Future CMB and Lensing constraints on fundamental physics

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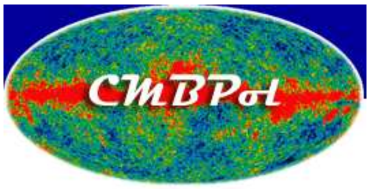
’Constraining Fundamental Physics with Future CMB Experiments’, Galli, S., Martinelli, M., Melchiorri, A., Pagano, L., Sherwin, B. D., & Spergel, D. N., 2010, PRD, 82, 123504

Berkeley CMB Lensing Workshop 4/21/2011

Outline

- Experiments and Specifications
- Forecasting Spectra, Hu and Okamoto Estimator, Analysis Method with Cosmomc.
- Standard ΛCDM model
- Bounds on fundamental physics
  - Neutrino Mass $\sum m_\nu$
  - Number of relativistic species N_{eff}
  - Helium Abundance Y_p
- Conclusion

Current CMB experiments detect the gravitational lensing potential in CMB temperature map.
Future probes will improve this measurement. This additional information can be used to improve our knowledge on several different parameters.



Experimental Configuration

Experiment	Channel [GHz]	FWHM [arcmin]	$\Delta T/T_{CMB}$ [$\mu K/K$]	$\Delta P/T_{CMB}$ [$\mu K/K$]
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 $f_{sky} = 0.097$	150	1.37'	5.4	7.6
CMBPol $f_{sky} = 0.72$	150	5.6'	0.037	0.052

In the following, the forecasts for these experiments will be compared to WMAP7 results (Larson et al. 2010) and WMAP7+ACT2008 results (Dunkley 2010).

MCMC and the Exact Likelihood

- Simulated dataset with fiducial model wmap-7 maximum likelihood
- Instrumental noise

$$N_l = w^{-1} \exp(l(l+1)/\theta^2) \tag{1}$$

where $w^{-1} = (\sigma\theta)^2$

- MCMC in the cosmological parameter space with cosmomc
- Simplified approach: Full Sky Exact Likelihood

$$-2 \log P(\hat{C}_l|C_l) \propto (2l+1) \left\{ Tr[\hat{C}_l C_l^{-1}] + \log|C_l| \right\} \tag{2}$$

- C_l is the observed ps and $\hat{C}_l$ is the estimator
- Reduction of the d.o.f. to take into account partial coverage, ignoring the correlations

$$2l+1 \rightarrow (2l+1) f_{sky} \tag{3}$$

A. Lewis and S. Bridle, Phys. Rev. D **66** (2002) 103511.

Hu and Okamoto estimator

- Together with the primary anisotropy we also take into account information from CMB weak lensing
- Power spectrum of the deflaction angle C_{dd} and the cross-correlation with the temperature C_{Td}
- 5 power spectra TT,EE,TE,dd,Td,
- We use the quadratic estimator method by Hu & Okamoto to get the N_l^{dd}
- C_{BB} not included. Assumed dominated by foregrounds at high ell

T. Okamoto and W. Hu, Phys. Rev. D **67** (2003) 083002 [arXiv:astro-ph/0301031].

L. Perotto, J. Lesgourgues, S. Hannestad, H. Tu and Y. Y. Y. Wong, JCAP **0610** (2006) 013 [arXiv:astro-ph/0606227].

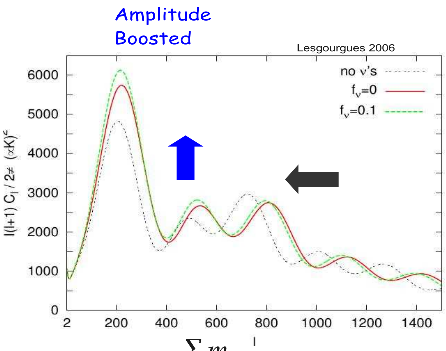
Standard ΛCDM model

Parameter	WMAP7	Planck	Planck+ACTpol		CMBPol	
% uncertainty	$\sigma(\theta)/\theta\%$	$\sigma(\theta)/\theta\%$	$\sigma(\theta)/\theta\%$		$\sigma(\theta)/\theta\%$	
$\Omega_b h^2$	2.5	0.57	0.41	(1.4)	0.15	(3.8)
$\Omega_c h^2$	5.0	0.91	0.70	(1.3)	0.25	(3.7)
τ	15.9	4.8	4.0	(1.2)	2.53	(1.9)
n_s	1.4	0.32	0.24	(1.3)	0.15	(2.2)
$\log[10^{10} As]$	5.0	0.41	0.31	(1.3)	0.17	(2.4)
H_0	3.5	0.74	0.37	(1.4)	0.17	(4.4)

Table: 68% c.l. relative percentual errors on cosmological parameters from actual current data for WMAP7 (Larson et al.2011) and future surveys. A "standard", 6 parameters Λ-CDM scenario is assumed. The numbers in brackets show the improvement factor $i = \sigma_{Planck}/\sigma$ respect to the Planck experiment.

Fundamental Physics Observables

Total neutrino mass $\sum m_\nu$ (effect on lensing ps)



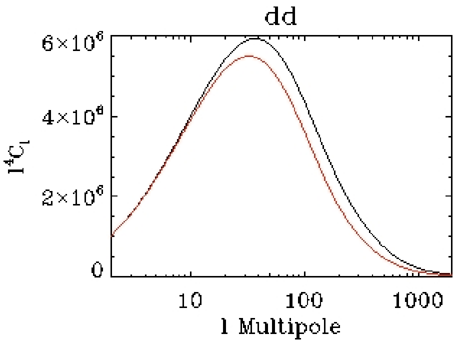
$$\Omega_\nu = \frac{\Sigma m_\nu}{94\text{eV}}$$

$$f_\nu = \Omega_\nu / \Omega_{cdm} = 0.1 \rightarrow \Sigma m_\nu = 1\,eV$$

If Ω_ν is different from zero (in flat universe with Ω_m ,Ω_Λ $\Omega_b$fixed):

- Equivalence of Matter/Radiation happens later More scales at bigger scales enter the horizon during Rad and are boosted by the potential fluctuation decay (Early ISW).
  - ➔ Peaks at big scales boosted
  - ➔ Sound horizon larger,shift of the peaks at larger scales
- Neutrinos do not cluster at small scales (smaller than neutrino Jeans lenght).
  - ➔ Suppression of the matter power spectrum and therefore of the lensing potential.

Total neutrino mass $\sum m_\nu$ (effect on p.s.)

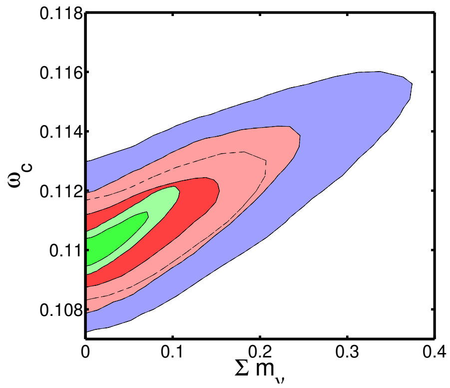


black = standard case
red = $\Sigma m_\nu = 1eV$

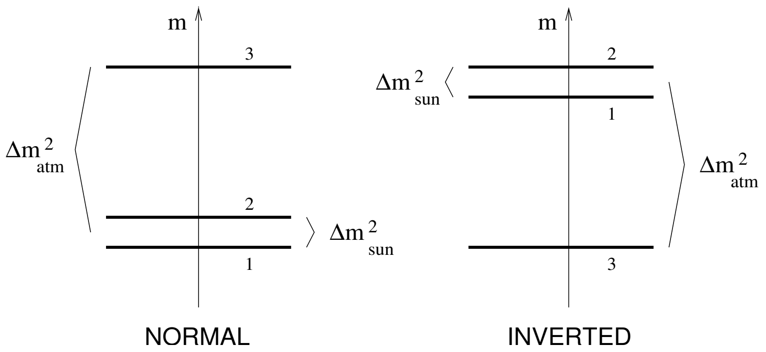
Total neutrino mass $\sum m_\nu$

- Total variation of neutrino mass eigenstates $\sum m_\nu$ at **95 % c.l.**

WMAP-7:	$<$ 1.2 eV	
Planck (blue):	$<$ 0.32 eV	
Planck+ACTpol (red):	$<$ 0.20 eV	(1.6)
CMBPol (green):	$<$ 0.10 eV	(3.2)



Normal and Inverted Hierarchy



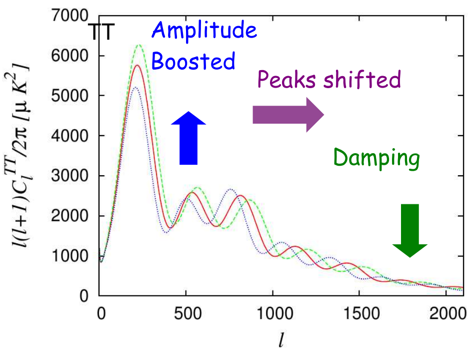
$$\Delta m^2_{atm} \sim 10^{-3} eV^2 \quad (4)$$
$$\Delta m^2_{sun} \sim 10^{-5} eV^2 \quad (5)$$

$$Min \sum m_\nu \sim 0.05 eV (Normal) \quad (6)$$
$$Min \sum m_\nu \sim 0.1 eV (Inverted) \quad (7)$$

J. Lesgourgues and S. Pastor, Phys. Rept. **429** (2006) 307
[arXiv:astro-ph/0603494].

Extra background of Relativistic Particles N_ν^{eff}

The Angular Power Spectra with N_{eff}



Neff=5 green
Neff=3 red
Neff=1 blue

If the Neff is **bigger:**

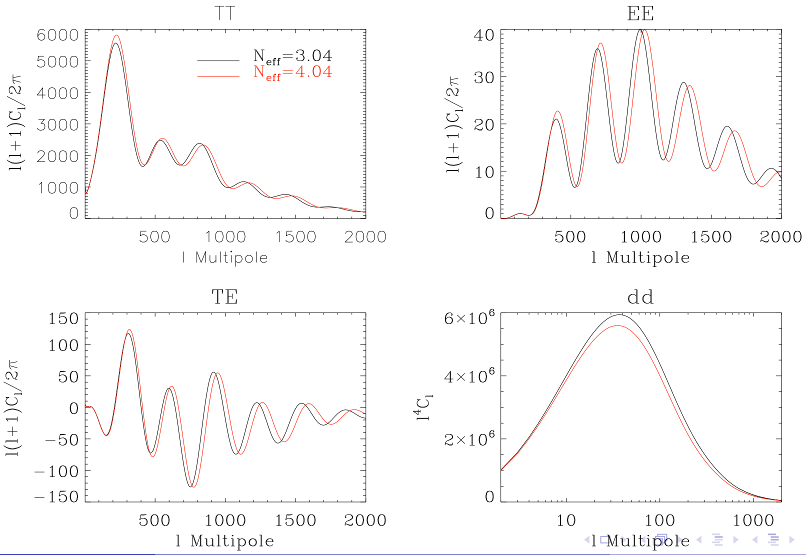
- Equivalence of Matter/Radiation happens later
  More Early ISW.
  - → Peaks at big scales boosted
- The size of the sound horizon $r_s \sim c_s \eta_{dec}$ at recombination is smaller. ($\eta_{de=}$conformal time at decoupling, c_s sound speed)
  - → peaks of the CMB angular spectrum are shifted at higher l (larger angular scales).

$$l_{peaks} \approx \frac{n \pi \eta_0}{r_s}$$

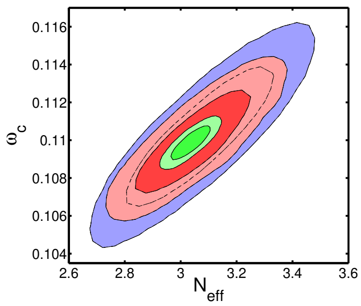
- → The Frequency r_s of the oscillations is larger.

- Relativistic species speed= speed of light, -> faster than the sound speed of photon-baryon fluid -> Free-stream erase fluctuations as components coupled via gravity. More effective for perturbations that enter the horizon during radiation epoch.
  - → Damping of small scales.
  - → Shift of peaks

Extra background of Relativistic Particles N_ν^{eff} (effect on p.s.)



Extra background of Relativistic Particles N_ν^{eff}

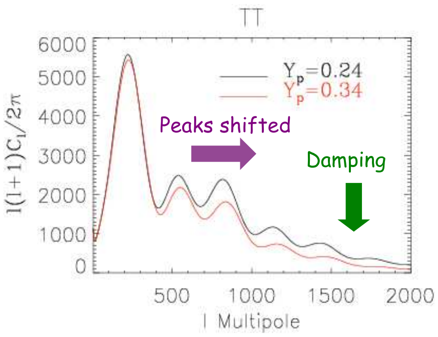


WMAP-7:	$N_{eff} > 2.7$ at 95% c.l.	
WMAP7+ACT2008:	$N_{eff} = 5.3 \pm 1.3$ at 68%*c.l.*	
Planck(blue):	N_{eff} = 0.18 at 68%*c.l.*	
Plank+ACTpol(red):	N_{eff} = 0.13 at 68%*c.l.*	(1.4).
CMBPol (green):	N_{eff} = 0.044 at 68%*c.l.*	(4.1)

From $\mathrm{WMAP7} + \mathrm{BAO} + \mathrm{H}_0$, $N_{eff} = 4.34 \pm 0.88$ (Komatsu 2010), slightly higher than the standard value $N_{eff} = 3.04$.

Helium Abundance

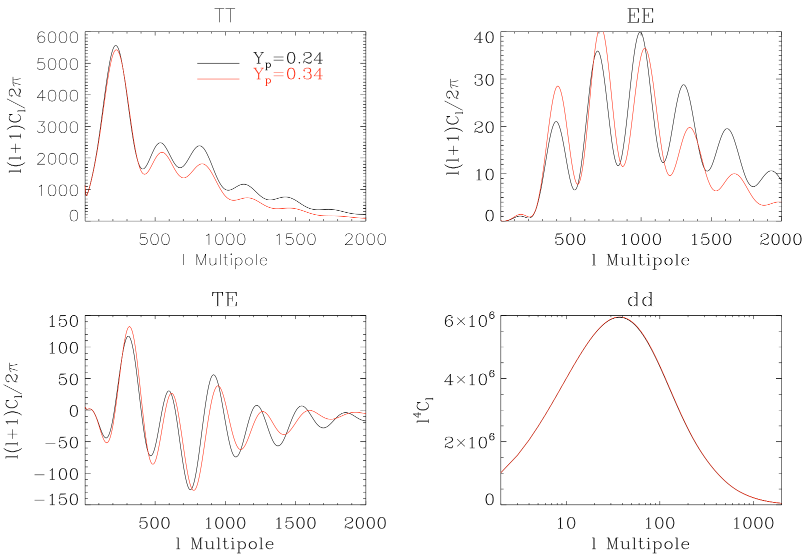
The Angular Power Spectra with Helium Abundance



If the Yp is **bigger**:

- More Electrons recombine in Helium atoms at early times (z~1800). Less free electrons for Hydrogen recombination:
  - → Decoupling happens earlier, shift of the peaks at smaller scales.
- As free electrons are less, the mean free path of photons is bigger for longer time before decoupling
  - → Silk Damping enhanced.

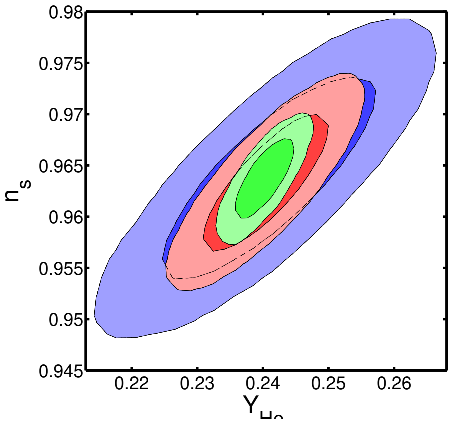
Primordial helium abundance Y_p (effect on p.s.)



Primordial helium abundance Y_p

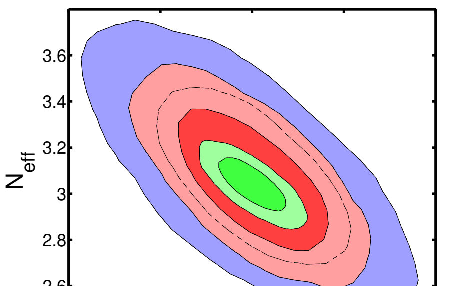
- Error on Primordial Helium abundance Y_p at 68 % c.l.

WMAP7:	$Y_p = 0.28^{+0.14}_{-0.15}$
WMAP7+ACT2008:	Y_p=0.313 $\pm$ 0.044
Planck (blue):	Y_p = 0.010
Planck+ACTpol (red):	Y_p = 0.0072
CMBpol (green):	Y_p = 0.0029



From measurement of HII extragalactic metal poor regions, $Y_p = 0.2561 \pm 0.0108$ (Aver 2010) and $Y_p = 0.2565 \pm 0.001(\mathrm{stat}) \pm 0.005(\mathrm{syst})$ (Izotov 2010), while from BBN $Y_p = 0.2487 \pm 0.0002$.

Degeneracies



Letting Y_p and N_{eff} vary at the same time weakens the constraints of a $\sim$ 50%.

Conclusions

- We have forecasted the constraints on fundamental physics parameters from Future CMB data.
- Adding small scale information from the ACT experiment will improve parameters of a 30%-40% compared to Planck data alone, while a future CMB satellite could improve constraints of a factor 2-4.
- Neutrino masses measurement from Planck+ACTpol will not be strong enough to discriminate between the inverted and normal hierarchy (in case of no detection).
- The measurement of N_{eff} will help in confirming or rejecting recent claims.
- Helium measurement will be competitive with measurements in HII extragalactic metal poor regions.