Supergravity and Supernovae

Timon Emken

Institute of Theoretical Physics, Göttingen

Supervisors: Prof. Dr. Laura Covi and Dr. Riccardo Catena

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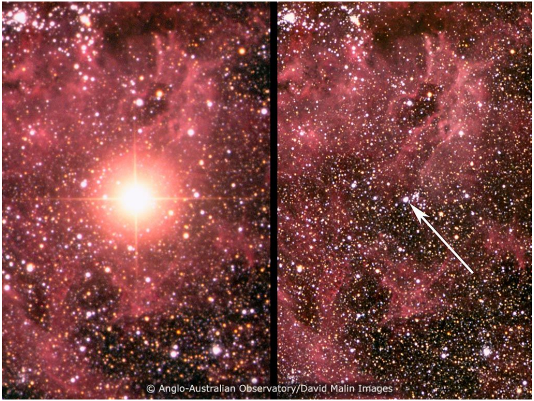
SN1987A



Outline

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Supersymmetry and Supergravity

Supersymmetry

- Supersymmetry is an hypothetical extension of the spacetime symmetries.
- Its generators satisfy the super algebra

$$\left\{ Q_\alpha , \overline{Q}_{\dot{\beta}} \right\} = 2\sigma^\mu_{\alpha\dot{\beta}} P_\mu$$

- These generators relate bosonic states with fermionic ones and vice versa,

$$Q|\text{boson}\rangle \sim |\text{fermion}\rangle \,, \quad Q|\text{fermion}\rangle \sim |\text{boson}\rangle$$

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SUSY Breaking

In a supersymmetric theory the particles form **supermultiplets** (ϕ, χ, F), whose bosonic and fermionic fields should be degenerate in mass. If this would be the case in nature, where is the selectron?

- If SUSY is a symmetry of nature, it must be a broken one.
- This can be achieved if one of the fields acquire a vacuum expectation value (VEV) $\langle F \rangle$.
- After SUSY breaking a massless Goldstone fermion, the goldstino, appears in the spectrum. It has scalar superpartners, the sgoldstinos.

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The SUSY generators are connected to the generators of the Poincaré group:

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Remarks on Supergravity

- The action of the gravity sector is given by

$$S = \int \mathrm{d}^4 x e \left[-\frac{1}{2\kappa^2} R - \frac{1}{2} \epsilon^{\kappa\lambda\mu\nu} \overline{\psi}_\kappa \gamma^5 \gamma_\lambda \partial_\mu \psi_\nu \right]$$

- Renormalizability?
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Local SUSY breaking and Gravitino Mass

A non-zero gravitino mass is a clear indicator of SUSY breaking. The mass $m_{3/2}$ is connected to the SUSY breaking scale Λ_{SUSY},

$$m_{3/2} \sim \kappa \Lambda_{\text{SUSY}}^2 \,, \quad \text{where } \kappa = \sqrt{8\pi G_N} \,.$$

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Gravitinos

- As a spin $\frac{3}{2}$ field its dynamics are governed by the Rarita-Schwinger equation,

$$\epsilon^{\mu\nu\kappa\lambda}\gamma^5\gamma_\nu\partial_\kappa\psi_\lambda + \frac{1}{2}m_{3/2}\left[\gamma^\mu, \gamma^\nu\right]\psi_\nu = 0\,.$$

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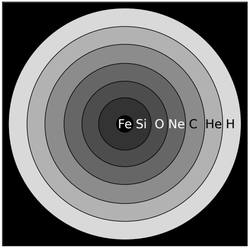
Supernovae Constraints on superlight Gravitinos

Supernovae



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- The mantle and radiation get ejected in a shockwave $\longrightarrow$ a 'Supernova' occurs.

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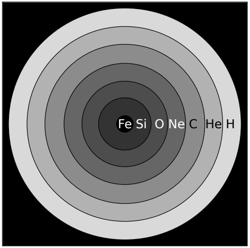

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Energy Loss Argument with Supernovae

Low mass WIMPs are able to contribute to the energy loss of stars and supernovae.

- During a Supernova, the binding energy of

$$E \sim \frac{G_N M^2}{R} \sim 3 \times 10^{53} \text{erg}$$

get released.
- SN neutrinos have been observed in the SN1987A by Kamiokande and IMB. They found $E_\nu \geq 2 \times 10^{53}$erg.
- $\longrightarrow$ Most energy ($> 99\%$) is released in the form of neutrinos.

Every anomalous energy loss mechanism is bounded by $L_X < 10^{52} \frac{\text{erg}}{\text{s}}$.

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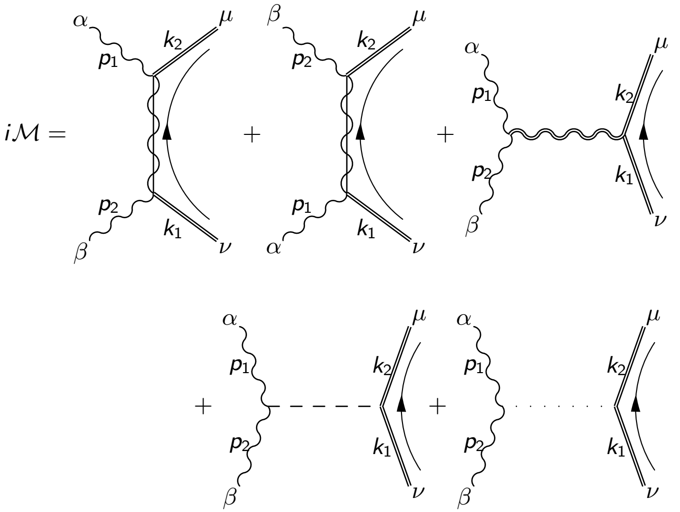
Feynman Diagrams for $\gamma\gamma \longrightarrow \tilde{G}\tilde{G}$



Cross-Section

The result for the cross-section is given by

$$\sigma(\gamma\gamma \to \tilde{G}\tilde{G}) = \frac{\kappa^4 m_{\tilde{\gamma}}^4 s}{1728\pi m_{3/2}^4} \left[\frac{1}{1+x}\left(x + 7 - \frac{12}{x} - \frac{24}{x^2}\right) + \frac{1}{x+2}\left(\frac{48}{x^3} + \frac{24}{x^2} - \frac{6}{x}\right)\log(1+x)\right],$$

where $x \equiv \frac{s}{m_{\tilde{\gamma}}^2}$. For this calculation we used the Mathematica package **FeynCalc**.

In the limit $m_{\tilde{\gamma}} \gg \sqrt{s}$ this yields

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Luminosity

The gravitino luminosity is given by

$$L = V \int \frac{d^3 p_1}{(2\pi)^3\, 2p_1^0}\, 2n_\gamma(p_1^0) \int \frac{d^3 p_2}{(2\pi)^3\, 2p_2^0}\, 2n_\gamma(p_2^0) \int \frac{d^3 k_1}{(2\pi)^3\, 2k_1^0} \int \frac{d^3 k_2}{(2\pi)^3\, 2k_2^0}$$
$$(2\pi)^4 \delta^{(4)}(p_1 + p_2 - k_1 - k_2)(k_1^0 + k_2^0)\overline{\left|\mathcal{M}(\gamma\gamma \to \tilde{\mathcal{G}}\tilde{\mathcal{G}})\right|^2}\,,$$

leading to

$$L > \frac{8V}{(2\pi)^6} \int d^3 p_1 d^3 p_2\, e^{-(p_1^0+p_2^0)/T} (p_1^0 + p_2^0)\,(1 - \cos\alpha)\,\sigma(\gamma\gamma \longrightarrow \tilde{G}\tilde{G})$$
$$= \frac{160}{\pi^5} \left(\frac{\kappa}{m_{3/2}}\right)^4 m_{\tilde{\gamma}}^2\, V T_{SN}^{11}.$$

The whole argument breaks down, if the gravitino is so light such that $\lambda_{\text{MFP}} \ll R_{\text{SN}}$. This gives us an upper bound on the gravitino mass.

Main Result

We can exclude the range

$$6.2 \times 10^{-8}\text{eV} < m_{3/2} < 1.8 \times 10^{-5}\text{eV}$$

for the gravitino mass based on the observation of SN1987A.

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Heavy Sgoldstinos

The result is indirectly based on the assumption of massless sgoldstinos.

This is not necessarily the case and some models inherit very heavy sgoldstinos.

Modified Result for heavy Sgoldstinos

$$\sigma(\gamma\gamma \to \tilde{G}\tilde{G}) \approx \frac{s^3\kappa^4}{5760\pi m_{3/2}^4},$$

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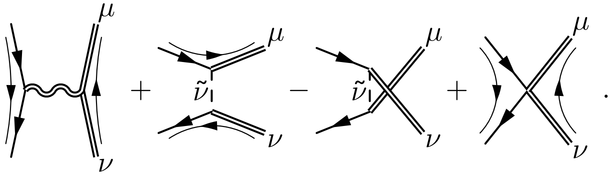
Additional Gravitino Production Channels for heavy Sgoldstinos

Processes like the following become relevant:

$$i\mathcal{M}(\nu\overline{\nu} \longrightarrow \tilde{G}\tilde{G}) =$$



	Light Sgoldstinos:	Heavy Sgoldstinos:
$\frac{L(\nu\overline{\nu}\to\tilde{G}\tilde{G})}{L(\gamma\gamma\to\tilde{G}\tilde{G})}$	$\sim \frac{T_{SN}^2}{m_{\tilde{\gamma}}^2} \sim 10^{-6}$	~ 0.7

The bounds seem to be very model-dependent.

Concluding Remarks

- In SUGRA models the graviton has a superpartner, the gravitino.
- After SUSY breaking the gravitino becomes massive, the mass is depending on the mechanism of symmetry breaking.
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- We want to investigate certain SUSY GUTs, so-called Pati-Salam models.
- These models are not as strictly constrained by the LHC observations as the standard MSSM.
- The models inherit an extended neutrino and neutralino sector and a type-III seesaw mechanism.

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