Highlights of Astronomy, Volume 14
IAU XXVI General Assembly, 14-25 August 2006
Karel A. van der Hucht, ed.

doi:10.1017/S1743921307011271

Observational evidence for origin of stellar exotica in globular clusters

Franciscus W.M. Verbunt

Astronomical Institute, Utrecht University, the Netherlands
email: f.w.m.verbunt@astro.uu.nl

Abstract. The formation of special binaries in a globular cluster is regulated by the total encounter rate Γ in the cluster, but their life expectancy by the number of encounters γ that one system experiences. The orbital periods indicate whether a neutron star or white dwarf entered a binary via direct collision, via tidal capture, or via exchange encounter. The numbers of X-ray binaries with a neutron star scales with Γ. Magnetically active binaries (including blue stragglers) are formed via evolution of primordial binaries, and their numbers scale with the cluster mass. Cataclysmic variables are formed by stellar encounters or via evolution of a primordial binary in clusters with high and low central density, respectively.

Keywords. globular clusters, binaries, X-rays: binaries

The strong over-abundance of bright X-ray binaries in globular clusters is the consequence of stellar encounters that allow a neutron star to become member of a binary. Direct collisions with a giant can lead to a binary with an ultrashort-period, of 5 - 20 min. The observed orbital periods indicate this origin for half of the systems. The other periods range from hours to a day, indicating that a neutron star catches a main-sequence star by tidal capture, or takes its place in a binary via an exchange encounter. All these mechanisms scale with the total encounter rate in a cluster Γ:

$$\Gamma \propto \int n_c n A v \mathrm{d}V \propto \int \frac{n_c n R}{v} \mathrm{d}V \propto \frac{\rho_o^2 r_c^3}{v} \propto \rho_o^{1.5} r_c^2 \tag{0.1}$$

where n_c and n are the number densities of the neutron stars and of the objects (giants, single stars, binaries) with which they interact, respectively, A is the encounter cross section, v the velocity dispersion, and the integral is over the cluster volume. The second proportionality follows because the cross section scales as $A \propto R/v^2$, with R the size of the object; the third assumes that the encounter rate is dominated by the core (radius r_c, mass density ρ_o) and that $n_c \propto n \propto \rho_o$; and the last equality uses the virial theorem: $v \propto \sqrt{\rho_o} r_c$. Another important number is the encounter rate for a single binary γ:

$$\gamma = nAv \propto \frac{\rho_0}{v} R \propto \frac{{\rho_o}^{0.5}}{r_c} \tag{0.2}$$

This rate must be low if a binary has to live long for an observed state to be reached (e.g., to leasurely spin up a neutron star to millisecond period, or to evolve from a wide initial binary into a cataclysmic variable).

If we superpose lines of constant Γ on the positions of clusters in a diagram showing central density of globular clusters versus core radius (Fig. 1 left), we find that a high value for Γ is a good predictor for the presence of a bright X-ray source. If we superpose lines of constant γ, we find that the two long-period binaries with pulsars are indeed in clusters where they can survive, with low γ.

Chandra has really opened up our research into the low-luminosity X-ray sources. As predicted, low-luminosity sources include low-mass X-ray binaries with low accretion

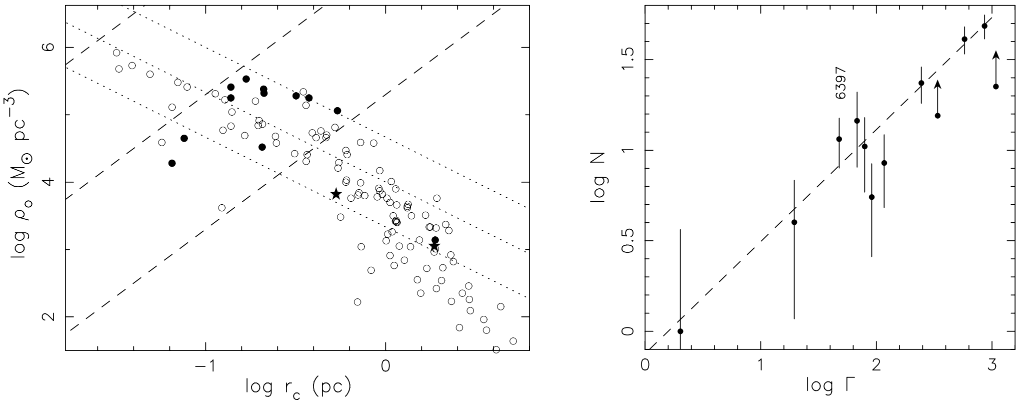

Figure 1. *Left*: Central density and core radius for globular clusters, with lines of constant Γ and γ. Clusters containing bright (above 10^{35} erg/s) X-ray sources are indicated with •, containing pulsars in long-period binaries with a star (after Verbunt 2003). *Right*: Number of low-luminosity sources as a function of Γ (Eq. 0.1), with fit $N \propto \Gamma^{0.62}$ (cf. Pooley *et al.* 2003).

rate (qLMXBs), cataclysmic variables (CVs), millisecond pulsars, and active binaries, as reviewed by Verbunt & Lewin (2006). Various efforts have been made to separate these classes, and investigate their numbers and the scaling with Γ. The number of qLMXBs appears to scale with Γ, but the number of CVs has a more shallow dependence, $N_{\rm CV} \propto \Gamma^{\alpha}$, with $\alpha \simeq 0.6$ - 0.7 (Heinke *et al.* 2003, 2006; Pooley & Hut 2006), possibly because the CV numbers are contaminated by active binaries. The low-density cluster NGC 288 has primordial cataclysmic variables (Kong *et al.* 2006). A dependence of N on metallicity, found for bright sources in globular clusters with other galaxies, is not found for the low-luminosity sources. NGC 6397 warns against premature conclusions on the exceptionality of individual clusters, being normal in Fig. 1 (*right*), but being away from the trend when Γ is computed by integrating a King model. Comparison of clusters through Γ doesn't take into account differences in mass segregation and in neutron star retention. It is therefore important to consider simulations as well (Ivanova, this volume).

An origin via stellar encounters is indicated by the study of several individual systems, such as a blue straggler triple and two sub-subgiants in the old open cluster M 67 (van den Berg *et al.* 2001; Mathieu *et al.* 2002), and the sub-subgiant companion to a pulsar in NGC 6397 (Orosz & van Kerkwijk 2003). The pulsar in the far outskirts of NGC 6752 now has an accurate mass, but may not belong to the cluster after all (Bassa *et al.* 2006).

References

Bassa, C. G., van Kerkwijk, M. H., Koester, D., & Verbunt, F. 2006, *A&A*, 456, 304
Heinke, C. O, Grindlay J. E., Lugger, P. M., *et al.* 2003, *ApJ*, 598, 501
Heinke, C. O, Wijnands, R., Cohn, H. N, *et al.* 2006, *ApJ*, 651, 1098
Kong, A. K. H., Bassa, C., Pooley, D., *et al.* 2006, *ApJ*, 647, 1065
Mathieu, R. D., van den Berg, M., Torres, G., *et al.* 2002, *AJ* 125, 246
Orosz, J., & van Kerkwijk, M. 2003, *A&A*, 397, 237
Pooley, D., & Hut, P. 2006, *ApJ* (Letters), 646, L143
Pooley, D., Lewin, W. H. G., Anderson, S. F., *et al.* 2003, *ApJ* (Letters), 591, L131
van den Berg, M., Orosz, J., Verbunt, F., & Stassun, K. 2001, *A&A*, 375, 375
Verbunt, F. 2003, in: G. Piotto, G. Meylan, G. Djorgovski & M. Riello (eds.), *New Horizons in Globular Cluster Astronomy*, *ASP-CS*, 296, 245
Verbunt, F., & Lewin, W. H. G. 2006, in: W. H. G. Lewin & M. van der Klis (eds.), *Compact stellar X-ray sources* (Cambridge: CUP), p. 341