FORENSIC COSMOLOGY :

PROBING NEUTRINOS WITH BBN AND THE CMB

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Abundances of D, ^{3}He, ^{7}Li

Are RATE Limited

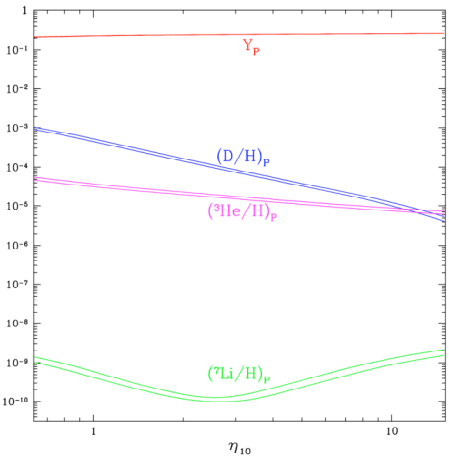
 D, ^{3}He, ^{7}Li Are

Possible Baryometers

 $\equiv n_N / n_\gamma$

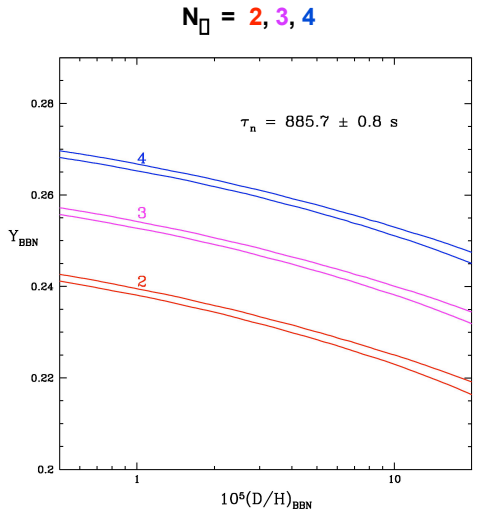
$\eta_{10} \equiv 10^{10} \eta \equiv 274\, \Omega_B h^2$

BBN – Predicted Primordial Abundances



- ^{4}He (mass fraction Y) Is NOT Rate Limited
- ^{4}He IS n/p Limited ⇒ Y Is Sensitive To The EXPANSION Rate (H)
- $S \equiv H'/H \equiv (1 + 7\Delta N_\nu / 43)^{1/2}$

$N_\nu \equiv 3 + \Delta N_\nu$



DEUTERIUM -- The Baryometer Of Choice

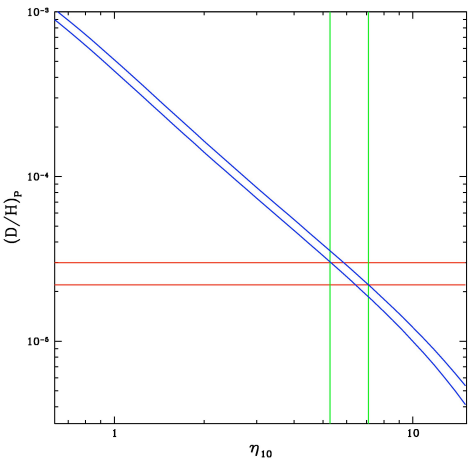
- D is only DESTROYED in stars ⇒ Anywhere, Anytime: D/H ⇒ $(D/H)_P$
- For $t \ll t_0$ ($Z \ll Z$; $z \gg 0$) ⇒ Deuterium Plateau: $(D/H)_t \approx (D/H)_P$
- $(D/H)_P$ is sensitive to the baryon density ⇒ $(D/H)_P \propto \eta_{10}^{-1.6}$
- BUT …
  - * HI and DI spectra are identical (except for a wavelength shift) ⇒ HI Interlopers Masquerading As DI ?
  - * Unresolved velocity structure ⇒ Systematic errors in N(HI) ?

"Measure" $(D/H)_P$

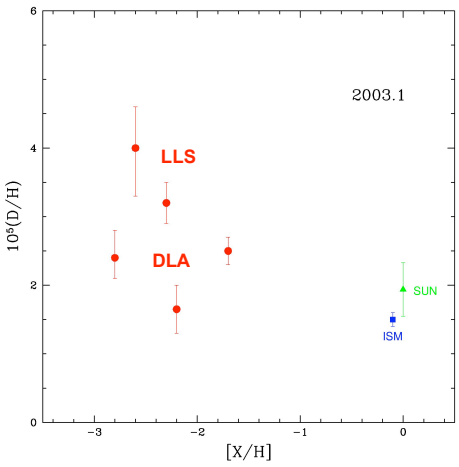
Use BBN $(D/H)_P$ vs. η_{10}

(ASSUME $N_\nu = 3$)

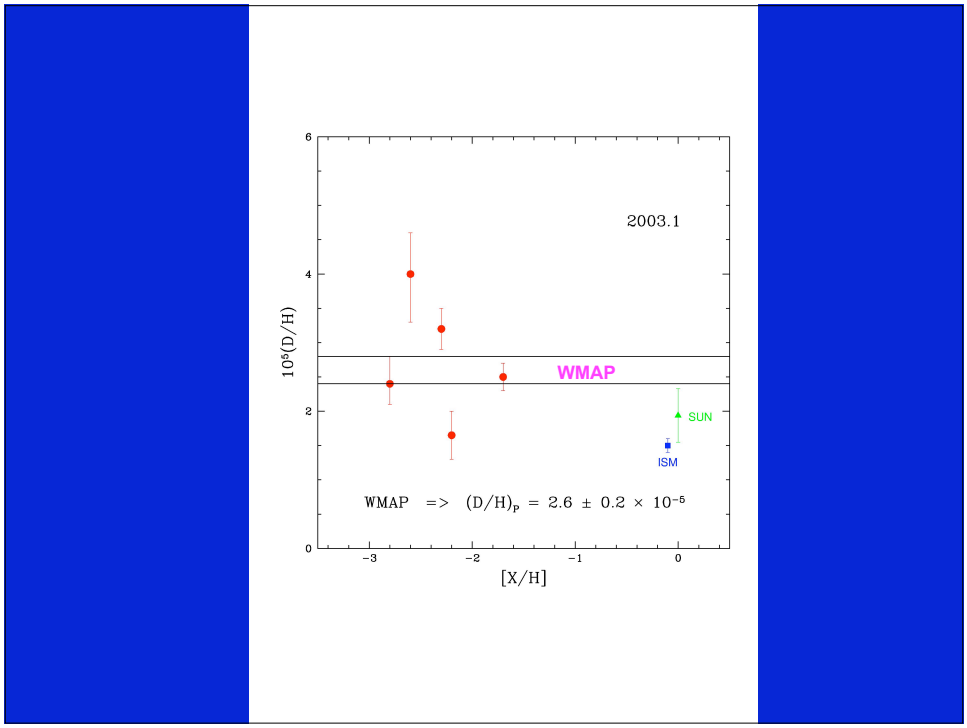
Infer η (η_B) At 20 Min.



D - Abundance Data



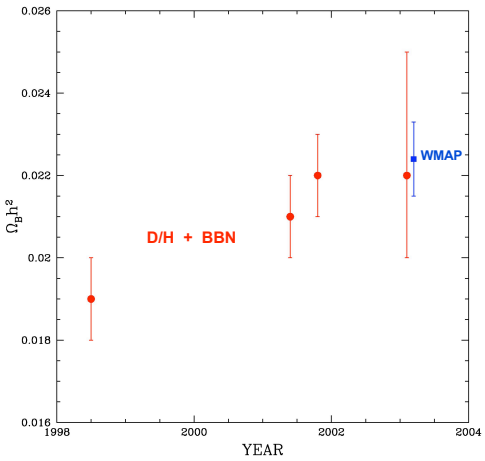
X = O, Si, …

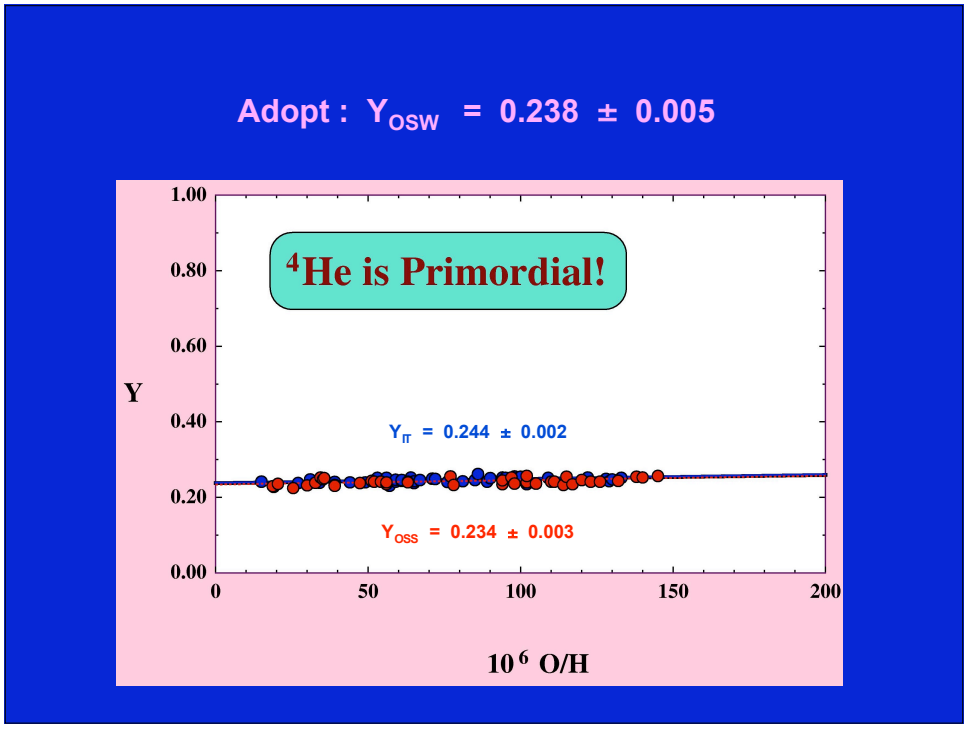


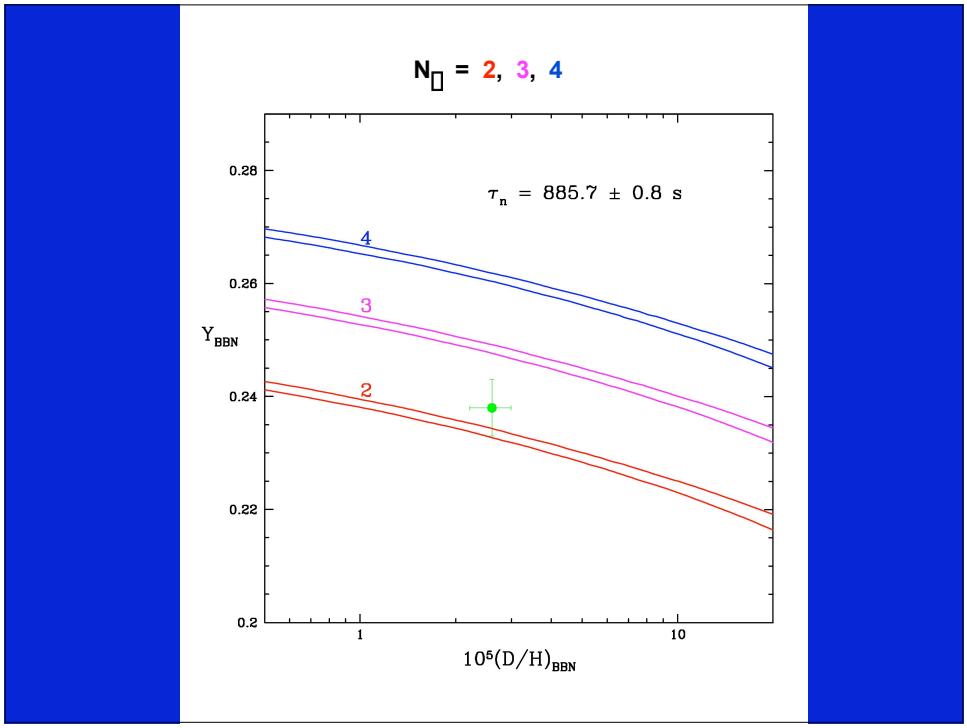
For $(D/H)_{obs} = 2.6 \pm 0.4 \times 10^{-5}$

$\Rightarrow (\Omega_B h^2)_{BBN} = 0.022 \pm 0.002$

$(\Omega_B h^2)_{WMAP} = 0.0224 \pm 0.0009$




Adopt : Y_{osw} = 0.238 ± 0.005
^{4}He is Primordial!
Y_{II} = 0.244 ± 0.002
Y_{oss} = 0.234 ± 0.003
Y
10^6 O/H


N_ν = 2, 3, 4
τ_n = 885.7 ± 0.8 s
Y_{BBN}
$10^5(D/H)_{BBN}$

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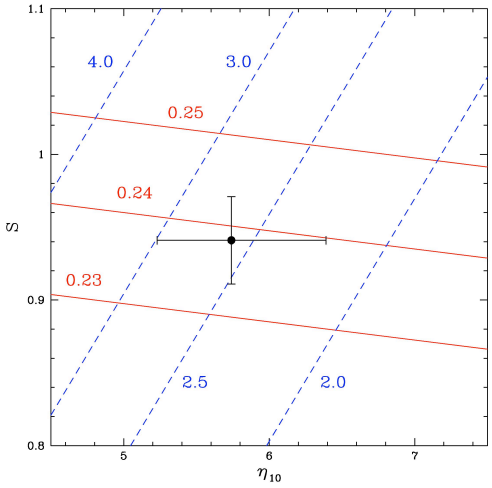
$(D/H)_P = 2.6 \pm 0.4 \times 10^{-5}$

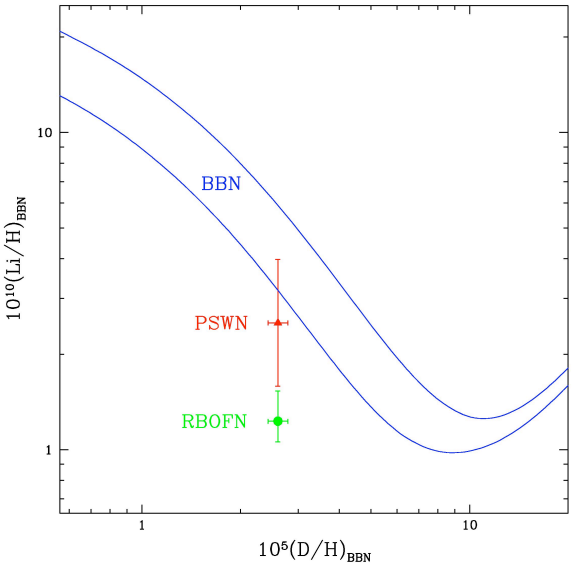
&

$Y_P = 0.238 \pm 0.005$ (OSW)

- $\Omega_B h^2 = 0.021 \pm 0.002$
- $S = 0.94 \pm 0.03$
- $\Delta N_\nu = -0.70 \pm 0.35$

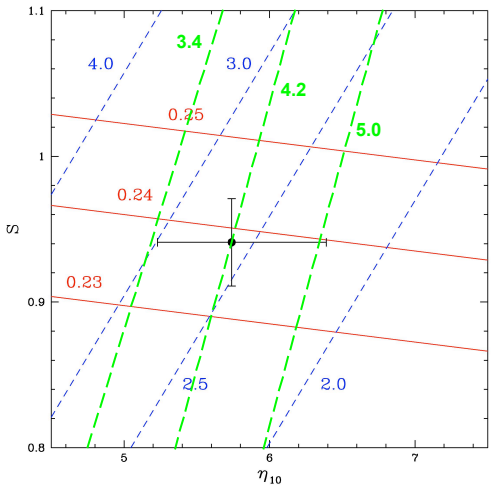


Observed Lithium Too Low ?



For Y_{osw} + D/H ⇒

Li/H = 4.2 ± 0.8 x 10^{-10}



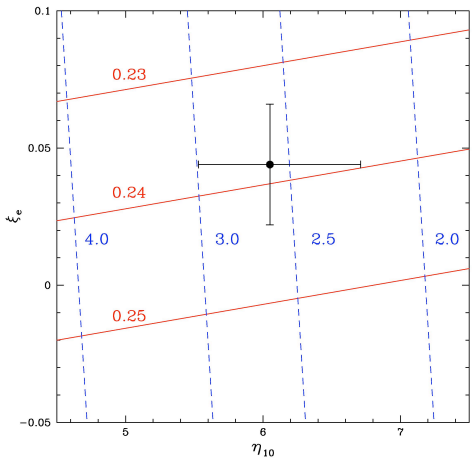
e – Neutrino Degeneracy

For $\xi_e = \mu_e/kT > 0$

⇒ n/p ⇓ ⇒ Y_P ⇓

⇒ ξ_e = 0.044 ± 0.022

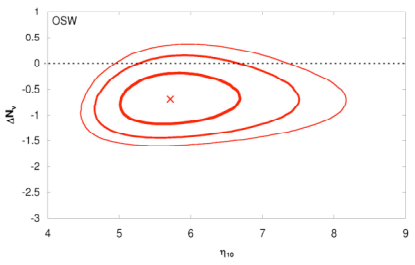
⇒ $\Omega_B h^2$ = 0.022 ± 0.002



OSW "Best Fit" (x) :

η_{10} = 5.7 ; $\Omega_B h^2$ = 0.021

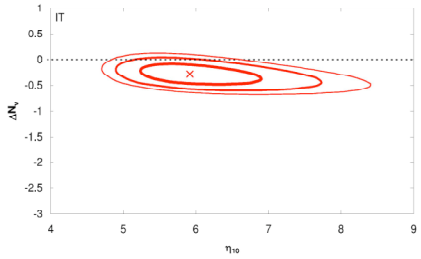
ΔN_ν = 0.69



IT "Best Fit" (x) :

η_{10} = 5.9 ; $\Omega_B h^2$ = 0.022

ΔN_ν = 0.29



CONCLUSIONS - BBN ALONE

- $(D/H)_P = 2.6 \pm 0.4 \times 10^{-5}$
- $Y_P = 0.238 \pm 0.005$
- $\xi_e = 0$
  - $\Omega_B h^2 = 0.021 \pm 0.002$ $(\eta_{10} = 5.74^{+0.65}_{-0.51})$
  - $\Delta N_\nu = -0.70^{+0.35}_{-0.34}$
  - BUT : $(Li/H)_P \approx 4.5 \times 10^{-10}$
- $\xi_e \neq 0$ $(N_\nu = 3)$
  - $\Omega_B h^2 = 0.022 \pm 0.002$ $(\eta_{10} = 6.15^{+0.68}_{-0.53})$
  - $\xi_e = 0.044 \pm 0.022$
  - BUT : $(Li/H)_P \approx 4.2 \times 10^{-10}$

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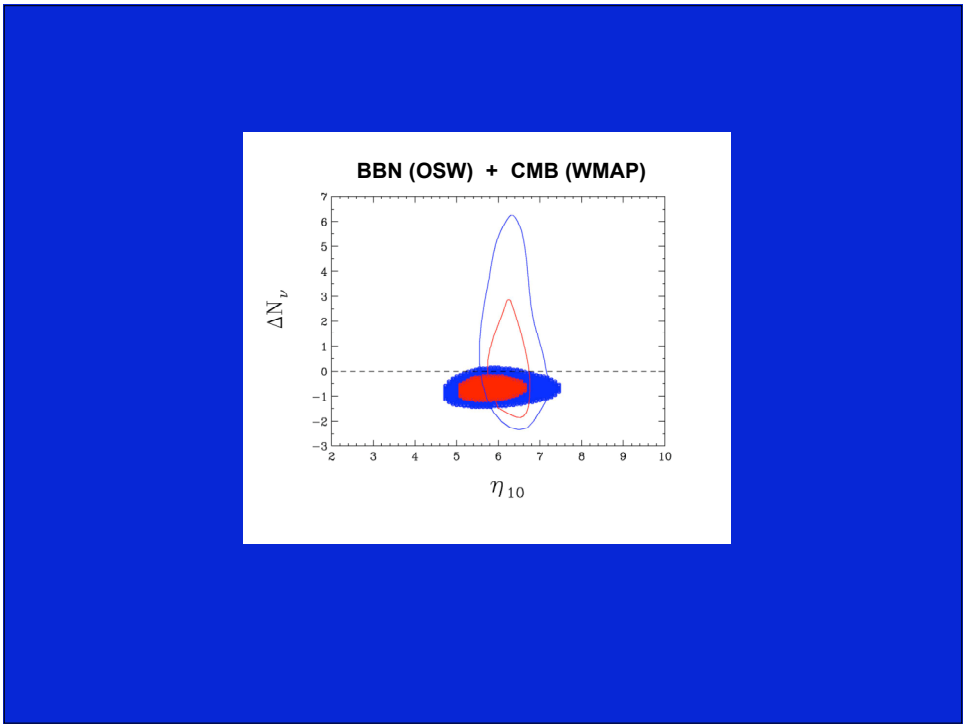

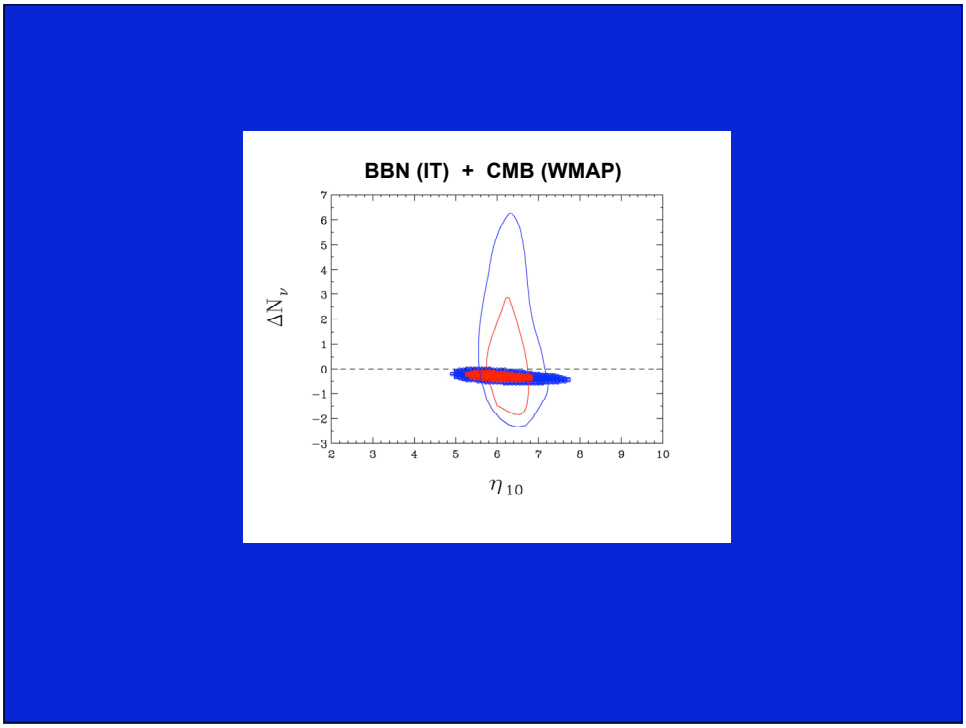

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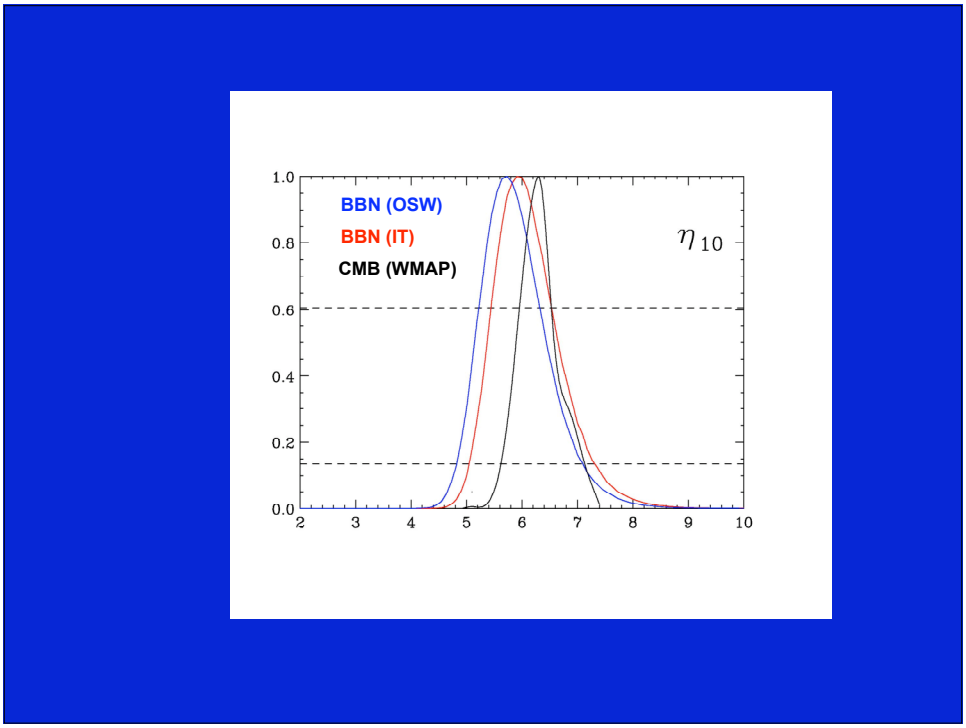

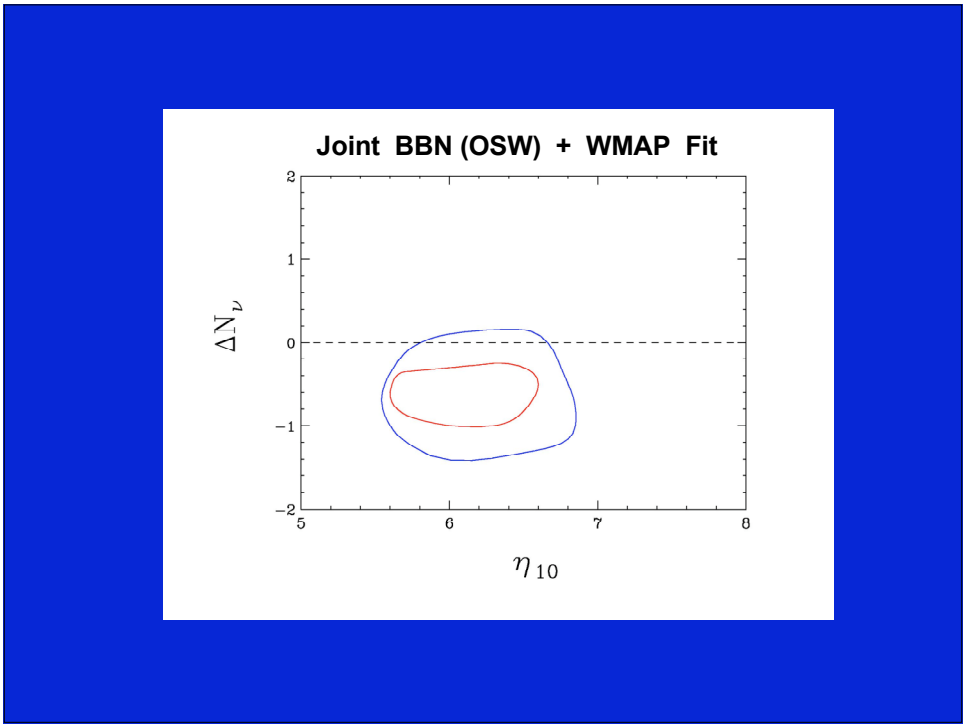

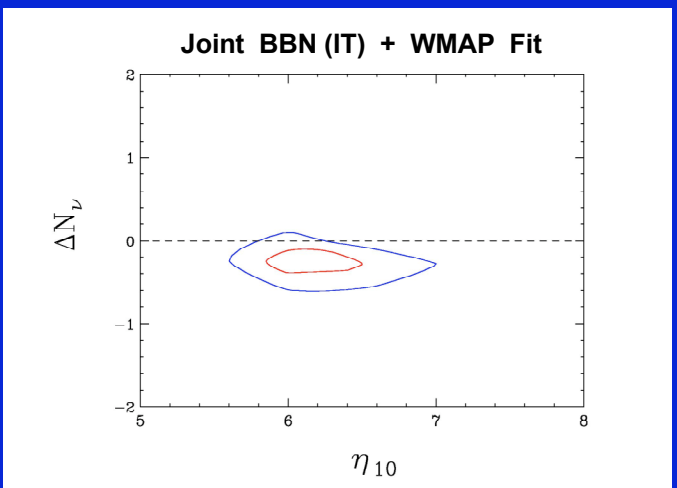

SUMMARY AND CONCLUSIONS

BBN and CMB are consistent

The Universe at 20 min. and 380 kyr AGREE !

Best : η_{10} = 6.16 (6.30) ; $\Omega_B h^2$ = 0.0225 (0.0230) ; N_ν = 2.25 (2.75)

95% Ranges : 5.57 $\leq \eta_{10} \leq$ 6.84 ; 0.0203 $\leq \Omega_B h^2 \leq$ 0.0250

(5.66 $\leq \eta_{10} \leq$ 6.84 ; 0.0207 $\leq \Omega_B h^2 \leq$ 0.0250)

1.80 $\leq N_\nu \leq$ 2.94 (2.49 $\leq N_\nu \leq$ 2.99)

$\xi_e = \xi_\mu = \xi_\tau =$ 0.044 ± 0.022