The general process of galaxy cluster formation through hierarchical merging is well understood, but many details, such as the impact of feedback sources on the cluster environment and radiative cooling in the cluster core are not. My thesis research has focused on studying these details via X-ray properties of the ICM in clusters of galaxies. I have paid particular attention to ICM entropy distribution and the role of AGN feedback in shaping large scale cluster properties.

My thesis makes use of a 350 observation sample (276 clusters; 11.6 Msec) taken from the *Chandra* archive. The picture of the ICM entropy-feedback connection (Fig. 1) emerging from my work suggests cluster radio luminosity and Hα emission are anti-correlated with cluster central entropy ($K = T_X n_e^{2/3}$). There also appears to be a bimodality in the distribution of central entropies (Fig. 2) which is likely related to AGN feedback (and to a lesser extent, mergers). I have found that clusters with central entropy ≤ 20 keV cm^2 exhibit star formation and AGN activity in the BCG while clusters above this threshold unilaterally do not have star formation and exhibit diminished AGN radio feedback. This entropy level is auspicious as it coincides with the Field length (assuming reasonable suppression) at which thermal conduction can stabilize a cluster core. It is possible we have opened a window to solving a long-standing problem in massive galaxy formation (and truncation): how are ICM gas properties coupled to feedback mechanisms such that the system becomes self-regulating? However, this result serves to highlight unresolved issues requiring further intensive study.

Most pressing of these issues is to better understand the fueling and feedback from AGN. We know low entropy ($K_0 \leq 20$) systems contain multi-phase gas (stars, cold molecular gas, warm/hot dust, et cetera), but as evidenced by copious radio emission, some of this gas is likely condensing onto the SMBH and resulting in episodic AGN feedback which retards further cooling in the cluster core. My work in the X-ray can only tell us about the hot atmospheres with which AGN are interacting, but to attain a more complete picture of this multi-phase gas, and its connection to fueling the AGN, it behooves us to look in other bands, specifically the infrared.

In Figure 3 I have plotted central entropy derived in my thesis work versus NVSS radio luminosity and overlaid symbols indicating availability of data in the *Spitzer* archive. Thus far, indications from the literature are that most, if not all, of the BCGs in X-ray luminous clusters with $K_0 \leq 20$ keV cm^2 are dominated by star formation. But we can see from the figure that most of these systems contain radio AGN. So one can ask the question: are there any AGN dominated nebular BCGs? An interesting project to pursue with the *Spitzer* archive would be to examine the shape of spectral energy distributions (SEDs) for all clusters with a BCG and attempt to reveal if the BCG is star formation or AGN dominated.

For those BCGs which do exhibit AGN dominance it will be interesting to exclude extended galaxy emission and analyze spectra from only the (unresolved) nuclear region in an effort to characterize AGN spectral features. The ultimate goal being an accounting of the very lowest entropy gas which is likely feeding the SMBH, and at the very least enshrouding the AGN. Clusters without star formation and no AGN will also be an important constraint in such a project.

There are a multitude of other directions I would also like to pursue which are essentially extensions of my thesis. The role of AGN feedback in shaping global cluster properties is still poorly understood. Models for the process of thermalizing energy in AGN blown bubbles have been proposed, but details of these models still need to be explored. For example, do bubbles contain a very low density non-relativistic thermal plasma or are they truly voids in the ICM (potentially an SZ experiment)? Maybe bubbles contain cosmic rays, a possibility which will make for an interesting GLAST project. How do bubbles rise to distances ≥ 100 kpc without being shredded by instabilities? The answer to this question will likely entail better understanding ICM $\vec{B}$ fields, with their origin being either from preheating, AGN deposition, or a combination of both.

I have also contributed to several successful *Chandra*, *XMM*, *Suzaku*, *NSF*, and *Subaru* proposals in addition to writing my own high scoring – although unsuccessful – *Chandra* proposal for time observing the amazing ULIRG IRAS 09104+4109. I am also planning Hα imaging observations for several previously unobserved BCGs using SOI on MSU's SOAR telescope, and will be active in submitting *Chandra* and *XMM* proposals (both spectroscopy and grating) for unobserved and interesting clusters, groups, and galaxies which have turned up in my thesis work.

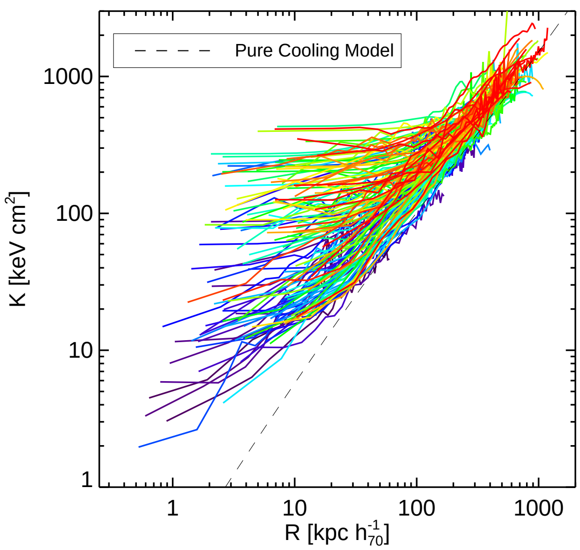

Figure 1: Entropy profiles for 143 clusters of galaxies in my thesis sample. The range of central entropies is consistent with models of episodic AGN heating which regulate the presence of low entropy gas in cluster cores. The so-called "cooling flow" problem does not appear to be a problem any longer.

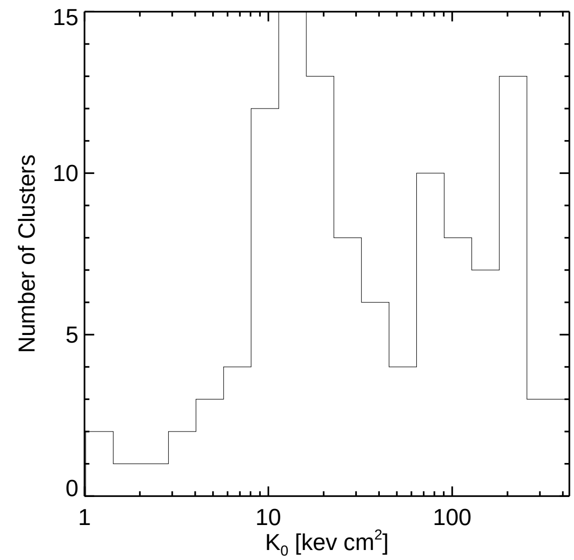

Figure 2: Distribution of central entropy for an unbiased sub-sample of the clusters analyzed for my thesis. Note the fall-off of clusters with $K_0 \sim 30 - 50$ keV cm^2. An explanation for this bimodality utilizing AGN feedback (the most likely candidate) does not currently exist.

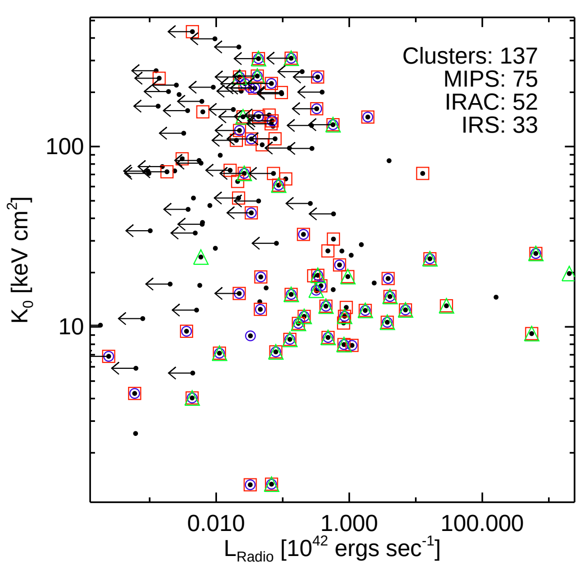

Figure 3: Central entropy derived in my thesis work plotted against radio luminosity calculated using NVSS. Cluster centers with MIPS observations are plotted with red squares; IRAC observations have blue circles; IRS observations have green triangles. The Spitzer archive provides excellent coverage for a possible study of low entropy, radio-loud and radio-quiet systems.