Neutralino dark matter, galactic centre gamma rays and the MSSM

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Based on 1711.09069, 1711.11477
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Introduction

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- It has to account for the entire dark matter relic density, or else it will cease to be 'minimal'.
- It turns out that MSSM perhaps gives an unfavourable fit to the γ-ray data.

γ-rays from galactic centre and other dwarf galaxies

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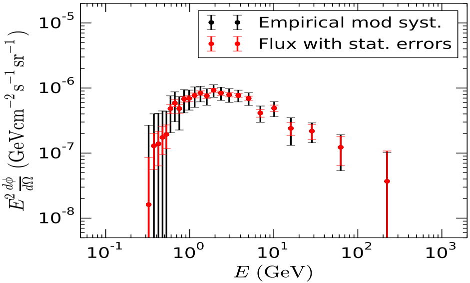

Figure : Galactic Centre γ -ray excess spectrum, averaged over the ROI $2^\circ < |b| < 20^\circ$ and $|l| < 20^\circ$ together with statistical and systematical errors. (F. Calore, I. Cholis and C. Weniger, 1409.0042; M. Ackermann *et al.* [Fermi-LAT Collaboration], 1704.03910).

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- A γ-ray excess was found in the range 2 - 10 GeV from the Reticulum II dwarf galaxy in Pass 7 analysis of Fermi-LAT data.
- Later (in Pass 8 analysis) disavowed such claims and set upper-limit on the flux.
- We found that the MSSM parameter space region in explaining the GC excess do not change appreciably whether using Pass 7 or Pass 8 analysis.

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- $J_{avg} = \frac{\int (\int_{l.o.s} \rho^2(r(s,\theta)) ds) d\Omega}{\int d\Omega}$

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- There are uncertainties in the evaluation of this J factor depending on the choice of the profile parameters.
- 2σ maximum value of the J factor, averaged over the mentioned ROI, is $J_{avg} = 1.09 \times 10^{24} \mathrm{GeV}^2 \mathrm{cm}^{-5}$. (G. Bertone, F. Calore, S. Caron, R. Ruiz, J. S. Kim, R. Trotta, C. Weniger, 1507.07008.) This gives the most optimistic explanation of the γ-ray excess in terms of MSSM.

Constraints on MSSM parameter space

- We have assumed neutralino (χ_1^0) of MSSM as DM candidate. In order to explain the γ-ray excess one has to scan over a reasonable region of MSSM parameter space.

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  Plank data $\longrightarrow \Omega h^2 = 0.12 \pm 0.0022$
  Taking MSSM theoretical uncertainty $\longrightarrow \Omega h^2 = 0.12 \pm 0.012$
  (J. Harz, B. Herrmann, M. Klasen, K. Kovarik and P. Steppeler, 1602.08103.)

Parameter space scanned in χ^2 fit

- In order to do a χ^2 fit of the GC excess data (satisfying other γ-ray data from Reticulum II, M31), we have done a parameter space scan of the four MSSM parameters: M_1, M_2, μ, m_A. Three different values of $\tan\beta$ has been studied.

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$\tan\beta$	M_1, M_2	μ	m_A
5	[-1000, 1500]	[-1000, 2000]	[350, 4000]
20	[-1000, 1500]	[-1000, 2000]	[450, 4000]
50	[-1000, 1500]	[-1000, 2000]	[850, 4000]

Table : The ranges over which the MSSM parameters have been varied in the χ^2-fit. All masses are in GeV.

- All other SUSY-breaking parameters (gluino and sfermion masses, trilinear couplings) have been adjusted properly to maintain all collider constraints including proper lightest higgs mass.

Continued.....

- We have used MCMC code EMCEE for the χ^2 fit.
- Code Suspect 2.41 has been used for MSSM spectrum generation and micOMEGAs 4.3.1 to calculate the γ-ray fluxes, relic density and direct search cross section.

Results

- Scenarios which have emerged as comparatively good fits for the spectra:

Case	$\tan\beta$		χ^2_{min}/DOF	p-value
1 (CF)	20	All sfermion and	1.93	2×10^{-3}
1 (FWDS)		gluino masses $>$ 2 TeV	1.55	3×10^{-2}
2 (CF)	50	Light stop mass $\sim$ 300	2.27	1×10^{-4}
2 (FWDS)		GeV	2.27	1×10^{-4}

Table : CF: Complete fitting. FWDS: Fit without direct search.

Results

- Best scenario is Case 1(CF), main annihilation channel $\chi_1^0\chi_1^0 \rightarrow w^+w^-(\sim 90\%), b\bar{b}(\sim 10\%)$.

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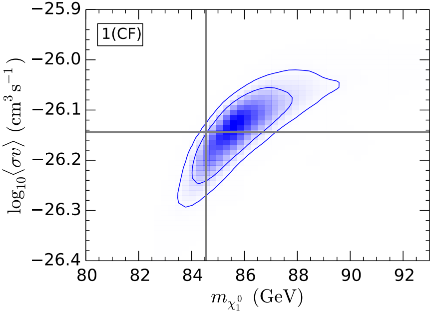

Figure : 1σ and 2σ contours in $m_{\chi_1^0} - \langle\sigma v\rangle$ plane along with their best-fit values (solid gray lines) for Case 1(CF). χ^2_{min}/DOF $= 1.93$, p-value $= 2 \times 10^{-3}$

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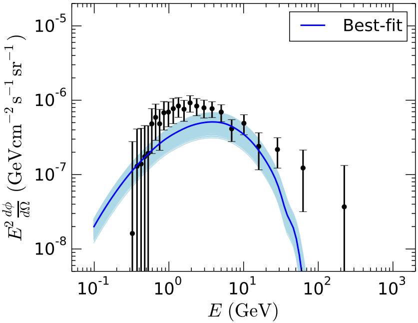

Figure : 2σ bands of GC excess spectrum (light blue region) for Case 1(CF). Deep blue line is the spectrum for best-fit point.

Results

- Another possibility (Case 2(CF)) is to have one light stop mass eigenstate around $\sim$ 300 GeV. Main annihilation channel, $\chi_1^0 \chi_1^0 \to t\bar{t}$.
- Neutralino (χ_1^0) is mostly Bino dominated.

Case	$\tan\beta$		χ^2_{min}/DOF	p-value
1 (CF) 1 (FWDS)	20	All sfermion and gluino masses $>$ 2 TeV	1.93 1.55	2×10^{-3} 3×10^{-2}
2 (CF) 2 (FWDS)	50	Light stop mass $\sim$ 300 GeV	2.27 2.27	1×10^{-4} 1×10^{-4}

Table : CF: Complete fitting. FWDS: Fit without direct search.

Results

- High $m_{\chi_1^0}$ shifts the spectrum towards high energy and the fit becomes worse.

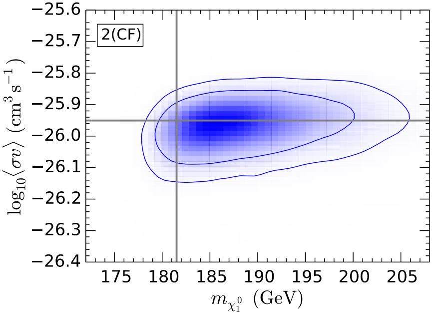

Figure : 95.6% C.L region for Case 2(CF). $\chi^2_{min}/\mathrm{DOF} = 2.27$, p-value $= 1 \times 10^{-4}$

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- This analysis gives better χ^2_{min} for Case 1.

Case	$\tan\beta$		χ^2_{min}/DOF	p-value
1 (CF) 1 (FWDS)	20	All sfermion and gluino masses > 2 TeV	1.93 1.55	2×10^{-3} 3×10^{-2}
2 (CF) 2 (FWDS)	50	Light stop mass ~ 300 GeV	2.27 2.27	1×10^{-4} 1×10^{-4}

Table : CF: Complete fitting. FWDS: Fit without direct search.

Results

- Parameter space corresponds to Case 1(FWDS) gets ruled out by the direct search constraint.
- For Case 2 the direct search constraint is found to be less restrictive.

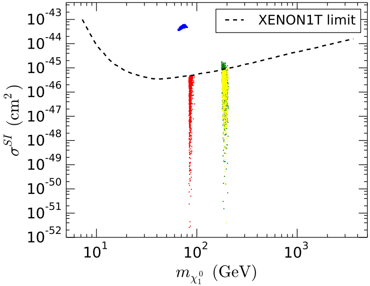

Figure : 95.6% C.L. region in the $m_{\chi_1^0} - \sigma^{SI}$ plane for various scenarios of cases 1 and 2. Red: 1(CF). Blue: 1(FWDS). Yellow: 2(CF). Green: 2(FWDS).

Results

- We have also done a similar analysis, but removing the relic lower limit constraint from Case 1(FWDS).
- Ruled out by direct search and relic density lower limit constraints.

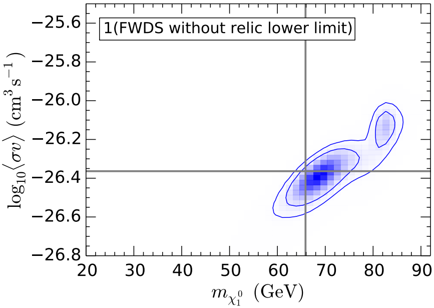

Figure : 95.6% C.L region for Case 1(FWDS) with out relic lower limit. $\chi^2_{min}/\text{DOF} = 1.5$, p-value $= 4 \times 10^{-2}$

Results

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- Stau co-annihilation with neutralino increase $\langle \sigma v \rangle$ in the early universe and reduce the relic density.
- Due to relic lower bound this case dose not give any appreciable fit to the γ-ray data.

Conclusion

- Maintaining all constraints Case 1(CF) seems to be comparatively better fit to the data.
- Though it has a poor χ^2_{min} and p-value. Not a good fit.
- Seeing the quality of fitting it can be said that the MSSM offers a somewhat unsatisfactory fit for GC γ-ray data.

THANK YOU

Backup

Other possible explanations of GC excess

- One possible explanation is that the GC excess arises from an unresolved population of millisecond pulsars.
  (R. Bartels, S. Krishnamurthy and C. Weniger, 1506.05104;
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- However; this explanation is known to face various challenges.
  (I. Cholis, D. Hooper and T. Linden, 1407.5625;
  T. Linden, 1509.02928.)
- While the resolution of this issue will depend on more observations expected in the future, we for the moment assume that the excess indeed arises from the dark matter particles and examine the consequences.

Ret II Pass 7 and Pass 8

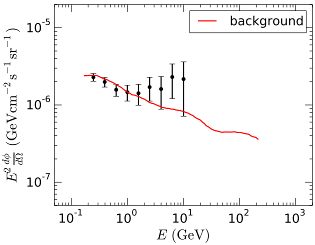


Figure : Result of Pass 7 (left) and Pass 8 (right) analysis of Reticulum II

Case 1(CF)

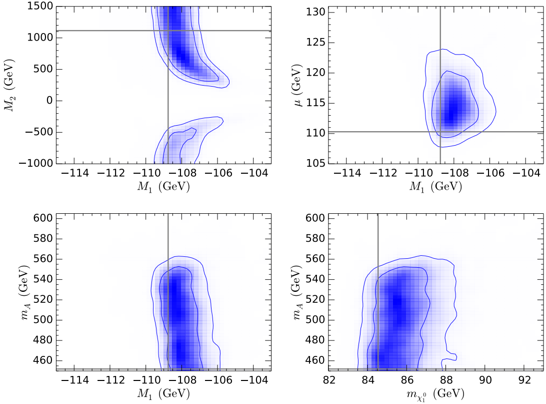


Figure : 1σ and 2σ contours plots in the plane of $M_1 - M_2$ (top left), $M_1 - \mu$ (top right), $M_1 - m_A$ (bottom left), $m_{\chi_1^0} - m_A$ (bottom right) for Case 1(CF). Solid gray lines indicate the best fit values.

stop mass limit

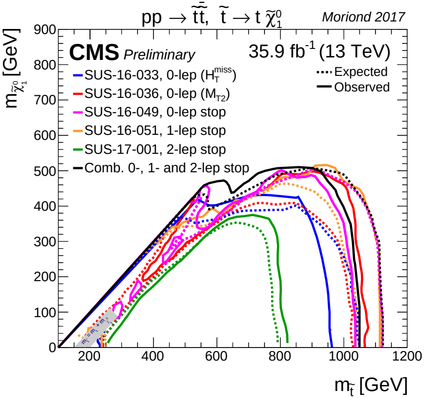
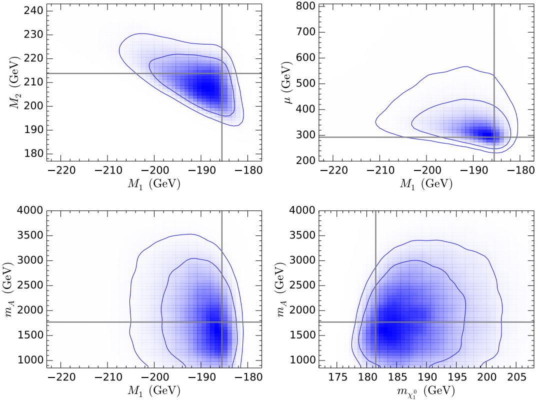


Figure : stop mass limit from LHC run II

Case 2(CF)



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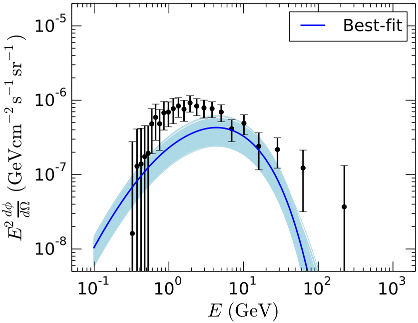
Case 2(CF)



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Stau co-annihilation

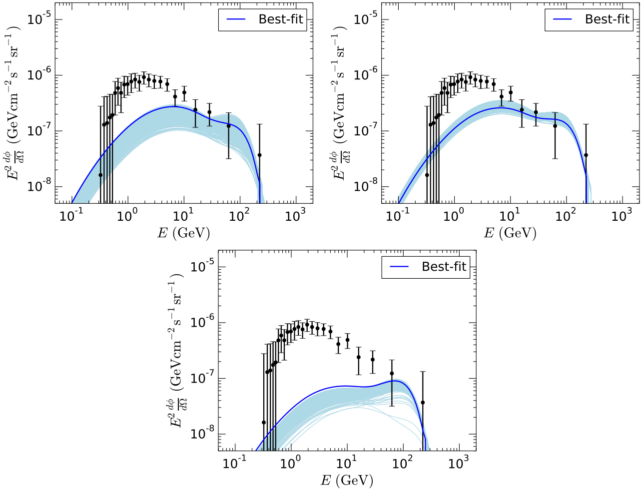

Figure : 2σ bands of GC excess spectrum for the cases where stau mass is within 4% of the χ_1^0 mass. Top left: $\tan\beta = 20$; top right: $\tan\beta = 5$; bottom: $\tan\beta = 50$

Stau co-annihilation

$\tan\beta$	$m_{\chi_1^0}$(GeV)	χ^2_{min}/DOF
20	$\sim 220 - 285$	3.1
5	$\sim 220 - 280$	3.2
50	$\sim 250 - 500$	3.5

Table : Various scenarios of stau co-annihilation case.