PROCEEDINGS OF SCIENCE

Suzaku observation of OJ 287; Quiescence and predicted flare in 2007

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Suzaku observations are reported of the BL Lacertae object OJ 287, performed on 2007 April 10–13 during the optical quiescent phase and on 2007 November 7–9 during the optical flaring phase. We organized the simultaneous the radio and optical observations with the Nobeyama Millimeter Array and optical KANATA telescope at Hiroshima University, respectively. The X-ray spectrum obtained in the quiescent phase was described by a single power-low model with a photon index of $\Gamma = 1.65 \pm 0.02$ and the flux density was measured to be 216 ± 6 nJy at 1 keV. In the flare phase, the X-ray spectrum became harder ($\Gamma = 1.50 \pm 0.01$), and the flux density has doubled to be 398 ± 7 nJy at 1 keV. Our multi-wavelength spectrum exhibited the SR and IC components, and the X-ray spectra cannot be explained as an extension from the SR components, but suggest that the X-rays are dominated by the IC component. We suggested electron spectrum indices are variable for each phase. Thus, for the 2nd-flare, SR and IC components increased without extending energy band.

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1. Introduction

Blazars, including BL Lacertae objects and flat-spectrum radio quasars (FSRQs), belong to a class of active galactic nuclei, whose spectra are dominated by non-thermal radiation from relativistic electron in jets pointing to us [1]. The Spectral Energy Distributions (SEDs) of blazars are characterized by two broad humps. The first one, ranging from radio to UV/X-ray wavelengths, is widely attributed to synchrotron emission (SR) from the jet, while the second extends from X-rays to GeV and TeV gamma-rays, is interpreted as inverse-Compton (IC) scattering component by the same population of electrons that produce the SR component.

OJ 287, at a redshift of $z = 0.306$ [8], is a prototype object for BL Lac class. An outstanding characteristic of OJ 287 is the apparently periodic long-term variability. The optical photometry of OJ 287, spanning more than 100 years, has exhibited major outbursts with a period of 11.65 year [6]. In 1994, a large multi-wavelength observation campaign was performed to detect the periodic outburst, called OJ 94. During this campaign, it was observed that OJ 287 has two separate flares in the outburst [7]. Interestingly the radio flare was observed only in the 2nd-flare although no X-ray to TeV gamma-rays observation has been carried out in the 2nd-flare occasions so far.

The 2005 – 2008 is predicted to happen periodic outburst, and 2nd-flare was predicted to take place in fall in 2007. Thus, we performed Target of Opportunity observation with Suzaku [5], with the aim of detecting 2nd-flare of OJ 287 in X-rays. In corporation with Suzaku, we organized a simultaneous observation in radio, optical, and gamma-ray bands of OJ 287 at the 2nd-flare. For comparison, we also observed OJ 287 in its quiescent phase, ahead of the 2nd-flare, although detailed description shall be published in the forthcoming paper.

2. Observation

We observed OJ 287 with Suzaku during 2007 April 10–13, and November 7–9 UT. For the observation in November, we proposed the Target of Opportunity to be triggered, when the brightness in the optical *R* band magnitude is less than 14-th and lasts for 1 week or more. Taking these opportunities, we have coordinated multi-wavelength simultaneous observations involving the radio Nobeyama Millimeter Array (NMA), the optical KANATA telescope at Hiroshima University [11], and the gamma-ray telescope MAGIC. Hereinafter we call these occasions as “quiescent phase” and “flare phase” for observations in 2007 April 10–13 and in November 7–9, respectively. We do not describe the HXD data in this paper, since it is still under analysis.

The X-ray Imaging Spectrometer (XIS; [4]) and the Hard X-ray Detector (HXD; [9]; [3]) onboard Suzaku were operated in the normal clocking mode with no window option and in the normal mode, respectively. The OJ 287 was placed at the HXD-nominal position. We analyzed the data with revision 2.0.6.13 and 2.1.6.16 processing for each observations, with HEADAS 6.4 software package. Following the standard data processing, we filtered the data by adopting the criteria that the spacecraft is outside the south Atlantic anomaly, the geometric cutoff rigidity is higher than 6 GV, the source elevation above the rim of bright and night earth is higher than 20 degree and 5 degree respectively, and the XIS data are free from telemetry saturation. In the scientific analysis below, we utilize the events only with a grade of 0, 2, 3, 4, or 6.

For the XIS, we accumulated events within 3′ from the observed source center, while background events were also taken from the axis-symmetric position on the optical axis of the Suzaku/XRT within the same radius, but we masked so as to exclude the contaminating point source. The two circular regions are shown in figure 1.

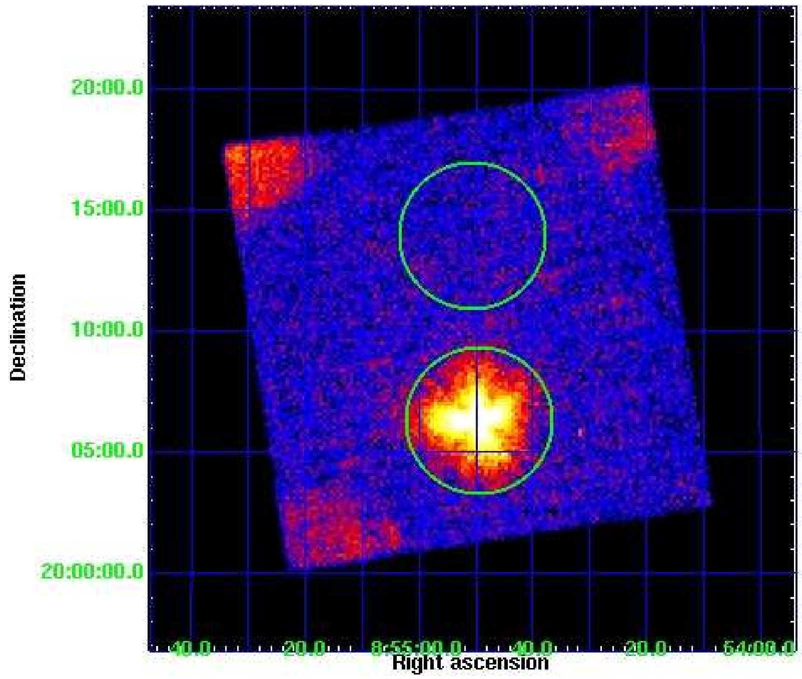

Figure 1: Synthesized X-ray image obtained with Suzaku/XISs. The north and south circles represent the data-accumulation region from the source and background,respectively.

3. Results

Figure 2 shows the background subtracted XIS0, 1 and 3 spectra of OJ 287 in the quiescent and the flare phases, without removing the instrumental response. The error bar of each plot represents the photon statistics. Thus, the X-ray signals were detected over the 0.5–10 keV range with the XIS. We fitted those spectra with a single power-law model with a photo-electric absorption. We fixed the absorption column density at the Galactic value, $N_{\rm H} = 2.56{\rm E}{+}20$ atoms cm^{-2}. Then, these spectra were successfully described with this model (see table 1). The derived photon indices are $\Gamma = 1.65 \pm 0.02$ and $\Gamma = 1.50 \pm 0.01$ for the quiescent and flare phase, respectively. The derived flux densities at 1keV are 213 ± 6 nJy and 398 ± 7 nJy for the quiescent and flare phase, respectively. The photon index for the flare becomes significantly harder, compared with that in the quiescent phase. The flux for the flare phase has been doubled.

4. Discussion

Figure 3 shows multi-wavelength lightcurves in the period from 2006 September 22 to 2008

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Table 1: Suzaku best-fit spectral parameters of OJ 287 in the quiescent and flare phases

Parameters	quiescent	flare
$N_{\rm H}$ $[10^{20}$ cm$^{-2}]$	2.56	2.56
$F_{\rm 1kev}$ [nJy]	213 ± 6	398 ± 7
Γ	1.65 ± 0.02	1.50 ± 0.01
χ^2/d.o.f.	259.2/257	556.3/538

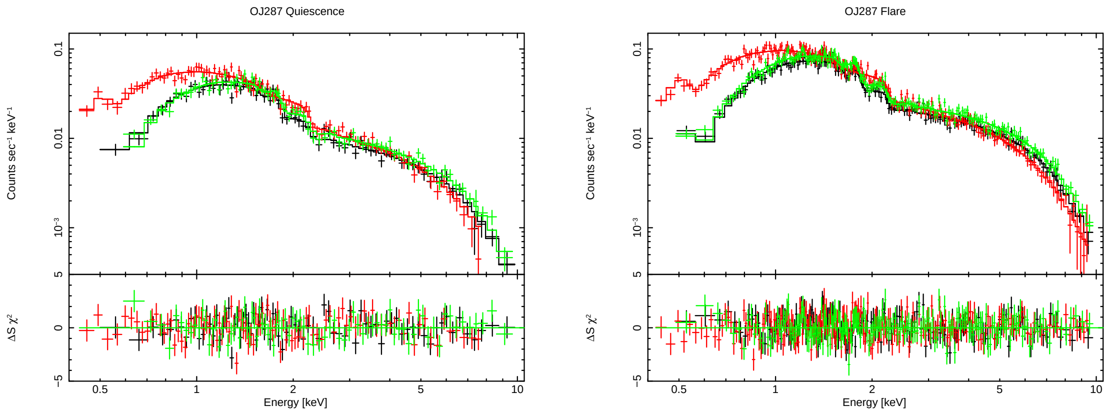

Figure 2: Suzaku Background-subtracted X-ray spectra of OJ 287 shown without removing the instrumental response, observed in the quiescent phase (left panel) and the flare phase (right panel) in 2007.

February 4, obtained by our observations. The top of figure 3 is optical flux on V band taken with KANATA using nightly averaged data, the middle of that is radio fluxes on 86.75 GHz and 98.75 GHz taken by NMA, we use nightly averaged data of those observations, the bottom of that is X-ray count rate summed up the two front-illuminated (FI) CCD sensors (XIS0, and 3) onbord Suzaku. After the quiescent state from 2006 September to 2007 April, the optical flux of OJ 287 was increased, toward the peak of the 2nd-flare in September 2007. At the peak of the flares the flux came up to 6 times brighter than that in the quiescent phase. In the flare phase, the object was so variable that we see many short flares on few days. In radio, the flux decreased in May. In October, however, the radio flux doubled the flux in May. X-ray count rate in November 2007 also doubled that in April 2007.

Figure 4 shows the SED of OJ 287 obtained in each phase. The blue plots are the quiescent phase observation in 2007 Apr 10–13 and the red one are the flare phase observation in 2007 Nov 7–9 including in NMA, KANATA, and Suzaku. Compared with smooth extrapolation from the lower frequency continua for two observation, the X-ray spectra obtained with Suzaku exceeds the extrapolation and exhibit flatter slopes in both occasions. Therefore, the X-ray spectra cannot be explained as an extension from the SR components, but suggest that the X-rays are dominated by the IC component. Thus, for 2nd-flare, SR and IC components were doubled without extending energy band.

On the other hand, Ciprini et al. reported that the 1st-flare spectra obtained XMM-Newton, is described with a broken power-law models [2]. This may suggest a soft component connecting to the SR component or an additional thermal component in the soft X-ray band. This obvious difference suggest that the 1st-flare and 2nd-one are produced in different states.

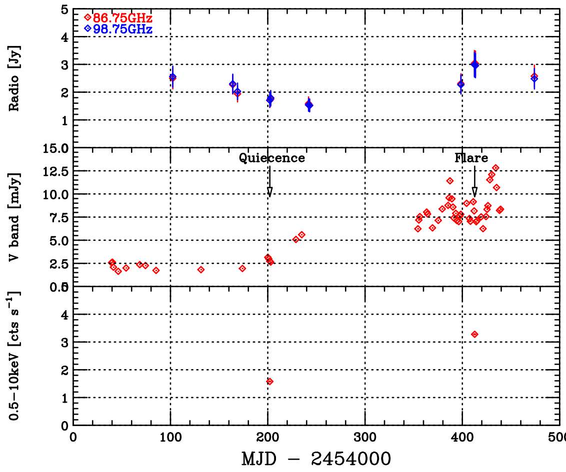

Figure 3: The multi-wavelength lightcurves of OJ 287. The top is radio flux on 86.75 GHz and 98.75 GHz taken by NMA, the middle is optical flux on *V* band taken with KANATA, the bottom is X-ray count rate summed up the two front-illuminated (FI) CCD sensors (XIS0, and 3) onbord Suzaku. The arrows in the middle panel show the periods of our suzaku observations.

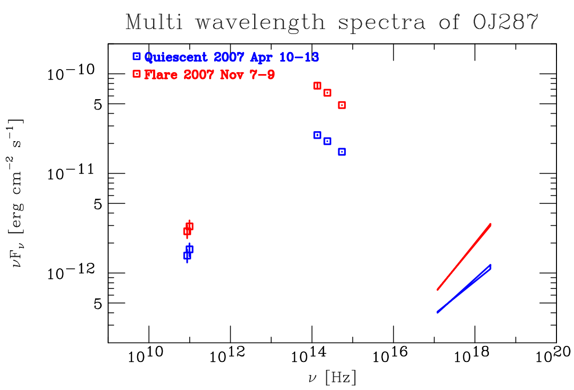

Figure 4: SED of OJ 287 during Suzaku and multi-wavelength observations in 2007. The blue plots are the quiescent phase observation, and the red plots are the flare phase observation. The data are NMA, KANATA, and Suzaku.

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