Outbursts and State Transitions in Black Hole Candidates Observed by MAXI

Hitoshi Negoro[1]
and MAXI Team

[1] Nihon University, 1-8 Kanda-Surugadai, Chiyoda, Tokyo, Japan 101-8308
E-mail(HN): negoro@phys.cst.nihon-u.ac.jp

Abstract

MAXI continuously observes several black hole candidates in our Galaxy and LMC. In the first 1 year and 4 months, MAXI detected state transitions in Cyg X-1, Swift J1753.5-0127, and outbursts from H 1743-322, GX 339-4, 4U 1630-472, XTE J1752-223, and MAXI J1659-152. Here, I review what MAXI has observed in these black hole candidates, and describe our reports to our mailing list and to *The Astronomer's Telegram*. Finally, a comparison of expected and observed numbers of new black hole transients and two kinds of the hard-to-soft state transitions observed by MAXI are discussed.

Key words: ISS: MAXI — compact objects: black holes — X-rays

1. Black Hole Transients Observed by MAXI

About 20 mass-estimated black hole candidates (BHCs) and about 30 second-class BHCs, which show similar X-ray properties to the former objects, have been found in our Galaxy (McClintock & Remilard 2007, Negoro 2009). More than 90 % of these BHCs are X-ray transients, and such a black hole transient is observed only for less than 1 year. During the outburst, the source exhibits various timing and spectral behaviors, which are related to some "state" of the accretion disk around the central object.

To investigate physical properties of the accretion disk in the various states and the relationship between observed properties and the black hole we believe, discovery and continuous observations of new black hole transients are very important.

MAXI, Monitor of All-sky X-ray Image, with very wide fields of views and high sensitivity is one of the best instruments so far to discover transient objects in the X-ray band (Matsuoka et al. 2009). Before the launch, It was expected from a simple statistical estimation that the discovery rate of black hole X-ray transients with MAXI are 5–10 times higher than before, and estimated to be about 10 objects a year (Negoro 2009).

The actual discovery rate during about 1.3 year is not so high. MAXI, however, detected outburts from recurrent BH transients, H 1743-322 twice and 4U 1630-472, and the newly discovered XTE J1752-223 and MAXI J1659-152 (see Fig 1). MAXI also detected state transitions of the persistent-emission sources, Cyg X-1 and Swift J1753.5-0127. The MAXI team soon circulated the beginnings of the outbursts and the transitions to our "New-transient" or "X-ray-star" mailing list,[1] and reported to *The Astronomer's Telegram*, ATel.

Here, I look around these transient events in BHCs detected with MAXI in about 1.3 year, and briefly summerize X-ray properties of these BHCs obtained from MAXI observations. I also present two kinds of the hard-to-soft state transitions from these observations, which are probably related to the bright/slow and dark/fast transitions first noticed by Gierliński and Newton (2006).

2. MAXI J1659-152

2.1. discovery

MAXI J1659-152 was first triggered by the Swift Burst Alert Telescope (BAT) at 08:05:05 UT on 2010 September 25, and referred to GRB 100925A (Mangano et al. 2010). At 10:08:05 on the day, the MAXI nova alert system (Negoro et al. 2010c, also see Ozawa et al. 2011 and Suwa et al. 2011) also independently triggered the source gradually increasing in X-ray intensity since the beginning of the day. We tentatively named the source MAXI J1659-152, and reported these nature of the source to ATel (Negoro et al. 2010a).

2.2. longterm monitoring

Fig. 2 shows a long-term X-ray light curve and hardness ratios obtained with MAXI/GSC, together with Swift/BAT 15-50 keV data. The spectral evolution during the outburst clearly can be seen from the hardness ratios. Note that variations of the ratios are similar to that of the count rates in the 15-50 keV band, implying

*1 http://maxi.riken.jp/mailman/listinfo

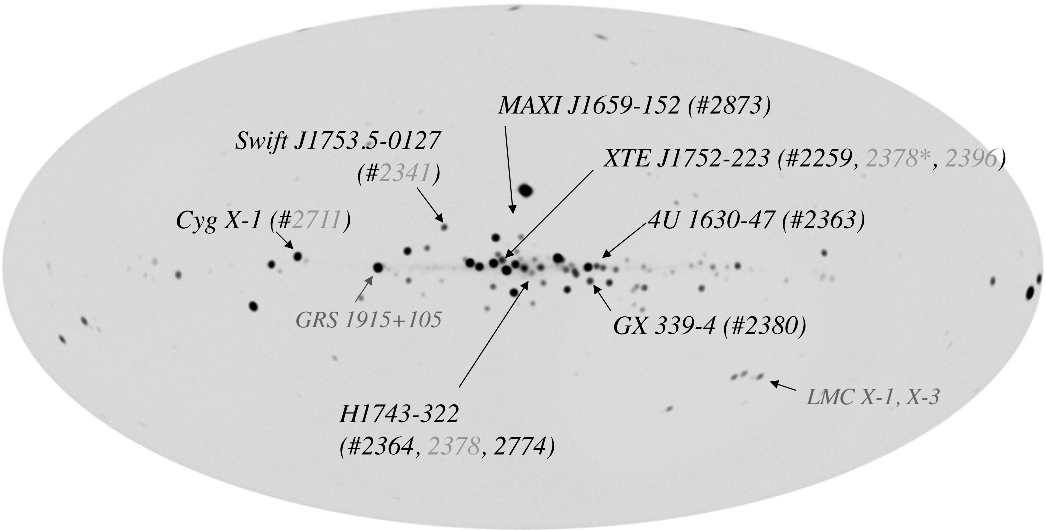

Fig. 1. MAXI all-sky image (Sugizaki et al. 2011) and black hole candidates detected in the first 1.3 year observation. Black/gray numbers following # indicate telegram numbers of ATel, to which outbursts /state-transitions were reported using MAXI data.

that the state transition is mainly due to variations of the hard power-law component.

This also demonstrates the data reduction of the public data archival is successful except for an occasional background subtraction problem.

Detailed description of the data will be reported elsewhere, and here I only note that the source soon underwent a transition from the hard state to the intermediate state, and stayed in the intermediate state so long. Possible soft state durations were on MJD = 55,486–55,489 and 55,496–55,501, where the 4-10 keV to 2-4 keV ratios are below 0.5.

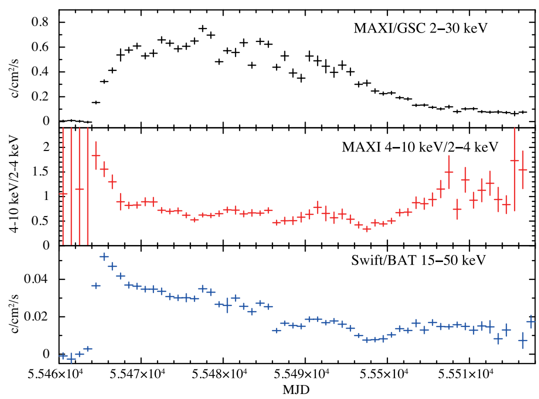

Fig. 2. MAXI J1659-152: (top) 2-30 keV light curves and (middle) count ratios of the 4-10 keV band to the 2-4 keV band obtained with MAXI/GSC. (bottom) A 15-50 keV light curve obtained with Swift/BAT is also shown.

2.3. XTE J1752-223

XTE J J1752-223 was discovered during the RXTE/PCA Galactic bulge scan survey on 2009 October 23 (Markwardt et al. 2009). Though MAXI/GSC was still performing the test operation, we reported the increase in X-ray intensity at the beginning of the outburst to ATel (Nakahira et al. 2009). Detailed study of the MAXI data can be found in the paper by Nakahira et al. (2010, hereafter NS10).

XTE J1752-223 stayed in the hard state for as long as $\sim$ 90 days before the soft state transition (Negoro et al. 2010b), which is similar to GX 339-4 in 2000 (see NS10). The track in the hardness-flux diagram also shows a simlar Q-curve to that of GX 339-4 (see the upper left panel in Fig. 9). A comparison with MAXI J1659-152 will be made in §4.

3. Outbursts and State Transitions in previously known BHCs

3.1. Cyg X-1

The primary black hole candidate Cyg X-1 had been in the hard state since at least 2005. The MAXI alert system produces false color all-sky images every 1 and 4 orbits, and 1 and 4 days, which let us know spectral information on sources (Negoro et al. 2010c).

In the all-sky map on June 27, 2010, the source color of Cyg X-1 changed from *blue* to *red*, indicating that the energy spectrum became much softer. The spectral change has been made with a rapid increase in soft X-ray intensity by a factor of two. The source, however, once went back to the hard state on June 29.

On July 1, the soft X-ray intensity below 2 keV rapidly increased again from approximately 0.3 Crab to 1.2 Crab almost in a day (Negoro et al. 2010d). While the hard X-ray intensity above 10 keV did not show a sudden drop, but a gradual decrease since the beginning of June (MJD $\sim$ 55350), which could be seen in the Swift/BAT light curve[2] (see the bottom panel in Fig. 3). It should be noted that at the beginning of the decrease in the hard X-ray flux AGILE has detected a gamma-ray flare from the direction of Cyg X-1 (Bulgarelli et al. 2010) though the relationship to this transition is not clear, yet.

After the transition from the hard state, the source has been in an unstable soft state or an intermediate state for at least 100 days. Cyg X-1 in that state sometimes produced large X-ray flares lasting a few hours (Fig. 4), which had not been observed in GX 339-4 in the soft state described later. Further discussion will be in §4.

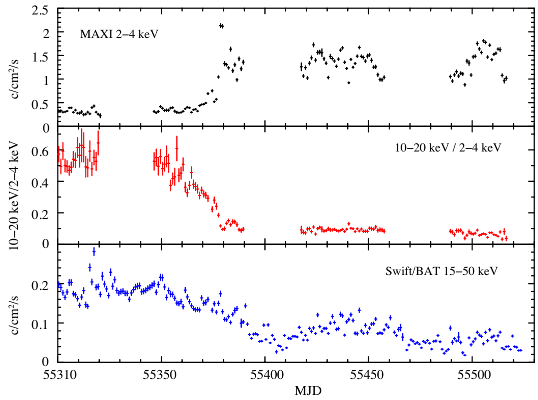

Fig. 3. Long-term light curves and hardness ratios of Cyg X-1 from April 24, 2010 (MJD 55310).

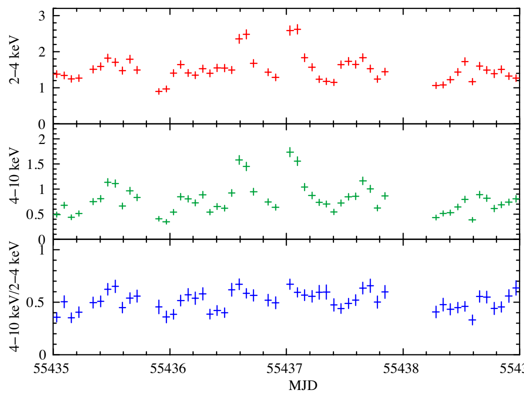

Fig. 4. Large soft X-ray flares observed in Cyg X-1 in the soft state. MJD 55437 is August 28, 2010.

*2 http://heasarc.gsfc.nasa.gov/docs/swift/results/transients/

3.2. GX 339-4

An outburst in 2010 from this source has detected since January 3 (MJD 55199) after the quiescent state. The MAXI nova alert system did not trigger the outburst automatically[3] , but the renew activity was recognized in MAXI daily images and Swift/BAT light curves (Yamaoka et al. 2010b).

The source had gradually increased for 110-120 days though MAXI could not observe the source during the hard-to-soft transition because the source was in invisible area of the detectors (Fig. 5). Note that the hard X-ray flux observed with Swift/BAT decreased for as short as about 10 days, while that in Cyg X-1 decreased for about 100 days or more (Fig. 3).

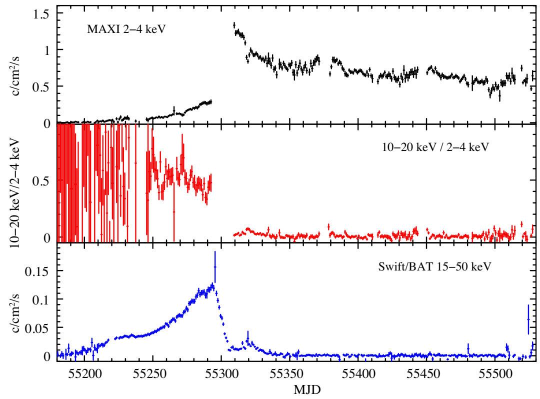

Fig. 5. Long-term light curves and hardness ratios of GX 339-4 from December 15, 2010 (MJD 55180).

3.3. Swift J1753.5-0127

One of the good example showing low energy sensitivity of MAXI/GSC below 2 keV was the detection of a significant spectral softening in Swift J1753.5-0127 from November 25.5, 2009 (Negoro et al. 2009). The source has been in the hard state since the discovery (e.g., Hiemstra et al. 2009).

The brightening in the soft energy band, however, lasted only 4-5 days (Fig. 6). Also note that hard X-ray emission observed with Swift/BAT also significantly dropped at that interval. Anti-correlation between the soft X-ray flux observed by MAXI and the hard one with Swift/BAT can be seen in other periods in the figure.

Increase in the soft energy band was recognized in previous observations by XMM-Newton (e.g., Miller et al. 2006). These observations were of course snap shots and the stability of the enhanced soft X-ray emission was unknown. MAXI data demonstrated that such enhancements lasted less than 10 days.

*3 This is because the source intensity increased so slow that the average counts and resultant trigger thresholds, estimated from the latest 10 days (currently max 40 days), also slowly increased.

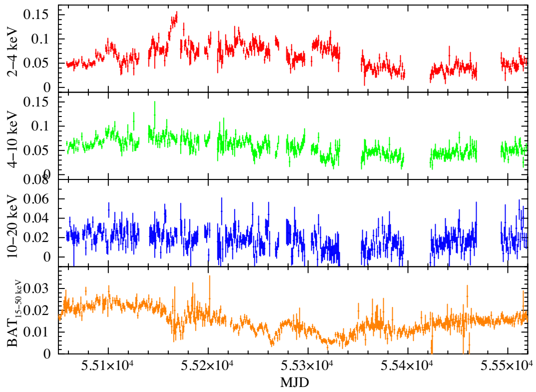

Fig. 6. Light curves in the various energy bands of Swift J1753.5-0127 from August 15, 2009 (MAXI/GSC data). Soft X-ray enhancements were observed around MJD 55170 and 55265.

3.4. H1743-322

H 1743-322 often exhibits outbursts, and MAXI also detected outbursts in 2009 (Yamaoka et al. 2009) and in 2010 (Nakahira et al. 2010b). Time profiles of the outbursts are found to be similar, and the soft state transition can be also clearly seen from MAXI/GSC data (Yamaoka et al. 2010a) as shown in Fig. 7.

The source is close to the Galactic center [$(l,\ b) = (357.255, -1.833)$] so that the Galactic ridge X-ray emission is not completely subtracted in the data. The data should be reanalyzed before detailed discussion using absolute values of hardness ratios.

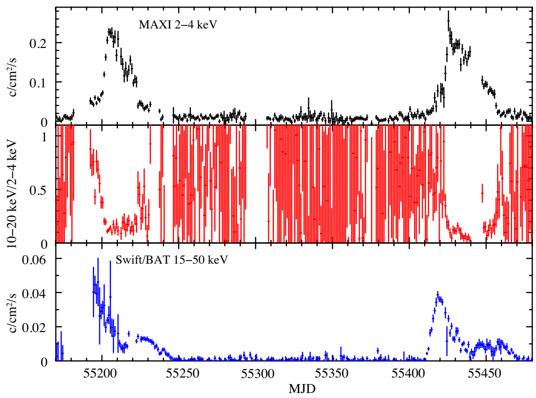

Fig. 7. Light curves and hardness ratios of H 1743-322 from December 5, 2009 (MJD 55170).

3.5. 4U 1630-472

At the end of 2009, MAXI detected renew activity of 4U 1630-472 (Tomida et al. 2009). Soft X-ray flux increased rapidly 2 or 3 days later from the begining of the outburst, and the outburst were recognized for about 200 days in the MAXI data (Fig. 8)

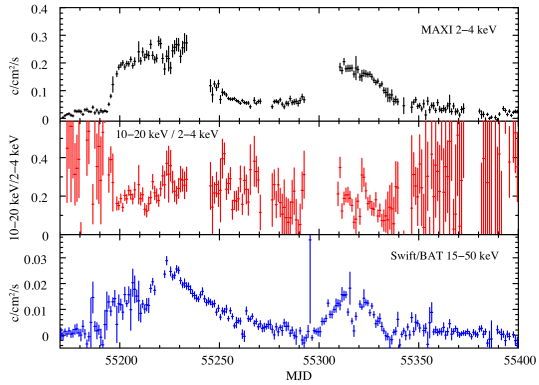

Fig. 8. The same with Fig. 7 but 4U 1630-472.

4. Discussion

As shown above, MAXI has detected the beginnings of the outbursts and the state transitions of the 7 black hole candidates, and provided continuous data for more than one year. New transients were, however, only XTE J1752-223 and MAXI J1659-152 though I simply estimated the discovery rate to be 7.5-15 new objects a year before the launch by observing distant transient sources (NH08).

One of the reasons of the small number of the discovery is due to a high background rate in the ISS environment especially above 10 keV, in which distant, obscured objects must be detected through the thick Galactic absorption. The high background rate at high latitudes and camera troubles also reduce the net exposure time by about half, resulting in lower sensitivity (e.g., Sugizaki et al. 2011). Another reason is due to limited spatial resolution especially for sources in the Galactic center region where about half the transients have been discovered. We have made efforts to improve the signal-to-noise by studying the nature of the background and performing onboard calibration.

What is the scientific topics to be addressed from the MAXI observations is two kinds of hard-to-soft state transitions. It is well known that the BHCs undergo the hard-to-soft state transition through the intermediate or very high state probably associated with relativistic jets (e.g., Fender et al. 2004).

MAXI data clearly show that there are two kinds of the transitions. One is the fast hard-to-soft transition observed in XTE J1752-223 and GX 339-4. The other is the slow or incomplete (or failed) transition, staying in the intermediate state so long, observed in MAXI J1659-152 and Cyg X-1, though the current state of Cyg X-1 might be a matter of discussion (see §3.1). Thus, the main difference between them is the duration of the intermediate state, and is not the duration from the beginning of the outburst to the soft state. These can be seen in the hardness-flux diagrams shown in Fig. 9. The

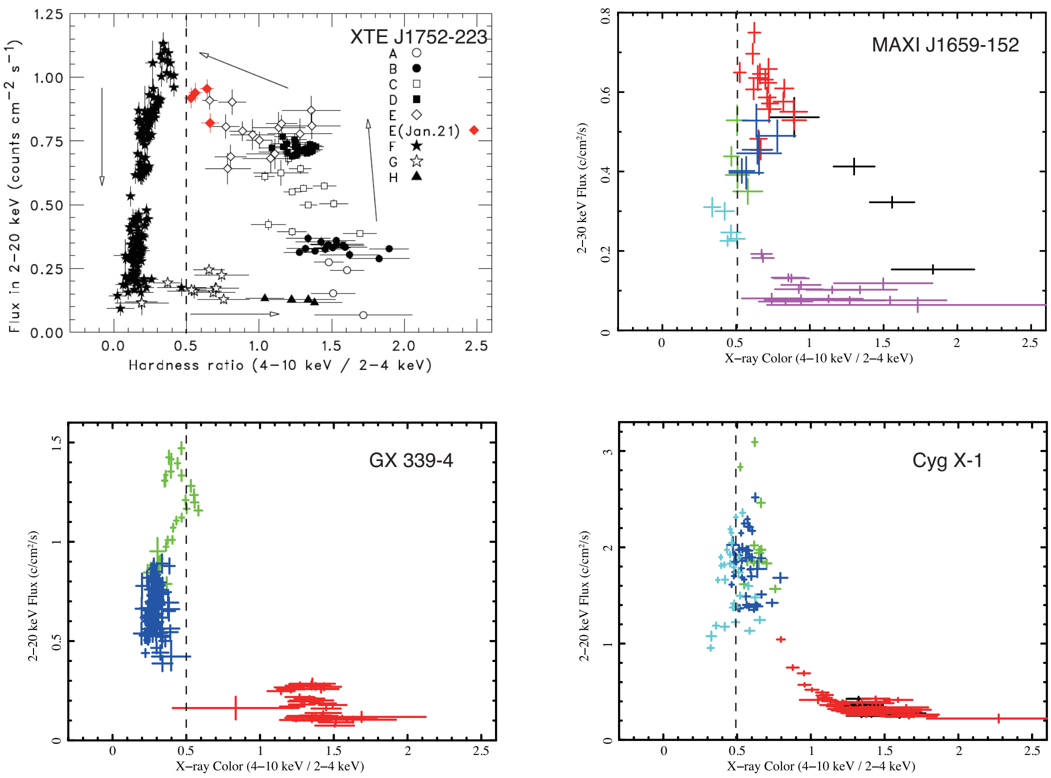

Fig. 9. Hardness-flux diagrams of the four BHCs observed with MAXI. (left panels) Fast hard-to-soft transitions of XTE J1752-223 from NS10 and GX 339-4. (right panels) Slow or incomplete transitions of MAXI J1659-152 and Cyg X-1.

hardness ratio 0.5 is likely to be the border line of the intermediate state and the soft state.

Gierliński and Newton (2006) first pointed out the possible two kinds of the transitions, the "dark/fast" transition and the "bright/slow" transition. Currently, uncertainty of the distances to the new transients does not allow us to estimate the luminosities of the sources. It is of great importance to investigate that the cause of the difference is simply related to the luminosity, and/or to the role of the magnetic field (Oda et al. 2010). This will be discussed in more detail in another paper.

This research was partially supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Grant-in-Aid No. 20041008 and 21340043. The author also thanks JAXA for continuous support and operation of the MAXI nova alert system and its financial support.

References

Bulgarelli, A. et al. 2010 ATel., 2512
Fender, R. et al. 2004 MNRAS., 355, 1105
Gierliński, M. and Newton, J. 2006 MNRAS., 370, 837
Hiemstra, B. et al. 2009 MNRAS., 394, 2080
Mangano et al. 2010 GCN Circular, 11296
Markwardt, C.B. et al. 2009 ATel., 2258
Matsuoka, M. et al. 2009 PASJ., 61, 999
McClintock J.E. and Remillard R.A. 2007 in *Compact Stellar X-ray Sources*, eds. W.H.G Lewin and M. van der Klis, Cambridge University Press. 39, Chap.4.
Miller, J., et al. 2006 ApJ., 652, L113
Nakahira, S., et al. 2009 ATel., 2259
Nakahira, S., et al. 2010a (NS10) PASJ., 62, L27
Nakahira, S., et al. 2010b ATel., 2774
Negoro, H. 2009 in *Astrophysics with All-Sky X-Ray Observations*, eds. N. Kawai et al., JAXA-SP-08-014E (Chofu, Tokyo: JAXA), 60
Negoro, H. et al. 2009 ATel., 2341
Negoro, H., et al. 2010a ATel., 2873
Negoro, H., et al. 2010b ATel., 2396
Negoro, H. et al. 2010c ASP Conf. Series., 434, 127
Negoro, H., et al. 2010d ATel., 2711
Ozawa, H. et al. 2011, in this volume
Oda, H., et al. 2010 ApJ., 712, 639
Sugizaki, M., et al. 2011 PASJ., (accepted)
Suwa, F. 2011, in this volume
Tomida, H. et al. 2009 ATel., 2363
Yamaoka, K. et al. 2009 ATel., 2364
Yamaoka, K. et al. 2010a ATel., 2378
Yamaoka, K. et al. 2010b ATel., 2380