Cosmological lepton asymmetry with a nonzero θ_{13}

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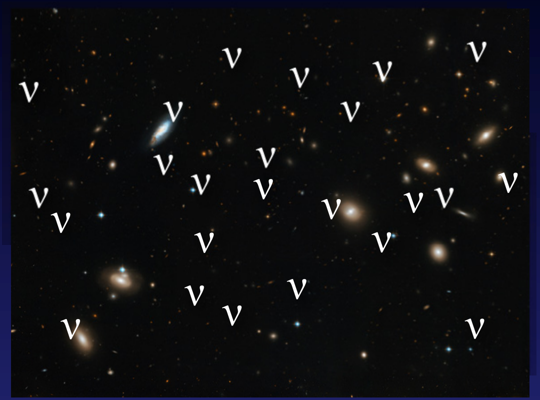
What is nu?
GGI Florence
29 June 2012

Picture from Hubble ST



Outline

Extra radiation &
Lepton/neutrino asymmetries (η_ν)

Effect of flavor
neutrino oscillations (θ_{13})

BBN bounds on
η_ν and $N_{eff}(\eta_\nu)$

Relativistic particles in the Universe

At $T<m_e$, the radiation content of the Universe is

$$\rho_r = \rho_\gamma + \rho_\nu + \rho_x = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\rm eff}\right]\rho_\gamma$$

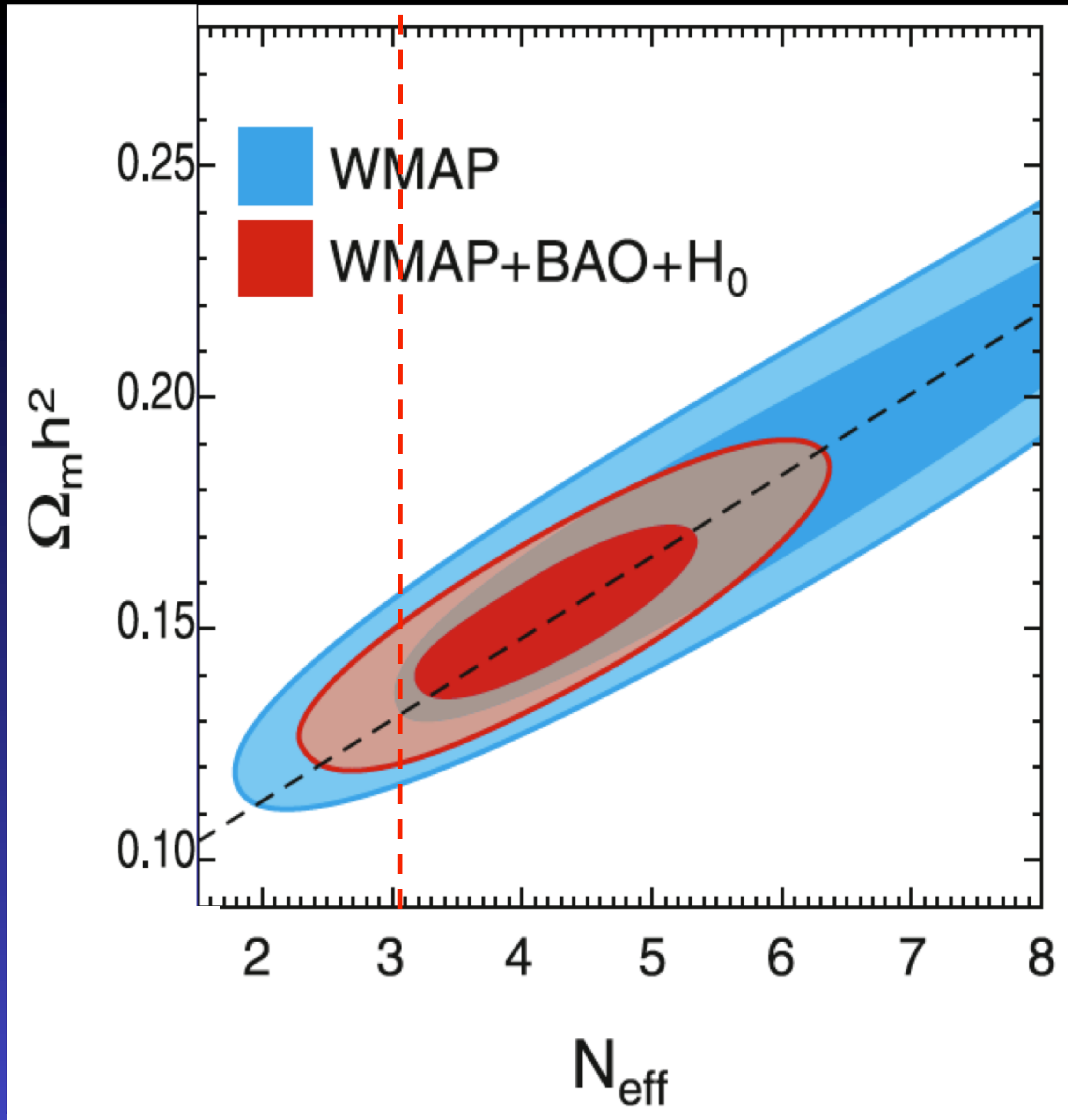
Effective number of relativistic neutrino species

Traditional parametrization of ρ stored in relativistic particles

N_{eff} is a way to measure the ratio $\dfrac{\rho_\nu + \rho_x}{\rho_\gamma}$

- standard neutrinos only: $N_{eff} \simeq 3$ (3.04)

allowed range for N_{eff}



WMAP [7-year], arXiv:1001.4538

$2.7 < N_{eff} < 6.2$ (WMAP+BAO+H_0, 95%CL)

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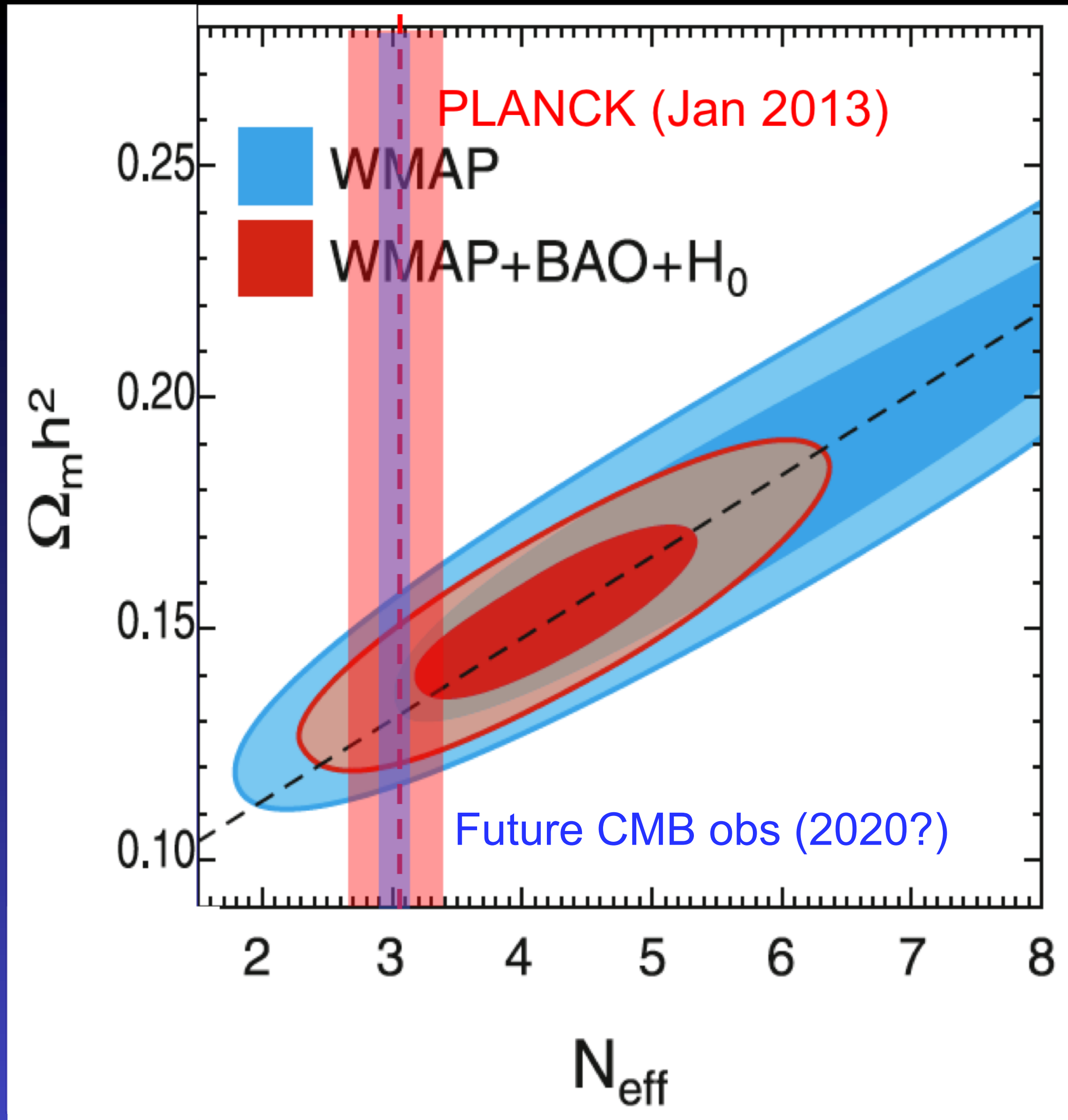

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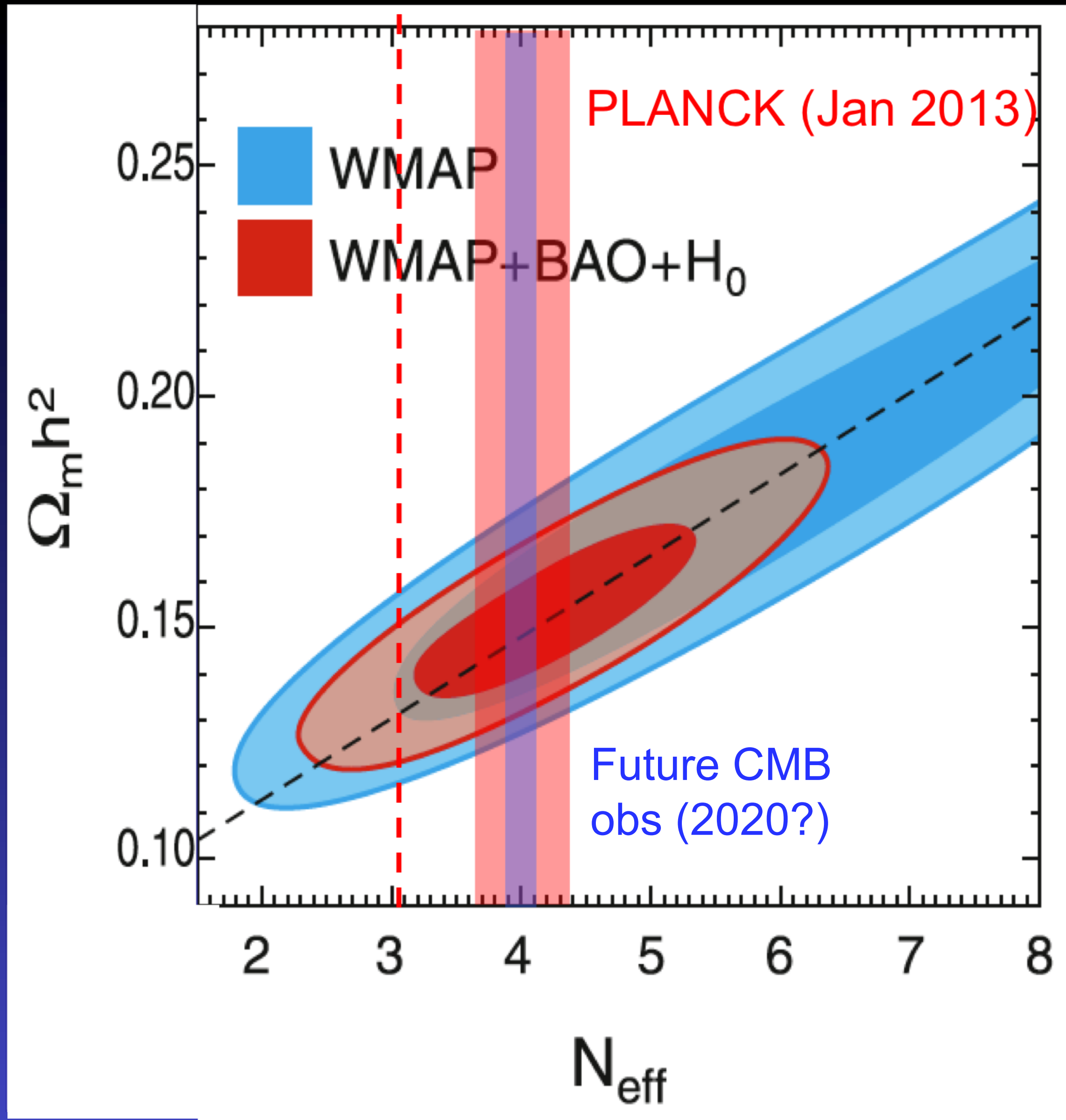

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- standard neutrinos only: $N_{eff} \simeq 3$ (3.04)
- with additional rel. particles: $N_{eff} > 3$

$N_{eff} > 3$ only with active neutrinos ? **Primordial neutrino asymmetries**

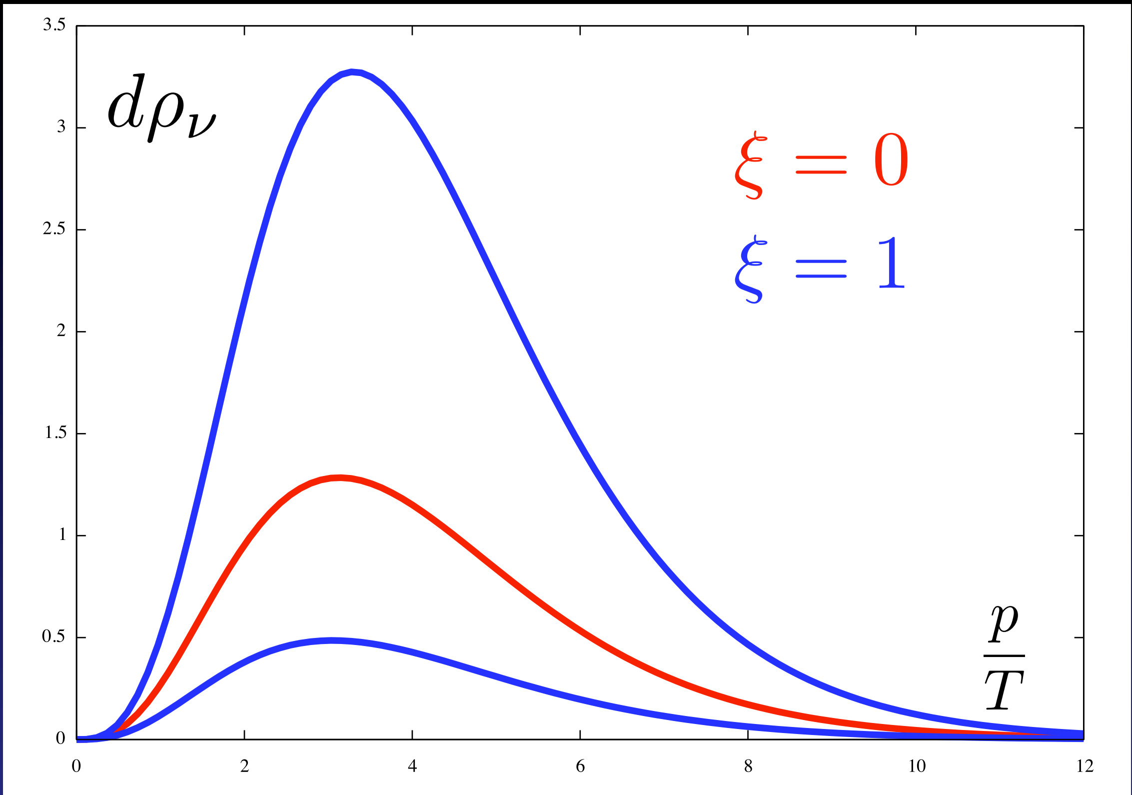
Baryon asymmetry $\eta_b = \frac{n_b - n_{\bar{b}}}{n_\gamma}$ (value 6×10^{-10})

Lepton asymmetry $\eta_l \gg \eta_b$ only if $\eta_l = \eta_\nu$

Primordial Neutrino asymmetries

Fermi-Dirac distribution
- Temperature T
- Chemical potential μ
  - +μ Particles
  - −μ Anti-particles

$$f_p = \frac{1}{\exp\left(\frac{p-\mu}{T}\right)+1}$$



Degeneracy parameter $\xi = \frac{\mu}{T}$ Invariant under cosmic expansion

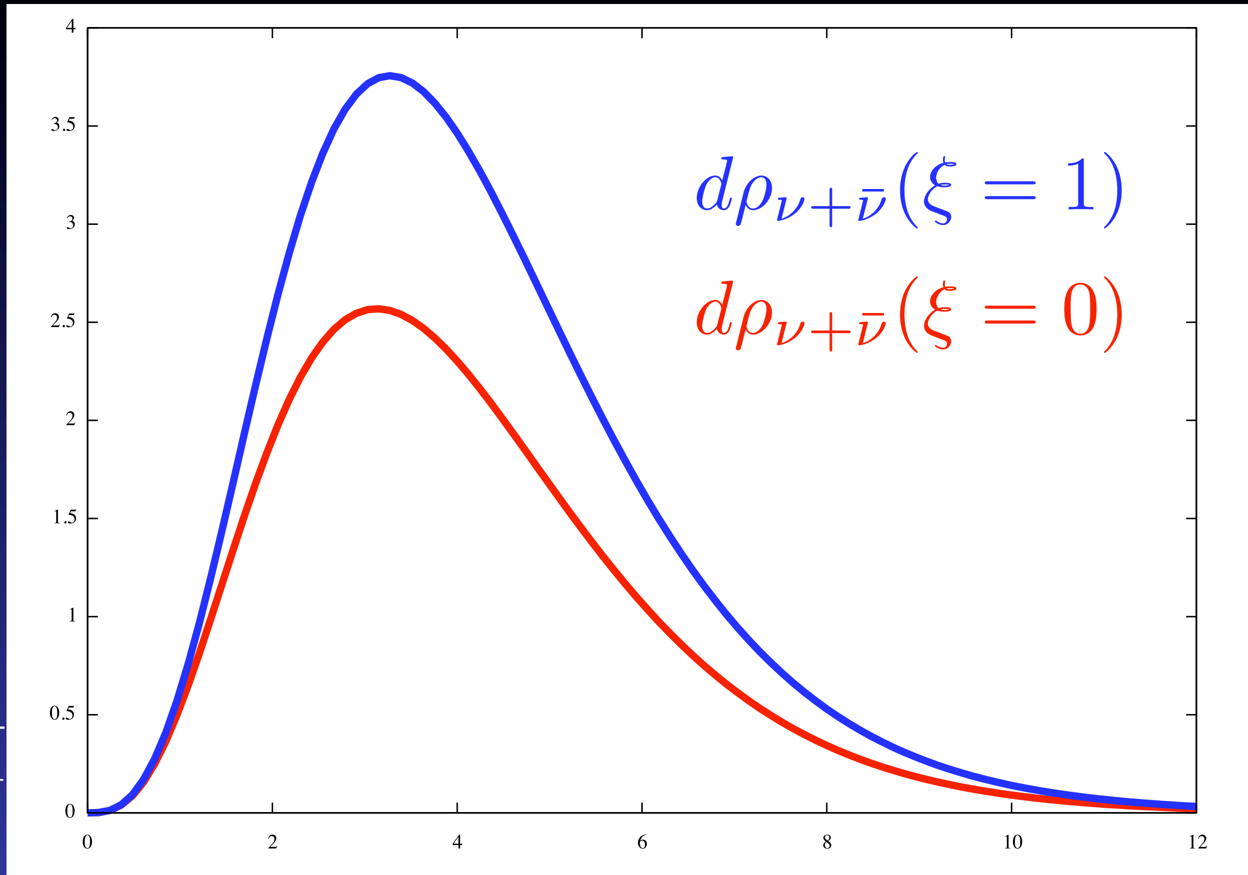
Number asymmetry

$$n_\nu - n_{\bar{\nu}} = \int \frac{dE}{2\pi^2}\left(\frac{E^2}{1+\exp(E/T-\xi)} - \frac{E^2}{1+\exp(E/T+\xi)}\right)$$

$$= \frac{1}{6\pi^2} T_\nu^3 \left[\xi^3 + \pi^2 \xi\right]$$

Extra radiation from neutrino asymmetries

$$f_{\nu_\alpha} = \frac{1}{\exp(p/T - \xi_{\nu_\alpha}) + 1}$$



Energy density in one neutrino flavor with degeneracy parameter $\xi = \mu/T$

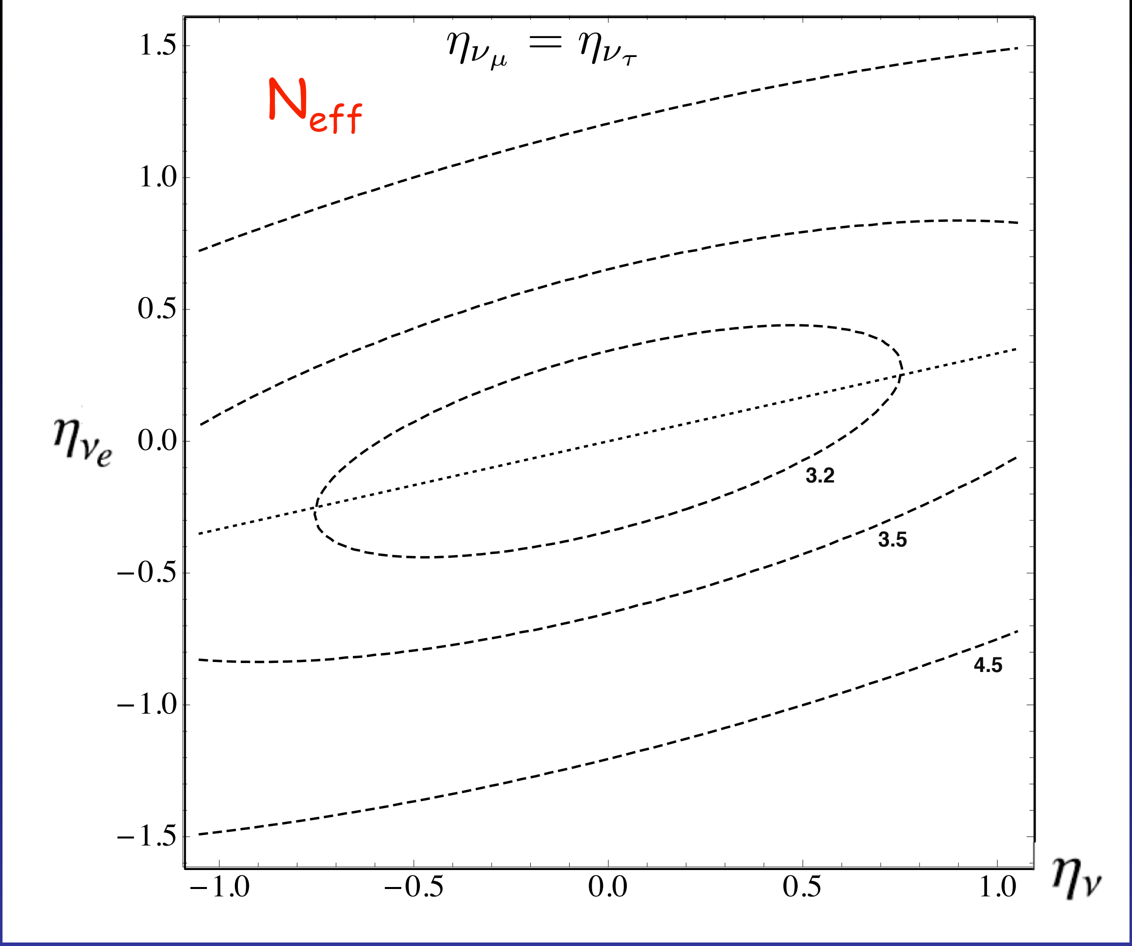
$$\rho_{\nu\bar{\nu}} = \frac{7\pi^2}{120} T_\nu^4 \left[1 + \underbrace{\frac{30}{7}\left(\frac{\xi}{\pi}\right)^2 + \frac{15}{7}\left(\frac{\xi}{\pi}\right)^4}_{\Delta N_{eff}} \right]$$

Extra radiation from Neutrino asymmetries

$$\eta_{\nu_\alpha} = \frac{n_{\nu_\alpha} - n_{\bar{\nu}_\alpha}}{n_\gamma}$$

$$\eta_\nu = \sum_\alpha \eta_{\nu_\alpha}$$

$$f_{\nu_\alpha} = \frac{1}{\exp(p/T - \xi_{\nu_\alpha}) + 1}$$



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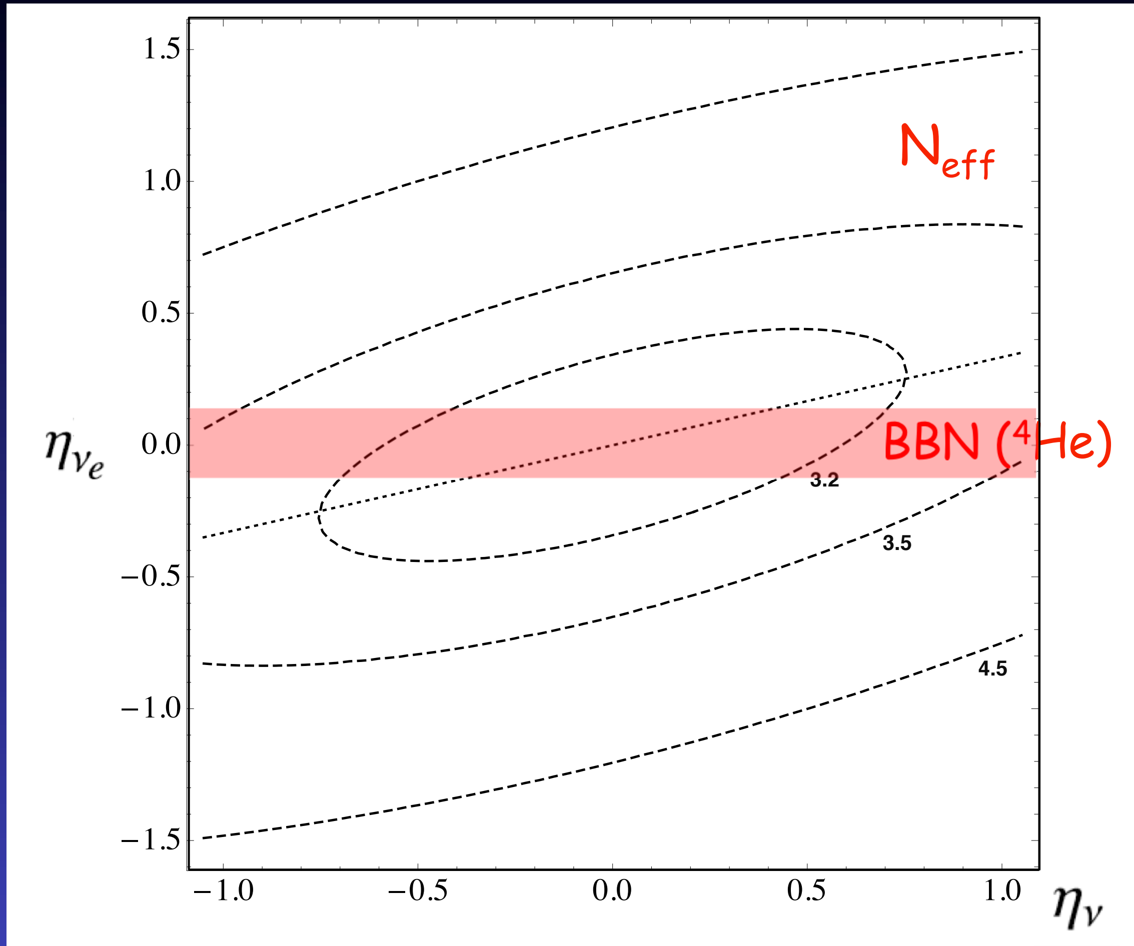
Primordial Nucleosynthesis and Neutrino asymmetries

Expansion Rate Effect (all flavors) ↑ ^{4}He	Energy density in one neutrino flavor with degeneracy parameter $\xi = \mu/T$ $$\rho_{\nu\bar\nu} = \frac{7\pi^2}{120} T_\nu^4 \Big[1 + \underbrace{\frac{30}{7}\left(\frac{\xi}{\pi}\right)^2 + \frac{15}{7}\left(\frac{\xi}{\pi}\right)^4}_{\Delta N_{\rm eff}}\Big]$$
Beta equilibrium effect for electron flavor $n + \nu_e \leftrightarrow p + e^-$	Helium abundance essentially fixed by n/p ratio at beta freeze-out $$\frac{n}{p} = e^{-(m_n - m_p)/T - \xi_{\nu_e}}$$ $\lvert\xi_{\nu_e}\rvert \lesssim 0.07$ Effect on ^{4}He equivalent to $\Delta N_{\rm eff} \sim -18\,\xi_{\nu_e}$

- ν_e beta effect can compensate expansion-rate effect of $\nu_{\mu,\tau}$

BBN and Neutrino asymmetries



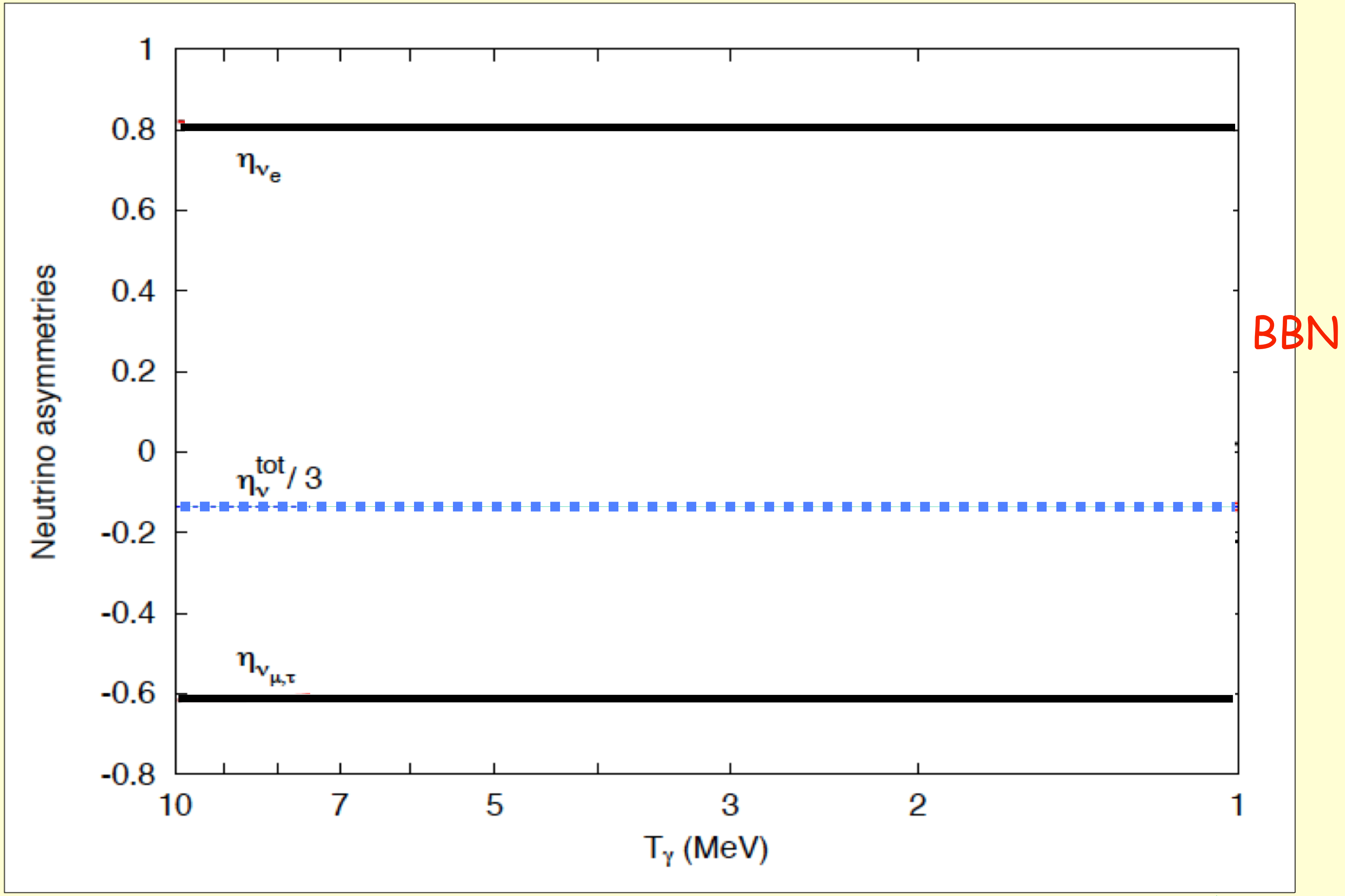
- ν_e beta effect can compensate expansion-rate effect of $\nu_{\mu,\tau}$

Weak BBN bounds on neutrino asymmetries & N_{eff}

$$|\eta_\nu| \lesssim 2$$

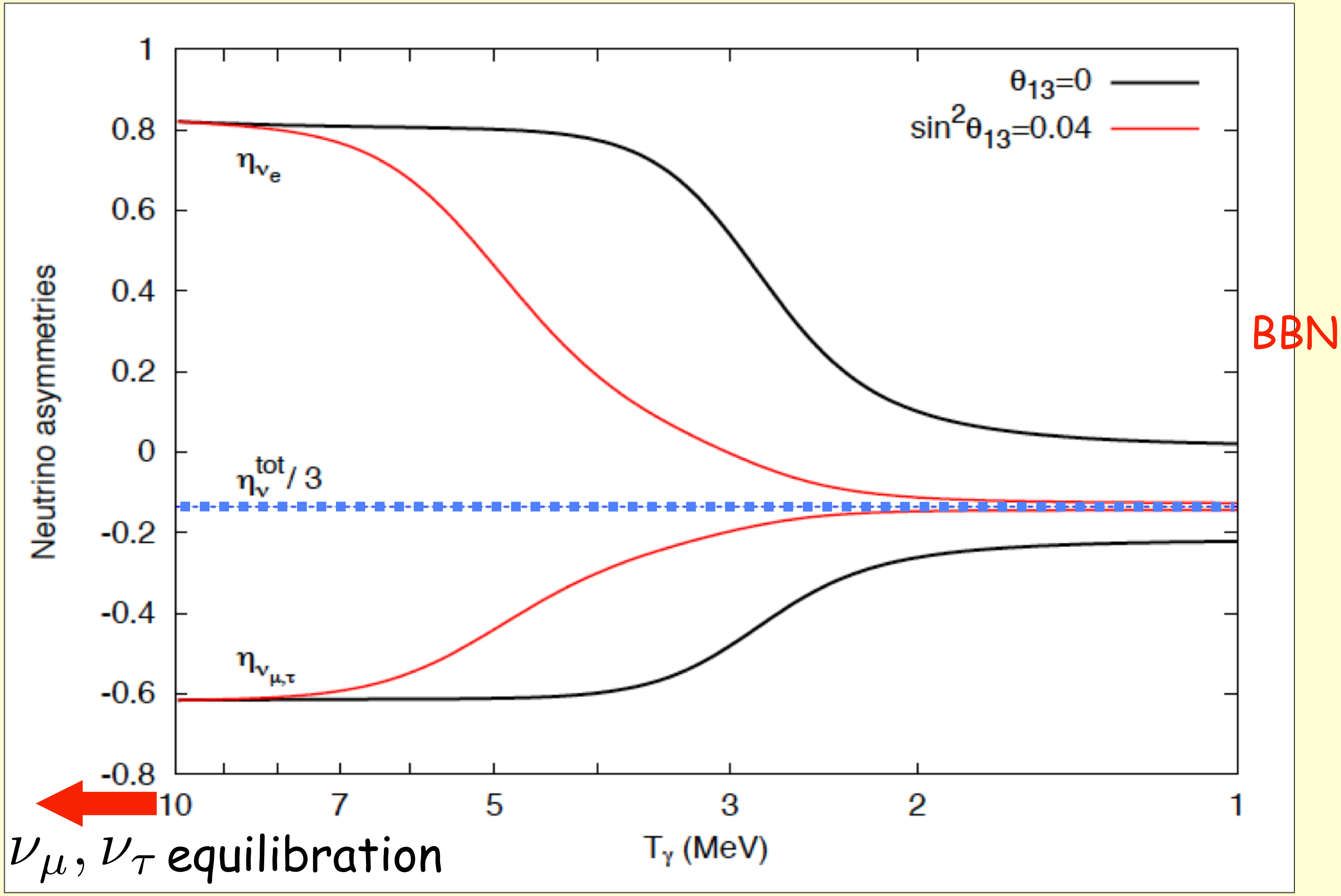
Relic neutrino asymmetries and flavour oscillations

Neutrino asymmetries before the onset of BBN



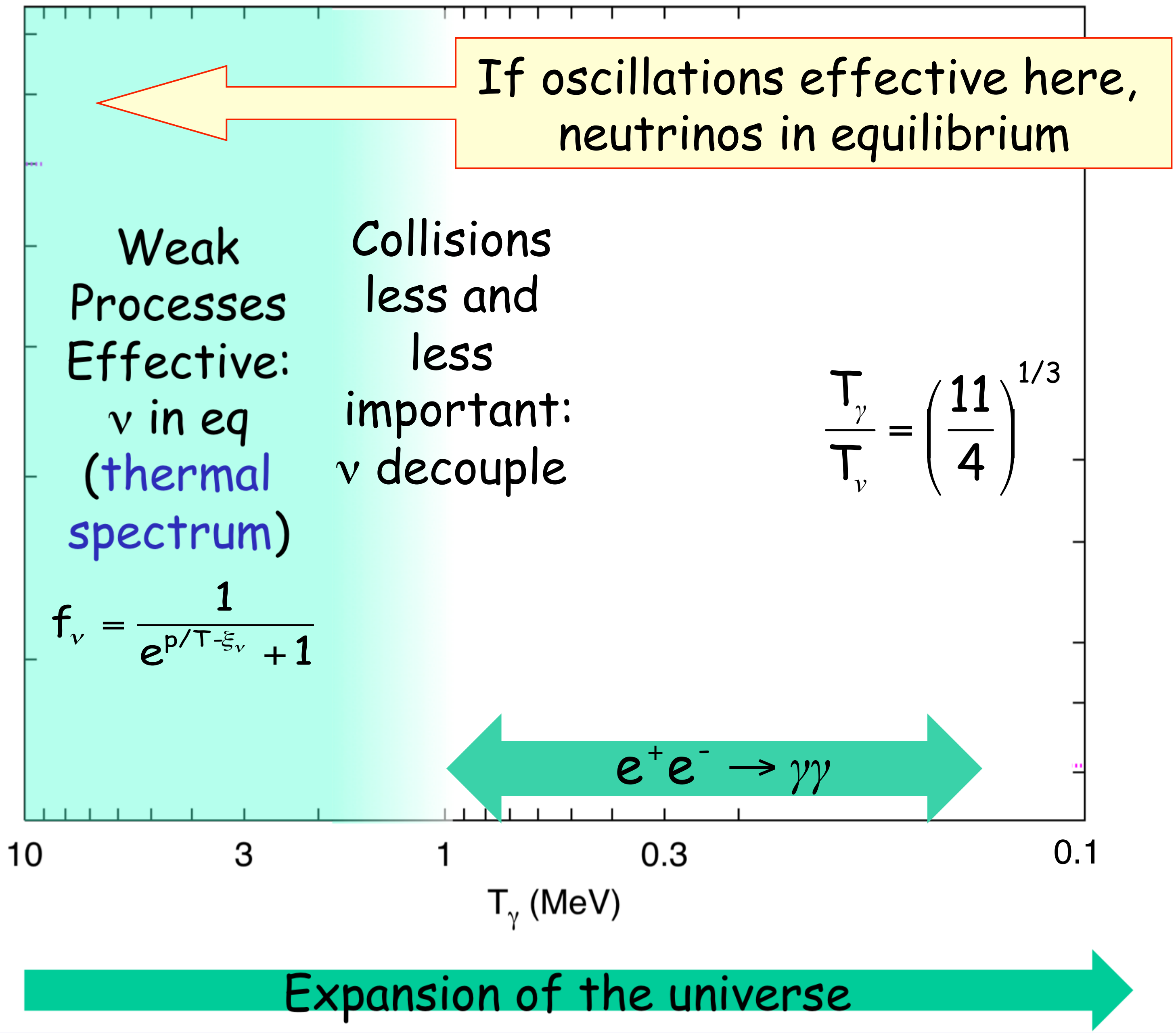
Expansion of the universe

Flavor Transformation for present mixing parameters



Mangano et al, JCAP 03 (2011) 035

ν interactions and decoupling at MeV temp.



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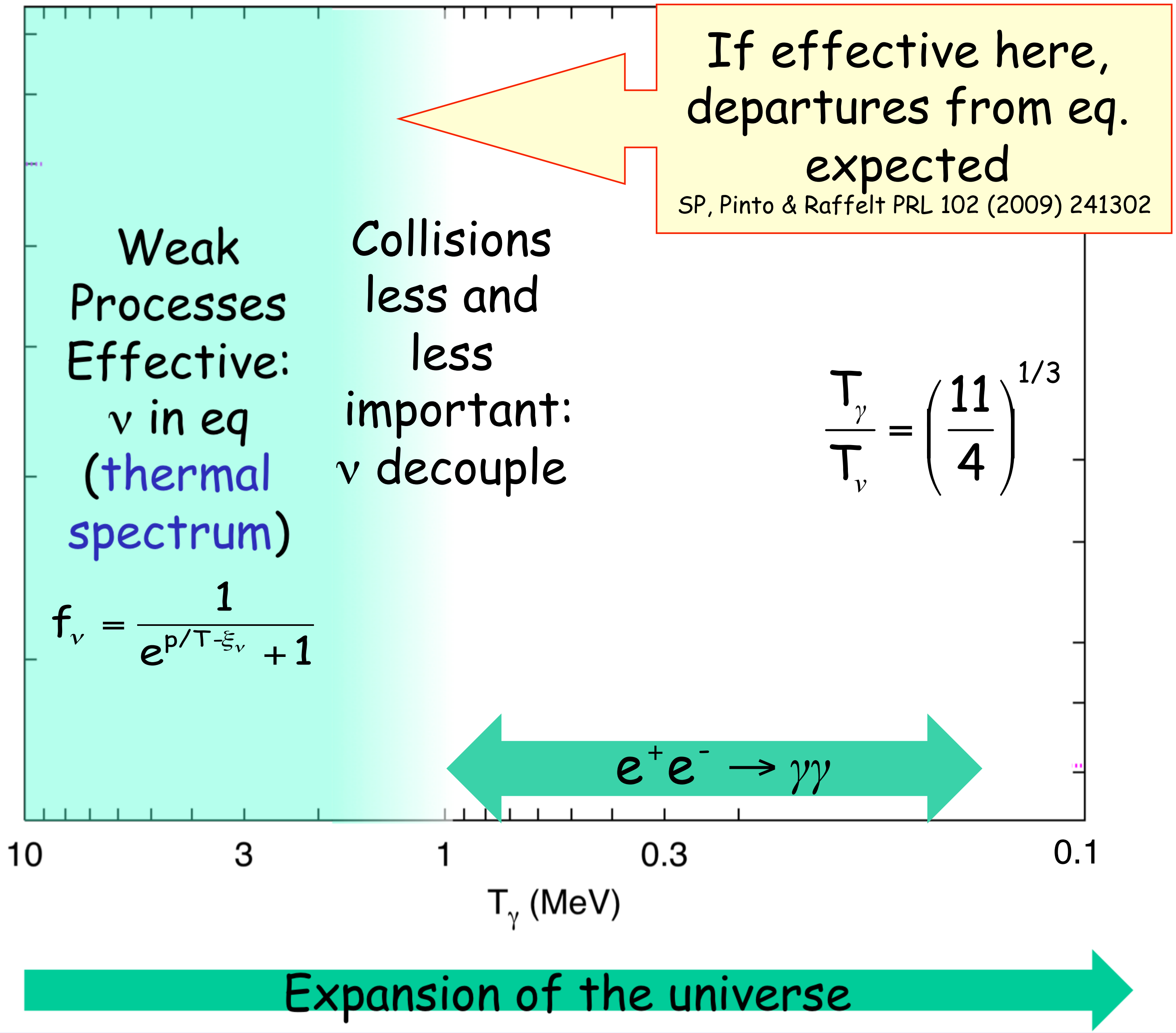
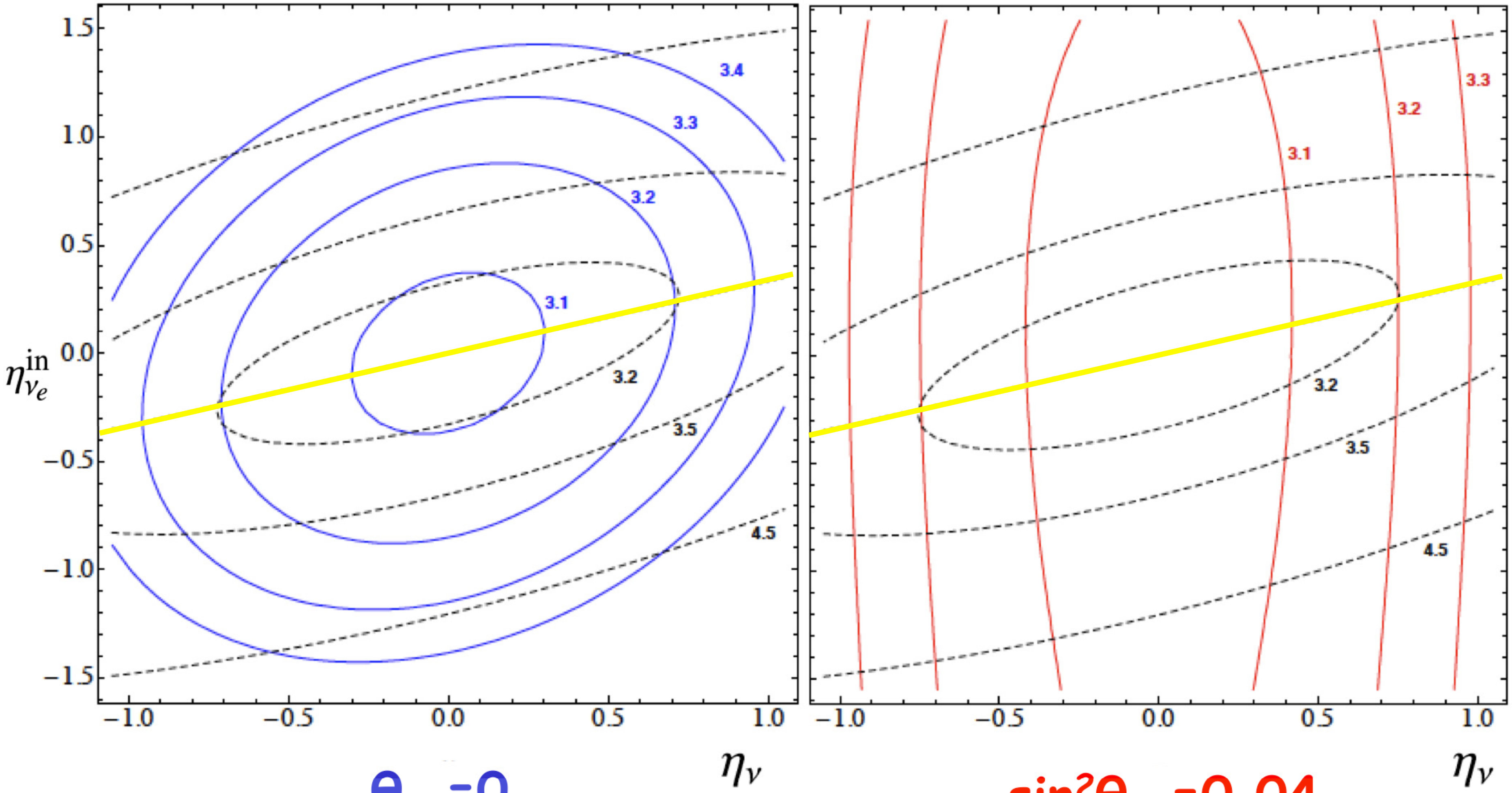


Flavor oscillations REDUCE the final N_{eff} from neutrino asymmetries (unless all initial $\eta_{\nu\alpha}$ very similar)

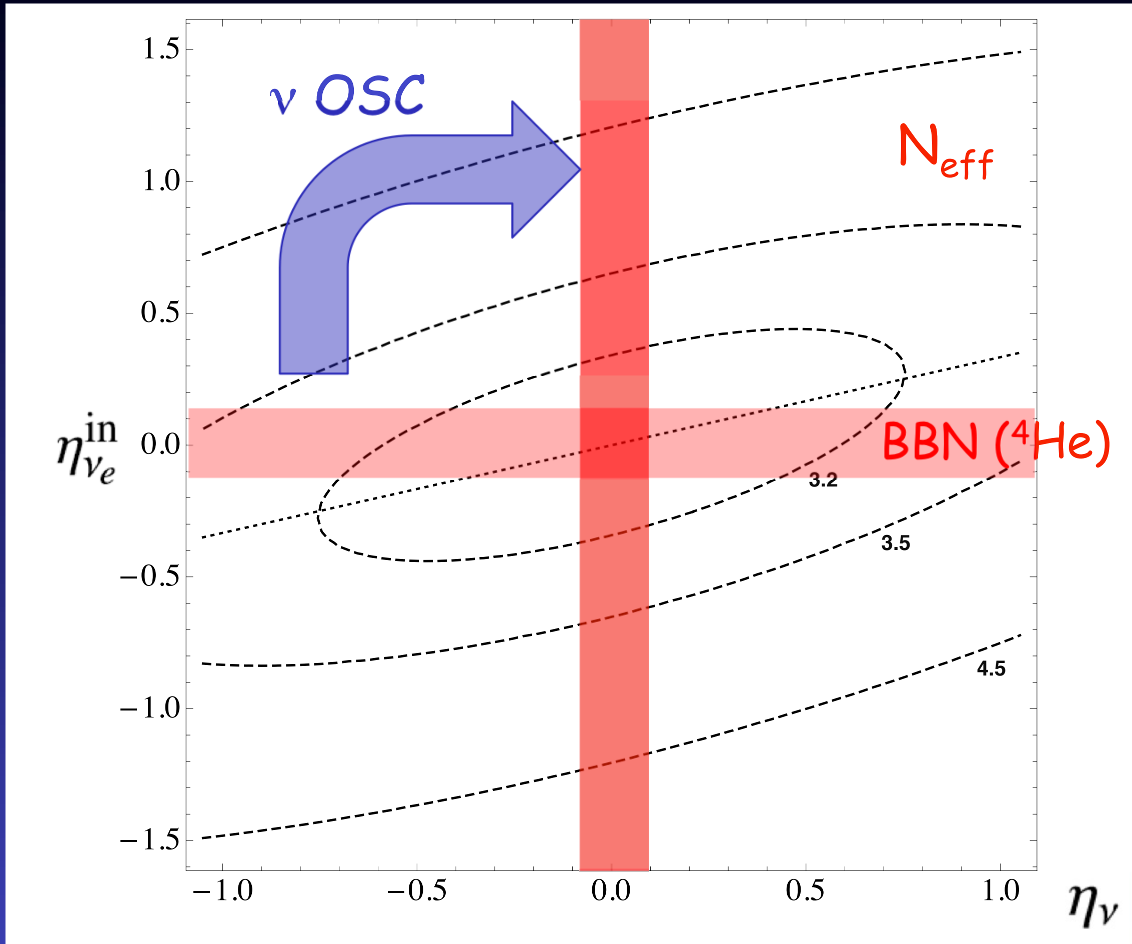


$\theta_{13}=0$

$\sin^2\theta_{13}=0.04$

BBN bounds on η_ν and $N_{eff}(\eta_\nu)$

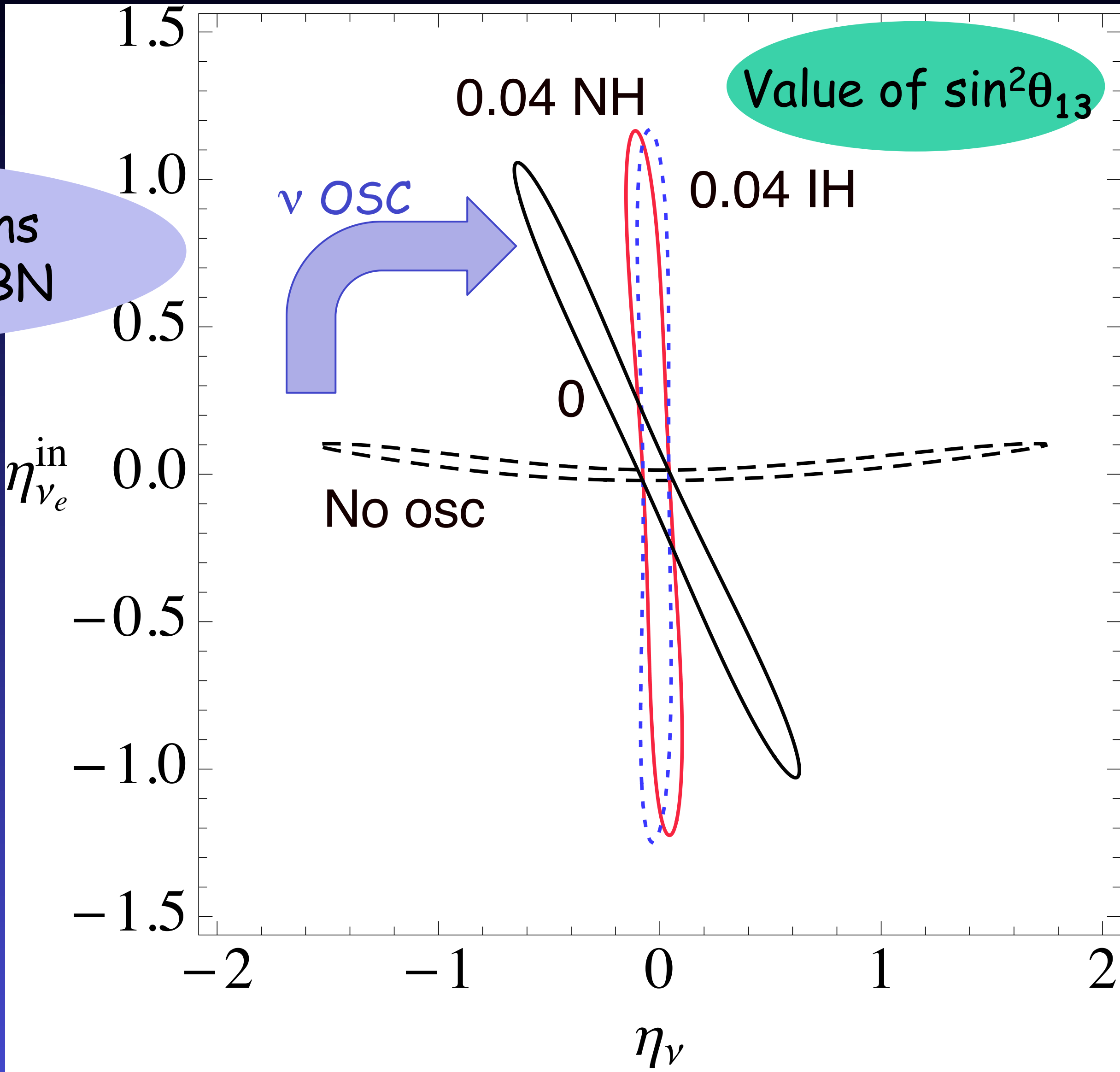
BBN and Neutrino asymmetries + oscillations



More stringent BBN bounds on
the cosmological lepton asymmetry

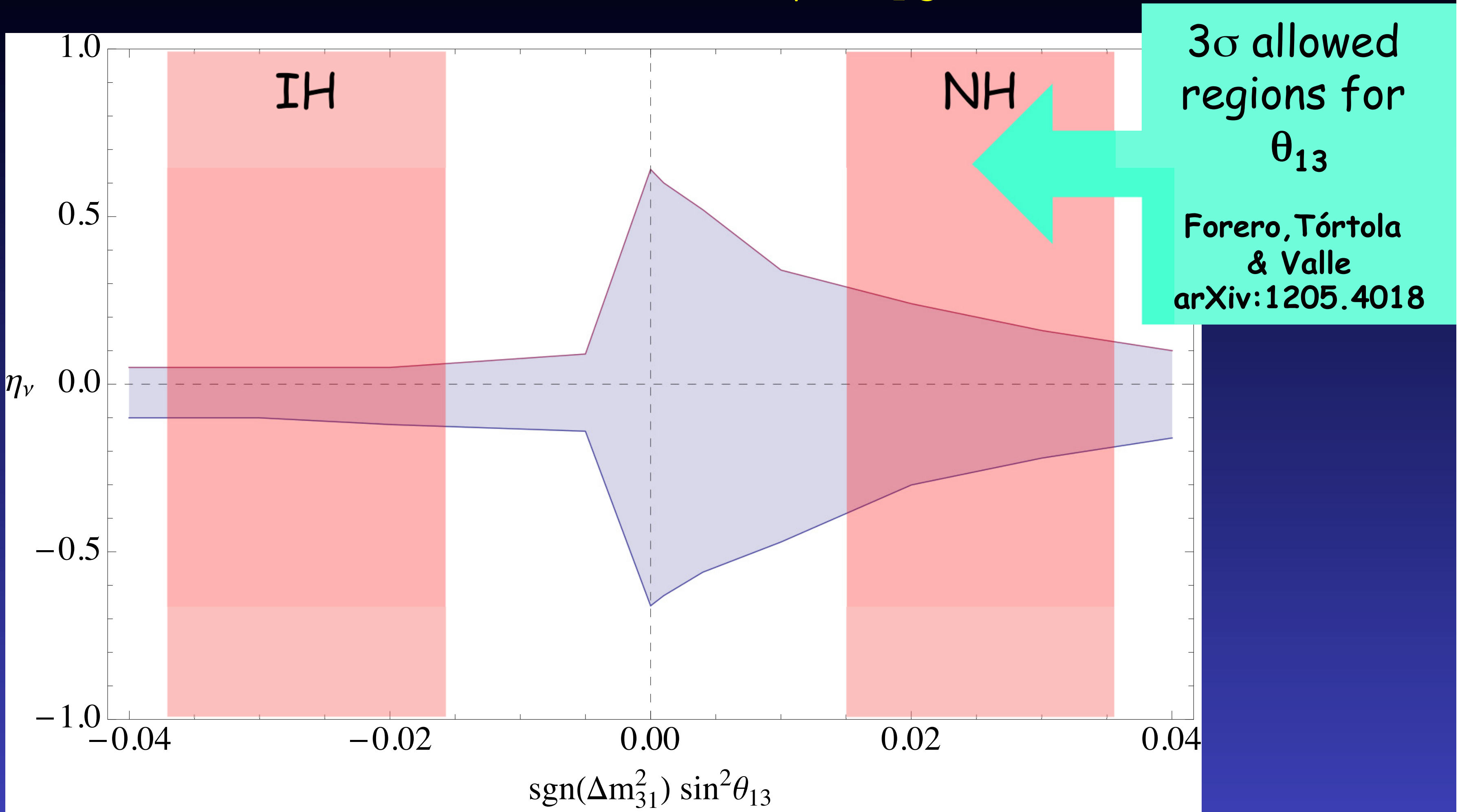
BBN Bounds on the cosmological lepton asymmetry

Flavour ν oscillations effective before BBN



G. Mangano et al, PLB 708 (2012) 1 [arXiv:1110.4335]

Bounds on η_ν (θ_{13})

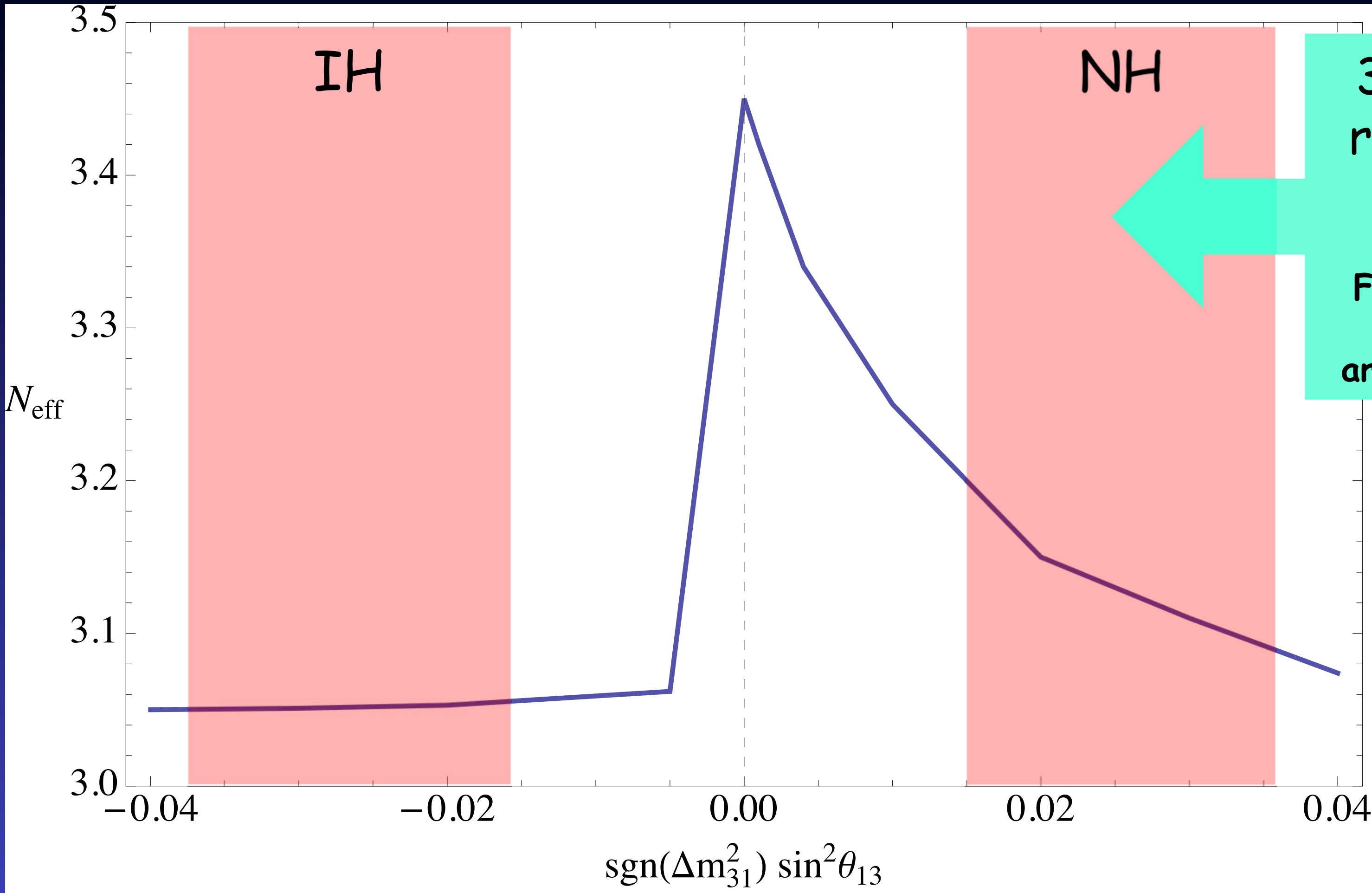


	$\theta_{13} = 0$	$\sin^2\theta_{13} = 0.04$
$Y_p = 0.250 \pm 0.003$	$-0.66 < \eta_\nu < 0.63$	$-0.13 < \eta_\nu < 0.07$
$Y_p = 0.2573 \pm 0.0033$	$-0.71 < \eta_\nu < 0.56$	$-0.20 < \eta_\nu < 0.02$

G. Mangano et al, PLB 708 (2012) 1

[arXiv:1110.4335]

Max contribution to radiation from η_ν (θ_{13})

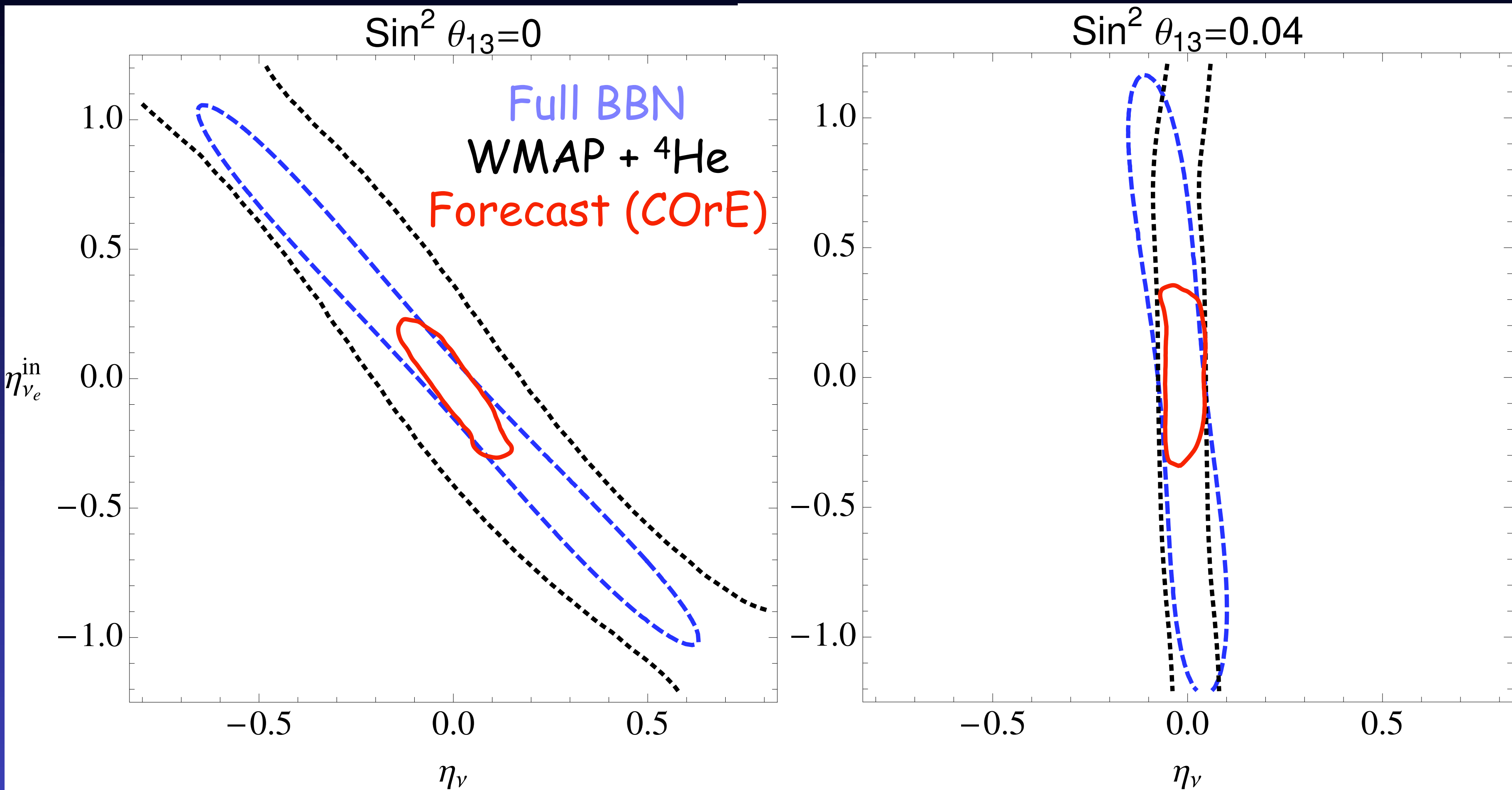


3σ allowed regions for θ_{13}

Forero, Tórtola & Valle arXiv:1205.4018

G. Mangano et al, PLB 708 (2012) 1 [arXiv:1110.4335]

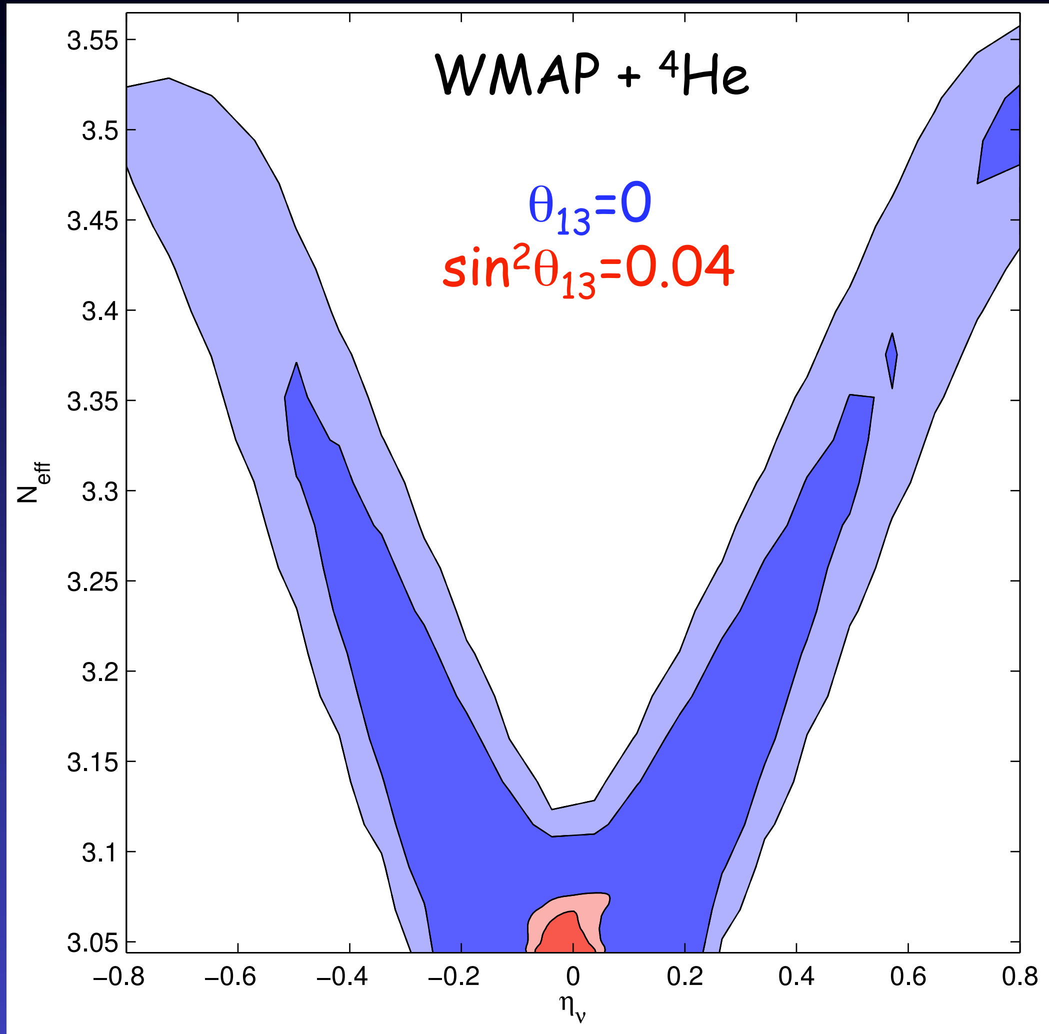
Beyond BBN: bounds on the lepton asymmetry



A nonzero η_ν <u>does not</u> modify the cosmological bounds on neutrino masses

E. Castorina et al, PRD (2012), to appear [arXiv:1204.2510]

Beyond BBN: bounds on $N_{eff}(\eta_\nu)$



A nonzero η_ν <u>can not</u> explain a significant excess of radiation

E. Castorina et al, PRD (2012), to appear [arXiv:1204.2510]

Summary

- Flavor neutrino oscillations with the measured mixing parameters do not always lead to full equilibrium before BBN, but it is established in practice for allowed values of θ_{13}

- We found the constraints on the cosmological lepton asymmetry (from neutrinos) and its maximum contribution to the excess radiation density: $N_{eff} < 3.1$ if θ_{13} as indicated by current oscillations experiments