The Observation Campaign of SS 433 in April 2006

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A radio-IR-optical-X-ray observation campaign of SS 433 has been performed in April 2006, when the jet axis is almost perpendicular to the line of sight. Five flares have been detected during the campaign by radio monitoring observation with RATAN-600. The X-ray astronomical satellite Suzaku observed the source in and out of eclipse. In the X-ray data out of eclipse, the flux shows a significant variation with a time scale of hours. The source seems to be in the active state during the campaign. The observation logs and preliminary results are presented.

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1. Introduction

SS 433 is the unique microquasar known for the very stable continuous jet emanating at a quarter of the speed of light [14, 5]. The optical and X-ray spectra are abundant in pairs of Doppler-shifted emission lines from the bipolar jets. The emission lines are evidence that the jet plasma contains baryons, while other microquasars' jets do not show such Doppler-shifted emission lines, presumably because they consist of pair plasma.

A multi-wavelength observation campaign is desirable for the comprehension of SS 433, because the behavior and relation of the system components, a synchrotron jet, an optically-thick accretion disk, and a high-energy jet engine, can be studied only with a multi-wavelength campaign [10, 3, 4, 12]. Especially, radio monitoring to diagnose the state of the system, optical spectroscopy to determine the precessional phase, and X-ray observation of the core of the system are essential. We present preliminary results from an intensive multi-wavelength observation campaign of the source in April 2006 with the X-ray observatory Suzaku and several large radio and optical telescopes.

2. Observations

The source has been observed with the X-ray astronomical satellite Suzaku [16] at MJD = 53830 and 53833 (Table 1). The orbital phases at the observations are 1.0 and 0.22, respectively [7]. An optical-IR-radio observation campaign was performed to cover the periods of the Suzaku observations (Table 2–4). Spectra have been taken with the 6-m Telescope (BTA) at the Special Astrophysical Observatory RAS (SAO RAS), the 122-cm Telescope at the Padova-Asiago Observatory, the 150-cm Telescope at the Gunma Astronomical Observatory [17], and the Nayuta Telescope at the Nishi-Harima Astronomical Observatory. Photometric data have been obtained with the KGB-38 Telescope at the Crimean Astrophysical Observatory, a 40-cm Telescope at the Kyoto University, MITSuME Akeno 50 cm [11] at the Akeno Observatory, MITSuME OAO 50 cm [11] at the Okayama Astrophysical Observatory (OAO), the 51-cm Telescope at the Osaka Kyoiku University [20], and telescopes in VSNET [9] and in the Variable Star Observers League in Japan (VSOLJ). Infrared photometry data have been obtained with the IRSF 1.4-m Telescope [8] at the South African Astronomical Observatory (SAAO). The radio activity from 1.0 GHz to 21.7 GHz has been monitored with the RATAN-600 at SAO in the period covering the campaign. The 32-m radio telescope (RTF-32) at the Institute of Applied Astronomy RAS (IAA RAS) and the Nobeyama Millimeter Array at the Nobeyama Radio Observatory have also participated in the campaign.

3. Precessional Phase

The Doppler shifts of the jets of SS 433 measured with the X-ray Imaging Spectrometers (XIS) [13] on Suzaku and the optical spectrometers are shown in Fig. 1. This plot provides information on the geometrical configuration of the system at that time. Observed Doppler shifts deviate from the sinusoidal curves of the five-parameter kinematic model [15] due to the nodding motion [6]. From Fig. 1, it is confirmed that the campaign has been performed at a precessional phase when the inclination angle of the jet axis slightly exceeds 90°.

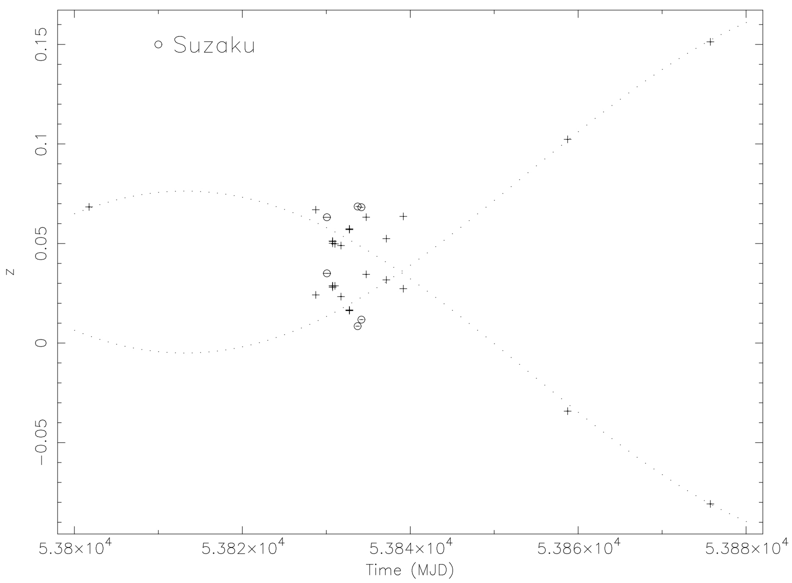

Figure 1: Doppler shifts. Optical data (crosses) and X-ray data (open circles) are plotted. Dotted lines are sinusoidal curves [15] shifted to fit the observational points.

4. Light Curves

Radio monitoring of the activity of the source is essential to a multi-wavelength campaign [19]. The radio light curves during the campaign are shown in Fig. 2. The curves exhibit five radio flares at MJD = 53837, 53847, 53855, 53866, and 53870, suggesting that the source has been in the active state successively ejecting massive jets. Optical spectroscopic observations with the 122-cm Telescope/Padova-Asiago and Nayuta/Nishi-Harima coincide with the flare at MJD = 53837. It is interesting that no lines are detected from the coinciding observation of Nayuta. The observations with Suzaku have been performed before the first detected flare. At that time, the 2 GHz flux densities fluctuate around 1 Jy, indicating a high activity even before the first detected flare. Suzaku might have observed the source in the interval between two flares.

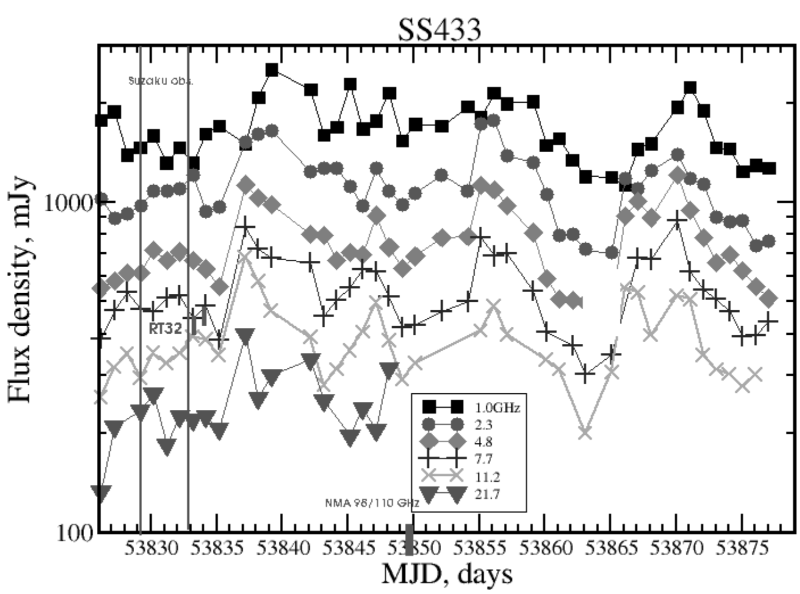

Figure 2: Radio light curves obtained with RATAN-600/SAO. The data obtained with RTF-32/IAA (MJD = 53833 and 53834) and NMA/Nobeyama (MJD = 53850) are also plotted. The epochs of Suzaku's observations are indicated by vertical lines.

The VRI optical light curves are shown in Fig. 3. The participating observatories/organizations are listed in Table 3. A continuous observation with MITSuME OAO 50 cm coincides with the Suzaku observation out of eclipse.

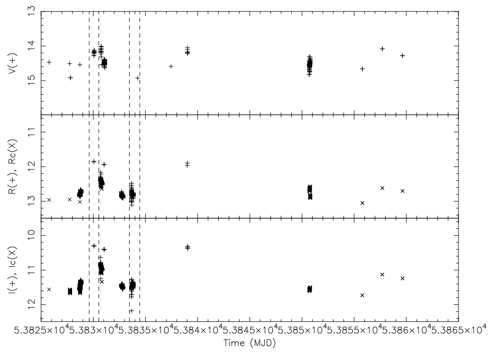

Figure 3: Optical light curves. The periods of two Suzaku observations are indicated by vertical dashed lines.

The X-ray light curves are shown in Fig. 4. The first observation has been performed during an eclipse. The X-ray flux recovers from the minimum, which is slightly different from the prediction by [7]. The cause of the shift is not known yet. In the second observation, the flux shows a significant variability, especially in the hard band above 5 keV.

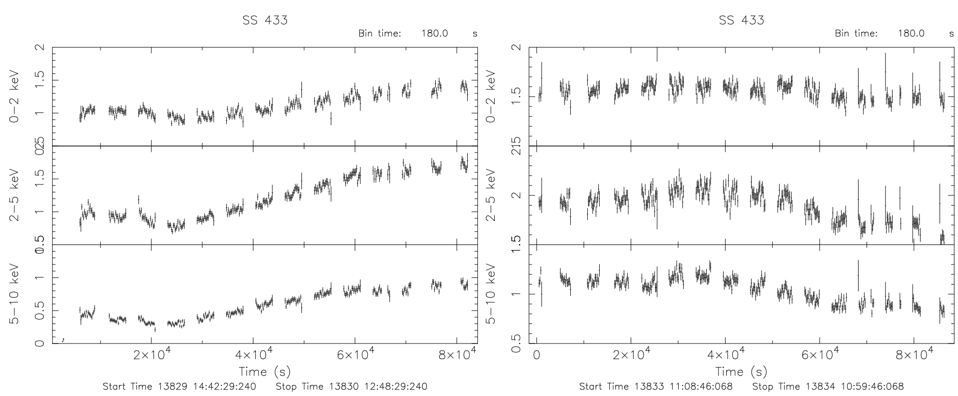

Figure 4: X-ray light curves obtained with XIS/Suzaku. Left: 2006/04/04 (MJD = 53829). Right: 2006/04/08 (MJD = 53833).

An example of simultaneous X-ray/optical observation is shown in Fig. 5. Correlation between these bands is to be searched. The optical emission from a geometrically thick super-critical accretion disk may precede to the X-ray emission from the hot base of the jet, while the emission from the downstream optical jet will lag behind the X-ray.

5. Radio spectra

Several radio spectra are plotted in Fig. 6. The sampled dates are MJD = 53829.192 (coinciding with Suzaku's observation in eclipse), 53833.181 (coinciding with Suzaku's observation out of eclipse), 53837.170 (a flare peak), and 53850 (with NMA data up to 110.21 GHz). The spectrum at the flare peak is flatter, which is a characteristics of optically thick synchrotron sources such as small expanding jet plasma. Other spectra are consistent with that of optically thin synchrotron emission with a spectral index of ~ 0.6. It should be noted that the power-law like spectrum is extended up to 110.21 GHz. And even the flux densities other than the flare peak are higher than

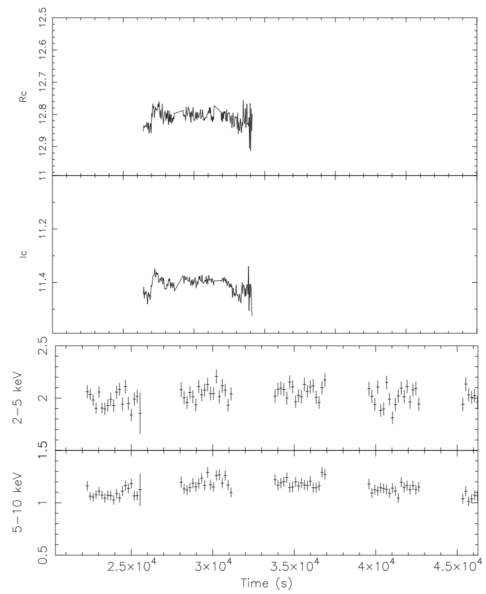

Figure 5: Simultaneous X-ray and optical observations. From top to bottom: Rc magnitude obtained with MITSuME OAO 50 cm, Ic with MITSuME OAO 50 cm, 2–5 keV count rate obtained with XIS/Suzaku, and 5–10 keV count rate with XIS/Suzaku. The horizontal range is from MJD = 53833.7 to 53834.0.

previously observed values (see, e.g., Fig. 3 in [18]). It also supports the assumption that the source has been in the active state during the campaign.

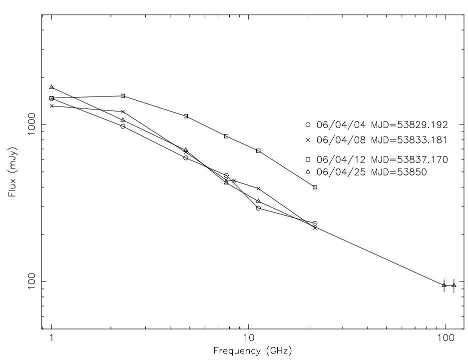

Figure 6: Radio spectra sampled at MJD = 53829.192, 53833.181, 53837.170, and 53850.

6. Multi-wavelength Spectrum

An exactly simultaneous multi-wavelength spectrum taken at MJD = 53833 is plotted in Fig. 7. Hard X-ray data of HXD/Suzaku and IR data of IRSF are not yet reducted. A spectral model for each energy band is plotted: The radio flux densities are expressed with a power-law model attenuated by interstellar matter of $A_{\rm v} = 8$ or $N_{\rm H} = 1.57 \times 10^{22}$ cm^{-2}. The optical model is the sum of a multicolor disk model with $T_{\rm in} = 10^5$ K and a blackbody emission from a companion star with $T = 1.5 \times 10^4$ K, both of which are attenuated by interstellar matter of $A_{\rm v} = 8$. The X-ray model consists of bremsstrahlung continuum and emission lines attenuated by $N_{\rm H} = 1.3 \times 10^{23}$ cm^{-2}.

7. Summary

A radio-IR-optical-X-ray observation campaign has been performed in April 2006, when the inclination of the jet axis slightly exceeds 90°. SS 433 has been active in the radio band and

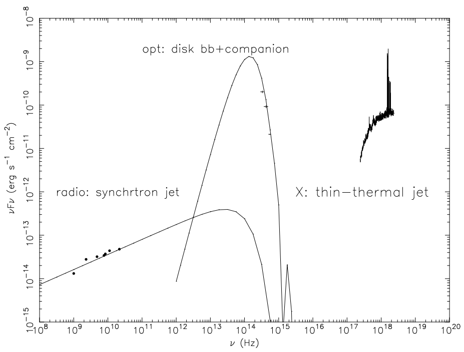

Figure 7: Exactly simultaneous multi-wavelength spectrum taken at MJD = 53833. Radio: RATAN-600 and RTF-32. Optical: VSNET and MITSuME OAO 50 cm. X-ray: XIS/Suzaku. A spectral model for each energy band is plotted in solid line.

exhibited five massive jet ejection events during the campaign. One of the ejection events coincides with optical spectroscopic observations. The source in and out of eclipse has been observed with the X-ray astronomical satellite Suzaku. In the data out of eclipse, the X-ray flux shows variation of a factor of 2 in a day, suggesting that the source are in the active state like that observed in 1979 with Einstein [18, 2]. The exactly simultaneous multi-wavelength spectrum can be expressed with a combination of three component, a synchrotron power-law model in the radio band, a multi-color blackbody model in the optical band, and a thin-thermal plasma model in the X-ray band. Temporal and spectral investigation are in progress.

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Start		End		Expos.	Remark
	(MJD)		(MJD)	(ks)	
Observatory: Suzaku [16]. PI: N. Kawai.					
2006/04/04 14:40	(53829.6108)	2006/04/05 12:47	(53830.5326)	40	Med Eclipse.
2006/04/08 11:04	(53833.4610)	2006/04/09 10:59	(53834.4578)	40	

Table 1: X-Ray observation log.

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[1] D. L. Band, and J. E. Grindlay, *Synchrotron and inverse Compton emission from expanding sources in jets - Application to SS 433*, *ApJ* **311** (1986) 595.

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Start	(MJD)	Exposure (s)	Remark
Telescope: BTA. Observatory: SAO RAS. PI: S. Fabrika.			
2006/04/06 00:45:35	(53831.0317)	590	
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	
Telescope: 150 cm [17]. Observatory: Gunma. PI: K. Kinugasa.			
2006/03/07 18:00	(53801.75)	120	
2006/04/02 18:00	(53827.75)	180	Line not detected.
2006/04/05 18:00	(53830.75)	120	
2006/04/06 18:00	(53831.75)	300	
2006/04/07 18:00	(53832.75)	300	
2006/04/09 18:00	(53834.75)	300	
2006/05/03 18:00	(53858.75)	180	
2006/05/20 18:00	(53875.75)	180	
Telescope: Nayuta. 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.

Table 2: Spectroscopic observation log.

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Start (MJD)	End (MJD)	Frames	Remark
Instrument: KGB-38. Observatory: Crimean. PI:T. Irsmambetova.			
53830.05325	53830.08605	V: 10, R: 2, I: 2	
53831.03587	53831.10694	V: 45, R: 2, I: 2	
53839.00955	53839.04312	V: 6, R: 2, I: 2	
Telescope: 40 cm. Observatory: Kyoto U. PI: K. Kubota.			
53826.72946	53826.83986	C: 243	
53828.72057	53828.79068	C: 91	
53841.67304	53841.82313	C: 316	
53848.74419	53848.81521	C: 171	
53850.79558	53850.81689	C: 55	
53852.80954	53852.82616	C: 51	
53886.72074	53887.24026	C: 51	
Telescope: MITSuME Akeno 50 cm [11]. Observatory: Akeno. PI: T. Shimokawabe			
53827.76578	53827.80385	V: 47, I: 47	
53828.72676	53828.79979	V: 91, I: 91	
53830.73239	53830.80104	V: 90, I: 90	
Telescope: MITSuME OAO 50 cm [11]. Observatory: OAO. PI: S. Yanagisawa.			
53828.68783	53828.83571	g': 321, Rc: 321, Ic: 321	
53830.69849	53830.84740	g': 360, Rc: 360, Ic: 360	
53832.70071	53832.84003	g': 340, Rc: 340, Ic: 340	
53833.67184	53833.84119	g': 220, Rc: 220, Ic: 220	
Telescope: 51 cm [20]. Observatory: Osaka Kyoiku U. PI: S. Nishiyama.			
53825.78	53825.80	V: 1, R: 1, I: 1	
53828.77	53828.79	V: 1, R: 1, I: 1	
53849.73734	53849.77499	V: 1, R: 15, I: 1	
53850.64105	53850.76927	V: 1, R: 30, I: 2	
53855.72479	53855.75851	R: 38	
53857.76686	53857.78237	R: 14	
53858.68045	53858.68667	R: 10	
53859.69379	53859.20651	R: 19	
Organization: VSNET [9].			
53823.79792	53823.80069	V: 1, Rc: 1, Ic: 1	S. Kiyota (Ibaraki, Japan)
53823.81339	—	V: 1	H. Maehara (Saitama, Japan)
53824.78819	53823.83194	V: 1, Rc: 1, Ic: 1	S. Kiyota (Ibaraki, Japan)
53827.75850	53827.76653	V: 1, Rc: 1, Ic: 1	K. Nakajima (Mie, Japan)
53827.81163	—	V: 1	H. Maehara (Saitama, Japan)
53828.73766	53828.79404	V: 1, Rc: 1, Ic: 1	K. Nakajima (Mie, Japan)
53830.81929	53830.82405	V: 1, Rc: 1, Ic: 1	H. Maehara (Saitama, Japan)
53834.24931	—	V: 1	D. J. Mendicini (Spain)
53837.44860	53837.44990	B: 1, V: 1	D. J. Mendicini (Spain)
53855.78171	53855.78499	V: 1, Rc: 1, Ic: 1	H. Maehara (Saitama, Japan)
53857.70069	53857.70138	V: 1, Rc: 1, Ic: 1	S. Kiyota (Ibaraki, Japan)
53859.64028	53859.64097	V: 1, Rc: 1, Ic: 1	S. Kiyota (Ibaraki, Japan)
53886.64912	53886.65486	V: 1, Rc: 1, Ic: 1	S. Kiyota (Ibaraki, Japan)

Table 3: Photometric observation log.

Start (MJD)	End (MJD)	Frames	Remark
Organization: VSOLJ.			
53824.80267	53824.82122	C: 24	K. Nakajima (Mie, Japan)
53825.75694	53825.75833	V: 1 , Rc: 1, Ic: 1	S. Kiyota (Ibaraki,Japan)
53825.78413	53825.82137	V: 1 , Rc: 1, Ic: 1	K. Nakajima (Mie, Japan)
53827.74097	53827.79264	V: 1 , Rc: 1, Ic: 98	S. Kiyota (Ibaraki, Japan)
53828.71944	53828.81230	V: 1 , Rc: 1, Ic: 184	S. Kiyota (Ibaraki, Japan)
53830.73455	53830.79178	V: 11, Rc: 1, Ic: 143	S. Kiyota (Ibaraki, Japan)
53842.14863	53842.17043	Rc: 59	H. Maehara (Saitama,Japan)
53850.66944	53850.78032	Rc: 204	K. Nakajima (Mie,Japan)
53850.69490	53850.79198	V: 67, Rc: 65, Ic: 66	S. Kiyota (Ibaraki,Japan)
Telescope: IRSF 1.4m [8]. Observatory: SAAO. PI: T. Nagata.			
53830.15679	53830.15889	J: 3, H: 3, Ks: 3	

Table 3: Photometric observation log. (Cont'd)

Start	(MJD)	End	(MJD)	Remark
Telescope: RATAN-600. Observatory: SAO RAS. PI: S. Trushkin.				
2006/04/01	(53826)	2006/05/22	(53877)	1.0 GHz–21.7 GHz
Telescope: RTF-32. Observatory: IAA RAS. PI: S. Trushkin.				
2006/04/08 01:06	(53833.0458)	2006/04/08 08:52	(53833.3694)	4 expos. 2.3 GHz 8.45 GHz
2006/04/09 00:53	(53834.0368)	2006/04/09 08:50	(53834.3680)	5 expos.
Telescope: Nobeyama Millimeter Array. Observatory: Nobeyama. PI: K. Nakanishi				
2006/04/25 22:10	(53850.9236)	2006/04/25 22:30	(53850.9375)	110.21 GHz, 98.201 GHz

Table 4: Radio observation log.

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