Cosmological dark matter annihilation signals: experimental constraints

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On behalf of the Fermi LAT Collaboration
The measurement

- 100 MeV-820 GeV
  - two custom event selections optimized for LOW (<13 GeV) and HIGH (>13 GeV) energies
  - detailed modeling of the Galactic Diffuse emission
  - Extensive detector-level simulations used for initial estimate of residual cosmic-ray background

Keith’s talk

![Graph showing E^2 dN/dE vs Energy [MeV] for different models.](image)
DM searches

- expect contribution from: Blazars, Radio Galaxies, Star Forming Galaxies... and **WIMP annihilations**, if contributing to the gamma ray sky.

- **IGRB** is a powerful tool to constrain DM annihilations. Both in terms of
  - IGRB spectral fluxes
  - **AND** angular anisotropy power spectrum (Jenny, Fiorenza, Nicolao, Sheldon, Kev...)

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**Why is this important?**

The Extragalactic Gamma-ray Background may encrypt the signature of the most powerful processes in astrophysics

- Blazars contribute 20-100% of the EGB (Stecker & Salomon 96, Mücke & Pohl 00, Narumoto & Totani 04, Dermer 07, Inoue & Totani 09)
- Emission from star forming galaxies (e.g. Pavlidou & Fields 02)
- Emission from particles accelerated in Intergalactic shocks (Loeb & Waxmann 00)

**Four components:**

- **73% Dark Energy**
- **23% Dark Matter**
- **4% Atoms**
- Emission due to the annihilation of Cosmological Dark Matter (e.g. Jungman et al. 96, Markevitch et al. 05)

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DM search in the IGRB spectral fluxes

• Challenges:

• What is DM *distribution* in the sky - which components contribute to *isotropic* emission?

• What are DM *clustering* properties at various *(small!)* scales -> determines the amplitude of the DM gamma ray signal (MASC talk)

• What are the ‘guaranteed’ (astrophysical) contributions to the isotropic signal (spectral shape and intensity)

• DM signal WITHIN our Galaxy: could it bias the measurement of the isotropic spectral flux?
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DM distribution over *full sky* is relevant. Three distinct components:

- smooth Milky Way component (main halo)
- Galactic substructure
- all extragalactic halos -> isotropic on large scales

Galactic DM distribution

- **Isotropic vs non isotropic components?**
  - Whole sky residuals of the IGRB measurement are at a \(<\sim 20\%\) level
  - ‘allowed’ level of departure from large scale ‘isotropic’ DM emission in our analysis.

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Fig. just an Illustration [taken from 1202.4039, Fermi LAT collaboration APJ (2012)]
• Isotropic vs non isotropic components?
  – smooth DM halo
  – Galactic substructure

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DM annihilation intensity of the smooth DM halo varies more than a factor of 16 for latitudes >20 deg. -> not included in the isotropic DM signal.

However, it might sufficiently close (in morphology and spectra) to the Galactic diffuse emission - discussed later.
depending on the simulation, Galactic substructure is expected to be isotropic at the level of ~10% to 20(80)%.

We include it in our isotropic signal with two choices for the overall magnitude.

- Isotropic vs non-isotropic components?
  - smooth DM halo
  - Galactic substructure
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Isotropic DM flux

- signal strength/recap:

\[
\frac{d\phi_\gamma}{dE_0} = \frac{\langle \sigma v \rangle c}{8\pi} \rho_0^2 \frac{c}{H_0 m_{DM}^2} \int dz (1 + z)^3 \Delta^2(z) \frac{dN(1 + z)}{dE} e^{-\tau(z,E_0)}
\]

FLUX from extragalactic DM annihilation

Cosmological signal (halos and subhalos): benchmark set by Halo Model, while the uncertainty band estimated in the Power Spectrum approach

Galactic substructure: two assumptions used: benchmark and a ‘MIN’ value.

uncertainty in the signal translates to the uncertainty on constraints of DM cross section

Preliminary

PS-max

PS-min

HM


[MASC&Prada, MNRAS accepted.]
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  • What are DM clustering properties at small scales -> determine the amplitude of the DM gamma ray signal (MASC talk)

  • **What are the ‘guaranteed’ (astrophysical) contributions to the isotropic signal (spectral shape and amplitude)**

  • DM signal WITHIN our Galaxy: could it bias the measurement of the isotropic spectral flux?
• **Level of extra Galactic astro contributions active field, not yet settled.**
• **Minimal** ‘guaranteed’ isotropic astrophysical contribution is at the ~50 % level of the signal (Marco, Mattia, Keith, Brian(s), ...)
• sets our **strategy** to setting the limits: conservative and optimistic.

M. Ajello’s talk
in this work two types of limits: **conservative** and optimistic.

- the ‘true’ limits in-between

DM signal does not overshoot the upper edge of the systematics band. 
CL set by considering the error-bar on the model A (stat+part syst).
No other isotropic contribution to the signal assumed.
Approach to setting the limits

- in this work two types of limits: conservative and optimistic.
- the ‘true’ limits in-between

We fit the data with a PL + EXP cut-off, and set limits at the amount to DM which worsens the overall chi2 by 4 (for 2 sigma limits).
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Note: for benchmark parameters Galactic and cosmological signals comparable. At high energies Gal SS dominates (EBL and red-shifting).
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Limits

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- The strongest Fermi LAT limits in the >~5 TeV range.
- The uncertainty band becomes narrower at higher DM masses, as the DM signal becomes dominated by the Galactic SS.
- Good sensitivity to WIMPs in the 10-100 GeV range - potentially might offer a possibility to check the signal detected elsewhere.
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Corresponding Galactic smooth DM component

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We repeated the original fits used to derive the IGRB, but this time adding DM galactic template (for which minimal Galactic DM content is assumed).
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For the cross sections in the gray region DM Galactic smooth signal would significantly alter the IGRB spectrum: 2σ from its syst band (left) or 2σ departure wrt to the IGRB error-bars (right). For most of the exclusion band our procedure is self consistent.

The DM limits in the intersection region are conservative, as IGRB gets lower in the presence of the Galactic smooth component.
Summary

- Derived limits on cosmological DM annihilation using the new IGRB measurement in the 100 MeV-820 GeV range.

- The strongest LAT limits >5 TeV range and competitive in the 10-100 GeV range.

- Improves upon older LAT work in the following respects:
  - Theoretical uncertainty on the DM cosmological clustering significantly lowered due to the new way of estimation (power spectrum approach) and advances within the halo model.
  - Defined a region in the cross section vs mass range for which the Galactic smooth DM component does not alter the IGRB measurement and the approach applied here is self-consistent.

- Next: account for astrophysical isotropic emission.