（2）ビッグバン元素合成と暗黒物質
SUSY 粒子モデル

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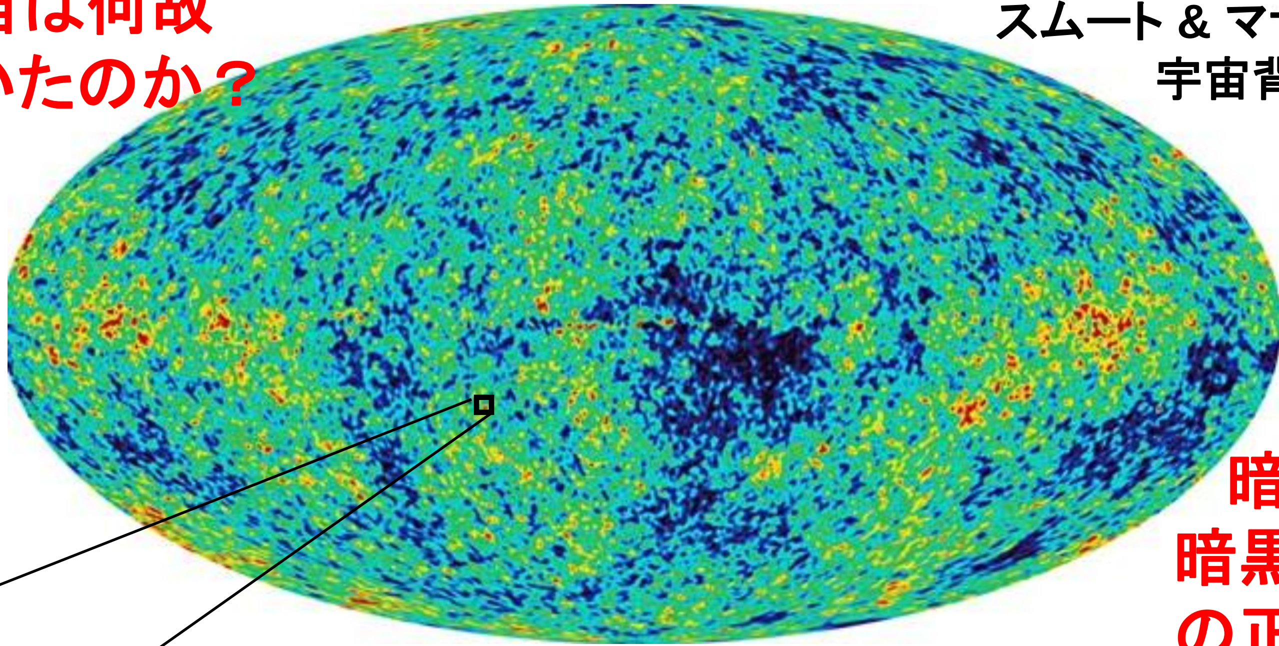
初期宇宙は何故
ゆらいでいたのか？

スムート & マザーが発見した
宇宙背景放射ゆらぎ



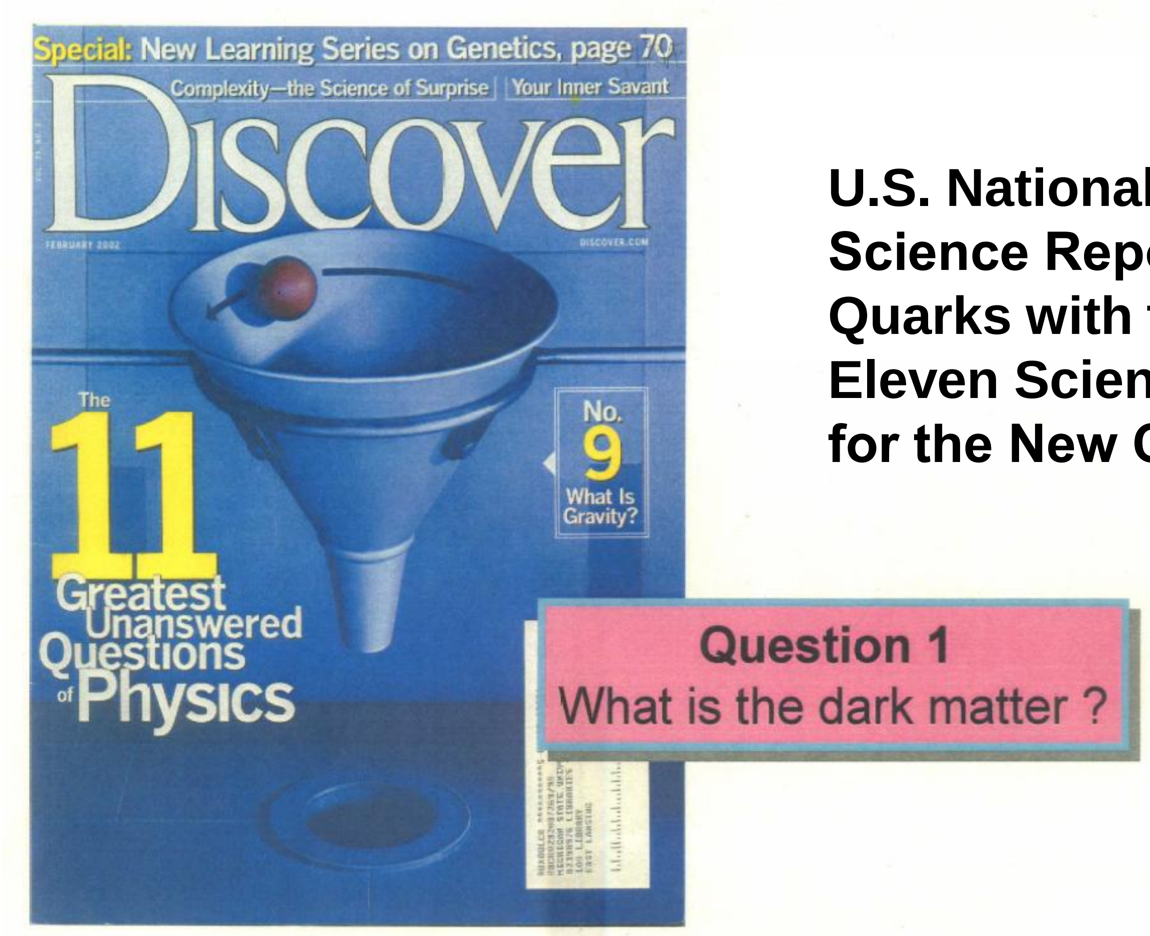
暗黒物質と
暗黒エネルギー
の正体は何か？

38万年 → 137億年

スーパーコンピュータを用いた宇宙構造形成過程のシミュレーション。
未知の暗黒エネルギー73% と暗黒物質23%を仮定すると、観測されている
現在の宇宙構造がうまく再現できる。

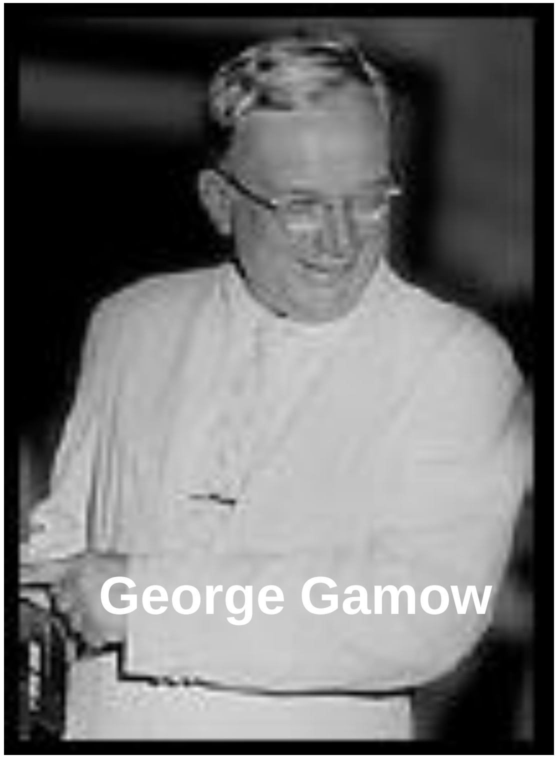
目的

「SUSY素粒子 Gravitino＝暗黒物質」仮説をビッグバン元素合成で検証する。



U.S. National Academy of Science Report "Connecting Quarks with the Cosmjos: Eleven Science Questions for the New Century"

George Gamow's predictions in 1948



1. If the Universe began from the Fire Ball of hot Big-Bang and then expanded, we can detect today the **Cosmic Background Radiation of T = 5 K !**

   — 2.7K CBR was discovered by Penzias & Wilson (1965)

   — CMB anisotropies by Smoot & Mathar (1992)

2. In the early hot Big-Bang Universe were created (hopefully) almost all **atomic nuclides** !

   ^{4}He & ^{7}Li, discovered by astronomers (1980')

Observational Signature ⟶ Big-Bang Nucleosynthesis !

The Power of BBN is that the Physics is Accessible

Thermodynamic Equilibrium of Particles and Nuclei

$$n_i(p)dp = \frac{1}{2\pi^2} g_i \, p^2 \left[\exp\left(\frac{E_i(p)-\mu_i}{kT}\right) \pm 1\right]^{-1} dp$$

$$\rho_i = \int p\left[n_i(p) + n_{\bar{i}}(p)\right] dp$$

$$\rho_\gamma = \frac{\pi^2}{15}(kT_\gamma)^4 \quad , \quad \rho_{\nu_i} = \frac{7}{8}\frac{\pi^2}{15}(kT_\nu)^4$$

$$\rho = \rho_\gamma + \rho_{\nu_i} + \rho_i = \frac{\pi^2}{30} g_{eff}(kT)^4$$

$$g_{\text{eff}}(T) = \sum_{\text{bose}} g_{\text{bose}} + \frac{7}{8}\sum_{\text{fermi}} g_{\text{fermi}}$$

Cosmic Expansion

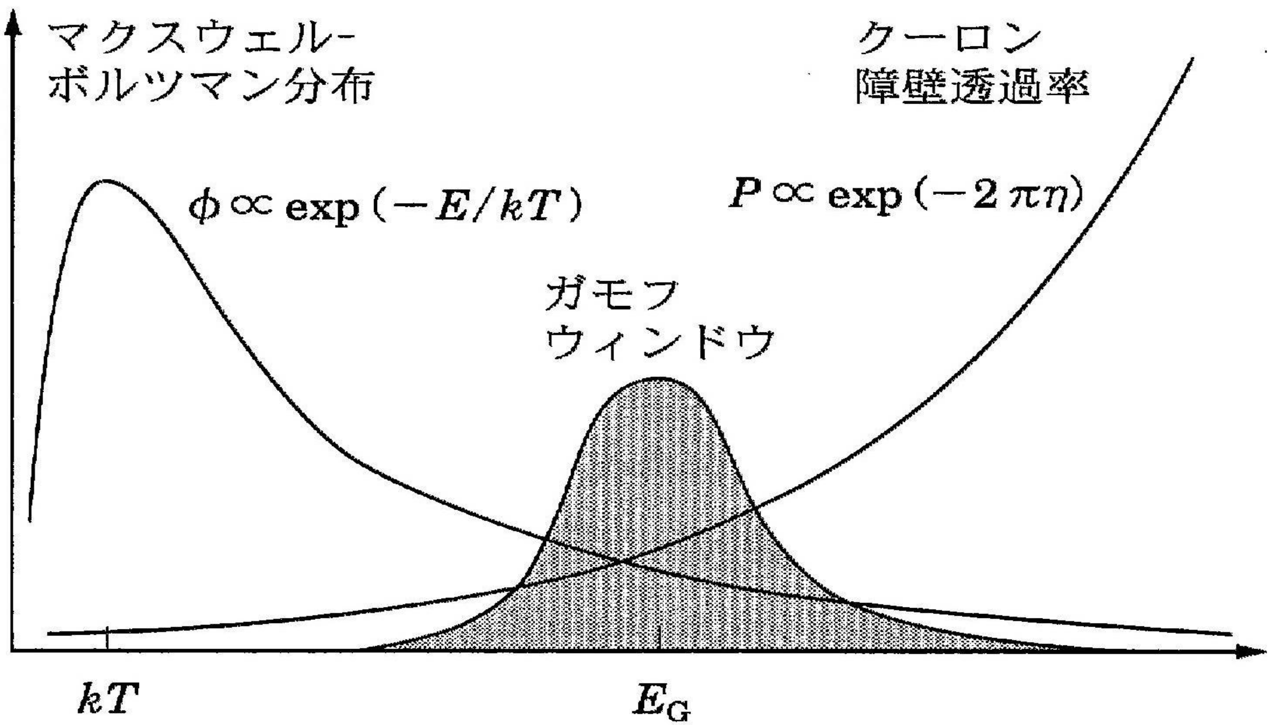
$$H^2(t) = \left(\frac{1}{R}\frac{dR}{dt}\right)^2 = \frac{8\pi G}{3}\rho + \frac{\Lambda}{3} - \frac{k}{R^2}$$

Nuclear Reactions

$$\frac{dY_i}{dt} = \sum_{ijk} N_i \left(\frac{Y_l^{N_l} Y_k^{N_k}}{N_l! N_k!} \langle n_k \sigma_{lk} v \rangle - \frac{Y_i^{N_i} Y_j^{N_j}}{N_i! N_k!} \langle n_j \sigma_{ij} v \rangle \right)$$

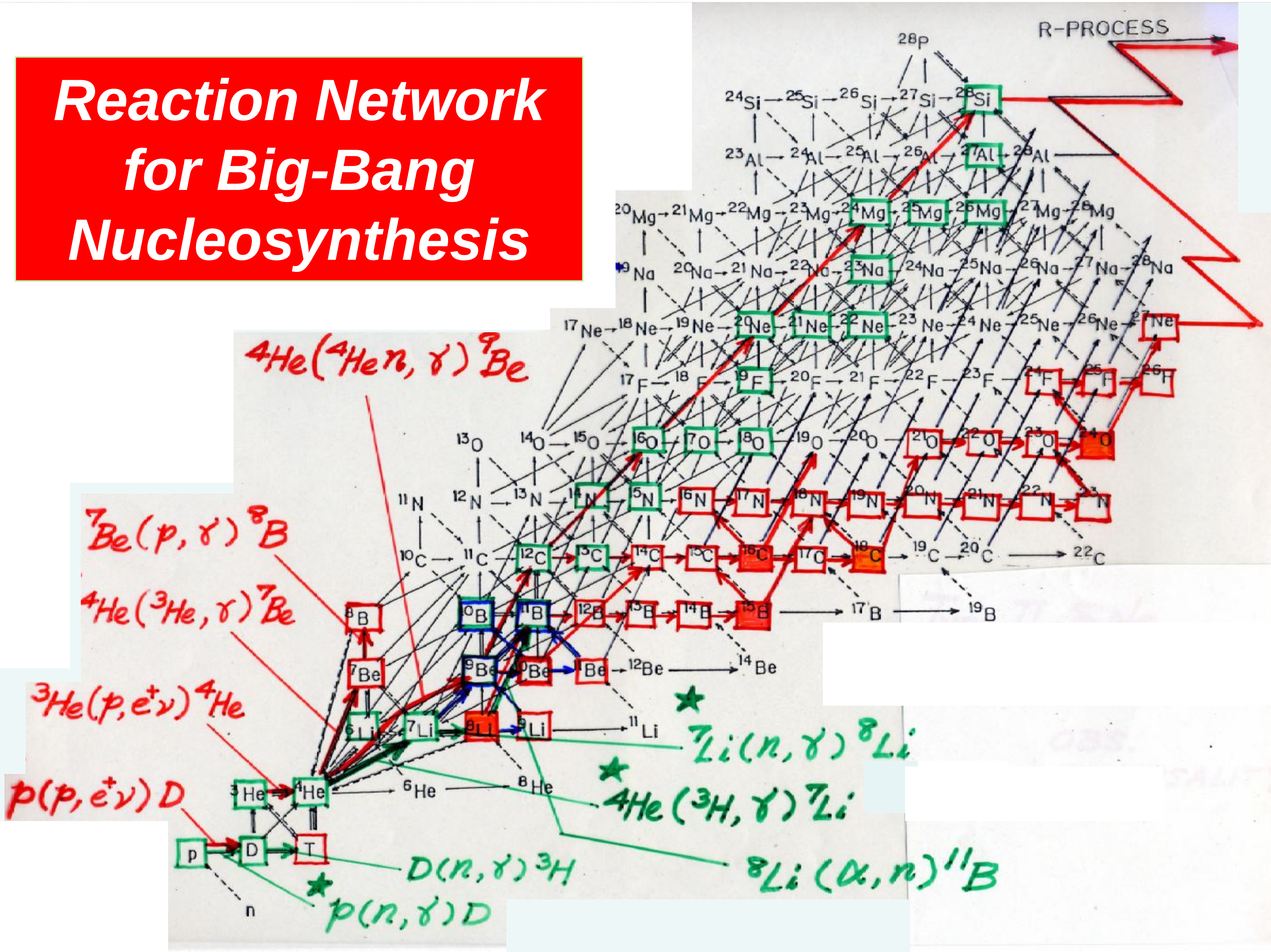
$$\sigma(E) = \frac{S(E)}{E}\exp(-2\pi\eta)$$

$$\langle \sigma v \rangle = \left(\frac{8}{\pi\mu}\right)^{1/2} \frac{1}{(kT)^{3/2}} \int S(E)\exp(-2\pi\eta)\exp(-E/kT)dE$$

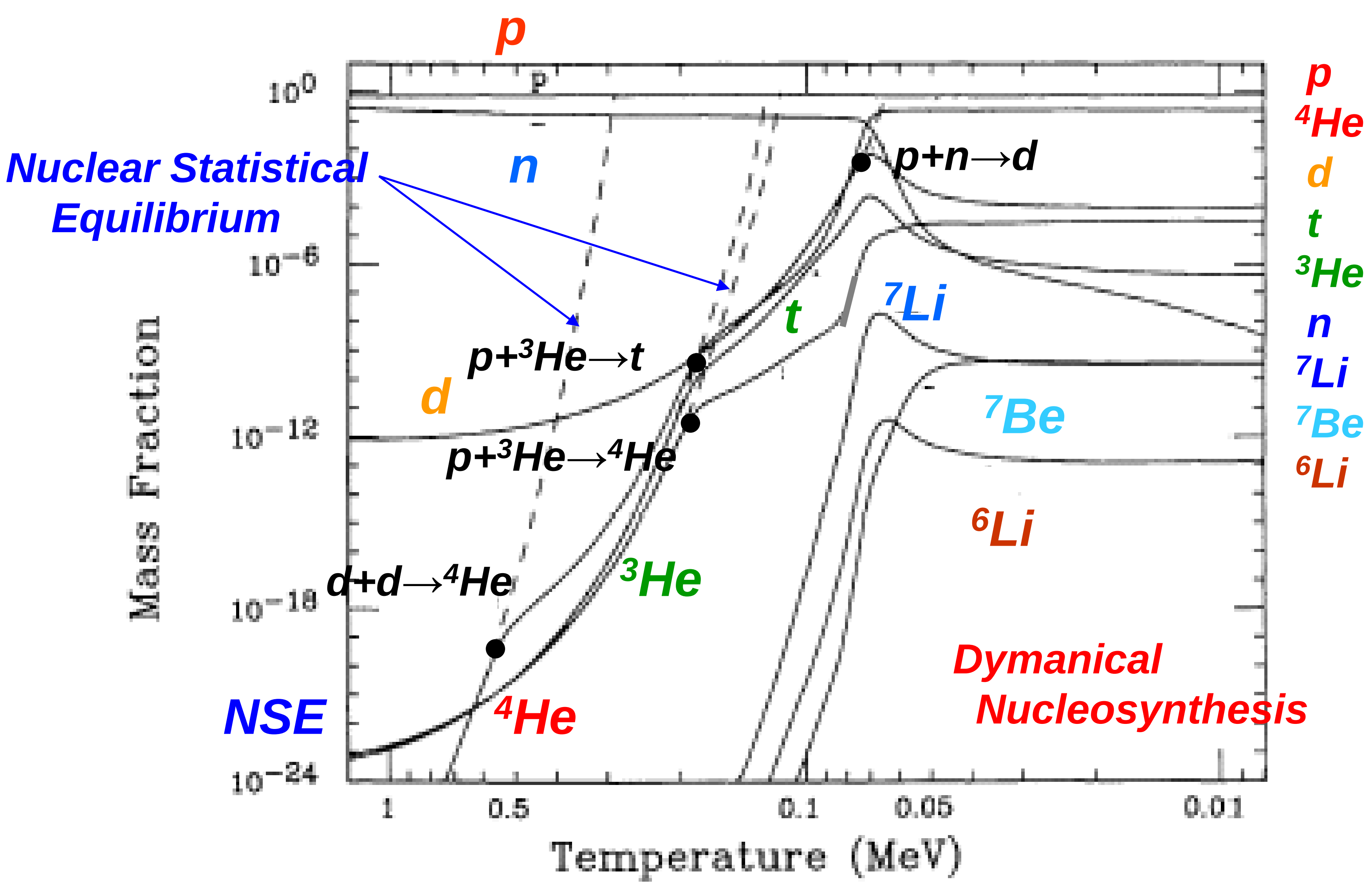


$$E_G = \left(\frac{\mu}{2}\right)^{1/3} \left(\frac{\pi Z_A Z_a e^2 kT}{\hbar}\right)^{2/3}$$

Reaction Network for Big-Bang Nucleosynthesis



Evolution of Abundances



Nuclear Statistical Equilibrium (NSE)

$$Z\,p + N\,n \longleftrightarrow A(Z,N) + \gamma$$

$$\underbrace{\text{nuclear mass A is the sum of protons and neutrons A=Z+N}}$$

$$Z\,\mu_p + N\,\mu_n = \mu_A + \mu_\gamma\,(=0)$$

$$Y_A = n_A/n_B = g_A(m_A T/2\pi)^{3/2} \exp\{(\mu_A - m_A)/T\}\,/n_B$$

NSE Equation

Binding Energy of Nucleus A

$$Y_{A(Z,N)} \approx \left[S^{1-A}\right] G \pi^{\frac{1}{2}(A-1)} 2^{\frac{1}{2}(A-3)} A^{3/2} \left(\frac{T}{m_b}\right)^{\frac{3}{2}(A-1)} Y_p^Z Y_n^N e^{Q_A/T}$$

Entropy/Baryon: $S = 10^{+9}$ (in Big-Bang), 10^{+2} (in Supernovae)

H, D, ^{3,4}He, ^{6,7}Li   Fe-Co-Ni

Beryon-to-Photon Ratio, $\eta = n_B/n_\gamma$, vs. Entropy per Baryon, S/k

Entropy density = s

$$s = 2\pi^2/45 \cdot g^* \cdot T^3 + s(NR)$$

$$g^* = \sum_{\text{Bosons}} g_B (T_B/T)^4 + 7/8 \sum_{\text{Fermions}} g_F (T_F/T)^4$$

Photon number density = n_γ

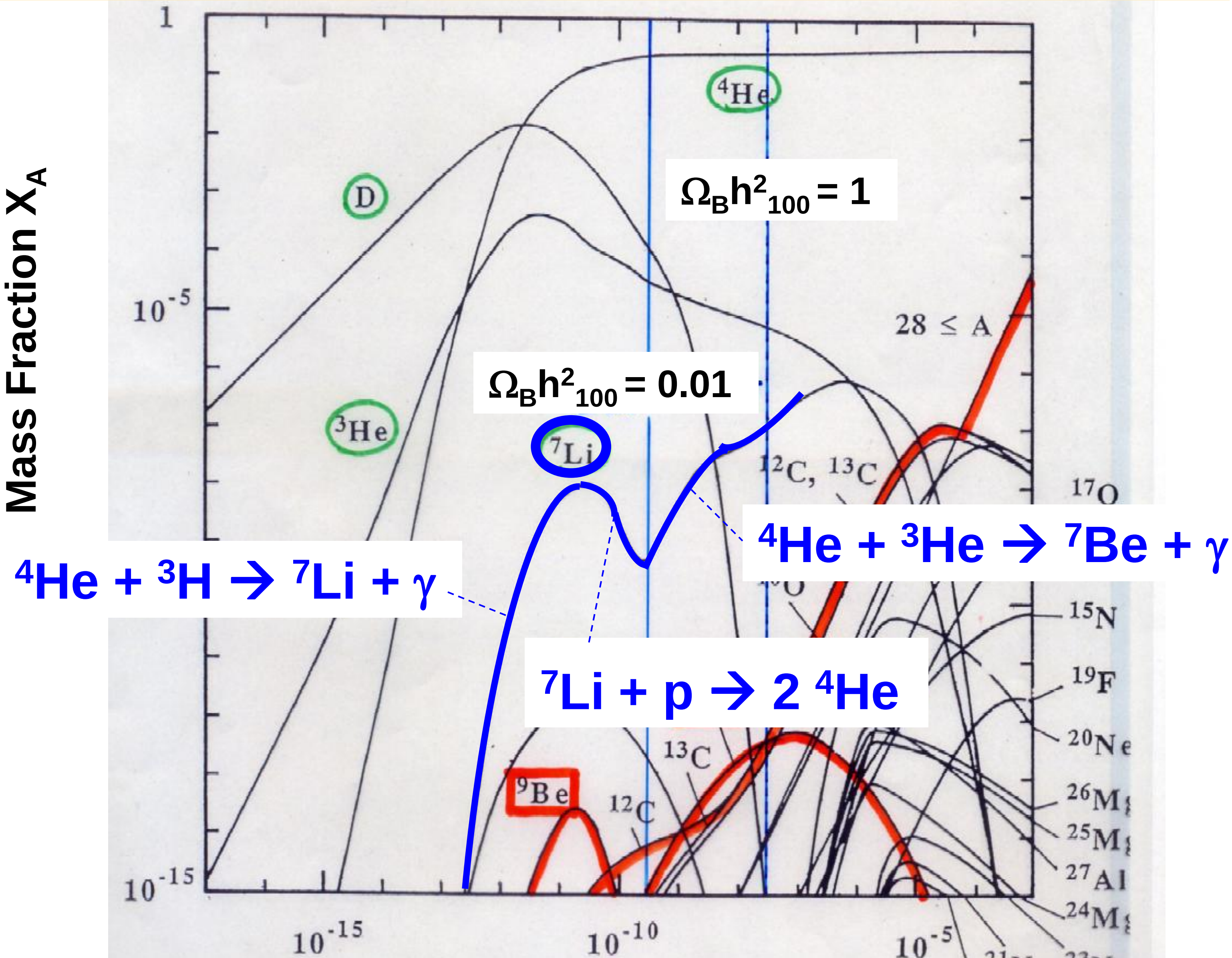
$$n_\gamma = \zeta(3)/\pi^2 \cdot g_\gamma \cdot T^3$$

Entropy per Baryon = S/k

$$S/k = s_\gamma/n_B \doteqdot 3.6\, n_\gamma/n_B = 3.6\, \eta^{-1}$$

Early Universe 10^9 $\eta = n_B/n_\gamma = 10^{-9}$ $\Omega_B h^2 = 3.73\text{x}10^7 \eta$

Big-Bang (Primordial) Nucleosynthesis



$$\eta = n_B/n_\gamma = 2.68 \times 10^{-8}\ \Omega_B h^2_{100}$$

Big-Bang Nucleosynthesis
D, ^{3}He, ^{4}He and ^{7}Li

Y_p - Extragalactic HII Regions

$0.240 \leq Y_p \leq 0.244$

Izotov & Thuan (2003)

$0.240 \leq Y_p \leq 0.258$

Olive & Skillman (2004)

D - QSO absorption systems

$2.4\times10^{-5} \leq D/H \leq 3.2\times10^{-5}$

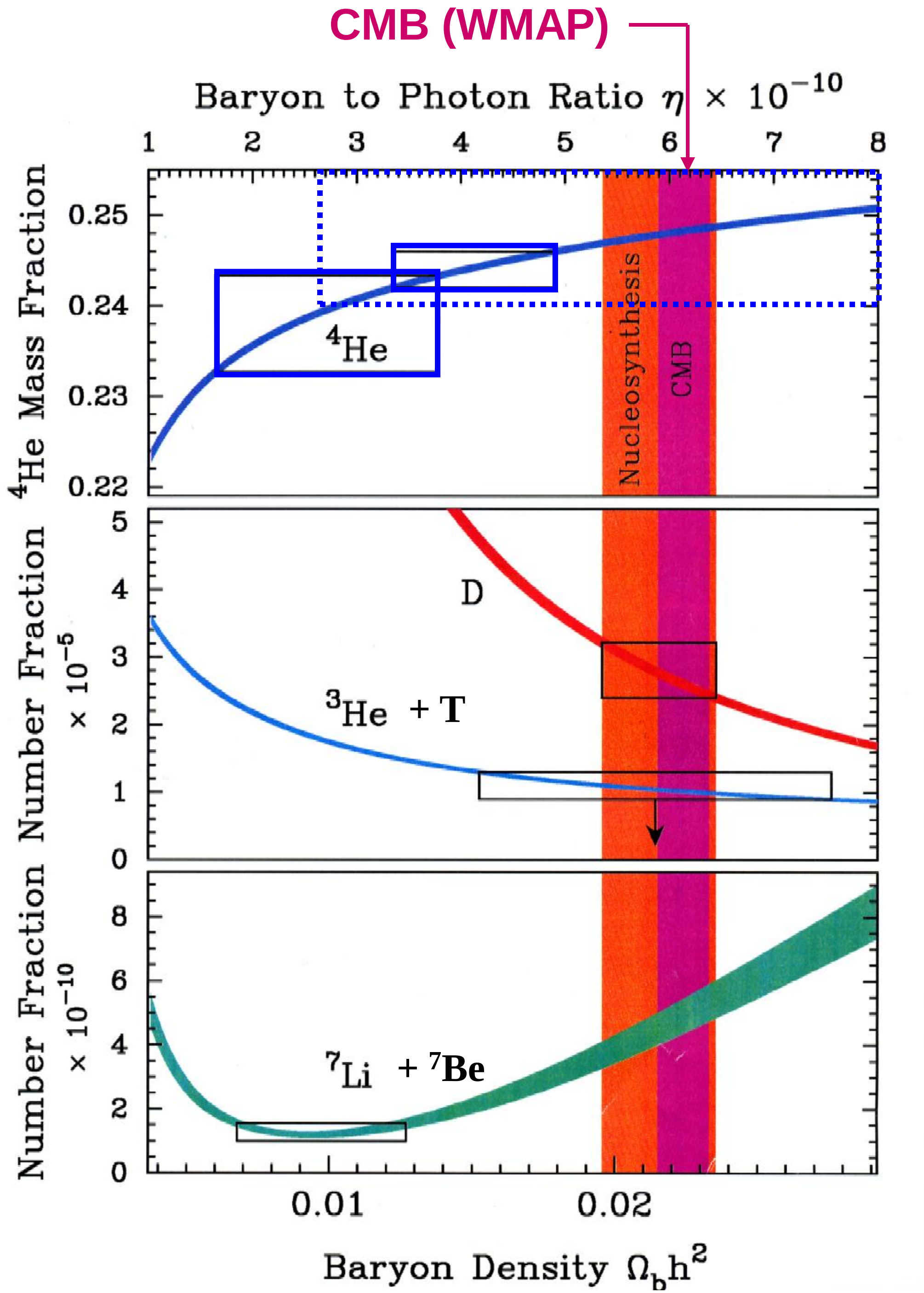
Kirkman et al. (2003)

WMAP

^{7}Li - Halo Stars

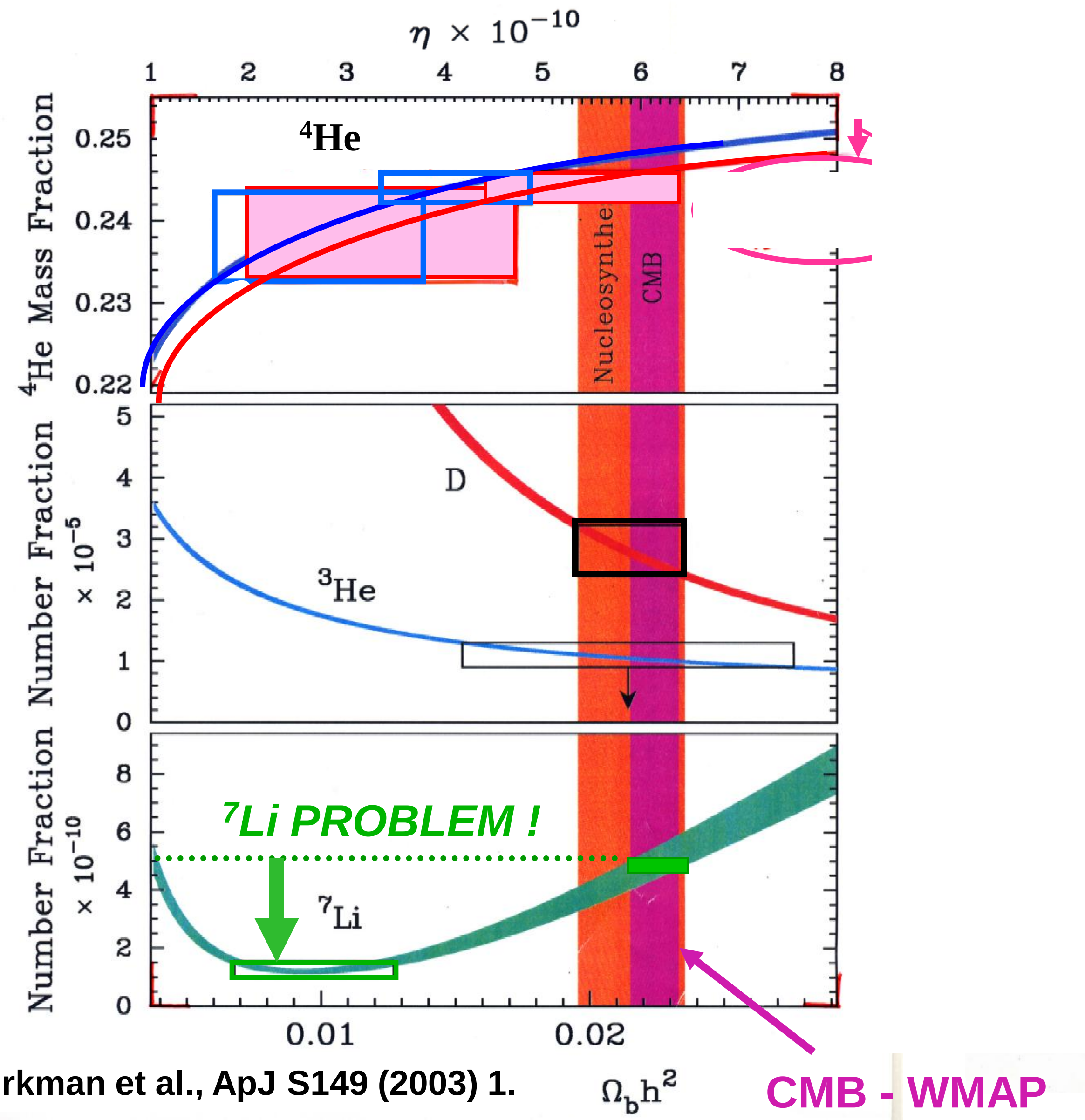
$0.91\text{x}^{-10} \leq {}^7Li/H \leq 1.91\ \text{x}10^{-10}$

Ryan et al. (2000)



BBN and Particle Physics

Smith, Kawano & Malaney, ApJ S85(2003) 219; Mathews, Kajino & Shima, PRD71 (2005) 21302 (R).



Kirkman et al., ApJ S149 (2003) 1.

Effect of Neutro-Life on BBN-^{4}He : $2p + 2n \longrightarrow {}^4He$

Boltzmann distribution

$$n_A = g_A \left(\frac{m_A T}{2\pi}\right)^{3/2} \exp\left(\frac{\mu_A - m_A}{T}\right)$$

Weak Equilibrium until $T \geqq T_d$ (Decoupling Temp.)

$$p + e^- \rightleftarrows n + \nu_e$$

$$\mu_p + \underset{\underset{0}{\wr\wr}}{\mu_e} = \mu_n + \mu_{\nu_e}$$

$$\boxed{r \equiv \frac{n_n}{n_p} = \left(\frac{m_n}{m_p}\right)^{3/2} \exp\left(-\frac{\Delta m}{T_d} - \frac{\mu_{\nu_e}}{T_d}\right) < 1.} \quad \text{—— (1)}$$

^{4}He Synthesis ($2p + 2n \rightarrow {}^4He$)

Approximation : All neutrons ($n_n < n_p$) are interconverted to ^{4}He, and nucleosynthesis quits suddenly when $n_n \approx 0$.

$$\boxed{Y_p \equiv \frac{4n_n}{2n_p + 2n_n} = \frac{2r}{1+r}.} \quad \text{———— (2)}$$

Weak Decoupling Temperature

$$\boxed{T_d^3 = \frac{1.66}{M_{pl}} \times \frac{\sqrt{g_*}}{G_F^2}.} \quad \text{———— (3)}$$

1st effect: $\delta\tau_n \rightarrow \delta T_d \rightarrow \delta(n/p) \longrightarrow \delta(^4He)$

$$(1);\quad \delta r = \frac{\Delta m}{T_d^2} e^{-\frac{\Delta m}{T_d}} \delta T_d = \frac{\Delta m}{T_d^2} r \,\delta T_d$$

$$(2);\quad \delta Y_p = \frac{2}{1+r}\delta r - \frac{2r}{(1+r)^2}\delta r = \frac{Y_p}{r}\left(1 - \frac{Y_p}{2}\right)\delta r$$

$$\therefore \boxed{\delta Y_p = Y_p\left(1 - \frac{Y_p}{2}\right)\left(\frac{\Delta m}{T_d}\right)\left(\frac{\delta T_d}{T_d}\right).} \quad \text{———— (4)}$$

$$\tau_n^{-1} = \Gamma_{n \to p e \bar{\nu}_e} = \frac{G_F^2}{2\pi^3}(1 + 3g_A^2)\, m_e^5 \int_1^q \underbrace{d\epsilon\, \epsilon(\epsilon - q)^2(\epsilon^2 - 1)^{1/2}}_{\approx 1.636}$$

($g_A \approx 1.26$ Axial-vector coupl.)

$$\tau_n \propto G_F^{-2}$$

$$\frac{\delta\tau_n}{\tau_n} = (-2)\frac{\delta G_F}{G_F}$$

$$(3);\quad 3\frac{\delta T_d}{T_d} = (-2)\frac{\delta G_F}{G_F} = \frac{\delta\tau_n}{\tau_n}$$

$$(4);\quad \delta Y_p = \frac{1}{3} Y_p\left(1 - \frac{Y_p}{2}\right)\left(\frac{\Delta m}{T_d}\right)\left(\frac{\delta\tau_n}{\tau_n}\right) \longrightarrow \boxed{\frac{\left(\frac{\delta Y_p}{Y_p}\right)}{\left(\frac{\delta\tau_n}{\tau_n}\right)} \approx 0.3\ !}$$

2nd effect: $\delta\tau_n \rightarrow \delta n \longrightarrow \delta(^4He)$

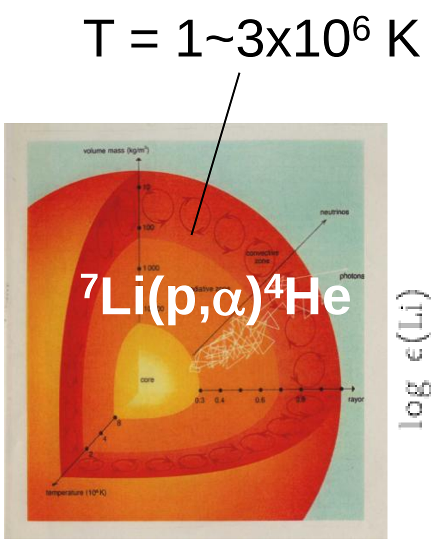
Freezeout time of $p + n \rightleftarrows D + \gamma$ changes.

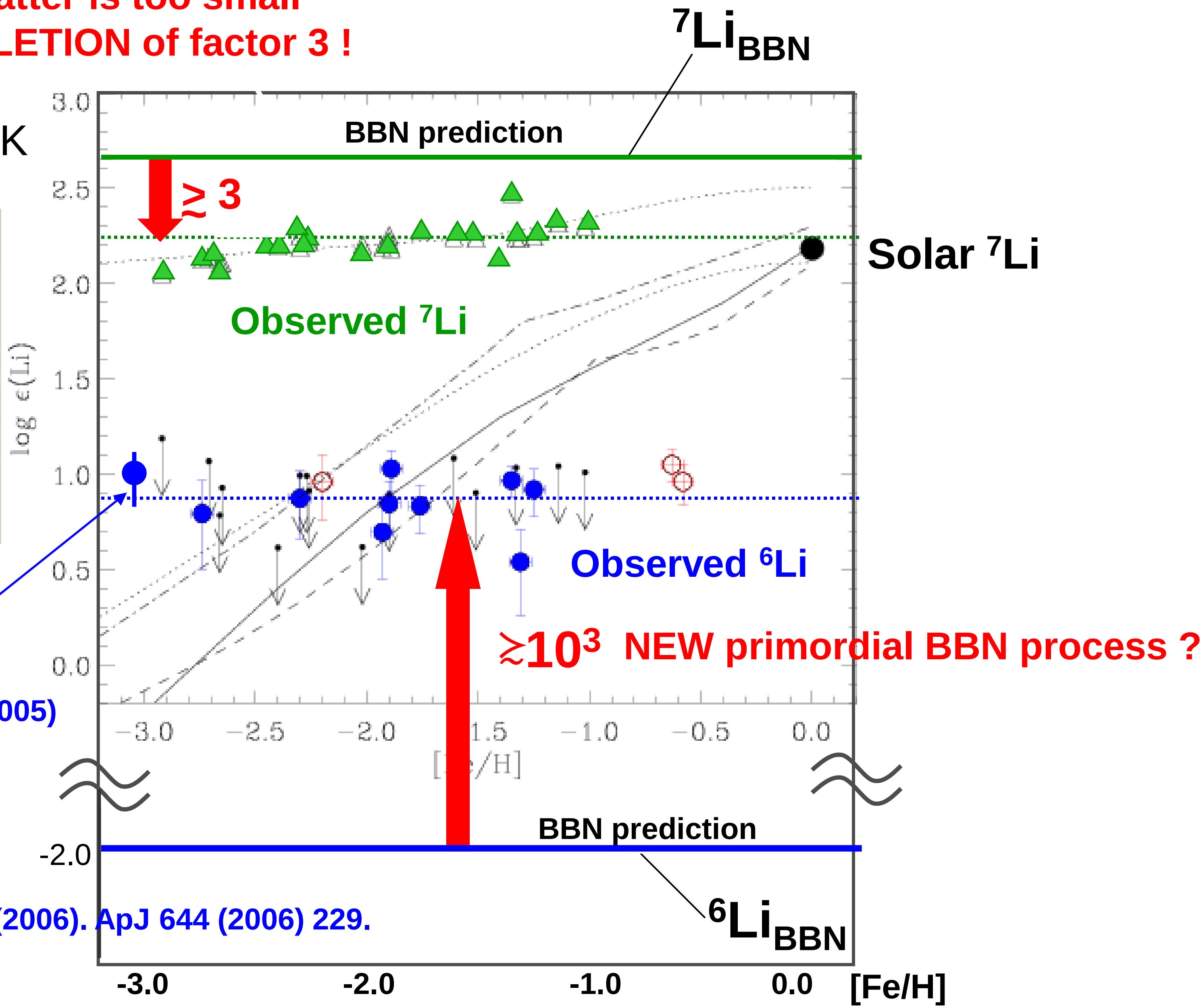
NET EFFECT:

$$\boxed{\delta\tau_n < 0 \longrightarrow \delta(^4He) < 0}$$

Plateau like HIGH ^{6,7}Li ABUNDANCE --- primordial ?

Abundance scatter is too small
to accept DEPLETION of factor 3 !





SUBARU OBS.
Inoue, Aoki et al (2005)

Asplund et al. (2006). ApJ 644 (2006) 229.

How to solve HIGH ^{6}Li primordial abundance?

Ellis et al. (1986); Moroi and Kawasaki (1994); Jedamzik PRL 84 (2000) 3248;
Cyburt et al., PRD 67 (2003) 103521; Ellis et al. PLB619 (2005) 30;
Kusakabe, Kajino & Mathews, D74 (2006), 023526, PR D76 (2007) 121302(R);
ApJ 680 (2008) 846

Cosmological Solution

1st possibility: SUSY Leptonic DM particles (Stau) X^{+-} are bound to ^{4}He, ^{7}Li, ^{7}Be and catalize new BBN:

$$^{4}\mathrm{He}_{X}(d,X^{-})^{6}\mathrm{Li}, \qquad ^{7}\mathrm{Be}_{X}(p,\gamma)^{8}\mathrm{B}_{X}$$

2nd possibility: Decaying relic DM particles X decay to non-th γ's:

$$^{4}\mathrm{He}(\gamma_{NT},n)^{3}\mathrm{He}(^{4}\mathrm{He},p)^{6}\mathrm{Li},$$

$$^{4}\mathrm{He}(\gamma_{NT},p)^{3}\mathrm{H}(^{4}\mathrm{He},n)^{6}\mathrm{Li}.$$

SUSY-CDM Model

stau (scalar tau) ($\tilde{\tau}$) ⟹ $X^{+/-}$

1) Supersymmetry partner (boson) of the tau-lepton (fermion)

stau (spin = 0)

2) Gravitino = a candidate of the lightest SUSY particle (LSP)

(Fermion partner of the graviton, a cadidate for CDM)

Then, the next lightest SUSY particle (NLSP) **stau decays!**

3) lifetime ~ $\tau_X > 10^3$ sec (decay to gravitino)

mass ~ m_X of order 100 GeV

4) charged lepton ; Coulombic interaction and weak interaction

stau is expected to be discovered at **LHC** at the early stage after the first beam.

A

Binding energy of A_X

nuclide	r_c^{RMS} (fm)	Reference	E_{Bind} (MeV)
^{1}H	0.875 ± 0.007	Yao et al. (2006)	0.025
^{2}H	2.116 ± 0.006	Simon et al. (1981)	0.049
^{3}H	1.755 ± 0.086	TUNL Nuclear Data Evaluation	0.072
^{3}He	1.959 ± 0.030	TUNL	0.268
^{4}He	1.80 ± 0.04	Tanihata et al. (1988)	0.343
^{6}Li	2.48 ± 0.03	Tanihata	0.806
^{7}Li	2.43 ± 0.02	Tanihata	0.882
^{8}Li	2.42 ± 0.02	Tanihata	0.945
^{6}Be	2.52 ± 0.02	We took ^{7}Be radius	1.234
^{7}Be	2.52 ± 0.02	Tanihata	1.324
^{8}Be	2.52 ± 0.02	We took ^{7}Be radius	1.401
^{9}Be	2.50 ± 0.01	Tanihata	1.477
^{7}B	2.68 ± 0.12	We took ^{8}B radius	1.752
^{8}B	2.68 ± 0.12	Fukuda et al. (1988)	1.840
^{9}B	2.68 ± 0.12	We took ^{8}B radius	1.917

$^{4}He\,X$

$^{7}Be\,X$

Binding energies of X-nuclei like ${}^4He_X$

Assumptions

- X^- has spin 0, charge -e, mass m_X>>1 GeV
- Nuclides have Gaussian charge distributions.

$$\rho(r) = Ze(\pi r_0{}^2)^{-3/2} \exp(-r^2/r_0{}^2)$$

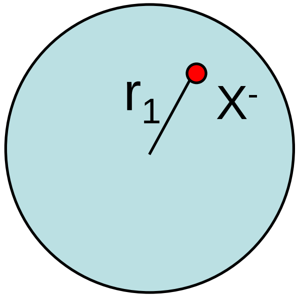
$$r_0{}^2 = \frac{2}{3}\left\langle r_c{}^2 \right\rangle$$

mean square charge radius

Two-body Schrödinger equation

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V(r) - E\right]\psi_{lm}(\mathbf{r}) = 0$$

$$V(r_1) = \int_0^{r_1} \rho(r)\frac{e}{r_1} d^3r = \frac{Ze}{r_1}\mathrm{erf}(r_1/r_0)$$



nuclide A

Gaussian expansion method, Kamimura, Kii & Hiyama et al. (2003)

Cosmological Solution

SUSY Leptonic DM (Stau)

$^{4}He_{X}(d,X^{-})^{6}Li$

$^{7}Be_{X}(p,\gamma)^{8}B_{X}$

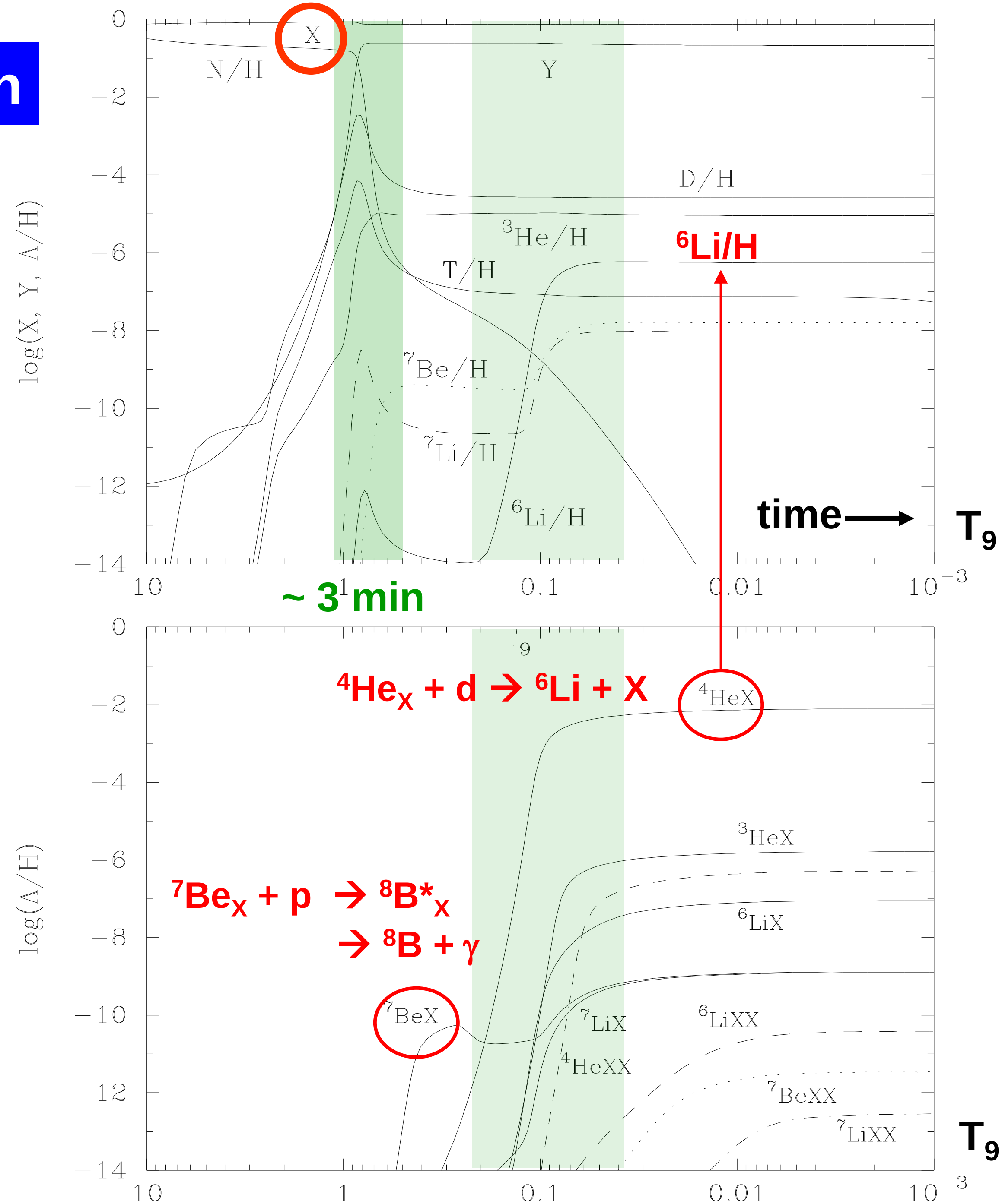
Kusakabe, Kajino, Boyd, Yoshida, and Mathews, Phys. Rev. D (2008)

Pospelov (2007)
Hamaguchi et al. (2007)
Bird et al. (2007)

Decaying relic DM X

$^{4}He(\gamma_{NT},n)^{3}He(^{4}He,p)^{6}Li$

$^{4}He(\gamma_{NT},p)^{3}H(^{4}He,n)^{6}Li$



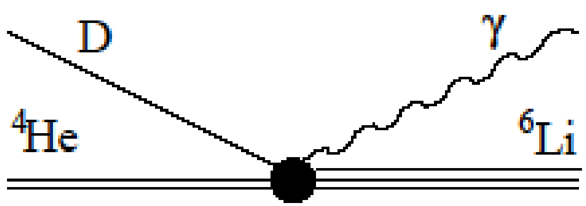
Quest for Nuclear Physics

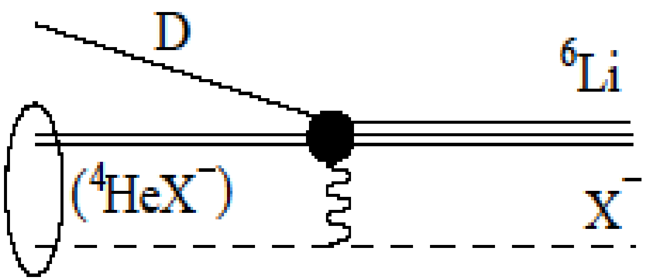
Stau-catalyzed ^{6}Li production in big-bang nucleosynthesis

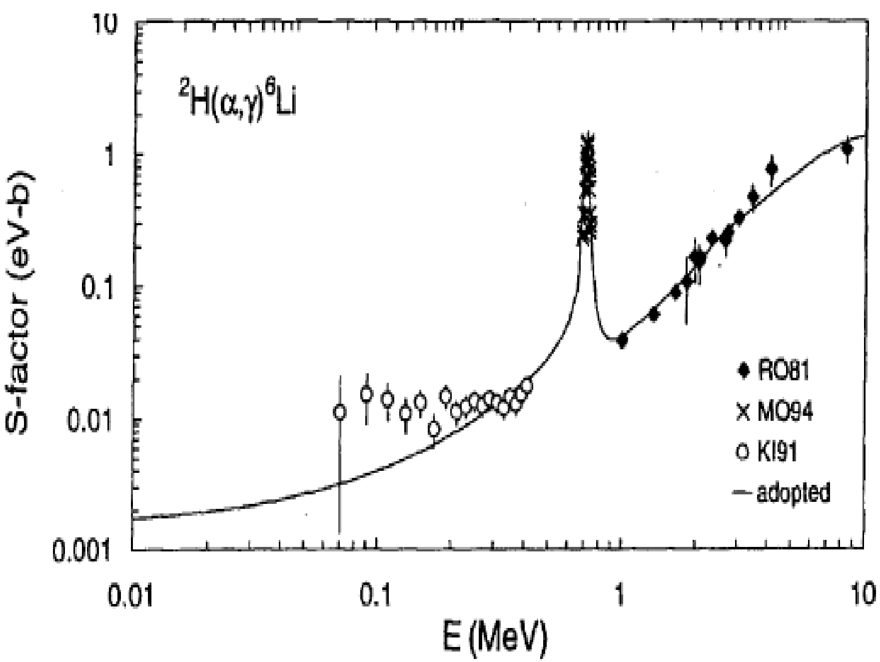
K. Hamaguchi [a,*], T. Hatsuda [a], M. Kamimura [b], Y. Kino [c], T.T. Yanagida [a]

Physics Letters B 650 (2007) 268–274

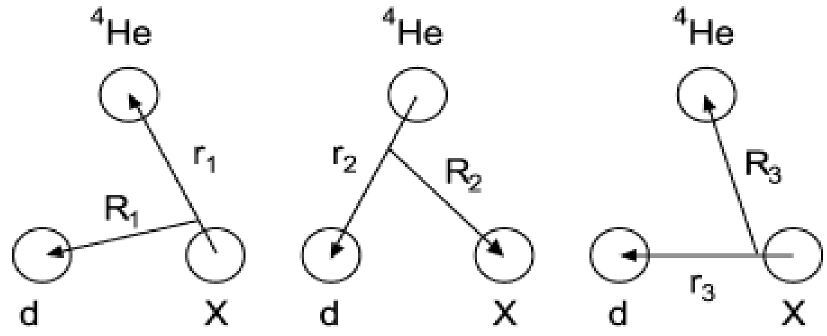
Radiative Fusion Reaction → **X-Breakup Fusion**



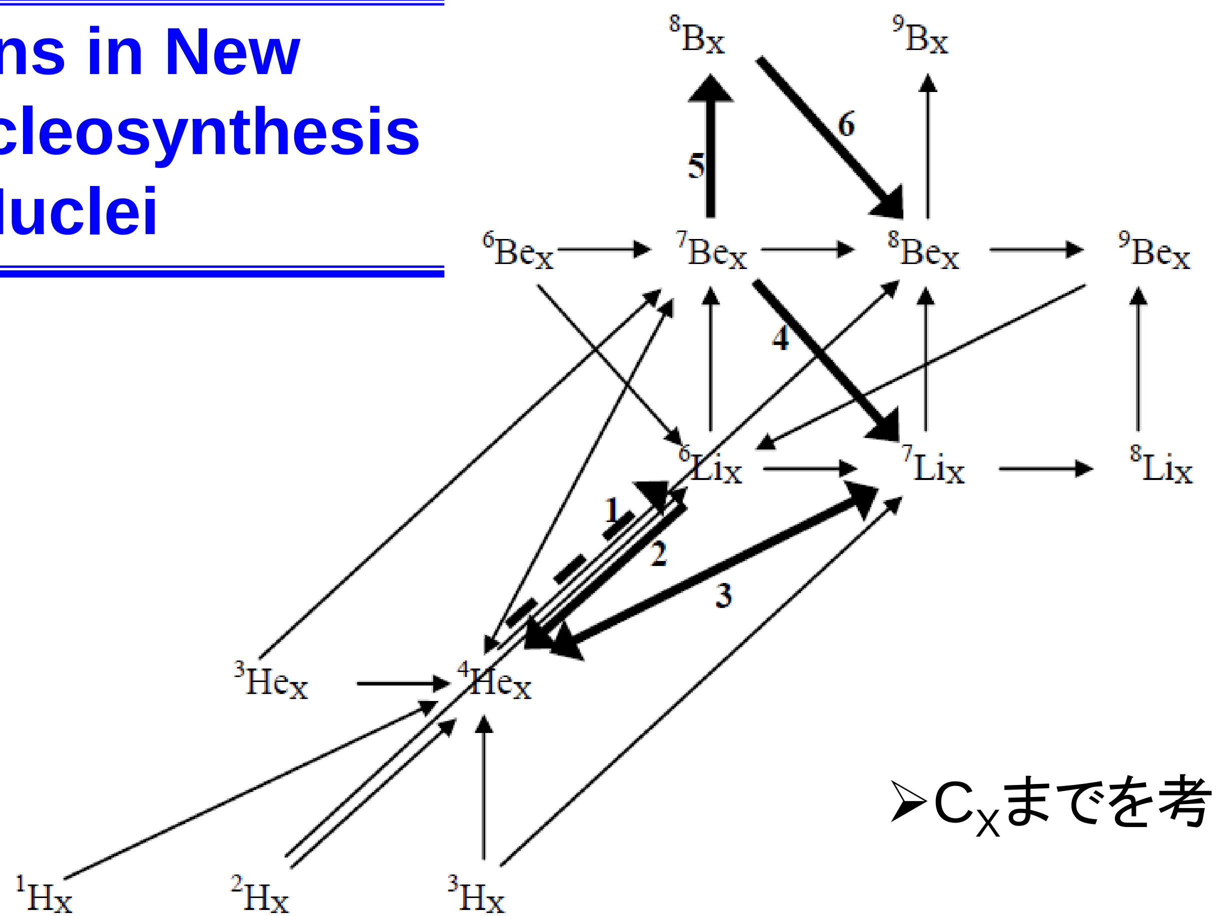




Three-Body Clustering Wave Function



Main Reactions in New Big-Bang Nucleosynthesis including X-Nuclei



➢C_Xまでを考慮

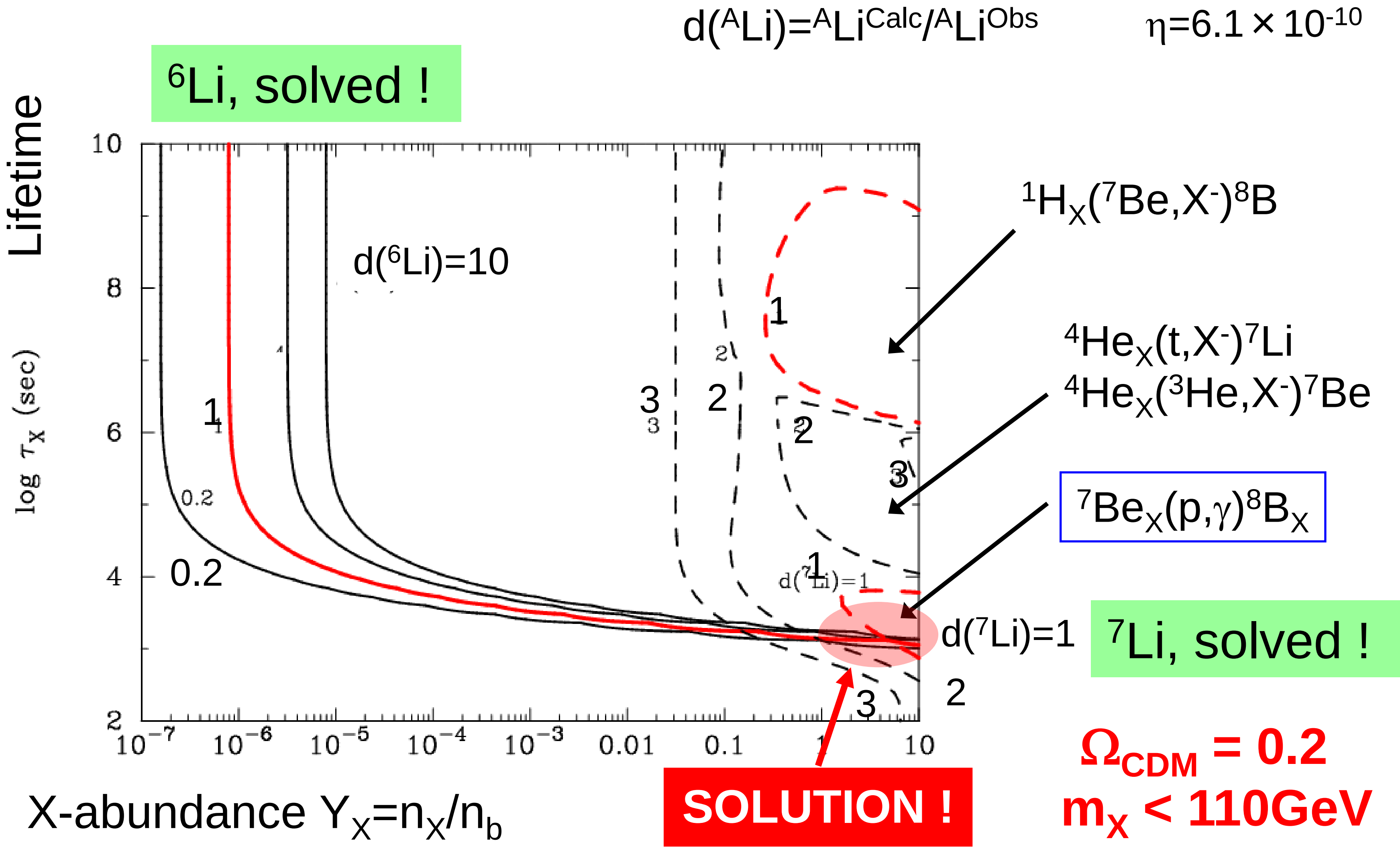
重要な過程

1. $^4He_X(d,X^-)^6Li$
2. $^6Li_X(p,^3He\ \alpha)X^-$
3. $^4He_X(t,\gamma)^7Li_X$ & $^7Li_X(p,2\alpha)X^-$
4. $^7Be_X(,X^0)^7Li$
5. $^7Be_X(p,\gamma)^8B_X$
6. $^8B_X(,e^+\nu_e)^8Be_X$

✓X^-再結合: 16
✓X核反応: 59
（含β崩壊: 2）
✓X^-荷電移行: 3
✓X-decay: 11

Cosmological Solution to both $^{6,7}Li$ problems

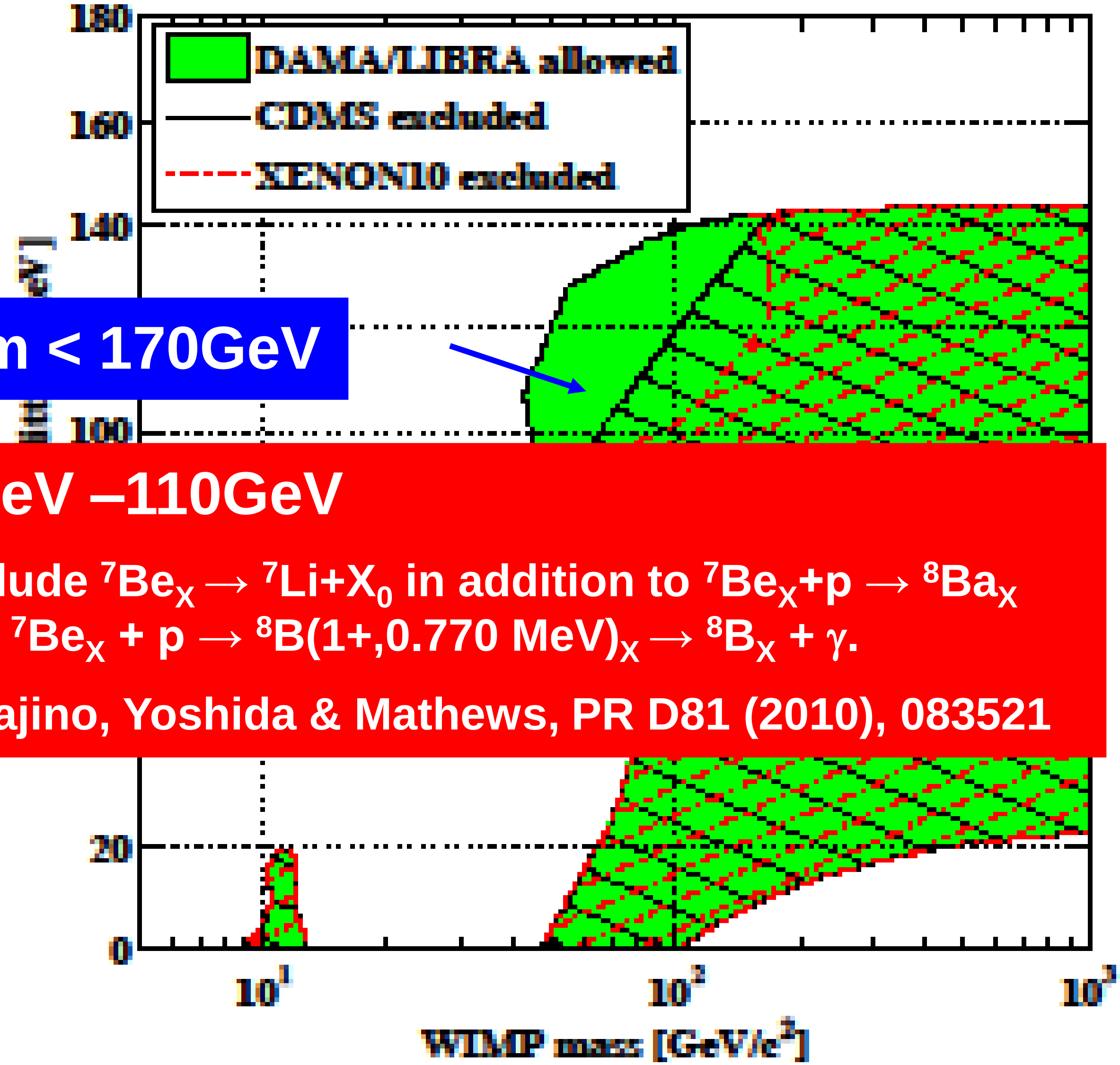
Kusakabe, Kajino, Boyd, Yoshida, and Mathews ApJ 680 (2008), 846: PRD 80 (2009), 103501.
80, 103501 (2009)



Results from the Final Exposure of the CDMS II Experiment

Z. Ahmed et al.
(CDMS Collaboration)

arXiv:0912.3592v1

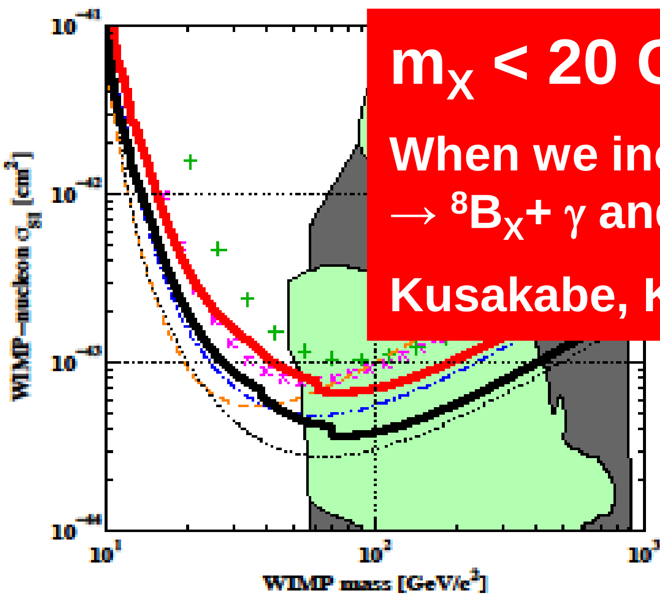


40GeV < m < 170GeV

m_X < 20 GeV –110GeV

When we include $^7Be_X \rightarrow {}^7Li + X_0$ in addition to $^7Be_X + p \rightarrow {}^8Ba_X \rightarrow {}^8B_X + \gamma$ and $^7Be_X + p \rightarrow {}^8B(1+, 0.770\ \mathrm{MeV})_X \rightarrow {}^8B_X + \gamma$.

Kusakabe, Kajino, Yoshida & Mathews, PR D81 (2010), 083521



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2nd possibility: Decaying relic DM particles X decay to non-th γ's:

$$^4He(\gamma_{NT},n)^3He(^4He,p)^6Li,$$

$$^4He(\gamma_{NT},p)^3H(^4He,n)^6Li.$$

Theoretical of X decay: X → γ_{NT}

Ellis et al. (1986); Moroi and Kawasaki (1994);Jedamzik PRL 84 (2000) 3248; Cyburt et al., PRD 67 (2003) 103521; Ellis et al. PLB619 (2005) 30; Kusakabe, Kajino & Mathews, D74 (2006), 023526.

Spectrum of non-thermal γ_{NT} $p_\gamma(E_\gamma)$

Primary γ_{NT} interacts with CBRs

Pair creation ($\gamma\gamma_{bg} \to e^+e^-$)

Inverse Compton ($e^\pm + \gamma_{bg} \to e^\pm + \gamma$)

Then it degrades its energy by:

Compton scattering ($\gamma + e^\pm_{bg} \to \gamma + e^\pm$)

Bethe−Heitler process (γ+nuclus$_{bg} \to e^+ + e^-$+nucleus)

Photon−photon scattering ($\gamma\gamma_{bg} \to \gamma\gamma$)

Two Parameters

Life time of X τ_X

Number density ∗ Eγ of X

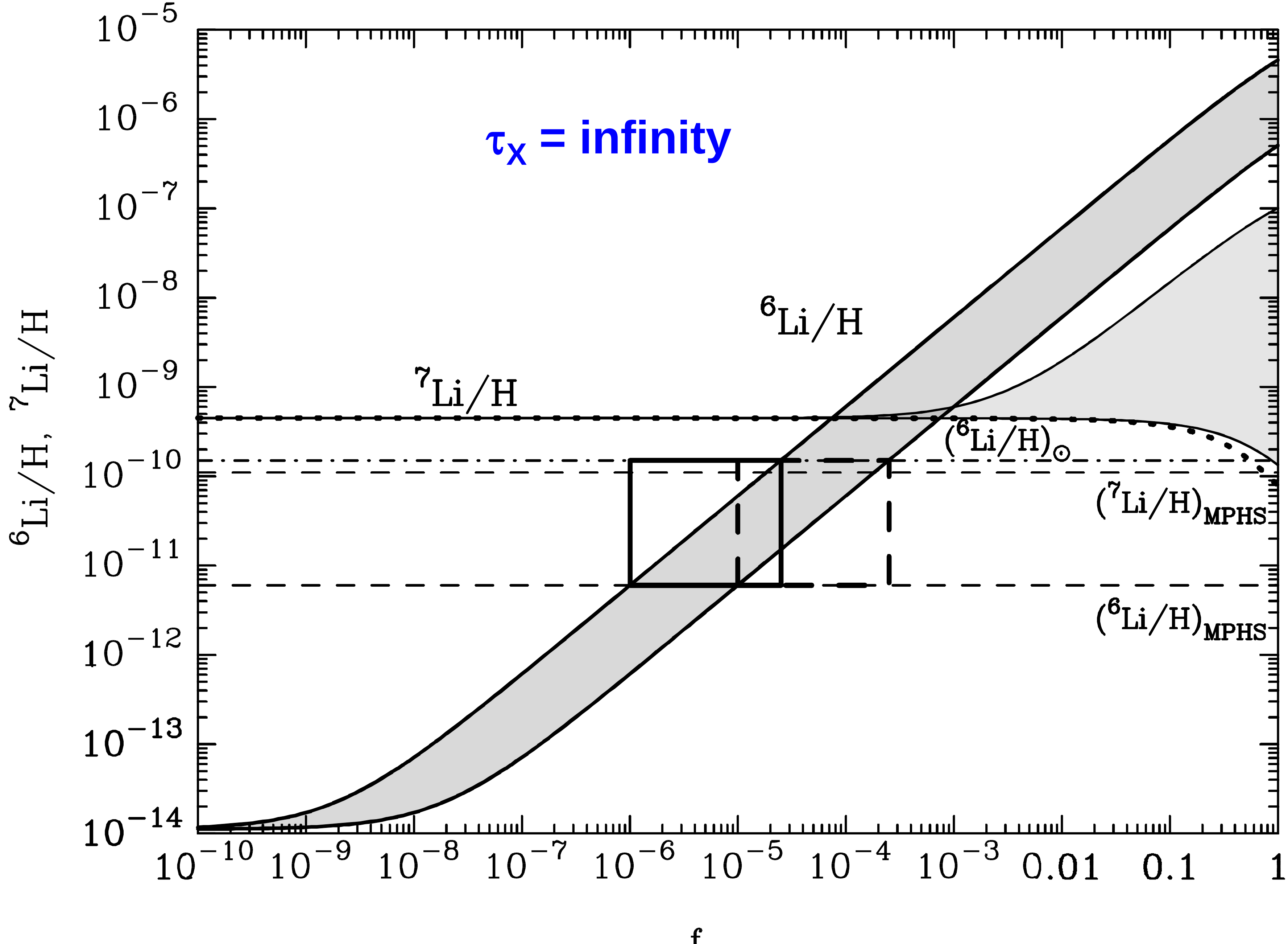
$$\zeta_X = \frac{n_X^0}{n_\gamma^0} E_{\gamma 0}$$

Reaction process

Rate equation
$$\frac{dY_A}{dt} = \sum_P N_A(P)\left(-\frac{Y_A}{N_A(P)!}[A\gamma]_P + \frac{Y_P}{N_P(P)!}[P\gamma]_A \right)$$ + SBBN

$$[A\gamma]_P \equiv \frac{n_\gamma^0 \zeta_X}{\tau_X}\left(\frac{1}{2H_r t}\right)^{3/2} \exp(-t/\tau_X)\int_0^\infty \left(\frac{\tau_X}{E_{\gamma 0} n_X} N_\gamma^{QSE}(E_\gamma)\right)\sigma_{\gamma + A \to P}(E_\gamma)$$

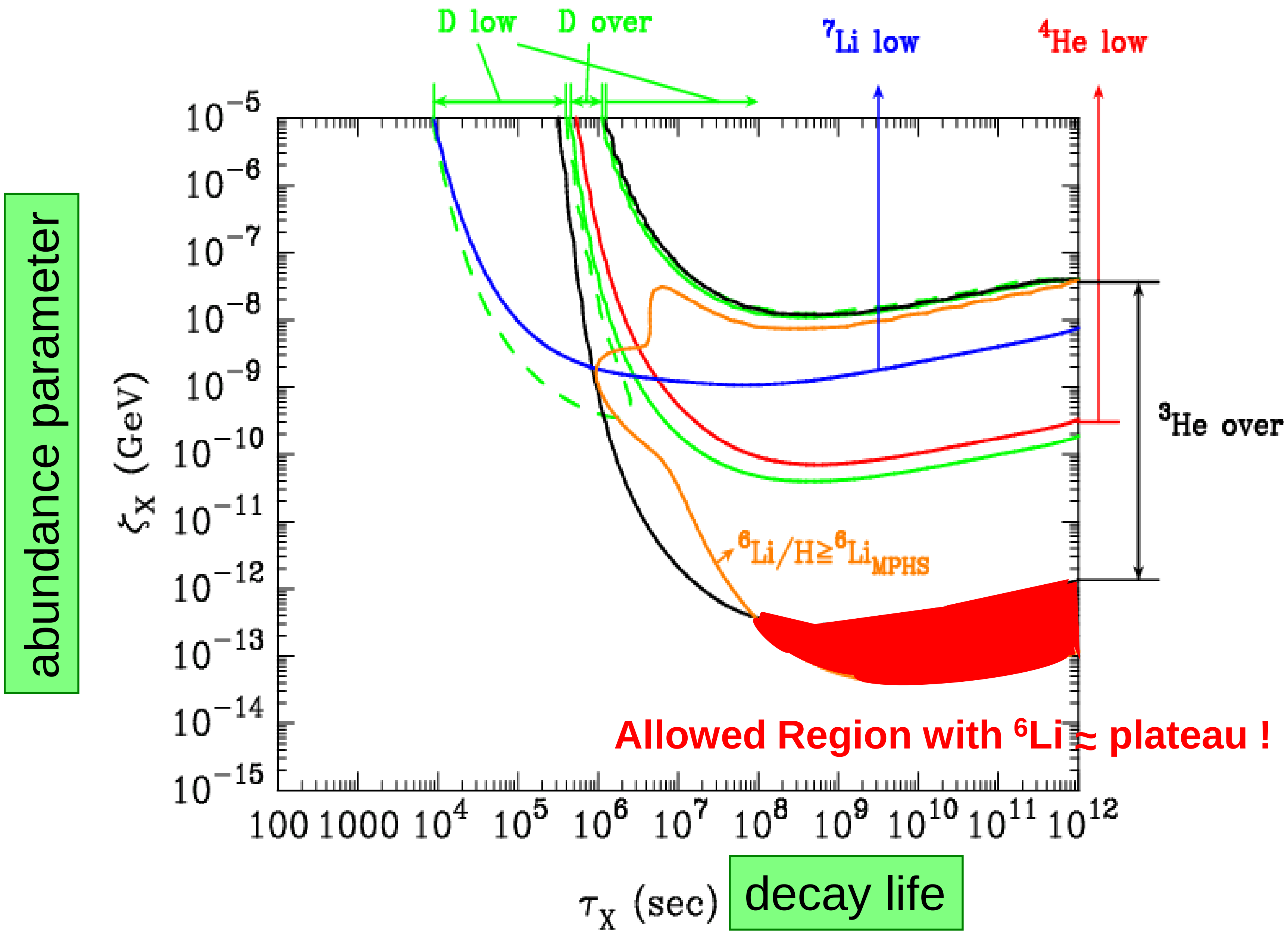
Photon # density
$$N_\gamma^{QSE}(E_\gamma) = \frac{n_X\, p_\gamma(E_\gamma)}{\Gamma_\gamma(E_\gamma)\tau_X} \qquad H_r = \sqrt{\frac{8\pi G \rho_{rad}^0}{3}}$$



τ_X = infinity
^{6}Li/H
^{7}Li/H
$(^6\mathrm{Li/H})_\odot$
$(^7\mathrm{Li/H})_{MPHS}$
$(^6\mathrm{Li/H})_{MPHS}$
^{6}Li/H, ^{7}Li/H
f_X
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
0.01
0.1
1

BBN Light Elemental Abundance Constraints on X particle properties

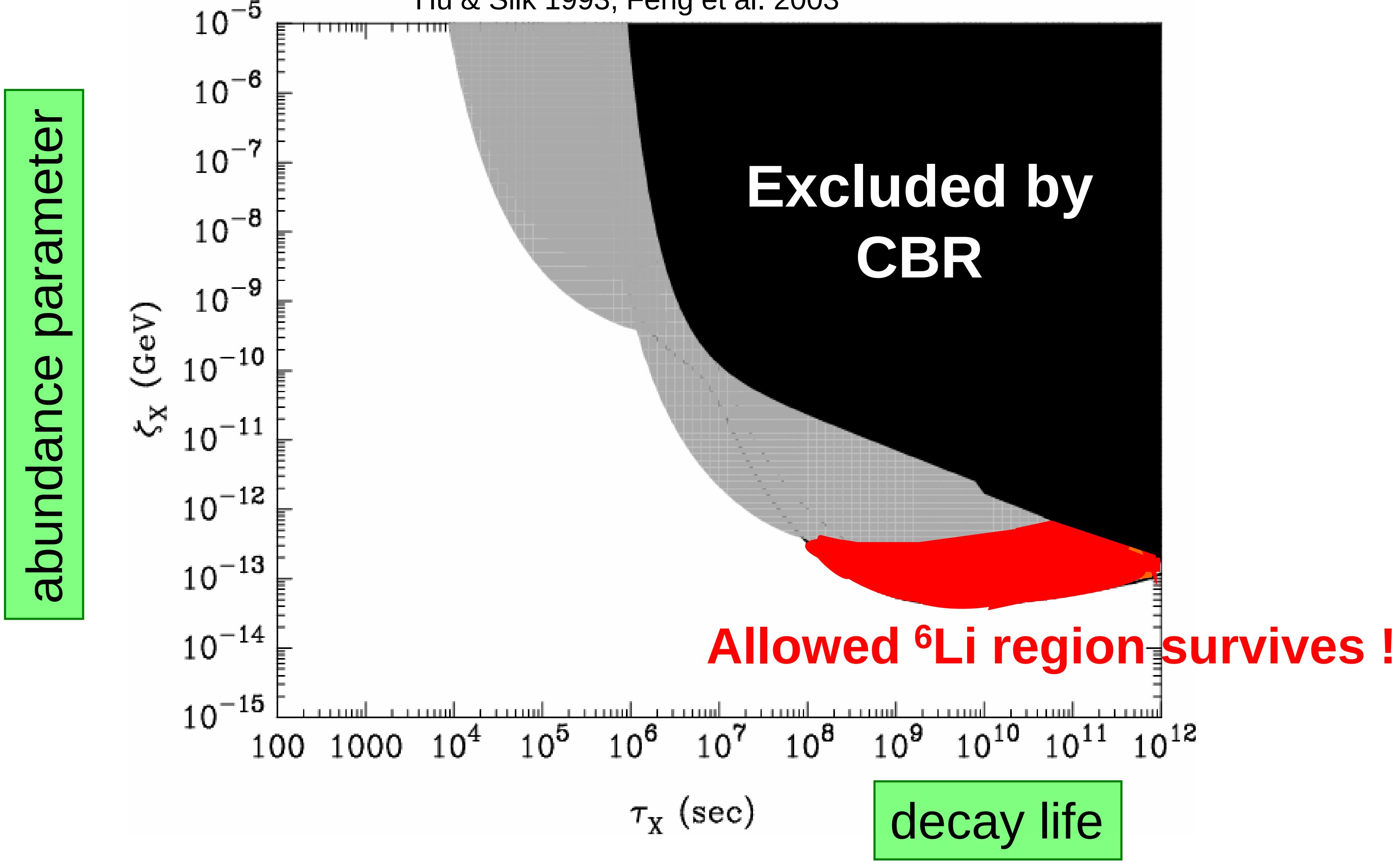
Kusakabe, Kajino & Mathews, Phys. Rev. D74 (2006), 023526.



Constraint from the CBR energy spectrum

Radiative decay causes CBR distortion from black-body distribution by $e^{\pm}\gamma_{BG} \rightarrow e^{\pm}\gamma$ ➡ **Another Constraint**

Hu & Silk 1993, Feng et al. 2003



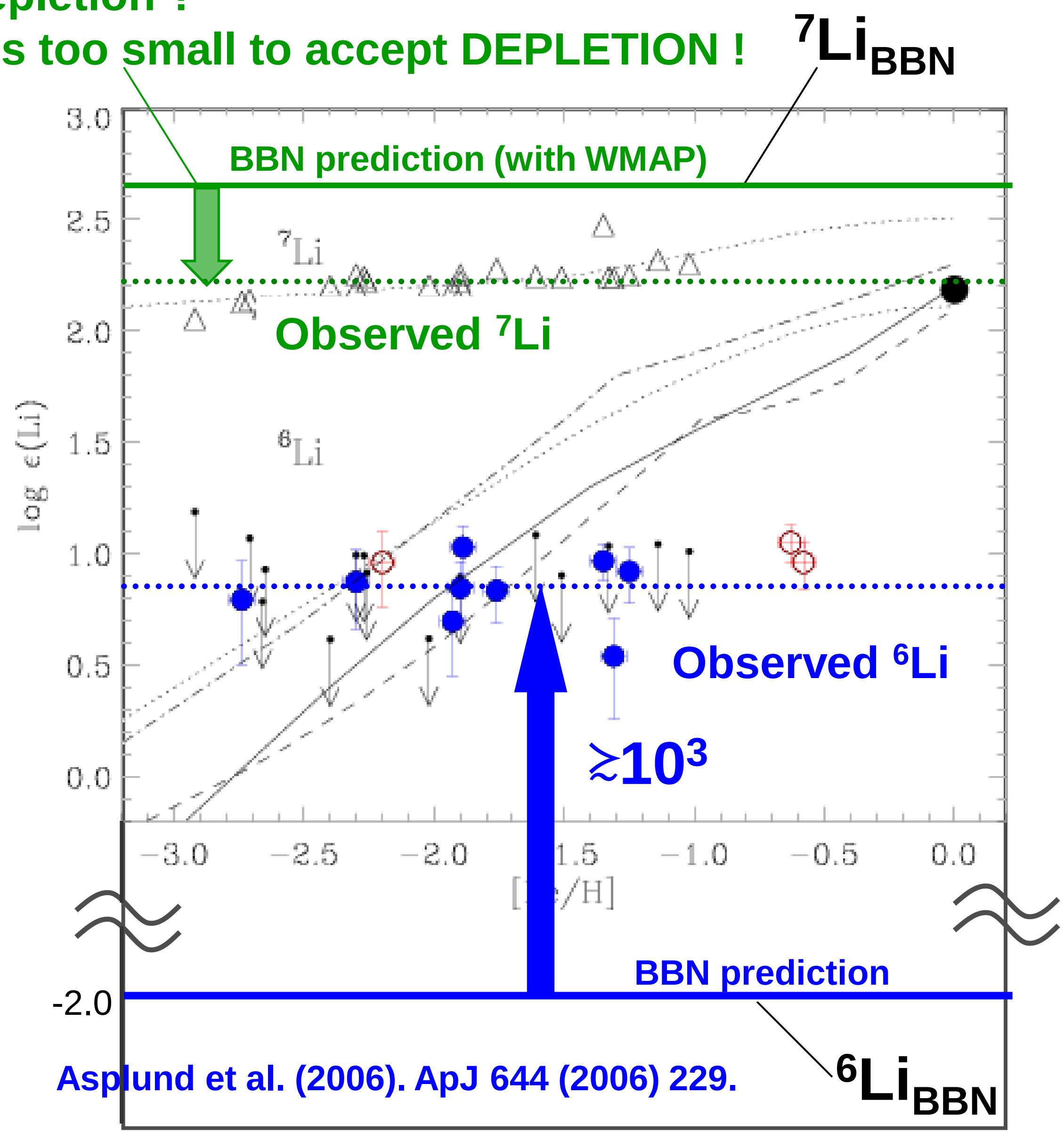
Plateau like HIGH ^{6}Li ABUNDANCE --- primordial ?

Factor 2~4 stellar depletion ?
Abundance scatter is too small to accept DEPLETION !

Cosmological radiative decay of relic CDM X partciles
or
New burst of BBN on leptonic X^--bound nuclei

can resolve
both ^{6}Li+^{7}Li problems!

Relic X = progenitor of CDM



Asplund et al. (2006). ApJ 644 (2006) 229.

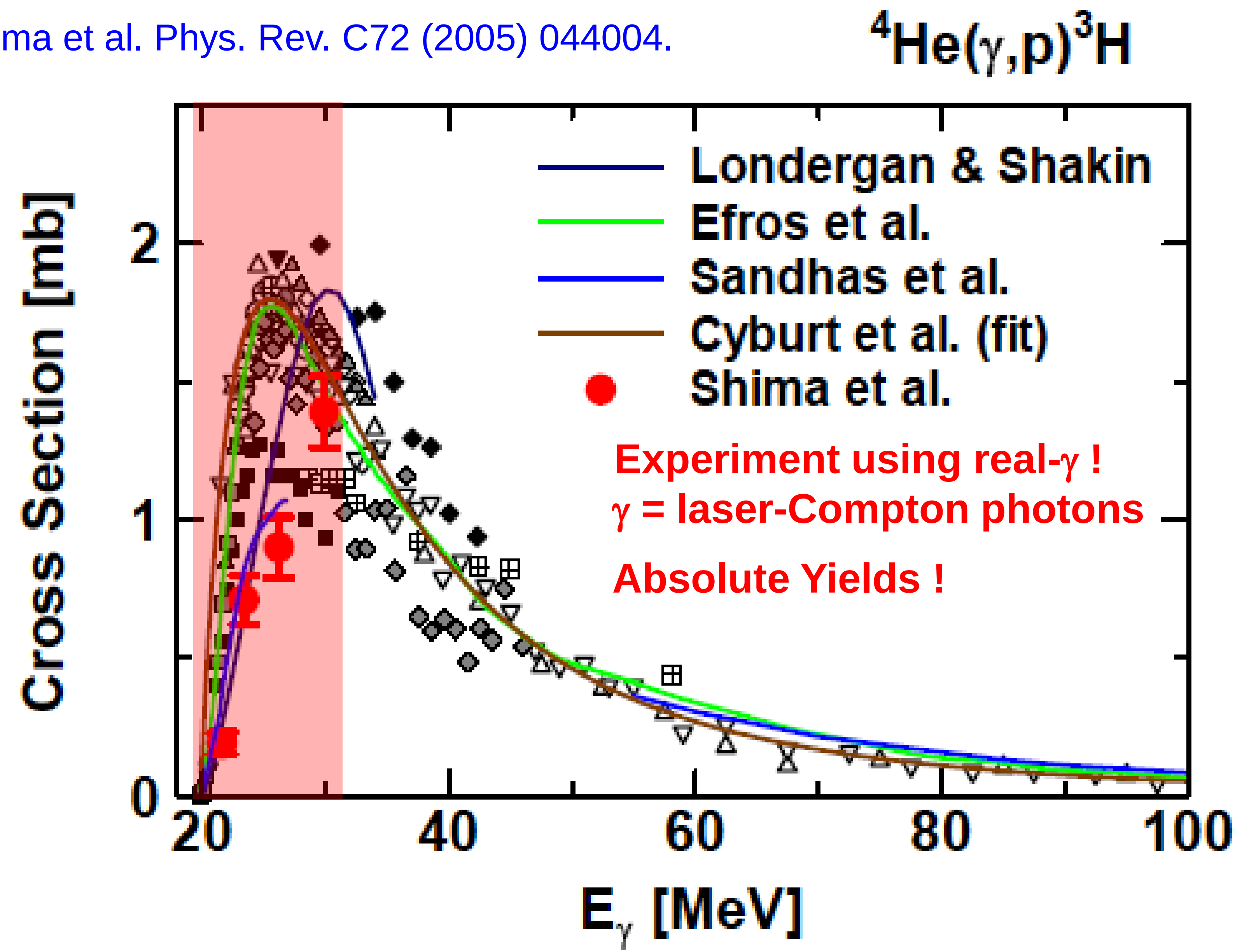
$^4He(\gamma_{NT},n)^3He(^4He,p)^6Li$,

$^4He(\gamma_{NT},p)^3H(^4He,n)^6Li$.

Experimental Cross Sections, well known ?

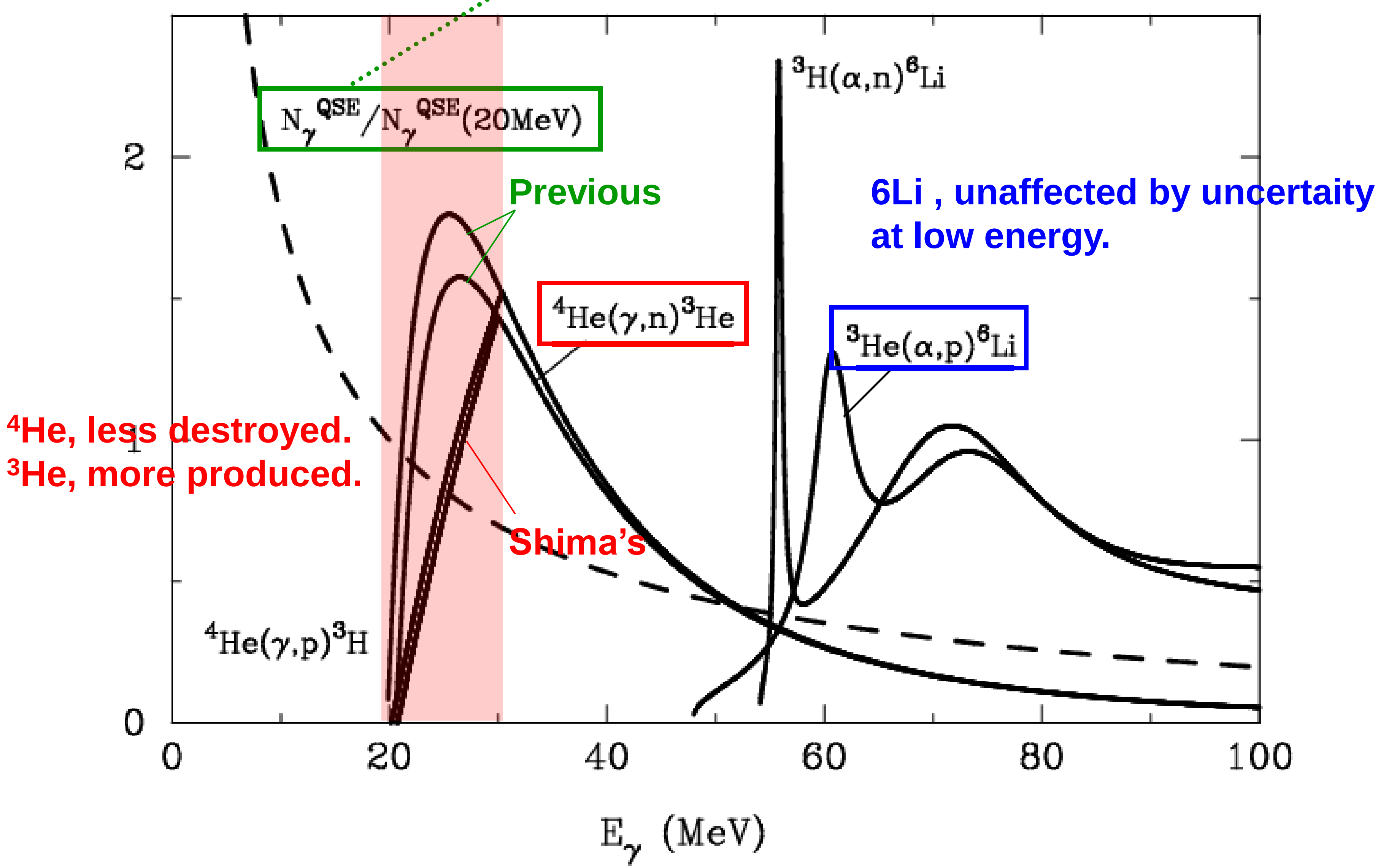
Exp. Data vs. Theor. Calculation

Shima et al. Phys. Rev. C72 (2005) 044004.

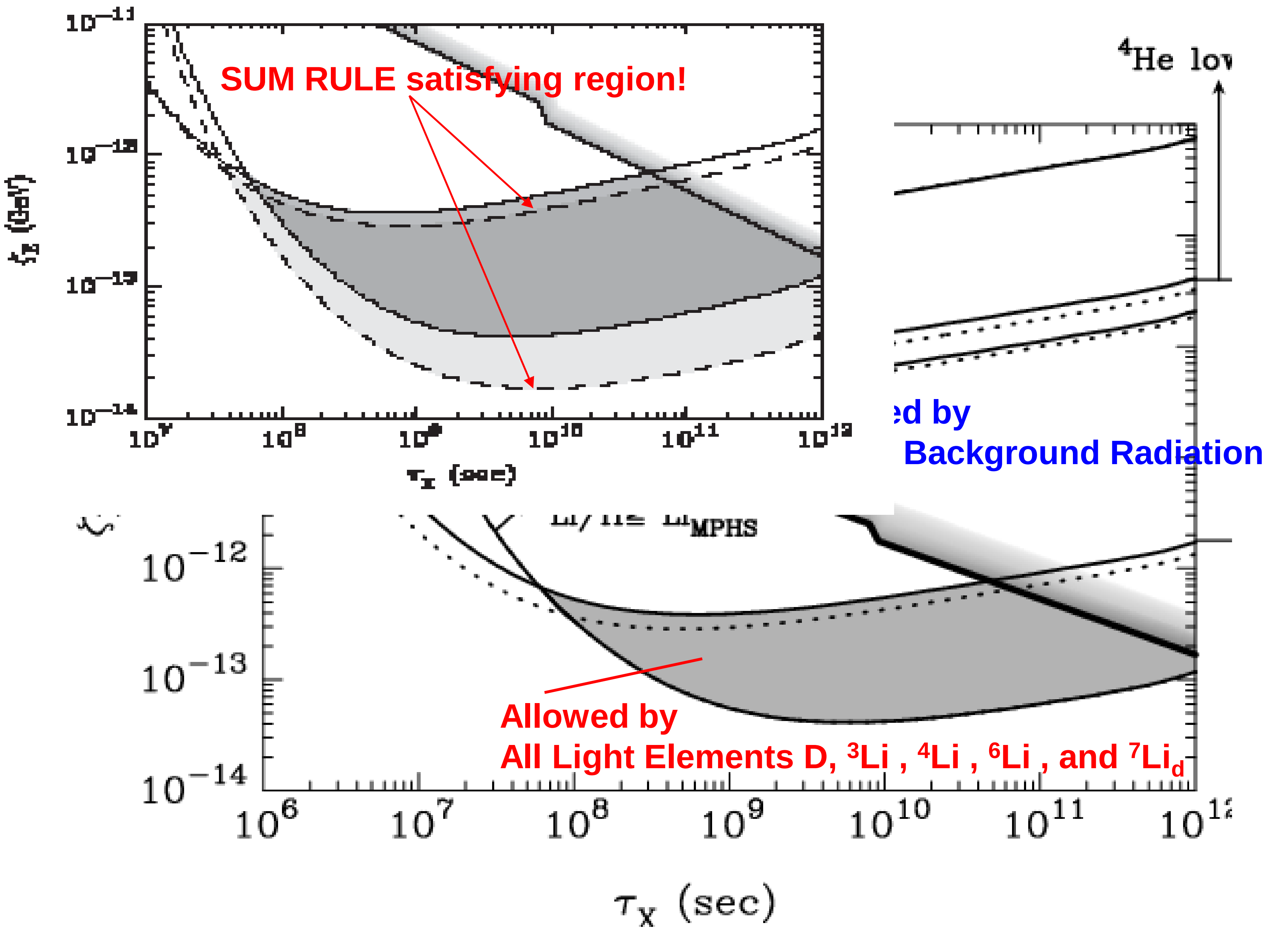


Kusakabe, Kajino, Yoshida, Shima, Nagai, and Kii, PRD 79 (2009), 123513.

$^4He(\gamma_{NT},n)^3He(^4He,p)^6Li$



Kusakabe, Kajino, Yoshida, Shima, Nagai, and Kii, PRD 79 (2009), 123513.



原子核の一体演算子に関する二つの和則

Kusakabe, Kajino, Yoshida, Shima, Nagai, and Kii, PRD 79 (2009), 123513.

E1 sum rule

$$\sigma_0 = \int_{E_{th}}^{\infty} \sigma(E_\gamma) dE_\gamma = \sigma_{TRK} \cdot (1+\kappa) = 59.74 \times (1+\kappa)$$

$$\sigma_{TRK} = \frac{2\pi^2 e^2 \hbar}{mc} \cdot \frac{NZ}{A} \quad , \quad \kappa = \langle \Psi_0 \| [D_Z, [V, D_Z]] \| \Psi_0 \rangle \times \left(\frac{m}{\hbar^2}\right) \frac{A}{NZ}$$

Thomas-Reihe-Kuhn

Meson-exchange current

QM calculation κ = 0.67~1.14 ⇒ σ_0 = 100~128 [MeV·mb]

Bremsstrahlung Sum rule

$$\sigma_B = \int_{E_{th}}^{\infty} \frac{\sigma(E_\gamma)}{E_\gamma} dE_\gamma = 4\pi^2 \frac{e^2}{\hbar c} \times \langle \Psi_0 | D_Z D_Z | \Psi_0 \rangle$$

$$= \frac{4\pi^2}{3} \cdot \frac{e^2}{\hbar c} \cdot \frac{NZ}{A-1} \cdot \left(\langle r_\alpha^2 \rangle - \langle r_p^2 \rangle \right) = 2.62 \pm 0.02 \ \text{[mb]}$$

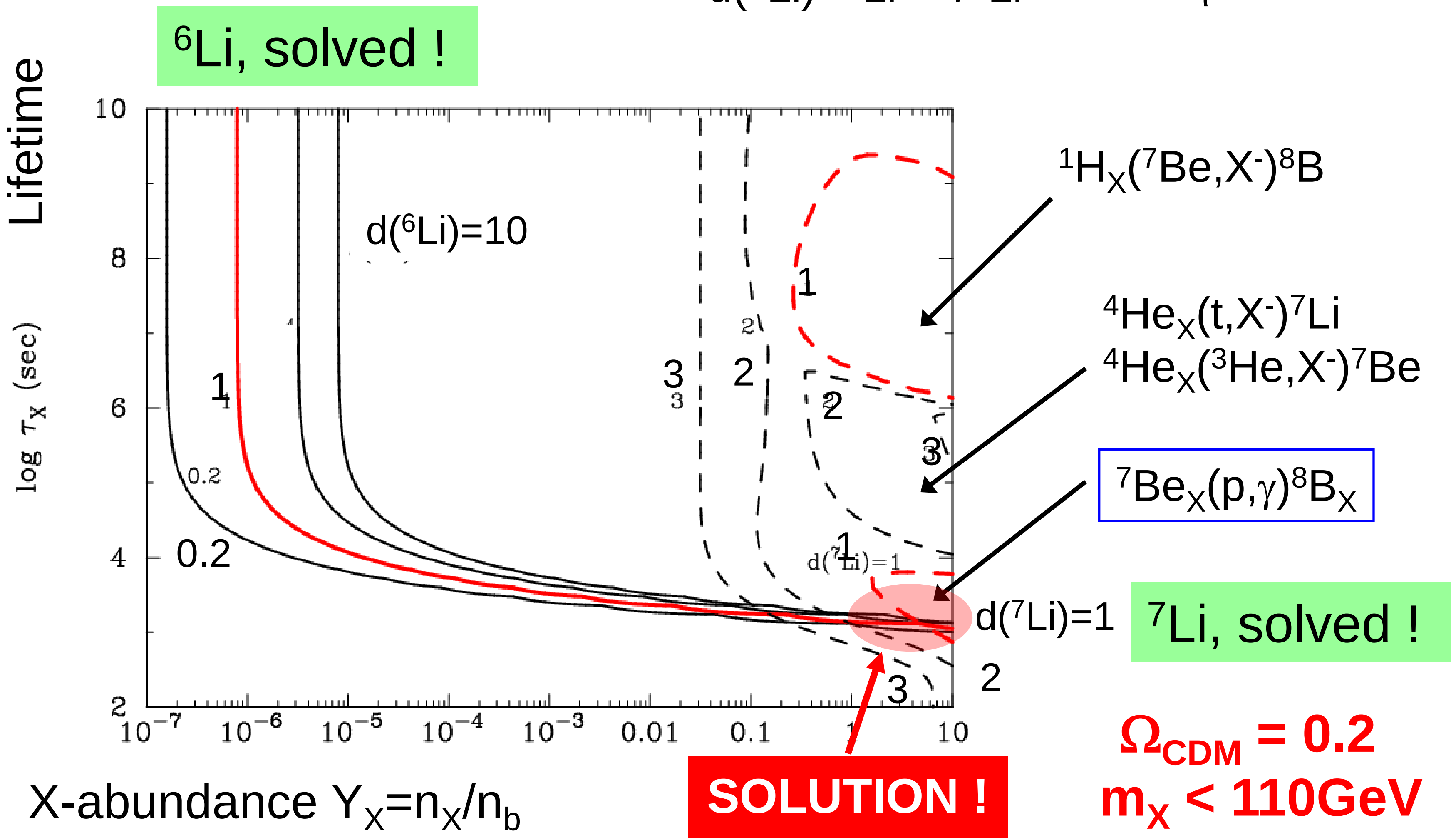
Proton's ms charge radius $\langle r_p^2 \rangle^{1/2} = 0.870 \pm 0.008$ [fm]

^{4}He's ms charge radius $\langle r_\alpha^2 \rangle^{1/2} = 1.673 \pm 0.001$ [fm]

Cosmological Solution to both ^{6,7}Li problems

Kusakabe, Kajino, Boyd, Yoshida, and Mathews ApJ 680 (2008), 846: PRD 80 (2009), 103501.
80, 103501 (2009)

$d(^{A}Li) = {}^{A}Li^{Calc} / {}^{A}Li^{Obs}$ $\eta = 6.1 \times 10^{-10}$



$\Omega_{CDM} = 0.2$

$m_X < 110$GeV

Particle Physics Experiment tests Cosmological and Astronomical Prediction !

Conclusion

Big-Bang Nucleosynthesis provides “critical test” for the particle and nuclear models of weak interactions (neutron decay in quark level) and even cosmological models (through CBR constraints on DM particles or th end of Inflation).

Relic SUSY particle - CDM model, if they are bound in normal nuclei or radiative decay to non-thermal photons, can solve both 6Li and 7Li problems in astronomy concerning primordial Big-Bang nucleosynthesis.