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AN INTENSE GAMMA-RAY FLARE OF PKS 1622−297

J. R. Mattox,[1,2] S. J. Wagner,[3] M. Malkan,[4] T. A. McGlynn,[2,5] J. F. Schachter,[6] J. E. Grove,[7] W. N. Johnson,[7] and J. D. Kurfess[7]

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ABSTRACT

We report the observation by the *Compton Gamma Ray Observatory* of a spectacular flare of radio source PKS 1622−297. A peak flux of $(17 \pm 3) \times 10^{-6}$ cm^{-2} s^{-1} ($E > 100$ MeV) was observed. The corresponding isotropic luminosity is 2.9×10^{49} ergs s^{-1}. We find that PKS 1622−297 exhibits γ-ray intraday variability. A flux increase by a factor of at least 3.6 was observed to occur in less than 7.1 hr (with 99% confidence). Assuming an exponential rise, the corresponding doubling time is less than 3.8 hr. A significant flux decrease by a factor of ~2 in 9.7 hr was also observed. Without beaming, the rapid flux change and large isotropic luminosity are inconsistent with the Elliot-Shapiro condition (assuming that gas accretion is the immediate source of power for the γ-rays). This inconsistency suggests that the γ-ray emission is beamed. A minimum Doppler factor of 8.1 is implied by the observed lack of pair-production opacity (assuming X-rays are emitted cospatially with the γ-rays). Simultaneous observation by EGRET and OSSE finds a spectrum adequately fitted by a power law with photon index of −1.9. Although the significance is not sufficient to establish this beyond doubt, the high-energy γ-ray spectrum appears to evolve from hard to soft as a flare progresses.

Subject headings: galaxies: individual (PKS 1622−297) — gamma rays: bursts — gamma rays: observations

1. INTRODUCTION

The Energetic Gamma Ray Experiment Telescope (EGRET) aboard the *Compton Gamma Ray Observatory* is sensitive in the energy range from 30 MeV to 30 GeV (Thompson et al. 1993). It has detected ~50 active galactic nuclei (AGNs) (von Montigny et al. 1995; Thompson et al. 1995; Mattox et al. 1997) in the blazar class [by which we mean the ensemble of BL Lacertae objects, high-polarization quasars (HPQ), and optical violently variable (OVV) quasars]. The absence of pair-production absorption in the EGRET spectra and the fact that only sources that show parsec-scale radio jet structure have been identified as EGRET sources indicate that the hard γ-rays are emitted in a relativistic jet directed toward us.

Most models feature inverse Compton scattering as the γ-ray emission mechanism, but there is not a consensus as to the origin of the low-energy photons, which are scattered. It has been suggested that they might originate within the jet as synchrotron emission (Marascchi, Ghisellini, & Celotti 1992; Bloom & Marscher 1993). This is designated as the synchrotron self-Compton (SSC) process. Another possibility is that the low-energy photons come from outside of the jet. This is designated as the external Compton scattering (ECS) process. Dermer, Schlickeiser, & Mastichiadis (1992) suggested that they come directly from an accretion disk around a black hole at the base of the jet. It was subsequently proposed that the dominant source of the low-energy photons for scattering could be reprocessing of disk emission by broad emission line clouds (Sikora, Begelman, & Rees 1994; Blandford & Levinson 1995; Levinson & Blandford 1995; Levinson 1996). Ghisellini & Madau (1996) suggest that the dominant source of low-energy photons for scattering is broad line region reprocessing of jet synchrotron emission. Hartman et al. (1996) find that the multiwavelength spectra of 3C 279 can be adequately fitted with either a SSC model or an ECS model in both the high and low states.

The correlation of multiwavelength variability promises a means to distinguish the SSC and the ECS models. However, this is difficult because the sensitivity of EGRET is insufficient to resolve variation on timescales shorter than ~1 week when blazars are faint and intense γ-ray flares are infrequent. Because of this, we proposed that a "quicklook analysis" of EGRET data be done to detect a γ-ray flare in progress. This led to our observation of PKS 1622−297.

PKS 1622−297 has not received much attention previously (being located in the Galactic center region, $l = 348\overset{\circ}{.}2$, $b = 13\overset{\circ}{.}2$). It is not cataloged by Hewitt & Burbidge (1987, 1989). No optical polarization measurement, nor search for rapid optical variability, has been previously reported. However, the radio properties indicate that it belongs to the blazar class. A 5 GHz flux density of 1.92 Jy and a spectral index of $\alpha = +0.07$ [$S(\nu) \propto \nu^{\alpha}$] were reported by Kühr et al. (1981). Steppe et al. (1993) report 90 GHz flux densities at three epochs of 1.5, 1.8, and 2.0 Jy and one 230 GHz observation at a flux density of 1.0 Jy. Preston et al. (1985) report a VLBI correlated flux density at 2.29 GHz of 0.29 Jy, 13% of the total. Impey & Tapia (1990) report a 5 GHz radio polarization of 4.6%. It was optically identified by Torres & Wroblewski (1984) at 21 mag, and by Saikia, Ashok, & Cornwall (1987) at 20.5 mag. A redshift of $z = 0.815$ is reported in the PKS catalog (Wright & Otrupcek 1990). PKS 1622−297 was detected by *ROSAT* during the sky survey at a flux of $3.2 \pm 0.8 \times 10^{-15}$ erg cm^{-2} s^{-1} in the 0.1–2.4 keV energy band (Voges 1996).

[1] Astronomy Department, Boston University, 725 Commonwealth Avenue, Boston, MA 02215.
[2] Former affiliation: Astronomy Department, University of Maryland, and Universities Space Research Association.
[3] Landessternwarte Heidelberg-Königstuhl, Königstuhl, D-69117 Heidelberg, Germany.
[4] University of California, Los Angeles, CA 90024.
[5] NASA/GSFC, Greenbelt, MD 20701.
[6] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138.
[7] Naval Research Laboratory, Washington, DC 20375.

2. THE OBSERVATION OF PKS 1622−297 WITH THE *COMPTON GAMMA RAY OBSERVATORY*

PKS 1622−297 has been deeply exposed previously by EGRET. A likelihood analysis (Mattox et al. 1996) of the sum of EGRET exposure for the first half of the mission (1991 April 22–1994 October 4, a total exposure of 1.4×10^9 cm^2 s) yields a 95% confidence upper limit of 0.10×10^{-6} cm^{-2} s^{-1} ($E > 100$ MeV). It was much brighter during our cycle 4 observation. The exposure is given in Table 1 for each cycle 4 viewing period (VP).

The position determined by likelihood analysis (Mattox et al. 1996) with the EGRET data ($E > 100$ MeV, VP 421.0–423.5) is J2000 R.A. = 246°49, Decl. = −29°95. The region of position uncertainty is nearly circular, with a radius of 15′ at 95% confidence. The significance of the detection is 25σ. The γ-ray position estimate is consistent with PKS 1622−297, differing by 6′. We use the method of Mattox et al. (1997) to assess the reliability of this identification. This method uses the number density of potentially confusing sources which are as flat as PKS 1622−297 and as bright at 5 GHz, the fraction of ~1 Jy sources detected by EGRET, and considers where PKS 1622−297 is located in the EGRET position error ellipse. Because flat-spectrum sources with a flux density of at least 1.9 Jy are rare (~1 per 500 deg^2), the identification is good. Assuming a prior probability of 5.4% that PKS 1622−297 is a γ-ray source (this is the fraction of blazars of this radio flux that EGRET detects; Mattox et al. 1997), the formal confidence of a correct identification is 99.6%. We show below that the γ-ray source exhibits dramatic variability. The only type of identified EGRET source that shows this type of variability is the blazar type of AGN. Because PKS 1622−297 is the only bright radio source with blazar properties near the EGRET position, the identification is even more secure than the formal confidence given above.

2.1. *The EGRET Light Curve*

The observations shown in Table 1 have been analyzed to obtain an EGRET light curve for the event energy selection $E > 100$ MeV. The exposure was binned according to the quality of the EGRET sensitivity and the strength of the emission to obtain as much time resolution as possible given the statistical limitations imposed by the very sparse EGRET data. The EGRET sensitivity to PKS 1622−297 was limited because it was observed at a substantial off-axis angle (except during VP 423.5) and the response of EGRET at the time was about half of what it originally was (Sreekumar 1996 indicates a response in VP 423 of 42% of the original response for $E > 100$ MeV) due primarily to degradation of the spark-chamber gas.

Maps of counts and exposure were constructed for adjoining time intervals. A likelihood analysis (Mattox et al. 1996) of these maps was done to obtain flux estimates. The substantial flux of PKS 1622−253 (EGRET team publication, in preparation) was simultaneously fitted in order to include it in a background model. We have also looked carefully at nearby γ-ray source 2EG J1631−2845 during our observation. It is not significantly detected in the sum of VP 421.0 through 423.5. The 95% confidence flux upper limit is 0.18×10^{-6} cm^{-2} s^{-1} ($E > 100$ MeV). A search for a short timescale flare of 2EG J1631−2845 found only the expected indication of variability due to nearby PKS 1622−297.

The result for PKS 1622−297 is shown in Figure 1. The flux is observed to vary dramatically during this observation. A major flare occurred at MJD 49894 (MJD = JD −2400000.5). The maximum flux was $21 \pm 7 \times 10^{-6}$ cm^{-2} s^{-1}) for the 0.14 day bin centered on MJD 49892.77. This small bin was chosen after the analysis of cumulative counts described below. It is expected that this maximum flux is somewhat enhanced by selection. The cumulative counts analysis described below indicates that the apparent decrease in flux between this bin and the subsequent bin has a 1.5% probability of being statistical. A more conservative estimate of the maximum flux of $(17 \pm 3) \times 10^{-6}$ cm^{-2} s^{-1} ($E > 100$ MeV) results from an analysis of the combination of these two bins and the following bin (MJD 49892.7–49893.7).

2.1.1. *An Analysis of Cumulative Counts*

The determination of the minimum timescale of variability of the high-energy γ-ray flux of blazars is not straightforward because of the sparse EGRET statistics. The average flux of PKS 1622−297 in cycle 4 divided by the average EGRET sensitivity is a count rate of ~1 per hr. However, the flare at MJD 49894 to a flux ~5 times this

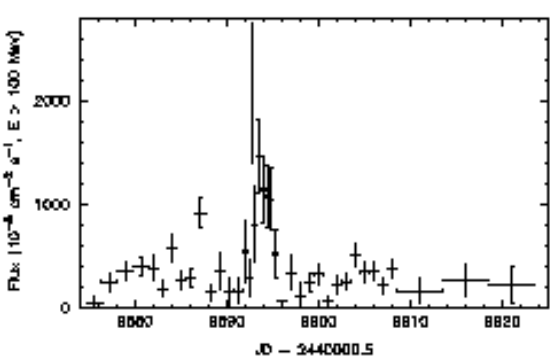

FIG. 1.—EGRET light curve for PKS 1622−297. The horizontal bars show the extent of the time bins. The vertical bars indicate the ranges of the 68% confidence flux estimates.

TABLE 1

GRO EXPOSURE FOR PKS 1622−297 DURING CYCLE 4

Viewing Period	Observation (Gregorian Calendar)	Interval (MJD)	Off-Axis Angle (deg)	EGRET Exposure (cm^2 s)	OSSE Exposure (cm^2 s)
421.....	1995 Jun 6–13	49874.8–49881.6	14	3.6×10^7	0
422.....	1995 Jun 13–20	49881.6–49888.7	14	4.6×10^7	0
423.....	1995 Jun 20–30	49888.8–49898.6	19	3.7×10^7	0
423.5.....	1995 Jun 30–Jul 10	49898.7–49908.5	2	7.7×10^7	2.7×10^8
424.....	1995 Jul 10–25	49908.6–49923.6	35	0.7×10^7	0.9×10^8

NOTE.—EGRET exposure is for the energy selection $E > 100$ MeV.

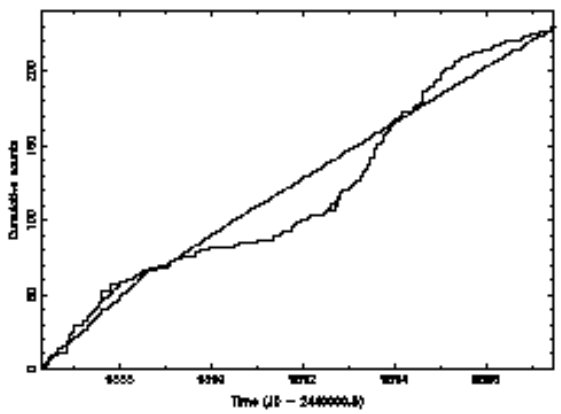

FIG. 2.—Time history of cumulative EGRET counts for PKS 1622−297 is shown with the bold line. Events with $E > 100$ MeV were selected from an energy-dependent cone that includes 68% of the PSF. The cumulative count time history expected for an invariant flux for the entire interval is shown with the continuous thin line. This is an integral of the EGRET effective area, which was determined through an examination of the effective area of each trigger mode for each orbit. The steps are due to Earth occultation during $\sim\frac{1}{3}$ of each 90 minute orbit. Perturbations due to SAA passages and the occasional unavailability of TDRSS satellites for telemetry downlink are also apparent. The two short thin lines show the time histories of invariant flux expected for shorter intervals corresponding to KS tests described in the text.

average potentially provides the statistics to detect variability on a short timescale. Therefore, the data have been examined in detail. The available information is summarized in the time history of cumulative counts shown in Figure 3. This figure indicates that the onset of the MJD 49894 flare was rapid. There were 5 counts detected in the orbit at MJD 49892.72 and 7 counts in the next orbit. In all eight preceding orbits, only 3 counts were detected. Unfortunately, the last of these eight orbits had only a small amount of exposure due to limited availability of TDRSS satellites for telemetry downlink. This increases the difficulty of determining the time and timescale of the flare onset (intensifying the problem caused by sparse statistics).

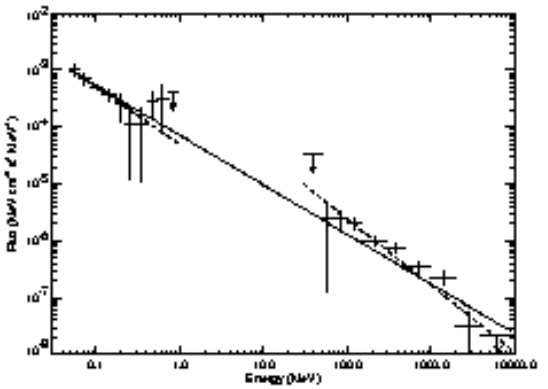

FIG. 3.—Spectrum of PKS 1622−297 for VP 423.5. The observed fluxes are shown as crosses. The horizontal bars show the extent of the energy bins. The vertical bars indicate the 1 σ ranges of the flux estimates. The first 10 energy bins are from CESRa, the last 10 are from EGRET. The best power-law fit to all the data is indicated by the solid line. Power-law fits to the data of each instrument alone are indicated by the dashed lines.

We will begin by finding a timescale for which the significance of a flux increase is beyond dispute. The significance of variability is assessed by a comparison of the observed cumulative counts and those expected for an invariant flux. The standard Kolmogorov-Smirnov (KS) test uses the maximum of the absolute value of the difference between observed and expected cumulative counts. Kuiper's variant of this test (Press et al. 1992) uses the sum of the maximum positive difference and the absolute value of the maximum negative difference. For Figure 2, the maximum positive and negative differences are 18.0 and 31.5 counts respectively. Confirming what is obvious by glancing at Figure 1, the significance of variation using Kuiper's variant of the KS test is 10^{-12} for the interval MJD 49889.5–49897.5.

Now that variability has been established, we may confidently seek variability in shorter intervals. We apply the standard KS test to the 10 orbit interval described above, MJD 49892.192 through 49892.812. The maximum deviation of the observed counts from those expected for invariant flux is 8.5 counts at MJD 49892.68 (where a cumulative 11.5 of 15 counts is expected for invariant flux). The corresponding significance of variability is 6×10^{-5}. The high significance reported above for flux variation in the 8 day interval allows us to obtain this result with not more than ~ 10 trial intervals.

Now that we have established that a significant flux increase occurred at MJD 49892.7, it is possible to examine the extent to which shorter timescale can be deduced. This can be done without substantial trials to dilute the significance of the result because we examine a very limited number of subintervals within the interval for which a significant flux increase has already been established. We apply the KS test to the five orbits ending with the two bright orbits (MJD 49892.517–49892.812). The expected time history of the invariant flux for this interval is shown with a short, thin line in Figure 2. The maximum deviation of the observed counts is 5.7 counts at MJD 49892.68 (where a cumulative 6.7 of 13 counts is expected for invariant flux, and 1 is observed). The standard KS test indicates a flux increase with a significance of 9×10^{-5}. This implies a flux increase in less than 7.1 hr with 99% confidence.

It is conventional to report the observed time for a doubling of the flux. However, it is not possible to measure a doubling time directly in this instance because of limited statistics. A likelihood analysis for the 3 day interval before the flare (9889.7–9892.7) yields a flux of $2.7 \pm 0.9 \times 10^{-6}$ cm^{-2} s^{-1} ($E > 100$ MeV). This flux uncertainty is the 1 σ error. The conservative peak flux obtained above is 17 ± 3. An integration of the probability distribution function for the factor by which the flux increases obtained from the ratio of these two Gaussian distributions (Papoulis 1991),

$$p(r) = \int_0^\infty G_\lambda(ry) G_f(y) y \, dy \, ,$$

indicates with 95% confidence that the flux increase is greater than a factor of 3.6. Assuming an exponential rise, the corresponding upper limit on the doubling time is 3.8 hr.

A rapid flux decrease is also noted. A KS test shows variability (with 99.996% confidence) for the interval MJD 49886.8–49888.6. Two brief intervals of high flux are apparent at MJD 49886.85 and 49887.61. The second is apparent with a KS test at 99.91% confidence for the interval MJD 49887.593–49887.996. The expected time history of the

invariant flux for the latter interval is also shown with a short, thin line in Figure 2. This interval indicates a flux decrease in less than 9.7 hr from a flux of 9 ± 3 (during MJD 49887.468–49887.624) to $3 \pm 2 \times 10^{-6}$ cm^{-2} s^{-1}, $E > 100$ MeV (during MJD 49887.660–49887.946).

It is possible that the timescale of the flux change is not resolved with EGRET, and is much faster.[8] If so, the observations of the proposed GLAST satellite (Michelson et al. 1997) will be of great interest with ~10 times the effective area of EGRET. The possibility of a γ-ray flux change in less than ~1 hr is very interesting. This would severely constrain the size (or the Doppler factor) of the γ-ray emission region.

3. THE SPECTRUM OF PKS 1622−297

The ToO pointing in VP 423.5 led to an OSSE detection (Kurfess et al. 1995). OSSE observes in the 50 keV to 10 MeV energy range. Its small field of view limits its observations to one object at a time so that coordinated observations of specific EGRET targets must be planned in advance or arranged via a ToO. Subsequent to the ToO pointing, OSSE was able to continue monitoring PKS 1622−297 during VP 424 with the reduced sensitivity provided by two of the four detectors at an off-axis angle of 2°.3.

We have obtained an OSSE/EGRET spectrum for VP 423.5 that is strictly simultaneous. The counts matrix and the response matrix for the standard EGRET spectral analysis (Nolan et al. 1993) were converted to the XSPEC format.[9] The XSPEC program was used to simultaneously analyze the EGRET and OSSE results. The result is shown in Figure 3. The OSSE data alone are well represented (reduced $\chi^2 = 0.74$) by a power law with a photon spectral index of -2.0 ± 0.2. The best power-law fit to EGRET data alone has a photon spectral index of -2.2 ± 0.1. With a reduced $\chi^2 = 1.64$, the EGRET fit is adequate but not compelling. It appears to break gradually to a steeper spectrum with increasing energy. Similar convexity is apparent in the EGRET spectra of several other blazars (see von Montigny et al. 1995), especially 1633+382 (Mattox et al. 1993).

Although these OSSE and EGRET spectra have the same index, the normalization of the EGRET spectrum is a factor of 5 larger than that for the OSSE spectrum at 10 MeV. When the OSSE and EGRET data are fitted together with a single power law, the result shown with the solid line in Figure 3 is obtained. The photon spectral index is -1.87 ± 0.02. The fit is not excellent, but acceptable with a reduced $\chi^2 = 1.14$. For comparison, the reduced χ^2 for the total OSSE and EGRET data for the two separate power-law fits described above is 0.86. The F test indicates that the separate fits do not offer a significant improvement (with a 14% chance probability). It is clear that the break at a few MeV to a harder X-ray spectrum that has been reported for four of the five blazars previously detected by both EGRET and OSSE (McNaron-Brown et al. 1996; observations were simultaneous for one object, only contemporaneous for the others) is not apparent for PKS 1622−297.

3.1. *Spectral Evolution*

We examined the EGRET data for evidence of spectral evolution during the flare. The result is shown in the hard/soft scatter plot of Figure 4. We have done a likelihood analysis of the flux for two γ-ray energy bands: the energy intervals 100–300 MeV and $E > 300$ MeV. We analyzed time intervals that were as short as possible to provide sensitivity to spectral evolution on the short timescales seen for flux changes. However, each interval had to be long enough to provide sufficient statistics. Thus, we used shorter time intervals when the flux was large. The intervals were primarily formed by combining the time bins shown in Figure 1. However, the b and c intervals correspond to a single interval in Figure 1. This interval was split after an examination of a scatter plot of event energy versus time indicated that the emission appeared much harder during the first part of the interval. Interval b corresponds to the interval of high flux apparent in Figure 2 at MJD 49886.85. The exact time intervals can be obtained from the caption of Figure 4.

Assuming an invariant spectrum, the ratio of these fluxes is expected to be consistent with that found for an analysis of the total exposure. Under this assumption, it is appropriate to assume the flux ratio observed in the total exposure and fit a single intensity parameter for each time interval. A χ^2 statistic is then obtained by summing the deviation of both energy ranges for each time interval. The result for all 12 time intervals ($\chi^2 = 15.2$ for 12 degrees of freedom) indicates spectral variation with only 77% confidence. We have also done the analysis with three time bins (49876.2–49892.7, 49892.7–49895.6, 49895.6–49908.6) and see colors consistent with an invariant spectrum.

It is interesting that all three intervals that are at a peak in Figure 1 (intervals b, e, and j) are harder than the average. This is consistent with the report of Mukherjee et al. (1996) of a marginally significant indication that the EGRET spectrum of PKS 0528+134 was harder during an interval of

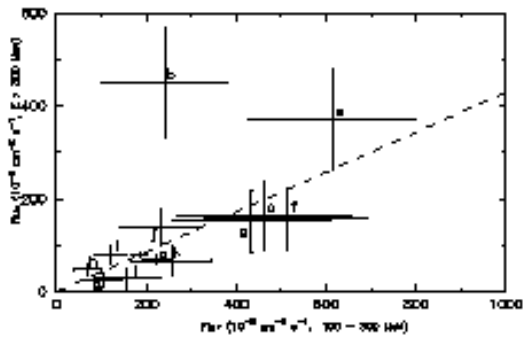

FIG. 4.—Search for the spectral evolution of PKS 1622−297. Each time interval is represented by a cross. The bars indicate the 68% confidence ranges of the flux estimates. The intervals are labeled sequentially with the letters a through l. The interval boundaries are MJD 49876.42, 49886.65, 49887.28, 49887.66, 49892.674, 49893.660, 49894.646, 49895.632, 49902.60, 49903.60, 49904.60, 49905.59, and 49908.57. The bold cross indicates the fluxes found for an analysis of the sum of the entire data set. The dashed line through this bold cross indicates where fluxes would be expected to lie if the spectrum were invariant.

[8] Mattox (in preparation) finds that five of the seven events in the orbit at the end of the brightest part the MJD 49894 flare occurred in the first 10 minutes of that orbit, which corresponds to only 14% of the exposure of the orbit. A KS test indicates a flux decrease within this exposure interval (48 minutes long) with a confidence of 99%. However, because of a substantial number of potential trials, this is not a definitive result.

[9] The conversion program is available: send e-mail to the author (Mattox@bu-ast.bu.edu), or contact personnel at the *Compton Observatory* Science Support Center (WWW URL http://cossc.gsfc.nasa.gov). XSPEC is described at http://legacy.gsfc.nasa.gov/docs/xanadu/xspec/n_manual.html.

high emission than it was during lower emission level intervals. The hardest interval is b for which $\chi^2 = 6.9$ (for 1 degree of freedom). This corresponds to a 2.4 σ deviation from an invariant spectrum. The most energetic PKS 1622−297 event (9.7 ± 1.7 GeV) occurred during this interval at MJD 49886.897. We note that the spectrum appears to evolve from hard to soft (clockwise in Fig. 4) for all three peaks. Further observation is required to confirm this indication of spectral evolution of the γ-ray emission of blazars.

4. MULTIWAVELENGTH OBSERVATIONS OF PKS 1622−297

The large flux of PKS 1622−297 was apparent to the EGRET team during a routine "quicklook" analysis of the VP 421 data. The news of the detection was conveyed to us on 1995 June 14 and triggered our ToO program. Fortuitously, this followed the first week of a 5 week observation of the Galactic center region, which included PKS 1622−297, and this source was opposite the Sun. The detection was announced in an IAU Circular (Mattox et al. 1995). We also notified directly a group of multiwavelength observers who had been previously enlisted. Unfortunately, the nearly antisolar position of PKS 1622−297 at the time prevented X-ray observation by either *ROSAT* or *ASCA*, and the *RXTE* satellite had not yet been launched. Detailed multiwavelength results, including multiwavelength spectra, will be published latter (Mattox, in preparation). We will also report subsequently on possible BATSE and COMPTEL detections and a possible correlation between the EGRET and OSSE fluxes in VP 423.5.

Extensively optical monitoring of PKS 1622−297 commenced when we learned of the EGRET detection. We found that PKS 1622−297 was 3 mag brighter than its quiescent state and that the brightness was observed to vary by as much as 150% in less than 24 hr. Thus, PKS 1622−297 displays optical IDV (intraday variability) as do all other blazars detected by EGRET that have been observed frequently enough for IDV to be detected (Wagner 1996). Several radio observations in the mm band occurred that showed a flux density significantly higher than previously observed. It was also detected by *IUE* (Bonnell et al. 1995), during observations on July 1, 5, 6, and 8, and found to be variable. In collaboration with Alan Marscher, a VLBA observation of PKS 1622−297 was made on 1995 July 25. Subsequent observations will be used to search for a new radio component corresponding to the γ-ray flare.

5. DISCUSSION

The maximum EGRET flux observed from PKS 1622−297 ($17 \pm 3 \times 10^{-8}$ cm^{-2} s^{-1}, $E > 100$ MeV) was a factor of 2 larger than that of the Vela Pulsar, which is normally the brightest EGRET source. It is a factor of 4 larger than the flux of 3C 279 at the peak of the 1991 flare (Kniffen et al. 1993). A peak energy flux of 1.6×10^{-9} ergs cm^{-2} s^{-1} for the observed energy range from 30 MeV to 10 GeV is obtained for PKS 1622−297 assuming a power-law spectrum with photon index of −1.9. The corresponding isotropic luminosity is 2.9×10^{49} erg s^{-1} assuming a Friedmann universe with $q_0 = 1/2$ and $H_0 = 75$ km s^{-1} Mpc^{-1}. For this luminosity to be less than the standard Eddington limit, the central black hole mass must exceed $2 \times 10^{11} M_\odot$. However, the standard Eddington limit does not pertain to the γ-ray luminosity because the Compton scattering cross section in the Klein-Nishina regime is much smaller than the Thomson cross section (Dermer & Gehrels 1995; Pohl et al. 1995). Using the expression of Dermer & Gehrels (1995) for the cross section in the Klein-Nishina regime for an EGRET flux of 70×10^{-8} cm^{-2} s^{-1} ($E > 30$ MeV), the lower limit for the mass of the PKS 1622−297 black hole is $8 \times 10^8 M_\odot$. The corresponding limit on the Schwarzschild radius is $R_s > 2.5 \times 10^{14}$ cm.

We apply the "Elliot-Shapiro argument" (Elliot & Shapiro 1974; Dermer & Gehrels 1995; Pohl et al. 1995; Dondi & Ghisellini 1995; we note that they err in assuming the Thomson cross section for Compton scattering in the Klein-Nishina regime) to establish that the γ-ray emission must occur in a relativistic jet by showing that a contradiction follows otherwise. Under the assumption that the γ-ray emission is unbeamed, the observed upper limit on the doubling time of $z = 3.8$ hr implies that the extent of the emission region is less than $cz/(1+z) = 2.2 \times 10^{14}$ cm. The fact that this upper limit is less than lower limit for R_s suggests that the γ-ray emission occurs in a medium that is moving relativistically with a lateral extent less than $cz\delta/(1+z) = 2.2 \times 10^{15}(\delta/10)$ cm, and an extent along the jet of less than $cz\delta^2/(1+z) = 2.2 \times 10^{17}(\delta/10)^2$ cm, where $\delta = \gamma^{-1}(1 - \beta\cos\theta)^{-1}$ is the relativistic Doppler factor, θ is the angle between the jet axis and the line of sight, and $\gamma = (1-\beta^2)^{-1/2}$, where β is the bulk velocity in units of the speed of light. This argument assumes that the accretion of optically thin material is the immediate source of power for the γ-rays. This may not be the case. Accretion energy could be stored in the rotation of a black hole, or in magnetic fields to power the γ-ray flare; or the γ-ray flare could result from the accretion of a star. Also, for a Kerr black hole, emission could occur as close as $R_s/2$.

Another argument for γ-ray emission in a relativistic jet can be made from the lack of γ-γ absorption in the γ-ray spectrum. If the emission does not take place in a relativistic jet, the γ-ray emission would be absorbed by γ-ray/X-ray pair production. Mattox et al. (1993) derived the expected optical depth under the assumption that the X-rays are produced cospatially with the γ-rays. Their expression was in error due a misunderstanding of the definition of luminosity distance. The corrected expression (assuming a Friedmann universe with $q_0 = \frac{1}{2}$) is

$$z = 2 \times 10^5 (1+z)^{(2\alpha)} (1 + z - \sqrt{1+z})^2 h_{75}^{-2} T_5^{-1} \times \frac{F_{1\,\mathrm{keV}}}{\mu\mathrm{Jy}} \left(\frac{E_\gamma}{\mathrm{GeV}}\right)^\alpha , \quad (1)$$

where T_5 is the timescale of variation in units of 10^5 s, $F_{1\,\mathrm{keV}}$ is the observed X-ray flux at a keV, α is the X-ray energy spectral index, $F(\nu) \propto \nu^{-\alpha}$, E_γ is the γ-ray energy, and $h_{75} = H_0/(75$ km s^{-1} Mpc$^{-1})$. The luminosity distance error of Mattox et al. (1993) also affected their expression for the lower limit of the Doppler factor. The corrected expression is

$$\delta \geq \left[5 \times 10^{-4} (1+z)^{-2\alpha} (1 + z - \sqrt{1+z})^{-2} h_{75}^2 T_5 \times \left(\frac{F_{1\,\mathrm{keV}}}{\mu\mathrm{Jy}}\right)^{-1} \left(\frac{E_\gamma}{\mathrm{GeV}}\right)^{-\alpha} \right]^{-(4+2\alpha)^{-1}} . \quad (2)$$

Assuming a spectral index ($\alpha = 0.7$) typical of blazars, the *ROSAT* sky survey flux for PKS 1622−297 is $F_{1\,\mathrm{keV}} = 0.054$

μJy. The corresponding optical depth from equation (1) is

$$\tau = 330\left(\frac{E_\gamma}{\mathrm{GeV}}\right)^{0.7}.$$

No indication of such absorption is apparent in the spectrum of Figure 3. The lower limit for the Doppler factor from equation (2) (for $h_{75} = 1$, and $z < 1$ for $E_\gamma = 3$ GeV) is $\delta \geq 8.1$. We note that the X-ray observation was not simultaneous. If it were a factor of 3 lower during the γ-ray flare, the lower limit on δ would decrease to 6.6.

6. CONCLUSIONS

We report the brightest, most luminous γ-ray blazar ever detected. It shows the most rapid γ-ray flux change yet seen for any blazar, with a flux doubling time of less than 3.6 hr. This is the first observation of γ-ray IDV for a blazar. We show that the Elliot-Shapiro argument and the lack of γ-γ absorption of γ-rays indicate that the emission occurred in a relativistic jet.

Our results are not inconsistent with the prediction of Ghisellini & Madau (1996) of an invariant γ-ray spectrum throughout the flare. If their model of Compton scattering of synchrotron photons reprocessed in the broad-line region pertains, the light curve shown in Figure 1 might indicate the radial profile near the jet of the density of the broad-line region. Romanova & Lovelace (1996) have also developed a model for γ-ray blazar flares, which is consistent with our data. In their model, flares occur when electrons are accelerated by a shock in the jet.

Our results do not demonstrate the soft to hard spectral evolution expected for a γ-ray emitting jet component emerging from a γ-ray photosphere (Blandford & Levinson 1995; Levinson & Blandford 1995; Levinson 1996). However, a comparison of a detailed calculation based on their model to these data must be done before quantitative limits can be placed on their model. Although the statistics of this exposure are not sufficient to establish this beyond doubt, the high-energy γ-ray spectrum appears to evolve from hard to soft as a flare progresses, the opposite of the prediction of this model.

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