Suzaku and multi-wavelength observations of a super massive binary black hole candidate, OJ 287

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Abstract

Suzaku observations of the blazar OJ 287 were performed in a quiescent and a flaring state in 2007. The X-ray spectra of the source were well described with single power-law models in both exposures. In the flaring state, the spectrum was harder with significant hard X-ray signals were detected up to ~ 27 keV, and the X-ray flux density was a factor of two higher, compared with that of the quiescent state. In cooperation with the Suzaku, simultaneous radio, optical, and very-high-energy γ-ray observations were performed with the Nobeyama Millimeter Array, the KANATA telescope, and the MAGIC telescope, respectively. The obtained spectral energy distribution of OJ 287 indicated that the X-ray spectrum was dominated by inverse Compton radiation in both observations, while the synchrotron component exhibited a spectral cutoff around the optical frequency. According to a simple synchrotron self-Compton model, it is estimated that the change of the spectral energy distribution was due to an increase in the energy density of electrons with small changes of both the magnetic field strength and the maximum Lorentz factor of electrons.

Key words: BL Lacertae objects: individual (OJ 287) — radiation mechanisms: non-thermal

1. Introduction

OJ 287 ($z = 0.306$) is one of the archetypal blazars. One of the outstanding characteristics of the object is its recurrent optical outbursts with a period of 11.65 years. It is known that the optical outburst consists of two peaks corresponding to flares with an interval of about one year (Sillanpää et al. 1996). The periodicity implies that OJ 287 is a promising candidate of a binary black hole system. Valtonen et al. (2008a) proposed an idea that the secondary black hole penetrates the accretion disk of the primary one, twice a period, producing the two observed flare peaks. To study the peculiar behavior, although multi-wavelength observations performed many times (e.g., Isobe et al. 2001), there is no information regarding the X-ray spectrum of OJ 287 in the second flare.

Based on the long term optical lightcurve, OJ 287 was expected to became active during 2005 and 2008. The detection of the first optical outburst (Valtonen et al. 2008b) in 2005 confirmed this prediction. Since the second flare of the source was expected to be in the fall of 2007, we organized two X-ray and simultaneous multi-wavelength observations, in the quiescent state (MWL I) between the two outbursts and in the second flaring state (MWL II), in order to reveal the characteristics of the second flare, in comparison with the quiescent state.

2. X-ray results

The Suzaku X-ray observation in MWL I was conducted during 2007 April 10 – 13, when the source was optically quiescent with an R-band magnitude of about 15. We triggered the MWL II Suzaku observation in 2007 November 7, on condition that the object remained brighter than 14-th magnitude for more than one week.

Figure 1 shows the background-subtracted XIS spectra. In this case, significant X-ray signals were de-

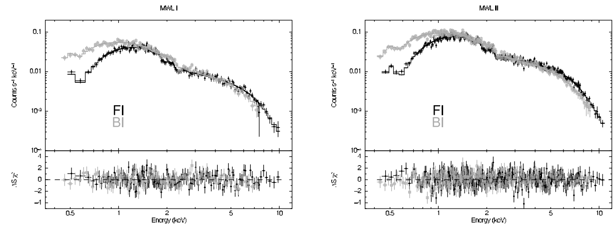

Fig. 1. The XIS spectra of OJ 287 in MWL I (left panel) and MWL II (right panel). Histograms in both panels indicate the best-fit PL models.

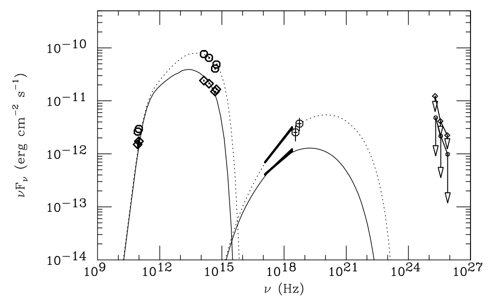

Fig. 2. The SED of OJ 287. The radio and optical data are shown with diamonds (MWL I) and circles (MWL II), and the X-ray data are shown with bow ties. The measured upper limits on the VHE γ-ray flux were shown with downward arrows. The solid (MWL I) and the dot lines (MWL II) indicate the simple one-zone SSC model.

tected in the range of 0.5 – 10 keV and 0.4 – 8 keV, with the front-illuminated (FI) CCDs and the backside-illuminated (BI) CCD, respectively. The spectra appear to be featureless.

We fitted the spectra with a single power-law (PL) model modified by a photoelectric absorption with the reported column density ($N_{\rm H} = 2.56 \times 10^{20}$ cm^{-2}; Kalberla et al. 2005). The PL model became acceptable, yielding the best-fit photon index of $\Gamma = 1.65 \pm 0.02$ and $\Gamma = 1.50 \pm 0.01$ for MWL I and MWL II, respectively. Thus, we found that OJ 287 showed a harder X-ray spectrum in MWL II. The flux density of the source in MWL II (404^{+6}_{-5} nJy) was higher than that in MWL I (215 ± 5 nJy) by a factor of 2.

After close examination on the non-X-ray background (Seta et al. 2009), hard X-ray signals in the range of 12 – 27 keV were detected by the HXD-PIN with a significance of 5 σ, in MWL II. However, we found no significant hard X-ray events in MWL I.

3. Discussion

Figure 2 summaries the overall multi-wavelength spectral energy distribution (SED) of OJ 287, in MWLs I and II. In the figure, we recognize two spectral components, which are typical of blazars. The low frequency SR component, extending from radio to optical frequencies, has a spectral turnover at around 5×10^{14} Hz. At the same time, the observed SR component is well above the extrapolation from the upper limit of the soft PL component in MWL II . Therefore, we naturally attribute the observed hard X-ray spectrum to the IC component rising toward the higher frequency range. The SED indicates that both the SR and IC intensities increased from MWL I to MWL II without any significant shift of the SR peak frequency.

As a working hypothesis, here we assume simply that the variation of the SED was caused by a change in electron energy density (or number density) and/or the maximum Lorentz factor of the electrons, with stable magnetic field, volume of emission region, minimum Lorentz factor, and break of electron energy distribution (e.g., Takahashi et al. 2000). In order to evaluate this hypothesis, we applied a one-zone synchrotron self-Compton (SSC) model to the SED by using the numerical code developed by Kataoka (2000). The electron number density spectrum was assumed to be a broken PL and the index of the electron spectrum (p) below the break Lorentz factor was determined by the X-ray photon index as $p = 2\Gamma - 1 = 2.3$ and 2.0, in MWL I and MWL II, respectively. We have following seven free parameters to describe the observed SED: the Doppler factor (δ), the electron energy density ($u_{\rm e}$), the magnetic field (B), the blob radius (R), and the minimum, break, and maximum Lorentz factor of the electrons ($\gamma_{\rm min}$, $\gamma_{\rm break}$, and $\gamma_{\rm max}$, respectively).

Figure 2 shows the resultant SSC model curves. The SED in MWL I was reproduced with $\delta = 15$, $B = 0.71$ G, $R = 7.0 \times 10^{16}$ cm, $\gamma_{\rm min} = 70$, $\gamma_{\rm break} = 700$, $\gamma_{\rm max} = 3300$, and $u_{\rm e} = 1.5 \times 10^{-3}$ erg cm^{-3}. The obtained values of δ and R are within a typical range for LBLs (Ghisellini et al. 1998). On the other hand, the SED in MWL II requires $u_{\rm e} = 2.1 \times 10^{-3}$ erg cm^{-3} and $\gamma_{\rm max} = 4500$ with the other parameters unchanged. Thus, the assumption was quantitatively justified that the increase of $u_{\rm e}$ produced the second flare of OJ 287. This behavior is different from that of first flare (Idesawa et al. 1997). More detailed discussions of the campaigns are described by Seta et al. (2009).

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