

***Chandra* observations of five *INTEGRAL* sources: new X-ray positions for IGR J16393–4643 and IGR J17091–3624**

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ABSTRACT

The *Chandra* High Resolution Camera observed the fields of five hard X-ray sources in order to help us obtain X-ray coordinates with sub-arcsecond precision. These observations provide the most accurate X-ray positions known for IGR J16393–4643 and for IGR J17091–3624. The obscured X-ray pulsar IGR J16393–4643 lies at R.A. (J2000) = 16^h 39^m 05^s.47, and Dec. = –46° 42′ 13″.0 (error radius of 0′.6 at 90% confidence). This position is incompatible with the previously-proposed counterpart 2MASS J16390535–4642137, and it points instead to a new counterpart candidate that is possibly blended with the 2MASS star. The black hole candidate IGR J17091–3624 was observed during its 2011 outburst providing coordinates of R.A. = 17^h 09^m 07^s.59, and Dec. = –36° 24′ 25″.4. This position is compatible with those of the proposed optical/IR and radio counterparts, solidifying the source’s status as a microquasar. Three targets, IGR J14043–6148, IGR J16358–4726, and IGR J17597–2201, were not detected. We obtained 3 σ upper limits of, respectively, 1.7, 1.8, and 1.5×10^{-12} erg cm⁻² s⁻¹ on their 2–10 keV fluxes.

Subject headings: accretion, accretion disks ; gamma-rays: general ; stars: neutron ; X-rays: binaries ; X-rays: individual (IGR J14043–6148, IGR J16358–4726, IGR J16393–4643, IGR J17091–3624, IGR J17597–2201)

1. Introduction

Surveys by *INTEGRAL* have enabled the discovery of hundreds of new high-energy sources (e.g., Bird et al. 2010; Krivonos et al. 2010). While the soft γ -ray imager has proven adept at finding new sources dubbed *INTEGRAL* Gamma-Ray sources or IGRs¹,

the position error radii are on the order of a few arcminutes. These are clearly too large to permit the identification of a single counterpart in the optical and infrared (IR) bands. Establishing the nature of the optical/IR counterpart is a key step in helping to categorize a gamma-ray source into one of the many groups of high-energy emitters.

Therefore, the classification of these sources depends on observations with X-ray focusing telescopes

¹a comprehensive list can be found at <http://irfu.cea.fr/Sap/IGR-Sources>

Table 1: Journal of *Chandra* observations of the five targets in this study.

Target	Obs. ID	Start Time (UTC)	Start Time (MJD)	Exposure Time (s)
IGR J14043–6148	12502	2010-12-06T02:42:53	55536.11311	1128.95
IGR J16358–4726	12503	2011-02-05T05:41:21	55597.23705	1142.88
IGR J16393–4643	12504	2011-03-05T03:12:11	55625.13346	1125.20
IGR J17091–3624	12505	2011-03-06T00:38:35	55626.02679	1124.89
IGR J17597–2201	12506	2011-02-20T11:33:00	55612.48125	1109.14

which provide position accuracies of a few arcseconds (e.g., Rodriguez et al. 2010). In some cases, these error radii encompass multiple potential counterparts, especially for X-ray sources located in crowded stellar fields such as the Galactic Center and Plane. In such cases, only a sub-arcsecond X-ray position obtained with *Chandra* will help localize the correct counterpart enabling follow-up spectral studies to be performed in the optical/IR, which will eventually help lead to a source classification.

Here, we present the results from *Chandra* snapshot observations of five IGRs located along the Galactic Plane: IGR J14043–6148, IGR J16358–4726, IGR J16393–4643, IGR J17091–3624, and IGR J17597–2201. These objects were previously observed with *RXTE*, *Swift*, or *XMM-Newton*, and so some of their spectral and timing behavior is known. They share a common trait in that the identity of the optical/IR counterpart was not firmly established when the *Chandra* observations were proposed. These *Chandra* observations are intended to help refine the positions to the X-ray sources. The observational history of our selected targets is summarized in the following paragraphs. Data and analysis methods are presented in Section 2. Results for detected sources are discussed in Section 3, while the implications for undetected sources are raised in Section 4.

1.1. IGR J14043–6148

This source was first listed in the 4th ISGRI Catalog (Bird et al. 2010). Within the 4'5 error radius from ISGRI, lies an X-ray source from the 2nd *XMM-Newton* Serendipitous Source Catalog (Watson et al. 2009): 2XMM J140417.3–614911, which is only 0'4 away from the centroid of the ISGRI position. Its position uncertainty of 2'5 is too large to permit the identification a single infrared counterpart in the 2MASS Catalog (Cutri et al. 2003; Skrutskie et al. 2006).

A *Swift*-XRT observation of the field was per-

formed on 2010 June 2 (i.e., around 6 months before our *Chandra* pointing) revealing an X-ray source at R.A. (J2000) = 14^h 04^m 29^s.63, and Dec. = –61° 47' 19".7 with a 90%-confidence error circle of 4'5 (Landi et al. 2011). In other words, the XRT source is compatible with the ISGRI position, but it is 2'4 away from (and incompatible with) the 2XMM source. Within the XRT error circle lies G311.45-0.13 which has been proposed to be either a supernova remnant (SNR) or a background active galactic nucleus (AGN).

1.2. IGR J16358–4726

Discovered early in the *INTEGRAL* mission by Revnivtsev et al. (2003), IGR J16358–4726 was serendipitously observed by *Chandra* during an observation of the field of SGR 1627–41 (Kouveliotou et al. 2003) and associated with 2MASS J16355369–4725398. Patel et al. (2004) discovered a coherent modulation period lasting nearly 6000 s, which could either be the spin period of a neutron star in an absorbed ($N_H \sim 3 \times 10^{23} \text{ cm}^{-2}$) HMXB system, or the orbital period of a low-mass X-ray binary (LMXB). The latter was ruled out once Patel et al. (2007) measured an increasing frequency for the period which points to an accretion-induced spin up of a highly-magnetized neutron star ($B \sim 10^{13} - 10^{15} \text{ G}$), i.e., a magnetar. Infrared observations of the field by Chaty et al. (2008) and Rahoui et al. (2008) suggest a faint, absorbed, and possibly blended counterpart with a spectral energy distribution (SED) typical of a supergiant B[e] star. This seemed to confirm the HMXB nature of IGR J16358–4726. However, based on the presence of CO absorption lines in the K_s -band spectra of the 2MASS source, Nespoli et al. (2010) suggest that the neutron star is not paired with an OB supergiant but with a KM giant, making the system a symbiotic X-ray binary.

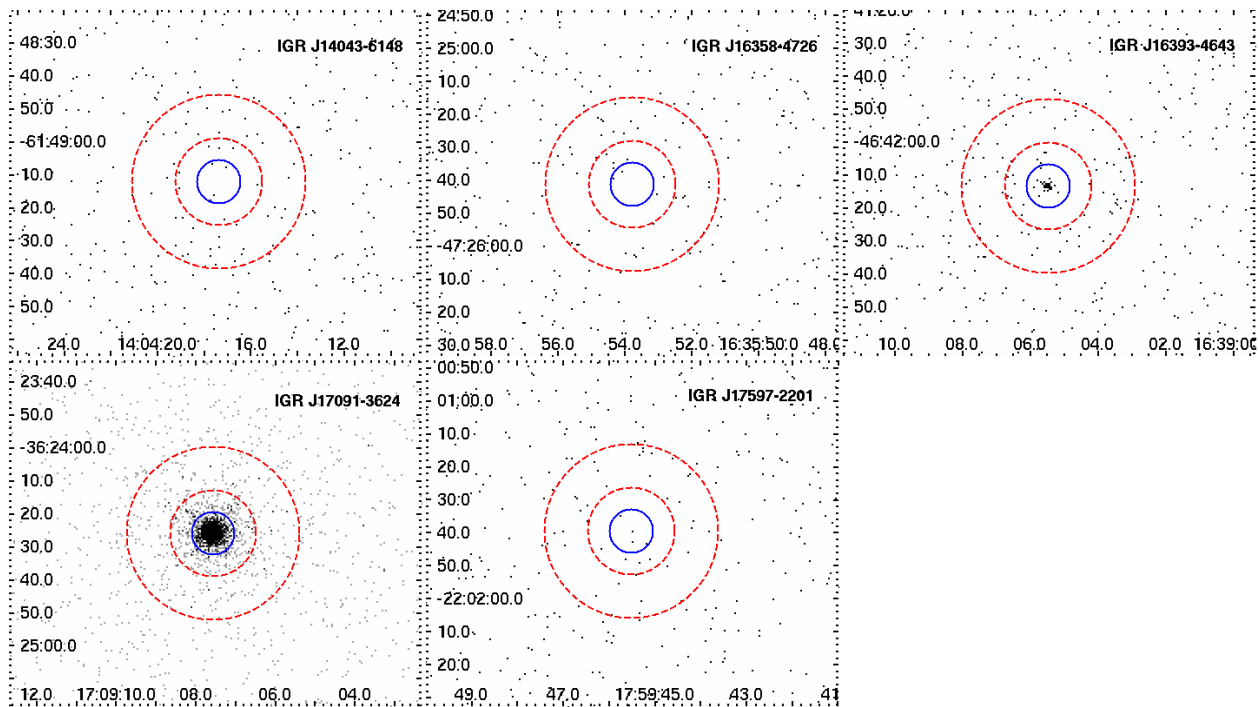


Fig. 1.— *Chandra*-HRC images (0.3–10 keV) of the fields of the five targets in our study. Coordinates are given as equatorial R.A. and Dec. (J2000) where North is up and East is left. The circle (solid line) and annulus (dashed line) represent the source and background extraction regions, respectively. Pixels have been grouped in blocks of 4 and the scaling is logarithmic.

1.3. IGR J16393–4643

Originally discovered by *ASCA* (Sugizaki et al. 2001), IGR J16393–4643 was re-discovered in high energies by *INTEGRAL* (Bird et al. 2004). The *ASCA* and *INTEGRAL* positions, which fall within the error box of an unidentified *EGRET* source, are consistent with the positions of sources from the radio and IR bands, leading to its initial classification as a microquasar candidate (Combi et al. 2004; Malizia et al. 2004). An *XMM-Newton* observation refined the position to a few arcseconds, thereby ruling out the previously proposed identifications and pointing towards 2MASS J16390535–4642137 as the counterpart (Bodaghee et al. 2006). The optical/IR SED of 2MASS J16390535–4642137 suggests a star of spectral class BIV-V (Chaty et al. 2008). However, analysis of the K_s -band spectrum of the same object hint at a late-type KM star in a symbiotic binary system (Nespoli et al. 2010), so there is disagreement about how to interpret the infrared SED, and there are lingering doubts about whether the 2MASS source is

really the counterpart: the *XMM-Newton* error circle includes 3 other candidates. The orbital period of the X-ray source was recently determined to be 4.2 d (Corbet et al. 2010) which is at odds with a symbiotic system (see also Thompson et al. 2006). This short orbital period paired with a slowly-rotating neutron star (spin period ~ 900 s: Bodaghee et al. 2006) are typical of wind-accreting HMXBs (Corbet 1986; Bodaghee et al. 2007).

1.4. IGR J17091–3624

An *INTEGRAL* Galactic Center Deep Exposure uncovered IGR J17091–3624 (Kuulkers et al. 2003). The refined X-ray position obtained by *Swift* (Kennea & Capitanio 2007) ruled out previously-proposed radio and optical counterparts, leaving two blended candidate NIR counterparts in the error circle (Chaty et al. 2008). Re-analysis of archival VLA data from this field revealed a new compact radio counterpart compatible with the *Swift* position (Capitanio et al. 2009).

In early 2011, Krimm et al. (2011) announced that

Swift-BAT detected an outburst from IGR J17091–3624. Optical/IR observations of the field (Torres et al. 2011) performed before and during the outburst showed variability from the location of “Candidate 2” (C2) of Chaty et al. (2008). Torres et al. (2011) concluded from PSF-fitting that C2 is actually composed of two stars, the brighter one of which is the likely counterpart: it has magnitudes $I = 18.35 \pm 0.03$ and $K_s = 16.98 \pm 0.04$, and a position of R.A. (J2000) = $17^{\text{h}} 09^{\text{m}} 07^{\text{s}}.62$ and Dec. = $-36^{\circ} 24' 25''.35$ (error of $\sim 0''.2$ at 90% confidence).

During this latest outburst, radio emission was detected again further cementing the source’s status as a microquasar consisting of an accreting black hole candidate captured in the low-hard state (Corbel et al. 2011; Rodriguez et al. 2011). Observations with *RXTE* unveiled low-frequency quasi-periodic oscillations (QPOs: Rodriguez et al. 2011) whose evolving timing signatures (Shaposhnikov 2011) were indicative of a transition to the high-soft state (Del Santo et al. 2011). Millihertz and high-frequency QPOs were discovered (Altamirano et al. 2011a; Altamirano & Belloni 2012) in addition to heartbeat oscillations (Altamirano et al. 2011b), and seven of the twelve variability classes seen in GRS 1915+105 (Altamirano et al. 2011c,d; Pahari et al. 2011). However, IGR J17091–3624 is less radio bright than is GRS 1915+105 (Rodriguez et al. 2011), and it loops through the hardness-intensity diagram in the opposite direction (Altamirano et al. 2011d). Assuming it is emitting at the Eddington limit during its outburst (in accordance with models that suggest the broad range of variability is exclusively due to disk instabilities at high luminosities: Altamirano et al. 2011d, and references therein), then IGR J17091–3624 either hosts the black hole with the lowest mass known (Altamirano et al. 2011d), or it is located far away in the Galaxy with distance estimates ranging from 17 kpc (Rodriguez et al. 2011) to more than 20 kpc (Altamirano et al. 2011d).

1.5. IGR J17597–2201

INTEGRAL detected IGR J17597–2201 in outburst (Lutovinov et al. 2003), and it was quickly associated with the transient X-ray source XTE J1759–220 (Markwardt & Swank 2003). In the optical/NIR band (Chaty et al. 2008), the *XMM-Newton* position error circle encompasses multiple stars, any one of which could be the counterpart to this dipping X-ray burster (i.e., a neutron star binary in a high-inclination orbit: Brandt et al. 2007). A *Chandra* observation per-

formed in 2007 (Ratti et al. 2010) gave source coordinates of R.A. (J2000) = $17^{\text{h}} 59^{\text{m}} 45^{\text{s}}.52$ and Dec. = $-22^{\circ} 01' 39''.2$ with an error radius of $0''.6$ (90% confidence). Ratti et al. (2010) found a single IR-band object within the *Chandra* error circle, and it is coincident with “Candidate 1” from Chaty et al. (2008). This object is probably a low-mass star (based on the properties of the X-ray source) and is the likely counterpart to IGR J17597–2201.

2. Observations & Analysis

2.1. *Chandra*

Our target list consists of five *INTEGRAL* sources for which *Chandra* could improve upon the position accuracy given by other X-ray imaging telescopes. The fields of these sources were observed for ~ 1 ks each by the High Resolution Camera (HRC: Murray et al. 1997) aboard *Chandra*. These observations were scheduled between 2010 December and 2011 March (PI: Bodaghee). Table 1 provides the observation logs.

Data reduction relied on CIAO 4.3 and HEASoft 6.11. Each events file was rebinned in blocks of 4 pixels with `dmcopy`, and the same was done for the reprojected background events file. The exposure-weighted background events were then subtracted using `dmgcalc`. An aspect histogram was computed with `asphist`, an instrument map (adopting the default value of 1 keV for the mono-energy parameter) was made with `mkinstmap`, and an exposure map was generated with `mkexpmap`. The tool `dmimgthresh` allowed us to select only those pixels with exposure times that were at least 1.5% of the maximum exposure in the map. Using `dmgcalc`, we divided the image by this exposure-selected map in order to obtain an image whose units are $\text{ph cm}^{-2} \text{s}^{-1} \text{pixel}^{-1}$.

We ran `wavdetect` on the full HRC energy range (0.3–10 keV) to create an output list of detected sources (if any), and we performed visual checks of each image. As a consistency check, we verified that the coordinates from `wavdetect` were statistically compatible with those obtained by centroid-fitting the pixel distribution with `dmstat`. We adopt a position uncertainty of $0''.6$ at 90% confidence which is equivalent to the *Chandra* boresight uncertainty for an on-axis source. All positions are given in the 2000.0 epoch. For detected sources, we extracted source counts with `dmstat` from a 50-pixel radius (in the binned image) around the optimal position

Table 2: Positions (J2000), detection significance, and background-subtracted HRC-I count rates (0.3–10 keV) of the IGR sources in this program. The position uncertainty is $0''.6$ at 90% confidence. Upper limits (3σ) on the count rate are given for sources which were not detected.

Source Name	<i>Chandra</i> Counterpart	R.A.	Dec.	Count Rate	Significance
IGR J14043–6148	—	—	—	≤ 0.008	—
IGR J16358–4726	—	—	—	≤ 0.005	—
IGR J16393–4643	CXOU J163905.5–464213	16 ^h 39 ^m 05 ^s .47	–46° 42′ 13″.0	0.033	12
IGR J17091–3624	CXOU J170907.6–362425	17 ^h 09 ^m 07 ^s .59	–36° 24′ 25″.4	37.050	776
IGR J17597–2201	—	—	—	≤ 0.009	—

found with `wavdetect`. Background counts were extracted from an annulus of between 100 and 200-pixel radius with the same center. When the target was not detected, we used the same source and background geometries, but we centered them at the best known X-ray position in the literature, and ran `aprates` to determine an upper-limit on the source flux assuming that 99% of the PSF is contained within the source region, and 1% is in the background region. Images from HRC (0.3–10 keV) are presented in Fig. 1. The results from `wavdetect`, as well as the area-scaled and background-subtracted flux (or upper limits) from each source, are summarized in Table 2.

Finally, it is important to note that in images created from standard processing, a jet-like feature protrudes from IGR J17091–3624 to a location ~ 5 – $8''$ away in the NE direction. Readout streaks are not expected for the HRC, but image artifacts that resemble hooks and jets have been noticed in certain images of bright point sources due to electronic ringing signatures (Juda et al. 2000; Murray et al. 2000; Kaplan & Chakrabarty 2008). The recommended correction for this effect is to exclude events where the amplification scale factor “AMP_SF = 3.” We generated an events file that excludes “AMP_SF = 3” events, and another file that contains only these events (27228 out of 138461 total events). The NE extension can only be seen in images produced from events files that include “AMP_SF = 3” events, suggesting that electronic ringing is responsible for its appearance. The position and flux measurements that we quote for IGR J17091–3624 in Table 2, as well as the image shown in Fig. 1, are based on the corrected events list.

2.2. Infrared Data

On 2011 July 19, we observed IGR J16393–4643 in the framework of a Norma Arm deep-field near-IR survey with the National Optical Astronomy Ob-

servatory (NOAO) Extremely Wide Field Infrared Imager (NEWFIRM), in the *J*, *H*, and *K_s* broadband filters. The instrument, mounted on the CTIO/Blanco 4 m telescope, has a $28' \times 28'$ field of view (FOV) and a $0''.392$ plate scale. In each filter, we obtained 10×15 s dithered frames, allowing an accurate median sky calculation in this very crowded field. We reduced the data using the dedicated NEWFIRM package available with the IRAF suite, following the standard near-IR procedure which includes the correction for bad pixels and dark current, flat fielding, and median sky subtraction.

We then performed accurate astrometry (rms less than $0''.1$) with `GATIA` included in the `starlink` suite, fitting an astrometric solution using the 2MASS stars located in the entire NEWFIRM field. The images were eventually flux-calibrated through relative photometry with respect to the 2MASS catalog. We derived the following zero-point magnitudes and atmospheric extinction coefficients: $Z_{pJ} = 22.64 \pm 0.08$, $Z_{pH} = 22.69 \pm 0.10$, $Z_{pK_s} = 21.83 \pm 0.15$; and $E_J = 0.098 \pm 0.031$, $E_H = 0.062 \pm 0.021$, and $E_{K_s} = 0.089 \pm 0.023$, respectively².

3. Detected sources

3.1. IGR J16393–4643

We detected IGR J16393–4643 with HRC at a count rate of $0.033 \text{ count s}^{-1}$ (0.3–10 keV), which corresponds to an absorbed flux of $1.5 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ (2–10 keV) assuming an absorbed power law with $N_H = 2.5 \times 10^{23} \text{ cm}^{-2}$ and $\Gamma = 0.8$ (Bodaghee et al. 2006). This is around twice the average flux measured by ISGRI when translated to the same energy range ($6.3 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, Bird et al. 2010).

²The conversion from the instrumental (m_{inst}) to apparent (m_{app}) magnitude is $m_{\text{app}} = Z_p + m_{\text{inst}} - E \times AM$, where AM is the average airmass during the integration.

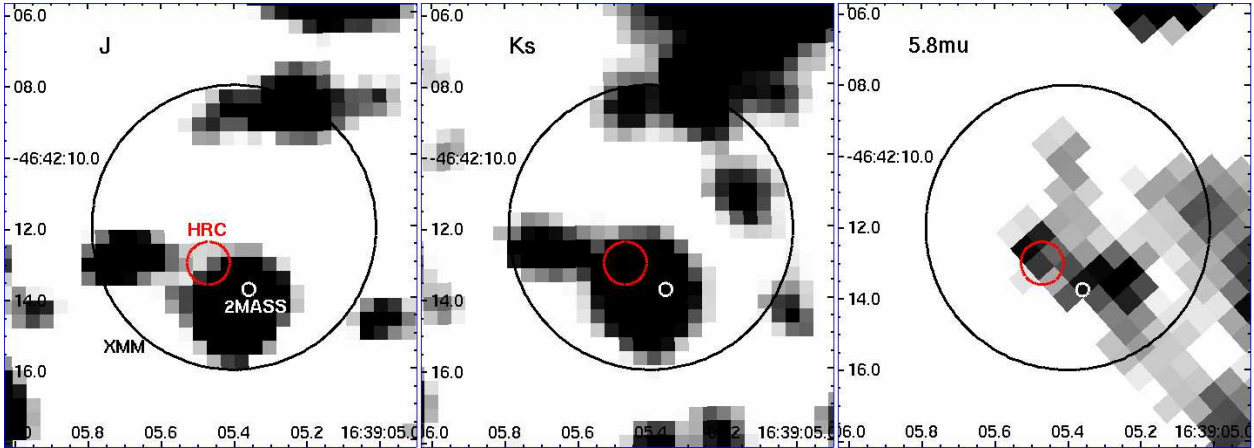


Fig. 2.— Image of the field of IGR J16393–4643 as captured by the NOAO/NEWFIRM telescope in the J and K_s bands (left and middle panels), and at $5.8\mu\text{m}$ (right panel) from *Spitzer*-IRAC (Benjamin et al. 2003). Coordinates are given as equatorial R.A. and Dec. (J2000) where North is up and East is left. The error circle corresponding to the HRC position from this work, the *XMM-Newton* position (Bodaghee et al. 2006), and that of the previously-proposed infrared counterpart 2MASS J16390535–4642137 (Cutri et al. 2003) are indicated.

Our *Chandra* observation of IGR J16393–4643 provides the most precise position for the X-ray source: R.A. (J2000) = $16^{\text{h}} 39^{\text{m}} 05^{\text{s}}.47$ and Dec. = $-46^{\circ} 42' 13''.0$ with an error radius of $0''.6$ (90% confidence). The HRC position is consistent with those obtained with *XMM-Newton* and with *INTEGRAL*. However, this position is incompatible with the position of 2MASS J16390535–4642137 which is located $1''.4$ away and which has an error radius of $0''.12$ (at 90% confidence, see Fig. 2). Thus, we conclude that 2MASS J16390535–4642137, whose optical/IR analysis led to diverging conclusions about its spectral class, is unlikely to be the counterpart to IGR J16393–4643. None of the four candidate counterparts proposed in Chaty et al. (2008) are consistent with the *Chandra* position.

This suggests that the true counterpart to IGR J16393–4643 might be a distant (and reddened) star that is blended with the bright 2MASS star. We acquired deep near-IR images of the field of IGR J16393–4643 with the NOAO/NEWFIRM telescope, and combined these with archival *Spitzer*-IRAC observations from the GLIMPSE campaign in the mid-IR (Benjamin et al. 2003). These images are presented in Fig. 2. As the wavelength increases, the point spread function (PSF) for the bright 2MASS source is displaced in the direction of the *Chandra* position. What appears as a single object in the J band is revealed as two distinct peaks in the counts map of the $5.8\mu\text{m}$ band: one corre-

sponds to the 2MASS object, and the other could be a deeply-reddened star situated on the wings of the PSF of the 2MASS star. At $8\mu\text{m}$ (not displayed), neither source candidate can be disentangled from the tail of a cloud-like region of diffuse emission.

If this candidate is real, and if it represents the true counterpart to IGR J16393–4643, then it has been effectively isolated at $5.8\mu\text{m}$. There are no objects listed in the GLIMPSE catalog (Benjamin et al. 2003) consistent with the *Chandra* position. The sensitivity limit of the GLIMPSE survey is 0.7 mJy at $5.8\mu\text{m}$ (Churchwell et al. 2009). This limit would place an undetected supergiant O9 star ($T_{\text{eff}} \sim 30,000\text{ K}$, and $R \sim 20 R_{\odot}$) with $A_V \sim 20$ at a minimum distance of 25 kpc , which is probably too far to be plausible. On the other hand, for an undetected main-sequence B star ($T_{\text{eff}} \sim 24,000\text{ K}$, and $R \sim 10 R_{\odot}$), the sensitivity limit implies a large, but reasonable distance ($\sim 12\text{ kpc}$ away). We point out that IGR J16393–4643 is positionally coincident with the edge of an active, massive star-forming (H II) region situated at a distance of $12.0 \pm 0.3\text{ kpc}$ (Russeil 2003). If the blended counterpart to IGR J16393–4643 is a main-sequence B star that originated from this H II region, then this would suggest a distance of $\sim 12\text{ kpc}$ to the X-ray source, consistent with our estimate from the sensitivity limit.

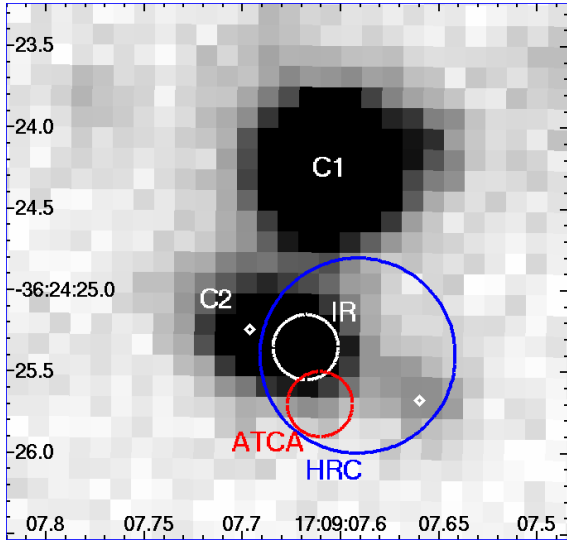


Fig. 3.— The field of IGR J17091–3624 in the I band as captured by the IMACS imaging spectrograph on the 6.5-m Magellan Baade Telescope at the Las Campanas Observatory during 2011 Feb. 6 (Torres et al. 2011). Coordinates are given as equatorial R.A. and Dec. (J2000) where North is up and East is left. The error circles corresponding to the *Chandra*-HRC position (this work), and that of the proposed infrared (Torres et al. 2011) and radio (ATCA: Rodriguez et al. 2011) counterparts are indicated. The *Swift*-XRT error circle of Kennea & Capitanio (2007) is larger than the image. Also indicated are the general locations of the two counterpart candidates (“C1” and “C2”) from Chaty et al. (2008), and the locations (represented by diamonds) of nearby infrared sources (Manuel A.P. Torres, private communication).

3.2. IGR J17091–3624

Our *Chandra* observation of IGR J17091–3624 coincided with the 2011 outburst so we were able to detect the source at a position of R.A. (J2000) = $17^{\text{h}} 09^{\text{m}} 07^{\text{s}}.59$ and Dec. = $-36^{\circ} 24' 25''.4$ with an error radius of $0''.6$ (90% confidence). This is the most accurate X-ray position known for this object and it is $0''.5$ away from, and is consistent with, the XRT position which has an uncertainty of $3''.5$ (Kennea & Capitanio 2007). It is also compatible with the optical/IR and radio counterparts proposed by Torres et al. (2011) and Rodriguez et al. (2011) which are both less than $0''.4$ away (their error radii are $0''.2$ at 90% confidence, see Fig. 3).

It is interesting to note (as illustrated in Fig. 3) that the IR and radio positions are only marginally compatible with each other at the 90% confidence limit. Nevertheless, they are both inside the HRC error circle so the coordinates from the three energy bands (radio, IR, and X-rays) can be considered to be consistent. Another point worth mentioning is that the HRC error circle contains another faint star (Fig. 3). This star, which is not one of the two blended objects that make up “C2,” can also be seen in the finding chart of Torres et al. (2011) when IGR J17091–3624 was in quiescence. The lack of IR variability during the X-ray outburst, and its incompatibility with either the IR or radio positions, implies that this faint star is not the counterpart to IGR J17091–3624.

Adopting an absorbed power law model with spectral parameters fixed to those of the XRT observation ($N_{\text{H}} = 7.8 \times 10^{21} \text{ cm}^{-2}$, and $\Gamma = 1.6$, Kennea & Capitanio 2007), the HRC count rate of 37 count s^{-1} (0.3–10 keV) converts to an absorbed flux of $2.1 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ (2–10 keV). This is a factor 35 times the 2–10-keV flux recorded by XRT ($6 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, Kennea & Capitanio 2007), and nearly two orders of magnitude larger than the average flux measured by ISGRI when translated to the 2–10-keV band ($3.5 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, Bird et al. 2010). The peak intensity measured by *Swift*-BAT³ on 2011 Feb. 15 (MJD 55607) is $2.5 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ (2–10 keV). The HRC count rate converts to an observed luminosity of $1.0 \times 10^{38} \left[\frac{d}{20 \text{ kpc}} \right]^2 \text{ erg s}^{-1}$.

4. Undetected sources

4.1. IGR J14043–6148

We did not detect IGR J14043–6148 during our observation, nor were any other sources detected inside the ISGRI error circle of $4'.5$ radius. The 3σ upper-limit on the source count rate is $0.008 \text{ counts s}^{-1}$ in the 0.3–10 keV band. A power law whose parameters are fixed to those derived from the XRT observation ($N_{\text{H}} = 7 \times 10^{22} \text{ cm}^{-2}$, and $\Gamma = 1.8$, Landi et al. 2011) yields an absorbed 2–10-keV flux $\leq 1.7 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ which is less than the flux measured with XRT ($2.9 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, Landi et al. 2011) or with ISGRI ($4.6 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, Bird et al. 2010) when translated to the same energy range (2–10 keV). This suggests that the source is variable in the X-rays which rules out a SNR, and points instead towards the AGN

³<http://heasarc.nasa.gov/docs/swift/results/transients>

scenario proposed originally by Bird et al. (2010) and by Landi et al. (2011).

4.2. IGR J16358–4726

Unfortunately, IGR J16358–4726 was not active (or it was very faint) during our 1-ks observation and so it was not detected. No other sources were detected in the field. The non-detection is not surprising given that monitoring observations with *RXTE*⁴ show few periods of activity in the last 7–8 years. We set a 3σ upper limit of $0.005 \text{ counts s}^{-1}$ on the 0.3–10-keV flux from IGR J16358–4726. An absorbed power law with parameters fixed to those from an *XMM-Newton* observation in which the source was detected ($N_{\text{H}} = 2 \times 10^{23} \text{ cm}^{-2}$ and $\Gamma = 1.5$, Mereghetti et al. 2006) gives an observed flux $\leq 1.8 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ in the 2–10-keV band. This upper limit from *Chandra* is less than the average flux observed with ISGRI when translated to the 2–10-keV band ($3.9 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$; Bird et al. 2010). For comparison, Mereghetti et al. (2006) used *XMM-Newton* to measure a flux of $(3.1 \pm 0.6) \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ during detections, with 3σ upper limits of $4 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ during non-detections.

4.3. IGR J17597–2201

IGR J17597–2201 was not active during our 1-ks observation, and so it was not detected. The 3σ upper limit on the X-ray flux (0.3–10 keV) at the Ratti et al. (2010) source position is $0.009 \text{ counts s}^{-1}$. For comparison, *Chandra* recorded $0.19 \text{ counts s}^{-1}$ in 2007 when the source was active (Ratti et al. 2010). Adopting the spectral parameters from the *XMM-Newton* observation of Walter et al. (2006), i.e., $N_{\text{H}} = 4.5 \times 10^{22} \text{ cm}^{-2}$ and $\Gamma = 1.7$, the upper limit converts to an absorbed flux (2–10 keV) of $\leq 1.5 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$. This is well below the average flux (2–10 keV) extrapolated from ISGRI ($3.5 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, Bird et al. 2010). The long-term light curve of IGR J17597–2201 from *RXTE* monitoring shows that the source was active during 2001–2008 (mostly concurrent with the ISGRI observations), and has been dormant since then. Therefore, this *Chandra* upper limit represents a boundary on the quiescent flux for this source. The distance to the source is not known, but Lutovinov et al. (2005) propose a distance of between 5 and 10 kpc, while Galloway et al. (2008) suggest an upper limit

of 16 kpc from the X-ray bursts. The *Chandra* upper limit corresponds to an observed quiescent luminosity of $\leq 1.8 \times 10^{34} \left[\frac{d}{10 \text{ kpc}} \right]^2 \text{ erg s}^{-1}$.

5. Summary & Conclusions

Our *Chandra* observations enabled us to derive sub-arcsecond X-ray coordinates for IGR J16393–4643 and IGR J17091–3624. The refined X-ray coordinates that obtained for IGR J16393–4643 excludes the 2MASS star that we had previously proposed as the optical/IR counterpart (whose spectral class was the subject of disagreement), and points instead to a new (and probably distant) counterpart candidate in the mid-IR that is blended with the bright 2MASS star. For IGR J17091–3624, we provide a precise X-ray position that is consistent with the reported optical/infrared and radio counterparts, cementing its status as a microquasar. Three of our targets were not detected: IGR J14043–6148, IGR J16358–4726, and IGR J17597–2201. Nevertheless, the upper limits that we derived for their fluxes helps to establish the range of dynamic variability, which can prove useful for clarifying their nature. The non-detection of IGR J14043–6148 suggests variability that favors an active galactic nucleus rather than a supernova remnant. The upper limit for IGR J17597–2201 sets the boundary on the quiescent flux from a probable low-mass X-ray binary that has been dormant since 2008.

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⁴<http://asd.gsfc.nasa.gov/Craig.Markwardt/galscan>

by the *Swift*/BAT team; and the IGR Sources page (<http://irfu.cea.fr/Sap/IGR-Sources>).

Facilities: Chandra.

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