THE FERMI/LAT EXTRAGALACTIC DIFFUSE BACKGROUND and ITS DARK MATTER INTERPRETATION

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ON BEHALF OF THE FERMI LAT COLLABORATION
The Isotropcic Gamma-Ray Background (IGRB)

- Resolved point sources
- Fermi two-year all-sky map
- Isotropic extragalactic diffuse emission
- Extragalactic Gamma-ray Background (EGB)
- IC scattering on the solar radiation field
- Moon

Galactic diffuse emission
(CR interactions with the interstellar medium)
- Inverse Compton
- π⁰-decay
- Bremsstrahlung

Residual charged cosmic rays
Protons, nuclei, electrons + positrons misclassified as gamma-rays by event selection filters

γ-rays from the Earth albedo
γ-rays << 1 GeV with poor directional reconstruction
The Fermi EGB

Simultaneous Maximum Likelihood fit to all \(|b|>10^\circ\) sky:
- Equal area pixels (0.8 deg\(^2\))
- All sources detected in 9 months
- 9 energy bins, 200 MeV \(<E< 100\) GeV
- 10 months of data, 19 Ms exposure

Power-law spectrum with index \(2.41 \pm 0.05\)

\[ \text{Flux (}>100\ \text{MeV, extrapolated}) = 1.03 \pm 0.17 \times 10^{-5}\ \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \]

Spectrum softer than EGRET measurement.

No spectral features in the GeV energy range.
Origin of the EGB in the LAT energy range

Unresolved sources

**Blazars**
Dominant class of LAT extragalactic sources.
Many estimates in literature.
EGB contribution ranging from 20% - 100%

**Non-blazar active galaxies**
27 sources resolved in 2FGL
~ 25% contribution to EGB expected (Inoue 2011)

**Star-forming galaxies**
4 galaxies besides local group (LMC, SMC, M31) resolved by LAT
Significant contribution to EGB expected. (e.g. Pavlidou & Fields, 2002)

**GRBs**
**High-latitude pulsars**
Small contributions expected
(e.g. Dermer 2007, Siegal-Gaskins et al. 2010)

Diffuse processes

**Intergalactic shocks**
Widely varying predictions of EGB contribution ranging from 1% to 100% (e.g. Loeb & Waxman 2000, Gabici & Blasi 2003)

**Dark matter annihilation**
Potential signal dependent on nature of DM, cross-section and structure of DM distribution
(e.g. Ullio et al. 2002)

**Interactions of UHE cosmic rays with the EBL**
Dependent on evolution of CR sources, predictions varying from 1% to 100% (e.g. Kalashev et al. 2009)

**Extremely large galactic electron halo** (Keshet et al. 2004)

**CR interaction in small solar system bodys** (Moskalenko & Porter 2009)

Courtesy of M. Ackermann
Main (and guaranteed) contributions to the Fermi EGB

Contribution from FSRQs + BL Lac + Radio galaxies + star-forming galaxies around 50—80%

What makes the rest?

[Courtesy of M. Ajello]
THE DARK MATTER CONTRIBUTION TO THE EGB
Cosmological DM annihilation

DM annihilation signal from all DM halos at all redshifts should contribute to the EGB.

In $\Lambda$CDM, smallest structures collapse first and then merge to form the largest ones.

Substructure expected at all scales down to a $M_{\text{min}}$ → Enhancement of the DM annihilation signal expected: substructure boost factor.

✓ Mass resolution in simulations above $10^8$ Msun (big volumes) or $10^5$ Msun (MW-sized halos) → Small structures below the resolution limit expected to be very important!

Zoom sequence from 100 to 0.5 Mpc/h Millenium-II simulation (Boylan-Kolchin et al. 2009)


Different gamma-ray spectraDM models
How can we know about the smallest halos?

Current N-body simulations are far from resolving the whole subhalo hierarchy.

Two possible approaches:

• Infer DM halo and substructure properties directly from simulations.
  • Power-law extrapolations below the resolution limit.

• Semi-analytical treatment using physically motivated scenarios for the growth of structure in the Universe.
  • later tuned to match simulations above resolution limit.

Example: c-M relation

Power-law extrapolations, e.g.:
- Springel+08
- Zavala+10
- Pinzke+11
- Gao+11
- Han+12

Non power-law extrapolations, e.g.:
- Bullock+01
- Kamionkowski+10 (3K10)
- MASC+11
Both approaches were used in Abdo+10 to bracket the uncertainties:

- Millenium II simulations, with power-law extrapolations to lower masses.
- Bullock+01 semi-analytical model for halo concentrations, which gives softer extrapolation.

\[
\frac{d\phi_\gamma}{dE_0} = \frac{\langle \sigma v \rangle}{8\pi} \frac{c}{H_0} \frac{\bar{\rho}_0^2}{m_{DM}^2} \int dz (1 + z)^3 \frac{\Delta^2(z)}{h(z)} \frac{dN_\gamma(E_0(1 + z))}{dE} e^{-\tau(z,E_0)}
\]

1) N-body simulations:
\(\Delta^2(z)\) calculated from MSII (Zavala+10)

2) Halo models:
\[\Delta^2(z) = \int dM \frac{dn}{dM} \int dc P(c) \frac{\langle \rho^2(M, c) \rangle}{\langle \rho(M, c) \rangle^2}\]

- Halo mass function (S&T)
- Density profiles and concentration

**FLUX from DM-induced extragalactic photons**

**Constant for a particular DM model**

"Flux multiplier"

**Redshifted DM spectrum**

**EBL**

Most optimistic power-law extrapolation

Semi-analytical

Conservative power-law extrapolation

Only resolved halos in MSII
DM constraints

DM annihilation limits can be obtained by imposing that the EGB spectrum is not violated:

- Assuming the whole EGB intensity is due to DM annihilations → conservative limits
- Assuming some astrophysical background (star forming galaxies and blazars) → stringent limits

For the BullSub scenario, DM limits are:
- comparable to the ones obtained for dwarf galaxies (w/o stacking)
- somewhat stronger than those for galaxy clusters.
The “extended” Fermi/LAT IGRB spectrum (200 MeV – 580 GeV)

Smooth spectrum for energies >100 GeV
Consistent with a spectral softening at high energies
Effort to extend it up to 1.5-2 TeV

24 months data
Better event selection
Energy range extended
Updated Galactic diffuse model
2FGL catalog sources included
Better estimate of the CR background based on MC simulations
Summary

- Fermi has measured the EGB spectrum from 200 MeV up to 580 GeV.
- The EGB spectrum is compatible with a featureless spectrum at least up to 100 GeV.
- Main astrophysical contributors seem to be not enough to account for the total EGB flux.

- Cosmological DM annihilation might contribute to the EGB.
- Competitive limits on the DM annihilation cross section can be obtained from the EGB.
- However, large uncertainties $O(3)$ mainly due to lack of knowledge of properties of the smallest halos.

Better modeling of astrophysical backgrounds crucial for DM searches in the EGB.

Improvements in both DM halo models and N-body simulations also crucial.

Amplitude and energy dependence of anisotropies a complementary tool (Ackermann+12).