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DETERMINING THE NATURE OF THE FAINT X-RAY SOURCE POPULATION NEAR THE GALACTIC CENTRE

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RESUMEN

Presentamos los resultados de un programa de longitudes de ondas múltiples con el fin de estudiar la población de la fuente de rayos X discreta débil descubierta por Chandra en el Centro Galáctico (GC). A partir de imaginería IR obtenida con el VLT identificamos contrapartes candidatas en banda K al 75% de las fuentes de rayos X de nuestra muestra. Combinando espectroscopía de seguimiento de banda K del VLT de un subconjunto de estas contrapartes candidatas con los límites de magnitud de nuestra exploración fotométrica sugerimos, que sólo un pequeño porcentaje de las fuentes son HMXBs, mientras que la mayoría son probablemente LMXBs y CVs canónicas, a la distancia de GC. Además, presentamos nuestro descubrimiento de extinción altamente estructurada de pequeña escala (5 -15") hacia el Centro Galáctico. Se trata de un estudio de extinción de la escala más fina del Centro Galáctico llevado a cabo hasta ahora.

ABSTRACT

We present results of a multi-wavelength program to study the faint discrete X-ray source population discovered by Chandra in the Galactic Centre (GC). From IR imaging obtained with the VLT we identify candidate K-band counterparts to 75% of the X-ray sources in our sample. By combining follow-up VLT K-band spectroscopy of a subset of these candidate counterparts with the magnitude limits of our photometric survey, we suggest that only a small percentage of the sources are HMXBs, while the majority are likely to be canonical LMXBs and CVs at the distance of the GC. In addition, we present our discovery of highly structured small-scale (5-15") extinction towards the Galactic Centre. This is the finest-scale extinction study of the Galactic Centre to date.

Key Words: **INFRARED: STARS — STARS: BINARIES — STARS: MASS LOSS — X-RAYS: STARS**

1. THE *CHANDRA* GALACTIC CENTRE SURVEY

In July 2001 Wang et al. (2002) performed an imaging survey with *Chandra*/ACIS-I of the central $0.8\times2°$of the Galactic Centre (GC), revealing a large population of previously undiscovered discrete weak sources with X-ray luminosities of $10^{32}-10^{35}$ erg s^{-1}. The nature of these ∼800 newly detected sources, which may contribute ∼10% of the total X-ray emission of the GC, is as yet unknown. In contrast to the populations of faint AGN discovered from recent deep X-ray imaging out of the Galactic plane, our calculations suggest that the extragalactic contribution to the hard point source population over the entire Wang et al. survey is ≤ 10%, consistent with the log(N)-log(S) function derived from the *Chandra* Deep Field data (*e.g.* Brandt et al. 2001). The harder (≥3 keV) X-ray sources (for which the softer X-rays have been absorbed by the interstellar medium) are likely to be at the distance of the GC, while the softer sources are likely to be foreground X-ray active stars or cataclysmic variables (CVs) within a few kpc of the Sun. The distribution of X-ray colours suggests that only a small fraction of the *Chandra* sources are foreground objects. The combined spectrum of the discrete sources shows emission lines characteristic of accreting systems such as CVs and X-ray binaries (XRBs). These hard, weak X-ray sources in the GC are therefore most likely a population of XRBs; candidate classes include quiescent black hole binaries or quiescent low-mass XRBs, CVs, and high-mass wind-accreting neutron star binaries (WNSs).

2. VLT OBSERVATIONS

The first step in determining the nature of this population is to identify counterparts to the X-ray sources. Achievement of our goals requires astrometric accuracy and high angular resolution to overcome the confusion limit of the crowded GC. We used ISAAC on the VLT to obtain high-resolution

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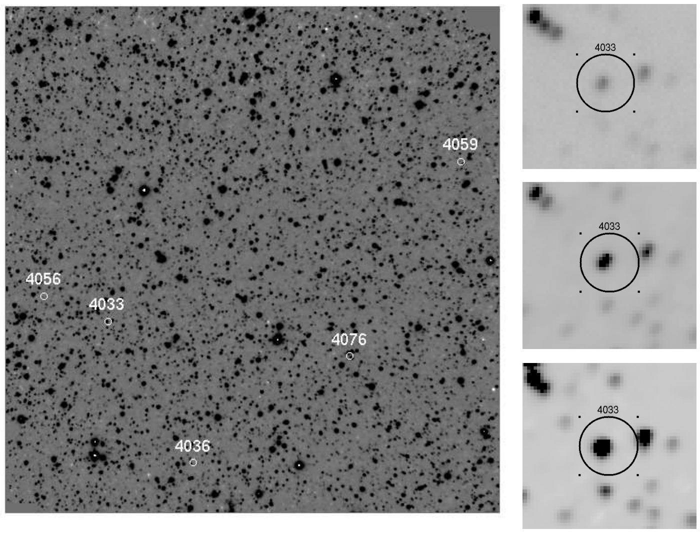

Fig. 1. Left: an example ISAAC K_s-band field (2.5 arcmin^2), showing the positions of 5 *Chandra* X-ray sources. Right: Zoom-in view ($8'' \times 8''$) of the $1.3''$ error circle of one of the *Chandra* sources in this field, overlaid on the J (top), H (middle), and K_s (bottom) ISAAC images.

JHK images in order to identify a statistically significant number of counterparts to the X-ray sources on the basis of the *Chandra* astrometry. We imaged 26 fields within the *Chandra* survey region, containing a total of 79 X-ray sources. The average extinction towards the GC is $K \sim$2–3. Therefore with our images, which have a magnitude limit of K=20, we will detect any XRBs with *early-type* (O, B, A) or *evolved* mass donors, all of which would have intrinsic K magnitudes $\leq$17 at 8.5 kpc.

After analyzing the photometric data (Bandyopadhyay et al. 2005), we selected 28 candidate counterparts (magnitudes $K \sim$12-17) for follow-up K-band spectroscopy, to search for the characteristic accretion signatures, such as Brackett γ emission, that would denote the identity of true X-ray source counterparts. The longslit spectra were obtained with ISAAC in service mode between April-September 2005, using a $1''$ slit width (R =450).

3. RESULTS: IMAGING

For 65% of the X-ray sources in our VLT fields, there are 1-2 resolved K-band sources within the $1''$ *Chandra* error circle (Figure 1); only a small number of X-ray sources have more than two potential counterparts. Over 50% of the *Chandra* sources have no potential J-band counterparts, and only a few of the potential IR counterparts have colours consistent with unreddened foreground stars (Figure 2). This is consistent with the expectation that the majority of the detected X-ray sources are heavily absorbed and thus are at or beyond the GC.

The magnitude and colour distribution of the identified candidate counterparts is redder than expected for WNS systems. For an average GC extinction of $A_K \sim$2-3, the peak of the expected reddened K magnitude distribution for the WNSs is $\sim$16-17. The peak of the observed reddened K magnitudes for the potential counterparts is $\sim$14-15, with an *(H-K)* colour of $\sim$1-2, as expected for later-type stars (Figure 3). However, some potential counterparts do have colours consistent with early-type stars.

There are no K-band counterparts for $\sim$35% of the *Chandra* sources. This is larger than the expected fraction of background AGN from the CDF estimate, though other groups have predicted larger fractions (up to 50%). However, we find that the extinction in the GC is highly structured on scales as small as $5''$–$15''$ (corresponding to a physical scale of 0.2–0.6 pc at 8.5 kpc), even in the K-band (Gosling et al. 2006). Comparison of areas of low apparent stellar density with the colour-colour diagrams of the fields confirms that these observed structures are due to extinction rather than to any intrinsic "clumpiness" in the underlying stellar distribution. Therefore we need to carefully determine which X-ray sources actually have no IR counterpart down to the K=20 magnitude limit, and which are located in areas of locally heavy extinction.

4. RESULTS: SPECTROSCOPY

The primary accretion signature in the K-band which distinguishes a true X-ray counterpart from

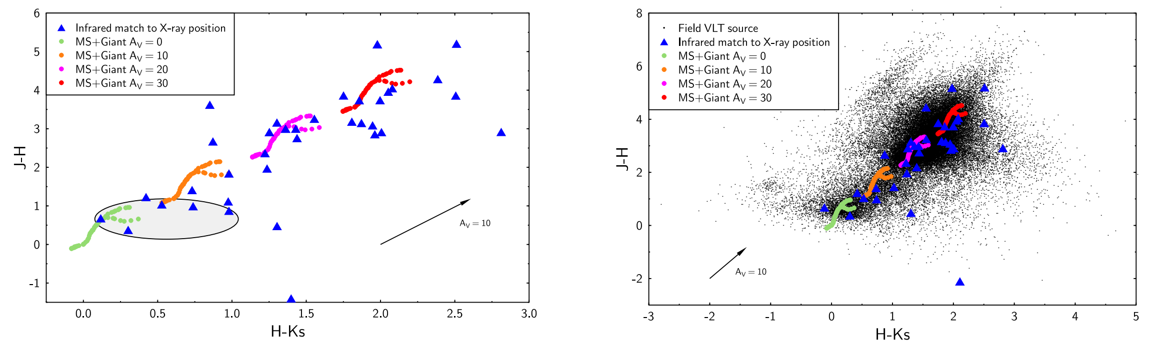

Fig. 2. *Left:* Colour-colour diagram of astrometrically-selected candidate IR counterparts to the *Chandra* sources. The shaded oval indicates where unreddened AGN/QSOs would most likely be located. The theoretical main sequence and giant branches are indicated at visual extinctions of 0, 10, 20, 30 ($A_K/A_V = 0.11$). *Right:* Colour-colour diagram showing all sources in our VLT fields. This illustrates that the vast majority of field stars are consistent with highly reddened stars; thus most of the stars (including potential X-ray counterparts) are at the distance of the GC (or beyond).

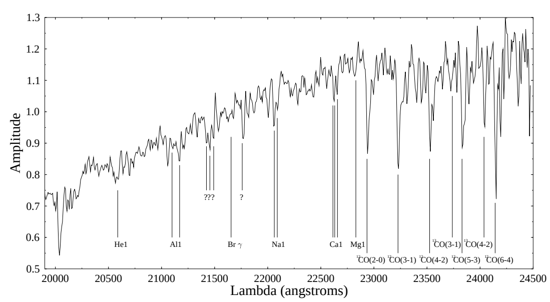

Fig. 3. Example of one of the K-band spectra obtained of possible counterparts to the GC X-ray sources. The spectrum is consistent with an M III star but shows none of the emission lines characteristic of accreting binaries. Thus this is likely not the true X-ray source counterpart.

a field star is strong Brackett γ emission; this technique of identifying XRB counterparts has been verified with observations of several well-studied GC XRBs (see *e.g.* Bandyopadhyay et al. 1999). As these *Chandra* sources are weaker in X-rays than the previously known population of Galactic XRBs, and thus have lower accretion rates, the emission signature will likely be somewhat weaker than in the more luminous XRB population.

The spectra indicate that almost all of the candidate counterparts are K/M giant stars, identified by the strong CO absorption bands above 2μm and several metal (Ca, Na, Mg) absorption lines. None of the observed spectra exhibited the emission line signatures characteristic of accreting binaries. A possible explanation for this result is that the accretion signatures could be too weak to be measureable, for example if the accretion rate was low at the time of observation, or if the emission was self-absorbed by the mass donor (as was observed for the transient V404 Cyg in quiescence; Shahbaz et al. 1996). However, the Br γ accretion signature is clearly detected in the IR spectra of CVs, which are only weak X-ray emitters with a similar X-ray luminosity range to the *Chandra* sources (Dhillon et al. 1997).

A more likely explanation for the lack of observed emission in the candidate spectra is that the stars we observed are not the true counterparts to the X-ray sources. Our imaging survey had a limiting magnitude of K=20, so our VLT survey would detect XRBs with either early-type or evolved mass donors. Therefore it is likely that the majority of the true IR counterparts belong to a lower mass population of stars that at GC distances are fainter than the limits of our survey. Combining our results with those of Mikles et al. (2006), who have one confirmed spectroscopic counterpart to a *Chandra* GC source, we are able to draw some preliminary conclusions about the nature of the X-ray source population. A small proportion, perhaps $\sim 2-3\%$, may be HMXBs/WNS. The remaining majority are likely to be canonical LMXBs and CVs with late-type main-sequence mass donors with K magnitudes ≥ 21 at 8.5 kpc.

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