Swift observations of black hole candidate XTE J1752-223 during outburst

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Abstract

Here we summarise the *Swift* broadband observations of the recently discovered X-ray transient and black hole candidate, XTE J1752-223, obtained over the period of outburst from October 2009 to June 2010. We offer a phenomenological treatment of the spectra as an indication of the canonical spectral state of the source during different periods of the outburst. We find that the high energy hardness-intensity diagrams over two separate bands follows the canonical behavior, confirming the spectral states. From *Swift*-UVOT data we confirm the presence of an optical counterpart which displays variability correlated, in the soft state, to the X-ray emission observed by *Swift*-XRT. The optical counterpart also displays hysteretical behaviour between the states not normally observed in the optical bands, suggesting a possible contribution from a synchrotron emitting jet to the optical emission in the rising hard state. Our XRT timing analysis shows that in the hard state there is significant variability below 10 Hz which is more pronounced at low energies, while during the soft state the level of variability is consistent with being minimal. These properties of XTE J1752-223 support its candidacy as a black hole in the Galactic centre region.

KEY WORDS: X-rays: binaries — X-rays: bursts — Individual: XTE J1752-223

1. Introduction

Low mass X-ray binaries are for the majority of the time in a state of quiescensce with faint or non-detected X-ray emission, though optical or near-infrared (nIR) counterparts may be visible due to emission from the donor star, or possibly the jet, hot spot, or outer accretion disk. They are often only discovered when they enter an active state of outburst when – powered by an increased level of accretion onto the central, compact object (black hole or neutron star) – there is a dramatic increase of the X-ray, optical/nIR and radio flux. During these outbursts the systems have been observed to go through a number of high energy spectral states before returning to a quiescent state, usually on times scales of weeks, months or even longer. These states are a generally low intensity, power-law dominated, *hard* state followed by a usually, higher intensity, *thermal-dominant*, *soft* state

which decreases in flux, via a late hard state, over time. Additionally, the hard states are associated with aperiodic variability of the light curve not present in the soft state see (McClintock & Remillard 2006 for a fuller description of the various possible states).

XTE J1752-223, a new X-ray transient and black hole candidate in the Galactic center region, was detected on 2009-10-23 at 19:55 UT (MJD 55128.33) by RXTE (Markwardt et al. 2009a). The high energy, variable emission of the source was confirmed in the following days by *Swift*-XRT & BAT (Markwardt et al. 2009b) and RXTE (Remillard et al. 2009, Shaposhnikov et al. 2009) as well as by MAXI/GSC (Nakahira et al. 2009) and *Fermi*/GBM (Wilson-Hodge et al. 2009). An optical and nIR counterpart was proposed (Torres et al. 2009a, 2009b) and a radio source coincident with the X-ray position, later confirmed as the jet (Yang et al. 2010), was detected (Brocksopp et al. 2009). The source

was observed to have undergone a state transition in mid-January 2010 (MJD $\sim$ 55210), from a spectrally hard to a spectrally soft X-ray state (Homan et al. 2010) . This was identified by a decoupling of high energy ($\gtrsim 4\,\mathrm{keV}$) and low energy ($\lesssim 4\,\mathrm{keV}$) MAXI light curves which had previously traced each other, and by the dominance of a thermal component in spectra. The source was observed to have reverted to a hard state at the end of March 2010 (MJD $\sim$ 55280; Muñoz-Darias et al. 2010), after the low energy light curve decreased to trace once more the high energy light curve; the thermal component was no longer dominant. Here we summarise our paper (Curran et al. 2010) detailing the *Swift* – Burst Alert Telescope (BAT), X-ray Telescope (XRT) and Ultraviolet/Optical Telescope (UVOT) – monitoring observations of XTE J1752-223, obtained over the period of the outburst. Based on these data, we identify the periods of the various states (McClintock & Remillard 2006) and compare the behavior of the major photometric, spectral and timing properties during these states to those expected from black hole X-ray binaries.

2. Defining the states

The states are defined by the XRT-BAT spectral analysis (Figure 1) which shows that in the initial hard state (MJD 55131 - 55138), the spectra are dominated by a single, hard power law component of photon index, $\Gamma = 1.46 \pm 0.03$, absorbed by a column density of $N_{\mathrm{H}} = 0.513 \pm 0.003 \times 10^{22}\,\mathrm{cm}^{-2}$. In the soft state (MJD 55233 - 55280) there is a significant additional contribution from a thermal component at $\sim 0.6\,\mathrm{keV}$, where the absorption is fixed at the previous value. In the intermediate state (MJD 55283 - 55328), a thermal component in no longer supported though the power law is still decreasing until it reaches its final, hard state (MJD 55329 - 55352) value of $\Gamma = 1.64 \pm 0.02$ where the column density is again fixed to that of the initial hard state. This steeper value at late times, like the value of hardness ratio (HR; section 5.), shows that the source has not returned to it's initial state or that the late hard state has different spectral properties, such as column density, than the initial hard state. Leaving column density free in the late spectral fits leads to a shallower photon index, consistent with the original, of $\Gamma = 1.53 \pm 0.02$ absorbed by a column density of $N_{\mathrm{H}} = 0.43 \pm 0.01 \times 10^{22}\,\mathrm{cm}^{-2}$. More detailed spectral fitting with better constrained photon indices are required to differentiate whether the column density is variable or the photon index is different at late times.

In the high energy *Swift*-BAT [15-150 keV], MAXI [4-10keV] and *Swift*-XRT [0.3-10 keV] light curves (Figure 2) during the period of outburst, the absence of data at MJD 55139-55233 (shaded area) is due to the various instruments becoming sun-constrained. The orange lines signify the dates of the state transitions: quiescence – hard state – soft state – intermediate state – hard state. It is clear from these that there is an excess of soft/low energy photons in the soft state as exhibited by the decoupling of high energy and low energy light curves which had previously traced each other. Unfortunately, due to the sun constraint, the intermediate state between the initial hard state and the soft state was unobserved.

3. Optical counterpart & hysteresis

UVOT v, b, u and $uvw1$ band light curves (Figure 3) for the proposed optical counterpart allowed us to confirm the association with XTE J1752-223 due to their variability. The accurate position of the counterpart was derived from a deep (1853 s) v band image as 17:52:15.08 $-$22:20:32.9 (J2000; 0.31 arcsecond 1σ error). Given the unknown Galactic extinction to the source and the quality of the data, we cannot examine the true colours or spectral shape of the optical source, neither can we confirm any possible spectral changes over the outburst. Assuming a power law spectrum, the spectral index could be anywhere between a rising value of 2.0 and a decreasing value of 5.3.

The correlation between the UVOT magnitudes in three bands and the XRT count rate during the soft state (Figure 3) further confirm the association between the proposed counterpart and XTE J1752-223. Such a correlation is more usually associated with the hard state (Russell et al. 2006) but we cannot say if the early, hard state data follows another correlation due to the very limited range of magnitudes and X-ray count rates over this period. Data points in grey indicate observations during the initial hard state and clearly exhibit a hysteresis with the later soft state data at a similar count rate. This is similar to the hysteretical behaviour observed in the nIR for a number of transients (Russell et al. 2007), most notably XTE J1550-564, where the additional hard state emission is attributed to optically thin synchrotron emission from a jet, which would be quenched in the soft state, and weak at low X-ray luminosities, leading to the hysteresis. Though this hysteresis is not normally observed in the optical bands, the optical data presented here is in good agreement with the synchrotron emitting jet making a significant contribution to the optical emission in the rising hard state.

4. X-ray variability

The average power density spectrum (PDS; Figure 2) for XRT light curve in the hard state exhibits an aperiodic variability of the light curve (RMS $\sim 54\%$) at frequencies up to 10 Hz, though no QPOs are detected. The average soft state PDS exhibits only minimum variability and only at frequencies below 0.2 Hz (RMS $< 12\%$). These PDS help confirm the identified states as they exhibit the
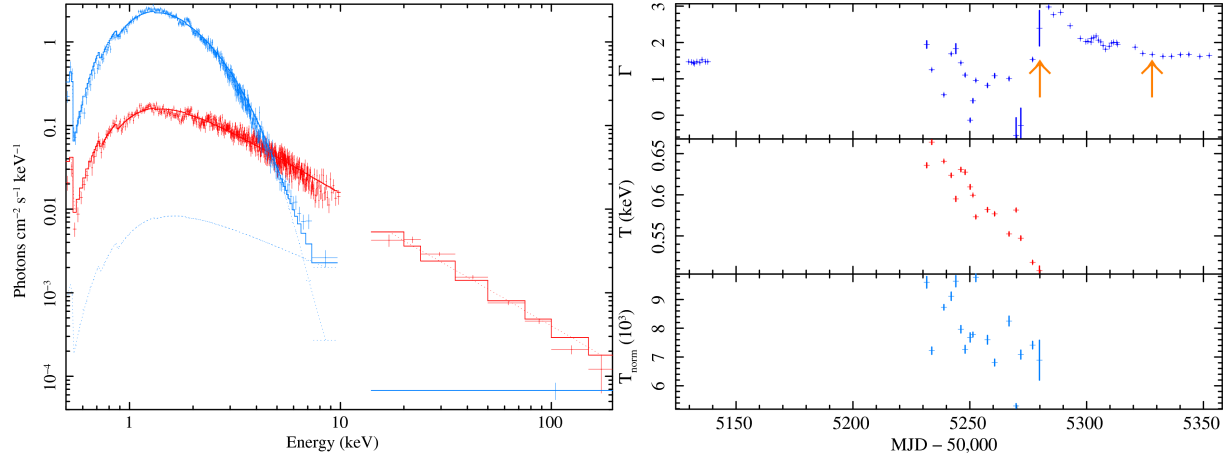
Fig. 1. *Left*: Example XRT-BAT spectra in the power-law dominated, hard state (red; MJD 55131) and in the soft state (blue; MJD 55248) which displays a strong thermal component. *Right*: Best fit parameters of the joint XRT-BAT spectral fits: power law photon index, Γ, thermal component temperature, T, and thermal component normalization, T_{norm}, in units of 10^3. Note that the photon indices, in the period where there is a thermal component, are not reliable. The absence of data from MJD 55139 to 55231 is due to the various instruments becoming sun-constrained. The arrows signify the dates between which the source is transitioning from the soft state to the late, hard state.
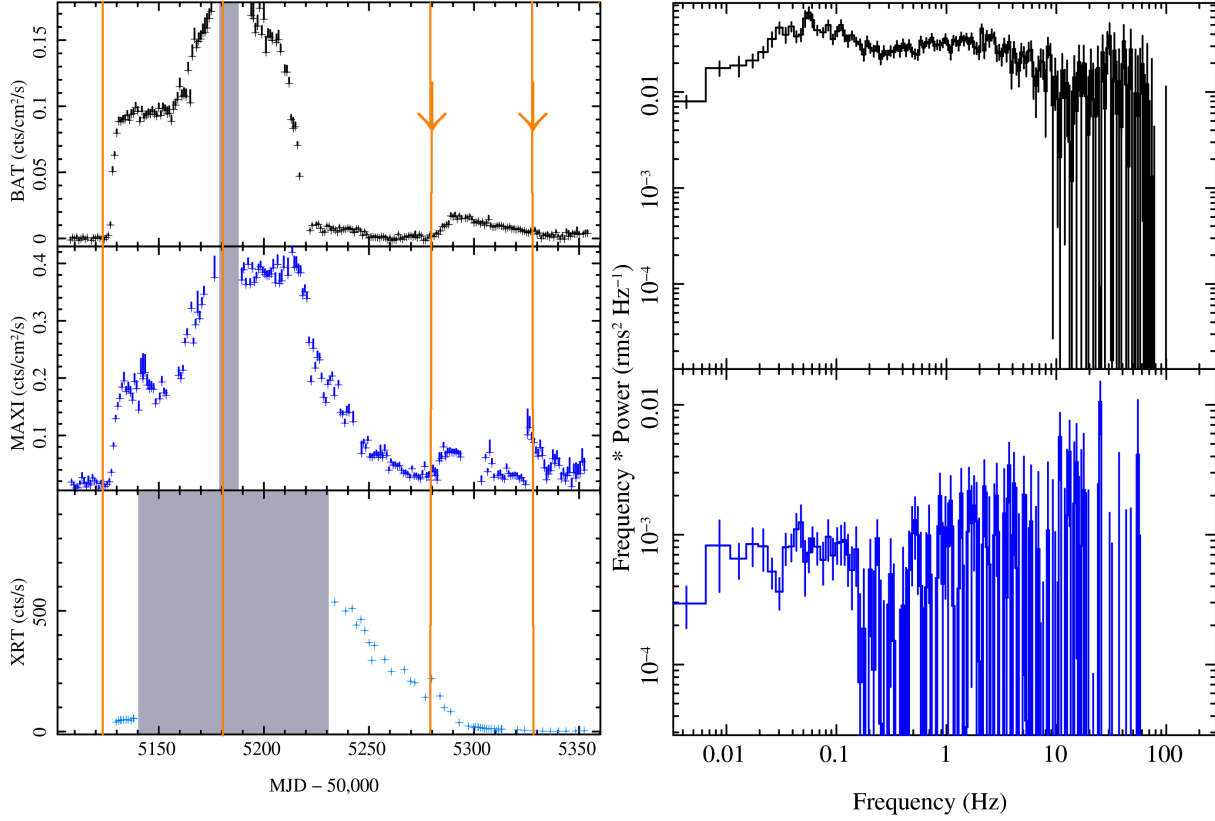

Fig. 2. *Left*: High energy (*Swift*-BAT [15-150 keV], MAXI [4-10 keV], *Swift*-XRT [0.3-10 keV]) light curves during the period of outburst. The absence of data around MJD ∼55180 (shaded area) is due to the various instruments becoming sun-constrained. The orange lines signify the dates of the state transitions: quiescence − hard state − soft state − intermediate state − hard state. *Right*: The average power density spectrum (PDS) for XRT light curve in the initial hard state (*upper*; RMS ∼ 54%) exhibits the aperiodic variability of the light curve not present in the average soft state PDS (*lower*; RMS < 12%).

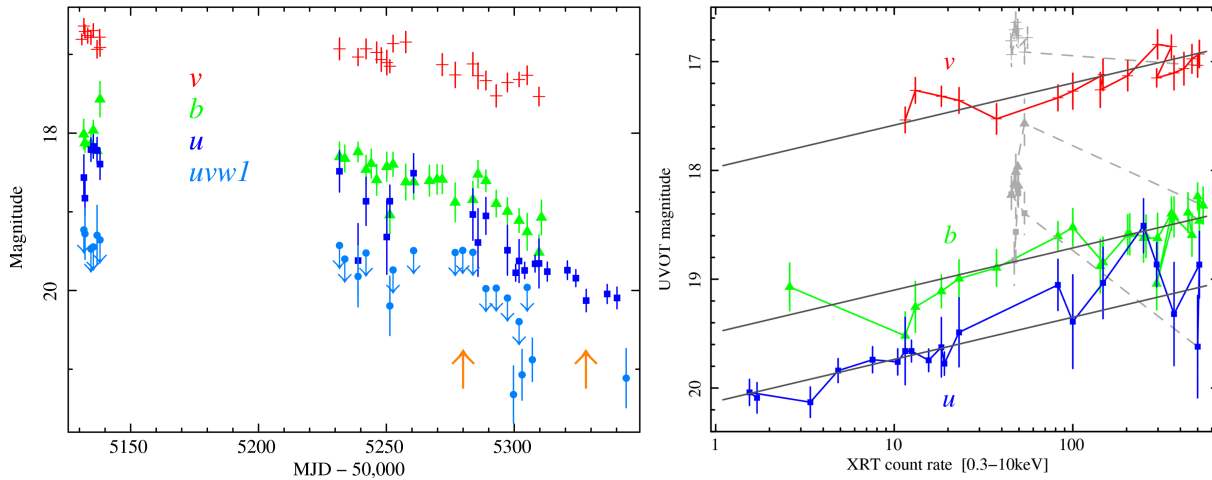Fig. 3. *Left*: UVOT v (crosses), b (triangles), u (squares) and $uw1$ (circles with 3σ limits) band light curves for the source show variability; dimming by 1 magnitude or more from the start to the end of observations. The up-pointing arrows signify the dates between which the source is transitioning from the soft state to the late, hard state. *Right*: UVOT magnitude in three filters versus XRT count rate. Data points in grey indicate observations before MJD ~ 55230, i.e., the initial hard state. The solid black lines represent the simultaneous power law fit to the data after MJD 55230.

same properties as observed in other black hole X-ray binaries. We also find that, in the initial hard state, there is an excess of variability at low energies: the low energy (0.3-1.5 keV) light curves having 20% higher RMS than the high energy (1.5-10 keV) light curves. This may suggest a contribution from intrinsic disk variability which is not obvious from the spectral fitting (section 2.). More detailed spectral fitting and better constrained column density are required to test this possibility.

5. Hardness-Intensity Diagrams

In the Hardness-Intensity diagrams (HID; Figure 4) for both BAT/MAXI and XRT, the grey lines, at high count rates, show the time during which the XRT was unable to observe, while the circles show the start and end of the intermediate state between the soft and hard states. Note that at low count rates (< 0.1) the BAT/MAXI HR is not reliable; the later, low count rate, data points are shaded for clarity of the plot. Both HID are consistent with the canonical trajectory of black hole binaries (Homan & Belloni 2005). It is clear from the XRT HID that the hardness has yet to increase to the original value, indicating that the source has not yet returned to its original hard state, though the count rate is lower than it was in that rising hard state, or that the late hard state has different spectral properties (e.g. column density).

6. Conclusions

Swift observations of the first, and so far only, observed outburst of XTE J1752-223 allow us to confirm and refine the epochs of the canonical X-ray states. The observa-

tions also allow us to confirm the optical counterpart for which we were able to produce a sub-arcsecond position. We show that there is a correlation between optical and X-ray emission in the soft state as well as a hysteresis effect where, for a given X-ray count rate, the magnitude in the rising hard state is significantly higher than that in the soft state. This is similar to the hysteretical behaviour observed in the nIR for a number of transients though it is not normally observed in the optical bands. The discussed X-ray and optical, photometric, spectral and timing properties of XTE J1752-223 support its candidacy as a black hole in the Galactic centre region.

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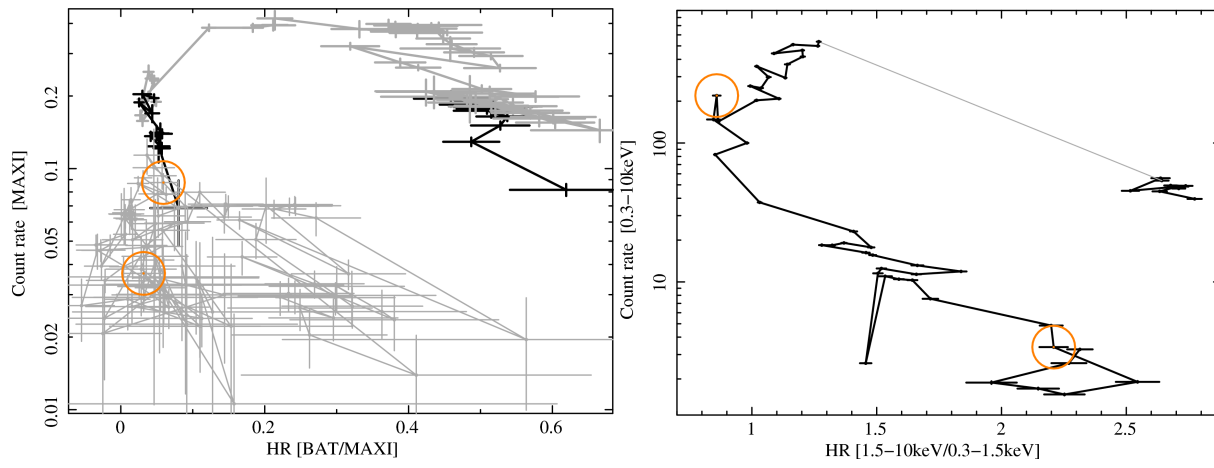Russell D.M. et al. 2006, MNRAS, 371, 1334

Fig. 4. Hardness-Intensity diagrams (HID) for both BAT/MAXI (*left*) and XRT (*right*). The grey lines, at high count rates in both plots show the time during which the XRT was unable to observe (MJD 55139-55233), while the circles show the start and end of the transition from the soft state. Note that at low count rates ($\lesssim 0.1$) the BAT/MAXI HR is not reliable; the later, low count rate, data points are shaded for clarity of the plot.

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