Mixed H/He bursts in SAX J1748.9–2021 during the spectral change of its 2015 outburst

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ABSTRACT

SAX J1748.9–2021 is a transiently accreting X-ray millisecond pulsar. It is also known as an X-ray burster source discovered by Beppo-SAX. We analysed the persistent emission and type-I X-ray burst properties during its 2015 outburst. The source varied from hard to soft state within half day. We modeled the broad-band spectra of the persistent emission in the (1 – 250) keV energy band for both spectral states using the quasi-simultaneous INTEGRAL and Swift data. The broad-band spectra are well fitted by an absorbed thermal Comptonization model, assuming in a slab geometry. The best-fits for the two states indicate significantly different plasma temperature of 18 and 5 keV and the Thomson optical depth of 3 and 4, respectively. In total, 56 type-I X-ray bursts were observed during the 2015 outburst, of which 26 detected by INTEGRAL in the hard state, 25 by XMM-Newton in the soft state, and 5 by Swift in both states. As the object transited from the hard to the soft state, the recurrence time for X-ray bursts decreased from $\approx 2$ to $\approx 1$ hr. The relation between the recurrence time, $\Delta \text{rec}$, and the local mass accretion rate per unit area onto the compact object, $\dot{m}$, is fitted by a power-law model, and yielded as best fit at $\Delta \text{rec} \sim (\dot{m})^{-1.02\pm0.03}$ using all X-ray bursts. In both cases, the observed recurrence times are consistent with the mixed hydrogen/helium bursts. We also discuss the effects of type-I X-ray bursts prior to the hard to soft transition.

Key words. pulsars: individual SAX J1748.9–2021 – stars: neutron – X-ray: binaries – X-ray: bursts

1. Introduction

Neutron stars (NSs), in low mass X-ray binaries (LMXBs), accrete matter from their companion stars, forming an accretion disk (Frank et al. 2002). The accreted matter on the NS surface can trigger thermonuclear flashes, called type-I X-ray bursts (see e.g., Lewin et al. 1993). The burst spectra are described by a blackbody with peak temperatures reaching $kT_{\text{bb}} \approx 3$ keV, and with a gradual softening due to the cooling of the NS photosphere (see Lewin et al. 1993; Strohmayer & Bildsten 2006; Galloway et al. 2008 for a review). The burst peak luminosity can reach the Eddington limit, $L_{\text{Edd}} \approx 2 \times 10^{38}$ erg s$^{-1}$, and the total burst energy release is of the order $\sim 10^{39}$−$10^{42}$ erg, depending on the burst type (e.g., Galloway et al. 2008).

During type-I X-ray bursts, the injected soft X-ray photons may affect the NS hot inner accretion flow or the surrounding hot corona. Indeed, a deficit has been observed at $30 – 50$ keV photons in IGR J17473–2721, Aql X-1, 4U 1636–536, and GS 1826–238, implying that the soft X-ray photons, emitted during type-I X-ray bursts, cool down the electrons producing hard X-ray emission (Chen et al. 2012, 2013, Ji et al. 2013, 2014a, 2015). The hard persistent X-ray component is thought to be derived from Comptonization in the hot corona (Chen et al. 2012, 2013). A similar study has also been performed during the hard state of the source 4U 1728–34, however, during the occurrence of type-I X-ray bursts the persistent X-ray deficit was not detected by Rossi X-ray Timing Explorer, due to the limitation of the response in hard X-ray band (Ji et al. 2014b), but confirmed by INTEGRAL (Kajava et al. 2017). The persistent emission level above 40 keV was about a factor of three lower compared with the persistent emission without burst activities (Kajava et al. 2017). Also in this case the interpretation indicates that the soft radiation injection into the accretion disk or corona may induce spectral variability during type-I X-ray bursts.
It is believed that with varying mass accretion rate the spectral changes of NSs in LMXBs follow an atoll or Z–track on an X-ray color–color diagram (CCD) (Hasinger & van der Klis 1989; van der Klis 2006). The accretion rate increases from the hard (island) spectral state, where the soft emission is much reduced and the spectrum is dominated by a power-law–like spectrum up to the energies of 200 keV, to the soft (banana) spectral state, where most of the energy is emitted below ∼ 20 keV (e.g., Barret 2001; Gierliński & Done 2002). The spectral change has been studied during type-I X-ray bursts (Falanga et al. 2006), while we study SAX J1748.9–2021, as an example to investigate if the large number of type-I X-ray bursts during its 2015 February–June outburst can trigger a spectral state change, i.e., from a persistent hard to a soft spectral state. In this paper, we report on the INTEGRAL and Swift observations of SAX J1748.9–2021. The properties of the largest set of X-ray bursts with the source in the soft and hard state are investigated.

1.1. The source SAX J1748.9–2021

The X-ray source SAX J1748.9–2021 was discovered by BeppoSAX during an outburst in 1998 (in ’t Zand et al. 1998). The source has been identified to be located within the globular cluster NGC 6440 at a distance of ≈ 8.2 kpc (in ’t Zand et al. 1999; Valenti et al. 2007; and references therein). The detection of a type-I X-ray burst associated to SAX J1748.9–2021 confirmed the source as a NS hosted in a LMXB system (in ’t Zand et al. 2001). SAX J1748.9–2021 has also been observed during its quiescent state with Chandra that identified its optical counterpart candidate (in’t Zand et al. 2001 and references therein). Altamirano et al. (2008) suggested that the companion star might be a main-sequence or a slightly evolved star with a mass ranging between (0.85 – 1.1) M⊙. Recently, the companion star has been confirmed by the Hubble Space Telescope, and it turns out to be a main-sequence star with a mass of (0.70 – 0.83) M⊙, a radius of (0.88 ± 0.02) R⊙, and a surface temperature of (5250 ± 80) K (Cadelano et al. 2017). This source has been observed in outburst in 1998, 2001, 2005, 2009 – 2010, and 2015 and classified also as an atoll source (in ’t Zand et al. 1998; in’t Zand et al. 2001; Markwardt & Swank 2005; Suzuki et al. 2009; Patruno et al. 2009; Bozzo et al. 2015; Sanna et al. 2016; Pintore et al. 2016). During both 2001 and 2005 outbursts the source showed intermittent pulsations at 442 Hz on timescales of hundreds of seconds (Gavriil et al. 2007; Altamirano et al. 2008), from which it was possible to infer the orbital period of ≈ 8.76 hr and the magnetic field of B ≥ 1.3×10¹¹ G (Altamirano et al. 2008). Therefore, this source has been classified as an accreting millisecond X-ray pulsar (AMXP; see Poutanen 2006; Patruno & Watts 2012) for reviews.

2. Observations and data

2.1. INTEGRAL

The data were obtained with INTEGRAL (Winkler et al. 2003) from 2015 February 16 to April 20, i.e., from satellite revolution 1508 to 1532 for a total effective exposure time of ∼ 856 ks. These revolutions include a public Target of Opportunity (ToO) observation for ∼ 100 ks during the revolution 1511.

We analyzed data from the coded mask imager IBIS/ISGRI (Ubertini et al. 2003; Lebrun et al. 2003), covering the 20 – 250 keV energy band, and from the two JEM-X monitors covering the 4 – 22 keV energy range (Lund et al. 2003). The observation in revolution 1511 was performed in the hexagonal dithering mode, which permits to keep always the source within both the field-of-view of IBIS/ISGRI and JEM-X. For all other revolutions, we considered all the pointings for which the source was located at a maximum off-set angle with respect to the satellite aim point of ≤ 12.0′ for IBIS/ISGRI and ≤ 2.5′ for JEM-X in order to minimize calibration uncertainties. The data reduction was performed using the standard offline science analysis (OSA) version 10.2 distributed by the ISDC (Courvoisier et al. 2003). The algorithms used for the spatial and spectral analysis of ISGRI and JEM-X are described in Goldwurm et al. (2003) and Lund et al. (2003), respectively.

In Fig. 1 we show part of the ISGRI field of view (significance map) centered on the position of SAX J1748.9–2021. The source is clearly detected in the mosaic, and we estimated a detection significance of ∼ 126 σ in the 20 – 100 keV energy range. The best determined position is δJ2000 = 17°48′52″:20 and δJ2000 = −20°21′32″:62 with an associated uncertainty of 0′/4 at 90% confidence level (Gros et al. 2003), consistent with the best determined position (Pooley et al. 2002).

Fig. 1. The IBIS/ISGRI sky image centered on SAX J1748.9–2021 in the 20 – 100 keV range of the ∼ 100 ks ToO observation. The size of each pixel is 3′.
Each burst spectrum was fitted by the model \( \text{tbabs} \) column \( \text{RAWX} \) was obtained in the range \( \text{RAWX} \) increased and decreased to 10% of its peak value above rate. The data were filtered with \( \text{FLAG} \) reduced and the last 5 ks of the data were ignored because of ton Imaging Camera (EPIC)-pn (Strüder et al. 2001) were re-standard procedure, the TIMING data from European Photon Imaging Camera (EPIC)-pn (Strüder et al. 2001) on March 4, 2015 (Obs.ID. 0748391301) continuously for about 100 ks with the first results reported in Pintore et al. (2016). We reanalysed the \( \text{XMM-Newton} \) observation to obtain each burst flux and its influence. Following the standard procedure, the \( \text{TIMING} \) data from European Photon Imaging Camera (EPIC)-pn (Strüder et al. 2001) were reduced and the last 5 ks of the data were ignored because of flaring background. The data were filtered with \( \text{FLAG}=0 \) and \( \text{PATTERN}=4 \). After the extraction of the lightcurve, for each burst, we located its start and end time at which the count rate increased and decreased to 10% of its peak value above the persistent intensity level, respectively. The spectrum of each burst was obtained in the range \( \text{RAWX}=[31:43] \) without the column \( \text{RAWX}=37 \) to reduce the pile-up effect. The persistent spectrum prior to a burst was regarded as its background. Each burst spectrum was fitted by the model \( \text{tbabs}^*\text{bbbodyrad} \), and the burst bolometric flux was calculated using the relation \( F = 1.076 \times 10^{-11}(kT_{\text{bb}}/1 \text{ keV})^4K_{\text{bb}} \text{ ergs cm}^{-2} \text{ s}^{-1} \) (Galloway et al. 2008), where \( kT_{\text{bb}} \) and \( K_{\text{bb}} \) are the blackbody temperature and normalization, respectively. The \( \text{XMM-Newton} \) data reduction and analysis was similar to the procedure described in Pintore et al. (2016). All reported fluxes are unabsorbed.

3. Outburst light curve

We report in Fig. 2 the outburst profile of SAX J1748.9–2015 from February 16 to May 2, 2015. \( \text{XMM-Newton} \) exhibited significant spectral variation during the outburst, passing from hard to soft state within \( \approx 0.5 \text{ d} \) around MJD 57079.5. The hard state lasted for the first \( \approx 10 \text{ d} \), while the soft state lasted about 50 d, until the source returned to quiescence. Most AMXPs that underwent an outburst for a few weeks to months showed a common outburst profile, i.e., the light curve decays exponentially until it reaches a break, after which the flux drops linearly to the quiescence level without exhibiting strong spectral variation (e.g., Gierliński & Poutanen 2005; Gierliński et al. 2002). However, this source is known to be an atoll source with significant flux variations between hard and soft state and showing intermittent pulsations whose origin is unclear (see e.g., Patruno et al. 2009).

4. Spectral analysis

The spectral analysis was carried out using \textit{xspec} version 12.6 (Arnaud 1996). We studied the broad-band X-ray spectrum divided in the hard and soft state, see Fig. 2. For the hard state we consider the \( \text{INTEGRAL}/\text{JEM-X} \) data starting on MJD 57078.43 for 1 ks (obs. ID. 00033646003). For the soft state we consider the \( \text{INTEGRAL}/\text{JEM-X} \) data starting on MJD 57079.5. For the soft state we consider the \( \text{INTEGRAL}/\text{JEM-X} \) data between MJD 57078.52 – 57077.82, and the quasi-simultaneous \( \text{Swift}/\text{JEM-X}/\text{WT} \) data starting on MJD 57078.43 for 1 ks (obs. ID. 00033646003). For the soft state we did not merge together the additional two close-by \( \text{Swift} \) pointings. The roll angle between the three pointings was different and the statistical quality of the first pointings we used was sufficient to perform an accurate broad-band fit. We verified a posteriori that performing the same broad-band fit with the other two \( \text{Swift} \) pointings would have resulted in similar values of the model parameters (to within the uncertainties). For all spectra the bursts intervals have been removed from the data set. For each instrument, a multiplication factor was included in the fit to take into account the uncertainty in the cross-calibration of the instruments. For all fits the factor was fixed at 1 for the \( \text{INTEGRAL}/\text{ISGRI} \) data. All uncertainties in the spectral parameters are given at a 1\( \sigma \) confidence level for a single parameter.

We fit all the combined \( \text{XRT}/\text{JEM-X}/\text{ISGRI} \) average spectra separately for the hard and soft spectral state, respectively, using first a simple and phenomenological cutoff power-law model and afterwards a physical motivated thermal Comptonization model, composed in the slab geometry (Poutanen & Svensson 1996). The later model has been used previously to fit AMXPs broad-band spectra (e.g., Gierliński et al. 2002; Gierliński & Poutanen 2005; Falanga et al. 2005b, 2007, 2009; Bragaglia et al. 2009; Falanga et al. 2011, 2012; De Falco et al. 2017b,a). The main parameters are the absorption column density, \( N_H \), the Thomson optical depth, \( \tau_T \), across the slab, the electron temperature, \( kT_e \), the temperature, \( kT_{\text{seed}} \), of the soft-seed thermal photons (assumed to be injected from the bottom of the slab), the apparent area of the seed photons, \( A_{\text{seed}} \), and cos \( \theta \) that we fixed at 0.5, where \( \theta \) is the inclination angle between the slab normal and the observer line of sight. The best-fit parameters of all models are reported in Table 1. At variance with Pintore et al. (2016) we could not find any evidence of the usskin component from the residuals of our best fit comptonization models (see also Fig. 3).

1 http://heaarc.gsfc.nasa.gov/docs/software.html.
We note that the column density between the two states changes from \(N_{\text{H}} \sim 0.5 \times 10^{23} \text{ cm}^{-2}\) to \(N_{\text{H}} \sim 0.8 \times 10^{23} \text{ cm}^{-2}\), as well as the plasma temperature, \(kT_e\), and the optical depth, \(\tau\) (see Table 1). It is remarkable how this spectral change from a hard to a soft state occurred within a half day (see Fig. 2). It is important to note that the column density between the two states changes from \(N_{\text{H}} \sim 0.5 \times 10^{23} \text{ cm}^{-2}\) to \(N_{\text{H}} \sim 0.8 \times 10^{23} \text{ cm}^{-2}\), as well as the plasma temperature, \(kT_e\), and the optical depth, \(\tau\) (see Table 1). It is remarkable how this spectral change from a hard to a soft state occurred within a half day (see Fig. 2).

### Table 1. Best fit parameters determined for the hard and soft spectral state of SAX J1748.9–2021.

| Parameter | Hard state | Soft state |
|-----------|------------|------------|
| \(N_{\text{H}} (10^{22} \text{ cm}^{-2})\) | \(0.57 \pm 0.03\) | \(0.8 \pm 0.1\) |
| \(\Gamma\) | \(1.37 \pm 0.03\) | \(1.1 \pm 0.1\) |
| \(E_{\text{cut}}\) | \(40 \pm 2\) | \(6.7 \pm 1.4\) |
| \(kT_e (\text{keV})\) | \(18.1 \pm 0.8\) | \(5.0 \pm 0.3\) |
| \(kT_{\text{seed}} (\text{keV})\) | \(0.39 \pm 0.06\) | \(0.28 \pm 0.015\) |
| \(\tau\) | \(2.9 \pm 0.1\) | \(3.8 \pm 0.5\) |
| \(A_{\text{seed}}\) | \(5000^{+1400}_{-1300}\) | \(10300^{+5000}_{-6000}\) |
| \(F_{\text{flux}} (10^{-9} \text{ cm}^{-2} \text{s}^{-1})\) | \(3.1 \pm 0.2\) | \(6.1 \pm 0.2\) |
| \(\chi^2/\text{dof}\) | 1.05/516 | 0.98/579 |

Notes. (1) Unabsorbed flux in the 0.1 – 250 keV and 0.1 – 50 keV energy range for the hard and soft states, respectively. For the cut-off-pl. model, the parameters are the photon index, \(\Gamma\), the cutoff energy, \(E_{\text{cut}}\). For the compss model, the main parameters are the Thomson optical depth, \(\tau\), across the slab, the electron temperature, \(kT_e\), the temperature, \(kT_{\text{seed}}\), of the soft-seed thermal photons and the apparent area of the seed photons, \(A_{\text{seed}}\).

### 5. The type-I X-ray bursts

SAX J1748.9–2021 is also known to be a burster source, as during its 2015 outburst 56 type-I X-ray bursts have been detected (see Fig. 2), of which 26 found by INTEGRAL/JEM-X, 5 by Swift, and for completeness we added also 25 bursts observed by XMM-Newton and reported by Pintore et al. (2016). These bursts occurred during both the hard and soft states. However, we analyzed in more detail the bursts detected during the continuous INTEGRAL ToO and XMM-Newton observations, where the bursts were separated by two distinct time intervals of around \(\Delta \tau_{\text{rec,hard}} \sim 2 \text{ hr}\) (hard state, INTEGRAL data) and \(\Delta \tau_{\text{rec,soft}} \sim 1 \text{ hr}\) (soft state, XMM-Newton data). All bursts lasted on average \(\approx 100\) s and showed a rise time of \(\sim 2 – 3\) s. The burst decay profile could be well fitted with an exponential function and the correspondingly derived e-folding time is \(\tau_{\text{fit}} = 23 \pm 3\) s, that is in agreement with the value reported by Pintore et al. (2016), estimated to be \(25 \pm 1\) s (typo in their article, private communication). We note, that all the bursts outside these two observations also showed comparable \(\tau_{\text{fit}}\) values and similar burst profiles.

The averaged flux in the 0.1 – 50 keV and 0.1 – 250 keV energy range of the persistent emission during the soft and hard states, respectively, was \(F_{\text{pers,soft}} = (5.48 – 6.13) \times 10^{-9} \text{ erg cm}^{-2} \text{s}^{-1}\) for XMM-Newton bursts and \(F_{\text{pers,hard}} = (2.88 – 3.35) \times 10^{-9} \text{ erg cm}^{-2} \text{s}^{-1}\) when INTEGRAL/JEM-X detected the bursts. The corresponding luminosities are \(L_{\text{pers,soft}} = (4.4 – 4.9) \times 10^{37} \text{ erg}\).
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For the bursts in the soft state, the total burst fluence is $f_{\text{b},\text{soft}} \approx 0.35 \times 10^{-8}$ erg cm$^{-2}$, obtained from the burst flux multiplied by the corresponding burst duration. For the bursts in the hard state, the peak flux is $F_{\text{peak,hard}} \approx 1.6 \times 10^{-8}$ erg cm$^{-2}$ s$^{-1}$, that multiplied by $T_{\text{fit}} \approx 23$ s give an estimation of the total burst fluence of $f_{\text{b,hard}} \approx 0.37 \times 10^{-6}$ erg cm$^{-2}$. We note, that these values are close to the directly measured total fluence per burst.

We can then estimate the ignition depth at the onset of the burst with the equation $y_{\text{ign}} = \frac{\alpha f_b d^2}{(1+z)} \left(4\pi R^2 Q_{\text{nuc}}\right)^{-1}$, where the nuclear energy generated for solar composition (assuming $X = 0.7$) is $Q_{\text{nuc}} \approx 1.31 + 6.95X - 1.92X^2$ MeV/nucleon $\approx 4.98$ MeV/nucleon (Goodwin et al. submitted). Note that the considered values $Q_{\text{nuc}}$ include losses owing to neutrino emission as determined by using KEPLER. Therefore we obtained $y_{\text{ign,soft}} \approx 0.59 \times 10^6$ g cm$^{-2}$ and $y_{\text{ign,hard}} \approx 0.63 \times 10^6$ g cm$^{-2}$ for the soft and hard state, respectively.

Once the ignition depth is known, the recurrence time between the bursts can be calculated by using the equation $\Delta t_{\text{rec}} = (y_{\text{ign}}/m)(1+z)$. For the soft state, we obtain $\Delta t_{\text{rec,soft}} \approx 0.81$ hr, and for the hard state we obtain $\Delta t_{\text{rec,hard}} \approx 1.6$ hr in the mixed hydrogen/helium burning case. For the pure helium burning, the predicted recurrence time is much longer. Compared with the observed recurrence time and $m$, these results confirm that the burst type is mixed hydrogen/helium with solar abundances for both the hard and soft state (see Fig. 4). In addition this can be additionally validated by the $\alpha$ value (see e.g., Ströhmayer & Bildsten[2006]). We computed the ratio of the integrated persistent flux to the burst fluence, $\alpha = \tau_{\text{rec}} F_{\text{per}}/F_b$, which are $64 \pm 10$ for the soft bursts and $60 \pm 6$ for the hard bursts. The $\alpha$-values are consistent with the mixed hydrogen/helium bursts from SAX J1748.9–2021 reported by Galloway et al.[2008].

If the anisotropy of the persistent and burst emission, i.e., with a factor of $\xi_p$ and $\xi_b$ respectively, are considered, it will introduce several consequences (see He & Keek[2016] and references therein). The local accretion rate ($\dot{m}$) should be multiplied by the factor $\xi_p$, however, it will not effect the obtained power-law index of the $\Delta t_{\text{rec}}\sim \langle \dot{m} \rangle$ relation if the accretion disk shape did not change dramatically from the soft to hard transition (in both cases, $\dot{m}$ is multiplied by the same factor). The predicted recurrence time is proportional to the observed value, $F_b/F_{\text{per}}$, so it should be changed with a factor of $\xi_b/\xi_p$ (Fujimoto 1988). The $\xi_b/\xi_p$ factor is estimated in the range $1 - 3$ for the low inclination system of SAX J1748.9–2011 (He & Keek[2016]). These modifications still support the mixed hydrogen/helium bursts occurred in SAX J1748.9–2021.

6. Discussions and Conclusions

SAX J1748.9–2021 has shown 17 bursts during the 1998 outburst detected by BeppoSAX, 16 bursts during the 2001 outburst, 2 bursts during the 2005 outburst, and 13 bursts during the 2009-2010 outburst, all detected by RXTE (Galloway et al.[2008]). The total number of X-ray bursts was enlarged by the 56 bursts detected during the 2015 outburst. The bursts in soft and hard states are similar in terms of their e-folding time, the peak flux, and the total fluence. Compared with the calculated recurrence time, we conclude that all bursts are generated from mixed hydrogen/helium burning on the NS surface. However, this source appeared to alternate between helium or mixed hydrogen/helium bursts independently of the persistent flux (Galloway et al.[2008]), while during the 2015 outburst, studied in detail in this work, the mixed hydrogen/helium bursts follow the...
We have studied the spectral behaviour of SAX J1748.9–2021 during its 2015 outburst by using the available integral, Swift, and XMM-Newton data. The source shows a spectral change from hard to soft state within ~0.5 day around MJD 57079.5 (see Fig. 2). Usually, the hard to soft transitions occurred in the rise phase of the outbursts in LMXBs (see Remillard & McClintock 2006 for reviews). The hard to soft transitions in LMXBs were explained in different ways, i.e., the increasing of mass accretion rate (Esin et al. 1997), the shrinking of the corona size (Homan et al. 2004), the competition between inner halo and outer standard thin accretion disc (Smith et al. 2002), and non-stationary accretion (Yu & Yan 2009). The duration of the outbursts’ rise phase in LMXBs can be regarded as the timescale of the hard to soft transition, which has a mean value of 5 days and a minimum value of ~1 day (Yan & Yu 2015). Compared with the large sample of outbursts in 56 LMXBs (Yan & Yu 2015), the rapid spectral transition in SAX J1748.9–2021 during the 2015 outburst had the shortest duration. We suggest that the production of soft X-ray photons from type-I X-ray bursts may have accelerated the hard-to-soft spectral transition.

Before the transition, the persistent emission in the 20–100 keV range maintained at a high level in ~5 days (see the bottom panel in Fig. 2). Considering the recurrence time of ~2 hrs in the hard state, we expect that a total number of type-I bursts of ~60 should have occurred in SAX J1748.9-2021, and so ~35 of these are probably missed because the source was outside the field of view of JEM-X. With the averaged energy release, ~×10^{39} ergs, of type-I X-ray bursts, the total energy of ~1.8 × 10^{41} ergs was emitted in the hard state. The X-ray bursts in SAX J1748.9–2021 may play two roles in the hard-to-soft transition by ejecting a bunch of soft X-ray photons and dragging the accretion flow inward to enhance the persistent X-ray emission (Walker 1992). In both cases, the produced soft photons pass through the corona and cool down the electrons there, which can reduce the corona size and shorten the duration of the hard-to-soft transition. Moreover, we found the source EXO 1745-248 showing a similar behavior, especially when considering the two outbursts at MJD 51776 and MJD 52459, respectively. The first outburst was more energetic than the second one. However, the hard to soft transition duration in the first outburst, i.e., ~4 days, was smaller than the second one, i.e., ~5 days (Yan & Yu 2015). Meanwhile, dozens of X-ray bursts happened before the hard to state transition in the first outburst (Galloway et al. 2008). Considering that more total energy released in the first outburst, we suggested that X-ray bursts may also accelerate the hard to soft spectral transition during the first outburst in EXO 1745-248.

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