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High Energy Gamma Radiation from PKS 0528+134 Observed by EGRET

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Abstract. A summary of EGRET observations of PKS 0528+134 is given, with special emphasis on the 1993 March observations when the source flared in gamma-rays. The flux history of PKS 0528+134 as well as spectra of the source are presented. Multiwavelength observations of PKS 0528+134 during the flare are also given. A detailed relativistic SSC jet model agrees well with the 1993 March multiwavelength spectrum. However, the data are insufficient to discriminate between this and other emission models.

1. Introduction

High energy gamma-rays from PKS 0528+134 were first detected by EGRET during the early pointings of CGRO from April to June, 1991 (Hunter et al. 1993). PKS 0528+134 is one of the brightest active galactic nuclei (AGN) de-

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tected by EGRET. It is located near the Galactic anticenter at $l = 191.37°$, $b = -11.01°$ ($\alpha = 5^h28^m6.759^s$, $\delta = +13°29'42.19''$ J2000). It has a redshift of $z = 2.07$ (Hunter et al. 1993), and a mean optical brightness of $m_v = 20$. Since the exposures in mid 1991, EGRET has made several subsequent observations of the anticenter region. In 1993, March 23–29, PKS 0528+134 was seen to flare and gamma-rays were detected at a level approximately three times greater than the observed intensity during the early part of the GRO mission (Sreekumar et al. 1993). In this paper we report on these observations of PKS 0528+134.

2. Gamma-ray observations

2.1. Flux history

Table 1. EGRET observations of PKS 0528+134

Viewing Period	Observation Dates	Flux $\times 10^{-7}$ ph cm^{-2} s^{-1}	Significance σ	Inclination Angle of Source (deg)
0.2-0.5	1991 Apr 22–May 07	12.9 ± 0.9	20.3	8.0
1.0	1991 May 16–30	8.5 ± 0.8	13.5	6.3
2.1	1991 Jun 08–15	3.6 ± 1.1	3.8	5.1
36.0+36.5	1992 Aug 11–20	2.3 ± 1.5	1.8	22.0
39.0	1992 Sep 01–17	3.2 ± 1.4	2.6	23.9
213.0	1993 Mar 23–29	30.8 ± 3.5	13.6	9.1
221.0	1993 May 13–24	2.3 ± 1.2	2.2	6.4
310.0	1993 Dec 01–13	< 4.0[a]	1.2	15.7
321.1+321.5	1994 Feb 08–17	4.9 ± 1.2	5.0	12.9
337.0	1994 Aug 09–29	3.2 ± 1.0	3.6	13.5
412.0	1995 Feb 28–Mar 07	GI data		13.1
413.0	1995 Mar 07–21	GI data		7.7
419.1	1995 Apr 04–11	GI data		17.4
419.5	1995 May 09–23	GI data		20.9
420.0	1995 May 23–Jun 06	GI data		9.8
426.0	1995 Aug 08–22	GI data		8.5
502.0	1995 Oct 17–31	5.7 ± 8.4[b]	8.5	0.86

[a] 2σ upper limit
[b] Marscher et al. 1996

Table 1 lists the dates of observation and viewing periods during which PKS 0528+134 was within 30° of the EGRET instrument axis. The integrated flux above 100 MeV as well as the significance of detection of PKS 0528+134 in each viewing period (VP) is also given in Table 1. Consecutive VPs with similar pointing directions (0.2, 0.3, 0.4 and 0.5; 36.0 and 36.5; 321.1 and 321.5) were added together in order to improve the significance of detection. Figure 1 shows the history of the gamma-ray flux of PKS 0528+134 above 100 MeV until 1995 October. The individual points correspond to the average flux for the VPs listed in Table 1. The highest flux from PKS 0528+134 was observed during 23–29 March, 1993, in VP 213.0. During the other observations of the source made in 1992 and 1993, the source was detected in the 'low' state (Nolan et al. 1993). Over the period covered by the EGRET observations, the high energy flux from PKS 0528+134 varied over the range (2.3 ± 1.2 to 30.8 ± 3.5) $\times 10^{-7}$

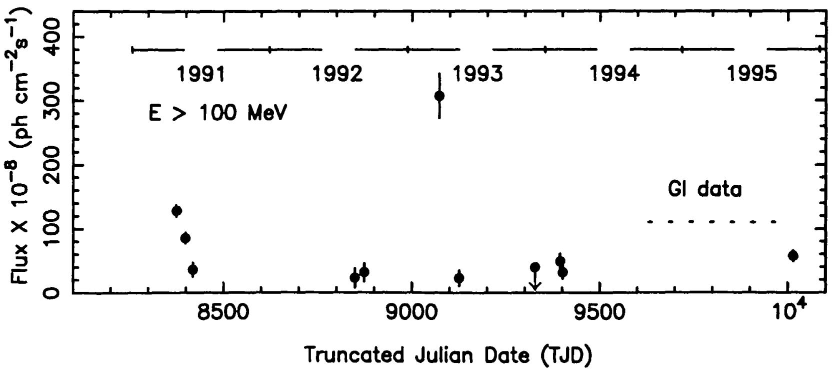

Figure 1. Flux of gamma-rays above 100 MeV from PKS 0528+134 over the period 1991 April to 1995 October (Phases 1 through 5). The Phase 5 data point is from Marscher et al. (1996). 2σ upper limits are shown as downward arrows.

photons cm^2 s^{-1}. A χ^2 test of the data yields a probability of $< 0.1\%$ that the fluctuations are consistent with a constant flux.

2.2. Spectrum

Figure 2 shows the photon spectra of PKS 0528+134 as observed during VP 213.0, when the source was in the 'high' state, and during VP 1.0. The best fit using a single power law model of the form $F(E) = k\left(E/E_0\right)^{-\alpha}$ photons cm^{-2} s^{-1} MeV^{-1} is shown as superimposed solid lines in the figure. Here α is the photon spectral index, and k is the coefficient. The energy normalization factor, E_0, is chosen so that the statistical errors in the power law index and the overall normalization were minimally correlated.

Table 2. EGRET spectral analysis

Viewing Period	Spectral Index	k $\times 10^{-9}$ ph cm^{-2} s^{-1} MeV^{-1}	E_0 MeV	χ^2/n_f of Source
0.2-0.5	2.27 ± 0.07	3.26 ± 0.19	199	1.53
1.0	2.48 ± 0.09	3.33 ± 0.26	172	0.83
213.0	2.21 ± 0.10	8.39 ± 0.77	198	0.78
321.1+321.5	2.45 ± 0.23	2.85 ± 0.46	160	0.70
337[a]	2.68 ± 0.44	2.15 ± 0.57	135	0.52

[a]Sambruna et al. 1996

The best fit parameters for the spectra of PKS 0528+134 in VPs 0.2–0.5, 1.0, 213.0, 321.1+321.5, and 337 are indicated in Table 2. The spectrum of PKS 0528+134 in VP 1.0 is found to be steeper than that in VP 213.0. The results on the spectral indices suggest that there is marginal correlation between the spectral index and the measured flux, with a tendency towards spectral hard-

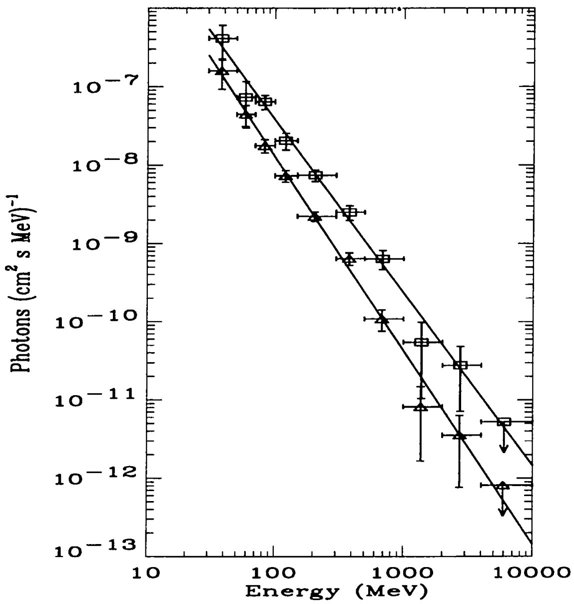

Figure 2. Photon spectra of PKS 0528+134 as observed during VP 1.0 (triangle) and VP 213.0 (square), when the source was in an outburst. The solid lines are the best fits to a single power law model.

ening when the flux from the source is higher. The linear correlation coefficient between the flux and the spectral index, measured for those VPs when the detection significance of PKS 0528+134 was $> 6\sigma$, is -0.87, and the probability that the two variables are not correlated is 13%. A χ^2 test indicates that a slope of zero can be ruled out with a probability of $\sim$ 93% (Mukherjee et al. 1996).

3. Radio light curves

Figure 3 shows the light curves of PKS 0528+134 measured at several different radio frequencies. The flux density measurement at 10.55 GHz was made with the Effelsberg 100-m telescope over a period of 3 years (Pohl et al. 1995). Data at 22 GHz and 37 GHz were obtained at the Metsahovi Radio Research Station, Finland. The radio light curves at 90 GHz and 230 GHz were measured with the Swedish-ESO Submillimeter Telescope (SEST). The epoch of the EGRET 'high' state (VP 213.0) is shown as a broken line. From the figure it is seen that at the time of the gamma-ray flare in VP 213.0 (1993 March), the flux at 32 GHz was at a high level of about 7 Jy. In mid 1993, following the gamma-ray flare, the flux densitiy at 32 GHz reached a maximum of 9 Jy. The flux density at 10.55 GHz remained approximately constant at a high level until the end of 1993. The gamma-ray flare occurred during a time when all except the lowest radio frequencies were rising, which is claimed to be a common occurrence by Valtaoja and Teräsranta (1995). Based on the data presented here, however, we cannot make any conclusive comments on the correlation of the gamma-ray and radio data.

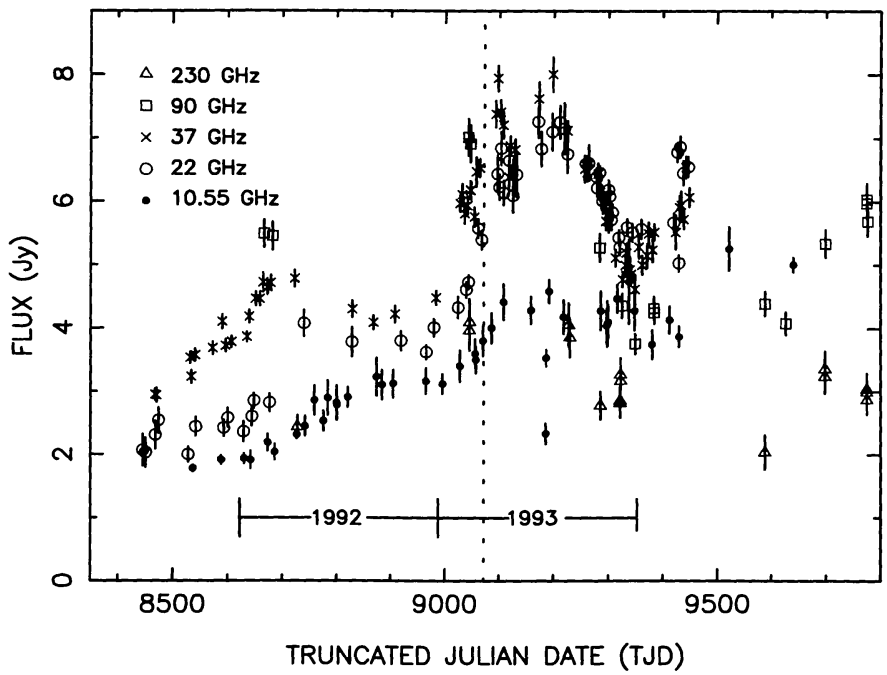

Figure 3. Flux from PKS 0528+134 at radio frequencies (10.55 GHz, 22 GHz, 37 GHz, 90 GHz, and 230 GHz). The broken line corresponds to the period of the EGRET observation (VP 213.0) when the source was in a flaring state.

4. Multiwaveband spectrum

The power per log frequency interval emitted by PKS 0528+134 is shown in Figure 4. Two sets of observations are shown in the figure: those that were simultaneous with the EGRET flare (VP 213.0) are shown as solid circles, while data taken during the gamma-ray 'low' state of PKS 0528+134 (VP 39.0) are depicted as open squares. Details of the individual observations shown in the figure may be found in Mukherjee et al. (1996). The multiwavelength spectrum of the source during the March 1993 flare was fit with the relativistic jet synchrotron self-Compton spectrum model of Marscher and Travis (1996). The superimposed solid lines in Figure 4 correspond to the synchrotron and first-order self-Compton emission from an adiabatic relativistic jet with a truncated cone geometry. The model is found to reproduce the data well. Details of the fit parameters, as well as a discussion of models suggested to explain the production of high energy gamma-rays from quasars is given in Mukherjee et al. (1996). On the basis of the spectrum alone of PKS 0528+134, it is not possible to distinguish between the different models of the production of high energy gamma-rays from quasars.

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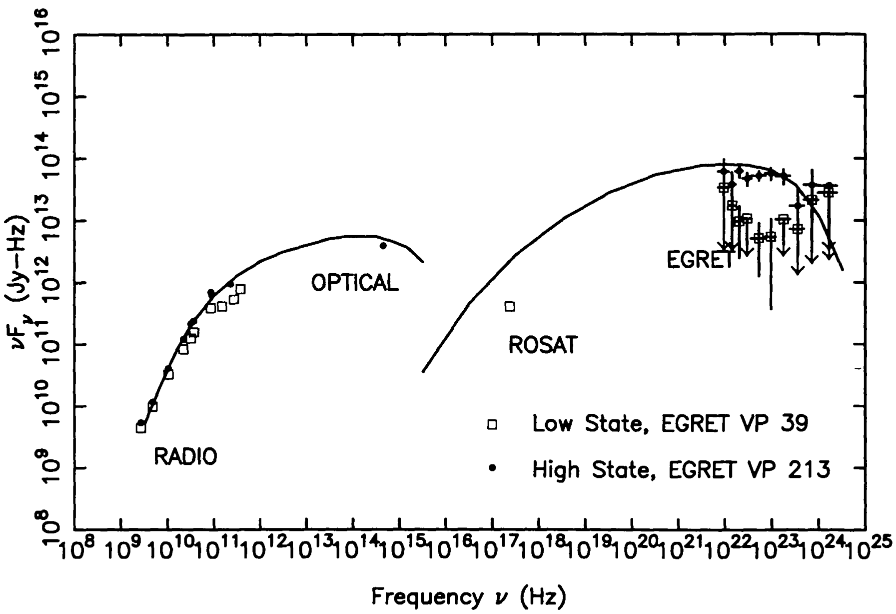

Figure 4. Multiwavelength spectrum of PKS 0528+134 during the 1993 March flare along with a model fit synchrotron self-Compton spectrum from a relativistic jet. EGRET upper limits are shown as downward arrows.

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