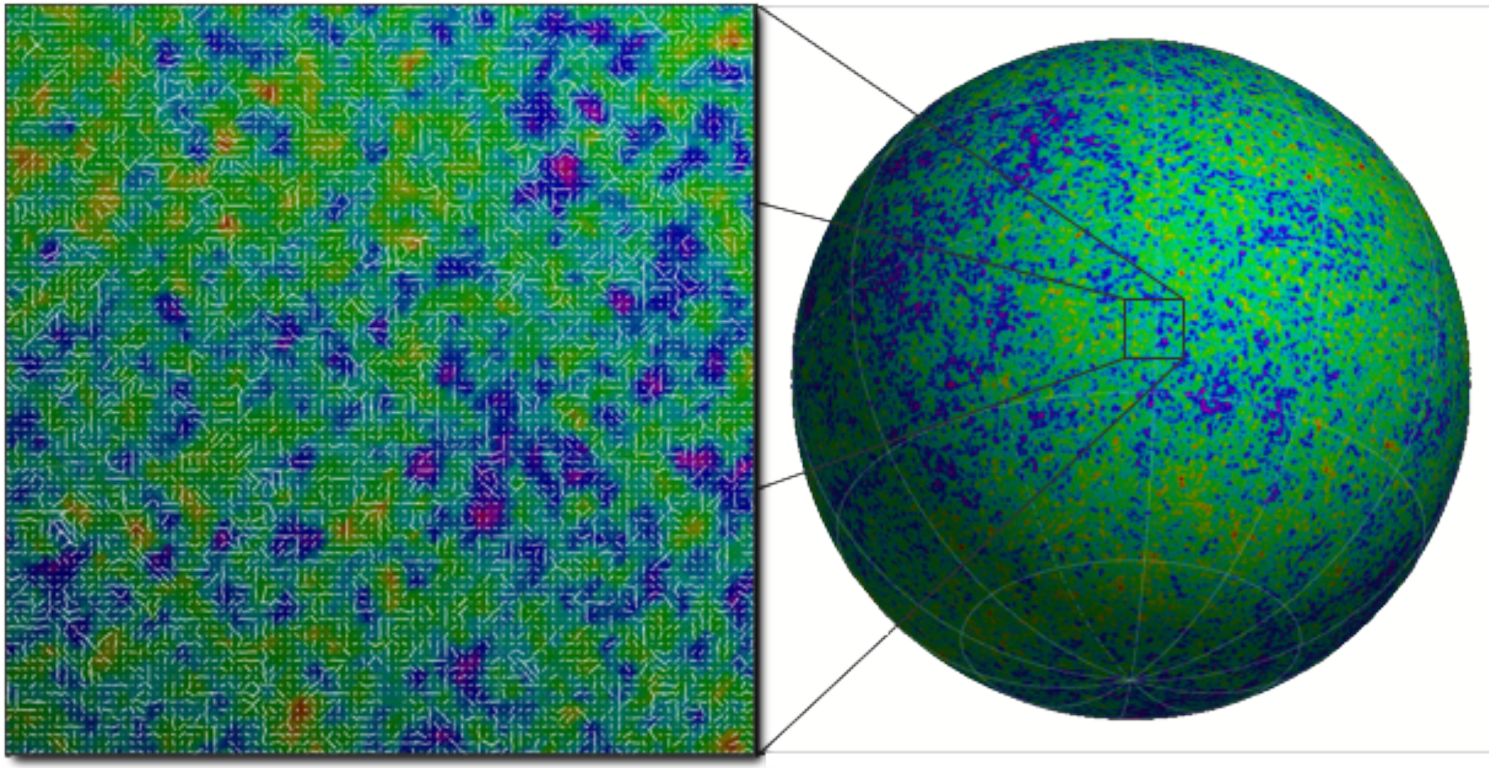
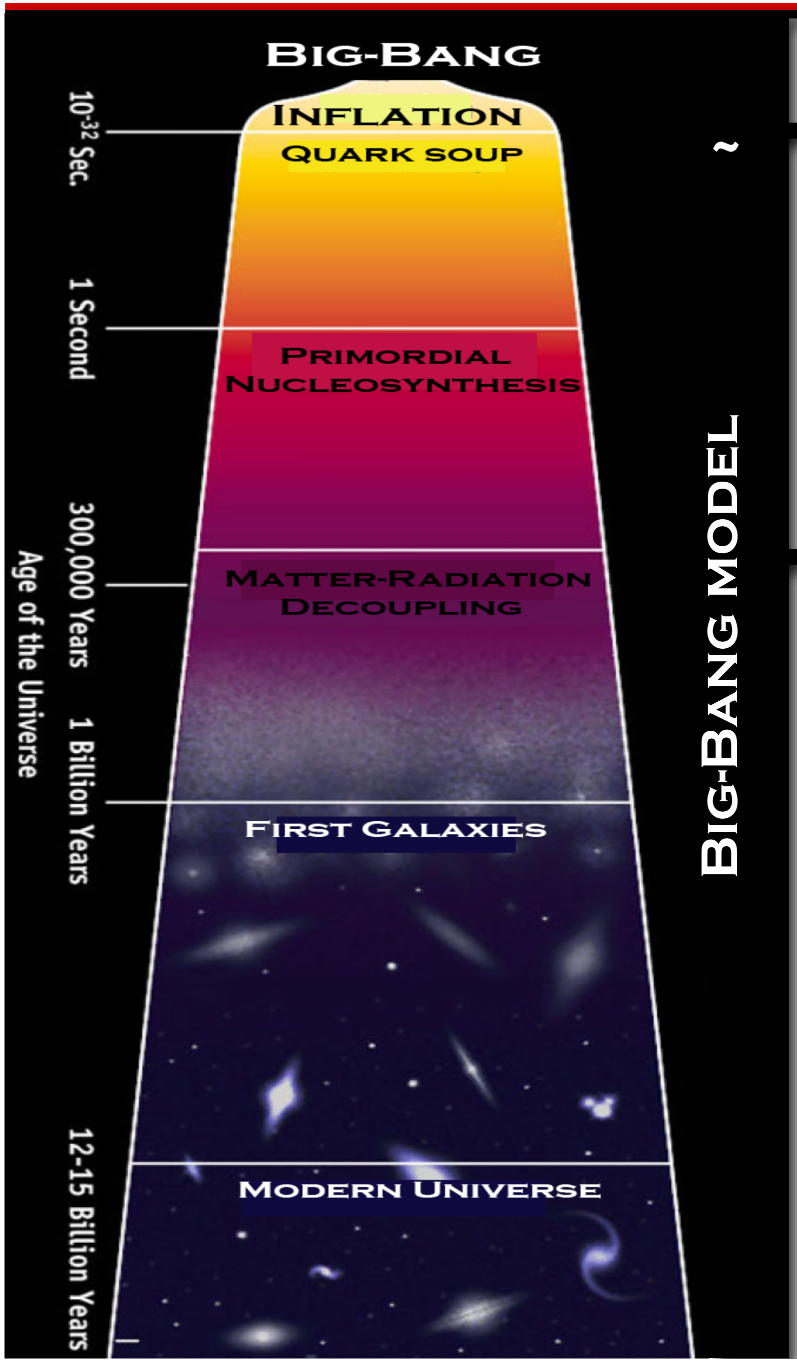
The Cosmic Microwave Background



Jonathan Aumont, IAS

Tuesday, June 8th 2010, PCHE workshop:
Galactic and extragalactic diffuse emissions

Story of the Universe



Inflation

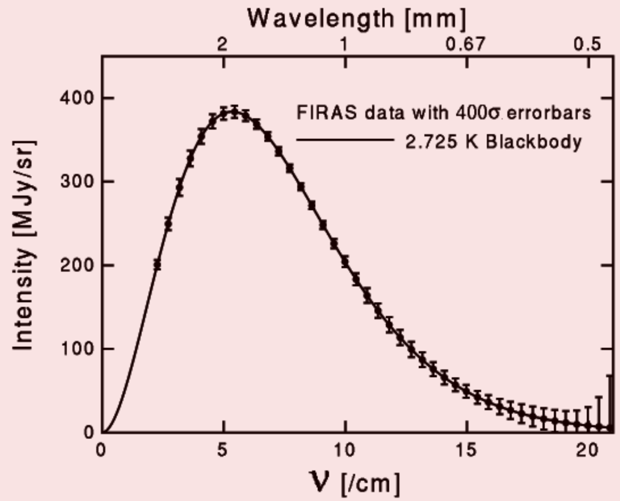
★*Exponentially accelerated expansion*
★*Scalar field*
★*Seed perturbations*

Matter-radiation decoupling

★*First atoms*
★*Emission of the CMB*

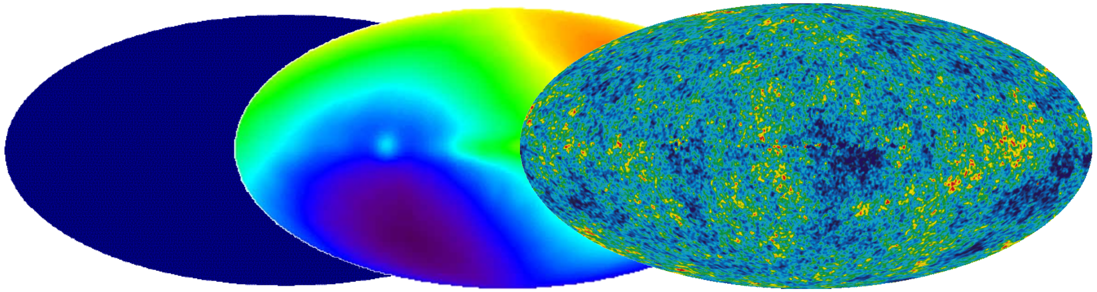
Universe at thermodynamic equilibrium

★*Black body spectrum*



The Cosmic Microwave Background

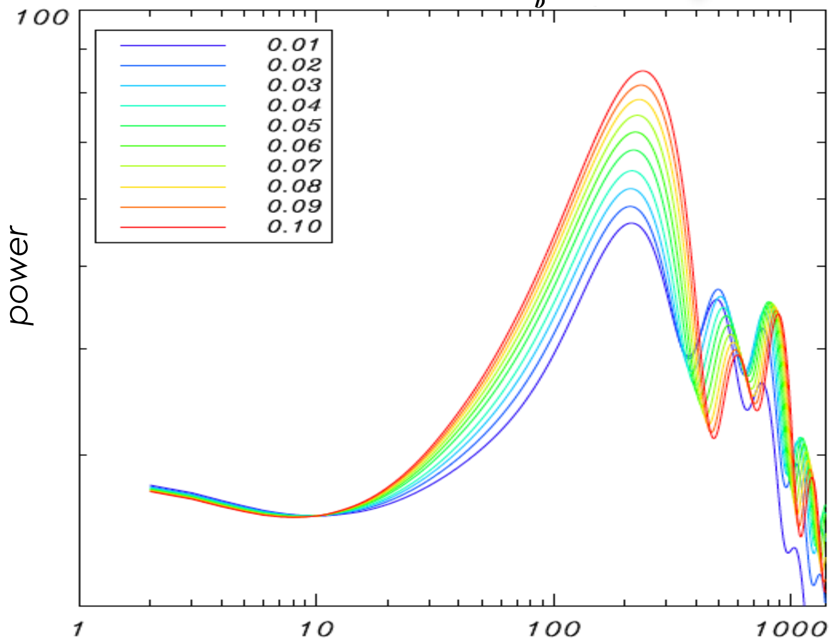
★*Radiation discovered by* [Penzias & Wilson 1965],
homogeneous and isotropic, $T = 2.725 \pm 0.001$ *K* [Fixsen & Mather 2002]
★*But anisotropies due to perturbations generated during Inflation epoch*



$T_0 = 2.725$ K $\Delta T = 3.353$ mK $\Delta T \approx 10\ \mu$K

$$\frac{\Delta T(\mathbf{n})}{T_0} = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a^T_{\ell m} Y_{\ell m}(\mathbf{n})$$

$$C_\ell^{TT} = \langle a^T_{\ell m} \cdot a^{T\star}_{\ell m} \rangle$$



Cosmological parameters
describing the content, geometry and story of the Universe

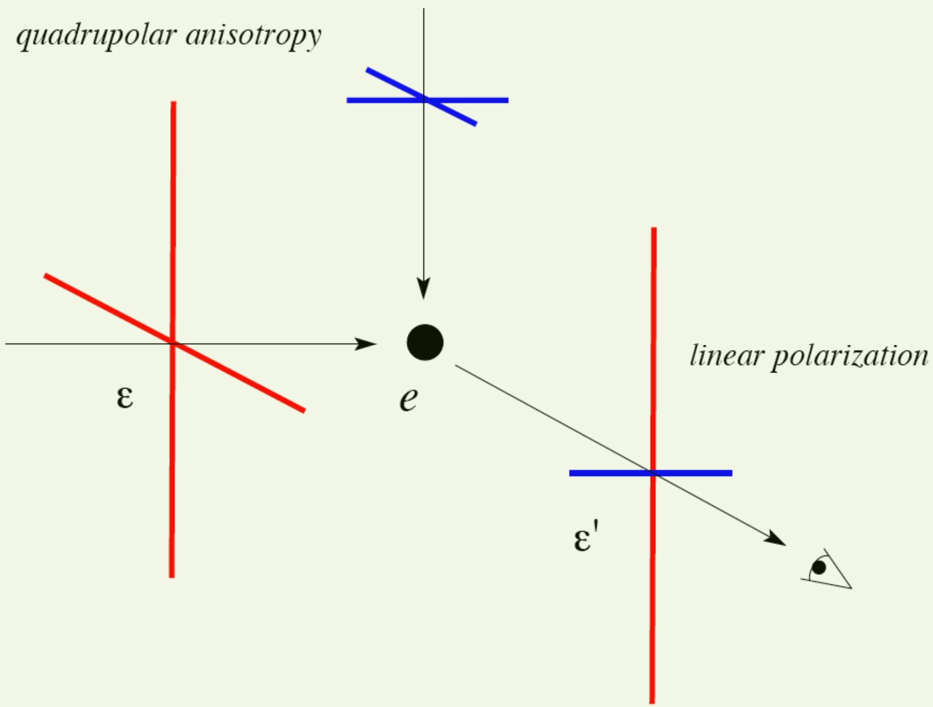
CMB polarization generation

CMB polarization generated by Thomson scattering

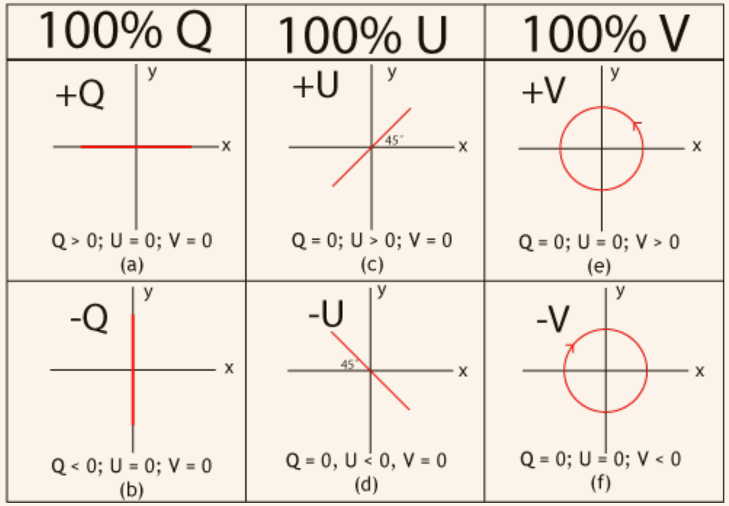
★Cross section:

$$\frac{d\sigma}{d\Omega} = \frac{3\sigma_T}{8\pi} |\varepsilon \cdot \varepsilon'|^2$$

★Local quadrupolar anisotropies responsible of CMB polarization



Stokes parameters formalism

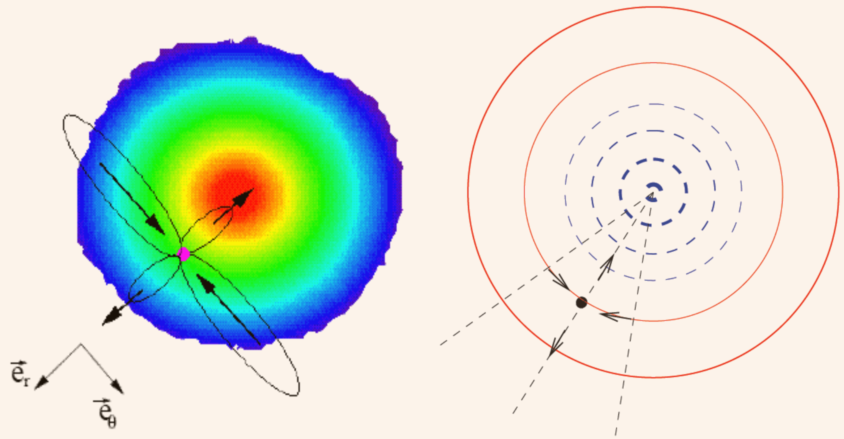


$$\begin{Bmatrix} I \\ Q \\ U \\ V \end{Bmatrix}$$

- ★ I, intensity
- ★ Q, U, linear polarization
- ★ V, circular polarization

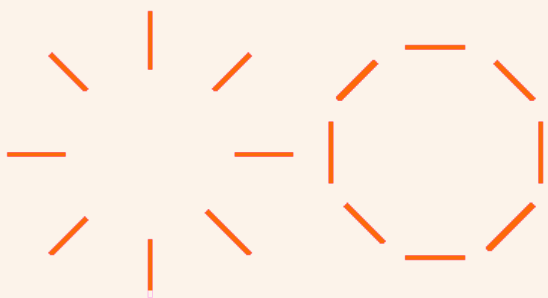
★in the case of the CMB, $V = 0$

Primordial perturbations

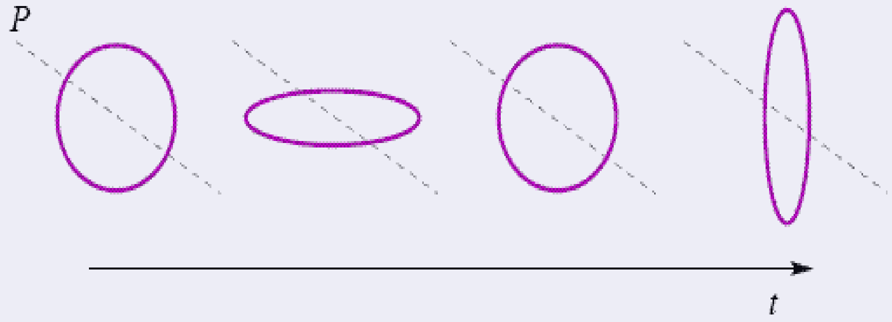


Scalar perturbations

(under- or over-densities) generate Q_r polarization



$+Q_r$ $-Q_r$

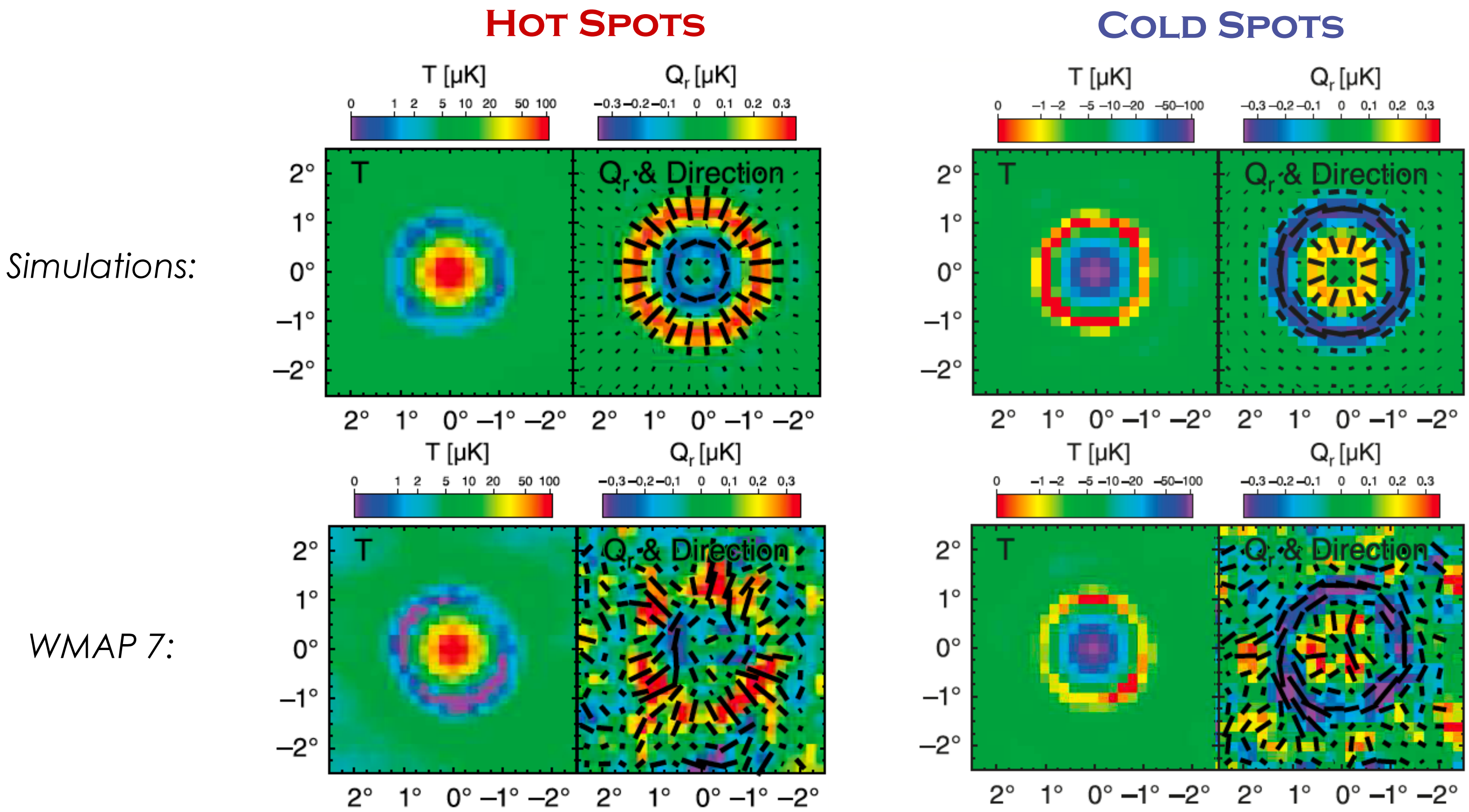


Tensor perturbations

(gravitational waves) generate Q_r and U_r polarization

$+U_r$ $-U_r$

Polarization patterns on the sky



★ *Stacking of the CMB degree-scale* $\boldsymbol{I}$, $\boldsymbol{Q}$ *and* $\boldsymbol{U}$ *maps at the positions of temperature hot (cold) spots*

★*Polrization pattern correlated to the temperature anisotropies clearly visible for the first time in WMAP 7 data*

[Dunkley *et al.* 2010]

Formalism of CMB polarization

Projection of the polarization
in the spinned spherical harmonics space

$$(Q \pm iU)(\mathbf{n}) = \sum_{\ell,m} a_{\pm 2\ell m} \cdot_{\pm 2} Y_{\ell m}(\mathbf{n})$$

*Construction of the **E** and **B** observables*
[Seljak & Zaldarriaga 1997]

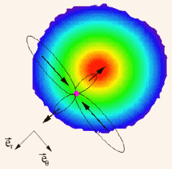
$$a^E_{\ell m} = -\frac{a_{2\ell m} + a_{-2\ell m}}{2}$$

$$E(\mathbf{n}) \equiv \sum_{\ell,m} a^E_{\ell m} Y_{\ell m} = \int w(\mathbf{n}-\mathbf{n}') Q_r(\mathbf{n}') d\mathbf{n}'$$

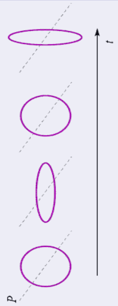
$$a^B_{\ell m} = i\frac{a_{2\ell m} - a_{-2\ell m}}{2}$$

$$B(\mathbf{n}) \equiv \sum_{\ell,m} a^B_{\ell m} Y_{\ell m} = \int w(\mathbf{n}-\mathbf{n}') U_r(\mathbf{n}') d\mathbf{n}'$$

★*new observables independent of the chosen frame*
★ $E = f(Q_r)$, $B = f(U_r)$



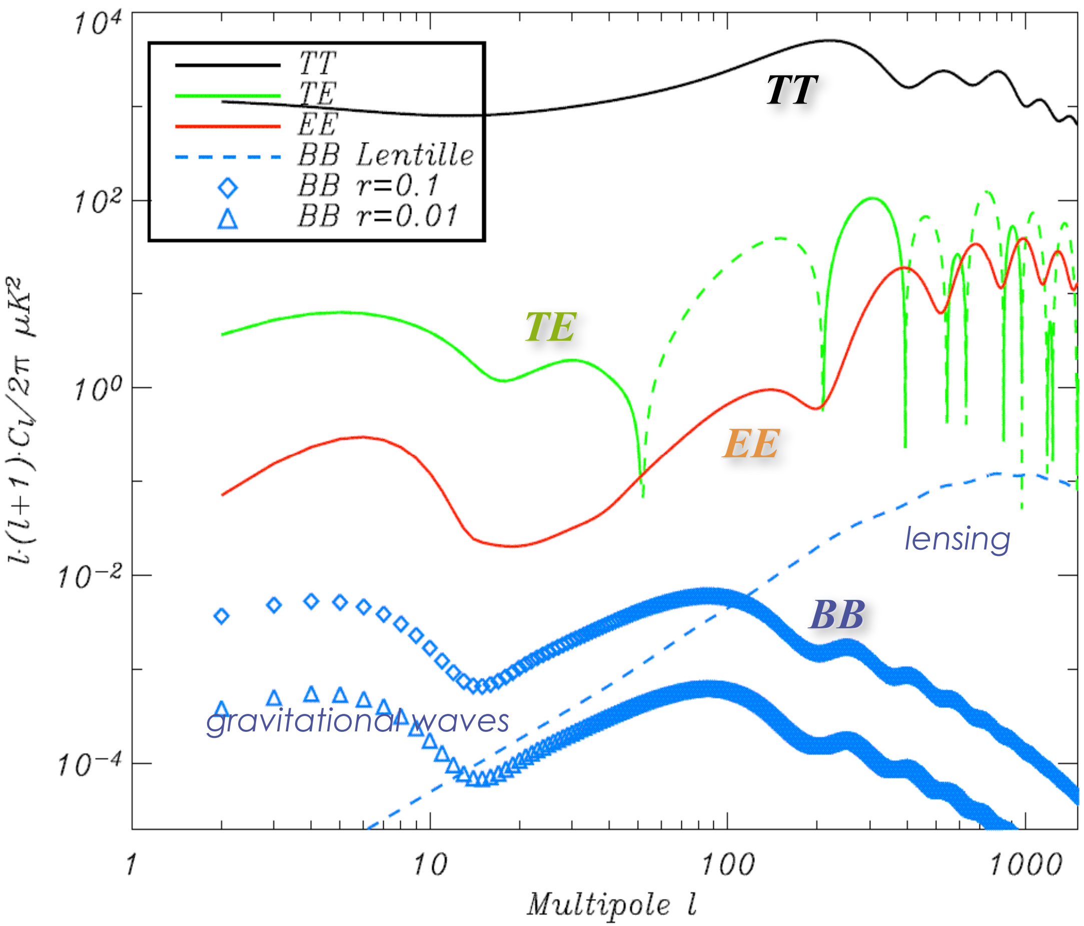
Scalar perturbations
generate Q_r *and thus* E



Tensor perturbations
generate Q_r *and* U_r
and thus E *and* B

Polarized angular power spectra

- ★CMB described by Stokes parameters: ***I***, ***Q*** and ***U***
- ★in spherical harmonics space, ***T***, ***E*** and ***B***
- ★6 angular power spectra ***TT***, ***EE***, ***BB***, ***TE***, ~~*TB*~~ and ~~*EB*~~

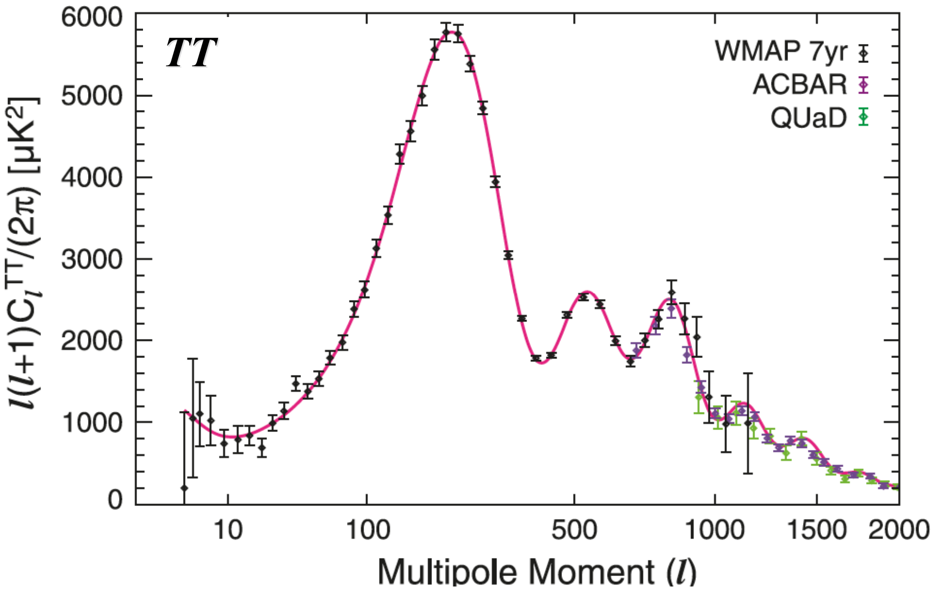


TT
- ★cosmological parameters measurements

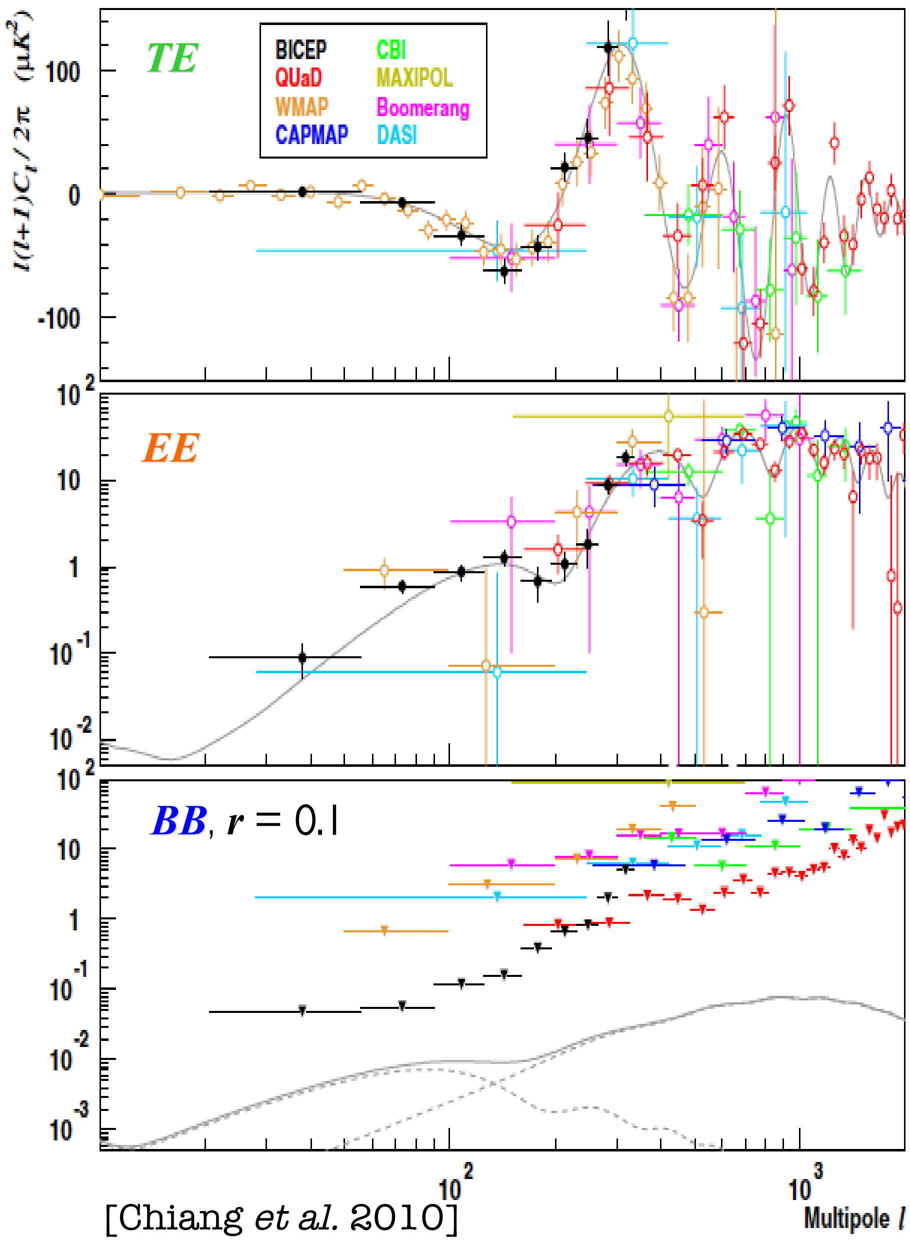
TE, ***EE***
- ★leave the degeneracies on cosmological parameters
  Model coherence
- ★reionization
- ★scalar spectral index

BB
- ★primordial grav. waves
  Inflation energy scale
- ★gravitational lensing
  Large-scale structures

Measurements of the C_ℓ



[Dunkley *et al.* 2010]



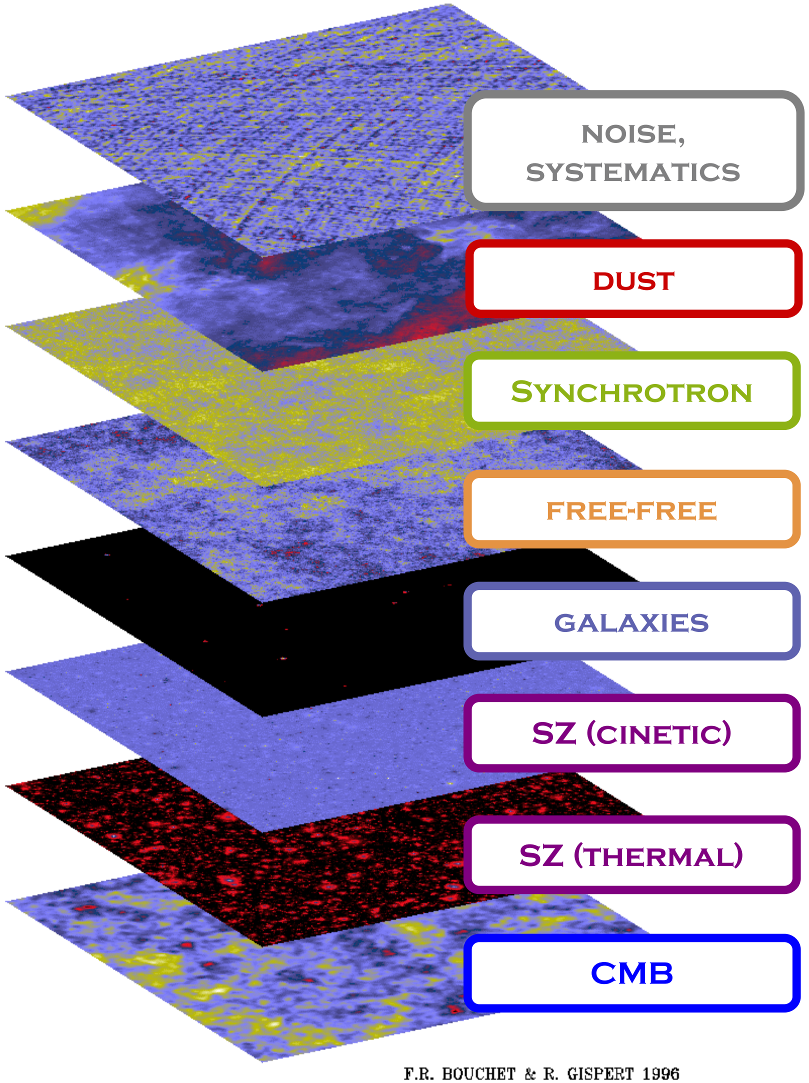
[Chiang *et al.* 2010]

For the moment

★*agreement between temperature and polarization measurements*

★*polarization allowed to measure: reionization, scalar spectral index ≠ 1*

CMB FOREGROUNDS



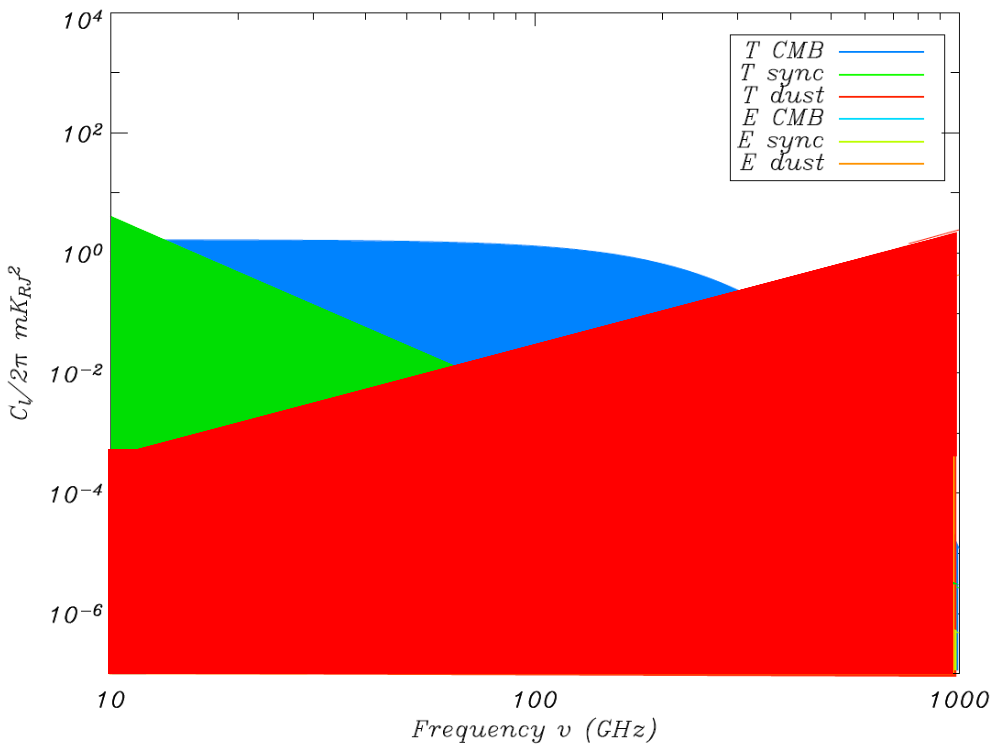
MANY EFFECTS OVERLAY THE CMB SIGNAL

secondary anisotropies, diffuse emissions, point sources

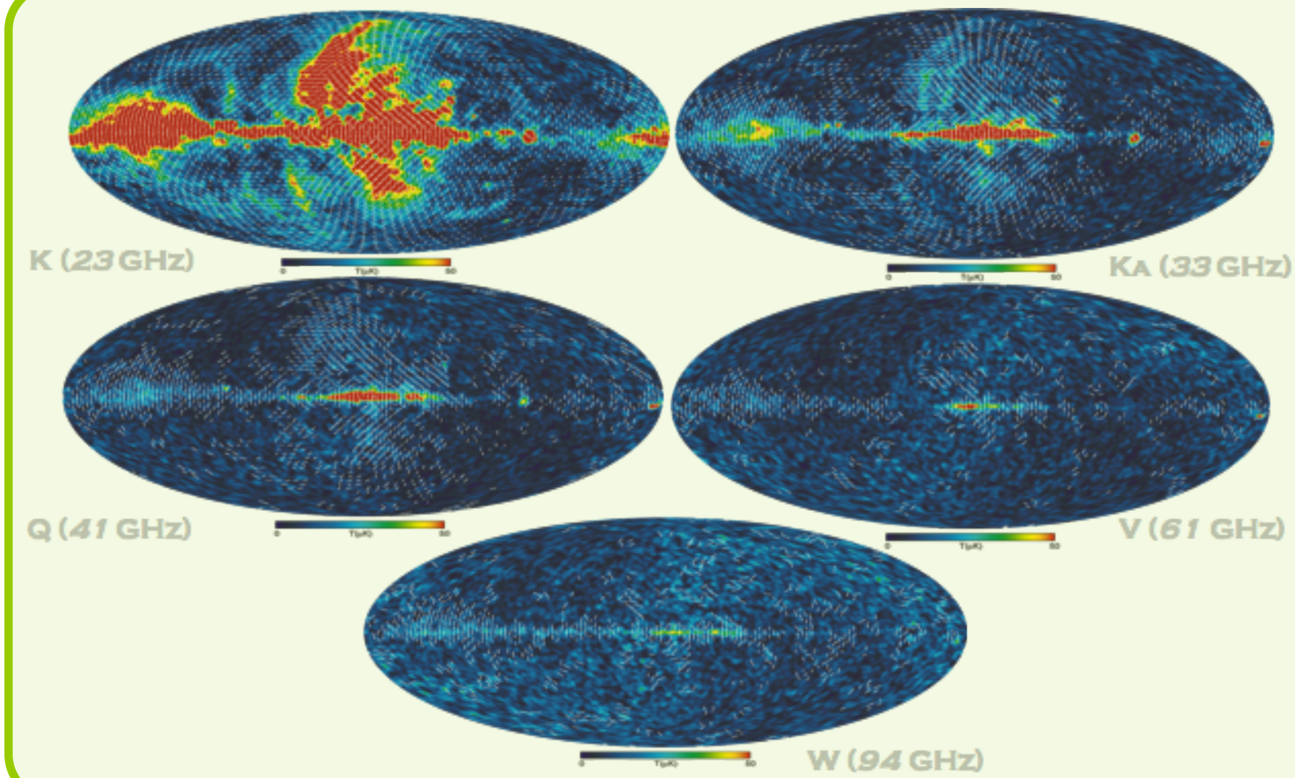
ISSUES

★*Galactic emissions are not well understood, especially in polarization*

★*polarized Galactic emissions predominate the CMB signal at all frequencies*



Polarized foregrounds



[Page *et al.* 2007]

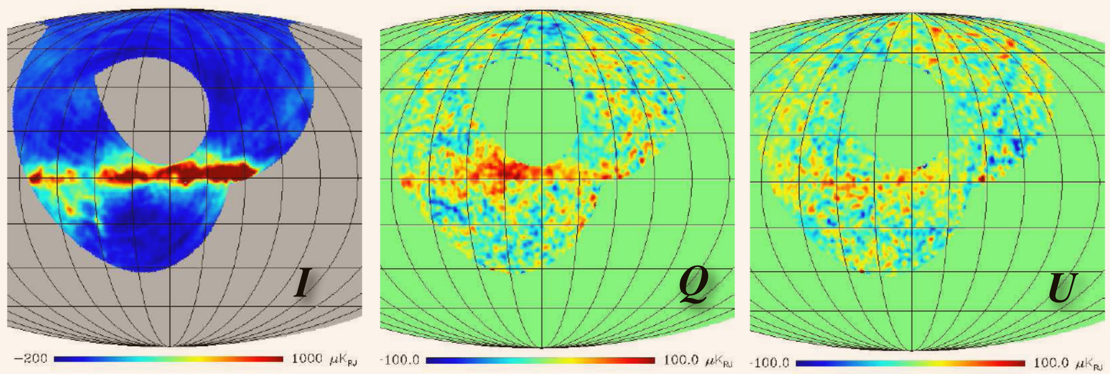
Synchrotron: WMAP polarized maps

★*polarized intensity decrease with frequency*
★*large scale polarization angle coherence*

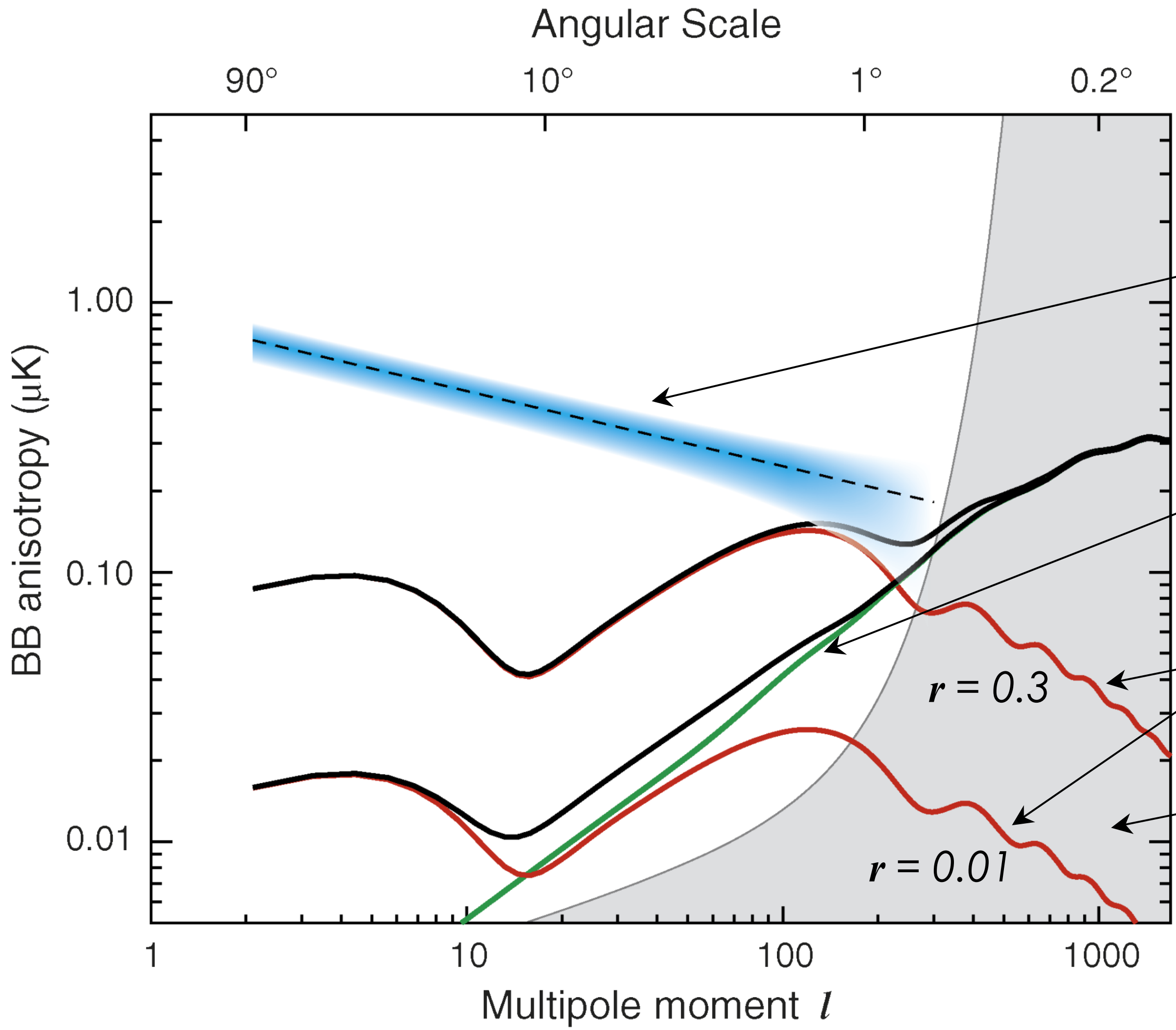
Dust: Archeops polarized maps @ 353 GHz

★*30% of the sky*
★*6 PSB*

[Ponthieu *et al.* 2006]



B MODES DETECTION



BLUE BAND:
Galactic foreground estimate from WMAP3, frequency dependent

GREEN LINE:
Lensing (EE → BB), frequency independent

RED LINES:
Gravity wave signal(s)

GREY SHADED BAND
1-sigma sensitivity for 1000-channel system with 1-yr integration, 1°FWHM resolution

[figure from G. Hinshaw's presentation in Moriond 2010]

Planck

Features

★ESA's satellite mission, launched on May the 14th 2009

★1.5 m off-axis Gregorian telescope

★two instruments LFI and HFI

- ★LFI: radiometers cooled to 20 K, @ 30, 40, 70 GHz
- ★HFI: bolometers cooled to 100 mK, @ 100, 143, 217, 353, 545, 857 GHz

★high sensitivity, high resolution, unprecedented frequency coverage

★complete sky coverage in 7 months

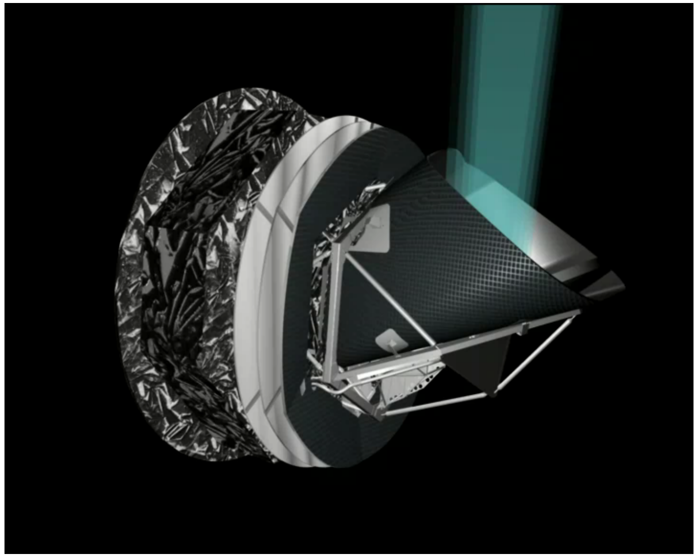
Scientific goals

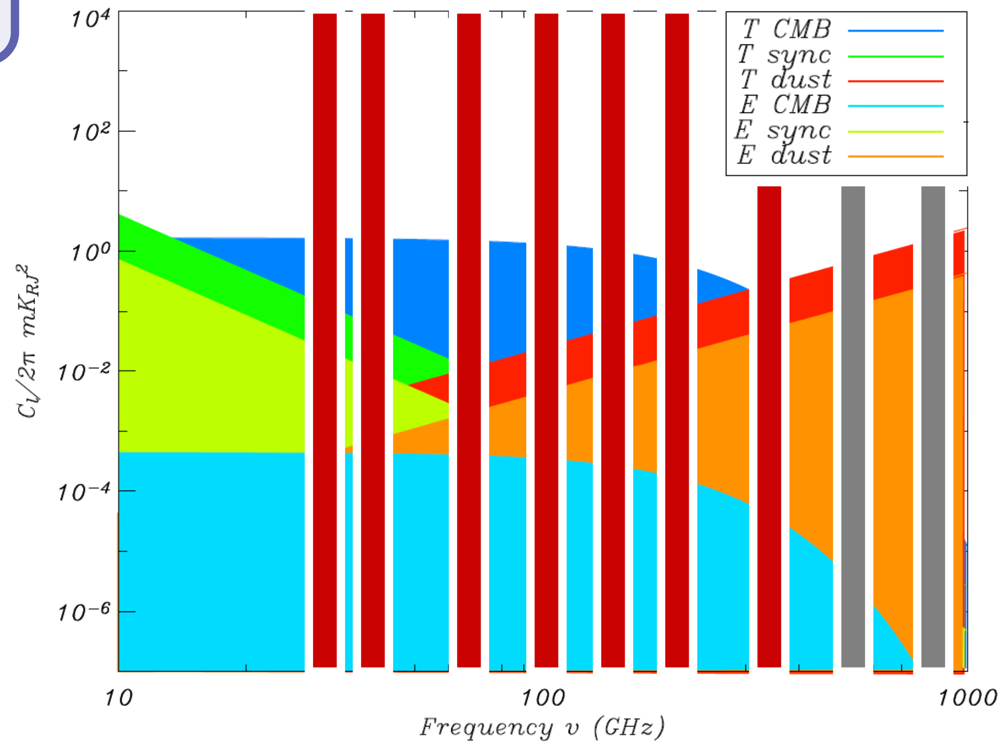
★"ultimate" measurement of the CMB temperature anisotropies (ℓ = 2-2000)

★unprecedented measurement of the polarization (essentially E modes)

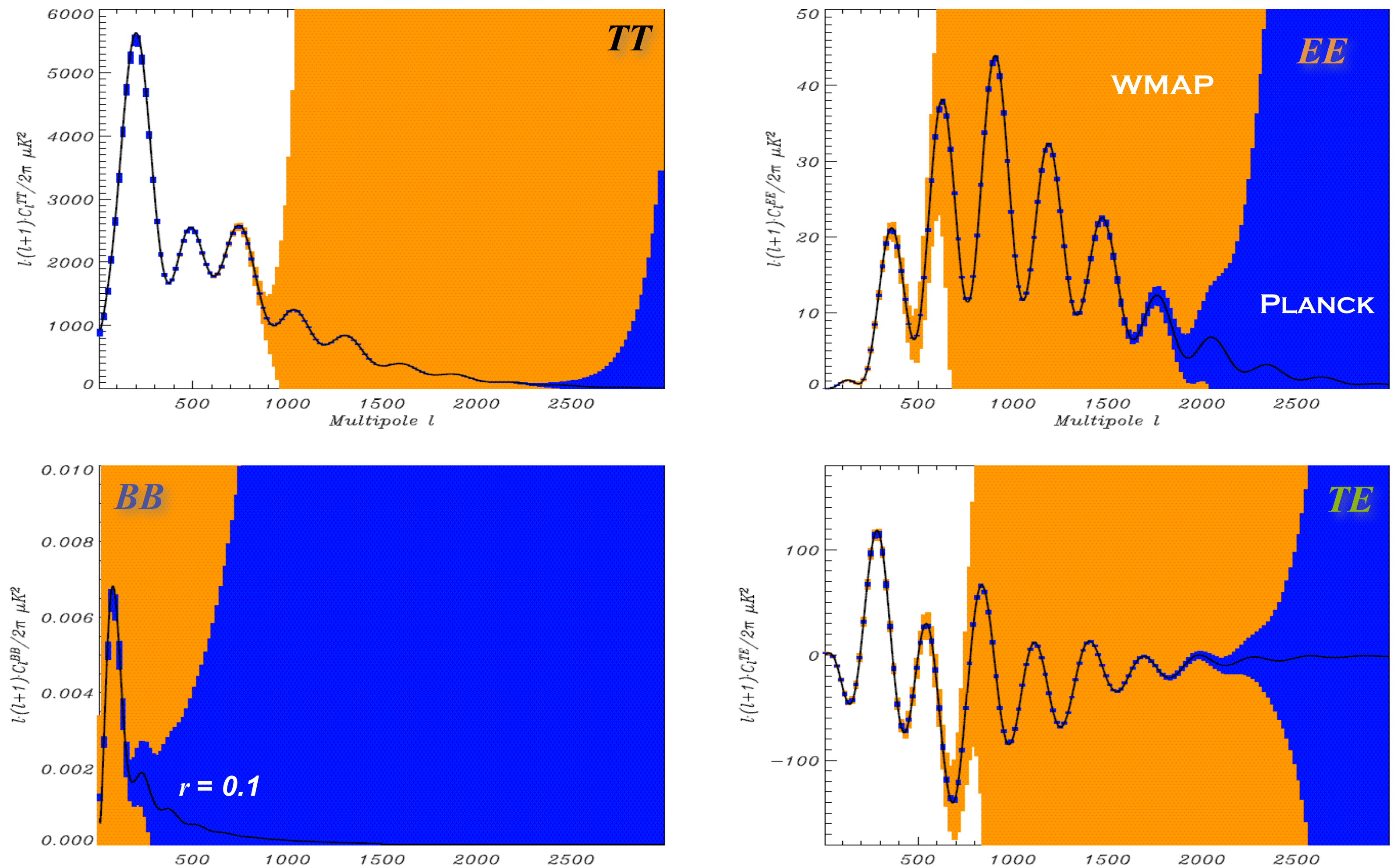
★gain of one order of magnitude in the determination of the cosmological parameters

★SZ, clusters, Galaxy





Planck expectations



★measurement of C_ℓ^{TT} until 8th acoustic peak

★unprecedented measurement of C_ℓ^{EE} and C_ℓ^{TE} leading to a break of degeneracies on reionization, scalar spectral index

★large scale measurement of C_ℓ^{BB} if $r > 0.1$

★improvement of one order of magnitude on cosmological parameters

Ongoing and future experiments