Why can soft X-ray transients remain in the low/hard state during outburst

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A few transient sources do not display the transition to the soft state during the outburst. We show how these exceptions can be understood.

§1. Introduction

Our investigation focuses on the understanding of the spectral state transitions in transient black hole X-ray binaries. The changes between a low-hard and a high-soft spectral state can be understood as resulting from accretion in form of a hot coronal flow/ADAF or via a disk in the innermost region. The spectral transitions allow to learn about the accretion flow in these binaries and also around supermassive black holes since the physics is the same in these objects of very different extension.

§2. Accretion in X-ray binaries

Now 18 confirmed black hole binaries are established, for a detailed description see the recent reviews (Charles and Coe 2003, McClintock & Remillard 2003). In X-ray transients the gas flows from the low mass secondary star via a disk towards the black hole. In quiescence the gas is accumulated in a cool disk, the mass flow rates in the disk are low, in the inner region the accretion is advection-dominated and the spectrum is hard. When the outburst is triggered by the disk instability the mass flow rate increases and usually the thin disk reaches inward to the innermost stable orbit, the spectrum changes to a soft multi-color black body spectrum. Those changes from hard/low to soft/high state and back are observed for several black hole transient and persistently bright X-ray binaries (and also for neutron stars binaries). Surprisingly a few transient sources remain in the low/hard state during outburst, best observed for XTE J1118 and GRO J0422.

§3. Comparison of peak luminosity and critical accretion rate

The amount of mass accumulated in the accretion disk during quiescence determines the peak mass flow rate in outburst. We investigated the mass accumulation in disks of classical X-ray novae (Meyer-Hofmeister & Meyer 1999, 2000). The amount of gas accumulated until the outburst starts depends on the disk size (larger for larger disks) and on the black hole mass (a larger black hole mass causes a more extended inner coronal flow/ADAF region and more gas has to be accumulated for triggering the outburst). The dependence on the mass overflow rate is weak (compare Fig.3 Meyer-Hofmeister & Meyer 2000, systems with long recurrence time).

We use these results for disk evolution during quiescence to evaluate the maximal mass flow rate in the hot disk in outburst (standard relation, viscosity parameter $\alpha = 0.2$). We assume that all gas accumulated then flows towards the black hole. We show the corresponding peak luminosities in Fig.1. With the now established black hole mass in A0620-00, the curve corresponding to half the disk mass seems more appropriate. The critical accretion rate is the maximal rate which can evaporate from the cool disk into the corona (Meyer et al. 2000) (gray area in Fig.1). Only if the mass flow rate in the disk exceeds this rate the disk can extend down to the last stable orbit. Then the spectrum becomes a multi-zone black body spectrum.

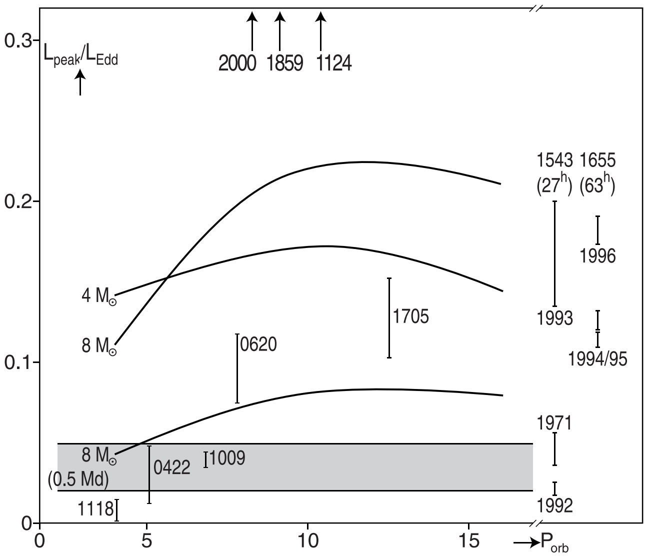

Fig. 1. Solid lines: theoretically determined peak luminosities in outburst, observed values for LMXBs from Chen et al. (1997), recent data added, black hole masses from McClintock & Remillard (2003), error bars from uncertainty in black hole masses; gray area: critical luminosity for spectral state transition: if the peak luminosity is lower the system is expected to remain in the hard state

As shown in Fig.1 the binaries with short orbital period have the low mass flow rates and might not reach the soft spectral state. This agrees well with the fact that XTE J1118 and GRO J0422 remain in the hard state during outburst. An interesting question is why some systems have accumulated so much gas. This cannot be caused by a high overflow rate, rather points to a low viscosity.

References

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