Don't put all your eggs in one basket

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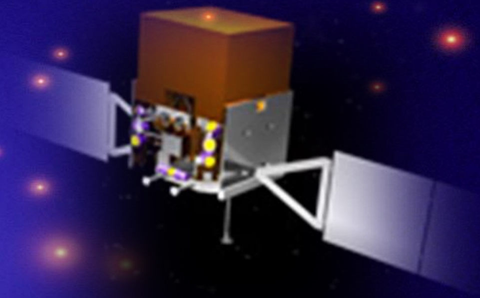
MultiDark Multimessenger Approach for Dark Matter Detection



2nd RED LHC workshop, Madrid, May 9-11, 2018

Prospects for detecting DM **OPTIMISTIC**

There has been an impressive progress on this issue in recent years, with significant improvements in the precision and sensitivity of experiments. We seem to be closer than ever to the detection of dark matter. This is a unique moment.

-Neutrino, took "only" 25 years the discovery **PESIMISTIC**

-Higgs, took "only" 50 years the discovery

-Dark Matter, proposed 85 years ago, not yet discovered

OPTIMISTIC This is NOT the world record:

-Gravitational waves, took 100 years the discovery

The detection of Dark Matter is similar to the detection of gravitational waves but more difficult!,

in the following sense:

-We are pretty sure that Dark Matter has to be there (like gravitational waves)

-BUT, we don't know which experiment is the right one for its detection, since we don't know what the Dark Matter is made of

Dark Matter versus High Energy (particle) experiments

To detect Dark Matter is more difficult OR different:

-To detect BSM Physics, basically ONLY ONE experiment: LHC

-To detect Dark Matter, we need to build many experiments, again because we don't know what the Dark Matter is made of

-Many scales from keV to 10^x GeV are possible

THIS IS THE PROBLEM

-We cannot put all our eggs in one basket

Experiments with different characteristics are necessary

-Some candidates can not be detected at the LHC: e.g. gravitinos in RPV

gamma ray detectors are needed

-May not even be detected (in the near future), depending on their masses, couplings, etc.

Multi-messenger/experiment approach is necessary

Having in mind that experiments which are complementary among themselves, may be orthogonal with other experiments

-WIMPs (e.g. neutralino, sneutrino, …)
Underground experiments (Canfranc, Gran Sasso, …)
gamma-ray telescopes (MAGIC, HESS, VERITAS,… CTA) + satellites (Fermi-LAT)
Neutrino telescopes (ANTARES, IceCube, KM3Net)
Antimatter satellites (AMS, PAMELA)
LHC

-AXIONS: need dedicated experiments

OR even that same the candidate may need different experimental techniques to be detected, depending on their range of masses

e.g. low mass WIMPs (superCDMS,…), heavier WIMPS (ANAIS, XENON, ArDM, …)

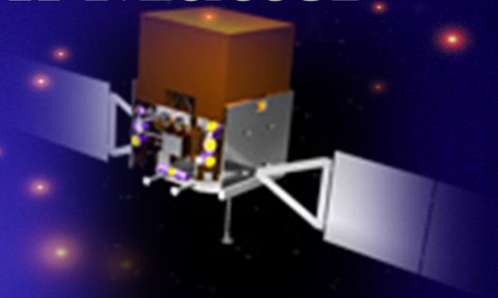
Conclusion, Part I

For experimentalists: to detect Dark Matter
is a bet

Fortunately, these are low cost experiments

compared with LHC

Part II
An example: Gravitino Dark Matter



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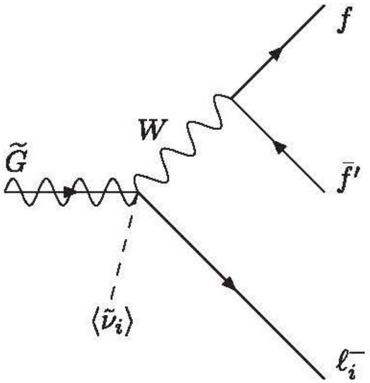
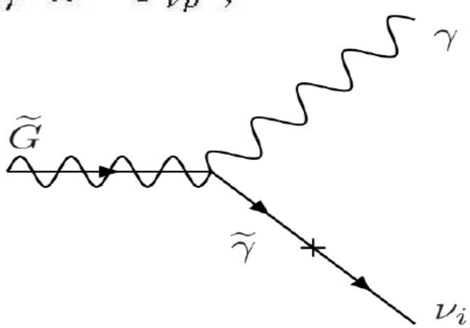
In RPV the gravitino can decay with a lifetime longer than the age of the Universe, because its decay is supressed both by the Planck mass and the R-parity breaking

$$\Gamma(\psi_{3/2} \to \gamma\nu) = \frac{1}{32\pi}|U_{\tilde{\gamma}\nu}|^2 \frac{m_{3/2}^3}{{M_\mathrm{P}}^2}\,.$$

$$\begin{aligned}\mathcal{L} \ni & -\frac{i}{\sqrt{2}M_P}[(D_\mu^* \phi^{i*})\bar{\psi}_\nu \gamma^\mu \gamma^\nu P_L \chi^i \\ & - (D_\mu \phi^i)\bar{\chi}^i P_R \gamma^\nu \gamma^\mu \psi_\nu] \\ & - \frac{i}{8M_P}\bar{\psi}_\mu[\gamma^\nu, \gamma^\rho]\gamma^\mu \lambda^{(\alpha)a} F_{\nu\rho}^{(\alpha)a},\end{aligned}$$



$+ \quad \cdots \quad \not\propto \quad |U_{\tilde{\gamma}\nu}|^2$



$\propto \quad |U_{\tilde{\gamma}\nu}|^2$

The photon spectrum consists then of a line from the two-body decay, plus a continuum distribution from the three-body decay

We have analyzed gravitino DM in the RPV **μνSSM**

Gómez-Vargas, López-Fogliani, C.M., Perez, Ruiz de Austri

$$W = \epsilon_{ab} \left(Y_u^{ij} \, \hat{H}_2^b \, \hat{Q}_i^a \, \hat{u}_j^c + Y_d^{ij} \, \hat{H}_1^a \, \hat{Q}_i^b \, \hat{d}_j^c + Y_e^{ij} \, \hat{H}_1^a \, \hat{L}_i^b \, \hat{e}_j^c + \underline{Y_\nu^{ij} \, \hat{H}_2^b \, \hat{L}_i^a \, \hat{\nu}_j^c} \right)$$

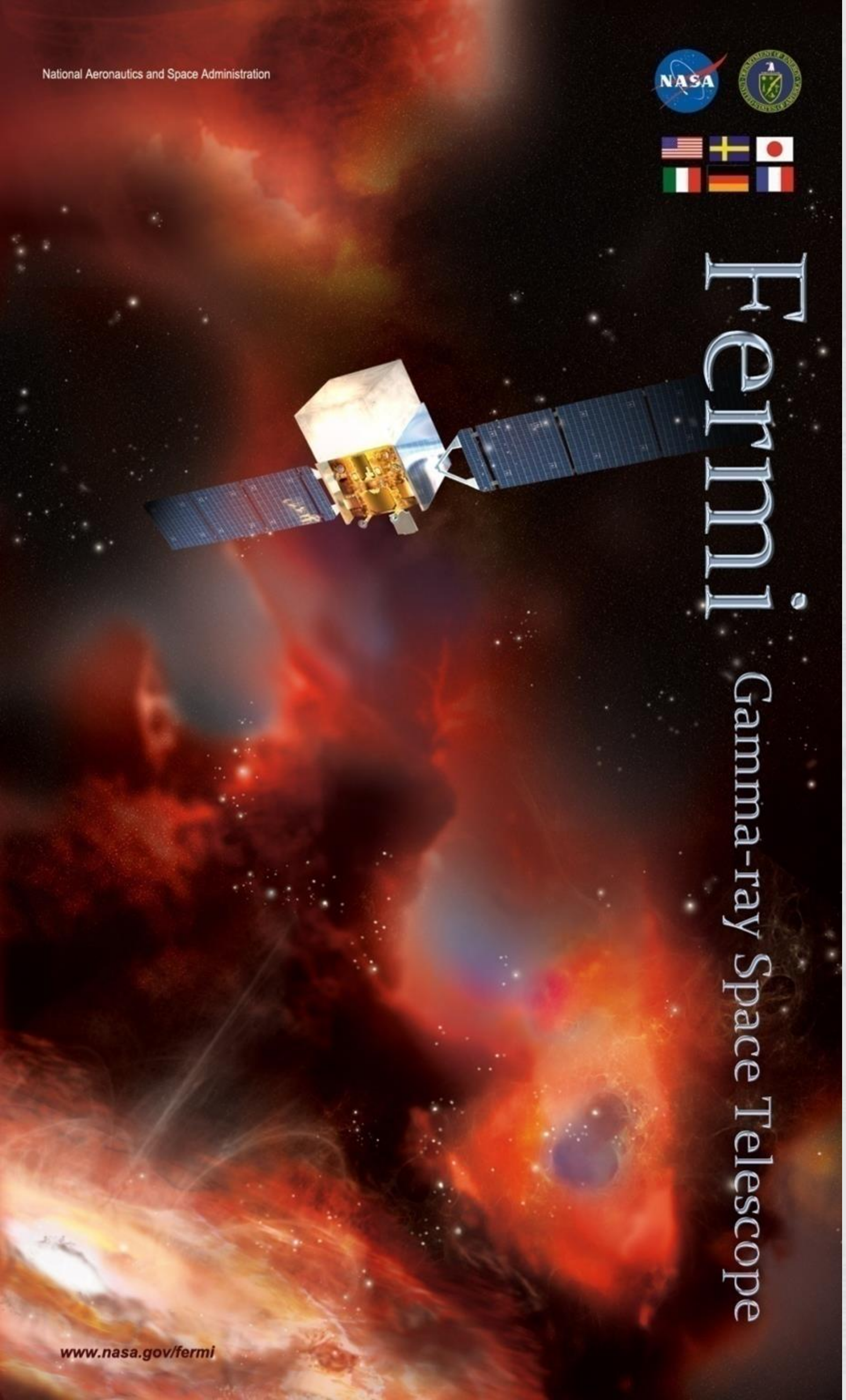
$$- \underline{\epsilon_{ab} \lambda^i \, \hat{\nu}_i^c \, \hat{H}_1^a \hat{H}_2^b} + \frac{1}{3} \underline{\kappa^{ijk} \hat{\nu}_i^c \hat{\nu}_j^c \hat{\nu}_k^c} \, ,$$

Dirac neutrino masses

effective μ term generated by
the VEVs of the **3** righ-handed sneutrinos

effective Majorana masses $M_M = \kappa_{ijk} \langle \tilde{\nu}_k^c \rangle$

$$\text{with } \mu \equiv \lambda^i \langle \tilde{\nu}_i^c \rangle .$$

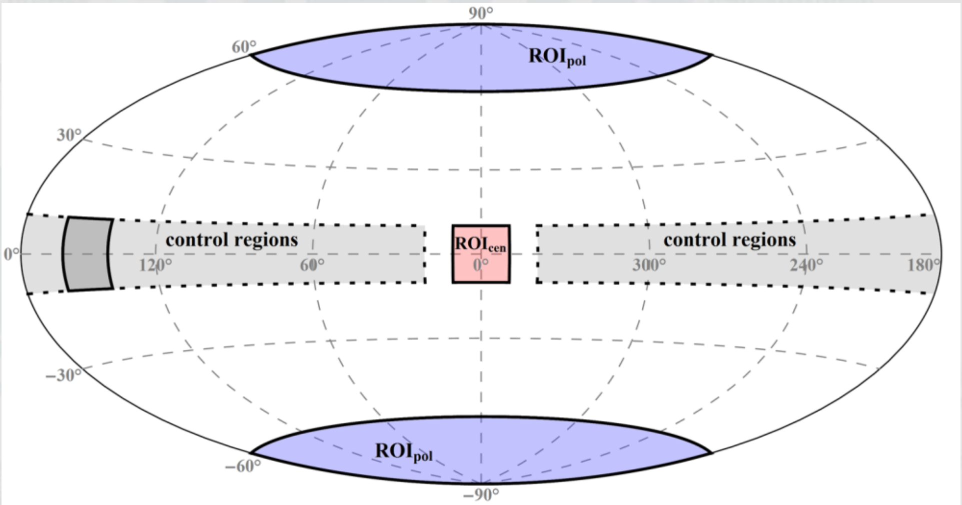


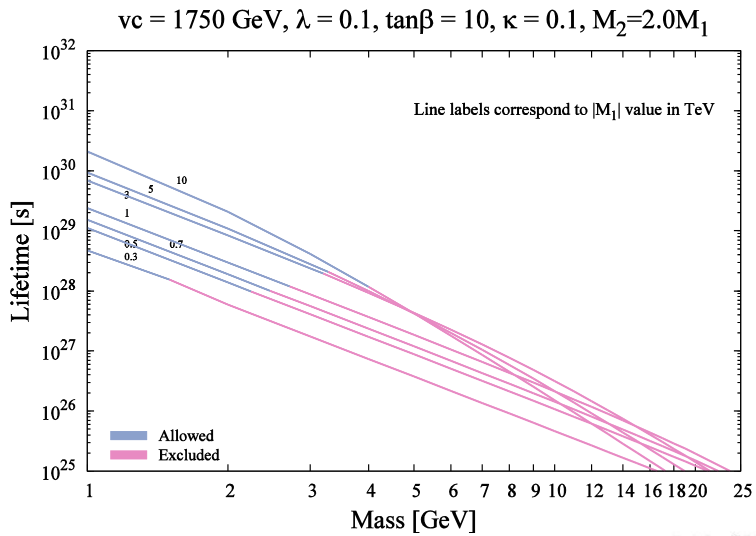
Fermi Gamma-ray Space Telescope

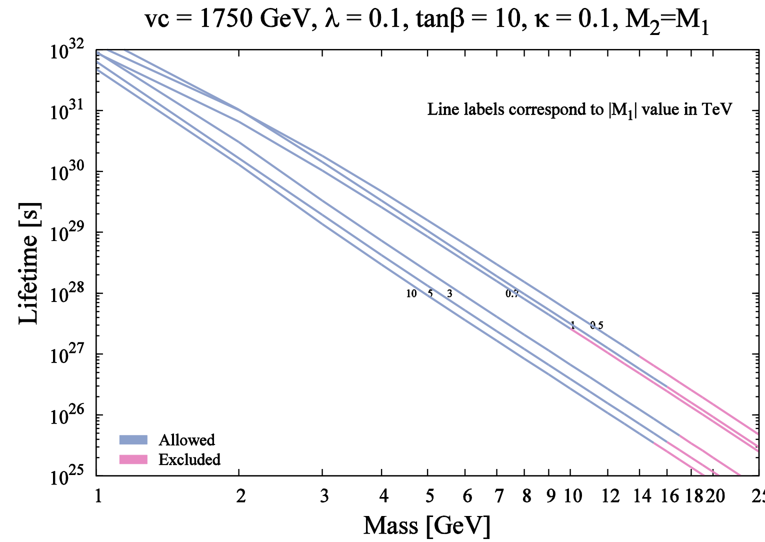
MultiDark
Multimessenger Approach for Dark Matter Detection

- Decays of **gravitinos** in the galactic halo, at a sufficiently high rate, would produce gamma rays that could be detectable in experiments

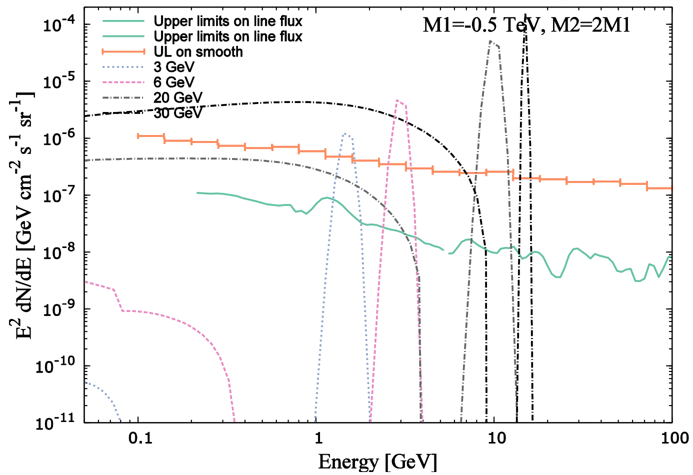
Results updated with 5.8 years of data from Fermi LAT

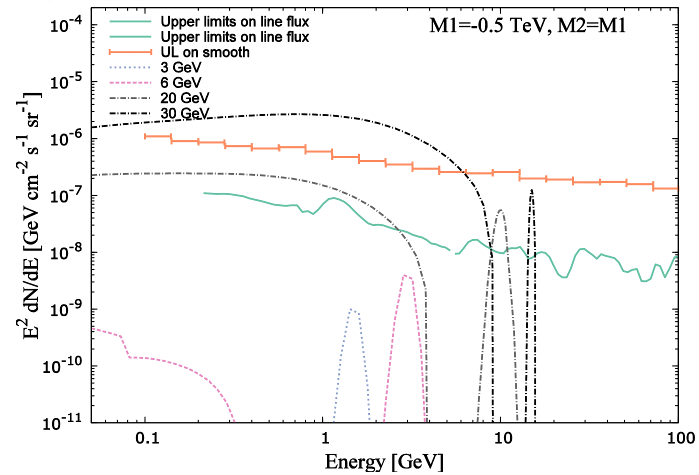






$$|U_{\tilde{\gamma}\nu}| \approx \frac{M_Z(M_2 - M_1)s_W c_W}{(M_1 c_w^2 + M_2 s_w^2)(M_1 s_W^2 + M_2 c_W^2)},$$





If the gravitino is the DM: $m_{3/2} < 17$ GeV , $\tau > 4 \times 10^{25}$ s

Conclusions, Part II

I just wanted to show you an example of a SUSY non-WIMP candidate (gravitino) that cannot be detected at the LHC

But there are also SUSY WIMP candidates (neutralino, sneutrino) that can be detected at the LHC

But also non-SUSY non-WIMP candidates (axion, …) that cannot be detected at the LHC

And also …

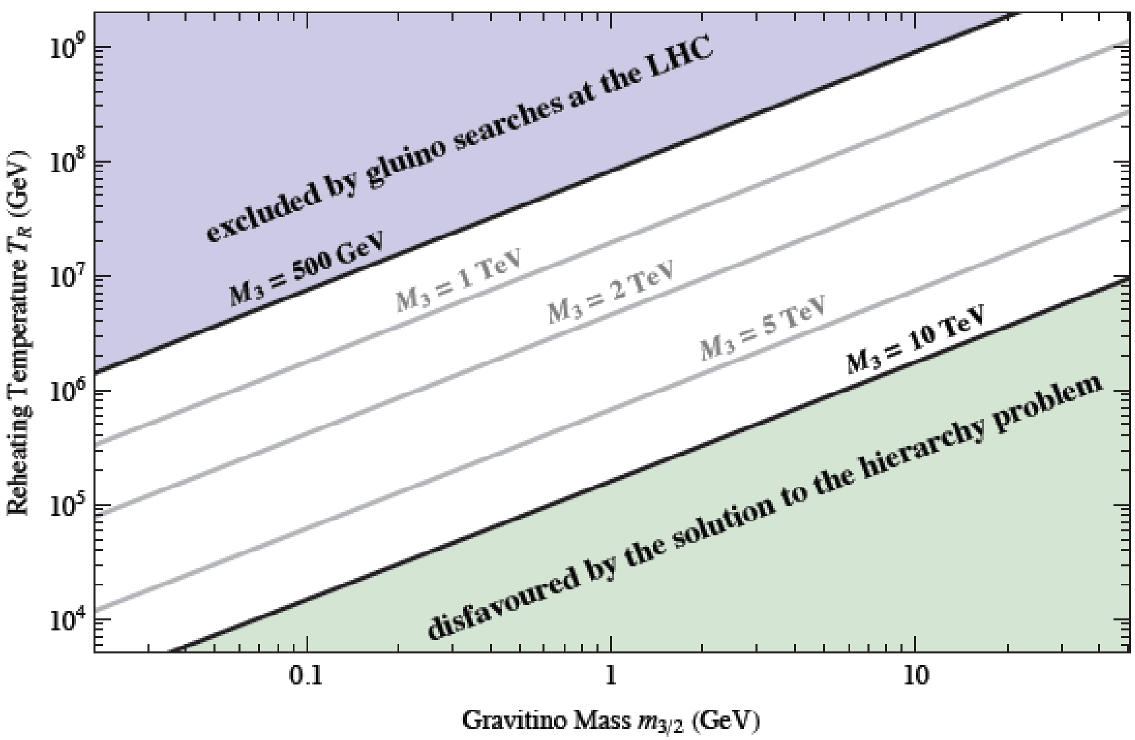
THE END

BACKUP SLIDES

gravitino relic density

If the gravitino is thermally produced, its relic density can match the observed dark matter density ~ 0.1 (diagonal lines) tuning the reheating temperature after inflation

$$\Omega_{3/2}h^2 \simeq 0.27 \left(\frac{T_R}{10^{10}\,\mathrm{GeV}}\right)\left(\frac{100\,\mathrm{GeV}}{m_{3/2}}\right)\left(\frac{m_{\tilde{g}}}{1\,\mathrm{TeV}}\right)^2,$$



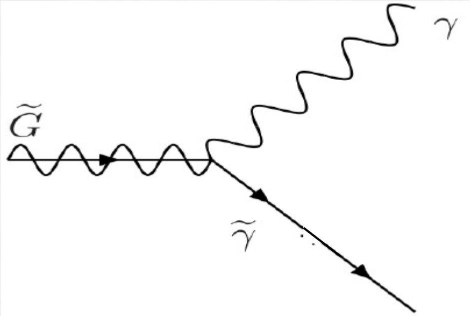
e.g., $m_{3/2} \sim$ 1-1000 GeV

$T_R \sim 10^8 - 10^{11}$ GeV

The addition of the gravitino to the SUSY spectrum leads to the so-called cosmological gravitino problems

In supergravity, the gravitino can decay.
E.g. through the interaction gravitino-photon-photino

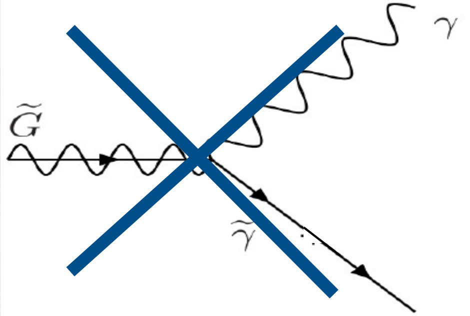
$$L_{int} = -\frac{i}{8M_{pl}}\bar{\psi}_\mu[\gamma^\nu,\gamma^\rho]\gamma^\mu\lambda F_{\nu\rho},$$



Although it is supressed by the Planck mass, the gravitino cannot be a candidate for DM:

$$\tau_{3/2} \sim \frac{M_{\rm Pl}^2}{m_{3/2}^3} \approx 3\,\text{years}\left(\frac{100\,\text{GeV}}{m_{3/2}}\right)^3.$$

Nevertheless, if it is the LSP, then it is stable in RPC models, and therefore a candidate for DM



However, the late NLSP decays may spoil the predictions of BBN

$$\tau_{\rm NLSP} \simeq \frac{48\,\pi\, M_{\rm Pl}^2\, m_{3/2}^2}{m_{\rm NLSP}^5} \approx 9\,\text{days}\left(\frac{m_{3/2}}{10\,\text{GeV}}\right)^2\left(\frac{150\,\text{GeV}}{m_{\rm NLSP}}\right)^5.$$