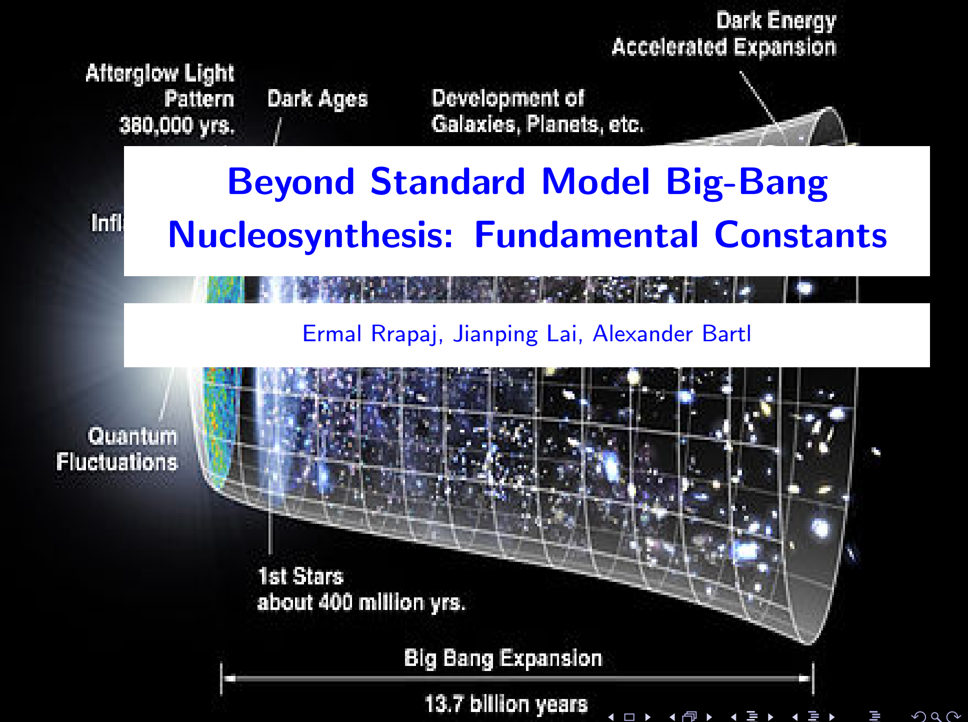
Beyond Standard Model Big-Bang Nucleosynthesis: Fundamental Constants

Ermal Rrapaj, Jianping Lai, Alexander Bartl



Physical Motivation

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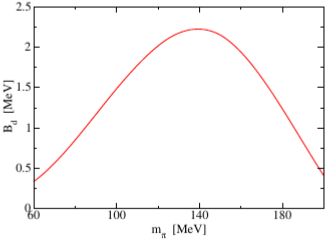
- BBN important for synthesis of light elements and evolution of universe
- Element abundances as probes of fundamental physics
- Impact of variations of Λ_{QCD}, G, μ_n on BBN

Overview of the talk

1. Background information
    - Λ_{QCD} and m_n, deuteron binding energy, neutron lifetime
    - $m + n \rightarrow d + \gamma$ reaction rate from μ_n
    - Graviational Constant
2. Calculations
3. Results
    - Abundance Plots
4. Conclusions

Impact of Λ_{QCD}

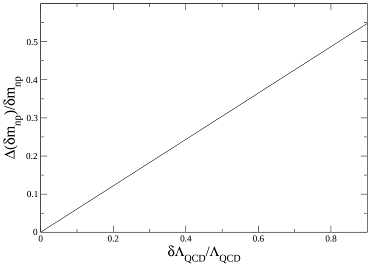


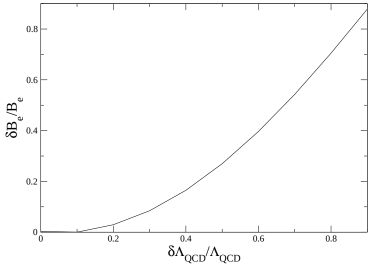
$B_D vs. m_\pi$ at NLO χEFT, Savage etal, 2002

Gail McLaughin etal, 2003

- $\Delta(\delta m_{np}) = -\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda_{QCD}}{\Lambda_{QCD}}\right)\alpha M_{elm}$
- $\frac{\Delta\alpha}{\alpha} \approx 1/30\frac{\Delta\Lambda_{QCD}}{\Lambda_{QCD}}$
- $\alpha M_{elm} \approx 0.76 MeV$
- $\frac{\Delta m_\pi}{m_\pi} = \frac{1}{2}\left(\frac{\Delta\Lambda_{QCD}}{\Lambda_{QCD}}\right)$

(Absolute values of differences on y-axis)



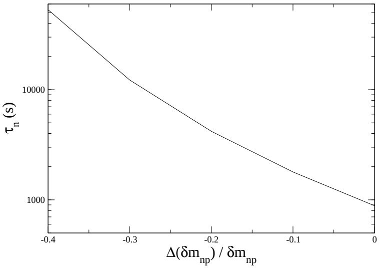


Impact Of Λ_{QCD}, G

Dependence of neutron lifetime:

$$\tau_n = \frac{(G_F \cos\theta_c)^2}{2\pi^3} m_e^5 (1+g_A^2) F(\Delta m_{np})$$

$$F(x) = \frac{1}{15}(2x^4 - 9x^2 - 8)\sqrt{x^2-1} + x\, log(x + \sqrt{x^2-1})$$



Friedman Equations:

$$H^2 + \frac{k}{a^2} = \frac{8\pi G}{3}\rho + \frac{\Lambda_{vac}}{3}$$

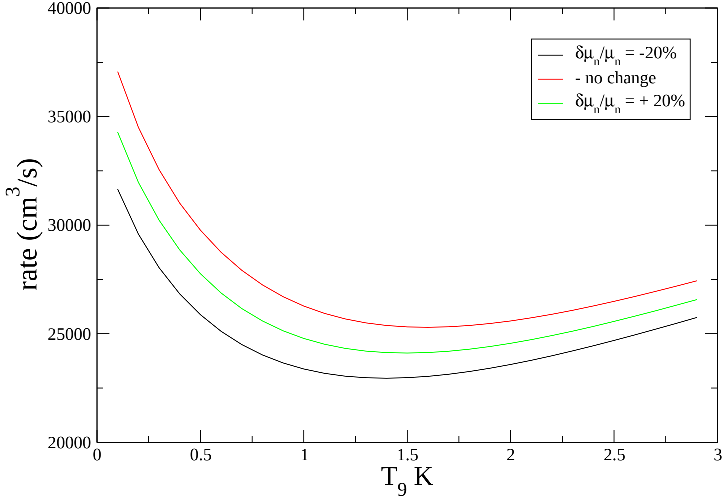
$$H^2 + \frac{dH}{dt} = -\frac{4\pi G}{3}(\rho + 3p) + \frac{\Lambda_{vac}}{3}$$

Radiation Dominated, $k \approx 0, \Lambda_{vac} \approx 0$:

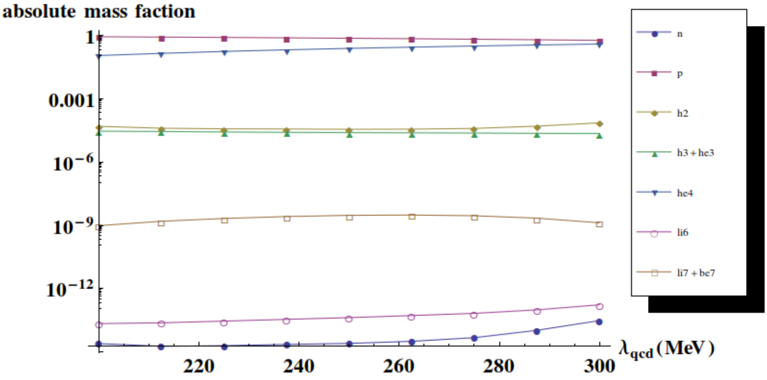
$$\rho = 3p; \;\; \rho = \frac{3}{32}\pi G t^2$$

$$\implies H = \frac{\pi}{2} G t$$

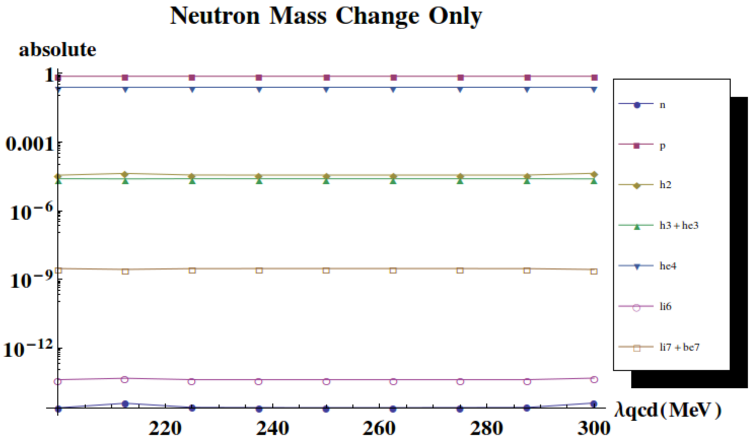
Impact of μ_n on neutron capture rate on protons



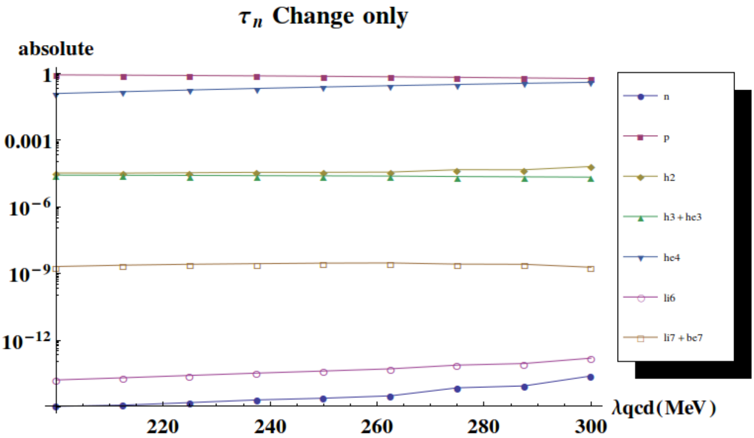
Results : Mass fraction as function of Λ_{QCD}, part 1



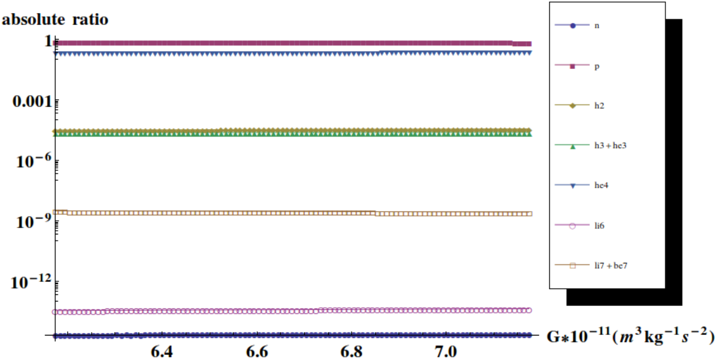
Results : Mass fraction as function of Λ_{QCD}, part 2



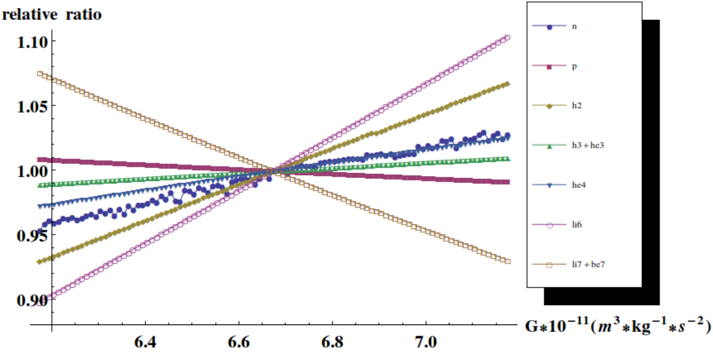
Results : Mass fraction as function of Λ_{QCD}, part 3



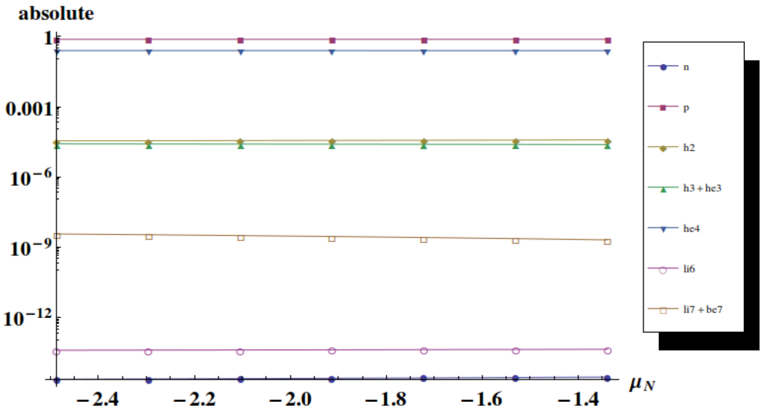
Results : Mass fraction as function of G, part 1



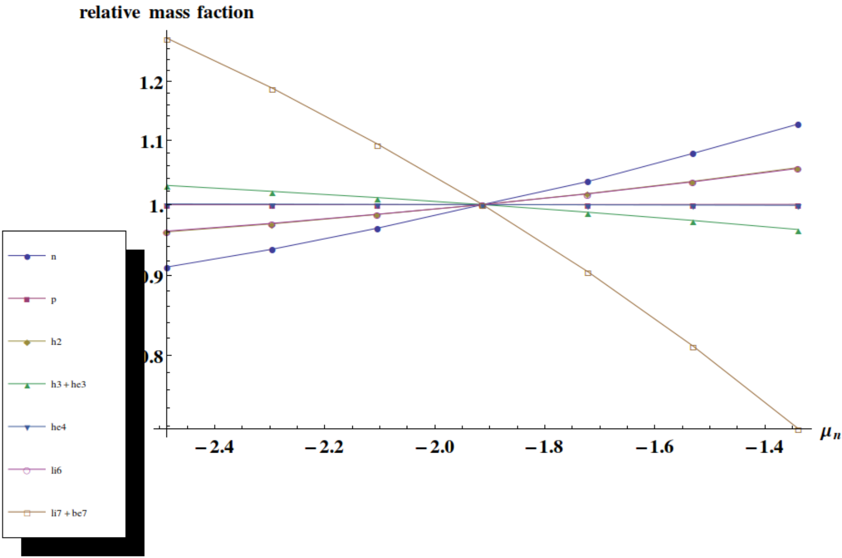
Results : Mass fraction as function of G, part 2



Results : Mass fraction as function of μ_n, part 1



Results : Mass fraction as function of μ_n, part 2



Conclusions

- We investigated the dependence of BBN abundances on the values of fundamental constants.
- Λ_{QCD} has a significant impact especially on the Helium-4 abundance, mainly through the change to the neutron decay time.
- The lithium abundance is highly sensitive to the value of the gravitational constant G.
- Changing μ_n decreases the rate of production of deuteron

- A change in Λ_{QCD} would probably affect more than the $p(n,\gamma)d$ rate and free neutron decay. Yet, modifying more interactions is beyond the scope of this 4-day project.