CMB anisotropies: current status and prospects

PASCOS-2012- Merida, Yucatan, Mexico

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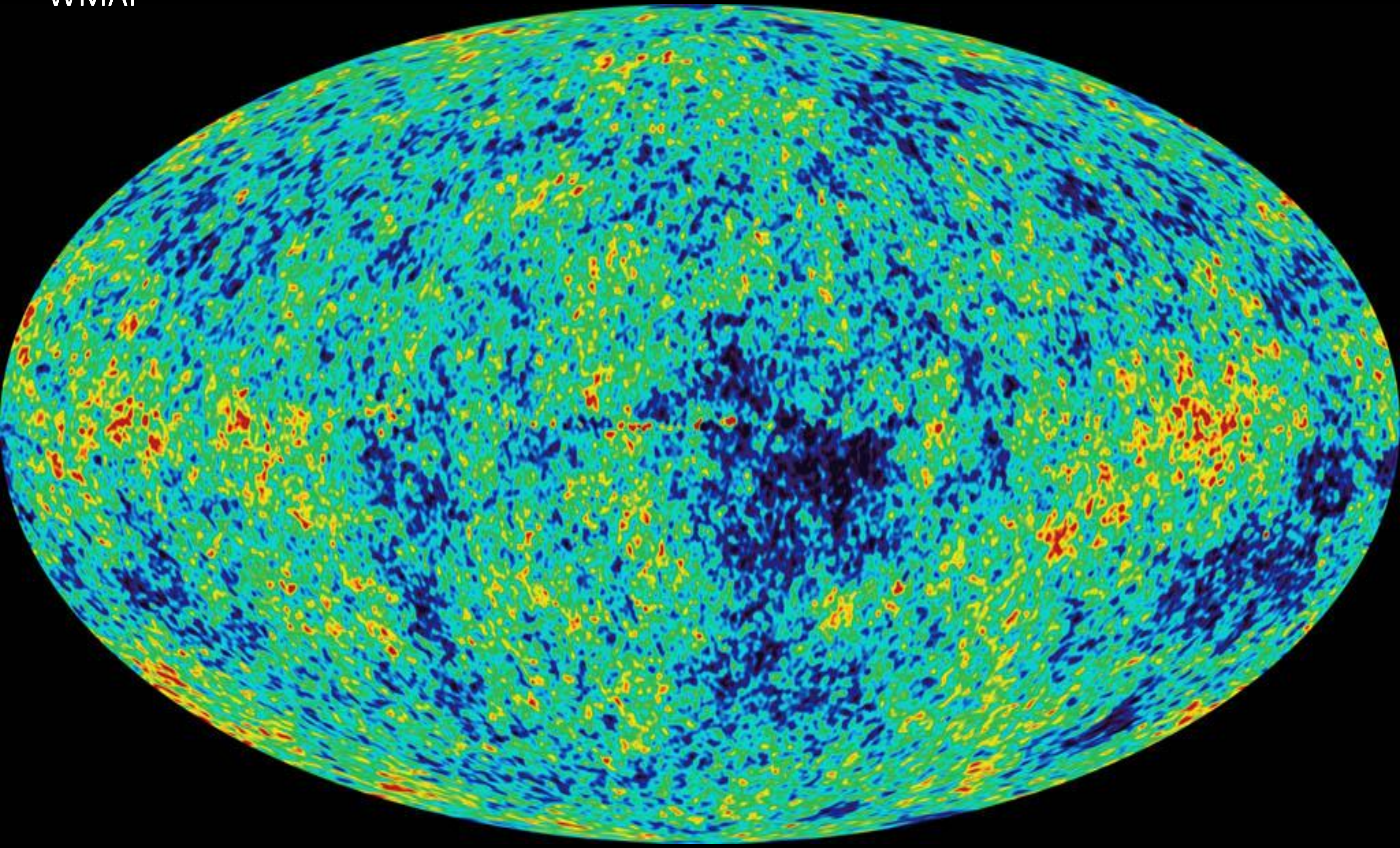
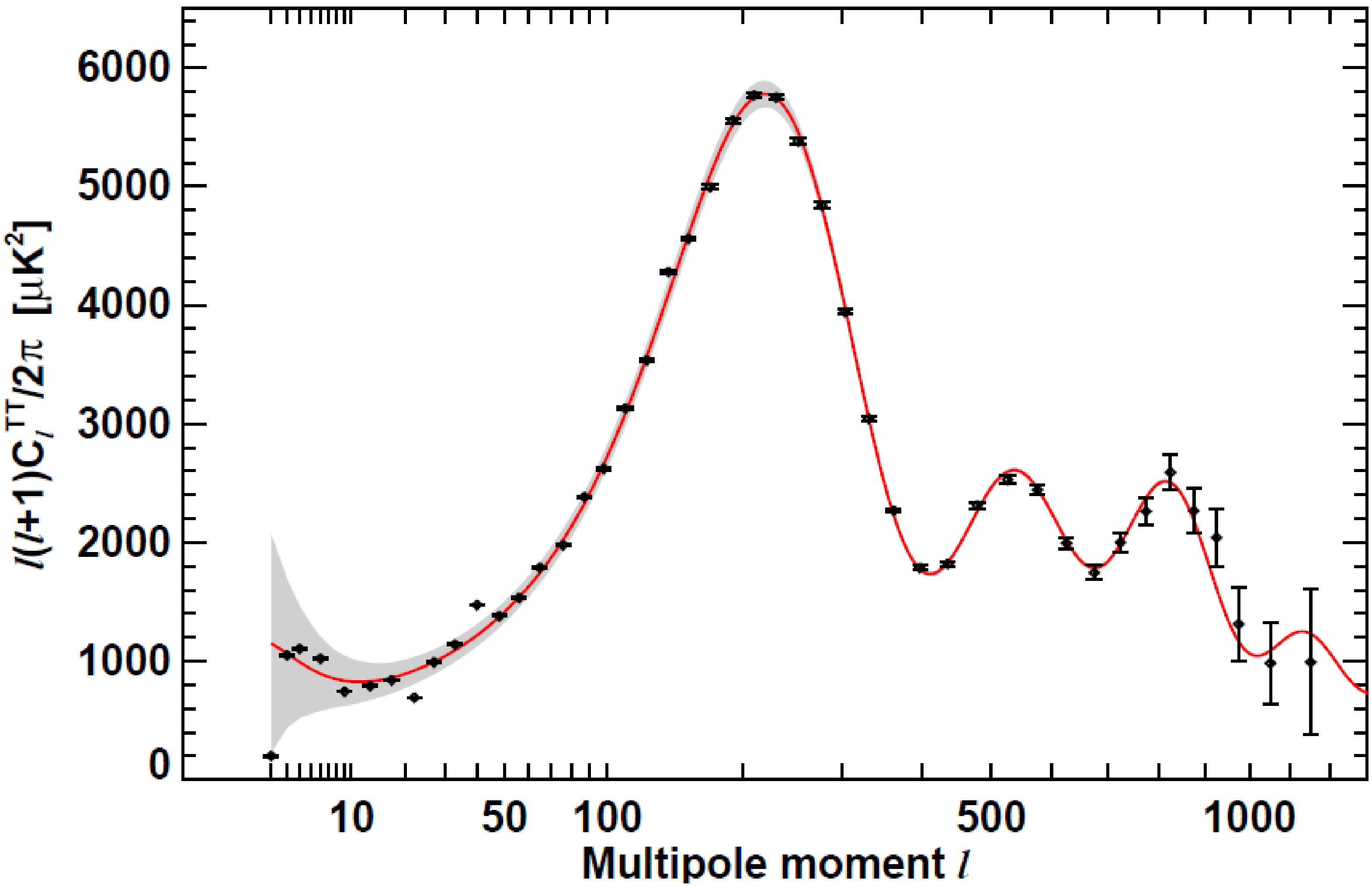
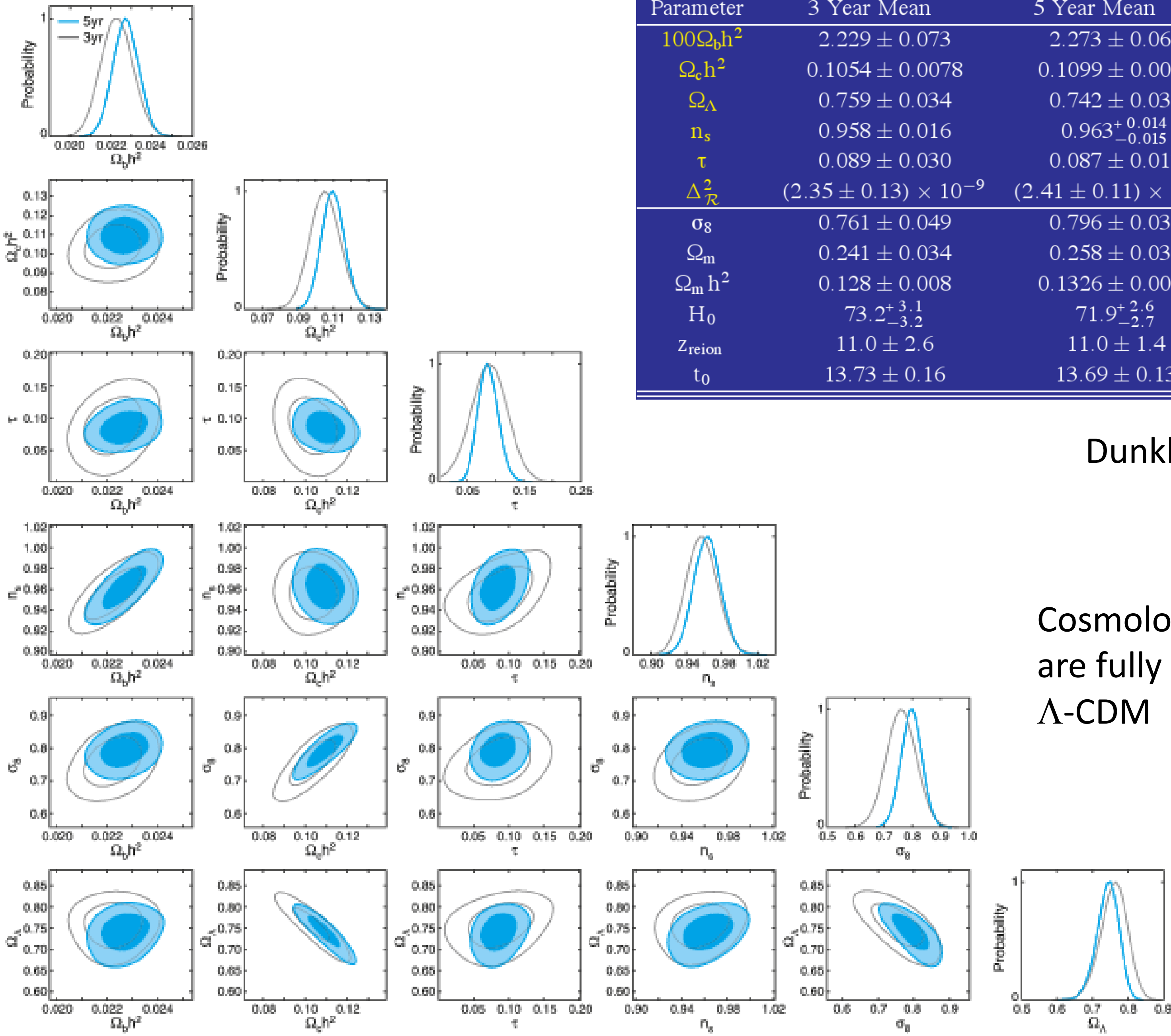
WMAP



New WMAP results from 7 years of observations



Komatsu et al, 2010, 1001.4538



Parameter	3 Year Mean	5 Year Mean	5 Year Max Like
$100\Omega_b h^2$	2.229 ± 0.073	2.273 ± 0.062	2.27
$\Omega_c h^2$	0.1054 ± 0.0078	0.1099 ± 0.0062	0.108
Ω_Λ	0.759 ± 0.034	0.742 ± 0.030	0.751
n_s	0.958 ± 0.016	$0.963^{+0.014}_{-0.015}$	0.961
τ	0.089 ± 0.030	0.087 ± 0.017	0.089
$\Delta^2_{\mathcal{R}}$	$(2.35 \pm 0.13) \times 10^{-9}$	$(2.41 \pm 0.11) \times 10^{-9}$	2.41×10^{-9}
σ_8	0.761 ± 0.049	0.796 ± 0.036	0.787
Ω_m	0.241 ± 0.034	0.258 ± 0.030	0.249
$\Omega_m h^2$	0.128 ± 0.008	0.1326 ± 0.0063	0.131
H_0	$73.2^{+3.1}_{-3.2}$	$71.9^{+2.6}_{-2.7}$	72.4
z_{reion}	11.0 ± 2.6	11.0 ± 1.4	11.2
t_0	13.73 ± 0.16	13.69 ± 0.13	13.7

Dunkley et al., 2008

Cosmological Parameters are fully consistent with Λ-CDM

From WMAP 5 to WMAP7 not much improvement…

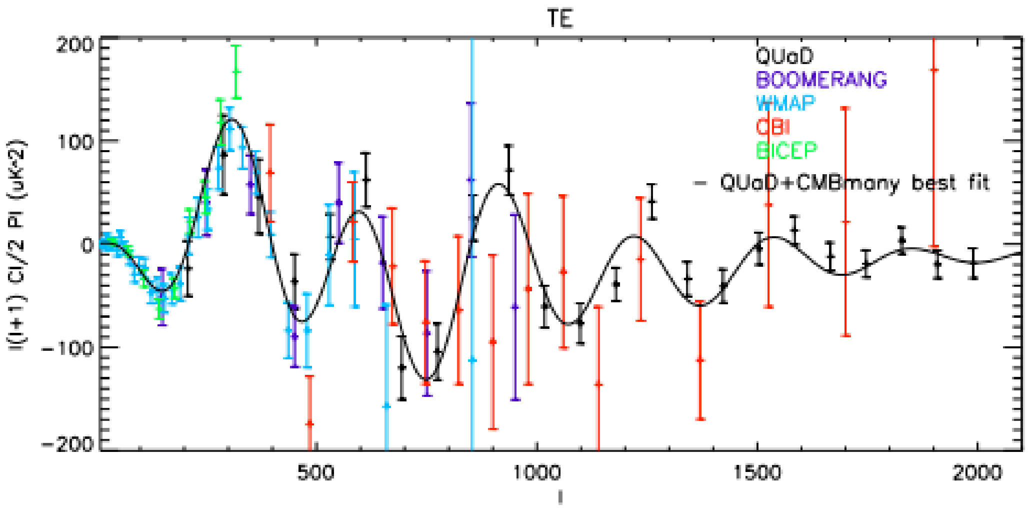
Table 3
Six-Parameter ΛCDM Fit [a]

Parameter	7-year Fit	5-year Fit
Fit parameters		
$10^2\Omega_b h^2$	$2.258^{+0.057}_{-0.056}$	2.273 ± 0.062
$\Omega_c h^2$	0.1109 ± 0.0056	0.1099 ± 0.0062
Ω_Λ	0.734 ± 0.029	0.742 ± 0.030
$\Delta^2_{\mathcal{R}}$	$(2.43 \pm 0.11) \times 10^{-9}$	$(2.41 \pm 0.11) \times 10^{-9}$
n_s	0.963 ± 0.014	$0.963^{+0.014}_{-0.015}$
τ	0.088 ± 0.015	0.087 ± 0.017
Derived parameters		
t_0	13.75 ± 0.13 Gyr	13.69 ± 0.13 Gyr
H_0	71.0 ± 2.5 km/s/Mpc	$71.9^{+2.6}_{-2.7}$ km/s/Mpc
σ_8	0.801 ± 0.030	0.796 ± 0.036
Ω_b	0.0449 ± 0.0028	0.0441 ± 0.0030
Ω_c	0.222 ± 0.026	0.214 ± 0.027
z_{eq}	3196^{+134}_{-133}	3176^{+151}_{-150}
z_{reion}	10.5 ± 1.2	11.0 ± 1.4

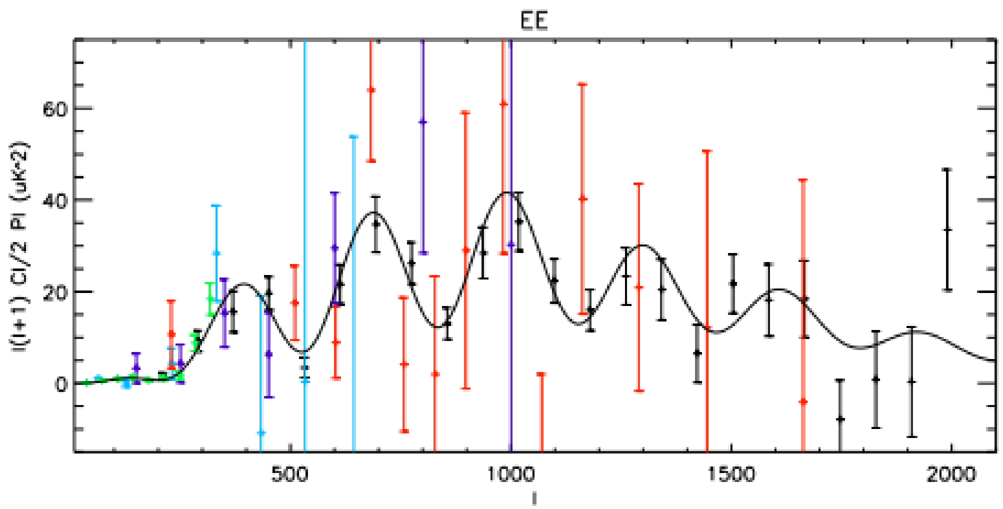
Boring…

Komatsu et al, 2010, 1001.4538

New polarization data from QUAD and BICEP experiments



QUAD, 1000 square degrees maps, observed at 43 & 95GHz.
Gupta et al,
Astrophysical Journal 716 (2010) 1 040-1046

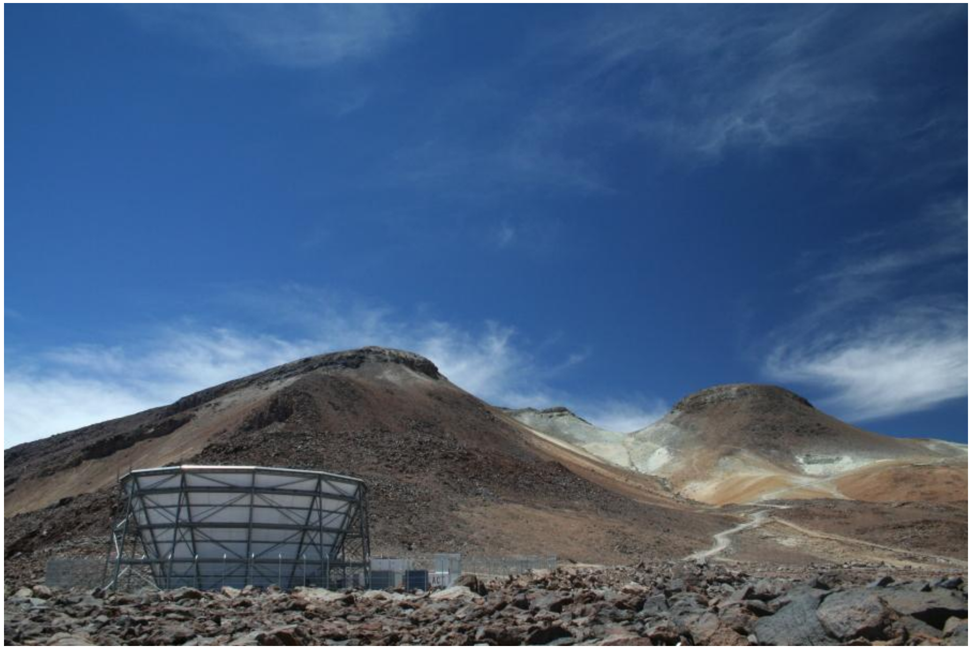


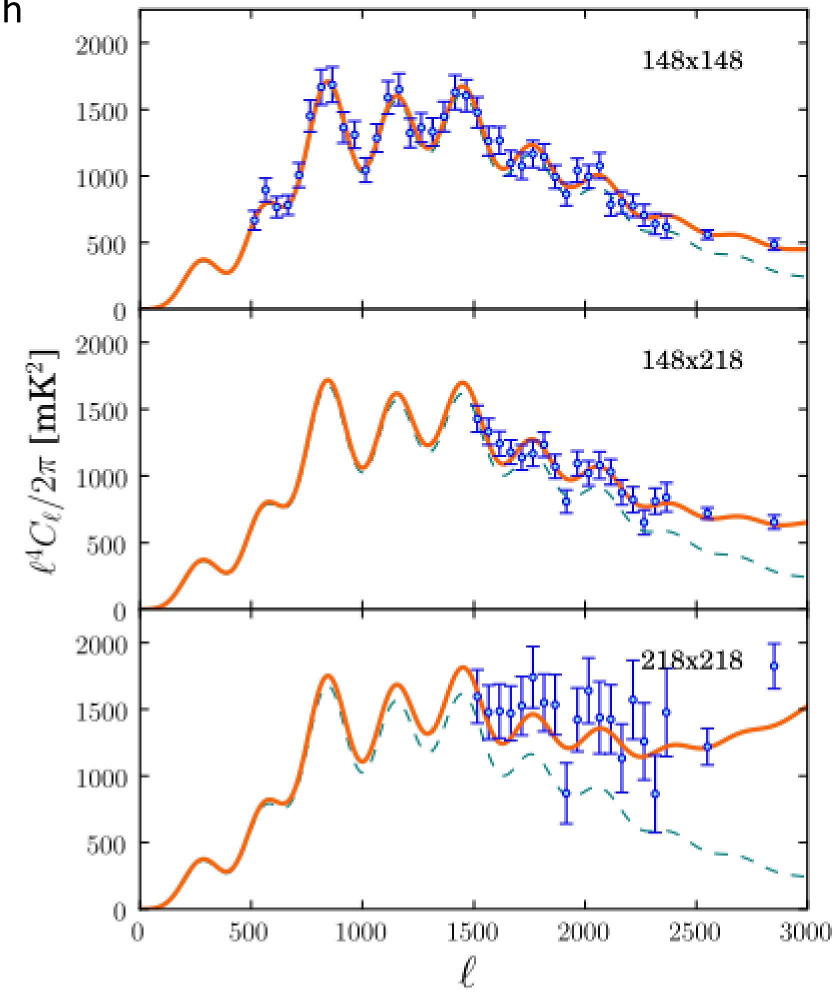
BICEP, 2000 square degrees map, observed at 100 & 150GHz
Chiang et al,
Astrophys.J.711:1123-1140,2010

Good agreement with the expectations of standard LCDM scenario.
No significant improvement on parameter estimation.

New ACT results

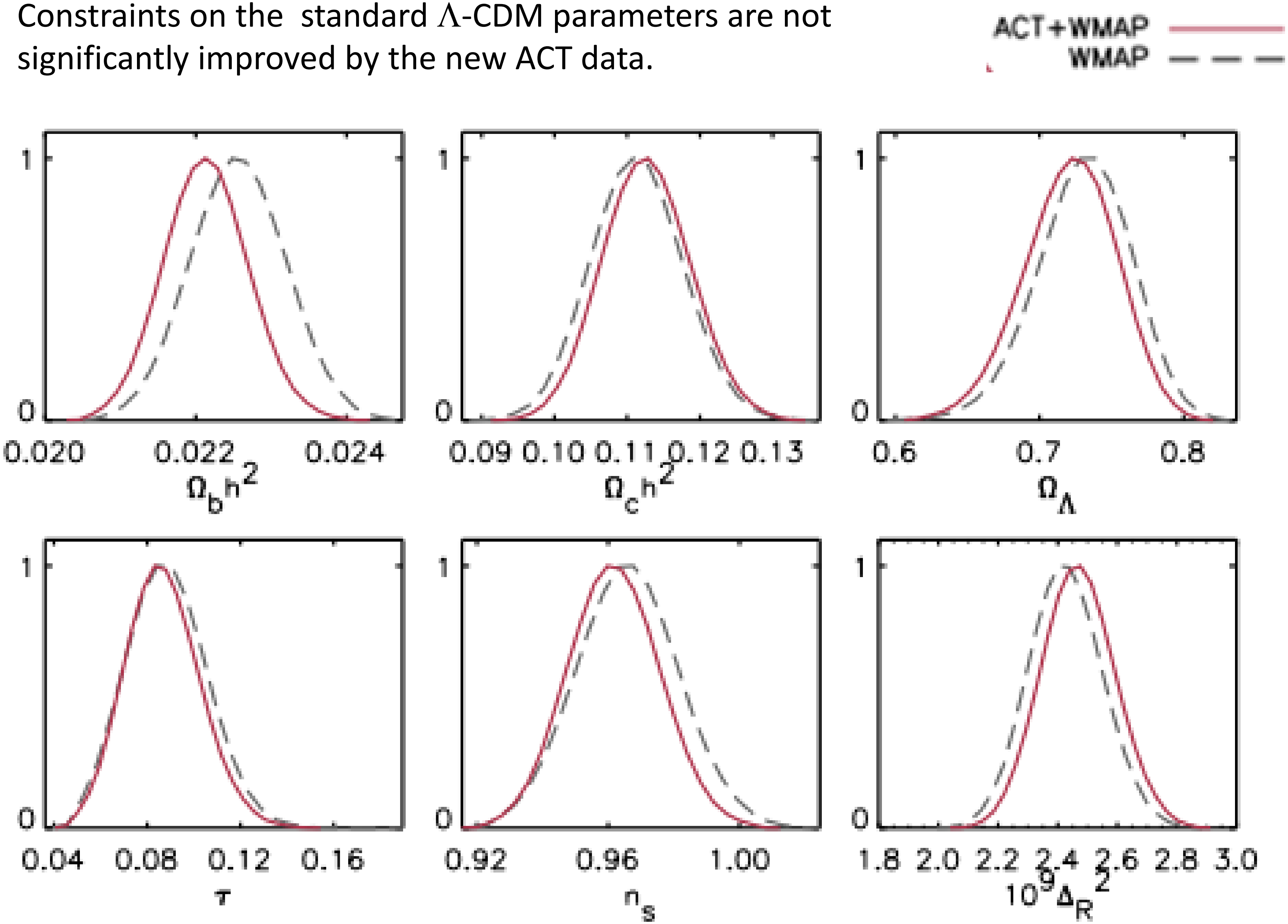
The **Atacama Cosmology Telescope** (**ACT**) is a six-meters telescope on Cerro Toco in the Atacama Desert in the north of Chile, at an altitude of 5190 metres.





S. Das et al, **Astrophys.J. 729 (2011) 62**

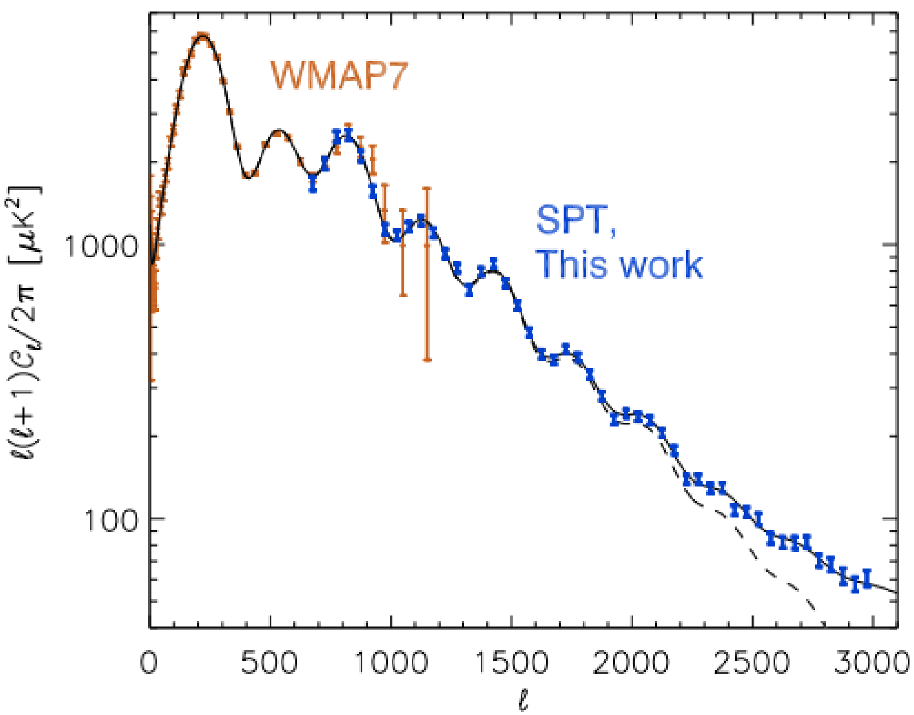
Constraints on the standard Λ-CDM parameters are not significantly improved by the new ACT data.

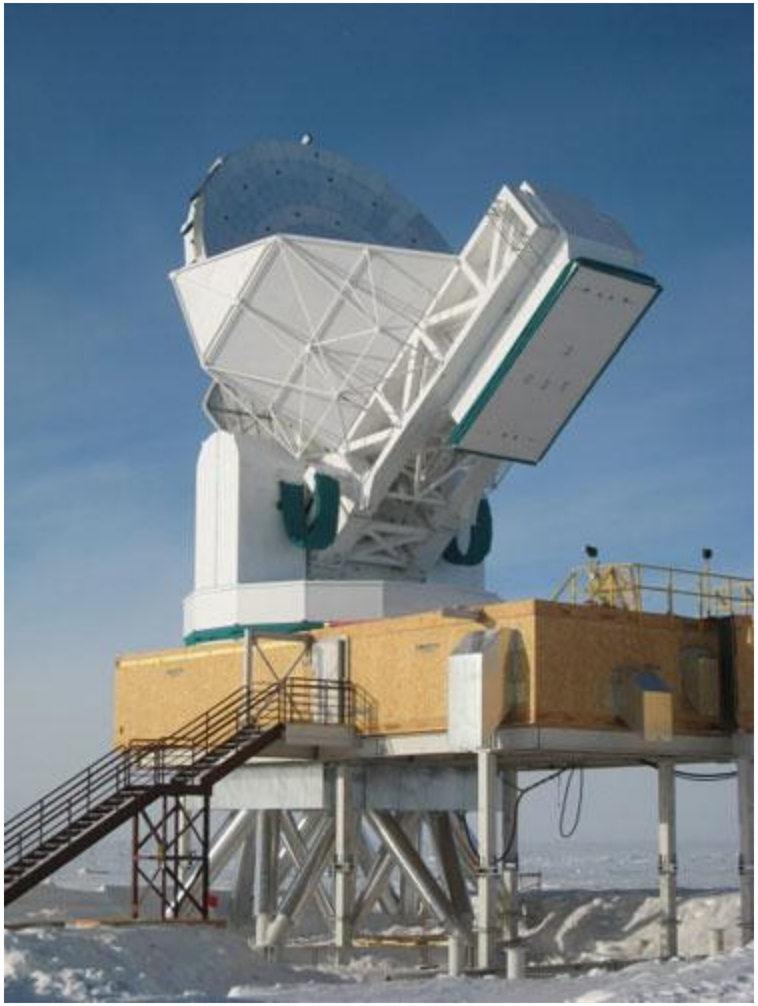


J. Dunkley et al, **Astrophys.J. 739 (2011) 52**

New SPT results

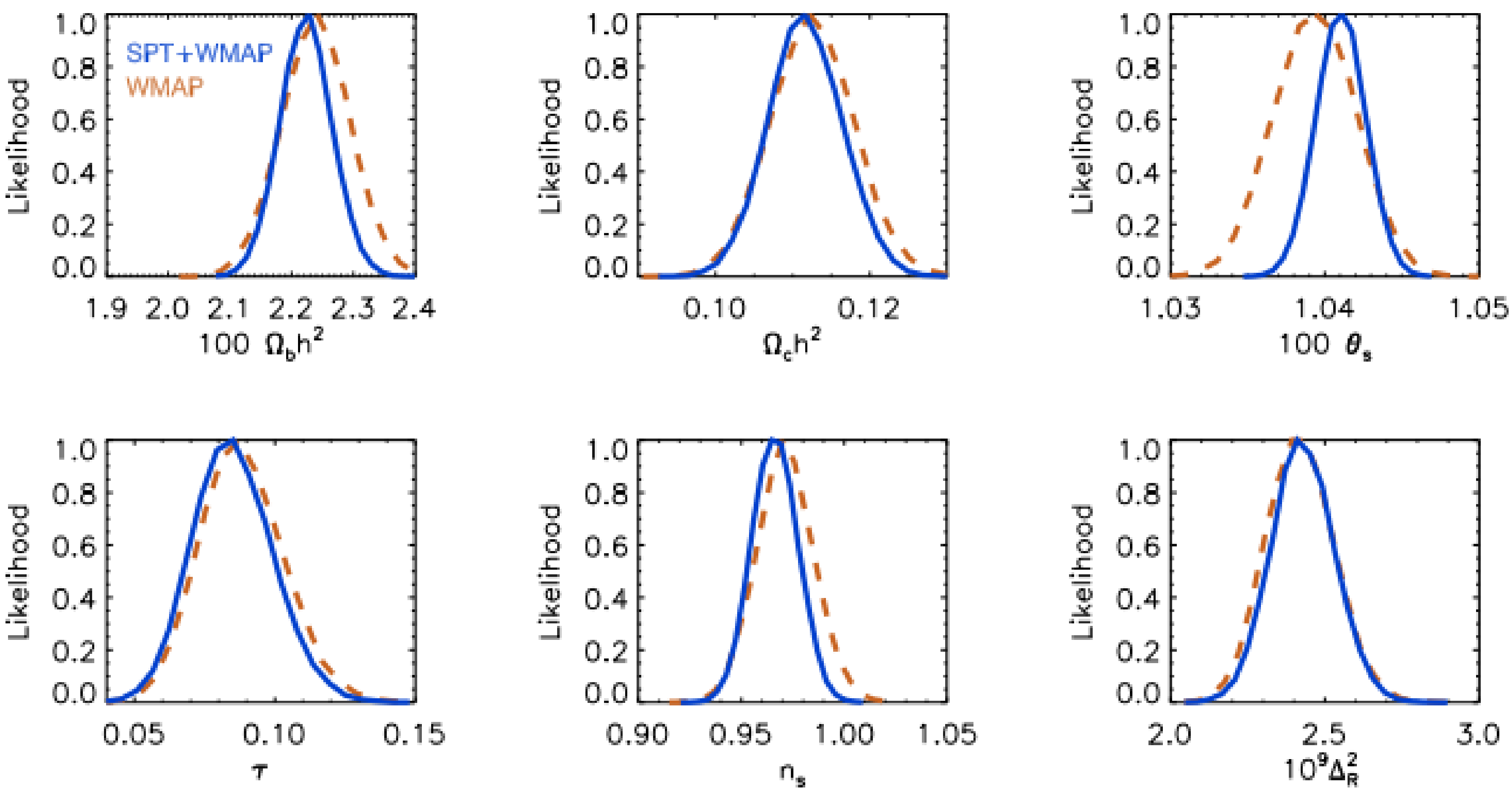
The South Pole Telescope (SPT) is a 10 meters diameter telescope located at the Amundsen-Scott South Pole Station, Antarctica.
The data consist of 790 square degrees of sky observed at 90, 150 & 220 GHz.





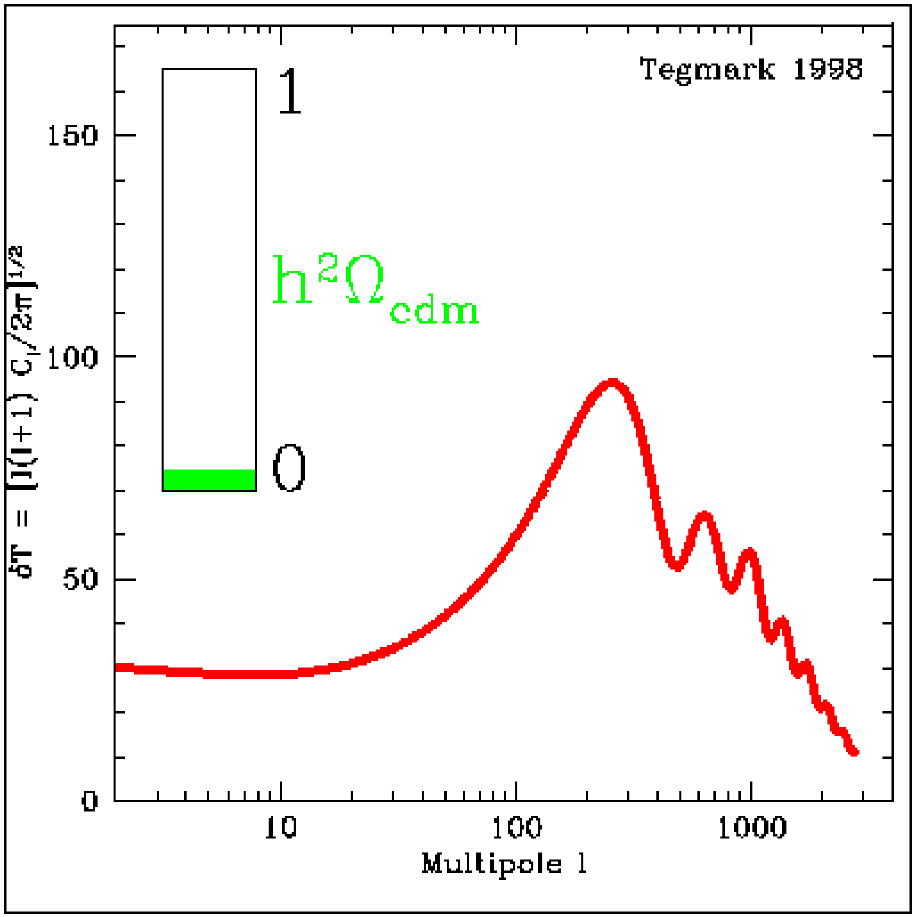
R. Keisler et al, **Astrophys.J. 743 (2011) 28**

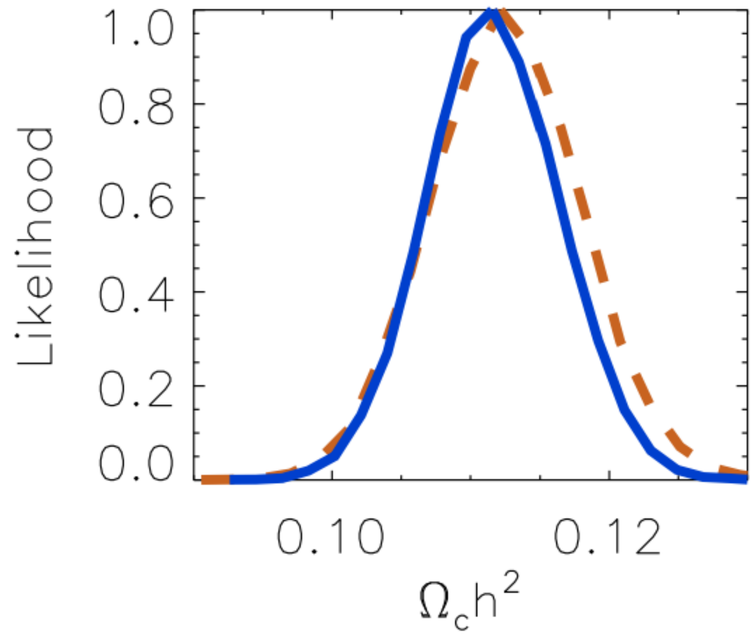
Constraints on the standard Λ-CDM parameters are not significantly improved by the new SPT data.



R. Keisler et al, **Astrophys.J. 743 (2011) 28**

Constraints on the CDM Abundance from Current CMB data



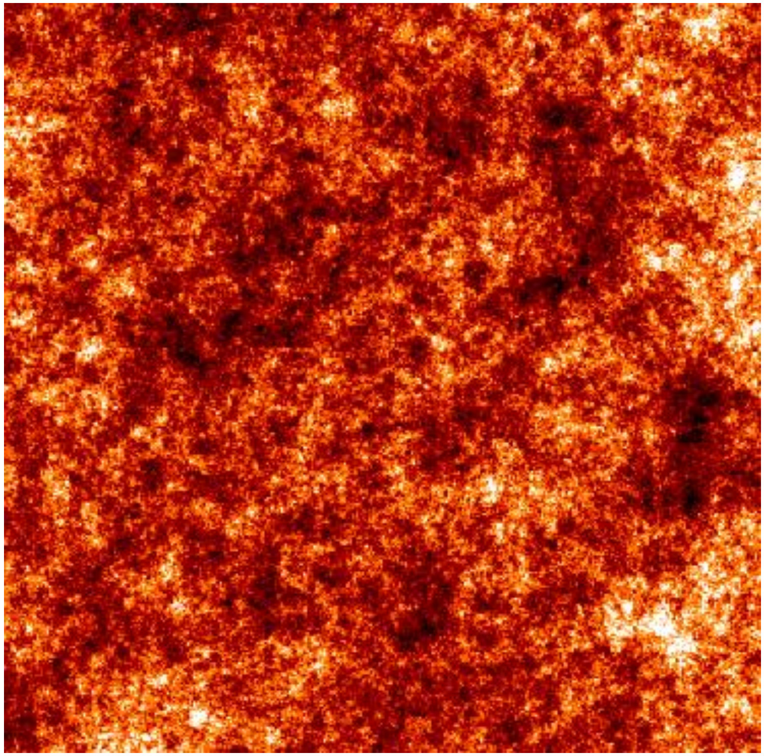


$\Omega_c h^2$ $\quad 0.112 \pm 0.0048$

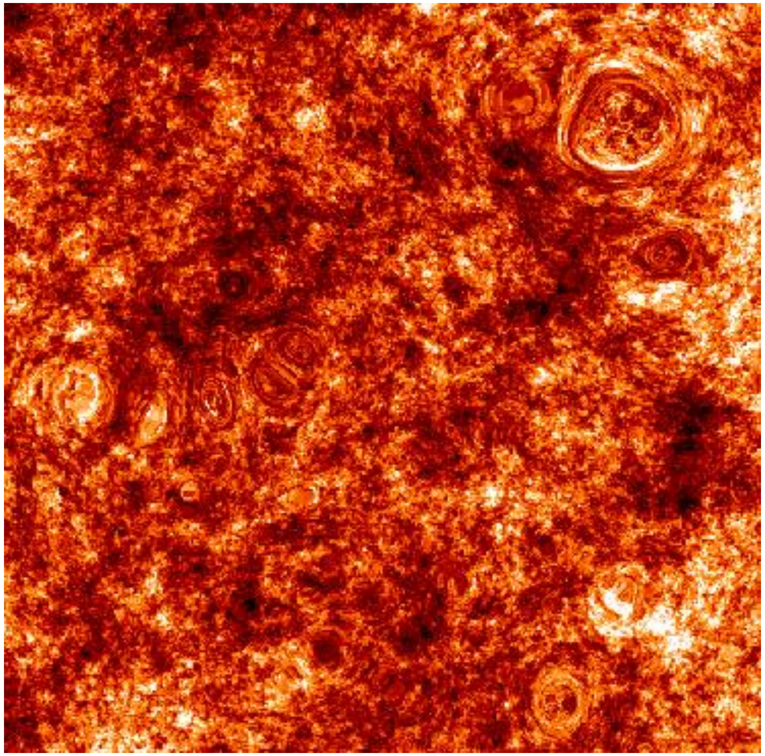
23 sigmas Evidence for CDM !!

CMB Temperature Lensing

unlensed



lensed



When the luminous source is the CMB, the lensing effect essentially re-maps the temperature field according to :

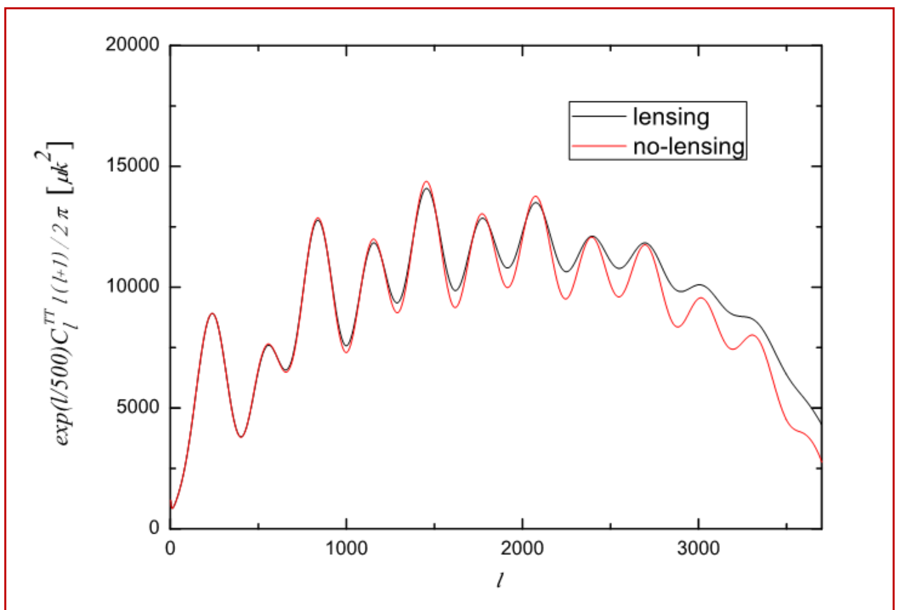
$$\begin{aligned}\tilde{\Theta}(\boldsymbol{x}) &= \Theta(\boldsymbol{x}') = \Theta(\boldsymbol{x}+\boldsymbol{\alpha}) = \Theta(\boldsymbol{x}+\nabla\psi) \\ &\approx \Theta(\boldsymbol{x}) + \nabla^a\psi(\boldsymbol{x})\nabla_a\Theta(\boldsymbol{x}) + \\ &\quad +\frac{1}{2}\nabla^a\psi(\boldsymbol{x})\nabla^b\psi(\boldsymbol{x})\nabla_a\nabla_b\Theta(\boldsymbol{x}) + \ldots\end{aligned}$$

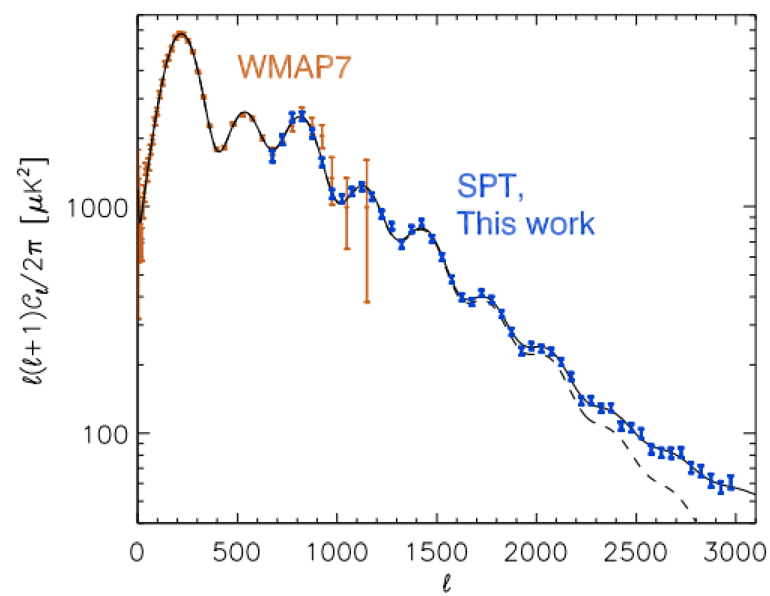
Lensing Effect on Temperature Power Spectrum

The effect is a convolution between the lensing potential power spectrum and the unlensed anisotropies power spectrum:

$$\tilde{C}_l^{\Theta} \approx C_l^{\Theta} + \int \frac{d^2 \boldsymbol{l}'}{(2\pi)^2} \left[\boldsymbol{l}' \cdot (\boldsymbol{l} - \boldsymbol{l}')\right]^2 C^{\psi}_{|\boldsymbol{l}-\boldsymbol{l}'|} C^{\Theta}_{l'} - C_l^{\Theta} \int \frac{d^2 \boldsymbol{l}'}{(2\pi)^2} (\boldsymbol{l} \cdot \boldsymbol{l}')^2 C^{\psi}_{l'}$$

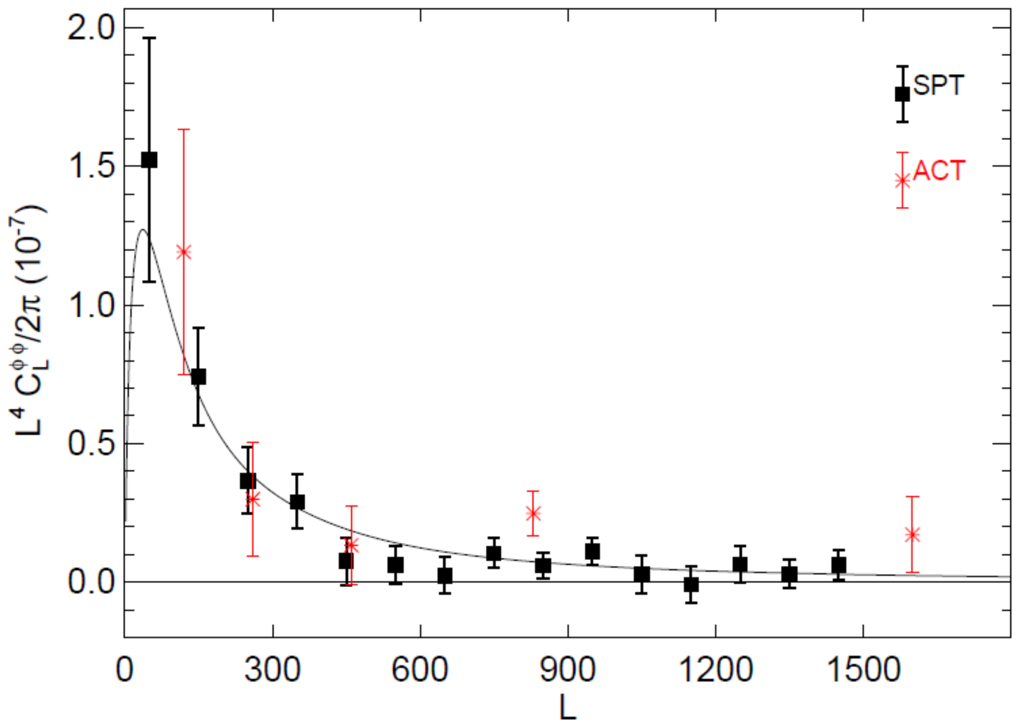
The net result is a 3% broadening of the CMB angular power spectrum acustic peaks





Lensing Effect on Temperature Trispectrum

Another effect from lensing is the creation of non-gaussianities in CMB maps. This will produce a non-zero signal in the four-point CMB correlation function (the so-called trispectrum).



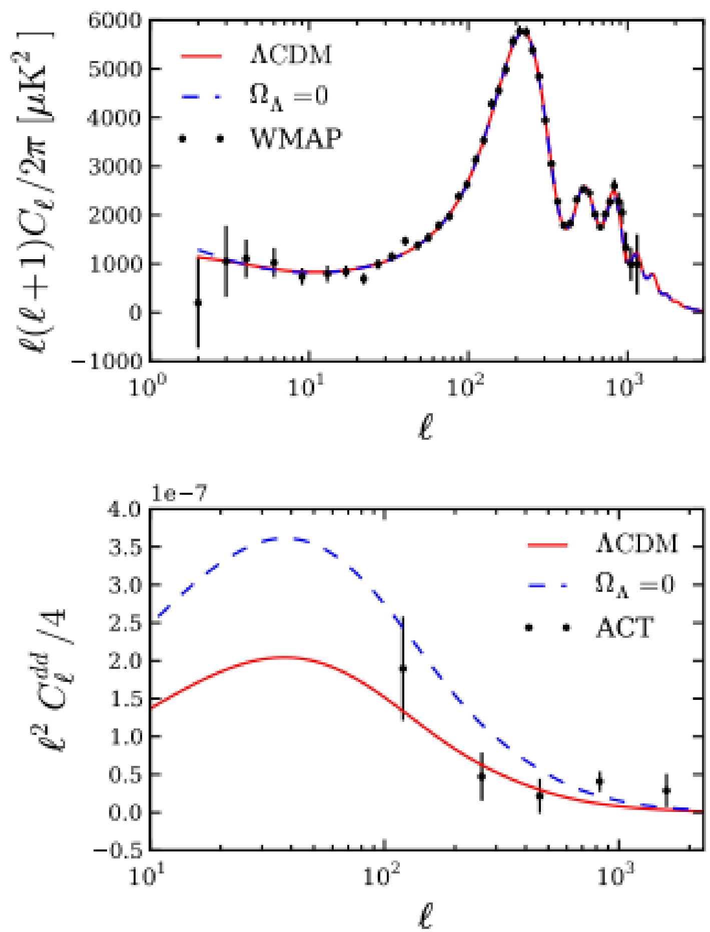
ACT: Das et al**,**
Phys.Rev.Lett. 107 (2011) 021301

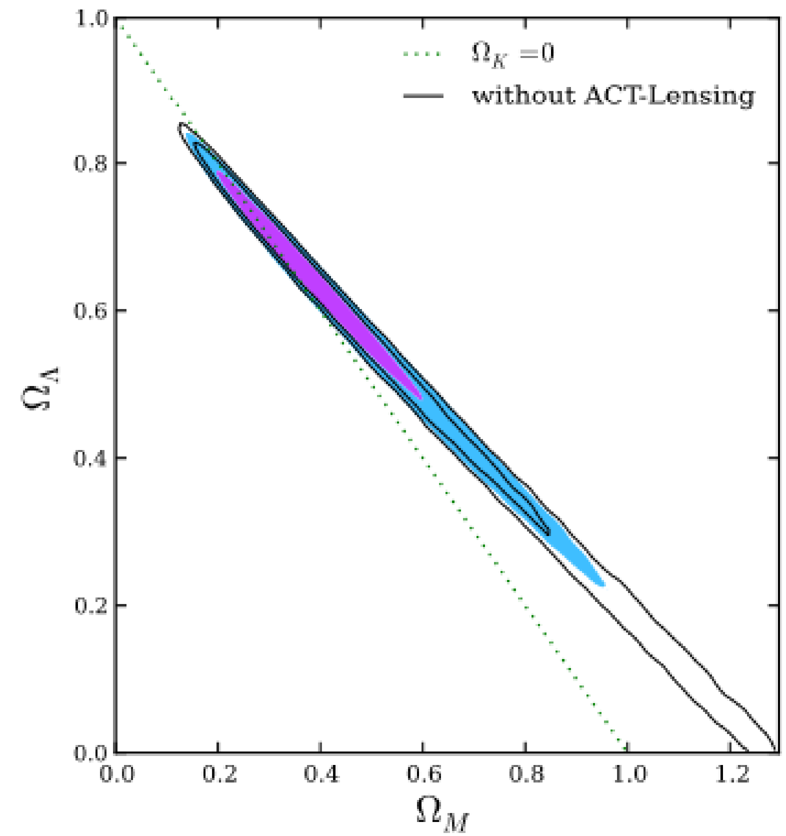
SPT: van Engelen et al,
arXiv:1202.0546 (2012)

This non-gaussian signal has been measured by both ACT and SPT experiments, letting a reconstruction of the lensing potential.

CMB Lensing and Cosmological Constant

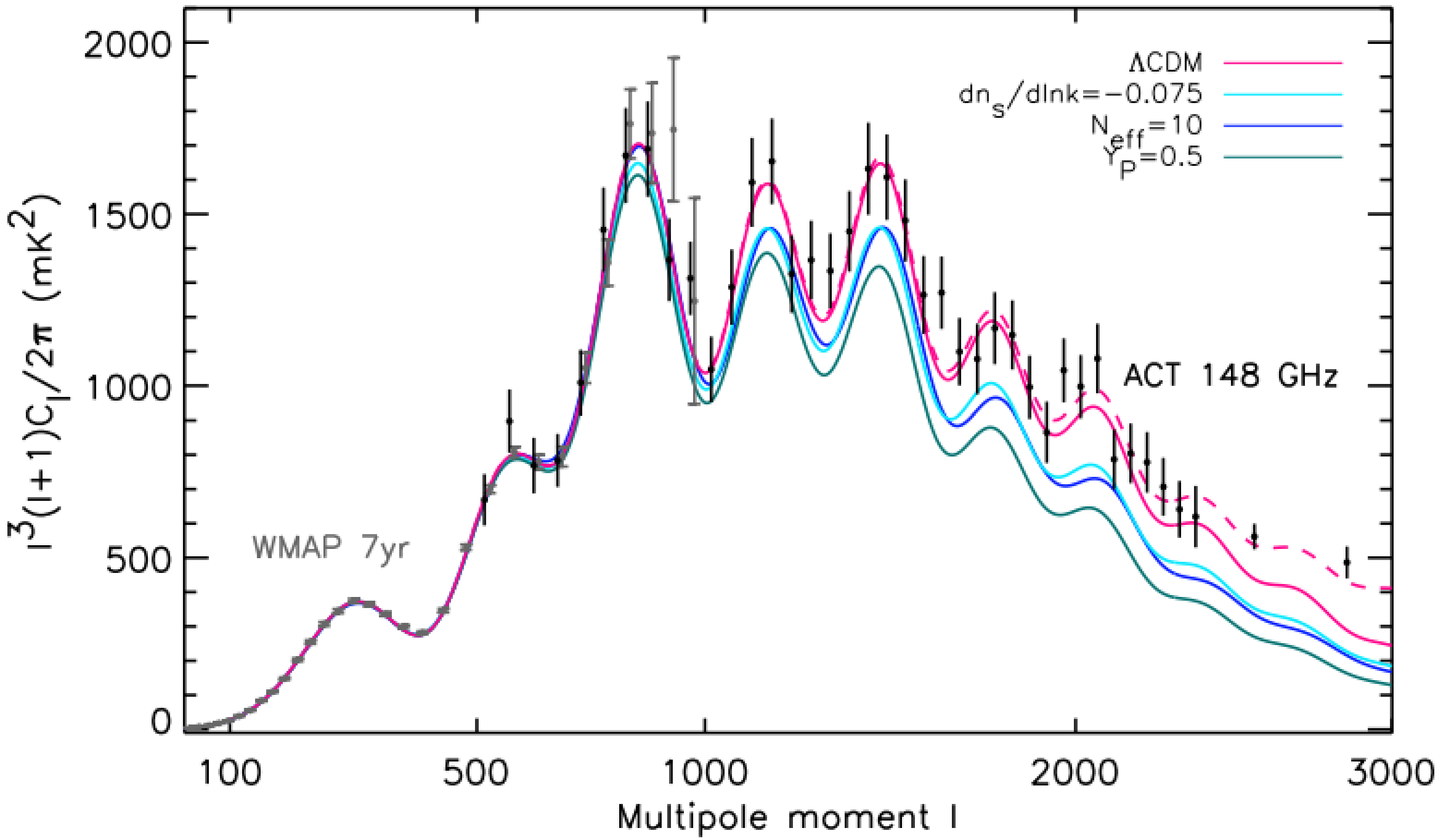
Current CMB lensing detection breaks the geometrical degeneracy and let CMB data alone to reveal a cosmological constant.





Sherwin et al.,
Phys.Rev.Lett.107:021302,2011

Small Scale CMB measurements test new parameters



Cosmological Neutrinos

Neutrinos are in equilibrium with the primeval plasma through weak interaction reactions. They decouple from the plasma at a temperature

$$T_{dec} \approx 1MeV$$

We then have today a Cosmological Neutrino Background at a temperature:

$$T_\nu = \left(\frac{4}{11}\right)^{1/3} T_\gamma \approx 1.945K \rightarrow kT_\nu \approx 1.68 \cdot 10^{-4} eV$$

With a density of:

$$n_f = \frac{3}{4}\frac{\varsigma(3)}{\pi^2} g_f T_f^3 \rightarrow n_{\nu_k, \bar{\nu}_k} \approx 0.1827 \cdot T_\nu^3 \approx 112 cm^{-3}$$

That, for a relativistic neutrinos translate in a extra radiation component of:

$$\Omega_\nu h^2 = \frac{7}{4}\left(\frac{4}{11}\right)^{4/3} N_{eff}^\nu \Omega_\gamma h^2$$

Standard Model predicts:

$$N_{eff}^\nu = 3.046$$

Dark Radiation

The total amount of relativistic particles in the Universe is therefore parametrized in the following way (see Hannestad talk) :

$$\Omega_R h^2 = \left[1 + \frac{7}{4} \left(\frac{4}{11} \right)^{4/3} N_{eff}^{\nu} \right] \Omega_\gamma h^2$$

Caveat: N_{eff} can be a function of time (i.e. massive neutrinos).
For most of the cases we consider here is assumed to be a constant.
A value of $N_{eff} > 3.046$ is equivalent to the presence of a new «dark radiation» component :

$$\left(\frac{H}{H_0} \right)^2 = \frac{\Omega_M}{a^3} + \frac{\Omega_\gamma}{a^4} + \frac{\Omega_\nu}{a^4} + \Omega_\Lambda + \frac{\Omega_{DR}}{a^4}$$

Probing the Neutrino Number with CMB data

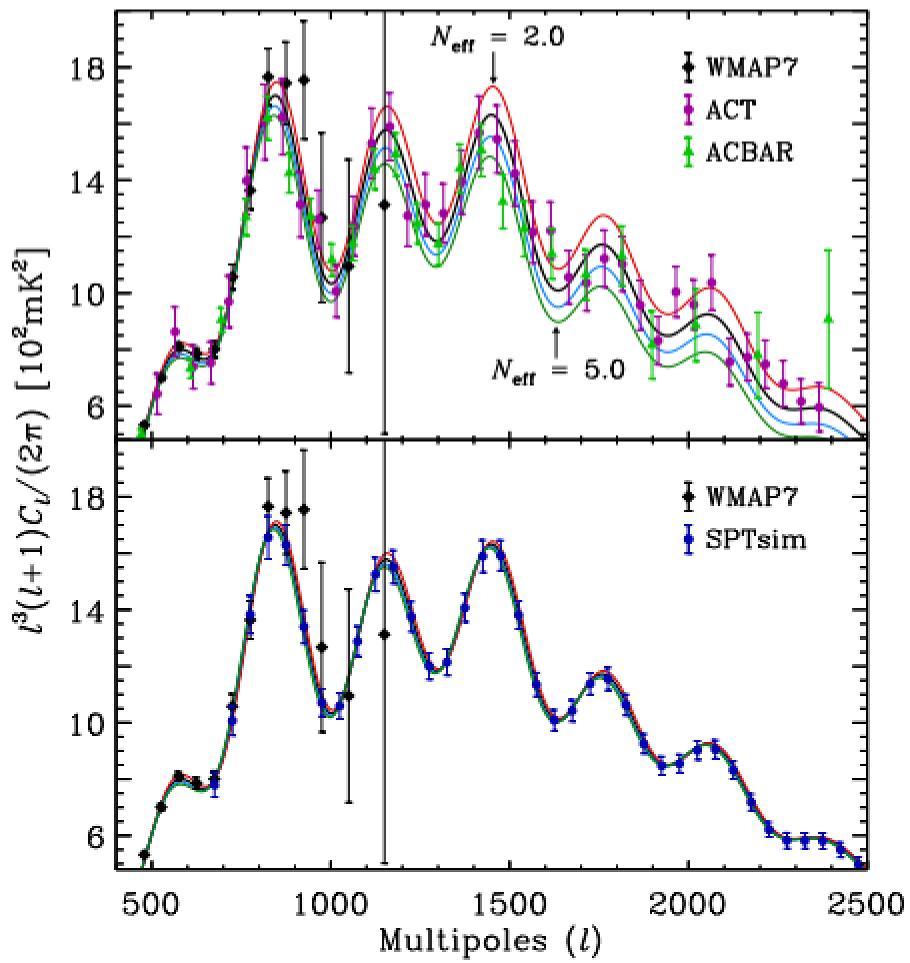
Changing the Neutrino effective number essentially changes the expansion rate H at recombination.
So it changes the sound horizon at recombination:

$$r_s = \int_0^{t_*} c_s\, dt/a = \int_0^{a_*} \frac{c_s\, da}{a^2 H}.$$

and the damping scale at recombination:

$$r_d^2 = (2\pi)^2 \int_0^{a_*} \frac{da}{a^3 \sigma_T n_e H} \left[\frac{R^2 + \frac{16}{15}(1+R)}{6(1+R^2)} \right]$$

$$\theta_s = \frac{r_s}{D_A} \qquad \theta_d = \frac{r_d}{D_A}$$

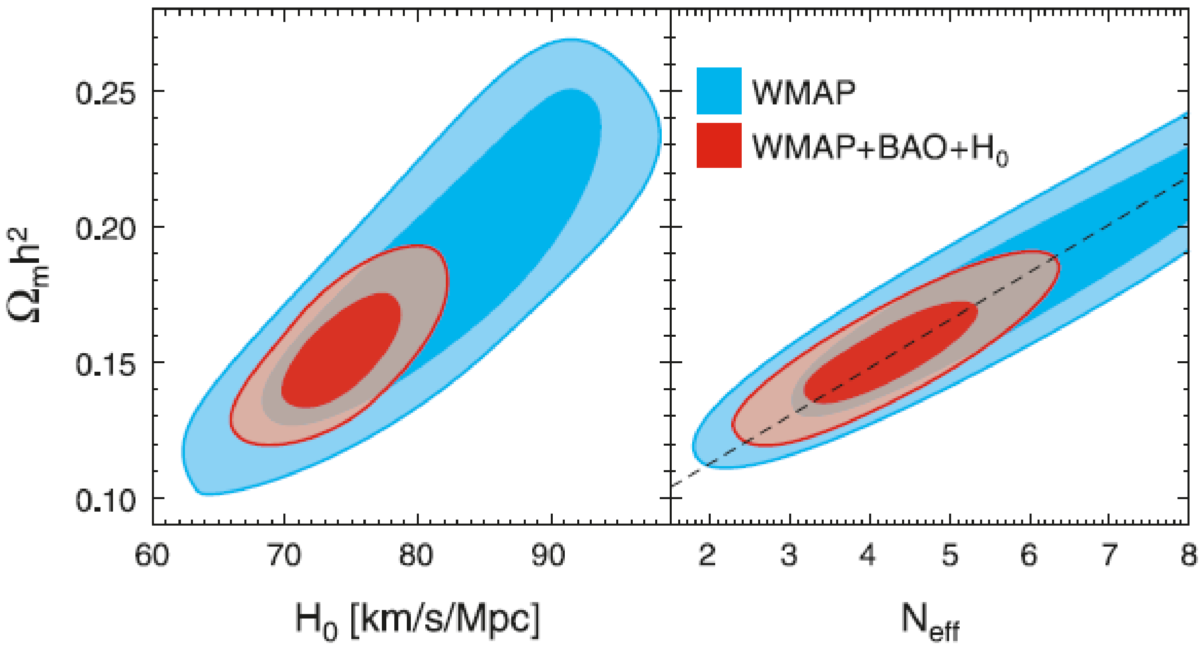


Moreover increases early ISW at Recombination (phase shift)

Hou et al, 2011

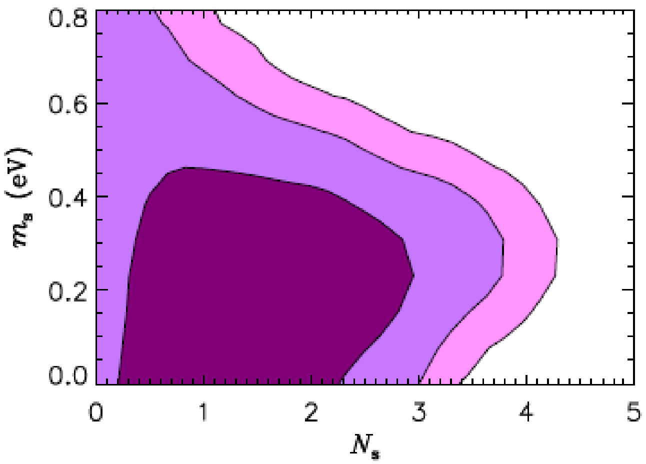
Komatsu et al, 2010, 1001.4538

WMAP provides first indication for the existance of the neutrino background from CMB data only.

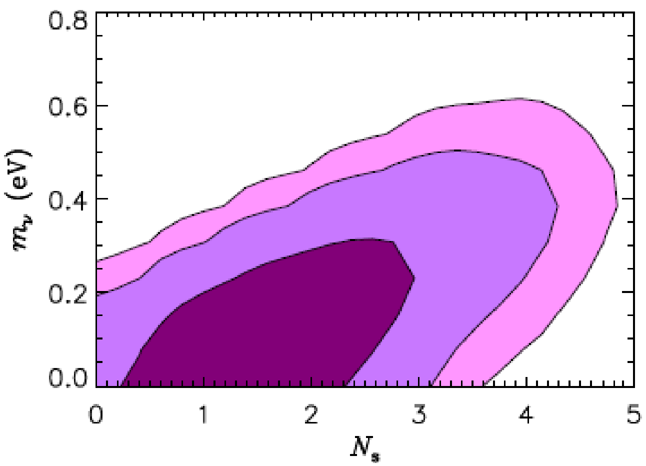


Parameter	Year	*WMAP* only	*WMAP*+BAO+SN+*HST*	*WMAP*+BAO+H_0	*WMAP*+LRG+H_0
z_{eq}	5-year	3141^{+154}_{-157}	3240^{+99}_{-97}		
	7-year	3145^{+140}_{-139}		3209^{+85}_{-89}	3240 ± 90
$\Omega_m h^2$	5-year	$0.178^{+0.044}_{-0.041}$	0.160 ± 0.025		
	7-year	$0.184^{+0.041}_{-0.038}$		0.157 ± 0.016	$0.157^{+0.013}_{-0.014}$
N_{eff}	5-year	> 2.3 (95% CL)	4.4 ± 1.5		
	7-year	> 2.7 (95% CL)		$4.34^{+0.86}_{-0.88}$	$4.25^{+0.76}_{-0.80}$

Subsequent analysis with WMAP+ACBAR+BICEP+QUAD+SDSS DR7+HST confirmed the «preference» for $N_{eff} > 3$.



3 Active massless neutrinos+ N_s massive neutrinos

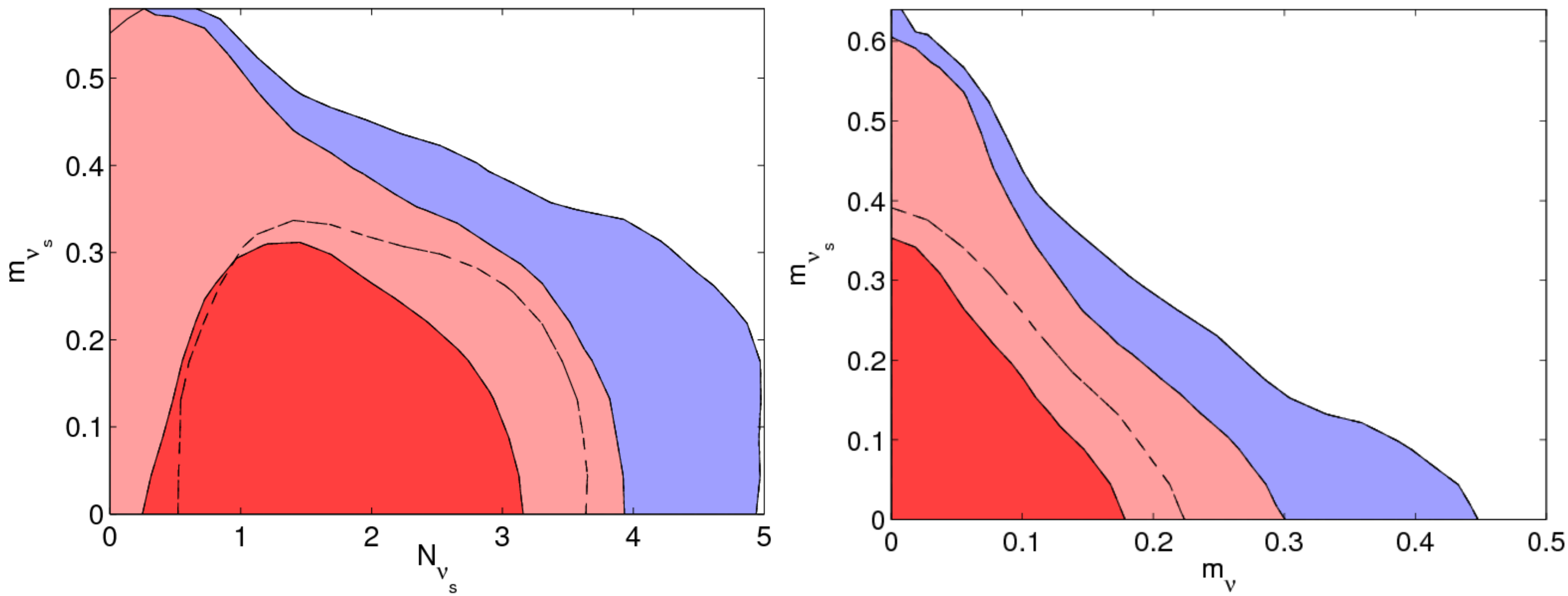


3 Active massive neutrinos + N_s massless neutrinos

J. Hamann et al, Phys.Rev.Lett.105:181301,2010

Massive Sterile

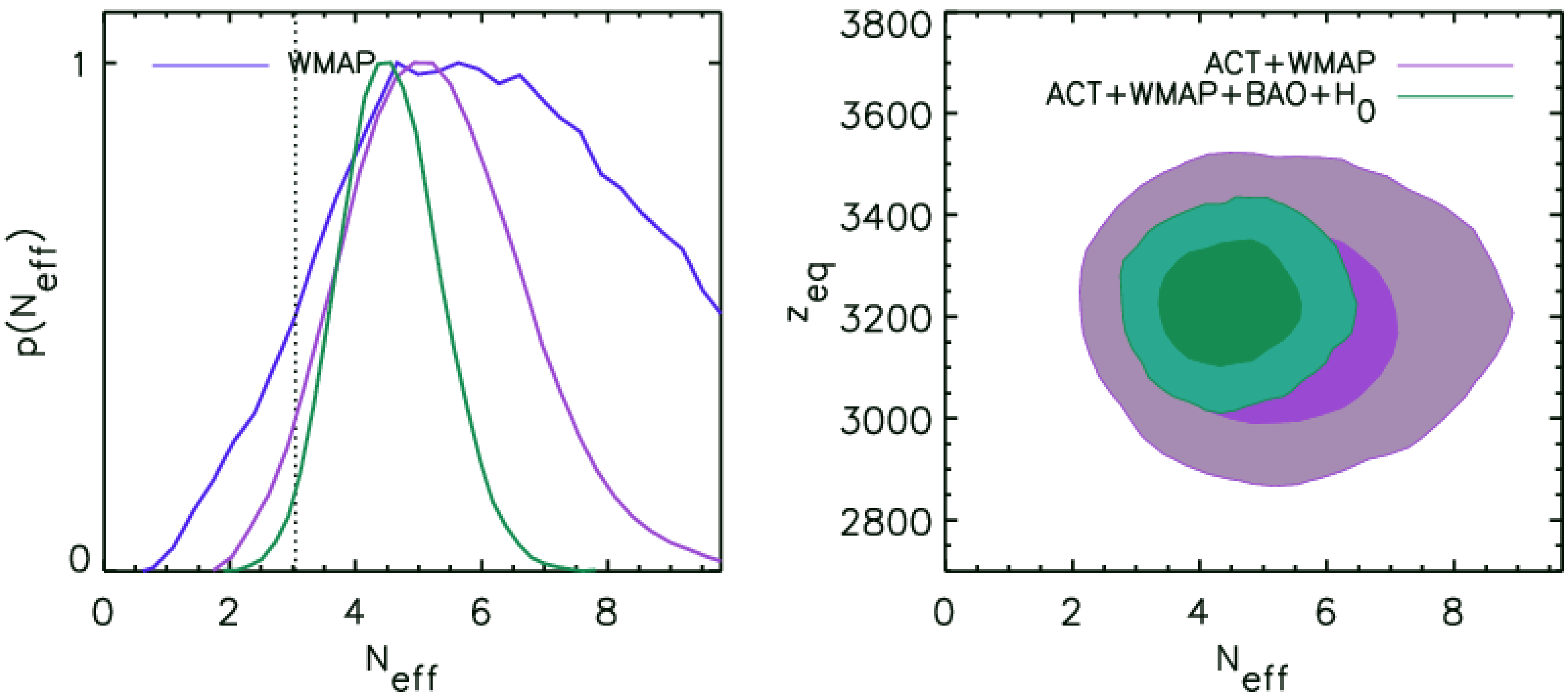
Giusarma et al., Phys.Rev.D83:115023,2011.
Includes masses both in active and sterile Neutrinos. Again preference for Neff > 3



Blue: CMB+HST+SDSS
Red: CMB+HST+SDSS+SN-Ia

Parameter	68% CL(r1)	95% CL(r1)	68% CL (r2)	95% CL (r2)
N_{ν_s}	$0.94 - 3.16$	$0.21 - 4.63$	$0.69 - 2.53$	$0.13 - 3.56$
m_ν [eV]	$0.02 - 0.19$	< 0.36	$0.01 - 0.14$	< 0.24
m_{ν_s} [eV]	$0.04 - 0.31$	< 0.70	$0.03 - 0.30$	< 0.70

ACT confirms indication for extra neutrinos but now at about two standard deviations



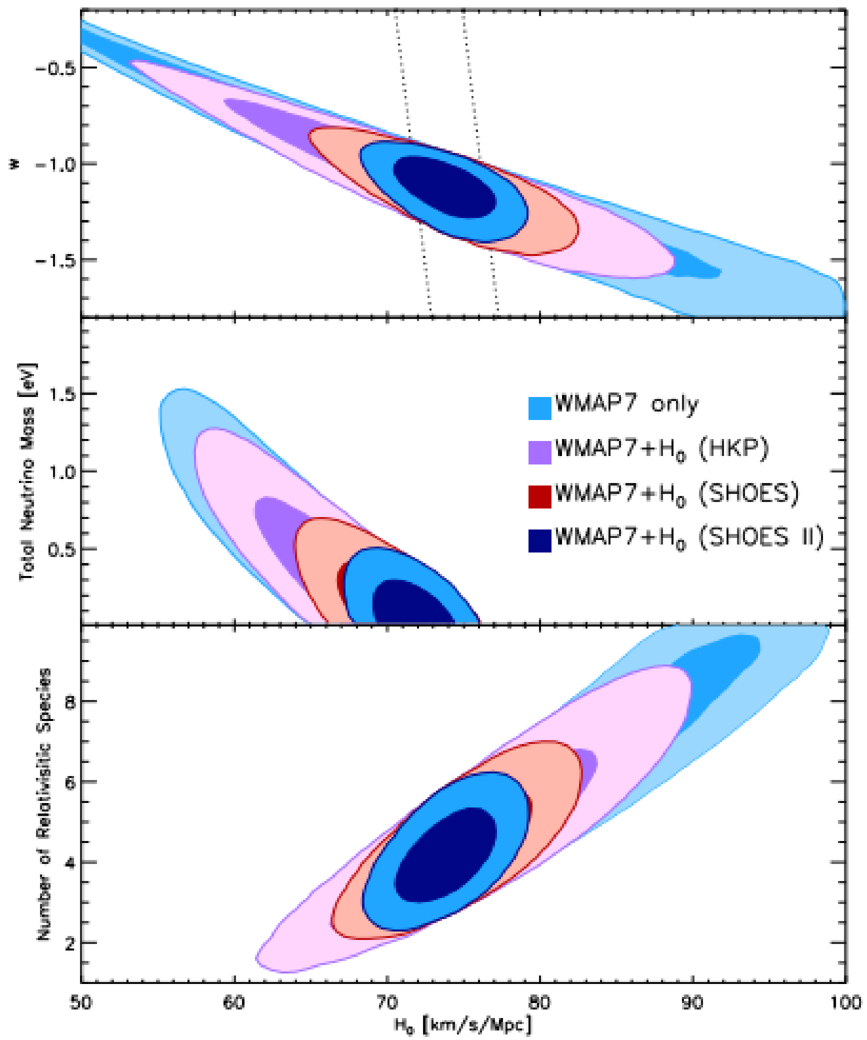
Latest results from ACT, Dunkley et al. 2010
(95 % c.l.)

$Neff = 5.3 \pm 1.3$ ACT+WMAP

$Neff = 4.8 \pm 0.8$ ACT+WMAP+BAO+H0

New HST determination of H_0

The new 3% determination of the Hubble Constant with the Hubble Space Telescope and Wide Field Camera 3 points towards $N_{eff} > 3$ when combined with WMAP-only data.

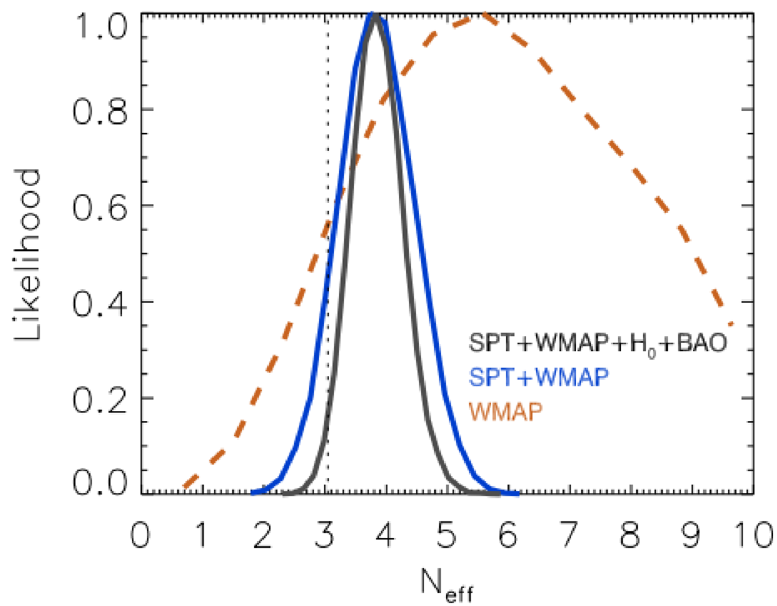


$h = 0.738 \pm 0.024$

$N_{eff} = 4.2 \pm 0.7$

Riess et al, **ApJ, 730, 119, 2011**

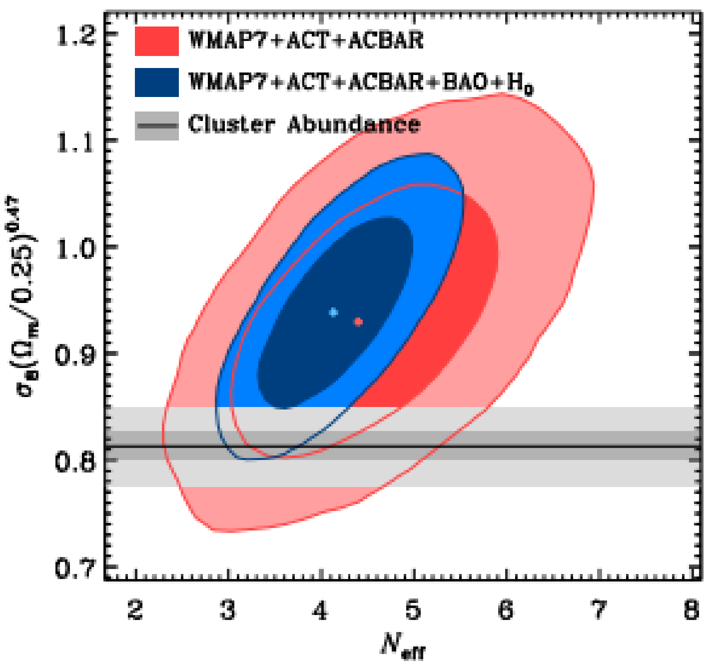
SPT confirms indication for extra neutrinos but at less than two standard deviations (and closer to 3)

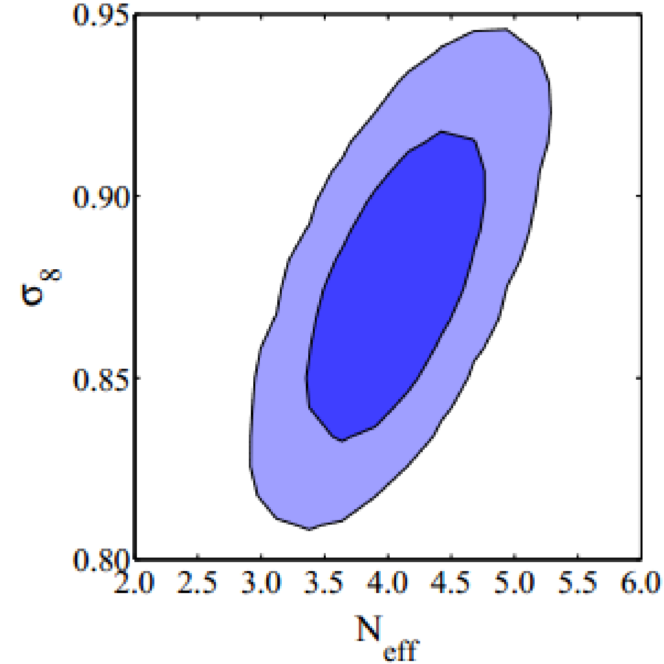


		ΛCDM	ΛCDM $+ A_L$	ΛCDM $+r$	ΛCDM $+ dn_s/d\ln k$	ΛCDM $+ Y_p$	ΛCDM $+ N_{\rm eff}$
Primary Parameters	$100\Omega_b h^2$	2.23 ± 0.038	2.22 ± 0.039	2.24 ± 0.040	2.23 ± 0.040	2.27 ± 0.044	2.26 ± 0.042
	$\Omega_c h^2$	0.112 ± 0.0028	0.112 ± 0.0029	0.112 ± 0.0030	0.114 ± 0.0031	0.114 ± 0.0032	0.129 ± 0.0093
	$100\theta_s$	1.04 ± 0.0015	1.04 ± 0.0016	1.04 ± 0.0015	1.04 ± 0.0016	1.04 ± 0.0020	1.04 ± 0.0017
	n_s	0.9668 ± 0.0093	0.9659 ± 0.0095	0.9711 ± 0.0099	0.9758 ± 0.0111	0.9814 ± 0.0126	0.9836 ± 0.0124
	τ	0.0851 ± 0.014	0.0852 ± 0.014	0.0842 ± 0.014	0.0934 ± 0.016	0.0890 ± 0.015	0.0859 ± 0.014
	$10^9 \Delta_R^2$	2.43 ± 0.082	2.44 ± 0.085	2.39 ± 0.088	2.35 ± 0.095	2.39 ± 0.085	2.41 ± 0.084
Extension Parameters	$A_L^{0.65}$	—	0.95 ± 0.15	—	—	—	—
	r	—	—	< 0.17	—	—	—
	$dn_s/d\ln k$	—	—	—	-0.020 ± 0.012	—	—
	Y_p	(0.2478 ± 0.0002)	(0.2478 ± 0.0002)	(0.2478 ± 0.0002)	(0.2478 ± 0.0002)	0.300 ± 0.030	(0.2581 ± 0.005)
	$N_{\rm eff}$	(3.046)	(3.046)	(3.046)	(3.046)	(3.046)	3.86 ± 0.42
Derived	σ_8	(0.818 ± 0.019)	(0.818 ± 0.019)	(0.816 ± 0.019)	(0.824 ± 0.020)	(0.841 ± 0.024)	(0.871 ± 0.033)
	$\chi^2_{\rm min}$	7510.7	7510.6	7510.7	7507.8	7508.0	7507.4

WMAP7+ACT+SPT+H0+BAO Analyses

Most recent analyses they all point towards Neff>3 at about 2.6-2.8 standard deviations.





$$N_{eff}^{\nu} = 4.08^{+0.71}_{-0.68}$$ At 95% c.l.

Archidiacono, Calabrese, AM, **Phys.Rev. D84 (2011) 123008**
Hou et al**, arXiv:1104.2333, (2011)**
Smith et al**, Phys.Rev. D85 (2012) 023001**
Hamann**, JCAP 1203 (2012) 021**

Probing the Neutrino Number with BBN data

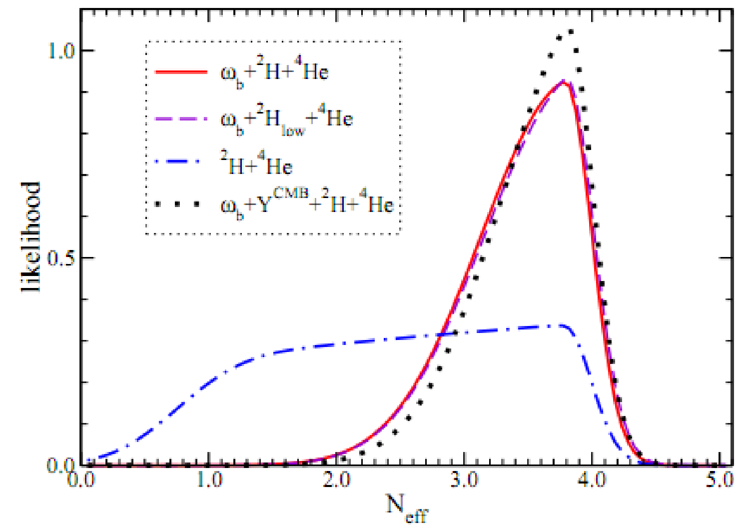
- BBN element abundances depend on nuclear interaction rates and expansion rate.

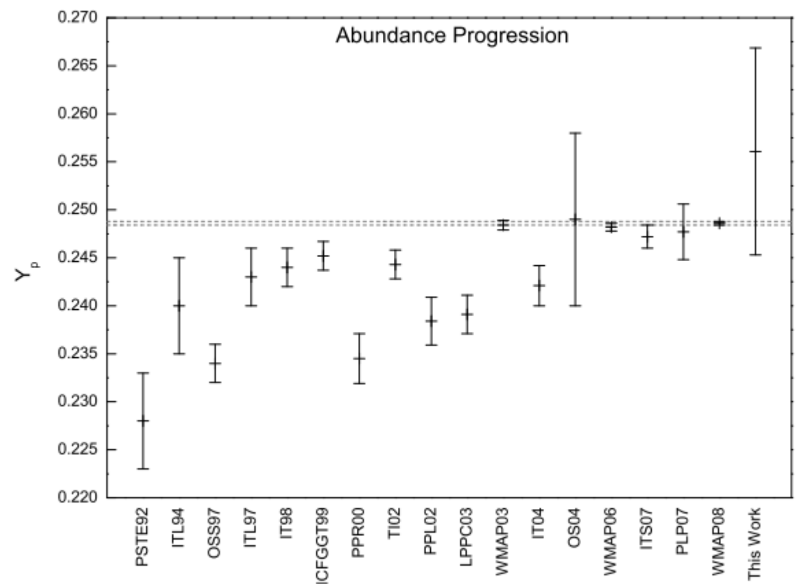
- Helium abundance Yp is the most sensitive probe for the neutrino number. Larger Helium -> Larger N_{eff}

Recently Mangano and Serpico (Mangano, Serpico, PLB 2011) obtained the upper limit:

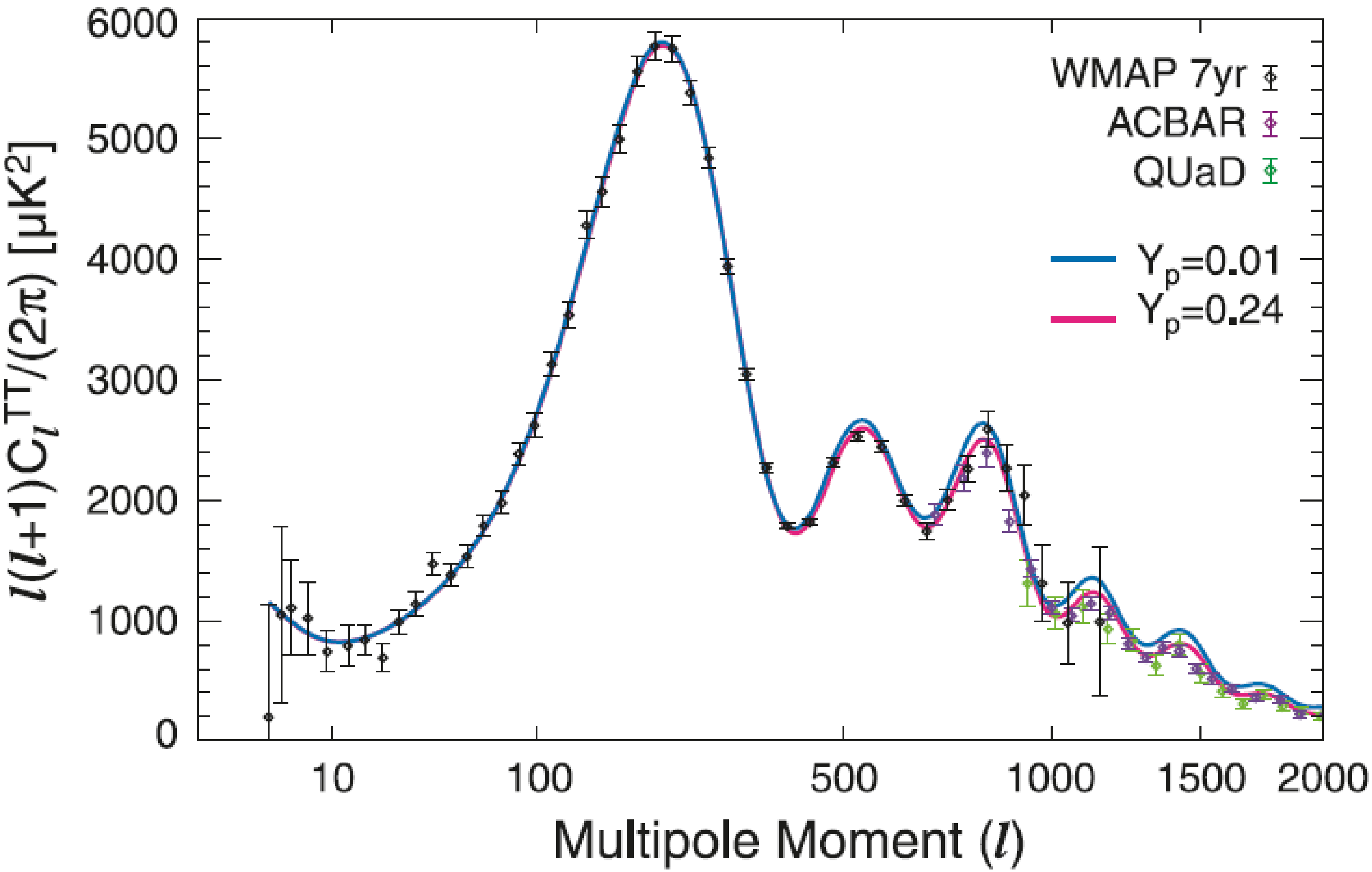
$$N_{eff} < 4 \text{ at } 95\ \%\ \text{c.l.}$$

However Yp is measured in metal-poor H-II regions subject to systematics (see Aver, Olive and Skillman, 2010)





Small scale CMB also probes Helium abundance at recombination.



See e.g.,

K. Ichikawa et al., Phys.Rev.D78:043509,2008

R. Trotta, S. H. Hansen, Phys.Rev. D69 (2004) 023509

Thermal History and Recombination

- Dominant element hydrogen recombines rapidly around z 1000.

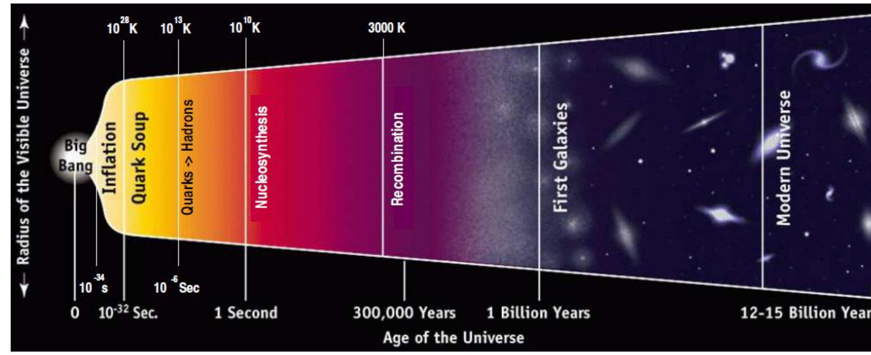
– Prior to recombination, Thomson scattering efficient and mean free path short cf. expansion time

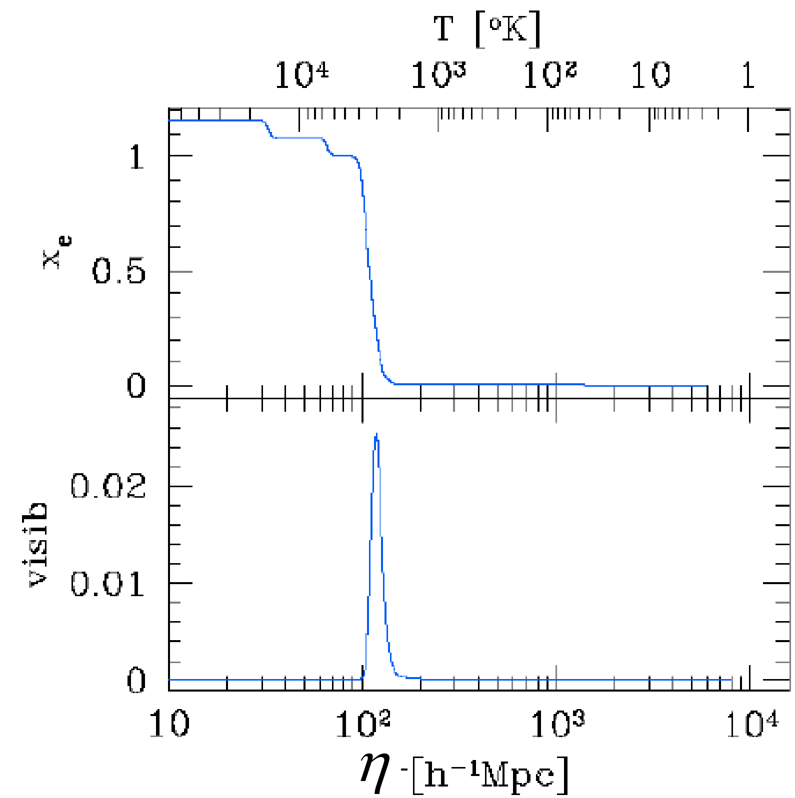
– Little chance of scattering after recombination ! photons free stream keeping imprint of conditions on last scattering surface

• Optical depth back to (conformal) time η_0 for Thomson scattering:

$$\tau(\eta) = \int_{\eta}^{\eta_0} a n_e \sigma_T \, d\eta'$$

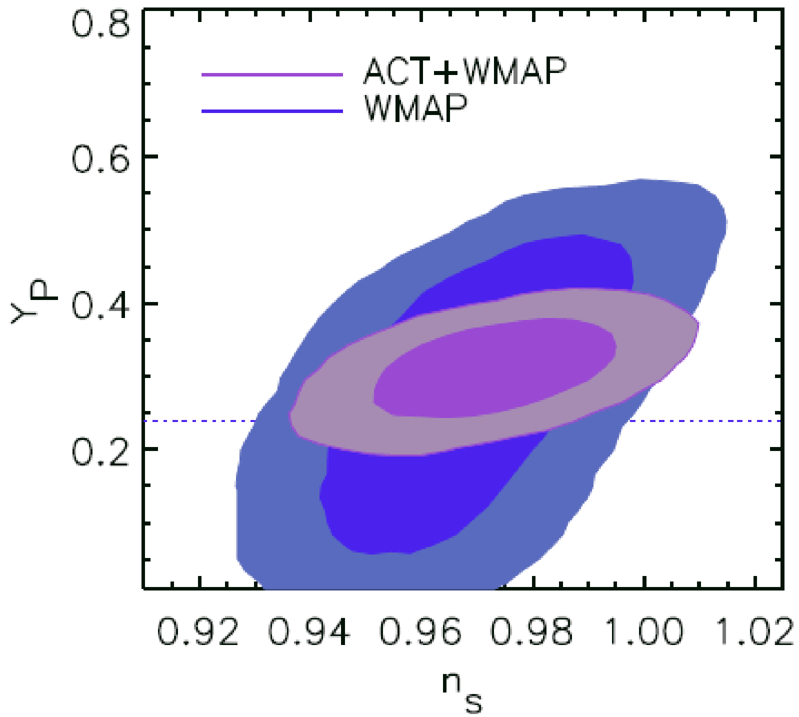
• The visibility function $-\dot{\tau} e^{-\tau}$ is the density probability of photon last scattering at time η





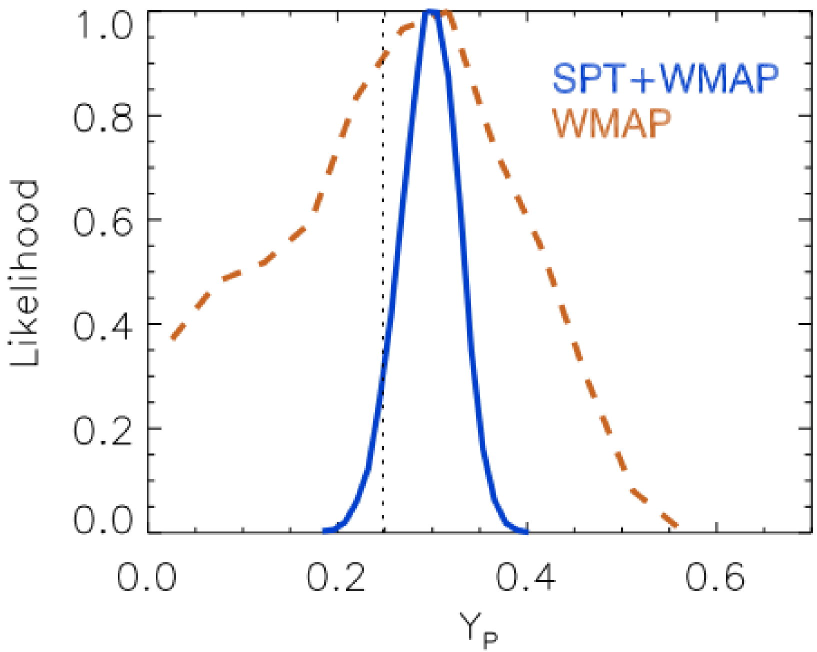
Primordial Helium: Current Status

Current CMB data seems to prefer a slightly higher value than expected from standard BBN.



WMAP+ACT analysis gives
(Dunkley et al., 2010):

Y_P = 0.313+-0.044



WMAP+SPT analysis gives
(Keisler et al, 2011):

Y_P = 0.296+-0.030

Probing the Neutrino Number with CMB data (now varying Helium!!)

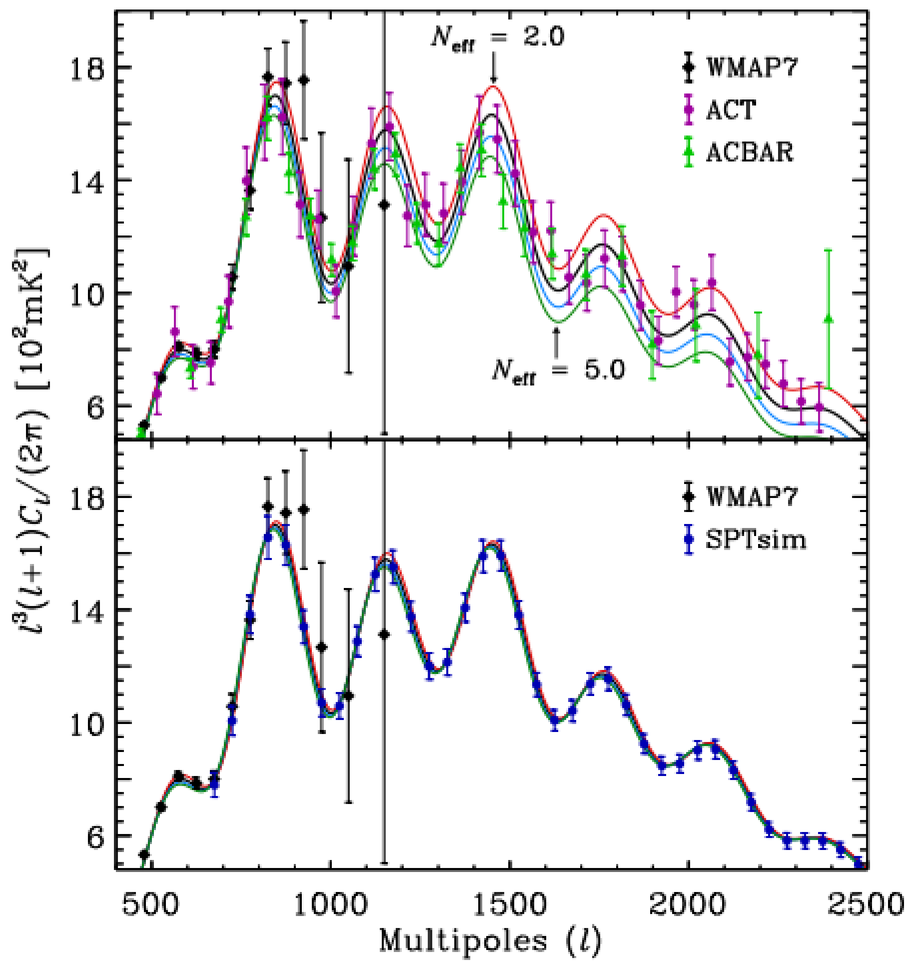
Changing the Neutrino effective number essentially changes the expansion rate H at recombination.
So it changes the sound horizon at recombination:

$$r_s = \int_0^{t_*} c_s\, dt/a = \int_0^{a_*} \frac{c_s\, da}{a^2 H}.$$

and the damping scale at recombination:

$$r_d^2 = (2\pi)^2 \int_0^{a_*} \frac{da}{a^3 \sigma_T n_e H} \left[\frac{R^2 + \frac{16}{15}(1+R)}{6(1+R^2)} \right]$$

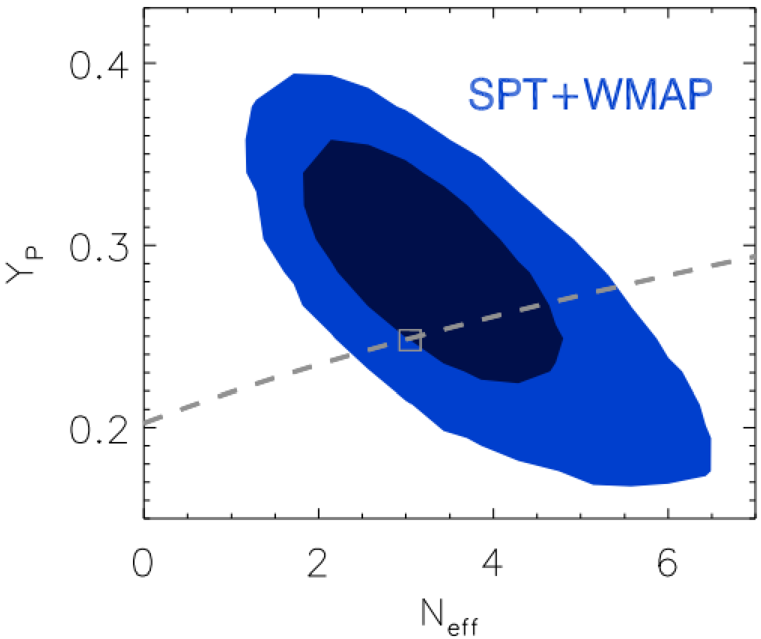
$$\theta_s = \frac{r_s}{D_A} \qquad \theta_d = \frac{r_d}{D_A}$$

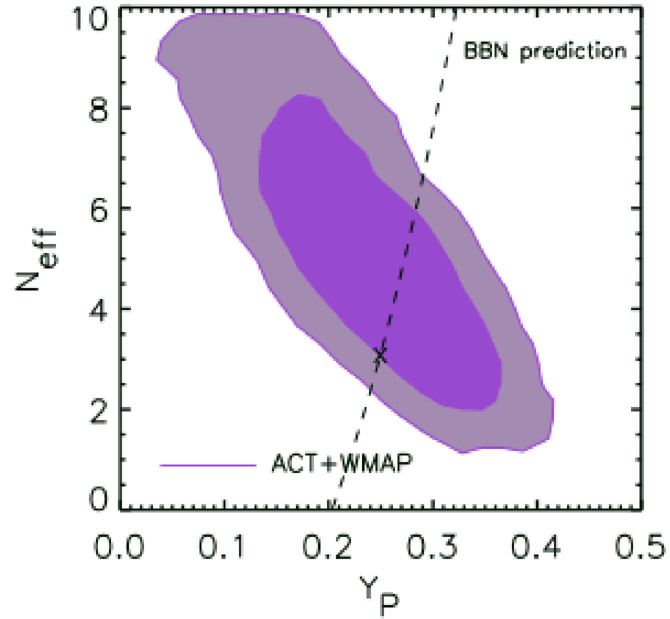


Varying Helium changes ne and can affect CMB neutrino constraints !!

Hou et al, 2011

Helium-Neutrino BBN/CMB complementarity





Current bounds on Neff from CMB only data are degenerate with the Helium abundance. When consistency with BBN is assumed current evidence for dark radiation is **weaker** (but still at about two standard deviations).

Why $N_{eff}>3$ is interesting

We have 1000 ways to explain this !!!

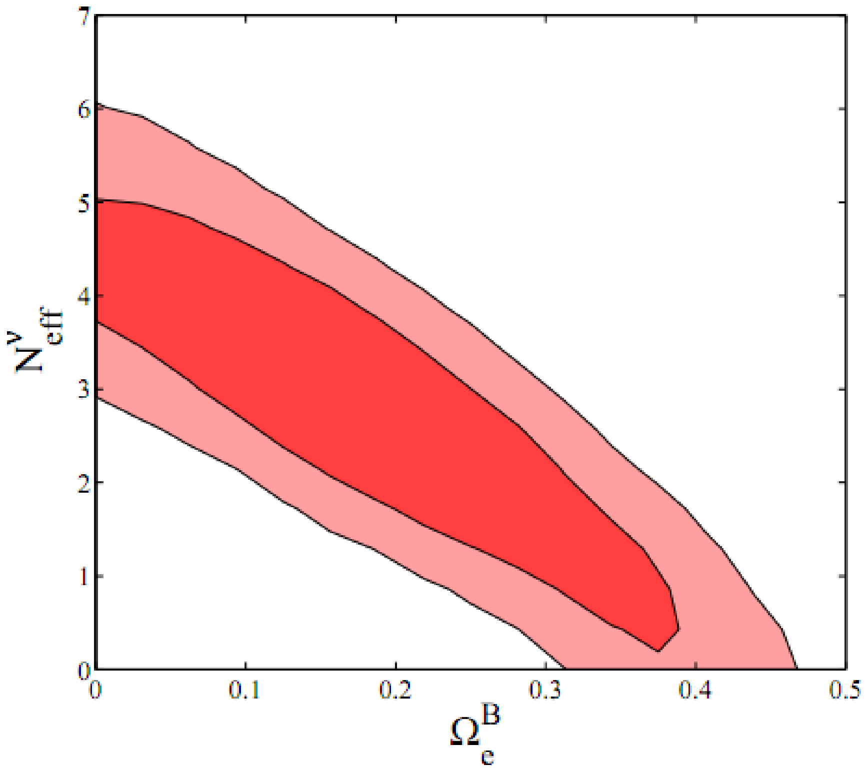
- Sterile Neutrino (hints from short base line experiments LSND, MiniBooNE).
- Non Standard Neutrino Decoupling
- Modified Gravity (Extra Dimensions)
- «Early» Dark Energy
- Gravity Waves
- Axions
- Variation of fundamental constants
- …

Extra Neutrinos or Early Dark Energy ?

An «Early» dark energy component could be present in the early universe at recombination and nucleosynthesis. This component could behave like radiation (tracking properties) and fully mimic the presence of an extra relativistic background !

Barotropic component:

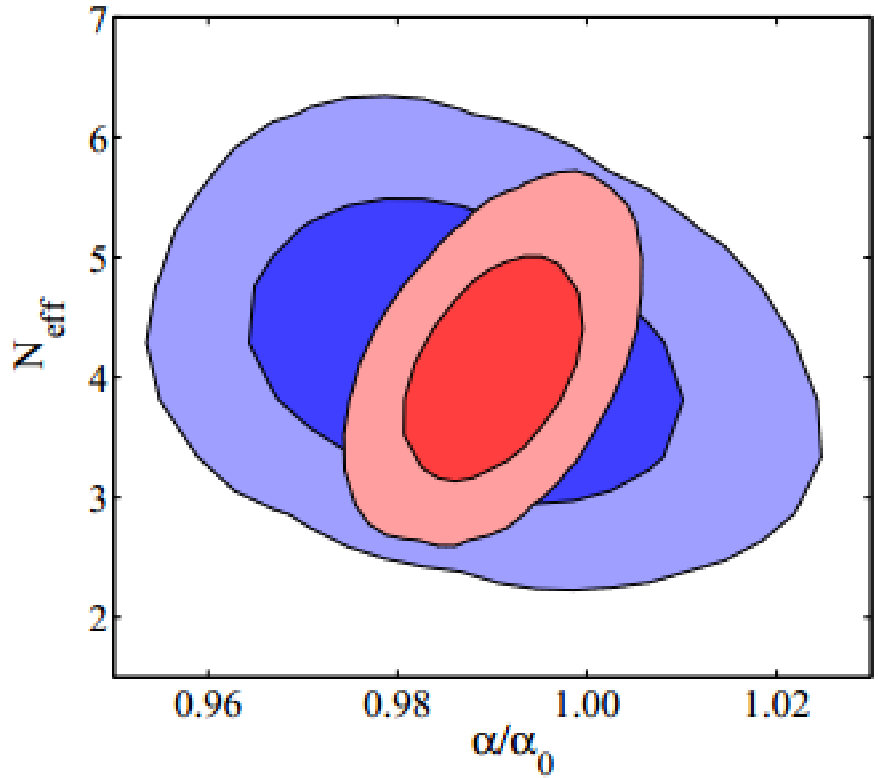
$$\rho_{\mathrm{baro}}(a) = \rho_\infty + C\rho_{r,0}a^{-4}$$



E. Calabrese et al, Phys.Rev.D83:123504,2011

E. Calabrese et al, Phys.Rev.D83:023011,2011

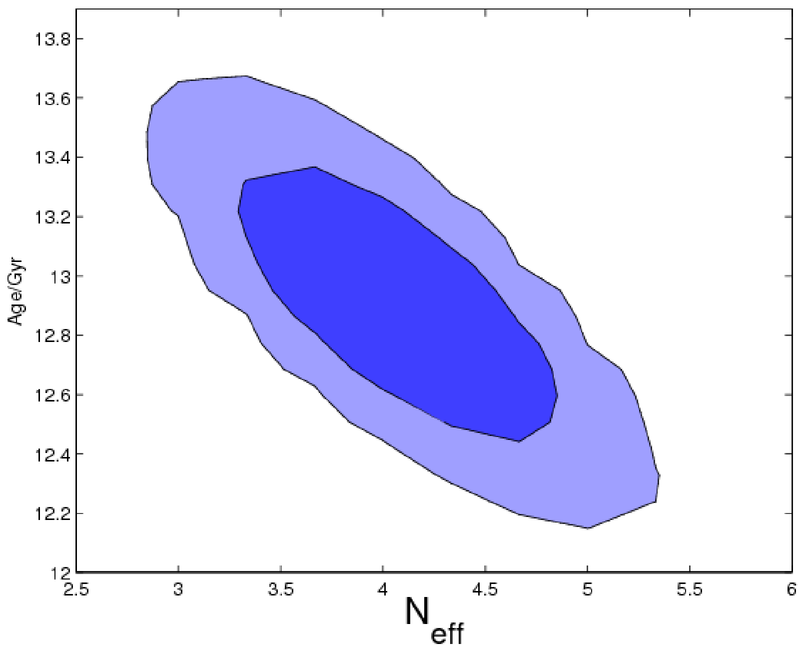
A variation in the fine structure constant at recombination ?



Red: analysis with Helium abundance fixed to Yp=0.24.
Blue: Yp is varied.

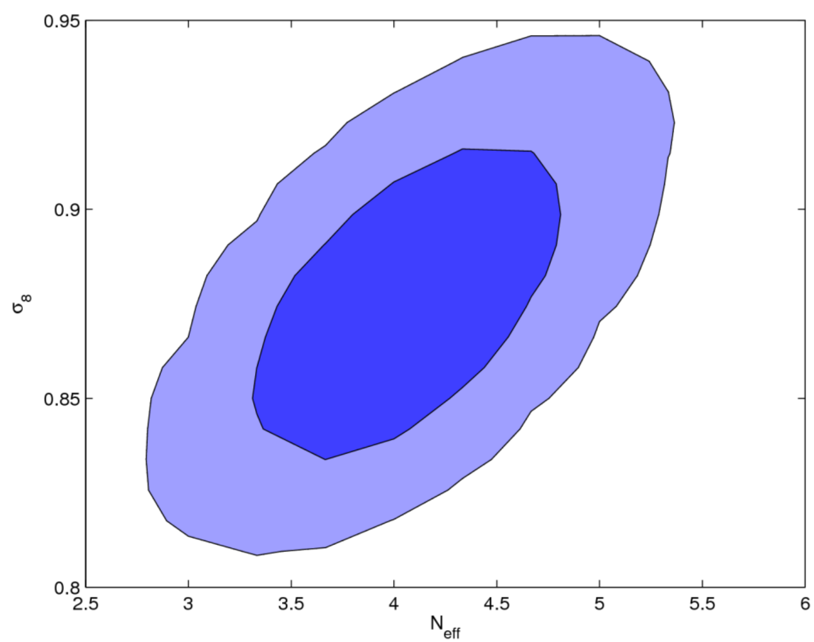
Menegoni et al, **Phys.Rev. D85 (2012) 107301**

What disfavours $N_{eff}>3$?

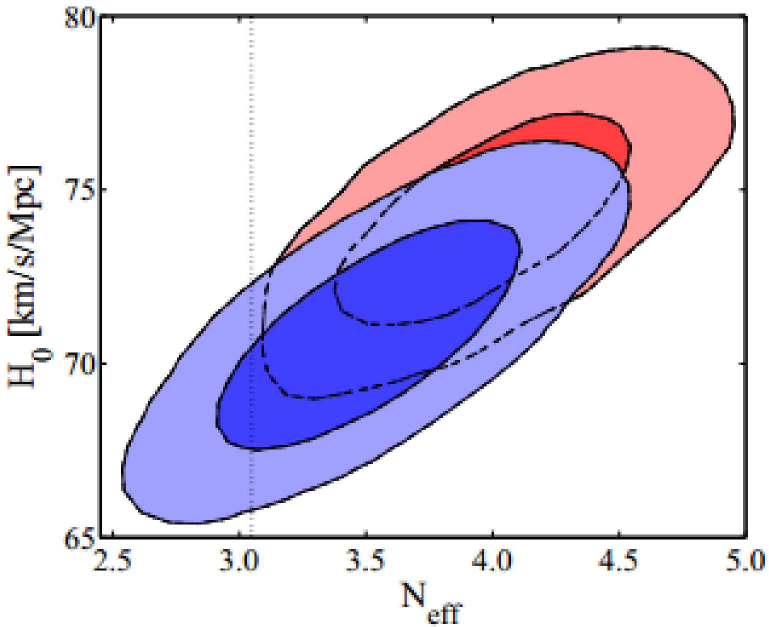


Larger values of the effective neutrino number are in better agreement with **lower** ages of the universe.
Globular clusters suggest **higher** ages.

Larger values of the effective neutrino number are in better agreement with **higher** σ_8.
Clusters abundance measurements prefer **lower** σ_8.



Is the HST prior driving N_{eff}>3 ?



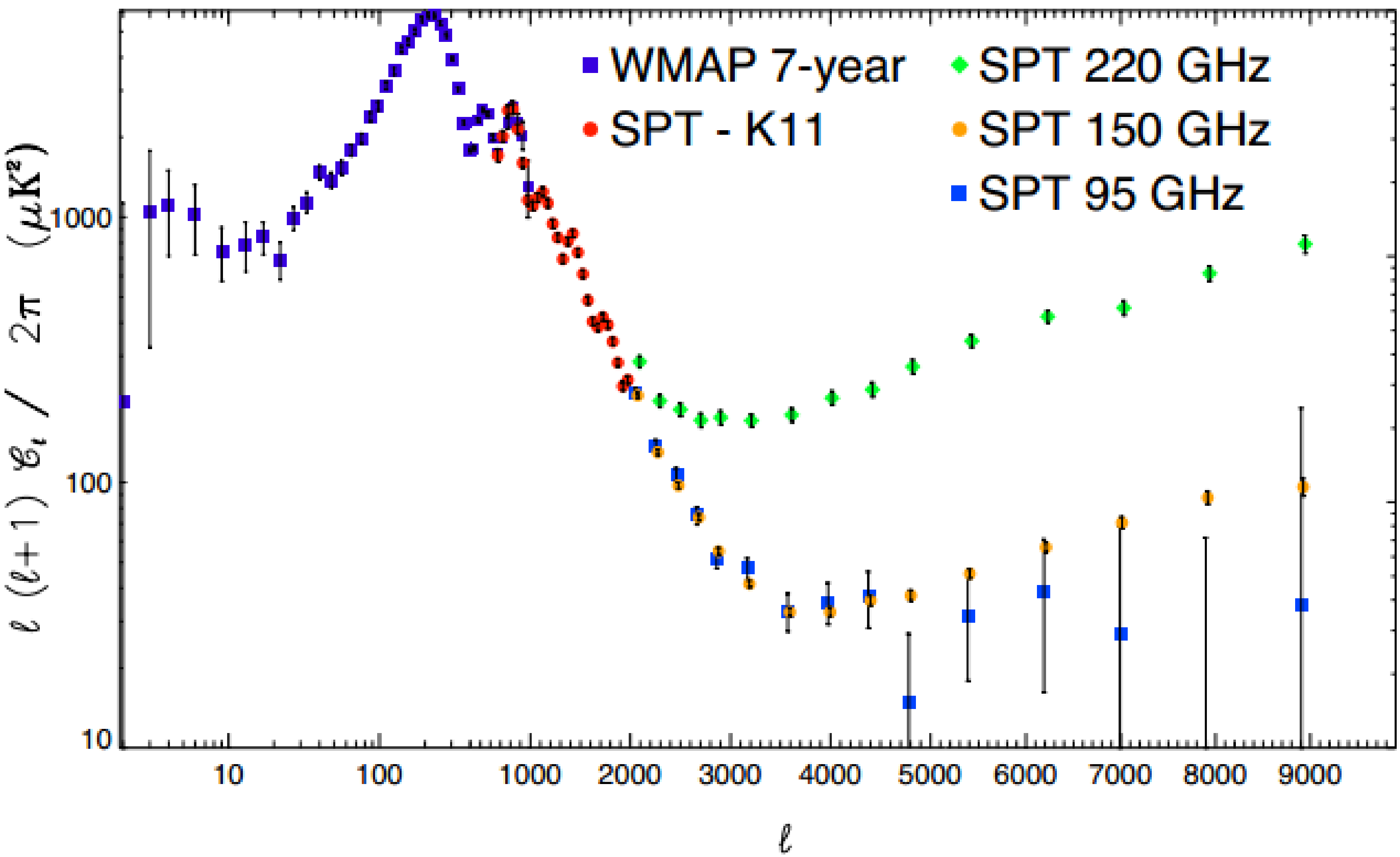
The HST prior on the Hubble constant plays and important role in the current evidence for Dark Radiation.

Constraints from CMB data alone on H0 are in tension with HST value when N_eff=3.046. This tension is solved when a fourth neutrino is included.
Assuming a different prior on HST, like the one coming from median statistics makes the evidence for dark energy below 2 sigma.

Parameters	No Prior	HST Prior		MS Prior	
		73.8 ± 2.4 km/s/Mpc		68 ± 2.8 km/s/Mpc	
$\Omega_b h^2$	0.02258 ± 0.00050	0.02248 ± 0.00039	0.02212 ± 0.00037	0.02211 ± 0.00040	0.02191 ± 0.00037
$\Omega_c h^2$	0.134 ± 0.010	0.1317 ± 0.0080	0.125 ± 0.011	0.1256 ± 0.0080	0.131 ± 0.012
θ	1.0395 ± 0.0016	1.0397 ± 0.0016	1.0411 ± 0.0016	1.0400 ± 0.0017	1.0402 ± 0.0016
τ	0.085 ± 0.014	0.084 ± 0.013	0.082 ± 0.013	0.080 ± 0.013	0.080 ± 0.013
n_s	0.984 ± 0.017	0.979 ± 0.012	0.9600 ± 0.0093	0.964 ± 0.012	0.9533 ± 0.0094
$N_{\rm eff}$	4.14 ± 0.57	3.98 ± 0.37	3.046	3.52 ± 0.39	3.046
$\sum m_\nu$[eV]	0.0	0.0	< 2.2	0.0	< 2.4
H_0[km/s/Mpc]	75.2 ± 3.6	74.2 ± 2.0	70.9 ± 1.4	70.9 ± 2.1	69.5 ± 1.4

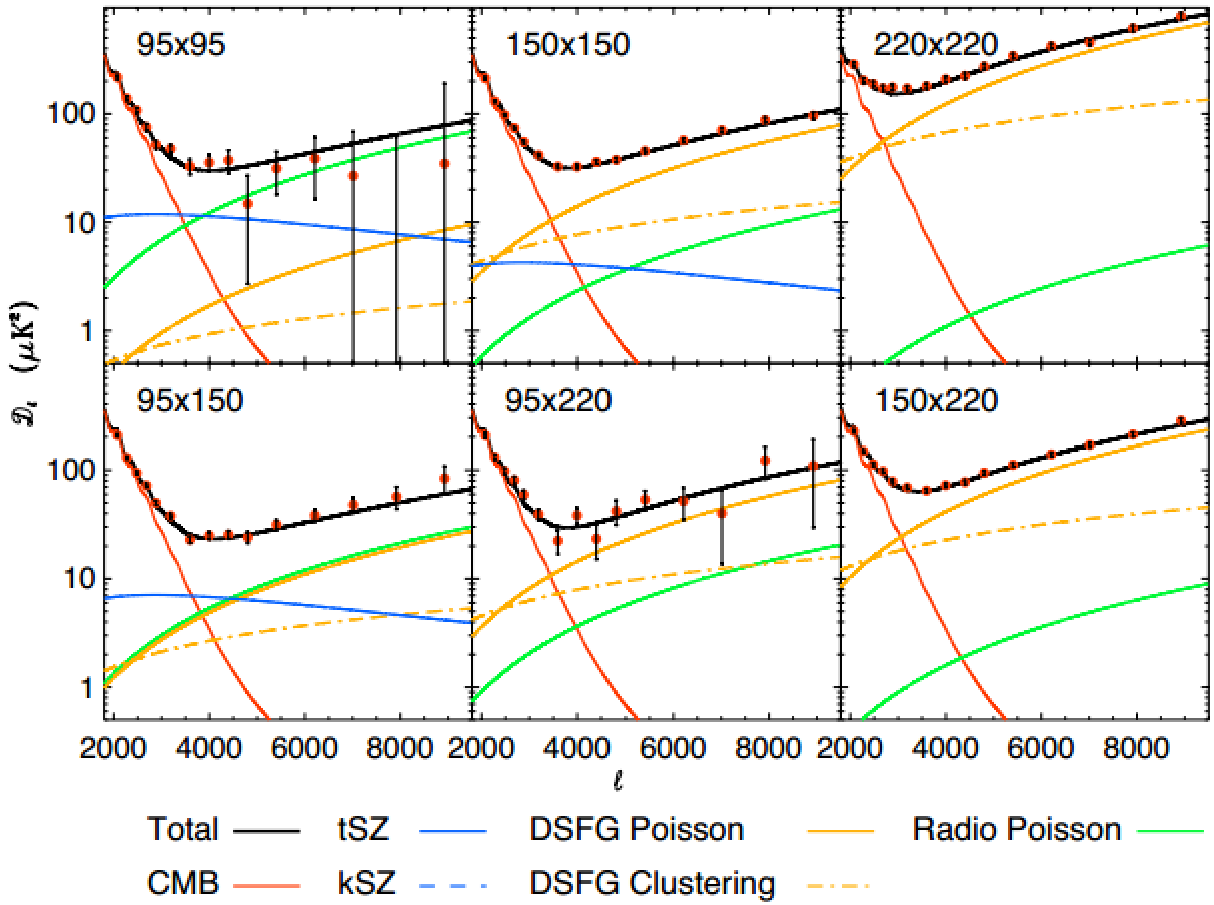
Calabrese et al., 2012, **arXiv:1205.6753**

Small Scale Foregrounds



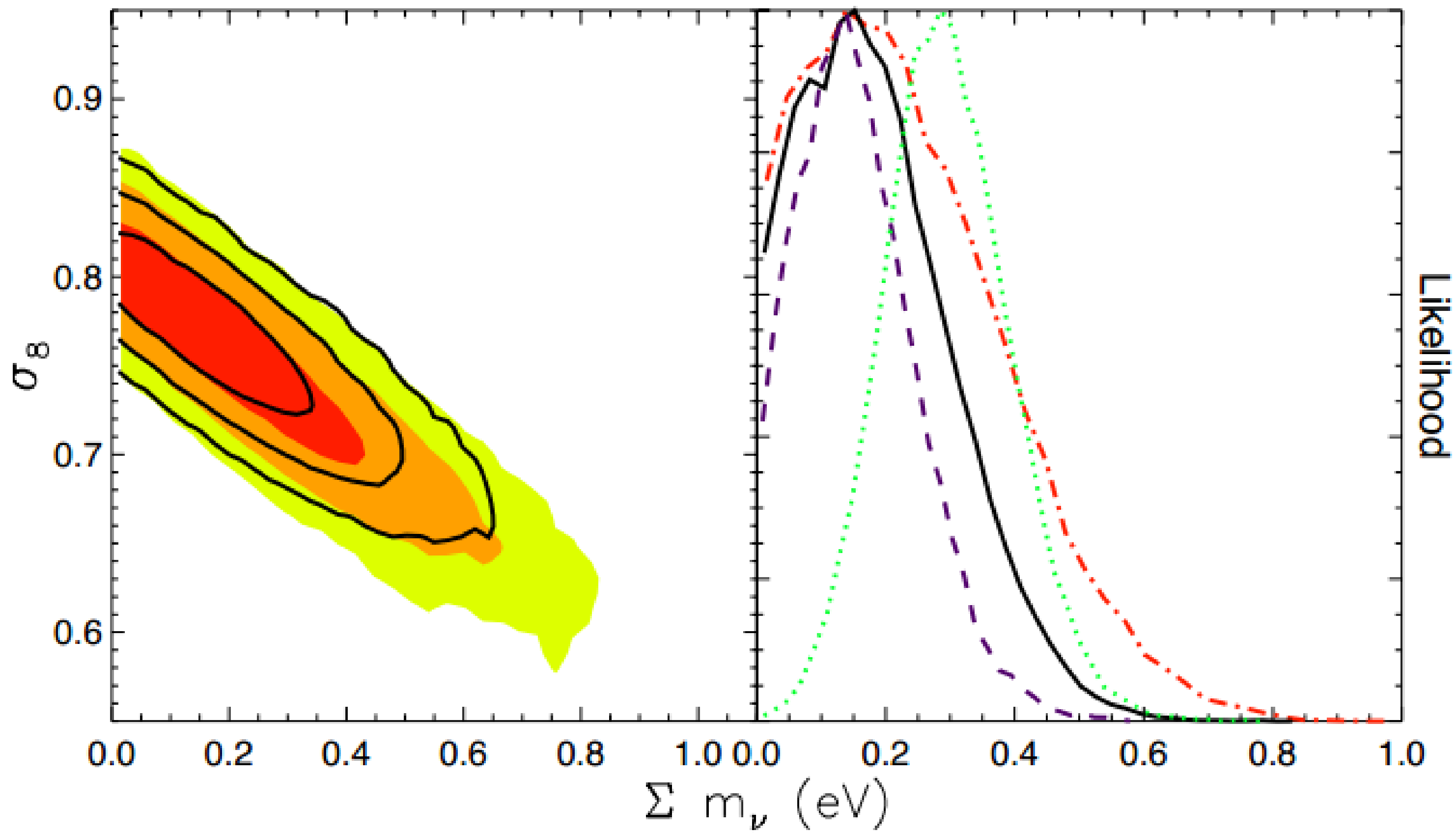
Going at even smaller angular scales the contribution from the local universe (galaxies, SZ from clusters , etc) become dominant

Small Scale Foregrounds



Reichardt et al, **arXiv:1111.0932**
Archidiacono et al, **Phys. Rev. D 85, 043015 (2012)**

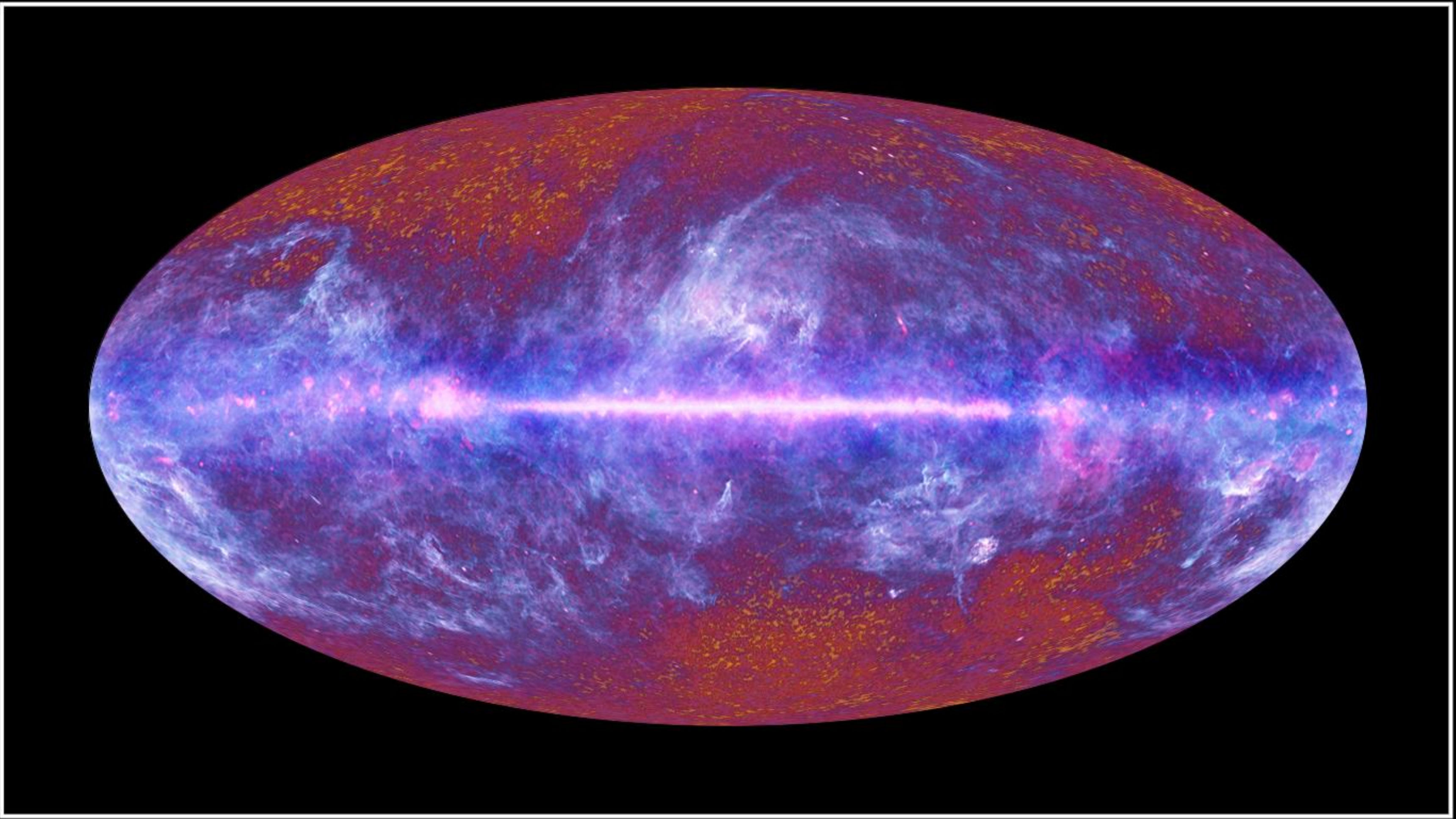
These foregrounds contributions can be parametrized and subtracted thanks to multifrequency measurements.



Reichardt et al, **arXiv:1111.0932**

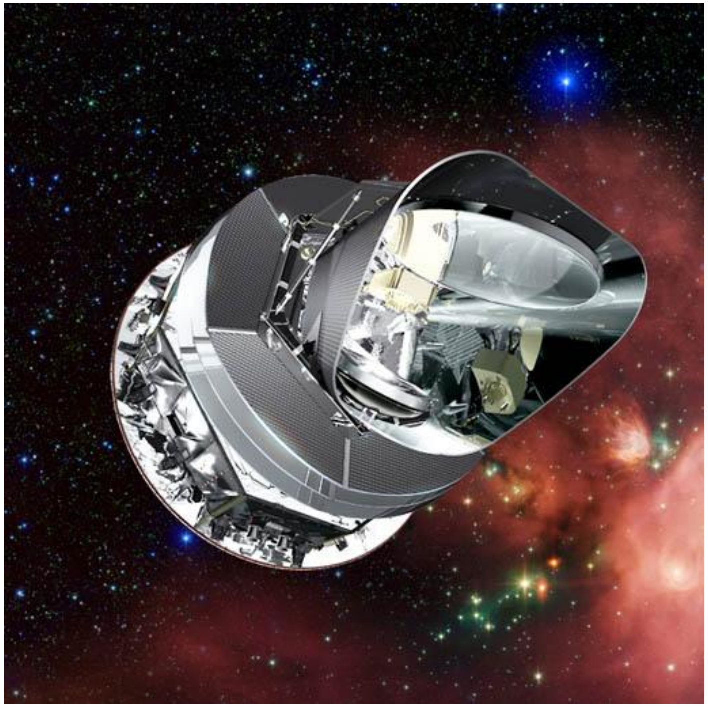
Foregrounds measurements can be useful also for cosmology !
Measuring the Thermal SZ component constrains the amplitude of matter fluctuations and improves current constraints on neutrino masses.


Planck
Satellite launch
14/5/2009
esa



The Planck one-year all-sky survey

First all-sky map (after 17 years Planck proposal accepted by ESA!)

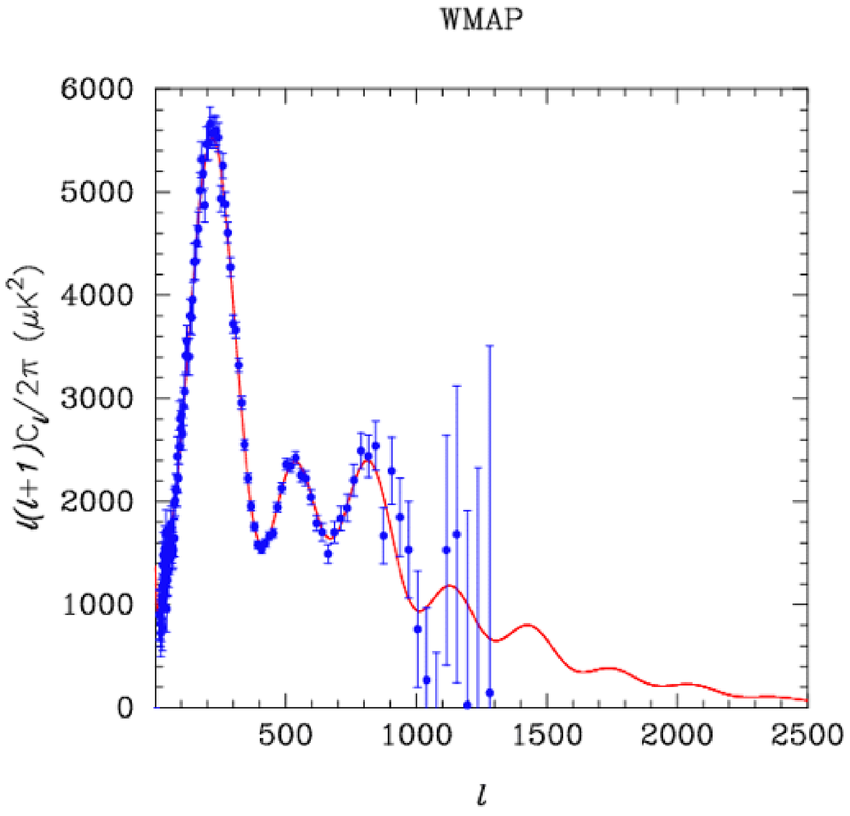


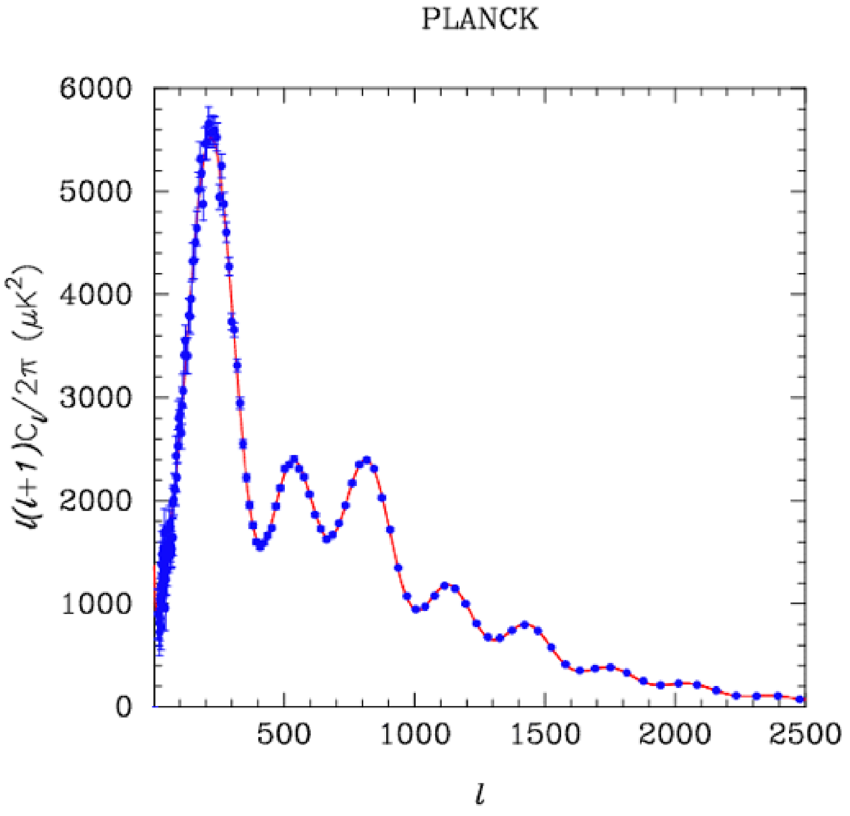
Papers submitted on Jan 11 2011

Planck identifier	Title (all titles are prefixed with "*Planck* Early Results: ")
2011a	The *Planck* mission
2011b	The thermal performance of *Planck*
2011c	First assessment of the Low Frequency Instrument in-flight performance
2011d	First assessment of the High Frequency Instrument in-flight performance
2011e	The Low Frequency Instrument data processing
2011f	The High Frequency Instrument data processing
2011g	The Early Release Compact Source Catalogue
2011h	The all-sky early Sunyaev-Zeldovich cluster sample
2011i	*XMM-Newton* follow-up for validation of *Planck* cluster candidates
2011j	Statistical analysis of Sunyaev-Zeldovich scaling relations for X-ray galaxy clusters
2011k	Calibration of the local galaxy cluster Sunyaev-Zeldovich scaling relations
2011l	Cluster Sunyaev-Zeldovich optical scaling relations
2011m	Statistical properties of extragalactic radio sources in the *Planck* Early Release Compact Source Catalogue
2011n	Early Release Compact Source Catalogue validation and extreme radio sources
2011o	Spectral energy distributions and radio continuum spectra of northern extragalactic radio sources
2011p	The *Planck* view of nearby galaxies
2011q	Origin of the submillimetre excess dust emission in the Magellanic Clouds
2011r	The power spectrum of cosmic infrared background anisotropies
2011s	All-sky temperature and dust optical depth from *Planck* and *IRAS* — constraints on the "dark gas" in our Galaxy
2011t	New light on anomalous microwave emission from spinning dust grains
2011u	Properties of the interstellar medium in the Galactic plane
2011v	The submillimetre properties of a sample of Galactic cold clumps
2011w	The Galactic cold core population revealed by the first all-sky survey
2011x	Dust in the diffuse interstellar medium and the Galactic halo
2011y	Thermal dust in nearby molecular clouds

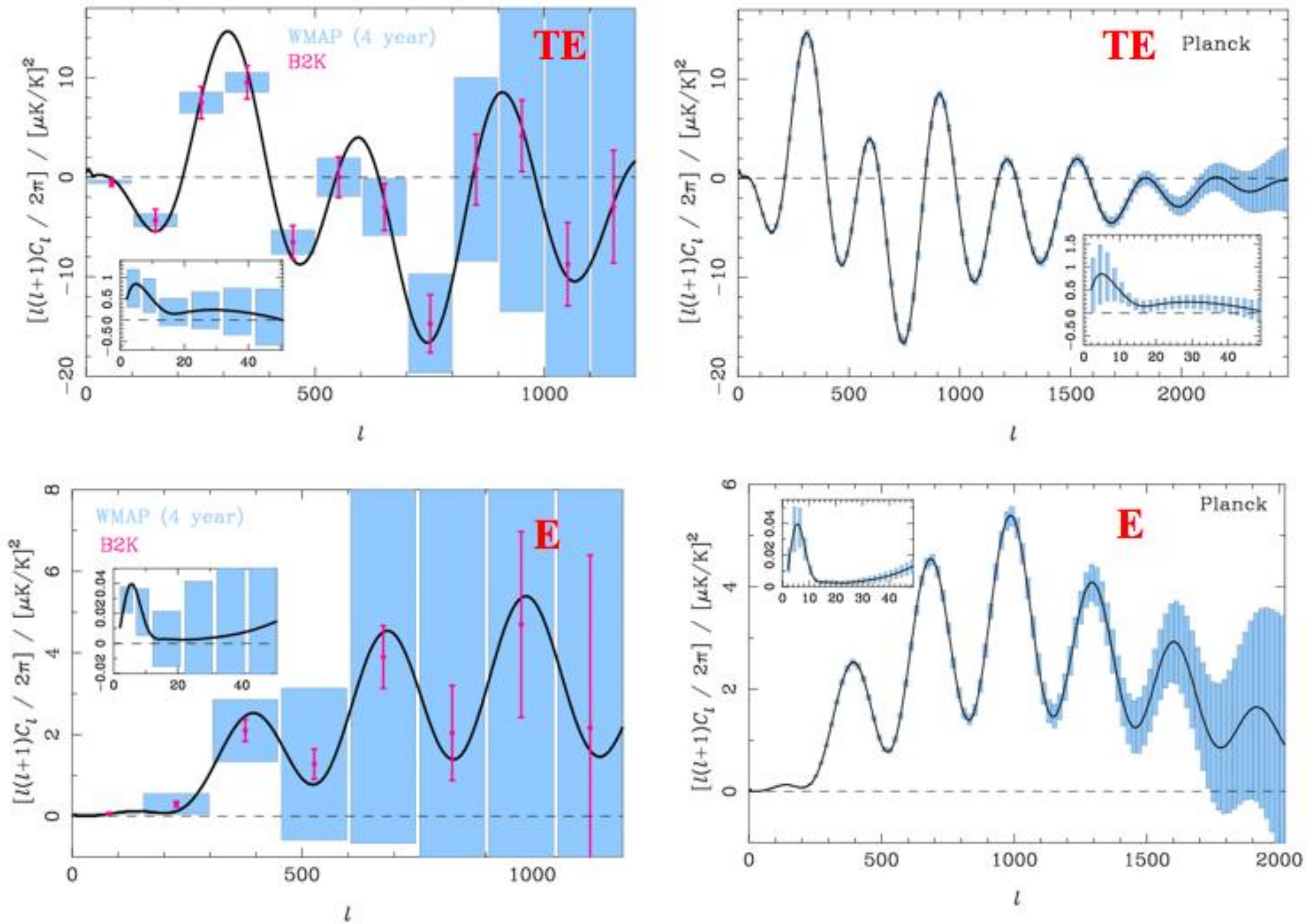
The Planck Collaboration
Released 23 Early Papers last January.
Results are mostly on astrophysical sources (no cosmology).
About 30 papers expected to be released during 2012 (but still «just» astrophysics).
Papers on cosmology (and neutrinos) MUST be released in January 2013.

Expected improvement on TT respect to WMAP (Real data in January 2013)

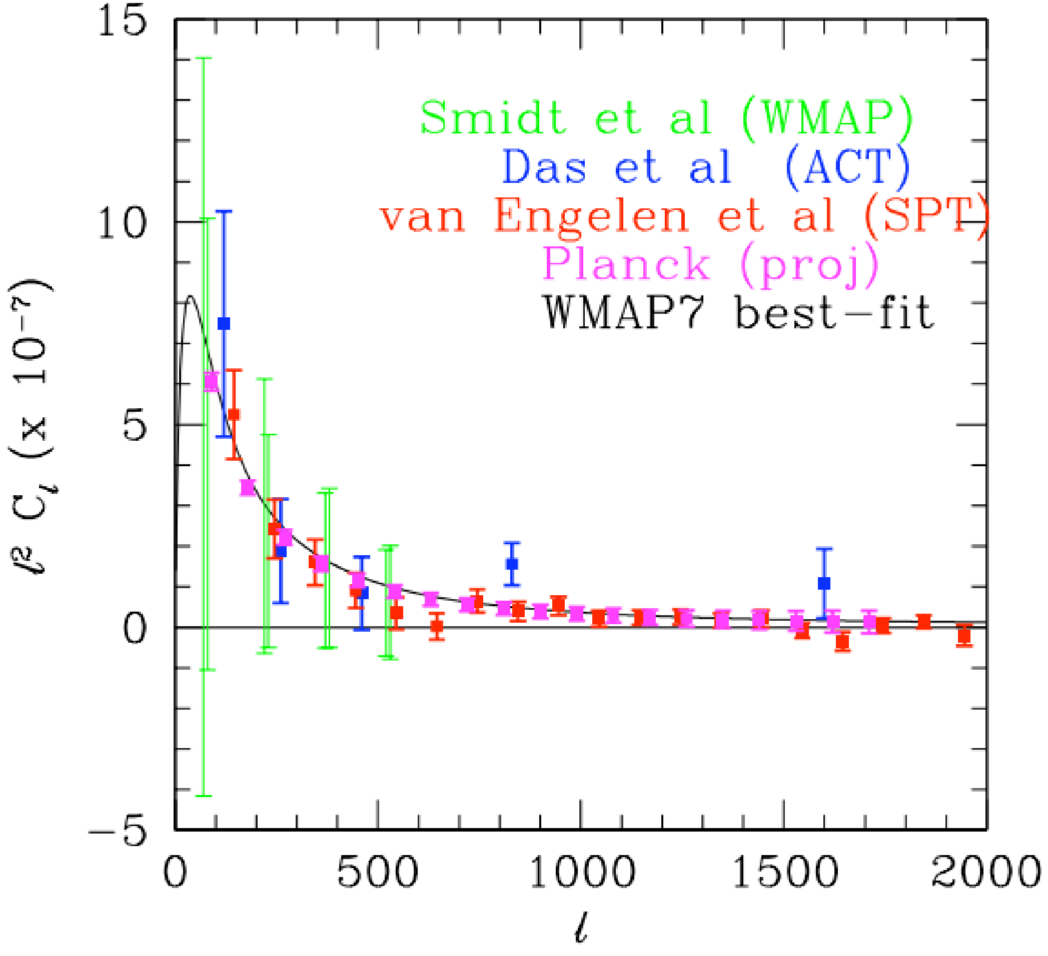




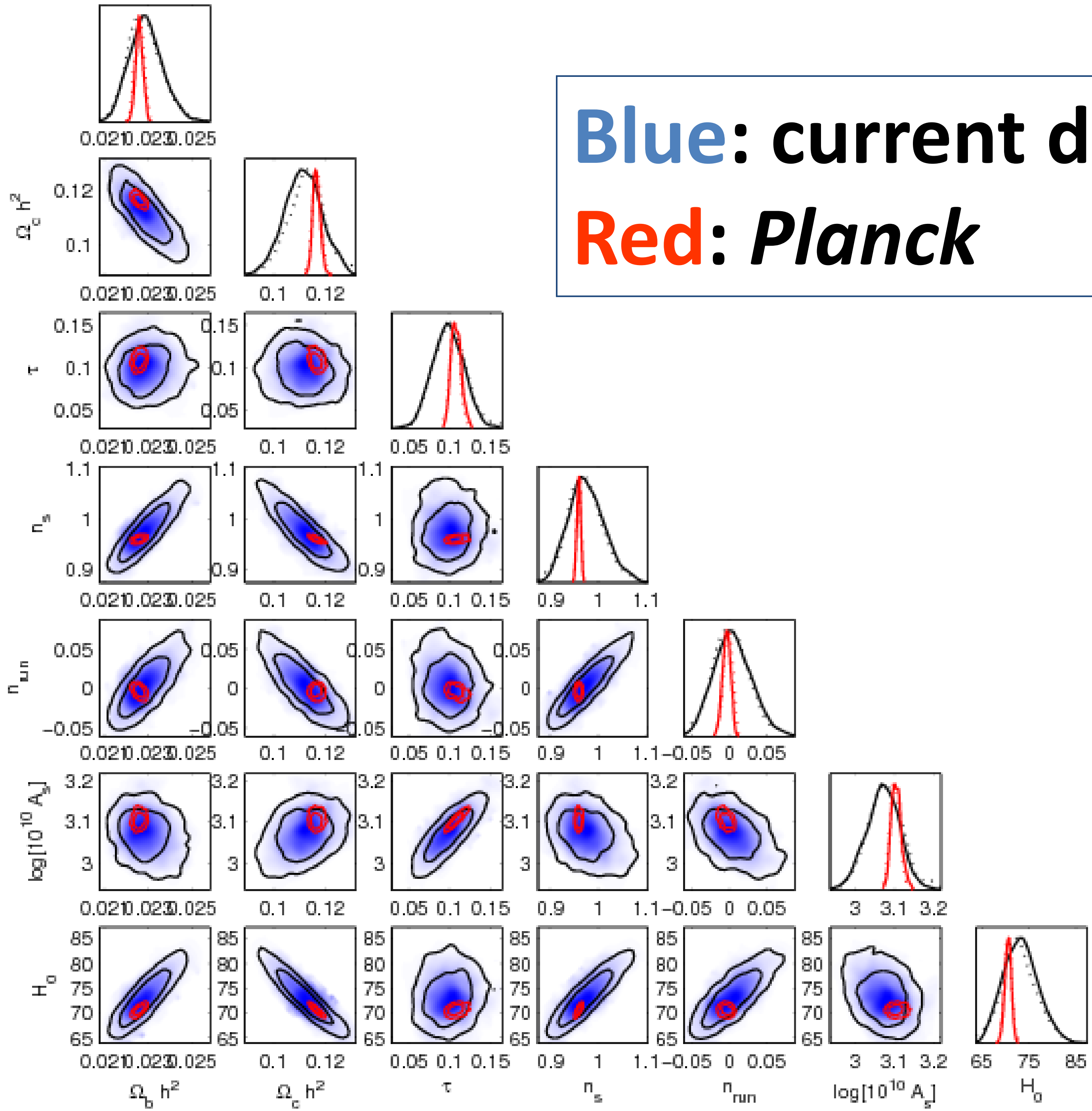
Expected improvement on TE and EE respect to WMAP (real data in January 2013 o 2014) .



PLANCK and CMB Lensing



Detection at about 20 sigmas is expected from Planck TT data in January 2013.
Greatly helpful in constraining parameters.



Blue: current data

Red: *Planck*

Let's consider not only Planck but also ACTpol (From Atacama Cosmology Telescope, Ground based, results expected by 2013) CMBpol (Next CMB satellite, 2020 ?)

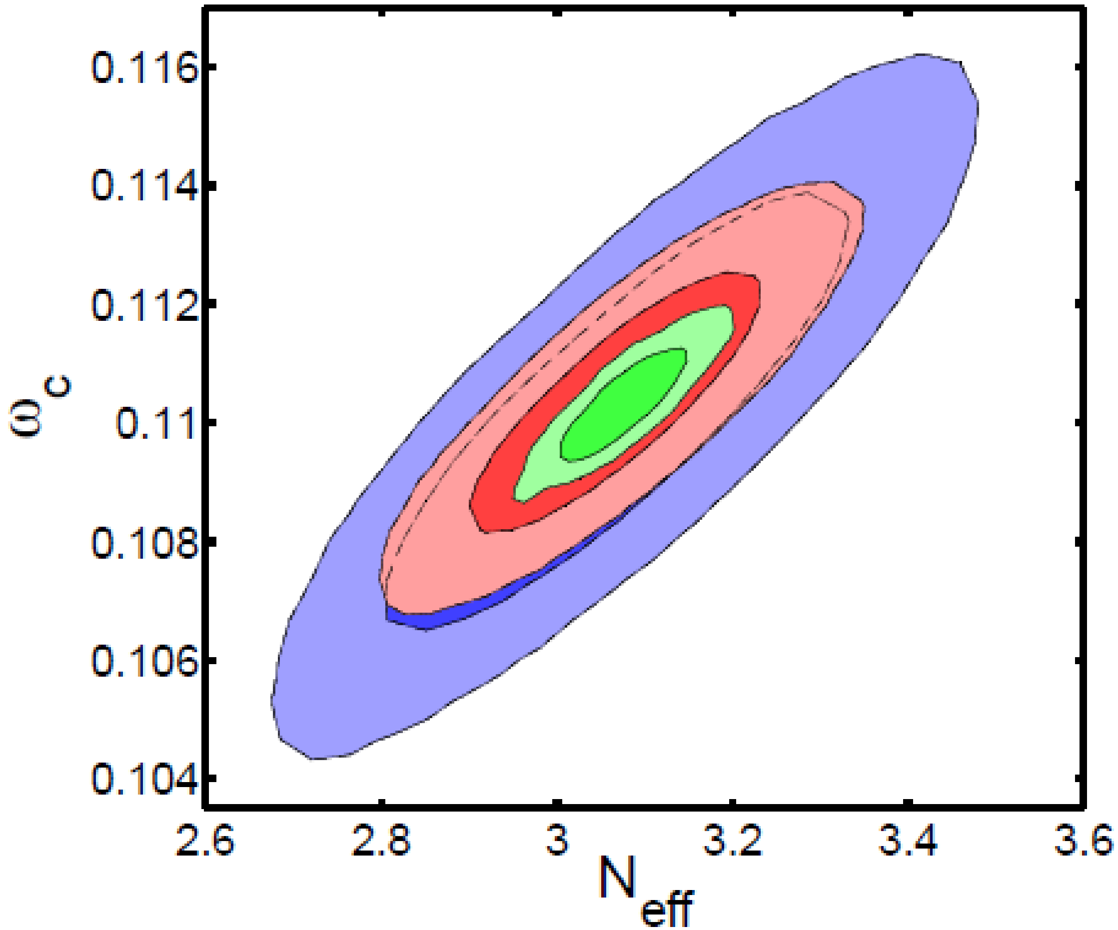
Experiment	Channel	FWHM	$\Delta T/T$	$\Delta P/T$
Planck	70	14'	4.7	6.7
$f_{sky} = 0.85$	100	10'	2.5	4.0
	143	7.1'	2.2	4.2
ACTPol	150	1.4'	14.6	20.4
$f_{sky} = 0.19$				
CMBPol	150	5.6'	0.037	0.052
$f_{sky} = 0.72$				

Parameter uncertainty	Planck	Planck+ACTPol		CMBPol	
$\sigma(\Omega_b h^2)$	0.00013	0.000078	(1.7)	0.000034	(3.8)
$\sigma(\Omega_c h^2)$	0.0010	0.00064	(1.6)	0.00027	(3.7)
$\sigma(\theta_s)$	0.00026	0.00016	(1.6)	0.000052	(5.0)
$\sigma(\tau)$	0.0042	0.0034	(1.2)	0.0022	(1.9)
$\sigma(n_s)$	0.0031	0.0021	(1.5)	0.0014	(2.2)
$\sigma(\log[10^{10} As])$	0.013	0.0086	(1.5)	0.0055	(2.4)
$\sigma(H_0)$	0.53	0.30	(1.8)	0.12	(4.4)

Galli, Martinelli, Melchiorri, Pagano, Sherwin, Spergel, Phys.Rev.D82:123504,2010

See also Shimon et al 2010.

Constraints on Neutrino Number



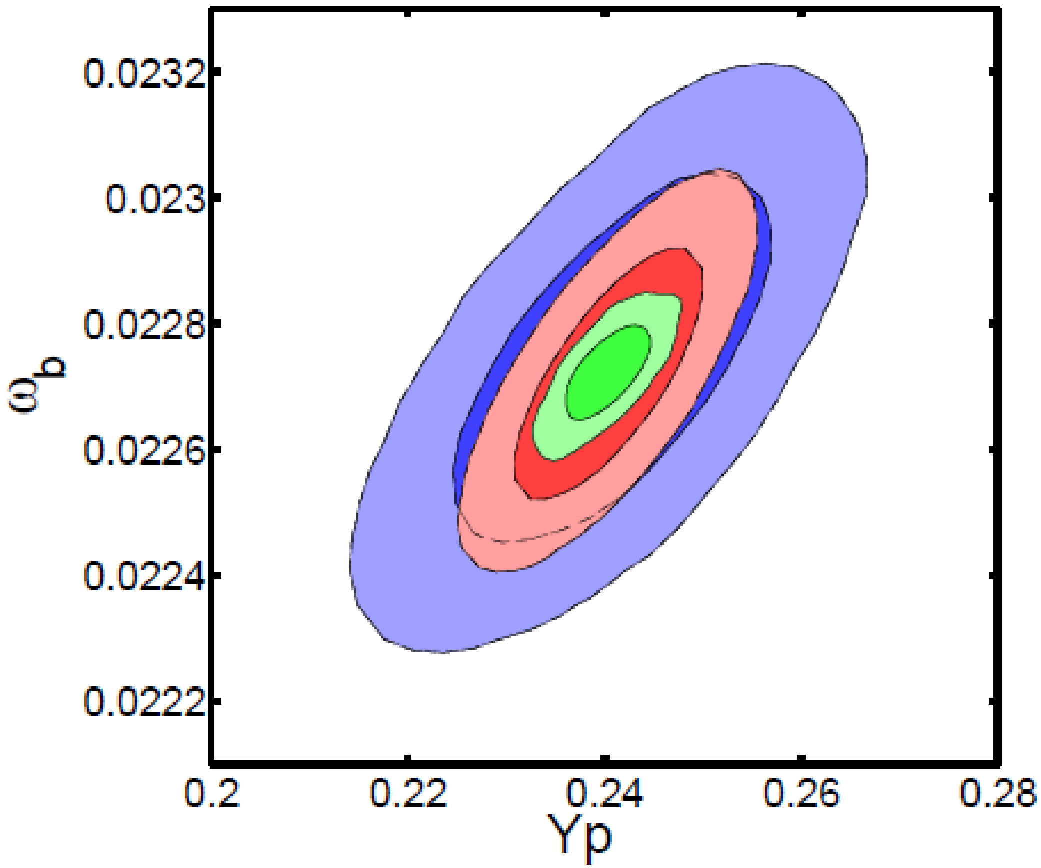
Blue: Planck $\Delta N\nu$=0.18

Red: Planck+ACTpol $\Delta N\nu$=0.11

Green: CMBPol $\Delta N\nu$=0.044

Galli, Martinelli, Melchiorri, Pagano, Sherwin, Spergel, Phys.Rev.D82:123504,2010

Constraints on Helium Abundance



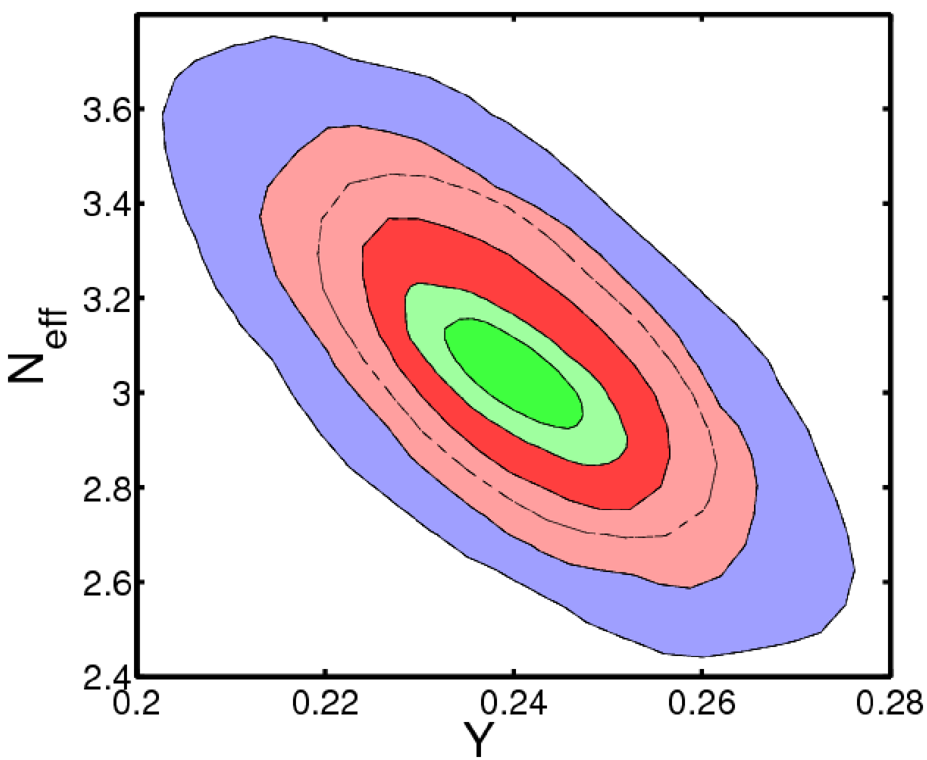
Blue: Planck $\Delta Yp=0.01$

Red: Planck+ACTpol $\Delta Yp=0.006$

Green: CMBPol $\Delta Yp=0.003$

Galli, Martinelli, Melchiorri, Pagano, Sherwin, Spergel, Phys.Rev.D82:123504,2010

Constraints on Helium Abundance AND neutrino number



Galli, Martinelli, Melchiorri, Pagano, Sherwin, Spergel, Phys.Rev.D82:123504,2010

CONCLUSIONS

• Recent CMB measurements fully confirm Λ-CDM.

• Hints for extra relativistic neutrino background (or something new) but HST prior is driving this result.

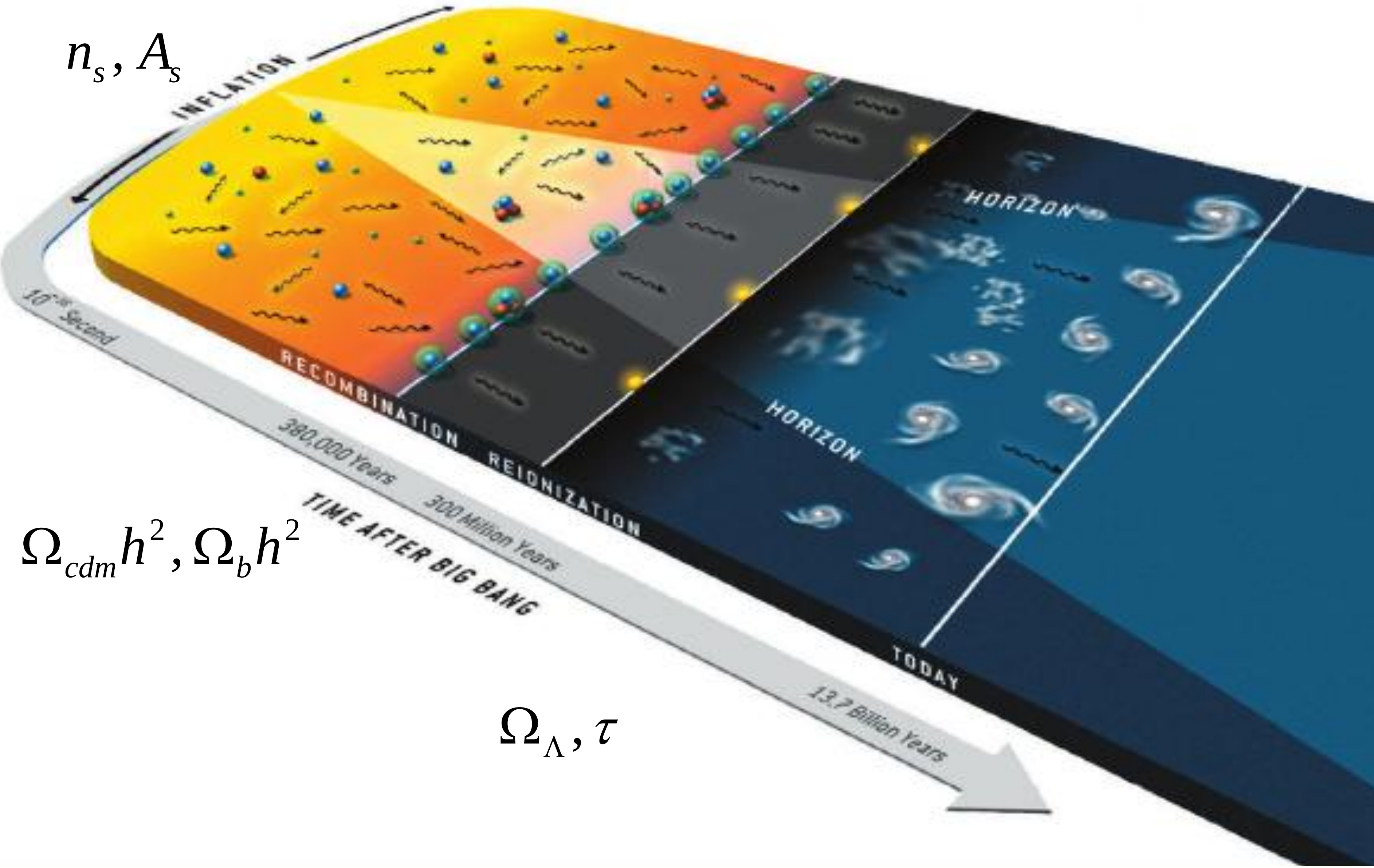
- Planck experiment working as expected. Early results promising.

In early 2013 from Planck we may know:

- If the total neutrino mass is less than 0.4eV from CMB only data (assuming LCDM).
- If there is evidence for an extra background of relativistic particles in cosmological data.
- Helium abundance with 0.01 Yp accuracy.

… and much more !

n_s, A_s



$\Omega_{cdm}h^2, \Omega_b h^2$

Ω_Λ, τ