Stellar X-ray Binary Populations in Elliptical Galaxies

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Abstract. Chandra’s high angular resolution can resolve emission from stellar X-ray binaries out of the diffuse X-ray emission from gaseous atmospheres within elliptical galaxies. Variations in the X-ray binary populations (per unit galaxian optical luminosity) are correlated with variations in the specific frequency of globular clusters in ellipticals. This indicates that X-ray binaries are largely formed in globular clusters, rather than being a primordial field population.

1. Introduction

The X-ray emission from normal elliptical galaxies has two major components: soft (0.2 – 1 keV) emission from diffuse gas and harder (5 – 6 keV) emission from populations of accreting (low-mass) stellar X-ray binaries (LMXB). The hardness of the LMXB component (placing its emission outside the most responsive parts of the ROSAT and ASCA bandpasses) and its spatial confusion with the softer gaseous component have made it difficult to constrain the global temperatures and luminosities of LMXB populations in elliptical galaxies. Chandra observations are now resolving out individual LMXBs in nearby ellipticals (Sarazin, Irwin & Bregman 2000, 2001; Kraft et al. 2000; Finoguenov & Jones 2001), making their composite spectral analysis much easier. Figure 1 compares optical images of two ellipticals, NGC 1407 and NGC 4552, to their X-ray images from the ROSAT PSPC and Chandra ACIS (White & Davis 2001). The PSPC images emphasize the diffuse gaseous atmospheres of these ellipticals, while the ACIS images are stretched to emphasize the discrete sources in each galaxy. Chandra imaging has clearly resolved out dozens of LMXBs from the diffuse gaseous emission in these ellipticals, as it has in several other ellipticals in the work cited above.

These recent Chandra observations show that the hard X-ray emission from normal ellipticals is dominated by LMXBs, not the advection-dominated accretion flows (ADAFs) onto massive, central black holes, advocated by Allen, di Mateo & Fabian (2000). Meanwhile, as Chandra continues to observe more nearby ellipticals, there is a large database of long ASCA observations which has more to yield for ellipticals.
2. Constraining the LMXB Component in Ellipticals

Strong spectral constraints on the hard stellar LMXB component in ellipticals can be made by simultaneously analyzing ASCA spectra from multiple ellipticals. Most ellipticals require both soft (gaseous) and hard (LMXB) components. I simultaneously fit ASCA GIS spectra of six ellipticals which provided individually reasonable spectral constraints on their hard emission. In the joint fits, the temperature of the LMXB component was assumed to be the same for all galaxies; the temperatures of any soft gaseous components (if present) were allowed to vary individually. The resulting best-fit global spectrum of LMXBs is fit equally well by a bremsstrahlung spectrum with $kT = 6.3$ (5.2-7.9) keV or a power-law spectrum with photon index = 1.83 (1.72-1.93), where 90% confidence limits are in parentheses. These are the tightest constraints to date on the spectral properties of the stellar LMXB component in ellipticals (White 2001) and are consistent with the spectral character of many individual LMXBs in our Galaxy. Fluxes for the LMXB components in an additional six ellipticals which had poorer photon statistics were determined by adopting the best fit LMXB temperature of 6.3 keV in fits to their GIS spectra.
In comparing the X-ray fluxes deduced for the LMXB component in these ellipticals to the total optical magnitudes for these galaxies, I find there is a factor of 4 range in the X-ray to optical flux ratio. Although this range is much smaller than that of the softer gaseous component (which has a factor of 100 range in X-ray/optical flux ratio), it is still larger than expected, since the LMXB component is supposed to be directly proportional to the stellar component. What is the source of the variance in the X-ray/optical flux ratio $f_{\text{LMXB}}/f_{\text{opt}}$?

3. Globular Cluster Population Variations in Ellipticals

Elliptical galaxies exhibit a wide range of globular cluster populations for a given galaxian luminosity. Furthermore, in our galaxy, LMXBs are produced much more efficiently in globular clusters than in the field: globular clusters contain $\sim 20\%$ of the known LMXBs, yet globular clusters contain $< 0.1\%$ of the stars in our galaxy. Apparently, globular clusters make LMXBs $> 200$ times more efficiently than the stellar field (Katz 1975), presumably through tidal interactions between stars (Clark 1975). It is therefore conceivable that nearly ALL stellar LMXBs are formed in globular clusters (Grindlay 1985; Kulkarni 2000). LMXBs which are not now in globular clusters may have been ejected from globulars by supernova kicks immediately after the primary collapsed to a neutron star. In this case, we might expect the X-ray luminosity of the LMXB component to be correlated with the globular cluster population of a galaxy, regardless of whether all LMXBs are currently resident in globular clusters.

To test this, I plot in Figure 2 the specific frequency of globular clusters (the number of globular clusters per unit galaxy luminosity, normalized by the luminosity corresponding to a visual absolute magnitude of $M_V = -15$), versus the X-ray/optical flux ratio of the LMXB populations to the optical flux (magnitude) of the host galaxies. The globular cluster data are from the compilation of Kissler-Patig (1997), while the X-ray data are from the ASCA elliptical sample described above (White 2001). There appears to be a strong correlation, with the X-ray/optical flux ratio directly proportional (within the errors) to the specific globular cluster frequency $S_{\text{gc}}$:

$$f_{\text{LMXB}}/f_{\text{opt}} \propto S_{\text{gc}}^{1.3 \pm 0.3}.$$  

This strongly suggests that LMXB populations are indeed controlled by globular cluster populations.

4. Conclusions

Variations in the X-ray binary populations of elliptical galaxies (per unit galaxian optical luminosity) are linearly correlated with variations in their specific globular cluster frequencies. This indicates that X-ray binaries are largely formed in globular clusters (Grindlay 1985), rather than being a primordial field population. We predict that Chandra observations of central dominant galaxies with unusually large globular cluster populations will be found to have proportionally large numbers of LMXBs, as well. For a more detailed analysis, see White, Kulkarni & Sarazin (2001).
Figure 2. The specific frequency of globular clusters plotted against the ratio of global LMXB X-ray fluxes to the optical magnitudes (fluxes) of the host ellipticals.

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