X-raying the super star clusters in the Galactic center

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Abstract: The Galactic center harbors some of the most massive star clusters known in the Galaxy: the Arches and the Quintuplet. Based on the Chandra observations of these clusters (PI: Wang) which recently became public, I discuss the X-ray emission from the massive stars in these clusters. Confirming the general trend for Wolf-Rayet (WR) stars being X-ray dim, none of them is detected in the Quintuplet cluster. The most massive star known in the Galaxy, the Pistol star, is also not detected, invoking questions regarding the proposed binary nature of this object. X-ray emission in the Arches cluster is dominated by three stellar point sources. All three sources as well as the cluster's diffuse radiation show strong emission at 6.4–6.7 keV, indicating the presence of fluorescenting cool material. The Arches point sources may be identified as colliding wind binaries, albeit other possibilities cannot be ruled out.

The X-ray emission from young stellar clusters, such as the Arches and the Quintuplet, is tightly coupled with the massive stars evolution. When a massive star evolves from O type to WN type, and finally to WC type, it keeps its bolometric luminosity nearly constant while its X-ray luminosity is likely to decline (Oskinova 2005). This trend is confirmed by the study of WR stars in the Galaxy and the LMC (Guerrero et al. in prep., also these proceedings). In the 1–3 Myr old Arches cluster (Figer et al. 2002, F02), the majority of massive stars are of O type. The most massive stars are the most X-ray luminous ones due to the $\log L_{\rm X} = \log L_{\rm bol} - 7$ correlation. The stellar wind input into the intracluster medium is expected to result in diffuse cluster wind emission. The level of cluster wind emission scales with stellar mass-loss rates and wind kinetic energy (Chevalier & Clegg 1985). Both quantities rise sharply when stars evolve to the WR phase, characterized by conspicuously powerful stellar winds. Therefore, in the 3–5 Myr old Quintuplet cluster (Figer et al. 1999, FMM99) where a significant fraction of massive stars has evolved to the WR stage the level of cluster wind emission is expected to rise. The same time the stellar X-ray emission becomes much less prominent with the most massive stars evolving fast to the WC stage and becoming X-ray dim.

The Arches and the Quintuplet were recently observed with Chandra in a nearly 100 ksec exposure. Figure 1 shows the ACIS-I image of the Arches cluster. Three bright prominent point sources (see Table 1) coincide with the stars F02-6 (A1S), F02-7 (A1N) and F02-9 (A2)

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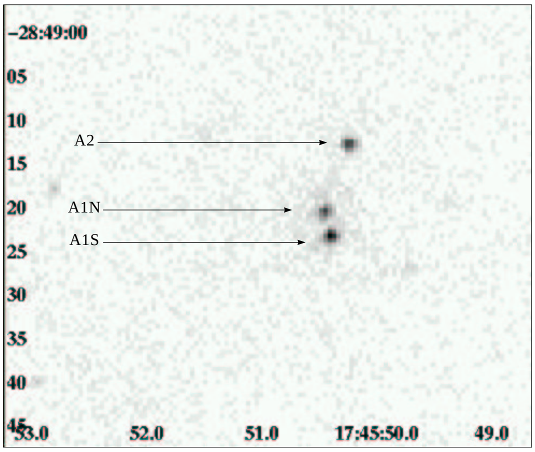

Figure 1: ACIS-I image of the Arches. The emission is dominated by three point sources, as indicated by arrows. Names of the sources are the same as in Law & Yusef-Zadeh (2004).

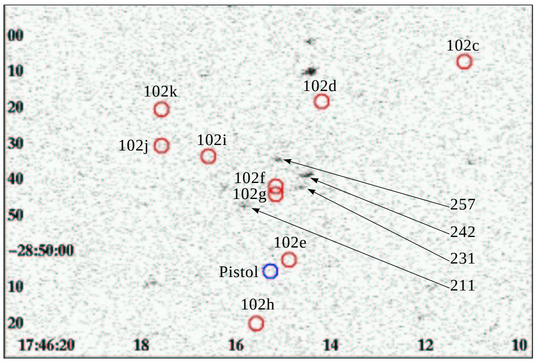

Figure 2: ACIS-I image of the Quintuplet. Positions of known WR stars (WR102c ... WR102k) and of the Pistol star are encircled. None of these is detected. Detected sources with known IR counterparts are indicated by arrows (object numbers are from FMM 99).

(numbers from Figer et al. 2002). F02-9 is an emission line star. The luminosities listed in the Table 1 are not corrected for absorption (the corrected L_X is ≈ 4 times higher). All three sources are suggested to be colliding wind binaries (Law & Yusef-Zadeh 2004). Their X-ray luminosity, however high, is not unique among Galactic binaries (e.g. HD 150136 has $L_X \approx 3 \times 10^{33}$ erg/s, Skinner et al. 2005). It is their X-ray spectra that are rather unusual (Figs. 3, 4).

Spectra of all three stars are remarkably similar in appearance, strongly resembling the spectrum of γ^2 Vel in the low state (Schild et al. 2004). The highly absorbed spectra of A1S, A1N and A2 can be fitted by a variety of models, all of them needing an additional component describing the dominant feature at 1.7-2.1 Å. The X-ray emitting plasma in stellar winds is conventionally modeled as a thermal collisional plasma. The spectra of the Arches stars can be fitted with temperatures above 2 keV and high absorption column densities (see Table 1). However, the flux predicted by such models at the iron K-shell line is a factor of 3 lower than the observed flux. The additional contribution can be attributed to the fluorescence of nearly neutral iron. The presence of the same $\lambda 1.7 - 2.1$Å emission feature in the spectra of the diffuse emission from the Arches supports this suggestion. However, the origin of cool fluorescenting material should be further explained. An exemplary fit with the *apec+gaussian* model to the spectrum of the emission line star A2 is shown in Fig. 4.

The Arches cluster contains hundreds of massive OB stars (F02), each of them expected to be an X-ray source. Yet only a handful of point sources is detected within the cluster radius. The scarcity of stellar X-ray sources in the Arches is naturally explained by the high interstellar absorption in the Galactic center. At the column density of $\sim 10^{23}$ cm^{-2} the photoelectric absorption attenuates photons up to energies of 2 keV. Only sources that are sufficiently luminous in the hard X-ray band (2.5 – 10 keV) can be observed.

X-ray temperatures of several keV are expected and have been observed in wide binary systems (e.g. WR140), where an *adiabatic* colliding wind shock is expected to occur. Antokhin et al. (2004) calculated X-ray spectra of *radiative* colliding winds shocks. They conclude that the presence of an "iron bump" at 6.7 keV can also be expected in relatively close binary systems (orbital period up to the order of 10 days).

However, by far not all binary stars show hard X-rays (harder than 2 keV). Many X-ray luminous spectroscopic binaries have X-ray temperatures not higher than the canonical 0.6 keV

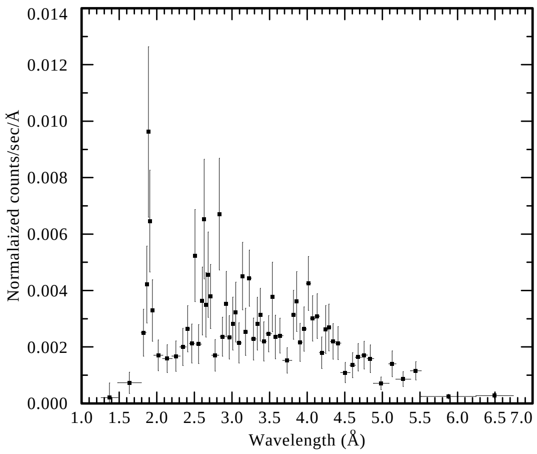

Figure 3: Observed background-subtracted spectrum of the brightest X-ray point source A1S (FMM 6) in the Arches cluster.

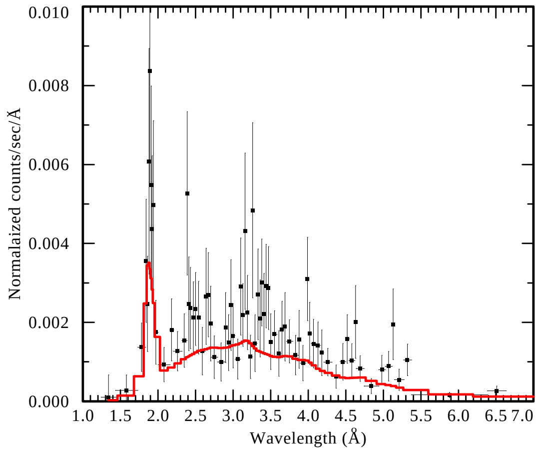

Figure 4: Observed background-subtracted spectrum of emission line star A2 (FMM 9). The solid line is a fitted thermal plasma model with $kT = 3.5 \pm 1.2\,\mathrm{keV}$ with an additional gaussian component at 1.7-2.1Å.

Object	Count Rate [c/s]	N_H [cm^{-2}]	L_X [erg/s]
A1N	0.005	$\approx 7 \times 10^{22}$	6×10^{32}
A1S	0.009	$\approx 7 \times 10^{22}$	1×10^{33}
A2	0.006	$\approx 7 \times 10^{22}$	9×10^{32}

Table 1: X-ray emission from point sources in the Arches

predicted for single O stars from hydrodynamic models (Feldmeier et al. 1997). An interesting example of such a binary is HD 150136, one of the most X-ray luminous O stars (Skinner et al. 2005). The emission from this binary star is dominated by plasma with temperature $\approx 0.3\,\mathrm{keV}$, with a small contribution of $\approx 1\,\mathrm{keV}$ plasma.

We employed the model used by Skinner et al. (2005) to fit the spectrum of HD 150136, but applied the interstellar absorption and distance appropriate for the Arches cluster. The flux of HD 150136 if it were located in the Arches would be at least thousand times smaller, and the system would remain undetected by this sensitive Chandra observation. The high interstellar absorption effectively selects sources with hard energy distribution. Soft sources, even intrinsically luminous, can not be seen in the Galactic center clusters.

A possible alternative to a colliding wind scenario to explain the hard X-rays from the Arches point sources is the generation of X-rays by magnetically confined wind flows, as observed in some young stars (e.g. θ^1 Ori C, Schulz et al. 2003). The hardness of the Arches sources spectra can be indicative for the presence of stellar or circumstellar magnetic fields. A study of the X-ray variability shall shed light on this proposition.

The Quintuplet cluster is 1–2 Myr older than the Arches, containing the largest conglomerate of WR stars known in the Galaxy (Figer et al. 1999). It is located in a similar environment and at approximately the same distance as the Arches (within 50 pc projected distance from the Galactic center). Its mass and stellar density are comparable with the Arches. Fig. 2 displays an ACIS-I image of the Quintuplet cluster.

There are a few luminous blue variable (LBV) candidates in the Quintuplet. LBVs are massive stars in a short phase of large, episodic mass loss. Famous is the Pistol star, which is considered to be the most massive star known in the Galaxy. To reconcile its prodigious mass estimated as $\sim 150-250 M_\odot$ with the recently proposed upper mass cut-off at $150\, M_\odot$ it was suggested that the star is a binary. The Pistol star is not detected by the long Chandra exposure, implying an upper limit $\log L_\mathrm{X}/L_\mathrm{bol} < -8$. Thus there is no support for the binarity assumption from hard X-rays, which would be an indication of colliding stellar winds.

The scatter of X-ray luminosities among field WR stars is significantly larger than among O stars. The X-ray bright WR stars are rare and are binaries (sometimes suspected). Fig. 2 shows the position of known WR stars in the Quintuplet cluster. None of these stars is detected, putting an upper limit on their X-ray luminosity at 10^{32} erg/s. The fact that such a young and massive star cluster as the Quintuplet is barely visible on the X-ray sky tells that the X-ray luminosity of a massive star diminishes significantly when the star evolves.

Among a few weak point sources detected by Chandra, two (FMM 231 and FMM 211) are members of eponymous quintuplet of cocoon-like objects (Glass et al. 1999). The nature of these objects is under debate; their possible identification with dusty WC stars has been proposed. However, the X-ray emission from a single WC star is highly unusual and is not detected elsewhere.

To conclude: 1) the stellar X-ray sources in the Arches clusters may be attributed to colliding wind binaries; 2) the strong emission at 6.4–6.7 keV is observed in both stellar and diffuse emission sources in the Arches cluster. The level of this emission cannot be reproduced by thermal plasma models. The strong 6.4–6.7 keV emission may indicate the presence of cool fluorescenting material in the cluster; 3) the non-detection of X-rays from the Pistol star constrains the hypothesis about its binary nature; 4) none of the WR stars known in the Quintuplet cluster is detected in X-rays, confirming the general trend of WR stars being X-ray dim.

Acknowledgments

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