

Observed redshift distribution of blazars

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Redshift distribution of EGRET blazars (histograms), separated into 46 FSRQs and 14 BL Lac Objects (BLs).

Uniform exposure: EGRET all-sky survey

Fichtel et al. (1994): 1EG

GLAST: essentially uniform exposure



Analytic Blazar Formation Rate



- 1. Constant Comoving Density
- 2. "Madau" curve
- 3. SFR with extinction corrections
- 4. Evolution of IR from IR galaxies

Simple analytic forms

(Peak) flux distribution of EGRET Blazars

Histogram showing the measured peak power flux size distribution of EGRET blazars, separated into FSRQs and BLs



Measured γ -ray blazar peak luminosity distribution

Distribution of observed peak luminosities of FSRQs and BLs as measured in the EGRET energy range.



Statistics of cosmological relativistic jet sources

ACDM cosmology, bursting sources

$$\frac{d\dot{N}}{d\Omega} = \frac{c}{H_0} \frac{d_L^2 \dot{n}_{co}(L_*,\alpha;z) dL_* d\alpha dz}{(1+z)^3 \sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}} \hat{f}_{\bar{\varepsilon}} : \nu F_{\nu} \text{ flux threshold}$$

$$\hat{f}_{\bar{\varepsilon}} \approx 2 \times 10^{-11} \ ergs \ cm^{-2} \ s^{-1}: \ EGRET \qquad \hat{f}_{\bar{\varepsilon}} \approx (1-5) \times 10^{-13} \ ergs \ cm^{-2} \ s^{-1}: \ GLAST$$
$$\bar{\varepsilon} \approx 200 \qquad \qquad \bar{\varepsilon} \approx 200 - 2000$$

Redshift distribution above f_{ϵ}

$$\frac{d\dot{N}}{dzd\Omega}(>f_{\epsilon}) = \frac{c}{H_0} \frac{d_L^2(z) \ \dot{n}_{co}(z)}{(1+z)^3 \ \sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}} \left[1 - \max(0, \hat{\mu}(z))\right]$$

Integrate over z to get f_{ε} flare size $\hat{\mu}(z) = \frac{1}{\beta} \left\{ 1 - \frac{1}{\Gamma} \left[\frac{\ell'_e \epsilon_z^{(3-p)/2}}{d_L^2(z) f_{\varepsilon}} \right]^{1/q} \right\}$ distribution: p for spectrum, q for beaming factor

Redshift distribution of model γ-ray blazars: BFH

Histogram showing the model redshift distributions of EGRET blazars, assuming constant comoving density of blazars and an $\Omega_m = 0.3$, $\Omega_{\Lambda} = 0.7$ cosmology with a Hubble constant $H_0 = 72$ for different blazar formation histories (BFHs)



Fig. 4.— Variation in the blazar redshift distribution above an EGRET-type sensitivity threshold $= 2 \times 10^{-11}$ ergs cm⁻² s⁻¹ at $\epsilon \approx 200$ for different blazar formation histories (BLHs). The linear scale on the left shows better BFH3 and 4 (left), and on the right shows better BFH 1 and 2, for standard model blazar with parameters indicated.

Redshift distribution of model γ -ray blazars: ℓ'_{λ}

Changing comoving directional luminosity. Standard value is: ℓ'_e : $10^{40} \ ergs \ s^{-1} \ sr^{-1}$ Note that BFH3 gives a peak redshift $\langle z \rangle \sim 2$ rather than $\langle z \rangle \sim 1$ (observed) unless ℓ'_e or Γ are small



Fig. 5.— Model redshift distributions for standard model blazars with only the comoving power changed, assuming a blazar formation history proportional to the star formation rate history with extinction corrections, BFH 3. (left) On a linear scale, with ℓ'_e changed by only 2 orders of magnitude. (right) On a log-log scale, with ℓ'_e changed by 8 orders of magnitude.

Redshift distributions of model γ **-ray blazars:** Γ

Changing Γ factor: standard value is 10; BFR 3



Fig. 6.— Blazar redshift distribution for a model blazar with Γ varied from 3 – 40, for EGRET detection properties, with a νF_{ν} threshold sensitivity of 2×10^{-12} ergs cm⁻² s⁻¹ at $\epsilon = 200$. (left) Linear scale. (right) Logarithmic scale.

Redshift distribution of model γ-ray blazars: beaming factor

Note different directional luminosities and Γ factors



Fig. 7.— Blazar redshift distribution for a model blazar with $\Gamma = 10$, EC statistics, and EGRET detection properties (upper blue dotted curve) compared with results for synchrotron statistics, with different directional jet powers ℓ'_e and Γ factors as labeled. (left) Linear scale. (Right) Logarithmic scale.

Preliminary predictions for FSRQs

Standard model blazar, $\Gamma = 10$, EC, directional luminosity of 10^{40} ergs s⁻¹ sr⁻¹, different BFHs



Fig. 8.— Model FSRQ redshift distribution for a standard model blazar with $\Gamma = 10$, EC statistics, and EGRET detection properties (upper blue dotted curve), for BFR 3 (left) and BFR 4 (right). GLAST predictions for $f_{\epsilon}^{thr} = 5 \times 10^{-13}$ ergs cm⁻² s⁻¹ and for $f_{\epsilon}^{thr} = 1 \times 10^{-13}$ ergs cm⁻² s⁻¹ are shown by the middle and upper pairs of curves, respectively. The observing frequency is $\epsilon = 200$ and $\epsilon = 2000$ for the higer and lower curve, respectively, in each pair of curves.

BLs not yet treated

GLAST Analysis of Blazars



Measure three characteristic redshifts:

- 1. Average redshift <z> for entire sample
- 2. Average redshift <z_> for z < <z>
- 3. Average redshift $\langle z_+ \rangle$ for $z \rangle \langle z \rangle$

Determine characteristic redshifts for groupings by:

- 1. class type (most simply, FSRQ vs. BL)
- 2. Peak flux or average flux
- 3. Photon energy

Better analysis: Kolmogorov-Smirnov test

Compare with models:

- 1. Choose BFR, Statistics
- 2. Determine best values of Γ and ℓ' .
 - **Degeneracy**?

Implications for parent pop?

3. Identify signatures of highredshift blazars (e.g., γγ high-frequency dropouts)

Model Fit to Blazar Redshift Distribution

Fit parameters for the FSRQs are $\Gamma = 8$ and comoving directional luminosity $l = 10^{40}$ ergs sr⁻¹ s⁻¹; EC statistics

Fit parameters for the BL Lacs are $\Gamma = 5$ and $l = 10^{42}$ ergs sr⁻¹ s⁻¹; syn/SSC statistics



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(Peak) flux function of EGRET Blazars

Histogram showing the measured peak power flux size distribution of EGRET blazars, the fit to the size distribution with the model, and predictions for gamma-ray blazar detectibility with GLAST for a sensitivity threshold of 1.3×10^{-12} ergs cm⁻² s⁻¹



NB: GLAST is much more sensitive than this: but this preserves a ratio of 50:1 (GLAST vs. EGRET)

Diffuse y-Ray Background

$$\epsilon I_{\epsilon} = \frac{c}{4\pi H_0} \int_0^{\infty} dz \oint d\Omega_* \frac{\epsilon_*^2 q_{co}(\epsilon_*, \Omega_*; z)}{(1+z)^3 \sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}}$$
$$\epsilon_*^2 q_{co}(\epsilon_*, \Omega_*; z) = \frac{dE_\gamma}{dt_* dV_{co} d\Omega_*} = n_{com}(z) \ell_e' \delta_{\mathrm{D}}^q \epsilon_z^{\alpha_\nu}$$
$$\epsilon I_{\epsilon}^{bl}(< f_{\epsilon}) \cong \frac{c \ell_{proc}' \epsilon^{\alpha_\nu}}{(q-1)H_0 \beta \Gamma^q} \int_0^{\infty} dz \, \frac{(1+z)^{\alpha_\nu - 3} n_{co}(z)}{\sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}} \left\{ [1 - \beta \min(1, \hat{\mu})]^{1-q} - 1 \right\}$$

- Subtract resolved AGNs
- Relate bursting and persistent sources



Sreekumar et al. (1998)

Model Diffuse γ-Ray Background



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Summary: What we need from and for GLAST

• Blazar catalogs and identification (Romani et al.)

a. Divide blazars into radio galaxies, BL Lac objects, LBL, and FSRQ (more or less BL Lac-like and FSRQ-like)
b Divide blazar class into persistent plus flaring component
c. Host galaxies of blazars: cosmic evolution

- Redshift distribution for different source classes, different peak-flux ranges: Minimal analysis: calculate 3 characteristic redshifts, compare with models Better analysis: KS comparison
- Peak flux size distribution for different source classes, different redshift ranges
- Prediction: GLAST will see a larger ratio of BL Lacs/FSRQs than EGRET

Cosmic evolution of supermassive black holes (tracks IR rather than SFR?) Highly-evolved structure formation in early universe Highest redshift persistent and persistently flaring sources EBL