SS 433: Results of a Recent Multi-wavelength Campaign

Sandip K. Chakrabarti [1,2] **, B.G. Ananda Rao** [3] **, S. Pal** [2] **, A. Nandi** [2] **, R. Sagar** [4] **, J.C. Pandey** [4] **, A. Bhattacharyya** [2] **, S. Mondal** [3] **, S. Mandal** [2] **, A. Pati** [5] **, S.K. Saha** [5]

[1] ***S.N. Bose National Centre for Basic Sciences, JD Block, Salt Lake, Kolkata 700098***

[2] ***Centre for Space Physics, 43 Chalantika, Garia Station Road, Kolkata 700 084***

[3] ***Physical Research Laborator, Navarangapura, Ahmedabad 380009***

[4] ***Aryabhatta Institute of Observational Sciences, Nainital, 263129***

[5] ***Indian Institute of Astrophysics, Koramongala, Bangalore 560034***

We conducted a multi-wavelength campaign in September-October, 2002, to observe SS 433. We used the Giant Meter Radio Telescope (GMRT) for radio observations, the Physical Research Laboratory Infra-red telescope at Mt Abu for IR, the ARIES telescope at Nainital for optical photometry, the telescope at the Vainu Bappu observatory for spectral measurements and Rossi X-ray Timing Explorer (RXTE) for X-ray observations. We find sharp variations in intensity in time-scales of a few minutes in X-rays, IR and radio wavelengths. Combining results of these wavelengths, we find a signature of delay of about two days between IR and Radio emission. The X-ray spectrum yielded double Fe line profiles which corresponded to red and blue components of the relativistic jet. We also present the broadband spectrum averaged over the campaign duration.

1 INTRODUCTION

SS 433 is a well studied bright emission line compact object which is known to have a companion with an orbital period of 13.1d, a large disk and two highly collimated relativistic jets moving at $v \sim 0.26c$. The disk axis makes an angle of $\sim 78^\circ$ with the line of sight, while the jet precesses with the axis at an angle of $\sim 19^\circ$ [1] with a periodicity of about 162.15d. Several observations have been carried out over the last three decades, and yet, the object alluded a proper identification. Most recent estimates [2]) suggest that the central object could be a low mass black hole ($2.9 \pm 0.7\ M_\Theta$) with a high mass ($10.9 \pm 3.1\ M_\Theta$) companion.

In the present paper we report the results of a multi-wavelength campaign using several instruments such as GMRT of Radio, Mt. Abu Telescope for Infra-red, Vainu Bappu telescope for optical spectroscopy, State Observatory Telescope at Nainital for optical photometry and RXTE satellite for X-ray photometry. The aim of our campaign on SS 433 was (a) to carry out observations in as many wavelengths as possible, (b) to detect the nature of the short time-scale variabilities in all the wavelengths, (c) to obtain a broad band spectrum of this enigmatic system in order to model the emission processes in future. We carried out the campaign in radio (1.28 GHz), in IR (J, H, and K' bands), in optical (B and V bands) and in X-ray (3-30 keV) wavelengths in September-October, 2002, when the jet is more or less normal to the line of sight and the X-ray intensity is statistically in its minimum. Given that the jet is produced out of matter ejected from the accretion disk, one would expect that small variabilities, if present, would exist in all the wavelengths and one would hope to correlate these variabilities in order to 'follow' individual flares or knots as they propagate through the jets. We did observe such variabilities in time scales of few minutes, though, given that quite 'unknown' time delays are present between X-rays and Optical, IR or radio emitting regions, we found it difficult to correlate these variabilities. However, we did find a lag of almost two days between the overall variation of intensities in the IR and radio emissions.

2 RESULTS AND INTERPRETATIONS

In Table 1, we present the log of our observations with various telescopes. Column 1 gives Modified Julian Day(MJD) and the date of observation, Column 2 gives the wave band, Column 3 gives the telescope used and its location. For the Giant Meter Radio Telescope (GMRT). Column 4 gives the duration of the observations in seconds. Details on the observational methods and results could be seen in Chakrabarti et al [3].

Table 1. Observation log of SS 433

MJD(Date)	Waveband	Telescope(location)	Duration(s)
52542 (25/9/02)	J	PRL(Mt. Abu)	1480
	H	PRL(Mt. Abu)	1720
	K'	PRL(Mt. Abu)	740
52543 (26/9/02)	1.28 GHz	GMRT(Pune)	2160
	J	PRL(Mt. Abu)	3640
52544(27/9/02)	1.28 GHz	GMRT(Pune)	21600
	J	PRL(Mt. Abu)	2500
	H	PRL(Mt. Abu)	2390
	K'	PRL(Mt. Abu)	2180
	B	State Obs.(Nainital)	1320
	Optical	VBT (Kavalur)	2400
	Spectroscopy	VBT (Kavalur)	2400
	3-30 keV	RXTE	5696
52545(28/9/02)	1.28 GHz	GMRT(Pune)	960
	B	State Obs. (Nainital)	4860
	Optical	VBT (Kavalur)	3900
	Spectroscopy	VBT (Kavalur)	3900
52546(29/9/02)	1.28 GHz	GMRT(Pune)	840
	J	PRL(Mt. Abu)	1160
	H	PRL(Mt. Abu)	780
	K	PRL(Mt. Abu)	475
52547(30/9/02)	1.28 GHz	GMRT(Pune)	24024
52548(1/10/02)	1.28 GHz	GMRT(Pune)	16027
52549(2/10/02)	1.28 GHz	GMRT(Pune)	6689
52550(3/10/02)	B	State Obs. (Nainital)	120
	V	State Obs. (Nainital)	120
52552(5/10/02)	610 MHz	GMRT(Pune)	1130
52553(6/10/02)	610 MHz	GMRT(Pune)	2850

Fig. 1a shows the light curve of all the complete set of observation done during our campaign. Various marks indicate the wavelengths at which observations are made. The minimum of Radio observation seems to lag by two days with respect to the minimum of IR. This is interpreted as the propagation time between the IR emitting region and the Radio emitting region. In Fig. 1b the results of IR observations are shown. The upper panel is the differential photometry result between SS 433 and a standard field star while the lower panel is the result of differential photometry between two standard stars. This clearly shows that there are distinct minute-scale time variation of the IR signals. In fact, we observed that this is the case at all wavelengths.

In Fig. 2(a-b), we show the spectrum of SS 433 in (a) optical wavelength and (b) X-rays respectively. In the optical spectrum we get the red and blue shifted H_α lines (marked as $H_{\alpha-}$ and $H_{\alpha+}$ respectively) along with the strong H_α line which is the characteristics of all objects in the SS catalogue. Some other lines as well as the absorption due to atmosphere have been marked. The X-ray spectrum (b) photon spectrum of 27th September, 2002 clearly showed the iron lines, blue and red shifted as appropriate on that date.

In Fig. 3, we show the broadband spectrum from radio to gamma rays of SS 433. This is the first time that such a broadband spectrum was obtained out of a single campaign. We also added three points from Trushkin et al [5], Cherepaschuk et al [6] and Dolan et al. [7] though not contemporaneous at which we had no data just to show that our points are consistent.

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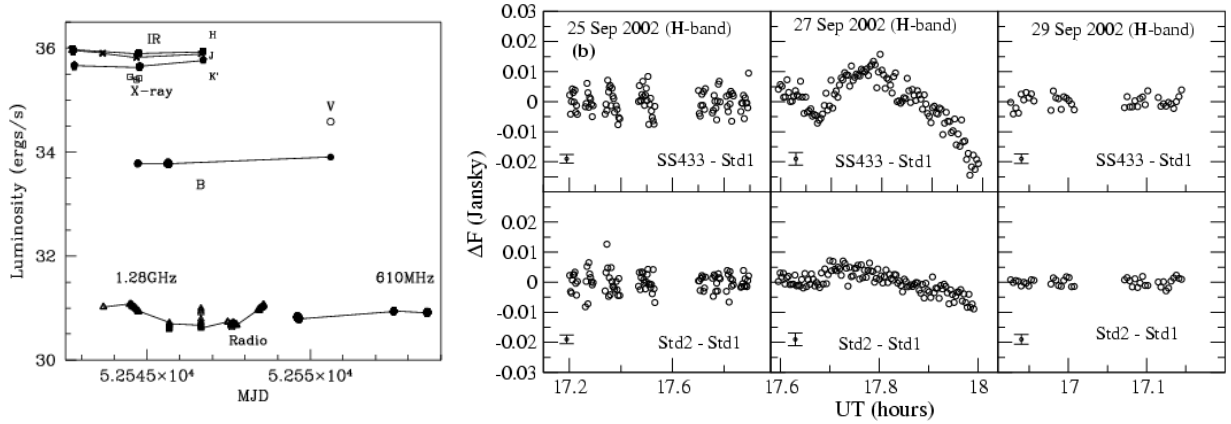

Fig. 1(a-b): (a) Multi-wavelength observation of SS 433 at 1.28 GHz (triangles) band and at 610 MHz (filled hexa-gons) in radio, at J (crosses), H (filled boxes), K' (filled pentagons) bands in IR, B (filled circles) and V (open circle) bands in optical, and 3-25 keV (open squares) in X-ray during the campaign. There seems to be a lag of minimum intensity region in the radio (MJD 52545.5 to MJD 52547.5) with respect to the Infra-red minimum region (~ MJD 52544-52545) by about 2 days. (b) Differential photometry of SS 433 in IR H bands with respect to a comparison star (std1) in the same frame of the object are plotted against the universal time on various days of the campaign in the upper panel while that for two comparison stars (std1 and std2) in the same frame of the object are plotted in the lower panel. The typical 3σ errors for differential measurements in both bands are plotted in each box. The *rms* differential flux variation in the SS 433 light curve is above 2σ level that in comparison stars.

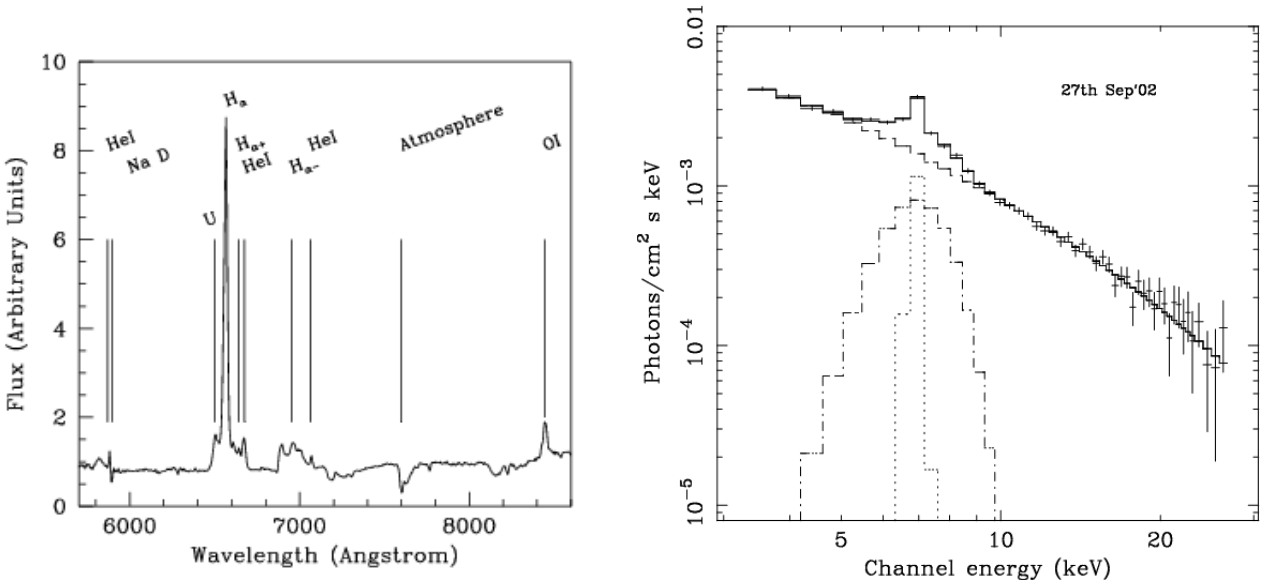

Fig. 2(a-b): (a) [left] The calibrated, continuum subtracted, optical spectrum of SS 433 on the 27th of September, 2002 is shown in the left. The H_α line, blue and red shifted H_α lines (denoted by $H_{\alpha-}$ and $H_{\alpha+}$ respectively), He-I lines, OI line, atmospheric and sodium absorption lines are identified. The Doppler shifted H_α lines are exactly where there are expected from kinematic model of Abell and Margon [4] within the instrumental resolution of 5Å. (b) [right] The X-ray spectrum of the first spell of the RXTE observation of the 27th of Sept., 2002. The spectrum was fitted with a bremsstrahlung and two iron lines showed with dotted and dot dashed curves.

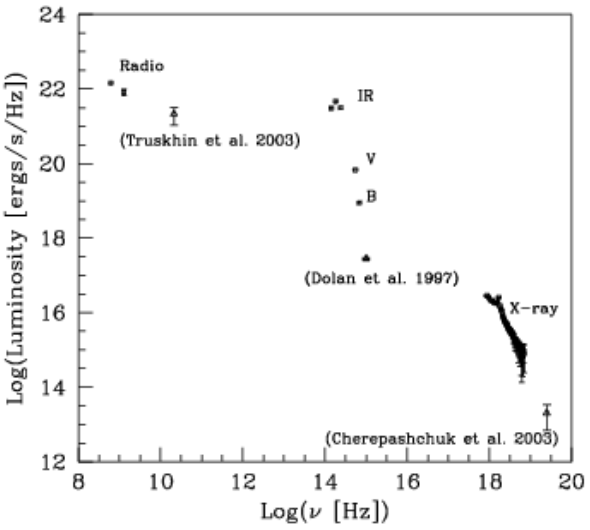

Fig. 3: The multi-wavelength spectrum of SS 433 as obtained by our campaign. Here, average luminosity (open boxes) over our available data has been plotted and the wavebands are marked. For comparison, we included three points, marked by open triangles with error bars, from literature (marked) which are not contemporaneous with our observation.

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