INTERNATIONAL JOURNAL OF RESEARCHES IN BIOSCIENCES, AGRICULTURE AND TECHNOLOGY
© VISHWASHANTI MULTIPURPOSE SOCIETY (Global Peace Multipurpose Society) R. No. MH-659/13(N)
www.vmsindia.org

Timing Study of the Transient X-ray Pulsar XTE J0111.2-7317 with the RXTE

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ABSTRACT
We present the timing study in the energy range of 2-30keV of the transient X-ray pulsar XTE J0111.2-7317 using the observations made with the proportional counter array of the Rossi X-ray Timing Explorer during the second peak and the declining phase of the outburst occurred in this source in December 1998. After suppressing the intervention in the data of the nearby bright binary X-ray pulsar SMC X-1 existing at about 65kps in the Small Magellanic Cloud (SMC), XTE J0111.2-7317 was detected with the X-ray luminosity of 7.8×10^{38} ergs/second and the pulse shape almost sinusoidal with an improved pulsation time of 30.7951± 0.0001 seconds. We examined energy dependence of the pulsed fraction and observed the decrease of 6-7% in the pulsed fraction towards the contribution of the hard X-rays beyond 10keV.
Keywords: X-ray Pulsar, timing studies, SMC

Introduction

Our prudential survey of the profound literature on the X-ray pulsars has indicated that there exist different types of the pulsars such as millisecond pulsars, magnetars and a series of X-ray pulsars discovered in Magellanic Clouds (MCs). All studies of the pulsars specially related to MC, in general, have revealed a fact that there are about 10 to 100 times more X-ray Binary Pulsars exist in the Small and the Large Magellanic Cloud (SMC &LMC) as compared to our galaxy (Frank et.al. 1992; Paul et al. 2002; Paul et al. 2004; Psaltis 2005 ; Mukherjee et al. 2006). Moreover, the detail timing and the spectral studies of these objects depend upon the magnitude of their X-ray luminosity and the absence of the strong local absorption column in the line of sight for the soft spectral components. Instead these objects are suitable for the experimental studies in order to investigate the local absorbing galactic material column when their density is low; otherwise it become very difficult for the objects, which exist in the galactic plane and possess large absorbing line of sight. One of the present soft X-ray transient pulsar of this kind, XTE J0111.2-7317 happens to live in the SMC as well as the 30' away from the nearby bright binary X-ray pulsar SMC X-1 and both fall in the field of view of the Proportional Counter Array (PCA) on board the Rossi X-Ray Timing - Explorer (RXTE) during their observations (Coe et al. 1998; Yokogawa et al. 2000). Later the presence of the X-ray pulsar XTE J0111.2-7317 in the SMC was confirmed by Coe et al. (2000) after observing the velocity shift of 166± 15 km/second in the optical emission lines. According to the literature, the timing and the spectral studies for the transient X-ray pulsar XTE J0111.2-7317 have been done in details by Yokogawa et al. (2000), in order to understand its physical properties using the data of the two Solid–state Imaging Spectrometer (SISs) and the two Gas Imaging Spectrometer (GISs) on board the Advanced Satellite for Cosmology and Astrophysics (ASCA).

The Pulsar

The discovery of a transient pulsar XTE J0111.2-7317 was made almost simultaneously in the month of November 1998 by the two launched space satellite X-ray detectors; PCA on board the RXTE and Burst &Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory (CGRO), in the energy range of soft and hard X-rays respectively (Chakrabarty et .al 1998b; Wilson &Finger 1998). The transient nature of the XTE J0111.2-7317 was established when EINSTEIN and ROSAT could not observe it prior to RXTE, CGRO and ASCA at the same position (Wang &Wu 1992; Kahabka & Pietsch 1996; Cowley et al. 1997). The earliest observation of the RXTE/PCA (Chakrabarty et.al. 1998a) first time lead to s discovery of a pulse period of 31 second for the pulsar XTE J0111.2-731 and the position of R.A. = 1h11m.2, and Decl. = -73° 17' .4 (equinox J2000.0) within an error radius of 1'.5 (90% confidence) by the raster scanning of the region on November 6 & 7, 1998. The Soft X-ray intensity 36(7) m Crab was measured on November 1998 at 6.6 UT in the energy band of 2 to 10 key except between the dates October 16 to 27.

Till now a cadence of data for the transient X-ray pulsar XTE J0111.2-7317 have already been procured from the rigorous observation of the RXTE/ ASM, CGRO/BATSE and ASCA/SIS/GIS (Chakrabarty et al. 1998a, & Chakrabarty et al.1998b) and are now available for the analysis on the web site "heasarc.gsfc.nasa.gov" .

Observation and Analysis

During 1998 October-November observation session, Chakrabarty et .al (1998a) used the RXTE/PCA to monitor the SMC X-1 region and observed an intense X-ray outburst , which led them to discovery a new pulsar XTE J0111.2-7317 in the SMC. There after chasing precisely the site of the pulsar XTE J0111.2-7317 as the target of the opportunity, two subsequent observations were recorded on 18th December and 22nd December to 19th February, 1999 for confirmation. Right now a cadence of data of twenty systematic observations collected by the All Sky Monitor (ASM) with an exposure time of about 2-3 kilo seconds are available and easily accessible on the "heasarc.gsfc.nas.gov" website. These observations are concurrently contaminated by the intervention of another nearby bright X-ray pulsar SMC X-1 existing within the vicinity of the error circle of 30' of XTE J0111.2-7317. Figure 1 represents the RXTE-ASM light curve over a period of 3000 days with the count rate, which remains minimum on an average of 0.5 counts/second to maximum of 2-3 counts/second during the observed peak of the intense 1998-99 outburst. It was a clear bright intense X-ray burst with the count rate of ~ 2.4 counts/second at its peak during 22nd December, 1998 to 19th February, 1999 as marked by an arrow ↓ '1998' close to the time scale of 1.11× 104 days. These features were clearly detectable by the RXTE (0.125 seconds time-resolution of the PCA) and appeared to be much prominent and sharp in the light curve expressed in Days rather than MJD along the horizontal X-axis (see Figure 1). Although there are about twenty systematic observations for the timing and the spectral analysis but in this report we present the analyzed results of the ten observations close to the peak of the bursts marked as ↓ '1998' in Figure 1 and are tabulated in table-1. During these observations X-ray pulsar XTE J0111.2-7317 was bright enough and suitable for us to make a detailed timing study in the energy range of 2-30keV.

Table-1 shows the observations, date of the observation along with their exposure time when the source XTE J0111.2-7317 was bright enough during outburst. The exposure time is the total amount of time an instrument was on-source during the observation, minus periods of Earth occultation and SAA passage, and not counting slews, scans, or observation segments which have gaps.

The data processing was carried by simulating the background count rates and subtracting from the Standard-1 light curves to generate the power spectrum. For further treatment, these generated power spectra were normalizes and then corrected for the expected white noise level. Thus the normalized power density spectrum, consequently obtained is shown in the Figure 2. It depicts the presence of the well reported 31 seconds pulsation with their subsequent sharp and prominent harmonics in the soft X-ray energy range which confirm the X-ray source XTE J0111.2-7317 likely to be a Be/X-ray binary system with the high mass companions (Bildsten et al. 1997). Fig. 3 shows 31 seconds pulsation of the pulsar XTE J0111.2-7317. On contrary, the complete absence of 0.7 seconds pulsation and its harmonics in Figure 2 proves that the contribution of the X-ray pulsar SMC X-1 is thus ruled out or eliminated (Kaur et al. 2007). We used the RXTE-PCA observations for the period MJD 51165.56 to 51177.32 for the timing and the spectral analysis of the transient X-ray pulsar XTE J0111.2-7317.

Timing Analysis

For the usual timing study of the transient pulsar XTE J0111.2-7317, the corrected data standard-1 (as discussed in the foregoing section) have been used to plot the power spectrum with the better time resolution (of 0.125 seconds) of the PCA on board the RXTE than (0.5 seconds) of the ASCA/SIS/GIS. As compared to the reported pulse period of 30.9497±0.0004 seconds from the ASCA (Yokogawa et. al.2000), the RXTE provided comparably improved time of 30.7951± 0.0001 seconds for the XTE J0111.2-7317(See figure 3). Further Pulse profiles have been generated for the pulse resolved spectroscopic in the various energy ranges 2-5keV, 5-8keV, 8-11keV, 11-14keV, 14-17keV, and 17-20keV as shown in Figure 4. These Pulse profiles represent the normalized intensity as the function of the pulse phase (0-2). In order to investigate the change in the shape and amplitude of the pulse profiles in the small segments of the energies 2-5keV, 5-8keV, 8-11keV, 11-14keV, 14-17keV, and17-20keV, we have plotted them on two panels. These are found more likely to be the sinusoidal. Critically there is no change in the shape and all the pulse profiles of different energy segments look alike with the almost equal modulation and appear to be independent of energy range, which contradicts, with the earlier results of Parmar et al. 1989, Reig & Coe 1999, and Yokogawa et al. 2000 for the similar kind of transient X-ray pulsar XTE J0111.2-7317.

Usually the pulse height variation for the mono-energetic incident radiation of the energy 'E' arises due to the excitation of the gas molecules instead of ionization in the proportional counter. Hence the Pulse height is proportional to the square root of the energy whereas the energy resolution is inversely proportional to the square root of the energy (Agrawal & Ramsey 1988). In the timing analysis it is worthwhile to measure the % Pulsed – fraction, by the following equation as:

$$\Delta = \frac{Pulse\ height}{total height} \times 100 \qquad (1)$$

Δ is found to vary between 16.69 %, to 23.36 % for the energy bands from 2-5keV, to 17-20keV with the estimated error of 0.70 % as shown in the Figure 5. Δ represents the spectral softening for the X-ray source. Figure 5 shows two systematic trends for Δ as a function of the various energy bands. The small window at the right top of the Figure 5(data marked as star) represents variation in Δ for small segments of energy bands: 2-5keV, 5-8keV, 8-11keV, 11-14keV, 14-17keV, and 17-20keV. Δ Increases with the soft X-ray energy range from 2-5keV to 11-14keV justifies the spectral softening characteristics of the PCA in its detection efficiency as well as the linear correlation between the pulse height and the energy of the incident soft component of the X-ray photons. This trend may be attributed to the probable emission of the soft component of X-ray from the upper hot part of the accretion column above the polar cap of the Neutron star with the large area of emission. Also Δ decreases (as shown in the same small window) from 23.36 to 17.65 % towards the hard X-ray component of the energy bands 14-17keV to 17-20keV. Reig &Coe (1999) also noticed this behaviour in their study of similar transient X-ray pulsar, EXO 2030 +375. They reported Hardness Ratio (HR): (6-1keV)/ (2-6keV) for the soft X-ray to be linearly correlated with the intensity but for the high-energy HR: (16-22keV)/ (12-16keV) disappeared. In order to investigate the contribution of the hard X-ray component towards the decrease ofΔ in more precise manner, we generated the pulse profiles again for the energy bands such as 2-12keV, 2-14keV, 2-16keV, and 2-30keV. For each energy band, Δ is measured and plotted with the data points marked as outside f the small window in the Figure 5. Graph clearly shows that there is 4-5 % decrease in the Δ.it may be construed to the hot matter of the accretion disk close to the surface of the Neutron star, which emits, according to the black body model, short-wavelength X-ray radiation with the decreasing intensity. Perhaps it might be one of the reasons for the decrease in Δ for the high energy X-ray component beyond the 10 keV.

In the light curve of the RXTE, an approximately 300 seconds time interval variation is apparently observed. Although the peaks between two minimal are not found prominent but 5 minutes interval is obvious due to the high resolution (0.125 seconds) of the RXTE between two successive minimal as shown by the down arrows ↓ in Figure 6. It may be related to some modulation in Keplerian frequency of the order of ~ 3.3 mHz for the transient X-ray pulsar XTE J0111.2-7317 in SMC during its outburst.

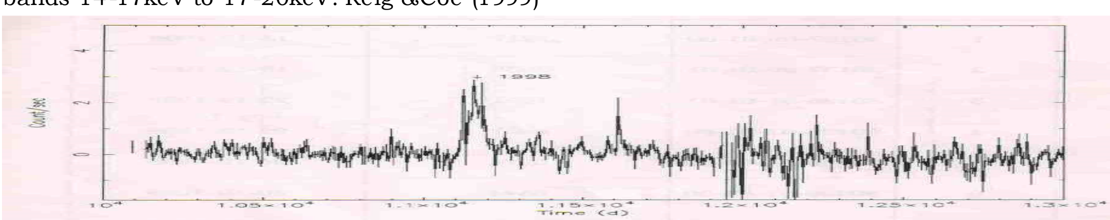

Figure 1 : RXTE –ASM light curve of the XTE J0111.2-7317 over a period 3000 days is shown with a prominent X-ray outburst occurred in December, 1998 (as marked by ↓ '1998') between the time period of the days 1.11×10^4 and 1.12×10^4. It is rescaled into ranges MJD 51165.56 to 51177.32 Table 1: Observation table of XTE J0111.2-7317

Table 1: Observation table of XTE J0111.2-7317

Serial No.	Observation	Exposure time (Sec.)	Date of Observation
1	30137-06-01-00	2217	18-12-1998
2	30137-06-01-01	2038	18-12-1998
3	30436-01-01-01	1051	22-12-1998
4	30436-01-01-00	6027	22-12-1998
5	30436-01-02-00	6274	26-12-1998
6	30436-01-03-00	6544	30-12-1998
7	40402-01-01-00	4939	02-01-1999
8	40402-01-02-01	1773	07-01-1999
9	40402-01-03-00	1756	10-01-1999
10	40402-01-03-01	1356	10-01-1999

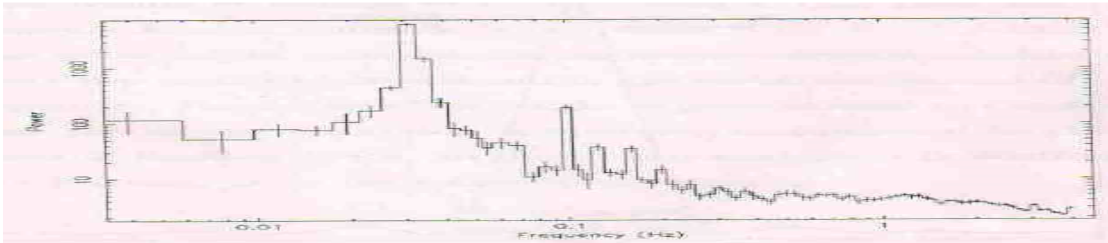

Figure 2: Power density spectrum generated from the light curve obtained from the data of RXTE-PCA of the pulsar XTE J0111.2-7317

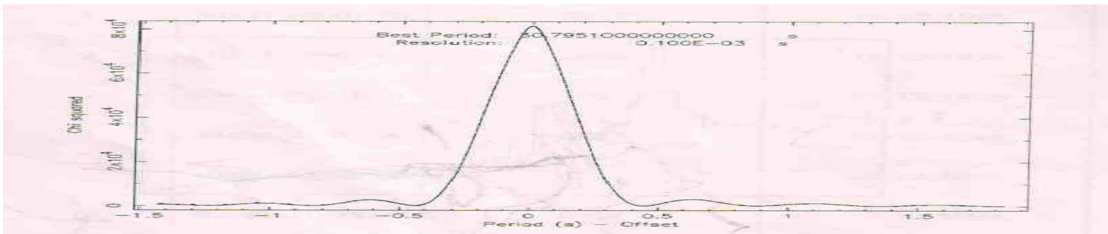

Figure 3: The best 30.7951 ± 0.0001 seconds pulsation period of the pulsar XTE J0111.2-7317.
outburst..

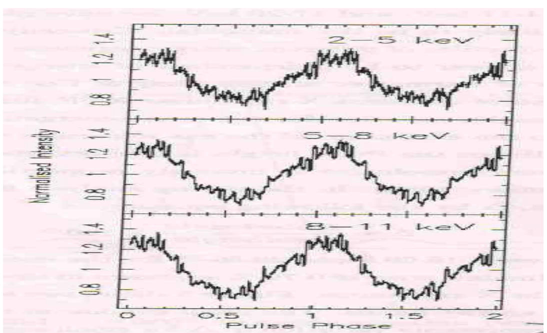

Figure 4: Pulse profiles obtained for the XTE J0111.2-7317 from the data of the PCA on board the RXTE after the background barycentric corrections in small energy segments 2-5, 5-8 and 8-11.

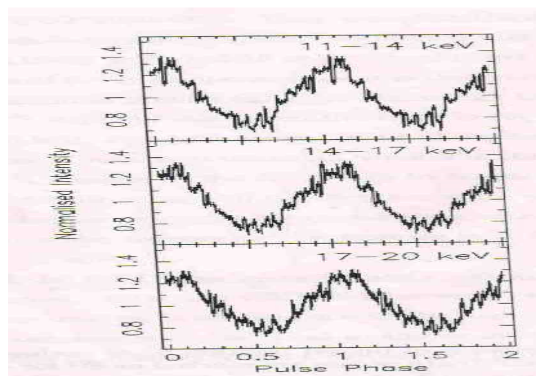

Figure 5: Pulse profiles obtained for the XTE J0111.2-7317 from the data of the PCA on board the RXTE after the background barycentric corrections in small energy segments 11-14, 14-17 and 17-20keV.

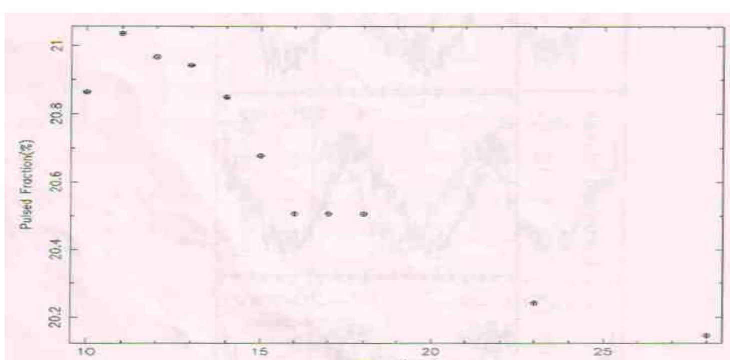

Figure 6: Energy dependence of pulsed fraction %, Δ exclusively towards the hard X-rays range from 10-30keV (data points are marked as +) for the XTE J0111.2-7317.

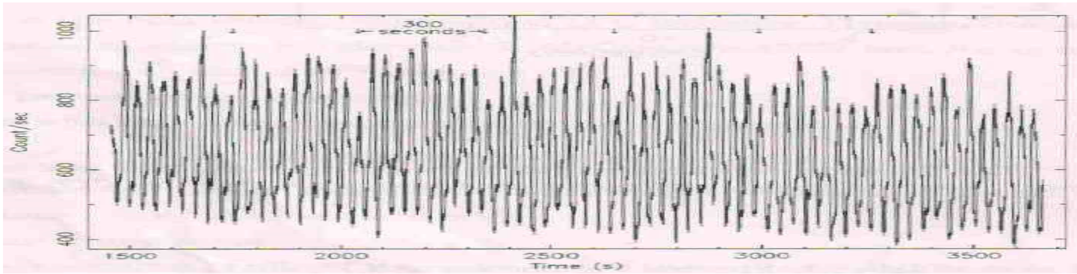

Figure 7: The light curve of the XTE J0111.2-7317, an approximately 300 seconds time interval variation is apparently observed. The peaks between two minimal are not found prominent but 5 minutes interval is obvious due to the high resolution (0.125 seconds of the RXTE between two successive minimal as shown by the down arrows ↓.

Discussion

We observed Δ to vary from 16.69 % to 23.36 % for the energy bands 2-5keV to 17-20keV (see fig 4 and fig 5). These results are consistent showing the linear correlation for the soft X-ray energy, E with Δ and exhibit the spectral softening character of the PCA in its detection efficiency of the incident radiation due to excitation of the gas molecules rather than ionization. It supports a well-known feature observed in the precedent studies of the pulsars that pulsed height is proportional to the energy of the soft X-ray components in the range of 2-10keV. It also suggests that soft components are produced in the upper part of the accreting column close to the polar cap of the neutron star and probably there is no intervention of hot accretion material except that of the SMC. On the other hand, hard X-ray components show declining Δ and hence spectral hardening. The spectral hardening may be construed to the hard X-ray emitters of the high order luminosity during their intense outbursts. The observed luminosity of the XTE J0111.2-7317 is found to be quite high 7.8×10^{38} ergs/ seconds and is comparable to its Eddington limit to exhibit itself as a hard X-ray emitters (Frank, J. et al 2002) and consequently it is expected to emit small fraction of their luminosity as thermal X-ray source. If it were to radiate the power more as a blackbody of short wavelength in the Wine Hump rather than the thermal source then the hardening is obviously believed to be present in the spectrum. Thus measured 6-7 % decrease in towards the contribution of the X-rays of higher energy range from 2 to 30keV (see Figure 5 with data marked as +) may be attributed to the optically thick and hot accreted material which comes in the thermal equilibrium with the short wavelength radiation emitted from the middle portion of the accretion column which is close to the surface of the neutron star where large gravitational energy is released. It gives rise the radiation temperature $T_{radiation}$ comparable to the blackbody temperature T_{black}. In this way accretion energy is converted in to the radiation and approaches with the energy degradation to the observer after the interaction and the thermal equilibrium with the optically thick material of the accretion disk and consequently shows a decrease in Δ. The dominated pulsations in the part of the soft X-ray power spectrum as shown in figure 2 has been the special feature of the XTE J0111.2-7317. Its manifestation may be referred to the observed high Galactic latitude of ~-43^0 for the transient X-ray pulsar XTE J0111.2-7317 in the line of the SMC from our Galactic plane, and the estimated few order larger size of the emission region of the soft X-ray component than neutron stars. As a result it gives rise feeble interstellar absorption for the soft component of the X-rays. Therefore presence of the prominent pulsation in the soft X-ray and may be construed on the basis of the bremstrahlung phenomena occurring at a close distance from the neutron star surface (Woo et al. 1996)and may not be due to the scattering of the power component by the circumsolar material (Nagase 1994).

300 seconds period is apparently detectable in light curve of 4200 seconds data (stand-1) but is little more obvious in the plot of short period of data 1500 seconds beginning with 5 seconds (see Figure 7). However it is much smaller than orbital period of 30-50 days as reported in the earlier studies of Corbet (1984) &Yokogawa et.al.(2000). Probably its origin could be attributed to some other orbital period close to above reported period, which may have to do with either very slow changing mass accretion rate or small orbital Doppler shift or a combination of both. Consequently it points out that XTE J0111.2-7317 is transient Be/X-ray binary system.

References

Bildsten, Lars; Chakrabarty, Deepto; Chiu, John; Finger, Mark H.; Koh, Danny T.; Nelson, Robert W.; Prince, Thomson A.; Rubin, Bradley C.; Scott, D. Matthew; Stollberg, Mark; and 3 coauthors, "Observations of Accreting Pulsars" 1997, *ApJS*, **113**,367

Chakrabarty, D.; Levine, A. M. Clark, G. W.; Takeshima, T. "XTE J0111.2-7317", 1998a, *IAUC*, **7048**, 1

Chakrabarty, D.; Takeshima, T.; Ozaki, M.; Paul, B.; Yokogawa, J. "XTE J0111.2-7317", 1998b, *IAUC,* **7062**, 1

Chakrabarty, Deepo; Morgan, Edward H. "The two-hour orbit of a binary millisecond X-ray pulsar", 1998c, *Natur*, **394**, 346

Charles, P.A., & Seward, F.D., "Exploring the X-ray Universe" *Cambridge Univ.Press*, 1995

Coe, M.J.; Stevens, J.B.; Buckley, D. A. H.; Charles, P. A.; Southwell, K.A. "The identification of the optical/IR counterpart to the ROSAT SMC X-ray transient RX J0117.6-7330", 1998, *MNRAS*, **293**, 43

Coe, M.J.; Haigh, N.J.; Reig, P. "The SMC X-ray transient XTE J0111.2-7317: a Be/X-ray binary in a supernova remnant?" 2000, *MNRAS*, **314**, 290

Corbet,R. H. D. "Be/neutron star binaries-A relationship between orbital period and neutron star spin period", 1984, A & A, **141**, 91

Covino, S.; Negueruela, I.; Campana, S.; Isrel, G..; Polcaro, V.F.; Stella, L.; Verrcchia, F. "The discovery and study of the optical counterparts of the transient X-ray pulsars RX J0052.1-7319 and XTE J0111.2-7317 in the SMC" , 2001, A & A, **374**, 1009

Cowley, A.P.; Schmidtke, P. C.; McGrath, T, K.; Ponder, A.l.; Fertig, M. R.; Hutchings, J. B.; Crampton, D., "Magellanic Cloud X-ray sources observed with ROSAT" 1997, *PASP*, **109**, 21

Frank, J., King, A.R., & Raine, D. "Accretion Power in Astrophysics", *Cambridge Univ.Press*, 1992

Frank, Juhan; King, Andrew; Raine, Derek J., "Accretion Power in Astrophysics: Third Edition", 2002, apa, book

Israel, G. L.; Stella, L.; Covino, S.; Campana, S.; Mereghetti, S. "RX J0052.1-7319 and XTE J0111.2-7317", 1999, *IAUC*, **7101**, 1

Kahabka, P.; Pietsch, W. "X-ray binary systems in the Small Magellanic Cloud.", 1996, A & A, **312**, 919

Kaur, Ramanpreet; Paul, Biswajit; Raichur, Harsha; Sagar, Ram "Quasi-periodic Oscillations in XTE J0111.2-7317: Highest Frequency among the HMXB Pulsars", 2007, *ApJ*, **660**, 1409

Luks, T. "Structure and Kinematics of the Magellanic Clouds", 1994, *RvMA,* **7**, 171

Morrison, R.; McCammon, D. "Interstellar photoelectric absorption cross sections, 0.03-10 keV", 1983, *ApJ*, **270**, 119

Mukherjee, U.; Bapna, S.; Raichur, H.; Paul, B.; Jaaffrey, S.N.A "Variable Quasi Periodic Oscillations during an Outburst of the Transient X-ray Pulsar XTE J1858+034", 2006, *JApA*, **27**, 25

Nagase, Fumiaki; Zylstra, Gregory; Sonobe, Takashi; Kotani, Taro; Inoue, Hajime; Woo, Jonathan"Line-dominated eclipse spectrum of VELA X-1" , 1994, *ApJ,* **436**, 1

Nagase, F., 1999, Proc. Highlights in X-ray Astronomy Conference in honor of Joachim Truemper's 65th birthday, ed. B. Aschenbach & M.J. Freyberg *MPE* Report, **272**, 74

Parmar, A.N.; White, N.E.; Stella, L. "The transient 42 second X-ray pulsar EXO 2030+375. II-The luminosity dependence of the pulse profile", 1989, *ApJ*, **338**, 373

Paul, B.; Nagase, F.; Endo, T.; Dotani, T.; Yokogawa, J.; Nishiuchi, M. "Nature of the Soft Spectral Component in the X-ray Pulsars SMC X-1 and LMC X-4",2002, *ApJ,* **579**, 411

Paul, B.; Jaaffrey, S.N.A.; S.; Agrawal, P.C. "Timing and Spectral Studies of the Transient X-Ray Pulsar EXO 053109-6609.2 WITH ASCA and BeppoSAX", 2004, *ApJ,* **602**, 913

Paul, B.; Raichur, H. Mukherjee, U. "Accretion mode changes in Centaurus X-3",2005 A & A, **442**,15

Psaltis, D., 2005, in Compact Stellar X-ray Sources, Eds. Lewin, W.H.G., Vander Kils, M., *Cambgide Univ.Press*

Ramsey, B.D.; Agrawal , P.C. "Gas mixtures for X-ray proportional counters", 1988, *SPIE*, bf 982, 258

Reig P., Coe M.J. 1999, *Mem. S.A.* It. **70-3/4**, 1121

Shirakawa, Akiko; Lai, Dong, "Magnetically Driven Precession of Warped Disks and Millihertz Variabilities in Accreting X-Ray Pulsars", 2002, *ApJ,* **565**, 1134

Shibazaki, N.; Lamb, F. K. "Power spectra of quasi- periodic oscillations in luminous X-ray stars", 1987, *ApJ*, **318**, 767

Van der Kils, M.; Stella, L.; White, N.; Jansen, F.; Parmar, A.N. "Intensity and source state dependence of the quasi- periodic oscillations Scorpius X-1" , 1987, *ApJ*, **316**, 411

Wang, Qingde; Wu, Xiaoyi "Acomprehensive X-ray study of the Small Magellanic Cloud", 1992, *ApJS*, **78**, 391

White, N. E.; Swank, J. H.; Holt, S. S. "Accretion powered X-ray pulsars", 1983, *ApJ,* bf 270,711

Wilson, C. A.; Finger, M.H. 'XTE J0111.2-7317", 1998, *IAUC*, **7048**, 2

Woo, Jonathan W.; Clark, George W.; Levine, Alan M.; Corbet, Robin H. D.; Nagase, Fumiaki "Orbital Decay, Spin- down, and Pulse-Phase-resolved Spectroscopy of LMC X-4 from GINGA and ROSAT Observations", 1996, *ApJ*, **467**, 811

Yokogawa, Jun; Paul, Biswajit; Ozaki, Masanobu; Nagase, Fumiaki; Chakrabarty, Deepto; Takeshima, Toshiaki "ASCA Observation of the New Transient X-Ray Pulsar XTE J0111.2-7317 in the Small Magellanic Cloud", 2000, *ApJ*, **539**, 191