Constraints and Signals from the Diffuse Gamma Ray and X-ray Backgrounds

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The Diffuse Gamma Ray Background
Lessons from the Cosmic X-ray Background
Chandra Deep Field: the resolved X-ray Background

CDF-South

Source Removal

Hickox & Markevitch 2006, 2007
The (Unresolved) Cosmic X-ray Background

Abazajian et al. 2007
Hickox & Markevitch 2007

Channel Energy [keV]
The Observed Fermi-LAT Gamma-Ray Sky

~15% of extragalactic flux had been found to be from resolved blazars.
Blazars in the Unified Model of AGN
Simplest Model: Integrate Extrapolations of Source Counts Below the Point Source Sensitivity
Difficulties in Source-Count Extrapolation

• Require a fixed spectrum of all blazars are of their average: often, a power law of two types (BL Lac & FSRQ) with a Gaussian dispersion

• Extrapolated source count distribution is characterized the entire source population of blazars as a broken power-law, which is not necessary nor consistent with population models

\[ \frac{dN}{dS d\Gamma} = f(\mathbf{x}) \cdot g(\mathbf{x}) \]

source count as broken power-law \( \times \) \( \uparrow \) \( \uparrow \) spectrum as power-law w/ Gaussian distribution

• Therefore, the DGRB flux calculated from such methods is problematic

\[ F_{\text{diffuse}} = \int_{S_{\text{min}}}^{S_{\text{max}}} dS \int_{\Gamma_{\text{min}}}^{\Gamma_{\text{max}}} d\Gamma \frac{dN}{dS d\Gamma} S \left( 1 - \frac{\Omega(\Gamma, S)}{\Omega_{\text{max}}} \right) \]
Blazar SED is Dependent on Luminosity I: c. 2000

G. Fossati et al 1998
D. Donato et al 2001
Shape of Blazar SEDs: Abdo et al arXiv:0912.2040
Inconsistent with a single-power law model (even with dispersion)
Blazar SED Dependence on Luminosity: Fermi-LAT Data

\[ \frac{dN}{dSd\Gamma} \neq f(S) g(\Gamma) \]
Tying the emission with the known X-ray population of AGN: the evolution of the blazar $\gamma$-ray luminosity function

$$\frac{dN}{dE_\gamma dAdtd\Omega} = \frac{c}{4\pi} \int_0^{z_{\text{max}}} dz \frac{dt_{\text{com}}}{dz} e^{-\tau(z,E_\gamma)}$$

$$\times \int_{L_{\gamma,\text{min}}}^{L_{\gamma,\text{lim}}(F_\gamma,z)} dL_\gamma \rho_\gamma(L_\gamma, z) \frac{1 + z}{h}$$

$$\times \frac{L_\nu[E_\gamma(1 + z)/h, P(L_\gamma)]}{E_\gamma(1 + z)}.$$

Inoue & Totani (2008) predicted the observed Fermi-LAT DGRB
Results: Resolution of the DGRB?

- The Blazar SED sequence LDDE model successfully matches the DGRB as originating from blazars and $dN/dF$

- > 95% of all blazars will be resolved at the 5-year Fermi-LAT forecast point-source sensitivity of $2 \times 10^{-9}$ photons cm$^{-2}$ s$^{-2}$

- Flux in the DGRB will decrease by a factor of 2-3 (95% CL) with the 5 year sensitivity

SED Sequence + GLF(z) Model

- Blazar population gamma-ray luminosity function (GLF) is dictated as a fraction of X-ray AGN population (XLF)

- DGRB Includes a contribution from non-blazar AGN at low energies (< 200 MeV)

- Three parameter model:
  - $\gamma_1$, the faint-end index of the GLF
  - $\kappa$, the normalization ratio of blazar GLF to AGN XLF (fraction of AGN as blazars)
  - $q$, scale of the blazar jet emission to disk X-ray luminosity

- We constrain this model with the observed Fermi-LAT DGRB spectrum and blazar flux source count distribution $dN/dF$
And Match to the Source Count Distribution

SED sequence model

Abazajian, Blanchet & Harding 2011
Fits & Forecasts for Fermi-LAT’s DGRB

Abazajian, Blanchet & Harding, 1012.1247
Luminosity Distribution of Blazars

Predicted

Fermi-LAT 2010

$\frac{dN}{d\log(L_{\text{rad}})}$

$\log(L_{\text{rad}}/(\text{erg s}^{-1}))$
Redshift Distribution of Blazars

- BL Lacs
- Full Blazar Population Prediction
- FSRQs
Flux Sensitivity Distribution
Dark Matter Search Implications

\[ \langle \sigma v \rangle = 3 \times 10^{-26} \text{cm}^3\text{s}^{-1} \]

\[ \chi\chi \rightarrow b\bar{b} \]

\( m_\chi = 10 \text{ GeV} \)

\( m_\chi = 100 \text{ GeV} \)

Abazajian, Blanchet & Harding 2010
Annihilation Channel Forecasts

\[ (\langle \sigma_A \rangle \text{ [cm}^3\text{s}^{-1}\rangle \]

(d) \( \chi\chi \rightarrow \tau^+\tau^- \)

Fermi-LAT
DGRB Current

MSSM/manySUGRA
MSSM/hsUGRA

\[ m_\chi \text{ [GeV]} \]

Abazajian, Blanchet & Harding 2010
Anisotropy in the “Isotropic” Diffuse $\gamma$-ray background

Fermi-LAT Collab. (Ackermann et al), 2012
Nonzero but small anisotropy

Fermi-LAT Collab. (Ackermann et al), 2012

Blazar SED + GLF(z) model prediction:

\[
C_P = \int_0^{z_{\text{max}}} dz \frac{d\chi}{dz} \int_{L_{\gamma,\text{min}}} L_{\gamma}^{\text{lim}}(F_\gamma, z) dL_\gamma \frac{\rho_\gamma}{d_L^2} \left[ \int (E_0^{\text{max}}(1+z)/h)^{-1} (E_0^{\text{min}}(1+z)/h)^{-1} d\nu \frac{L_\nu(\nu, P)}{\nu} \exp \left[ -\tau(z, h\nu/(1+z)) \right] \right]^2
\]
Diffuse $\gamma$-ray background from Blazars Limited by Anisotropy

- **Maximal Blazar Contribution**
  - Given Anisotropy Level

Harding & Abazajian, 2012

Similar results using source count extrapolation: Cuoco, Siegal-Gaskins, Komatsu 2012
Further Applications of the GLF(z) + SED Sequence Model

Murase et al 2014
The GLF(z) + SED sequence is Far from Complete...

Meyer, Fossati et al 2011

Figure 9. Same as Figure 6, but for the eight brightest HSP-BLLacs in the LBAS sample.
Summary

- Extrapolating source count distribution functions beyond point source thresholds is problematic...

- Cosmological evolution models with SED dependence on luminosity are physically well motivated.

- The intensity of the DGRB is consistent with being produced by blazars with an evolving SED sequence + GLF (z) model

- The anisotropy of the DGRB is inconsistent with being produced by blazars with an evolving SED sequence + GLF (z) model

- Resolution of the DGRB into blazars with further exposure in Fermi-LAT test evolution models for the blazar population, their GLF(z)

- The blazar SED sequence plus GLF(z) is a very rich model compared to source count extrapolation models yet remains quite simplistic: the dependence of spectrum on luminosity is not singularly parametric (e.g., Meyer & Fossati 2011)
DGRB from Star Forming Galaxies?

- Potentially matches a portion of the DGRB at low energies as seen by Fermi-LAT for models at the edge of the star forming galaxy predictions (Fields et al. 2010)
- Mikaya et al. (2010) find a contribution of likely 4% to 7% of the DGRB from star forming galaxies
- Stecker & Venter (2010) showed that the spectrum generally underpredicts the DGRB, and does not match the shape measured by EGRET at low energy

Stecker & Venter 2010
A Different Model for the Blazars as the DGRB?

- Stecker & Venter (2010) used a different model, correlating the gamma-ray luminosity to the radio luminosity for the FSRQs and ignoring the BL-Lac contribution.

- SV 10 also used a power-law spectral distribution that omitted spectral curvature in the spectrum and the hardness-luminosity relation seen in the Blazar SED sequence.