High-mass X-ray Binaries: Illuminating the Passage from Massive Binaries to Merging Compact Objects
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Firm detection of 7-year X-ray periodicity from X Persei

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Abstract. We report on the detection of long-term X-ray periodicity from the Be/X-ray binary pulsar X Persei. Based on over 23 years of X-ray data observed using RXTE/ASM, Swift/BAT and MAXI/GSC, we confirmed that X Persei exhibits quasi-periodic X-ray flares with a period of ∼7 years. The recurrence timescale corresponds to approximately 10 times its binary orbital period of 250 days. Spectral and hardness ratio changes were not detected along with long-term periodic activity. If we interpret the observed 7 year periodicity of X-ray band flux as a superorbital modulation, then this would be the first observation among the Be/X-ray binaries.

Keywords. pulsars:individual(X Persei), X-rays:stars

1. Long-term X-ray and optical variations

X Persei (X Per or 4U 0352+309) is a classical persistent Be/X-ray binary composed of a slowly rotating X-ray pulsar ($P_{spin} \sim 835$ second; Yatabe *et al.* 2018) and (09.5III-B0Ve) optical companion (HD 24534; Lyubimkov *et al.* 1997). This source was independently discovered by Ariel 5 and Copernicus (White *et al.* 1976). Delgado-Marti *et al.* (2001) reported that the binary system has an orbital period of ~ 250 days, a projected semi-major axis of the neutron star of $a_x \sin i = 454$ lt-s, and a moderate eccentricity of $e = 0.11$.

Unlike general Be/X-ray binaries, X Per does not show a normal X-ray outburst at periastron due to mass accretion from the circumstellar disc of the Be star (e.g. Reig 2011); however, it has been observed that its X-ray flux has increased at a rate of approximately twice every 7-years since 2003. This “superorbital” modulation with a 7-year period is clearly evident in Figure 1(a). Interestingly, the time interval between the 2003 X-ray flare and the 1975 event also exhibited a 7-year repetition. Furthermore, it was confirmed that all of the decrease timescales in three X-ray flares have same time duration (∼250 days). In contrast to the X-ray flux modulation, the hardness ratios did not exhibit clear variations as shown in Figure 1(b).

Figure 1(c) and 1(d) show the long-term fluctuations of the optical brightness and Hα equivalent width (EW). As already reported in previous studies on Be/X-ray binaries (e.g. A0535+26; Yan *et al.* 2012), there is a correlation between the Hα EW and the X-ray flux. Based on this figure, we can confirm that a clear X-ray flux and Hα EW

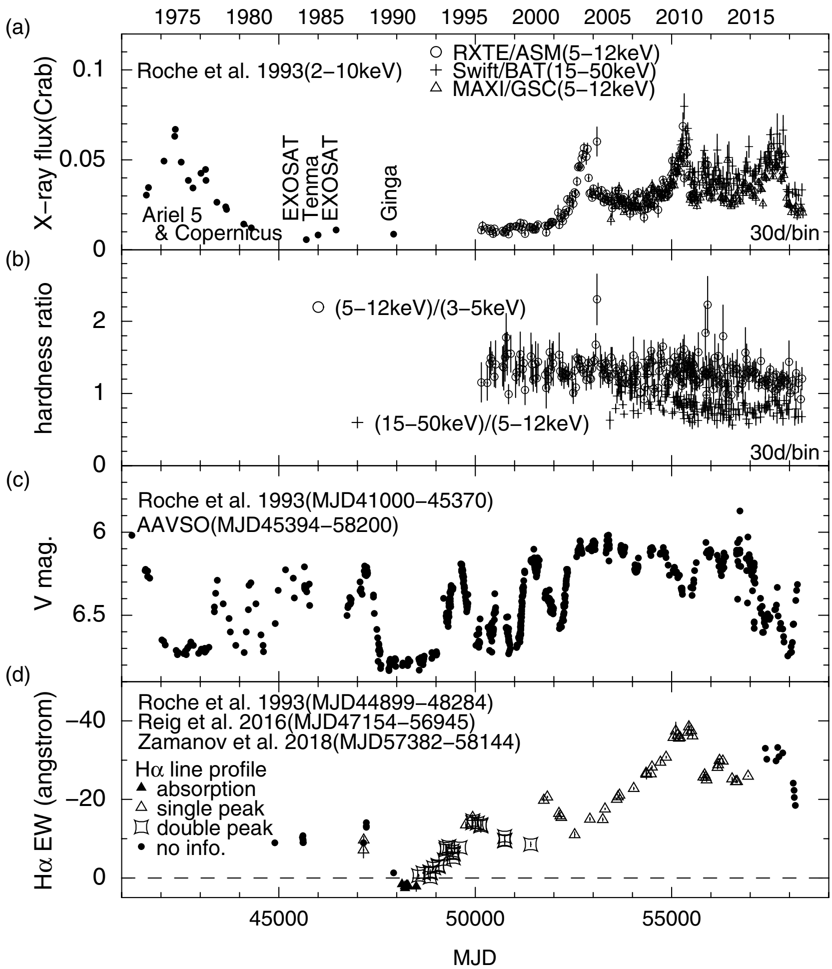

Figure 1. Long-term X-ray flux, hardness ratio, V-band magnitude and Hα equivalent width (EW) history.

correlation, and an anti-correlation between the optical brightness and X-ray flux was evident during the 2010 and 2017 X-ray flare event. As to the X-ray flux and Hα EW variation, Zamanov *et al.* (2018) reported that the correlation is probably due to wind Roche lobe overflow. However, an optical - X-ray correlation was not observed for the 2003 flare.

2. Period Search

In order to determine the superorbital periodicity, an epoch folding χ^2 search was performed on combined 5-12 keV RXTE/ASM and MAXI/GSC data. As a result, the superorbital modulation period was determined to be 2441 ± 83 d (6.7±0.2 yr). This period corresponds to 10 times the binary orbital period. The 5-12 keV light curves were folded over 2441 d, with phase 0 set at the flux maximum at MJD 52800 as shown in the left panel of Figure 2.

3. X-ray spectral analysis

Since the pulse-phase resolved spectroscopy results and the orbital modulation of X Per have already been discussed in several papers (e.g. Lutovinov *et al.* 2012;

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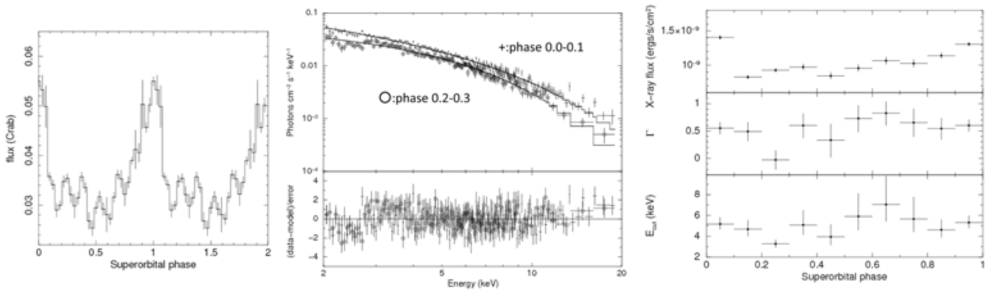

Figure 2. (left) The 5–12 keV light curve folded over the 2441 d superorbital period. (center) The unfolded X-ray spectra of X Per showing the different superorbital phase data. (right) Valiability of 2–20 keV flux, photon index of power-law with exponential cutoff, and cutoff energy over the superorbital period. The errors quoted in this panel are 90% confidence level.

Maitra *et al.* 2017; Yatabe *et al.* 2018), our analysis is focused on X-ray spectrum variability in superorbital modulation. We utilized the 2-20 keV data obtained by the MAXI/GSC (MJD 55058–58331) which covers 1.3 superorbital cycles. The data were divided into 10 phase resolved groups separated by 0.1 phase bins.

Firstly, we attempted to fit each data using a power-law model with an exponential cutoff. This model can be successfully applied to all the superorbital phase resolved data. The center panel of Figure 2 shows the representative spectra extracted from the 0.0-0.1 and 0.2-0.3 superorbital phase. The right panel of Figure 2 shows the dependence of the spectral parameters on the superorbital phase. Systematic parameter changes over the superorbital period were not observed.

In addition, we also examined the results extracted from other models (e.g. black-body plus power-law). However, we did not identify any phase dependent changes of the spectral parameters, such as black-body temperature or column density.

4. Conclusions

We investigated the superorbital variabilities with 6.7 years periodicity observed from X Per. This represents the first detection of superorbital modulation in X-rays among the Be/X-ray binaries. The modulation in the prototypical system (e.g. Her X-1; Kotze & Charles 2012) is caused by the precessing of the warped Be disc. Thus, a large variation of column density is expected. However, no such modulations could be confirmed based on our analyses. Therefore, we consider that the long-term periodicity seen in X Per is related to the variation of the mass accretion rate caused by an unknown mechanism.

In general, there are two accretion schemes in X-ray binaries; wind capture and disk accretion. In the case of wind-capture accretion in supergiant high-mass X-ray binaries, Corbet & Krimm (2013) discussed the relation between their modulation and the geometry of binary systems and determined that the superorbital period is proportional to the binary orbital period. In contrast, as claimed by Yatabe *et al.* (2018), X Per has a disk accretion scheme similar to that of the other Be/X-ray binaries. Thus, the variation of the mass-transfer rate from a circumstellar disc to a neutron star is the cause of the periodic superorbital modulation. Laplace *et al.* (2017) predicted that Kozai-Lidov oscillation might produce a periodic giant X-ray outburst. If this oscillation is present in X Per, then the oscillation would be ≥ 20 years, which is significantly longer than the observed modulation period. Consequently, another scenario is needed to explain the superorbital modulation in Be/X-ray binaries. Further discussions will be presented in a forthcoming paper.

References

Corbet, R. H., & Krimm, H. A. 2013, *ApJ*, 778, 45
Delgado-Marti, H., Levine, A. L., Pfahl, E., & Rappaport, S. A. 2001, *ApJ*, 546, 455
Kotze, M. M., & Charles, P. A. 2012, *MNRAS*, 420, 1575
Laplace, E., Mihara, T., Moritani, Y., Nakajima, M., Takagi, T., Makishima, K., & Santangelo, A. 2017, *A&A*, 597, 124
Lutovinov, A., Tsygankov, S., & Chernyakova, M. 2012, *MNRAS*, 423, 1978
Lyubimkov, L. S., Rostopchin, S. I., Roche, P., & Tarasov, A. E. 1997, *MNRAS*, 286, 549
Maitra, C., Raichur, H., Paradhan, P., & Paul, B. 2017, *MNRAS*, 470, 713
Reig, P. 2011, *Ap&SS*, 332, 1
Reig, P., Nersesian, A., Zezas, A., Gkouvelis, L., & Coe, M. J. 2016, *A&A*, 590, 122
Roche, P., Coe, M. J., Fabregat, J., McHardy, I. M., Norton, A. J., Percy, J. R., Reglero, V., Reynolds, A., & Unger, S. J. 1993, *A&A*, 270, 122
White, N. E., Mason, K. O., Sanford, P. W., Murdin, P. 1976, *MNRAS*, 176, 201
Yan, J., Li, H., & Liu, Q. 2012, *ApJ*, 744, 37
Yatabe, F., Makishima, K., Mihara, T., Nakajima, M., Sugizaki, M., Kitamoto, S., Yoshida, Y., & Takagi, T. 2018, *PASJ*, 99Y
Zamanov, R., Stoyanov, K. A., Wolter, U., Marchev, D. 2018, *arXiv:1811.09162*

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