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# ACCOUNTING FOR THE DISPERSION IN THE X-RAY PROPERTIES OF EARLY-TYPE GALAXIES

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Early-type galaxies are found to have diffuse X-ray emission, with X-ray luminosities ranging from $L_X \approx 10^{39} - 10^{42}$ erg s$^{-1}$ (Forman, Jones and Tucker 1985; Canizares, Fabbiano and Trinchieri 1987 [CFT]). The source of X-ray emission is thought to be thermal radiation from hot gas permeating the galaxies; coarse X-ray spectra of the most luminous galaxies reveal gas temperatures of $\sim 1$ keV. The inferred amount of X-ray emitting gas, $10^9 - 10^{10}\ M_\odot$, is generally consistent with the amount expected from the integrated history of normal stellar mass loss in the galaxies. Since the cooling time of the hot gas is typically less than a Hubble time, the gas is likely to be involved in cooling flows (White and Chevalier 1984; Nulsen, Stewart and Fabian 1984; Thomas *et al.* 1986). For the *least* optically luminous early-type galaxies, it is not yet clear whether their X-ray emission is from diffuse gas or from (hotter) discrete sources.

The X-ray luminosities of early-type galaxies are correlated with their optical (e.g. blue) luminosities ($L_X \sim L_B^{1.6}$), but the X-ray luminosities exhibit considerable scatter for a given optical luminosity $L_B$. This dispersion in X-ray luminosity is much greater than the dispersion of other properties of early-type galaxies (for a given $L_B$), such as luminosity scale-length, velocity dispersion, color, and metallicity. In particular, early-type galaxies with blue luminosities of $L_B \approx 10^{11}\ L_\odot$ (assuming $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$) have X-ray luminosities which range nearly two orders of magnitude, from $L_X \approx 10^{40} - 10^{42}$ erg s$^{-1}$. It is not clear whether the scatter in $L_X$ reflects variations in the *intrinsic* properties of galaxies (i.e. stellar mass loss rates, supernova rates, velocity dispersions, masses, etc.) or whether it reflects variations in the *environment* of the galaxies (i.e. variations in the amount of ram-pressure stripping). Therefore, when X-ray observations of early-type galaxies are used to constrain the intrinsic properties of early-type galaxies, it is not clear how theoretical models should properly be compared to the data. If the scatter in $L_X$ is intrinsic, theoretical models should at least reproduce median values of $L_X$ as a function of $L_B$. Alternatively, if the scatter is environmentally induced, theoretical models should provide an *envelope* for $L_X$ as a function of $L_B$. This ambiguity has significant consequences: for example, the supernova rate in early-type galaxies as inferred from their X-ray properties is then uncertain by a factor of $\sim 3$.

We consider several possible sources for the dispersion in X-ray luminosity:

Some of the scatter in X-ray luminosity may result from stellar population variations between galaxies with similar $L_B$. Since the X-ray emitting gas is from accumulated stellar mass loss, the $L_X$ dispersion may be due to variations in integrated stellar mass loss rates. For example, more metal-rich galaxies of a given $L_B$ may have more mass loss than less metal-rich galaxies, due to the increased stellar opacity at higher metallicities. Population variations may also affect supernova rates. Galaxies with higher supernova rates (at fixed $L_B$) will have larger $L_X$. Since significant stellar population differences should manifest themselves through color variations, we look for correlations between the X-ray luminosities and optical colors $(U-V)$ of early-type galaxies for fixed $L_B$ (that is, we look for a correlation between the residuals of the mean $L_X - L_B$ and $(U-V)$-$L_B$ relations).

Another possible cause of the $L_X$ dispersion may be variations in the amount of cool material in the galaxies; cool gas may act as an energy sink for the hot gas. Sources of cool (atomic or molecular) material include 1) the infall of gas-rich dwarf galaxies; 2) thermally unstable density perturbations in the hot gas; or 3) the incomplete thermalization of stellar ejecta. Infrared emission may be used to trace such cool material, so we look for a correlation between the infrared emission and the X-ray emission of early-type galaxies at fixed $L_B$.

Velocity dispersion variations between galaxies of similar $L_B$ may also contribute to the $L_X$ dispersion. Galaxies with greater stellar velocity dispersions will have the stellar mass loss heated to higher temperatures, which will also increase $L_X$ for a given amount of gas. If velocity dispersions are well-correlated with the total masses of early-type galaxies, then galaxies with higher velocity dispersions will retain more gas in stripping encounters with other galaxies or with intracluster gas. Thus, higher velocity dispersions would again be correlated with higher $L_X$ at fixed $L_B$.

The most likely *a priori* source of the dispersion in $L_X$ is probably the varying amount of ram-pressure stripping in a range of galaxy environments (CFT, Sarazin and White 1988). The hot gaseous halos of early-type galaxies can be stripped in encounters with other galaxies or with ambient cluster gas if the intracluster gas is sufficiently dense. Since the timescale for a stripped galaxy to replenish its gas is much longer than a typical crossing time in a galaxy cluster or group, we do not expect a *tight* correlation between X-ray luminosity deficit (for a given $L_B$) and local galaxy density. Stripped, X-ray deficient galaxies need not remain near the spot where they were stripped in the distant past. However, if stripping is important, we may expect to find that the *least* stripped galaxies, i.e. the most X-ray luminous galaxies for a given $L_B$, will tend to be in less dense environments.

Of these various possibilities for the cause of the dispersion in the X-ray properties of early-type galaxies, we find that the most likely cause is probably the ram-pressure stripping of gaseous halos from galaxies. For a sample of 81 early-type galaxies with X-ray luminosities or upper limits derived from *Einstein Observatory* observations (CFT) we calculated the cumulative distribution of angular distances between the X-ray sample members and bright galaxies from the *Revised Shapley – Ames* catalog. Collectively, galaxies with low X-ray luminosities (for a given $L_B$) tend to be in denser environments than galaxies with higher X-ray luminosities: galaxies with low $L_X$ have $\sim$50% more neighbors between 1 and $\sim$ 5 degrees than do galaxies with high $L_X$ (for a given $L_B$). This is indicative of an environmental cause for the $L_X$ dispersion. We are currently checking whether this dichotomy in the angular density of bright galaxies is manifested in the space density of bright galaxies, as well, or only in projection on the sky.

As for the other possibilities mentioned for the cause of the $L_X$ dispersion, we find no compelling correlations which support any of the causes other than stripping for the dispersion in X-ray luminosity.

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