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.
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 Kyuiku 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 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°.
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.

The X-ray light curves are shown in Fig. 3. 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.

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 $\sim 0.6$. 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
Observation Campaign of SS 433 in April 2006

T. Kotani

Figure 5: Simultaneous X-ray and optical observations. From top to bottom: $R_C$ magnitude obtained with MITSuME OAO 50 cm, $I_C$ 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 $A_v = 8$ or $N_H = 1.57 \times 10^{22}$ cm$^{-2}$. The optical model is the sum of a multicolor disk model with $T_{in} = 10^5$ 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 $A_v = 8$. The X-ray model consists of bremsstrahlung continuum and emission lines attenuated by $N_H = 1.3 \times 10^{23}$ 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
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 (MJD) | End (MJD) | Expos. (ks) | Remark               |
|------------|-----------|-------------|----------------------|
| 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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Observation Campaign of SS 433 in April 2006

T. Kotani

| Start Exposure | Remark |
|---------------|--------|
| (MJD) (s)     |        |
| 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 |  |
| Telescope: 150 cm. Observatory: Gunma. PI: K. Kinugasa. 2006/04/14 02:37:01 (53839.1090) 1200 |  |
| Telescope: Nayuta. Observatory: Nishi-Harima. PI: S. Ozaki. 2006/04/03 18:04:52 (53828.7534) 1800 |  |
| 2006/04/05 18:00 (53830.75) 120 | Line not detected. |
| 2006/04/06 18:00 (53831.75) 300 |  |
| 2006/04/09 18:00 (53834.75) 300 |  |
| 2006/05/03 18:00 (53858.75) 120 |  |
| 2006/05/06 18:00 (53857.75) 180 |  |
| 2006/04/05 17:55:00 (53830.7465) 1800 × 2 |  |
| 2006/04/07 17:48:03 (53832.7417) 592, 540 |  |
| 2006/04/09 18:00 (53834.75) 300 |  |
| 2006/05/03 18:00 (53858.75) 180 |  |
| 2006/05/05 18:00 (53857.75) 180 |  |
| 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 |  |

Table 2: Spectroscopic observation log.

[4] A. M. Cherepashchuk, R. A. Sunyaev, S. N. Fabrika, K. A. Postnov, S. V. Molkov, E. A. Barsukova, E. A. Antokhina, T. R. Irsenbetova, et al., INTEGRAL observations of SS433: Results of a coordinated campaign, A&A 437 (2005) 561.

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### Table 3: Photometric observation log.

| Start (MJD) | End (MJD) | Frames | Remark |
|-------------|-----------|--------|--------|
| 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 |        |
| 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 |        |
| 53827.76578 | 53827.80385 | V: 47, I: 47 |        |
| 53828.72676 | 53828.79979 | V: 91, I: 91 |        |
| 53830.73239 | 53830.80104 | V: 90, I: 90 |        |
| 53828.68783 | 53828.83571 | g': 321, Rc: 321, Ic: 321 |        |
| 53830.69849 | 53830.84003 | 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 |        |
| 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 |        |
| 53859.63797 | 53859.20651 | R: 19 |        |
| 53823.79792 | 53823.80069 | V: 1, Rc: 1, Ic: 1 | S. Kiyota (Ibaraki, Japan) |
| 53823.81339 | — | V: 1 | H. Maehara (Saitama, Japan) |
| 53824.78819 | 53824.83194 | 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) |
| 53828.73666 | 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) |
Observation Campaign of SS 433 in April 2006

T. Kotani

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) |
| 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) |
| 53850.66944 53850.78032 Rc: 59 H. Maehara (Saitama, Japan) |
| 53869.6940 53869.79198 V: 67, Rc: 65, Ic: 66 S. Kiyota (Ibaraki, Japan) |

Telescope: IRSF 1.4m. Observatory: SAAO. PI: T. Nagata.

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

| 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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