Constraining the Variation of Fundamental Constants with Tritium Decay and the Cosmic Microwave Background

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Joining Multiple Ideas

Motivations from theories beyond the Standard Model

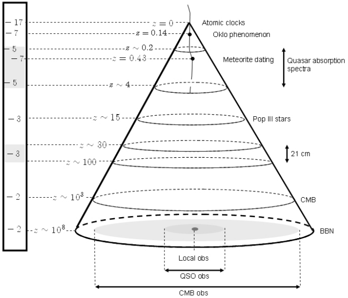
Varying Constants in Nuclear Physics

Cosmological Signature

Varying Constants

Started with Dirac with his *Large Numbers hypothesis* (based on numerology...)

Now we have many theories : scalar-tensor theories of gravity, string theory...



Taken from (Uzan, 2010).

Recent bounds coming from CMB anisotropy using WMAP-7yr data

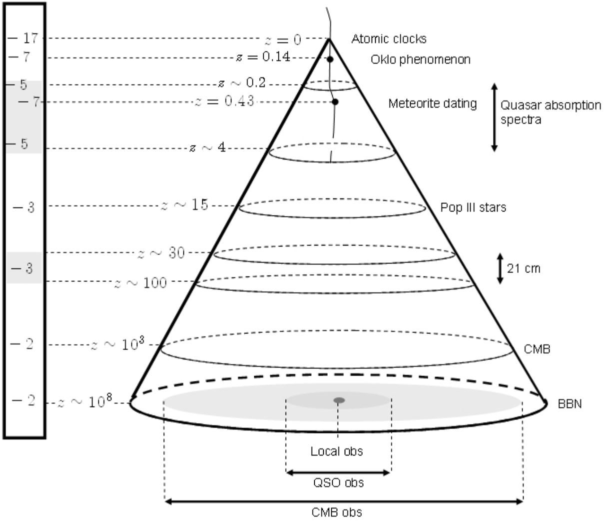
$$-0.025 < \frac{\Delta\alpha_{em}}{\alpha_{em}} < -0.003 \qquad 0.009 < \frac{\Delta m_e}{m_e} < 0.079 \qquad \text{at } 1\sigma \text{ (Uzan, 2010)}$$

They come from changing σ_T and ionization fraction.

$\rightarrow$ The values were straighforwardly changed in the equations.

$\rightarrow$ No new mechanisms considered.

Varying Constants



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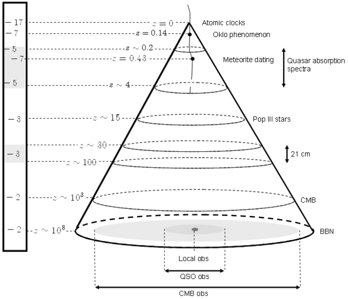

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BBN predicts atomic abundances very well.

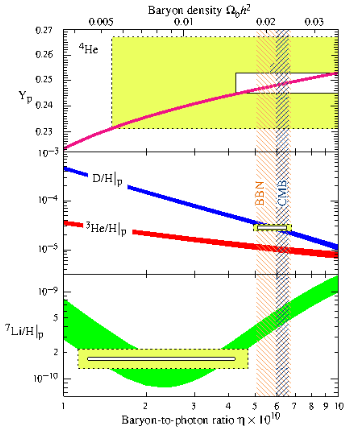
$\Rightarrow$ Binding energies consistent with change $\sim 1\%$

We need a process with significant impact from a variation of constants.

In tritium decay, $Q = 18.59$ keV

(recall $m_T \sim 2.8$ GeV)

$\Rightarrow$ a small variation of constants can lead to significant change in Q-value.

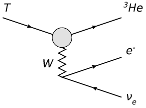


Taken from PDG.

From quarks masses : $\Delta m_{T\to 3He} = \Delta m_{d\to u} \sim 3$ MeV $\Longrightarrow \Delta m_q \sim 1\% \sim Q$

From α : $BE_{em}/A \propto \alpha$, $BE_T \sim 8$ Mev $\Longrightarrow \Delta\, \alpha \sim 1\% \sim Q$

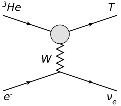
Tritium decay



happens via beta decay

$$\Gamma_{\mathrm{T}\to{}^3\mathrm{He}}(Q) = \frac{(G_F V_{ud})^2}{2\pi^3}(g_v^2 + 3g_a^2)\int_{m_e}^{m_e+Q} \mathrm{d}E F(2,E) E\sqrt{E^2 - m_e^2}(Q + m_e - E)^2$$

Helium-3 decay



happens via electron capture

$$\Gamma_{\mathrm{He}\to\mathrm{T}}(Q) = \frac{4}{\pi^2} G_F^2 V_{ud}^2 Q^2 m_e^3 \alpha^3 (g_v^2 + 3g_a^2)$$

Cosmological Context

If $Q < 0$ after BBN $\Rightarrow$ accumulation of tritium

When $Q \to Q_{\mathrm{SM}}$ $\Rightarrow$ T $\to$ ^{3}He
ejecting energetic electrons and antineutrinos.

Ionization History

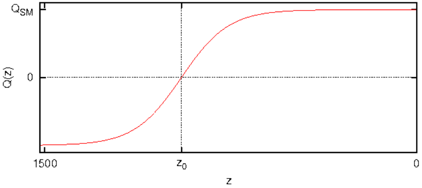
The Cosmic Microwave Background is a picture of the Universe when it became neutral.

Tritium decays after recombination $\Rightarrow$ ejected electrons partially reionize the Universe.

Ionization potential $\bar{Q}_{\rm SM} \sim 6$ keV $\Rightarrow \Delta x_e \sim \frac{6 \text{ keV}}{13.6 \text{ eV}} \underset{\frac{E_i}{E}}{\underset{\uparrow}{\frac{1}{3}}} \underset{Y_T}{\underset{\uparrow}{10^{-5}}} \sim 10^{-3}$

The Model

$$Q(t) = Q_{SM} \tanh\left(\frac{t - t_0}{\tau}\right)$$



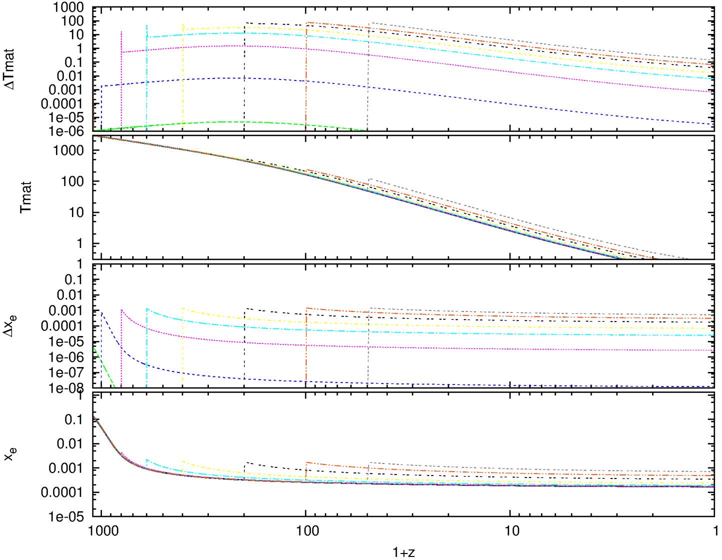
$$f(z) = \frac{n_T(z)}{n_b(z)} = Y_T e^{-\Gamma(z)\left(t(z) - t(z_0)\right)}$$

$$\frac{\mathrm{d}x_i}{\mathrm{d}z} = \frac{-1}{H(z)(1+z)} \chi_i(z) \frac{\bar{E}(z)}{E_i} f(z)\Gamma(z)$$

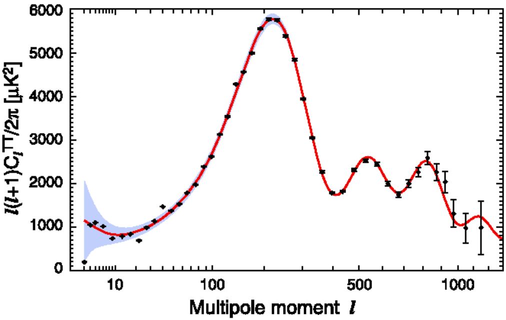
$$\frac{\mathrm{d}T_b}{\mathrm{d}z} = \frac{-1}{H(z)(1+z)} \chi_h(z) \frac{2}{3k_B} \frac{\bar{E}(z) f(z)\Gamma(z)}{1 + x_e + f_{He}}$$

$$\chi_i = \frac{1 - x_e}{3} \qquad \chi_h = \frac{1 + 2x_e}{3}$$

Ionization History



The anisotropy power spectrum



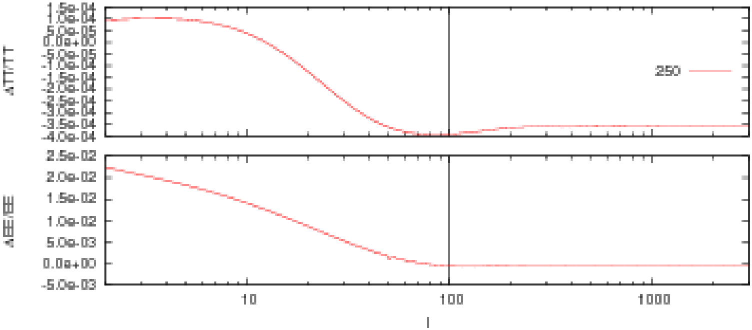
Taken from WMAP/NASA.

Small l $\Rightarrow$ Large scale   Large l $\Rightarrow$ Small scale

Each z has a characteristic distance, the sound horizon $\Rightarrow l_z$

$l \leq l_z$ casually disconnected at z

For $\tau \gg t_{1/2}$ $\Rightarrow$ 10^{-2} ionization potential



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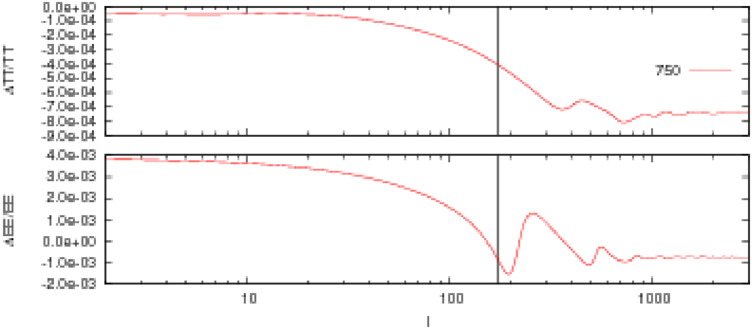

For $\tau \ll t_{1/2}$, preliminary results $\Rightarrow$ $\frac{\Delta TT}{TT} \sim 1\%$, $\frac{\Delta EE}{EE} \sim 100\%$

Acknowledgement

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THANK YOU