The Contribution of Astrophysical Sources to the Extragalactic \textit{\textgamma}-ray Background

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The Gamma-ray Sky ala Fermi LAT

Inverse Compton

π⁰-decay

Bremsstrahlung

Galactic diffuse emission
(CR interactions with the interstellar medium)

Isotropic diffuse emission
(presumably extragalactic)

Resolved Point Sources

Ackermann 2009
The EGRB (after subtraction)

Isotropic diffuse emission
(presumably extragalactic)

Ackermann 2009
The Spectrum of the EGRB
Contributions to the EGRB

Guaranteed gamma-ray emission from:
- Star-forming galaxies
- Active galactic nuclei (blazars, maybe some from other types of radio galaxies)
- Unidentified gamma-ray sources

Possible gamma-ray emission from:
- Diffuse emission (e.g. VHE photon propagation? cosmic ray propagation?)
- Exotic physics (e.g. dark matter annihilation?)
Contributions to the EGRB

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Gamma-ray Spectra of Sub-populations of Blazars

Abdo et al. 2009
log $N$ - log $S$ for Fermi and EGRET Blazars
Fig. 7.— Detection efficiency as a function of measured source flux for $|b| \geq 20^\circ$, $TS \geq 50$ and for a sample of sources with a mean photon index of 2.40 and dispersion of 0.28. The error bars represent statistical uncertainties from the counting statistic of our Monte Carlo simulations.
Source Confusion

Georges Seurat
Angular Resolution for Fermi and EGRET
The Effect of Source Confusion at 100 MeV

NASA’s Fermi telescope reveals best-ever view of the gamma-ray sky
The Effect of Source Confusion at 100 MeV

EGRET (10 years)
log $N$ - log $S$ Data vs. Models

- Fermi Blazars (incl. modeled Monte Carlo LAT efficiency)
- Fermi FSRQs (incl. modeled Monte Carlo LAT efficiency)
- Stecker & Venters (2010)
Radio/γ-ray Correlation

The shape of the blazar contribution depends on the spread in the distribution of spectral indices: little spread ⇒ little curvature; large spread ⇒ large curvature

Ghirlanda et al. 2010
Gamma-ray Spectra of Sub-populations of Blazars

Abdo et al. 2009
The shape of the blazar contribution depends on the spread in the distribution of spectral indices: little spread $\Rightarrow$ little curvature; large spread $\Rightarrow$ large curvature.
The Likelihood Approach

\[ P(x_i \mid y_j) \propto P(x_i) \times \mathcal{L}(y_j \mid x_i) \]

\[ \mathcal{L} = \prod_{j=1}^{N} l_j \]

\[ l_j = \int d\alpha \frac{\exp\left[-\frac{(\alpha - \alpha_j)^2}{2\sigma_j^2}\right]}{\sqrt{2\pi} \sigma_j} \frac{\exp\left[-\frac{(\alpha - \alpha_0)^2}{2\sigma_0^2}\right]}{\sqrt{2\pi} \sigma_0} \]

\[ \mathcal{L} = \left( \prod_{j=1}^{N} \frac{1}{\sqrt{\sigma_0^2 + \sigma_j^2}} \right) \exp \left[ -\frac{1}{2} \sum_{j=1}^{N} \frac{(\alpha_j - \alpha_0)^2}{\sigma_0^2 + \sigma_j^2} \right] \]
Background from Unresolved Blazars and Data
A Galaxy’s γ-ray flux is mainly from π⁰ production in CR-gas interactions followed by π⁰ decay.

∴ γ-ray flux ∝ (CR flux) x (gas density).

CR flux ∝ supernova rate ∝ star formation rate (SFR).
Three Strategies for Estimating $\gamma$-Ray Luminosity in Star Forming Galaxies:

- Relate the galaxy $\gamma$-ray luminosity to its SFR, which, in turn, is related to an observable for which there is a redshift distribution (e.g., IR luminosity).
- Relate the galaxy gas mass to its stellar mass assuming a gas fraction that evolves with redshift.
- Relate the cosmic density of gas in star forming galaxies to the star formation rate density.
γ-ray Luminosity vs. Star Formation Rate for Star-forming Galaxies

$L_\gamma \propto \Psi^{1.2}$
Background From Unresolved Galaxies and Data
The EGRET and Fermi γ-ray data do not, as yet, rule out a scenario in which the background is dominated by γ-rays from unresolved blazars.

γ-rays from unresolved star forming galaxies may or may not contribute significantly to the background (see also, Fields & Pavlidou 2010; Makiya et al. 2010). Starburst galaxies make a negligible contribution to the background (see also, Stecker 2007, Makiya et al. 2010).

Fermi will be taking data for a few more years, so there’ll be plenty of time to keep arguing about this issue.
Extra Slides
SFR Density vs. z (Ly 2010)
Spectral Features of a Background from Dark Matter Annihilation
Maximum Background from EM Cascades of UHE Electrons from
Efficiency of a γ-ray telescope for detecting extragalactic sources determined by:

- The flux of the source
- The spectral index of the source
- The intrinsic detector background from cosmic-ray induced events
- The foreground from the Milky Way
- The extragalactic background