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Luminous Supersoft X-Ray Sources in Globular Clusters

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1 Observations

Globular clusters have been well-studied by ROSAT. Yet, the existence of just a single luminous supersoft X-ray source (SSS) has been reported.

1.1 The Lone Observed SSS in a Globular Cluster

The single detected source, 1E 1339.8+2837, located in M3 (NGC 5272), was observed both in the ROSAT all-sky survey (Verbunt *et al.* 1994, 1995), and in pointed observations using the HRI (Hertz, Grindlay & Bailyn 1993). Estimates of the temperature and bolometric luminosity based on the all-sky survey were $kT \sim 45$ eV, and $L \sim 10^{35}$ erg s^{-1}. The source is a transient. Note that the inferred luminosity (though uncertain) is smaller than typical for SSSs found in the Galaxy, the Magellanic Clouds, and M31.

1.2 Null Results

Most ROSAT studies have not discovered evidence for SSSs in globular clusters. For example, Verbunt *et al.* (1995) reported that, of the 17 clusters in which the ROSAT XRT sky survey could have discovered a source like 1E 1339.8+2837, there were 15 null results, and only one possible detection (in NGC 1851), in addition to the detection of 1E 1339.8+2837 itself.

2 Comparison with LMXBs

Globular clusters are known to have a per capita population of low-mass X-ray binaries (LMXBs) that is roughly 100 times larger than that of the Galactic disk. This has been thought to provide evidence that stellar interactions within clusters are responsible for the formation of many cluster LMXBs. If the same ratio held for SSSs, then the globular cluster population would contain on the order of 100 SSSs—roughly one per globular cluster. If, on the other hand, the per capita population of SSSs in globular clusters is the same as that inferred for the Galactic disk, then the entire globular cluster system should contain $\mathcal{O}(1)$ SSS.

Table 1. The results of seeding 9 Globular clusters with SSSs

Globular Cluster	E(B-V)	Distance (kpc)	t_{exp} (ksec)	Galactic SSSs ⟨Counts⟩	Fraction	1E 1339.8+2837 ⟨Counts⟩	Fraction
NGC 6341	0.02	7.5	6.7	3.E5	0.93	2.E3	1.0
NGC 6752	0.04	4.2	5.2	7.E5	0.95	2.E4	1.0
NGC 7099	0.06	7.4	6.2	3.E5	0.93	2.E3	1.0
ω Cen	0.15	4.9	12.	8.E4	0.83	3.E2	1.0
NGC 6397	0.18	2.2	2.4	4.E4	0.82	1.E2	1.0
NGC 6656	0.36	3.0	8.4	1.E4	0.63	0	0.0
NGC 6642	0.37	8.0	7.6	1.E3	0.46	0	0.0
NGC 6626	0.38	5.9	4.3	1.E3	0.44	0	0.0
NGC 6544	0.74	2.5	2.7	1.E3	0.33	0	0.0

The results of ROSAT PSPC observations of these clusters were reported by Johnston, Verbunt, and Hasinger (1994). The 5th and 6th columns show the results of seeding the clusters with a population of SSSs with properties similar to those of sources found in our Galaxy, the LMC and SMC, and M31. ⟨Counts⟩ is the lifetime-weighted average number of counts per source that would have been recorded during an exposure of duration t_{exp}, and "fraction" is the fraction of seeded sources that would have been detected (i.e., which contributed 10 or more counts). The 7th and 8th columns show the analogous quantities when the clusters are "seeded" with the single observed source, 1E 1339.8; the count rates are lower because the source has a smaller L and somewhat lower value of T than the "galactic" sources. Note the dramatic dependence on N_H.

3 Are There SSSs in Globular Clusters?

We want to turn the observational results, which have mainly been null, into limits on the total population of SSSs in globular clusters. To this end we have "seeded" each of the globular clusters observed by Johnston *et al.* 1994, with a population of SSSs, and have determined the count rate associated with each seeded source (see Di Stefano, Becker & Fabbiano 1996 for a description of an analogous procedure).

Table 1 indicates that SSSs like those detected in our own Galaxy cannot be hidden in globular clusters. The majority of such sources would have been detected if they were on during ROSAT observations. Furthermore, most detected sources would have contributed large numbers of counts. A significant fraction of sources from the lower L and T edges of the distribution could have been missed only in clusters viewed behind significant columns of gas and dust. Thus, even sources such as the single observed source are not common.

4 Should There be SSSs in Globular Clusters?

The two main types of SSS in the Galaxy and the Magellanic Clouds are symbiotics and candidates for the close-binary supersoft source model (CBSSs; see Di Stefano & Nelson [DN; 1996]). Primordial binaries should not have yielded

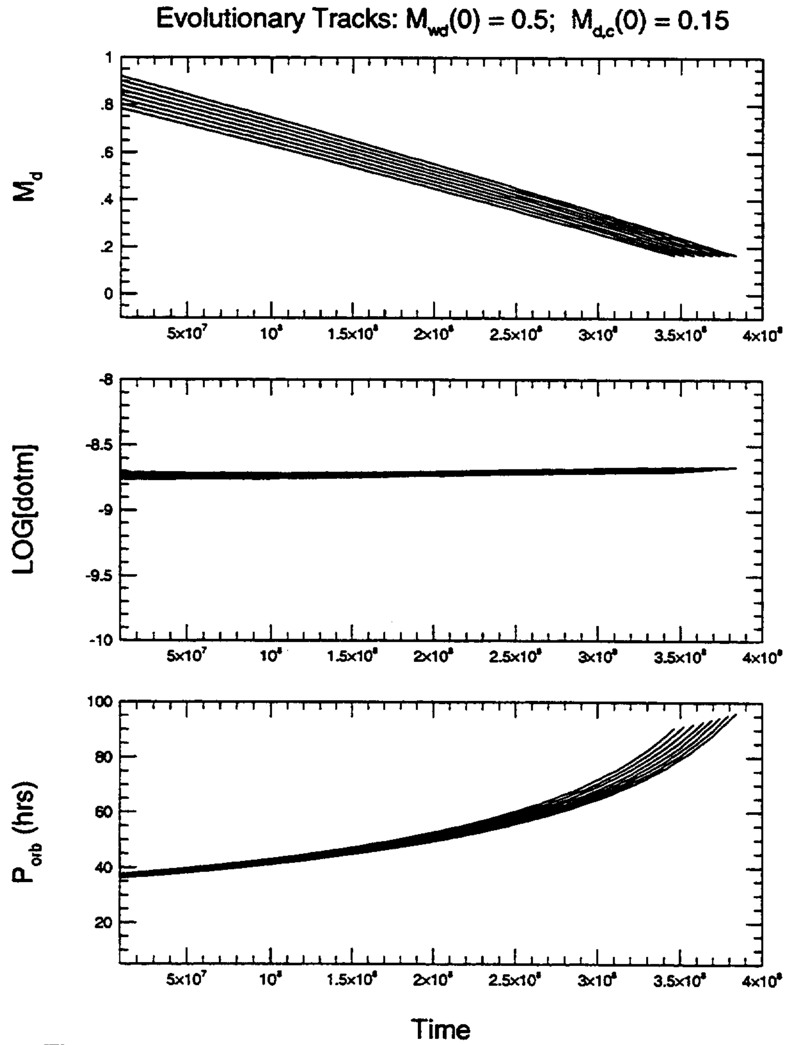

Fig. 1. The top, middle, and lower panels show the mass of the donor, its mass loss rate, and the orbital period, respectively, as functions of time.

significant numbers of either system in globular clusters today. Stellar interactions, however, should create CBSSs in the dense central regions of globular clusters. The donor star would be a blue straggler, formed through the merging of two lower-mass stars. (In fact, M3 is rich in blue stragglers [Guhathakurta et al. 1994].) We have performed simulations for two clusters, 47 Tuc and ω Cen. These will be described in detail elsewhere (Di Stefano & Davies 1996). Briefly, we use a code that follows thousands of systems, each through multiple interactions (Davies and Benz 1995; Davies 1995). States in which a white dwarf is in a close orbit with a blue straggler are evolved with a binary evolution code (see, e.g., Di Stefano et al. and DN). Typical evolutions are shown in Figure 1; the systems formed tend to have values of $\dot{m}$ below the steady-burning region, and should therefore appear as SSS transients. The total numbers are small—fewer than 10 in each cluster during the past 2 Gyrs. Thus, given the short lifetime and low duty cycle of activity, we would not expect to find active SSSs in either cluster. The mismatch is not so large, however, as to preclude the existence of a few SSSs "on" at any given time in the globular cluster system.

5 Results and Prospects

Theory predicts that SSSs may be formed in clusters via interactions in or near the dense cluster cores. The rate of formation tends to be small ($< 10^{-8}$ /yr), and the time duration of SSS activity is shorter by at least an order of magnitude than even the lowest estimates presently made for LMXB lifetimes. Thus, it may not be surprising that observations seem to rule out the possibility that SSSs are 100 times as numerous per capita in globular clusters as they are in the Galactic disk. The factor that makes it most difficult to place concrete observational limits on the SSS population in all Galactic globular clusters is that some are seen through a large column density (see, e.g., Rappaport *et al* 1994). We are working to refine our calculations. Preliminary indications are that the theoretical predictions will continue to be in harmony with the observations. Nevertheless, the process of carrying out a detailed test will lead to the derivation of useful ratios between observable systems, such as blue stragglers and CVs, and will help us to further classify the supersoft source and related occupants of the globular cluster binary zoo.

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