Suzaku observation of TeV blazar the 1ES 1218+304: clues on particle acceleration in an extreme TeV blazar

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Abstract

We observed the TeV blazar 1ES 1218+304 with the X-ray astronomy satellite *Suzaku* in May 2006. At the beginning of the two-day continuous observation, we detected a large flare in which the 5−10 keV flux changed by a factor of ∼2 on a timescale of 5×10^4 s. During the flare, the increase in the hard X-ray flux clearly lagged behind that observed in the soft X-rays, with the maximum lag of 2.3×10^4 s observed between the 0.3−1 keV and 5−10 keV bands. Furthermore we discovered that the temporal profile of the flare clearly changes with energy, being more symmetric at higher energies. From the spectral fitting of multi-wavelength data assuming a one-zone, homogeneous synchrotron self-Compton model, we obtain $B \sim 0.047$ G, emission region size $R = 3.0 \times 10^{16}$ cm for an appropriate beaming with a Doppler factor of $\delta = 20$. This value of B is in good agreement with an independent estimate through the model fit to the observed time lag ascribing the energy-dependent variability to differential acceleration timescale of relativistic electrons provided that the gyro-factor ξ is 10^5.

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1. Observation results

1ES 1218+304 is categorized as a high-frequency BL Lac object (HBL), as a redshift $z = 0.182$. It was discovered as a TeV emitter by MAGIC at energies > 100 GeV (Albert et al. 2007) and subsequently confirmed by VERITAS (Fortin, 2007). The source was observed with *Suzaku* during 2006 May 20-21 UT, yielding a net exposure time of 79.9 ks.

Figure 1 (*left*) shows the averaged light curves of the four XISs in the six X-ray energy bands. Interestingly, the observed flare shows the following characteristics: (1) The flare shape is asymmetric in time ($t_{\rm r}/t_{\rm d} \leq 1$) especially in the lower energy band (but note $t_{\rm r}/t_{\rm d} \simeq 1$ for $5-10$ keV light curve). (2) The flare amplitude becomes larger as the photon energy increases. (3) The risetime of the flare is almost constant below 2 keV, while it becomes gradually longer at higher energy bands. In this context, we try to evaluate lags of temporal variations in various energy bands. We found that the hard X-ray ($5-10$ keV) peak lagged behind that in the soft X-ray ($0.3-1$ keV) by $\sim 2.3\times10^4$ s.

The time averaged XISs and HXD/PIN background subtracted spectra were fitted using XSPEC ver.11.3.2, including data within the energy band 0.6−50 keV. The best fit model is a broken power-law with Galactic absorption. The photon index below the break energy $E_{\rm brk}$ is $\Gamma_1 = 2.04 \pm 0.01$ while the index above $E_{\rm brk}$ is $\Gamma_2 = 2.17 \pm 0.01$, where $E_{\rm brk}$ is 1.42 ± 0.05 keV. The flux over 2-10 keV is $\sim 2.0 \times 10^{-11}$ erg cm^{-2} s^{-1}.

Figure 1 (*right*) shows the spectral energy distribution (SED) of 1ES 1218+304 with currently available datasets. In order to specify the SED of 1ES 1218+304, we applied a one-zone homogeneous SSC model developed in Kataoka et al. (1999). Noting that the characteristic variability time scale of the flare is $t_{\rm var} \simeq 5\times10^4$ s, which is most probably determined by the light travel time across the source emitting region, we obtain $R = ct_{\rm var}\delta = 3.0\times10^{16}$ cm for a moderate beaming factor of $\delta = 20$ (e.g., Kataoka et al. 1999; 2000 for self-consistent determination of physical parameters in TeV blazars). The resulting parameters are listed in Figure 1 caption. We note that the energy densities of electrons and fields are $u_e = 8.3 \times 10^{-3}$ erg/cm^3 and $u_B = 8.8 \times 10^{-5}$ erg/cm^3, respectively. Thus the jet in 1ES 1218+304 is particle dominated, and the ratio $u_e/u_B \sim 100$ is well within the range of typical TeV blazars.

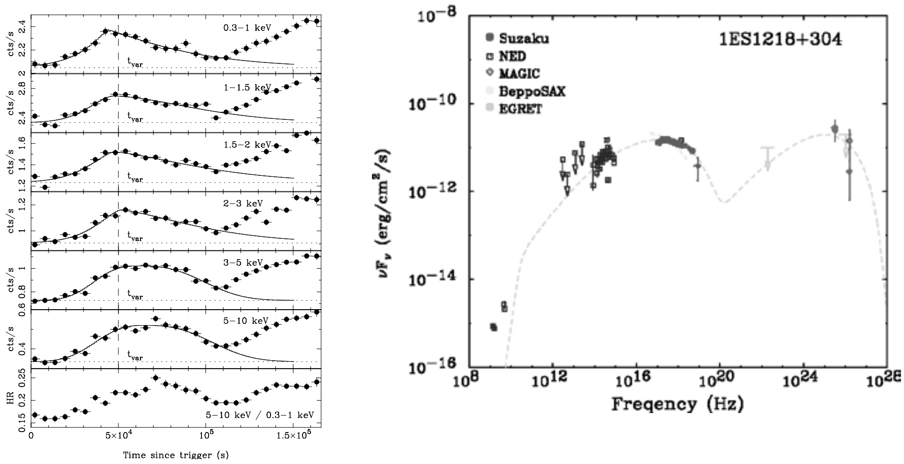

Fig. 1. *Left*: Light curves of 1ES 1218+304. The energy bands are 0.3-1, 1-1.5, 1.5-2, 2-3, 3-5 and 5-10 keV (from the upper panel), respectively. The bottom panel shows the HR of count rates, defined as (5-10 keV)/(0.3-1 keV). The dashed line shows the characteristic variability time scale of a flare $t_{\rm var} \simeq 5\times10^4$ s. *Right*: Overall SED of 1ES 1218+304. The dashed line shows a one-zone SSC model assuming the parameters: $B = 0.047$G, $\delta = 29$, $s = 1.7$, $\gamma_{\rm min} = 1$, $\gamma_{\rm brk} = 8 \times 10^3$ and $\gamma_{\rm max} = 8 \times 10^5$, where s is the electron spectral index.

2. Discussion

In our observation we detected a large flare during which the hard X-ray variation lagged behind that in the soft X-rays, $\sim 2.3\times10^4$ s. This is completely opposite to a well-known "soft-lag", as has been obtained from the past observations. In the theoretical context, however, hard lag is actually expected especially in the X-ray variability of TeV blazars, but has never been observed so clearly before. It has been suggested that a hard-lag is observable only at energies closer to the maximum electron energy (Kirk, Rieger & Mastichiadis 1998), where the acceleration time is almost comparable to the cooling time scale of radiating electrons: $t_{\rm acc}(\gamma_{\rm max}) \simeq t_{\rm cool}(\gamma_{\rm max})$.

Noting that the typical synchrotron emission frequency, averaged over pitch angles, of an electron with energy γmc^2 is given by $\nu \sim 3.7\times10^6 B\gamma^2$ Hz, we obtain;

$$t_{\rm acc}(E) = 9.65 \times 10^{-2}(1+z)^{3/2}\xi B^{-3/2}\delta^{-3/2}E^{1/2}{\rm s},$$
$$t_{\rm cool}(E) = 3.04 \times 10^{+3}(1+z)^{1/2}B^{-3/2}\delta^{-1/2}E^{-1/2}{\rm s},$$

where E is the observed photon energy in unit of KeV, z is the redshift, B is the magnetic field strength, and δ is the beaming factor. Note that for lower energy photons, $t_{\rm acc}(E)$ is always shorter than $t_{\rm cool}(E)$ because higher energy electrons need longer time to be accelerated ($t_{\rm acc}(\gamma) \propto \gamma$) but cool rapidly ($t_{\rm cool}(\gamma) \propto \gamma^{-1}$). This energy dependence of acceleration/cooling time-scales may qualitatively explain the observed characteristics of the X-ray light curves of 1ES 1218+304.

It is thus interesting to consider a simple toy model in which the rise time of the flare is primarily controlled by the acceleration time of the electrons corresponding to observed photon energies, while the fall time of the flare is due to the synchrotron cooling time scale. In this model, the amount of hard-lag is simply due to the difference of $t_{\rm acc}$, and independent of the energy dependence of $t_{\rm cool}$:

$$\begin{aligned}\tau_{\rm hard} &= t_{\rm acc}(E_{\rm hi}) - t_{\rm acc}(E_{\rm low}) \\ &\sim 9.65 \times 10^{-2}(1+z)^{3/2}\xi B^{-3/2}\delta^{-3/2} \\ &\times (E_{\rm hi}^{1/2} - E_{\rm low}^{1/2}) \ \ {\rm s},\end{aligned}$$

where $E_{\rm low}$ and $E_{\rm hi}$ are the lower and higher X-ray photon energies to which the time-lag is observed. Assuming a beaming factor $\delta = 20$ from multiband spectral fitting (see Figure 1), the best fit parameter of the magnetic field B can be written as $\simeq 0.05\xi_5$ G, where ξ_5 is the gyro-factor in units of 10^5. As discussed in detail in Sato et al. (2008), the above toy model qualitatively well represents the observed spectral/temporal features of 1ES 1218+304, in particular: (1) the synchrotron component peaks around the *Suzaku* XIS energy band in the multiband spectrum (Figure 1, *right*) and (2) the observed light curve is symmetric in shape when measured at the high energy band, while being "asymmetric" (i.e., fall time longer than the rise time) at the lower energy band.

References

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