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CLUSTERS OF GALAXIES: FRONTIERS OF THE CANONICAL PICTURE

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Abstract

After decades of study, a canonical picture of massive ($> 10^{14}\,h^{-1}\,\mathrm{M}_{\odot}$) clusters has emerged. The underlying framework postulates that clusters form from the gravitational amplification of an initially Gaussian noise field in a universe whose matter content is dominated by cold, dark matter with $\Omega_m = 0.3 \pm 0.1$. Consistent with recent supernova and microwave background studies as well as inflation theory, the universe should be flat with stress-energy content dominated by a vacuum component $\Omega_\Lambda = 0.7 \pm 0.1$ (the favoured ΛCDM model). Within an evolving cosmic web of mildly non-linear density structure, massive clusters are born from merging of sub-clusters at the intersections of large-scale filaments. Defining the cluster population using a spherical density contrast algorithm centered on filtered density maxima, the canonical picture holds that such clusters:

(i) are similar in their dark matter, intracluster medium (ICM) and galaxy structures;
(ii) are close to (within $\sim$15%) virial/hydrostatic equilibrium (except major mergers);
(iii) retain nearly the cosmic mix of mass components;
(iv) have ICM thermodynamics dominated by gravitationally-induced shocks;
(v) harbor intermittent central cooling phenomenon;
(vi) contain galaxies less clustered (*i.e.*, "anti-biased") than the dark matter.

These elements are supported by observation and numerical simulation, but quantifying the degree of such support remains a challenging exercise for several of them. I focus in this talk on points (i) through (iv), providing evidence that these elements are tied down at levels approaching ten percent. Despite the fact that massive clusters are in the process of assembly at essentially all epochs of observation, the merging process is sufficiently "non–violent" that equilibria are quickly re-established and structural variations are limited.

The frontiers for cluster cosmology and astrophysics lie in two, arguably orthogonal directions. Firstly, we need to explore more fully the dynamical and thermodynamical history of clusters' visible components. In particular, galaxy formation within clusters and its impact on the ICM remains poorly understood, and the importance of non-thermal components and cooling within the ICM require clarification. An open question that can be decided with near-future observations is the issue of the baryon budget in poor clusters and groups. Secondly, we need larger, deeper and more homogeneous samples of clusters in order to provide more stringent constraints on both our underlying cosmology and on the evolutionary history

of the cluster population. In this regard, local calibration of (and confirming expected evolution in) the virial mass—temperature relation using binding masses estimated from weak gravitational lensing remains an important goal.