What Can The Temperature Profiles Of Hot Halos Tell Us?

Liam Traynor[1,2], Dong-Woo Kim[1] and the Chandra Galaxy Atlas team[1]
[1]Harvard-Smithsonian Center for Astrophysics
[2]University of Southampton
liam.traynor@cfa.harvard.edu

Introduction

The temperature profiles of hot gas in early type galaxies (ETG) contain a wealth of information about the galaxy formation and evolution, including AGN/stellar feedback, gas inflow/outflow, environment and mergers. As a part of the Chandra Galaxy Atlas (CGA) project, we determine the temperature profiles of 60 local ETG's and investigate the characteristics of the hot gas thermal properties. We plan to further compare them with other important galaxy properties (e.g. age, radio emission, total mass, mass of SMBH).

Four spatial binning in CGA

Circular annuli (AB), weighted Voronoi tessellation (WB), contour (CB) and hybrid (HB) adaptive binning are used.

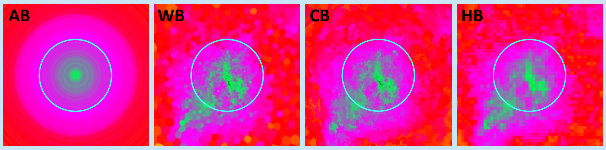


Fig. Temperature maps for AB, WB, CB and SB binning for NGC 5044.

2D and 3D (deprojected) profiles

3D profiles are calculated by assuming a temperature profile in 1D, using this to create a spherically symmetric 3D temperature profile which is then projected down the line of sight and compared to the data.

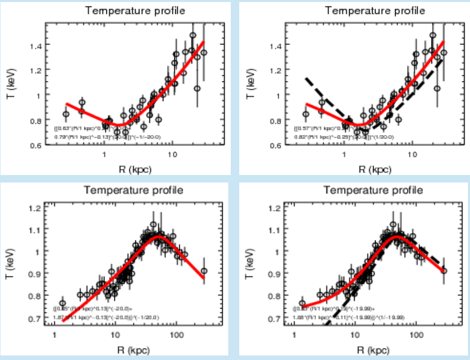


Fig. 2D and 3D temperature profiles for NGC 1407 (top) and NGC 4325 (bottom).

Correlation results- cool core vs. hot core

Lx-GradT$_{core}$ Slope: 4.54 ± 0.76 GradT$_{core}$-<Tx> Slope: 0.859 ± 0.113

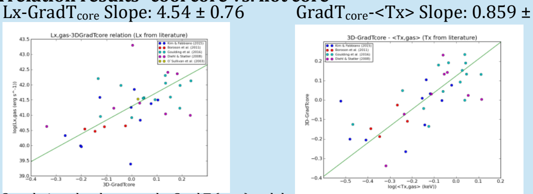


Fig. Correlation plots between the Grad T (core) and the total X-ray gas luminosity (left), the average X-ray gas temperature and the Grad T (core) (right).

The positive correlations show that for the most massive ETG's (largest Lx and <Tx>) the temperature is decreasing towards the centre (cool core), similar to the cluster/group profile. While for the least massive ETG's there is additional, non-gravitational heating (hot core).

Future work

So far correlation plots only incorporate core properties corresponding to the temperature profiles from annulus binning, we want to expand this. We want to add other galaxy properties; radio emission, total mass, mass of SMBH, σ etc., we also want to use Lx and <Tx> within 1R_e and 5R_e to correlate with T$_{core}$ and GradT$_{core}$ (d log[T$_{core}$] / d log[R]) etc. to test which has the strongest correlation.

- Pie cuts:

For galaxies which do not have symmetric gas distribution, pie cuts can be taken to get a more accurate temperature profile, by removing the effects of cool arm projections and nearby more massive galaxies halos.

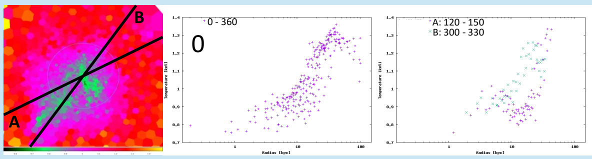


Fig. Examples of pie cuts along a cool extended arm and along a symmetric pie compared to 0 - 360° for NGC 5044.

Universal temperature profile

Groups (Sun 2009) and clusters (Vikhlinin 2005) have universal temperature profiles.

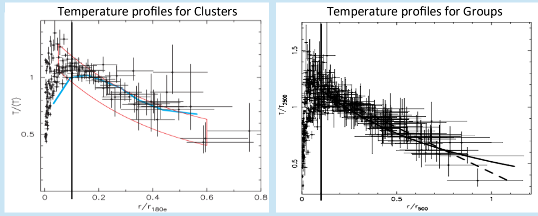


Fig. Temperature profiles for clusters (left), groups (right) which show peaks around 0.1R_{vir} (~100 kpc).

Do ETG's have a universal temperature profile?

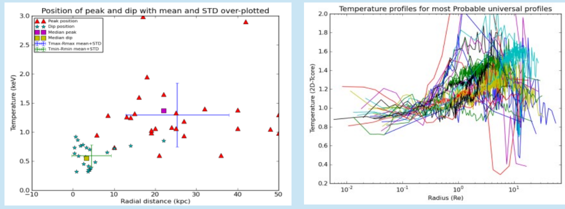


Fig. Positions of dips and peaks in hybrid type profiles, over-plotted with the mean and standard deviation (left) and a sample of temperature profiles scaled with R$_e$ and 2D-T$_{core}$.

Temperature profiles typically show a peak at a few Re (~0.05R_{vir}), there may also be a dip at a few kpc (< 1R_e) for galaxies with hot cores. The cause for these hot cores is likely AGN outburst, SF, gravitational infall.

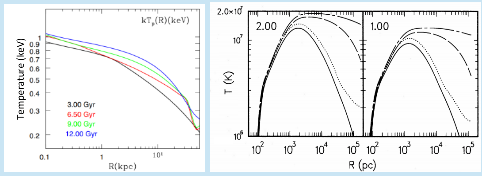


Fig. (left) results from a simulation by Pellegrini (2012) showing the effects of AGN/stellar feeback, SF and gravitational heating on the temperature profile. (right) results from Sarazin & White (1987), numbers in top left of panels are optical luminosities, L$_B$ in units of 10^{11} L$_⊙$. The four lines are; solid line: no halo or supernovae heating (SN) 'Bare model', dotted line: SN only, dashed line: Halo only and dash-dot line: both halo and SN.

What could a universal ETG profile look like?

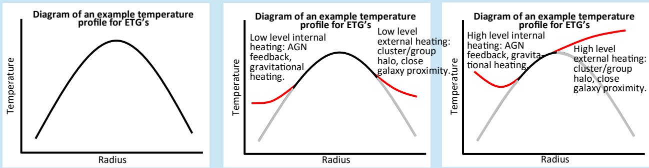
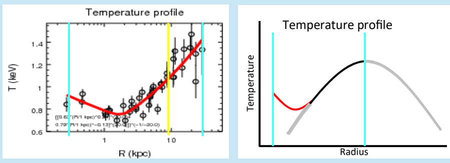
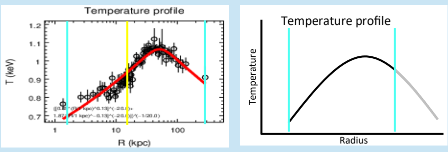


Fig. Example of a ETG universal temperature profile (left), example of a ETG universal profile with effects due to internal and external factors (middle) and example of a ETG universal profile with strong effects due to internal and external effects (right).

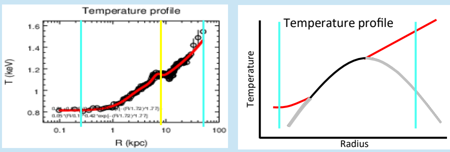
Examples:
Cyan lines indicate observational limitations, yellow lines indicate position of r = 1R_e.



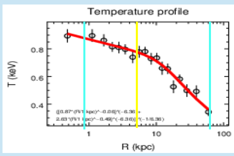
NGC 1407 (brightest in group)
Hot core, dip around 2 kpc and a continually rising temperature but the FOV cuts out large radii so there may be an unseen peak.



NGC 4325 (brightest in group)
Cool core, continues to rise (possibly a small dip) until peaking at a few R$_e$ and then decreasing.



NGC 4472 (Virgo cluster)
Flat core, then a almost constant positive gradient, but there may be a feature at ~ R$_e$ prehaps a peak before cluster ICM starts to dominate at large radii.



NGC 6482
Hot core, no peak, doesn't fit with universal type. Closer examination of these types of galaxies is needed.

Fig. NGC 6482 data , example of a temperature profile that doesn't fit into the universal type.

How many Universals?
There are 32/60 galaxies with a profile that can be described by a peak at a few R$_e$ (and 21/60 also with a dip/flattening at < R$_e$). 8 galaxies show a negative gradient (see left) that does not fit this type of profile.

References
1) Choi, E., *et al.* 2017, ApJ, 844, 31 2) Eisenreich, M., *et al.* 2017, MNRAS, 468, 751 3) Ciotti, L., *et al.* 2017, ApJ, 835, 15 4) Pellegrini, S., *et al.* 2012, ApJ, 758, 94
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