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Infrared AKARI observations of magnetars 4U 0142+61 and 1E 2259+586

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Abstract. We observed two magnetars, 4U 0142+61 and 1E2259+568, with the Japanese infrared satellite *AKARI* to search for the time variability at wavelengths between 2-4 μm. We significantly detected 4U0142+61 in the 4μm band, and determined flux upper limits in the other two bands. We did not detect 1E 2259+586 in any of the bands, and determined upper limits. Comparing the detection of 4U 0142+61 in the 4μm band with the *Spitzer* observation from 2005, we found the flux was reduced to be 64%. We interpret this time variability in the infrared band as an increase of the inner radius of the dust disk around the neutron star, where the increase is due to the sublimation of the dust by the large flare of neutron star itself.

Keywords. stars: neutron – infrared: stars – X-rays: individual (4U 0142+61, 1E 2259+586)

1. Introduction

Magnetars are neutron stars with ultra-strong magnetic fields (10^{14}–10^{15} G). They emit X-ray and gamma-ray photons by releasing magnetic energy; however their exact emission mechanism is still an open question. Therefore these sources have been intensively observed, at multiple wavelengths from radio to gamma-rays, to reveal that emission mechanism.

Some magnetars have optical and infrared (IR) counterparts. The most luminous magnetar, 4U 0142+61, is a 8.7 s pulsar and its IR-optical counterpart has been most intensively observed. In the Spitzer observation, a mid-IR hump was discovered in the spectral energy density. While the optical component is demonstrably of magnetospheric origin, the mid-IR component may arise from a dust disk around the magnetar (Wang *et al.* 2006). So far no time variability was reported for the dust disk component. The 7 s pulsar 1E 2259+586, has been also detected in the mid-IR band, but there was no mid-IR hump (Kaplan *et al.* 2009).

Here, we report on our IR observations of 4U 0142+61 and 1E 2259+586 with the Japanese infrared satellite *AKARI*. The bands AKARI observed, 2–4μm, are thought to be dominated by the dust disk. The main purpose of our study is to search the time variability of this min-IR component.

We will present the details of our results in this paper.

2. Observational results of 4U 0142+61 and 1E2259+586 with AKARI/IRC

We carried out imaging observations of 4U 0142+61 and 1E 2259+586 with AKARI/IRC in 2009 and 2010. The 2μm and 4μm bands have been observed with terrestrial telescopes and Spitzer, but only AKARI/IRC can observe the 3μm band, which is dominated by the dust disk component. Therefore, this 3μm observation is important to test the dust disk model.

We performed PSF photometry for the position of 4U 0142+61 and 1E 2259+586. Figure 1 shows the 2-4μm images of 4U 0142+61. We could significantly detect 4U 0142+61 at the pulsar position in 4μm image. But, unfortunately, there was no significant detection of 4U 0142+61 in either the 2μm or 3μm band. Therefore we determined the upper limit of the infrared flux of these bands. Magnetar 1E 2259+586 could also not be detected in two bands, 2μm and 3μm, and there too we determined the upper limit of the flux. Figure 1 shows the spectral energy distribution of these two magnetars. The left and the right panel show the results of 4U 0142+61 and 1E 2259+586, respectively.

We discovered the flux of 4U 0142+61 in the 4μm band decreased to 64% of the previous flux obtained by Spitzer observation in 2005 (6.4 σ). Our result suggests that the MIR emission from 4U 0142+61 is variable.

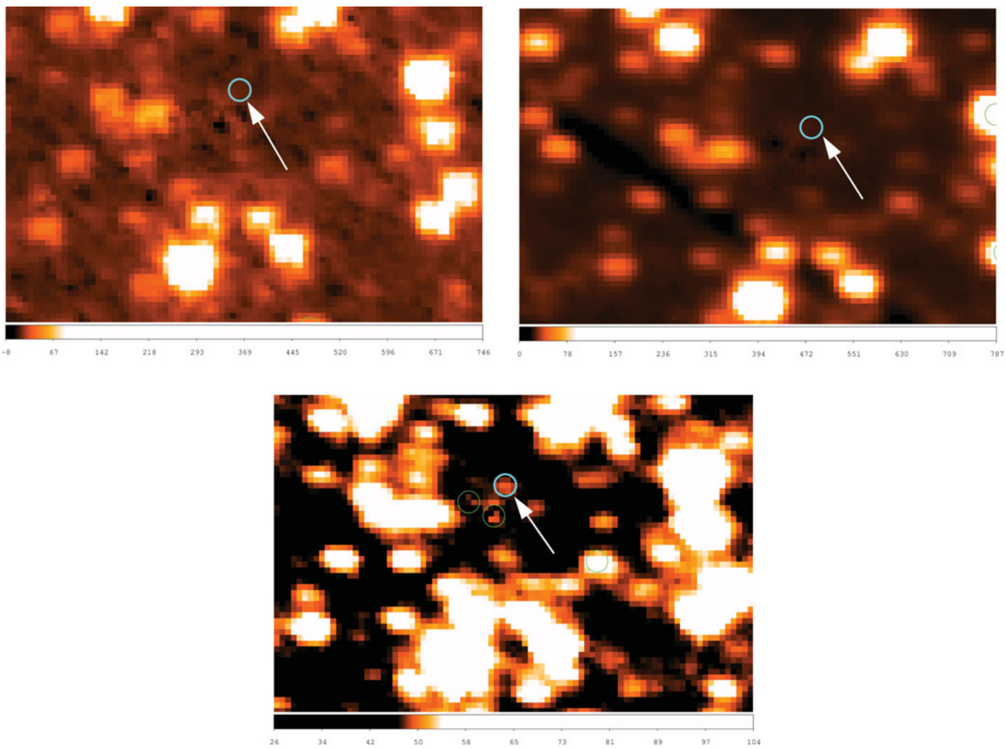

Figure 1. Infrared images of 4U 0142+61. These images were taken with AKARI/IRC in 2009. Left, middle, and right pannel shows 2μm, 3μm, and 4μm bands images respectively. The blue circle in all images (upper right of all images) shows the position of 4U 0142+61.

3. Discussion

In this discussion, we concentrate on the result on 4U 0142+61.

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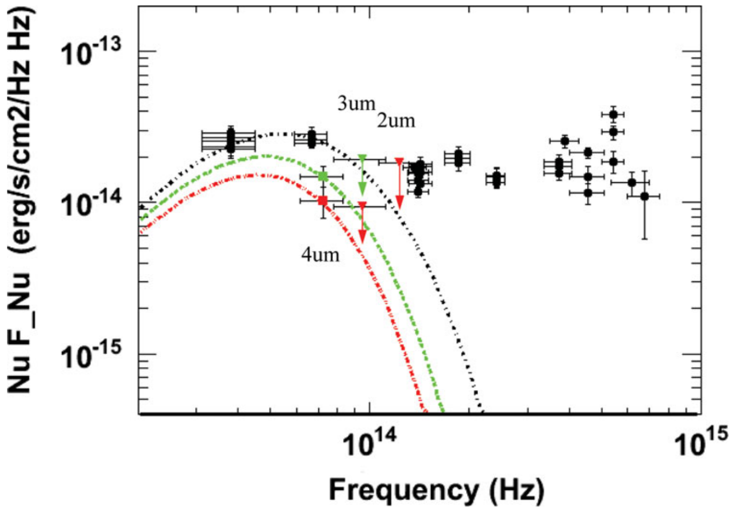

Figure 2. The disk model consistent with the Spitzer data is shown in black line (upper dashed line), where the rin is 20×10^{10} cm. Our results are explained by red (middle dashed line) and green ones (lower dashed line), where $r_{\rm in}$ of red line is 55×10^{10} cm and $r_{\rm in}$ of green line is 40×10^{10} cm.

Before our two AKARI observations in 2009 and 2010, we found a large flare from 4U 0142+61 in the *RXTE* ASM light curve (Kohmura *et al.* 2012). Assuming the "dust disk model" as the infrared emission mechanism, that dust disk was expected to be heated and sublimated by this large flare.

If the X-rays produced by the large flare of the central X-ray pulsar have energies large enough to sublimate the disk, the inner part of disk will vanish and then inner radius increased. As a result, the size of dust disk decrease, and the infrared flux must decrease too.

To check this scenario, we applied an X-ray heated disk model (Vertilek *et al.* 1990) as the dust disk around magnetar and calculated the energy spectra by changing the inner disk radius as shown in Fig. 2. In the X-ray heated disk mode, the temperature of the disk is a function of radius from the central neutron star. For the temperature distribution in our calculation, we follow the model shown in Wang *et al.* (2006). This model has five parameters, the value of inclination angle i, distance to the source d, albedo of the disk η_d, outer radius of disk $r_{\rm out}$, and inner radius of disk, $r_{\rm in}$.

In our calculation, we fixed four parameters without $r_{\rm in}$ and changed inner radius of disk. As a result, we succeeded in describing the infrared flux variability by only changing the inner radius of the dust disk.

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