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Feedback of type-I bursts to the XRB disc-corona system

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Type-I X-ray bursts are thermonuclear explosions on the surface of neutron stars. Intense soft X-ray emissions are observed during type-I X-ray bursts, which are expected to interact with the accretion flow around the neutron stars. In the low state it is believed that there are some hot plasmas (so-called "corona") surrounding the neutron stars, which may be cooled under the shower of soft X-rays coming from type-I bursts. Therefore, the type-I X-ray burst is a unique probe into the accretion disc-corona system. Up to date, the hard X-ray shortage and fast recovery during the evolution of bursts are discovered in 6 sources, which will shed lights on the origin of the corona.

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1. Introduction

Low mass X-ray binaries (LMXBs) consist of a compact (neutron star or black hole) and a low mass companion star. The former accretes mass from the latter and forms an accretion disc, during which the gravitational potential energy is converted into X-ray radiation [3, 4]. The LMXBs are known to display distinct spectral states according to the variation of their accretion rate during the evolution of an outburst. At the high accretion rate state (hereafter referred to as the high state), the spectrum is usually dominated by thermal components, which is believed to result from the accretion disc or the surface of the neutron star. And at the low accretion rate state (the low state), significant non-thermal hard X-ray can be observed, which is thought to originate from the corona or the jet [5]. A jet would also show up in the radio band. Considering that the black hole binaries are $\sim$30 times louder in radio than neutron stars, it is believed that the non-thermal X-rays in neutron stars are mainly dominated by the corona [17]. Although the concept of the "corona" (i.e., a hot gas flow radiating inefficiently) has been widely used to model spectral states and connect between the accretion disc and jets, the intrinsic mechanism of these coronae still remain poorly understood. In theory, they can result from evaporation mechanism [16, 5, 6] or magnetic re-connection mechanism [22, 15].

Previous observations of the evolution of the corona were mainly in the outburst transitions, of which the time-scale is days or months. During the transition from the low state to the high state, the hard X-rays diminish gradually, which is explained as the cooling of the corona by the increasing soft photons coming from the accretion disc. And vice versa, during the transition from the high state to the low state, the hard X-rays recover, which is believed as the reheating of the corona. In this report, we introduce another source of soft photons—type-I X-ray burst that can influence the corona but with much a smaller time scale. Type I X-ray bursts are thermonuclear explosions on the surface of NSs other than releasing the gravitational potential-energy. They manifest as a rapid increase in soft X-ray intensity, followed by powerlaw or exponential decay. The time-scale of type-I bursts is $\sim$ tens to hundreds of seconds. This means that type-I X-ray bursts can be regarded as a finer probe to study the corona.

The spectrum of bursts is a diluted blackbody spectrum with a characteristic temperature $\sim$ 2-3 keV [19]. And the spectrum of the corona can be modeled as a powerlaw spectrum with a cutoff of several tens of keV. This means the hard X-rays (i.e. above 30 or 40 keV) are dominated by the corona and are influenced little by the bursts. Thus, the hard X-rays can be regarded as a clean probe to describe the intensity of the corona. The pioneer research was reported in Aql X-1 [14]. Maccarone & Coppi (2003) found a hard X-ray shortage during a type-I burst at a significance of about 2 σ. After *Rossi X-Ray Timing Explorer*'s (RXTE) 15 years observation, more than 1000 X-ray bursts were found, which allows us to study it statistically. Chen et al. (2012) first stacked the bursts and found a significant hard X-ray shortage during bursts in the low state of IGR J17473–2721 [1]. Subsequently, similar results were reported in other five atoll sources, i.e., 4U 1636–536, Aql X–1, GS 1826–238, 4U 1705–44, and KS 1731–260[8, 2, 9, 11]. In this report, we mainly summarize these recent findings.

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2. Observations and results

The main breakthrough in probing the possible hard X-ray shortages performed by Chen et al. (2012) is to stack a large amount of bursts from an atoll source. The Event mode data of pointing observations carried out by *RXTE* Proportional Counter Array (PCA) were used to search for the possible hard X-ray shortages because of its unparalleled effective area. In practice, they first tried to extract the net lightcurves of the bursts in the low state in the 2–10 keV and 30–50 keV bands with a time resolution of 1 s. Note that in the high state the corona is too weak to detect possible shortages statistically. They used the time when the burst reached its peak at 2–10 keV as a reference to stack the lightcurves. They found significant diminishment and recovery of hard X-rays along with the evolution of the bursts, which can be explained as the cooling and reheating of the corona. Subsequently, the similar results are reported in other 5 atoll sources, i.e., 4U 1636–536, Aql X-1, GS 1826–238, 4U 1705–44, and KS 1731–260[8, 2, 9, 11]. As an example, figure 1 shows the result in GS 1826–238, in which the hard X-ray shortage is most significant. We also note that there are several sources that have significant persistent hard X-rays, but their hard X-ray storages during bursts are undetected. One possibility could be that, bursts with high temperature would contribute un-negligible hard X-ray while bursting to dilute the expected shortage. An additional possibility is that the corona may be located too far away from the neutron star to be effectively cooled off by the bursts. Another possibility could be that persistent hard X-rays do not result from the corona [9].

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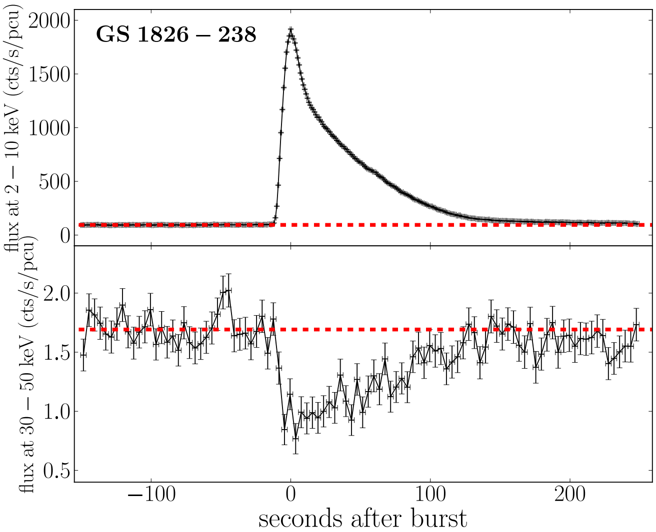

Figure 1: The hard X-ray shortage in GS 1826–238 [11]. In other sources the shape of light curves is similar.

Figure 1 clearly shows that the shortage of the hard X-rays follows the variable burst intensity in a dynamical time scale. The cross-correlation can be calculated to estimate the time delay between these two lightcurves. For the sources having hard X-ray shortages their time delays are summed up in a Figure 2. It is interesting that all the time delays are of seconds regardless of their different luminosities and properties of outbursts. An average over all the 6 sources gives a mean time delay of about 2.43 ± 0.63 seconds This result seems to suggest that in different sources the physical process dominating the corona production is similar, hence shedding a light on the so far unknown mechanism by putting a constraint on the theoretical model. In theory, evaporation models [16, 5, 6] are usually used to explaining the behavior of the corona evolution in long-term outbursts in a viscous heating scenario, which has a typical time scale of larger than hours for corona formation. Thus they should find a non-viscous process to explain the reheating of the corona. Alternative to the evaporation models, the corona can also be formed through magnetic reconnection process, in which the time scale is dynamical time scale that is similar to above results [16, 5, 6].

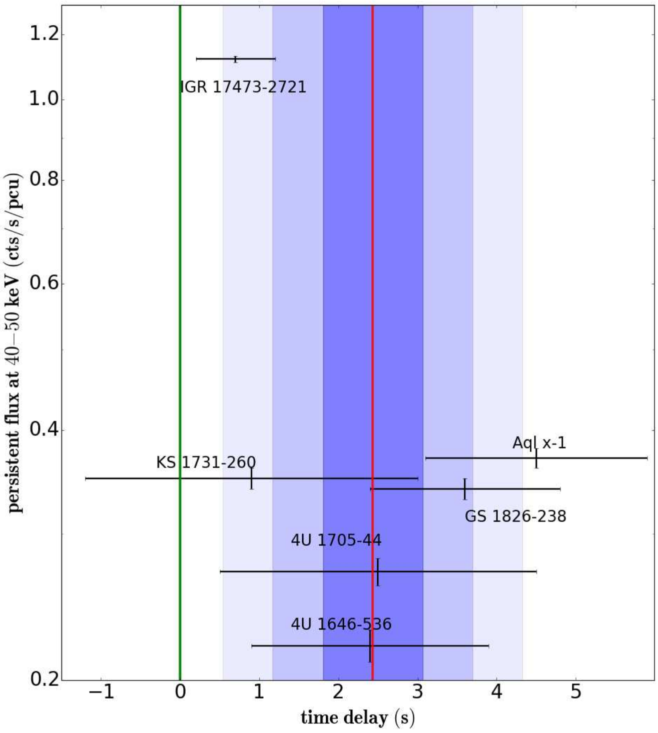

Figure 2: The time delay versus the hard x-ray persistent flux. The average of the time delay is about 2.43 seconds (the red line) and the blue colors show three regions covered by taking an error of 1 σ, 2 σ and 3 σ, respectively. A zero time delay is denoted with the green line.

3. Outlook

In this report, we concentrate on the variable hard X-ray lightcurves during the type-I bursts. We found that the corona can be cooled by the shower of soft x-rays emitted by the bursts and recovered to the initial level in the tails of bursts. The short time delay of $\sim$ seconds between the soft and hard lightcurves can be used to restrict the formation mechanism of the corona. However, we note that the detailed processes between the burst photons and the corona are very complex and so far still poorly known. Worpel et al. (2013) proposed that the persistent emission intensity would be enhanced during photospheric radius expansion bursts[20]. Subsequently, the enhanced persistent emission were reported in many papers [7, 18, 13, 12, 10]. The burst duration is usually

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very short, preventing us from studying the coronal spectra directly. Recently Keek et al. (2014) analyzed the data of a superburst (a rare burst having very long duration), and they found both the enhanced persistent emission and the decreased electron temperature in the corona, which is consistent with the hard X-ray shortage mentioned above [13]. In order to increase the statistics, we should find a proper way to stack the spectral information of different bursts for studying the evolution of the persistent spectrum in a broad energy band. And also the numerical simulation may play an important role in studying the interaction between the bursts and the corona surrounding neutron stars. In the future, the X-ray instruments that have much larger effective areas than the *RXTE*/PCA at hard X-rays, such as Chinese *Hard X-ray Modulation Telescope (HXMT)*[21, 23], may allow direct probing the fine details of the microscopic processes in the accretion and corona formation by observing the interplays between type-I X-ray bursts and the rapid spectral evolution of LMXBs.

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