

Determining the neutron star surface magnetic field strength of two Z sources

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Abstract. From the extreme position of disk motion, we infer the neutron star (NS) surface magnetic field strength (B_0) of Z-source GX 17+2 and Cyg X-2. The inferred B_0 of GX 17+2 and Cyg X-2 are $\sim(1-5)\times 10^8$ G and $\sim(1-3)\times 10^8$ G, respectively, which are not inferior to that of millisecond X-ray pulsars or atoll sources. It is likely that the NS magnetic axis of Z sources is parallel to the axis of rotation, which could result in the lack of pulsations in these sources.

Keywords. Compact object, Neutron star, Accretion disk

1. Introduction

The neutron star (NS) surface magnetic field strength (B_0) could be a critical parameter responsible for the behaviors of NS X-ray binaries (NSXB). However, it is difficult to measure B_0 directly. Nevertheless, it is feasible to estimate B_0 from some observable phenomena, such as quasi-periodic oscillations (QPOs) (e.g. Fock 1996) or “propeller” effects (e.g. Zhang *et al.* 1998), or inferred from theoretical models (Zhang & Kojima 2006). From previous studies, it is believed that B_0 is larger in Z sources than in atoll sources (ref. Fock 1996, Zhang *et al.* 1998, Chen *et al.* 2006, Ding *et al.* 2011) or millisecond X-ray pulsars (ref. Cackett *et al.* 2009, Di Salvo & Burderi 2003). Unlike in millisecond X-ray pulsars or atoll sources, pulsations have never been observed in Z sources, why?

2. Method and Data Analysis

As discussed by Zhang *et al.* (1998), during the regular accretion state the inner disk radius (R_{in}) of an NSXB, which is equal to the magnetospheric radius (R_{m}) (Lamb *et al.* 1973), will vary between the radius of the innermost stable circular orbit (ISCO) and the corotation radius (R_{c}). Therefore, assuming $R_{\text{in}} = R_{\text{c}}$, we will get the upper limit of B_0 , because more magnetic pressure is needed to push the accretion disk further, having

$$B_{0, \text{max}} = 1.5 \times 10^{12} \left(\frac{\dot{M}_{\text{in}}}{\dot{M}_{\text{Edd}}} \right)^{1/2} \left(\frac{M_{\text{ns}}}{1.4 M_{\odot}} \right)^{5/6} \left(\frac{R_{\text{ns}}}{10^6 \text{ cm}} \right)^{-3} f^{-7/6} \xi_1^{-7/4} \text{ G}, \quad (2.1)$$

where f is the NS spin frequency and ξ_1 is a coefficient in the range of 0.87–0.95 (Wang 1995). Similarly, letting $R_{\text{in}} = R_{\text{ISCO}}$, we will obtain the lower limit of B_0 , because less magnetic pressure is needed to balance the gas pressure from the disk, getting

$$B_{0, \text{min}} = 2.8 \times 10^8 \left(\frac{\dot{M}_{\text{in}}}{\dot{M}_{\text{Edd}}} \right)^{1/2} \left(\frac{M_{\text{ns}}}{1.4 M_{\odot}} \right)^2 \left(\frac{R_{\text{ns}}}{10^6 \text{ cm}} \right)^{-3} \xi_1^{-7/4} \text{ G}. \quad (2.2)$$

With software HEASOFT 6.11 and FTOOLS V6.11, we use the *RXTE* observations made during Oct. 3–12, 1999, a total of ~ 297.6 ks for GX 17+2 and those during Jul. 2–7, 1998, a total of ~ 42 ks for Cyg X-2 to perform our analysis. We divide the track on the hardness-intensity diagrams (HIDs) into some regions and then produce the spectrum of each region. XSPEC version 12.7 is used to fit the spectra with spectral models. From the spectral fitting parameters, we calculate mass accretion rates. Then, with the known NS mass and radius, making use of the above equations, we calculate the limits of B_0 .

3. Result and Discussion

With mass accretion rates and $f_{\max} = 584$ Hz for GX 17+2 and $f_{\max} = 658$ Hz for Cyg X-2 (Yin *et al.* 2007), we infer the limits of B_0 and get $(1 \leq B_0 \leq 5) \times 10^8$ G and $(1 \leq B_0 \leq 3) \times 10^8$ G for GX 17+2 and Cyg X-2, respectively, which are higher than the reported $B_0 \sim (0.3 - 1) \times 10^8$ G of atoll source Aql X-1 (Zhang *et al.* 1998), compatible with $B_0 \sim (1 - 5) \times 10^8$ G of accreting millisecond X-ray pulsar SAX J1808.4–3658 (Di Salvo & Burderi 2003), but lower than $B_0 \sim (1 - 3) \times 10^9$ G of the first transient Z source XTE J1701-462 (Ding *et al.* 2011) or $B_0 \sim (1 - 8) \times 10^9$ G of Cir X-1 (Ding *et al.* 2006).

Since the B_0 of Z sources is not inferior to that of millisecond X-ray pulsars or atoll source, pulsations should have been observed in the former, as in the latter. However, pulsations have not been detected in Z sources, why? Pringle & Rees (1972) proposed that the NS pulsation emission would depend on the shape of emission cone, the orientations of the magnetic and rotation axes, and the line of the sight, and, furthermore, Lamb *et al.* (1973) suggested that the detected pulsation could be resulted from the condition that the NS magnetic axis does not coincide in direction with the axis of rotation. Therefore, it is likely that the NS magnetic axis of Z sources is parallel to the axis of rotation, or the orientation of the rotation axis is in agreement with the line of the sight, any of which could result in lack of pulsations in these sources.

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