The ionization instability driven outbursts in 4U 1630-472

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We show that two outbursts observed in X-ray lightcurves of the transient source, 4U 1630-472, can be well explained by an accretion disk instability mechanism. The instability is caused by hydrogen partial ionisation in the outer part of the disk. When the unstable front moves toward the central object, classical outburst appears with duration from 30 up to 400 days.The shape of an outburst can be very regular like fast rise exponential decay profile (FRED) very characteristic for ionisation instability mechanism or irregular suggesting that, beside FRED, additional flickering occurs. We use the model which predicts time dependent evolution of ionisation instability in an accretion disk around black hole, assuming viscosity parameter to be proportional to the gas pressure. As a result, modelled lightcurves fit to the observed RXTE lightcurves, indicating that disk instability occurs in this source. For both outbursts we obtain the same black hole mass of the compact object M = 4 $M_\odot$.

1 Observations

Soft X-ray transients (SXTs) are the subclass of accreting low-mass X-ray binaries (LMXB) and they spend most of their lifetime in quiescent state as the faint sources. Those objects can be discovered only during outburst phase when they become one of the brightest sources in the X-ray sky. SXTs include neutron star or black hole as a central object, and K-type subgiant or dwarf as a secondary star. Typical timescales of outburst are: reccurence time of 0.5-50 yr, rise and decay of an outburst of 2-10 and even to 30-50 days respectively (Mineshige & Wheeler, 1989). Characteristic peak luminosity of SXT is 10^{38} erg s^{-1}(Tanaka, 1992) and in quiescence state the luminosity goes down to the 10^{33} erg s^{-1} or even less (Wu et al., 2010). We have found examples of FRED-type outbursts in the X-ray light curves of black hole binaries, obtained by *Rossi X-Ray Timing Explorer* (RXTE) satellites. In this paper we present data and careful modelling of black hole candidate 4U 1630-472, which is known for X-ray outbursts that repeat within 600–690 days (Jones et al., 1976; Parmar et al., 1995). Black hole mass of the system is currently unknown, but the distance to system amounts 10 kpc (Dunn et al., 2011). The distance measurement error was not specified so we assume that it is 10% of the given value. The data are taken by RXTE/ASM starting from 20.02.1996, but selected outbursts occured in Feb. 1998 and Nov. 2000. Parameters for two parts of lightcurves considered by us are presented

Name	Outburst [MJD]	Total duration [days]	Rise [days]	Max. [days]	Decay [days]
a	50850	110	20	8	82
b	51850	100	25	15	60

Table 1: Observed parameters of 4U 1630-472 two FRED type outbursts taken from RXTE ASM data. In column named Outburst, the information of the beginning of an outburst in the form of starting date is given.

in Tab. 1 and marked as *a* and *b* respectively. In data reduction we have used standard HEASOFT ftools[1] described in (Blackburn, 1995).

2 Ionisation Instability

The disk ionisation instability mechanism (Osaki, 1974) is most likely responsible for X-ray novae outbursts . This type of instability is caused by partial ionisation of hydrogen which occurs in unstable zone located in outer parts of an accretion disk. As a result of instability, disk begins to oscillate between two states: hot and partially ionised state at high local accretion rate, and cold and neutral state of low local accretion rate (for review see: Lasota, 2001). Viscous parameter is crucial in determining instability cycle. To properly explain discovered outburst we need to assume the existence of two viscosity parameters (α_{hot} and α_{cold}) (Smak, 1984). Parameter α_{hot} forms timescale of an outburst and α_{cold} is responsible for separation between outbursts. Difference between both parameters determines the amplitude of an outburst (Janiuk & Czerny, 2011). The timescale of this cycle activity strongly depends on primary star mass (Janiuk et al., 2004). In case of 4U 1630-472 we consider black hole mass in the range between 3 and 15 $M_{\odot}$ as an input to model computations.

3 Model

We compute time evolution of an accretion disk taking into account ionisation instability. As first, we calculate the stability curve i.e. the sequence of local solutions of the disk vertical structure, plotted on the surface density temperature plane (the effective temperature is equivalent to the local accretion rate). For our study, we performed calculations for disks with different chemical compositions in order to find the best stability curve which can produce outbursts that fit to observed data. In the previous work, we have shown that stability curve depends on helium and metalicity abundance (Bagińska et al., 2014), therfore we assume solar abundance in ruther modelling. In the next step, this curve is used for solution of radial time dependent equation of motion, producing final total light curve. Results of modelling strongly depend on outer mean accretion rate, viscosity parameters and mass of the central object. In our models we use opacity tables of Alexander (Alexander et al., 1983) and Seaton (Seaton et al., 1994). For 25 black hole masses from 3 to 15 $M_{\odot}$ and 12 mean accretion rates (from 10^{-9} to 10^{-7} $M_{\odot}$ yr^{-1}) we generated the set of lightcurves showing the behaviour of outbursts caused by ionisation instability. A constant viscosity model does not represent properly the observed amplitudes of outbursts in many sources (see Janiuk et al., 2004, and references therein) and therefore we model the instability using different viscosity parameters in the cold and hot states for the disk ($\alpha_{hot} = 0.1$ and $\alpha_{cold} = 0.01$). For every observed source we have obtained 1800

[1] http://heasarc.gsfc.nasa.gov/ftools/

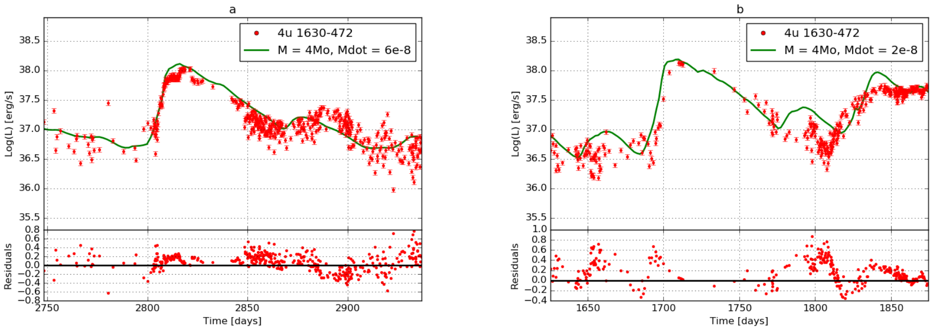

Fig. 1: Theoretical lightcurves (green solid line) fitted to the RXTE observational points (red dots) for two outbursts which occured in 4U 1630-472. Left and right panels show *a* and *b* outbursts from Tab. 1, respectively.

models.

4 Results and conclusions

In Fig. 1 we present the best fitted model to observational data for two outbursts of 4U 1630-472. Black hole mass of this object was previously unknown. After fitting process we chose best fitted models with χ^2 of 0.540668 in *a* and 0.694891 in *b* outburst, which gave us the same mass of M = 4 $M_\odot$ for both outbursts. Also accretion rate has exact range (6 x 10^{-8} $M_\odot$ yr^{-1} and 2 x 10^{-8} $M_\odot$ yr^{-1}) during both outbursts in 4U 1630-472. We can assume that our fit is consistent with accepted black mass range (for galactic X-ray binaries). According to the obtained data we conclude that our method allows us to estimate the mass of the central object and accretion rate in the outer part of the disk. This modelling also shows that the ionisation instability is very good explanation for the outbursts in examined source. We can also state that change of the chemical composition (higher amount of metals abundances) explains the stochastic variability pattern. We plan to examine more sources in the forthcoming paper.

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