Eclipse Timings of the LMXB XTE J1710–281: Discovery of a third orbital period glitch

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ABSTRACT

We present an updated measurement of orbital period evolution of LMXB XTE J1710–281 by using eclipse timing technique. Using data obtained with XMM-Newton, Suzaku, RXTE, Chandra and AstroSat observatories, we report 21 new measurements of X-ray mid-eclipse times. We have discovered a third orbital period glitch in XTE J1710–281 with an F-test false alarm probability of ~0.7% for occurrence of the third glitch and report detection of four distinct epochs of orbital period in this system. This work presents a more robust estimation of occurrence of the second orbital period glitch. However, the epoch of occurrence of the third glitch is poorly constrained, between MJD 55726 to 56402. We have put lower limits of 1.48 ms, 0.97 ms and 0.45 ms, on sudden changes in orbital period between the successive epochs. We discuss the implications of our findings in context of magnetic nature of the companion star and possible scattering events with circum-binary objects around this binary system.

Key words: binaries: eclipsing, binaries: general, stars: individual: XTE J1710–281, stars: neutron, X-rays: stars

1 INTRODUCTION

The orbital period is one of the most fundamental parameter that characterizes a binary system. Therefore, in order to understand and constrain the properties of the binary components, astronomers have extensively studied the evolution mechanism of the orbital period. Several measurements have been done for both Low Mass X-ray Binaries (LMXBs) and High Mass X-ray Binaries (HMXBs) with observations spanning up to a few decades. The measurement techniques include pulse timing technique (LMXBs: Deeter et al. 1991; Jain et al. 2007; Staubert et al. 2009; HMXBs: Naik & Paul 2004; Mukherjee et al. 2006; Baykal et al. 2006; Raichur & Paul 2010; Jenke et al. 2012), eclipse timing technique (LMXBs: Wolff et al. 2009; Jain et al. 2010; Jain & Paul 2011; Jain et al. 2017; Ponti et al. 2017; HMXBs: Falanga et al. 2015; Islam & Paul 2016), use of stable orbital intensity profile as a time marker (Chou & Grindlay 2001; Singh et al. 2002; Peuten et al. 2014) and measurement of the Doppler shift in the spectrum of the companion star (González Hernández et al. 2014).

The orbits of X-ray binaries are expected to evolve due to mass transfer and re-distribution of the angular momentum arising from the interaction of the binary components (van den Heuvel 1994), mass loss from the binary system due to processes such as, jet emission from the compact object, irradiative evaporation of the secondary star or in the form of accretion disc winds (Ruderman et al. 1989; Brookshaw & Tavani 1993; Ponti et al. 2012), tidal interactions between the binary components (Lecar et al. 1976; Zahn 1977) and loss of orbital angular momentum via gravitational wave radiation or magnetic braking of the tidally coupled primary (Rappaport et al. 1983; Applegate 1992; Verbunt 1993).

As a result of these mechanisms, the orbital separation in X-ray binaries can increase (Homer & Charles 1998; Parmar et al. 2000; Jain et al. 2007, 2010) or decrease (Deeter et al. 1991; van der Klis et al. 1993; Paul et al. 2004). However, it has been observed that in most of the LMXBs, the orbital period is increasing at a rate much higher than that predicted by a conservative mass transfer or by gravitational wave radiation (Jain et al. 2007, 2010; Sanna et al. 2016). The orbital decay in X-ray binary systems is also unusual and is much faster than that predicted by conventional methods of gravitational radiation, magnetic braking and mass loss from the system (Peuten et al. 2014). In addition, there are two LMXB systems that show sudden changes in the orbital period (Wolff et al. 2009; Jain & Paul 2011). Another interesting LMXB is MXB 1658-298, which shows orbital period decay on a timescale spanning about four decades. But on shorter timescales, there are indications of presence of a third body around the binary system (Jain et al. 2017).

The object of this research work is LMXB XTE J1710–281 which was discovered with Rossi X-ray Timing Explorer (RXTE) in 1998 (Markwardt et al. 1998). It is located at a distance of ~15 kpc and has an inclination of about 80° (Frank et al. 1987; Markwardt et al. 2001). The compact object in this binary system is a neutron star (Markwardt et al. 2001). The orbital period of XTE J1710–281 is 3.28 h. This source exhibits dipping activity and complete, sharp eclipse transitions (Markwardt et al. 1998, 2001). The eclipse phase lasts for a duration of about 420 s (Jain & Paul 2011). From observations spanning more than a decade, Jain & Paul (2011) have detected the presence of three distinct epochs of orbital period. However, due

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to non-availability of sufficient data points at that time, the time of occurrence of second orbital glitch was uncertain. Therefore, for this work, we have extended the time-base for XTE J1710–281 observations and present the updated results of eclipse timing analysis.

2 OBSERVATIONS

Data for the present analysis were obtained from observations made with instruments on-board XMM-Newton, Suzaku, RXTE, Chandra and AstroSat. Table 1 lists the log of observations used in the present work. XMM-Newton (Jansen et al. 2001) consists of three focal plane instruments (EPIC: European Photon Imaging Camera) - one pn-CCD camera (Strüder et al. 2001) and two MOS detectors (Turner et al. 2001). XTE J1710–281 was observed with XMM–Newton in 2004 for an exposure of about 14 ks (Table 1). The observation data files were processed using the XMM Science Analysis System (SAS version 20.0.0). For this work, 0.5–10 keV EPIC-pn imaging mode data has been used. The X-ray events were extracted from a circular region of radius 45 arcsec centered on the source position. The background events were extracted from a source-free circular region of same radius as the source. The background subtracted light curve was barycenter corrected using the SAS tool barycen.

The X-ray Imaging Spectrometer (XIS) on-board Suzaku (Mit-suda et al. 2007) consists of four units and covers the energy range of 0.2–12 keV (Koyama et al. 2007). Of the four XIS units, three are front-illuminated CCDs (XIS0, XIS2, and XIS3) and one is back-illuminated CCD (XIS1). For the current analysis, we have utilized the data from XIS0 and XIS3 detectors. XTE J1710–281 was observed by Suzaku in 2010 for a duration of about 190 ks. The net exposure time was about 76 ks (Table 1). XIS detectors were operated in the standard data mode with normal window operation that provided a timing resolution of 8 s. The unfiltered event data were processed with the CALDB version 20181010 by using aepipeline. The XIS event files did not suffer from photon pile-up (Raman et al. 2018; Sharma et al. 2020b). We combined the cleaned event files for both 3×3 and 5×5 pixel mode for each CCD, by using the xselct. The combined cleaned events were corrected for the solar system barycenter using aebarycen. The clean event files were then used to extract the 0.5–10 keV light curve from a circular region of 3.5 arcmin centered on the source. An annular region of inner (outer) radius of 4.5 arcmin (6.5 arcmin) around the source was selected for the background. The light curves from XIS0 and XIS3 were added using cmath.

The RXTE-Proportional Counter Array (PCA) consists of an array of five collimated proportional counter units having a total photon collection area of 6500 cm² (Jahoda & PCA Team 1996; Jahoda et al. 2006). For the current work, we have used all the RXTE observations subsequent to our previous compilation of mid-eclipse times (Table 1, Jain & Paul 2011). The RXTE-PCA data was collected in the Good Xenon mode. The 2–20 keV light curves were generated by using fttool-seextrct. The background counts were estimated by using the ftool–pcabackest, assuming a faint source model. The background subtracted light curves were corrected for solar system barycenter by using the ftool-fbxay.

XTE J1710–281 was observed with the Chandra Advanced CCD Imaging Spectrometer (ACIS) detector (Weisskopf et al. 2002; Garmire et al. 2003) in 2011 for an exposure of ~75 ks (Table 1). The data was collected from ACIS-S CCDs in the timed exposure mode having a time resolution of ~1.74 s. The Chandra Interactive Analysis of Observations (CIAO) software version 4.14 was used to generate level 2 files by using chandra_repro. The 0.5–8 keV light curves were extracted from a circular region of radius 10 arcsec. A region of similar radius away from source was used to obtain the background events. Barycenter correction was done using CIAO tool axbary.

AstroSat is India’s first multi-wavelength astronomy mission (Agrawal 2006; Singh et al. 2014) and the Large Area X-ray Proportional Counter (LAXPC) is one of its primary payloads (Yadav et al. 2016; Agrawal et al. 2017). It consists of three co-aligned proportional counters (LAXPC10, LAXPC20 and LAXPC30) which are sensitive to the X-ray photons in the 3–80 keV energy range, with a total effective area of 6000 cm² at 15 keV. We have used Event Analysis (EA) mode data from LAXPC10 and LAXPC20 for the present work. Data from LAXPC30 was not used due to high background and gain variations of the instrument (Agrawal et al. 2017; Antia et al. 2017). In order to minimize the contribution of background in our analysis, we used data from the top layers (L1, L2) only (also see, Beri et al. 2019; Sharma et al. 2020a, for details). The level 1 data were processed by using the standard LAXPC software (LaxpcSoft: version 3.4.2)1. The 3–15 keV source and background light curves were extracted by using the tool laxpc1. The photon arrival times in level 2 files were corrected to the solar system barycenter by using as1bary2 tool. The barycenter and background corrected light curves from LAXPC10 and LAXPC20 were added using cmath.

Barycenter correction for all the light curves has been done using the JPL DE–405 ephemeris. The source coordinates used for this conversion were R.A. = 17h 10m 12.3s and and dec = -28° 07’ 54″ (Ebisawa et al. 2003).

3 ANALYSIS AND RESULTS

From data spread over ~13 years (2004–2017), we have found 21 complete eclipses (1 with XMM-Newton, 1 with Suzaku, 13 with RXTE, 2 with Chandra and 4 with AstroSat). Figure 1 shows the eclipse phase of background subtracted light curves obtained from XMM-Newton, Suzaku, RXTE, Chandra and AstroSat. For the observations of XMM-Newton-PN, RXTE-PCA and AstroSat-LAXPC mentioned in Table 1, all the eclipses were analyzed individually. But the light curves from CCD detectors onboard Suzaku-XIS and Chandra-ACIS have been folded to obtained a single eclipse profile. The Suzaku-XIS and Chandra-ACIS light curves were folded with the period mentioned in Jain & Paul (2011). The folded orbital profiles from Suzaku and Chandra data are shown in Figure 1 with respect to respective mid-eclipse time as the epoch. The Suzaku observation duration was ~190 ks, therefore 16 cycles were folded to obtain the orbital profile. This gives a reasonably good resolution for the orbital profile as well as the measurements of eclipse parameters, even though the normal observation mode of the Suzaku data had a time resolution is 8 s. Similarly, for the Chandra data, about six cycles were folded to obtain the orbital profile. And looking at a time resolution of 1.74 s, it gives a fairly good sensitivity in the measurement of eclipse parameters.

In order to determine the mid-eclipse times, we fitted an eclipse profile to each eclipse phase. As seen in our earlier paper (Jain & Paul 2011), for all the observations, the out-of-eclipse count rate did not seem to have any significant variability. It was found that the values of pre–ingress and post–egress count rate were similar and the

1 https://www.tifr.res.in/~astrosat_laxpc/LaxpcSoft.html

2 http://astrosat-ssc.iucaa.in/?q=data_and_analysis
Table 1. Log of observations and mid-eclipse time measurements of XTE J1710–281.

| Mission–Instrument | Observation Id | Date of Observation (DD-MM-YYYY) | Exposure (ks) | Orbital Cycle* | Mid-eclipse Time MJD (d) | Uncertainty 1σ (d) |
|--------------------|----------------|----------------------------------|--------------|---------------|-------------------------|------------------|
| XMM-Newton-PN      | 0206990401     | 22-02-2004                      | 13.9         | 13214         | 53057.423293            | 0.000015         |
| Suzaku-XIS         | 404068010      | 23-03-2010                      | 76           | 92972         | 55280.070265            | 0.000005         |
| RXTE-PCA           | 94314-01-07-03 | 10-10-2010                      | 9.2          | 30933         | 55479.805016            | 0.000016         |
| RXTE-PCA           | 94314-01-07-03 | 10-10-2010                      | 9.2          | 30933         | 55479.941720            | 0.000011         |
| RXTE-PCA           | 94314-01-08-00 | 31-10-2010                      | 6.9          | 31084         | 55500.448340            | 0.000015         |
| RXTE-PCA           | 94314-01-09-01 | 08-11-2010                      | 6.7          | 31142         | 55508.377619            | 0.000052         |
| RXTE-PCA           | 94314-01-10-00 | 13-01-2011                      | 15.4         | 31627         | 55574.682446            | 0.000011         |
| RXTE-PCA           | 94314-01-11-00 | 23-04-2011                      | 13.6         | 32357         | 55674.481414            | 0.000017         |
| RXTE-PCA           | 94314-01-11-01 | 24-04-2011                      | 6.9          | 32365         | 55675.575093            | 0.000017         |
| RXTE-PCA           | 96329-01-01-00 | 06-07-2011                      | 14           | 32901         | 55748.852182            | 0.000017         |
| Chandra-ACIS       | 12468          | 23-07-2011                      | 75           | 33026         | 55765.41025             | 0.000018         |
| RXTE-PCA           | 96329-01-02-01 | 24-07-2011                      | 1.8          | 33028         | 55766.214455            | 0.000017         |
| RXTE-PCA           | 96329-01-02-00 | 24-07-2011                      | 19.7         | 33030         | 55766.487866            | 0.000011         |
| RXTE-PCA           | 96329-01-02-00 | 24-07-2011                      | 19.7         | 33031         | 55766.624630            | 0.000011         |
| RXTE-PCA           | 96329-01-03-000| 05-08-2011                      | 25           | 33115         | 55778.108319            | 0.000011         |
| Chandra-ACIS       | 12469          | 07-08-2011                      | 75           | 33135         | 55780.842543            | 0.000013         |
| AstroSat-LAXPC     | 9000001188     | 19-04-2017                      | 11           | 48361         | 57862.404031            | 0.000040         |
| AstroSat-LAXPC     | 9000001188     | 19-04-2017                      | 11           | 48362         | 57862.540720            | 0.000046         |
| AstroSat-LAXPC     | 9000001382     | 14-07-2017                      | 12.5         | 48991         | 57948.531930            | 0.000017         |
| AstroSat-LAXPC     | 9000001382     | 14-07-2017                      | 12.5         | 48992         | 57948.668632            | 0.000017         |

* w.r.t. MJD 51251.061141 (Jain & Paul 2011).

eclipse ingress and egress duration (∼ 20 s) were also similar within errors. The parameter space for the eclipse model, thus consisted of, (i) The mid-eclipse time, (ii) The eclipse duration, (iii) The ingress transition, (iv) The egress transition and (v) The pre-ingress and the post-eclipse count rate. In all the eclipse profiles, the eclipse duration was consistent and was observed to last for about 420 s, excluding the ingress and egress transition. We took ∼ 150 s of data before and after the eclipse phase to fit the eclipse profile.

A sample of the best fit eclipse model from all the five observatories is shown with a solid line in Figure 1. The mid-eclipse times and the corresponding 1σ errors were determined for all the 21 X-ray eclipse profiles. The results are given in Table 1. In this table, the orbital cycle is in concurrence with Jain & Paul (2011).

We combined our measurements with the previous measurements (Jain & Paul 2011). Out of a total 78 eclipse measurements, we have 56 observations during epoch 2 (MJD 52132 - 54410, labelled in Figure 2). To determine the secular change in orbital period (other than the glitches) we fitted a constant and a linear model to the eclipse measurements in epoch 2. We obtained an updated constant orbital period of 0.1367109674 (2) d with measurements in epoch 2. We obtained an updated constant orbital period with the standard deviation of the three glitch model. This gave us a detection significance of 5σ for the fourth epoch.

3.2 Case II: Three Orbital Glitches; Four Epochs

Due to limited number of data points during epoch 1, we have obtained a lower limit on orbital period change (ΔP) of 1.5 ms between epoch 1 and epoch 2. It is evident from Figure 2 (left panel), that the second orbital period glitch occurred around orbital cycle 24301 which corresponds to MJD 54573. The results of the fit are given in Table 2.

3.2 Case II: Three Orbital Glitches; Four Epochs

From a careful review of Figure 2 (left panel), it appears that on the O-C diagram, the four measurements from AstroSat observations of 2017 lie significantly away from the best fit solution. We therefore fitted the O-C diagram for XTE J1710–281 with piece-wise linear function comprising of four epochs. The best fit functional form along with the residue from the fitted model is shown in Figure 2 (right panel). The best fit model had a reduced χ² of 2.2 for 72 degrees of freedom. As per this model, the second and third glitch occurred around orbital cycle of 22639 and 35639. This corresponds to MJD 54345 and 56123 respectively.

Following (Jain & Paul 2011), the O-C values are shown with respect to the second epoch. In order to determine the detection significance of the fourth epoch w.r.t. the second epoch, we fitted a constant to residuals of the fourth epoch. The value of the best-fit constant was divided by the quadrature sum of 1σ error associated with the constant fit and the standard deviation of the three glitch model. This gave us a detection significance of 5σ for the fourth epoch.

From Table 2 it is clear that there is a marginal improvement of about 23 in the value of χ² from results of case I to those of case II for two additional parameters. The statistical significance of the three glitch model over the two glitch model can be ascertained from the fact that we have obtained an F-test false alarm probability of ∼0.7% which corresponds to a confidence level of 2.7 σ. However, given the insufficient number of data points between epoch 3 and epoch 4, it is difficult to determine the exact epoch of the third glitch. As
Figure 1. The eclipse profile of background subtracted light curve of XTE J1710–281 obtained from XMM-Newton, RXTE, AstroSat, Suzaku and Chandra. The solid line in each plot represents the best fit five parameter eclipse model.

Figure 2. “Observed minus Calculated (O-C)” diagram of XTE J1710–281 with two orbital period glitches (Case I) and three orbital period glitches (Case II). The bottom panel in both the diagrams displays the residuals from the best-fit model.

mentioned in Table 2, we report limits of MJD 55726 – 56402 on the occurrence of the third orbital period glitch.

Continuing with the statistical model validation, we have also determined the correlation of change in orbital period ($\Delta P$) with orbital cycle corresponding to the occurrence of the first and third glitch. This correlation is shown in Figure 3. In both the graphs of this figure, the contour plot between orbital cycle and $\Delta P$ is shown for 68% (red), 90% (green) and 99% (blue) confidence level. Clearly, the magnitude of change in the orbital period is correlated with epoch of occurrence of glitch. This figure also establishes that $\Delta P$ reported in this work and in Jain & Paul (2011) represents the lower limit of $\Delta P$ only.

Another important inference from the best fit model is the fact that during the first glitch, the orbital period decreased by about 1.48 ms. After about 5 years, the orbital period increased by about 0.97 ms and it increased by about 0.45 ms after a gap of about 6 yr.
Figure 3. Correlation of magnitude of $\Delta P$ with orbital cycle corresponding to the occurrence of first and third glitch. The red, green and blue contours in both the graphs corresponds to 68%, 90% and 99% confidence level, respectively.

Table 2. Updated orbital ephemerides of XTE J1710–281. All the uncertainties quoted in this table are at 90% confidence level. In this table, $n$ refers to orbital cycle.

| Parameter Case | Case II |
|----------------|---------|
| $n_{\text{glitch}_1}$ (MJD) | 6452* |
| epoch$_{\text{glitch}_1}$ (MJD) | 52133* |
| $n_{\text{glitch}_2}$ (MJD) | 24301 (807) |
| epoch$_{\text{glitch}_2}$ (MJD) | 22639 (585) |
| $n_{\text{glitch}_3}$ (MJD) | 54573 (110) |
| epoch$_{\text{glitch}_3}$ (MJD) | 54345 (80) |
| $P_{\text{epoch}2} - P_{\text{epoch}1}$ (ms) | -1.50 (13) |
| $P_{\text{epoch}3} - P_{\text{epoch}2}$ (ms) | -1.48 (13) |
| $P_{\text{epoch}4} - P_{\text{epoch}3}$ (ms) | 1.24 (9) |
| $\chi^2$/dof | 2.5/74 |

*Although fitting the first glitch is expected to yield a realistic estimation, but owing to only two data points during the first epoch, it will be impractical to mention the error in the estimation of $n_{\text{glitch}_1}$ and epoch$_{\text{glitch}_1}$ (Jain & Paul 2011).

4 DISCUSSION

This work reports measurement of 21 new mid-eclipse times in XTE J1710–281 spread across 13 years. Our results have increased the total number of mid-eclipse time measurements in XTE J1710–281 to 78 spanning about 49000 binary orbits. By using data obtained from observations of XMM-Newton, Suzaku, RXTE, Chandra and AstroSat, we have discovered occurrence of a third orbital period glitch in XTE J1710–281.

The orbital period in XTE J1710–281 shows a decrease as well as an increase. As a result, the orbital period glitches have net change of 0.06 ms in about 20 yr timeline. This implies a net period derivative of $0.09 \times 10^{-12}$ d$^{-1}$. Even if the glitches had same direction, the net period derivative would have been $4.6 \times 10^{-12}$ d$^{-1}$. In the following sub-sections, we have explored the various possible mechanism for the long-term orbital evolution in XTE J1710–281 along with their caveats.

4.1 Stellar Magnetic Convection

On the probable cause of orbital period glitches, Wolff et al. (2009) had proposed magnetic activity associated with the secondary star as the likely cause in EXO 0748–676. This source was discovered in 1985 and it went into quiescence after about 24 year long X-ray outburst (Parmar et al. 1985; Degenaar et al. 2009). Thus through optical emission, it has been possible to map the magnetic activity in the companion star thereby giving clues on sudden change in the orbital period (Applegate & Patterson 1987; Hertz et al. 1997) in this binary system.

On the other hand, XTE J1710–281 is a persistent system where the accretion disc dominates the optical emission. The companion star is expected to become visible only during quiescence. And hence, the magnetic nature of the companion star in XTE J1710–281 has not been investigated yet (Ratti et al. 2010).

4.2 Gravitational Wave Radiation

The rate at which the orbital period shrinks due to loss of energy and angular momentum from a binary system to gravitational waves, is of the order of $10^{-13}$ d$^{-1}$ (Paczynski 1967; Verbunt 1993). Considering gravitational wave radiation as the only cause for orbital period evolution, the orbital period decays ($P_{\text{orb}}$) according to Equation 1 (Landau & Lifshitz 1971; Ergma & Antipova 1999)

$$P_{\text{orb}} = \frac{192\pi}{5} \left( \frac{2\pi}{P_{\text{orb}}} \right)^{5/3} \frac{M_cM_nM^{-1/3}}{c^5} \left( \frac{GM\varpi}{c^2} \right)^{5/3}$$

For XTE J1710–281, mass of neutron star ($M_n$) can be taken as 1.4 $M_\odot$. The mass of the companion star ($M_c$) is not known. But assuming it to be a low mass companion with mass in the range 0.01 $M_\odot$ to 1 $M_\odot$, the total binary mass ($M$) becomes 1.41 $M_\odot$ - 2.4 $M_\odot$. Plugging in an orbital period ($P_{\text{orb}}$) of 0.1367109674 d in Equation 1 gives $P_{\text{orb}} \sim -(0.07 - 6) \times 10^{-13}$ d$^{-1}$. From the orbital period glitches, we have estimated a net period derivative of $0.9 \times 10^{-13}$ d$^{-1}$. Therefore, orbital period glitches are definitely an important clue for understanding the orbital evolution mechanism in XTE J1710–281 but looking at the uncertainty in the companion mass, they are certainly not the sole factor responsible for the long term orbital decay.

4.3 Hierarchical triple system

The presence of a third object in an orbit around a binary system is known to alter the evolution of the binary system. Although there are no direct observational clues, nevertheless there are reported works that have established that presence of a massive third object orbiting a binary system is capable of shrinking and expanding its orbital period (Iaria et al. 2015; Getley et al. 2017; Jain et al. 2017). In case of XTE J1710–281, the occurrence of distinct glitches rules out the possibility of triple hierarchical system because the changes in
orbital period are expected to evolve continuously as a function of the orbital phase of the third body.

4.4 Orbital Scattering

Possible detection of positive and negative orbital period glitch in XTE J1710–281 opens up several interesting scenarios and challenges our understanding of the environments of the binary systems. Similar to the solar system, if there are ensemble of smaller bodies and occasional scattering of these bodies by the binary takes place (like comets in the solar system), then that can cause sudden changes in angular momentum and this process can give either a positive or a negative glitch.

Taking a as the binary separation, the total orbital angular momentum (J) is given by Equation 2.

\[ J = M_{ns}M_c \left( \frac{Ga}{M} \right)^{1/2} = M_{ns}M_c G^{2/3} \left( \frac{P_{orb}}{2\pi M} \right)^{1/3} \tag{2} \]

Due to impact of an object of mass m, the total angular momentum of the system (given in Equation 2) will change owing to the fact that the total system mass will increase to \( M_{ns} + M_c + m \) and the binary period will increase by \( \Delta P \). This implies that the change in angular momentum due to impact of third object will be (Equation 3)

\[ \Delta J = \frac{M_{ns}G^{2/3}}{(2\pi)^{1/3}} \left( \frac{(M_c + m)}{M + m} \right)^{1/3} \left( \frac{P_{orb} + \Delta P}{M + m} \right)^{1/3} - \frac{M_c}{M} \left( \frac{P_{orb}}{M} \right)^{1/3} \tag{3} \]

Assuming that the object of mass m is falling freely onto the binary and considering extreme case that this object is captured by the companion star, the change in the total angular momentum of the binary (\( \Delta J \)) will be given by Equation 4.

\[ \Delta J = m \sqrt{2GMa} \tag{4} \]

Taking extreme range of 0.01 – 1 \( M_\odot \) for the companion mass and simultaneously solving Equations 3 and 4, for \( P_{orb} \sim 11833 \) s, \( \Delta P \sim 1.5 \) ms, and \( M_{ns} = 1.4 \) \( M_\odot \), the mass of the third object interacting with the binary system is expected to be \( 10^{23} – 24 \) g (Hughes 1985, 1990).

Considering our solar system, although the cometary mass depends on its size and the mean density of its nucleus, nevertheless, the most massive comets are known to have mass in the range \( 10^{17} – 10^{19} \) g (Hughes 1985, 1990). But these comets are not known to induce a significant perturbation in the orbit of solar system satellites. So any hypothesis of labelling the third object in the XTE J1710–281 system as an exo-comet needs a strong argument.

It is known that a significant fraction of white dwarfs harbour a large number of extra-solar minor bodies having mass in the range of \( 10^{19} \) to \( 10^{26} \) g (Farhi et al. 2010; Veras et al. 2014; Veras 2016; Strom et al. 2020). These minor objects are often considered equivalent to highly eccentric asteroids which get tidally disrupted around the compact object (Campana et al. 2011). In fact, long term monitoring of several neutron star systems has indicated presence of an asteroid belt around pulsars (Shannon et al. 2013; Brook et al. 2014). There are also cases where debris in the supernova fallback accretion disk around a neutron star gets periodically perturbed by a large orbiting object (likely to be a planet) (Cordes & Shannon 2008).

In case of XTE J1710–281, looking at the probable mass of the third body, it could be possible that extra-solar planetesimals are present around the binary system. But it is too early to comment on the viability of this conjecture. The results presented in this work are encouraging to plan future X-ray observations during the current active phase to refine the occurrence of orbital period glitch, to explore the possibility of another glitch, to investigate detailed/alternative interpretation of the cause for occurrence of orbital glitch and thereby monitor the orbital evolution in XTE J1710–281. It will also be useful to carry out optical observations of the companion star during a future quiescent phase (if any).

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DATA AVAILABILITY

Data used in this work can be accessed through the Indian Space Science Data Center at https://astrobrowse.issdc.gov.in/astro_archive/archive/Home.jsp, and HEASARC archive at https://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/w3browse.pl.

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