Constraints on Decaying Dark Matter from the Isotropic Gamma-ray Background

CARLOS BLANCO

arXiv:1811.05988

C. Blanco, D. Hooper

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Isotropic Gamma-Ray Background

- Blue points + Bars: Fermi observed data & stat. unc.
- Blue band: Systematic Errors related to
  - Modeling galactic diffuse emission
  - Cosmic ray subtraction
  - Fermi effective area
- Colored bands: IGRB contributions from
  - Star forming galaxies
  - Non-Blazar AGN
  - FSRQs
  - BL Lac
  - UHE Cosmic rays

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Isotropic Gamma-Ray Background

• Combining astrophysical contributions is in good overall agreement with the IGRB

• Systematic Errors:
  • Fermi has not quantified bin-to-bin correlation

• Two analyses (26 d.o.f.) :
  • Fully correlated $\Rightarrow \chi^2 \approx 9.4$ (too low!)
  • Fully uncorrelated $\Rightarrow \chi^2 \approx 24.5$
The Galactic Contribution: Prompt

- Assume NFW DM profile:
  \[ \rho_X(r) = \frac{\rho_0}{(r/r_s)[1+(r/r_s)]^2} \]
  \[ r_s = 20 \text{kpc} \]
  \[ \rho_0 \quad \text{s.t.} \quad \rho_X(r = 8.25 \text{kpc}) = 0.4 \text{GeV/cm}^3 \]

- Prompt Gamma-ray flux given by line-of-sight integral:
  \[ \frac{dN_\gamma}{dE_\gamma}(E_\gamma, \Omega) = \left( \frac{dN_\gamma}{dE_\gamma} \right) \frac{1}{4\pi \tau_X m_X} \int_{\text{LOS}} \rho_X(l, \Omega) dl \]

- Region of Interest: \[ |b| > 20^\circ \]
The Galactic Contribution: I.C.S.

- Inverse Compton Scattering (ICS) on ISRF:
  
  $e^\pm \xrightarrow{\text{Synchrotron Cooling}} \text{Inv. Compton} \xrightarrow{\gamma}$

- ICS Gamma-ray flux given by:

  $$\frac{dN_\gamma}{dE_\gamma} \left( E_\gamma, E_e \right) \propto \int \frac{dn}{d\epsilon} \left( \epsilon \right) \frac{d\sigma_{ICS}}{dE_\gamma} \left( \epsilon, E_\gamma, E_e \right) d\epsilon$$

ISRF (Figures): (I. V. Moskalenko, T. A. Porter and A. W. Strong, 2016)

(top): Solid line: $L = 8.5\text{kpc}$

(Bottom): Solid line: $(R, z) = (0\text{kpc}, 0\text{kpc})$
Electromagnetic Energy Loss: ISRF

- ICS Energy loss (Klein-Nishina Steps): Model ISRF as collection of Grey Body Spectra

\[
\frac{dE_e}{dt} = \frac{4\sigma_T}{3m_e^2c^3} \sum_i \rho_{i,\text{rad}} E_e^2 \left( \frac{\gamma_{i,k}^2}{\gamma_{i,k}^2 + \gamma^2} \right)
\]

\[\gamma_{i,k} \equiv \frac{3\sqrt{5}m_ec^2}{8\pi k_b T_i}\]

- Synchrotron cooling rate:

\[
\frac{dE_e}{dt} = \frac{4\sigma_T \rho_B E_e^2}{3m_e^2c^3}
\]

\[\rho_B = 0.2 \times (\rho_{\text{star}} + \rho_{\text{IR}})\]

- Diffusion length:

\[L_{\text{dif}} \sim 0.6 \text{ kpc} \times (\text{TeV}/E_e)^{0.3} \left[ (\rho_B + \rho_{\text{rad}}) / (\text{eV/cm}^3) \right]^{-0.5}\]
The Extragalactic Contribution

Cosmological Redshifting

Inv. Compton

Pair Production

Synchrotron Cooling

γ-Cascade Code:
arXiv: 1804.00005

https://github.com/GammaCascade/GCascade
Electromagnetic Cascades

- Quasi-analytical calculation of cascades: $\gamma$-Cascade Code

- Takes into account:
  - Pair production/ICS cascades
  - Cosmological redshifting
  - Synchrotron cooling
  - Constant average Comoving DM density
  - Empirical EBL model (Domingez '11)

- Example: flat spectrum source at $z = 0.0001$
  - Red: Only pair production (attenuation)
  - Blue: Full cascade calculation

(C. Blanco 2018)
Analysis: Maximum Decay Contribution

- **Dotted**: Direct (prompt) production
- **Dot-Dashed**: ICS production
- **Thin Dashed**: Cosmological Component
- **Thick Dashed**: Sum of all components
Results: Quark & Lepton Final States

- **Thick Dashed**: Independent systematic errors (main results)
- **Thin Dashed**: Systematic errors fully correlated

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Results: Bosonic Final States

- **Thick Dashed**: Independent systematic errors (main results)
- **Thin Dashed**: Systematic errors fully correlated
Results: Complementarity with AMS
Prospects/ Potential Improvements

• Better understanding of covariances.
• Anisotropy modeling.
• Higher energy observation of IGRB: e.g. HAWC.
• Similar analysis can constrain EMDE (arXiv:1906.00010)

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Summary

• FERMI-LAT observed IGRB can be largely accounted for.
• Thus DM contribution is constrained
• Galactic contribution comes from prompt + ICS
• Extragalactic contribution can be calculated readily ($\gamma$-Cascade code)
• Bounds between GeV and EeV: $\tau \approx (1 - 5) \times 10^{-28}$ s
• Higher energy IGRB data could further improve bounds, e.g. HAWC.
• Understanding FERMI’s covariance to better define bounds.
• Similar analysis can constrain EMDE (arXiv:1906.00010)