



Linking the lithium problem and the H_0 tension: the gravitational constant at BBN

S. Franchino-Viñas

16th. Marcel Grossman meeting, e-Roma, Italia, Luglio 2021

The collaboration



S. Franchino Viñas

ITP, Universität Heidelberg Dept. of Physics, Universidad Nacional de La Plata



M. Mosquera

Faculty of Astronomy and Geophysics Universidad Nacional de La Plata



1 Introduction to BBN

② Variation of constants

3 The H_0 problem

Conclusions

soup of e^{\pm} , protons, neutrons, photons, neutrinos, in equilibrium



 \sim 10 min \sim 30 keV: no more available n and a gap at mass 8







D: only destroyed (small binding energy);

⁴He: produced in stars by burning hydrogen; keep track of metallicity/look at extragalactic regions;

⁷Li: more involved...

- burned in inner layers of stars;
- may survive in outer layers of coolest stars;
- produced in hotter interiors (super red giants), collisions of cosmic ray nuclei (unfortunately including α-α fusion);

Solutions:

modify the astrophysics;

Aug 2006

6

2

arXiv:astro-ph/0608201

- 2 check the involved nuclear reactions:
- 3 invoke Beyond Standard Model physics;

Nature 442 Gen ent	
442, 037-659 (10 August 2006)	
A probable stollar	
to the cosmal solution	Slars the ex-
discreponentiological lithium	pronounced in other expected to be many
chancy	greater age, difficient k-ution k-ution faire fa
A.J. Kom ¹ E. Communication	sizeable effects than in women time to produce
Barklem ¹ , L. Mashorli ² , O. Richard ³ , P.S.	Detailed element-by-element by-
Piskunov ¹ & B. Gustafecon ¹ , R. Collet ¹ , N	including offer
The	
free measurement of the cosmic mic	
cal parameters of constrained the	AUGUST 28, 2020 and in AASTeX61
sured density of home Universe ¹ . Wh	BAPT VERSION VERSION THEORY THOUGHT AND A STATEMENT
bined with standard Rive R	Spear and PRIMORDIAL NUCLEOST
calculations ^{2,3} , the amounts of h	DEACTION RATES AND FRAME
can be produced shortly after the	THERMONUCLEAR REACTION
The predicted with unprecedented pre-	11105 111018 1110 1127599-3255, USA
factor of two to three high abunda	CHRISTIAN North Carolina at Chopa 19708, USA
sured in the atmospheres of the vali	E Astronomy, Uniorraty of TUNL), Durham, North St
estimated errors of 10 to 25 %, data	Department of Physics Nuclear Latornics Coc
derstanding seriously challenges	Truning Batiment, 104, Forgan
thesis or both. Castal	a anapa, IJCLab, Université Paravesa
thesis have been pronosed?	(Received August 20, and
tally not to be viable ⁸ . Different experim	Submitted to ApJ
ever, predicts atmospheric abundances of the	The second
tion of the disce, which offers a possible evaluation	ABSTING density and the expanses if the observed prime
scopic observations of st	ine for the cosmic baryone. It is important to assume that the simulations over provided by unknown
ular cluster NGC 6397 that	the best numerical value is a parameter-free mous studies have shown may be characterized that t
spheric abundance with evolution are of atmo-	Assuming the bang nucleosynthesis simulations. Numerous observations. The errors in thermonuces on the likelih
reproduced by These element-specific land	standard og standard og standard og standard som standard nodel. Here, we de standard nodel i transformer at the standard standa
sion and turbulant	abundance of the predicted abundance of the pred
that diffusion is predominent. We thus conclude	systematics in ² Li observation synthesis, the key nuclear reaction rates are investigation and beryllium synthesis, the key nuclear reaction and the uncertainties of the section rates are investigation and the section and the section rates are investigation and the section and the section rates are investigation and the section and the section and the section are investigation and the section and the section are set and the section and the section are set as a section are set
low apparent stellar lithium abund	part in the lithium the most recent reaction rates abundances and reaching the abundance.
deep into the	of a nuclear performed with the more Correlations of a nuclear the prime for simulations of a nuclear performed with the more control of the perform
Diffusive measure of the star.	Simulations and a Monte Carmation. The rates of Journal of a genetic and provide the solutions are found.
sition in stars have been been all composed	established in the metric of mutual information ${}^{7}Be(n,p)^{7}Li$. We employed primordial atom as a company of the metric of mutual information ${}^{7}Be(n,p)^{7}Li$. We employed primordial atom as a company of the metric of mutual information ${}^{7}Be(n,p)^{7}Li$.
Evidence for their immediate for decades9,11 stage	$d(p,\gamma)^{3}$ He, ${}^{7}\text{Be}(d,p)2d$, that may account for meaning reported unready unlikely for the cosmological
helioseismology12 and the study of here from telesc	in these four reactions that are much where conclude that it is mighty a
pecunar abundance patterns ¹³ . Among with requir	reaction rate range with a sailable evidence, we say the sail and a sail and a sail a sa
Department of Astronomy Solar-type 10 obtained	on the currence solution.
sity, Box 515, 75120 Uppsala, Swoton These of	a nuclear pro-
Ny Munkegade, 8000 Arbus C. D. University of Act	Keywords: metuota
GRAAL-UMRS024/ISTEEM (CNPS) 11-	Chows
"Institute of Astronomy Res. Montpellier, France, aburn day	80
staya 48, 119017 Moscow, Russia, Academy of Science, Pyanit- globular at	ŬŎ
Contract Ch	Ċ.
	2



Introduction to BBN

2 Variation of constants

3 The H_0 problem

④ Conclusions

Why should the fundamental constants that we use in our daily physics be the same as those 10⁹ years ago?



SF, and M. Mosquera (2107.xxxx):

independent variation of G_N and α (and $\langle v \rangle$) at BBN (AlterBBN, Arbey 2018) + statistical analysis to obtain the best fit of the yields

	$\Delta lpha / lpha [10^{-2}]$	$\Delta \langle v angle / \langle v angle [10^{-2}]$	$G_{ m BBN}/G_N$	χ^2_{min}
Fit 1	-2.83 ± 0.24		$1.167^{+0.015}_{-0.016}$	1.95
Fit 2	-3.35 ± 0.45	-1.50 ± 0.20	1.170 ± 0.020	0.70

	$\rm D/H[10^{-5}]$	$Y_{ m P}$	$^{7}{ m Li/H}[10^{-10}]$
Fit 1	2.605 ± 0.040	0.2472 ± 0.0016	2.09 ± 0.12
Fit 2	2.545 ± 0.058	0.2561 ± 0.0050	2.03 ± 0.22
Observational weighted mean value	2.541 ± 0.022	0.2542 ± 0.0014	2.01 ± 0.14
Standard computation	2.547 ± 0.050	0.2466 ± 0.0001	4.60 ± 0.32

(Observational data from the last decade)

Motivations for a varying $\boldsymbol{\alpha}$



0, angle from best-fitting dipole (degrees)



Webb, King, Murphy, Flambaum, Carswell and Bainbridge 2011 (QUASAR absorption spectra from Very Large Telescope and Keck telescope)



A varying G_N ? Motivations from GUTs, but more simply from QFT in curved spaces.

Quantum contributions to the gravitational action! For free fields, $% \left({{{\left[{{{C_{{\rm{B}}}}} \right]}_{{\rm{A}}}}} \right)$

$$\Gamma_{
m scalar}[g] = rac{1}{2} {
m Tr}_{
m s} \log \left(\Delta + \xi R + m_{
m s}^2
ight),$$
 (1)

render the gravity action non-local,

$$\begin{split} & \Gamma[g] = \Gamma_{\rm loc}[g] + \frac{m^2}{2(4\pi)^2} \int \mathrm{d}^4 x \sqrt{g} \, B(\frac{\Delta}{m^2}) R \\ & + \frac{1}{2(4\pi)^2} \int \mathrm{d}^4 x \sqrt{g} \left\{ C^{\mu\nu\alpha\beta} \, C_1(\frac{\Delta}{m^2}) \, C_{\mu\nu\alpha\beta} + R \, C_2(\frac{\Delta}{m^2}) \, R \right\}, \end{split}$$

infinities lead to renormalization/running G_N (SF, Paula-Netto, Shapiro, Zanusso, 2019).

However effects suppressed by M_P . Two bypass:

 a phenomenological approach, e.g. Running Vacuum Models (Solà Peracaula+ 2021); running of cosmological constant and G_N so that

$$\rho_{\rm vac}(H) = \frac{3}{8\pi G_N} \left(c_0 + \nu H^2 + \tilde{\nu} \dot{H} \right); \ (2)$$

• reinterpret the variation of G_N at BBN as extra relativistic degrees of freedom ΔN_{eff} :

$$\frac{\Delta G}{G_N} \approx \frac{7}{43} \Delta N_{\rm eff} \,. \tag{3}$$



Introduction to BBN

Ø Variation of constants

3 The H_0 problem

4 Conclusions

 $\Delta N_{\rm eff}$ implies a change in H_{\dots}

Can we translate our ΔG_N to a ΔH_0 ?

Consider

- two different universes, one with $N_{\rm eff} = 3$ and another with $N_{\rm eff}$ arbitrary;
- both of them should have the same r_sH₀, to avoid disagreements with observations;







Other approaches



50



Introduction to BBN

Ø Variation of constants

3 The H_0 problem



- Revisit the lithium problem with the latest observations.
- Joint variation of α , G_N (and $\langle v \rangle$) could provide a solution.
- Well-motivated?
- $\label{eq:alpha} \begin{array}{l} \rightarrow \ \Delta \alpha : \mbox{ sign of } \Delta \alpha \ \mbox{seems OK}. \\ \mbox{ If running: should be one order of magnitude smaller}. \\ \mbox{ Consider runnings in each single reaction}? \end{array}$
- $\rightarrow \Delta G_N$: interpretation in terms of $\Delta N_{\text{eff}} \sim 1$. related to H_0 ! Lithium as Hubblemeter? sterile neutrino? interactions to avoid σ_8 constraints?

$$\Gamma_{\rm fermion}[g] = -\mathrm{Tr}_{\rm f} \log \left(\not D + m_{\rm f} \right), \tag{4}$$

$$\Gamma_{\rm proca}[g] = \frac{1}{2} \operatorname{Tr}_{\rm v} \log \left(\delta^{\nu}_{\mu} \nabla + \nabla_{\mu} \nabla^{\nu} + R_{\mu}^{\nu} + \delta^{\nu}_{\mu} m_{\rm v}^2 \right), \tag{5}$$

$$\frac{B(z)}{z} = -\frac{4Y}{15a^4} + \frac{Y}{9a^2} - \frac{1}{45a^2} + \frac{4}{675} + \left(\xi - \frac{1}{6}\right)\left(-\frac{4Y}{3a^2} - \frac{1}{a^2} + \frac{5}{36}\right),$$
(6)

and the relevant R divergent term is

$$\Gamma_{\rm loc}[g] \sim \frac{1}{2(4\pi)^2} \int d^4 x \sqrt{g} \left\{ -2m^2 \left(\xi - \frac{1}{6}\right) \frac{1}{\bar{\epsilon}} R \right\}$$
(7)

In order to renormalize we have to introduce a counterterm or Pauli-Villar's fields. Let's just consider that some counterterm δ_{ct} is introduced at the level of the action for the graviton. In that case

$$S_{\text{ren}}[g] = \frac{m^2}{2(4\pi)^2} \int d^4 x \sqrt{g} \left(-2\left(\xi - \frac{1}{6}\right) \frac{1}{\epsilon} + B(z) + \delta_{ct} \right) R$$

$$= \int d^4 x \sqrt{g} \, b_1(z) R \tag{8}$$

If we fix $b_1(\mu_0^2) = b_1^{(0)} = (16\pi G_0)^{-1} = \frac{M_p^2}{2}$, with $G_0 = 6,710^{-33}\hbar c^5 \text{MeV}^{-2}$ the DPG measured value of Newton's constant measured at an energy scale μ_0 , or the Planck mass $M_p \sim 2.410^{15} \text{MeV}$, then

$$\delta_{ct} = 2\left(\xi - \frac{1}{6}\right)\frac{1}{\bar{\epsilon}} - B(\mu_0^2) + \frac{2(4\pi)^2}{16\pi m^2 G_0} \tag{9}$$

This fixes b_1 to be

$$b_1(z) = \left[\frac{m^2}{2(4\pi)^2} \left(B(z) - B(\mu_0^2)\right) + \frac{1}{16\pi G_0}\right]$$
(10)

and the associated beta function would be

$$\beta_{b_1} \stackrel{notquiteright}{=} -\frac{m^2}{2(4\pi)^2} \frac{\mu_0 \partial}{\partial \mu_0} B(\mu_0^2) \tag{11}$$

There is one subtle point: the form factor associated to a_3 and b_1 is the same. In order to disentangle this, the first proposal is

$$\beta_{a_3} = -\frac{1}{(4\pi)^2} z \,\partial_z \left[\frac{B(z) - B(0)}{z} \right], \qquad \beta_{b_1} = \frac{m^2}{(4\pi)^2} z \,\partial_z \left[B(z) - B_\infty(z) \right]. \tag{12}$$



Self-interaction counterbalances the excess of damping caused by an additional neutrino



Mutual information: the system develops new minima but for larger

|p|



Alcaniz, Bernal, Masiero, Queiroz 2020

Right Ascension (hours)



FIG. 5. Supplementary figure. Same all-sky illustration as in Fig. 1 showing the combined Keck and VLT $\Delta \alpha / \alpha$ measurements. Squares are VLT points. Circles are Keck points. Triangles are quasars observed at both Keck and VLT. Symbol size indicates deviation of $\Delta \alpha / \alpha$ from zero, i.e. $\Delta \alpha / \alpha = A \cos \Theta$. The blue dashed line shows the equatorial region. The grey shaded area shows the Galactic plane with the Galactic centre indicated as a bulge. More and larger blue squares are seen closer to the α -pole (red filled area) and more and larger red circles are seen closer to the α -antipole.

Webb, Flambaum+ 2011



With depletion



The tension between CMB and late measurements can be rephrased as a tension between BBN and late measurements

Figure 2: 68% and 95% confidence levels on Ω_m and H_0 with various data sets: BAO+BBN for galaxy BAO (blue), Lyman- α BAO (green), and combined (red). Additionally displayed is the Riess et al 2019 measurement (orange), and the Planck 2018 measurement (purple). Left: Minimal Λ CDM model. **Right:** The Λ CDM model extended with N_{eff} .

Schöneberg+ 2019







Kawasaki+ 2021



Figure 1: Simplified BBN nuclear network: 12 normally important reactions shown in blue, and proposed/tested new reactions in red.

Fields 2012

Main reactions



Best CMB fit of varying α

Hart and Chluba 2020



Steigman+ 2003

-		• -			
Variant	Y_p	$\mathrm{D/H}$	$^{3}\mathrm{He}/\mathrm{H}$	$^{7}\mathrm{Li/H}$	$^{6}\mathrm{Li/H}$
$\eta ~(6.1 \times 10^{-10})$	0.039	-1.598	-0.585	2.113	-1.512
N_{ν} (3.0)	0.163	0.395	0.140	-0.284	0.603
G_N	0.354	0.948	0.335	-0.727	1.400
n-decay	0.729	0.409	0.145	0.429	1.372
$p(n,\gamma)d$	0.005	-0.194	0.088	1.339	-0.189
$^{3}\mathrm{He(n,p)t}$	0.000	0.023	-0.170	-0.267	0.023
$^7\mathrm{Be}(\mathrm{n,p})^7\mathrm{Li}$	0.000	0.000	0.000	-0.705	0.000
$d(p,\gamma)^3He$	0.000	-0.312	0.375	0.589	-0.311
$d(d,\gamma)^4 He$	0.000	0.000	0.000	0.000	0.000
$^{7}\mathrm{Li}(\mathbf{p},\alpha)^{4}\mathrm{He}$	0.000	0.000	0.000	-0.056	0.000
$d(\alpha, \gamma)^6 Li$	0.000	0.000	0.000	0.000	1.000

Sensitivities of the yields on several variations