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MULTIWAVELENGTH STUDY OF X-RAY SOURCES IN THE GLOBULAR CLUSTER NGC 2808: CHANDRA, XMM-NEWTON, HST AND ATCA OBSERVATIONS

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Abstract. We aim to detect and identify the faint X-ray sources belonging to Galactic globular clusters in order to understand their role in the evolution of globular clusters. We present a new Chandra X-ray observation of the Galactic globular cluster NGC 2808. Previous observations with XMM-Newton and ultraviolet observations with the Hubble Space Telescope are re-investigated to help identify the Chandra sources associated with the cluster. From statistical analysis, 16 sources are very likely to be linked to NGC 2808. We found one likely neutron star low-mass X-ray binary in quiescence and 8 cataclysmic variable candidates in the core of NGC 2808. The other core sources are also cataclysmic variable candidates, but some of the faintest could possibly be chromospherically active binaries or millisecond pulsars. This significant population of close binaries is likely to play an important role in slowing down the core collapse of this cluster. We found a possible deficit of X-ray sources compared to 47 Tuc which could be related to the metallicity content and the complexity of the evolution of NGC 2808. From X-rays and radio (ATCA) observations, we found no evidence of an intermediate mass black hole in NGC 2808 and derived mass constraints of several hundreds solar masses.

1 Introduction

Globular clusters (GCs) are old, gravitationally bound stellar systems which can have extremely high stellar densities, especially in their core regions. In such an environment, dynamical interactions between the cluster members are inevitable, leading to a variety of close binary (CB) systems and other exotic stellar objects. The observed overabundance of neutron star (NS) low-mass X-ray binaries (LMXBs) in GCs relative to the Galactic field was explained by the dynamical processes occurring in the dense cores of GCs (Fabian et al. 1975). Observations also support the fact that quiescent LMXBs (qLMXBs) in GCs scale with the cluster encounter rate (Gendre et al. 2003; Pooley et al. 2003), implying that qLMXBs are formed through dynamical processes in the dense cores. As white dwarfs (WDs) are far more common than NSs, we would then also expect many more CBs containing an accreting WD primary, i.e. cataclysmic variables (CVs). The dynamically-formed CBs are expected to be found in the cores of GCs, where the stellar densities are at a maximum (Hurley et al. 2007).

CBs are important for our understanding of GC evolution, since the binding energy of a few, very close binaries can rival that of a modest-sized GC (e.g. Hut et al. 2003 and references therein). In the core, binaries are subject to encounters and hard binaries become harder while transferring their energy to passing stars. The presence of many CBs could lead to violent interactions, which heat the cluster, delay the core collapse, and promote its expansion. This depends critically on the number of CBs, which is still poorly known. Faint X-ray sources belonging to the clusters have been identified as qLMXBs, CVs, active binaries (ABs, generally RS CVn systems), or millisecond pulsars (MSPs). These sources are thus directly connected with the CB population, and their study is of interest for the understanding of the dynamical evolution of globular clusters.

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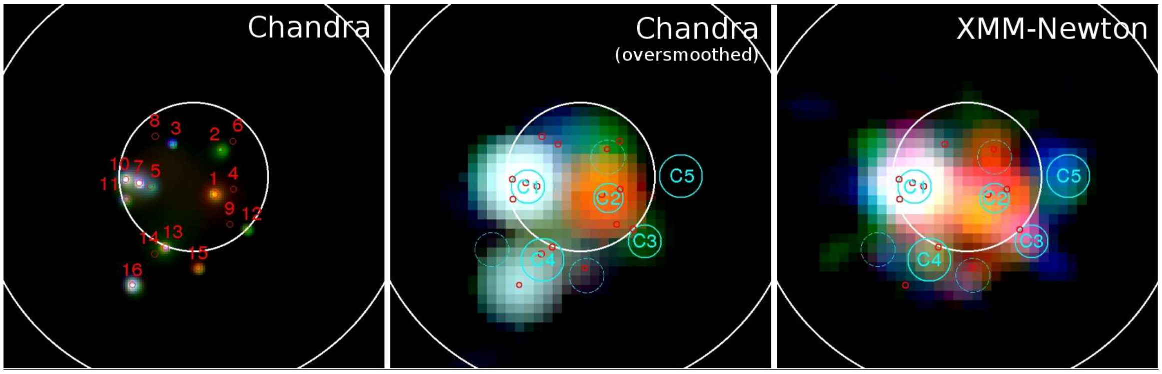

Fig. 1. Images of the core of NGC 2808. Colours correspond to different energy bands, red: 0.5–1.5 keV, green: 1.5–3 keV, blue: 3–8 keV. The absolute 1σ positional error for each source is represented as a circle, red (small) for Chandra and blue (large) for XMM-Newton. Core and half-mass radii are shown. **Left:** Chandra image, smoothed using the adaptative smooth tool *csmooth*. **Center:**: Chandra image, over smoothed with a Gaussian filter to be compared with the XMM-Newton image. **Right:** XMM-Newton combined image (pn, MOS1 and MOS2), smoothed with a Gaussian filter. Only Chandra detected sources which could have been detected by XMM-Newton are represented (small red circles).

As these faint X-ray sources can have similar emissions in X-ray observations, multiwavelength studies are needed in order to constrain their nature. We performed such a multiwavelength study of the globular cluster NGC 2808, which is massive, dense, with an intermediate metallicity (Harris 1996). This GC is known to harbour an elongated horizontal branch, and a triple main sequence in its colour–magnitude Diagram, related to the evolution of the helium and metallicity content of the cluster (Piotto et al. 2007).

2 Data

NGC 2808 has been observed with the Chandra ACIS-I instrument on 2007 June 19–21. The data reduction has been presented in Servillat et al. (2008b), and led to 56.9 ks of clean observation, down to a limiting flux of $F_{0.5-8\mathrm{keV}} \sim 0.9 \times 10^{-15}$ erg cm^{-2} s^{-1}, corresponding to a limiting luminosity of $L_{0.5-8\mathrm{keV}} \sim 1.0 \times 10^{31}$ erg s^{-1} (at the distance of the cluster). We found 16 sources in the half-mass radius that are statistically associated with the cluster. Two sources are variable during this observation. One additional variable source is just outside this radius, and also likely to be linked to the cluster.

NGC 2808 has been previously observed with the XMM-Newton EPIC instruments on 2005 February 1st (28 months before the Chandra observation). The data reduction led to 38 and 30 ks of clean observation for MOS and pn detectors, respectively (Servillat et al. 2008a). It reached a limiting flux of $F_{0.5-8\ \mathrm{keV}} \sim 4.0 \times 10^{-15}$ erg cm^{-2} s^{-1}, corresponding to a limiting luminosity of $L_{0.5-8\ \mathrm{keV}} \sim 4.2 \times 10^{31}$ erg s^{-1} for sources in the core of NGC 2808. Five sources were found within the half-mass radius and are statistically associated with the cluster. However, several sources remained unresolved.

The Chandra and XMM-Newton images are in general very similar (Figure 1). XMM-Newton source C5 is clearly missing in the Chandra observation, and Chandra source 16 was not detected with XMM-Newton. We found that Chandra source 16 has varied by a factor of at least ~ 5. XMM-Newton source C5 has also varied by a factor of at least ~ 5 (Servillat et al. 2008b).

The core of NGC 2808 has been observed with the STIS instrument on board the HST in January/February 2000. The dataset in far ultra-violet (FUV, 1590 Å) and near ultra-violet (NUV, 2700 Å) is presented by (Dieball et al. 2005). After alignment of the Chandra and HST images, we found 10 possible FUV counterparts to 8 X-ray sources (Servillat et al. 2008b). Statistically, one would expect 5–6 matches by chance, thus 2 or 3 real matches. Three sources have probabilities that indicate that they may be associated with a FUV source: Chandra sources 7 and 14 which are located in the CV region in the colour–magnitude diagram, and Chandra source 10 which is in the blue horizontal branch.

We used the optical catalogue obtained by Piotto et al. (2002) with the HST PC detector to look for optical counterparts. Nearly all of the optical counterparts found are either located on the main sequence, red giant branch or red horizontal branch. However, two of the optical sources are on the blue horizontal branch (Chandra 8 and 11) and four sources are in the optical blue straggler region (Chandra 3, 4, 9 and 12). There are four sources that are faint and blue with $B - V < 0.4$ and $V > 20.4$ mag, as expected for CVs (corresponding to Chandra 8 and 11).

3 Discussion

3.1 *Identification of sources*

From their colour and luminosities, it is possible to propose a possible nature for several sources (see Servillat et al. 2008b for a detailed discussion): Chandra source 1 is a qLMXB candidate hosting a neutron star. Its XMM-Newton spectrum is well fitted by a neutron star hydrogen atmosphere model (Servillat et al. 2008a; Webb & Barret 2007); Chandra sources 7, 10 and 16 are among the brightest sources ($> 10^{32}$ erg s^{-1}) and are thus CV candidates; Chandra sources 2, 5, 11, 12, 13 and 15 have a lower luminosity and could be either CVs or ABs; The other sources which are detected with 4–6 counts are not constrained by their X-ray emission and could be either CVs, ABs or MSPs.

X-ray and UV emission from Chandra sources 7 et 14 are consitant and compatible with the expected emission of CVs. Chandra sources 3 and 16, and XMM-Newton C5 showed variability more likely to come from CVs rather than ABs. Chandra sources 8 and 11 have optical counterparts which could indicate that they are CVs. This lead to 8 CV candidates in the core of NGC 2808. Chandra source 17 is close to the half-mass radius of NGC 2808, and showed an eruption compatible with a CV or an AB linked to the cluster.

3.2 *Deficit of X-ray sources: does metallicity play a role?*

Assuming a completeness in the detection of sources at a luminosity of $L_{0.5-8\mathrm{keV}} \sim 2 \times 10^{31}$ erg s^{-1}, we can estimate the number of expected X-ray sources in NGC 2808. Taking into account the specific encounter frequency of NGC 2808, as defined in Pooley & Hut (2006), and our completeness limit, we expect 30 ± 6 X-ray sources by dynamical formation (Pooley & Hut 2006). In 47 Tuc, which is similar in mass, density and concentration to NGC 2808, about 31 ± 3 X-ray sources are detected above our completeness limit (Heinke et al. 2005). However, we detected only 11 sources in the half-mass radius of NGC 2808 and above the completeness limit, which is significantly lower than the expected number of dynamically formed X-ray sources.

Metallicity seems to be a key parameter that could highly affect the number of X-ray sources in GCs at a given age. Indeed, due to the lower opacity, metal poor stars are generally hotter and more compact. Concerning interacting binaries, which are generally X-ray sources, this could determine if, when and how mass transfer occurs (de Mink et al. 2007). NGC 2808 and 47 Tuc have very different metallicities, which could explain the differences in the number of detectable X-ray sources. In the same way, Kundu et al. (2007) found that metal-rich extragalactic GCs host three times as many LMXBs than metal-poor ones.

3.3 *X-ray to UV ratios of selected CVs: a look at intermediate polars?*

From the UV observations, ~ 30 CV candidates were detected (located in the CV region of the colour–magnitude diagram). With Chandra, we obtained 8 CV candidates (at most 15). If we take into account only significant matches, we found 2 UV counterparts that have UV properties clearly compatible with the CV hypothesis (Chandra sources 7 and 14). It seems that X-ray and UV emission from CVs are decorrelated, as the brightest X-ray sources in NGC 2808 are generally not the brightest UV sources.

We estimated a F_X/F_{NUV} ratio for several CVs belonging to different classes, where F_{NUV} is the flux density between 2500–3000 Å (corresponding to the NUV observations), and F_X the flux in the band 0.5–8 keV. Polars have ratios greater than 5000 and intermediate polars appear to have ratios greater than 2000 (see discussion in Servillat et al. 2008b). The detection limit of the NUV observation is 6×10^{-19} erg cm^{-2} s^{-1} Å^{-1}, and the limit in X-rays is 9×10^{-16} erg cm^{-2} s^{-1}. Therefore, the X-ray/NUV ratio for the CV candidates detected in UV is lower than ~ 1500. The ~ 30 CV candidates detected in UV and not in X-rays are thus likely to be mostly non-magnetic systems (such as the dwarf nova YZ Cnc with a ratio of ~ 500, Hakala et al. 2004).

Most intermediate polars (IPs) in the field are more luminous than 10^{31} erg cm^{-2} s^{-1} in X-rays (Verbunt et al. 1997, see also the Intermediate Polar Home Page maintained by K. Mukai, where 12 out of 14 have luminosities above this limit). We should have detected most of these in our Chandra observation if their emission is similar to IPs in the field. This would lead to a maximum of ~ 14 IPs (we exclude Chandra source 14 whose X-ray/NUV ratio is lower than 2000, and Chandra source 1 which is a qLMXB candidate). The proportion derived is $\sim 30\%$ of the detected CV candidates (in UV and X-rays), and $\sim 7\%$ of the expected GC CV population (estimated to be ~ 200 CVs, Ivanova et al. 2006). This is somewhat higher, but still coherent with the proportion of IP candidates in the field, which can be estimated to $\sim 5\%$ from the catalogue of Ritter & Kolb (2003, updated Feb. 2008).

The estimation of the fraction of IPs in GCs is particularly interesting as an excess of IPs was proposed to explained the lack of CV outburst observed in GCs (Dobrotka et al. 2005). Due to the incompleteness of our observations, this result does not allow us to confirm or rule out a possible excess of IPs in NGC 2808. However, with a deeper sample, this method could allow us to better quantify the proportion of IPs.

3.4 Observational constraints on an intermediate mass black hole and millisecond pulsars

According several authors (e.g. Miocchi 2007), NGC 2808 is a good candidate for hosting an intermediate mass black hole (IMBH, 10^3–10^4 $M_\odot$). If such an IMBH exists in NGC 2808, it should be located at the center of mass of the cluster due to mass segregation. We reduced radio data from the ATCA observatory (Maccarone & Servillat 2008), and found no radio source in the core of NGC 2808. The limiting flux was used to derive a mass constrain. We estimated the material density in the cluster, and considered the most probable parameters for the fraction of the Bondi rate accretion, the efficiency of this accretion and the correlation between X-ray and radio power (see Maccarone & Servillat 2008, for a detailed estimation). This yield limits on the black hole mass of 370 $M_\odot$ (most probable limit), and 2100 $M_\odot$ (most conservative limit). A similar approach can be used with the X-ray data. No sources are found at the center of mass of the cluster, which lead to mass limits of several hundreds of solar masses (Servillat et al. 2008a,b). Along with other mass limits for several globular clusters, these results cast doubt on suggestions that globular clusters may follow the same $M_{BH} - \sigma$ relation as galaxies (Maccarone & Servillat 2008).

The non detection of radio sources in the core also implies that the number of MSPs associated with NGC 2808 could be lower than the number of MSPs in 47 Tuc. Again, metallicity could be a key parameter that would highly affect the number of MSPs in GCs.

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