Summary of Experience and Future Interests

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 in clusters of galaxies via X-ray properties of the ICM. Utilizing a 350 observation (276 clusters; 11.6 Msec) sample taken from the CDA, I have paid particular attention to ICM entropy distribution, the process of cluster virialization, and the role of AGN feedback in shaping large scale cluster properties.

The picture of the ICM entropy-feedback connection emerging from my research suggests cluster cD radio luminosity and core Hα emission are anti-correlated with cluster central entropy. Following analysis of 169 cluster radial entropy profiles (Fig. 1), I have found an apparent bimodality in the distribution of central entropy and central cooling times (Fig. 2) which is likely related to AGN feedback (and to a lesser extent, mergers). I have also found that clusters with central entropy $\lesssim 20$ keV cm^2 show signs of star formation (Fig. 3) and AGN activity (Fig. 4), 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 at which thermal conduction can stabilize a cluster core against ICM condensation. These results are highly suggestive that conduction in the cluster core is very important to solving the long-standing problem of how ICM gas properties are coupled to feedback mechanisms such that the system becomes self-regulating.

The final phase of my thesis is focused on further understanding why we observe bimodality, what role star formation is playing in the cluster feedback loop, refining a model for how conduction couples feedback to the ICM, and examining the peculiar class of objects which fall below the Field length criterion but *do not* have star formation and/or radio-loud AGN (blue boxes with red stars in two of the figures).

There are additional areas of my present research I'd like to expand on in the future. **(1)** To check if bimodality is archival bias, I am submitting a *Chandra* Cycle 10 observing proposal for a sample of clusters which predictably fall into the $t_{\rm cool}$ and K_0 gaps. **(2)** Two classes of peculiar objects warrant intensive multiwavelength study: high-K_0 clusters with radio-loud AGN (e.g. AWM4) and low-K_0 clusters without any feedback sources (e.g. Abell 2107). The former likely have prominent X-ray corona, while the latter may be showing evidence that extremely low entropy cores inhibit the growth of gas density contrasts. **(3)** Thus far I have only focused on AGN which are radio-loud according to the 1.4 GHz eye of NVSS, but recent work has shown AGN radio halos are very powerful at low frequencies too. I'd like to know what the radio power is at these wavelengths for (ideally) my entire thesis sample and see if the K_0-radio correlation tightens. **(4)** Using the near-UV sensitivity of *XMM*'s Optical Monitor and the far-IR channels of *Spitzer*, I plan to propose a joint archival project to disentangle which $K_0 \lesssim 20$ cDs are star formation dominated and which are AGN dominated.

In another part of my thesis research I studied an aspect-independent measure of temperature inhomogeneity as a means for quantifying cluster virialization state. I found the hard-band to full-band temperature ratio was robustly correlated to mergers and the absence of cool cores. This project touched on quantifying and reducing the scatter in mass-observable relations to bolster the utility of clusters as cosmology tools. I am eager to keep this area of my work alive as we get closer to having access to enormous catalogs of SZ detected clusters (*e.g.* from *Planck*) which require X-ray follow-up. To maximize the utility of these surveys, we must continue to investigate scatter, evolution, and covariance in the X-ray observables which serve as vital mass surrogates.

There are additional areas of study which I have not touched on in this summary but still interest me. Such as the micro-physics of ICM heating (e.g. turbulence and weak shocking), the thermalization of mechanical work done by bubbles, and the importance of non-thermal sources, like cosmic rays, in bubble heating. How prevalent are cold fronts? Can they be used to robustly quantify ICM magnetic fields and viscosity? Are they important in the feedback loop? How robust is the "X-ray Butcher-Oemler Effect" of Paul Martini if one studies a large sample of clusters? Can we deduce a low-scatter relation (or at least constrain one) between jet power and radio power? What is the explanation for the thermal inefficiency of jets? Many questions abound as a result of my thesis work, I hope to pursue the answers to them as a post-doc with you at Irvine.

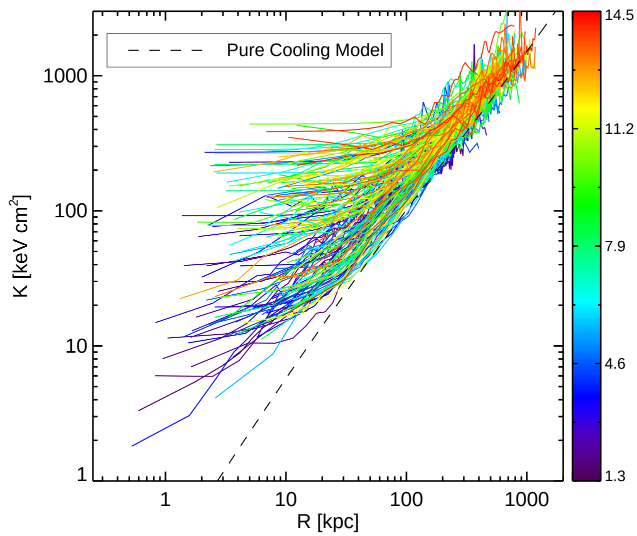

Figure 1: Radial entropy profiles of 169 clusters of galaxies in my thesis sample. The observed range of $K_0 \lesssim 70$ keV cm^2 is consistent with models of episodic AGN heating. Color coding indicates global cluster temperature (in keV) derived from core excised apertures of size R_{2500}.

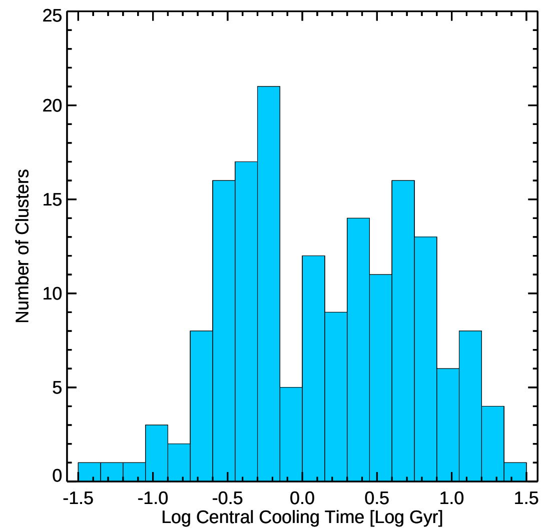

Figure 2: Distribution of central cooling times for 169 clusters in my thesis sample. The peak in the range of cooling times (several hundred Myrs) is consistent with inferred AGN duty cycles of both weak ($\sim 10^{40-50}$ ergs) and strong ($\sim 10^{60}$ ergs) outbursts. However, note the distinct gap at $0.6-1$ Gyr. An explanation for this bimodality does not currently exist.

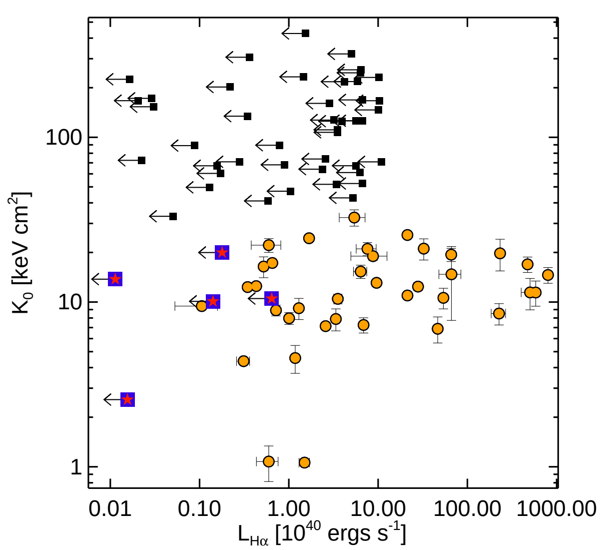

Figure 3: Central entropy plotted against Hα luminosity. Orange dots are detections and black boxes with left-facing arrows are non-detection upper-limits. Notice the characteristic entropy threshold for star formation of $K_0 \lesssim 20$ keV cm^2. This is also the entropy scale at which conduction no longer balances radiative cooling and condensation of low entropy gas onto a cD can proceed.

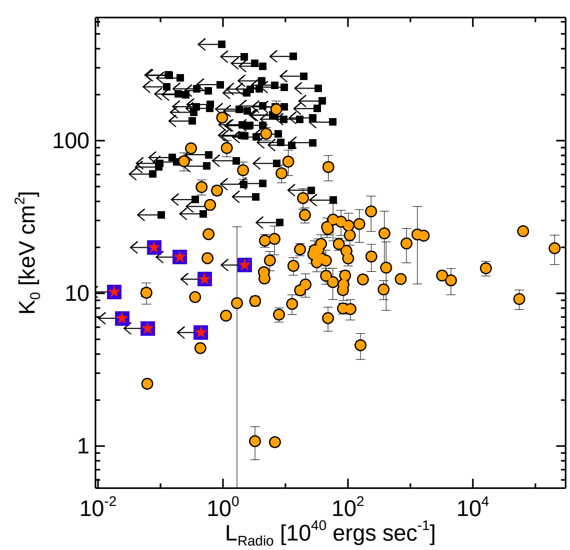

Figure 4: Central entropy plotted against NVSS radio luminosity. Orange dots are detections and black boxes with left-facing arrows are non-detection upper-limits. Radio-loud AGN clearly prefer low entropy environs but the dispersion at low luminosity is large. It would be interesting to radio date these sources as this figure may have an age dimension.