



planck



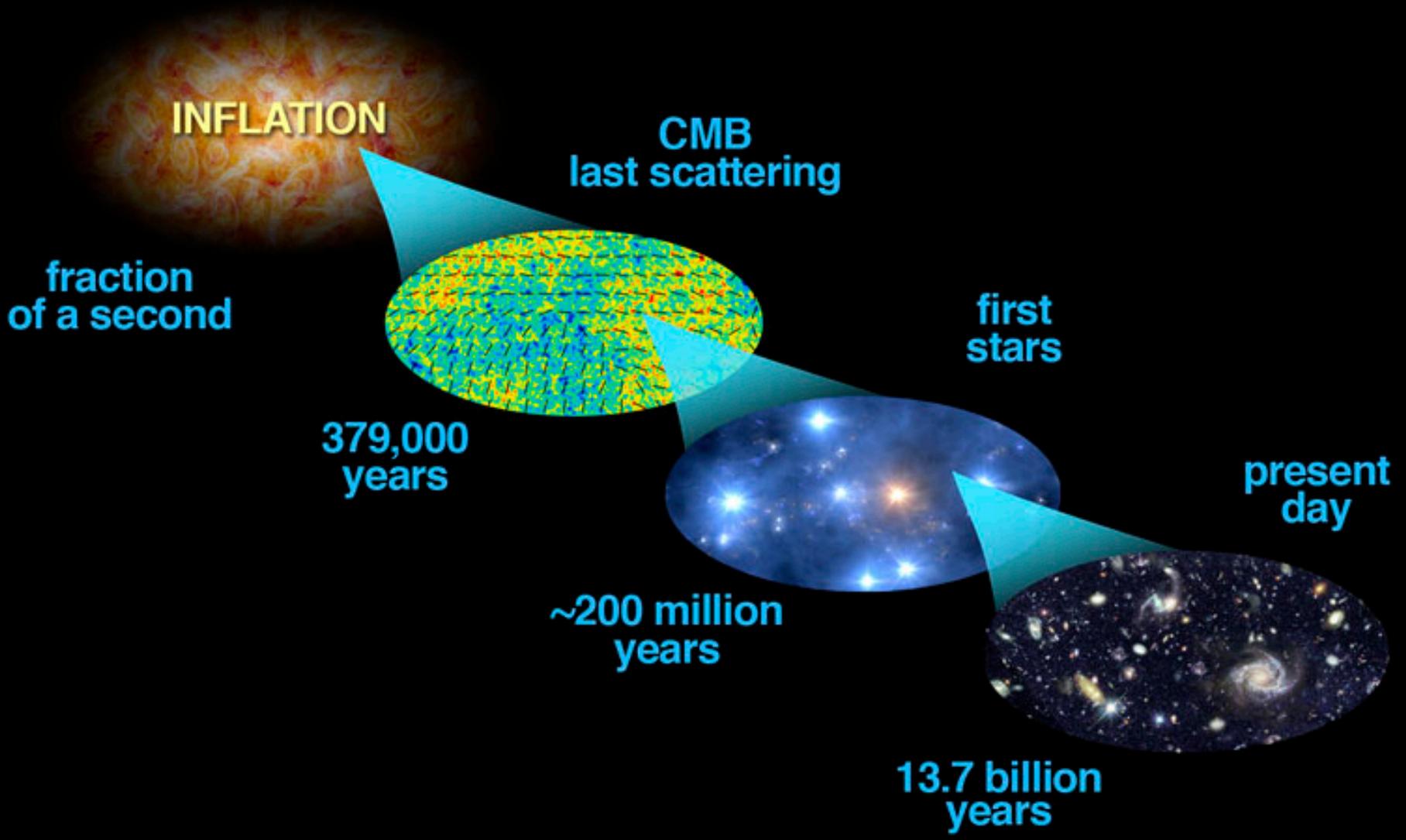
The Planck Mission

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



Fluctuation and GW generator

Fluctuation amplifier
But GW dissipator...

INFLATION

CMB
last scattering

fraction
of a second

379,000
years

first
stars

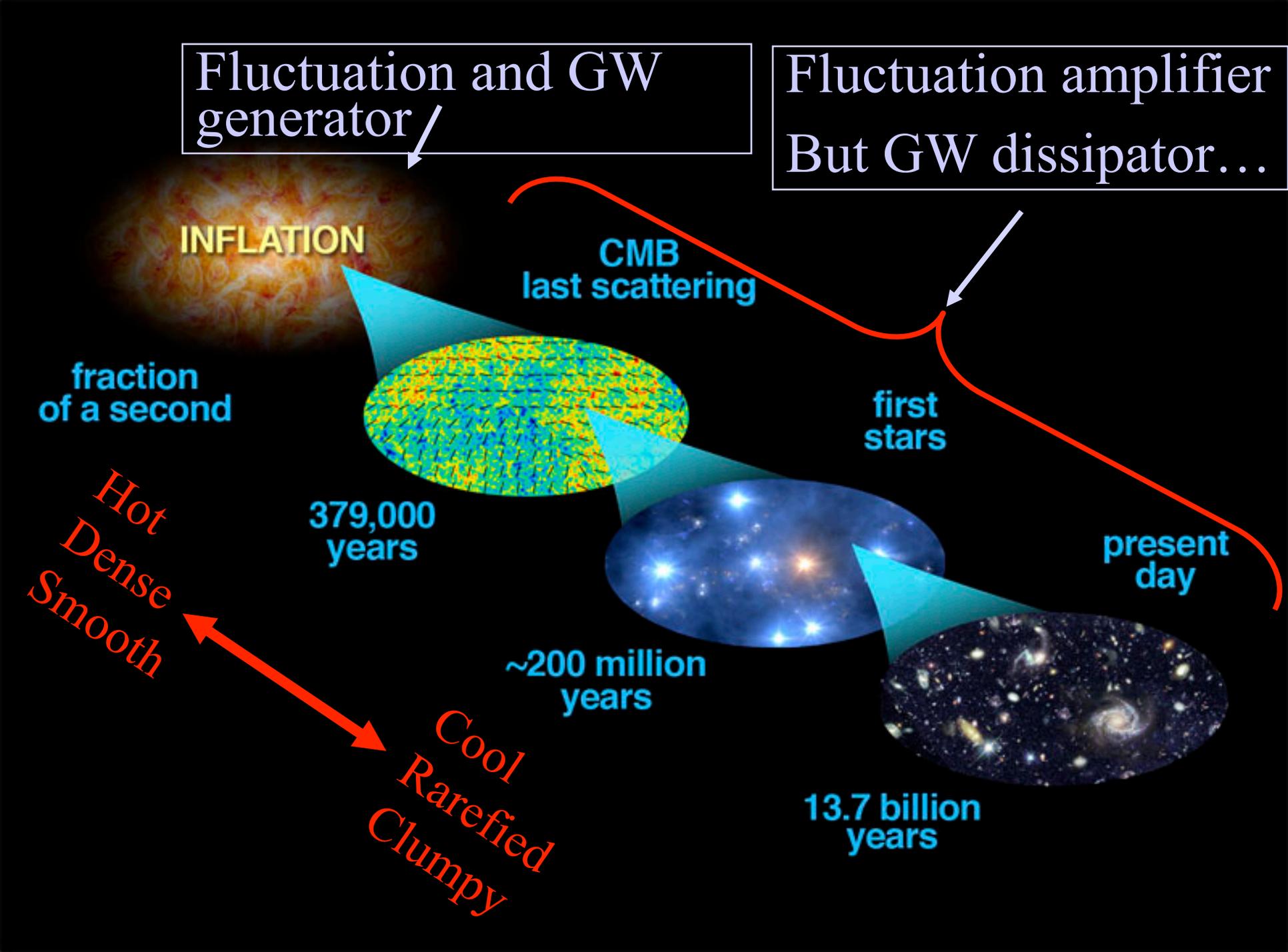
present
day

Hot
Dense
Smooth

Cool
Rarefied
Clumpy

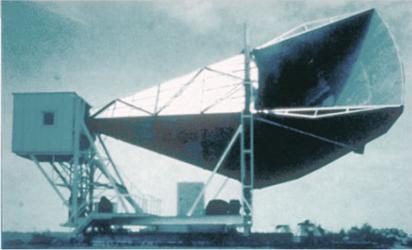
~200 million
years

13.7 billion
years

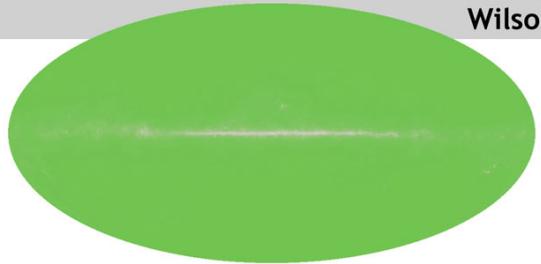


Cosmic Microwave Background Radiation Overview

1965



Penzias and Wilson



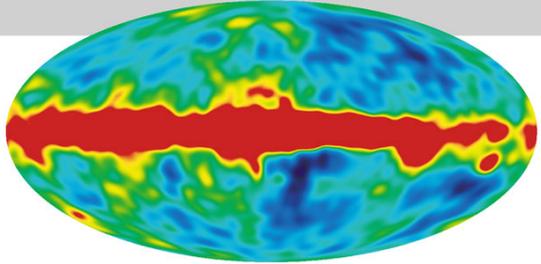
The oldest light or the first light of the Universe

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

1992

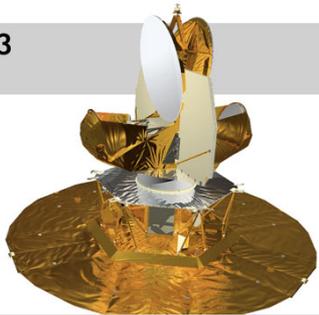


COBE

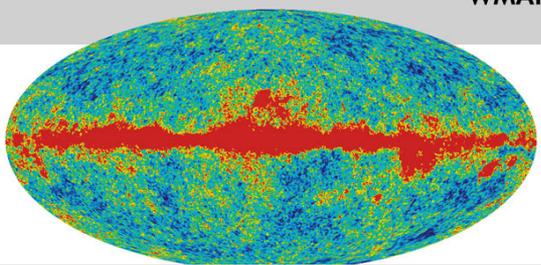


Blackbody radiation,
Discovered the patterns (**anisotropy**) in the afterglow.
→ **angular scale ~ 7°** at a level $\Delta T/T$ of 10^{-5}

2003

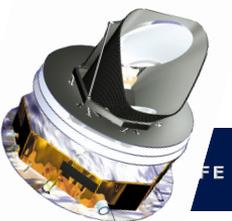


WMAP

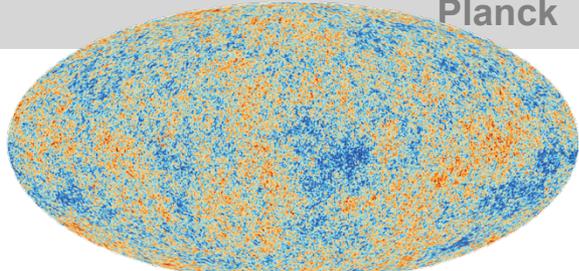


(Wilkinson Microwave Anisotropy Probe):
→ **angular scale ~ 15'**

2009



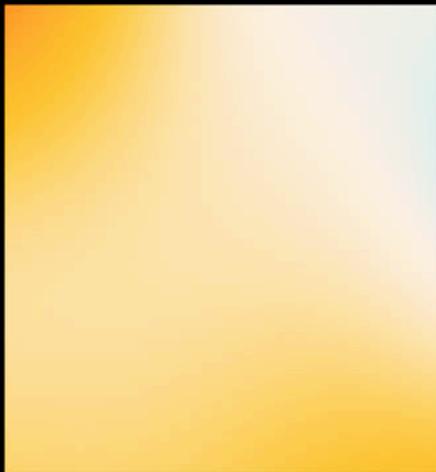
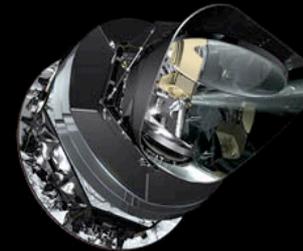
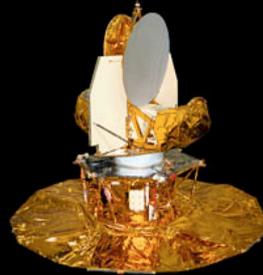
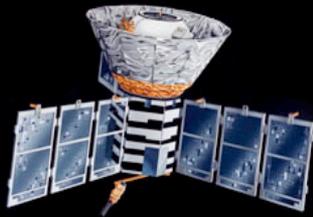
Planck



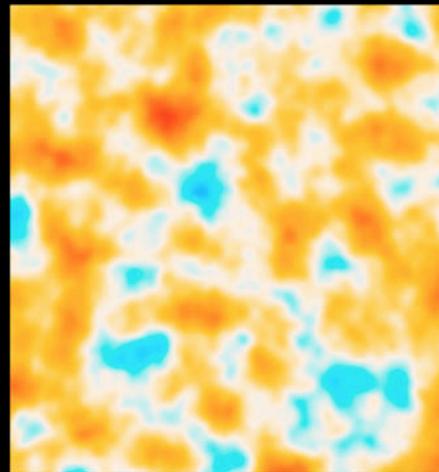
→ **angular scale ~ 5'**,
 $\Delta T/T \sim 2 \times 10^{-6}$, 30~867 Hz



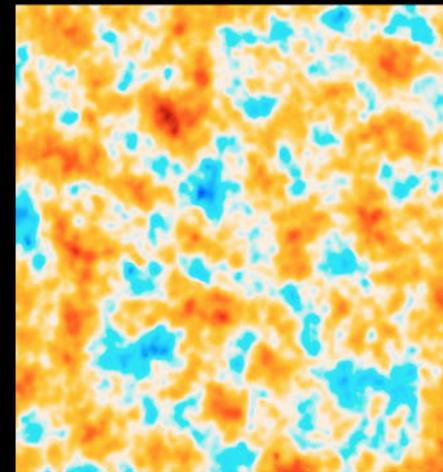
Comparison with forerunners



COBE



WMAP

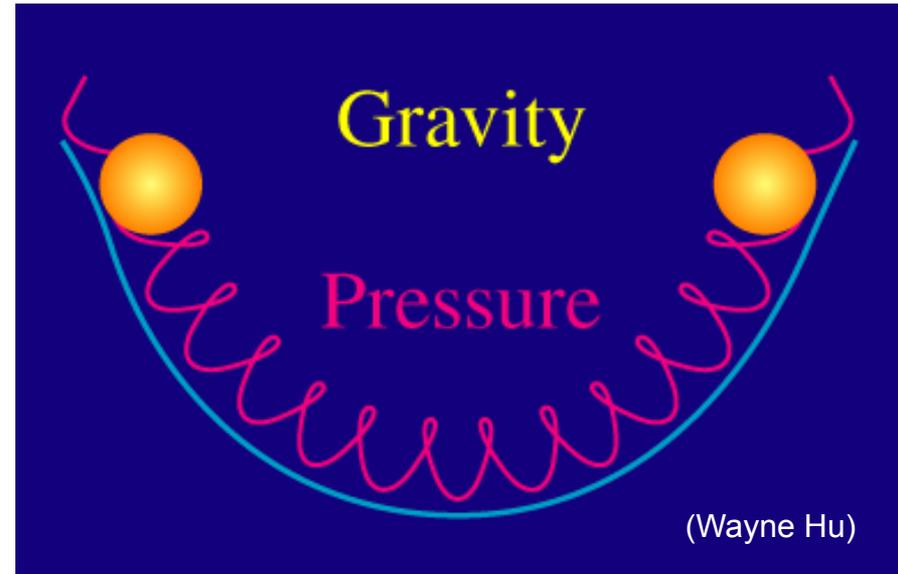


Planck

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} !

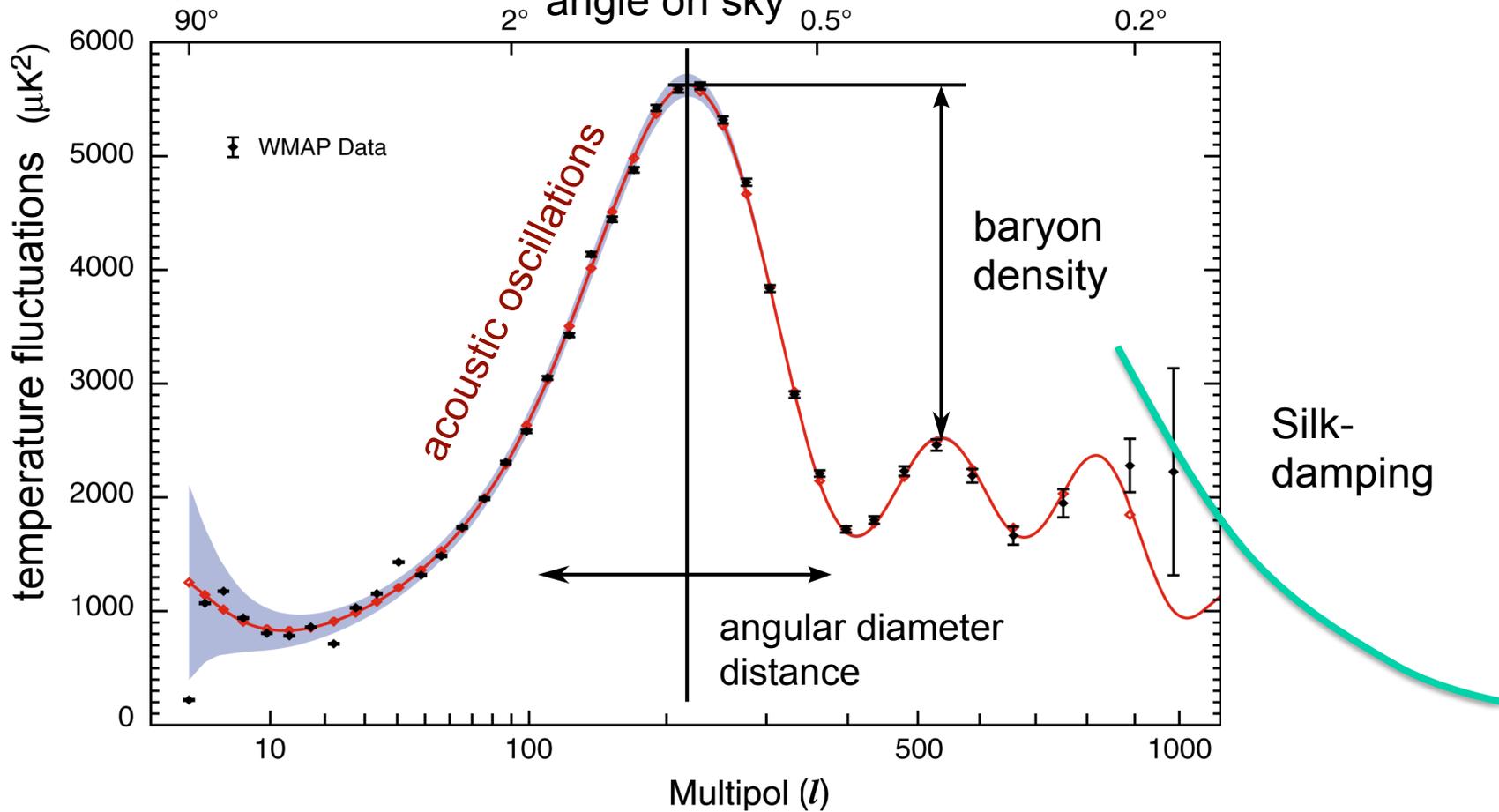


The largest scale that had just time to collapse will create the first peak, the scale that collapsed and re-expanded the second peak, etc.
→ **angular diameter distance to $z=1100$!**

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

The CMB power spectrum

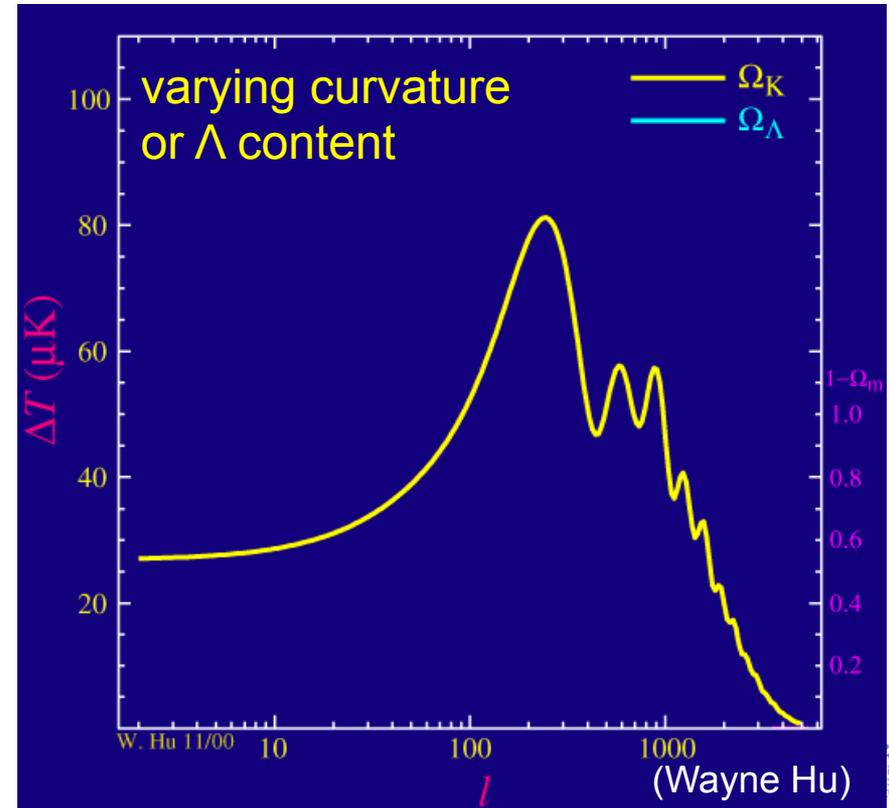
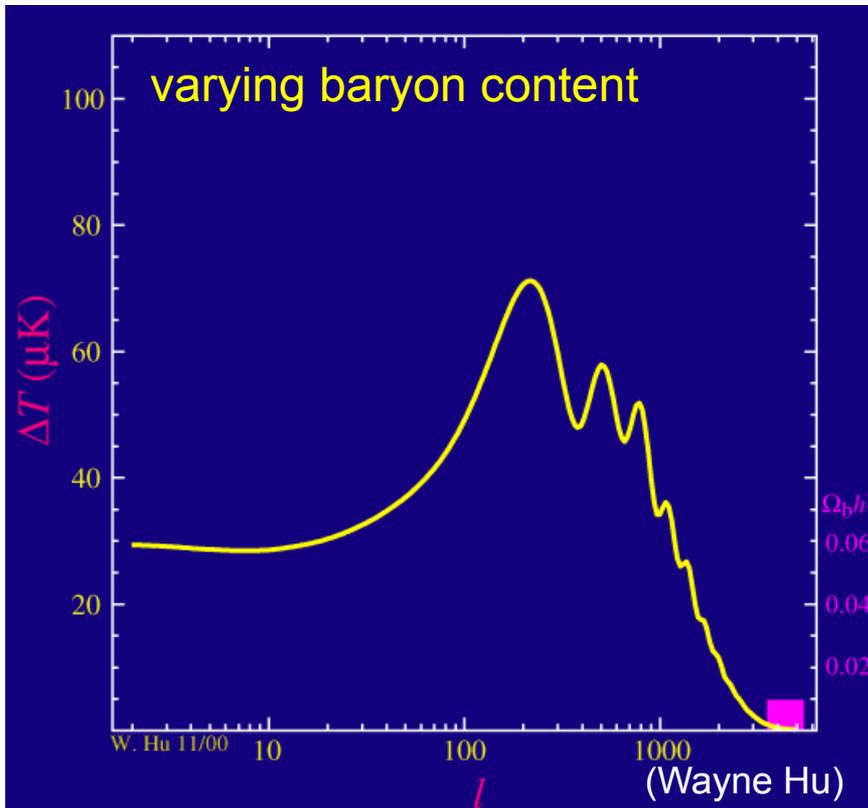
$\left\langle \frac{\Delta T}{T}(\vec{\gamma}) \frac{\Delta T}{T}(\vec{\gamma}') \right\rangle$: Two-point correlation function seen in Fourier space



CMB physics is mostly linear -> very clean probe!

measuring cosmological parameters

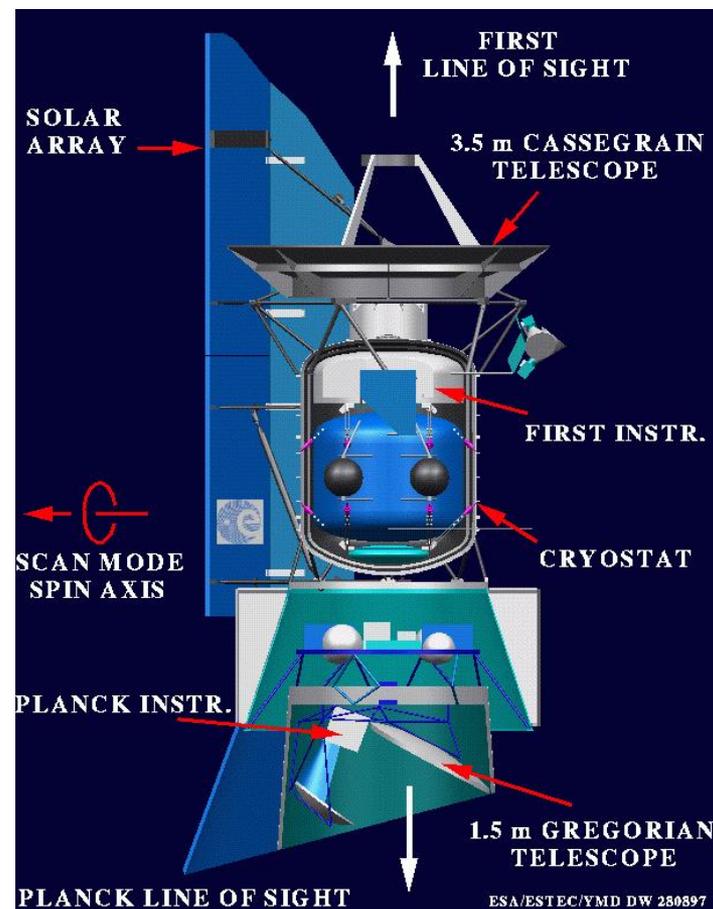
The CMB fluctuations depend on the values of the parameters
→ we just vary all of them to find the best values



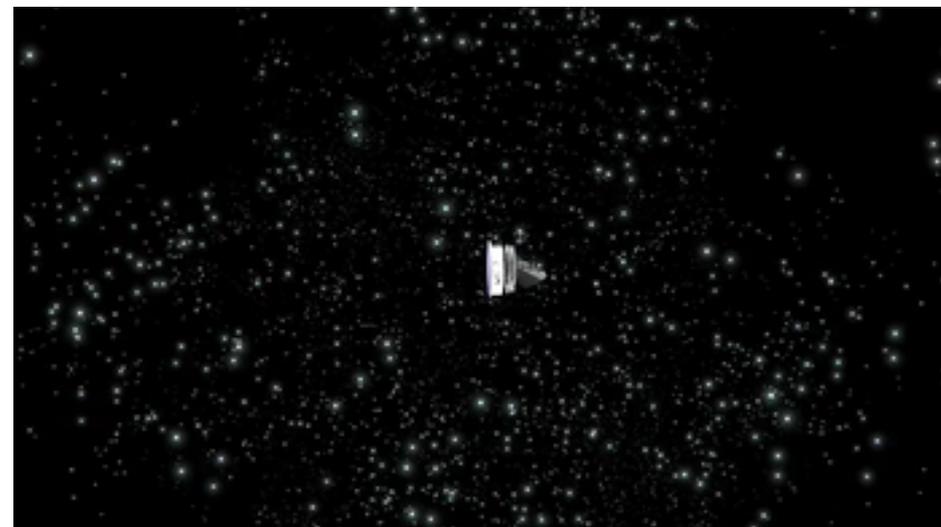
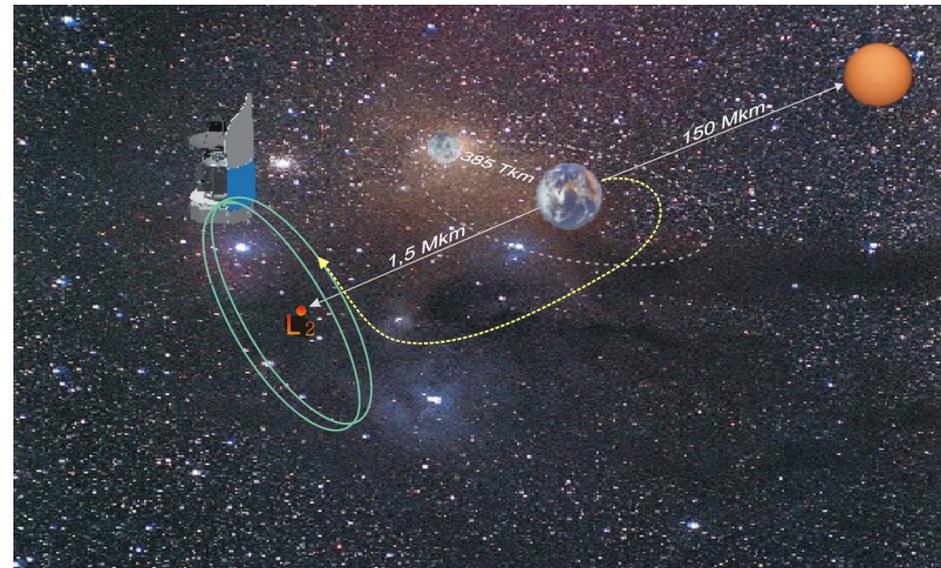
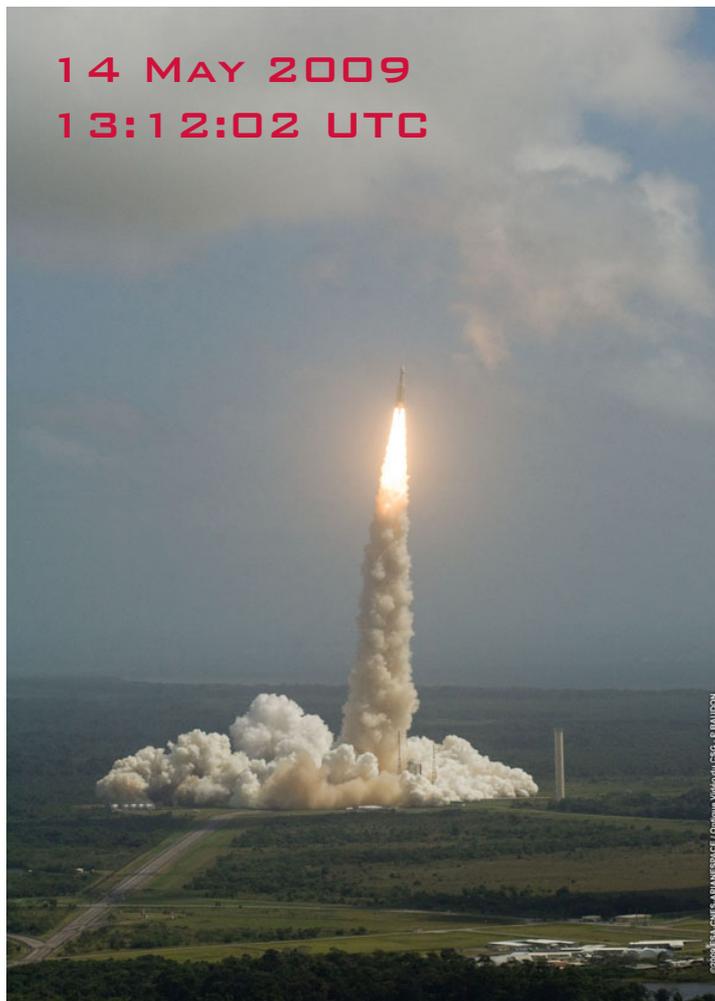
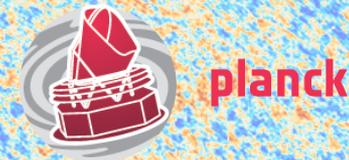
A brief history of Planck



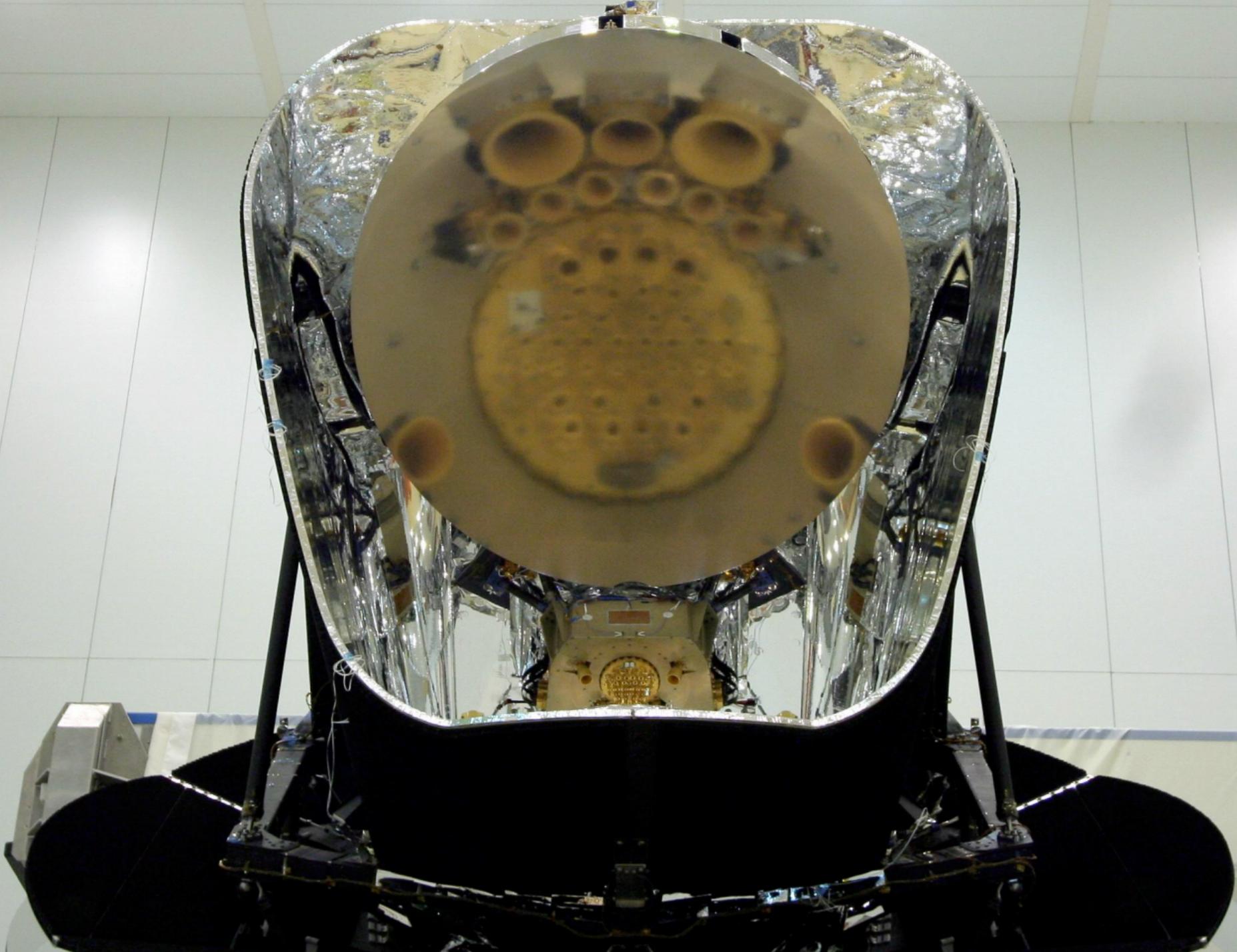
- **1993**: COBRAS & SAMBA proposals for M3 Horizon launch slot [**2003**]
- (1995: WMAP proposed to NASA)
- **1996**: selection of COBRAS/SAMBA, then named Planck [**2004**]
- **1997**: instrument AO [**2006**]
- **1998**: ESA runs into financial difficulties, FIRST/Planck studies [**2007**]
- (2001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



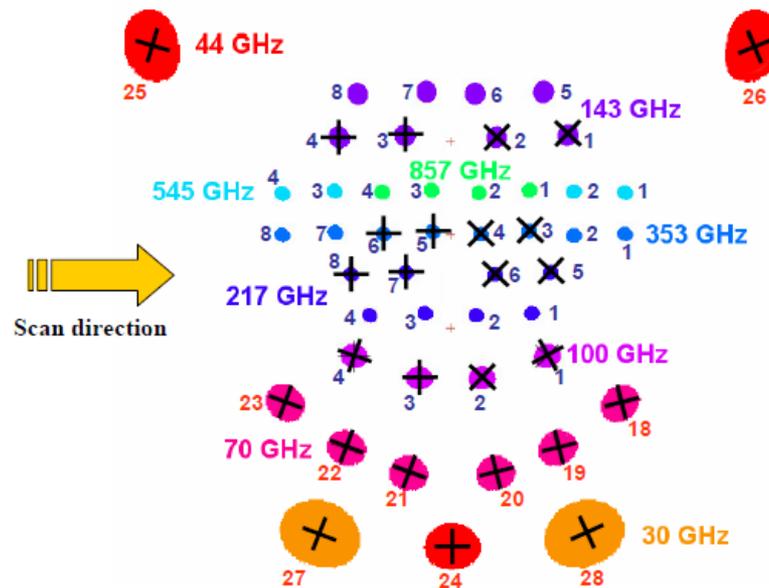
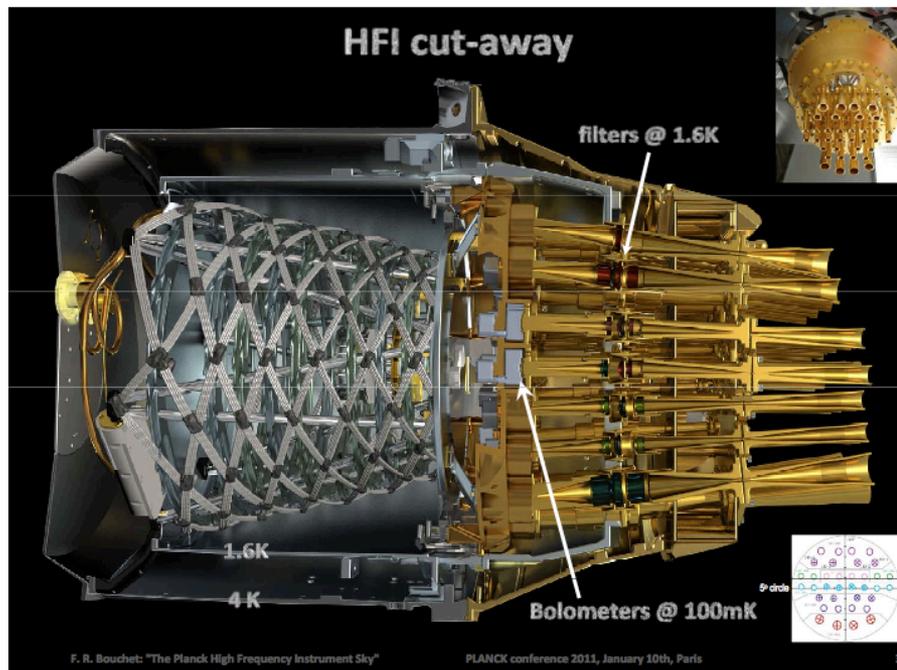
the Planck mission







the Planck focal plane



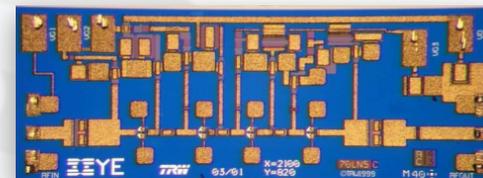
PLANCK	LFI			HFI					
Center Freq (GHz)	30	44	70	100	143	217	353	545	857
Angular resolution (FWHM arcmin)	33	24	14	10	7.1	5.0	5.0	5	5
Sensitivity in I [$\mu\text{K.deg}$] [$\sigma_{\text{pix}} \Omega_{\text{pix}}^{1/2}$]	2.7	2.6	2.6	1.0	0.6	1.0	2.9		
Sensitivity in Q or U [$\mu\text{K.deg}$] [$\sigma_{\text{pix}} \Omega_{\text{pix}}^{1/2}$]	4.5	4.6	4.6	1.8	1.4	2.4	7.3		

Planck-LFI: the Instrument

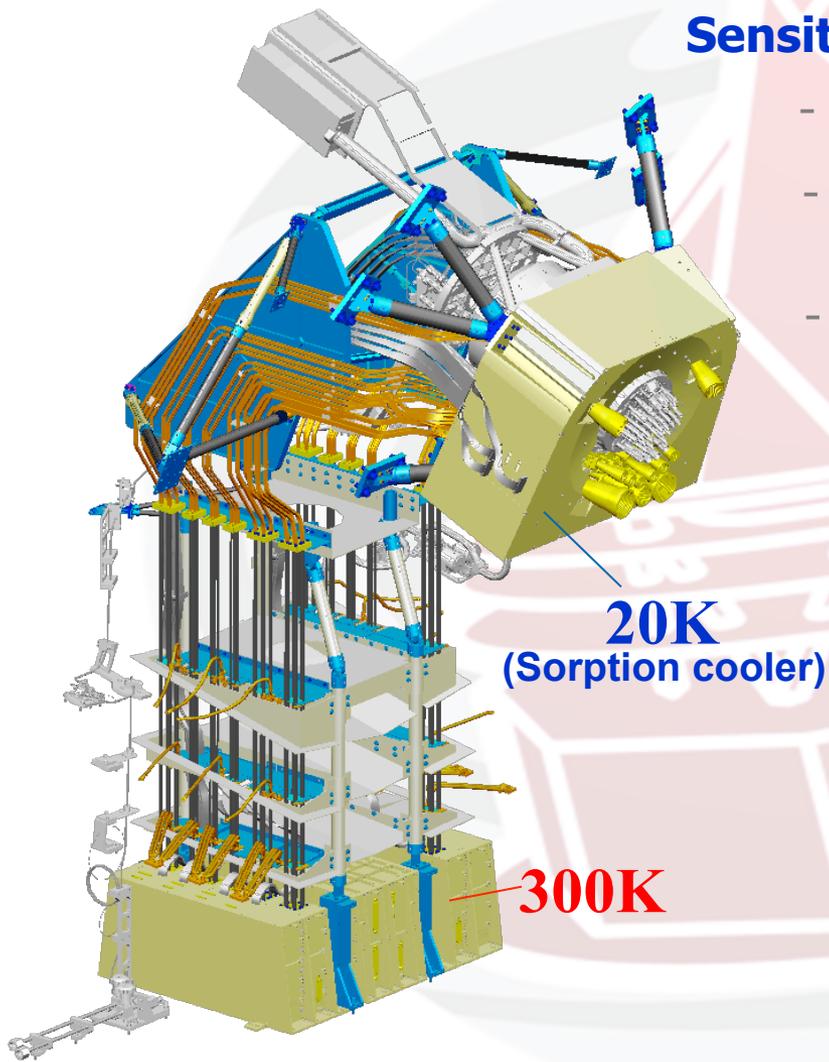
Sensitivity, stability & low systematics

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

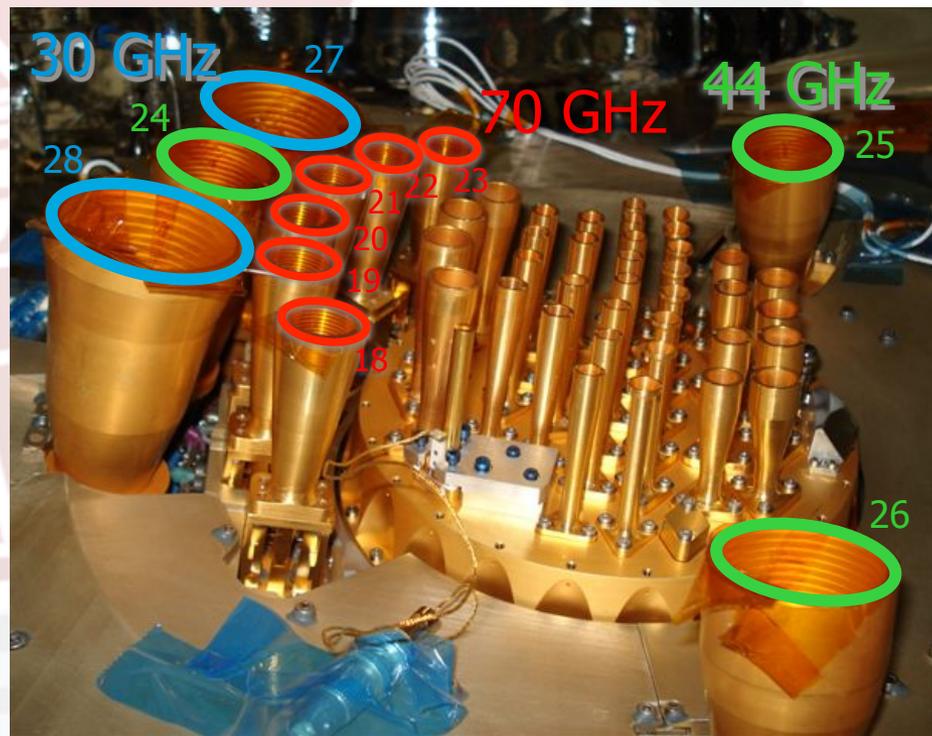
- State-of-the-art InP LNA technology
- Cryo operation
20K Sorption Cooler
- 22-element array



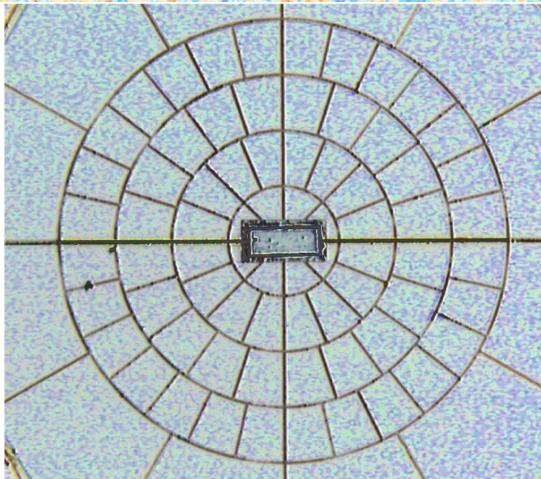
70 GHz MMIC HEMT



(MB et al 2010, Mandolesi et al 2010)

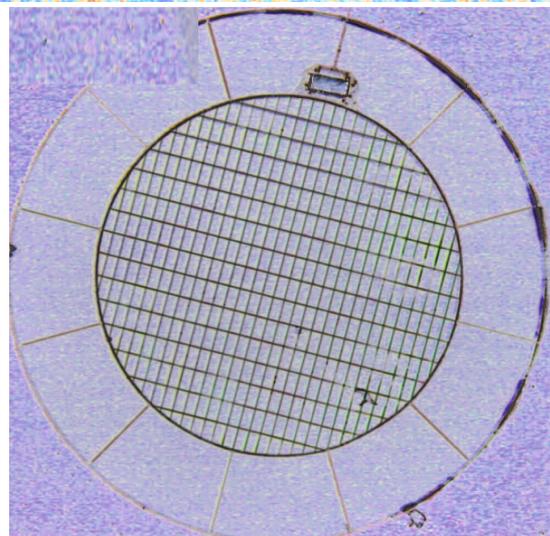


the Planck detectors



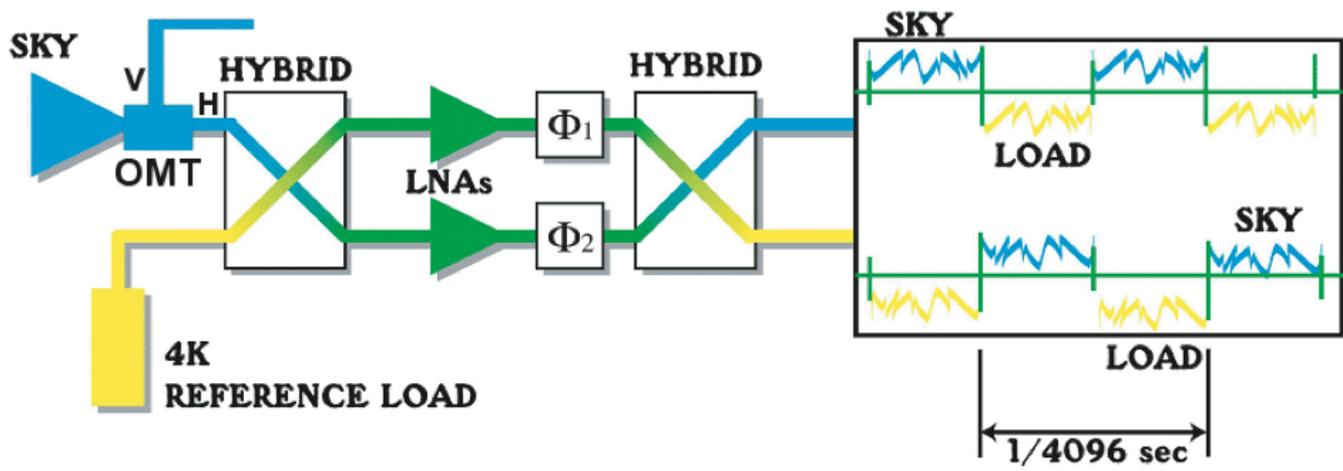
HFI
spiderweb
bolometers

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



HFI
polarisation
bolometers

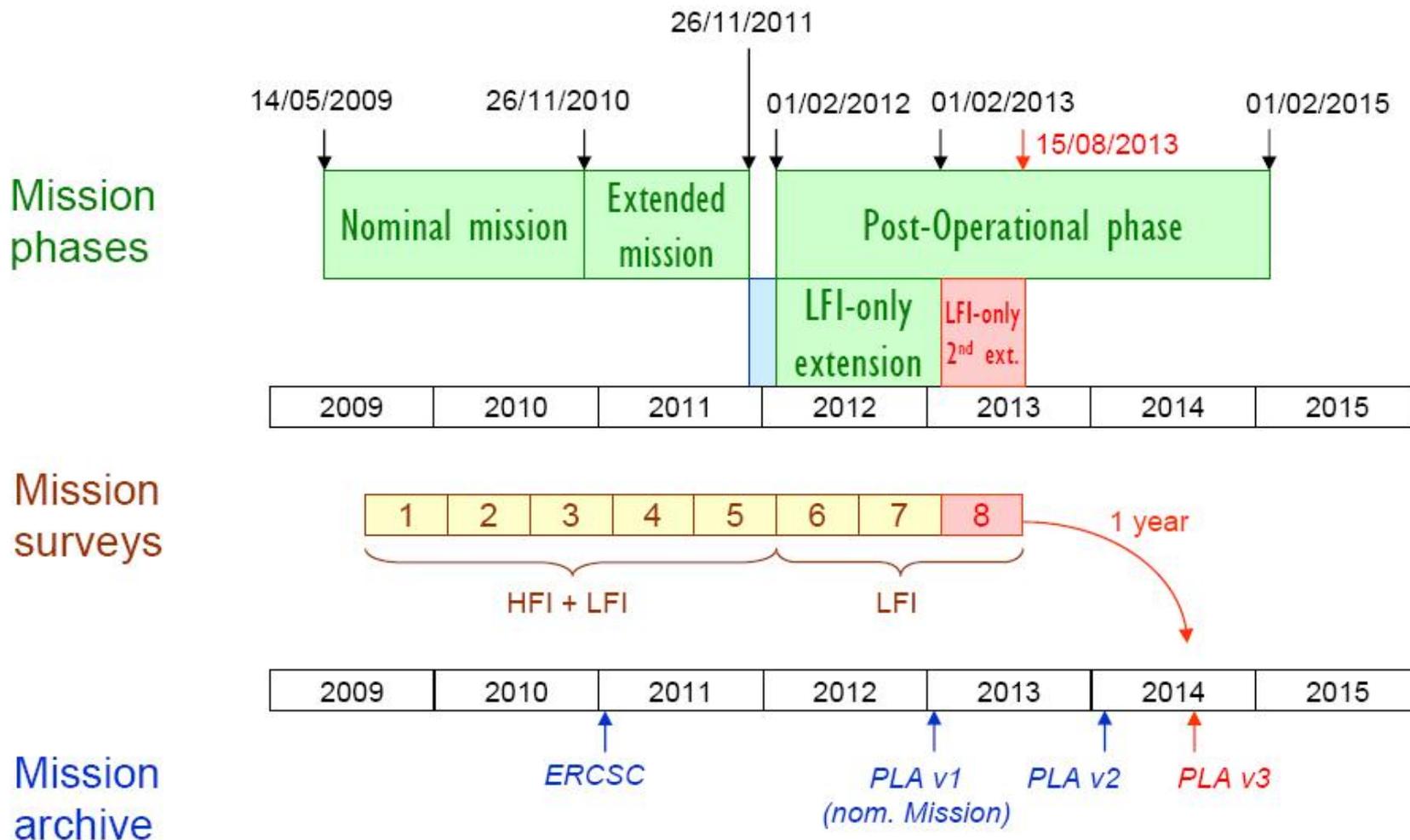
- 8x 100GHz
- 8x 143GHz
- 8x 217GHz
- 8x 353GHz



LFI
high-electron
mobility
transistors

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

operational timeline



THE MILLIMETER AND SUBMILLIMETER WAVELENGTHS IN THE PLANCK MISSION

PARIS, FRANCE
JANUARY 10-14 2011
CITÉ DES SCIENCES

The Planck satellite has been operating with outstanding accuracy, reaching the ambitious goals of Planck in Cosmic Microwave Background (CMB) on the ability to remove all foregrounds (galactic and extragalactic).

This conference will be aiming mostly at the physics particular of the lesser known polarized ones. The Planck implications of the cosmological goals for the CMB accuracy of the foreground removal will be reviewed.

SCIENCE ORGANIZATION

PLANCK SCIENCE TEAM

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ASTROPHYSICS FROM THE MILLIMETER
TO THE SUBMILLIMETER
PLANCK AND OTHER EXPERIMENTS
IN TEMPERATURE AND
POLARIZATION

13-17 February 2012

Area della Ricerca del CNR
BOLOGNA, ITALY

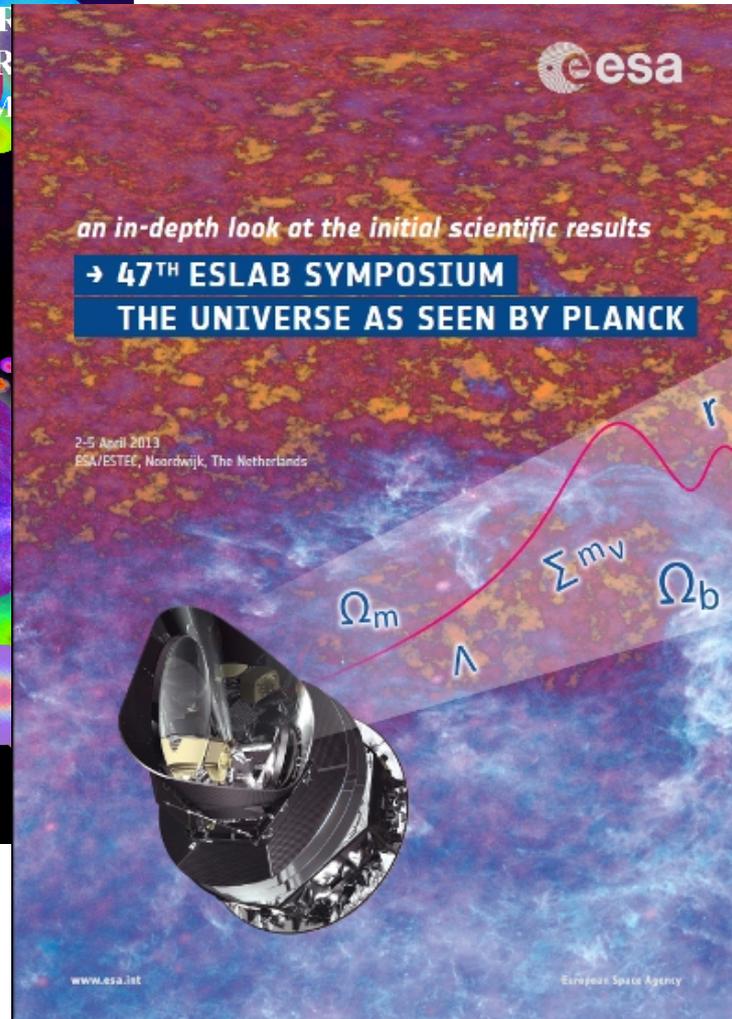


an in-depth look at the initial scientific results

→ **47TH ESLAB SYMPOSIUM**

THE UNIVERSE AS SEEN BY PLANCK

2-5 April 2013
ESA/ESTEC, Noordwijk, The Netherlands



www.esa.int

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
His whole affair named...
ECB situation on bank bailout...
Cyprus unveils fresh rescue plan

The universe that isn't as we know it
New view of oldest light in the sky

Existing homeowners can take advantage of Help to Buy scheme

Cricket Academy

Football Health

The New York Times

International Herald Tribune

Obama asks Israel and Palestinians to talk again

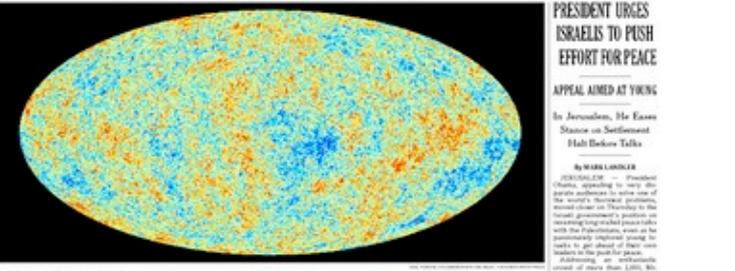
Once rarity, women are U.S. Senate force

Fast-Growing Brokerage Firm Often Tangles With Regulators

Once Few, Women Hold More Power in Senate

Moody Downside in Cyprus Ahead of Bailout Deadline

O Revelations! Letters, Once Banned, Flesh Out Wilka Cather



The Moon, Seen as the Day
An image from James Webb's Space Agency will show a clear view of the moon as it appears at 270,000 miles from the Big Bang. Page A15.

Once Few, Women Hold More Power in Senate

By JENNIFER SCHLESINGER

Ms. Olympia's induction that January day in 1992 into the Senate... A second time women are leading... The 40 years since Barbara...



Chief of Police

Fast-Growing Brokerage Firm Often Tangles With Regulators

By NATHANIEL POPPER

The firm searched for an optimal... Whether to jump ahead of the stock market's recent rebound...



Mood Darkens in Cyprus Ahead of Bailout Deadline

An outbreak of anger in Cyprus... Moody's downgraded the island nation's credit rating...

O Revelations! Letters, Once Banned, Flesh Out Wilka Cather

By JENNIFER SCHLESINGER

From the days of O. J. Simpson... Cather was believed to have...

esa

UNIFE

Business

Spain Inquiry in Europe

Computers at a New Level

New Legal Tactic for Embellish

Editorial: Of Eds and Aps

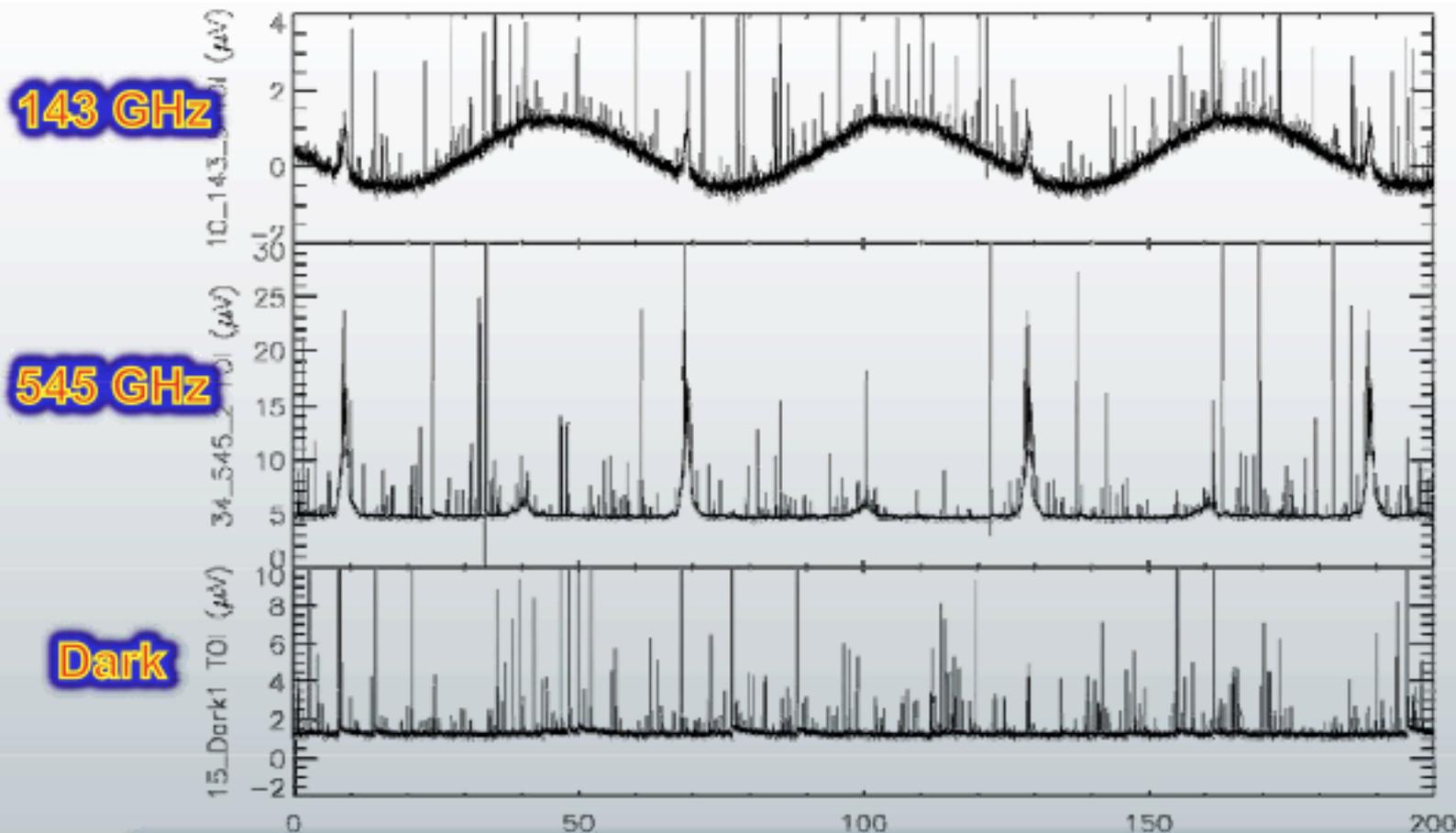
Paul Krugman

Cartier

AGENZIA SPAZIALE ITALIANA

INAF ISTITUTO NAZIONALE DI ASTRONOMIA

(nearly) raw data stream

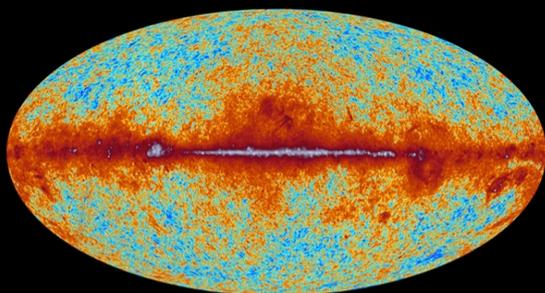


3 minutes of quasi 'raw' data (i.e. only demodulated). The Solar (cosmological) dipole is clearly visible at 145GHz with a 60 seconds period (the satellite rotates at 1 rpm), while the Galactic plane crossings (2 per rotation) are more visible at 545 GHz than at 143 GHz. The Dark bolometer sees no sky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

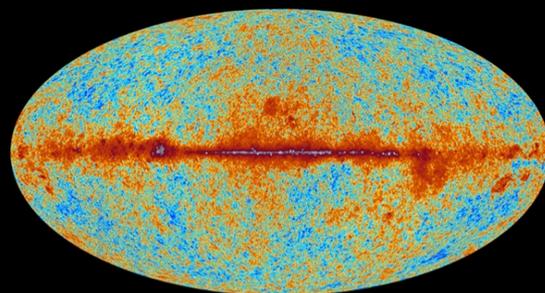


planck

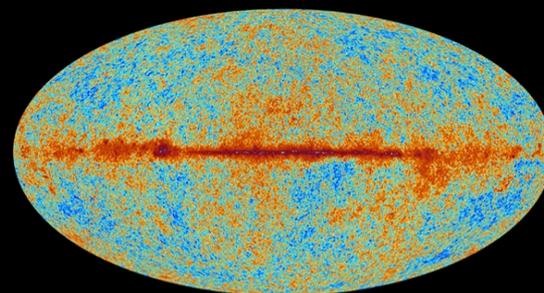
The sky as seen by Planck



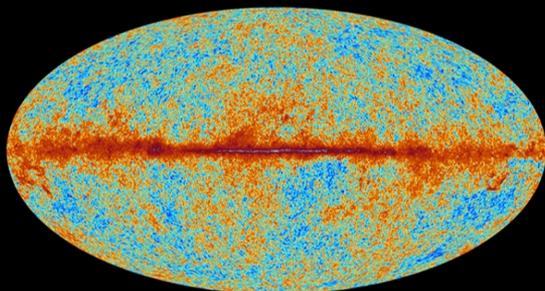
30 GHz



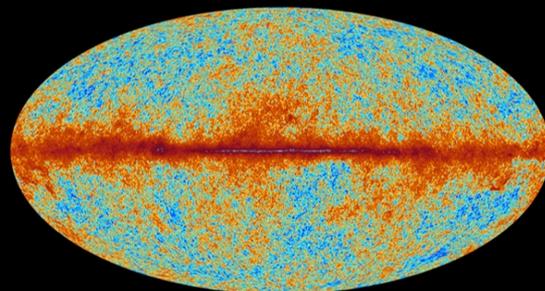
44 GHz



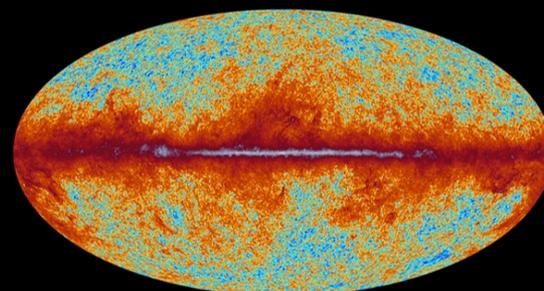
70 GHz



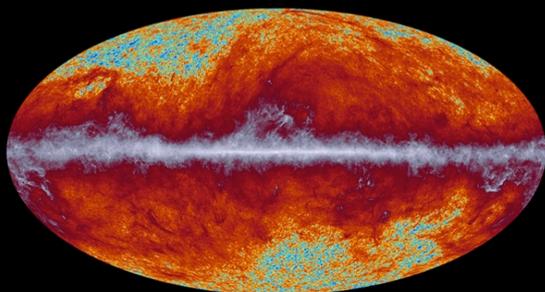
100 GHz



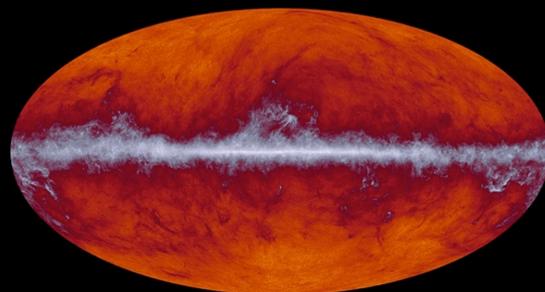
143 GHz



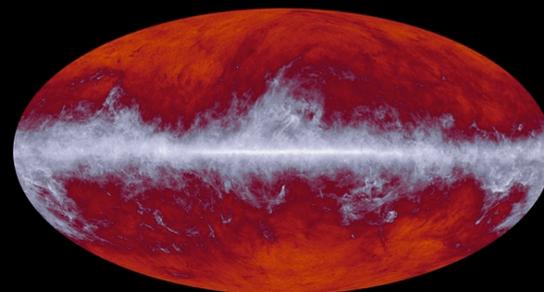
217 GHz



353 GHz



545 GHz

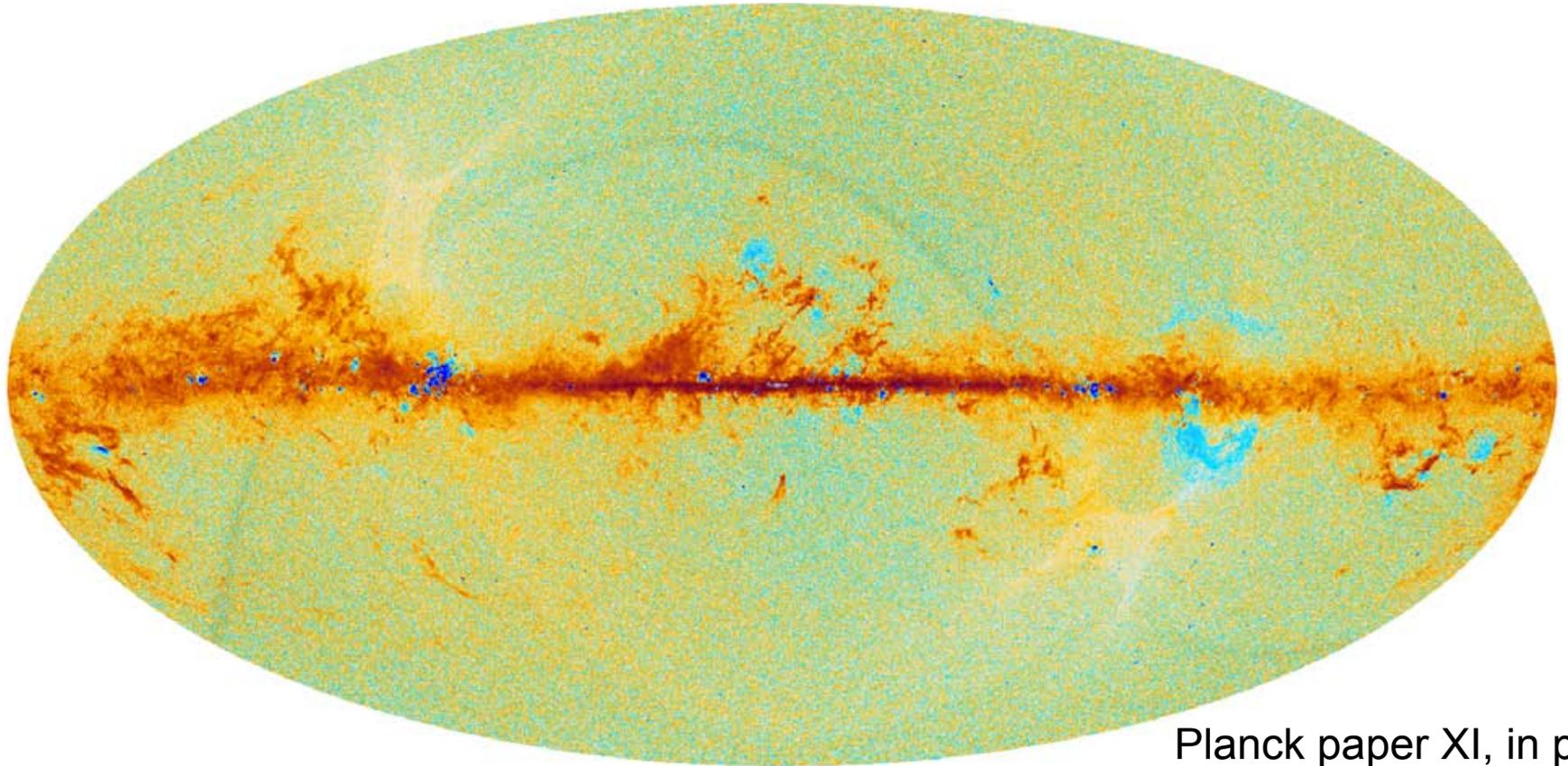


857 GHz

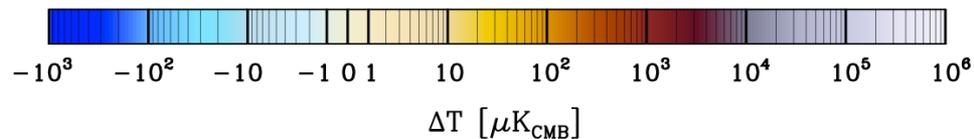
See next talk by Maude le Jeune.

Consistency: HFI 100 GHz – LFI 70 GHz

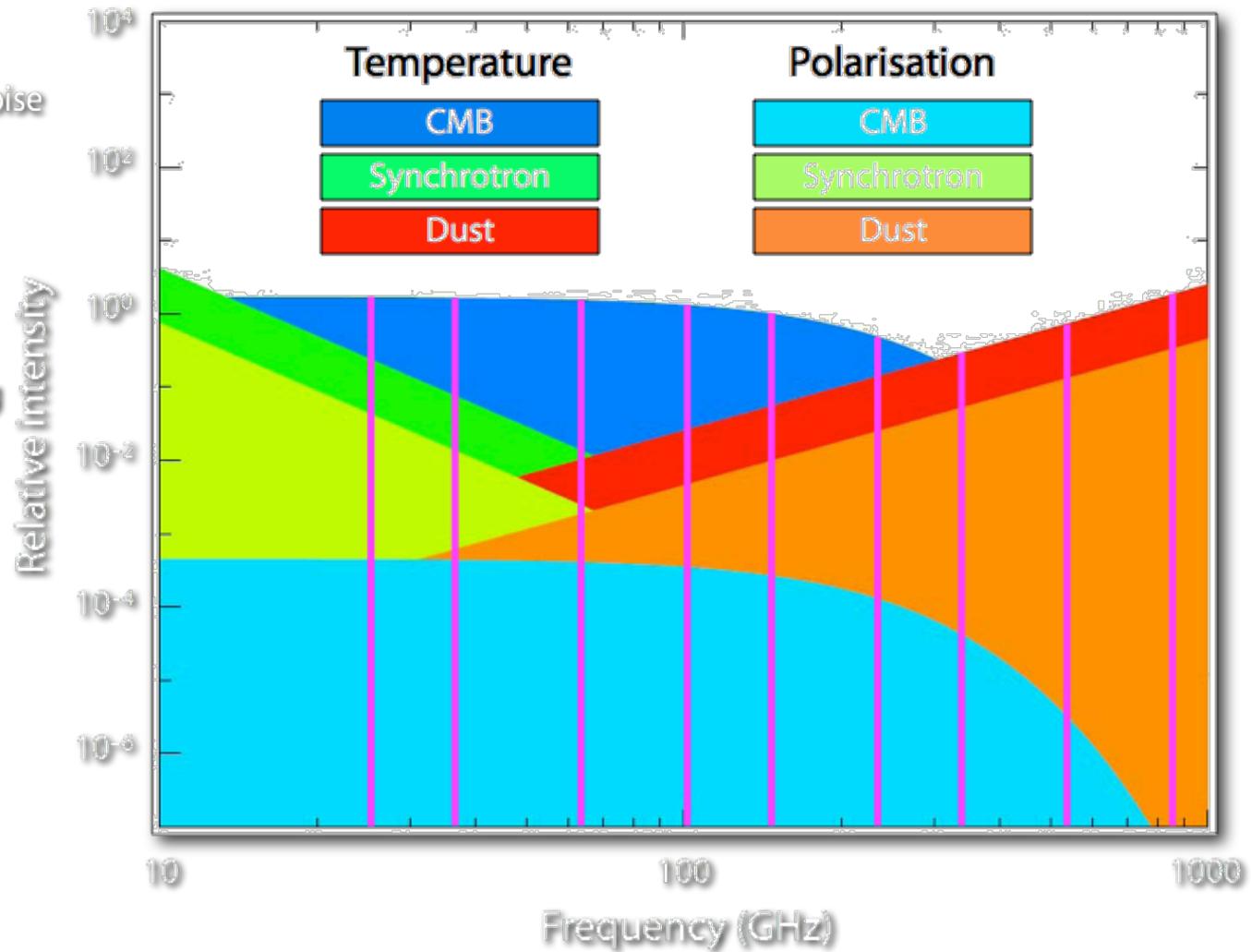
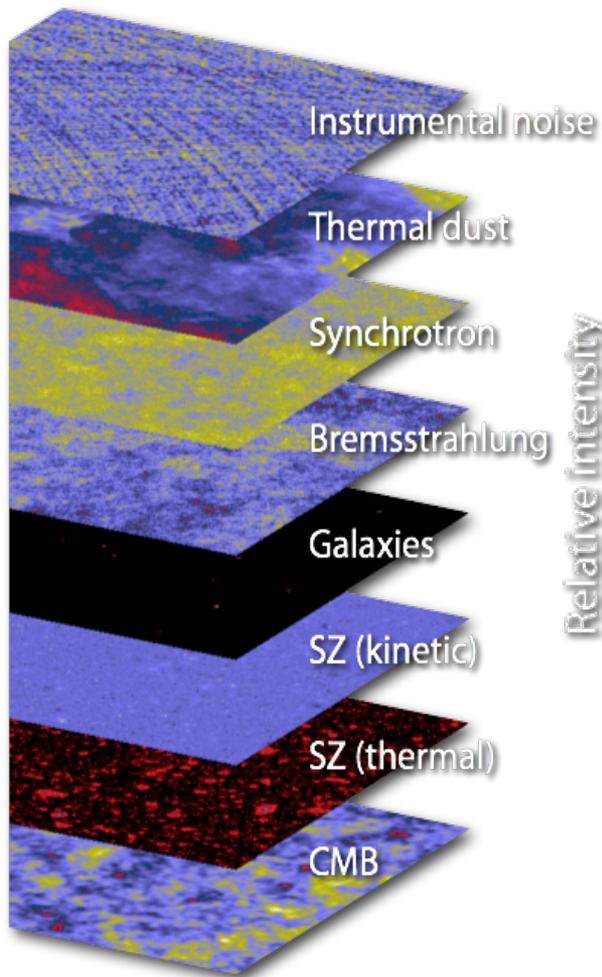
Red is mostly CO, Blue is mostly free-free. CMB is gone!



Planck paper XI, in prep.

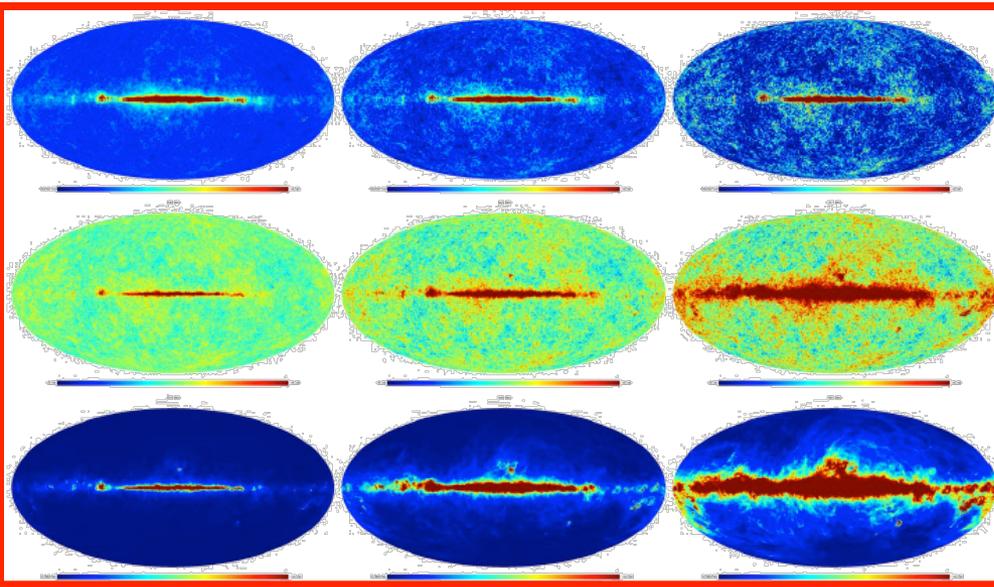


Layers on the sky

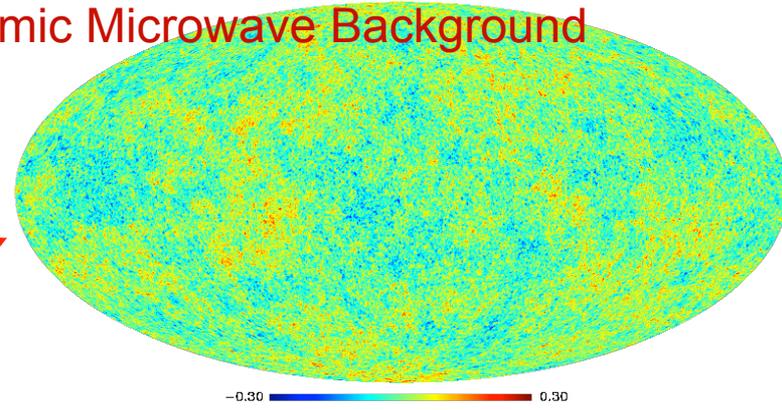


Expected results from simulations

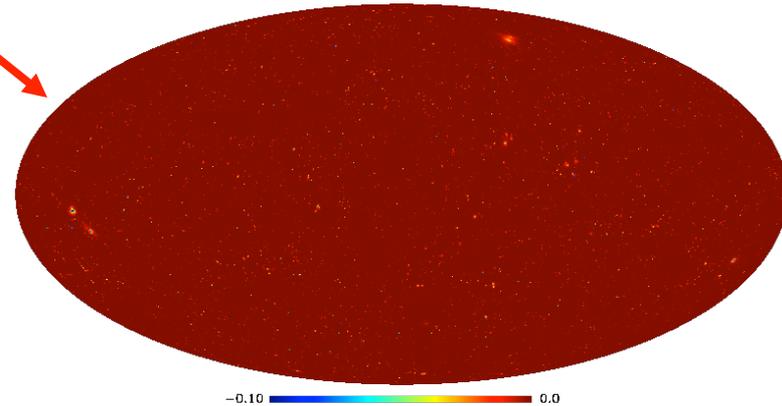
30, 44, 70, 100, 143, 217, 353, 545, 857 GHz – I, Q, U at all channels
Except 545 & 857 GHz



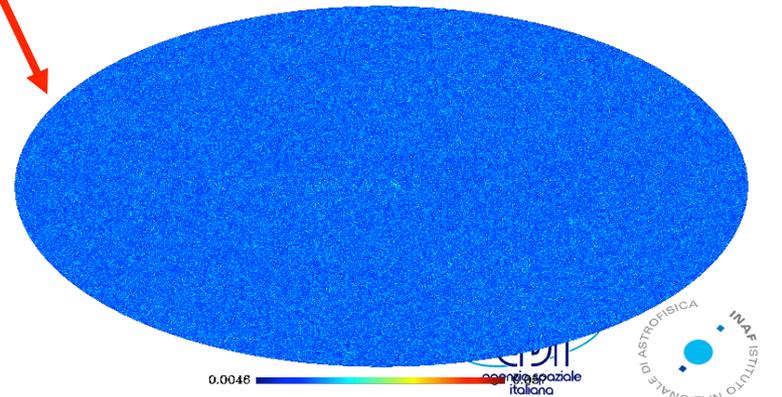
Cosmic Microwave Background



Sunyaev-Zeldovich

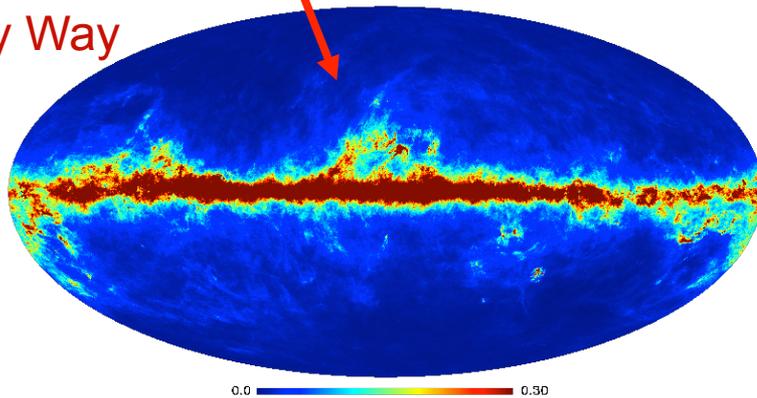


Point & Compact sources



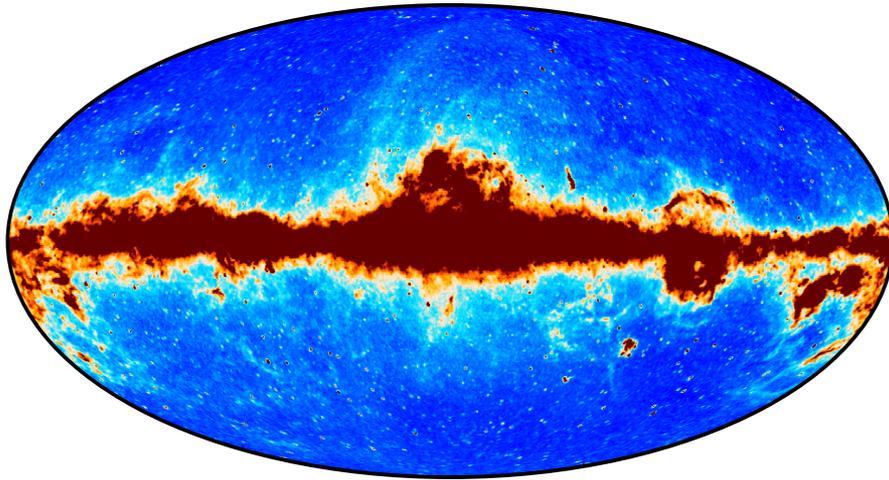
galaxy_143GHz_2048.fits: UNKNOWN1

The Milky Way

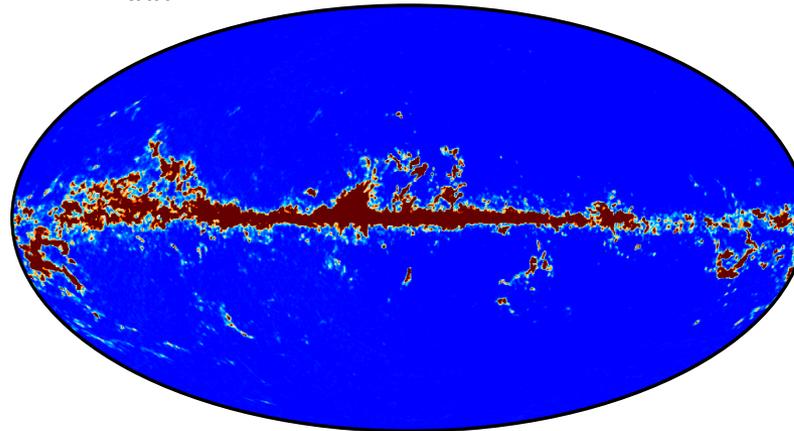
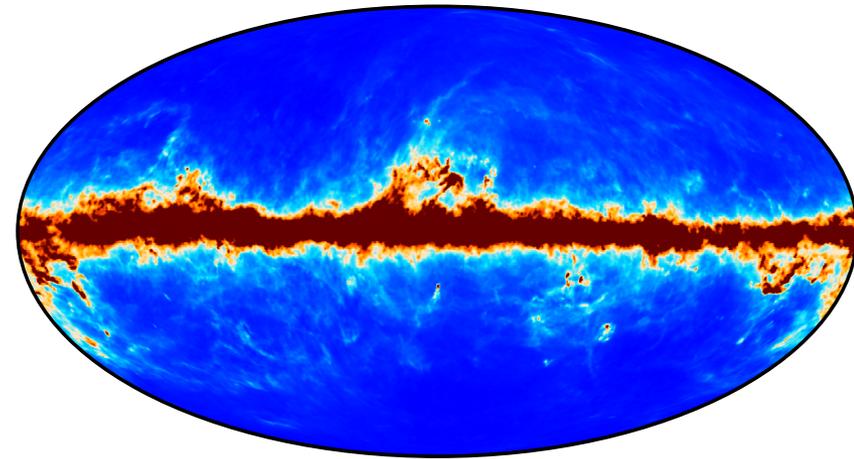


Emission from the Milky Way

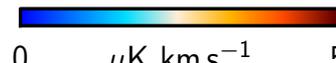
Non-thermal radio emission



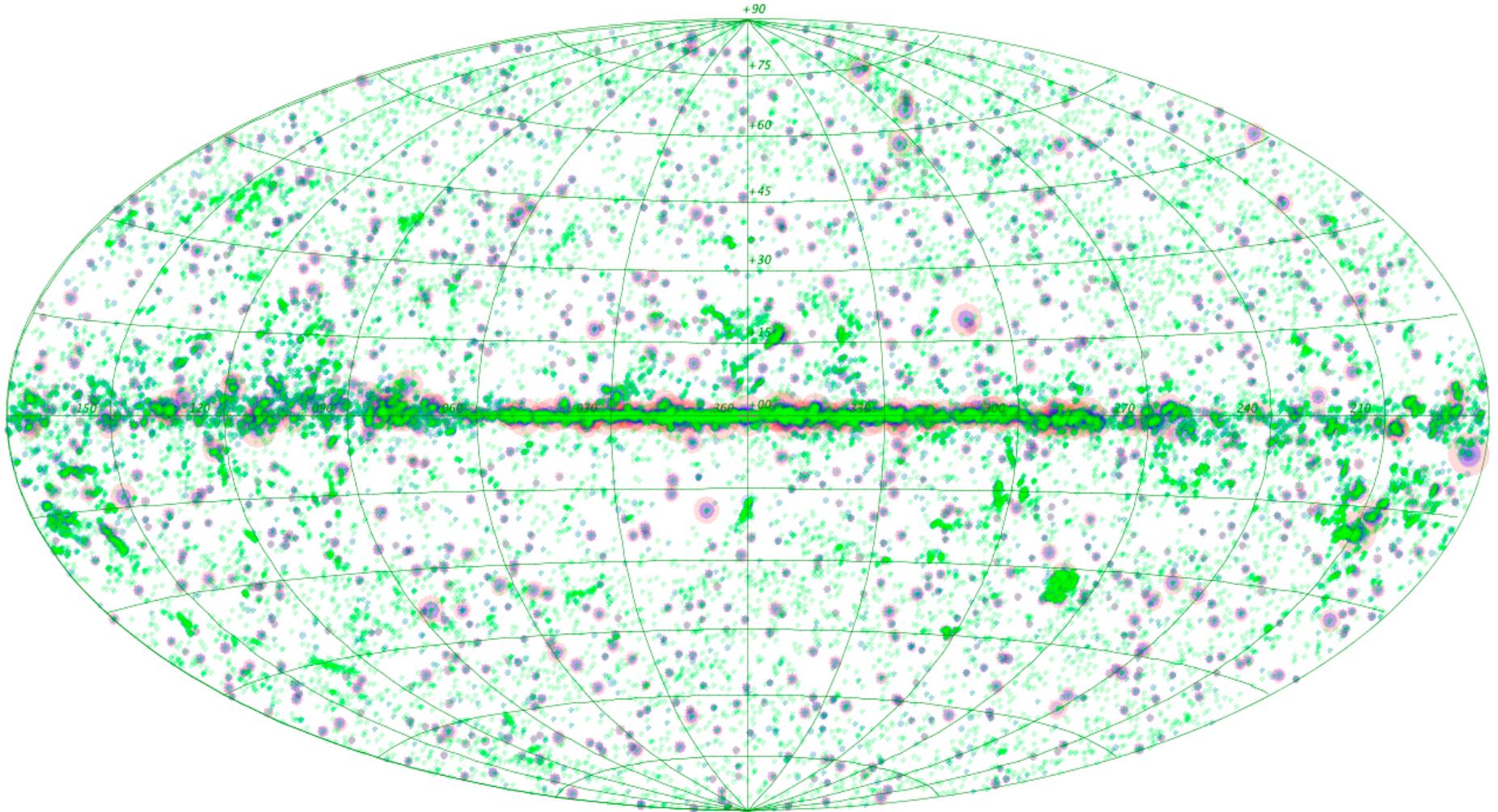
Thermal dust emission



Carbon monoxide

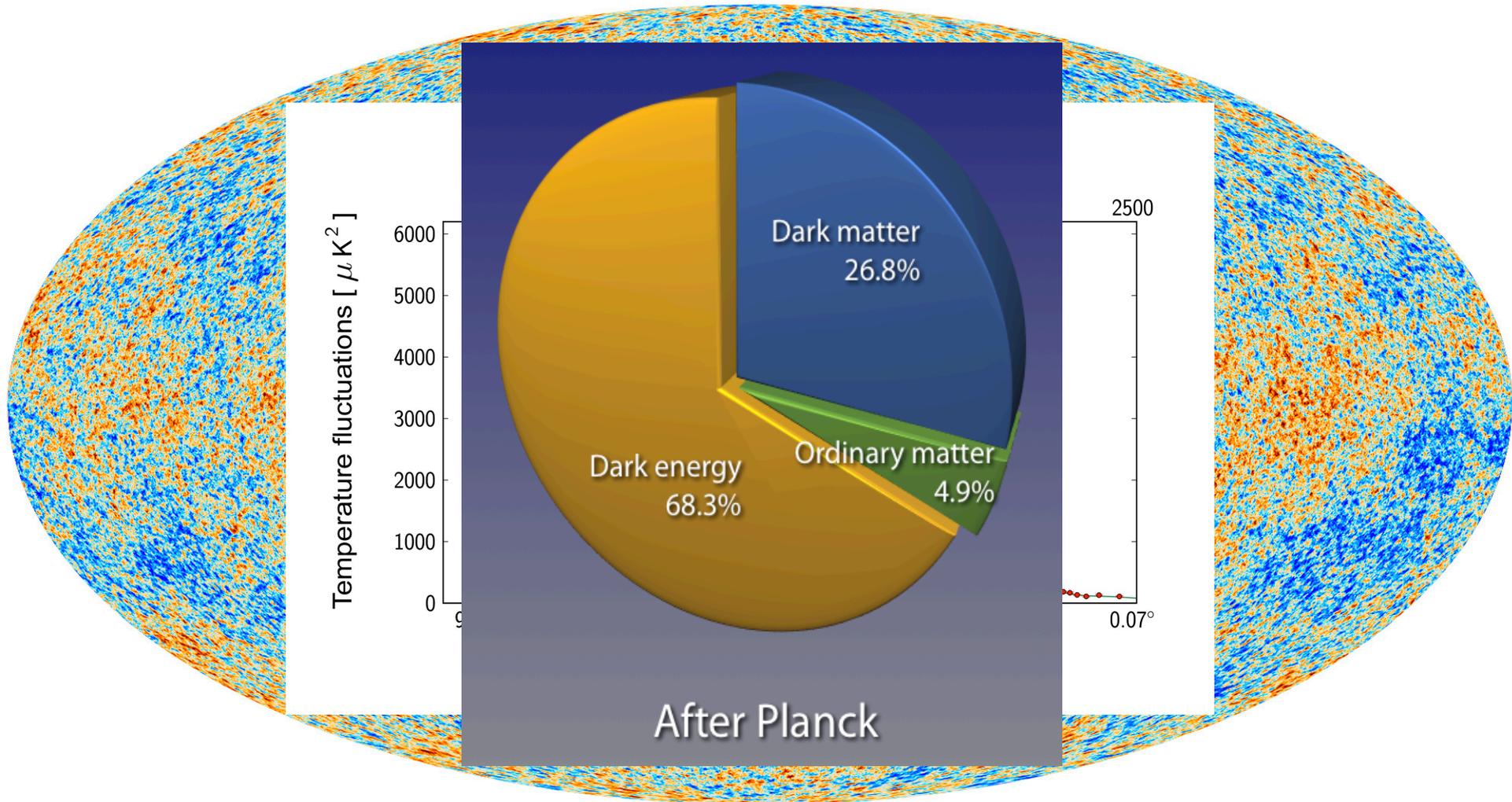


Compact galactic and extragalactic sources

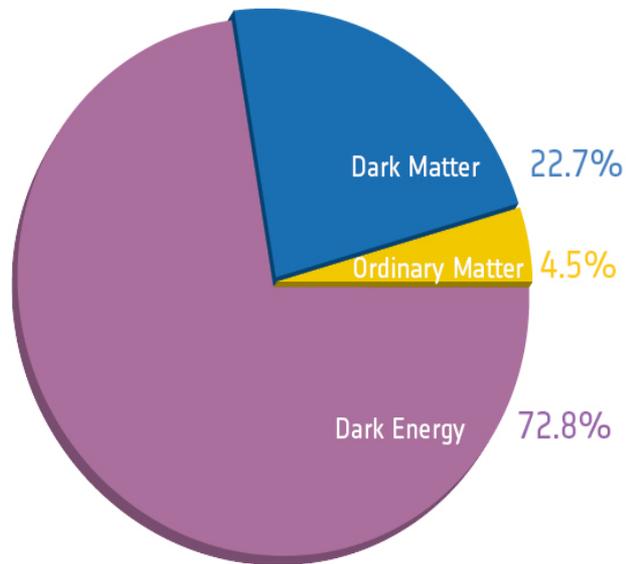


See talks by Ludovic Montier and Marcos Lopez Caniego

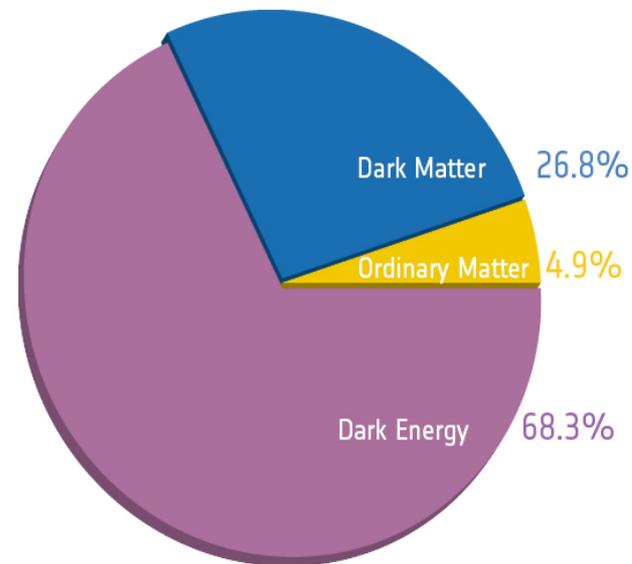
The anisotropies of the CMB



The basic content of the Universe



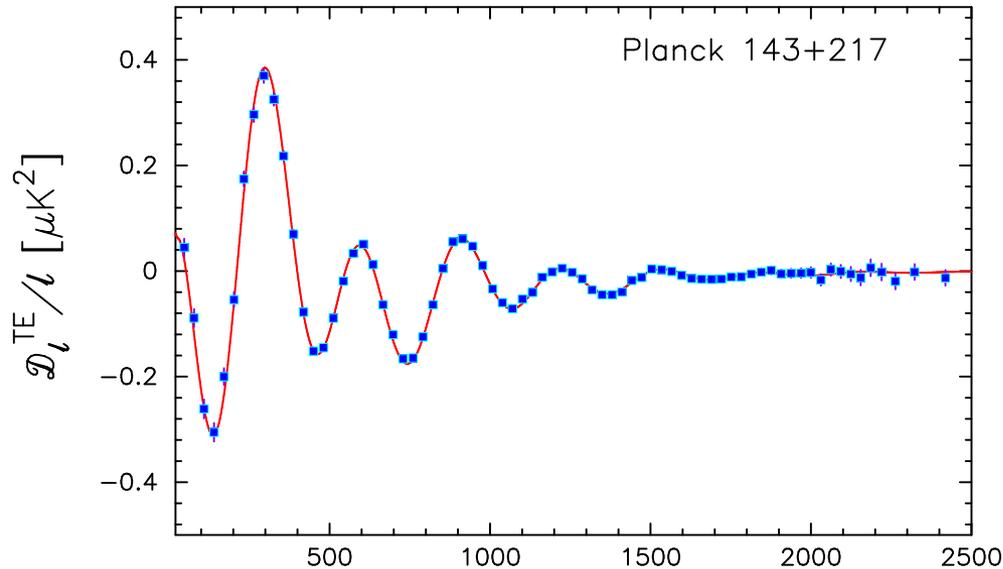
Before Planck



After Planck

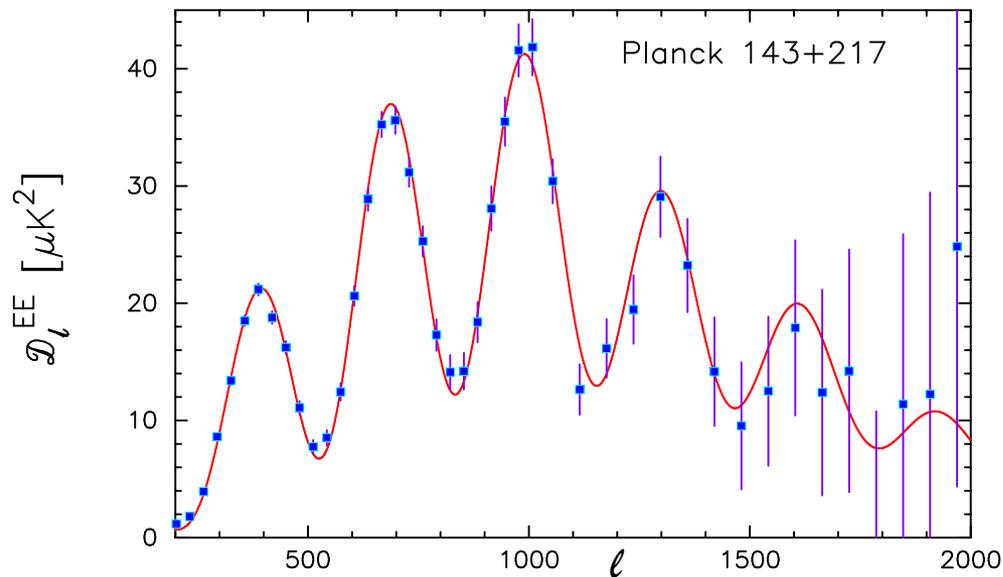
...has changed! (More about cosmological parameters later)

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.

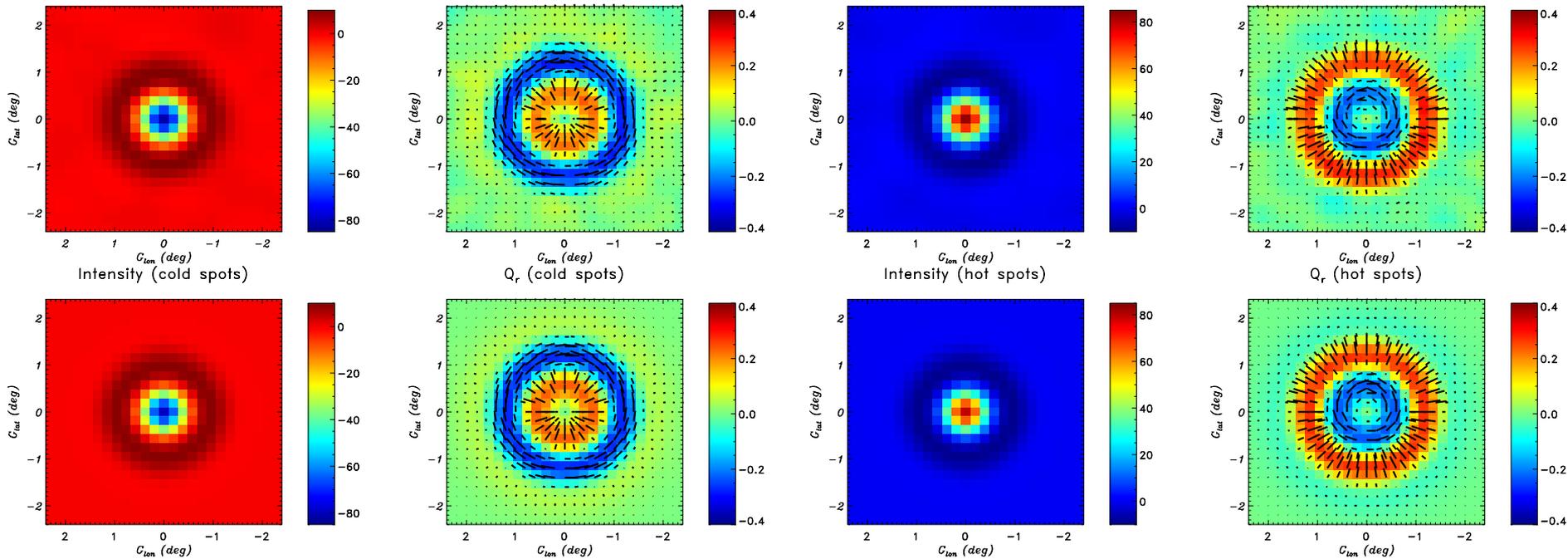
The red line is not a fit to the polarization data, but the predicted curve from the Λ CDM model assuming the temperature data!



Polarization and hot spots

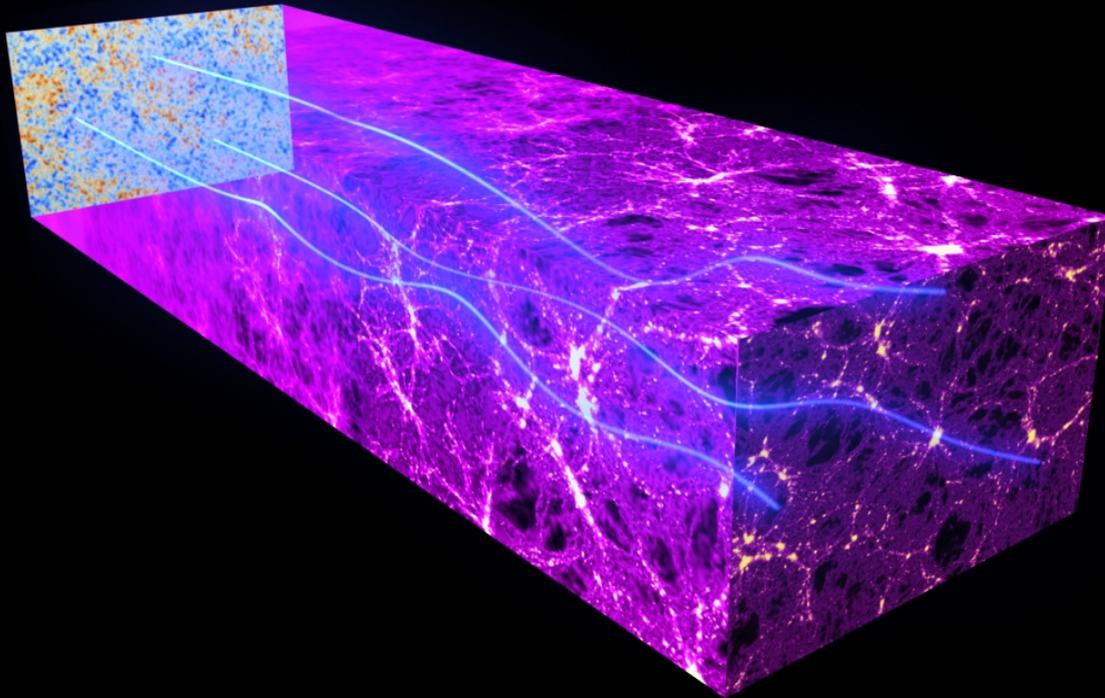
Stack hot/cold spots in the CMB. See the TE correlation in real space!

Remarkable proof of inflation: existence of super-horizon fluctuations



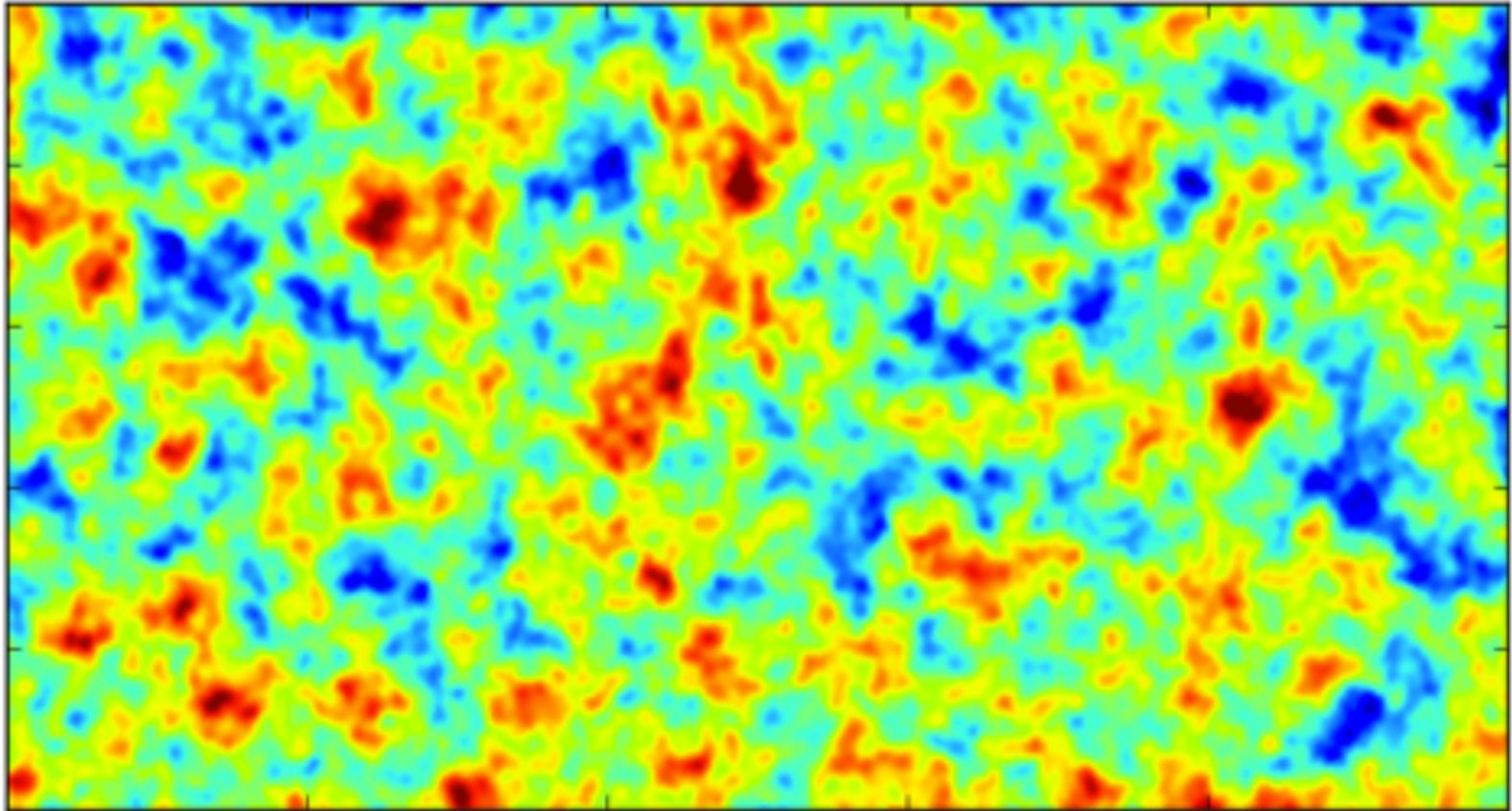
PLANCK PROBES AND EXPLOITS CMB LENSING

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

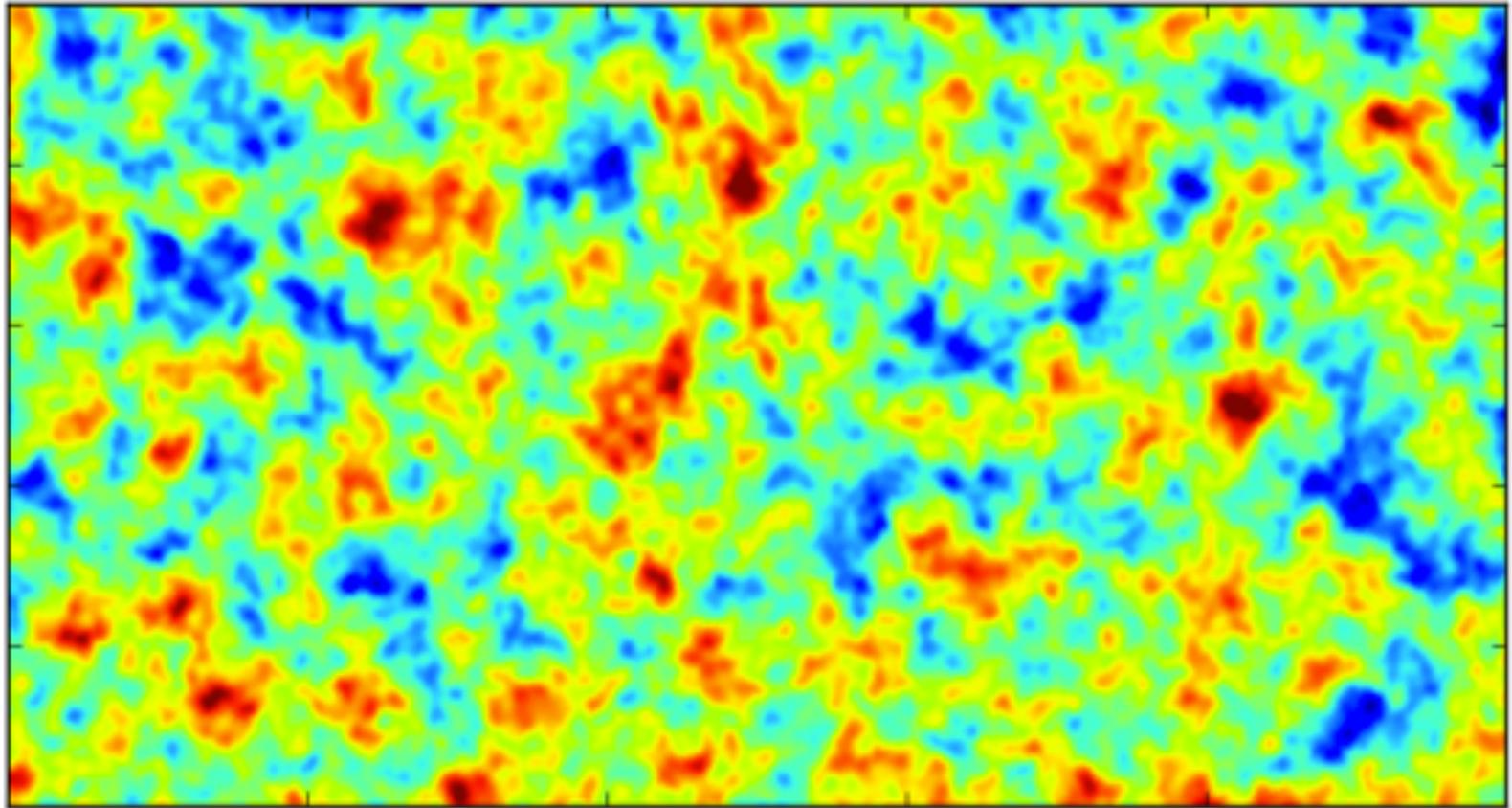
A simulated patch of CMB sky – **before lensing**



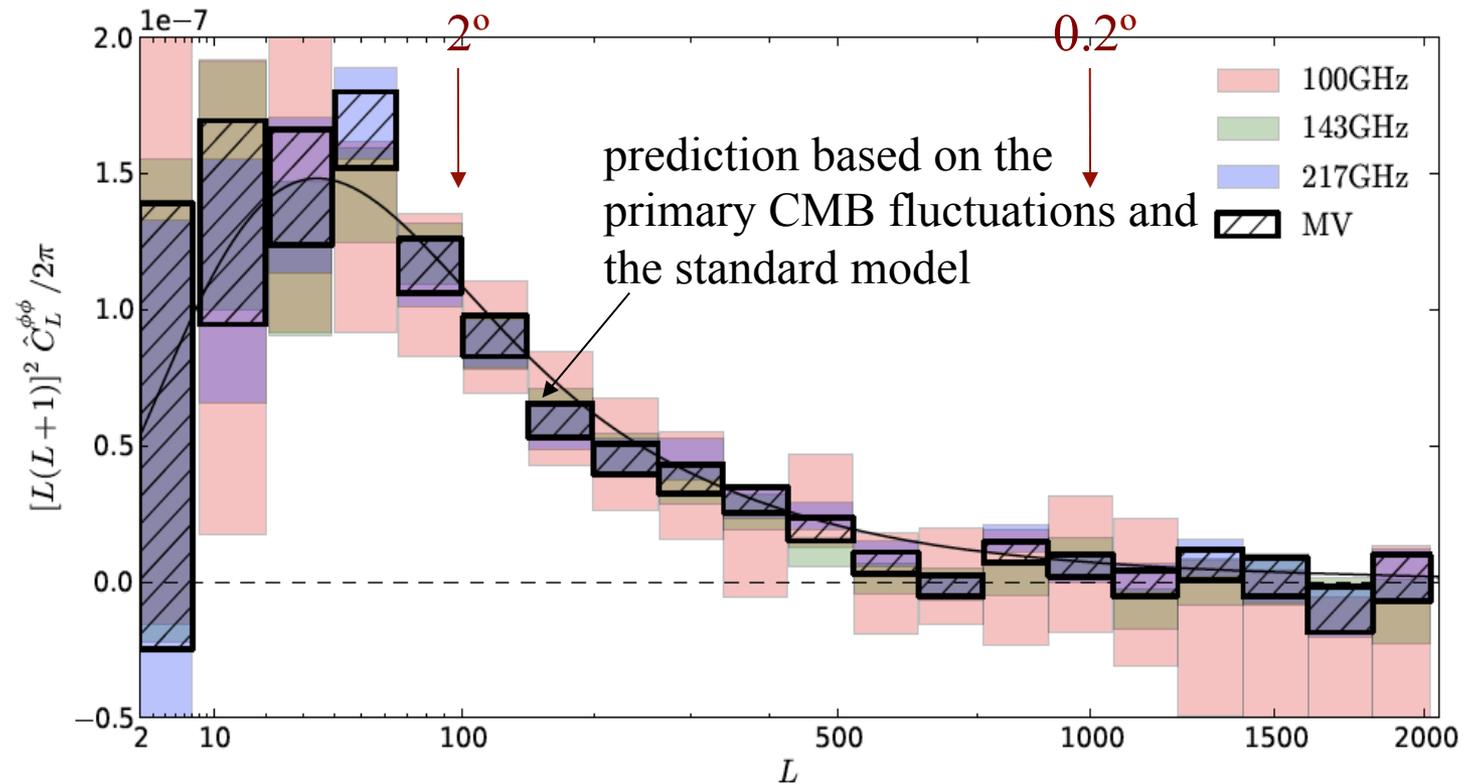
10°

GRAVITATIONAL LENSING OF THE CMB

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



PLANCK LENSING POTENTIAL POWER SPECTRUM



It is a 25 sigma effect!!

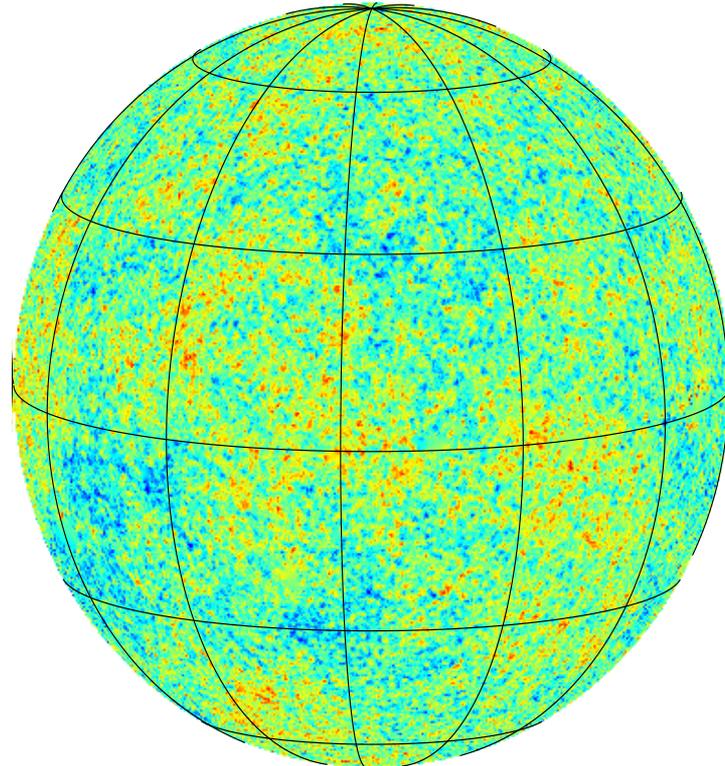
Non Gaussianity in the CMB

Nearly perfectly Gaussian fluctuations are a prediction of the inflation.

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

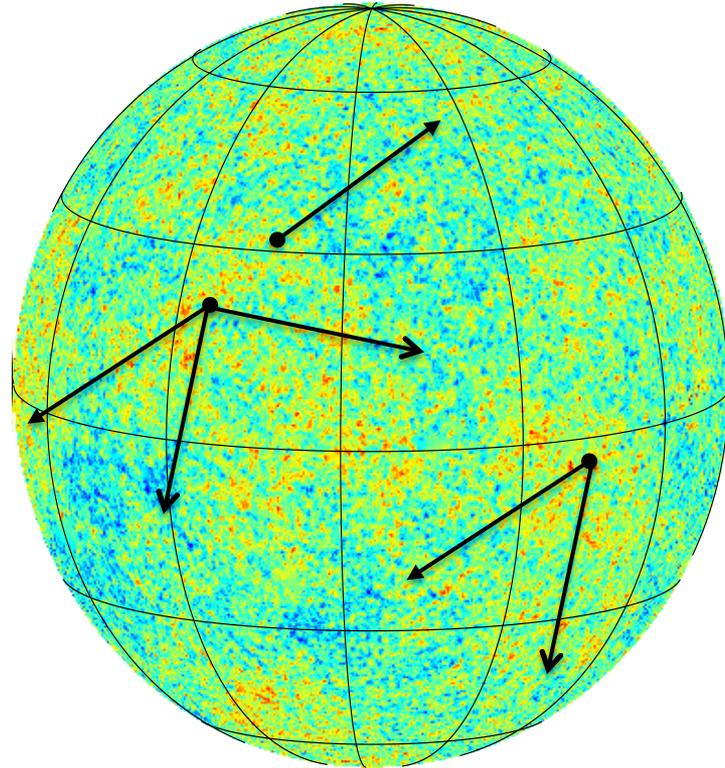
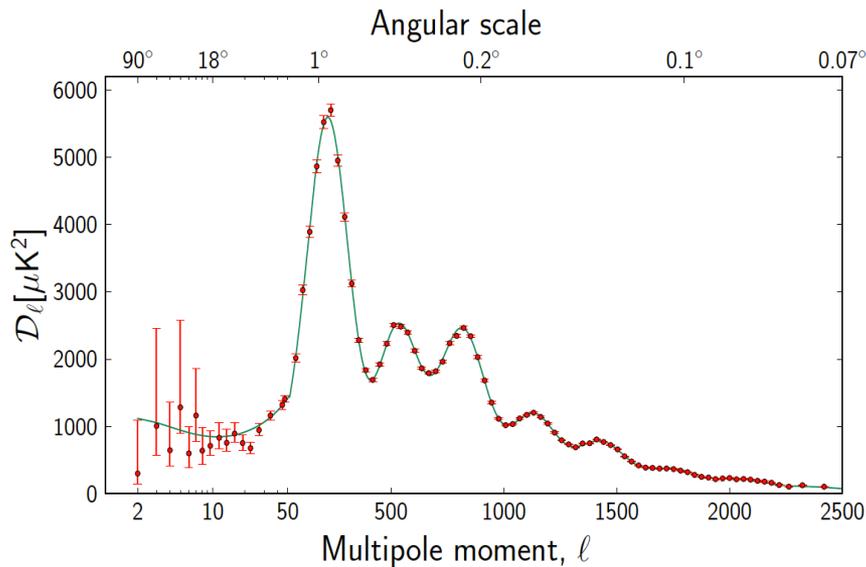
$$\frac{\Delta T}{T} + \text{const.} \times f_{NL} \left(\frac{\Delta T}{T} \right)^2$$

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



How test for Gaussianity? And how?

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

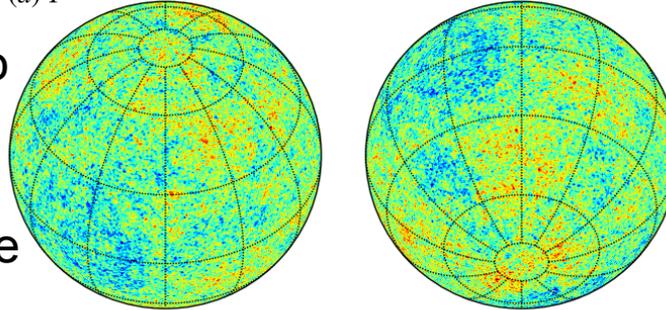


To check for non Gaussianity you can compare three points at more angles: the “power” bispectrum (TTT) and trispectrum (TTTT).

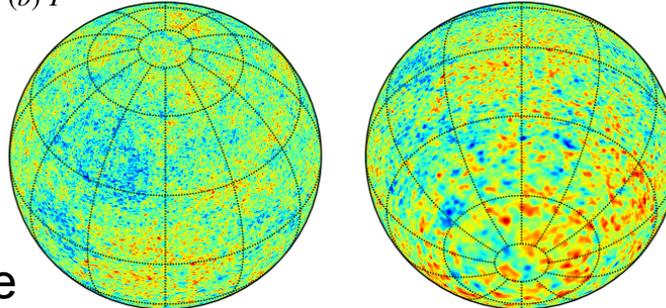
See talk by Michele Liguori

Doppler boosting of the CMB: eppur si muove!

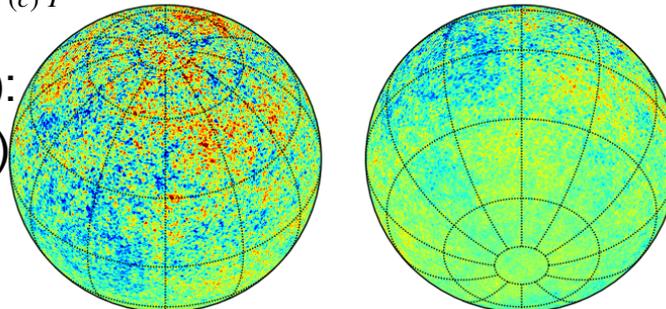
(a) $T^{\text{PRIMORDIAL}}$



(b) $T^{\text{ABERRATION}}$



(c) $T^{\text{MODULATION}}$



Simulated CMB

Aberration
for $\beta=0.85$

Modulation
for $\beta=0.85$

- 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 $\beta = v/c \sim 1/1000$
- Two main effects: aberration and dipole modulation
- This yielded the first measure of the Earth velocity independent from the CMB dipole (observed since 1977):
- $V=384 \pm 78$ (stat) ± 115 (sys) Km/s

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 Λ CDM model (but few hints of anomalies, stay tuned for the other talks)
- Strongly supports the **inflationary** scenario (Gaussianity, 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 reionization (presently still using WMAP)
 - Improved constraints on GW from inflation 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"