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Analysis of the EINSTEIN Sample of Early-Type Galaxies

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The EINSTEIN galaxy catalog (Fabbiano, *et al.* 1992, ApJSup. 80, 531) contains x-ray data for 148 early-type (E and S0) galaxies. We are engaged in a detailed analysis of the global properties of this sample. By comparing the x-ray properties with other tracers of the ISM, as well as with observables related to the stellar dynamics and populations of the sample, we expect to determine more clearly the physical relationships that determine the evolution of early-type galaxies.

Previous studies with smaller samples have explored the relationships between x-ray luminosity (L_X) and luminosities in other bands (see Fabbiano 1989, ARAA. 27, 87). Using our larger sample, and the statistical techniques of survival analysis (Schmitt 1985, ApJ. 293, 178; Isobe *et al.* 1986, ApJ. 306, 490), we have repeated a number of these earlier analyses. For our full sample, we find a strong statistical correlation between L_X and L_B (the probability that the null hypothesis is upheld is $P < 10^{-4}$ from a variety of rank correlation tests. Regressions with several algorithms yield consistent results. All give a relationship of the form

$$\text{Log}(L_X) = 1.80(\pm 0.15)\text{Log}(L_B) - 37.47(\pm 6.31). \quad (1)$$

Or, dropping the Local Group dwarf galaxies M32 and NGC 205,

$$\text{Log}(L_X) = 2.01(\pm 0.18)\text{Log}(L_B) - 46.49(\pm 7.93). \quad (2)$$

In all cases, luminosities are in ergs/sec. Both of these results are inconsistent with a simple slope-1 relationship to greater than 5σ . The relationship between L_X and L_{6cm} is also clearly steeper than slope-1: the best fit value for the full data set has a slope of $m = 1.62 \pm 0.09$.

Other strong correlations exist between L_X and $L_{12\mu m}$, and L_X/L_B . A weak correlation ($P \approx 0.03 - 0.06$, depending on the test) exists between L_X and $L_{100\mu m}$. This weak correlation vanishes when only E-type galaxies are considered ($P \approx 0.15$), but becomes stronger for the S0s ($P \approx 0.01 - 0.02$). As a rule, however, there do not tend to be significant differences between the Es and S0s in the luminosity-luminosity relations.

We are also examining relationships between the x-ray emission and structural parameters of the galaxies in our sample. Simple two-parameter correlation tests show that both L_X and L_X/L_B are strongly correlated with $\text{Log}(a/b)$, $\text{Log}(\sigma_v)$, and with the a_4 parameter as defined by Bender *et al.* (1989, AAp. 217, 35). Our a/b values come from the RC3, σ_v from Faber *et al.* (1989, ApJSup. 69, 763), and a_4 from Bender *et al.* and Peletier *et al.* (1990, AJ. 100, 1091). The relationships are such that more luminous x-ray galaxies tend to be rounder, have larger velocity dispersions, For the last, $P = 0.025$. While the last relationship was discussed by Bender *et al.* (1989), they did not test its significance. There is also a strong correlation between L_X and the Mg_2 parameter from Faber *et al.* ($P \approx 0.007$) in the sense that more luminous x-ray galaxies also tend to have higher values of Mg_2 .

Because we are examining relationships among a large number of parameters, it is useful to ask if inter-relationships amongst multiple parameters will effect the results of simple two-parameter tests. One way of addressing this is the partial Spearman-rank method (Kendall and Stuart 1976, "Advanced Theory of Statistics, Vol. II). Kim *et al.* (1992, ApJ. Submitted) used this method to demonstrate relations between C_{21} and L_X , C_{21} and L_X/L_B , a/b and L_X , and a/b and L_X/L_B . C_{21} is the ratio of the mid- to soft-xray flux, defined by Kim *et al.* (1992, ApJSup. 80, 645), and effectively measures the line of sight absorption (N_H). These relations are in the sense that more luminous x-ray galaxies are rounder, and have larger N_H . The total N_H often exceeds the Galactic foreground value for the most luminous galaxies. With our current sample we have run tests on the combination (L_X , L_B , L_X/L_B , a/b , a_4), and confirmed the correlations ($P \leq 0.03$) between L_X and a_4 and L_X/L_B and a_4 that appeared in the two-parameter tests. Adding Mg_2 and σ_v , we confirm that L_X also correlates strongly with each of these parameters. We note, however, that our sample shows no evidence of correlation between a_4 and Mg_2 .

Our analysis of these results is still somewhat preliminary. An overall picture has begun to emerge, however. Low-luminosity ellipticals and S0s have x-ray fluxes and spectra that are indistinguishable from spirals (Kim *et al.* 1992, ApJ. 393, 134). Above some limiting luminosity (ie., mass) the galaxy is able to retain some or all of its primordial and reprocessed ISM. The fraction of material retained appears to be a strongly increasing function of mass (σ_v). Thus more massive systems were also able to recycle their ISM, for a time, into new stars, leading to their higher metallicities (Mg_2). The high σ_v in these systems, plus energy input from SNe heats the gas up to x-ray temperatures, effectively preventing current large-scale star formation.

The steep correlation between L_X and L_{6cm} also indicates a physical interaction between the media generating these fluxes. The standard model (see Fabbiano 1989 for references) is that the x-ray gas acts as a confining medium for outflowing material from an active nuclear source. Our sample is large enough that we will be able to examine the details of this model. In particular, how the core and extended radio flux components relate to the x-ray emission. The lack of correlation between L_X and $L_{100\mu m}$ for ellipticals indicates that there is no relationship between the cool ISM traced by the $100\mu m$ emission and the x-ray gas. This supports the notion that the material responsible for the $100\mu m$ emission in ellipticals is either accreted or otherwise transitory. There does appear to be a correlation (at the $\sim 2.5\sigma$ level) between L_X and $L_{100\mu m}$ for the S0s. The slope of the regression is, however, consistent with 1, indicating that this is a 'bright-things-are-bright' correlation. This is in keeping with other work indicating that the FIR in S0s galaxies does not, as a rule, require appeals to accretion (Eskridge and Pogge 1991, AJ. 101, 2056).

The relationships between L_X , a/b , a_4 , and C_{21} that the shape of the potential, as well as the total mass is important for determining the evolution of the ISM in ellipticals. For a given optical luminosity (or mass), rounder galaxies have larger L_X . These same galaxies also tend to have significant *intrinsic* N_H . It may be that the lack of rotation in these systems allows a significant amount of material to collect in their nuclei and cool to the neutral phase. The lack of rotation in these more massive ellipticals may be pointing toward differing evolutionary pathways for producing current elliptical galaxies. Brighter, rounder, boxier galaxies could be the products of mergers between rather sizable objects. Less luminous, more flattened, disk galaxies may be "primordial" ellipticals.