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The Integrated X-Ray Spectrum of Galactic Populations of Luminous Supersoft X-Ray Sources

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Abstract. We compute the composite X-ray spectrum of a population of unresolved SSSs in a spiral galaxy such as our own or M31. The sources are meant to represent the total underlying population corresponding to all sources which have bolometric luminosities in the range of $10^{37} - 10^{38}$ ergs s^{-1} and kT on the order of tens of eV. These include close-binary supersoft sources, symbiotic novae, and planetary nebulae, for example. In order to determine whether the associated X-ray signal would be detectable, we also "seed" the galaxy with other types of X-ray sources, specifically low-mass X-ray binaries (LMXBs) and high-mass X-ray binaries (HMXBs). We find that the total spectrum due to SSSs, LMXBs, and HMXBs exhibits a soft peak which owes its presence to the SSS population. Preliminary indications are that this soft peak may be observable.

1 Motivation

Computations of the fraction of luminous supersoft X-ray sources (SSSs) that could have been detected by ROSAT surveys indicate that SSSs form a significant population in the Local Group (Di Stefano & Rappaport 1994; DR). DR estimated that the numbers of presently active and not self-obscured SSSs in M31, the Milky Way, and the Magellanic Clouds are $800 - 5000$, $400 - 1000$, and $50 - 100$, respectively.

Observations of some spiral galaxies have revealed the presence of soft excesses in their X-ray spectra (see, e.g., Kim, Fabbiano, and Trinchieri 1992). These observations, in concert with the predictions of large galactic SSS populations for spiral galaxies, lead to the natural question: Are SSSs responsible for the observed soft excesses?

2 Method

We approach the answer in two steps. First we compute the composite X-ray spectrum of a population of unresolved SSSs in a "typical" spiral galaxy. Spirals with a significant hot ISM, or with an active nucleus would require a separate treatment. The galaxy is "observed" by folding the composite spectrum through the ROSAT PSPC response matrix (pspcb_gain2_256.rsp); the simulated pulse height spectrum is computed. Second we add the composite spectra due to other types of sources, to determine if any unique signature of the SSS population can be unambiguously identified. To test the sensitivity of the results to input assumptions, we carry out a number of different simulations. We vary (a) the input spectra of LMXB and HMXB "contaminants", and (b) the angle, θ, the disk of the external spiral galaxy makes with our line of sight to it.

Interstellar Gas In our simulations, the X-ray sources are embedded in the galaxy's gas distribution, which is modeled as an exponential disk with scale height $z_{\rm gas}$. We take the column density along a line of sight perpendicular to the disk to be 10^{21} cm^{-2}. To this we add a column density chosen uniformly from the range $2 - 5 \times 10^{20}$ cm^{-2}, comparable to that associated with looking out of the plane of the Galaxy.

Luminous Supersoft X-Ray Sources Using the results of DR, we seed the galaxy with 1000 SSSs. The temperature and luminosity distribution is taken from the work of Rappaport, Di Stefano, & Smith (1994; RDS). Although RDS modeled close-binary systems, the distributions of properties compare well with known SSS of all types (e.g., old novae). DR and Motch, Hasinger, and Pietsch (1994) found that SSSs are likely to be part of a disk population. We have therefore chosen $z_{\rm SSS}/z_{\rm gas} = 0.4$.

Other X-Ray Sources Fabbiano (1989) indicates that X-ray emission from normal spiral galaxies is dominated by neutron star binaries. We therefore consider LMXBs and HMXBs as "contaminants" to the SSS contribution. Based on observations of the Milky Way and M31 (Fabbiano 1989), we seed our galaxy with 30 HMXBs (scale height: $z_{\rm HMXB}/z_{\rm gas} = 0.4$) and 100 LMXBs (scale height: $z_{\rm LMXB}/z_{\rm gas} = 1.5$).

In addition, other sources of X-radiation are present in typical galaxies; these include cataclysmic variables, stars with active coronae, supernovae, and black hole candidates. Since we are primarily interested in the sources as "contaminants" to the composite spectrum of SSSs, it is the low energy portion of the source X-ray spectra that is of most concern to our simulations. Unfortunately, the effects of interstellar absorption at these wavelengths lead to significant uncertainties. Given these uncertainties, we have attempted to simplify our simulations by (1) explicitly including only LMXBs and HMXBs as contaminants to the composite SSS spectrum, and (2) characterizing the associated spectra so as to systematically vary the soft component most relevant to our study. We carry out all of our simulations three times, first, with spectra for both LMXBs and HMXBs that we regard to be "pessimistic", in that the soft components of these sources are overemphasized by choosing only the softest observed spectra for LMXBs and HMXBs. In this "worst case" scenario, the copious soft radiation emitted by our too-soft population of LMXBs and HMXBs should also provide an upper limit to the soft radiation likely to be associated with the other types of X-ray source that we have not explicitly included in our simulations. In two separate sets of simulations we have used spectra that are in the mid-range (the "realistic" case) and upper end ("optimistic" case) of hardness observed for both LMXBs and HMXBs (see the caption to Figure 2 for details).

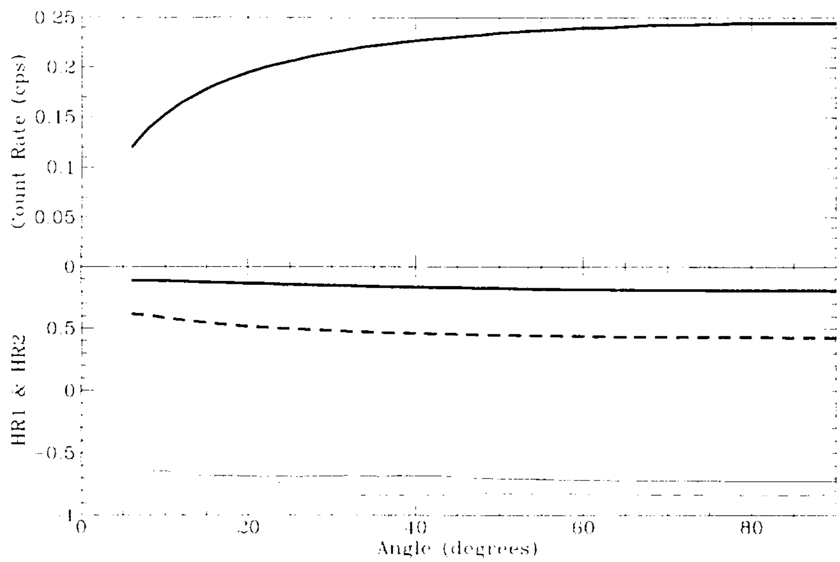

Fig. 1. The angular dependence of the (a) count rate, (b) HR1 = (C+B-A)/(C+B+A) (solid) and HR2 = (C-B)/(C+B) (dashed), where A = (0.1 – 0.4 keV), B = (0.4 – 0.9 keV), and C = (0.9 – 2.0 keV). The SSS component of the composite spectrum is represented by the thin line. Thick lines correspond to the composite spectrum due to all sources in the "realistic" case.

3 Results

Significant features of the composite SSS spectrum as observed by the ROSAT PSPC are shown in Figure 1. Our simulation results, which include the spectra of LMXBs (thermal bremsstrahlung) and HMXBs (power law), are shown in Figure 2. The SSS component is clearly identifiable in the realistic and optimistic cases, where the soft excess can not be explained through any linear combination of LMXB and HMXB components in the optimistic case. The more complete analysis required for the pessimistic case is underway.

4 Conclusions

If SSSs exist in typical spiral galaxies in the numbers inferred by Di Stefano & Rappaport (1994) for both our own Galaxy and M31, then they are likely to be associated with a soft X-ray excess. Further work will quantify the effect and explore whether the observed soft excesses in some spirals may in fact be due to the presence of a population of luminous supersoft X-ray sources. A parallel investigation for elliptical galaxies is also underway. The present work indicates the possibility of detecting evidence of SSSs populations in distant galaxies through the observation of soft excesses in galactic spectra is promising.

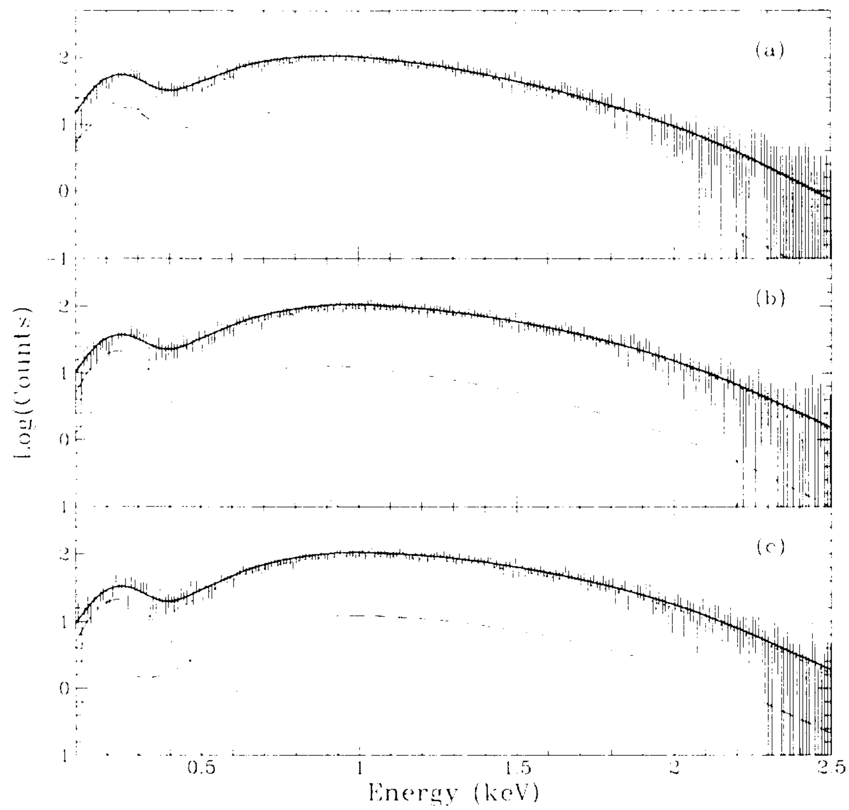

Fig. 2. Simulated 50 ks observation of a galaxy at 5 Mpc in the (a) pessimistic case: $kT = 1.3$, $\alpha_{ph} = 3.5$; (b) realistic case: kT= 5.0, $\alpha_{ph} = 2.5$; and (c) optimistic case: kT= 10.0; $\alpha_{ph} = 1.5$. The dashed traces (longest to shortest) are the contributions to the composite spectrum from the SSS, HMXB, and LMXB components. Note that all cases are somewhat "pessimistic", in that HMXBs are embedded with the same scale height used for SSSs

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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), 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}; estimates based on the HRI observations were $kT \sim 20$ eV and $L \sim 1.6 \times 10^{36}$ erg s^{-1}. The source is a transient. Note that the inferred luminosities (though uncertain) are 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, Johnston, Verbunt, and Hasinger (1994) present the results of deep observations of 9 globular clusters with the ROSAT PSPC; no SSSs were detected during their study.

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 10 Globular clusters with SSSs

Globular Cluster	E(B-V)	Distance (kpc)	t_{exp} (ksec)	Galactic SSSs ⟨Counts⟩	Galactic SSSs Fraction	1E 1339.8+2837 ⟨Counts⟩	1E 1339.8+2837 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
47 Tuc	0.04	4.6	61.	7.E6	0.97	5.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 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 that Verbunt *et al.* 1995 have also reported the discovery of a soft X-ray source in NGC 5272, through data taken during the all-sky survey.

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, as well as 47 Tuc, 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

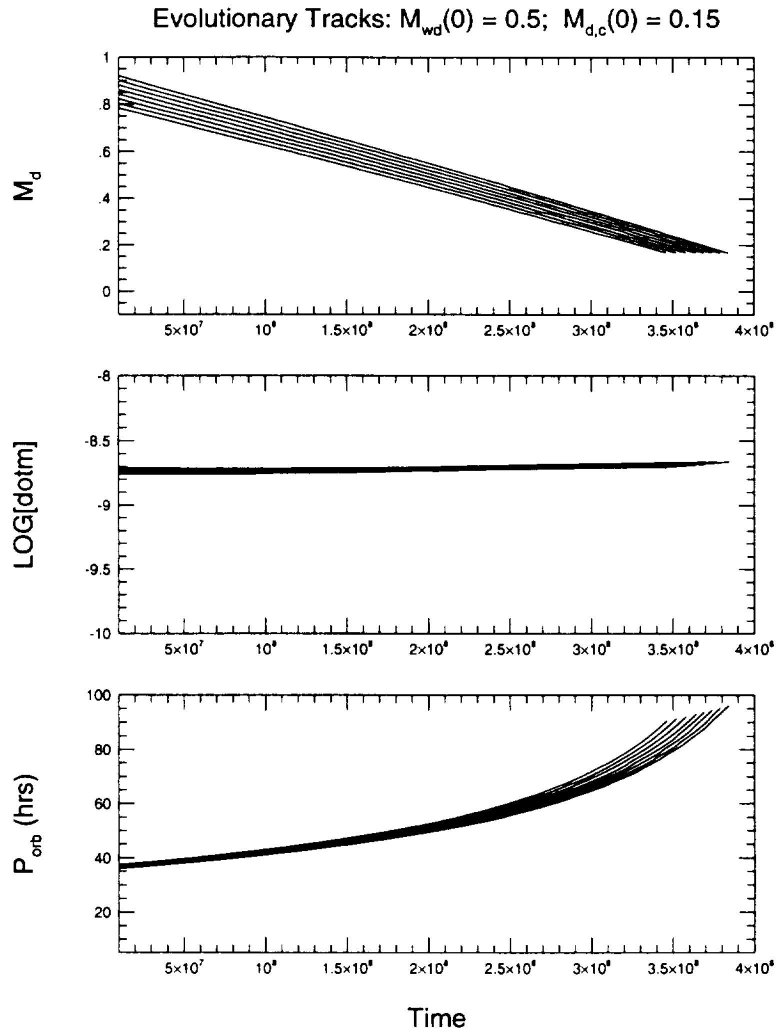

Fig. 1. The top, middle, and lower panels show the mass of the donor, its mass loss rate, and the orbital period, respectively, as functions of time.

DiStefano & Nelson [DN; 1996]). Primordial binaries should not have yielded 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 (DiStefano & 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

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. Theory predicts, however, 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.

We are working to refine the calculations whose results are sketched above. 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.

Summary Observations to date indicate that there are not many SSSs in globular clusters. Theory predicts that there shouldn't be. Ongoing work will better quantify the agreement between observations and theory and further classify the supersoft source and related occupants of the globular cluster binary zoo.

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