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X-RAY BINARIES IN GLOBULAR CLUSTERS*

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ABSTRACT

It appears to be very unlikely that primordial binaries in globular clusters have evolved to produce high-luminosity X-ray sources like the four variable sources detected in observations by the *Uhuru* and OSO-7 satellites. Therefore, it is suggested that the cluster X-ray sources are binaries formed by capture from the remnants of massive single stars that exploded with sufficient isotropy to remain bound in the cluster. These remnants have lurked near the centers of the clusters where the high stellar densities have favored their capture of field stars which eventually turn the remnants on as X-ray sources when the captives enter the post–main-sequence expansion phase of their evolution. A case is made for the conclusion that there is approximately one potential binary X-ray source near the center of each of the globular clusters.

Subject headings: binaries — globular clusters — X-ray sources

Observations by the *Uhuru* and OSO-7 satellites have revealed four X-ray sources in globular clusters, and have shown that all four are variable (Giacconi *et al.* 1974; Clark, Markert, and Li 1975; Canizares and Neighbours 1975). The data are summarized in Table 1.

The rate of occurrence of X-ray sources in globular clusters is remarkably high compared with other regions of the Galaxy (Katz 1975). The 119 known globular clusters have only about 2×10^{-4} of the mass of the whole Galaxy (Arp 1965), yet they contain four of the ~70 known variable X-ray sources. Thus, the ratio of the number of sources to the mass of the surrounding stellar system is more than two orders of magnitude greater for globular clusters than it is for the whole Galaxy.

Cluster sources, like most of the variable X-ray sources in other parts of the Galaxy, may be close binary systems in which X-rays are generated by the conversion of gravitational potential energy of matter flowing from the surface of a nuclear-burning component and accreting onto a compact component which is a neutron star or black hole (see, e.g., Blumenthal and Tucker 1974; Gursky and Schreier 1974). Alternative models with white dwarfs require excessive rates of accretion and offer no natural explanation of why the X-ray luminosity function has a maximum near 10^{37} ergs s^{-1}. Being a member of the ancient Population II of globular clusters, the nuclear-burning component of a cluster source cannot be a massive star like the primaries of Cen X-3 and Cyg X-1 which lose mass by intense stellar winds. Rather, it must be a star with mass just above the present main-sequence turnoff value of 0.8 $M_\odot$ which begins to transfer matter at the stage of its evolution when it has expanded to fill its Roche lobes and begins to overflow them through the inner Lagrangian point, as in Her X-1.

However, it appears to be very unlikely that a primordial binary, formed ~10^{10} years ago during the original condensation of a globular cluster, evolved so as to produce a high-luminosity X-ray source at the present epoch. Only stars of initial mass greater than 3 $M_\odot$ leave neutron stars or black holes as remnants, as evidenced by the presence of white dwarfs in the Hyades cluster where the present main-sequence turn-

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TABLE 1

DATA ON X-RAY SOURCES IN GLOBULAR CLUSTERS

X-Ray Source	1–10 keV X-Ray Flux (Variability) (10^{-10}ergs cm^{-2} s^{-1})	Globular Cluster	b^{II} l^{II} (deg)	Conc Class	Dist. (kpc)	X-Ray Luminosity (10^{36}ergs s^{-1})
MX 0513−40...	4.7 (≥5)	NGC 1851	−34.9 244.5	II	9.5	4.7
3U 1746−37....	20. (2)	NGC 6441	− 5.0 353.6	III	(10)	23.
3U 1820−30....	88. (5)	NGC 6624	− 7.9 2.8	VI	(10)	100.
3U 2131+11.....	3.0 (2)	NGC 7078 (M15)	−28.1 65.6	IV	10.5	3.7

off is only down to 2–3 $M_\odot$ (Iben 1969). Thus, the compact member of an X-ray binary must have had an initial mass greater than 3 $M_\odot$ and a main-sequence life less than 3×10^8 years. As the primary of a primordial binary with separation less than $\sim$1 AU, it would have transferred more than 1 $M_\odot$ to the companion during post–main-sequence expansion (Kippenhahn, Kohl, and Weigert 1967; Paczynski 1971), thereby speeding up the evolution of the companion so that its nuclear burning life would also have ended long before the present epoch. Alternatively, if the separation were so great that substantial mass transfer did not occur before the explosive formation of the compact remnant, then the explosion would have disrupted the binary or expelled it from the cluster. Katz (1975) has pointed to this latter problem as evidence that there exists a "quiet" process for neutron star production, entailing only a very small mass loss. Such a conclusion appears to be unwarranted in view of the plausibility of the following alternative hypothesis.

I suggest that the cluster X-ray sources are binaries formed exclusively through the capture of field stars by the remnants of massive single stars which completed their evolution in explosions that were sufficiently isotropic to avoid ejecting the remnants from the shallow gravitational potential wells of the clusters. Unlike single remnants wandering outside clusters, a remnant inside has lived in a region of high stellar density where it has had a relatively high probability of capturing a more slowly evolving low-mass star. The latter eventually leaves the main sequence, overflows its Roche lobe, and turns the remnant on as an X-ray source.

Numerical studies by Aarseth (1972) of the evolution of model star clusters with 250 and 500 stars with realistic mass spectra demonstrate that one or two massive close binaries generally form by capture within 10–20 crossing times. They sink toward the center and thereafter play a dominant role in the subsequent dynamical evolution of the cluster, absorbing binding energy and ejecting lower-mass objects from the cluster in multibody encounters. Computation time limitations have so far precluded direct extension of these studies to globular clusters with 10^5 stars. Nevertheless, it is reasonable to suppose that formation of one or more massive binaries is a likely occurrence in a real globular cluster of which the typical age is more than $\sim 10^4$ crossing times, and which may harbor several massive remnants.

If these views are correct, then the number, N_x, of active X-ray sources in globular clusters is the product of the number, N_R, of heavy remnants with close captured companions lurking near the cluster centers and the probability, ξ, that the companion is transferring mass at the rate required to produce the observed X-ray luminosity. An accurate evaluation of ξ will require more study of the capture processes in clusters. We note in this connection that all four clusters with observed X-ray sources are in the more compact half of all clusters. Meanwhile, however, it is interesting to proceed on the simple assumption that the population of the captives is similar to the general population of stars in the clusters. The probability ξ is then the probability that a random field star is in a phase of post–main-sequence expansion in which it would supply matter for accretion at the required rate. Here, too, detailed calculations are desirable. Nevertheless, a rough estimate can be derived by examining the H-R diagram and the luminosity function of M3 measured by Sandage (1957, 1970). Approximately 6000 of the $\sim 2 \times 10^5$ stars in M3 are in their post–main-sequence expansion phase. Canizares (1975) has pointed out that in the case of a very luminous source, such as 3U 1820 −30, the effective life of a captive star as a supplier of accretion matter will be significantly shorter than the total duration of the post–main-sequence expansion of a single star of the same mass due simply to exhaustion of the supply. In fact, the effective life cannot be much longer than

$$t_{\max} \approx \frac{GM_1M_2}{2RL_x},$$

where M_1 and M_2 are the masses of the two stars, R is the effective accretion radius of the compact component, and L_x the X-ray luminosity. For the lower-luminosity sources with $L_x \approx 5 \times 10^{36}$ ergs s^{-1}, $M_1 = 2$ $M_\odot$, $M_2 = 0.8\ M_\odot$, and $R = 10^6$ cm, one finds $t_{\max} \approx 1.4 \times 10^9$ yr, which is comparable to the total duration of the post–main-sequence phase of the evolution of 0.8 $M_\odot$ stars. Thus, I shall assume that $\xi \simeq 6000/2 \times 10^5 = 0.03$. Since the number of lower-luminosity cluster X-ray sources with $L_x \approx 5 \times 10^{36}$ ergs s^{-1} is 3, the total number of potential X-ray sources in all globular clusters is $N_R = N_x/\xi \simeq 3/0.03 = 100$. The fact that this is approximately the number of globular clusters in the Galaxy suggests that there is approximately one heavy potential binary X-ray source lurking at the center of every globular cluster.

Observations can be made in the near future to determine whether the cluster sources are, in fact, located near the centers of their clusters where the massive binaries are expected to reside. Also of great interest will be observations of the time structure of the variations which may reveal whether the sources pulse or eclipse like Her X-1.

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REFERENCES

Aarseth, S. J. 1972, in *IAU Colloquium No. 10, Gravitational N-Body Problem*, ed. M. Lecar (Dordrecht: Reidel), p. 88.
Arp, H. C. 1965, in *Galactic Structure*, ed. A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), chap. 19.
Blumenthal, G. R., and Tucker, W. H. 1974, *Ann. Rev. Astro. and Ap.*, **12**, 23.
Canizares, C. 1975, private communication.
Canizares, C., and Neighbours, J. 1975, *Ap. J.* (*Letters*), **199**, L97.
Clark, G. W., Markert, T. H., and Li, F. K. 1975, *Ap. J.* (*Letters*), **199**, L93.
Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., Matilsky, T., Koch, D., and Tananbaum, H. 1974, *Ap. J. Suppl.* No. 237, **27**, 37.
Gursky, G., and Schreier, E. 1974, *IAU Symposium No. 67 on Variable Stars*.

Iben, I. 1969, *Stellar Astronomy*, Vol. **2**, ed. H. Chiu *et al.* (New York: Gordon & Breach).
Katz, J. I. 1975, *Nature*, **253**, 698.
Kippenhahn, R., Kohl, K., and Weigert, A. 1967, *Zs. f. Ap.*, **66**, 58.
Paczynski, B. 1971, *Ann. Rev. Astr. and Ap.*, **9**, 183.
Sandage, A. R. 1957, *Ap. J.*, **125**, 422.
———. 1975, *ibid.*, **162**, 841.

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