A Definitive Signal of Multiple SUSY breaking

JHEP 1007:035,2010 [arXiv:1004.4637]

Cliff Cheung, JM, Yasunori Nomura and Jesse Thaler

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Following on from

Goldstini (1002.1967) – C.Cheung, Y.Nomura and J.Thaler

Outline

- Motivation
- Review of the Goldstini framework
- An simple setup
- A smoking-gun collider signature
- Cosmology with goldstini
- Cosmology and Colliders collide
- Conclusions

Motivation

An old philosophy: simplicity

- Believe new physics should be as simple as possible to explain data
- ⇒ expect **SM sector** + (e.g.) **~~SUSY~~ sector** + **desert** ?

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(Of course, Standard Model doesn't look especially simple...)

Motivation

Another philosophy: many many sectors

- Complexity of string compactifications

  → many sequestered hidden sectors?

  (e.g. Giddings et.al. hep-th/0105097
  Dimopoulos et.al. hep-th/0104239
  . . .)

- Is it testable?
- Fantastical astrophysical/collider consequences
  - “axiverse”

    Arvanitaki et.al. 0905.4720
  - “photini”

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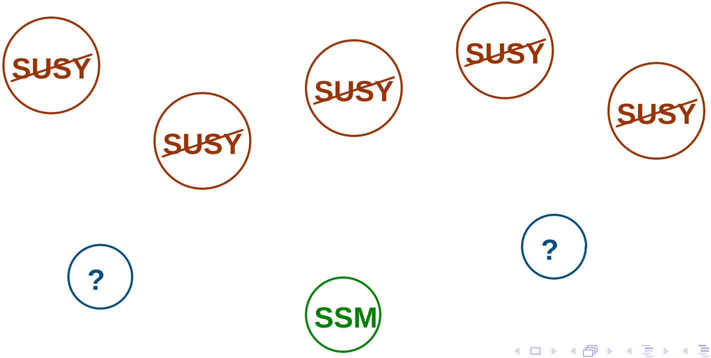
Goldstini

- N sequestered ~~SUSY~~ sectors

  ⇒ N copies of global SUSY

- ⇒ N massless goldstini-fermions ??



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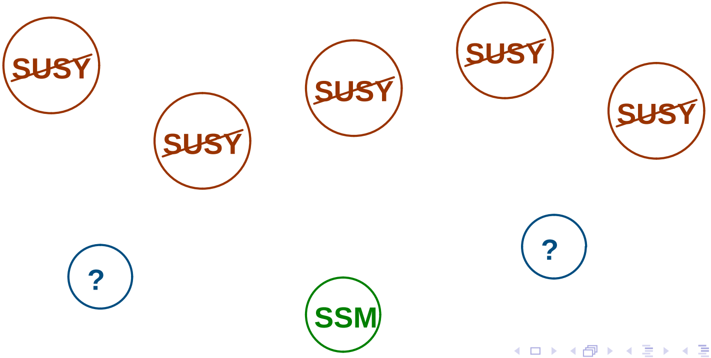

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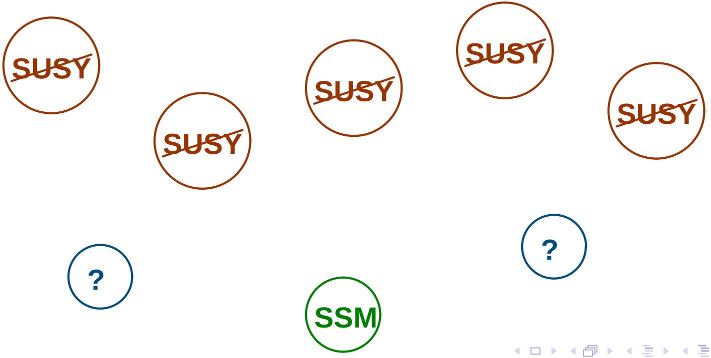
- Include gravity: **only one true SUSY**

$$\text{SUSY}^N \longrightarrow \text{SUGRA} \times (\text{SUSY}_{approx})^{N-1}$$

- $\cancel{\text{SUGRA}} \Rightarrow$ **massive gravitino**
- $(\cancel{\text{SUSY}}_{approx})^{N-1} \Rightarrow N-1$ **massive "goldstini"** $\zeta_1, \zeta_2 \dots \zeta_{N-1}$



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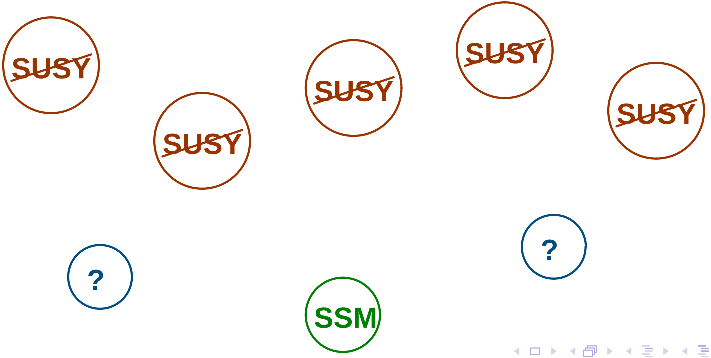

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Goldstini have:

- mass $= 2m_{3/2}$ **(universal!)***
- interactions with SM sector **similar to gravitino's***
- ...but with coupling *strength* a **free parameter**

*conditions apply

The Factor of Two

a quick treatment

Consider the field X_i that breaks SUSY in sector i:

$$\mathcal{L} = \int d^4\theta \, (X_i^\dagger X_i + \ldots) + \int d^2\theta \, \mu_i^2 X_i + \text{h.c.}$$

A non linear parametrization is appropriate:

$$X_i = e^{Q\eta_i/\sqrt{2}F_i}(x_i + \theta^2 F_i) = x_i + \eta_i^2/2F_i + \sqrt{2}\theta\eta_i + \theta^2 F_i$$

Low-energy effects of supergravity found by reinstating the conformal compensator:

$$\mathcal{L} = \int d^4\theta \, C^\dagger C(X_i^\dagger X_i + \ldots) + \int d^2\theta \, C^3 \mu_i^2 X_i + \text{h.c.}$$

with: $C = 1 + \theta^2 m_{3/2}$

Rescale $CX_i \to X_i$ to canonically normalize:

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$$\mathcal{L} \supset \int d^2\theta \, C^2 \mu_i^2 X_i \supset (2m_{3/2})\mu_i^2(\eta_i^2/2F_i) = -\frac{1}{2}(2m_{3/2})\eta_i^2$$

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goldstini get a mass $2m_{3/2}$

- The gravitino eats one linear combination:

$$\tilde{G} \supset \eta_{\text{long}} = (F_1\eta_1 + F_2\eta_2 + \ldots)/\sqrt{F_1^2 + F_2^2 + \ldots}$$

... and gets standard mass $m_{3/2} = \frac{F_{tot}}{\sqrt{3}M_{Pl}}$

- other linear combinations are physical goldstini ζ_a,

with mass $m_\zeta = 2m_{3/2}$

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Aside: How exact is the 2

- Assumes F-term breaking (for simplicity)
- Valid at tree level for sequestered sectors
  - Anomaly mediation
    $\longrightarrow \delta m_\zeta \sim$ (loop suppression) $\times\, m_{3/2}$
  - Multiple sectors mediating $\cancel{\text{SUSY}}$ to SM sector
    $\longrightarrow \delta m_\zeta \sim$ (loop suppression) $\times\, \tilde{m}$

Goldstini and Gravitino Couplings

- standard goldstone-fermion couplings:

$$\mathcal{L} \supset \frac{\tilde{m}^2_{[i]}}{F_i} \eta_i \ell \tilde{\ell}^\dagger - \frac{i}{\sqrt{2}} \frac{M_{[i]}}{F_i} \eta_i \sigma^{\mu\nu} \tilde{g} G_{\mu\nu}$$

  ($\tilde{m}^2_{[i]}$ and $M_{[i]}$ are the contributions to soft masses from sector i)

- → gravitino has couplings $\sim \frac{\tilde{m}^2}{F_{tot}}, \frac{M_{1/2}}{F_{tot}}$
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$$m_{3/2} = \frac{F_{tot}}{\sqrt{3}M_{Pl}}; \qquad \text{coupling} \sim \frac{m^2_{soft} \text{or} M_{1/2}}{F_{tot}}$$

Goldstini have:

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- ...but with coupling strength $\sim \tilde{m}^2_{[i]}/F_i$ **(free parameter)**

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A New BSM Playground

Interesting Possibilities:

- Colliders?

  ...

- Cosmology?

  ...

But could we ever see unambiguous evidence for a Goldstini setup?

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An Simple Setup

Part 1: SUSY-breaking

- Just 2 $\not{\text{SUSY}}$ sectors $\rightarrow$ **gravitino** $\tilde{G}$ $+$ **goldstino** ζ
- SUSY is dominantly broken in sector 1

$$F_1 \gg F_2$$

- The 2 sectors mediate similar $\not{\text{SUSY}}$ masses to SM sector

  $\Rightarrow$ goldstino couples much more strongly than gravitino

- LOSP heavier than goldstino or gravitino

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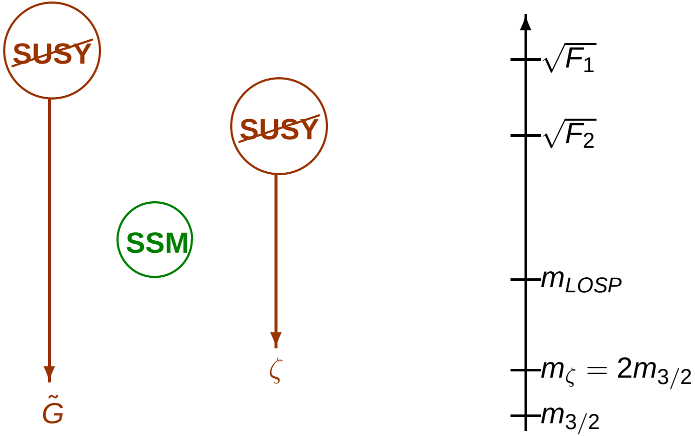
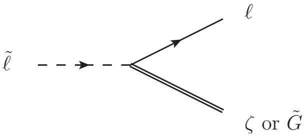


An Simple Setup

Part 2: Observable Sector

Imagine LOSP is a charged slepton

- LOSP can decay to ζ or $\tilde{G}$



F_2 controls

- coupling to ζ: $\sim 1/F_2$

F_1 controls

- masses: $m_{3/2} \approx \frac{1}{2} m_\zeta \approx \frac{F_1}{\sqrt{3}M_{Pl}}$

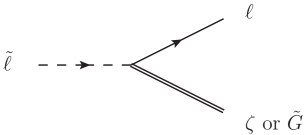
- coupling to $\tilde{G}$: $\sim 1/F_1$

$$\tau_\ell \sim 20\text{s} \times \left(\frac{300\text{GeV}}{m_\ell}\right)^5 \left(\frac{\sqrt{F_2}}{10^9\text{GeV}}\right)^4$$

$$\text{Br}_{\ell\to\tilde{G}} \sim \left(\frac{F_2}{F_1}\right)^2$$

A Smoking Gun Signature

- long-lived charged sleptons at LHC



- Fraction stopped in detector or in stopper
  $\longrightarrow$ decays studies
- Expect decay to gravitino
  $\longrightarrow$ measurement of mass and decay rate allows reconstruction of M_{Pl} (Buchmuller et al '04)

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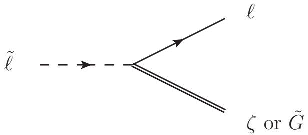

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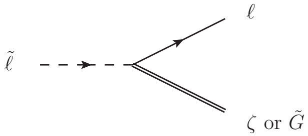

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But decay is primarily to *goldstino*

$\longrightarrow$ mismeasurement of M_{Pl}
$\longrightarrow$ alarm bells
$\longrightarrow$ search for rare decays to $\tilde{G}$
$\longrightarrow$ predict both $m_{3/2}$ and Br(LOSP$\longrightarrow \tilde{G}$)

- Observing rare decays to gravitinos confirms the setup.

Is this generic?

- $m_{3/2,\zeta}$ reconstructed from $m_{\tilde{\ell}}$ and E_ℓ (from $\tilde{\ell}$ decay)
  $\rightarrow$ limited by $m_{\tilde{\ell}}$ and E_ℓ resolution
  $\rightarrow$ better for larger $m_{3/2,\zeta}$
  $\rightarrow$ need $m_{3/2} \gtrsim (0.05 - 0.2) m_\ell$ for mass measurement
  (Corollary: don't worry about deviations from factor 2)
- Need to see *some* gravitinos
  $\rightarrow$ need $\mathrm{Br}(\tilde{\ell} \rightarrow \tilde{G}) \gtrsim 10^{-4} - 10^{-3}$
  (assuming 100-1000 fb^{-1} and $m_{\tilde{\ell}} \sim 150\mathrm{GeV}$)

(Hamaguchi et.al. hep-ph/0612060)

i.e. We need to be in the right part of parameter space.

But what we learn:

- Discovery of gravitino *and* goldstino
- Demonstration of SUGRA
- Existence of sequestered sectors with ~~SUSY~~

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Goldstino Cosmology

1: Overabundance problem

Abundance

- Gravitinos with $\sim$GeV mass very weakly coupled
  $\longrightarrow$ never in thermal equilibrium
- Rare scattering and decay processes produce small abundance
- Solve Boltzmann equations to find yield Y

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Coupling to scalar–fermion is dim. 4

$$\rightarrow \frac{dY}{d\ln T} \sim M_{Pl}\left(T\sigma v + \Gamma/T^2\right) \sim \frac{M_{Pl} m_{\tilde{f}}^4}{F^2 T} + \frac{M_{Pl} m_{\tilde{f}}^6}{F^2 T^3}$$

→ **dominated by low-T** (cuts off around $m_{\tilde{f}}$)

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Coupling to gaugino–gauge-boson is dim. 5

$$\rightarrow \frac{dY}{d\ln T} \sim M_{Pl} T\, \sigma v \sim \frac{M_{Pl} M_{1/2}^2 T}{F^2}$$

→ **high-T dominated** → **sets a bound on T**$_{\mathrm{Reheat}}$

Gravitino Cosmology

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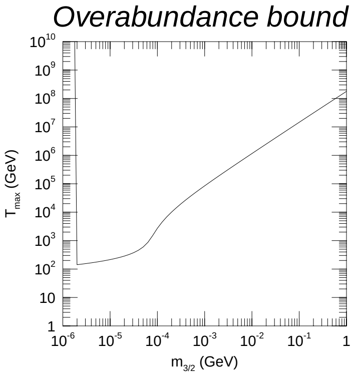

(de Gouvea et al ’97)

Gravitino Cosmology

1: BBN problem

- Slepton LOSP freezes out and then decays later
- decay products can change primordial element abundances
- → **bound on LOSP lifetime**

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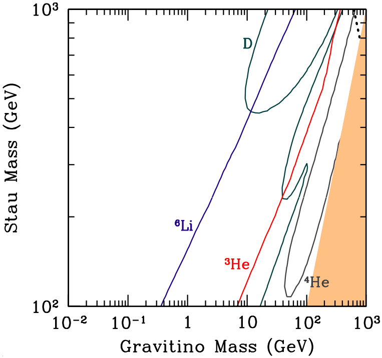
Late LOSP decay ruins BBN



(Kawasaki et al '08)

$\boxed{\tilde{G} \text{ heavy enough for LHC mass measurement} \Leftrightarrow \text{BBN problem}}$

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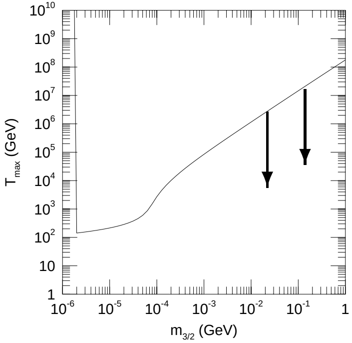
Alleviating the gravitino problem

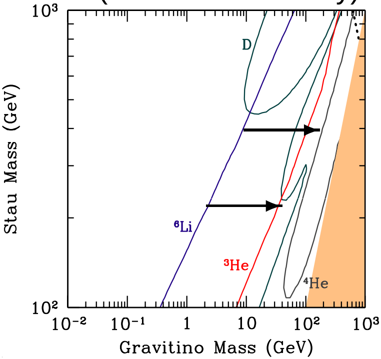
Goldstino is like a gravitino with extra large coupling to SSM



overabundance bound becomes stronger (*unless...*)

BBN bound becomes weaker

(faster LOSP decay)



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- bound set by F_2 not F_{tot}
- $m_{3/2}$ bound weakened by factor F_2/F_1

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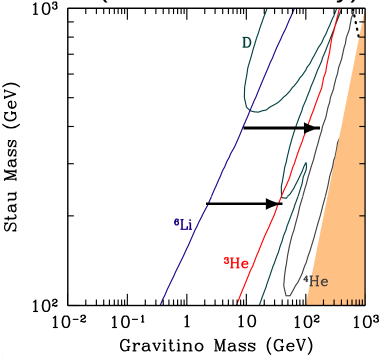

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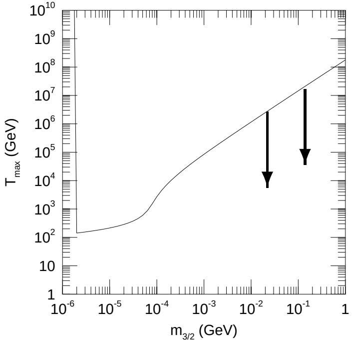
Alleviating the gravitino problem

Goldstino is like a gravitino with extra large coupling to SSM



- *high T production:*

  T_R bound lower by factor $(F_2/F_1)^2$

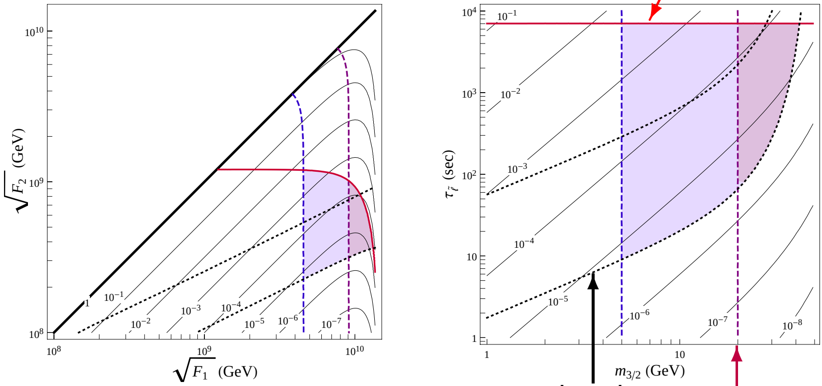
- *low T production:*

  $m_\zeta/\tau_{LOSP} \sim F_1/F_2^2$ bounded from below

overabundance bound becomes stronger *(unless...)*

Smoking gun signature $+$ Cosmology $=$ Success

$m_{\tilde{\ell}} = 100\text{GeV}$



BBN

overabundance

LHC mass measurement

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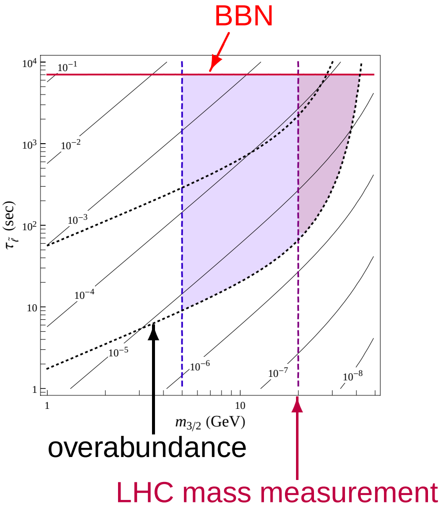
Results:

- **Smoking-gun signature possible, consistent with cosmological bounds.**
- Saturating T_R bound $\rightarrow$ goldstino DM

Need $T_R \lesssim 10^5$-10^7 GeV?

(big improvement on standard gravitino

...but no thermal leptogenesis?)



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R symmetry in 2nd ~~SUSY~~ sector?

- Goldstino does not couple to gauginos
- Only gravitinos produced at high T_R
- **Allow T_R up to $\sim 10^{10}$GeV** $\rightarrow$ Thermal leptogenesis + gravitino DM

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- May be seen at the LHC *consistently with cosmology*

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    - SUGRA
    - $\cancel{\text{SUSY}}$ at scales $\sim 10^8 - 10^{10}$GeV
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