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# EGRET DETECTION OF HIGH-ENERGY GAMMA RADIATION FROM THE OVV QUASAR 3C 454.3

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## ABSTRACT

High-energy gamma radiation has been observed from the optically violent variable (OVV) quasar 3C 454.3 (PKS 2251+158) by the Energetic Gamma-Ray Experiment Telescope (EGRET) on the *Compton Observatory*. During the 1992 January–February observation, the emission showed a power-law photon spectrum with an exponent of $-2.18 \pm 0.08$. The flux density ($E > 100$ MeV) was observed to vary within the range (0.4–1.4) $\times 10^{-6}$ photon cm$^{-2}$ s$^{-1}$ on a time scale of less than a week. Lower sensitivity observations during 1992 April and May also detected emission within that range, but with lower statistical significance. An earlier low-sensitivity exposure during 1991 August gave a 95% confidence upper limit of $0.26 \times 10^{-6}$ photon cm$^{-2}$ s$^{-1}$. The similarity of the gamma-ray emission of 3C 454.3 to that of 3C 279 parallels the similarity of these two objects at lower frequencies.

*Subject headings:* gamma rays: observations — quasars: individual: 3C 454.3

## 1. INTRODUCTION

The discovery of high-energy gamma radiation from the OVV quasar 3C 279 (Hartman et al. 1992a) and ~20 additional AGNs (Bertsch et al. 1993a; Hunter et al. 1993a, b; Lin et al. 1993; Mattox et al. 1993; Nolan et al. 1993; Thompson et al. 1993a, b; Fichtel et al. 1993) has opened a new and exciting path toward increased understanding of these remarkable objects. One of the most dramatic aspects of the 3C 279 discovery is the observation of time variation of its high-energy gamma radiation on time scales as short as a few days (Kniffen et al. 1993). Such variations place strong constraints on the size of the gamma-ray emission region, and therefore also severely constrain quasar models.

The OVV quasar 3C 454.3 (=PKS 2251+158; $z = 0.859$) has also been detected as a gamma ray source by EGRET (Hartman et al. 1992c). In some ways, this object is similar to 3C 279. Both are subject to intense outbursts in the radio and optical bands, although the 3C 454.3 variations observed so far have not been as dramatic as those of 3C 279. Comparison of their X-ray variations is not possible because the observations of 3C 454.3 have been rather sparse. 3C 454.3 was detected by *Einstein* (Worrall & Wilkes 1990), but little spectral information was obtained. *Ginga* observations of OVV X-ray spectra (Ohashi et al. 1989) have shown that the 3C 454.3 spectrum is significantly softer than those seen from most such objects, including 3C 279. Both 3C 279 and 3C 454.3 are classified as high-polarization quasars (HPQ), typically 9% for 3C 279 (Impey & Tapia 1990) and 3% for 3C 454.3 (Moore & Stockman 1981; Smith et al. 1988). Both objects have demonstrated polarization excursions into the range 15%–20% (Angel & Stockman 1980). Although their dramatic variations make comparisons difficult, 3C 454.3 and 3C 279 appear to show similar quiescent optical magnitudes (Webb et al. 1988; Pica et al. 1988). Optical polarimetry and photometry by Smith et al. (1988) has provided evidence for substantial thermal emission from 3C 454.3, which might be attributed to an accretion disk with $B_{\rm disk} = 18.1$. Taking into account its 1.6 times higher redshift as well as the minimum optical brightness of 3C 279, $B = 18.01$ (Sandage et al. 1965), the disk luminosity of 3C 354.3 is at least a factor of 2.5 greater than that of 3C 279. VLBI observations (Whitney et al. 1971; Pauliny-Toth et al. 1987; Unwin et al. 1989) have shown both 3C 279 and 3C 454.3 to be "superluminal," and Cotton et al. (1979) have found the two objects to have similar apparent velocities near $\beta = 9$ (assuming $q = 0.5$). Recent VLBI observations have revealed in 3C 454.3 two barely resolved components, separated by only ~6 mas, but with very different radio spectra (Charlot 1991).

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## 2. THE EGRET OBSERVATIONS

EGRET has been described in detail by Hughes et al. (1980), Kanbach et al. (1988, 1989), and Hartman et al. (1992b). It covers the energy range 30 MeV to ~30 GeV with energy resolution of ~25% FWHM, and has a field of view of ~0.5 sr. The effective area (on-axis) is ~1500 cm$^2$ around 500 MeV; it falls slowly at higher energies and rather rapidly below 100 MeV. The effective area falls to half-maximum at ~20% from the telescope axis. The calibration procedures and resulting instrument properties are given by Thompson et al. (1993c).

3C 454.3 was observed at 22° from the EGRET axis during the period 1992 January 23–February 6, and at 18° from the axis during the two periods 1992 April 23–28 and May 7–14.

During the period 1991 August 8–15, a low-sensitivity exposure (33° off-axis) was obtained.

The data were processed according to the standard EGRET procedures described by Bertsch et al. (1989). Flux densities and spectra were obtained using a maximum likelihood method (Mattox 1993), incorporating into the background a model for the galactic diffuse gamma-ray emission described by Bertsch et al. (1993b), and allowing for isotropic extragalactic gamma radiation consistent with that observed by *SAS 2* (Fichtel, Simpson, & Thompson 1978; Thompson & Fichtel 1992).

### 3. RESULTS

The discovery of high-energy gamma-ray emission from 3C 454.3 (Hartman et al. 1992c) was based on the 1992 January-February EGRET observation. During that 2 week period, a gamma-ray source was noted with an average flux density ($E > 100$ MeV) of $(8 \pm 1) \times 10^{-7}$ cm$^{-2}$ s$^{-1}$. Based on a likelihood analysis, the most probable position for the source is $\alpha$(J2000) = 22$^h$352$^m$ $\pm$ 12$^m$ (343°.15 $\pm$ 0°.2), $\delta$(J200) = 16°.6′ $\pm$ 9′ (16°.1 $\pm$ 0°.15). The NED data base shows six objects within 0°.4 of the EGRET position: an *IRAS* source, a normal galaxy, three low-to-moderate intensity radio sources, and the OVV quasar 3C 354.3. The identification with 3C 354.3 thus cannot be absolutely certain; it is based on the fact that most of the gamma-ray sources detected by EGRET at high Galactic latitudes are close to similar objects (for which the best description seems to be "bright core-dominated flat-spectrum radio sources"). No more than ~1% of a random sample of high-latitude points would be similarly close to such objects, based on the number of flat-spectrum core-dominated objects with $S$(5 GHz) > 1 Jy listed by Kühr et al. (1981).

The flux density observed from 3C 454.3, similar to that from 3C 279 during the EGRET observation in 1991 October (Kniffen et al. 1993), permits subdividing the 14 day observation into five equal periods of 2.8 days to look for short-term variability. The result is shown in Figure 1. A decreasing trend is evident; a $\chi^2$ test indicates that the probability of constant gamma-ray output during the observation is ~1/800. Although not as significant statistically as the 3C 279 outburst seen by EGRET in 1991 June (Kanbach et al. 1992; Kniffen et al. 1993), this is an additional example of blazar gamma-ray variability on a time scale of a week or less.

The results from the 3C 454.3 observations in 1992 April and May are compared with the January-February observation in Figure 2. The April and May flux densities are comparable to the earlier ones; there is no statistically significant evidence for variations during the spring observations. The low-sensitivity observation during 1991 August is also shown in Figure 2. Although only an upper limit, it suggests that the gamma-ray emission at that time was lower than that seen during the 1992 observations.

The spectrum obtained from the 1992 January-February observation is shown in Figure 3; if the 30–70 MeV point is disregarded, the spectrum is compatible with a power-law form,

$$F_\gamma = (2.01 \pm 0.12) \times 10^{-6}(E/0.214\ \text{GeV})^{-2.18 \pm 0.08}\ \text{photon}\ (\text{cm}^2\ \text{s GeV})^{-1}\ .$$

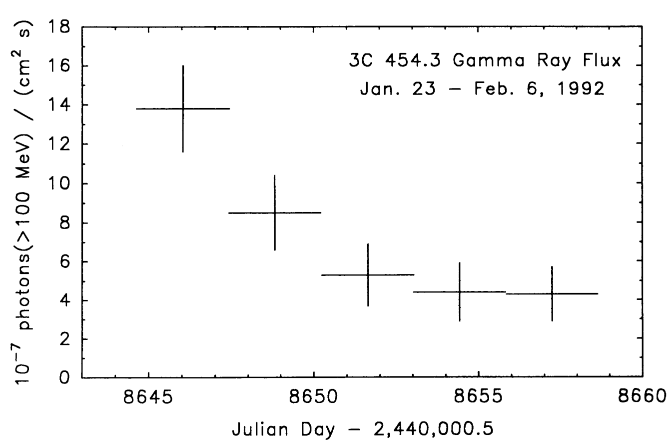


FIG. 1.—Time variation of the high-energy gamma radiation from 3C 454.3 during the interval 1992 January 23 to February 6.

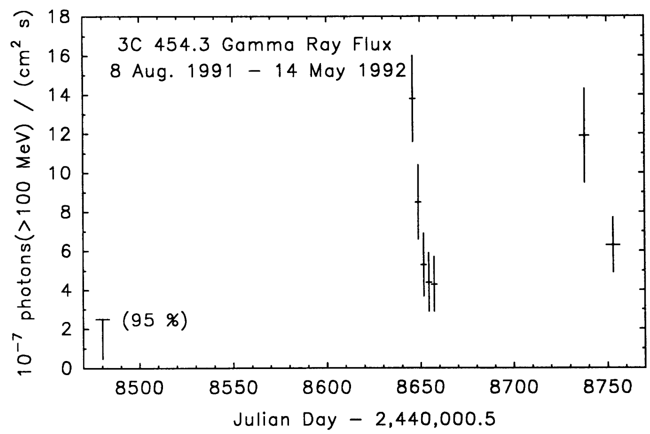


FIG. 2.—Time history of the high-energy gamma radiation from 3C 454.3 for all EGRET observations.

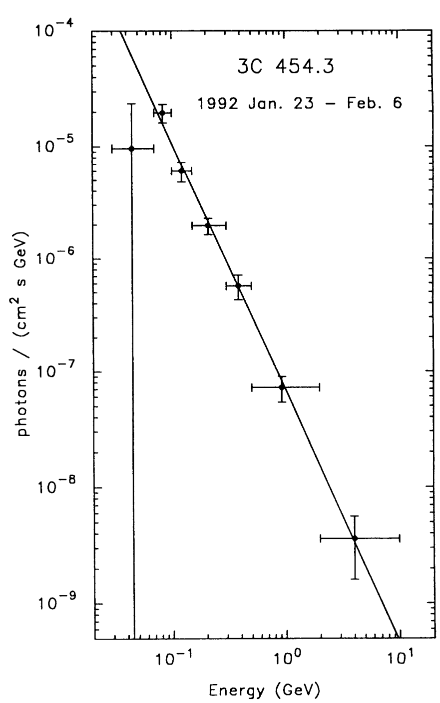


FIG. 3.—High-energy gamma ray spectrum of 3C 454.3 during the time interval 1992 January 23 to February 6. See text for comments on the 30–70 MeV point.

(The normalization energy 0.214 GeV is chosen so that the errors on the multiplier and the exponent are uncorrelated.) The spectral index of $-2.18$ is slightly steeper than that observed for 3C 279 during 1991 October (Kniffen et al. 1993). There is no evidence for a rollover or knee at the highest energies observed.

In deriving the 30–70 MeV point in Figure 3, a poorly known correction factor, based on information obtained since launch, has been applied to the EGRET sensitivity for that range derived from prelaunch calibration data. The large uncertainty in the correction has been incorporated into the errors shown for that point in the figure. The detection in the 30–70 MeV range has a significance of less than 1 $\sigma$.

Spectra for the April and May observations show photon indices of $-2.29 \pm 0.15$ and $-2.25 \pm 0.33$, respectively; the statistical errors are sufficiently large that the differences when compared with the January–February observation are not compelling. (The poorer statistics occur not only because the observing periods in April and May were shorter than the earlier one; the failure of the *Compton Observatory* tape recorders in 1992 March led to a lower observing efficiency during the April and May periods.)

## 4. DISCUSSION

The similarity between 3C 454.3 and 3C 279 mentioned in the introduction is now seen to extend into the high-energy gamma-ray regime: (1) both objects appear to vary in gamma-ray emission by factors of $\sim 3$ on time scales of less than a week; (2) both exhibit rather hard power-law spectra of similar exponent over the entire observable energy range of at least 2 decades; (3) although the observed variation leaves considerable uncertainty about the minimum levels of gamma-ray output from the two sources, the levels observed translate to similar isotropic gamma-ray luminosities. Figure 4, which compares the spectra of 3C 454.3 and 3C 279 over the entire observed electromagnetic spectrum, reemphasizes the overall correspondences between these two objects, despite the difficulties imposed by the varying gamma-ray emission. Since for both (highly variable) objects the gamma-ray observations are not simultaneous, or even contemporaneous, with the lower frequency observations, detailed comparisons are not likely to be meaningful.

It should be noted that the 1992 January–February observation of 3C 454.3 occurred during a time when its 22 and 37 GHz radio emission was increasing dramatically (H. Teräsranta, private communication). However, the radio emission continued to rise through the 1992 April–May period, whereas no obvious increase was seen in the gamma-ray output. Thus no clear time correlation is apparent between these widely differing frequency bands despite the apparent correlation between gamma-ray sources and radio-bright AGN (Fichtel et al. 1993).

Ever since the COS-B detection of gamma-ray emission from 3C 273 (Swanenburg et al. 1978; Bignami et al. 1981), models have been generated to explain and predict gamma-ray emission from AGNs (Königl 1981; Reynolds 1982; Begelman & Sikora 1987; Bloom & Marscher 1992; Marscher & Bloom 1992; Maraschi, Ghisellini, & Celotti 1992; Ghisellini 1993). Because of gamma-ray obsorption via photon-photon pair production, the EGRET observation of substantial gamma-ray emission extending to more than 1 GeV, coupled with the short time scales for variation, appear to rule out generation of the gamma radiation in the same volume as the observed X-rays unless they are both beamed toward us (Jelley 1966; McBreen 1979; Maraschi et al. 1992). Models based on inverse Compton scattering of highly relativistic electrons by various lower energy photon fields within a compact relativistic jet have had considerable success in reproducing the gamma-ray levels observed. The low-energy photons can be either self-generated by the electrons as synchrotron radiation (Marscher 1980; Königl 1981; Marscher & Bloom 1992; Maraschi et al. 1992), or ambient thermal photons arising from an assumed accretion disk (Begelman & Sikora 1987; Melia & Königl 1989; Dermer et al. 1992). To explain the observed time variations, inhomogeneity is probably required in the jet, possibly including outward-propagating shocks. These models appear to be able to account for gamma-ray emission up to at least 5 GeV. Models which are nucleon-driven (Morrison, Roberts, & Sadun 1984; Kazanas 1992, and references therein) are probably more attractive if the power-law form is eventually found to extend significantly beyond 5 GeV; the recent detection of emission from the BL Lacertae object Mrk 421 at TeV energies

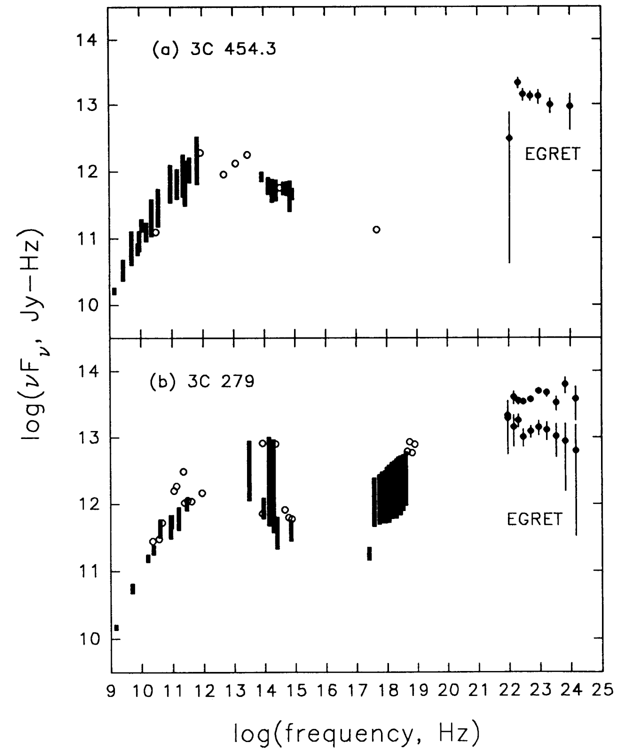


FIG. 4.—Comparison of the multifrequency spectra of 3C 454.3 and 3C 279. For frequencies below $10^{19}$ Hz, thick vertical bars represent range of variation at a particular frequency; open circles represent single measurements at the corresponding frequency. For the EGRET data, the thin vertical bars represent the statistical errors of the measurements. (*a*) For 3C 454.3, the EGRET points are derived from those of Fig. 3. The lower frequency data points over roughly the time period 1975–1990, and were obtained from Kühr et al. (1981), Lloyd (1984), Aller et al. (1985), Gear et al. (1985), Ledden & O'Dell (1985), Simonetti, Cordes, & Heeschen (1985), Maraschi et al. (1986), Edelson (1987), Hoddock, Aller, & Aller (1987), Impey & Neugebauer (1988), Smith et al. (1988), Steppe et al. (1988), Valtaoja et al. (1988), Chini et al. (1989), Ohashi et al. (1989), Bloom & Marscher (1991), Jackson & Brown (1991), Waltman et al. (1991), Wright et al. (1991), Sitko & Sitko (1991), Aller & Aller (private communication), Robson (private communication), Teräsranta (private communication), Tornikoski (private communication). (*b*) For 3C 279, the EGRET points are from Kniffen et al. (1993). The lower frequency data points were adapted from Fig. 2 of Hartman et al. (1992a), and cover the approximate period 1980–1990.

(Punch et al. 1992) might support the nucleon-driven scenario. Up to now, however, those models have not been shown to accommodate the short–time scale gamma-ray variations observed by EGRET.

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