Comparison of Spitzer/IRAC Galactic Center 3.6–8.0 μm survey results with X–ray emission in the central 40×40 parsecs

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Abstract. We have studied the correlation between 2357 Chandra X–ray point sources identified by Muno et al. (2003) in a 40×40 parsec field and ~20,000 infrared sources we observed in the corresponding subset of our 2×1.5 degree Spitzer/IRAC Galactic Center Survey at 3.6–8.0 μm (see Stolovy et al.; this conference), using various spatial and brightness thresholds. The correlation was determined for source separations of less than 0.5, 1.0 or 2.0 arcsec. No significant correlation was found between the X–ray and infrared point sources on these scales. Only one compact infrared source, IRS 13, can be identified with any of the dozen prominent X–ray emission features in the 3×3 parsec region centered on Sgr A*, and the diffuse X–ray and infrared emission around Sgr A* seems to be anti–correlated on a few–arcsecond scale. We compare our results with previous identifications of near infrared companions to Chandra X–ray sources.

1. Chandra–Spitzer/IRAC point source correlation study
We have calculated the correlation between 2357 hard and soft Chandra X–ray sources identified and catalogued by Muno et al. (2003) in a 40×40 parsec field in the Galactic Center (Figure 1) and the ~20,000 infrared point sources brighter than L = 12 that we extracted from the corresponding field in our Spitzer/IRAC Galactic Center Survey. Our survey imaged a 2.0×1.5 degree (265×200 parsec at 7.6 kpc) region of the Galactic Center at 3.6, 4.5, 5.8 and 8.0 μm with 1.2 arcsec pixels and nominal resolution of 2 arcsec for the entire survey (see Stolovy et al.; this conference).
Figure 1. The 40×40 parsec infrared and X-ray field that was used for the X-ray/infrared point source correlation study. Left: Composite 3.6, 5.8 and 8.0 μm Spitzer/IRAC image of the 40×40 parsec study field. It yielded ~20,000 infrared point sources. Right: Composite Chandra image of the study field (Wang et al. 2003; red = 1–3 keV, green = 3–5 keV, blue = 5–8 keV).

We searched for infrared sources that fell within 0.5, 1.0 and 2.0 arcsec of the Muno et al. (2003) X-ray source positions. The X-ray and infrared sources in the study field show an extremely weak correlation. Fewer than 7% of the 2357 X-ray sources had infrared counterparts in our list of IRAC infrared sources brighter than 12 mag at 4.5 μm in a 1 arcsec sampling radius. However, nearly all of these are likely to be false identifications. We determined the likelihood of false correlations in the crowded infrared field by doing the same correlation analysis with the X-ray source position template offset 5.0 arcsec from the nominal location, in a grid of eight positions N–S and E–W off center. The number of coincidences found in excess of chance is typically 1% of the X-ray sources. For soft X-ray sources there is a modest excess in the number of infrared counterparts above that expected from random chance. There is a 3-4 σ excess in the number of soft X-ray sources with IR counterparts at 3.6 μm compared to a 2 σ excess in the correlations at 8.0 μm. Based on the soft X-rays observed from these sources (and therefore their relatively low column densities), we expect that the soft X-ray sources are foreground objects, and not at the distance of the Galactic Center. The excess soft X-ray/IR correlation is therefore likely due to these sources being nearby, rather than being intrinsically bright in both wavebands. The hard X-ray sources seem to have only as many infrared counterparts as would be expected from random associations.

2. Infrared and X-ray sources are uncorrelated in the central few parsecs
Although casual inspection of the Chandra and Spitzer/IRAC images gives the impression that the bright X-ray central cluster would have many infrared stellar counterparts, close examination shows that only one of the brighter, compact infrared sources is associated with any of the dozen distinct X-ray sources in the central 3×3 parsecs. With the exception of IRS 13 (which notably has been proposed as a candidate host for an intermediate mass black hole; see e.g., Maillard et al. 2004), none of the other infrared point sources coincide with any bright X-ray features. Otherwise the infrared sources are completely uncorrelated with Chandra X-ray sources in the central 3×3 parsec field of view on all but the largest (> 1 parsec) spatial scale.
Near Infrared Stars (J+H+K) X–ray Chandra Spitzer/IRAC (3.8–8.0 μm)

Figure 2. Near infrared stars (left, Blum et al. 1996), Chandra X–ray sources (center) and Spitzer/IRAC compact 3.6–8.0 μm infrared sources (right) in the central 3×3 parsecs.

None of the X–ray point sources in this field can be identified with any near infrared star (K < 14) imaged by Blum et al. (1996), with any of the point sources imaged in the Spitzer/IRAC 3.6–8.0 μm survey, or with the compact 12 μm IRS sources imaged with sub–arcsecond resolution by Gezari et al. (1996). The poor correlation even extends to the bright central knot of extended X–ray emission immediately surrounding Sgr A*. The bright X–ray plume that is elongated N–S adjacent to Sgr A* actually lies in a dark region a few arcseconds north of the bright infrared point sources IRS 7 and IRS 3. The peak of diffuse X–ray emission around SgrA* coincides with the “mini–cavity”, a local minimum in infrared and radio–continuum emission.

The radio point source and black hole candidate Sgr A* coincides with one of the brightest Chandra X–ray point sources in the field. Sgr A* itself has no unambiguous infrared counterpart brighter than K = 14, although an extremely faint, flaring 2.2 μm point source has recently been detected at the nominal Sgr A* position using advanced imaging techniques (Genzel et al. 2003, Ghez et al. 2005, Eckart et al. 2006, Gillessen et al. 2006). The relationship between SgrA* and the central cluster of X–ray sources has been discussed by Baganoff et al. (2003).

3. Infrared/X–ray source colors
The color–magnitude diagram for the 9542 IRAC sources in the 40×40 parsec study region that were detected in both channels 2 and 3 is shown in Figure 3. The enlarged filled circles indicate 373 stars that are identified with some of the 2357 X–ray sources in the Muno et al. (2003) catalog. The distribution of colors of those infrared stars that have coincident X–ray sources is essentially the same as the distribution of all other infrared stars in our sample. There is also no apparent differentiation between the colors of infrared stars as a function of their distance from the X–ray source, or between the infrared candidates and the larger sample of 9542 infrared sources in the field. The “tail” on the plot at 6 mag is due to saturation of the 4.5 μm IRAC detector.

4. Discussion
Bandyopadhyay et al. (2005), reported that roughly 75% of a sample of 77 hard X–ray sources had faint (K = 13 – 20) candidate K–band counterparts within a 1.3 arcsec radius. They interpret these infrared candidates as highly reddened main sequence and supergiant stars at large distances rather than in the foreground. However, they noted that this is exactly the number of random associations that they predict from a Monte Carlo simulation. Thus although Bandyopadhyay et al. identified 58 K–band “candidates” none of these sources are likely to be
Figure 3. Color–magnitude diagram for 9542 IRAC sources (black dots) that were detected in both channels 2 and 3 (4.5 μm and 5.8 μm) in the 40×40 parsec study region. 31 X–ray sources had IRAC sources lying within 0.5 arcsec of the nominal X–ray positions (large gray circles), 99 had IRAC sources within 1.0 arcsec (medium gray circles), and 331 had IRAC sources within 2.0 arcsec (small gray circles).

They conclude that most of these hard X–ray sources are likely to be accreting binaries located at the Galactic Center, although the relevance of their correlation analysis to this conclusion is not clear. However, Laycock et al. (2006) compared 1453 hard and 105 soft X–ray sources with near infrared stars from the 2MASS survey and concluded that high–mass X–ray binaries are not the dominant hard X–ray source population.

If the conclusions reached by Bandyopadhyay et al. and by Laycock et al. are both correct we can conclude that the dominant population of hard X–ray sources must be primarily low–
mass X-ray binaries and/or cataclysmic variables. Neither of these would be expected to be infrared–bright, which is consistent with our study result.

5. Summary
We have analyzed the possible correlations between the largest number of candidate sources to date: 2357 X-ray sources (of which 1809 are hard X-ray sources most likely located at the Galactic Center) and ∼20,000 infrared point sources that we found with our Spitzer/IRAC survey in the 40×40 parsec comparison field. The lack of any significant correlation between hard X-ray sources and infrared point sources suggests that there is no unique population of sources that are both X-ray and infrared bright. Based on this study, we can set the upper limit on the fraction of all hard X-ray sources that can be both X-ray and infrared bright to be <1.7% (3 sigma).

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