MAXI Light Curves of Non-Blazar Type Active Galactic Nuclei

Shiro Ueno,[1] Tatehiro Mihara,[2] Mutsumi Sugizaki,[2] Masaru Matsuoka,[2] Naoki Isobe,[3] and MAXI team

[1] ISS Science Project Office, ISAS, JAXA, 2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan
[2] MAXI team, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198
[3] Department of Astronomy, Kyoto University, Kitashirakawa, Oiwake-cho, Sakyo-ku, Kyoto 606-8502
E-mail(SU): ueno.shiro@jaxa.jp

Abstract

We have examined the current quality of the MAXI light curves of non-blazar type AGN using three bright samples, Centaurus A, NGC 2110, and NGC 4151. Although the constant flux hypothesis is rejected in χ^2 tests, this will be due to artificial flux fluctuations (such as background subtraction errors) beyond photon counting statistics. Using clusters of galaxies showing the same flux level (10–30 mCrab), we have estimated the artificial fluctuations to be around 3–10 mCrab (3σ) for one-week-bin light curves. To improve the sensitivity of the MAXI light curves, and to conduct systematic studies of AGN X-ray variability, we will estimate source flux and uncertainty of each time bin by two-dimensional image fitting.

Key words: AGN, X-ray, variability

1. Introduction

The different character of the radiation emitted by blazars and by non-blazar type AGN (radio-quiet AGN and misaligned blazars) dictates different observational goals (Ulrich et al. 1997). For blazars, the goal is to understand the structure and physical state of the plasma in the jet. For non-blazar type AGN the focus is on the emission mechanisms, material distributions around the central engine, and the kinematics of the gas.

The usefulness of the MAXI light curves in the diagnosis of bright AGN has been proved by Isobe et al. (2010) in analysis of the blazar Mrk 421. On the other hand, the MAXI light curves of non-blazar type AGN have not been exploited, because of low brightness.

For several non-blazar type AGN, long-term (days to years) X-ray studies have already been performed (for example, Vaughan et al. 2003). MAXI will enable systematic studies using homogeneous sky and time coverage lasting more than five years. In this paper, we examine the MAXI light curves of non-blazar type AGN.

Table 1. Source type distribution of the MAXI public light curves

Source type	Number
Non-blazar type AGN	30
Blazars	26
Cluster of galaxies	35
Galactic sources	144
Unclassified	3

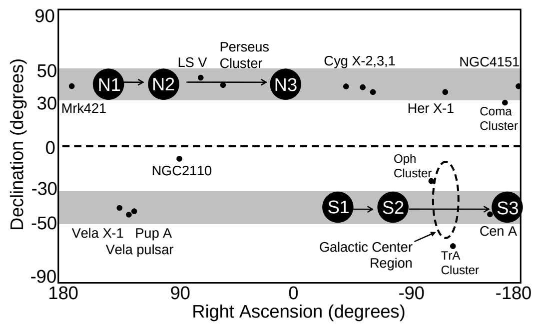

Fig. 1. MAXI's invisible regions moving along the lines of declination, shown with the positions of some X-ray sources (see §3).

2. Source Type Distribution of the MAXI Light Curves

As of November 2010, the MAXI public data archive at http://maxi.riken.jp/ provides the MAXI Gas Slit Camera (GSC) light curves of more than 230 known sources, which were selected based on brightness or scientific interest. Table 1 shows the source type distribution of the light curves.

The MAXI data reduction processes are described in Sugizaki et al (2011). For the public light curves, subtracted backgrounds are estimated from the count rates of the adjacent sky regions, which corresponds to the data obtained in the successive time periods.

3. Light Curve Quality and Declination Dependence

For an individual X-ray source, the quality of the MAXI light curve is affected by the time profile of sky coverage and the time-variable behaviour of non X-ray background. Such observation conditions mainly depend on the declination of the X-ray source in the equatorial coordinate system, when averaged over a time span longer than the orbital precession period of the International Space Station (approximately two months).

To examine the MAXI/GSC light curves of non-blazar type AGN, we have selected three bright ones: Centaurus A, NGC 2110, and NGC 4151. Because of the small number of bright AGN, this sampling is not uniform in the declination space. Instead, we show the declinations (and the right ascensions) of these AGN samples in Figure 1, together with those of other X-ray sources.

In Figure 1, the solid circles denoted as N1 and S1 are the sky regions which are not covered by the MAXI/GSC fields of view during a given one-orbit scanning ($\sim$92 minutes). This pair of 10-degree-radius regions (N1 and S1) are unobservable during the scanning because the total width of the MAXI/GSC fields of view is 160 degrees, narrower than 180 degrees by $10+10$ degrees. N1 is located around the north pole of the rotation axis of the MAXI scanning observation, and S1 is around the south pole. The north unobservable region moves from N1 through N2 to N3 at a constant speed. It traces the the gray-colored zone located in the declination range from 30 to 50 degrees, and comes back to N1 after one cycle of the ISS orbital precession (or in two months). The south unobservable region moves in the same manner.

4. The MAXI Light Curves of Non-Blazar Type AGN

Figure 2 shows the MAXI/GSC light curves of three bright non-blazar type AGN: Cen A, NGC 2110, and NGC 4151. Only the best calibrated energy band, 4–10 keV, is presented. In each panel of light curves, the 10-mCrab flux level is tentatively shown by a dashed line as a flux reference.

X-ray sources located in the gray zones in Figure 1 (declinations from -50 to -30, and from 30 to 50 degrees) fall outside the MAXI/GSC view repeatedly at two-month intervals. Even falling inside the MAXI/GSC view marginally, the sources close to the unobservable regions are known to suffer relatively strong non-X-ray backgrounds, which degrade the quality of light curves. This is one example of the declination dependence of the MAXI light curve quality.

Cen A and NGC 4151 are located inside the gray zones of Figure 1, while NGC 2110 is outside. Without validating the size of errors, we routinely applied χ^2 tests against the constant flux hypothesis. The hypothesis is rejected at greater than 99.99% confidence for all the three light curves. To judge whether individual fluctuations in the light curves are intrinsic to the AGN, we need further study. In this paper, we just examine if there is any hint of variability in the MAXI/GSC light curves by

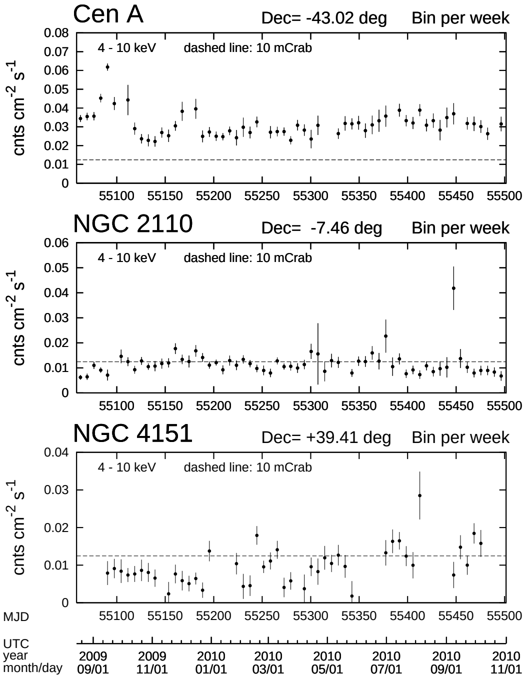

Fig. 2. MAXI light curves of non-blazar type AGN. The dashed lines tentatively show the 10-mCrab flux level as a reference.

comparing them with the RXTE All Sky Monitor (ASM) quick-look results provided by the RXTE/ASM team.

Figure 3 shows the correlation plots between the MAXI/GSC and the RXTE/ASM light curves. In the horizontal axis, the negative time offset means that the MAXI light curve leads the RXTE/ASM ones. If the source flux changes at the time scales of one to ten weeks, and if both the MAXI/GSC and the RXTE/ASM light curves are sensitive enough, we may expect a peak of correlation coefficient at the time offset of zero. Figure 3 does not show such a peak. Considering that the RXTE/ASM sensitivity is not higher than the MAXI/GSC one, we do not need to reject the possibility of real flux variations as an origin of fluctuations of the MAXI light curves. At the same time, however, it is possible that a large part of the fluctuations are artifacts such as background subtraction errors.

To evaluate the magnitude of any additional uncertainty beyond statistical photon counting errors, we use the light curves of cluster of galaxies in the next section.

5. The MAXI Light Curves of Cluster of Galaxies

Figure 4 shows the MAXI/GSC light curves of the Coma cluster, the Ophiuchus cluster, and the Triangulum Australis cluster. They show the same flux level in the MAXI light curves as the AGN in Figure 2. We use these clusters as sources of constant X-ray flux.

Since the MAXI point spread function has a FWHM of 1.5 degrees, the spatial extension of these clusters does

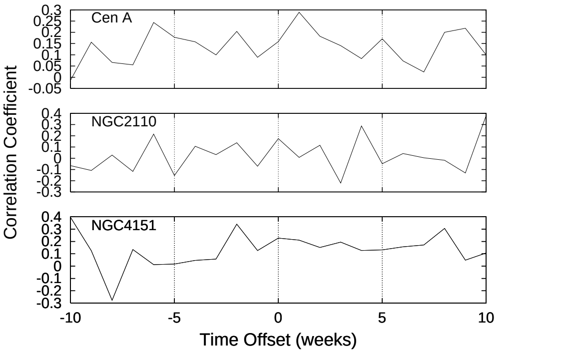

Fig. 3. Correlation plots between the MAXI/GSC and the RXTE/ASM light curves. A negative time offset means the MAXI 4-10 keV light curve leads the RXTE/ASM one. Data between MJD55120 and 55520 are used.

not affect the result of this section. Many clusters of galaxies are know to harbor an AGN (for example, the Perseus cluster; Ezawa et al. 2001). By properly selecting clusters and energy bands, however, we can regard them as constant flux sources.

We applied χ^2 tests to the MAXI light curves of Coma, Ophiuchus, and Triangulum Australis. The constant flux hypothesis is rejected at confidence of 99.96%, $>$ 99%, and 95%, respectively.

To evaluate the amplitude of additional uncertainty beyond photon counting statistics, we added constant uncertainty to the 1σ error of each light-curve bin so that the reduced χ^2 value becomes 1.0 in χ^2 tests of the constant flux hypothesis. Although we do not expect Gaussian distributions for the additional uncertainty, we used the procedure of χ^2 testing as one practical method to quantify the magnitude of additional uncertainty. The result is listed in Table 2. We estimate additional 3σ uncertainty of 3 to 10 mCrab for the light curves of clusters of galaxies in Figure 4.

Additional 3σ uncertainty of 10 mCrab also makes the constant flux hypothesis acceptable for the AGN light curves of NGC 2110 and NGC 4151. For Cen A, the hypothesis is still rejected at 99.96% confidence.

These estimates of additional uncertainty are valid for the current quality of light curves. We need to create higher quality light curves for systematic studies of AGN X-ray variability with MAXI.

6. Current Status and Future Prospects

Currently the MAXI team is capable of identifying and issuing an alert on X-ray brightening with amplitudes larger than 20$\sim$30 mCrab. Except for the bright blazar Mrk 421, the MAXI team has not reported such brightening of AGN since the beginning of the MAXI observation in August 2009.

To improve the sensitivity of the MAXI light curves of AGN, we will estimate source flux and uncertainty in each time bin by two-dimensional image fitting of the MAXI/GSC data with a point spread function and a background model, both simulated for each target AGN (Hiroi et al. 2011).

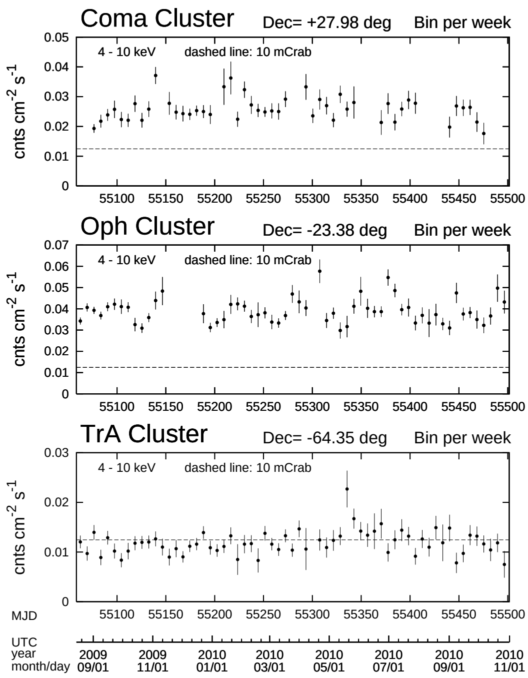

Fig. 4. MAXI light curves of clusters of galaxies. The dashed lines tentatively show the 10-mCrab flux level as a reference.

Table 2. Light curve quality assessment using clusters of galaxies

Cluster name	Additional uncertainty*	Estimated total uncertainty†
Coma Cluster	±6 mCrab	±10 mCrab
Oph Cluster	±10 mCrab	±14 mCrab
TrA Cluster	±3 mCrab	±6 mCrab

* Additional 3σ uncertainty for each weekly bin. Its addition to photon counting uncertainty makes the constant flux hypothesis acceptable.

† Averaged 3σ uncertainty for each weekly bin, estimated by $\{(\text{photon counting uncertainty})^2 + (\text{additional uncertainty})^2\}^{1/2}$.

References

Ezawa, H. et al. 2001, PASJ, 53, 595
Hiroi, K. et al. 2011, in this proceedings
Isobe, N. et al. 2010, PASJ, 62, L55
Sugizaki, M. et al. 2011, in this proceedings
Ulrich, M.H. et al. 1997, ARA&A, 35, 445
Vaughan, S. et al. 2003, ApJ, 598, 935