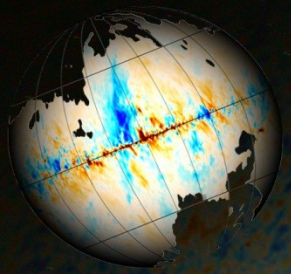
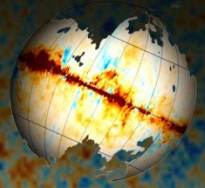
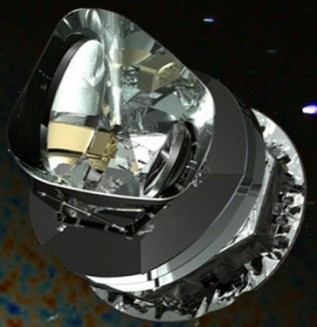
PLANCK 2014

THE MICROWAVE SKY IN TEMPERATURE AND POLARIZATION







Understanding the uncertanties in the Planck data

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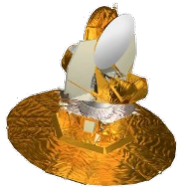
Università degli Studi di Milano

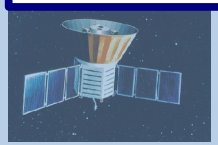
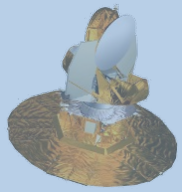
on behalf of the Planck Collaboration

Understanding systematic effects is key

	Angular resolution	Sensitivity (90 GHz) (0.5 deg pixel)	Component separation
	7°	420 μK	31.5–90 GHz 3 channels
	0.22°	16 μK	22–90 GHz 5 channels
	0.08°	1 μK	30–857 GHz 9 channels

Understanding systematic effects is key

With extraordinary sensitivity systematic error control is a major challenge

		Sensitivity (90 GHz) (0.5 deg pixel)	Component separation
	7°	420 μK	31.5–90 GHz 3 channels
	0.22°	16 μK	22–90 GHz 5 channels
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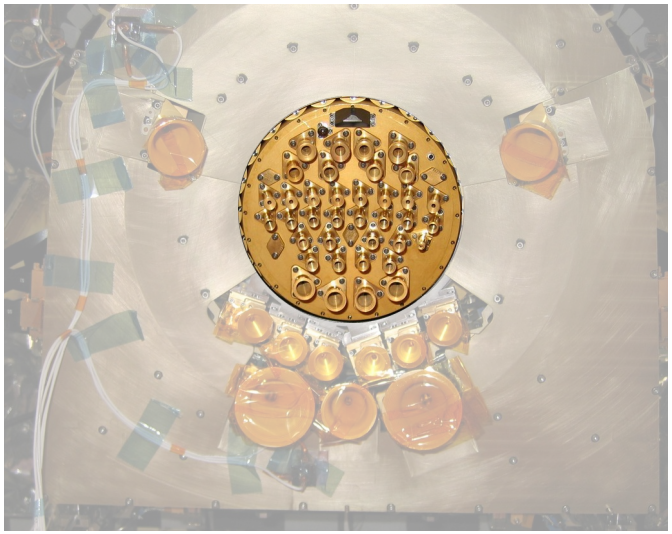
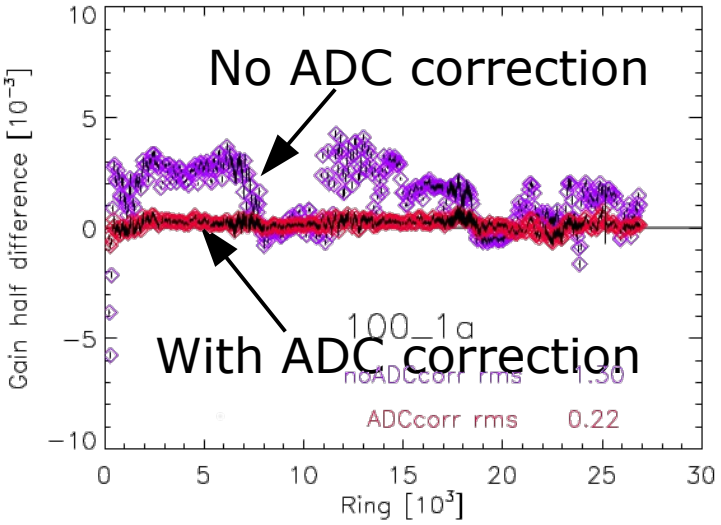
Know your instrument

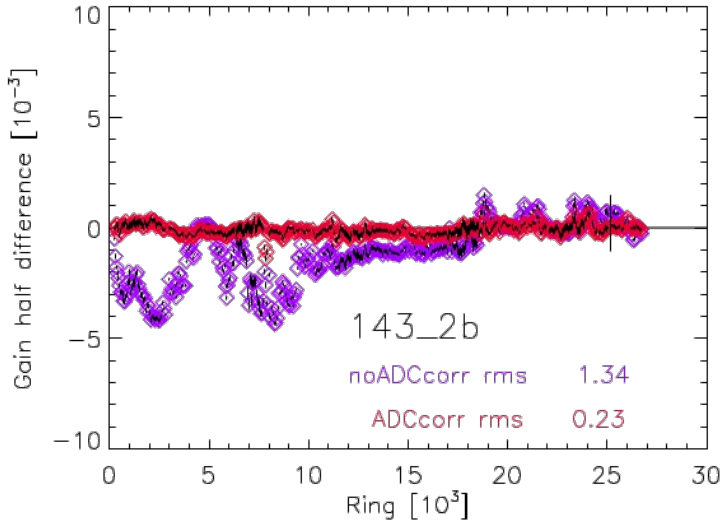
HFI known systematic effects, corrected in data processing

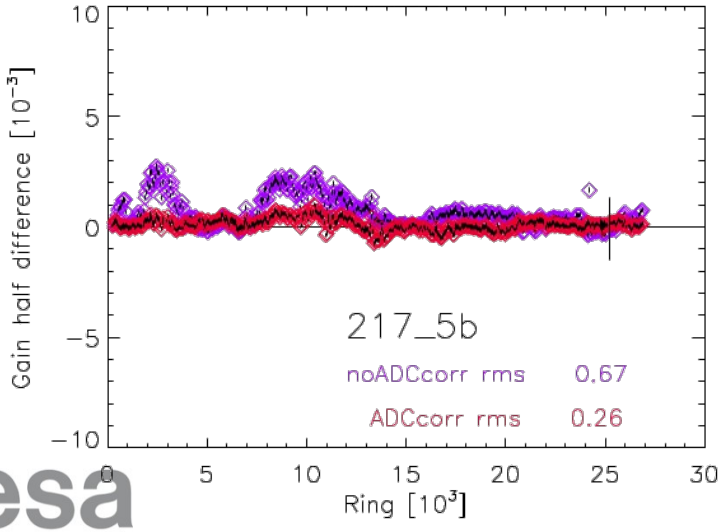


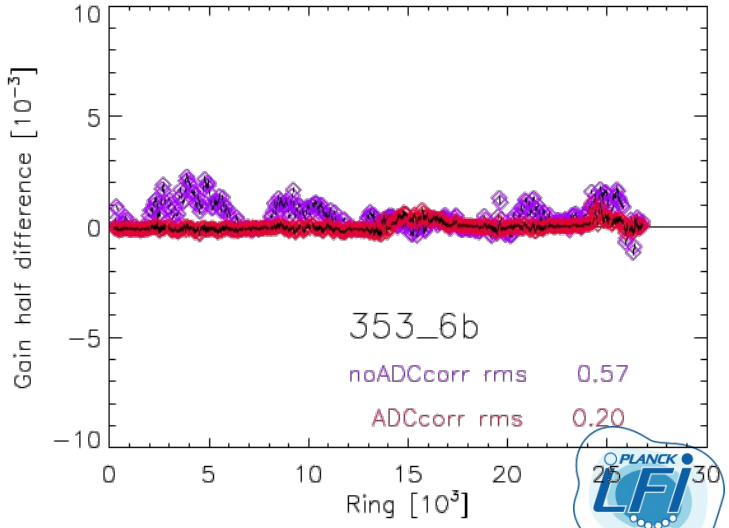
- ADC non linearity
- 4K electronics inducing lines at specific frequencies in the time data (EMI-EMC effects)
- Cosmic ray glitches removal improved by the better understanding of the long time constants
- Near and far side lobes effects
- Long time constant shifting dipoles and affecting the orbital dipole calibration
- Better beam measurements

HFI – ADC correction



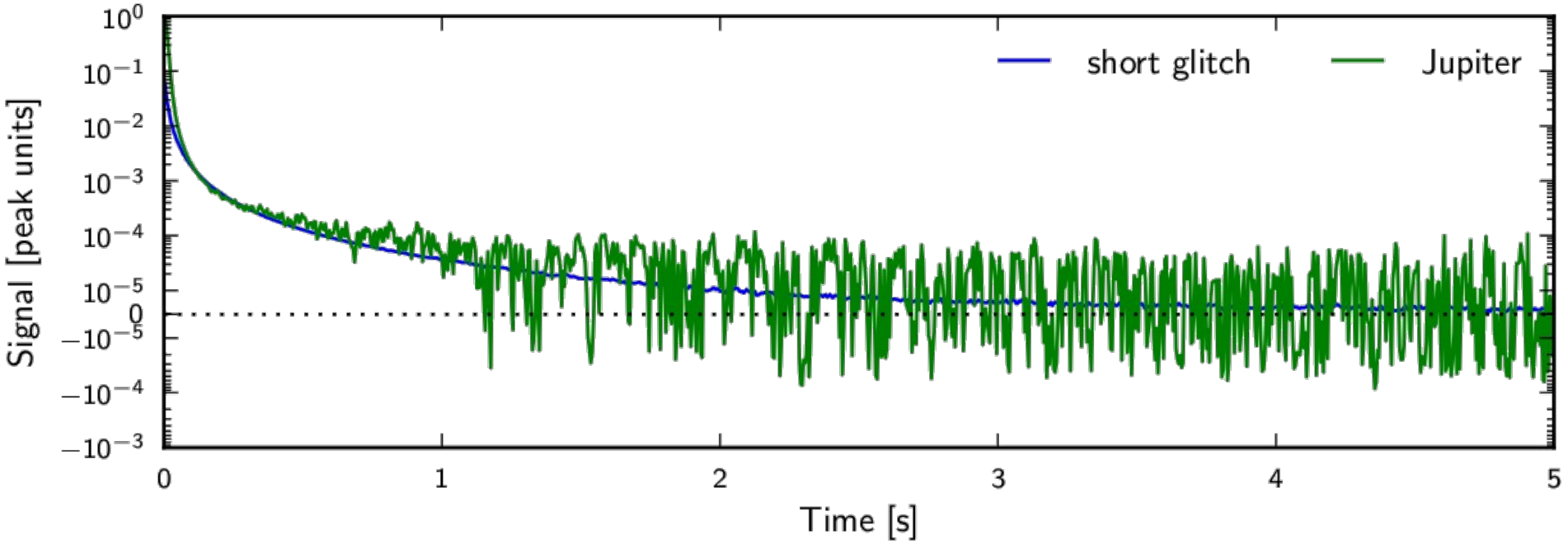






HFI – Time constant characterization

- Short glitches effective to characterize bolometer time constants to a level better than 10^{-4}
- Glitch removal improved from much better knowledge of bolometer time constants

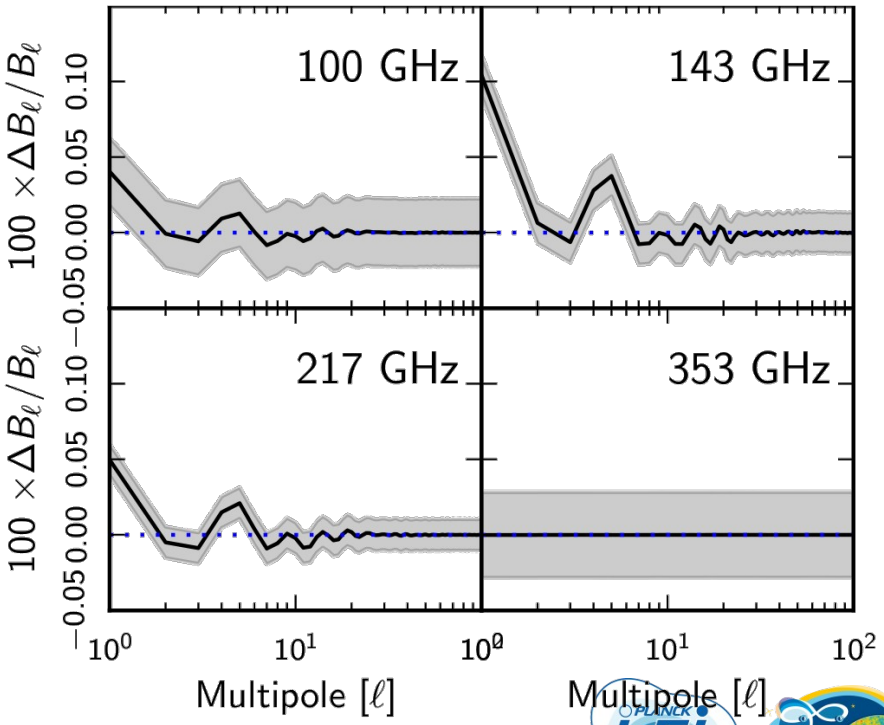


HFI – near and far sidelobes effect

- Main beam reconstruction extended from 40' to 100' to account for fraction of near sidelobes
- Far sidelobes simulated with GRASP and effect on window function estimated

Band [GHz]	Ω_{SB} [arcmin^2]	$\Delta\Omega_{MC}$
100	104.62	0.13 %
143	58.80	0.07 %
217	26.92	0.13 %
353	25.93	0.09 %
545	25.23	0.08 %
857	23.04	0.08 %

- Uncertainties larger than correction except at large angular scale.
- Therefore sidelobes accounted for only in calibration at large scales



LFI – Know your instrument

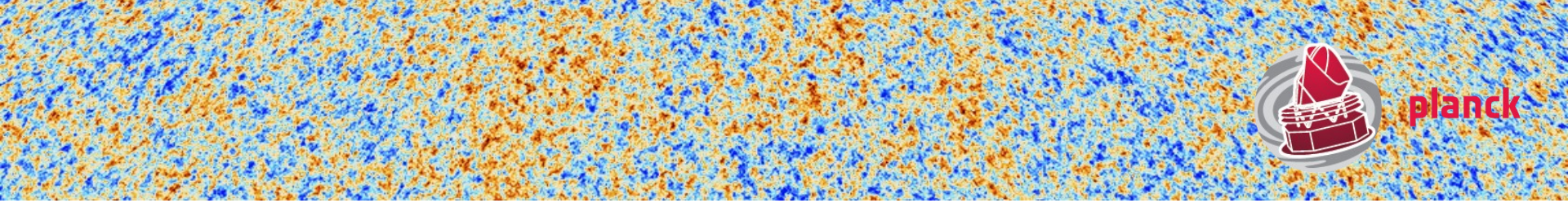
LFI known systematic effects

Assessment not completed yet

Effect	Source	Control/Removal
	Effects independent of sky signal (T and P)	
White noise correlation	Phase switch imbalance	Diode weighting
$1/f$ noise	RF amplifiers	Pseudo-correlation and destriping
Bias fluctuations	RF amplifiers, back-end electronics	Pseudo-correlation and destriping
Thermal fluctuations	4 K, 20 K and 300 K thermal stages	Calibration, destriping
1 Hz spikes	Back-end electronics	Template fitting and removal
	Effects dependent on the sky signal (T and P)	
Main beam ellipticity	Main beams	Accounted for in window function
Intermediate sidelobes pickup	Optical response at angles $< 5°$ from the main beam	Masking of Galaxy and point sources
Far sidelobes pickup	Main and sub-reflector spillovers	Model sidelobes removed from timelines
Analogue-to-digital converter non linearity	Back-end analogue-to-digital converter	Template fitting and removal
Imperfect photometric calibration	Sidelobe pickup, radiometer noise temperature changes and other non-idealities	Calibration using the 4 K reference load voltage output
Pointing	Uncertainties in pointing reconstruction, thermal changes affecting focal plane geometry	Negligible impact anisotropy measurements
	Effects specifically impacting polarization	
Bandpass asymmetries	Differential orthomode transducer and receiver bandpass response	Spurious polarisation removal
Polarization angle uncertainty	Uncertainty in the polarization angle in-flight measurement	Negligible impact
Orthomode transducer cross-polarization	Imperfect polarization separation	Negligible impact

LFI – approach to assess systematic effect uncertainties)

1. **Bottom-up approach**
    a. Simulate datastreams of systematic effects
    b. Produce maps and power spectra of spurious signal
    c. Assess systematic effects amplitudes on maps and power spectra
    d. Compare with expected signals in temperature and polarization
2. **Top-down approach**
    a. Build null maps at various time scales
    b. Calculate pseudo-spectra and compare with noise spectra from simulations
    c. Assess residuals over expected noise level



MAPS

Assessment of LFI uncertainties via simulations – maps

Calculated on FWHM resolution element

r.m.s. of systematic effect residual on maps (30 GHz)

	I	Q	U
	values in μK		
ADC non linearity	0.143	0.177	0.171
Bias fluctuations	0.012	0.014	0.014
Intermediate sidelobes	0.088	0.014	0.014
Pointing uncertainty	0.088	0.009	0.006
Polarization angle uncert.	0.003	0.167	0.159
1-Hz spikes	0.105	0.023	0.019
4K stage temperature fluct.	0.053	0.013	0.013
300 K stage temperature fluct.	0.001	$< 10^{-3}$	$< 10^{-3}$
20 K stage temperature fluct.	0.025	0.017	0.017
Sum of all effects	**0.226**	**0.252**	**0.234**

Assessment of LFI uncertainties via simulations – maps

Calculated on FWHM resolution element

r.m.s. of systematic effect residual on maps (44 GHz)

	I	Q	U
	values in μK		
ADC non linearity	0.084	0.105	0.103
Bias fluctuations	0.006	0.010	0.009
Intermediate sidelobes	0.016	0.001	0.001
Pointing uncertainty	0.062	0.003	0.002
Polarization angle uncert.	0.007	0.104	0.095
1-Hz spikes	0.383	0.189	0.213
4K stage temperature fluct.	0.044	0.012	0.011
300 K stage temperature fluct.	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
20 K stage temperature fluct.	0.015	0.013	0.010
Sum of all effects	**0.400**	**0.242**	**0.256**

Assessment of LFI uncertainties via simulations – maps

Calculated on FWHM resolution element

r.m.s. of systematic effect residual on maps (70 GHz)

	I	Q	U
	values in μK		
ADC non linearity	0.307	0.437	0.432
Bias fluctuations	0.129	0.180	0.180
Intermediate sidelobes	0.065	0.003	0.003
Pointing uncertainty	0.117	0.006	0.006
Polarization angle uncert.	0.003	0.018	0.019
1-Hz spikes	0.076	0.036	0.032
4K stage temperature fluct.	0.074	0.008	0.009
300 K stage temperature fluct.	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
20 K stage temperature fluct.	0.080	0.018	0.016
Sum of all effects	**0.383**	**0.474**	**0.471**

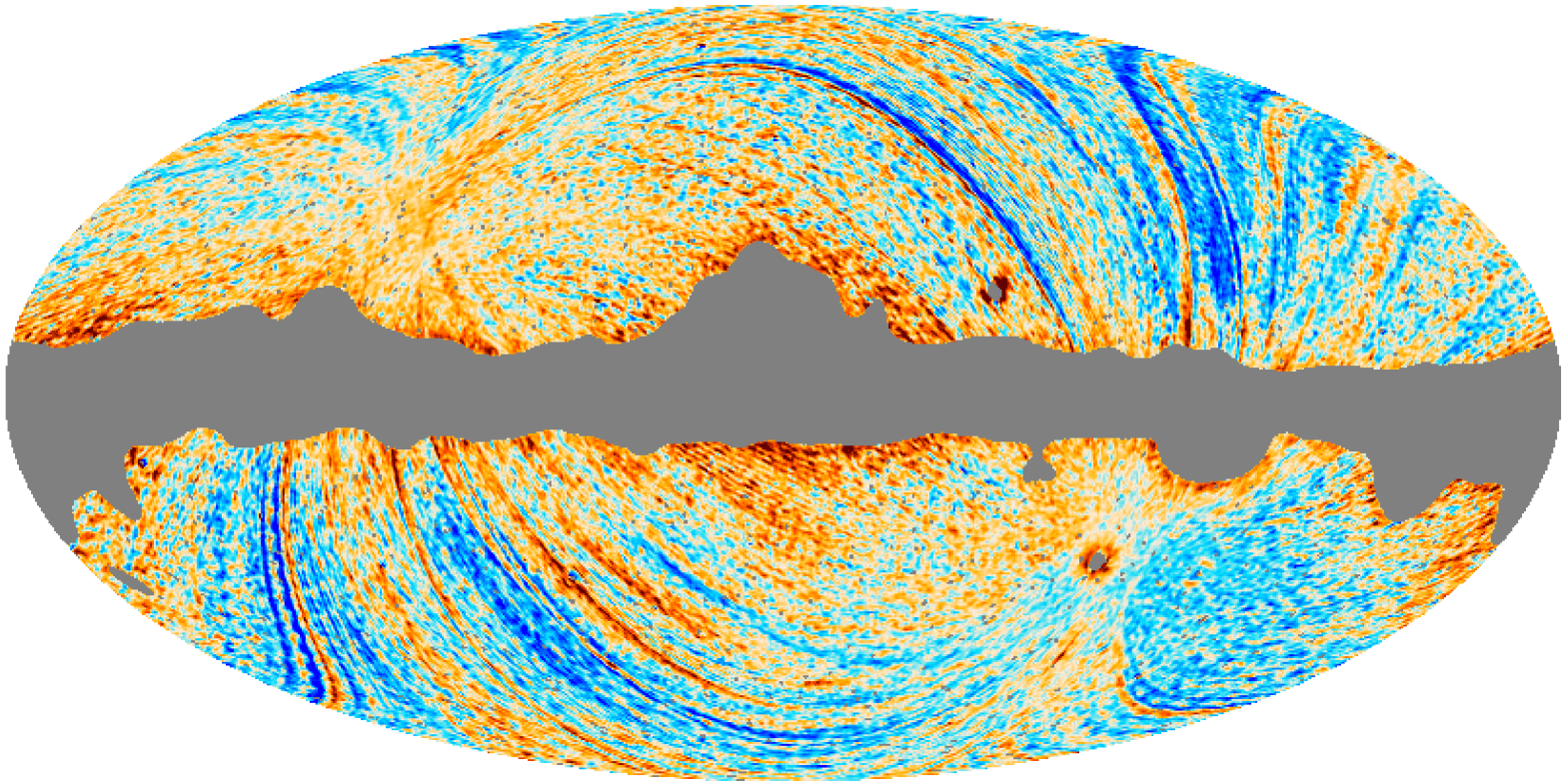
Assessment of LFI uncertainties – maps

Sum of systematic effects - 30 GHz

I

PRELIMINARY RESULTS

Smoothed to FWHM



$-0.5\,\mu$K $0.5\,\mu$K

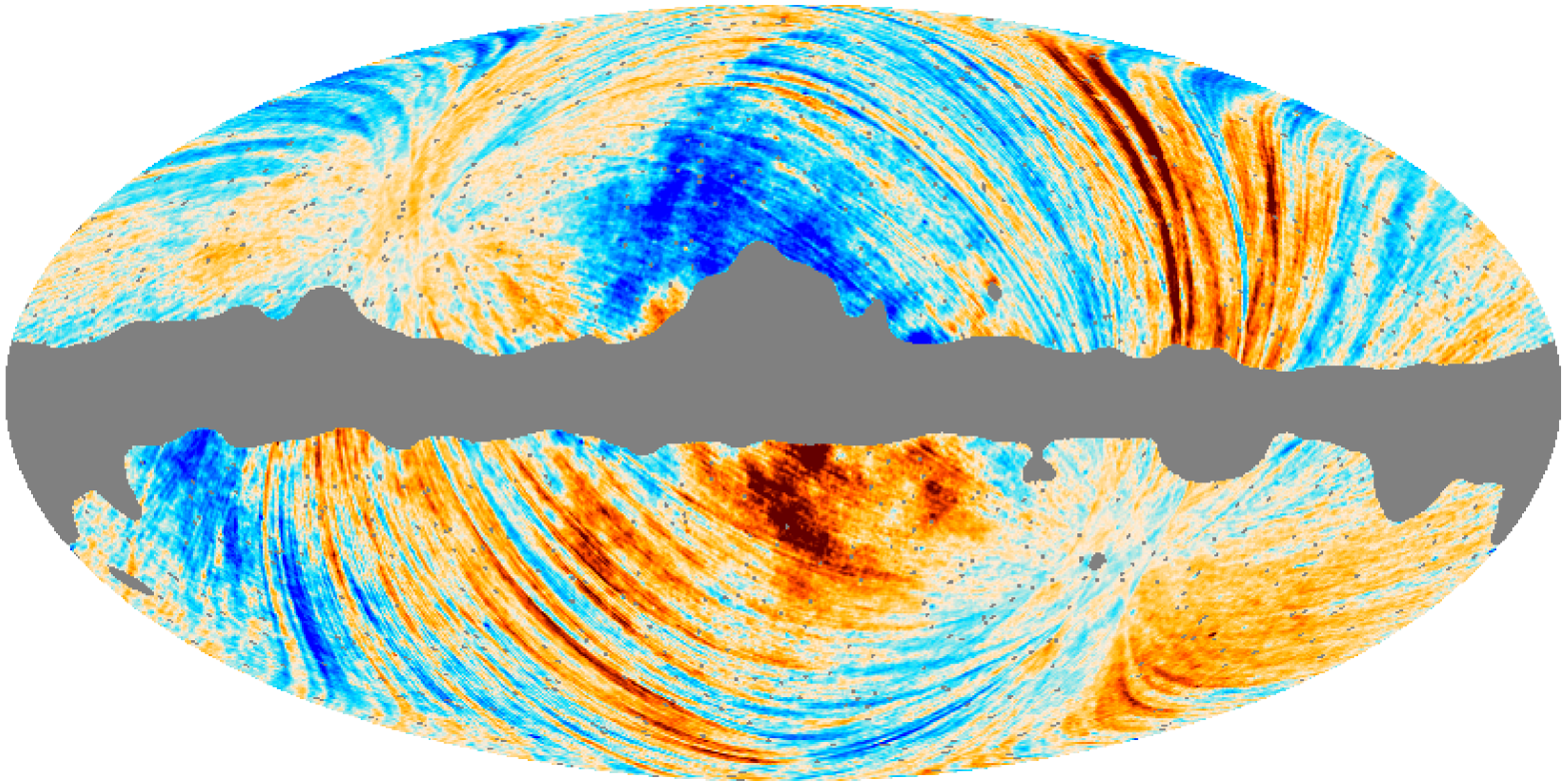
Assessment of LFI uncertainties – maps

Sum of systematic effects - 30 GHz

Q

PRELIMINARY RESULTS

Smoothed to FWHM



$-0.7\,\mu$K $0.7\,\mu$K

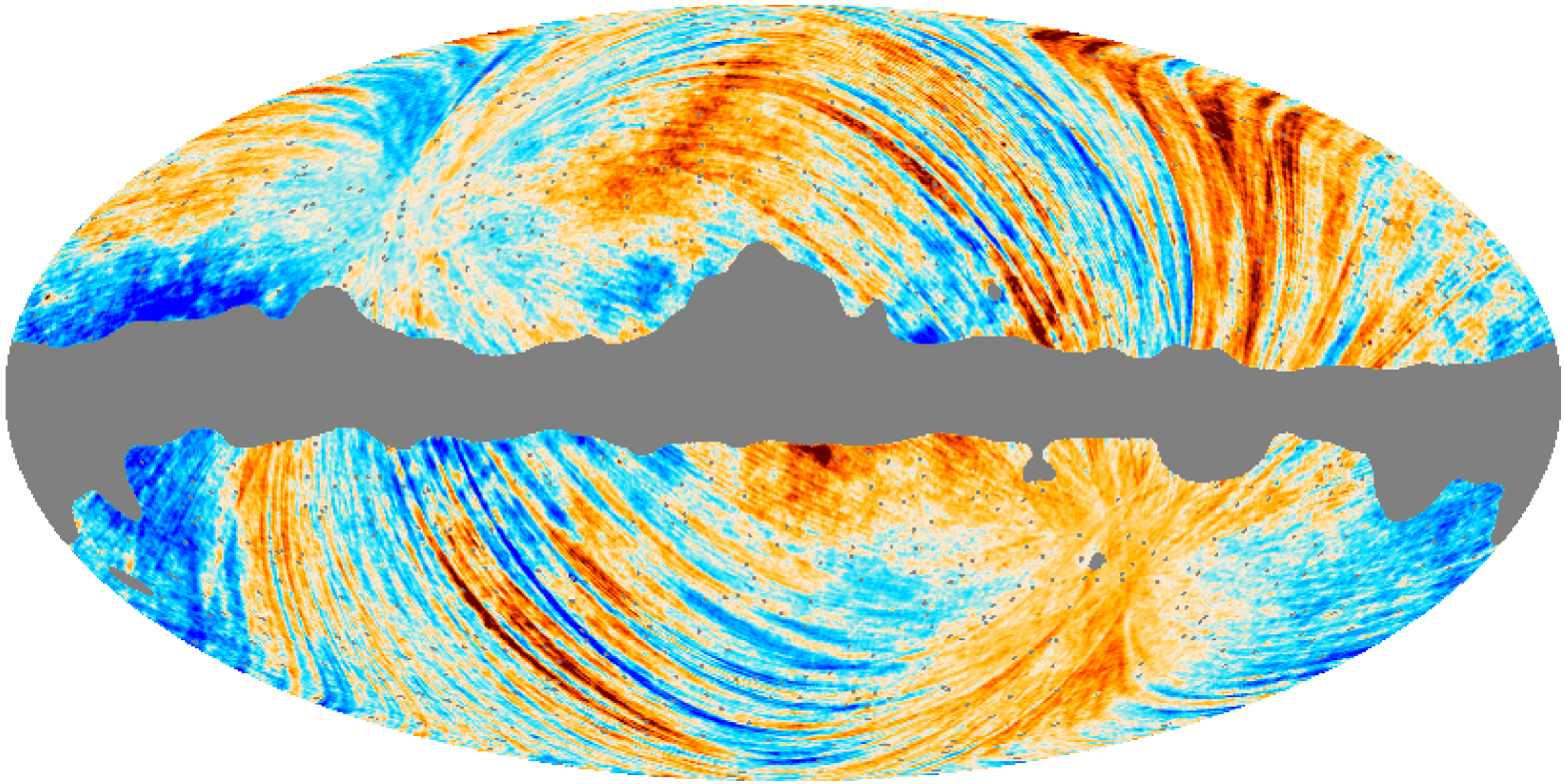
Assessment of LFI uncertainties – maps

Sum of systematic effects - 30 GHz

U

PRELIMINARY RESULTS

Smoothed to FWHM



$-0.6\,\mu\mathrm{K}$ $0.6\,\mu\mathrm{K}$

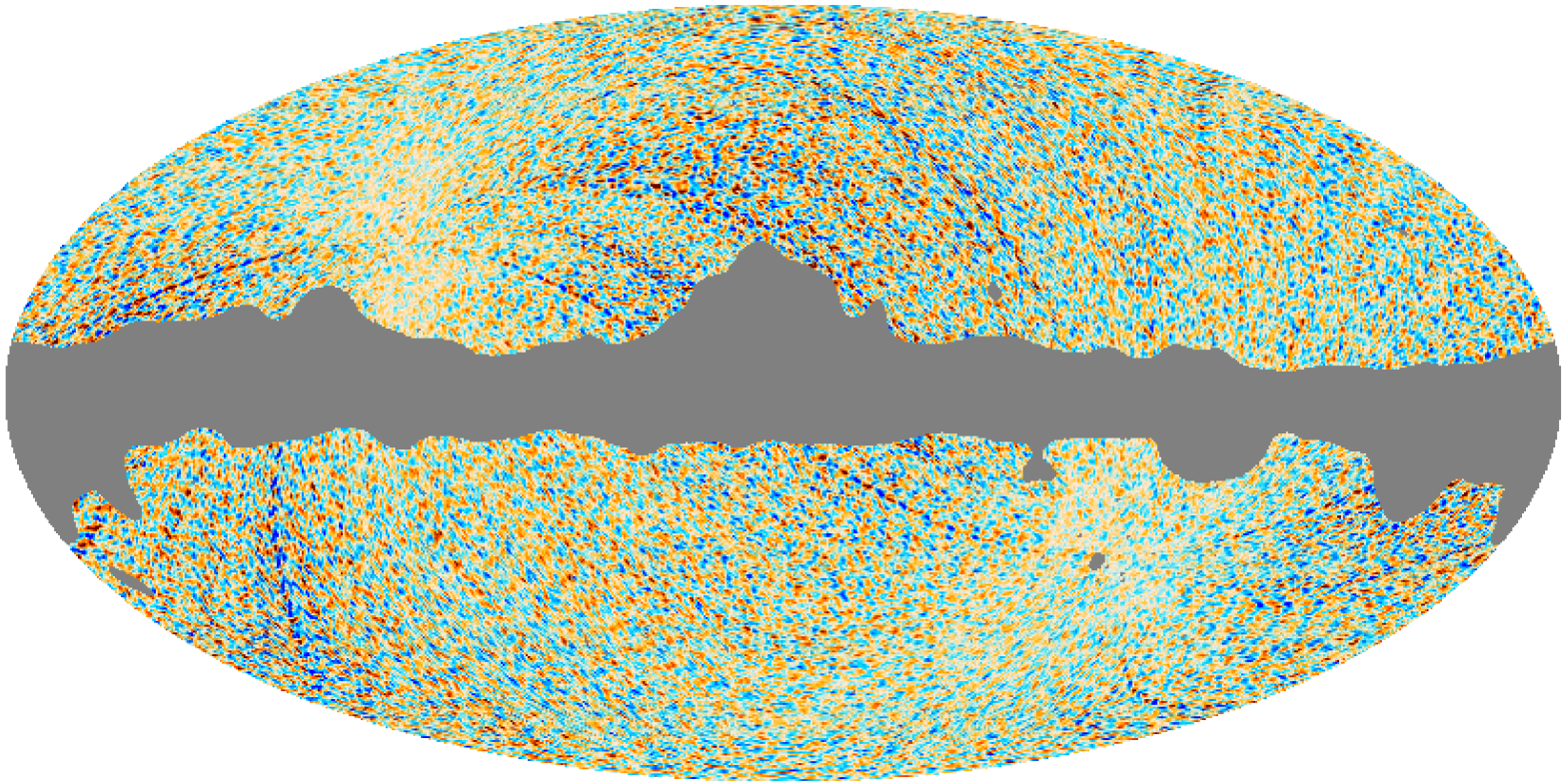
Assessment of LFI uncertainties – maps

Sum of systematic effects - 44 GHz

I

PRELIMINARY RESULTS

Smoothed to FWHM



$-0.9\,\mu$K — $0.9\,\mu$K

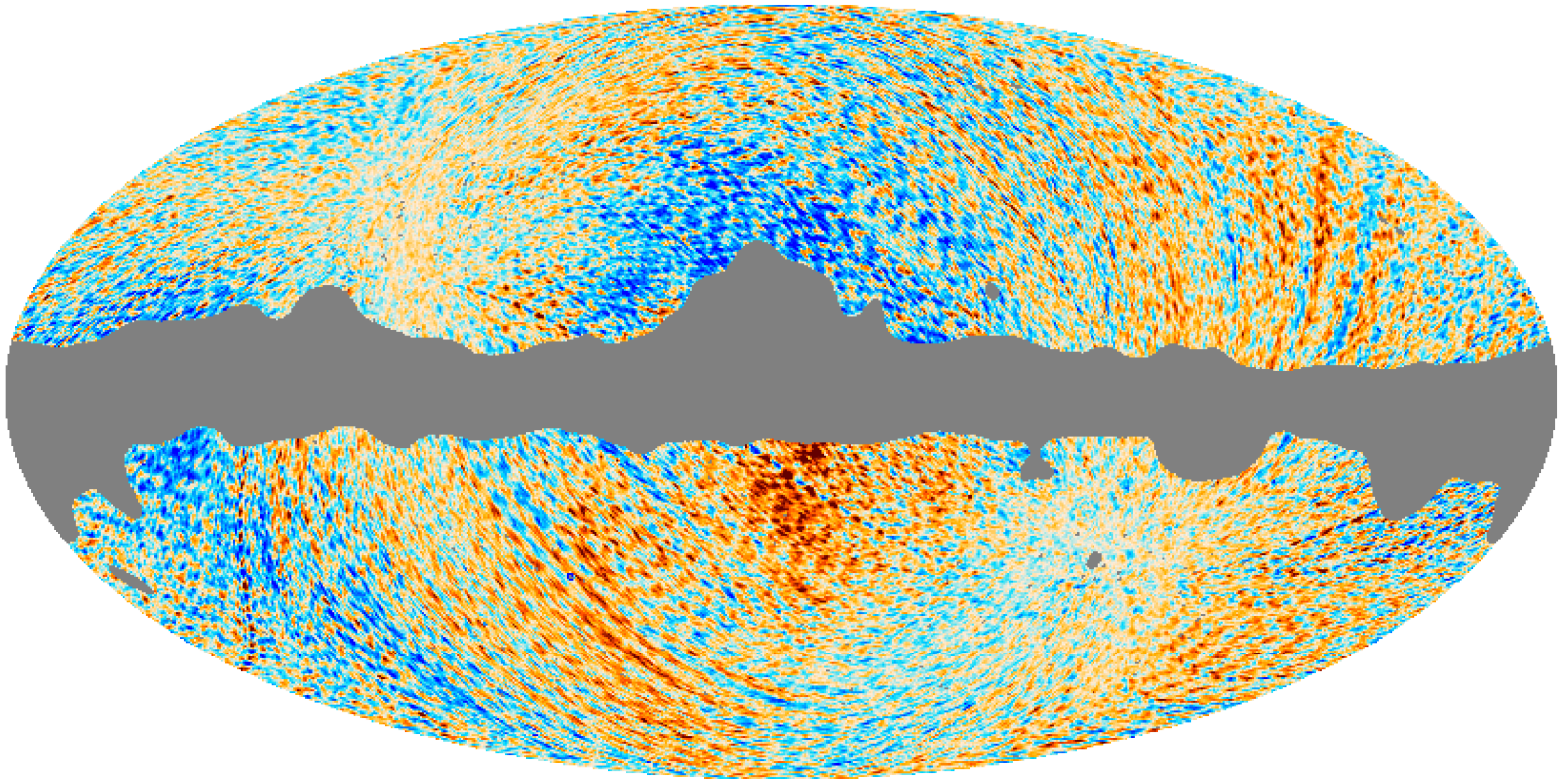
Assessment of LFI uncertainties – maps

Sum of systematic effects - 44 GHz

Q

PRELIMINARY RESULTS

Smoothed to FWHM



$-0.6\,\mu\mathrm{K}$ $0.6\,\mu\mathrm{K}$

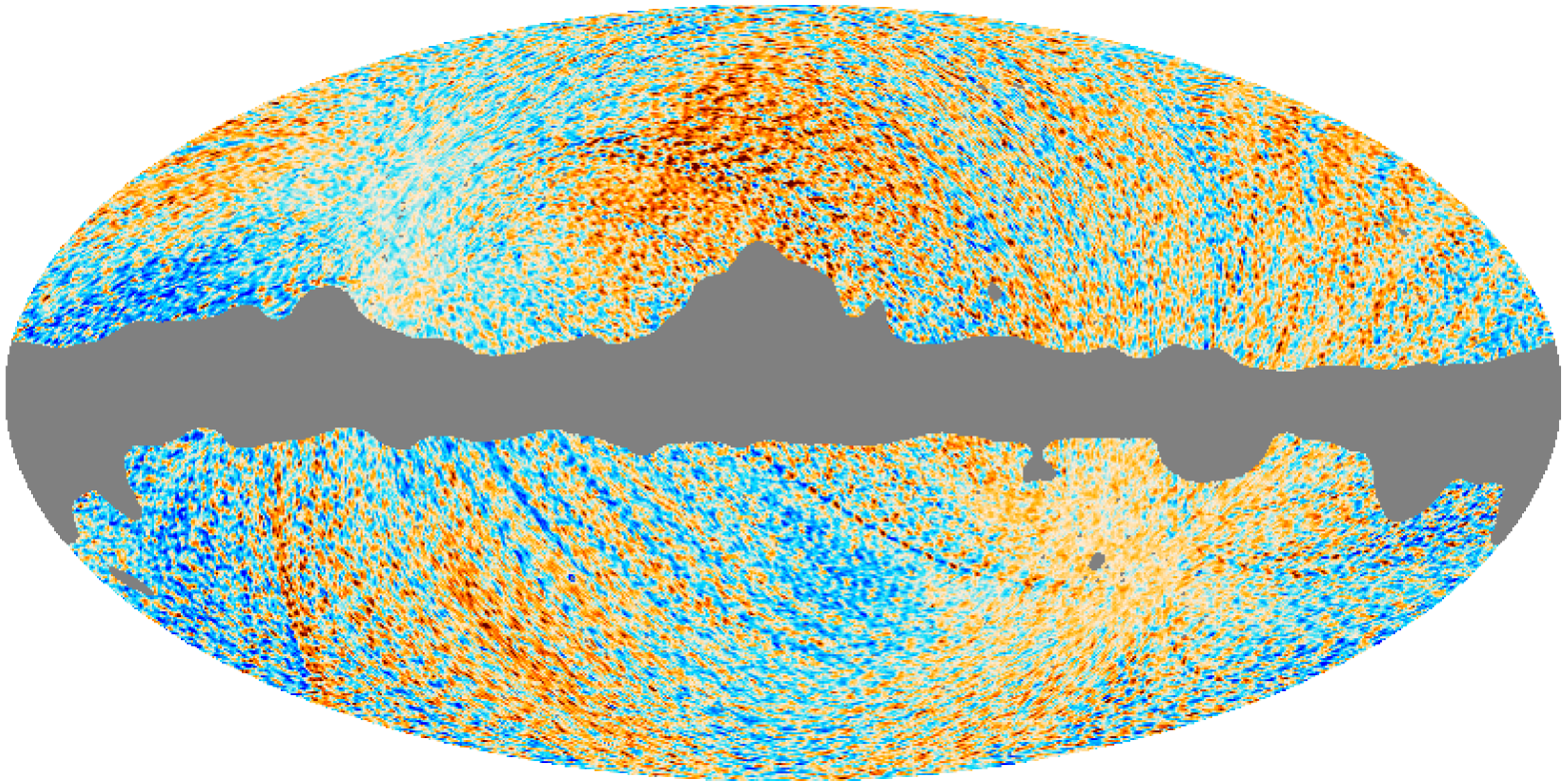
Assessment of LFI uncertainties – maps

Sum of systematic effects - 44 GHz

U

PRELIMINARY RESULTS

Smoothed to FWHM



$-0.6\,\mu\mathrm{K}$ $0.6\,\mu\mathrm{K}$

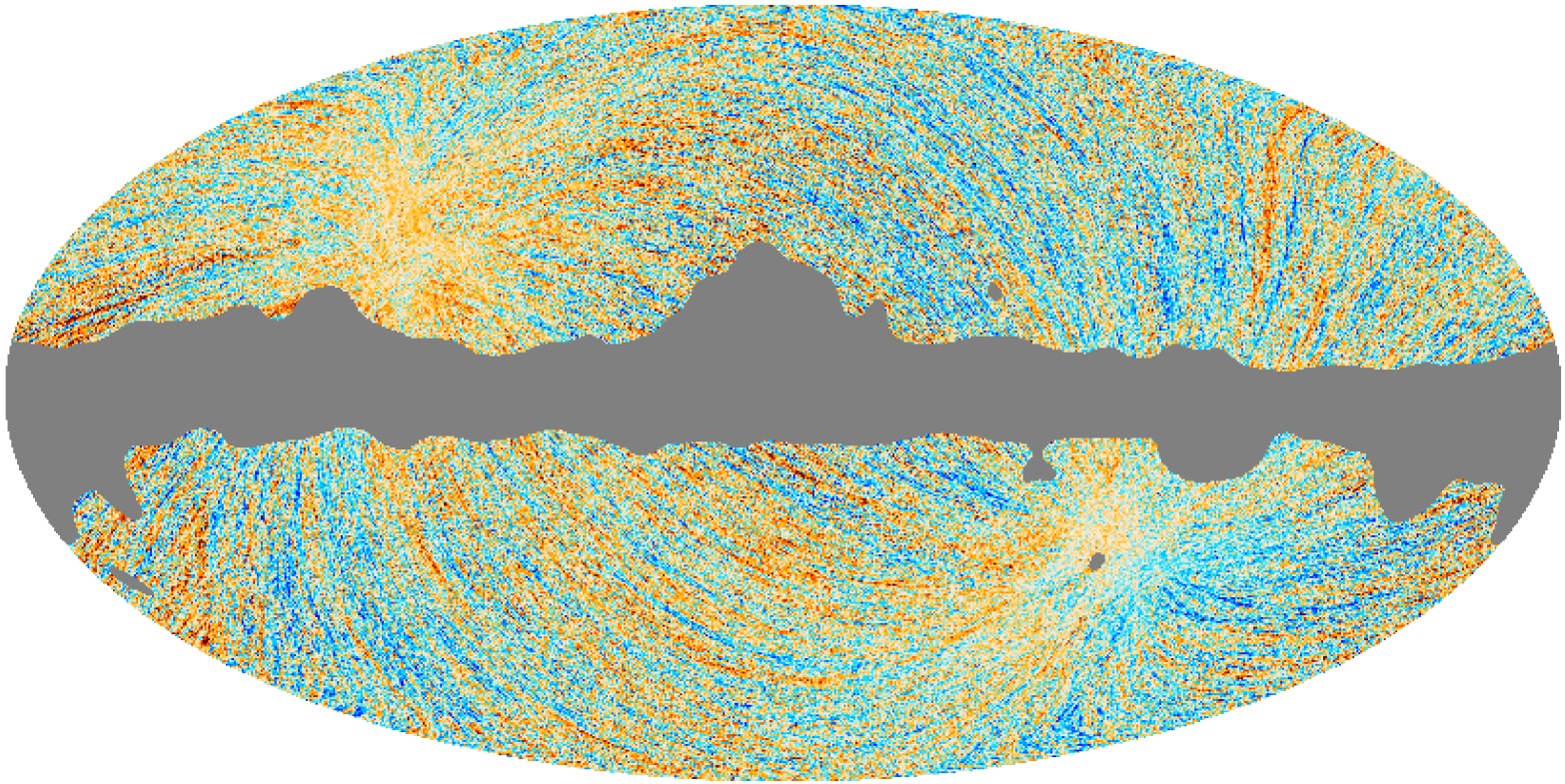
Assessment of LFI uncertainties – maps

Sum of systematic effects - 70 GHz

I

PRELIMINARY RESULTS

Smoothed to FWHM



$-0.9\,\mu$K $0.9\,\mu$K

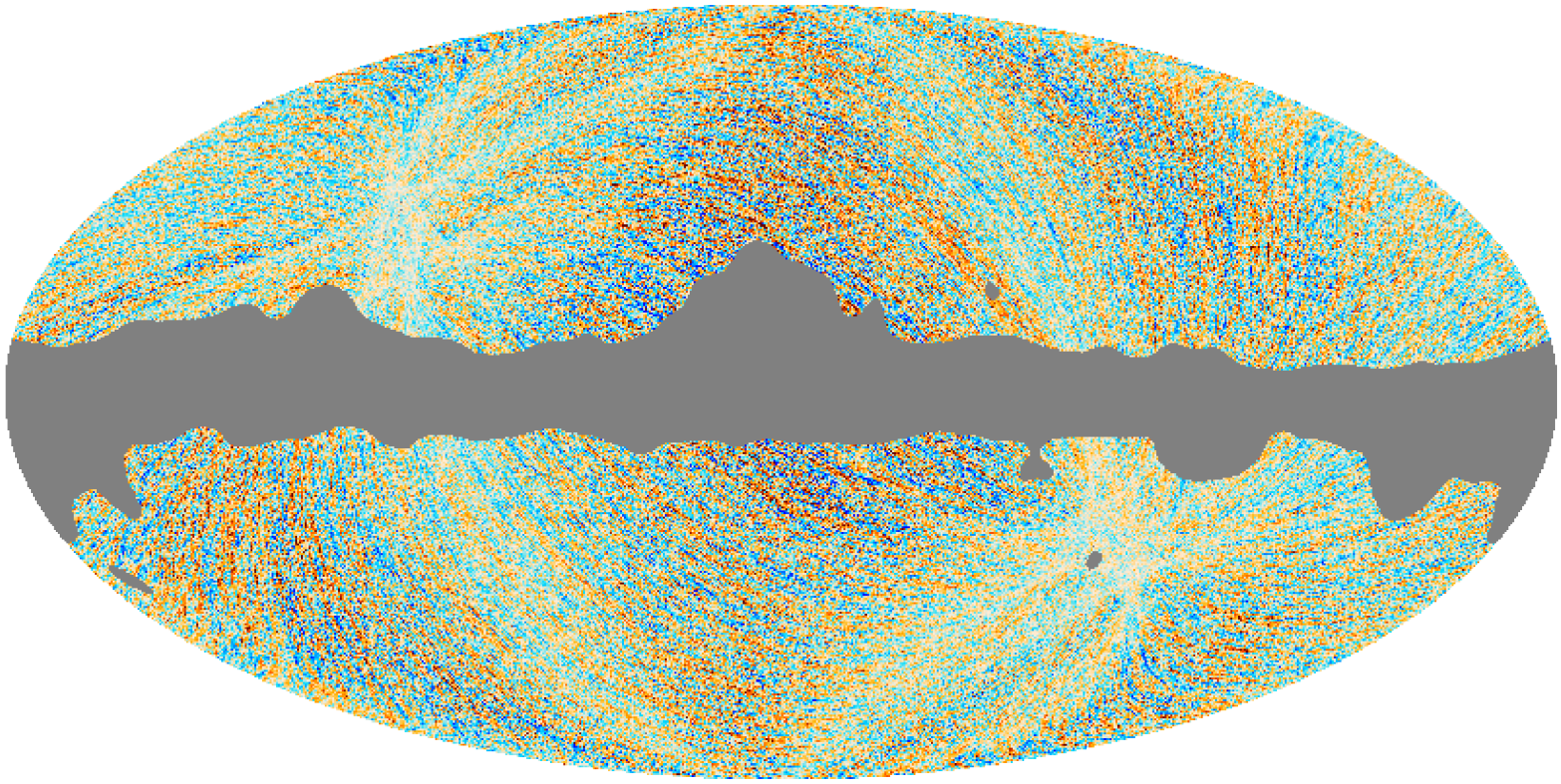
Assessment of LFI uncertainties – maps

Sum of systematic effects - 70 GHz

Q

PRELIMINARY RESULTS

Smoothed to FWHM



$-1.1\,\mu\mathrm{K}$ $1.1\,\mu\mathrm{K}$

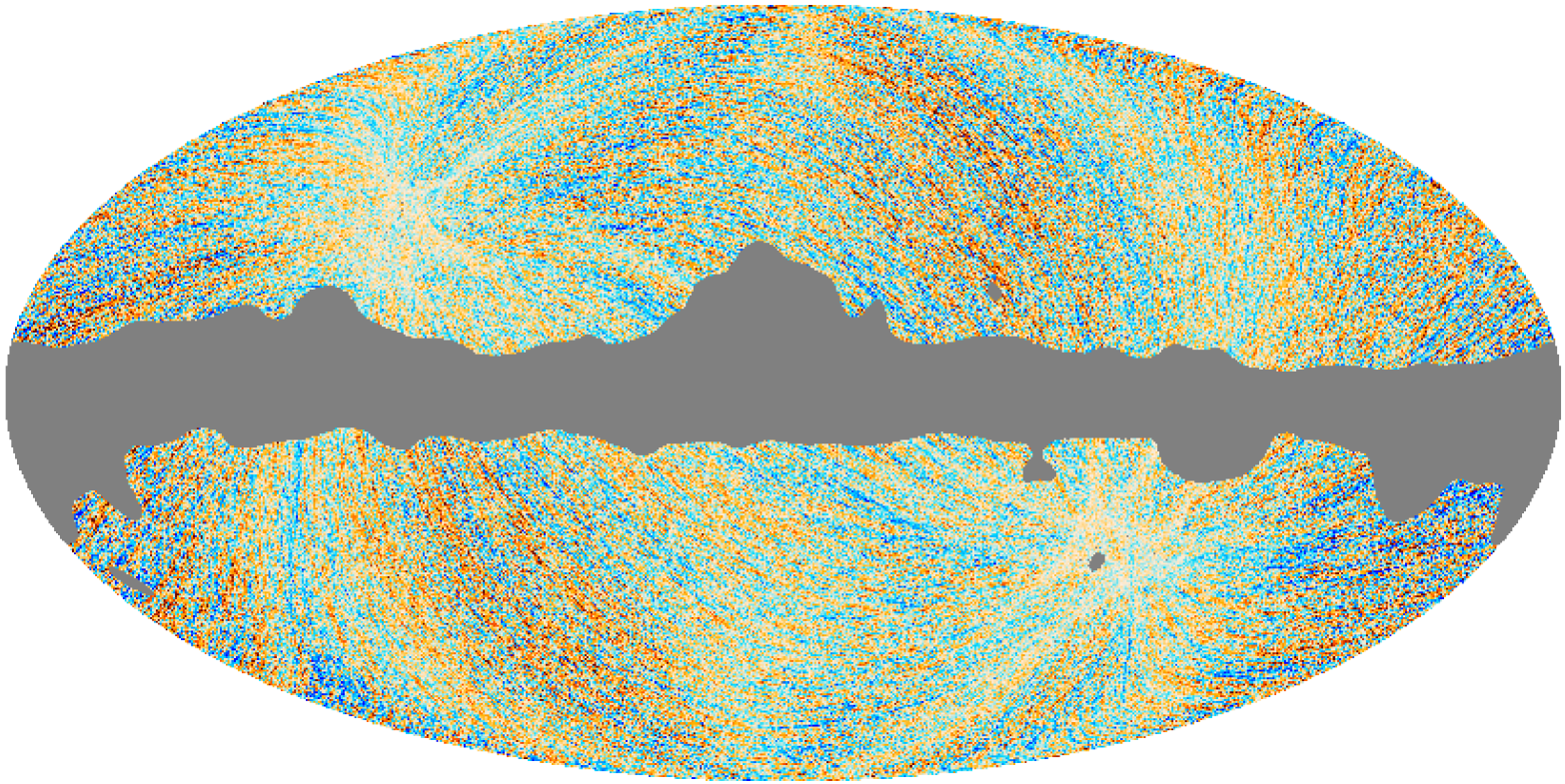
Assessment of LFI uncertainties – maps

Sum of systematic effects - 70 GHz

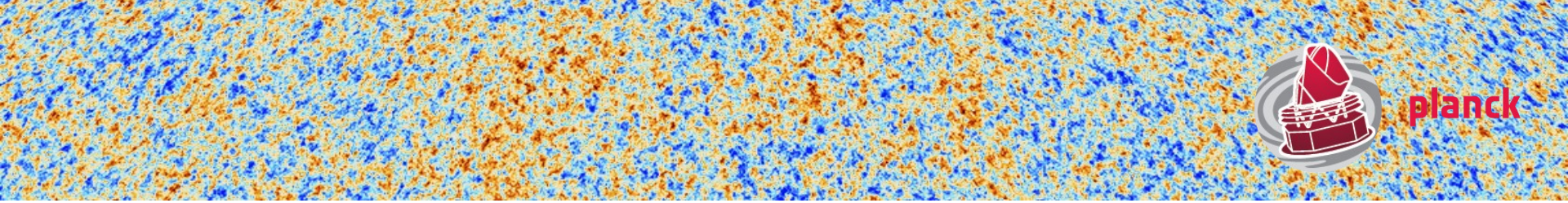
U

PRELIMINARY RESULTS

Smoothed to FWHM

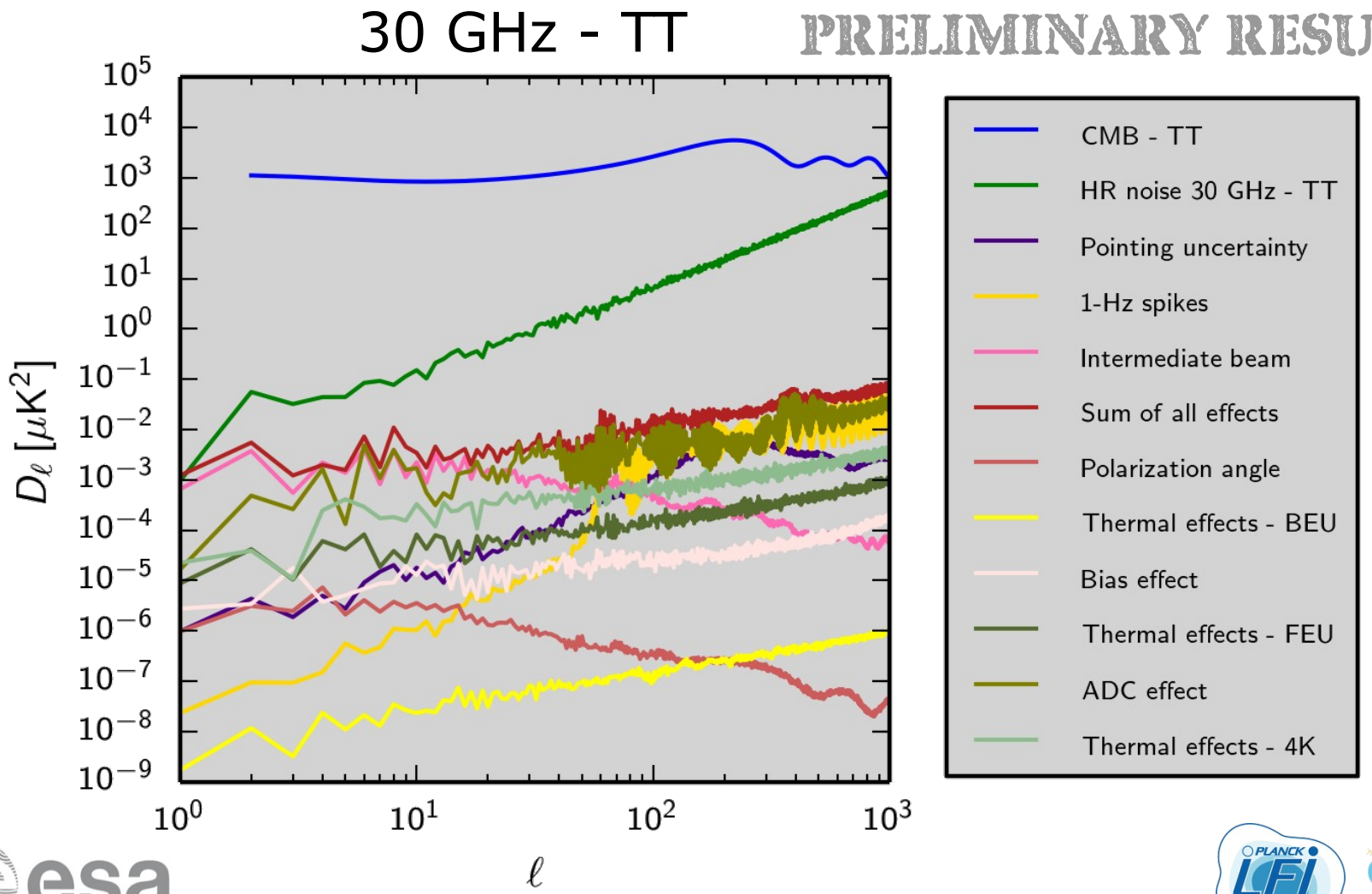


$-1.1\,\mu\mathrm{K}$ $1.1\,\mu\mathrm{K}$

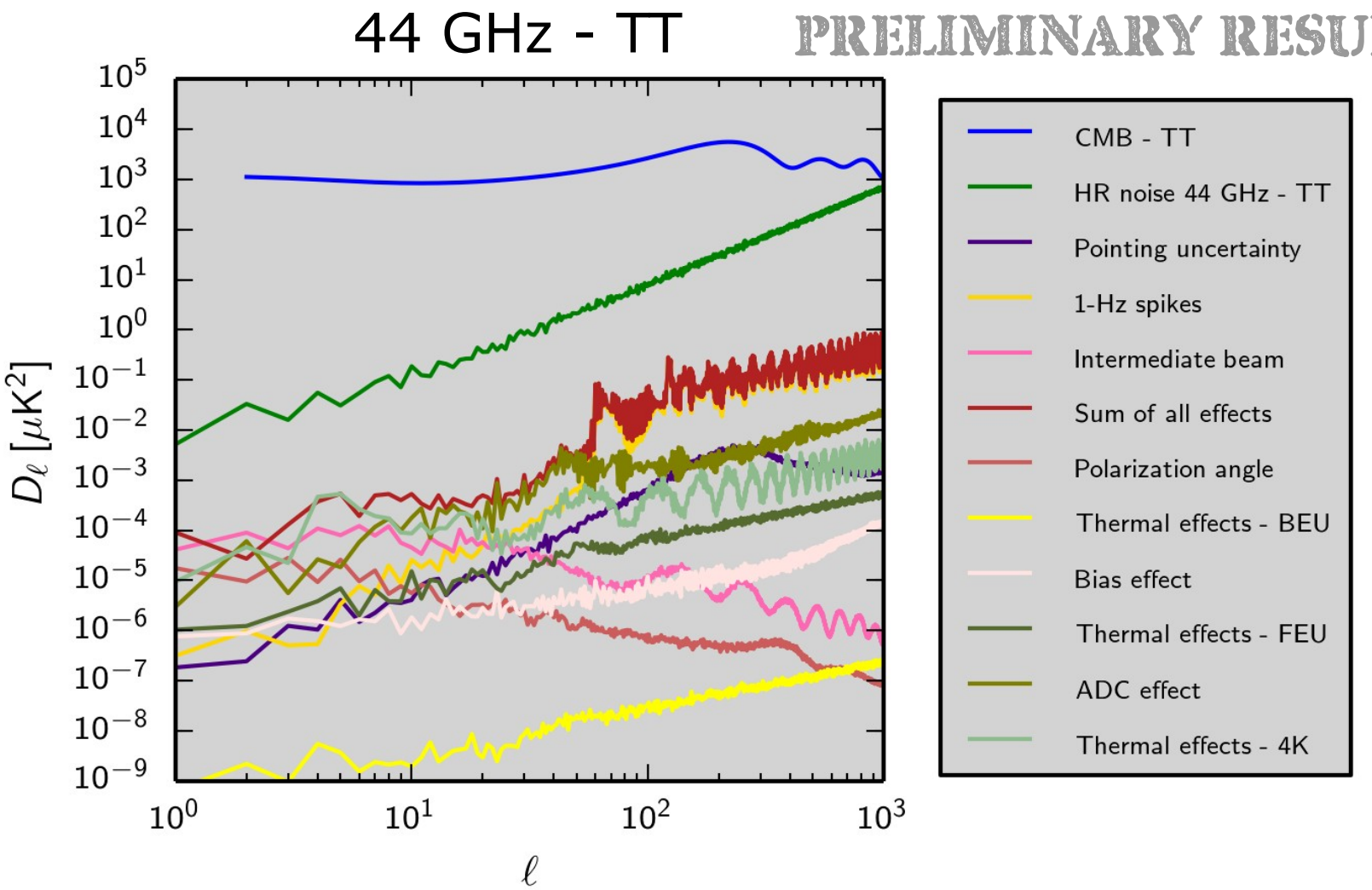


POWER SPECTRA

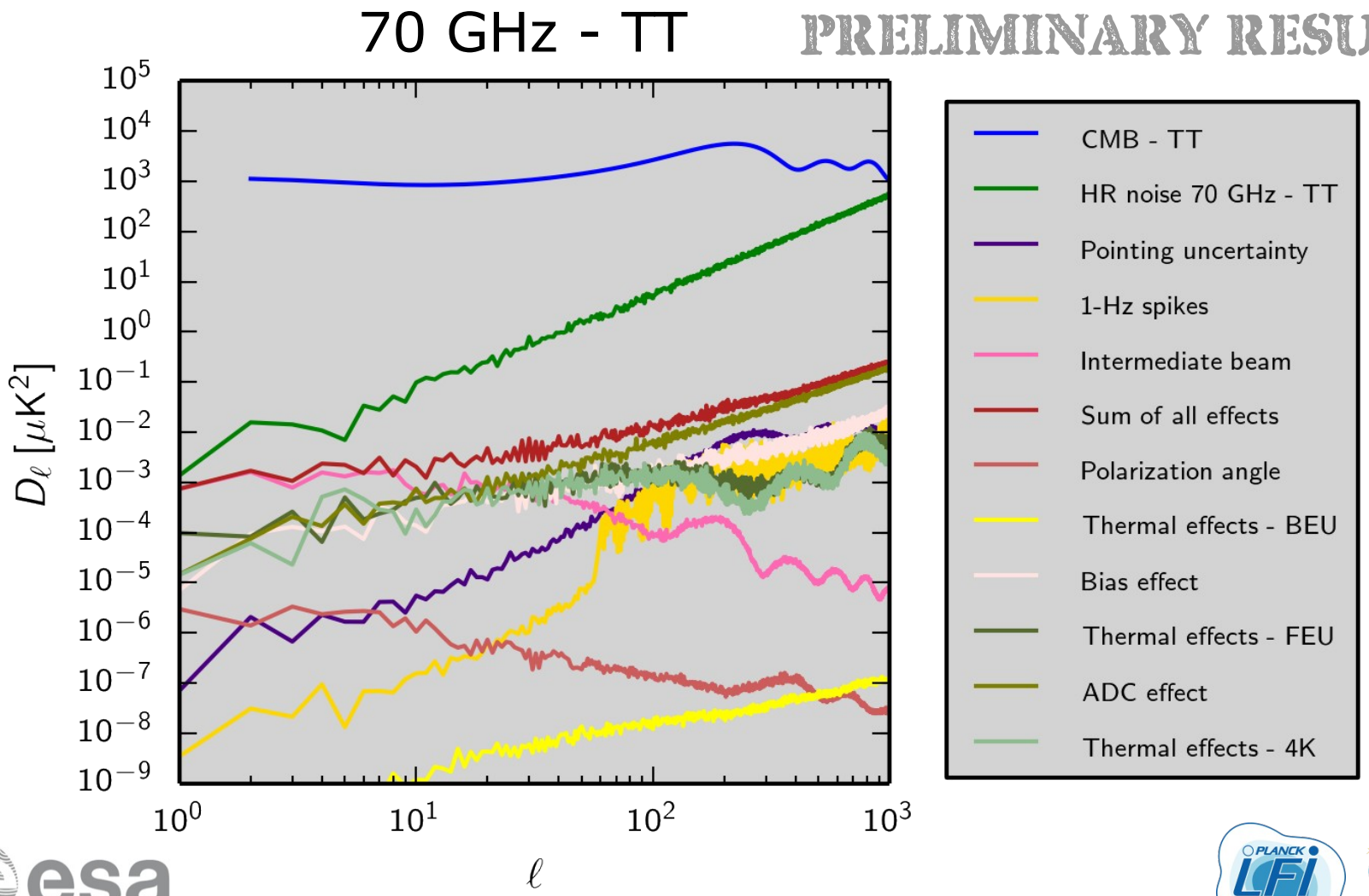
Assessment of LFI uncertainties – power spectrum



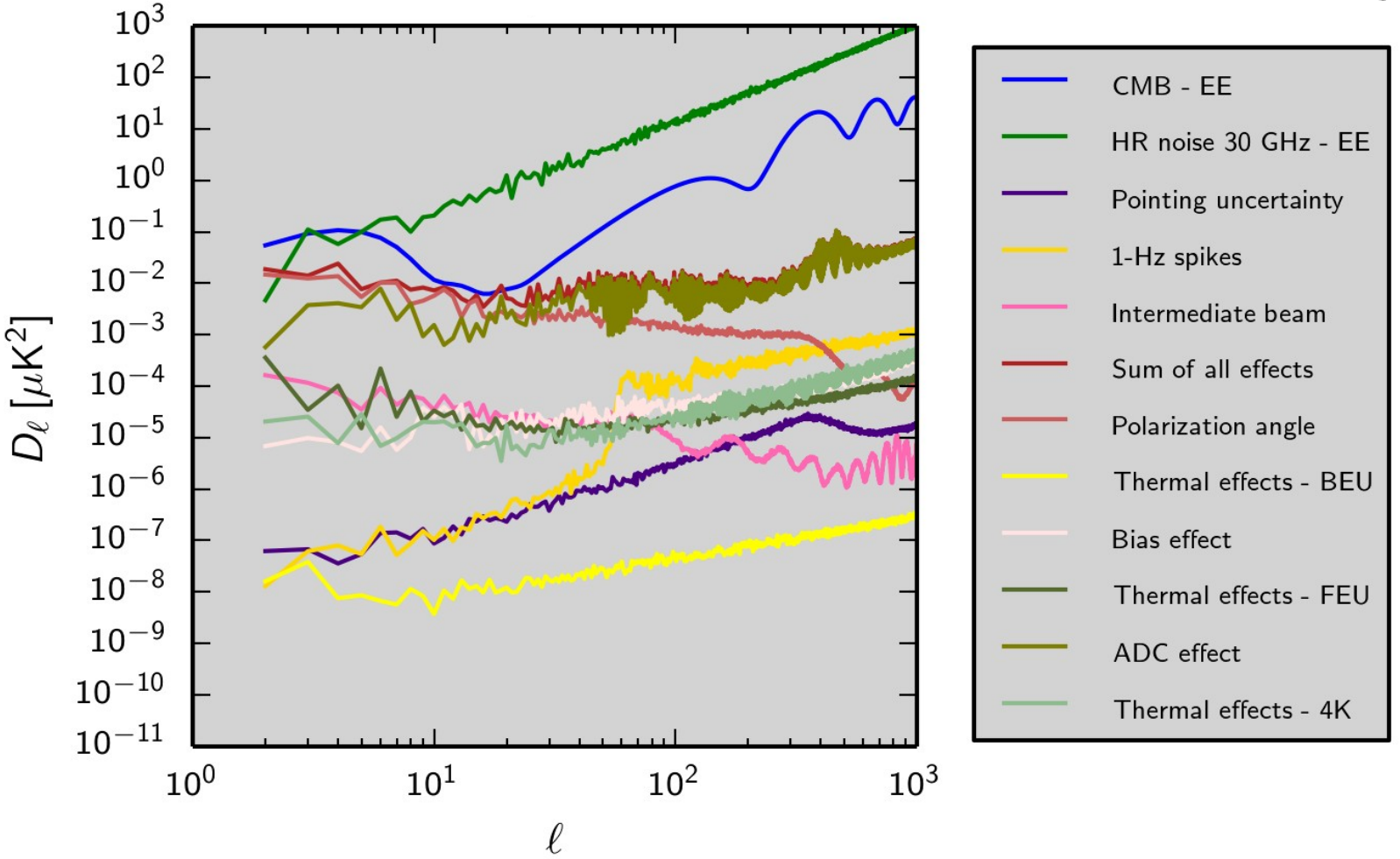
Assessment of LFI uncertainties – power spectrum



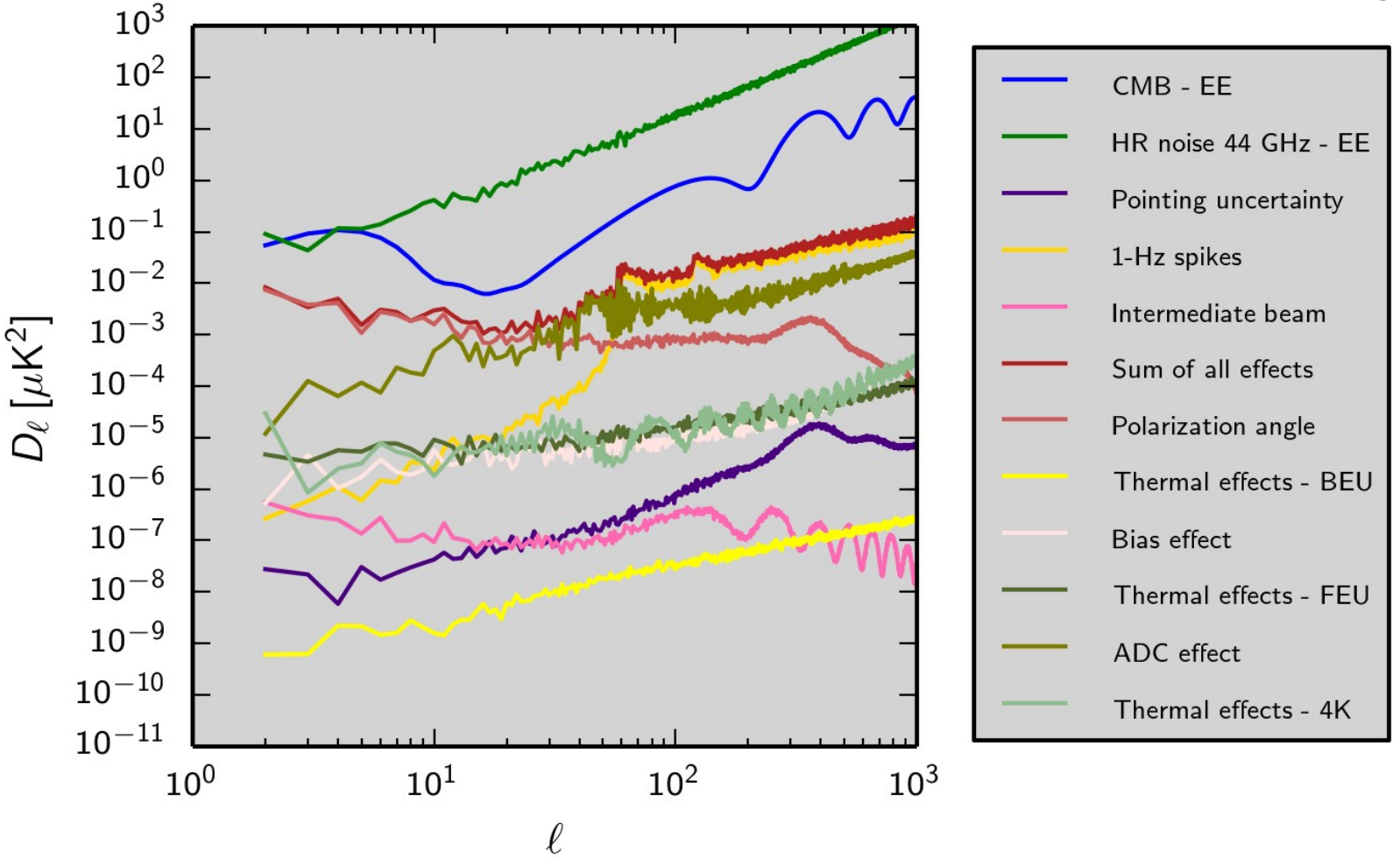
Assessment of LFI uncertainties – power spectrum



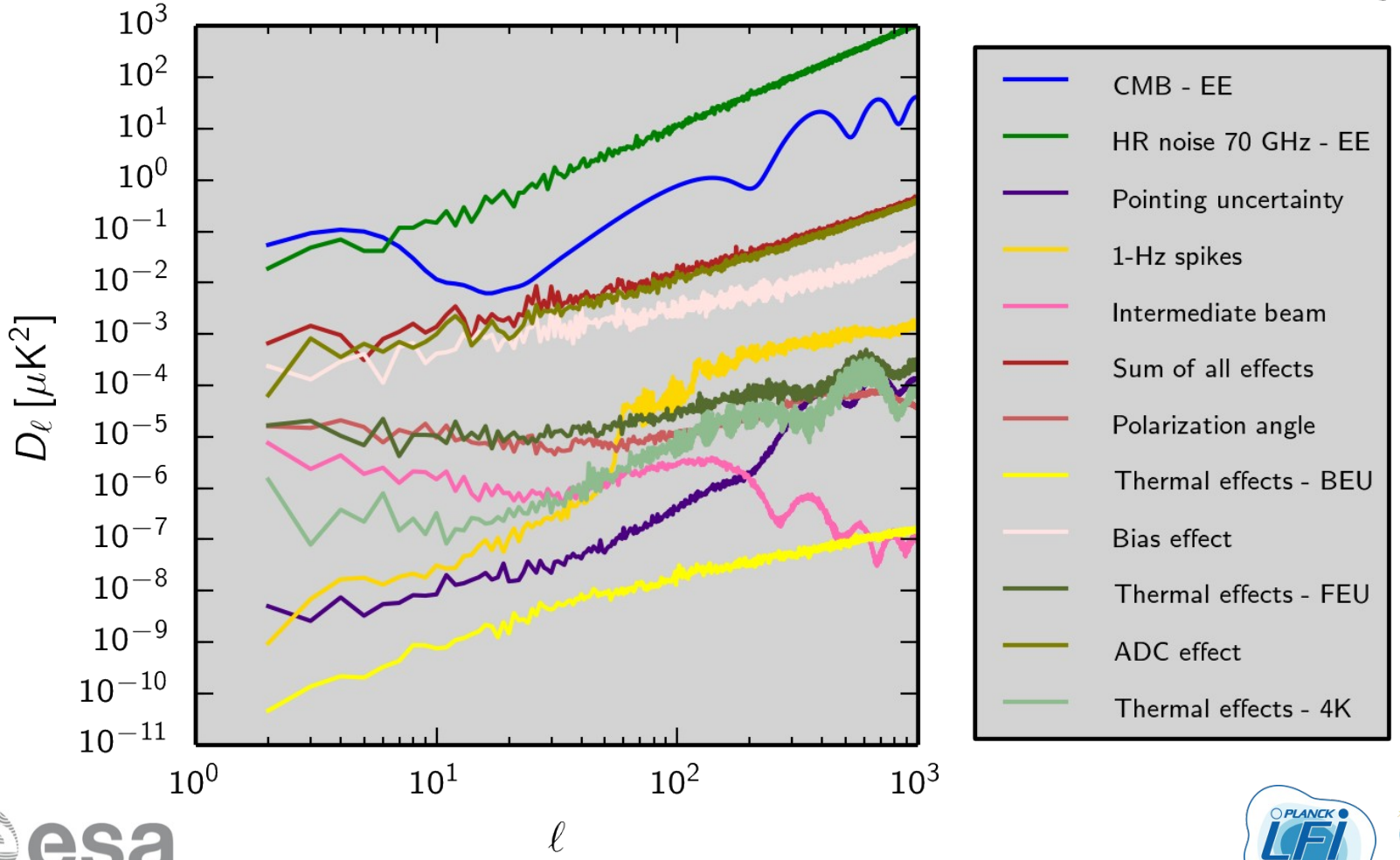
Assessment of LFI uncertainties – power spectrum

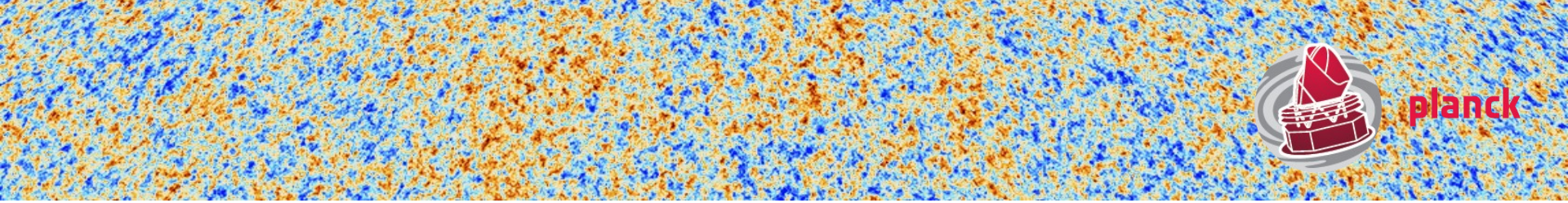


Assessment of LFI uncertainties – power spectrum



Assessment of LFI uncertainties – power spectrum



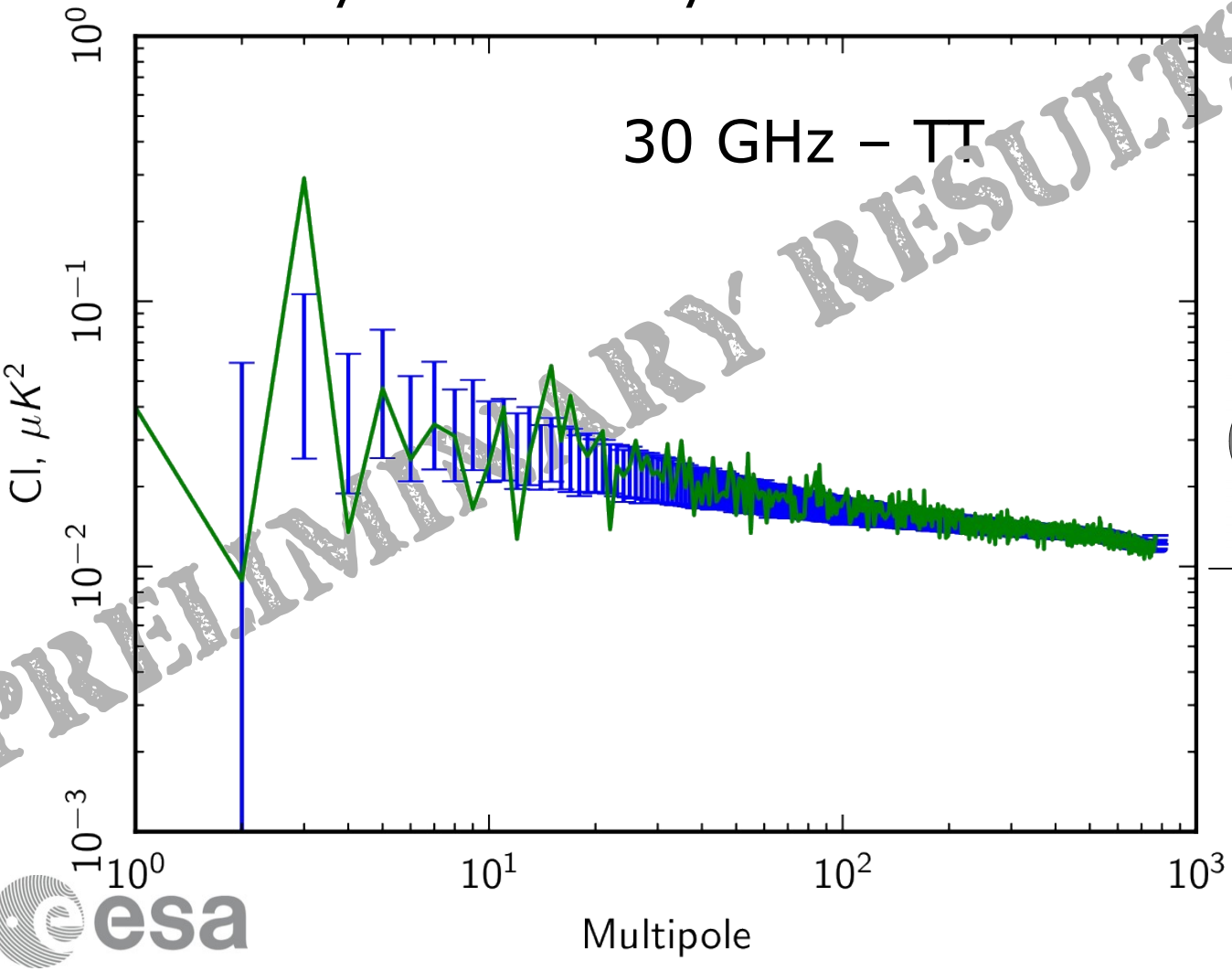


NULL MAPS AND SPECTRA

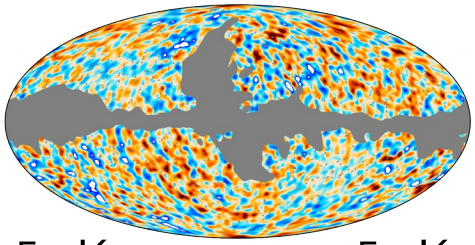
Assessment of LFI uncertainties via null tests – power spectra

year 1+3 – year 2+4

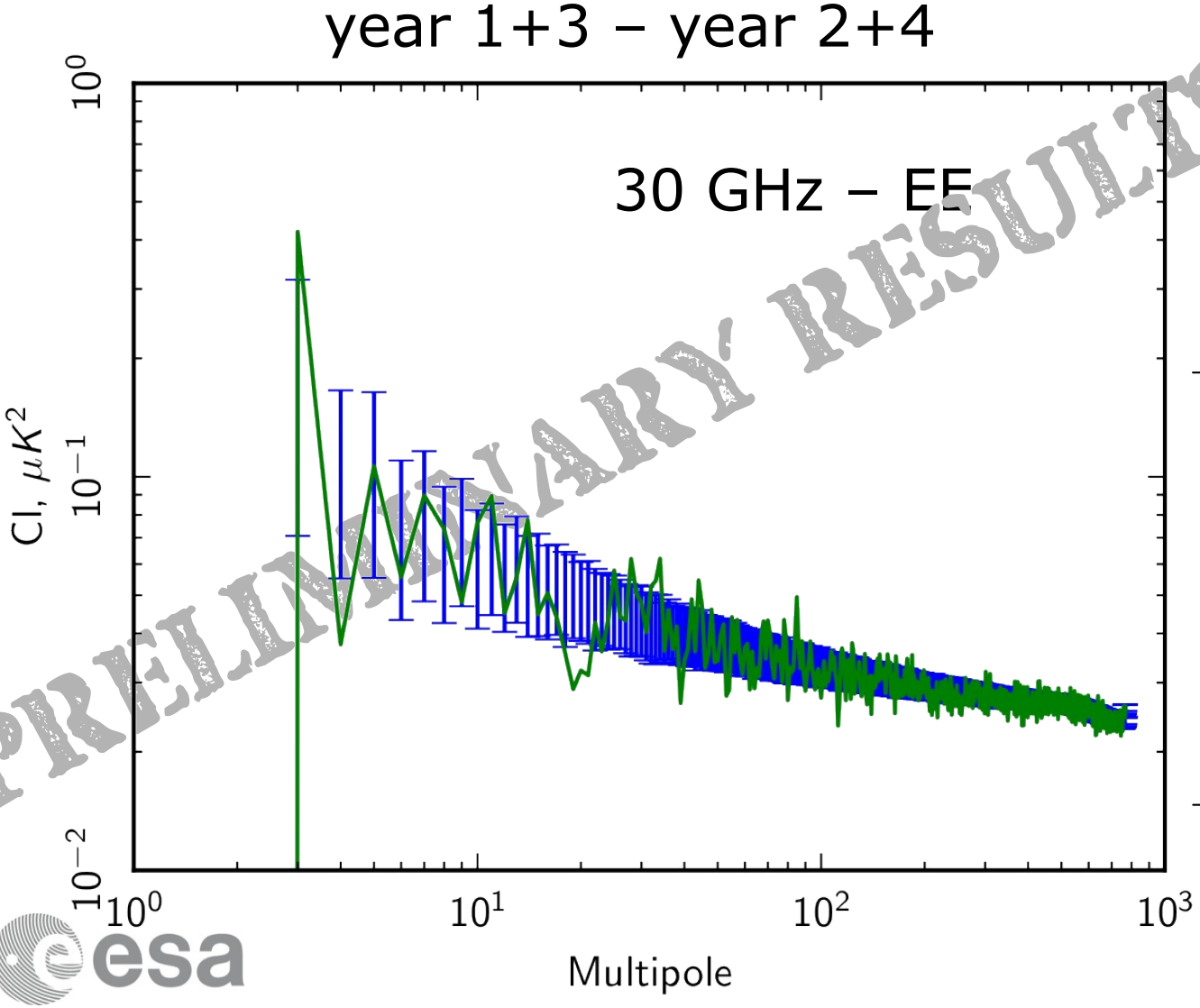
30 GHz – TT

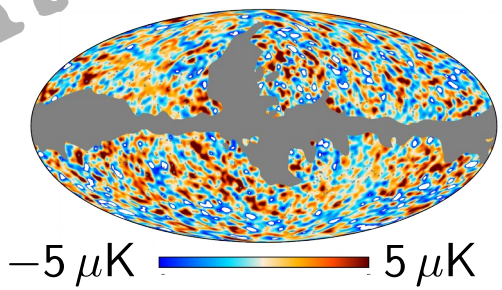


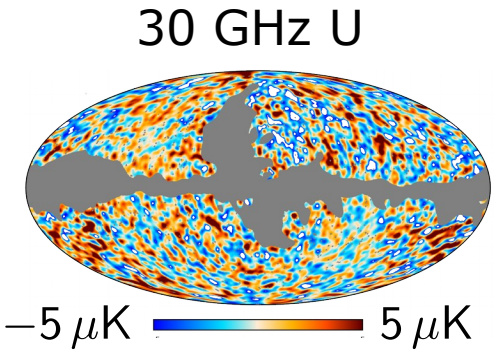
30 GHz I



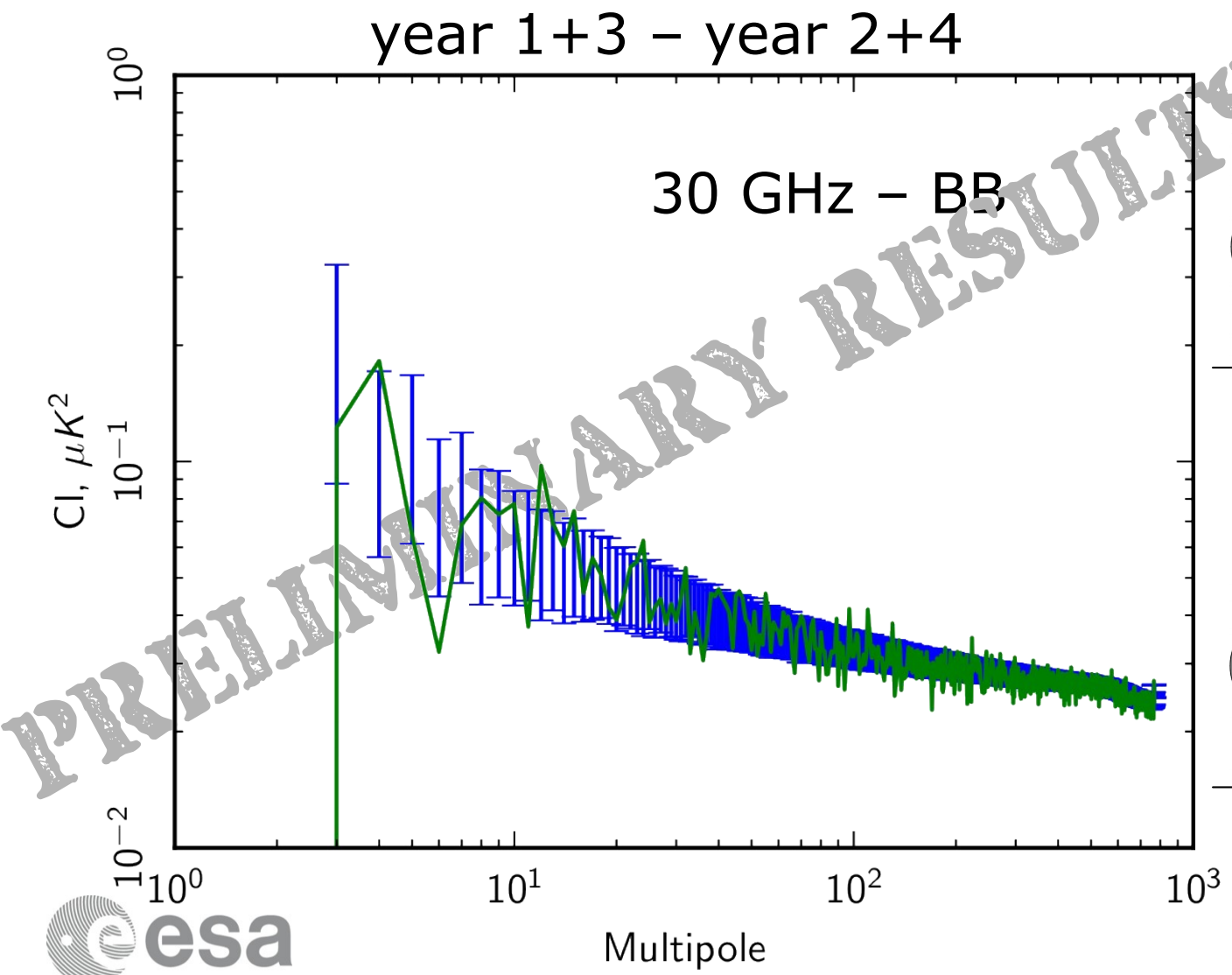
Assessment of LFI uncertainties via null tests – power spectra

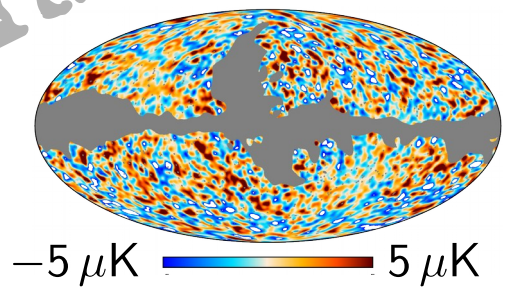


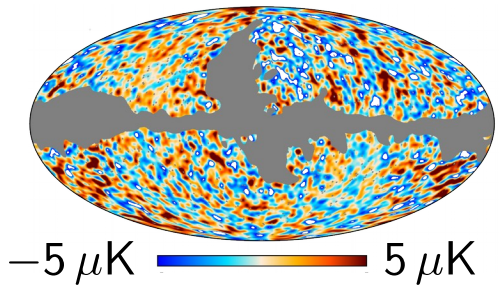




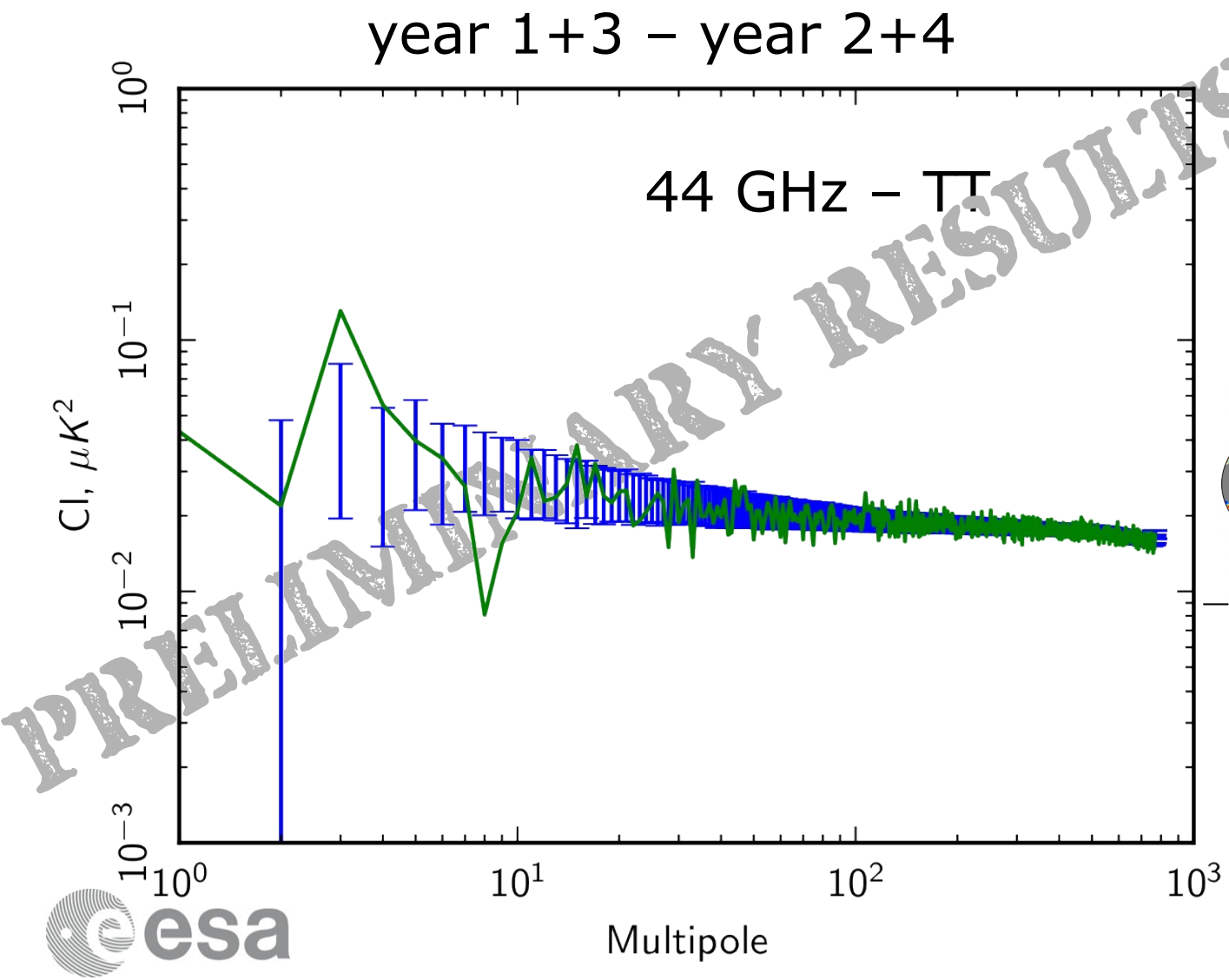
Assessment of LFI uncertainties via null tests – power spectra

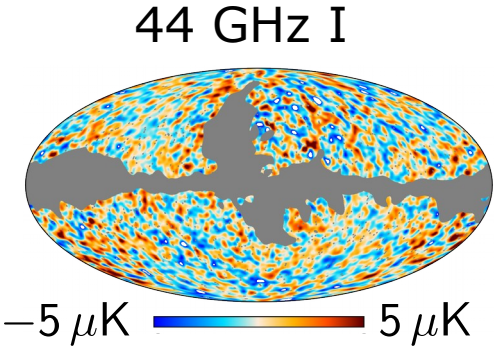




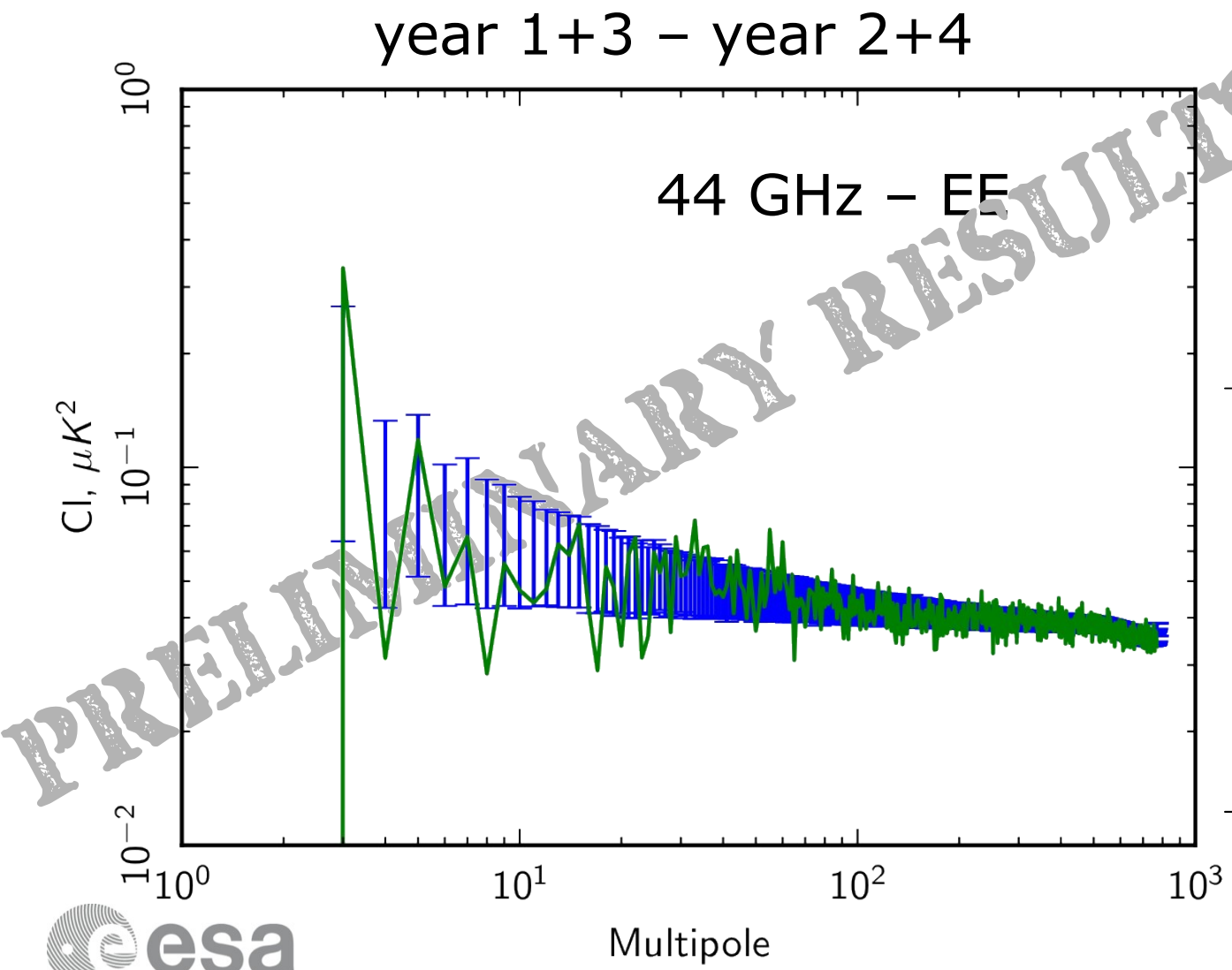


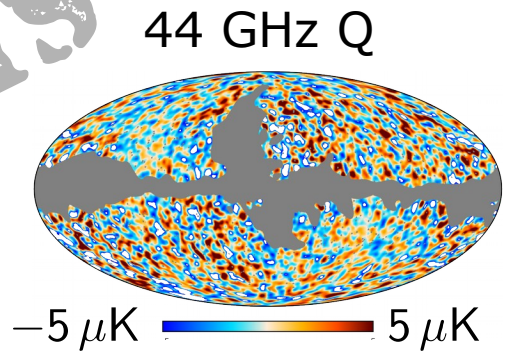
Assessment of LFI uncertainties via null tests – power spectra

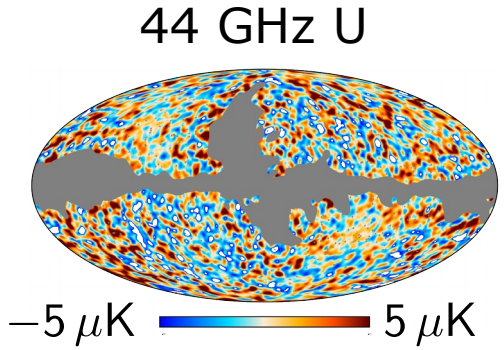




Assessment of LFI uncertainties via null tests – power spectra



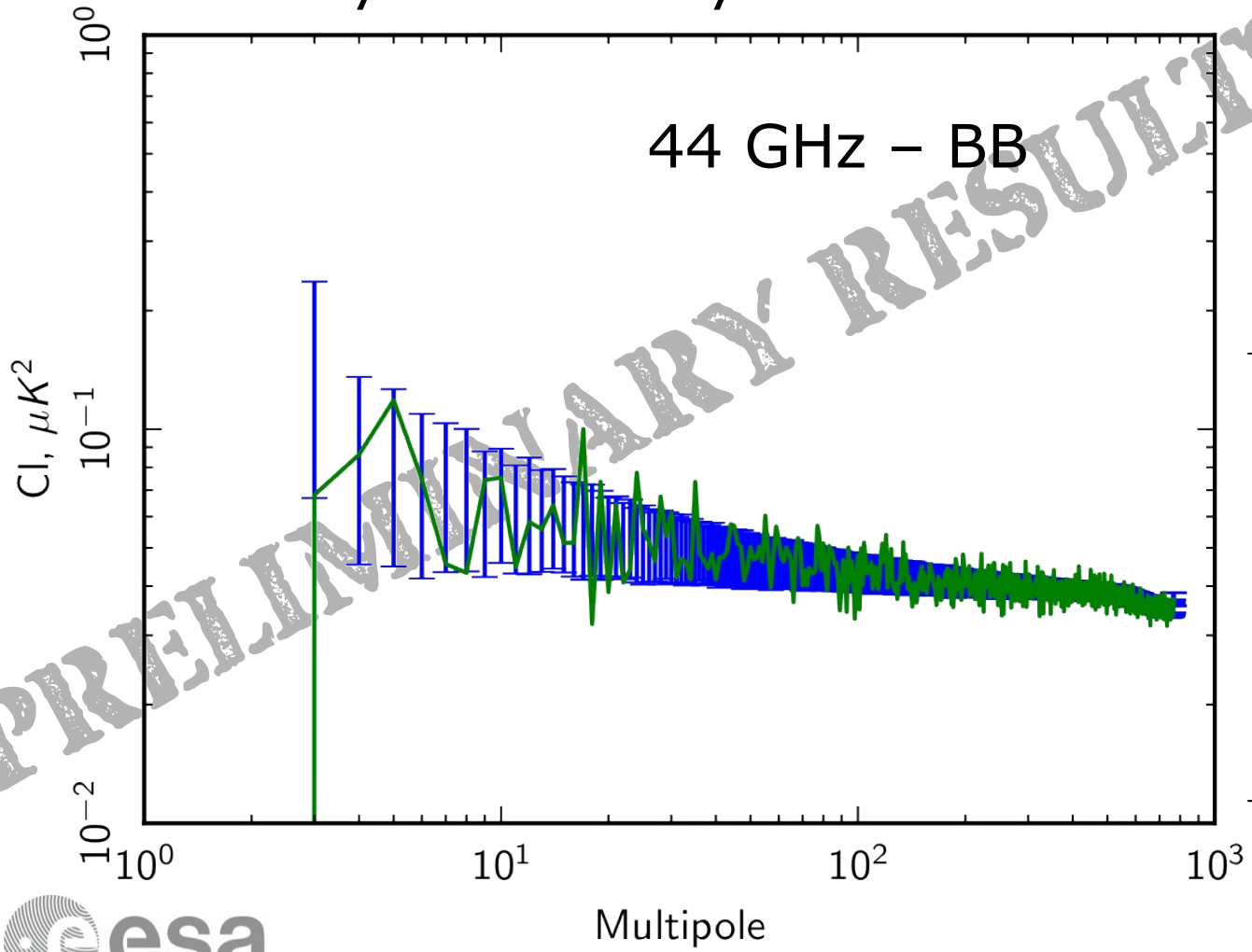




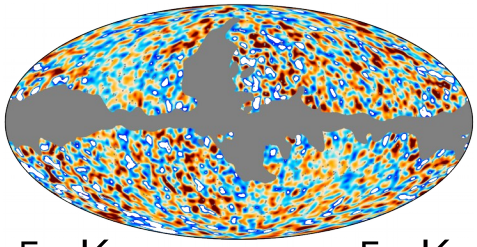
Assessment of LFI uncertainties via null tests – power spectra

year 1+3 – year 2+4

44 GHz – BB

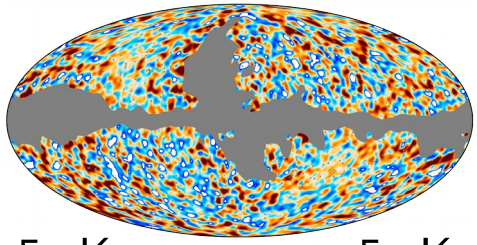


44 GHz Q



−5 μK 5 μK

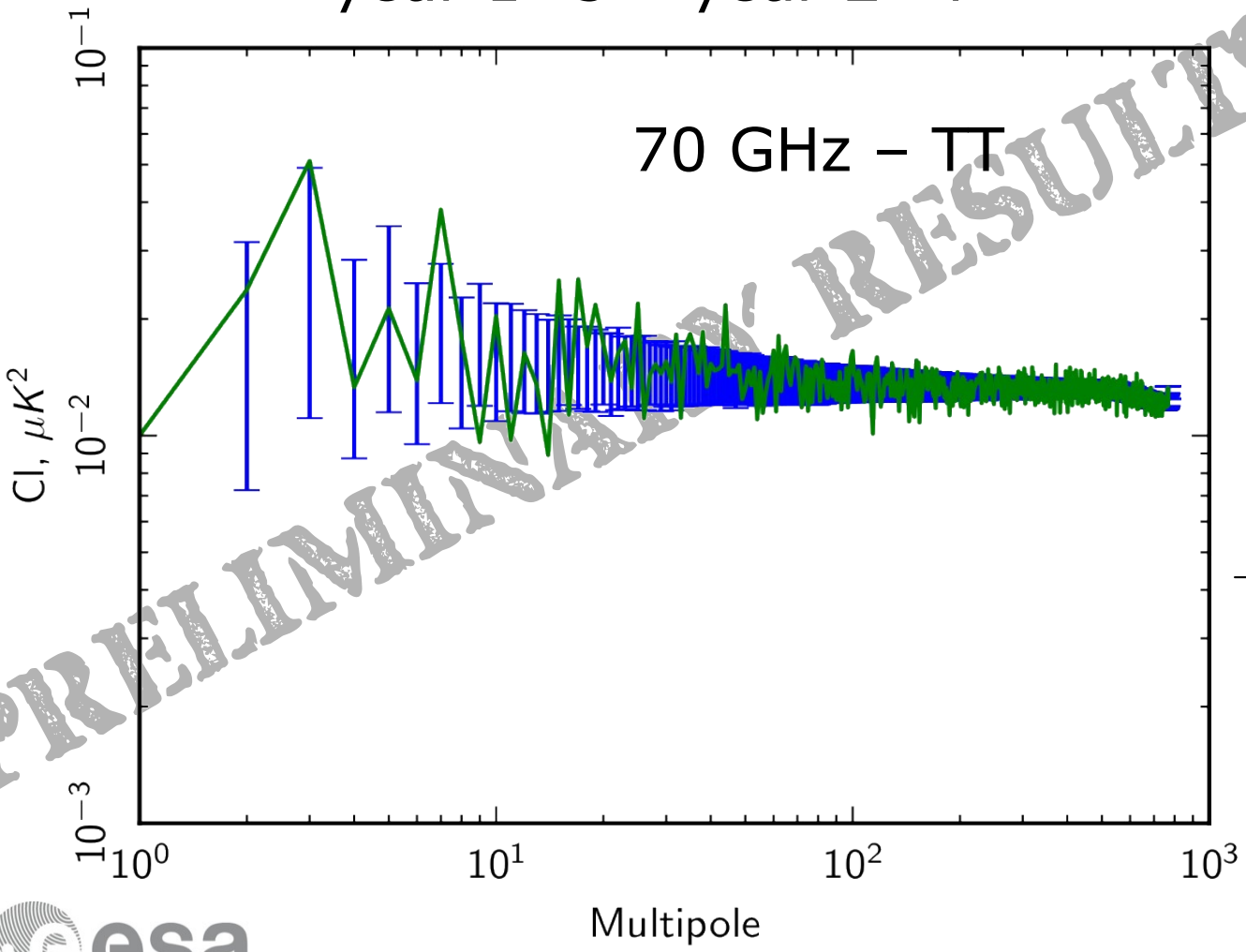
44 GHz U



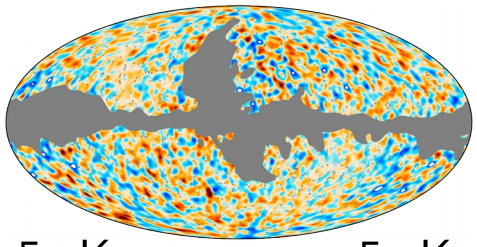
−5 μK 5 μK

Assessment of LFI uncertainties via null tests – power spectra

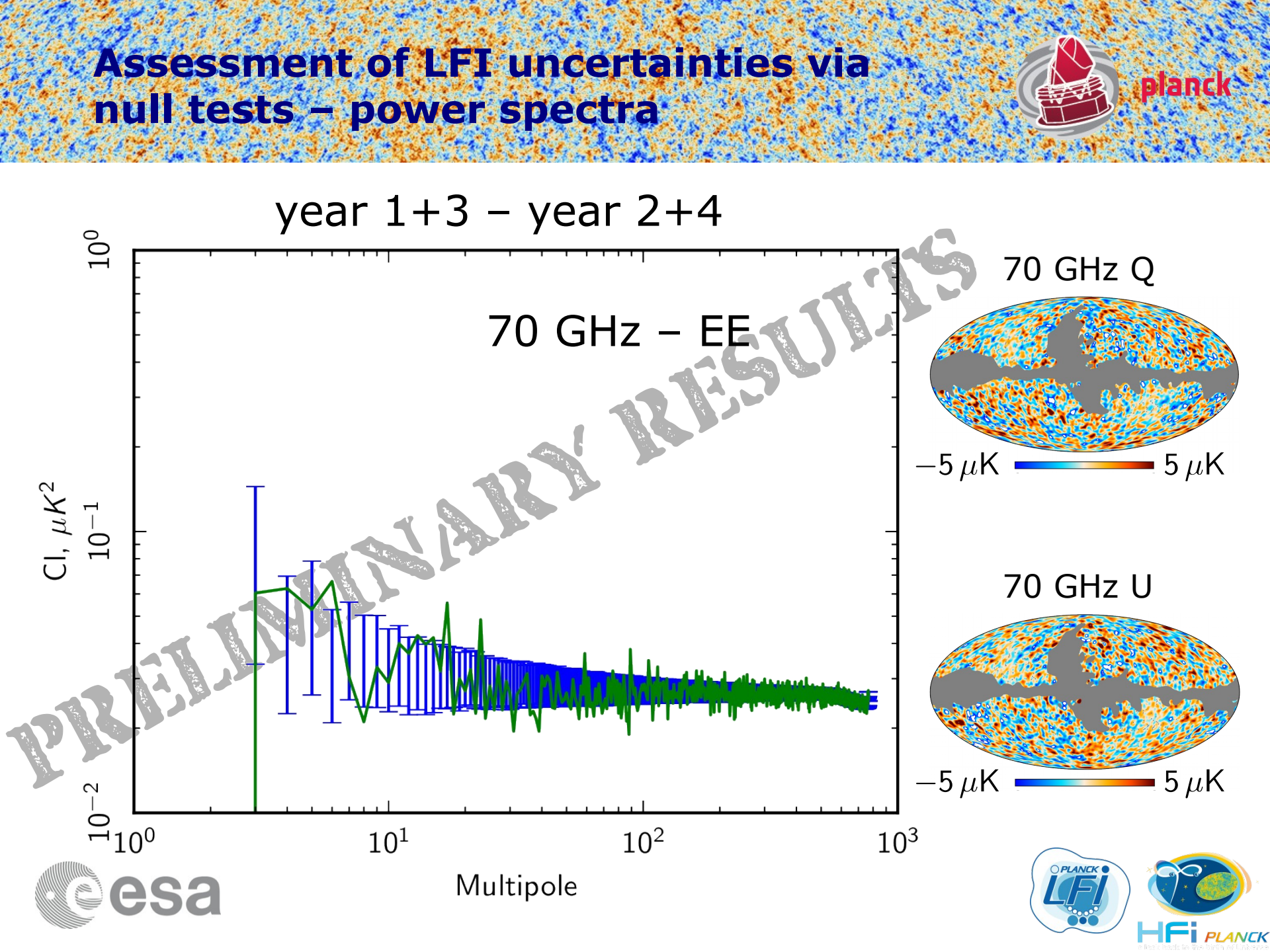
year 1+3 – year 2+4



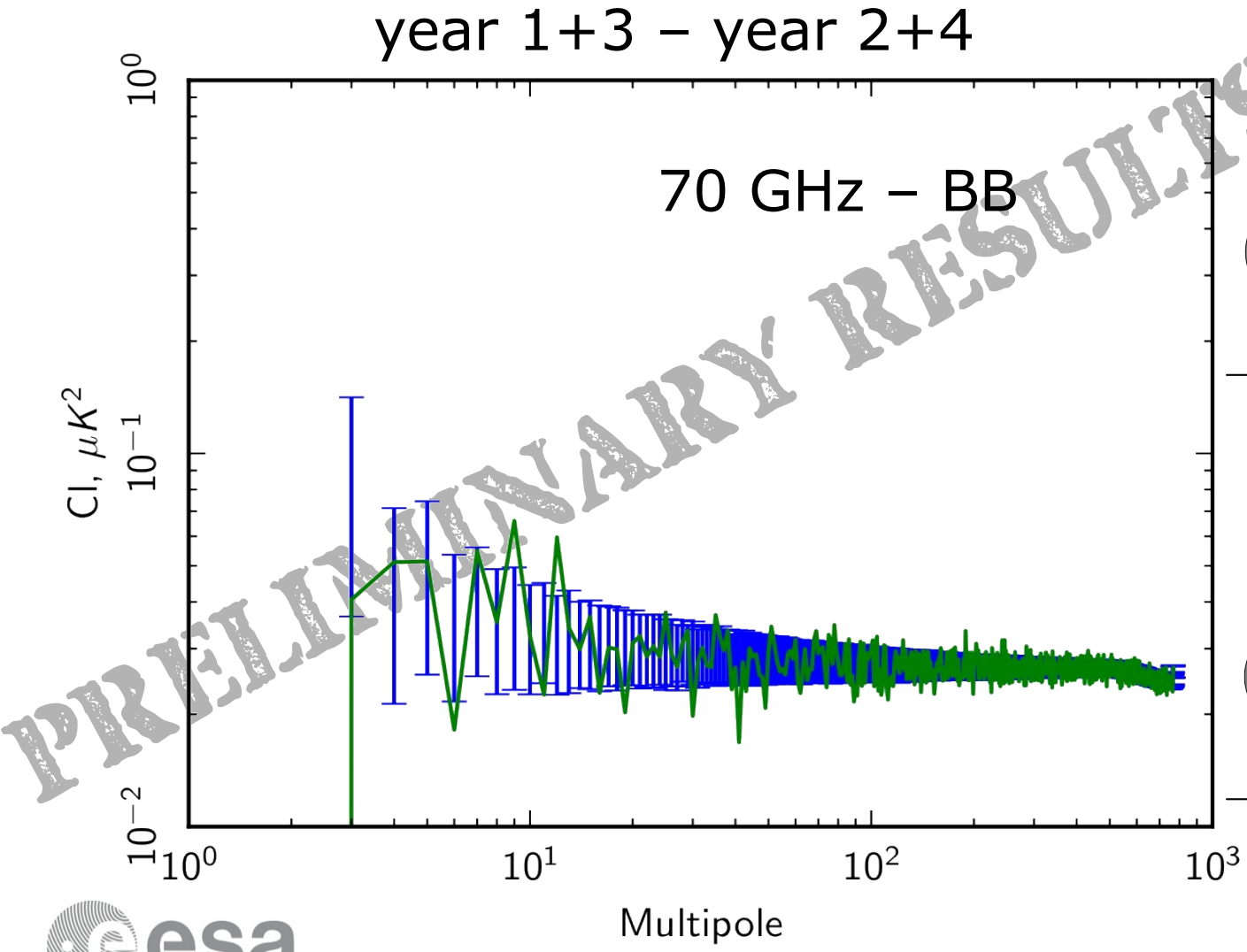
70 GHz I

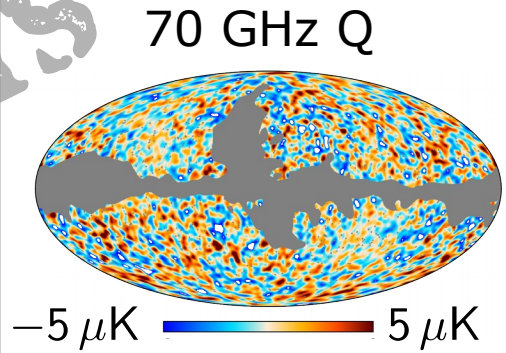


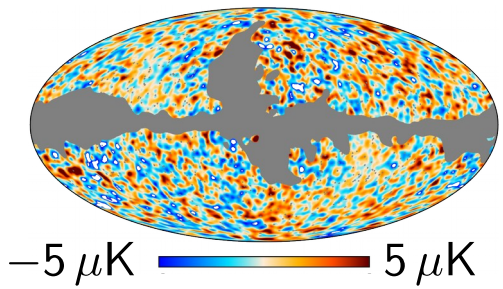
Assessment of LFI uncertainties via null tests – power spectra



Assessment of LFI uncertainties via null tests – power spectra







Conclusions

1. **Sound data**
    a. Fought systematic effects from instrument development
    b. Continued in data analysis, especially in polarization at large scales
    c. Temperature and polarization data are signal dominated
    d. Systematic uncertainties are quantified and understood [some frequency channels still under work]

Conclusions

2. Work to do

a. Analysis ongoing on some frequency channels in polarization

b. Residuals from uncertainty in sidelobes removal and gain model under assessment

c. Propagation of systematic effects through component separation [last-minute first results already produced]

d. Impact of systematic effects on CMB statistic analysis and cosmological parameters

Conclusions

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3. Big challenge

a. Extraordinary sensitivity and increasing instrument complexity challenges every CMB experiment. Planck is no exception

b. Challenge due to increase in the future. Deep understanding of the instrument and its data is key

esa

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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.

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Thank you