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Research Paper

Detection of Cyclotron Frequency ~5Mhz in The Low Mass X-Ray Pulsar 4U 1608-522

Physics

KEYWORDS :

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ABSTRACT

We report the detection of cyclotron frequency at ~5 mHz in bright low mass x-ray binary 4U1608-522 using data from the Rossi x-ray Timing Explorer (RXTE) observatory. The observation used in present work were carried for all sky monitoring in TJD 10093 – 15841 (1996 January 06 – 2011 October 06) and for power density spectrum TJD 14467 4:03:30:062 – 14467 4:35:05:062 (2008 January 01 – January 02). During all sky monitoring we observe five major outbursts, first during November 1997, second during August 2002, third during July 2005, fourth during September 2008 and fifth during July 2011. Apart from first outburst, RXTE/ASM show that source was to exhibit outbursts after approximately 3 years. The analysis showed that cyclotron frequency 5 milliHertz was produced by the amount of hot plasma of moles 65.07 – 108.93 i.e. between 3.91 x10^{25} and 6.55 x 10^{25} particles falling on the pulsar of unexpected immense magnetic field estimated to be the order of 1.61 - 2.695 x 10^{10} Tesla using the Chandrasekhar Mass limit 1.39 M_o and Oppenheimer-Volkoff limit 1.5 – 2.5 M_o respectively.

INTRODUCTION:

The X-ray binaries divide into two different classes, (i) High mass X-ray binaries (Mass of companion star ≥ 10 M_o) and (ii) Low mass X- ray binaries (Mass of companion star ≤ 1 M_o), where M_o is the mass of sun M_o ~ 1.99X10^{30}kg (Van paradijs et al. 1995). A low mass X-ray binary (LMXB) in a celestial compact X-ray binaries accretes material from companion star via Roche lobe overflow (Kippenhahn & Weigert et al. 1967; Tauris & van den Heuvel et al. 2006). 4U1608-522 is bright low mass X-ray binaries (LMXB) with a primary neutron star (Belian et al. 1976) and detected by UHURU and OSO-7 in 1971-73. It is an X-ray transient (Barret et al. 2005) and prototypical light frequency QPO source. This source exhibits type I outburst (Belian et al. 1976) because of thermo-nuclear flashes on the surface of neutron star. Type I bursts were confirmed with HAKUCHO and EXOSAT observation (Murakani et al 1980; White et al. 1984.). The quasi periodic oscillation of pulsar in about ~83 MHz between the 4-6 and 11-17 KeV bands (Vaughan et al. 1998). Along with type I burst it also exhibits super-bursts which occur in system with the neutron star for at last 10 years (kuulkers et al. 2004) but these phenomena not seen in every system. The major outbursts observed is ~4x10^{37} erg/second for distance of 3.6 kpc and hence this distance is estimated from a number of bursts which give a clear idea of photosphere radius expansion (Nakamura et al. 1989, Zhang et al. 1996) first detected its hard burst in low state i.e. 20-100 keV with the BATSE/ CGKO.

OBSERVATIONS AND DATA ANALYSIS:

RXTE was launched on December 30, 1995 and decommissioned on January 5, 2012. The main purpose of timing study of celestial compact X-ray binaries is to make vast contribution to understand high-energy astrophysics. RXTE has been three instruments –the proportional counter Array (PCA), the High energy X-ray Timing Experiment (HEXTE), and the All sky Monitor (ASM). We have used RXTE observation of low mass x-ray binary (LMXB) 4U1608-522. The observation were taken 2008 Jan 01 to 2008 Jan 02 for power density spectrum and 1996 Jan 06 to 2011 October 06 for all sky monitor (ASM). The all sky monitor (ASM) was sensitive in (1.5-12) keV energy range (Levine et al. 1996). The PCA which was consisting of five Xenon filled proportional counters was sensitive in 2-60 keV energy range. The effective area, energy resolution and time resolution of PCA were ~6500 cm^2 at 6 keV ≤ 18% at 6 keV and 1 μs, respectively. The third instrument HEXTE was operating in 15-250 keV energy range (Rothschied et al. 1998). We analyzed data from all PCA and were the standard 1 data with time resolution of 0.125 second in the present analysis. Data reduction was carried out by using the software package FTOOLS while data analysis filtered by using HEA soft package (version 6.16).

The RXTE/ASM light curve of low mass X-ray binary 401608-522 from 1996 Jan 06 to 2011 October 06 is shown in figure 1. During this time period five major outbursts were detected.

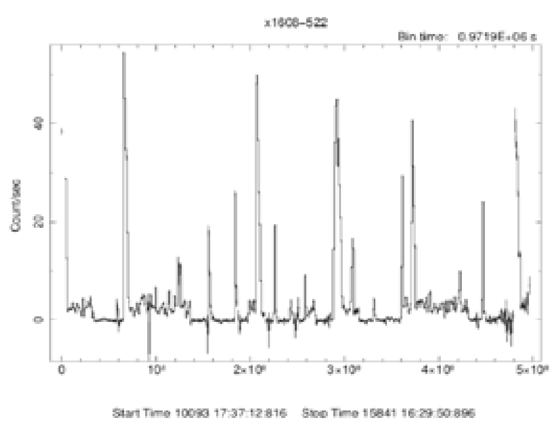

Figure 1. EXTE/ASM light curve of low mass x-ray binary 4U1608-522in 1.5-12 keV energy range from 1996 January 06 (TJD 10093) 2011 October 06 (TJD). During this period major five major outbursts were detected in the ASM light curve. First outbursts during November 1997, second during August 2002, third during July 2005, fourth during September 2008 and fifth during July 2011.

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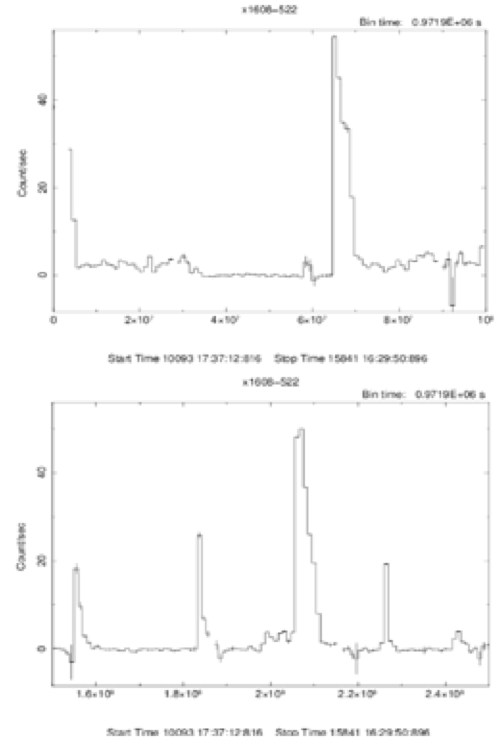

Figure 2 RXTE/ASM light curve of x-ray binary 4U1608-522shows first and second outburst first outburst during 1997 November (upper panel), Second outburst during 2002 August (lower panel).

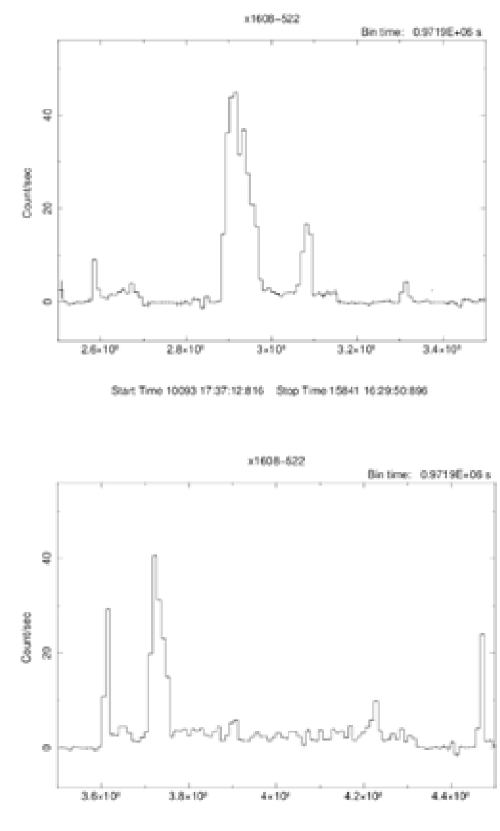

Figure-3 RXTE/ASM light curve of x-ray binary 4U1608-522 shows third and fourth outburst third outburst during 2005 July (upper panel), fourth outburst during 2008 September (lower hand panel).

It is observed that average ASM count rate during first Outburst occur at ≈55 count/sec on November 1997, while other four outbursts occur at ≈40 count/sec on August 2002, July 2005, September 2008, July 2011 respectively. In this work we also analyze data recorded by the PCA on board RXTE on 2008 Jan 01 (ObsID-93408-01-27-05).

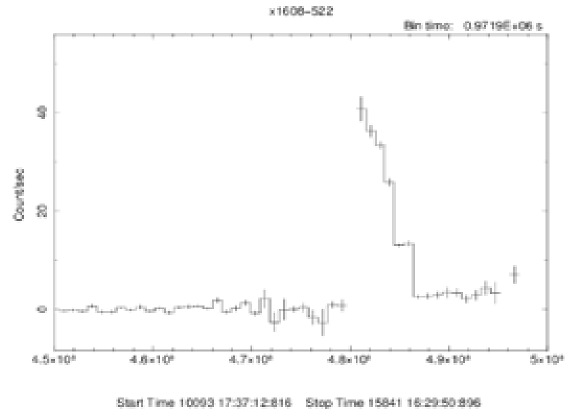

Figure 4 RXTE/ASM light curve of x-ray binary 4U1608-522 shows fifth outburst during 2011 July.

To produce power density spectrum we were use powspec FTOOLS. PDS draw between power and frequency and normalized to estimate while noise level. PDS was then examined for presence of cyclotron frequency.

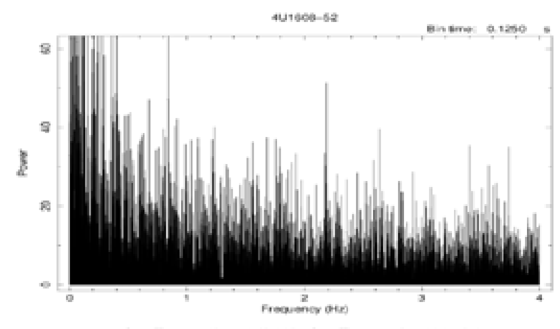

Figure5. The power density spectrum of LMXBs 4U 1608-522 obtained from RXTE/PCA observation on 2008 January 01 with bin size 0.1250 second.

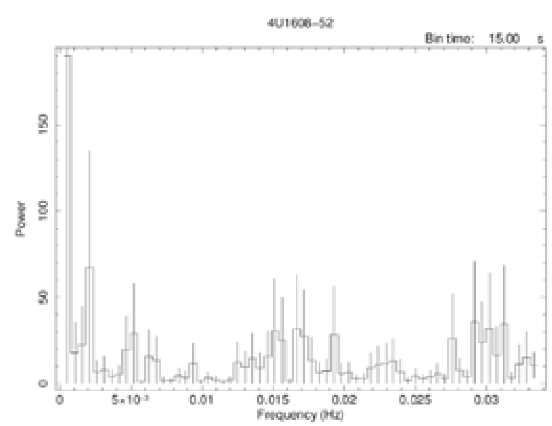

Figure6. The power density spectrum of LMXBs 4U 1608-522 obtained from RXTE/PCA observation on 2008 January 01 with bin size 15.00 Second clearly indicate cyclotron frequency~5milliHz.

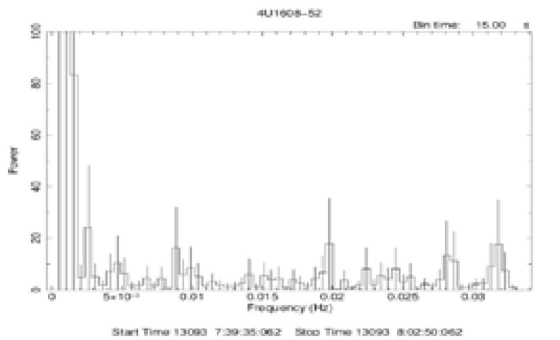

Figure-7: The power density spectrum of LMXBs 4U 1608-522 obtained from RXTE/PCA observation on 2000 January 10 with bin size 15.00 Second clearly indicate cyclotron frequency~5mHz.

RESULTS AND DISCUSSION

We have demonstrated cyclotron frequency (~5mHz) of source 4U1608-522. The observation were obtained on date 2008 January 01 as well as 2000 January 10. The energy of highly magnetized plasma and therefore resonant scattering of plasma take place in the X-ray binaries. In most of the transient pulsar, cyclotron lines were observed. For examples, in the case of Her-1 in 1976 (Truemper et al. 1978), cyclotron lines detected in 16 accreting pulsars (Makishima et al. 1999; Heindl et al. 2004). In 1608-522 pulsars the cyclotron frequency ~5mHz detected which is powerful tool to provide the magnetic field of compact x-ray binaries. Various compact X-ray binaries in which cyclotron energy lines have been detected. For examples 4U0115+64 (wheaton et al. 1979), 41907+09 (Makishima ey al. 1992), 4U 1538-52 (clark et al. 1990), 4U 1626-67 (Heindl et al. 1999), EXO 2030+375 (Wilson et al. 2008), LMC X-4 (La Barbera et al. 2001).

The magnetic field is the evidence of cyclotron frequency of X-ray binaries (Kreykenbohm et al. 2004) and clearly seen cyclotron frequency f =5milliHertz which may be justified by following formula

$$B = 2\pi\mu_o \, Na\, n\, f\, m / q \qquad - (1)$$

Where B be the magnetic field of the compact star (Neutron star with order of $B = 10^{12}$G) surrounded by the accretion disk of particles of mass m having charge state q and with number of particles measured in terms of moles n. (Na = Avogadro number= number of particles per mole, therefore number of particles N = Na n). As per phenomenon known for binaries comprising of normal star and compact star of very high gravitational potential starts attracting matter. The matter of accretion disk from normal star falls on to the compact star which allows to rise the internal temperature of the order $T=10^8$ Kelvin and surface temperature $T=10^6$ Kelvin (Yakovlev & Pethick et al. 2004)due to internal friction among the revolving matter. It is sufficient to ionize the atoms and to disintegrate the nuclei into nucleons. The complete matter is in the form of quite hot plasma comprising of protons, neutrons and electrons. Neutrons are neutral and fall directly on to the compact star along the magnetic lines of force because of the magnetic moment -1.95 μ_n associated with it. The protons and electrons do not fall directly but cycle around under the influence of the magnetic field of compact star producing cyclotron frequency. In falling matter as such enhances the magnetic field of the neutron star and depends upon the amount of moles n enter into the compact star. Energy emission in the form of bursts of radiation in the range of X-rays pulsation comes from gravitational potential energy of in falling matter on to the neutron star.

Now putting the value of the observed cyclotron frequency f = 5 milli Hertz, Na = 6.02×10^{23} , m = 1.67×10^{-27} kg and q = 1.6×10^{-19} Coulomb we get expected value of magnetic field to be

$$B = n\mu_o (1.97 \times 10^{14})$$

$$B = n (2.47 \times 10^8) \text{ Tesla} \qquad -(2)$$

In classical model of magnetic field of neutron star, the Magnetic field B can be derived with the analogy of the sphere of volume V filled with N number of aligned neutrons having tiny magnetic moments of μn along with the axis of magnetic field as

$$B = N\mu_o (\mu_n / V) \qquad -(3)$$

Where N can be expressed as N = Na Mn /Atomic weight. Mn is the mass of the neutron star with unity atomic weight of neutrons. The value of magnetic moment of neutron is $\mu_n = -9.66 \times 10^{-27}$ J/T, now the formula in classical model for the magnetic field becomes as

$$B = 13.89 \times 10^{-4} \mu_o (M_n / R^3) \text{ Tesla} \qquad -(4)$$

The mass of neutron star can vary between currently accepted value of Chadrashekar Mass limit 1.39 times the solar mass (2.765×10^{30} kg above which electron degeneracy pressure in the stars core is insufficient to balance the star›s own gravitational self-attraction. Consequently, white dwarfs with masses greater than the limit would be subject to further gravitational collapse evolving into neutron star) and Oppenheimer-Volkoff limit M_{ov} = 1.5 – 2.5 times the solar mass (critical mass above which a neutron star cannot be maintained against gravity). This critical mass exerts the extreme pressures which cause electrons to combine with protons to form neutrons. Thus, any star which collapses to such an extent that its radius becomes significantly less than that characteristic of a white-dwarf is effectively transformed into a gas of neutrons. Eventually, the mean separation between the neutrons becomes comparable with their de Broglie wavelength (Sean Carroll, 2007). At this point, it is possible for the degeneracy pressure of the neutrons to halt the collapse of the star. A star which is maintained against gravity in this manner is called a neutron star. Thus, we know that neutrons stars satisfy the mass-radius law:

$$R / R_\Theta = 1.1 \times 10^{-5} (M_\Theta / M)^{1/3} \; -(5)$$

It follows that the radius of a typical solar mass neutron star is a mere 10km (Hawking, S.W. et al. 1989). A more realistic calculation, which does not assume constant density, does not treat the neutrons as point particles, and takes general relativity into account, gives a somewhat lower value of

$$M_{ov} = 1.5 - 2.5\, M_\Theta \qquad -(6)$$

A star whose mass exceeds the Oppenheimer-Volkoff limit cannot be maintained against gravity by degeneracy pressure, and must ultimately collapse to form a black-hole (Hans A. Bethe and Gerald Brown, 2003). Now from equations (4) and (5) we get

$$B = 13.89 \times 10^{-4} \mu_o (M_n / R^3)$$

$= 131.07 \times 10^4 (Mn^2 / M_\Theta \; R_\Theta^3)$

$= 0.390 \times 10^{-20}(M_n^2 / M_\Theta)$ Tesla -(7)

Now using the Chandrasekhar Mass limit 1.39 times the solar (2.765×10^{30} kg) and Oppenheimer-Volkoff limit 1.5 – 2.5 times the solar mass in equation (7), the values of B are turned out to be 1.61×10^{10} Tesla and 2.695×10^{10} Tesla respectively (Mazzali, P. A.; Röpke, F. K.; Benetti, S.; Hillebrandt, W. ,2007.). On comparing these values with equation (2) ,the number of moles of accretion infalling matter on Neutron star from normal companion star are in the range of 65.07 – 108.95 i.e. between 3.91×10^{25} and 6.55×10^{25} particles in the form neutrons are received.

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REFERENCES:

1. Barret.D, Vaughan. S., 2005, APJ, 746, 131
2. Belian, R.D., Conner, J.P., & Evants, W.D. 1976, APJ, L135
3. Clark, G.W., Woo, J.W., Nagase, F., Makishima, K., & Sakau,T.,1990,APJ,353,274
4. Hans A. Bethe and Gerald Brown, 2003 , How A Supernova Explodes in Formation And Evolution of Black Holes in the Galaxy: Selected Papers with Commentary, New Jersey: World Scientific: 2003. pp. 51–62.
5. Hawking, S.W. 1989,. Three hundred years of gravitation (1st pbk. ed., with corrections. ed.). Cambridge [Cambridgeshire]: Cambridge University Press. ISBN 0-521-37976-8.
6. Heindl, W.A., Chakrabarty, D.,1999, in Highlight in X-ray astronomy, ed. B. Aschenbach & M.J. Freyberg,25
7. Heindl,W.A., Rothschild,R.E., Coburn,W.,Staubert,R.,Wilms,J.,Kreykenbo hm,I., and Kretschmar,P., 2004, in AIP conf. Proc. 714,
8. Kippenhahn, R., Weigert, A., 1967, Zeitschrift fur Astrophysik, 65,251
9. Kuulkers, E. 2004, Nucl. Phys. Proc. Suppl., 132, 4
10. Kreykenbohm, I., Wilms, J., Coburn,W., et al. 2004, A&A, 427,975
11. La Barbera, A.,Burderi, L., Di salvo, T., Iaria, R., & Robba, N.R.2001, APj, 553,375
12. Levine A.M., Bradt H., Cui W., Jernigan J.G., Morgan E.H., Remillard R., 1996,APJ,469,L33
13. Makishima, K., Mihara, T., 1992, in Frontiers science series, et. Y. Tanaka & K. koyana,23
14. Makishima,K.,mihara,T.,Nagase,F.,Tanaka,T.,1999,APJ,525,978
15. Mazzali, P. A.; Röpke, F. K.; Benetti, S.; Hillebrandt, W. ,2007. "A Common Explosion Mechanism for Type Ia Supernovae". Science (PDF) 315 (5813): 825–828.
16. Murakani, T. et al. 1980, APJ. (letter), 240, L143
17. Nakamura, N., Dotani, T., Inoue., 1989, PAST,41,617
18. Rothschild R.E. et al., 1998, APJ, 496, 538
19. Sean Carroll, 2007 , Dark Matter, Dark Energy: The Dark Side of the Universe, Guidebook Part 2(, Cal Tech , The Teaching Company) page 44.
20. Tauris, T.M., van den Heuvel, E.P.J., 2006, Formation and evolution of compact steller X-ray sourves, p. 623
21. Truemper,J.,Pitsch,W.,Reppin,C.,Voges,W.,Ataubert,R.,Kendziorra,E.,197 8,APJ,219,L105
22. Van Paradijs J., Clintock J.E., Lewin, W.H.G., van den Heuvel, E.P. 5, 58-121 (1995)
23. Vaughan, B.A., Vander klis, M., Mendez, M., 1998, APJ, L509, L145
24. Wilson,C.A.,Finger,M.H., & Camero – Arranz, A.,2008,APJ, 678,1263
25. Wheaton, W.A., Doty, J.P., Primini, F.A., et al. 1979, Nature, 282,240
26. White,N.E., Kaluziensky,J.L., & Swank,J.H.,1984, In AIP conf.Proc. 115,High transient in Astrophysics,ed. S. Woosley (New Yark; AIP),31
27. Yakovlev, D.G., & Pethick,C.J.,2004, ARA&A, 42,169
28. Zhang, S.N., Harmon, B.A., Paciesas, W.S., 1996, A&AS, 120,279