The Planck mission: first results

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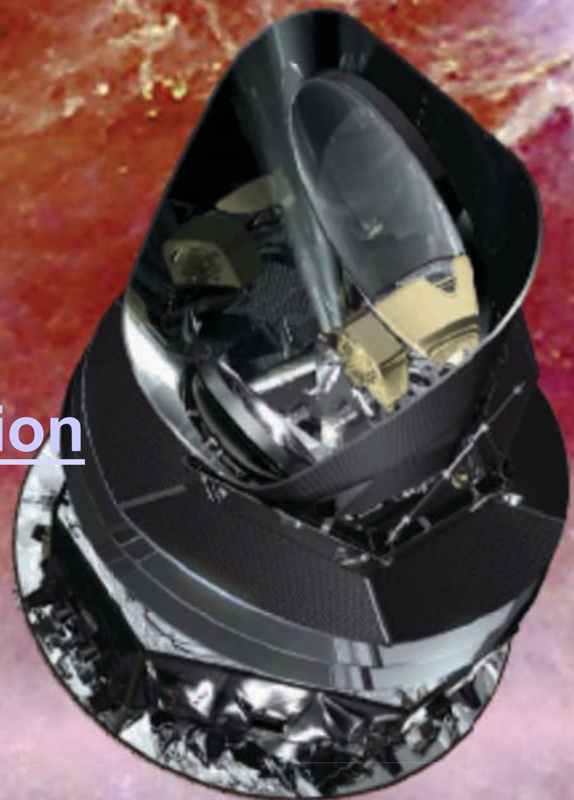
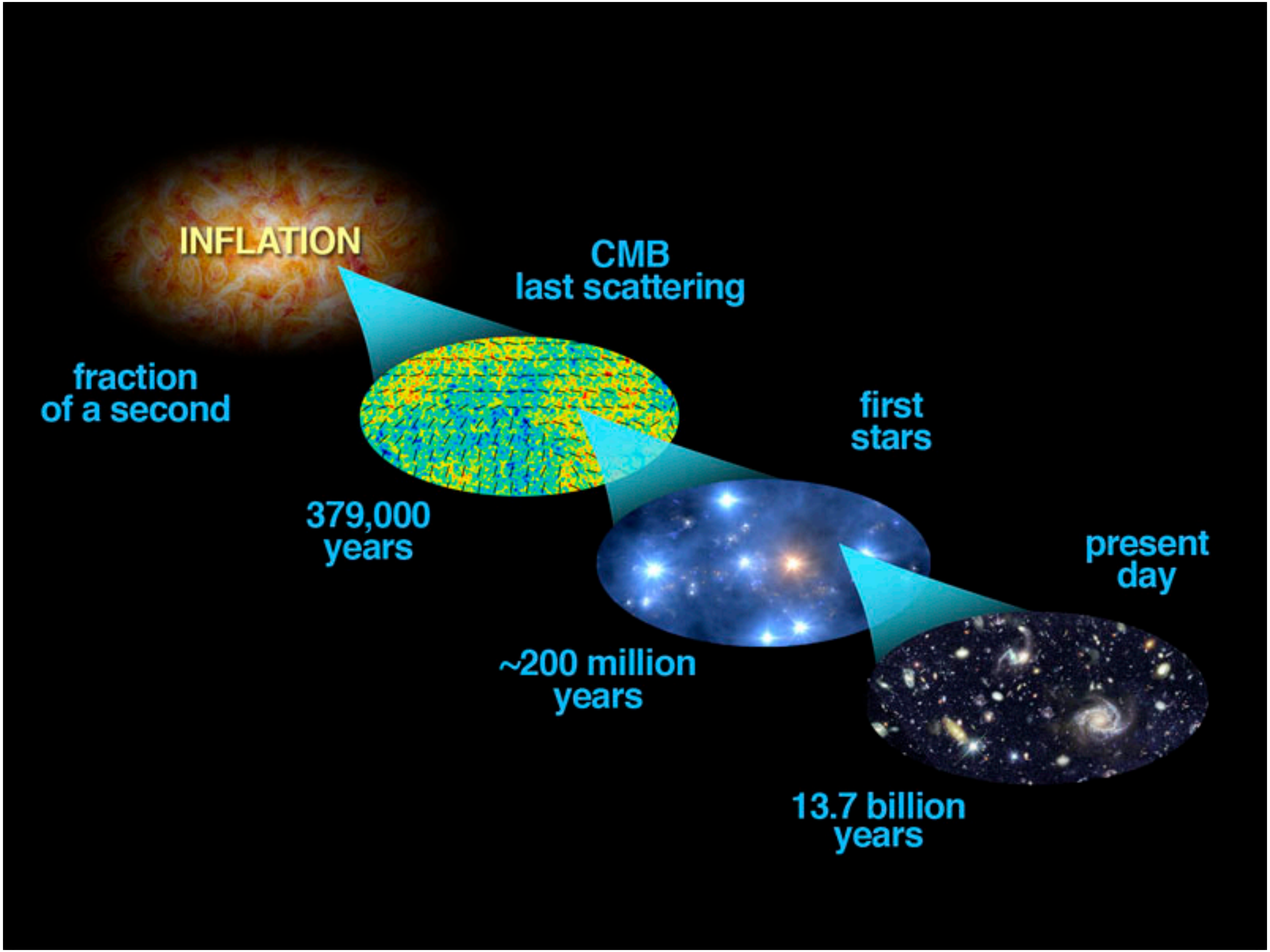


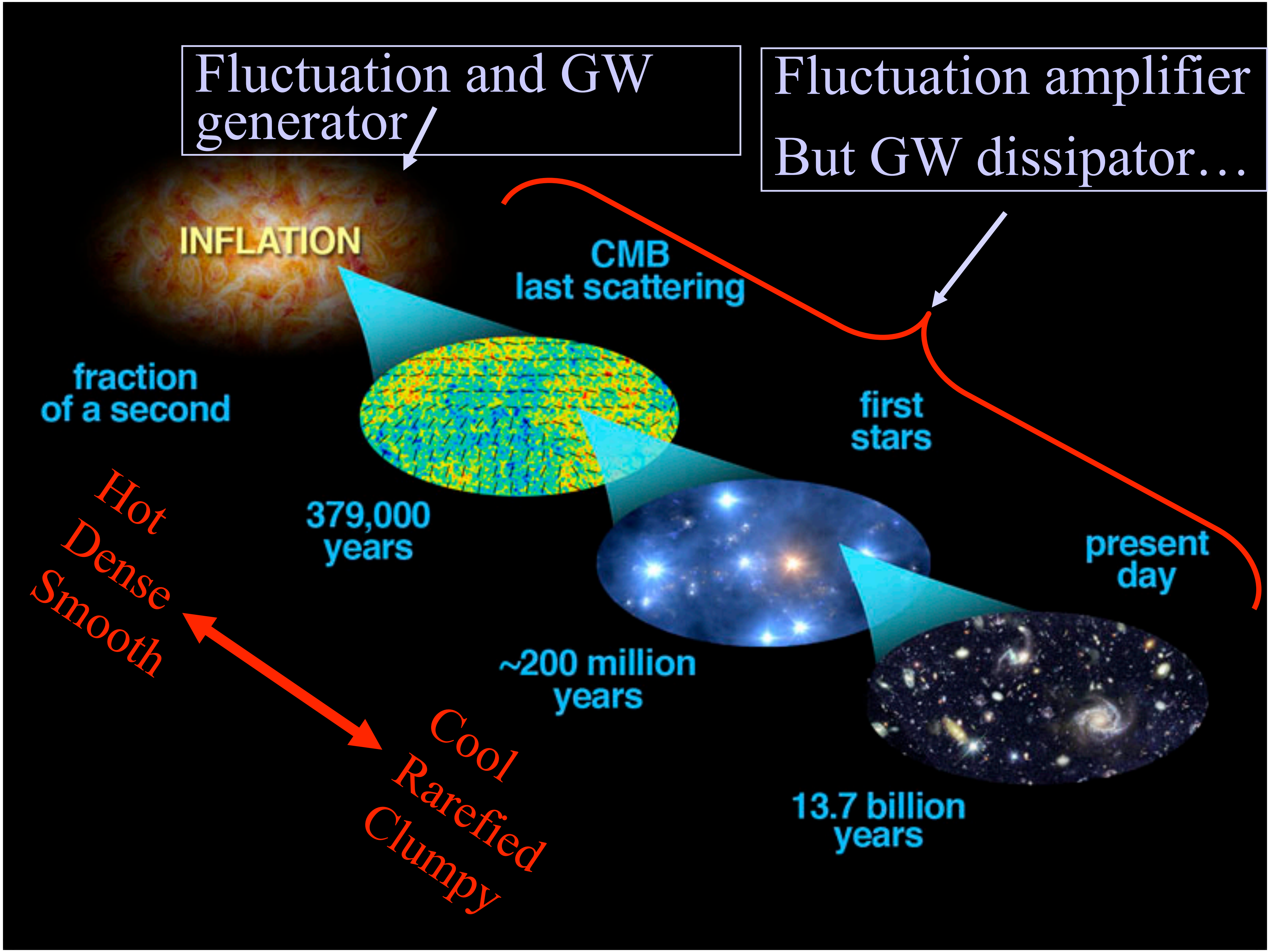
On behalf of the Planck collaboration

http://www.esa.int/Planck

La Thuile, March 1, 2011



INFLATION
CMB
last scattering
fraction
of a second
first
stars
379,000
years
present
day
~200 million
years
13.7 billion
years

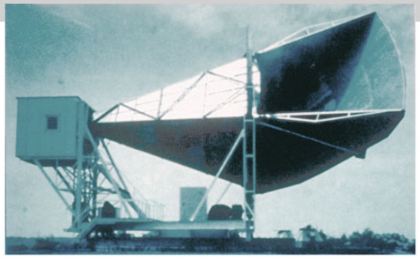


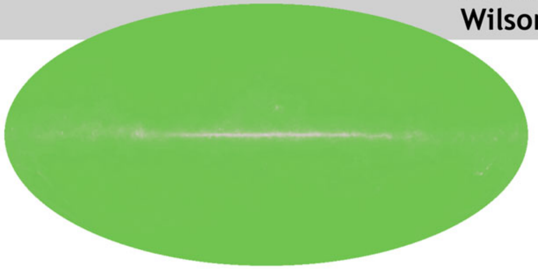
Fluctuation and GW generator
Fluctuation amplifier
But GW dissipator…
INFLATION
CMB
last scattering
fraction
of a second
first
stars
379,000
years
present
day
~200 million
years
13.7 billion
years
Hot
Dense
Smooth
Cool
Rarefied
Clumpy

Cosmic Microwave Background Radiation Overview

The oldest light or the first light of the Universe

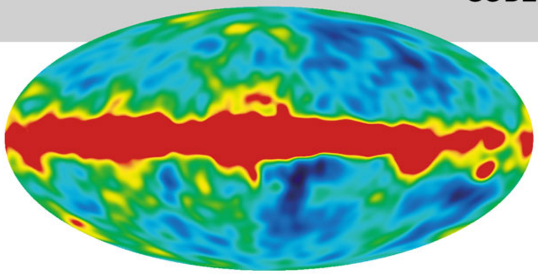
1965 — Penzias and Wilson





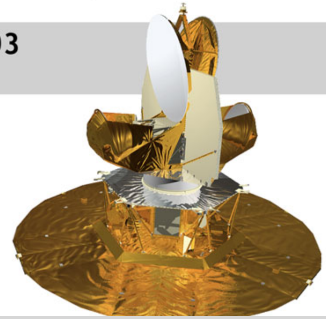
Discovered the remnant afterglow from the **Big Bang**.
→ **2.7 K**

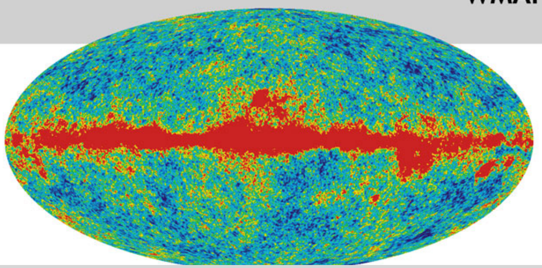
1992 — COBE



Blackbody radiation,
Discovered the patterns (**anisotropy**) in the afterglow.
→ **angular scale ~ 7°** at a level $\Delta T/T$ of 10^{-5}

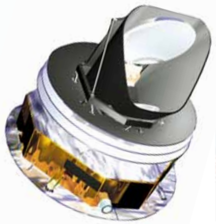
2003 — WMAP





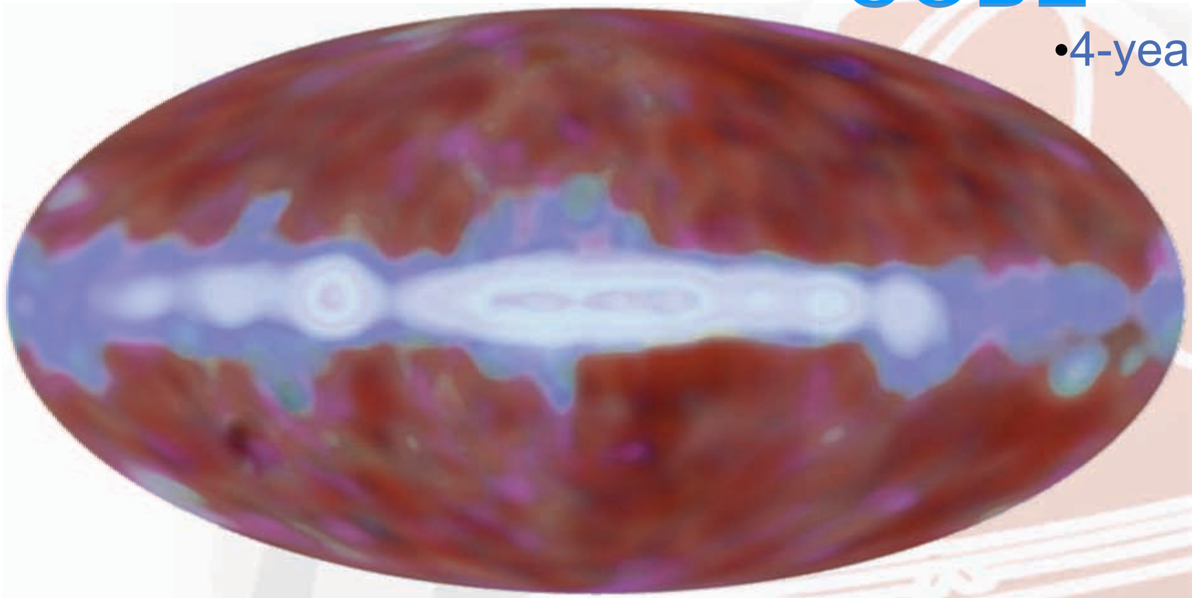
(Wilkinson Microwave Anisotropy Probe):
→ angular scale ~ 15'

2009 — Planck



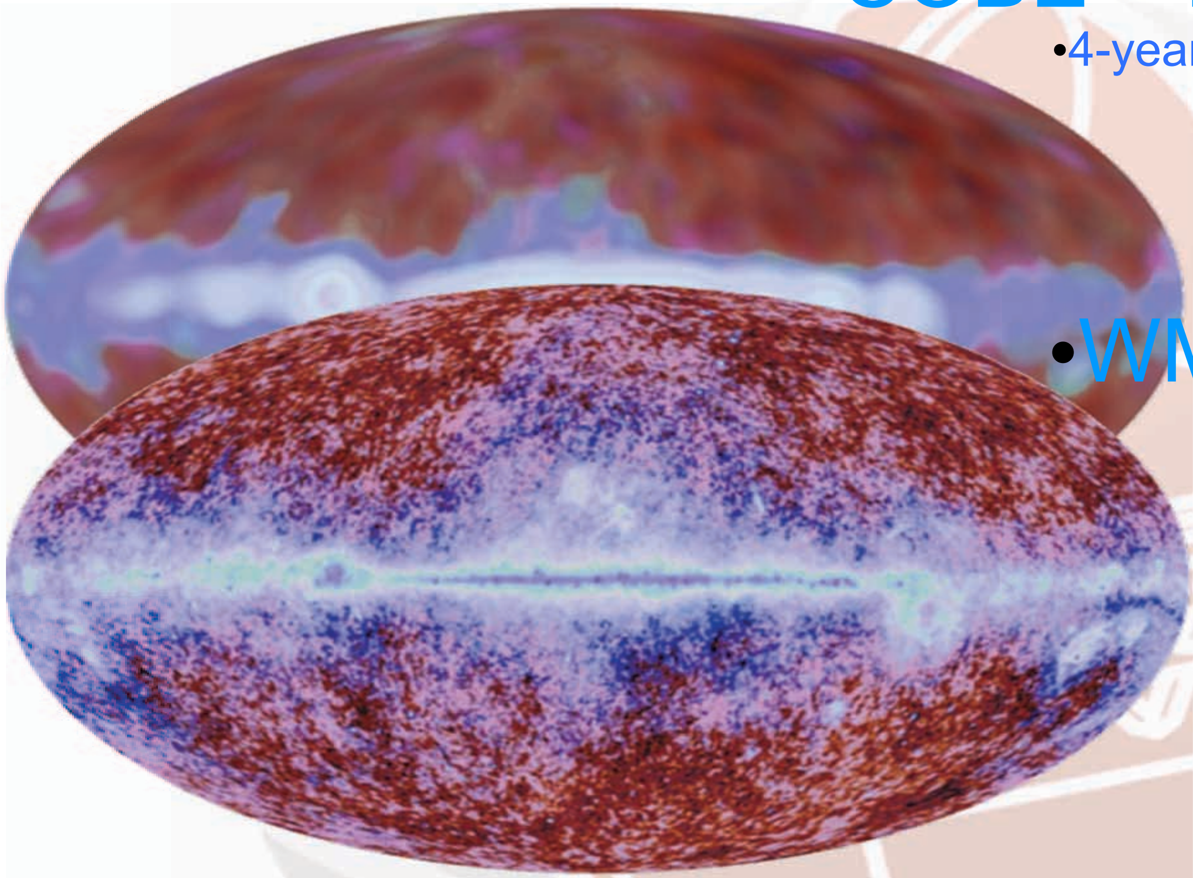
→ **angular scale ~ 5',**
$\Delta T/T \sim 2\times10^{-6}$, 30~867 Hz

- COBE - 1989
  - 4-years data



- Why Planck?

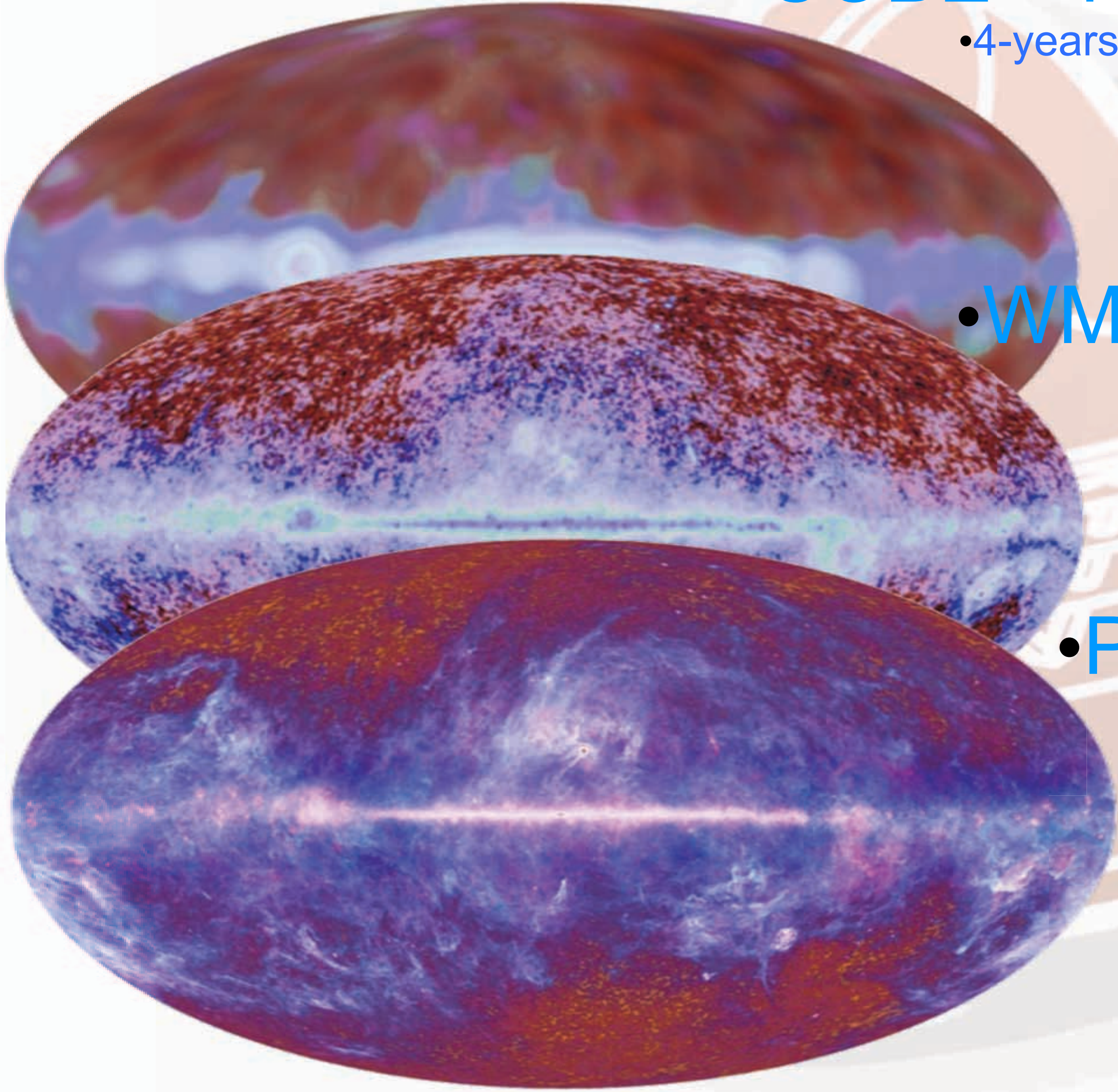
• Why Planck?



- COBE - 1989
  - 4-years data

- WMAP - 2001
  - 7-years data

•Why Planck?

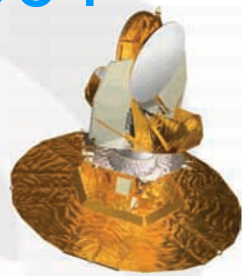


•COBE - 1989

•4-years data

•WMAP - 2001

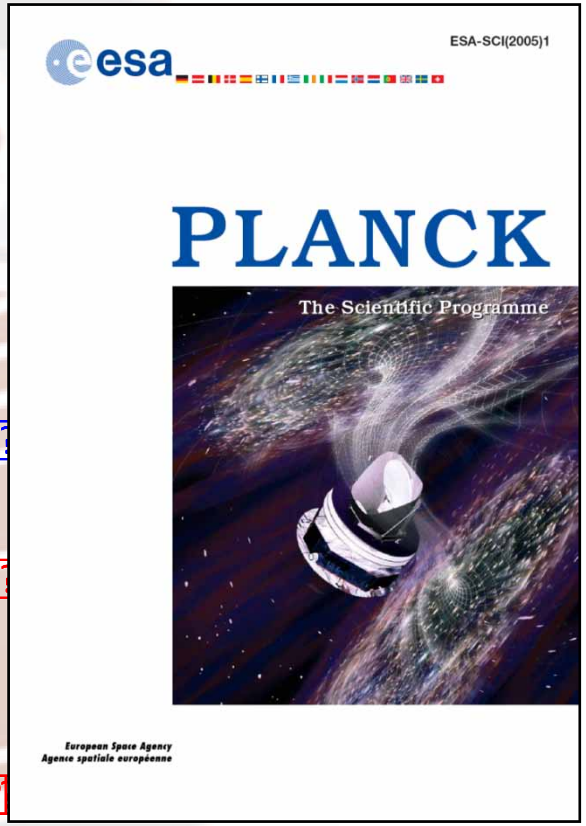
•7-years data



•PLANCK - 2009

•6-months data

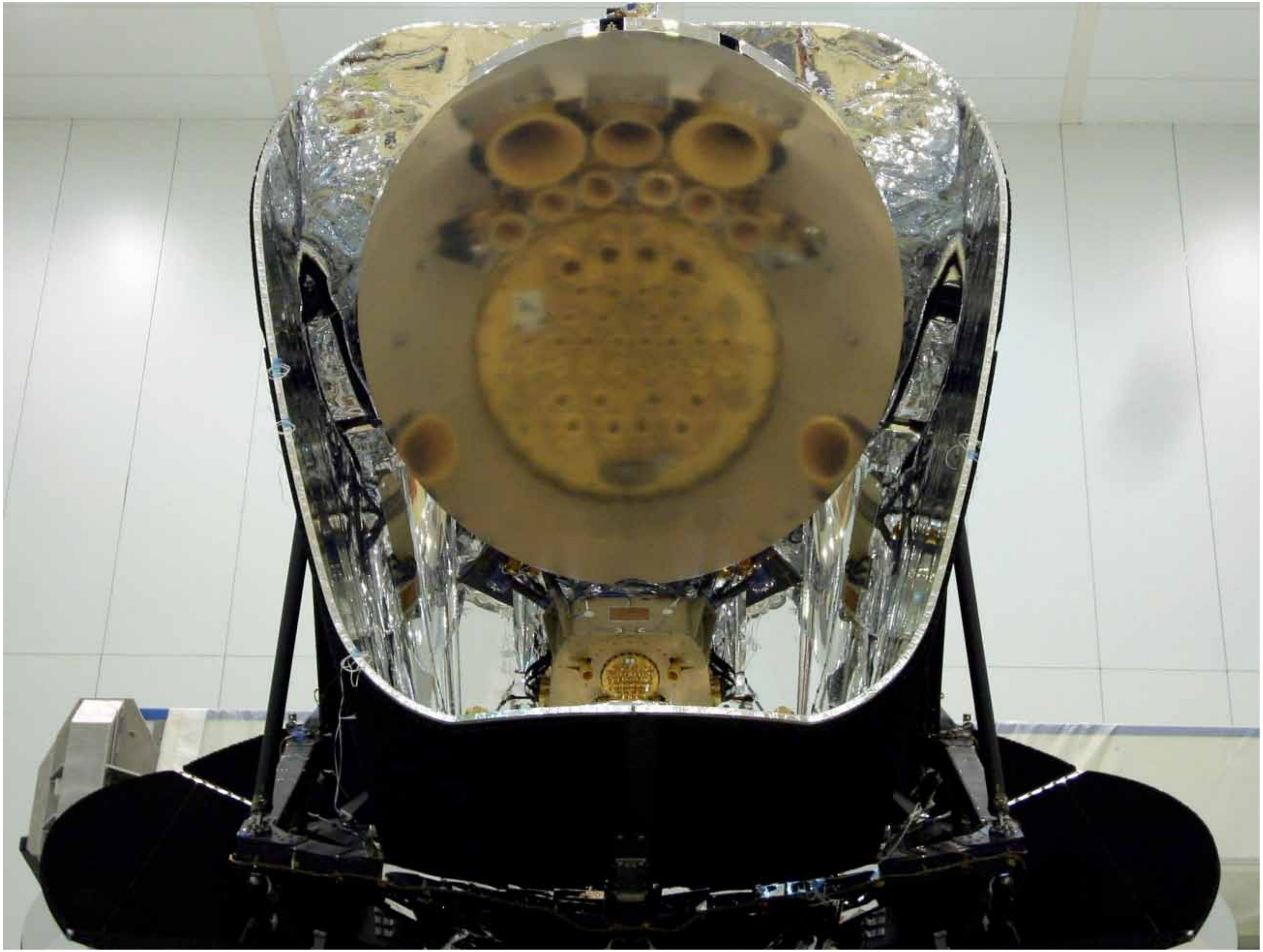
Science with Planck

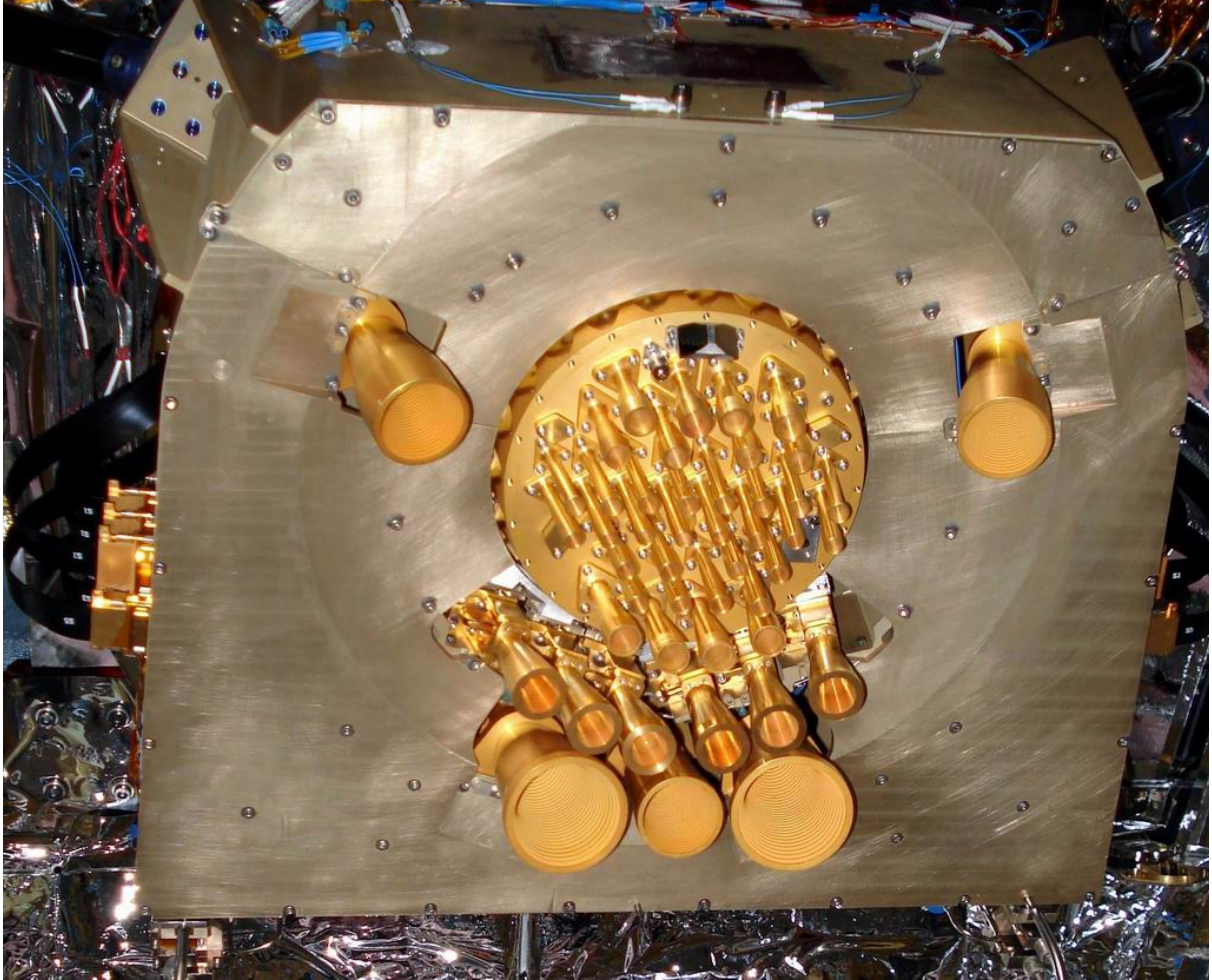


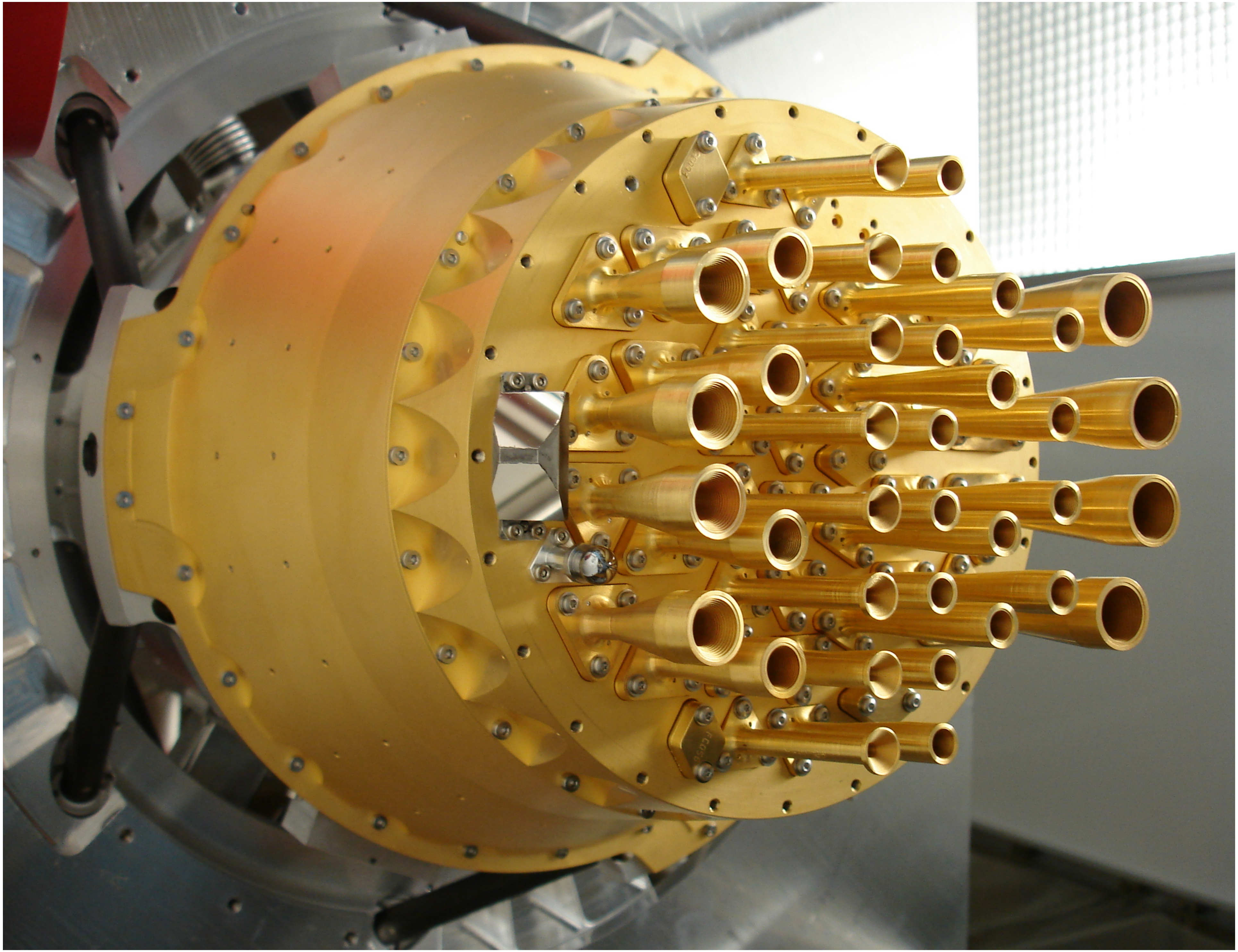
•*http://www.rssd.esa.int/Planck*

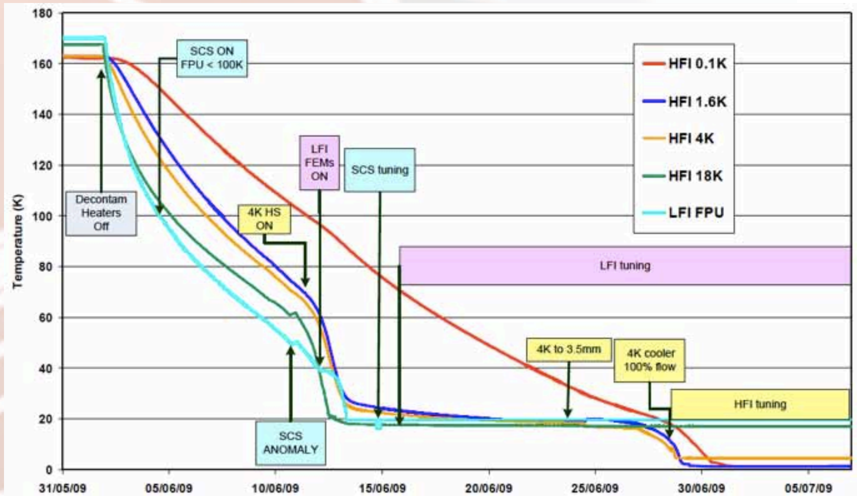
Planck: the 3rd generation space CMB experiment

- Planck gains a factor 3 in angular resolution and up to10 in instantaneous sensitivity with respect to WMAP
- LFI uses coherent detection and HEMTS based amplifiers in 3 bands 30 to 70 GHz, photometric reference loads on the 4K box of the HFI FPU. LFI is cooled at 18 K, reads in total power (22 polarized channels, 44 total power signals). Small 1/f noise.
- HFI bolometers are cooled to 100 mK, 6 bands 100 to 857 GHz, read in total power mode with a white noise from 10 mHz to 100 Hz (no 1/f noise in the signal range), nearly photon noise limited in the CMB channels (100-200 GHz)
- Intensity power spectrum sensitivity is limited by the ability to remove foregrounds (supported by the broad frequency coverage: 30 GHz-1 THz)

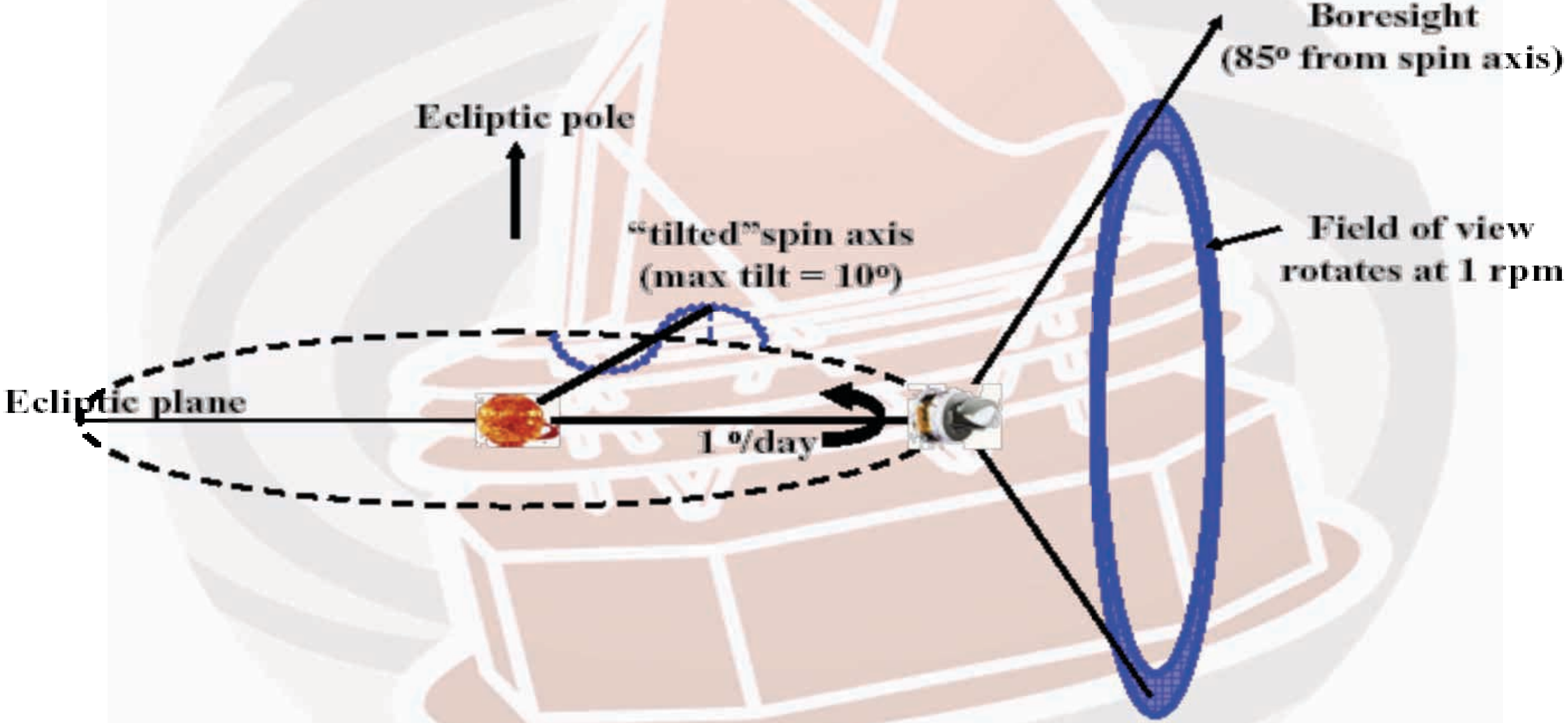


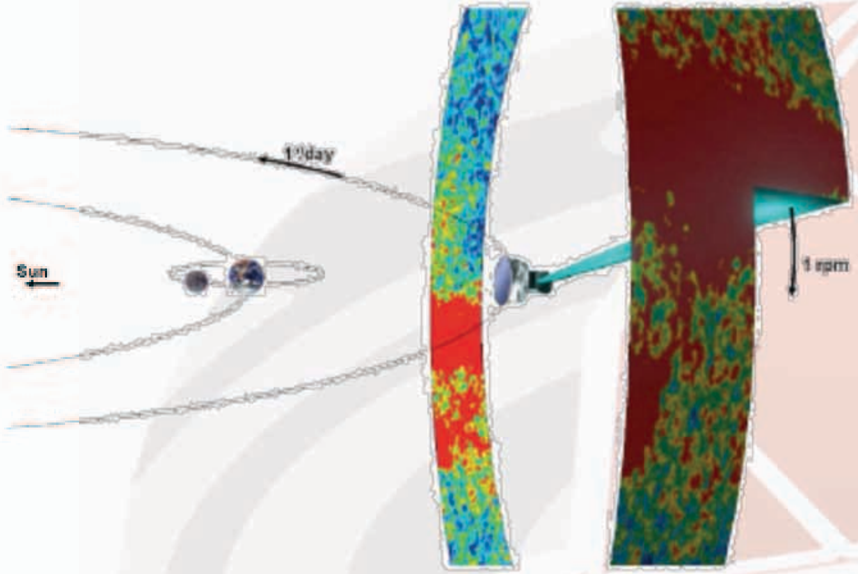





Temperature (K)
180
160
140
120
100
80
60
40
20
0
31/05/09
05/06/09
10/06/09
15/06/09
20/06/09
25/06/09
30/06/09
05/07/09
HFI 0.1K
HFI 1.6K
HFI 4K
HFI 18K
LFI FPU
SCS ON FPU < 100K
Decontam Heaters Off
LFI FEMs ON
SCS tuning
4K HS ON
LFI tuning
SCS ANOMALY
4K to 3.5mm
4K cooler 100% flow
HFI tuning

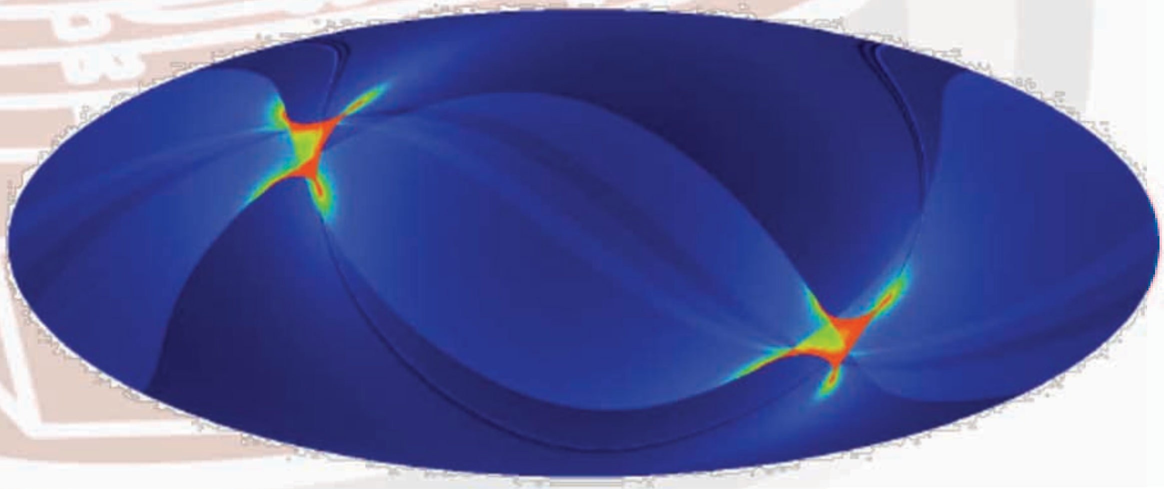
Observing strategy



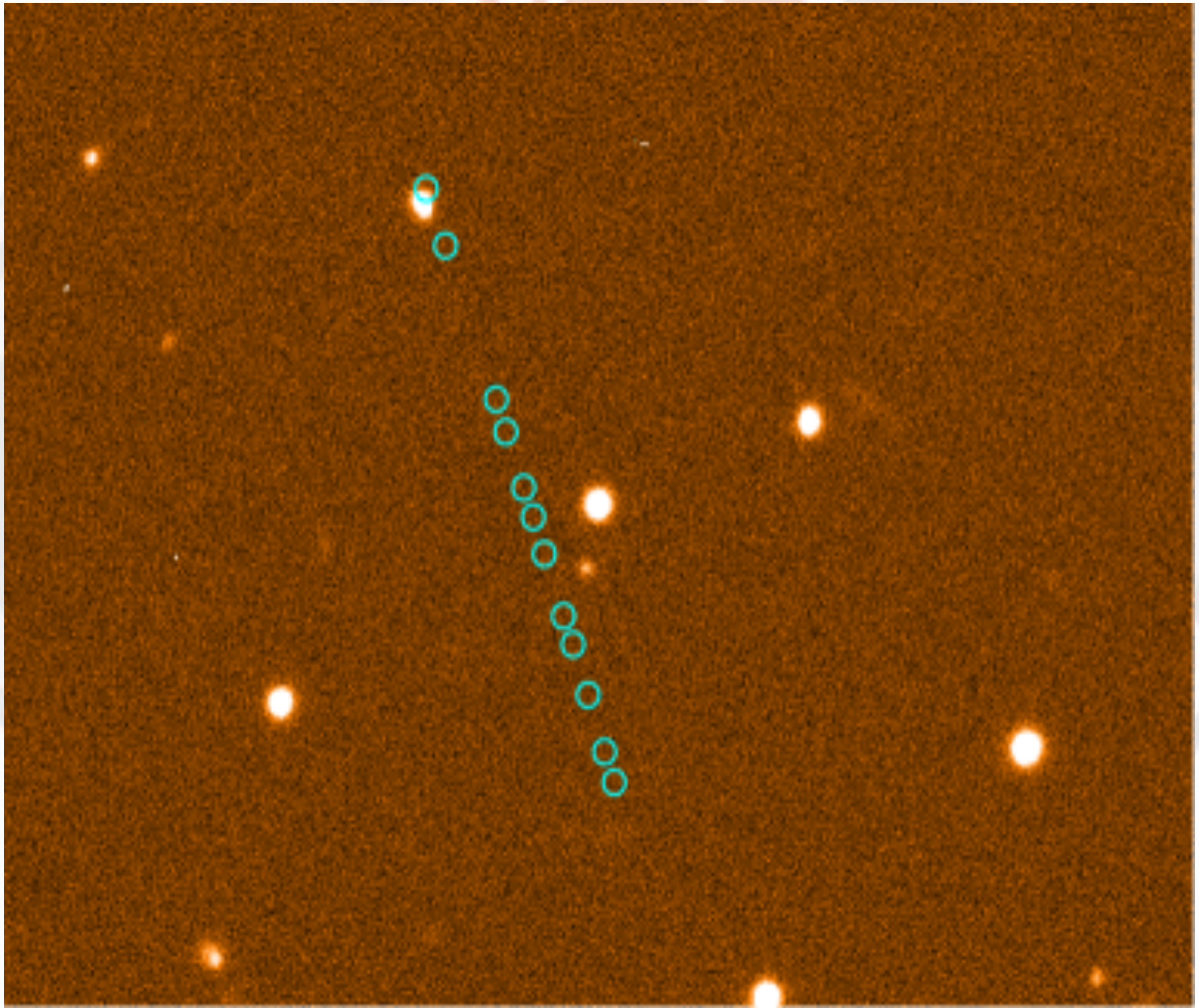


Planck is a survey mission

About 6 months are needed to cover ~95% of the sky.



Planck seen with the 2.2 m ESO telescope



Current Status

- 687 days since launch.
- Satellite and instruments working nominally and continuously since start of sky surveys (mid August 2009)
- Sky coverage is 100%
  - **All the sky has been surveyed about three times.**
  - The currently approved mission operation (to end Nov 2011) will do over > four sky surveys, until the end of the cold phase (end January 2012) with two instruments: HFI + LFI
  - A further 12 months extension has been approved with LFI only

Planck data products

The unrivalled accuracy of Planck will allow us to:

- Pin down the basic characteristics of the Universe: age, contents, dynamics, geometry, …
- Examine the origins of the Universe and test inflation
- Probe physics at extremely high energies, e.g. superstrings, neutrinos
- Probe the birth of the first stars and galaxies

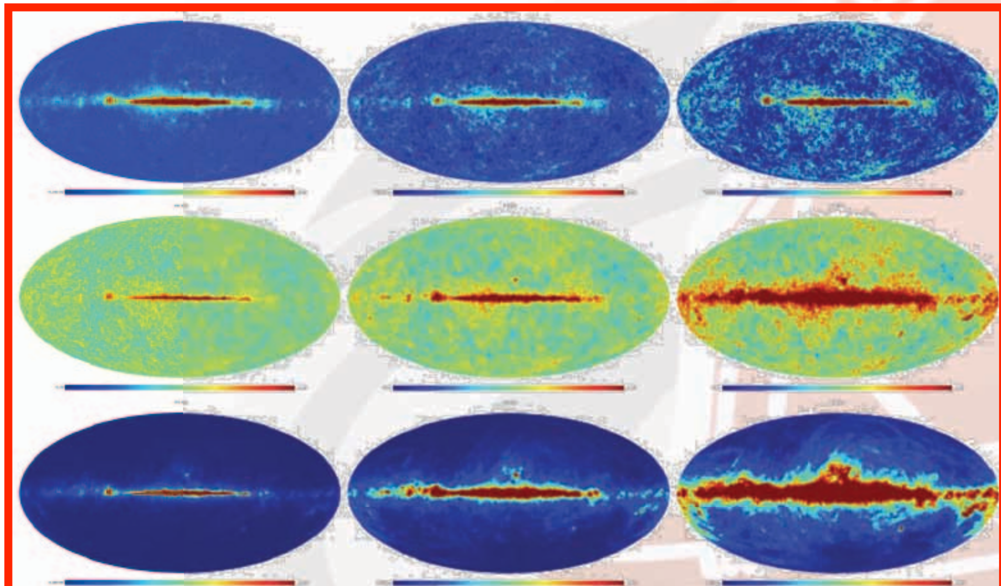
But also

- Understand the evolution of structures, galaxies and clusters of galaxies
- Observe our own Galaxy as never seen before…

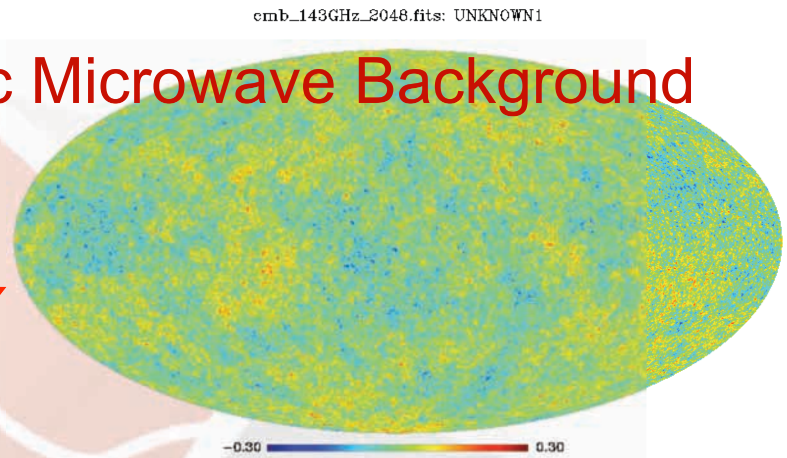
The release of the Planck "Early Release Compact Source Catalogue" is a first step in this direction

Expected results from simulations

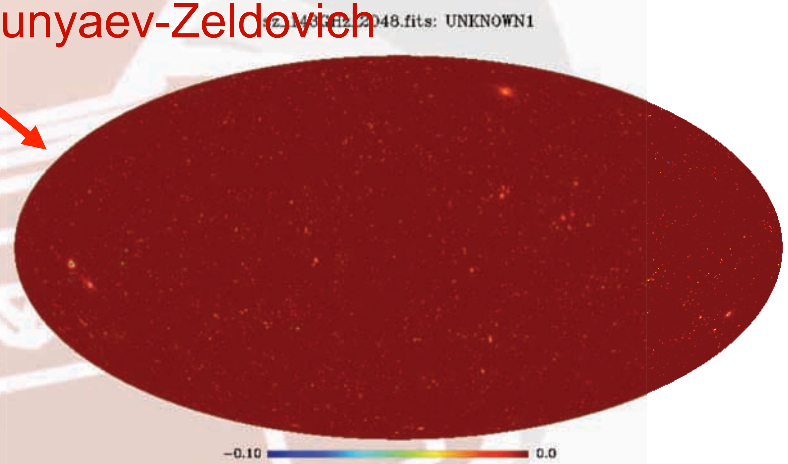
30, 44, 70, 100, 143, 217, 353, 545, 857 GHz – I, Q, U at all channels
Except 545 & 857 GHz



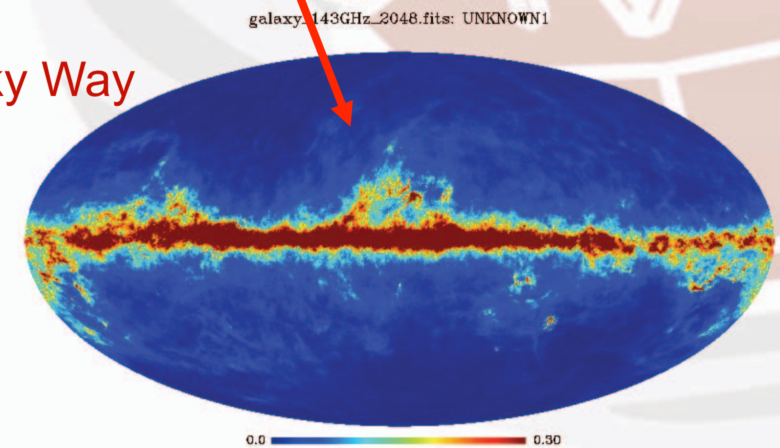
Cosmic Microwave Background



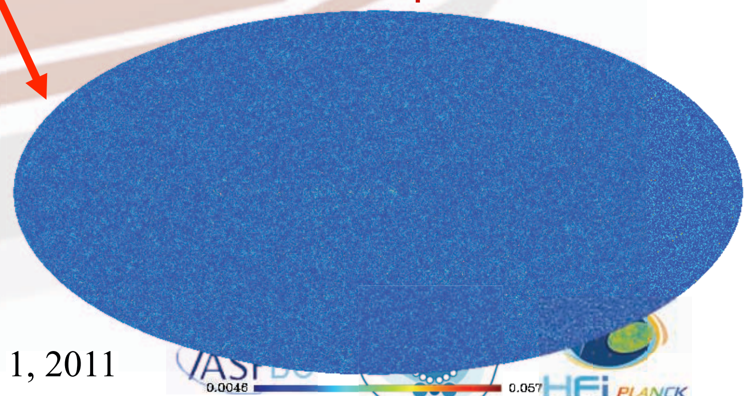
Sunyaev-Zeldovich

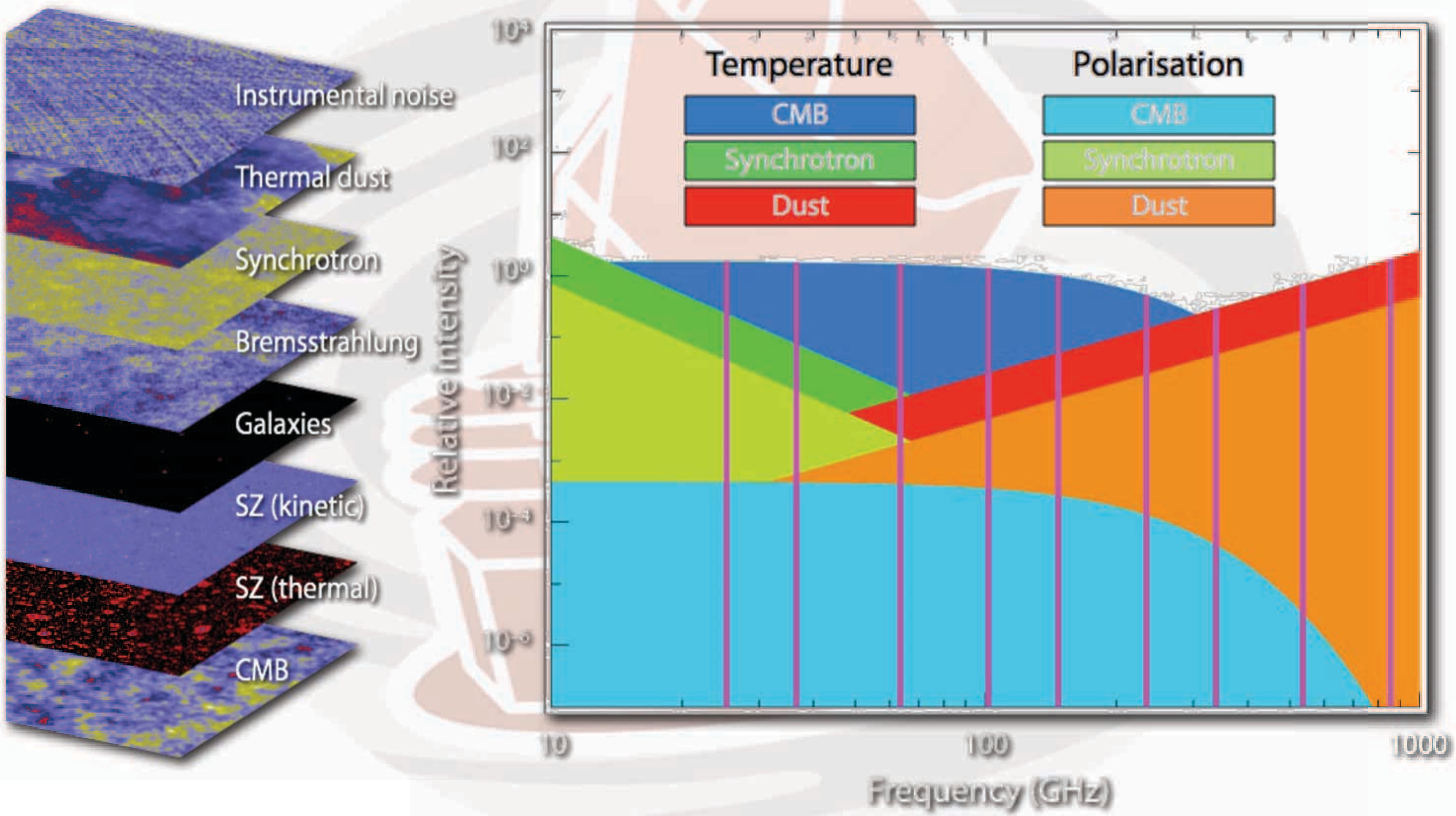


The Milky Way

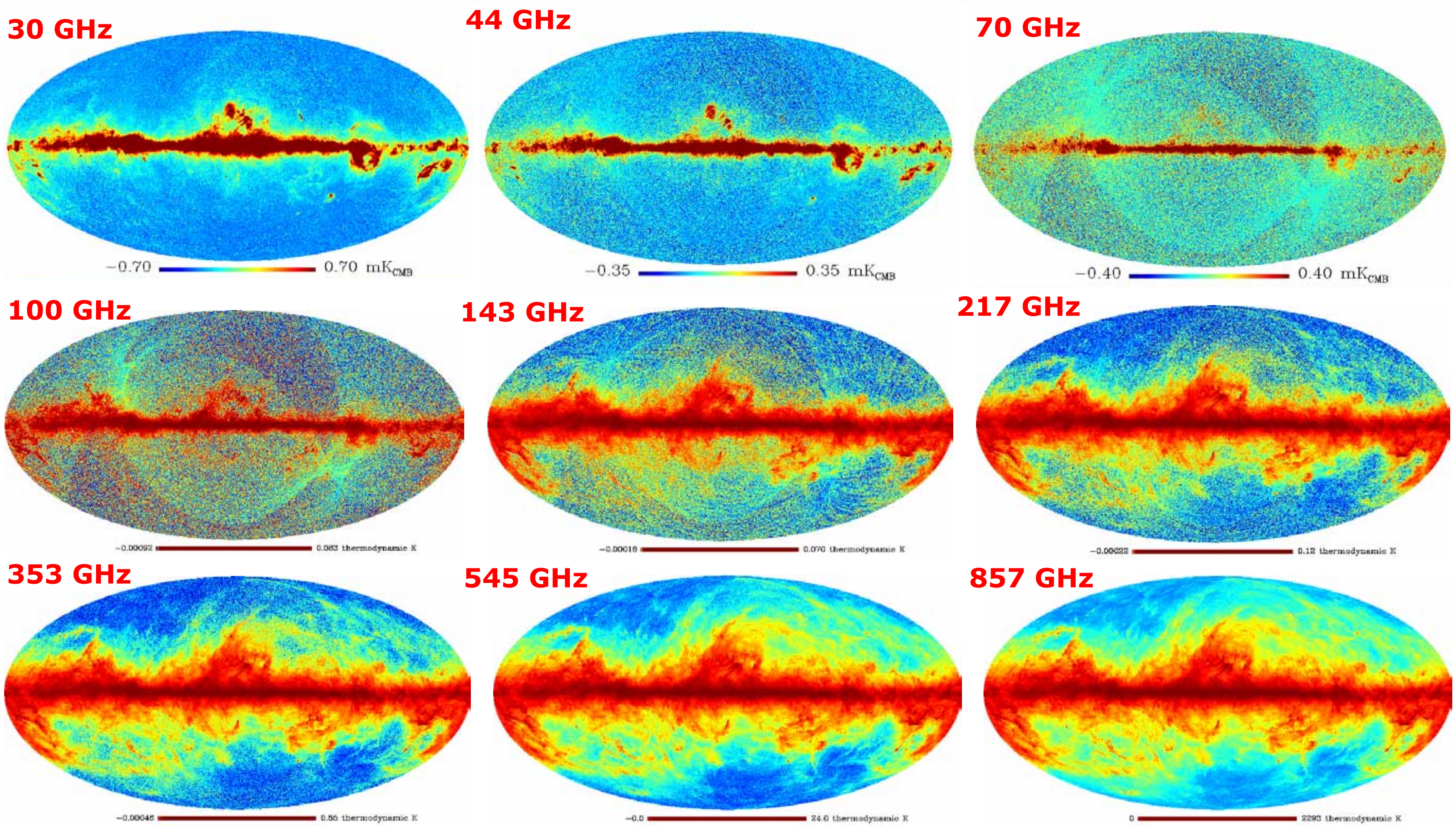


Point & Compact sources




Instrumental noise
Thermal dust
Synchrotron
Bremsstrahlung
Galaxies
SZ (kinetic)
SZ (thermal)
CMB
Temperature
CMB
Synchrotron
Dust
Polarisation
CMB
Synchrotron
Dust
Relative Intensity
10
100
1000
Frequency (GHz)

The Planck view of the sky after almost one year of operations (CMB removed)



The Early Release Compact Source Catalogue

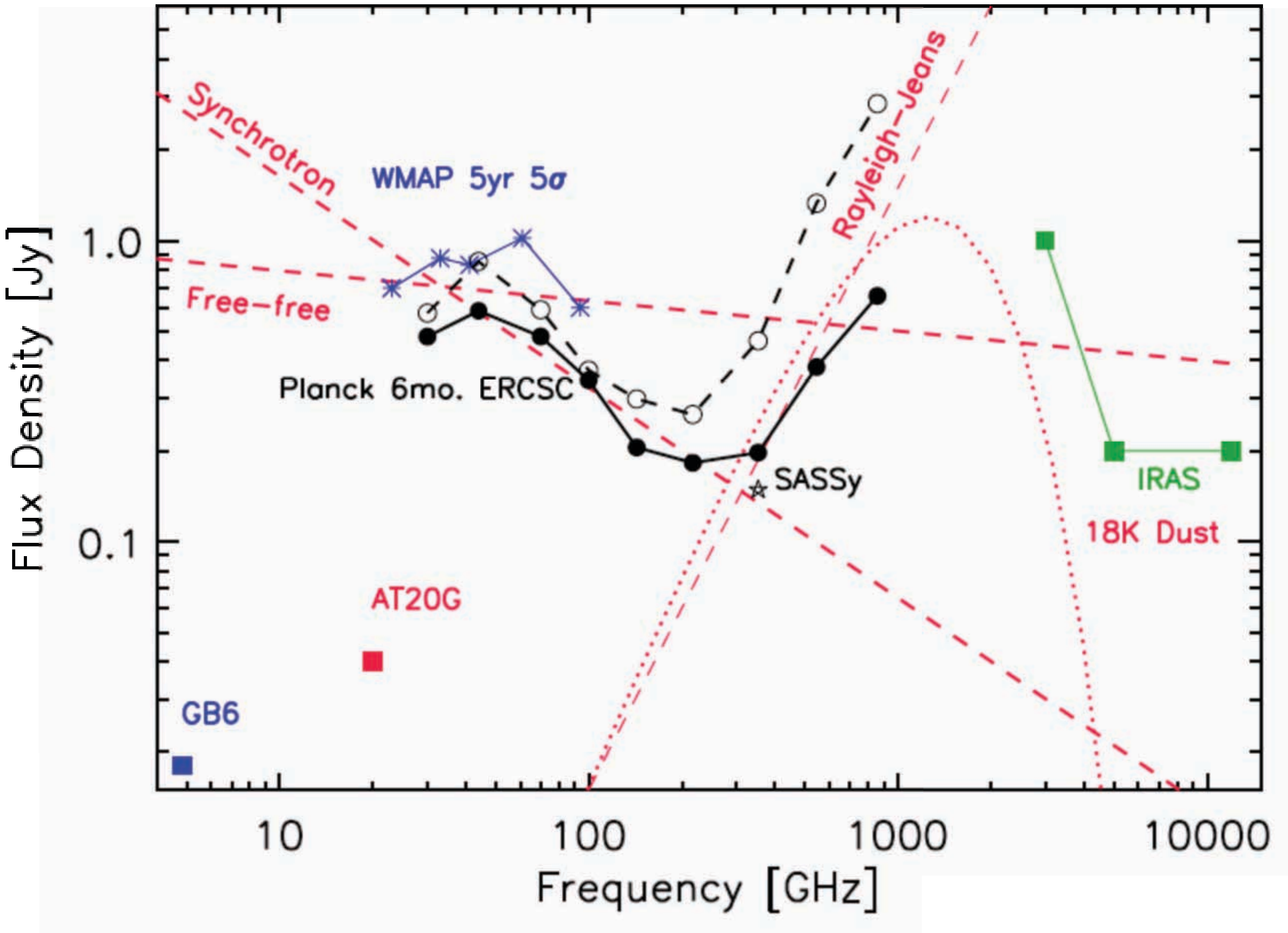
- First release to the public of a Planck data product
- A catalogue of compact sources extracted from the first all-sky survey with high reliability (>90%) - designed for follow-up
- It contains
  - ~15000 individual sources with detectable fluxes in individual Planck channels (range 30-857 GHz)
    - Sources in the Milky Way
    - Near and distant galaxies
  - A catalogue of cold cores, selected by their temperature
  - A catalogue of galaxy clusters selected via the Sunyaev-Zeldovich effect
- It offers a treasure trove of scientific and observing possibilities to the community
- *It is a foretaste of the legacy catalogues to be published in early 2013 !*

The Early Release Compact Source Catalogue

- The ERCSC has been released to the public Tuesday 11 January at 11:00 CET
  - It is accessible via the Planck web site

    http://www.rssd.esa.int/Planck

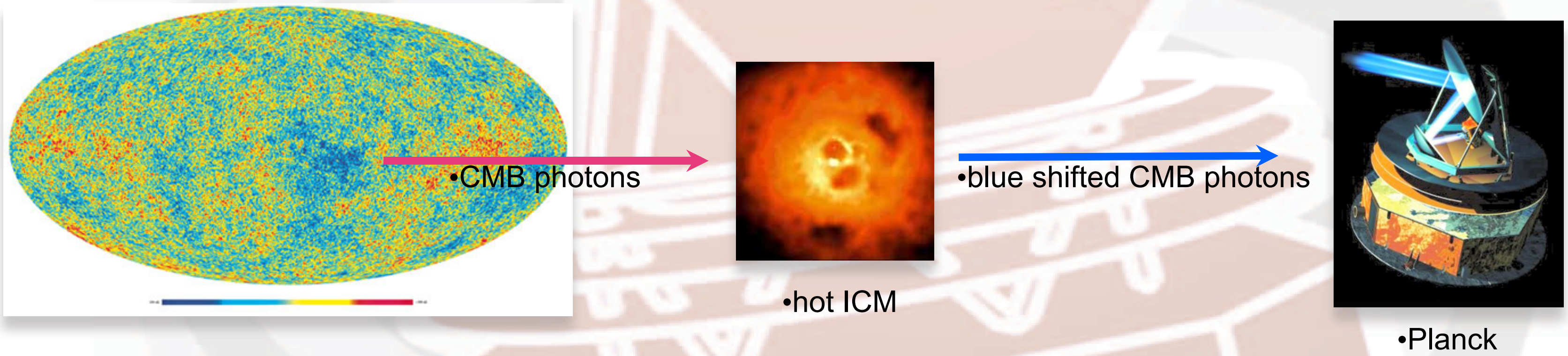
- Together with the catalogue, 25 scientific papers are being submitted to Astronomy & Astrophysics, covering
  - The performance of Planck and its payload in the first year of operations, and the initial data processing steps
  - The production of the ERCSC and the characteristics of the main source populations that it contains, including validation of the catalogues by correlation with other catalogues and follow-up
  - Selected astrophysical topics related to diffuse emission
  - They are accessible through the same site above or at astro-ph



Synchrotron
WMAP 5yr 5σ
Rayleigh-Jeans
1.0
Free-free
Planck 6mo. ERCSC
SASSy
IRAS
18K Dust
0.1
AT20G
GB6
Flux Density [Jy]
10
100
1000
10000
Frequency [GHz]

Sunyaev-Zeldovich effect: basics

- It is a secondary anisotropy predicted in 1972 due to inverse Compton Scattering between CMB photons (~0.3 meV) and free electrons (~ few KeV) of the hot Intra-Cluster Medium. CMB photons acquire energy!



- Thermal SZ : CMB photons are scattered by random motion of thermal electrons
- Kinetic SZ : CMB photons are scattered by bulk motion of electrons

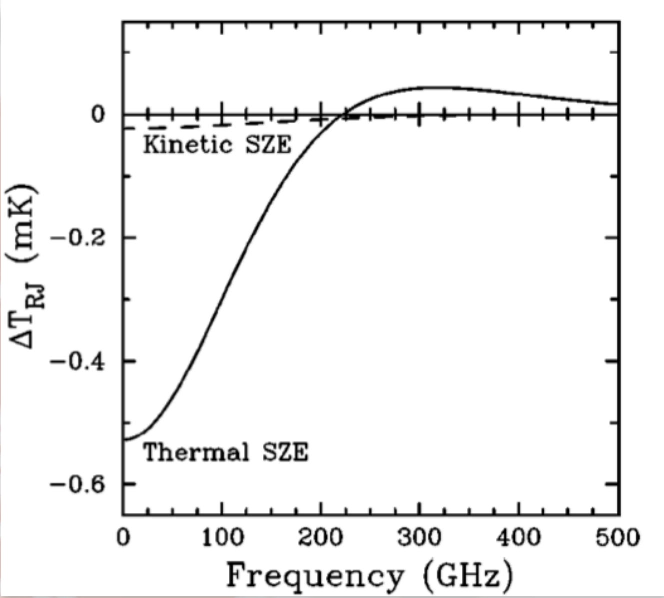
Sunyaev-Zeldovich effect: properties

$$\frac{\Delta T_{SZ}}{T_{CMB}} = f(x)\, y$$

$$y = \int_{los} n_e \sigma_T \frac{kT_e}{m_e c^2} d\ell$$ •y-Compton parameter

$f(x)$ •provides the frequency dependence $x = \frac{h\nu}{kT_{CMB}}$

$$Y = \int_{cluster} y\, d\Omega \qquad Y D_A^2 = \frac{\sigma_T}{m_e c^2} \int P\, dV$$



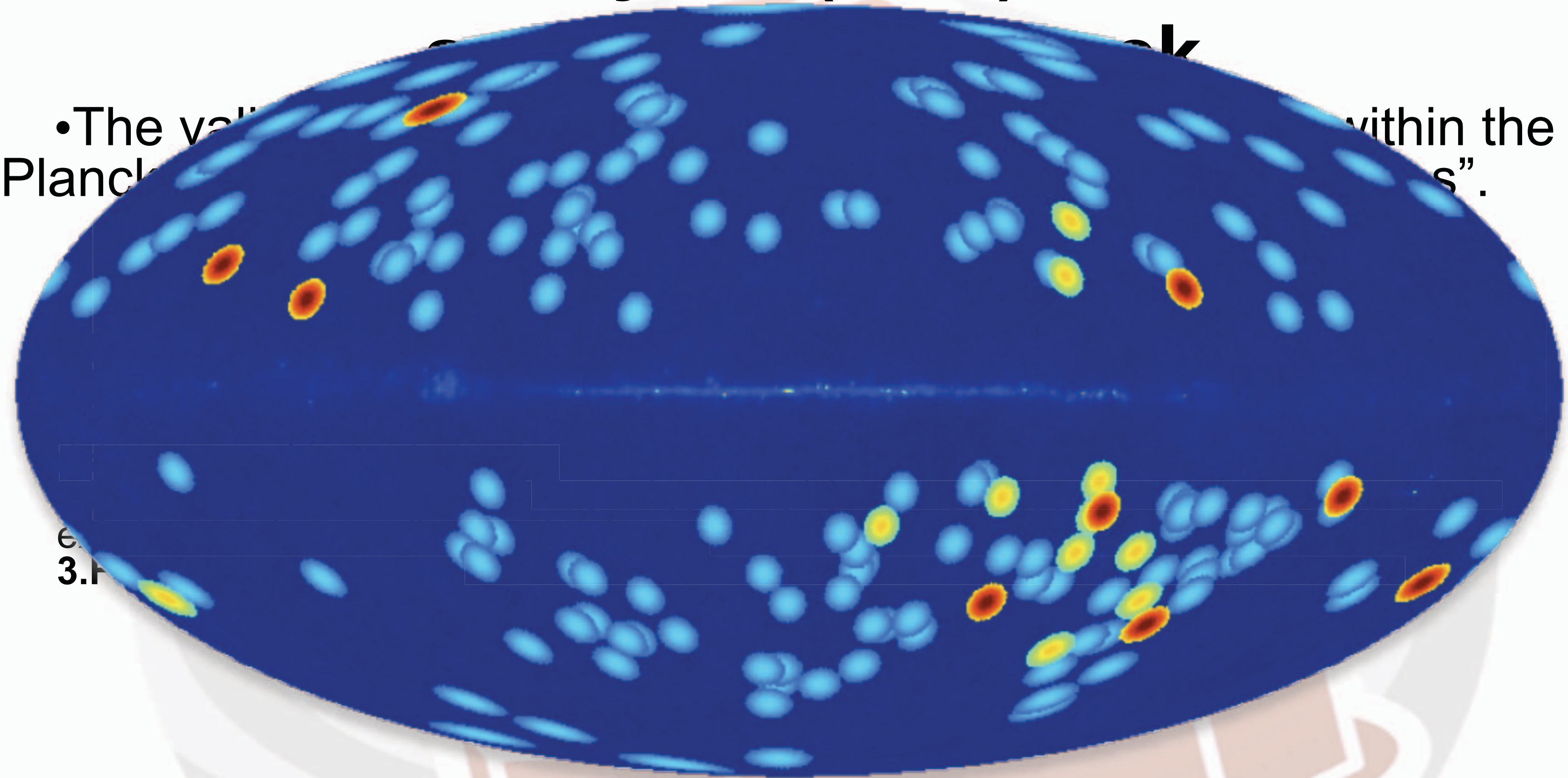
•Carlstrom, Holder and Reese 2002

• SZ effect does not depend on z;
• y-Compton gives the amplitude of the effect (~ 1 mK);
• SZ vanishes for ~217 GHz (signature of the effect; one of the Planck channels is centered @ 217 GHz specifically to identify the zero transition of TSZ);
• Y is the integrated Compton that is proportional to the temperature-weighted mass of the cluster divided by the angular diameter distance D_A which is the only term depending on z (weakly). This is an useful relation for extracting cosmological information (that are in D_A) when combined with other observations (X-ray typically).

The Early SZ (ESZ) cluster

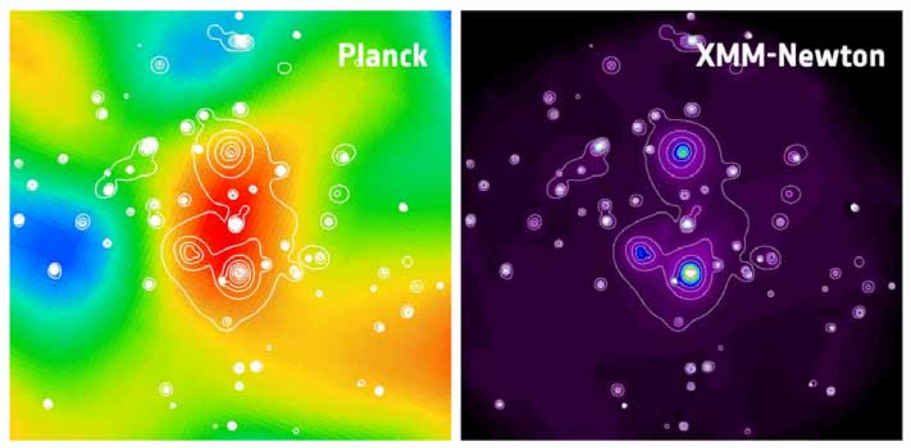
•The va… …within the
Planc… …s".

e…
3.F…



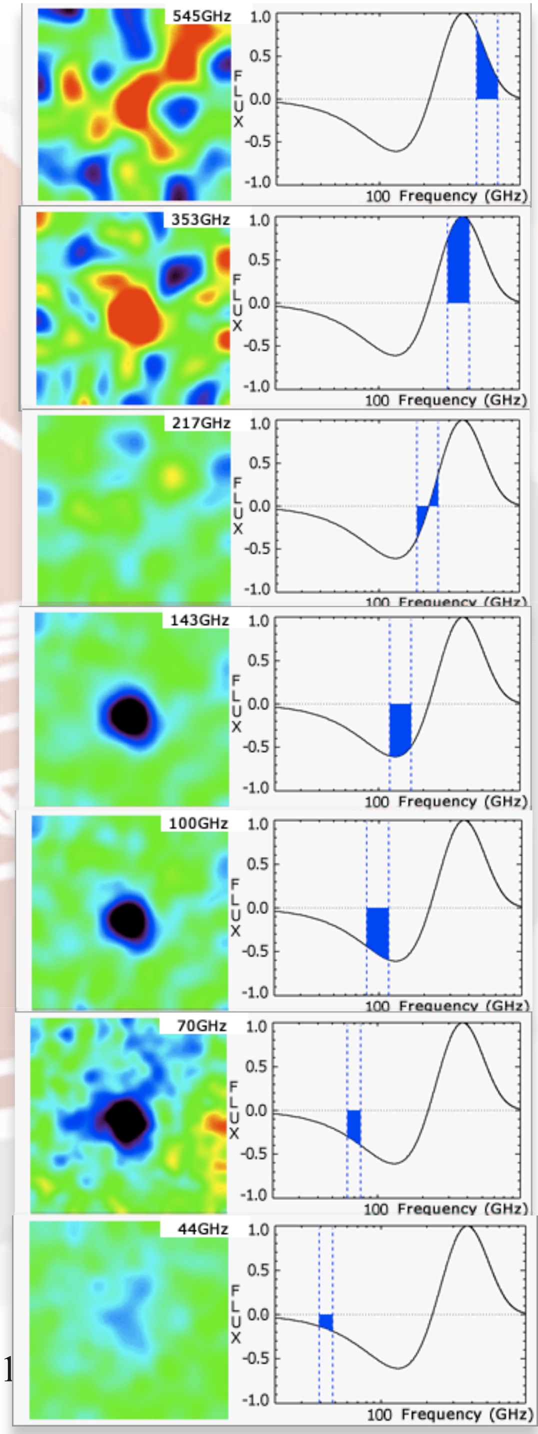
•189 clusters detected (ESZ sample)
•169 are known
•20 are new Planck clusters
•12 have been confirmed (11 by XMM and 1 by AMI)
•8 are candidate new clusters

The Early SZ (ESZ) cluster sample from Planck

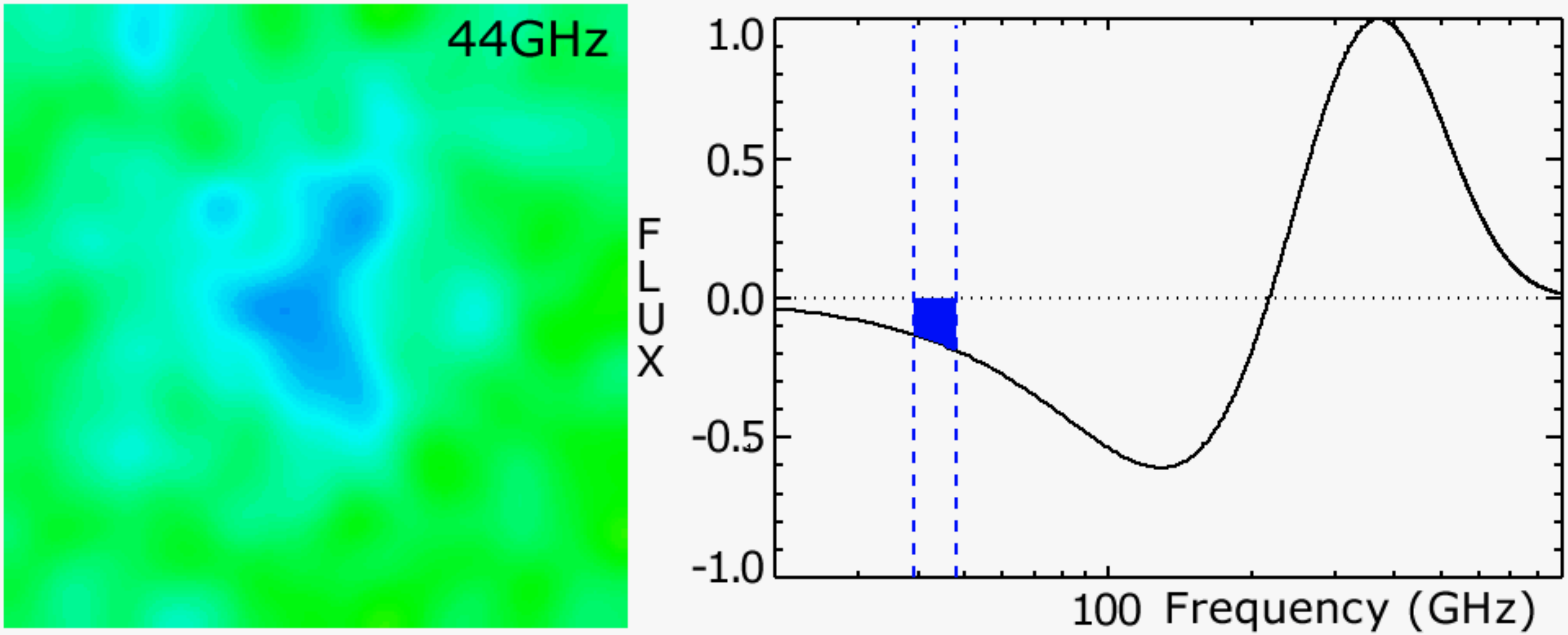


•newly discovered supercluster, PLCK G214.6+37,
•Planck (left) and XMM-Newton (right panel)

•At the end of the mission it will be delivered the Planck SZ cluster catalogue containing many hundreds of clusters at z~1.
The previous all-sky catalogue is RASS (Rosat All Sky Survey) but at much lower depth (i.e. z~0.1)

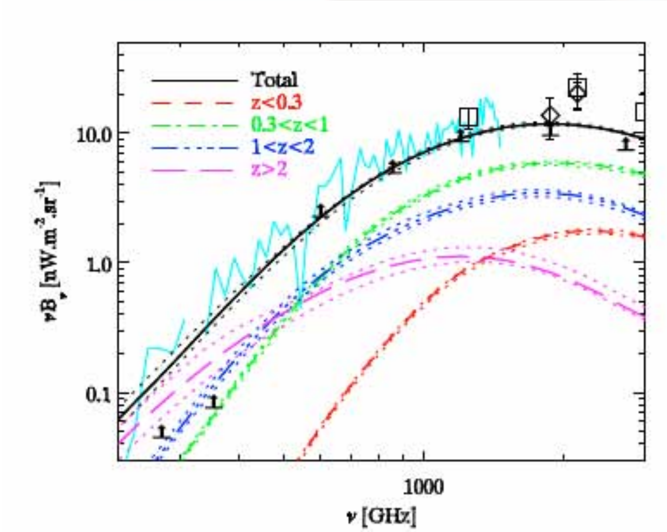


•Abell 2319


44GHz
1.0
0.5
0.0
-0.5
-1.0
FLUX
100 Frequency (GHz)

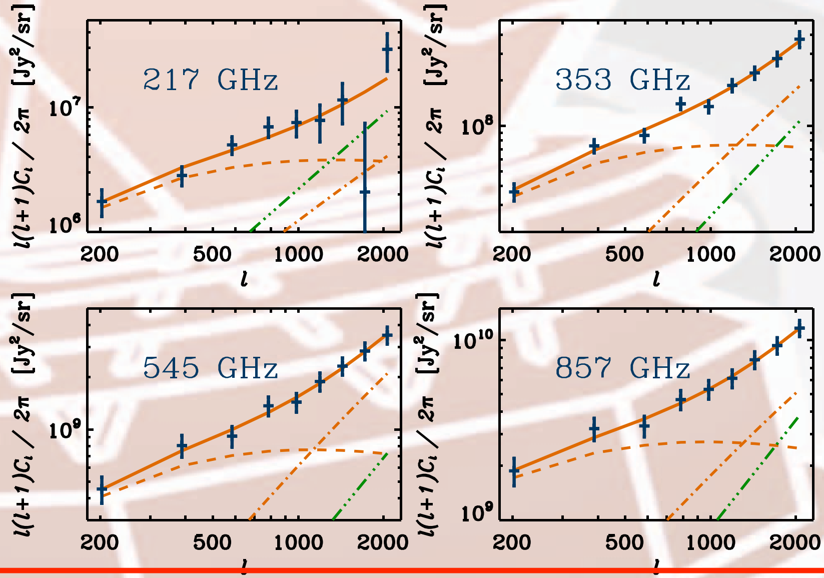
•Planck Early Results: Power spectrum of CIB anisotropies with Planck/HFI

•Cosmic Infrared Background records much of the radiant energy released by processes of structure formation that have occurred since the decoupling of matter and radiation following the Big Bang.



•Contribution to the CIB per redshift slice, extracted from Bethermin et al. (2010b). Black solid line: CIB spectrum predicted by the model.

•Due to its frequency coverage from 100 to 857 GHz, the HFI instrument onboard Planck is sensitive to the complete history of star-formation and is thus ideally suited to probe the dark matter/star-formation connection.

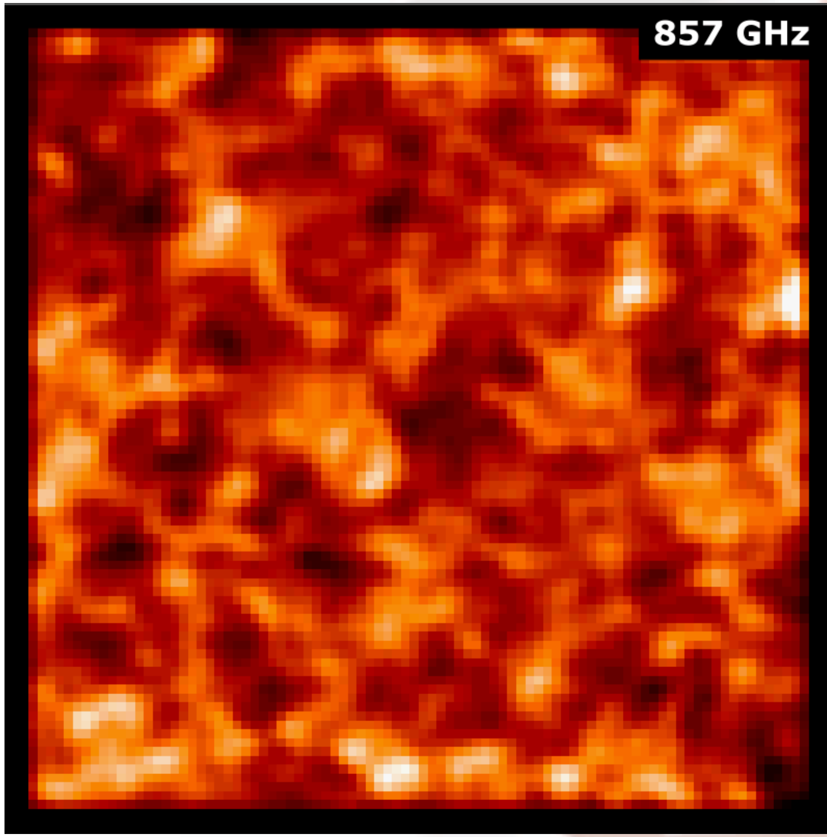


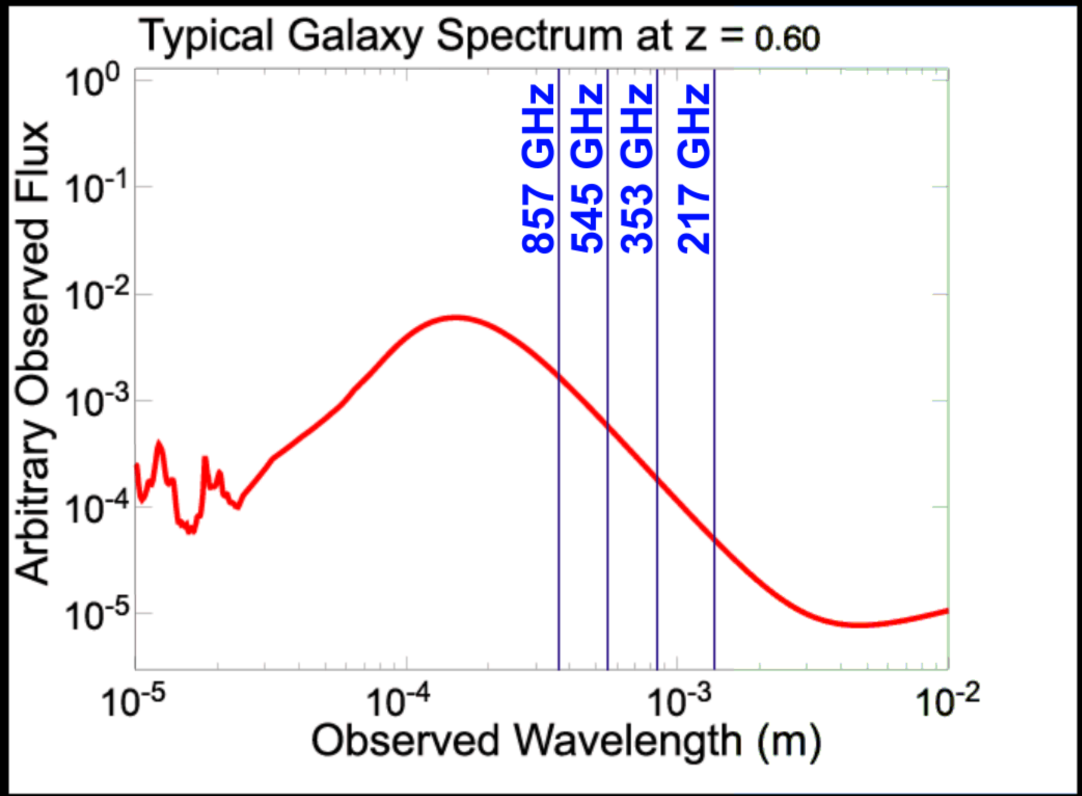
•Power spectra are measured independently for the 6 fields and are then combined.

•- First measurements at those wavelengths and spatial scales;

•- We measure strong frequency-correlated structures consistent with the expected CIB signal. The correlation decreases with increasing frequency;

•- No significant difference between the frequency spectrum of the CIB anisotropies and the CIB mean is observed;


857 GHz


Typical Galaxy Spectrum at z = 0.60
Arbitrary Observed Flux
Observed Wavelength (m)
857 GHz
545 GHz
353 GHz
217 GHz

Galactic studies with Planck

- The Planck multifrequency view of our Galaxy allows for the first time a detailed investigation of many interesting topics
- Early studies/papers achieved crucial results on the following aspects:
  - Dark gas in the Galaxy
  - Microwave anomalous emission
  - Interstellar medium
  - Cold cores
  - Thermal dust on nearby molecular clouds

New Light on Anomalous Microwave Emission from Spinning Dust Grains – I

Planck, combined with ancillary radio and FIR data, has provided a unique opportunity to establish a comprehensive spectrum of AME

→ important basis for understanding the emission mechanism and the environment in which it occurs

The evidence from the present observations strongly favours the spinning dust (electro-dipole radiation) mechanism

The two best-studied AME sources that have extensive ancillary data are in:

Perseus and ρ Ophiuchus molecular clouds

Their spectrum is well-fitted by free-free, thermal dust and spinning dust, with a small contribution from the CMB

Spinning dust provides a good fit to the microwave (10 − 100 GHz) part of their spectra

which peaks at ≈ 30 GHz, we present the most precise spectra for spinning dust to date

Planck has revealed the high frequency side of the peak for the first time

Theoretical spinning dust curves are presented, based on a physical model consisting of molecular, atomic and ionized states

We show that it is possible to derive physical parameters that are consistent with the environment, including previous measurements, and still provide a good fit to the data

New Light on Anomalous Microwave Emission from Spinning Dust Grains – II

Using parameters constrained at smaller angular scales, the 20 − 40 GHz AME peak in Perseus is well explained with spinning dust emission arising from dense, molecular gas (nH > 200 cm−3) subjected to a few times the interstellar radiation field. The contribution from low density gas appear to only play a minor role.

In the case of ρ Ophiuchus, irradiated, high density molecular gas from the PDR appears to contribute in the range 50 − 100 GHz. The picture seems to be that smaller PAHs are found in PDRs (G0 > 100) as suggested by recent Spitzer observations

- Determination of the PAH size degenerate with that of nH and G0 and quantitative conclusions will only be obtained from consistent modeling of the gas state, radiative transfer and spinning dust.
- At this level of modelling it is not possible to constrain the electric dipole moment of PAHs
- The 2 first precise spinning dust spectra presented in this paper
- A search of new AME regions in the Planck data has been Planck successful
- They were uncovered by subtracting synchrotron, free-free and thermal dust emission based on the usual spatial 101 templates.
- Two new candidate regions that show AME have been presented:

  they are located in different areas of the Galaxy compared with Perseus and ρ Ophiuchus
- Additional high resolution observations are needed to understand the detailed structure of the AME in these regions
- Planck data provide a rich source of observations that can be used as a basis for developing a realistic understanding of the AME mechanism in a range of Galactic environments

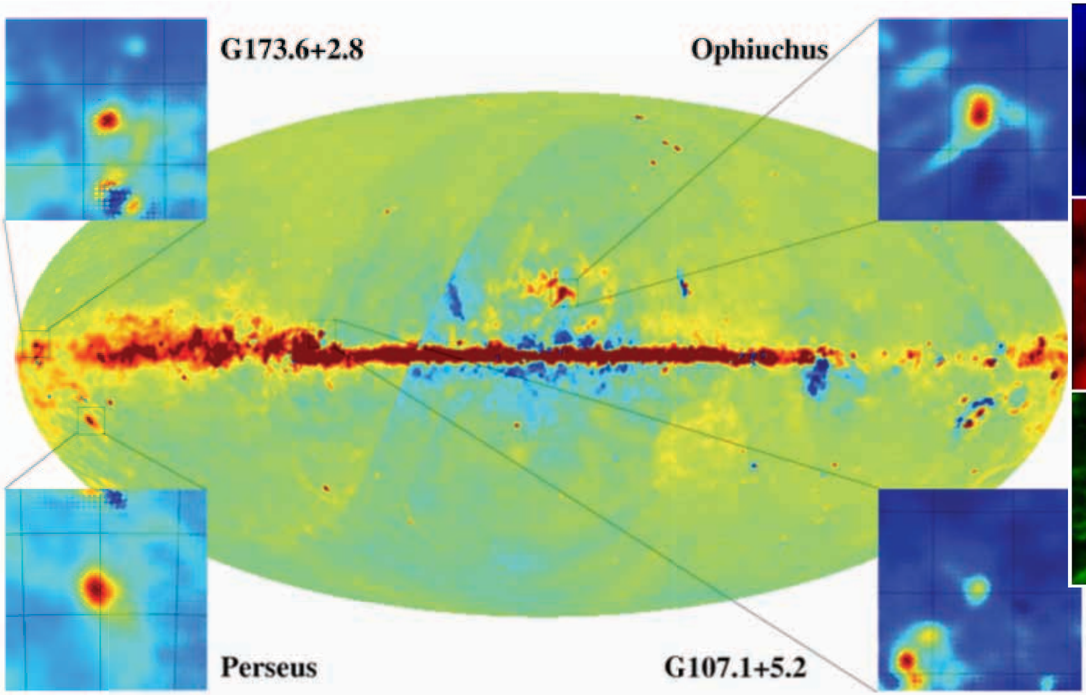
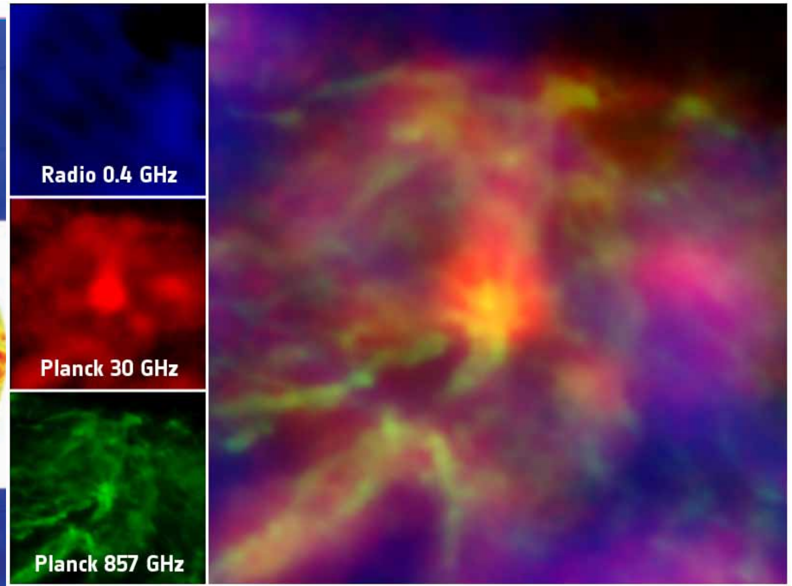


Fig. 10. Residuals in the full sky *Planck* LFI 28.5 GHz 1° smoothed map after subtraction of synchrotron, free-free and thermal dust emission (see text). 12.°5 × 12.°5 cut out maps are shown for the Perseus and ρ Ophiuchus molecular clouds, and the two new regions of AME, G107.1+5.2 and G173.6+2.8.



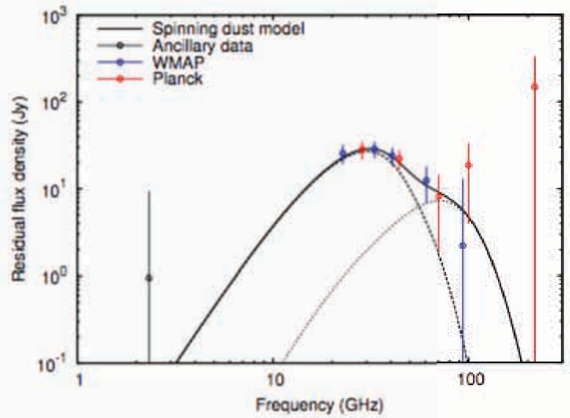


Fig. 9. Spectrum of G353.05+16.90 in the ρ Ophiuchus molecular cloud after subtracting the best fit free-free, CMB and thermal dust components. A theoretical spinning dust model consisting of two components (dark cloud and PDR; see text), is shown.

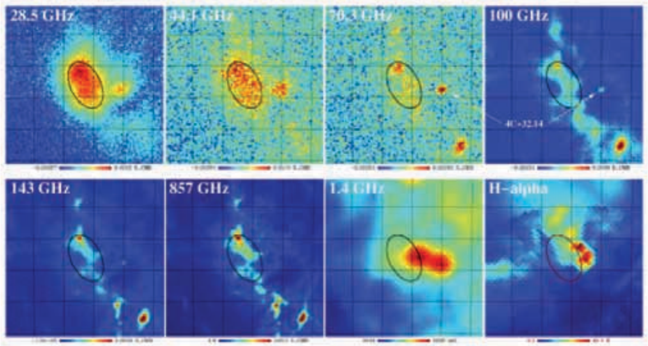


Fig. 1. Maps of the Perseus molecular cloud region at their original angular resolution. From left to right, top row: *Planck* 28.5, 44.1, 70.3 and 100 GHz, bottom row: *Planck* 143 and 857 GHz, 1.4 GHz and Hα. The maps cover 5° × 5° centred on $(l, b) = (162.°26, -18.°62)$ and have linear colour scales. The graticule has 1° spacing. The FWHM of the elliptical Gaussian model used to fit the flux density in the filtered maps (see text) is shown. The strong AME is evident at 30 – 70 GHz.

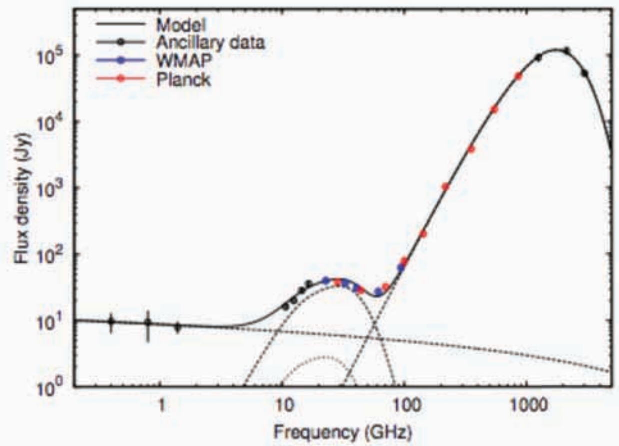
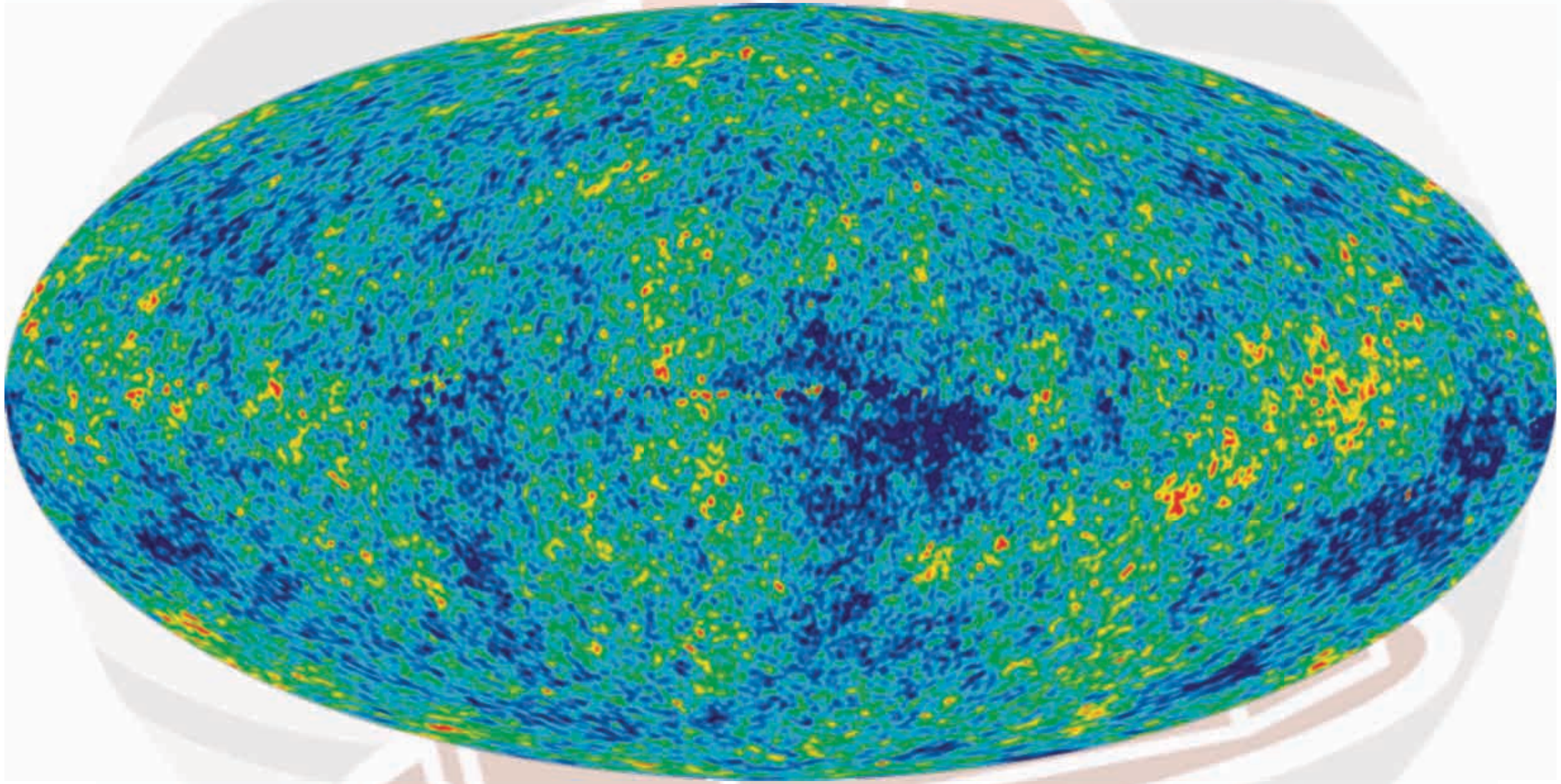


Fig. 4. Spectrum of G160.26-18.62 in the Perseus molecular cloud. The best-fitting model consisting of free-free, spinning dust (2 components), and thermal dust is shown.

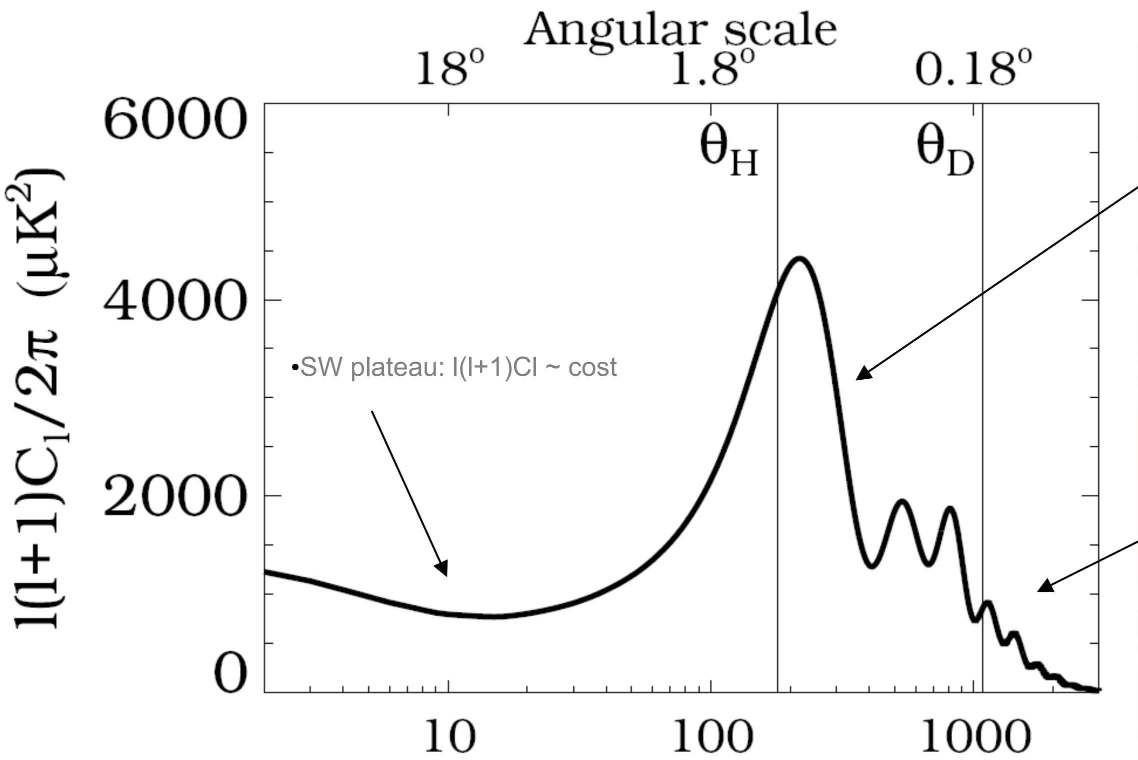
WMAP 7 CMB map



•Courtesy WMAP Science Team

Typical model prediction for CMB anisotropy APS

$$\frac{\Delta T}{T}(\vec{x},\hat{\gamma}) = \sum_{\ell=0}^{\infty}\sum_{m=-\ell}^{\ell} a_{\ell m}(\vec{x})Y_{\ell m}(\hat{\gamma}) \quad \Longleftrightarrow \quad a_{\ell m}(\vec{x}) = \int_{4\pi} Y_{\ell m}^{*}(\vec{\gamma})\frac{\Delta T}{T}(\vec{x},\vec{\gamma})$$



•Pre recombination (acoustic) oscillations of photon-baryon fluid

•Photon diffusion damping

$$\langle a_{\ell m} a^{\star}_{\ell' m'}\rangle = C_\ell \delta_{\ell\ell'}\delta_{mm'}\,.$$

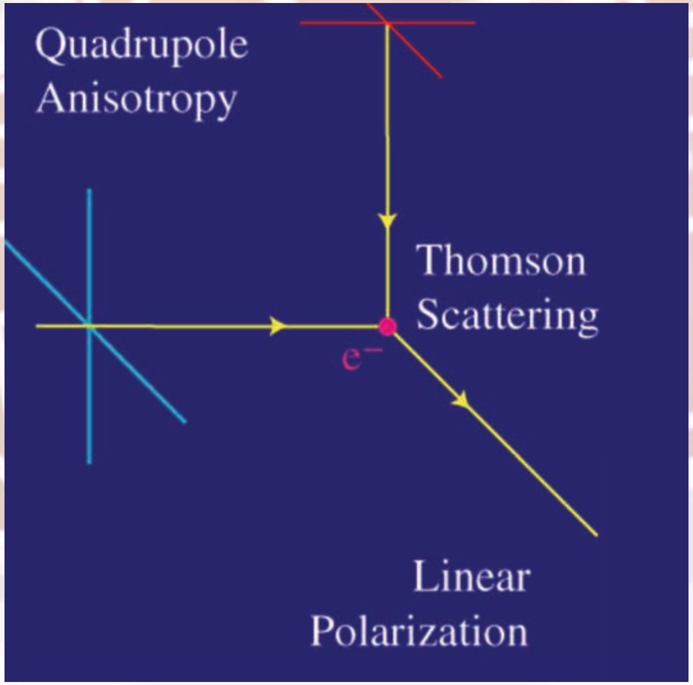
Why is CMB radiation polarized? <= Anisotropic Scattering

The CMB radiation is polarized because it was scattered off of free electrons during decoupling.

When an electromagentic wave is incident on a free electron, the scattered wave is polarized perpendicular to the incidence direction. If the incident radiation were isotropic or had only a dipole variation, the scattered radiation would have no net polarization. However, if the incident radiation from perpendicular directions (separated by 90°) had different intensities, a net linear polarization would result. Such anisotropy is called "quadrupole" because the poles of anisotropy are 360°/4 = 90° apart.

hotter radiation ↓

colder radiation →



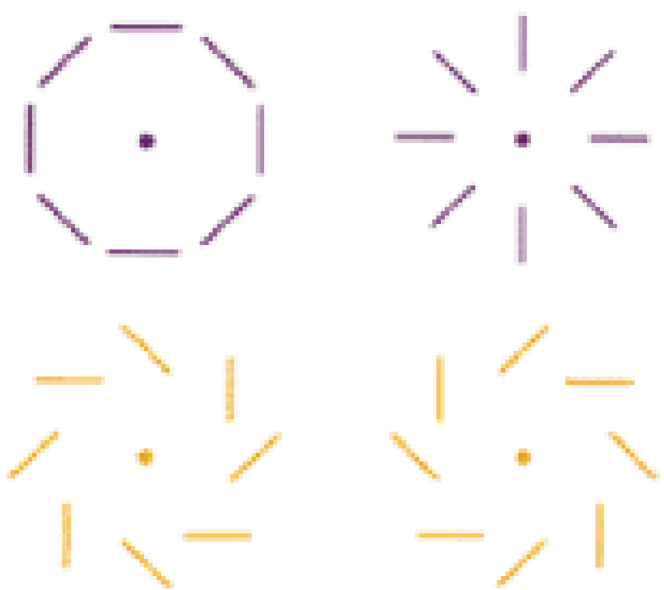
CMB Polarization

- **Linear Polarization is described by Stokes-Q and -U**
- **These are coordinate dependent**
- **The two dimensional field is described by a gradient of a scalar (E) or curl of a pseudo-scalar (B).**

Temperature map: $T(\hat{n})$

Polarization map: $P(\hat{n}) = \nabla E + \nabla \times B$

Scalar perturbations: energy density perturbations in the plasma
Tensor perturbatons: Gravity waves stretch and squeeze space in orthogonal directions and stretch wavelength
Gravity waves coming from inflation would produce tensor perturbations

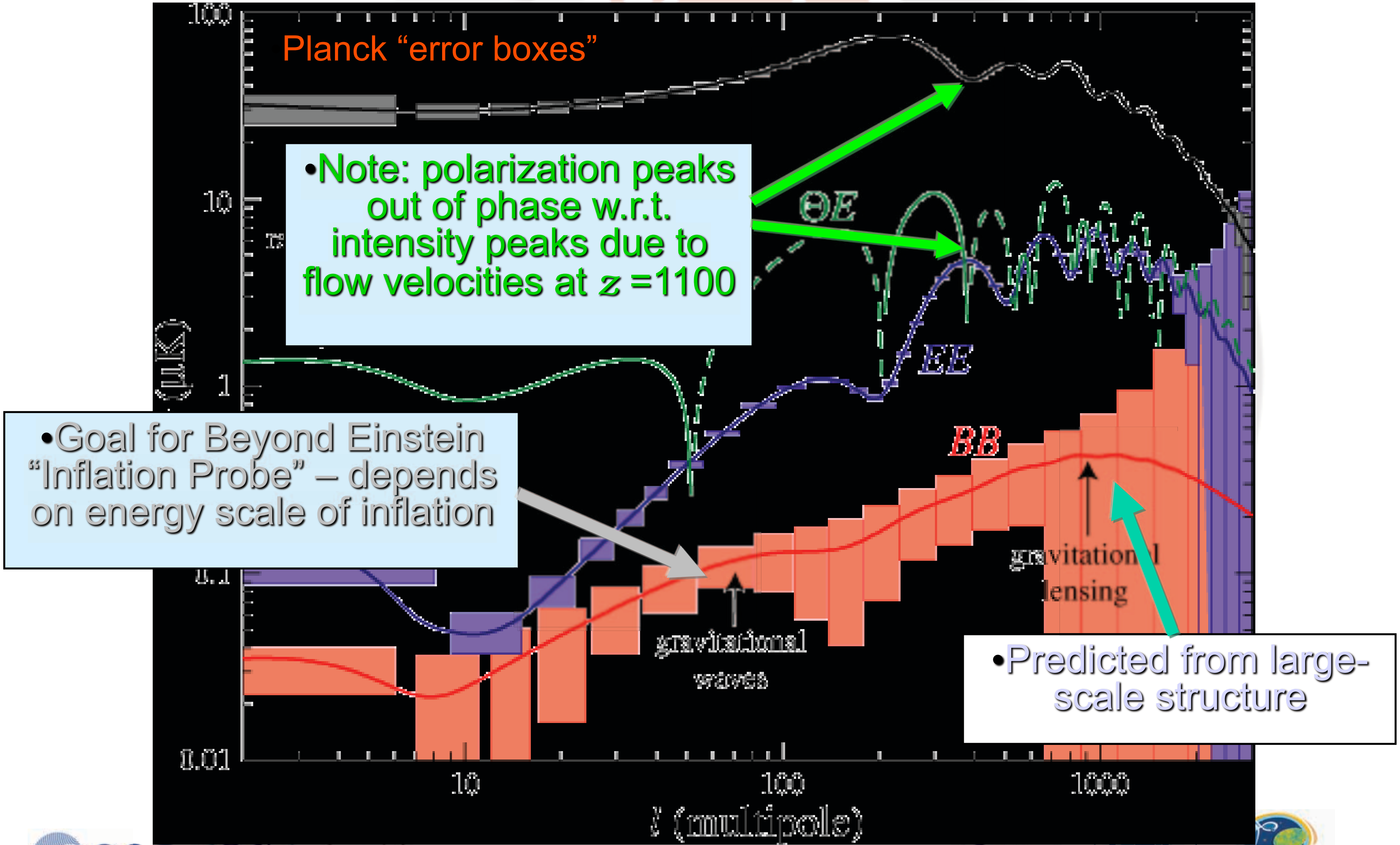


Grad (or E) modes
due to scalar and tensor perturbations

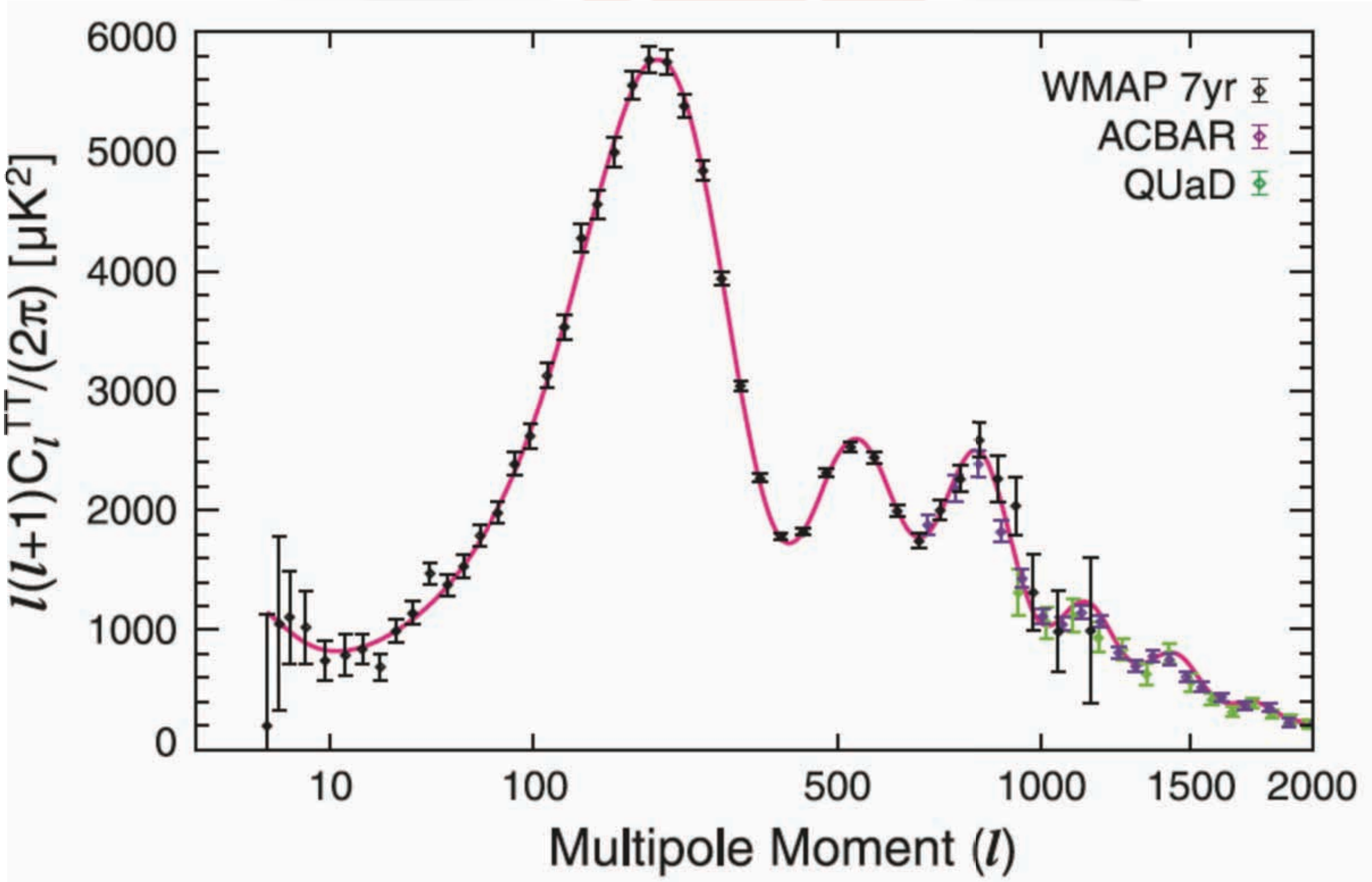
Curl (or B) modes
due to tensor perturbations

(density fluctuations have no handedness, so no contribution to B-modes).
B-Modes=Gravity Waves !!

Planck: Predicted Power Spectrum



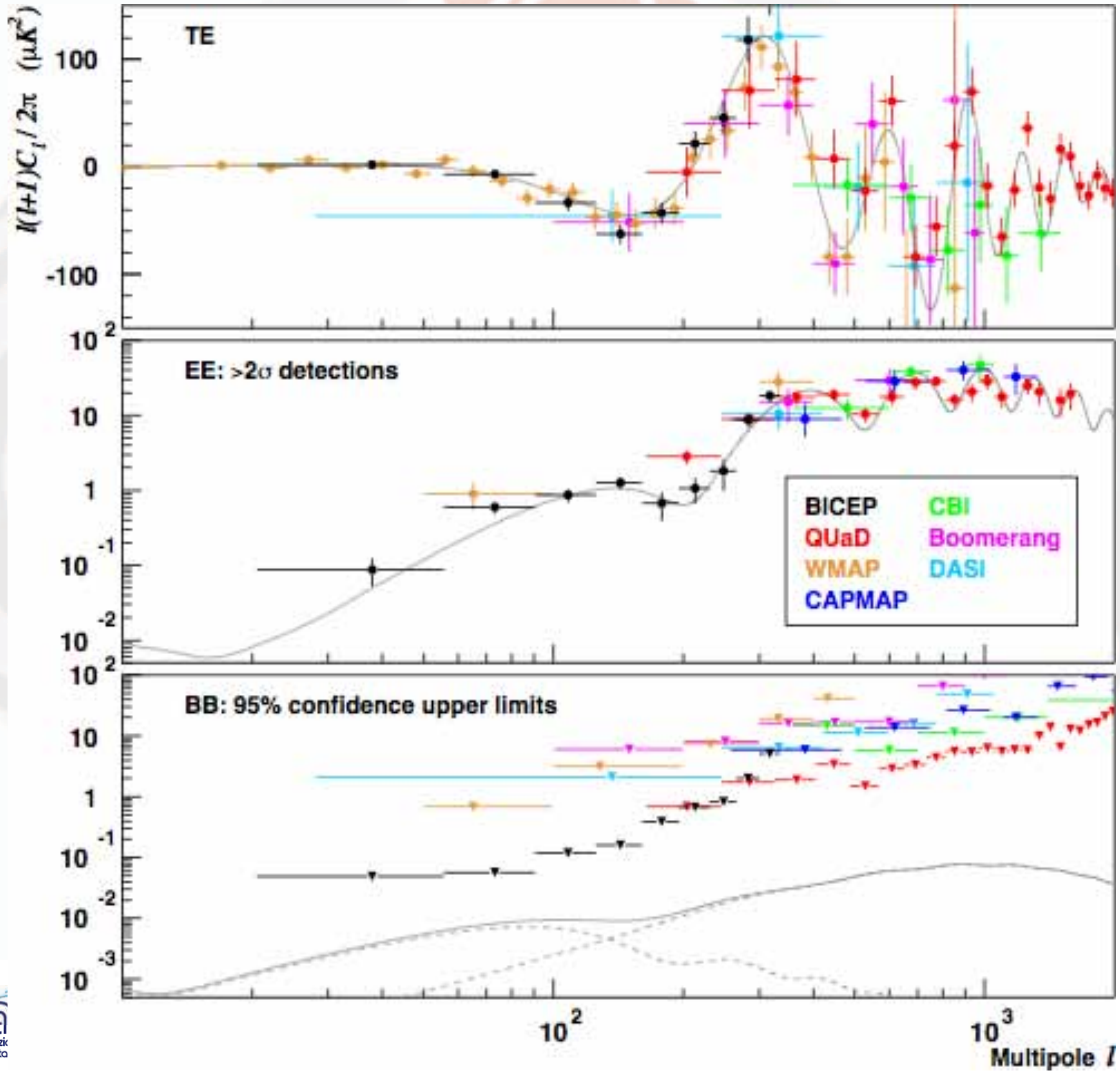
CMB Angular Power Spectrum



WMAP+ 7yr TT power spectrum (Komatsu et al. 2010)

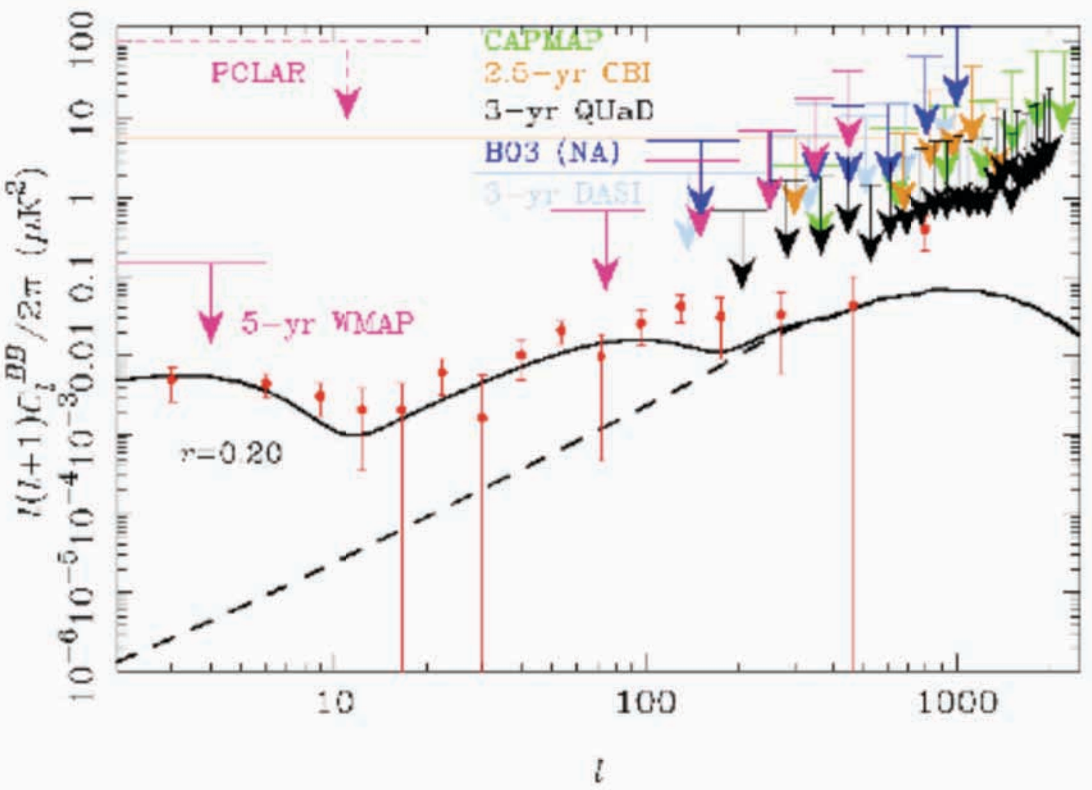
•Courtesy WMAP Science Team

Current Status - 6/2009



B-modes: present limits

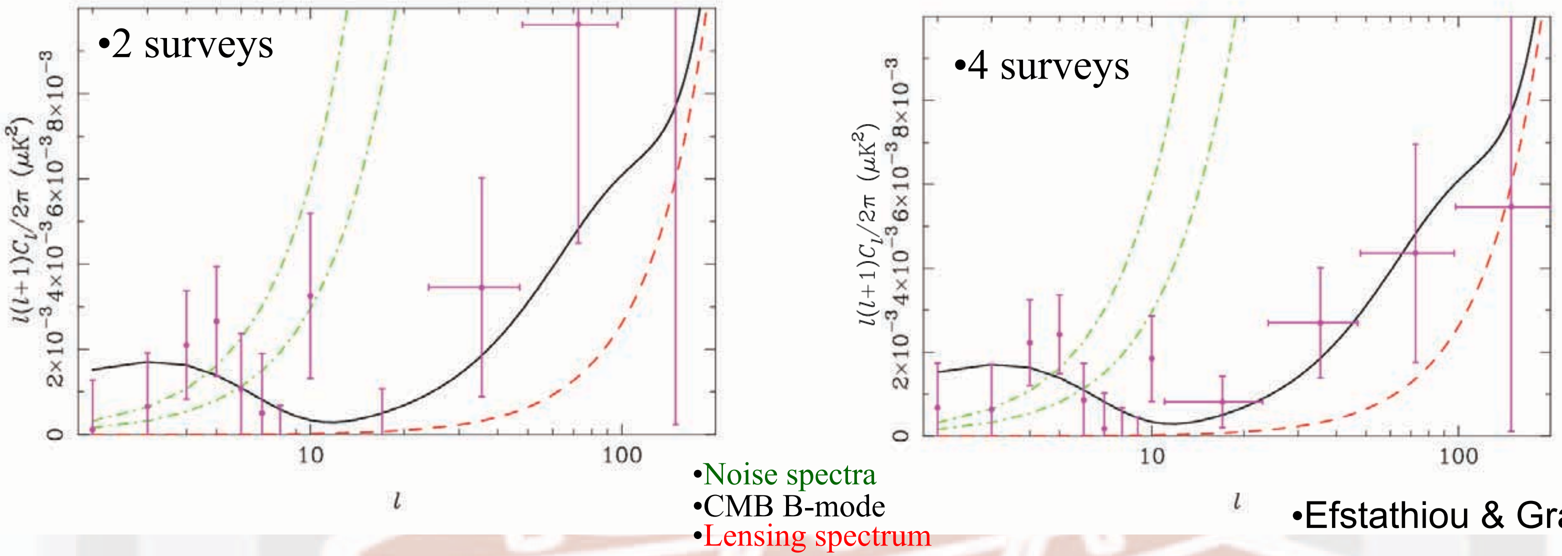
•Present best direct upper limit is 0.3 one sigma (Bicep: Chiang et al 2009)



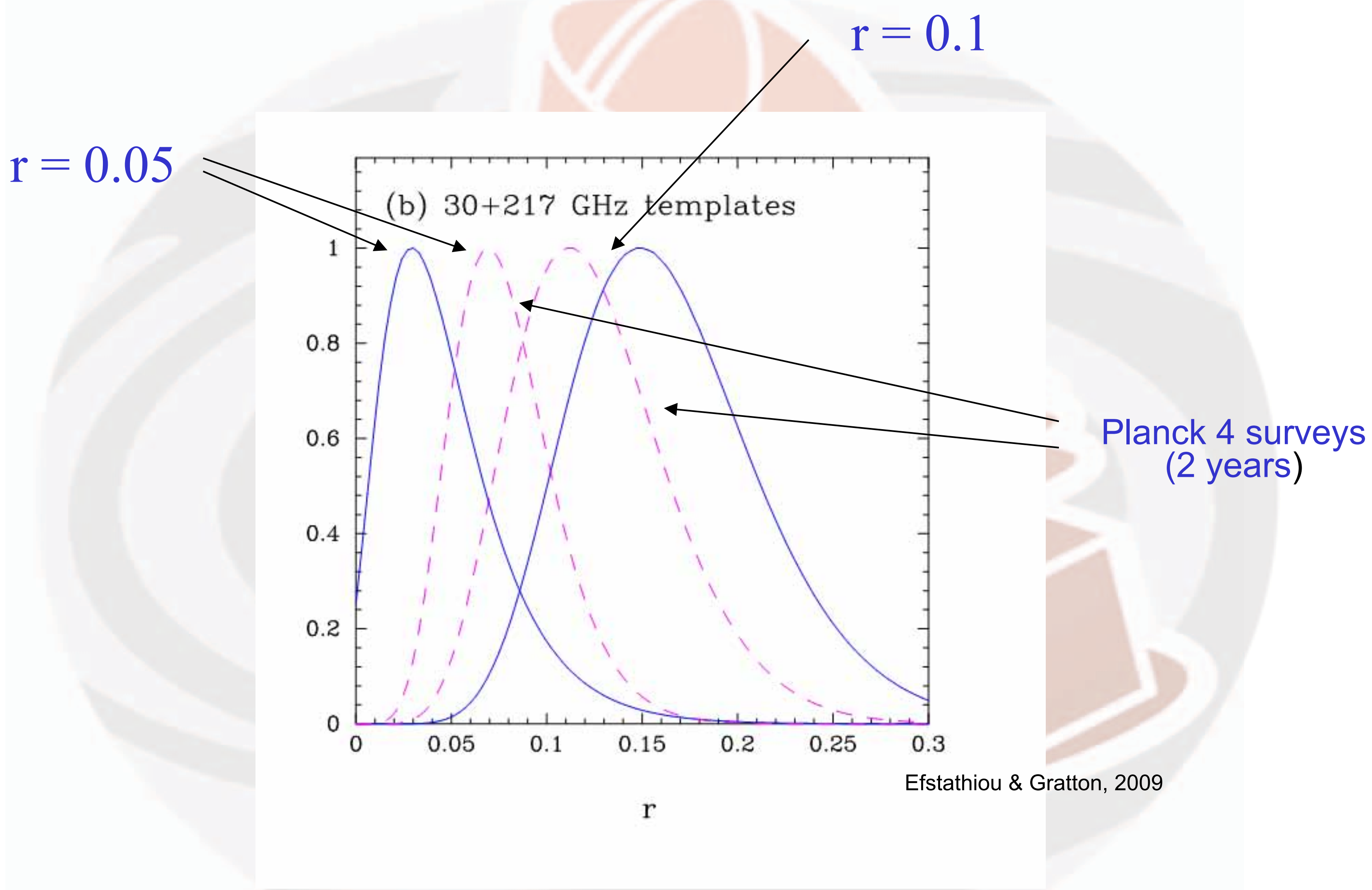
George Efstathiou 19

European Space Agency

•B-mode detectability



•Efstathiou & Gratton 2009


r = 0.1
r = 0.05
(b) 30+217 GHz templates
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
r
Planck 4 surveys
(2 years)
Efstathiou & Gratton, 2009

Acknowledgments

It is difficult to thank individually every single person (ESA, Industries, Funding Agencies, scientists, engineers, managers, technical staff in our Institutesand Universities; all over more than 1000 people) who has been deepley involved in Planck in the past 18 years, but we should always remember everyone with deep gratitude.

The scientific results that have been presented yesteray 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 -- ESA -- 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.

The Planck Sky: results and perspectives

Bologna, 13 -17 February 2012