Search for X-ray Counterparts of Gravitational Wave Events

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Abstract

The Gas Slit Camera (GSC) of Monitor of All-sky X-ray Image (MAXI) on the ISS scans most of the sky in the 2–20 keV X-ray band every 92 minutes with the orbital revolution of the ISS. Thus it can be used to search for an X-ray counterpart without prompt precise location of the GW event if the emission lasts for tens of minutes. We examined the MAXI/GSC all-sky X-ray images (2–20 keV) obtained in the orbits preceding and following the gravitational wave event GW150914 and GW151226. In each of the 92-min orbits, MAXI/GSC scanned more than 90% of the localization (90% confidence) regions of the GW skymap. No significant new source was found in these scans with typical upper limit of about 1×10^{-9} erg s^{-1} cm^{-2} in 2–20 keV. Based on this sensitivity, we argue that MAXI may be able to detect afterglows of short GRBs within the LIGO/Virgo/KAGRA range for neutron star merger.

Key words: gravitational waves — methods: observational — X-rays: general

1. Introduction

X-ray/γ-ray emission is expected from a gravitational wave (GW) source of neutron-star (NS)-NS or NS-black-hole (BH) binaries, while coalescence of BH-BH binary is not expected to emit electromagnetic (EM) wave. "Short GRB" has been the prime candidate for EM counterpart of promised GW source. There are some evidence of collimation with opening angle of ~ 6–30° for the emissions of short GRBs (Fong et al. 2015), and thus the probability of observing jet emissions is only $\sim 4\%$.

There are several scenarios for soft X-ray production on the GW sources. Kisaka et al. (2015a) calculated the light curves with two emission models from thermal ejecta: one is powered by nuclear decay, and the other is powered by engine activity such as jet, disk wind, or Poynting flux etc. Kisaka et al. (2015b) suggested that reflected photons from GRB jet can also be a source of X-ray emission.

The only observation of a prompt emission in 2–25 keV from a short GRB is GRB 050709, which was detected by HETE-2 (Villasenor et al. 2005). Initial short spike of GRB 050709 was followed by a soft extended emission, which was observed in 2–25 keV. If short GRBs associate with GW events and they are followed by soft extended emissions, MAXI may observe these emissions.

2. MAXI observations of GW sources

MAXI observed the localization regions of two GW events, GW150914 and GW151226. At the time of the first event (2015-09-14 09:50:45 UT; Abbott et al. 2016a) the ISS was about to leave the region with a high particle flux. The MAXI GSC camera was off at the moment, but resumed observation 4 minutes later. The second event occurred at 2015-12-26 03:38:53 UT (Abbott et al. 2016b) when the MAXI GSC was on. Figure 1 shows MAXI all-sky images observed within an orbit (92 minutes) of the GW events. No significant new source was found in these scans with typical upper limit of about 1×10^{-9} erg s^{-1} cm^{-2} in 2–20 keV. This flux corresponds to the luminosity of $\sim 2 \times 10^{46}$ erg, if the source is at a distance of 410 Mpc (Abbott et al. 2016a). The upper limits for various time scales are shown in table 1.

3. Discussion

We compared the upper limits shown in table 1 with other observations. Connaughton et al. (2016) reported that Fermi GBM observed a possible gamma-ray transient associated with GW 150914. Assuming the photon index of -1.4 and using the flux averaged over 1 s, the extrapolated X-ray flux in 2–20 keV is $\sim 2 \times 10^{-8}$ erg cm^{-2} s^{-1}. An X-ray event with this flux level can be detected by MAXI GSC even if the emission lasts only one second.

Another interesting comparison is that with short

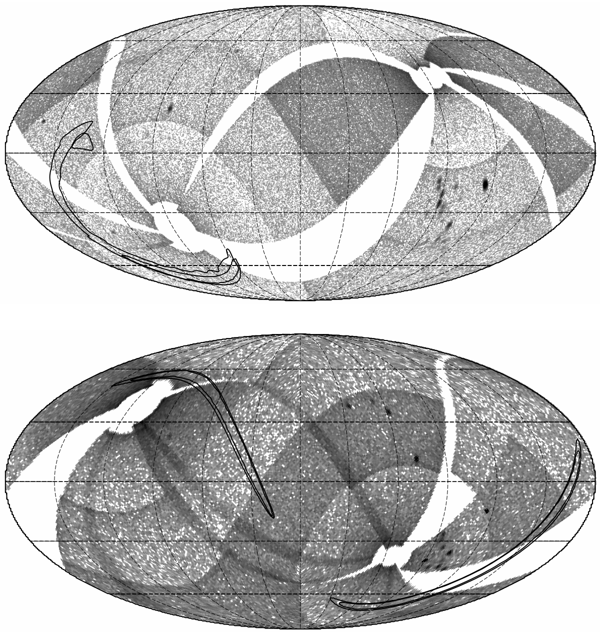

Fig. 1. MAXI all-sky images observed within one orbit of the GW events GW150914 (top) and GW151226 (bottom). The thick black curves show the GW localization regions.

Table 1. Typical upper limits of the MAXI GSC observations in 2–20 keV for various time scales.

	timescale (s)	Flux (erg cm^{-2} s^{-1})	Luminosity (erg s^{-1})
1 orbit	1000	$< 9.5 \times 10^{-10}$	$< 1.9 \times 10^{46}$
1 day	8.6×10^{4}	$< 2.3 \times 10^{-10}$	$< 4.6 \times 10^{45}$
10 days	8.6×10^{5}	$< 0.8 \times 10^{-10}$	$< 1.6 \times 10^{45}$

A distance of 410 Mpc is assumed for the luminosity.

GRB 050709, which was observed by HETE-2 (the short pulse and the extended emission; Villasenor et al. 2005) and Chandra (the afterglow; Fox et al. 2005). Figure 2 shows the MAXI upper limits in three time scales and observed fluxes of GRB 050709 in the short pulse, the extended emission, and the afterglow phase. The open symbols are observed fluxes of GRB 050709. The filled symbols are those scaled to 100 Mpc, which is the expected distance of the NS-NS merger event for the next observation run (O2) of LIGO. The figure shows that MAXI is capable of detecting X-ray emissions from short GRBs like GRB 050709, which may associate with GW events.

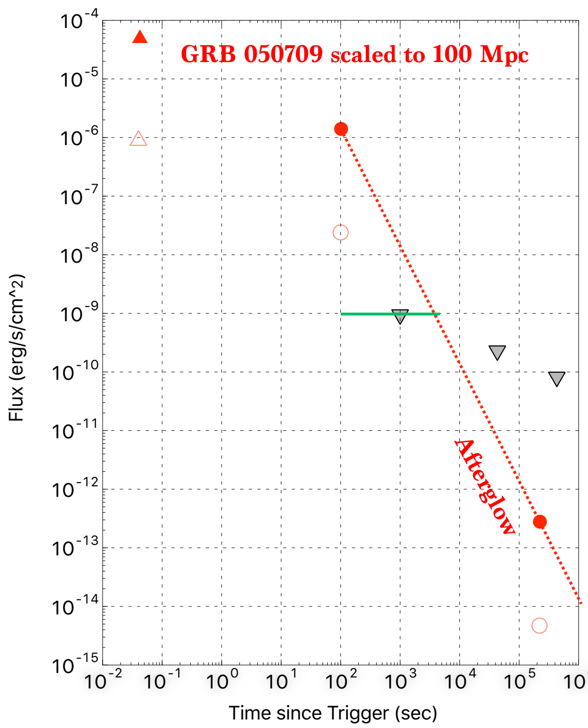

Fig. 2. The MAXI upper limits for three time scales (▽) are compared with the observed X-ray fluxes of GRB 050709 during the short pulse (△), the soft extended emission, and the afterglow (○). The open symbols are observed fluxes of GRB 050709. The filled symbols are the fluxes scaled to 100 Mpc.

4. Summary

Soft X-ray band is unexplored for rapid transients, including possible counterparts of GW events. A large fraction of GW150914 and GW151226 regions were covered in an orbit, yielding a flux upper limit $\sim 10^{-9}$ erg s^{-1} cm^{-2}. An upper limit for 10 days could be an order of magnitude smaller. MAXI can constrain the short GRB scenarios for NS-NS merger at <100 Mpc (O2 range). Instantaneous field of view of MAXI is 2% of the sky. It is too small for observing rare GW events. Observations with instruments of larger field of view are needed.

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