The World According to Planck

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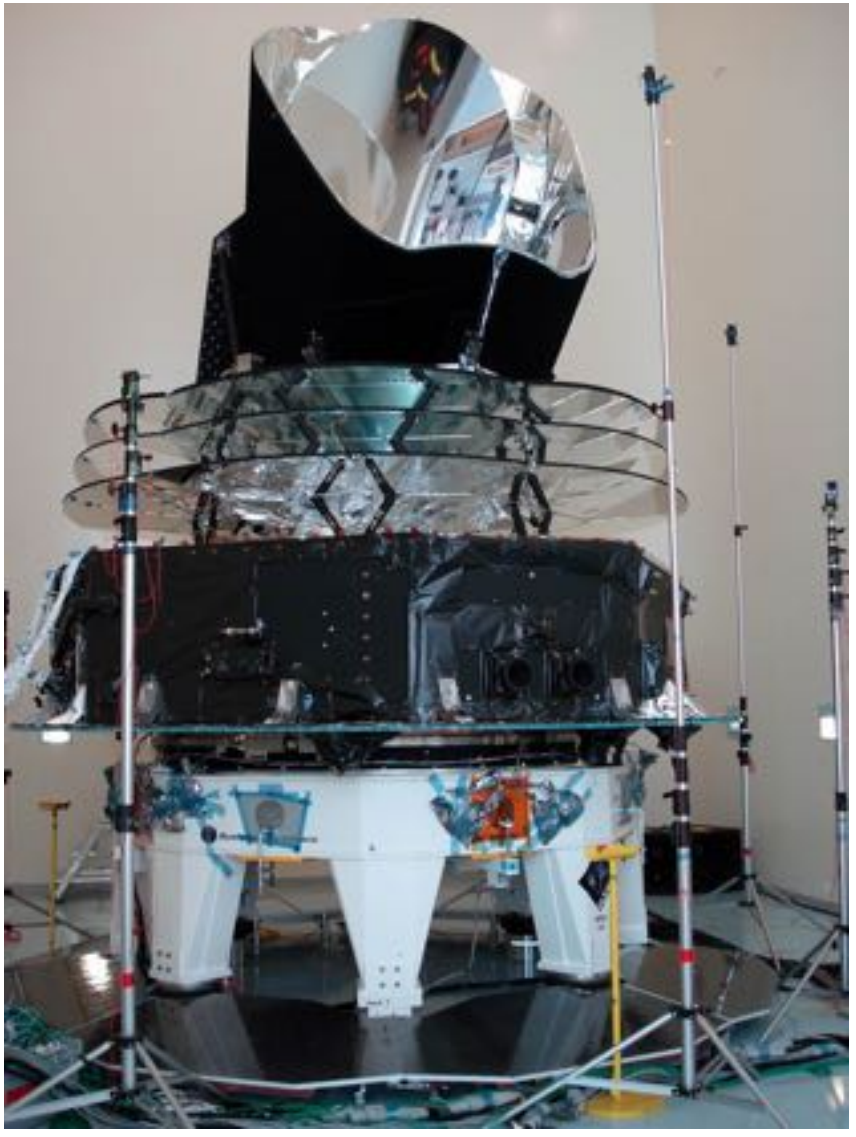
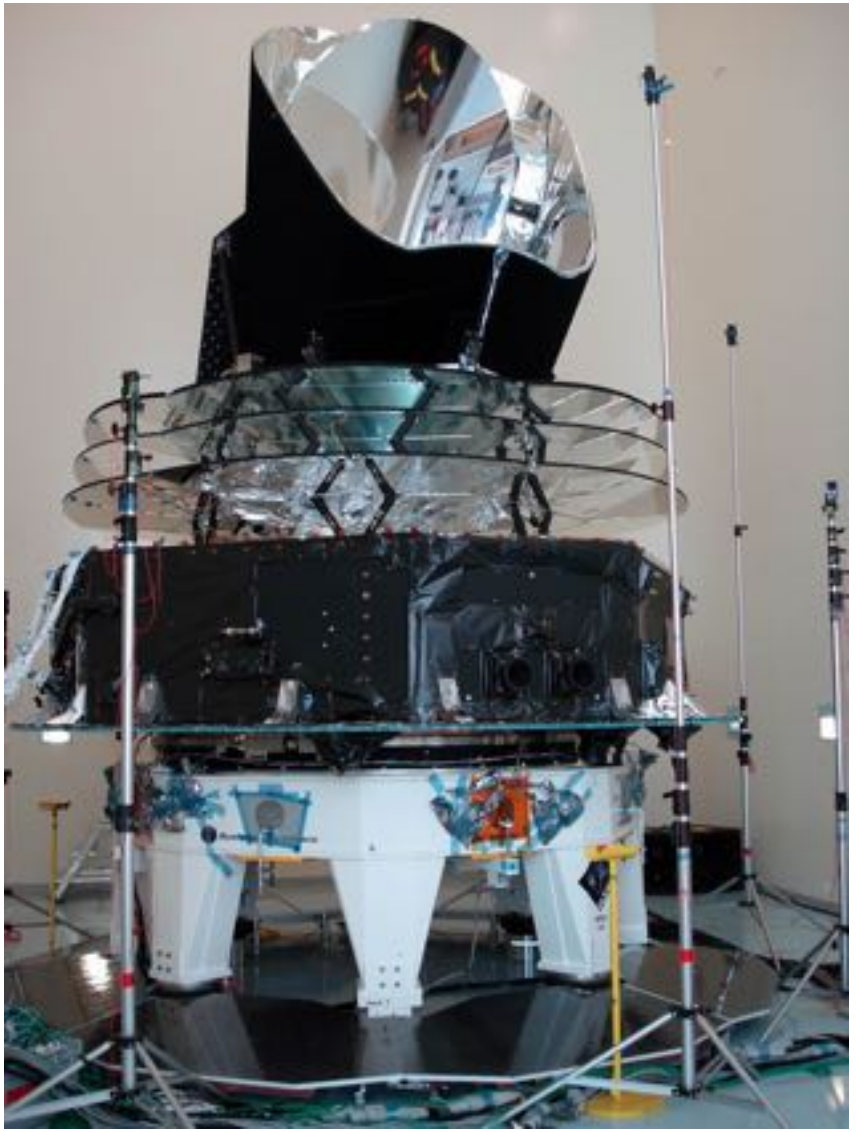
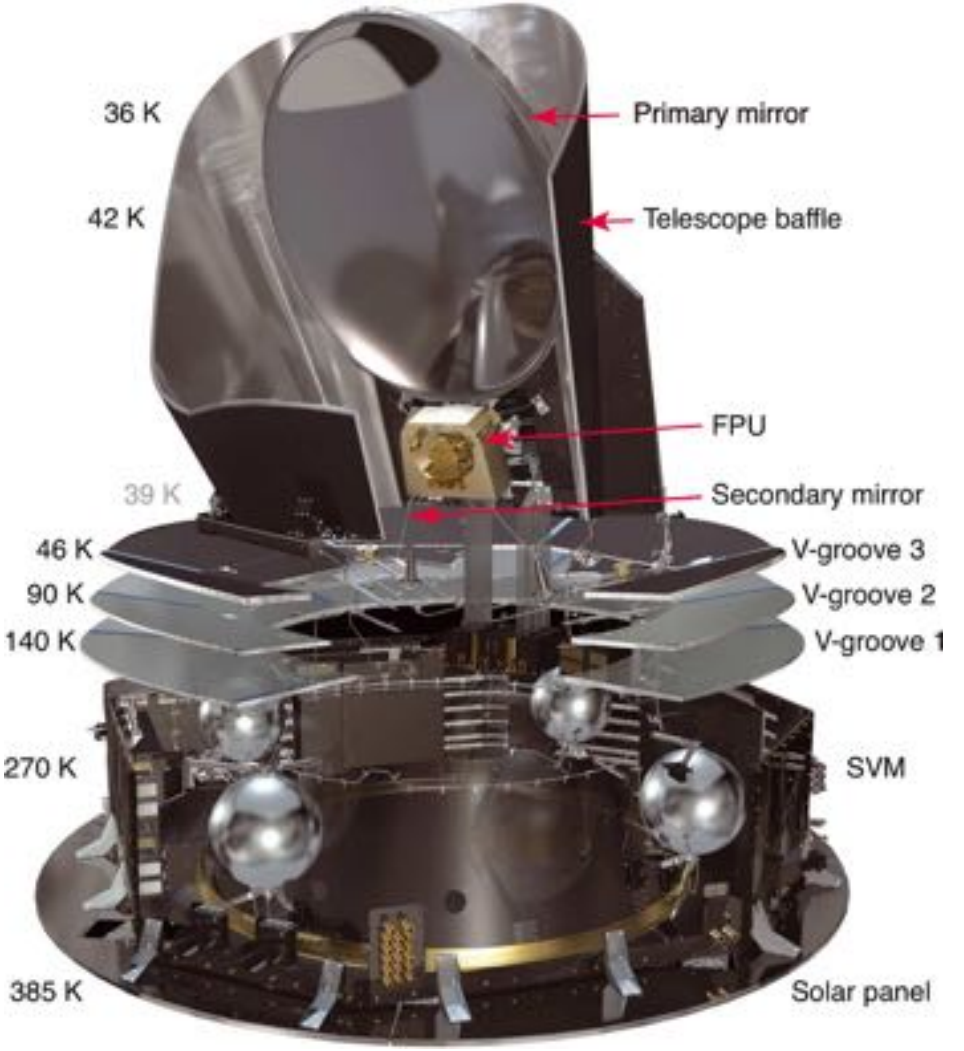
Planck, the spacecraft



Planck, the spacecraft

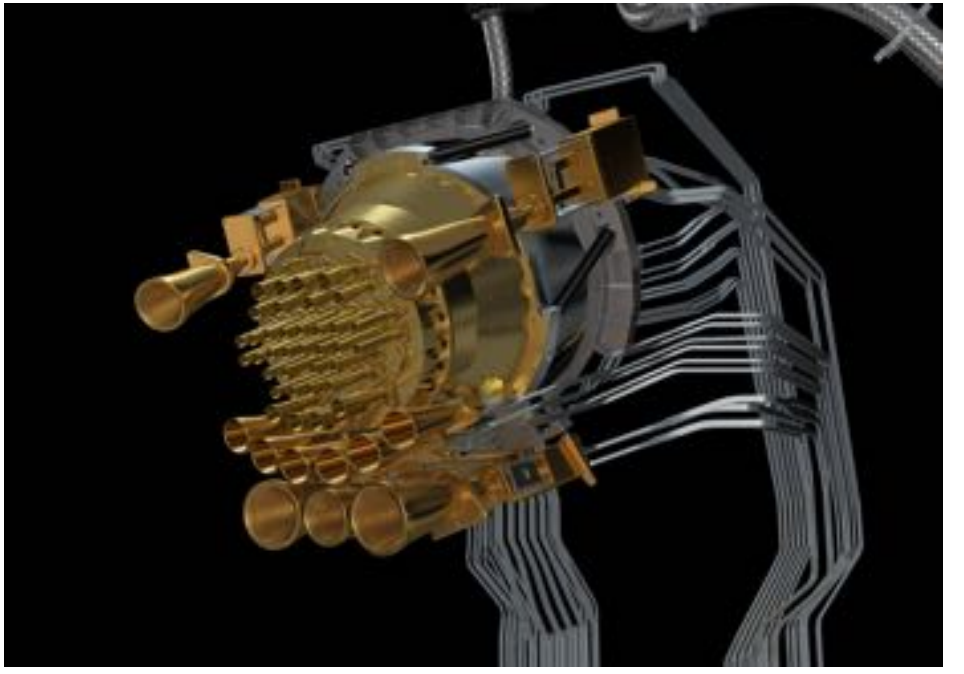




Tasks and design

Tasks:

- Map the microwave sky at 5′ angular resolution
- Near the quantum limit of the detectors
- In nine frequency bands from 30 – 857 GHz



- High-electron mobility transistors below 100 GHz (LFI)
- Bolometers above (HFI)

Operations

Kourou, May 14, 2009, 15:12 MESZ

Operations

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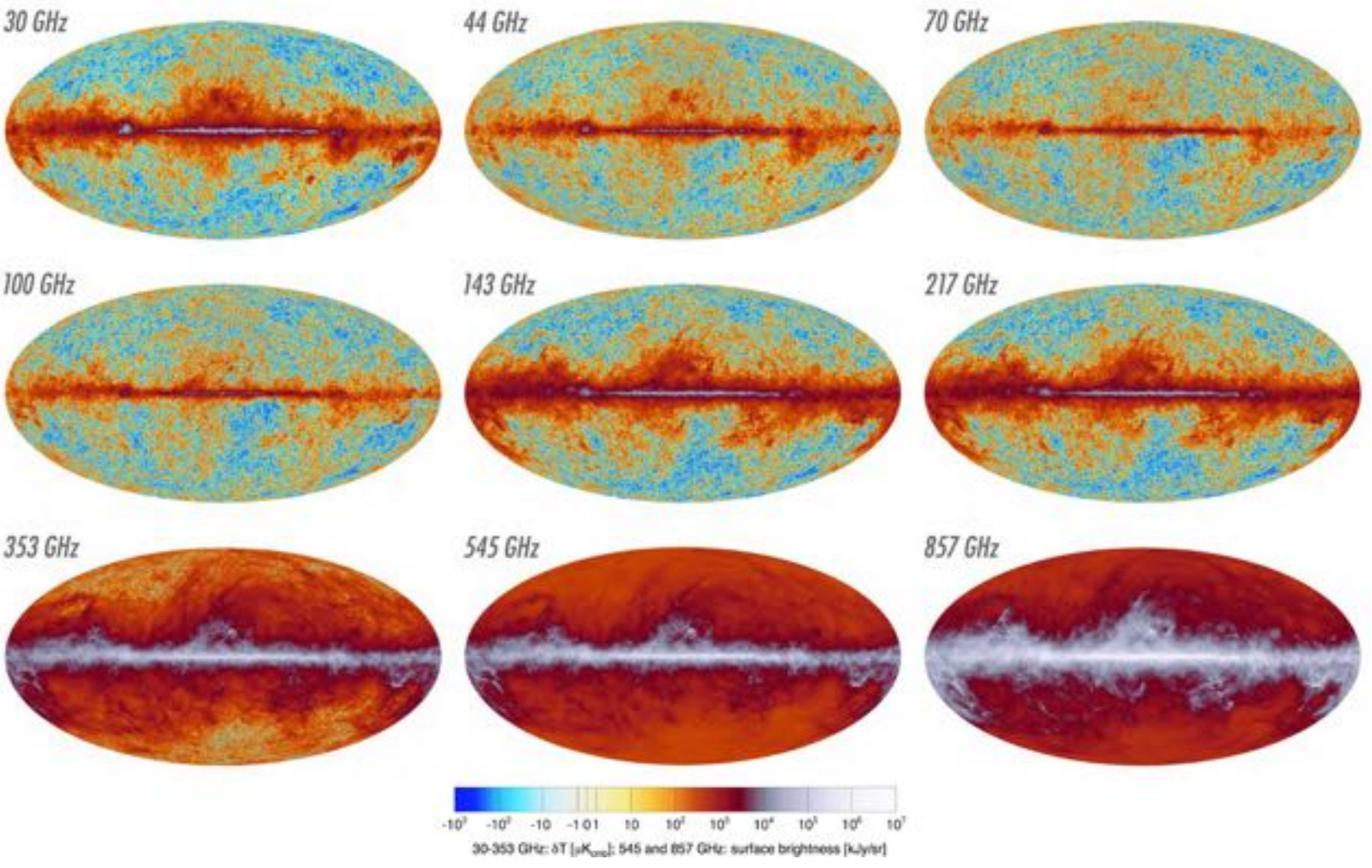
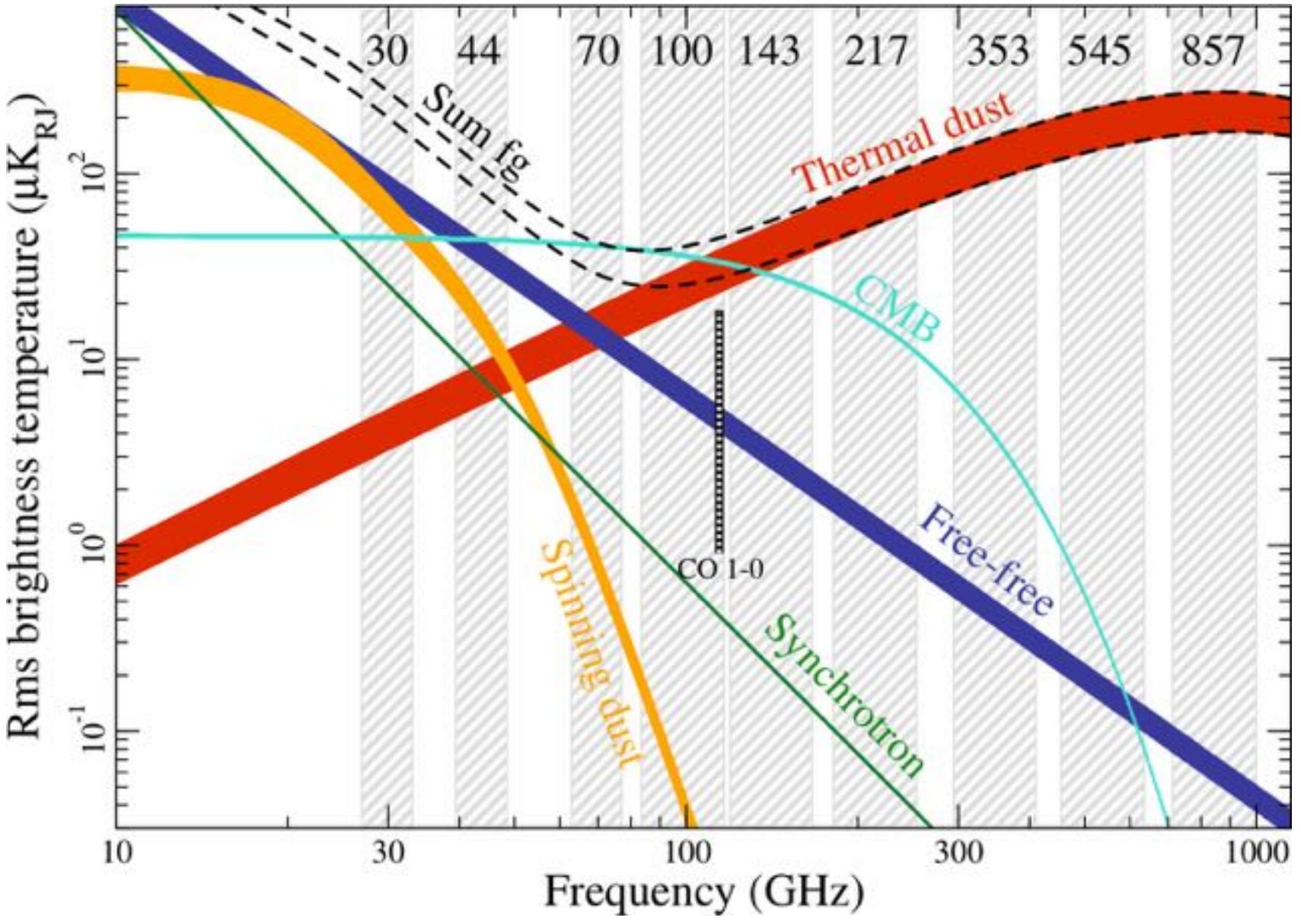
in operation between Aug. 13, 2009 and Oct. 23, 2013

Frequency maps



Component spectra



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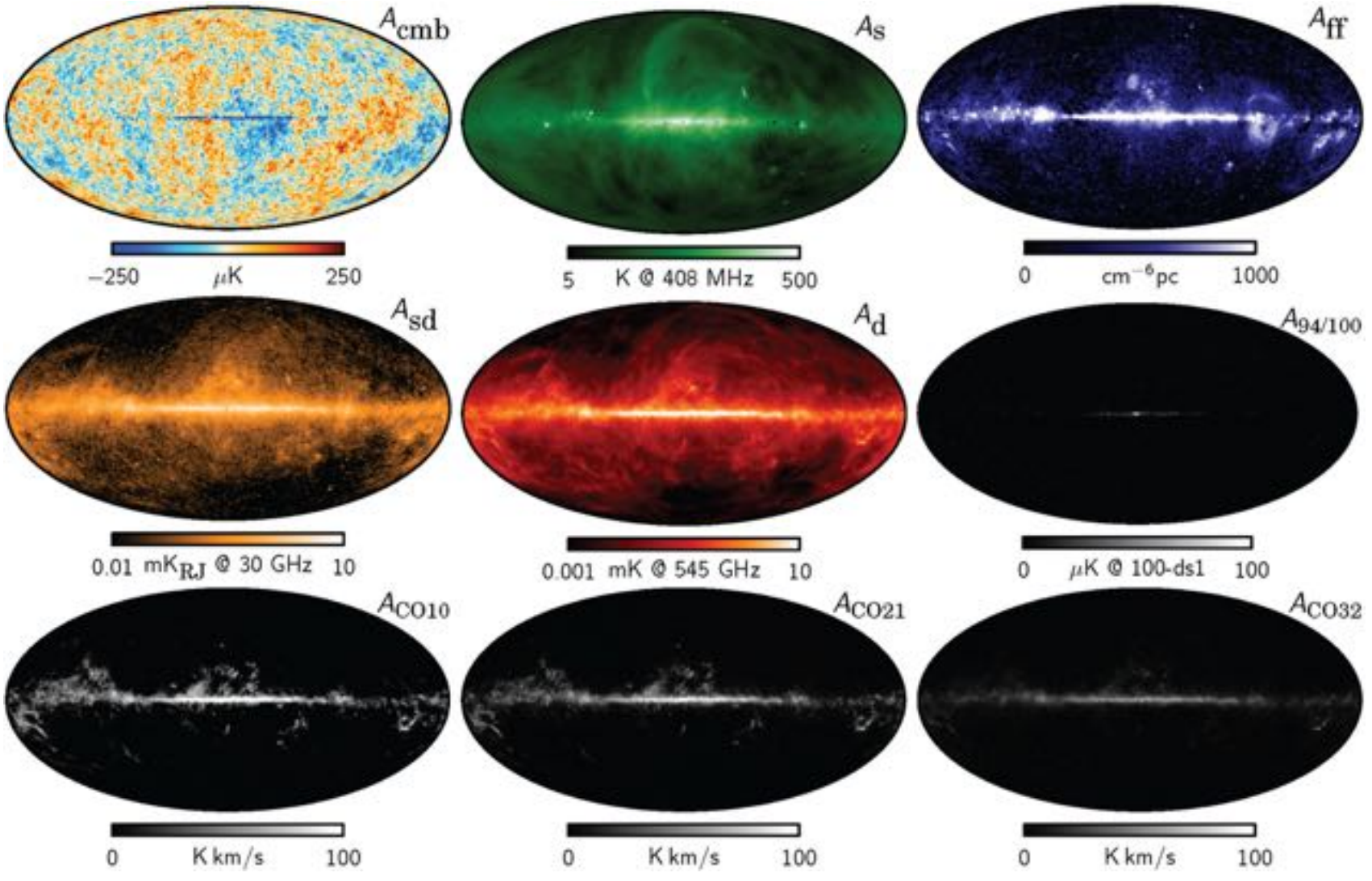
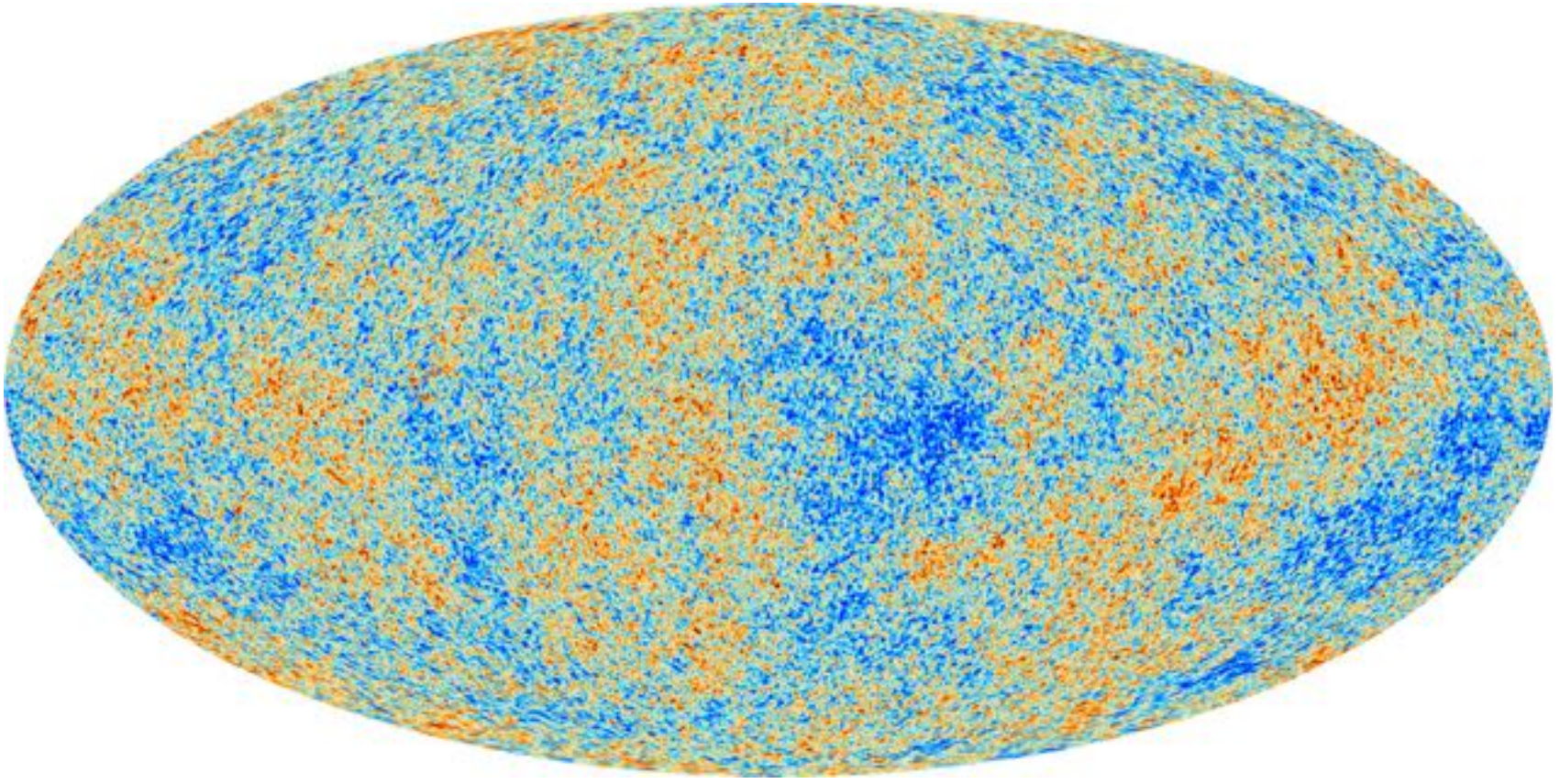
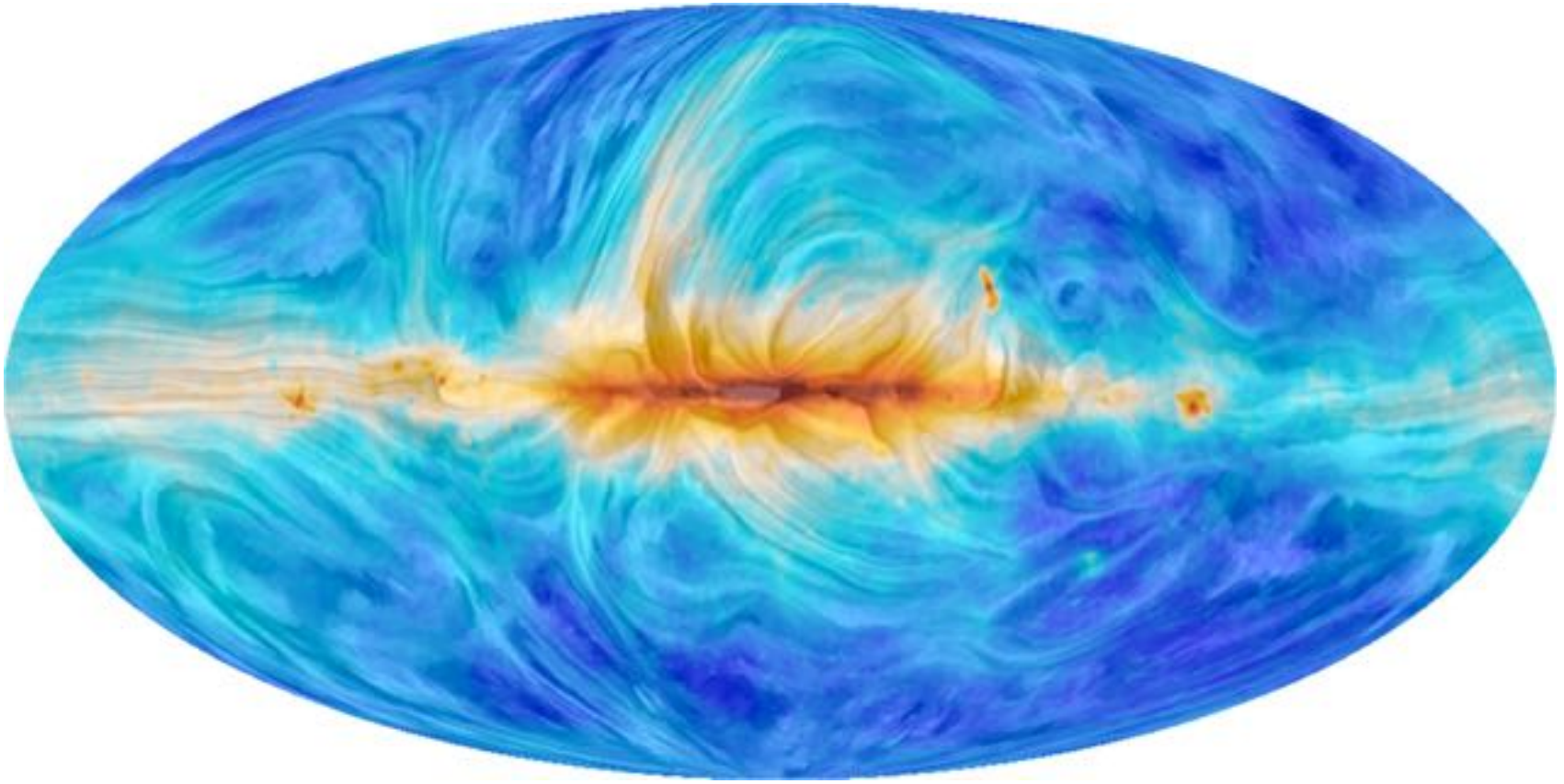


CMB temperature map



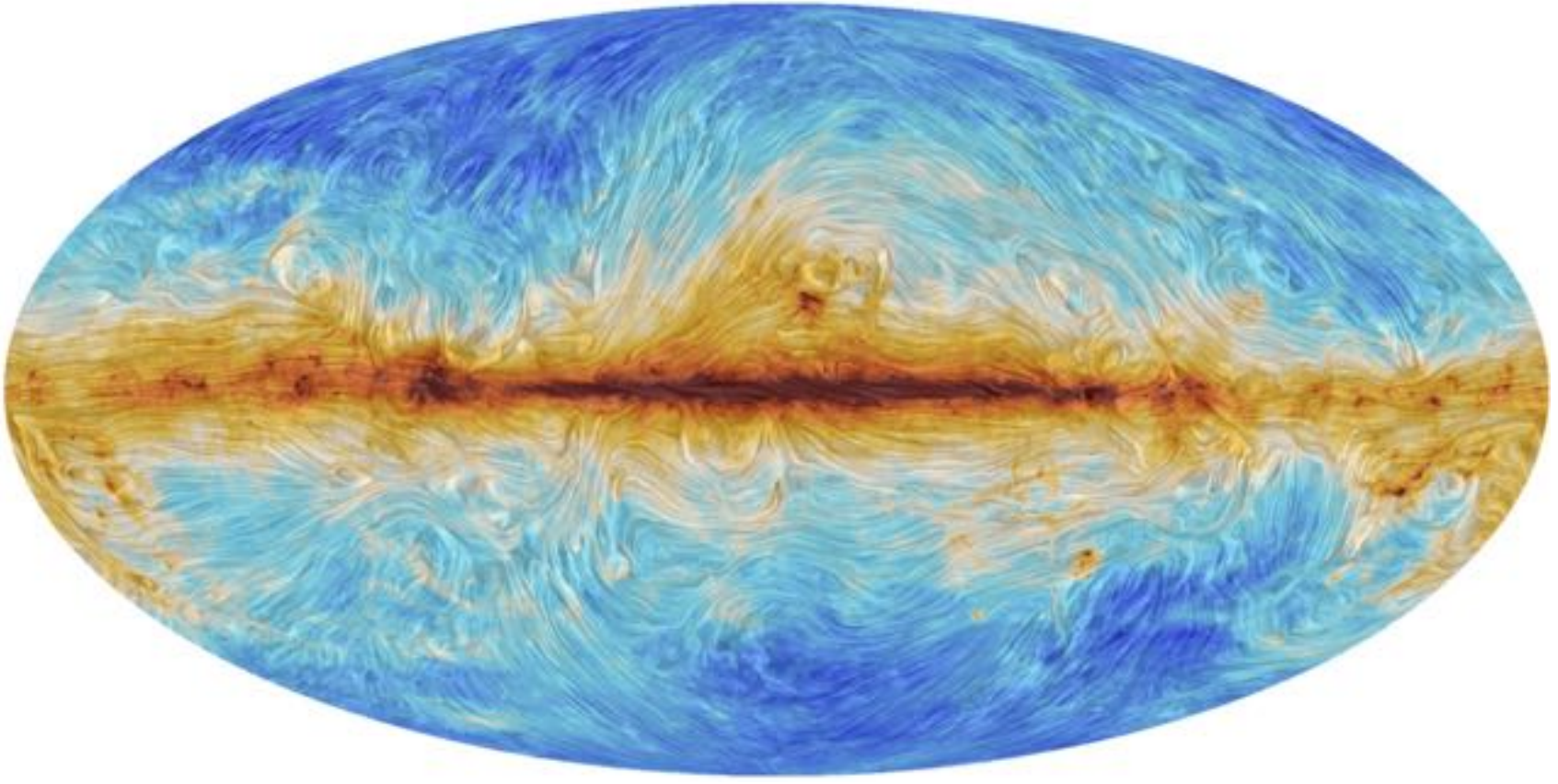
temperature

CMB temperature map



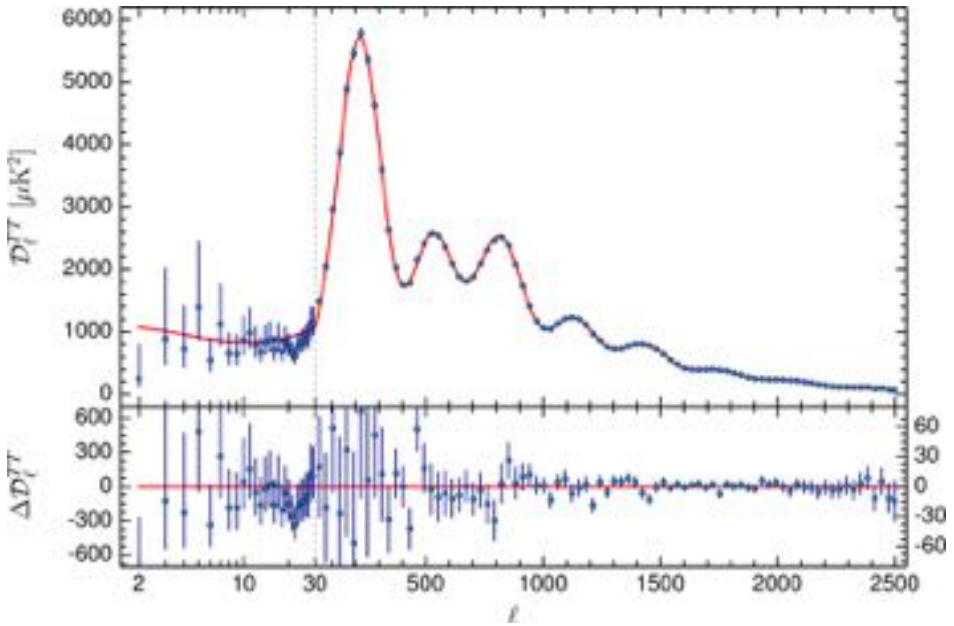
polarisation angle at 30 GHz

CMB temperature map

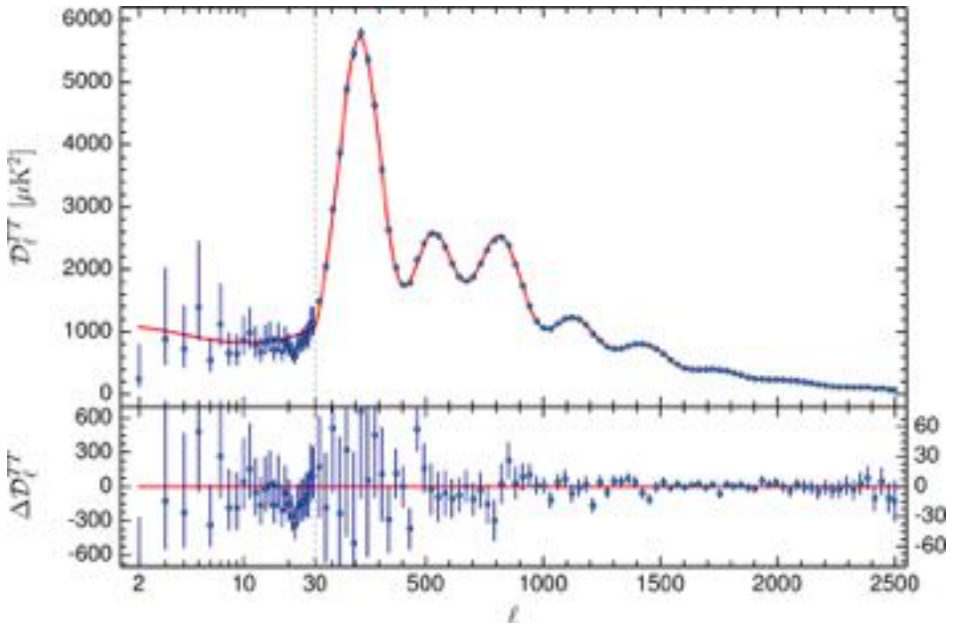


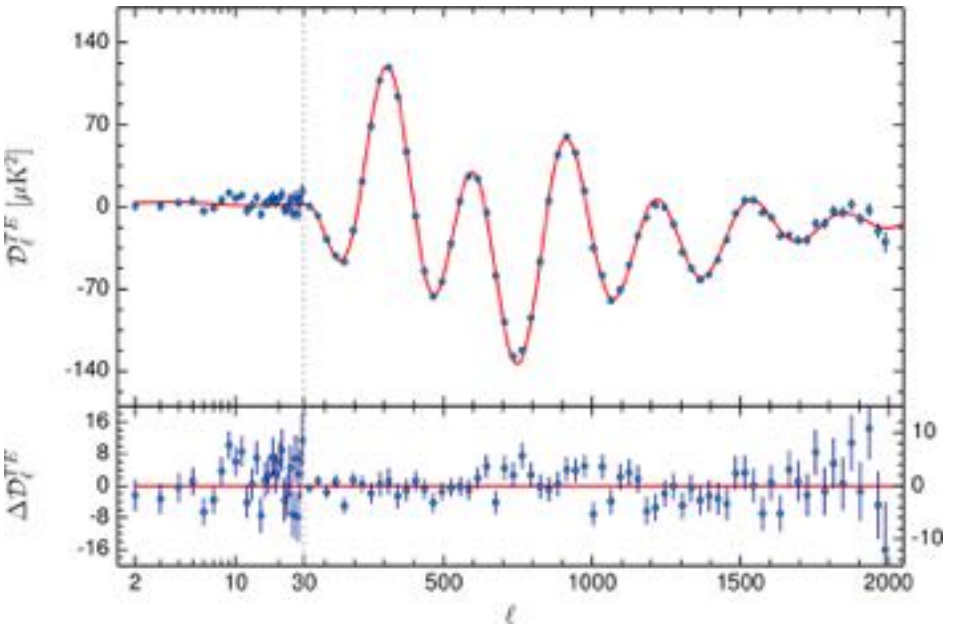
polarization angle at 353 GHz

Power spectra



Power spectra



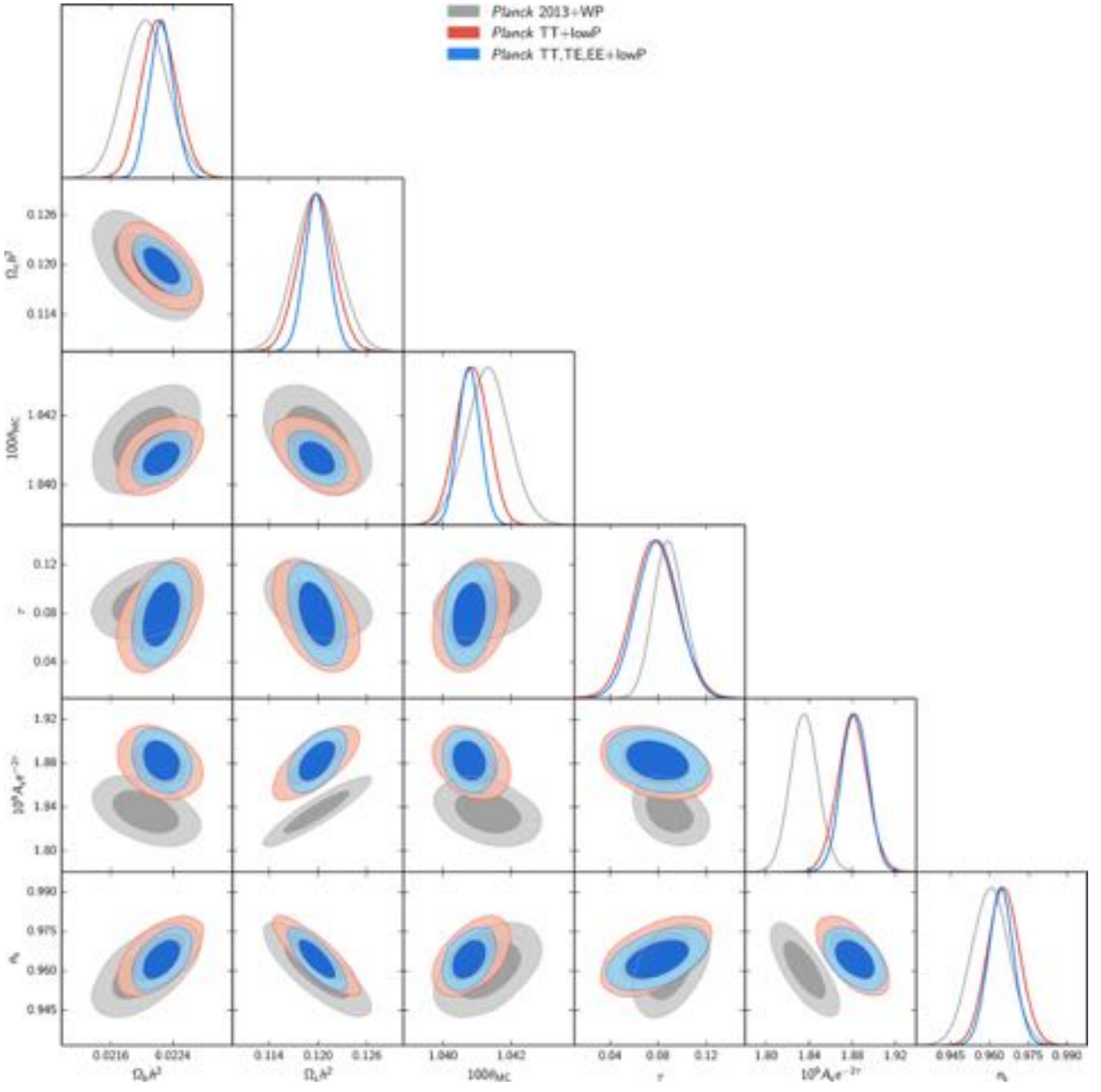


The minimal six-parameter model

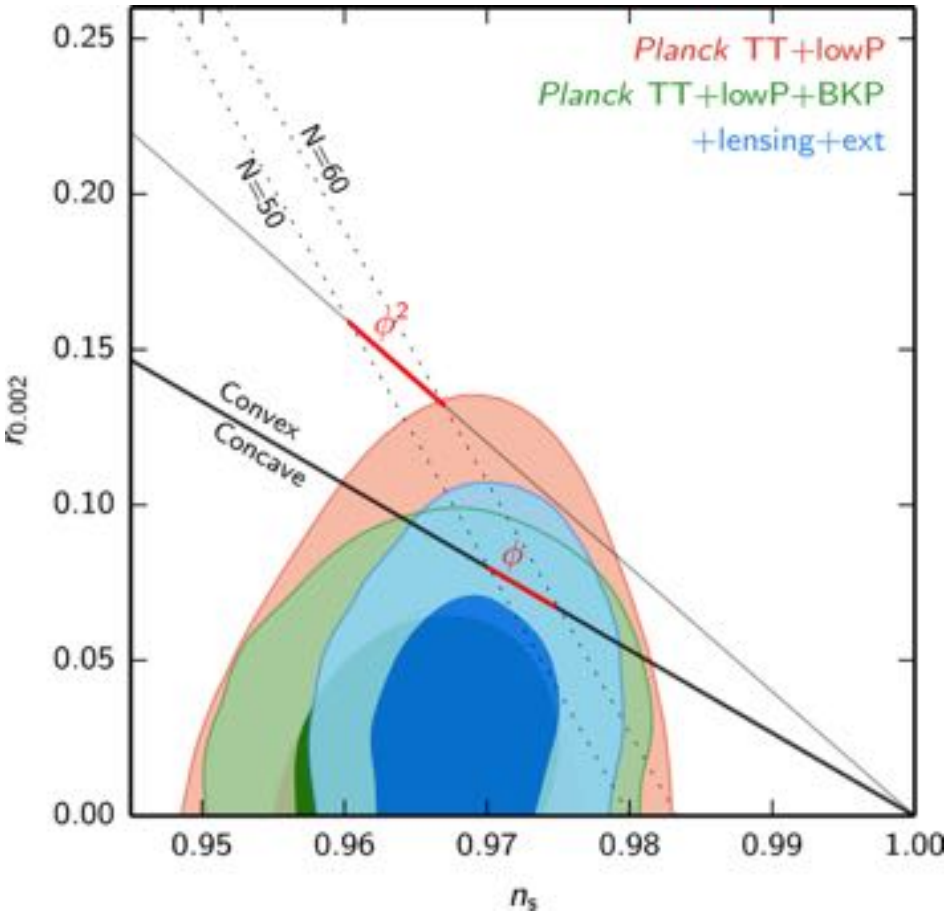
Parameter	Wert			Meaning
$100\,\Omega_{\mathrm{B0}}h^2$	2.226	$\pm$	0.016	Baryon density
$\Omega_{\mathrm{c0}}h^2$	0.1193	$\pm$	0.0014	Dark-matter density
$100\,\theta$	1.04087	$\pm$	0.00032	Peak scale
τ	0.063	$\pm$	0.014	Scattering optical dept
$\ln(10^{10}A_{\mathrm{s}})$	3.059	$\pm$	0.025	Temperature amplitude
n_{s}	0.9653	$\pm$	0.0048	Spectral index

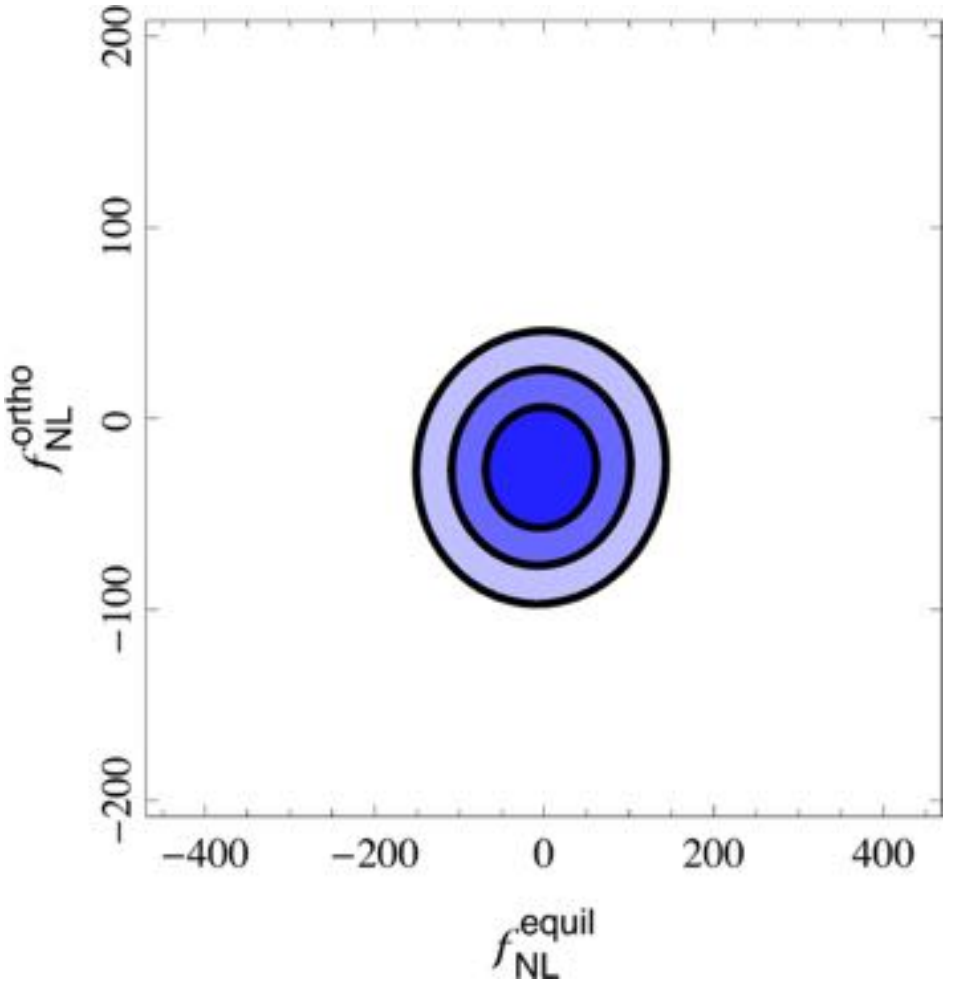
Complications of the model do not improve the agreement.

The minimal six-parameter model



Inflation

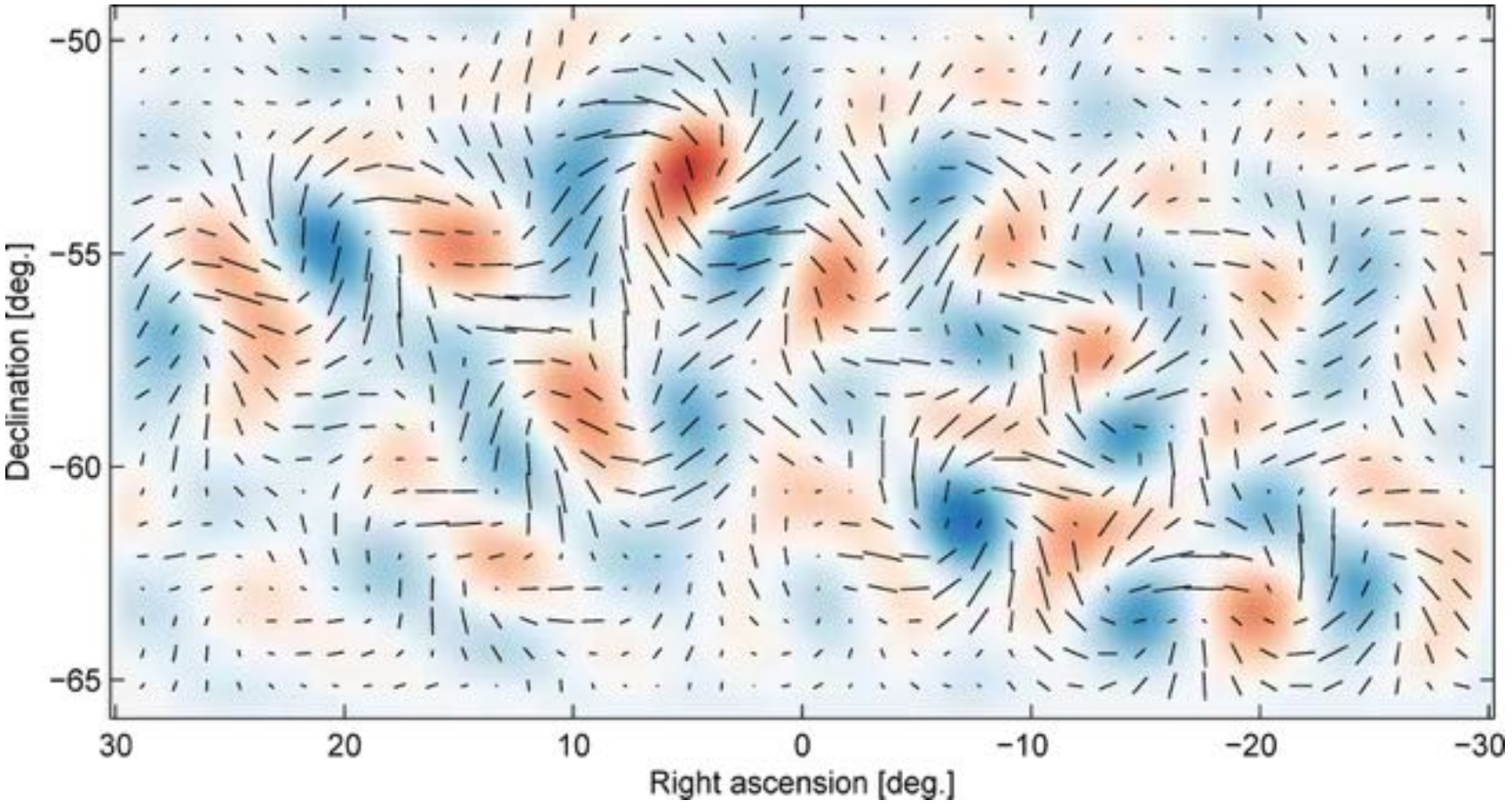




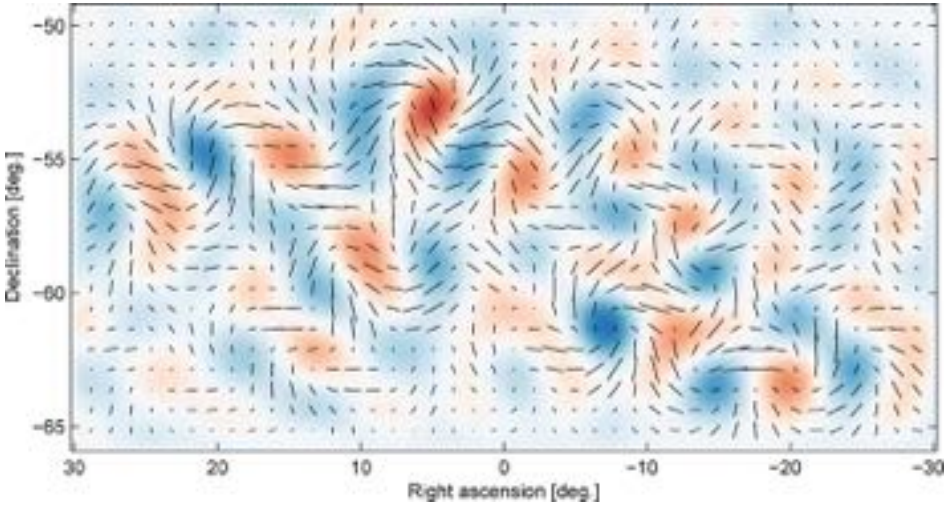
$n_s = 1 + 2\eta - 6\varepsilon\,, \quad r = 16\varepsilon$

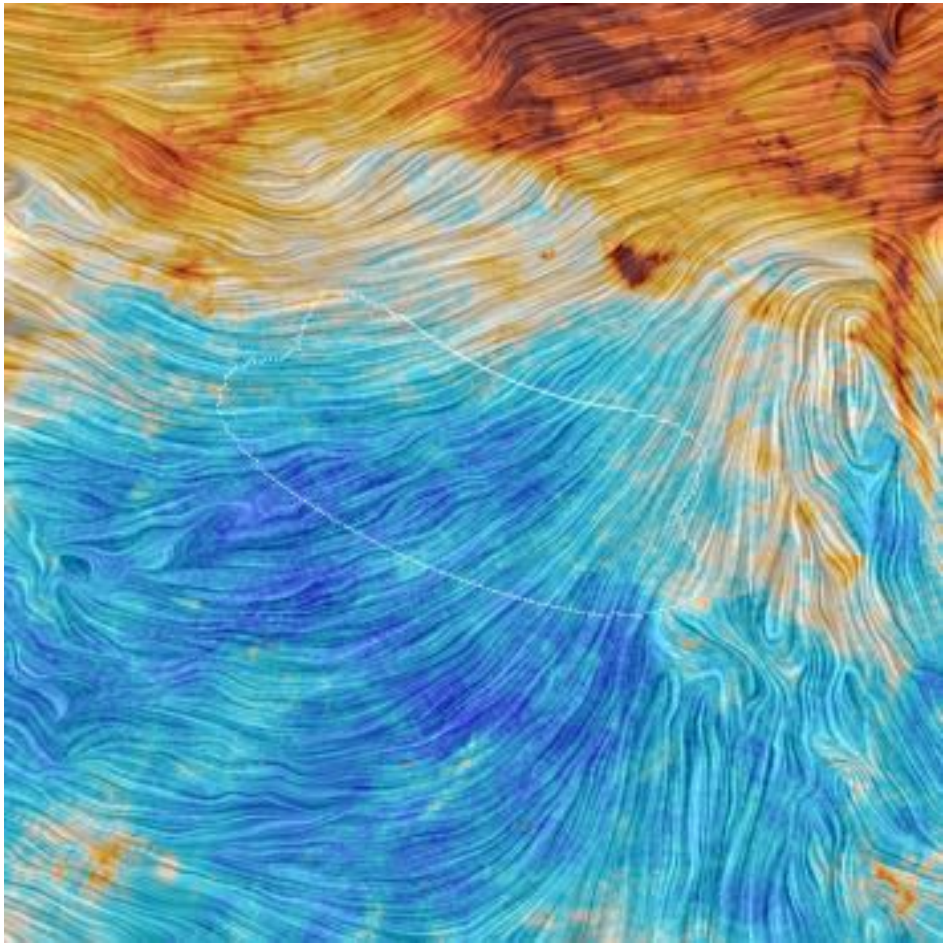
Gaussianity

Gravitational waves?

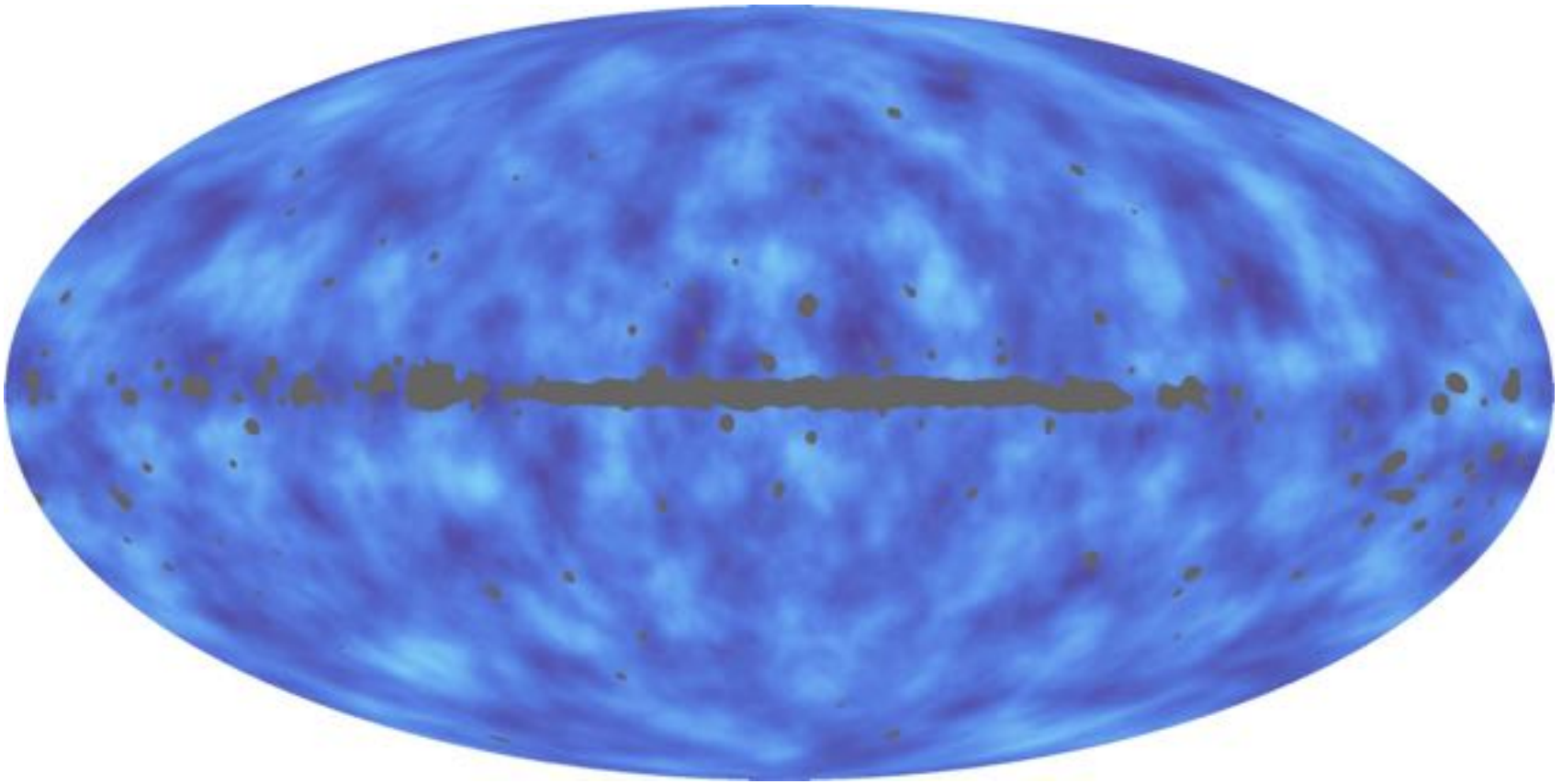


Gravitational waves?



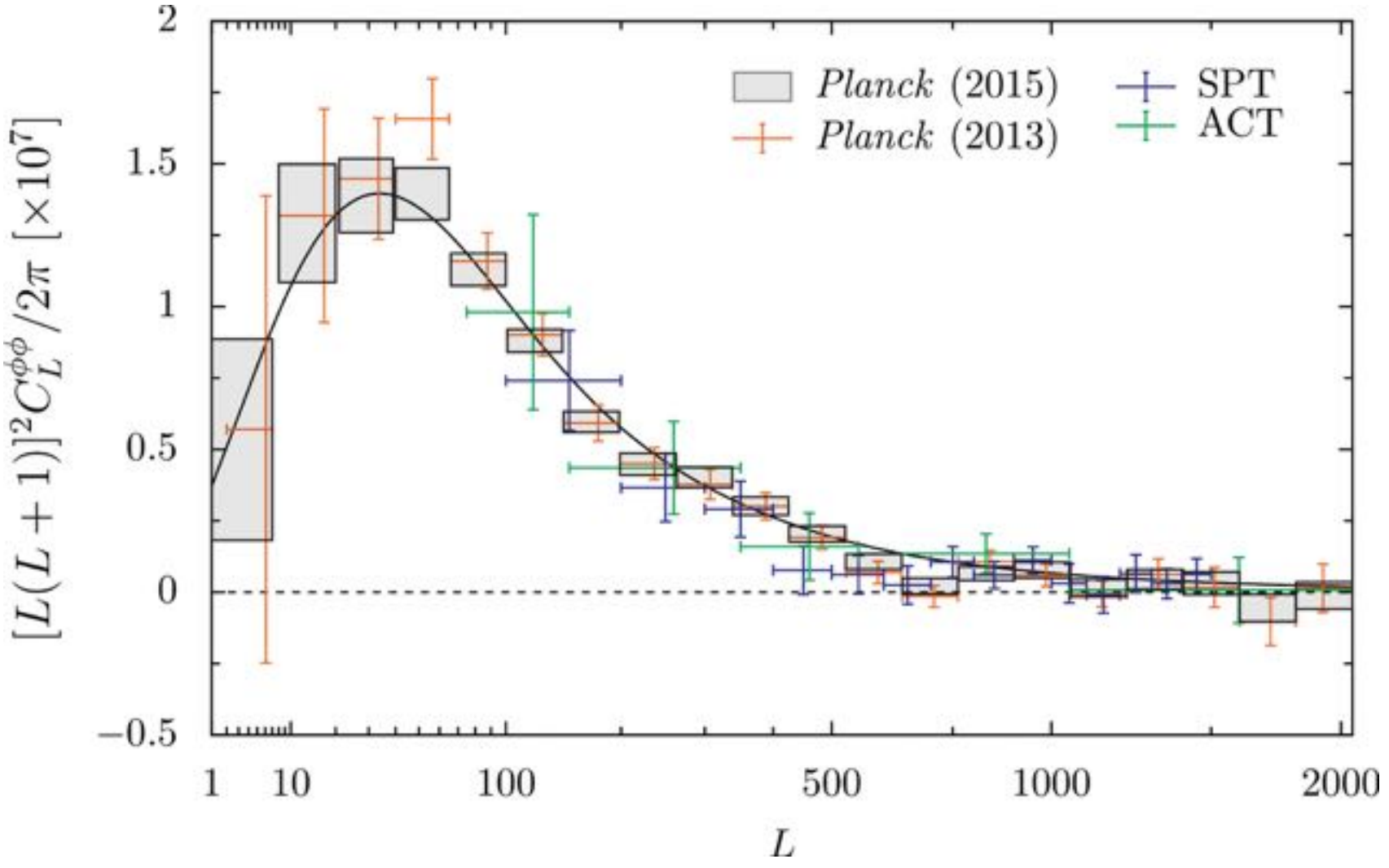


Gravitational lensing

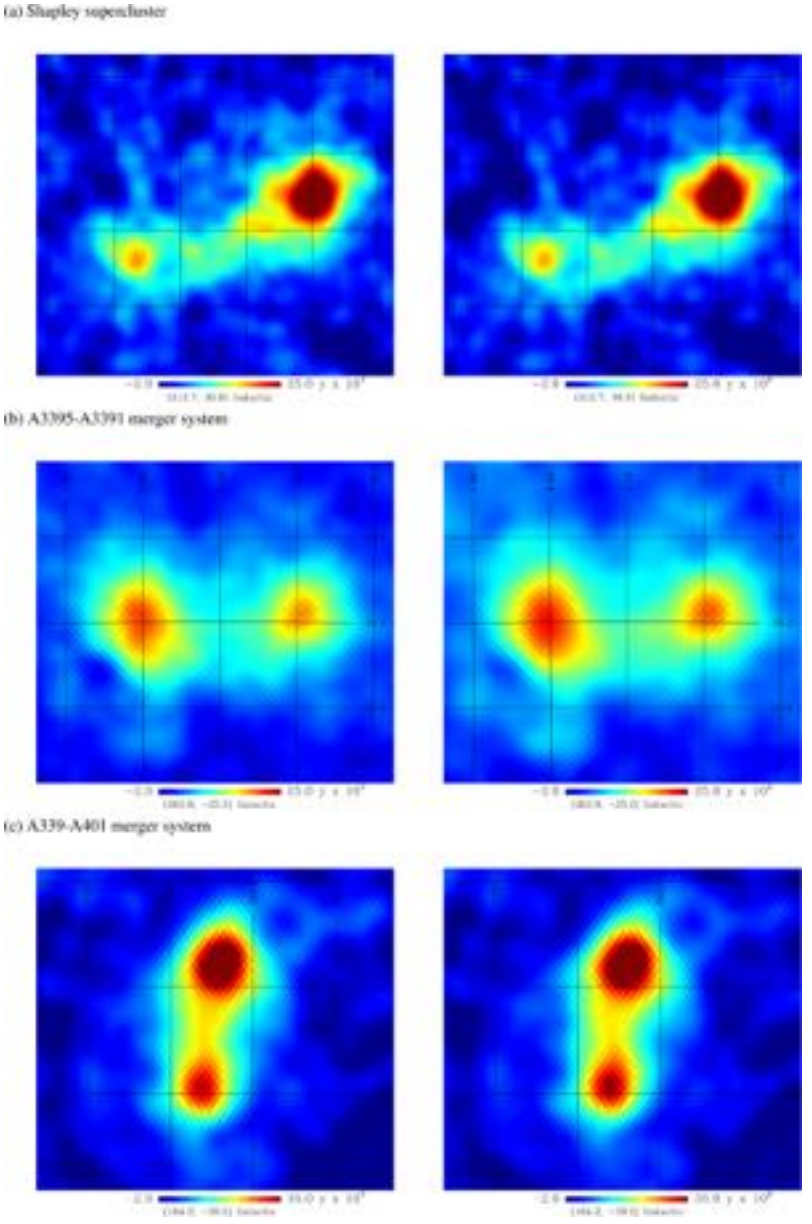


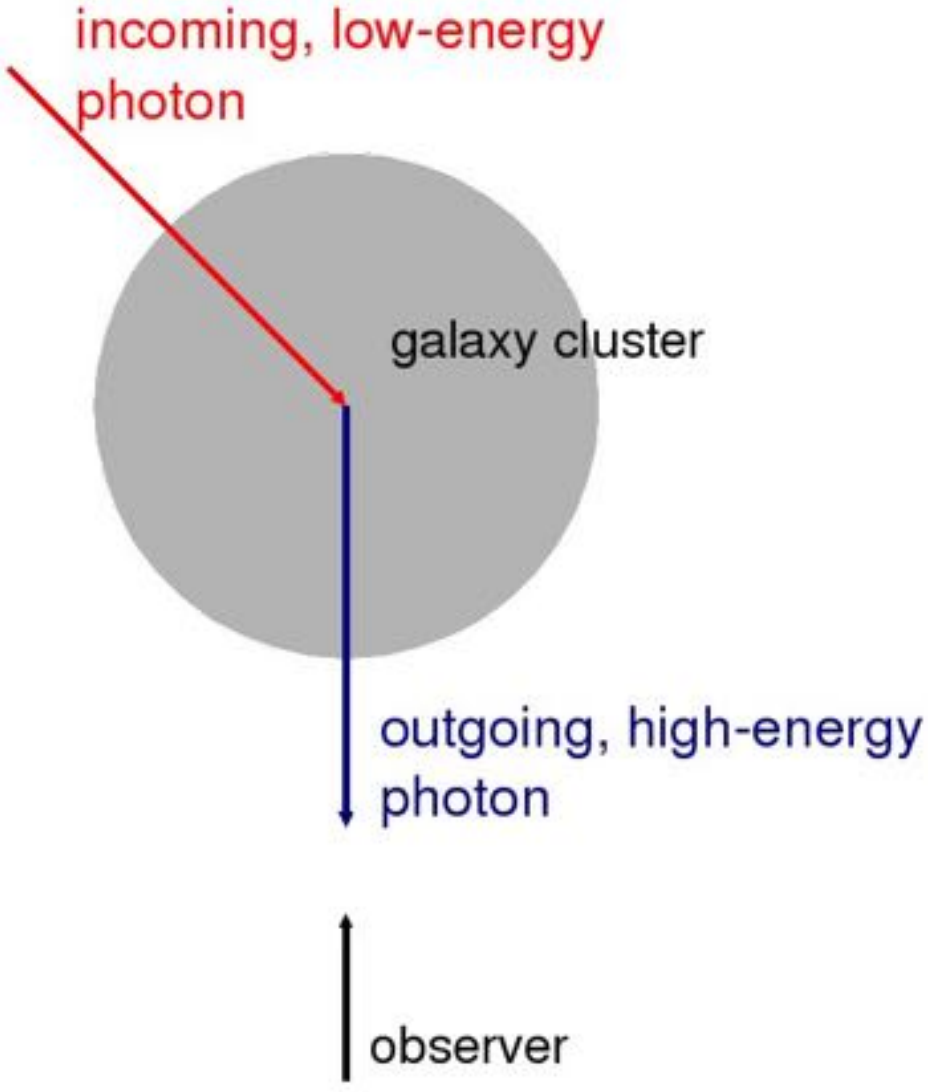
Reconstructed gravitational-lensing potential

Gravitational lensing



Galaxy clusters





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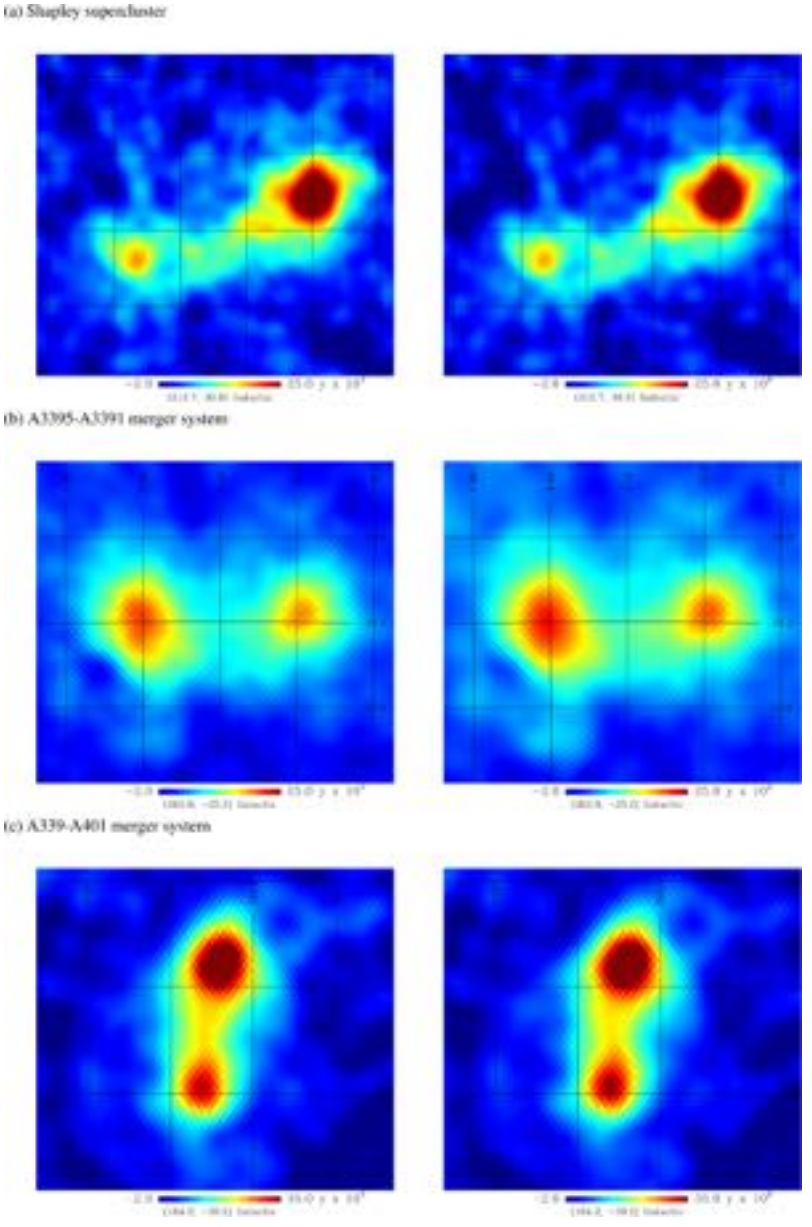
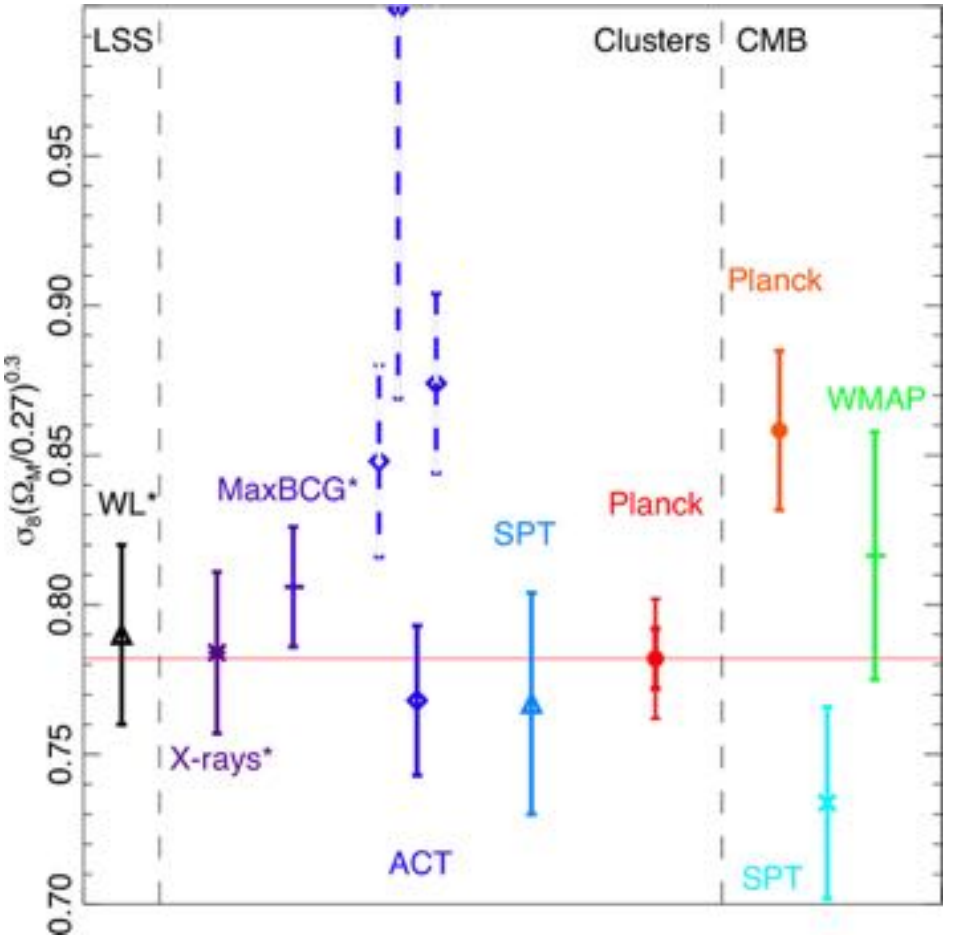
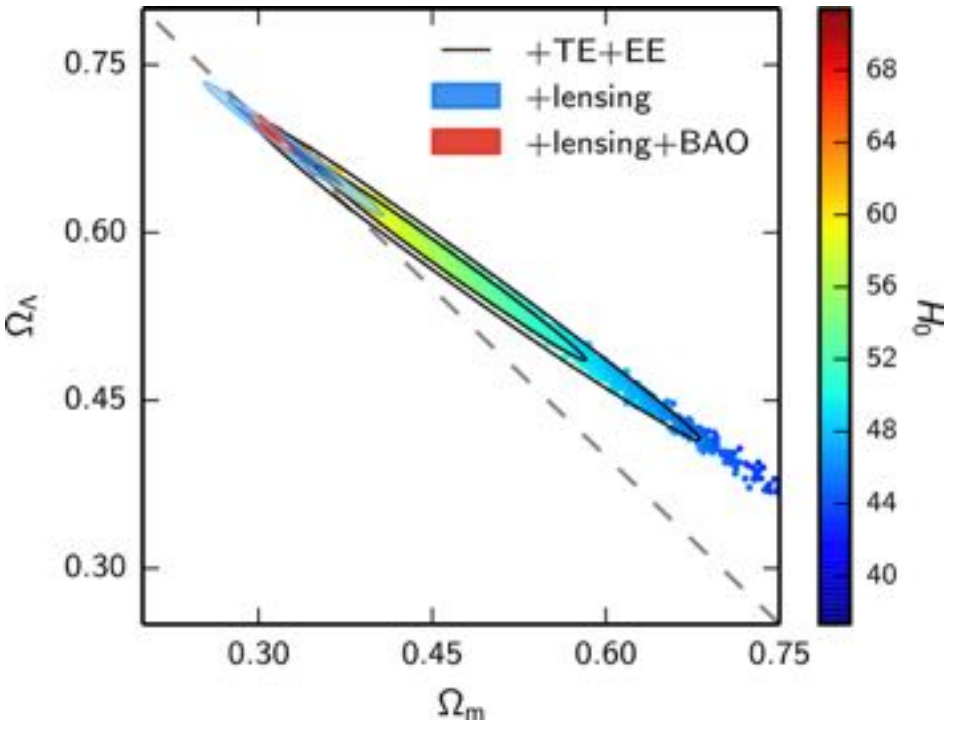




Hubble constant



- Planck:

$$67.51 \pm 0.64 \ \frac{\text{km}}{\text{s Mpc}}$$

- Local measurements:

$$73.24 \pm 1.74 \ \frac{\text{km}}{\text{s Mpc}}$$

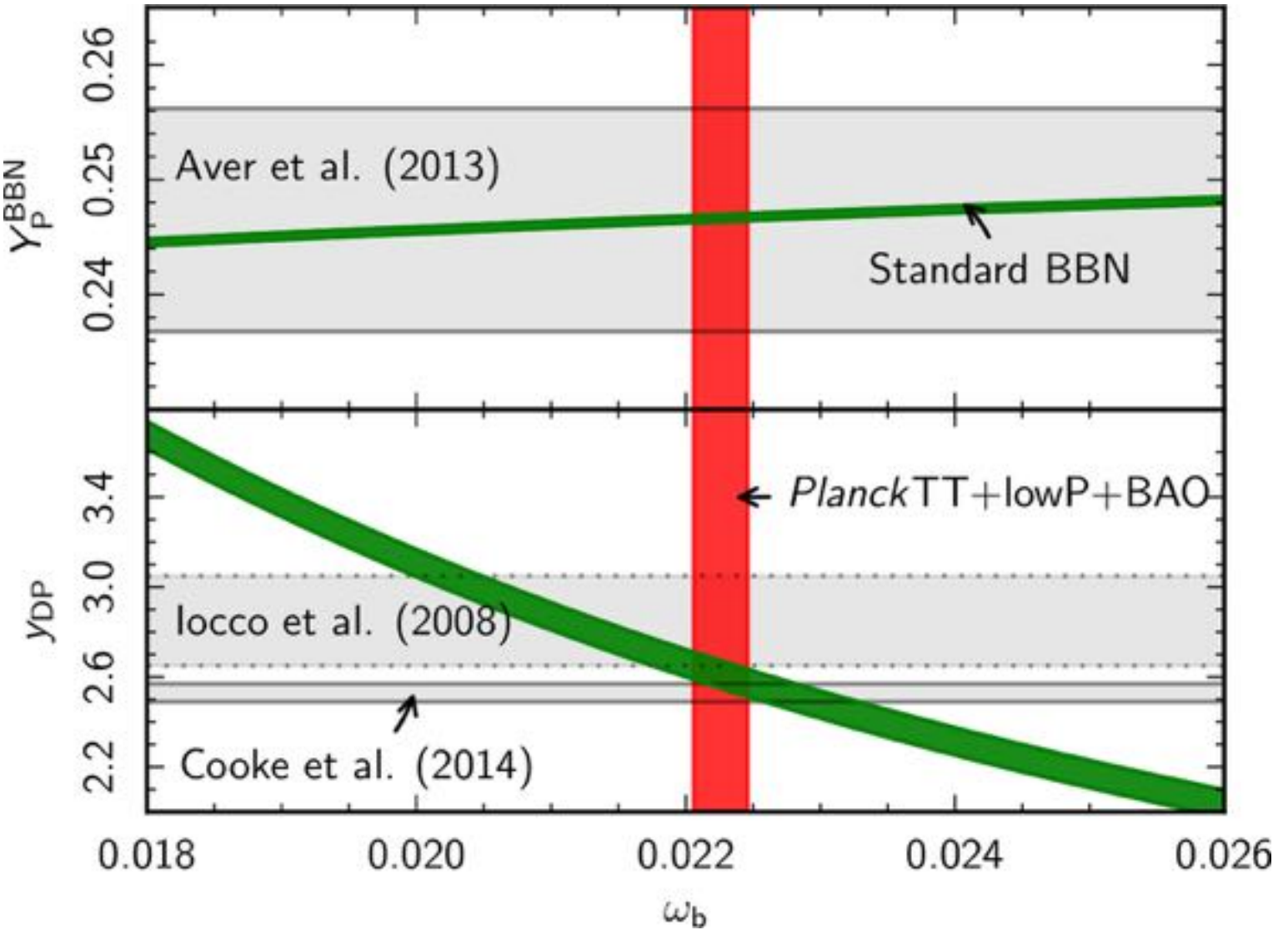
- Lensing time delays:

$$71.9^{+2.4}_{-3.0} \ \frac{\text{km}}{\text{s Mpc}}$$

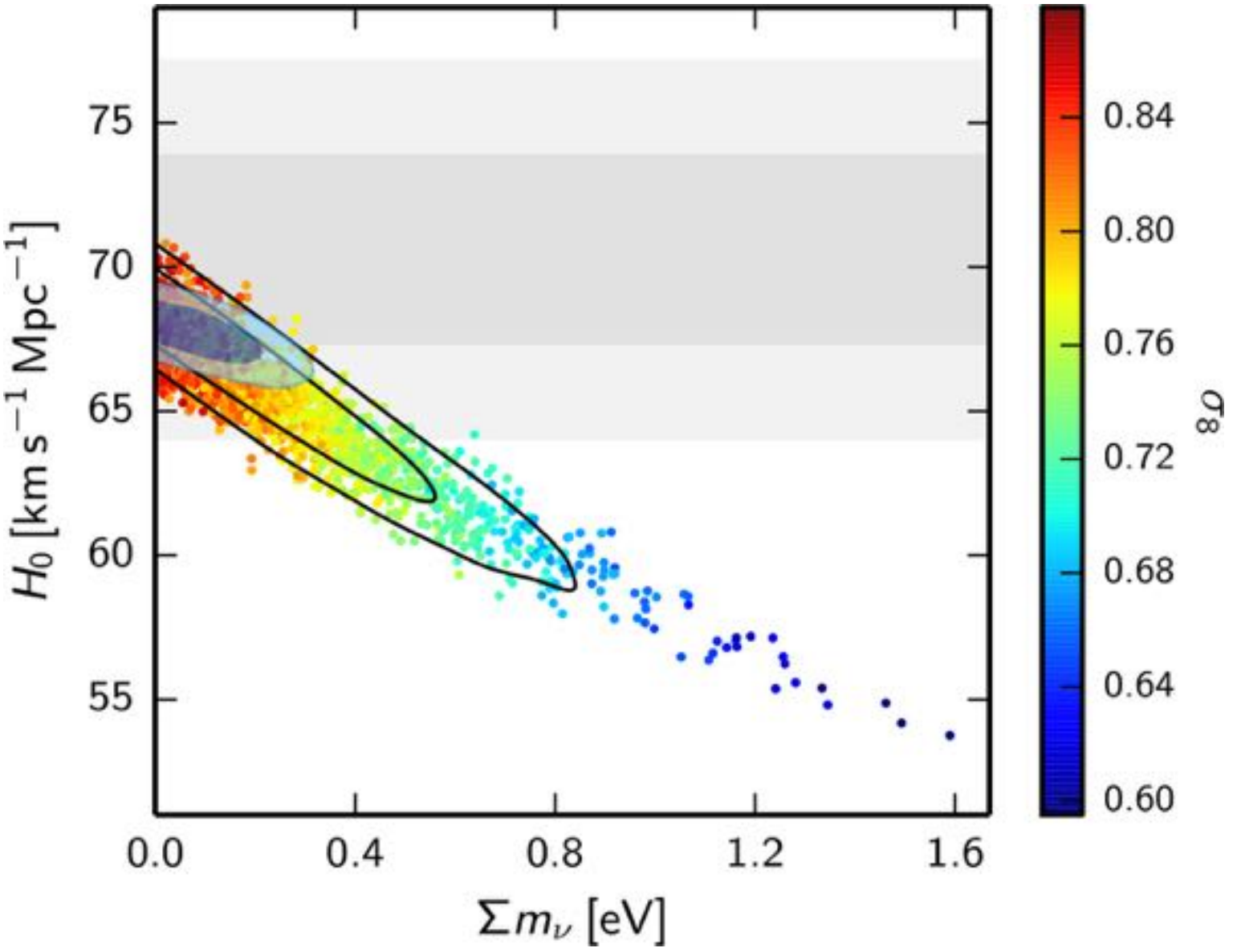
Problems

- Power deficit between 80° and 170° angular scale;
- Hemispherical asymmetry: lower temperature fluctuations in the North;
- Too few galaxy clusters: clusters and lensing require lower fluctuation level;
- Planck's Hubble constant seems too low;
- Low Thomson optical depth: late reionization;

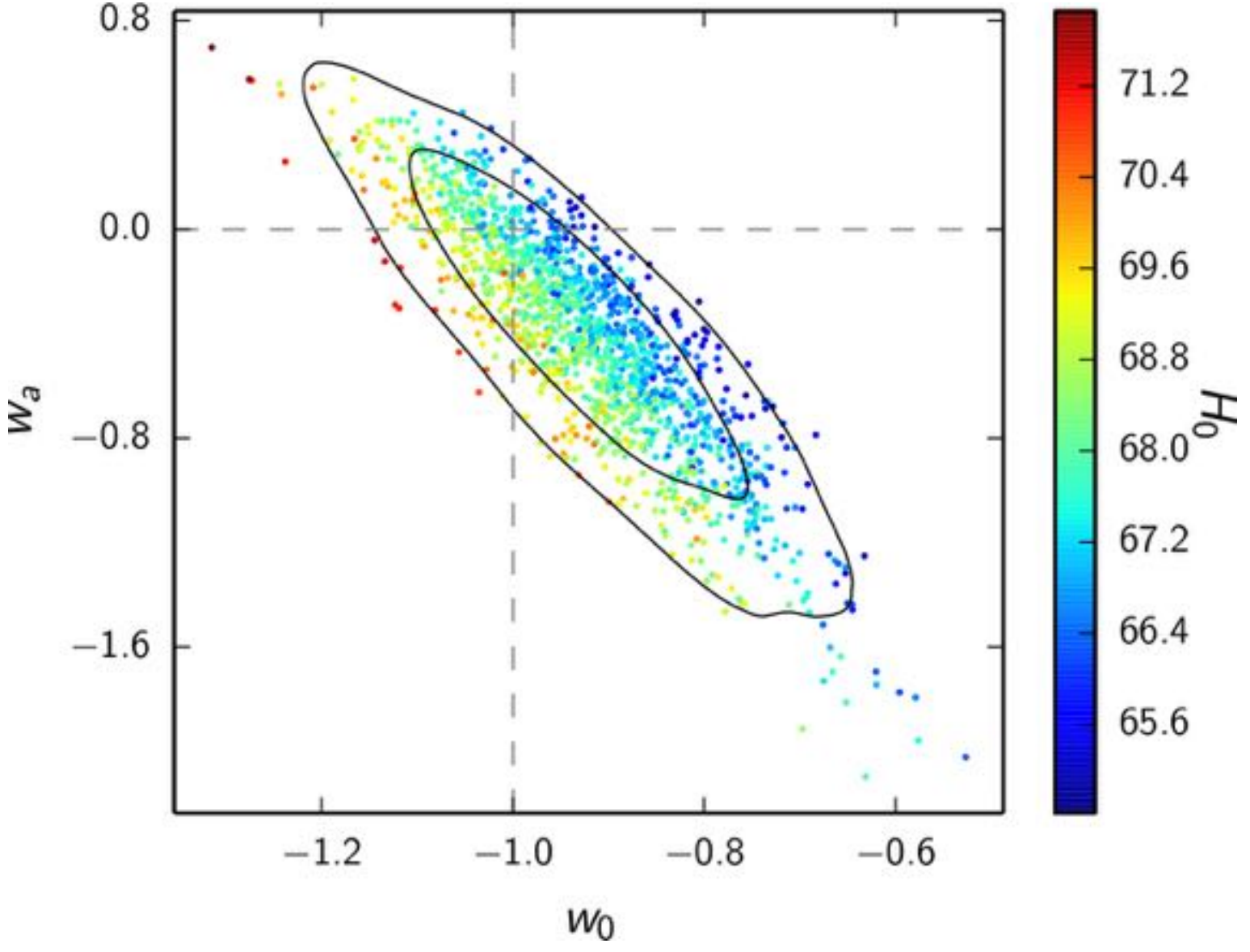
Primordial nucleosynthesis



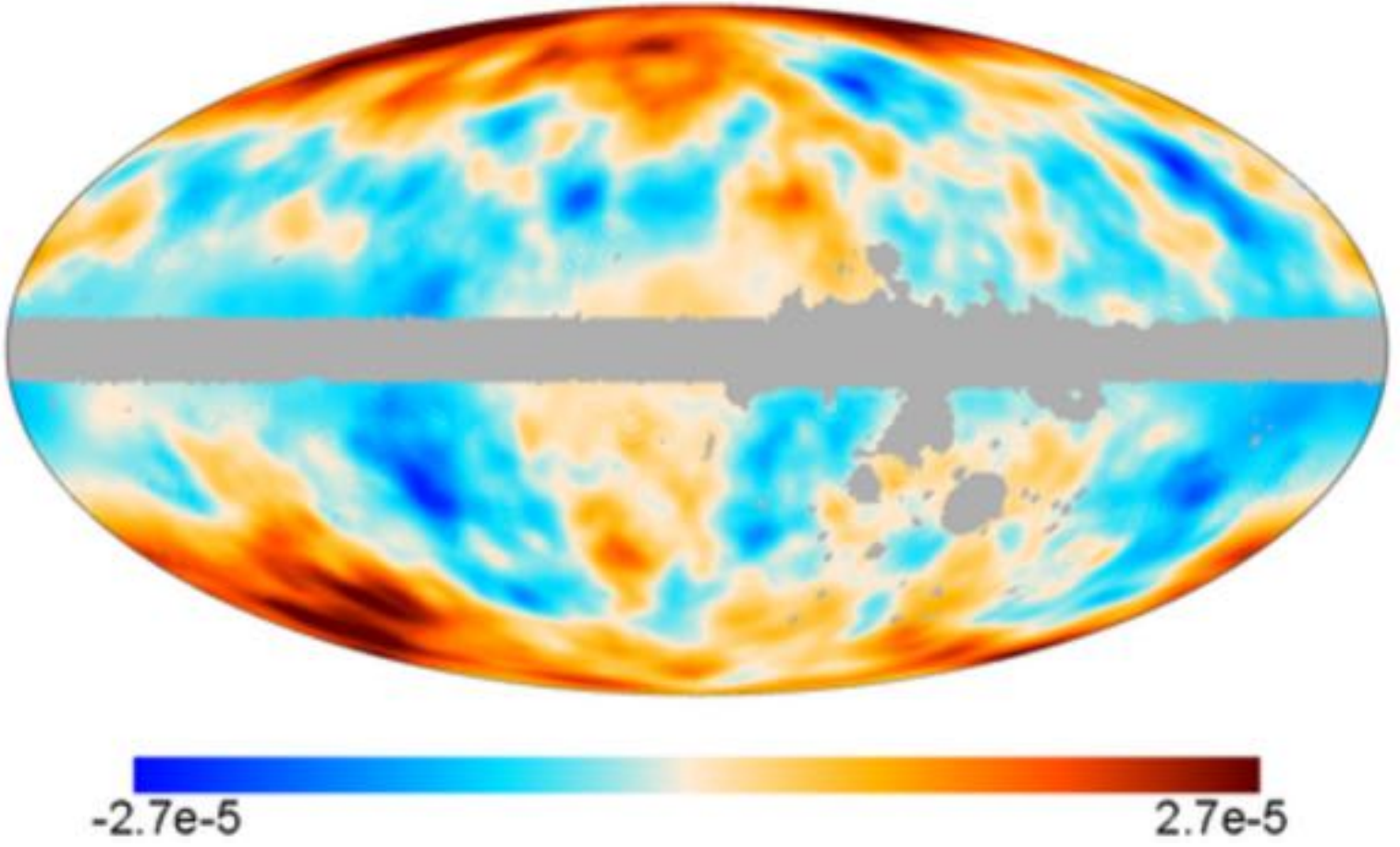
Neutrino masses



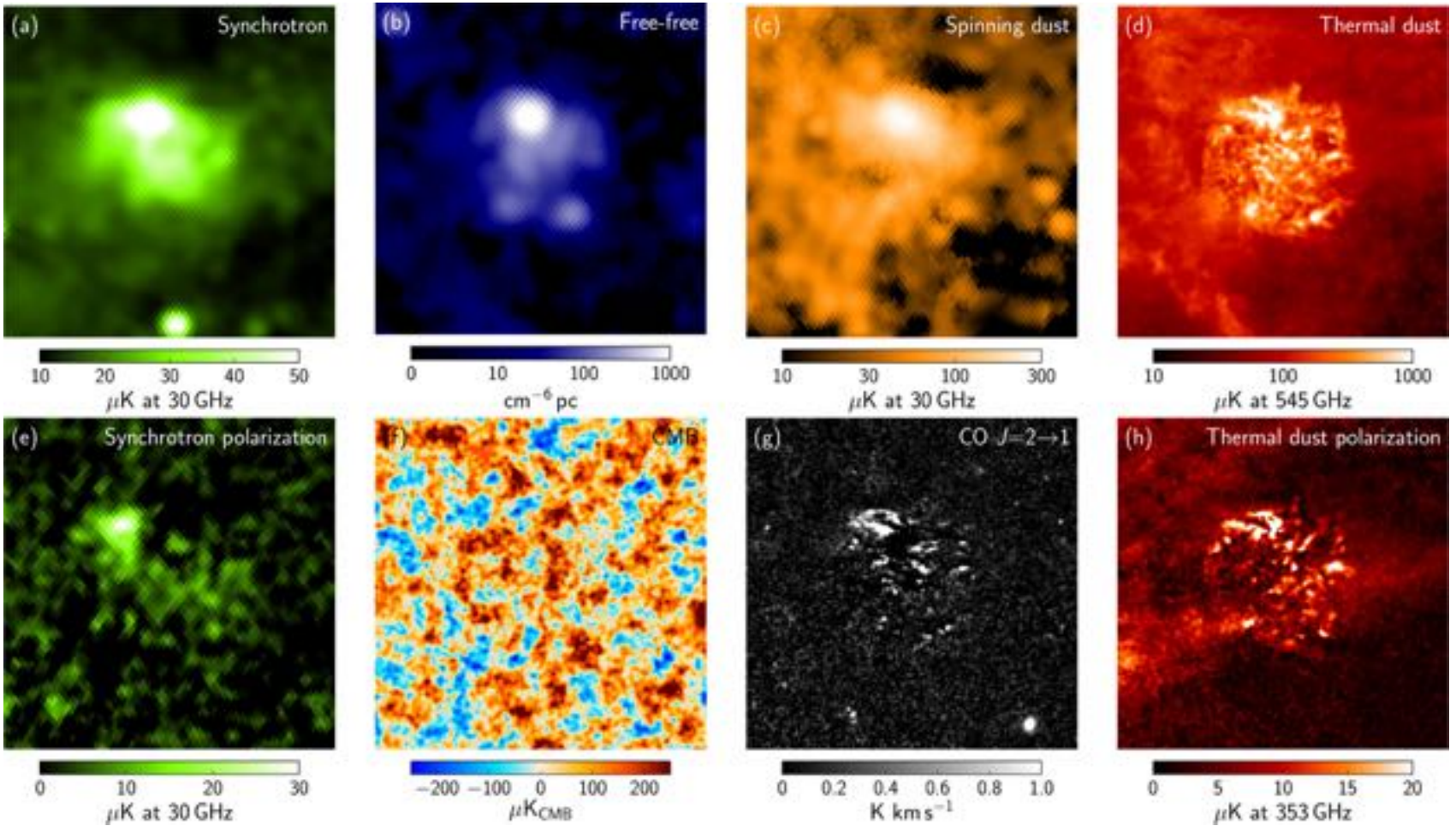
Dark energy?



Integrated Sachs-Wolfe signal



Astronomical signals



Polarised emission by the Galaxy