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Chandra observations of isolated early-type galaxies

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Abstract. In this paper, we present a statistical study of the X-ray properties of 11 isolated early-type galaxies (IEGs) observed with the *Chandra* ACIS-S3, and then discuss the implications of these properties.

1. Introduction

Isolated early-type galaxies have generated much interest because of their simple environment: their properties can be detected clearly due to their relatively low or lack of surrounding intra-cluster medium (ICM). Throughout this paper, we use a cosmology with a Hubble constant H_0=75 km s^{-1} Mpc^{-1}, $\Omega_{\rm m} = 0.3$, and $\Omega_\lambda = 0.7$. All the uncertainties are quoted at the 90% confidence level unless otherwise mentioned.

2. Sample selection

In fact, the determination of an objective definition of "isolated" is very difficult. Although many groups have introduced samples of IEGs (e.g. Karachentseva 1973; Reduzzi, Longhetti & Rampazzo 1996; Silva & Bothun 1998; Colbert, Mulchaey & Zabludoff 2001; Aars, Marcum & Fanelli 2001; Smith & Martinez 2003; Stocke *et al.* 2004; Reda *et al.* 2004), each has its own advantages and limitations. For many reasons, we did not define a sample of isolated early-type galaxies by ourselves, but just adopted a sample from the recent literature, loosely grouped them as IEGs and then compared them to the data in the *Chandra* public archive. With some selection criteria we obtain 11 IEGs finally.

3. Data analysis and results

X-ray images: In Fig. 1, we present the smoothed soft X-ray (0.3-2.0 keV) images (left) and optical images (DSS) overlaid with soft X-ray contours (right) for 3 galaxies in our sample. We can see that some galaxies have very extensive X-ray emission, larger than their optical images, but for some galaxies, their X-ray emission is smaller than their optical image.

Surface brightness profiles: We extracted the surface brightness profiles (SBPs) of the soft X-ray energy band, and confirmed the existence of very extensive diffuse X-ray emission. We find that a double β-model gives a better description for the SBPs of NGC 315, NGC 1132, NGC 1600, and NGC 7618 than a single β-model indicated by

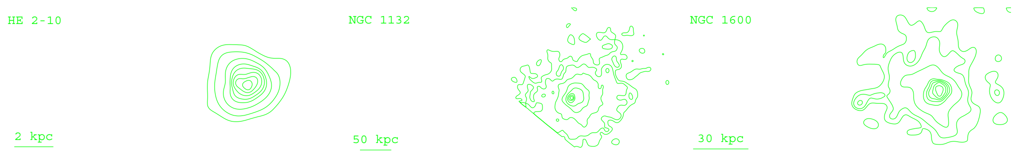

Figure 1. Smoothed soft X-ray (0.3–2.0 keV) images (left) and optical images (DSS, right) overlaid by soft X-ray contours at 3, 5, 10, 20, 30, 50, 100, and 300σ levels, respectively (we only show 3 IEGs here).

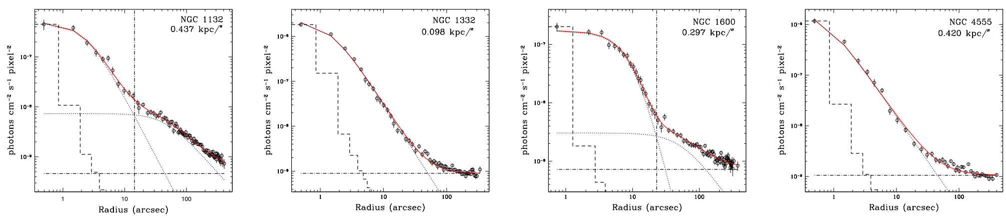

Figure 2. Soft (0.3–2.0 keV, open circles) X-ray azimuthally-averaged SBPs for 4 IEGs. The solid red line presents the best-fit model, the dotted line presents the β-model(s), the approximate soft X-ray background level is indicated by a dashed line and the other dashed line shows the corresponding PSF.

the standard F-test (e.g. Lupton 1993). For the remaining IEGs, a single β-model can fit the SBPs well.

Spectral analysis: We performed detailed spectral analysis of the resolved and unresolved diffuse emission separately, and present the radial dependence of the temperature and abundance. We notice that some galaxies have decreasing temperature profiles, while some galaxies have increasing temperature profiles. The temperature in the outer regions are consistent with that of hot gas in groups of galaxies. We also sum the total luminosities of the thermal and non-thermal components, and the bolometric luminosities of the hot diffuse gas in our sample IEGs.

Gas cooling time: We estimate the cooling time for the IEGs, and find that NGC 1132 has the largest cooling region ($\sim$ 50 kpc) where the cooling time is shorter than the Hubble time. This picture supports the interpretation that NGC 1132 is really a fossil group (fossil groups are generally old and relaxed). It is old, giving time for the most massive galaxies to have merged to produce a larger cooling region.

Mass determination: Following previous SBP and spectral analysis results, we estimate the gas and the total gravitational mass for the IEGs within r_{200} (the radius at which the mean gravitational mass density is 200 times the critical density of the Universe). We find that the gas mass and the total gravitational mass of NGC 1132 and NGC 741 are very large, of the order of poor galaxy groups or fossil groups. NGC 1132 also has the largest gas ratio, so it is reasonable that NGC 1132 also is the most luminous galaxy in our sample IEGs in the hot diffuse gas emission.

4. Summary and discussion

***L_X:T* relations:** we compare the L_X-T relation of the hot diffuse gas of our sample IEGs with that of elliptical galaxies, groups of galaxies, and fossil groups as ULIRGs from the literature. We notice that the L_X-T relation of the hot diffuse gas in our sample IEGs overlap with that of the elliptical galaxies, groups of galaxies, fossil groups, and ULIRGs.

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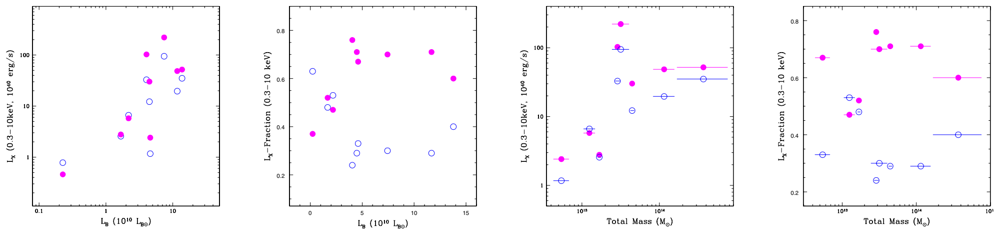

Figure 3. Relation of the luminosities of LMXBs (open circle) and hot gas (solid circle) in 0.3-10 keV versus the B-band luminosities (1) and total mass (3); the fraction of LMXB luminosity and hot gas over the total X-ray luminosity (LMXBs+Gas) in 0.3-10 keV versus the B-band luminosities (2) and the total mass (4).

A straight-forward interpretation is that there is an evolutionary relation among groups of galaxies, ULIRGs, fossil groups, and elliptical galaxies. Some IEGs may evolve from a group of galaxies which collapse with its luminous galaxies merging together.

L_X:L_B and L_X:M_{total} relations: We investigated the relationship between the luminosities of the LMXBs (resolved and unresolved) and the hot diffuse gas in 0.3-10 keV versus the B-band luminosities and the total gravitational mass, as fractions of the total luminosities in X-ray emission (LMXBs+Gas) versus the B-band luminosities and total mass. In Fig. 3, the luminosities of the LMXBs and the hot gas roughly increase with the B-band luminosities and total mass. From their fractions versus the B-band luminosities and total mass, we can see that the more luminous and massive the galaxies, the more X-ray emission that is contributed by the hot gas, also indicating that the brighter galaxies are richer in dark matter to bind the hot gas.

Comparing with fossil groups: By comparing the X-ray extension, hot gas temperature and luminosities, gas and total gravitational mass, cooling times, and the region with that of the fossil groups, we find that the properties of some IEGs are very similar to that of fossil groups. Our conclusion is that they may evolve from merged groups of galaxies.

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