PROCEEDINGS OF SCIENCE

Suzaku Observations of SS 433 in the 2006 April Multiwavelength Campagin

K. Kubota,[a] Y. Ueda,[a] T. Kotani,[b] N. Kawai,[c] M. Namiki,[d] K. Kinugasa,[e] S. Ozaki,[f] T. Iijima[g] and S. Fabrika[h]

[a] *Kyoto University, Japan*
[b] *Aoyama Gakuin University, Japan*
[c] *Tokyo Institute of Technology, Japan*
[d] *Osaka University, Japan*
[e] *Gunma Astronomical Observatory, Japan*
[f] *Okayama Astrophysical Observatory, Japan*
[g] *Astronomical Observatory of Padova, Italy*
[h] *Special Astrophysical Observatory, Russia*
E-mail: kaori.k@kusastro.kyoto-u.ac.jp

We report the results of the 2006 April multi-wavelength campaign of SS 433, focusing on the X-ray data taken with Suzaku. The campaign includes two Suzaku observations (in and out of eclipse) and a large set of optical spectroscopy, optical/IR photometory, and radio observations. The X-ray light curve in the out-of-eclipse phase had shown significant variability, particularly in the hard band above 5 keV. By analyzing the time sliced spectra of Suzaku, we detected rapid variability of the Doppler shift of the jet ($dz/dt \approx 0.011/0.33$ day), which is larger than those expected from the precession and/or nodding motion. This may correspond to a "jitter" motion observed for the first time in X-rays. From the comparison of Doppler curves between optical and X-ray bands, we determine the length of the optical jets to be $3.4(\pm 0.5)\times 10^{14}$ cm.

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Table 1: Optical Spectroscopic Observation Log

Start	(MJD)	Exposure (s)	Remark
Telescope: BTA 6 m. Observatory: SAO. PI: S. Fabrika.			
2006/04/06 00:45:35	(53831.0317)	590	
Telescope: 150 cm. Observatory: Gunma. PI: K. Kinugasa.			
2006/03/07 19:57:47	(53801.8297)	600(the sum of 120×5)	
2006/04/02 18:47:00	(53827.7826)	900(the sum of 180×5)	Line not detected.
2006/04/05 19:15:28	(53830.8024)	900(the sum of 180×5)	
2006/04/06 18:39:53	(53831.7777)	900(the sum of 180×5)	
2006/04/07 18:40:42	(53832.7783)	900(the sum of 180×5)	
2006/04/09 18:38:27	(53834.7783)	1080(the sum of 180×6)	
2006/05/03 18:16:07	(53858.7612)	720(the sum of 180×4)	
2006/05/20 17:35:43	(53875.7441)	900(the sum of 180×5)	
Telescope: Nayuta 2 m. Observatory: Nishi-Harima. PI: S. Ozaki.			
2006/04/03 18:04:52	(53828.7534)	1800	
2006/04/05 17:55:00	(53830.7465)	1800×2	
2006/04/07 17:48:03	(53832.7417)	592, 540	
2006/04/12 08:07:16	(53837.3384)	1800	Line not detected.
Telescope: 122 cm. Observatory: Padova-Asiago. PI: T. Iijima.			
2006/04/12 03:12:57	(53837.1340)	1200	
2006/04/14 02:37:01	(53839.1090)	1200	

1. Introduction

SS 433 is a unique X-ray binary having continuous relativistic jets, whose axis is precessing with a period of 162 days [2, 7]. The optical and X-ray spectra show several pairs of Doppler shifted lines from the bipolar jets. The emission lines are evidence that the jets contain a baryonic plasma.

Multiwavelength observations of SS 433 are important to study the relation between different components of the system: the jets, the optically-thick accretion disk, and the central engine of the high energy emission. For this purpose, we organized a multi-wavelength observation campaign in the period from 2006 March 29 to April 15. The campaign includes two Suzaku observations and a large set of optical spectroscopy, optical/IR photometry and radio observations. As for details of this campaign, refer to papers by Kotani et al.[5, 6].

In this paper, we present the results from the Suzaku observations and those from optical spectroscopy. Tables 1 and 2 show the logs of the optical and X-ray observations, respectively.

2. Analysis of Suzaku XIS data

Figure 1 shows the X-ray light curves taken on 2006 April 8 (out of eclipse). As noticed,

Table 2: X-Ray Observation Log

Start		End		Expos.	Remark
(MJD)			(MJD)	(ks)	
Observatory: Suzaku. PI: N. Kawai.					
2006/04/04 14:40	(53829.6108)	2006/04/05 12:47	(53830.5326)	40	Mid Eclipse.
2006/04/08 11:04	(53833.4610)	2006/04/09 10:59	(53834.4578)	40	

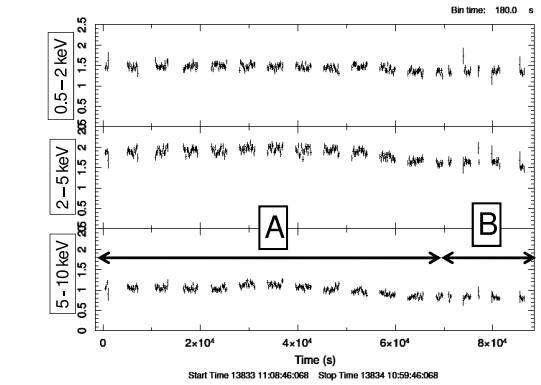

Figure 1: The X-ray light curves obtained with the Suzaku XIS on April 8 (out of eclipse).

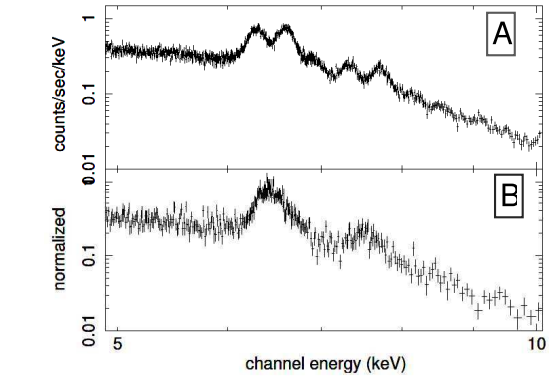

Figure 2: The spectra in epoch A and B. The spectral variability is evident.

significant variability is found particularly in the hard band above 5 keV. We confirm this trend in the light curve of the HXD/PIN covering the 12 - 60 keV band. Figure 2 shows the XIS spectra in epochs A and B (see Figure 1 for the definition). It is seen that the spectrum also changed significantly between the two epochs.

Figure 3 shows the X-ray light curves on 2006 April 5 (in eclipse). The time-averaged XIS spectrum is shown in Figure 4.

3. Abrupt Change of the Doppler Shift of the Jets

To examine spectral variability, we divide the one-day data into eight parts and perform spectral fitting to each one. The time variability of the $\mathrm{Fe_{XXV}\,K}\alpha$ line center energies are shown in Figure 5. In the data of April 8, we detect rapid variability of the Doppler shifts ($\mathrm{d}z/\mathrm{d}t \approx 0.011/0.33$ day), which is much larger than expected from the precession and/or nodding motion of the jets. (The maximum value expected from the nodding motion is $\mathrm{d}z/\mathrm{d}t \approx 0.0030/0.33$ day[3].) This may correspond to "jitter" motion[4, 1] observed for the first time in X-ray.

4. Time Lag of Optical to X-ray Variability

Utilizing our simultaneous X-ray and optical spectroscopic data, we can determine a time lag

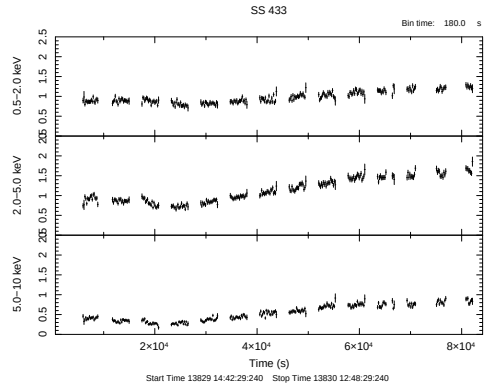

Figure 3: The X-ray light curve obtained with the Suzaku XIS on April 5 (in eclipse).

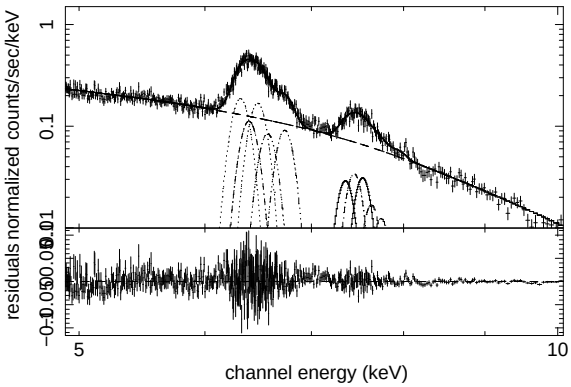

Figure 4: The spectra taken in the eclipse phase.

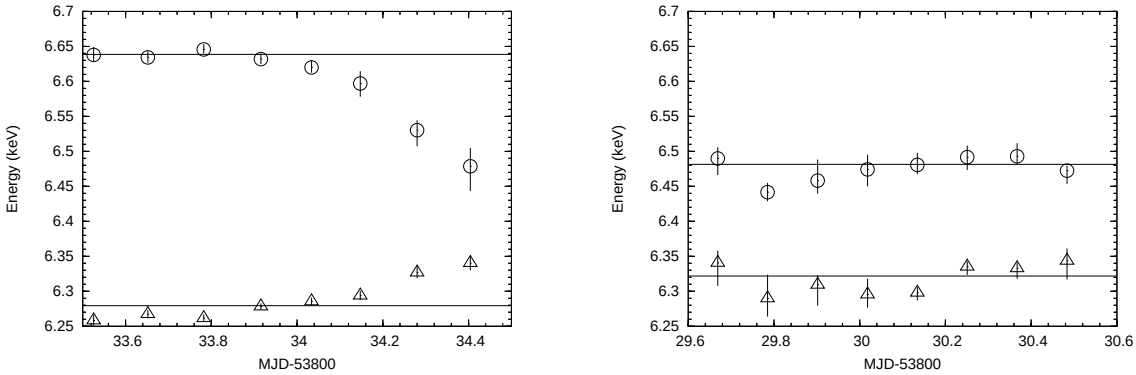

Figure 5: The time variability of the $Fe_{XXV}\,K\alpha$ line center energy determined from the fit to Suzaku spectra on April 8 (left) and on April 5 (right). The horizontal lines show the values determined from the time averaged spectra. It is seen that the line energy abruptly changed on April 8 (left).

between when the jets emit X-ray and optical lights. The lag estimated from the blue jet (arrow 1 in Figure 7) is 0.636±0.077 day and from the red jet (arrow 2) is 0.380±0.077 day. The average of the two jets are 0.50±0.06 day. Assuming that the jets speed is constant at 0.26*c*, we estimate the length of the optical jets to be $3.4(\pm 0.5)\times 10^{14}$ cm.

5. Summary

Here we summarize the new results from the Suzaku-maltiwavelength observation campaign of SS433 performed in 2006 April, focusing on the Suzaku XIS data and optical spectroscopic data.

1. The X-ray light curve on April 8 showed significant variability, especially in the hard band above 5 keV. By analyzing the time sliced X-ray spectra, we detected rapid variability of the Doppler shift of the jets of ($dz/dt \approx 0.011/0.33$ day), which is larger than those expected from the precession and/or nodding motion. This may correspond to a "jitter" motion detected in the X-ray band.

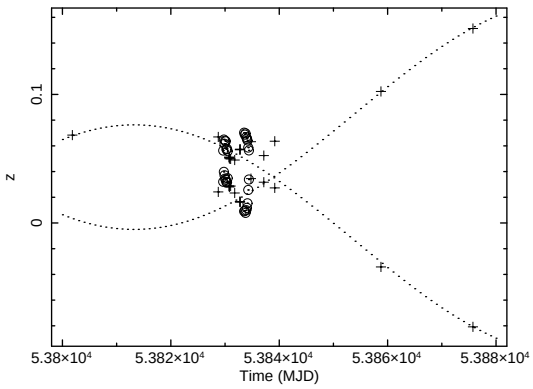

Figure 6: A summery of Doppler shifts of the jets. The results determined from optical Hα (circles) and X-ray data (crosses) are plotted. Dots correspond to 164-days sinusoidal curves.

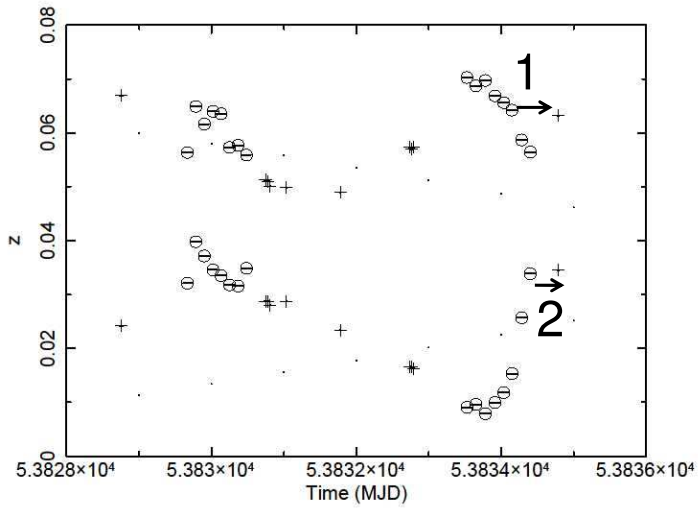

Figure 7: The Doppler curve around the epoch of the Suzaku observations.

2. From the comparison of the Doppler curves between the optical and X-ray bands, we determine the length of the optical jets to be $3.4(\pm0.5)\times10^{14}$ cm.

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