Scaling Relations of Galaxy Clusters: X-ray and Lensing vs. Simulations

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Abstract:
The Local Cluster Substructure Survey (LoCuSS, Smith et al.) is a systematic multi-wavelength survey of more than 100 X-ray luminous galaxy clusters in the redshift range 0.14–0.3 selected from the ROSAT All Sky Survey (RASS). We used data on 37 LoCuSS clusters from the XMM-Newton archive. The scaling relations based on the X-ray data obey empirical self-similarity. The mean X-ray mass-based mass to weak lensing mass ratio of these clusters is ~1 with 31–51% scatter. The normalization of the M–Y relation using X-ray mass estimates is lower than the one from simulations by 18%–24% at 2σ significance. This is in good agreement with the M–Y relation based on the weak lensing masses, the normalization being ~29% lower than the one from simulations at 3σ significance. The average of the X-ray mass based weak lensing mass ratio is 0.89 ± 0.09, setting the limit of the non-thermal pressure support to 9 ± 4%. To better understand the systematics of cluster mass estimates, we attempt to use the XMM-Newton data of the Highest X-ray Flux Galaxy Cluster Sample (HIFLUGCS, Reichert & Böhringer 02) to make a detailed comparison between radial profiles and 2-D maps. This will allow us to identify mergers and the departure from hydrostatic equilibrium. The LoCuSS sample at z ~ 0.2 complement each other and it is therefore a unique combination to serve the precision cluster cosmology.

LoCuSS vs. HIFLUGCS

Scientific Goals
Robust cluster cosmology experiments require well-calibrated measurements of the shape, scatter and evolution of the mass-observable scaling relations based on large statistical samples of clusters of galaxies that are unbiased with respect to cluster morphology. Elimination of systematic uncertainties from this calibration demands: (1) that the cluster mass measurements are cross-checked between independent mass measurement techniques, including X-ray and weak lensing approaches, and (2) that major cluster mergers and their effect on the systematics of cluster mass estimates are identified. XMM-Newton’s unique large-field-of-view (FOV), large area chip, high spectral resolution, and reduction are complementary to the systematic mass sampling of LoCuSS clusters (PI: G. P. Smith). This will provide us a unique powerful tool for the precision cluster cosmology.

LoCuSS vs. HIFLUGCS

The main attractions of our approach are the well-defined sensitivity limit of such surveys and the minimal biases towards different cluster morphologies. The Local Cluster Substructure Survey (LoCuSS, PI: G. P. Smith) is such a systematic multi-wavelength survey of more than 100 galaxy clusters at (0.14-0.3) selected from the RASS (of which 63 are observed by XMM-Newton). Both LoCuSS and HIFLUGCS provide unbiased samples of X-ray luminous galaxy clusters. The LoCuSS at redshift of 0.2, better serves our first goal, and the HIFLUGCS at redshift of 0.0, better serves the 2nd goal. The combination provides us a unique powerful tool for the precision cluster cosmology.

HIFLUGCS: Profile vs. 2-D map

Data and Reduction Strategy
63 HIFLUGCS clusters have been observed by XMM-Newton (148 pointings) with 2–3 Ms (~1 Ms) exposure time for MOS (GS). The Background subtraction method follows the philosophy in Snowden et al. (08) with some complications adjusted to our project. For example, we used multiple iterative Gaussian bump observations to assist the modeling of the CXB and we extended the background subtraction into the empty data gaps. Width of annuli for spectral analysis are determined by (1) that the width of each annulus is <0.5", (2) that the signal-to-noise ratio is greater than 4 per MOS2 spectrum in the 0.5–7.8 keV band. The FoV is divided into 130 contamination to clusters with less than 4 annuli in total for each, which is 75%.

Weak lensing to X-ray mass ratio shows (1) scatter almost independent on the chosen radius (upper left in Figure 1), indicating good agreement between X-ray and weak lensing masses for most clusters, (2) 31–51 per cent scatter derived from the Gaussian fit (upper right in Figure 1), and (3) an average of 1.90 ± 0.06 (lower left in Figure 1), indicating non-thermal pressure support within 9% at 3σ.

One Example: EXO 0422
Temperature and metallicity profiles for EXO 0422 (left in Figure 2). The profiles serve as the reference curves for the cluster.

Temperature and metallicity maps for EXO 0422 (right in Figure 2). Despite the regular appearance of the temperature and metallicity profile, the temperature/metallicity abundance map reveals some small but significant fluctuations from the data points, and indicated cold fronts and shocks in temperature, entropy and pressure maps, which will be used to test the cluster dynamics.

Conclusion
In HIFLUGCS Short Term Goal
Profile vs. 2-D map suggests a statistical way for the HIFLUGCS provides a global view for a representative sample of massive galaxy clusters on: (1) merging fractions indicated by different merging features, (2) effects of merging on the mass systematics caused by deviations from hydrostatic equilibrium in the scaling relations introduced by merging clusters. Such analyses which are necessary to provide the knowledge to constrain the physics behind the X-ray scaling relations and their scatter.

References

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