The 3.5 keV line from decaying gravitino dark matter

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Outline

Introduction
- Dark matter signals
- Gravitino dark matter

Cosmic rays from decaying gravitinos
- Available decay channels
- Constraints and the early universe

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What do we know about dark matter?

- It exists.
- It is non-baryonic.
- It has a mass less than 10^{50} GeV.
- Its self-interaction is $\frac{\sigma}{m} \lesssim 1 \frac{\text{cm}^2}{\text{g}}$
- It interacts at most weakly with matter.

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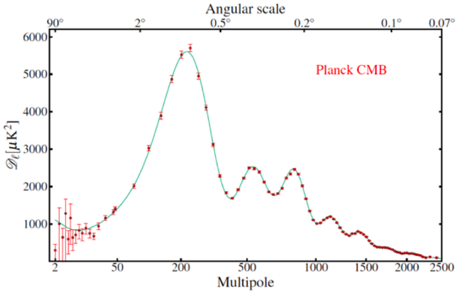

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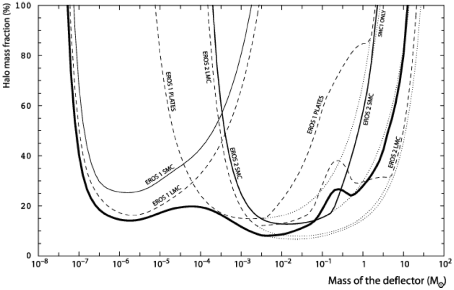

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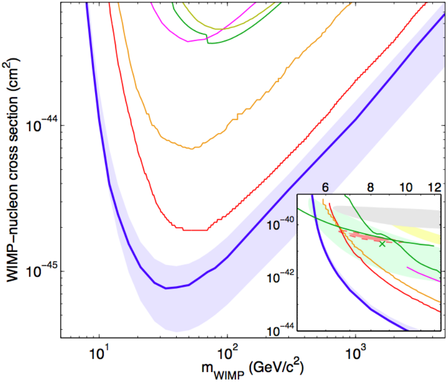

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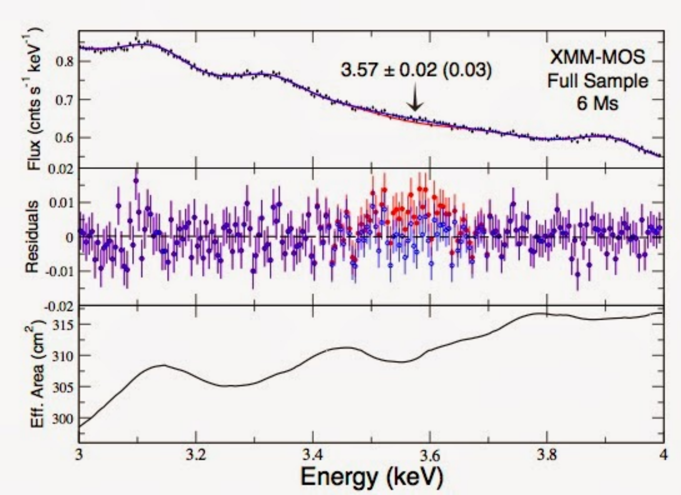
Do we have more information now?



$\Rightarrow m_{\text{DM}} \approx 7$ keV, $\tau_{\text{DM}} \approx 10^{28}$ s ?

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The gravitino

- Has almost no interactions with ordinary matter.
- Essentially does not annihilate nor self-interact.
- Can have (almost) any mass and relic abundance.
- Does not need a discrete symmetry to be stable enough.
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R-parity Violating Couplings.

$$\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \mu_i H L_i$$

L_i, Q_i, H – lepton, quark, Higgs doublets
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Bilinear operators

$$\mu_i H L_i$$

- Neutrino-neutralino mixing.
- $\tilde{G} \to W^{\pm}\ell^{\mp}$, $\tilde{G} \to Z^0\nu$, $\tilde{G} \to \gamma\nu$, $\tilde{G} \to H\nu$
- For $m_{\tilde{G}} \ll M_W$, $\tilde{G} \to \gamma\nu$

$$t_{\tilde{G}} \approx 4 \times 10^{11}\ \mathrm{s}\ |U_{\nu\tilde{\gamma}}|^{-2} \left(\frac{m_{\tilde{G}}}{10\ \mathrm{GeV}}\right)^{-3}$$

$$m_{\tilde{G}} = 7\mathrm{keV} \Rightarrow t_{\tilde{G}} \approx 1.1 \times 10^{30}\ \mathrm{s}\ |U_{\nu\tilde{\gamma}}|^{-2}$$

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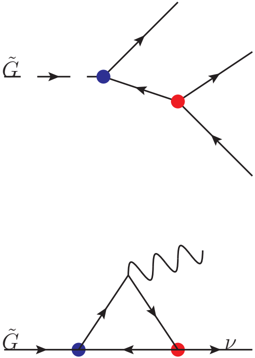

- $L_i L_j \bar{E}_k$
  - $e,\ \mu,\ \tau \Rightarrow e^{\pm},\ \nu,\ \gamma,\ \pi$
  - ν
  - $i, j = k \Rightarrow \tilde{G} \to \gamma + \nu$
- $L_i Q_j \bar{D}_k$
  - $l,\ \nu$
  - Quarks $\Rightarrow \bar{p},\ \pi(e^{\pm},\ \nu,\ \gamma)$
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Line signal

Three-body: $\Gamma_{\tilde{G}} \propto m_{\tilde{G}}^7 \Rightarrow$ negligible for $m_{\tilde{G}} = 7$ keV

For the loop decay[1]:

$$\Gamma_{\tilde{G}} = \frac{\alpha\lambda^2 m_{\tilde{G}}}{2048\pi^4} \frac{m_f^2}{M_p^2} \overline{|\mathcal{F}|^2}$$

- $\Gamma_{\tilde{G}} \propto m_{\tilde{G}}$
- $\Gamma_{\tilde{G}}$ independent of $m_{\tilde{f}}$ (as long as $m_{\tilde{G}} \ll m_{\tilde{f}}$)
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Possible loops

particle in loop	λ required for $t_{\tilde{G}} = 10^{28}$ s	Couplings
e	23	$\lambda_{121}, \lambda_{131}$
μ	0.11	$\lambda_{122}, \lambda_{232}$
τ	0.0066	$\lambda_{133}, \lambda_{233}$
d	1.9	λ'_{i11}
s	0.065	λ'_{i22}
b	0.0016	λ'_{i33}

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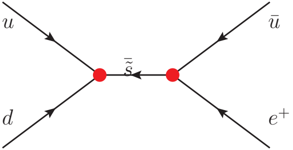
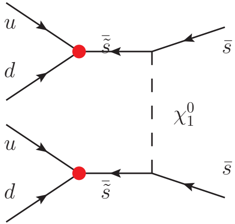
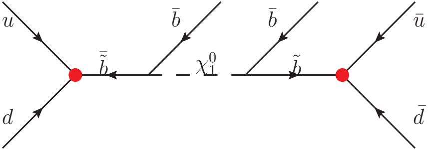
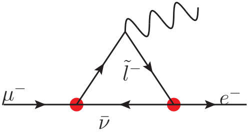
Constraints on couplings









Gravitino production

$$\Omega_{\tilde{G}} h^2 = 0.27 \left(\frac{100\ \mathrm{GeV}}{m_{\tilde{G}}} \right) \left(\frac{T_R}{10^{10}\ \mathrm{GeV}} \right) \left(\frac{m_{\tilde{g}}}{1\ \mathrm{TeV}} \right)^2$$

How light can the gluino be?
For gluino NLSP and λ'_{i33}, $\tilde{g} \to q\bar{q}\nu$.

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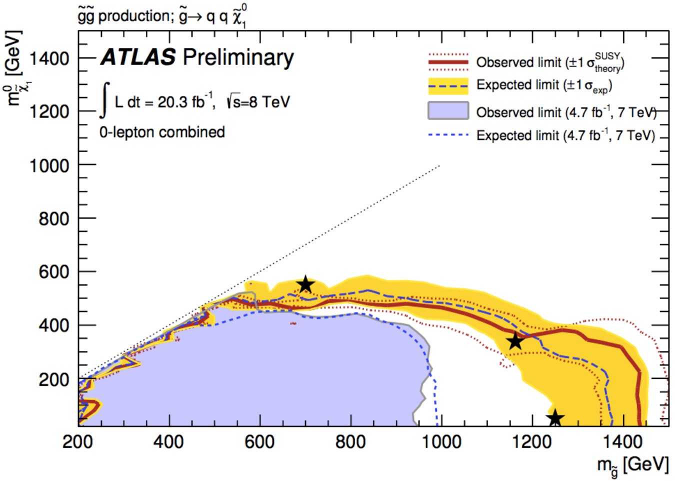

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$m_{\tilde{g}} \gtrsim 1400$ GeV $\Rightarrow T_R \lesssim 170$ GeV.

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$m_{\tilde{g}} \gtrsim 1400$ GeV $\Rightarrow T_R \lesssim 170$ GeV.
However, late time entropy production from decay of heavy fields can alleviate this.

Baryogenesis

With $T_R \lesssim 170$ GeV thermal leptogenesis does not work.
Moreover, L violating couplings will erase lepton asymmetry.

But EW baryogenesis,
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Conclusions

- The 3.5 keV line, if confirmed, is possibly the most interesting potential dark matter signal to date.
- Decaying gravitinos can explain the line through loop decays to photons and neutrinos.
- In order not to overproduce gravitinos we need $T_R \lesssim 170$ GeV, unless there is significant late time entropy production.
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