Abstract: If the spontaneous breaking of Peccei-Quinn symmetry comes from soft supersymmetry breaking, the fermionic partners of the symmetry-breaking fields have mass of order the gravitino mass, and are called flatinos. The lightest flatino, called here the flaxino, is a CDM candidate if it is the lightest supersymmetric particle. We here explore flaxino dark matter assuming that the lightest ordinary supersymmetric particle is the stau, with gravity-mediated supersymmetry breaking. The decay of the stau to the flaxino is fast enough not to spoil the standard predictions of Big Bang Nucleosynthesis, and its track and decay can be seen in future colliders.
Flaxino dark matter and stau decay

Kazunori Kohri

Physics Department, Lancaster University

Kohri, Takayama, PRD (2007)

Chun, Kim, Kohri and Lyth, JHEP (2008)


Introduction of SUSY

Supersymmetry (SUSY)

- Solving “Hierarchy Problem”
- Realizing “Coupling constant unification in GUT”

Fermion ↔ Boson

- quark ↔ squark
- lepton ↔ slepton
- photino ↔ photon
- gravitino ↔ graviton
- neutralino

axino ↔ axion
Realistic candidates of particle dark matter:

- **Neutralino** $\chi \sim 100\%$ Bino or photino
  Most famous Lightest Supersymmetric Particle (LSP) with $m_\chi \sim 100\text{GeV}$ (appears even in global SUSY)

- **Gravitino** $\psi_\mu$
  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 $\alpha$
  solving strong CP problem, $m_\alpha \sim 10^{-5}$eV ($10^{11}$GeV/$F_\alpha$)

$$L_{PQ} \sim \theta_{QCD} F_{\mu\nu}^a \tilde{F}_\mu^\nu_a$$

$$\theta_{QCD} \sim \frac{\alpha}{F_\alpha} < 10^{-9}$$

- Axino $\tilde{\alpha}$
  super partner of axion

- "Flaxino" (Lightest flatino)
  Superposition of axinos in DFSZ models
Upper bound on reheating temperature

Kawasaki, Kohri, Moro, Yotsuyanagi (08)

gravitino “NLSP” and neutralino LSP

Hadronic decay

\[ B_n \leq O(1) \quad (B_\gamma \leq O(1)) \]

\[ T_R \leq 10^7 \text{GeV} \left( \frac{Y_{3/2}}{10^{-14}} \right) \]

\[ m_{3/2} \leq 10^3 \text{GeV} \left( \frac{\tau_{3/2}}{4 \times 10^5 \text{ sec}} \right)^{-1/3} \]
Long-lived NLSP can be scalar tau lepton (stau)?

Steffen (2006)
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Relic neutralino NLSP ($m_\chi \ll \text{ TeV}$) and its daughter gravitino SP DM scenario might be disfavored by BBN (w/o tuned $T_R$ to fit $\Omega_{\text{CDM}}$ or for $m_\chi > 2 \text{ TeV}$).
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Slepton NLSP should be attractive!!!

See also Frank Steffen’s and Joesef Pladler’s talks in preceding workshop
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Then, LSP would be gravitino or axino / flexino (flatino)
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
stau, selectron ...
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“CHAMP recombination” with light elements

\[ T_c \sim \frac{E_{\text{bin}}}{40} \sim 10\text{keV} \]
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$(E_{\text{bin}} \sim a^2 m_i \sim 100\text{keV})$

CHAMP captured-nuclei, e.g., $(C,^4\text{He})$ changes the nuclear reaction rates dramatically in BBN
He4 bound-state ratio
Catalyzed BBN


- CHAMP bound state with $^4\text{He}$ enhances the rate

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

Catalysis BBN is in crisis III
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- Enhancement of cross section

$$\sim \left( \frac{\lambda_\gamma}{a_{\text{Bohr}}} \right)^5 \sim (30)^5 \sim 10^{7-8}$$

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

Catalysis BBN is in crisis III
BBN in stau NLSP and gravitino LSP Scenario in gauge mediation

Lifetime

Difficulties in CBBN for long lifetime (> 1000 sec)
BBN in stau NLSP and gravitino LSP
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Any other possibilities? 2

- Sneutrino NLSP and gravitino LSP
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for dilution of dangerous relics such as moduli, dilatons, polonyi, etc.
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Decaying "flatons" after thermal inflation, reheats the universe and produce staus

\[ T_R \sim O(10) \text{ GeV} \]

Lifetime of stau is very short due to milder suppression (\( \propto F_a^{-1/2} \)), and tree level couplings in DFSZ

\[ 10^{-8} \text{ sec} \lesssim \tau_{\tilde{\tau}} \lesssim 10^{-2} \text{ sec} \]
Stau NLSP and axino/flatino/"flaxino" LSP in DFSZ models in Gravity Mediation


Naturally $\mu$-term is produced
Spontaneously broken PQ symmetry

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

$$m_a \approx 0 \quad m_P \approx m_Q \quad \square 100 \text{ GeV}$$

Scaler masses (axion and 3 flaxions)

$$m_{F_1} \approx m_{F_2} \approx m_{F'} \approx 100 \text{ GeV}$$

Fermion masses (2 flaxinos)

$$m_{\tilde{F}} \approx m_{\tilde{F'}} \approx 100 \text{ GeV}$$
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No BBN Catalysis

Stau can be found in LHC!!!
Large Hadron Collider (LHC) will start this year
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10m
\sim 10^{-7}\text{sec}

ATLAS detector in CERN, Geneva, Switzerland
(March 2007)
Place another stopper near ATLAS or CMS to stop long-lived charged SUSY particles (even for $cT > 10$ m)

- 5 m Iron wall (Hamaguchi, Kuno, Nakaya, and Nojiri (04))

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On the other hand, stau NLSP and flaxino(axino) LSP scenario in gravity mediated SUSY breaking is attractive with much shorter stau's lifetime (detectable in LHC!!!) because of no BBN catalysis.