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Investigating the Faint X-ray Sources in Globular Clusters with XMM-Newton

N.A. Webb[1], B. Gendre[1] and D. Barret[1]

CESR, 9 Avenue du Colonel Roche, 31028 Toulouse Cedex 04, France

Abstract. Globular clusters (GCs) harbour a large number of faint X-ray sources whose nature, until recently, was largely unknown. Using the new X-ray observatories, it is possible to identify populations of low mass X-ray binaries, cataclysmic variables, millisecond pulsars, as well as other types of binaries belonging to the GCs, along with fore- and background objects. We present a variety of binaries, identified in four GCs observed by *XMM-Newton*. We show that through population studies we can begin to understand the formation of individual classes of binaries and hence start to unfold the complex evolutionary paths of such systems.

Key words. globular clusters: general – X-rays: binaries – Stars: neutron

1. Introduction

It is expected that GCs should contain many binary systems, due to interactions occurring within the clusters. These systems could play a critical role in the dynamical evolution of GCs, serving as an internal energy source which counters the tendency of cluster cores to collapse (see Hut et al. 1992 for a review). The binaries are difficult to locate, because of high stellar densities. However, the binaries are also visible in X-rays, where the crowding is less severe. Indeed the small population of bright X-ray sources ($L_x > 10^{36}$ erg s^{-1}), known to be X-ray binaries (Hertz & Grindlay 1983), were detected primarily through their X-ray bursts. However, there is also a population of low-luminosity ($L_x \lesssim 10^{34.5}$ erg s^{-1}) X-ray sources. A variety of objects have recently been identified with the new X-ray observatories; *XMM-Newton* and *Chandra*, e.g: quiescent neutron star low mass X-ray binaries (qNSs) (e.g. Gendre et al. 2003b; Rutledge et al. 2002); cataclysmic variables (e.g. Carson et al. 2000; Gendre et al. 2003a); millisecond pulsars (e.g. Grindlay et al. 2001); active binaries (e.g. Kaluzny et al. 1996); and fore- and background objects, i.e. stars (e.g. Gendre et al. 2003a) or clusters of galaxies (e.g. Webb et al. 2004).

Send offprint requests to: N.A. Webb
Correspondence to: Natalie.Webb@cesr.fr

2. Data and analysis

We observed the GCs: M 22 (NGC 6656); ω Cen (NGC 5139); M 13 (NGC 6205); and NGC 6366 with the *XMM-Newton* EPIC cameras. We used the full-frame imaging mode and the medium filter. After screening for high background, 20-40 ks of good observation time remained. The data have been reduced with V. 5.4.1 of the *XMM-Newton* SAS. The MOS and PN data were reduced using 'emchain' and 'epchain', respectively. The MOS and PN

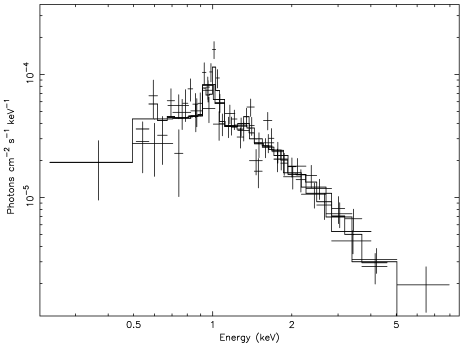

Fig. 2. The EPIC spectrum for the cluster of galaxies in M 22, fit = MEKAL model.

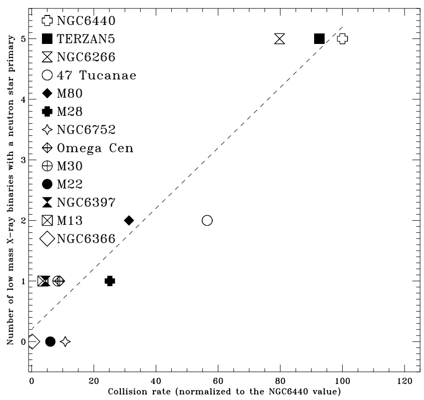

Fig. 1. qNSs versus collision rate (normalized to 100 for NGC 6440) and a linear fit $n_{\rm qNS} \sim 0.04 \times \rho_0^{1.5} r_c^2 + 0.2$.

event lists were filtered to retain only 0-12 and 0-4 of the predefined patterns respectively. We also filtered in energy. The source detection was done as Gendre et al. (2003a,b); Webb et al. (2004), using the SAS wavelet detection algorithm on the 0.5-5.0 keV data.

3. Results and Discussion

We have discovered a soft X-ray source in M 13, which is well fitted by a hydrogen atmosphere model, with the radius and temperature expected from a neutron star (Gendre et al. 2003b). Its luminosity is also consistent with that of a qNS ($10^{32} \lesssim L_X \lesssim 10^{33}$ erg s^{-1}). There is a similar source in ω Centauri (Gendre et al. 2003a). A reasonable question to ask is whether we expect so many qNSs? Thus we studied all the *XMM-Newton* and *Chandra* GC observations, where the luminosity limits are $\sim 10^{30} - 10^{31}$ erg s^{-1}, which allowed us to detect all the qNSs present. In GCs, the number of qNSs is expected to scale with the collision rate which is proportional to $\rho_0^{1.5} r_c^2$ for virialized clusters, where ρ_0 is the central density of the cluster and r_c its core radius (Verbunt 2002). Fig. 1 shows the number of qNSs as a function of the collision rate, normalized so that the value for NGC 6440 is 100. There is a striking correlation between the number of qNSs and the collision rate. This strongly supports the idea that qNSs are indeed primarily produced by stellar encounters in GCs.

We have found a variety of binaries in the four GCs studied, see above, Sect. 1 and references therein. We have also found a cluster of galaxies behind M 22, see Fig. 2 and Webb et al. (2004).

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