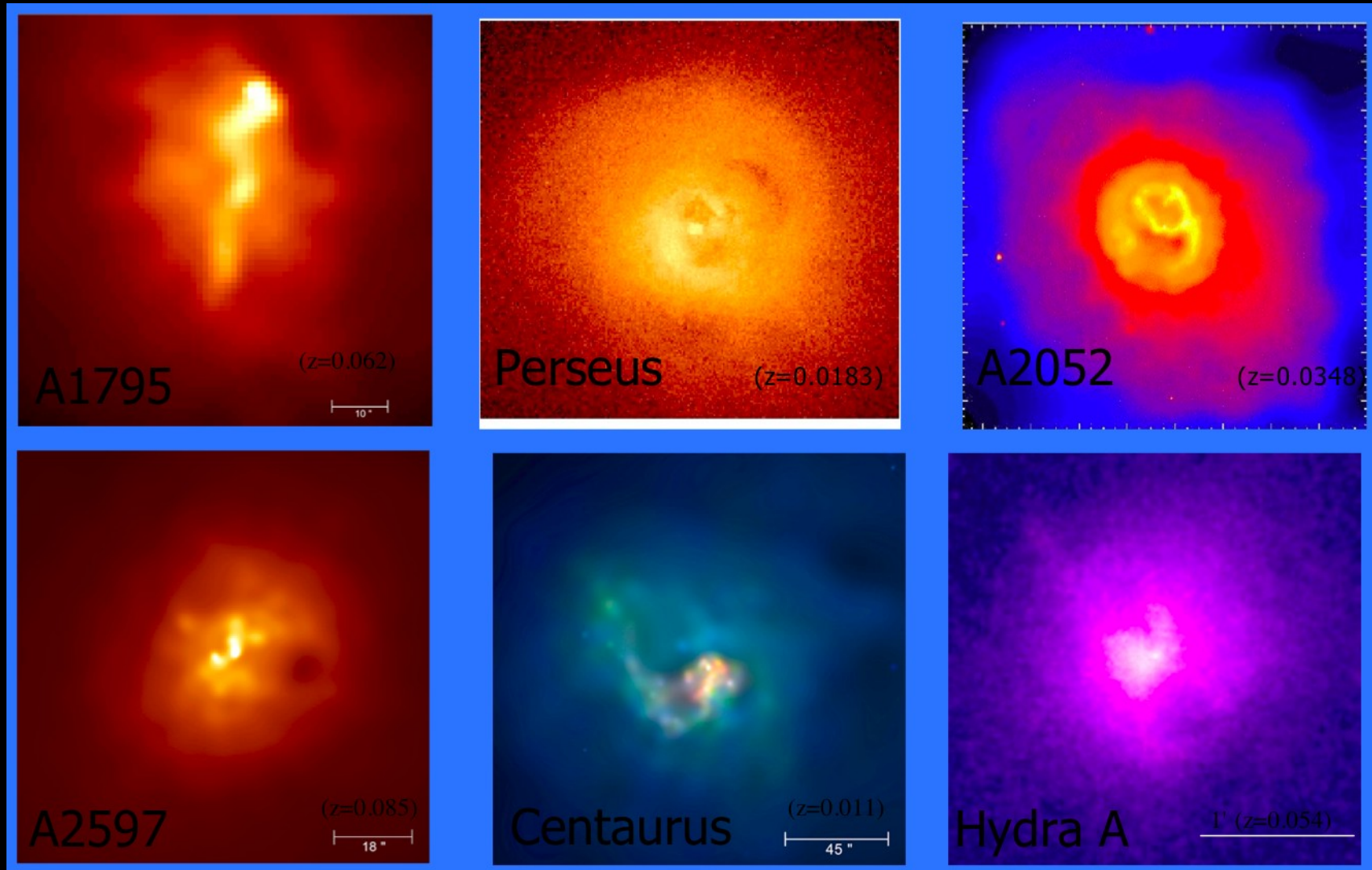


Feedback in Galaxy Clusters



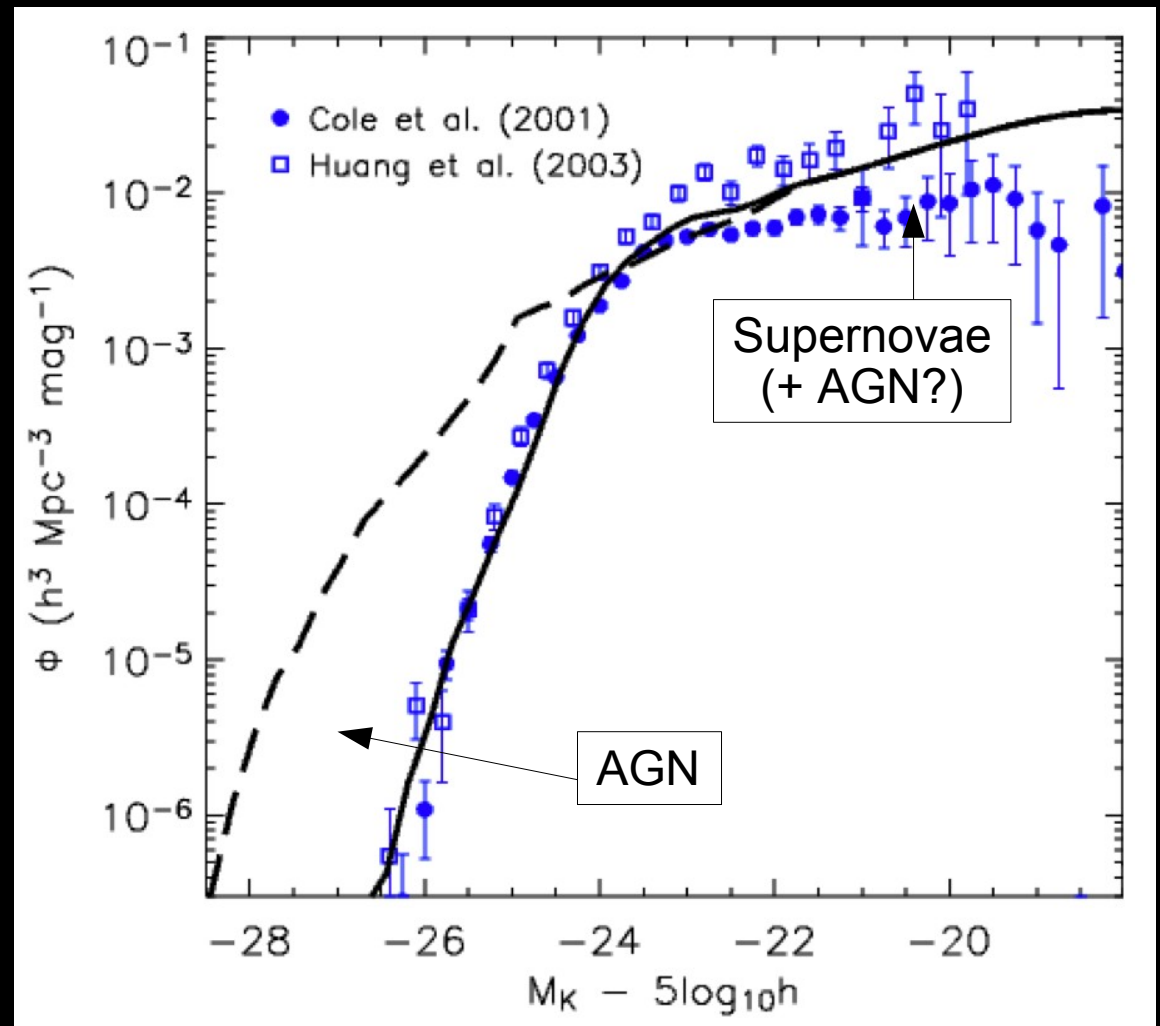
Feedback in Galaxy Clusters



- Why galaxy clusters and feedback are important
- The cause and effect of cluster feedback mechanisms
- The importance of understanding intracluster gas entropy
 - Calculating entropy from observables
- Results of my Chandra archival study

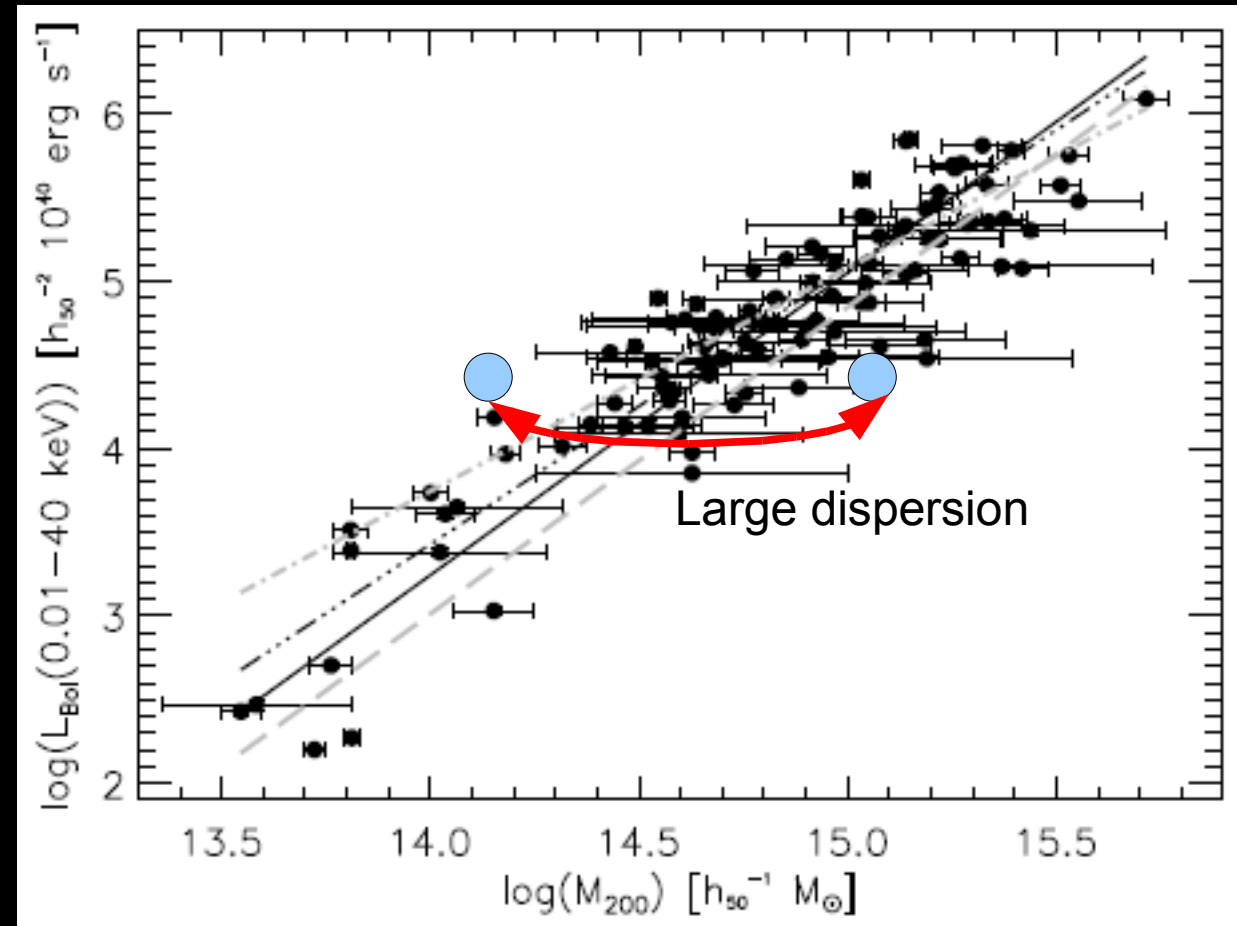
Importance of Clusters and Feedback

- Cosmology tests
 - Power spectrum
 - Structure growth
 - Observables
- Galaxy formation models
- Feedback affects mass-scaling relations



Importance of Clusters and Feedback

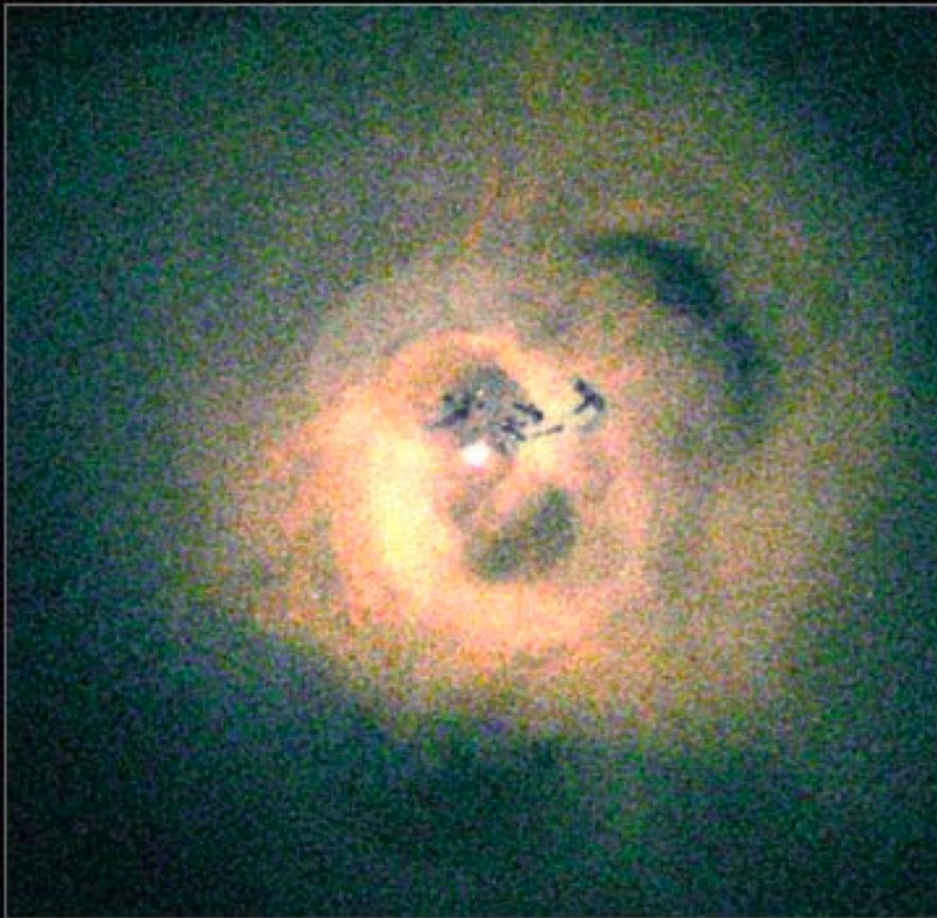
- Cosmology tests
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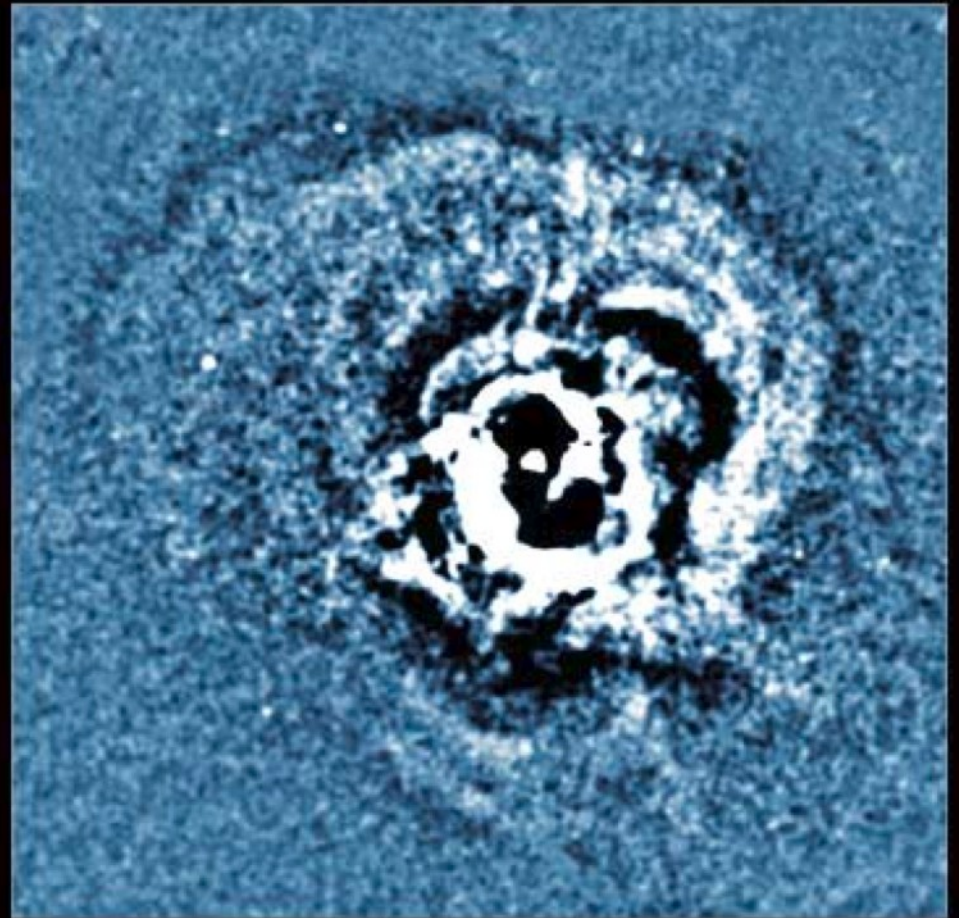
Reiprich 2001

What causes feedback?

- $t_{\text{cool}} \sim \Lambda(T, Z) \rho^2$
- Cooling time shorter than Hubble time
- Gas “flows” to bottom of potential well
- Mergers can also provide fuel

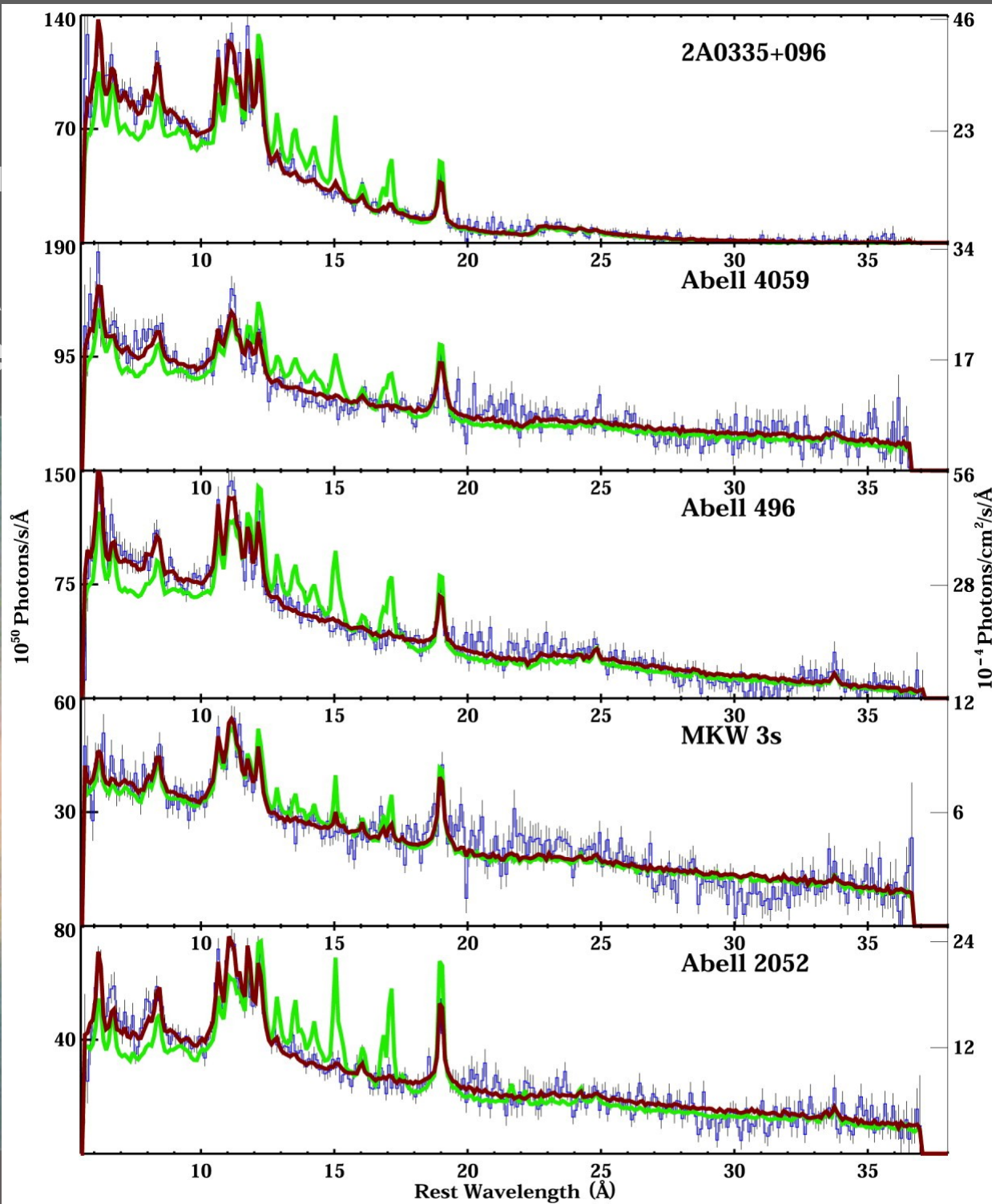


CHANDRA X-RAY [3-COLOR]



CHANDRA X-RAY [SOUND WAVES]

t_{cool}
 Co
 Ga
 Me

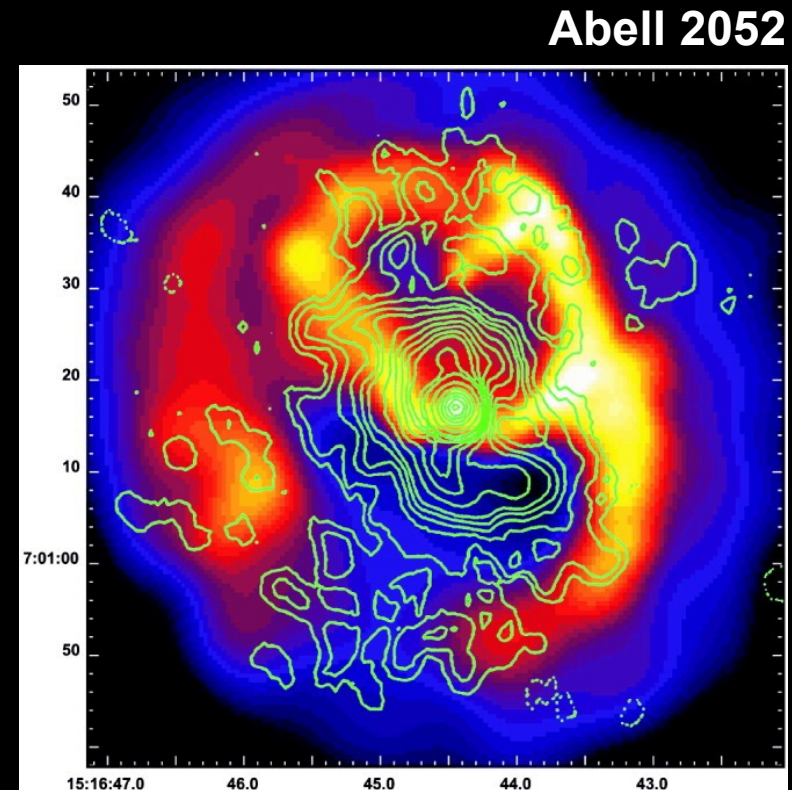
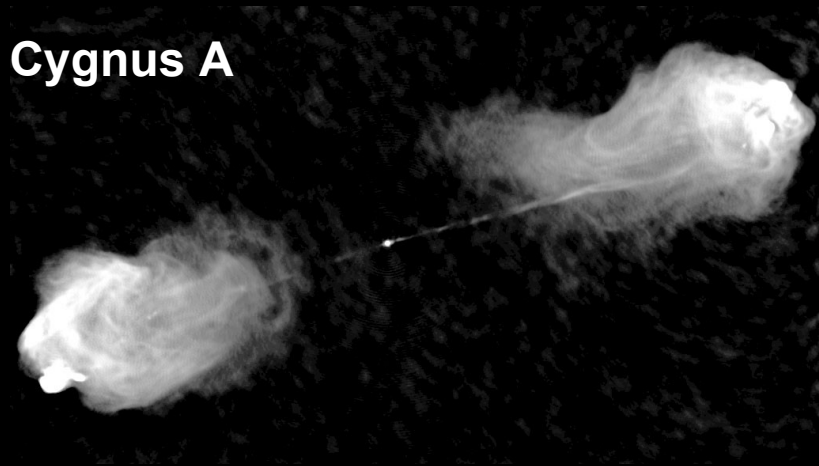


**Cooling
 trickles**
 Peterson
 &
 Fabian

[SOUND WAVES]

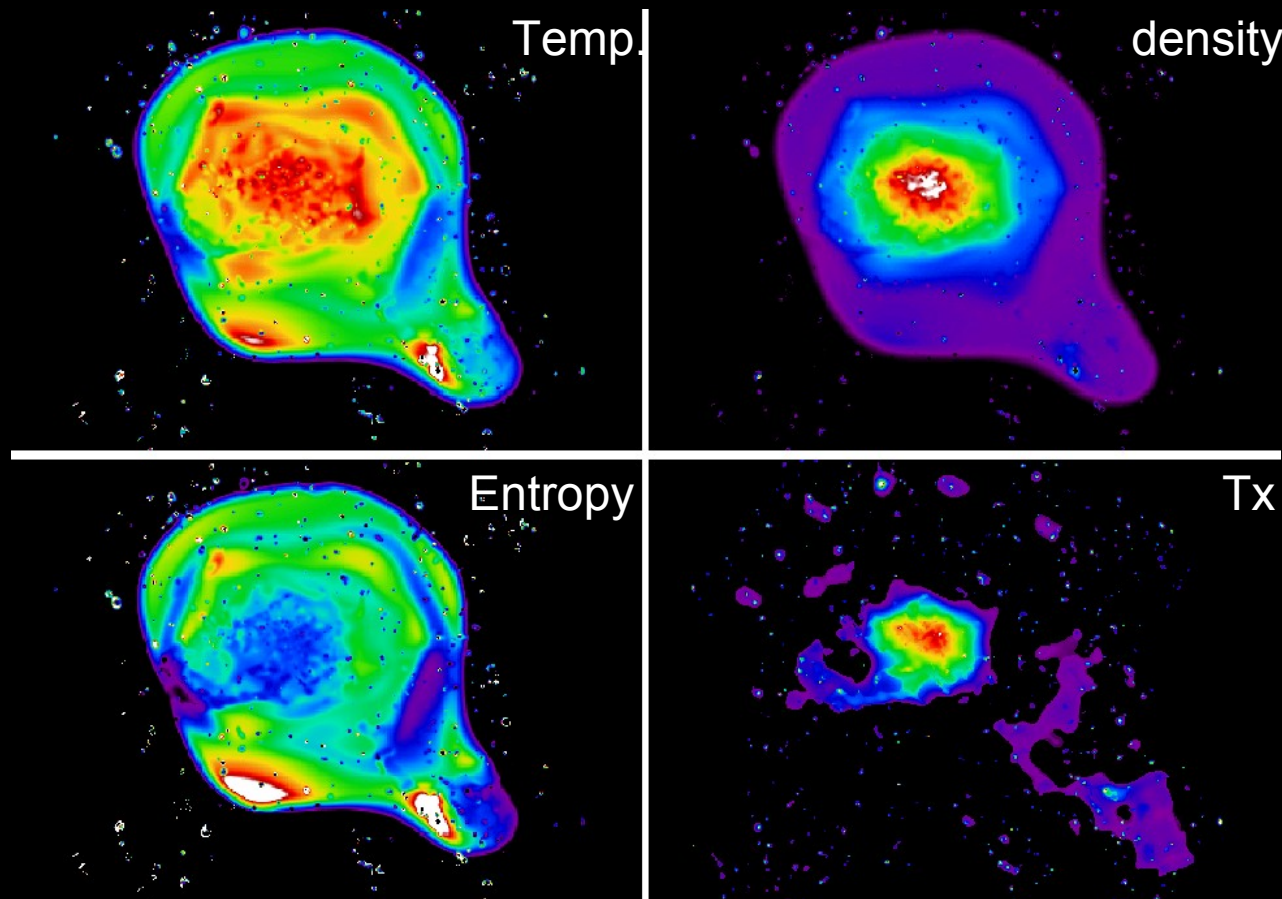
The results and effects of feedback

- Star formation
- Active galactic nuclei (AGN)
- Heating of ICM
- Self-similar scaling relations need help?
 - Mass vs. T_X , L_X , f_{SZE} , ...
- Grassroots:
 - Study cold ICM
 - Understand feedback



What is ICM entropy?

- Entropy is a fundamental property of the ICM
- Entropy dictates density in isobaric system
- X-ray observables are manifestation of dark matter halo and entropy structure
- Entropy *is* the thermal history
- We define entropy as $K = T n_e^{-2/3}$
- ICM is convectively stable when $dS/dr \geq 0$
- Classify clusters by entropy?



Feedback in Galaxy Clusters

or: How I Learned to Stop Worrying and Love
Radiative Transfer

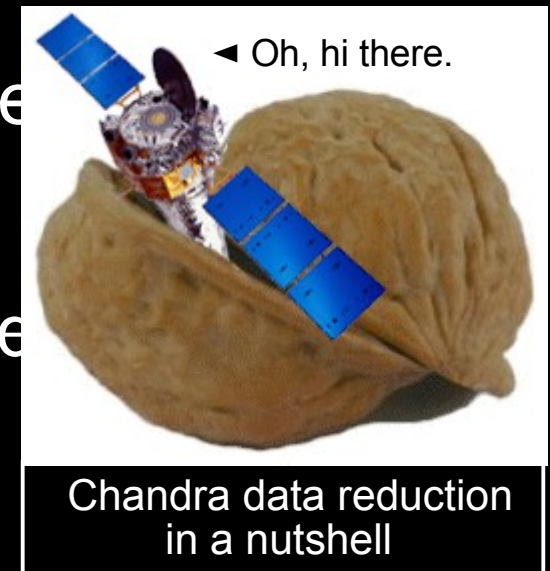
- Why should you care about galaxy clusters and what I do?

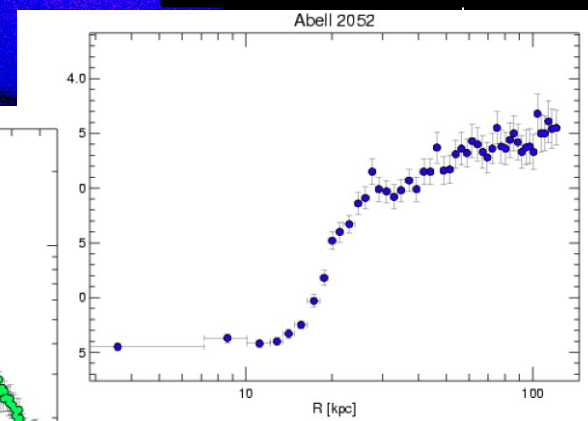
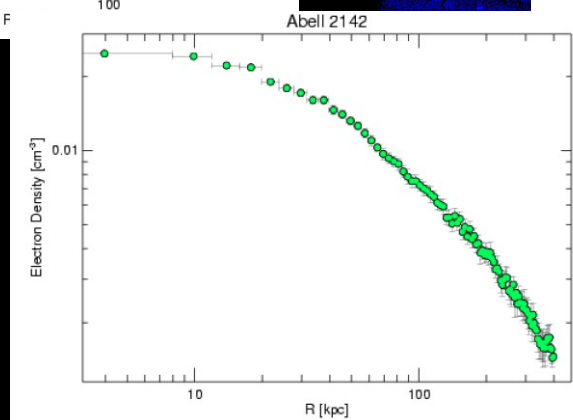
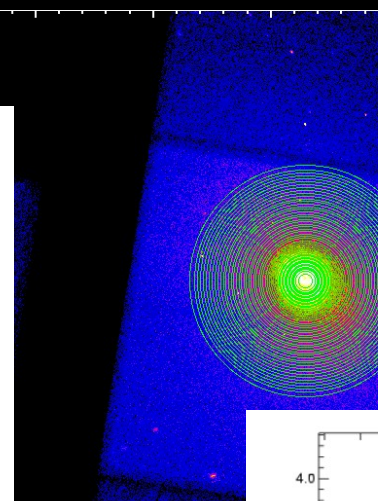
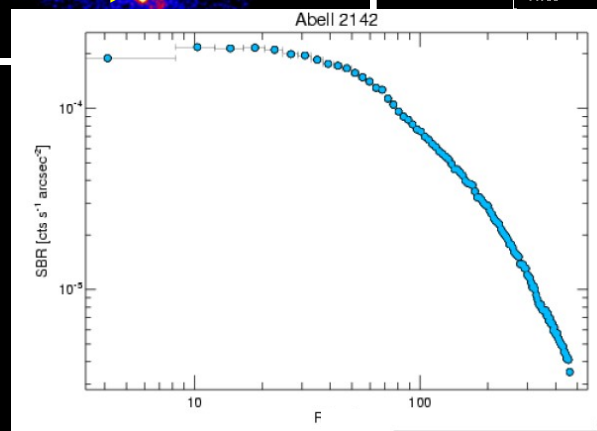
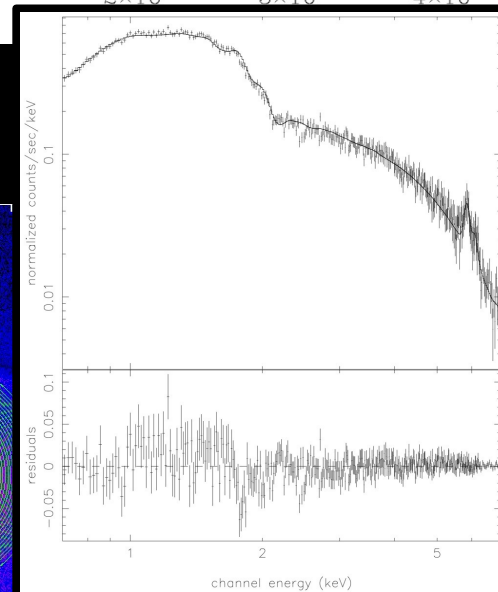
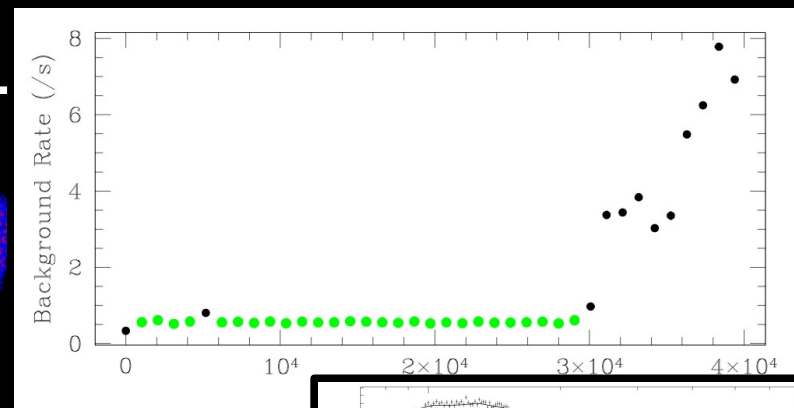
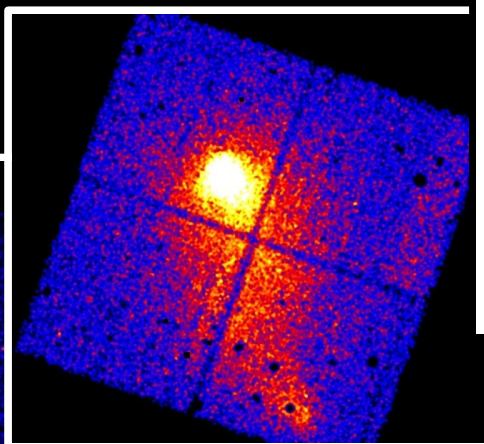
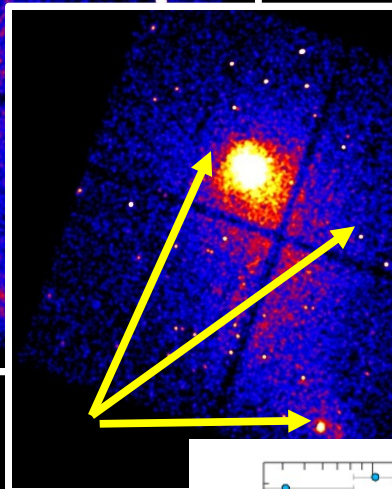
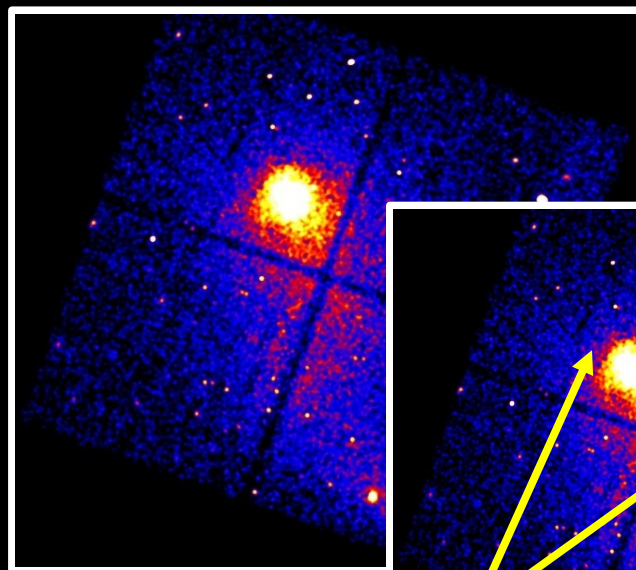
- The cause and effect of cluster feedback mechanisms

- The importance of understanding intracluster gas entropy

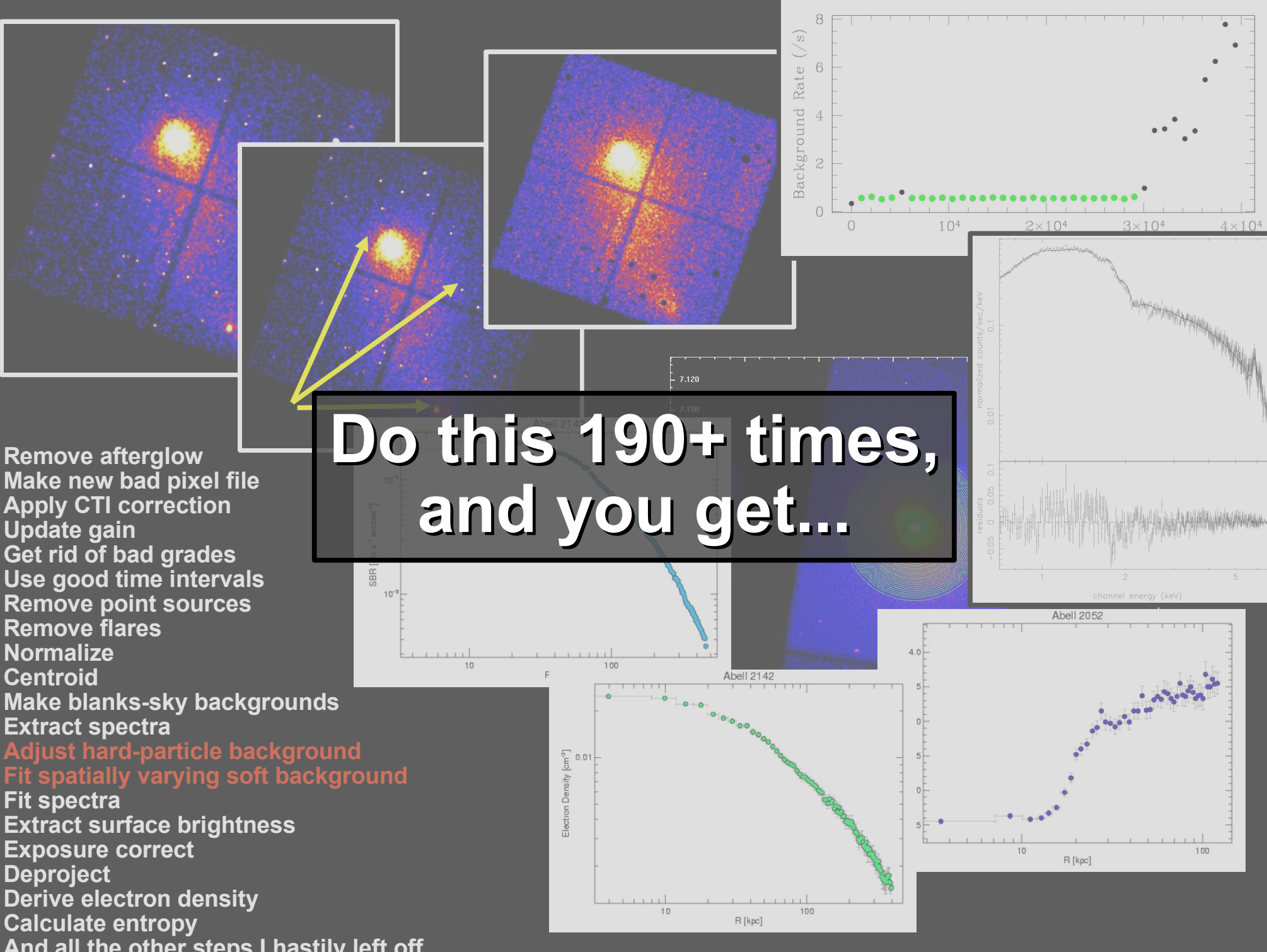
- Calculating entropy from observables

- Results of my Chandra archival study





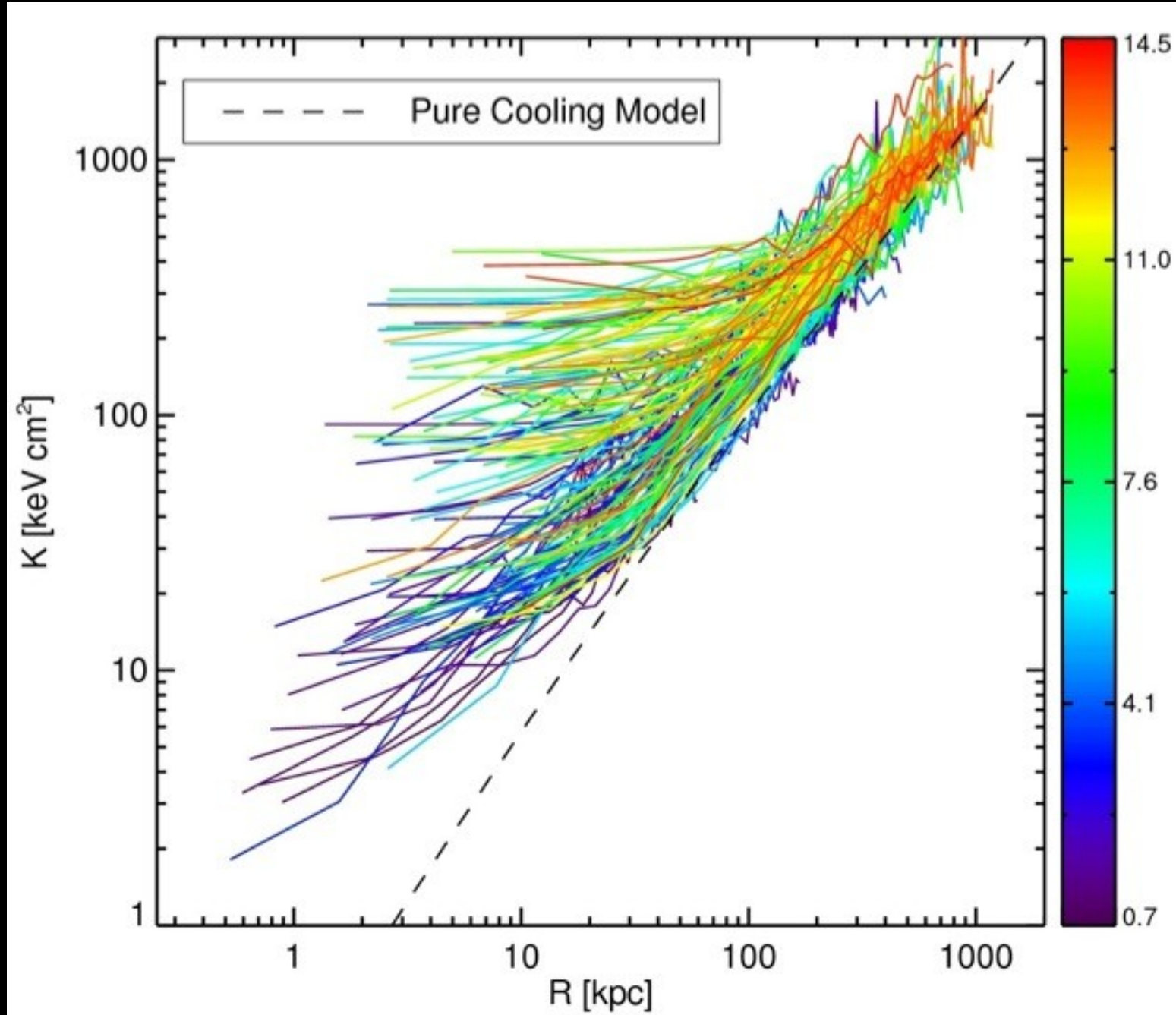
- Remove afterglow
- Make new bad pixel file
- Apply CTI correction
- Update gain
- Get rid of bad grades
- Use good time intervals
- Remove point sources
- Remove flares
- Normalize
- Centroid
- Make blanks-sky backgrounds
- Extract spectra
- **Adjust hard-particle background**
- **Fit spatially varying soft background**
- Fit spectra
- Extract surface brightness
- Exposure correct
- Deproject
- Derive electron density
- Calculate entropy
- And all the other steps I hastily left off



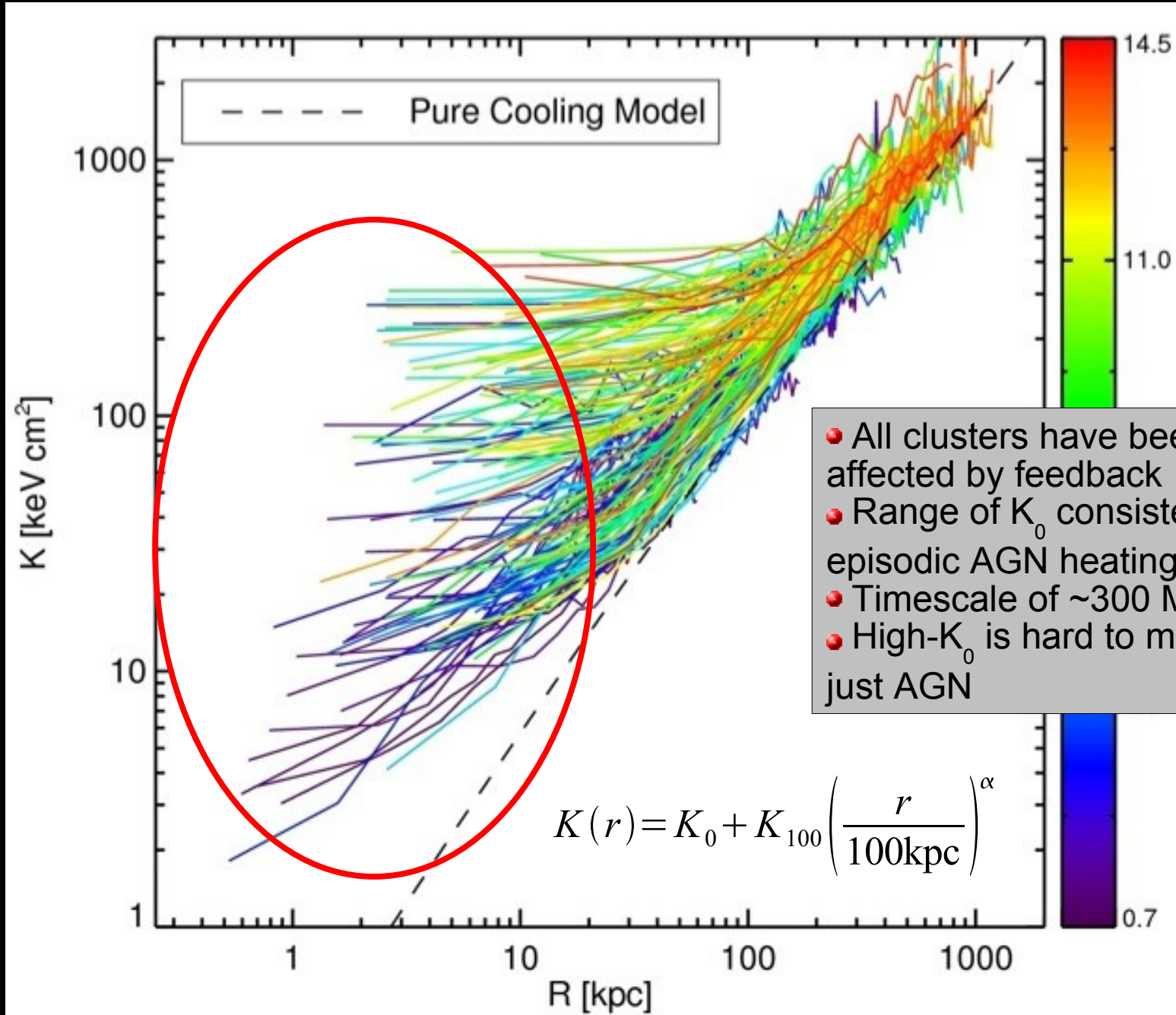
**Do this 190+ times,
and you get...**

- Remove afterglow
- Make new bad pixel file
- Apply CTI correction
- Update gain
- Get rid of bad grades
- Use good time intervals
- Remove point sources
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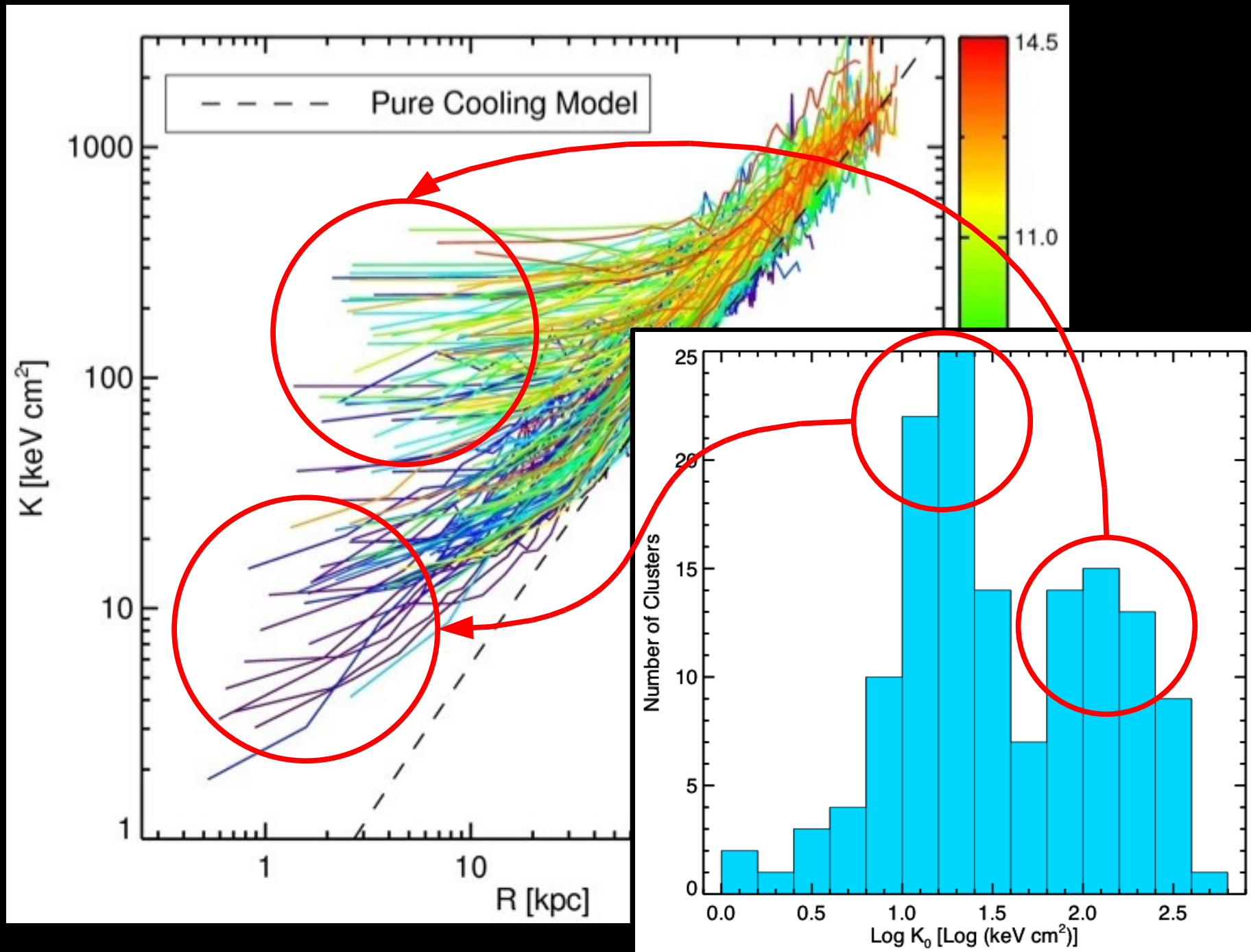
ACCEPT: Athenæum(?) of Chandra Cluster Entropy Profiles

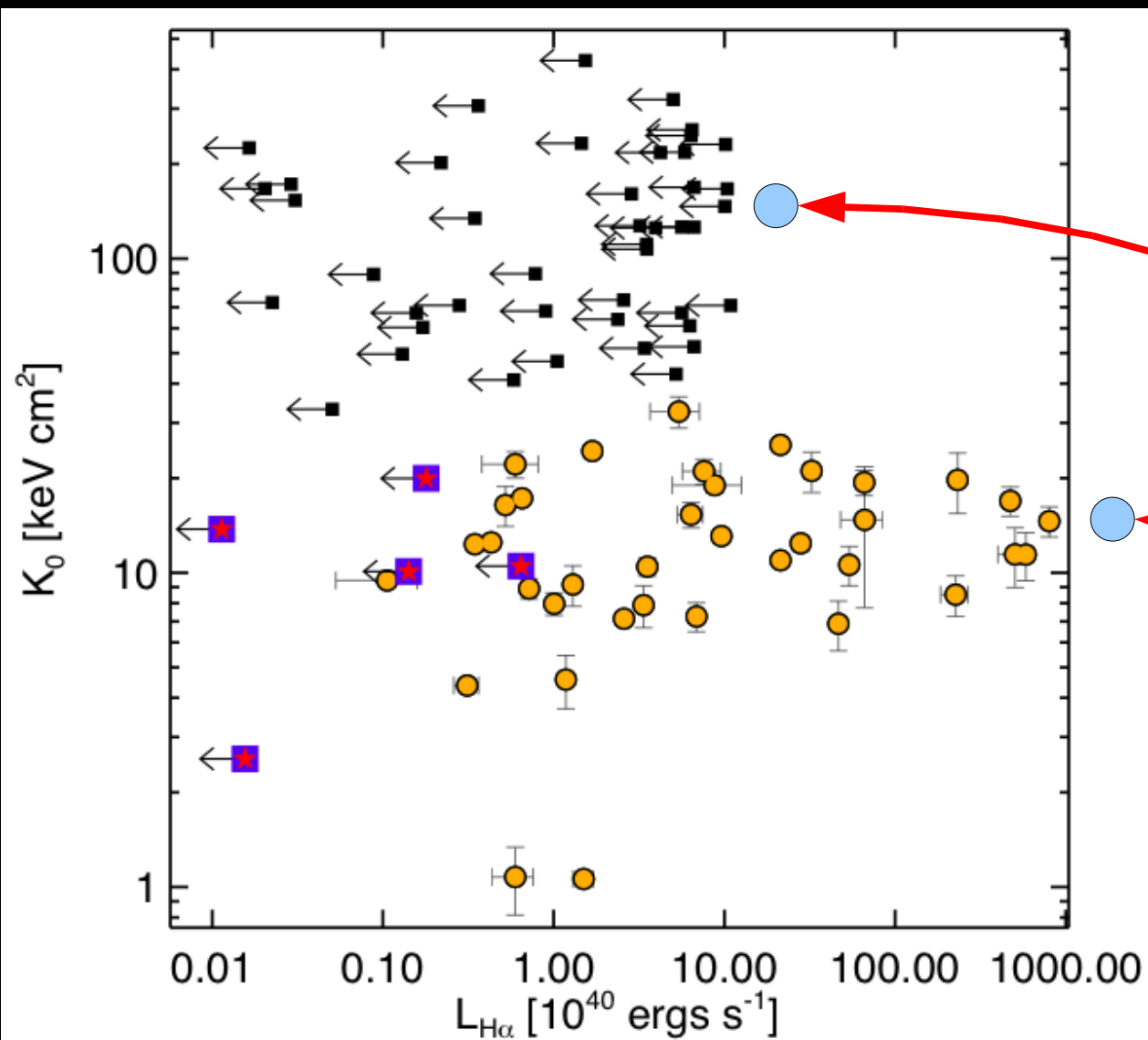


Universal entropy pedestal



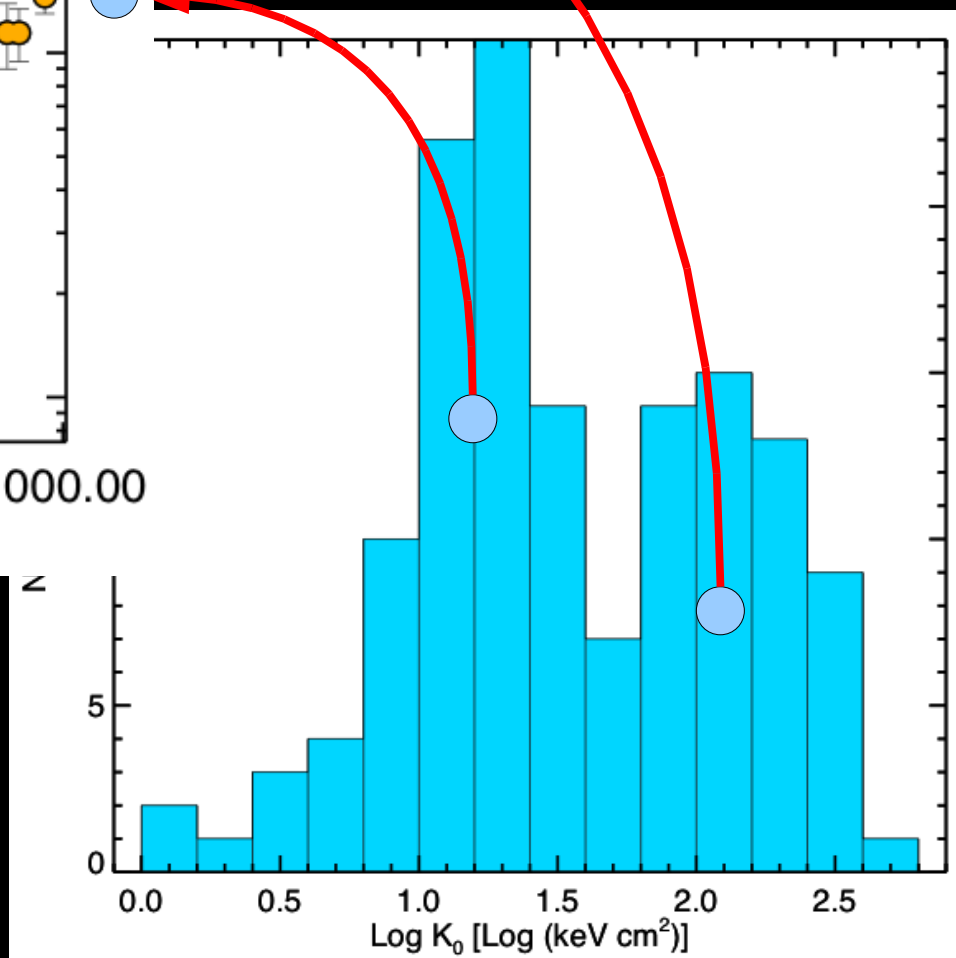
Bimodal entropy distribution

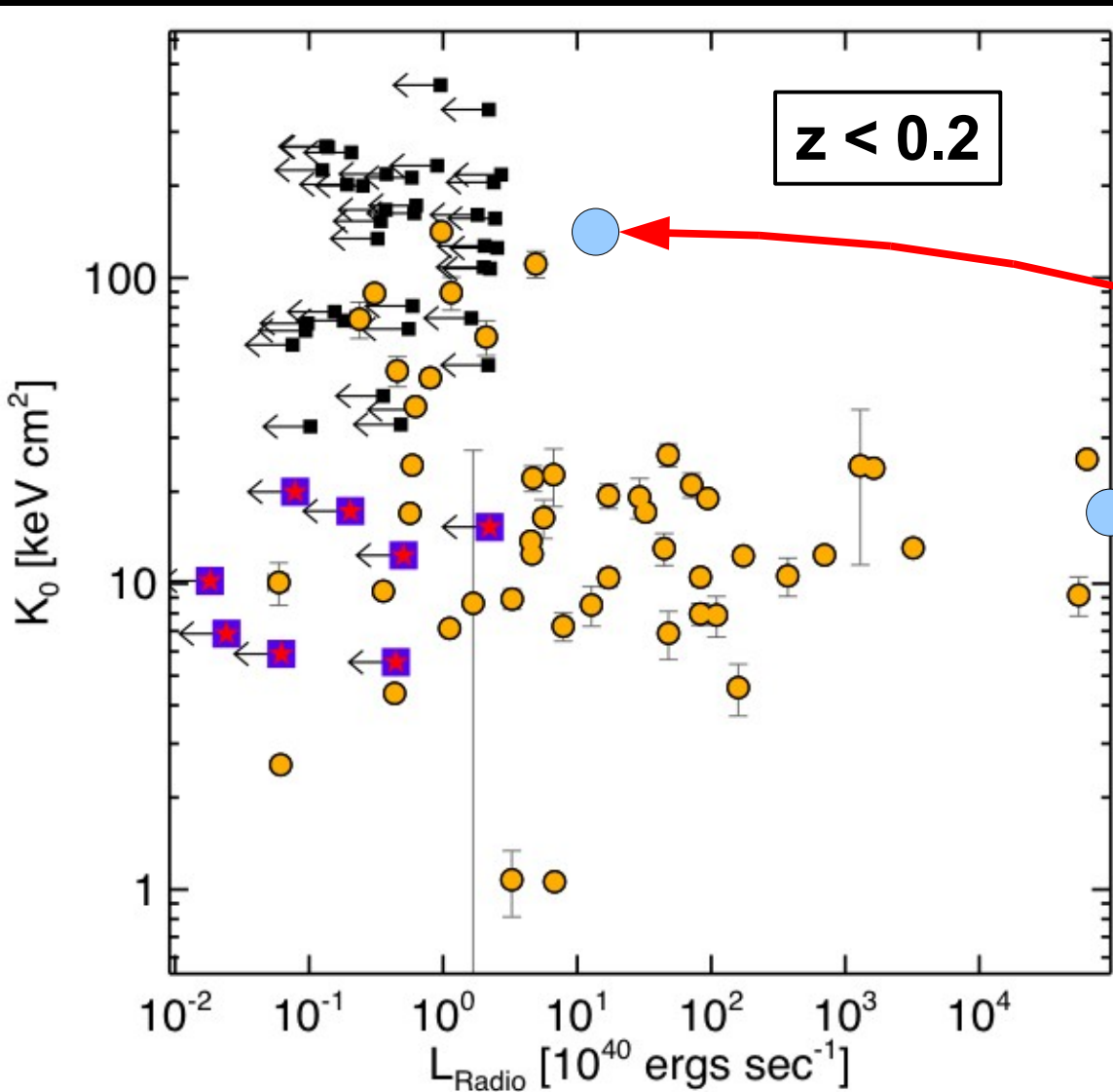




**Star Formation
loves low entropy**

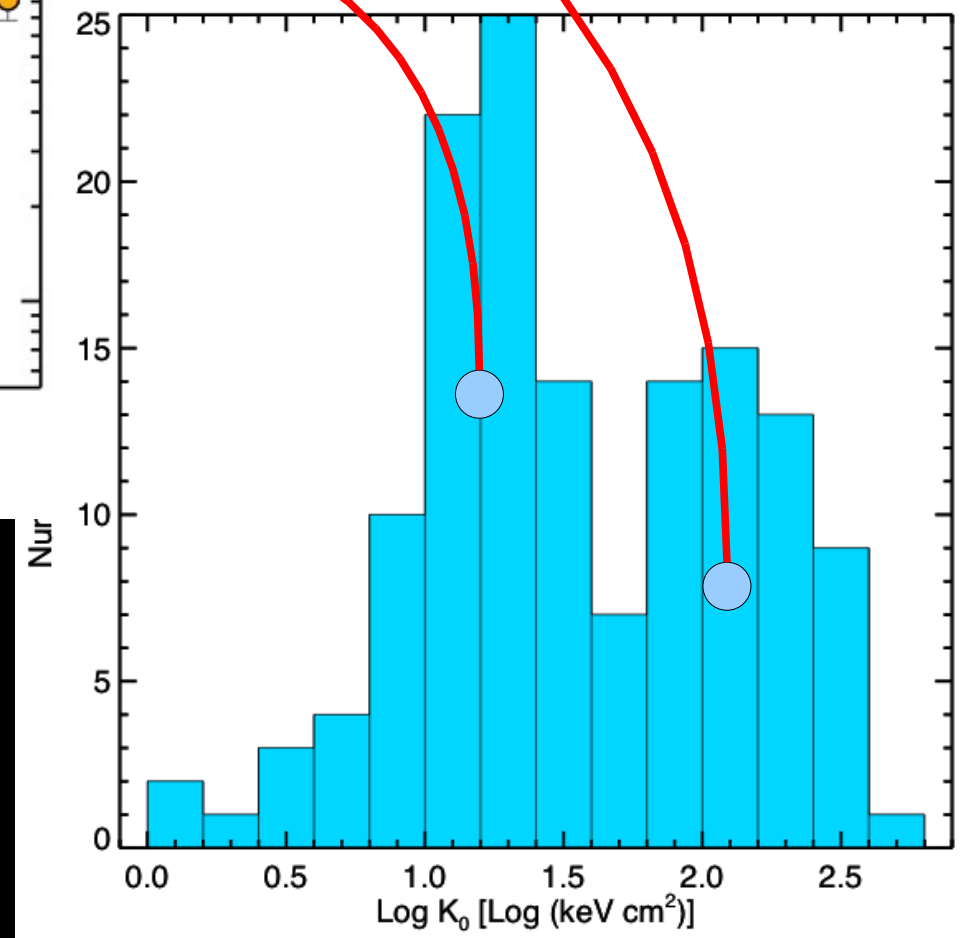
**Conduction
interfaces can
also produce H α**





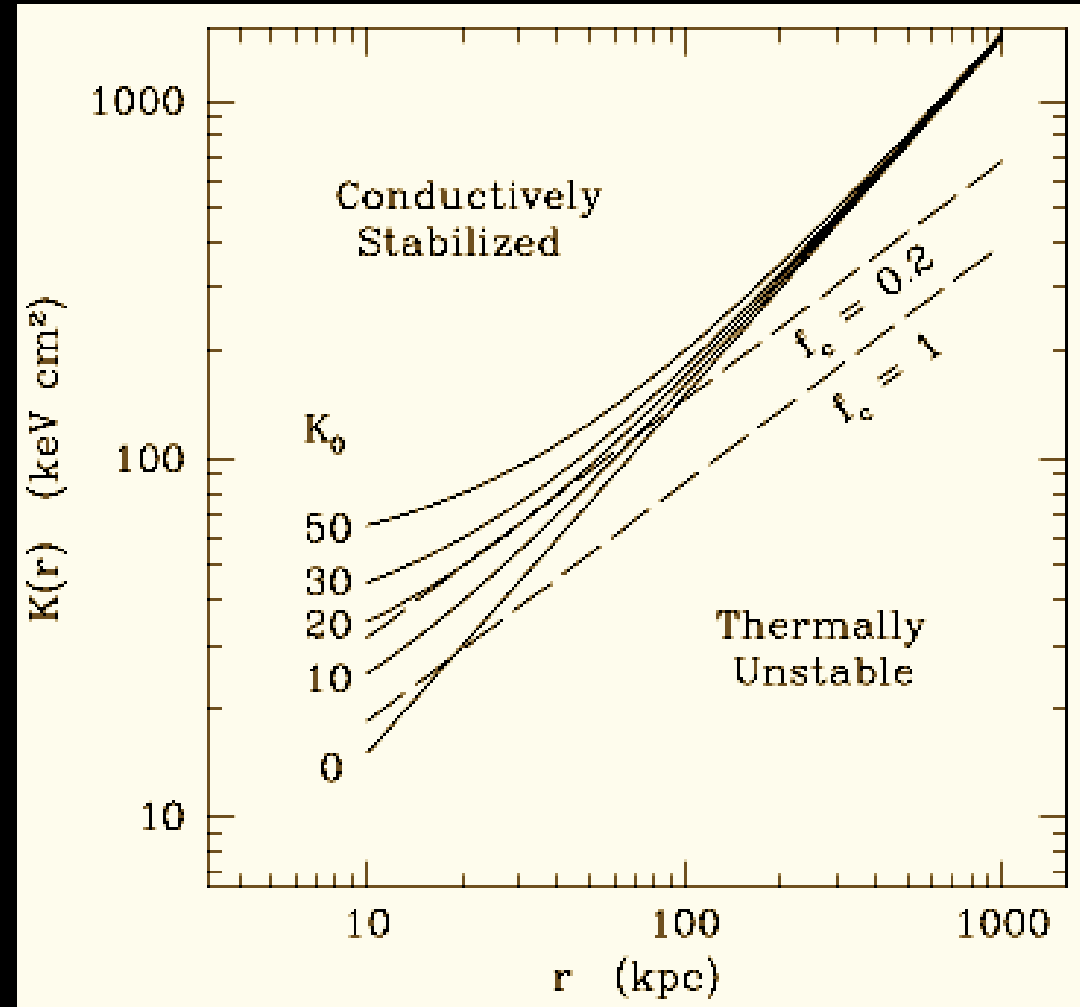
**Radio-loud
sources do too!**

**Most likely AGN, but
could also be relics,
ghosts, detached lobes,
etc.**



Conductive Stability

- Assume free-free cooling: $\Lambda \sim T^{1/2}$
- Set radiative losses equal to Spitzer conduction: $\kappa \sim T^{5/2}$
- Field Length is function of entropy only: $\lambda_F \sim K^{3/2} \sigma_s^{1/2}$
- Gas cloud smaller than Field length = condensation
- Gas cloud larger than Field length = evaporation
- $K_0 = 20 \text{ keV cm}^2$ is critical length scale
- Maybe AGN push ICM to conductive stability and subsequent mergers up entropy further...



Where to from here?

- Entropy scaling relations
- Explain bimodality
- Model for conduction
- Low entropy & no feedback
- High entropy & with feedback
- IR and near-UV star formation rates
- Low frequency radio survey
- Radio dating?
- Interferometry SZE to study high- z entropy?
- Test various pre-heating models
- 2D analyses
- Online searchable database