Title: TBA

Date: Oct 22, 2015 11:00 AM

URL: http://pirsa.org/15100117

Abstract:

Main results of the Planck mission

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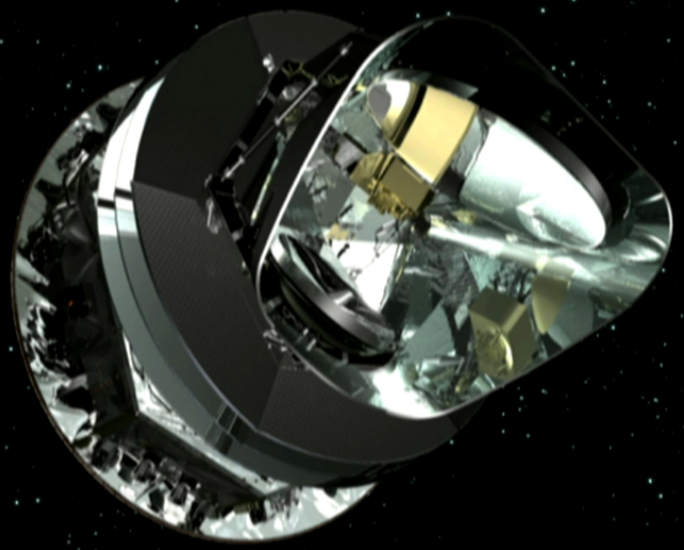
Laboratoire de Physique Subatomique et de Cosmologie
Grenoble, France

HINTERGRUNDILLUSTRATION: ESA, ESO UND STECF, WOLFRAM FREUDLING; ILLUSTRATION PLANCK: ESA / AOES MEDIALAB

the PLANCK satellite



ESA mission: first European satellite dedicated to the relic radiation

1m50 ø telescope
→ angular resolution up to 5'

2 instruments :

Low Frequency Instrument
30 to 70 GHz @ 20 K
under Italian supervision

High Frequency Instrument
100 to 857 GHz @ 0.1 K
under French supervision

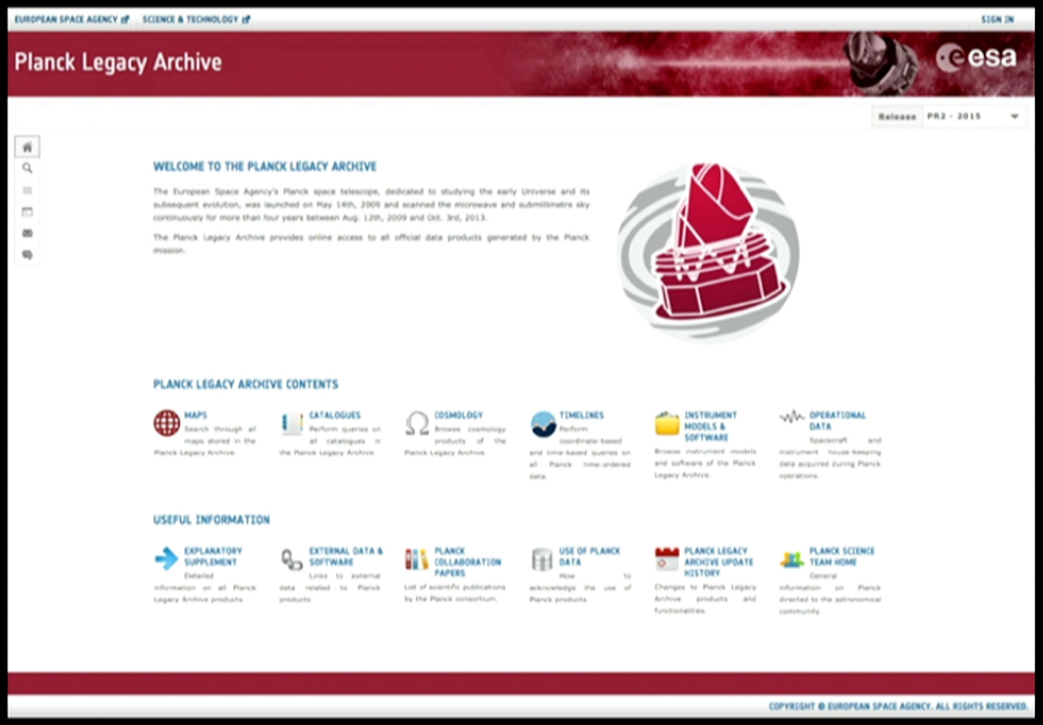
"ultimate" sensitivity in temperature

First full sky map in polarization

The Planck collaboration

~ 600 persons. Mainly from Europe + US & Canada

Data are available



ESA webpage (*PLA Planck* in google)

&

LAMBDA

- **2013**: temperature only, nominal mission (2 full sky)
- **2015**: temperature+polarisation, full mission (8 LFI & 5 HFI full sky)

→ February: main product delivery (all LFI + HFI T+P ≥ 353) + papers

→ July: delivery of postponed products (HFI P 100 – 217 GHz)

- **2016**: improved polarisation

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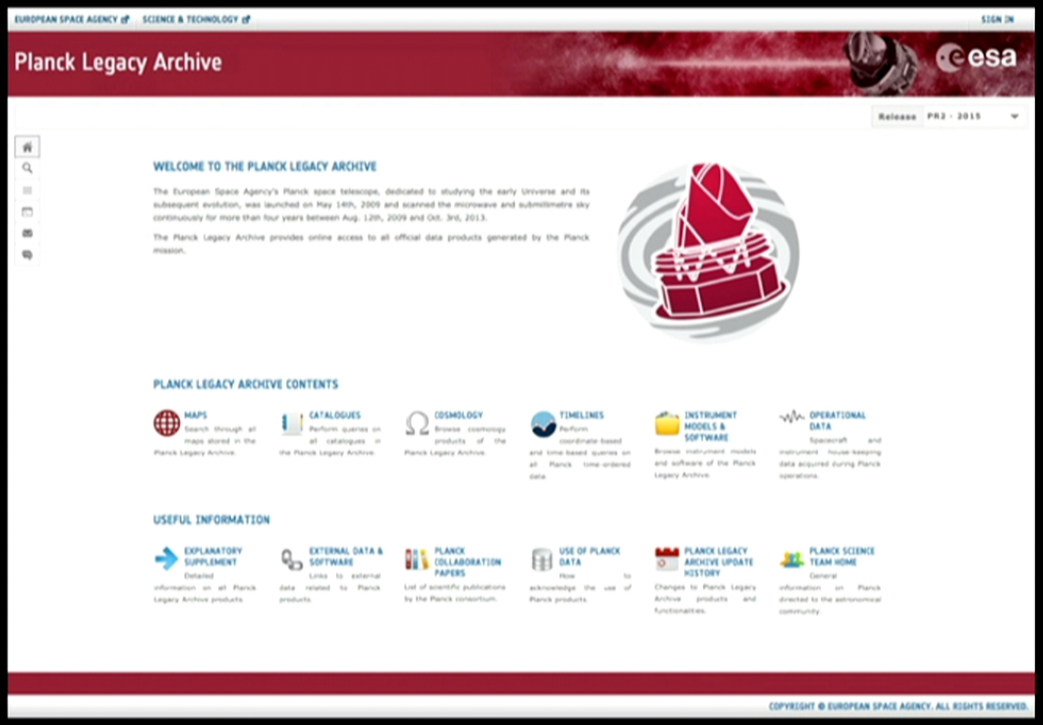

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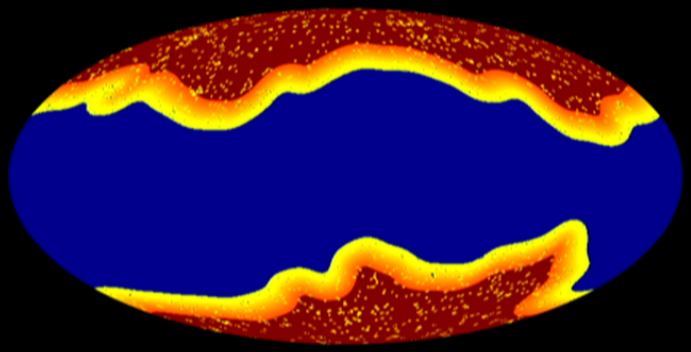
- **2016**: improved polarisation

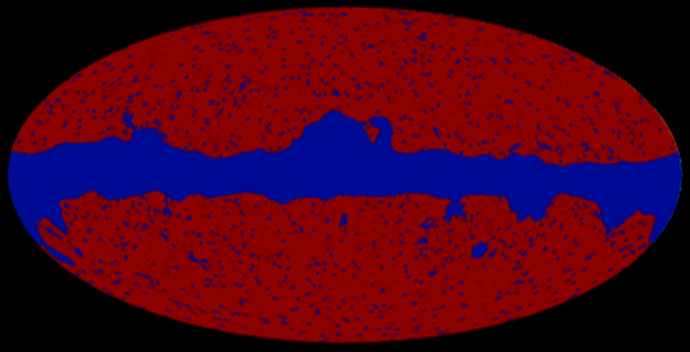
Many available maps

- full mission, nominal mission, per survey, per year, per half-mission
- Nside (30 & 44 GHz @ 1024, 70 GHZ @ 1024 & 2048, 100 to 857 GHz @ 2048)
- per frequency
- I + Q, U when available
- 8 foregrounds
- CMB with 4 component separation methods

+ Galactic & PS masks + effective beams

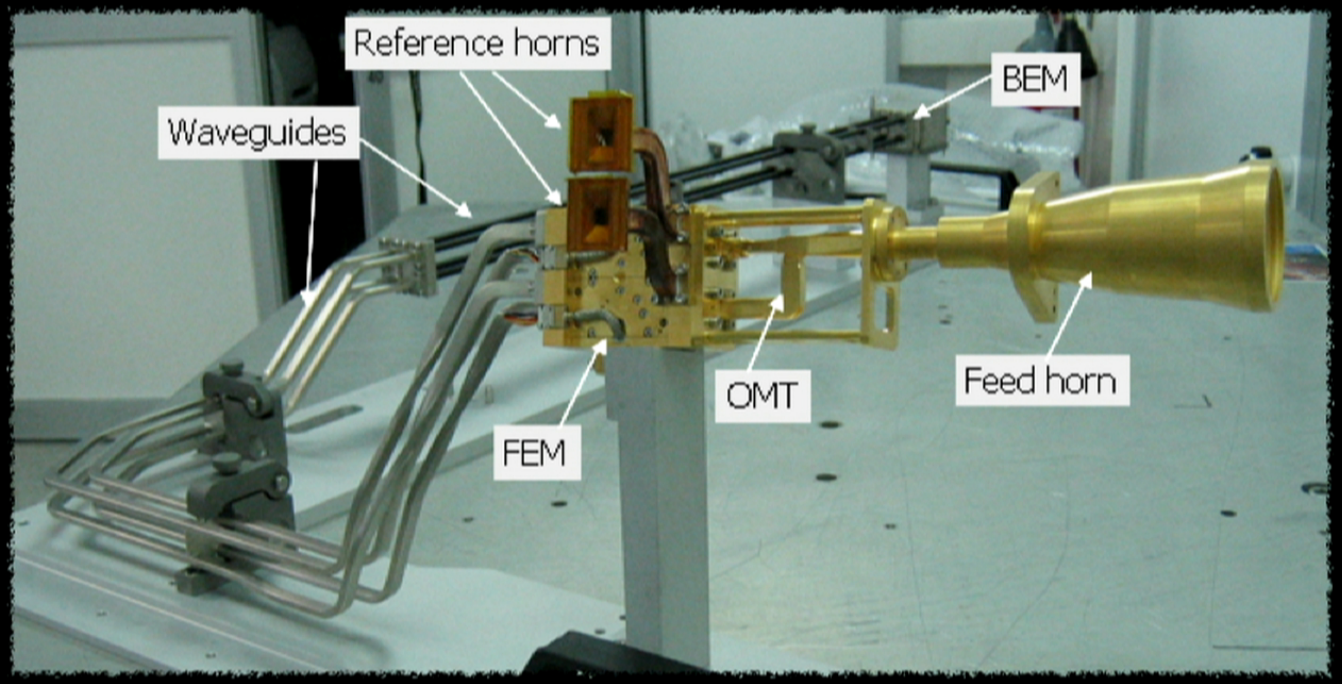


Likelihood mask



CMB union mask

LFI detector = radiometer

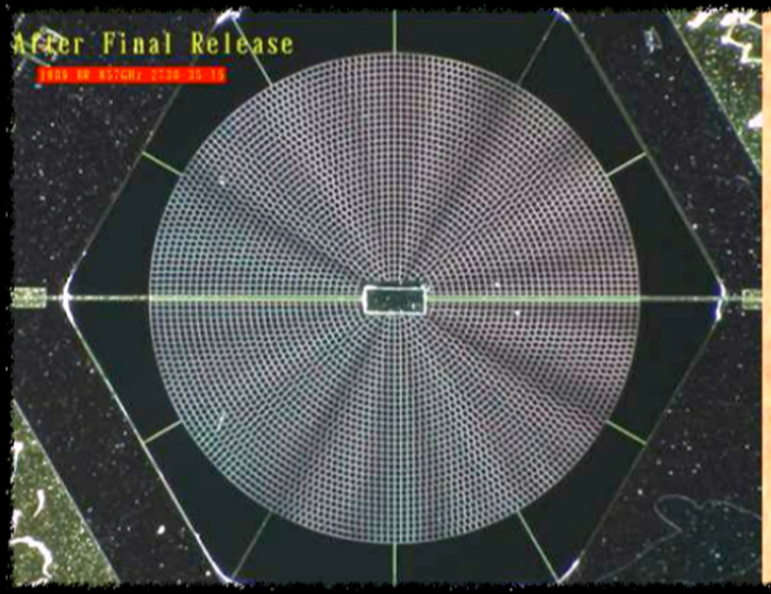


Foregrounds:
2 @ 30 GHz
3 @ 44 GHz

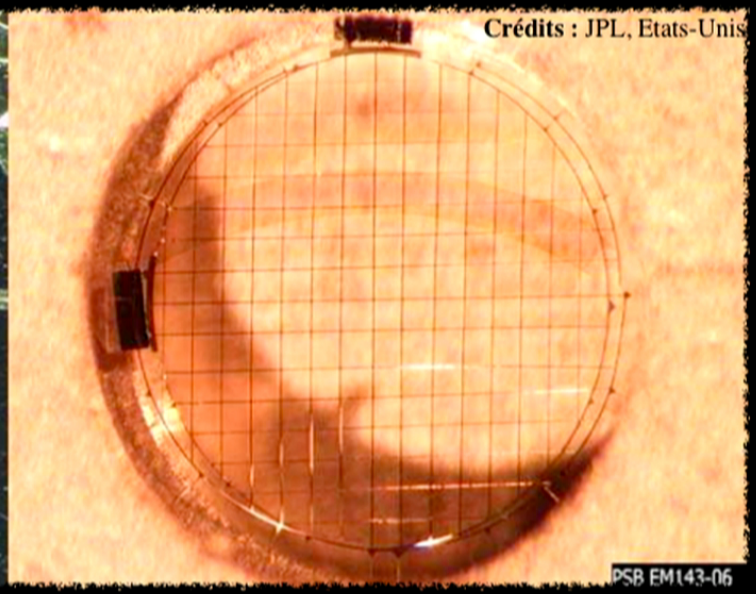
CMB:
6 @ 70 GHz

Reference @ 4K
intrinsically sensitive to polarization

HFI detector = bolometer



SWB for temperature only



pair of PSBs for temperature & polarization

CMB:
8 PSB @ 100 GHz
8 PSB + 3 SWB @ 143 GHz
8 PSB + 4 SWB @ 217 GHz

Foregrounds:
8 PSB + 4 SWB @ 353 GHz
4 SWB @ 545 GHz
4 SWB @ 857 GHz

Technical:
2 dark bolometers

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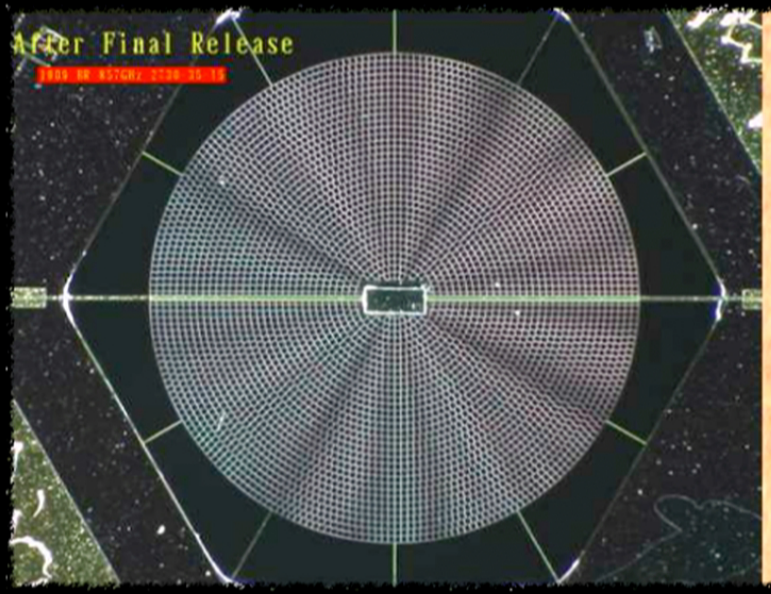

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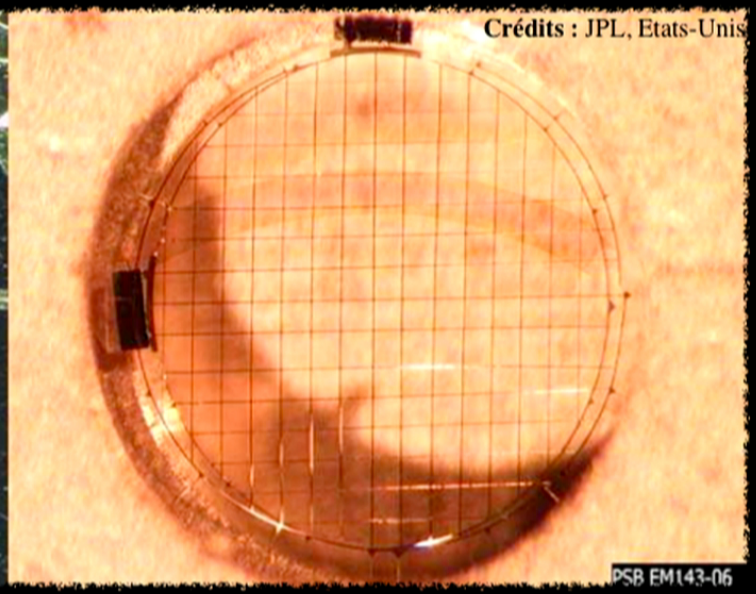

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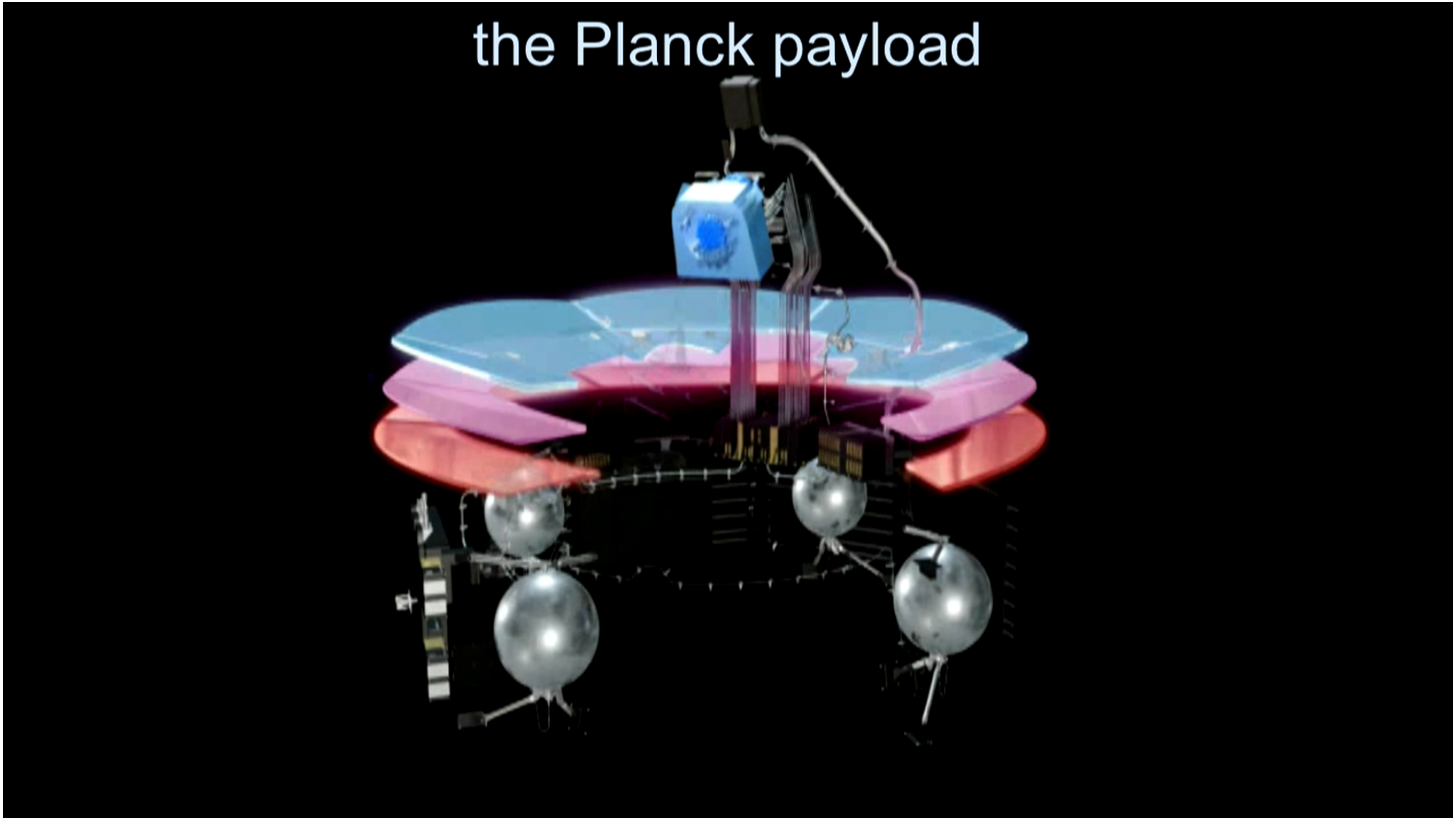
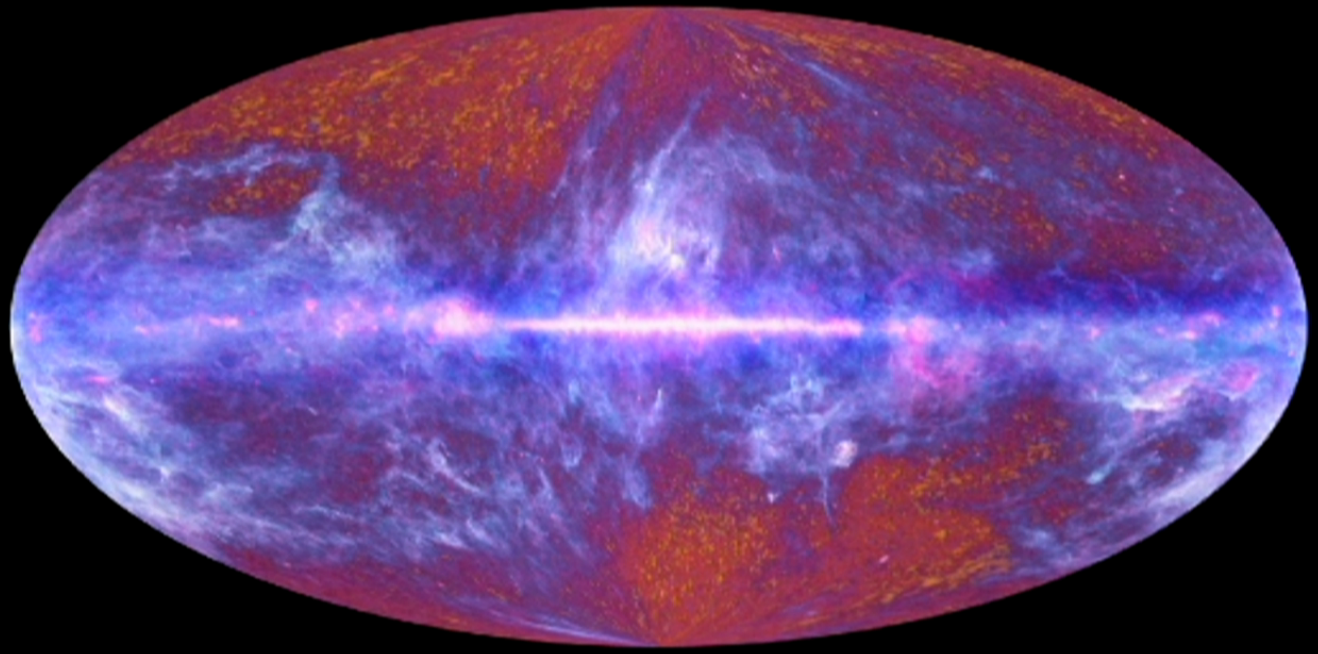
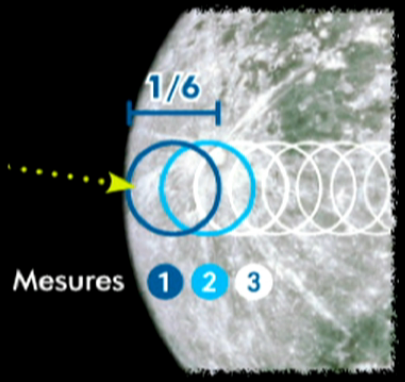
the Planck payload



PLANCK scans the sky



Main steps of the data analysis



29 months of data for HFI

48 months of data for LFI

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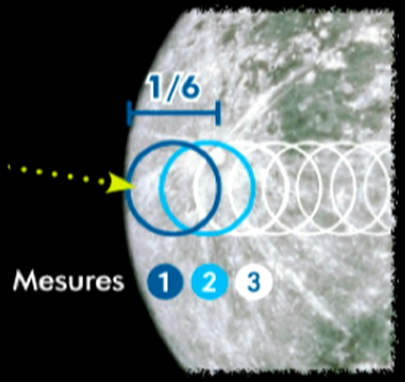

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the HFI focal plane

Sky signal in pixel *p*

$$D_t = P_{tp}\left[I_p + \rho\left(Q_p \cos 2\gamma_t + U_p \sin 2\gamma_t\right)\right] + n_t$$

noise

Intensity and polarisation

Pointing matrix links pixel *p* to time *t*

Scanning strategy

Each pixel on the sky is visited from ~2 main directions only (except near ecliptic poles)

→ cannot invert the problem for each detector independently

Detector signals are combined to measure **I**, **Q** and U

[Rosset et al. 2010]

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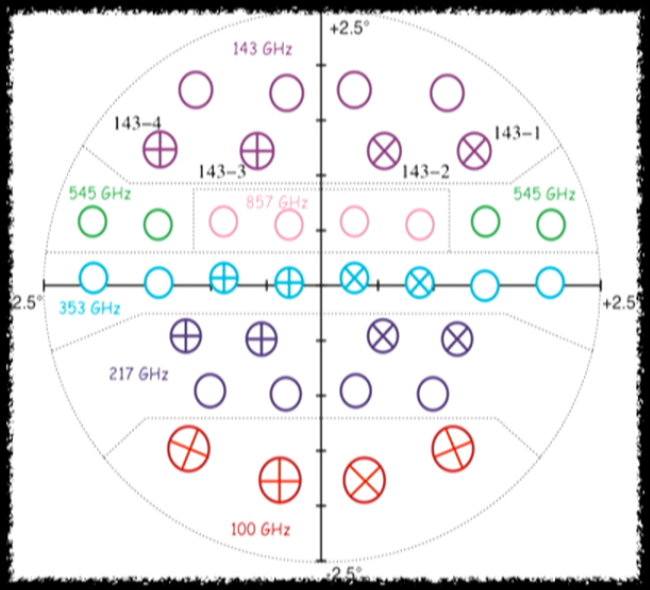

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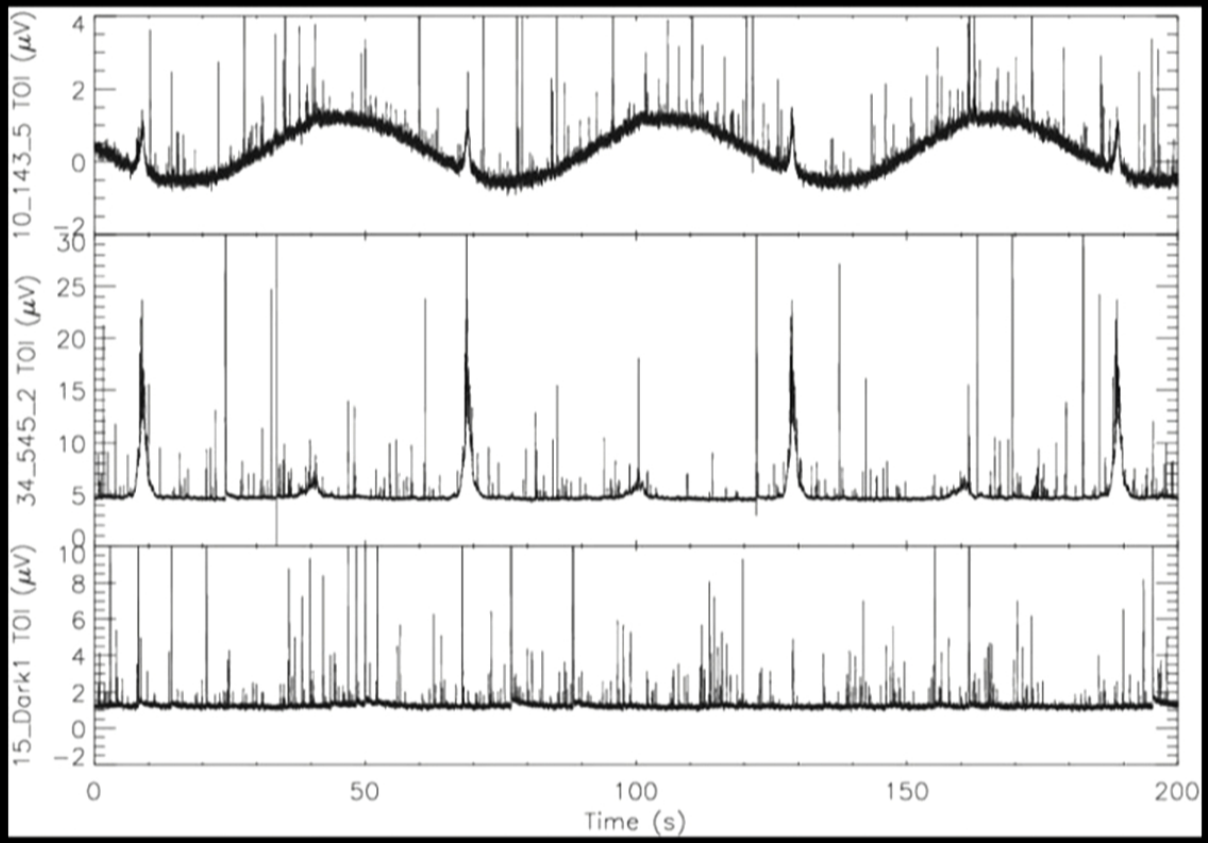
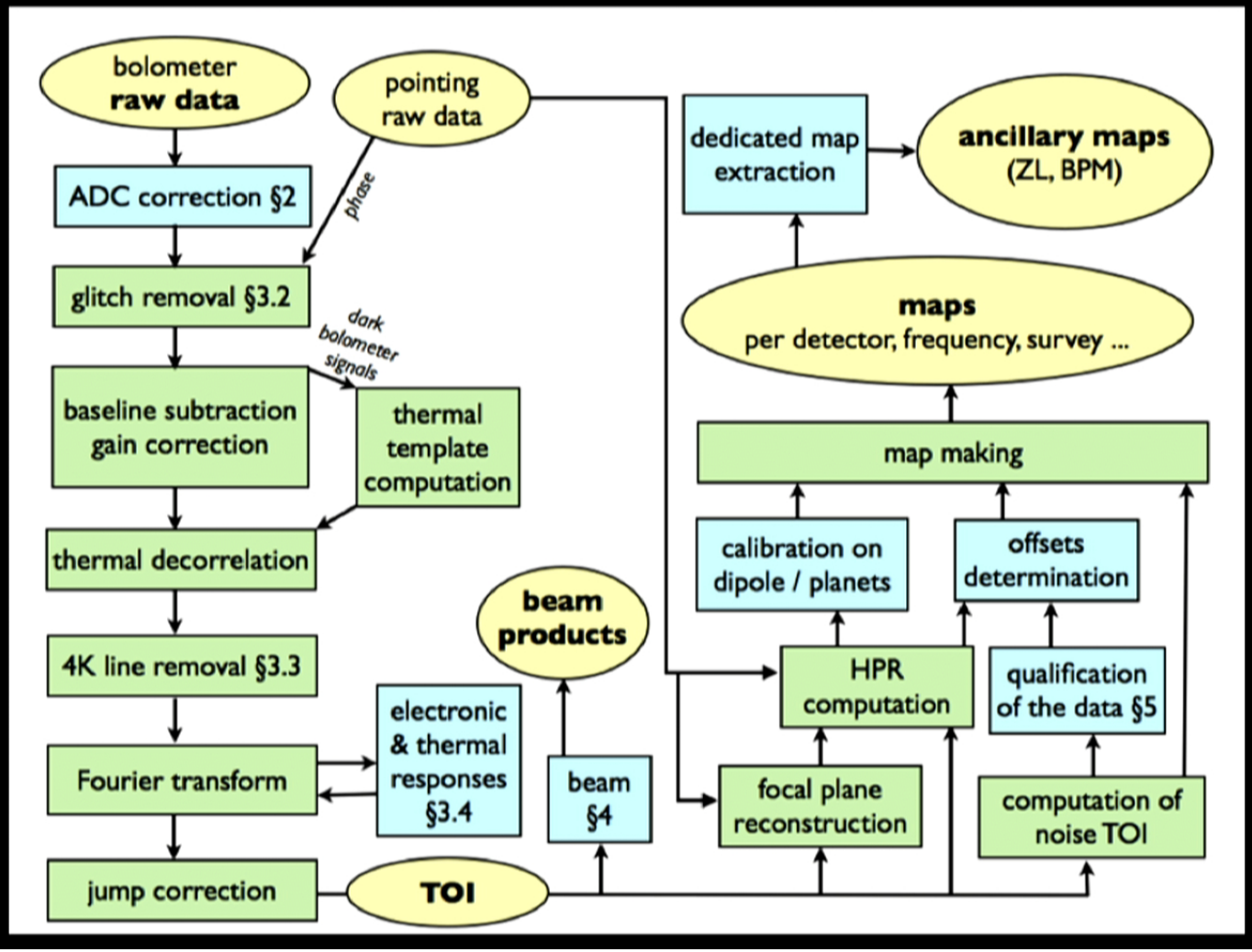
Raw TOI



~ 3 circles @ 143 GHz, 545 GHz and a dark bolometer

HFI data processing



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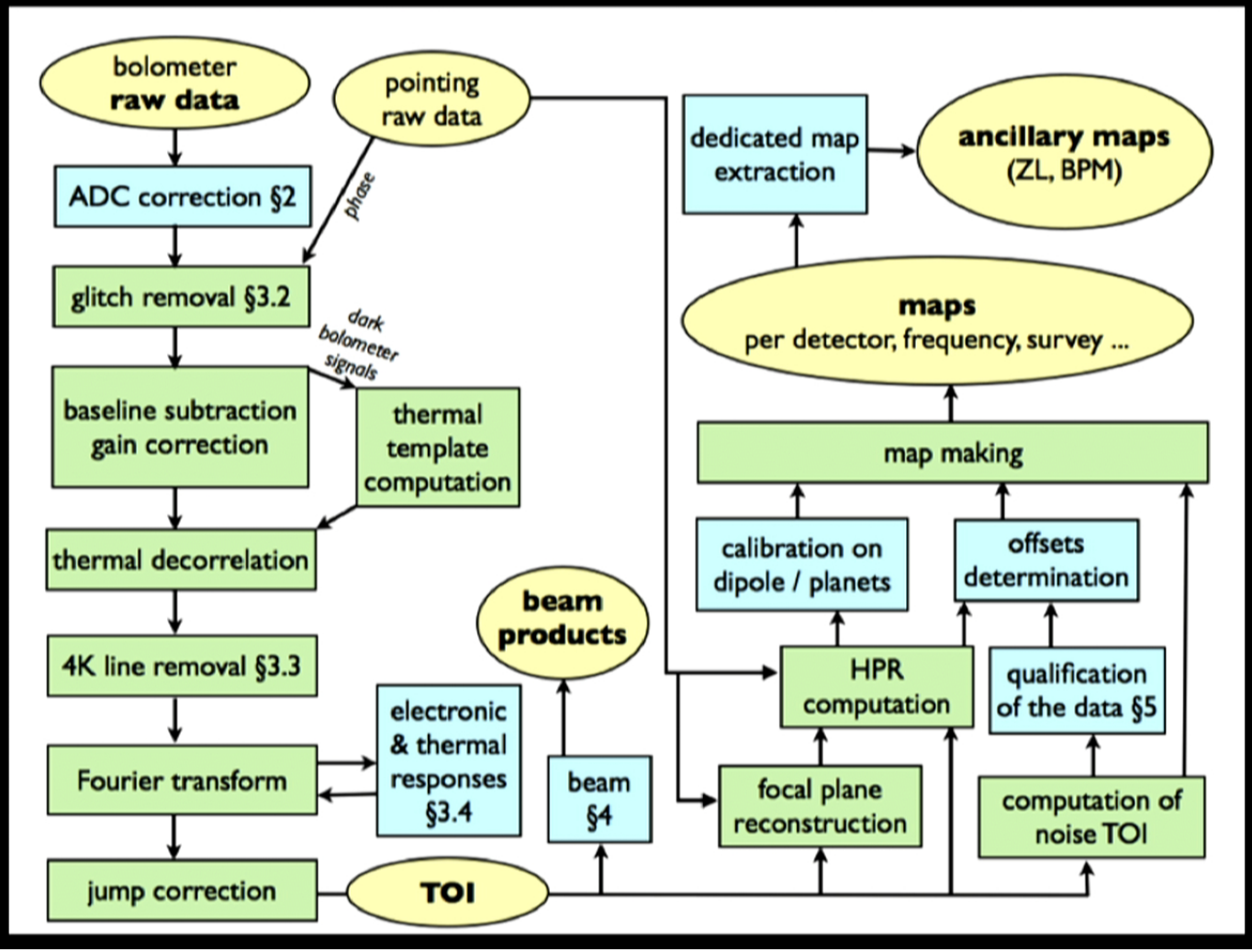
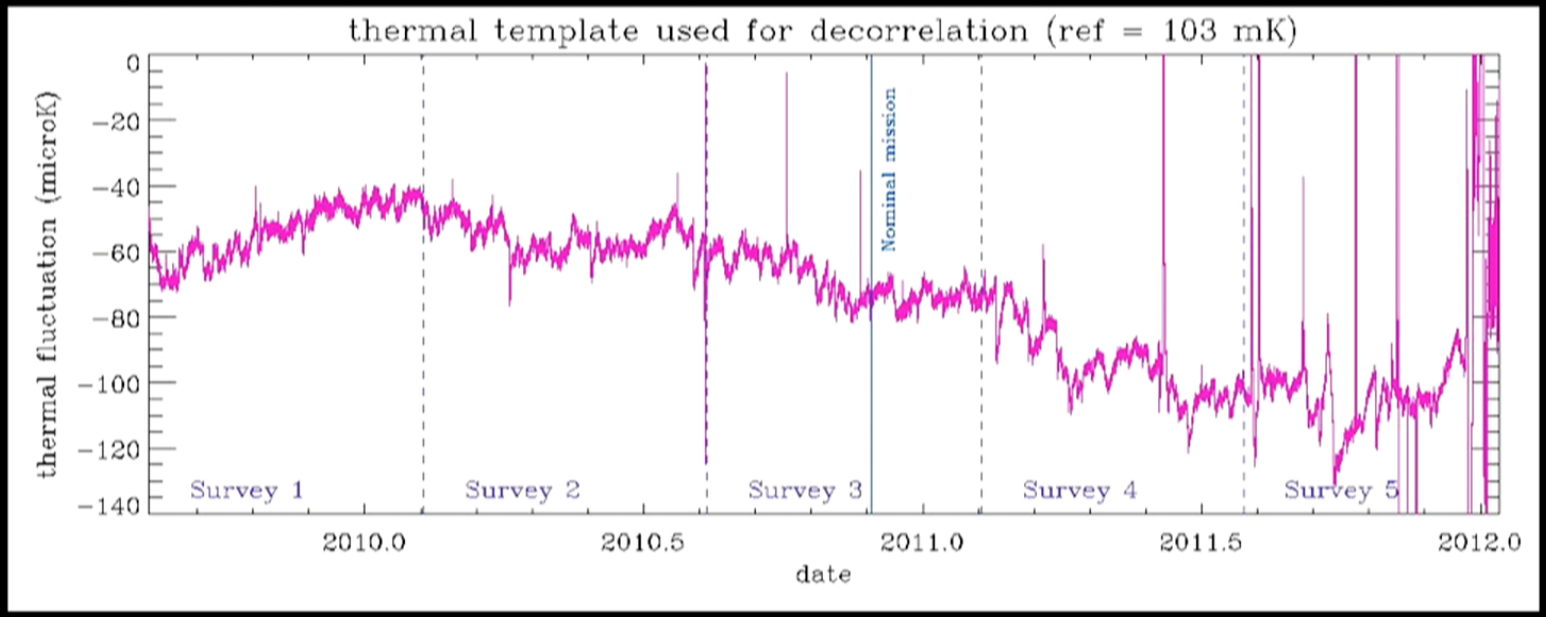


Thermal template

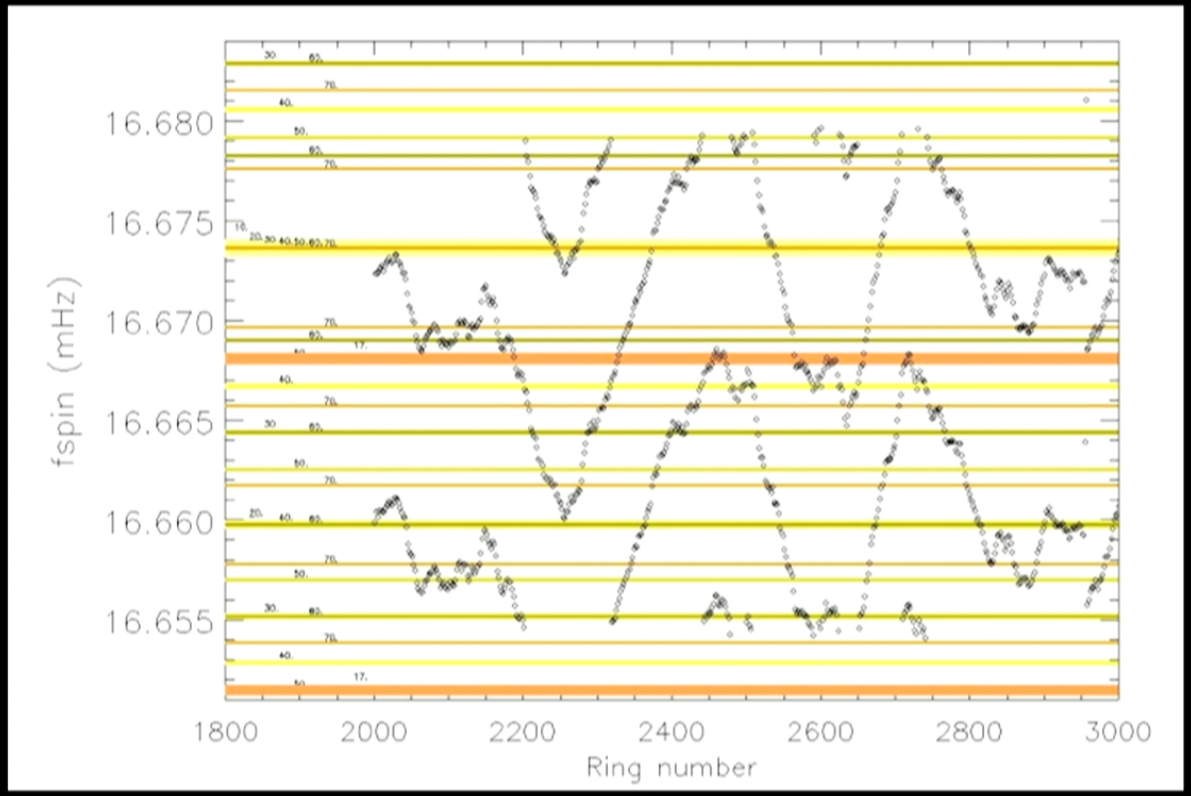


Computed from the two dark bolometers (thermometers useless)

Global shape ↔ Sun activity

Allows to recover data after huge & common cosmic event

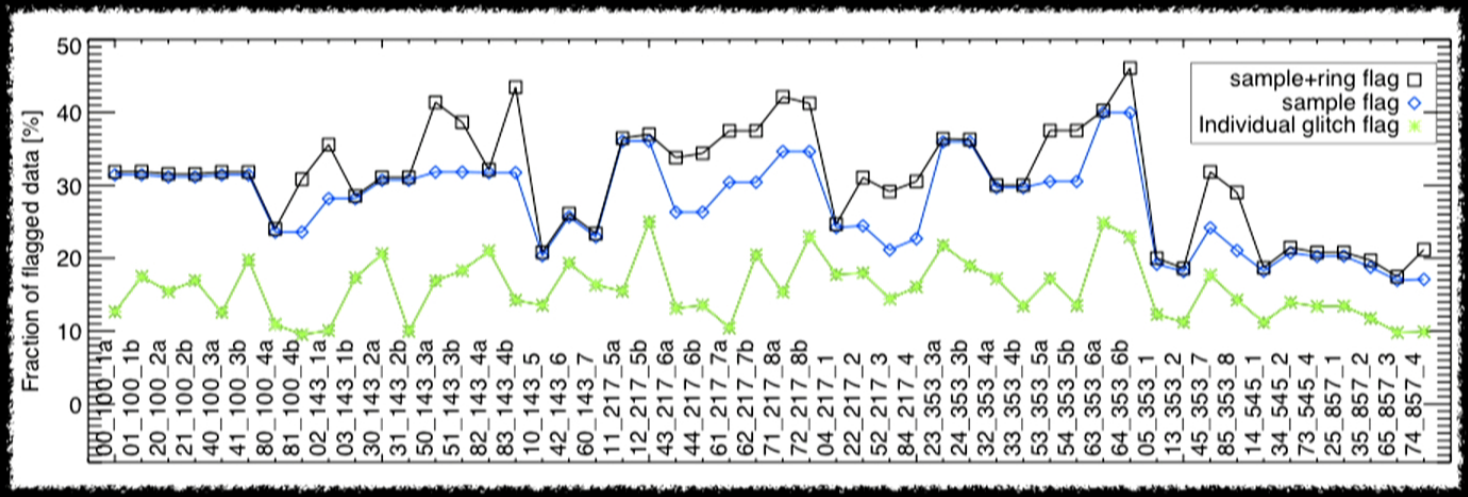
4K cooler lines



Instrumental signal @ 10, 17, 20, 30, 40, 50, 60, 70 Hz

Not undestood features for the 30 Hz line --> rings discarded

Time ordered data (HFI)



About 70% of the data are used for astrophysics & cosmology

Main reasons to discard data are cosmic rays, depointing & manoeuvers, planet crossing, 4K lines, solar flares & RTS.

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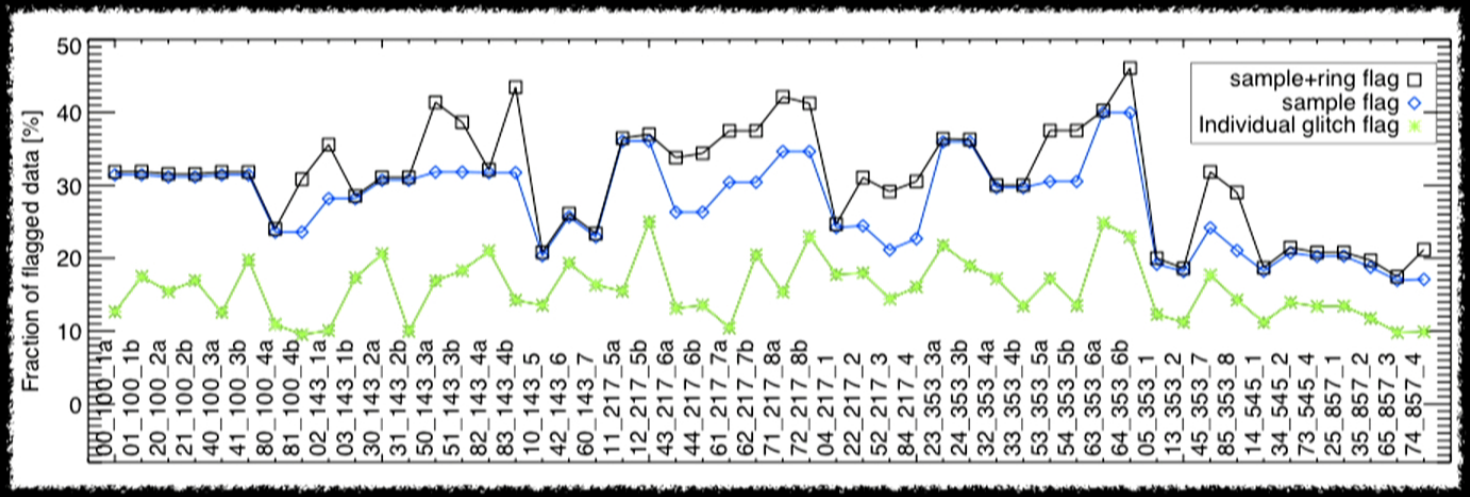

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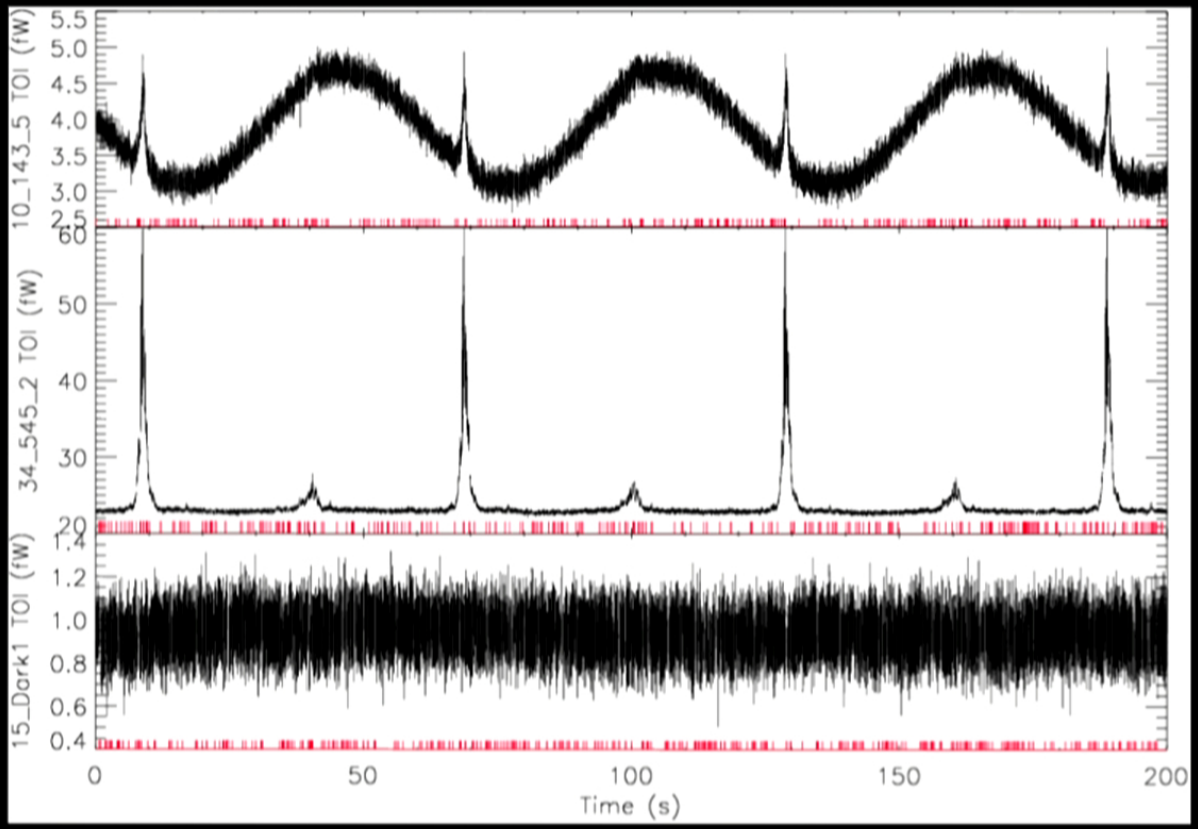
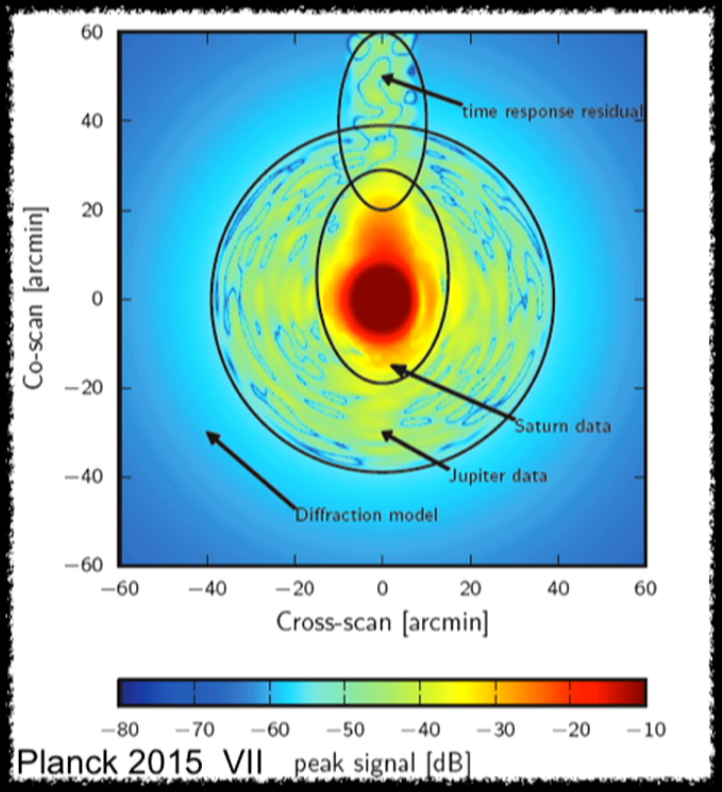
Processed TOI



Flagged samples Samples to project on maps

The detector answer



The effective beams are computed using Mars, Saturn & Jupiter signals

5 time constants /bolometer

- The 2 fastests from planet observation
- The next 2 from glitch stacking + Jupiter for the amplitude
- The 5th from glitch stacking + CMB dipole shift for the amplitude
- 2 others @ 353 GHz

Frequency (GHz)	100	143	217	353	545	857
Beam (arcmin)	9.69	7.30	5.02	4.94	4.83	4.64

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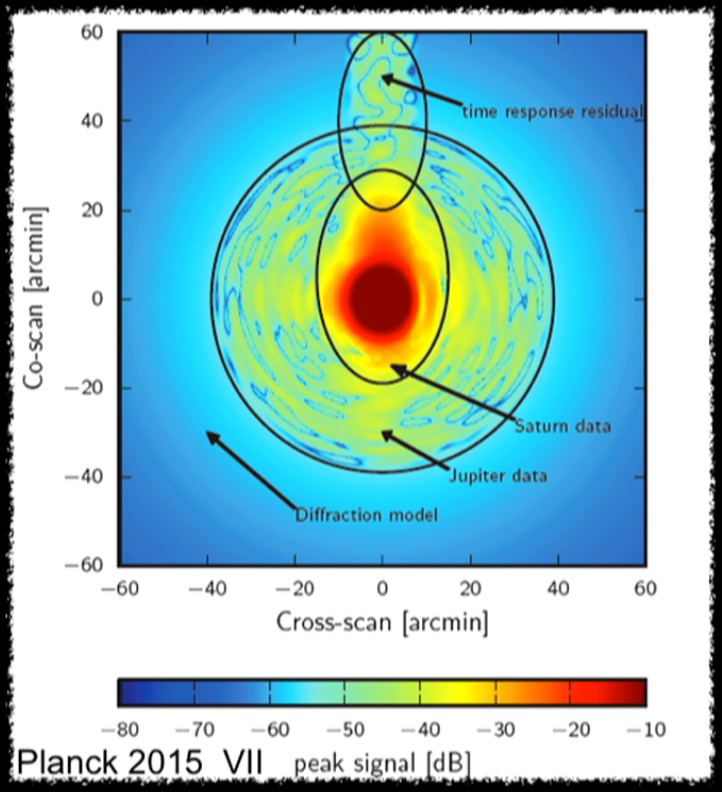

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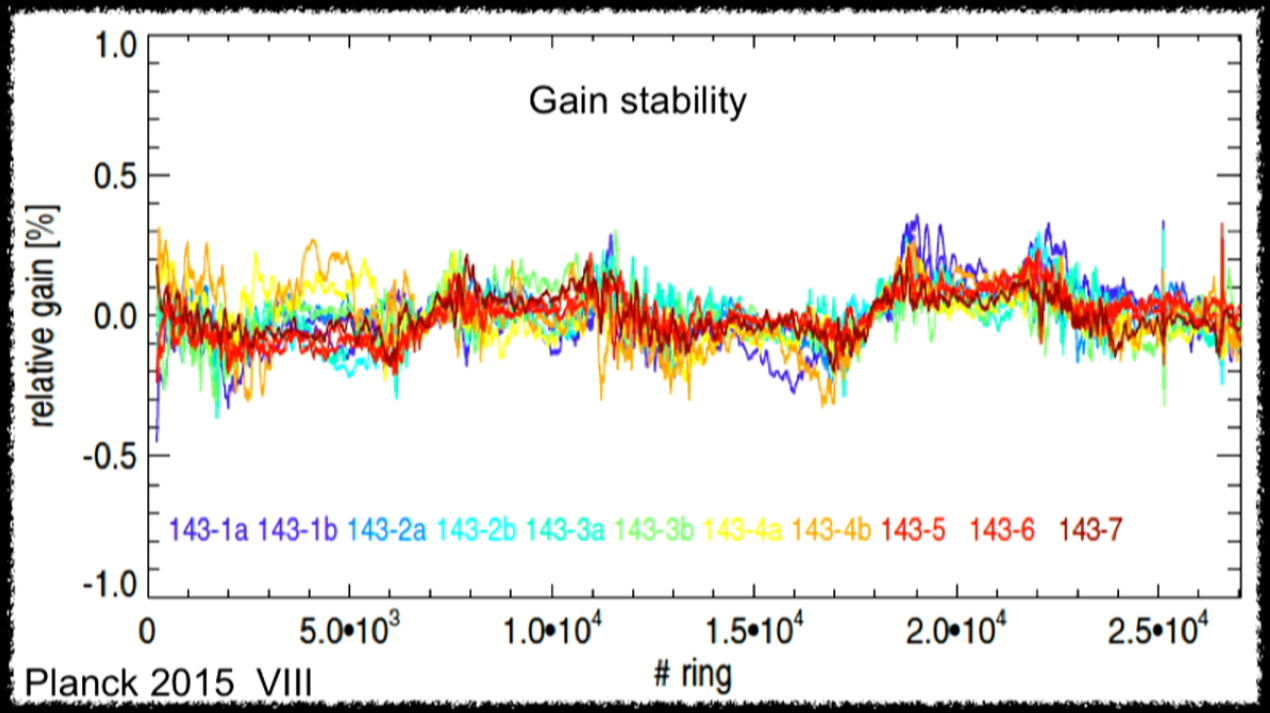

545 & 857 GHz channels calibrated using Uranus & Neptune signals
CMB channels are calibrated using the orbital dipole

Solar dipole: amp=3364.5 ± 2.0 μK(sys)
lon =264.00 ± 0.03°(sys), lat = 48.24 ± 0.02° (sys)

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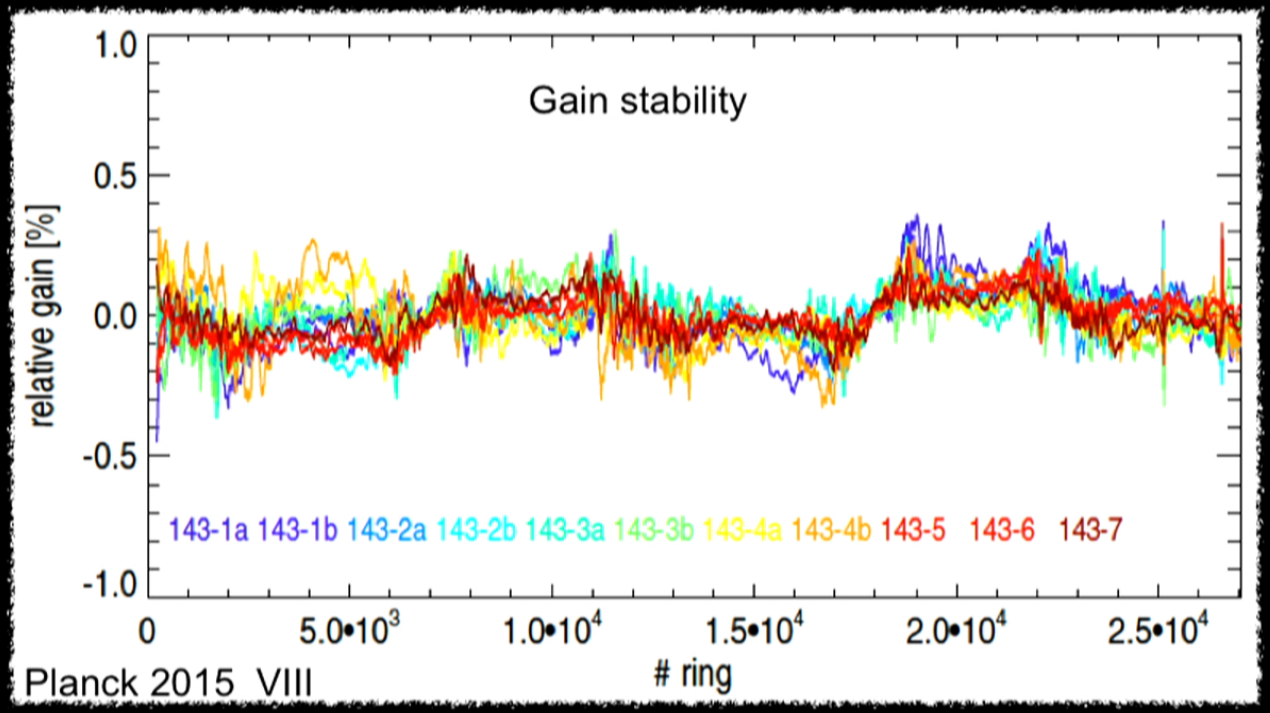

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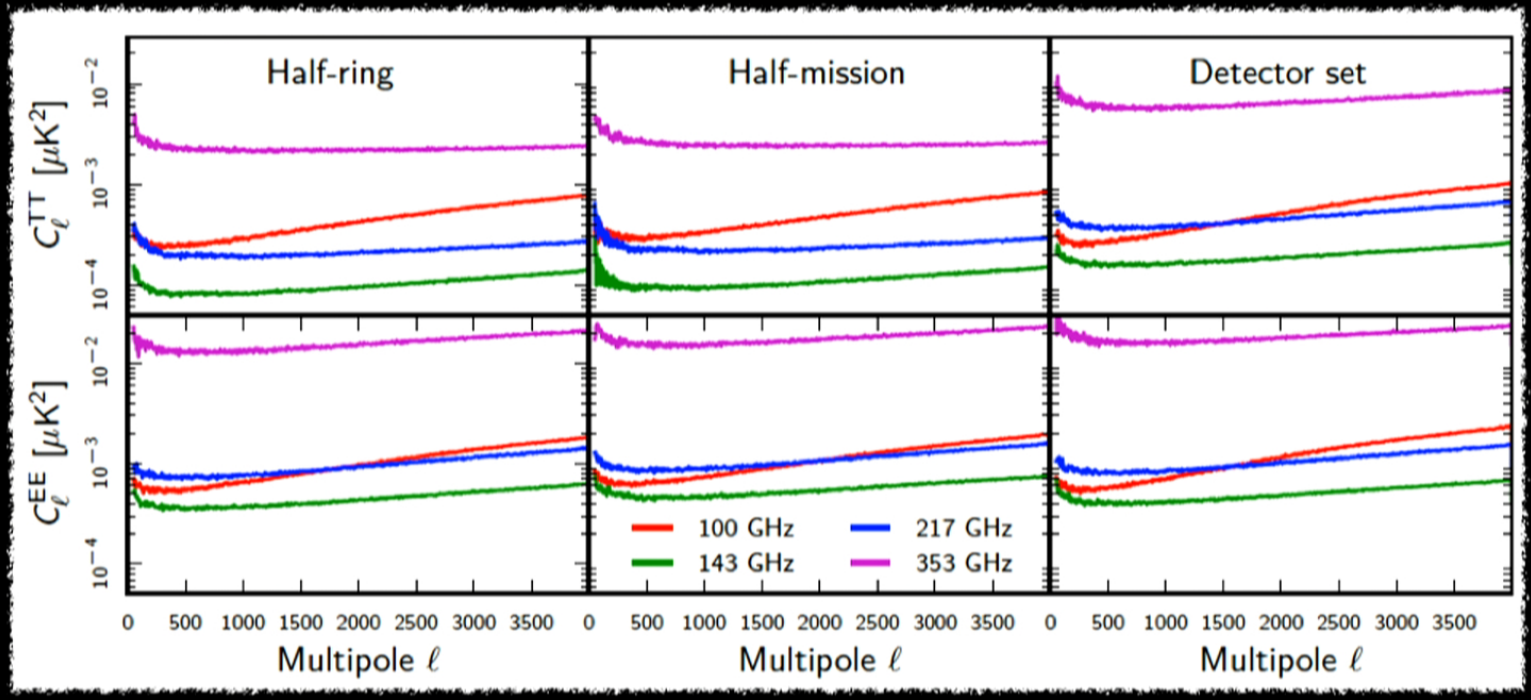
Noise spectra

correlations < 1h correlations > 1h time response +calibratiom

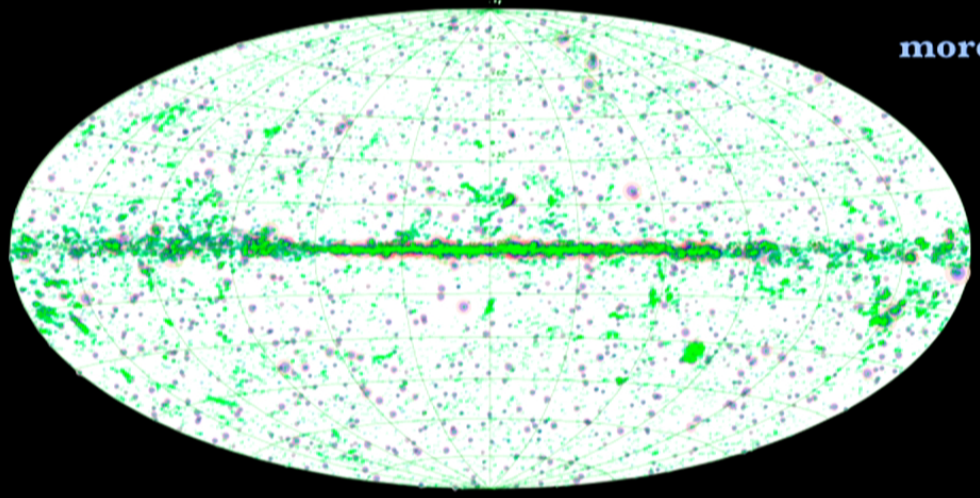


TT & EE power spectra from the half-difference as M = $(M_A - M_B)$ / 2
PS+Galaxy masks leave 65, 59, 48, and 32% unmasked @ 100, 143, 217, and 353 GHz

Catalogues

almost 8,000 extragalactic sources

Type of galaxy	Frequency	Emission process	Nb of sources
radio-galaxies & blazars	30-217 GHz	emission by synchrotron effect of e^- in the host galaxy or in the jets.	few hundreds
Close galaxies, or luminous or ultra-luminous infrared galaxies	353-857 GHz	thermal emission of the dust	few thousands



more than 17,000 galactic sources

bright enough to be visible above the diffuse background

mainly cores of cold molecular clouds

detailed study by Herschel

Catalogue provides position, flux, shape, validation flags, info on neighbours

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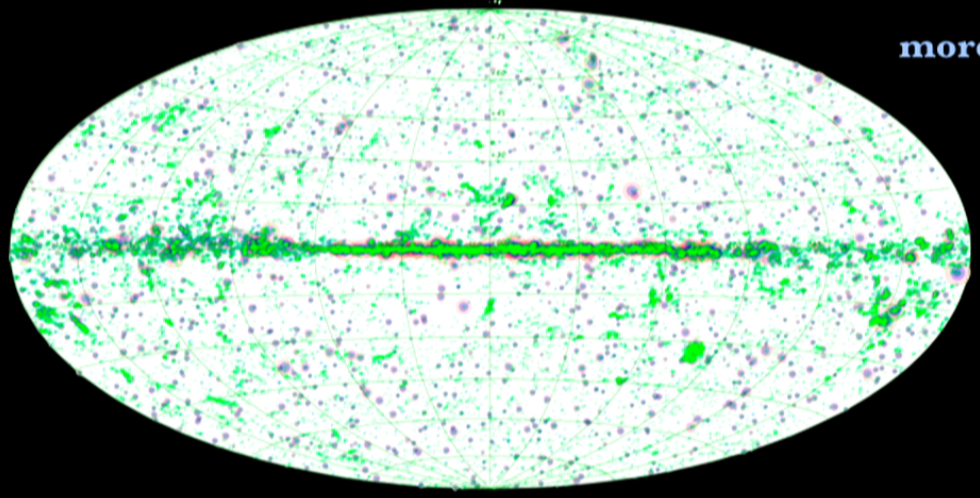

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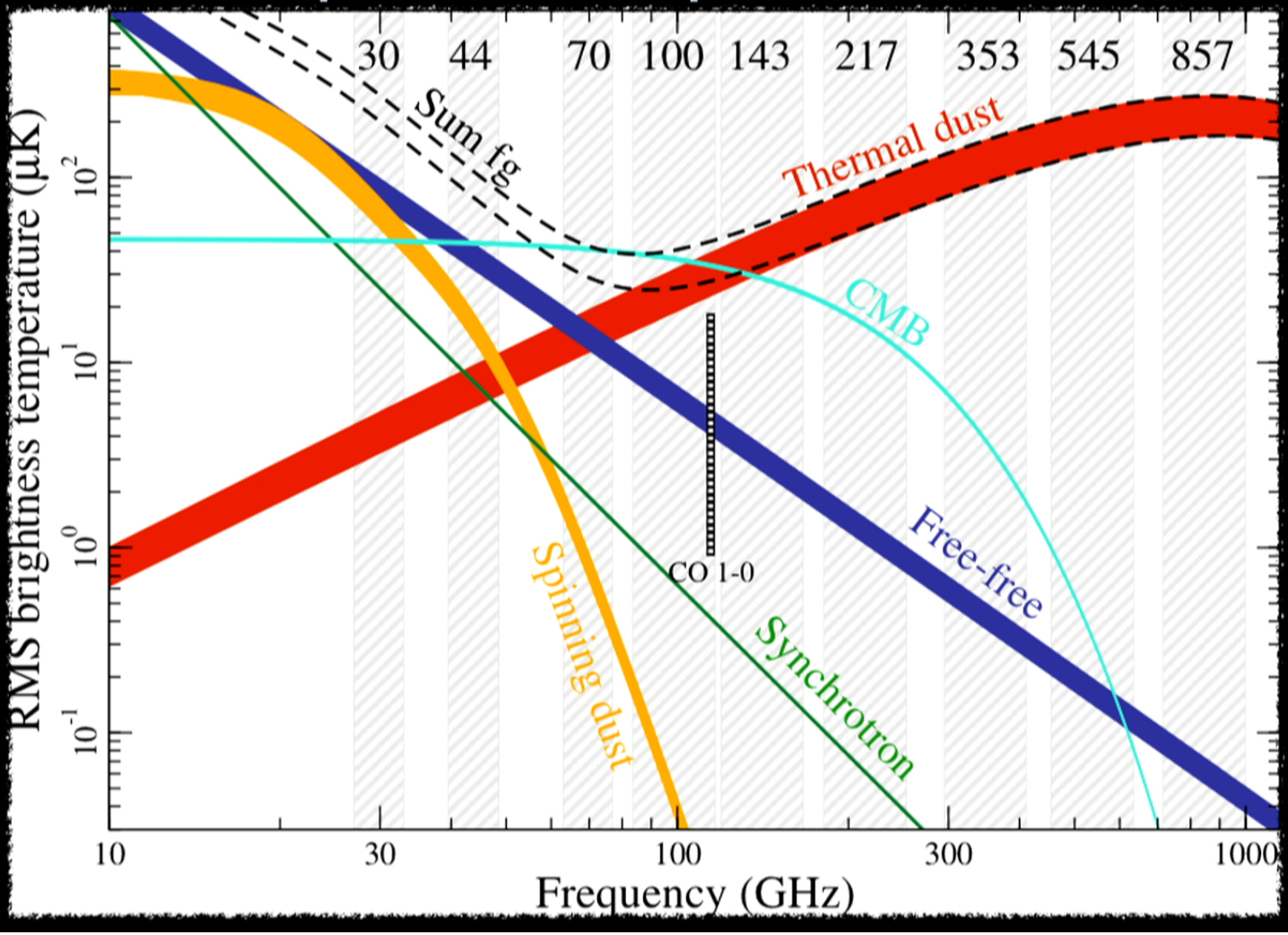
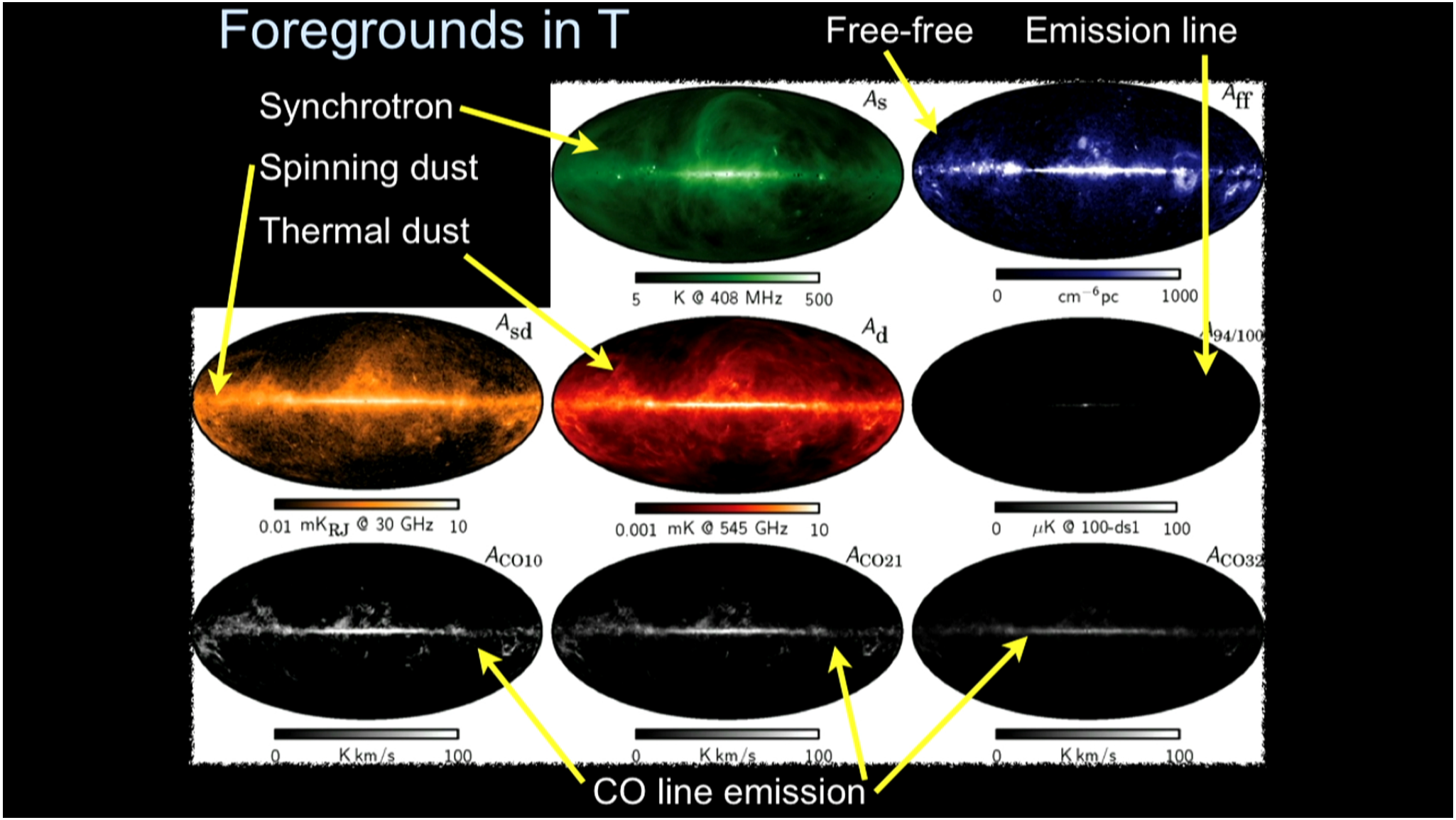
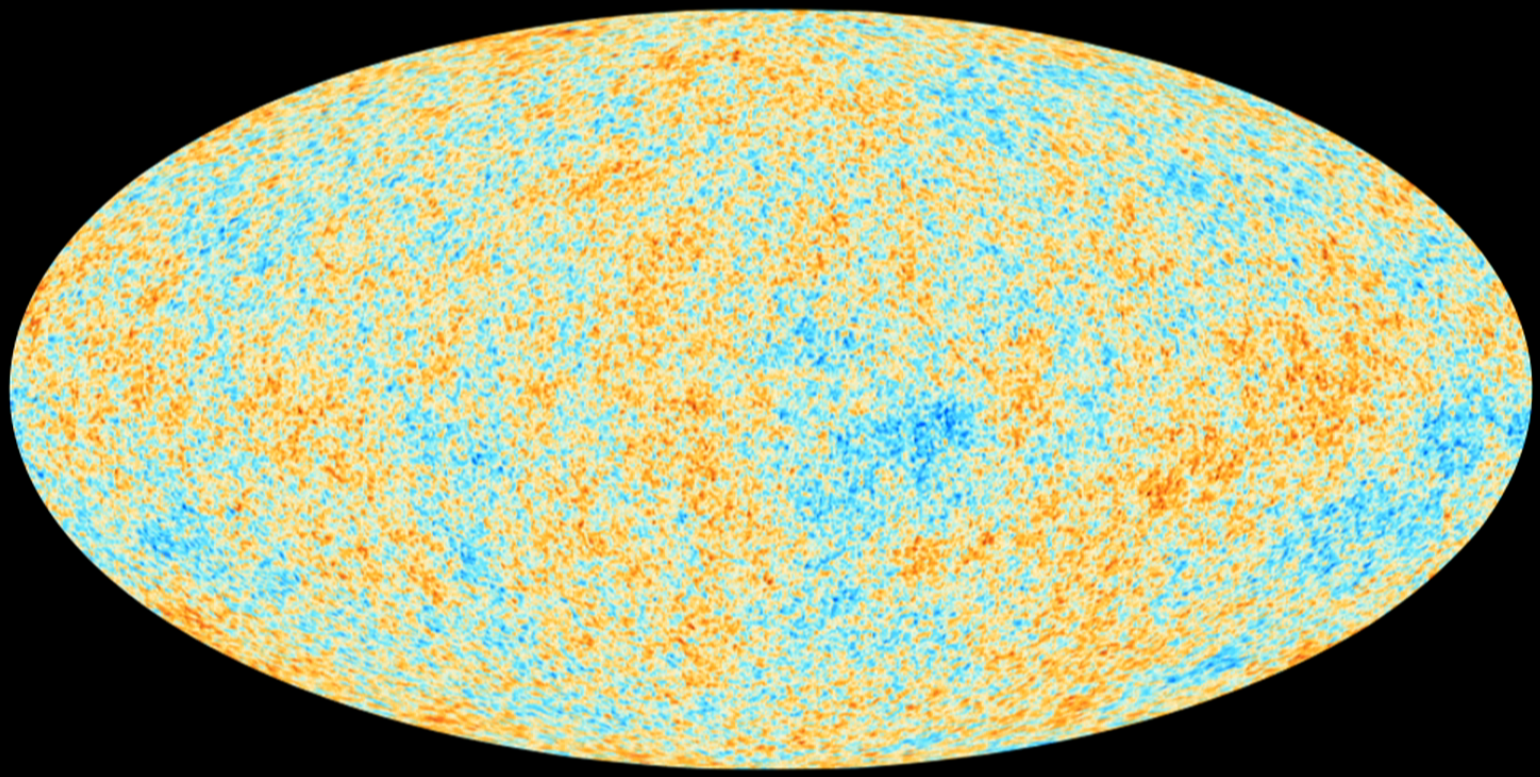
Component separation in T




Foregrounds in T
Free-free
Emission line
Synchrotron
Spinning dust
Thermal dust
A_s
A_{ff}
5 K @ 408 MHz 500
0 cm^{-6}pc 1000
A_{sd}
A_d
$A_{94/100}$
0.01 mK$_{RJ}$ @ 30 GHz 10
0.001 mK @ 545 GHz 10
0 μK @ 100-ds1 100
A_{CO10}
A_{CO21}
A_{CO32}
0 K km/s 100
0 K km/s 100
0 K km/s 100
CO line emission

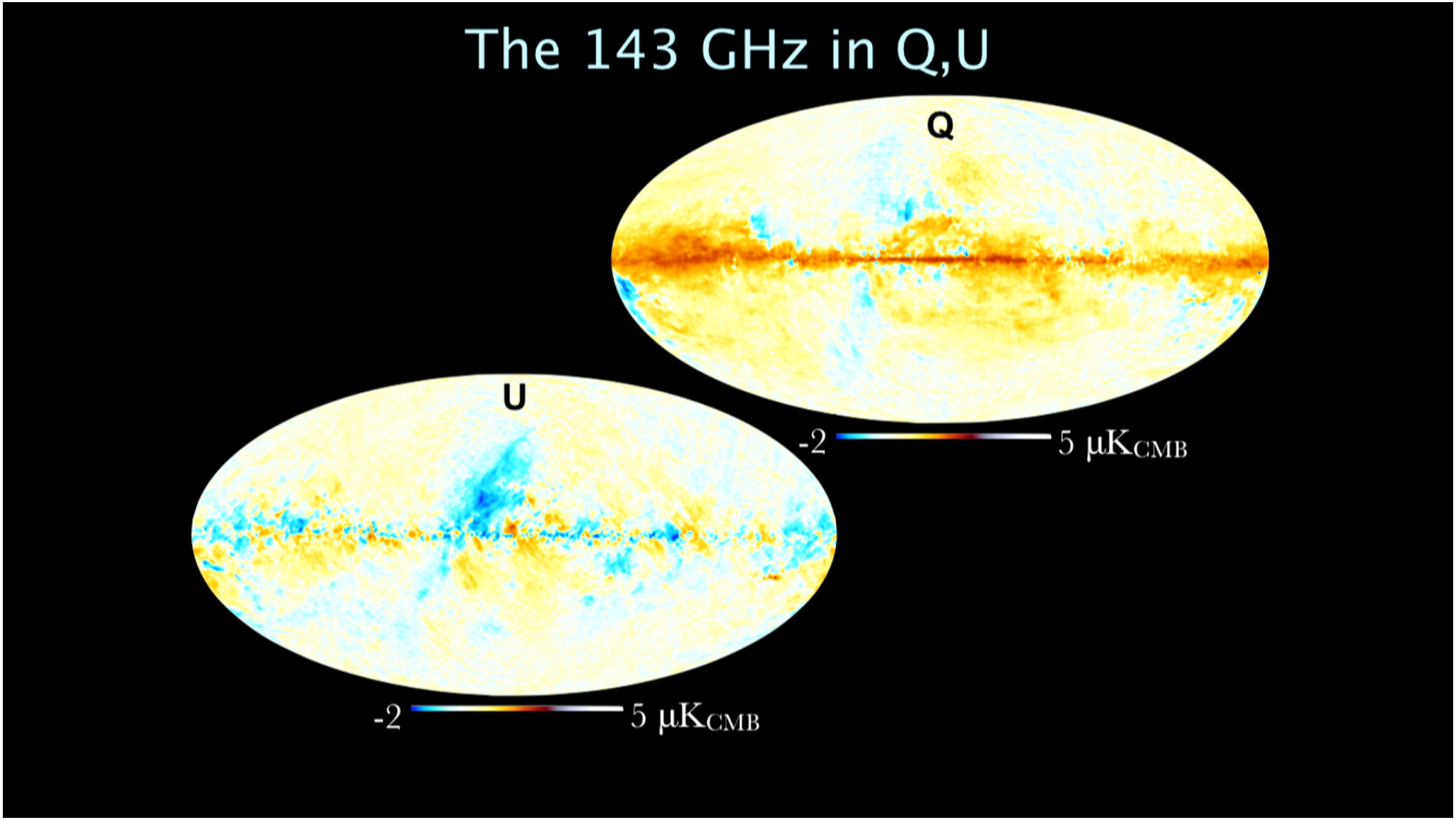
Intensity of the primary anisotropies



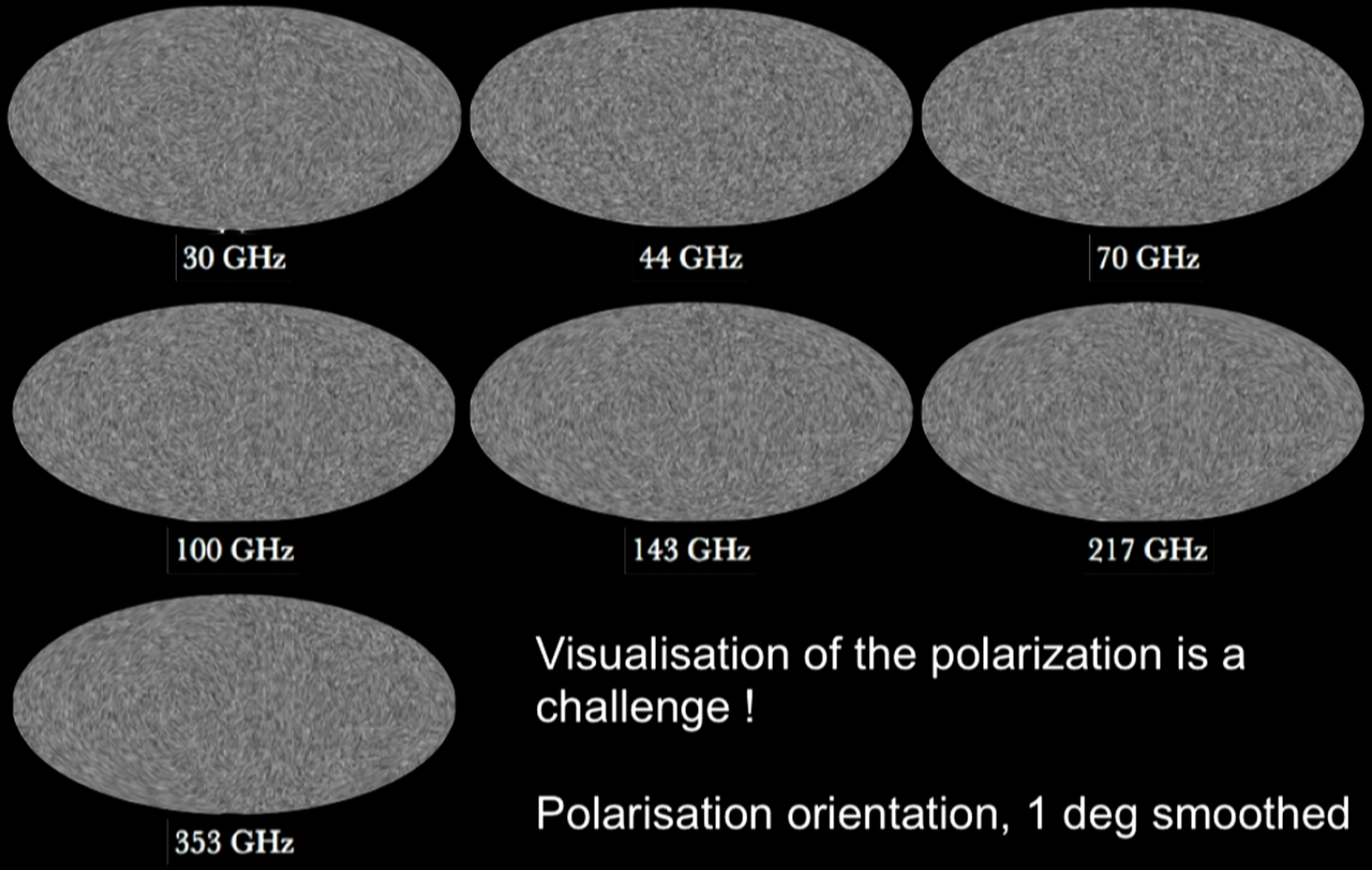
-500 500 μK_{CMB}

Methods are linear combination in pixel or in harmonic space with weighting on the sky or with templates (from Planck data) optimized to extract the CMB component

✔ Sensitivity of a few μK_{CMB} / pixel (26 μK_{CMB} / arcmin)


The 143 GHz in Q,U
Q
-2
5 μK$_{CMB}$
U
-2
5 μK$_{CMB}$

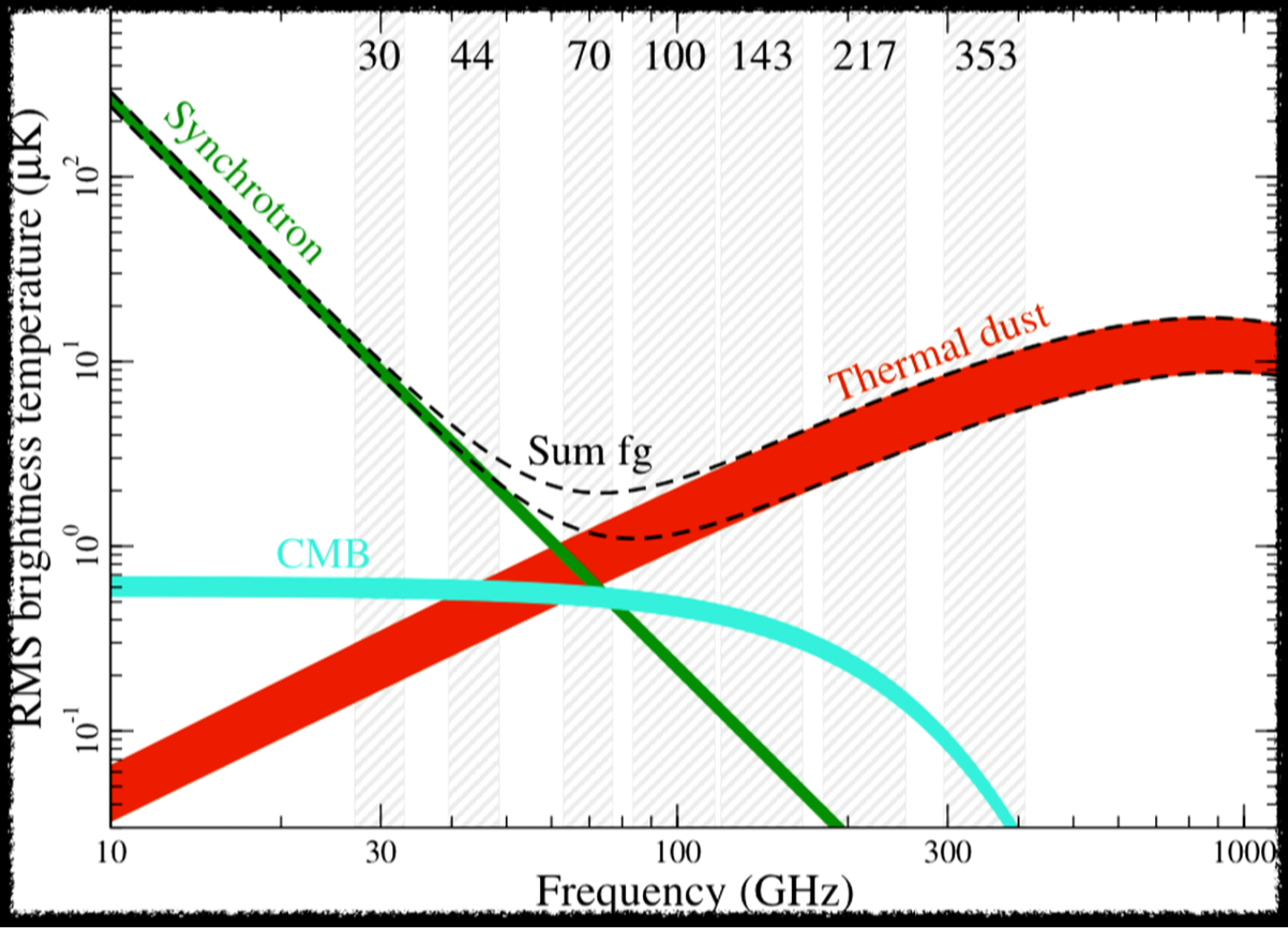
The sky seen by Planck in polarization



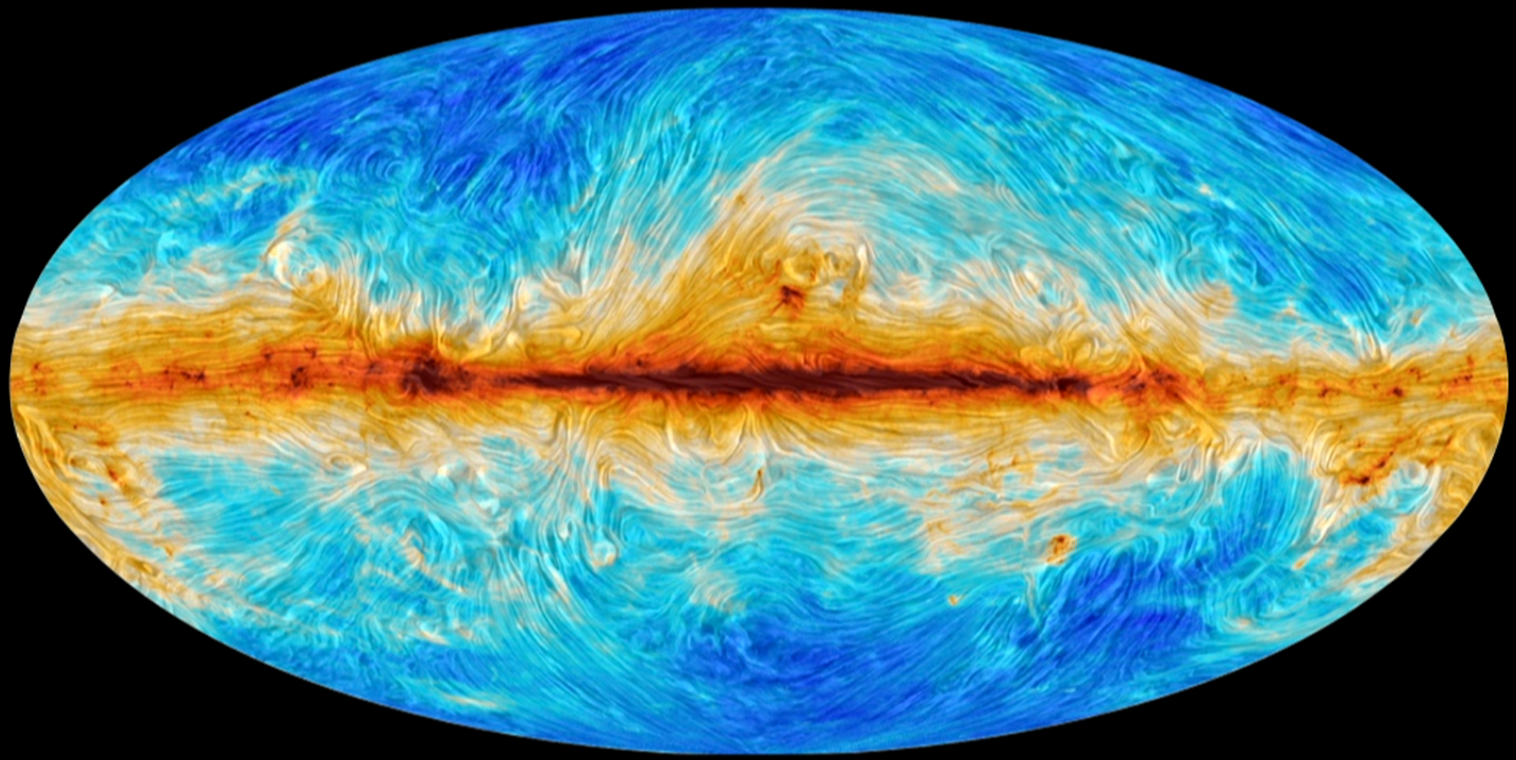
Visualisation of the polarization is a challenge !

Polarisation orientation, 1 deg smoothed

Component separation in P



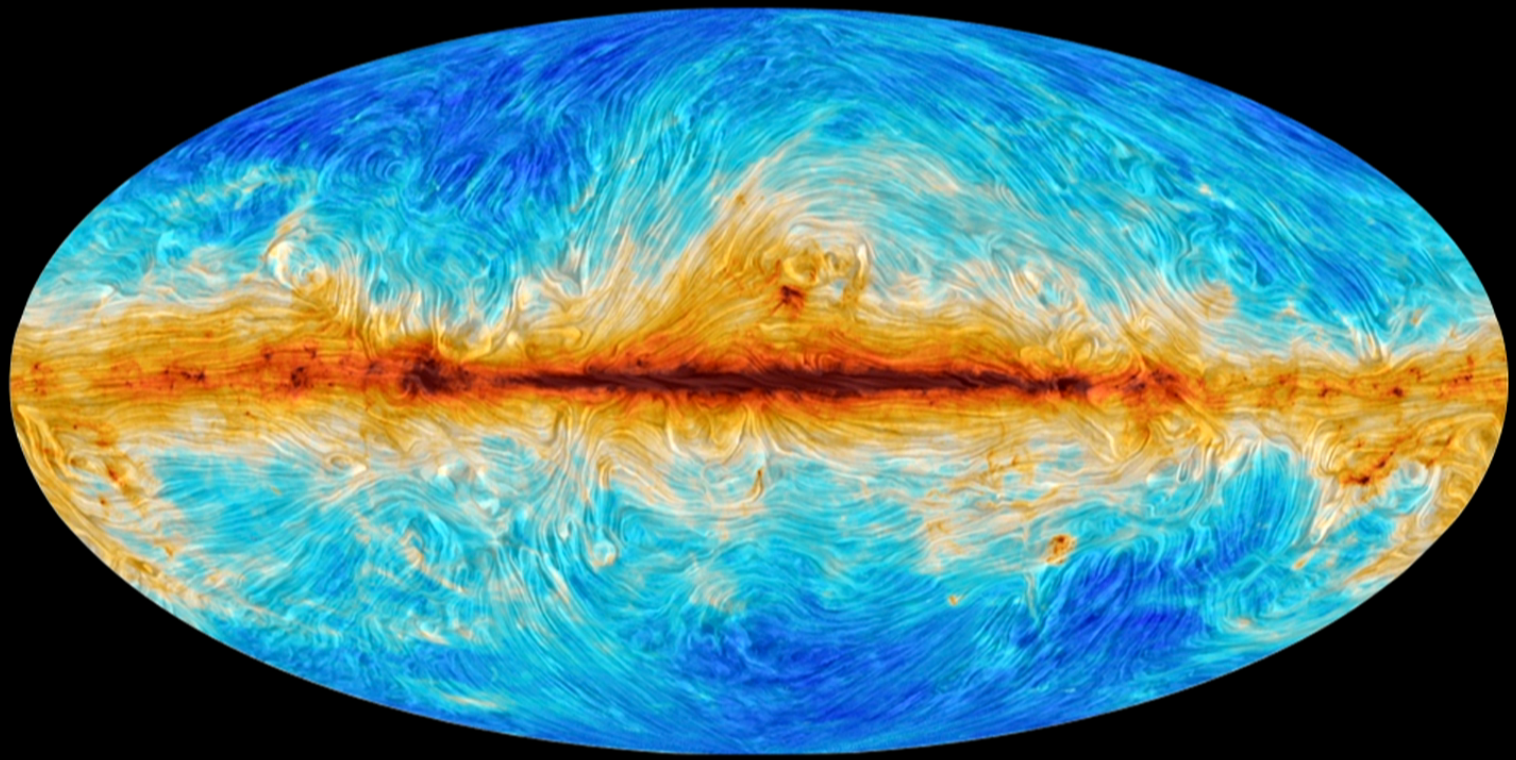
Planck is well suited for Galactic studies



353 GHz: color = temperature, depth = direction of polarization

Dust (& synchrotron) reveals the magnetic field direction

Planck is well suited for Galactic studies



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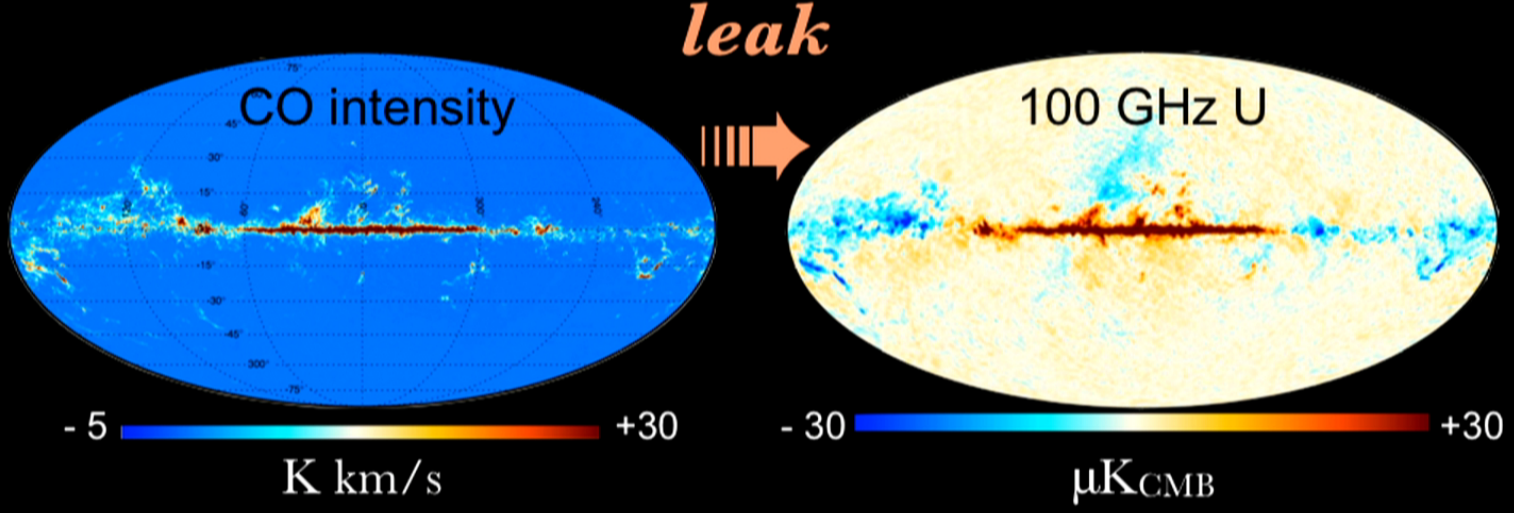
Foregrounds & related systematics

Intensity to polarisation leakage introduce a "fake" polarsiation signal

- Calibration mismatch [between detectors in a given channel]
- Zero-level mismatch
- Bandpass mismatch – Any foreground with SED different from CMB will leak from intensity to polarisation



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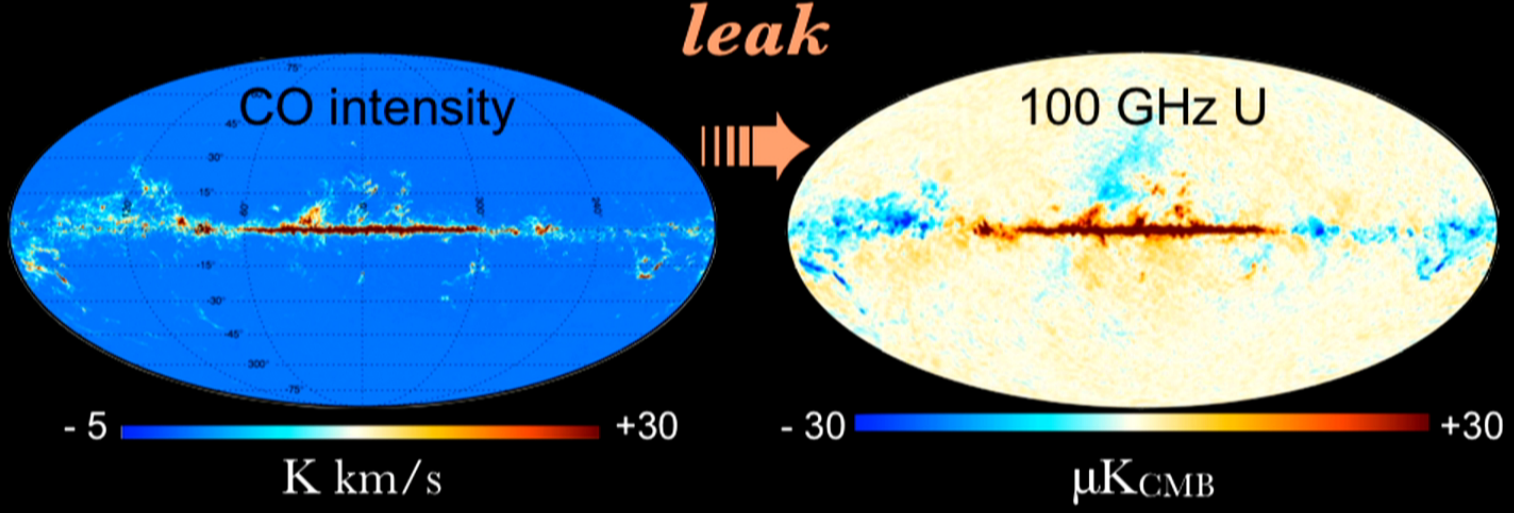

Foregrounds & related systematics

• Planck 2015 HFI polarisation data are affected by intensity-to-polarisation leakage
(dust, CO, free-free, dipole and monopole)
→ **problem for large angular scales** ($l < 30$)

• Two approaches have been developped to estimate this effect
→ 'Theoretical' estimate for bandpass mismatch
→ global fit for all combined leakages

• Corrections maps provided in the 2015 release should be use to test the stability of any given result. The CO must be masked.

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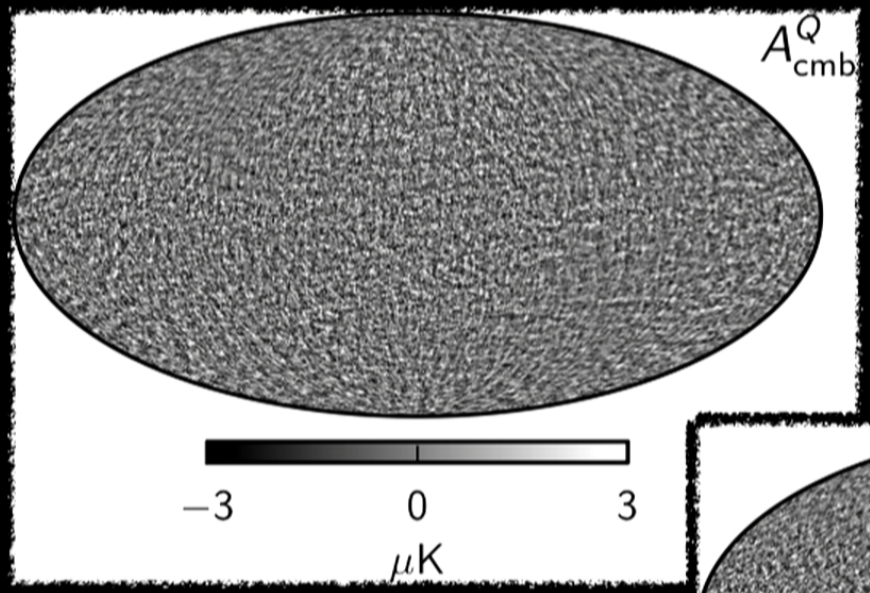
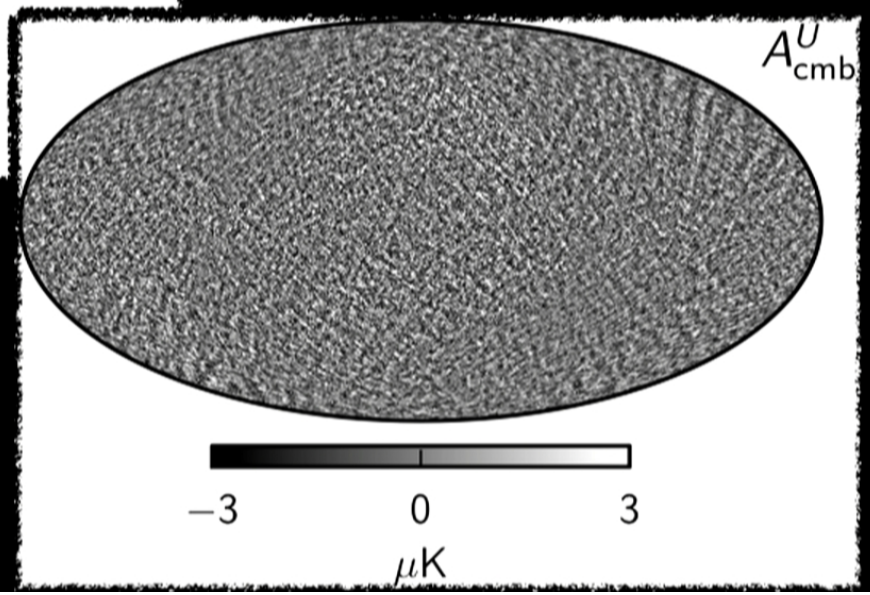
→ 'Theoretical' estimate for bandpass mismatch
→ global fit for all combined leakages

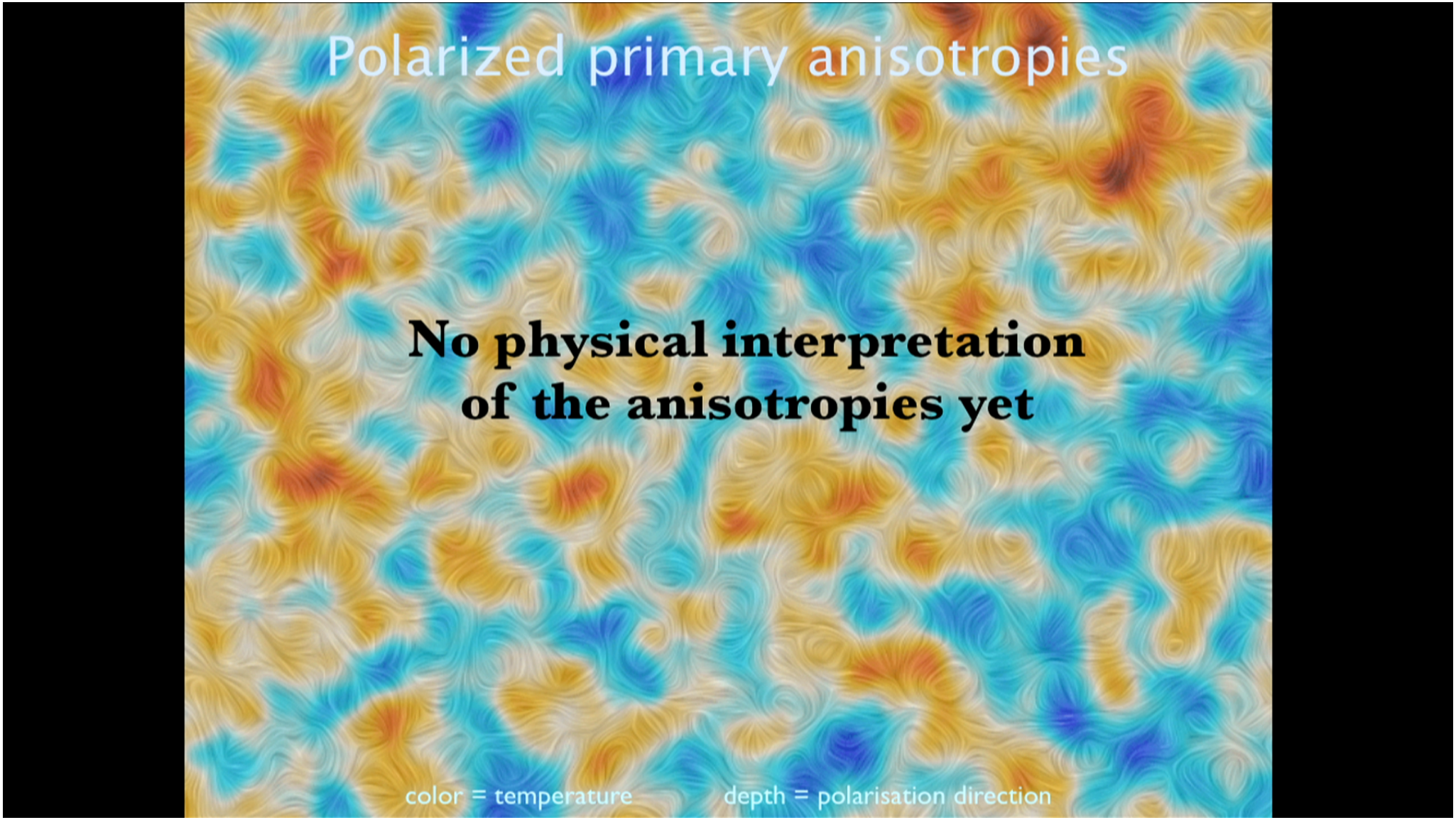
• Corrections maps provided in the 2015 release should be use to test the stability of any given result. The CO must be masked.

Polarisation of the primary anisotropies

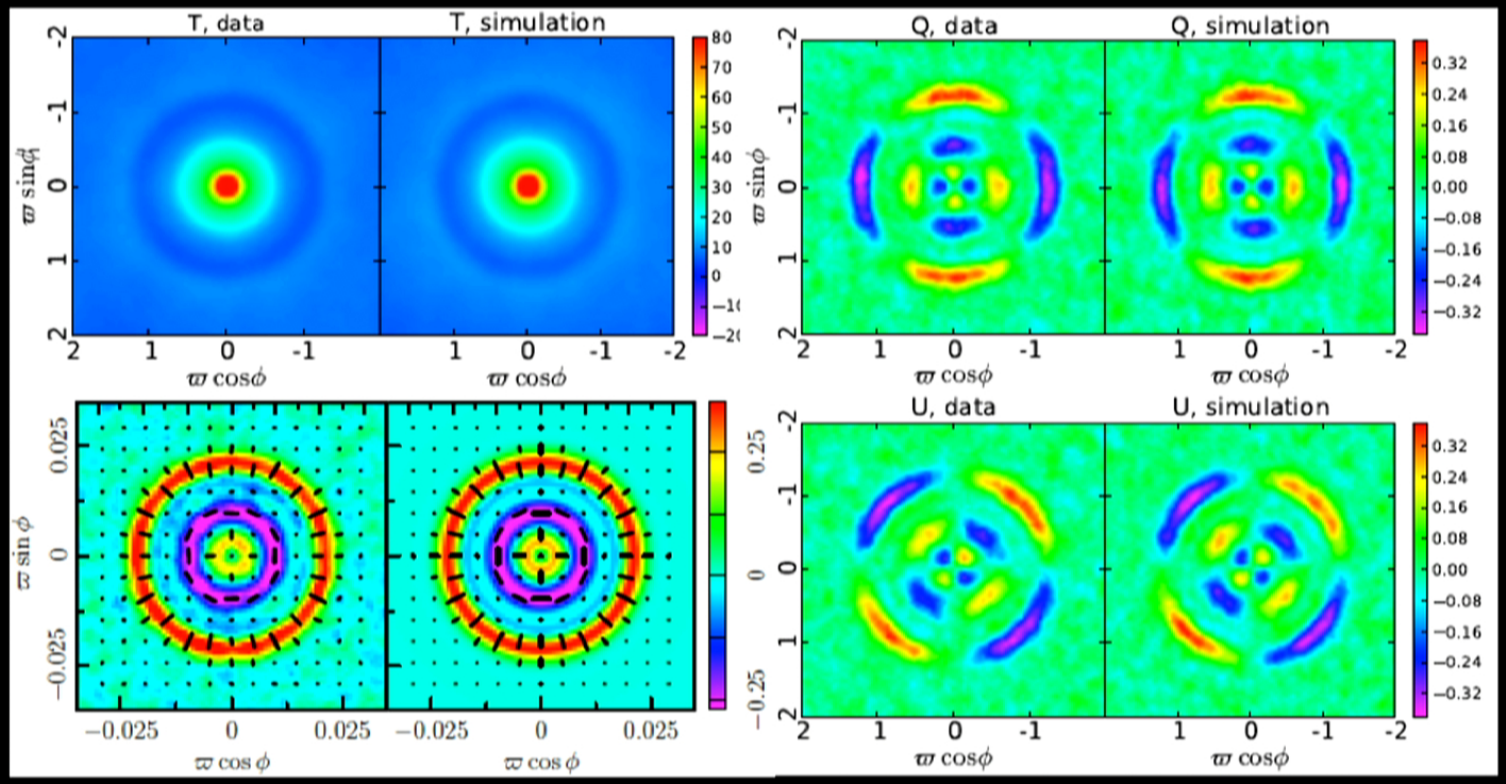


HFI aggregated sensitivity (referring to a weighted average of the 100, 143, and 217 GHz channel maps) is 52 μK_{CMB}/ arcmin in polarization.




Polarized primary anisotropies
No physical interpretation
of the anisotropies yet
color = temperature
depth = polarisation direction

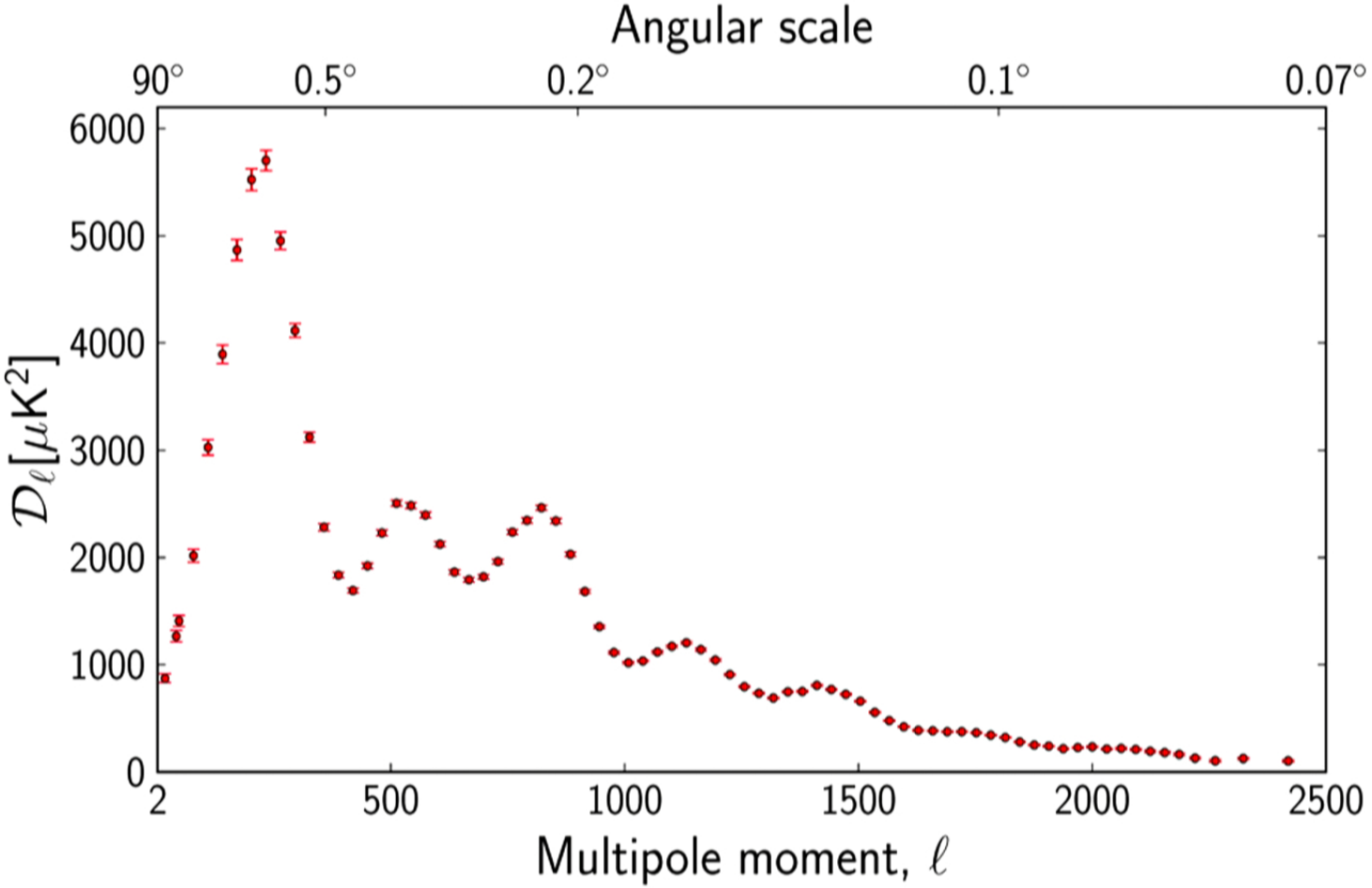
Temperature and polarization



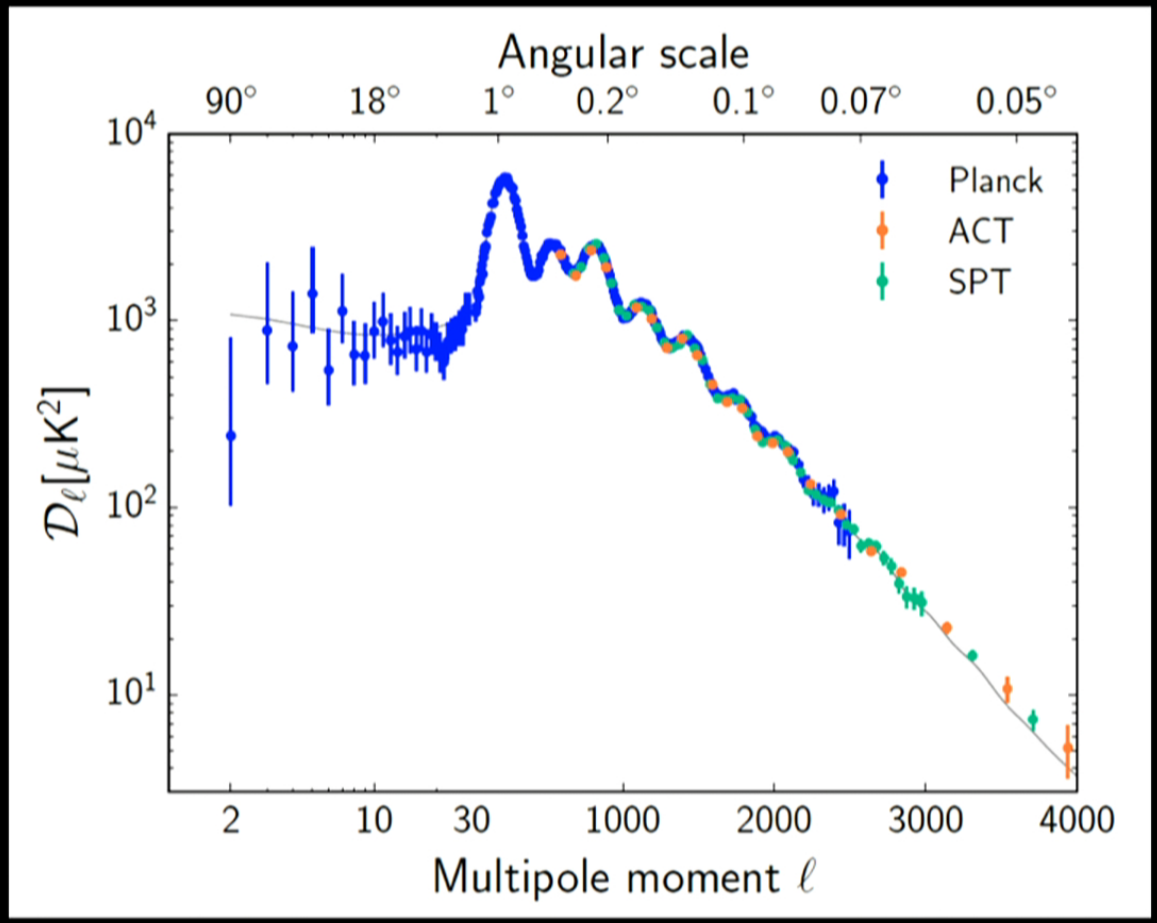
Right: data - Left: simulation

Stacking in T, Q, U of hot spots ➙ it seems that the model works quite well !

TT power spectrum



With high-ℓ experiments



Improved likelihood

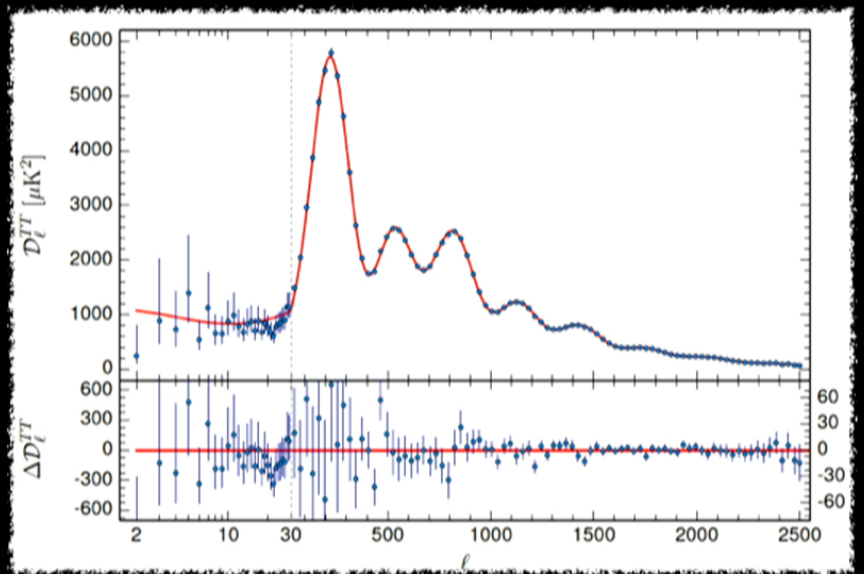
6 parameters
+ 11 nuisance parameters

(i) joint temperature-polarization pixel-based likelihood at $\ell \leq 29$, with more high-frequency information used for foreground removal, and smaller sky masks.

(ii) improved Gaussian likelihood at $\ell \geq 30$

- uses half-mission data instead of detector sets (which allows us to reduce the effect of correlated noise between detectors)
- better foreground templates, especially for Galactic dust that allow us to mask a smaller fraction of the sky and to retain large-angle temperature information from the 217 GHz map.

Planck 2015 XI



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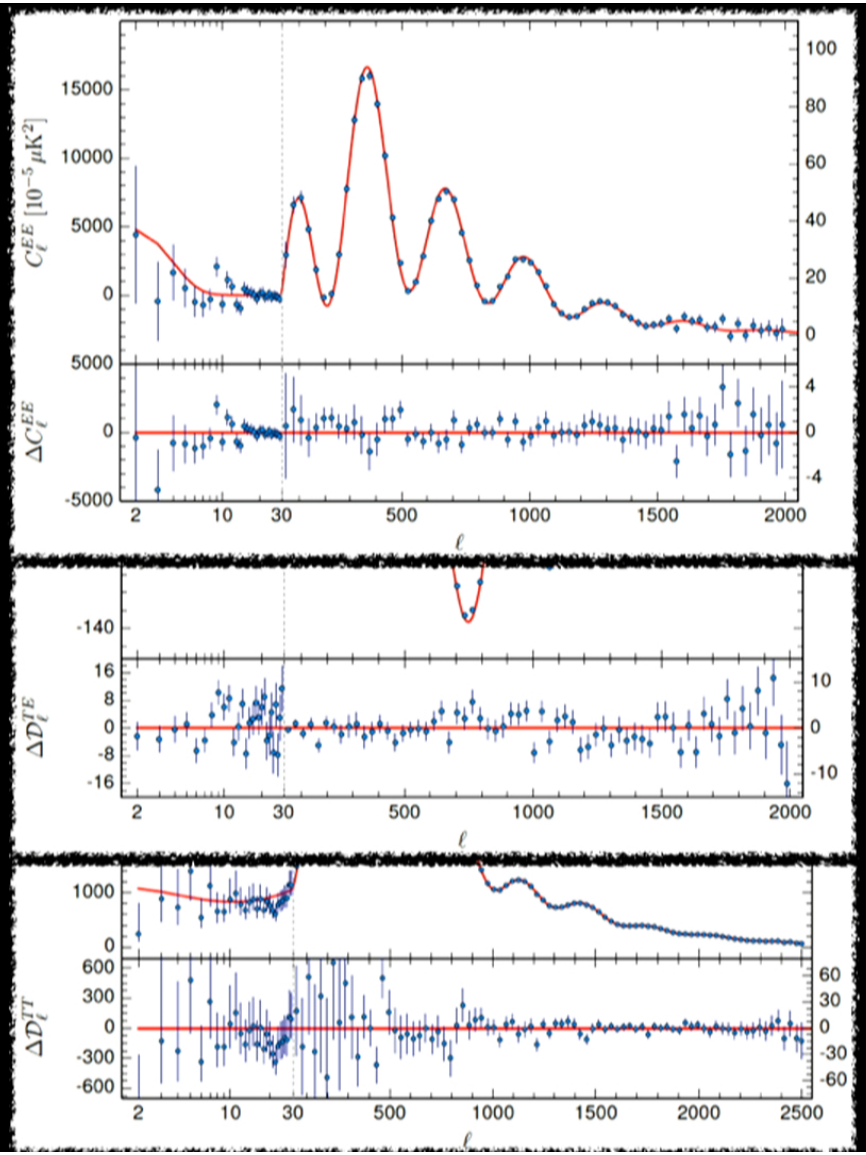
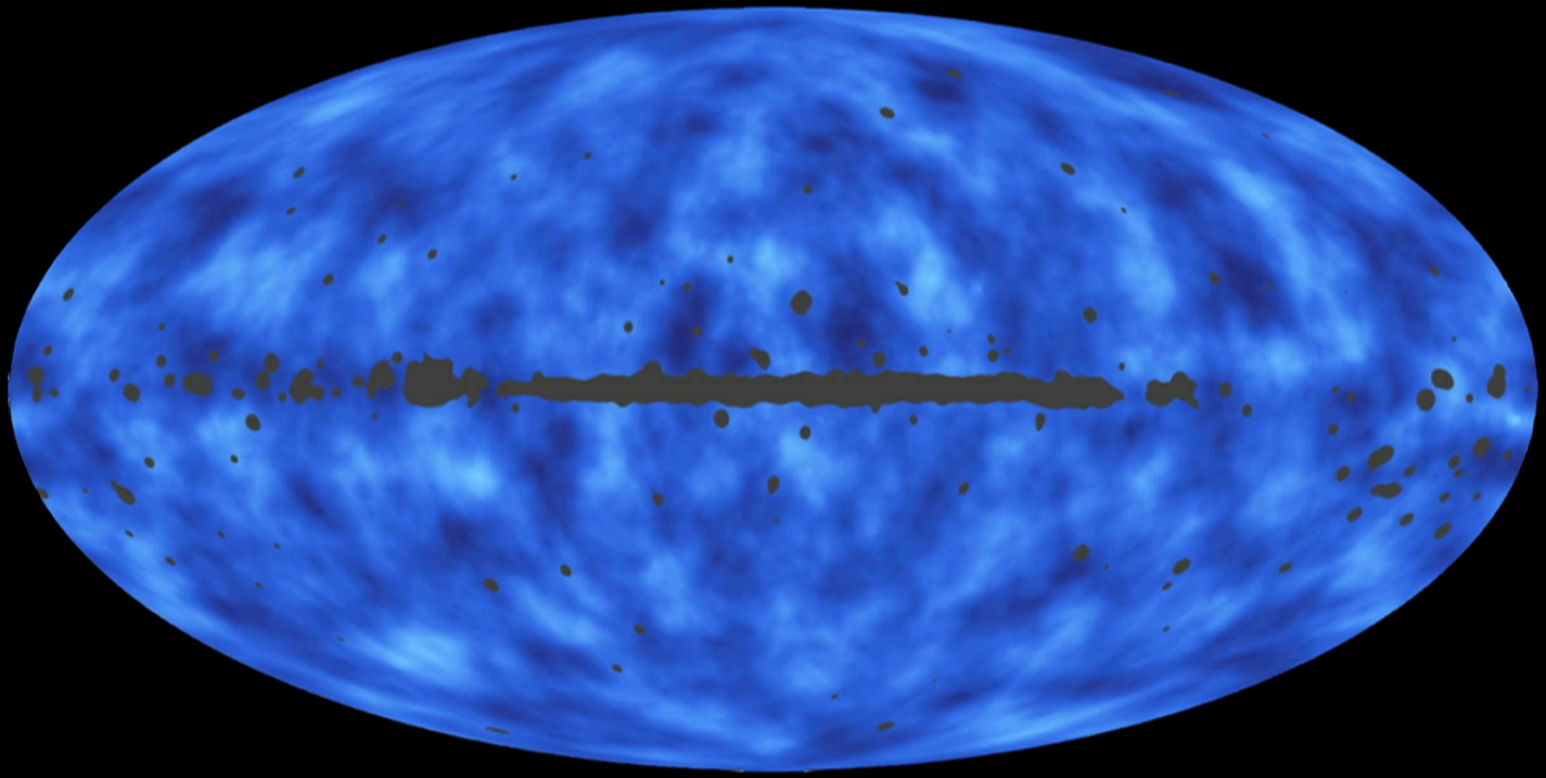


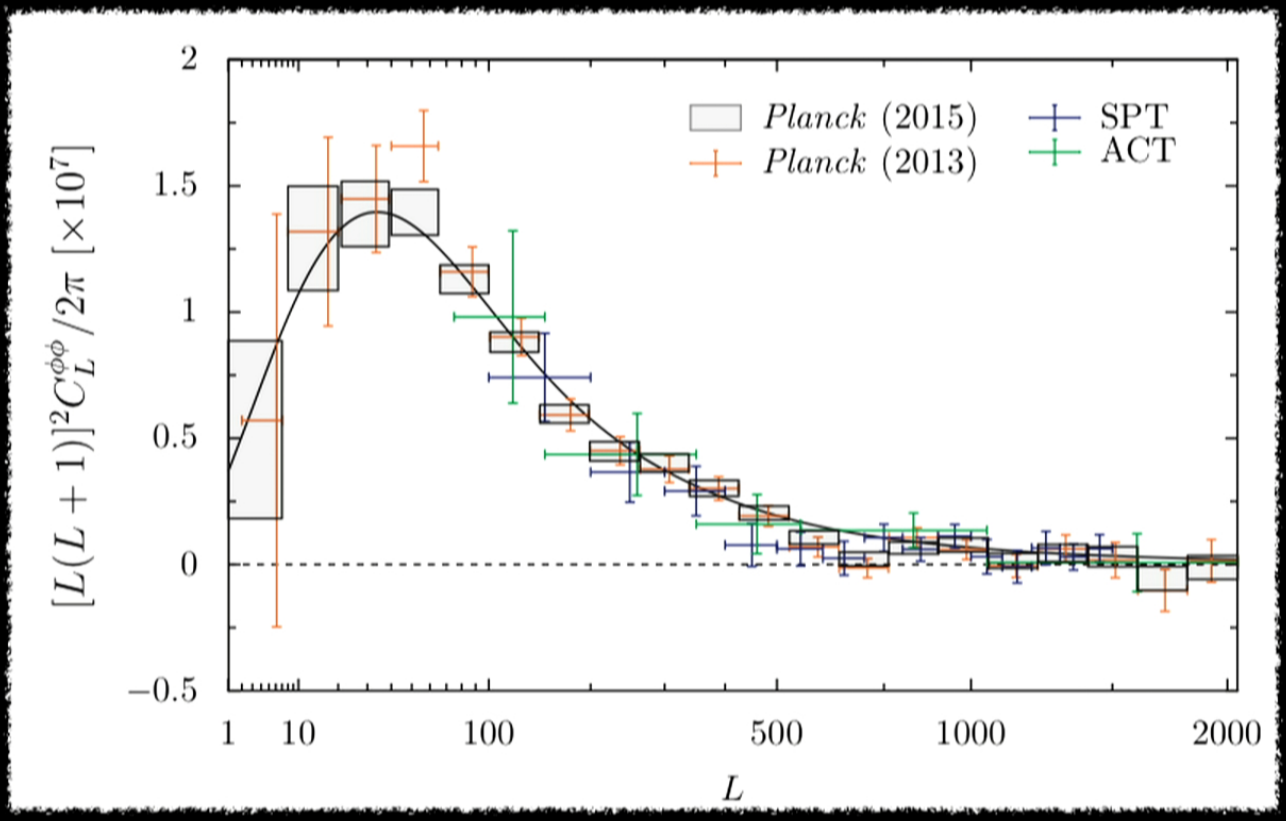
Map of the mass distribution

integrated along the line of sight



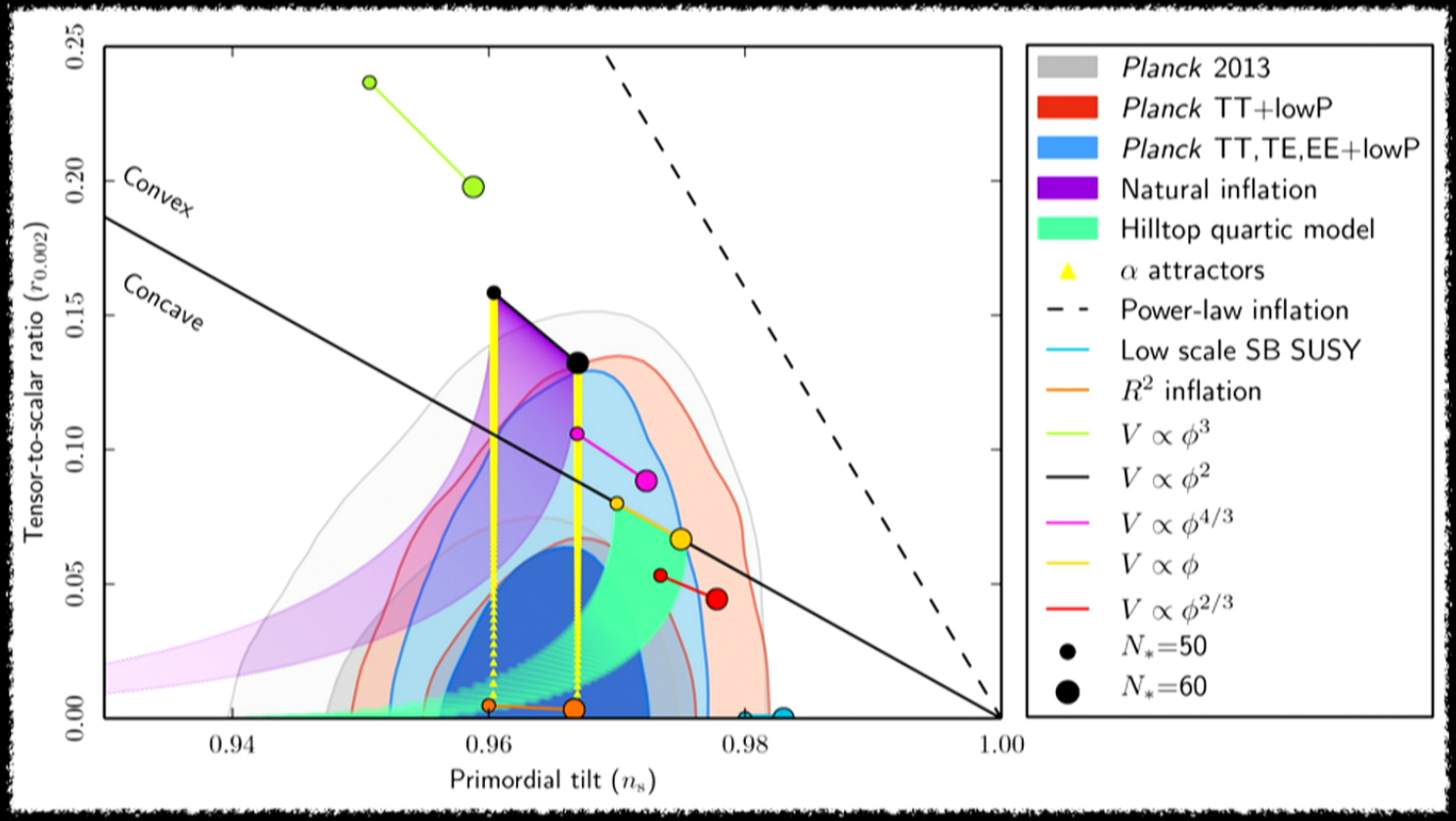
Map of the gravitationnal potential from the mean deflection of the relic radiation

Lensing potential power spectrum



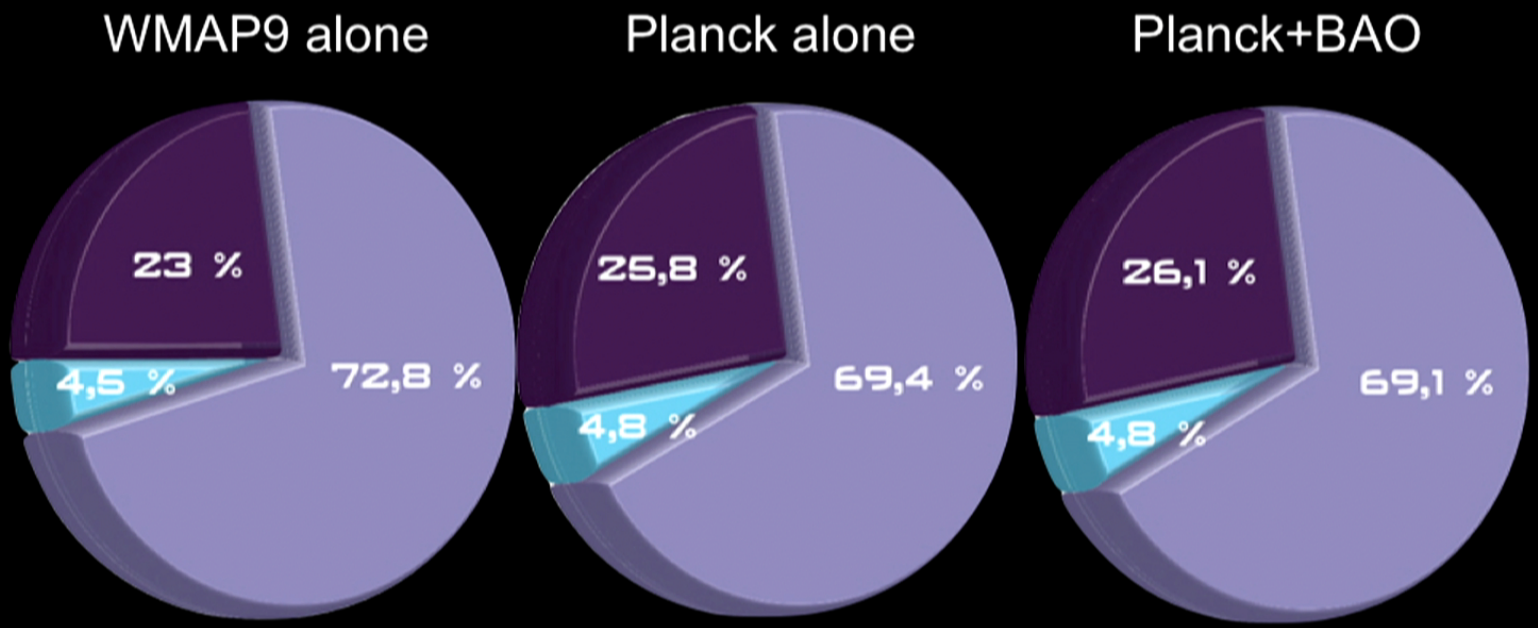
Mainly sensitive to the matter distribution 2-3 billion of years after BB.

Constrains on inflation



n_s < 1 @ more 5 σ

Energy content



ΛCDM

Results very stable with respect to combination with other results

Reionization

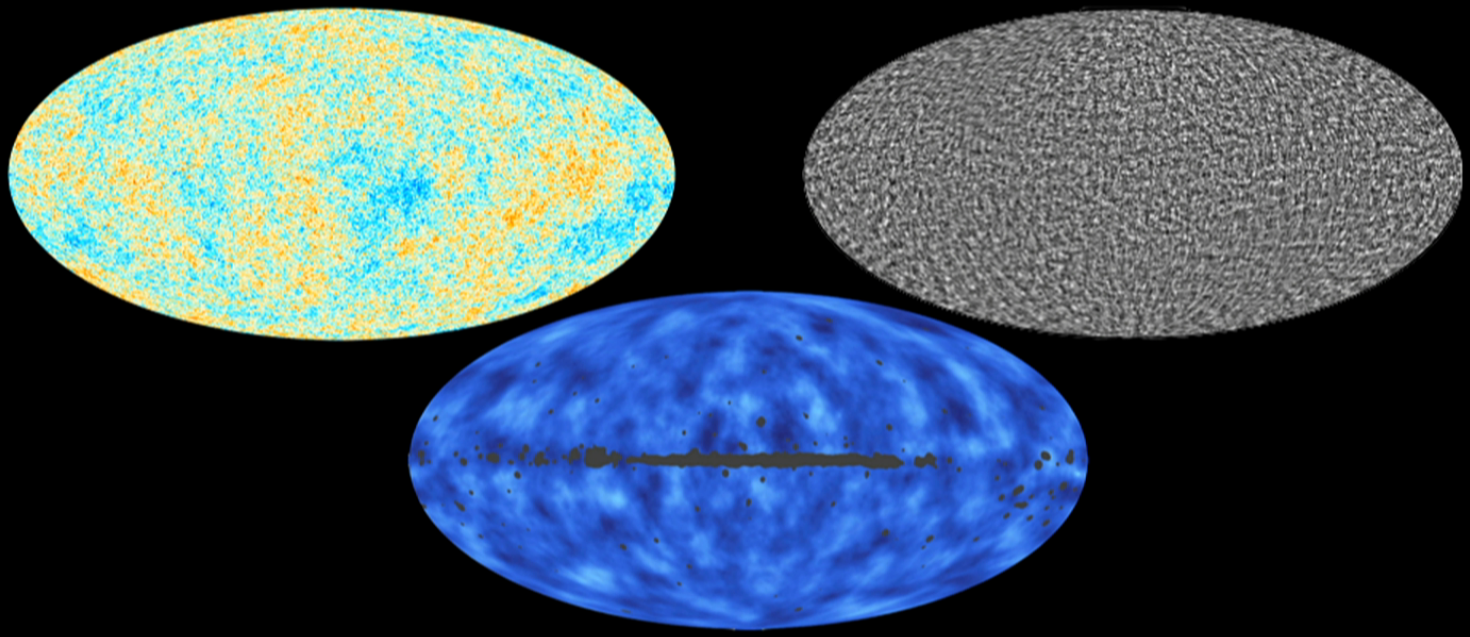
Completely degenerated with A_s in T
Unique signature in E

Reionization optical depth of $\tau = 0.066 \pm 0.016$
corresponding to $\mathbf{z}_{re} = 8.8^{+1.7}_{-1.4}$

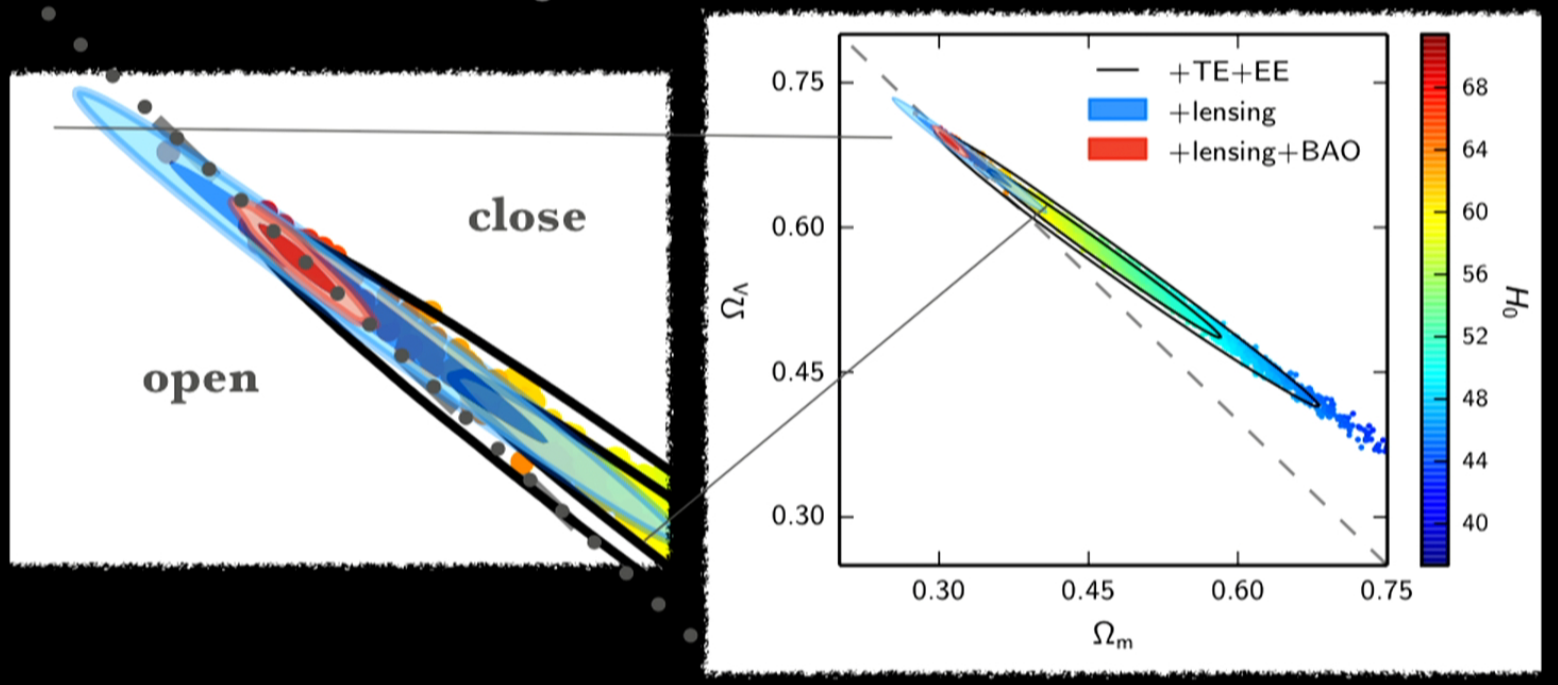
Reionization is assumed to be relatively sharp with a mid-point parameterized by a redshift z_{re} and width $z_{re} = 0.5$

Extensions of the standard model

What is compatible with this set of data ?



H_0 and flatness



Ω_K = -0.040 +/- 0.04 Planck (CMB)

Ω_K = -0.004 +/- 0.015 Planck (CMB + lensing)

Ω_K = -0.0008 +/- 0.004 Planck (CMB + lensing) + BAO + H_0 + SNe

Planck+BAO = **euclidien space** + moderate expansion velocity (67.9 km/s/Mpc)

Neutrinos

In the ΛCDM model:

- null mass
- 3 species
- particule without any interaction

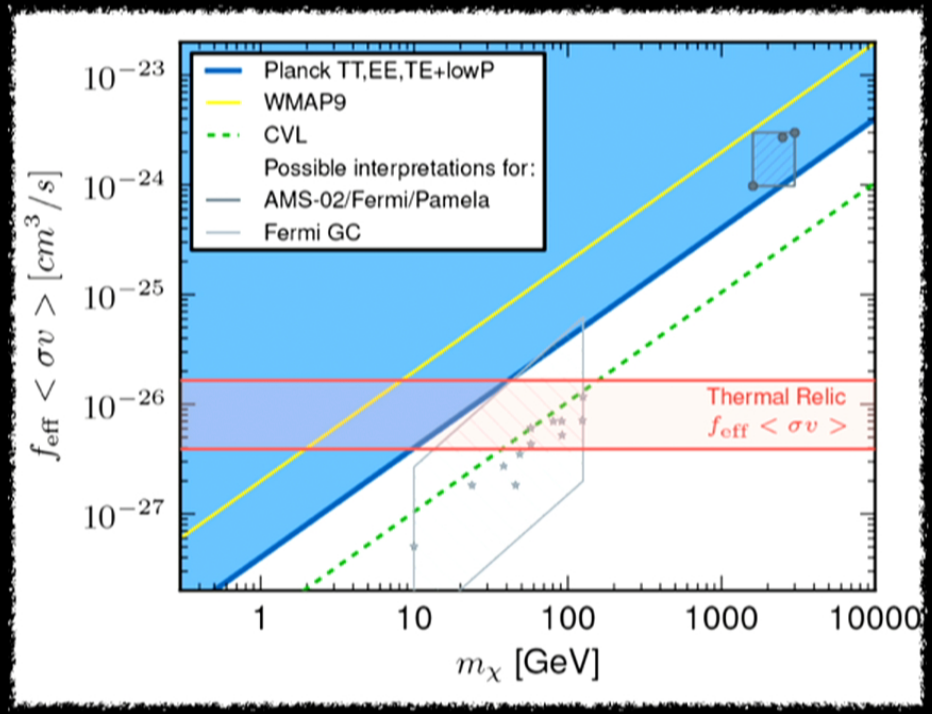
PARAMETER	THEORETICAL VALUE	ALL PLANCK	ALL PLANCK + BAO
N_{eff}	3.046	2.98 +/- 0.20	3.04 +/- 0.18
C^2_{visc}	0.333	0.336 +/- 0.039	0.338 +/- 0.040
C^2_{eff}	0.333	0.3256 +/- 0.0063	0.3257 +/- 0.0059

$+ \Sigma \text{ mass} < 0.23 \text{ eV}$

We measure parameters of a component massively present in the primordial Universe when radiation domninated. These parameters totally agree with the neutrino properties.
--> Planck "sees" the relic neutrinos

Dark matter annihilation

Hypothesis in the ΛCDM model: stable particule



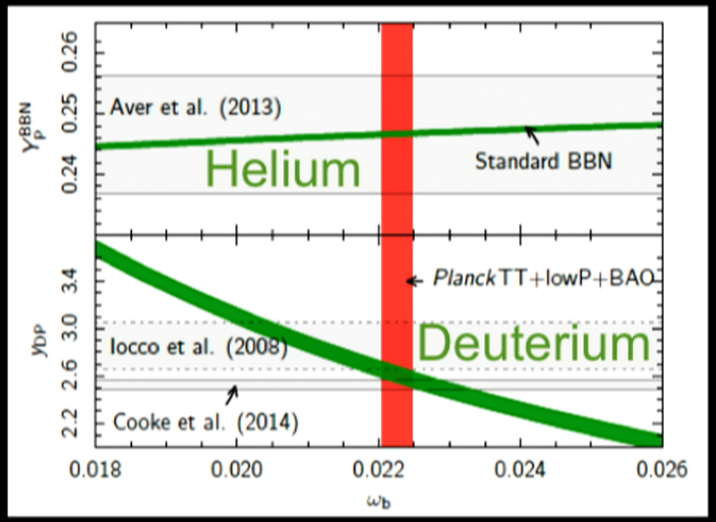
Maximal input of energy compatible with CMB observations

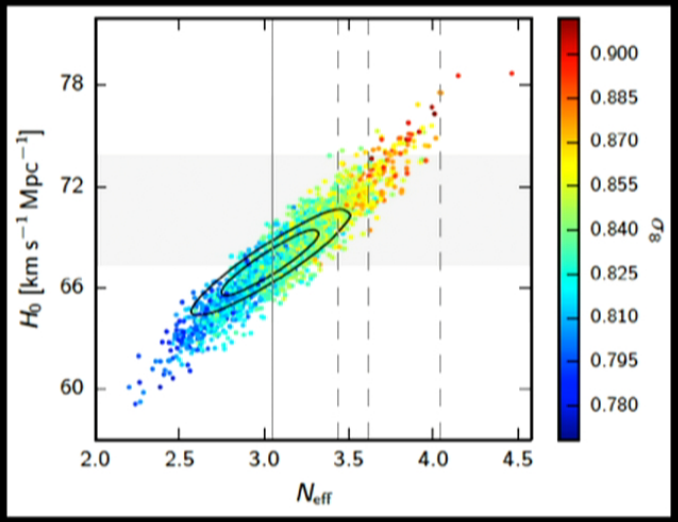
--> excludes dark matter annihilation in a scenario of AMS/PAMELA data explained by DM annihilation (case of thermal models).

Many additionnal studies

Tests of skewness, kurtosis, multi-normality, N-point functions, and Minkowski functionals indicate consistency with Gaussianity

First examination of polarization data: morphology of stacked peaks consistent with the expectations of statistically isotropic simulations Planck 2015 XIV





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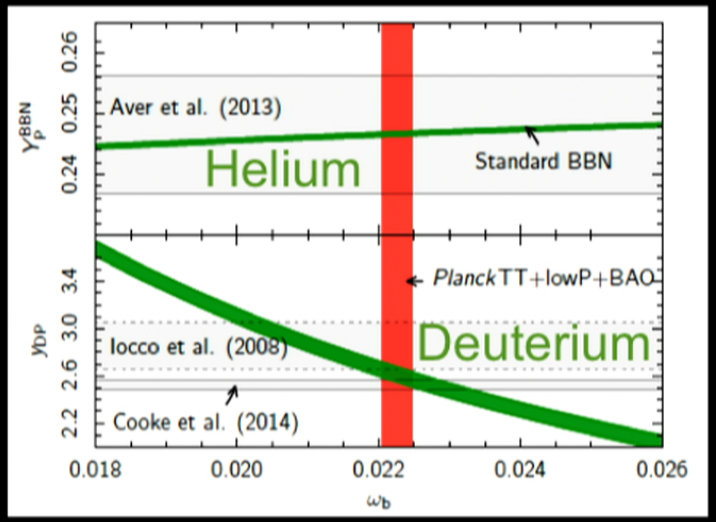
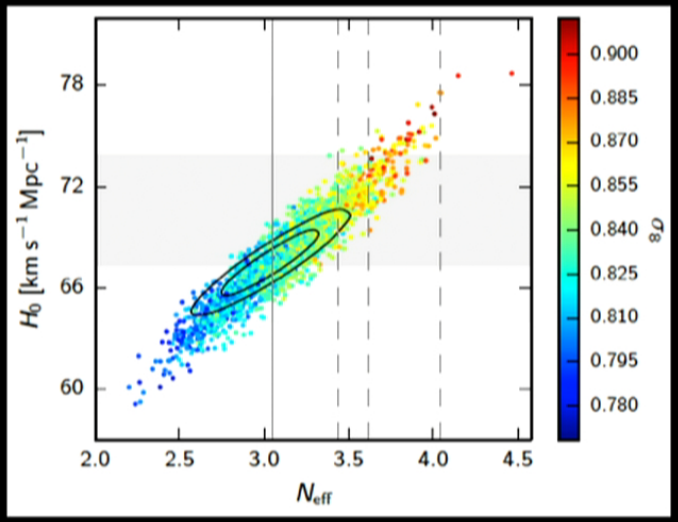
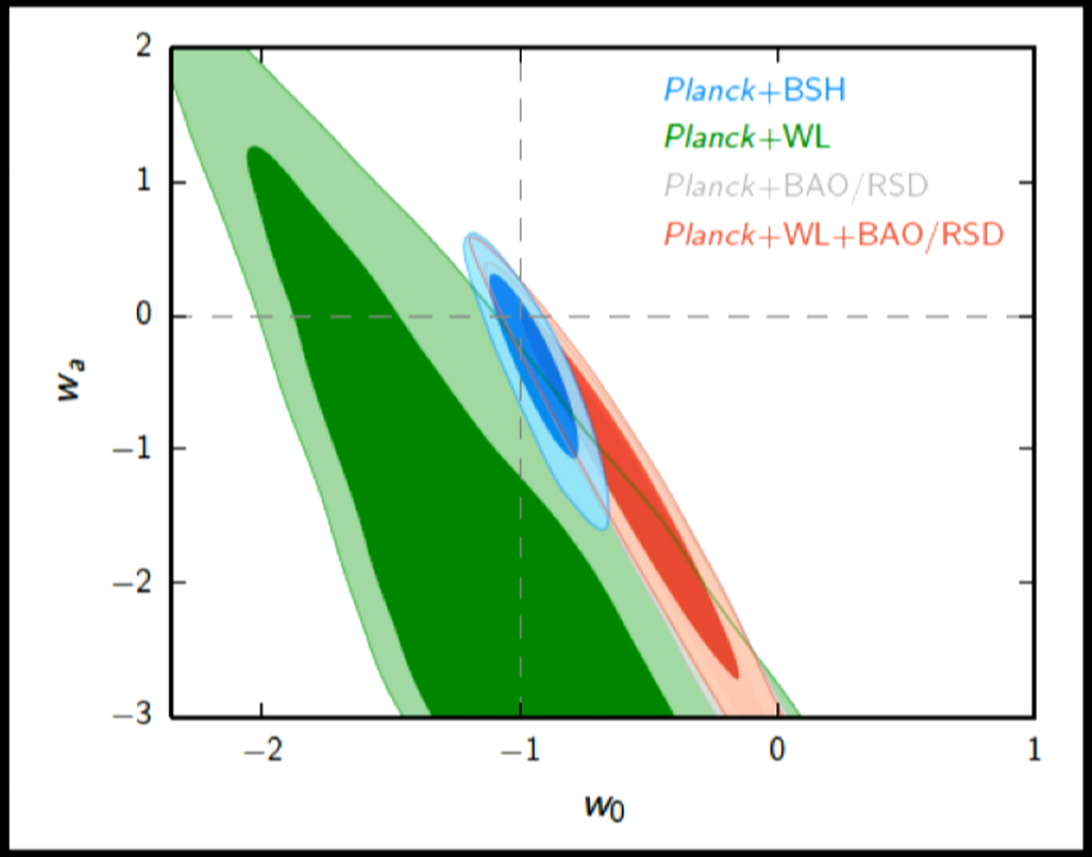




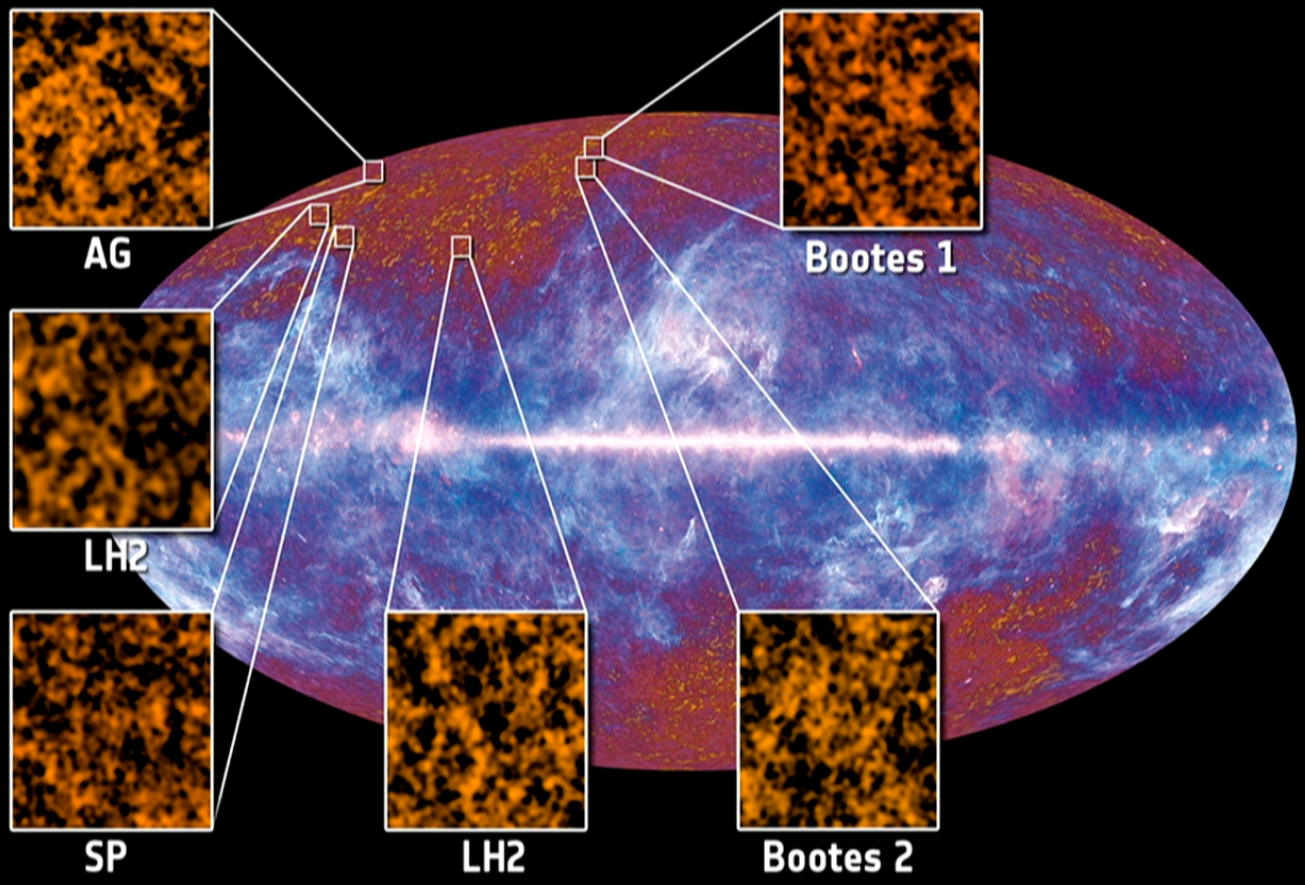
Dark energy equation of state



BSH =
BAO
+
SN-Ia
+
H0

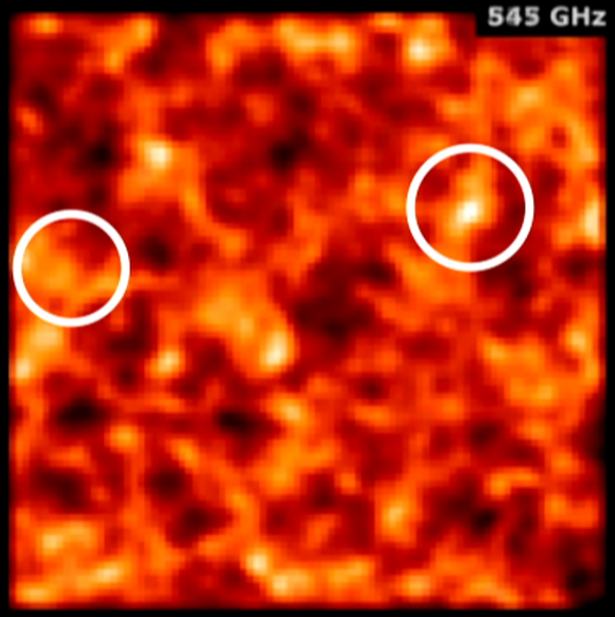
Planck 2015 XIV

Cosmic infrared background



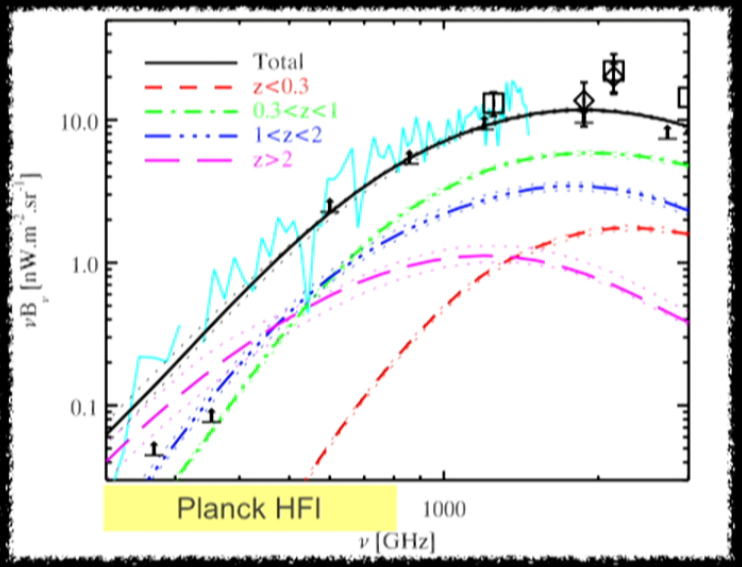
Fields *almost* free of Galactic emission → access to extragalatic sky

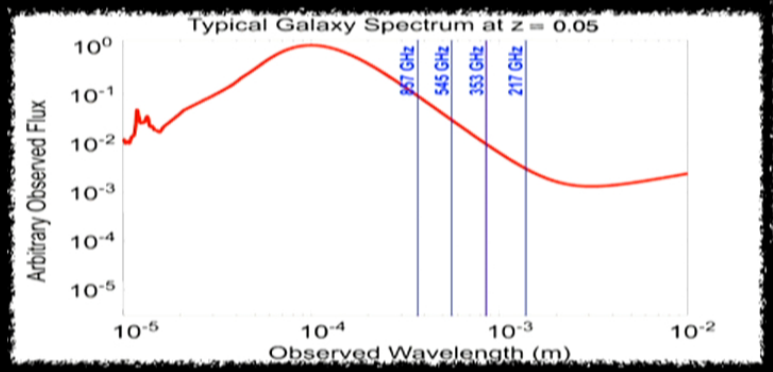
Probing galaxy evolution



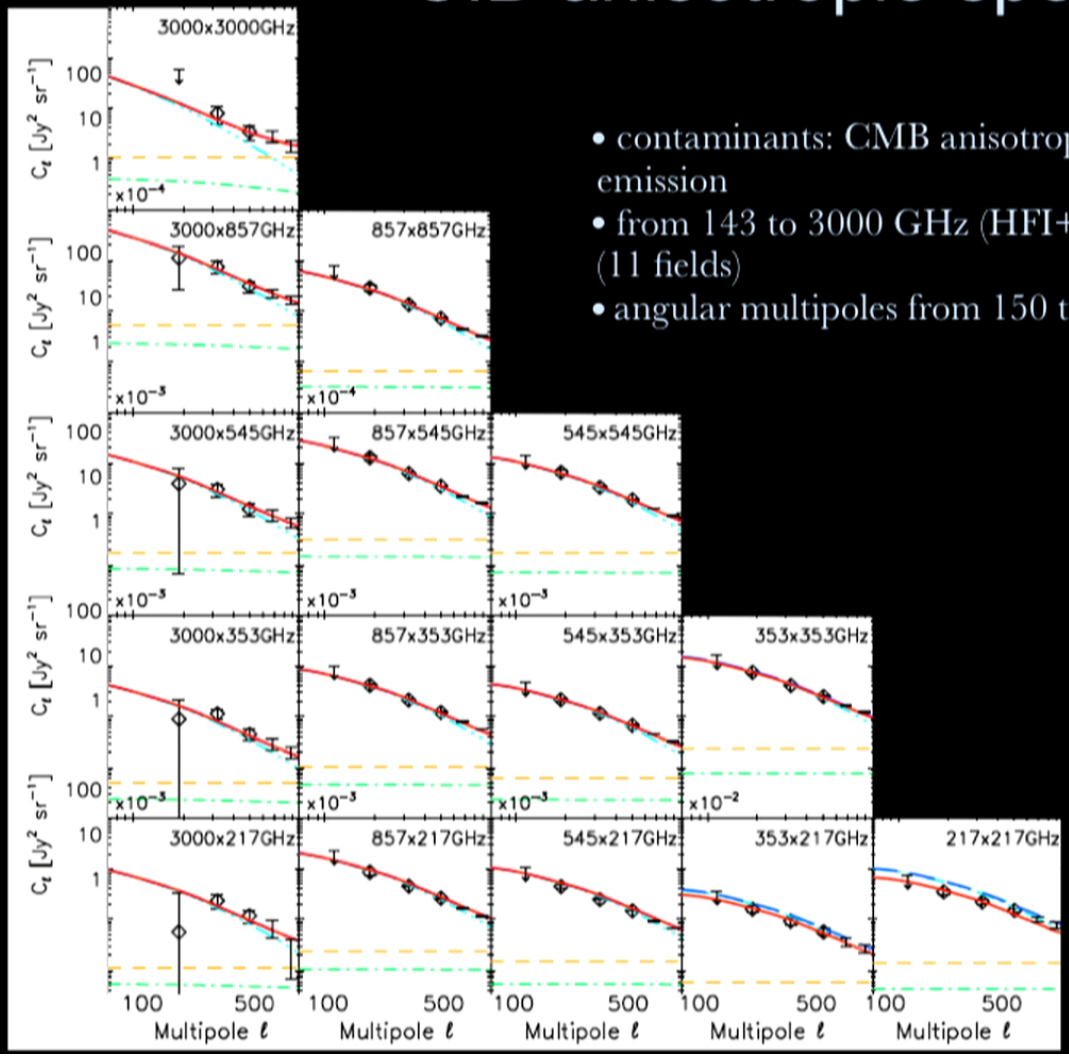
Projection of the history of star formation over 10 billions of years

Access to high z galaxies





CIB anisotropie spectrum



- contaminants: CMB anisotropies, Galactic dust and SZ emission
- from 143 to 3000 GHz (HFI+IRAS), area ~ 2240 deg^2 (11 fields)
- angular multipoles from 150 to 2500

linear model +
shot noise +
1-halo model

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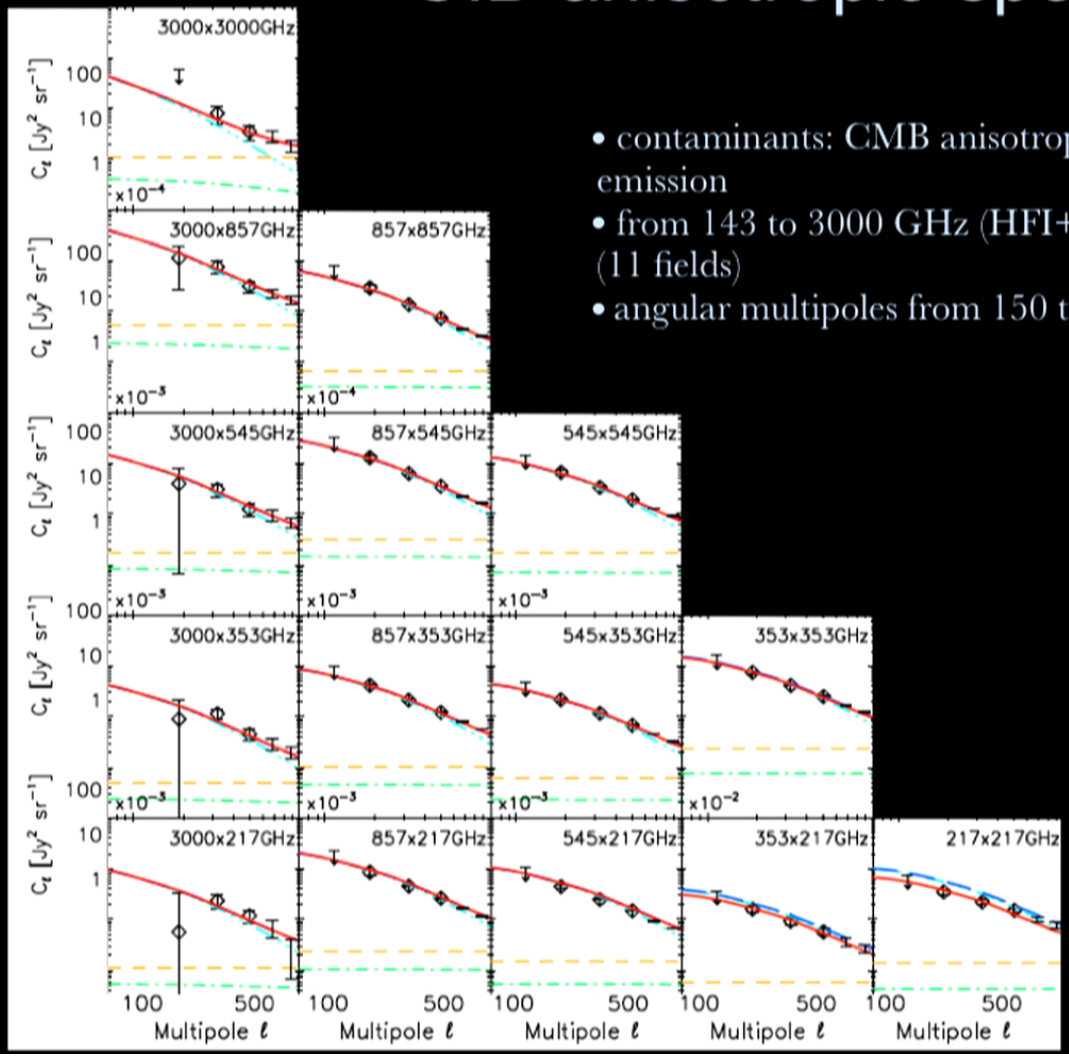

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Constrains on star formation & DM haloes

$$\delta(\vec{x}) = \frac{\rho(\vec{x}) - \bar{\rho}}{\bar{\rho}} \qquad \delta_{\rm gal}(\vec{x}) = \frac{n_{\rm gal}(\vec{x}) - \bar{n}_{\rm gal}}{\bar{n}_{\rm gal}}$$

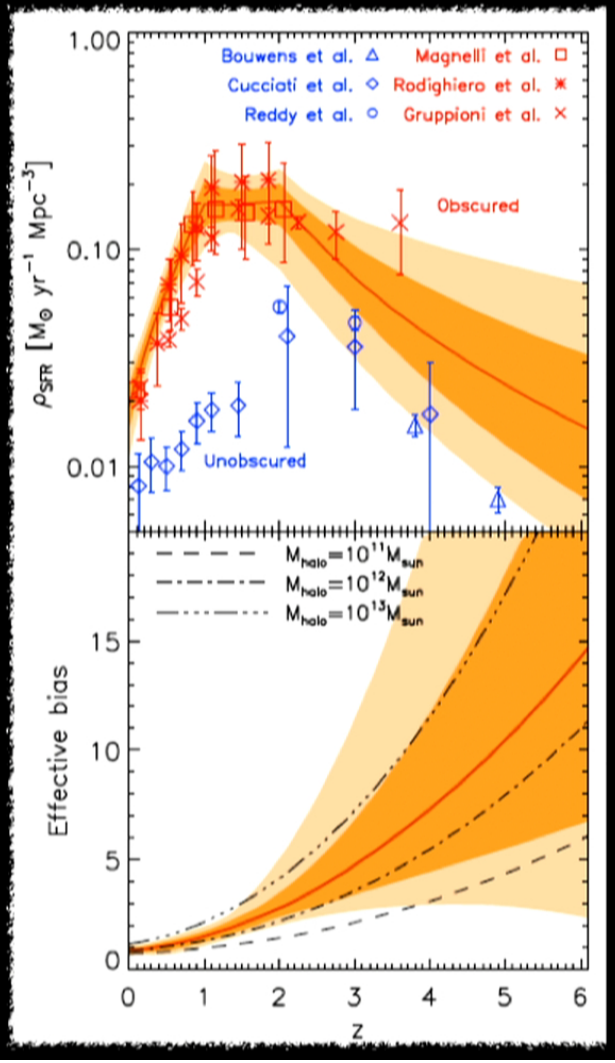
Mass distribution **Galaxy distribution**

galaxy bias $b(\vec{x}) = \delta_{\rm gal}(\vec{x})/\delta(\vec{x})$

galaxy bias = halo bias
+ halo occupation

- star formation history is well constrained up to redshifts ~ 2

→ agrees with estimates of the obscured star-formation density using Spitzer & Herschel



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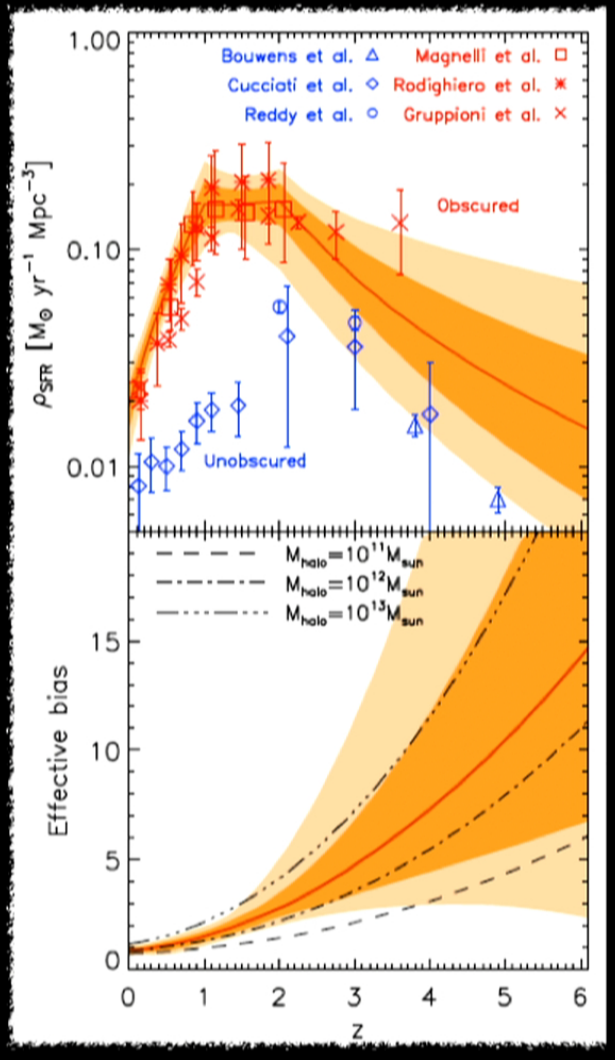
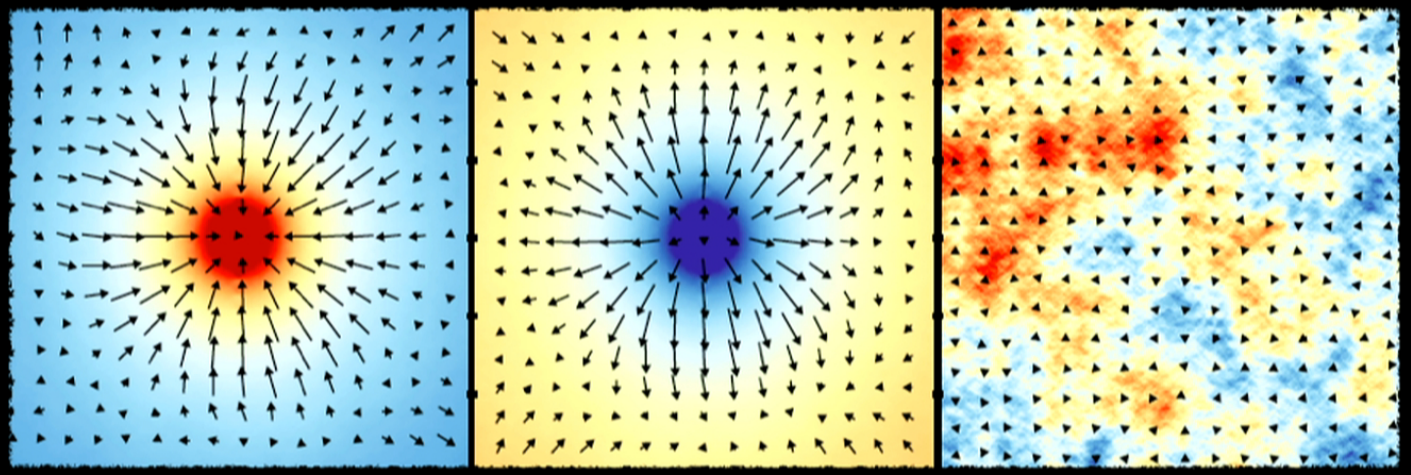


CIB / lensing

Stacking of CIB hot/cold spots,
stacking of lensing on same locations



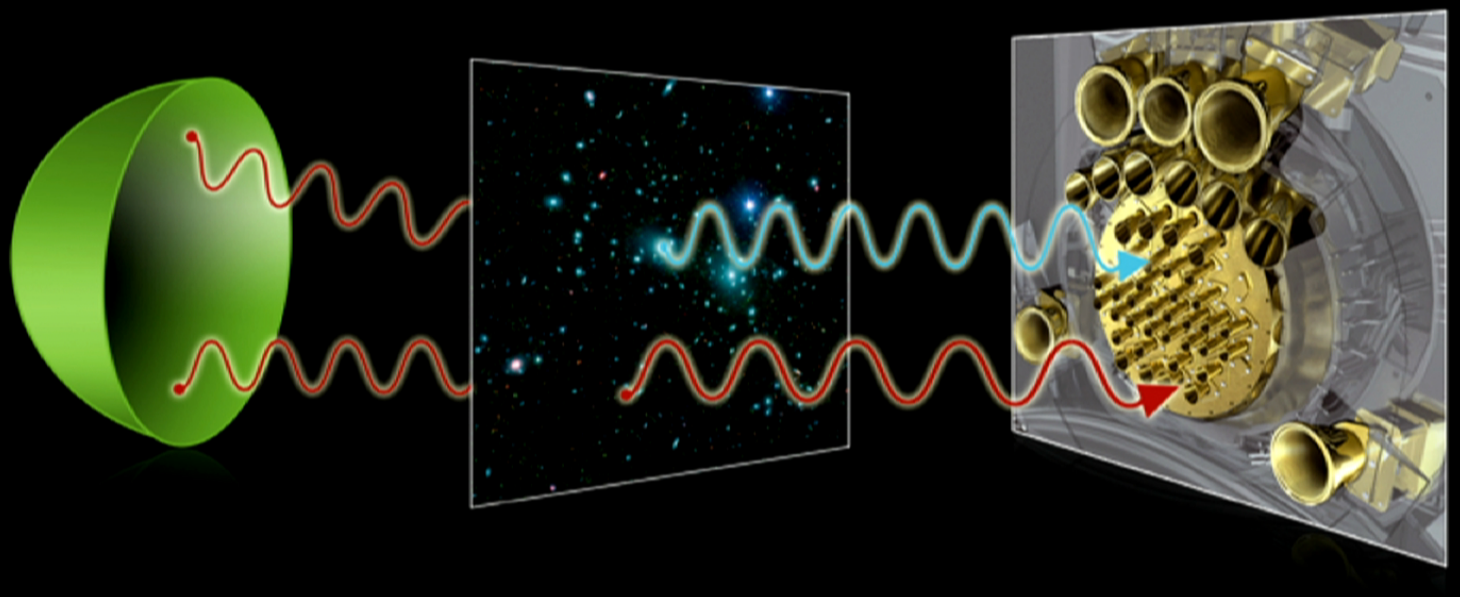
Concentration of galaxies focuses the CMB

The CMB is spread out around empty places

nothing special in CIB nor in CMB

The mass distribution and the galaxy distribution are highly correlated

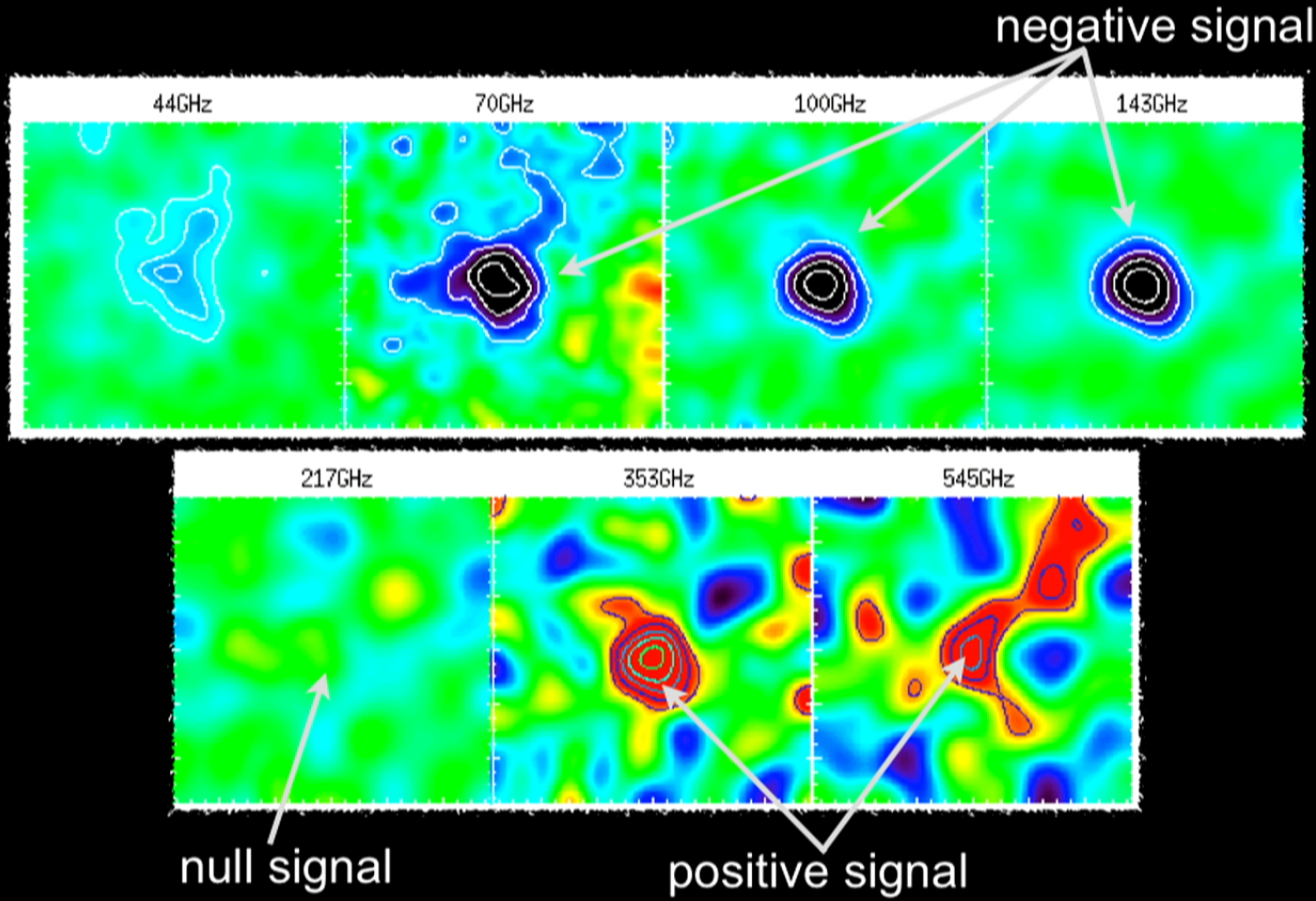
The Sunyaev-Zeldovich effect



Interaction between CMB photons and inter-cluster hot gaz

- linked to number and T of electrons
- independant of the cluster distance

Planck designed for the SZ effect



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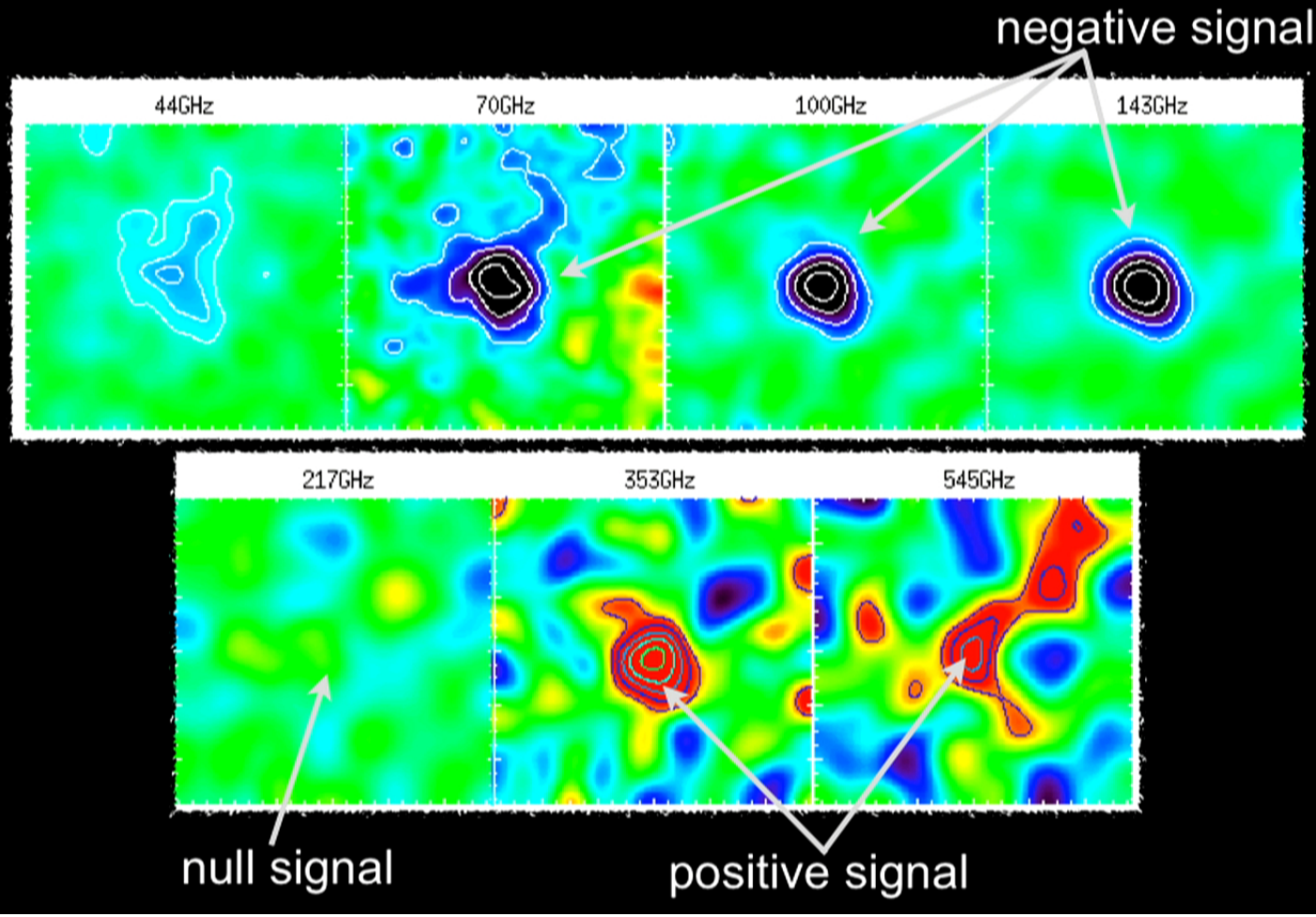
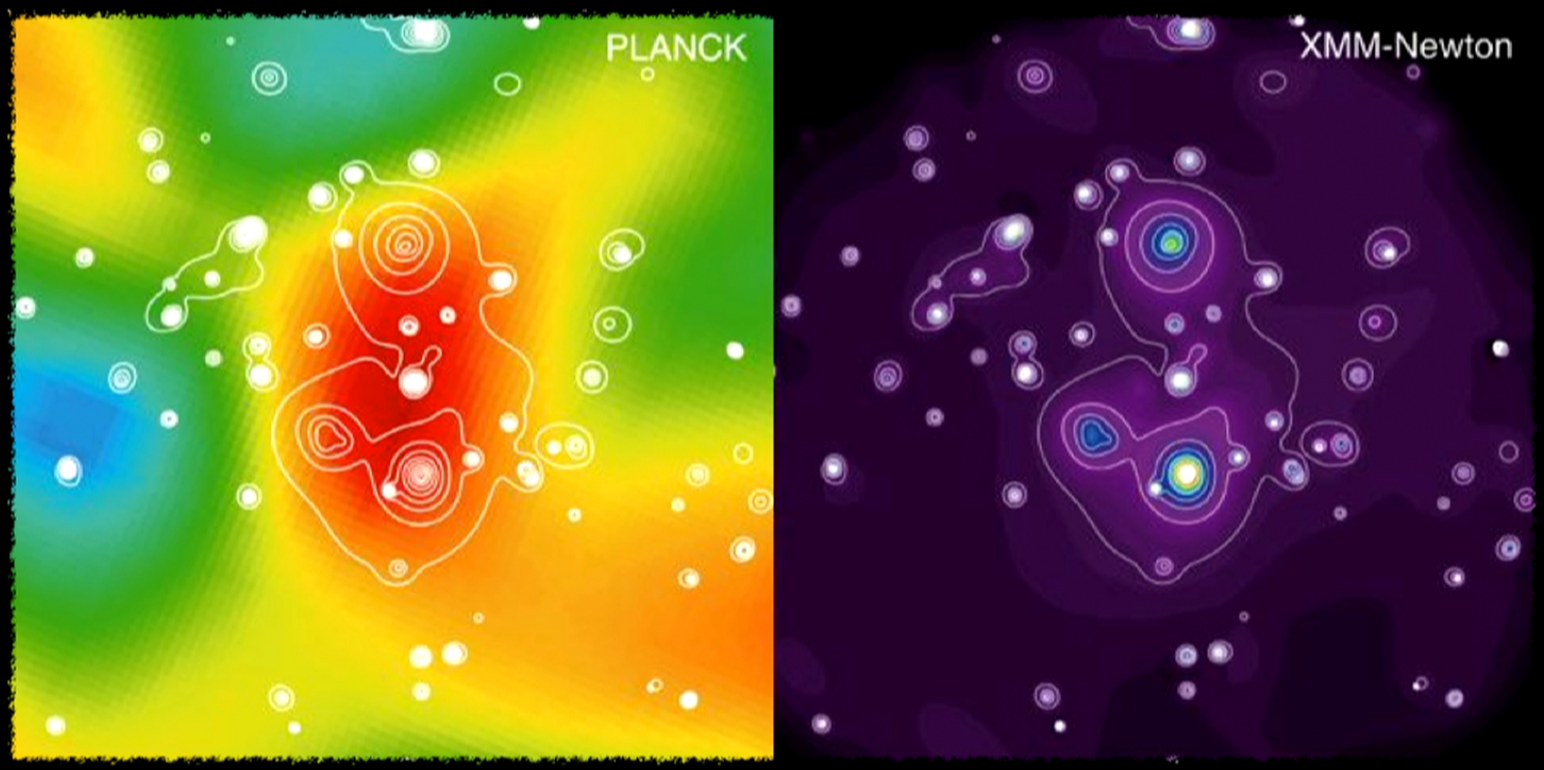


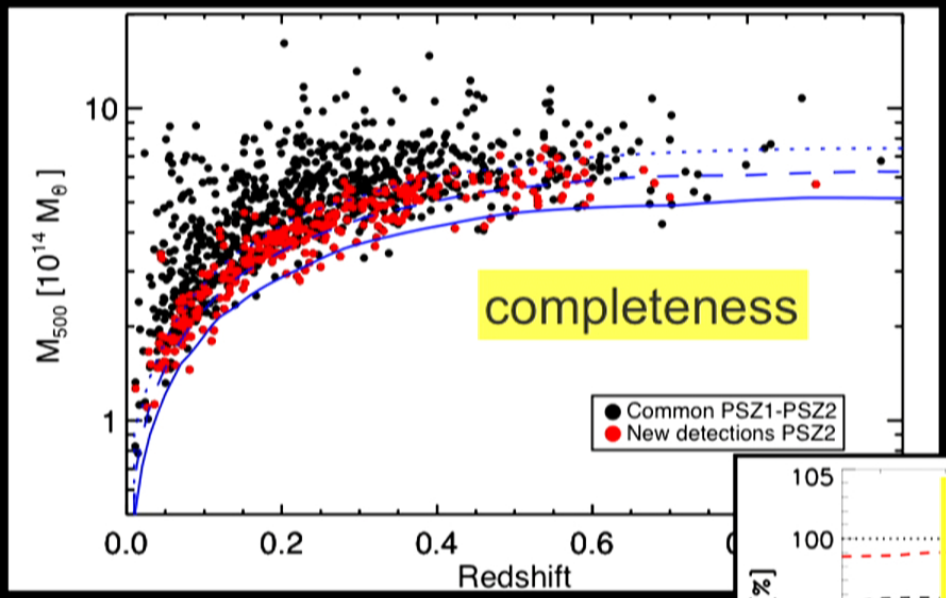
Complementary to the XMM-Newton observatory



Additionnal data mandatory to have the redshift of the source

1653 clusters & superclusters

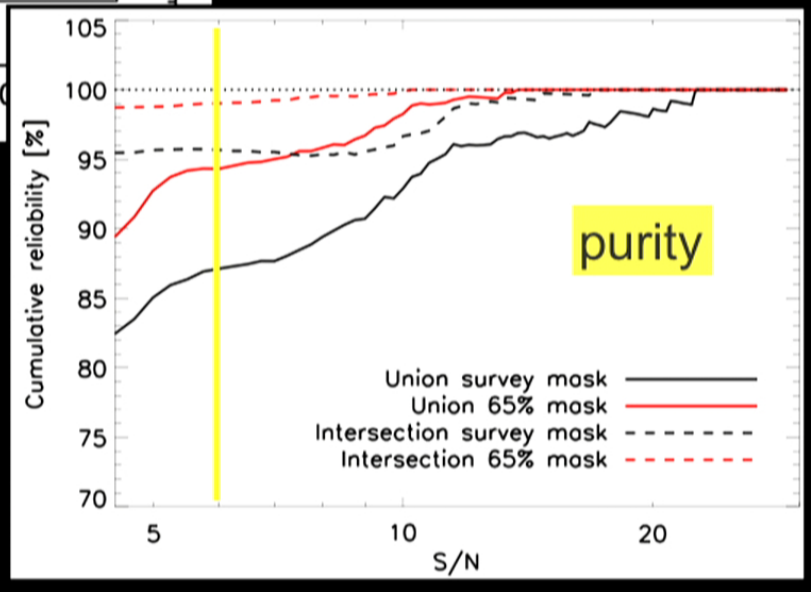
Planck 2015 XXVII



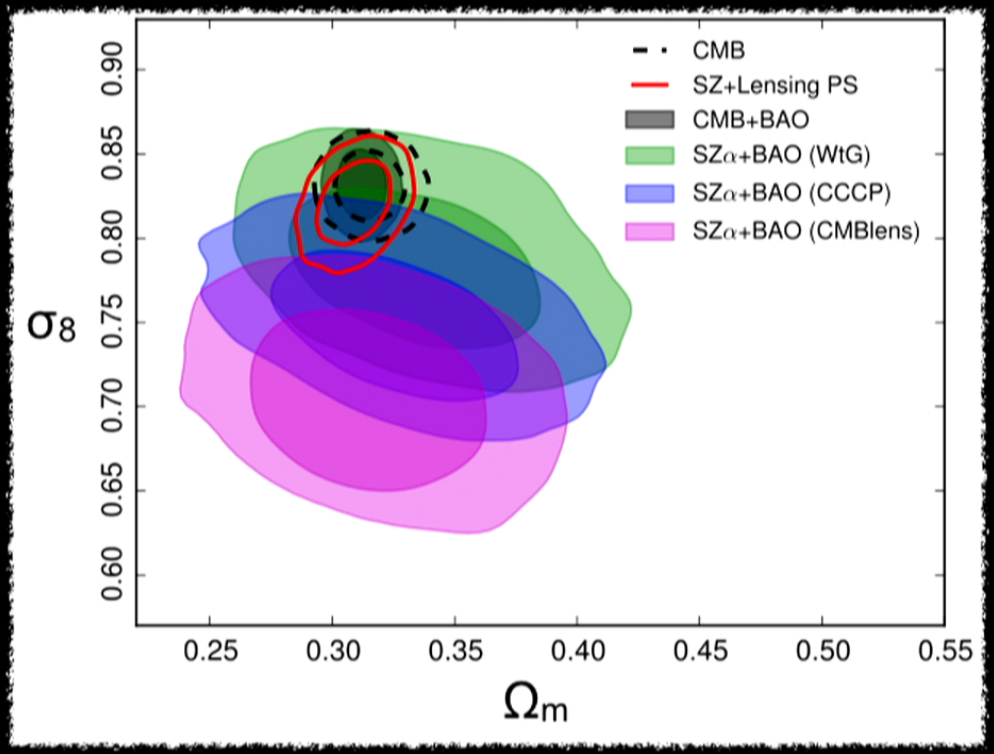
- **83.6% of the sky**
- **1203 confirmed** with identified counter-parts (Feb 2015)

1094 PSZ2 clusters with counterparts with known redshift

Solid, dashed and dotted lines indicate respectively the 20%,50% and 80% survey completeness contours for the PSZ2.



Cosmology with Planck clusters

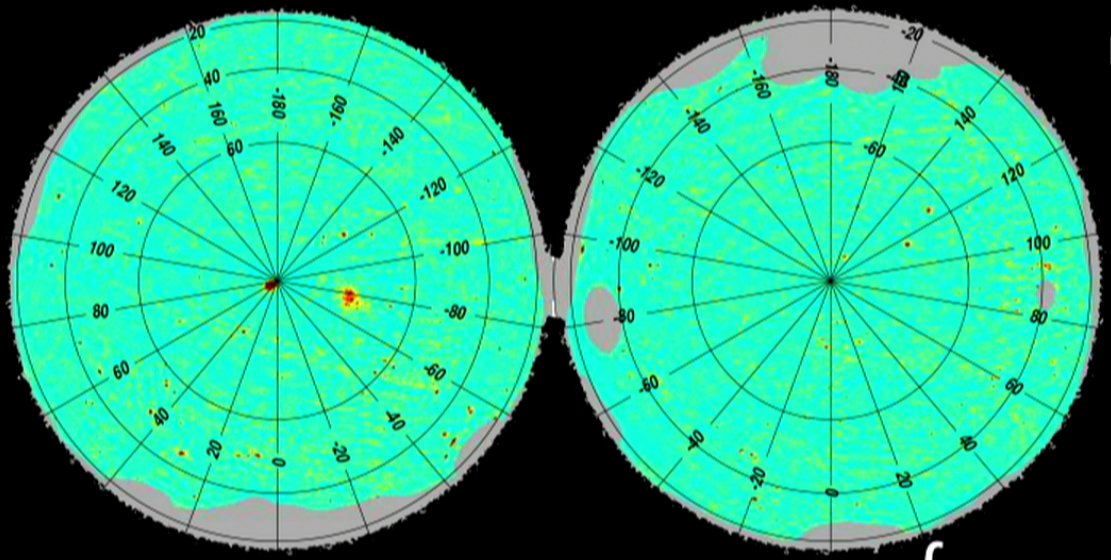


from a subset of 439 clusters

Tension between CMB & clusters constrains

... also tension between different ways to estimate the mass of the clusters
--> mainly astrophysical issue, probably.

Diffuse SZ emission



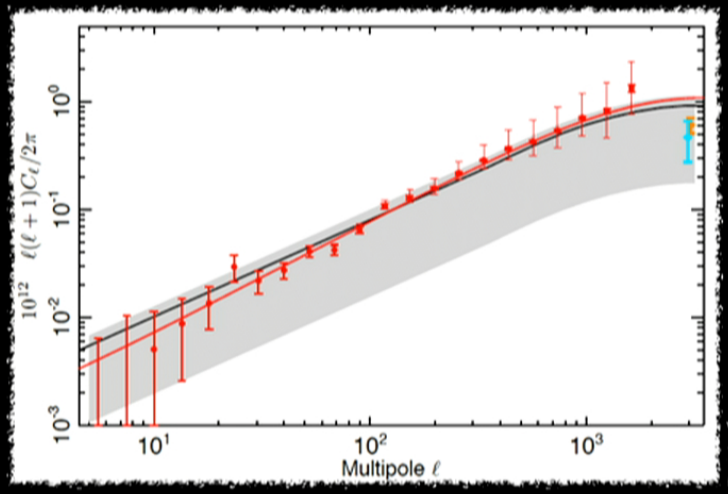
Planck 2015 XXII

-3.5 $5\ 10^6$

$$y(n) = \int n_e \, (k_B T_e) / (m_e c^2) \, \sigma_T \, ds$$

- 2 adapted component seperation method used: preserve tSZ effect and remove CMB
- simultaneous spatial (pixel domain) and spectral (multipole domain) localisation
- Use HFI channels from 100 to 857 GHz (857 GHz only @ ell < 300)
- Common resolution of 10 arcmin, validation on FFP simulations
- excellent agreement with the PSZ fluxes

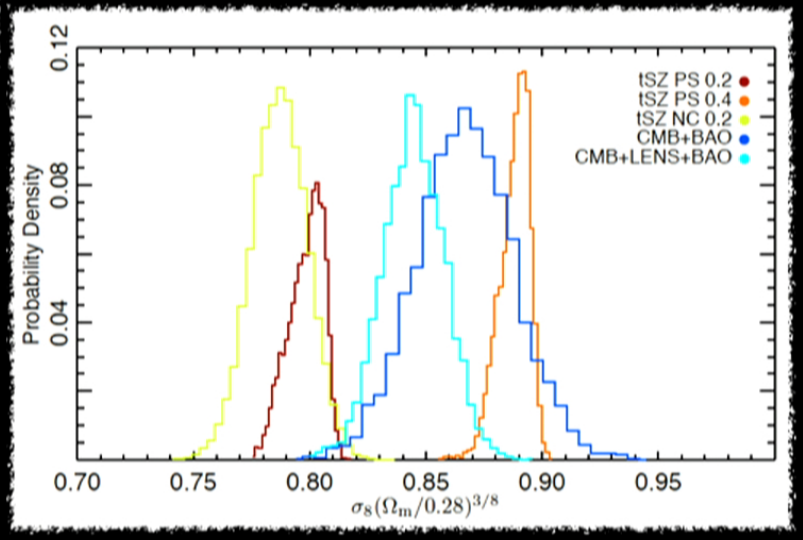
Cosmology with the y-map



Power spectrum estimates
after foreground subtraction
Atacama Cosmology Telescope (ACT)
South Pole Telescope (SPT)

Black/grey = tSZ power spectrum template used in CMB analysis with its best fit amplitude +/- 2σ

Marginalised likelihood distribution for tSZ (different mass biais) and CMB based analyses



- sensitivity of the **y**-map is sufficient to detect faint and diffuse structures
- constraints on σ_8 are consistent with cluster number counts
- @ 2.7 σ level / Planck CMB analysis: **uncertainties on physics of clusters need to be accounted for**

The cosmological standard model

Big-Bang in the **General Relativity** framework

+

Composition of the universe (today)

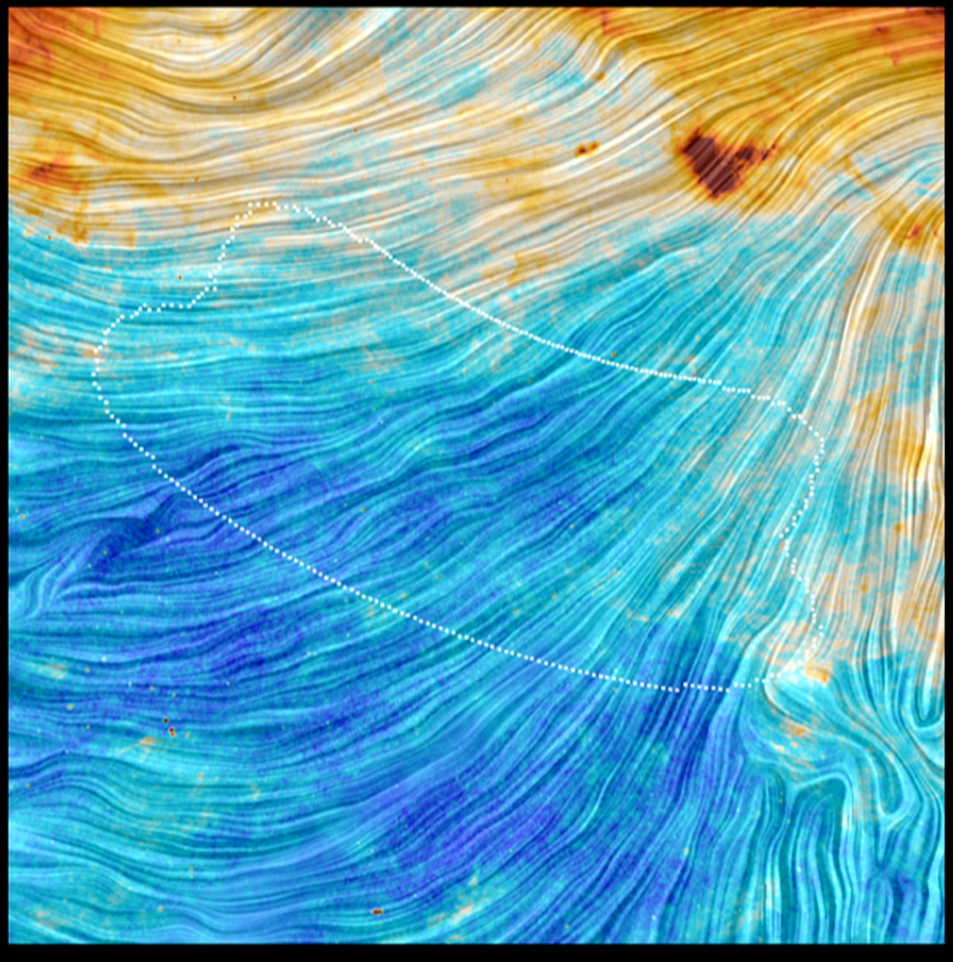
- negligible : 3 neutrinos
- in minority : baryonic matter
- in majority : cold dark matter
- cosmological constant

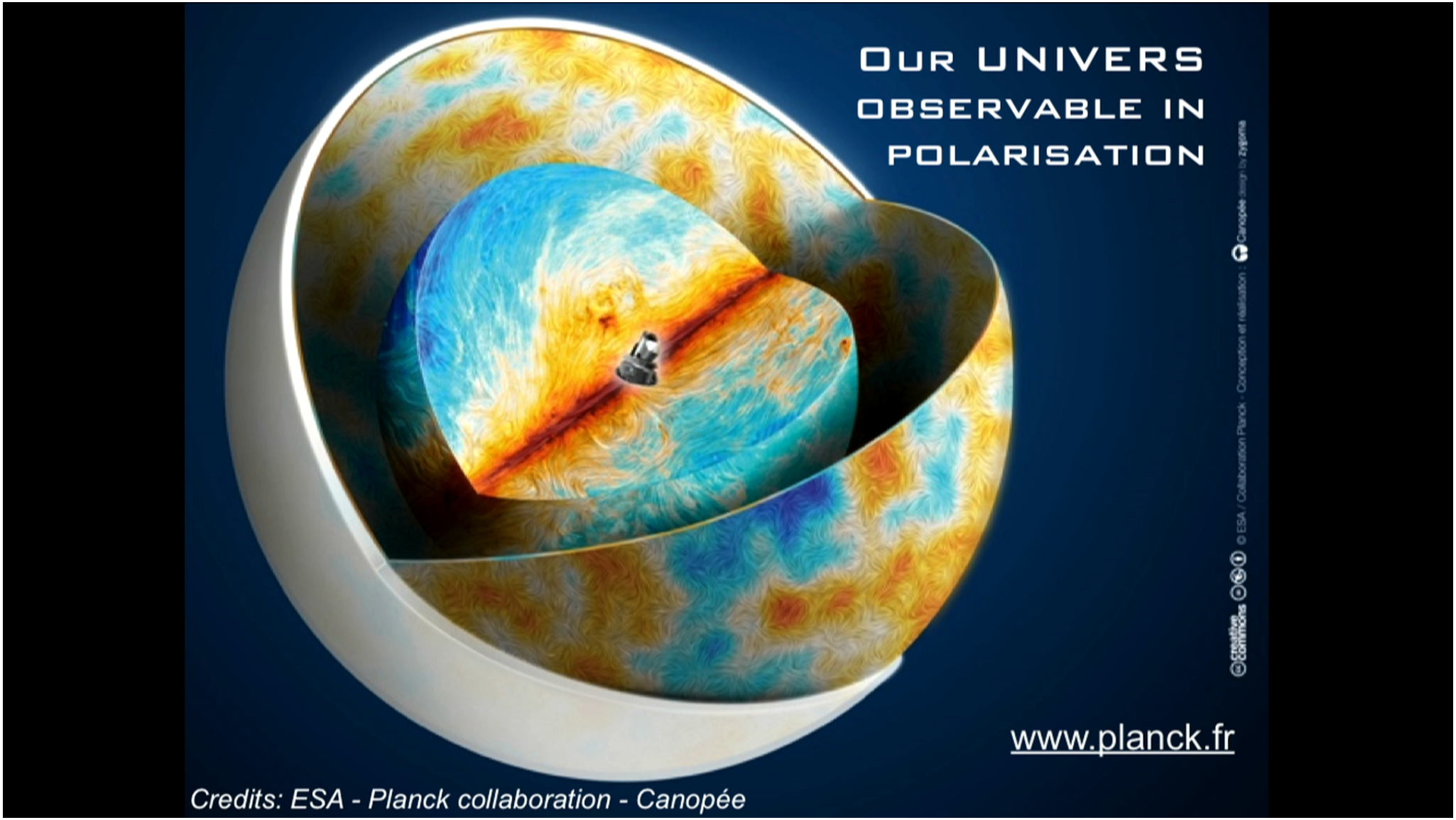
+

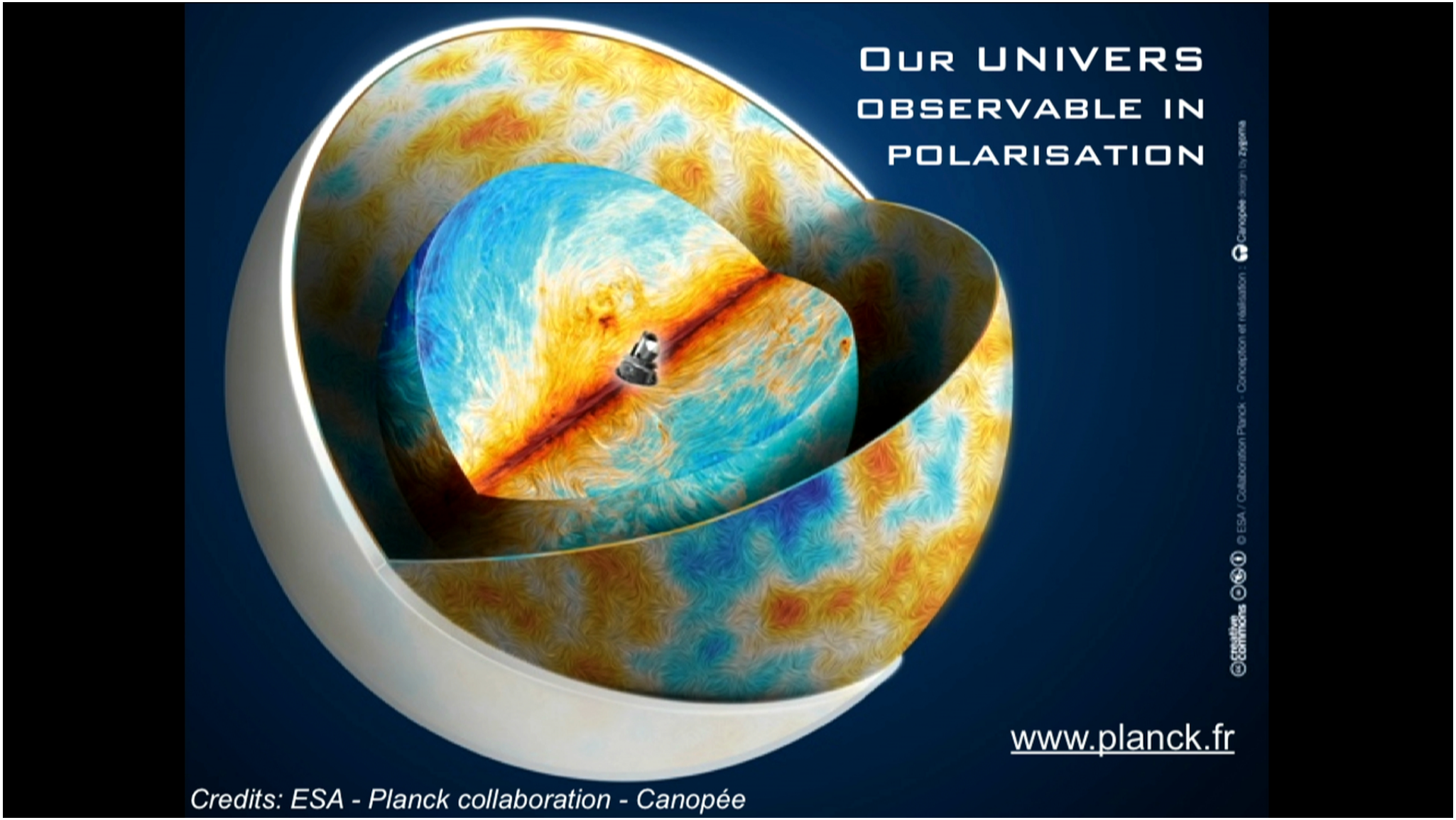
Primordial inflation

Gravitationnal waves : not yet detected

Common study with Planck-BICEP2/KECK




OUR UNIVERS
OBSERVABLE IN
POLARISATION
www.planck.fr
Credits: ESA - Planck collaboration - Canopée


Our UNIVERS
observable in
polarisation
www.planck.fr
Credits: ESA - Planck collaboration - Canopée