PHENO 08, Madison, 29 April 2008

Axino Dark Matter

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EJC-Kim-Kohri-Lyth, 0801.4180

Motivation

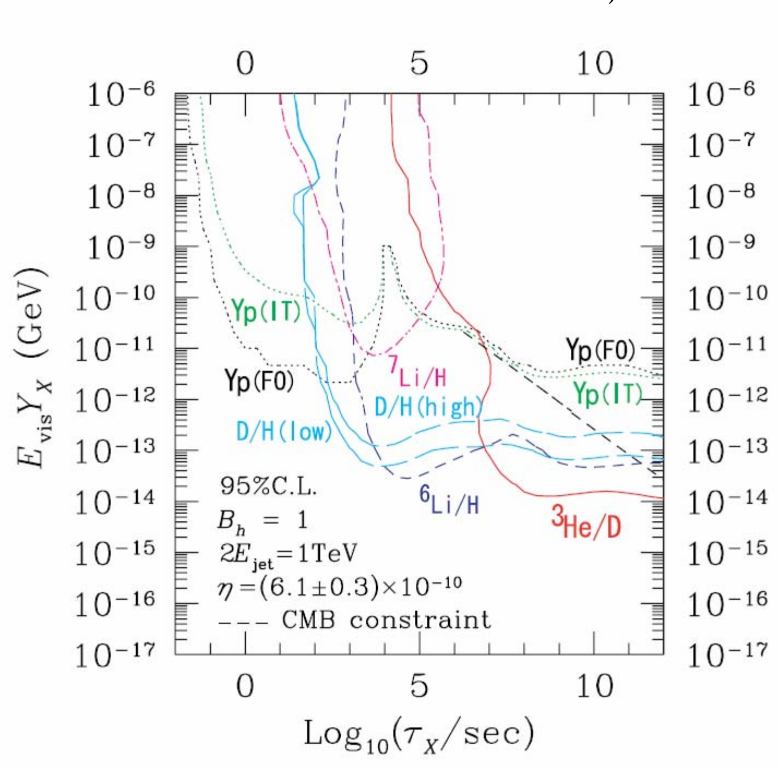
- Axino is predicted by the PQ solution to the strong CP problem in supersymmetry.
- It can be the LSP DM. (EJC–Lukas, 1995)
- Its couplings to the ordinary superparticles are suppressed by the PQ scale; $F_a \sim 10^{10}-10^{12}$ GeV. (compare with gravity coupling suppressed by $M_P \sim 10^{19}$ GeV.)
- BBN bounds can be easily avoided.
- LHC may see NLSPs decaying to axino: $P(L) = L/\tau\beta\gamma$ although $\tau > 1$m. (Martin, 2000)

BBN constraints

- BBN constrains the abundance and lifetime of long-lived particles.
- Unstable gravitino:

  for $B_h=10^{-3}$, $T_R>10^{10}$ GeV if $m_{3/2}>40$ TeV; $T_R<10^{6-8}$ GeV if $m_{3/2}< 10^{2-3}$ TeV.
- Stable gravitino: severe constraints on NLSP decays.

Kawasaki-Khori-Moroi, 2006



m_X=1 TeV

Gravitino LSP

- Neutralino NLSP: very strong constraint ($B_h \sim 1$) ruling out m>100 GeV.

$$\chi_1^0 \to \tilde{G} + \gamma/Z/h$$

- Stau NLSP: catalized BBN -> overproduce ^{6}Li ruling out m>100 GeV.

$$\tilde{\tau} \to \tilde{G} + \tau \; (+q\bar{q}) \qquad D + {}^4HeX^- \to {}^6Li + X^- + \gamma$$

- Sneutrino NLSP: less stringent but

$\Omega_{3/2}^{\text{non-th}} \sim 0.2$ for $m_{sneu} > 1$ TeV.

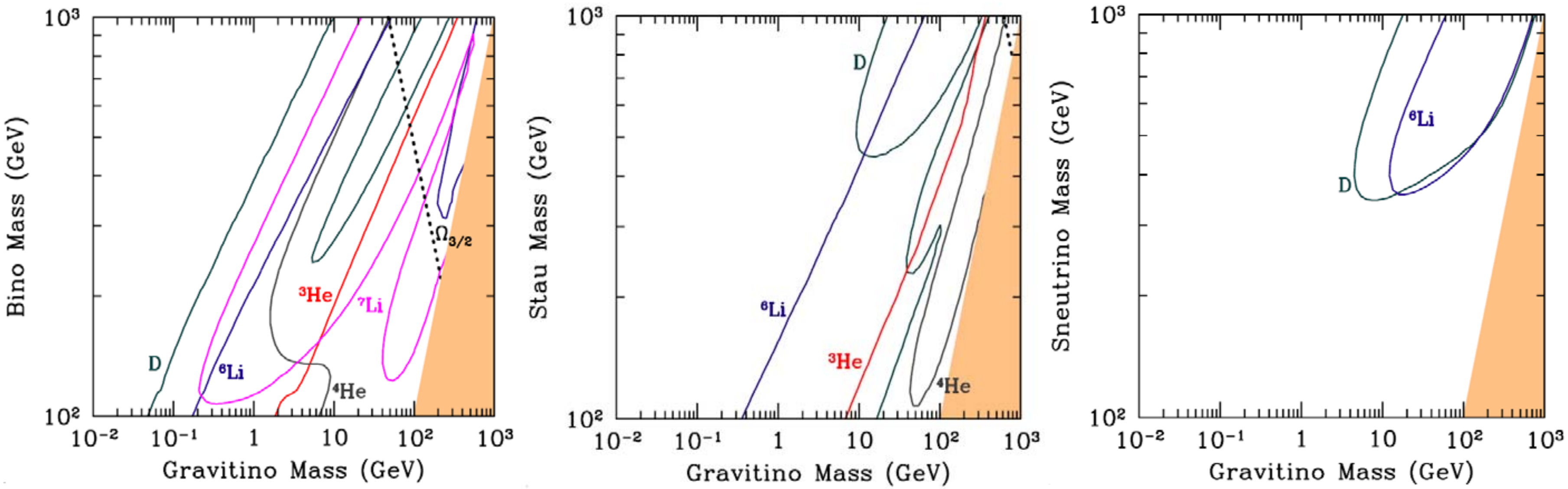
$$\tilde{\nu} \to \tilde{G} + \nu \; (+q\bar{q})$$

$$\Omega_{\tilde{\nu}} h^2 \simeq 0.2 \times \left(\frac{m_{\tilde{\nu}}}{1\ \text{TeV}}\right)^2$$

$$\Omega_{\tilde{G}} h^2 = \frac{m_{\tilde{G}}}{m_{\text{NLSP}}} \Omega_{\text{NLSP}} h^2 = 0.13$$

Gravitino LSP

- Constraints on neutralino, stau, sneutrino NLSP:



Kawasaki-Kohri-Moroi-Yotsuyanagi, 2008

Saving gravitino LSP

- Increasing $H^2 \sim \rho$ for sneutrino NLSP: brane world; quintessential kination.
- RpV to make NLSP decay earlier & gravitino live long enough: NLSP decay signature and/or diffuse γ ray flux from gravitino decay.

Okada–Seto, 2007

$$\Omega_{\tilde{\nu}(b)} h^2 \simeq 0.1 \times \left(\frac{m_{\tilde{\nu}}}{100\ \mathrm{GeV}}\right)^2 \left(\frac{23}{x_{d(s)}}\right) \left(\frac{x_t}{2100}\right)$$

Buchmuller, et.al., 2007

$$W_{\Delta L=1} = \lambda_{ikj} l_i e^c_j l_k + \lambda'_{kji} d^c_i q_j l_k$$

$$\tau_{\mathrm{NLSP}} \simeq 10^3 \mathrm{s} \left(\frac{\lambda}{10^{-14}}\right)^{-2} \left(\frac{m_{\mathrm{NLSP}}}{100\ \mathrm{GeV}}\right)^{-1}$$

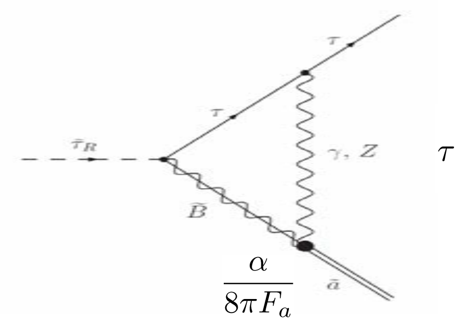
$$\tau_{3/2} \sim 10^{26} \mathrm{s} \left(\frac{\lambda}{10^{-7}}\right)^{-2} \left(\frac{m_{3/2}}{10\ \mathrm{GeV}}\right)^{-3}$$

Axino LSP

- KSVZ axino:

  suppressed axino-NLSP coupling induced by anomalous axino-gaugino-gauge boson coupling; $\alpha/8\pi F_a$.

Covi, et.al. 2004
Brandenburg, et.al. 2005



$$\tau \sim 10^8 \mathrm{m} \left(\frac{F_a}{10^{10}\ \mathrm{GeV}} \right)^2$$

- DFSZ axino:

  lager axino-NLSP coupling through axino-Higgsino mixing.

Motivated by the solution to the μ problem:

$$W = h \frac{PQ}{M_P} H_1 H_2$$

Flat direction DFSZ model

Choi–EJC–Kim, 1997

$$W = h\frac{PQ}{M_P}H_1H_2 + f\frac{P^3Q}{M_P} \qquad V_{\rm soft} = f\frac{A_f}{M_p}P^3Q + h.c.$$

- Spontaneous generation of F_a: $v_{P,Q} \sim (m_{3/2}M_P)^{1/2} \sim 10^{10}$ GeV
- Solves μ problem: $\mu = h\frac{v_P v_Q}{M_P} \sim m_{3/2}$
- Large axino–Higgsino mixing: $\delta_{\tilde{F}\tilde{h}} \sim \frac{v}{F_a}$

  Flatino/axino: $\tilde{P}, \tilde{Q} \to \tilde{F}_{1,2}$
- NLSP decay inside collider; τ~1–10^4 m: $\tilde{\tau}_1 \to \tau \tilde{F}_1$

Flaton/Flaxino Spectrum

EJC-Kim-Lyth, 2000

- Bosons and Fermions from PQ sector at TeV scale.
- 3 bosons (flatons): 2 scalar+1 pseudo scalar:
- Two flatinos/axinos:

Model parameters:

$$x = \frac{v_P}{v_Q},\ \tilde{\mu} = \mu\frac{f}{h},\ \xi = -\frac{A_f}{\tilde{\mu}}$$

$$m_{F_{1,2}} = \frac{\tilde{\mu}}{\sqrt{2}}\sqrt{3(12-\xi)+x^2(12+\xi)\pm|12-\xi|\sqrt{x^4+42x^2+9}}$$

$$m_{F'} = \tilde{\mu}\sqrt{\xi(x^2+9)}$$

$$m_{\tilde{F}_{1,2}} = 3\tilde{\mu}\left(\sqrt{x^2+1}\pm 1\right)$$

$$[m_{F'}, m_{F_2}, m_{F_1}, m_{\tilde{F}_2}, m_{\tilde{F}_1}] = \begin{cases} [216, 175, 162, 184, 112] & (\tilde{\mu}=12) \\ [616, 500, 462, 525, 320] & (\tilde{\mu}=34) \end{cases}$$

(a)
(b)

$$x = 4, \xi = 13, \tilde{\mu} = 34 \text{ GeV}$$
$$\mu = 813 \text{ GeV}, M_1 = 530 \text{ GeV}$$

Flaxino couplings

- Flaxino–gaugino mixing:

$$\delta_1 \equiv \frac{v}{F_a}\frac{\sqrt{x^2+1}}{x}\left(\cos\tilde{\phi} + x\sin\tilde{\phi}\right) \qquad \tan(2\tilde{\phi}) \equiv x$$

$$M^{(5)} = \begin{pmatrix} m_{\tilde{F}_1} & 0 & 0 & -\delta_1 s_\beta \mu & -\delta_1 c_\beta \mu \\ 0 & M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\ 0 & 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\ -\delta_1 s_\beta \mu & -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\ -\delta_1 c_\beta \mu & s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0 \end{pmatrix}$$

- Stau decay: $\Gamma_{\tilde{\tau}_1} \sim \frac{m_{\tilde{\tau}_1}}{16\pi}\delta_1^2$

Flaxino abundance

- Flaxino abundance: thermal (from thermal background after reheat) + non-thermal (from stau decay).
- Flaton model induces thermal inflation.

$$\Omega_{\tilde{F}_1,\mathrm{nonth}}h^2 = 0.1\left(\frac{m_{\tilde{F}_1}}{400\mathrm{GeV}}\right)\left(\frac{m_{\tilde{\tau}}}{400\mathrm{GeV}}\right)$$

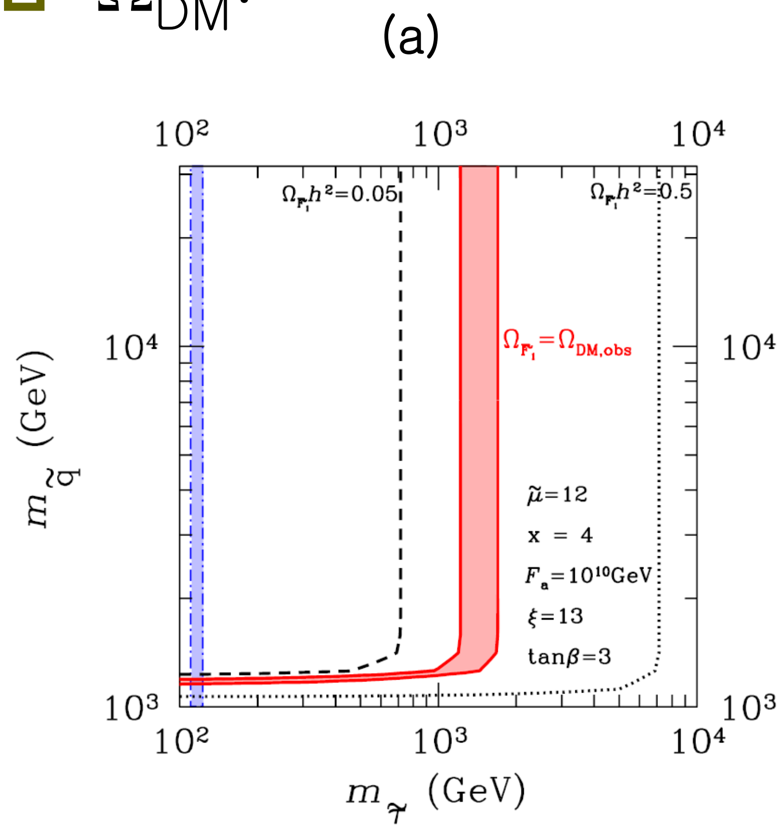
$$\Omega_{\tilde{F}_1,\mathrm{th}}h^2 = 0.1\left(\frac{m_{\tilde{F}_1}}{m_{\tilde{q}}}\right)\left(\frac{\epsilon_{\tilde{q}\tilde{q}\tilde{F}_1}}{10^{-8}}\right)^2\left(\frac{x_{\tilde{q}}}{19.45}\right)^2\exp\left[-0.98(x_{\tilde{q}}-19.45)\right]$$

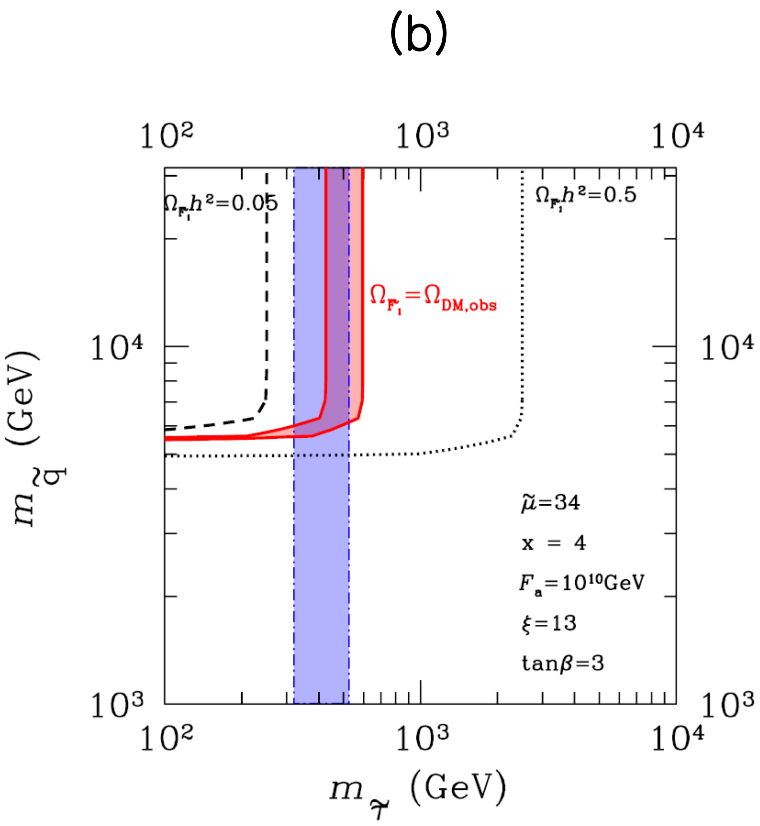
$$x_{\tilde{q}} \equiv m_{\tilde{q}}/T_{\mathrm{RH}}$$

$$T_{\mathrm{RH}} = 19\mathrm{GeV}\left(\frac{m_{F_1}}{10^2\mathrm{GeV}}\right)^{3/2}\left(\frac{F_a}{10^{10}\mathrm{GeV}}\right)^{-1}\left(\frac{B_a}{0.1}\right)^{-1}$$

Results I

- Ω_{DM}:

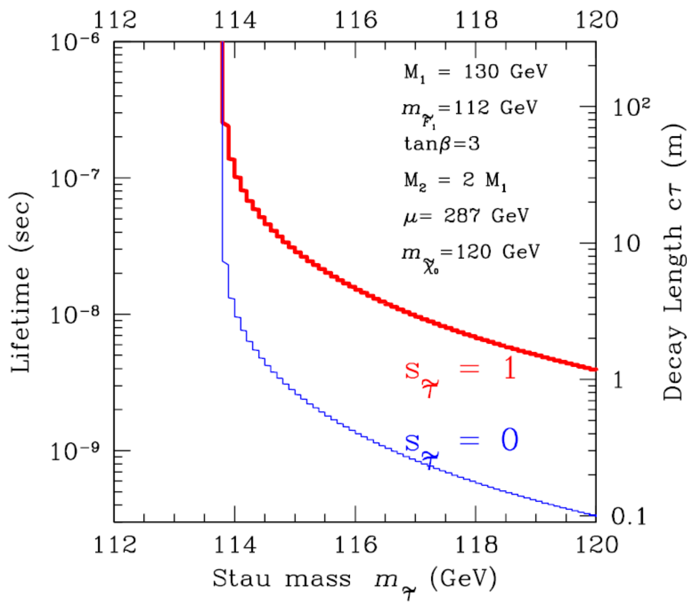




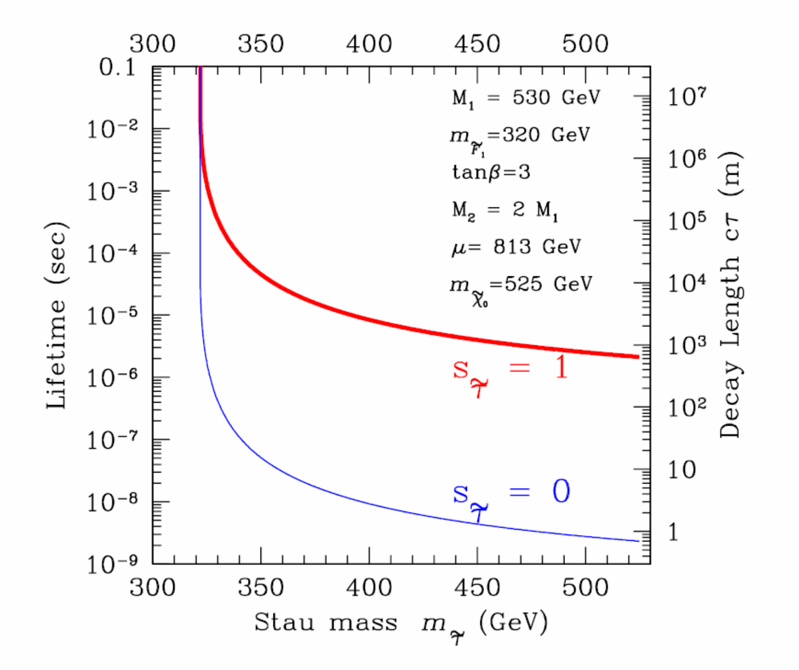
Results II

- Stau decay length:

(a)



(b)



Conclusion

- Flat direction DFSZ axion model is motivated by the resolution of the μ problem and spontaneous generation of the intermediate axion scale.
- (FI)Axino can be a good DM candidate circumventing BBN constraints.
- LHC hinting at the PQ mechanism with stau decaying to flaxino if $F_a \sim 10^{10}$ GeV.
- Gravitino can be lighter than flaxino and thus DM without contradicting BBN.