SS 433: Results of a Recent Multi-wavelength Campaign

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\textbf{ABSTRACT}

We conducted a multi-wavelength campaign in September-October, 2002, to observe SS 433. We used 45 meter sized 30 dishes of Giant Meter Radio Telescope (GMRT) for radio observation, 1.2 meter Physical Research Laboratory Infra-red telescope at Mt Abu for IR, 1 meter Telescope at the State Observatory, Nainital for Optical photometry, 2.3 meter optical telescope at the Vainu Bappu observatory for spectrum and Rossi X-ray Timing Explorer (RXTE) Target of Opportunity (TOO) observation for X-ray observations. We find sharp variations in intensity in time-scales of a few minutes in X-rays, IR and radio wavelengths. Differential photometry at the IR observation clearly indicated significant intrinsic variations in short time scales of minutes throughout the campaign. Combining results of these wavelengths, we find a signature of delay of about two days between IR and Radio. 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.

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1 INTRODUCTION

The enigmatic compact star SS 433 is an well studied bright emission line 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 $v \sim 0.26c$. 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 $\sim 19^\circ$ (Margon, 1984) 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 (Hillwig et al, 2004) suggest that the central object could be a low mass black hole ($2.9 \pm 0.7 M_\odot$) with a high mass ($10.9 \pm 3.1 M_\odot$) companion.

So far, there has been a few multi-wavelength campaign in SS 433 (e.g., Neizvestnyj, Pustilnik & Efrenov, 1980; Ciatti et al. 1981; Seaquist et al. 1982; Vermeulen et al. 1989; Band & Gordon 1998; and Kotani et al. 1999). However, these are confined to two or three wavelengths. The aim of our campaign 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 two days between overall variation of intensities in IR and Radio wavelengths. Our radio observation was carried out during 26th September to 6th of October, 2002. The IR observations were made during 25th to 29th of September, 2002. The optical photometry was made during 27th September to 3rd October, 2002, while X-ray observation was taken only on the 27th of September, 2002. Optical spectra were taken on the 27th and 28th of September, 2002. A brief report on the variabilities in radio, IR and X-rays, observed on the 27th of September, 2002 has already been published in Chakrabarti et al. (2003).
In the following Sections, we present the results of our multi-wavelength campaign. In §2, we briefly describe the observations and the data reduction. In §3, we present our results including the lightcurve and the broadband spectrum. Finally, in §4, we draw conclusions.

Our major results are as follows: (a) The short time-scale variations are present (2 – 8 minutes) on all the days in all the wavelengths. We present differential photometry results in IR for all the days. (b) The optical and X-ray spectra contain the blue and red-shifted lines which are compatible with the kinematic model (Abell & Margon, 1979). (c) For the first time, we obtained the broadband spectrum over ten decades of frequency range based on contemporaneous data. Observations in X-rays and radio waves at regular intervals are in progress and we plan to present results over longer time scales in future.

2 OBSERVATIONS AND DATA REDUCTION

Table 1 gives a log of our observations during the campaign and brief remarks on each observation. 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), we also give the number of antennas working during the observation in squared brackets. Column 4 gives the duration of the observations in seconds.

Radio observations were carried out with the GMRT which has 30 antennas each of 45m in diameter in a Y-shaped array with the longest baseline interferometry over 25km region (Swarup et al. 1991) near Pune, India along roughly Y shaped array. The observations were carried out at 1.280 GHz (bandwidth 16 MHz) during Sept. 26th, 2002 to Oct. 1st, 2002 and at 610 MHz (bandwidth 16 MHz) during 2nd-6th October, 2002. However, results of 3rd-4th October were full of scintillations. The data was binned at every 16 seconds. AIPS package was used to reduce the data. Bad data was flagged using tasks UVFLG and TVFLG and the standard deviation at each time bin using UVPLT package was computed. Generally, 3C48 and 3C286 were used as the flux calibrators whenever available.

Infrared observation was made using the Physical Research Laboratory (PRL) 1.2m Mt. Abu infrared telescope equipped with Near-Infrared Camera and Spectrograph (NICMOS) having 256 × 256 HgCdTe detector array cooled to the liquid nitrogen temperature 77K. One pixel corresponds to 0.47 arcsec on the sky, giving a field of view of 2 × 2 arcmin². The filters used were standard J (λ=1.25 µm, Δλ= 0.30 µm), H (λ=1.65 µm, Δλ= 0.29 µm) and K' (λ=2.12 µm, Δλ= 0.36 µm) bands. Short exposures were taken in immediate
### Table 1. Observation log of SS 433

| MJD (Date)   | Wave Band | 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) | J         | GMRT(Pune) [20]      | 2160         |
|              |           | PRL(Mt. Abu)         | 3640         |
| 52544(27/9/02) | J         | GMRT(Pune) [28]      | 21600        |
|              | H         | PRL(Mt. Abu)         | 2500         |
|              | K         | PRL(Mt. Abu)         | 2390         |
|              |           | State Obs.(Nainital) | 1320         |
|              | Optical   | VBT (Kavalur)        | 2400         |
|              | spectroscopy | VBT (Kavalur)    | 2400         |
|              | 3-30 keV  | RXTE                 | 5096         |
| 52545(28/9/02) | B         | GMRT(Pune) [24]      | 960          |
|              | Optical   | State Obs. (Nainital)| 4860         |
|              | spectroscopy | VBT (Kavalur)    | 3900         |
| 52546(29/9/02) | J         | GMRT(Pune) [13]      | 840          |
|              | H         | PRL(Mt. Abu)         | 1160         |
|              | K         | PRL(Mt. Abu)         | 780          |
| 52547(30/9/02) | J         | GMRT(Pune) [26]      | 3777         |
|              | H         | PRL(Mt. Abu)         | 120          |
|              | V         | State Obs. (Nainital)| 120          |
| 52550(3/10/02) | B         | GMRT(Pune) [29]      | 1130         |
| 52552(5/10/02) | V         | GMRT(Pune) [10]      | 2850         |
| 52553(6/10/02) | V         | GMRT(Pune) [10]      | 2850         |

a) The number of antennas working during the observation.

succession in the three bands. Single-frame exposure time during whole observations in the J and H filters were 10 seconds. Observations in K' filter were taken with 2 sec exposure and 5 successive frames were binned to obtain 10 sec for a better signal to noise ratio. On the 26th of Sept. only J band observation could be made before clouds covered the sky. At each dithered position ten frames were taken with each integration time of 10 seconds. The nearby infrared bright standard star GL748 (Elias et al. 1982) were used as the flux calibrator and it was observed for 50 frames with exposure time of 10 sec were observed in each filter during each night.

Data reduction of JHK' images were performed in a standard way using the DAOPHOT task of IRAF package. All the objects and standard star frames were de-biased, sky-subtracted and flat fielded. The sky frames were created by usual practice of median combining of at least five position-dithered images where the source was kept within the field of NICMOS of $2' \times 2'$. At each dithered position at least 10 frames of 10 sec exposure were taken for J and H bands while 20 frames of 2 sec exposure were taken for K' band. The zero point of the instrument was taken from the standard star observations. We measured the stellar
magnitudes using the aperture photometry task (APPHOT) in IRAF. Our derived mean JHK′ magnitudes on Sept. 25th, 27th and 29th are 9.51±0.04, 8.48±0.03 and 8.49±0.08; 9.47±0.02, 8.48±0.02 and 8.32±0.02; 9.51±0.01, 8.49±0.04 and 8.38±0.03 respectively. On the 26th of September J magnitude was 9.52±0.02. The magnitudes are converted to flux density (Jansky) using the zero-magnitude flux scale of Bessell, Castelli & Plez (1998) for plotting purpose. The differential magnitudes are determined using two brightest stars in the same frame of the object. The error in individual flux density measurement is the usual propagation error of the observed photometric magnitude. Photometric errors \( \epsilon \) are calculated for individual frame of every star and for the subtracted differential magnitude the final error was calculated as \( \sqrt{\epsilon_1^2 + \epsilon_2^2} \), where \( \epsilon_1 \) and \( \epsilon_2 \) are the error-bars of the individual stars.

The optical photometry was carried out at the State Observatory (currently known as ARIES), Nainital, India using its 1m reflector. The photometric observations in Johnson B and V bands were carried out using a CCD camera at f/13 Cassegrain focus of the telescope. The CCD system consists of \( 24 \times 24 \mu^2 \) size pixel, having \( 2048 \times 2048 \) pixels. To improve the signal-to-noise ratio the observations have been taken in a binning mode of \( 2 \times 2 \) pixel\(^2\), where each super pixel corresponds to \( 0.72 \times 0.72 \) arcsec\(^2\). The CCD covers a field of view of \( \sim 13 \times 13 \) arcminute\(^2\). Multiple CCD frames were taken with the exposure time of 120 secs. A number of bias and twilight flat field frames were also taken during the observing run. The frames were cleaned employing the IRAF/MIDAS software. The magnitude of the star is determined by using the DAOPHOT. The value of atmospheric extinction in B pass band is 0.26 during the observation and this was taken into account. Due to scattered clouds, only a few exposures could be made on the 27th of September, 2002 and only one exposure on each of the B and V bands could be made on the 3rd of October, 2002. Several exposures were taken on the 28th of September, 2002.

The optical spectroscopic study of SS 433 was carried out with the 2.3 meter Vainu Bappu Telescope (VBT) at the Vainu Bappu Observatory (VBO), Kavalur, India. CCD images were obtained during the period of 27th - 28th September’02. Detailed description of the telescope characteristics and observation techniques are given in Prabhu et al. (1995). The source was pointed at for a maximum exposure time of 20 min with the source positioned at the center of the CCD frame. The data was analysed with PC-IRAF 2.12.1-EXPORT version. The spectrum processing comprised of several subroutines which were performed in pipe-line. These include (a) making the MASTERBIAS using all the bias files supplied
with the data with median combine option, (b) making the MASTERFLAT using all flat files supplied with data with median combine option, (c) checking one of the flat files to get range of useful data, (d) using CCDPROC on all the science and science calibration files to correct for BIAS, FLAT fielding, trimming out of noise, (e) removal of cosmic rays using cosmicrays utility, (f) aperture synthesis of science data after checking dispersion axis and matching with apall parameters, (g) using apall for science calibration file with reference to the science data to calibrate with the proper science data, (h) calibration of spectrum lines in calibration data, (i) wavelength calibration (non-linear) of science data file using science calibrator file using dispcor (j) continuum calibration of wavelength calibrated science data. Since we did not have a standard spectrum (due to bad weather), we could not perform absolute flux calibration and so we had to rely on the simple continuum calibrated data. Iron and Neon lines were used to calibrate lines.

X-ray observation was carried out using the Proportional Counter Array (PCA) aboard RXTE satellite. The data reduction and analysis was performed using software (LHEA-SOFT) FTOOLS 5.1 and XSPEC 11.1. We extract light curves from the RXTE/PCA Science Data of GoodXenon mode. We combine the two event analyzers (EAs) of 2s readout time to reduce the Good Xenon data using the perl script make.se. Once make.se script was run on the Good_Xenon.1 and Good_Xenon.2 pairs, the resulting file was reduced as Event files using seextract script to extract light curves. Good time intervals were selected to exclude the occultations by the earth and South Atlantic Anomaly (SAA) passage and also to ensure the stable pointing. We also extracted energy spectra with an integration time of 16s from PCA Standard2 data in the energy range 3 - 30 keV (out of the five PCUs only data from No. 2 and No. 3 PCUs are added together). For each spectrum, we subtracted the background data that are generated using PCABACKEST v4.0. PCA detector response matrices are created using PCARSP v7.10. We perform fits to the energy spectra in the energy range 3-27 keV with the so-called ‘traditional model’ for SS 433, consisting of the super-position of thermal bremsstrahlung and Gaussian lines due to the emission from the iron atoms, modified by the interstellar absorption.

3 RESULTS AND DISCUSSIONS

Before we present the results of our campaign, we would like to give an overview of the long term behaviour of SS 433 in X-rays (Nandi et al. 2004). Figure 1 shows the average RXTE
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Fig. 1: The average All Sky Monitor (ASM) light curve of SS 433 as taken by RXTE satellite. The dotted vertical lines show the days of the present campaign, indicating that the object was expected to be X-ray quite.

All Sky Monitor (ASM) data. The complete set of ASM data since 1996 till date have been averaged after folding it around 368 days. This shows clear periodicity which is shown in Fig. 1. This ‘flaring’ is probably due to special alignment of SS 433 with the sun as seen by ASM. The vertical dashed lines represent the duration of our campaign. Thus our campaign took place in a time-frame away from such confusing region where X-ray was generally weak. Because of this we expected that even small variations in intensities would be detectable. In Chakrabarti et al. (2003) such short time variations have been reported.

In Fig. 2a, we present the images of SS 433 obtained by our Radio observation at 1.28GHz on the 1st of October, 2002. The contours are drawn at intervals of 0.055Jy. The beam size is shown as a circle in the lower left. In Fig. 2b, the image of SS 433 on the 27th of Sept. 2002, along with the those of the two standard stars in J band are shown. The magnitudes of the standard stars are also given.

Figure 3 shows the results of our multi-wavelength observation of SS 433 at 1.28 GHz (triangles) band and at 610 MHz (filled hexagons) 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 minimum in IR data on ∼ MJD 52544.674 (see, Fig. 5 below) while the radio shows minimum at ∼ MJD 52546.7, almost two days later. If the IR data could be taken as the pre-cursor of the radio data, one would infer that IR was also in a state of minimum intensity during the campaign. However, it is to be noted that this IR intensity is the sum of the components coming
from the companion and the jet. From the IR observation of Kodaira, Nakada & Backman (1985), one notices that at the precessional and orbital phases of SS 433 corresponding to our campaign, the relative $K$ magnitude was expected to remain almost constant ($\sim 0 \pm 0.05$), while in our observation we find it to be highly variable ($\sim 0.225$) which suggests that there are intrinsic variation in IR band which may have been reflected in the Radio band two days later. The H-band result was found to be higher compared to the J and $K'$ band results during the whole period. A similar result of turn-around at about 4 micron was reported earlier by Fuchs (2003). This turn over could be possibly due to free-free emission in optically thin limit. Absorption in the J band by the surrounding matter or the jets may also be a possibility.

In Fig. 4 we present the multi-wavelength lightcurves in radio (1.28GHz), in J,H, and $K'$ bands, in B band and in X-rays (3-30 keV). The mean radio flux was seen to gradually go down while behaviours in other wavebands were not so straightforward. For instance, the flux in $H$ band was found to be the higher compared to $J$ or $K'$. This was not clearly understood, while a monotonic behaviour was expected. As we mentioned above, extra emission at $H$ band is possible due to bremsstrahlung.

In Fig. 5 we present the entire IR observations taken during the campaign. The flux was clearly diminishing during 25th to 27th and it started rising again on the 28th. The minimum is at around MJD 52544.674. The data is clearly variable in a few minutes time scale. This
Fig. 3: Multi-wavelength observation of SS 433 at 1.28 GHz (triangles) band and at 610 MHz (filled hexagons) 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 radio (MJD 52545.5 to MJD 52547.5) with respect to the Infra-red minimum region (~MJD 52544-52545) by about 1.7 days.

Fig. 4: Light curves of SS 433 on the 27th of September, 2002, as obtained by our multi-wavelength campaign at different wavelengths. Upper panel: Radio observation at 1.28 GHz at GMRT, Pune. Second panel: IR observation at J, H and K′ bands at Mt. Abu. Third panel: B band observation at the State Observatory, Nainital and the Bottom panel: Background subtracted X-ray count rates by RXTE satellite.
considerable variations could be seen in all the days. The size of the error-bars are well below the size of the circles. The intensity seems to be minimum (around 0.25 Jy) on MJD 52544.674.

could be seen more clearly in the differential photometry results in the IR observations. In Figs. 6(a-b) this is presented. In Figs. 6a (upper panel) the results in J band are presented, while in Fig. 6b (lower panel) the results in H band are presented. In each panel, the upper box shows the difference between SS 433 and the Standard 1 star while in the lower box, the difference between the two standard stars have been plotted. The error-bars are also shown. In general, the upper boxes show at least twice more variation that the lower boxes. The $1\sigma$ error-bar ($J=0.00035 \text{ Jy}, \ H=0.00085 \text{ Jy}$) of the differential flux variation between SS 433 and std1 for the whole light curve is a factor of 3.5 and 2.5 in the J-band and H-band respectively in comparison to that between two standards ($J=0.0001 \text{ Jy}, \ H=0.00035 \text{ Jy}$). The $1\sigma$ for the light curve is more than a factor of 5$\sigma$ of single point measurement error.

The $1\sigma$ for the light curve is more than a factor of 5$\sigma$ of single point measurement error. Thus, the variation in the IR light curves of SS 433 is likely to be intrinsic and the analysis shows above 2$\sigma$ level variability in the both bands. Short time-scale variation on the order of ten minutes have also been reported by Kodaira & Lenzen (1983).

Since the optical results depended heavily on the local sky conditions, the data acquisition was not uninterrupted. Indeed, although two observatories, one in southern part of India (VBT, Kavalur) and the other in the northern part of India (ARIES, Nainital) were chosen, both observations were affected by the late monsoon activities. Table 1 showed the duration
Fig. 6(a-b): Differential photometry of SS 433 in IR with respect to a standard star (std1) in the same frame of the object are plotted against the universal time on various days of the campaign in the upper panels. Also shown in lower panels are the differences of intensities $\Delta F$ (Jansky) of one standard star (std1) to the other (std2). The upper plots are for the data for the J band and in the lower plots are the data for the H band. Differential flux variation of SS 433 is above 2$\sigma$ level in comparison to that of the standard stars.

of the data acquisition and the exposure time taken. In Figs. 7(a-b) we present the spectrum of SS 433 taken at VBT. Fig. 7a shows the raw spectrum, while Fig. 7b shows the spectrum on the 27th of Sept. 2002 corrected as described in Sec. 2. In Fig. 8a, the wavelength calibrated spectrum is shown and major lines were identified. On this date, both the jets were showing redshifts. The shifted line wavelengths match with what is expected from the kinematic model of Abell and Margon (1979) within the instrument resolution of 5Å. For instance, at 13:49 UT, on 27th of Sept. 2002, the expected red shifts were 0.05901 and 0.01234 respectively and the $H_\alpha$− and $H_\alpha$+ lines were expected at 6950Å and 6644Å respectively. Our observed lines were at 6961 Å and 6642 Å respectively. The spectra on the 28th of September, 2002, presented in Fig. 8b, had two bright lines (marked by ‘U’ on the figure) at 7029Å and 6481Å respectively apart from the usual lines. The red/blue shifted $H_\alpha$
Fig. 7(a-b): a) The raw and (b) the corrected spectrum of SS 433 taken at the 2.3m Vainu Bappu Telescope. See text for detailed procedure.

Fig. 8(a-b): The calibrated, continuum subtracted, optical spectrum of SS 433 on the (a) 27th and (b) 28th of September, 2002. In (a) the H$_\alpha$ line, blue and red shifted H$_\alpha$ lines (denoted by H$_{\alpha+}$ and H$_{\alpha-}$ respectively), Hel lines, OI line, atmospheric and sodium absorption lines are identified. The Doppler shifted H$_\alpha$ lines are exactly where there are expected from kinematic model of Abell and Margon (1979) within the instrumental resolution of 5 Å. In (b) we also see two bright lines, marked by ‘U’ at 7029.07Å and 6481.09Å respectively.

lines had very low intensity, indicating the decaying phase of the so-called optical bullets (Margon 1984; Vermeulen et al. 1993). On the 28th, the spectrum was taken 6 times, and in all the spectra these two unidentified lines were seen. The origins of the brighter ‘U’-marked lines are not totally clear as they are not close the expected H$_{\alpha\pm}$ lines expected on that day. On the 27th of September, 2002, there was an unidentified line on the blue-ward side of the H$_\alpha$ line at 6503Å as well. This is also marked as ‘U’ in Fig. 8a. These could be from the accretion streams or from the winds from of the companion itself. If correct, and are identified as the blue and red-shifted lines of the H$_\alpha$ line from the companion, then,
Fig. 9: 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. 10: 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.

The projected velocity components long the line of sight required to produce these lines would be 21,300 km s$^{-1}$ (away from the observer) and 3748 km s$^{-1}$ (towards the observer) respectively. Abnormal activities in the jets may not be ruled out either, in which case the asymmetry of the red and blue-shifts would be due to probable intrinsic red-shifts of the...
relativistic system. Unfortunately the spectrum on the 30th of September, 2002 could not be used, as there was focusing error in the telescope.

The three spells of X-ray data (see, Fig. 4, bottom panel) were analyzed separately. We found that generally speaking, two line model with a thermal bremsstrahlung is necessary for statistically and physically acceptable fit to the X-ray spectra. However, the significance depends on the duration of observation. In Fig. 9, we present the X-ray spectrum of the first spell of our RXTE observation. The single line fit to the spectra yields $\chi^2/\nu = 44.94/45$ ($\nu$ is degrees of freedom) whereas the double line fit gives more acceptable value with $\chi^2/\nu = 34.84/43$. The requirement of the 2nd line in the spectrum is tested from the \textit{ftest task} within XSPEC and found that the fit is significant at (2.4$\sigma$) level. The best fitted two lines found at energies 6.966 keV and 6.898 keV correspond to the Doppler-shifted values of $z= -0.00014$(FeXXVI) and $z= -0.032$ (FeXXV) or $+0.0096$(FeXXVI) respectively. Therefore, both the lines that we have identified are coming from the blue-jet of SS 433. The observed flux is $2.6524 \times 10^{-10}$ ergs cm$^{-2}$ sec$^{-1}$ in the energy range 3-25 keV with the bremsstrahlung temperature at 15.77 keV. We failed to fit with a model having a blackbody emission component. Thus, no evidence for a Keplerian disk was found. Similarly, the single line fit to the spectra of the second spell yields a $\chi^2/\nu = 54/45$ whereas a double line fit gives more acceptable value with $\chi^2/\nu = 35.7/43$. The requirement of the 2nd line in the spectrum is tested and found that the fit is significant at (3$\sigma$) level. The best fitted two lines found at energies 7.012 keV and 6.802 keV which correspond to the Doppler-shifted values of $z= -0.007$(FeXXVI) and $z= -0.018$ (FeXXV) respectively. Here too, both the lines are from the blue-jet of SS 433. The observed flux is $2.375 \times 10^{-10}$ ergs cm$^{-2}$ sec$^{-1}$ in the energy range 3 – 25 keV with the bremsstrahlung temperature at 13.92 keV.

Figure 10 gives the broadband spectrum of SS 433 that we obtained using our multi-wavelength campaign. Campaign average data has been used for simplicity. In radio, results of 610 MHz and 1.28 GHz data have been put, while in infra-red, the results of I,J, K' bands have been put. We included V and B band observations which clearly show heavy extinction and the luminosity drops dramatically. X-ray spectrum in 3 – 27 keV is also shown. To compare with the results of others, we have included three observations at wavelengths which were not covered during our campaign (triangles). Thus, 21.7GHz observation of Trushkin et al (2003), ultra-violet observation of Dolan et al. (1997) and gamma-ray observation of Cherepashchuk et al. (2003) have been included. These three points were not contempo-
raneous to our campaign, but yet, they generally fall at reasonable values in the overall spectrum.

4 CONCLUDING REMARKS

In this paper, we have presented results of a recent multi-wavelength campaign on SS 433 carried out during 25th September, 2002 till 6th of October, 2002 using radio, IR, optical and X-ray instruments. Average ASM result indicated that the campaign was conducted when X-ray intensity was generally low which we also verify from our observations. We found that there is a tendency for the radio intensity variation to lag the IR variation by about two days. The broadband spectrum clearly showed evidence of very high extinction in optical region, possibly due to large scale obscuration of the central object by matter coming from the companion wind (Paragi et al. 1999). The X-ray data could be fitted with two Fe lines, both of which appear to be coming from the blue-shifted jet, i.e., the jet pointing towards us. We also find very small time-scale (few minutes) variations in all the wavelengths which could be suggestive of small bullets propagating from the base of the jet on the accretion disk to the radio regions as originally suggested in earlier communications (Chakrabarti 2002, 2003). The differential photometry in IR gives very clear indications that these short time scale variations were intrinsic to the jet. In optical spectra we observed that the blue- and red-shifted $H\alpha$ lines to appear at the same location on the 27th of Sept. 2002 – on the 28th the intensities of these lines were very low possibly because the so-called optical bullet emission was on the decaying phase. We also see two bright, unidentified lines in all the frames taken on the 28th Sept. which could be due to sudden winds in the companion. Our optical and X-ray spectra indicated that the kinematic model generally gives the correct description even today.

SS 433 has always been a puzzle and it is still so even after 25 years of its discovery. The mass estimate of the recent observation (Hillwig et al. 2004) is an indication that the central compact object could be a small mass black hole. Given that in the last decade fresh understanding about the accretion processes onto black holes have emerged, it may be necessary to look into this system with a fresh look. Our result gives some idea about the physical processes that is going on near the compact object (a) The X-ray spectrum does not show any indication of a Keplerian disk. Thus the flow may be totally sub-Keplerian or advective (Chakrabarti, 1990), as is expected if the accretion is from winds. (b) Broadband
spectrum indicated heavy extinction in the optical/UV region. This is expected from the matter that is accumulated around the system (Paragi et al, 1999). (c) Short-time scale variations may indicate ejection of bullet-like entities, which could be formed due to shock oscillations in the advective flows (Chakrabarti et al. 2002). (d) There is a general indication that the radio intensity follows the IR by about two days. This could not be rigorously confirmed as the coverages in the campaign were not very high. If correct, and if we assume that the same matter generally propagates from the IR jet to radio jet, this would indicate that the radio emission takes place only about $6.73 \times 10^{14}$ cm away from IR emitters. This seems to be quite reasonable. In fact, while comparing the results of Kodaira, Nakada & Backman (1985) with our observation, we conclude that there are intrinsic variation in IR band which may have been reflected in the Radio band two days later.

According to Brinkmann et al. (1991), the length of the X-ray jet is smaller than $\sim 10^{11}$ cm. Marshall et al (2002), further quantified this limit at $2 \times 10^{10}$ cm. In our analysis, we find the temperature of X-ray emitting region to be $kT \sim 15$ keV which, using the model of Kotani et al. (1996), correspond to even smaller distance of $\sim 10^{10}$ cm. While analysing RXTE data of SS 433 for over two years, Nandi et al. (2004) found the temperature to be even higher. Therefore, the X-ray emission must be from a region much closer to the compact object. On the other hand, IR emission of the jet may be emitted some where around $10^{12}$ cm (Fuchs 2003). Thus, the time lag between X-rays and IR should be at most a few hundreds of seconds. Lack of continuous X-ray observation during our campaign does not allow us to make definite comment on whether this lag was observed or not.

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