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OBSERVATIONS OF A CORRELATED GAMMA-RAY AND OPTICAL FLARE FOR BL LACERTAE

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ABSTRACT

BL Lacertae was detected by the EGRET instrument on the *Compton Gamma Ray Observatory* at the 10.2 σ level with an average flux of $(171 \pm 42) \times 10^{-8}$ photons $\mathrm{cm^{-2}\ s^{-1}}$, at energies greater than 100 MeV, during the optical outburst of 1997 July. This flux is more than 4 times the previously highest level. Within the July 15–22 observation there was a dramatic factor of 2.5 increase in the gamma-ray flux on July 18.75–19.08, apparently preceding, by several hours, a brief optical flare. The gamma-ray flux decreased to its previous level within 8 hr, and the optical flux decreased to its prior level in less than 2 hr. The gamma-ray photon spectral index of 1.68 ± 0.12 indicates that the spectrum during the 7 day observation was harder than the previous detection.

Subject headings: BL Lacertae objects: individual (BL Lacertae) — galaxies: active — gamma rays: observations

1. INTRODUCTION

BL Lacertae ($z = 0.069$) is one of about 60 blazars that have been detected by the EGRET instrument on the *Compton Gamma Ray Observatory* (*CGRO*) over the last 6 yr (Hartman et al. 1997). Although bright and variable across most of the electromagnetic spectrum, it has not been an outstanding gamma-ray source before this most recent outburst (Catanese et al. 1997 and references therein). This object was first detected at gamma-ray energies greater than 100 MeV by EGRET in 1995 (Catanese et al. 1997; see Fig. 1), but prior to this, BL Lac gamma-ray observations only yielded upper limits. During a recent optical outburst of BL Lac (Noble et al. 1997; Maesano et al. 1997) the *CGRO* was repointed to observe the BL Lac flare in gamma rays. BL Lac is the prototypical object for a class of active galactic nuclei (AGNs) that typically have very weak emission and absorption lines and are characterized by variability in continuum emission and polarization (Peterson 1997). Approximately 20% of those blazars detected by *CGRO* are BL Lac objects, and the rest are flat-spectrum radio quasars (FSRQs). Although some gamma-ray properties are similar for these two classes, BL Lac objects tend to have lower flux and less prominent variability than FSRQs (Mukherjee et al. 1997).

The nature of the high-energy gamma-ray emission of blazars has been disputed, with several models fitting data well for particular sources at specific times (e.g., Hartman et al. 1996). However, most processes discussed in the literature are of the inverse Compton type. Inverse Compton emission is a natural consequence of high soft-photon densities in the vicinity of the relativistic electron populations of blazar jets. If the seed photons are created via synchrotron emission in the jet and then scatter off the same population of electrons that produced them (synchrotron self-Compton or SSC; see Bloom & Marscher 1996), the gamma rays will be observed to vary simultaneously with the low-energy photons (submillimeter through optical). In the external scattering "mirror" model of Ghisellini & Madau (1996), the optical outburst would lead the gamma rays by roughly 1 day, since the optical emission is created via synchrotron emission within the jet, and the optical photons are then scattered off the broad-line–region clouds and back into the jet, where they are scattered finally by the relativistic electrons, producing high-energy gamma rays. The multiple relativistic Doppler boots involved greatly enhance the observed gamma-ray emission. External scattering models that involve soft optical photons from an accretion disk (Dermer & Schlickeiser 1993) are much harder to test, since it is likely that the optical spectra of blazars are dominated by synchrotron emis-

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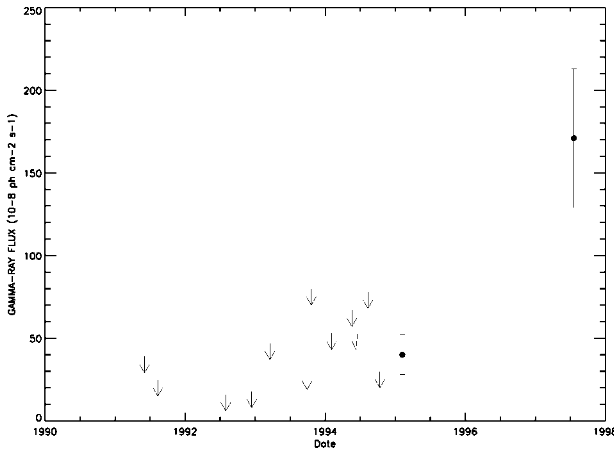

FIG. 1.—Complete time history of EGRET gamma-ray observations for BL Lacertae. Until 1995 January, this source was not detected. The arrows represent 95% confidence (2 σ) upper limits

sion from the jet, which "washes out" the optical emission from an accretion disk. However, in this case one would also expect optical emission leading the gamma-ray emission.

Section 2 will summarize the gamma-ray and optical observations, and § 3 will discuss the results in light of the processes mentioned above.

2. OBSERVATIONS

During 1997 July 15–22, the EGRET instrument observed the region centered on BL Lac in narrow field-of-view mode, which effectively looks at gamma-ray sources within 20° of the *CGRO* pointing axis. Details of the EGRET instrument can be found in (Hartman et al. 1992). Maps of the photon counts were created using the standard techniques. We initially broke up the 7 day total exposure into seven 1 day maps and then broke up the fourth 1 day map into three equal 8 hr intervals, once it was established that the gamma-ray emission peaked on the fourth day. A maximum likelihood analysis (Mattox et al. 1996) was performed on the map in order to determine fluxes for individual sources, taking into account the Galactic diffuse background model of Hunter et al. (1997) and the extragalactic diffuse model of Sreekumar et al. (1998). The gap of several hours seen between the points for days 3 and 4 of the gamma-ray observations (Fig. 2) was caused by a scheduled loss of telemetry.

Degradation of the EGRET spark chamber gas has led to a decreased efficiency in detecting gamma rays, mainly because of the reduced capability of characterizing "good" gamma-ray events. Thus, scale factors have been applied to the current data, so that they are calibrated consistently with data acquired at earlier points in the EGRET mission (see Esposito et al. 1997 for details of the in-flight calibration). These scale factors are determined by taking the ratio of the average intensity of the diffuse emission from a well-studied region of the sky (and at a given energy interval) from early in the mission and the diffuse emission from the same region at the later time of interest. Since the Galactic diffuse emission is not expected to show any time variability, the diminished intensity is completely a result of decreased instrument performance. Thus, these scale factors represent an accurate relative calibration of the EGRET data with time. Prior to this observation, a scale

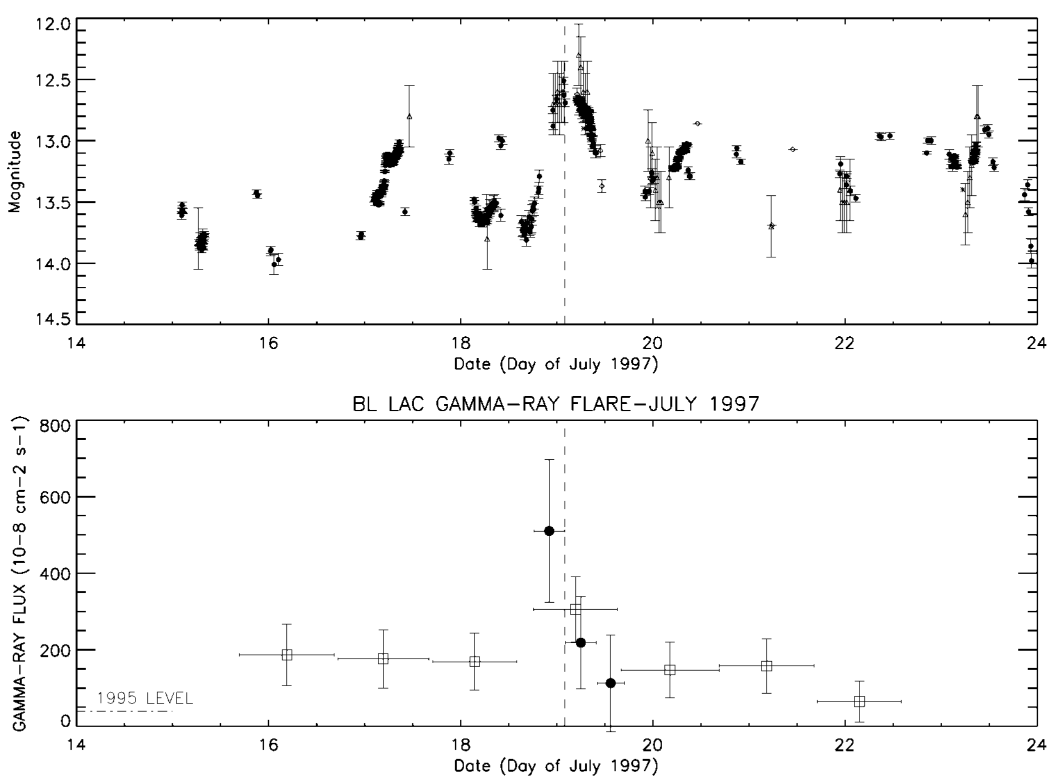

FIG. 2.—Optical and gamma-ray light curves for the 1997 July flare. Both plots show that there was a peak on July 19. *Top:* Visual magnitudes (recorded by eye) corrected for $V-R=0.7$ (*triangles*); V magnitudes recorded by CCD with V filter (*asterisks*); R magnitudes of Ma & Barry (1997) (*diamonds*); R- and V-band data acquired by the authors at the sites mentioned in the text (*circles*). The dashed vertical line crossing both plots shows the end of the gamma-ray flare, for comparison with the optical flare.

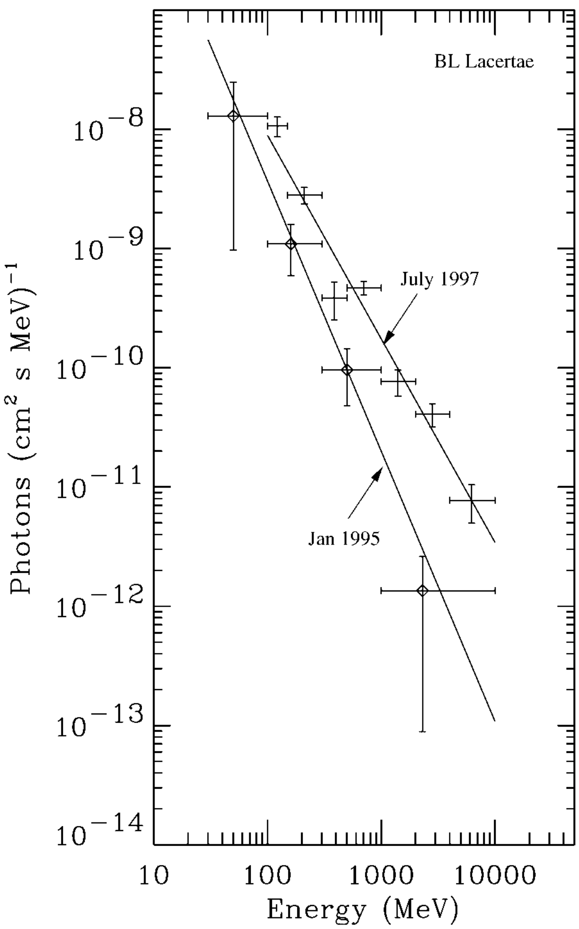

FIG. 3.—Gamma-ray spectra for BL Lac. The most recent data (1997 July) suggest that the spectrum has hardened, as compared to the earlier measurement of 1995 January.

factor of 1.6 was calculated. We have now determined an additional scale factor of 2.02 (total scaling is 1.6 × 2.02 = 3.2) with an uncertainty of 20% determined by recent analysis. Of course, the amplitude of this flare relative to previous measurements depends on the size of this correction, but this does not affect relative variations within a viewing period.

Visual magnitudes were determined by several amateur observers, and these results were retrieved from the American Association of Variable Star Observers (AAVSO) database (J. A. Mattei 1997, private communication). Though all of the observers have used the same comparison stars, many magnitude determinations were made by eye, and thus there may be some scatter in the measurements that is not intrinsic to the source (these measurements also have large error bars). However, in Figure 2 we see that there is agreement between visual magnitudes determined by eye and those determined by a CCD. R magnitudes measured using the 16 inch (~41 cm) telescope of Foggy Bottom Observatory (Colgate), the 0.4 m telescope at Georgia State University, the 0.4 m telescope at Perugia University Observatory, the 0.5 m telescope at Vallinfreda, Italy, the 0.7 meter telescope at Landessternwarte Heidelberg, and the Kyung Hee University telescope are used, along with R magnitudes from Ma & Barry 1997. The $V-R$ color is approximately 0.7, and we have applied a Δm correction of 0.7 to the AAVSO data and to our V-band data (from the Italian sites) to place them on the same scale as the R-band data. We note that BL Lac was also detected by the OSSE instrument in the 50–300 keV range (Grove & Johnson 1997) and was observed to vary in the X-ray range at 2–10 keV with both *RXTE* and *ASCA* (Makino et al. 1997; Madejski et al. 1997).

3. DISCUSSION

From Figure 1 we can see clearly that the average gamma-ray flux is at least 4 times the value from 1995. Also, this measurement is 12 times greater than the summed 95% confidence upper limit for phases 1–3 (Catanese et al. 1997). Though the precise peak of the gamma-ray flare is uncertain, Figure 2 suggests that there is a lag of several hours between the peak optical and peak gamma-ray measurements. Unfortunately, the sampling of the optical data does not completely rule out the possibility of a very rapid optical flare, of larger amplitude than the observed optical peak, occurring during the peak of the gamma-ray flare (or preceding it). However, the gamma-ray flux had already decreased by the time of the peak optical magnitude. We do note that, as there were many other comparable optical flaring events during this time period, we cannot be certain that the peak of the gamma-ray outburst is physically related to this optical maximum. In addition, the exact value of the gamma-ray fluxes are somewhat dependent on the arbitrary binning used here. Comparable effects have been seen for other blazars. For the blazar PKS 1406−076, the gamma-ray peak lagged behind the optical peak by one day (Wagner et al. 1995). The 1991 June flare of 3C 279 showed a similar effect (Hartman et al. 1996). However, none of these observations had optical data that were as densely sampled as this most recent observation of BL Lac. In order to determine the best model for the high-energy emission, the relative lags must be determined accurately.

One possibility is that the gamma rays are created via SSC emission from electrons accelerated in a front, possibly a shock, moving through a jet (Romanova & Lovelace 1997; Marscher 1996). However, if the optical emission lags behind the gamma-ray emission, then the optical flare cannot be the source of soft photons for the gamma-ray flare, unless the emitting region is initially optically thick to optical radiation. Such extreme opacity conditions have not been previously observed for outbursts of blazars. The near simultaneity of the gamma-ray and optical peaks (with the possible delay of several hours) rules out external scattering models mentioned above.

Figure 3 shows that the gamma-ray spectrum was harder during this flare, as compared to that during the previous detection (a photon spectral index of 1.68 ± 0.16 for the recent detection and 2.27 ± 0.30 for the earlier observation; Catanese et al. 1997). Spectral hardening during gamma-ray flares has been seen previously for other blazars (Sreekumar et al. 1997; Mukherjee et al. 1996, 1997) and is likely caused by injection of higher energy electrons that scatter soft photons preferentially to the higher energies of the EGRET range. It is possible that second-order energy dependencies of the scale factor mentioned above could contribute, in part, to this spectral hardening.

To our knowledge, this is the first Target-of-Opportunity study of a blazar that has made extensive use of observations conducted by the international amateur astronomy community. We suggest that other investigators make use of this valuable resource in future studies. We also wish to stress the importance of including optical monitoring telescopes on future X-ray and gamma-ray satellites, since it is likely that some of the confusion over time correlation of flares would be resolved by such instruments.

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