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Low mass X-ray source GX340+0 harbors milli-Hertz QPO

KEYWORDS Accretion, accretion disks- stars: individual: GX340+0 – stars: neutron- X-rays: stars

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ABSTRACT *We report discovery of Quasi Periodic Oscillations (QPOs) frequencies 25±2.1 mHz, 4±1.3 mHz, 15±1.8 mHz for different outburst of Low mass X-ray source GX340+0 on dated April 1997, November 1998, August 2000 respectively. The flux below the surface layer produced due to conduction of energy during X-ray bursts pours slowly upward and hence generates stable burning on the surface of compact object (neutron star). The mHz QPO only occurs if burning fuel rate (dm/dt) = (dm/dt) = (dm/dt)EDD. These types of mHz QPOs appear in weak magnetized X-ray source because strong magnetic field compresses conduction of heat flux below the core of neutron star*

INTRODUCTION

Temporal studies are powerful tool for astronomers to investigate the properties of celestial compact X-ray binaries. X-ray binaries divide in to two different classes, (i) High mass X-ray binaries (Mass of companion star > 1 M_Θ but ≤ 10 M_Θ) and (ii) Low mass X-ray binaries (Mass of companion star ≤ 1 M_Θ, Where M_Θ is the mass of sun i.e. M_Θ ~1.99 x 10^{30} kg) (Van Paradijs et al. 1995; Hayakawa 1985; Bradt and Mc Clintock 1983). Low mass X-ray binaries are divided in to two sub classes (i) Z-sources (ii) atoll sources, based on their spectral and timing properties during state evaluation in X-ray wavelength (Hasinger et al. 1989). Z-sources and atoll sources are basically two groups of bright low mass X-ray binaries, also Z-sources are more Luminous than atoll sources. The Z-track is investigated by using Color-Color Diagram (CCD) and Hardness Intensity Diagram (HID).

GX 340+0 is regarded as bright low mass X-ray binaries (LMXB's) harboring probably a neutron star which was discovered by Geiger counter (Friedman et al.1967) with Aerobee rocket. It is termed as Z-source (Vander Klis et al.1996a) with X-ray flux varying completely irregularly in the range 4x10^{-9} erg $cm^{-2}s^{-1}$ (Forman et al. 1978; Market et al.1979; Warwick et al. 1981; Wood et al. 1984). When source is on Horizontal Branch (HB) then mass accretion rate (dm/dt) increases up to almost 10 times of Eddington limit while dm/dt is nearly equal to Eddington limit on "Flaring Branch" FB. The Quasi Periodic Oscillation (QPO) frequency increases with increasing (dm/dt). The QPO has been detected in various Z-track, GX5-1 (Vander klis et al. 1996), SCO X-1 (Vander klis et al 1996b), GX17+2 (Wijnands et al. 1997), Cyg X-2 (Wijnands et al. 1998) in the kilo-Hertz(kHz) QPO range. The QPO's have only detected on near small fraction of FB and close to "Normal Branch"NB (Van Paradijs et al.1988). GX340+0 exhibits very high frequency (kHz) QPO's which was detected with Rossi X-ray Timing Explorer (RXTE). It is detected that lower QPO in the frequency of range 247 Hz to 625 Hz while frequency of upper QPO ranging from 567 Hz to 820 Hz along HB (Jonker et al. 1998). A broad component of frequency ranging (9-14) Hz with RXTE lying very close to half of the HB of QPOs (Jonker et al. 2000).

OBSERVATIONS AND DATA ANALYSIS:

The Rossi X-ray Timing Explorer (RXTE) is a satellite which was used to observe temporal activity of celestial compact X-ray binaries specifically in the present study of **Low mass x-ray source GX340+0**. RXTE has three instruments on board All Sky Monitor (ASM), Proportional Counter Array (PCA), and High-Energy X-ray Timing Experiment (HEXTE). The ASM was sensitive in 1.5-12 keV energy spectrums (Levine et al. 1996). We have used RXTE/ASM observations of bright low mass X-ray binary GX340+0 at different X-ray outbursts occurring at different point of times. The observation were taken from 1996 January 06 (02:42:17.2) to 2011 August 31 (00:41:59.6). ASM light curve of GX340+0 obtained from RXTE/ASM from one day averaged dwell data as dated above is shown in Fig 1.

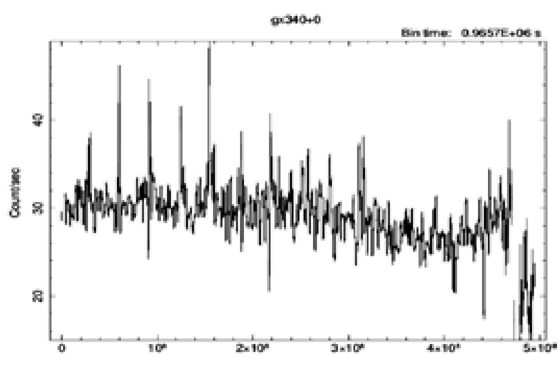

Figure1. RXTE/ASM one day averaged light curve of Z-source GX340+0 in energy spectrum 1.5-12 keV from 1996 January 06 to 2011 August 31.

Four major outbursts were initially detected and out of four outbursts three of them were filtered for QPOs feature

Volume : 6 | Issue : 10 | October 2016 | ISSN - 2249-555X | IF : 3.919 | IC Value : 74.50

investigations as given in figures-2, 3, 4, 5 below.

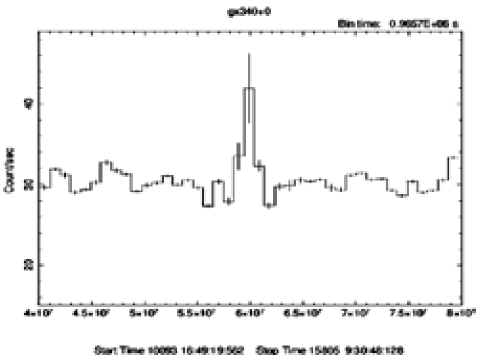

Figure2. RXTE/ASM light curve of X-ray binary bright source GX340+0 shows first outburst during October- December 1997.

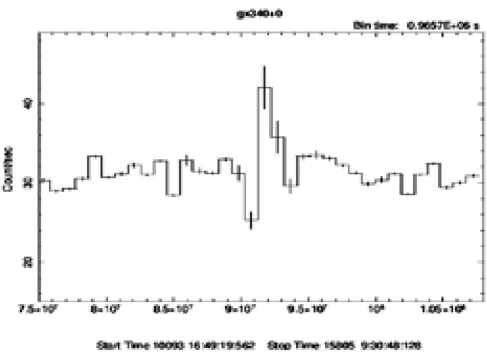

Figure3. RXTE/ASM light curve of X-ray binary bright source GX340+0 shows second outburst during October - December 1998.

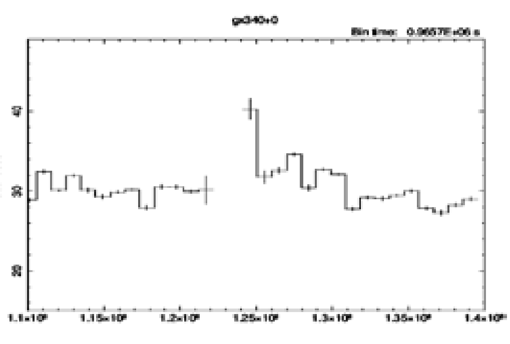

Figure4. RXTE/ASM light curve of X-ray binary bright source GX340+0 shows third outburst during October – December 1999.

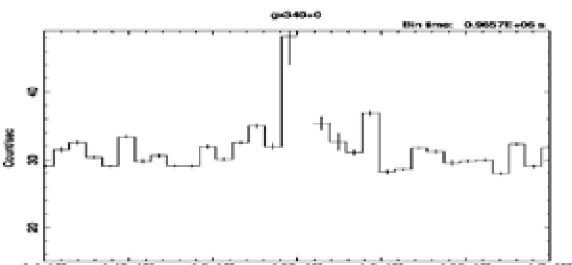

Figure5. RXTE/ASM light curve of X-ray binary bright source GX340+0 represents fourth outburst during September – November 2000.

During period 1996 January 06 to 2011 August 31 we plotted all sky monitor using RXTE/ASM data. Four major outburst were detected with more than 40 counts /second. First outburst with 47 counts /second were detected in October- December 1997, second outburst ~45 counts /second during October - December 1998, Third outburst ~42 counts /second during October – December 1999 and fourth outburst ~50 counts/second during September – november2000. These outbursts were periodic i.e. repeated at same time interval of about 1 year in the data of RXTE/PCA. These outbursts were used for QPO detection.

We retrieved the archived data of PCA on board RXTE for observation of temporal studies. The PCA which was consisting of five Xenon filled proportional counters and sensitive in 2-60 keV energy range. The effective area was ~6500 cm^2 with 18% energy resolution at 6 keV while time resolution ~145 (Jahoda et al. 1996; Jahoda et al. 2006). Detail of retrieved archival data with RXTE/PCA having observation ID P20054, P20053, P50016 and sub constituent observations are shown in table- 1 below.

Table-1

Observation ID	Sub observations	Date	Time	Duration	Exposure
P20054	20054-04-01-00	1997-04-17	13:26:20.5	31314	19754
P30040	30040-04-01-05	1998-11-15	09:48:25.6	3551	2522
P50016	50016-01-01-03	2000-08-17	03:23:04.1	3900	1610

Using standard 1b PCA data, we plotted power density spectrum using HEASOFT package (version 6.16) on dated April 1997, November 1997 and August 2000. These power density spectrums (PDS) were traced to detect presence /absence of QPOs in frequency range 1 mHz to 1 Hz. The sharp peak of power density spectrum showed exactly periodic variation but when number of broader peaks appeared in PDS of Lorentzian shape became the subject of present research paper. PDS has many features like an energy spectrum.

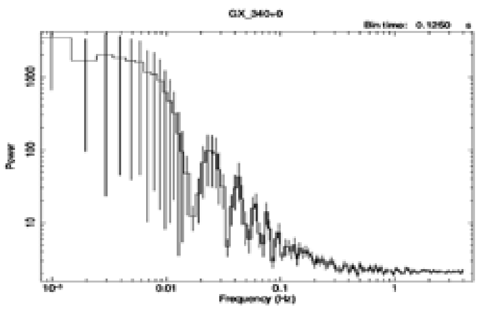

Figure- 6: The power density spectrum of Z- source GX340+0 around first burst.

PDS obtained from RXTE/PCA observation on 1997 April 17 with bin size 0.125 second is shown in figure-6. The pulsations and its harmonics are seen at higher frequencies of 25±2.1 mHz, 45±2.3 mHz, 60±2.7 mHz, 75±2.4 mHz, 90±2.9 mHz i.e. multiple of 15 mHz except 25 mHz first peak which may be regarded as a clearly detected QPO present in the power spectrum with quality factor ($\nu_{Qpo}/\Delta\nu_{Qpo}$) of value around 2 and maximum power of 100.

Volume : 6 | Issue : 10 | October 2016 | ISSN - 2249-555X | IF : 3.919 | IC Value : 74.50

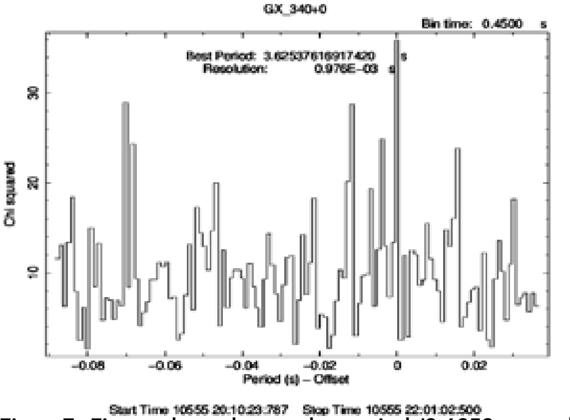

Figure7. Figure shows best pulse period (3.6253 second with resolution of 0.000976 seconds) of Z- source GX340+0 (ID 20054-04-01-00) for outburst 1997.

The pulse period is analyzed and the best estimated value for the pulse period turned out to be 3.6253 second with resolution of 0.000976 seconds for the Z- source GX340+0 having got the sub observed ID 20054-04-01-00 during the outburst 1997. It clearly demonstrates that harbored compact object neutron star spins very fast with frequency of 275.83± 3.67 mHz.

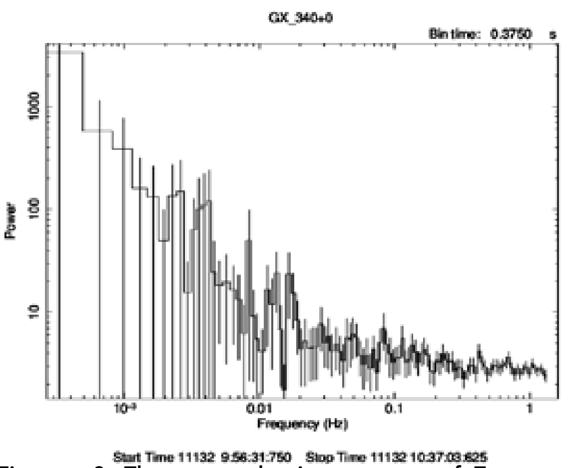

Figure - 8. The power density spectrum of Z- source GX340+0 around second burst.

PDS obtained from RXTE/PCA observation for outburst 1998 with bin size 0.3750 second. The pulsations and its harmonics are seen at higher frequencies of 4±1.3 mHz, 8±2.3 mHz, 12±1.8 mHz, 16±2.1 mHz, 28±2.7 mHz, 48±3.3 mHz, 80±3.1 mHz which are multiple of 4 mHz. The presence of clearly detected 4 mHz QPO is endorsed having observed quality factor ($\nu_{Qpo}/ \Delta \nu_{Qpo}$)of value of ≤2 and power 200 as compared to other peaks shown in figure-8 above.

Also the pulse period is analyzed for the sub observation ID 30040-04-01-05 identified in the outburst of 1998 of the Z-source GX340+0 and found to be of 3.72788 seconds with resolution of 0.00266 seconds keeping bin time of 0.45 seconds as shown in figure-9 below. This is referred to the spinning of neutron star with frequency of 268.24 ± 7.65 mHz which matches well with the spin frequency of 275.83± 8.27 mHz obtained in ID 20054-04-01-00.

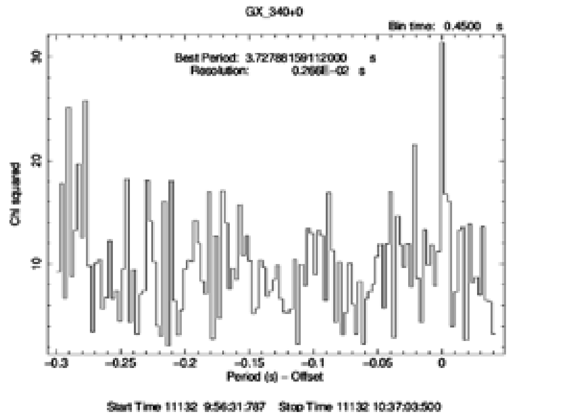

Figure-9 shows best pulse period (3.72788 second with resolution of 0.00266 seconds and bin time of 0.45 seconds) of Z-source GX340+0 (ID 30040-04-01-05) for outburst 1998.

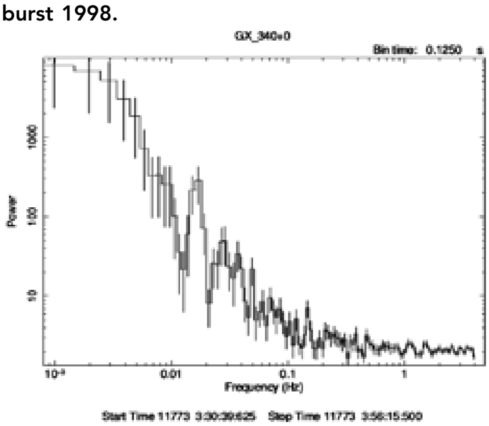

Figure-10 represents power density spectrum of Z-source GX340+0 outburst of 2000.

With bin size of 0.125 seconds the power density spectrum is plotted as shown in figure-10 above for Z-source GX340+0 during the outburst of 2000. The PDS is obtained from RXTE/PCA observation with sub observation ID 50016-01-01-03. The pulsations and its harmonics are seen at higher frequencies of 15±1.8 mHz, 30±2.2 mHz, 46±2.4mHz, 60±2.6mHz, 75±2.1mHz, and 150±3 mHz, which are observed to be the multiple of fundamental frequency 15±1.8 mHz. These harmonics are very identical belonging to the outburst of 1997 but QPO clearly happens to be at frequency 15±1.8 mHz as its Q- factor ($\nu_{Qpo}/ \Delta\nu_{Qpo}$) detected is ≤ 1.5 and power is 270 which is three times more than observed in outburst of 1997 and 1998.

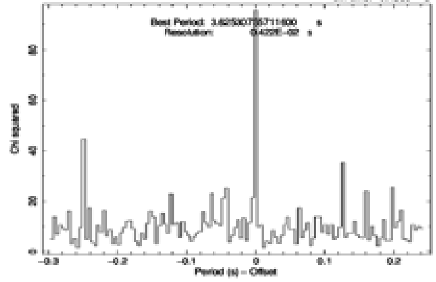

Figure-11 shows best pulse period (3.62530 second with resolution of 0.00422 seconds) of Z- source GX340+0 (ID 50016-01-01-03) for outburst 2000.

Volume : 6 | Issue : 10 | October 2016 | ISSN - 2249-555X | IF : 3.919 | IC Value : 74.50

The Pulse period is tried to obtain by analyzing the data for the Z-source GX340+0 using the sub observation ID 50016-01-01-03 taken for the outburst 2000 as shown in figure-11 above. The best pulse period turned out to be of 3.62530 seconds with resolution of 0.00422 seconds at bin time size of 0.45 second. The corresponding spin frequency of neutron star is 275.83 ± 8.93 mHz and it is just same as that observed in the outburst of 1997.

RESULT AND DISCUSSION

The most common phenomenon detected in above all power density spectra (PDS) around outbursts is QPO. The QPO pattern generally is observed in transient source as compare to persistent sources because of at bursts persistent luminosity $L_{pers} \geq (0.2\ L_{edd})$ and hence it is very difficult to detect in persistent one (Cornelisse et al. 2003; Galloway et al. 2008). The frequency of QPO in number of celestial compact X-ray binaries varies in the range of ~1milli Hertz to 40 Hertz. QPOs in X-ray binaries appear due to the non homogeneously distribution of plasmas at the interior of accretion disc. QPO pattern gives useful information about physical structure of accretion disc, brightness fluctuation of plasmas, radii of accretions disk, spin period of compact object and magnetosphere around neutron stars. We have detected QPO for bright Z-source GX340+0 in three observations as shown by table- 2, below.

Table-2

S.No.	Outbursts time	Observation ID	QPO Frequency (νQpo)	Pulsations
1.	April 1997	20054-04-01-00	25±2.1 mHz	3.62537±0.00097 s
2.	November 1998	30040-04-01-05	4±1.3 mHz	3.72788±0.00266 s
3.	August 2000	50016-01-01-03	15±1.8 mHz	3.62530±0.00422 s

QPO frequencies ν_{QPO} for outbursts of 1997,1998 and 2000 are obtained to be 25±2.1 mHz, 4±1.3 mHz, and 15±1.8 mHz respectively which lie within the proposed frequency range of 1 mHz to 1 Hz and their PDS with average pulsations of period of 3.65951 second (υ_{spin} = 273.26 mHz) of compact neutron star.

This process clearly indicates that QPOs deal with nuclear burning at the surface of compact object (Yu & van der Klis 2002) because surface temperature of compact object exhibits fluctuations with constant frequency and accretion rate (dm/dt) takes place between stable and unstable burning (Heger et al. 2007). The mHz QPO only occurs if burning fuel rate (dm/dt) = $(dm/dt)_{EDD}$ and if burning fuel fraction varies with time then it cannot be assumed that complete fuel was burnt during last X-ray bursts. Another theory of occurring mHz QPO is that a amount of heat flux heats the core of neutron star and develop marginally stable burning (Altamirano et al.2008). The flux below the surface layer produced due to conduction of energy during X-ray bursts pours slowly upward and hence generates stable burning on the surface of compact object. Most of thermonuclear bursts and burning on accreting compact object assume that the compact object magnetic field is very weak (Fujmoto et al. 1981; Taam 1982; Wooslety et al. 2004) because of strong magnetic field (B≥ 10^{12} G) can affect the stability of nuclear burning (Joss & Li 1980). This strong magnetic field reduces heat flux which is responsible for conduction of energy during outbursts. In number of X- ray binaries for example, 4U 1636-53 (Hasinger et al. 1989), AqlX-1 and 4U 1608-522 (Revnistev et al. 2001), 4U 1626-67 (shirakawa & Lai 2002), T5X2 (Herger et al. 2007 b), 4U 0614+091 (Zhang et al. 2012), 4U 0115+634 (Dungair et al. 2013) mHz QPO were observed.

According to magnetosphere beat frequency model, QPO frequency (υ_{QPO}) appears due to beat between spin frequency (ν_{spin}) of compact object and Keplerian frequency ($\nu_{keplr.}$) at inner accretion disk. The beat frequency at magnetosphere boundary of compact object (Alper & Shahanj 1985; lamb et al. 1985) is given by-

$$\nu_{QPO} = \nu_{spin} - \nu_{keplerian} \qquad -1$$

Due to this beat frequency plasma fluctuates and generates QPO. Using the data of ν_{spin} = 275.83 ± 8.93 mHz and υ_{QPO} to be 25±2.1 mHz, 4±1.3 mHz, and 15±1.8 mHz , we get $\nu_{keplerian}$ to be 250.83± 11.03 mHz, 271.83± 10.23 mHz, 260.83± 10.73 mHz. These $\nu_{keplerian}$ may be expressed as

$$(\nu_{keplerian})^2 R^3 = GM_n/4\pi^2 \qquad -2$$

where R is radius of orbiting warp produced in accretion disk as a QPO due to fluctuation delivered by beating process between spin of neutron star of mass M_n and Keplerian motion of accreted matter falling from companion star under gravitational pull across Lagrazian point on neutron star. Spin frequency of Low mass X-ray source GX340+0 observed to be almost same around 275.83 ± 8.93 mHz during bursts detected in the years 1997,1998 and 2000 which indicates that mass of neutron star is constant according to the principle of conservation of spin angular momentum ($I_n\ 2\pi\ \nu_{spin}$). I_n represents moment of inertia of neutron star. Right hand side of Equation -2 is constant where as on left hand side, $(\nu_{keplerian})^2$ is inversely proportional to R^3. Now estimated values of $\nu_{keplerian}$ as 250.83± 11.03 mHz, 260.83± 10.73 mHz and 271.83± 10.23 mHz decide the locations of harbored QPOs in accretion disk towards inner orbiting radii i.e 250.83± 11.03 mHz orbiting QPO is rather away from neutron star than , 260.83± 10.73 mHz QPO but QPO orbiting with 271.83± 10.23 mHz is closest to neutron star. The closest orbiting QPO would have more temperature as a result of internal friction between particles of accreted matter and hence expectedly radiates more power (number of X-rays photons emission per seconds represented by area under the peak of QPO) than which is far away from neutron star as shown in sixth column of table-3.

Table-3

S.no.	Out-burst year	$\nu_{keplerian}$ **of QPO**	QPO power [(rms/mean)²/Hz]	**Quality factor** $\nu_{Qpo}/\Delta\nu_{Qpo}$	X-ray photons radiated per seconds
1.	1997	250.83± 11.03 mHz	100±9.6	~2	3800±45.12
2.	1998	271.83± 10.23 mHz	200±11.5	≤ 2	19999.5±120.23
3.	2000	260.83± 10.73 mHz	270±12.2	≤ 1.5	15000±98.56

CONCLUSION

We Report discovery of three milli-Hertz QPOs in the X-ray bursts of years 1997,1998 and 2000 with observed frequency ν_{Qpo} of 25±2.1 mHz, 4±1.3 mHz, and

15±1.8 mHz in bright Z-source of Low mass X-ray source GX340+0 having quality factor $\nu_{Qpo}/\Delta \nu_{Qpo}$ to be ~2, ≤ 2 and ≤ 1.5 respectively. The X-rays photons radiated per second by these QPOs are observed to be 3800±45.12, 19999.5±120.23, and 15000±98.56 which are justified by the different values of radius of the Keplerian orbits where temperature is decided by the inter layer friction between orbiting particles of accreted matter. The size of the radius is inversely proportional to the $(\nu_{keplerian})^{2/3}$ and plasma interaction energy determines the power of QPOs. QPOs near neutron star delivers more power than which are apart in accretion disk. Such phenomenon usually are observed in low mass X-rays binaries and harbor most of the time milli-Hertz QPOs. These mHz QPOs occur due to thermonuclear burning on the surface of celestial compact X-ray binaries. The flux below the surface of neutron star produced due to conduction of energy during X-ray bursts pours slowly upward and hence generates stable burning on the surface of compact object. These types of mHz QPOs appear in weak magnetized X-ray source because strong magnetic field compresses conduction of heat flux below the core of neutron star.

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