THE UNIVERSITY OF CHICAGO

Kavli Institute for Cosmological Physics at The University of Chicago

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

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arXiv:1811.05988

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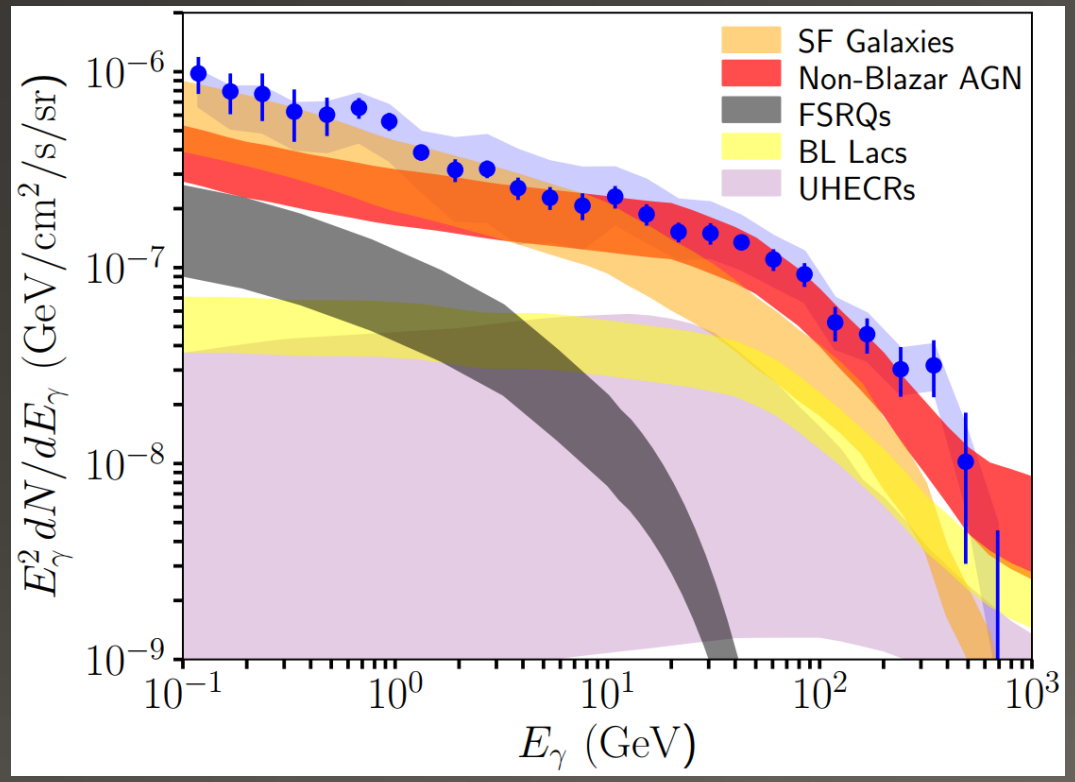
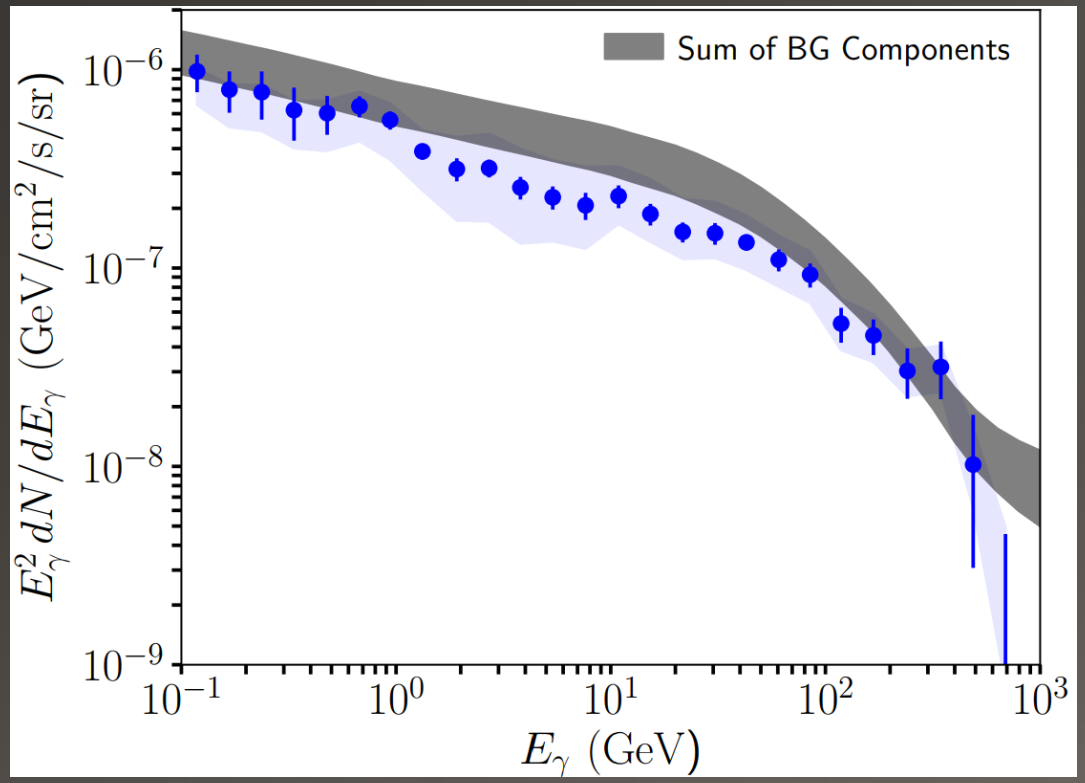
Isotropic Gamma-Ray Background



(IGRB)

- 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

Isotropic Gamma-Ray Background



(IGRB)

- 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 → $\chi^2 \approx 9.4$ (too low!)
  - Fully uncorrelated → $\chi^2 \approx 24.5$

The Galactic Contribution: Prompt

- Assume NFW DM profile:

$$\rho_X(r) = \frac{\rho_0}{(r/r_s)[1+(r/r_s)]^2}$$

$$r_s = 20\mathrm{kpc}$$

ρ_0 s.t. $\rho_X(r = 8.25\mathrm{kpc}) = 0.4\mathrm{GeV/cm}^3$

- Prompt Gamma-ray flux given by line-of-sight integral:

$$\frac{dN_\gamma}{dE_\gamma}(E_\gamma, \Omega) = \underbrace{\left(\frac{dN_\gamma}{dE_\gamma}\right)\frac{1}{4\pi\tau_X m_X}}_{\text{Particle Physics (PYTHIA/micrOMEGAS)}}\underbrace{\int_{los}\rho_X(l,\Omega)dl}_{\text{Astrophysical (Observations)}}$$

- Region of Interest: $|b| > 20°$

The Galactic Contribution: I.C.S.

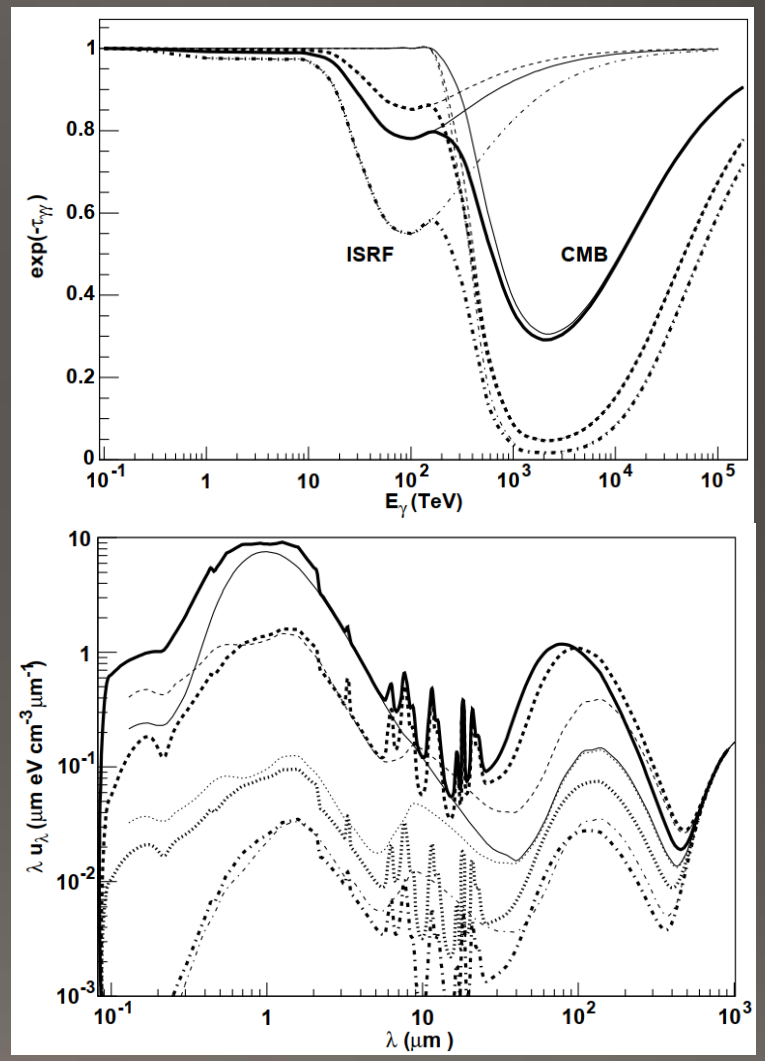
- Inverse Compton Scattering (ICS) on ISRF :

$e^{\pm}$ → Synchrotron Cooling

$e^{\pm}$ → Inv. Compton → γ

- ICS Gamma-ray flux given by :

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



ISRF (Figures): (I. V. Moskalenko, T. A. Porter and A. W. Strong, 2016)
(top): Solid line: $L = 8.5\mathrm{kpc}$
(Bottom): Solid line: $(R, z) = (0\mathrm{kpc}, 0\mathrm{kpc})$

Electromagnetic Energy Loss: ISRF

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

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

$$\gamma_{i,k} \equiv 3\sqrt{5}m_e c^2/8\pi k_b T_i$$

- Synchrotron cooling rate:

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

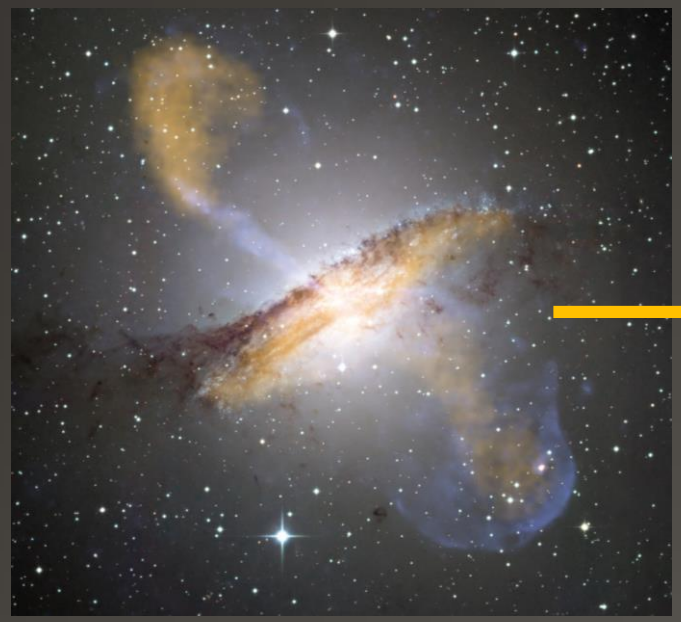
$$\rho_B = 0.2 \times (\rho_{\mathrm{star}} + \rho_{\mathrm{IR}})$$

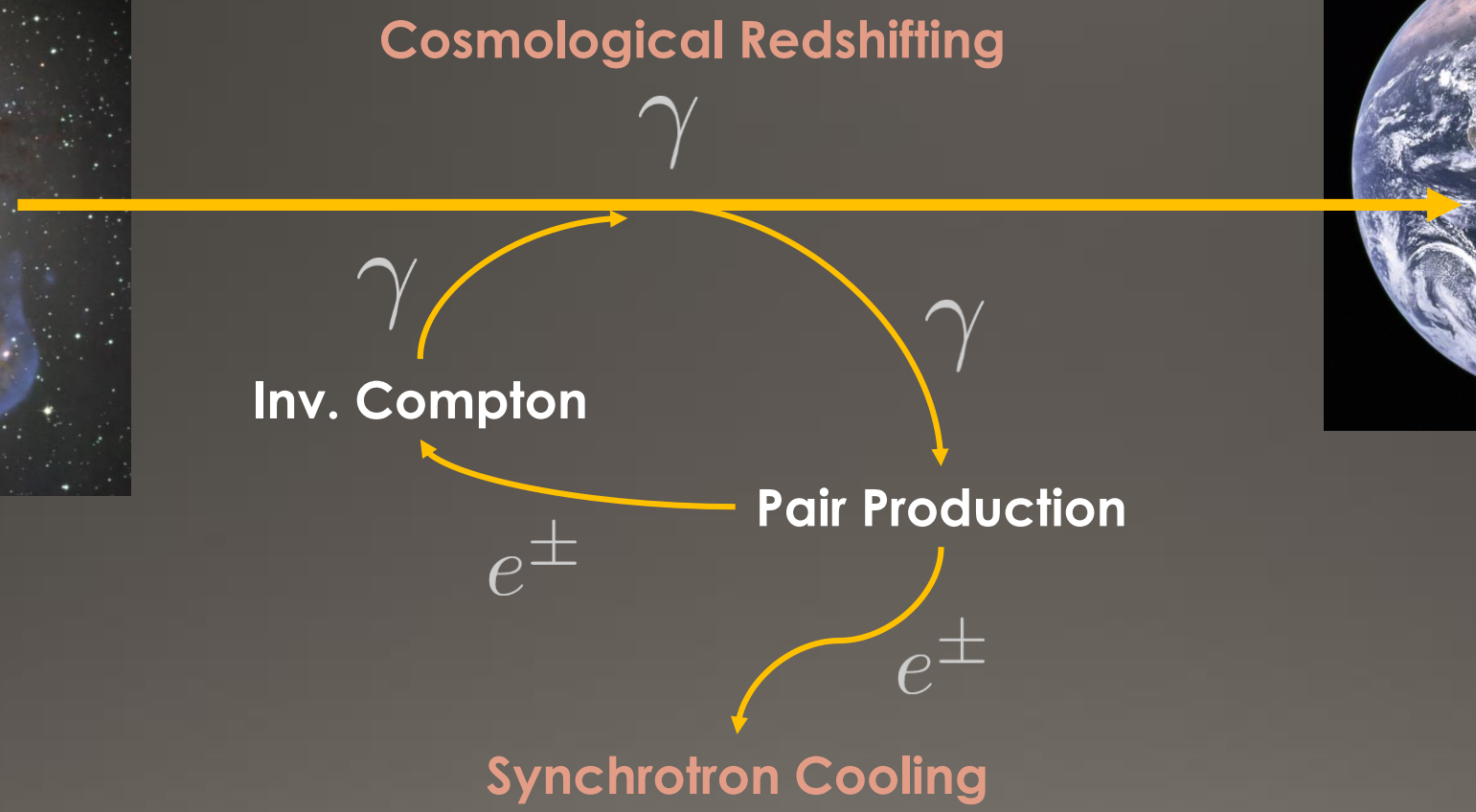
- Diffusion length:

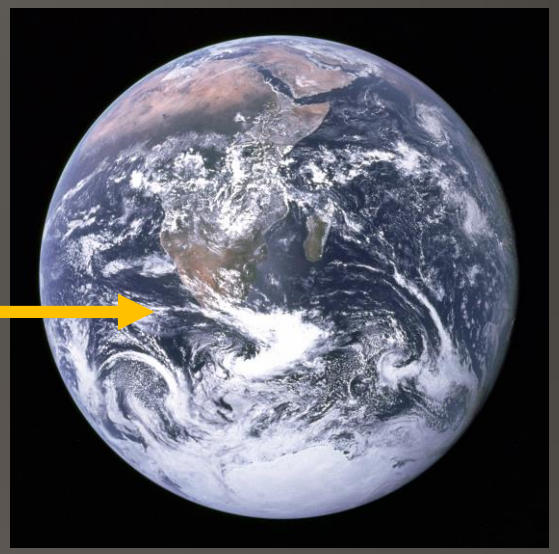
$$L_{\mathrm{dif}} \sim 0.6\,\mathrm{kpc} \times (\mathrm{TeV}/E_e)^{0.3} \left[(\rho_B + \rho_{\mathrm{rad}})\,/\,(\mathrm{eV/cm^3})\right]^{-0.5}$$

arXiv:1811.05988

The Extragalactic Contribution







γ-Cascade Code:
arXiv: 1804.00005

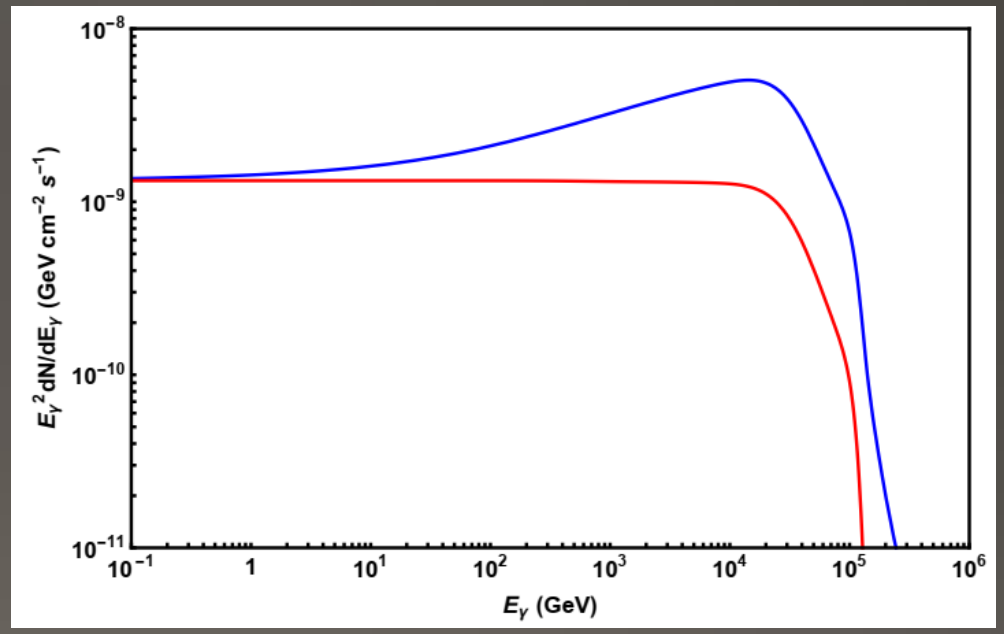
https://github.com/GammaCascade/GCascade

Electromagnetic Cascades

- Quasi-analytical calculation of cascades: γ-Cascade Code

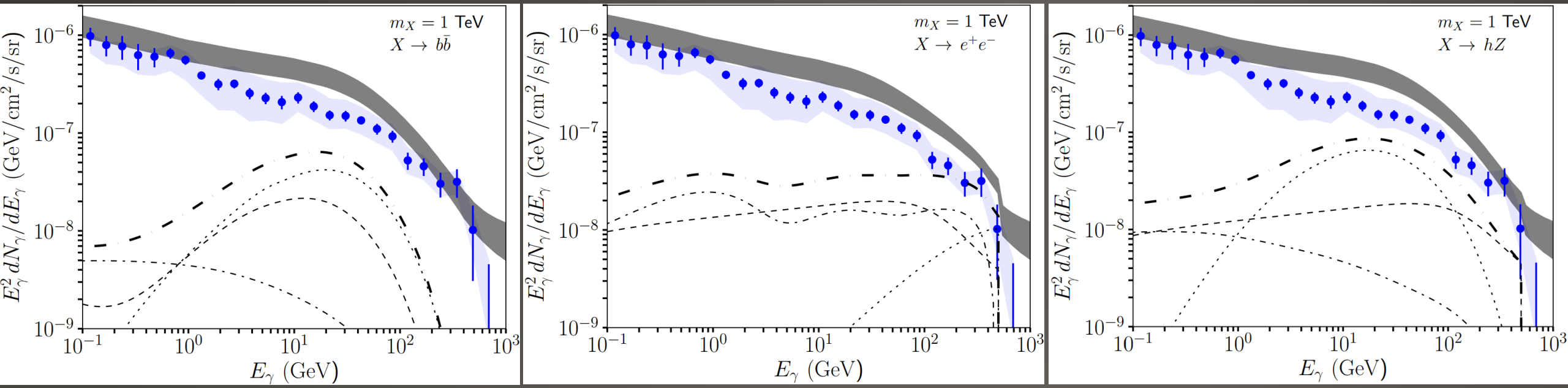
- Takes into account:
  - Pair production/ICS cascades
  - Cosmological redshifting
  - Synchrotron cooling
  - Constant average Comoving DM density
  - Empirical EBL model (Domingez '11)

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



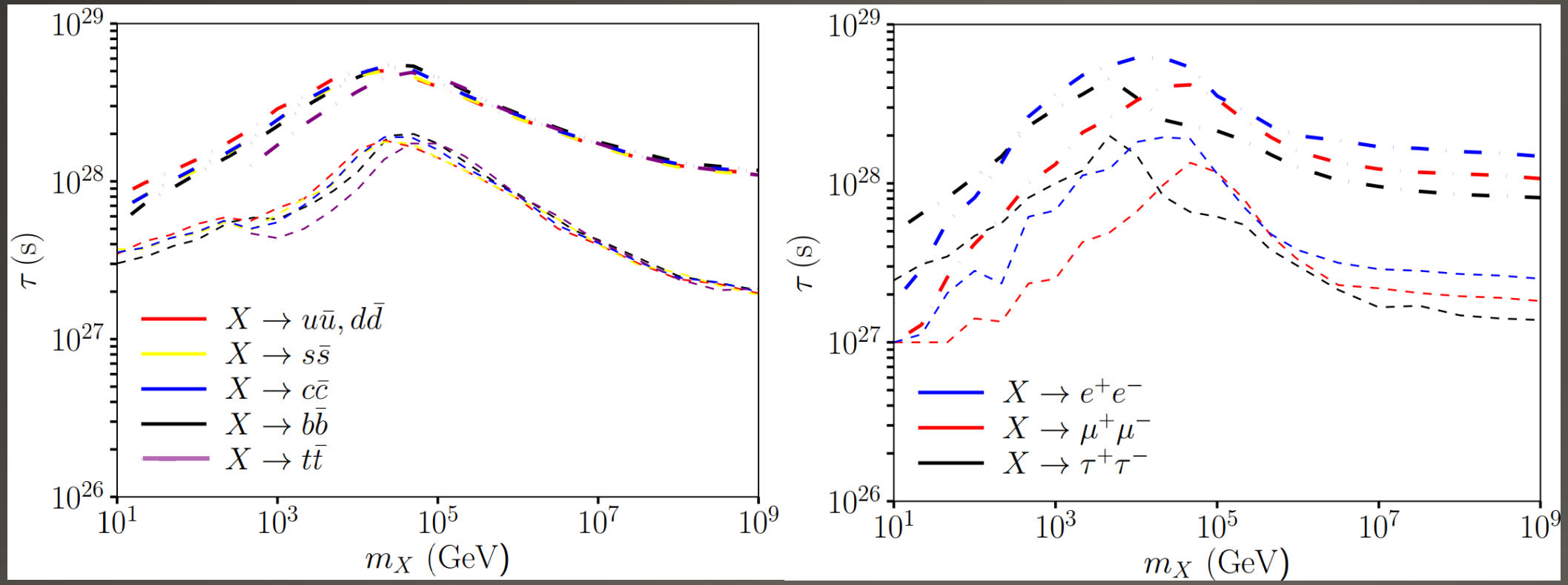
(C. Blanco 2018)

Analysis: Maximum Decay Contribution



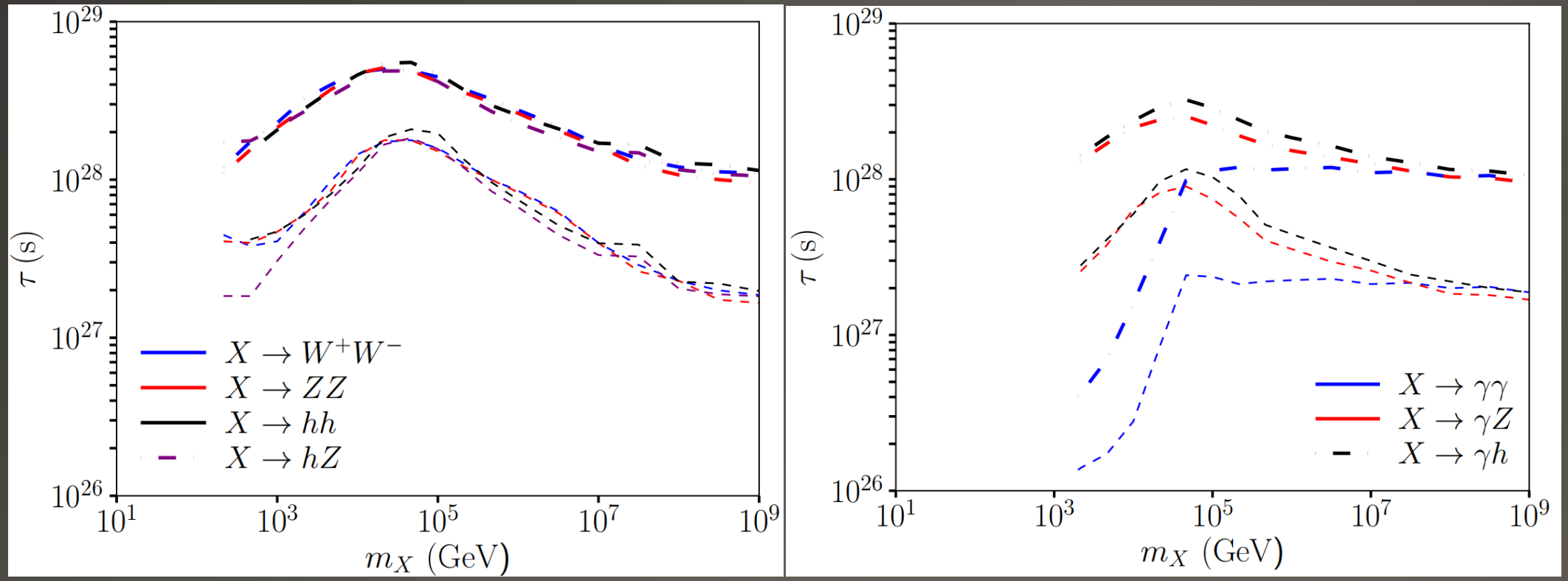
- **Dotted**: Direct (prompt) production
- **Dot-Dashed**: ICS production
- Thin Dashed: Cosmological Component
- **Thick Dashed**: Sum of all components

Results: Quark & Lepton Final States



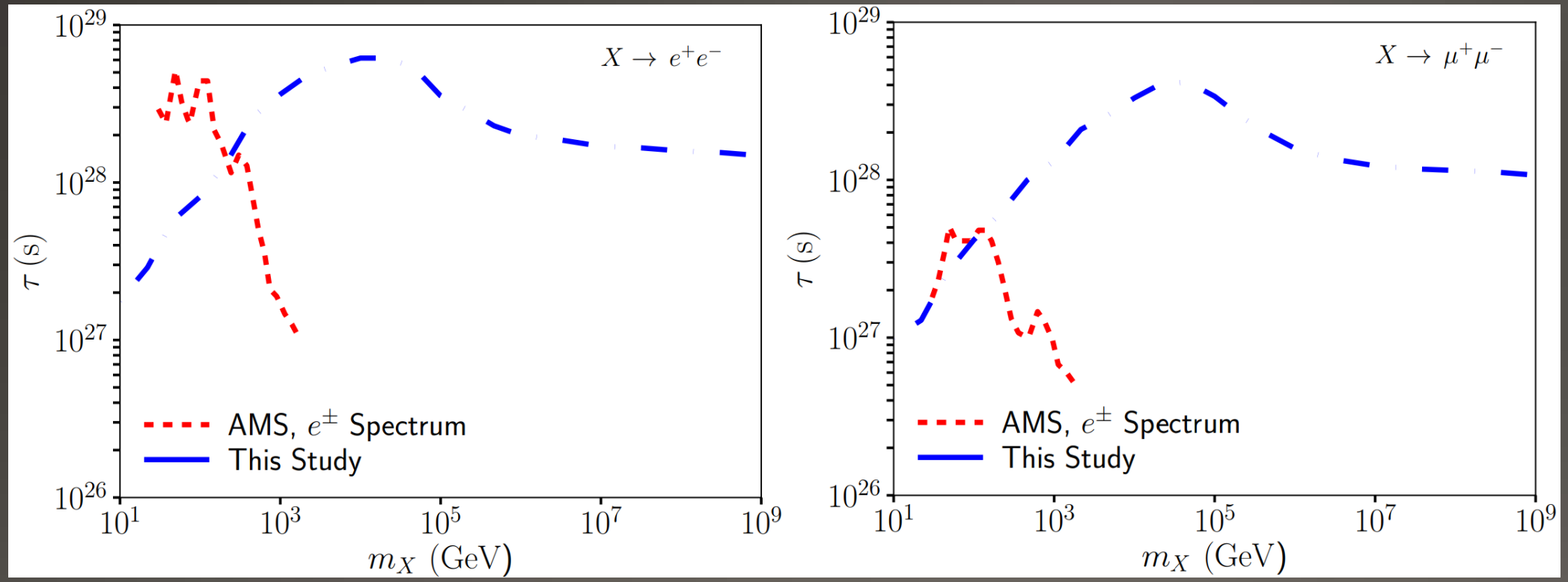
- **Thick Dashed**: Independent systematic errors (main results)
- Thin Dashed: Systematic errors fully correlated

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)

Acknowledgements

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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 (γ-Cascade code)
- Bounds between GeV and EeV: $\tau \approx (1-5) \times 10^{-28}\mathrm{s}$
- 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)