June 25th 2026

NEWS colloquium

Can a Varying Higgs VEV Solve the Cosmic Lithium Problem?

Hongrui Feng 冯虹瑞

Beihang University

Couthors: Yudong Luo; Toshitaka Kajino; Bao-Hua Sun; Tatsushi Shima

* Paper submitted to PRD, under review

Content

Standard BBN and its Multiple Puzzles

The Big-Bang theory

Gravity

W^+ Z^0 W^-

n p

Planck Era

All four known fundamental forces were unified.

10^{-43}s

GUT Era

Gravity freezes out

10^{-38}s

Electroweak Era

The strong force “freezes out”. Higgs bosons collide to create W and Z bosons that carry the electroweak force and quarks.

10^{-10}s

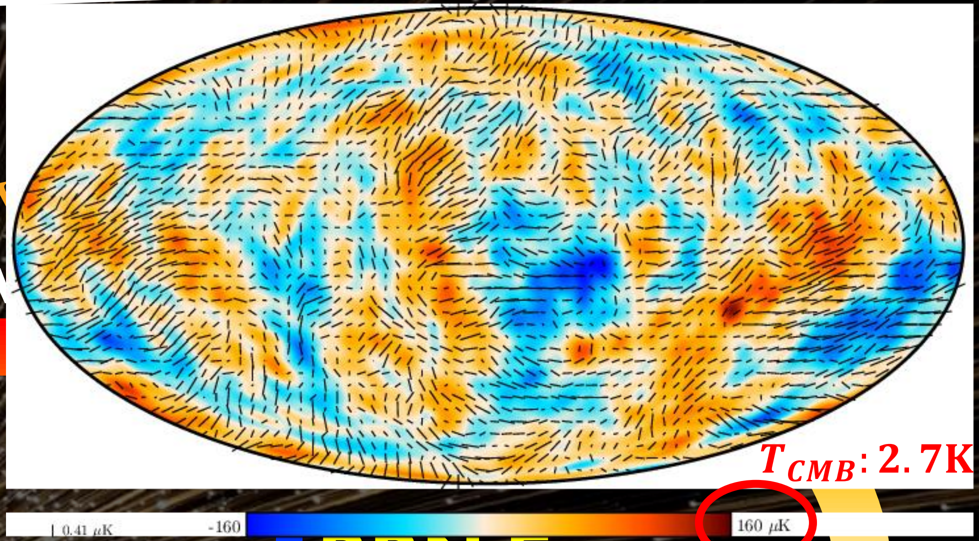
Particle era

protons and neutrons begin to form out of free quarks.

10^{-3}s

The Big-Bang theory

*Planck 2018 results



Gravity

Planck Era | GUT Era | Electrow

10^{-43}s 10^{-38}s 10^{-10}s

T_{CMB}: 2.7K

ΔT_{CMB} ~ 160 μK

Today

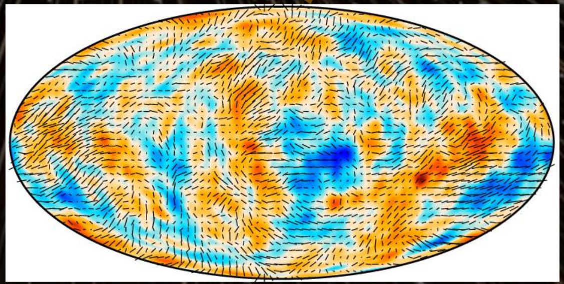
We are here

Era of Galaxies
First galaxies form.

CMB Era
Electrons and nuclei recombined to create atoms. photons decoupled and streamed freely, producing the characteristic CMB power spectrum.

BBN Era
Most neutrons went into ^{4}He, with trace amounts of D and ^{7}Li.

13.8 Gyr 200 Myr 400,000 yr 3m



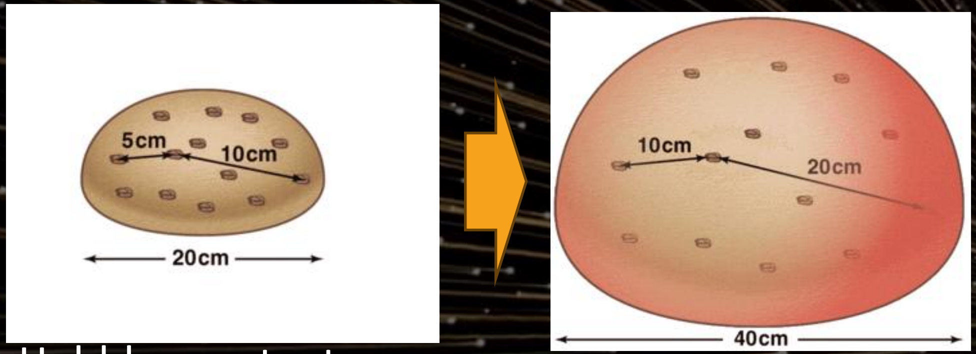
Atoms

^{4}He ^{7}Li D

Hubble tension

The Expansion:

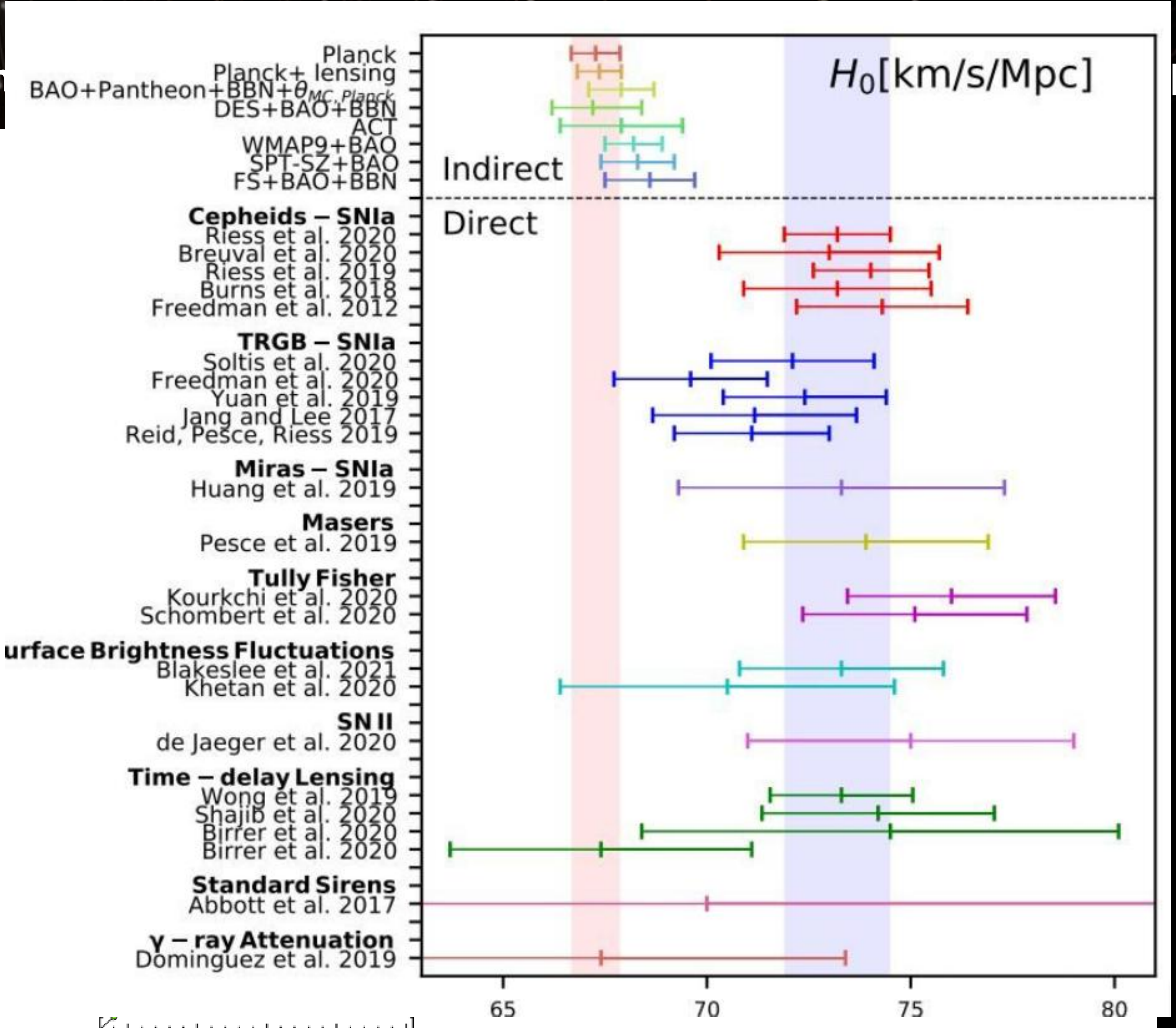
*Illustration taken from Wikipedia

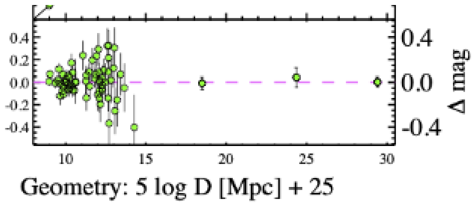


Hubble constant:

$$H_0 = \frac{v}{d} = \left(\frac{\dot{a}}{a}\right)_0$$

describes the present fractional expansion rate of the universe, where a is thescale factor, which determines how distances between comoving galaxies change with time.

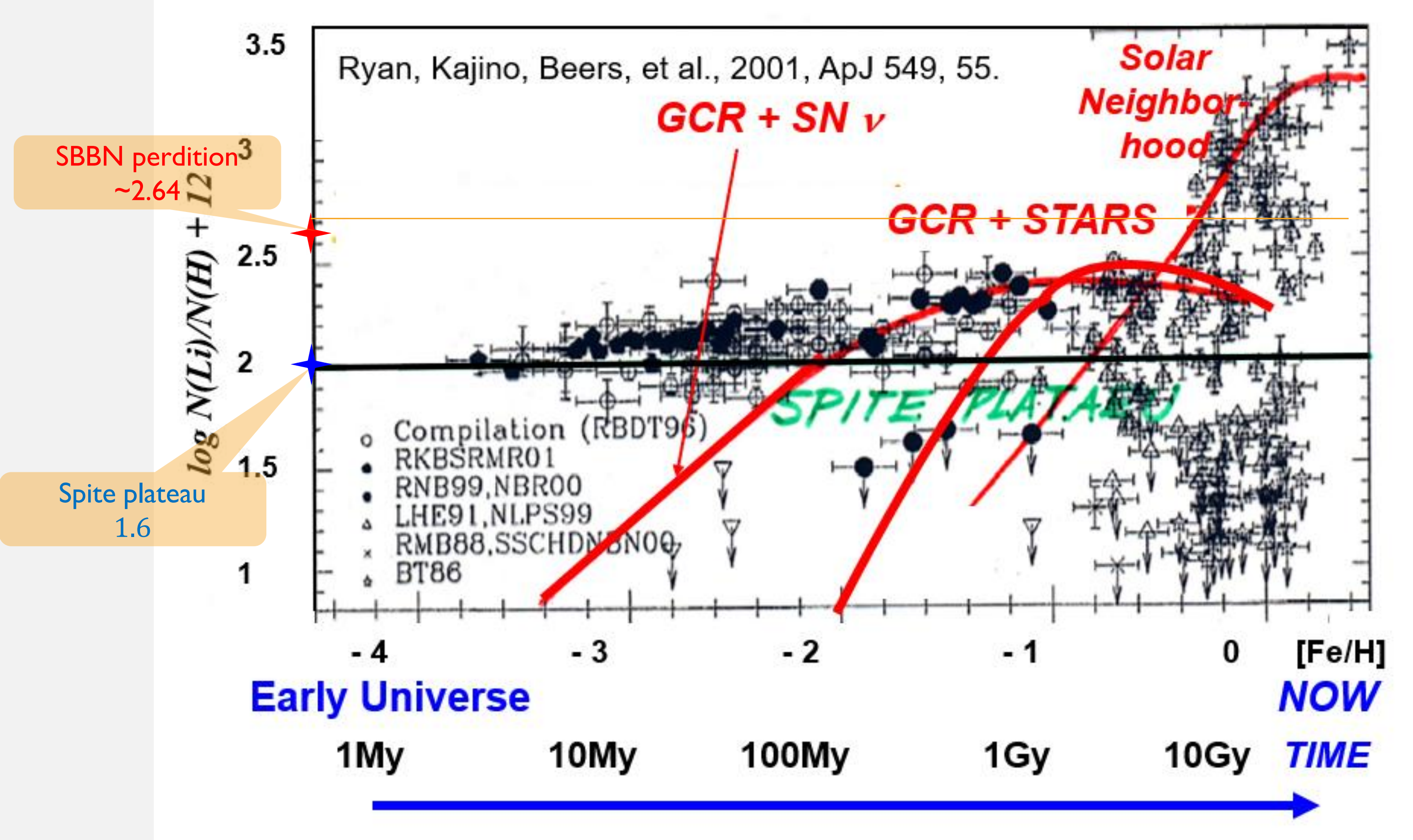




Pla
H_0
Mp

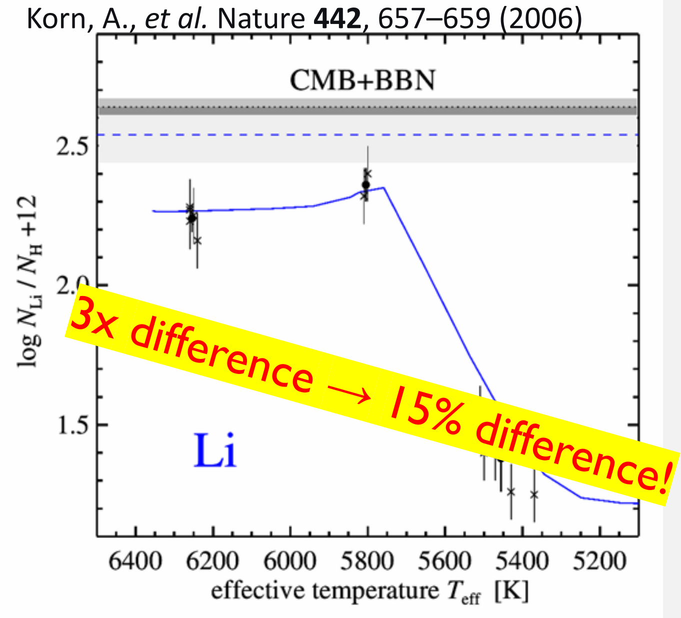
Hubble tension

Primordial Lithium-7 Problem



- Stellar depletion

Stellar depletion: Destruction of primordial 7Li in early stars

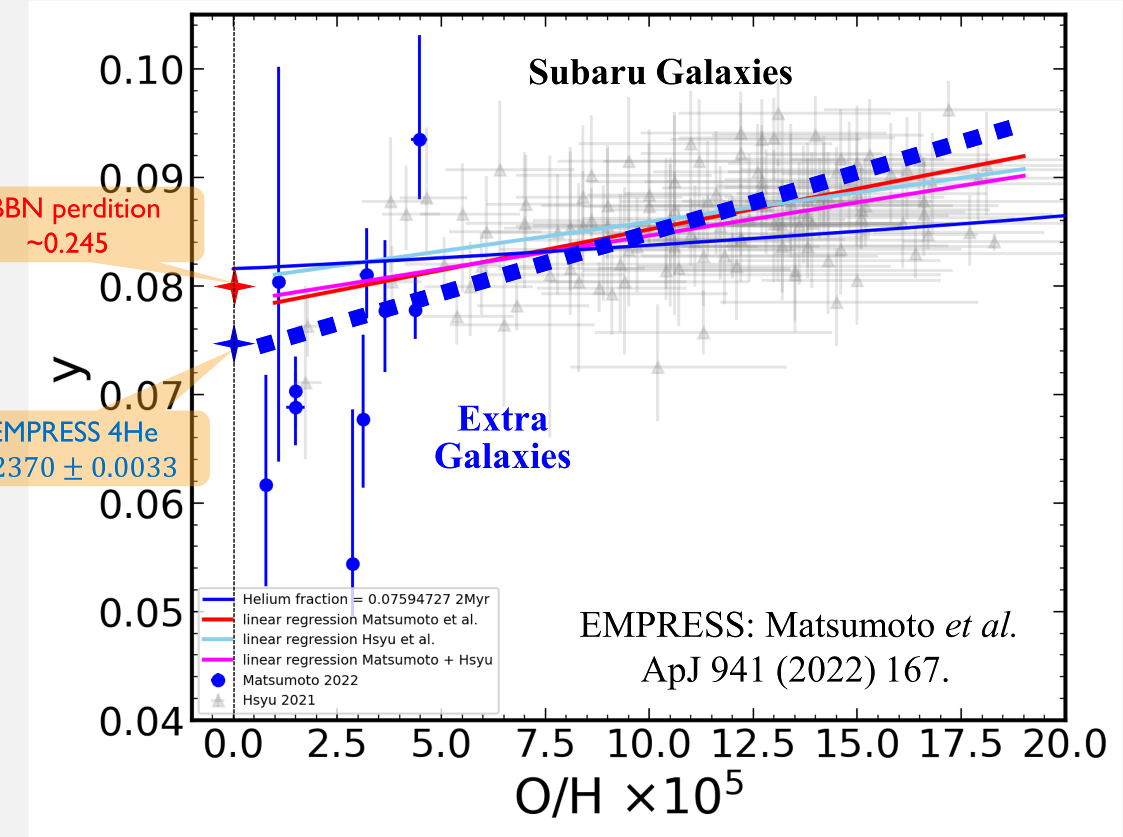


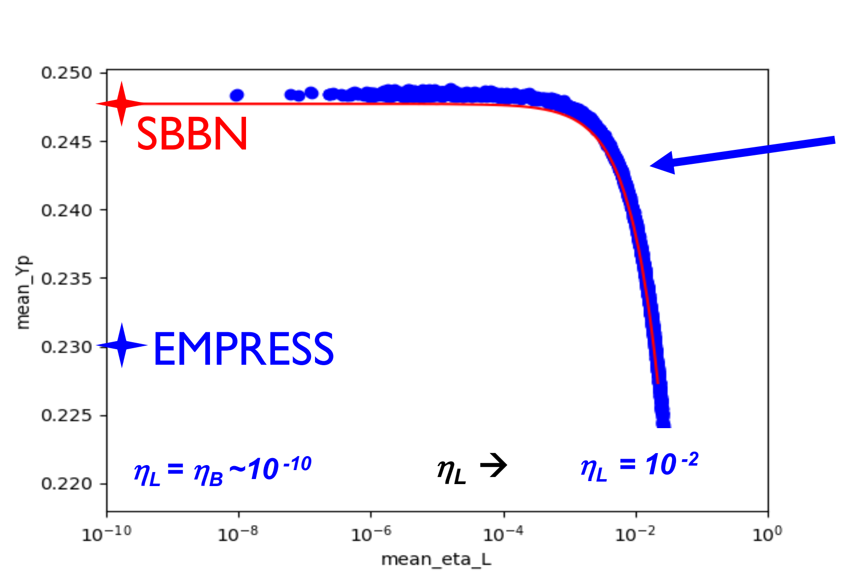
- The famous 7Li problem refers to a 3x(9σ) difference between BBN predicted and observed primordial 7Li abundance.

No perfect solution yet

Primordial Helium-4 Problem

- Recent EMPRESS survey of Extremely metal-poor Galaxies yield a very low primordial ^{4}He abundance that standard model cannot explain:





Lepton asymmetry?

^{4}He difference is to large to be explained only by L_e asymmetry!

Broken L_e-symmetry ?

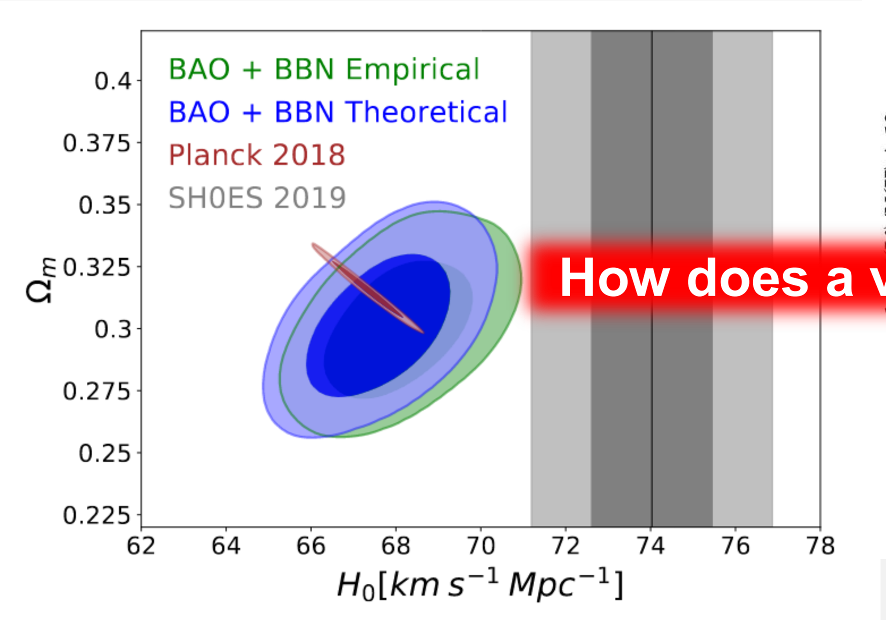
$\eta_L \sim 10^{-2}$ too large!

$\eta_B \sim 10^{-10}$

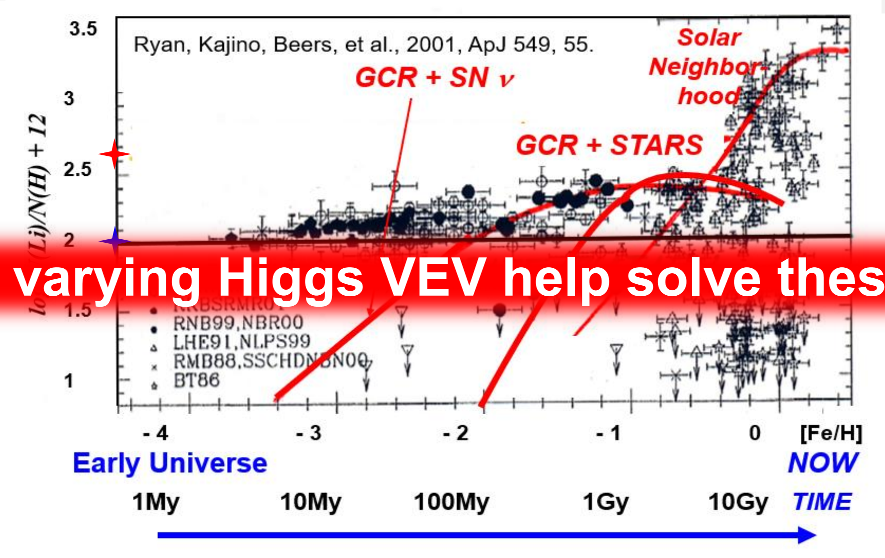
If B << L_e → Crisis of Unified Theory

Purpose of this work

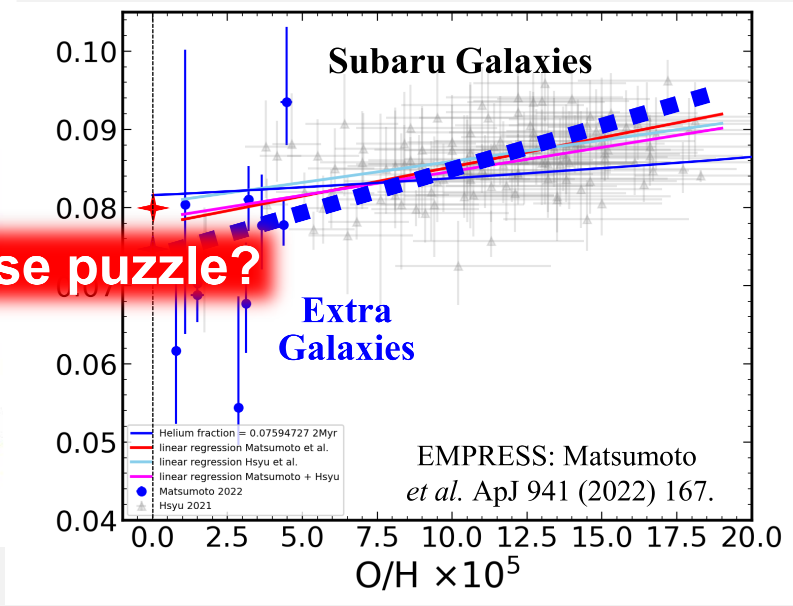
- Hubble tension



- Primordial Lithium-7 problem



- Primordial Helium-4 problem



How does a varying Higgs VEV help solve these puzzle?

Weak interaction

H. Meyer and U. G. Meisner, JHEP 06, 074 (2024)

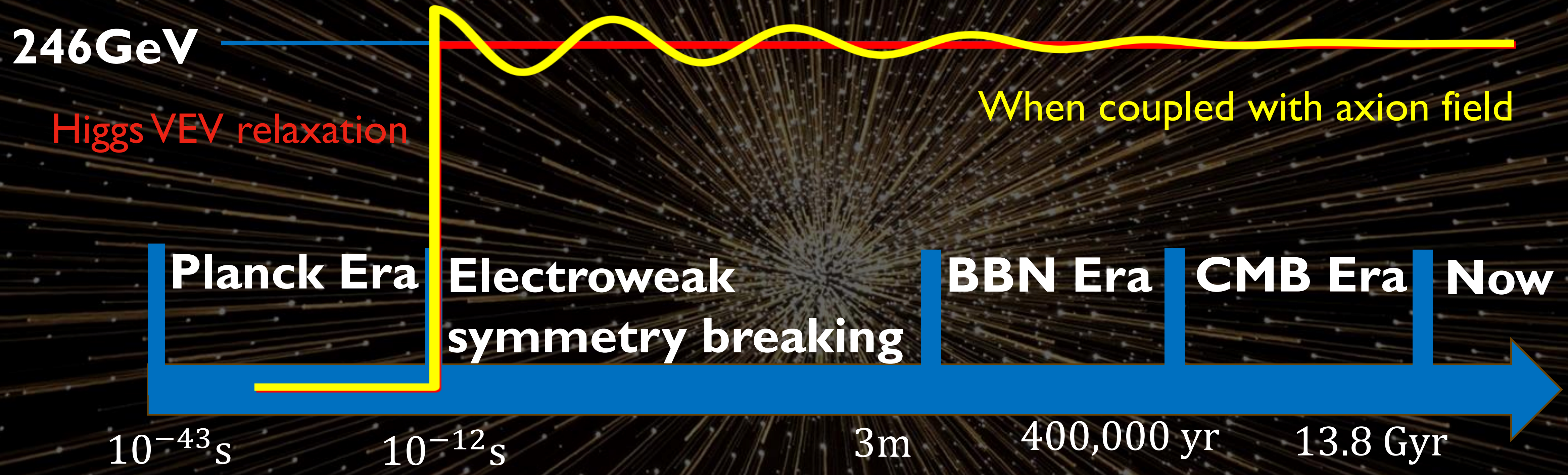
Strong interaction **Electromagnetic interaction**

M. K. Cheoun *et.al.*, PRD 84, 043001 (2011)
K. Mori and M. Kusakabe, PRD 99, 083013 (2019).

First consistent study!

How a Changing Higgs VEV Reshapes the Weak and Nuclear Processes of BBN

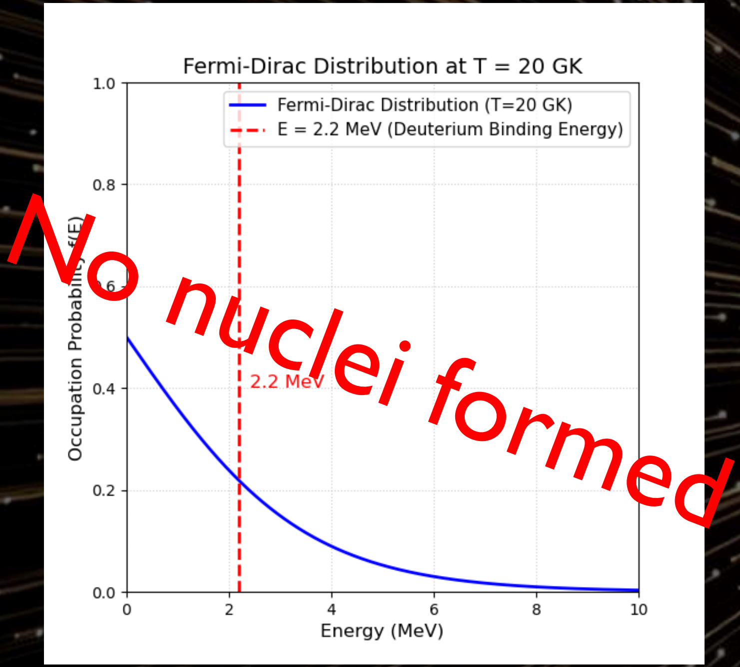
The rolling of Higgs VEV



* Illustration only. NOT TO SCALE.

From weak Equilibrium to weak decoupling

High-energy photons destroy D.



t~0.01s, T~10GK

n/p ratio determined only by their masses:

$$n/p = \exp\left(-\frac{m_n - m_p}{kT}\right)$$

1 6

n p

$$n + \nu_e \leftrightarrow p + e^-$$
$$n + e^+ \leftrightarrow p + \bar{\nu}_e$$
$$n \leftrightarrow p + e^- + \bar{\nu}_e$$

Effect of Higgs VEV on weak interactions

- Fermon acquire their mass through spontaneous symmetry breaking of the electroweak theory via Yukawa interactions:

$$m_e = \frac{\lambda_e v}{\sqrt{2}}, m_d = \frac{\lambda_d v}{\sqrt{2}}, m_u = \frac{\lambda_u v}{\sqrt{2}}$$

Weak interaction | **Weak & strong interaction**

Mass difference between neutron and proton will affect weak interactions:

$$Q_{np} = -0.76\text{MeV} + 2.053\text{MeV} * \frac{\Delta m_q}{\Delta m_{q0}}$$

- Higgs VEV would also alter Fermi constant:

v = ＜0|ϕ|0＞ : Higgs field

$$|\mathcal{M}_{fi}|_F = \frac{G_F}{V} c_V |\langle uud| \sum^{3} T_{i,+} |udd\rangle| \quad \propto g_V^2$$

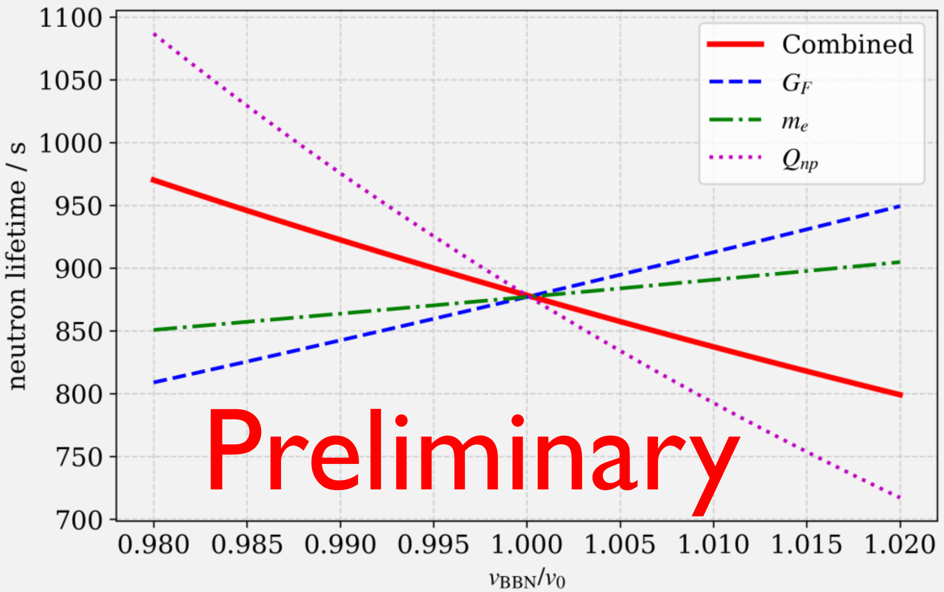
$$|\mathcal{M}_{fi}|_{GT} = \frac{G_F}{V} c_A |\langle uud| \sum_{i=1}^{3} T_{i,+} \sigma |udd\rangle| \quad \propto 3g_A^2$$

$$\frac{G_F}{\sqrt{2}} = \frac{\pi\alpha}{2} \cdot \frac{g^2}{e^2} \cdot \frac{(\hbar c)^3}{M_W^2 c^4}$$

$n \leftrightarrows p$ rate can be given by "V-A" theory of weak interactions.

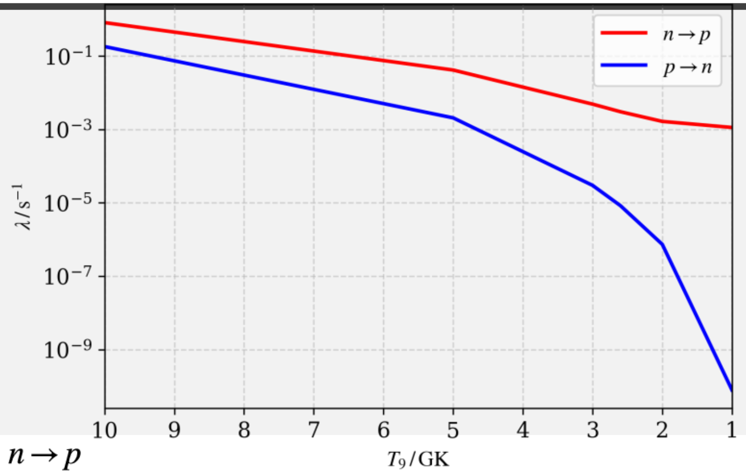
E.g. $p + e^- \longrightarrow n + \nu_e$:

$$\lambda = \frac{1}{(2\pi)^5} \int f_e(E_e)[1 - f_\nu(E_\nu)] |\mathcal{M}|^2 \delta^4(p + e - \nu - n) \frac{d^3 p_e}{2E_e} \frac{d^3 p_\nu}{2E_\nu} \frac{d^3 p_n}{2E_n}$$



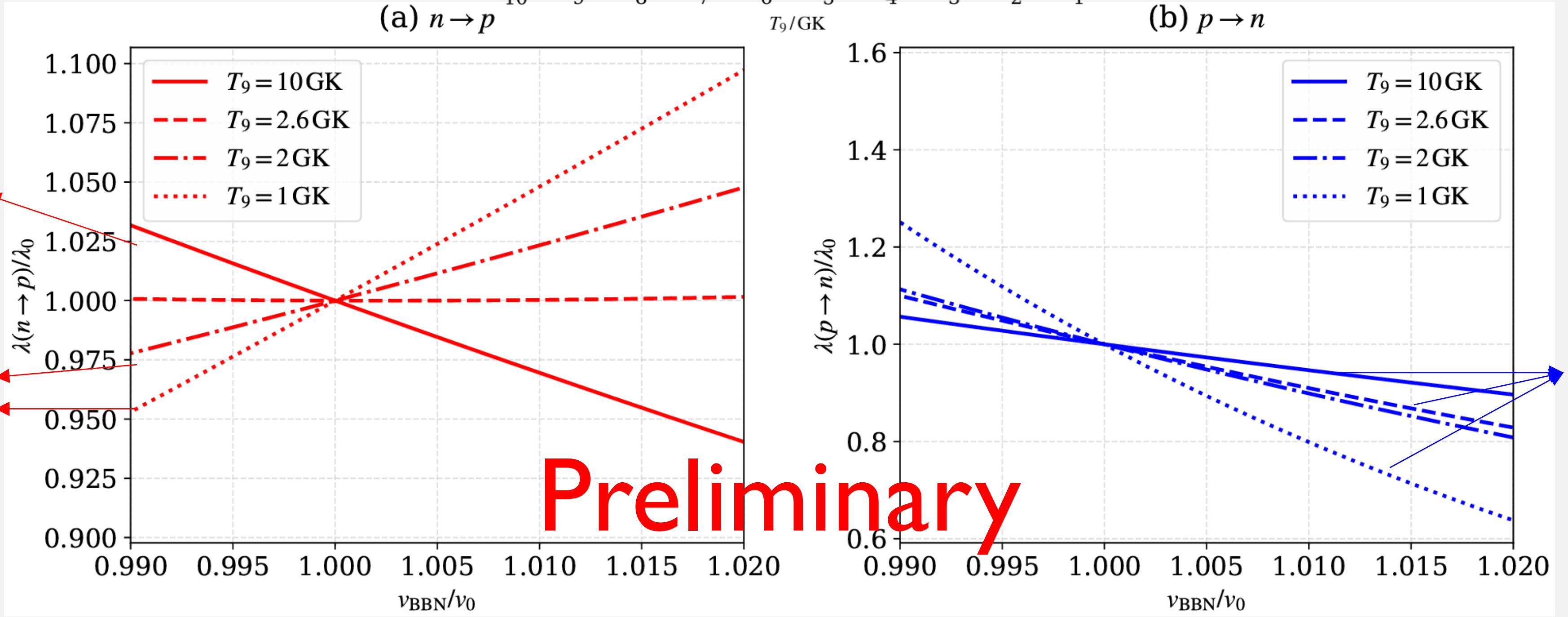
Effect of G_F, m_e and Q_{np} on neutron lifetime.

How will change in G_F, m_e and Q_{np} affect weak interaction?



Q_{np} governs n/p ratio

Positive correlation of Higgs VEV comes from joint effect of Q_{np}, m_e and G_F

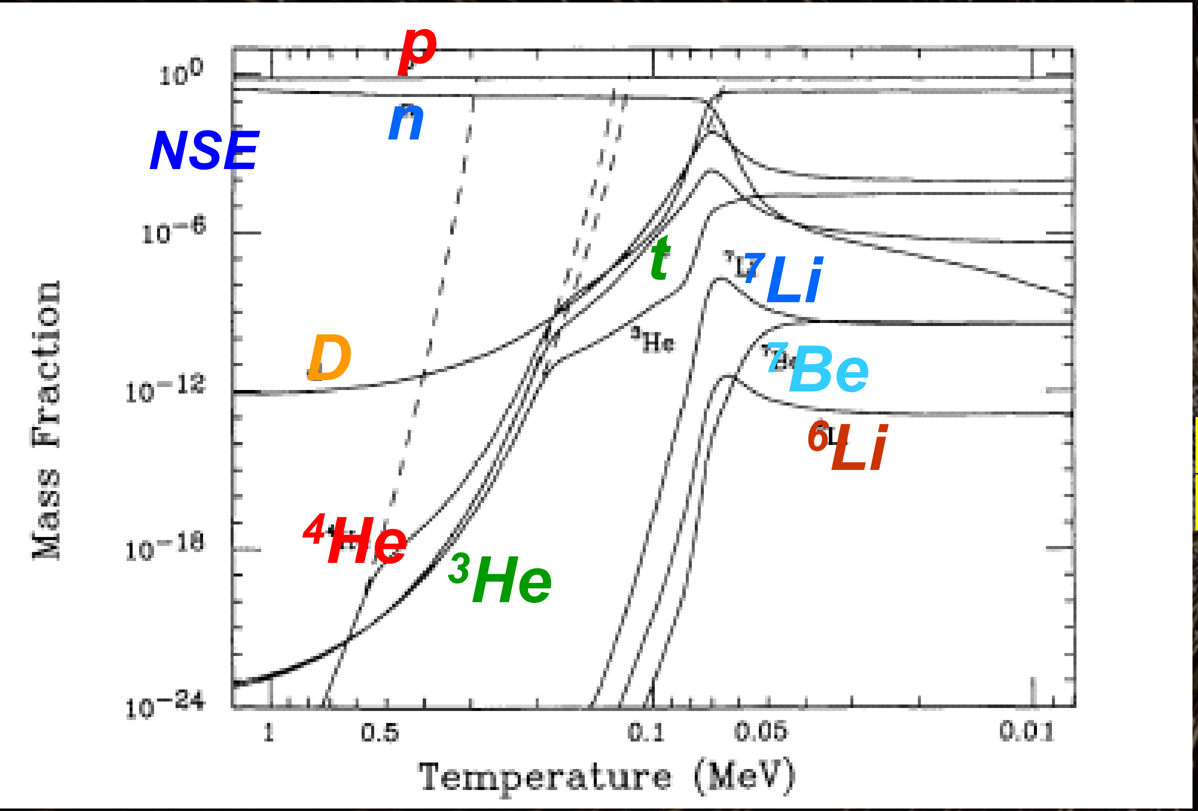


Negligeable p→n rates at or below 2.6GK

In BBN: Higgs VEV's impact on weak interaction.

Big-Bang nucleosynthesis

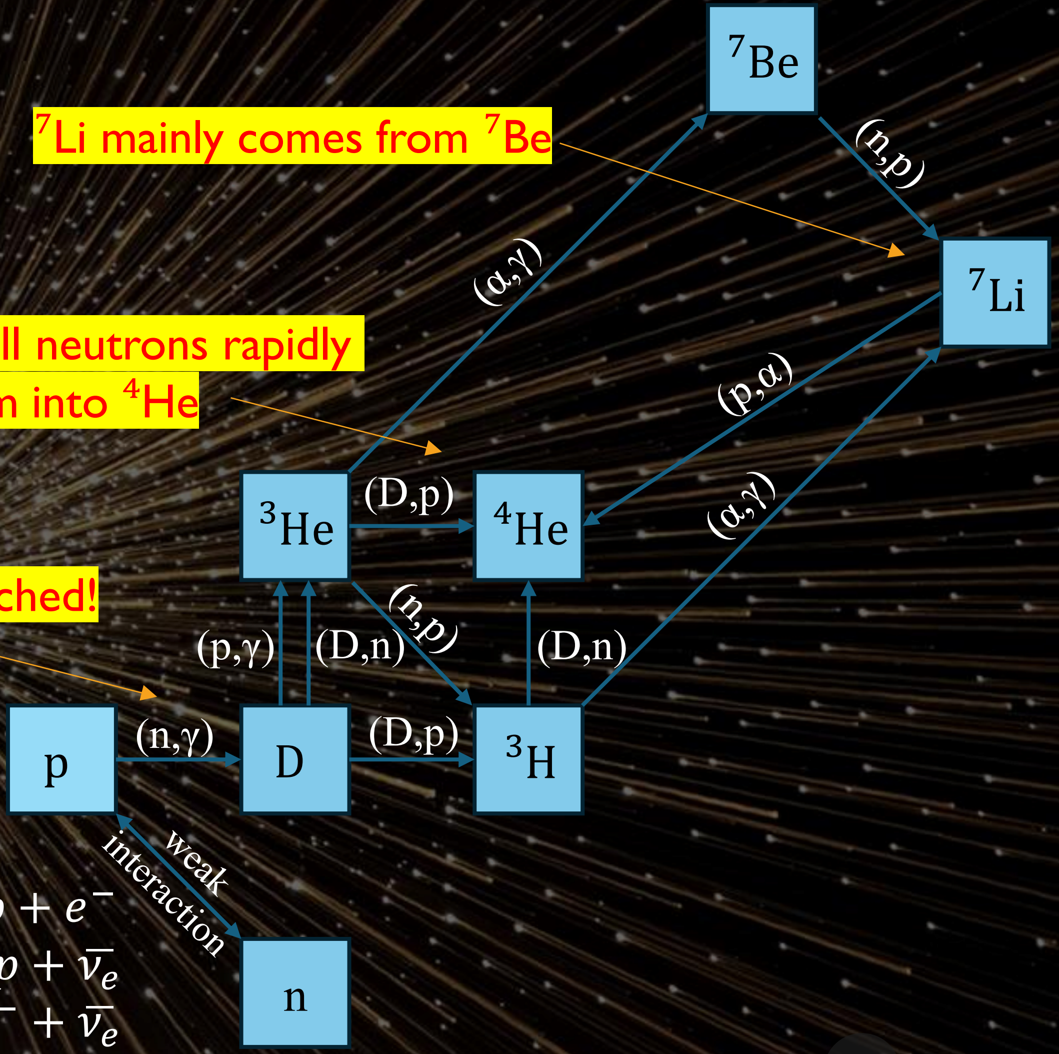
From t~0.01s, T~10GK
To t~3min, T~1GK



^{7}Li mainly comes from ^{7}Be

Almost all neutrons rapidly transform into ^{4}He

Deuterium barrier breached!



$n + \nu_e \leftrightarrow p + e^-$
$n + e^+ \leftrightarrow p + \overline{\nu_e}$
$n \leftrightarrow p + e^- + \overline{\nu_e}$

Effect of Higgs VEV on nuclear reactions

Weak & strong interaction

$$m_d = \frac{\lambda_d v}{\sqrt{2}}, m_u = \frac{\lambda_u v}{\sqrt{2}} \longrightarrow m_q = \frac{1}{2}(m_d + m_u) \propto v$$

- Averaged light quark mass m_q directly impact binding energy E_i of a given nucleus by:

$$K = \frac{\delta E_i/E_i}{\delta Xq/Xq} = \frac{\delta E_i/E_i}{\delta v/v}$$

Where K is sensitivity coefficient of binding Energy, obtained by AV18+UIX nuclear two-body interaction calculations.

TABLE I. Dimensionless derivatives $K = \frac{\delta E/E}{\delta X_q/X_q}$ of the binding energy over $X_q = m_q/\Lambda_{QCD}$.

^{2}H	^{3}H	^{3}He	^{4}He	^{5}He	^{6}He	^{6}Li	^{7}He	^{7}Li	^{7}Be	^{8}Be	^{9}Be
−1.39	−1.44	−1.55	−1.08	−1.24	−1.50	−1.36	−1.93	−1.50	−1.57	−1.35	−1.59

V V Flambaum *et al.* Phys. Rev. C **76**, 054002 (2007)

Effect of Averaged light quark mass - reaction energy

- Reaction Energy is directly impacted:

$$Q = \sum_{\text{enter}} E_i - \sum_{\text{exit}} E_j$$

- Reaction Energy as a function of Higgs VEV:

$$\delta Q = \sum_i E_i K_i \left(\frac{v_{\text{BBN}}}{v_0} - 1 \right) - \sum_j E_j K_j \left(\frac{v_{\text{BBN}}}{v_0} - 1 \right)$$

- Forward and reverse rates are linked by detailed balance:

$$\frac{\langle \sigma v \rangle_{\text{fwd}}}{\langle \sigma v \rangle_{\text{rev}}} = \frac{(2j_0+1)(2j_1+1)(1+\delta_{23})}{(2j_2+1)(2j_3+1)(1+\delta_{01})} \left(\frac{m_{01}}{m_{23}} \right)^{\frac{3}{2}} e^{-\frac{Q}{k_B T}}$$

Change of Q directly impacts the ratio of forward and reverse reactions.

Effect of Averaged light quark mass - exit-channel kinetic energy

- For charged particles release reactions, cross section is sensitive to the kinetic energy E of the exit channel:

phase space factor ← $\sigma(E) \sim \sqrt{Q+E}\, e^{-\sqrt{E_G/(Q+E)}}$ → Coulomb barrier penetration

As for gamma release reactions:

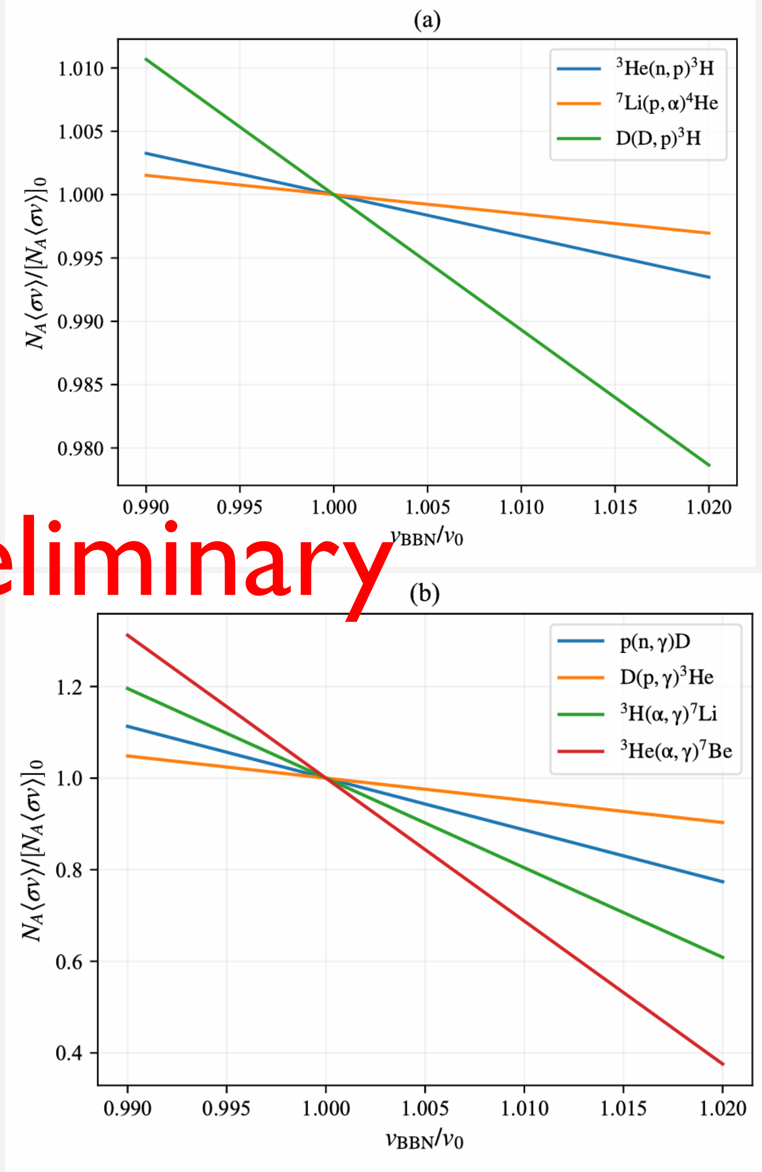
$$\sigma(E) \sim (Q+E)^3$$

→ gamma-decay strength: E1 dominance

- For n(p,γ)d reaction, additional sensitivity is given by virtual energy level 0.07MeV:

$$\sigma = \sigma_0 \left[1 + \left(\frac{5}{2} + \sqrt{\frac{Q}{0.07\text{MeV}}} \right) \frac{\delta Q}{Q} \right]$$

Preliminary

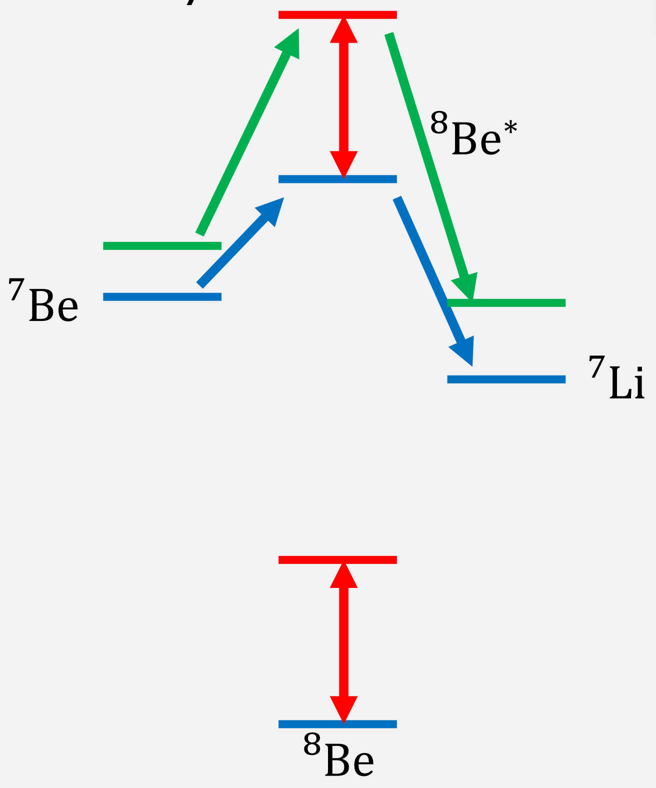


Correlation of reaction rates to Higgs VEV

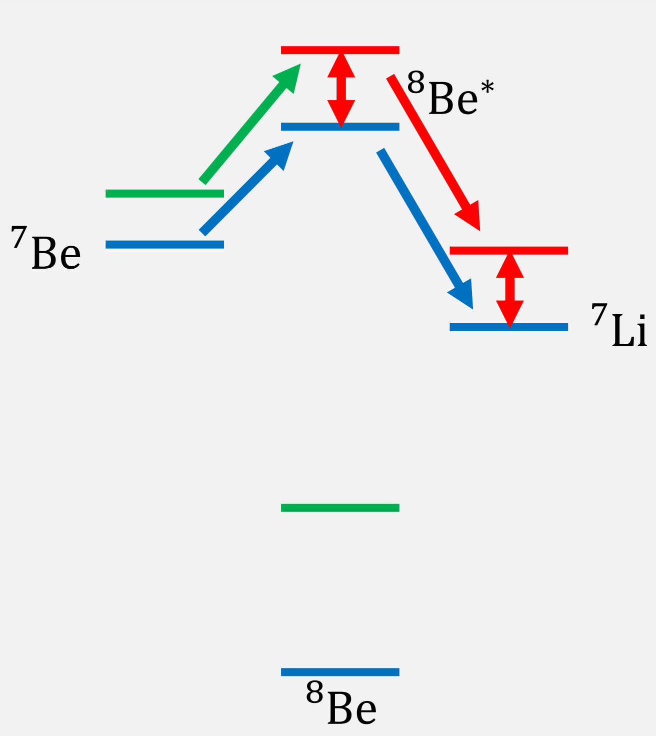
Resonance reactions – How would resonance energy level change?

* Illustration only. NOT TO SCALE.

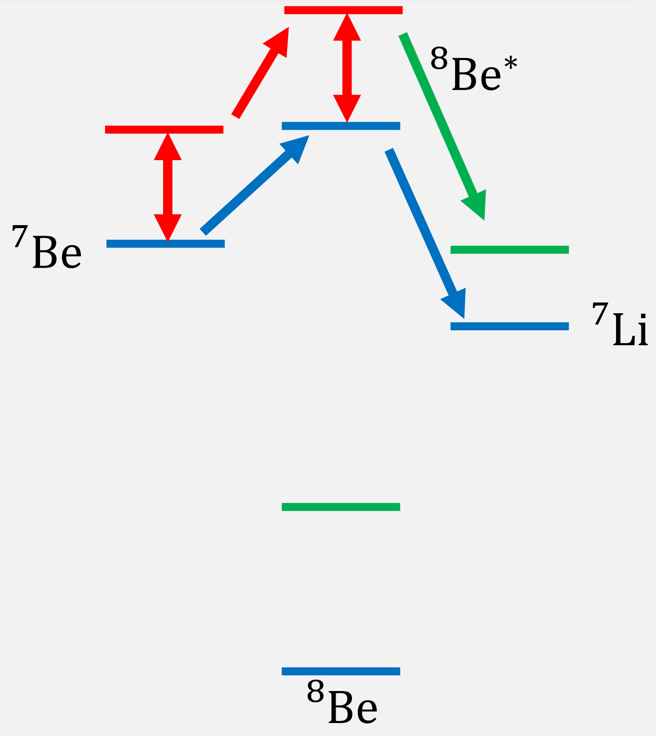
Resonance response to quark mass change is difficult to predict!



Case 1:Variations in binding energies of excited states are the same as that of the ground state



Case2:The resonance strength in the reverse reaction to remain unchanged.



Case 3: No shifts in the resonance energy, corresponding to a resonance-state shift that follows the entrance-channel threshold.

Effect of quark mass change on nuclear reactions - resonance excitation energies

- Resonance reactions follow the B-W formula:

$$\sigma(E) = \pi \lambda\!\!\!^{-}(E)^2 \frac{\omega \Gamma_i(E) \Gamma_f(E)}{(E - E_r)^2 + [\Gamma_r(E)/2]^2}$$

For resonance reactions, cross section, and therefore reaction rate, is sensitive to resonance energy Er.

In BBN we have 2 narrow resonance reactions:

$$^3\mathrm{He} + \mathrm{D} \rightarrow\ ^5\mathrm{Li}^* \rightarrow 4\mathrm{He} + \mathrm{p}$$

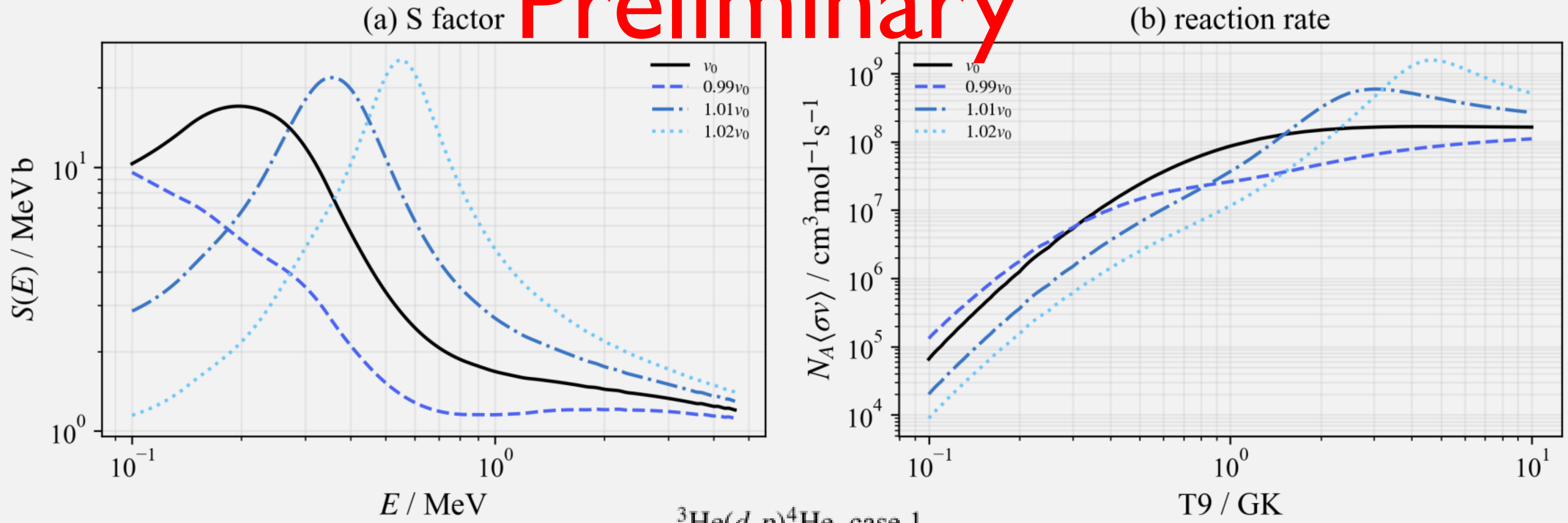
$$\mathrm{T} + \mathrm{D} \rightarrow\ ^5\mathrm{He}^* \rightarrow 4\mathrm{He} + \mathrm{n}$$

With just 1 peak, we can simplify the effect of resonance energy Er:

$$[N_A\langle\sigma v\rangle] = [N_A\langle\sigma v\rangle]_0 \times \left[1 + \frac{1}{2}\left(1 + \sqrt{\frac{E_G}{Q}}\right)\frac{\delta Q}{Q} + \cdots\right] \times \frac{1 + [(E_0 - E_r^0)/(\Gamma_r(E)/2)]^2}{1 + [(E_0 - E_r)/(\Gamma_r(E)/2)]^2}.$$

Effects of variations in the Higgs VEV on narrow resonance reaction.

Preliminary



^{3}He$(d,p)^4$He, case 1

Effect of quark mass change on nuclear reactions - resonance excitation energies

As for broad resonance reaction:

$$^{7}\mathrm{Be} + \mathrm{n} \rightarrow\ ^{8}\mathrm{Be}^{*} \rightarrow\ ^{7}\mathrm{Li} + \mathrm{p}$$

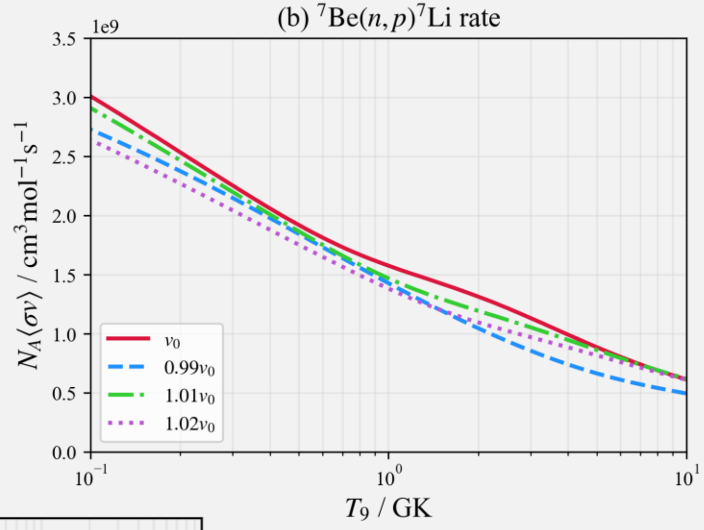
We compute the reaction cross-section and rate directly from BW formula, with values determined by descovomont(2003):

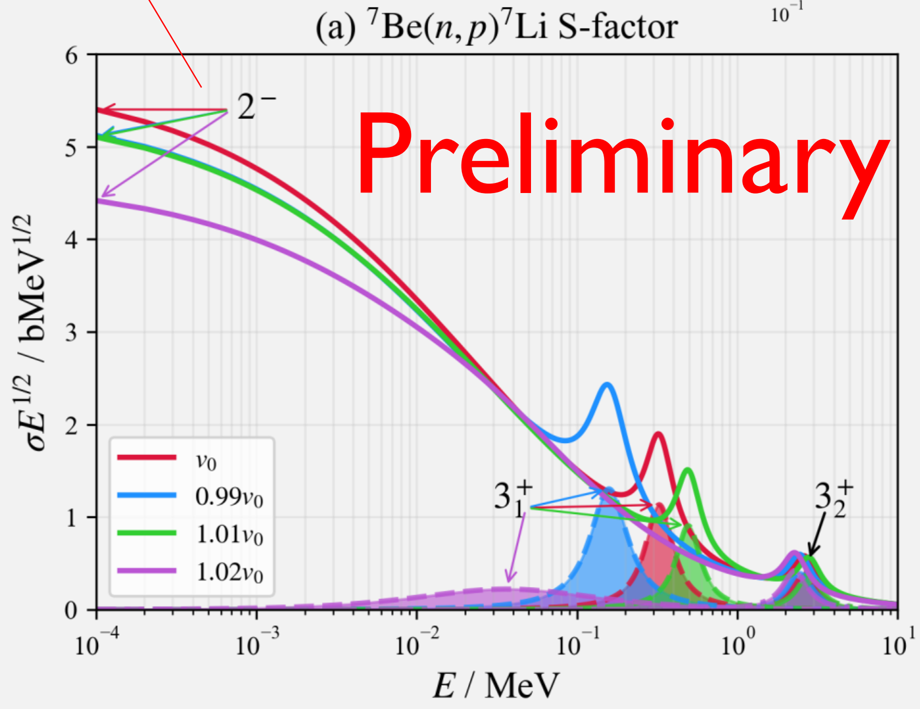
J^π	(ℓ, I)	E_r	γ_n^2	γ_p^2	Γ_n	Γ_p
2^-	0, 2	0.0027	2.11[a]	0.697[a]	0.225[a]	1.409[a]
3^+	1, 2	0.33[a]	0.253	0.062	0.077	0.088
3^+	1, 2	2.66	0.198	0.199	0.490	0.610

J^π	(ℓ, I)	R_{nn}	R_{pp}
2^+	1, 2	3.01	2.90

[a] Not fitted.

Only 2^- state contributes to 0 energy S factor!

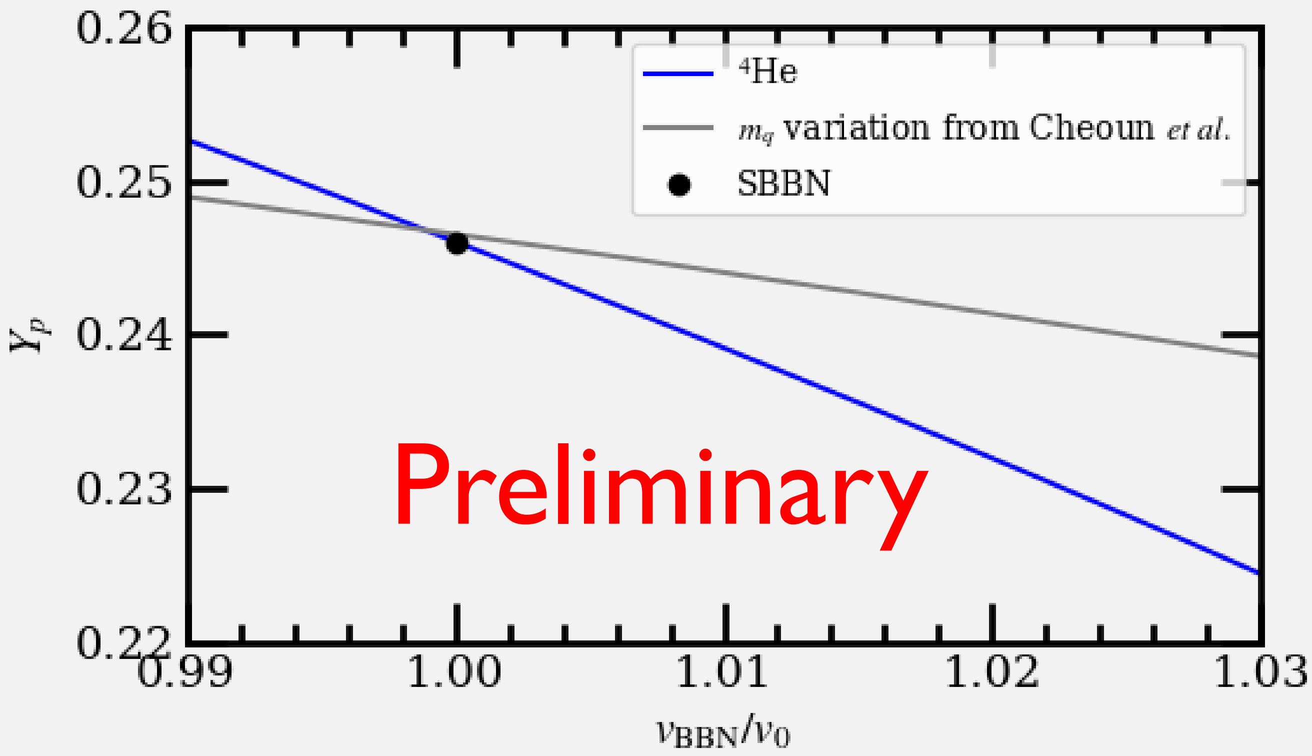


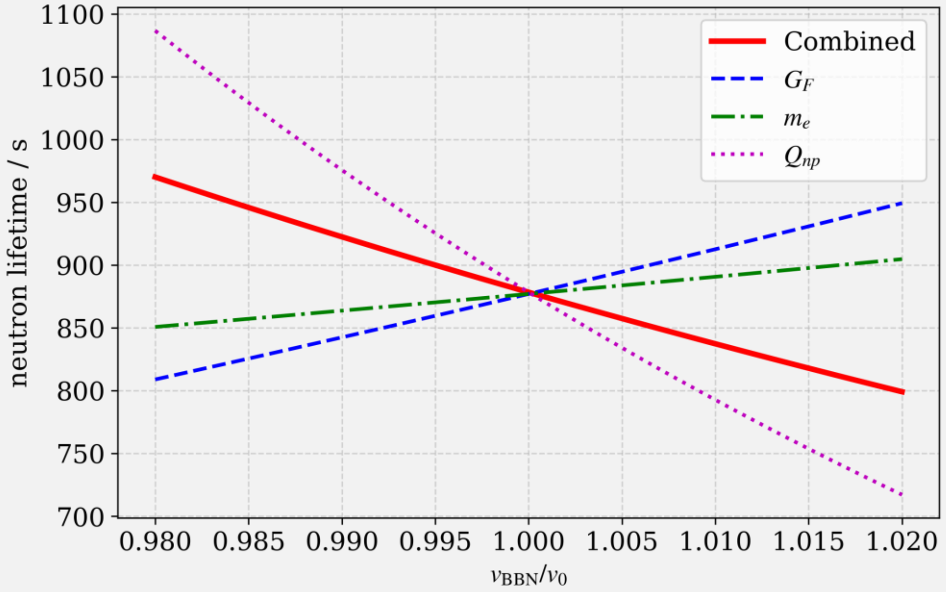


Effects of variations in the Higgs VEV on broad resonance reaction. $^{7}\mathrm{Be}(n,p)\ ^{7}\mathrm{Li}$

Sensitivity of Light Element Yields to the Higgs VEV

How would Higgs VEV variation affect BBN?



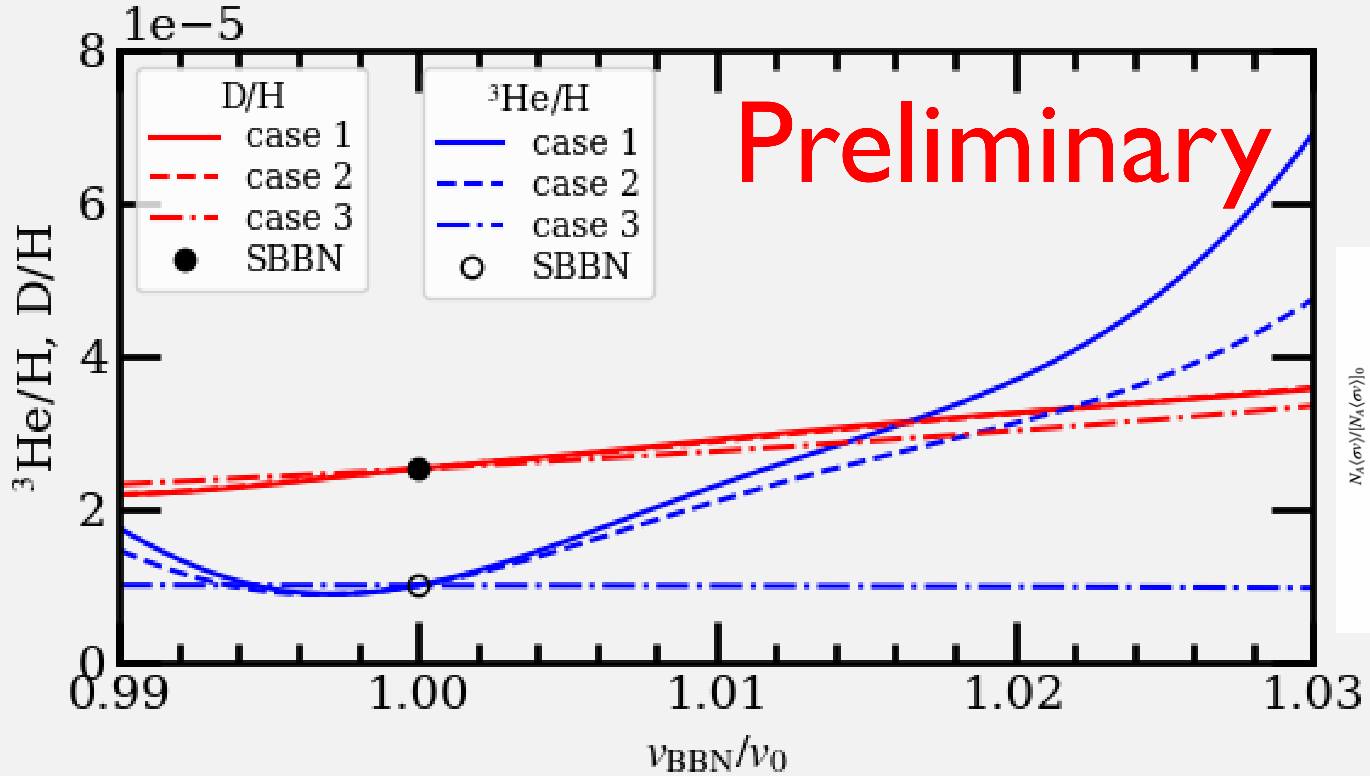


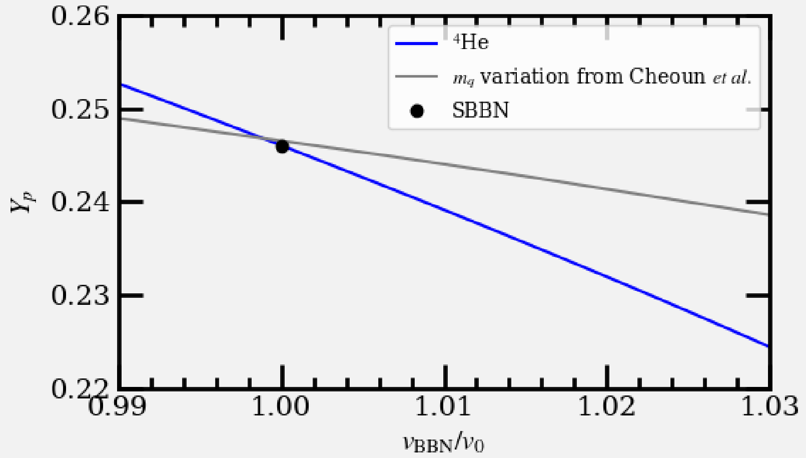
Effect of G_F, m_e and Q_{np} on neutron lifetime.

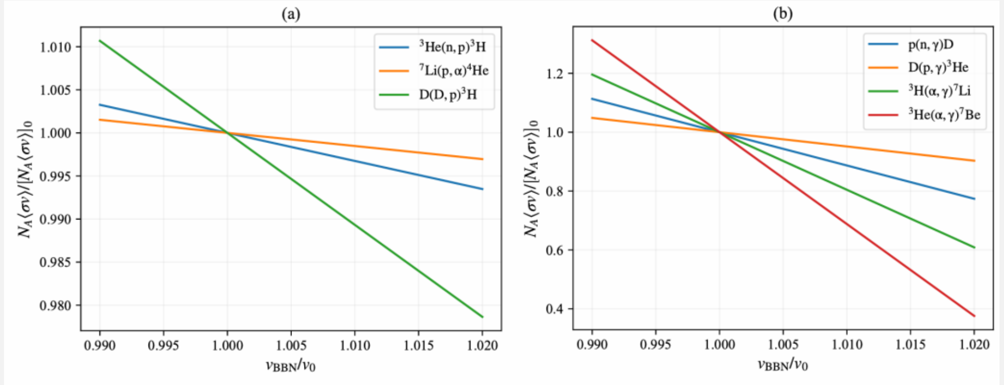
- Primordial ^{4}He exhibits a large negative correlation with Higgs VEV.

Dominant effect comes from Q_{np}, altering weak interaction

How would Higgs VEV variation affect BBN?





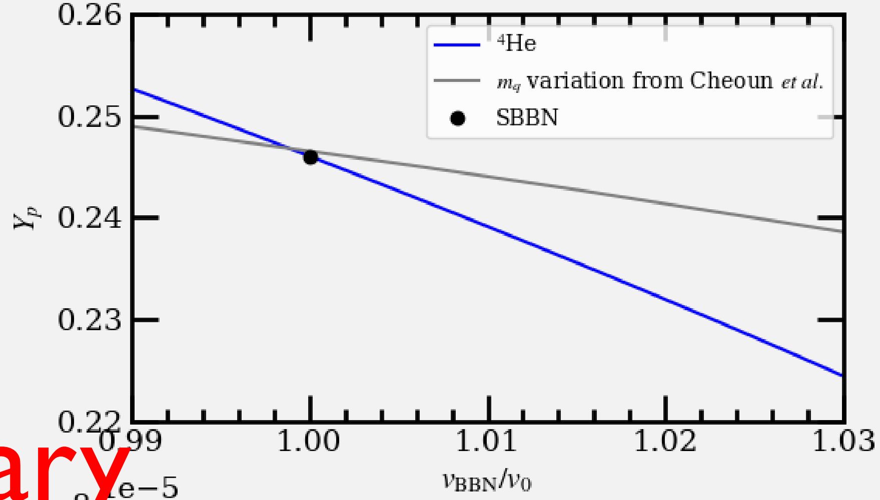


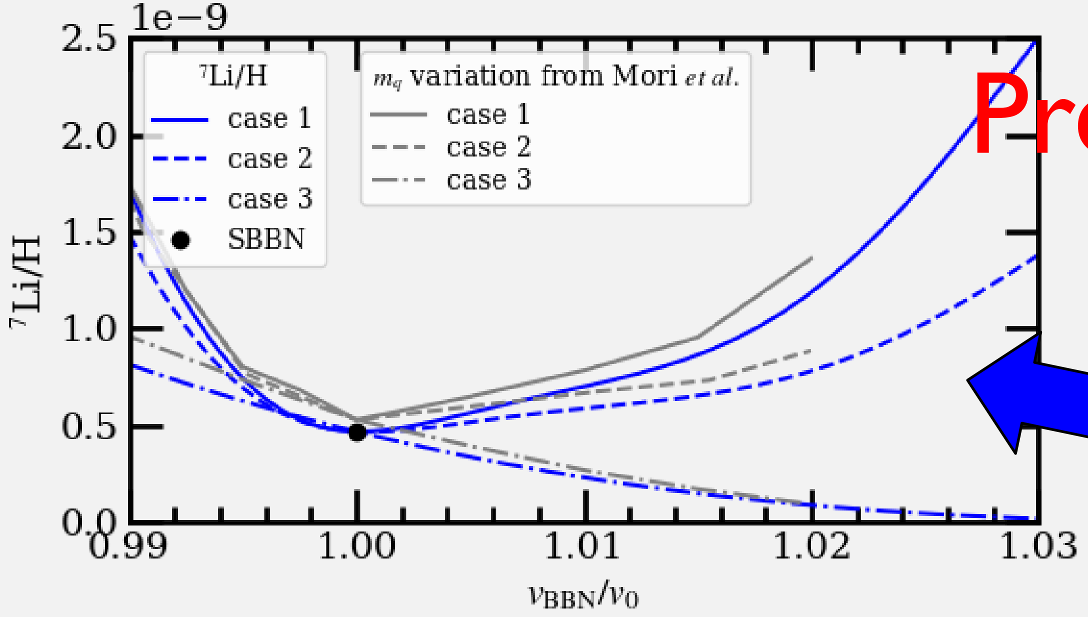
Correlation of reaction rates to Higgs VEV

- Primordial D exhibits a positive correlation with Higgs VEV.

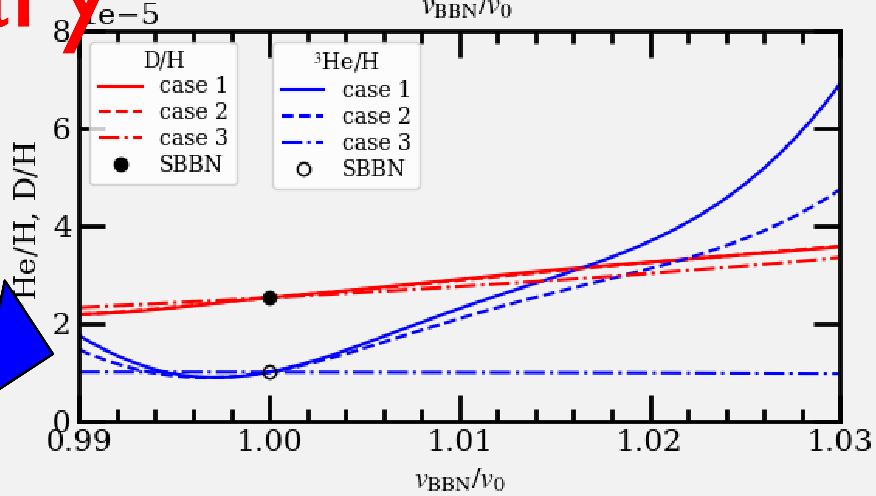
Reason: $^1H(n,\gamma)^2H$, $^2H(p,\gamma)^3He$, $^2H(d,n)^3He$, and $^2H(d,p)^3H$ rates are all negatively correlated with Higgs VEV.

How would Higgs VEV variation affect BBN?





Preliminary



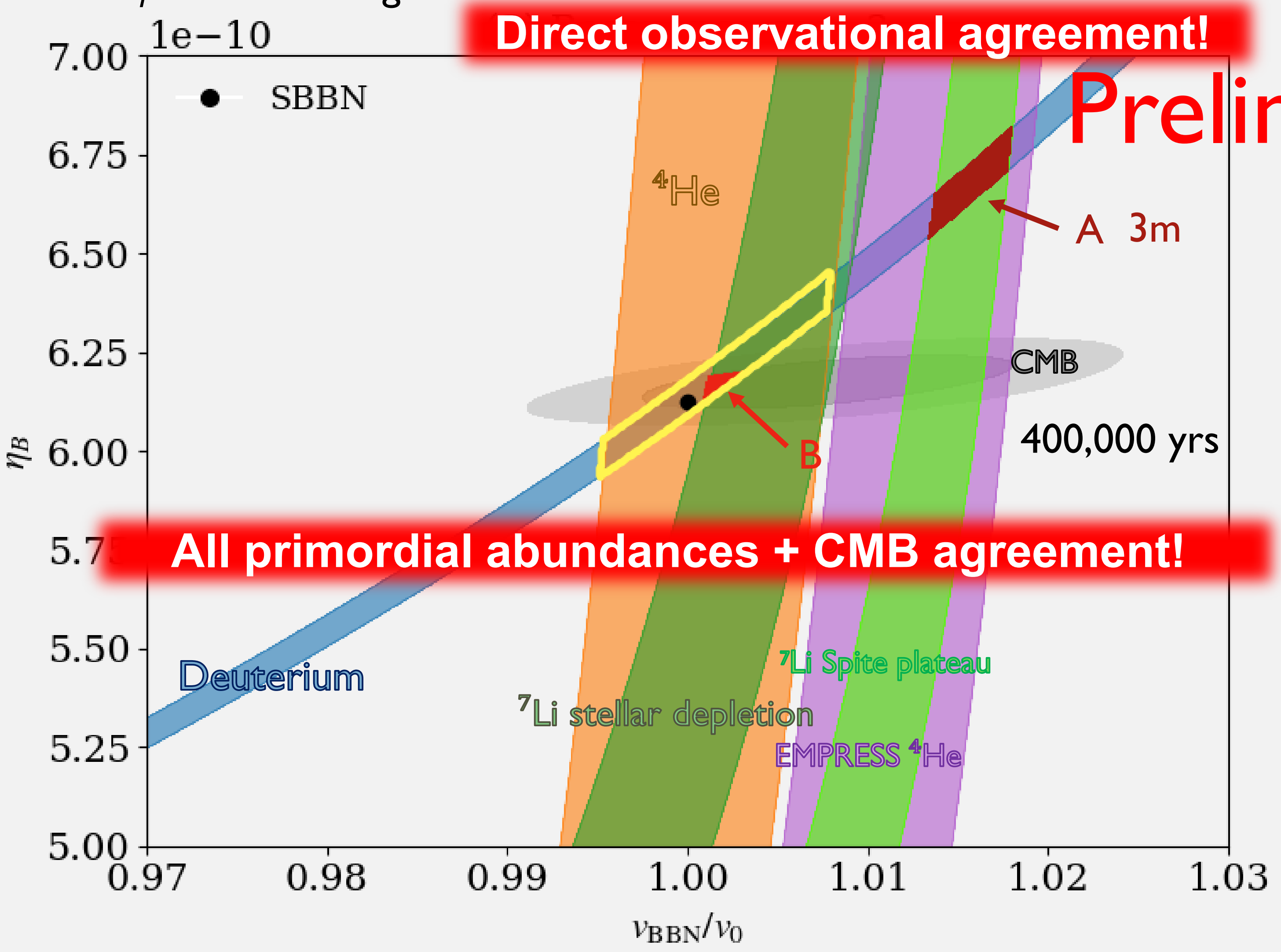
- Primordial ^{7}Li follows the trend of ^{3}He.
- As ^{3}He(d,p)^{4}He resonance peak shifts, it suppresses the ^{3}He depletion rate at the BBN-sensitive temperature T = 1 GK, creating a trend in the primordial ^{7}Li abundance that first decreases and then increases.

Effect of variations in the Higgs VEV on ^{3}He(d,p)^{4}He reaction.

Constraining the Early-Universe Higgs VEV with BBN and CMB

Observational constrain on Higgs VEV and baryon density

Case 3 E_r doesn't change

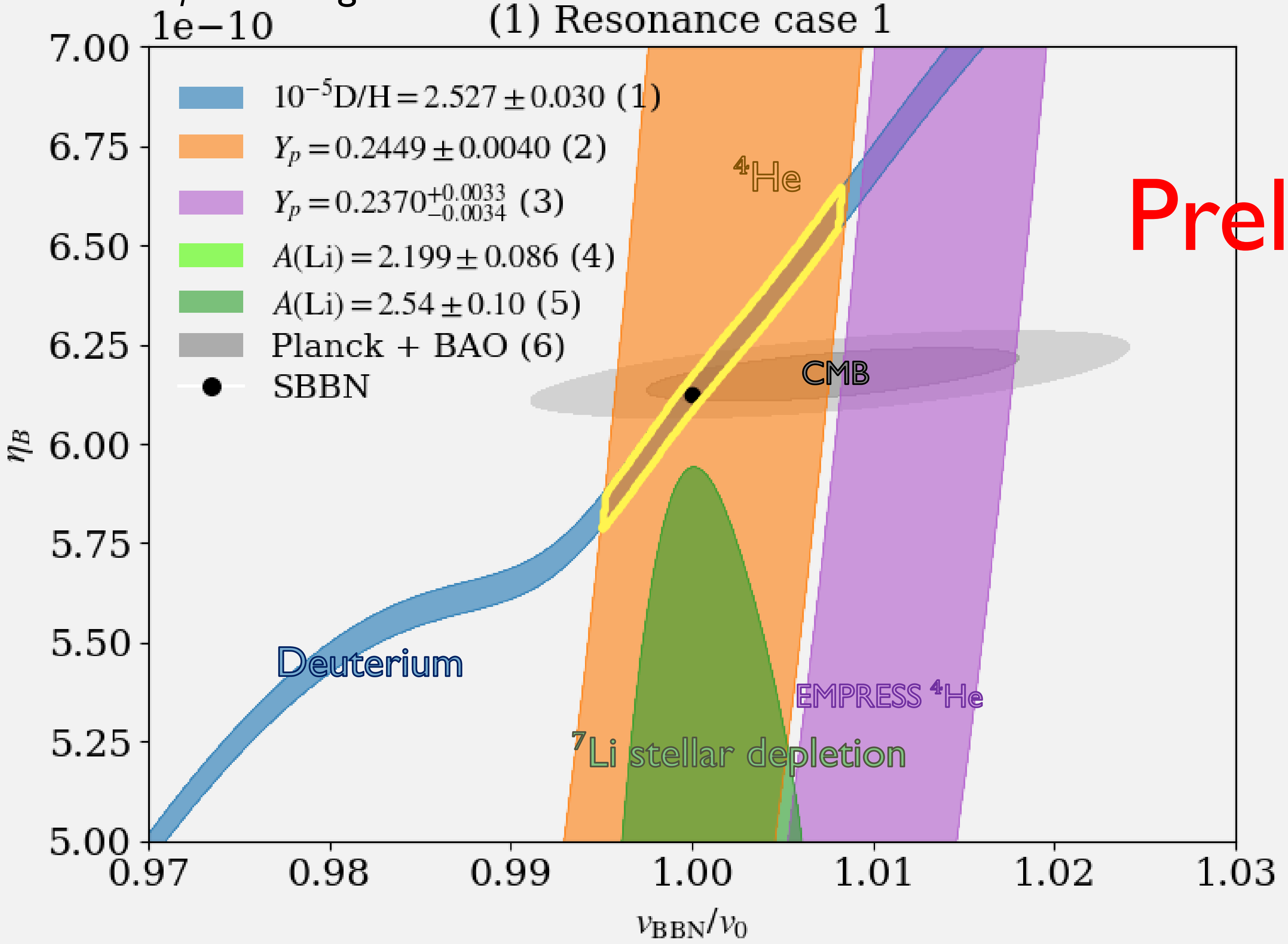


Preliminary

Constraint	η_B	$v_{\rm BBN}/v_0$
^{4}He and D constraints (cases 1, 2, and 3)		
Aver ^{4}He + Cooke D + Planck + BAO	$(6.16 \pm 0.05) \times 10^{-10}$	1.0010 ± 0.0027
Aver ^{4}He + Cooke D	$(6.22 \pm 0.44) \times 10^{-10}$	1.0019 ± 0.0067
^{4}He , D and ^{7}Li constraints (case 3)		
Matsumoto ^{4}He + Cooke D + Sbordone ^{7}Li (area A)	$(6.68 \pm 0.12) \times 10^{-10}$	1.0158 ± 0.0022
Aver ^{4}He + Cooke D + Korn ^{7}Li + Planck + BAO (area B)	$(6.16 \pm 0.04) \times 10^{-10}$	1.0022 ± 0.0012

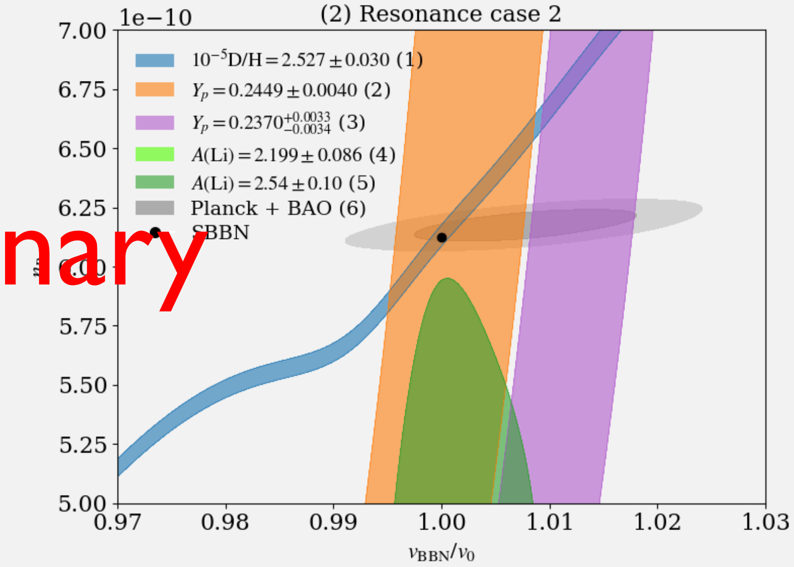
Observational constrain on Higgs VEV and baryon density

Case1 E_r shift as ground state



Observational constrain on Higgs VEV and baryon density

Case 2 Reverse reaction height doesn't change



Preliminary

Conclusion

- We for the first time take into account the Higgs VEV's joint effect on weak interactions and nuclear reactions.
- Primordial ^{4}He exhibits a large negative correlation with Higgs VEV.
- Observations of primordial He, D, and the CMB power spectrum constrain the Higgs vacuum expectation value in the early Universe to within −0.2% to +0.4% of its present value.
- Under assumption that the resonance energy levels do not change with Higgs VEV:

Agreement can be achieved among the new primordial 4He abundance, observed by the EMPRESS group, Deuterium abundance, and Lithium abundance at the Spite plateau, with a 4σ CMB tension.

When we take stellar lithium depletion in Population III stars into account, a 0.2% uplift of Higgs VEV during BBN era would provide a plausible solution to the "cosmic Li problem" with CMB agreement.

Constraint	η_B	v_{BBN}/v_0
^{4}He and D constraints (cases 1, 2, and 3)		
Aver ^{4}He + Cooke D + Planck + BAO	$(6.16 \pm 0.05) \times 10^{-10}$	1.0010 ± 0.0027
Aver ^{4}He + Cooke D	$(6.22 \pm 0.44) \times 10^{-10}$	1.0019 ± 0.0067
^{4}He , D and ^{7}Li constraints (case 3)		
Matsumoto ^{4}He + Cooke D + Sbordone ^{7}Li (area A)	$(6.68 \pm 0.12) \times 10^{-10}$	1.0158 ± 0.0022
Aver ^{4}He + Cooke D + Korn ^{7}Li + Planck + BAO (area B)	$(6.16 \pm 0.04) \times 10^{-10}$	1.0022 ± 0.0012

- Future: Improved stellar depletion models and a better understanding of how nuclear resonances respond to quark mass changes would help strengthen our constraints.

Thanks