Long-term processes in soft X-ray transients

Vojtěch Šimon

Astronomical Institute, AS CR, 25165 Ondřejov, Czech Republic

The thermal-viscous instability of the accretion disk is thought to lead to large outbursts in soft X-ray transients (SXTs). The long-term evolution of the resulting X-ray emission is little studied. We show the long-term behavior of selected neutron star (NS) SXTs and their importance for astrophysics. We also show that the peak mass accretion rate onto the NS in the individual outbursts of GRS 1747-312 is considerably more stable than in two other similar systems, Aql X-1 and 4U 1608-52. In Aql X-1 and 4U 1608-52, the amount of the acreted matter largely varies for the individual events while the outburst recurrence time T_C varies on a significantly longer time scale. The conditions in the disk allow the cyclic modulation of T_C to show itself in GRS 1747-312. The activity of the donor in GRS 1747-312 is translated into variations of T_C via interaction of the magnetic field of the spots on the donor with the magnetic field of the disk. We also show that KS 1731-260 is a fascinating example of the time evolution of a system with a unique configuration of the disk, i.e. a thermally stable inner region surrounded by a thermally unstable outer annulus.

1. Introduction

• A sufficiently low time-averaged mass transfer rate dm_{tr}/dt in some low-mass X-ray binaries (LMXBs) leads to the thermal instability of the disk, which manifests as outbursts (e.g. King & Ritter 1998, Dubus et al. 2001). Such LMXBs are called soft X-ray transients (SXTs).

• The observed activity of SXTs mainly depends on the mass accretion rate onto the compact object, dm_C/dt, disk viscosity, magnetic field strengths... A search for the common features of the activity requires a formation of an ensemble of SXTs with a sufficient number of outbursts covered.

2. Observations and data analysis

The 1.5-12 keV ASM/RXTE and 15-150 keV BAT/Swift data. The ASM data were fitted by the code HEC13 written by Harmanec (1992) (based on the method of Vondrák 1969, 1977). Method of the O-C residuals (e.g. Vogt 1980, Šimon 2000, 2002) enables us to determine the recurrence time of outbursts, T_C, and to study its variations even if some outbursts were missed due to the gaps in the data.

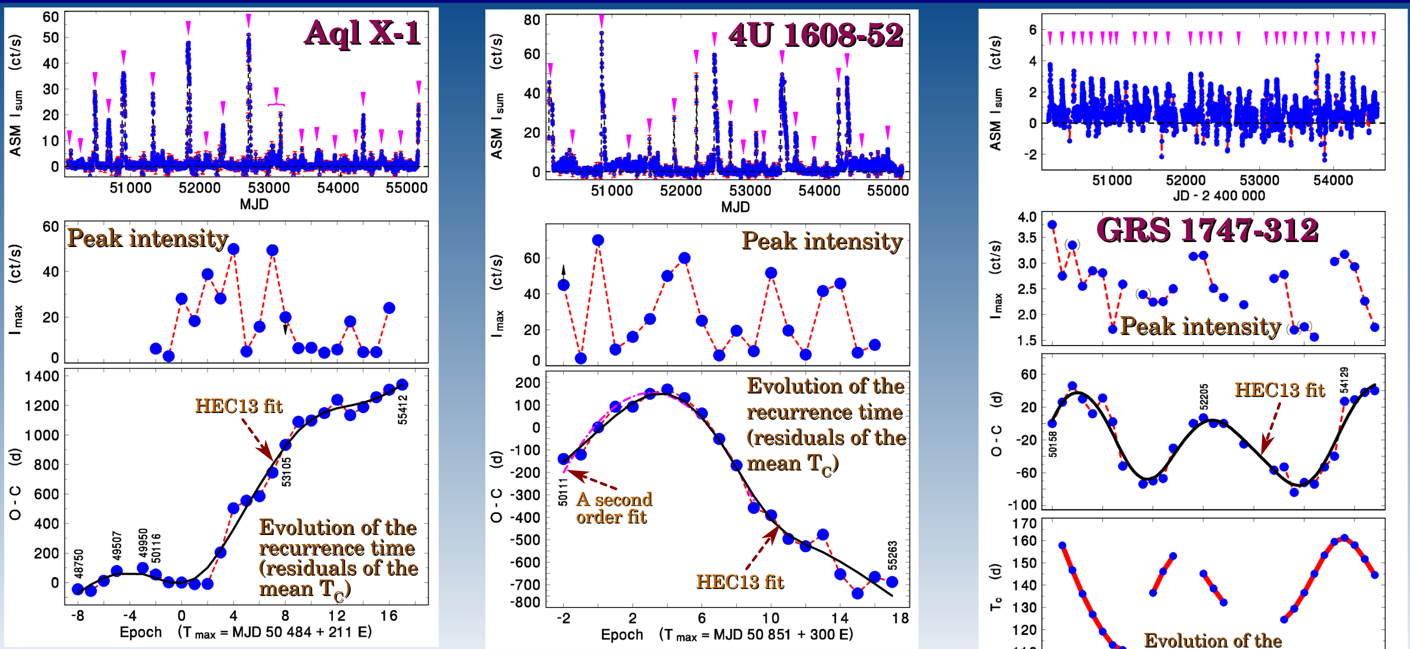

Fig.1: The long-term X-ray light curves (one-day means of ASM data). Triangles: maxima of the outbursts. Evolution of the peak intensity I_{max} of the outburst. O-C diagram of the recurrence time T_C of outbursts. Also the evolution of T_C determined from the O-C diagram is shown for GRS 1747-312.

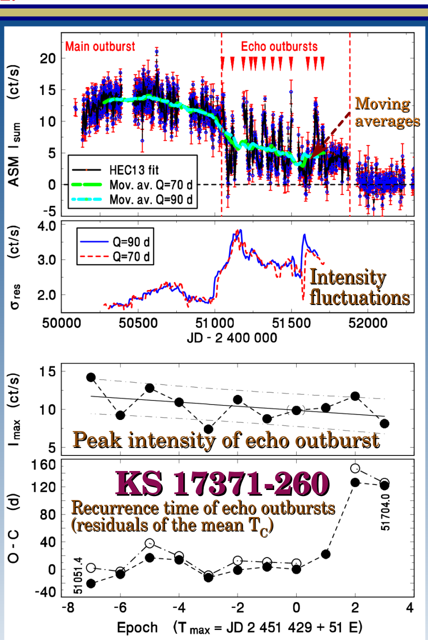

Fig.2: Segments of the outburst. Notice the rapid increase of the scatter of the light curve, $sigma_{res}$, when the echo outbursts started. Time evolution of the parameters of the echo outbursts determined from HEC13 fits. The O-C diagram for the evolution of the echo outbursts.

3. Discussion

• We find that the variations of the recurrence time of outbursts, T_C, in the ensemble of SXTs are large, but not chaotic, and long-term trends can be clearly distinguished. The amplitude of the outburst-to-outburst fluctuations of T_C is significantly smaller than that of the long-term evolution of T_C. The individual outbursts in a given SXT thus depend on each other.

• T_C shows occasional jumps and/or cyclic variations, which is not explicable by the evolutionary processes in the system. The behavior of T_C in SXTs is quite similar to that in dwarf novae (e.g. Vogt 1980, Šimon 2000).

• Large variations of the peak intensity I_{max} of outburst can be explained if the amount of mass accreted onto the neutron star largely varies for the individual outbursts in a given SXT (they are much greater than what can be explained by the changes of the absorption of X-rays).

• The fact that T_C evolves more gradually than I_{max} can be explained if the outburst is triggered near the inner edge of the disk and if the conditions in this inner disk region are decisive for the mass density and distribution in the beginning of the subsequent outburst. Strong evidence that the disk is not considerably depleted in outburst can be mainly found in 4U 1608-52.

• We find clearly cyclic variations of T_C in GRS 1747-312. The most intense outbursts occur near the phase of the longest T_C during its ~5.4 yr cycle. Nevertheless, their peak intensities are more stable than in Aql X-1 and 4U 1608-52.

• Parameters of the subgiant donor in GRS 1747-312 are consistent with the spectral type late FIV to early KIV (in't Zand et al. 2003, Takeda 2007), hence magnetic dynamo and cycles of stellar activity are expected. In this framework, the site of the variations of T_C is located in the donor star. Variations of the disk viscosity in quiescence or efficiency of the removal of the angular momentum from the disk by external force can play a great role. Interaction of the disk's magnetic field with that of the spots on the donor can provide the coupling mechanism, as modelled by Meyer-Hofmeister et al. (1996).

• On the remarkable system KS 1731-260 we show that a slowly decaying soft X-ray luminosity of the prolonged main outburst smoothed in time is the key factor that governs the presence or absence of the echo outbursts. They started abruptly and a large fraction of the outer part of the disk was rapidly brought out of steady-state (see model by King & Ritter 1998).

• Peak luminosity of the echo outbursts in KS 1731-260 is comparable to that of the late phase of the main outburst. This speaks in favor of the outside-in outbursts.

• The relatively smooth profile of the O-C curve, with the amplitude of the superimposed fluctuations being significantly smaller than that of the long-term profile, suggests that the individual echo outbursts in KS 1731-260 are dependent on each other. The non-uniform time evolution of T_C and the parameters of the echo outbursts cannot be explained by acting of a single one-way process. We interpret it in terms of variations of the disk viscosity between them.

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