Assessing Log-normal Scaling Relation Model

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Cluster Cosmology Challenge

Goals:

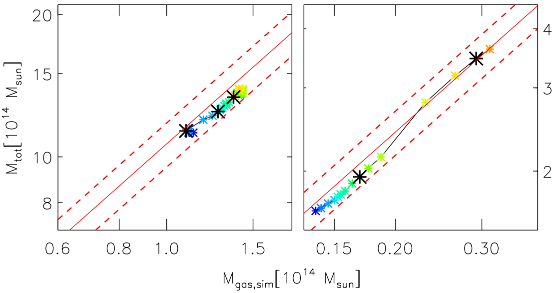
- Constrain Cosmological parameters
- Mass Calibration
- Astrophysics

Key Messages:

- **Scaling parameters run with halo mass**
- **Log-normal is a sufficient model of halo properties**
- **Constraining the property covariance is achievable**

Questions need to be answered

- Are our Mass-Observable relation Models accurate?
  - Is log-normal $p(S|M,z)$ a good approximation?
  - Does the local slope and scatter/covariance run with mass and redshift?
- Test population model of Evrard et al. (2014) using sims
  - Can we achieve one percent prediction in expected mass?

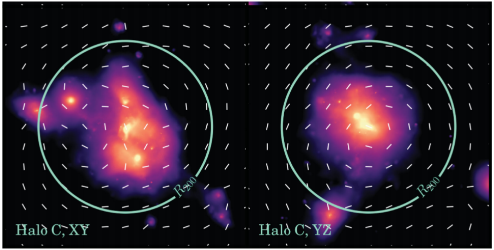


Credit: Rasia et al. (2011)

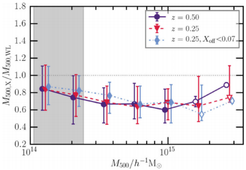
BAHAMAS + MACSIS simulations

BAHAMAS [McCarthy et al. (2016)], MACSIS [Barnes et al. (2017)]

- SPH simulations with star formation, SN+AGN feedback
- BAHAMAS = 400$[\mathrm{Mpc}/h]$ box with 2×1024^3 particles
- MACSIS = 390 resimulations of very high mass halos chosen from 3.2$[\mathrm{Gpc}]$ N-body sim
- Same hydro model parameters for both studies
- Sub-grid params tuned by stellar mass function and X-ray scaling relations
- Samples of 10,000 halos above $10^{13.5}[M_\odot]$



Credit: Henson et al., (2017)

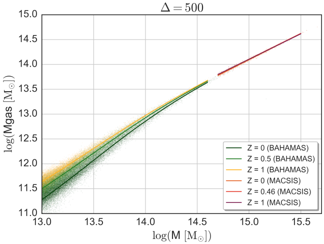


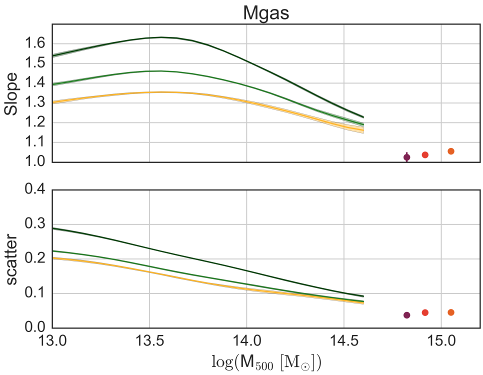
Credit: Henson et al., (2017)

Above: synthetic X-ray surface brightness (color) and shear field for 2 projections of a merging halo.
Left: X-ray to lensing mass ratio from analysis of synthetic images

Mass-Observable Relation (MOR) of halos: gas mass

- Focus on spherical $M_{\rm gas}$ and $M_{\rm star}$ within $\Delta = 2500, 500, 200$
- Locally linear regression (LLR) applied to BAHAMAS
- Simple LR on MACSIS





Slope and scatter run with mass (primarily) and redshift

Mass-Observable Relation (MOR) of halos: Stellar mass

- Focus on spherical $M_{\rm gas}$ and $M_{\rm star}$ within $\Delta = 2500, 500, 200$
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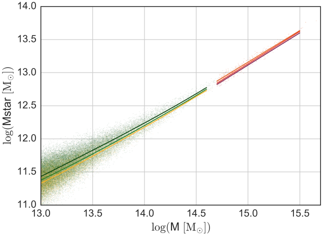
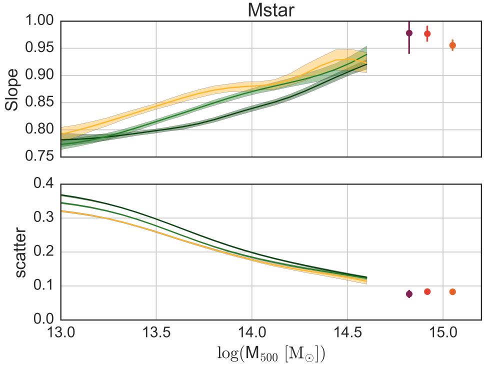
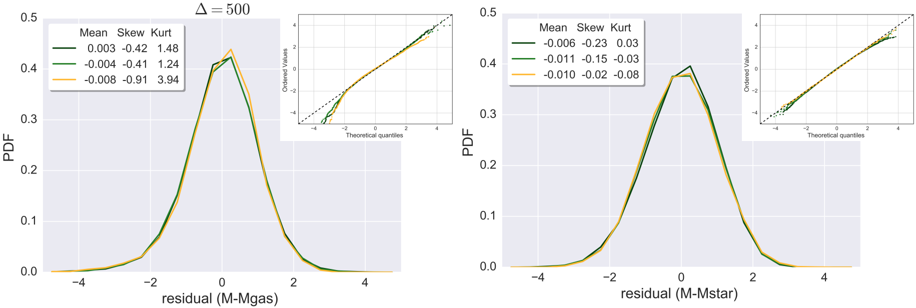




Slope and scatter run with mass (primarily) and redshift

Mass-Observable Relation (MOR) of halos: Stellar mass

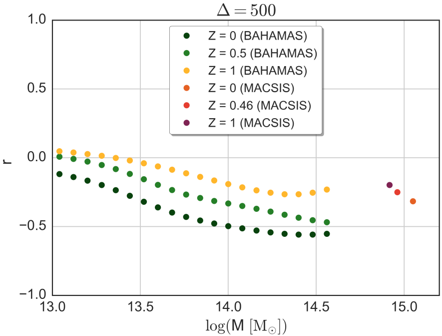
- **LOG-NORMAL** shape
- expected when multiple factors compete multiplicatively



PDF of residuals in gas and stellar mass about the local regression verifies the log-normal form. Residuals of $M_{\rm gas}$ (left panels) and $M_{\rm star}$ (right panels) respect to the local fit.

Mass-Property Relation (MPR) of halos: hot and cold baryon phase covariance

- Anti-correlation in higher mass halos
- deeper potential wells act more like closed baryon boxes



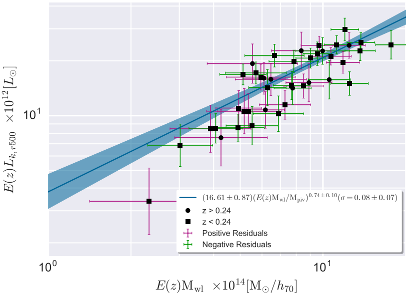
Why it is important

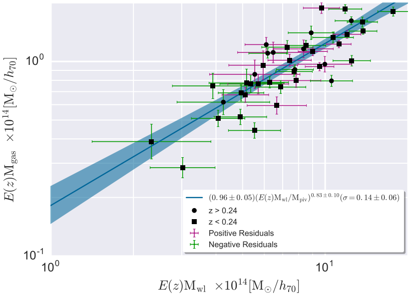
- Constraining physics of clusters [e.g. Stanek et al. (2010), Wu et al. (2015)]
- It is an essential part of any Multi-wavelength cluster cosmology [e.g. Cunha et al. (2009)]

The Local Cluster Substructure Survey [PI: G. Smith]

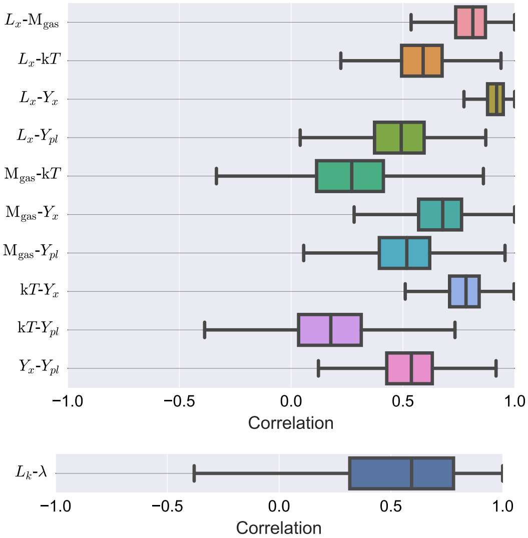
PRELIMINARY RESULT - Observational data provided by Sarah Mulroy

- multi-wavelength survey of galaxy clusters at $0.15 < z < 0.35$.
- selected from the ROSAT All-sky Survey catalogs (luminosity limited Sample)





The property covariance for LoCuSS sample



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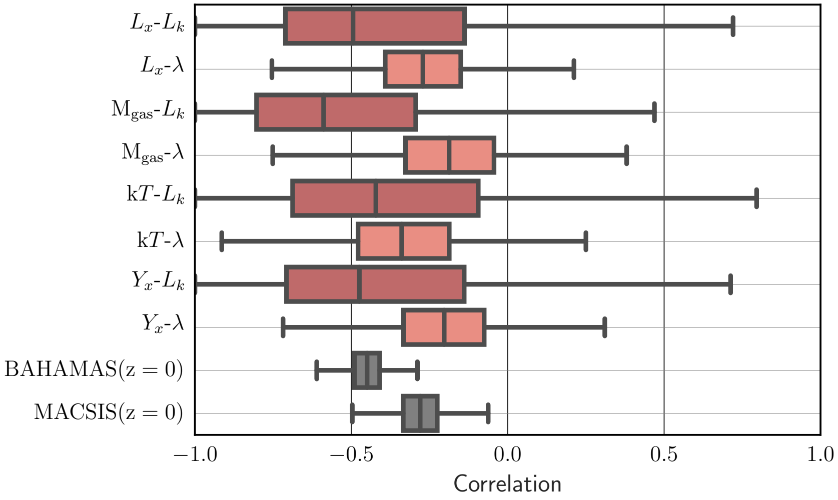


Analytical Model

$$\mathcal{L}_{full} = \mathcal{L}_{cosmology} \times \mathcal{L}_{scaling}$$

Typically the following relation is constrained observationally

$$\langle \ln M | \ln S \rangle = \pi + \alpha \ln S \quad \text{where} \quad S = \lambda \quad \text{or} \quad M_{gas} \quad \text{or} \quad L_k, \cdots$$

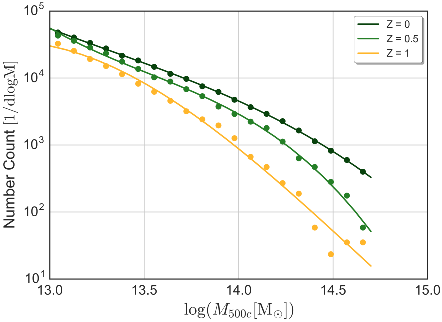
and the observable is $N_{\Delta \ln(S), \Delta z}$

- In general α can run with mass
- The Model assumes log-normal distribution

A model for mass function

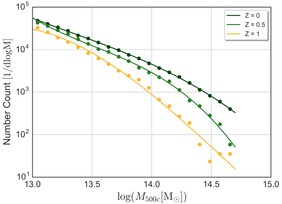
Because the form of the mass function, $\frac{dn(\mu,z)}{d\mu}$, as a function of $\mu \equiv \ln(M/M_p)$ is smooth, according to Evrard et al (2014), one can use a polynomial expansion to fit the mass function. Here M_p is a free pivot mass with characteristic value of $10^{14}\ M_\odot$. We take a 3^{rd}-order polynomial approximation to the mass function

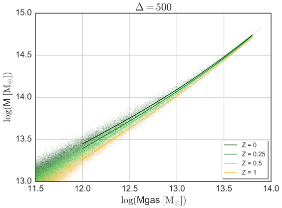
$$\frac{dn(\mu,z)}{d\mu} = \exp\left[\beta_0 + \beta_1\ \mu + \beta_2\ \mu^2 + \beta_3\ \mu^3\right]$$

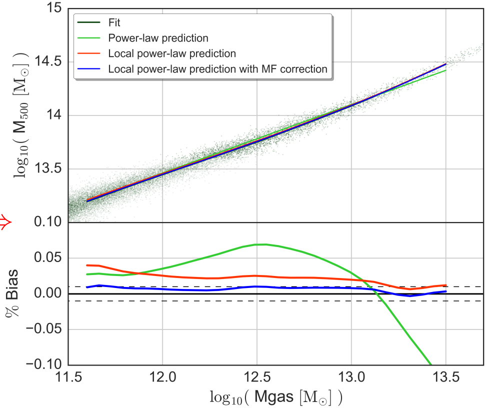


Points = BAHAMAS counts as function of total mass
Lines = fits using pivot mass of $10^{14}\ M_\odot$

Test #1: log-mean total mass at fixed M_{gas}



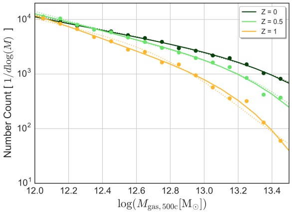


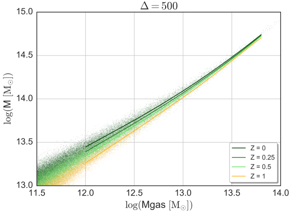


Observables [Input]

Inferred $\langle \log(M) \rangle$ [Output - only redshift zero]

Test #2: recovering MF shape parameters





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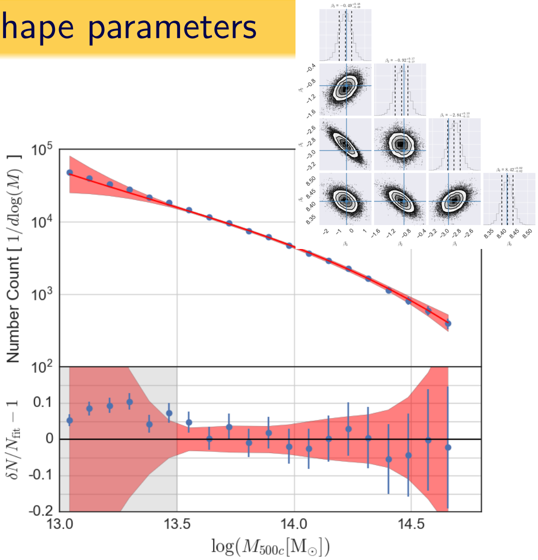

Observables [Input]

Inferred MF [Output - only redshift zero]

Conclusion

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- Scaling Parameters run with the halo mass
- Log-normal model is an adequate model to study Galaxy Clusters scaling relation
- The most massive clusters are well approximated by "close box" models
- Evrard et al. (2014) is a sufficient model to characterize the cluster population