Some Aspects of the Radio Emission of EGRET-Detected Blazars

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Abstract. It has long been recognized that the high-latitude EGRET sources can be identified with blazars of significant radio emission. Many aspects of the relation between high-energy gamma-ray emission and radio emission of EGRET-detected blazars remain uncertain. In this paper, we use the results of the recently published Third EGRET Source Catalog to examine in more detail to what extent the EGRET flux and the radio flux are correlated. In particular we examine the correlation (or the lack of it) in flux level, spectral shape, temporal variation, and detection limit. Many significant previous studies in these areas are also evaluated.

INTRODUCTION

Ever since EGRET began in 1991 to detect extragalactic objects generally referred to as blazars, the radio emission of such EGRET sources has been found to be closely related to the detected gamma radiation [1–3]. Over the years, many studies have been carried out to investigate the question of radio-γ-ray connection. In this paper, we examine and summarize such results for blazars.

FLUX CORRELATION

Among the EGRET-detected blazars, there are cases when strong γ-ray sources are found to have strong radio fluxes as well, as pointed out by, e.g., Mattox et al.

[4]. But the true nature of the flux correlation between radio and γ-ray emission is more complicated than a simple one-to-one correspondence.

One-to-One Flux Correlation

Mücke et al. [5] have made a thorough and comprehensive study and found no statistically significant one-to-one correlation between radio flux and EGRET flux. This study provides in-depth analyses on this correlation question. It produces a negative result. Unless future data can sustain a claim otherwise, it is advisable that the radio flux and the EGRET flux should not be regarded as being proportional to each other or having a one-to-one relationship.

A Possible Correlation Pattern

The radio flux and the high-energy γ-ray flux of EGRET-detected blazars could be correlated in some other ways. In Figure 1, we plot the radio fluxes at 5 GHz versus the EGRET fluxes for E > 100 MeV in individual viewing periods with the EGRET measurement significance $\sqrt{\mathrm{TS}} > 3.0$. The radio fluxes are taken from the NED database, one value for each source. The EGRET fluxes are those listed in the Third EGRET Catalog [3]. The radio fluxes and the EGRET fluxes are

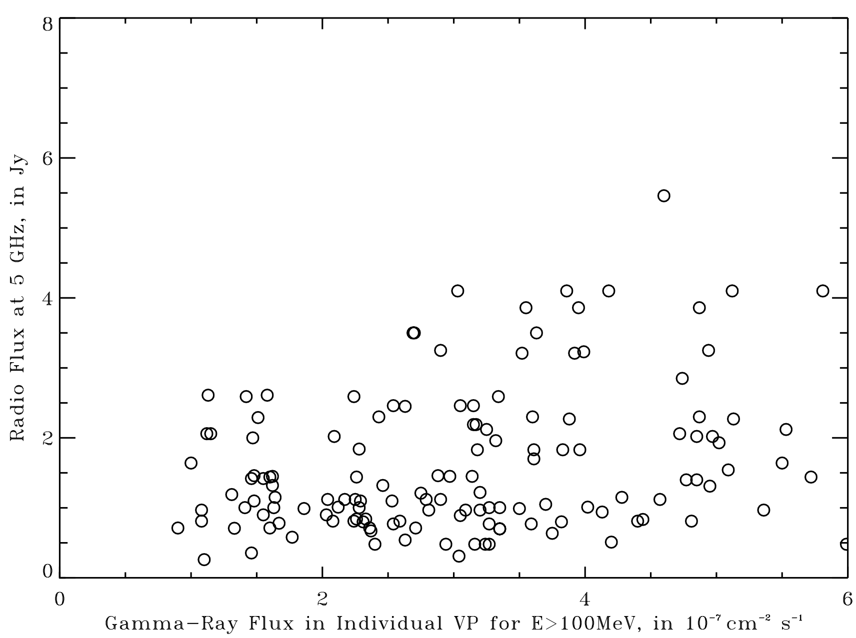

FIGURE 1. Radio flux density at 5 GHz vs EGRET flux for E>100 MeV in individual viewing periods with $\sqrt{TS} > 3.0$.

not simultaneous data. One can see that the data points in Figure 1 occupy the lower right half of the graph. The EGRET flux limit at $\sim 1.0 \times 10^{-7}$ cm^{-2} s^{-1} for E $>$ 100 MeV reflects the EGRET sensitivity. Beyond the radio flux of $\sim$ 2 Jy, the minimum detected EGRET flux for a source seems to increase with the corresponding radio flux, or at least the EGRET flux level seems more likely to become higher when the radio flux increases in Figure 1. But five of the EGRET-detected blazars, off scale in radio fluxes in Figure 1, do not follow this pattern: 3C 273, 3C 279, 3C 454.3, PKS 0521−365, and PKS 1830−210. These are all very strong radio sources. Their EGRET fluxes are much lower than what this pattern would indicate. At this time, we do not know whether such prominent sources form a true subclass of EGRET-detected blazars or this pattern will disappear under more extensive observations. Furthermore, the variability of radio fluxes, which can easily rearrange the data points in Figure 1, is not considered here. Maybe future high-energy γ-ray missions like the GLAST telescope [6] can confirm or disprove this pattern.

Flux Correlation during Radio Flares

Valtaoja et al. [7] have published a result on the correlation of EGRET flux with radio flux during radio flares. They have found that during a flare the EGRET flux is correlated with the *increase* in the radio flux at the time of the EGRET measurement, but not to the size of the flare. This study is based on about thirty simultaneous measurements between EGRET observations and Metsähovi 22 GHz monitoring data. The statistical significance is thus not very high, but this is a very interesting result. It is directly related to the radio state at the time of EGRET detection. See the section "RADIO STATE FOR Γ-RAY EMISSION."

SPECTRUM CORRELATION

Both the radio spectral indices and the high-energy γ-ray spectral indices of the EGRET-detected blazars extend over large ranges of values. It would be interesting to see if the spectral indices in these two wavebands are correlated in some way. We have calculated the two-point radio spectral indices with data taken from the NED database between 2.7 and 5 GHz, 5 and 31 GHz, and 5 and 90 GHz, for EGRET-detected blazars. The two radio measurements for each spectral index calculation are required to be in the same radio catalog and simultaneous data are used whenever available. The EGRET spectral indices are taken from the Third EGRET Catalog [3]. No correlation whatsoever can be seen between the radio spectral indices and the EGRET spectral indices. It may seem that, although the radio and high-energy γ-ray bands are closely related to each other, the beam of particles that produces one band is unlikely to be the same one that produces the other band. These two bands of radiation are likely to be related to each other at a deeper level of the radiation mechanism.

RADIO AND EGRET FLUX LIMITS

When the EGRET Team first tried to search for counterparts in radio sources for the high-latitude EGRET sources, the radio flux was restricted to $>\sim$ 1 Jy, later changed to $>\sim$ 0.5 Jy, at 5 GHz in order to reduce the number of source candidates [1]. This has created an uncertainty as to whether the unidentified high-latitude EGRET sources are actually radio sources with fluxes lower than this artificial search limit. To answer this question, Sreekumar et al. [8], Nolan et al. [9], Dingus et al. [10], and Lin et al. [11] have devoted special attention to search for counterparts for the unidentified high-latitude ($|b| > 10°$) EGRET sources in the Second EGRET Catalog [2] among radio sources with fluxes as low as 0.3 Jy at 5 GHz or even lower. Only one possible identification was found in this way. It now appears certain that the radio flux limit of $\sim$ 0.5 Jy at 5 GHz is an instrinsic property of the EGRET-detected blazars for the EGRET detection limit of $\sim 1.0 \times 10^{-7}$ cm^{-2} s^{-1} for E $>$ 100 MeV in one viewing period. It is true that some of the EGRET-detected blazars do have radio fluxes below 0.5 Jy at 5 GHz [3]. Furthermore, some of the radio sources with fluxes above 0.5 Jy at 5 GHz could be historically much weaker. But it seems that to find many more γ-ray-emitting blazars with radio fluxes lower than $\sim$ 0.5 Jy at 5 GHz, the γ-ray detection limit would have to be much lower than what EGRET can provide.

RADIO STATE FOR Γ-RAY EMISSION

From the studies of Reich et al. [12], Mücke et al. [13], Valtaoja et al. [14], Pohl et al. [15], Lähteenmäki et al. [16], and Marscher et al. [17,18], opinions now all seem to converge to the picture that: (1) higher the radio activities are, more often high-energy γ-rays are detected; (2) high-energy γ-rays are most likely detected when the source is in the rising phase of a radio flare; (3) it is moderately likely when the radio flux is in a high-flux stage; (4) it is least likely when the source is in the declining phase of a flare. We must also mention, as described above, that the high-energy γ-ray flux is moderately correlated with the *increase* of radio flux at the time of the EGRET measurement, but not to the flare size itself [7]. This picture represents the current understanding of the radio state when an EGRET flux is detected. It points to the possibility that the high-energy γ-rays as detected by EGRET are most likely emitted in flares and the durations of γ-ray flares are much shorter than the radio flares. But it does not preclude the possibility that low-level continuous fluxes of high-energy γ-rays may also exist in blazars.

RADIO MORPHOLOGY

Recently Piner and Kingham [19] published their VLBI study of six EGRET blazars and a number of blazars not detected by EGRET for comparison. Based on their observations, they indicate that the γ-ray flares do not necessarily correlate with component ejections, (component ejections during γ-ray flares have been reported before; see e.g. Wehrle et al. [20]), the γ-ray blazars do not preferentially belong either to the population with misaligned jets or to the population without misaligned jets, and the γ-ray blazars are not found to be more strongly beamed than those which have not been detected by EGRET. In an ongoing VLBA monitoring program by Marscher et al. [17,18], with a large sample size and a long observation history, it has been found that about 50% of the observed radio flares are correlated with EGRET detections; the lack of detections in the other 50% can be explained with paucity of EGRET observations and brevity of γ-ray flares. Marscher et al. [17,18] also indicate that EGRET-detected blazars do show evidence of being more strongly beamed than those not detected by EGRET. This is at variance with what Piner and Kingham [19] find in this beaming question. But as pointed out by Piner [21], the measured average speed of EGRET sources, at 6 $h^{-1}c$, by Piner and Kingham [19], is very similar to the value obtained by Marscher et al. [17,18]. The difference lies in the choice of objects for the sample of blazars not detected by EGRET. Marscher's sample [17,18] contains more recent results. We can perhaps draw a tentative conclusion for the beaming question at this time that EGRET-detected blazars are indeed more strongly beamed on the average than those not detected by EGRET.

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