Gravitino Phenomenology in Astrophysics

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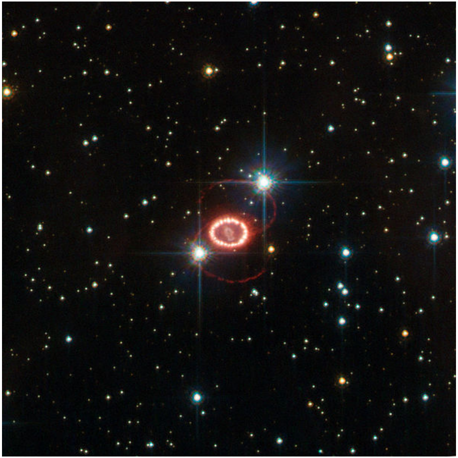
- What is the gravitino?
- And what does it have to do with this[1]?



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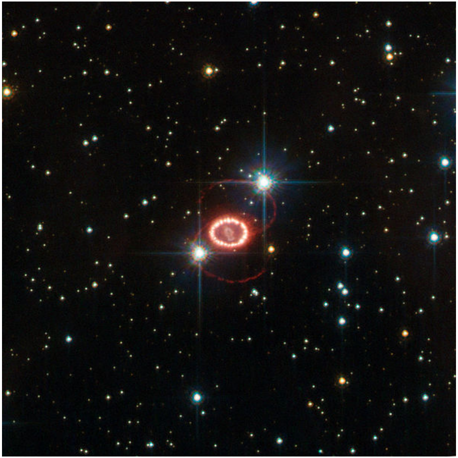

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Supersymmetry and Supergravity

Supersymmetry

- Supersymmetry is a proposed symmetry connecting bosons and fermions.
- In supersymmetric versions of the SM every particle obtains a superpartner (e.g. electrons $\rightarrow$ selectrons, Higgs boson $\rightarrow$ Higgsino).
- If SUSY was an exact symmetry of nature, these new particles should have the same mass.
- This is clearly excluded, therefore SUSY must be a broken symmetry, if it is a symmetry of nature.

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Supersymmetry - Motivations

Gauge Coupling Unification

- In the MSSM the gauge couplings unify at high energies.

Hierarchy Problem

- The quantum corrections to the Higgs mass of bosons and fermions can cancel in a supersymmetric theory.

Dark Matter

- SUSY leads to the introduction of new particles which could act as DM.

Theoretical Appeal

- The SUSY algebra is the most general Lie algebra of a symmetry of the S-matrix (Haag-Łopuszański-Sohnius-Theorem).

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Supergravity

Supergravity = The combination of Supersymmetry and General Relativity

- By promoting SUSY to a **local** symmetry one directly obtains a theory of gravity.
- The spin-2 graviton obtains a spin-3/2 superpartner called the **gravitino**.
- Of course Supergravity is an effective field theory and should therefore be regarded as a low-energy limit of a unkown fundamental theory.

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Gravitino Phenomenology

Properties of the Gravitino

- It is a spin 3/2 particle, described by the Rarita-Schwinger equation.
- Before SUSY breaking the gravitino is massless, as you might expect for the graviton's superpartner.
- After SUSY breaking it obtains a mass $m_{3/2}$.
- Its interactions are suppressed by a factor of M_P^{-1}.

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Super-Higgs effect

The mechanism how the gravitino attains its mass is similar to the Higgs effect in electroweak symmetry breaking.

- After global SUSY breaking a Goldstone particle appears in the spectrum.
- In the case of SUSY this is a fermion, the **goldstino**.
- After local SUSY breaking the gravitino 'eats' the two spin 1/2 helicity states of the goldstino to obtain the four degrees of freedom of a massive spin 3/2 particle.
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Superlight gravitinos

The gravitino mass is given by

$$m_{3/2} = \frac{\Lambda_{\mathrm{SUSY}}^2}{\sqrt{3}M_P} \,. \tag{1}$$

- The actual value of $m_{3/2}$ depends heavily of the mechanism of SUSY breaking.
- There are models (e.g. models with gauge-mediated SUSY breaking) in which the gravitino can be superlight.
- But why are superlight gravitinos of special interest for us?

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Interactions with matter

- The gravitino interacts with matter via gravity.
- Is it even possible to obtain observable effects with such weak interactions?

Yes, but only if the gravitino is very light ($\sim \mathcal{O}(1\text{eV})$).

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Equivalence Theorem

For very small masses the gravitino's interactions are dominated by its two longitudinal helicities. In other words, at high energies the gravitino acts like the goldstino.

If this is the case, we can use the **equivalence theorem** and write the gravitino field as

$$\Psi_\mu = \sqrt{\frac{2}{3}}\frac{1}{m_{3/2}}\partial_\mu\chi\,. \tag{2}$$

This will simplify our further calculation.

But one has to take care. In some processes this approximation is not applicable.

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Probing SUGRA in Astrophysics

The Idea

Astrophysics and Cosmology are great for testing light gravitinos indirectly.

- We will focus on **supernovae**.
- From the supernova SN1987A we have a limit on the energy carried away by particles other than neutrinos.

This allows us to find observational constraints on the gravitino mass and the SUSY breaking scale.

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Constraints on $m_{3/2}$ from Supernovae - Our Approach

1. Find the dominating channels of gravitino production in a supernova.
2. Calculate the cross-section.
3. Use known properties of supernovae to calculate the luminosity of the gravitinos produced in a supernova.
4. The luminosity is bounded by $L < 10^{52} \frac{\text{erg}}{\text{s}}$. This constraint comes from
   - Stellar Models,
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5. This can be translated into constraints on $m_{3/2}$ or Λ_{SUSY}.

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Production via Photon-Annihilation

- It turns out that the leading gravitino production channel is $\gamma\gamma \to \tilde{G}\tilde{G}$.
- The relevant Feynman rules are given by the Lagrangian

$$\mathcal{L} = -\frac{M_P^2}{2} eR - \frac{1}{2} e\epsilon^{\kappa\lambda\mu\nu}\overline{\psi}_\kappa \gamma^5 \gamma_\lambda \tilde{\mathcal{D}}_\mu \psi_\nu - \frac{1}{4} e\, m_{3/2} \overline{\psi}_\alpha \left[\gamma^\alpha, \gamma^\beta\right] \psi_\beta$$
$$- \frac{1}{4} eF_{\mu\nu}F^{\mu\nu} + \frac{1}{2} e\overline{\lambda}^{(a)} \left[\gamma^\mu \tilde{\mathcal{D}}_\mu - m_\gamma\right] \lambda^{(a)}$$
$$- \frac{i}{8M_P} e \left[\overline{\psi}_\mu \left[\gamma^m, \gamma^n\right] \gamma^\mu \lambda_{(a)}\right] F_{mn}^{(a)} . \qquad (3)$$

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Gravitino Production Channels

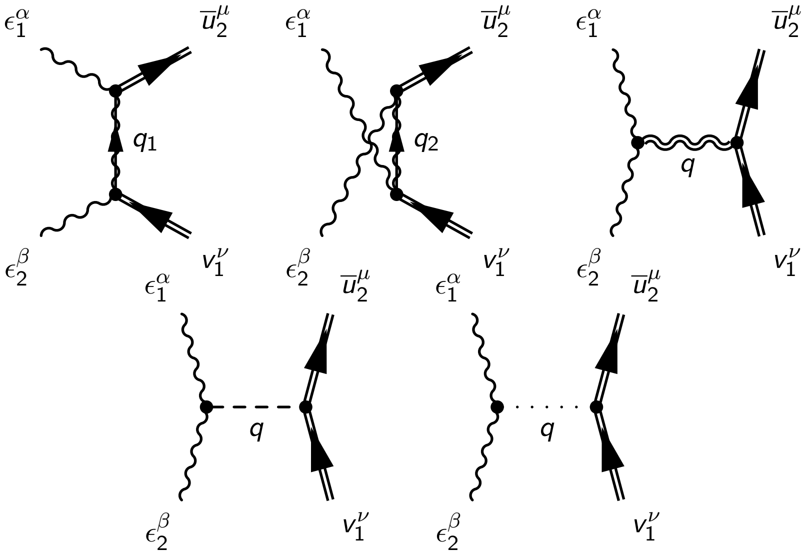

Figure: Feynman Diagrams for $\gamma\gamma \longrightarrow \tilde{G}\tilde{G}$

Results

- In the limit $m_{\tilde{\gamma}} \gg \sqrt{s}$ the cross-section is given by

$$\sigma(\gamma\gamma \to \tilde{g}\tilde{g}) = \frac{\kappa^4 s^2 m_{\tilde{\gamma}}^2}{576\pi m_{3/2}^4} + \mathcal{O}(x^0)\,. \qquad (4)$$

- With this result we can estimate the gravitino luminosity of a supernova,

$$L > \frac{20}{\pi^5}\left(\frac{1}{M_P m_{3/2}}\right)^4 m_{\tilde{\gamma}}^2 V T^{11}\,. \qquad (5)$$

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- From the constraint $L < 10^{52}\frac{\text{erg}}{\text{s}}$ we find

$$m_{3/2} > 2.2 \cdot 10^{-6} \left(\frac{m_{\tilde{\gamma}}}{100\text{GeV}}\right)^{1/2} \left(\frac{T}{50\text{MeV}}\right)^{\frac{11}{4}} \left(\frac{V}{4.2 \cdot 10^{18}\text{cm}^3}\right)^{\frac{1}{4}} \text{eV}.$$

Concluding Remarks

- These calculations were published in the mid-90s.
- During the last months we verified this result.
- There are various difficulties and subtleties in the calculation.
- It will be interesting to further explore this fascinating possibility of probing SUGRA by looking to the stars.

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