Improved constraints on lepton asymmetry from the CMB

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Baryon asymmetry of Universe : $\eta_{\mathrm{b}} = \dfrac{n_{\mathrm{b}} - n_{\bar{\mathrm{b}}}}{n_\gamma} = (6.099 \pm 0.044) \times 10^{-10}$

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→ Baryogenesis, Leptogenesis

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Possible caveats?

- sphaleron processes experimentally not confirmed
- suppress sphaleron processes?
  (S. Eijima, M. Shaposhnikov 2017; G. Barenboim, W. Park 2017;...)
- create large lepton asymmetry at later times, when sphaleron processes are inefficient
  (Affleck-Dine mechanism; active-sterile neutrino oscillations, Barbieri & Dolgov 1991; ...)

Lepton asymmetry = key parameter for origin of matter-antimatter asymmetry

What do we know about the lepton asymmetry of our Universe?

charge neutrality:

→ possibly hidden in cosmic neutrino background

→ no direct measurement possible ($T_\nu = 1.9\,\mathrm{K}$)

→ could be larger than baryon asymmetry by orders of magnitude

$$\eta_\mathrm{l} \approx \sum_{\alpha=e,\mu,\tau} \frac{n_{\nu,\alpha} - n_{\bar{\nu},\alpha}}{n_\gamma} = \frac{1}{12\zeta(3)} \sum_{\alpha=e,\mu,\tau} \left(\frac{T_{\nu,\alpha}}{T_\gamma}\right)^3 \left(\pi^2 \xi_\alpha + \xi_\alpha^3\right)$$

chemical potentials: $\dfrac{\mu_\alpha}{T_{\nu,\alpha}}$

Standard assumption: $\eta_\mathrm{l} \approx \eta_\mathrm{b}$

Agnostic point of view: lepton asymmetry = free parameter for cosmology

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$$N_{\text{eff}} = 3.046 + \frac{15}{7}\sum_{\alpha} \underbrace{\left(\frac{\xi_\alpha}{\pi}\right)^2 \left[2 + \left(\frac{\xi_\alpha}{\pi}\right)^2\right]}_{\geq 0}$$

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$$\left(\frac{n}{p}\right)_{\xi_{\rm e}} \approx \left(\frac{n}{p}\right)_{\xi_{\rm e}=0} \times \begin{cases} e^{-\xi_{\rm e}} & \text{for } \xi_{\rm e} < 0 \\ e^{-1.2\xi_{\rm e}} & \text{for } \xi_{\rm e} > 0 \end{cases}$$

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→ BBN codes, e.g. AlterBBN *(A. Arbey)*

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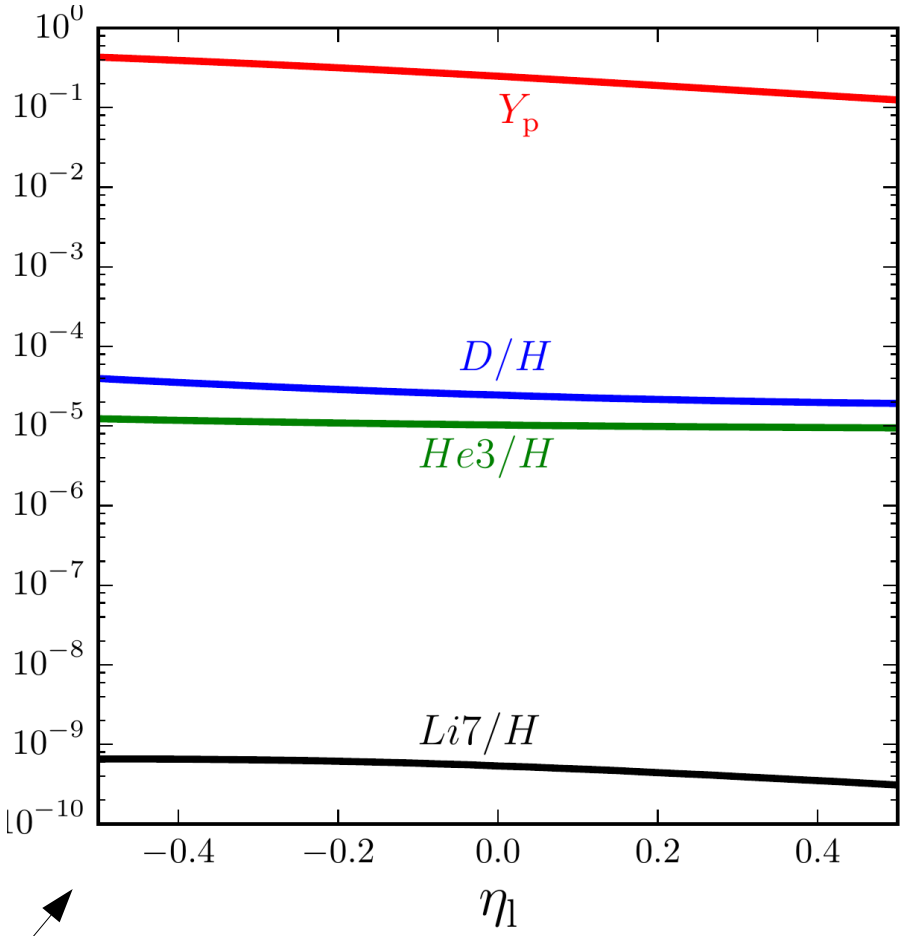


assuming $\xi_{\rm e} = \xi_\mu = \xi_\tau$

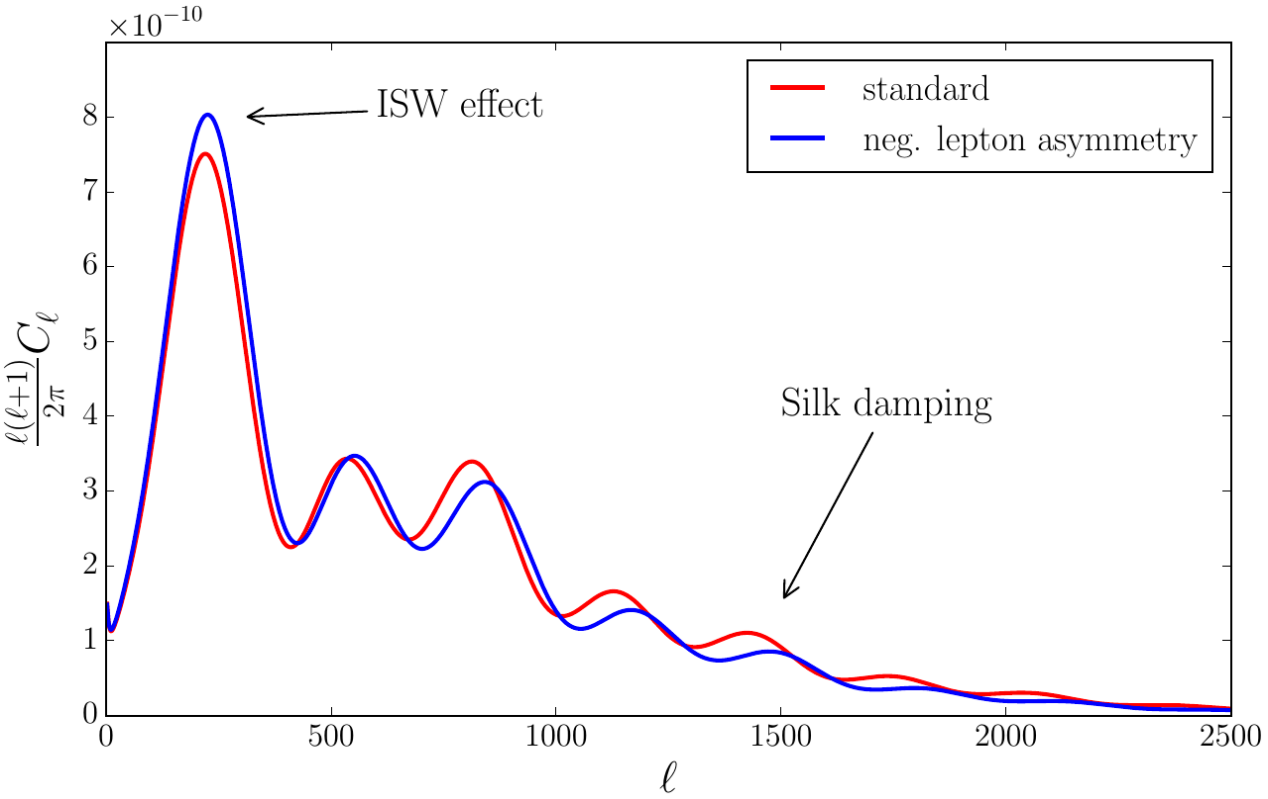
2.) Cosmic Microwave Background

I) increased relativistic energy density, $N_{\rm eff}$

II) modified BBN → modified helium fraction (AlterBBN input)

III) for massive neutrinos: modified neutrino hierarchy
(J. Lesgourgues, S. Pastor 1999)

Implement in CLASS
(J. Lesgourgues)



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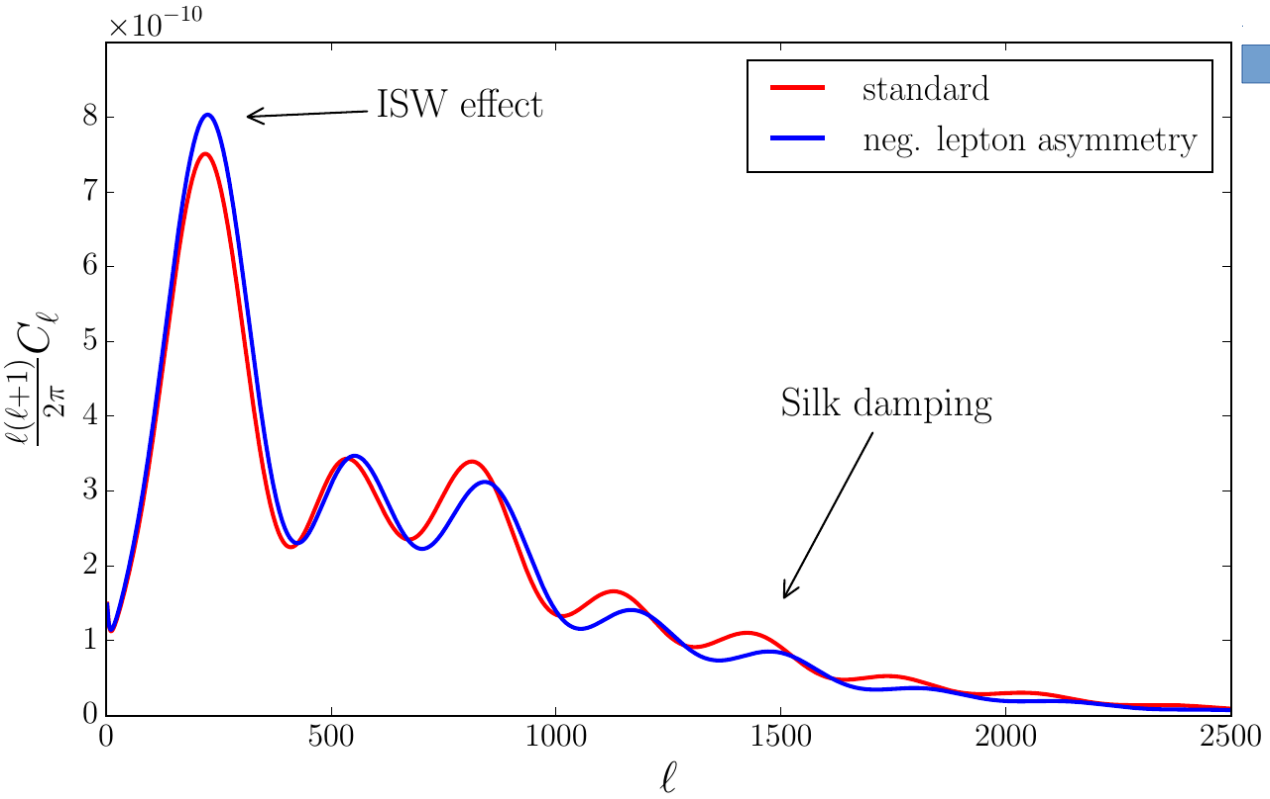


Constrain lepton asymmetry with Planck 2015 data

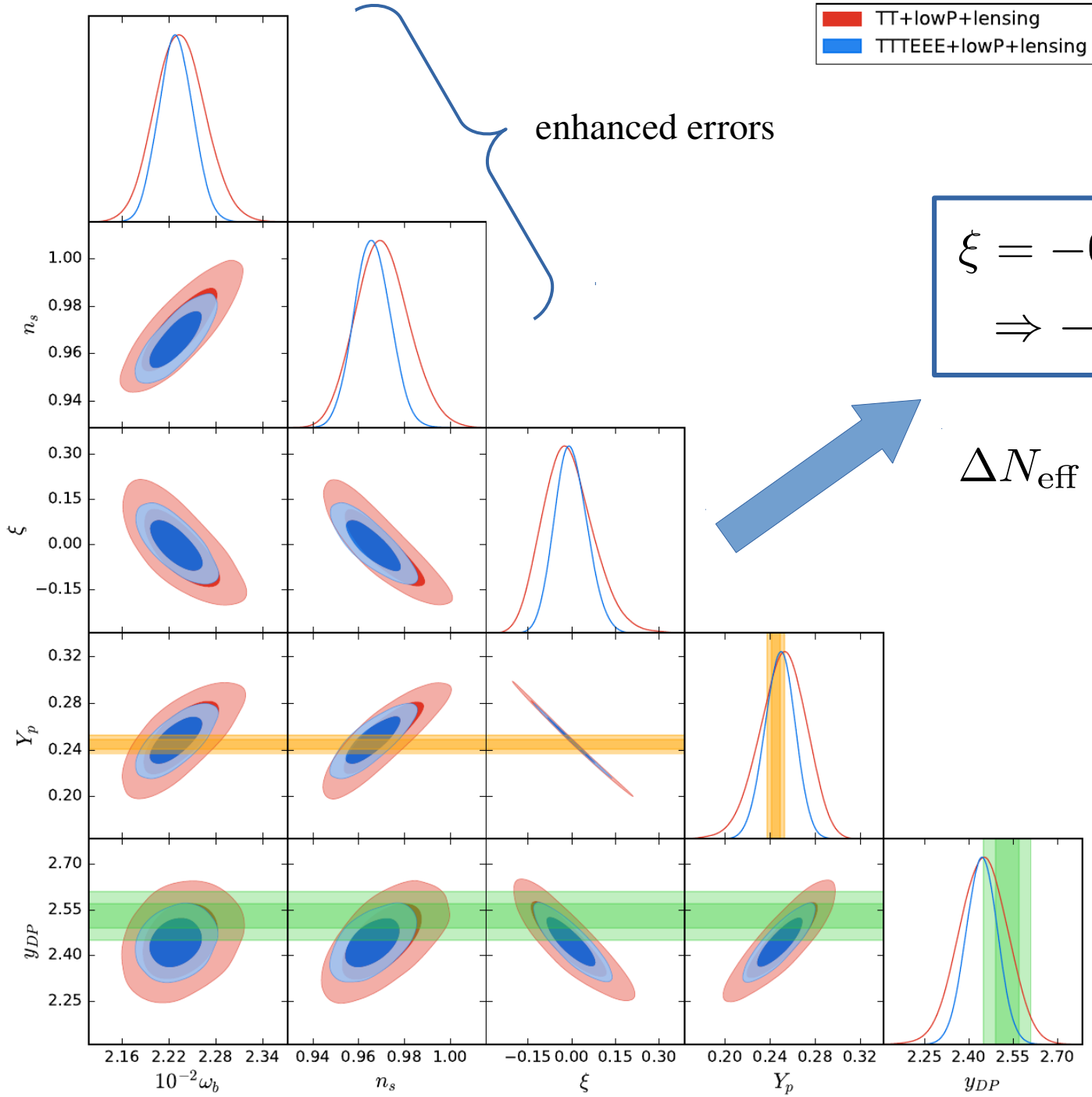
Assumptions

1.) Equal flavour asymmetries

$$\xi_\alpha = \xi$$

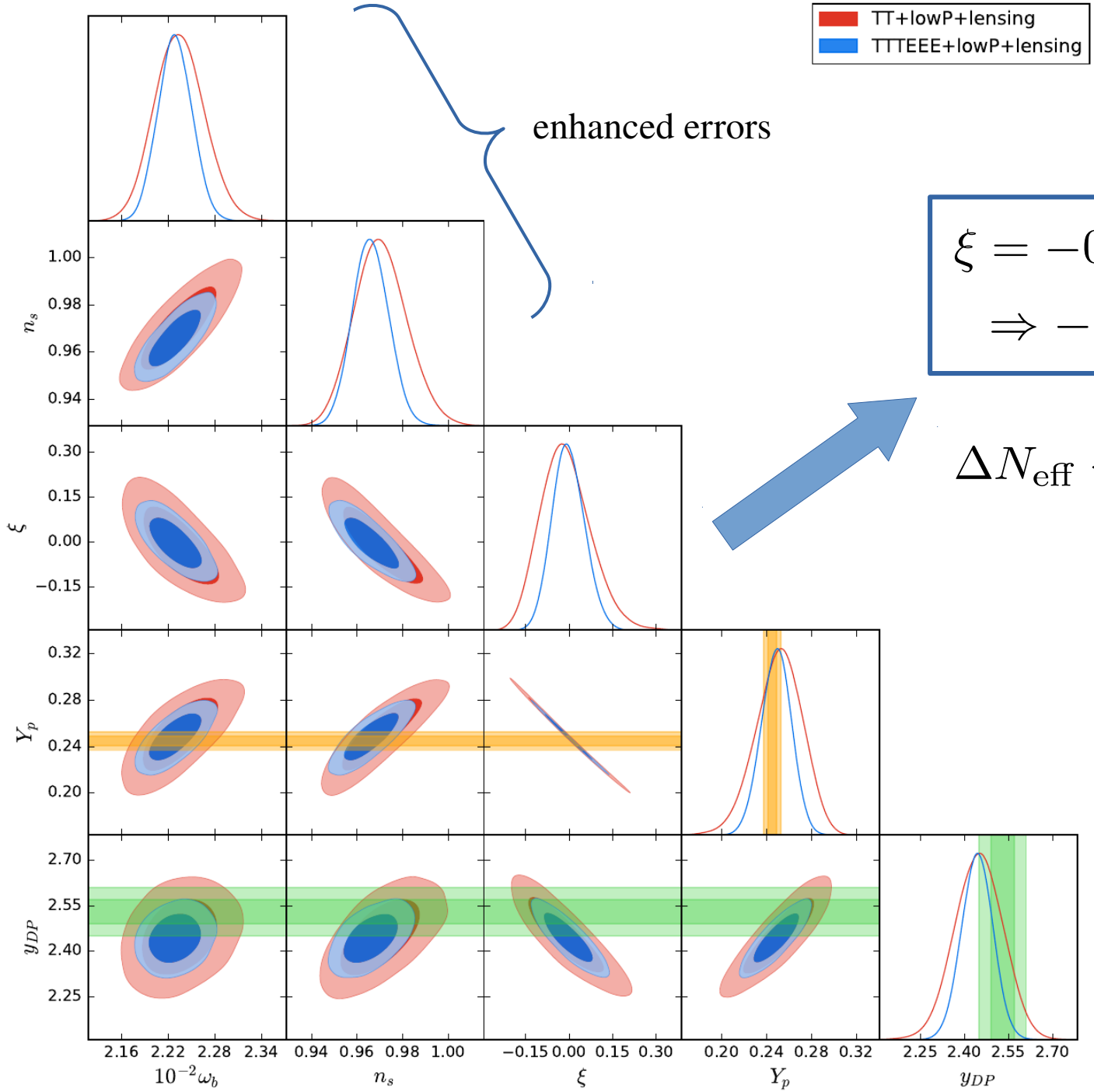
(A. D. Dolgov 2002, Y. Y. Y. Wong 2002)

2.) Ultrarelativsitic neutrinos



$$\xi = -0.002^{+0.114}_{-0.111}\ (95\%\ \mathrm{CL})$$
$$\Rightarrow -0.085 \leq \eta_1 \leq 0.084$$

$$\Delta N_{\mathrm{eff}} < 0.017 (95\%\,\mathrm{CL})$$



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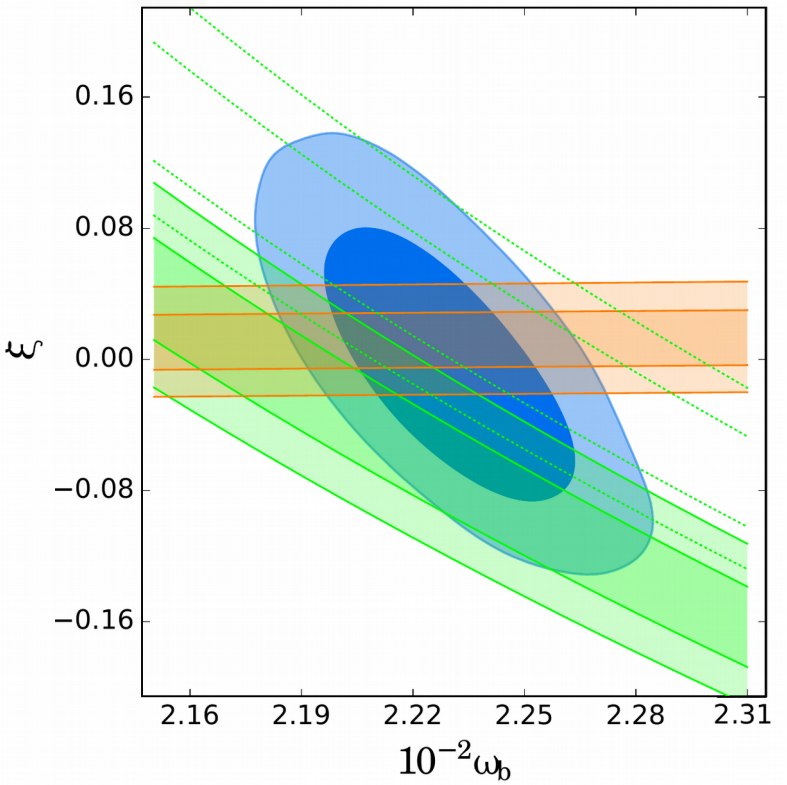
Consistent with direct measurements

(E. Aver et al, 2015, R. Cooke et al. 2014)

Can we improve CMB constraints by adding direct measurements of primoridal light element abundances?

Constraints in the $(\xi, \omega_b) -$ plane



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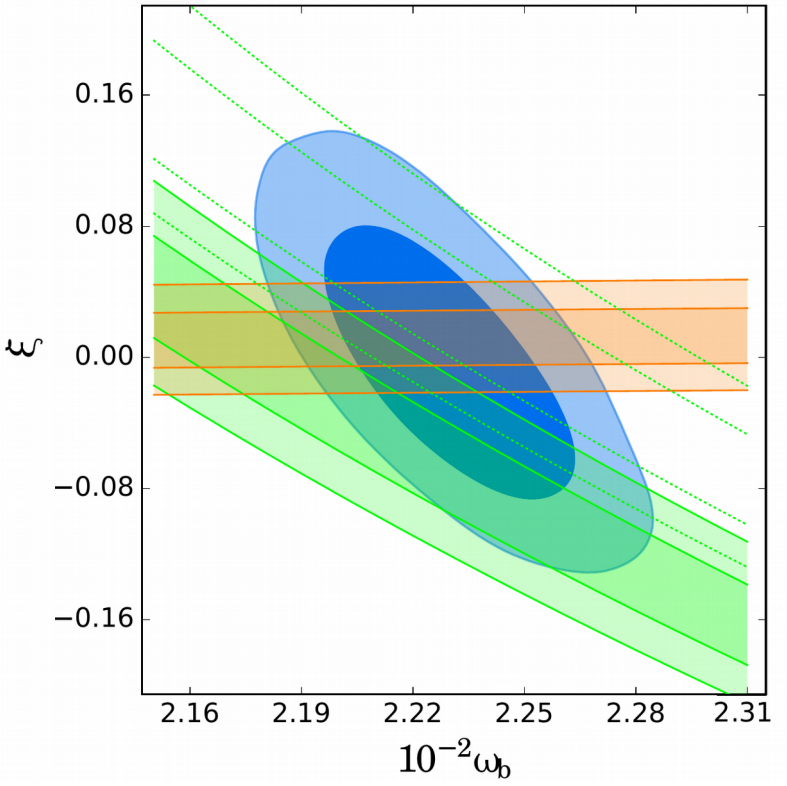
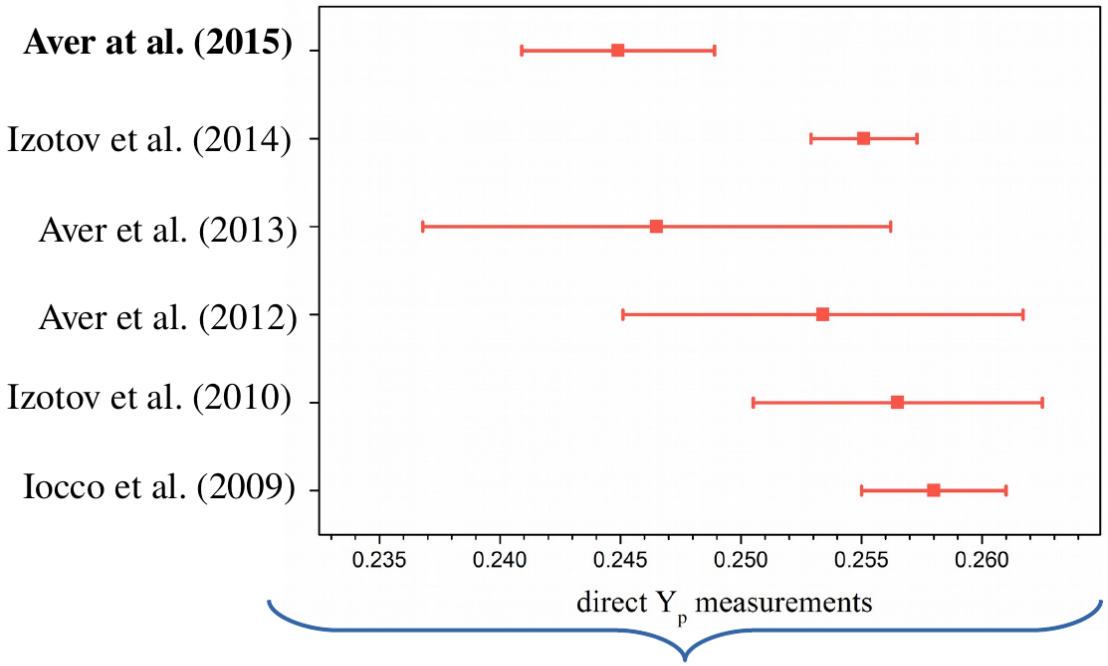


Looks promising, but…:



Systematic uncertainties...

CMB constraints are more robust.

Take-home message:

- CMB consistent with small lepton asymmetry, but still allows lepton asymmetry to be much larger than baryon asymmetry

- CMB consraints competitive with constraints from light element abundances → more trustworthy

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Thank you for your attention!

	TT+lowP+lensing	TTTEEE+lowP+lensing	(no lepton asymmetry) TTTEEE+lowP+lensing
ξ	$-0.011^{+0.076}_{-0.098}$ $\left(^{+0.179}_{-0.167}\right)$	$-0.002^{+0.053}_{-0.060}$ $\left(^{+0.114}_{-0.111}\right)$	0
$\omega_{\rm b}$	$0.02235^{+0.00031}_{-0.00035}$ $\left(^{+0.00066}_{-0.00064}\right)$	$0.02229^{+0.00022}_{-0.00023}$ $\left(^{+0.00043}_{-0.00044}\right)$	$0.02228^{+0.00016}_{-0.00017}$ $\left(^{+0.00032}_{-0.00032}\right)$
$Y_{\rm p}$	$0.251^{+0.025}_{-0.020}$ $\left(^{+0.041}_{-0.042}\right)$	$0.248^{+0.014}_{-0.014}$ $\left(^{+0.027}_{-0.027}\right)$	$0.24784^{+0.000067}_{-0.000069}$ $\left(^{+0.000136}_{-0.000134}\right)$
$y_{\rm DP}$	$2.448^{+0.086}_{-0.084}$ $\left(^{+0.166}_{-0.166}\right)$	$2.443^{+0.055}_{-0.054}$ $\left(^{+0.107}_{-0.109}\right)$	$2.439^{+0.029}_{-0.029}$ $\left(^{+0.057}_{-0.058}\right)$
$n_{\rm s}$	$0.9704^{+0.011}_{-0.013}$ $\left(^{+0.024}_{-0.023}\right)$	$0.9660^{+0.0078}_{-0.0083}$ $\left(^{+0.0158}_{-0.0159}\right)$	$0.9654^{+0.0047}_{-0.0049}$ $\left(^{+0.0096}_{-0.0094}\right)$