EGRET Gamma-Ray Blazars: Luminosity Function and Contribution to the Extragalactic Gamma-Ray Background

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Abstract

We describe the properties of the blazars detected by EGRET and summarize the results on the calculations of the evolution and luminosity function of these sources. Of the large number of possible origins of extragalactic diffuse $\gamma$-ray emission, it has been postulated that active galaxies might be one of the most likely candidates. However, some of our recent analysis indicate that only 25\% of the diffuse extragalactic emission measured by SAS-2 and EGRET can be attributed to unresolved $\gamma$-ray blazars. Therefore, other sources of diffuse extragalactic $\gamma$-ray emission must exist. We present a summary of these results in this article.

\textit{Key words:} galaxies: active - galaxies: luminosity function - gamma rays: observations - quasars: general

1 Introduction

EGRET has detected a total of 66 active galactic nuclei (AGN) in high energy ($>100\text{ MeV}$) gamma rays since the launch of CGRO in April 1991 (Hartman et al. 1999). These sources all appear to be members of the blazar class of AGN (BL Lac objects, highly polarized ($>3\%$) quasars (HPQ), and optically violently variable (OVV) quasars) and are radio-loud sources with flat-spectrum at radio bands. Many of the blazars exhibit variability in their $\gamma$-ray flux on timescales of several days to months (McLauglin et al. 1996, Mukherjee et al. 1997). The photon spectra of the blazars in the energy range 30 MeV to 30 GeV are generally well represented by power laws in energy with photon spectral indices in the range 1.4 to 3.0. The sources have non-thermal continuum spectra with the $\gamma$-ray luminosity exceeding those at other frequencies.
in most cases. The high $\gamma$-ray luminosities of the blazars suggest that the emission is likely to be beamed and, therefore, Doppler-boosted along the line of sight. The spectral energy distribution of blazars can be modeled as follows: the radio to UV emission can be explained as synchrotron emission from relativistic electrons in a uniform relativistically moving plasma. The high energy emission is due to the inverse Compton scattering of seed photons off the relativistic electrons, although the source of the soft photons still remains unresolved (see Hartman et al. 1997 for a review).

In this article we summarize the luminosity function and evolution properties of the EGRET blazars and use the results to examine the contribution of the $\gamma$-ray-loud AGN to the diffuse extragalactic background.

2 Luminosity function of EGRET blazars

The evolution and luminosity function of the EGRET blazars was calculated by Chiang & Mukherjee (1998) using data from the Phase 1 through Cycle 4 CGRO observations. Inclusion in the 1 Jy catalog of Kühr et al. (1981) of the EGRET blazars was used to account for possible biases introduced by missing optical identifications. A $V/V_{\text{max}}$ test was used to show evidence of evolution. Here $V$ is the minimum volume that contains an object with redshift $z$; $V_{\text{max}}$ is the largest volume that could contain an object with the same luminosity, and still be detected at the given flux limit. For a limiting significance of detection of $4\sigma$, a value of $\langle V/V_{\text{max}} \rangle = 0.7$ was obtained, which means that we are preferentially detecting more sources at larger redshifts. No evidence of a density evolution of EGRET blazars was found. The evolution is consistent with pure luminosity evolution. (That is, the luminosity of the object is changing with time (i.e. redshift), while the co-moving number density remains the same).

The luminosity of a given object as a function of redshift $z$ can be described by $L(z) = L_0 f(z)$ where $L_0 = L(z = 0)$. Chiang & Mukherjee (1998) have discussed several different forms for the luminosity evolution function, including the power-law and exponential forms.

The redshift distribution of EGRET blazars was used to characterize the low end of the luminosity function better. The high end of the luminosity function was fixed by the non-parametric estimate mentioned above. The redshift distribution of the EGRET data was used to fit both the break luminosity and power law index of the low end of the luminosity function. A likelihood function of the redshift distribution was constructed. The probability density for the redshift of a given blazar was computed and normalized assuming the flux limit derived for that blazar. The data were best fit with a single power law at high luminosities and a luminosity cutoff of $1.1 \times 10^{46}$ ergs s$^{-1}$. 
The data points are the luminosity function estimates using the smoothed non-parametric method of Caditz & Petrosian (1993). The solid line is the cumulative luminosity function derived from a broken power-law differential distribution (Chiang & Mukherjee 1998).

Using the lower limit of the de-evolved luminosity function, the $\gamma$-ray loud AGN contribution to the extragalactic $\gamma$-ray flux is estimated to be $4.0^{+1.0}_{-0.9} \times 10^{-6}$ photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$. The sky-averaged flux contribution of identified EGRET blazars is $\simeq 1 \times 10^{-6}$ photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$. Contribution to the diffuse background by unresolved blazars, therefore, is $\sim 3.0^{+1.0}_{-0.9} \times 10^{-6}$ photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$. The extragalactic diffuse flux for $E > 100$ MeV estimated by Sreekumar et al. (1998) is $\sim 1.36 \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$. We therefore find that blazars cannot account for all of the diffuse extragalactic $\gamma$-ray background at the energies considered.

3 Summary

The luminosity function and evolution properties of $\gamma$-ray-loud blazars imply that only $\sim 25\%$ of the diffuse extragalactic emission measured by SAS-2 and EGRET can be attributed to unresolved $\gamma$-ray blazars. This is contrary to other estimates which assume a linear correlation between the measured radio and $\gamma$-ray fluxes (e.g., Stecker & Salamon 1996). However, we note that our result is consistent with recent work by Mücke & Pohl (1998) where the extragalactic diffuse contribution from blazars is synthesized using a specific blazar emission model (Dermer & Schlickeiser 1993) and an extrapolation of the observed log$N$–log$S$ distribution of EGRET blazars. As in our study, Mücke & Pohl make no assumptions regarding supposed correlations between the $\gamma$-ray fluxes with any other spectral band.

Our results lead to the exciting conclusion that other sources of diffuse extragalactic $\gamma$-ray emission must exist. The spectrum of the measured extragalactic emission implies that the average quiescent energy spectra of these
sources extend to at least 50 GeV and maybe up to 100 GeV, without a significant change in the slope. If gamma-ray blazars continue to make a significant contribution to the diffuse emission at these energies, then the spectra of the parent relativistic particles in blazars which produce the gamma-rays must also remain hard to even higher energies.

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