Millimeter Interferometer Observations of the Magnetar 4U 0142+61

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Abstract. The Anomalous X-ray Pulsar 4U 0142+61 is the only neutron star where it is believed that one of the long searched-for 'fallback' disks has been detected in the mid-IR by Wang et al. [1] using *Spitzer*. Such a disk originates from material falling back to the NS after the supernova. We search for cold circumstellar material in the 90 GHz continuum using the Plateau de Bure Interferometer. No millimeter flux is detected at the position of 4U 0142+61, the upper flux limit is 150 μJy corresponding to the 3 σ noise rms level. The re-processed Spitzer MIPS 24μm data presented previously by Wang et al. [2] show some indication of flux enhancement at the position of the neutron star, albeit below the 3σ statistical significance limit. At far infrared wavelengths the source flux densities are probably below the *Herschel* confusion limits.

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INTRODUCTION

There is only one suspected disk around an isolated neutron star. It was reported by Wang et al. [1], who detected the Anomalous X-ray Pulsar (AXP) 4U 0142+61 in mid-Infrared in the *Spitzer* IRAC 8.0 μm and 4.5 μm bands. They explained their detection with a passive, debris disk around the AXP – the only fallback disk thought to be detected so far. Ertan et al. [3] explained the same spectrum with a viscously active, gaseous disk model, in which accretion is possible. An accretion flow with bulk-motion Comptonization of soft X-ray photons can explain both the hard and the soft X-ray spectra of AXP 4U 0142+61 ([4] and these proceedings). 4U 0142+61 is known to be variable, especially at NIR-wavelengths, but also at X-ray wavelengths as investigated by, e.g., Hulleman et al. [5], Durant and van Kerkwijk [6], Gonzalez et al. [7]. Currently, these variations cannot constrain the disk properties. The flux density of the AXP does not vary in the Spitzer IRAC bands [8].

MILLIMETER OBSERVATIONS

We observed 4U 0142+61 at 90 GHz (3mm) applying the Plateau de Bure Interferometer (PdBI) covering baselines from 24 m to 97 m. The standard calibration and the data reduction were performed in terms of the Grenoble Software environment GILDAS.

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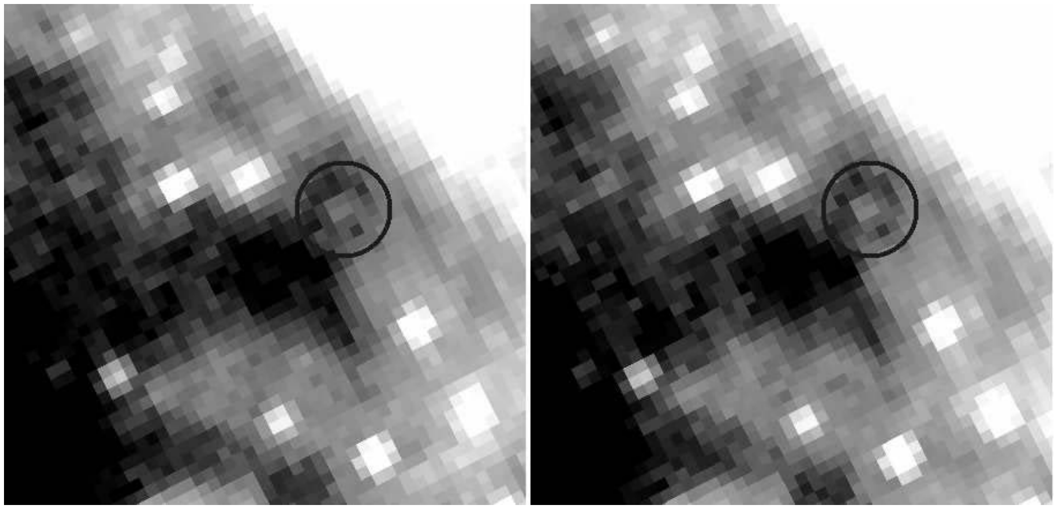

FIGURE 1. The archival *Spitzer* MIPS 24μm observations of 4U 0142+61 by Wang et al. [2], reprocessed with the *Spitzer* pipeline version S18.12.0. Shown are the two independent AORs with the target region marked by a circle with $r = 10$ arcsec. North is up, East to the left.

The field of view (primary beams) covers $\approx 56''$, the synthesized beamsize amounts to $5.84'' \times 4.99''$, position angle (PA) 106.7°. There is no significant amount of cold dust emission around 4U 0142+61. We obtain a $3\,\sigma$ rms limit of 150 μJy. Assuming the conventional dust mass formula for optically thin dust emission and a temperature of 10 K we estimate a cold dust mass limit of ~ 3000 Earth masses at a distance of 3.6 kpc [9, 10].

SPITZER MIPS OBSERVATIONS

Wang et al. [2] obtained a *Spitzer* MIPS 24μm flux density limit of $3\sigma = 38\,\mu$Jy. Since these data have been first processed the *Spitzer* data reduction pipeline has undergone significant updates, the most important one is a much better flat field treatment. The two independent, re-processed AORs (Astronomical Observation Requests) show some indication of a faint source at the target position (see Fig. 1). However, the usual PRF (point response function) fitting fails and aperture photometry is highly uncertain due to a complicated background. We estimate an aperture corrected flux of around 41 μJy corresponding to roughly 2σ at the target position. Thus, the seen flux enhancement is insignificant, but its appearance in two independent AORs is intriguing.

SUBMILLIMETER OBSERVATIONS WITH HERSCHEL ?

In May 2009 the 3.5 m *Herschel* Space Observatory was launched, with the Photodetector Array Camera and Spectrometer (PACS) covering wavelengths of $55-210\,\mu$m [11], and the Spectral and Photometric Imaging REceiver (SPIRE) covering wavelengths of

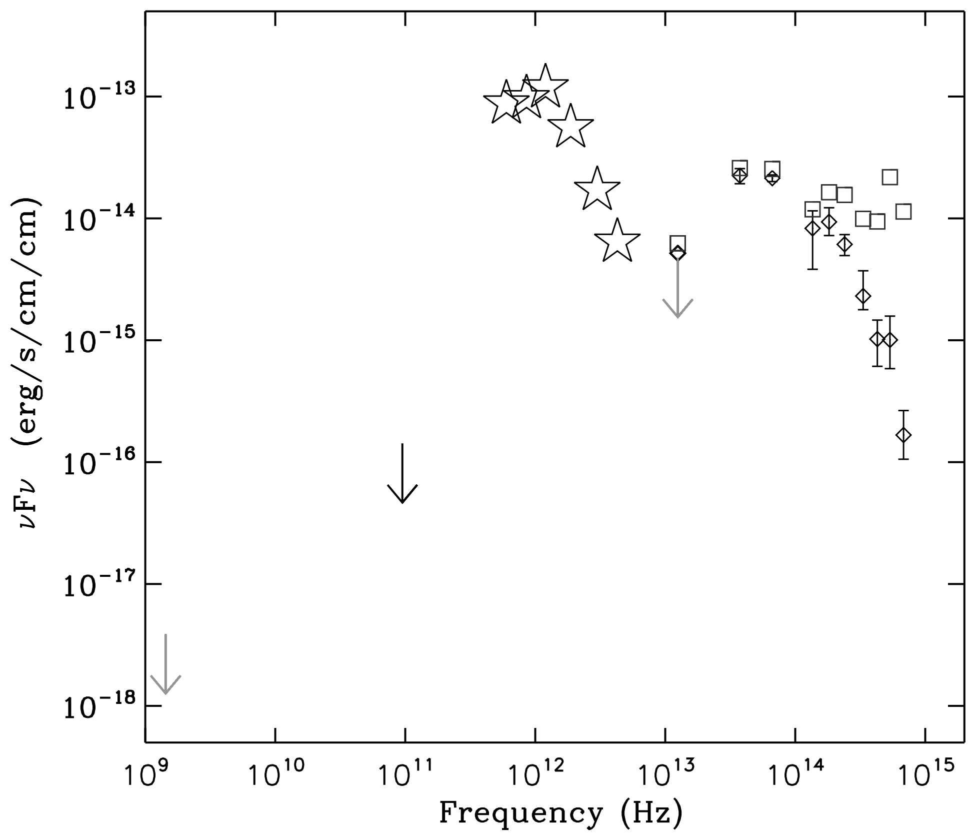

FIGURE 2. The spectral energy distribution of 4U 0142+61 from radio to optical wavelengths. The diamonds show the *average* of the measurements reported, e.g., by Hulleman et al. [5], Durant and van Kerkwijk [6], Wang and Kaspi [8]. Note that the 'error bars' are actually a sum of the spread in magnitudes and the respective errors. The squares are the extinction corrected values, using $A_V = 3.5$ [9] and the extinction curves by Fitzpatrick [13] with $R_v = 3.1$, and Indebetouw et al. [14]. The black arrow indicates our millimeter interferometer 3σ limit (base of arrow). Grey arrows indicate the VLA limit (5σ) by Gaensler et al. [15] and the MIPS 24μm limit (3σ) by Wang et al. [2]. The latter is overplotted by our MIPS 24μm flux estimation of the reprocessed *Spitzer* data and its extinction corrected value [16, 14]. Stars represent the confusion noise limits at the *Herschel* wavelengths 500 μm, 350 μm, 250 μm, 160 μm, 100 μm and 70 μm as obtained by HSpot (v5.0).

194 – 672 μm [12]. Investigations of 4U 0142+61 at these longer wavelengths would be very interesting for confirming and constraining the fallback disk properties. We use the HSpot software (version 5.0) to obtain an estimate of the confusion noise at the source position, which considers both criteria – the average fluctuation amplitude of the background and the background source density. The calculated confusion limits are plotted in Fig. 2. The flux densities of 4U 0142+61 which one would expect from the current spectral energy distribution are below the confusion limits at the respective *Herschel* wavelengths. Thus, it will be very difficult to constrain the fallback disk with PACS or

SPIRE.

CONCLUSIONS

There is no significant amount of cold dust around 4U 0142+61. At $T \sim 10\,\mathrm{K}$, we derive a cold dust mass limit of ~ 3000 Earth masses. Reprocessed *Spitzer* MIPS 24μm data indicate a very faint, statistically insignificant source at the position of the AXP. If this infrared emission can be confirmed, it would be consistent with an outer disk radius of $R_{out} \geq 10^{12}$ cm within the fallback disk model by Ertan et al. [3].

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