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Comparative Timing Studies of LMC X-4 and EXO 053109-6609.2

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Abstract: EXO 053109-6609.2 and LMC X-4 are transient sources. These pulsars are situated at a distance 17' and ever observed simultaneously in the field of view of the narrow field instrument of BeppoSAX. We adopted the data of RXTE for LMC X-4 having time resolution 0.125 s and data of BeppoSAX LECS and MECS with time resolution of 0.25s. We did comparative timing study of LMC X-4 and EXO 053109-6609.2. RXTE exclusively observed LMC X-4 in December 1999 which was closely the source time of observations of January 2000 of BeppoSAX LECS and MECS. We applied barycenter correction for photon arrival times in the event files before extraction of light curves. With the help of RXTE, we obtained the pulse period of 13.5s for LMC X-4 and 13.7 s for EXO053109-6609.2 with the help of BeppoSAX. Both the pulsars show almost same pulsation time and may be due to same category of HMXBs. Pulse-profile was obtained from the background subtracted light curves in various energy range 2-5 kev,5-8 kev and 8-11 kev. These indicated that X-rays are emitted from the central part of the accretion disk. The pulse-profile clearly shows luminosity dependence with a single peaked profile only at low luminosity and a double peak profile at high luminosity which is clear from the pulse fraction i.e. 30% to 60%.

***IndexTerms* - Pulsar, RXTE, Beppo SAX, HMBs, Accretion disk**

1. INTRODUCTION:

In the categories of High Mas X-ray binaries (HMXBs) LMC X-4 and EXO 053109-6609.2 both are HMXBs hosting a neutron star and a B-emission spectral type (Be) Star. The common thing about them is that both the systems are in the Large Magellanic Cloud (LMC), and ~17' away from each other. It is noticed that in comparison with our Galaxy, the small Magellanic Cloud (SMC) and the LMC have larger number density of HMXBs. As usual in HMXBs a neutron star or a black hole orbits and a massive early-type star accretes matter either via Roche-lobe overflow or from the stellar wind which powers the X-ray emission. However, according to the stellar type of the mass donor star one divides the class of HMXBs into supergiant X-ray binaries and Be/X-ray binaries. Often Be/X-ray binaries show their transient nature through two types of outbursts. X-ray outbursts repeating with the orbital period are most likely associated with the passage of the neutron star through the circumstellar disk in an eccentric orbit while giant outbursts, often lasting longer than a binary period, probably arise due to the expansion of the disk. Nevertheless the SMC whose mass is about 1% of our Galaxy, has a total of about 70 HMLXBs and HMXB candidates, this number is almost comparable to our Galaxy (Haberl, F. & Sasaki, M.2000). In the LMC, the number density of HMXBs is not as high as in the SMC, it is still significantly higher than the Galactic value (Sasai et al. 2000).There are many HMXBs in the LMC and SMC but all the objects have not been studied in great details except for SMC X-1 and LMC X-4. High X-ray luminosities have been detected for several Be/X-ray stars in their high state close to or exceeding the Eddington limit for one solar mass object. It is believed that an excess in the soft X-ray spectrum, now detected in several accreting pulsars, could be a common features of the HMXB pulsars. Since both LMC X-4 and EXO 053109-6609-2 are in the Galactic plane of Magellanic clould so expected large line-of sight absorption must be same for them. A comparative study would give detail understanding about them as well as the local absorption column density around them.

2. About the Sources:

2.1 LMC X-4

The HMXB LMC X-4 is an eclipsing pulsar in the LMC. This peculiar eclipsing pulsar was first mentioned in the second Uhuru catalog (Giacconi et al. 1972) and its eclipsing nature was discovered by Li, Rappaport & Epstein (1978) and White (1978). The observed X-ray intensity of the source varies between high states and low states by a factor of ~60 with a periodic cycle time of 30.3 days (Lang et al. 1981). The eclipsing LMC X-4 has precessing accreting disk with its plane titled with respect to the orbital plane. Under observation these tilting blocks direct X-rays and provides long term variations (Lange et al. 1981; Priedhorsky & Holt 1987; woo, Clark, & Levine 1995). The regular monitoring of about once per day LMC X-4 exhibits a "Flaring episode" during which the intensity increases sporadically by factors of up to ~20 for times ranging from ~20 second to 45 minutes (Epstein et. At. 1977; White 1978; Skinner et al. 1980; Kelley et al. 1983; Pietsch et al. 1985; Dennerl 1989; Levine et al. 1991). Inspite of that flaring episode on an average is much softer than the average spectrum and found to be of the order of energy less than 1 KeV.

The characteristics periodic pulsations of LMC X-4 were discovered by Kelly et al. (1983) in data collected during flare events. Although the same 13.5s pulsations can be detected during no flaring out-of-eclipse times with EXOSAT observations (Pietch et al. 1985). The associated binary orbit of the system is nearly circular. The observed orbital period is found to decay with a time scale of 10^6 year in LMC x-4 (Lavine et Al 2000).

2.2 EXO 053109-6609-2

In the another high ass X-ray binary categories, the transient X-ray pulsar EXO 053109-6609-2 is a HMXB hosting a neutron star and a B-emission spectral type Be star (Harbel et al.1995). With unique properties of transient, this was discovered in 1983 deep EXOSAT exposures of the LMC x-4 region (Pakull et al.1985). Later the second outburst of the source was detected with the coded mask X-ray telescope SL2 XRT on board the shuttle challenger in the month of July and August, 1985. However, this time the luminously of the source was ~ 10^{37} erg sec^{-1} between 2-10 KeV. For further pursuance, the source was then monitored with ROSAT PSPC (Harberl et al. 1995) between June,1990 to July,1994.With the help of regular monitoring for the EXO 053109-6609.2, spin states were estimated and from these observations in the X-ray flux alternating high states (L_x~ 10^{37} erg s^{-1}) and low states (L_x ~ 10^{36} erg s^{-1}) were discovered. X-ray pulsations were also discovered with ROSAT (Dennerl et al. 1995). Harbel et al. (1996) detected another outburst from March to May, 1993. This time the luminosity between 0.1-2.4 KeV was ~2.4 x 10^{36} erg $s^{-1.}$

The pulsar EXO 053109-6609.2 is in the LMC, located at a distance of ~17' away from the luminous high mass X-ray binary pulsar LMC X-4 (La Barbera et al.2001). After rigorous analysis, Dennerl et al. 1996 reported the spin period of the pulsar ~13.67133 s with the October 1991 ROSAT observations. The orbiting of EXO 053109-6609.2 showed the orbital period and was proposed to be 600-700 days (Harbel et al. 1995) with an orbital eccentricity of e ~0.4 -0.5. Further Denerl et al. (1996) corrected the proposed orbital period, finding an orbital solution with P orb = 25.4 days and an eccentricity of e~01. Under the assumption that period changes are caused by Doppler shifts. Moreover, during a Beppo SAX observation obtained in March,1997 the system revealed coherent pulsations at a period of ~13.67590 s and two period derivatives: Ploc= (3.7$\pm$0.5) x $10^{`11}$ $s8^{-1}$ (Secular period derivative, calculated from ROSAT observation) (Burderi et al. 1998).

For details investigations the source was also observed with XMM- Newton in October 2000 (Haberl et al. 2003), during which it was in a relatively bright state (7 x 10^{-12} erg cm^{-2} s^{-1} in 0.2 10ke V range, corresponding to a luminosity of about 2.1 x 10^{36} erg s^{-1}).

3. Observations:

A series of observations of LMC X-4 reported here were made during August 19-20, 1996 January 14-15, 1998; June 11, 1998; October 23-30, 1998; December 19-21, 1999 and some observations are of year 2004-2005 listed in table 6.1. Subsequently, out of these observations we only compare the result of 1999 observations with EXO 053109-6609.2. For systematic studies, we have analyzed archival data from three observations of the pulsar EXO 053109-6609.2 made with Beppo SAX listed in table 6.2 (already done by Paul et al. 2004). The space telescope Beppo-SAX observed EXO 053109-6609.2 with its narrow field instruments (NFT;Boella et al. 1997) during the observation of LMC X-4 from March 13, 1997 to March 15, 1997; from October 20, 1998 to October 22, 1998 and from January 1, 2000 to February 26, 2000. During the 1997 observation, the source was in a transient outburst. The Pulsation properties during the outburst have been reported earlier (Burderi et al. 1998). For the Low-Energy Concentrator Spectrometer (LECS) the useful exposures in 1997, 1998 and 2000 are 42, 31 and 15 is respectively and for Medium-Energy Concentrator Spectrometer (MECS) the useful exposures are 117, 82 and 32 ks respectively.

3.1 Timing Analysis:

As we have already mentioned that X-ray pulsar LMC X-4 and EXO 053109-6609.2 are situated at a distance of 17' and were observed simultaneously in the field of view of the narrow field instrument of Beppo SAX. Paul et al (2004) have studied EXO 053109-6609.2 with the data of ASCA and Beppo SAX with time resolution of 0.5 sec and 0.25 sec respectively. We adopted the data of RXTE for LMC X-4 having time resolution 0.125s and data of Beppo SAX LECS and MECS with time resolution of 0.25s. We did comparative timing and spectral study of LMC X-4 and EXO 053109-6609.2 RXTE exclusively observed LMC X-4 in December 1999 which was closely the same time of observation of January 2000 of BeppoSAX. Light curves from these observations e extract for RXTE and BeppoSAX LECS and MECS. We applied barycenter correction for photon arrival times in the event files before extraction of light curves. This correction is essential because orbiting satellite observes X-ray photons longer time and it may be comparable to orbit period which may bring change in arrival time of photons. Paul et. Al. (2004) also extracted light curve with the time resolution of 0.25 seconds for BeppoSAX LECS and MECS for EXO 053109-6609.2. The pulse period analysis of EXO 053109-6609.2 with BeppoSAX gives the pulse period 13.7 s which is in agreement with the reported pulsar period (figure 1 and 2). It is surprising to note that both pulsars show almost same pulsation time and may be due to same category of HMXBs, hosting a neutron star and a Be-star residing in the same LMC along the Galactic plane. This result is promoting towards the more studies to be conducted to examine this unique feature for such celestial systems.

3.2 Pulse Profile:

For more comparative studies, pulse profiles were obtained from the background subtracted lightcurves in various energy range 2-5kev, 5-8 kev, and 8-11 kev towards soft X-ray spectrum for LMC X-4with 17%, 21%, and 26% respectively. They indicated that X-rays are emitted from the central part of the accretion disk likely to be present at larger distance from the surface of the X-ray pulsar LMC X-4. Further the shape of pulse is much more distorted pointing out towards the energy dependent feature. It is well reported that pulse shape is energy range 2-5 keV and 8-11 keV were poor, but 5-8 Ke V range has not sufficient statistics. However, complex double peak in the case of LMC X-4 as evident from pulse profile supports neither fan beam geometry, nor the pencil beam model (Leahy & Li 1995). Further it indicates that X-rays emission and detection have to suffer a complicated mechanism during their passage through LMC which distorts plus profile and becomes energy dependent.
For same LMC, Paul et al.(2004) observed pulse profiles of all occasion of EXO 053109-6609.2 taken with ASCA and Beppo SAX for various observations. They also showed that pulse profiles are distorted in energy range 2-10 keV and gave a hint of slight energy dependence of the pulse profile in the ASCA observations. The pulse profile clearly shows luminosity dependence with a single-peaked profile only at low luminosity and a double peak profile at high luminosity shown in figure 6.3 and figure 6.4. It becomes clear due to high statistics in their data showing 30%-60% pulse fraction. Nevertheless, results for both the HMXBs are consistent for timing studies with the common fact that pulse shape is energy dependent.

Table1: Observation table for LMC X-4

S.No.	Date	Observation ID	Start Time	Stop Time
1	19-08-1996	10135-01-01-02	01:54:26	06:31:13
2	19-08-1996	10135-01-01-000	12:26:27	19:09:05
3	19-08-1996	10135-01-01-00	19:09:05	23:20:13
4	20-08-1996	10135-01-01-040	12:51:28	19:09:05
5	20-08-1996	10135-01-01-04	19:09:05	02:42:13
6	14-01-1998	30125-04-01-00	12:46:34	13:33:14
7	15-01-1998	30125-04-01-01	04:48:23	06:07:14
8	11-06-1998	30125-04-06-01	23:09:43	00:01:14
9	23-10-1998	30085-01-20-00	19:11:43	22:21:14
10	26-10-1998	30085-01-27-00	15:12:46	19:04:15
11	30-10-1998	30085-01-31-02	20:20:27	20:35:14
12	30-10-1998	30085-01-31-03	21:56:16	22:11:14
13	19-12-1999	40064-01-01-010	11:39:10	18:13:08
14	20-12-1999	40064-01-01-020	03:17:59	09:50:08
15	20-12-1999	40064-01-01-02	09:50:08	14:10:15
16	20-12-1999	40064-01-01-000	14:56:52	21:19:08
17	20-12-1999	40064-01-01-001	21:19:08	04:44:08
18	21-12-1999	40064-01-01-00	04:44:08	06:24:15
19	11-06-2004	90086-05-04-00	19:21:27	22:40:15
20	03-07-2004	90086-05-05-00	23:50:44	06:48:15
21	03-08-2004	90086-05-06-02	12:27:50	12:42:15
22	06-11-2004	90086-05-09-00	13:51:38	16:32:15
23	08-01-2004	90086-05-11-00	05:01:49	07:12:15

Table2: Observation table for EXO 053109-6609.2

S.No.	Date	Observation ID
1	1997-03-13	20274001
2	1998-10-20	20671001
3	2000-02-26	20947006

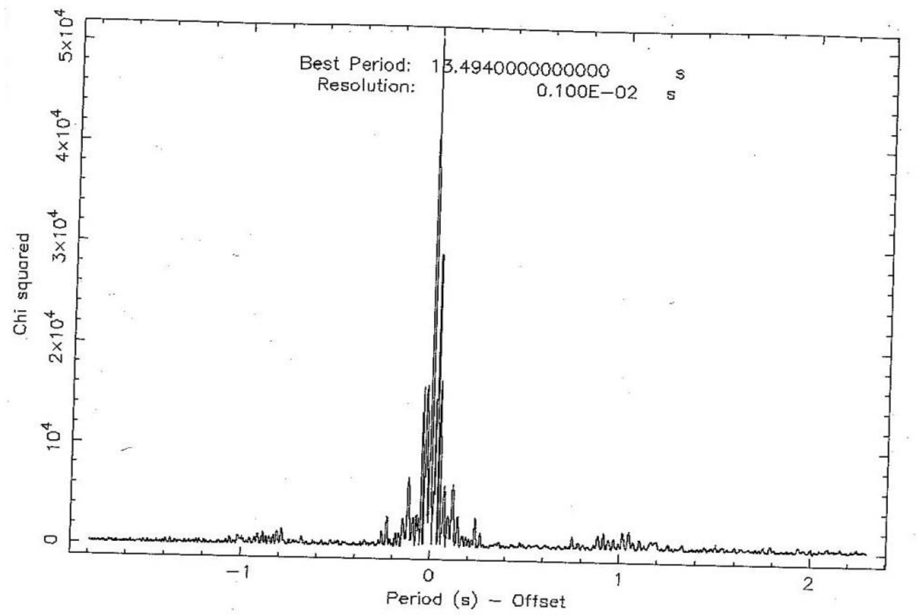

Figure 1: Pulse period of LMC X-4. The best period is 13.494 seconds

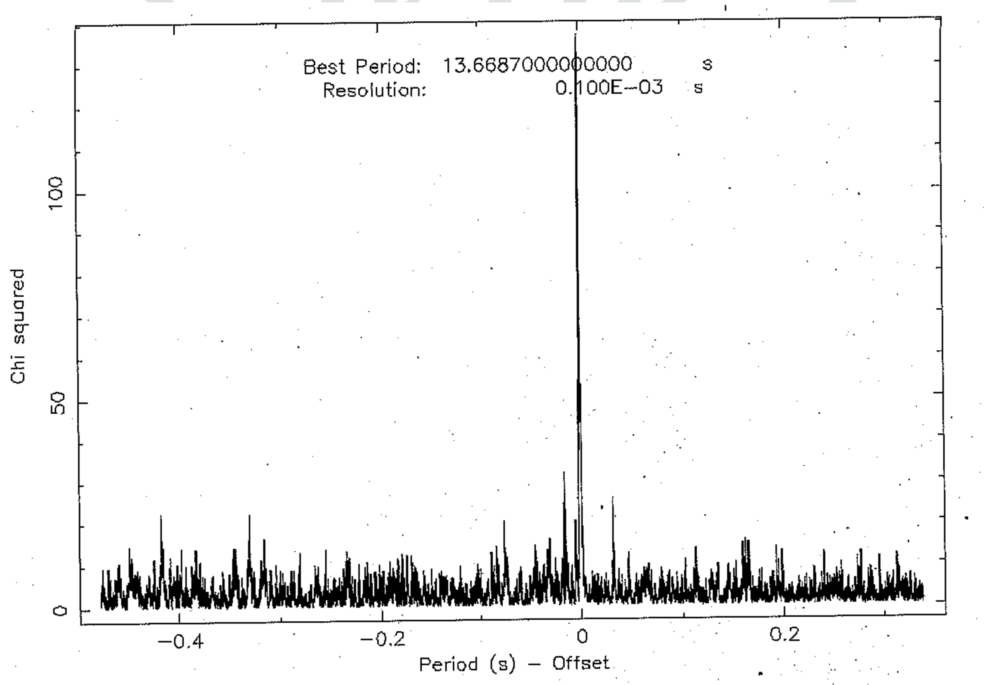

Figure 2: Pulse period of EXO 053109-6609.2. The best period is 13.668 second

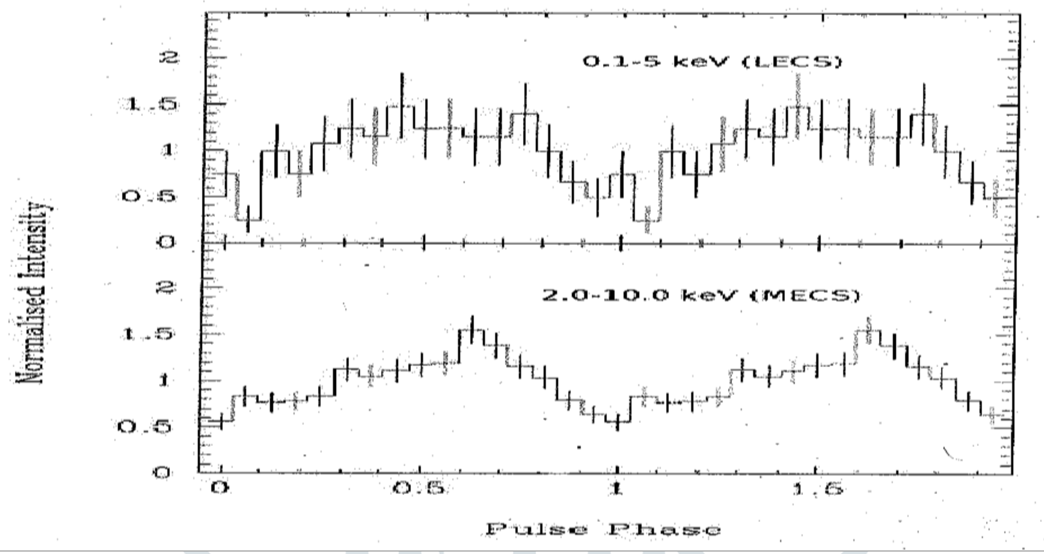

Figure 3: Pulse profile of EXO 053109-6609.2 in the different energy ranges 0.1-5.0 kev and 2.0-10 kev with LECS and MECS detectors of MJD 51600.72

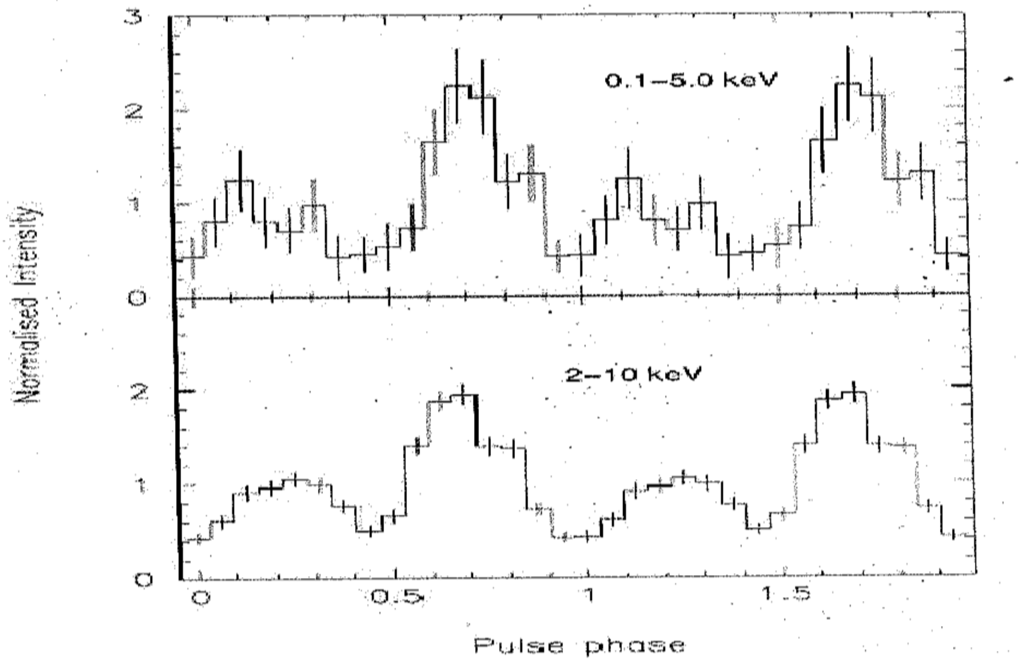

Figure 4: Pulse profile of EXO 053109-6609.2 in the different energy ranges 0.1-5.0 kev and 2.0-10 kev with LECS and MECS detectors of MJD 51107.6

4. RESULTS AND DISCUSSION:

The LMC X-4 and EXO 053109-6609.2 are believed to be a transient source. These pulsars are bright, at a luminosity level of 3 x 1035 to 6 x 1036 ergs s-1 in most of the X-ray observations.

The pulse profiles of LMC X-4 and EXO 053109-6609.2 indicate a dependence on the mass accretion rate. Due to different mass accretion rates the X-ray emission can consist a different geometrical pattern. The geometrical pattern changes from fan beam in a high luminosity state to a pencil beam in a low luminosity state. The pulse profile of the EXO 053109-6609.2 is single peaked and nearly sinusoidal in the low intensity state and it has double peak at high intensity state.

Light curves from our observations were extracted for RXTE and BeppoSAX LECS and MECS. We applied barycenter corrections which was essential because orbiting satellite observes X-ray photons longer time and it may be comparable to orbital period.

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