Gas and Dark Matter Haloes of Isolated Elliptical Galaxies

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Introduction
Most elliptical galaxies reside in groups and clusters, but these environments make determination of intrinsic X-ray properties difficult, as galaxies interact with the ICM and their neighbours. The halo properties of group/cluster dominant ellipticals are known to be only weakly related to the galaxy itself, and more closely connected to the larger surrounding structure (Heliodon et al. 2001). Isolated galaxies provide an opportunity to examine galaxy gas haloes away from such influences. They may also provide insight into how formation processes determine galaxy properties. Two possible mechanisms for forming isolated ellipticals have been suggested:
• Multiple mergers of all major galaxies in a group at an early epoch to form a single giant elliptical in a group-scale dark matter halo, referred to as a Fossil Group (Ponman & Bertram 1993).
• Near-equal mass mergers at a late epoch, probably between isolated spiral pairs (Reda et al. 2004).

We expect more massive systems to build up a hydrostatic gas halo more rapidly after formation (e.g. Pellegrini & Ciotti 1998), to be more able to retain gas heated by AGN activity or supernovae, and therefore more luminous and massive. However, it is not clear whether the two mechanisms produce two distinct classes of galaxies or whether there is a continuum of properties.

Sample
To address some of these issues, we observed four ellipticals: NGC 4555 (23h Chandra: 3.0 to 4.0 keV), NGC 57 (1.2 to 2.5 keV), NGC 7796 (75 ks Chandra) and IC 1531 (~16 ks XMM, 40 ks Chandra). All four are optically luminous (L_e > 4x10¹⁰ L☉) and isolated (see discussion below), and in this paper we describe their gas properties and an analysis of their mass profiles.

Isolation
Our galaxies are selected from the LEDA catalogue, to have no neighbours within 0.67 h−1 kpc, 700 km/s and 2 B-band magnitudes. This should ensure that any neighbouring galaxies are too small to have a significant influence on the isolated elliptical. The fossil group definition is similar: no neighbours less than 2 magnitudes.

Results
NGC 4555 and IC 1531 have more (and more luminous) neighbours. From the velocity distribution of the nearby galaxies we estimate the mass required for them to form gravitationally bound systems. For NGC 4555, this is ~4x10¹⁰ M☉, while IC 1531 ~1x10¹⁰ M☉, equivalent to clusters with temperatures of 8-10 keV and luminosities as high as 10¹⁰ ergs/s. We therefore conclude that NGC 4555 and IC 1531 are not part of larger gravitationally bound structures, though they may be in low-density filaments or sheets of large-scale structure.

Gas Properties: We fit 2D surface brightness models and radial spectral profiles to each of the ellipticals. IC 1531 was found to have a compact (15 kpc radius) halo of 0.55 keV, 0.6 Z☉ gas, with a mass of ~6x10¹³ M☉. From the expected rate of stellar mass loss in IC 1531 (~0.3 M☉/yr), it seems likely that AGN heating is driving a galactic wind, preventing the build-up of a larger halo.

We were able to fit models to the radial temperature profiles of the other three galaxies (see plot above). NGC 57 and NGC 7796 are both approximately spherical, NGC 4555 has a 1-2 kpc halo with a central temperature rise and a small cool core (excluded for the X-ray model). NGC 7796 has ~0.5 Z☉ abundance, with the other two galaxies showing central peaks of ~1 Z☉.

Combining the X-ray surface brightness models, we determine profiles for gas mass, entropy and cooling time (see below). NGC 57 and NGC 4555 have very extended gas haloes (125-150 kpc) with similar properties. NGC 7796 is smaller and cooler, containing ~10¹¹ M☉ of gas.

The major difference between NGC 57 and NGC 4555 is the lack of a cool core in NGC 57 despite its relatively short central cooling time. It is possible that the core is too small to be resolved by the large XMM-Newton point size, or cooling may have been countered by AGN feedback.

Conclusions: Our isolated galaxies fall in two categories:

• NGC 7796 and IC1531:
  - Compact gas haloes 15-25 kpc in radius.
  - Gas temperature ~0.5 keV, abundance ~0.5 solar.
  - Probably in a galactic wind phase, driven by supernovae or AGN.

• NGC 4555 and NGC 57:
  - Extended (125-150 kpc) gas haloes with kT~1 keV, 1 Z☉ abundances.
  - Massive (~10¹³ M☉) extended (~500 kpc) dark matter haloes.
  - NGC 4555 luminous enough to meet fossil group criterion (10⁹ ergs/s).
  - NGC 57 a factor of 4 fainter.

These categories may reflect the formation histories of the ellipticals either through rapid early mergers to form fossil-type systems, or via site mergers between isolated dwarf haloes, where gas can easily escape as a wind. Deep optical observations may resolve this issue, as fossil groups are known to have extensive dwarf galaxy populations.