Title: Short-lived NLSP and Cosmology

Date: May 30, 2008 02:00 PM

URL: http://pirsa.org/08050049

Abstract:

Introduction of SUSY

Supersymmetry (SUSY)

- Solving "Hierarchy Problem"
- Realizing "Coupling constant unification in GUT"

Fermion	⟷	Boson
quark	⟷	squark
lepton	⟷	slepton
photino	⟷	photon
gravitino	⟷	graviton
axino	⟷	axion

neutralino

SUSY Breaking

- Gravity mediated SUSY breaking model

Observable sector	Only through gravity	Hidden sector
quark, squark, ...	⟷	~~SUSY~~ M_{SUSY}

- Masses of squarks and sleptons

$$m_{\tilde{q}}, m_{\tilde{l}} = M_{SUSY}^2 / M_{pl} = 10^2 - 10^3 \ GeV$$

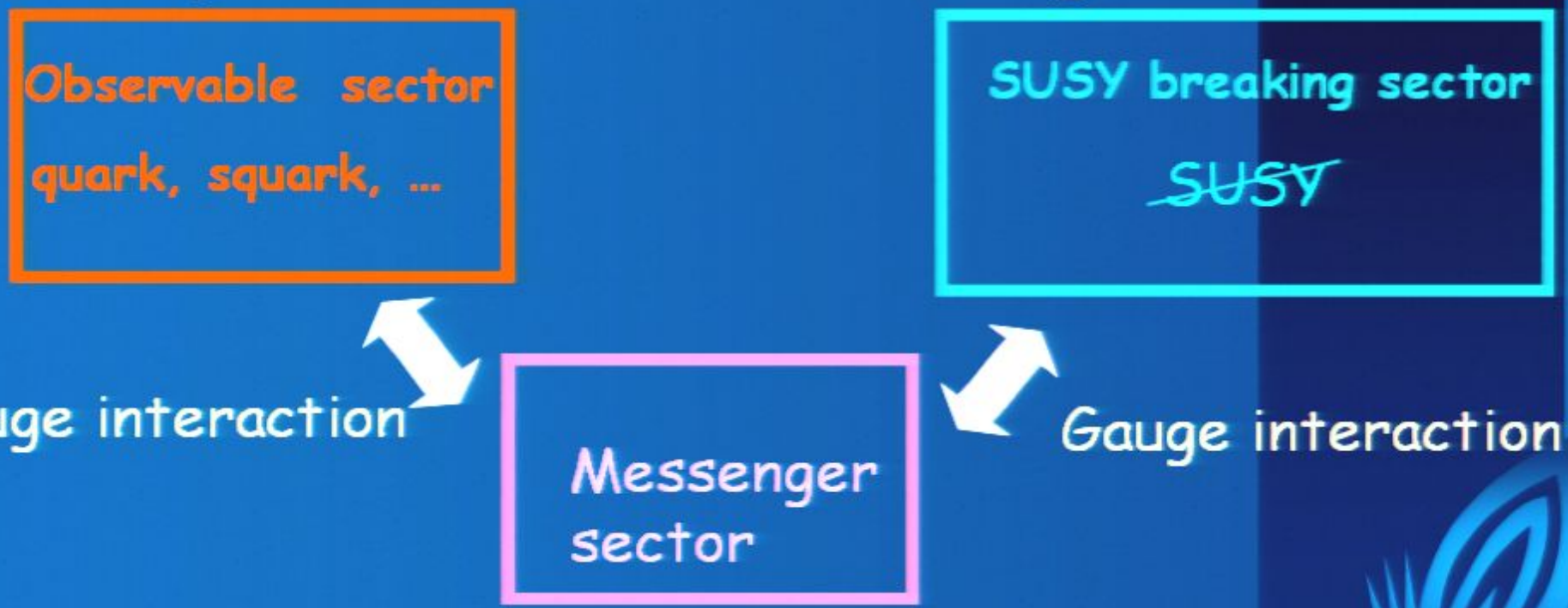
$$(M_{SUSY} = 10^{10} - 10^{11} \ GeV)$$

- Gravitino mass

$$m_{3/2} = M_{SUSY}^2 / M_{pl} = 10^2 - 10^3 \ GeV$$

SUSY Breaking II

- Gauge-mediated SUSY breaking model (Dynamical SUSY brasking)



$m_{3/2} < 10\text{GeV}$

Realistic candidates of particle dark matter I

- Neutralino χ (~100% Bino or photino)

  Most famous Lightest Supersymmetric Particle (LSP) with m_χ ~100GeV (appears even in global SUSY)

- Gravitino ψ_μ

  super partner of graviton with spin 3/2 and $m_{3/2} \lesssim 100\text{GeV}$ (massive only in local SUSY)

Realistic candidates of particle DM II

- Axion a

  solving strong CP problem, $m_a \sim 10^{-5}\text{eV}\ (10^{11}\text{GeV}/F_a)$

$$\mathcal{L}_{\text{PQ}} \sim \theta_{\text{QCD}} F^a_{\mu\nu} \tilde{F}^{\mu\nu}_a \qquad \theta_{\text{QCD}} \sim \frac{a}{F_a} < 10^{-9}$$

- Axino $\tilde{a}$

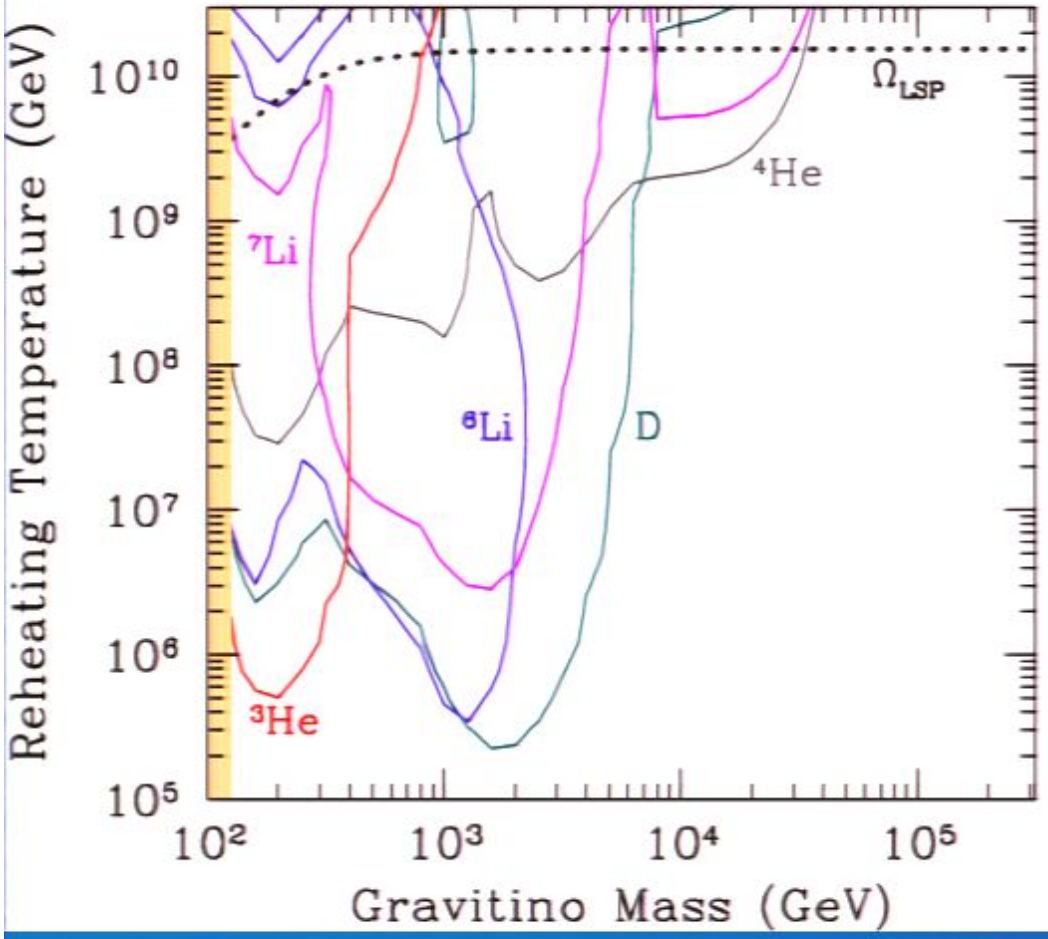
  super partner of axion

- "Flaxino"/Flatinos

  Superposition of axinos in DFSZ models

Upper bound on reheating temperature

Kawasaki, Kohri, Moro, Yotsuyanagi (08)



gravitino NLSP and

neutralino LSP

Hadronic decay

$$B_h \sim O(1) \quad (B_\gamma \sim O(1))$$

$$T_R \sim 10^7\,\mathrm{GeV}\left(Y_{3/2}/10^{-14}\right)$$

$$m_{3/2} \sim 10^3\,\mathrm{GeV}\,(\tau_{3/2}/4\times 10^5\,\mathrm{sec})^{-1/3}$$

Long-lived NLSP can be scalar tau lepton (stau)?

Feng, Su, and Takayama (2003)

Steffen (2006)

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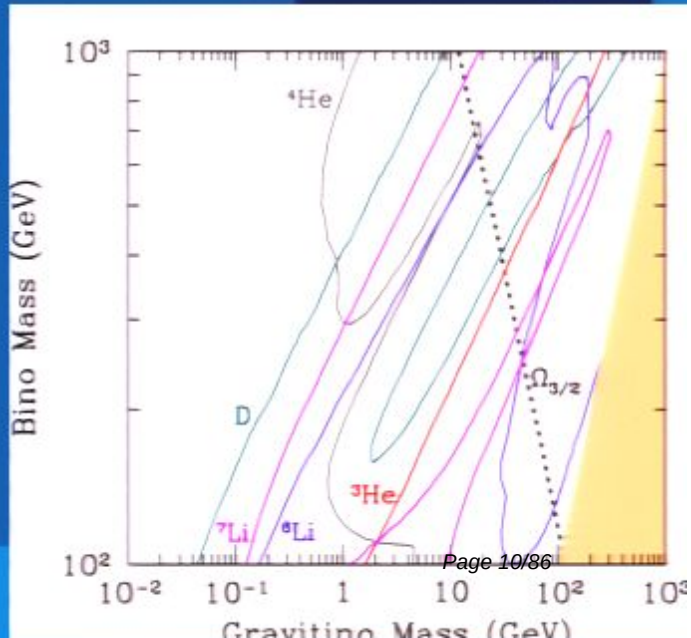

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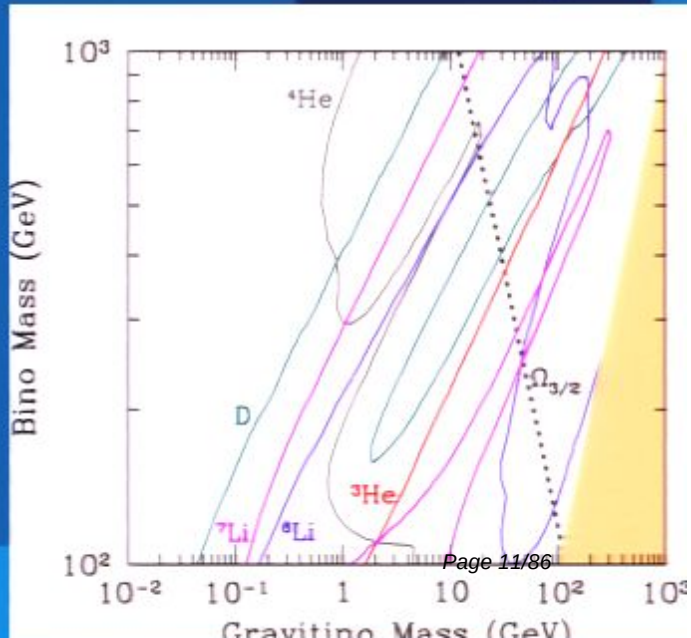
Stau NLSP is attractive!!!

See also Frank Steffen's and Joesef Pladler's talks



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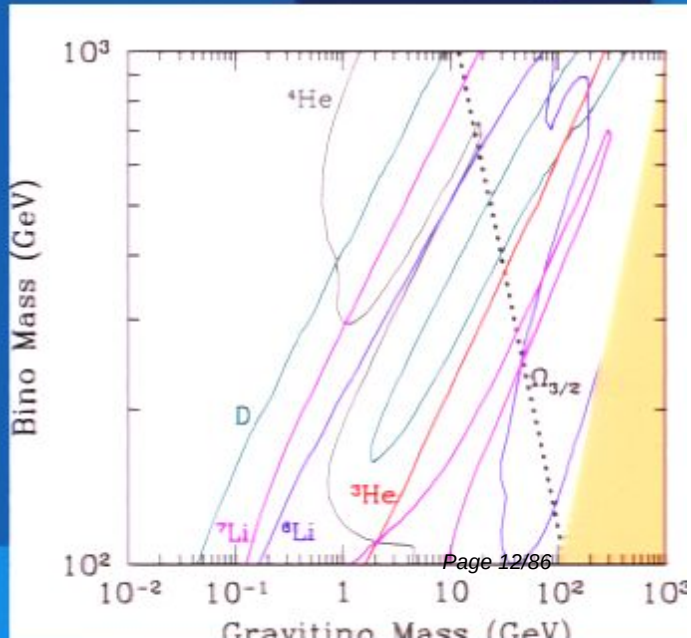
- Then, LSP would be gravitino or axino/flatino/flaxino



CHArged Massive Particle (CHAMP)

Kohri and Takayama, hep-ph/0605243
See also literature, Cahn-Glashow ('81)

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Candidates of long-lived CHAMP in modern cosmology

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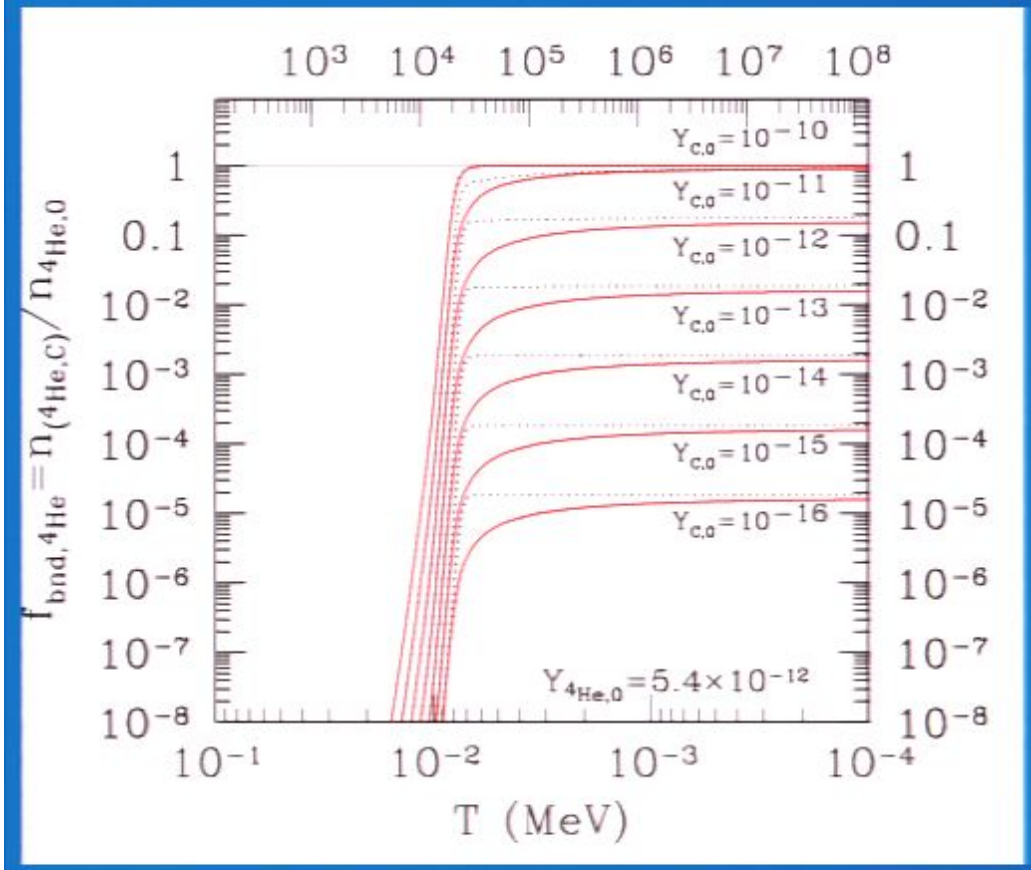
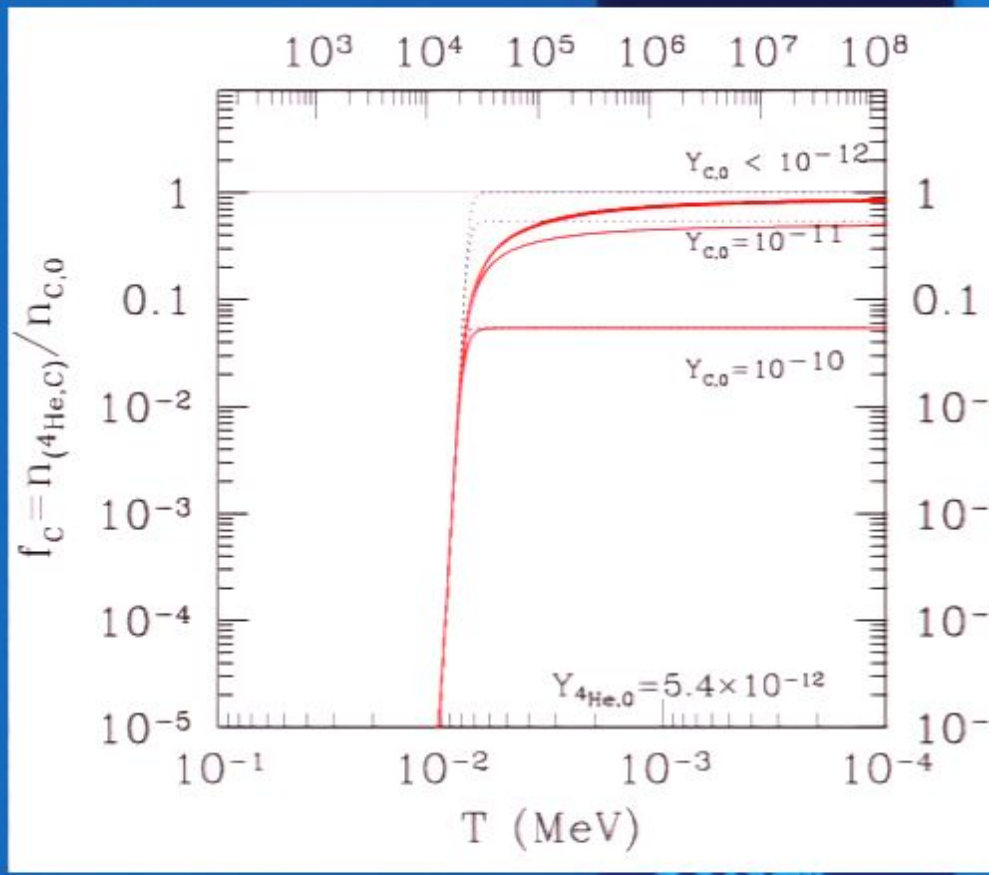
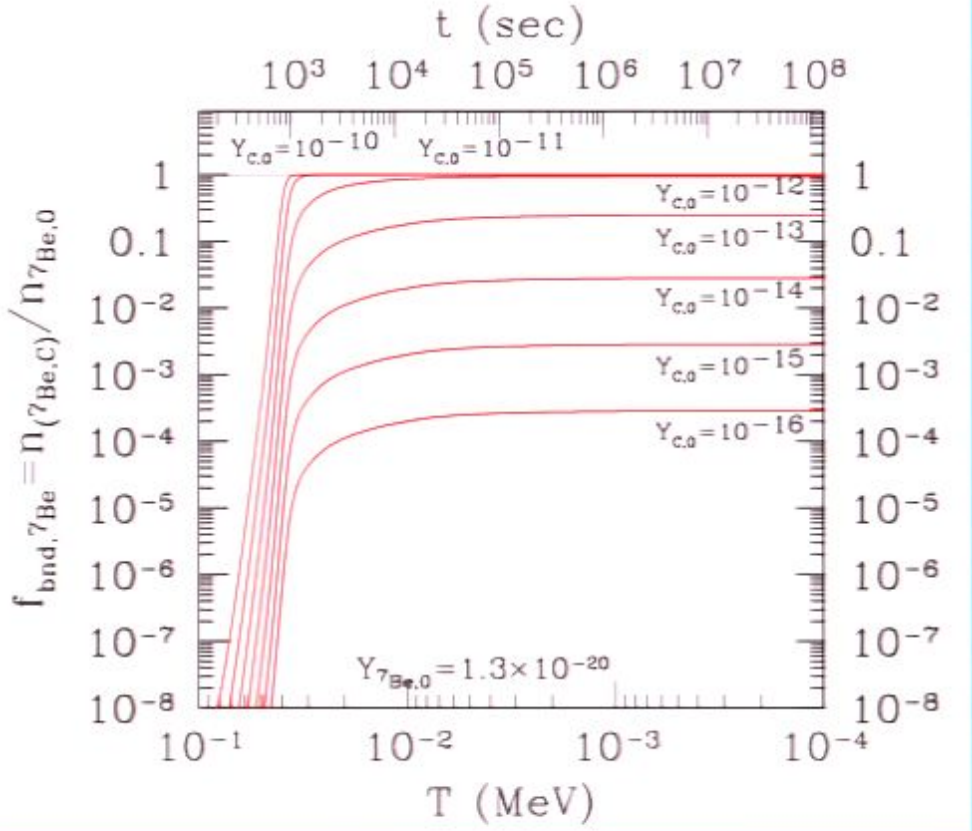
CHAMP captured-nuclei, e.g., $(C, {}^4He)$ changes the nuclear reaction rates dramatically in BBN

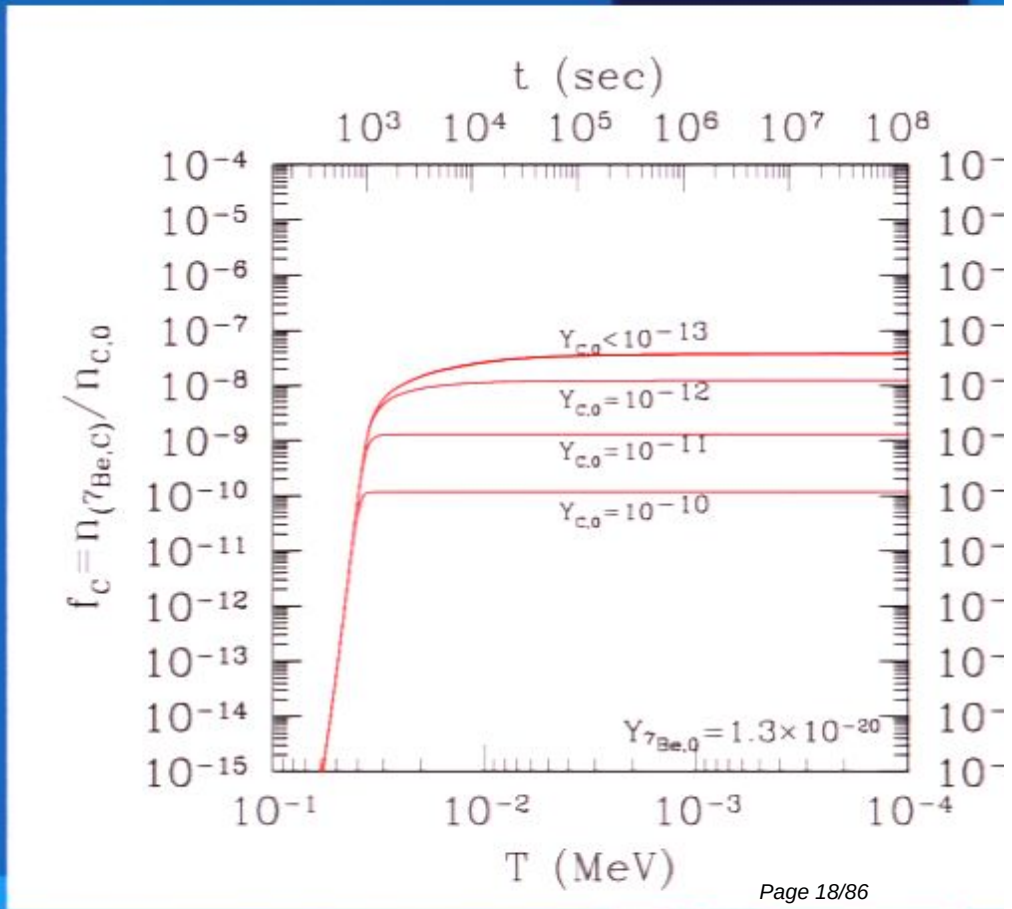
He4 bound-state ratio



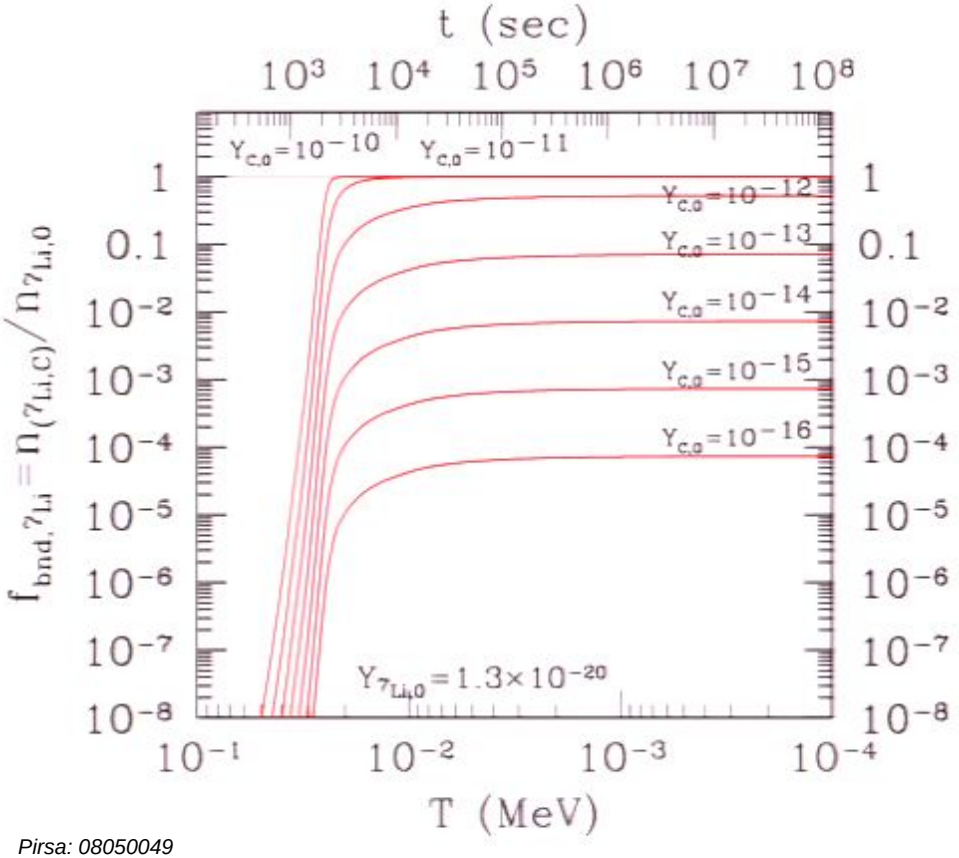


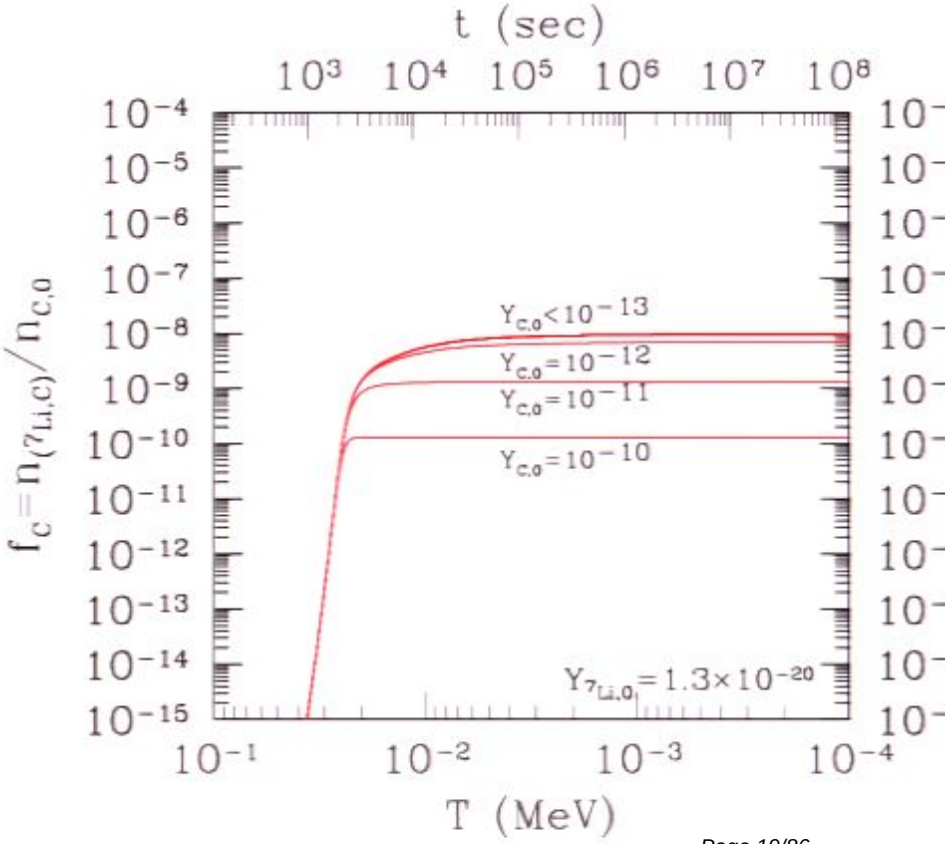
Be7 bound-state ratio





Li7 bound-state ratio





Catalyzed BBN

Pospelov (2006), **hep-ph/0605215**

- CHAMP bound state with ^4He enhances the rate

$$D + (^4He, C^-) \rightarrow {}^6Li + C^- + \gamma$$

Catalysis BBN is in crisis !!!

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- Enhancement of cross section

$$\sim (\lambda_\gamma / a_{Bohr})^5 \sim (30)^5 \sim 10^{7-8}$$

Confirmed by Hamaguchi etal (07), hep-ph/0702274

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BBN in stau NLSP and gravitino LSP Scenario in gauge mediation

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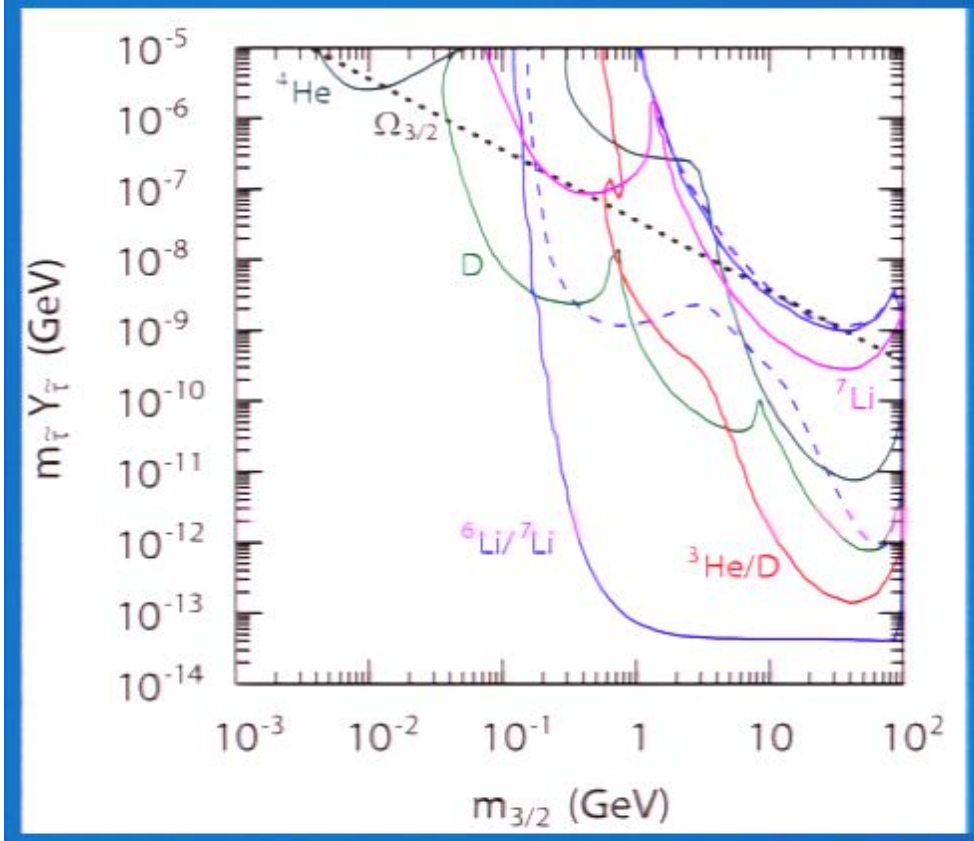

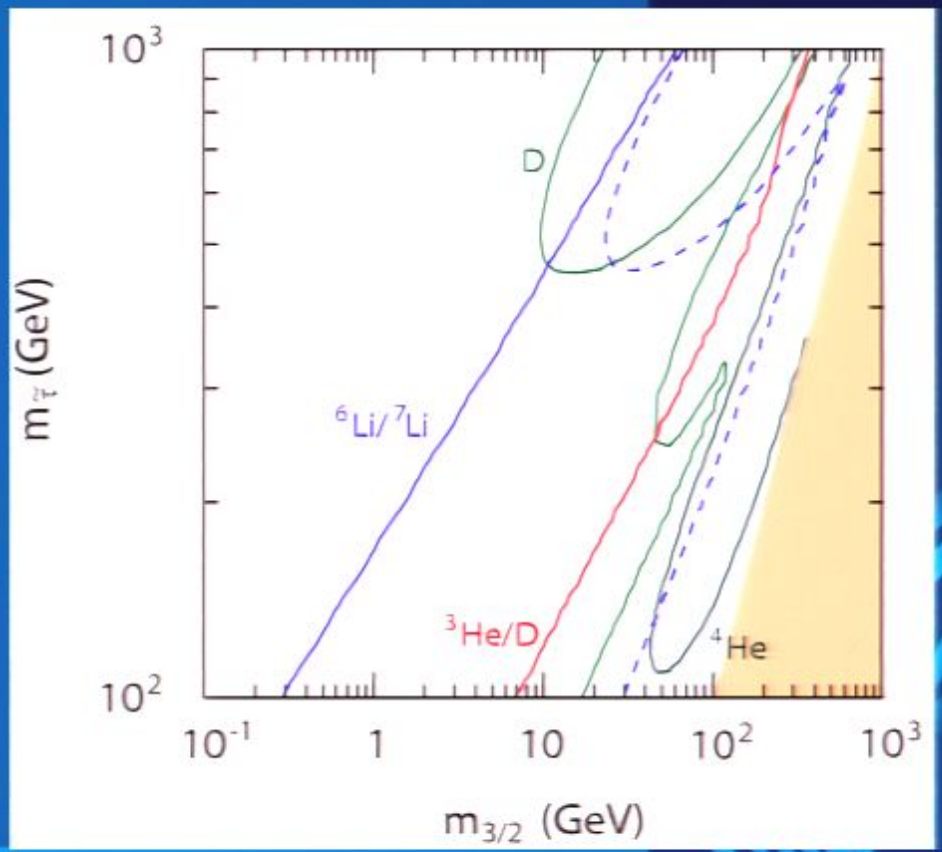

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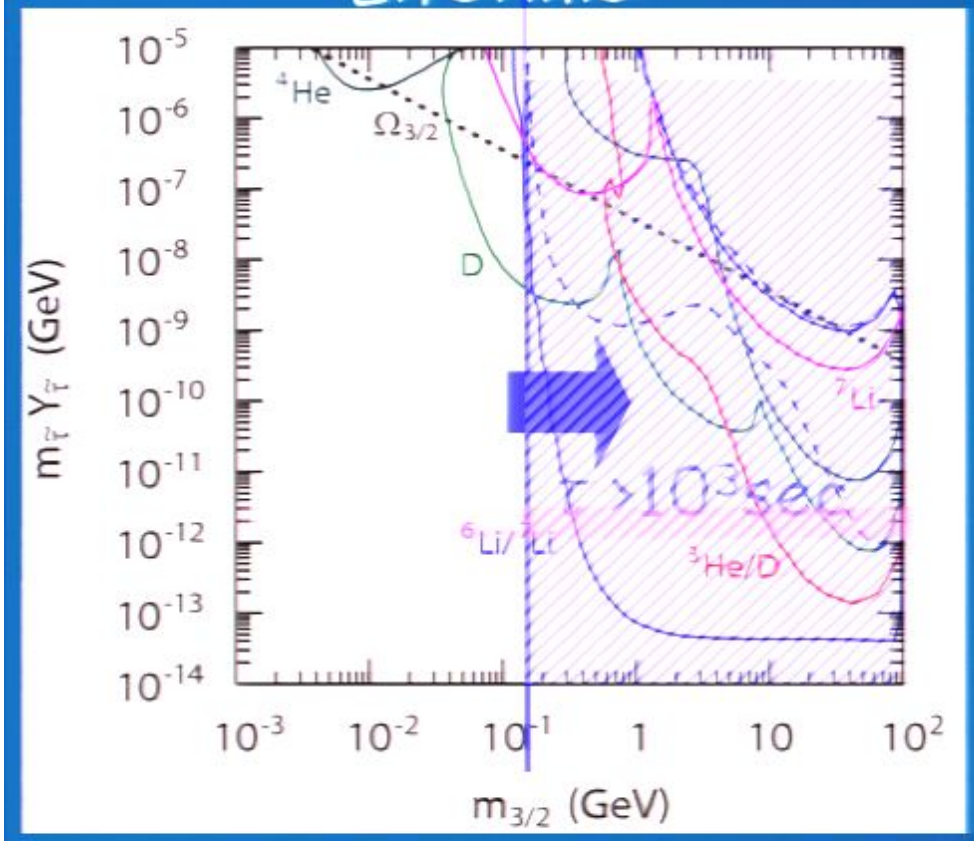

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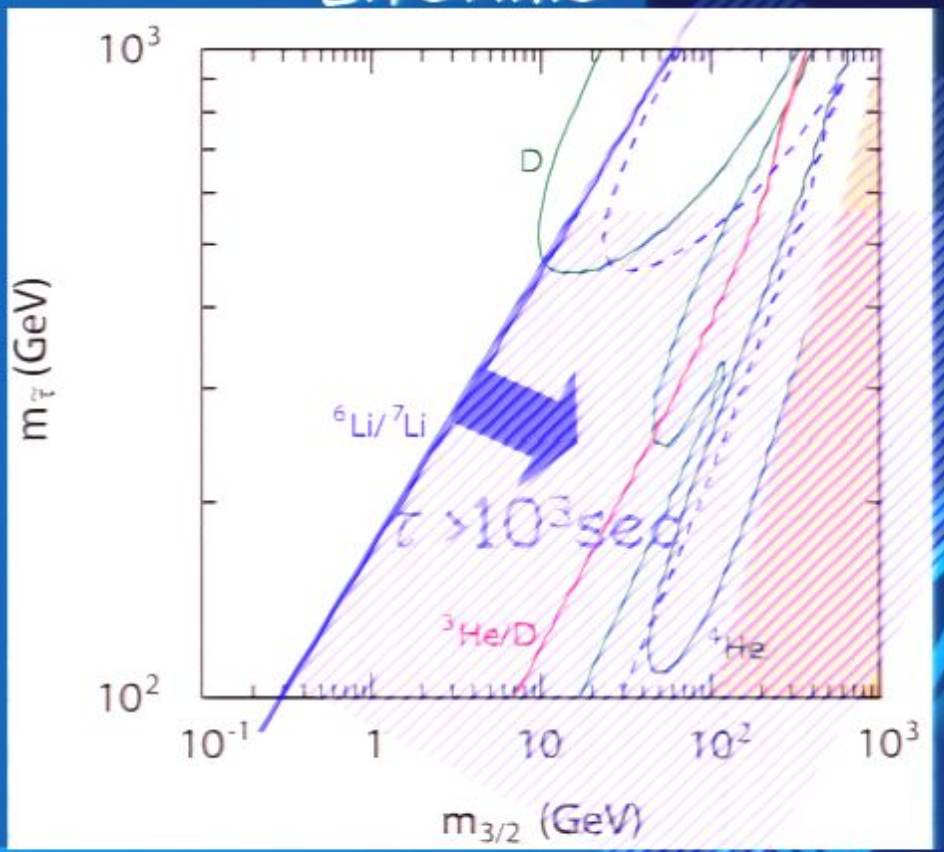

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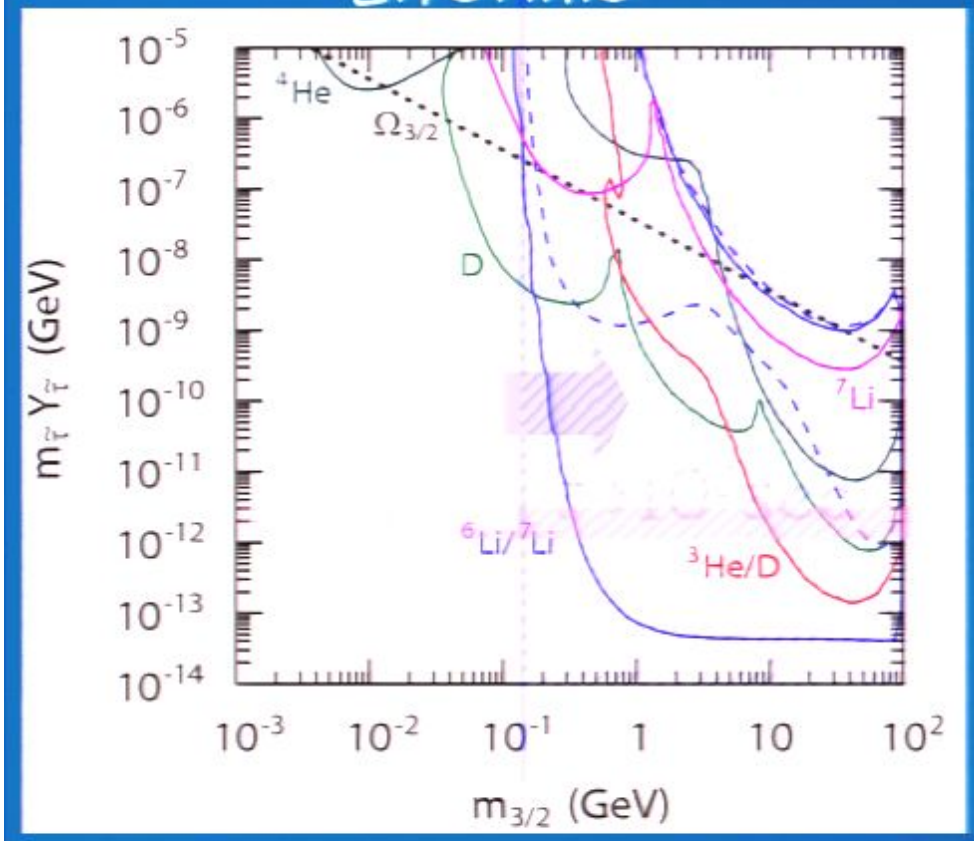

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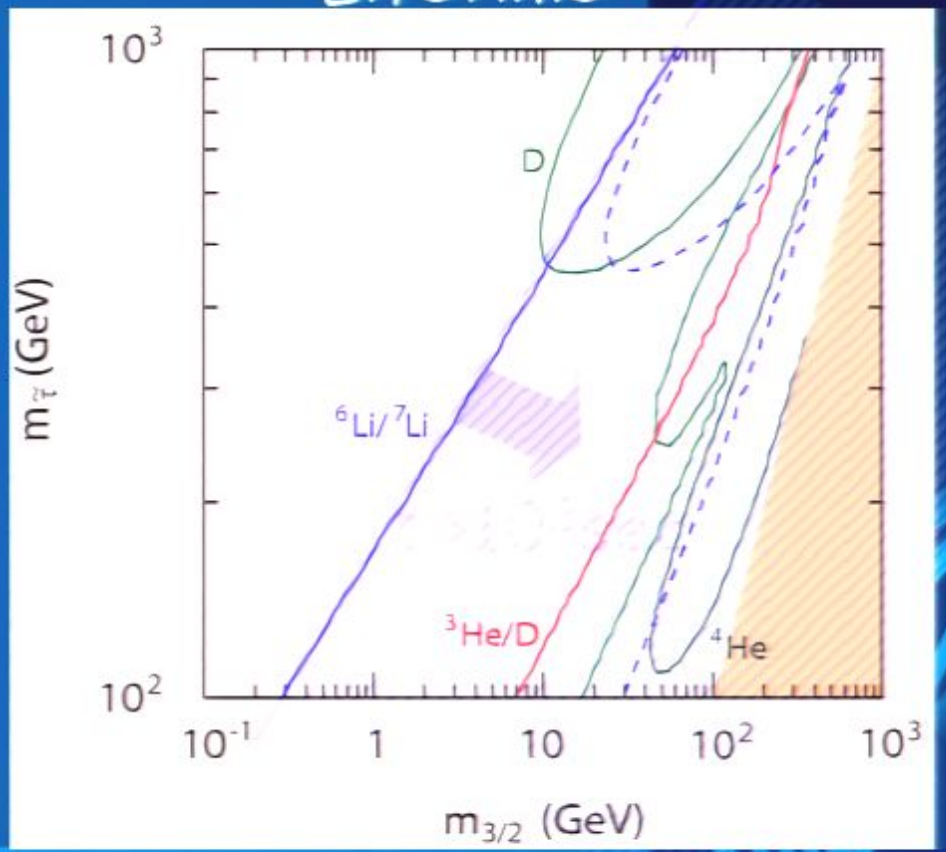

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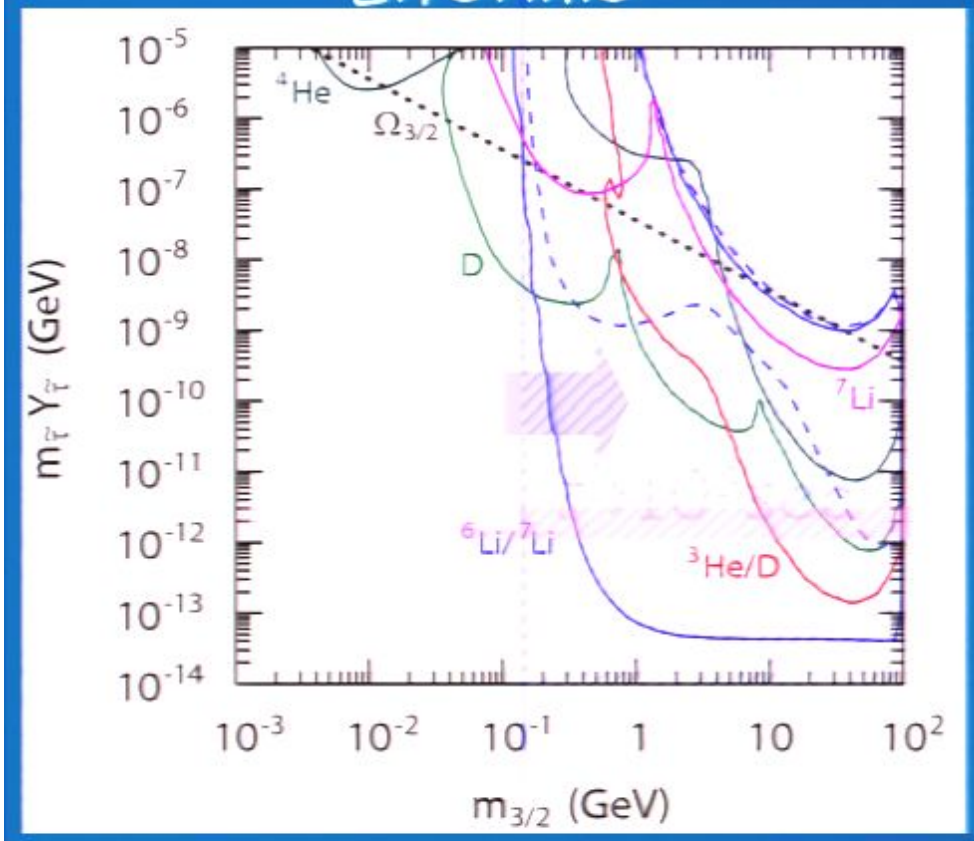

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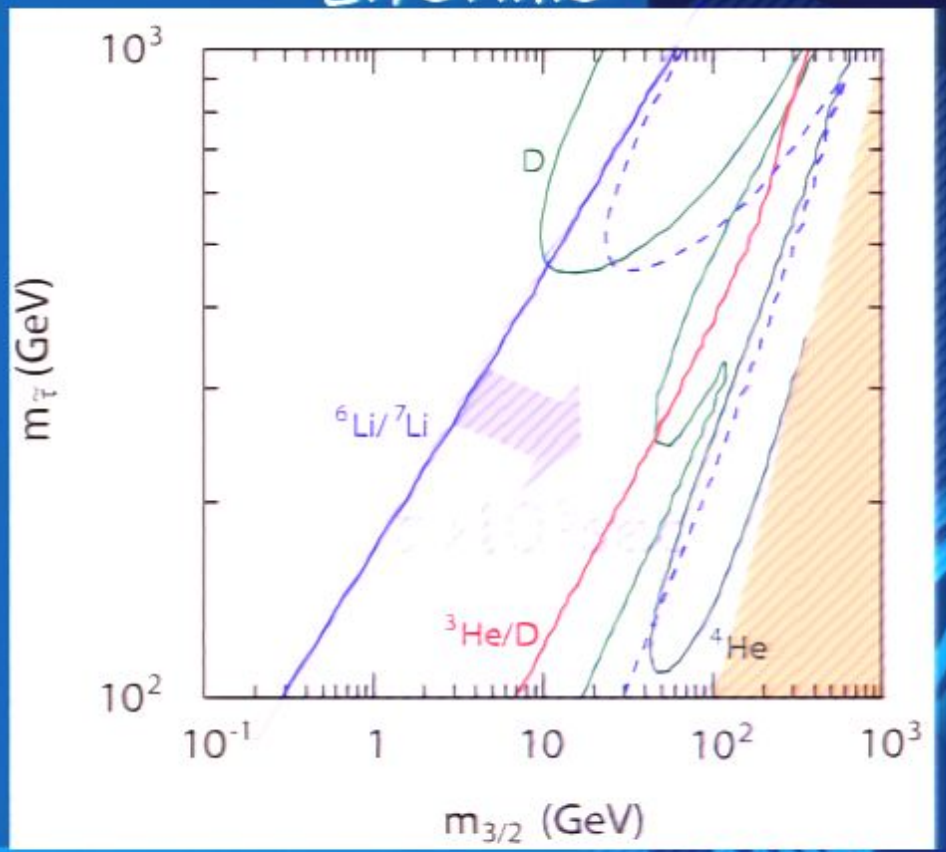

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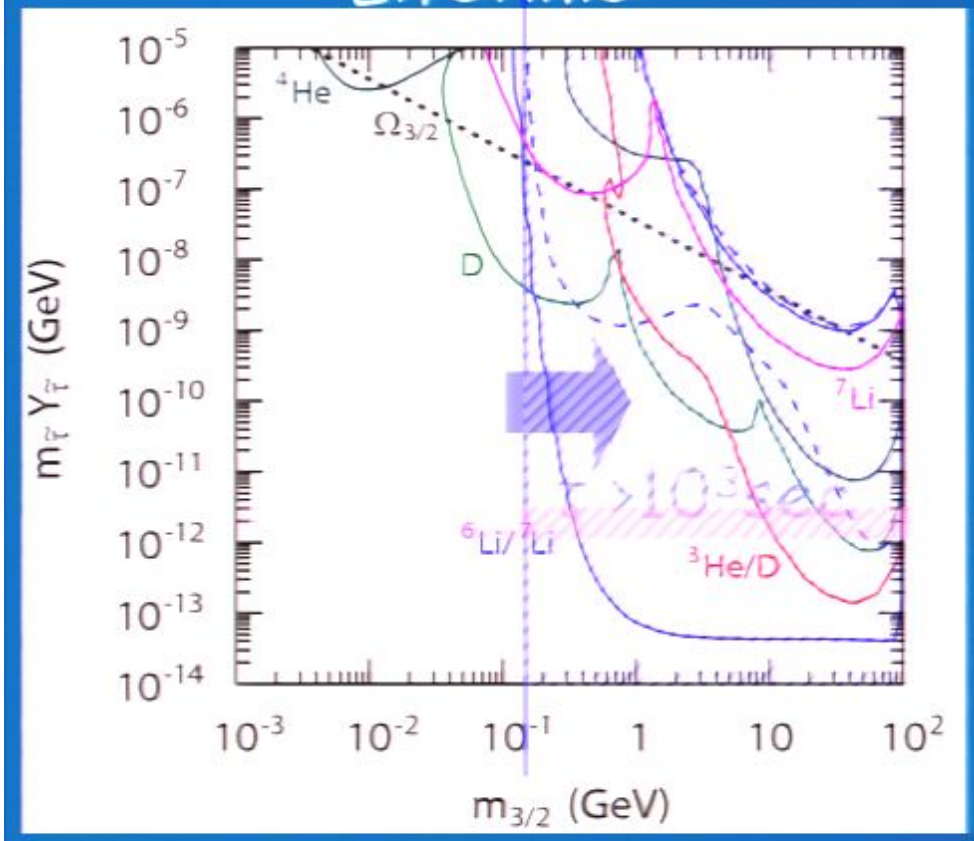

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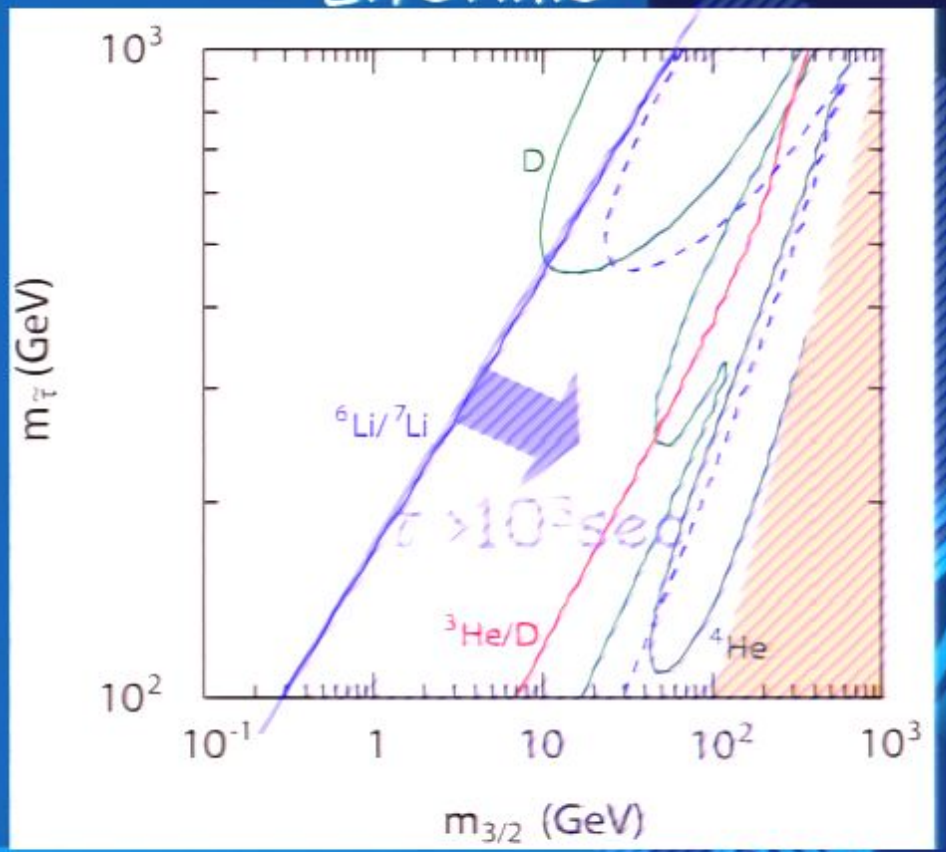

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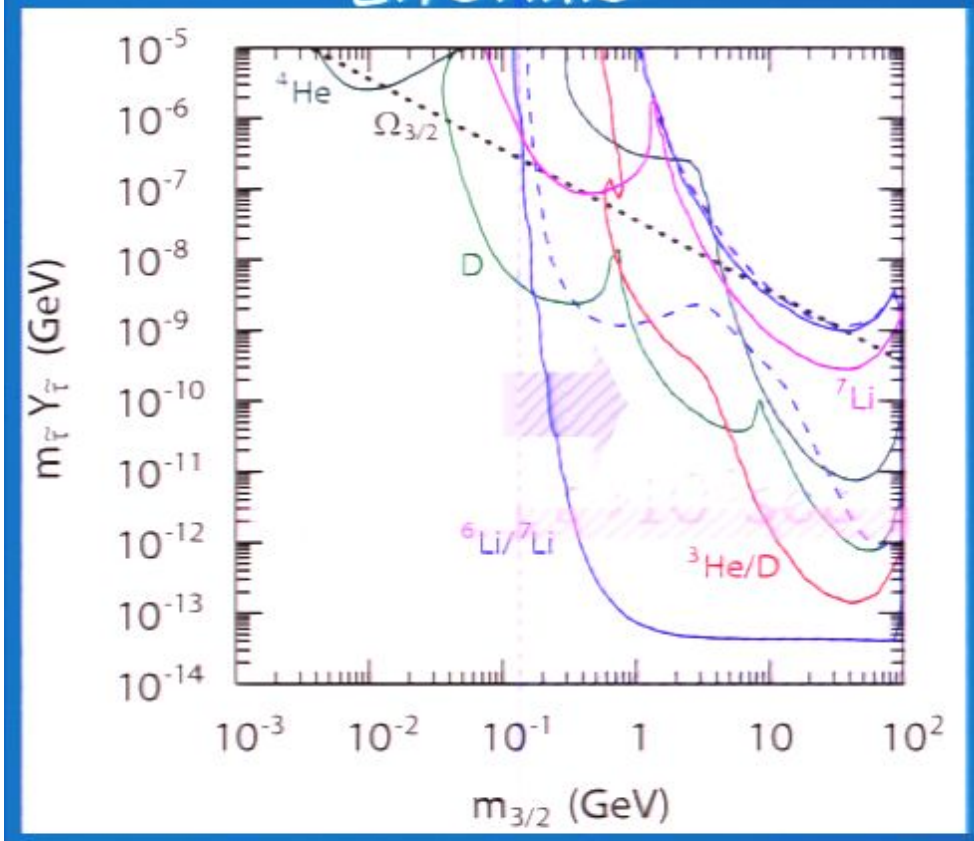

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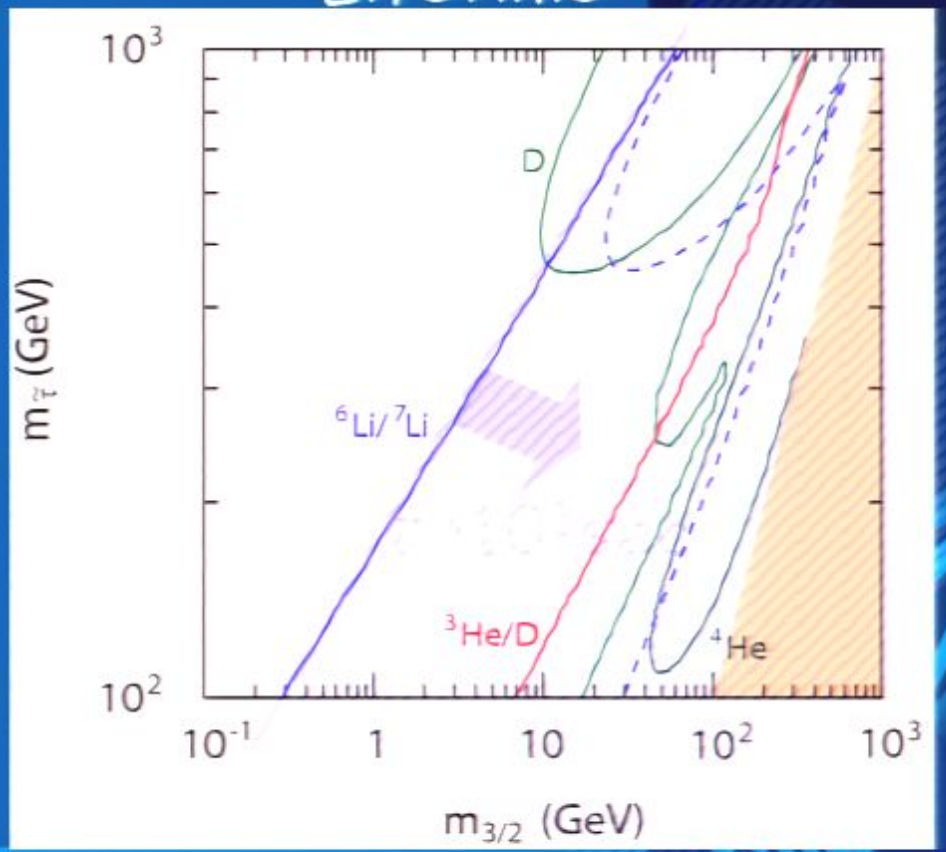

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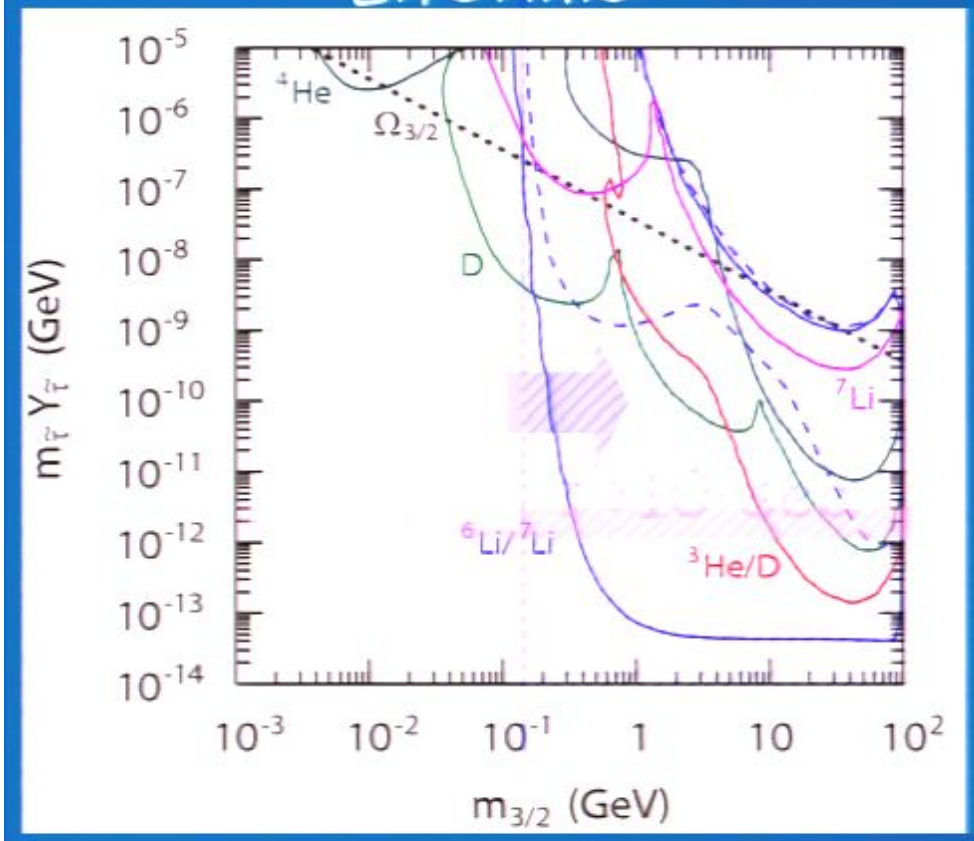

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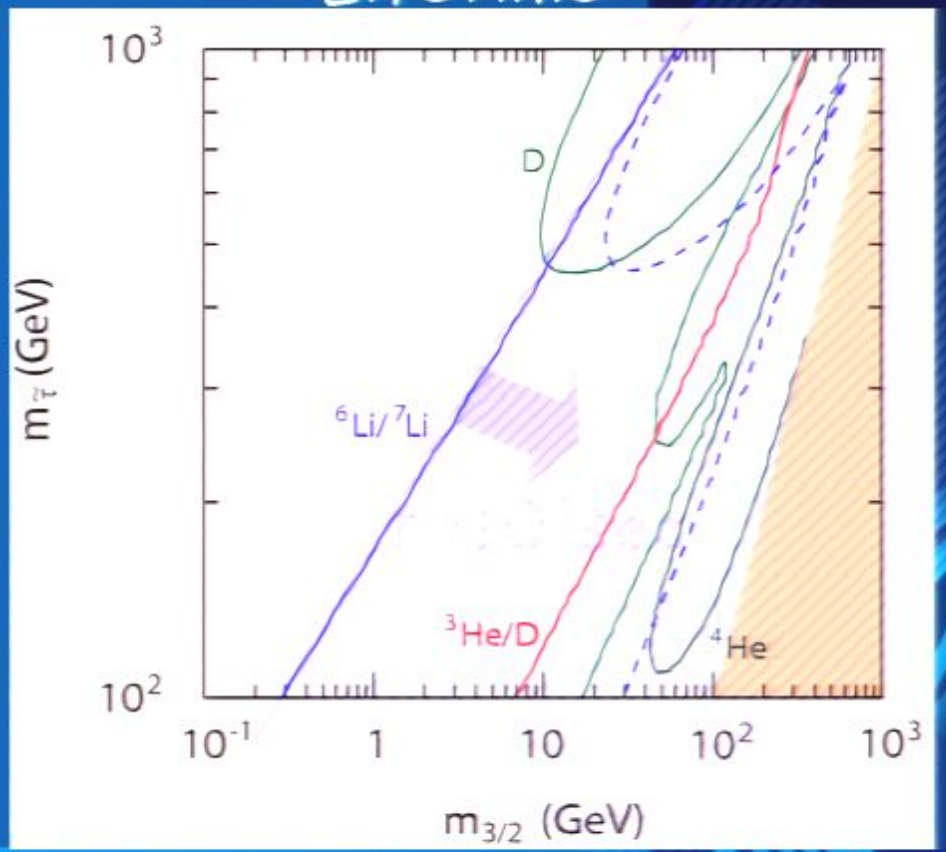

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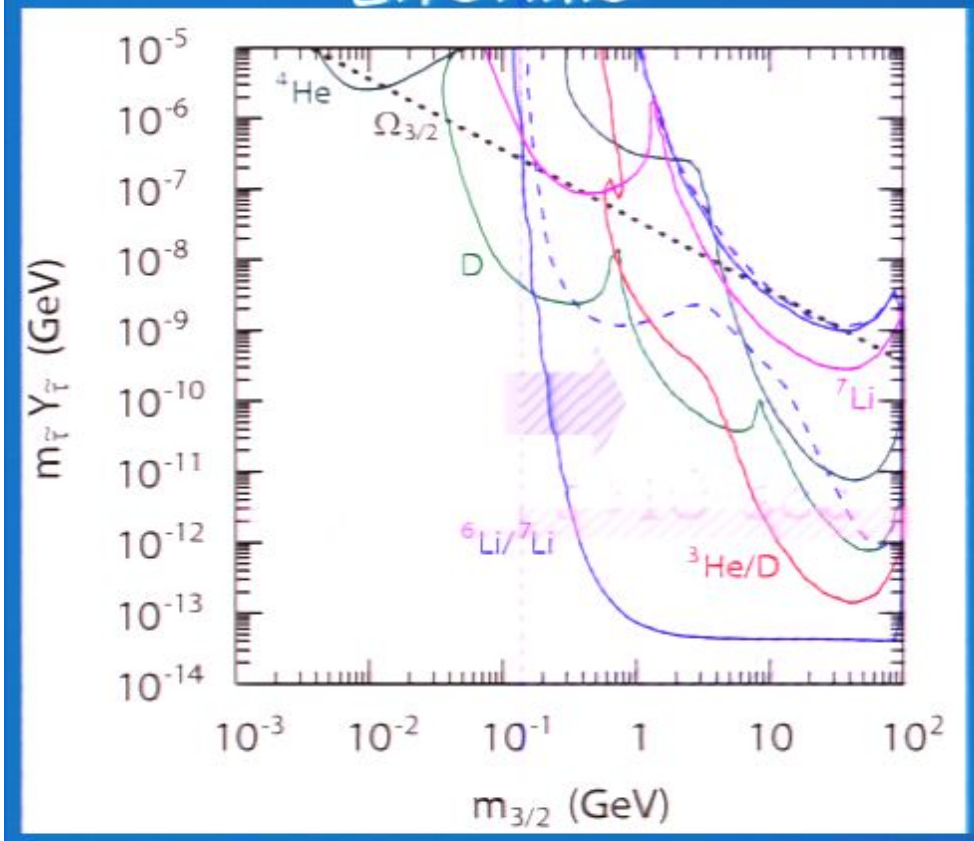

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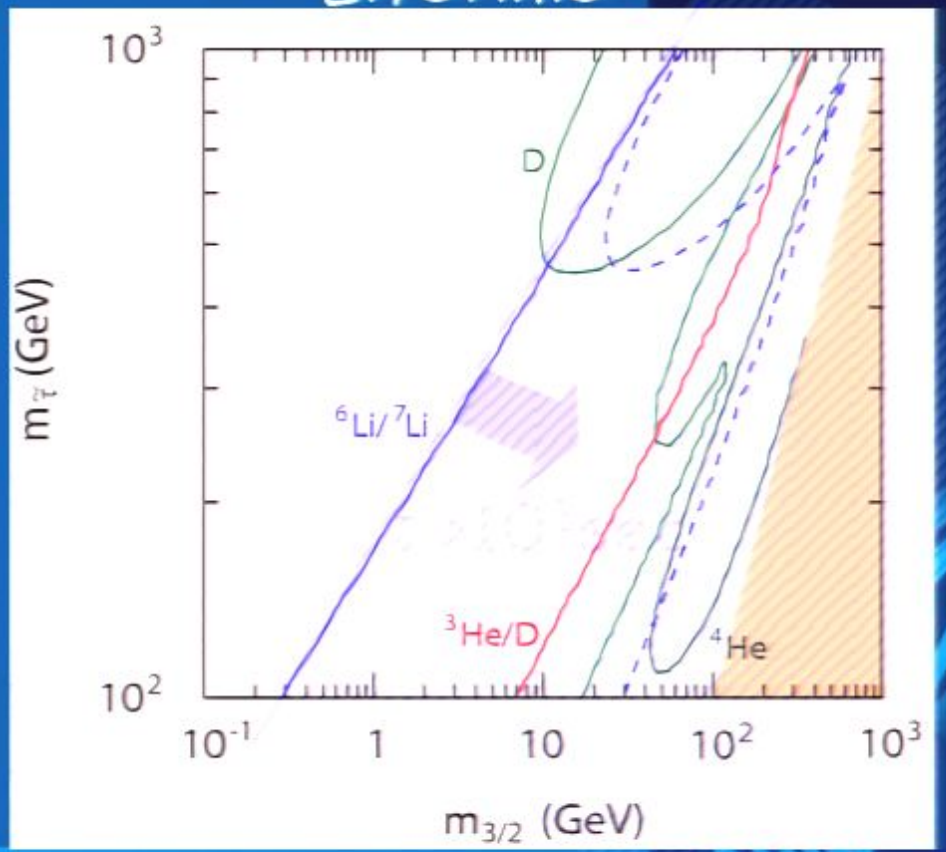

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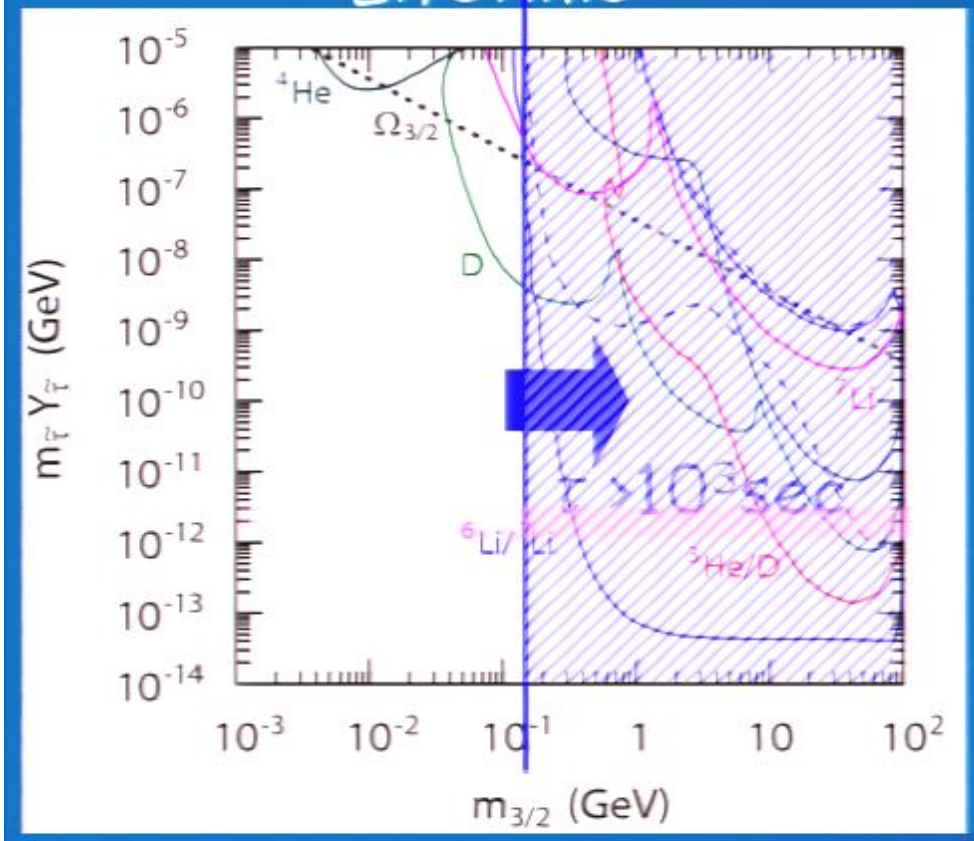

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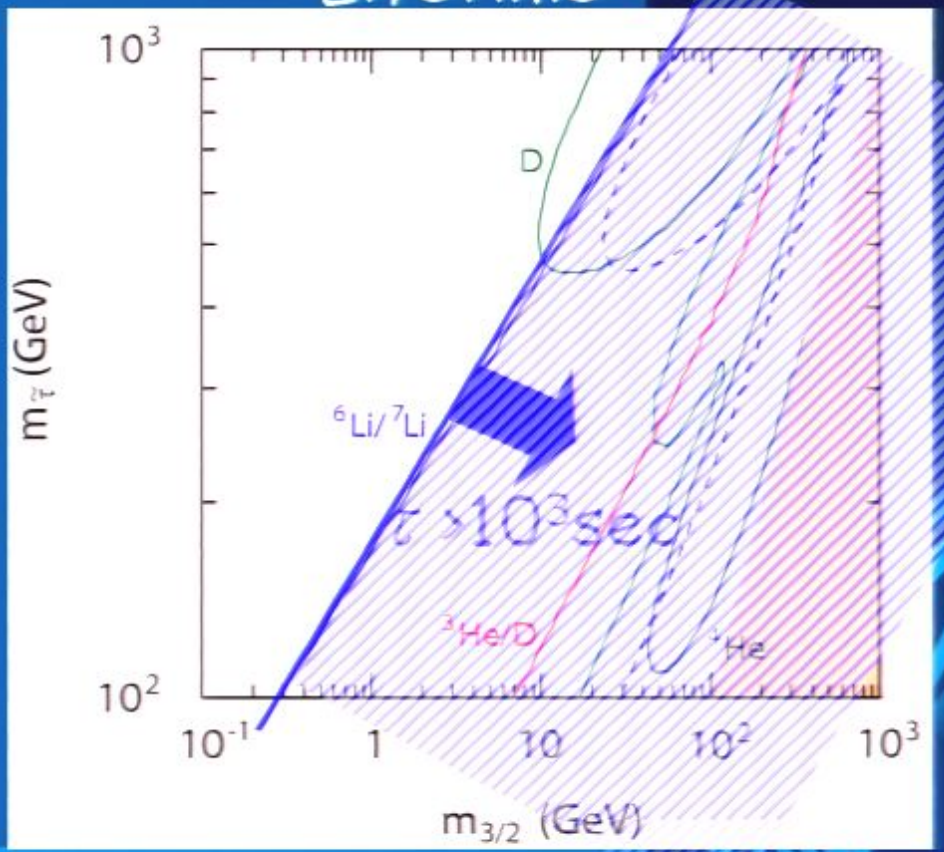

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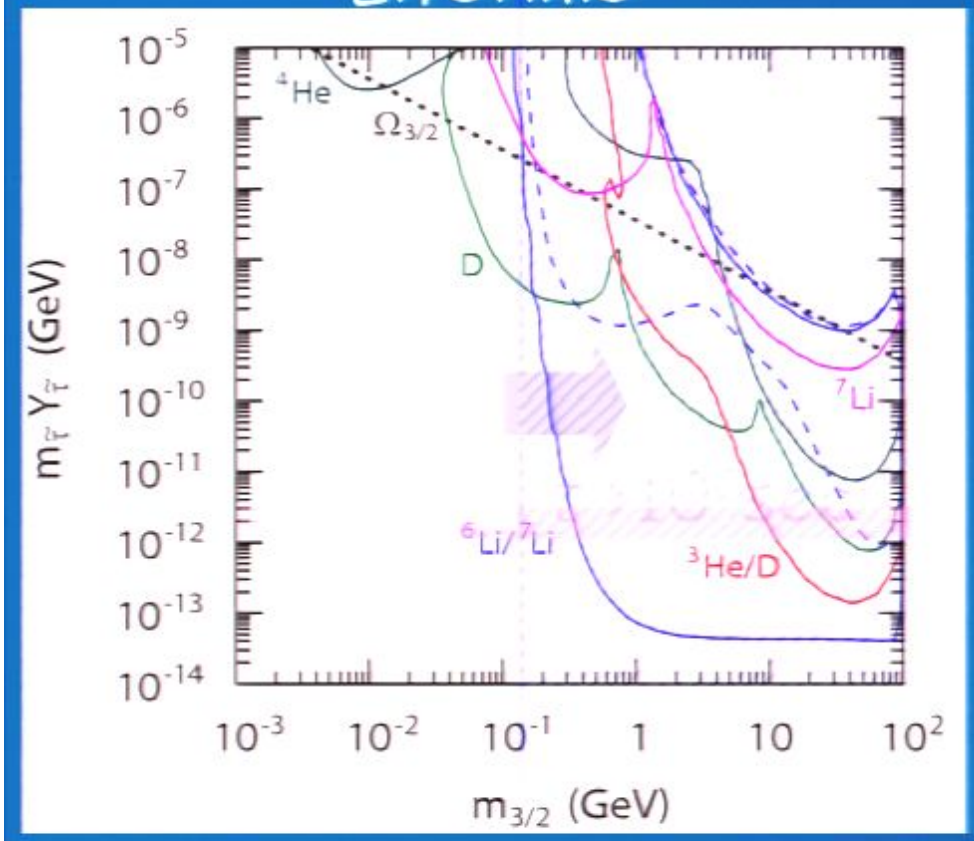

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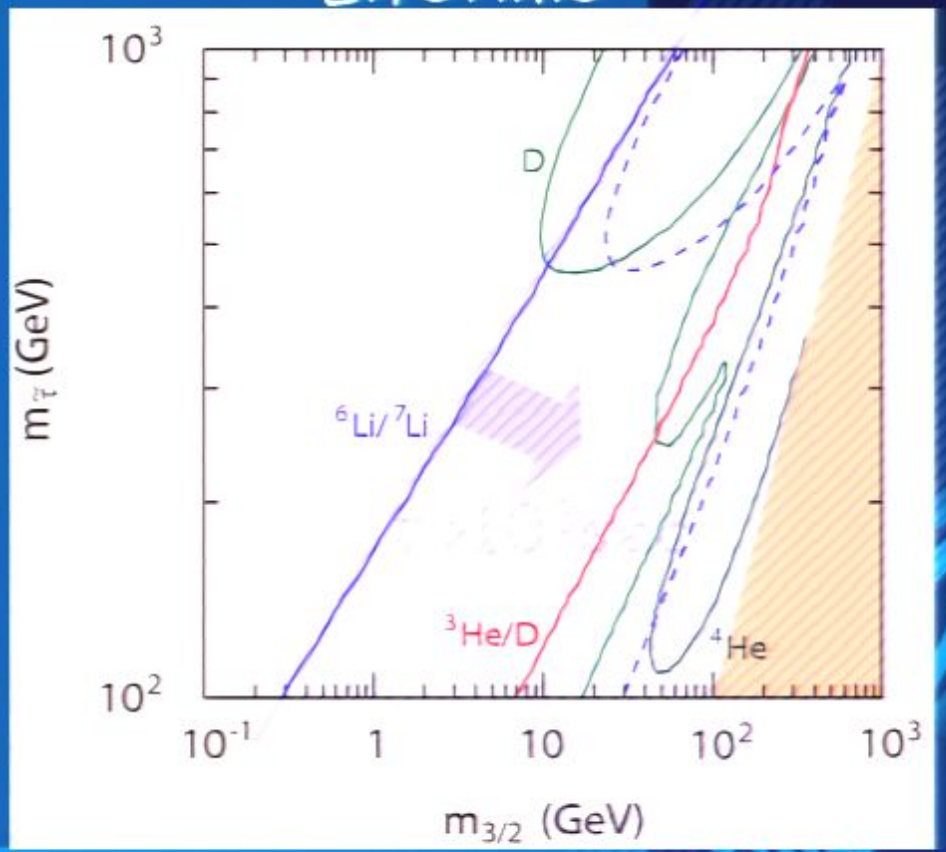

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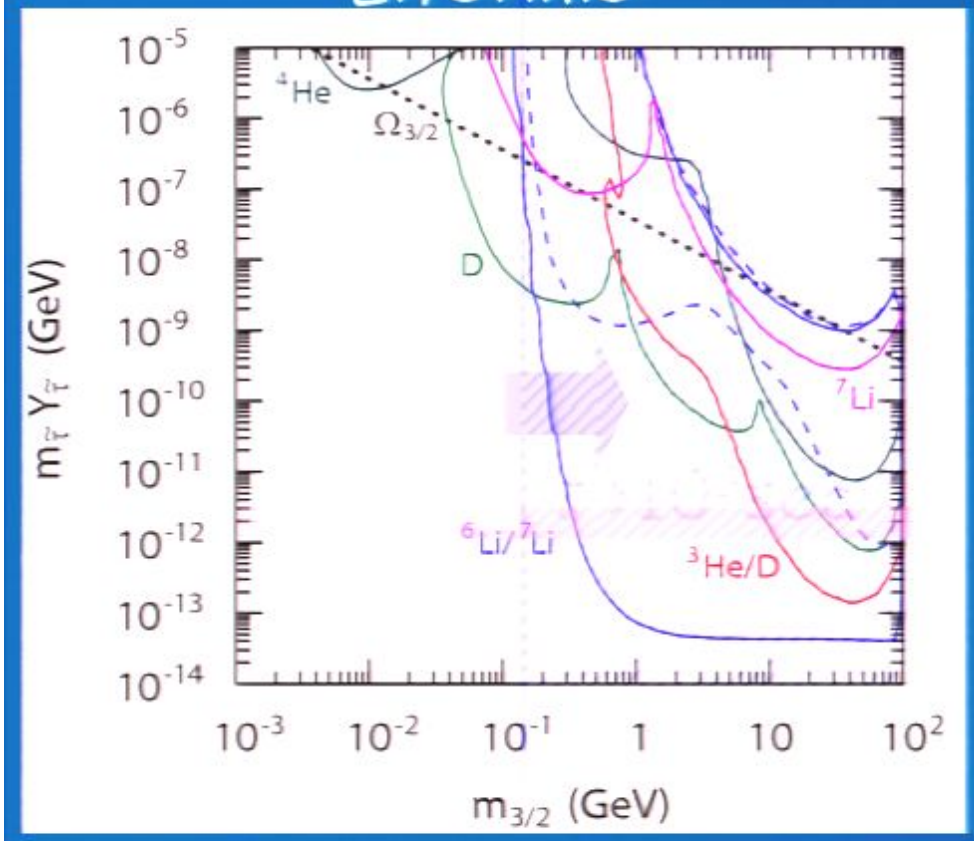

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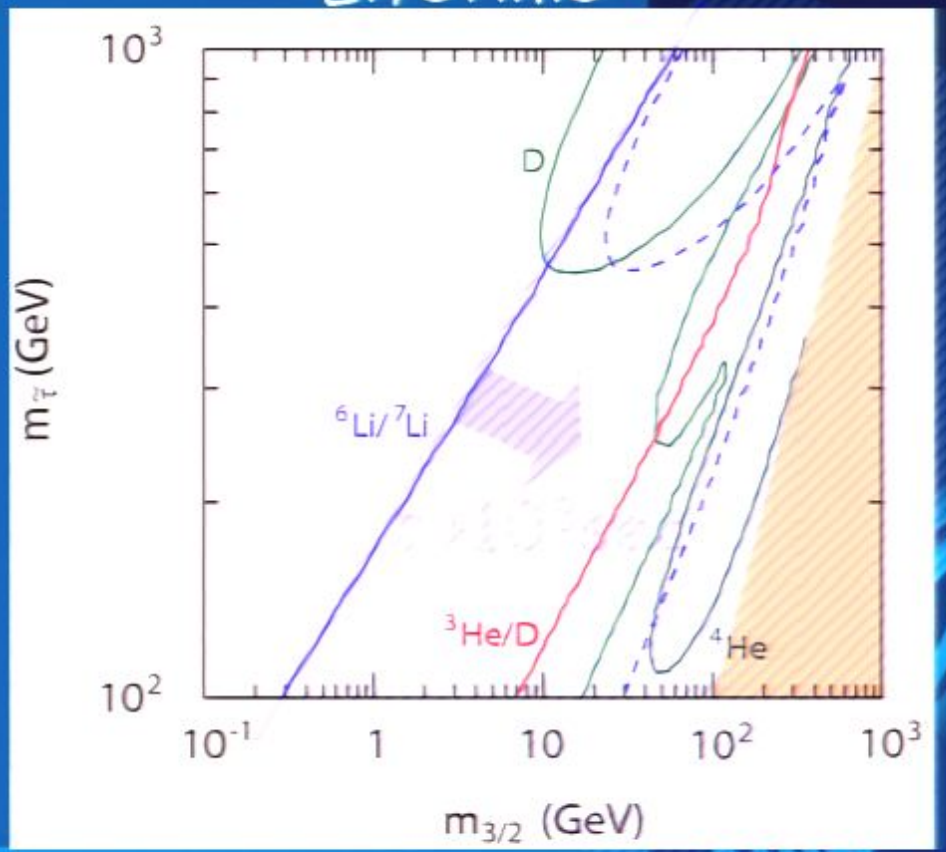

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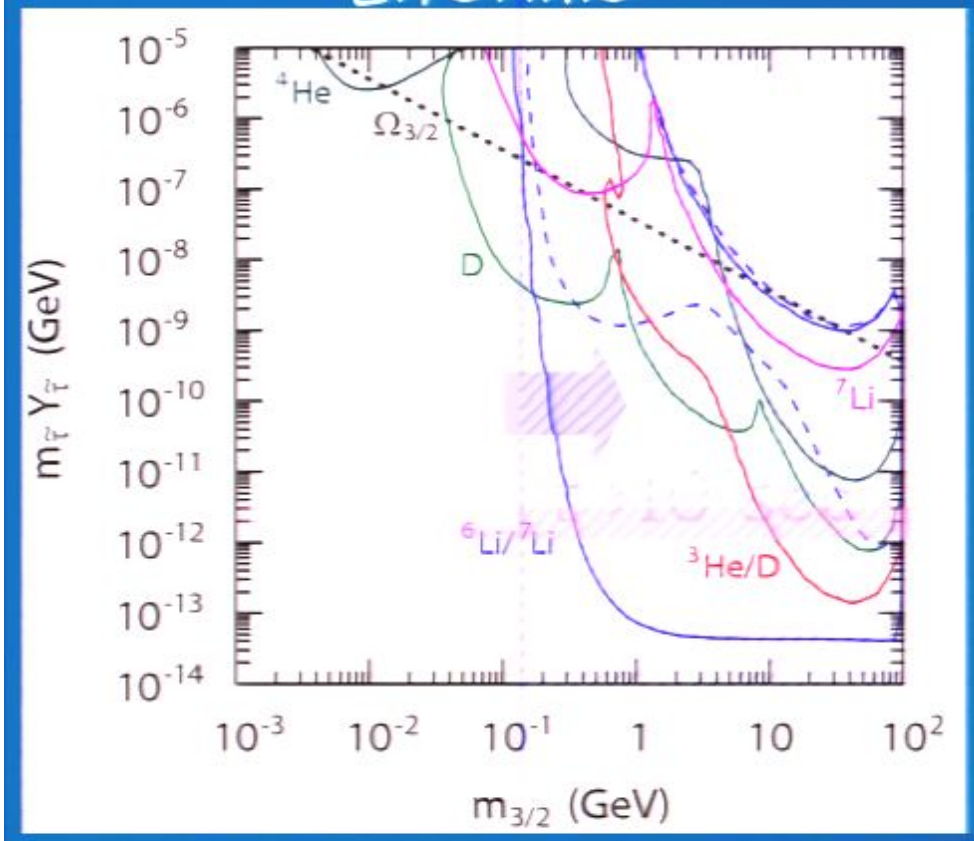

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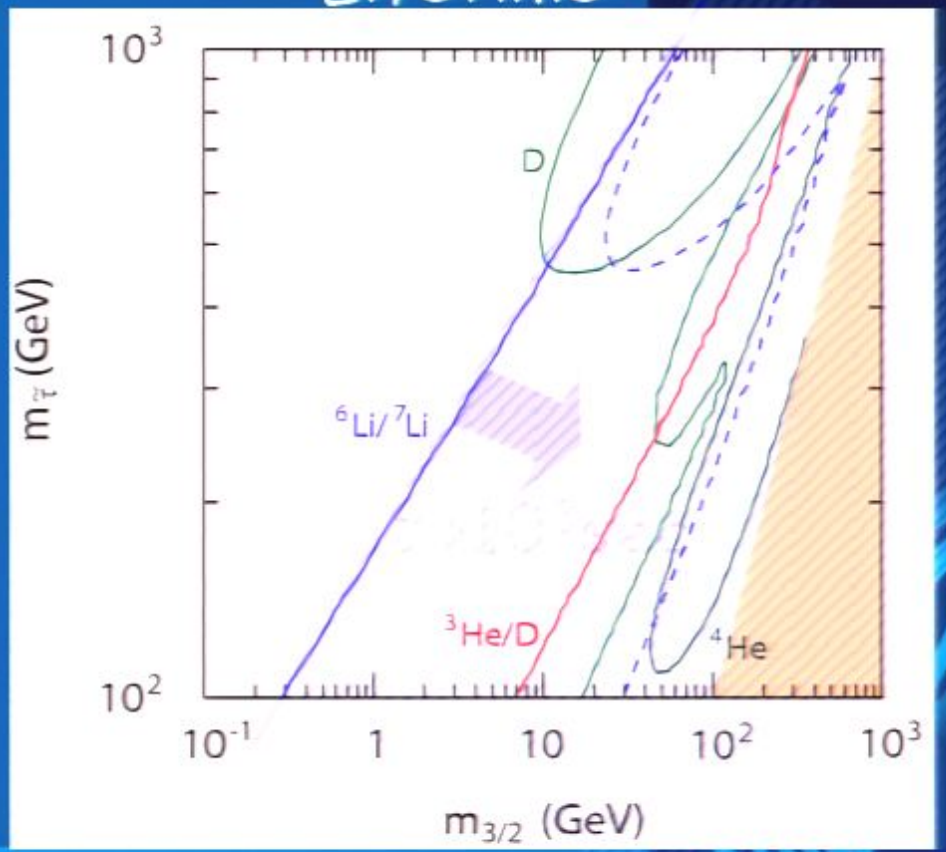

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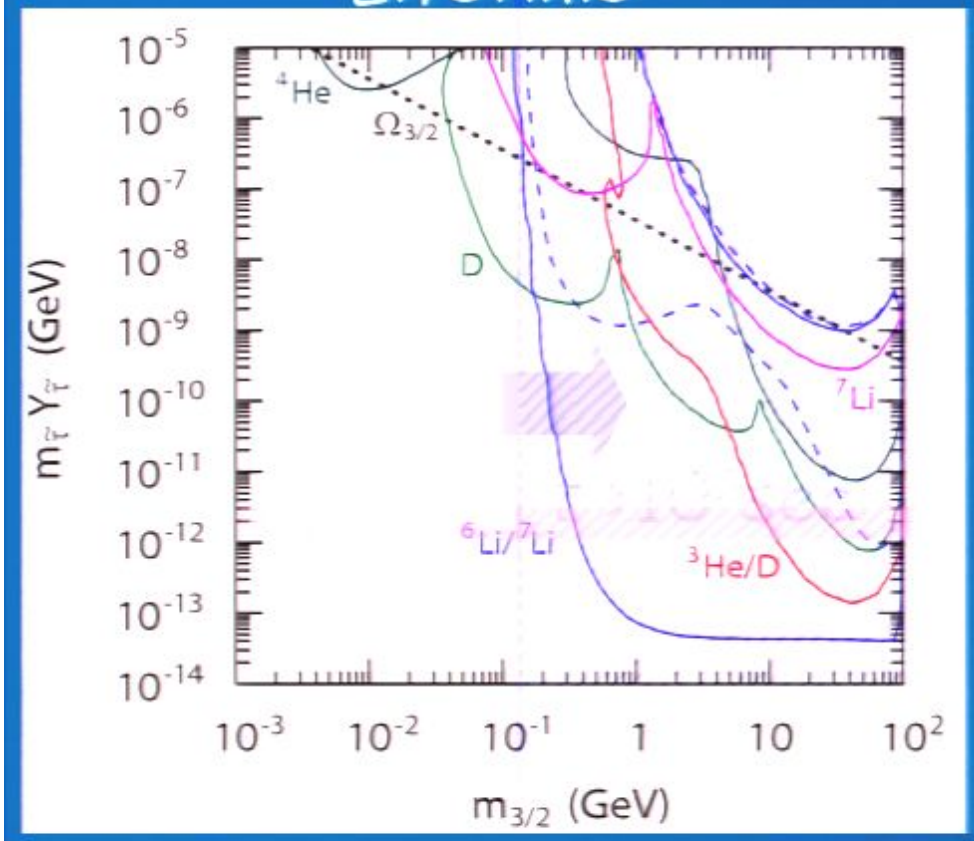

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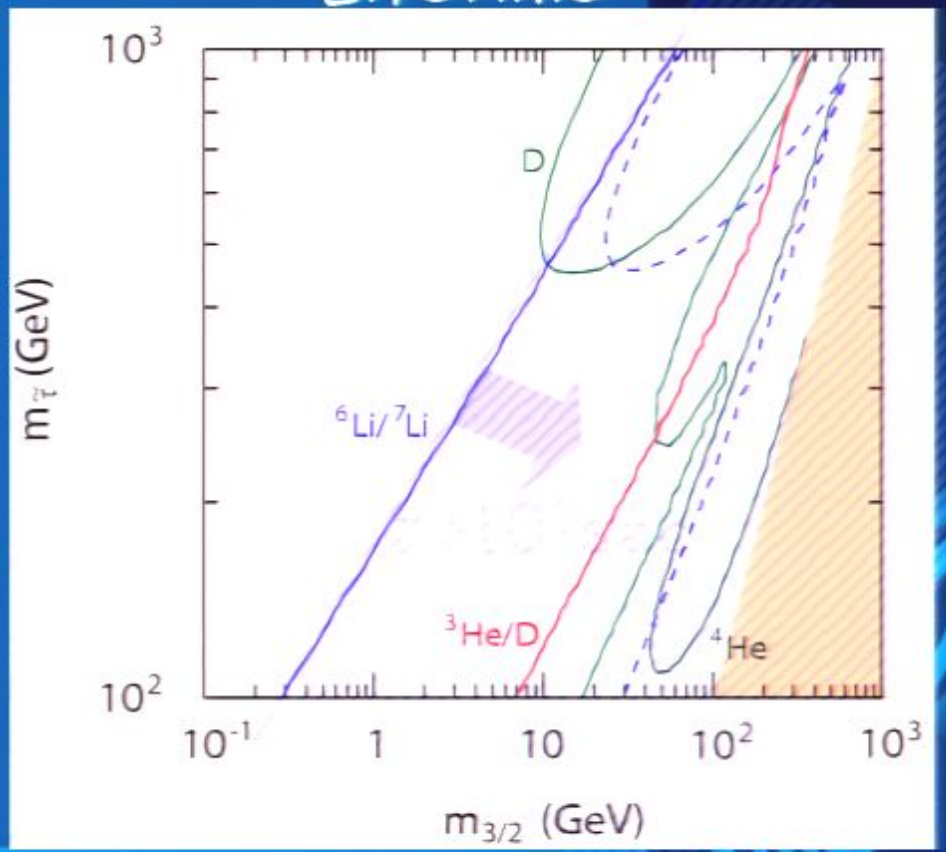

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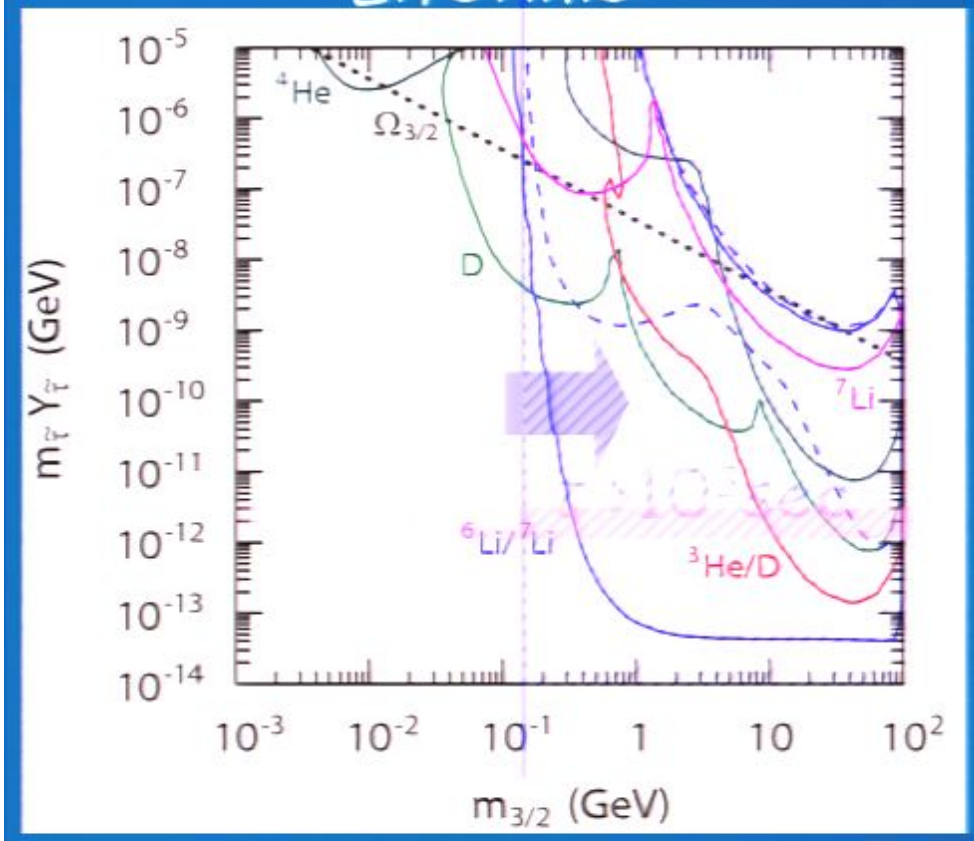

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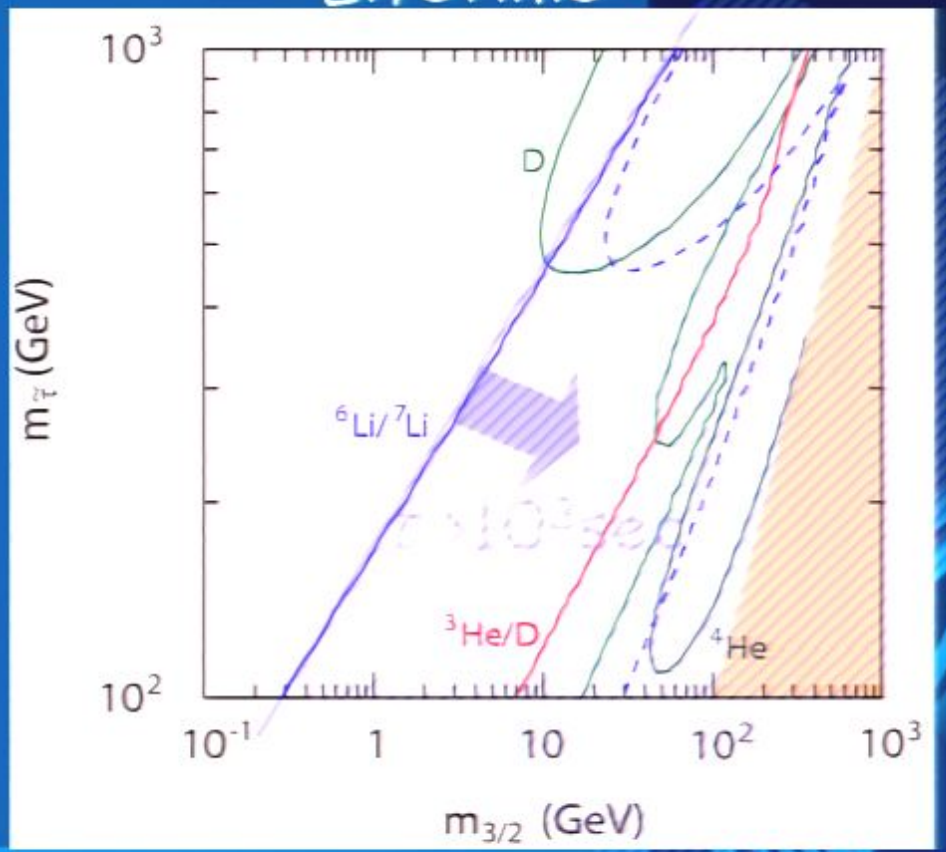

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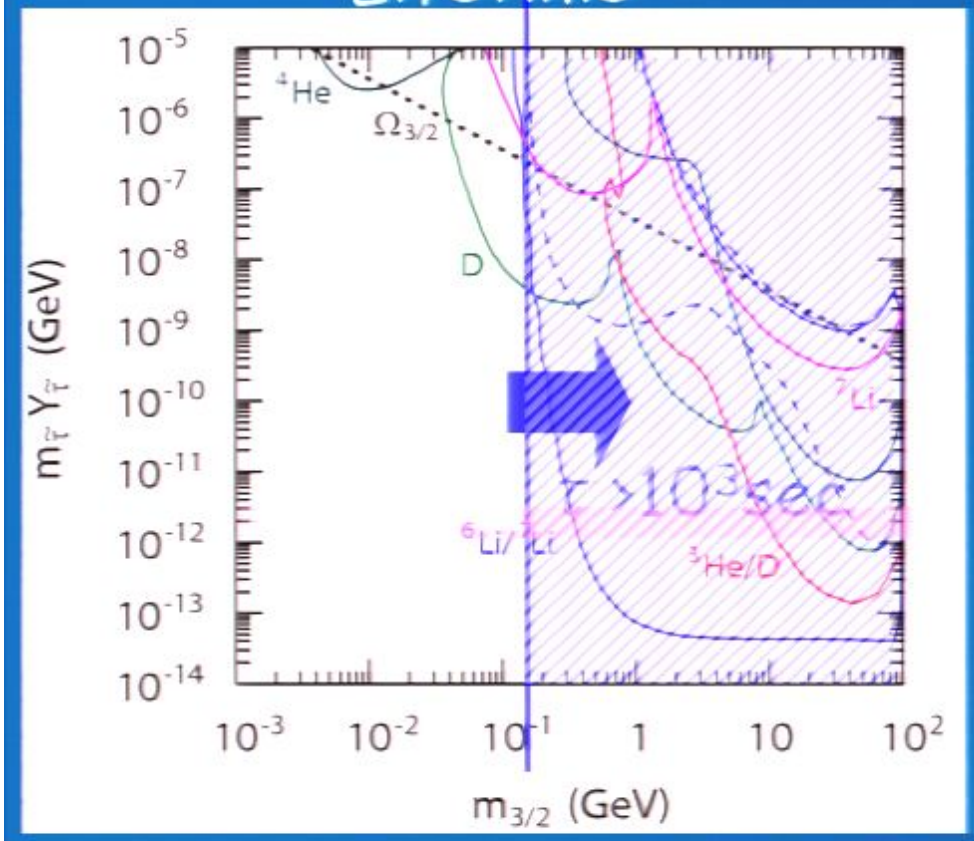

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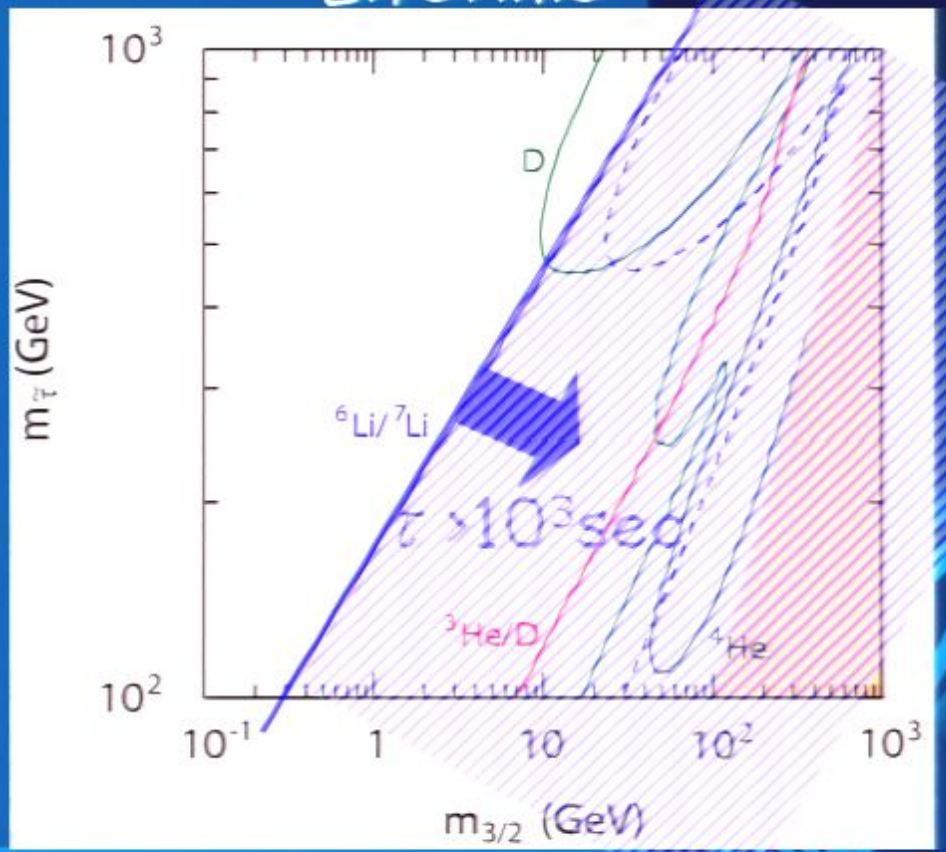

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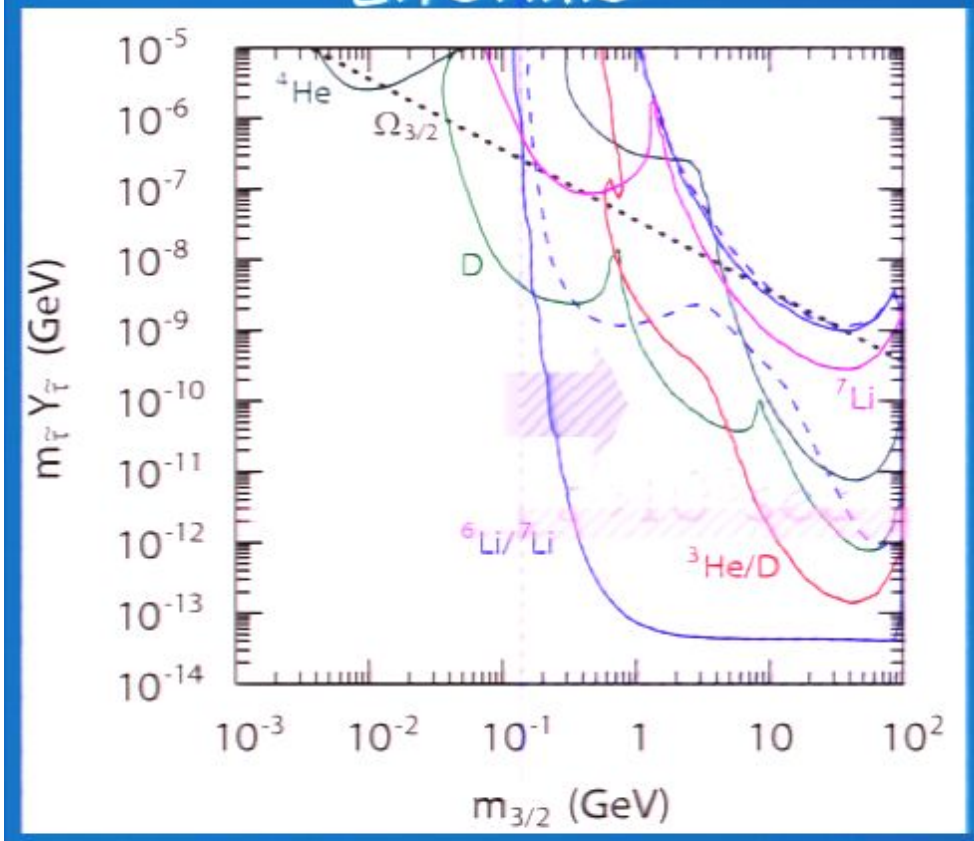

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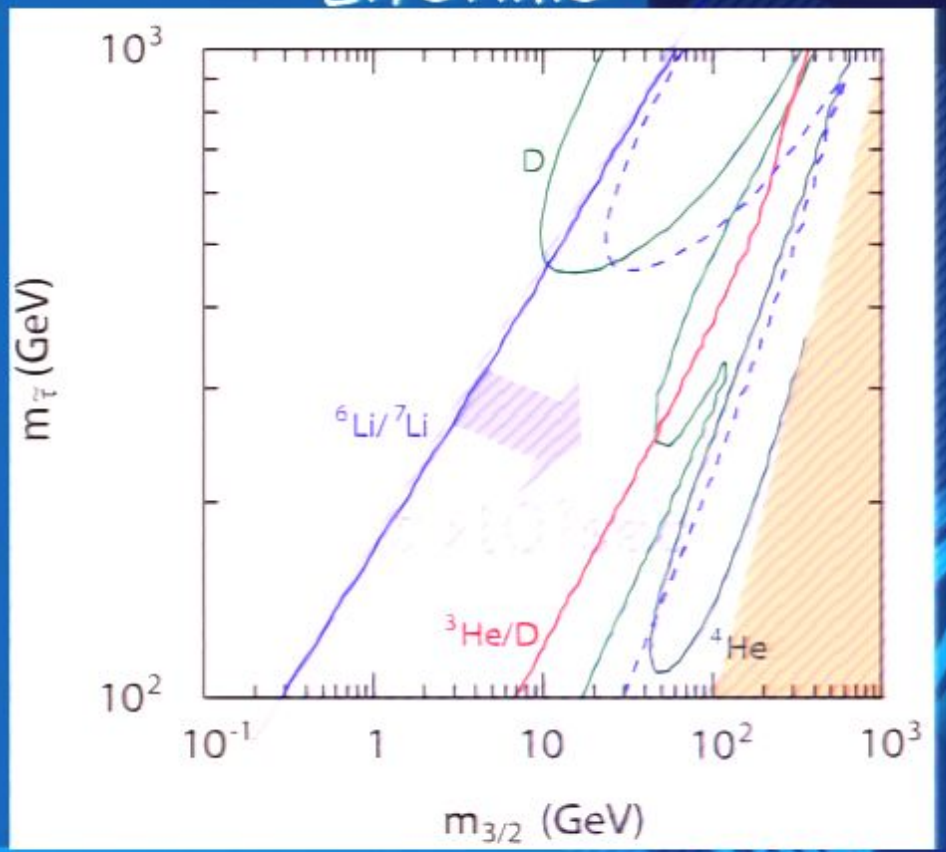

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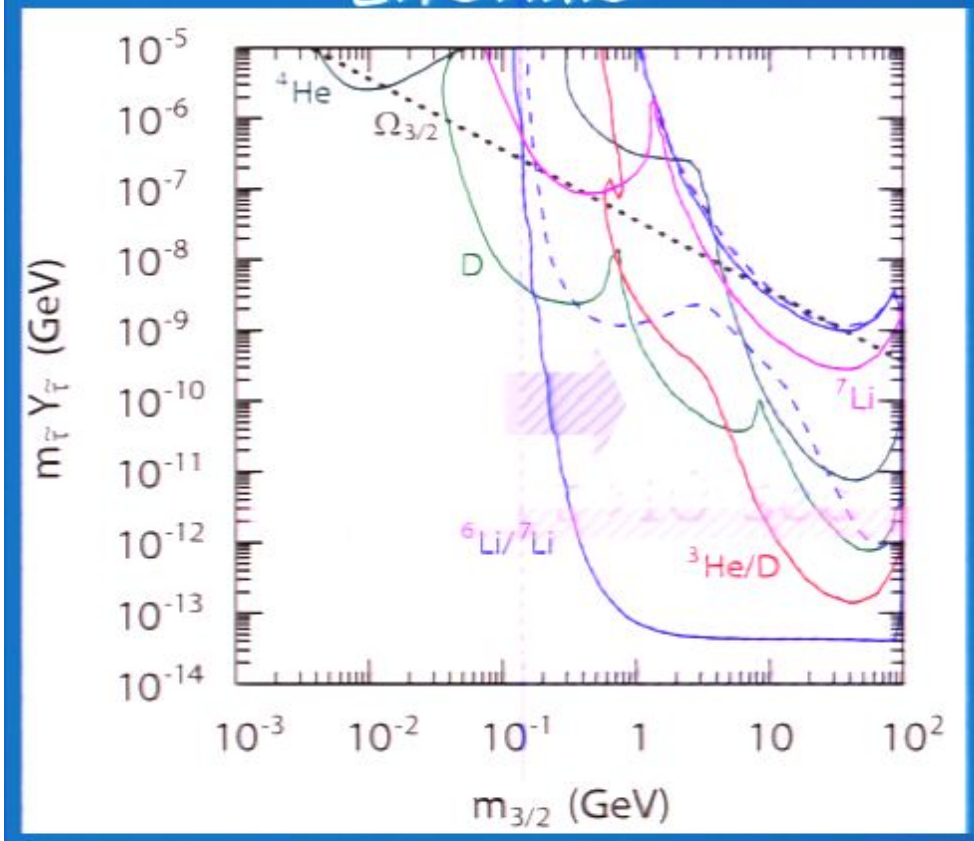

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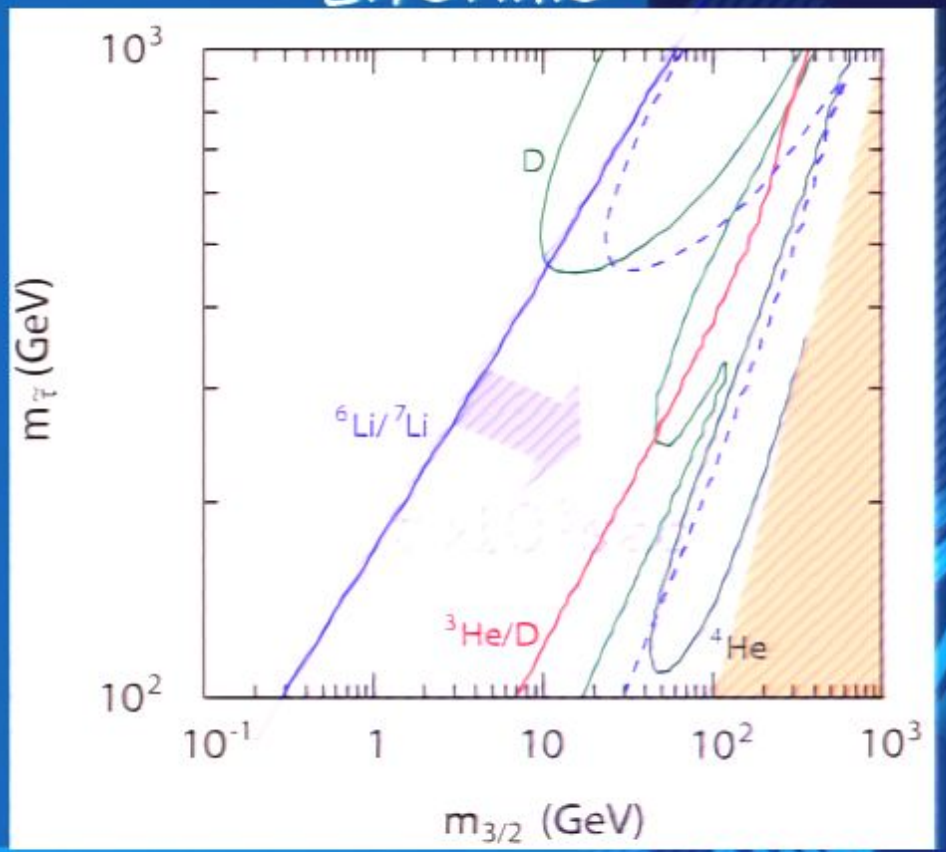

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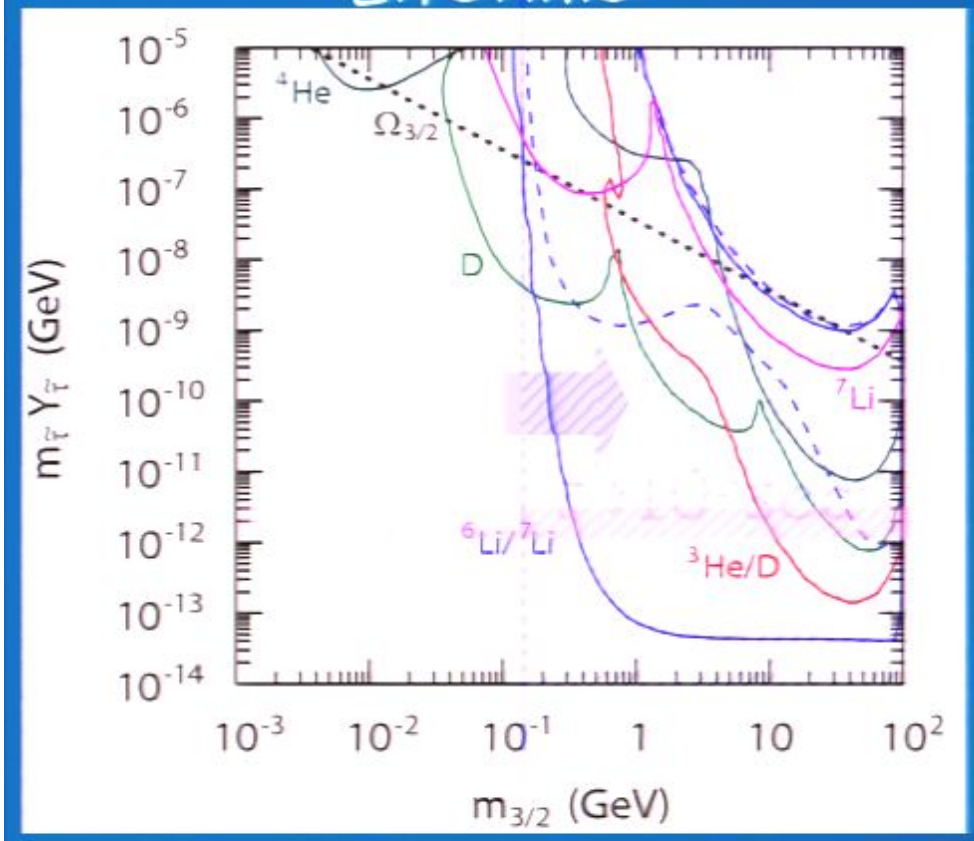

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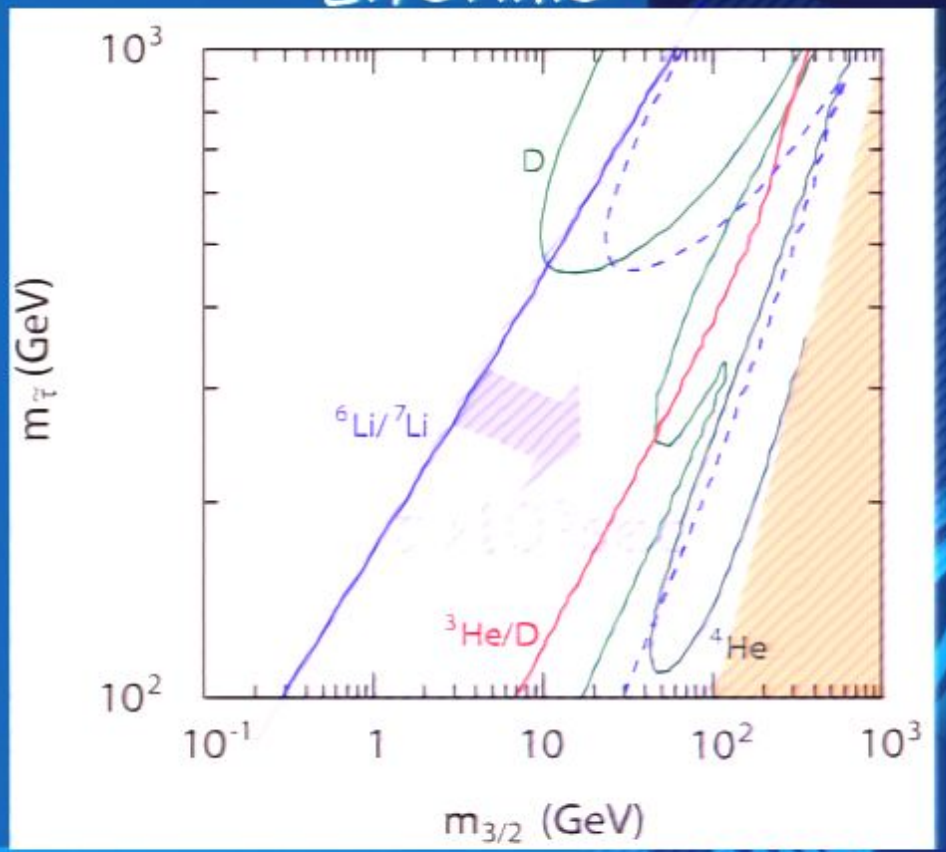

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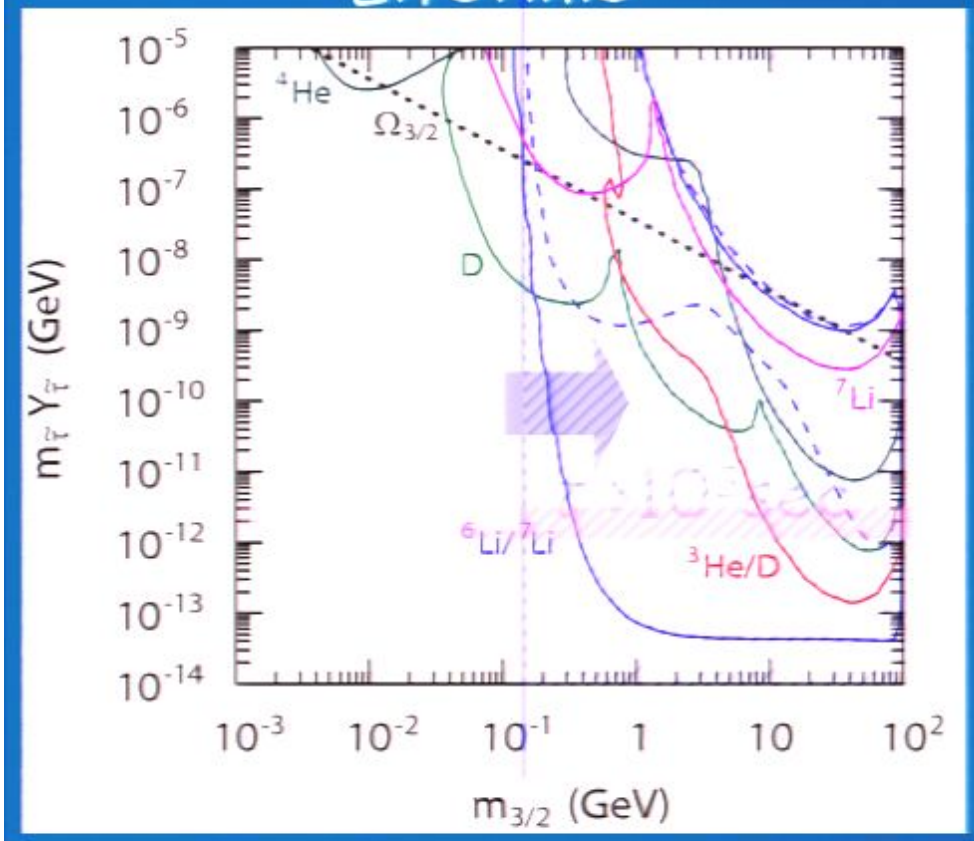

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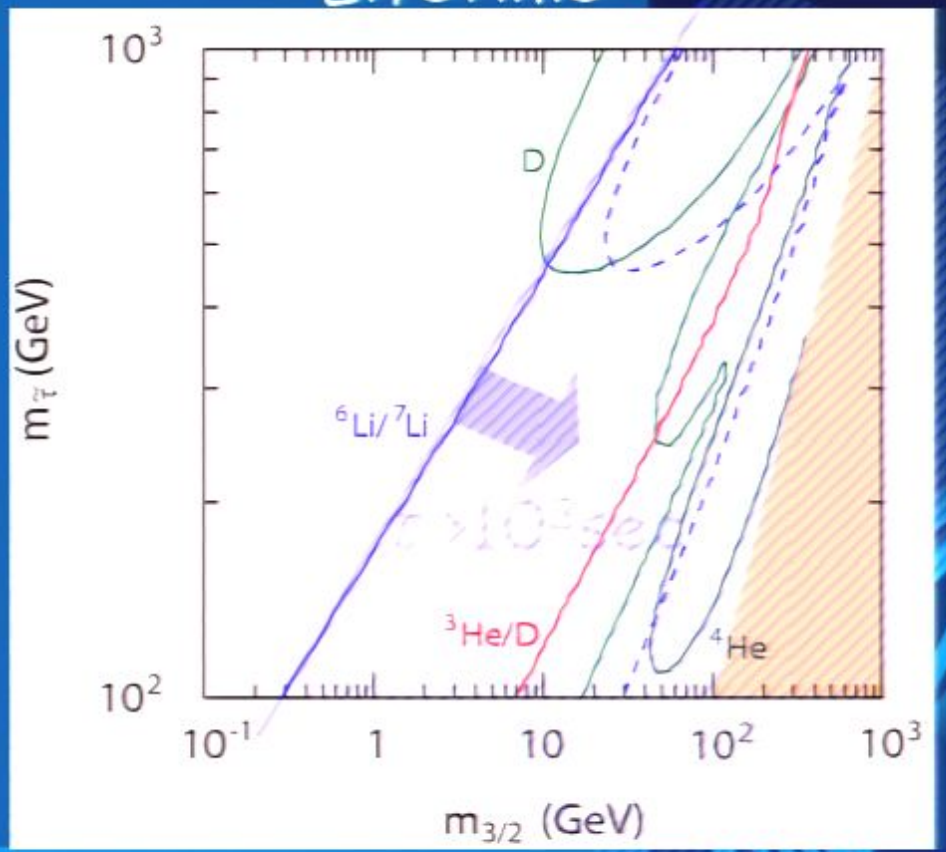

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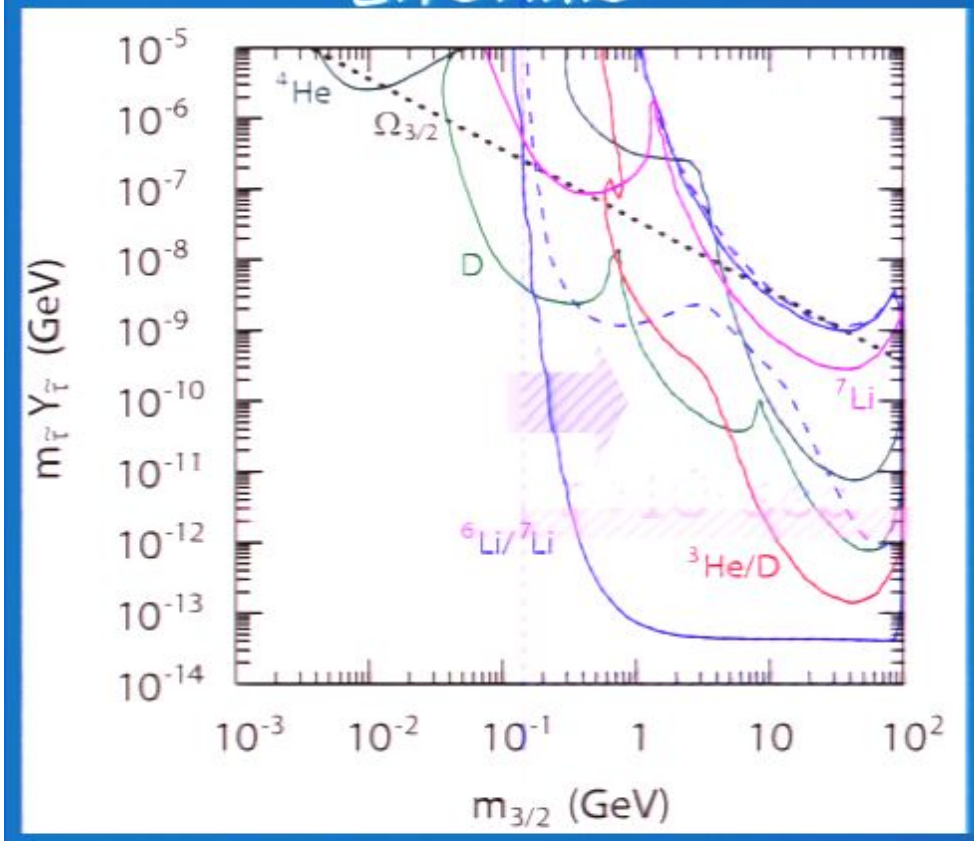

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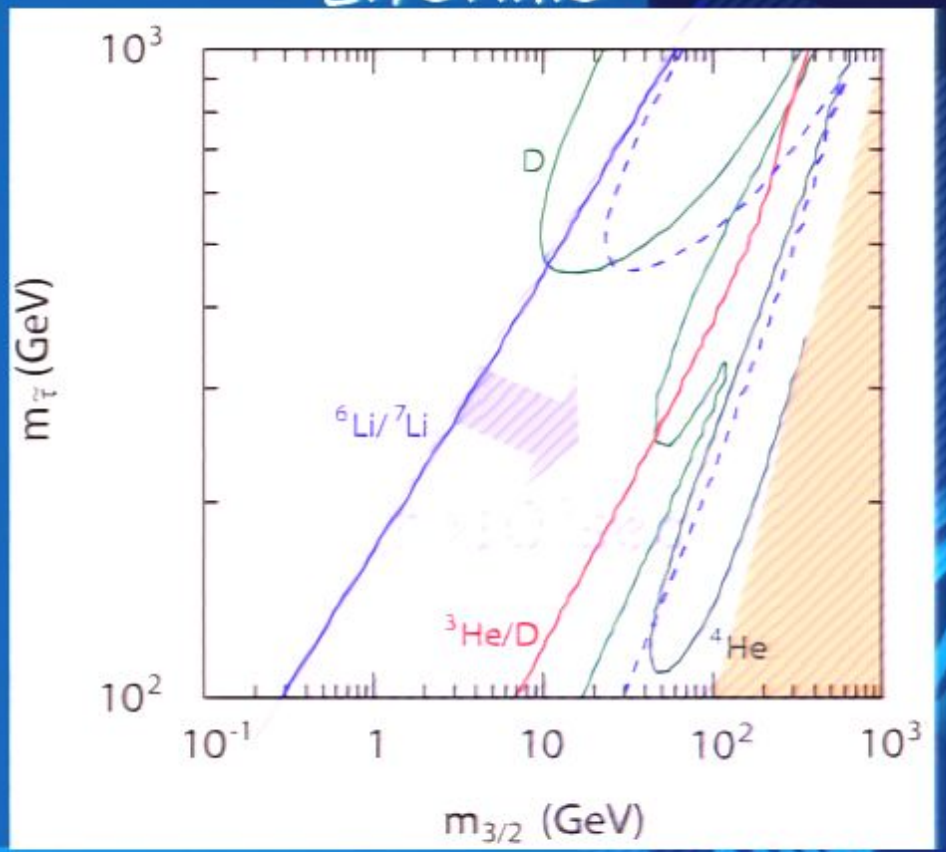

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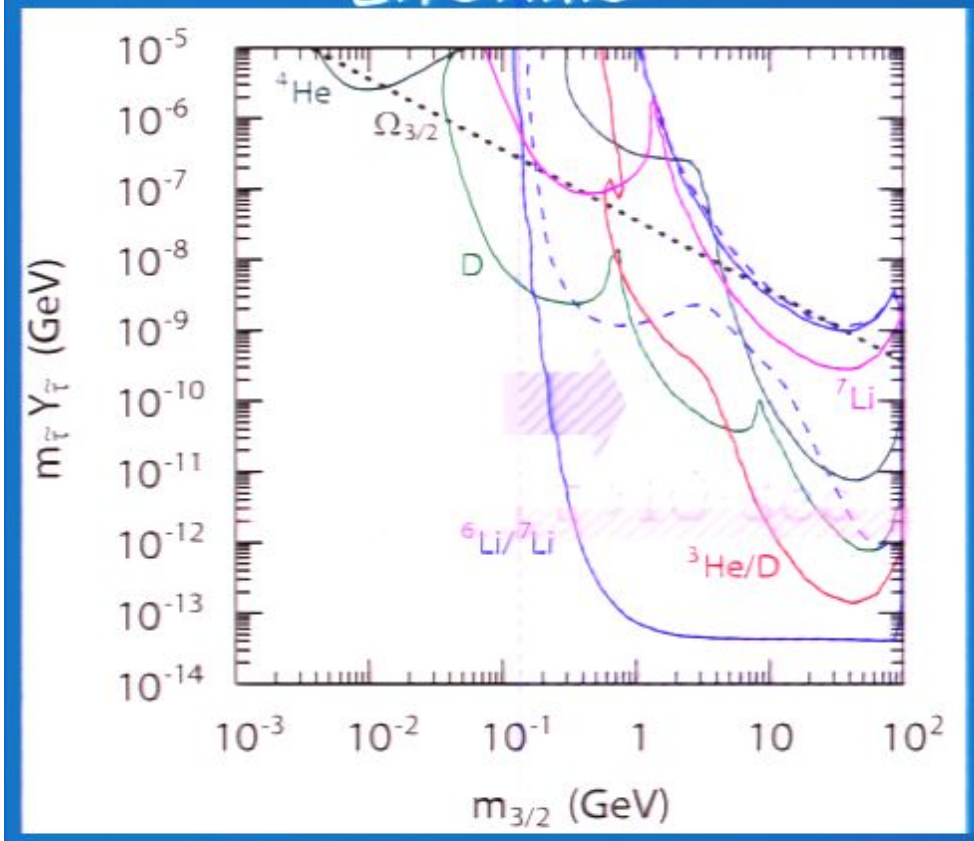

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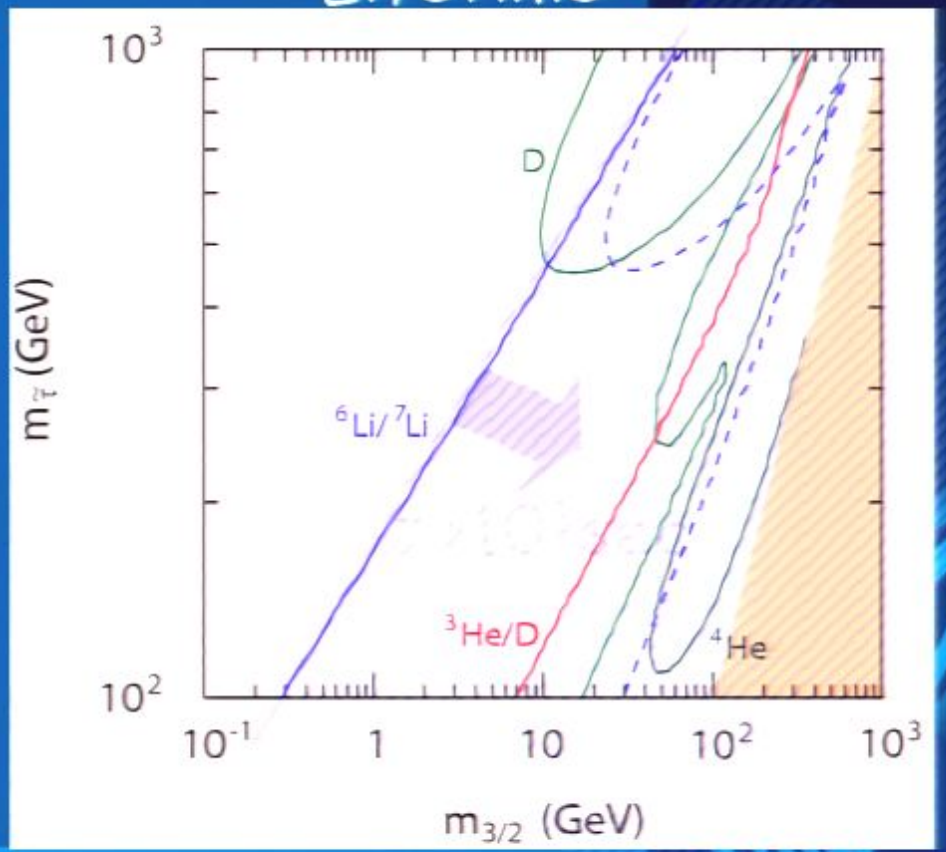

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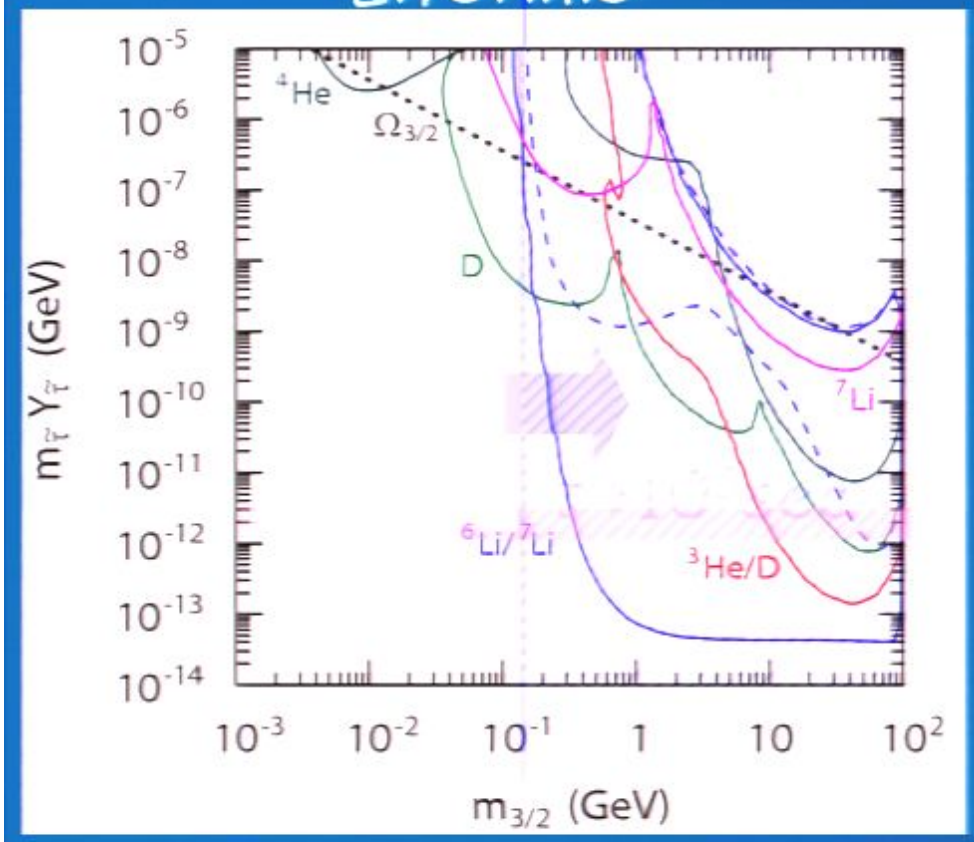

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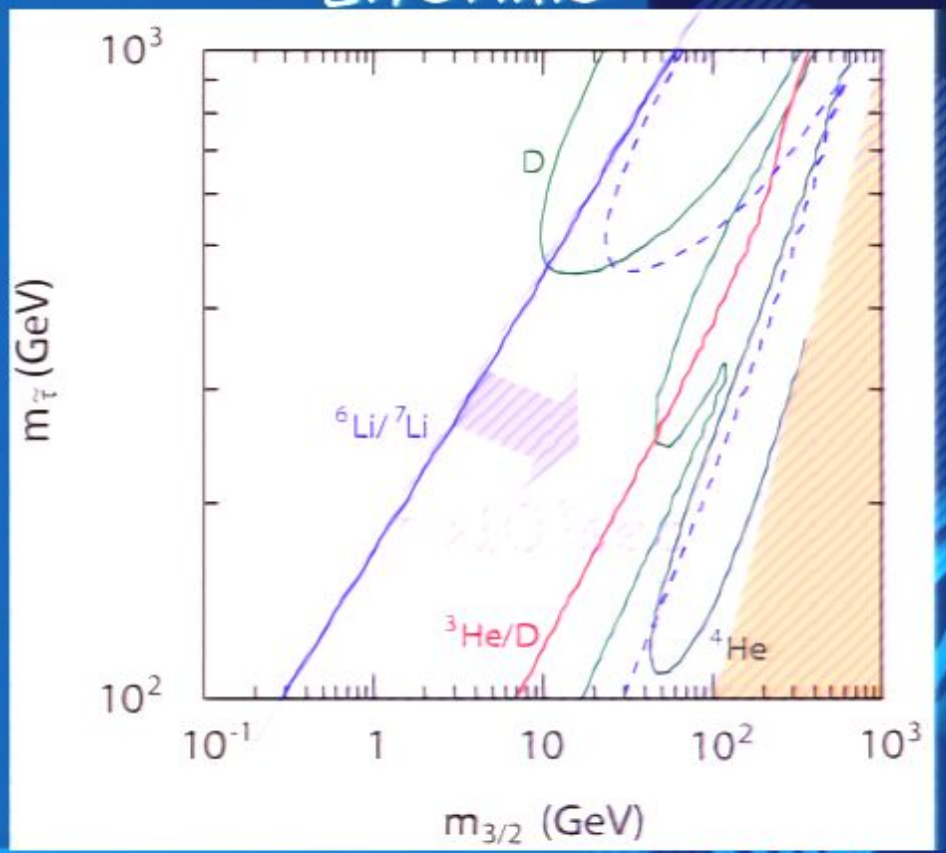

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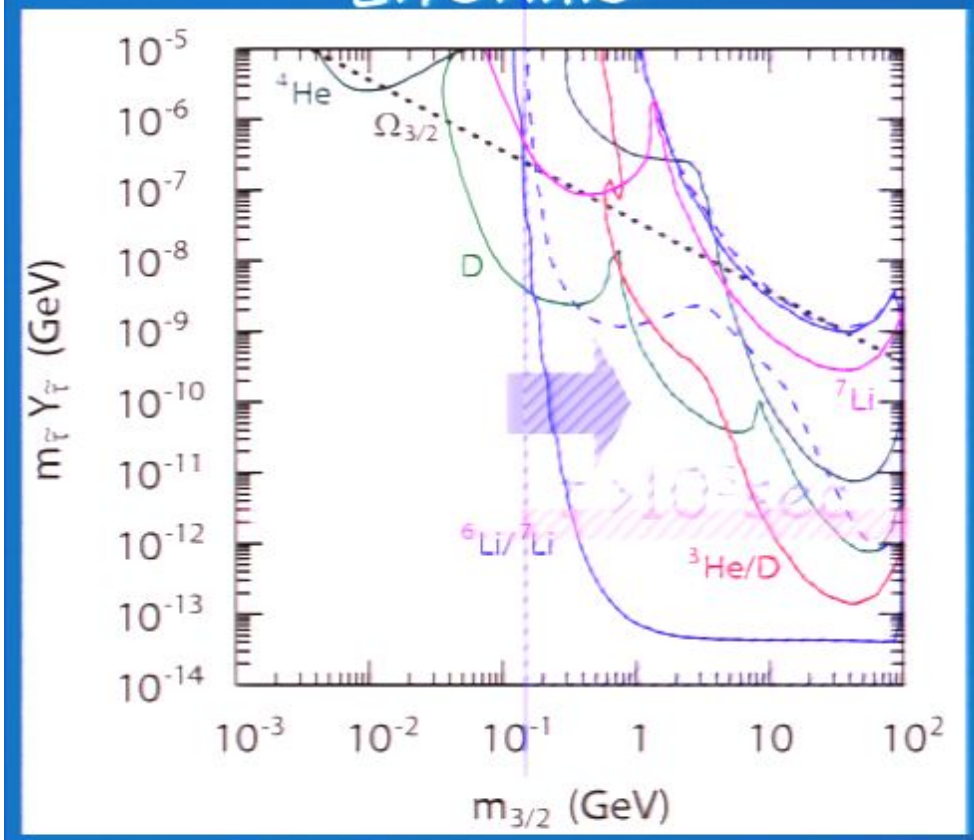

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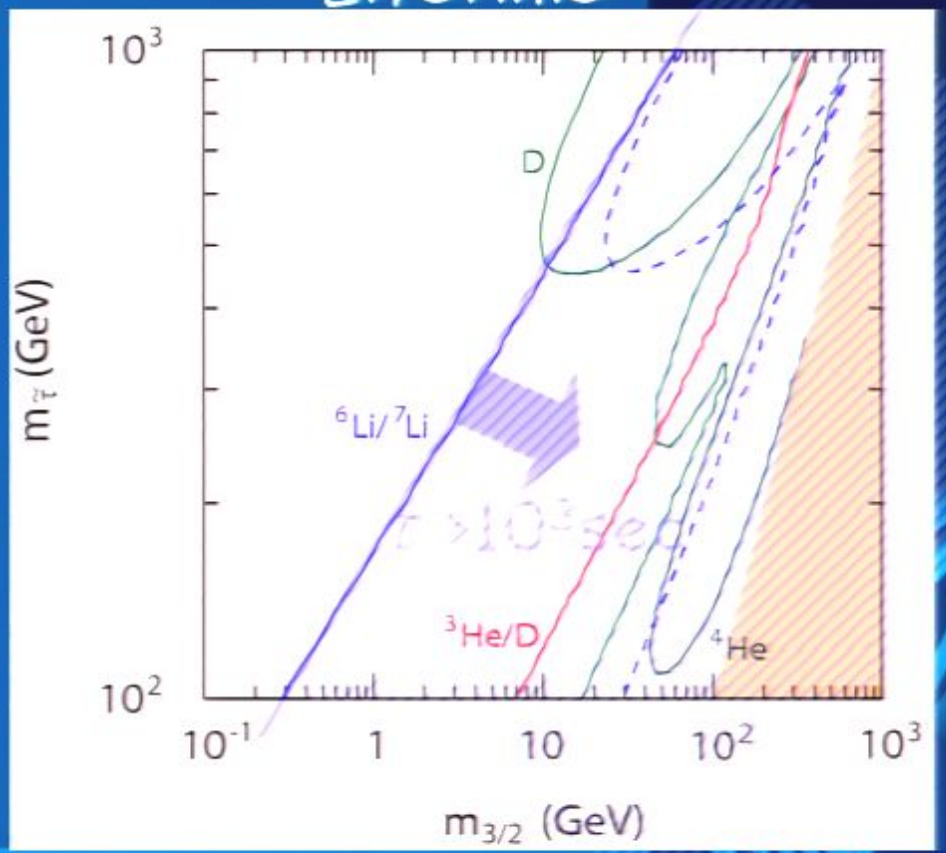

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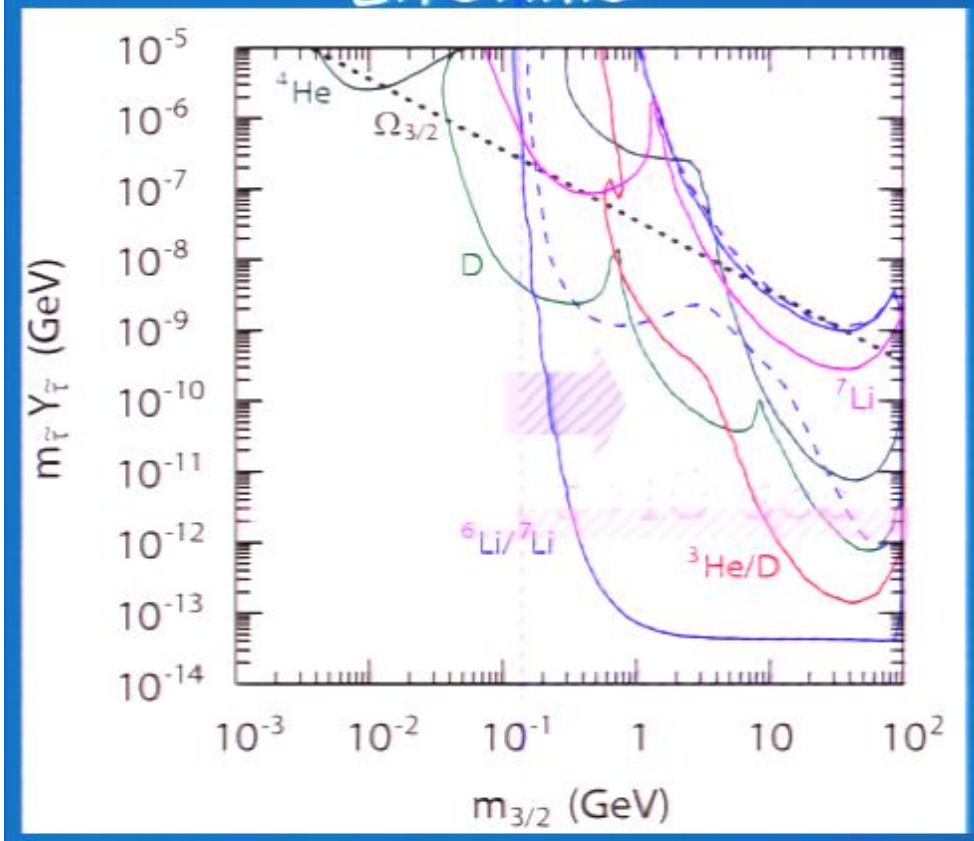

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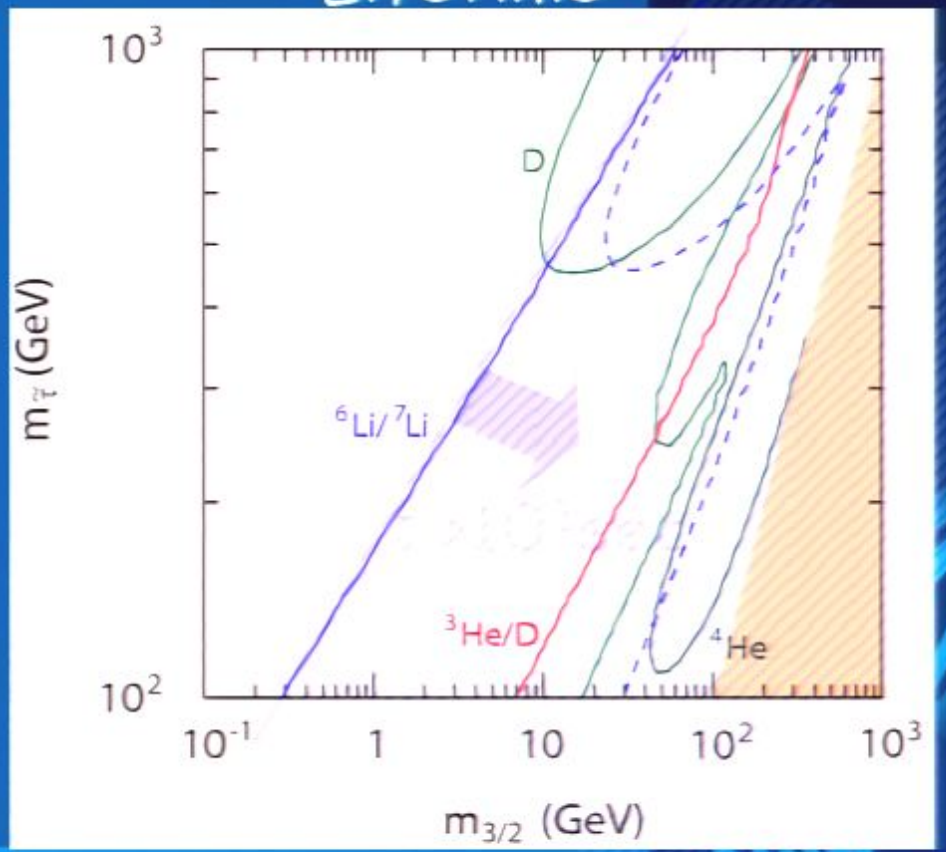

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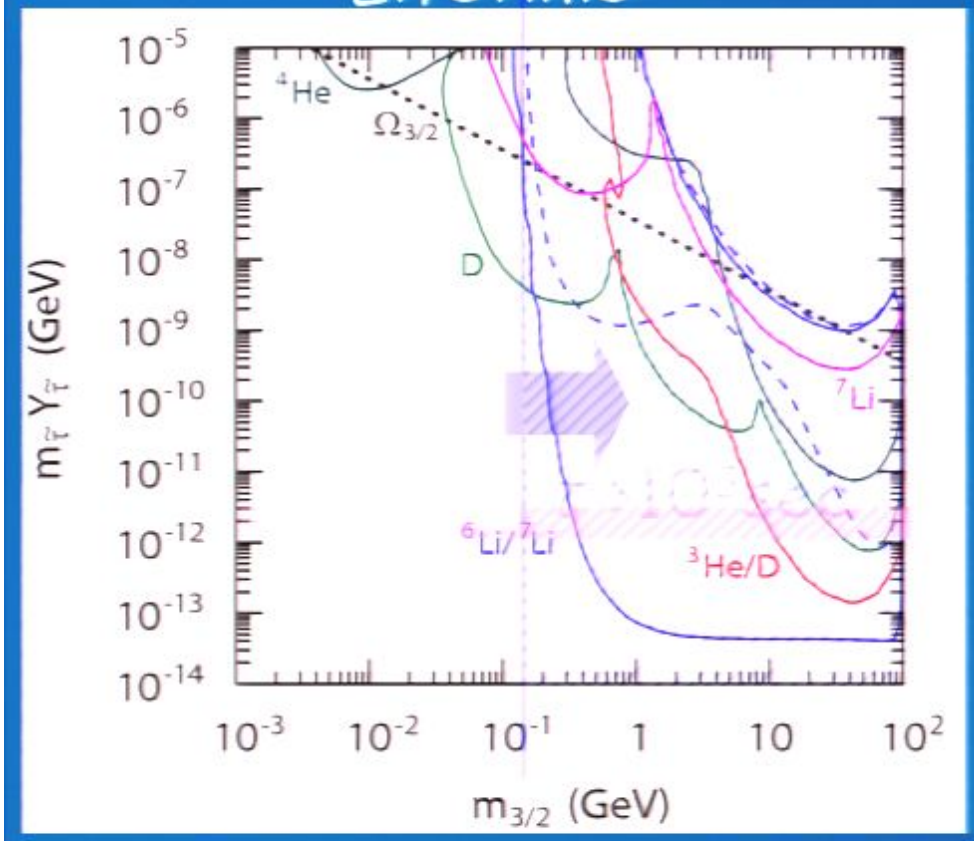

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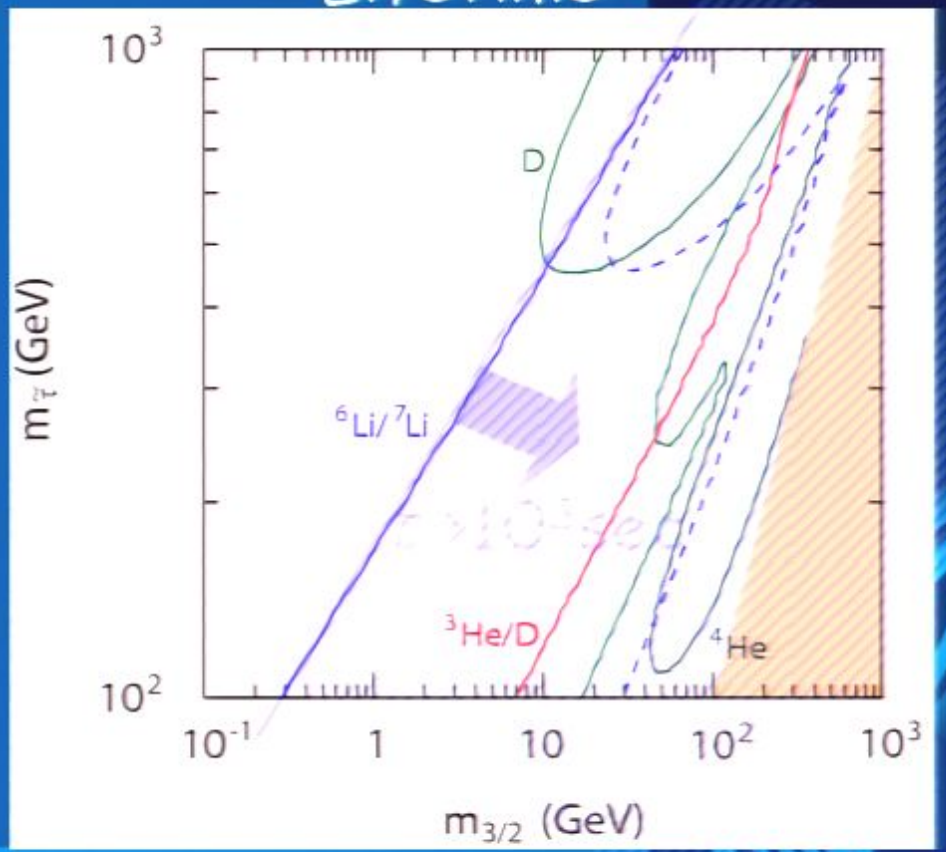

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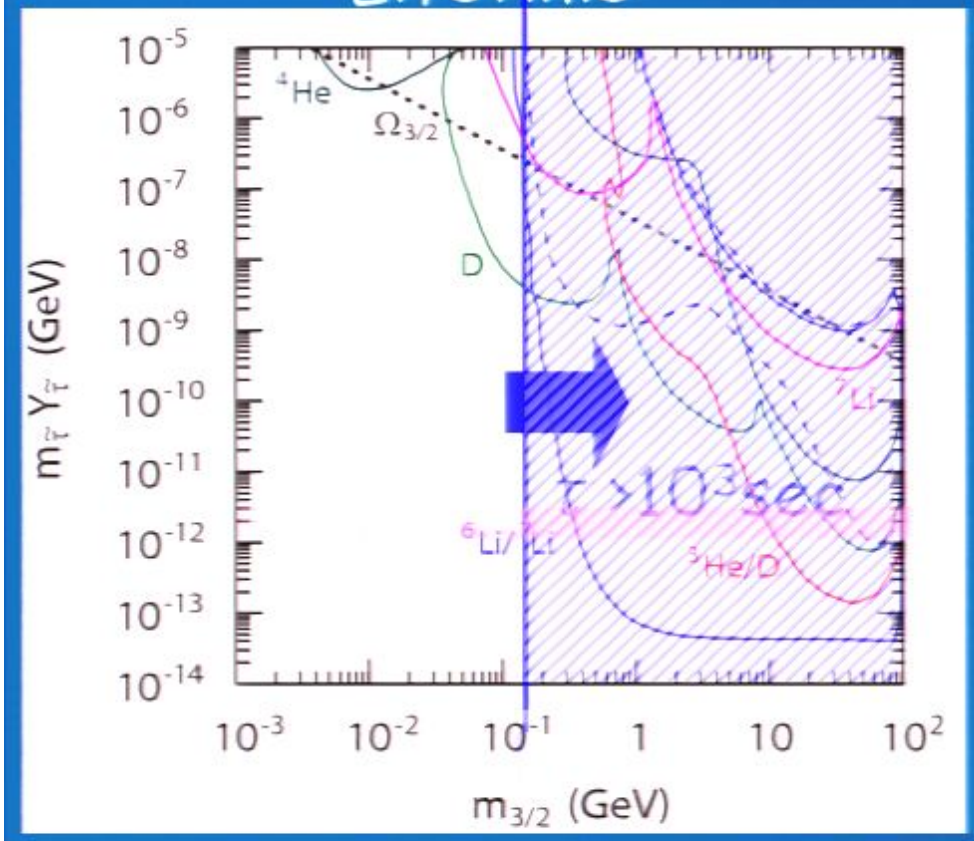

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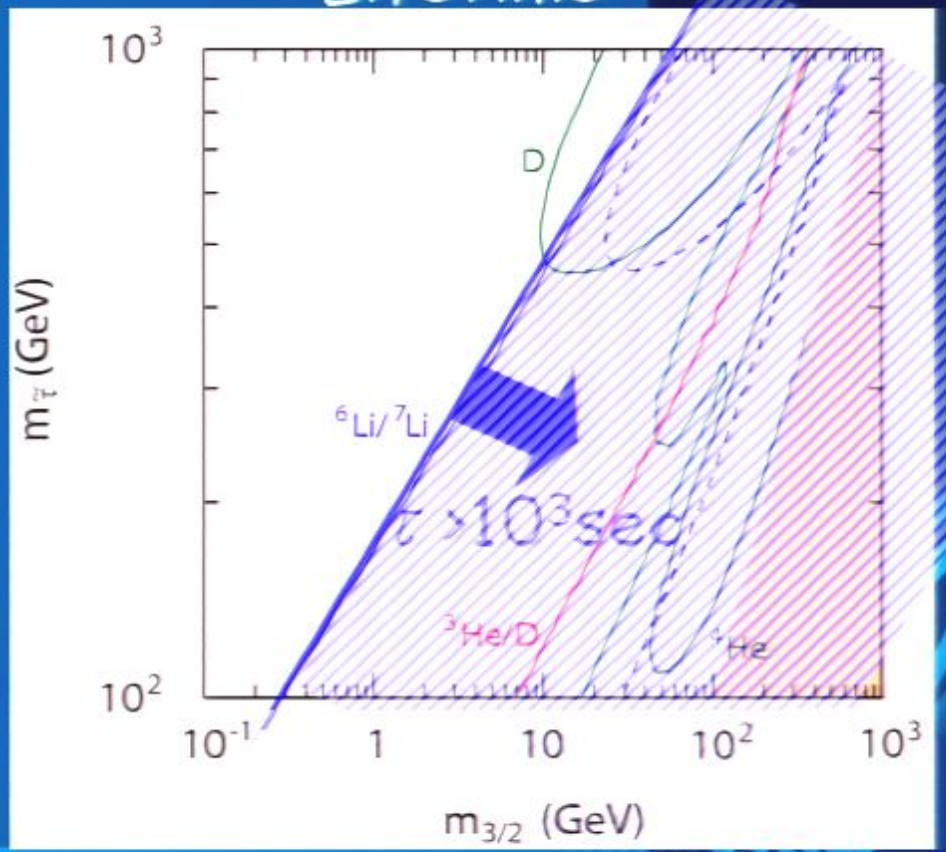

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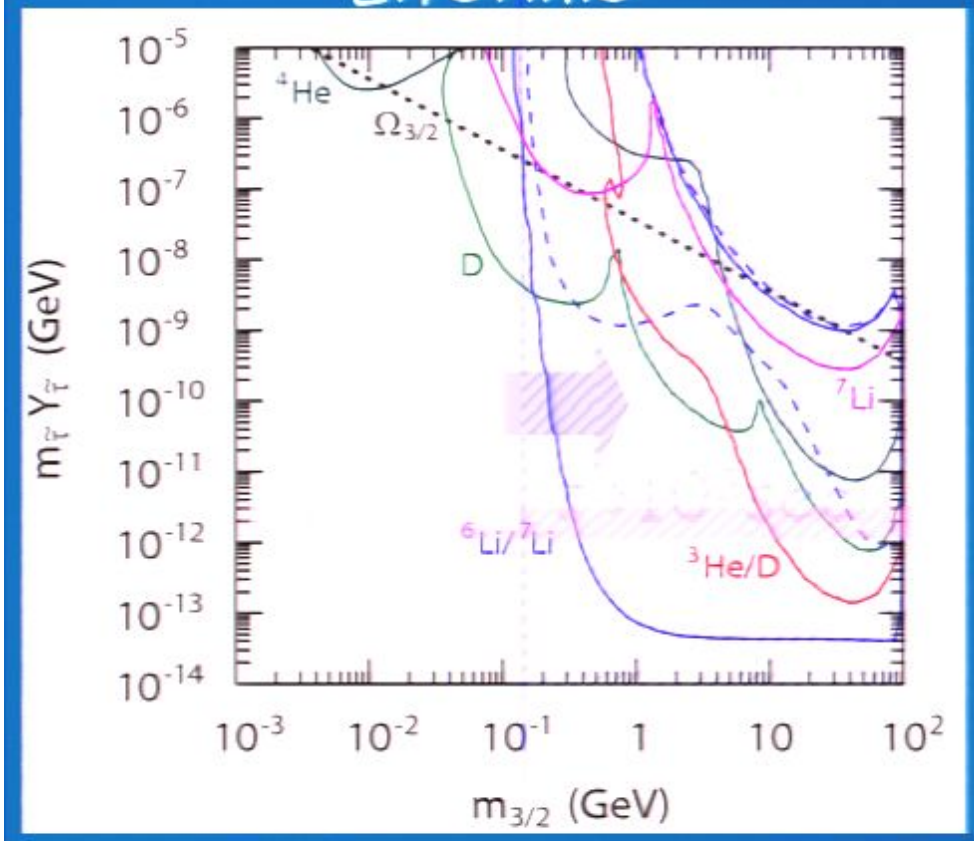

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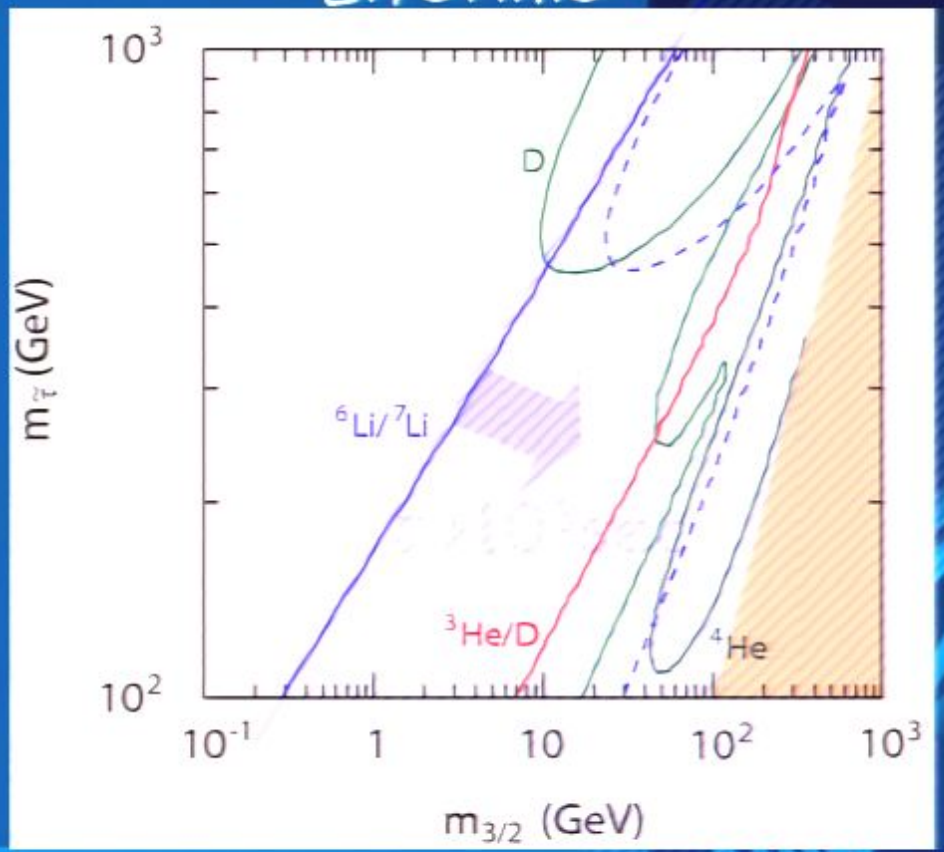

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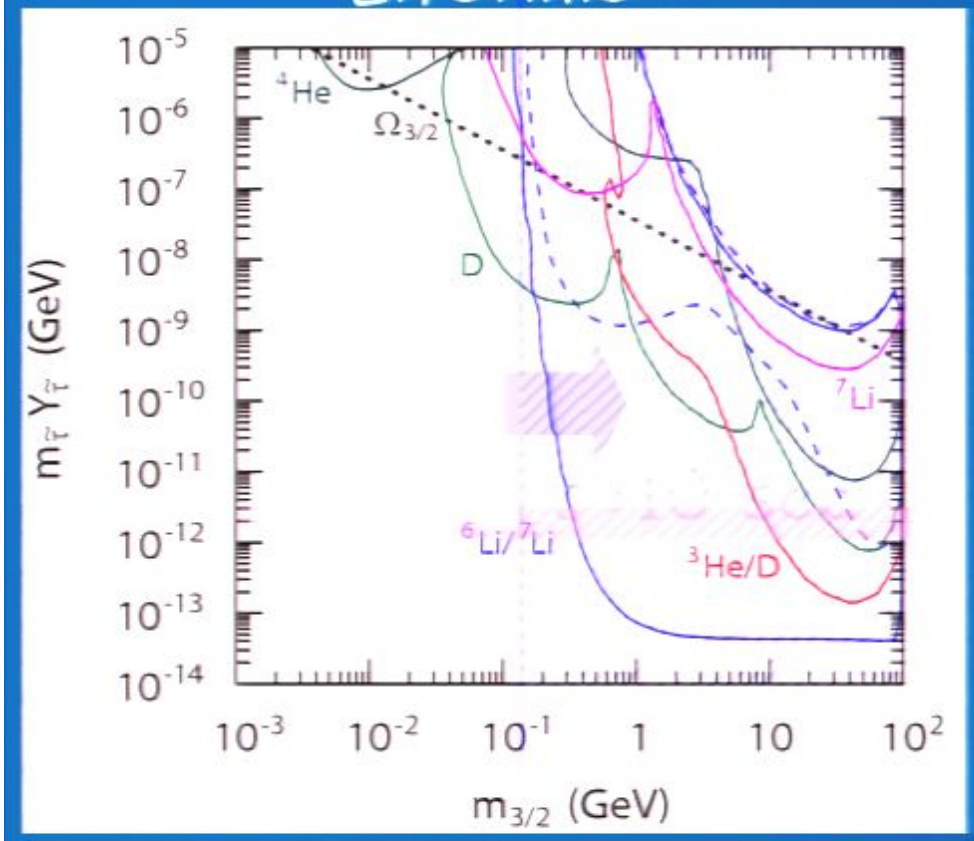

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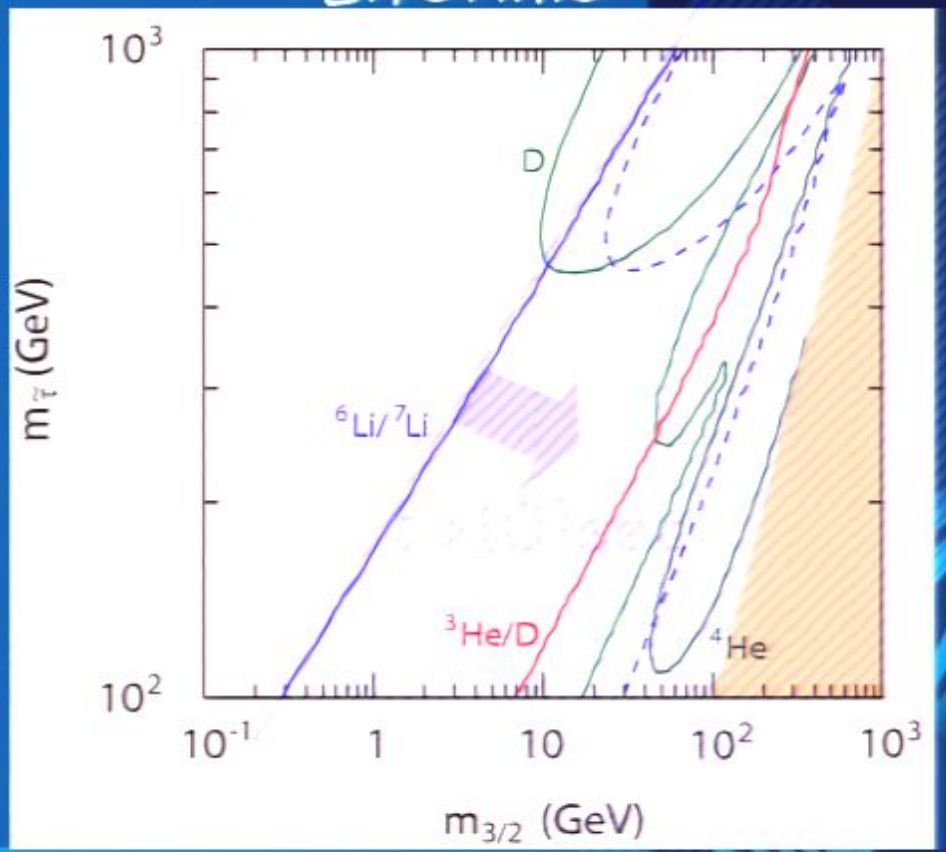

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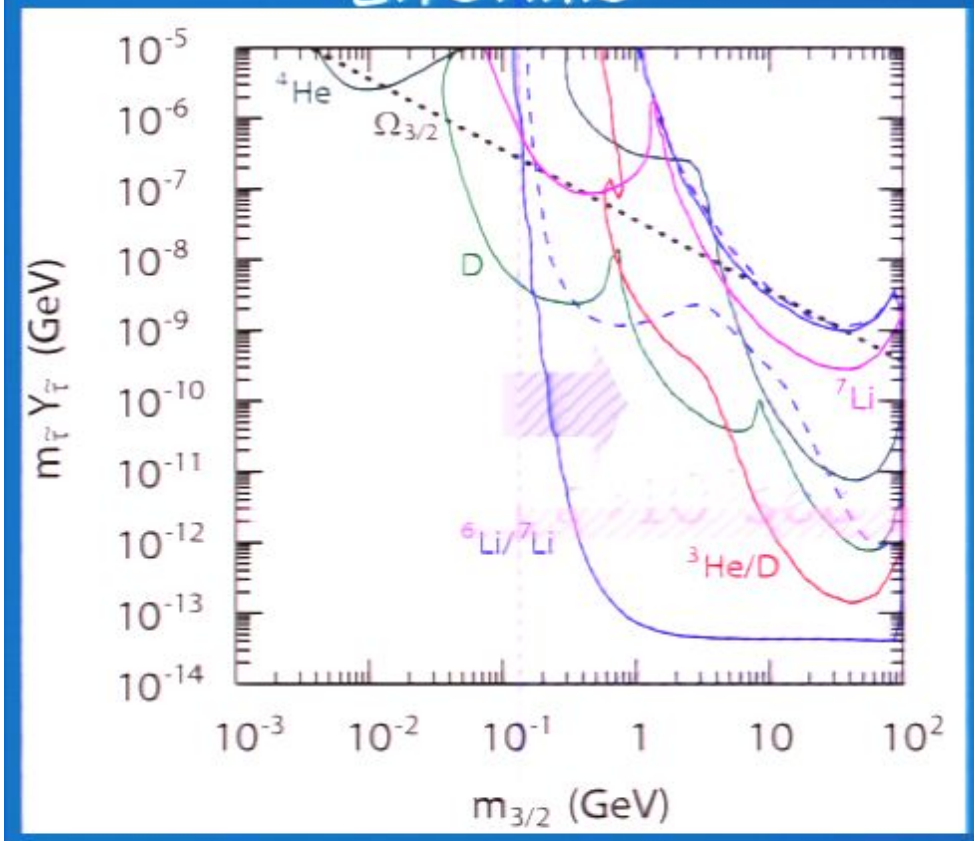

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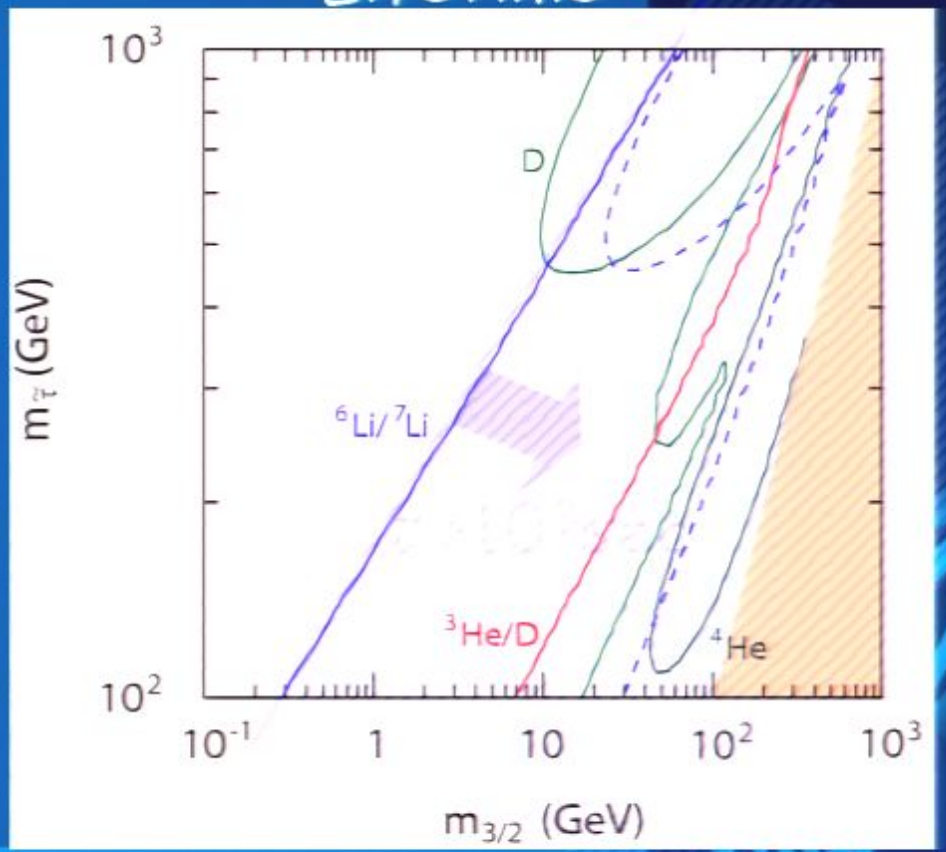

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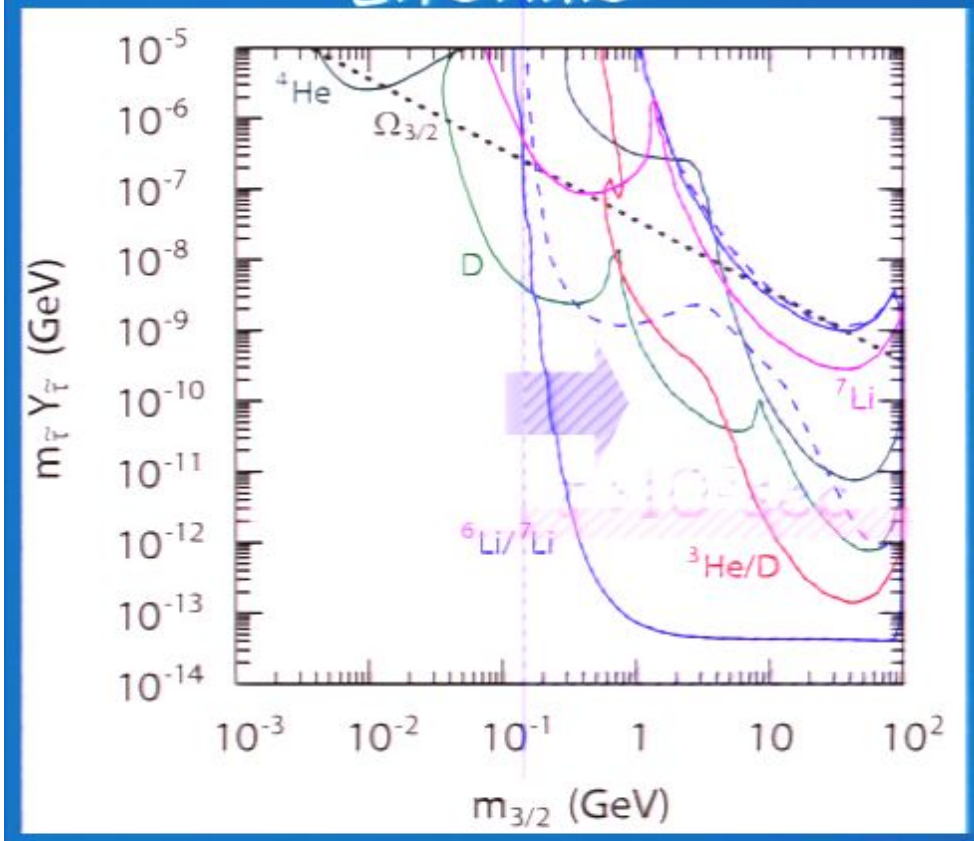

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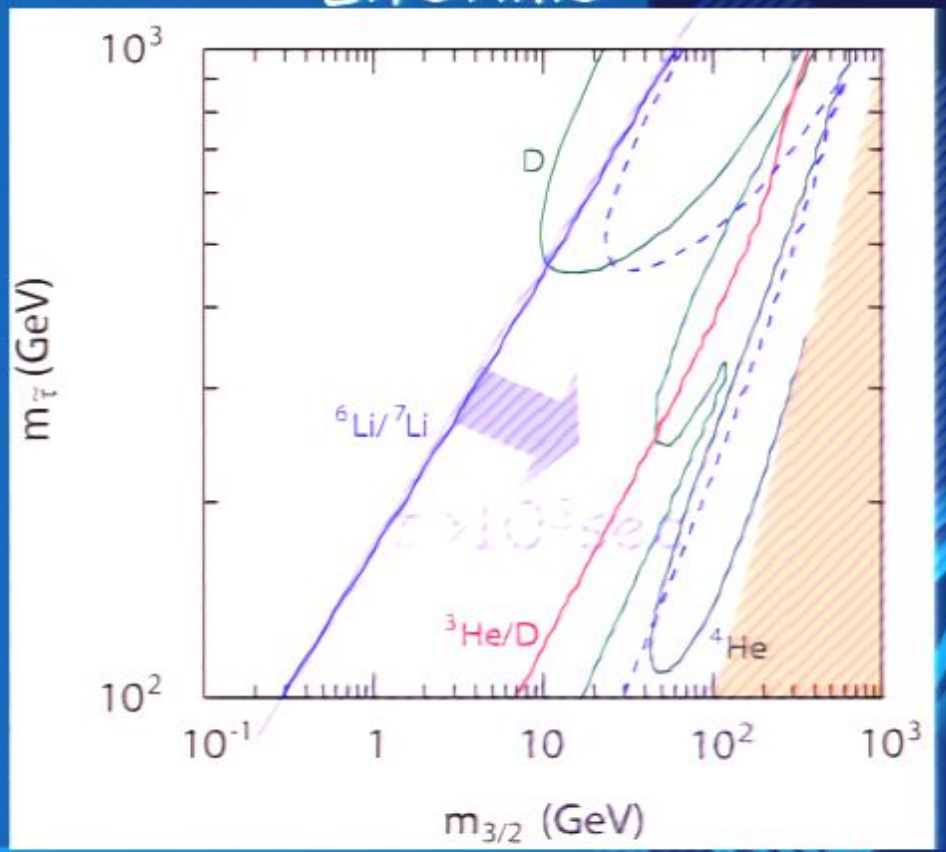

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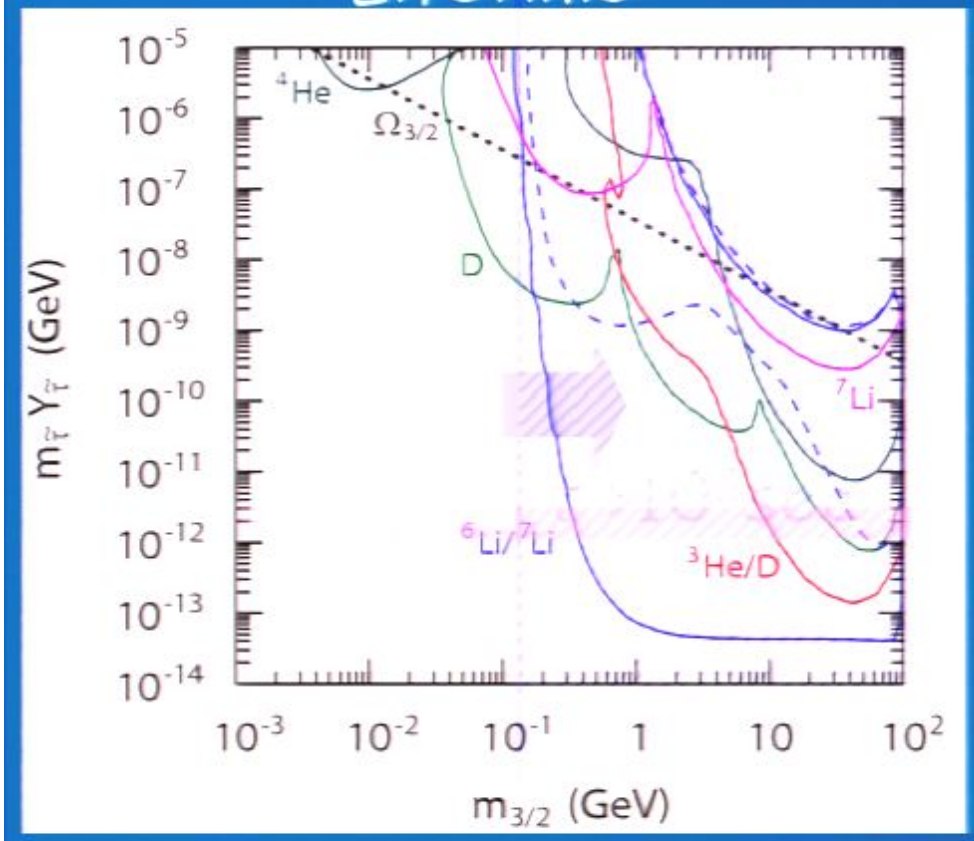

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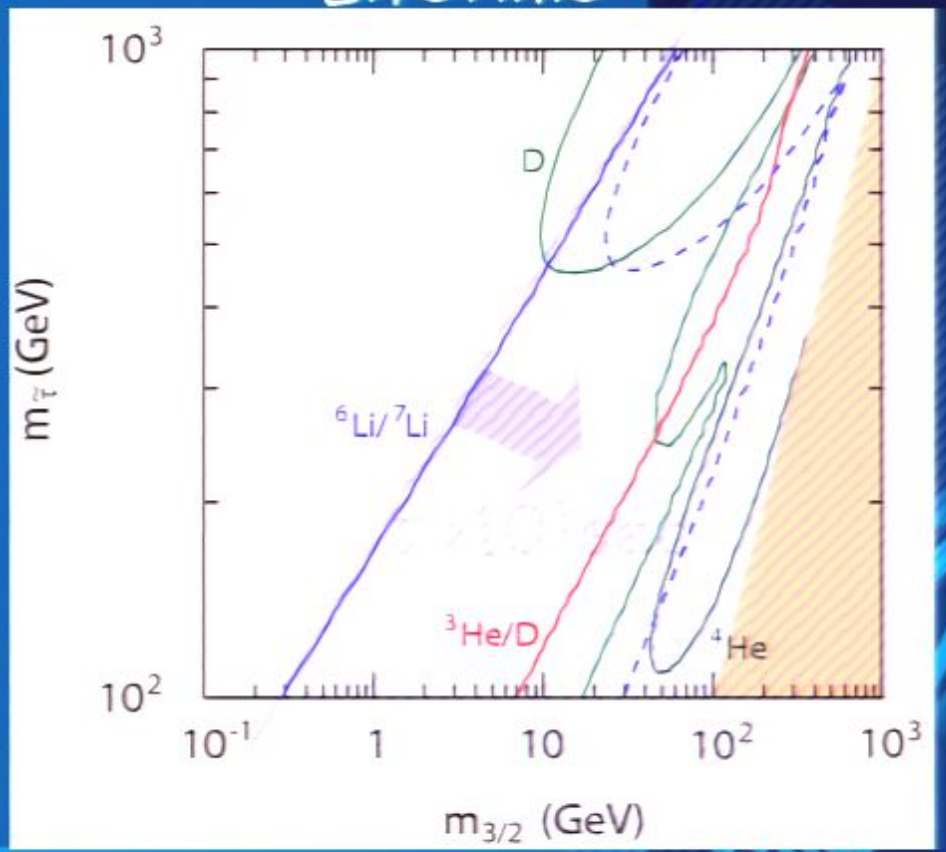

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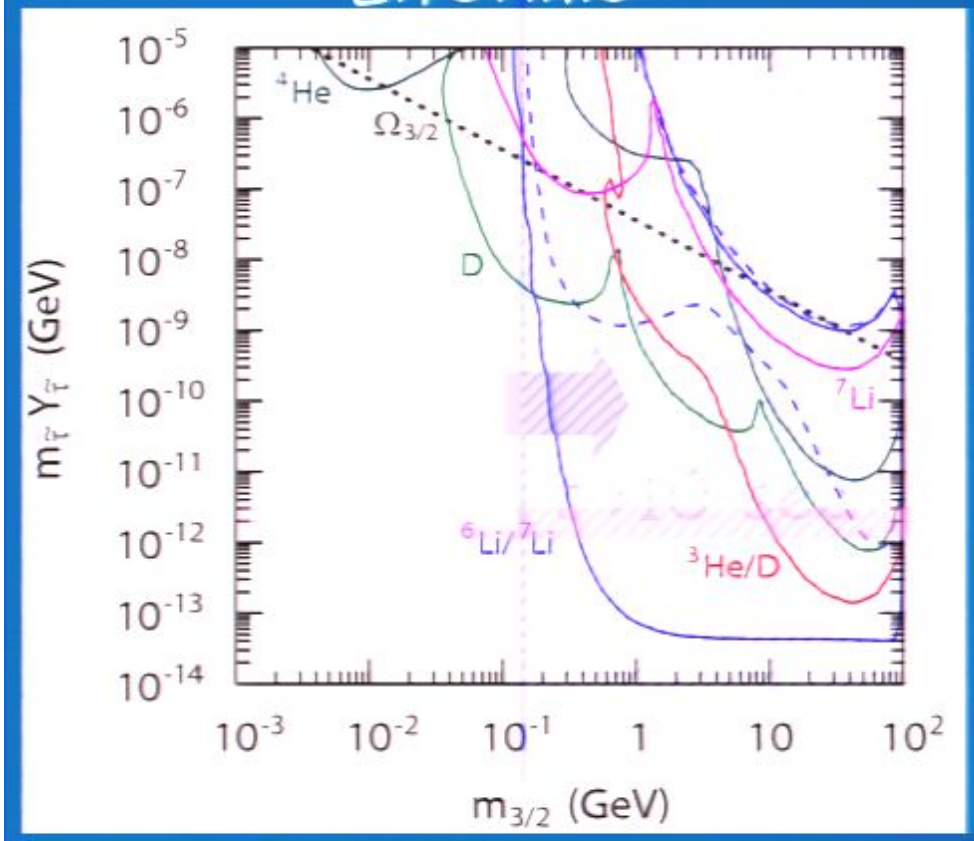

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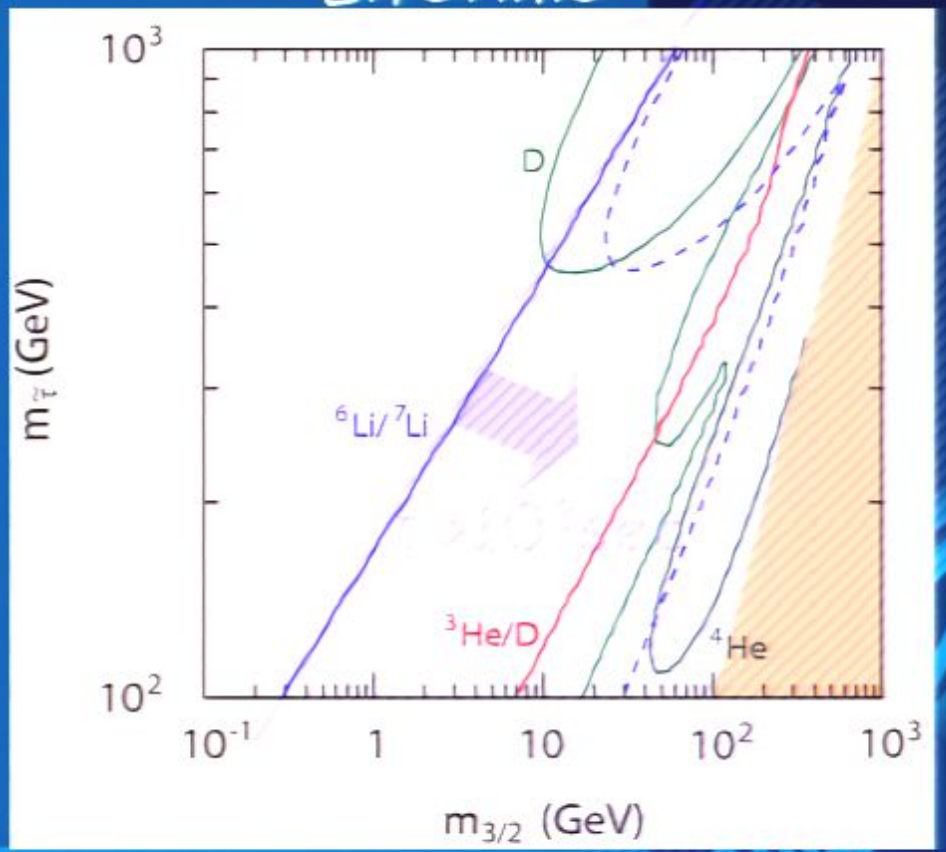

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Any other possibilitities?

- Stop NLSP and gravitino LSP

Diaz-Cruz, Ellis, Olive, Santoso (07)

There is surely an allowed parameter space in NUHM model

(different parameterization such as m_1 and m_2 instead of μ and m_A)

Complicated scenario of stop-mesons formation

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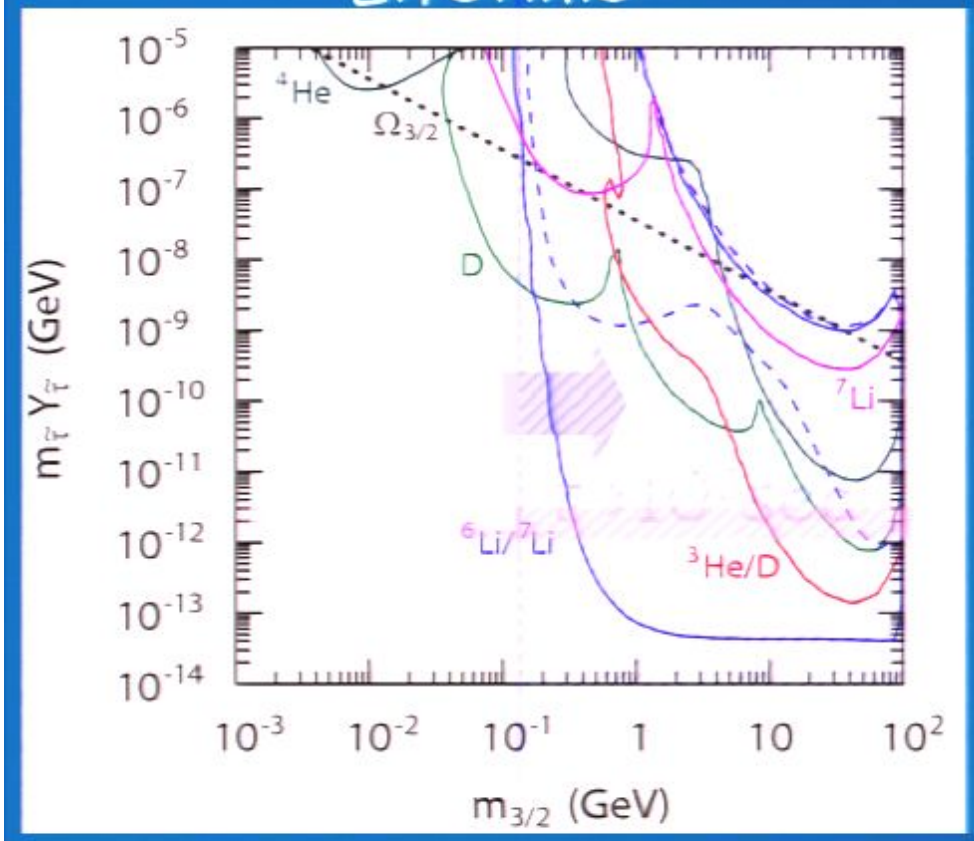

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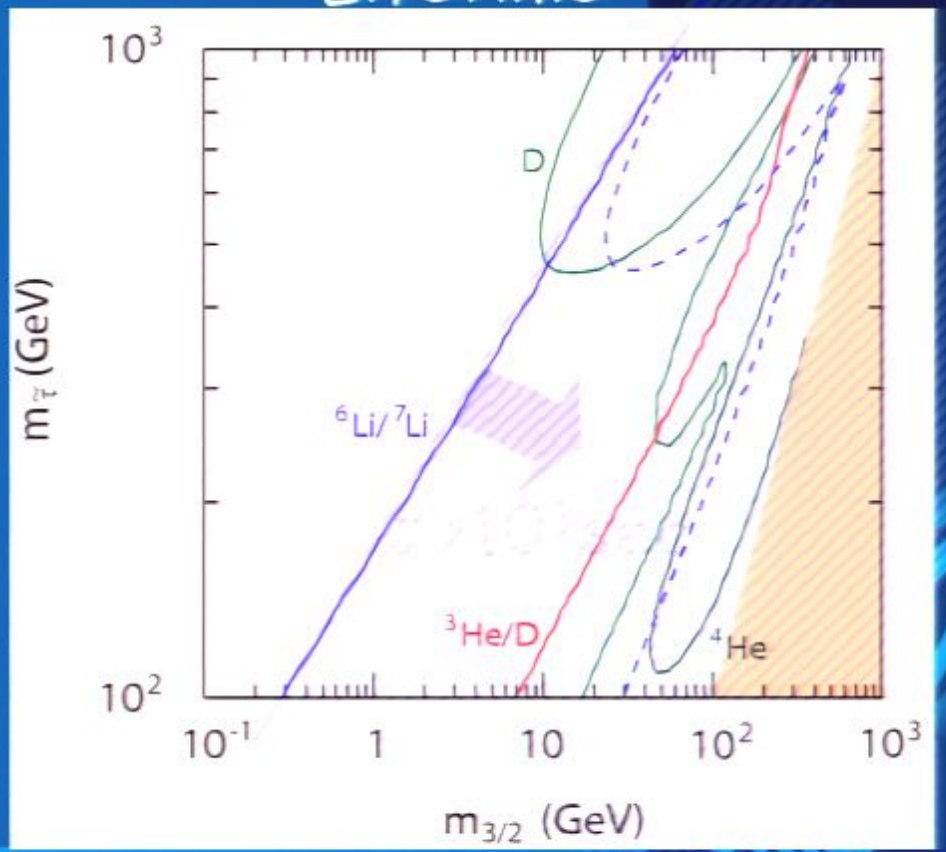

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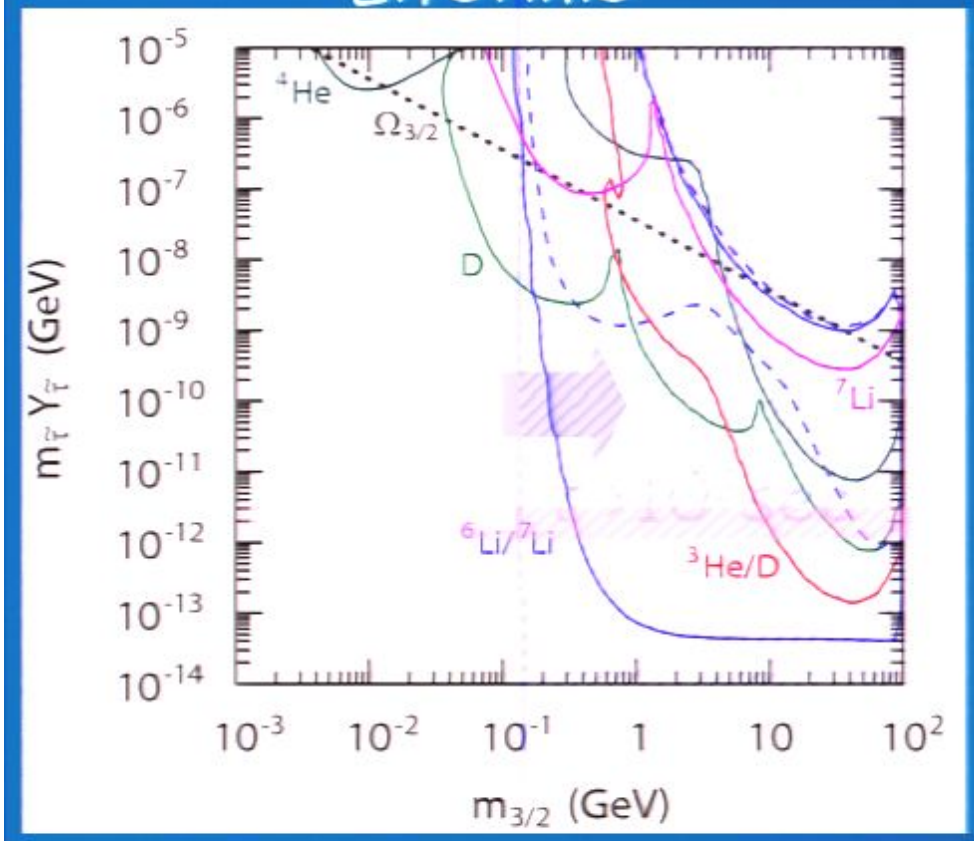

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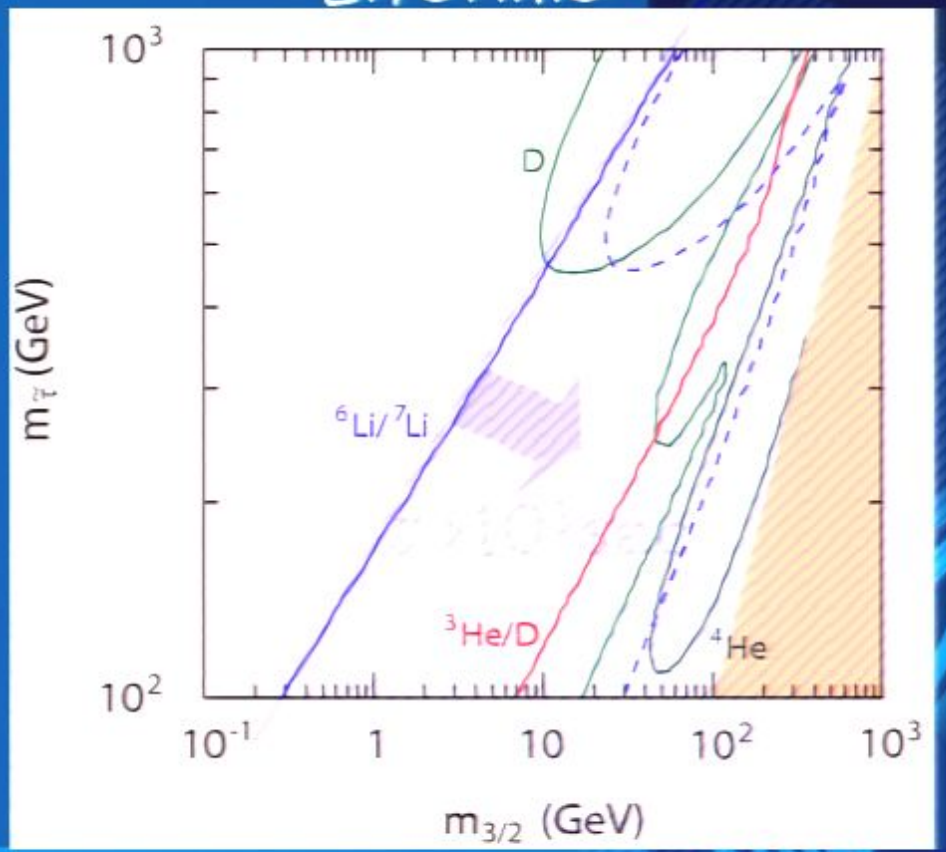

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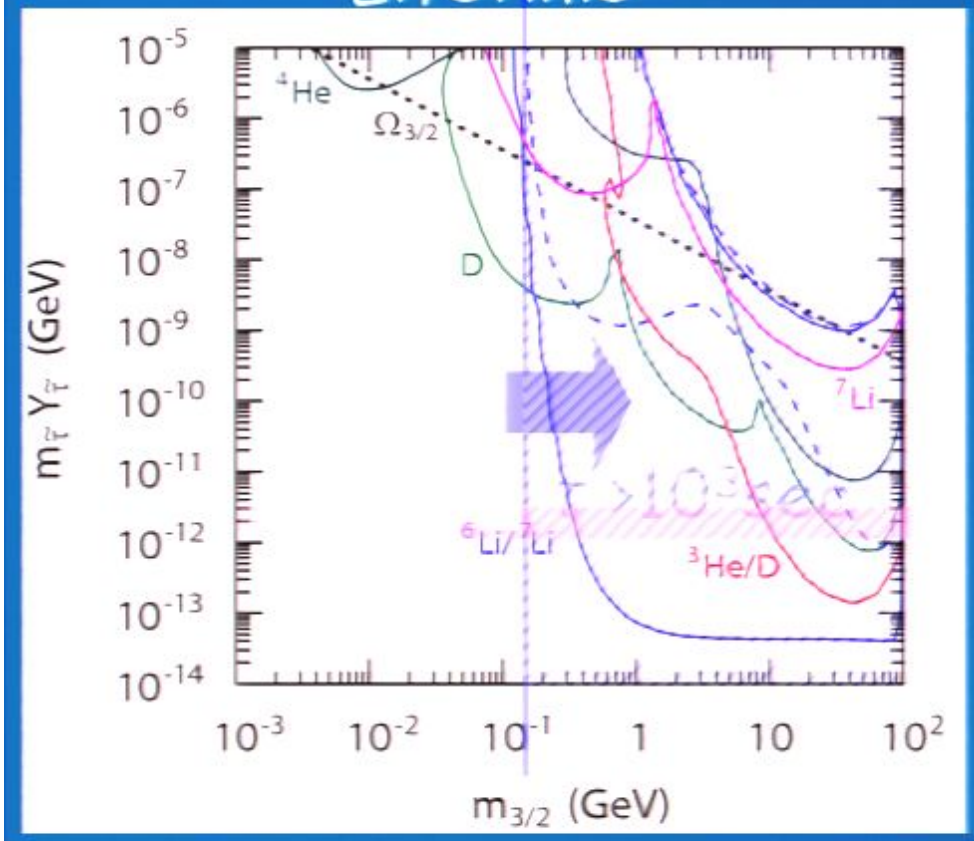

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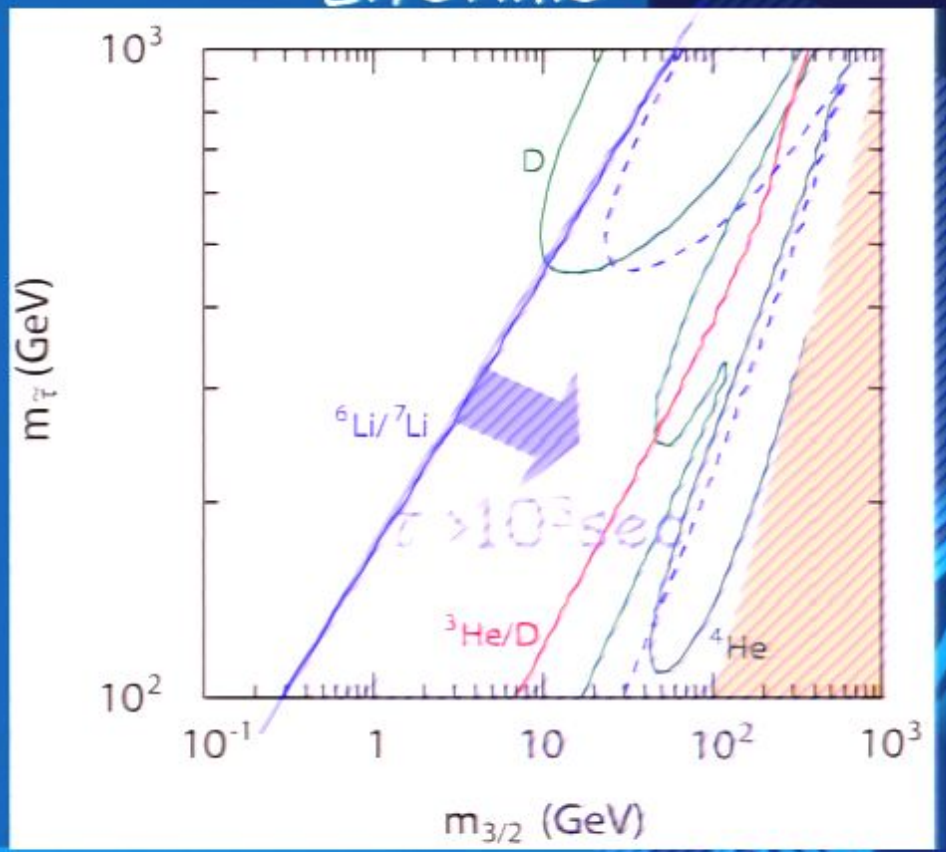

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BBN constraints are much milder!

We may need a fine tuning for T_R to get $\Omega_{\psi_\mu} = \Omega_{\rm CDM}$

- R-parity violation in gravitino LSP?

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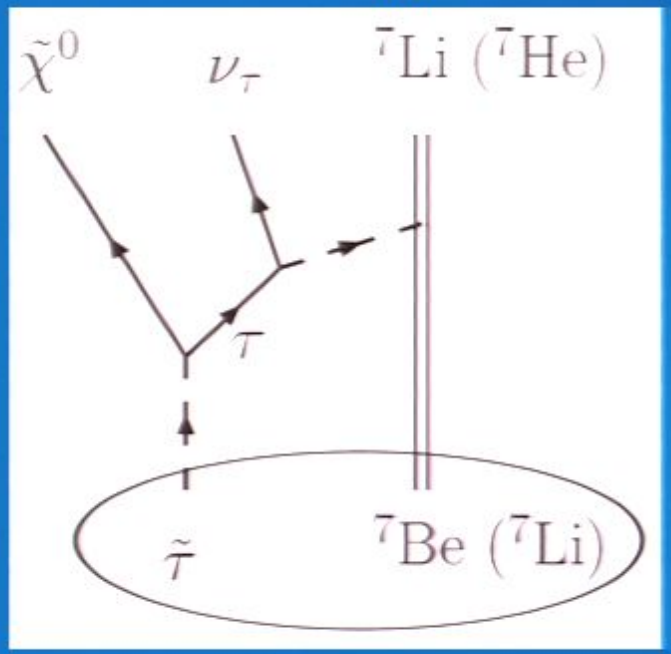
Jittoh, Kohri, Koike, Sato, Shimomura, Yamanaka, 2008

$$\delta m = m_{\tilde{\tau}} - m_{\chi_0} < 0.1\mathrm{GeV}$$



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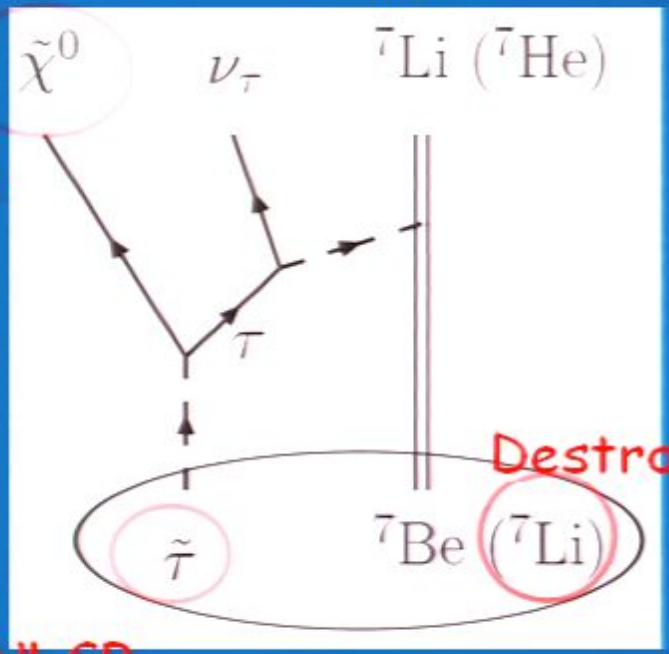

NLSP

Effectively Be7, Li7 are destroyed!!!

See also Bird, Koopman and Pospelov (07)

No CBBN Catalysis

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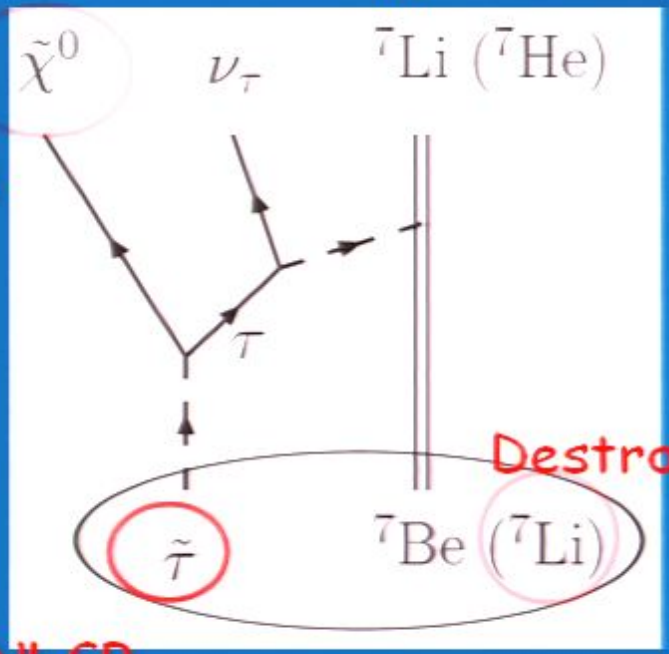

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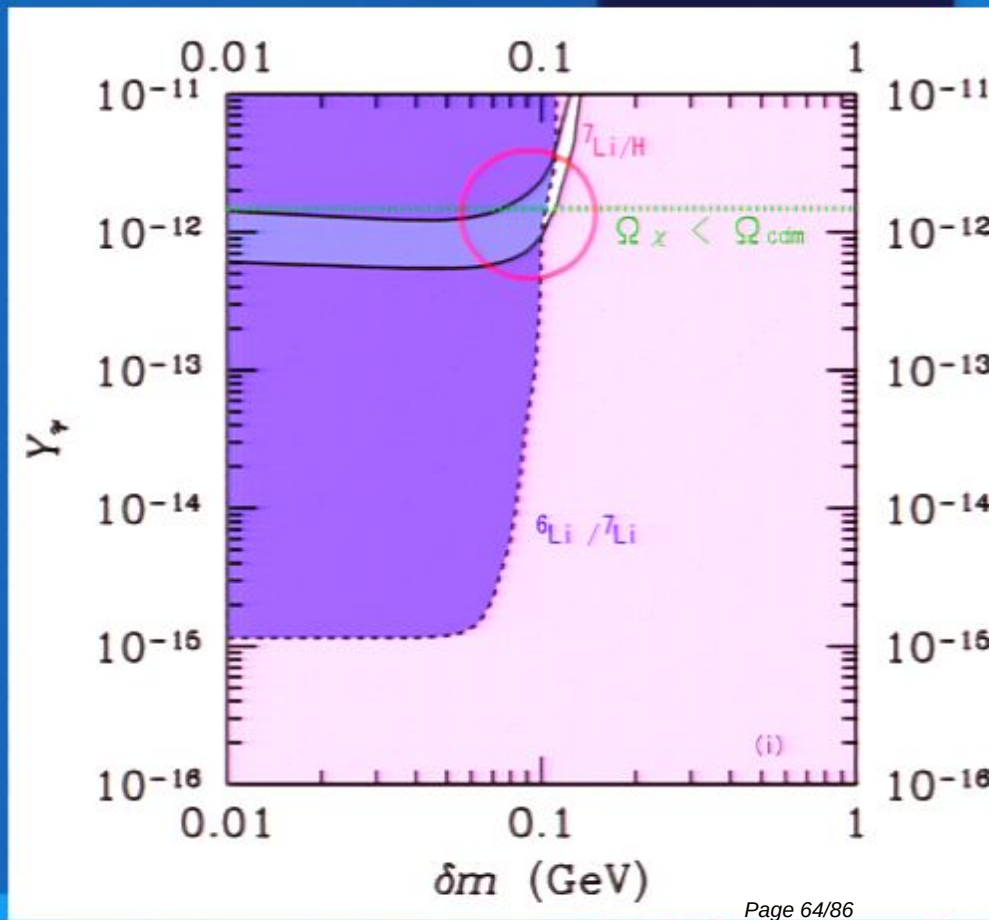

No CBBN Catalysis

Stau NLSP and axino/flatino/"flaxino" LSP in DFSZ axion models in Gravity Mediation

Chun, Kim, Kohri, and Lyth (08)

Soft(er) potential, gravitiy mediation in SUSY beaking

Murayama, Suzuki, Yanagida (92)

$$W = \frac{1}{4}\sqrt{\lambda} PQ^3 / M_G + h\frac{PQ}{M_G} H_1 H_2$$

$$V \supset \lambda\left(|P|^6 + 9|P|^4 |Q|^2\right)/M_G^2 - m_P^2 |P|^2 + m_Q^2 |Q|^2$$

$$+\mathrm{Re}\left(\mathrm{A}_\lambda \sqrt{\lambda} PQ^3 / M_G\right)$$

$$+\mathrm{A}_\mathrm{h} h\left(PQ/M_G\right) H_1 H_2 + c.c.$$

Stau NLSP and axino/flatino/"flaxino" LSP in DFSZ models in Gravity Mediation

Chun, Kim, Kohri, and Lyth (2008)

Naturally μ-term is produced

Spontaneously broken PQ symmetry

$$\sqrt{\langle P\rangle^2 + 9\langle Q\rangle^2} \equiv F_a \approx \sqrt{M_G m} \approx 10^{10}\,\mathrm{GeV}$$

$$m_P \approx m_Q \sim 100\mathrm{GeV}$$

Scaler masses (axion and 3 flaxions)

$$m_a \approx 0 \qquad m_{F_1} \approx m_{F_2} \approx m_{F'} \approx 100\mathrm{GeV}$$

Fermion masses (2 flaxinos)

$$m_{\tilde{F}} \approx m_{\tilde{F}} \approx 100\mathrm{GeV}$$

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Stau NLSP and axino/flatino/"flaxino" LSP in DFSZ models in Gravity Mediation

Chun, Kim, Kohri, and Lyth (2008)

Decaying "flatons" after thermal inflation, reheats the universe and produce staus

Stau NLSP and axino/flatino/"flaxino" LSP in DFSZ models in Gravity Mediation

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$$T_R \sim O(10)\ GeV$$

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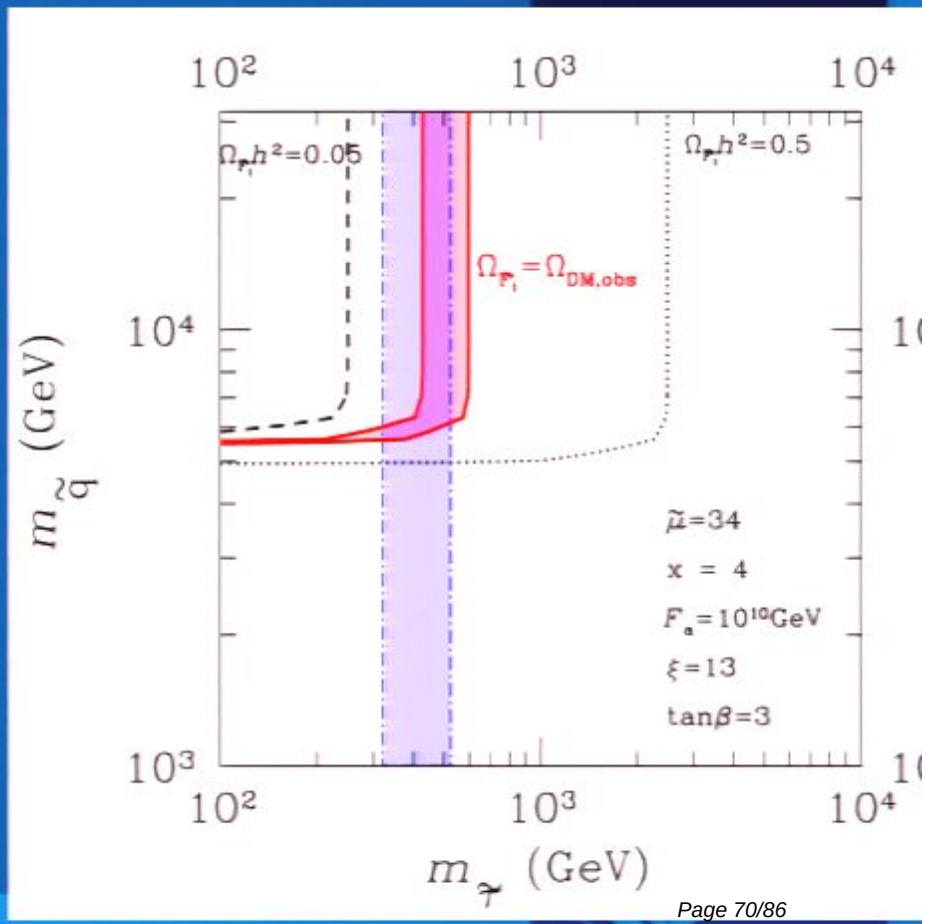
No BBN Catalysis

Stau can be found in LHC!!!



Large Hadron Collider (LHC) will start from coming April

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10m

~10^{-7}sec

ATLAS detector in CERN, Geneva, Switzerland

(March 2007)

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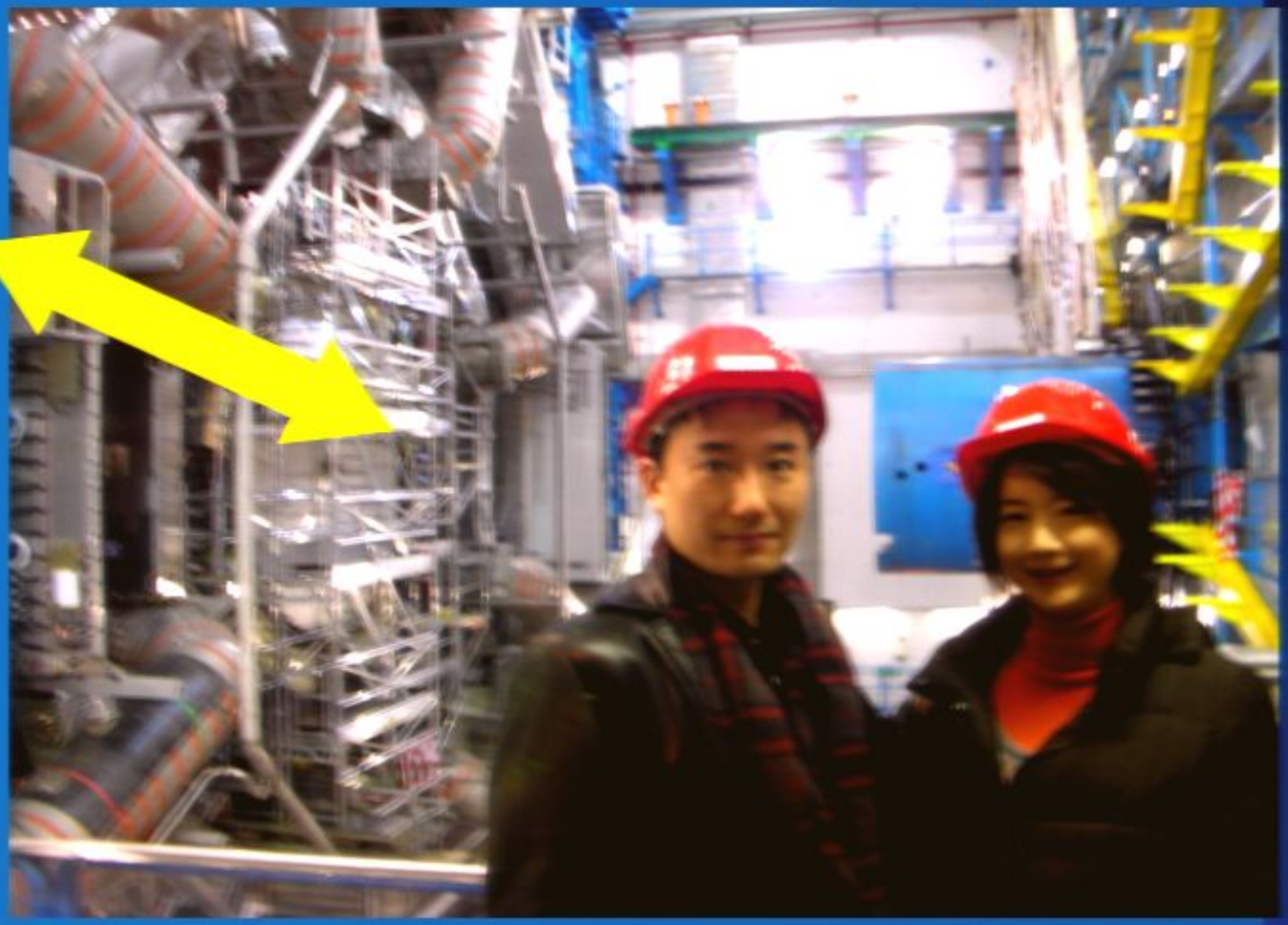

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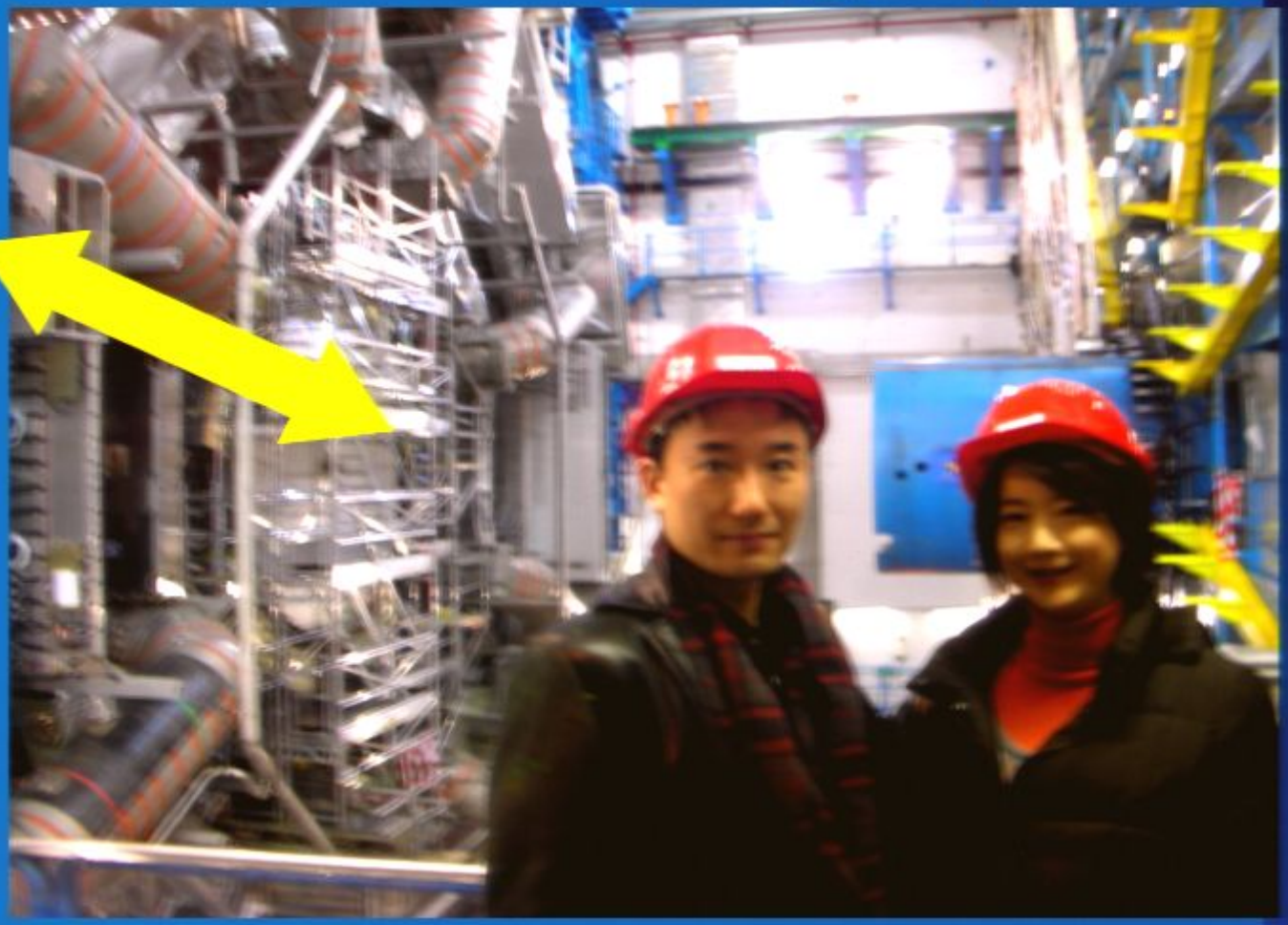

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ATLAS detector in CERN, Geneva, Switzerland

(March 2007)

Place another stopper near ATLAS or CMS to stop long-lived charged SUSY particles (even for $c\tau$ > 10 m)

- 5 m Iron wall (Hamaguchi, Kuno, Nakaya, and Nojiri (04)
- Water tank (Feng and Smith (04)
- Surrounded rock (De Roek, Ellis, Gianotti, Mootgat, Olive and Pape (05)

Conclusion

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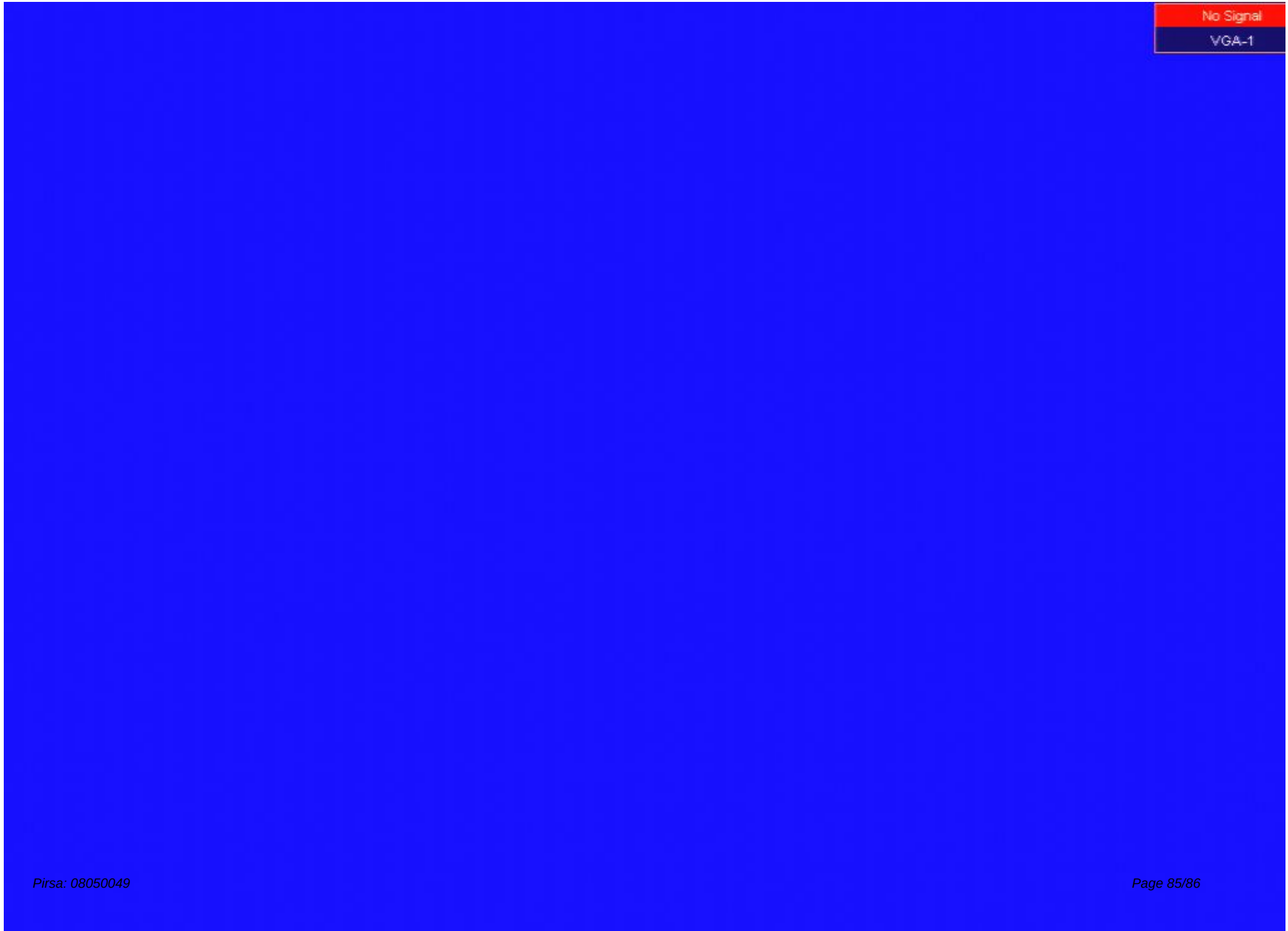
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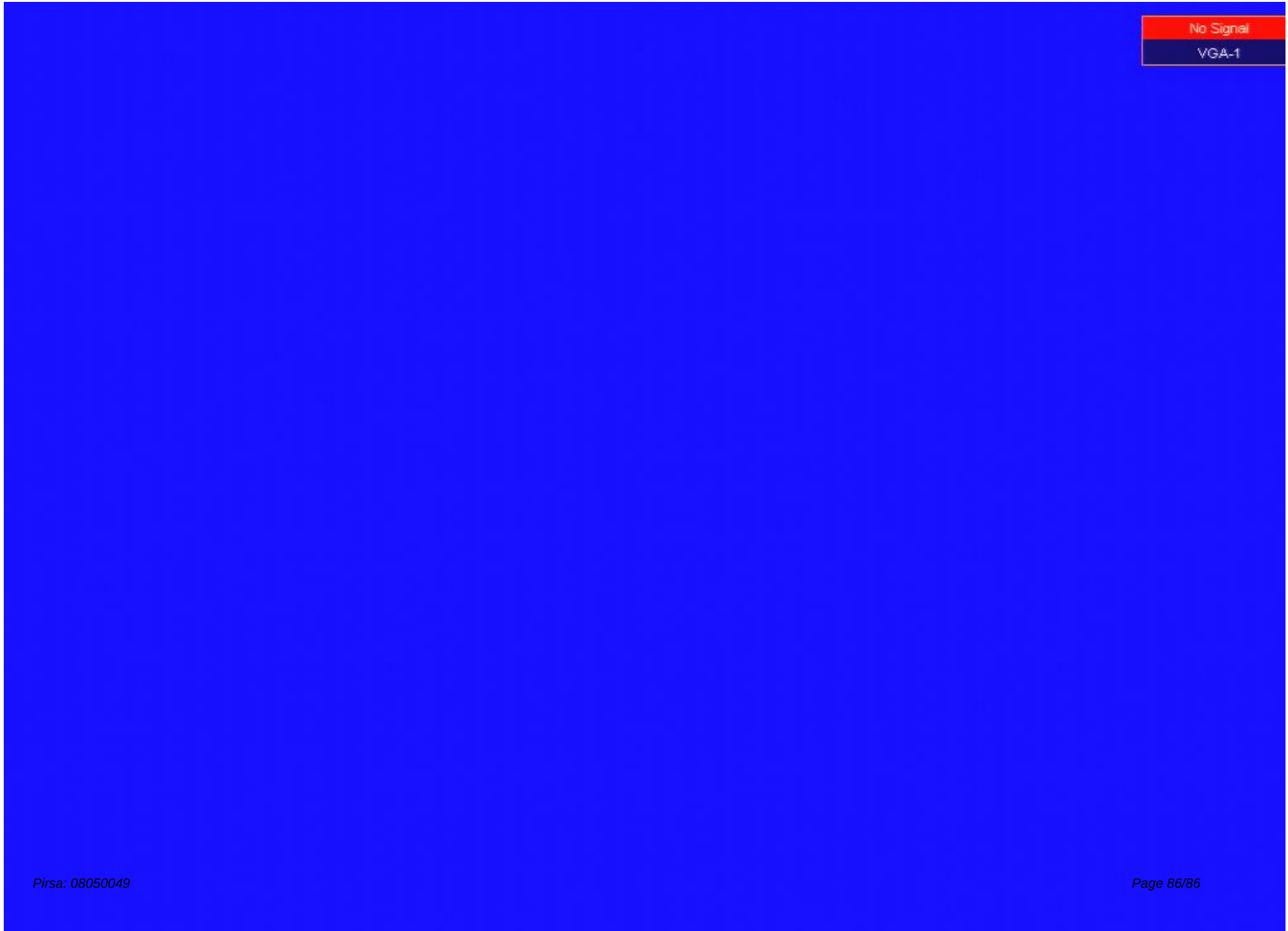
VGA-1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