

# Primordial Nucleosynthesis and Solar Neutrinos: Finding Concordance in Nuclear Astrophysics

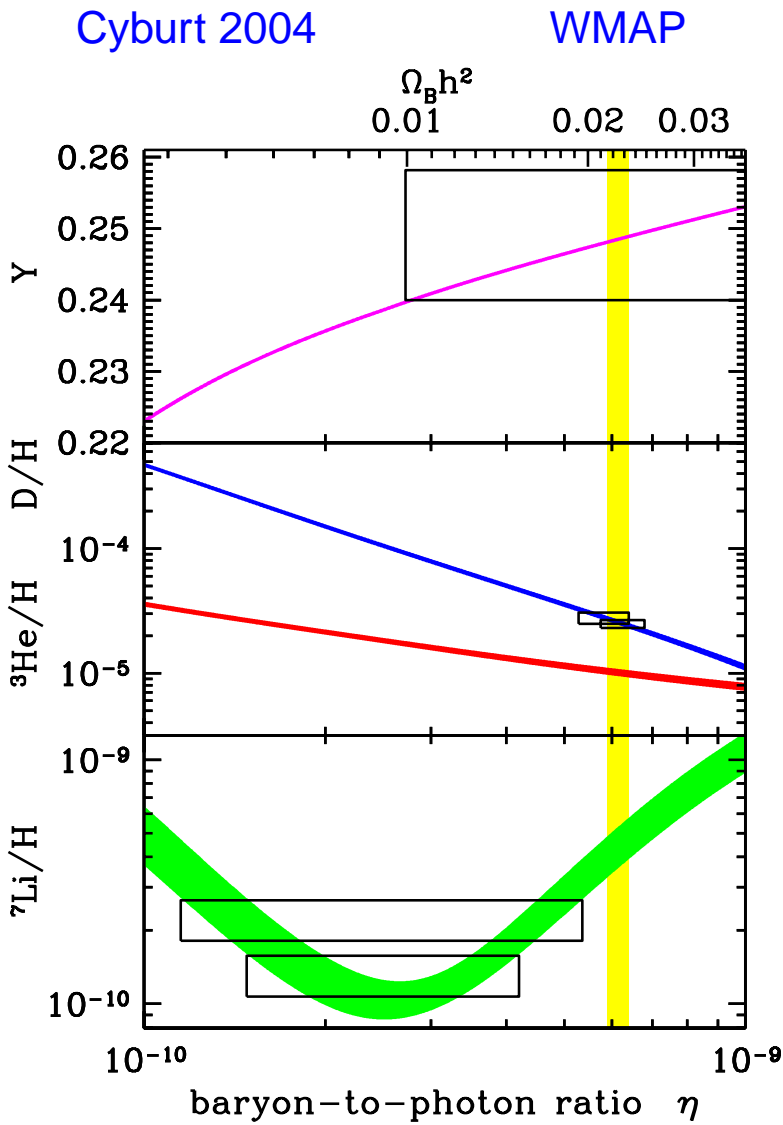
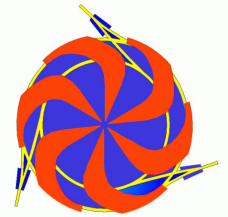
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# Big Bang Nucleosynthesis



- $40 \text{ keV} < T < 1 \text{ MeV}$

Weak freezeout  $T \sim 1 \text{ MeV}$

End of D-bottleneck  $T \sim 70 \text{ keV}$

Coulomb barrier stops BBN  $T \sim 40 \text{ keV}$

- $n, p \rightarrow {}^4\text{He}, \text{D}, {}^3\text{He}, {}^7\text{Li}$

- Compare to Obs.

4%  $\eta$ : CMB Anisotropy (WMAP)

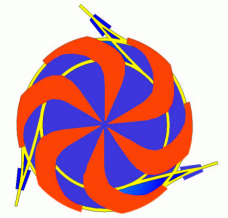
4%  ${}^4\text{He}$ : Olive & Skillman

8-16% D: Burles, Kirkman, O'Meara, Pettini

17-30%  ${}^7\text{Li}$ : Spite & Spite, Ryan, Bonifacio

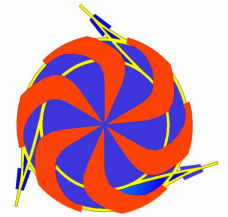
- only  ${}^7\text{Li}$  discordant

# What is the Fix?



- There are many possibilities...
  - Obs./Exp. Systematics  
Olive & Skillman 2000, Ryan *et al.* 2000  
Nollett & Burles 2000; Cyburt 2004; Serpico *et al.* 2004
  - Stellar Astrophysics/Chemical Evolution  
Vangioni-Flam *et al.* 2002; Bono *et al.* 2002; Cassisi, Salaris & Irwin 2003
  - Physics beyond the Standard Model  
Sarkar 1996, Cyburt, Fields & Olive 2004
- Lets try a nuclear £x!

# A Nuclear Fix



- $\frac{{}^7\text{Li}}{\text{H}} \propto [{}^3\text{He}(\alpha, \gamma){}^7\text{Be}]^{0.96} \times [{}^7\text{Be}(n, p){}^7\text{Li}]^{-0.71}$

Cyburt 2004; Cyburt, Fields & Olive 2004

- Currently,  $S_{34}(0) \approx 0.50 \text{ keV b}$

Cyburt, Fields & Olive 2000; Descouvemont *et al.* 2004; Serpico *et al.* 2004

- $S_{34}(0) \approx 0.27 \text{ keV b} \rightarrow \text{glob. cluster}$

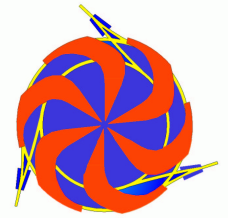
Bonifacio *et al.*

- $S_{34}(0) \approx 0.14 \text{ keV b} \rightarrow \text{pop. II halo stars}$

Ryan *et al.*

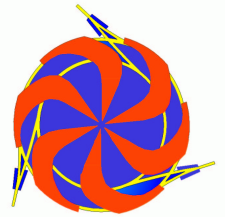
- But... We screw up Solar Neutrinos!

# Solar $\nu$ 's and $S_{34}$



- Total  $^8\text{B}$  neutrino flux is changed  
$$\phi_8 \approx 5.15 \times 10^6 \text{cm}^{-2} \text{s}^{-1} \propto S_{34}^{0.81} S_{17}$$
  
Bahcall 1989, 2004
- $\phi_8^{\text{SNO}} = [5.21 \pm 0.47] \times 10^6 \text{cm}^{-2} \text{s}^{-1}$   
Ahmed *et al.* 2004
- $S_{17}(0) = 20.7 \pm 1.2 \text{ eV b}$  indep. norm.  
Cyburt, Davids & Jennings 2004
- $\text{SNO} + S_{17} \rightarrow S_{34}(0) = 0.52_{-0.10}^{+0.12} \text{ keV b}$   
Cyburt, Fields & Olive updated with CDJ  $S_{17}$
- $^7\text{Li}$  renorm of  $S_{34}$  excluded at  $> 99\%$  level

# Conclusions



- No nuclear  $\chi$  for  ${}^7\text{Li}$   
Coc *et al.* 2003, Angulo *et al.* 2004, Cyburt, Fields & Olive 2004
- Priority: understand systematic uncertainties!  
Olive & Skillman 2004, Cyburt 2004
- New Physics/ ${}^7\text{Li}$ -Evolution most likely  $\chi$ es
- New Exp/Obs Data needed!