THE FORMATION AND EVOLUTION OF BINARIES IN GLOBULAR CLUSTERS

Frank Verbunt
Max Planck Institut für Extraterrestrische Physik
D-8046 Garching bei München
Federal Republic of Germany

Abstract. The number density of stars in the cores of globular clusters is high enough for close encounters between stars to be frequent. These encounters may lead to the formation of binaries. Those binaries which do not easily form via the evolution of primordial main-sequence star binaries, and are therefore rare in the galactic disk, can be common in globular clusters. Examples of such binaries are the low-mass X-ray binaries. Such binaries may evolve into radiopulsars.

1. Introduction

Binaries have long escaped detection in globular clusters. In 1987 the binary period was finally found for two X-ray sources (Table 1). Subsequently, five radiopulsars were found in globular clusters, three of which are in a binary (Table 1). These binaries are thought to have evolved from low-mass X-ray binaries, and the single radiopulsars may originate in binaries too. Several other binaries were found via accurate radial velocity measurements of cluster giant stars /8/. I limit myself here to the discussion of the formation and evolution of binaries containing a neutron star. The formation of other binaries may follow a similar pattern. More detail, and references, are given in /11-13/.

Table 1. *Parameters for binaries containing neutron stars, and for single radiopulsars in globular clusters. X = X-ray source, PSR = radiopulsar.*

source	P	P_{orb}	e	cluster	ref
X1820 − 30		864s		NGC 6624	/10/
X2127 + 12		0.35d		M 15	/5/
PSR1821 − 24	3.1ms			M 28	/6/
PSR0021 − 72A	4.5ms	1924s	0.33	47 Tuc	/1/
PSR0021 − 72B	6.1ms	7-95d		47 Tuc	/1/
PSR1620 − 26	11.1ms	191.4d	0.025	M 4	/7/
PSR2127 + 12	110.7ms			M 15	/15/

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2. Formation mechanisms

A star is deformed by the gravitational pull when another star passes nearby. The deformation energy is taken from the relative kinetic energy, and exceeds it at a distance d less than about three times the radius of the deformed star, for masses of $\sim M_\odot$, and velocities ~ 10 km/s. The two stars are then bound /2/. Because the energy in the deformation is proportional to d^6, a rough estimate of the deformation energy gives a pretty accurate estimate of the closest distance required. In this way, a neutron star passing close to a main-sequence or giant star can be tidally captured by it.

Another possibility is an exchange encounter between a binary and a single neutron star, leading to the formation of a temporary triple system, from which one of the original binary members escapes, leaving the other two stars in a binary /4/. Because the number of binaries is small, most low-mass X-ray binaries in globular clusters are probably formed via tidal capture /13/.

3. Stellar content of the core of a globular cluster

To determine what stars will participate in close encounters, one assumes that all stars in a globular cluster were formed simultaneously, with a distribution of masses m according to an initial mass function (IMF) $dN(m) = C_o m^{-1-x} \mathrm{d}m$. The normalization constant C_o and the slope index x can be determined by counting main-sequence stars, which are still unchanged in the cluster. The more massive stars have evolved, the most massive ones have left neutron stars, the less massive ones have left white dwarfs. The number of neutron stars can be estimated by extrapolating the IMF, but two problems arise: i) the large extrapolation required (from the main-sequence stars at $\lesssim 0.8 M_\odot$ to neutron-star progenitors at $\gtrsim 8 M_\odot$) introduces a large uncertainty, ii) from observations of radiopulsars in the galactic disk it appears that many of them are born with velocities exceeding the escape velocity from a globular cluster. Thus, the number of neutron stars in a globular cluster is very uncertain, even if the IMF is well studied /13/.

Around the turnoff mass, stars are evolving into (sub)giants, and their number can be found with help of the IMF. Although the number of giants is small, their size is large, and they account for a sizable fraction of the tidal captures. Virtually all close encounters occur in the cluster core, since the density is highest there. Mass segregation must therefore be taken into account: the most massive stars will be concentrated towards the cluster center, which enhances close encounters involving these stars, including the (sub)giants. Depending on the concentration of the cluster, the fraction of captures by giants varies between about 10 % and 30 % /14/.

4. Tidal capture of neutron stars, and their consequences

Figure 1 gives a schematic overview of the most common capture processes involving

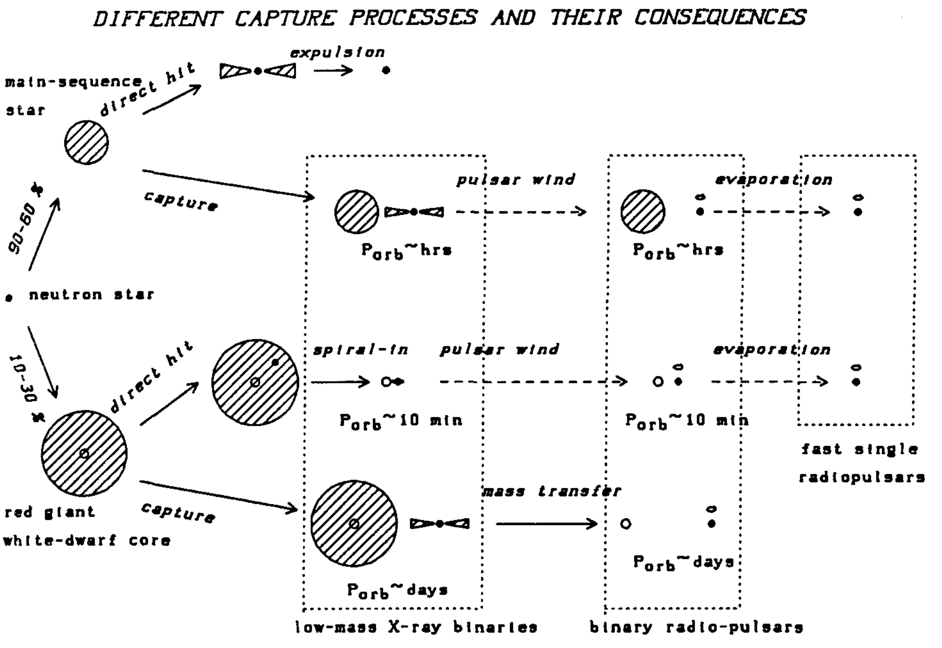

Figure 1. Schematic overview of the formation via tidal capture of X-ray binaries, and of their subsequent evolution. After /11/.

neutron stars, and of subsequent occurrences.

A neutron star can be captured by either a main-sequence star, or by a (sub)-giant. A direct hit on a main-sequence star destroys it, and after a short intermediate phase where some gas still floats around the neutron star, the neutron star emerges pretty much as it was. In a slightly wider encounter, a binary may be formed. Loss of angular momentum, due to gravitational radiation or magnetic braking by stellar wind, drives the two stars together, and causes mass transfer. The ensuing X-ray binary has P_{orb} ~1-8 hr. It appears that interruption of the mass transfer can cause the neutron star to switch on as a radiopulsar, which subsequently evaporates its companion /3/. Thus a binary radiopulsar is formed, and, after complete evaporation, a single radiopulsar.

A direct hit of a neutron star on a giant, may cause it to spiral in, until the released energy expells the envelope, leaving the white-dwarf giant core in close orbit around the neutron star. Gravitational radiation drives the two stars together until mass transfer stars at $P_{orb} \sim 10$ min. Again, it is possible that the neutron star switches on as a radiopulsar, and evaporates its companion. A wider encounter with a giant leads to the formation of a binary with P_{orb} ~1-50 days. Mass transfer in such a binary is caused by expansion of the giant radius. After exhaustion of the giant's envelope, a wide binary with a radiopulsar is left.

Comparison with the observed sources (Table 1) shows that one X-ray binary (in NGC 6624) originated in a direct hit between a neutron star and a giant, and another one (in M 15) in a wider encounter, followed by some loss of angular momentum. Evolution of a wide X-ray binary has led to a radiopulsar in M 4 and one in 47 Tuc. The origin of the 1924.3s binary in 47 Tuc probably involved a spiral-in in a giant, but the origin of its high eccentricity is a mystery. The single radiopulsar in M 28 may have evaporated an earlier companion, but the pulsar in M 15 rotates too slowly for such a process. Wide radiopulsar binaries like those in M 4 and 47 Tuc live long, and are subject to encounters with single cluster stars /9/. Such encounters may induce eccentricity, which explains the e of the M 4 binary, and leads to the prediction that the wide binary in 47 Tuc has a high e. More rare encounters can liberate the neutron star from a wide binary by exchanging it with a single cluster star. This may well be the origin of the single radiopulsar in M 15, a cluster with a dense core, in which encounters are frequent.

5. Summary.

Tidal capture of neutron stars by main-sequence or (sub)giant stars explains the variety of X-ray sources and radiopulsars in the cores of globular clusters. It is not possible to predict the absolute number of sources, due to the large uncertainty in the number of neutron stars in globular clusters.

References

1. Ables, J.G., Jacka, C.E., McConnell, D., Hamilton, P.A., McCulloch, P.M. & Hall, P.J. 1988, *IAU Circ.*# 4602.
2. Fabian, A.C., Pringle, J.E. & Rees, M.J. 1975, *Mon. Not. R. astr. Soc.* **172**, 15p.
3. Fruchter, A.S., Stinebring, D.R. & Taylor, J.H. 1988, *Nature* **333**, 237.
4. Hills, J.G. 1976, *Mon. Not. R. astr. Soc.* **175**, 1p.
5. Ilovaisky,S.A., Aurière, M., Chevalier, C., Koch-Miramond, L., Cordoni, J.P. & Angebault, L.P. 1987, *Astron. Astrophys.* **179**, L1.
6. Lyne, A.G., Brinklow, A., Middleditch, J., Kulkarni, S.R., Backer, D.C. & Clifton, T.R. 1987, *Nature* **328**, 399.
7. Lyne, A.G., Biggs, J.D., Brinklow, A., Ashworth, M. & McKenna, J. 1988, *Nature* **332**, 45.
8. Pryor,C.P., McClure, R.D., Hesser, J.E. & Fletcher, J.M. 1987, *BAAS* **19**, 676.
9. Rappaport, S., Putney, A. & Verbunt, F. 1988, *Astrophys. J.* submitted.
10. Stella, L., Priedhorsky, W. & White, N.E. 1987, *Astrophys. J. (Letters)* **312**, L17.
11. Verbunt, F. 1988a, in: *The physics of compact objects, theory vs. observation*, eds. N.E. White and L. Fillipov, Pergamon Press, Oxford, p.529.
12. Verbunt, F. 1988b, in: *The physics of neutron stars and black holes*, eds. Y. Tanaka, ISAS Tokyo, in press.
13. Verbunt, F. & Hut, P. 1987, in: *The origin and evolution of neutron stars*, IAU Symp. # 125 Nanjing P.R. China, eds. D.J. Helfand and J.H. Huang, Reidel, Dordrecht, p.187.
14. Verbunt, F. & Meylan, G. 1988, *Astron. Astrophys.* in press.
15. Wolszczan, A., Middleditch, J., Kulkarni, S.R. & Fruchter, A.S. 1988, *IAU Circ.*# 4552.