Indications for a long-term periodicity in EXO 2030+375

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Abstract

The X-ray source EXO 2030+375 (spin period: 42 s; orbital period: 46.021 d) is known for being the Be X-ray binary system showing the largest number of recurring low-luminosity X-ray outbursts (type I) every orbital period. Recent changes in the source behavior, which include a fading of the X-ray flux and a torque reversal in 2016, were found to be very similar to events which occurred 20.5yr earlier, just before the source experienced a sudden shift of the orbital phase of the outburst peak (orbital phase jump) in 1995 (Wilson et al. 2002). Moreover, the observation that the type II outbursts observed in 1985 (Parmar et al. 1989) and 2006 (Corbet et al. 2006) occurred at times just in-between these events lead to the interpretation that the source has a cyclic behavior with a time-scale of 21 or 10.5 yr. In our previous paper (Laplace et al. 2017), we predicted the future behavior of the source depending on two possible interpretation. Here, we report the observation of an orbital phase shift in July 2016 which confirms the prediction and supports the existence of a 21 yr periodicity of the source behavior, which is best explained by Kozai-Lidov oscillations of the circumstellar disk.

Key words: stars: individual: EXO 2030+375 –stars: neutron, emission-line, Be – X-rays: binaries

1. Introduction

EXO 2030+375 was discovered in 1985 (Parmar et al. 1989) and is characterized by an orbital period of 46.02 d and a spin period of 42 s (Wilson et al. 2002). It is composed by a neutron star and a BO Ve companion (Coe et al. 1988) and as such belongs to the class of Be/X-ray binaries. These sources are characterized by a transient X-ray radiation, which is divided into two characteristic types: (i) type I outburst, which typically occur every orbital period and are understood as the accretion of matter from the companion star at periastron, (ii) type II outbursts, very luminous outbursts which can last for several orbital periods. Their origin remains unclear, with accretion of large amounts of matter from a warped and eccentric disk surrounding the Be star the most likely candidate (Okazaki et al. 2014; Martin et al. 2014a).

2. Recurrent behavior

In Laplace et al. (2017), we investigated the relationship between recent changes in the source behavior and similar events in 1995. The source had recently shown an unusual drop in X-ray flux and a change from a steadily increasing spin frequency to a constant spin frequency (Fuerst et al. 2016). We noticed that the type II outbursts observed in 1985 (Parmar et al. 1985) and 2006 (Corbet & Levine 2006) were occurring at peculiar times, just in between the drops in flux and spin frequency derivative. The data suggested a recurrence of about 21 years with alternating particular events (orbital phase shifts and type II outbursts) every 10.5 years.
After studying possible interpretations for this phenomenon, we found that the time-scale of Kozai-Lidov oscillations predicted for EXO 2030+375 nicely matched a 10.5 period between negative orbital phase shifts and giant outbursts. Based on this interpretation, we predicted the observation of a giant outburst or of an orbital phase shift around 2016 December, depending on the Be disk state (highly eccentric or highly inclined with respect to the orbital plane). Here, we present observations of an orbital phase shift in June 2016 (first reported in Laplace et al. (2016)), which confirm our prediction and indicate that there is indeed a recurrent pattern in the source.

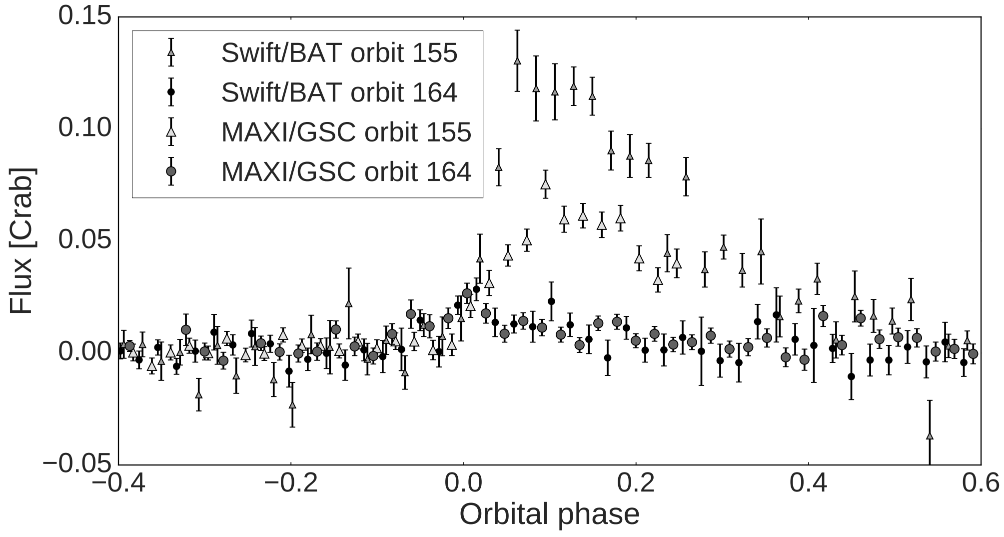

Fig. 1. Folded MAXI/GSC and Swift/BAT light-curve of EXO 2030+375. See text for more information.

3. Observation of an orbital phase shift

Data for our observations were obtained from MAXI/GSC and Swift/BAT, which are publicly available. The outburst occurred earlier than expected. We folded the light-curve with the orbital period and observed a shift of the outburst peak of about 4.3 days, as shown in Fig. 1. The peak of the outburst was attained on 2016 July 20, 5 days earlier than the almost constant peak time of the last 7 years. In terms of the orbital phase, the peak of the outburst shifted from an orbital phase of 0.13 to 0.015. It is interesting to notice that the phase shift was in the same direction as the one in 1995, that is, earlier than the previous peak time. The orbits are calculated starting from the time of the first periastron passage of the source observed by the RXTE/ASM sattelite, MJD 50086.967.

3.1. Discussion and Conclusion

In our previous work, we predicted the observation of an orbital phase shift or of a type II outburst, depending on the interpretation used for the recurrent behavior. The observation of an orbital phase shift was predicted in the case of recurrent Kozai-Lidov oscillations in the circumstellar disk and the observation we report here confirms this prediction. However, it does not constrain the oscillation time-scale discussed in our previous work, since such an observation was expected for both an eccentric, low-density disk and a highly inclined disk.

The fact that the orbital phase shift occurred much earlier than what we expected can be explained by the large uncertainty of our estimation and by the fact that simulations of Kozai-Lidov oscillations in hydrodynamical disks (Martin et al. 2014b; Fu et al. 2015) have shown that the oscillations can vary depending on various parameters, including the disk viscosity, the disk warp and the disk tilt, leading to a different time-scale of the oscillations. However, the time-scale of Kozai-Lidov oscillations calculated in our previous work suggest that orbital phase shifts occur when the disk is highly eccentric. Optical and infrared observations are needed to verify the disk state. To obtain and analyze these data constitutes our next challenge.

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