Using Chandra Localizations and Gaia Distances and Proper Motions to Classify Hard X-Ray Sources Discovered by INTEGRAL

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Abstract

Here, we report on X-ray observations of ten 17–60 keV sources discovered by the International Gamma-Ray Astrophysics Laboratory satellite. The primary new information is sub-arcsecond positions obtained by the Chandra X-ray Observatory. In six cases (IGR J17040-4305, IGR J18017-3542, IGR J18112-2641, IGR J18434-0508, IGR J19504+3318, and IGR J20084+3221), a unique Chandra counterpart is identified with a high degree of certainty, and for five of these sources (all but IGR J19504), Gaia distances or proper motions indicate that they are Galactic sources. For four of these, the most likely classifications are that the sources are magnetic cataclysmic variables (CVs). J20084 could either be a magnetic CV or a high-mass X-ray binary. We classify the sixth source (J19504) as a likely active galactic nucleus (AGN). In addition, we find likely Chandra counterparts to IGR J18010-3045 and IGR J19577+3339, and the latter is a bright radio source and probable AGN. The other two sources, IGR J12529-6351 and IGR J18013-3222, do not have likely Chandra counterparts, indicating that they are transient, highly variable, or highly absorbed.

Unified Astronomy Thesaurus concepts: High energy astrophysics (739); Surveys (1671); Astrometry (80)

1. Introduction

The International Gamma-Ray Astrophysics Laboratory (INTEGRAL; Winkler et al. 2003), which launched in 2002, has uncovered a large number of new or previously poorly studied sources by surveying the sky and Galaxy in the ~20–100 keV band. These are called INTEGRAL Gamma-Ray (IGR) sources. To produce emission in this energy band, particles must be accelerated to high energies, and most of the IGR sources are places where extreme physics is taking place. In many cases, the extreme physics is related to accretion onto compact objects (black holes, neutron stars, or magnetic white dwarfs) or to highly magnetized neutron stars (pulsars or magnetars).

An INTEGRAL catalog based on 8 yr of observations includes 939 persistent and transient sources detected above the 4.5σ significance level in the 17–100 keV band (Bird et al. 2016). The largest groups of sources include 369 active galactic nuclei (AGNs), 129 low-mass X-ray binaries (LMXBs), 116 high-mass X-ray binaries (HMXBs), and 56 cataclysmic variables (CVs). Of the 939 sources, the source type was identified for 219 at the time Bird et al. (2016) was written. The 939 sources include both previously known sources and 447 IGR sources. The main reasons that INTEGRAL has found new (IGR) sources are (1) the relatively large field of view has allowed for the full sky to be covered; (2) the high-energy bandpass is not affected by Galactic absorption; and (3) most high-energy sources are transient or variable. While there are many notable sources among the IGR sources, INTEGRAL’s capabilities have been especially good for finding new HMXBs, including a population of obscured HMXBs (Matt & Guainazzi 2003; Walter et al. 2006) and a population of Supergiant Fast X-ray Transients (Negueruela et al. 2006; Sguera et al. 2006; Romano et al. 2014).

While the Bird et al. (2016) analysis was carried out for INTEGRAL observations of the whole sky and included enhancements for finding transient sources, another INTEGRAL analysis effort has focused on sources within 17.5° of the Galactic plane (Krivonos et al. 2012). The Krivonos et al. (2012) 9 yr survey resulted in detections of 402 sources. While these included persistent and transient sources, the search focused on sources that were detected in the combined 9 yr of observations, which favors the detection of persistent sources. The most recent report on this survey used 14 yr of INTEGRAL data (Krivonos et al. 2017), and we selected sources from this catalog for the current work.

The current work is focused on making progress toward classifying IGR sources of currently unknown nature by observing a selection of them with the Chandra X-ray Observatory. INTEGRAL provides detections, high-energy spectra, and localization with 90% confidence uncertainties of 1°–5°, depending on source strength. With such positional uncertainties, it is not usually possible to identify an optical or near-IR counterpart, especially in the Galactic plane. Thus, the most important information that Chandra can provide is a more precise source position. In addition, with its 0.3–10 keV
Table 1
Source Information from the 2017 INTEGRAL Catalog

| IGR Name | $l^a$ | $b^a$ | R.A.$^b$ | Decl.$^b$ | Flux$^d$ (17-60 keV) | Significance$^e$ |
|----------|-------|-------|----------|-----------|---------------------|----------------|
| J20084+3221 | 70.04 | -0.23 | 302.124 | +32.350 | 0.68 ± 0.08 | 8.4 |
| J18434-0508 | 27.45 | -0.56 | 280.855 | -5.138 | 0.52 ± 0.08 | 6.2 |
| J12529-6351 | 303.10 | -1.00 | 193.241 | -63.868 | 0.49 ± 0.09 | 5.5 |
| J17040-4305 | 343.61 | -1.02 | 256.010 | -43.080 | 0.44 ± 0.07 | 6.2 |
| J19577+3339 | 69.95 | +2.38 | 299.429 | +33.658 | 0.46 ± 0.08 | 5.6 |
| J19504+3318 | 68.87 | +3.50 | 297.615 | +33.311 | 0.63 ± 0.09 | 7.4 |
| J18010-3045 | 0.12 | -3.82 | 270.271 | -30.764 | 0.37 ± 0.05 | 7.2 |
| J18112-2641 | 4.78 | -3.83 | 272.854 | -26.707 | 0.48 ± 0.06 | 8.7 |
| J18013-3222 | 358.74 | -4.65 | 270.326 | -32.371 | 0.34 ± 0.05 | 6.4 |
| J18017-3542 | 355.90 | -6.27 | 270.371 | -35.638 | 0.42 ± 0.06 | 7.0 |

Notes.

$^a$ Galactic longitude converted from INTEGRAL position.

$^b$ Galactic latitude converted from INTEGRAL position.

$^c$ Source position measured by INTEGRAL and reported in Krivonos et al. (2017). Individual position uncertainties are not provided in Krivonos et al. (2007), but it is indicated that the typical 90% confidence INTEGRAL error radius for these sources is 3.6$''$.

$^d$ The flux measured by INTEGRAL in units of $10^{-11}$ erg cm$^{-2}$ s$^{-1}$.

$^e$ The significance of the INTEGRAL detection in terms of signal to noise.

We have carried out similar studies in the past (e.g., Tomsick et al. 2012, 2016), and many of the analysis techniques that we employ in this work are the same as described in Tomsick et al. (2020).

1.1. Target Selection

We selected targets to observe with Chandra from the 72 new sources detected in the 17–60 keV band and reported in the 14 yr INTEGRAL catalog (Krivonos et al. 2017). This catalog includes only sources that were not detected in the previous catalog version (Krivonos et al. 2012). We eliminated sources with likely or definite classifications and with previous coverage with Chandra, XMM-Newton, or Swift. As our scientific focus is on Galactic sources, we also used Galactic latitude as a criterion, and $|b|$ is between 0.23$^\circ$ and 6.27$^\circ$ for the sources we study in this work. We obtained Chandra observations for eight sources in Chandra cycle 20 (observations carried out in 2019) and five sources during cycle 19. Results from three of the cycle 19 observations are reported in Hare et al. (2019) and Hare et al. (2021), providing classifications of one HMXB and two magnetic CVs. We report the results for the Chandra observations for the other two sources in this work.

In summary, we are reporting on short ($\sim$5 ks) Chandra observations of the 10 IGR sources listed in Table 1. They are listed in order of how close they are to a Galactic latitude of $b = 0^\circ$. In addition to the INTEGRAL source coordinates, we provide the flux and detection significance from Krivonos et al. (2017). We note that Krivonos et al. (2017) does not provide position uncertainties for individual sources but indicates that the 90% confidence INTEGRAL error radii are typically 3.6$''$. In Section 2, we describe the Chandra observations, analysis, and results, including searching for Chandra counterparts to the IGR sources, carrying out Chandra photometry, and providing X-ray localizations. Section 3 includes the results of fitting Chandra and INTEGRAL energy spectra. In Section 4, we search for multiwavelength counterparts using the accurate Chandra localizations. Sections 5 and 6 include a discussion of the results and conclusions, respectively.

Table 2
Chandra Observations

| IGR Name | ObsID | Start Time (UT) | Exposure Time (s) |
|----------|-------|-----------------|-------------------|
| J18017-3542 | 20200 | 2018 Jul 15, 21.8 hr | 4956 |
| J12529-6351 | 20201 | 2018 Feb 20, 3.3 hr | 4952 |
| J20084+3221 | 21248 | 2019 Jan 9, 19.5 hr | 4949 |
| J18434-0508 | 21249 | 2019 Mar 5, 3.4 hr | 4942 |
| J17040-4305 | 21250 | 2019 May 29, 1.5 hr | 4956 |
| J19577+3339 | 21251 | 2018 Nov 30, 8.7 hr | 4959 |
| J19504+3318 | 21252 | 2019 Jan 12, 1.4 hr | 4956 |
| J18010-3045 | 21253 | 2019 May 14, 3.0 hr | 4962 |
| J18112-2641 | 21254 | 2019 Mar 6, 8.4 hr | 4955 |
| J18013-3222 | 21255 | 2019 May 13, 10.4 hr | 5057 |

2. Chandra Observations, Analysis, and Results

Table 2 provides the basic information for the 10 Chandra observations, which occurred between 2018 February 20 and 2019 May 29. We used the ACIS-I instrument (Garmire et al. 2003) with exposure times of $\sim$5000 s, which is sufficient to expect $>100$ counts based on the INTEGRAL fluxes and extrapolation of a hard power law into the Chandra bandpass. The field of view of the four ACIS-I chips is $16.9' \times 16.9'$, which easily contains the 90% confidence INTEGRAL error regions with one pointing per source. In each case, the pointing positions are the INTEGRAL positions given in Table 1.

We reduced the data using the Chandra Interactive Analysis of Observations (CIAO; Fruscione et al. 2006) version 4.13 software with the Calibration Database version 4.9.4, largely following instructions in the CIAO science threads.12 We used chandra_repro for reprocessing the data, resulting in a photon list along with other instrument files.

We created exposure-corrected images in the 0.3–10 keV band for each of the 10 Chandra observations using flux-image. These images were then combed for sources by applying the wave detection algorithm wavdetect, using wavelets with scales of 1, 2, 4, 6, 8, 12, 16, 24, and 32, and

12 See http://asc.harvard.edu/ciao/threads/index.html.
with a detection threshold set to produce just one spurious source among the detection results. The number of sources detected for each observation is given in Table 3.

In order to account for any systematic uncertainty in our Chandra astrometry due to telescope pointing, we compared the detected source positions with several optical and near-IR catalogs using wcs_match, and shifted the source positions for each ObsID accordingly. The catalogs we used to match our detected Chandra sources, while ignoring the candidate IGR counterpart (when applicable, see Section 2.1 for details on counterpart selection), and these results are provided in Table 3. We also include the average and maximum residuals between the Chandra and optical/near-IR catalog positions, after translation of the Chandra coordinates. In observations where fewer than three crossmatches were found, as was the case for ObsIDs 21248, 21250, 21251, and 21252, we did not shift the Chandra positions.

We performed Chandra aperture photometry to determine the number of counts for all of the detected sources. We made a point-spread function (PSF) map using mkpsfmap for an energy of 2.3 keV (the typical average photon energy for the full 0.3–10 keV Chandra bandpass), and determined the 95% encircled energy radius for each source. After defining background regions for each observation, we used dmextract to extract background-subtracted counts in the 0.3–2, 2–10, and 0.3–10 keV energy bands.

### 2.1. Selecting the Most Likely Counterparts

As in previous work (e.g., Tomsick et al. 2020), we calculated the probability that sources with the brightnesses we observe would be found in a search area with a radius of $\theta_{\text{search}}$ by chance. In cases where the source is within the 90% confidence INTEGRAL error radius ($\theta_{\text{INTEGRAL}}$), $\theta_{\text{search}} = \theta_{\text{INTEGRAL}} = 3.6''$. If the source is outside the INTEGRAL error circle, then $\theta_{\text{search}}$ is equal to the angular distance from the best estimate of the INTEGRAL position. Another factor that is important in determining the probability that the Chandra/INTEGRAL association is spurious is the brightness of the source.

As in Tomsick et al. (2020), we determine the relative probabilities for all sources using

$$P_{\text{rel}} = 1 - e^{-\left(\frac{N_{\text{2-10 keV}}}{C_0}\right)^{-1.0} \cdot \theta_{\text{search}}^2},$$

where $N_{\text{2-10 keV}}$ is the number of counts in the 2–10 keV band, $C_0$ is a normalization constant set to a value of 140 so that the brightest sources have $P_{\text{rel}}$ values near 1%, and we use $-1.0$ as the slope of the log $N$ vs. log $S$, which is intermediate between previously published profiles (Sugizaki et al. 2001; Formisani et al. 2014). In our case, with all of the observations having the same exposure, it is valid to use counts (as opposed to count rates) for this calculation. The $P_{\text{rel}}$ values for all the sources detected in the 10 Chandra observations are plotted in Figure 1. This results in the field sources clustering at low numbers of counts and high values of $P_{\text{rel}}$. For six of the IGR fields (IGR J17040-4305, IGR J18017-3542, IGR J18112-2641, IGR J18434-0508, IGR J19504+3318, and IGR J20084+3221), there are clear Chandra counterparts that are well separated from the field sources. There are also potential counterparts in the IGR J18010-3045 and the IGR J19577+3339 fields. The IGR J12529-6351 and IGR J18013-3222 fields do not appear to have likely counterparts.

The candidate Chandra source in the IGR J19577+3339 field has $P_{\text{rel}} = 16.4\%$, which is the highest spurious association probability of any of the eight candidates we consider, and Figure 1 shows that there are even some field sources with lower probabilities. However, searching in VizieR at this position finds a likely match with the radio source ICRF J195740.5+333827. The Chandra and radio Very Long Baseline Interferometry (VLBI) positions are consistent with a separation of $0.56'' \pm 0.93''$ (90% confidence). This is a bright radio source with a flux of $295 \pm 9$ mJy at 1.4 GHz that appears in a number of radio catalogs. The radio source is suspected to be an AGN, but no

### Notes

a The number of Chandra sources detected on the four ACIS-I detector chips.

b The number of matches between the Chandra detections and the survey catalog.

c The shifts in the x and y detector coordinate directions in pixels. The conversion is 1 pixel = 0.492''.

d Average residual (in arcseconds) between the Chandra and O/IR sources.

e Maximum residual (in arcseconds) between the Chandra and O/IR sources.

### Table 3

| IGR Name     | ObsID  | $N_{\text{Chandra}}^*$ | Survey | $N_{\text{matches}}^b$ | $x_{\text{shift}}^c$ | $y_{\text{shift}}^c$ | Avg. Residual$^d$ | Max. Residual$^d$ |
|--------------|--------|------------------------|--------|-------------------------|----------------------|----------------------|-------------------|-------------------|
| J18017-3542  | 20200  | 19                     | Vista VVV | 5                       | −0.08                | −0.20                | 0.55              | 0.90              |
| J12529-6351  | 20201  | 14                     | Gaia EDR3 | 5                       | 0.20                 | −0.56                | 0.51              | 0.78              |
| J20084+3221  | 21248  | 11                     | PanSTARRS | 2                       | ...                  | ...                  | ...               | ...               |
| J18434-0508  | 21249  | 22                     | Gaia EDR3 | 6                       | 0.13                 | −0.33                | 0.59              | 0.85              |
| J17040-4305  | 21250  | 12                     | Gaia EDR3 | 2                       | ...                  | ...                  | 2.12              | ...               |
| J19577+3339  | 21251  | 11                     | Gaia EDR3 | 2                       | ...                  | ...                  | ...               | ...               |
| J20040+3318  | 21252  | 13                     | PanSTARRS | 2                       | ...                  | ...                  | ...               | ...               |
| J18010-3045  | 21253  | 19                     | Gaia EDR3 | 8                       | −0.13                | −0.14                | 0.45              | 0.84              |
| J18112-2641  | 21254  | 18                     | Vista VVV | 3                       | −0.59                | −0.35                | 0.26              | 0.37              |
| J18013-3222  | 21255  | 15                     | Gaia EDR3 | 7                       | −0.27                | 0.49                 | 0.57              | 0.72              |
source. For the statistical uncertainty, we calculate the 90% confidence intervals following Equation (13) from Kim et al. (2007), which uses the number of counts as well as the angular distance of the source from the Chandra aimpoint. The Chandra counterpart to IGR J18012-2641 has the greatest separation from its INTEGRAL position, at 6.05'. We also include the potential counterpart to IGR J18010-3045 in Table 4 as well as in the rest of our analysis, although we cannot be as confident (with fewer counts and a separation of 5.95') that the detected Chandra source is a true match.

In Section 3, we determine fluxes for the eight most likely counterpart candidates and use previously measured surface density (log N − log S) profiles (Sugizaki et al. 2001; Fornasini et al. 2014) to calculate absolute spurious probabilities for the Chandra/INTEGRAL associations.

3. Chandra Energy Spectra

For the eight candidate counterparts, we extracted Chandra energy spectra using specextract. We used the same source regions (circles with radii corresponding to 95% encircled energy) and background regions as for the photometry. We rebinned the spectra with the requirement of a detection in each bin at the 3σ−5σ level, depending on the total number of counts in the spectrum. The one exception is J19577, for which we binned to 1.5σ because the spectrum only includes 10 counts. We used XSPEC (Arnaud 1996) to fit the Chandra spectra with an absorbed power-law model, and the parameters are reported in Table 5. One of the bright sources, J17040, was also located close to the center of the field of view where the PSF is small. This resulted in significant photon pileup, and we included the XSPEC model pileup (Davis 2001) to account for this in the spectral fitting. Photon pileup does not impact the spectra of the other sources. We performed the fits by minimizing the C-statistic, and we give the C values and number of degrees of freedom (dof) in Table 5.

We use the C values and the variances in C (see Kaastra 2017) to assess the quality of the fits. The Preject values in Table 5 indicate the probability that an absorbed power law does not provide a good description of the spectrum. The Preject value is only meaningful if C is larger than the number of dof, and this is only the case for J17040 (41%), J19504 (41%), and...
Table 5
Chandra Spectral Parameters and Absolute Spurious Probabilities

| IGR Name | $N_{\text{H}}$ $^a$ ($\times 10^{22}$ cm$^{-2}$) | $N_{\text{H, Galactic}}$ $^b$ ($\times 10^{22}$ cm$^{-2}$) | $\Gamma$ | Absorbed Flux$^c$ (2–10 keV) | Unabsorbed Flux$^d$ (2–10 keV) | $C$/dof | $P_{\text{reject}}$ | Probability$^e$ |
|-----------|-----------------|-----------------|-----------|-----------------|-----------------|--------|-----------------|-----------------|
| J17040    | 0.5$^{+0.7}_{-0.5}$ | 1.2 | 0.2 ± 0.4 | 7.45 $\times 10^{-12}$ | 7.56 $\times 10^{-12}$ | 23/19$^g$ | 41% | 0.19%–0.34% |
| J18010    | 0.03$^{+0.15}_{-0.10}$ | 0.3 | 0.4$^{+0.3}_{-0.4}$ | 3.57 $\times 10^{-13}$ | 3.57 $\times 10^{-13}$ | 1.2/2 | ... | 10%–21% |
| J18017    | 5$^{+3}_{-1.3}$ | 0.2 | 0.0$^{+0.2}_{-0.1}$ | 7.05 $\times 10^{-13}$ | 7.08 $\times 10^{-13}$ | 2.2/3 | ... | 2.2%–3.5% |
| J18112    | 0.5$^{+0.7}_{-0.5}$ | 0.3 | 0.9$^{+0.7}_{-0.5}$ | 7.50 $\times 10^{-13}$ | 7.59 $\times 10^{-13}$ | 3.5/4 | ... | 5.8%–8.9% |
| J18434    | 0.4$^{+0.2}_{-0.1}$ | 1.4 | 0.7 ± 0.3 | 3.91 $\times 10^{-12}$ | 3.96 $\times 10^{-12}$ | 8/14 | ... | 0.59%–0.80% |
| J19504    | 1.1 ± 0.4 | 0.5 | 1.8 ± 0.3 | 2.17 $\times 10^{-12}$ | 2.24 $\times 10^{-12}$ | 22/18 | 41% | 1.4%–1.5% |
| J19577    | 1.1$^{+1.3}_{-0.1}$ | 0.9 | -0.6$^{+0.5}_{-1.3}$ | 2.52 $\times 10^{-13}$ | 2.57 $\times 10^{-13}$ | 0.2/1 | ... | 4.9%–12% |
| J20084    | 1.0$^{+0.9}_{-0.7}$ | 0.9 | 0.1$^{+0.2}_{-0.1}$ | 3.17 $\times 10^{-12}$ | 3.24 $\times 10^{-12}$ | 15/9$^b$ | 77% | 0.69%–0.86% |

Notes:
$^a$ The errors on the parameters are 90% confidence. The column density is calculated assuming Wilms et al. (2000) abundances and Verner et al. (1996) cross sections.
$^b$ From the HI4PI survey (HI4PI Collaboration et al. 2016).
$^c$ In units of per square centimeter per second.
$^d$ Only corrected for Galactic absorption.
$^e$ The probability that an absorbed power law does not provide a good description of the spectrum based on a calculation of the variance of $C$ according to the method described in Kaasstra (2017).
$^f$ Absolute probability that a source of this brightness would be found by chance in the search region calculated using Equation (4). The range comes from using the two log $N$ – log $S$ distributions in Equations (2) and (3).
$^g$ This includes a pileup correction. There is an improvement to C/dof = 11/17 if an iron emission line is added (see Section 3).

J20084 (77%). For these three sources the largest residuals are single bins at 6.7 keV (3.6σ above the continuum), 1.7 keV (2.8σ above the continuum), and 6.5 keV (2.7σ above the continuum), respectively. While there is no immediate interpretation for the 1.7 keV residual, it is possible that J17040 and J20084 have iron Kα emission lines.

Adding a narrow line for J17040 improves the fit to C/dof = 11/17, and the parameters, with 90% confidence uncertainties, are $E_{\text{line}} = 6.7 \pm 0.1$ keV and $N_{\text{line}} = (6.4^{+19}_{-5.6}) \times 10^{-5}$ ph cm$^{-2}$ s$^{-1}$. The equivalent width is EW = 1.5$^{+8.5}_{-1.5}$ keV, where the uncertainties come from simulations using the eqwidth command in XSPEC. Although the improvement in the fit and the fact that $N_{\text{line}}$ is greater than zero at the 90% confidence level indicate that an iron line may be present, this is not a robust detection for at least three reasons: (1) The small value of C relative to the number of dof suggests that adding the emission line may be over-fitting the spectrum; (2) $P_{\text{reject}}$ = 41% indicates that it is fairly likely (59%) that a power law provides a good description of the spectrum; and (3) the simulations for determining the EW indicate that the data are consistent with EW = 0 at 90% confidence.

For J20084, adding a narrow line improves the fit to C/dof = 7/7, and the parameters are $E_{\text{line}} = 6.7^{+0.1}_{-0.5}$ keV, $N_{\text{line}} = (3.1^{+2.9}_{-2.3}) \times 10^{-5}$ ph cm$^{-2}$ s$^{-1}$, and EW = 0.9$^{+13}_{-0.8}$ keV. We estimate the significance of the emission line by determining the confidence level that makes the $N_{\text{line}}$ error range consistent with zero, which is $\Delta C = 7.7$. This indicates a significance of approximately 99.2%, which corresponds to a 2.6σ detection.

We use the fluxes resulting from the spectral fits to determine the absolute spurious source probabilities for the eight Chandra candidates. As in Tomski et al. (2020), we use

$$N(>F_{2\text{--10 keV, abs}}) = 9.2(F_{2\text{--10 keV, abs}}/10^{-13})^{-0.79} \text{ deg}^{-2},$$

(2)

described in Kaastra which is based on the parameters, with 90% confidence. Also, the candidates to J19504 and J18017 are unlikely (a few percent) to be detected in the search regions by chance. The ranges of probabilities (from the two log $N$ – log $S$ curves) for each source are given in Table 5. This shows that the candidate Chandra counterparts to J17040, J20084, and J18454 are very unlikely (<1%) to be detected in the search regions by chance. Also, the candidates to J19504 and J18017 are unlikely (one to a few percent) to be chance detections. The J18112, J19577, and J18010 candidates have somewhat higher spurious probabilities (5.8%–8.9%, 4.9%–12%, and 10%–21%, respectively), and although, in the following, we perform the same analyses for these three as for the other five, they may possibly be field sources rather than the actual counterpart to the IGR sources (although see Section 2.1 concerning the association of J19577 with a bright radio source).
Figure 2 shows the Chandra spectra with the absorbed power-law fits. As given in Table 5, the spectra have hard power-law photon indices with best-fit values between $\Gamma = -0.6$ and 1.8. In Figure 2, we have added a 17–60 keV point measured by INTEGRAL (Krivonos et al. 2017) for comparison to the extrapolation of the power law. In making this comparison, it is important to keep in mind that the INTEGRAL flux point is an average over 14 yr, while the Chandra spectra are a single observation. Thus, differences can be related to source variability or to a change in spectral slope between the Chandra band and the INTEGRAL band. The 17–60 keV flux point is lower than the extrapolation of the power law for J17040, J18010, J18017, J18434, J19577, and J20084, which makes it possible that the spectrum has a break or a cutoff above 10 keV. These are also the six sources with the hardest power-law indices (best-fit $\Gamma$ values between $-0.6$ and 0.7). For J18112, the 17–60 keV point is consistent with the power-law extrapolation.

Although the softest source (J19504 with $\Gamma = 1.8 \pm 0.3$) has a 17–60 keV point that is higher than the power-law extrapolation, a reinspection of the INTEGRAL image shows significant noise in the part of the sky where J19504 lies due to
the proximity to the bright source Cygnus X-1. In fact, J19504 clearly sits on top of a positive noise artifact, indicating that the INTTEGRAL flux reported in Krivonos et al. (2017) and shown in Figure 2 is an overestimation.

### 4. Optical/IR Identifications

We used the VizieR database to search for optical/IR counterparts to the eight Chandra sources. In Table 6, we provide details on the matches found using Gaia EDR3, including the $G$, $BP$, and $RP$-band magnitudes, the parallax, the astrometric noise, and the proper motion. For three of the sources, a reliable distance measurement is available, and we quote the geometric distances\(^\text{15}\) calculated by Bailer-Jones et al. (2021). Those distances are $0.937 \pm 0.046$ kpc, $1.58 \pm 0.13$ kpc, and $3.0^{+0.12}_{-0.07}$ kpc for J17040, J18017, and J18434, respectively. These three sources also have high proper motions as do J18112 ($5.74 \pm 0.09$ mas yr\(^{-1}\)) and J20084 ($4.77 \pm 0.23$ mas yr\(^{-1}\)). Thus, we conclude that all five of these sources are Galactic. J19504 has a proper motion of $0.12 \pm 0.17$ mas yr\(^{-1}\), which is consistent with zero. The small proper motion does not distinguish between a Galactic or extragalactic nature for J19504, but it does allow for the possibility that the source is extragalactic. The Gaia counterpart to J18010 does not have parallax or proper motion measurements, presumably because it is too faint. J19577 does not have a Gaia counterpart. The closest Gaia source is 1.59″ away.

Although the Bailer-Jones et al. (2021) catalog provides distance estimates for J18112, J19504, and J20084, it also provides information about these estimates suggesting that they may not be reliable. For J18112 and J19504, the astrometric noise is larger than the value of the parallax (Table 6). For J20084, while there is no astrometric noise, the uncertainty on the parallax is almost twice that of the parallax value, and Figure 6 in Bailer-Jones et al. (2021) shows that, in such cases, the distance estimate is highly dependent on the prior distribution assumed.

We also used VizieR to search for All Wide-field Infrared Survey Explorer (AllWISE) (Cutri et al. 2021) IR counterparts to the eight Chandra sources. We found just two matches in the AllWISE catalog. These are for the Chandra counterparts to J19504 and J20084. Both AllWISE counterparts are consistent with being point sources according to the extended source parameter “ex.,” which has a value of zero in both cases. The J19504 counterpart is AllWISE J195019.73+331416.3, which has magnitudes of $W_1 = 12.057 \pm 0.025$, $W_2 = 11.209 \pm 0.020$, $W_3 = 9.028 \pm 0.026$, and $W_4 = 7.14 \pm 0.10$. The $W_1$-$W_2$ and $W_2$-$W_3$ colors place J19504 is a region of the near-IR color plot that is commonly populated by AGN (Mateos et al. 2012; Secrest et al. 2015). We have also checked the near-IR colors for J20084, but it does not fall in the AGN region. The positions of both of the AllWISE sources are consistent with the Gaia positions to within $<0.3″$.

In Table 7, we include the other identifications from the results of VizieR searches, focusing our results to the near-IR matches. These include those matches found in VISTA VVV (Minniti et al. 2010; McMahon et al. 2013; Minniti et al. 2017), the 2 Micron All-Sky Survey, (2MASS; Cutri et al. 2003), UKIDSS (Lucas et al. 2008), and PanSTARRS (Chambers et al. 2016). Across these four survey catalogs, we have measurements of the source magnitudes in the $Y$, $J$, $H$, and $K$/$K_s$ bands, except for J18010, which does not have a reliable $Y$-band measurement due to the source being too faint at those wavelengths. In all cases, the near-IR positions are consistent with the Gaia positions. In Figure 3 we provide the $K$/$K_s$ images of the region in the sky covering each Chandra counterparts position, marked with a red circle in each image. Figure 4 provides the $Y$-band images for each of the eight Chandra counterparts as well. The images for J19577 show that there is no optical or near-IR counterpart in the Chandra error circle. Also, the VLBI radio position, which is inside the Chandra error circle, is marked.

In summary, by utilizing the Chandra counterpart positions and searching the VizieR database, we are able to find optical/IR counterparts for seven sources and a radio counterpart for J19577. From the Gaia EDR3 data, we established distances to three sources, while the proper motions of two of the remaining sources indicate that they are also Galactic in nature. For J19504, the fact that the AllWISE colors place it in a region populated by AGN suggest that J19504 is an AGN, and while the low proper motion in Gaia does not prove that the source is extragalactic, it is consistent with that interpretation. The near-IR counterpart information, including magnitudes, is provided in Table 7 and Figures 3 and 4.

The VizieR search also uncovered counterparts in the VST\(^\text{16}\) Photometric Hα Survey of the Southern Galactic Plane and Bulge (VPHAS+ Data Release 2) for J17040 and J18434 (Drew et al. 2016). For J17040, the counterpart is VPHASDR2 J170405.0-430538.0 with magnitudes of $15.68 \pm 0.01$ for the Hα filter, $r = 16.10 \pm 0.01$, and $i = 15.47 \pm 0.01$. For J18434, the counterpart is VPHASDR2 J184311.4-050545.5 with magnitudes of $17.83 \pm 0.02$ (Hα), $r = 18.31 \pm 0.01$, and $i = 17.71 \pm 0.01$. These correspond to $r-Hα = 0.42 \pm 0.01$ and $r-i = 0.63 \pm 0.01$ for J17040 and $r-Hα = 0.48 \pm 0.02$ and $r-i = 0.60 \pm 0.01$ for J18434. Comparing to the field star distribution in Figure 17 of Drew et al. (2014), these measurements indicate that J17040 and J18434 have an excess at Hα, suggesting the presence of an emission line.

### 5. Sources Without Clear Chandra Counterparts to the IGR Sources

The Chandra observations for IGR J18013-3222 and IGR J12529-6351 did not lead to detections of clear counterparts, but here we consider the Chandra sources in each field with the lowest values of $P_{\text{rel}}$.

For J18013, the sources with the lowest values of $P_{\text{rel}}$ have values of 37.2% and 33.5%, indicating that there is a high chance that they are spurious. In addition, the one with $P_{\text{rel}} = 33.5\%$, CXOU J180143.1-321540, is 8.4’ from the center of the INTEGRAL error circle, which is another reason to doubt that it is the correct counterpart. Within the 3.6’ INTEGRAL error circle, the brightest Chandra source only has four counts. We conclude that the upper limit on the 2–10 keV flux is $<1 \times 10^{-13}$ erg cm\(^{-2}\) s\(^{-1}\).

For J12529, CXOU J125231.0-635021 is within the INTEGRAL error circle and has $P_{\text{rel}} = 24\%$ and 5.7 ± 3.6 detected ACIS counts. While this is a small number, they are all $>2$ keV, suggesting that it is a hard source. It is possible that this is the correct counterpart of the INTEGRAL source, but the evidence is not strong enough to consider it as a likely

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\(^{15}\)Although the Bailer-Jones et al. (2021) catalog includes both geometric and photogeometric distances, we use the geometric distances because the colors of the sources we are studying may deviate from the assumptions made for the photogeometric distances.

\(^{16}\)Very Large Telescope (VLT) Survey Telescope.
| IGR Name | Gaia Number (in EDR3) | Separation\(^a\) (arcsec) | G-magnitude | BP-magnitude | RP-magnitude | Parallax (mas) | Astrometric Noise (mas) | Distance\(^b\) (kpc) | Proper Motion (mas yr\(^{-1}\)) |
|----------|----------------------|---------------------------|-------------|--------------|--------------|-----------------|------------------------|----------------|-------------------------|
| J17040   | 5965412985207709184   | 0.470                     | 16.312 ± 0.005 | 16.798 ± 0.014 | 15.627 ± 0.012 | 1.03 ± 0.06  | 0                      | 0.937 ± 0.046   | 6.53 ± 0.07     |
| J18010   | 4044148421630416256   | 0.784                     | 20.133 ± 0.034 | ...           | ...           | ...            | ...                    | ...            | ...                     |
| J18017   | 4038975665929542784   | 0.273                     | 15.714 ± 0.008 | 15.827 ± 0.026 | 15.451 ± 0.020 | 0.61 ± 0.04  | 0                      | 1.58 ± 0.13   | 6.89 ± 0.04     |
| J18112   | 4064533126752366464   | 0.790                     | 16.625 ± 0.003 | 16.991 ± 0.546 | 15.429 ± 0.015 | 0.37 ± 0.11  | 0.673                 | ...            | 5.74 ± 0.09     |
| J18434   | 4256616815760182528   | 0.366                     | 18.248 ± 0.011 | 18.743 ± 0.043 | 17.625 ± 0.045 | 0.44 ± 0.15  | 0                      | 3.0 ± 0.27     | 3.98 ± 0.16     |
| J19504   | 2034764091072416384   | 0.460                     | 18.698 ± 0.012 | ...           | ...           | −0.35 ± 0.16  | 0.338                 | ...            | 0.12 ± 0.17     |
| J20084   | 205489068576667392    | 0.250                     | 19.461 ± 0.006 | 20.893 ± 0.083 | 18.223 ± 0.021 | 0.15 ± 0.27  | 0                      | ...            | 4.77 ± 0.23     |

Notes.

\(^a\) The angular separation between the Chandra position and the Gaia catalog position.

\(^b\) From Bailer-Jones et al. (2021).
counterpart. We conclude that the upper limit on the 2–10 keV flux is $<1 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$.

6. Discussion

From Chandra observations of 10 IGR sources, we have found definite or candidate soft X-ray counterparts in eight cases. The Chandra positions provide information about the multiband properties of these sources, and we discuss the nature of the sources based on the X-ray and multiband information.

6.1. Galactic Sources with Distances

J17040, J18017, and J18434 are the three sources with distance constraints from Gaia (Table 6). Based on the X-ray luminosities measured by Chandra (Table 5) the 2–10 keV luminosities are $(7.9 \pm 0.8) \times 10^{32}$, $(2.1 \pm 0.4) \times 10^{32}$, and $(4.2_{-0.4}^{+0.5}) \times 10^{33}$ erg s$^{-1}$, respectively. Based on these X-ray luminosities and the hardness of the spectra, the emission is not from isolated stars (consistent with them being detected by INTEGRAL), and the most likely possibility would be that these are accreting binaries, such as CVs or X-ray binaries. For sources with X-ray spectra with power-law photon indices of $\Gamma < 1$, there are two types of binaries that are the most likely possibilities: magnetic CVs, such as intermediate polars, and HMXBs with highly magnetized neutron stars. The magnetic CVs typically have late-type donor stars, while the HMXBs have O or B type stars (by definition). In the following, we use the distances and near-IR magnitudes to consider the most likely classifications for J17040, J18017, and J18434.

Interpreting the near-IR magnitudes of these sources (Table 7) requires that we correct them for Galactic extinction, and we have used 3D dust maps to determine this. For J17040 and J18017, we use the mwdust code\textsuperscript{17} (Bovy et al. 2016) to obtain the $E(B-V)$ values shown in Table 8. The errors come from the $E(B-V)$ range for the Gaia distance range. For J18434, we use the Bayestar\textsuperscript{19} map from Green et al. (2019), accessing $E(g-r)$ values using a web interface\textsuperscript{18} and multiplying by 0.94 to convert to $E(B-V)$.

\textsuperscript{17} See https://github.com/jobovy/mwdust.

\textsuperscript{18} See http://argonaut.skymaps.info/query.

\textsuperscript{19} See http://argonaut.skymaps.info/usage.

Notes.

\textsuperscript{a} The angular separation between the Chandra position and the catalog position.

\textsuperscript{b} For VISTA VVV and UKIDSS, the classification is based on the spatial profile, where $-2$ is a probable star, $-1$ is a star with probability $>90\%$, and 1 is a galaxy with probability $>90\%$. For PanSTARRS, quality flag 61 indicates that the source is extended, and flags 52 and 60 indicate that the criterion for the detection of source extension is not met.

Table 7

| IGR Name | Catalog | Source (arcsec) | Separation$^a$ | $Y$ | $J$ | $H$ | $K/K_*$ | Class$^b$ |
|----------|---------|----------------|---------------|-----|-----|-----|---------|----------|
| J17040   | VISTA VVV | VVV J170404.96-430538.07 | 0.530 | 14.885 $\pm$ 0.003 | 14.627 $\pm$ 0.003 | 14.499 $\pm$ 0.006 | $K_*$ = 14.197 $\pm$ 0.001 | -1 |
| J18010   | VISTA VVV | VVV J180100.64-303957.56 | 0.879 | ... | 18.404 $\pm$ 0.487 | 16.681 $\pm$ 0.173 | $K_*$ = 15.640 $\pm$ 0.095 | -1 |
| J18017   | VISTA VVV | VVV J180112.51-353912.10 | 0.191 | 15.288 $\pm$ 0.011 | 15.008 $\pm$ 0.008 | 14.945 $\pm$ 0.014 | $K_*$ = 14.821 $\pm$ 0.022 | -1 |
| J18112   | VISTA VVV | VVV J181106.38-264114.93 | 0.839 | 14.467 $\pm$ 0.008 | 13.943 $\pm$ 0.007 | 13.290 $\pm$ 0.007 | $K_*$ = 13.024 $\pm$ 0.008 | -1 |
| J18112   | PanSTARRS | 7597272741145261 | 0.776 | 15.425 $\pm$ 0.002 | ... | ... | ... | 52 |
| J18434   | UKIDSS | J184311.43-050545.6 | 0.403 | ... | 18.932 $\pm$ 0.173 | 18.087 $\pm$ 0.206 | 16.883 $\pm$ 0.131 | -1 |
| J18434   | PanSTARRS | 10188207975695145 | 0.364 | 17.671 $\pm$ 0.027 | ... | ... | ... | 52 |
| J19504   | 2MASS | 19501973+3314166 | 0.115 | ... | 15.423 $\pm$ 0.060 | 14.542 $\pm$ 0.068 | 13.682 $\pm$ 0.049 | ... |
| J19504   | PanSTARRS | 147889275821426046 | 0.166 | 17.136 $\pm$ 0.026 | ... | ... | ... | 61 |
| J20084   | UKIDSS | J200844.16+321818.2 | 0.375 | ... | 16.037 $\pm$ 0.007 | 15.306 $\pm$ 0.006 | 14.885 $\pm$ 0.011 | -1 |
| J20084   | PanSTARRS | 146763021840106679 | 0.279 | 17.652 $\pm$ 0.033 | ... | ... | ... | 60 |
absolute magnitude. Although the $T_{\text{eff}}$ temperatures from the optical are not formally consistent with the near-IR, the measurements are still consistent with emission from an accretion disk, and the different temperatures may be caused by source variability. In addition, for J18434, $T_{\text{eff}} > 7900$ K while $T_{\text{type}}$ is constrained to be lower. Since the Gaia and near-IR measurements are made at different times, the likely interpretation is that J18434 also has emission from a variable accretion disk. A comparison of the VISTA and PanSTARRS magnitudes provides additional evidence that J18434 is variable in the optical and near-IR (Table 7). The evidence for H$\alpha$ emission lines for J17040 and J18434 from the VPHAS + survey presented in Section 4 is consistent with emission from an accretion disk for these two sources.

Given the presence of hard X-ray emission, finding evidence for an accretion disk is expected. The presence of accretion, the evidence for late-type companions, and the very hard values of the X-ray power-law index suggests a possible magnetic CV nature. For J17040, $\Gamma = 0.2 \pm 0.4$, which indicates that a magnetic CV nature is very likely. The power-law photon index is not as well constrained for J18017 ($\Gamma = 0.7^{+0.3}_{-0.2}$), but the source may also be a magnetic CV. At $\Gamma = 0.7 \pm 0.3$, J18017 is somewhat softer than J17040, but we still consider it to be a strong magnetic CV candidate.

### 6.2. Other Galactic Sources

J18112 and J20084 both have large Gaia-measured proper motions and are Galactic, but the source distances are not known. Both have hard spectra with $\Gamma = 0.9^{+0.7}_{-0.5}$ for J18112 and $0.1^{+0.4}_{-0.2}$ for J20084, suggesting that they may be magnetic CVs or HMXBs.

In the direction of J18112 ($l = 4.78^\circ$, $b = -3.83^\circ$, which is in the Galactic bulge), $E(B - V)$ increases from 0.14 at a distance
The distance \( d \) of 500 pc and reaches a maximum of 0.68 at \( d = 4 \) kpc (Bovy et al. 2016). At 500 pc and using the near-IR magnitudes in Table 7, \( J - H - (A_J - A_H) = 0.615 \), corresponding to \( T_{\text{eff}} = 3660 \) K, which is the temperature for an early M-type star. The absolute magnitude at 500 pc would be \( M_J = 5.34 \), corresponding to a late K-type main-sequence star. It is clear that the nearby distance scenario strongly disfavors the HMXB possibility. For distances \( d > 4 \) kpc, \( J - H - (A_J - A_H) = 0.463 \pm 0.011 \), corresponding to \( T_{\text{eff}} = 4830-5100 \) K (K2V-K3V). The absolute magnitude is \( M_J < 0.39 \) for \( d > 4 \) kpc. While the absolute magnitude at large distances allows for the presence of a high-mass companion star, the low temperature derived from the colors is inconsistent with this scenario. Thus, we conclude that a magnetic CV with a low-mass star is strongly favored. The brightness in the near-IR may indicate that the companion is an evolved giant star. However, there also may be a component of the emission from an accretion disk based on the fact that J18112 is variable in the \( Y \) band (Table 7).

J20084 is essentially in the middle of the Galactic plane \( (b = -0.23^\circ) \), and it has relatively high extinction. Using Green et al. (2019), we find \( E(B - V) > 1.5 \) if the distance is \( d > 1.8 \) kpc and \( E(B - V) > 2.0 \) if \( d > 4.5 \) kpc. Given the near-IR magnitudes (Table 7), \( J - H - (A_J - A_H) < 0.30 \) at the lower distance and \( < 0.16 \) for larger distances. These colors correspond to temperature limits of \( T_{\text{eff}} > 5900 \) K and \( > 6700 \) K. Without a distance, \( M_J \) is highly uncertain. At a distance of \( 4.5 \) kpc and \( A_J = 1.6, M_J = 1.2 \), which would indicate an early-A spectral type if the stellar component dominates the near-IR emission. However, the distance could be larger, which would make the spectral type even earlier. Thus, we cannot rule out the possibility that J20084 is an HMXB.

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**Figure 4.** \( Y \)-band images from the VISTA VVV and PanSTARRS surveys for the eight IGR sources with candidate Chandra counterparts. The red circles indicate the Chandra positions (90% confidence). For J18010, although the near-IR counterpart is marginally visible, no \( Y \)-band magnitude is given in the VISTA VVV DR2 database.
Table 8
Galactic Sources with Distances

| Parameter              | J17040                     | J18017                     | J18434                     |
|------------------------|----------------------------|----------------------------|----------------------------|
| \( T_{\text{eff}} \)   | \( (7.9 \pm 0.8) \times 10^{32} \) | \( (2.1 \pm 0.4) \times 10^{32} \) | \( (4.2^{+1.6}_{-3.2}) \times 10^{33} \) |
| \( E(B - V) \)         | \( 0.237^{+0.010}_{-0.012} \) | \( 0.326^{+0.005}_{-0.016} \) | \( 0.75^{+0.07}_{-0.17} \) |
| \( A_{V} \)            | \( 0.73^{+0.04}_{-0.04} \)   | \( 1.01^{+0.02}_{-0.05} \)   | \( 2.3^{+0.3}_{-0.5} \)    |
| \( A_{J} \)            | \( 0.190^{+0.008}_{-0.010} \) | \( 0.262^{+0.005}_{-0.013} \) | \( 0.60^{+0.08}_{-0.13} \) |
| \( A_{R} - A_{H} \)    | \( 0.066^{+0.03}_{-0.04} \)   | \( 0.091^{+0.007}_{-0.002} \) | \( 0.21^{+0.03}_{-0.05} \) |
| \( J - H - (A_{J} - A_{H}) \) | \( 0.062^{+0.008}_{-0.007} \) | \( -0.028^{+0.017}_{-0.016} \) | \( 0.64 \pm 0.27 \) |
| \( T_{\text{eff}} (K) \) | \( 7680 \pm 90 \)           | \( 9600 \pm 800 \)           | \( 2200-5300 \) |
| \( M_{J} \)            | \( 4.58 \pm 0.11 \)          | \( 3.75 \pm 0.18 \)          | \( 9.2^{+0.5}_{-0.7} \)    |
| Limit on type          | K2V or later                | G2V or later                | K5V or later                |
| \( T_{\text{type}} (K) \) | \(< 5100 \)                 | \(< 5770 \)                 | \(< 4400 \)                 |

Notes.

* 2–10 keV luminosity in erg per second with 68% confidence errors.
* Spectral type if the J-band luminosity is dominated by emission from a star. If there is another contribution (from an accretion disk, for example), then any stellar component in the system would have a later spectral type.

6.3. Sources with Likely AGN Classifications

The evidence that J19504 is an AGN is primarily based on the fact that its Wide-field Infrared Survey Explorer (WISE) colors place it in the AGN region. Although it is marked as an extended source in PanSTARRS (Table 7), it is unclear whether it is truly extended or if the nearby and partially blended star (Figure 4) is the reason it is flagged as extended in the PanSTARRS processing. The Gaia measurements give a negative parallax and a proper motion consistent with zero (Table 6), which is consistent with but does not prove the AGN hypothesis. J19504 is also an outlier in its X-ray spectral parameters with a softer power-law slope (\( \Gamma = 1.8 \pm 0.3 \)) and possible evidence for absorption greater than the Galactic value (Table 5). We conclude that IGR J19504+3318 is very likely to be an AGN, but more proof is needed.

For J19577, even though the flux of the Chandra counterpart allows for the possibility that it is unrelated to the INTEGRAL source, the fact that the source is actually more unusual in being a 295 mJy radio source increases the likelihood that it is related to IGR J19577+3339. The radio source does not have a redshift. We conclude that IGR J19577+3339 is likely to be an AGN.

6.4. Unclassified Sources

While three sources remain unclassified (J18010, J18013, and J12529), this study has provided useful information. For J18010, there is a candidate Chandra counterpart with a relatively hard spectrum that extrapolates to a flux in the INTEGRAL bandpass that is consistent with the flux measured by INTEGRAL (Figure 2). In addition, the Chandra position is consistent with an optical/near-IR source detected by Gaia (although it is too faint for a distance or proper motion measurement) and VISTA. The \( K_{\text{s}} \)-band magnitude is \( 15.640 \pm 0.095 \), which is bright enough to obtain a near-IR spectrum, which would greatly help in the classification of this source. We also note that the source is \(< 4^{+3}_{-1} \) from the center of the Galaxy, which increases the probability that it is Galactic.

Neither J18013 nor J12529 have likely Chandra counterparts. The flux upper limits are low enough compared to the flux measured by INTEGRAL that the source is likely to be variable or transient. However, since the Chandra and INTEGRAL bands do not overlap, we cannot rule out the possibility that Chandra does not detect the source due to a high column density.

7. Summary and Conclusions

The larger context for this work is the INTEGRAL Galactic plane surveys, which are providing new information about hard X-ray Galactic populations. Table 9 provides a summary of the results obtained using the 10 Chandra observations. In five cases, the Chandra localization identifies a Gaia source with a distance or high proper motion measurement, indicating that the sources are Galactic. They all have hard X-ray spectra, suggesting that they are either magnetic CVs or HMXBs. For the three sources with distance measurements (IGR J17040-4305, IGR J18017-3542, and IGR J18434-0508), we argue that the magnetic CV classification is the most likely one. For the other two Galactic sources, IGR J18112-2641 is also more likely to be a CV than an HMXB based on analysis of the near-IR magnitudes and the fact that the source shows variability by a magnitude in the \( Y \) band. IGR J20084+3221 could be a CV or an HMXB. IGR J19504+3318 and IGR J19577+3339 are candidate AGN. With the exception of J19577, the sources are bright enough for optical or near-IR spectroscopy, which will provide definitive classifications.
Table 9
Summary of Results

| IGR Name       | Chandra Counterpart or 2–10 keV flux limit | Galactic or Extragalactic | Source Type | Evidence                                      |
|----------------|------------------------------------------|---------------------------|-------------|-----------------------------------------------|
| J12529-6351    | <1 \times 10^{-13}                       | ...                       | ...         | ...                                           |
| J17040-4305    | CXOU J170404.9-430537                    | Galactic                  | magnetic CV?| Gaia distance (0.937 ± 0.046 kpc)            |
| J18010-3045    | CXOU J180100.6-303958                    | ?                         | ?           | ?                                             |
| J18013-3222*   | <1 \times 10^{-13}                       | ...                       | ...         | ...                                           |
| J18017-3542    | CXOU J180175.5-353912                    | Galactic                  | magnetic CV?| Gaia distance (1.58 ± 0.13 kpc)              |
| J18112-2641    | CXOU J181105.8-264115                    | Galactic                  | magnetic CV?| Gaia proper motion; variability in Y          |
| J18434-0508    | CXOU J184311.4-050545                    | Galactic                  | magnetic CV?| Gaia distance (3.0 \pm 0.1 kpc)              |
| J19504-3318    | CXOU J195019.7-331416                    | Extragalactic             | AGN?        | WISE colors                                   |
| J19577-3339    | CXOU J195740.5-333828                    | Extragalactic             | AGN?        | Bright radio source                           |
| J20084+3221    | CXOU J200844.1+321818                   | Galactic                  | magnetic CV? or HMXB? | Gaia proper motion |

Note.
* The Chandra limit indicates that the IGR source is transient, highly variable, or highly absorbed.

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Facilities: CXO, INTEGRAL, Gaia, WISE, VLT, UKIRT.

Software: CIAO (Fruscione et al. 2006), XSPEC (Arnaud 1996).

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