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# The X–ray Emission in Post–Merger Ellipticals

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## ABSTRACT

The evolution in X–ray properties of early–type galaxies is largely unconstrained. In particular, little is known about how, and if, remnants of mergers generate hot gas halos. Here we examine the relationship between X–ray luminosity and galaxy age for a sample of early–type galaxies. Comparing normalized X–ray luminosity to three different age indicators we find that  $L_X/L_B$  increases with age, suggesting an increase in X–ray halo mass with time after a galaxy’s last major star-formation episode. The long-term nature of this trend, which appears to continue across the full age range of our sample, poses a challenge for many models of hot halo formation. We conclude that models involving a declining rate of type Ia supernovae, and a transition from outflow to inflow of the gas originally lost by galactic stars, offers the most promising explanation for the observed evolution in X-ray luminosity.

**Key words:** galaxies: interactions – galaxies: elliptical and lenticular – galaxies: evolution – X-rays: galaxies

## 1 INTRODUCTION

A potential problem with forming ellipticals from merging spirals is how to account for the different gas properties in the two types of galaxies. In particular, spirals contain relatively high masses of cold ( $T \sim 100$  K) gas, whereas ellipticals have very little. The opposite situation is true for the hot ( $T \sim 10^6$  K) gas masses – normal spirals contain rather little hot gas, while ellipticals may possess extensive hot halos. Since the total gas masses per unit stellar mass are broadly comparable in early and late-type galaxies, this raises the possibility that inefficient merger–induced star formation might heat the cool interstellar gas in spirals to form the hot halo in post–merger ellipticals. Recently, Georgakakis et al. (2000) have shown that the cold gas mass indeed decreases in an ‘evolutionary sequence’ from merging spirals to post–merger ellipticals.

However, it is not clear that gas heated in an intense starburst can be retained within the galactic potential. Read & Ponman (1998) examined the X–ray properties of eight on–going mergers placed in a chronological sequence. Their study revealed that material is ejected from merging galaxies soon after the first encounter. Massive extensions of hot gas are seen (involving up to  $10^{10} M_\odot$ ) at the ultraluminous peak of the interaction, as the two nuclei coalesce. There is evidence for this in the *Antennae*, Arp 220, and NGC 2623. However, after this phase of peak activity, the

X–ray luminosity actually declines. For example, NGC 7252 (a prime example for the remnant of a merger that occurred 0.7 Gyr ago) shows some evidence of a hot halo, but one that is much smaller than the halos seen in typical ellipticals.

Two post–merger ellipticals were studied in the X–ray by Fabbiano & Schweizer (1995). They found that neither galaxy had an extensive hot halo. Given the correlation between X–ray luminosity and isophotal boxiness (thought to be a signature of a past merger) demonstrated by Bender et al. (1989), this was a somewhat surprising result. If post–merger ellipticals are to resemble ‘normal’ ellipticals they need to acquire a hot gas halo. Possible mechanisms include:

- 1) The late infall (i.e. after a few Gyr) of HI gas associated with the tidal tails (Hibbard et al. 1994). This cold gas may be shocked to X–ray emitting temperatures as it falls back into the merger remnant.
- 2) A reservoir of hot gas, possibly expelled at the nuclear merger stage, might infall from large radii, where its low density makes it undetectable to current X–ray satellites.
- 3) After the initial violent starburst, the continued mass loss from stars and heating from stellar winds recreates a hot ISM.

The first study to attempt an ‘evolutionary sequence’ for post–merger ellipticals was that of Mackie & Fabbiano (1997). For 32 galaxies they showed a weak trend for  $L_X/L_B$  to increase with a decreasing  $\Sigma$  parameter. The  $\Sigma$  parame-

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ter is defined by Schweizer & Seitzer (1992), and is a measure of a galaxy’s fine structure, *i.e.* optical disturbance. They showed that it correlates with blue colours and Balmer line strength, and is thus a rough indicator of dynamical youth. The Mackie & Fabbiano trend therefore suggested that post–merger ellipticals became more X–ray luminous, for a given optical luminosity, as the galaxy aged. They also plotted  $L_X/L_B$  against  $H\beta$  absorption line EW, which revealed a similar trend. A more recent study by Sansom et al. (2000) confirms the trend in X–ray overluminosity with  $\Sigma$  for 38 galaxies, and suggests that it might be explained by the build up of hot gas in post–merger galaxies. However, both  $\Sigma$  and  $H\beta$  EW have their drawbacks –  $\Sigma$  is only semi-quantitative at best and the strength of  $H\beta$  is affected by both stellar age and metallicity.

Here we reexamine the trend seen by Mackie & Fabbiano (1997) for a larger sample, and investigate two new measures of galaxy age: residual from the Fundamental Plane and spectroscopic age. Using these three measures we explore the X–ray luminosity evolution of post–merger ellipticals.

Throughout the paper we assume  $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$  and normalise  $L_B$  using the solar luminosity in the B band,  $L_{B\odot} = 5.2 \times 10^{32} \text{ erg s}^{-1}$ .

## 2 RESULTS

We first reexamine the trend of normalized X–ray luminosity with Fine Structure parameter  $\Sigma$ , presented initially by Mackie & Fabbiano (1997) for 32 galaxies. Here we use a sample of 47 early–type galaxies with  $\Sigma$  taken from Schweizer & Seitzer (1992), and normalized  $L_X$  values from our recent catalogue (O’Sullivan et al. 2000) of X–ray luminosities (mostly based on *ROSAT* data). The  $L_X$  values are approximately bolometric. The  $L_B$  values are based wherever possible on  $B_T$  magnitudes taken from Prugniel & Simien (1996). If these are unavailable, values from NED are used. Fig. 1 shows the sample of 47 early–type galaxies plotted in order of decreasing  $\Sigma$  or increasing age.

As noted by Mackie & Fabbiano, the scatter at low values of  $\Sigma$  is large, covering around 2 orders of magnitude in  $L_X/L_B$ , while at higher  $\Sigma$  the scatter appears to be smaller and  $L_X/L_B$  limited to low values. A similar trend was seen by Sansom et al. (2000) for 38 galaxies. This suggests that dynamically young galaxies have low X–ray luminosities and that aging produces a range of luminosities, presumably dependent on other factors.

In order to test the strength of this relation we apply Kendall’s K test to the X–ray detections from our sample. The test does not assume any distribution in the data, and the K statistic is unit normal distributed when at least 10 data points are present. For our data we find  $K = -2.31054$  (using 27 data points), indicating an anti correlation between  $\text{Log } L_X/L_B$  and  $\Sigma$  of  $\sim 2\text{-}\sigma$  significance. For comparison, we also apply the test to the sample of Sansom *et al.*, and find a correlation of very similar significance,  $K = -2.28749$  for 30 detections.

### 2.1 $L_X/L_B$ versus Spectroscopic Age

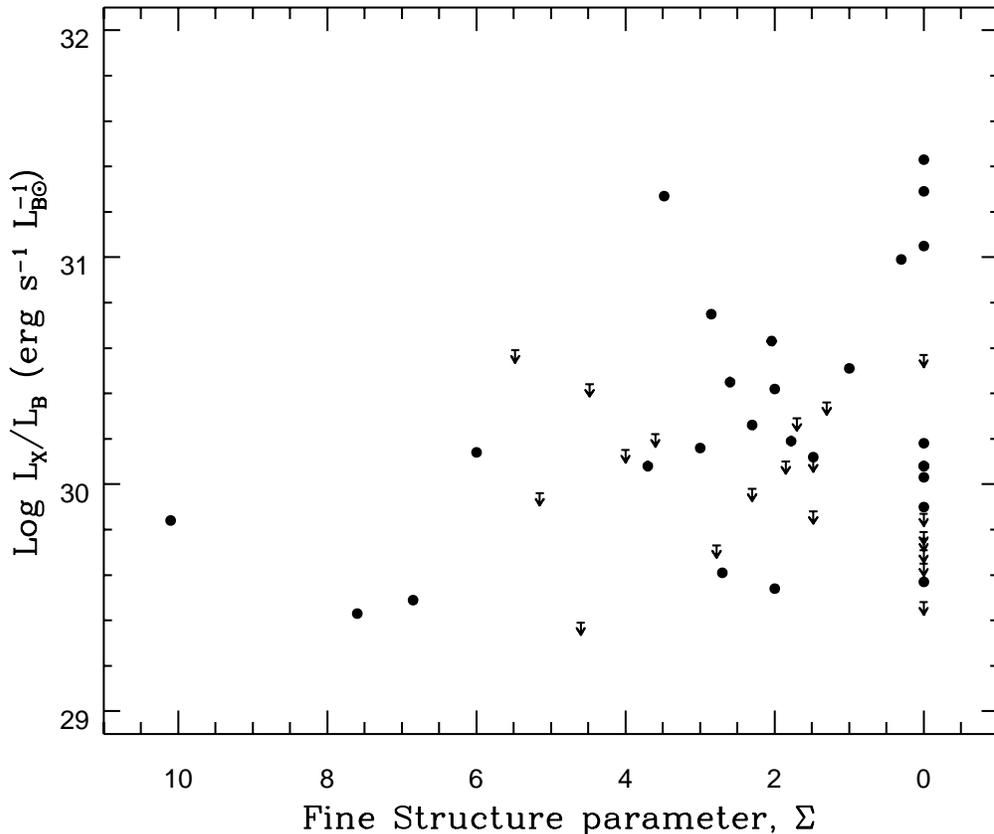
Fine structure only persists in dynamically young galaxies, so Fig. 1 provides information only on the early galaxy evolution of these objects. A more general measure of age is needed to show how X–ray properties evolve over a longer timescale. Galaxy spectroscopic ages are now available for a large number of early–type galaxies from the catalogue of Terlevich & Forbes (2000). These ages are generally based on  $H\beta$  absorption line measurements and the stellar population models of Worthey et al. (1994). The line index measurements come from the galaxies’ central regions, and are luminosity weighted. Thus they are dominated by the last major burst of star formation, which is presumably triggered by a major merger event. Although not a reliable absolute measure of the age of each galaxy, these spectroscopic ages do provide us with a much more useful estimate of their ages relative to one another. In Fig. 2 we show  $L_X/L_B$  plotted against spectroscopic age (from Terlevich & Forbes 2000).

The plot shows a large degree of scatter, most notably in the age range between 4 and 10 Gyrs. This is likely to be in part caused by the uncertainties in calculating ages, which we estimate lead a typical error of  $\sim 20\%$ . We also expect a mean  $1\text{-}\sigma$  error in X–ray luminosity of  $\sim 15\%$ . Typical error bounds for points at 1, 7 and 15 Gys are shown in Fig. 2 by the diamonds at the top of the plot. The graph also contains a relatively large number of upper limits, so we have used the survival analysis packages available under IRAF to assess the strength of any correlation and fit regression lines. The Cox proportional hazard, Spearman’s rho and generalized Kendall’s tau tests are used to determine correlation strength. Linear regression fitting is carried out using the expectation and maximization (EM) algorithm and the Buckley–James (BJ) algorithm. In all cases we found that the two fitting algorithms agreed closely.

Using the full sample of 77 early–type galaxies, we find a correlation of at least 99.6% significance between  $L_X/L_B$  and age. Line fits to the sample produce slopes of  $0.066 \pm 0.022$  (EM) and  $0.063 \pm 0.025$  (BJ). The former is shown as the dashed line in Fig. 2.

Recent work on the X–ray properties of galaxies in groups (Helsdon et al. 2000) lead us to suspect that some of the scatter seen in Fig. 2 might be caused by inclusion of group or cluster dominant galaxies (marked as crossed circles) in our sample. It is also important to note that there is evidence to suggest that the largest ellipticals may have non–solar abundance ratios (*e.g.* Carollo et al. 1993). This could lead to their ages being underestimated by a small amount, again adding to the scatter. We therefore removed from our sample a number of galaxies listed by Garcia (1993) as group dominant or known cDs and retested the sample. This improves the correlation slightly (to  $>99.75\%$ ) and makes the line fit slightly shallower;  $0.063 \pm 0.019$  (EM) and  $0.061 \pm 0.022$  (BJ). The EM fit is plotted as a solid line in Fig. 2.

To confirm that the increase in  $L_X/L_B$  occurs across the range of ages, rather than just the first few Gyrs, we also binned the sample into subsets by age. The age range of each subset was chosen so as to have roughly equal numbers of detections in each bin. We then calculated a mean  $L_X/L_B$  for each bin, using the Kaplan–Meier estimator. The results are shown in Table 1, and as large crosses on Fig. 2. These show the same trend for increasing  $L_X/L_B$  with age, and



**Figure 1.** Normalized X-ray luminosity versus fine structure parameter  $\Sigma$  for early-type galaxies. Filled circles are detections, arrows denote upper limits. Dynamically young galaxies (high  $\Sigma$ ) have low  $L_X/L_B$ .

Age (Gyrs)	No. of detections	No. of upper limits	Log $L_X/L_B$ (erg s <sup>-1</sup> L <sub>B⊙</sub> <sup>-1</sup> )	error
$A < 4$	9	12	29.56	±0.11
$4 \leq A < 6$	6	11	29.83	±0.15
$6 \leq A < 8$	9	4	29.93	±0.22
$8 \leq A < 10$	9	6	30.15	±0.14
$A \geq 10$	8	4	30.32	±0.09

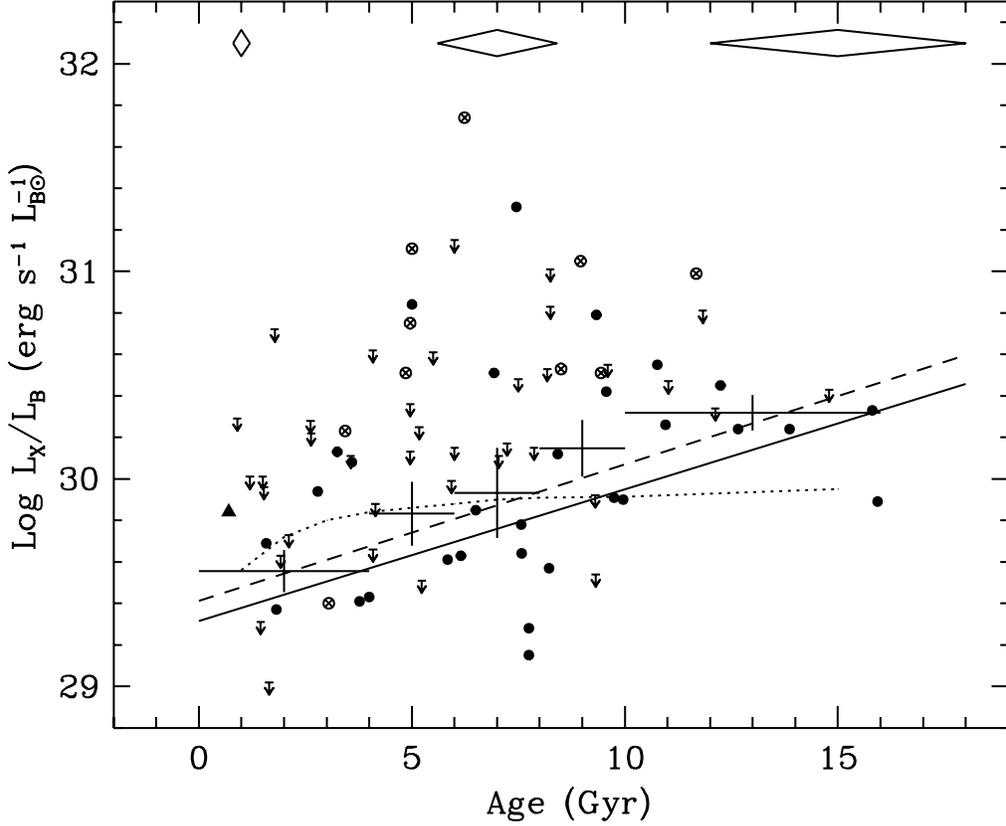
**Table 1.** Mean  $L_X/L_B$  values for 5 age bins, calculated using the Kaplan–Meier estimator.

indicate that the trend is continuous across the age range covered by the data.

The Kaplan–Meier estimator (Feigelson & Nelson 1985) includes upper limits by constructing a probability distribution function for the data in which the probability associated with each upper limit is redistributed equally over detected values which lie below the upper limit. So long as there is no systematic difference between the detected and undetected systems, this should be a reasonable procedure. A problem arises when the *lowest* point in a given bin is an upper limit (since there are no lower points over which to re-

distribute the corresponding probability). When this occurs, the Kaplan–Meier estimator treats the limit as a detection and hence may be biased.

Of the five bins chosen, two (the youngest and second oldest) have upper limits as their lowest values. For the second oldest bin, the problem data value is only slightly lower than a detected point, so the bias will be small. However, the youngest bin has two upper limits as its lowest points, one of which is considerably below the nearest detection. To check for bias, we recalculated a mean log  $L_X/L_B$  of 29.66 for this bin excluding these points, compared to 29.56 pre-



**Figure 2.**  $\text{Log}(L_X/L_B)$  plotted against spectroscopic age. Crossed circles represent group or cluster dominant galaxies, filled circles all other detections. Arrows denote upper limits and the filled triangle represents NGC 7252, a young post-merger. The three diamonds at the top of the graph show typical age and  $L_X/L_B$  errors for galaxies of age 1, 7 and 15 Gyrs. The two lines are fits to the data, including (dashed line) or excluding (solid line) the group and cluster dominant galaxies. The large crosses represent mean  $L_X/L_B$  for the five age bins described in the text. The dotted line shows the expected increase in  $L_X/L_B$  caused by the decrease of  $L_B$  with age. Normalisation of this line is arbitrary, and the position shown can be considered to represent a “worst case” scenario.

viously. This indicates that although the youngest bin may be slightly biased, it still supports the trend observed.

As a further check of the robustness of our conclusions, we examined the  $L_X/L_B$ :Age relation using detected points only, and find a correlation significant at  $\sim 2.1\text{-}\sigma$ . The upper limits also show a correlation with age (at  $\sim 2.3\text{-}\sigma$ ). These trends cannot be selection effects in the data, since neither source distance, nor X-ray exposure time are correlated with age. They therefore point to a genuine trend in the data. Galaxies with larger spectroscopic ages typically have higher  $L_X/L_B$  than younger ones.

As the merger-induced starburst fades, we would expect the blue luminosity to decline with time. This will cause an increase in  $L_X/L_B$ , even for constant  $L_X$ , which will combine with any trends in  $L_X$  which are present. With this in mind, we show in Fig. 2 the expected change due to a fading starburst from stellar population models (Worthey 1994). Here we have crudely assumed that the progenitor galaxies consisted of a solar metallicity, 15 Gyr old popula-

tion, and that the new stars created in the merger also have solar metallicity. The relative mass ratios are 90% progenitor stars and 10% new stars. The total B band luminosity fading of this composite stellar population is shown in Fig. 2 (we assumed that the fading of the progenitor stars after reaching 18 Gyrs old is insignificant). It can be seen that the starburst fades rapidly in the first few Gyrs, roughly matching the trend seen in  $L_X/L_B$ , but at later times there is very little change, whereas the observed mean  $L_X/L_B$  value continues to rise. So although the  $L_X/L_B$  evolution at early times could be simply driven by the fading starburst, this cannot account for the evolution at late times.

A further possibility to be checked is that our sample might contain a trend in mean optical luminosity with age. Since  $L_X/L_B$  has been widely reported (see however Helsdon et al. (2000)) to rise with  $L_B$ , this could lead to a consequent correlation between age and  $L_X/L_B$ . To test this, we show in Fig. 3 a plot of  $\log L_B$  with measured age. An anti-correlation between  $L_B$  with age could produce the ob-

served trend in  $L_X/L_B$ . Fig. 3 does not appear to show any such trend, and in order to test for a correlation, we apply Kendall’s K test to the data. We find a K statistic (which is unit normal distributed) of  $\sim 0.44$  (for 77 galaxies), and excluding group dominant galaxies reduces this to  $\sim 0.33$  (for 65 galaxies). This result indicates that there is no trend in the data, even at the  $1\sigma$  level. We therefore conclude that our sample does not show an anti-correlation of  $L_B$  with age, and that the  $L_X/L_B$  trend with age reflects an increasing X-ray luminosity.

## 2.2 $L_X/L_B$ versus Fundamental Plane Residual

As further evidence of X-ray evolution with age we have compared  $L_X/L_B$  to residual from the Fundamental Plane (FP). Work by Forbes et al. (1998) has shown that galaxy age appears to be a “fourth parameter” affecting the position of a galaxy relative to the FP plane. Galaxies below the plane (negative residual) are generally young, while older objects lie on or above the plane (positive residual). Fig. 4 shows 212 galaxies with Fundamental Plane residuals taken from Prugniel & Simien (1996).

As with Figs. 1 and 2, this shows a trend of increasing  $L_X/L_B$  with age. For the complete data set, the correlation strength is  $>99.98\%$ . However, only a small number of points lie outside the range  $-0.5 < \text{FP residual} < 0.5$ . These are unlikely to be representative of the general population, but will have a strong influence on the statistical tests. Excluding them lowers the correlation strength to  $\sim 99.95\%$ , with a slope of  $1.39 \pm 0.40$  (EM). This line is shown in Fig. 4. Again the trend shown in Fig. 4 is one of increasing X-ray luminosity, relative to the optical, as a galaxy evolves.

## 3 DISCUSSION

In the previous section we have used three age estimators to show a strong correlation between normalized X-ray luminosity and galaxy age. The X-ray emission from early-type galaxies is known to be produced by sources of two main types; discrete sources such as X-ray binaries, and hot gas. The contribution of discrete sources has been shown to be important in low luminosity early-type galaxies (Fabbiano et al. 1994; Irwin & Sarazin 1998; Sarazin et al. 2000) and in late-type galaxies, where they are generally the dominant source of X-ray emission. On the other hand, most early-type galaxies have a strong hot gas component, and massive ellipticals are certainly dominated by hot gas emission (Matsushita et al. 2000; Matsushita 2000). As the contribution of hot gas is known to vary a great deal, while the contribution from discrete sources is generally believed to scale with  $L_B$  (Matsushita et al. 2000; Fabbiano et al. 1992), it seems likely that the trend we observe in  $L_X/L_B$  is caused by changes in the hot gas content of these objects with age. We now go on to discuss possible hot halo formation mechanisms which may be responsible for this trend of increasing X-ray gas content with age.

### 3.1 Gas infall

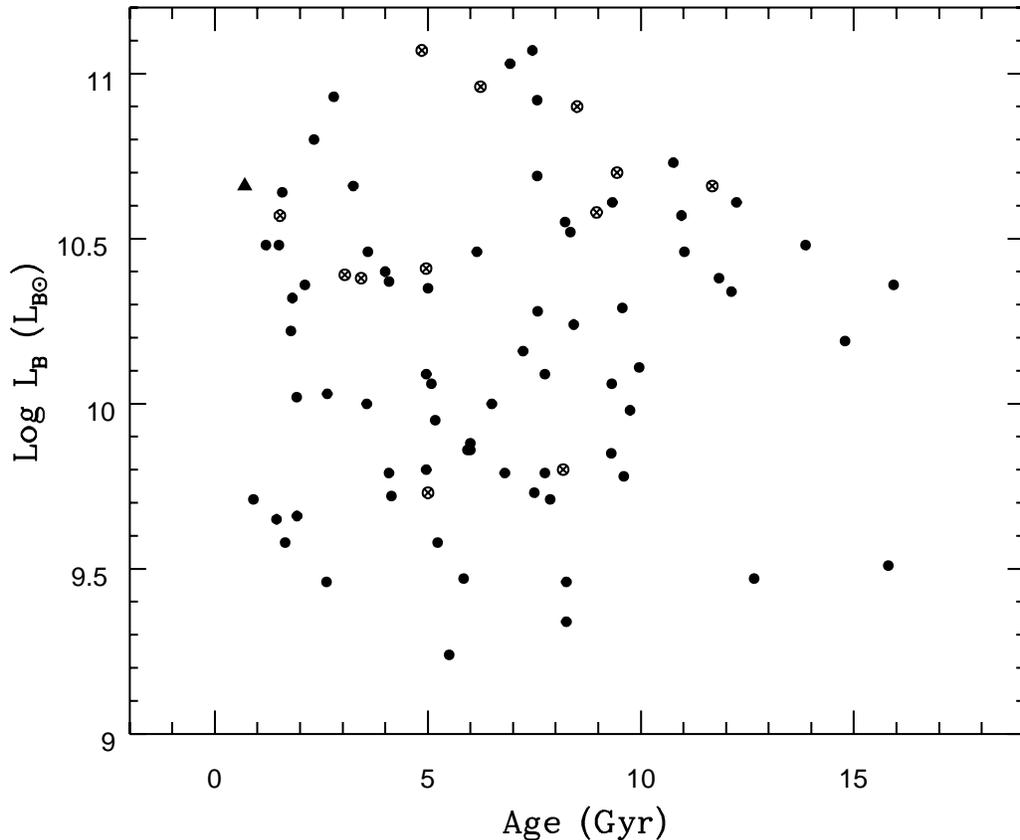
It has been suggested (Hibbard & van Gorkom 1996) that the hot gas in elliptical galaxies may be produced during

a merger by the shock heating or photoionization of cool gas from the progenitor galaxies. In some ongoing mergers the tidal tails are thought to contain up to half the H I gas originally present in the progenitor galaxies (Hibbard et al. 1994). When this gas falls back into the body of the galaxy, shock heating should be capable of heating it to X-ray temperatures. An alternative is that the temperature of the gas is caused by heating in the starburst phase of the merger. In this case the hot gas would be blown out to large radii, but might be contained by the dark matter halo of the galaxy (Mathews & Brighenti 1998). At these large radii it would be too diffuse to be detected, but would eventually fall back into the galaxy, forming the observed X-ray halo.

In terms of available masses of gas, both these models appear to be viable formation processes. Bregman et al. (1992) derived X-ray and cold gas masses for a large sample of early-type galaxies, finding  $M_X$  of between  $\sim 10^6$  and  $10^{11} M_\odot$ . The mean X-ray gas mass was a few  $10^9 M_\odot$ . On the other hand, very few detections of H I were made in early-type galaxies, although Sa galaxies were found to contain between  $10^7$  and  $\sim 5 \times 10^{10} M_\odot$  of H I. Studies of H I masses in later-type galaxies (Huchtmeier & Richter 1989; Huchtmeier & Richter 1988) give an average of a few  $10^9 M_\odot$ , depending on the range of morphologies chosen. Given that large elliptical galaxies are likely to have been formed by the merger of many smaller spiral galaxies, these results suggest that fairly modest conversion efficiencies could produce the expected X-ray halo gas masses either from infalling H I or via starburst heating and later infall.

However, the infalling H I model fails to explain the timescale over which we observe the  $L_X/L_B$  trend. In the well known merging galaxy NGC 7252, 50% of the cold gas currently in the tidal tails is expected to fall back into the main body of the galaxy within the next 2–3 Gyr (Hibbard & van Gorkom 1996). This suggests that we should expect to see a rapid build up of X-ray emission in the first few gigayears after merger. This increase should be made even more noticeable by the fading of the stellar population, as this is the period during which  $L_B$  is dropping most quickly. Rapid generation of the X-ray halo is inconsistent with our results.

A model involving infall of hot gas is likely to have similar problems. It is difficult to see how gas falling back into the body of the galaxy can do so at the steady rate needed to produce a smooth increase in  $L_X/L_B$ . Infall may be delayed, as the hot gas reaches larger radii than the cold, but it will still occur on a galaxy dynamical timescale. Models involving cooling and infall of gas onto central dominant galaxies in groups or clusters (Brighenti & Mathews 1999) may be able to produce an inflow over a longer period, but these are unlikely to be generally applicable. Group dominant galaxies have exceptionally large dark halos, making them more able to retain (or accrete) hot gas. They also lie at the bottom of a group potential well, and may be at the centre of a group X-ray halo, providing them with an extra reservoir of hot gas. These conditions do not apply to the majority of early-type galaxies. Therefore we suggest that infall of (cold or hot) gas is unlikely to be the dominant process in the generation of X-ray halos in typical ellipticals.



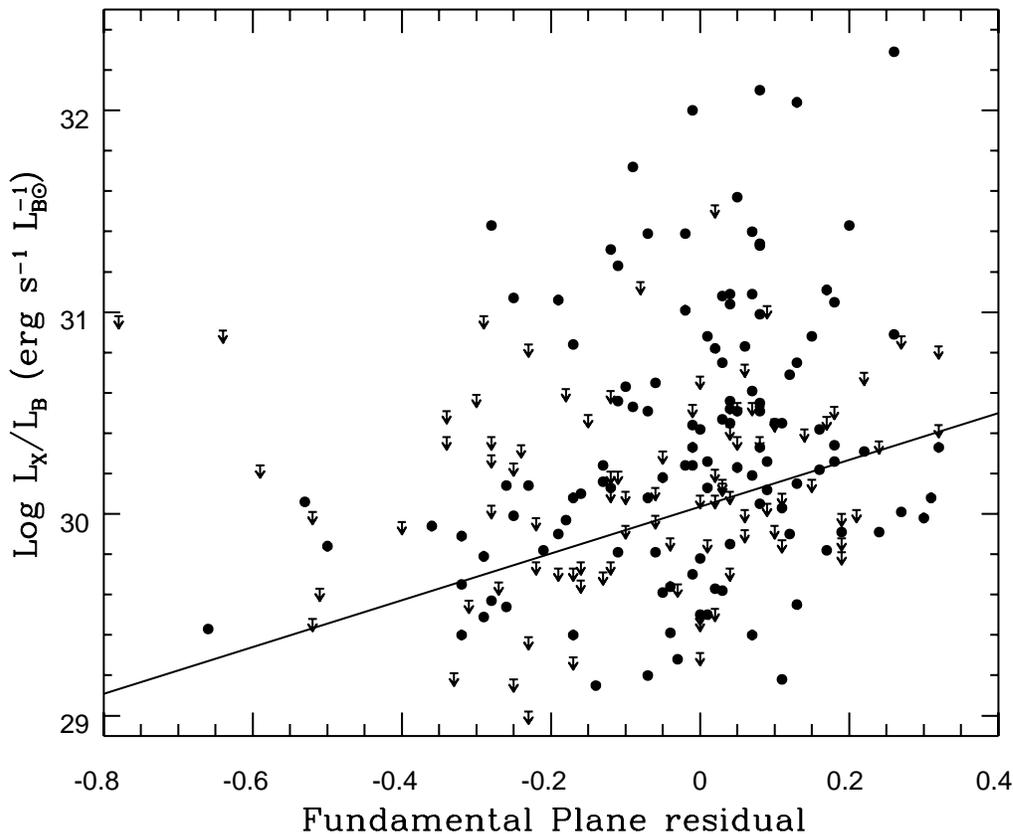
**Figure 3.** Optical luminosity versus spectroscopic age. Crossed circles represent cluster or group dominant galaxies and filled circles all other detections. The triangle is the recent merger remnant NGC 7252. The cE galaxy, M32, has been excluded from the plot and associated statistical tests.

### 3.2 Ongoing stellar mass-loss and galaxy winds

Since infall of either hot or cold gas seems unable to provide the sort of long term trend in  $L_X/L_B$  seen in Fig. 2, we now look to models involving gas generated by mass loss from the galactic stars. This source of gas is fairly well understood, and can provide the sort of gas masses required to account for the halos of many early-type galaxies (though probably not the very brightest – Brighenti & Mathews 1998), provided that the gas is retained within the galactic potential. Two main timescales are involved. One is the mass loss rate from stars, primarily giant stars. The second is the rate of type Ia supernovae (SNIa) which provide the main heat source (after the brief SNII phase). These two factors, and the interplay between them, can potentially lead to changes in the hot gas content of elliptical galaxies on timescales much longer than a dynamical time, and so have the potential to explain the slow trend we observe. The stellar mass loss rate is fairly well understood (e.g. Ciotti et al. 1991), and for a single-aged stellar population it declines approximately as  $t^{-1.3}$ . However, the SNIa heating rate, which dominates the effective specific energy of the injected gas, is highly uncertain. Recent estimates of the SNIa rate in old stellar pop-

ulations (e.g. Cappellaro et al. 1999) have revised the classic Tammann (1982) value of the rate in old stellar populations down by a factor 3-4, and the evolution of this rate with population age is very model-dependent. Given our continuing ignorance about the precise nature of SNIa, it must therefore be regarded as largely unknown.

The specific energy of the injected gas determines whether gas is retained in a hydrostatic hot halo, or escapes the galaxy as a wind. The way in which the specific energy evolves, depends upon the evolution of the SNIa rate relative to the stellar wind loss rate. There are therefore two fundamentally different classes of models: those in which the SNIa rate is constant, or declines more slowly than the stellar mass loss rate (e.g. Loewenstein & Mathews 1987; David et al. 1991) and those in which the supernova rate drops more quickly than the gas injection rate (Ciotti et al. 1991; Pelegrini & Ciotti 1998). Broadly speaking, when the specific energy of the injected gas is smaller than its gravitational binding energy it will be retained in a hot halo. It may subsequently cool in a luminous cooling flow. However, if the specific energy of the gas substantially exceeds its binding energy it will escape from the galaxy in a fast



**Figure 4.** X-ray luminosity versus Fundamental Plane residual for early-type galaxies. Filled circles represent detections and arrows upper limits. The solid line is a fit to all points with  $-0.5 < \text{FP residual} < 0.5$

wind, which results in a much lower X-ray luminosity. The first class of models, in which the specific energy rises with time, therefore produces an evolution from an early inflow phase to a later wind phase, predicting a *declining* X-ray luminosity with time. Such models are clearly inconsistent with our results.

Models in which the SNIa rate drops more quickly than  $t^{-1.3}$  evolve, in broad terms, from a low luminosity wind phase, towards a more luminous halo/cooling flow phase. The timescale for this evolution depends upon a variety of factors, such as the depth and shape of the potential, but it is typically  $\sim 10$  Gyr (Ciotti et al. 1991). In fact, none of the models studied to date shows the rather simple monotonic rise in  $L_X$  with age which we observe. The models of Ciotti et al. (1991) predict an initial luminous phase, when the gas loss rate from stars is very high. The X-ray luminosity then declines as the wind loss rate drops, and then rises again during the transition to a bound hydrostatic halo, at which point the X-ray luminosity is essentially equal to the SNIa luminosity. This whole development describes a fairly symmetrical dip and rise, lasting  $\sim 5 - 15$  Gyr, which is again not what we see in the data. However, this model describes a galaxy in which *all* stars are formed at  $t = 0$ . In

contrast, the spectroscopic age of our galaxies probably denotes the time since a merger-induced starburst involving only a few percent of the stellar mass. In this case, the early stellar mass loss rate will be much lower than in the Ciotti et al models, and the X-ray luminosity correspondingly less (scaling approximately as the square of the mass loss rate). The main change in  $L_X$  will be a rise associated with the slowing wind and transformation into a hydrostatic halo. In addition, as shown in Fig. 2, the decrease in optical luminosity as the starburst population fades will produce a rise in  $L_X/L_B$  over the first 1-2 Gyr.

#### 4 CONCLUDING REMARKS

We have examined the evolution of the X-ray properties of early-type galaxies. For three galaxy age estimators (fine structure parameter, Fundamental Plane residuals and spectroscopic ages) we find that the normalized X-ray luminosity evolves with time. In particular, the X-ray luminosity, which reflects the mass of hot halo gas, appears to increase at a steady rate over  $\sim 10$  Gyrs.

Comparing the long term trend in  $L_X/L_B$  which we

observe with expectations from possible mechanisms for hot halo formation, we conclude that the only viable mechanism appears to be the slow evolution from an outflowing wind to hydrostatic halo phase driven by a declining SNIa rate. Infalling gas seems unlikely to be the main cause of such a long term trend. Our results suggest that some of the scatter seen in the global  $L_X$  versus  $L_B$  relation is due to the evolutionary state, and past merger history, of early-type galaxies.

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