Astron. Astrophys. 354, 938–942 (2000)

ASTRONOMY AND ASTROPHYSICS

Observation of X-ray transient XTE J1748−288 by the Indian X-ray astronomy experiment

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Received 15 March 1999 / Accepted 7 January 2000

Abstract. The observations of a newly discovered X-ray transient source XTE J1748−288 were made in the energy band 2 − 18 keV with the Indian X-ray Astronomy Experiment(IXAE) on the IRS−P3 satellite during 1998, June 14−25. The source count rate declined gradually with an exponential decay time of 19 $\pm$ 1.6 days. The X-ray light curves showed no significant intensity variations on short time scales ($\leq$ 10s). The power density spectrum obtained from timing analysis of the data shows no quasi-periodic oscillations in the frequency range of 0.002 Hz to 5 Hz. From the observed X-ray and radio characteristics, it is suggested that the X-ray source in XTE J1748−288 is more likely to be a black hole rather than a neutron star.

Key words: accretion, accretion disks – black hole physics – stars: individual: XTE J1748-288 – X-rays: stars

1. Introduction

X-ray transients constitute an important class of binary X-ray sources. Although a majority of transient sources are low mass X-ray binaries (LMXBs), a large number (about 40%) are high mass X-ray binaries (HMXBs). Most of the HMXB transients have a X-ray pulsar with a Be star optical companion. The LMXB transients may contain either a neutron star or a black hole as X-ray source. Of the 33 LMXBs classified as transients by Tanaka & Shibazaki (1996), 18 are listed to be black-hole binaries. Thus almost all the LMXBs with a black-hole X-ray source are transients. The neutron star transients, on the other hand, comprise only a small fraction (15%) of the LMXBs with a neutron star. For a review of the LMXB transients refer to Tanaka & Shibazaki (1996).

A new transient X-ray source XTE J1748−288 was first detected with the All Sky Monitor (ASM) onboard the ROSSI X-ray Timing Explorer (RXTE) on 1998 June 4.69 UT at a flux level of about 860 mCrab in 1.5 − 12 keV band (Smith, Lewin & Wood (1998)). The source had a hard spectrum as indicated by BATSE detection of a bright object with a flux of about 310 mCrab in 20-70 keV interval on June 3 which increased to 730 mCrab on June 4 (Harmon et al. 1998). Following the discovery with the ASM, the X-ray transient was scanned with the Proportional Counter Array (PCA) on board the RXTE on June 5 to measure its position more precisely (Strohmayer & Marshall 1998). A radio candidate was detected within one arc minute of the center of the error box of the X-ray transient at a flux level of 28 $\pm$ 2 mJy at 4.86 GHz by Hjellming & Rupen (1998a). Further radio observations revealed that the radio source became brighter and was highly variable with a flux of about 110 mJy at 4.86 GHz on June 10 which increased to 410 mJy on June 14 (Hjellming & Rupen 1998a; Fender & Stappers 1998). The VLA observations revealed the radio source to be a relativistic jet source. It was unresolved with a size of $< 0''.1$ on June 10.19 UT which became extended along the East-West with a size of $0''.25$ on June 14.31 UT (Rupen, Hjellming & Mioduszewski 1998). The one-sided jet was found to be linearly polarised and moving at a rate of 20 mas year^{-1}. This corresponds to a jet velocity of 0.93c for a distance of $\geq$ 8 kpc obtained from measurement of 21 cm absorption when the source was bright (0.5Jy) (Hjellming, Rupen & Mioduszewski 1998b) There is no report so far of any optical or infrared identification of the source.

Following the announcement of the discovery of XTE J1748−288, we made observations of the X-ray transient with the Pointed-mode Proportional Counters (PPCs) of the Indian X-ray Astronomy Experiment (IXAE) during 1998 June 14 − June 25. From a detailed timing analysis of the IXAE data we did not find any QPOs in the frequency range of 0.002 Hz 5 Hz in the power density spectra of XTE J1748−288. In this paper we report these results and discuss their implications.

2. Instrument and observations

The X-ray observations of the source XTE J1748-288 were carried out with the PPCs of the Indian X-ray Astronomy Experiment (IXAE) on board the Indian Remote Sensing satellite IRS-P3 which was launched on 1996, March 21 from India. The IXAE includes three co-aligned and identical, multi-wire, multi-layer proportional counters with a total effective area of

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Table 1. X-ray Observation of XTE J1748−288 with the IXAE for 1 sec time resolution mode.

Day of 1998 June	M.J.D.	From hh mm ss (UT)	To hh mm ss (UT)	Counts per sec
14	50978	13:29:00	13:47:40	530
		15:10:00	15:28:00	496
		16:49:00	17:09:52	540
		18:32:00	18:50:40	514
15	50979	16:29:00	16:48:52	481
		18:11:00	18:30:00	498
17	50981	14:06:00	14:25:00	445
		15:47:00	16:06:00	435
		17:29:00	17:47:00	386
		19:17:00	19:30:00	375
18	50982	13:46:00	14:04:00	478
		15:27:00	15:45:00	402
		17:07:00	17:26:00	366
		18:54:00	19:08:00	412
19	50983	16:47:00	17:06:00	390
		18:28:00	18:47:00	363
20	50984	13:03:00	13:21:00	220
		14:45:00	15:03:00	218
		16:25:00	16:44:00	410
		18:07:00	18:26:00	392
21	50985	12:41:00	13:01:00	438
		14:24:00	14:42:00	364
		16:05:00	16:23:00	343
		17:45:00	18:04:00	421
		19:35:00	19:46:00	410

Table 2. X-ray Observation of XTE J1748−288 with the IXAE for 0.1 sec time resolution mode.

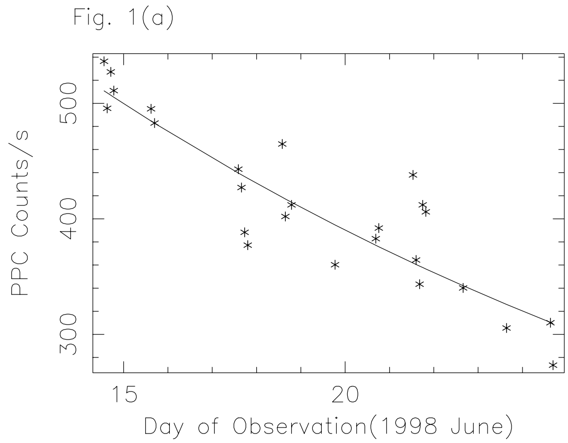
Day of 1998 June	M.J.D.	From hh mm ss (UT)	To hh mm ss (UT)	Counts per sec
22	50986	14:01:00	14:23:00	367
		15:43:00	16:04:00	340
		17:24:00	17:44:40	352
23	50987	13:39:00	14:02:00	290
		15:20:00	15:42:00	305
		17:03:00	17:23:00	321
24	50988	15:00:00	15:23:00	310
		16:40:00	17:02:00	273
		18:23:00	18:43:40	291
25	50989	14:39:00	15:01:00	276
		16:19:00	16:41:00	283
		18:23:00	18:43:00	260

1200 cm^2, covering 2 to 18 keV energy range. The PPCs are filled with a gas mixture of 90% Argon and 10% Methane at a pressure of 800 torr with an average detection efficiency of about 60% at 6 keV. There are three layers in each PPCs, each containing eighteen anode cells with a cross-sectional area of 1.1 cm$\times$ 1.1 cm. The bottom layer and the end cells are joined together to form a veto layer for rejecting the charged particles. The alternate anode cells in each layer and the top two layers are operated in mutual anti-coincidence and form the X-ray detection volume. The entrance window of the detectors is a 25 micron thick aluminized mylar film. Each PPC is equipped with a honeycomb type collimator having a field of view of $2^\circ.3 \times 2^\circ.3$. The overall energy resolution of the PPCs is 22% at 6 keV. X-rays from a radioactive source Cd^{109}, mounted on the rear side of each PPC, are collimated to irradiate the veto cells to monitor gain stability of the detectors. Modular and identical processing electronics, to make each PPC to be independent and replaceable, is used to collect the data either in the time tagged mode or the spectral mode. The electronic logic of the PPCs is designed to accept the genuine X-ray events and reject the background which is produced by the charged particles and the Compton scattering of the high energy photons. The accepted genuine X-ray events are stored in counters in $2-6$ keV and $2-18$ keV band for the top layer, $2-18$ keV band for the middle layer, >18 keV (ULD counts) for all the layers and >2 keV counts from the veto layers. In the spectral mode, the above five count rates are stored separately in an onboard memory for selectable integration times of 1 second and 0.1 second. The pulse height analysis of each accepted count is also carried out using a 64 channel analyser and stored in an onboard memory in the form of a histogram with integration time of 100 s in nominal mode. In the present analysis, we have not used spectral information of the data.

In the time tagged mode each event is time tagged to an accuracy of 0.4 msec (for PPC-3) or 0.8 msec (for PPC-1 and PPC-2). The IXAE instrument also includes a remote sensing camera and an oceanographic instrument. For a detailed description of the PPCs refer to Agrawal (1998) and Rao et al. (1998).

The IRS-P3 satellite is in a circular orbit at an altitude of 830 km and inclination of 98°. Pointing towards any particular source is done by using a star tracker with an accuracy of $\leq 0^\circ.1$. Because of the very low value of the geomagnetic cut-off rigidity at high latitudes, the charge particle background rises sharply beyond $b < -30^\circ$ and $b > +50^\circ$. The useful observation time is thus limited to the latitude range typically from 30°S to 50°N. The South Atlantic Anomaly (SAA) region restricts the observation to 5 of the 14 orbits per day. The high voltage to the detectors is reduced to about 500 V whenever the satellite enters the SAA region and the data acquisition is stopped. The data are downloaded twice per day.

As the PPCs are co-aligned, simultaneous background measurements are not possible. For a given source, background counts are measured before or after the observation of a source by pointing the PPCs to a source-free region in the sky, close to the target source. The source XTE J1748−288 was observed from June 14 to June 25, 1998. The log of observations is given in Table 1 and Table 2, for those observations which are used for the present analysis. The total useful exposure for XTE J1748-288 was 27,060 sec in the 1 sec integration mode and 15,440 sec for the 0.1 sec mode. Due to a suspected shift in the gain



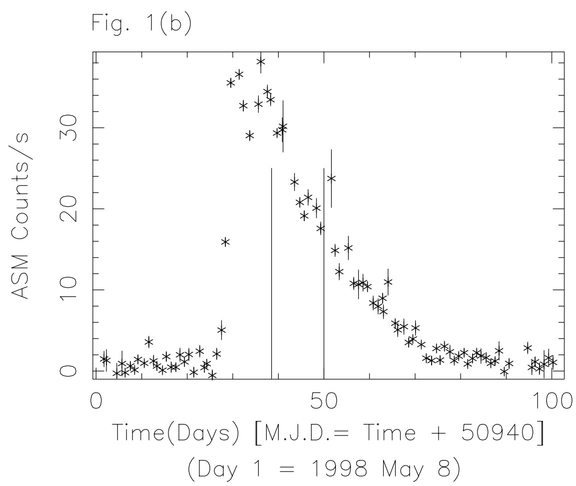


Fig. 1a and b. **a** The light curves obtained from the observations of XTE J1748−288 for the period 1998, June 14 − 25 for 2 − 18 keV energy band. The ASM light curve for XTE J1748−288 for 1-day average data is shown in Fig. 1b. The region between two vertical lines in Fig. 1b is the period of observation by the PPCs. The decay time for the source is calculated by exponential fitting to the light curves.

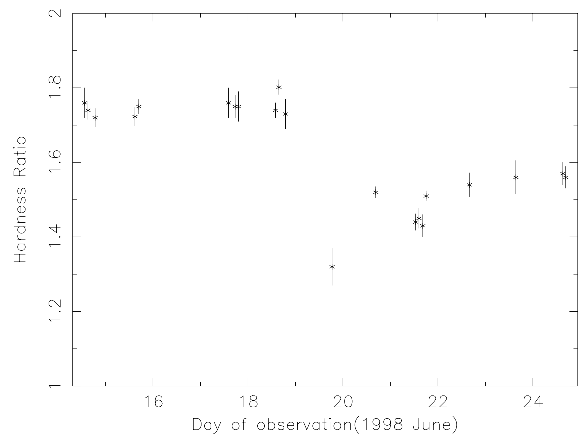


Fig. 2. The hardness ratio i.e count rate in 6 − 18 keV energy range/counts rate in 2 − 6 keV energy range, for the source XTE J1748−288 for the PPC observation during 1998 June.

of PPC-2, data from PPC-1 and PPC-3 are used in the analysis and normalised to the three PPCs.

3. Analysis and results

3.1. Long-term X-ray light curve

The X-ray light curve of XTE J1748-288 from the IXAE observations for 2 − 18 keV energy range was constructed by using the summed count rates from PPC-1 and PPC-3, averaged over each orbit of the satellite. The background count rates obtained by observing a nearby source-free region were subtracted from the count rates obtained during the source observations. The data were also corrected for vignetting by using aspect information from the star tracker. The event processing time for each PPC is about 20 μs which leads to a dead time correction of less than 1% for the maximum observed count rates of 200 counts s^{-1} for each PPC. Therefore dead time correction was not done. The X-ray light curve for the entire period of IXAE observations (1998 June 14−25) is shown in Fig. 1a for 2 − 18 keV energy band. The continuous line in Fig. 1a is the exponential fit to the light curve which gives an e-folding time of 19.0 ± 1.8 days. Fig. 1b is the light curve of the source from one day averaged data in 1.3 − 12 keV energy range obtained from the All Sky Monitor(ASM) on the RXTE. This light curve was obtained from the publicly available ASM data archive. The IXAE observations, which were made during the declining phase of the source are indicated by two vertical lines in the light curve for ASM data in Fig. 1b. A gradual decrease in the X-ray intensity of the source with time can be clearly seen in both the light curves. The summed PPC count rate at the beginning of observation e.g. June 14, was about 550 counts s^{-1} in 2 − 18 keV band which declined to about 260 counts s^{-1} on June 25. From the ASM light curve, it is clear that the intensity of the source was maximum on 1998, June 6 with a count rate of 38 ASM counts s^{-1} (Crab = 75 ASM counts s^{-1}) After staying at the maximum for 8 days, the intensity decayed exponentially over the next 30 days. An exponential fit to the ASM data gives a decay time of 15.6 ± 0.4 days. The decay time obtained from the PPCs agrees with the ASM data within errors. Using 2 − 6 keV and 6 − 18 keV count rates from PPC-3, the hardness ratio (counts in 6 − 18 keV band / counts in 2 - 6 keV band) was computed for all the observations. PPC-1 data are not used for computing the hardness ratio as data for 2 − 6 keV energy channel for some of the observations were not available due to data readout problems. The hardness ratio computed from the PPC-3 data is shown in Fig. 2 for the entire observation period. There is no significant short term variation in the hardness ratio in the individual observations. From Fig. 2, it can be noticed that the average hardness ratio which was 1.75 ± 0.013 during June 14 − 19, changed to 1.50 ± 0.012 after June 19, indicating a softening of the spectrum during the decay phase. Similar spectral softening has been reported by Revnivtsev et al. (1999) from PCA observations when the source made transition from a Bright Hard State (BHS) to a High State (HS).

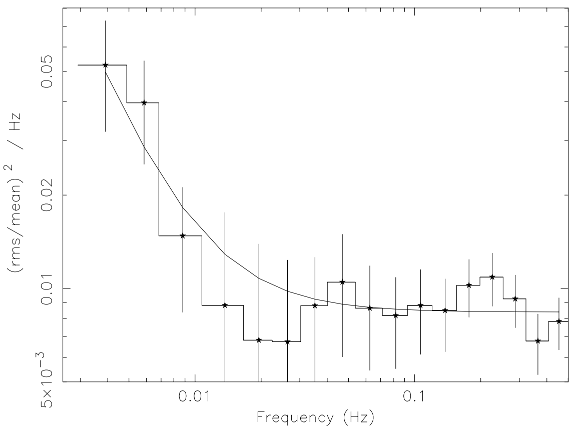


Fig. 3. The power density spectrum for XTE J1748−288 obtained from observations during 1998 June 14 − 25 for 2 − 18 keV energy band using 1 sec time resolution.

3.2. Light curves of individual observations

The X-ray light curves for individual observations of XTE J1748−288 were constructed after correcting the data for the background and vignetting, in the energy band 2-18 keV using 1 s and 0.1 s bin data. No significant variability was detected over time scales of 0.1 s to a few seconds. To investigate variability on a longer time scale, 1 second data bins were added to generate light curve in 10 sec bins. There is suggestion of irregular intensity variations in individual observations of the source on time scale of 10 s and longer. A constant intensity fit to the 10 s light curves gives a reduced $\chi^2 \geq 2$ for 50 or more degrees of freedom.

3.3. The power density spectrum

The timing behaviour of XTE J1748−288 was studied by taking the fast Fourier transform of the 1 s and 0.1 s time resolution data. We generated count rate profiles of XTE J1748−288 in the 2−18 keV bands with a time resolution of 1 s and also for 0.1 s. The PDS are obtained for the individual data segments of the observation and then co-added and the final PDS is produced. The data from the two PPCs are added to obtain the PDS for improving the statistics. The PDS are normalised to the mean count rate.

It may be noticed from the PDS for 2 − 18 keV energy range, in Fig. 3, that it is flat and featureless in the frequency range of 0.01 Hz to 0.5 Hz and goes up below 0.01 Hz. The PDS in the frequency range 0.003 Hz to 0.5 Hz fits well with a model comprising of a power law component with index 1.7 and a constant giving reduced χ^2 of 0.41 for 14 degrees of freedom. The Poisson fluctuation level is subtracted during the normalisation of the PDS to (rms/mean)^2/Hz. The rms fractional variation of the PDS in Fig. 3 is calculated for different frequency ranges. It is found to be 1.6% in 0.002 − 0.01 Hz range, 2.6% in 0.01 − 0.1 Hz and 5.9% in the higher frequency range 0.1 − 0.5 Hz.

A similar PDS is also obtained using data of 0.1 s mode for the combined observations. This PDS is also flat with no indication of any QPO in the frequency range of 0.002 to 5 Hz. A search for the presence of regular X-ray pulsations in the period range of 5 to 100 s gave negative results.

4. Discussion

The exponential decay of the source intensity with a time constant of 10 to 40 days is a common characteristic of several black hole X-ray novae (Tanaka & Shibazaki 1996; Shabhaz, Charles & King 1998). The outburst profiles are characterised by fast rise and slow decay. The exponential decay time for the source XTE J1748−288 is calculated from the PPC data to be 19 days. The decay time for XTE J1748−288 is in the range of decay times of other black hole X-ray transients e.g. 26.3 days for A0620−00, 28.3 days for GS 1124−683, 30.1 days for GS 2000+25 (Shahbaz et al. 1998) and 30.0 days for GRO J1655−40 (Remillard 1998). This similarity supports the black hole nature of the transient source XTE J1748−288.

In the black hole sources the QPOs have been detected over a wide spectral band but mainly in the hard spectral state of the sources. The QPOs are, however, not always present in the PDS of black hole binaries. In Cyg X−1, out of 13 observations with the EXOSAT ME detectors, the QPOs were detected only on 4 occasions. Since our observations of XTE J1748−288 were made in the decay phase it is possible that the QPOs were either absent or had an amplitude below the detection limit. It is also conceivable that the QPOs, if present, had a frequency of more than a few Hz in which case it will be undetectable in our observation due to the limited time resolution (0.1 s). The X-ray transient XTE J1748−288 has been observed extensively with the PCA on the RXTE. Fox & Lewin (1998) have reported the presence of QPOs in their observation of this source on 1998 June 6.4 with the PCA. Their 2700 sec observations were made when the source was near its maximum intensity. They found two QPO peaks in the power density spectrum, a broad peak at 0.5 Hz and a narrow peak at 32 Hz. During the course of their observation, the low-frequency QPO with rms strength of 3.4% shifted to the 0.35 to 0.50 Hz range while the high-frequency QPO remained stationary. A more detailed study of the PCA observations by Revnivtsev, Trudolyubov & Borozdin (1999) showed that the variability characteristics of the source are strongly dependent on its luminosity state. In the bright hard state of the source, the power density spectrum (PDS) shows strong QPO features with centroid frequency in 20-30 Hz range and an additional broad QPO peak at 0.5 Hz. When the source made transition to the high state, only a low frequency broad QPO feature was observed at 0.03 Hz which disappeared in the low state (Revnistev et al. 1999). These timing characteristics show strong resemblance to those of other black hole X-ray transients and suggest that XTE J1748−288 is also likely to be a black hole.

Hjellming & Rupen (1998a) reported the presence of an unresolved radio source with flux densities of 50 ± 3 and 28 ± 2 mJy at 1.46 and 4.86 GHz. The flux of the radio source varies strongly by a factor of 3 - 4 in 3 days, which strongly suggests the source to be the radio counterpart of the X-ray transient XTE J1748−288. Radio outbursts have been detected from a number of black hole binaries. These include Cyg X−1, GRS 1124−68, GS 2023+33, GS 2000+25 and GRO 0422+32 (Tanaka & Lewin 1995) which are all found to be variable radio sources. The recurrent transient A 0620−003, which is also a black hole candidate, shows radio emission during its outburst which decays rapidly within a few weeks. The radio characteristics of XTE J1748−288 i.e. variable radio emission and its growth in size along the East-West direction, bear resemblance to those of the superluminal sources GRS 1915+105 and GRO 1655−40 and therefore favour a black hole as the X-ray source.

There are many similarities in the accretion flow around a low-magnetic field neutron star and a stellar-mass black hole. The X-ray characterstics, such as very soft spectra, rapid variability, high energy power-law, which are typically believed to be the properties of black holes, are also seen in some neutron star binaries. In the X-ray transient XTE J1748−288, there is no significant variation in the intensity over time scales of 1 s or less. The variation in the source intensity at longer time scales is similar to that seen in other black hole candidates. The longer time scale intensity variations can be explained by a change in the temperature of the accretion disk due to change in the mass accretion rate into the disk. If the radiation, emitted from the radial part of the disk is a black body emission, the luminosity and temperature at a given radius are proportional to $\dot{M}$ and $\dot{M}^{1/4}$, respectively. The disk precession modulates the mass accretion rate according to the change in the disk configuration relative to the companion star. Based on the RXTE observations Revnivtsev et al. (1999) have recently reported that the low energy ($<$ 20 keV) X-ray spectrum of XTE J1748−288 changed from a soft spectrum to a hard spectrum when the source made transition from high state to a low state. This suggests a bimodal behaviour of the source similar to that of the black hole candidates Cyg X−1 and GX 339−4. All the observed characteristics of XTE J1748−288 thus strongly suggest that it is most likely a black hole rather than a neutron star.

Acknowledgements. We express our sincere thanks to an anonymous referee for his critical comments and suggestions which greatly improved the contents and presentation of the paper. We acknowledge the contributions of the scientific and technical staff of TIFR, ISAC and ISTRAC for the successful fabrication, launch and operation of the IXAE. It is a pleasure to acknowledge the support of Shri K. Thyagarajan, Project Director IRS−P3 satellite, Shri Tyagi, project manager of IRS-P3 and Shri J. D. Rao and his colleagues at ISTRAC.

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