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Chandra X-ray observations of the globular cluster M28 and optical HST identification of the X-ray sources

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Abstract. We present here the results of *Chandra* X-Ray Observatory observations of NGC 6626 (M 28), and a first search for optical counterparts by using archival HST data. 46 sources have been detected within the field-of-view of *Chandra*, 12 of which lie within 1 core radius from the cluster center. We measured for the first time the unconfused X-Ray spectrum of the ms pulsar B1821-24 and present spectral identification for other 5 bright unidentified sources. The brightest one shows spectral parameters suggesting that it is a transiently accreting neutron star in a low-mass X-ray binary in quiescent phase. The apparently extended core emission seen by ROSAT is due to superposition of multiple source for which the X-ray luminosity function is determined. Using *Chandra* derived position, we also present a preliminary report on the search for the optical counterparts of these sources by using archival HST data.

Key words. X-Ray sources – millisecond pulsar – globular clusters: M 28

1. Introduction

Since the *Einstein* era, it has been clear that globular clusters contain X-ray sources of very different luminosities Hertz & Grindlay

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(1983). The stronger sources exhibit X-ray bursts which led to their identification as low-mass X-ray binaries (LMXBs). Fainter ones could not be safely characterized and their nature remained open for discussion (see, e.g., Cool et al. 1993; Johnston & Verbunt 1996). The advent of *Chandra* X-ray Observatory (CXO), with its subarcsecond resolution, led to a considerable improvement in detection and understanding of these sources. Observations with *Chandra* have been performed for several clusters, and, particularly, for NGC 104 (=47 Tuc, Grindlay et al. 2001), in which 108 sources have been detected within 5 core radii from the center. NGC 6626 (M 28) lies close to the galactic plane ($b^{II} = -5.58°$) and to the galactic center ($l^{II} = 7.8°$), with a distance estimates range from 5.1 kpc (Rees & Cudworth 1991) to 5.7 kpc (Harris 1996). M 28 is a relatively compact cluster with a core radius $r_c \sim 0.4$ *pc* and half mass radius $r_h \sim 2.6$ *pc* (Harris 1996). These radii are smaller than those for 47 Tuc. Thus, although its central luminosity density is comparable to that of 47 Tuc, the two-body encounter rate is smaller and thus we expect fewer binaries acting as dim X-ray sources. The first millisecond pulsar has been discovered in this cluster (B1821-24, Lyne et al. 1987).

2. Chandra Observations

M 28 was observed three times for approximately 13 ksec between July and September 2002, in order to detect time variability on scales up to weeks. The position of B1821-24 has been measured separately on the three data sets and on the merged data. The absolute positioning of all the sources has been adjusted to the radio position of the pulsar (Rutledge et al. 2003). However the offset was very small ($\Delta\alpha = 0.''042, \Delta\delta = 0.''029$). 12 out 46 total detected sources lie within one core radius. In addition, some diffuse emission remains.

The projected surface density of detected X-ray sources was compared to a King profile $S(r) = S_0[1 + (r/r_0)^2]^{-\beta} + C_0$, where C_0 was added to account for backgrund sources. We fit a core radius comaprable to the distribution of the optical light $r_c = 10.9^{+8.8}_{-4.7}$ and, a best fit mass of the X-ray sources $M_x = 1.87^{+1.25}_{-0.49} M_\odot$, assuming the dominant visible stellar population has a mass of $M \sim 0.7 M_\odot$, barely overlapping the results for 47 Tuc of Grindlay et al. (2002) (1.1 - 1.4 $M_\odot$).

3. Spectral analysis

Only 6 sources had enough counts to warrant an individual spectral analysis. In descending order these are #26, #19, #4, #17, #25, #28. Figure 1 shows the spectra of the two brightest sources. Source #19 is the ms pulsar PSR B1821-24. It is best described by a power-law model, which gives out a column density $N_{22} = 0.16^{+0.07}_{-0.08}$, consistent with the reddening determination for this cluster, and a power-law index $\Gamma = 1.20^{+0.15}_{-0.12}$. By subtracting the power-law to the spectrum, a residual feature at 3.3 keV is visible, whose significance is at 98% confidence level. If we assume it is real, it is likely to be an electron cyclotron line, formed in a strong magnetic field with multipolar components or a strong off-centering of the magnetic dipole, or both.

The brightest source is luminous and shows a soft spectrum. The best fitting model is a non-magnetic H atmosphere, which gives a stellar radius compatible with a neutron star ($\sim$ 15 km), and a column density ($N_{22} = 0.26 \pm 0.04$) consistent with the value found for PSR B1821-24. We interpret this source as a low-mass X-ray binary in quiescent phase. The X-ray color magnitude diagram is shown in Fig. 2. The two brightest sources are indicated. In particular, PSR B1821-24 has the hardest spectrum, while source #26 (qLMXB) has the softest. The other sources are presumably a mix of CVs, main-sequence binaries, MSPs, and other (unknown) systems.

4. HST Observations

Archival HST data have been used to try to identify optical counterparts of the detected X-ray sources. Data were observed in August and September 1997 in the two F555W (V) and F184W (I) filters with the WFPC2 and were centered approximately on the same point, but with a slight reciprocal rotation $\sim 5°$. Data

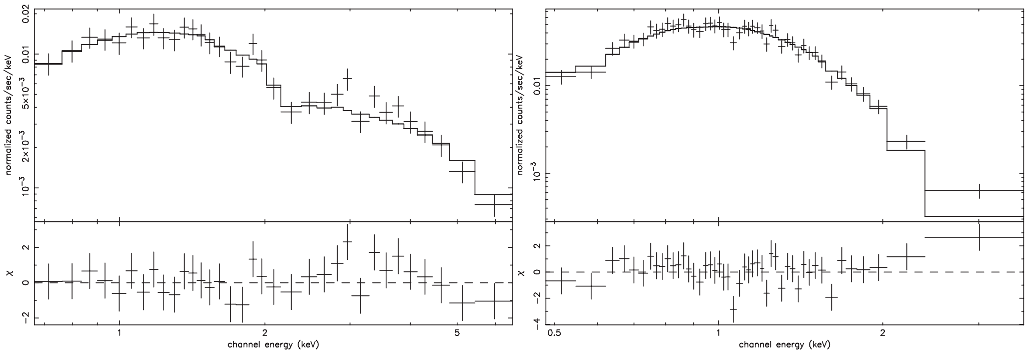

Fig. 1. Left panel: X-ray spectrum of source #19 (B1821-24). In the bottom part, the residual feature at 3.3 keV is visible. Right panel: X-ray spectrum of source #26, that is softer than B1821-24 and is interpreted as a LMXB in quiescence.

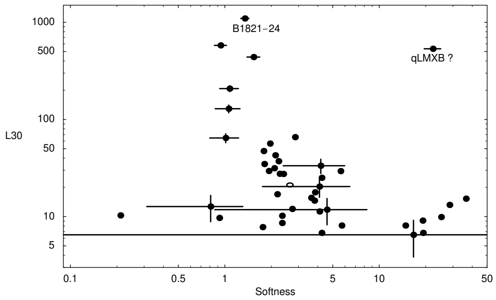

Fig. 2. X-ray color-luminosity relation for the detected point sources.

from the September data set were published by Testa et al. (2001) and we used their photometry as a starting point. August data have been reduced by using the standard WFPC2 pipeline and DAOPHOT (Stetson 1987). We selected all the sources lying within an error circle given by the combination of the *Chandra* pointing error and the HST astrometry uncertainty, which gives the largest contribution to the error. For this reason, the average error circle has a radius of $\sim 1''$ and the initial candidates list consists of 376 sources. In order to further constraint the identification of the possible counterpart, we searched for variability on the two data-sets. At this stage, we did not find any evidence for variability and hence no safe identification of the optical counterparts. A CMD showing the position of the 376 sources among the whole photometric sample of M 28 is shown in Fig. 3.

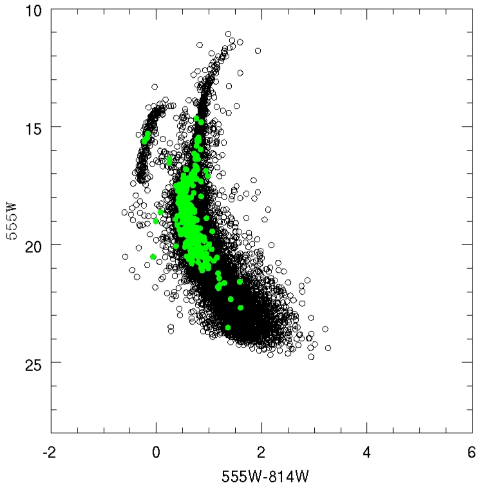

Fig. 3. HST CMD of M 28 with the possible counterparts superimposed.

5. Summary

Forty-six X-ray sources have been detected in the globular cluster M 28 with CXO. Many are concentrated in the center. Six of them have individual spectral analysis. The brightest is identified as a qLMXB, while the hardest is the ms pulsar PSR B1821-24. Search for optical identification with HST data gave out a list of 376 possible candidates. None of them shows variability and no safe identification can be given at this stage. A full description of this work can be found in Becker et al. (2003). Work on the X-ray/optical counterparts is in progress.

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