Exploring the Outskirts of Galaxy Clusters

Eric D. Miller (MIT Kavli Institute)
Mark Bautz (MIT Kavli Institute)
Jithin George, Richard Mushotzky (U. Maryland)
David Davis (GSFC), Patrick Henry (U. Hawaii)

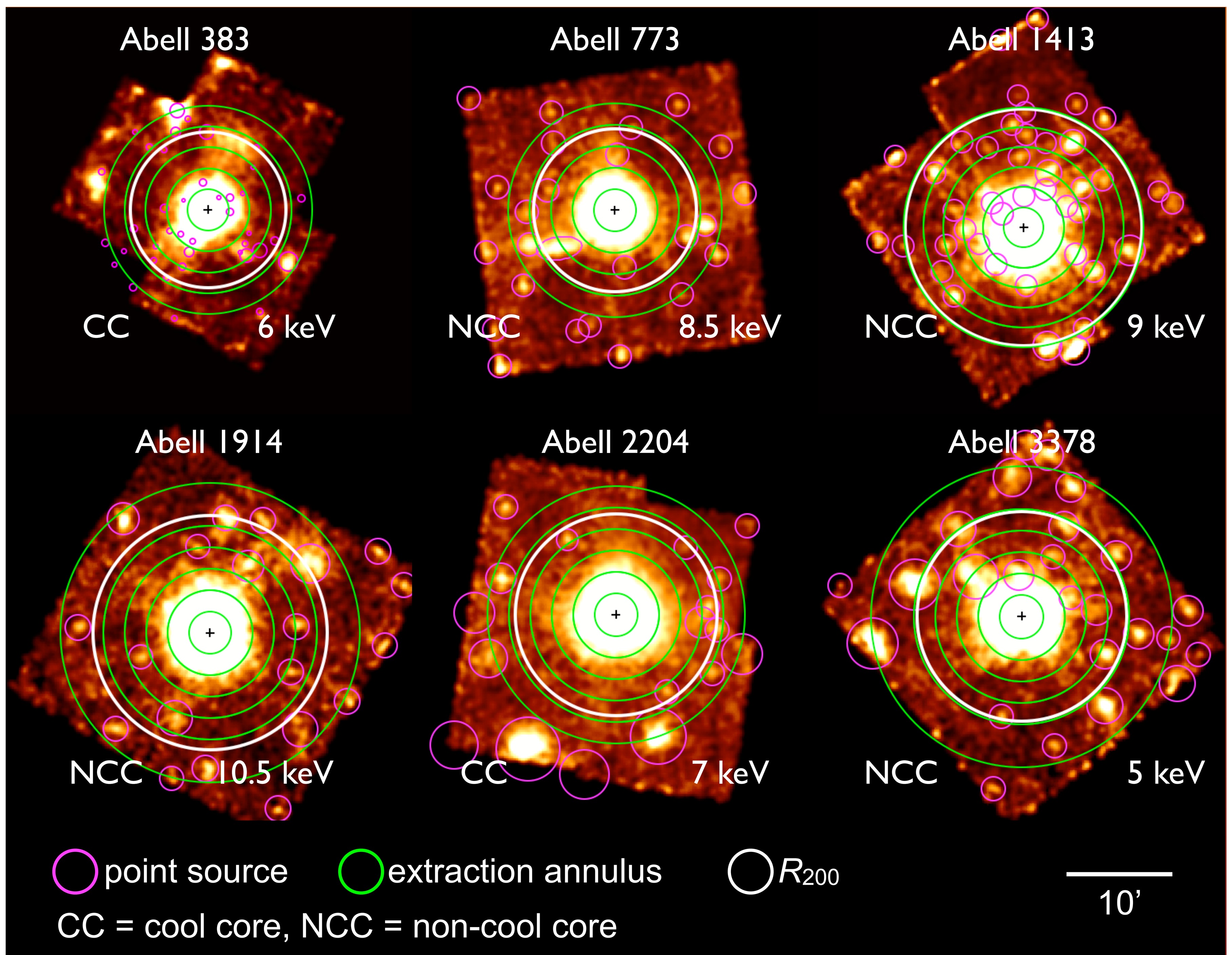
Motivation

The formation of structure in the universe is largely governed by gravity, with over-dense regions collapsing to become groups and clusters of galaxies. Non-gravitational processes such as radiative cooling and feedback from star formation and AGN activity will alter the thermodynamic conditions in these systems. The importance of such effects is not well known in the outskirts of clusters, where much of the mass resides and where accretion is ongoing. Understanding the ICM conditions here has consequences for cosmology, chemical enrichment, and cluster astrophysics.

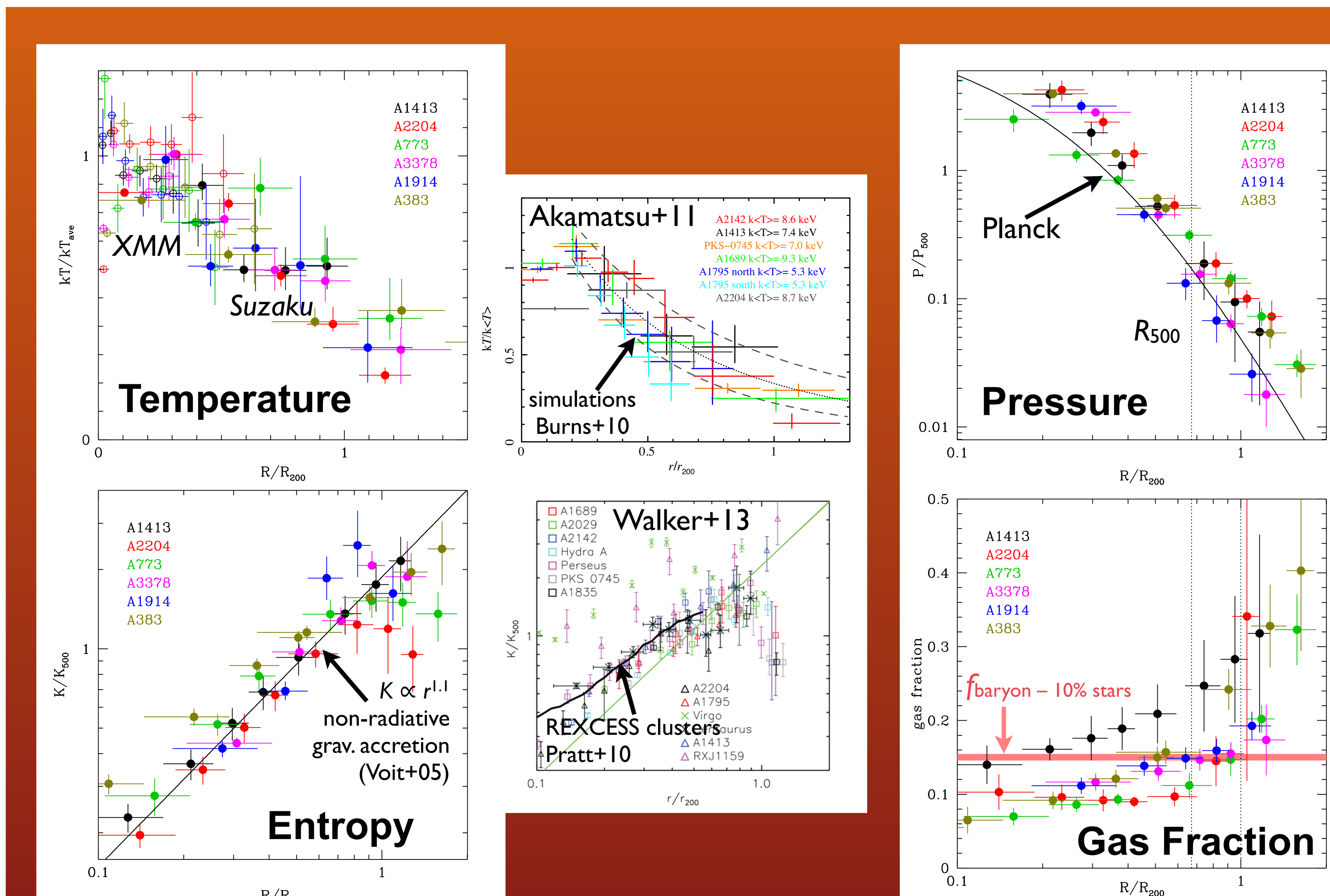
Cluster	z	R_{200}	ksec	date obs.
A383	0.187	9.3	110	July 2010
A773	0.216	9.5	200	May 2011
A1413	0.135	14.8	170	May 2010 + arch.
A1914	0.174	14.5	160	June 2010
A2204	0.151	11.8	140	Sep 2010 + arch.
A3378	0.137	12.2	150	May 2010
A665	0.179	11.7	200	April 2012
A1068	0.147	10.8	200	Oct 2011
A2597	0.080	15.0	200	Feb 2013
A2667	0.221	10.0	200	July 2011

Project Summary

Our program to probe the outskirts of a large sample of relaxed clusters uses data from the *Suzaku* X-ray Observatory, leveraging complementary data from *XMM* and *Chandra*. The sample of clusters is shown to the left, with results from those in green presented in this poster. We measure thermodynamic profiles of temperature, entropy, and pressure, and estimate the gas fraction under the assumption of hydrostatic equilibrium. These results are compared to others in the literature, and one particular source of systematic error is discussed below.



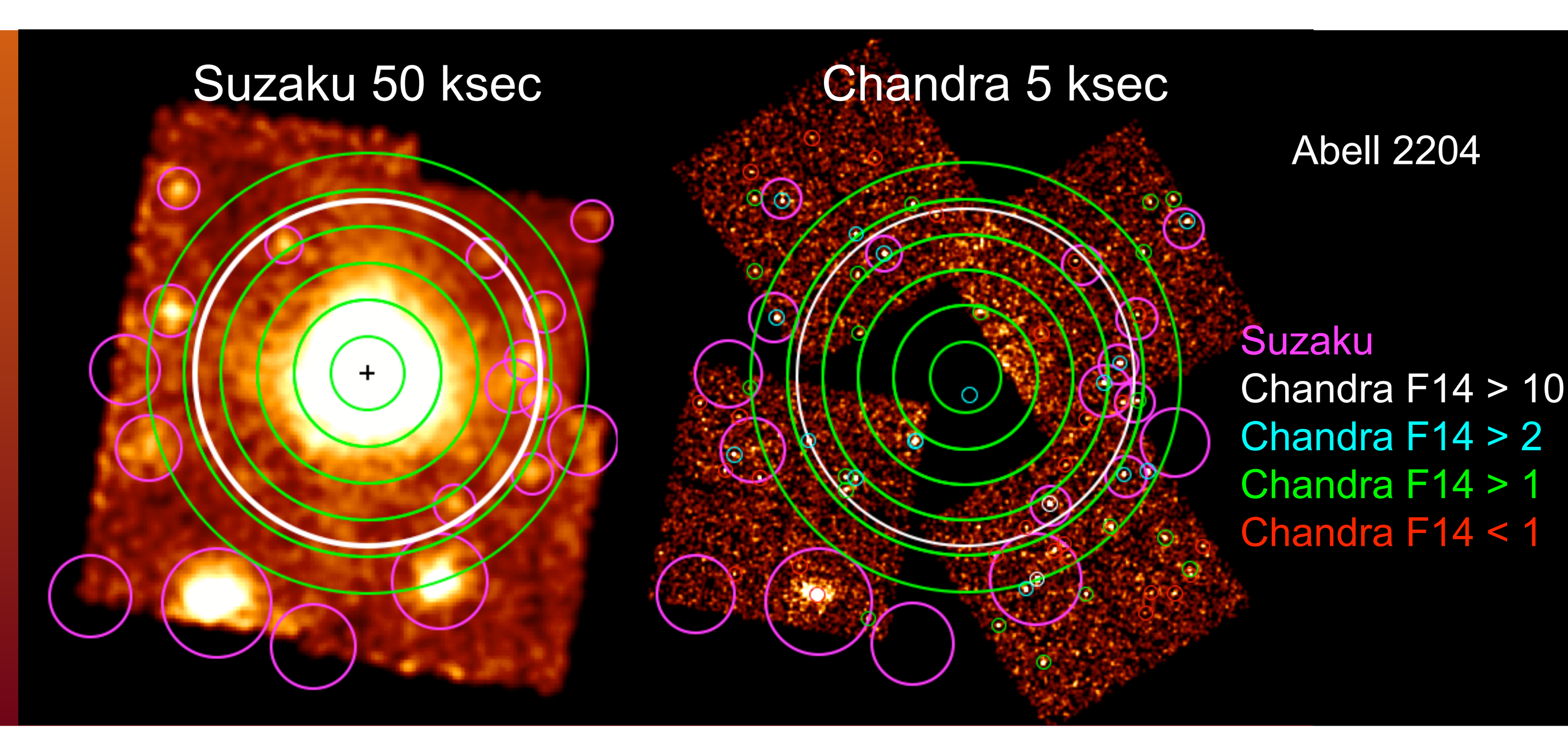
Mosaic images of six of the clusters in our sample. Each cluster is fully observed in azimuth to R_{200}, the radius within which the mean mass density is 200 times the critical density. Spectra were extracted from each annulus and fit with an absorbed thermal component for the cluster, along with a suitable X-ray background model fit to the regions outside R_{200} and to large-scale *ROSAT* emission.

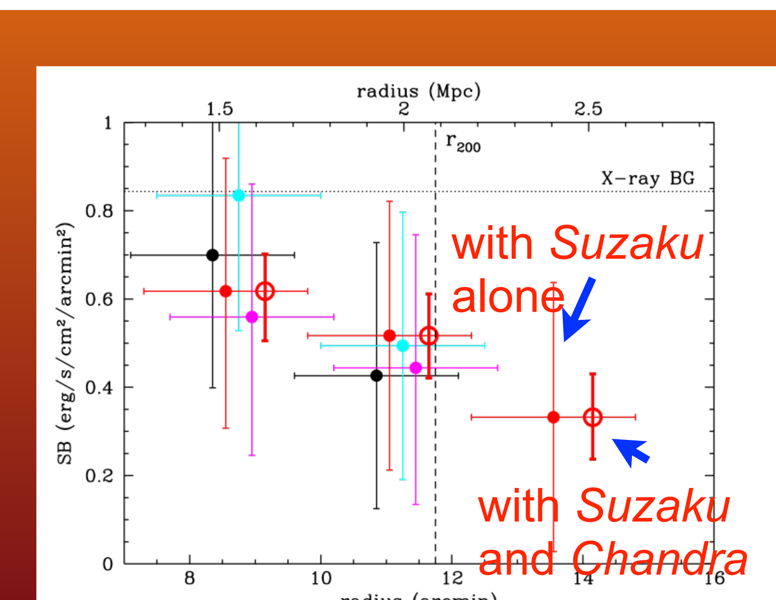


Thermodynamic profiles for six of the clusters in our sample. The profiles of temperature, entropy, and pressure are similar to previous results indicating "universality" of these scaled relations. Entropy, which encodes the thermal history of the ICM, turns over near R_{200}. We are unable to distinguish between the various possible explanations for the entropy turnover, including gas clumping, electron-ion non-equilibrium, pressure support from turbulence or bulk motion, or weakened efficiency of accretion shock heating. The gas fraction is greatly enhanced, however it is likely that the gas is not in hydrostatic equilibrium.

Unresolved Point Sources

Due to the small size of our extraction regions, the Poisson variation of point sources just below the *Suzaku* detection threshold limits our surface brightness sensitivity. Identifying point sources with *Chandra* increases the sensitivity by a factor of 4. The figures to the right show this in detail for one cluster, Abell 2204. Even a *Chandra* snapshot observation of 5 ksec is sufficient to reach the necessary detection threshold.





Summary

Hydrostatic equilibrium breaks down near the virial radius in galaxy clusters, yet there is a remarkable similarity in the thermodynamic profiles across a broad range of systems. Systematic errors limit our ability to probe the very faint ICM beyond the virial radius, but fortunately the effects are sensitively dependent on the details of the observation (size of extraction region, roll angle, epoch), and different observing strategies can help alleviate these issues.

PKS 0745-191 — George+2009, Walker+2012
Abell 2204 — Reiprich+2009
Abell 1795 — Bautz+2009
Abell 1413 — Hoshino+2010
Abell 1689 — Kawaharada+2010
Perseus — Simionescu+2011, Urban+2013
Abell 2142 — Akamatsu+2011
RXJ 1159+5531 — Humphrey+2012
Centaurus — Walker+2013
ESO 3060170 — Su+2013
....and more!