NON-BLAZAR GAMMA-RAY VARIABLES IN THE GALACTIC PLANE: A NEW CLASS OF GAMMA-RAY SOURCES

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Abstract.

We discuss recent detections of time-variable gamma-ray sources near the Galactic plane. A new bright gamma-ray transient was detected by EGRET in June 1995 near the Galactic center (GRO J1838-04). Also one of the most interesting unidentified gamma-ray sources in the plane, 2CG 135+1, was recently shown to be variable. Both GRO J1838–04 and 2CG 135+1 share many characteristics: variability of the gamma-ray flux within days/weeks, occasional peak gamma-ray emission of comparable flux ($\sim 4 \times 10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$), absence of radio-loud spectrally-flat AGNs or prominent radio pulsars within their error boxes, lack of strong X-ray and/or hard X-ray counterparts. These characteristics do not match those of either gamma-ray blazars or isolated pulsars. Therefore, GRO J1838–04 and 2CG 135+1 provide strong evidence for the existence of a *new* class of variable gamma-ray sources.

1. Introduction

The Energetic Gamma-Ray Experiment Telescope (EGRET) on board of CGRO detected about 150 sources above 100 MeV [20, 21]. Only about half of these sources have been identified either as active galactic nuclei (AGN) associated with spectrally flat radio-loud sources of the blazar type [20, 8, 3, 6], or as isolated young/intermediate age pulsars [20, 11]. Approximately constant gamma-ray fluxes are detected from gamma-ray pulsars (within observational uncertainties), whereas blazars show variability within days/weeks [8]. Variable gamma-ray sources are particularly interesting among the ~40 unidentified gamma-ray sources concentrated near the Galactic plane [20, 21]. The likelihood of detecting an AGN similar to those detected by EGRET at high latitudes is small in the Galactic plane. Detecting a variable gamma-ray source in the Galactic plane is therefore of great importance: it would imply the existence of a new class of gamma-ray emitters different from blazar-like AGNs and isolated pulsars.

Theoretically, several Galactic systems are expected to be *time-variable* gamma-ray sources, including: (1) binary pulsars emitting gamma-rays by shocked ultrarelativistic particles in pulsar winds stopped by gaseous material from companion stars (as in the case of the pulsar/Be star system PSR B1259-63 [16]), (2) jet X-ray sources with ejection axis aligned towards the Earth, (3) unstable pulsar magnetospheres, (4) peculiar accretion phenomena onto compact objects, (5) exotic transients. To date, indication for γ-ray emission was obtained only for sources of the type (1). Variable X-ray/gamma-ray emission was observed near periastron from the PSR B1259-63 system [16]. Motivated by these theoretical reasons, we started an investigation of the Galactic plane in search for variable gamma-ray transients. In the process of studying a Galactic region with possibly variable gamma-ray sources, we discovered the new bright transient GRO J1838-04. We also observed several times with CGRO the unidentified gamma-ray source 2CG 135+1(ref. [15]).

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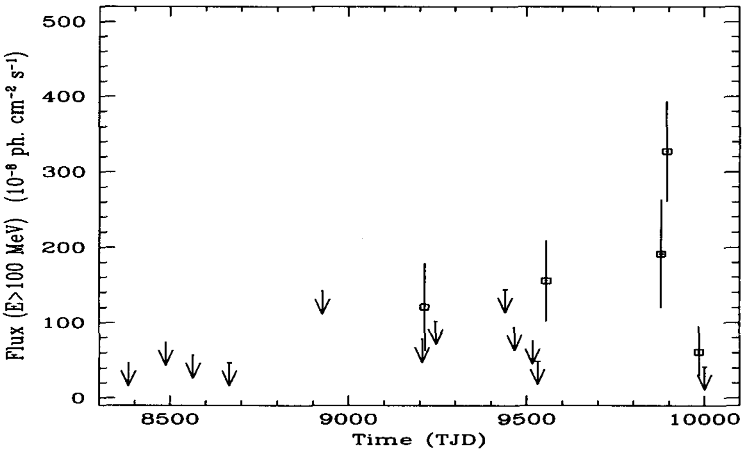

Figure 1. Time history of γ-ray flux detected by EGRET from GRO J1838–04. TJD is the truncated Julian date (JD), TJD=JD–2,440,000.0. 1σ flux errors and 2σ upper limits are reported, the upper limits being shown as downward arrows. The time interval is from April 1991 through early October 1995. EGRET data for VPs 421 and 422 have been combined. Figure adapted from ref. [17] with the inclusion of the last point obtained from public data of CGRO Cycle 5.

2. The new gamma-ray transient GRO J1838-04

During the viewing period (VP) 423 (June 20-30, 1995) a new gamma-ray transient (GRO J1838–04) was discovered by EGRET. This source is located near the Galactic plane in a field centered at Galactic coordinates $l = 27.31°$ and $b = +1.04°$ with an elongated error box (99% confidence) of major axis $\sim 1.4°$ and minor axis $\sim 0.8°$. The average γ-ray flux above 100 MeV for the whole VP 423 is $\Phi = (3.3 \pm 0.7) \cdot 10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$. Fig. 1 shows the EGRET lightcurve of GRO J1838–04 since the beginning of the CGRO mission with the inclusion of a crucial Cycle 5 EGRET observation in October 1995 that failed to detect the source. The intensity level reached during the γ-ray flare had peak flux above 100 MeV of $(4.0 \pm 1.1) \cdot 10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ during the last 3.5-day interval of VP 423. The peak γ-ray luminosity for isotropic emission is $L_\gamma \simeq 7.2 \times 10^{34}\, d_{kpc}^2\,\mathrm{erg\,s^{-1}}$, where d_{kpc} is the source distance in kpc. This is a very intense γ-ray transient with a γ-ray flux comparable with that of the Geminga pulsar [20] and of AGN flare peak intensities as for 3C 279 ($z = 0.538$) [5] and 0528+134 ($z = 2.07$) [12]. The EGRET spectrum above 30 MeV during the peak emission is consistent with a power-law of photon index 2.09 ± 0.18 [17]. Neither COMPTEL or BATSE detected significant high-energy emission during the gamma-ray flare of GRO J1838–04 .

2.1. SEARCH FOR COUNTERPARTS

The Galactic plane near GRO J1838–04 was surveyed in the radio band at 20 cm by Helfand et al. [4]. No spectrally-flat bright radio source with blazar characteristics is within the 99% confidence error box of GRO J1838–04. The brightest radio source in the error box, 27.920+0.977 (source 'A' in Fig. 3 of ref. [17]) was determined to have a constant flux ($\sim$ 500 mJy at 2.2 GHz) and a steep radio spectral index $\alpha_r \simeq -1$ from data obtained at the Green Bank radio interferometer at 2.25 and 8.3 GHz during the period December 14 1995 - January 13 1996. This radio source certainly does not resemble the radio-loud blazars associated with gamma-ray sources detected by EGRET at high Galactic latitudes [8, 6]. Other radio sources in the GRO J1838–04 error box are weaker and unlikely to be blazar counterpart candidates.

Two radio pulsars are known in the error box, PSR B1831–04 and PSR B1834–04 with relatively small spindown luminosities ($10^{32.5}$ and $10^{33.1}\,\mathrm{erg\,s^{-1}}$, respectively [19]). The supernova remnant

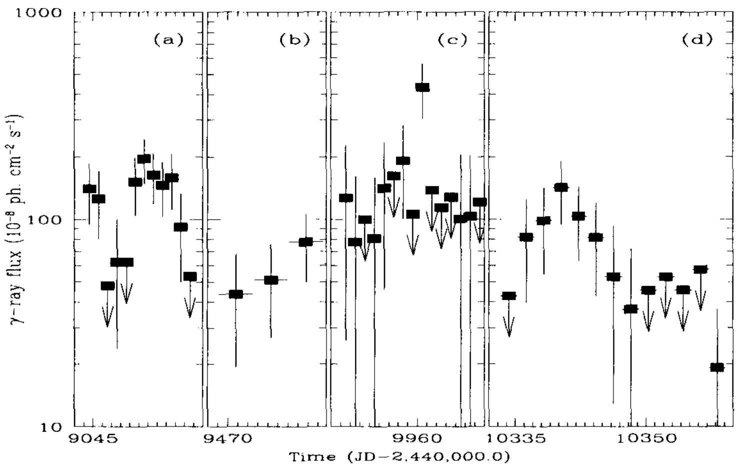

Figure 2. EGRET lightcurve of 2CG 135+1 (from ref. [18]; vertical axis in logarithmic scale) for photon energy larger than 100 MeV and four different observations: **(a)** February-March 1993 (ref. [5]), **(b)** April-May 1994, **(c)** August-September 1995, and **(d)** September 1996 (JD is time in Julian Days). The right panel shows the latest and longest 4-week EGRET observation during September 1996. Error bars and upper limits are 1σ.

SNR27.8+0.6 is also in the error box. No pulsar is associated with the remnant which appears to be of a center-filled plerionic type from its radio extended and core emission. Three X-ray sources in the ROSAT all-sky survey database are within the 99% confidence error box of GRO J1838–04. None is associated with the radio sources of ref. [4]. More data are necessary to obtain information on the GRO J1838–04 counterpart, and X-ray observations as well as optical and radio searches are under way.

3. The variable gamma-ray source 2CG 135+1

Among the unidentified gamma-ray sources near the Galactic plane [20] 2CG 135+1 is one of the most enigmatic. Since its discovery by the COS-B satellite [14], 2CG 135+1 was observed in the gamma-ray range by several instruments including MISO [10], OSSE [15, 13], COMPTEL [23], and EGRET [5]. No radio-loud AGN [1] or strong radio pulsar [9] is known within its refined gamma-ray error box [5] which includes the cyclic radio flaring Be star LSI 61° 303 [2]. By analyzing and comparing all EGRET observations, we find that the gamma-ray flux of 2CG 135+1 is variable on both short (~days) and long (~ months) timescales, and cannot be associated with a standard isolated gamma-ray pulsar [18]. Fig. 2 shows a summary of all high-quality EGRET observations of 2CG 135+1. The average flux above 100 MeV is $\Phi = (7.9 \pm 0.5) \times 10^{-7}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ corresponding to a luminosity $\sim 5 \times 10^{34}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,d_{kpc}^2}$, with d_{kpc} the distance in kiloparsecs.

The variability index V (see ref. [7] for its definition) is $V \simeq 2$ for all EGRET observations. Typically , blazars showing gamma-ray flares have a variability index $V \gtrsim 1$ [7, 6], and gamma-ray pulsars show $V \lesssim 0.7$ [22]. The gamma-ray variability of 2CG 135+1 is similar to what observed in blazars. However, no radio-loud source above a flux level of $S_5 \simeq 0.2$ Jy at 5 GHz is detected within its error box [1]. There is a very strong correlation between the peak gamma-ray flux of blazars and the average 5 GHz radio flux [6]. All unambiguously identified gamma-ray blazars have $S_5 \gtrsim 1$ Jy [8, 6]. It is easy to demonstrate that interpreting 2CG 135+1 as a radio-quiet AGN near the Galactic plane would contradict what is known about the population of extragalactic sources detected by EGRET [17]. We are left with the conclusion that 2CG 135+1 does not belong to the radio-loud blazar or standard isolated pulsar populations [18]. This conclusion is reached independently of the possible association of 2CG 135+1 with the Be star LSI 61° 303.

4. A new class of gamma-ray sources

The probability of finding a single gamma-ray blazar as bright as GRO J1838–04 and 2CG 135+1 in the Galactic plane sky area within $\pm 2°$ of Galactic latitude is $\sim 4 \times 0.4/4\pi \simeq 0.1$ [17]. At the γ-ray flux level near $10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$, there is no lack of sensitivity for EGRET observations near the Galactic plane. If radio-quiet AGNs also contributed to the gamma-ray emission, EGRET would have detected many more sources than observed. Therefore, GRO J1838–04 and 2CG 135+1 are not bright γ-ray blazars of the kind usually detected. If GRO J1838–04 is an extragalactic source, it is highly improbable that a first detection of a new type of γ-ray AGN would occur near the Galactic center.

Both of these non-blazar gamma-ray sources strongly suggest the existence of a new class of gamma-ray sources of Galactic origin. The transient GRO J1838-04 is within $\sim$ 27 degrees in Galactic longitude from the Galactic center, and its detectability is strongly affected by diffuse emission. On the other hand, 2CG 135+1 is in a region of the Galactic plane relatively unaffected by diffuse emission. However, it is clear from Fig. 2 that if 2CG 135+1 were close to the Galactic center, only high values of its gamma-ray flux could be detectable by EGRET. A population of sources similar to 2CG 135+1 near the Galactic center region could be detected only because of large gamma-ray variability. Future high-sensitivity searches for gamma-ray transients supported by quick multiwavelength follow-up observations in the Galactic plane may lead to the detection of more of these enigmatic sources, and contribute to resolve the issue of their ultimate origin.

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