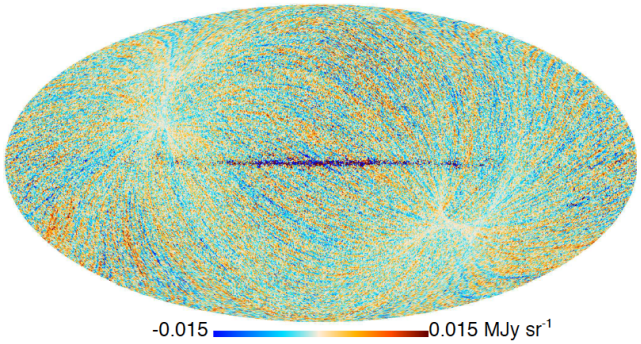
217 GHz



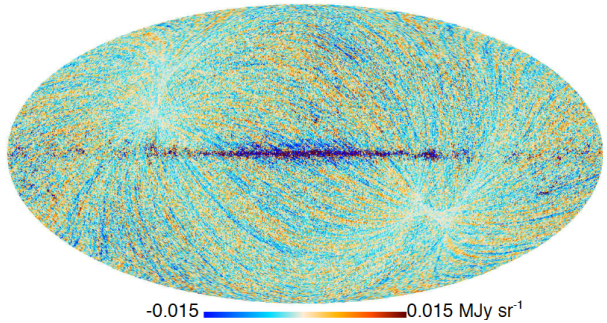
353 GHz



545 GHz

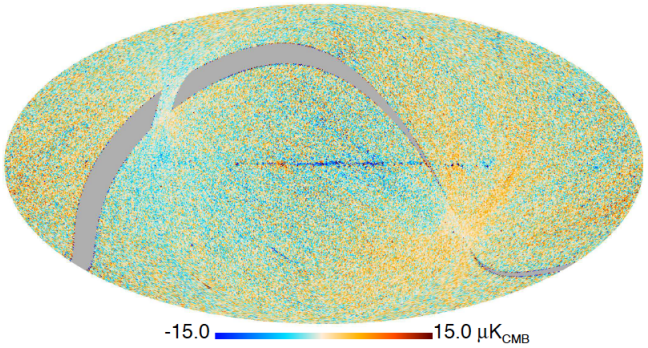


857 GHz

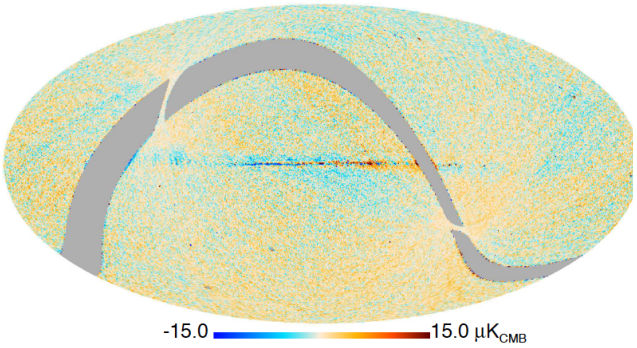


Survey differences

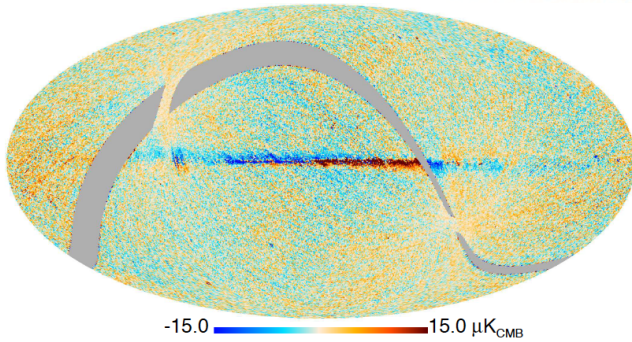
100 GHz



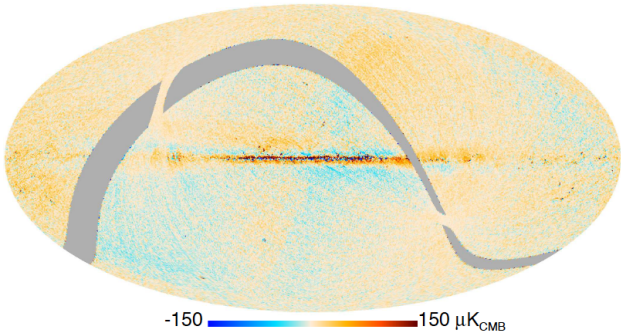
143 GHz



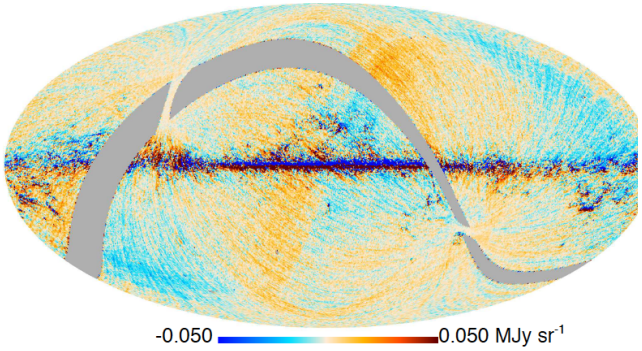
217 GHz



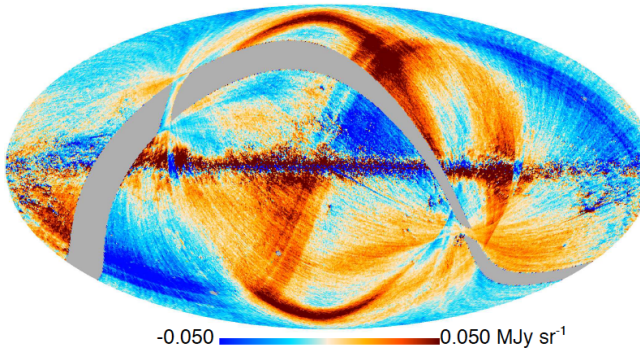
353 GHz



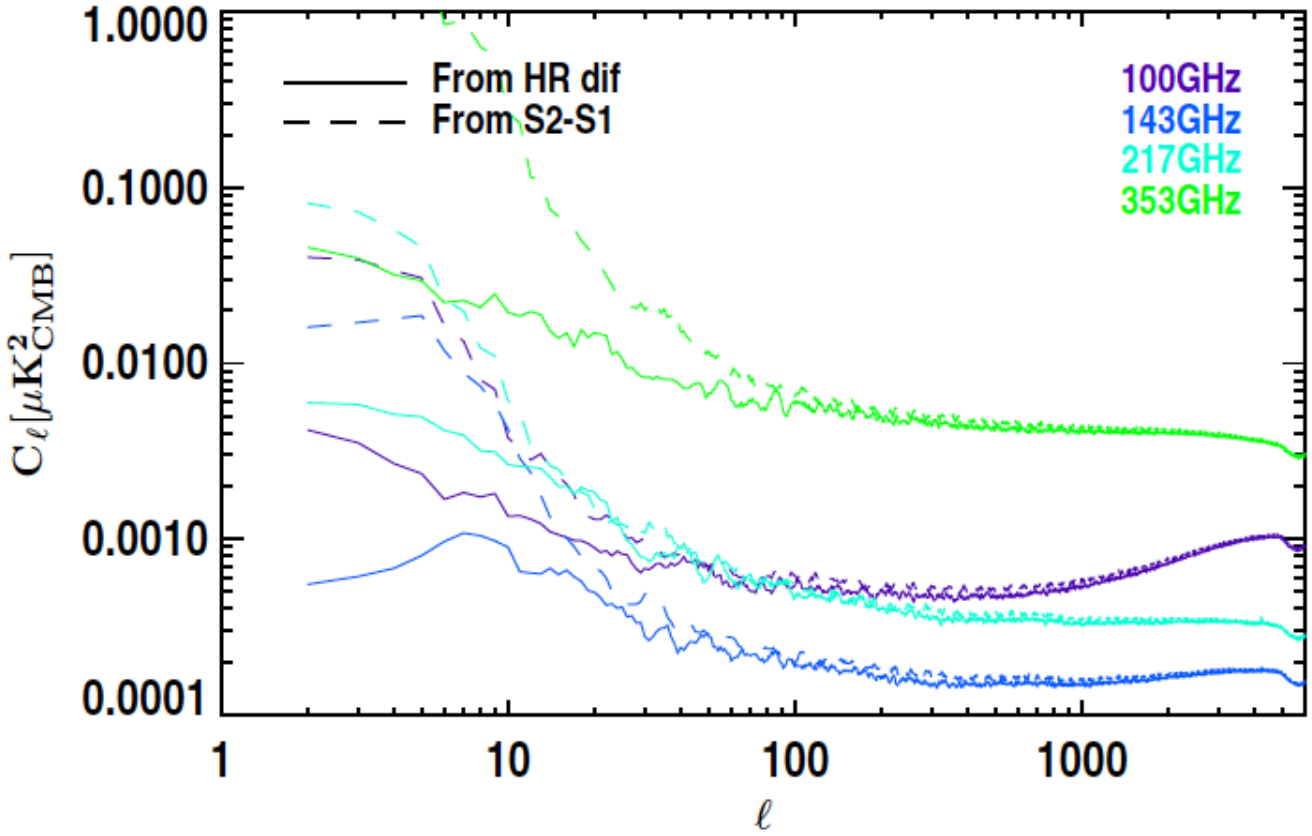
545 GHz



857 GHz

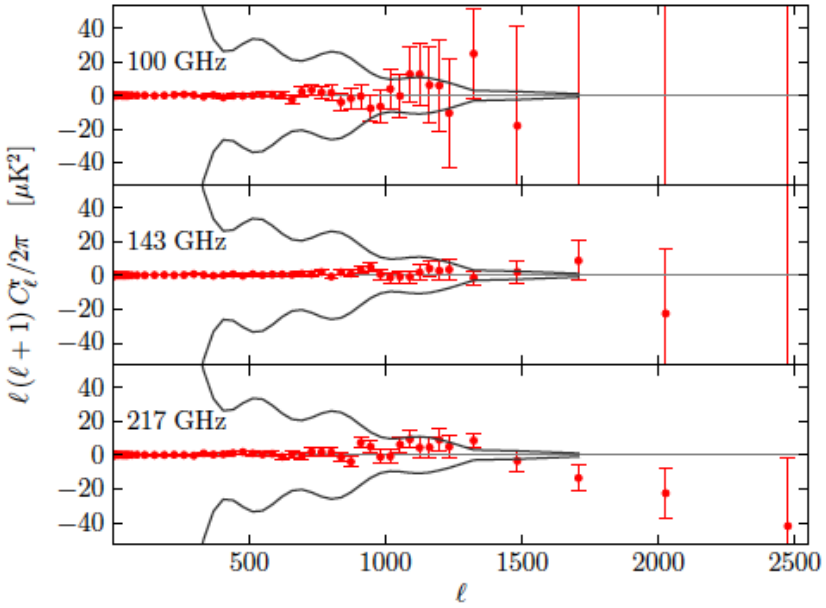


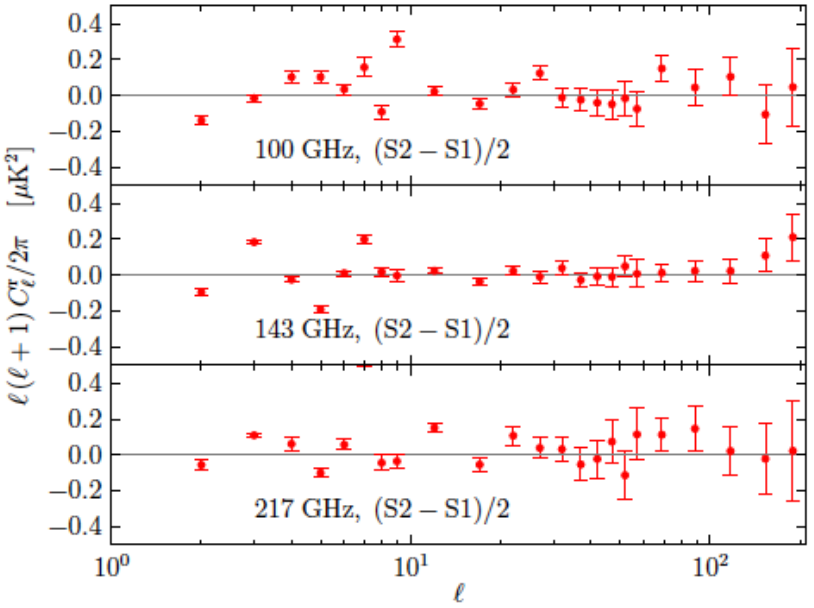
Power spectra of differenced maps

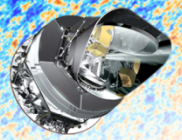


HFI null tests: Survey 1 vs. Survey 2

- Compare survey difference power spectra [galactic mask applied] with simulations







Conclusions

- HFI's maps are of exceptionally good quality
  - Tiny residuals in survey null tests have no impact on cosmology
- Some systematic challenges handled:
  - Beams, measured to ~1e-5 level
  - Higher than expected cosmic ray flux, templates fitted out
  - ADC nonlinearity, corrected as a fitted gain with time
- Significant angular power spectrum discrepancy with WMAP must be understood
- Polarization measurements to be delivered in 2014


esa
planck
cnes
agenzia spaziale italiana
NASA
cnrs
DTU Space
National Space Institute
Science & Technology Facilities Council
CSIC
National Research Council of Italy
CSA ASC
DLR
Deutsches Zentrum für Luft- und Raumfahrt e.V.
UK SPACE AGENCY
PLANCK LFI
HFI PLANCK
IAS orsay
IAP
INAF - IASF BO
ISTITUTO NAZIONALE DI ASTROFISICA
UNIVERSITY OF CAMBRIDGE
CARDIFF UNIVERSITY
irfu
saclay
CESR
CITA–ICAT
IASF
INSU
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ipac
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esa
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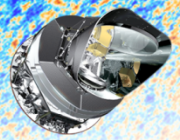
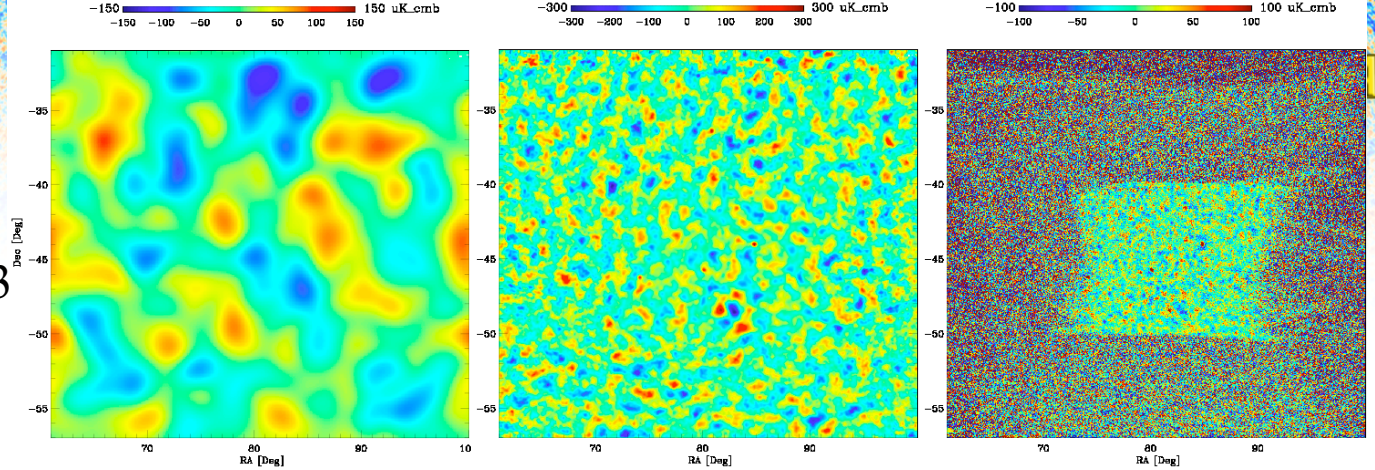
UNIVERSITÉ DE GENÈVE
UNIVERSITY OF TORONTO
UNIVERSITÉ DE PARIS-SUD XI
asdc

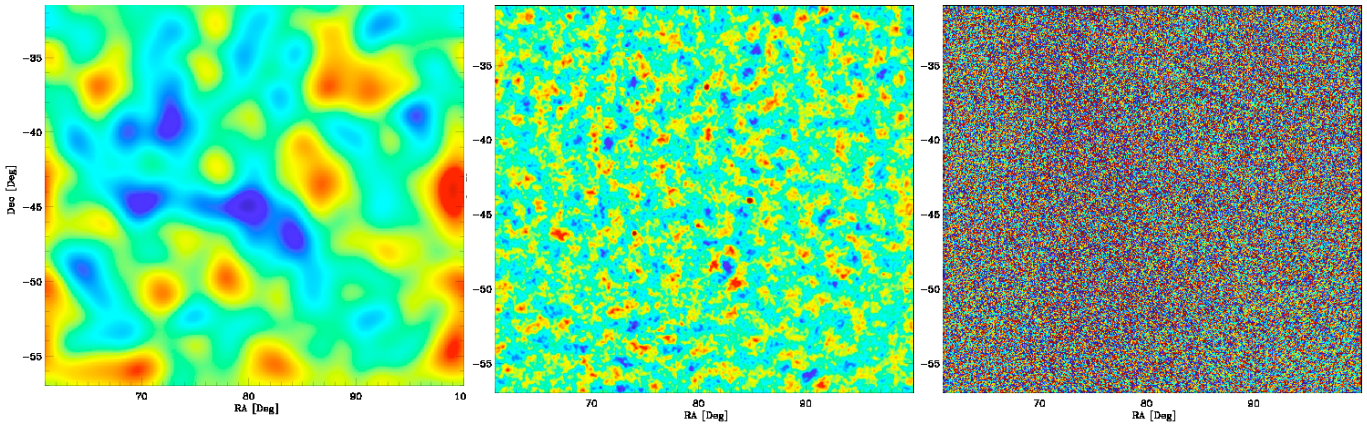


Boomerang 2003
145 GHz

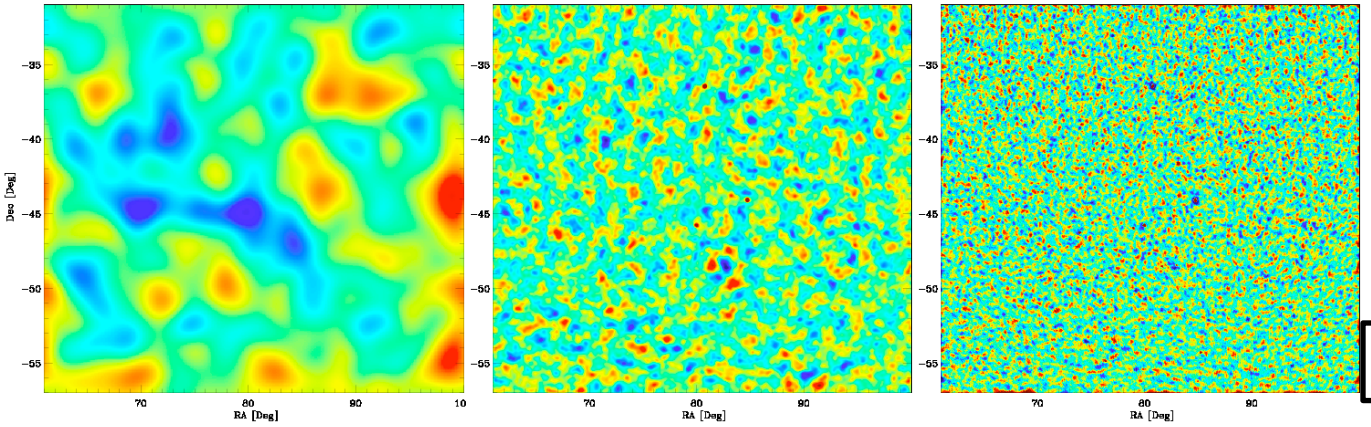


$\theta > 2°$ $2° > \theta > 15'$ $\theta < 15'$

WMAP7 2010
Q Band



Planck 2013
143GHz



KITP 22 April 2013

W. Jones