THE COMPACT X-RAY SOURCE 1E 1547.0−5408 AND THE RADIO SHELL G327.24-0.13:
A NEW PROPOSED ASSOCIATION BETWEEN A CANDIDATE MAGNETAR
AND A CANDIDATE SUPERNOVA REMNANT

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ABSTRACT

We present new observations of the field centered on X-ray source 1E 1547.0−5408. Analysis of a new Chandra observation shows that it is unresolved at arcsecond resolution, and analysis of a new XMM-Newton observation shows that its X-ray spectrum is best described by an absorbed power-law and blackbody model. A comparison of the X-ray flux observed from 1E 1547.0−5408 between 1980 and 2006 reveals that its absorbed 0.5−10 keV X-ray flux decreased from $\sim2 \times 10^{-12}$ to $\sim3 \times 10^{-13}$ ergs cm$^{-2}$ during this period. The most recent XMM-Newton observation detected no pulsations from 1E 1547.0−5408, allowing us to put a 5 $\sigma$ confidence upper limit of 14% for the 0.5−10 keV peak-to-peak pulsed fraction for sinusoidal pulses with periods slower than 1.8 s. A near-infrared observation shows a magnitude $K_s = 15.9 \pm 0.2$ source near 1E 1547.0−5408, but the implied X-ray to infrared flux ratio indicates that it is an unrelated field source, limiting the IR magnitude of any counterpart to 1E 1547.0−5408 to $\gtrsim 17.5$. Archival radio observations reveal that 1E 1547.0−5408 sits at the center of a faint, small radio shell, G327.24-0.13, possibly a previously unidentified supernova remnant. The X-ray properties of 1E 1547.0−5408 suggest that it is a magnetar, and the spatial coincidence between this source and G327.24-0.13 suggests that 1E 1547.0−5408 is associated with a young supernova remnant, supporting a neutron star interpretation. If both the nature of 1E 1547.0−5408 and G327.24-0.13 and their physical association are confirmed, this pair will be an important addition to the small number of known associations between magnetars and supernova remnants.

Subject headings: ISM: individual (G327.24-0.13) — stars: neutron — supernova remnants — X-rays: individual (1E 1547.0−5408) — X-rays: stars

1. INTRODUCTION

Massive stars ($M \gtrsim 8 M_\odot$) end their lives in supernovae, often forming neutron stars. For many decades, it was thought that these neutron stars had short initial spin periods ($P_0 < 1$ s), dipole surface magnetic fields with strengths $B \sim 10^{12}$ G, and were most often observed as radio pulsars. While this describes the majority of known neutron stars, several new classes of neutron stars have since been discovered. Most notable of these are anomalous X-ray pulsars (AXPs) and soft gamma repeaters (SGRs), which have spin periods longer than most normal radio pulsars ($P \gtrsim 5−12$ s) and high period derivatives ($P \sim 10^{-11}$ s$^{-1}$; Woods & Thompson 2006). Due to the strong surface dipole magnetic fields inferred from these timing properties ($B \sim 10^{14}−10^{15}$ G), these sources are believed to be "magnetars": neutron stars whose X-ray emission is powered by the decay of these extremely strong fields (Duncan & Thompson 1992; Thompson & Duncan 1995, 1996).

Currently there are only 13 confirmed magnetars. As a result, it is difficult to determine the spatial distribution, birth rate, and active lifetime of these sources, information vital to understanding the relationship between magnetars and other products of core-collapse supernovae. This uncertainty is further exacerbated by the presence of at least one transient magnetar, XTE J1810−197 (Ibrahim et al. 2004). A powerful way of determining the relationship between magnetars and other classes of neutron stars is to use environmental information to constrain their ages and progenitors of these populations. This is most easily done for those neutron stars associated with supernova remnants (SNRs), since observations of SNRs allow independent estimates of distances and ages, the densities of the surrounding medium, and the explosion energies of the progenitor supernovae. To date, there are only two secure magnetar/SNR associations: 1E 2259+586 in SNR CTB 109 (Fahlman & Gregory 1981) and 1E 1841−045 in SNR Kes 73 (Vasisht & Gotthelf 1997), although SGR 0526−66 is possibly associated with Large Magellanic Cloud SNR N49 (Marsden et al. 1996; Gaensler et al. 2001b). Based on the ages of these SNRs (not including SNR N49), as well as the offset between these magnetars and the centers of their SNRs, Gaensler et al. (2001b) concluded that magnetars are young (<10,000 yr) neutron stars with low projected space velocities (<500 km s$^{-1}$). This assertion that magnetars have a low spatial velocity is also supported by recent proper motion measurements of XTE J1810−197 (Helfand et al. 2007). In addition, an analysis of the X-ray emission from these SNRs implies that the level of energy injection at early times, both from supernova ejecta and from the magnetar spin down, was $\sim 10^{51}$ ergs, constraining the initial spin period of these magnetars to $P_0 \gtrsim 5$ ms (Vink & Kuiper 2006). While much has been learned from detailed studies of the few associations between magnetars and SNRs, much more can be gained by identifying additional examples of such associations.

In this paper, we propose a new potential magnetar/SNR association between the X-ray source 1E 1547.0−5408 and the Galactic radio shell G327.24-0.13. In § 2 we present both X-ray (§ 2.1) and near-infrared (near-IR; § 2.2) observations of the field around 1E 1547.0−5408. In § 3 we present archival radio observations that show that 1E 1547.0−5408 is located at the center of G327.24-0.13. In § 4 we argue that the compact nature of 1E 1547.0−5408, its lack of a bright near-IR counterpart,
and its location of the 1E 1547.0—5408 source at the center of G327.24-0.13 imply that this source is a neutron star, and that the X-ray spectrum and variability of 1E 1547.0—5408 strongly suggest that it is a magnetar.

2. OBSERVATIONS OF 1E 1547.0—5408

2.1. X-Ray Data

X-ray source 1E 1547.0—5408 was discovered by *Einstein* during a search for X-ray counterparts of unidentified γ-ray sources (Lamb & Markert 1981)—in this case, the γ-ray source 1C G327-0 detected by *COS-B* (Hermsen et al. 1977). This detection was confirmed by the *Advanced Satellite for Cosmology and Astrophysics* (*ASCA*) Galactic plane survey, in which the source AX J155052—5418 was detected at the same position (Sugizaki et al. 2001). Recently, this field has been observed twice with *XMM-Newton* (an archival observation in 2004 and a new observation in 2006), and again with the *Chandra X-Ray Observatory* in 2006. A summary of these observations is given in Table 1. Both *XMM-Newton* data sets were processed using the standard tasks given in *XMM-SAS* version 6.5.0, while the *Chandra* data were analyzed using CIAO version 3.4. All data sets were then filtered using the standard energy and quality criteria.

As shown in Figure 1, due to the improved spatial resolution of *XMM-Newton* and *Chandra*, we detect two point sources in the overlapping position error circles of 1E 1547.0—5408 and AX J155052—5418: a bright source that we designate CXOU J155054.1—541824 (=XMMU J155054.3—541825) and a much fainter source we designate XMMU J155053.7—541925. This second source is detected in both *XMM-Newton* observations but not the *Chandra* observation, because it fell in a chip gap. For both sources, their extents are consistent with the point-spread function of the telescope at that position. The most accurate position for CXOU J155054.1—541824 comes from the *Chandra* observation, which gives R.A. = 15°50′54.1″, decl. = −54°18′23.8″ (J2000.0). This position has not been registered to an external reference frame, due to the lack of field X-ray sources with counterparts at other wavelengths. Therefore, the error in this position is dominated by the pointing accuracy of *Chandra*—a typical 99% confidence radius of ~0.8″. As shown in Table 2, the observed count rates of both CXOU J155054.1—541824 and XMMU J155053.7—541925 declined between the 2004 and 2006 *XMM-Newton* observations; in the case of CXOU J155054.1—541824, the count rate declined by ~30%, while for XMMU J155053.7—541925 the count rate declined by ~85%.

We have quantified the apparent variation of the X-ray flux from CXOU J155054.1—541824 via a more detailed spectral analysis of the observations listed in Table 1. Here, and in the subsequent discussion, we assume that 1E 1547.0—5408 and AX J155052—5418 correspond to the same X-ray source, and that this source is a blend of CXOU J155054.1—541824, XMMU J155053.7—541925, and other adjacent field sources that can be seen at the high angular resolution of *XMM-Newton* and *Chandra*, but not with *ASCA* and *Einstein*. Since CXOU J155054.1—541824 substantially dominates the emission, we hereafter use 1E 1547.0—5408 to indicate this main source, except...
that a distinction with fainter, adjacent sources needs to be made. For the Einstein observation, we used the procedure defined by McGarry et al. (2005) to determine the flux of 1E 1547.0—5408. To do this, we assume that the X-ray spectrum of 1E 1547.0—5408 is well modeled by an absorbed power law, assuming a hydrogen column density $N_H = 4.2 \times 10^{22} \text{ cm}^{-2}$ and a photon index $\Gamma = 4.7$, as derived below from spectral fits to the ASCA, XMM-Newton, and Chandra observations. To determine the X-ray flux of 1E 1547.0—5408 as measured by ASCA, XMM-Newton, and Chandra, we simultaneously fit the observed spectrum of this source to an absorbed power-law model using XSPEC version 11.3.1. We chose an absorbed power-law model since this model provides a good fit to each of these spectra individually. For the XMM-Newton and Chandra observations, spectral regions were chosen to minimize contamination from CXOU J155054.1—541824 and other field sources. For the ASCA observation, this was not possible due to the poor point-spread function of this instrument. Holding the $N_H$, $\Gamma$, and normalization constant among these different observations, which implies a constant flux, resulted in a poor fit (reduced $\chi^2 = 2.19$). Allowing the normalizations to vary independently, but holding $N_H$ and $\Gamma$ fixed, lowered the reduced $\chi^2$ to 1.26, a substantial improvement. As shown in Table 3, the results from this analysis imply that 1E 1547.0—5408 is a variable X-ray source.

To determine which physical model best describes the X-ray spectrum of 1E 1547.0—5408, we used XSPEC version 11.3.1 to jointly fit the spectrum of this source measured during the 2006 August XMM-Newton observation by the MOS1, MOS2, and pn instruments to a number of different models, including a power law, bremsstrahlung, power-law plus blackbody, and two blackbodies, all attenuated by interstellar absorption. During this observation, between 0.5 and 10 keV a total of 1005 ± 33 counts above the background were collected from this source by the MOS1 detector, 1062 ± 34 by the MOS2 detector, and 2351 ± 51 by the pn detector. The resultant X-ray spectrum is shown in Figure 2. As shown in Table 4, an absorbed power-law plus blackbody model produces the best fit. According to the F-test, the decrease in $\chi^2$ for the best two-component model (absorbed power-law plus blackbody) over the best one-component model (absorbed bremsstrahlung) is statistically significant at 99.9% confidence, so the use of a second component is justified. Therefore, we conclude that either an absorbed power-law plus blackbody or an absorbed two blackbodies (these two models produced statistically indistinguishable fits) provides the best description of the X-ray spectrum of 1E 1547.0—5408.

Also searched for pulsed X-ray emission from 1E 1547.0—5408 using the data collected during the 2006 XMM-Newton observation using the $Z^2$ test (Buccheri et al. 1983). To do so, we first extracted events from two circular regions centered around the position CXOU J155054.1—541824, one 9.5\text" in radius and the other 26.5\text" in radius, from the filtered MOS1, MOS2, and pn data sets. We then barycentered the arrival times of these photons to the solar system reference frame. This search was conducted on the MOS1 (0.9 s time resolution), MOS2 (0.9 s time resolution), and pn (73.4 ms time resolution) data sets individually, as well as on them jointly. To allow for the possibility that the pulsed fraction might have a strong energy dependence, we applied various energy cuts to the event lists derived from both spatial regions. For all searches, the minimum frequency was $2 \times 10^{-5}$ Hz, the maximum frequency was 0.6 Hz for the MOS and joint data sets and 6.8 Hz for the pn data, and the frequency step was $2 \times 10^{-6}$ Hz, oversampling the Nyquist frequency by a factor of 5. For each combination of spatial region, detectors, and energy range, we searched for periods summing up to a maximum harmonic $n = 1, 2, \ldots, 10$. In none of these different combinations did we detect a statistically significant signal. Between 0.5 and 10 keV, the most sensitive data set for a sinusoidal $(n = 1)$ pulse profile comes from combining the three detectors and using the large spatial region. In this data set, we have 5305 photons in 52,201 independent trials. Using the equations in Leahy et al. (1983) we are able to place a 5 $\sigma$ upper limit on the peak-to-peak pulse fraction $f_{\text{pulse}}$, defined as (Patel et al. 2003)

$$f_{\text{pulse}} = \frac{N_{\text{max}} - N_{\text{min}}}{N_{\text{max}} + N_{\text{min}}}$$

where $N_{\text{max}}$ and $N_{\text{min}}$ are the maximum and minimum number of counts in the pulse profile, of $f_{\text{pulse}} < 14\%$.

2.2. Near-IR Observation of 1E 1547.0—5408

Using the position of CXOU J155054.1—541824 as measured by Chandra, we searched for a near-IR counterpart in a 3 minute
$K_s$ ($\lambda = 2.15 \mu m$) observation of this field taken on 2006 June 13 with Persson’s Auxiliary Nasmyth Infrared Camera (PANIC) on the 6.5 m Baade Magellan telescope at the Las Campanas Observatory in Chile. This image was sky-subtracted using the standard procedures in the IRAF software package, and registered using the position of Two Micron All Sky Survey (2MASS) sources in the field. We used the IRAF task DAOFIND to identify objects in this field and measure their instrumental magnitudes, and used the 144 2MASS stars in this field with only one counterpart within 1" of their position to determine the conversion between instrumental and astronomical magnitudes. To search for a counterpart, we used the 99% error (\(-0.8''\)) of the Chandra position quoted in § 2.1. As shown in Figure 3, only one source was detected inside this region, and this source has an observed magnitude of $K_s = 15.9 \pm 0.2$. Using the source–magnitude distribution of objects detected in our $K_s$ observation, we determine that our image is complete to sources with a $K_s$ magnitude $<17.5$.

3. THE GALACTIC RADIO SHELL G327.24-0.13

1E 1547.0$-$5408 falls within the field of view of multiple recent southern hemisphere radio surveys: the Molonglo Galactic Plane Survey (MGPS, 843 MHz; Green et al. 1999), the Sydney University Molonglo Sky Survey (SUMSS, 843 MHz; Bock et al. 1999; Green 2002), and in both the test region (Gaensler et al. 2001a) and survey region (Haverkorn et al. 2006) of the Southern

![Figure 2](image_url)

**FIG. 2.—** X-ray spectrum of CXOU J155054.1$-$541824, as measured by the MOS1, MOS2, and pn detectors in the 2006 XMM-Newton observation. The MOS1 and MOS2 channels were binned such that there were a minimum of 25 counts per bin, and the pn channels were binned such that there were a minimum of 50 counts per bin. The lines indicate the fit of the absorbed power-law plus blackbody model given in Table 4, and the bottom plot indicates the number of standard deviations the data deviates from the model.

**TABLE 4**

**SPECTRAL FITS TO THE 2006 AUGUST XMM-NEWTON OBSERVATION OF CXOU J155054.1$-$541824**

| Parameter            | PHABS$^a$POW | PHABS$^a$BREMS | PHABS$^a$ (POW+BB) | PHABS$^a$ (BB+BB) |
|----------------------|---------------|----------------|---------------------|-------------------|
| $N_H$ (cm$^{-2}$)     | $4.3^{+0.3}_{-0.2} \times 10^{22}$ | $3.0 \pm 0.2 \times 10^{22}$ | $3.1^{+0.7}_{-0.8} \times 10^{22}$ | $2.5^{+0.3}_{-0.2} \times 10^{22}$ |
| $\Gamma/kT$ (kT)      | $4.8 \pm 0.2$ | $1.1 \pm 0.1$ | $3.7^{+0.9}_{-0.4} \times 10^{-0.04}$ | $0.45^{+0.04}_{-0.06}$ |
| $kT_2$ (kT)           | ...           | ...            | ...                 | ...               |
| Absorbed flux (ergs cm$^{-2}$ s$^{-1}$) | $3.1^{+0.1}_{-0.3} \times 10^{-13}$ | $3.0^{+0.3}_{-0.6} \times 10^{-13}$ | $3.1^{+0.3}_{-1.2} \times 10^{-13}$ | $3.1^{+0.3}_{-0.9} \times 10^{-13}$ |
| Unabsorbed flux (ergs cm$^{-2}$ s$^{-1}$) | $2.8^{+0.1}_{-0.0} \times 10^{-11}$ | $2.3^{+0.1}_{-0.0} \times 10^{-12}$ | $3.6^{+0.1}_{-0.0} \times 10^{-12}$ | $1.0^{+0.0}_{-0.0} \times 10^{-12}$ |
| $\chi^2$/dof (reduced $\chi^2$) | $147.9/126 (1.17)$ | $144.7/126 (1.14)$ | $134.4/124 (1.08)$ | $135.3/124 (1.09)$ |

**Notes.—** The results from an absorbed power law (PHABS$^a$POW), an absorbed bremsstrahlung (PHABS$^a$BREMS), an absorbed power law plus blackbody [PHABS$^a$ (POW+BB)], and an absorbed blackbody plus blackbody [PHABS$^a$ (BB+BB)] fit to the MOS1, MOS2, and pn spectra of CXOU J155054.1$-$541824 obtained during the 2006 XMM-Newton observation. The fits were done between 0.5 and 10 keV. The MOS1 and MOS2 channels were binned such that there were a minimum of 25 counts per bin, and the pn channels were binned such that there were a minimum of 50 counts per bin. Errors indicate 90% confidence intervals for each quantity, and dof stands for degrees of freedom. Both the absorbed and unabsorbed flux were calculated between 0.5 and 10 keV.
Galactic Plane Survey (SGPS, 1.4 GHz). All four surveys detected a faint ~4' diameter shell centered on CXOU J155054.1−541824, which we designate G327.24−0.13. In both the MGPS and SUMSS (Fig. 4) images, there is some evidence for enhanced emission from the center of G327.24−0.13. At both frequencies, the flux was determined by subtracting the observed flux from G327.24−0.13 by estimates for the diffuse Galactic background at this position obtained using nearby regions, and the error is dominated by the uncertainty in the background. At 843 MHz, the flux density of G327.24−0.13—excluding any interior emission—is 0.5 ± 0.1 Jy, while at 1.4 GHz, the flux density is 0.3 ± 0.1 Jy. These fluxes correspond to a radio spectral index between 843 MHz and 1.4 GHz of α = −0.9 ± 0.6 (Sν ∝ να).

4. DISCUSSION

In this section, we use the observational results presented in §§ 2 and 3 to determine the nature of 1E 1547.0−5408 and G327.24−0.13. Based on the results of the XMM-Newton and Chandra observations, we believe 1E 1547.0−5408 is a blend of compact X-ray sources dominated by the X-ray emission of CXOU J155054.1−541824. Therefore, we conclude that XMMU J155053.7−541925 and the other sources detected by XMM-Newton and/or Chandra are negligible contributors to the X-ray properties of 1E 1547.0−5408 as measured by Einstein and ASCA. We also believe that these sources are unrelated to CXOU J155054.1−541824.

Since CXOU J155054.1−541824 is unresolved by Chandra, 1E 1547.0−5408 is most likely an active galactic nucleus (AGN), a neutron star (either a rotation-powered pulsar, a magnetar, or a compact central object [CCO]), a nondegenerate star, an X-ray binary, or a cataclysmic variable (CV). A major clue into the nature of 1E 1547.0−5408 is its possible association with a near-IR source, as discussed in § 2.2.

If 1E 1547.0−5408 is associated with this near-IR source, it is most likely either a nondegenerate star in the Milky Way or an AGN. If it is a nondegenerate star, then the absorbed bremsstrahlung is the most realistic description of the X-ray emission. If it is an AGN, only the absorbed bremsstrahlung fit to the observed spectrum gives parameters similar to that observed from other AGNs. To determine if either identification is reasonable, we compared the X-ray and IR fluxes of this source to those of known stars and AGNs, similar to the approach used by Kaplan et al. (2004). For stars, we used data obtained by the Chandra Orion Ultradeep Project (Getman et al. 2005), and for AGNs, we used the X-ray (Kenter et al. 2005) and near-IR (Jannuzi et al. 2004) data from the XBoötes survey. For both surveys, we used only the observed 2−7 keV flux, since this quantity is less sensitive to interstellar absorption and choice of X-ray spectral model than the 0.5−2 keV flux. To correct for the difference in NH observed toward 1E 1547.0−5408 from the Galactic value of NH toward sources in the Boötes field (NH = 10^{-20} cm^{-2}; Kenter et al. 2005) and the value observed toward sources in the Orion field (NH = 10^{-21−23} cm^{-2}; Getman et al. 2005), we determined the 2−7 keV X-ray and near-IR fluxes of 1E 1547.0−5408 over this range of NH. As shown in Figure 5, the IR and X-ray properties of 1E 1547.0−5408 are inconsistent with both populations. Therefore, we conclude that 1E 1547.0−5408 is not associated with this near-IR source. To compute the probability of their association being a coincidence, we shifted the right ascension and declination of 1E 1547.0−5408 by a random amount between ±0.8′′ and ±10′′ determined whether there is a near-IR source within 0.8′′ of its adjusted position. This analysis implies a false coincidence rate of ~14%, implying that there is a reasonable possibility that the near-IR object is an unrelated field source. As a result, we adopt a Ks magnitude of 17.5 as an upper limit on the Ks magnitude 1E 1547.0−5408.

As a result, we are left with the possibility that this X-ray source is a neutron star, X-ray binary, or CV. The location of 1E 1547.0−5408 in the center of SNR candidate G327.24−0.13 strongly implies that this source is a neutron star. This identification is supported by the fact that the bremsstrahlung and power-law fits to the X-ray spectrum of 1E 1547.0−5408 shown in Table 4 are inconsistent with the spectra expected from X-ray binaries (a modified blackbody with kT ~ 1−2 keV; White et al. 1988) and CVs (bremsstrahlung emission with kT > 1 keV; Eracleous et al. 1991). The X-ray spectrum of 1E 1547.0−5408 is also inconsistent with that observed from rotation-powered pulsars (a power law with Γ = 1−2; Cheng et al. 2004). However, the parameters for the
absorbed power law, the absorbed power law and blackbody, and the absorbed two blackbody models are similar to those observed from both magnetars (Mereghetti 2001) and CCOs (Pavlov et al. 2004). As shown in Table 5, the observed X-ray variability of 1E 1547.0—5408 described in § 2.1 is similar to that observed from several magnetars. CCOs, on the other hand, appear to be steady X-ray sources, and therefore we conclude that 1E 1547.0—5408 is most likely a magnetar. One crucial difficulty with this interpretation is our failure to detect pulsed X-ray emission from this source. Magnetars typically have high pulsed fractions in the X-ray regime; for example, before its recent outburst, CXOU J164710.2—455216 had a pulsed fraction of ~50% (Muno et al. 2006), much higher than the 5 σ upper limit derived in § 2.1 of 14% on the 0.5—10 keV peak-to-peak pulsed fraction from 1E 1547.0—5408 for a sinusoidal pulse profile, the characteristic pulse profile for magnetars. However, this upper limit is higher than the pulsed fraction of at least one magnetar, 4U 0142+61, which has a 0.5—7 keV peak-to-peak pulsed fraction of ≈7% (Patel et al. 2003; Göhler et al. 2005).

If this identification is correct, we can compare the X-ray properties of 1E 1547.0—5408 to those of other magnetars. For the power-law plus blackbody model of the spectrum, the 2—10 keV unabsorbed flux of 1E 1547.0—5408 is in the range of f ≈(0.5—3) × 10^{-12} ergs cm^{-2} s^{-1}. For a distance d = 4d_{4} kpc (it will be argued below that d_{4} ≈ 1 is a reasonable distance estimate), this translates to a luminosity range of (0.9—7)d_{4} × 10^{33} ergs s^{-1}. Comparing this value to those given in the SGR/AXP online catalog, this falls within the X-ray luminosity range spanned by confirmed magnetars. With this information, we can also compare the near-IR and X-ray properties of 1E 1547.0—5408 to those of other magnetars, whose properties are listed in Table 5. As shown in Figure 5, the range of X-ray fluxes observed from 1E 1547.0—5408, as well as the upper limit on the near-IR flux, is consistent with that observed from confirmed magnetars.

The radio spectral index of G327.24-0.13 derived in § 3 is consistent with a nonthermal origin, implying that this source is either a stellar wind bubble or a SNR. The lack of any mid-IR counterpart to G327.24-0.13 in the Spitzer GLIMPSE survey (Benjamin et al. 2003) gives support to the latter interpretation. If 1E 1547.0—5408 is a magnetar and G327.24-0.13 is the SNR created by its progenitor, then this system becomes a new addition to the handful of associations between magnetars and SNRs. Assuming that the two sources are indeed associated, we can obtain initial constraints on the possible distance to 1E 1547.0—5408/G327.24-0.13 as follows. Recent evidence has suggested that magnetar progenitors are especially massive stars (Gaensler et al. 2005; Muno et al. 2006), and therefore we expect significant star formation activity in their vicinity. Indeed, in this case there are two nearby (~0.5 away) thermal radio sources, G326.96+0.03 and G327.99-0.09, both associated with a large star-forming

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4 Available online at http://www.physics.mcgill.ca/~pulsar/magnetar/main.html.
complex in the Scutum-Crux spiral arm. H absorption and hydrogen recombination line measurements indicate that the distance to G326.96+0.3 and G327.99-0.9 both fall within the range $d = 3.7 – 4.3$ kpc (Caswell & Haynes 1987; McClure-Griffiths et al. 2001). By associating 1E 1547.0–5408/G327.24-0.13 with this region, we argue that $d_{1E} \approx 1$. If so, the observed size of G327.24-0.13 ($\sim 4^\prime$) implies a diameter of $\sim 5d_{1E}$ pc, making G327.24-0.13 one of the smallest, and therefore probably youngest, known SNRs.

As mentioned in § 2.1, 1E 1547.0–5408 was originally discovered in a search for the X-ray counterpart of unidentified $\gamma$-ray source IC 5327-0. Quiescent emission from magnetars has been detected at energies as high as $\sim 100$ keV by the INTEGRAL satellite (Götz et al. 2006; Kuiper et al. 2004), but not in the $\gtrsim 100$ MeV range detected by COS-B from IC 5327-0 (Hemsen et al. 1977). Although magnetars have been known to be the source of intense $\gamma$-ray flares (Hurley et al. 2005), these events are rare (only three have been detected in the past 30 years), and the maximum photon energy detected from these flares ($\sim 1$ MeV; Hurley et al. 2005) is significantly less than the photon energies detected from IC 5327-0. As a result, we do not believe that 1E 1547.0–5408 is the X-ray counterpart of IC 5327-0. Another possibility is that 1E 5327-0 is associated with G327.24-0.13, since high-energy $\gamma$-ray emission has been detected from some SNRs. However, the non-detection of IC 5327-0 by EGRET implies that this source is variable, making any association of IC 5327-0 with the SNR candidate G327.24-0.13 unlikely. Future Gamma-Ray Large Area Space Telescope (GLAST) observations of this region should determine whether IC 5327-0 is a real $\gamma$-ray source and, if so, whether it is affiliated with 1E 1547.0–5408 or G327.24-0.13.

To summarize, in this paper we presented X-ray, near-IR, and radio observations of 1E 1547.0–5408 and of the field around it. A consistent explanation of these observations is that 1E 1547.0–5408 is a magnetar possibly associated with SNR candidate 5408-0 and some magnetars.

\begin{table}[h]
\centering
\caption{2–7 keV Absorbed X-Ray Flux and $K_s$ Flux of 1E 1547.0–5408 and Some Magnetars}
\label{tab:5}
\begin{tabular}{|l|c|c|c|}
\hline
Source & X-Ray Flux & $K_s$ Flux & References \\
& ($\text{ergs cm}^{-2} \text{s}^{-1}$) & ($\text{ergs cm}^{-2} \text{s}^{-1}$) & \\
\hline
1E 1547.0–5408 & (0.3–1.7) $\times 10^{-12}$ & $\leq 1 \times 10^{-14}$ & \ldots \\
SGR 1900+14 & (0.4–1.9) $\times 10^{-11}$ & $\leq 5 \times 10^{-16}$ & 1, 2 \\
SGR 1627–41 & (0.1–1.9) $\times 10^{-12}$ & $\leq 1 \times 10^{-15}$ & 3, 4 \\
SGR 1806–20 & (0.7–1.6) $\times 10^{-11}$ & (0.2–2.1) $\times 10^{-15}$ & 5, 6, 7, 8 \\
SGR 0526–66 & (4.1–4.4) $\times 10^{-10}$ & $\leq 3 \times 10^{-16}$ & 9, 10 \\
XTE J1810–197 & (0.002–2.8) $\times 10^{-12}$ & (3.2–5.4) $\times 10^{-16}$ & 11, 12, 13 \\
1E 1048.1–5937 & (4.2–9.7) $\times 10^{-11}$ & (0.3–2.0) $\times 10^{-15}$ & 14, 15, 16 \\
4U 0142+61 & (5.6–6.7) $\times 10^{-11}$ & (0.6–1.5) $\times 10^{-15}$ & 17, 18, 19 \\
CXOU J164710.2–455216 & (0.001–1.7) $\times 10^{-10}$ & $\leq 4 \times 10^{-16}$ & 20, 21 \\
IRXS J170849.0–400910 & (2.6–2.8) $\times 10^{-11}$ & (2.2–3.2) $\times 10^{-15}$ & 22, 23 \\
\hline
\end{tabular}
\end{table}

Notes: — Only confirmed magnetars that had sufficient X-ray spectral information available in the literature are included in this table. The X-ray fluxes quoted in this table are the absorbed flux, and no corrections have been made to either the X-ray flux or $K_s$ fluxes for the different values of $N_H$ measured toward these sources. The X-ray flux range of 1E 1547.0–5408 was calculated using the same procedure described in the notes of Table 3.

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G327.24-0.13. Deeper X-ray observations of 1E 1547.0–5408 are needed to confirm its identification as a magnetar by detecting X-ray pulsations from this source, deep near-IR observations of this source are required to discover its near-IR counterpart, and additional radio observations of G327.24-0.13 are required to determine whether it is a SNR. The identification of 1E 1547.0–5408 as a magnetar candidate illustrates the importance of follow-up observations of other bright, unidentified X-ray sources in the Galactic plane for understanding the X-ray population of the Milky Way and for discovering new members of exotic classes of neutron stars.

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