Planck 2013 cosmological results

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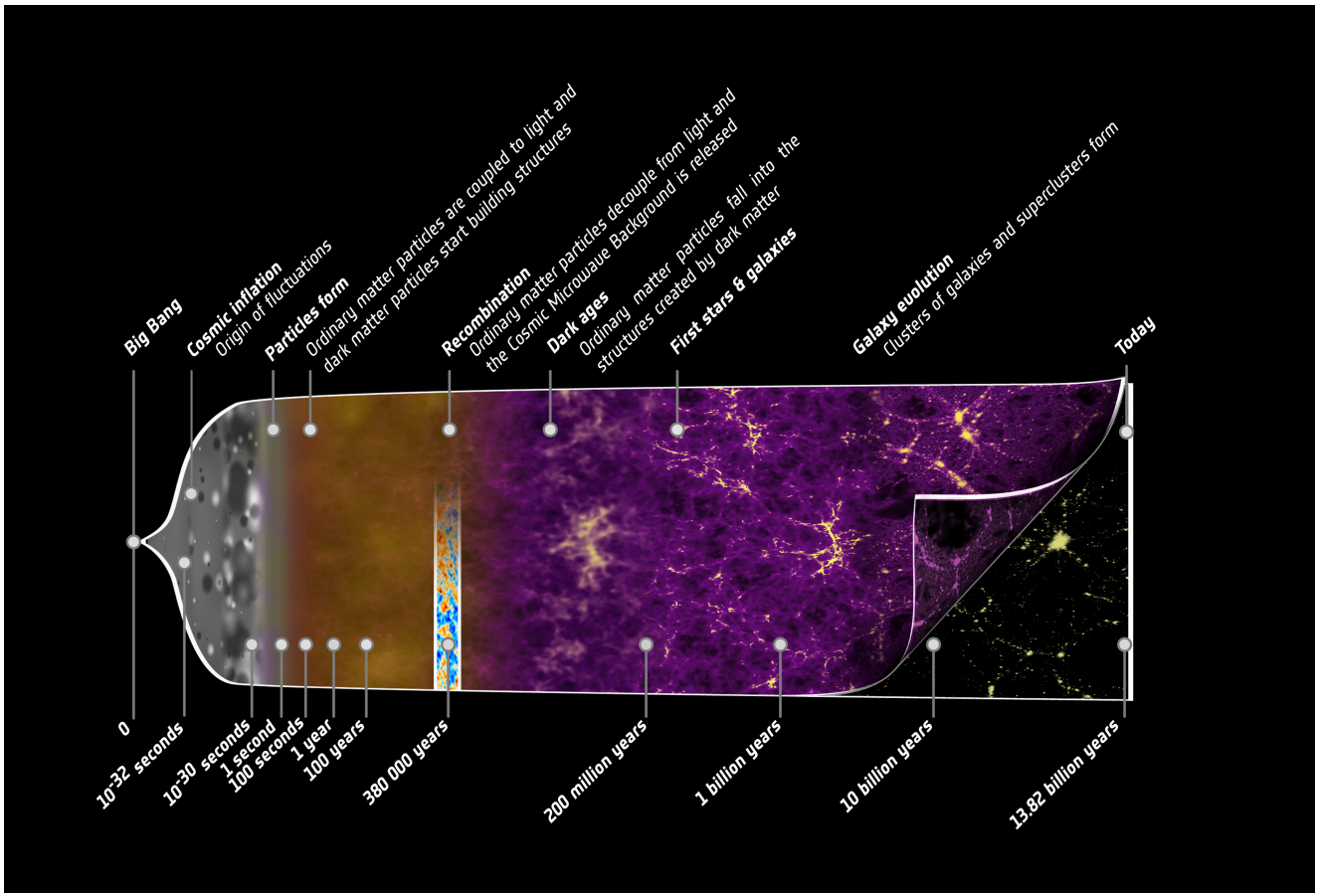
Rencontres de Moriond 2014 - Electroweak session

Outline

- Introduction
- The Planck mission
- CMB temperature anisotropies analysis & constraints
- Adding more datasets
- Prospects

Cosmology



- RG based condordance ΛCDM model : $\sim$ 7 parameters
- inflation paradigm $\Rightarrow$ origin of anisotropies
- CMB $\Rightarrow$ “snapshot” of density field $\sim$ 300000 y after BB

Cosmological parameters

"vanilla" ΛCDM (Planck alone + low ℓ WMAP polar) :

- primordial spectrum : normalisation A_s, spectral index n_s ($P_k = A_s(k/k_0)^{n_s-1}$)
- present expansion rate H_0 ($h = (H_0/100km/s/Mpc)$)
- energy densities : $\Omega_b h^2$, $\Omega_{\rm CDM} h^2$
- reionisation optical depth τ (low ℓ polarization)

Assumptions (addressed using extensions, including more data sets) :

- flat universe
- light neutrinos : $\sum M_\nu = 0.06eV$
- 3 families of ν ($N_{eff} = 3.05$)
- no tensor modes ($r = A_t/A_s = 0$)

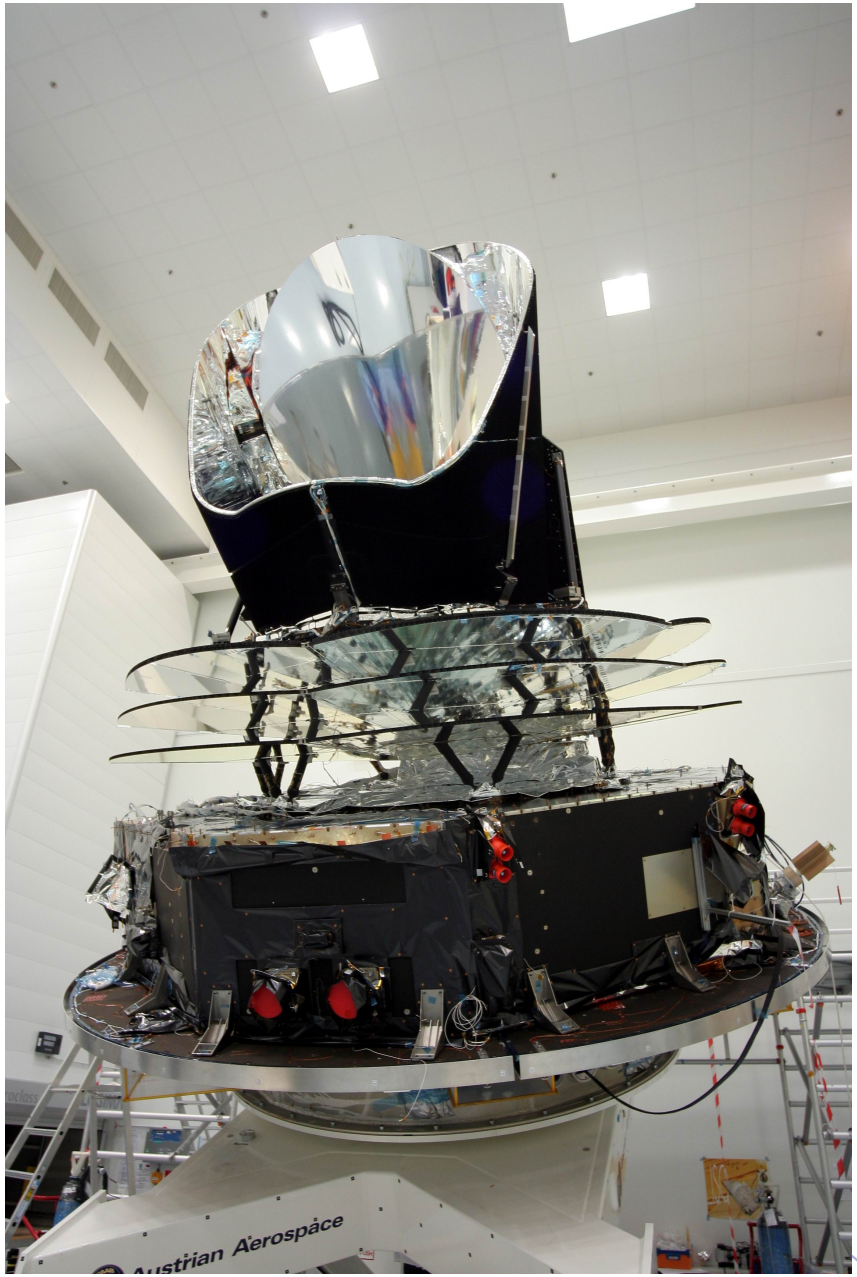
NB : Results depend on fitted model + dataset(s) (check their compatibility !)

The Planck mission

ESA mission launched on 15/05/2009
(jointly with Herschell)
orbit around L2 (1.5Mkm)
guaranteed duration : 14 months (2 surveys)
extended till mid January 2012 (HFI) / mid 2013 (LFI)

1. Telescope (1.5m) - danish consortium
2. LFI (HEMTs 30-70GHz, 20 K, 15-30 arcmin beams) - consortium coordinated by Bologna Univ. (+US, Sp, It,...)
3. HFI (bolometers 100-857 GHz, 100 mK, 10-5 arcmin beam) - coordinated by IAS (PI J.L. Puget, IAS) ; institutes from Ca, CH, Ge, Fr, Irl, It, NL, Sp, US, UK,...

Cost : $\sim 600 Meuros$
(HFI $\sim 150 Meuros$)



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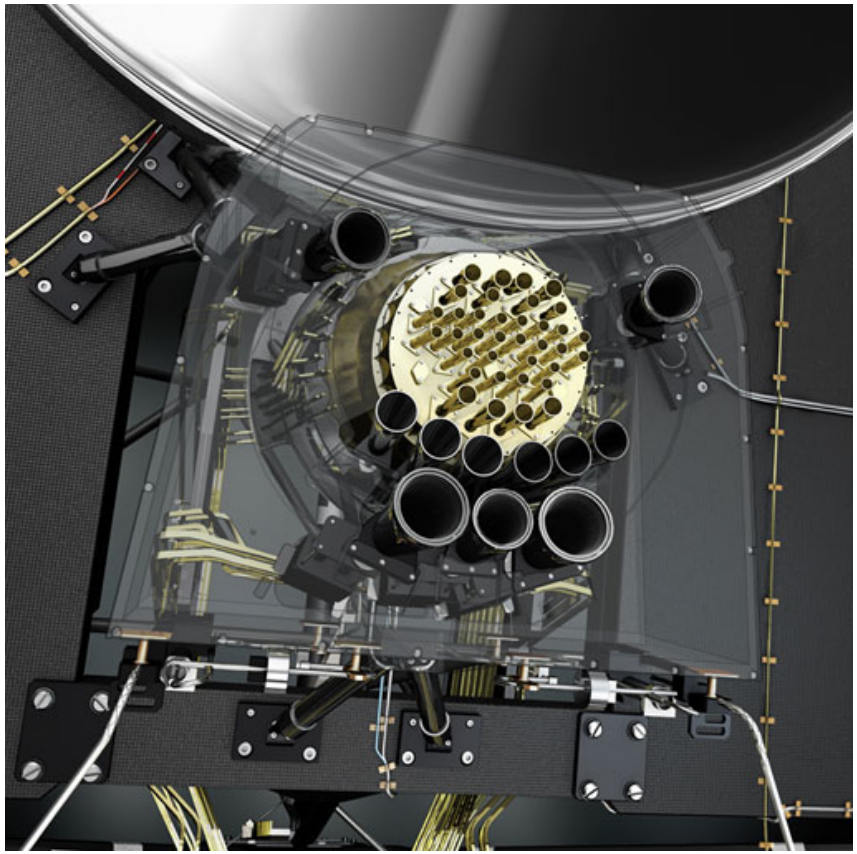
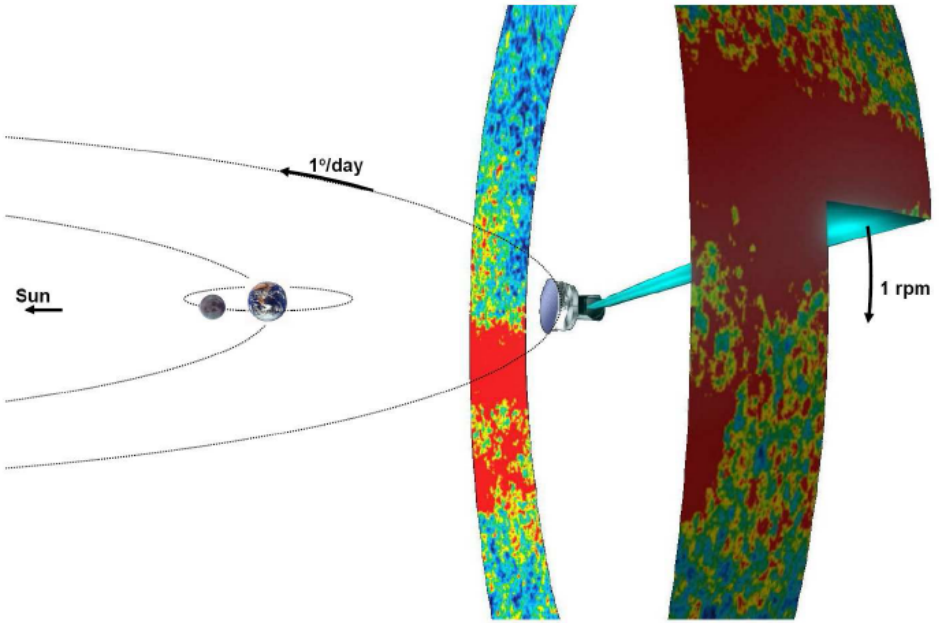
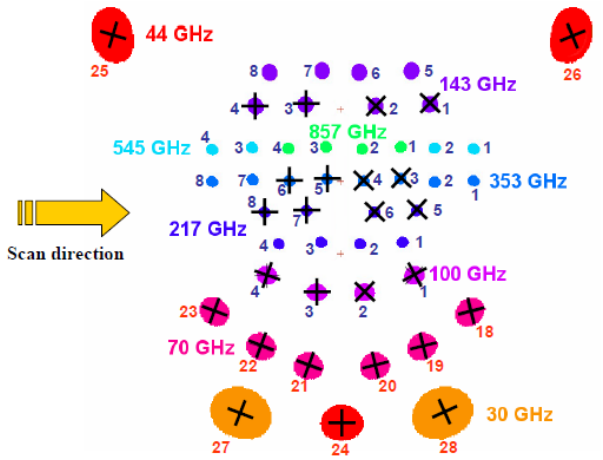


Planck at L2

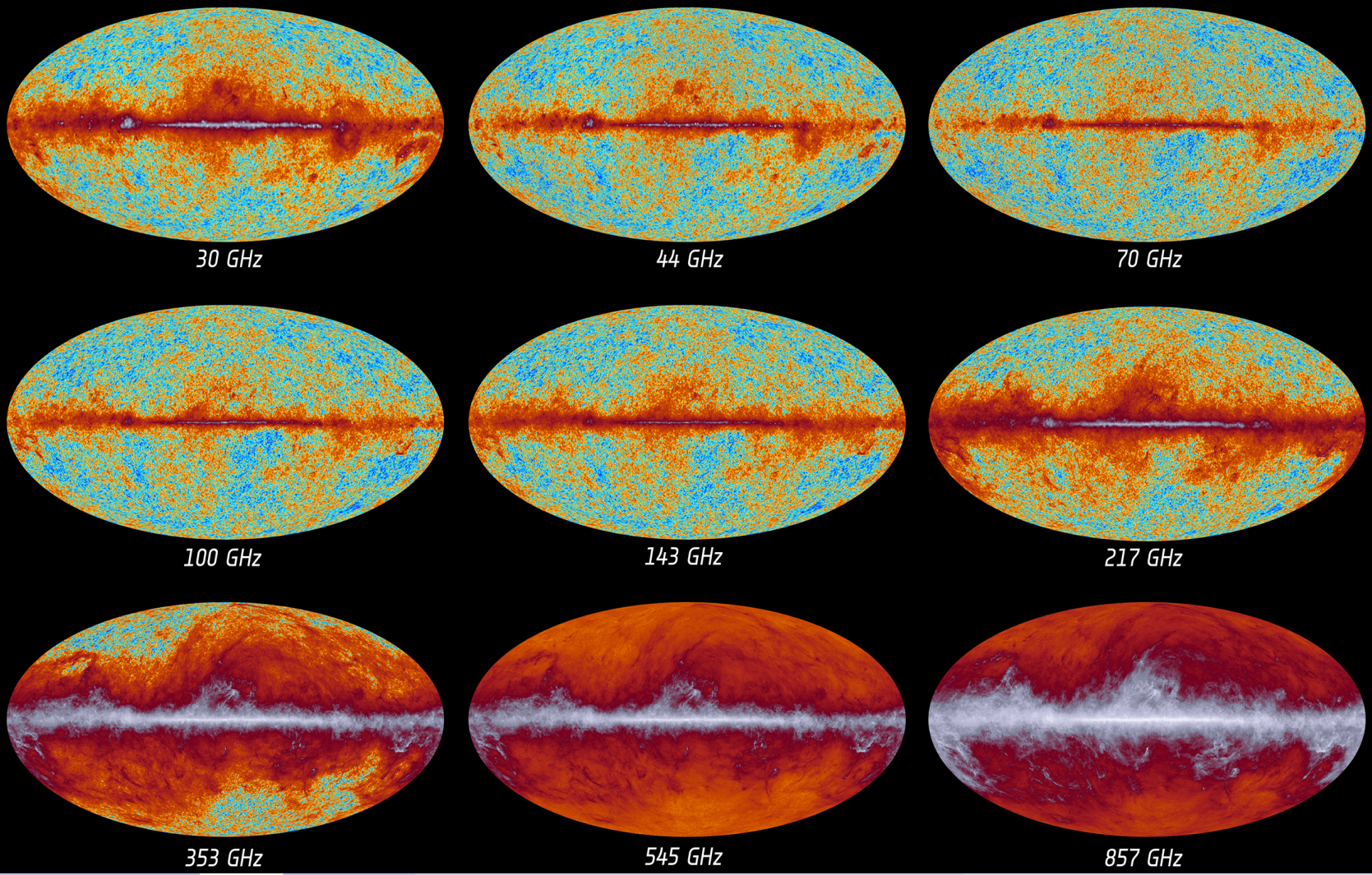




~ 8*x*8 degree field

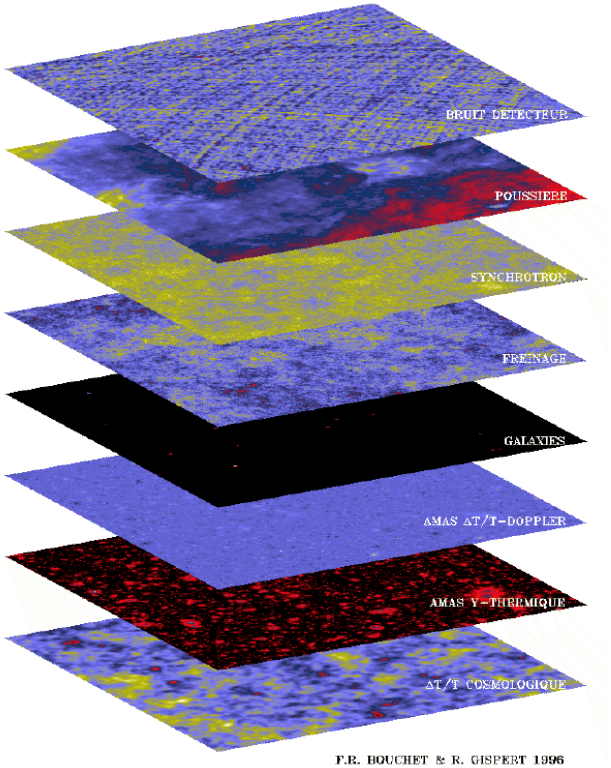
Continuous observations (7 months → all sky)
redundancies on different timescales (systematics)
Calibration accuracies .5% → 10% , beams ~ 5 → 30 *arcmin*

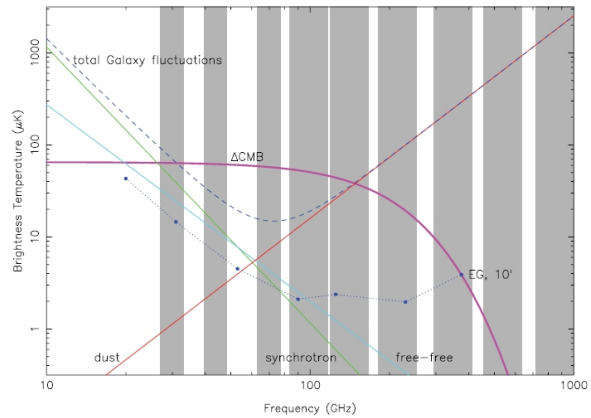
The sky as seen by Planck



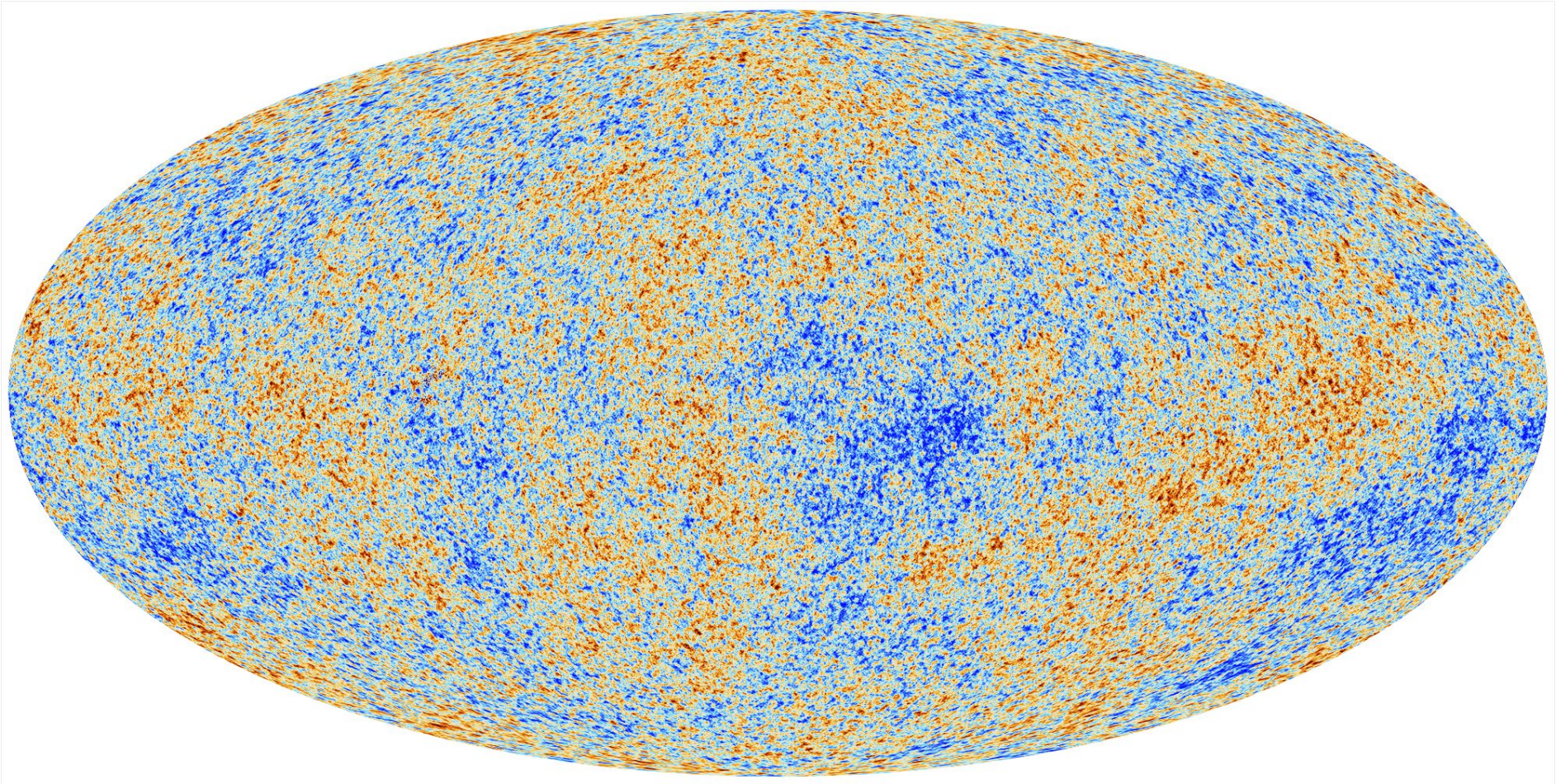
Planck physics

- primary objective(s) : CMB anisotropies (T and polarization) photon noise limited for T and E modes
- many astrophysical components observed together with CMB :
  - Solar system : planets, asteroids, zodiacal light ...
  - Galactic : dust, synchrotron, free-free
  - extragalactic : clusters (SZ), CIB, radio sources,...
- different frequency dependence ⇒ component separation
- rich physics program
- first full sky maps at 200-800 GHz





Planck 2013 CMB temperature anisotropies map



4 methods compared in : Planck 2013 results. XII. Component separation

Cosmological parameter analysis in a nutshell

- Spherical harmonic decomposition ($\ell \sim 1/angle$) :

$$\frac{\delta T}{T}(\theta,\phi) = \sum_{\ell}\sum_{m} a_{\ell m} Y_{\ell m}(\theta,\phi)$$

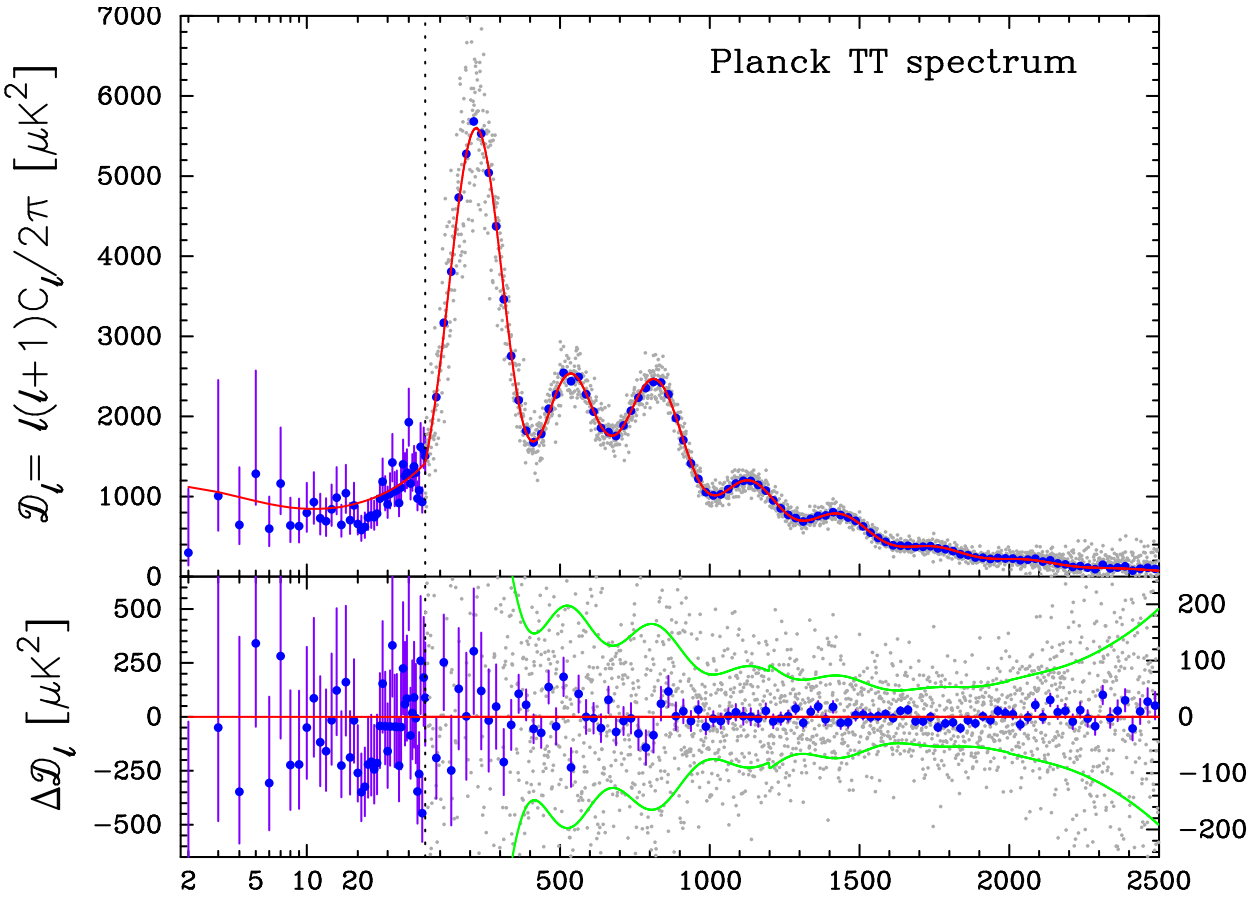
- general assumption $\Rightarrow$ $a_{\ell m}$ are random variables (gaussian p.d.f.) ; $\langle a_{\ell m}\rangle_m = 0$; all information contained in their variance

$$C_\ell = \frac{1}{2\ell+1}\sum_m a_{\ell m} a^\dagger_{\ell m}$$

predicted by our model

- only one realization is observable $\rightarrow$ intrinsic dispersion wrt model ("cosmic variance")
- Planck 2013 analysis : 100, 143 and 217 GHz maps cross spectra (suppression of instrumental noise) with masks ($\Rightarrow$ low foregrounds contamination) (high ℓ) ; CMB map ML (low ℓ)
- fit cosmological parameters using a likelihood function (accounting for CMB, residual foregrounds, instrumental nuisance parameters - $\sim$ 20 parameters)

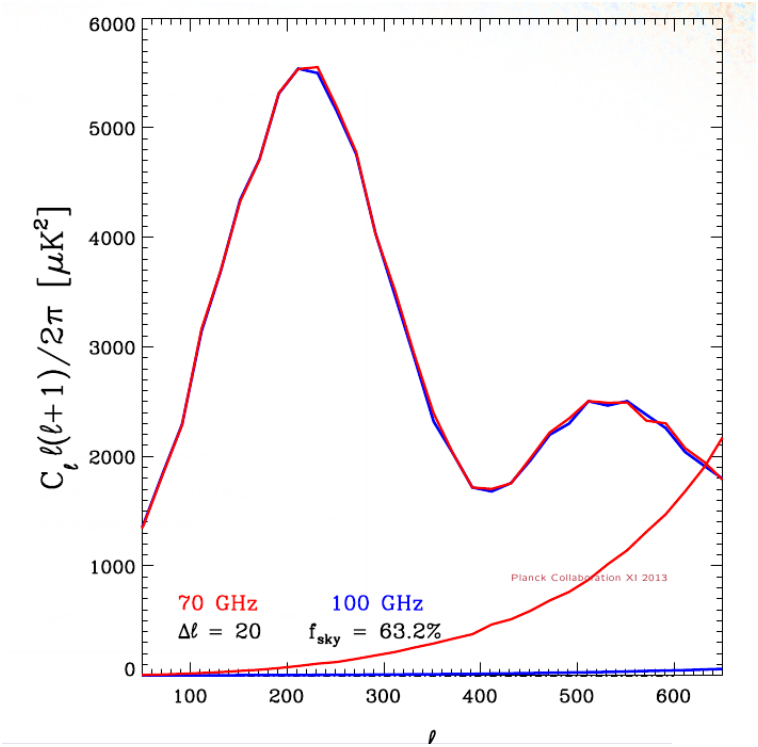
CMB TT power spectrum (Planck 2013)

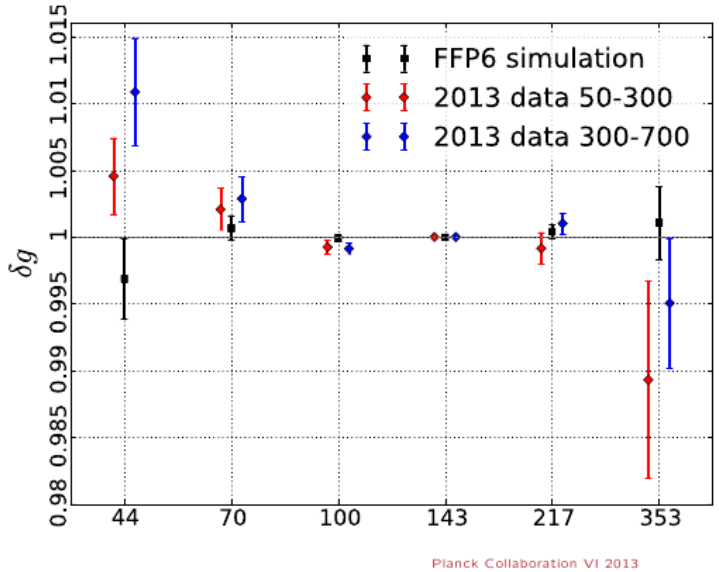


output of Planck likelihood - foregrounds subtracted

Hybrid method : map based ML (low ℓ) / pseudo-spectra (high ℓ) of masked raw maps

Internal checks

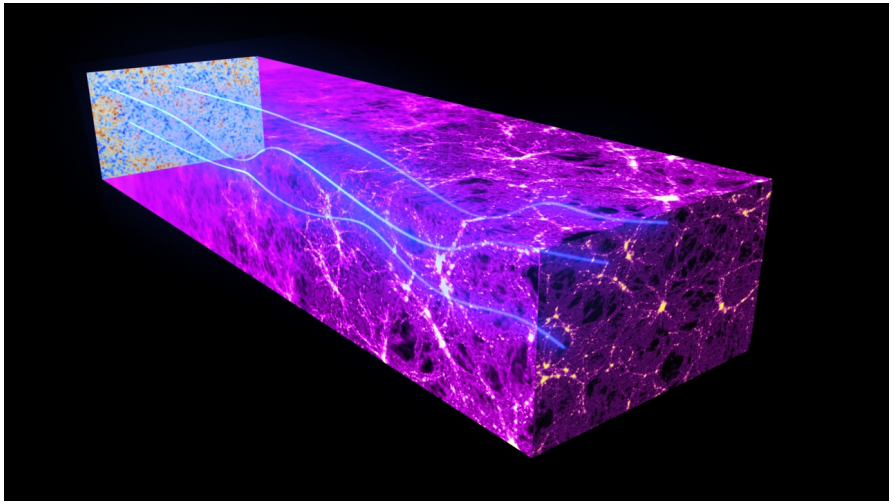




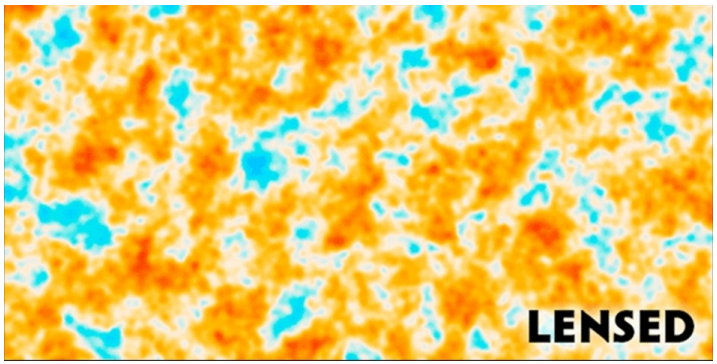
+ split data in independent sets (many ways) ⇒ noise estimation, systematic checks

CMB lensing by Large Scale Structures

LSS distorsion of the CMB photons' paths



→ small "smearing" of the C_ℓ spectra + distorsion of the CMB image



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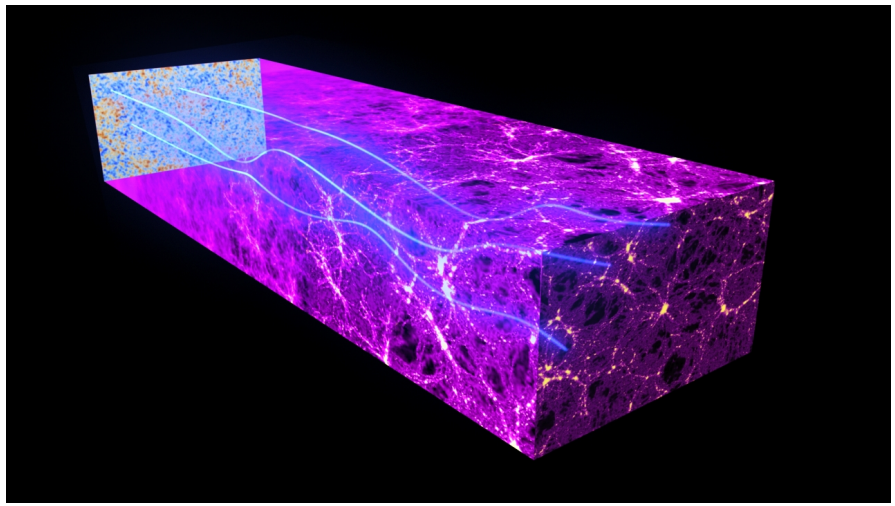

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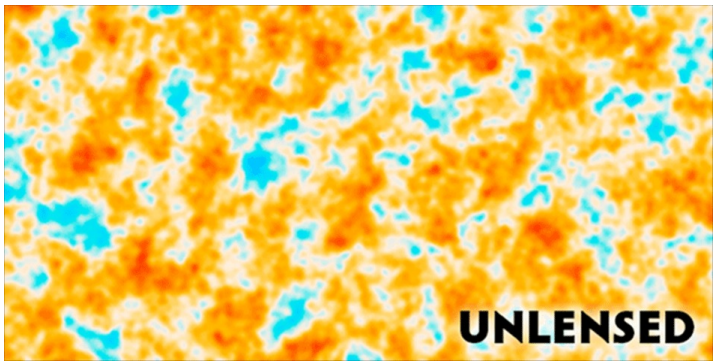
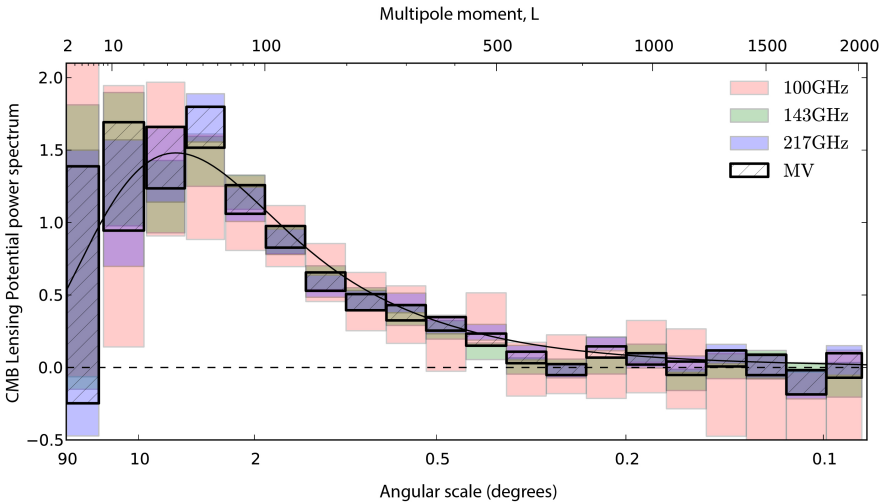
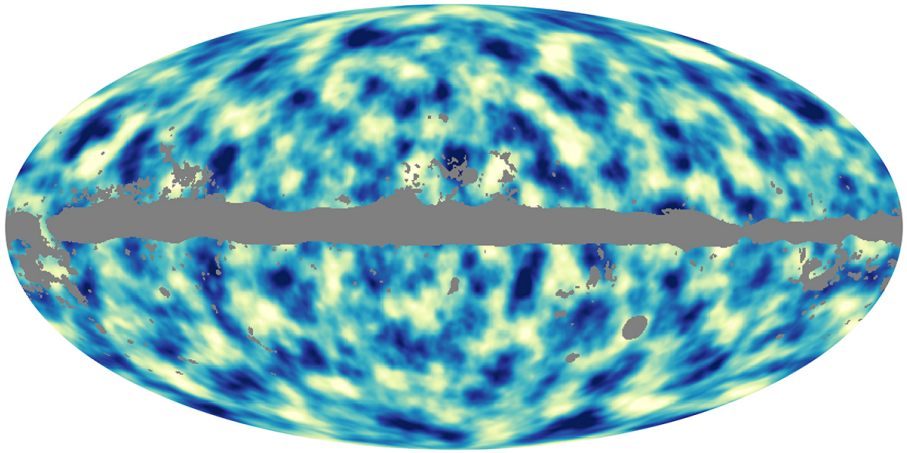


Mapping the lensing structures





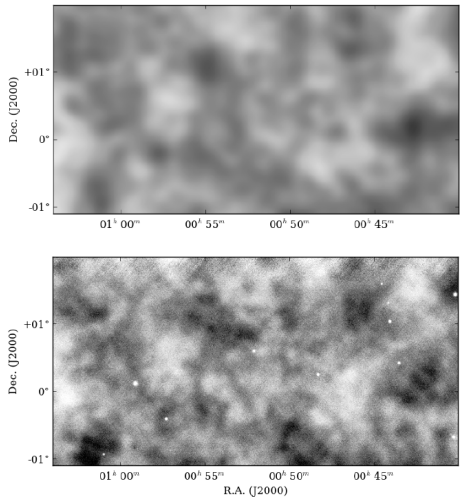
Analysis of CMB anisotropies 4 points statistics ⇒ Power spectrum of the deflexion field (integrated information on LSS @ $z \approx 2.5$)

used in cosmological parameter fits together with C_ℓ

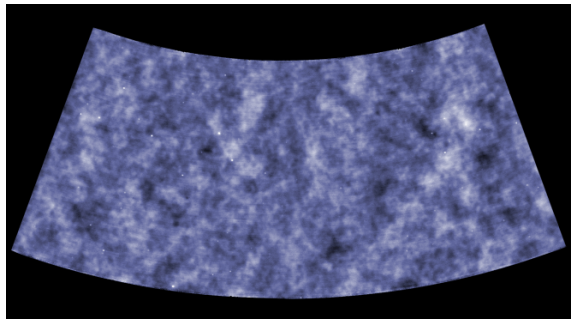
High resolution CMB observations : ACT and SPT

ACT (Sievers et al arXiv :1301.0824) SPT (Hou et al., arXiv :1212.6267)

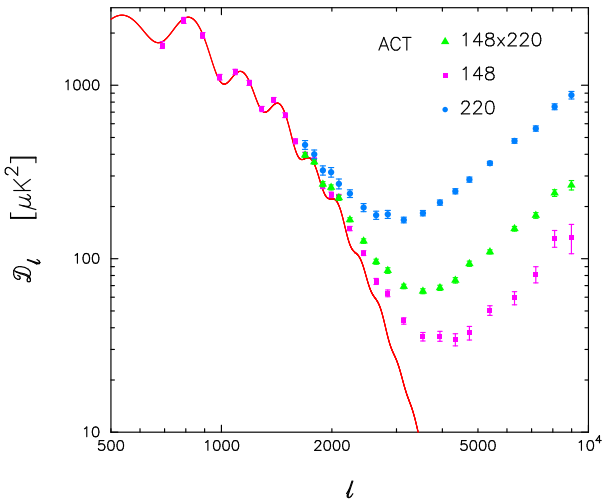
WMAP

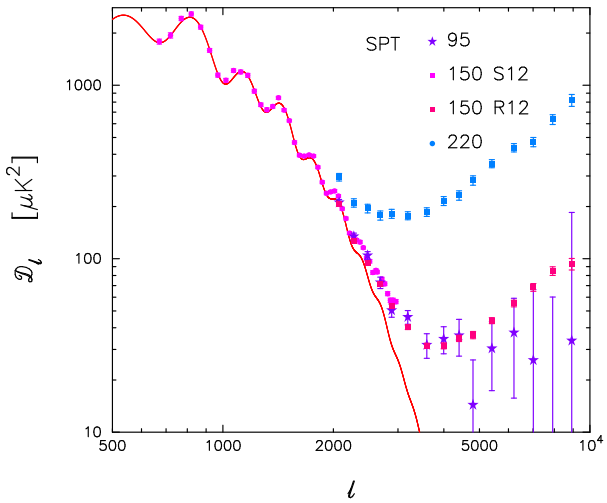


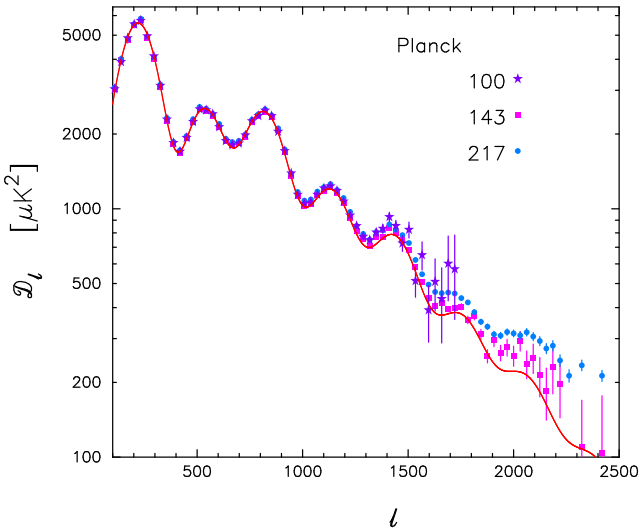
ACT

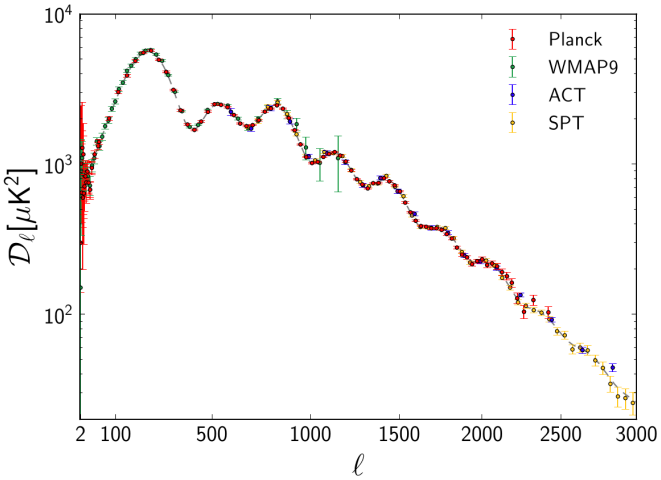


Extending the ℓ coverage (needed for e.g. n_s)





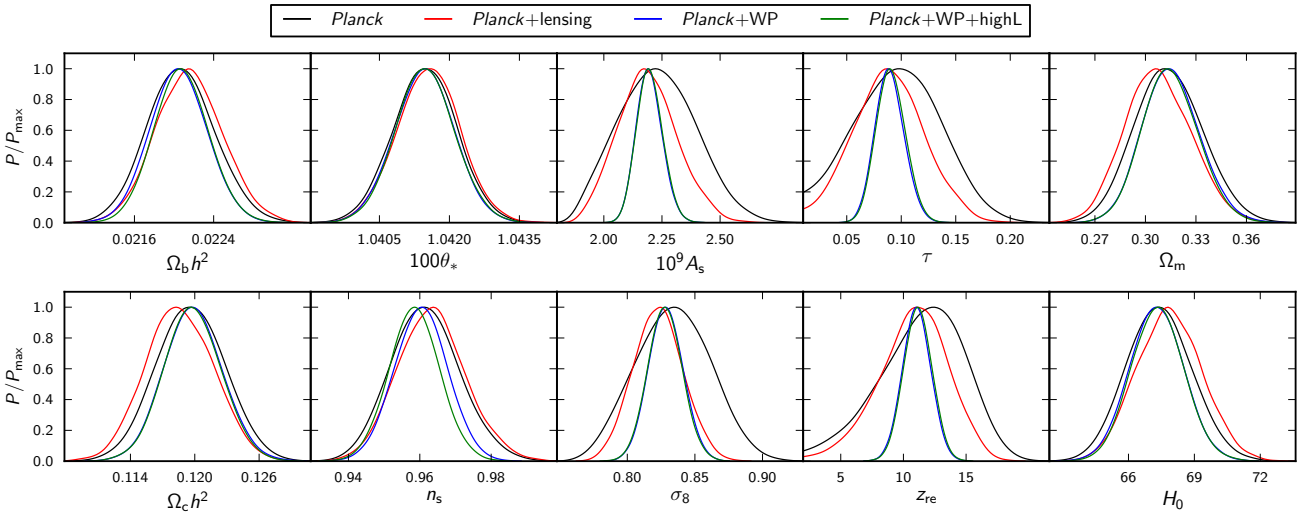


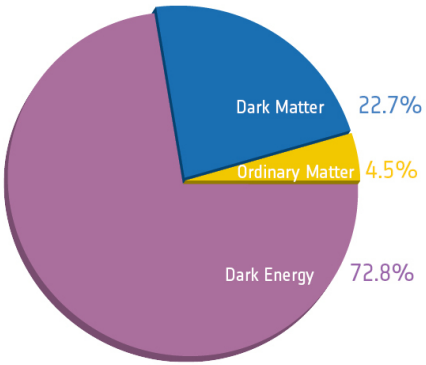


ACT/SPT ⇒ constraint high ℓ foregrounds (point sources, CIB, SZ,...)

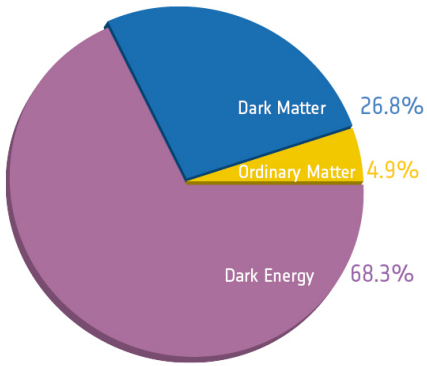
CMB only parameter fits

Planck 2013 results. XVI. Cosmological parameters

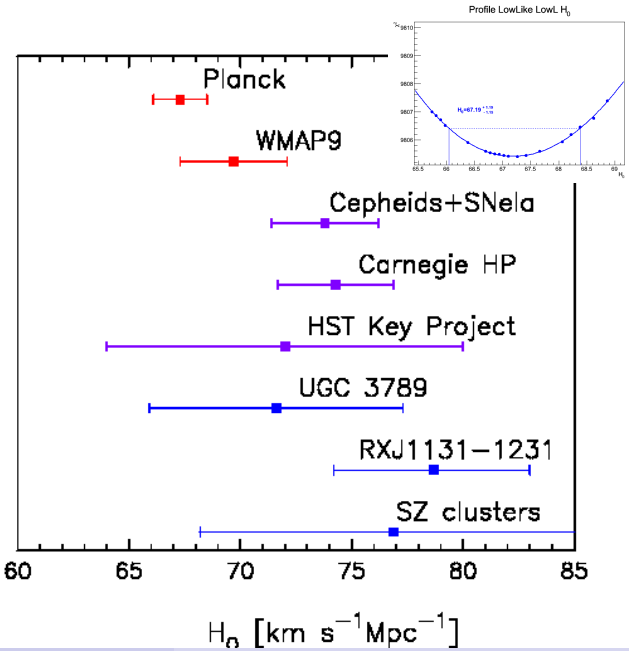




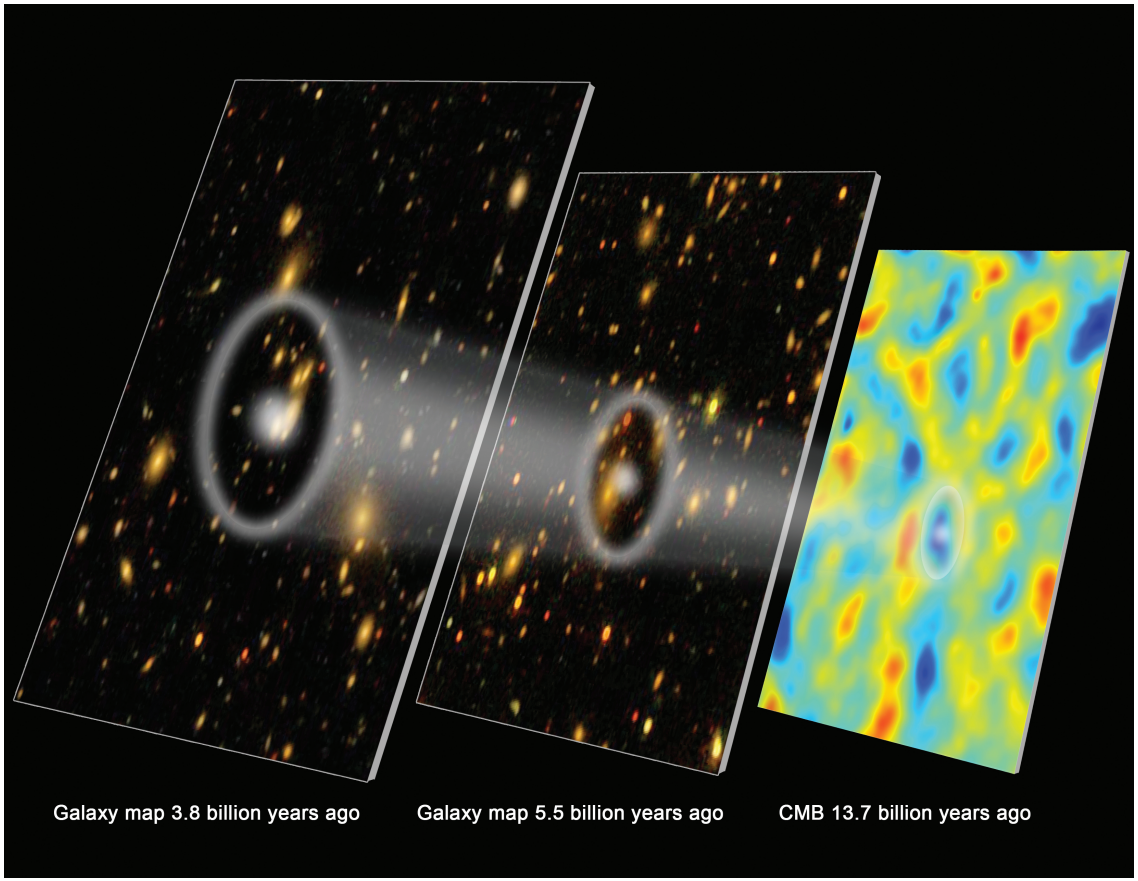
Before Planck



After Planck

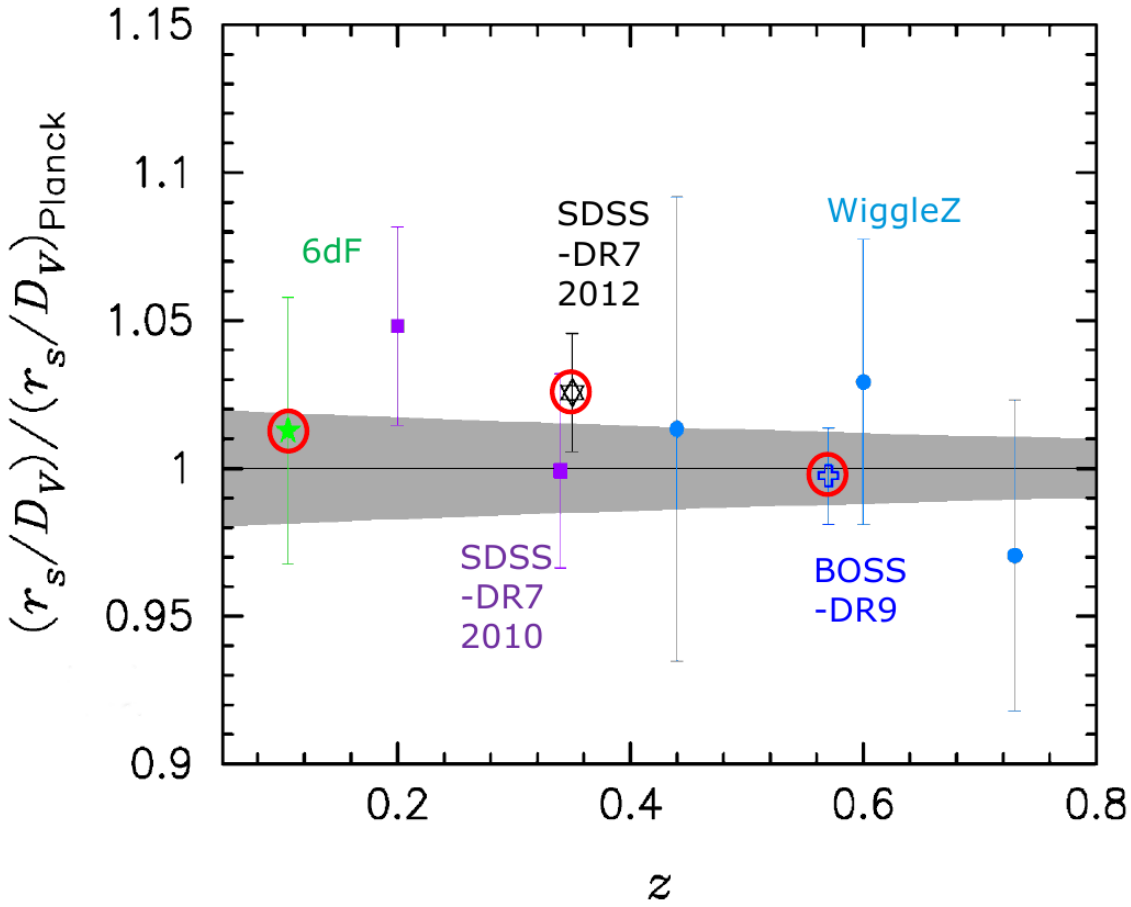


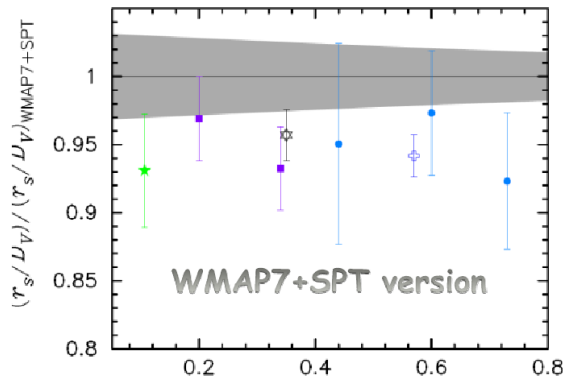
Baryon Acoustic Oscillations (BAO)



- At recombination one observes a preferred size of density anisotropies
- $\Rightarrow$ "standard ruler" (large enough to stay in linear regime)
- first observation in SDSS-II DR 7 using LRG (Eisenstein et al 2005)
- several other groups/targets since (6dF, WiggleZ, BOSS / SDSS-III DR9/10/11)
- measurements at various epochs (or redshifts z) $\Rightarrow$ $D_A(z)$, H(z) (expansion rate vs z)

Comparison with CMB best fit



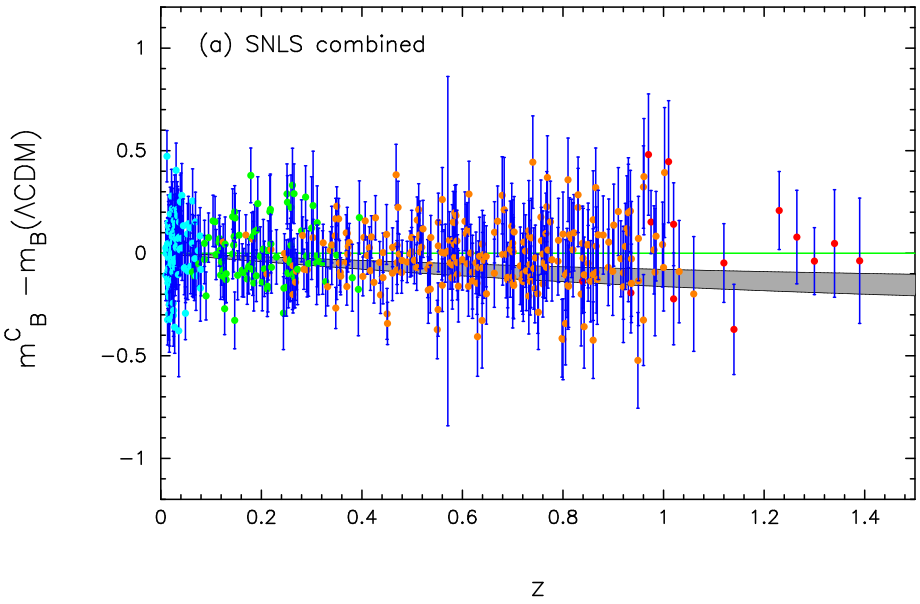


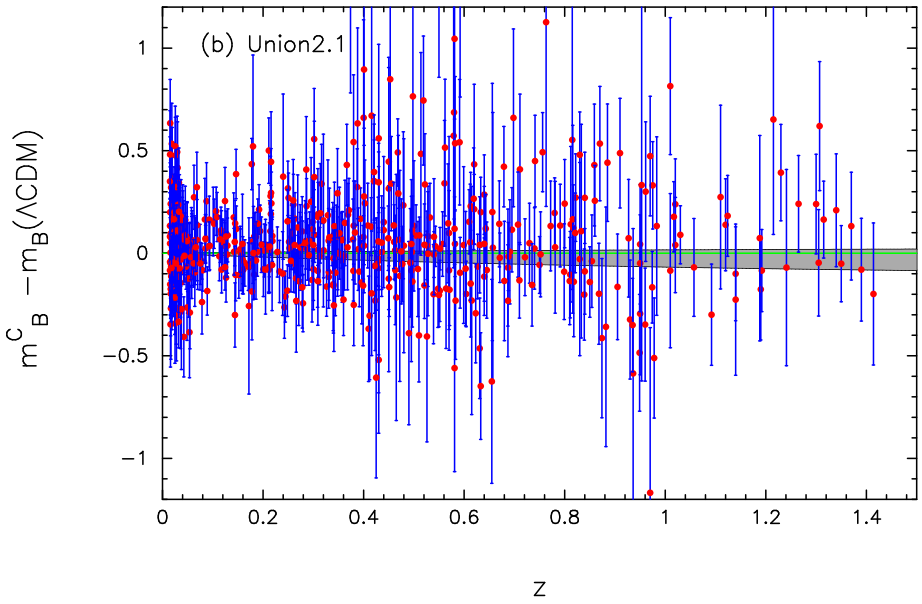
see e.g. Hu et al (2012)

Planck 2013 results. XVI. Cosmological parameters

⇒ BAO results agree with Planck (CMB) best fit cosmology

SNIa vs CMB cosmology





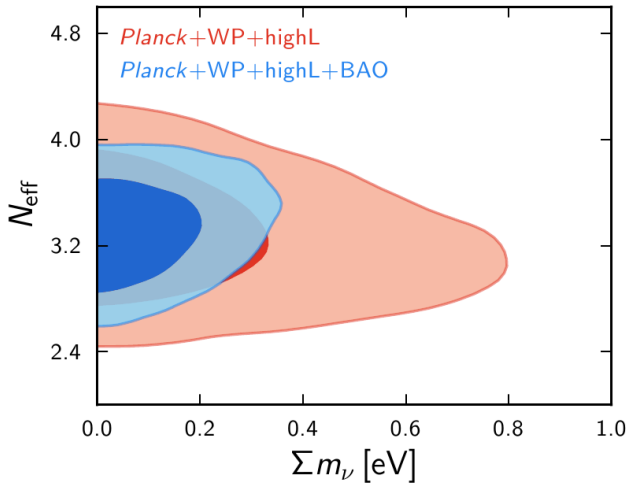
$\sim$ 2 sigma tension between Planck 2013 (gray band $\pm 2\sigma$) and SNLS3/SDSS results (Conley et al 2011)
Union 2.1 (Suzuki et al 2011) best fit closer but more dispersion
$\Rightarrow$ use only BAO in current fits

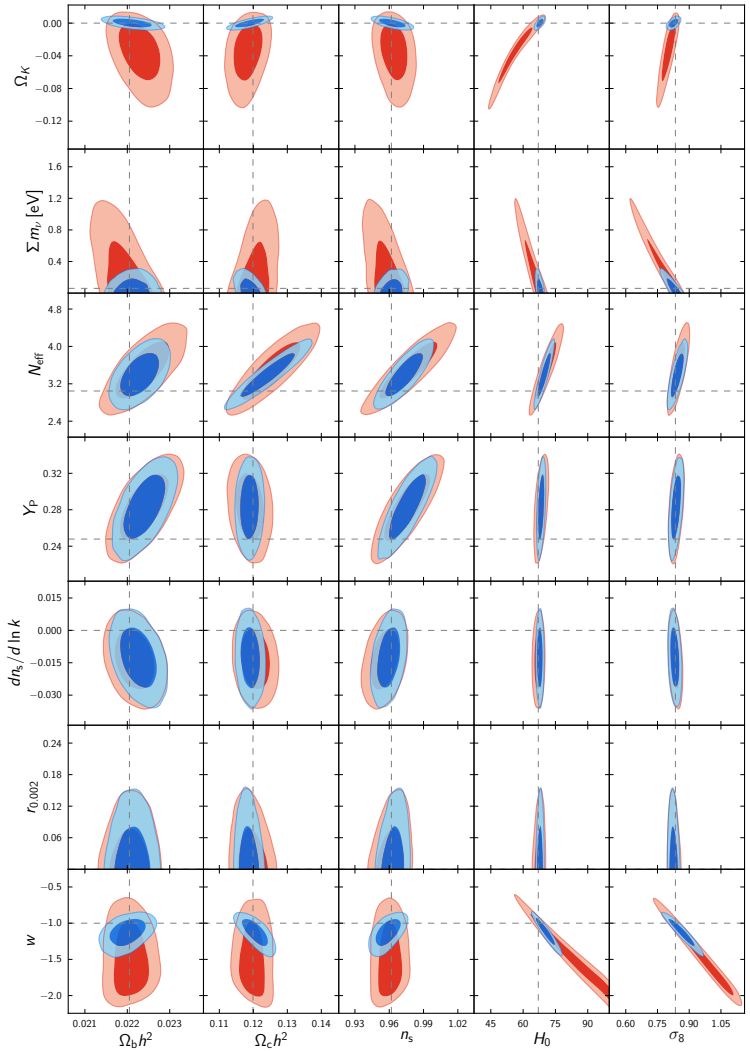
Improvements on SNLS/SDSS analysis (Betoule et al 2014) $\Rightarrow$ to be revisited in 2014 ?

Planck 2013 results. XVI. Cosmological parameters

Cosmological constraints (Planck 2013 + BAO)

- The 6 parameter ΛCDM is a good fit !
- lower H_0 , larger Ω_m
- Flat universe : $100\Omega_K = -0.1 \pm 0.6$ (95% c.l.)
- $N_{eff} = 3.30 \pm 0.54$ (95% c.l.) ; $\Sigma m_\nu < 0.23$ (95% c.l.)
- dark energy : $w = -1.13 \pm 0.24$ (95% c.l.)
- good agreement with BBN
- no evidence for primordial non gaussianities
- large angular scale $\sim 2\sigma$ “anomaly”
- $n_s = 0.96$ at more than 5σ, no evidence for running, limit on tensor modes





Planck 2013 results. XVI. (parameters) & XXII. (inflation constraints) - and others !

Conclusions and prospects

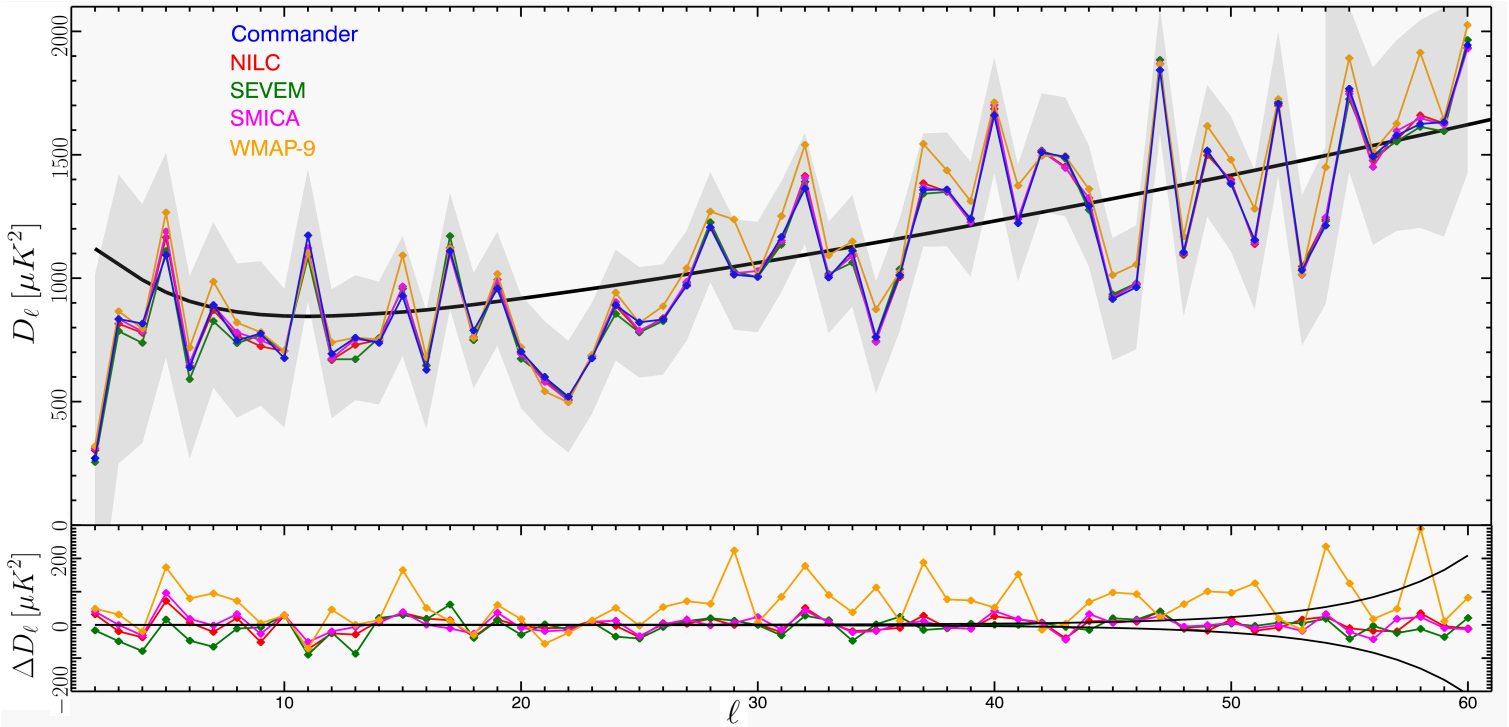
- Planck launched on May 14th 2009 after a long (17y) preparation
- quasi perfect data-taking from L2 (ended Aug. 14th 2013)
- 29 papers (O(1000) pages) issued on 2013 March 21st on cosmology results (from T, nominal mission i.e. 14 months)
- "vanilla" ΛCDM model fully supported + parameters precisely measured
- uncertainties dominated by 'cosmic variance' and systematics
- Full dataset + polarization release (Oct. 2014 TBC) : high ℓ looks great, low ℓ more challenging, new measurement of τ ? r ? ?
- more info : http ://www.rssd.esa.int/index.php ?project=Planck, www.planck.fr

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.

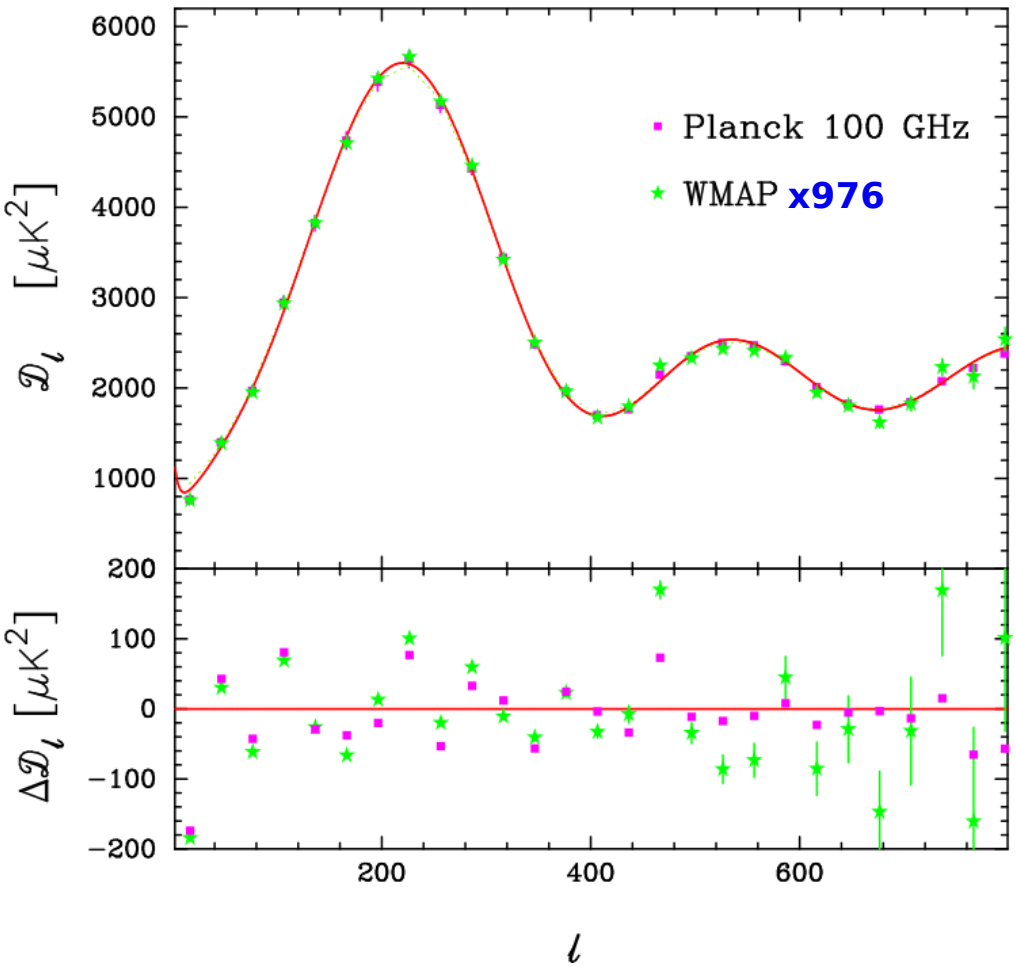
Back-ups

Low ℓ anomaly ?



O(10%) deficit of measurements wrt best fit (O(2σ))
already seen by WMAP
no effect on parameter fit

Comparison with WMAP : power spectra

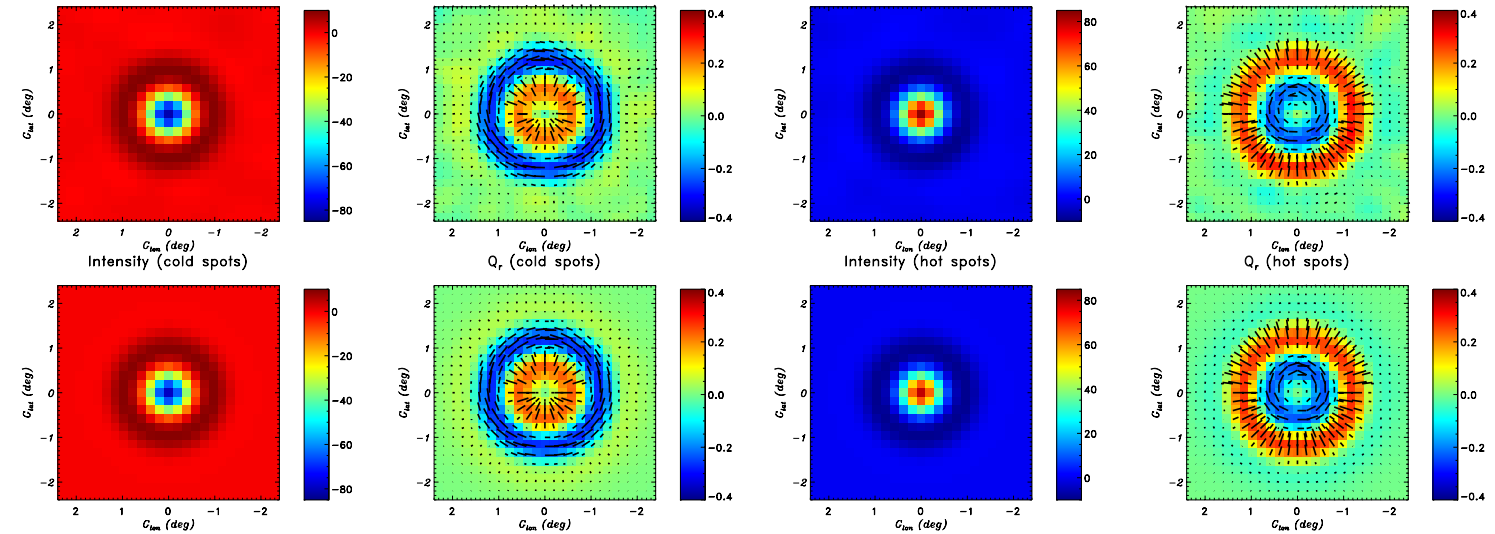


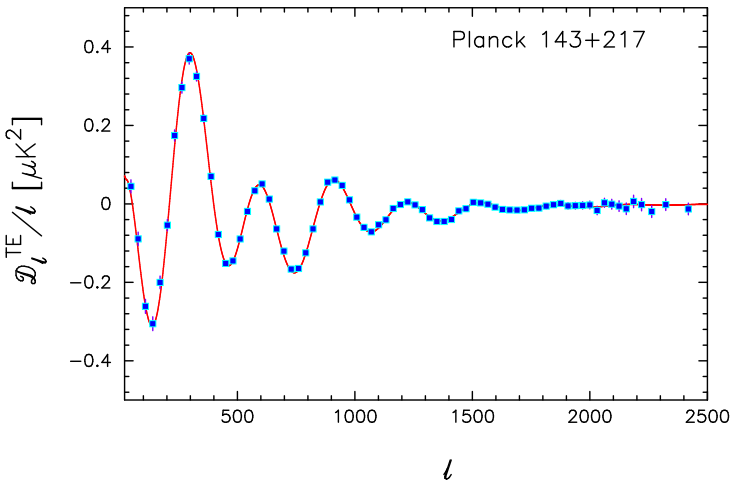
$\sim$ 2.5% normalisation difference (under study by both groups)

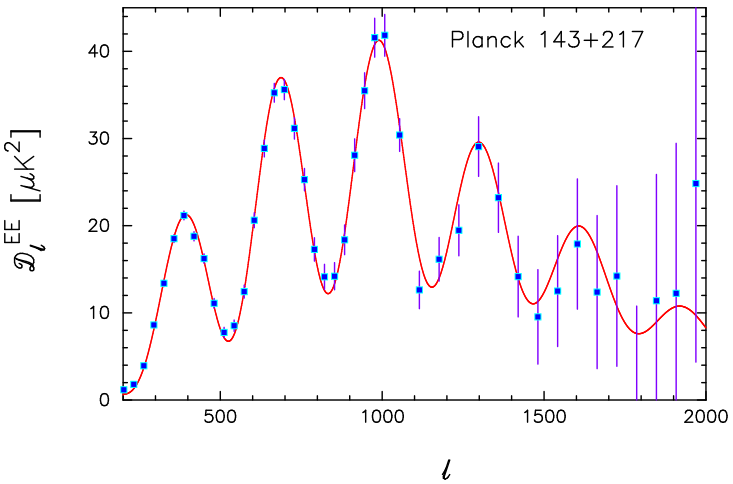
no influence on cosmological parameters but A_s

Polarization teasers

Cold and hot spots stacking (data and sims)







curves = expectation from fit on T only ΛCDM model

CMB maps : Planck vs WMAP