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 (Helsdon et al. 2001). Isolated galaxies provide an opportunity to examine galaxy gas haloes away from such influences.

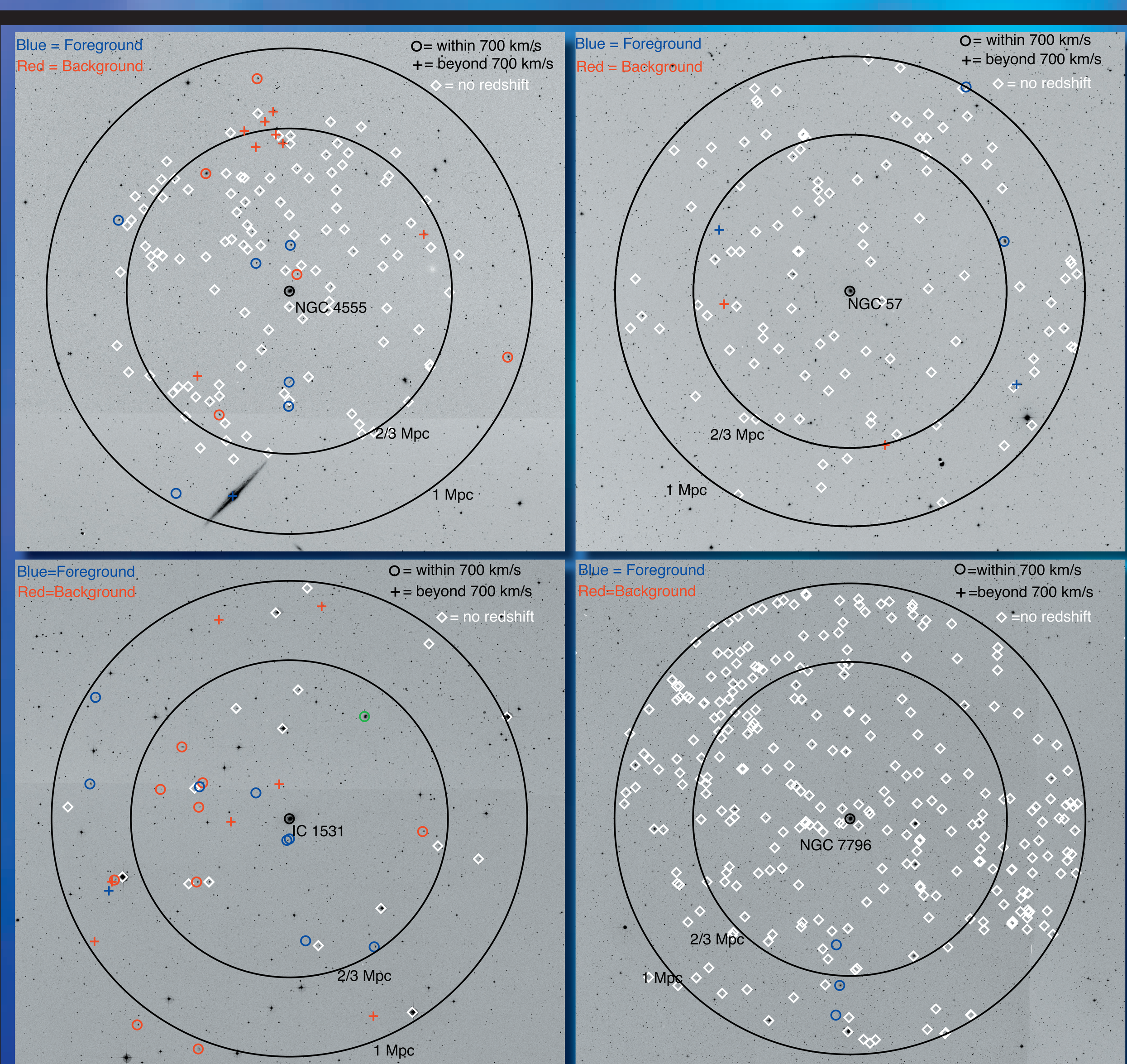
They may also provide insight into how formation processes determine galaxy properties. Two possible mechanisms for forming isolated ellipticals have been suggested:

- 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 to be more luminous and metal rich. 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 (23ks *Chandra*, ~60 ks *XMM*), NGC 57 (~21 ks *XMM*), NGC 7796 (75 ks *Chandra*) and IC 1531 (~16 ks *XMM*, 40 ks *Chandra*). All four are optically luminous (L_B>4x10^{10} $L_\odot$) and isolated (see discussion below), and in this poster 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_{75}^{-1} kpc, 700 km s^{-1} 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 fainter within half the projected Virial radius, and the system must have an extended X-ray halo with luminosity >10^{42} erg/s.

The plots above and below show the positions of all galaxies within 1 Mpc (projected) of our four targets. NGC 57 and NGC 7796 appear to be extremely isolated, with at most a handful of dwarf satellites.

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 ~4x10^{14} $M_\odot$, for IC 1531 ~3x10^{15}$M_\odot$, equivalent to clusters with temperatures of 8-10 keV and luminosities as high as 10^{45} erg/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.

References

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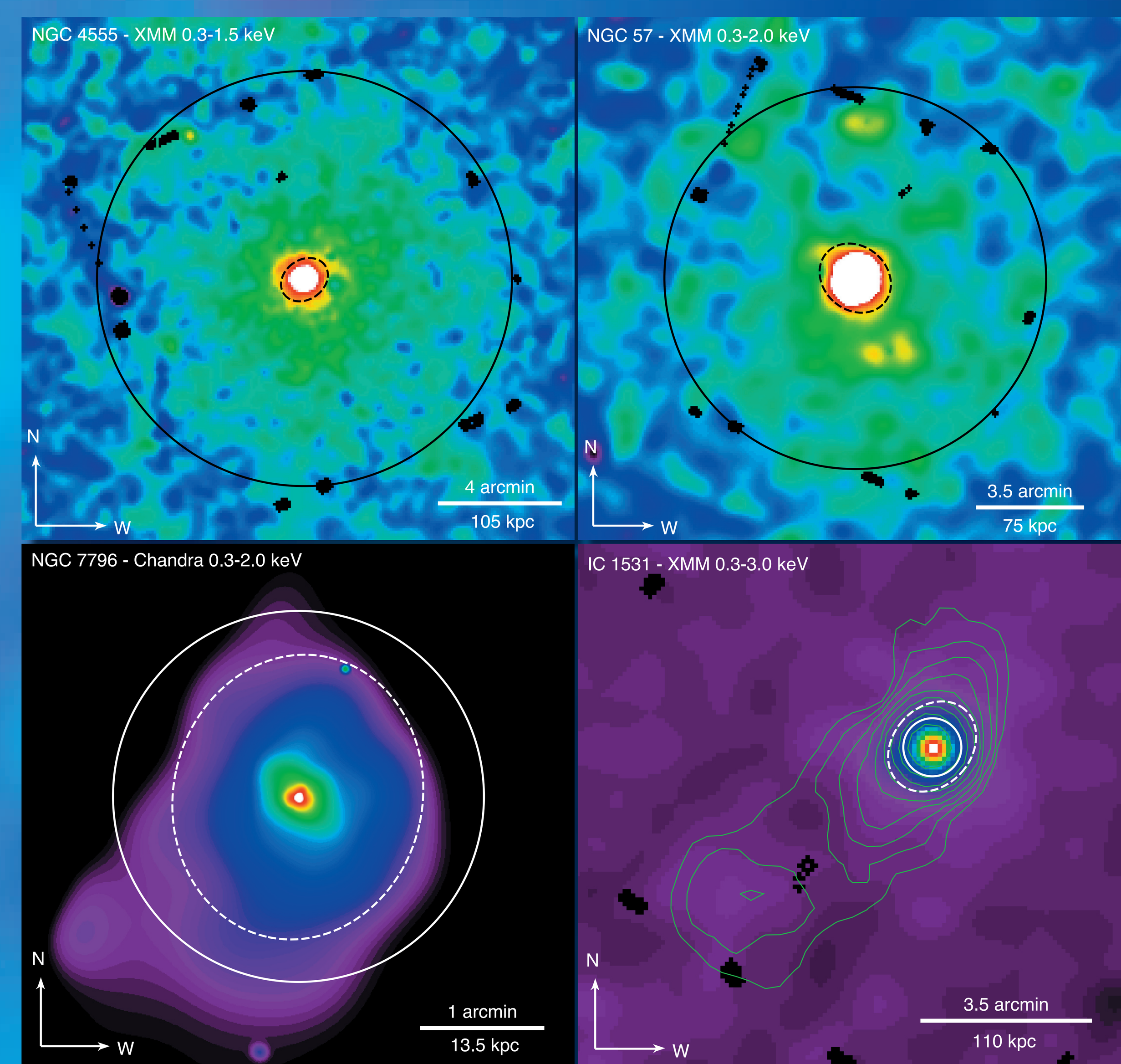


Adaptively smoothed *XMM-Newton* and *Chandra* images of our four isolated ellipticals. Smoothing was performed using either SAS ASMOOTH (S/N=15) or CIAO CSMOOTH (S/N=3-5). Dashed ellipses show the D_{25} contour, solid circles the radius to which spectra are measured. 1.4 GHz NVSS radio contours are overlaid on the IC 1531 image.

Mass modelling:

from the temperature and density models we calculate total mass profiles, under the assumption of hydrostatic equilibrium. We also calculate the M/L ratio profile, assuming the stars follow an r$^{1/4}$ law and that only the central elliptical contributes to luminosity (see plots to the right).

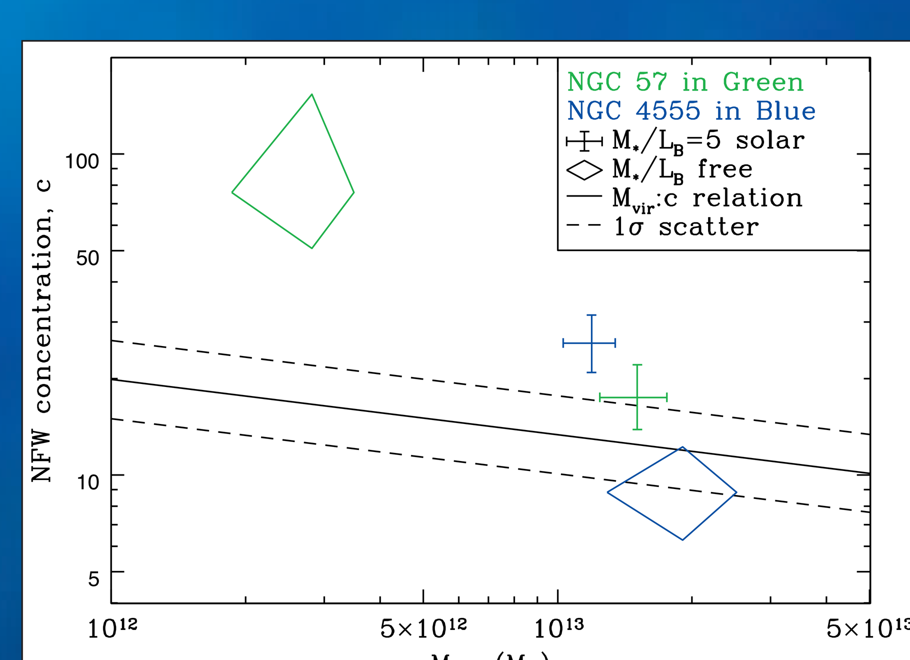
For NGC 7796 M/L at the limit of the profile is only ~10 $M_\odot$/$L_{B\odot}$, and it drops below 5 $M_\odot$/$L_{B\odot}$ (the expected value for an old stellar population) within 10 kpc. This probably indicates that the halo is not in hydrostatic equilibrium, and is more likely in a galactic wind phase driven by stellar mass loss and supernova heating (as in NGC 3379, Pellegrini & Ciotti 2006).

NGC 57 and NGC 4555 have hydrostatic haloes (at least in to a few kpc). We estimate the Virial mass and radius by fitting models to the mass profiles - an NFW component representing the dark matter (Navarro, Frenk & White 1997), a Hernquist (1990) model for the stellar mass, and gas mass from our density model. Fitted NFW parameters are plotted below.

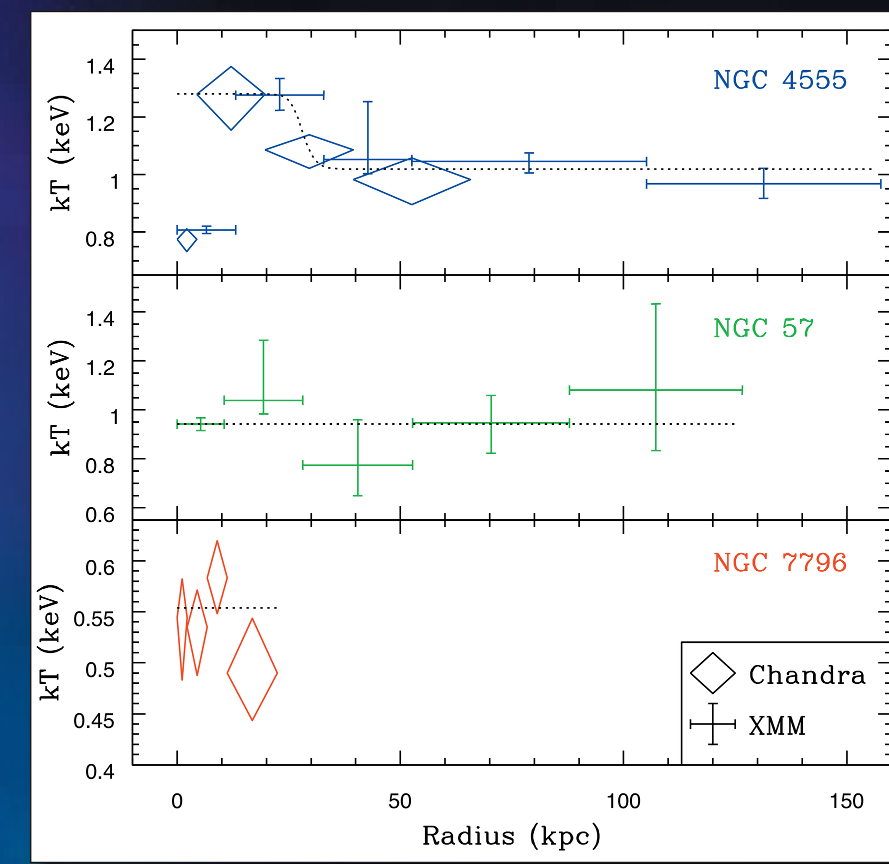
As pointed out by Humphrey et al. (2006) resolution in the core is key for these fits and the coarser *XMM* temperature bins lead to larger uncertainties in NGC 57. Fitting with stellar M/L ratio (M_*/L_B) fixed at 5 $M_\odot$/$L_{B\odot}$ we find:

- **NGC 57:** **R_{vir}=485 (+209,-158) kpc**
  M_{vir}=1.50 (∓0.26) x10^{13} $M_\odot$
- **NGC 4555:** **R_{vir}=447(+169,-131) kpc**
  M_{vir}=1.19 (+0.15,-0.17) x10^{13} $M_\odot$

These fits compare well with the Buote et al. (2007) M_{vir}:c relation. Fitting NGC 57 with M_*/L_B free results in a very high concentration, an unphysically high M_*/L_B and a poor match to the M_{vir}:c relation. NGC 4555 is gives a better constrained fit, but the fitted M_*/L_B=17.8 (+8.4,-7.1) $M_\odot$/$L_{B\odot}$, very high for an old stellar population. We therefore consider fitting with fixed stellar M/L the safer option until higher resolution mass profiles can be produced.



NFW model parameters from fits to the mass profiles of NGC 4555 and NGC 57. Error bars and diamonds represent fits with stellar M/L ratio frozen at 5 $M_\odot$/$L_{B\odot}$,or left free. The lines show the best fit M_{vir}:c relation and scatter from Buote et al (2007). All uncertainties are 1σ.



Temperature profiles for the three ellipticals with extended haloes. For NGC 4555 both *XMM* and *Chandra* profiles are deprojected. 90% errors regions are shown. Dotted lines show the temperature models used in the mass analysis.

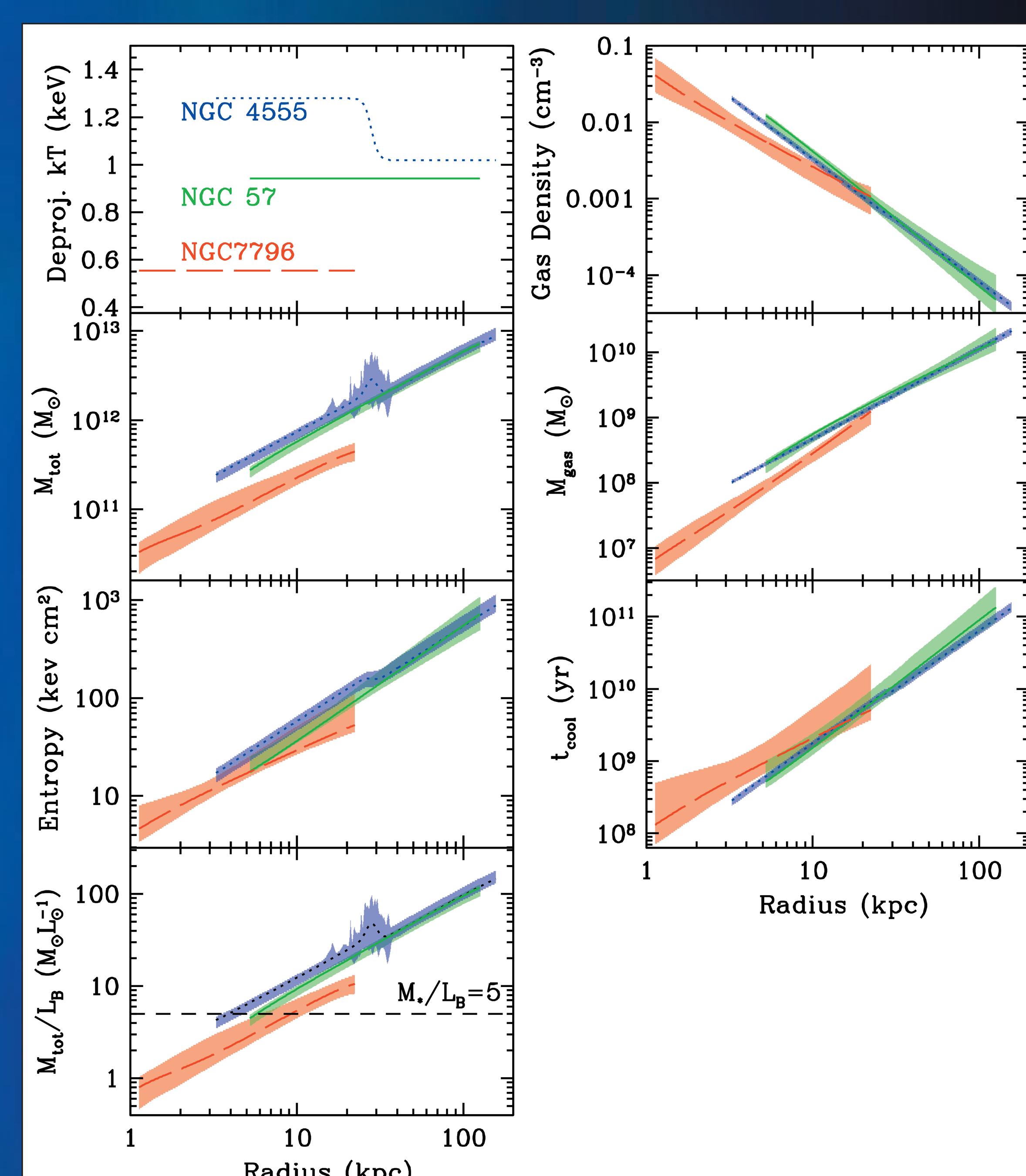
Gas Properties:

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 $Z_\odot$ gas, with a mass of ~6x10^8 $M_\odot$. From the expected rate of stellar mass loss in IC 1531 (~0.3 $M_\odot$/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 isothermal. NGC 4555 has a ~1 keV halo with a central temperature rise and a small cool core (excluded for the kT model). NGC 7796 has ~0.5 $Z_\odot$ abundance, with the other two galaxies showing central peaks of ~1 $Z_\odot$.

Combining the kT and 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 (125/155 kpc) with similar properties; NGC 7796 is smaller and cooler, containing ~10^9 $M_\odot$ 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* spectral bin size, or cooling may have been countered by AGN feedback.



Deprojected temperature, gas density, gravitational and gas mass, entropy, cooling time and M/L_B ratio for the three galaxies with extended haloes. Shaded regions show 1σ errors. A dashed line shows a typical stellar M/L ratio of 5 $M_\odot$/$L_{B\odot}$. Note that for NGC 7796, M/L falls below this line out to ~10 kpc, indicating our assumption of hydrostatic equilibrium may be at fault.

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 supernova or AGN.

NGC 4555 and NGC 57:
- Extended (120-160 kpc) gas haloes with kT~1 keV, 1 $Z_\odot$ abundances.
- Massive (1-2x10^{13} $M_\odot$), extended (R_{vir}~500 kpc) dark matter haloes.
- NGC 4555 luminous enough to meet fossil group criterion (10^{42} erg/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 late mergers between less massive haloes where gas can more easily escape as a wind. Deep optical observations may resolve this issue, as fossil groups are known to have extensive dwarf galaxy populations.