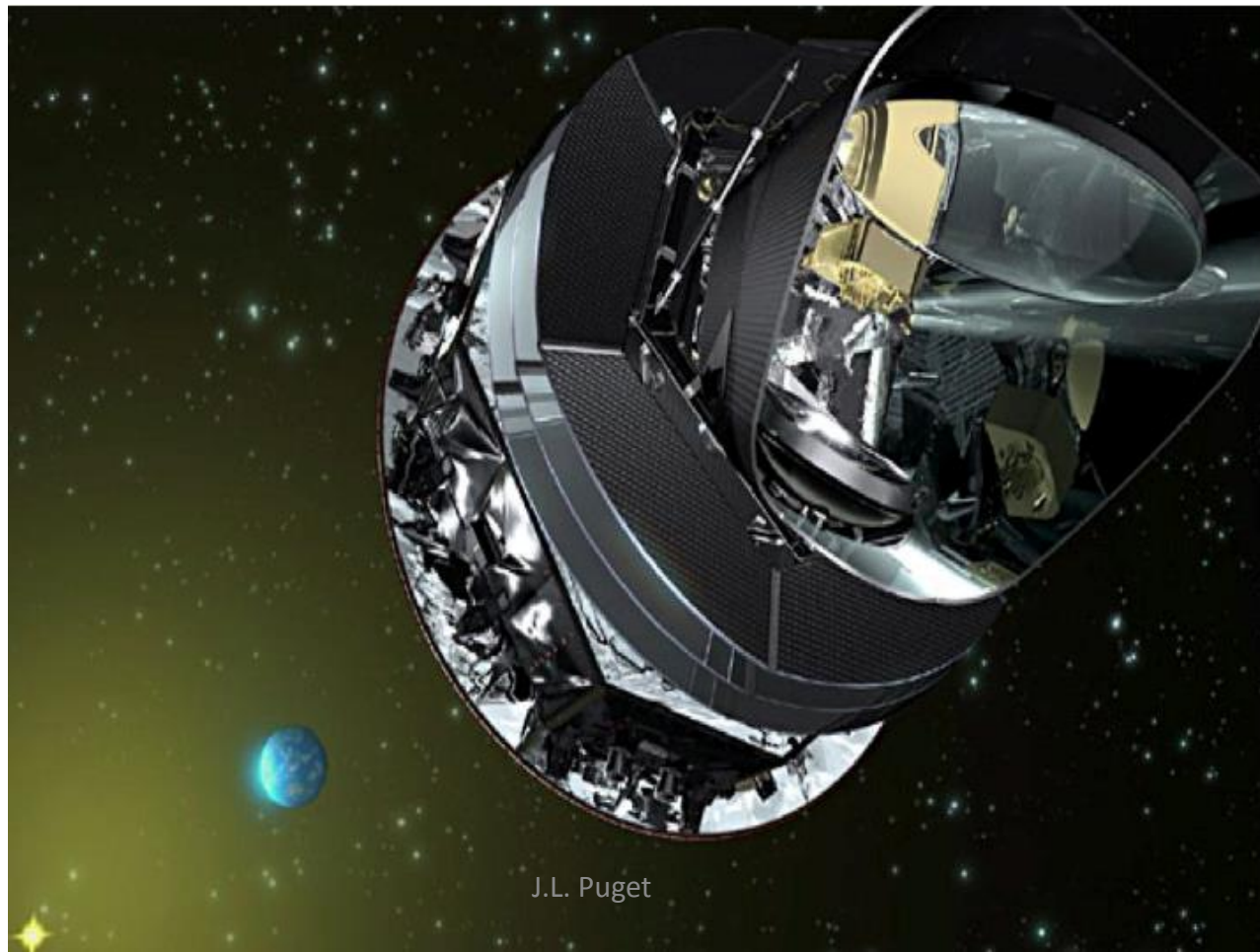


CERN May 2016-Next CMB Space Probes
Low Ell Polarization from Planck

Systematic effects and foregrounds

J.L. Puget

on the behalf of the Planck collaboration



the Planck concept for polarization: limits and advantages

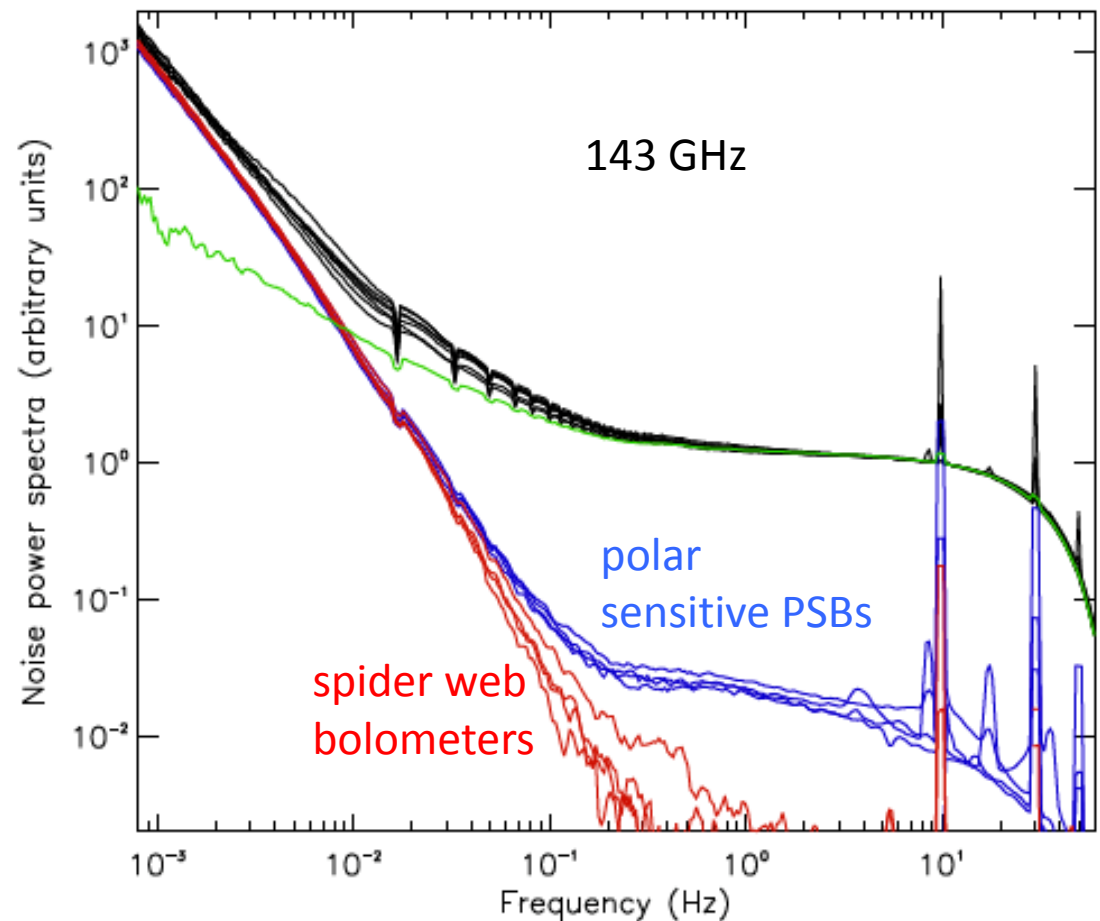
- measuring polarization with combination of several bolometers induces severe requirements
 - extreme accuracy of inter-calibration and leakage coefficients
 - many redundancies at many time scales and thus extreme stability
- measuring large scales implies also extreme stability
- Bolometers have a very stable response
- time variability of 100 mK temperature stage is limited by cosmic rays modulation

Design and trade-offs

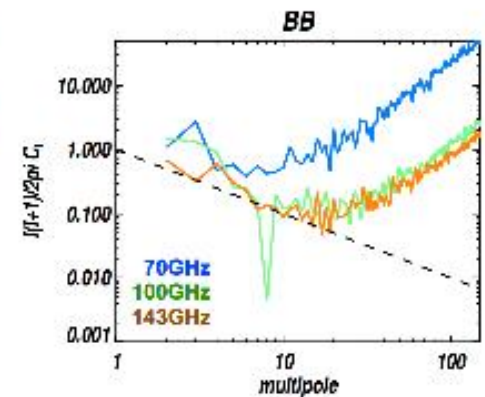
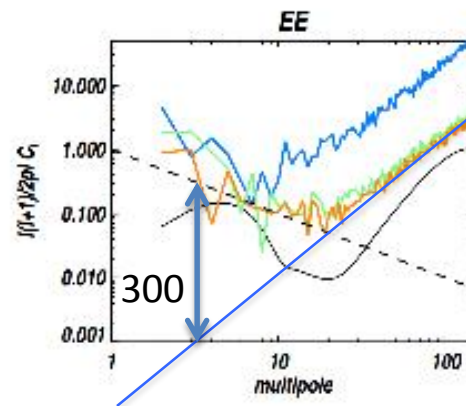
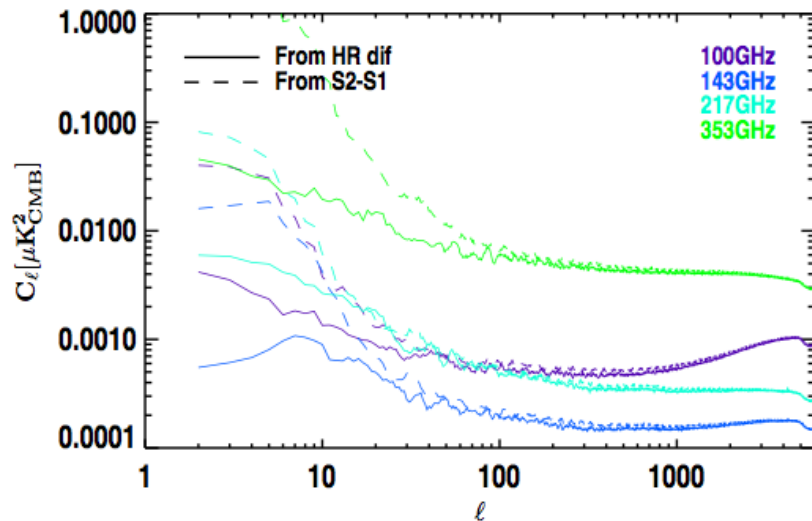
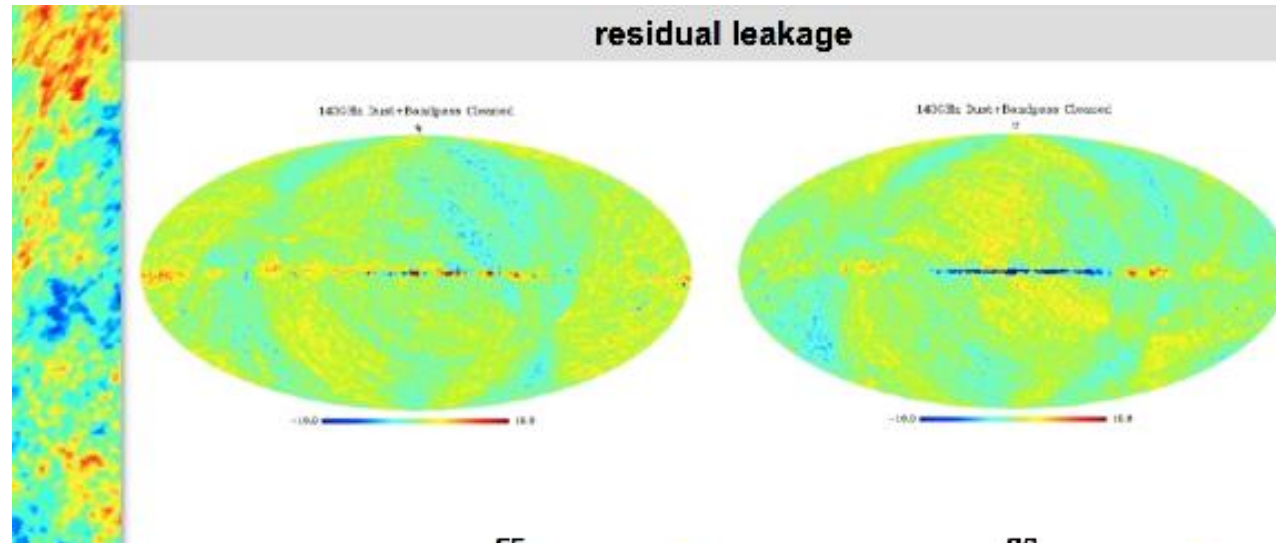
- goals were
 - to extract most of the cosmological information from the CMB Temperature acoustic peaks
 - to be background-photon-noise limited
- detectors (HEMTS and bolometers) were chosen from the start
- many trade-offs
 - scanning strategy, several time-scales redundancies
 - spin rate vs bolometer time constant and sensitivity, $1/f$ knee freq for HEMTS
 - number and width of spectral bands
- a narrow range of parameters was found to accommodate all these
- polarization was in but not as a driver (useful to have ambitious goals not in the requirements)
- Polarization it became a key one after WMAP

how far can we test space experiments on the ground

- cosmic rays
- sub Kelvin cryogenic systems in space



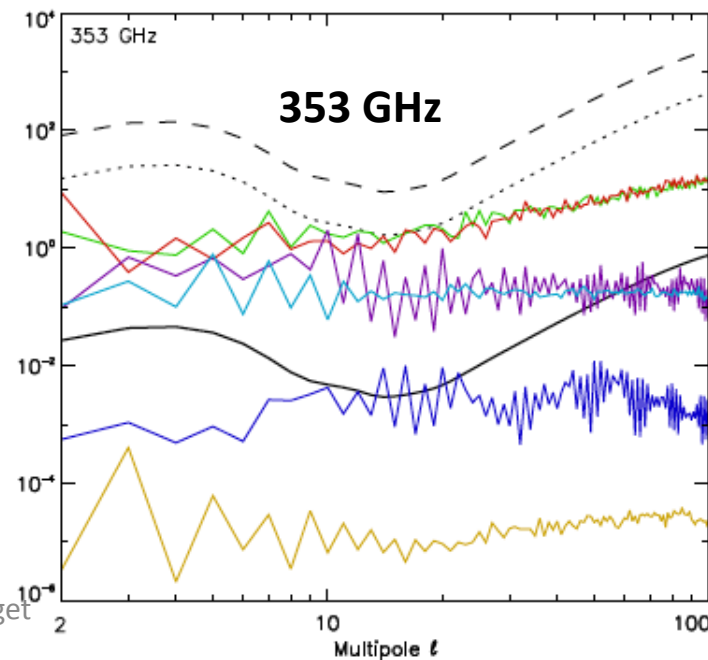
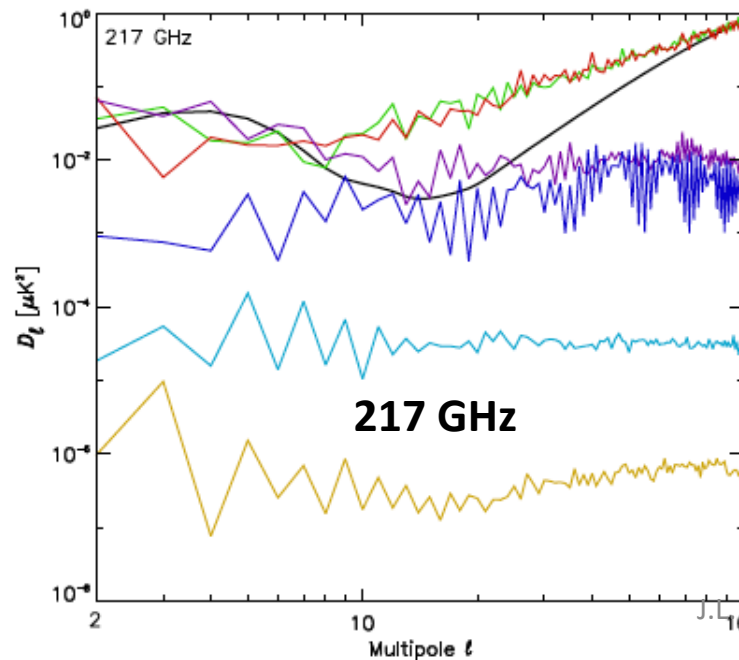
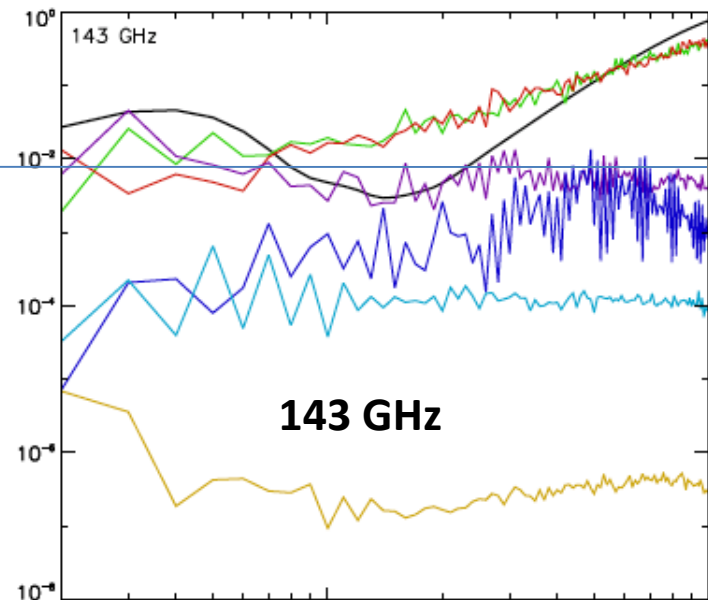
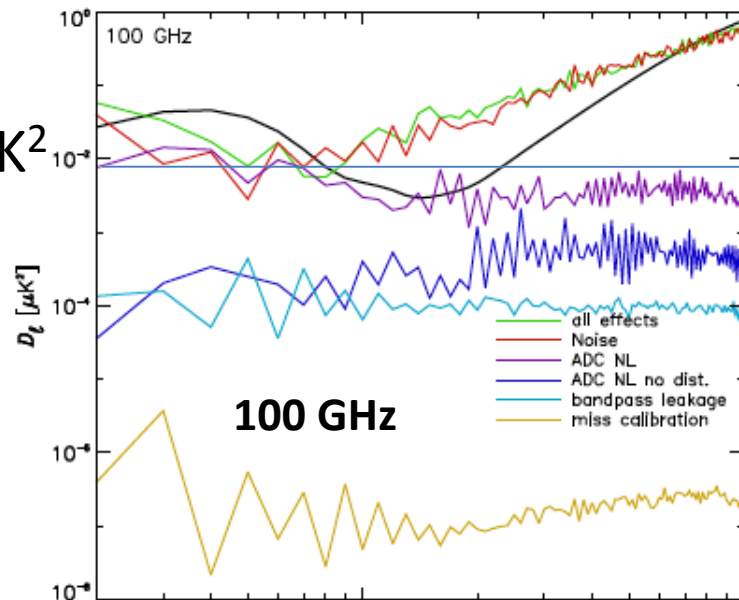
The data had strong noise excesses at low ℓ in polarization



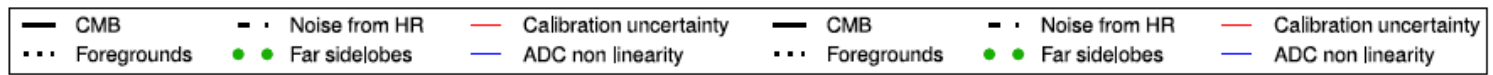
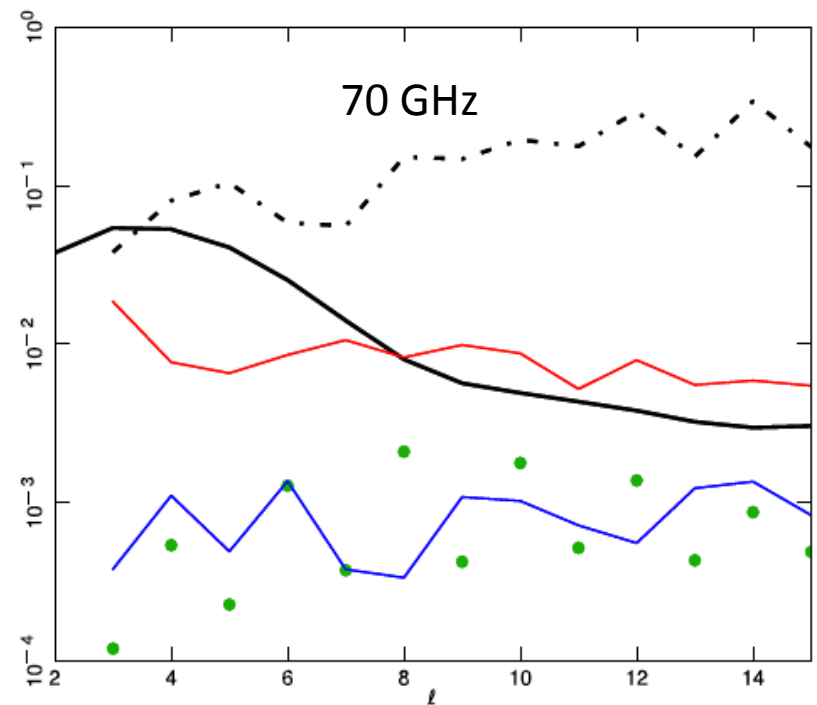
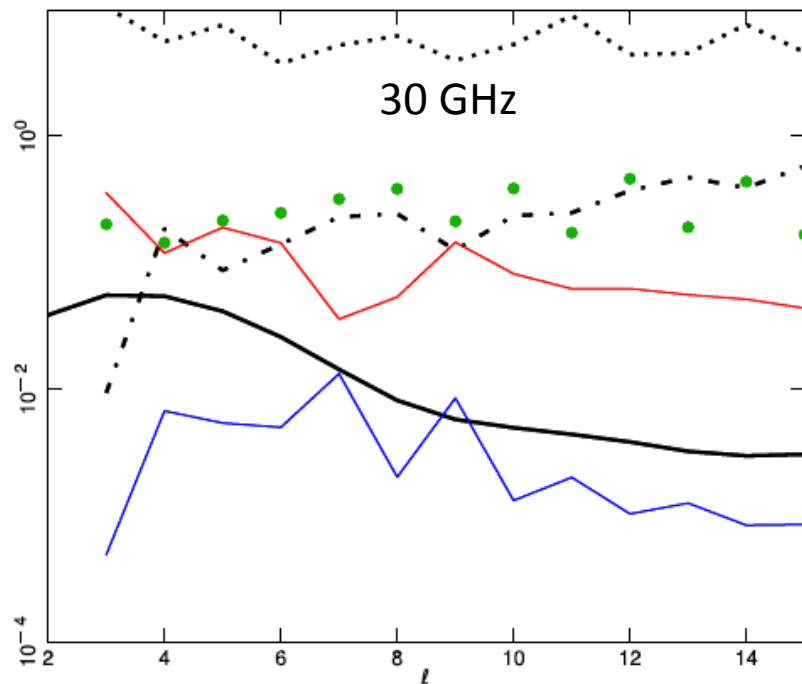
December 2012 situation
(2013 release)

E2E simulations: all systematic effects residuals for HFI

$10^{-2} \mu\text{K}^2$



- systematic effects for LFI



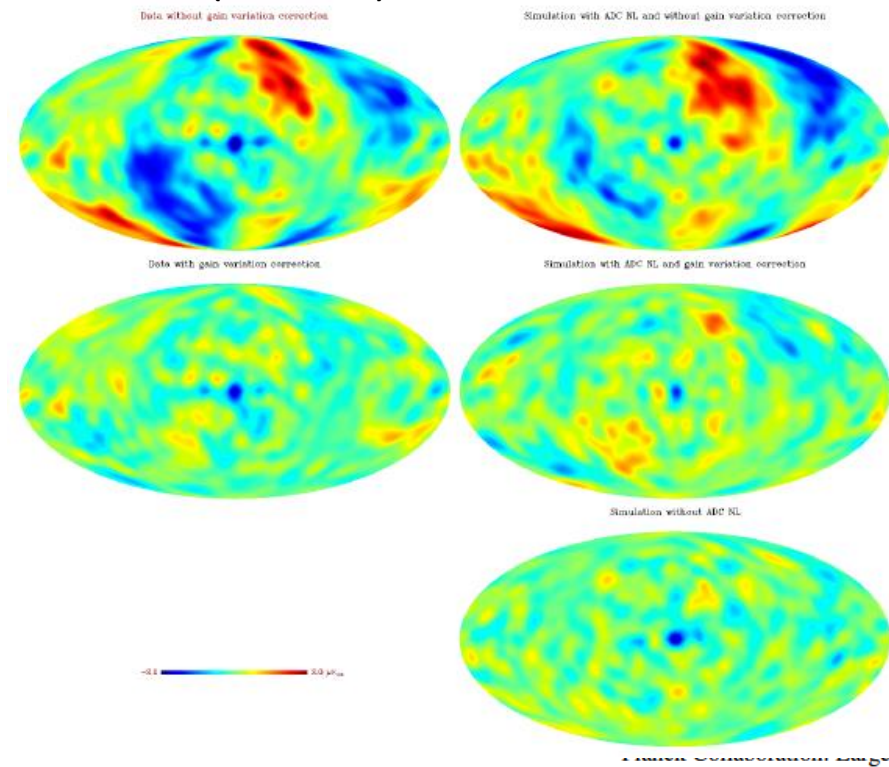
Systematics

- HFI took longer because of the lower noise
- most systematics were well under the noise
- the main HFI systematic effect at low frequency is the ADC nonlinearity
- it was partially corrected in 2013 and 2015 but only brought below the noise in 2016
- at high frequency intensity to polarization leakages dominate at low ℓ

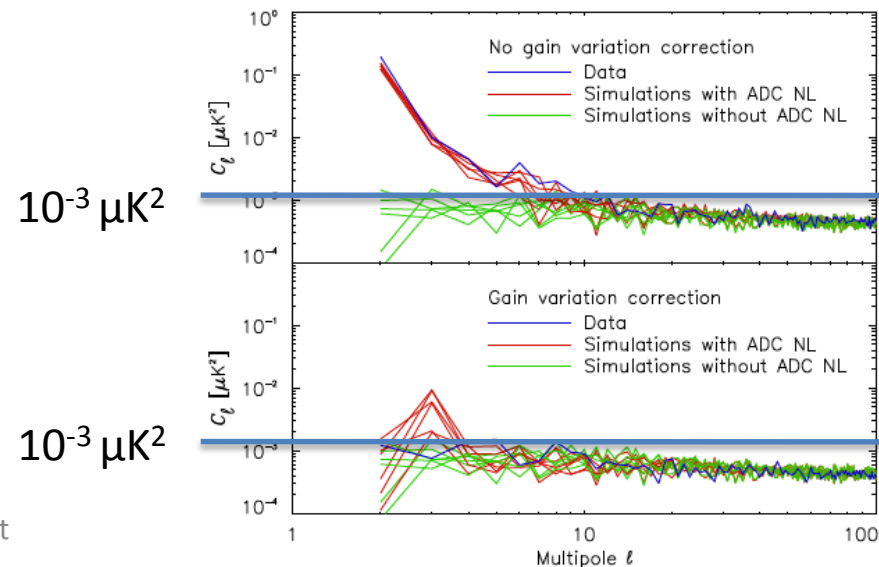
- Top figure
 - 1st row maps: is total ADC NL
 - 2nd row maps: is apparent time dependant gain correction
 - 3rd row map: is ADC NL dipole distortion effect (for simulation only as we did not remove it in the pre2016 data)

Data (100GHz)

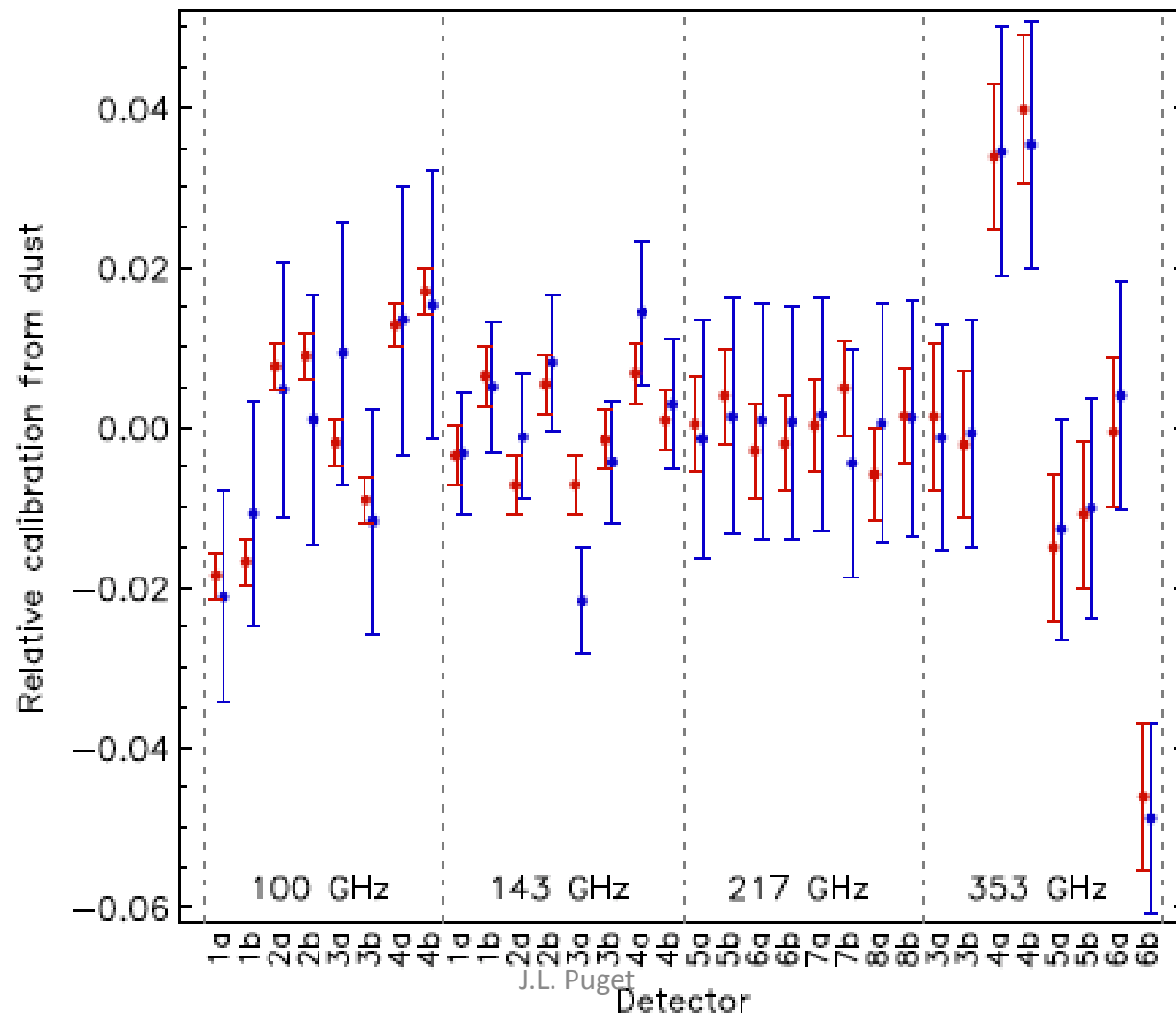
Simulations



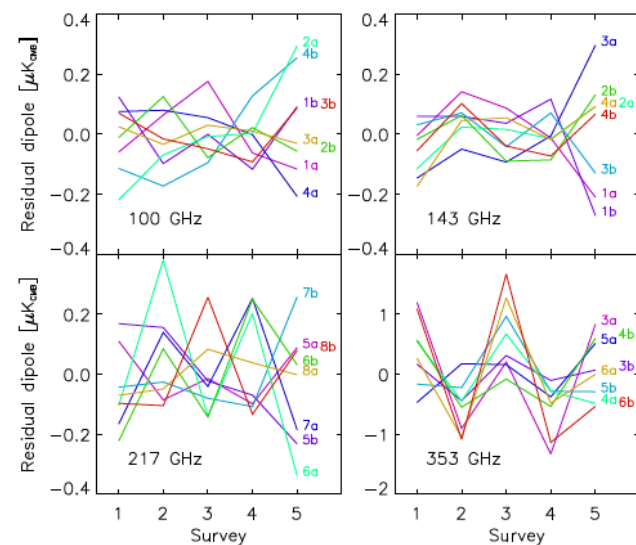
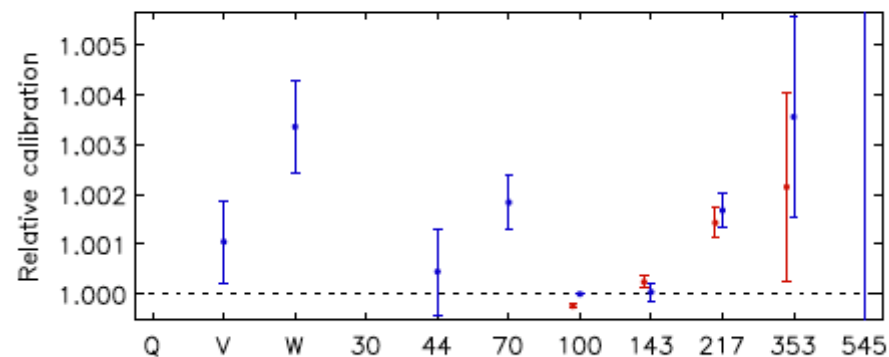
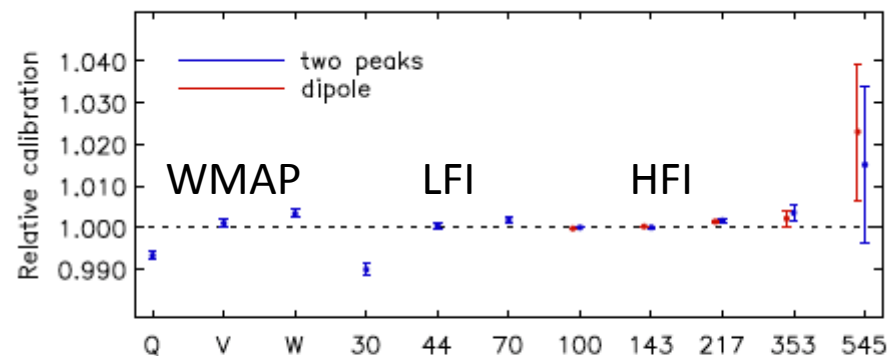
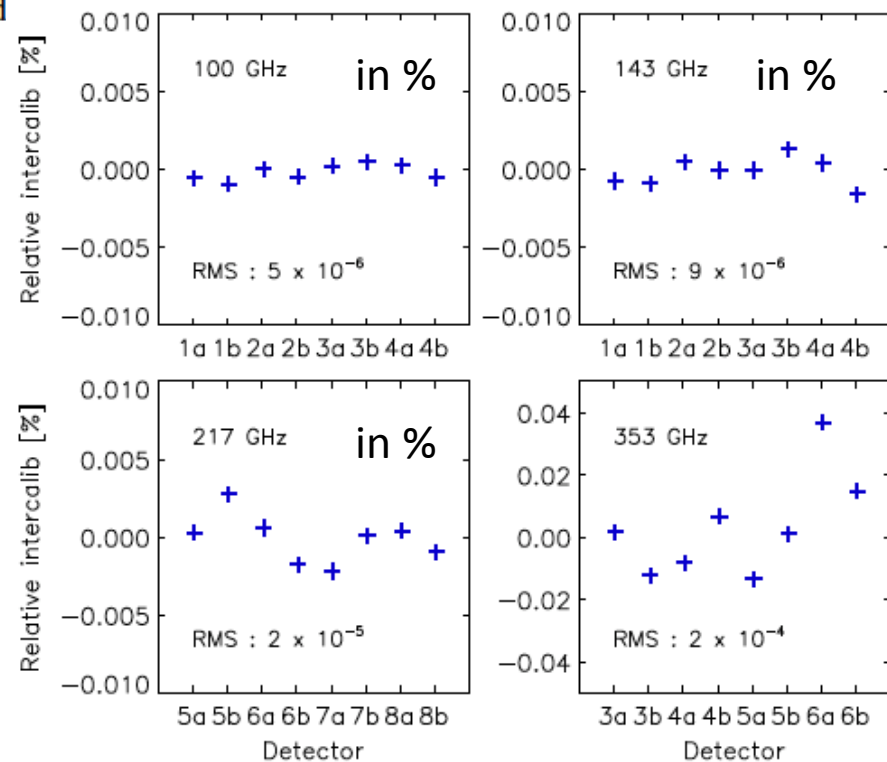
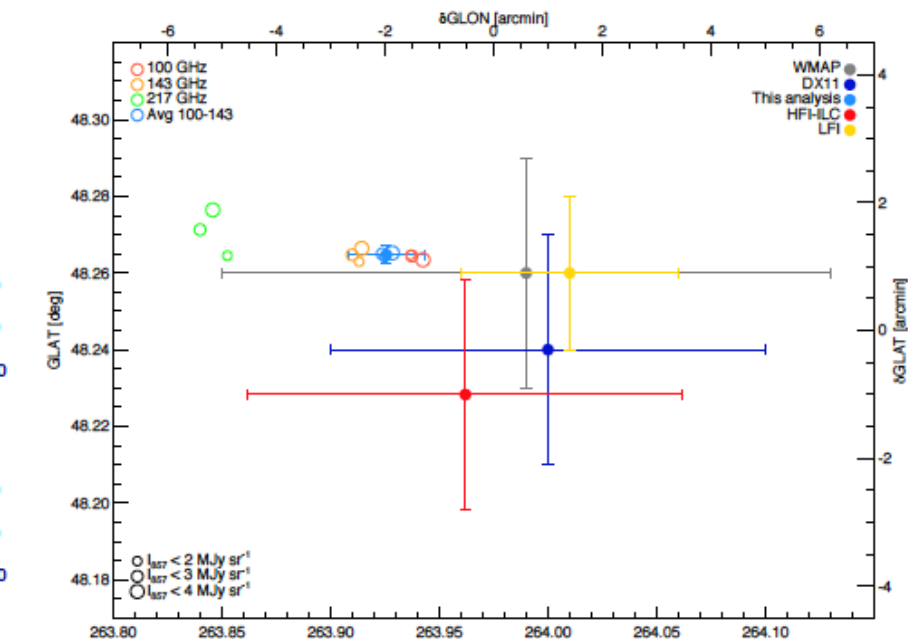
- Bottom figure : the spectra are
 - top : full ADC NL syste (top maps)
 - bottom : is after removal of apparent time gain variation



an example of a systematic effect: ground based vs sky destripping
dust passband mismatch leakage



Intercalibration



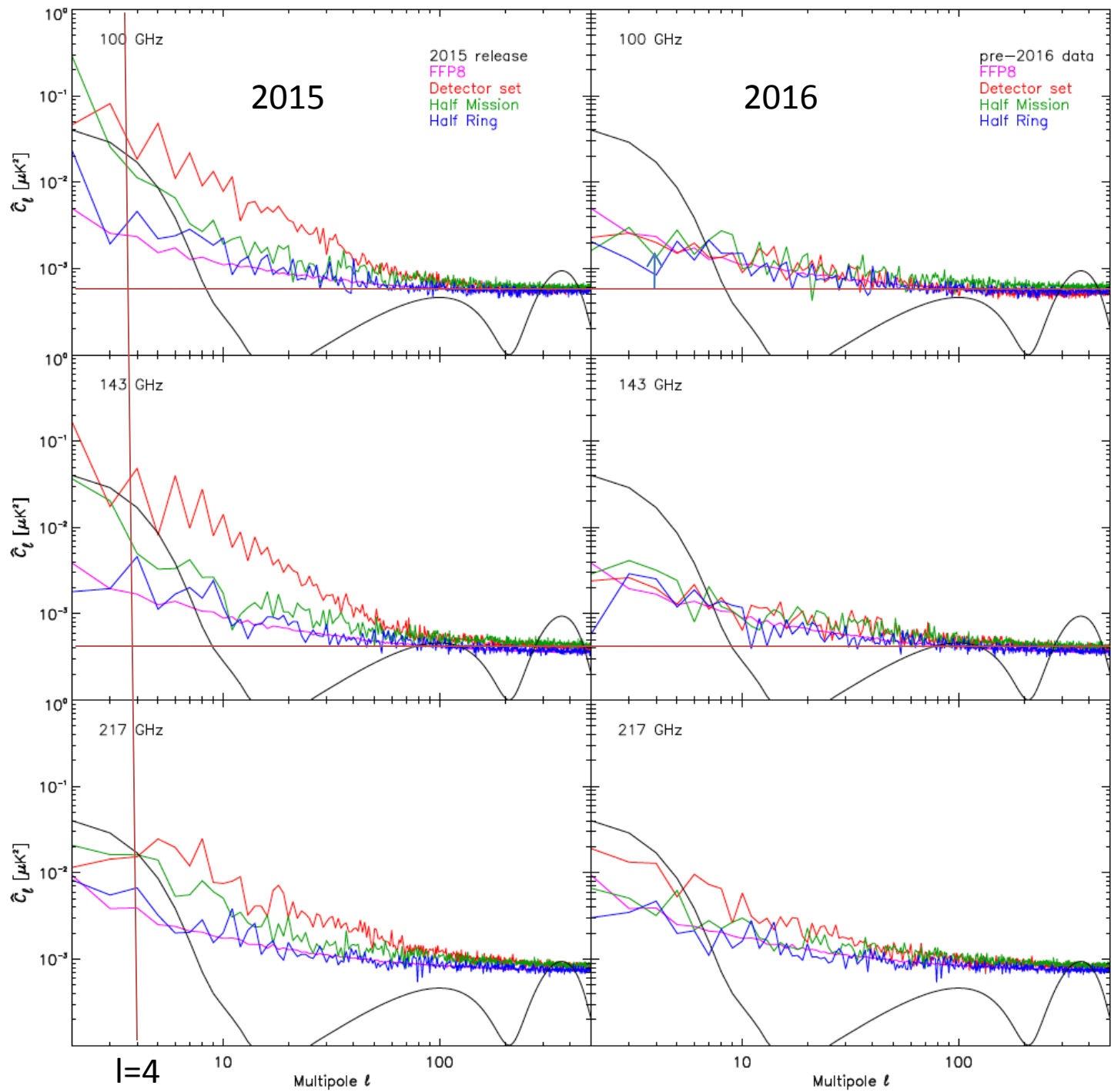
Frequency [GHz]	Solar dipole				First and second peak	Transfer function
	Amplitude [μ K]	l [deg]	b [deg]	Rel. amplitude [%]	Rel. amplitude [%]	$\Delta\ell = 1-300$ [%]
44 .....	...	...	...	...	0.05	...
70	3363.1	263.97	48.26	0.06	0.18	0.13
94 (WMAP)....	3355	...	...	-0.19	0.34	0.52
100	3361.25	263.937	48.2647	0.00	Ref.	Ref.
143	3362.85	263.913	48.2629	0.05	0.00	-0.04
217	3366.56	263.852	48.2645	0.16	0.17	0.01
353	3364.19	263.385	48.3191	0.09	0.36	0.27
545	3440 (TBC)	...	...	2.34	1.51	-0.83

SOLAR DIPOLE

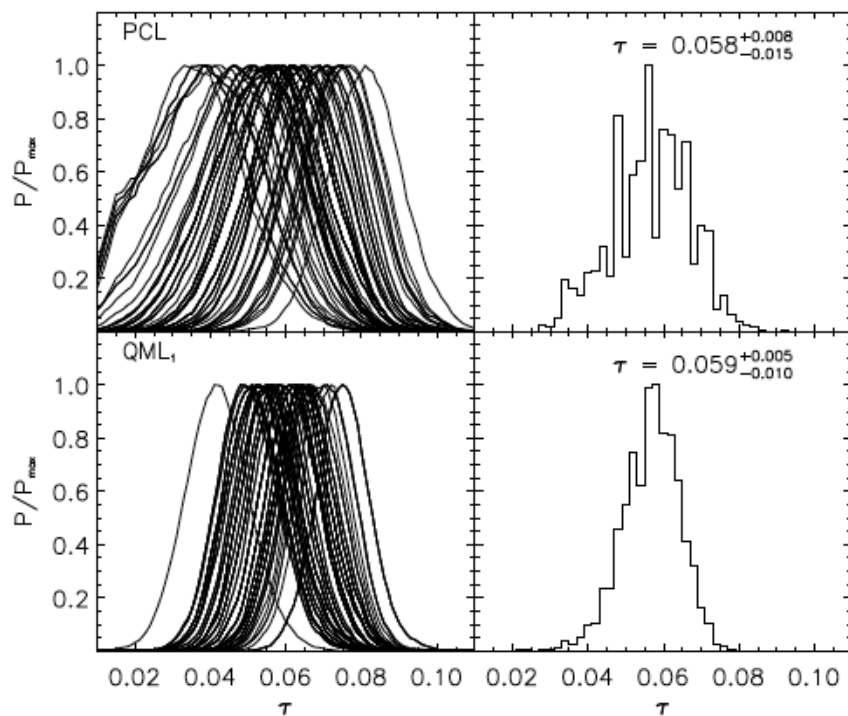
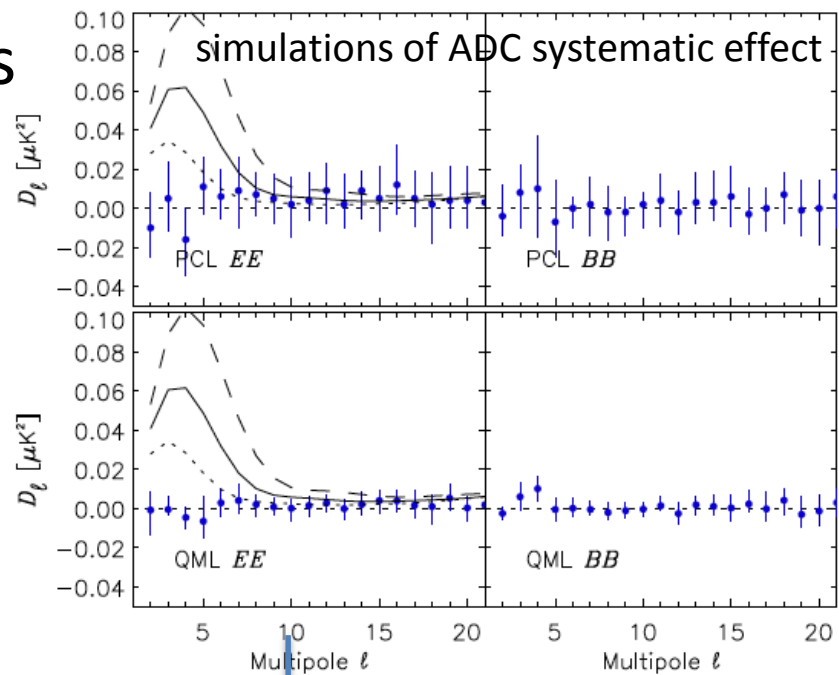
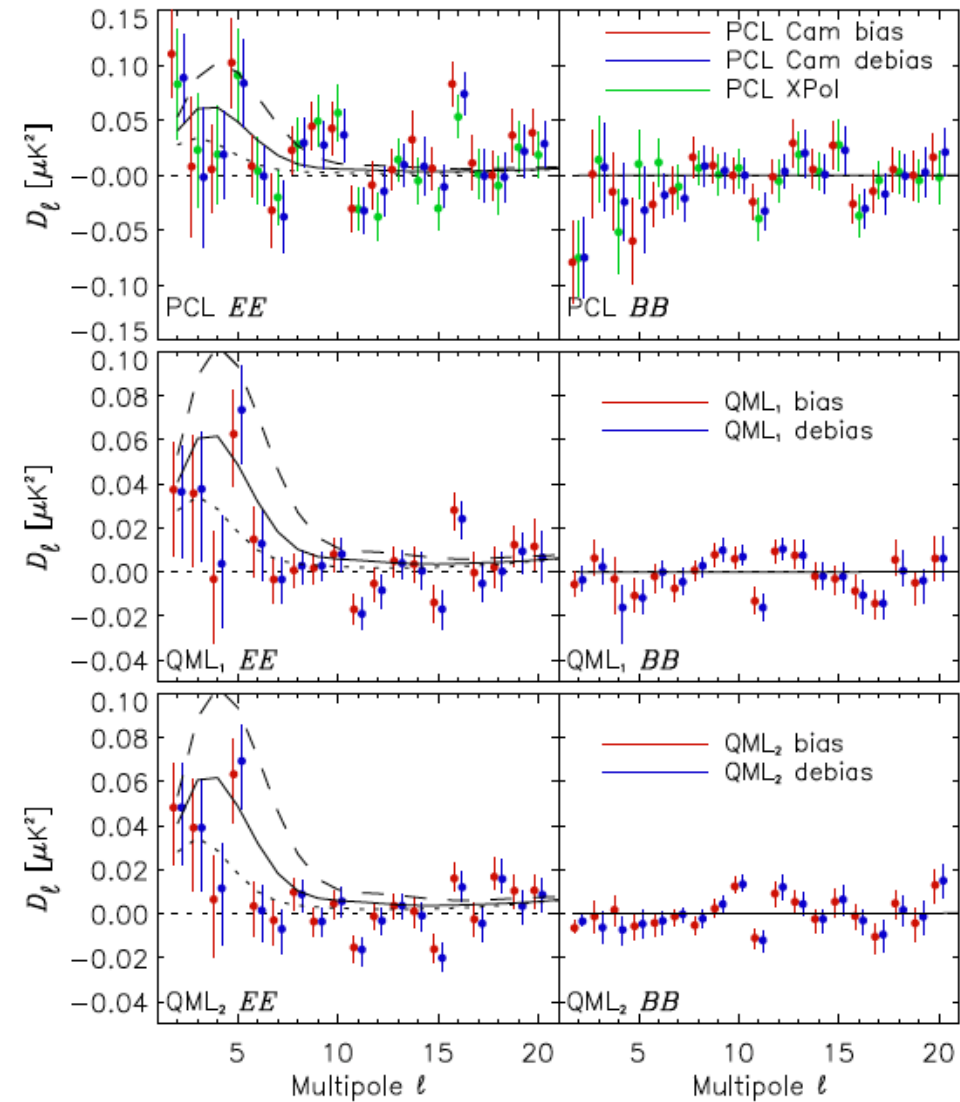
$\hat{GLON}=263^{\circ}.937 \pm 0^{\circ}.005,$

$GLAT=48^{\circ}.265 \pm 0^{\circ}.001,$

$Amplitude= 3361.25 \pm 0.25 \mu K$



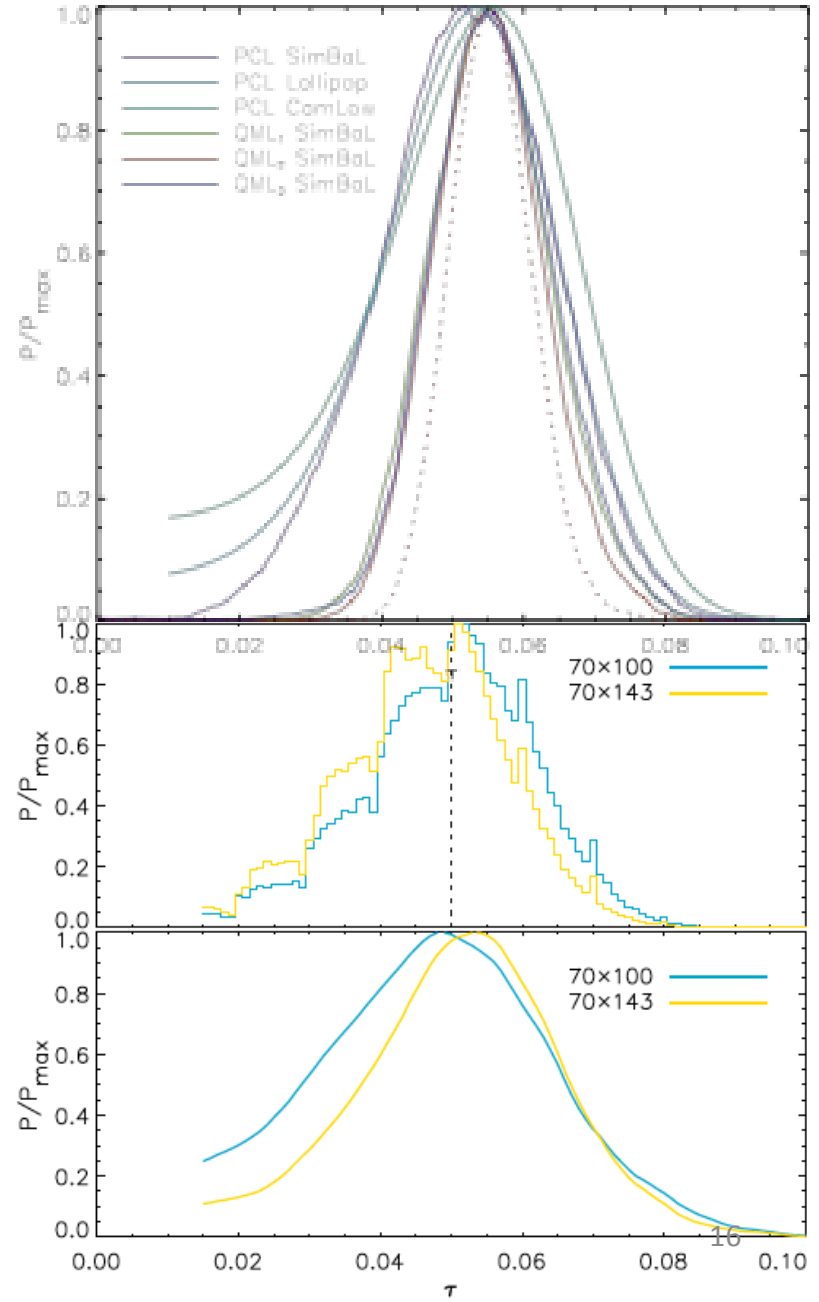
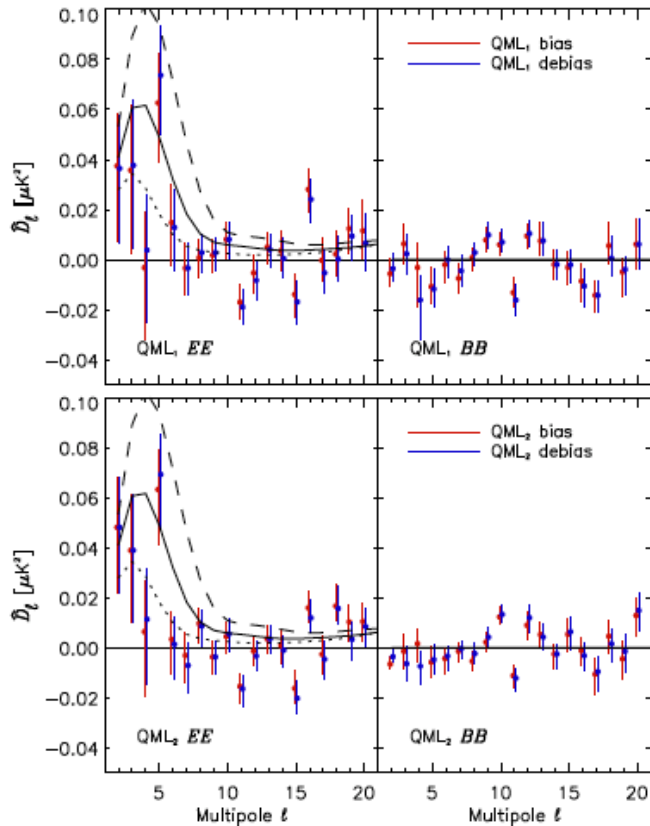
Testing debiasing E2E simulations



Tau deterlination

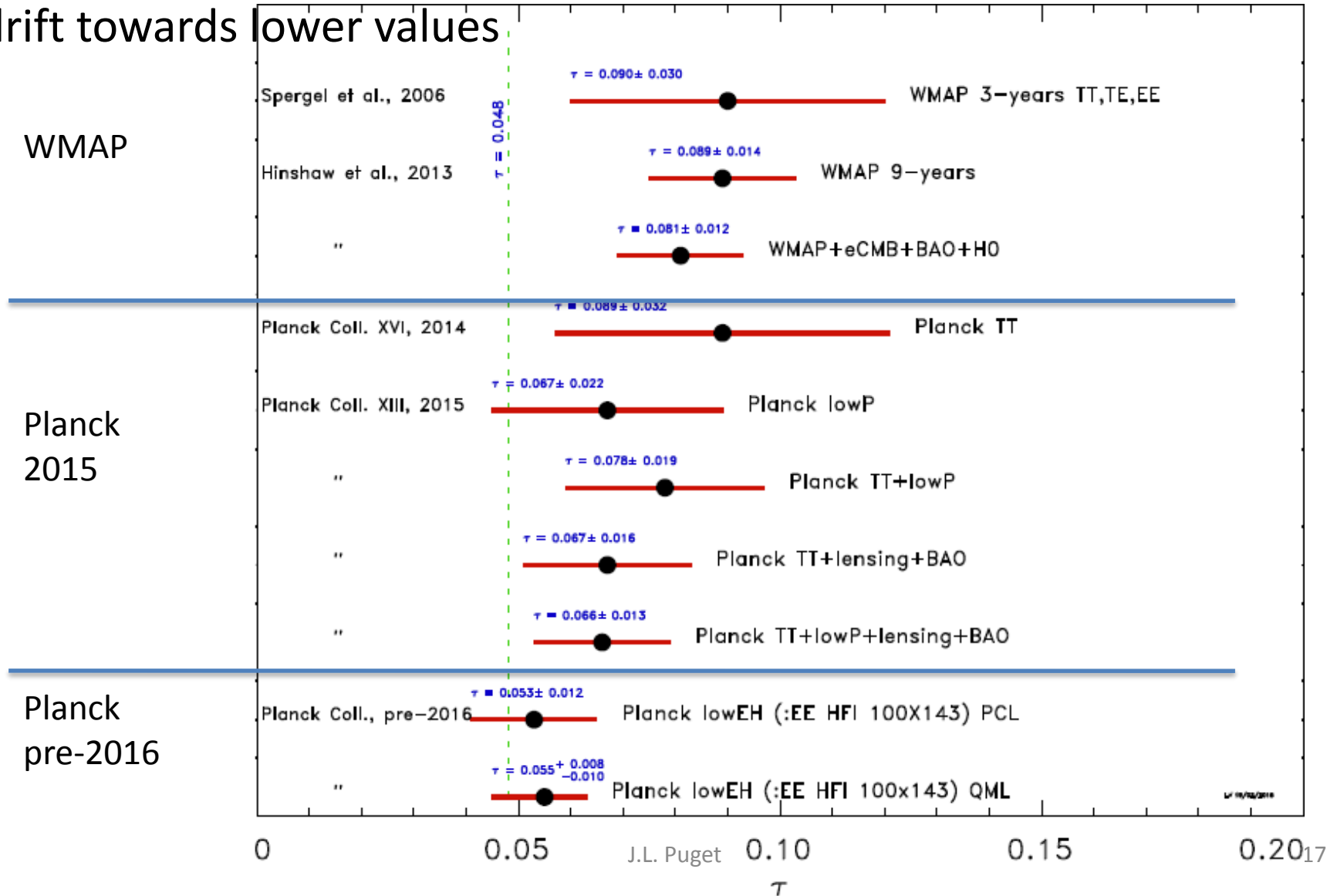
Method	PCL		QML	
	peak $\pm 1\sigma$	peak $+2\sigma$	peak $\pm 1\sigma$	peak $+2\sigma$
Lollipop ...	$0.053^{+0.011}_{-0.016}$	0.075	...	...
SimBaL1	$0.052^{+0.011}_{-0.014}$	0.076	$0.055^{+0.009}_{-0.009}$	0.073
SimBaL2 ....	...	...	$0.055^{+0.008}_{-0.008}$	0.071
SimBaL3 ....	...	...	$0.055^{+0.009}_{-0.008}$	0.073

HFIXLFI $\tau = 0.049^{+0.015}_{-0.019}$ for the 70×100 cross-spectra,
 $\tau = 0.053^{+0.012}_{-0.016}$ for the 70×143 cross-spectra.



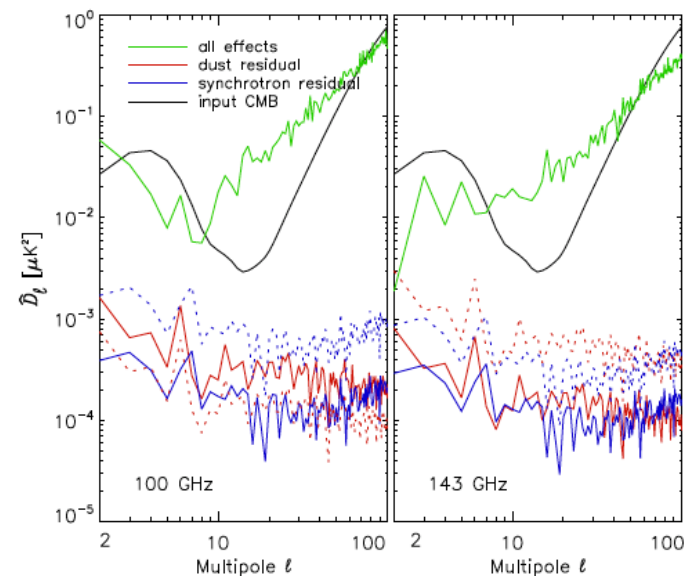
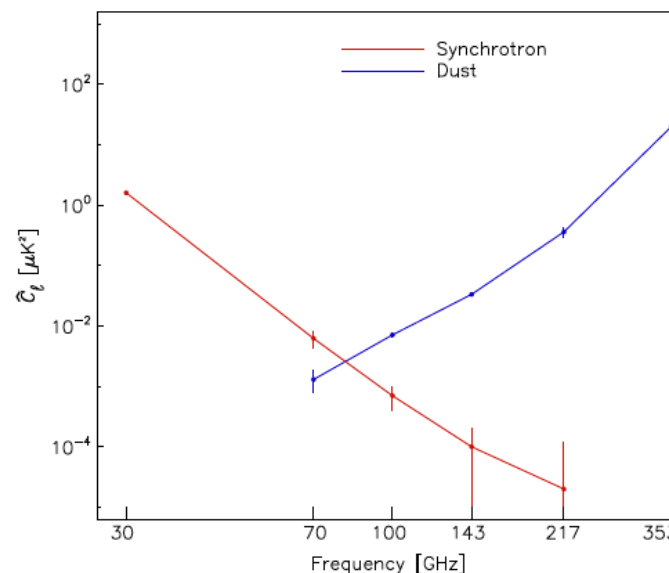
- consistency of all Planck results
- improvements of uncertainties
- drift towards lower values

τ from CMB (historical)



Cleaning E and B modes polarised foreground

- only 2 polarised foregrounds (so far !) dust and synchrotron
- the degree of polarization is larger and highly variable on the sky for foregrounds than for CMB
- using 100x143 cross spectra allows to remove only the dust
- for EE removal of foregrounds is not a major problem
- for BB it is and will be !

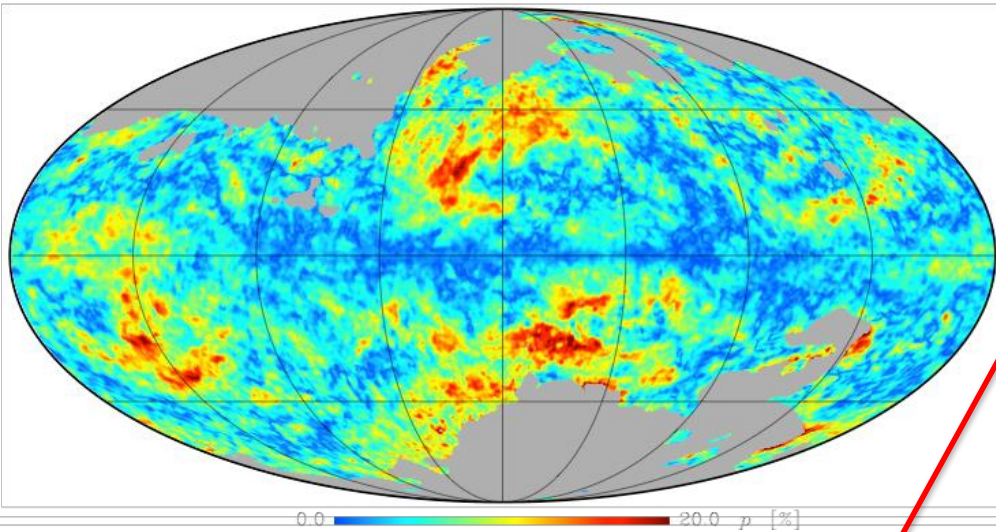


How variable are the dust and synchrotron SEDs ?

- We know that the dust properties varies on the sky
- Dust is colder in IS clouds (especially molecular cluds)
- emissivity at long wavelengths changes
- the very small grains abundance is highly variable (associated or not with the spinning dust)
- there are trade off between
 - lever arm: better separation, less noise added to the CMB
 - variable SED: measure the foreground at a nearby frequency
 - broad bands : better sensitivity but passband mismatch leakage, difficulty to calibrate very accurately (colour corrections), IS lines
 - narrow bands or low res spectrometer (complex instrument)

IS dust power spectrum level

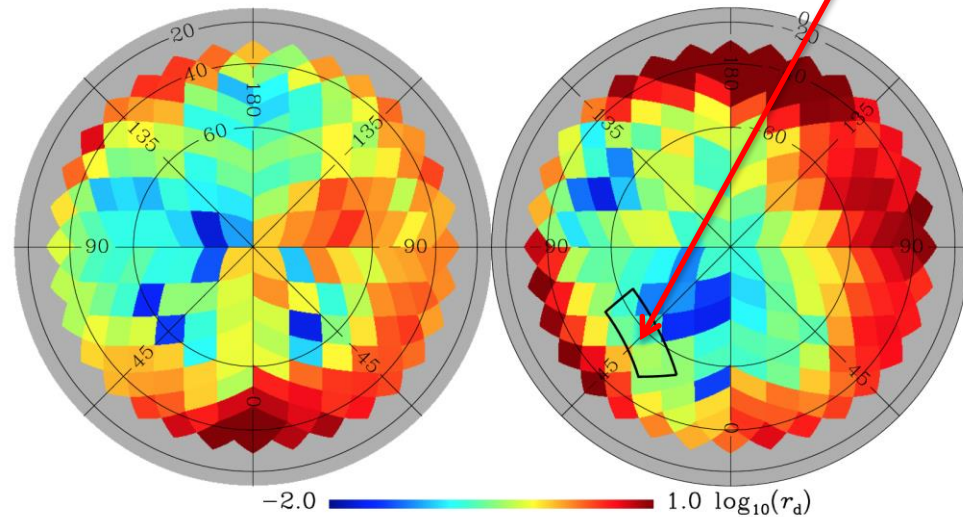
Polarization degree



galactic poles

North

South

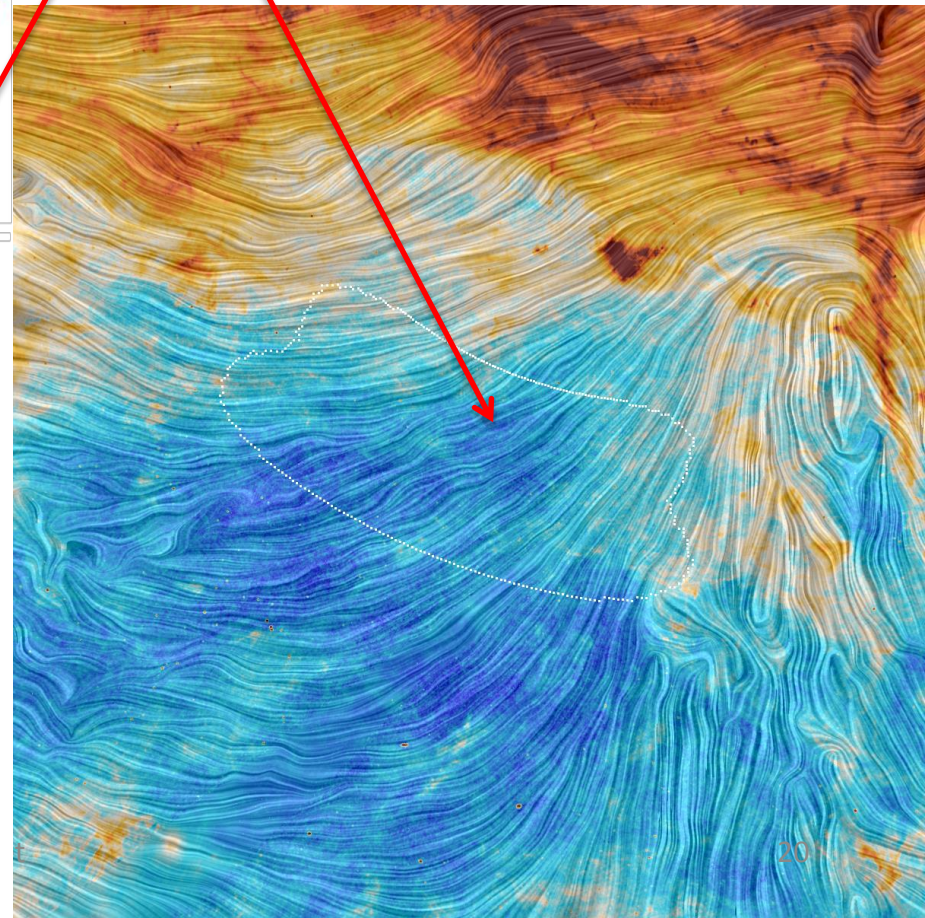


FM5 J. Aumont

galactic magnetic field traced
by the polarized dust emission

BICEP2 field

galactic coordinates



$3 \cdot 10^{-4} \mu\text{K}^2$

100, 143, 70 GHz

Cross spectra → signal

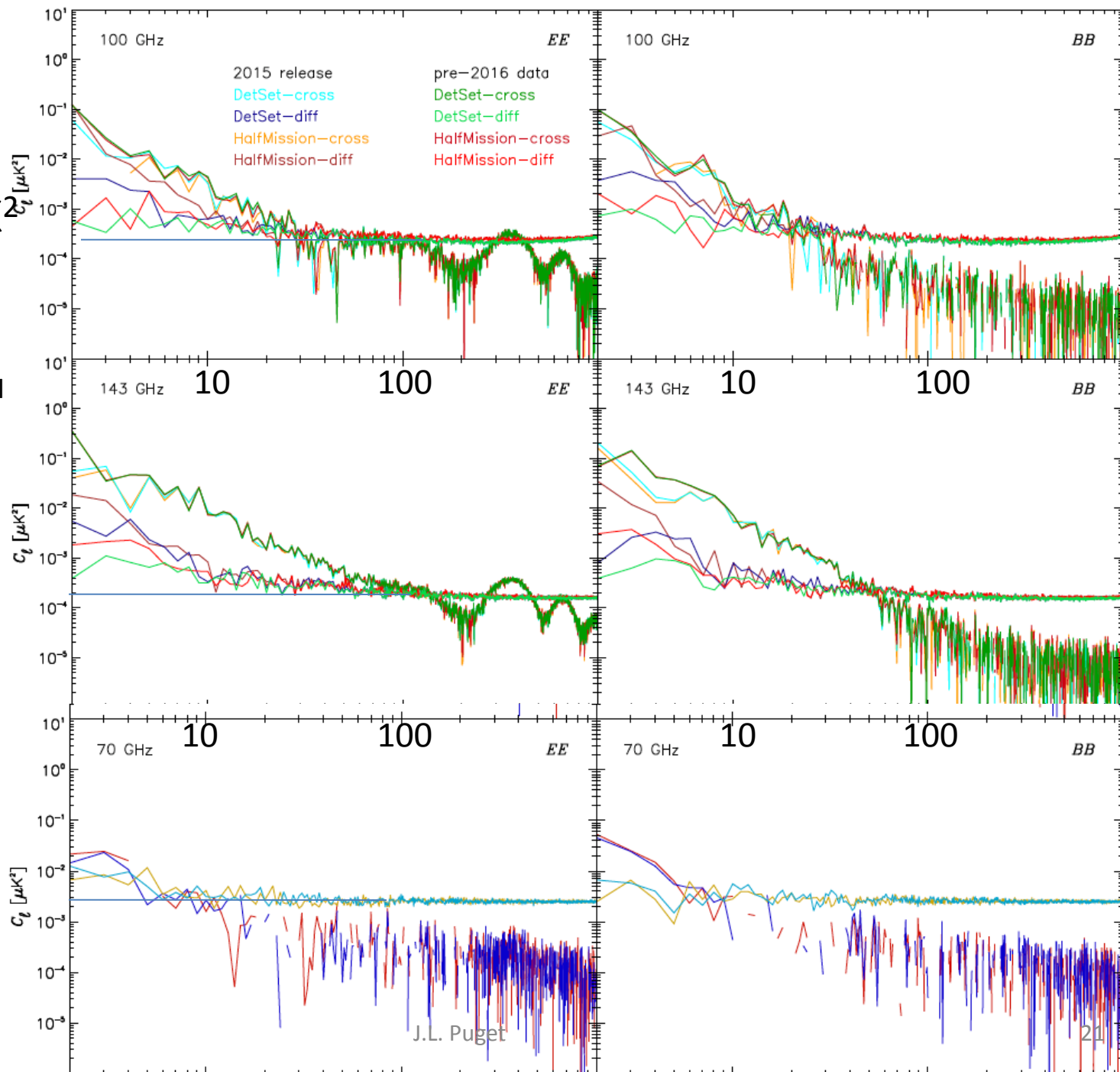
and Null tests →

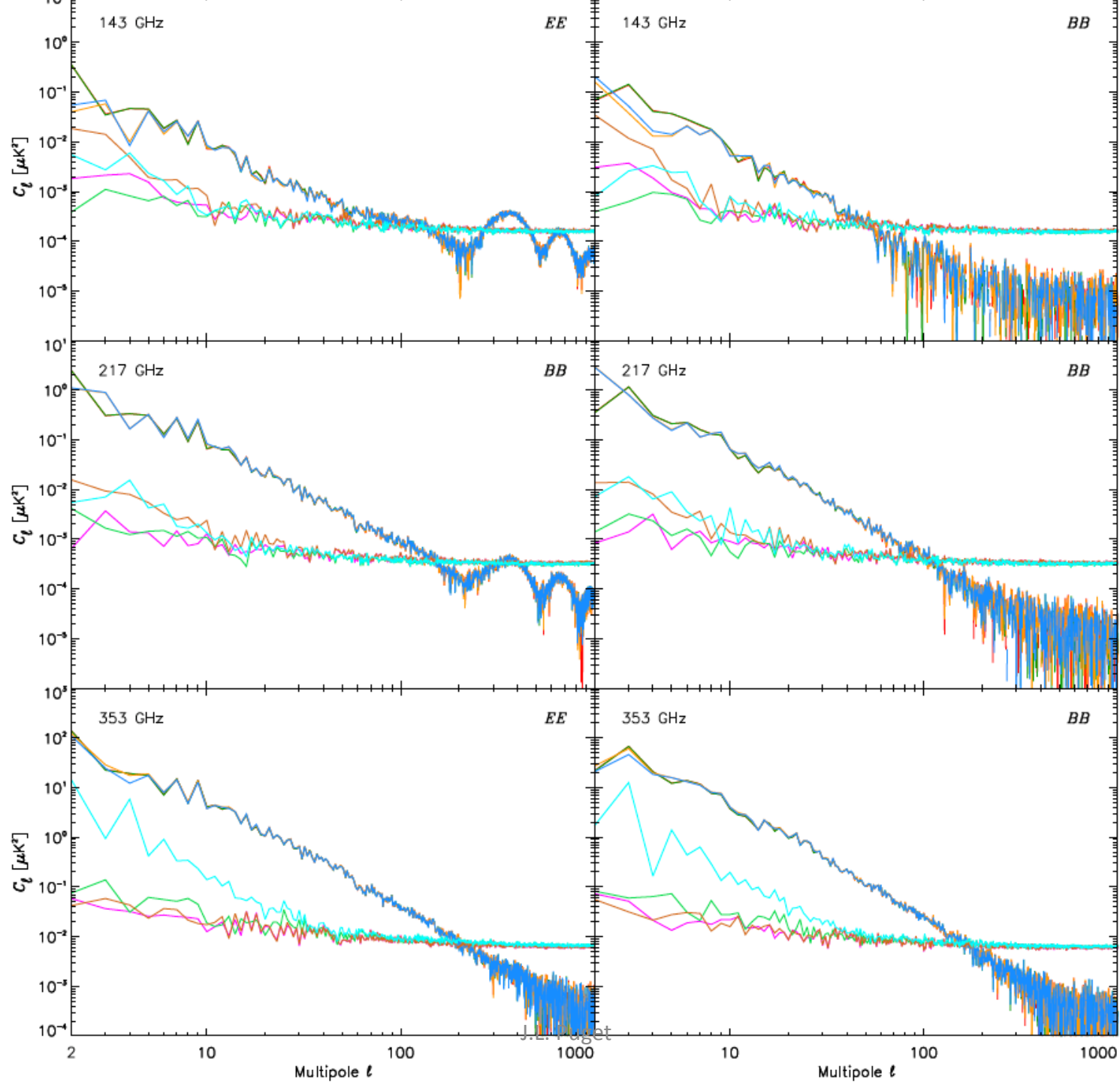
noise at high ℓ

systematics at low ℓ

$2 \cdot 10^{-4}$

$2 \cdot 10^{-3}$





Dust removal

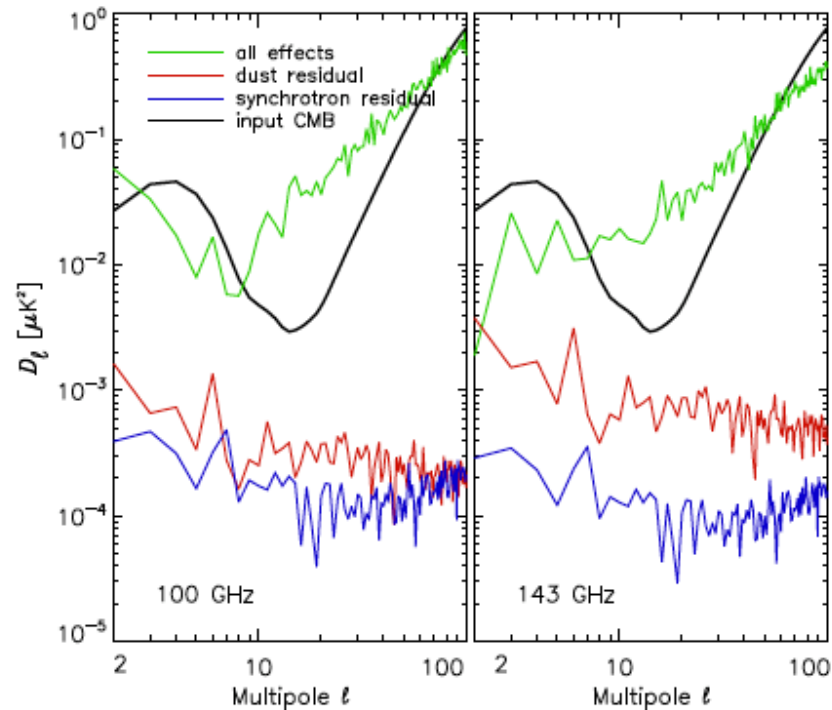
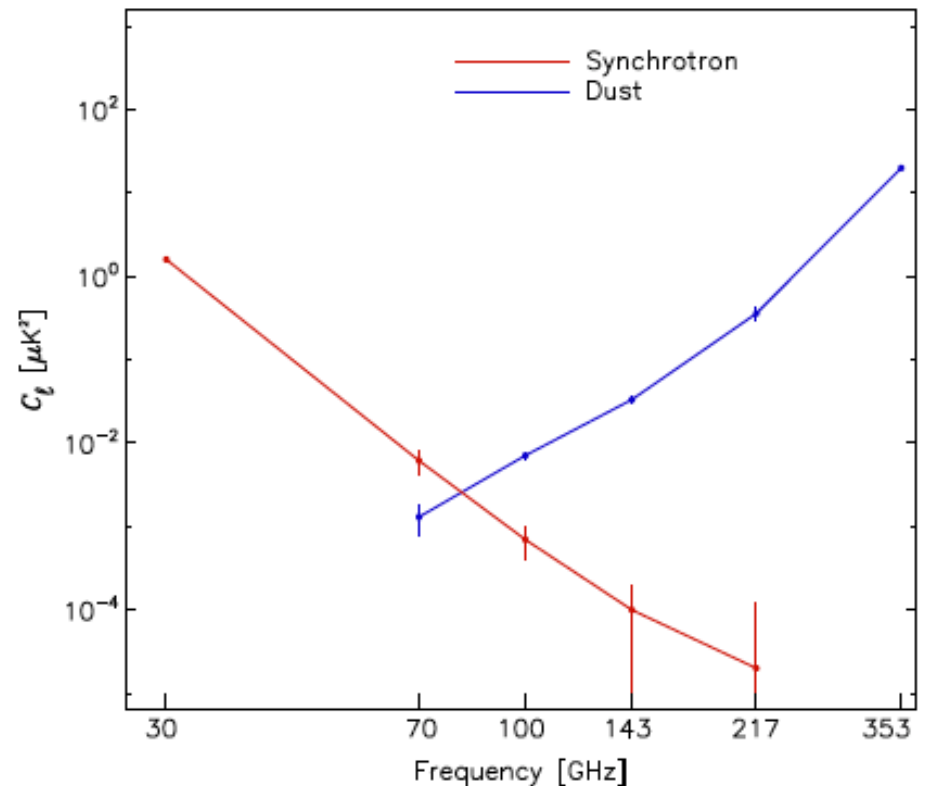
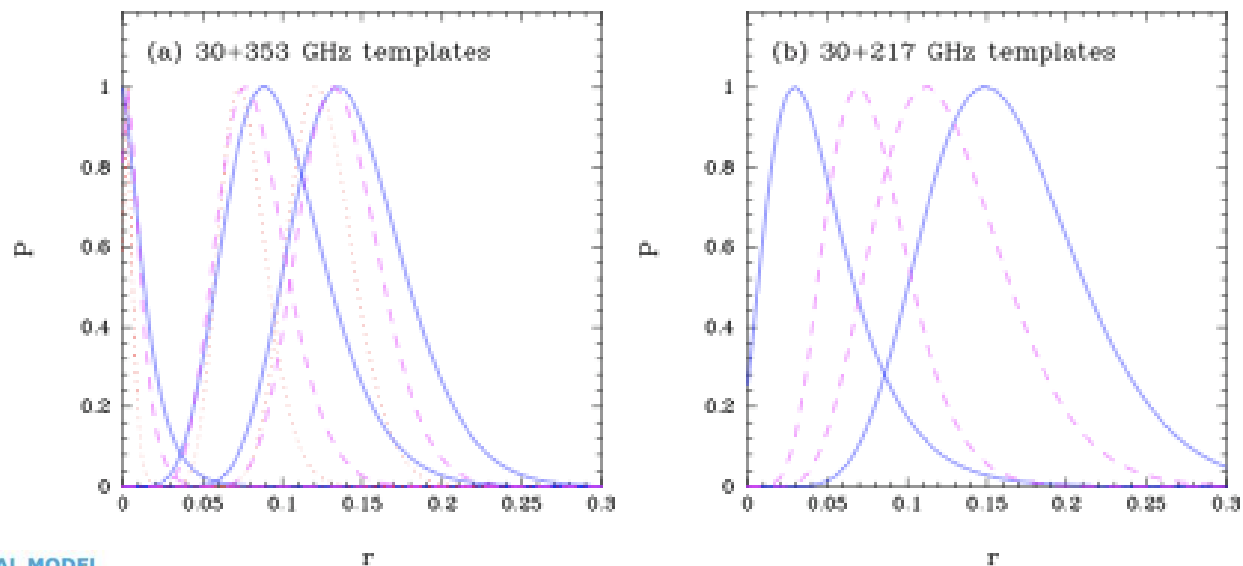


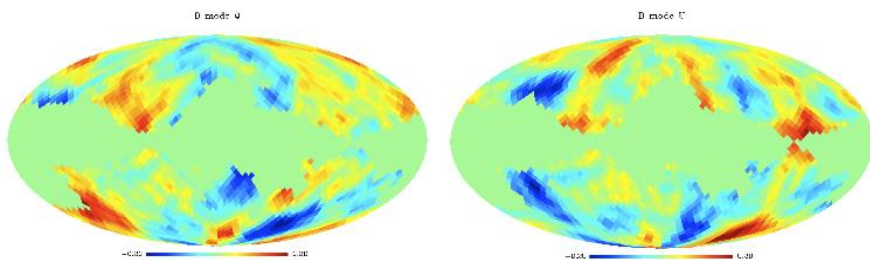
Fig. 29. EE residual errors in power spectrum from component separation. It is estimated taking the scatter of the component separation coefficients. The EE fiducial spectrum and the noise plus systematics residuals (green line) are also shown.



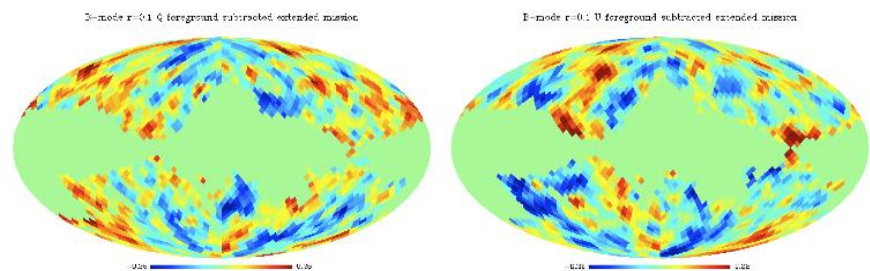
Planck B modes detection simulation (Efsthathiou Gratton 2009)



GRAVITATIONAL WAVES THEORETICAL MODEL



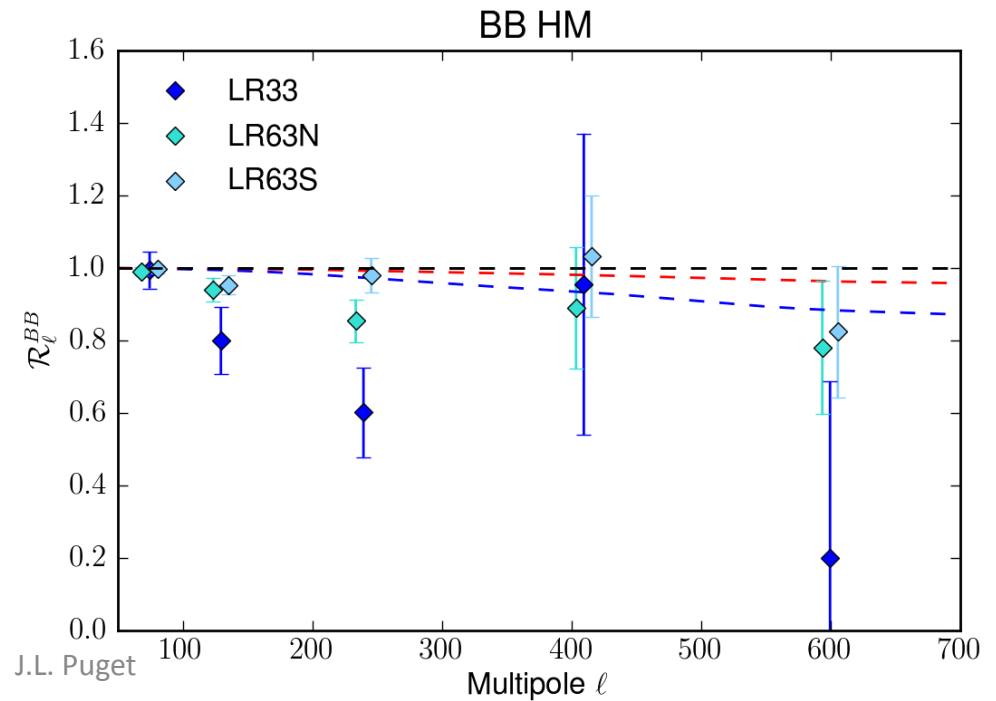
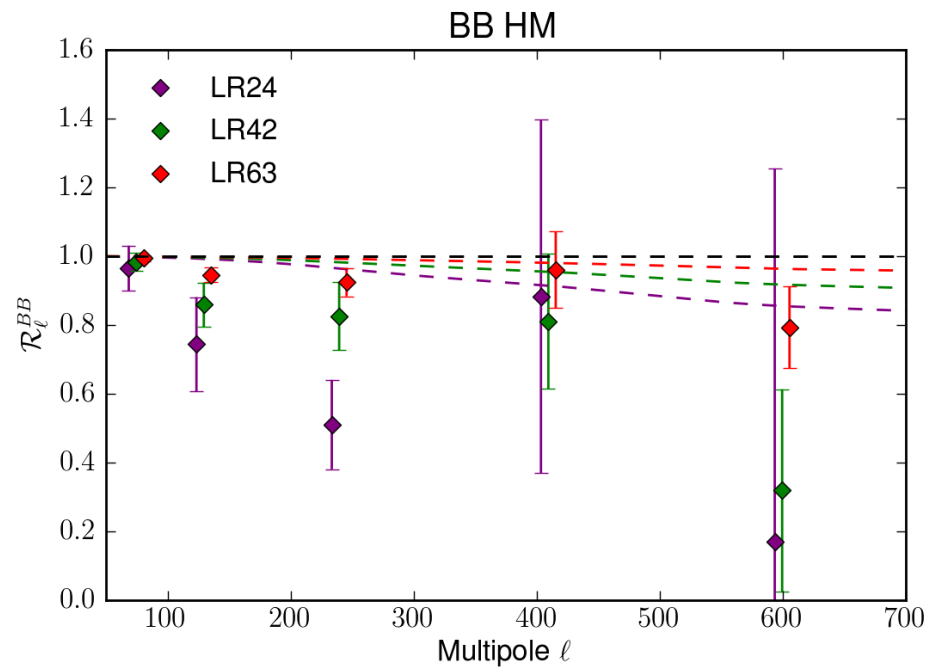
GRAVITATIONAL WAVES NOMINAL MISSION: 4 SKY SURVEYS



- Planck can detect tensor to scalar ratio down to 0.05 if detector noise limited

Dust 353-217 GHz decorrelation

$$\mathcal{R}_\ell^{XX} \equiv \frac{C_\ell^{XX}(353 \times 217)}{\sqrt{C_\ell^{XX}(353 \times 353) \cdot C_\ell^{XX}(217 \times 217)}},$$



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.