A SEARCH FOR THE OPTICAL COUNTERPART TO THE MAGNETAR CXOU J010043.1−721134

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ABSTRACT

After our tentative detection of an optical counterpart to CXOU J010043.1−721134 from archival Hubble Space Telescope (HST) imaging, we have followed up with further images in four bands. Unfortunately, the source originally identified is not confirmed. We provide deep photometric limits in four bands and accurate photometry of field stars around the location of the magnetar.

Subject headings: pulsars: individual (CXOU J010043.1−721134)

1. INTRODUCTION

Magnetars are neutron stars that derive their large X-ray luminosity from the decay of a superstrong magnetic field or the order \(10^{15}\) G (and even greater internally), many orders greater even than normal radio pulsars and accreting X-ray sources (Woods & Thompson 2006). They are found preferentially in the Galactic plane, in accordance with their presumed youth and high-mass progenitors (e.g., Figer et al. 2005). This makes observations in soft X-rays and the optical difficult, due to the large columns of extincting material to each of the objects (Durant & van Kerkwijk 2006a). For the nearest of the magnetars, 4U 0142+61, an intriguing break was seen in the broadband optical spectrum between the \(Y\) and \(B\) bands (Hulleman et al. 2004). Due to the faintness and extinction to this source, it has not proved possible so far to further characterize the optical feature.

A source for which the extinction will be much less of an issue is CXOU J010043.1−721134, a magnetar in the Small Magellanic Cloud. This source was detected by Chandra as a slow-spinning X-ray source, with a bright thermal or power-law spectrum (Lamb et al. 2002). Although relatively faint in the first observations by Lamb et al. and Majid et al. (2004) in later Chandra and XMM observations, the object had brightened somewhat toward a similar luminosity to the other anomalous X-ray pulsars (~2 \(\times\) \(10^{33}\) ergs s\(^{-1}\), 0.5–10 keV range; McGarry et al. 2005). The AXPs (the more stable type of magnetar) all seem to have the same 2–10 keV luminosity (~\(1 \times 10^{33}\) ergs s\(^{-1}\); Durant & van Kerkwijk 2006b).

In Durant & van Kerkwijk (2005a, hereafter DvK05), we presented evidence for the detection of an optical counterpart to CXOU J010043.1−721134 in archival HST imaging with the Wide Field Planetary Camera 2 (WFC2). The serendipitous detection was based on a single exposure from a survey of the SMC (Tolstoy 1999). Although a faint source, the detection parameters and statistics of non-detections in the field pointed to it likely being a true detection.

Here we present deeper HST imaging of the field of CXOU J010043.1−721134 in four bands to attempt to confirm the tentative detection presented in DvK05.

2. OBSERVATIONS

Following the failure of the Advanced Camera for Surveys (ACS), we planned an imaging campaign with the Wide Field

### Table 1

| Position | Magnitude |
|----------|-----------|
|           |           |

\(1\) See Guide Star Catalog 2.2, Space Telescope Science Institute (STScI) & Osservatorio Astronomico di Torino 2006, VizieR Online Catalog I/305.

\(2\) See R. Cutri et al. 2003, VizieR Online Catalog II/246.
Fig. 1.—Images of the field of CXOU J010043.1−721134 in the F814W, F606W, F439W, and F336W filters (left to right, top to bottom). The positional 90% confidence circle based on the Chandra detection is shown, and the stars listed in Table 1 are labeled.
to the images in Figure 1, one can see that some of these sources are not good detections.

The 3 σ photometry limits for the field were: 24.2 in F336W, 25.6 in F439W, 26.2 in F606W, and 25.9 in F814W. These magnitudes are flight system, defined such that a star of zero color in the Johnson-Cousins UBVRI system has zero color in any pair of WFPC2 filters, and the F555W magnitudes \( m_{555} = V \) (Holzman et al. 1995). A color-magnitude diagram of stars in the field is shown in Figure 2 for the two filters F606W and F814W, which have the highest number of detections. All of the detected stars are consistent with being part of the normal stellar population in the field.

3. DISCUSSION

Given the nondetection probability of \(~1.5\%\) estimated in DvK05, it is rather surprising that the deeper observations presented here failed to detect the same source. The estimate was based on the number of good detections in the field which would also have been considered interesting (by color), had they fallen within the positional error circle. Only one new source is detected within the positional error circle, star 6, and this is red enough in \( m_{606} - m_{814} \) to appear as a normal star on the color-magnitude diagram, Figure 2.

Star Y does not appear to have varied significantly between the two observations in either filter where it was detected, and star Z is still consistent with a bright early-type star.

Two distinct possibilities exist for the non-detection of the counterpart to CXOU J010043.1–721134 proposed in DvK05: the original detection was false, or the detection was real, but the source has faded considerably in the intervening time. For the detected object to physically leave the positional uncertainty circle at the distance of the SMC, or even by a foreground white dwarf is not possible, the proper motion required would be too great.

One obvious solution is that the detection in DvK05 was, in fact, a cosmic ray or some other artifact. HSTphot rejects detections as cosmic rays if they are much sharper than typical stars, and this source was, if anything, more diffuse. Some objects were, however, in the same part of the color-magnitude diagram as star X, so there is a small but nonnegligible chance that this was a mere fluke. In this deeper set of observations, there remain a few detections of similar brightness in \( m_{606} \) and blueness in \( m_{606} - m_{814} \) as the original detection. The large scatter at the bottom of Figure 2 is not significant in this respect, as these sources (including the couple near the error circle) are more poorly measured than star X appeared to be in DvK05.

Although the detection in DvK05 is clearly in doubt following these observations, it is possible that the object faded considerably in the optical, and became undetectable. The only AXPs that have been detected multiple times in the optical, 4U 0142+61, does at times show large variations in flux, and the X-ray to optical flux ratio inferred in DvK05 was much larger for star X than it had typically been for 4U 0142+61. Assuming that none of the sources detected is the counterpart to CXOU J010043.1–721134, we derive a limit on the flux ratio \( f_x/f_O > 114 \) (with \( V \approx m_{606} \), \( A_V = 0.3 \) from Hilditch et al. 2005; and X-ray flux in the 2–10 keV range from Woods & Thompson 2006), which compares to a typical value of 460 for 4U 0142+61. Thus, the general consistency found between different AXPs (Durant & van Kerkwijk 2005b) could still hold for this source as well.

To summarize, follow-up HST WFPC2 observations of the field of CXOU J010043.1–721134 have failed to confirm our earlier tentative detection of an optical counterpart. No convincing counterpart is seen, with much better limiting magnitudes than before. The absence of a detection could either mean that the original detection was false, or that the counterpart has faded significantly. If the latter, its X-ray to optical flux ratio could now be the same as for 4U 0142+61.

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