Mass measurement of accreted material during Superburst using MAXI data

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1. Introduction

An X-ray burst is a phenomenon observed in a binary system consisting of a neutron star and a relatively low-mass gas companion star. Gas falling from the companion star into the neutron star accumulates, reaches a critical state, and undergoes a thermonuclear fusion reaction that causes it to glow in X-rays. This is an X-ray burst.

Normal X-ray bursts last only a few seconds, but there are bursts that last more than an hour. The frequency of occurrence of Superbursts is about 0.3% of all X-ray bursts, and there are still many unknowns. Therefore, a study of the mass of accreted material required for a single Superburst should help to understand the full nature of Superbursts.

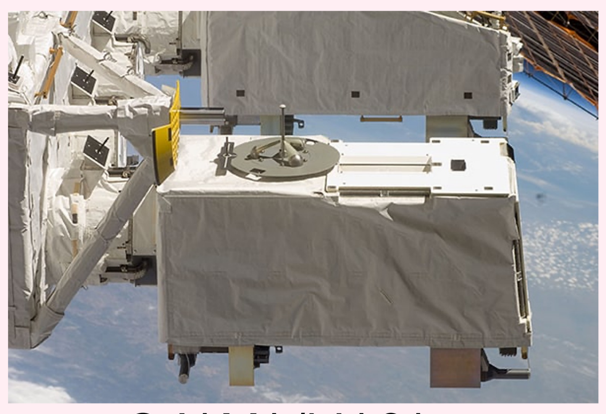
This study combines MAXI (Monitor of All-sky X-ray Image) data with data from a previous satellite (RXTE) to determine the mass of accreted material required for a single Superburst for two objects, Aql X-1 and 4U 1608-52.

2. All-sky monitor

The All-sky monitor is an ideal instrument for observing Superbursts, which can occur at any time.

Rossi X-ray Timing Explorer (RXTE) was a satellite orbiting at an altitude of 600 km from the Earth with a period of about 90 min and was equipped with the All-sky monitor (ASM).

Monitor of All-sky X-ray Image (MAXI; right picture) is attached to the Japanese Experiment Module "Kibo" on the International Space Station (ISS). It can observe about 85% of the entire sky in 92-minute cycle. It started observations on August 15, 2009, and is still in operation.



3. Analysis procedure

The emission from an X-ray binary is essentially proportional to its mass accretion rate. The accretion rate and luminosity at Eddington limit are expressed as $\dot{M}_{\mathrm{Edd}}$ and L_{Edd}. The relation between $\dot{M}$ and L is

$$\frac{\dot{M}}{\dot{M}_{Edd}} = \frac{L}{L_{Edd}},$$

where $\dot{M}_{Edd}$ and L_{Edd} are constants, 2×10^{-8} [$M_\odot/year$] and 3.8×10^{38} [erg/s] respectively.

Therefore, it is sufficient to know the luminosity [erg/s] from observation.

The count rate obtained by direct observation can be converted to flux, and the luminosity can be calculated from the flux with a correction for the distance to the source. The distance to the two sources, Aql X-1 and 4U 1608-52 are summarized in the table below.

Star name	Distance(kpc)
Aql X-1	5.5
4U 1608-52	3.2

Finally, we can calculate $\dot{M}$ from luminosity and integrate over time to obtain the accreted mass.

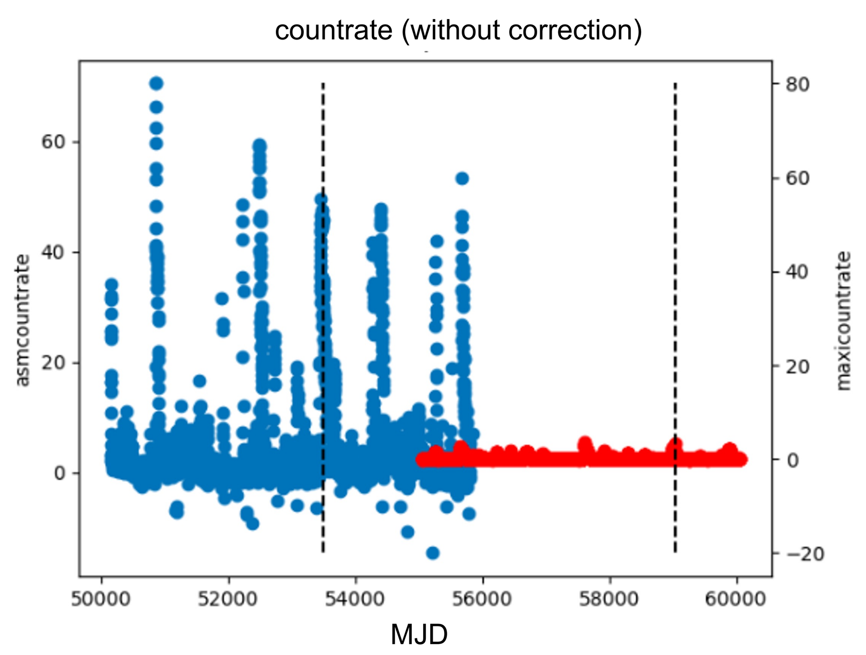
4. Combining ASM and MAXI light curves

Aql X-1 had two superbursts during the MAXI observation, but the first superburst of 4U 1608-52 occurred before the MAXI observation started. Therefore, we used the count rate of the ASM from the time of the first burst until the start of the MAXI observation.

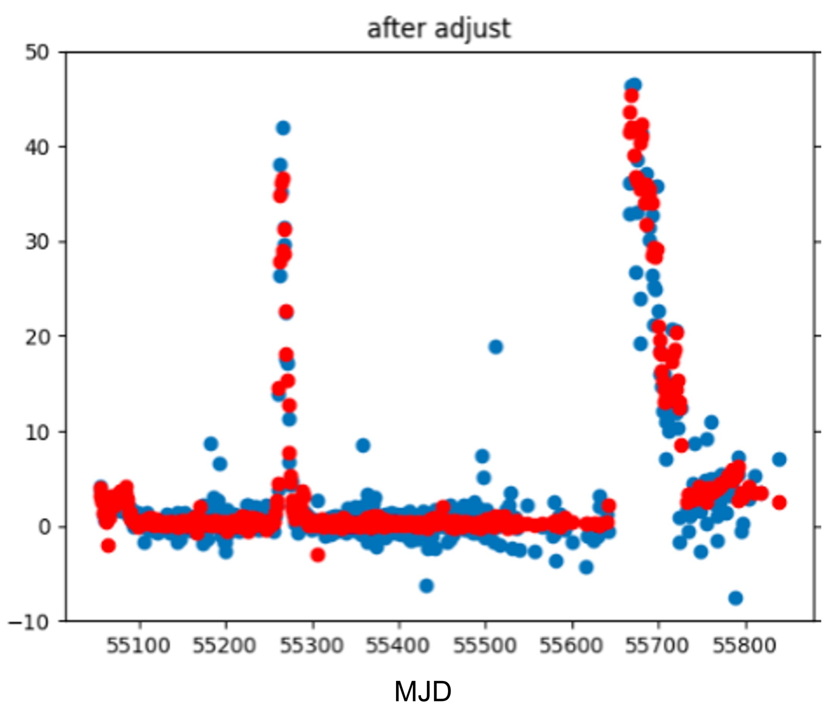
Since we want to use the relationship between the count rate and bolometric flux from RXTE/ASM in the previous study, we need to convert the count rate of MAXI to that of ASM.

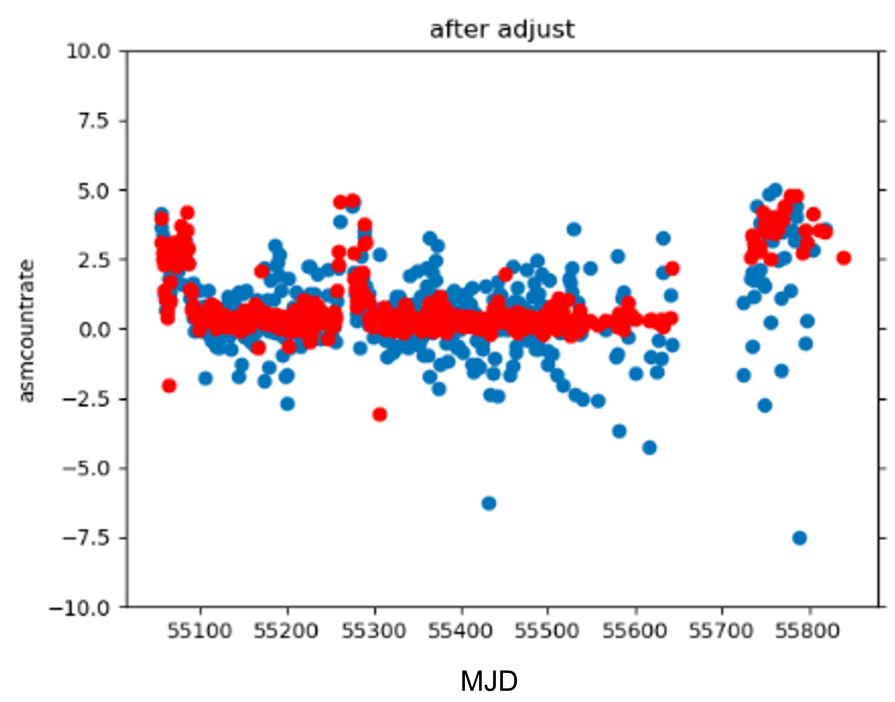
To combine the ASM data with the MAXI data, we estimated a coefficients where the ASM light curves match the MAXI light curves.

The figure below shows the count rate of ASM (blue) and MAXI (red) for 4U 1608-52. The horizontal axis is MJD. The dotted line is the day of the two superbursts in 4U 1608-52, and as the figure shows, the first superburst occurred outside the MAXI observation.



The figures below extract the short periods when both RXTE and MAXI were in operation.

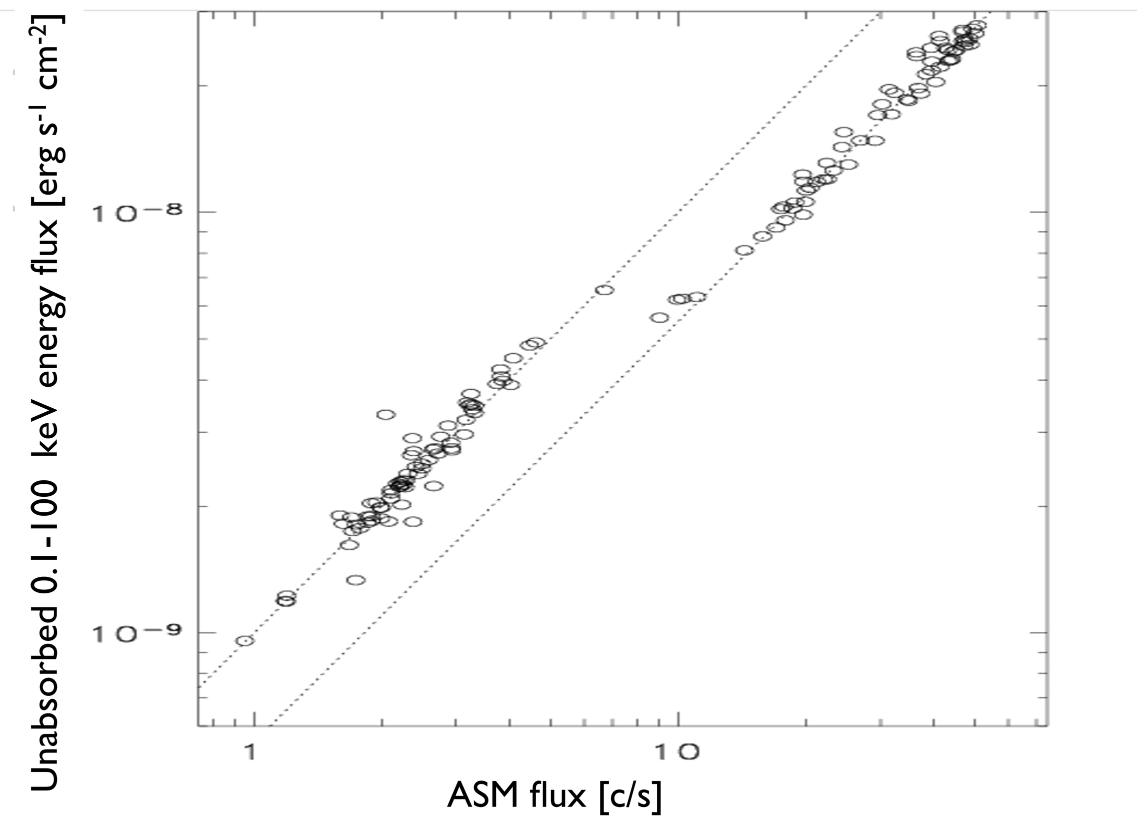




The figure on the left shows the correction for the SOFT state, which contains the data with high count rates.

The figure on the right shows the correction for the HARD state, which contains the data with relatively low count rate < 5.0 counts/s. Both light curves match with the same coefficient of 22.

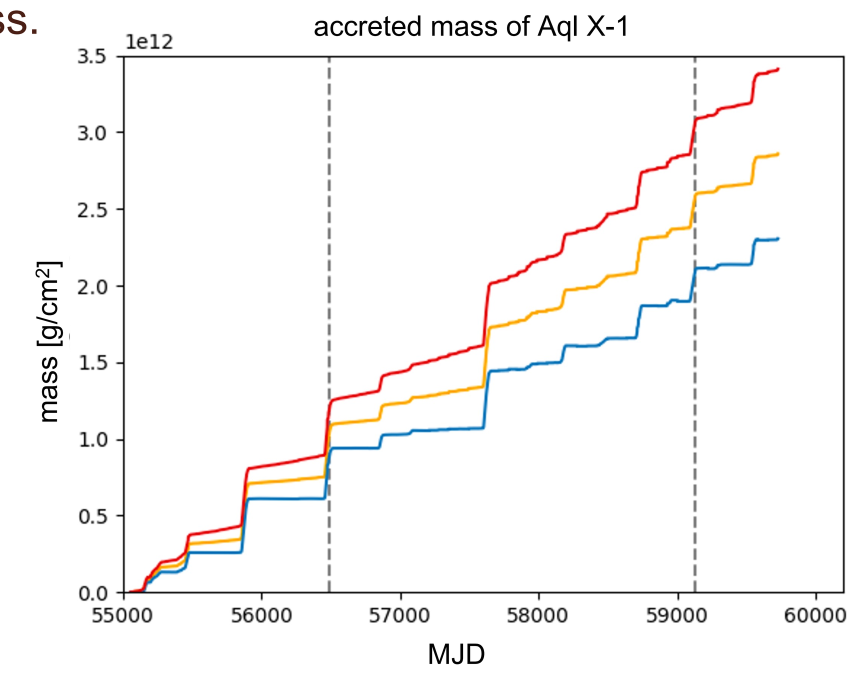
Next, we calculated bolometric flux referring to the count rate-flux correlation from Keek et al. 2008 (the figure below). It can be seen that a jump of the correlation at a count rate of approximately 7.



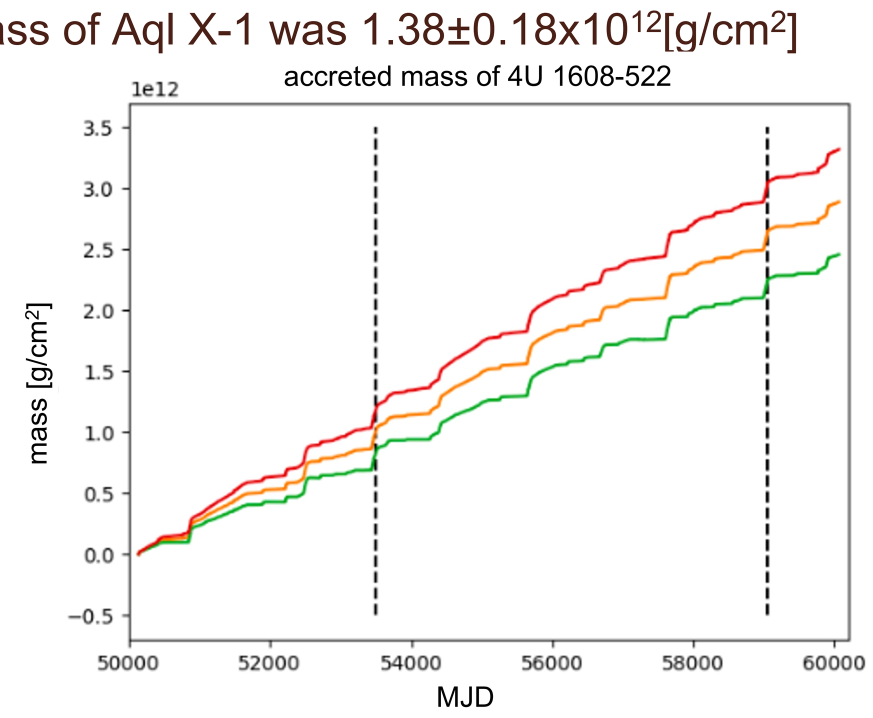
Keek 2008

The upper line represents the hard state of the source, and the lower line represents the soft state of the source. For the conversion factor, we applied 1.0×10^{-9} [erg/c*cm^2] to the count rate for the hard state and 5.5×10^{-10} [erg/c*cm^2] for the soft state.

Then the flux was converted to accretion rate through the luminosity, integrated to the accreted mass.



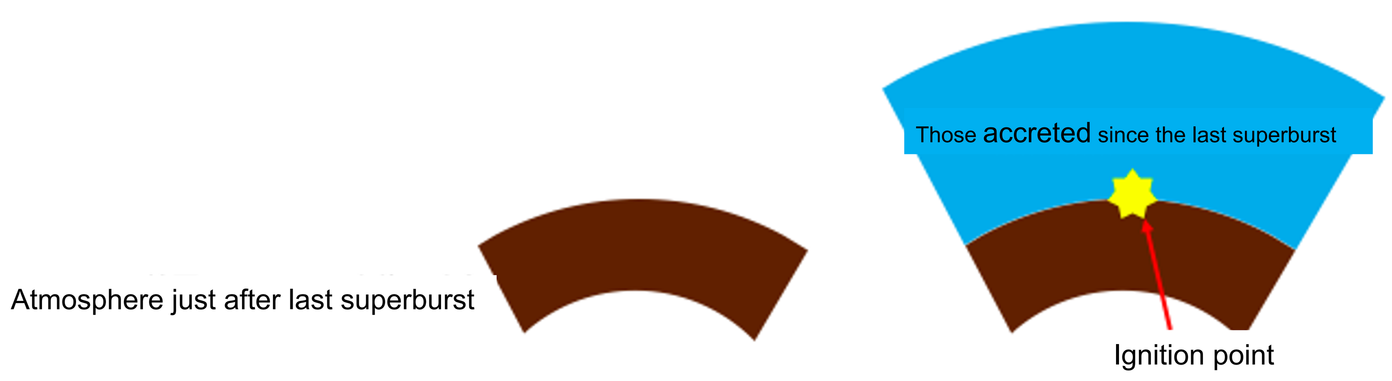
The accreted mass of Aql X-1 was $1.38\pm0.18\times10^{12}$[g/cm^2]



The accretion mass of 4U 1608-52 was $1.52\pm0.34\times10^{12}$[g/cm^2].

5.Future prospective

There is a method to calculate a depth of the burst ignition (Cuming & Macbeth 2004), and the depth for the two sources are known to be order of 10^{12} [g/cm^2]. The depth of the burst ignition and the accreted mass matched in order, indicating that the accreted material is directly used for Superburst.



We hope that similar investigations will be made for other celestial bodies in the future.