Galactic Transient Sources with MAXI

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Abstract

Thanks to its superior sensitivity, energy resolution and wide energy coverage, MAXI is expected to open a new window in the study of Galactic X-ray transients. In this paper, I selected the following eight areas in which MAXI is expected to make significant contributions to our understanding of the Galactic transient sources: (1) Detailed study of bright transients, (2) Monitor spectral variations, (3) Accretion disk spectral variation, (4) Faint transients, (5) Transient search in crowded region, (6) Supergiant fast X-ray transients, (7) Ultra-soft transients, and (8) Extragalactic stellar transients. For each area, I explain what MAXI will be able to do, in contrast to previous observations by all sky monitors.

Key words: Galactic transients: black holes — neutron stars — white dwarfs

1. Introduction

The MAXI launch planned during the first half of 2009 may sound like a blessing for the study of Galactic transient sources, because operation of the RXTE ASM, MAXI's predecessor in a sense, is planned to be terminated in 2009. The RXTE ASM has been providing the "weather map" of the X-ray sky, such that light curves of several hundreds of X-ray sources in 2–10 keV are available for the last ∼12 years. MAXI will take over this important task, and will provide source light-curves of known X-ray sources or report discovery of new X-ray transients promptly to the world-wide community.

MAXI observations will be made contemporaneously with Chandra, XMM, Suzaku, INTEGRAL, Swift, and also *Fermi*. Furthermore, MAXI is much more sensitive than RXTE ASM at as low as 1 mCrab (GSC) or 3 mCrab (SSC) for one-week exposure, and its spectral resolution can go down to ∼2 % (SSC @ 6 keV). The much wider energy coverage than RXTE ASM, 0.5–30 keV, is also extremely useful to study spectral features of Galactic transient sources. Because of these characteristics, MAXI is expected to open a qualitatively new science in the study of Galactic transients. In this paper, I will introduce several topics, in my opinion, in which MAXI is expected to make significant contributions in the understanding of Galactic transient sources.

2. Detailed study of Bright Transients

MAXI will be able to study bright transient sources in much more detail than previous instruments. In particular, the following two topics are presumably intriguing in the study of bright transients.

2.1. Study of Very Initial-phase

It is extremely difficult to catch just the "onset" of X-ray novae, since we never know when and where the X-ray novae would appear on the sky. In a very rare and lucky situation, the GINGA ASM detected the onset of GS2000+25, because the source had been coincidentally in the ASM FOV before the nova was discovered (Tsunemi et al. 1989). After the source became brighter than ∼50mCrab (ASM sensitivity), up to the peak of 12 Crab, the X-ray light-curve and spectral evolution were closely monitored. It is well-known that X-ray novae often exhibit peculiar spectral evolution in the very beginning. One of such examples is GS2023+338, which is also discovered by GINGA ASM (Kitamoto et al. 1989). The source exhibited rather a soft spectrum in 1-10 keV (photon-index ∼ 2) during the initial week or so, while in just a few days the spectrum became extremely hard (photon-index ∼ 0). However, for both of GS2000+25 and GS2023+338, we never know the spectral evolution in the beginning before the source was dimmer than ∼50mCrab, which is crucial to know the outburst mechanism of X-ray novae.

Thanks to its sensitivity, wide sky coverage and frequent monitoring, MAX will not miss onsets of bright X-ray novae, and will be able to study their spectral evolutions from the very beginning when the source is just a few mCrab.

2.2. Spectral Transition

Many bright X-ray transients are known to exhibit spectral transitions, in most cases between the high-soft state and the low-hard state, at around a threshold luminosity of $\sim 10^{37}$ erg s^{-1} $(2-10$ keV). One notable example is GS1124–68 (Ebisawa et al. 1994), where the source was in the high-soft state when observed at $\sim$ 100 days after the outburst by the Ginga main detector (LAC), while it was obviously in the low-hard state when observed at $\sim$ 160 days after the outburst. Meanwhile, the source seemed to be in the intermediate state at $\sim$130 days when the flux is about 0.1 Crab. Because the pointing observations by LAC were not continuous but patchy, we do not know the source behavior between these discrete observations.

We would like to know in which time-scale the state transition of X-ray novae takes place, and study detailed spectral evolution. If similar X-ray transients like GS1124–68 take place, MAXI will be able to carry out detailed study of spectral transition taking place at around $\sim$0.1 Crab.

3. Monitor Spectral Variation

Most X-ray binaries show spectral variations at various time-scales. Previous all sky monitors on-board Ginga, RXTE and other satellites did not have a sensitivity to detect these spectral variations taking place below $\sim$ 50 mCrab, thus such studies had to be made by pointing observations with main detectors, which were necessarily not continuous but rather patchy or sporadic.

Still, thanks to its great maneuverability, RXTE was able to carry out rather regular monitoring observations by the main detector (PCA) of Galactic X-ray binaries and AGNs. In one of such monitoring campaigns, spectral variation of a prime black hole binary LMC X-3 was studied, and the low-hard state of the source was discovered for the first time below $\sim$20 mCrab (Wilms et al. 2001).

Not only black holes, but also neutron binaries are known to have bimodal spectral states. For instance, the low-hard state of X1608-522 was studied with GINGA LAC at $\sim$40 mCrab, and its spectral and timing characteristics have been found to be very similar to those of black hole binaries (Yoshida et al. 1993). MAXI will be able to regularly study spectral variations of such rather dim black hole and neutron star binaries below $\sim$ 50 mCrab, increase the number of such samples significantly, and expect to reveal common properties of these these sources in the low state.

Bright neutron star binaries such as GX5-1 are known to show characteristic “Z-shape” spectral branches on the X-ray color-color diagram. For such bright sources (as bright as $\sim$ Crab), even GINGA ASM could study the spectral variations (van der Klis et al. 1991). Long-term monitoring of GX5-1 by GINGA ASM revealed that the Z-pattern is remarkably stable over the three years of observation. MAXI will be able to study such long-term spectral variations of practically all the bright low mass X-ray binaries brighter than 10 mCrab or so.

4. Accretion Disk Spectral Variation

The standard accretion disk model (Shakura and Sunyaev 1973) is established to explain the soft state X-ray energy spectrum of black hole binaries. In the soft state, if the standard accretion disk model is applied to explain the spectral variation, the inner disk radius is constant while the source luminosity and the disk temperature varies significantly (e.g. Ebisawa et al. 1993). The constant inner-radius corresponds to the inner-most stable circular orbit (ISCO) around the black holes, which is between three times the Schwarzschild radius and half the Schwarzschild radius, each corresponding to the non-rotating black holes and extremely fast-rotating black holes. Thus, from the X-ray measurements of ISCO, black hole mass and spin are expected to be constrained.

In the case of LMC X-3, such accretion disk variation was studied above $\sim$ 10 mCrab, which was so far only possible with pointing observations. Using MAXI, we can carry out such a study not only for bright X-ray binaries but also for rather dim black hole like LMC X-3. In this manner, MAXI may constrain the important black hole parameters, mass and spin, for many known black hole X-ray binaries.

When accretion rate becomes higher and the disk luminosity gets close to the Eddington limit, radial advection takes place, and the standard disk is considered to transform into the “slim disk” (e.g., Abramowicz et al. 1995). Slim disk and standard disk spectra are observationally distinguishable; disk temperature of the standard disk depends on the radius as $T \propto r^{-3/4}$, while in the case of slim disk the exponent becomes lower down to 0.5 (Watarai et al. 2000). Difference of the exponent is reflected in the X-ray energy spectra, and we may constrain the exponent p in $T \propto r^{-p}$ from model fitting for bright sources.

In fact, at the peak luminosity of the X-ray nova XTE J1550–56 ($\sim$2Crab), the standard disk model fit was not acceptable, but the slim disk model fits better with $p \sim 0.6$ (Kubota and Makishima 2004). This may be considered as an evidence of the slim disk in XTE J1550–56. From similar model fitting analysis, slim disk is considered to present in the Ultra-luminous X-ray sources too (ULXs; e.g. Okajima et al. 2006, Vierdayanti et al. 2006).

We do not have enough number of examples of the slim disk in X-ray binaries, since there are not many chances to observe the luminosity peaks of the accretion disk spectra. Since MAXI will continuously monitor bright transients and have sufficient spectral capability to constrain precise spectral models, we may obtain more examples of the slim disk in bright X-ray binaries.

5. Faint Transients

In 2–10 keV band, GINGA and RXTE all sky monitors had sensitivities of about ∼50 mCrab, while the LAC and PCA *scan* observations were very sensitive to detect sources a low as a few mCrab. Systematic scan observations with GINGA LAC and RXTE PCA were made on Galactic plane and center regions covering wide area, and many new transient sources have been discovered, almost always when new scans are made (e.g., Koyama et al. 1989). Even today, careful re-analysis of GINGA archives of the scan data lead to retrospective discovery of new X-ray transients (Yamauchi et al. 2005, 2007). Since MAXI‘s sensitivity is comparable to that of GINGA and PCA scan observations, new transient sources at a few mCrab are expected to be *regularly* discovered on the Galactic plane and center region.

Above ∼20 keV, coded mask is currently the only technology for imaging observation. INTEGRAL and Swift coded masks have sensitivities of ∼mCrab, and discovered many new hard X-ray sources. INTEGRAL discovered 225 new sources (“IGR” sources) in four years[1] , most of them heavily absorbed transients, while it does not cover the all sky regularly (the field of view is $30^\circ \times 30^\circ$). MAXI is sensitive up to 30 keV, has comparable sensitivity with INTEGRAL and Swift coded mask, and covers the entire sky regularly. Therefore, MAXI is expected to detect at least 50 transient sources per year which are as fain as a few mCrab above 20 keV.

6. Transients Search in Crowded Region

Galactic center/bulge region is known to nest many X-ray transient sources. While INTEGRAL and Swift may resolve individual sources above 20 keV, they may not detect sources which are bright only below 10 keV. Ginga and RXTE scan observations were powerful tools to detect such transient sources in the Galactic center/bulge region, but they are always suffer from source contamination, thus precise determination of the source position was often difficult (e.g., Yamauchi et al. 2007). MAXI is expected to precisely determine the positions of such soft transient sources below 10 keV in the Galactic center/bulge region which is crowded with many sources.

7. Supergiant Fast X-ray Transients

Super Fast X-ray Transients (SFXTs) are discovered with INTEGRAL serendipitously (e.g., Leyder et al. 2007). They have sharp rise (∼ tens of minutes), only a few hour durations, and complex time profiles. The peak luminosities are typically $\sim 10^{36}$ erg s^{-1}. Because of their short durations and low brightness, they are extremely hard to detect. In fact, existence of such sources had not been known before INTEGRAL, which could detect them because of the large field of view.

Characteristics of SFXTs below 10 keV are hardly known, since observations of SFXTs below 10 keV are scarce. MAXI is an ideal instrument to observe SFXTs both above and below 10 keV, since all the sky is covered in every 90 minutes – any SFXTs lasting for a few hours are hardly missed.

8. Ultra-soft Transients

Another strength of MAXI compared to previous all sky monitors is superior sensitivity below 2 keV. MAXI is practically the first all sky monitor which is sensitive in 0.5 – 2 keV energy range, where different kind of sources are dominant from those above 2 keV. One of the kinds of bright transients below ∼ 2 keV is novae, which is accreting or bursting white dwarfs. Novae have thin thermal spectra, which show prominent emission lines of below 2 keV, C, N, O and Si, which may be resolved with MAXI SSC.

Another kind of sources prominent below ∼ 2 keV is Super-Soft Sources (SSSs), which are nuclear burning white dwarfs. Many SSSs have been discovered in LMC, SMC and nearby Galaxies, but only a few Galactic SSSs have been known, because of the significant Galactic absorption. However, systematic monitoring of Galactic transient SSSs has hardly been made. It is possible that MAXI detect dozens of Galactic bright transient SSSs like GQ Muscae (Novae Muscae 1983; Ögelman et al. 1993), which was detected with EXOSAT and ROSAT.

9. Extragalactic Stellar Transients

Thanks to its superior sensitivity, MAXI may become the first X-ray monitor that may detect extragalactic stellar transients. LMC, SMC and M31 are known to be the nests of many transient sources. If we take an example of SMC, more than 24 transient pulsars have been detected after 1994 with ROSAT, ASCA, RXTE and BeppoSAX, while only SMC X-1 was the known pulsar previously. Obviously, there is a great discovery space of extragalactic stellar transients.

Another possible target of extragalactic compact sources is ULXs. Recently, M82 X-1 was detected for the first time above 10 keV with Suzaku PIN, which has a $30'' \times 30''$ FOV, though source contamination was not fully resolved (Miyawaki et al. 2008). In the case of MAXI observation of extragalactic stellar sources, source confusion becomes always a problem. However, if significant ULX outbursts take place, MAXI might be able to detect them. Some ULXs are known to have very soft spectrum (e.g., M101 X-1; Kong and Stefano 2005), so MAXI’s superior sensitivity in low energy band is helpful.

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10. Summary

MAXI will take over the important task of RXTE ASM since 2009, such that it continuously monitors the X-ray all sky, provides light curves of known sources and reports discovery of transient sources promptly. More over, thanks to its superior sensitivity, energy resolution and wide energy coverage, MAXI will be able to open a new window in the study of Galactic X-ray transients.

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