Investigating the Central Regions of the *HIFLUGCS* Clusters with Chandra

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We present a preliminary analysis of the Chandra follow up to the *HIFLUGCS* sample (Hudson et al, *in prep*). By plotting the central temperature profiles, normalized to the global cluster temperature, against the fraction of the virial radius, we find no evidence for a universal central temperature profile. Similarly by fitting the central temperature profile to a powerlaw, we find a continuous range of values for the slope. Interpreting a positive temperature gradient as an indication of a cooling core, we find that exactly half (32 of 64) of the clusters in the *HIFLUGCS* sample are classified as cooling core clusters. Additionally, we find a flattening of the central entropy, consistent with other observations and predictions from simulations [3]. Perhaps the most interesting feature is the bi-modal distribution in the plot of global temperature versus central entropy. The distributions can be easily divided at 40 keV cm^2. Interpreting the clusters with a low central entropy as cooling core clusters, 27 of the clusters are classified as cooling core clusters with this method.

1 Introduction

Today one of the greatest mysteries of X-ray astronomy is what mechanism prevents the dense gas in the centers of clusters from cooling in significant quantities. To that end, it is important to ask: why do some clusters have cool dense cores and others do not? Is it possible to uniquely divide clusters between cooling core (CC) and non-cooling core (NCC) clusters?

In an attempt to probe these questions, we investigated the properties of the cores of the 64 *HIFLUGCS* clusters. The *HIFLUGCS* sample is a statistically complete sample of the 64 X-ray brightest galaxy clusters outside of the galactic plane [2]. The clusters are therefore bright and close, making them ideal candidates for detailed core studies. Moreover, *Chandra* observations exist for all 64 clusters, allowing a high spatial resolution study of the cores.

2 Central Temperature Profiles

Figure-1 shows the central projected temperature (*left*) and entropy (*right*) profiles for all 64 *HIFLUGCS* clusters. It is clear with that there is no universal temperature or entropy profile in the central regions of clusters. The profiles show a ranges of slopes, from flat to steeply decreasing.

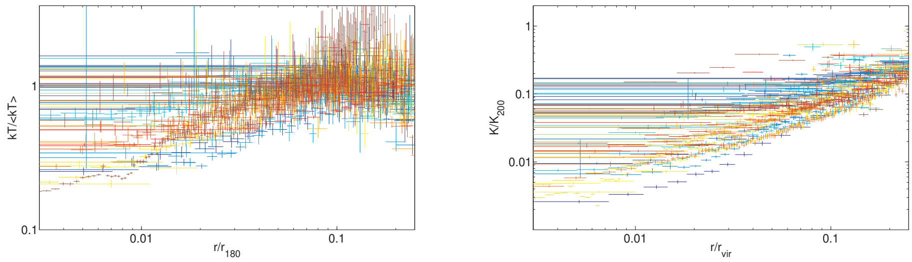

Fig. 1. *Left*: A plot of the radial temperature profile normalized to the global cluster temperature versus the fraction of the virial radius. The plot has been cut at a quarter of the virial radius to emphasize the central temperature profile. The scatter suggests there is no universal central temperature profile. *Right*: This plot shows the central entropy profile scaled to the entropy at r_{200}. The observed flattening and large scatter are consistent with the predictions from simulations. The low central values in this plot can be attributed to projection effects.

To quantify the steepness of the temperature profile, we took temperatures from all annuli within 0.1 r_{180} or the radius of the third inner-most annulus, whichever was greater, and fit this curtailed profile to a powerlaw. Fig.-2 (*left*) shows the best fit slopes and 1-σ errors. The clusters are ordered from steepest (Abell 2204) to shallowest (Abell 2147). It is clear that there is a continuos spread in the slopes. If there were a universal profile, then one would expect two distributions, one for clusters with cool centers and one for clusters with isothermal centers.

If we classify cooling core (CC) clusters as those clusters with a slope < 0 (within 1-σ), we find exactly half (32) of our clusters are CC clusters. However, as we pointed out, since there is a continual distribution of slopes, this is an arbitrary cut. In an effort to find a more definitive cut between CC and NCC clusters, we plotted overall cluster temperature versus projected central entropy, K_0, where we define $K_0 \equiv kT\, n_0^{-2/3}$. n_0 is calculated from the normalization of the spectral fit to central circle assuming density is constant. This rough calculation creates a bias such that smaller regions estimate a higher density than larger regions. However, since CC clusters have denser (and therefore brighter) cores, the central annulus will be smaller than for an

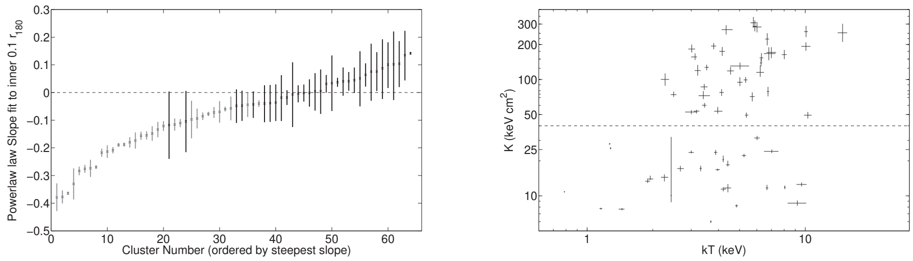

Fig. 2. *Left*:This plot shows the slopes of the power law fit to the cluster temperature profile within 0.1 r_{vir}. The continuous range of values suggests that there is no universal temperature profile. Gray (lighter) points have a slope which is inconsistent (at the 1-σ level) with a flat profile. *Right*: This plot shows the global cluster temperature versus the central entropy. The clear separation of the two distributions suggests this may be a robust method for identifying cooling core clusters.

NCC cluster[1]. This bias, therefore acts to enhance the separation between CC and NCC clusters. Moreover, this method will classify clusters with dense cores as CC, regardless of their inner temperature profile. Fig-2 (*right*) shows the plot of kT versus K_0. Two populations are apparent and can be separated between clusters with $K_0 > 40$ keV cm^2 and $K_0 < 40$ keV cm^2. Using this classification to separate CC from NCC clusters, we find 27 of 64 *HIFLUGCS* clusters are CC clusters.

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3 Acknowledgements

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References

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[1]We acknowledge there is also a bias on the length of the observation and the proximity of the cluster, but experience has shown that the brightness of the core is a stronger effect. That is, for a short observation of a CC cluster, the central annulus will be smaller than for a long observation of an NCC cluster.