Bull. Astr. Soc. India (2001) **29**, 355–360

Pulse profiles of binary X-ray pulsars in 20-200 keV band

R.K. Manchanda

Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Bombay 400005, India

Abstract. Hard X-ray observations of the binary X-ray pulsars were made using a balloon-borne large area scintillation counter telescope in the 20-200 keV band. Apart from many other galactic and extragalactic X-ray sources, three X-ray pulsars namely Her X-1, GS 1843+00 and 4U 1907+09 were tracked during two flights launched in March 1997 and Nov. 1998. The observations of the transient sources GS 1843+00 correspond to near intensity maximum in its burst phase. We discuss the morphology of the pulse profiles in terms of geometrical constraints and the X-ray emission mechanism.

1. Introduction

X-ray pulsars in binary systems represent a complex high energy astrophysics laboratory and continue to be of both theoretical and observational interests. Built into these exotic sources is the evolution of both high and low mass companion stars, rotating magnetized neutron stars with super strong magnetic and gravitation fields, accretion disks, self organizing instabilities leading to mass accretion on to the compact object and the cyclotron absorption/emission features and the temporal variation in their X-ray luminosity. The complex pulse profile of these systems carries the signature of both dynamical properties of the underlying object and geometrical and statistical properties of the X-ray emission environment.

From a sample of almost 90 X-ray pulsars identified so far only about one-third of these objects have been observed in hard X-rays. In fact no systematic investigation of X-ray pulsars in hard X-ray band like those performed at low energies below 10 keV has been performed yet. Since the high energy X-ray emission arises close to the base of the accreting column, the pulse profile behaviour and the change in its topology with time is a sensitive probe for the emission mechanism, the photon escape and the basic rotation and precession parameters of the source. A large number of theoretical models in literature have discussed the pulse properties in terms of intrinsic beaming mechanism, strength of the magnetic field and the orientation angles with respect to the observer. Experimentally, a change from a pencil beam emission to a fan-beam pulse profile in the case of GX 1+4 has been reported (Paul et al. 1996) and probably it is caused by the sudden change in the accretion rate. The low energy pulse profile in any source is affected by the circum-stellar material, however, at higher energies, the pulse profiles are less influenced due to the sharp decrease in the photoelectric cross-section with increasing energy.

The results of the pulse profiles measurements of the X-ray pulsar Her X-1, GS 1843+00 and 4U 1907+09 are presented in the following sections. The observations are part of our programme of hard X-ray observations of galactic and extragalactic sources in the 20-200 keV using a highly sensitive large area scintillation counter experiment (LASE) in a series of balloon flight from Hyderabad, India.

2. Experimental details

The LASE payload is designed to detect microsecond variations in the flux of X-ray sources in hard X-ray upto 200 keV. The instrument consists of a X-ray telescope made of three detector modules of scintillation counters having both passive and active shielding. Each detector module consists of a back-to-back geometry and has an area of 400 cm^2. The field of view of each module is 4.5° x 4.5° and is defined by a graded slat collimator and is effective upto 250 keV. The overall observed energy resolution for 60 keV photons from Am-241 is 30% in the main detector and 25% for the veto counters. The pre-flight calibration of the X-ray detectors is done at different energies using radioactive sources, Cd^{109} (22.1 and 87.5 keV), Am^{241} (24.7 and 59.6 keV) and Ba^{133} (32.4 and 81 keV). In addition, an Am^{241} source is mounted on the payload for calibration of the detectors during flight. This mode is activated using a ground command.

The signals from all the three modules are amplified separately and fed to the event selection logic and flag-generator. Selected events are then pulse-height analyzed and the arrival time of these events is stored simultaneously. The arrival time of each accepted event is stored with an accuracy of 25 μsec. LASE payload is fully automatic and uses a on-board stand-alone microprocessor controlled star tracker; which can provide the instantaneous target co-ordinates. The detailed description of the payload and its flight performance is published elsewhere (D'Silva et al., 1998, Madhwani & Manchanda 2000). A 3σ sensitivity of the LASE telescope in the entire energy range up to 180 keV is ~ 1.5 x $10^{-6} cm^{-2} s^{-1} keV^{-1}$ for a source observation of 10^4 sec.

3. Results and Discussion

The results included in the present paper corresponds to the data obtained during two balloon flights launched on 30th March 1997 and Nov 20, 1998 from Hyderabad, India (cut-off rigidity 16.8 GV). A number of X-ray sources Her X-1, GR 1744-28, GS 1843+00, GRS 1905+105 and Cyg X-1, Sco X-1, NGC 5506 and 3C 273 were observed during these experiments. In general, the background for our data is derived from the observations of a blank field before, midway and after the source pointing. The 1997 experiment carried only two detector modules. The basic arrival time resolution for the LASE data is 25 μsec and therefore, during the present analysis for pulse timing and the pulse light curve, the data were first binned into appropriate larger time intervals and period analysis was performed with the re-binned data.

4. GS1843+00

Hard X-ray transient pulsar GS 1843+00 with a period of 29.5 sec was observed in the 20-180 keV region during its 1997 flare on March 30. The source was observed for a period of 55 minutes in two sightings of 25 and 30 minutes. The background was derived from three observations of a nearby source free region, before midway and after the source pointing. A positive excess from the source with a combined statistical significance of ~ 37σ was detected. The hard X-ray spectral details of the source are presented elsewhere (Manchanda, 1999).

For the timing analysis, the data was first binned into 240 msec intervals. The search for the periodic component was made by folding the data with different periods in a narrow band close to the extrapolated BATSE barycentric period of $29^s.486$ on 30th March 1997 and then corrected. The data from the two observation intervals in both detectors was analyzed separately and co-added. A total of 11 trials were made to scan the period between $29^s.45$ and $29^s.55$ and the best fit period is given as 29.49 ± .01 *sec*. The pulse period derived in the present analysis compares well with the derived value from the BASTE data.

The phase histograms were then constructed by folding the data in different energy bands with the best fit period. Figure 1 shows the folded data for the energy band corresponding to 20-100 keV. It is seen from the figure that the pulse profile has a single peak in the hard X-ray band and this differs from the low energy data of Koyama et al. (1990) and the BATSE data at high pulse fraction phase, both of which showed a broad double hump pulse structure. Our observation of hard X-ray emission from GS1843+00 is consistent with the models for Be-star transients, which hypothesize a sporadic accretion on to the neutron star either from a expanding gas envelope of the companion or traversing a slow wind during its periastron passage in the binary orbit. The measurement of low pulsed fraction (~ 7%) from the present experiment when combined with the BATSE data leads to some interesting conclusions about the source geometry.

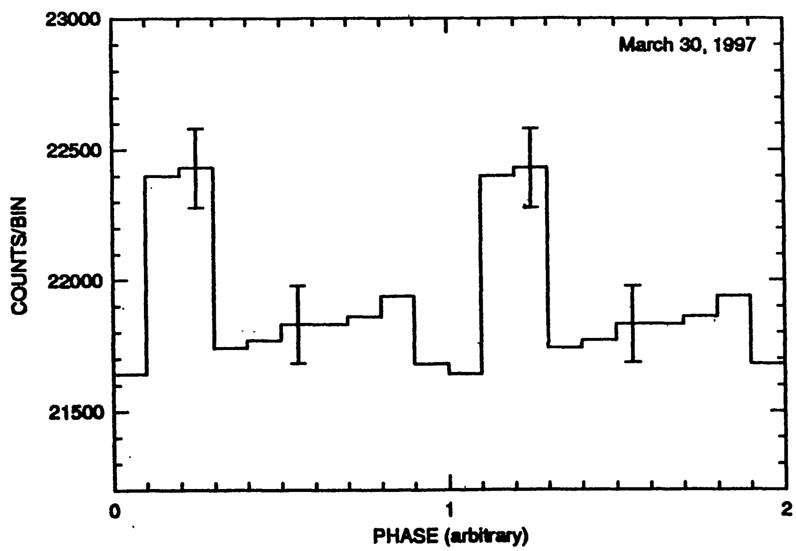

Figure 1. Pulse profile of GS 1843+00 in the 20-100 keV band for P = 29.49 sec. The source free background level for the plot corresponds to about 20400.

During the 90 day active phase of the source, the pulsed fraction increased for 11 days and then showed a continuous decline to a point of near absence almost coinciding with the mid-point of the active phase. The disappearance of the pulsed emission in spite of a strong continuum flux from the source can therefore, be only attributed to geometrical effects due to orbital motion and the orientation coordinates of the beam geometry (Manchanda 2000a, 2000b).

5. Her X-1

Her X-1 was observed for a continuous stretch of 40 min between 2240 and 2310 UT on March 29th. Using the ephemeris of JD 2446208.3 for the cyclic turn-on with an average period of 34.85 ± 0.001 days and JD 2443805.03 for the mid-eclipse of the $1^d.70016772$ binary period, the corresponding phases at the time of observations are $\phi_{1.7} = 0.86$ and $\phi_{35} = 0.226$. A detailed look at the RXTE soft-X-ray monitor data indicates that high state of the source during the present turn-on cycle persisted for ~ 12 days during JD 2450529 to 2450540. Accordingly, our observation made on JD 2450537.45 represents the 5th binary orbit.

Figure 2. shows the pulsation light curve derived from the on-source data from the two detectors in the 20-50 keV energy band. The best period of 1237.782 ± 0.006 millisec was derived from the χ^2 analysis is quite consistent with the value of 1237.775 seen in the one day averaged data from CGRO satellite. No significant pulsed flux was seen in the higher energy channels. The pulse fraction of ~ 35% derived from the present data corresponding to 5th binary cycle points to anomalous character of the source.

The source history of different 35^d ON-OFF cycles from the RXTE data also show that our observations correspond to an extraordinary activity cycle. The observed day-to-day period changes were quite abrupt during this phase while in the preceding and succeeding turn-on cycles, the period changes were gradual.

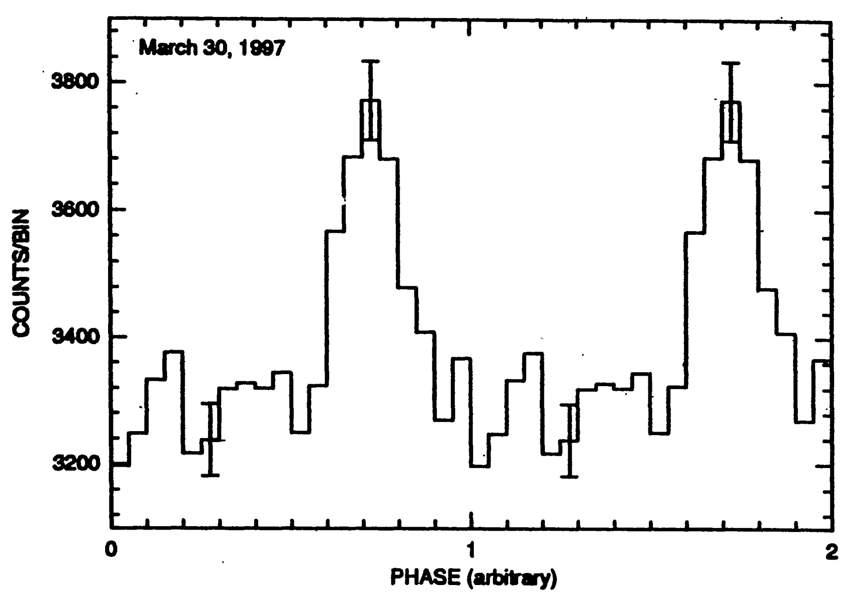

Figure 2. Observed pulse profile of Her X-1 in the 20-50 keV energy band.

Among the known X-ray pulsar, Her X-1 occupies the boundary between the fast and the slow rotating compact objects. Long term study of the source shows the gradual changes both in intensity and the pulse period. Since in the case of Her X-1, binary orbit is nearly circular, mass function and orbital element are very well determined. It is difficult to postulate free unknown variables to describe the presence of strong pulsations into the 5th binary cycle as well as the chaotic behaviour of day-to-day changes in the pulse period seen in RXTE data. The secular changes as seen in the present epoch may therefore, be ascribed to the chaotic changes in the accretion rate resulting into the torque noise. In the standard accretion model, the Roche geometry and the finite resident time of the incoming material in the accretion disk tend to moderate any sharp changes in intensity and pulse period and it is difficult to reproduce the magnitude of period variation.

6. 4U 1907+09

The X-ray pulsations from 4U 1907+09 with a period of 437.5 sec were discovered by the Tenma satellite in 1984 (Makishima et al., 1984) and is known to be monotonically spinning down since discovery, at a rate of 0.23 ± 0.01 s yr^{-1}. The X-ray source is in a binary system with an orbital period of 8.3753 ± 0.0001^{d}, an eccentricity of 0.28 ± 0.04 and the primary companion is believed to be a Be star. The X-ray emission from the source exhibits a fairly hard spectrum with the spectral index $\alpha \sim 1.5$ between 20-100 keV energy band and the flux appears to peak twice per orbit at binary phase value of 0.0 and 0.45 (Chitnis et al., 1993).

The source was observed for a continuous stretch of 3300 sec between 0720 and 0825 UT on November 20, 1998 and the background was measured for 20 min each before and after the observation. We have performed only the period analysis for the source as the balloon height

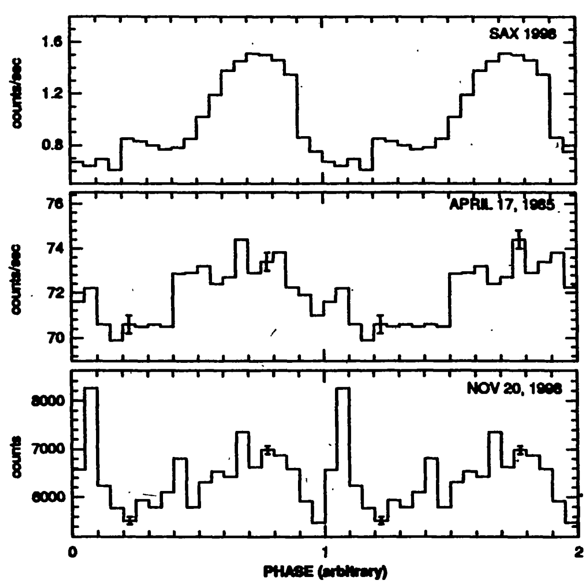

Figure 3. Hard X-ray pulse profile of 4U 1907+09 in 35-175 keV energy band. The 20-80 keV data of Manchanda et al. (1987) and 20-38 keV data from BeppoSAX are also shown in the middle and upper panels. Curves are phase shifted for visual clarity.

varied slowly during the observations. The data points were first binned with 1.77446014 sec (5 telemetry sub-frames) time resolution and were subjected to period search using Lomb-Scargil period search routine (Press and Rybici, 1989). The best fit period was found to be 437.637 ± 13.9 sec. The large error in the period determination is due to the limitation on the data stretch corresponding to about 8 pulse cycles. The phase histogram obtained by folding the light curve obtained during the source observation with the best fit period is shown in figure 3. The available hard X-ray pulse-shape data above 30 keV is very limited. The hard X-ray pulse profile in the 20-80 keV obtained in 1985 (Manchanda et al., 1987) and more recently from the BeppoSAX satellite in the 20-38 keV energy band (IN'T Zand et al. 1998) are also shown for comparison. It is clearly seen from the figure that in all the measurements, a single broad peak is the main feature in the high energy pulse profile.

A single humped light curve for the pulsed emission in 4U1907+09 is in complete contrast with the low energy data all of which show a double peaked pulsed light curve. A comparison of the folded data of BeppoSAX in six band passes between 2-38 keV indicates a clear pulse profile switch for energy above 20 keV (IN'T Zand et al. 1998). This variation in the pulse profile therefore, suggests that two peaks arise from the two opposite poles of the neutron star and the presence of an asymmetry in the X-ray production at the two poles, in which the low energy photons emerge from one of the poles only.

I thank LASE team of Shri JAR D'Silva, P.P. Madhwani, N.V. Bhagat, B.G. Bagade and Ms N. Kamble for their dedicated support in the hardware building and the balloon flights. Thanks are also due to RXTE and BATSE teams for making the data available on public archives.

References

Chitnis V.R., Rao A.R., Agrawal P.C., Manchanda R.K., 1993, Astron. Astrophys., L82
D'Silva J.A.R., Madhwani P., Tembhurne N., Manchanda R.K., 1998, Nucl. Instr. Meth., A 412, 342
IN'T Zand J.J.M., Bakyal A., Strohmayer T.E., 1998, Ap. J., 496, 386
Maurer G.S., Dennis B.R., Coe M.J., et al., 1979 Ap. J., 231, 906
Koyama K., Kawada M., Takeuchi T., et al., 1990, Ap. J. (Letters), 356, L47
Madhwani P.P., Manchanda R.K., 2000, Bull. Astron. Soc. India, 28, 451
Makishima K., Kawai N., Koyama K., et al., 1994, PASJ, 36, 679
Manchanda R.K., 1987, Proc. 20th ICRC, 1, 99
Manchanda R.K., 1999, M.N.R.A.S., 305, 495
Manchanda R.K., 2000, Bull. Astron. Soc. India, 28, 277
Manchanda R.K., 2000b, Astrophys. Letters & Communications, *in print*
Paul B., Agrawal P.C., Manchanda R.K., Rao A.R., 1996, Bull ASI, 24, 729
Press W.H., Rybici G.G., 1989, Ap.J., 338, 27