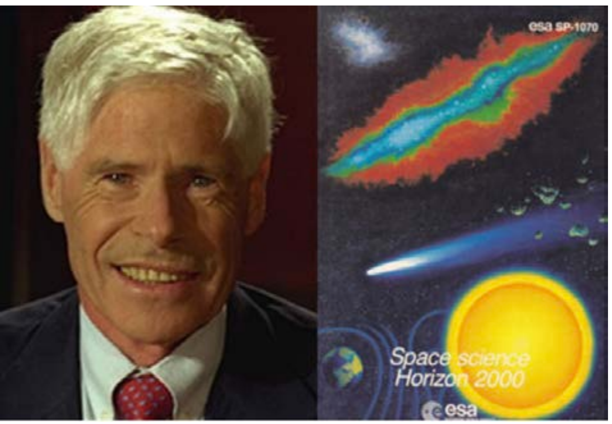
The oldest light
Planck



J.L. Puget
Institut d'Astrophysique Spatiale

ESTEC Feb 2018

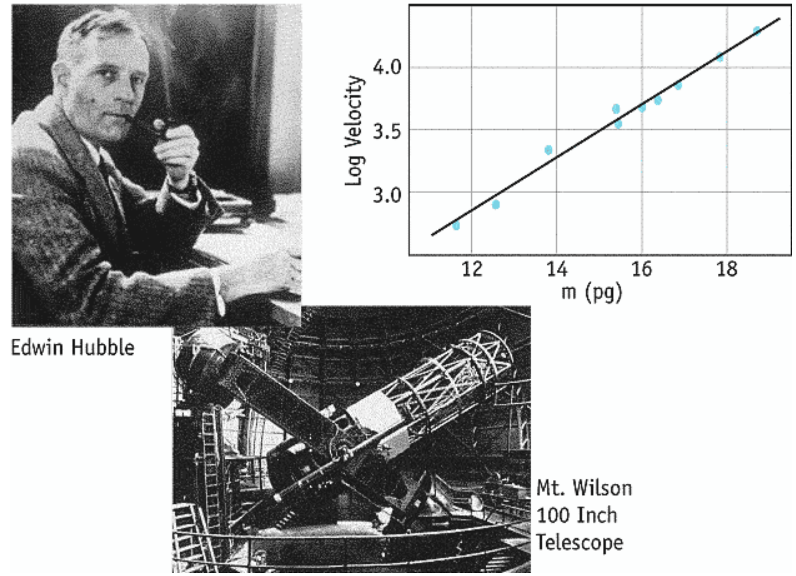
large scale structure, CMB anisotropies and acoustic peaks

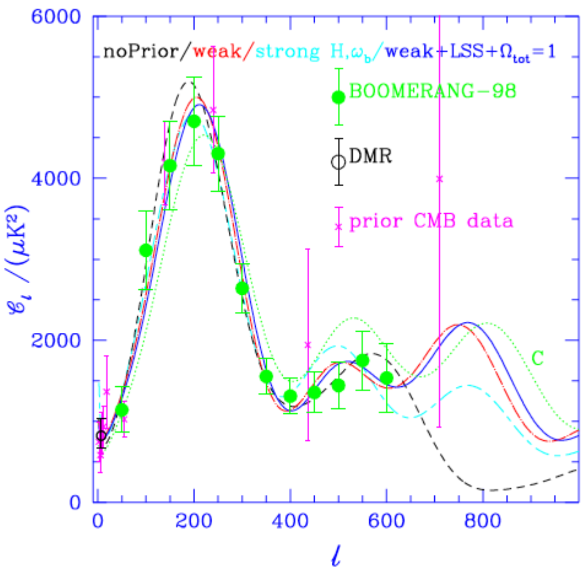
- Zeldovich, Kurt and Sunyaev 1968 ZhETF
- Sunyaev and Zeldovich, 1970 ApSS 7,20
- Peebles and Yu 1970, ApJ 162, 815
- Silk 1968 ApJ 151, 459
- Bond, Efstathiou, 1984, ApJ286,L45

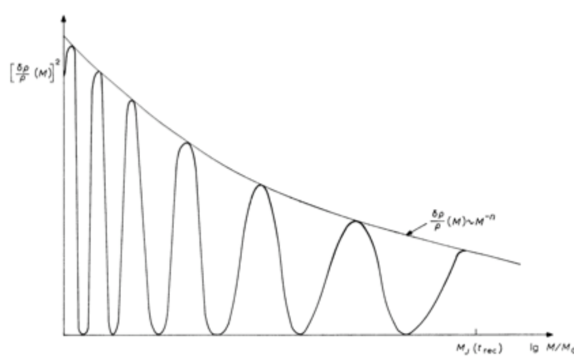
1987, MNRAS 226,655

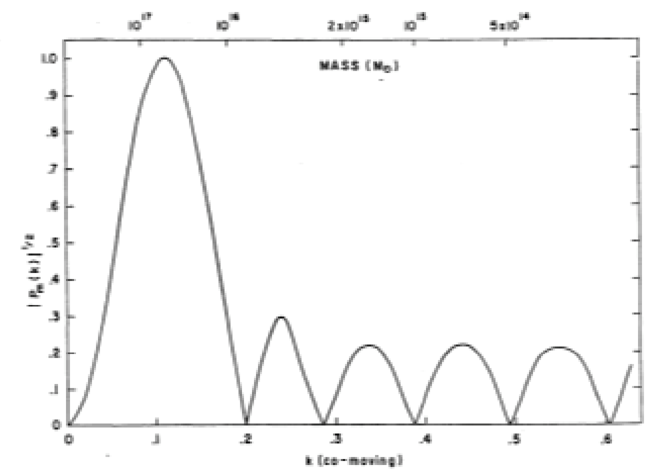
- Efstathiou, Bond, White 1992, MNRAS, 258,1

COBE background radiation and LSS in the universe





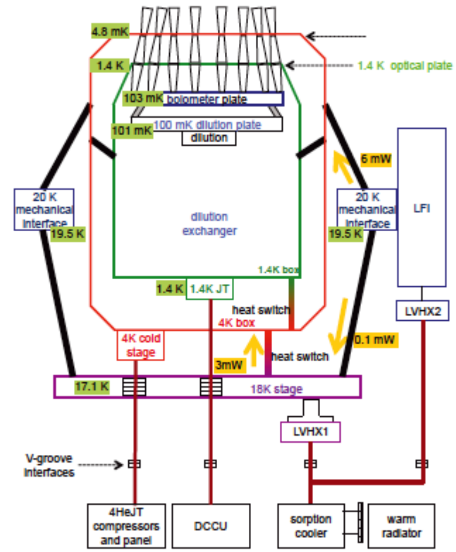


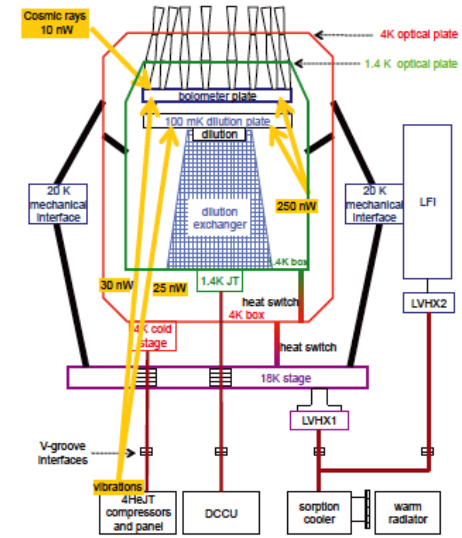


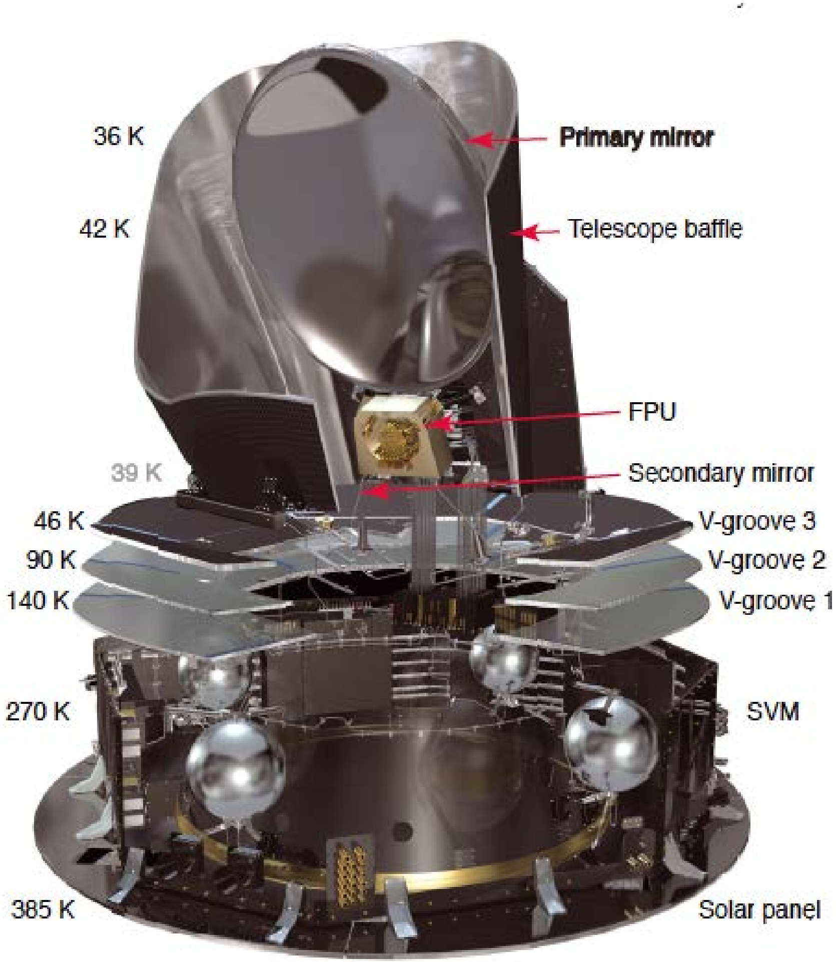
- M3 call (1993)
- 2 proposals to detect the acoustic peaks
  - Reno Mandolesi COBRAS: HEMT based not cooled
  - JLP SAMBA: Dilution cooler (A Benoit) Bolometers cooled at 100 mk Caltech
  - H Sorption cooler (JPL) + 4K cooler (UK)
  - merged into CBRAS-SAMBA → Planck mission

Planck cryogenic system

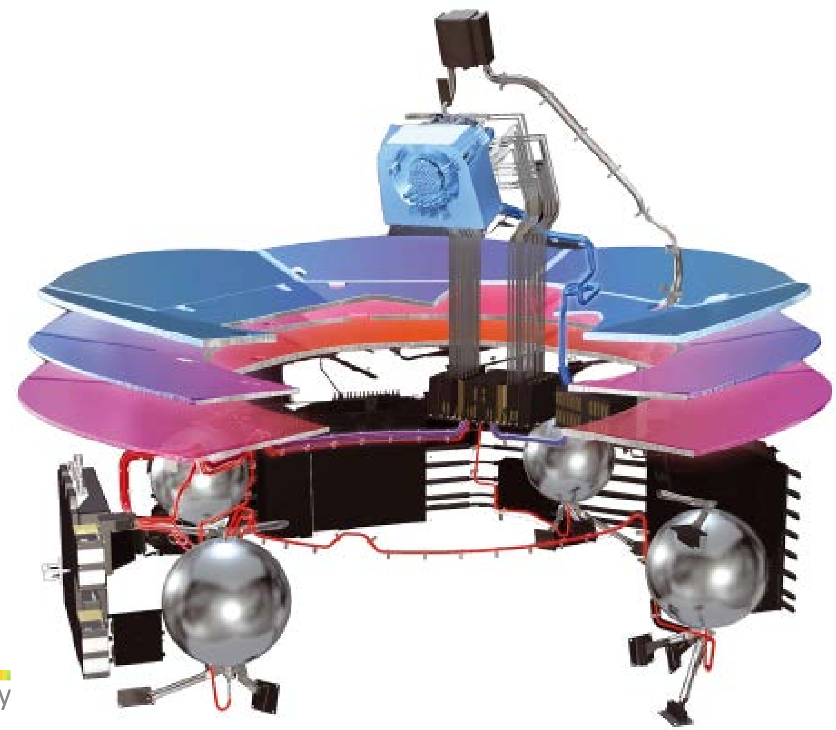
Dilution cooler in space (Alain Benoit)
Sorption Cooler
Bolometers 0.1K (A. Lange, N.Coron)
HEMT at 100 GHz



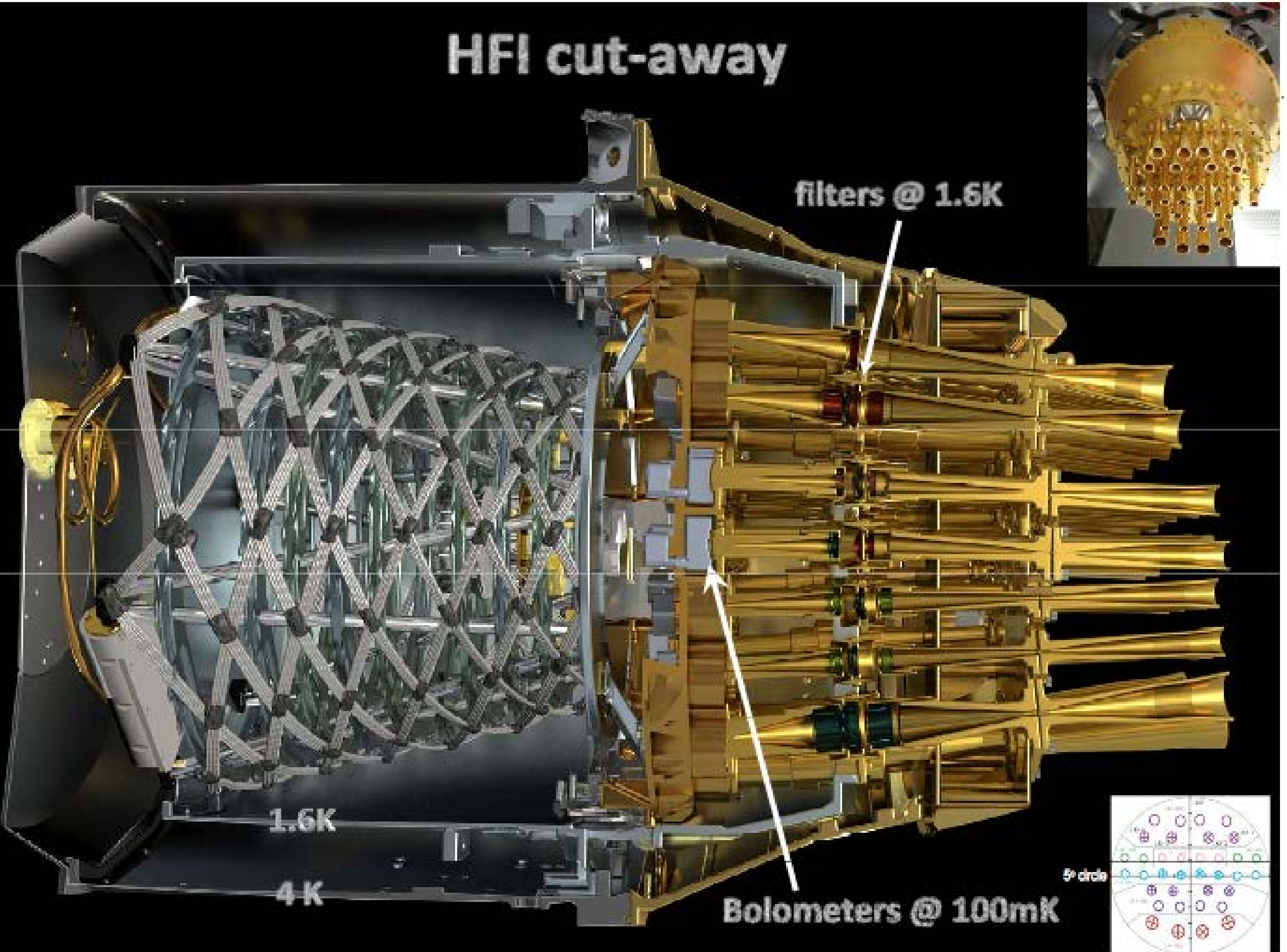




Puget, IAS Orsay

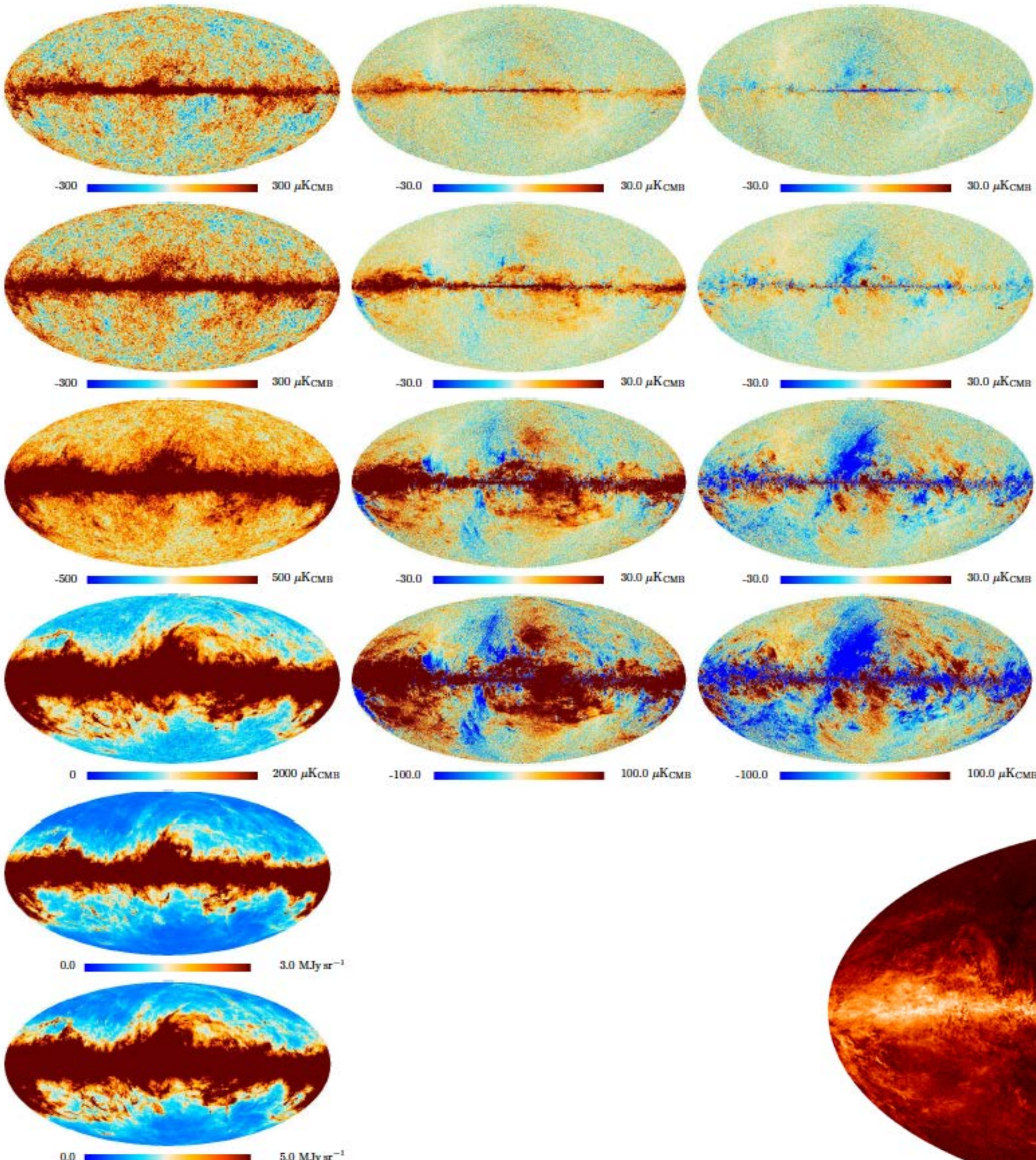


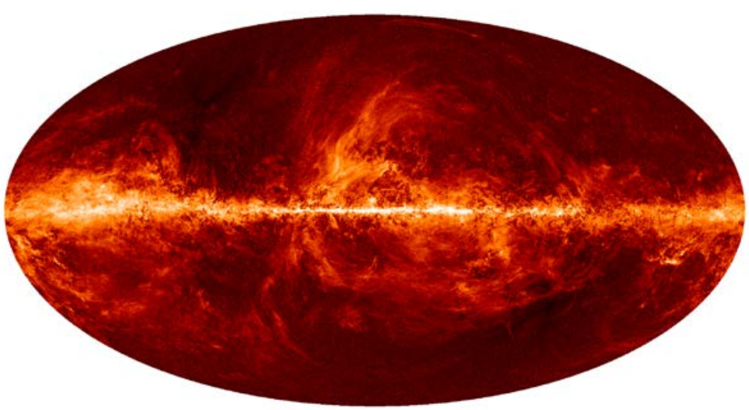
HFI cut-away



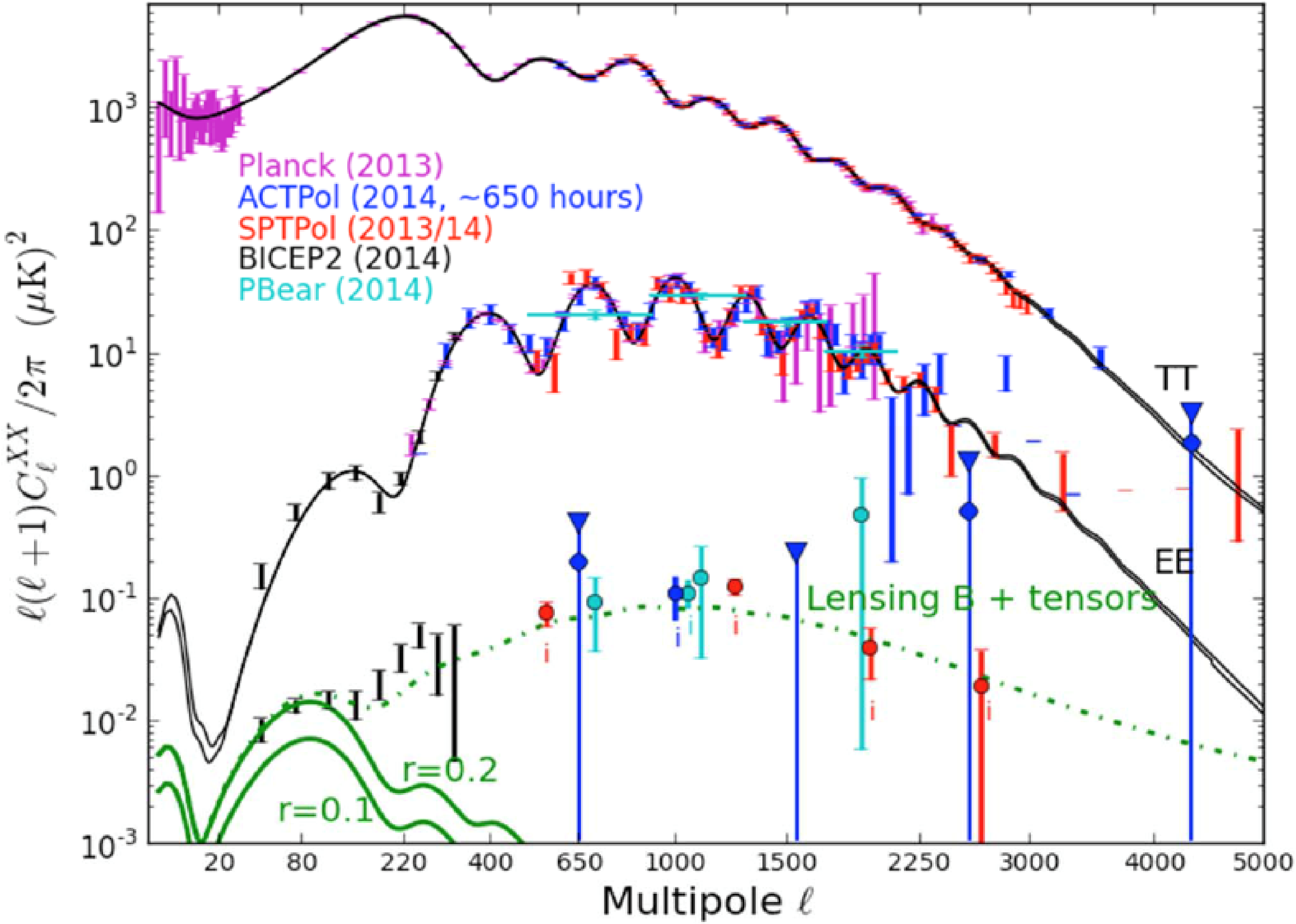
The 2018 HFI maps

- freq
- 100
- 143
- 217
- 353
- 545
- 857





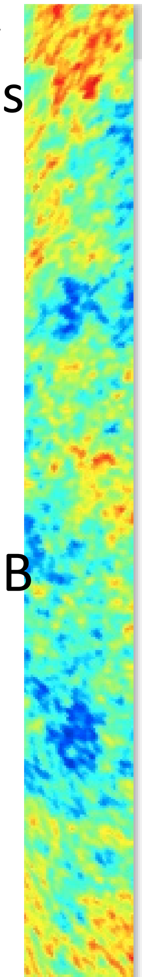
- *POLARBEAR & ACTPol are direct BB*
- *SPT & "preliminary" ACTPol are indirect lensing BB*

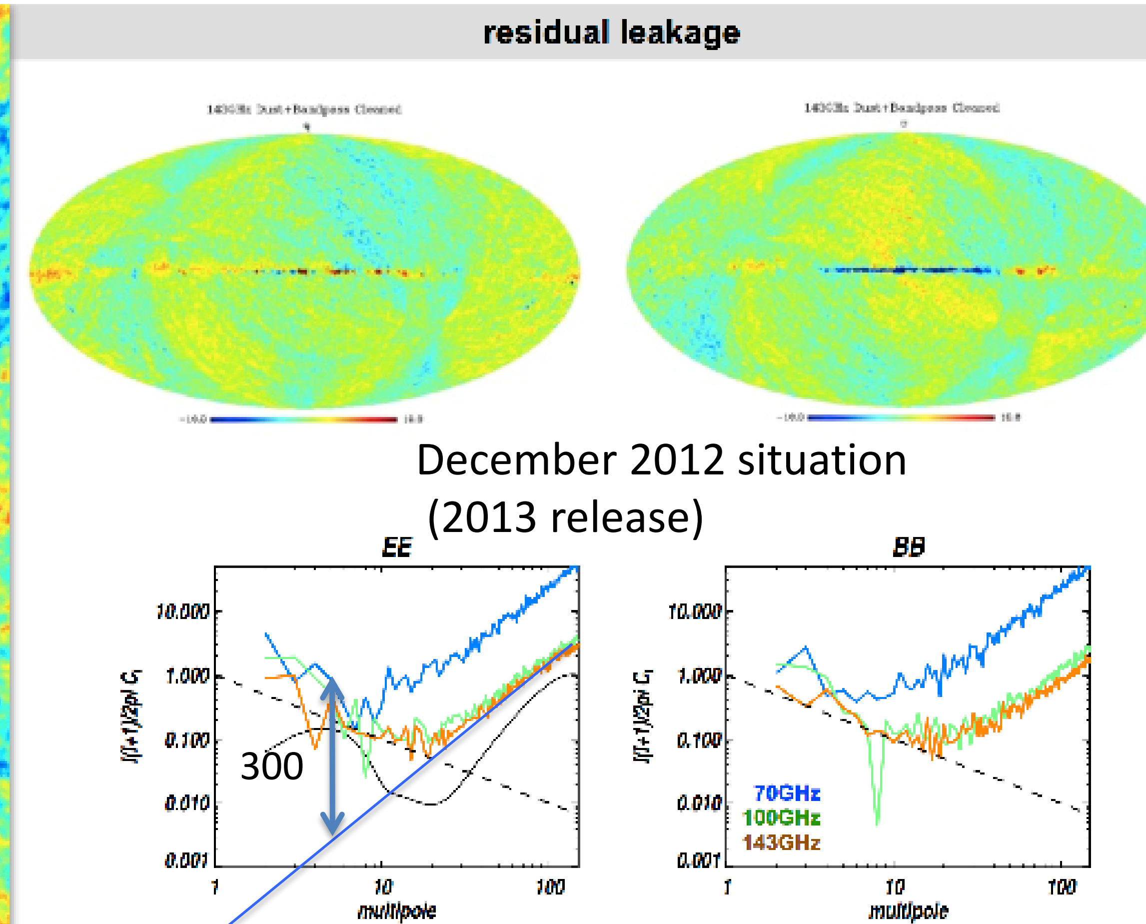


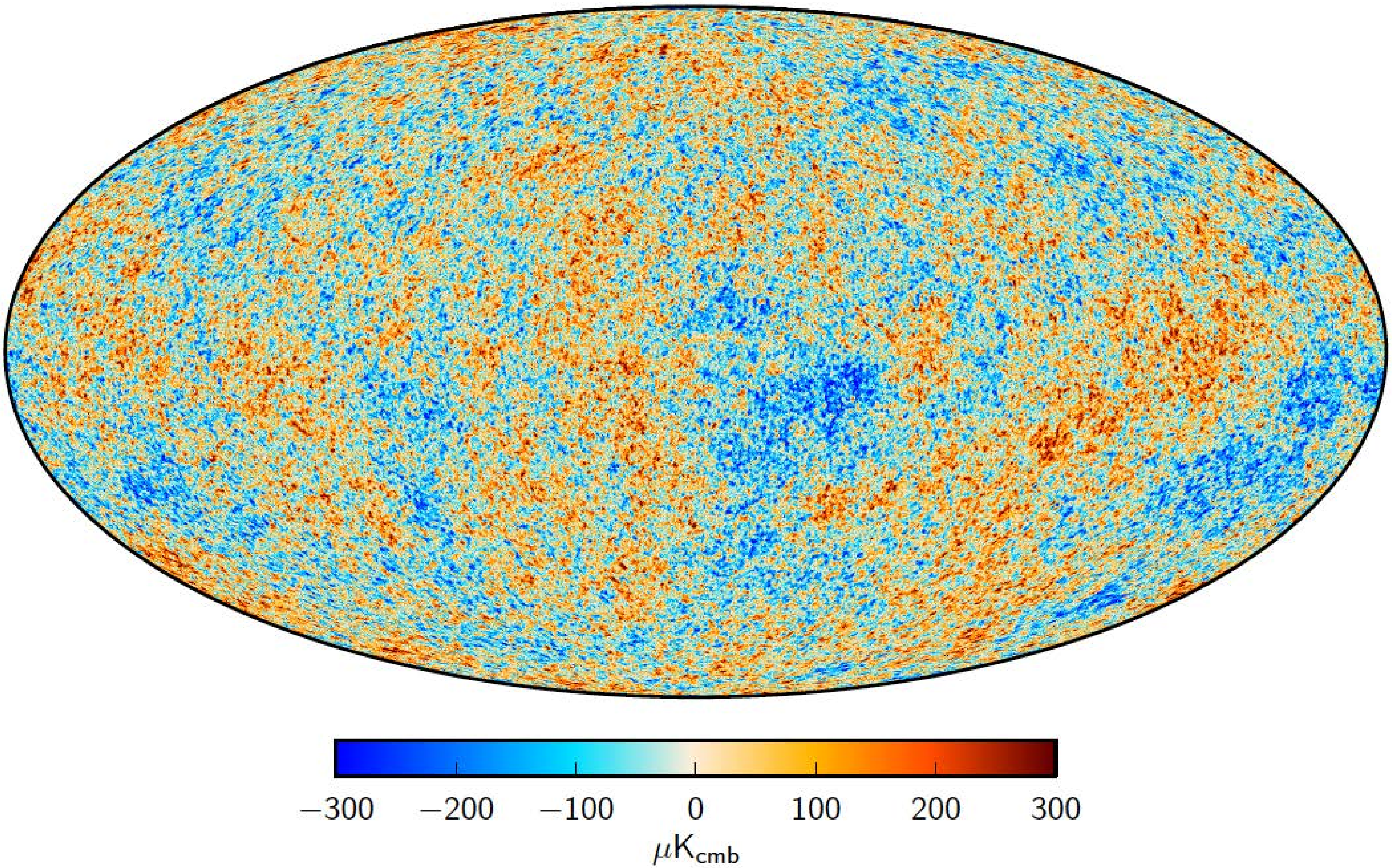
Plot from L. Page

The 2013 data had strong noise/systematic excesses at low ℓ in Polarization

- noise limited sensitivity of Planck channels maps limited at 100, 143 and 217 GHz
- Gaussian 1/f noise mostly associated with glitches tails not removed
- strong low ℓ excess due to leakages T into E and B
- the problem was more severe in relative terms for HFI than for LFI



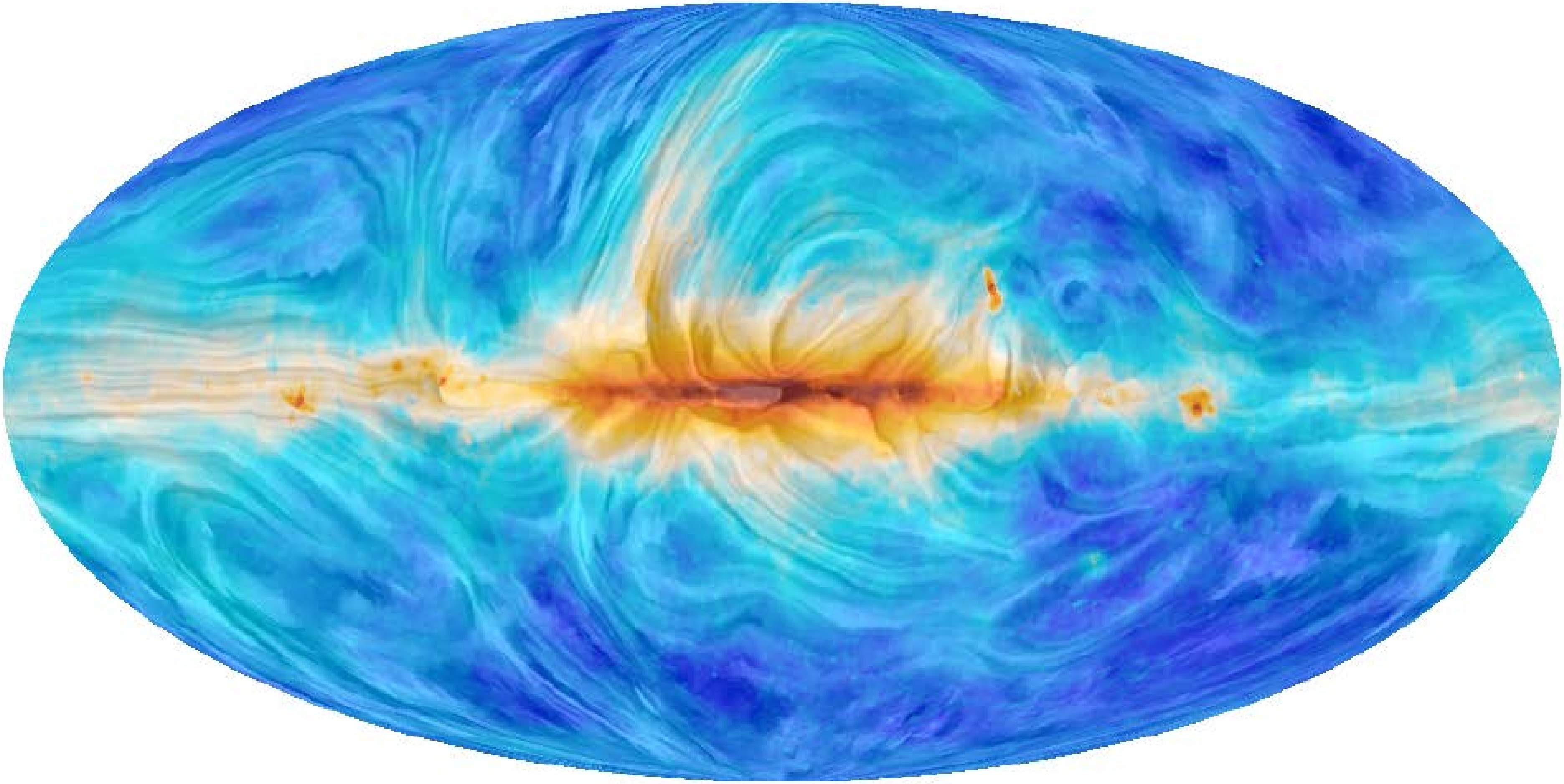




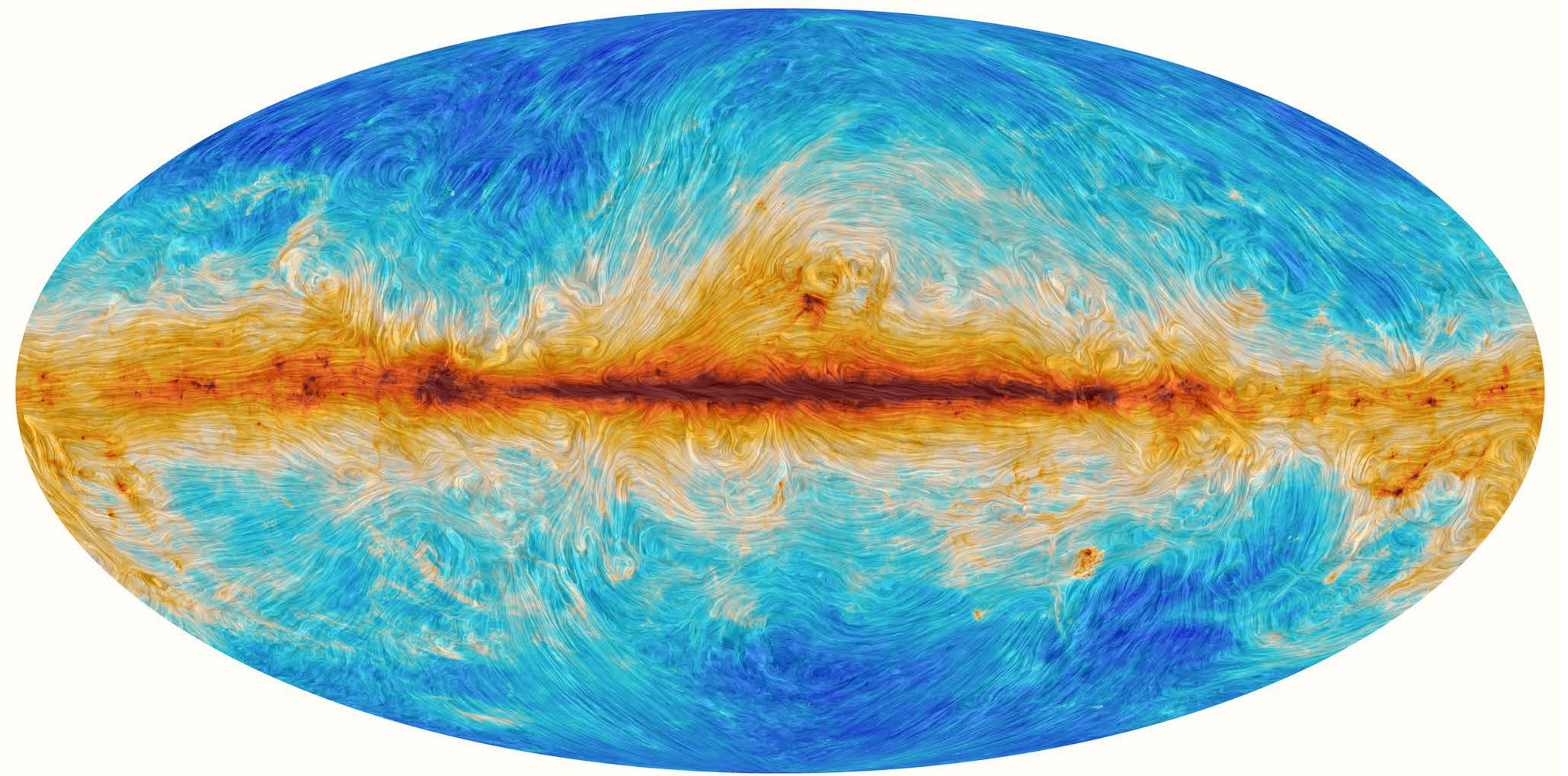
−300
−200
−100
0
100
200
300
μK_cmb

Synchrotron polarization map

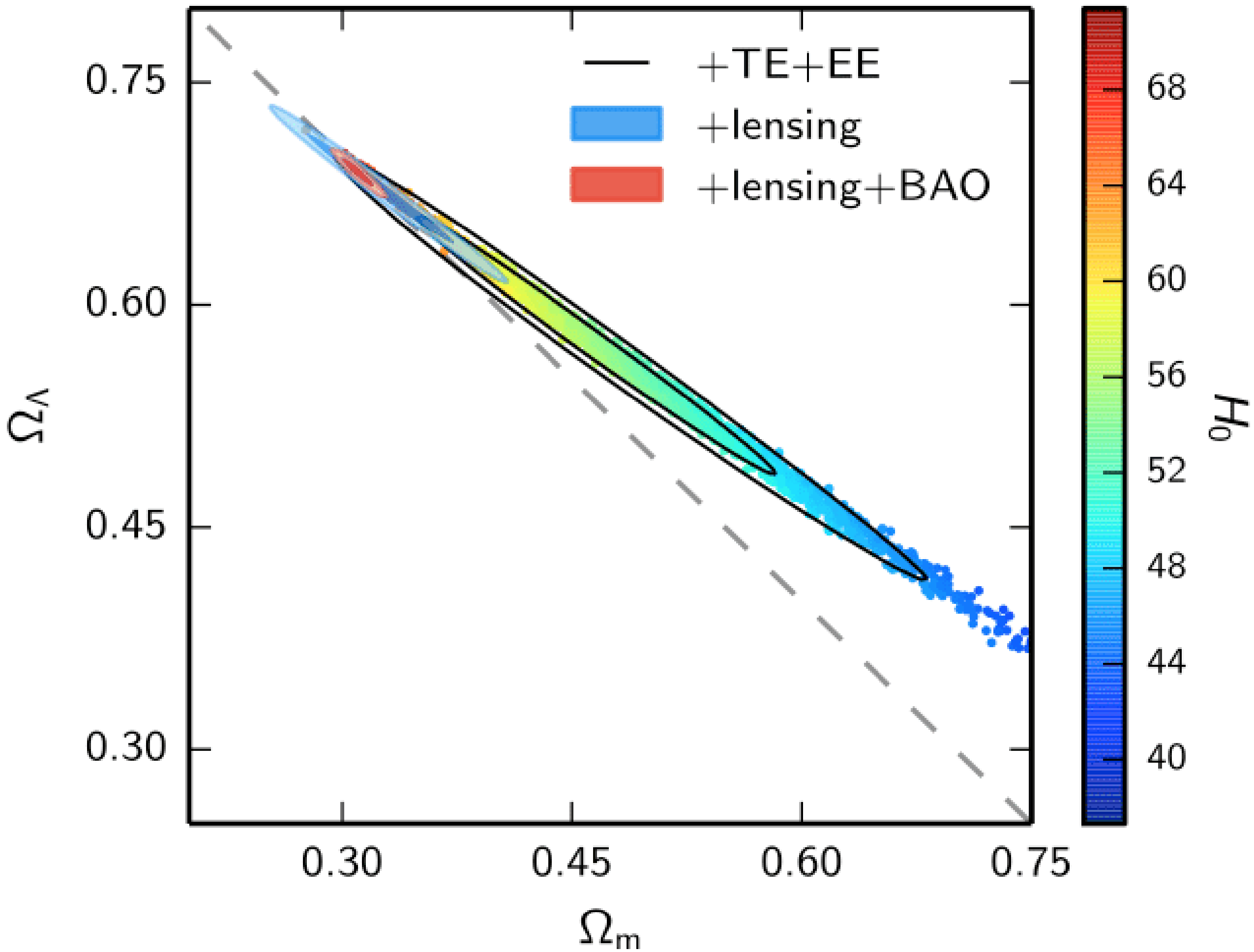
- Derived from the LFI data



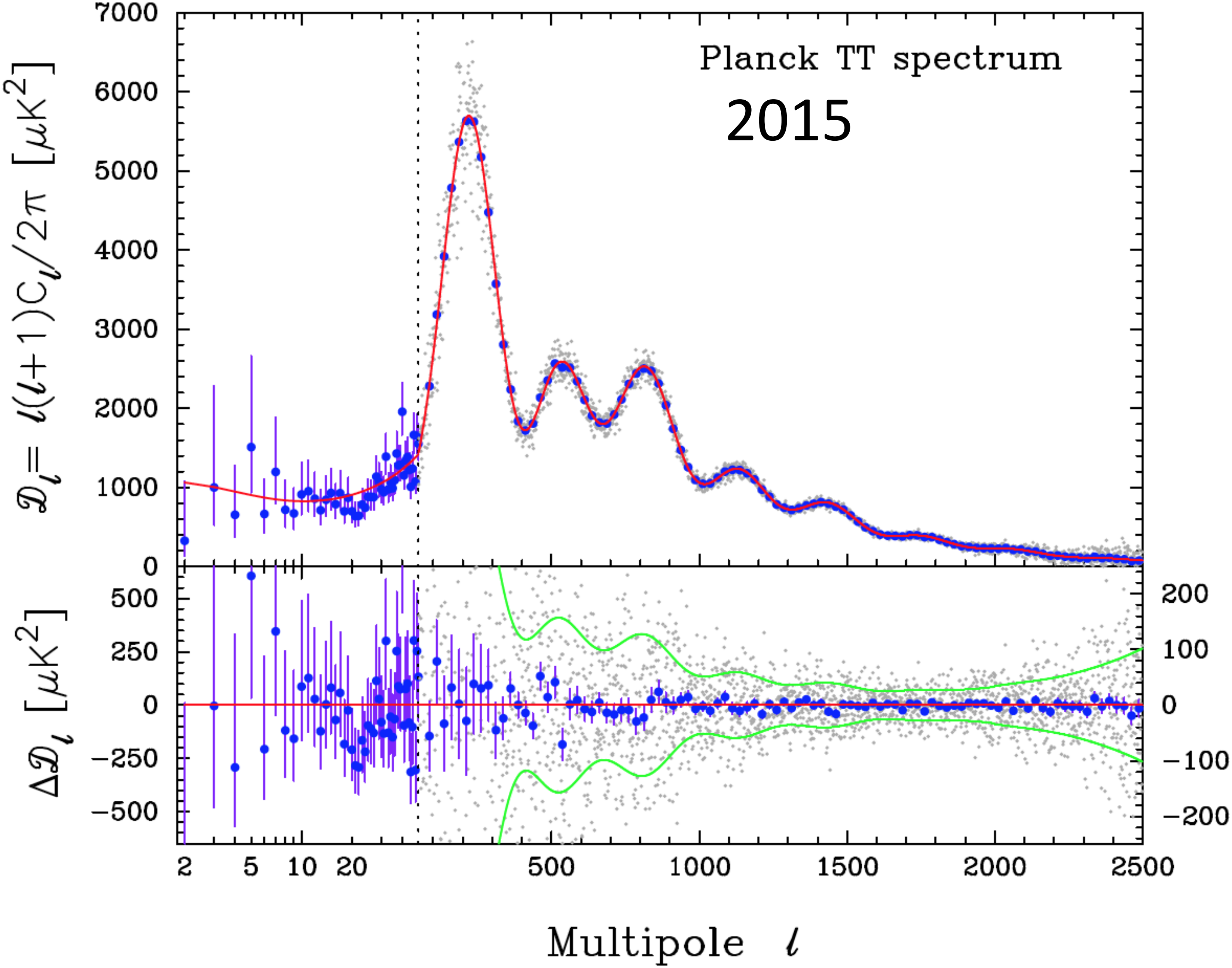
Magnetic field lines derived from interstellar dust polarization



CMB geometric degeneracy

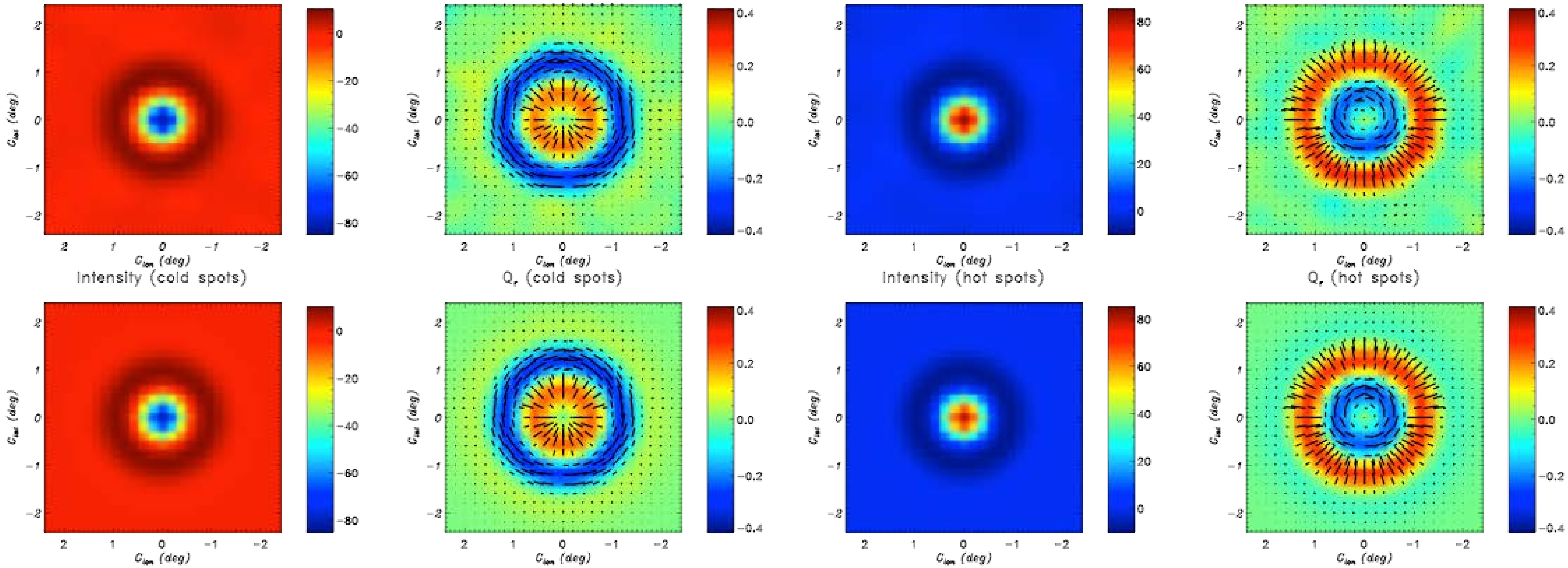


- CMB alone cannot measure accurately the parameters without the assumption of flat space
- having enough sensitivity to measure CMB lensing gives a constraint on the late evolution
- adding BAO removes completely the need for the flat space prior



Planck TT spectrum
2015
$\mathcal{D}_\ell = \ell(\ell+1)C_\ell/2\pi\ [\mu K^2]$
$\Delta\mathcal{D}_\ell\ [\mu K^2]$
Multipole ℓ

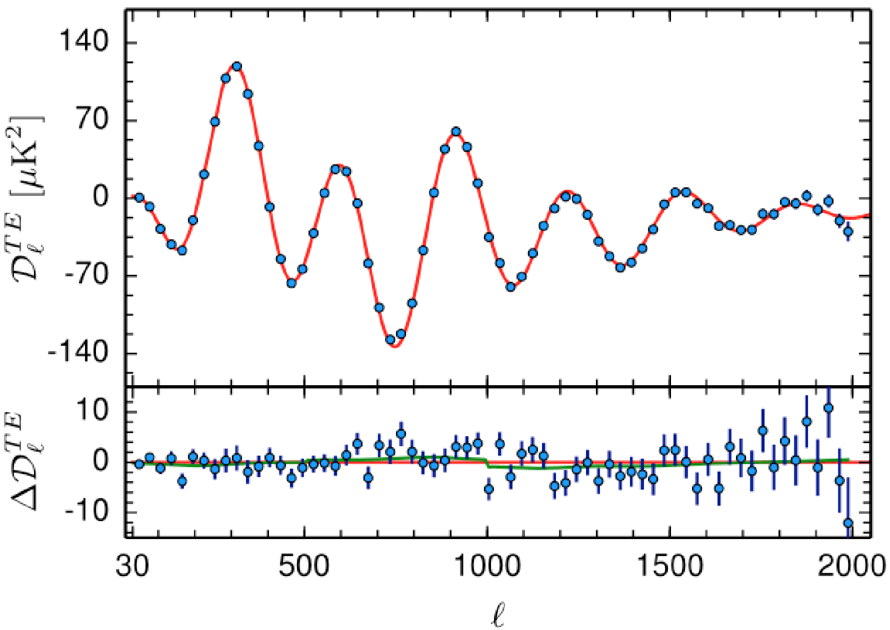
stacking of Planck polarization on T peaks and troughs

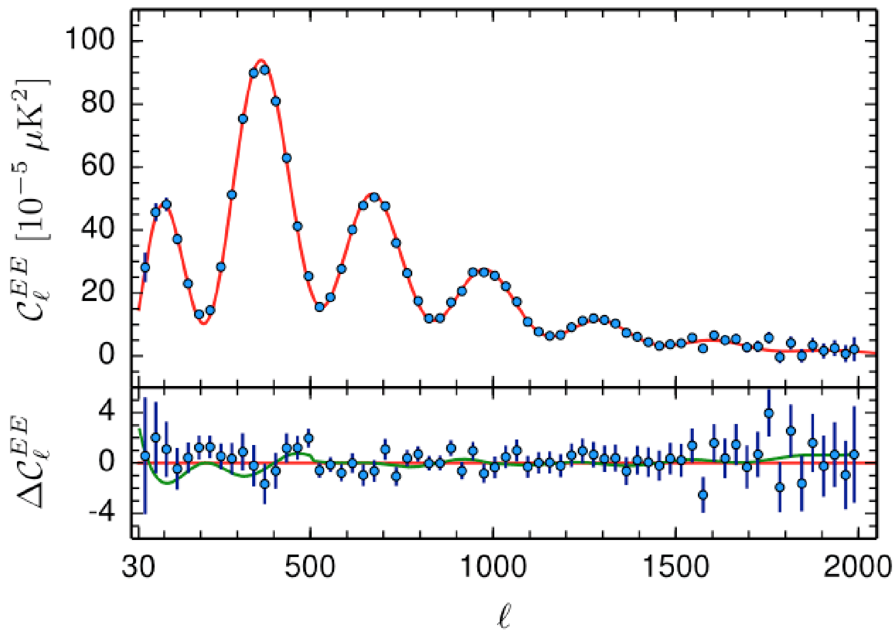


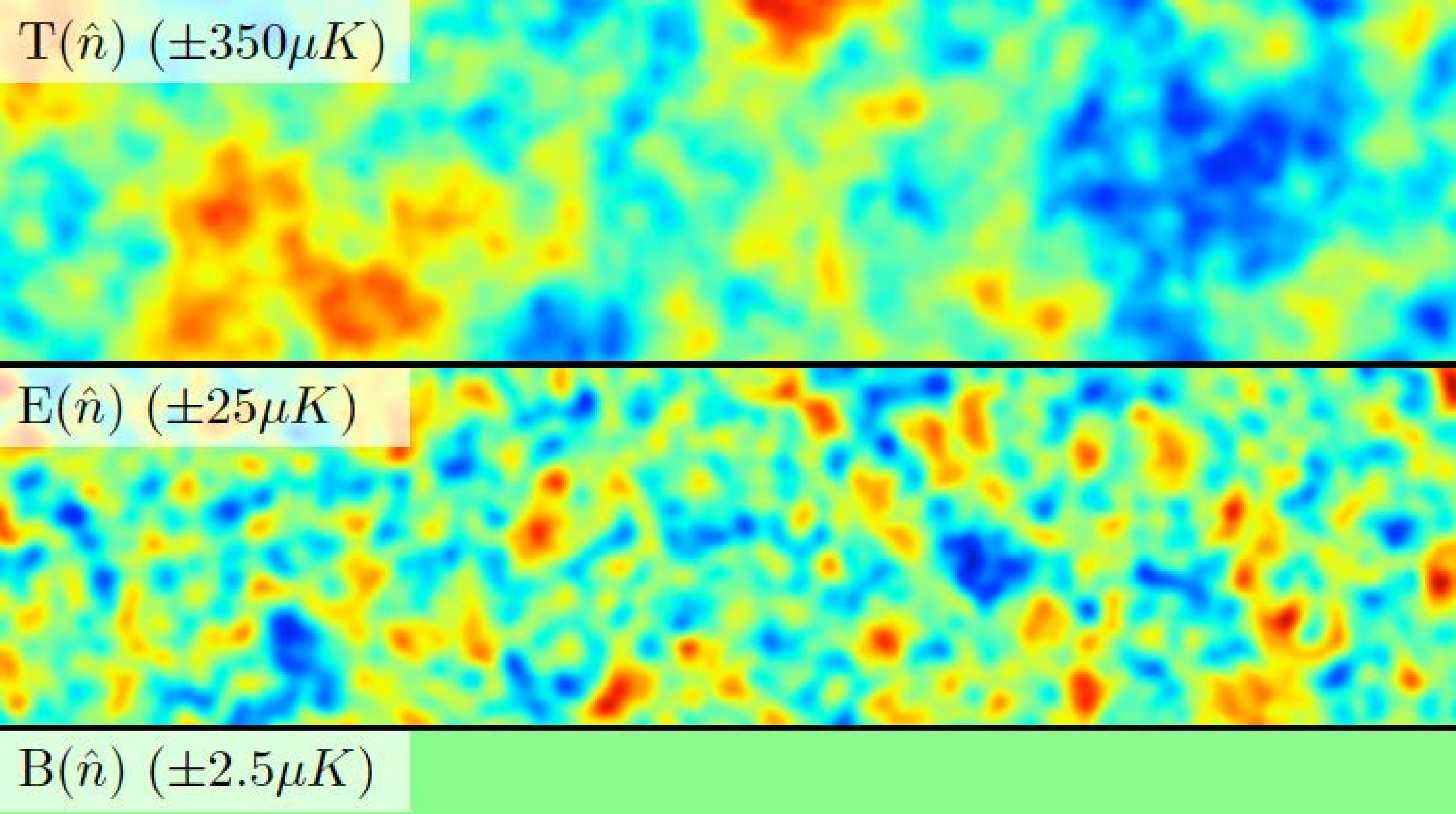
Polarization

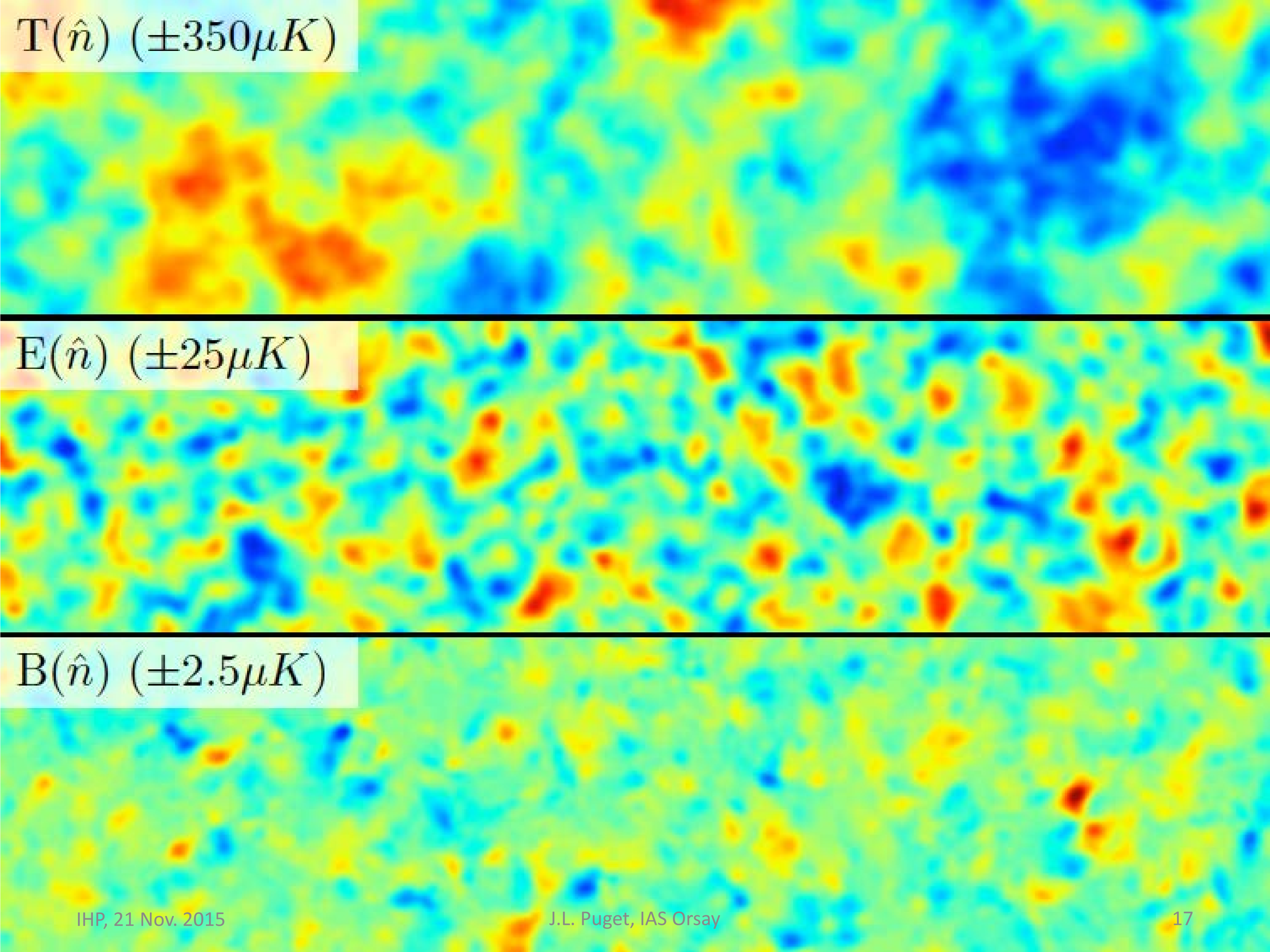
- use of TT or add TE gives models differing by < 0.5 ♦
- need either WMAP or Planck low ell EE or prior
-

- use of EE and their low ell part only is an almost independent model
- differences associated
  - with ♦
  - with recalibration of spectra



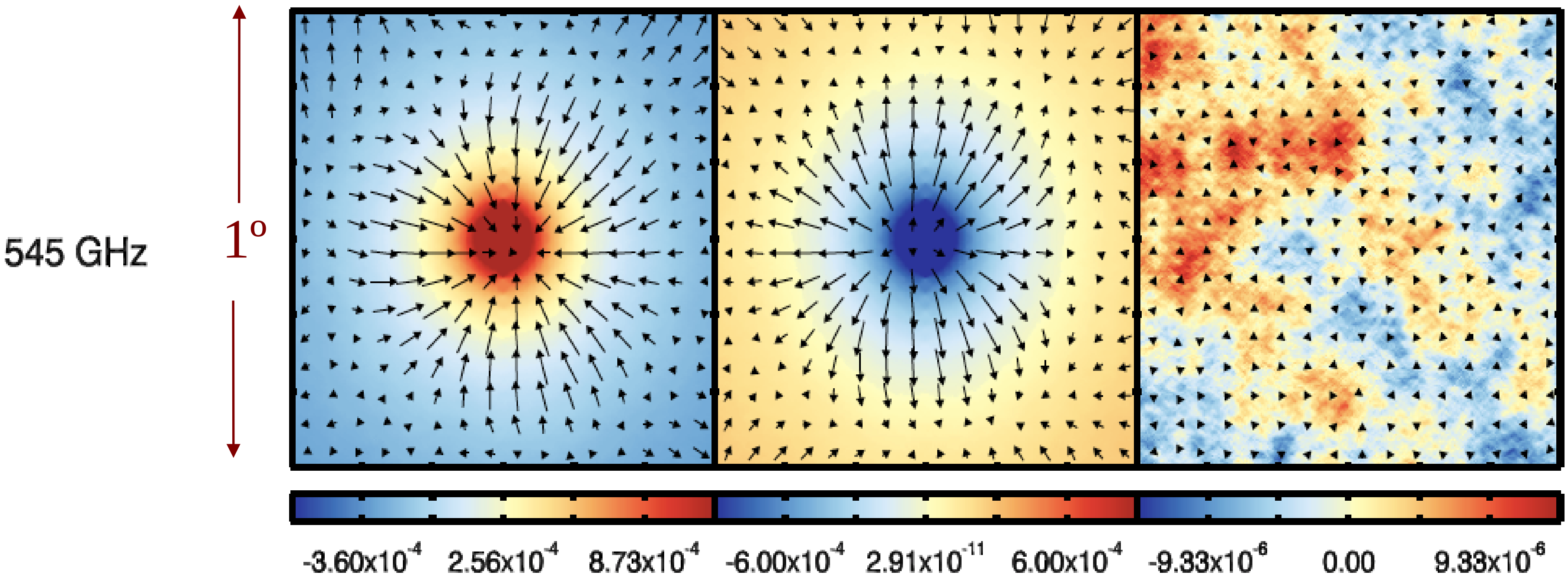



$T(\hat{n})$ $(\pm 350\mu K)$
$E(\hat{n})$ $(\pm 25\mu K)$
$B(\hat{n})$ $(\pm 2.5\mu K)$


$T(\hat{n})$ $(\pm 350\mu K)$
$E(\hat{n})$ $(\pm 25\mu K)$
$B(\hat{n})$ $(\pm 2.5\mu K)$

stacking the lensing displacement mini-maps on the CIB peaks

Stacking the Planck mass maps at the positions of peaks and troughs of Cosmic Infrared Background leads to a strong detection of the mass associated with these distant star forming galaxies. This is mostly Dark Matter,



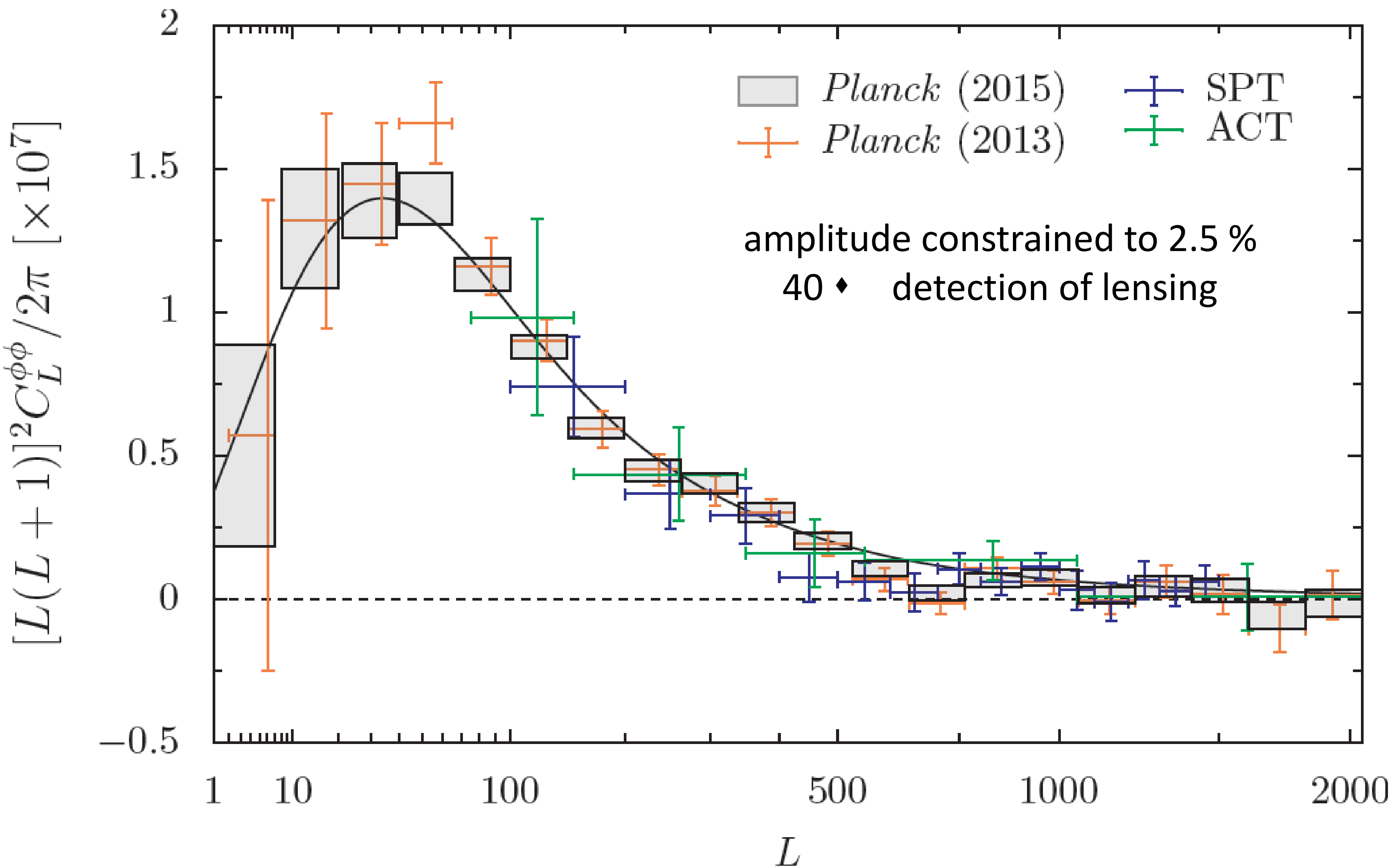
Planck foregrounds| S.White| Paris | 21.3.2013 | Planck press conf | Pag. 18

Temperature vs Polarization

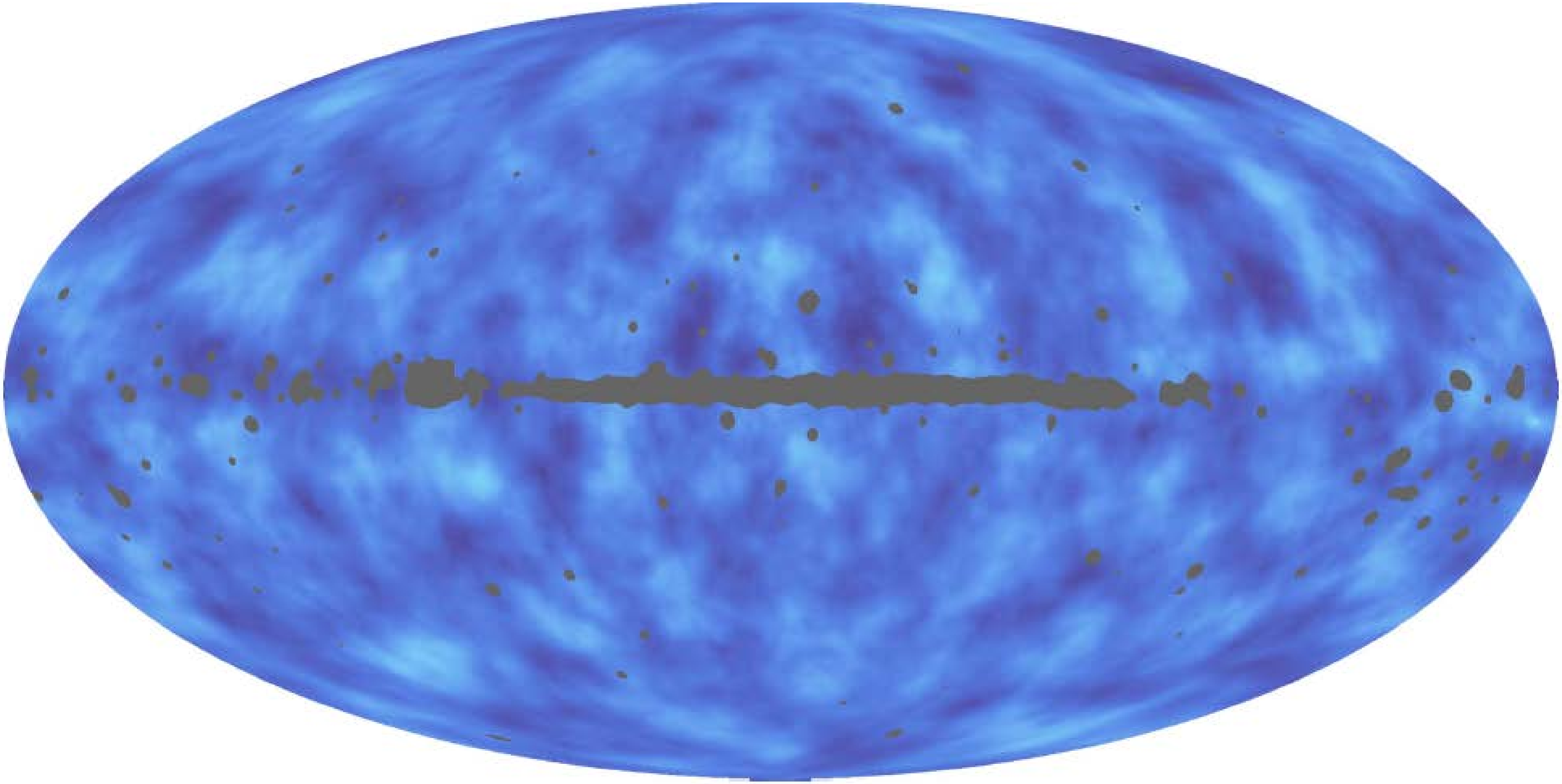
Parameter	[1] *Planck* TT+lowP	[4] *Planck* TT,TE,EE+lowP	$([1]-[4])/\sigma_{[1]}$
$\Omega_b h^2$	0.02222 ± 0.00023	0.02225 ± 0.00016	-0.1
$\Omega_c h^2$	0.1197 ± 0.0022	0.1198 ± 0.0015	0.0
$100\theta_{MC}$	1.04085 ± 0.00047	1.04077 ± 0.00032	0.2
τ	0.078 ± 0.019	0.079 ± 0.017	-0.1
$\ln(10^{10}A_s)$	3.089 ± 0.036	3.094 ± 0.034	-0.1
n_s	0.9655 ± 0.0062	0.9645 ± 0.0049	0.2
H_0	67.31 ± 0.96	67.27 ± 0.66	0.0
Ω_m	0.315 ± 0.013	0.3156 ± 0.0091	0.0
σ_8	0.829 ± 0.014	0.831 ± 0.013	0.0
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.882 ± 0.012	-0.1

- note the degeneracy A_s – ♦ : $10^9 A_s e^{-2\tau}$ is very well measured
- lensing can break the degeneracy
- best way is to use large angular scales E modes
-

lensing power spectrum

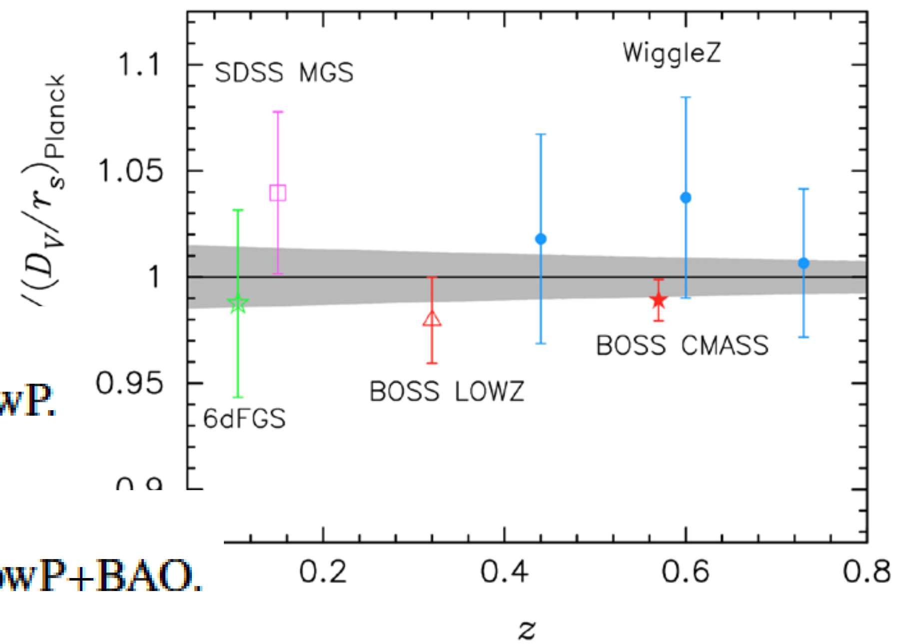


Wiener filtered lensing potential



Astrophysical cosmology measurements vs Planck best model

Acoustic-scale distance ratio



- BAO
  - Baryonic acoustic oscillations are geometric measurements in the line-of-sight and in the transverse direction

$$\left.\begin{aligned} H_0 &= (67.3 \pm 1.0)\ \mathrm{km\ s^{-1}Mpc^{-1}} \\ \Omega_m &= 0.315 \pm 0.013 \end{aligned}\right\} \textit{Planck}\ \mathrm{TT{+}lowP.}$$

$$\left.\begin{aligned} H_0 &= (67.6 \pm 0.6)\ \mathrm{km\ s^{-1}Mpc^{-1}} \\ \Omega_m &= 0.310 \pm 0.008 \end{aligned}\right\} \textit{Planck}\ \mathrm{TT{+}lowP{+}BAO.}$$

- H0
  - from Planck TT: 67.3 +-1 Km/s/Mpc
  - adding BAO: 67.6 +-0.6
  - revision by Efstathiou 2014 of Reiss 2011 with revised maser for NGC4258: 73.8 → 70.6
  - the tension with Freedman 2012(74.3) and Bennet 2014 (73.0) remains and even increases with the full mission data

Primordial universe

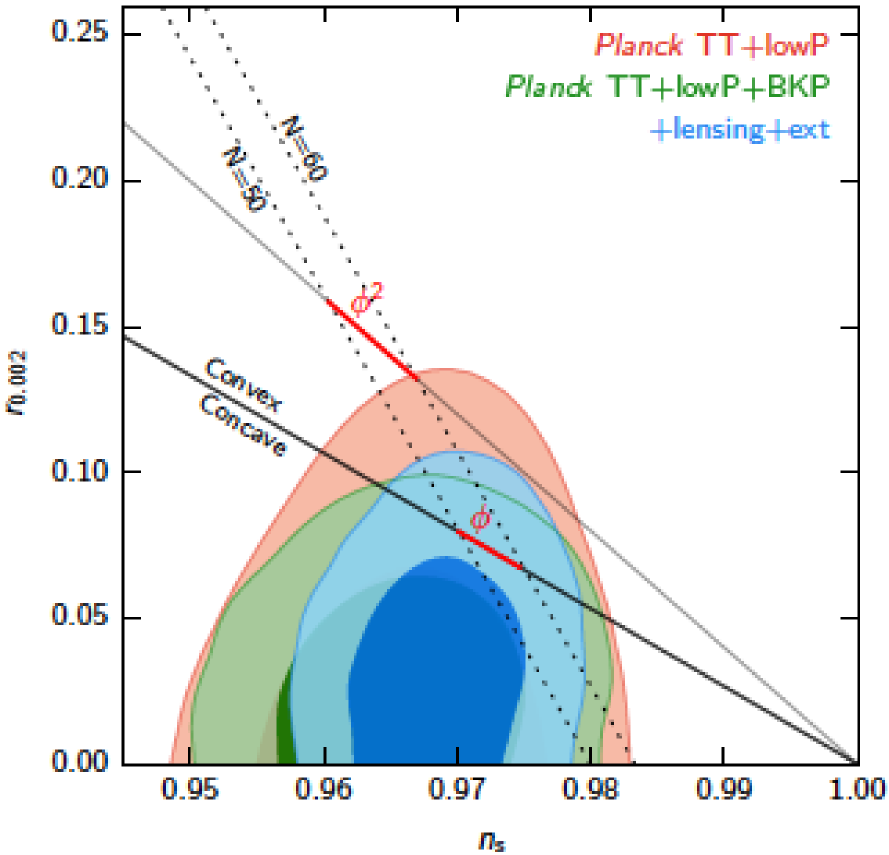
- testing the predictions of the quantum origin of fluctuations
- Ω_K= -0.052 +-0.05 TT Planck alone,
- $\Omega_K = -0.005^{+0.016}_{-0.017}$ (95%, *Planck* TT+lowP+lensing).
- Ω_K= -0.0008 +-0.004 (combining Planck and external data) space is flat
- n_s= 0.9645 +-0.0049 deviation from scale invariance 7.2 ♦

Inflation related parameters

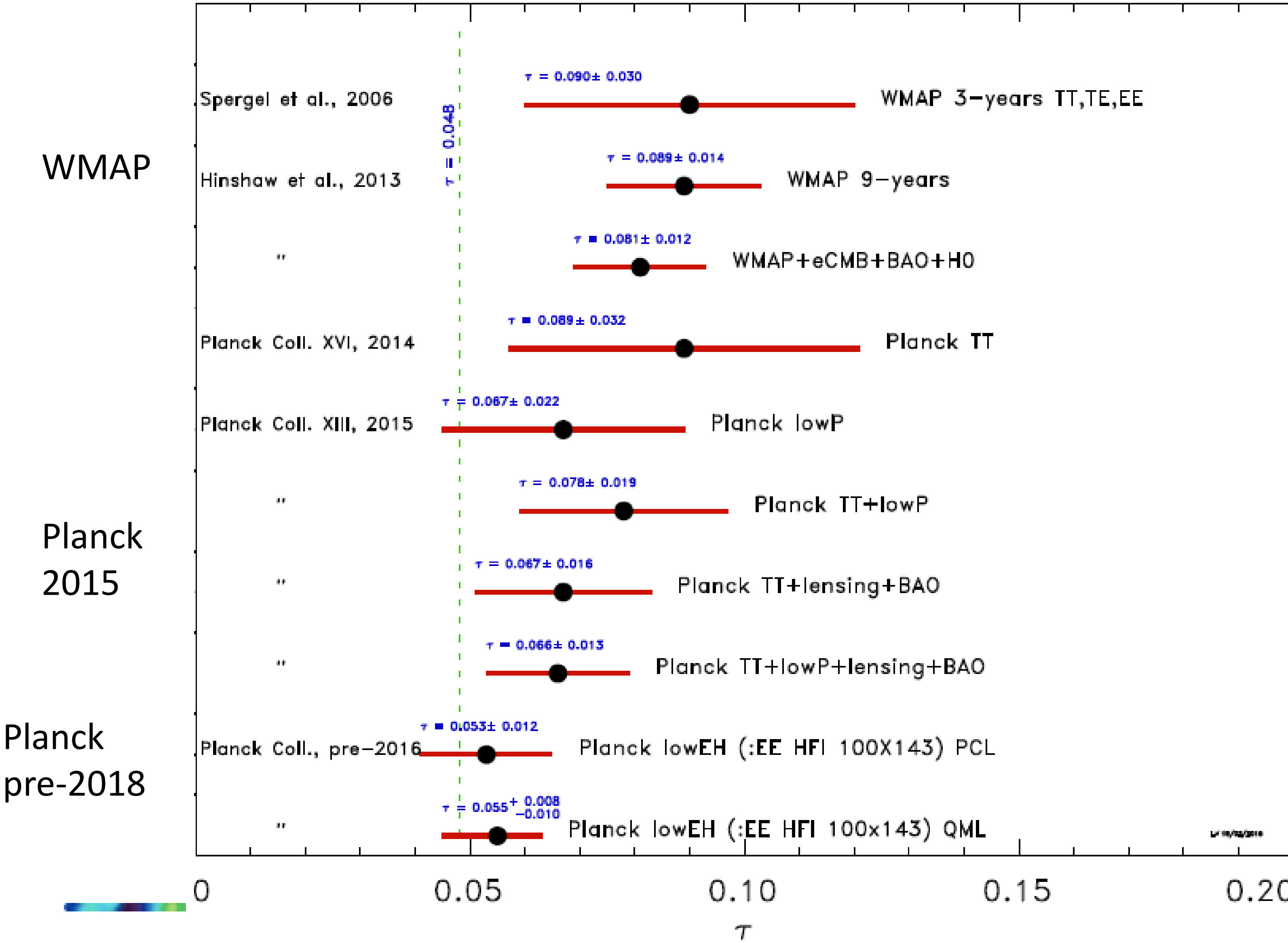
- Planck alone $r_{0.002} < 0.11$
- Bicep2-Keck-Planck (95%)

$$r_{0.002} < 0.08, \quad \textit{Planck}\ \mathrm{TT{+}lowP{+}BKP},$$
$$r_{0.002} < 0.09, \quad \textit{Planck}\ \mathrm{TT{+}lowP{+}lensing{+}ext{+}BKP}.$$

- illustration of sensitivity to extension 👎 Neff = 0.39

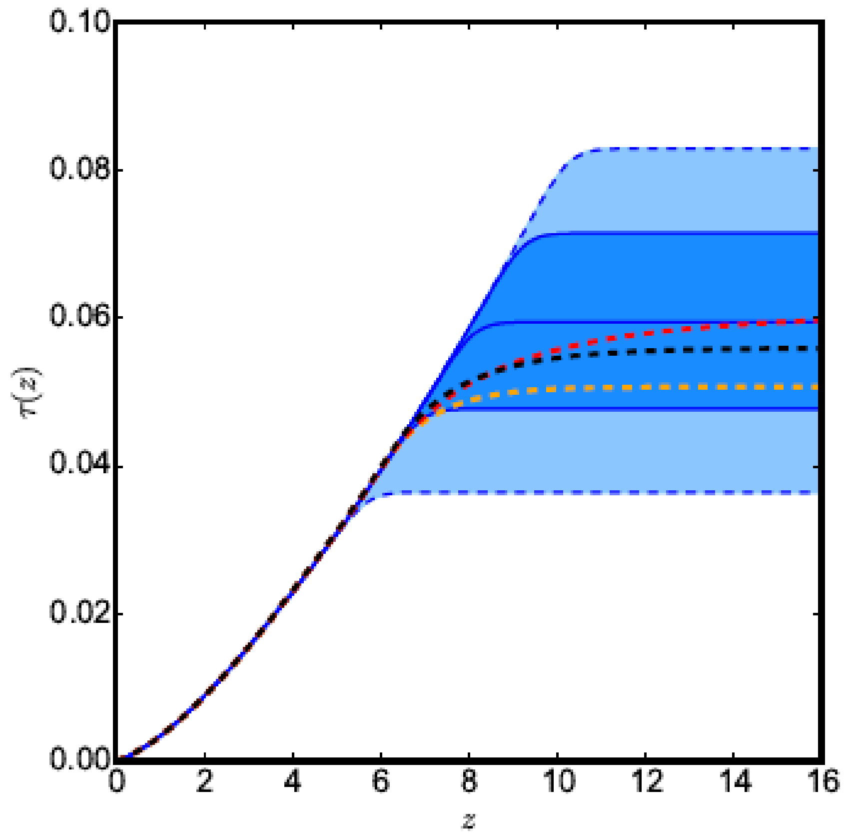


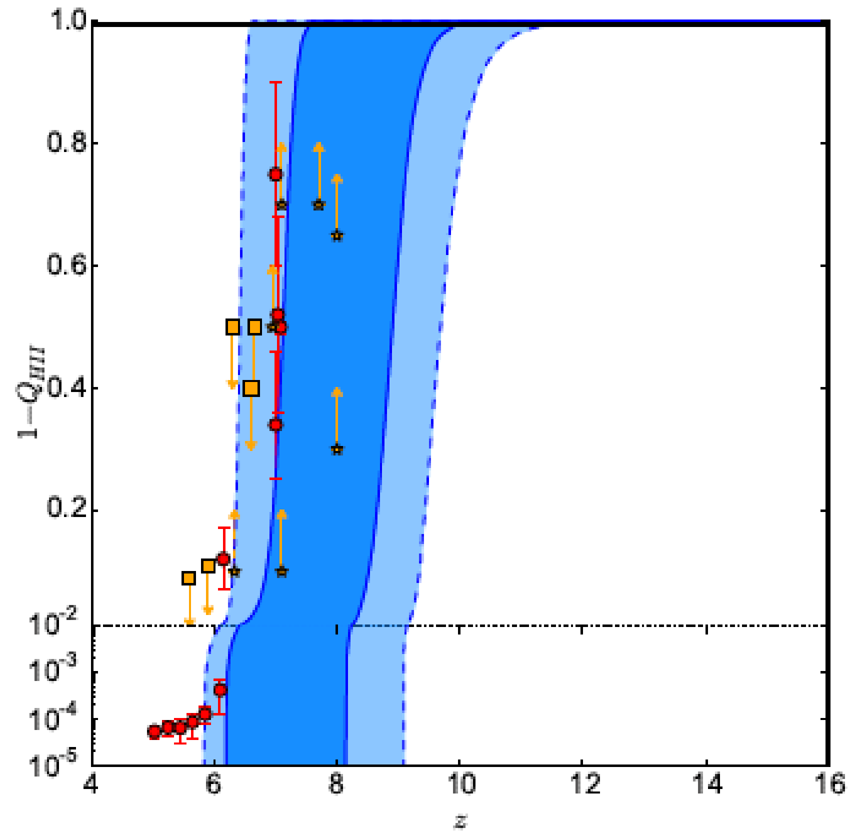
Reionization parameter τ from CMB (historical)



models of reionization

PRELIMINARY, soon on ArXiv

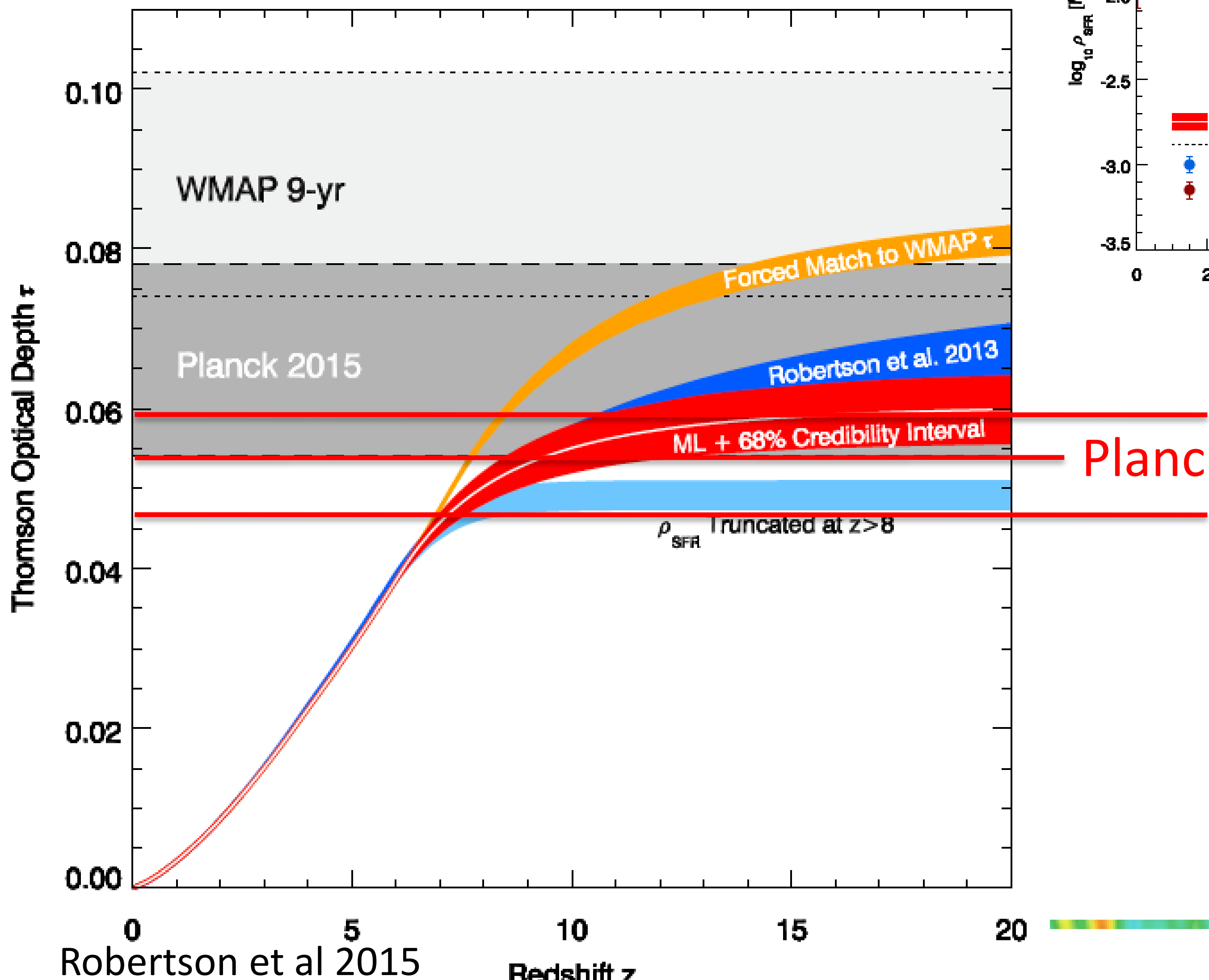




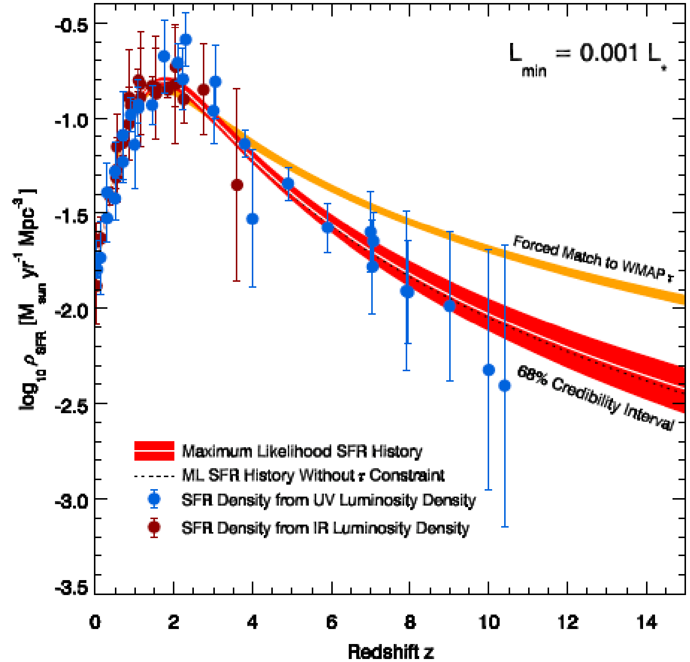
- CMB polarised EE
- high redshift sources
- HI 21cm
- other lines…

combined to constrain the first sources history

models of reionisation based on the high redshift sources observations with the new Planck constraints



Planck pre 2016



Robertson et al 2015

BB power spectrum level

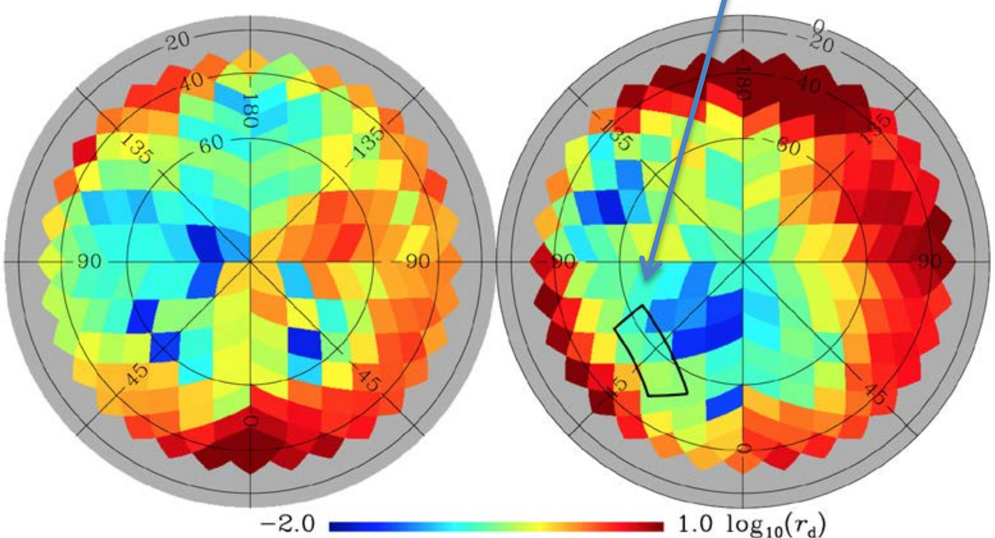
BICEP2 field

galactic magnetic field traced by the polarized dust emission

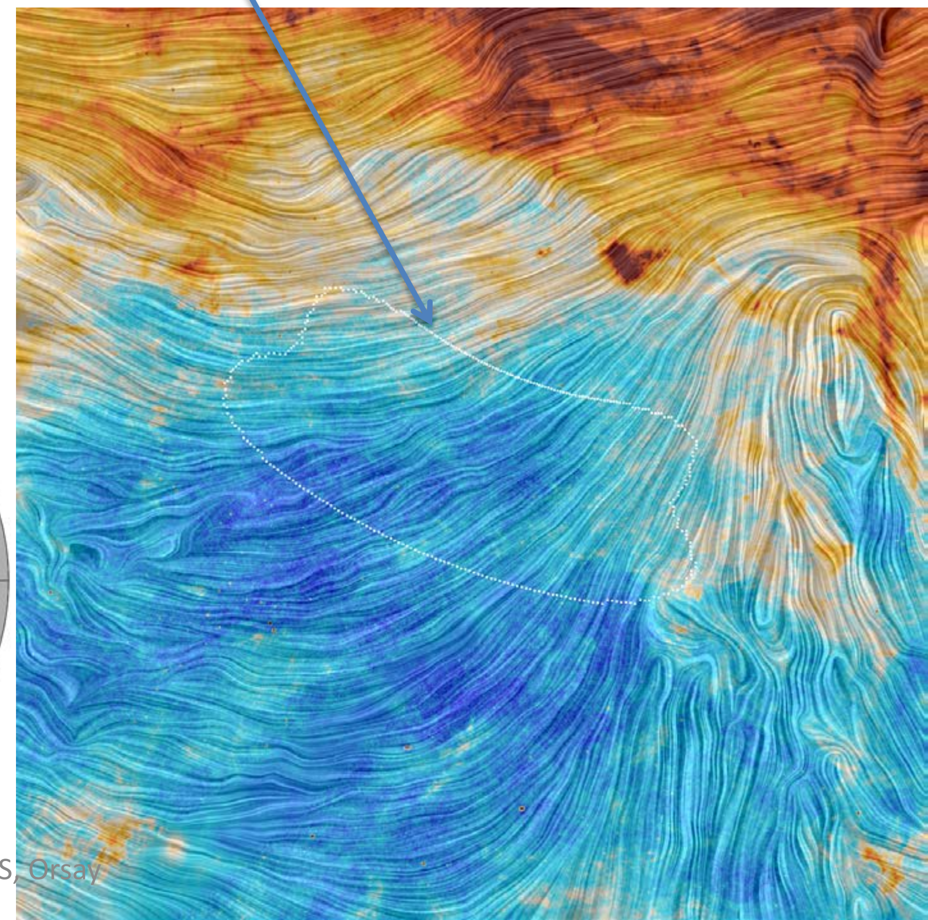
galactic poles

North

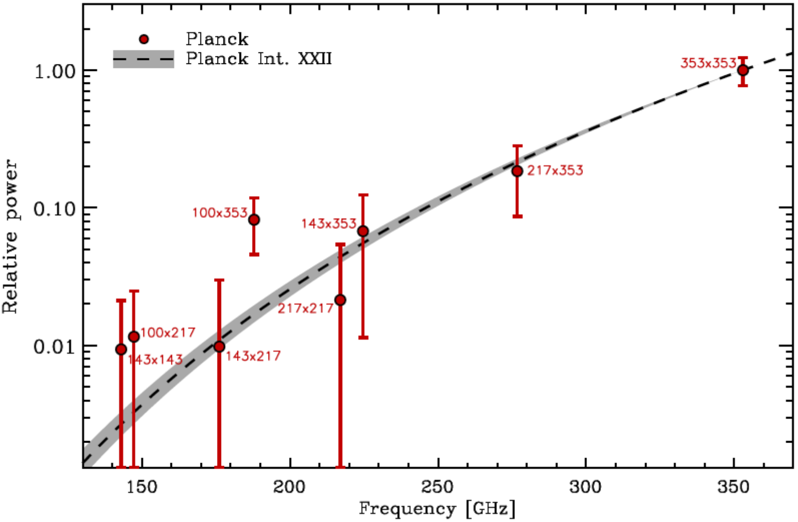
South

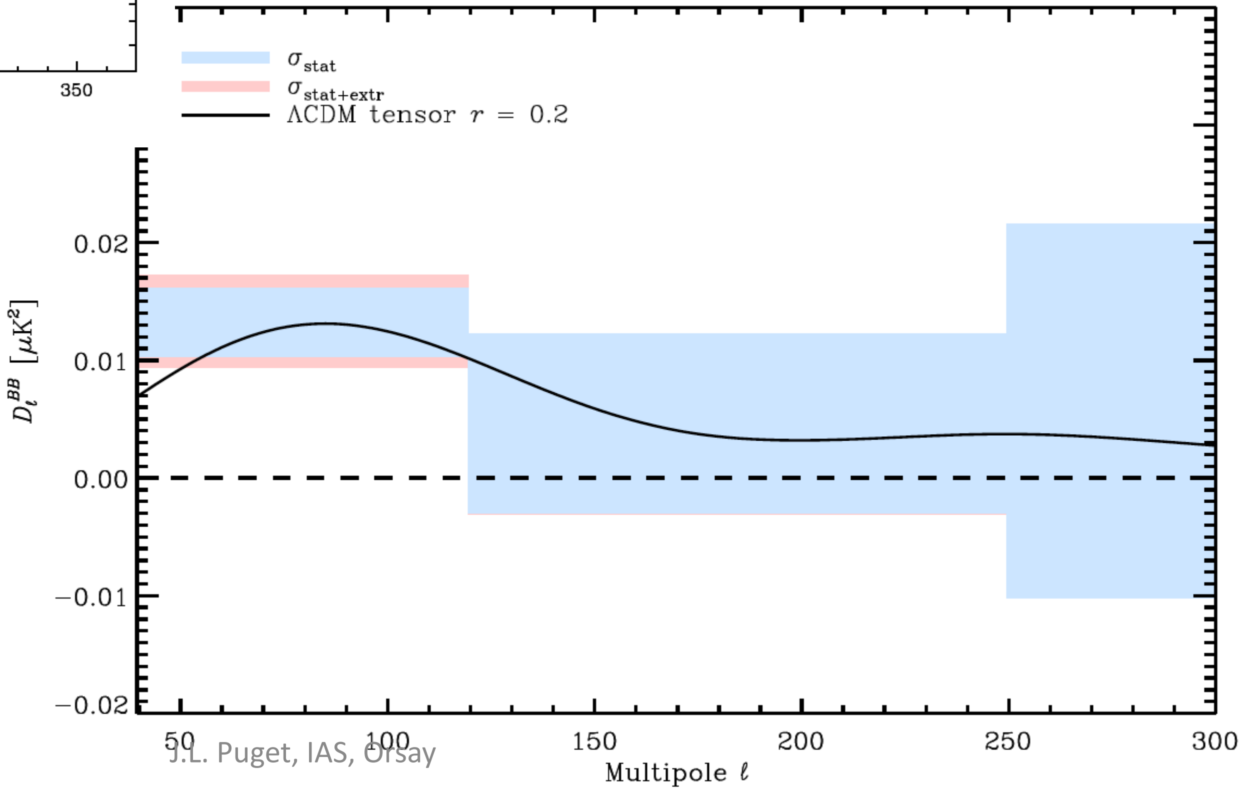


galactic coordinates



BICEP2 field: estimate of the dust contribution





Improving Planck HFI 353 GHz

- The Planck 353 GHz is the best all sky dust foreground tracer today
- we improve it by correcting systematic effects at very low ell
- for B-modes detection: limitation introduced the dust correction using 353 GHz assumed to be white noise limited