RAPID SYNCHROTRON FLARES FROM BL LACERTAE DETECTED BY ASCA AND RXTE

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ABSTRACT

We report the variable X-ray emission from BL Lacertae detected in the ASCA ToO observation conducted during the EGRET and RXTE pointings, coincident with the 1997 July outburst. The source showed a historically high state of X-ray, optical, and γ-ray emission, with its 2–10 keV flux peaking at ~3.3 × 10⁻¹¹ ergs cm⁻² s⁻¹. This is more than 3 times higher than the value measured by ASCA in 1995. We detected two rapid flares that occurred only in the soft X-ray band, while the hard X-ray flux also increased, but decayed with a much longer timescale. Together with the requirement of a very steep and varying power law dominating the soft X-ray band in addition to the hard power law, we suggest that both the high-energy end of the synchrotron spectrum and the hard inverse Compton spectrum were visible in this source during the outburst. We discuss the possible origins of the observed variability timescales, and interpret the short timescales of the soft X-ray variability as reflecting the size of the emission region.

Subject headings: BL Lacertae objects: individual (BL Lacertae) — galaxies: active — radiation mechanisms: nonthermal — X-rays: galaxies

1. INTRODUCTION

Rapid variability, nonthermal emission observed from radio to γ-rays, and very weak emission lines are the main characteristics of BL Lac objects. Those objects are a subclass of blazars, and the most promising explanation for these characteristics is the scenario in which the radiation is emitted by energetic electrons contained in a relativistic jet. This jet points close to the line of sight, and thus the radiation is beamed and Doppler-boosted (Blandford & Konigl 1979).

Recently, many simultaneous multiwavelength observations have been made, providing important tests for the emission mechanisms in blazars. The broadband spectra of blazars consist of two peaks, one in the radio to optical-UV range (and in some cases, reaching to the X-ray band), and the other in the X-ray to γ-ray region. From the high polarization of the radio to optical emission, the lower energy peak is believed to be produced via the synchrotron process by relativistic electrons in the jet. The higher energy peak is believed to be produced via the synchrotron process emitted by energetic electrons contained in a relativistic jet. These characteristics is the scenario in which the radiation is beamed and Doppler-boosted (Blandford & Konigl 1979).

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Several possibilities exist for the source of the seed photons; these can be the synchrotron photons internal to the jet (e.g., Jones, O’Dell, & Stein 1974; Ghisellini & Maraschi 1989), but also external, such as from the broad emission-line clouds (Sikora, Begelman, & Rees 1994) or from the accretion disk (Dermer, Schlickeiser, & Mastichiadis 1992; Dermer & Schlickeiser 1993). BL Lac objects are often separated into two groups by whether the synchrotron peak frequency is in the UV–X-ray region (HBLs, or high-energy peaked BL Lacs) or in the IR–optical region (LBLs, or low-energy peaked BL Lacs) (Padovani & Giommi 1996; Sambruna, Maraschi, & Urry 1996; Kubo et al. 1998).

BL Lacertae is the prototype object for the BL Lac class and thus is one of the best-studied blazars; it is an LBL. The active nucleus lies in a giant elliptical galaxy at a redshift of 0.069 (Miller, French, & Hawley 1978). While the optical and UV spectra of BL Lac type objects are usually devoid of emission lines, the unusual aspect of BL Lacertae is the relatively recent appearance of optical emission lines (Vermeulen et al. 1995; Corbett et al. 2000), obscuring the boundary between quasars and BL Lacs. Other than the emission lines, LBLs tend to have properties intermediate between quasars and HBLs, such as luminosities or frequencies where the peaks are located (Kubo et al. 1998; Ghisellini et al. 1998; Fossati et al. 1998). The 1988 Ginga observation of BL Lacertae showed that the X-ray spectrum of BL Lacertae is relatively flat, with a photon index of 1.7 to 2.2, and located above the extrapolation of the optical-UV continuum (Kawai et al. 1991). In 1995 it was observed with ASCA, showing the photon index Γ = 1.94 ± 0.04 (Madejski et al. 1999; Sambruna et al. 1999); it was also observed by ROSAT, which showed Γ = 1.94 ± 0.46 (Urry et al. 1996), and by Einstein, where the index was 1.68 ± 0.18 (Bregman et al. 1990). In 1995, the γ-ray emission above 100 MeV was detected for the first time by the EGRET instrument onboard the Compton Gamma Ray Observatory, or CGRO (Catanese et al. 1997).

BL Lacertae was observed by ASCA following the report of a major outburst in 1997 discovered by optical observations (Noble et al. 1997; Maesano, Massaro, & Nesci 1997). Such outbursts are particularly valuable for investigating correlations between different wavelengths, which led many observatories to point at BL Lacertae. EGRET...
observations indicated that the flux level above 100 MeV was 3.5 times higher than that observed in 1995 (Hartman et al. 1997; Bloom et al. 1997). It was also detected in the 50–300 keV OSSE range (Grove & Johnson 1997), and 2–10 keV *RXTE* range (Madejski, Jaffe, & Sikora 1997; Madejski et al. 1999). Intraday time variability was observed in the optical band (Massaro et al. 1998; Nesci et al. 1998) and in the X-ray band with *ASCA* (Makino et al. 1997). Fits to the spectral energy distributions have been done by several authors, and interestingly, they all argue that the high-energy emission detected from BL Lacertae is likely to reveal Comptonization of both internal (synchrotron) and external (broad-line) photons (Madejski et al. 1999; Sambruna et al. 1999; Bottcher & Bloom 2000).

In this paper, we present and interpret the results of the *ASCA* observation of BL Lacertae, together with the simultaneous *RXTE* observations. The observations are presented in §2. In §3, we describe in detail the different variability patterns seen in the soft and hard X-ray bands; in §4, we discuss the radiative processes responsible for the X-ray emission, and summarize our results in §5.

2. OBSERVATIONS AND DATA REDUCTION

We observed BL Lacertae with *ASCA* during 1997 July 18.60–19.62 UT. The data were extracted by using the standard *ASCA* procedures for SIS (Solid State Imaging Spectrometer; Burke et al. 1991; Yamashita et al. 1997) and GIS (Gas Imaging Spectrometer; Ohashi et al. 1996). GIS was used in the PH-nominal mode, and SIS was used in 1 CCD mode. Source photons were extracted from a circular region centered at the target with 3̊ and 6̊ radii for SIS and GIS, respectively. The background data were taken from source-free regions in the same respective images. During the net exposure of 37 ks for SIS and 60 ks for GIS, the average count rates in the energy range of 0.7–7 keV were 0.47 count s⁻¹, 0.41 count s⁻¹, 0.33 count s⁻¹, 0.43 count s⁻¹, for SIS0, SIS1, GIS2, GIS3, respectively. The *RXTE* data were the same as presented in Madejski et al. 1999.

During the 1997 July outburst, BL Lacertae was monitored intensively in the optical, and in the high-energy γ-rays by EGRET. Comparing the optical and γ-ray light curves measured over the 10 day span shown in Figure 2 of Bloom et al. 1997 to the *ASCA* light curve shown in Figure 1, one can see that our 1 day observation occurred exactly at the time of the correlated optical / γ-ray flare. In the top and middle panels of Figure 1, we plot the soft (0.7–1.5 keV) and hard (3–7 keV) X-ray light curves. The X-ray flare—which occurred close to the time of the optical and GeV γ-ray flares—is strongly suggestive of a correlation of emission in the three wave bands. During the increase of the X-ray flux by a factor of nearly 4, the flux increased by a factor of 2.5 in the EGRET band (30 MeV–30 GeV), and a factor of 4 in the optical band (Bloom et al. 1997). However, we must note that the correlation (and any lags) cannot be precisely measured because of the rather sparse sampling and limited sensitivity of EGRET (but should be accomplished by the upcoming missions such as *GLAST*).

Most important, we discovered an apparent difference between the soft and hard X-ray variability, and this is well illustrated in the bottom panel of Figure 1, showing the time series of the calculated hardness ratio. In the soft X-ray band, we detected two rapid flares with the rise and decay times on the order of 2–3 hours. The hard X-ray flux also flared up, but with a somewhat smaller amplitude, and decreased with a longer timescale. This suggests that two separate emission processes may be responsible for the X-ray emission from this source. We also had two simultaneous *RXTE* observations, labeled [a] and [b] in Figure 1, which extended our energy range up to 20 keV.

The average 2–10 keV flux during the observation was \(\sim 2.6 \times 10^{-11} \text{ ergs cm}^{-2} \text{ s}^{-1}\), which is about 3 times higher than the flux level above 100 MeV observed in 1995. The soft power law appears to dominate the lower energy X-ray band during the flare state.
than the previous ASCA observation in 1995 (Madejski et al. 1999; Sambruna et al. 1999). We fitted the ASCA spectrum with a power law with absorption (model wabs + pegpwrlw using XSPEC version 10.0). We fixed the absorption at the Galactic value, $N_H = 4.6 \times 10^{21}$ atoms cm$^{-2}$, which is a sum of gas columns measured in H and CO as summarized in Madejski et al. (1999). Here the ASCA data (using 0.7–7.0 keV) showed a significant excess below ~1 keV. The excess is also indicated from the low value of absorption when it was allowed to vary in the fitting process. On the other hand, the simultaneous RXTE data (using 3–20 keV) are well fitted by the same model. The fitting results are summarized in Table 1. We also found an indication of harder spectrum compared with previous observations in 1995 by ASCA ($\Gamma = 1.94 \pm 0.04$; Madejski et al. 1999) and in 1988 by Ginga ($\Gamma = 1.7 \pm 0.1, 2.2 \pm 0.2$; Kawai et al. 1991).

3. THE TWO-COMPONENT NATURE AND VARIABILITY OF THE X-RAY SPECTRUM

Because the source was varying, we first selected two sets of spectra including the two pairs of RXTE and ASCA data sets, labeled [a] and [b] in Figure 1. Note that one set was during a state of relatively low flux (which is still higher than the 1995 value) and the other close to the maximum of the flaring state; this provided two different flux states for a comparison of the spectra. As reported in Madejski et al. (1999), spectral variability (although at a modest level) was seen among various segments of the RXTE observation.

Before performing joint spectral fits to the ASCA and RXTE data, we selected the common energy range of 3–7 keV for both data sets to verify the consistency between the two instruments. In selecting the same time regions for ASCA, we extended the time intervals to 5 ks in order to collect a sufficient number of counts. We fitted both ASCA and RXTE data with a single power law plus Galactic absorption model. For all the spectral fitting hereafter, we combined the data from 2 SISs and 2 GISs for the ASCA data, and the data from PCU 0, 1, and 2 for the PCA data. The resulting best fits for region [a] and [b] for ASCA were: photon index $\Gamma = 1.5 \pm 0.4$ and $1.4 \pm 0.2$, with 3–7 keV flux $F_{3-7\text{keV}} = 1.1 \pm 0.1$ and $1.67 \pm 0.09 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$. For the RXTE data, they were: $\Gamma = 1.60 \pm 0.15$ and $1.4 \pm 0.1$, $F_{3-7\text{keV}} = 1.28 \pm 0.04$ and $1.95 \pm 0.04 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$. This indicates that the photon indices are consistent, but the flux inferred by the RXTE is larger by ~10%. Regarding this as an uncertainty of the calibration of two instruments, we added a multiplying parameter (constant in XSPEC) to account for the difference in the normalization. We fixed the value to 1 for ASCA, and allowed it to vary for RXTE. We fitted the 3–7 keV spectrum of ASCA and RXTE together, and resulted with a normalization factor of RXTE to be $1.1 \pm 0.1$ and $1.16 \pm 0.06$ for regions [a] and [b].

We then fitted the full 0.7–20 keV combined data set with a single power law plus Galactic absorption model, with the normalization of the PCA data kept free. We found that although the single power-law model provides an adequate fit to the low state spectrum [a], it is rejected for the flaring state spectrum [b] at a confidence level of more than 99.9%. Thus we fitted the spectrum [b] with an additional soft power law, where the fit improved to be acceptable. Again,

### Table 1

| Instrument | Date (UT) (July 1997) | $N_H$ ($\times 10^{21}$ cm$^{-2}$) | $\Gamma$ | $F_{2-10\text{keV}}$ ($\times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$) | $\chi^2 \text{ (dof)}$ |
|------------|------------------------|------------------------------------|---------|-------------------------------------------------|-----------------|
| SIS ....... | 18.60–19.62            | 4.6$^a$                            | 1.75 ± 0.01 | 2.52 ± 0.03 | 1.93 (313) |
|            |                        | 2.7 ± 0.1                          | 1.51 ± 0.02 | 2.71 ± 0.03 | 1.93 (313) |
| GIS ....... | 18.60–19.62            | 4.6$^a$                            | 1.72 ± 0.01 | 2.61 ± 0.02 | 2.98 (375) |
|            |                        | 0.9 ± 0.1                          | 1.39 ± 0.02 | 2.78 ± 0.03 | 1.84 (372) |
| PCA ....... | 18.78–18.80 ([a])      | 4.6$^a$                            | 1.58 ± 0.06 | 2.50 ± 0.01 | 0.72 (42)   |
| PCA ....... | 19.30–19.32 ([b])      | 4.6$^a$                            | 1.44 ± 0.03 | 3.72 ± 0.01 | 0.85 (43)   |

**Note:** All errors are 1σ.

$^a$ Fixed to Galactic absorption.

### Table 2

| Model | $\Gamma_1$ | $F_1^2$ | $\Gamma_2^1$ | $F_2^2$ | $\chi^2 \text{ (dof)}$ |
|-------|------------|---------|---------------|---------|-----------------|
| Low state (region [a]$^c$) | 1.76 ± 0.04 | 2.4 ± 0.1 | ... | ... | 0.71 (100) |
| Flare state (region [b]$^b$) | 1.68 ± 0.03 | 3.6 ± 0.1 | ... | ... | 1.50 (166) |
| Single power law | 3.7 ± 0.4 | 0.23 ± 0.01 | 1.38 ± 0.06 | 3.1 ± 0.2 | 0.65 (164) |

**Note:** The absorption is fixed to the Galactic value. All errors are 1σ.

$^a$ Photon index.

$^b$ 2–10 keV flux in units of $10^{-11}$ ergs cm$^{-2}$ s$^{-1}$.

$^c$ The ASCA time region is extended to 5 ks in order to collect sufficient photons.
Perhaps the most natural explanation of this behavior is that BL Lacertae is classified as an LBL; in the context of the scenario described in the §1, the main emission process in the X-ray band above ~1 keV is the inverse Compton process. However, for the flaring state spectrum, we found that another soft spectral component, well-described as a steep power law, begins to dominate below ~1 keV.

Any detailed modeling of the source requires the knowledge of fluxes of the two spectral components separately. Since both the $E < 1$ keV and $E > 1$ keV count rates are affected by both components and not just by the soft or hard component alone, we had to model the time-resolved spectrum to unravel the light curves of each component. This is particularly important since the combined ASCA and RXTE data revealed the soft component varying with larger amplitude at flaring states. We separated the entire observation into 9 time regions, labeled (1)–(9) in the top panel of Figure 1, and fitted the entire spectrum with a model including two power laws plus Galactic absorption. Since we found that the ASCA spectrum above 2 keV can be well fitted by a single power law plus Galactic absorption model, we inferred that the spectrum above 2 keV is only modestly affected by the soft component. Thus, we first fitted the ASCA data set above 2.5 keV with a single power law plus Galactic absorption model to determine the initial parameters of the hard power law. In the subsequent fitting of the full spectrum, we kept all four parameters of the two power laws free. All such spectra were well fitted by the two power law plus Galactic absorption model. The index and the flux of each component are plotted in Figure 3. We found that the soft power law is very steep, with the photon index $\sim 3$–$5$, which appears to vary, while the hard power law has an index that varies little, between $\sim 1.3$–$1.6$. The flux variability is a factor of 2 for the hard component, and a factor of 4 for the soft component. The derived fitting parameters are summarized in Table 3.

The ASCA observation of BL Lacertae showed that the flux is highly variable on a timescale of hours and that the variability in the soft and hard X-ray bands appears significantly different, indicating that two different emission processes are responsible for the X-rays detected by ASCA. Perhaps the most natural explanation of this behavior is

**Table 3**

| Time Region | $\Gamma_{\text{soft}}$ | $F_{\text{soft}}$ | $\Gamma_{\text{hard}}$ | $F_{\text{hard}}$ | $\chi^2$ (dof) |
|-------------|---------------------|-----------------|---------------------|-----------------|----------------|
| 1           | 5.1 ± 1.2           | 2.4 ± 0.5       | 1.6 ± 0.1           | 7.7 ± 0.2       | 1.04 (223)     |
| 2           | 3.0 ± 0.5           | 6.9 ± 1.8       | 1.3 ± 0.3           | 9.1 ± 1.7       | 0.96 (254)     |
| 3           | 4.3 ± 0.5           | 7.4 ± 0.8       | 1.3 ± 0.1           | 16.1 ± 0.4      | 0.89 (245)     |
| 4           | 4.7 ± 0.5           | 8.9 ± 0.7       | 1.4 ± 0.1           | 16.9 ± 0.4      | 1.14 (314)     |
| 5           | 6.2 ± 0.8           | 4.8 ± 1.4       | 1.2 ± 0.2           | 15.4 ± 1.2      | 0.87 (288)     |
| 6           | 5.6 ± 0.5           | 7.9 ± 1.2       | 1.4 ± 0.1           | 14.8 ± 0.7      | 0.93 (321)     |
| 7           | 4.1 ± 0.5           | 7.3 ± 0.8       | 1.4 ± 0.1           | 15.2 ± 0.4      | 1.14 (353)     |
| 8           | 3.0 ± 0.8           | 3.7 ± 1.2       | 1.2 ± 0.2           | 12.0 ± 1.1      | 1.14 (322)     |
| 9           | 3.2 ± 1.4           | 2.6 ± 1.7       | 1.4 ± 0.2           | 13.1 ± 1.2      | 1.04 (297)     |

Note.—Two SISs and two GISs are combined for the spectral fits; all errors are 1σ.

* Photon index.

b 0.7–1.5 keV flux in units of $10^{-12}$ ergs cm$^{-2}$ s$^{-1}$.

c 3.0–7.0 keV flux in units of $10^{-11}$ ergs cm$^{-2}$ s$^{-1}$.
where the high-energy “tail” of the rapidly flaring synchrotron component is mixing into the less variable inverse Compton spectrum. The very steep power law required in the soft spectrum in addition to the hard power law also supports this idea. The existence of the soft component was also suggested from the spectrum in the previous ASCA observation in 1995 (Sambruna et al. 1999; Madejski et al. 1999). However, the reality of this soft component as intrinsic to BL Lacertae—inferred on the basis of the excess of soft X-ray flux—was somewhat uncertain, as it also could be interpreted by the overestimated value of the CO absorption. Our ASCA results of 1997 July are the first to confirm the existence of the soft component in BL Lacertae not based solely on the photon spectrum, but on the different variability patterns of both components. This will be the third source following S5 0716+714 (Cappi et al. 1994; Giommi et al. 1999) and ON 231 (Tagliaferri et al. 2000), which reveals two components inferred on the basis of the difference in the variability patterns. We thus suggest that the soft power law dominating the soft X-ray band is the high-energy tail of the synchrotron spectrum, representing its steep cutoff. Because the synchrotron emission frequency is proportional to the square of the energy of the radiating electrons, we can regard the soft X-ray band as reflecting the most energetic electrons. The flat index of the hard component indicates that the hard X-rays are representing the onset of the inverse Compton spectrum reflecting the lower energy end of the electron population, consistent with what we have known from previous observations.

The overall spectral energy distribution (SED) of BL Lacertae during the July 1997 outburst is shown in Figure 4; this figure also illustrates the literature and archival data for pre-1997 observations. The two peaks common in blazar spectra are clearly seen, with the higher energy part of our combined ASCA and RXTE spectrum smoothly connecting to the \( \gamma \)-ray band observed by OSSE and EGRET. The upturn in the soft X-rays is evident, illustrating the synchrotron spectrum extending to the ASCA band. The X-ray light curve of BL Lacertae shown in Figure 1 reveals that the rapid flares are more prominent in the soft X-ray band. One possibility is that the flare is caused by the increase of the maximum energy of the electron population, similar to the flares observed in several HBLs, such as from Mrk 501 (Kataoka et al. 1999; Pian et al. 1998). However, we must remark that BL Lacertae also requires some other mechanism to account for the changes in the hard X-ray flux, which presumably forms the low-energy end of the SSC spectrum. The most likely explanation for this is the increase of the normalization of the electron population, although variability of the magnetic field or the beaming factor is also possible.

Rapid variability in blazars is generally assumed to be triggered by shocks propagating along a relativistic jet, and such a shock front is thought to be the most promising region where the electron acceleration may be taking place. The cutoff (the maximum) of the electron population is likely to result from the electron cooling timescale \( \tau_{\text{cool}} \) balancing the acceleration timescale \( \tau_{\text{acc}} \) in this region (e.g., Inoue & Takahara 1996; Kirk, Rieger, & Mastichiadis 1998; Kusunose, Takahara, & Li 2000). In this case, the photon spectrum also cuts off at a corresponding frequency, \( \nu_{\text{max}} \sim 1.2 \times 10^6 B \delta \gamma_{\text{max}}^2 \) (using the peak frequency of the synchrotron spectrum; see, e.g., Rybicki & Lightman 1979), followed by a steeper decline. Here, \( B \) is the magnetic field in

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**Fig. 4.—** Multifrequency SED of BL Lacertae during the 1997 July outburst, plotted together with the archival data. The diamonds represent the data during the outburst, and the two combined ASCA and RXTE data sets correspond to the two time regions marked [a] and [b] in Fig. 1. The Ginga data are from Kawai et al. (1991), the ROSAT data are from Urry et al. (1996), the EGRET data are from Bloom et al. (1997) and Catanese et al. (1997), and the Whipple data are from Catanese et al. (1997). The OSSE and ASCA 1995 data is from the HEASARC public data, and the radio-to-optical data are from the NED data base.
units of Gauss, and $\gamma_{\text{max}}$ is the Lorentz factor of the maximum energy electrons. Because the photon index of the soft component in our ASCA data was mainly steeper than 3, the cutoff of the synchrotron spectrum most likely occurs at an energy lower than the ASCA band, $\sim 0.1 \text{ keV}$ or less. Using 0.1 keV, we can calculate, $\gamma_{\text{max}} \leq 4.5 \times 10^{6}(h\nu/0.1 \text{ keV})^{0.5}B_{\text{c}}^{-0.5}\delta_{10}^{-0.5}$, where $B_{\text{c}}$ is the magnetic field in units of Gauss, and $\delta_{10}$ the beaming factor $\delta/10$. We used $B = 1$ G and $\delta = 10$ inferred from the fits to the SED by Madejski et al. (1999) and Sambruna et al. (1999).

From the calculated maximum energy of the relativistic electrons, we can now estimate the energy at which the overall spectrum cuts off. As suggested by Madejski et al. (1999) and Sambruna et al. (1999), assuming that the highest energy ($\gamma$-ray) range of the spectrum is produced by the Compton mechanism via scattering of external photons from the broad line region, the overall spectrum should extend only up to the energy corresponding to these photons interacting with the most energetic electrons. If Klein-Nishina effects become important, the spectrum should also steepen above a certain energy. Taking the typical energy of the broad line photons to be $h\nu_{\text{BL}} \sim 1.9$ eV (or wavelength ~6600 Å, the Hz line) and $\delta = 10$, Klein-Nishina effects set in for electrons with Lorentz factors exceeding $\gamma_{\text{KN}} \sim m_{e}c^{2}/(h\nu_{\text{BL}}) \sim 2.7 \times 10^{4}$, where $m_{e}$ is the electron mass, and $c$ the velocity of light. This is slightly below the maximum Lorentz factor inferred from the soft X-ray cutoff. Thus the $\gamma$-ray spectrum should break above $h\nu_{\text{KN}} \sim \delta^{2}h\nu_{\text{BL}} \times \gamma_{\text{KN}}^{2} \sim 140 \text{ GeV}$. The maximum attainable $\gamma$-ray energy corresponds to the maximum electron energy, $h\nu_{\text{max}} \sim \gamma_{\text{max}}^{2}m_{e}c^{2} \sim 230 \text{ GeV}$. Accordingly, BL Lacertae is not likely to be a TeV emitter, consistent with the observations showing only upper limits (Catanese et al. 1997). This is in contrast to the “TeV blazars” such as Mrk 421 or Mrk 501, where the $\gamma_{\text{max}}$ is thought to extend up to $\sim 10^{6}$, and this high value of the maximum electron energy should be one of the main factors responsible for a blazar being a TeV emitter.

The decay time of the variability in the ASCA data for BL Lacertae appears to be longer for hard X-rays—presumably produced by the low end of the distribution of electron energies—than for soft X-rays, produced by the most energetic electrons. This is reasonable given that the electron cooling time is shorter for higher energy electrons ($\tau_{\text{cool}} \sim 7.7 \times 10^{6}(1 + u_{\text{soft}}/u_{\gamma})^{-1}B^{-2}\gamma^{-1}$) (see, e.g., Rybicki & Lightman 1979), where $u_{\gamma}$ and $u_{\text{soft}}$ are the energy density of the magnetic field and the soft photons to be up-scattered. As the scattering is expected to occur mainly in the Thomson regime, $u_{\text{soft}}/u_{\gamma}$ can be estimated from the peak luminosity of the synchrotron ($L_{\text{syn}}$) and inverse Compton ($L_{\text{IC}}$) components in the observed spectrum (see Fig. 4) via $u_{\text{soft}}/u_{\gamma} = L_{\text{IC}}/L_{\text{syn}} \sim 4$. Applying $B \sim 1$ Gauss and $\delta \sim 10$, the cooling time for the maximum energy electrons is calculated to be $\tau_{\text{cool,obs}}(\gamma_{\text{max}}) = \tau_{\text{cool,int/obs}}(\delta \leq 3.5 \times 10^{2}(h\nu/0.1 \text{ keV})^{0.5}B_{\text{c}}^{-1.5}\delta_{10}^{-0.5})$ s, which is much shorter than the X-ray variability timescales of 2–3 hours that we have observed. This can be interpreted as resulting from the fact that timescales faster than the source light-crossing time $\tau_{\text{crs}}$, which is the time for the photons to propagate across the emission region, will always be smoothed out by $\tau_{\text{crs}}$ (see Chiaberge & Ghisellini 1999).

The soft X-ray light curve indicates that the rise and decay times are similar to each other. This is nicely consistent with the scenario where the soft X-ray band reflects the highest energy electrons, both $\tau_{\text{cool}}$ and $\tau_{\text{acc}}$ are shorter than the $\tau_{\text{crs}}$, and thus both rise and decay times are reflecting the $\tau_{\text{crs}}$. Regarding the hard X-rays, in the context of the two-component Comptonization model (see Madejski et al. 1999), those are produced by lower energy electrons, where the seed photons for the Comptonized spectrum are probably the synchrotron photons in the optical band, at $\nu \sim 10^{14}$ Hz. With this, the 5 keV $(\sim 10^{18} \text{ Hz})$ X-rays are produced by electrons with $\gamma \sim 100$, and for those electrons, $\tau_{\text{cool}}$ is about 40 hr. This is now significantly longer than the $\tau_{\text{crs}}$ estimated to be 2–3 hr, so those electrons are not expected to cool within $\tau_{\text{crs}}$. The long, gradual decay of the hard X-rays is then probably due to other causes, such as escape of particles from the radiating region, or decrease in the effective density of soft (target) photons.

In contrast to the hard X-rays, adopting the above parameters—and assuming that the region producing the optical radiation is cospatial with that producing the soft X-rays—we infer that the cooling times of the electrons producing the optical synchrotron photons (which should have $\gamma \sim 6500$ for $\lambda = 6000$ Å) are $\sim 2500$ s, which, just as for the case of soft X-rays, is shorter than the source crossing time. This is supported by the very rapid variability of the optical flux with similar rise and decay times (Massaro et al. 1998; Nesci et al. 1998), similar to that seen in the soft X-ray band.

However, we must also remark that we cannot completely exclude the possibility of variability on a shorter timescale that we cannot measure. The detected flares can actually consist of a superposition of more rapid undetectable flares, and there is actually a data point indicating a more rapid variability in the middle of the second flare, but the statistics do not let us distinguish such small flares. We expect future missions with larger effective area to provide sufficiently sensitive observations to completely resolve the most rapid events.

5. CONCLUSIONS

ASCA X-ray observations of BL Lacertae during the 1997 July outburst revealed that the X-ray flux was in a high state throughout the observation, in similarity to the optical and high-energy $\gamma$-ray behavior. We detected two rapid flares with a timescale of 2–3 hours, but only in the soft X-ray band. The hard X-ray flux also increased, but decayed with a much longer timescale. The spectrum of the source in the highest flux states required two separate power law components, a soft and steep one, dominating for the case of soft X-rays, is shorter than the source crossing time. This is supported by the very rapid variability of the optical flux with similar rise and decay times (Massaro et al. 1998; Nesci et al. 1998), similar to that seen in the soft X-ray band.
the radiating region, or decrease in the effective energy density of soft photons.

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