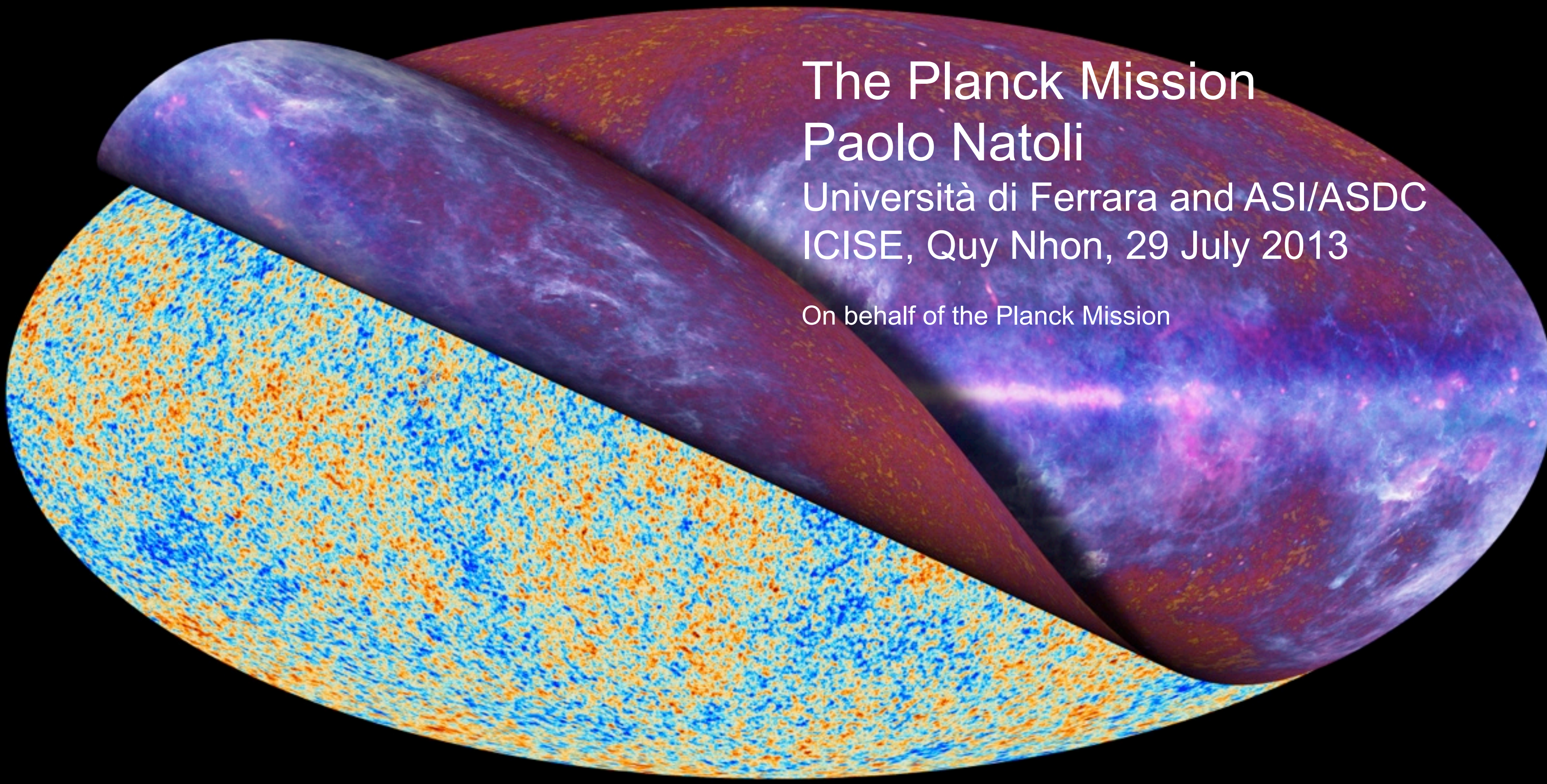
The Planck Mission

Paolo Natoli

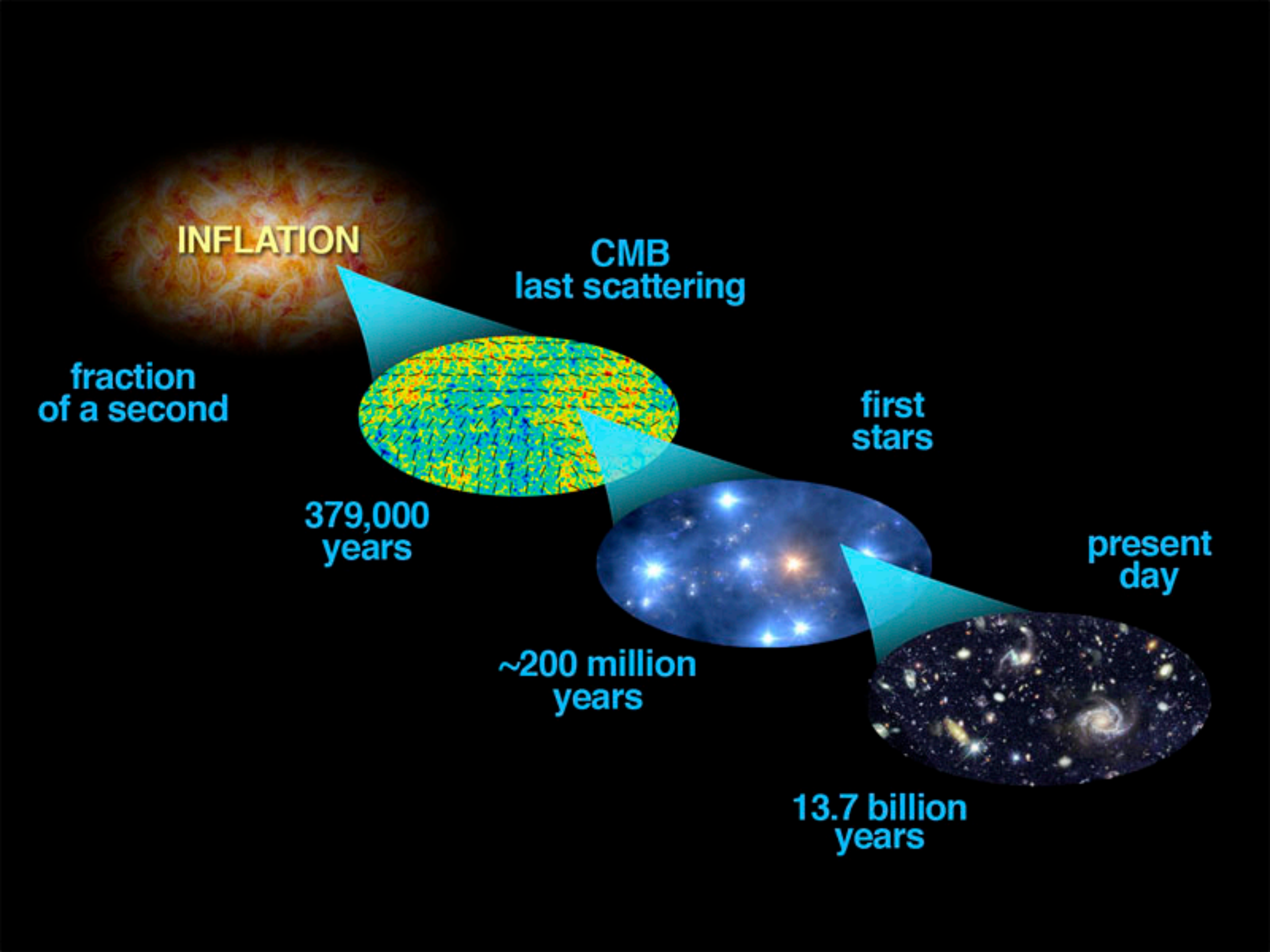
Università di Ferrara and ASI/ASDC

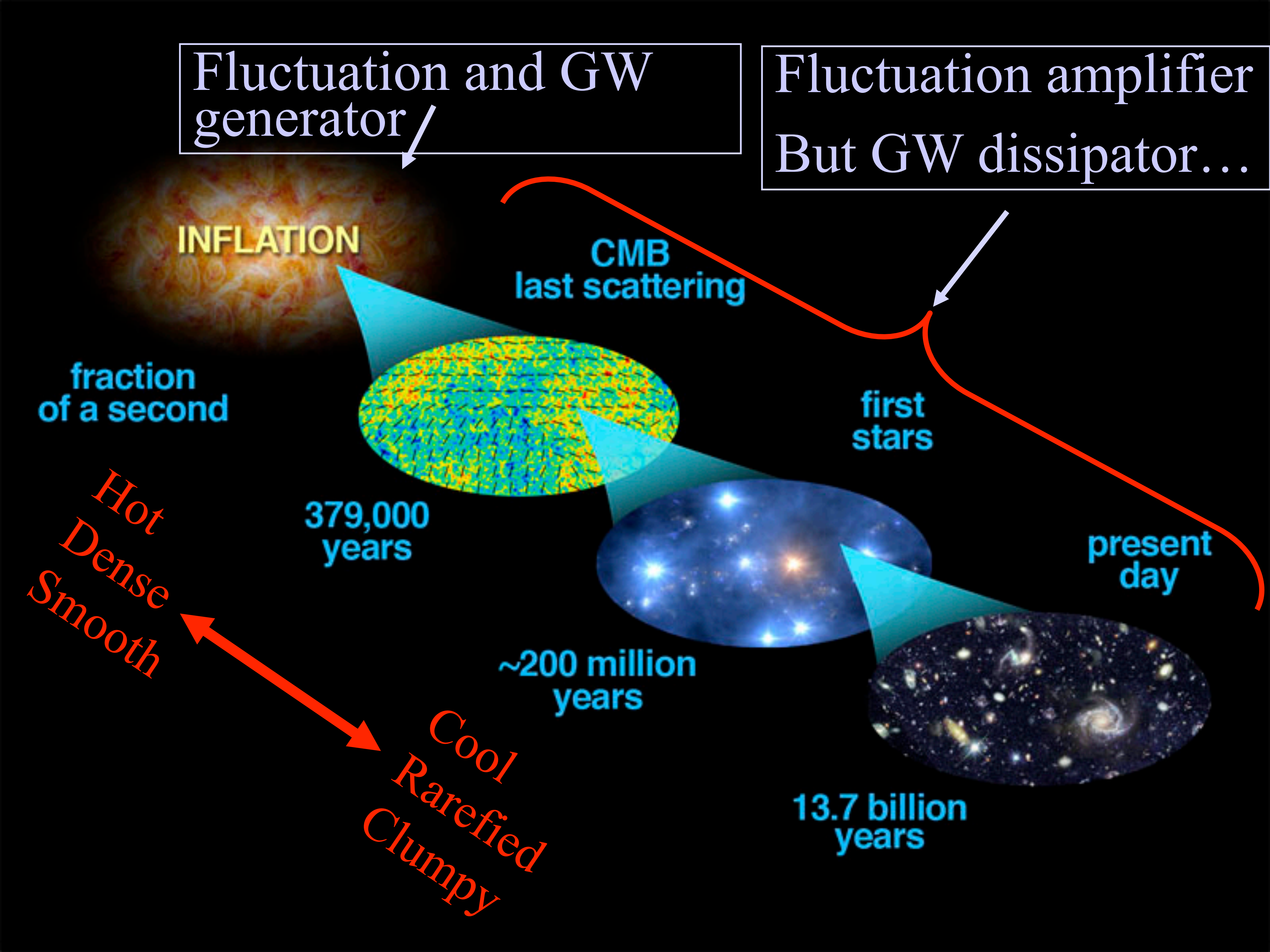
ICISE, Quy Nhon, 29 July 2013

On behalf of the Planck Mission



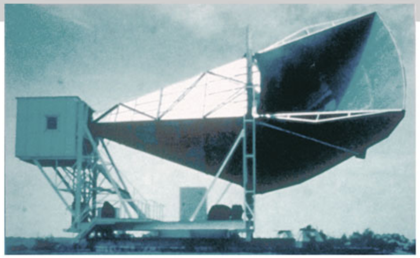
Planck unveils the Cosmic Microwave Background

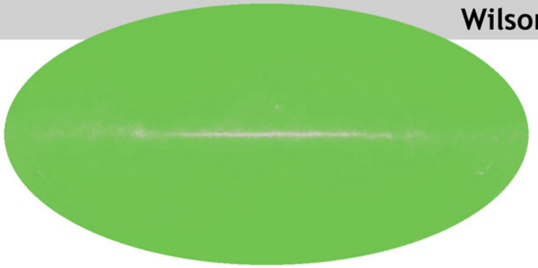

INFLATION
fraction
of a second
CMB
last scattering
379,000
years
first
stars
~200 million
years
present
day
13.7 billion
years


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

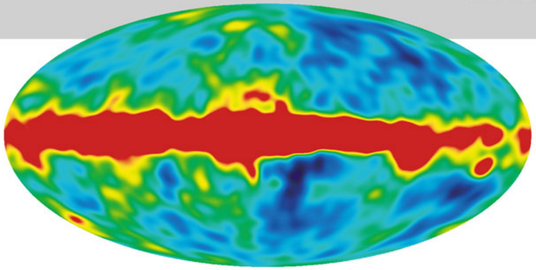
Cosmic Microwave Background Radiation Overview

1965 — Penzias and Wilson

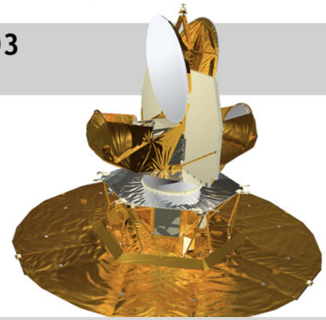


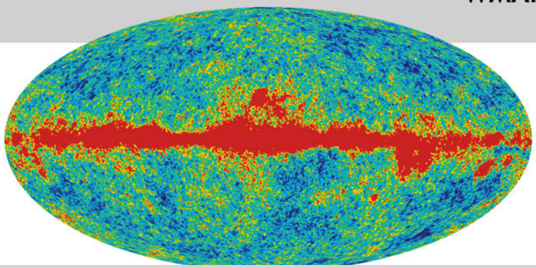


1992 — COBE

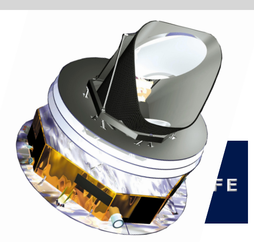


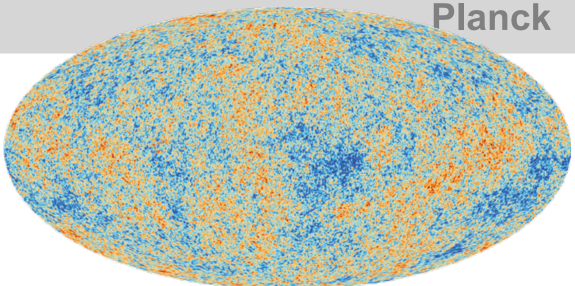
2003 — WMAP





2009 — Planck





The oldest light or the first light of the Universe

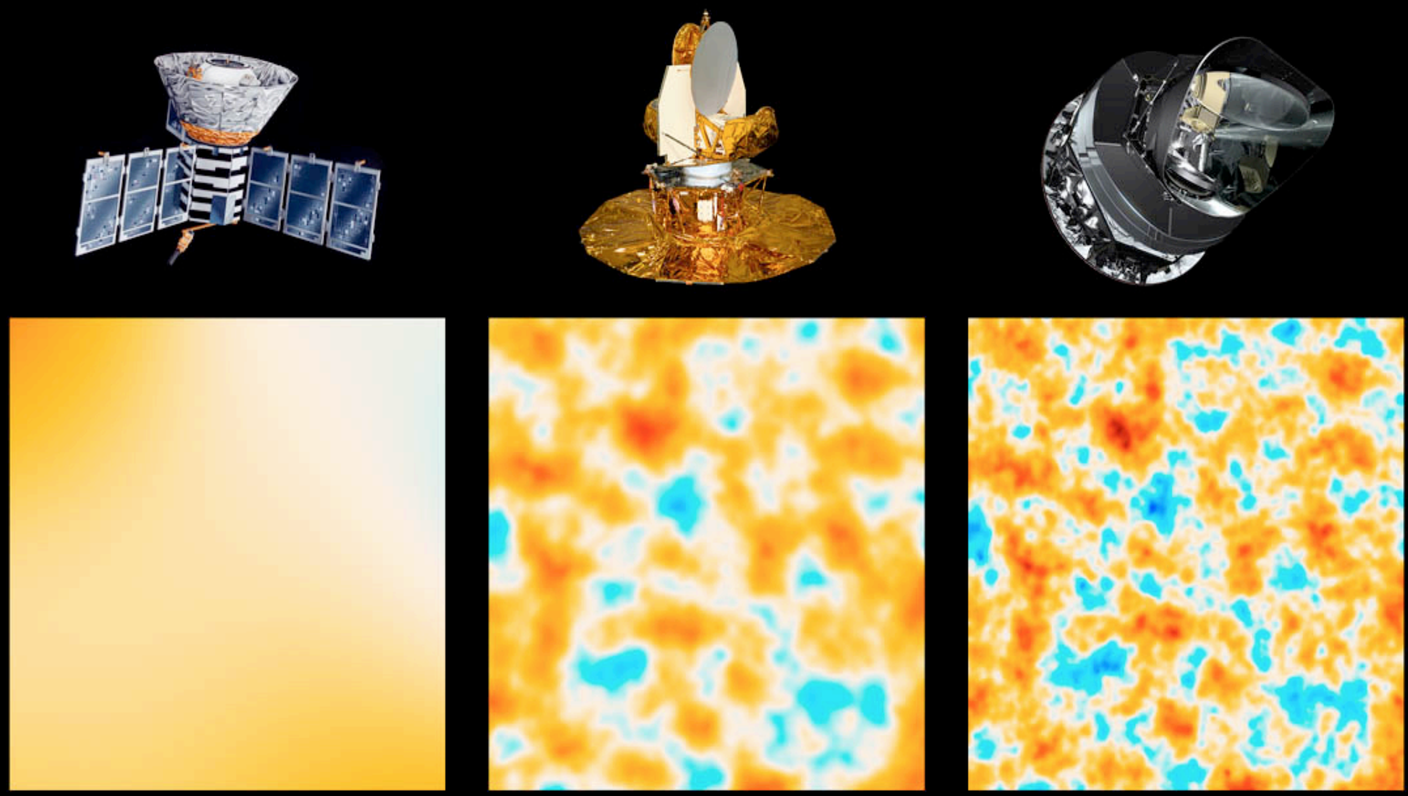
Discovered the remnant afterglow from the **Big Bang**.
→ **2.7 K**

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

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

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

Comparison with forerunners

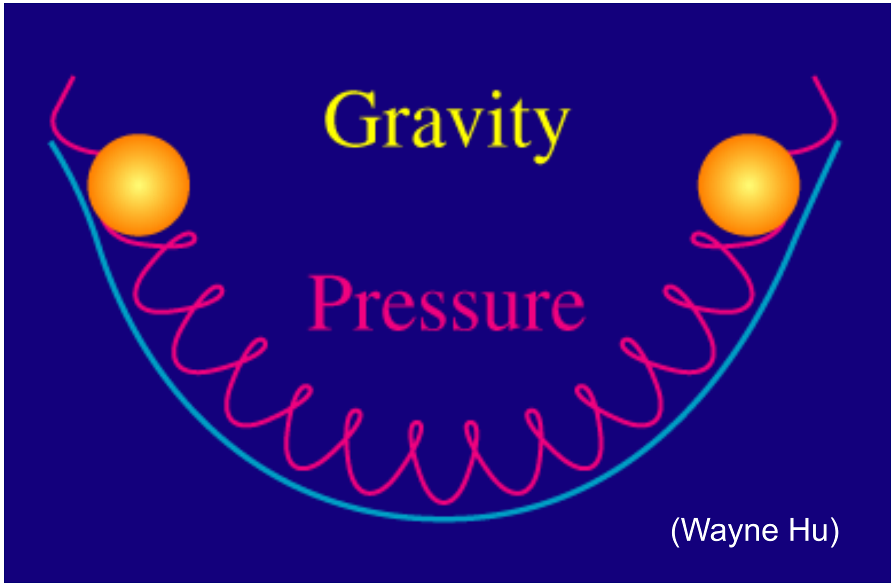


COBE WMAP Planck

Evolution of cosmological perturbations

The overdensities in the baryon-photon fluid collapse under the influence of gravity, until the pressure is strong enough to resist. Then the plasma starts to oscillate, until recombination.

We therefore see (mostly) the oscillation pattern at t_{rec}!

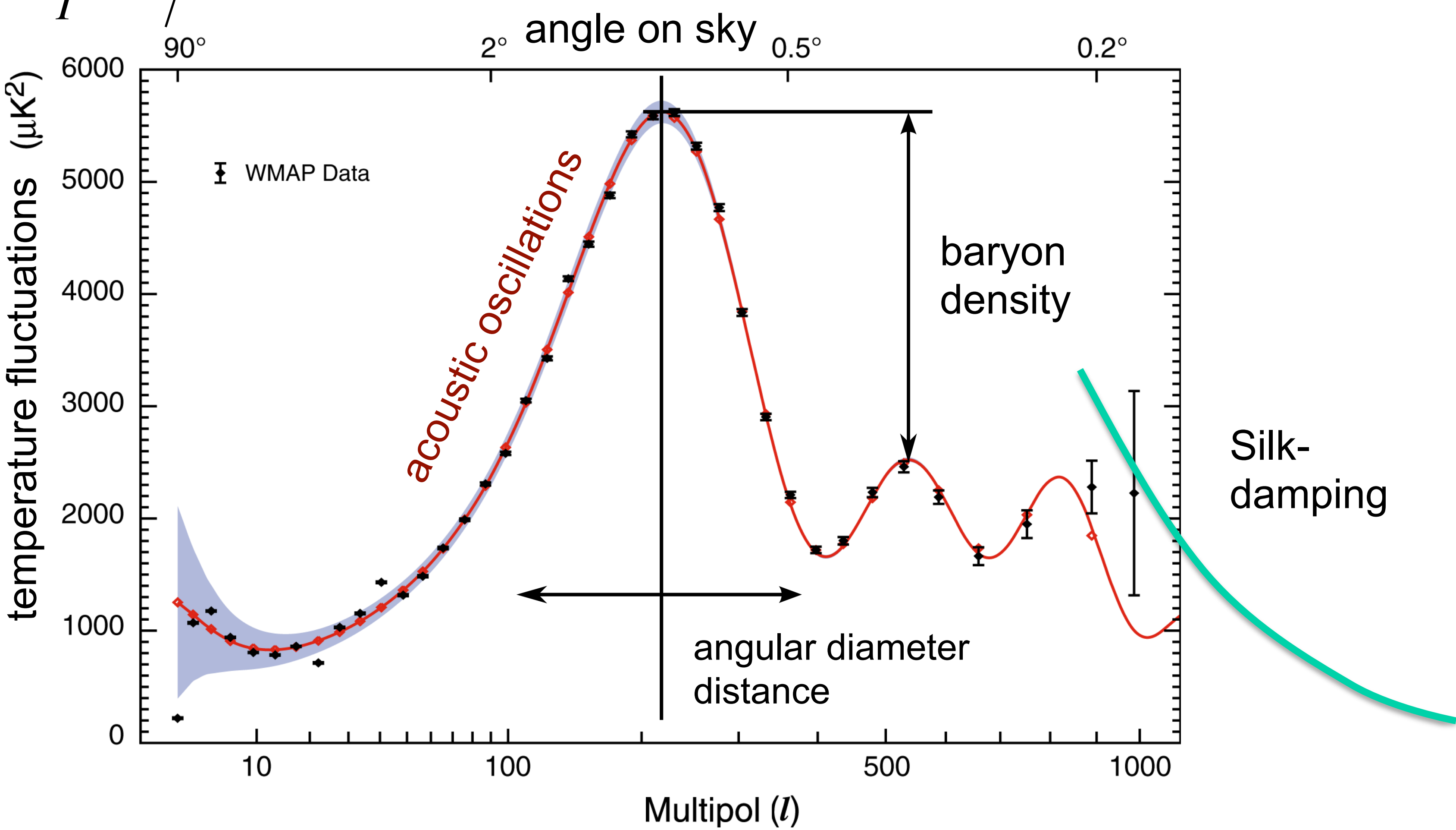


The largest scale that had just time to collapse will create the first peak, the scale that collapsed and re-expanded the second peak, etc.
→ **angular diameter distance to z=1100!**

(Photons are also affected by physics on the way to us, like time-evolving potentials, lensing, and other things.)

The CMB power spectrum

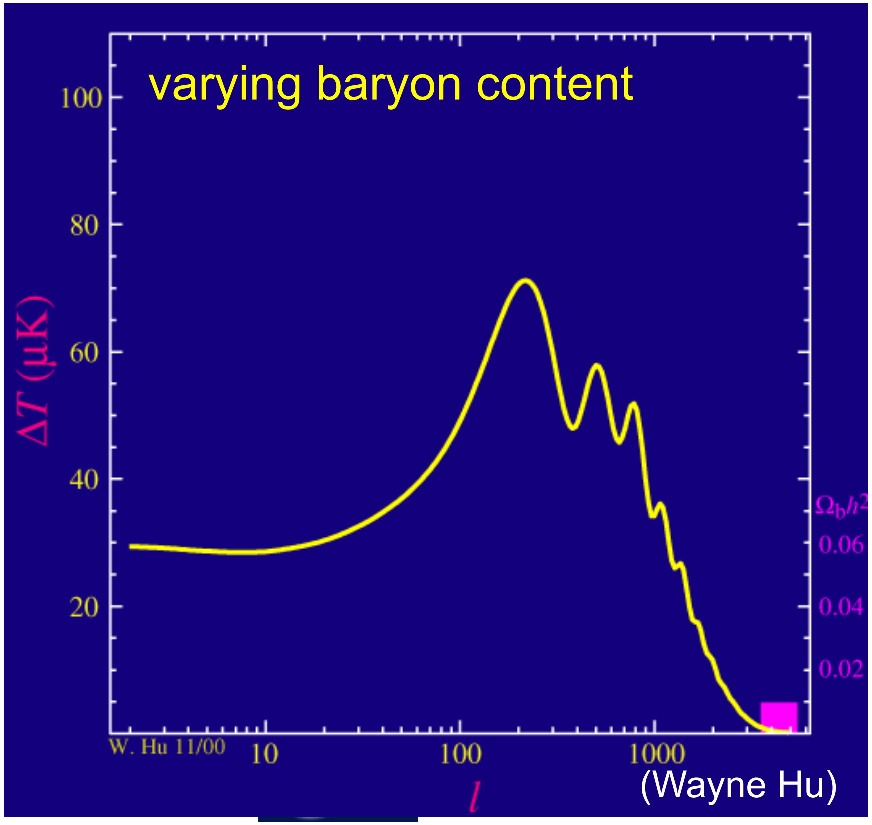
$$\left\langle \frac{\Delta T}{T}(\vec{\gamma})\frac{\Delta T}{T}(\vec{\gamma}')\right\rangle:$$ Two-point correlation function seen in Fourier space

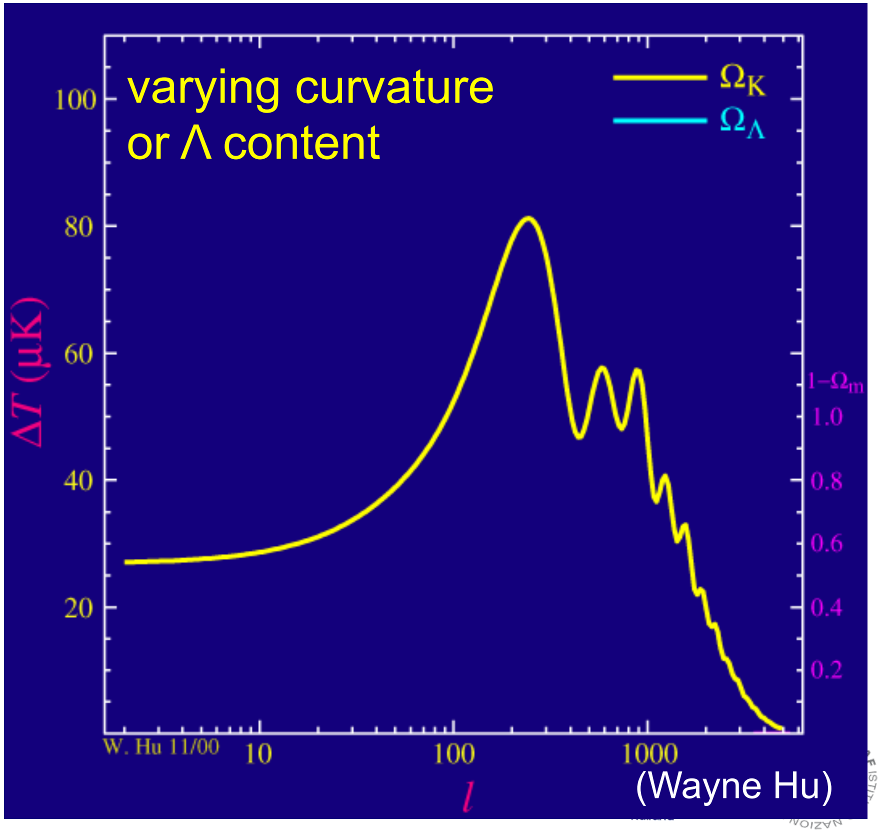


CMB physics is mostly linear -> very clean probe!

measuring cosmological parameters

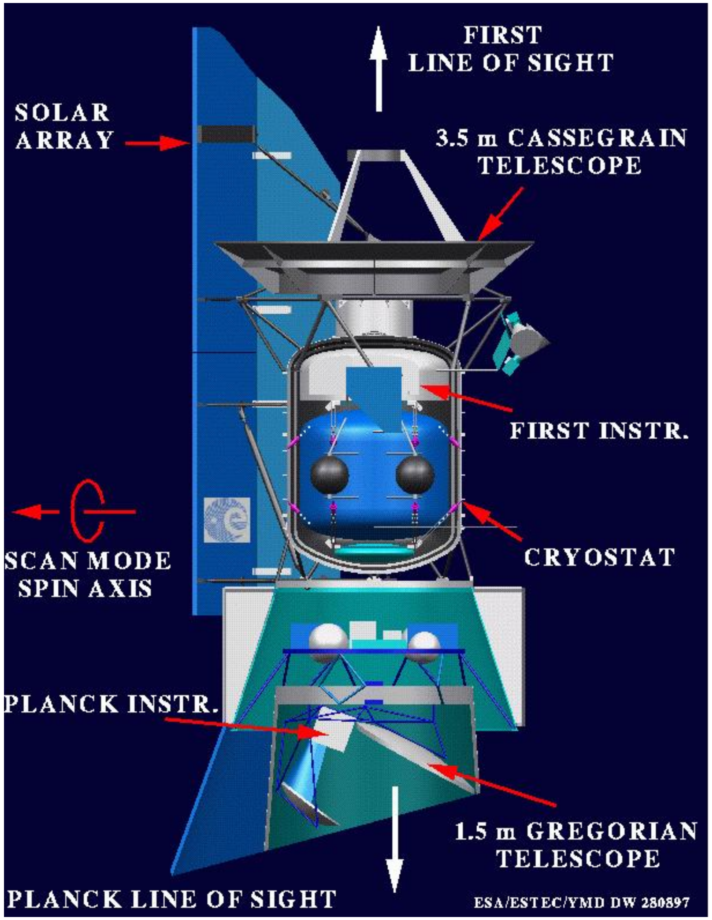
The CMB fluctuations depend on the values of the parameters
→ we just vary all of them to find the best values





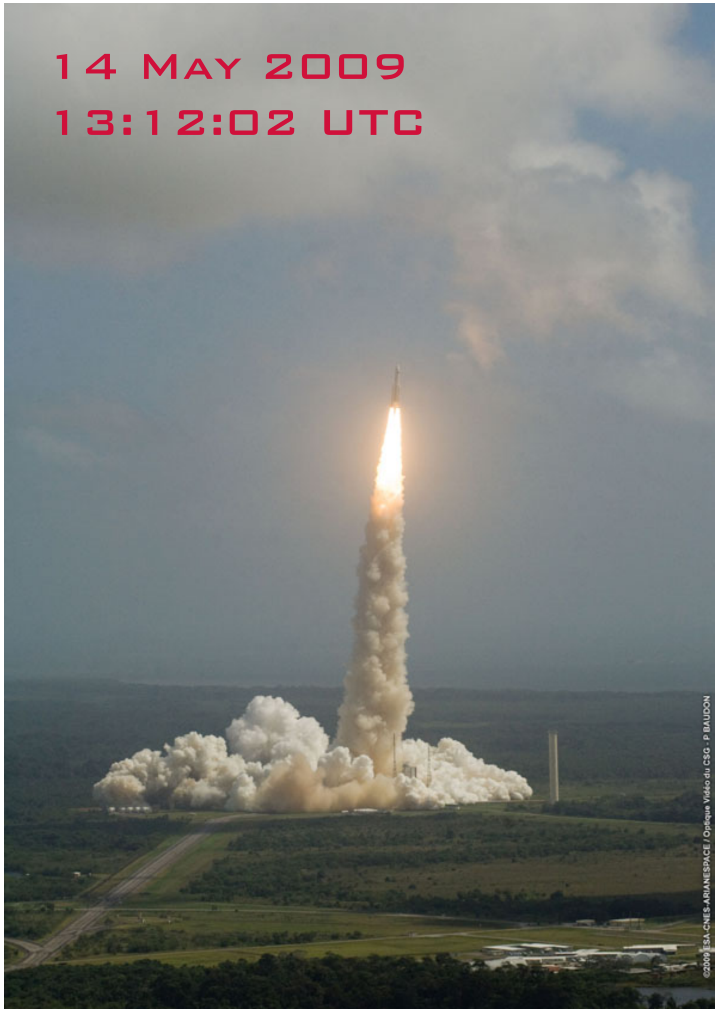
A brief history of Planck

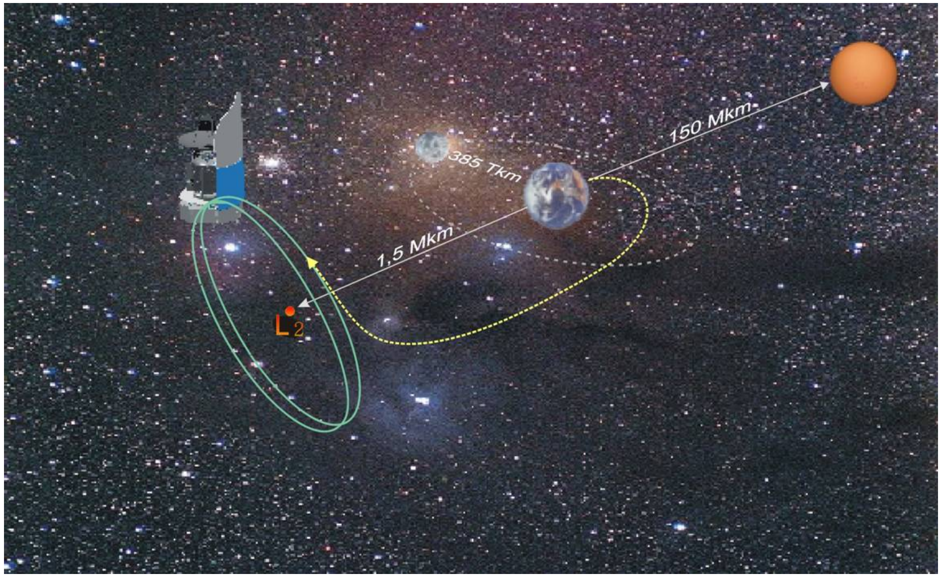
- **1993**: COBRAS & SAMBA proposals for M3 Horizon launch slot [**2003**]
- (1995: WMAP proposed to NASA)
- **1996**: selection of COBRAS/SAMBA, then named Planck [**2004**]
- **1997**: instrument AO [**2006**]
- **1998**: ESA runs into financial difficulties, FIRST/Planck studies [**2007**]
- (2001 WMAP launch)
- … lots of work …
- **2009** Planck **launch** [**2009**]

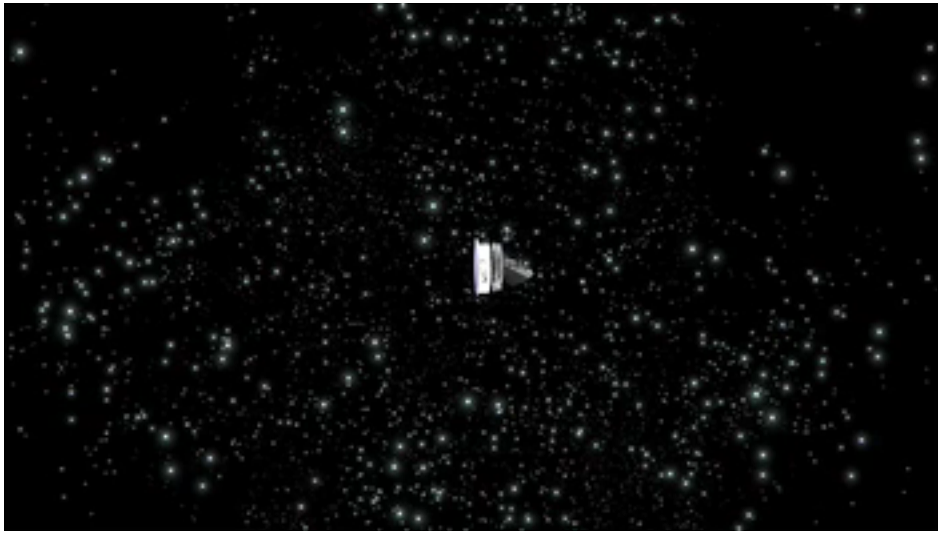


the Planck mission

planck







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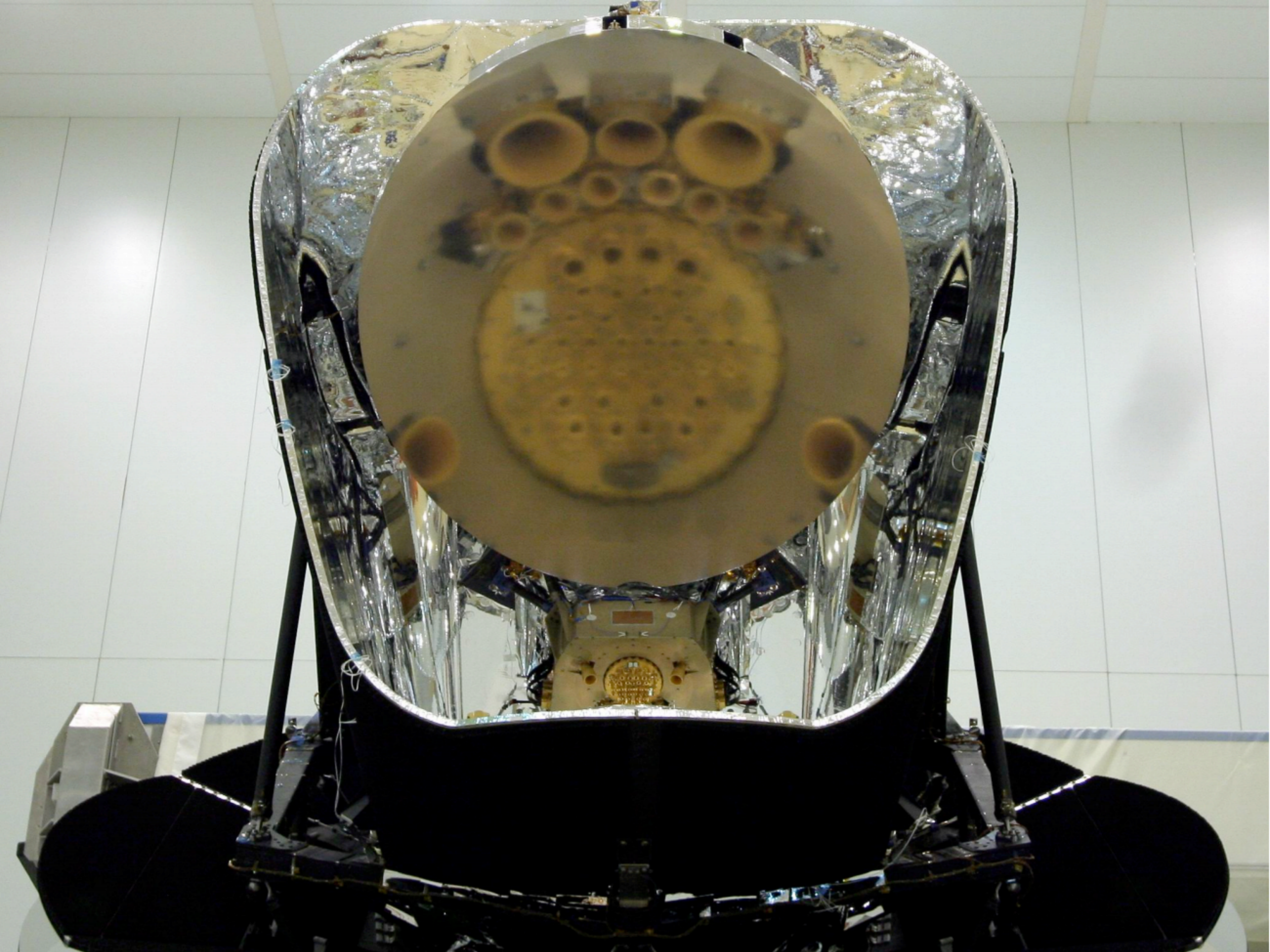
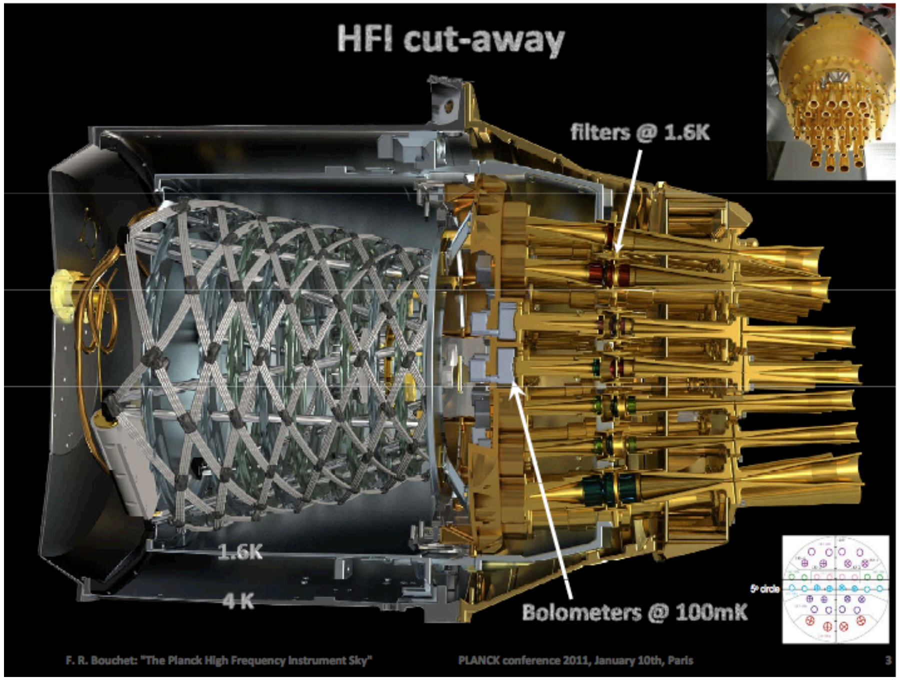
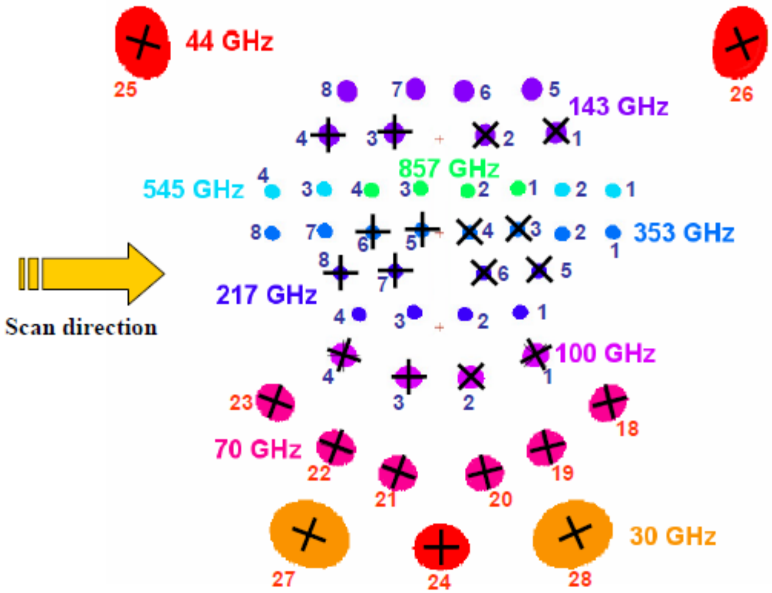
Agency


NORD



the Planck focal plane

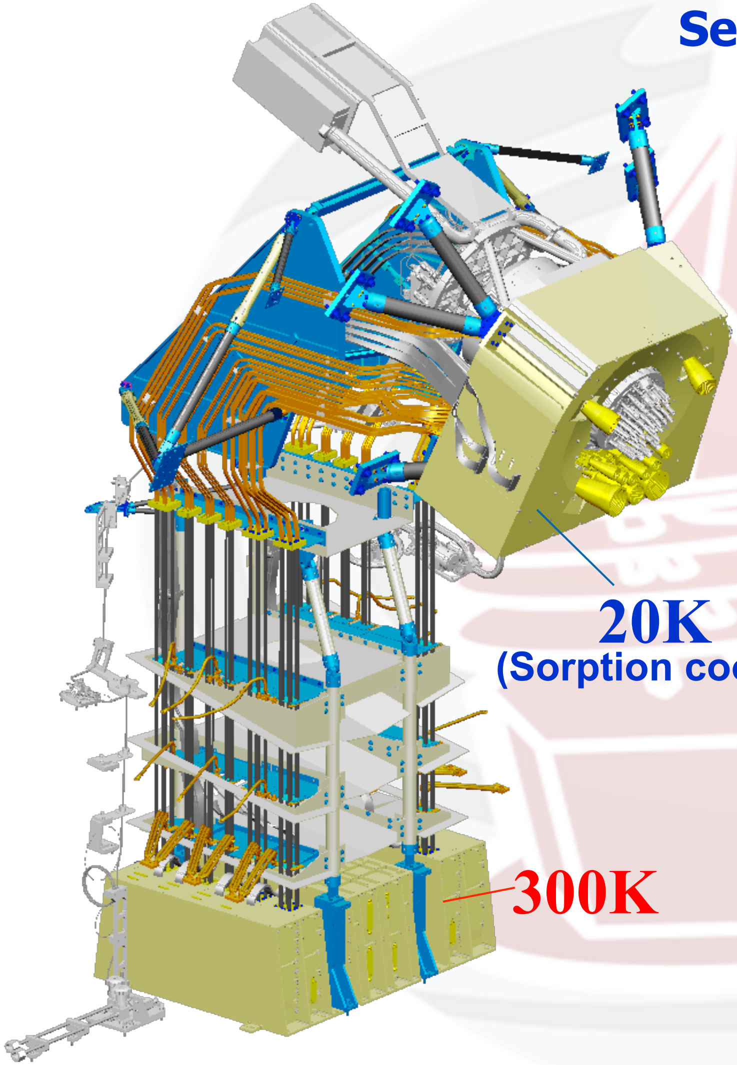




PLANCK	LFI			HFI					
Center Freq (GHz)	30	44	70	100	143	217	353	545	857
Angular resolution (FWHM arcmin)	33	24	14	10	7.1	5.0	5.0	5	5
Sensitivity in I [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	2.7	2.6	2.6	1.0	0.6	1.0	2,9		
Sensitivity in Q or U [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	4.5	4.6	4.6	1.8	1.4	2.4	7.3		

Planck-LFI: the Instrument

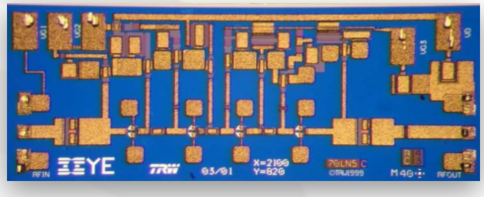
Sensitivity, stability & low systematics



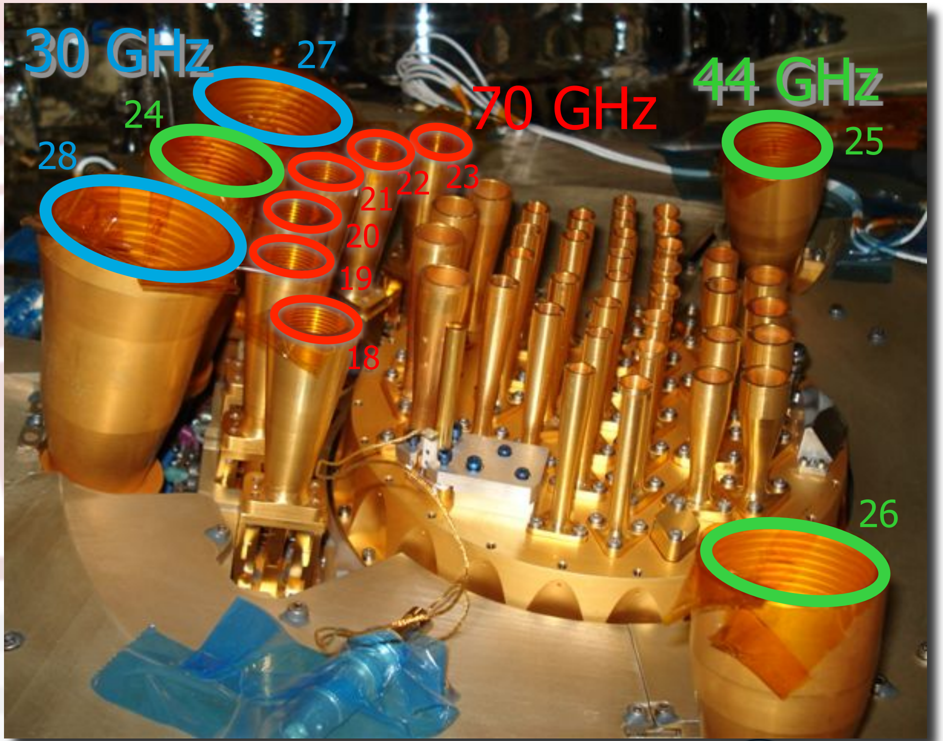
(MB et al 2010, Mandolesi et al 2010)

Sensitivity ($\Delta T/T \sim 3 \times 10^{-6}$/pix)

- State-of-the-art InP LNA technology
- Cryo operation
  20K Sorption Cooler
- 22-element array

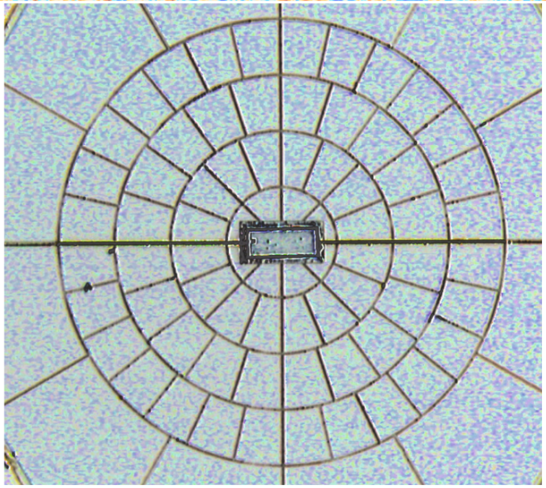


70 GHz MMIC HEMT



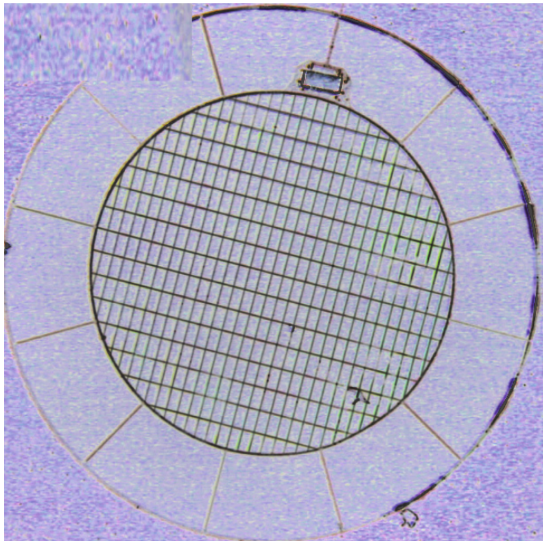
the Planck detectors

planck



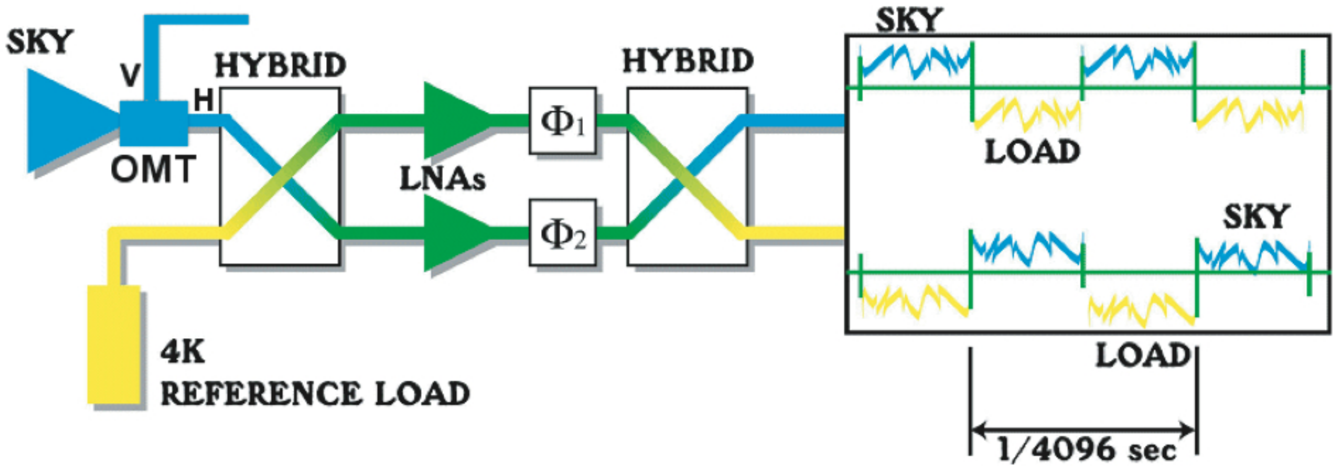
HFI
spiderweb
bolometers

4x 143GHz
4x 217GHz
4x 353GHz
4x 545GHz
4x 857GHz



HFI
polarisation
bolometers

8x 100GHz
8x 143GHz
8x 217GHz
8x 353GHZ

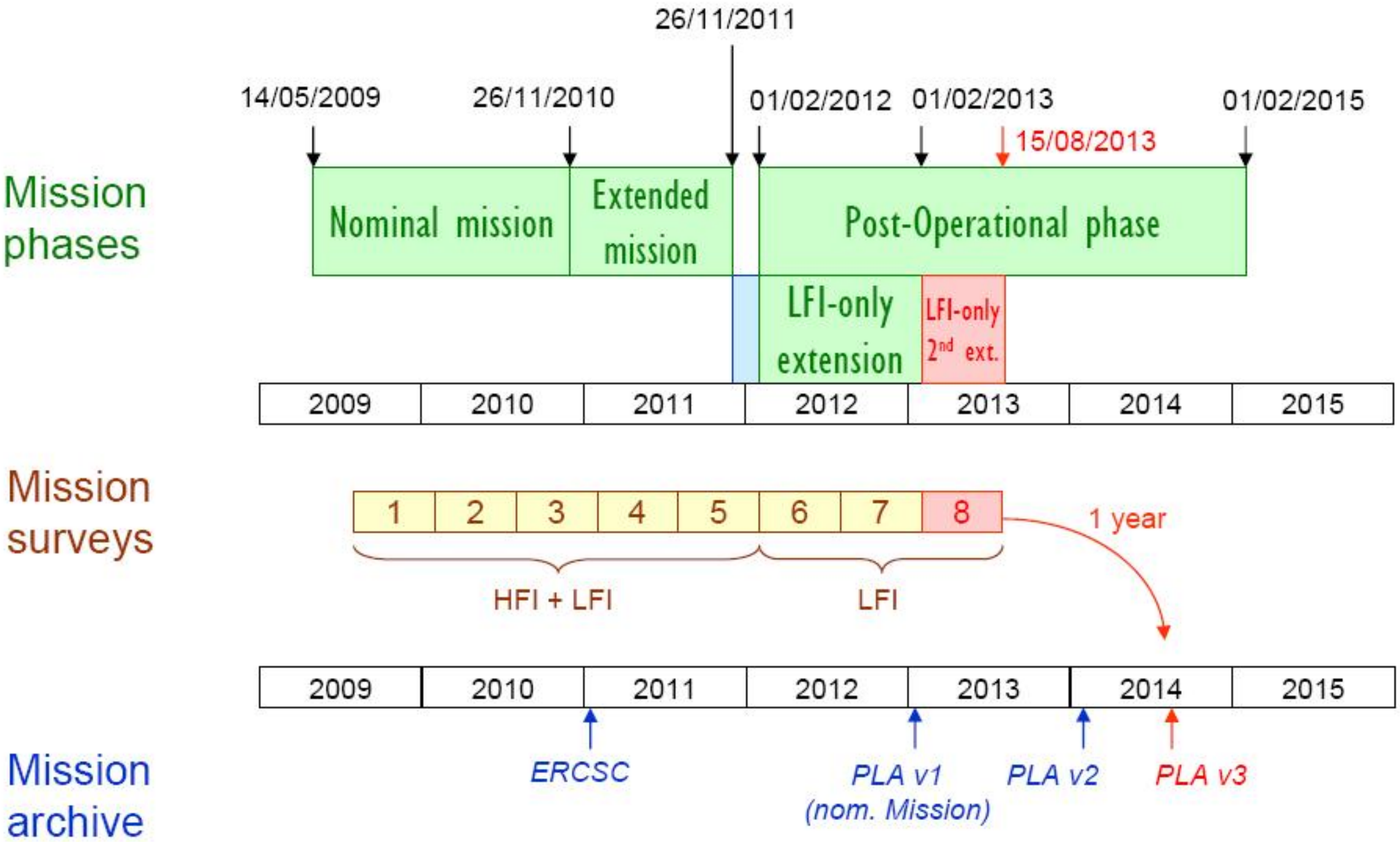


LFI
high-electron
mobility
transistors

2x 30GHz
3x 44GHz
6x 70GHz

operational timeline

planck



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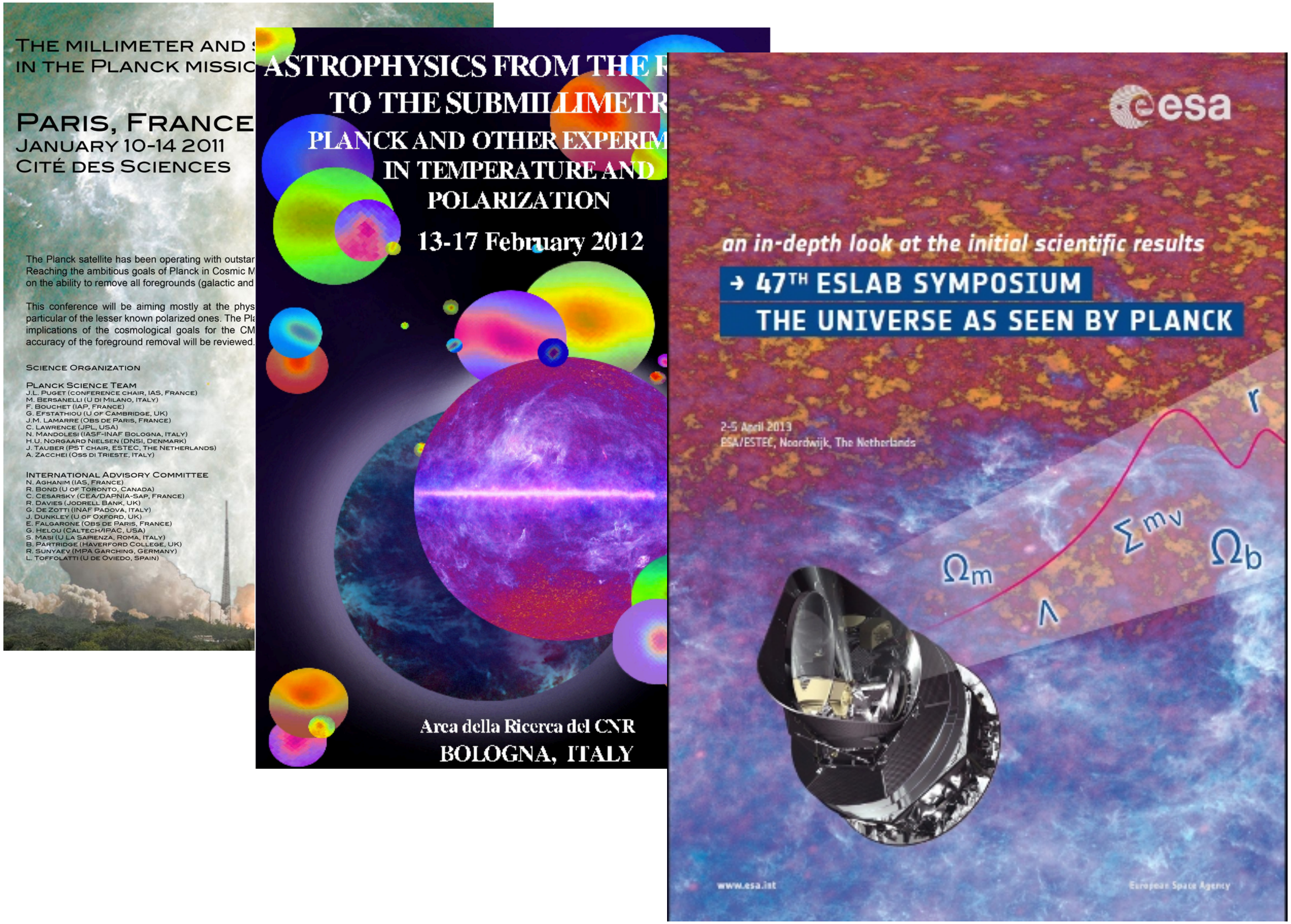
European Space Agency

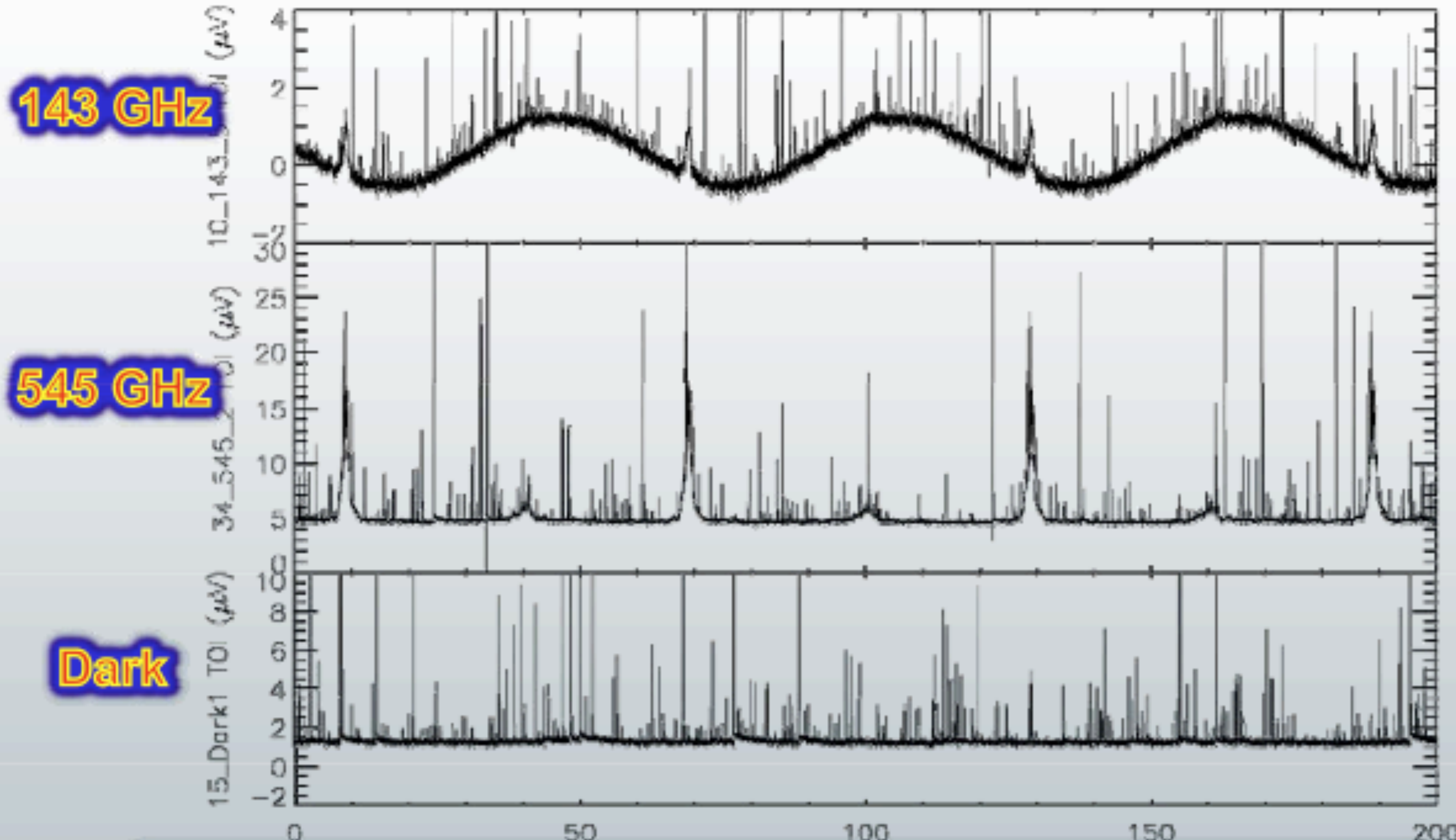


29 "Planck Cosmology" papers delivered on March 21, 2013
~ 1000 pages all together + several Gb of data!

FINANCIAL TIMES
Dimon's not forever
Cyprus unveils fresh rescue plan
The universe
New view of oldest light in the sky
Existing homeowners can take advantage of Help to Buy scheme
Rugby Academy
Cricket Academy
FT Health
International Herald Tribune
Kurd leader issues a call for cease-fire with Turkey
Obama asks Israelis and Palestinians to talk again
Once rarity, women are U.S. Senate force

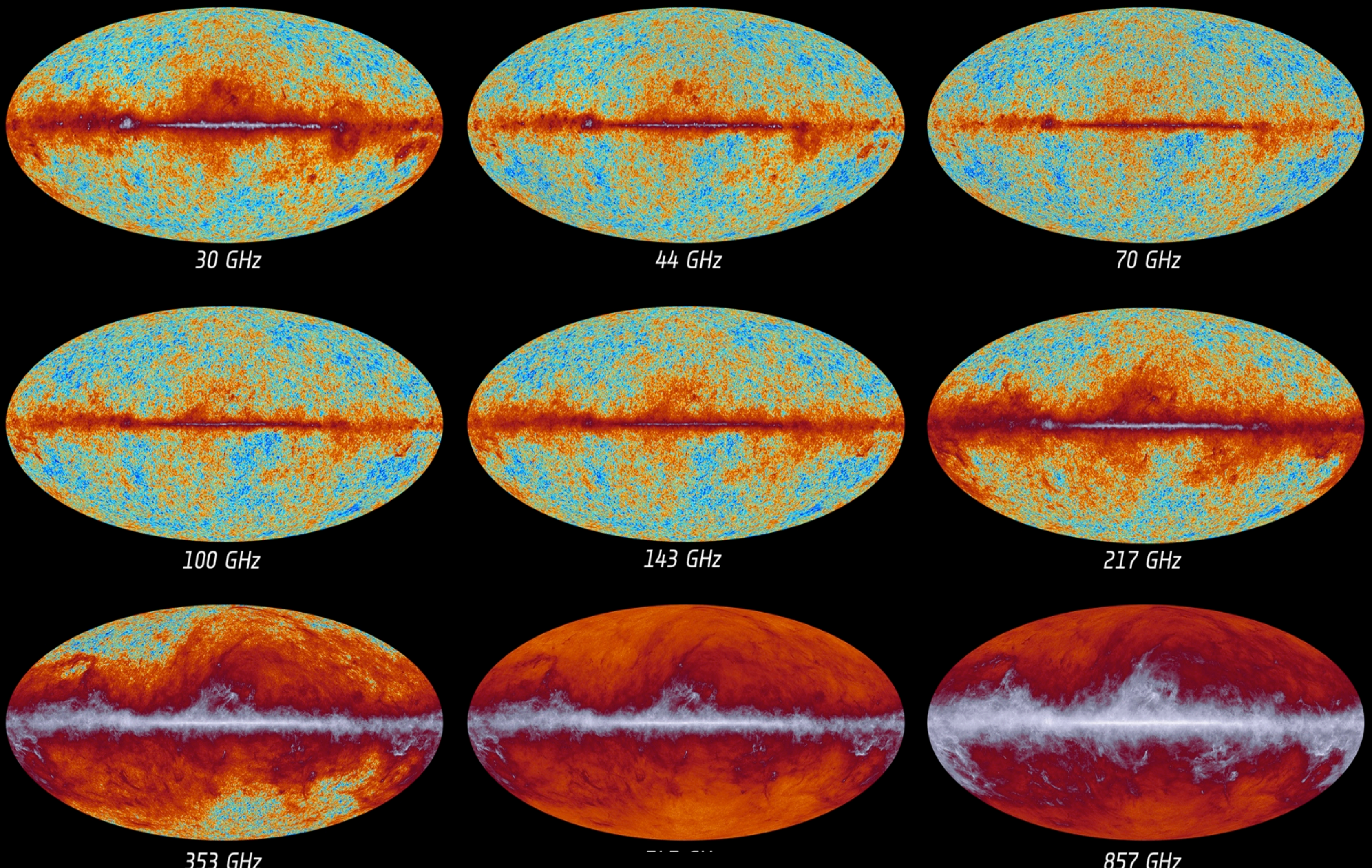
"All the News That's Fit to Print"
The New York Times
Late Edition
VOL. CLXII . . . No. 56,043
NEW YORK, FRIDAY, MARCH 22, 2013
$2.50
PRESIDENT URGES ISRAELIS TO PUSH EFFORT FOR PEACE
APPEAL AIMED AT YOUNG
In Jerusalem, He Eases Stance on Settlement Halt Before Talks
The Cosmos, Back in the Day
Bronx Inspector, Secretly Taped, Suggests Race Is a Factor in Stops
Once Few, Women Hold More Power in Senate
Fast-Growing Brokerage Firm Often Tangles With Regulators
Mood Darkens in Cyprus Ahead of Bailout Deadline
O Revelations! Letters, Once Banned, Flesh Out Willa Cather
Cartier

(nearly) raw data stream



3 minutes of quasi 'raw" data (i.e. only demodulated).The Solar (cosmological) dipole is clearly visible at 145GHz with a 60 seconds period (the satellite rotates at 1 rpm), while the Galactic plane crossings (2 per rotation) are more visible at 545 GHz than at 143 GHz. The Dark bolometer sees no sky signal, but displays a similar population of glitches from cosmic rays.

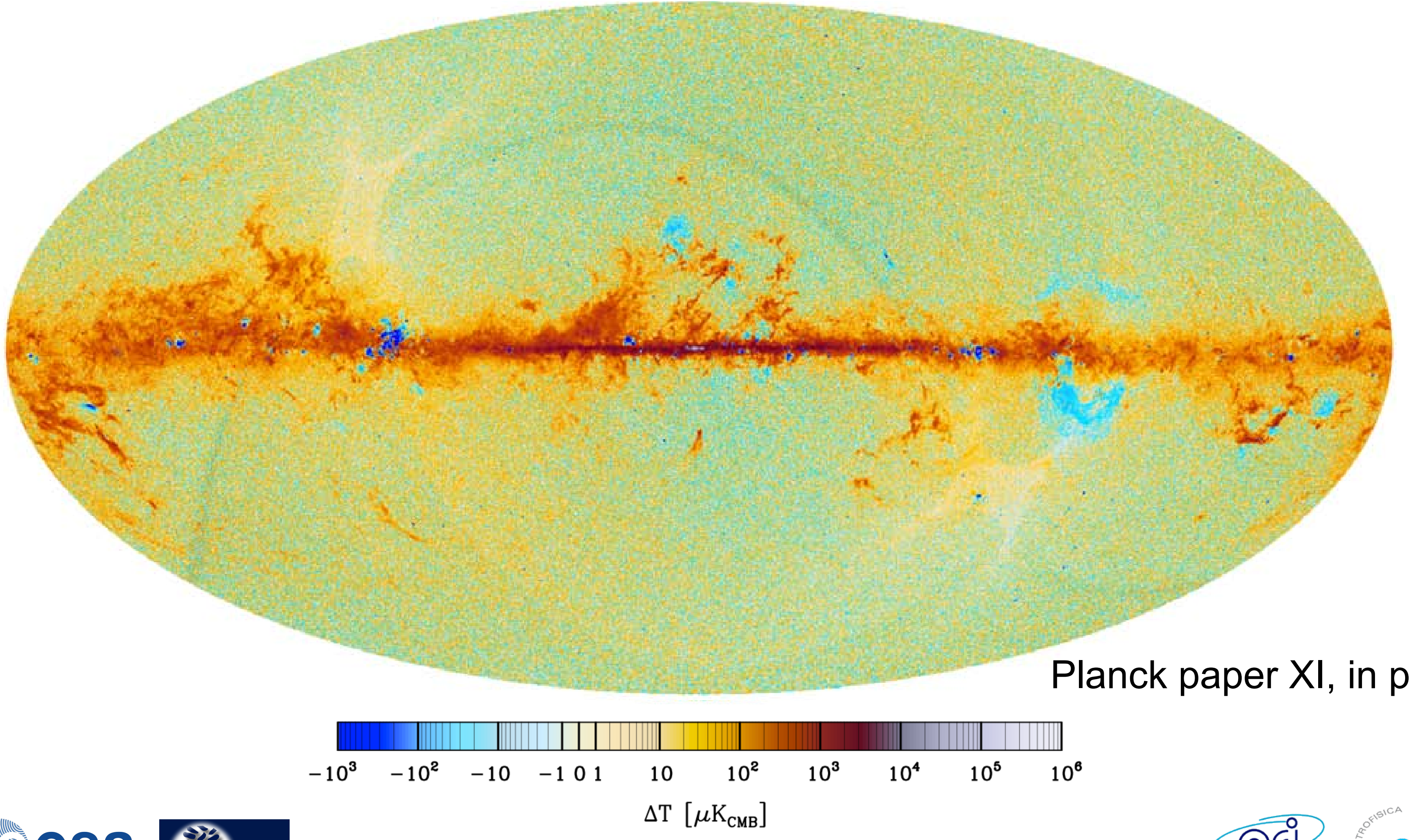
The sky as seen by Planck



See next talk by Maude le Jeune.

Consistency: HFI 100 GHz – LFI 70 GHz

Red is mostly CO, Blue is mostly free-free. CMB is gone!



Planck paper XI, in prep.

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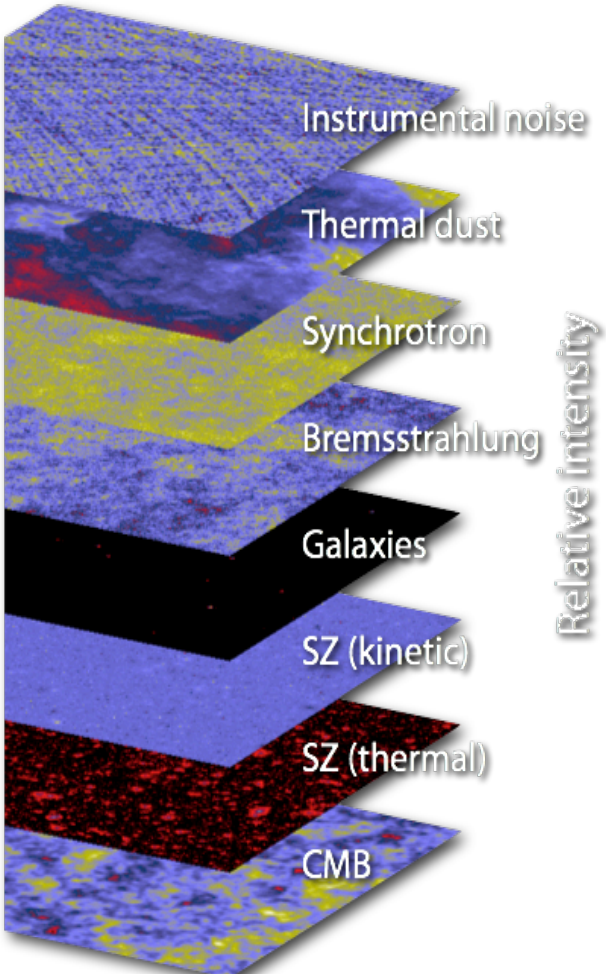
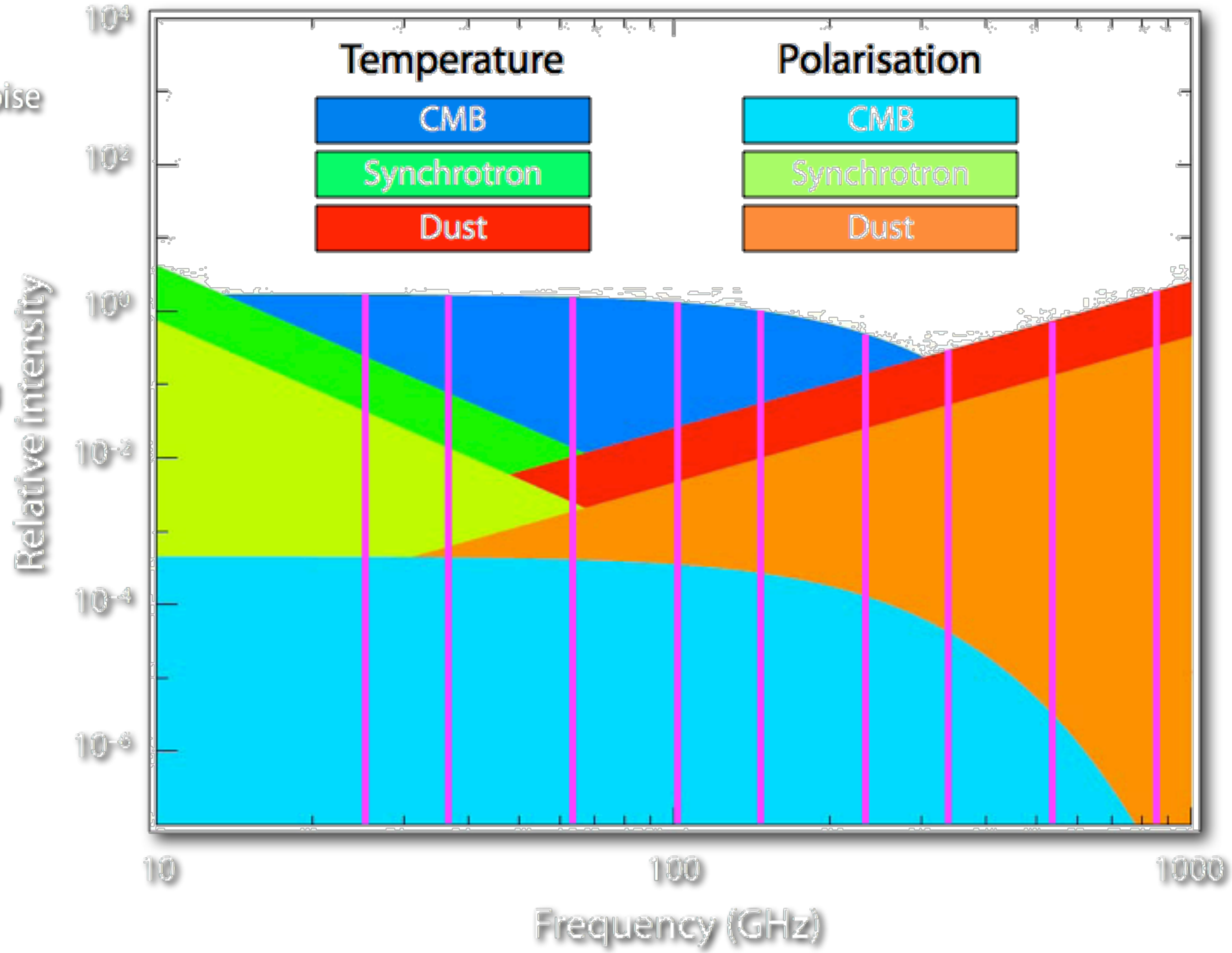
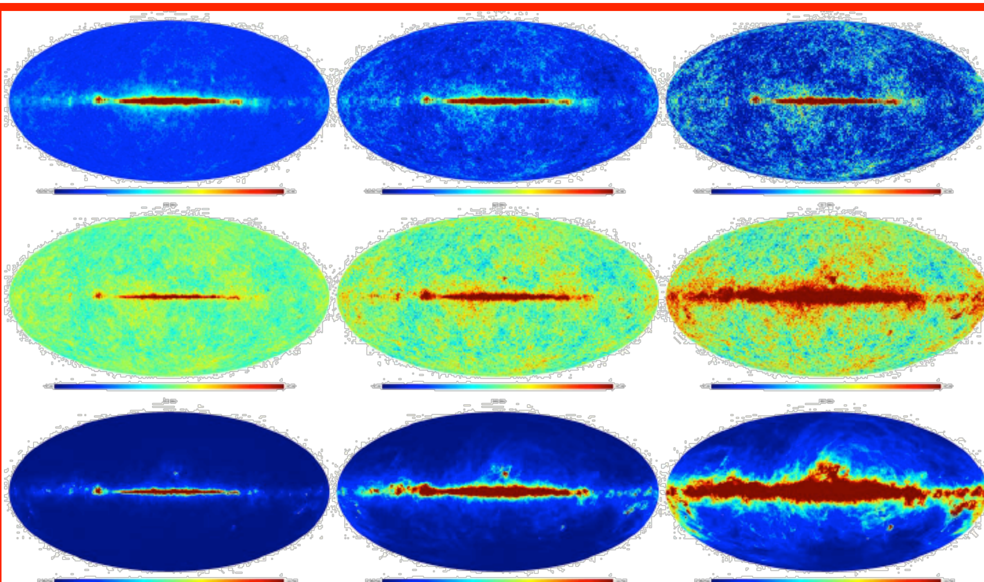
Layers on the sky



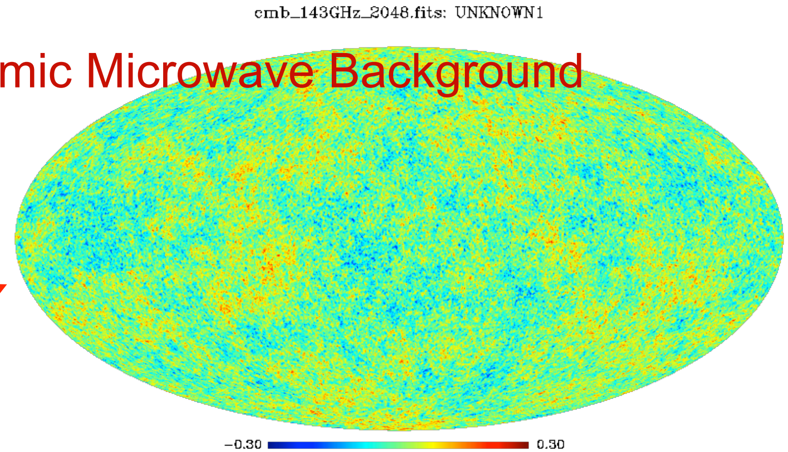


Expected results from simulations

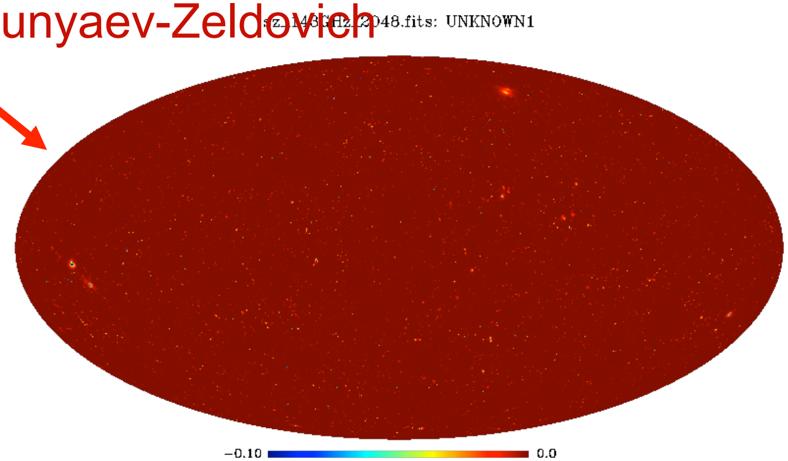
30, 44, 70, 100, 143, 217, 353, 545, 857 GHz – I, Q, U at all channels
Except 545 & 857 GHz



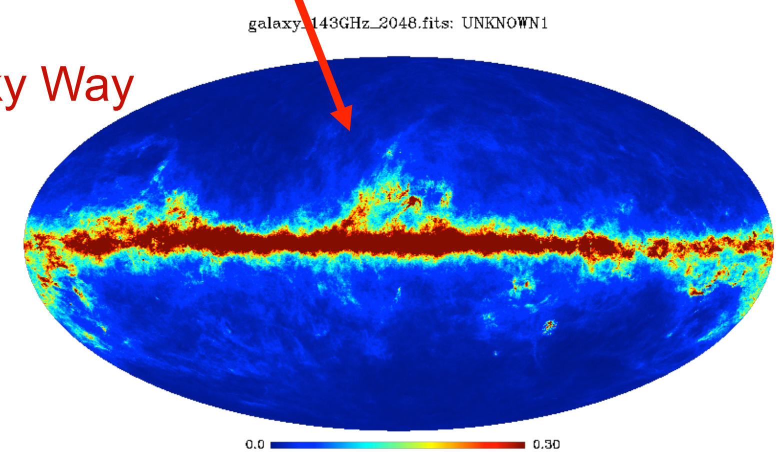
Cosmic Microwave Background



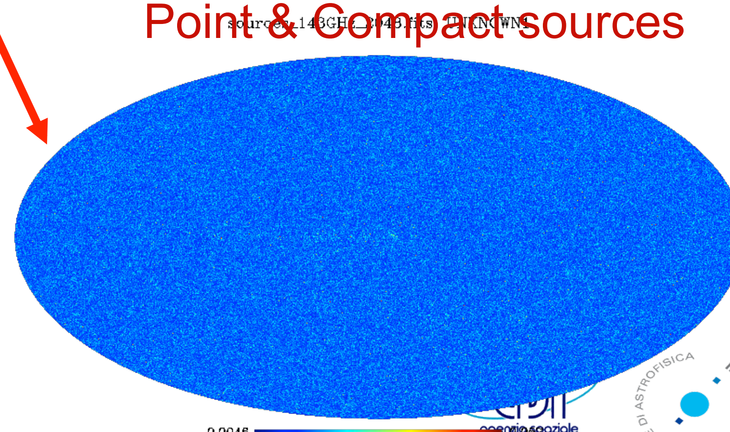
Sunyaev-Zeldovich



The Milky Way

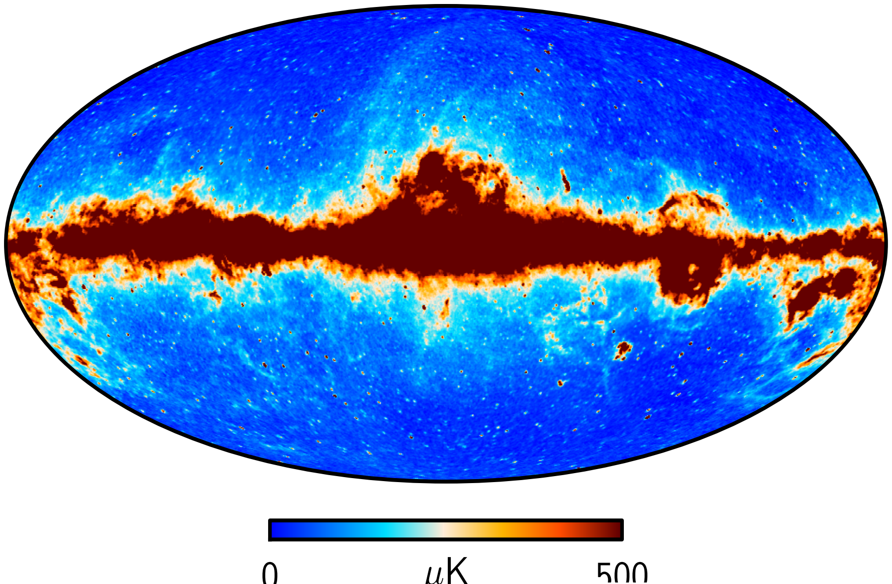


Point & Compact sources

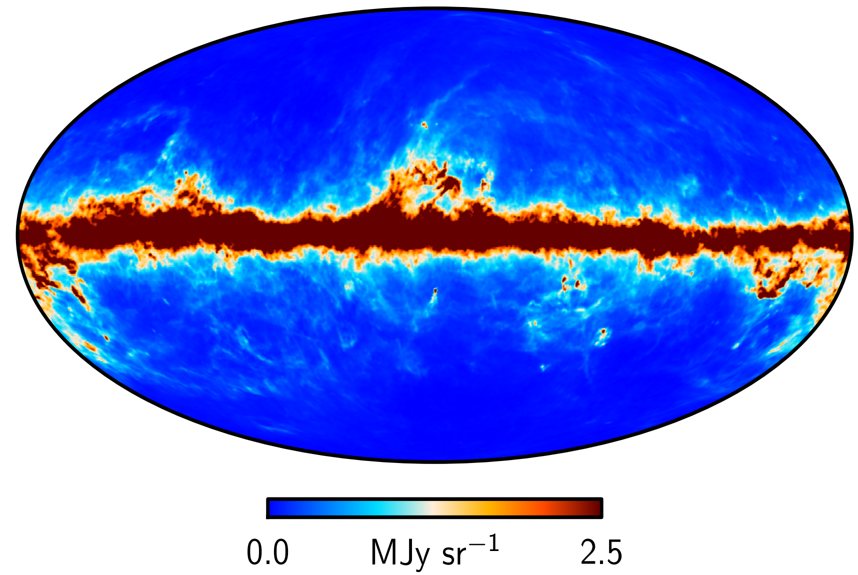


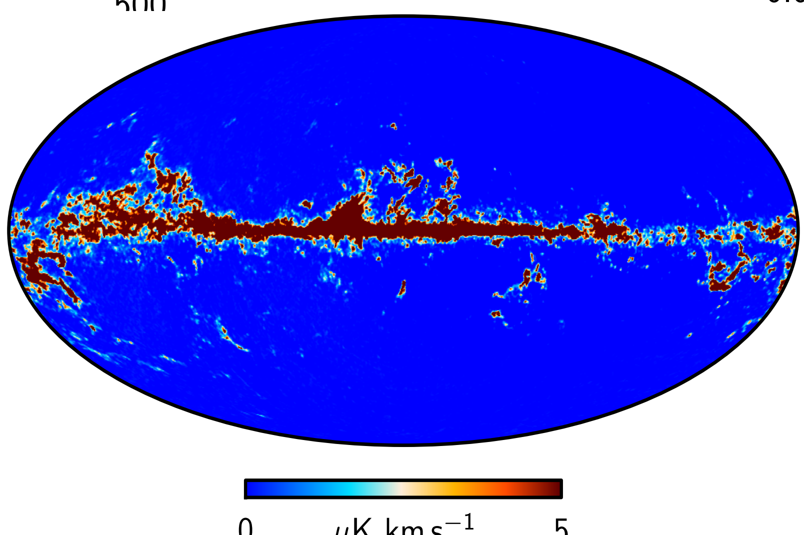
Emission from the Milky Way

Non-thermal radio emission



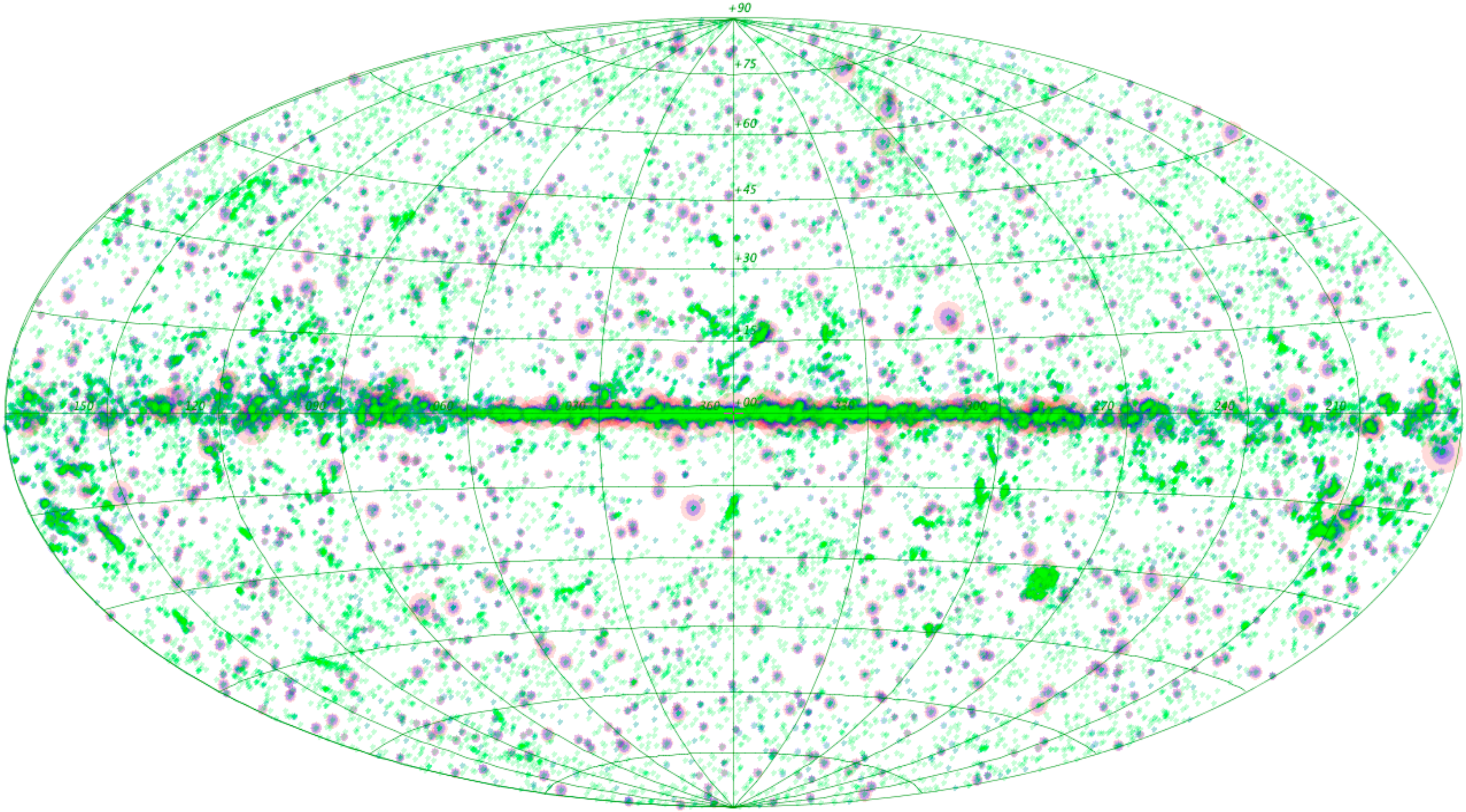
Thermal dust emission





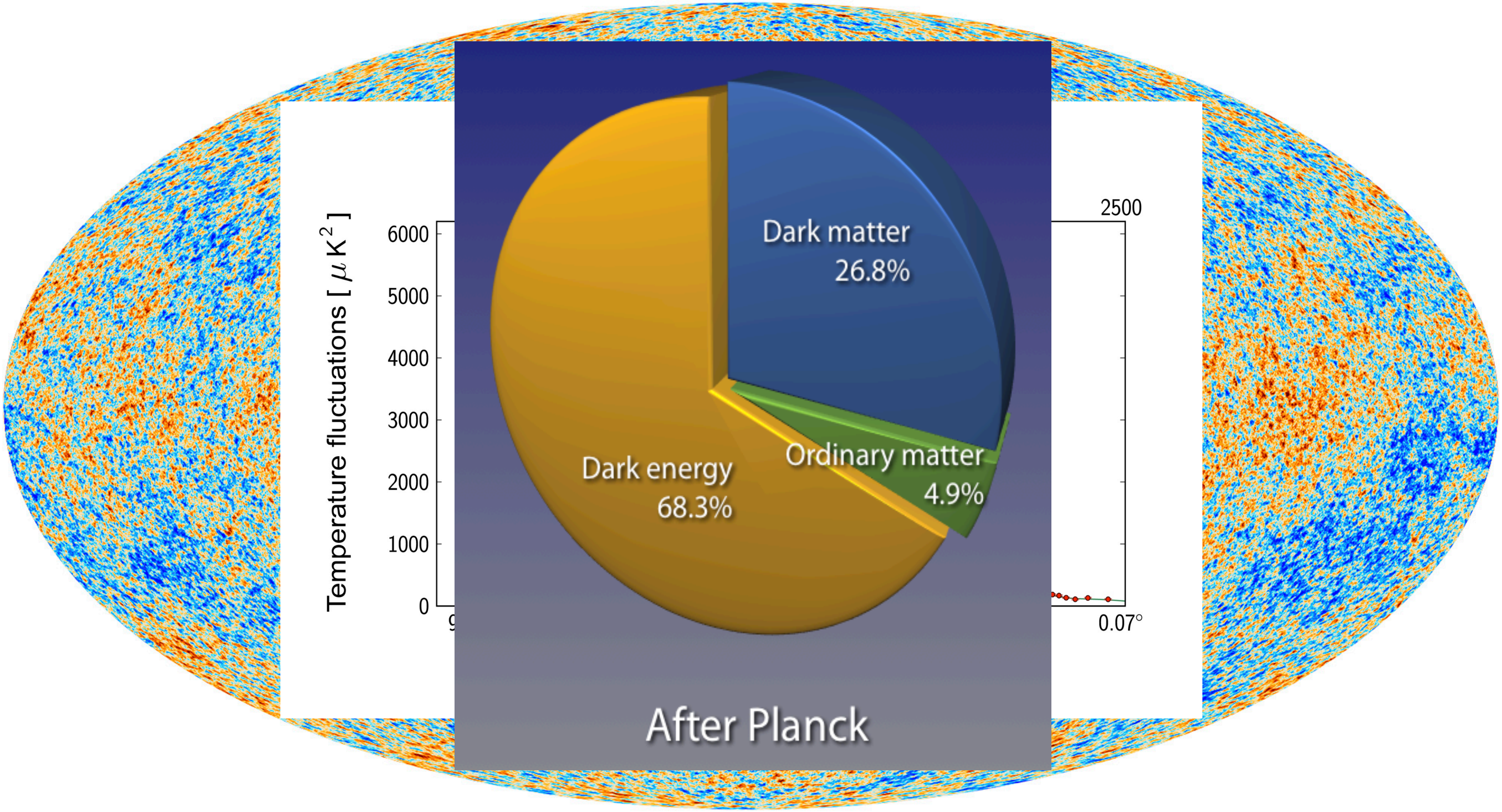
Carbon monoxide

Compact galactic and extragalactic sources



See talks by Ludovic Montier and Marcos Lopez Caniego

The anisotropies of the CMB



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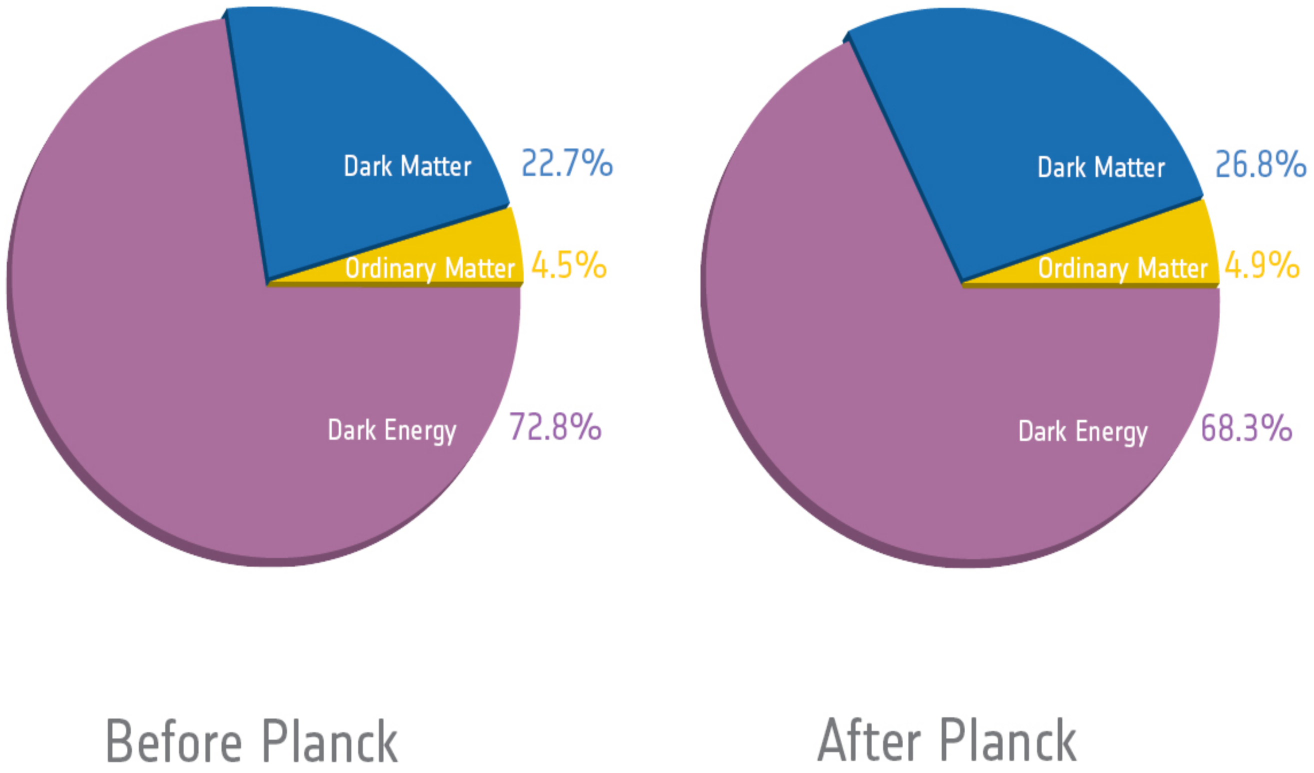
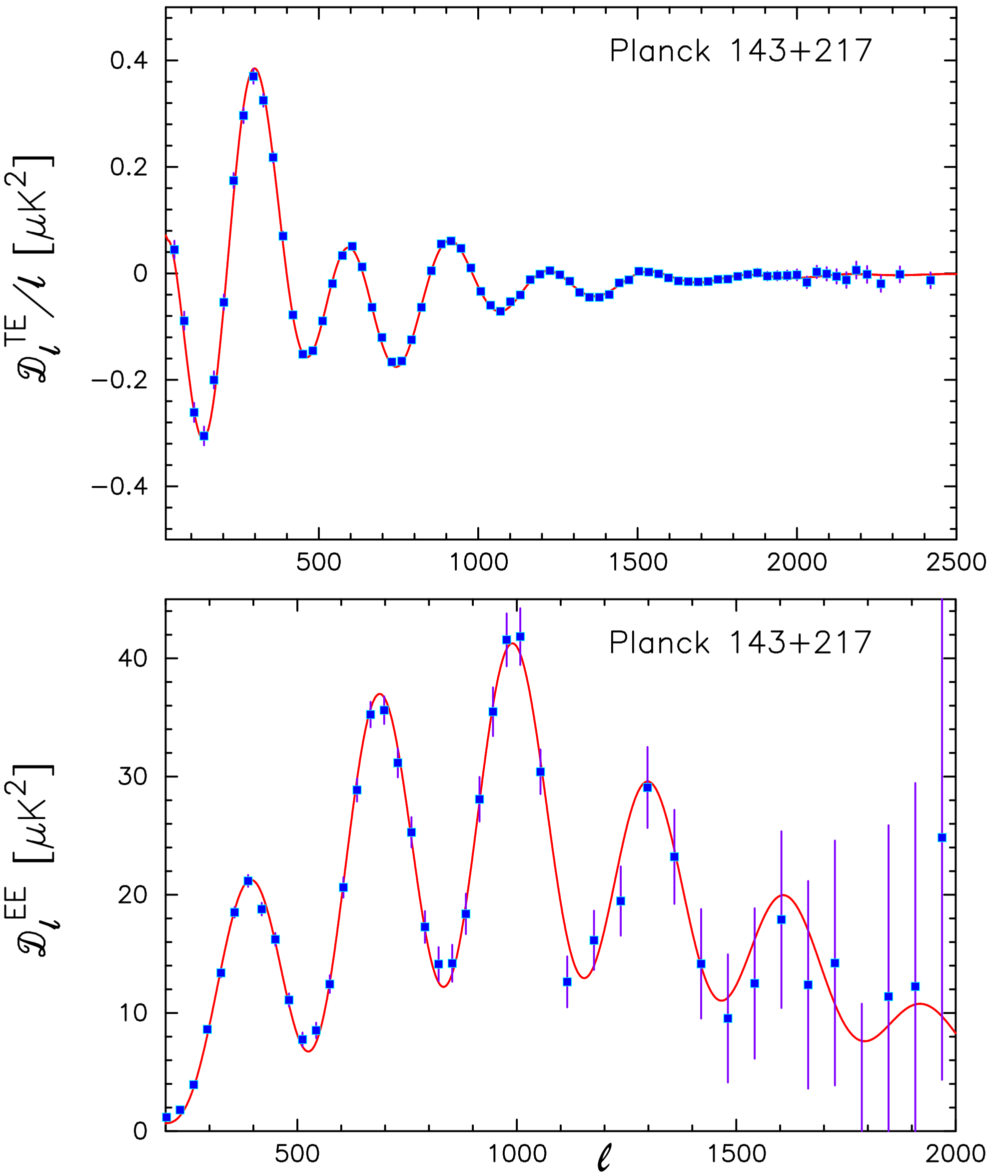
The basic content of the Universe



...has changed! (More about cosmological parameters later)

CMP polarization with Planck



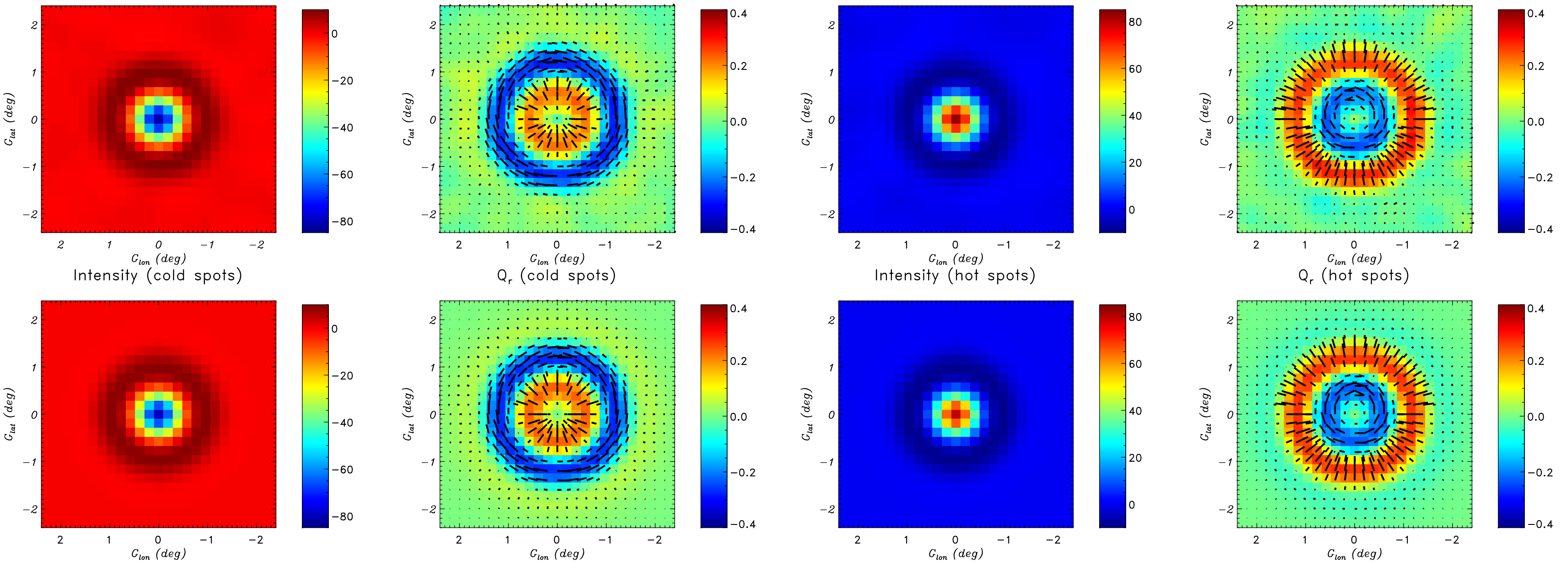
Polarization non delivered in 2013. Large angular scales need better cleaning. Small angular scale are already in good shape as shown.

The red line is not a fit to the polarization data, but the predicted curve from the ΛCDM model assuming the temperature data!

Polarization and hot spots

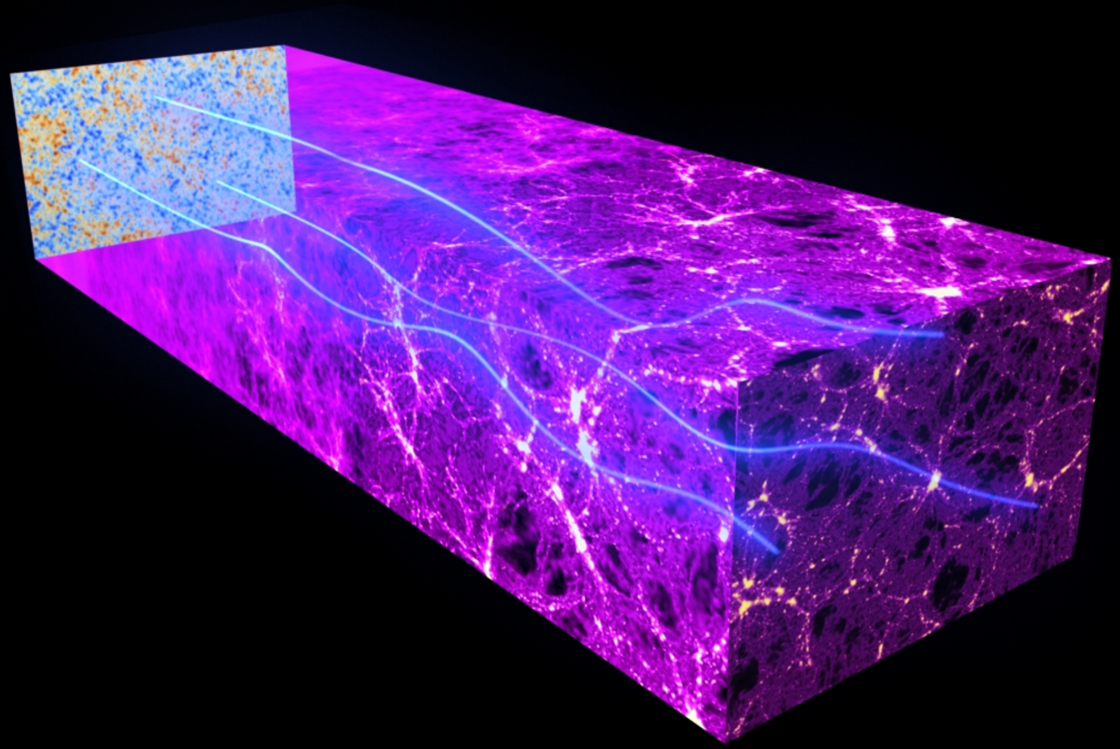
Stack hot/cold spots in the CMB. See the TE correlation in real space!

Remarkable proof of inflation: existence of super-horizon fluctuations



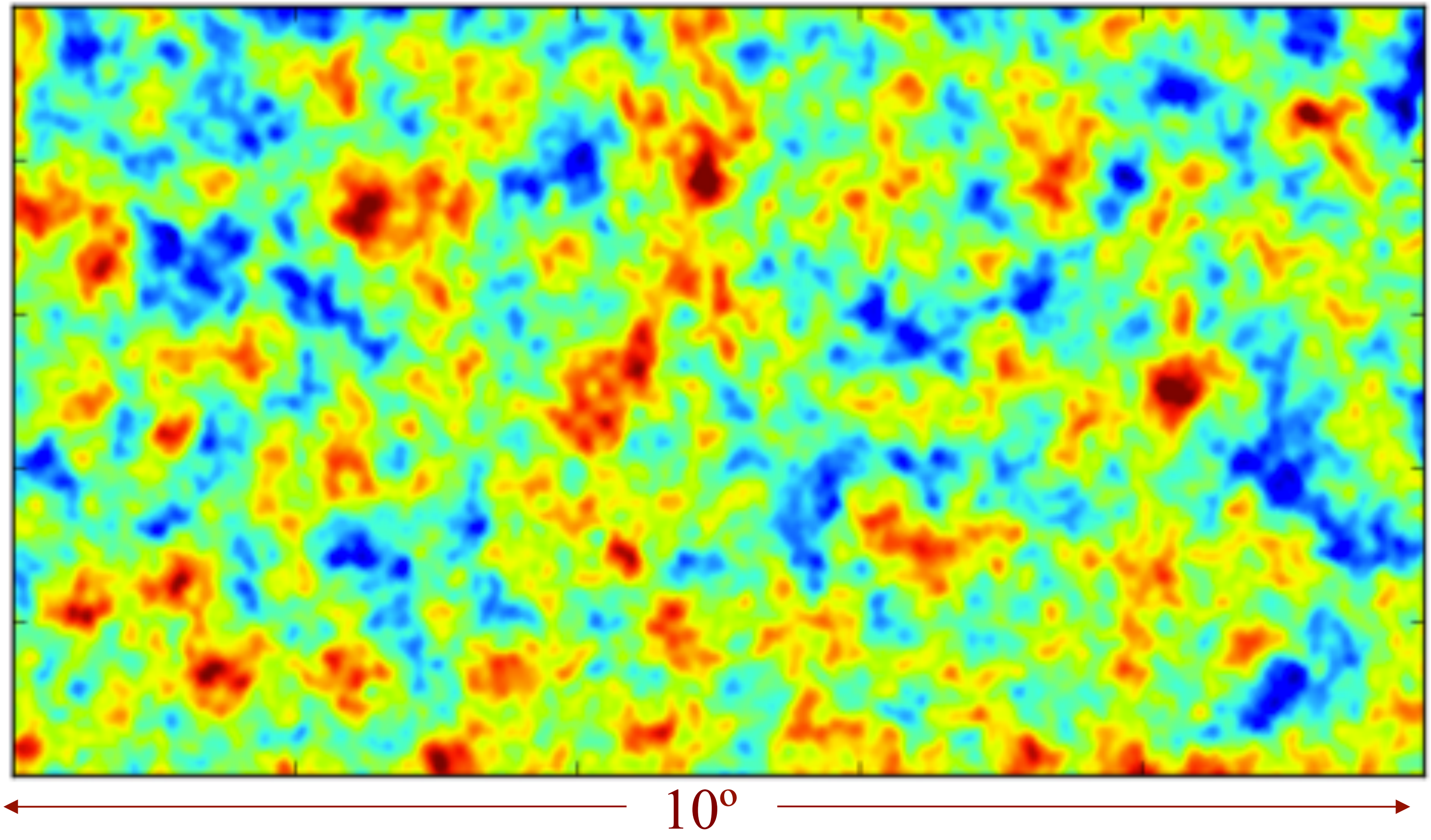
PLANCK PROBES AND EXPLOITS CMB LENSING

The gravitational effects of intervening matter bend the path of CMB light on its way from the early universe to the Planck telescope. This "gravitational lensing" distorts our image of the CMB



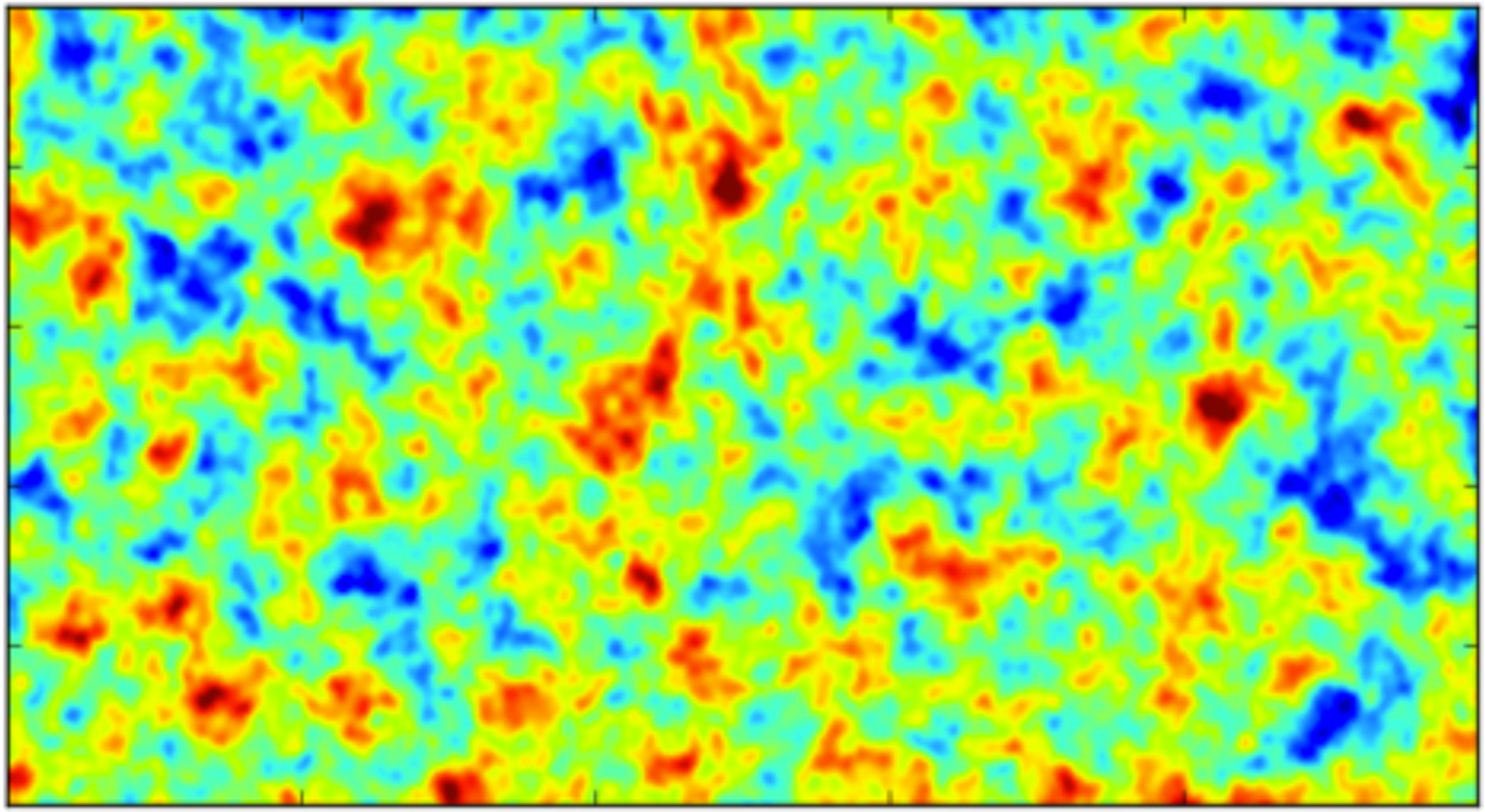
GRAVITATIONAL LENSING OF THE CMB

A simulated patch of CMB sky – **before lensing**



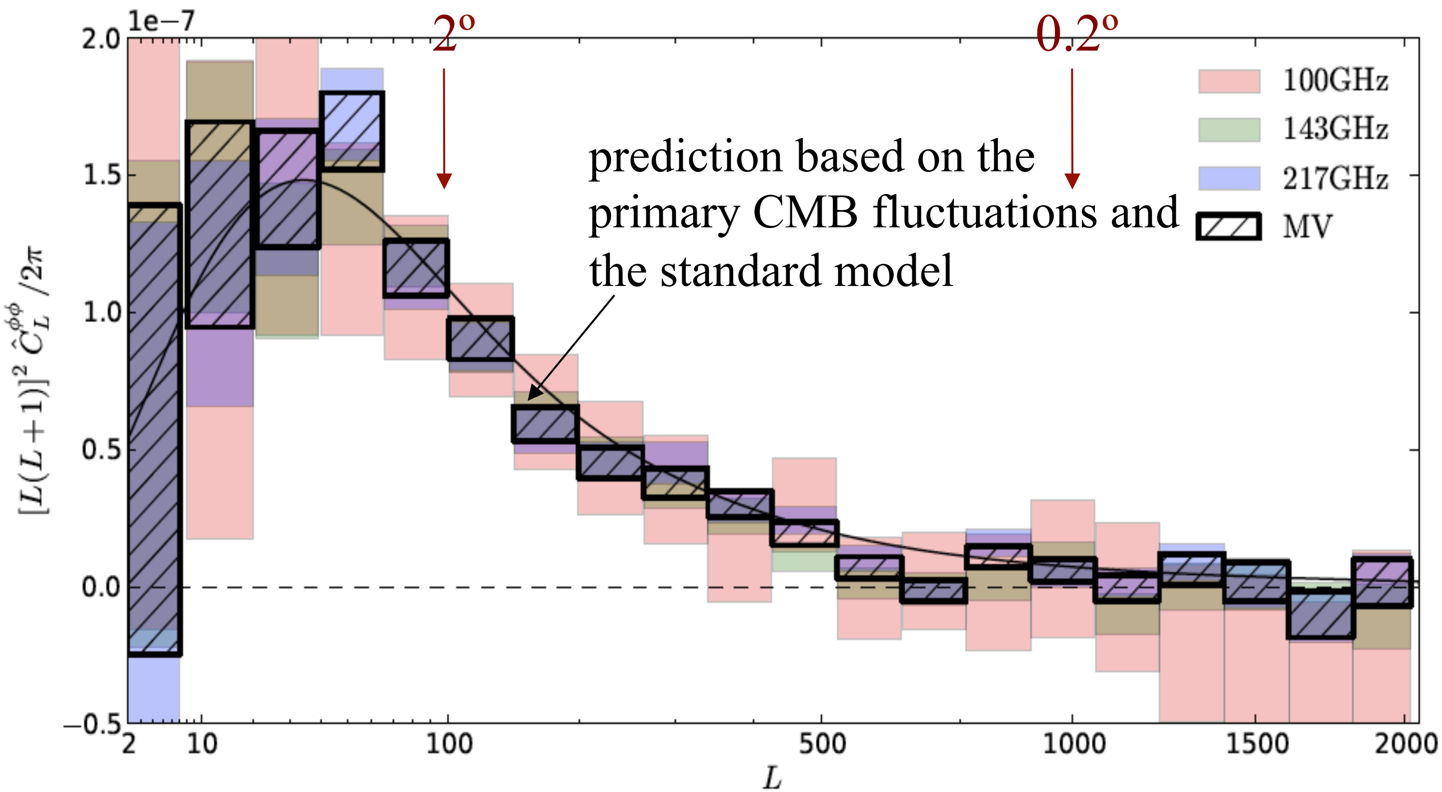
GRAVITATIONAL LENSING OF THE CMB

A simulated patch of CMB sky – **after lensing**



10°

PLANCK LENSING POTENTIAL POWER SPECTRUM



It is a 25 sigma effect!!

See talk by Aurelien Benoît-Lévy

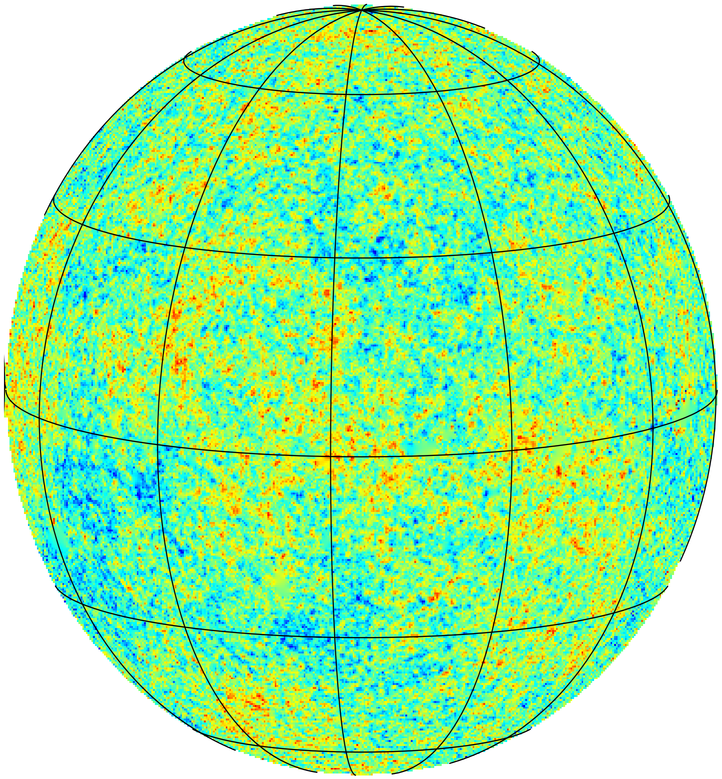
Non Gaussianity in the CMB

Nearly perfectly Gaussian fluctuation are a prediction of the inflation.

$$\frac{\Delta T}{T} \approx 10^{-5}$$

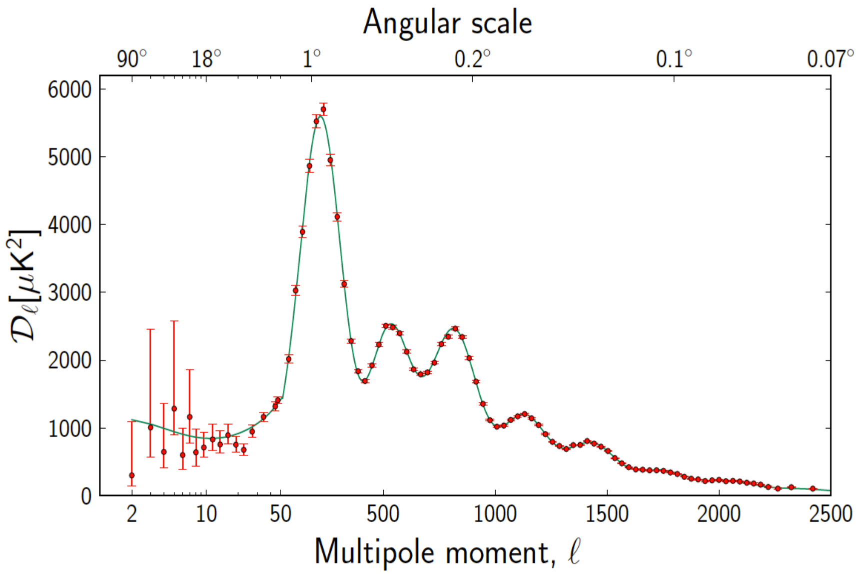
$$\frac{\Delta T}{T} + \text{const.} \times f_{NL} \left(\frac{\Delta T}{T} \right)^2$$

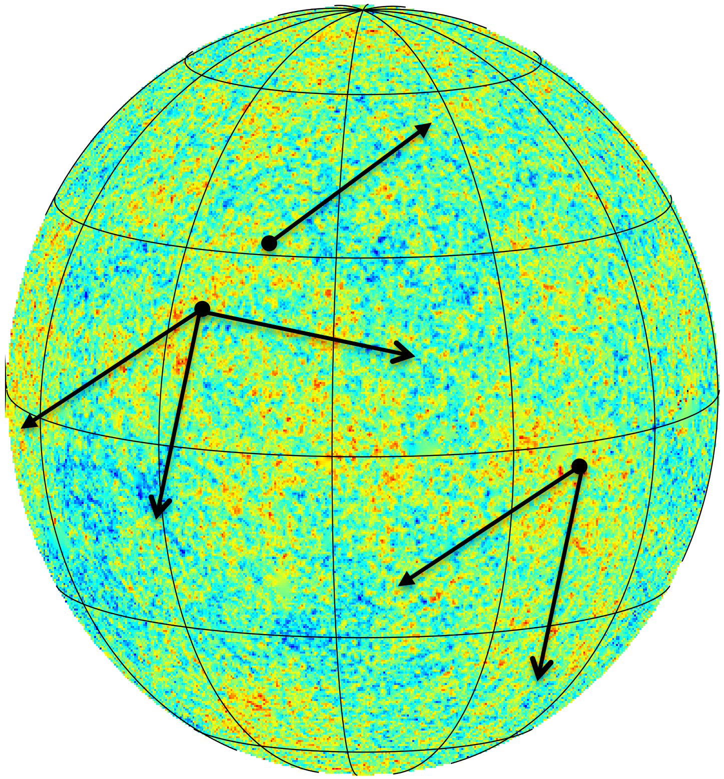
$$\left(\frac{\Delta T}{T} \right)^2 \approx 10^{-10}$$



How test for Gaussianity? And how?

The power spectrum compares two points separated by one angle (TT):



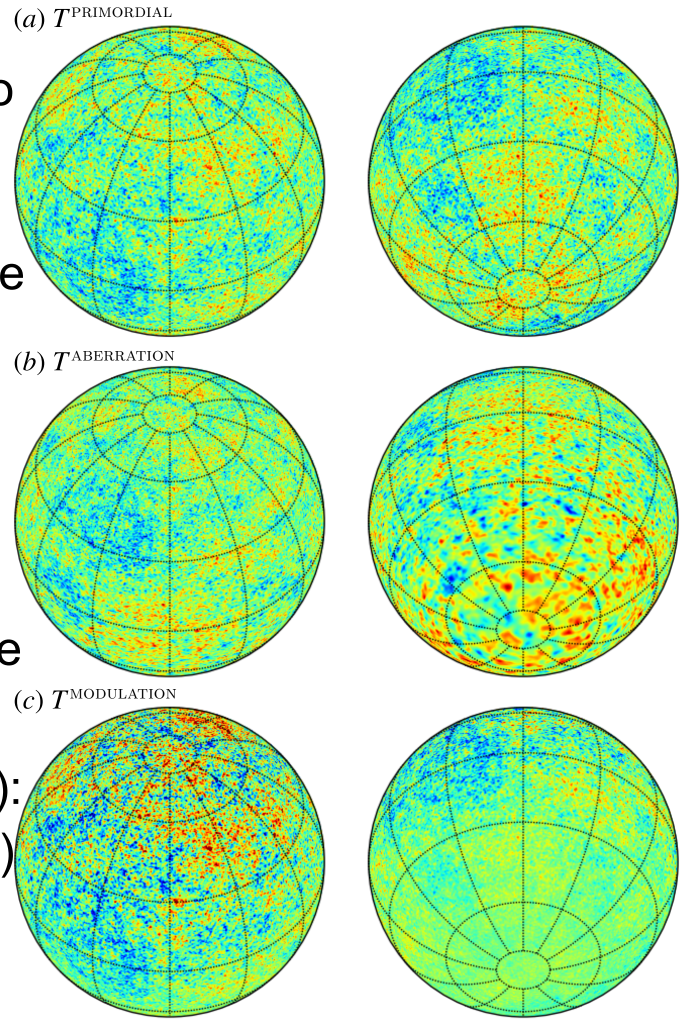


To check for non Gaussianity you can compare three points at more angles: the “power” bispectrum (TTT) and trispectrum (TTTT).

See talk by Michele Liguori

Doppler boosting of the CMB: eppur si muove!

- Planck is sensitive enough to measure the tiny doppler boosting effect on the anisotropies due to the observer peculiar velocity (we are not perfectly comoving observers!)
- Tiny effect: order β = v/c ~ 1/1000
- Two main effects: aberration and dipole modulation
- This yielded the first measure of the Earth velocity independent from the CMB dipole (observed since 1977):
- V=384 ± 78 (stat) ± 115 (sys) Km/s



Simulated CMB

Aberration for β=0.85

Modulation for β=0.85

Summary and what to expect in 2014

Planck has worked very well:

- Will leave us with the ***definitive*** CMB temperature for many years to come (after 2014)
- Very good consistency with the flat **ΛCDM** model (but few hints of anomalies, stay tuned for the other talks)
- Strongly supports the **inflationary** scenario (Guassianity, primordial spectrum)
- Precision constraints on model parameters (typically < 1%)

Planck 2014 will deliver:

- More than twice as much data
- Improved instrument models, calibrations etc.
- Polarization at large and small angular scales:
  - Planck's own measure of the optical depth at reionazation (presently still using WMAP)
  - Improved constraints on GW from inlfation through primordial polarization B modes (no detection promised of course!)

(*: uses extra non-CMB data, limit is 0.85eV else)

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

Planck is a project of the European Space Agency, 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.

A. Zacchei
"Frequency maps