The Impact of Cluster Physics on Scatter in Cluster Scaling Relations

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Collaborators

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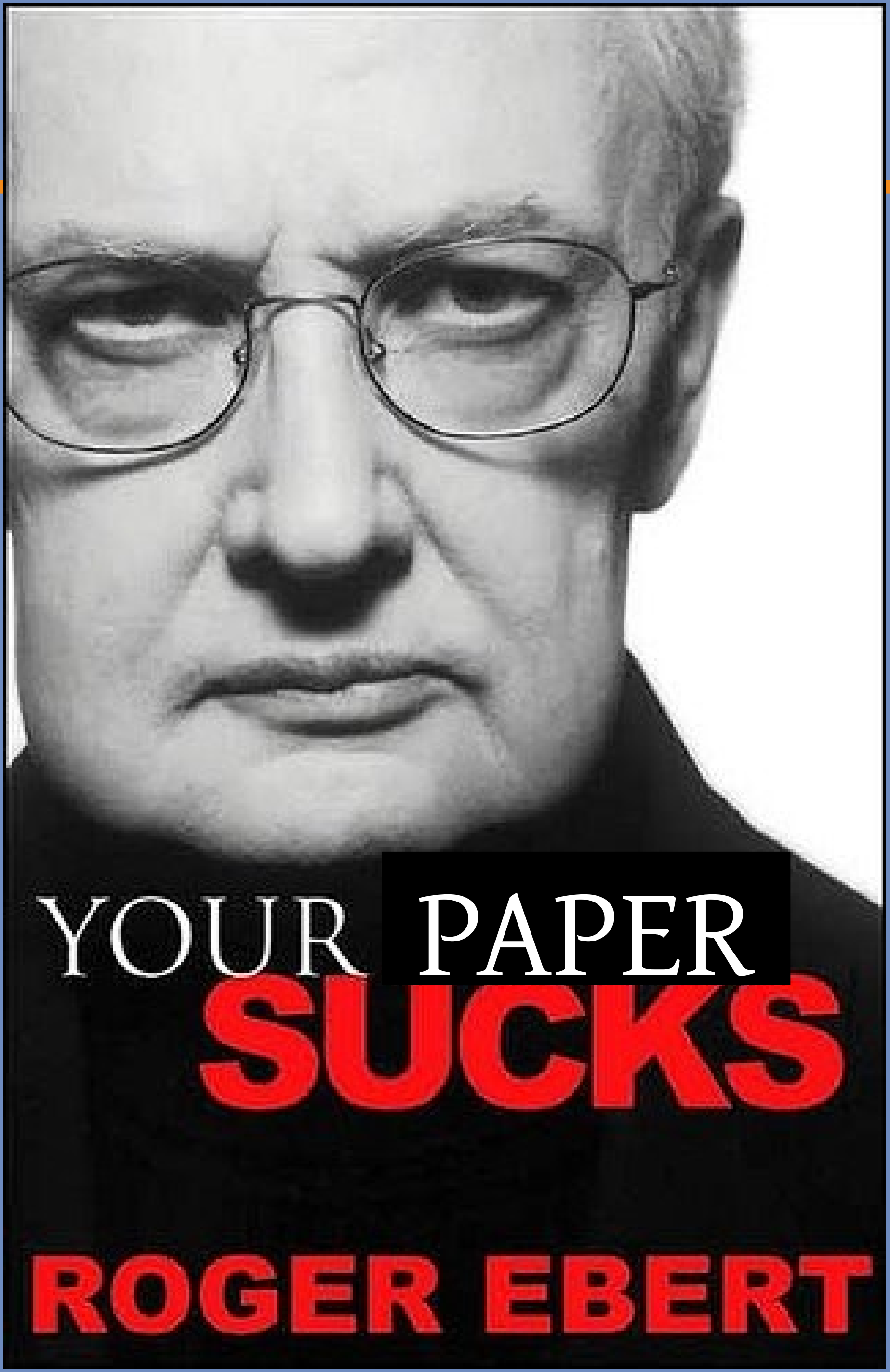
Sutter, Yang, & Ricker 2010 in preparation
Yang, Bhattacharya, & Ricker 2010 ApJ, submitted
Sutter & Ricker 2010 ApJ, submitted (arXiv:1006.2879)
Yang, Ricker, & Sutter 2009 ApJ, 699, 315
Yang, Ricker, & Sutter 2009 arXiv:0909.1574 (Monster's Fiery Breath)
Sutter, Ricker, & Yang 2009 arXiv:0911.1029 (Monster's Fiery Breath)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ROGER EBERT

Cluster masses are useful for cosmology...

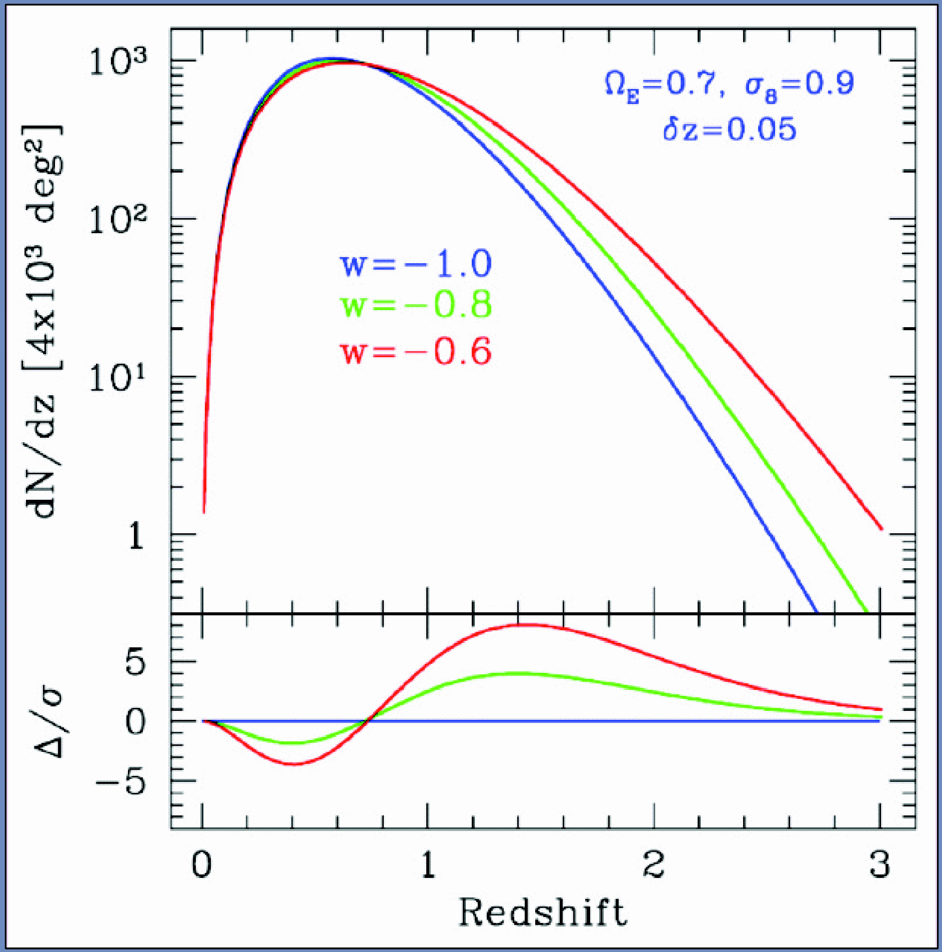
Cluster abundance as a function of mass and redshift

$$\frac{d^2 N}{dM\, dz} = \frac{dV}{dz} n(M, z)$$

$$n(M, z) \propto \frac{\rho_b}{\sigma M} \int_{\delta_c}^{\infty} d\delta \, \exp\left(-\frac{\delta^2}{2\sigma^2}\right)$$

Depends on:

- Volume-redshift relation dV/dz
- Linear growth factor ($\rightarrow \delta(z)$)
- Power spectrum ($\rightarrow \sigma(M,z)$)



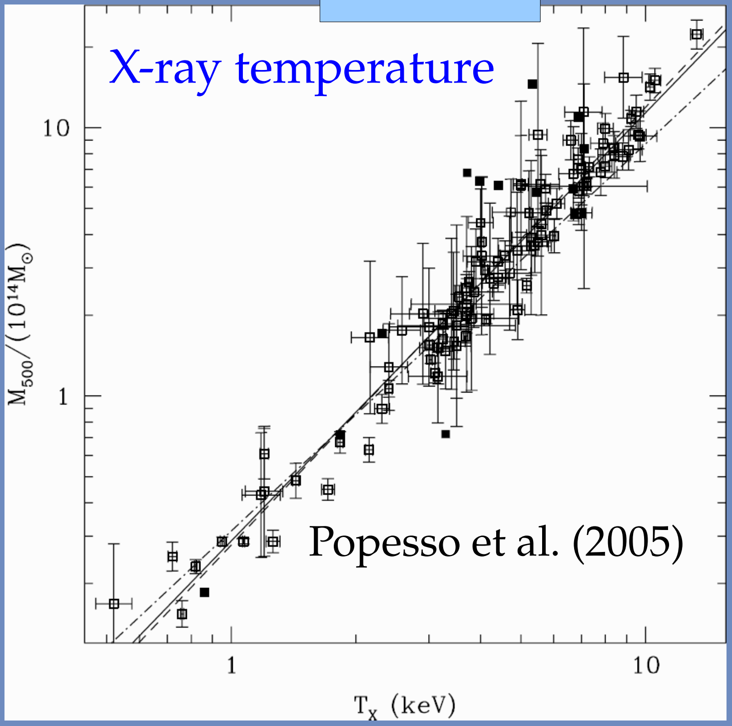
Mohr (2005)

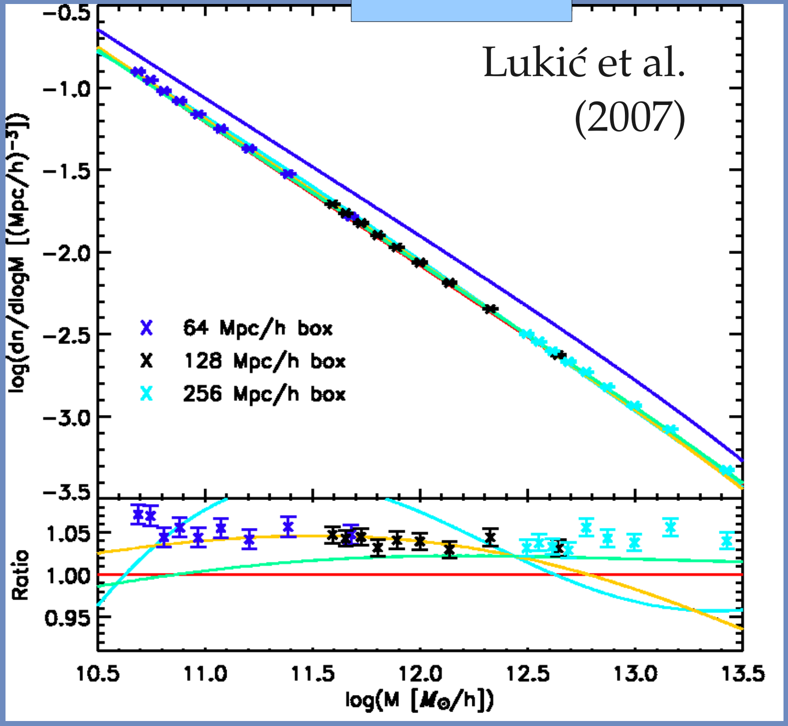
… but they must be measured via proxies

$$P(X|\text{cosmology}) \approx \underbrace{P(X|M,\eta_1,\eta_2,\ldots)}_{\text{Mass-observable relation}}\ \underbrace{P(M,\eta_1,\eta_2,\ldots|\text{cosmology})}_{\text{Mass function}}$$

Scaling relations

N-body





Systematic exploration of scatter

- **Physics**
  - Adiabatic hydro (dynamical state + history)
  - Cooling + AGN
  - Magnetic fields
  - Conduction and viscosity
  - Cosmic rays
- **Observables**
  - X-ray
  - Sunyaev-Zel'dovich effect
  - Lensing mass
  - Optical richness
  - Radio

Fully cosmological simulations

Cosmology and physics

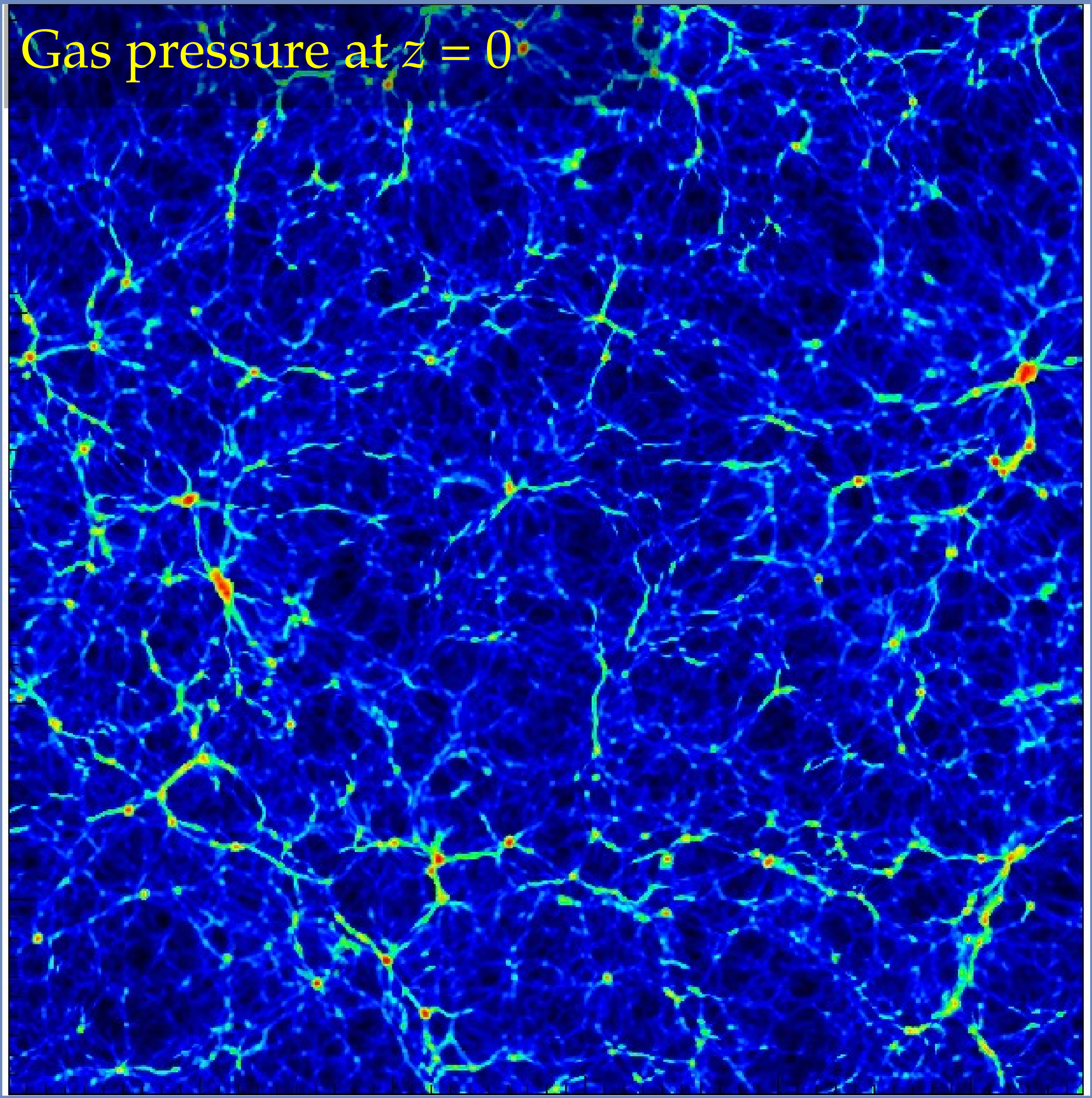
- ΛCDM cosmology: $\Omega_{m0} = 0.262$, $\Omega_{b0} = 0.0437$, $h = 0.708$, $\sigma_8 = 0.74$
- Dark matter + hydro

Numerics

- FLASH 2.4-uiuc
- 256 h^{-1} Mpc box
- 1024^3 particles, 1024^3 grid
- Particle mass $1.3 \times 10^9\ M_\odot$

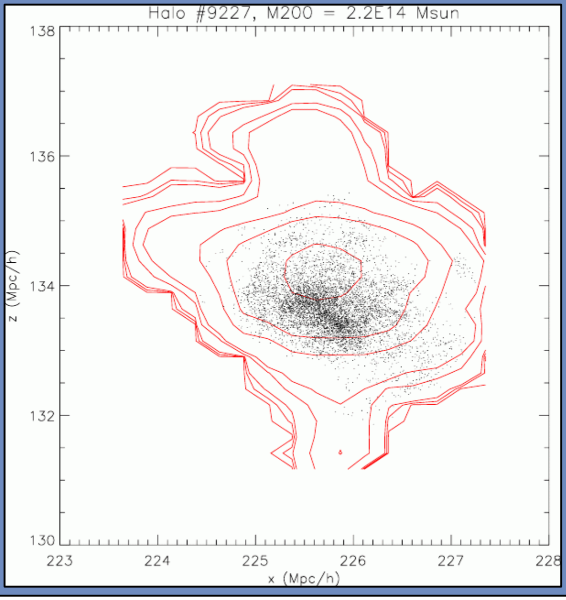
Outcome

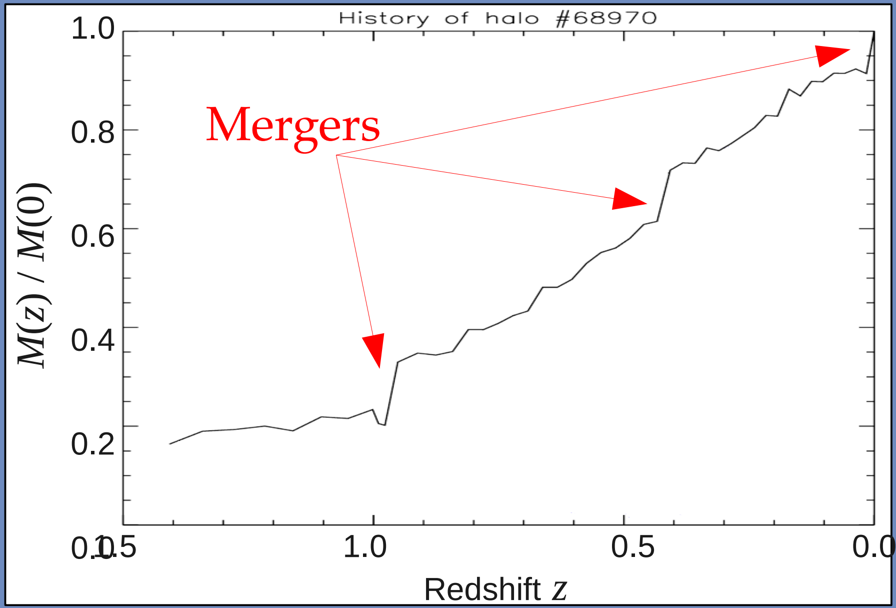
- 336/622 merging at $z = 0$ ($M_{500c} > 2\times10^{13}\ M_\odot$)



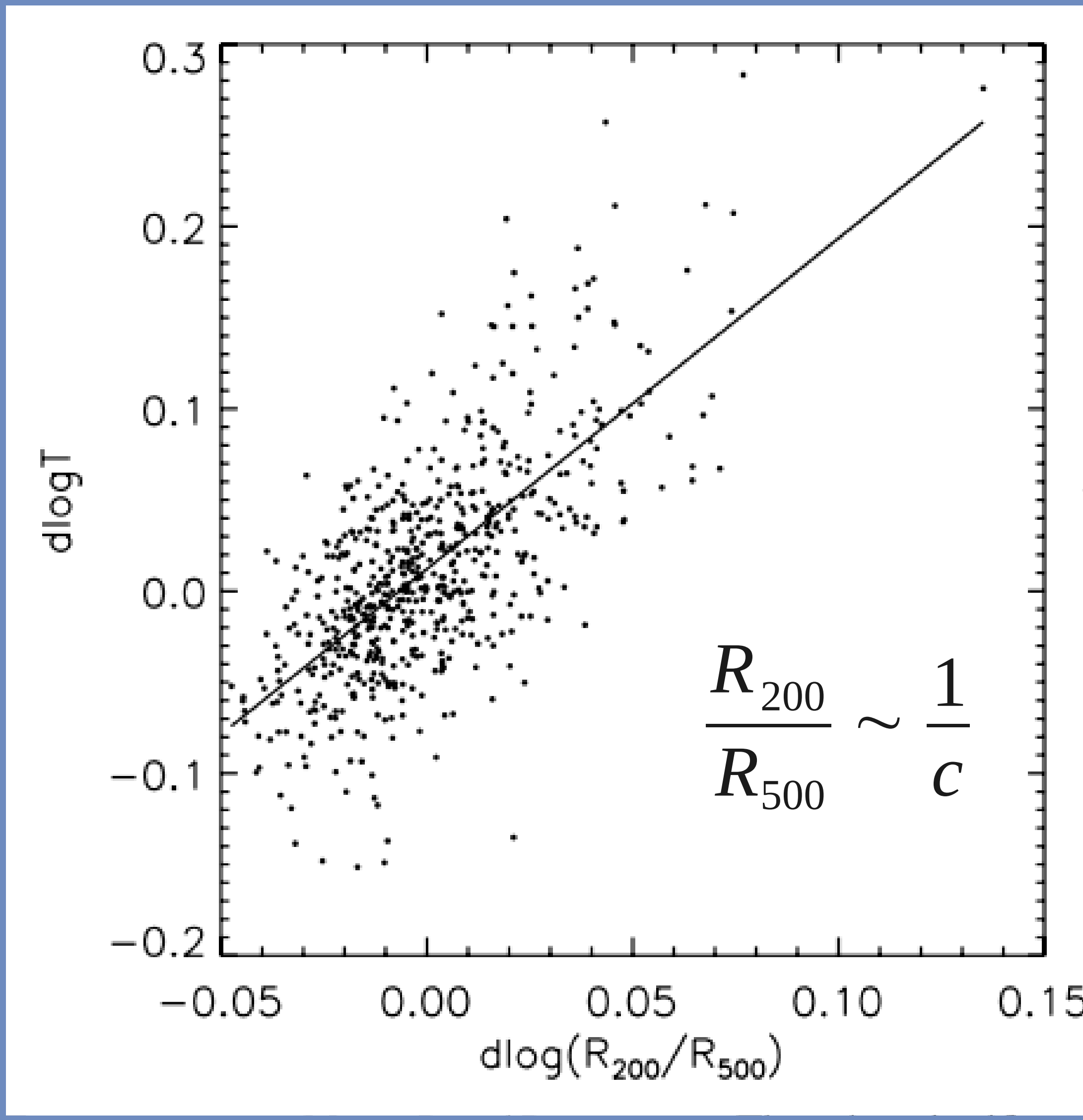
Dynamical state measures

- **Centroid offset** (Mohr et al. 1995)
- **Multipole power** (Buote & Tsai 1995, 6)
- **Merger history** (Cohn & White 2005)
  - Use particle tags to trace halo progenitors
  - Identify merging events using
    - *Mass jump* – ratio of halo mass to mass of largest progenitor
    - *Mass ratio* – ratio of masses of two largest progenitors





Mass-temperature vs. dynamical state



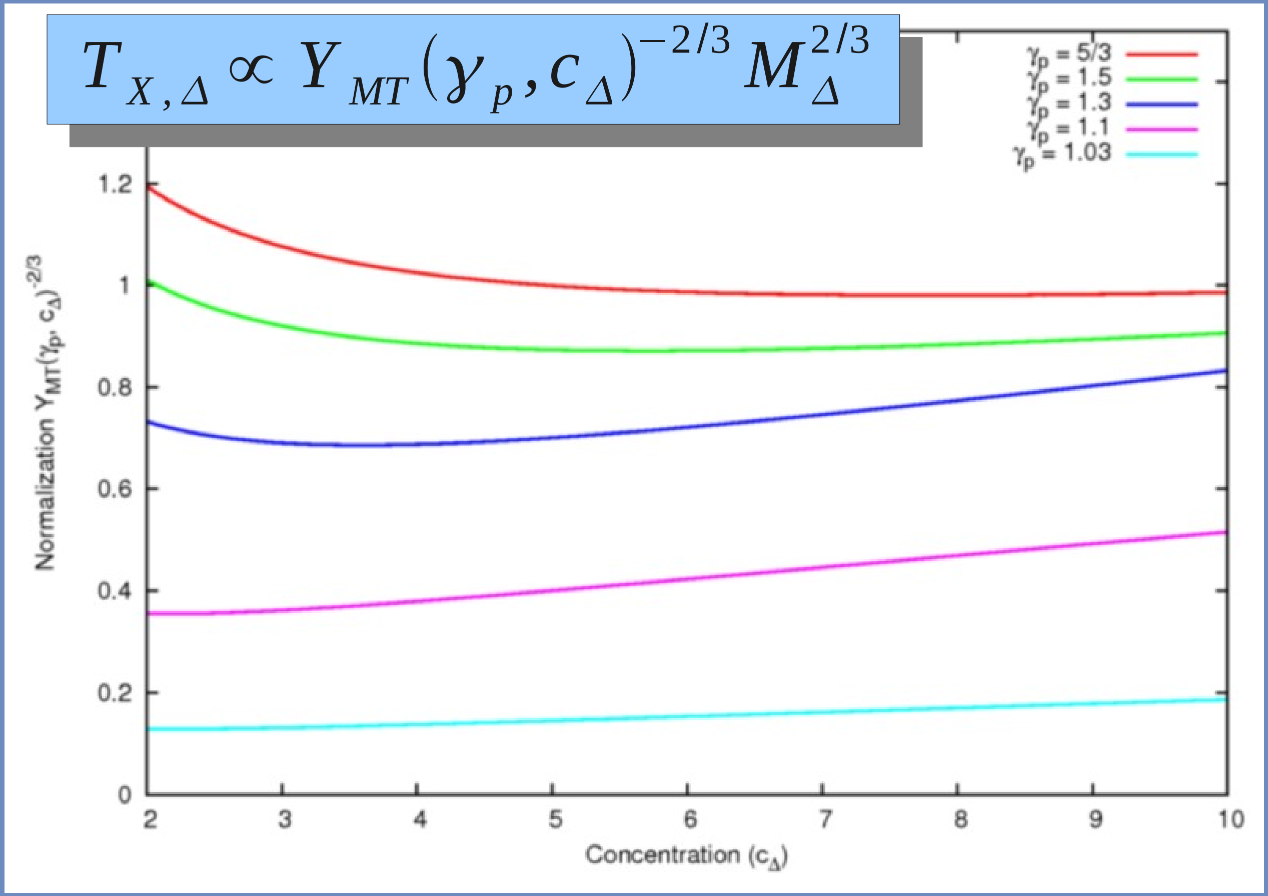
Yang, Ricker, & Sutter (2009)

- At best a weak anticorrelation in scatter vs. dynamical state
- Power ratios do not provide unambiguous indicator of recent merging
- Instead see a correlation of scatter with halo concentration – formation time important?

Answer to Doug's question

- Sense of correlation disagrees with Shaw et al. 08
- Difference lies in equation of state (Ascasibar et al. 06)
  - Polytropes $P \propto \rho^{\gamma_p}$
  - Extra physics reduces γ_p from $5/3 \rightarrow 1$
  - Slope flattens and then changes sign as γ_p decreases

$$T_{X,\Delta} \propto Y_{MT}(\gamma_p, c_\Delta)^{-2/3} M_\Delta^{2/3}$$



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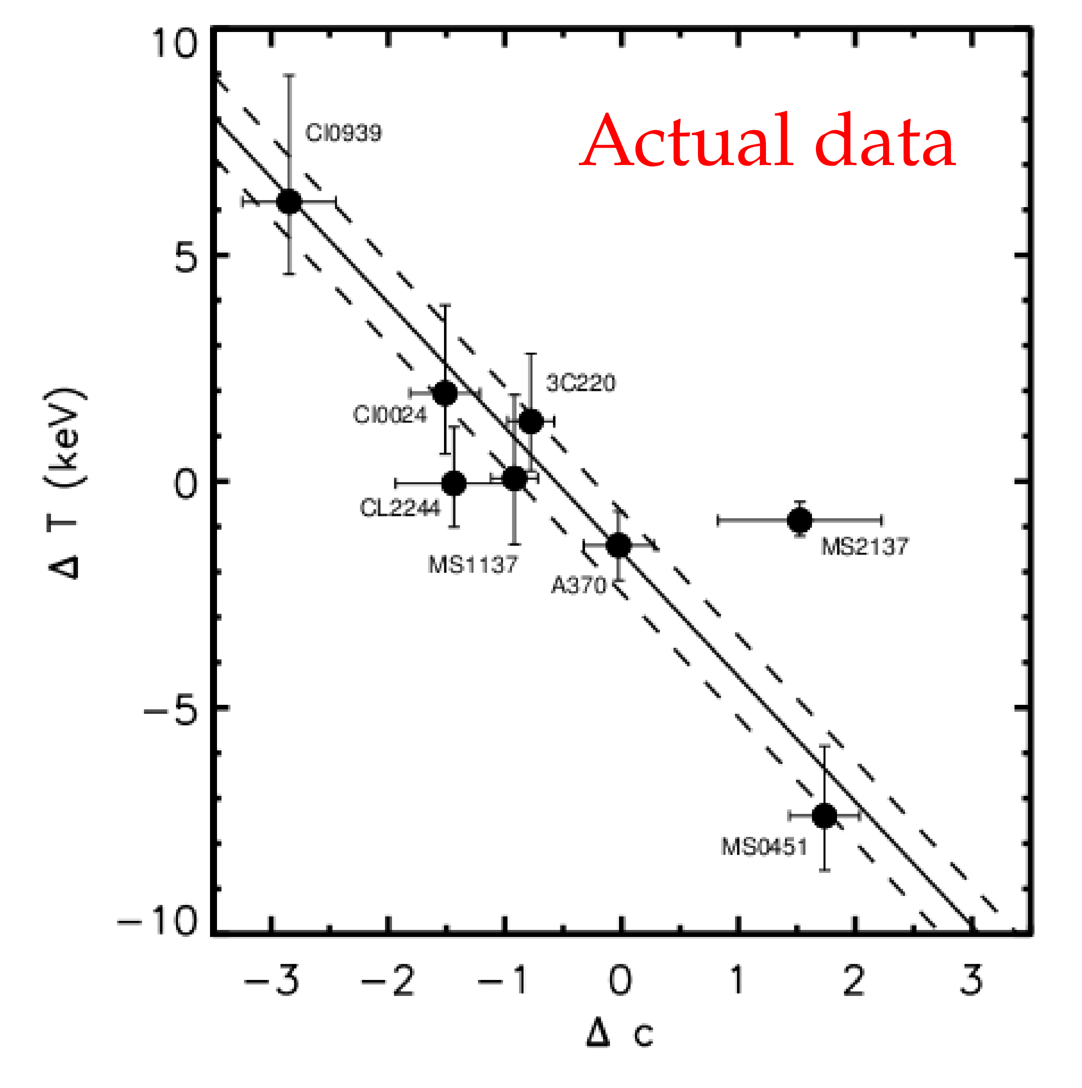
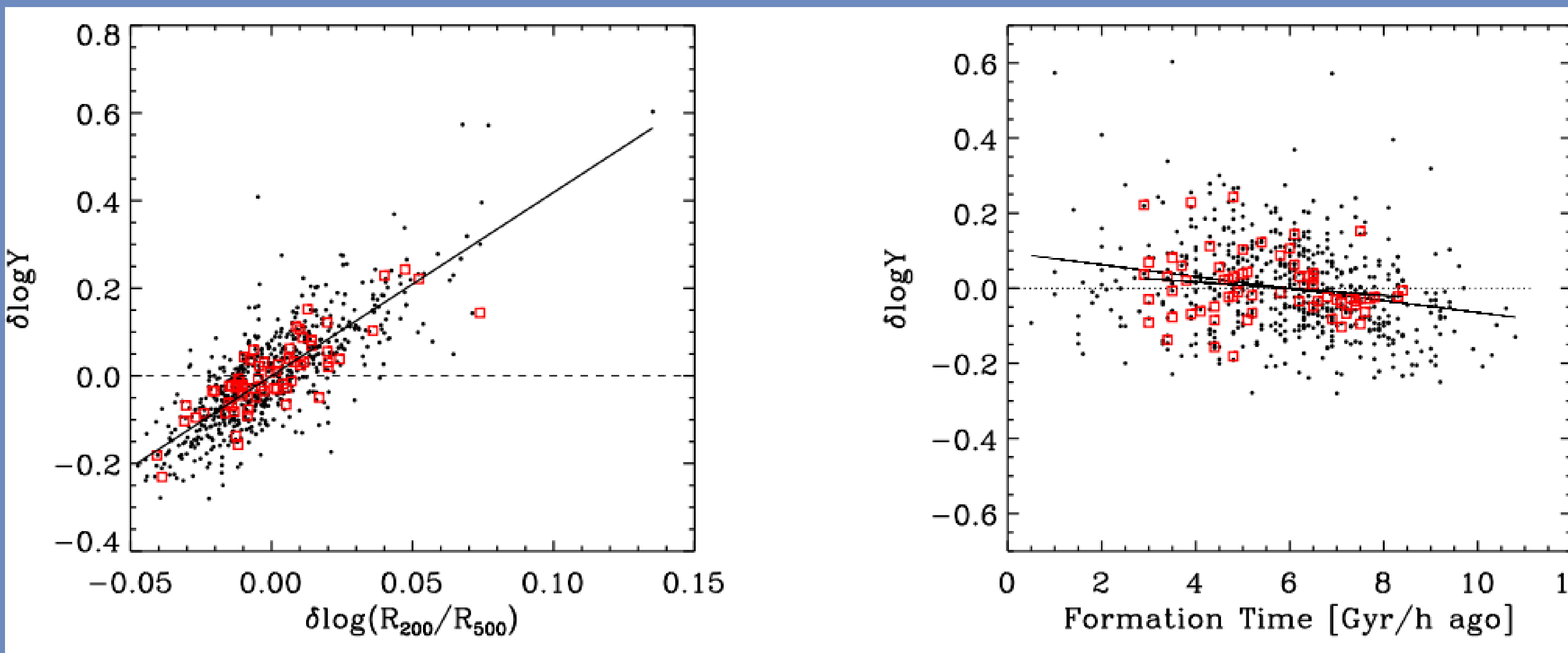


Comerford et al. (2010)

Mass-SZ effect vs. dynamical state

Yang, Bhattacharya,
& Ricker (2010)



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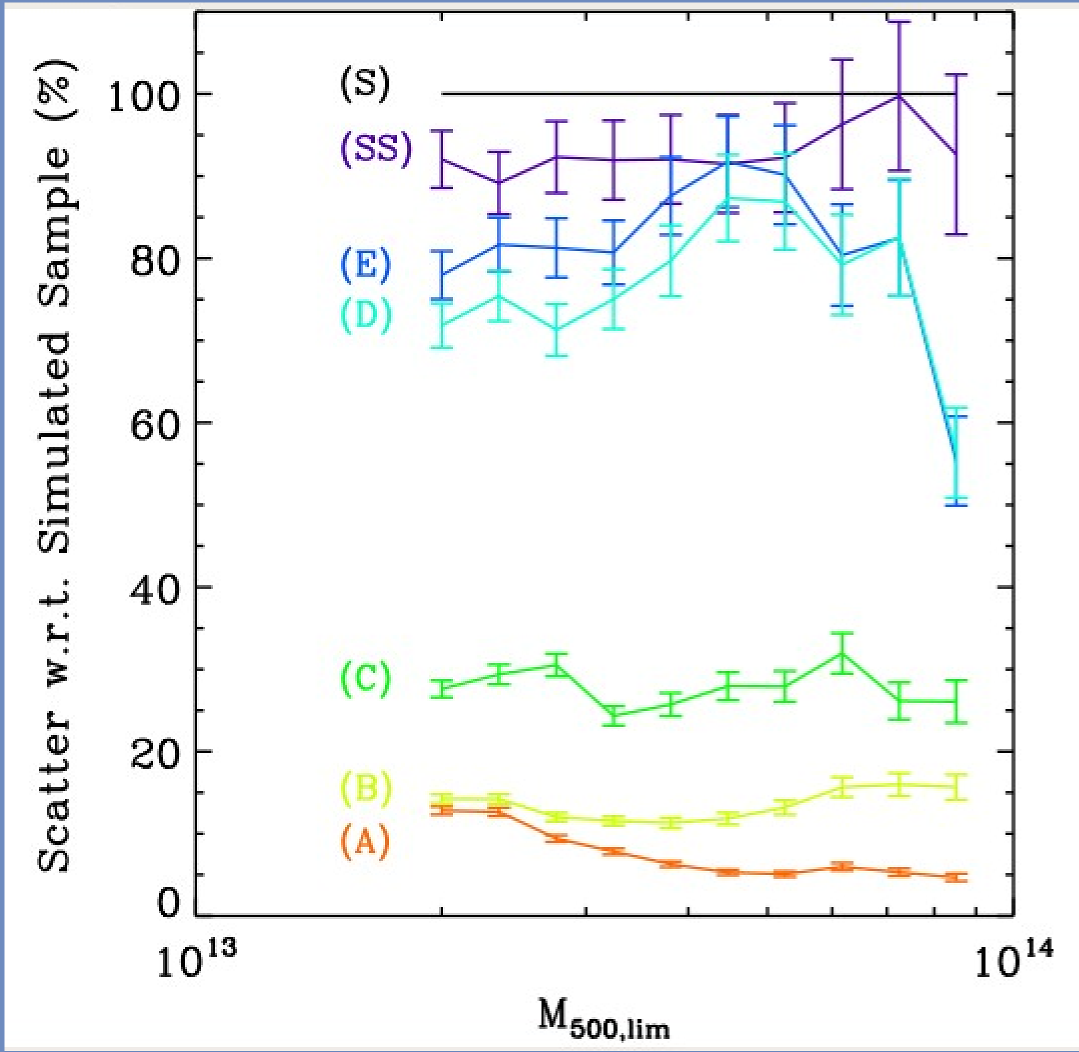


Simulation

Simulation (spherical)

Spherical

Spherical + gas fraction

Spherical + gas fraction + no merger boost

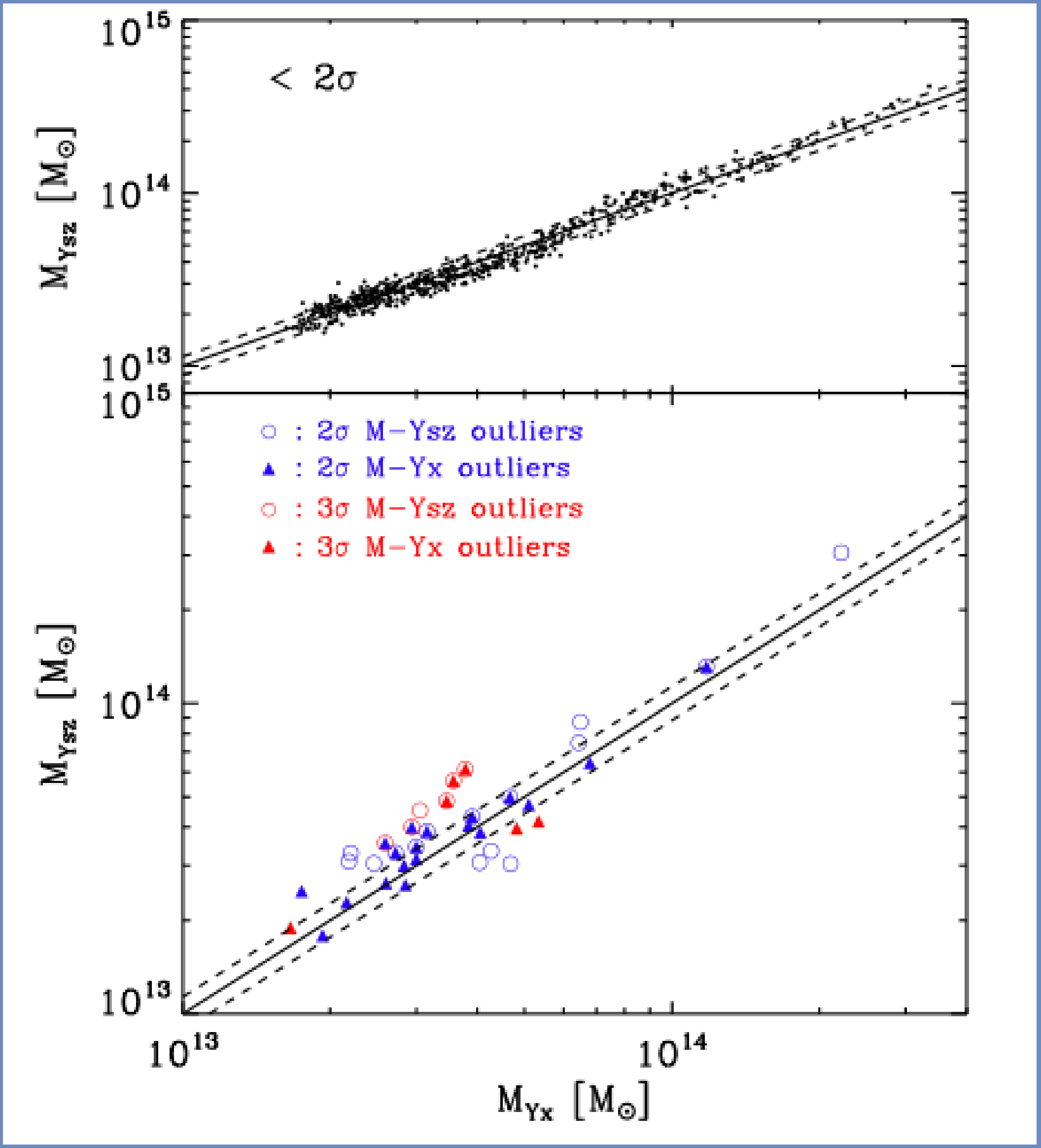
Spherical + gas fraction + hydrostatic

Spherical + gas fraction + hydrostatic + $c(M)$

Using multiple mass estimators

Yang, Bhattacharya, & Ricker (2010)

- Clusters that are outliers in both $M - Y_X$ and $M - Y_{SZ}$ have inconsistent mass estimates
- Offers hope that these cases can be excluded from samples

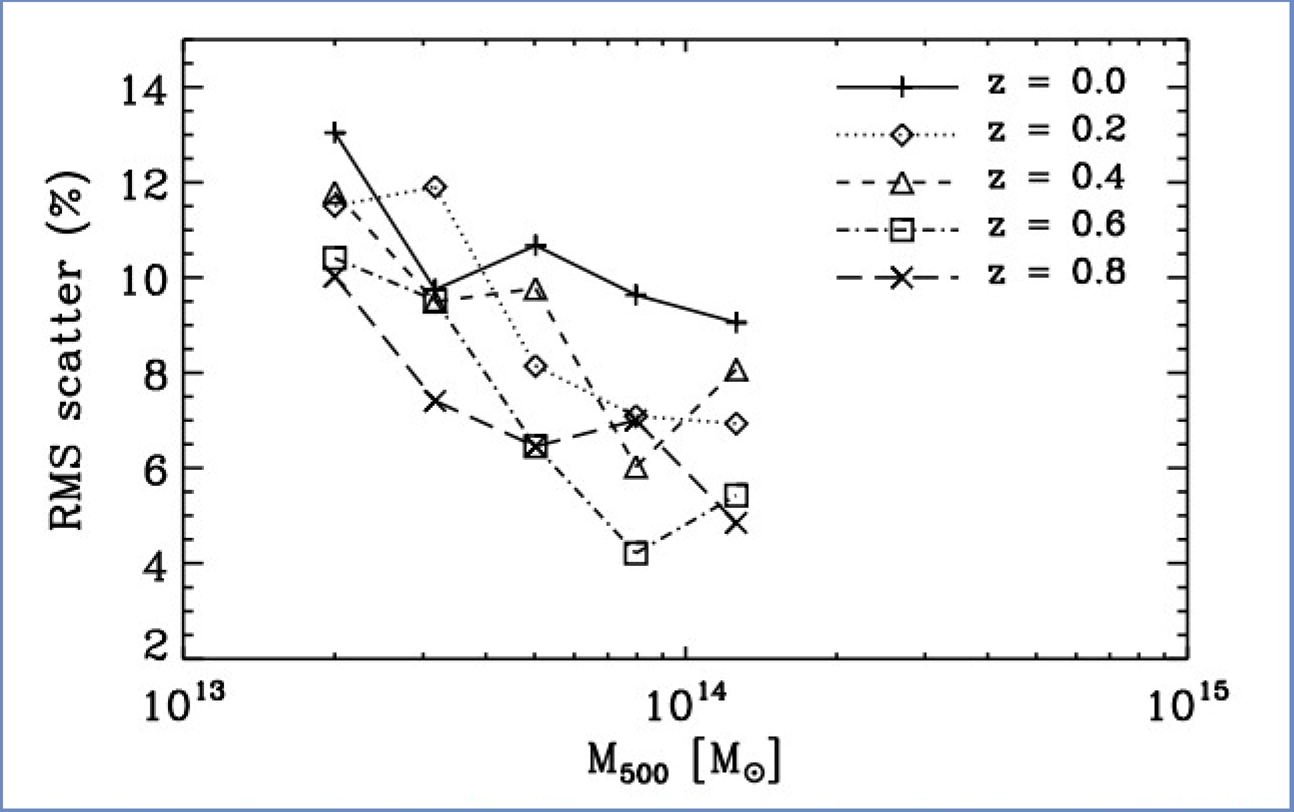


Guidance for self-calibrators

- Y-M scatter: (all within R_{500c})

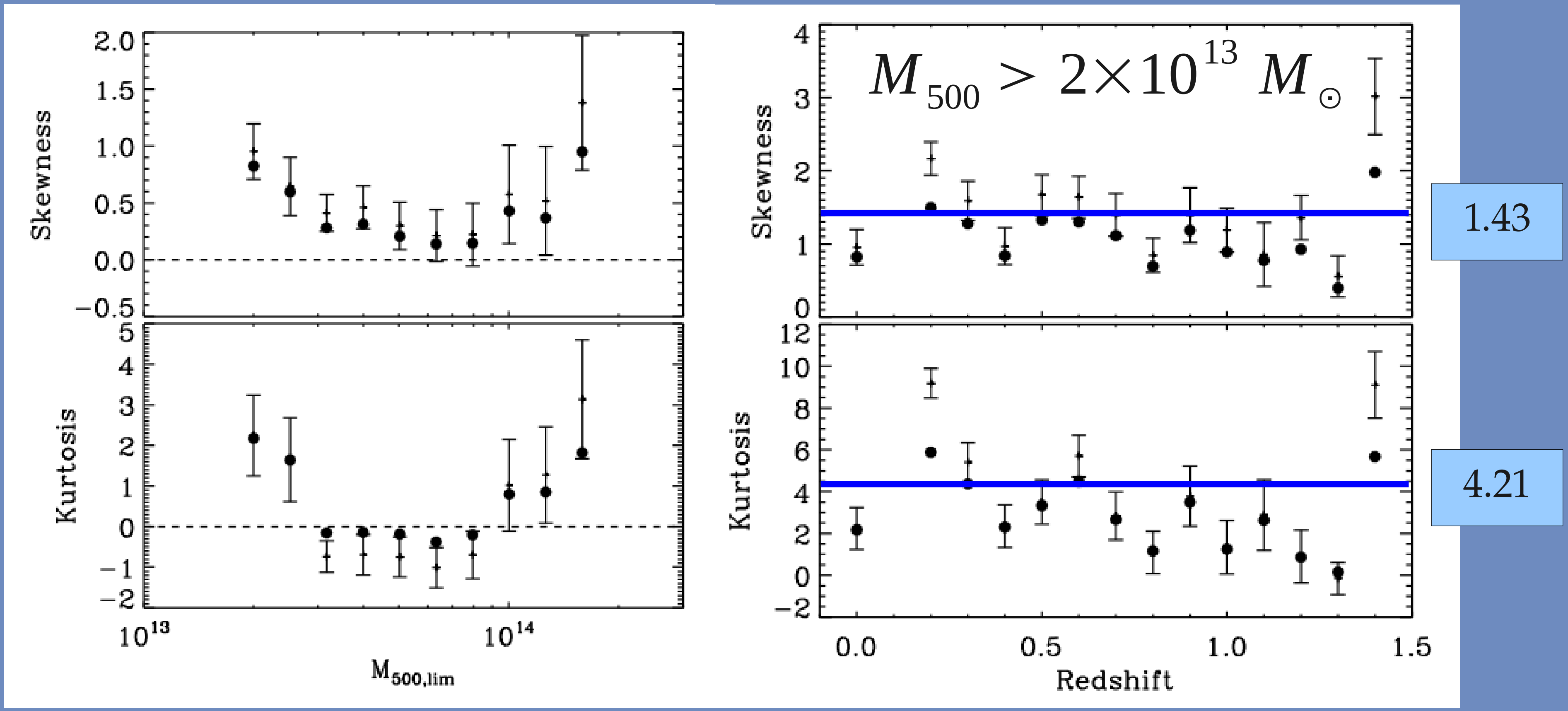
$$\sigma(M,z) = A \log M + B \log(1+z) + C$$

$$A = -7.06 \pm 0.28 \qquad B = -11.20 \pm 0.81 \qquad C = 7.70 \pm 0.19$$



Guidance for self-calibrators

- Deviations from gaussianity due to projection effects (low mass) and Poisson statistics (high mass)



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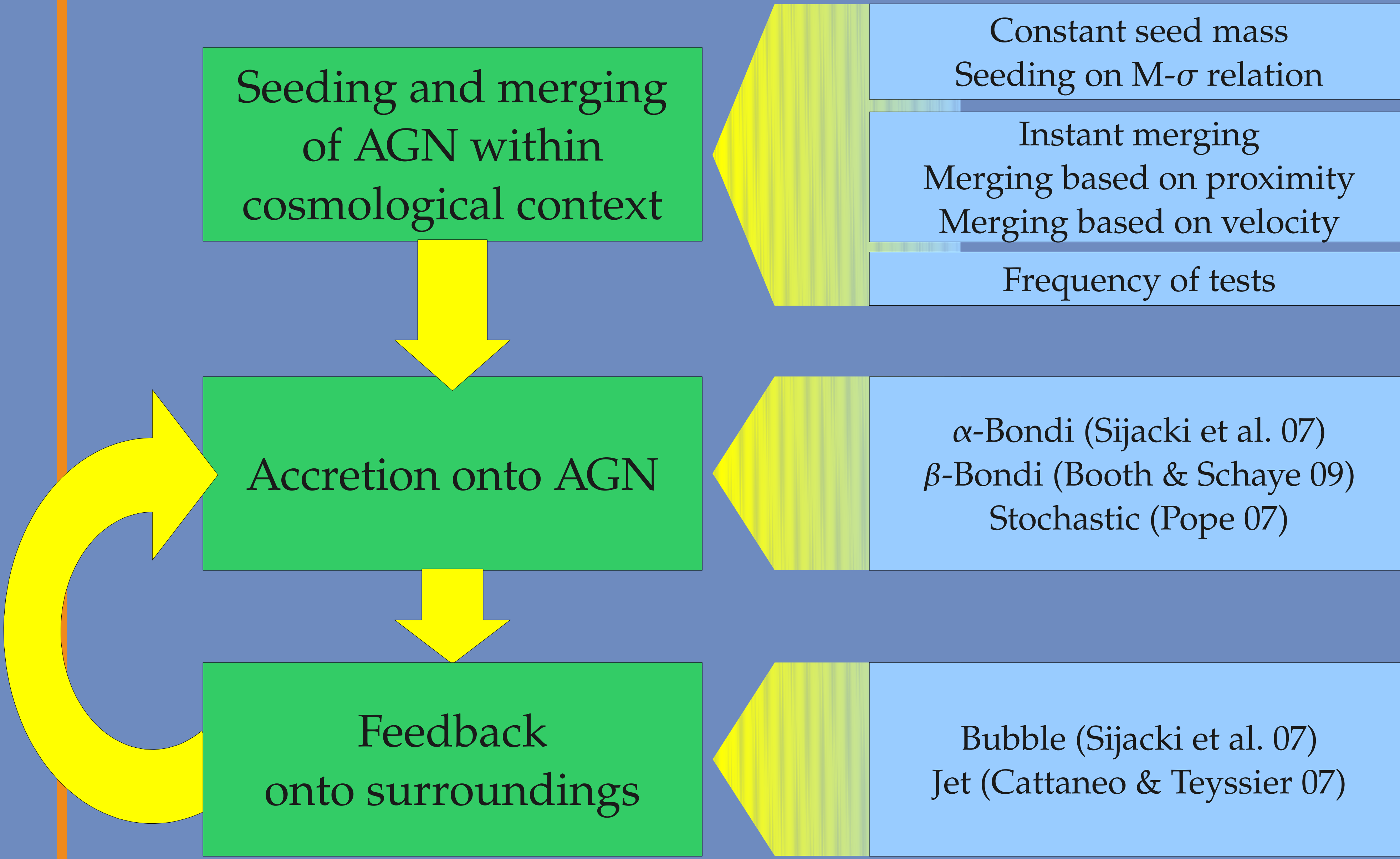
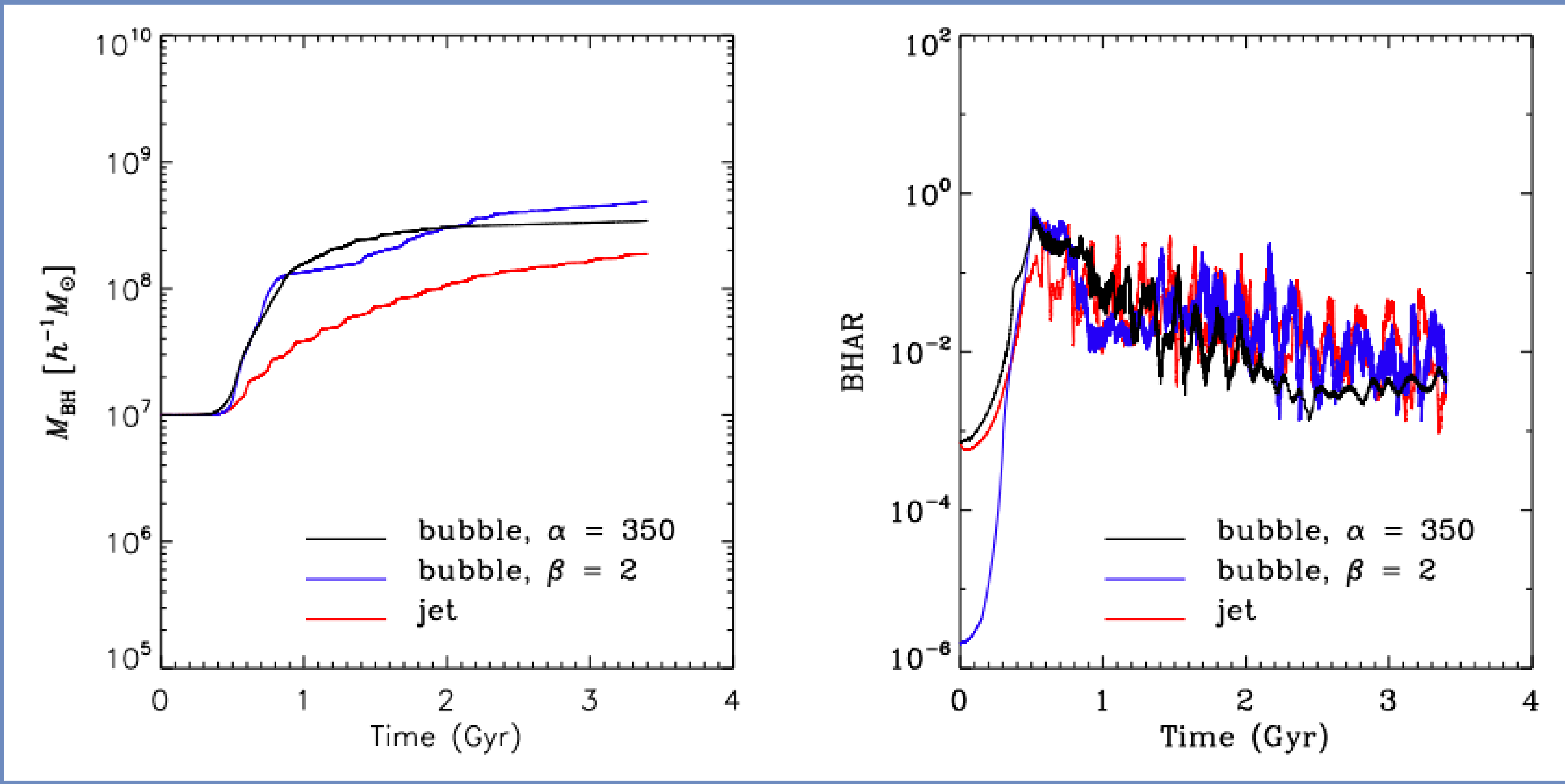
Components of an AGN subgrid model



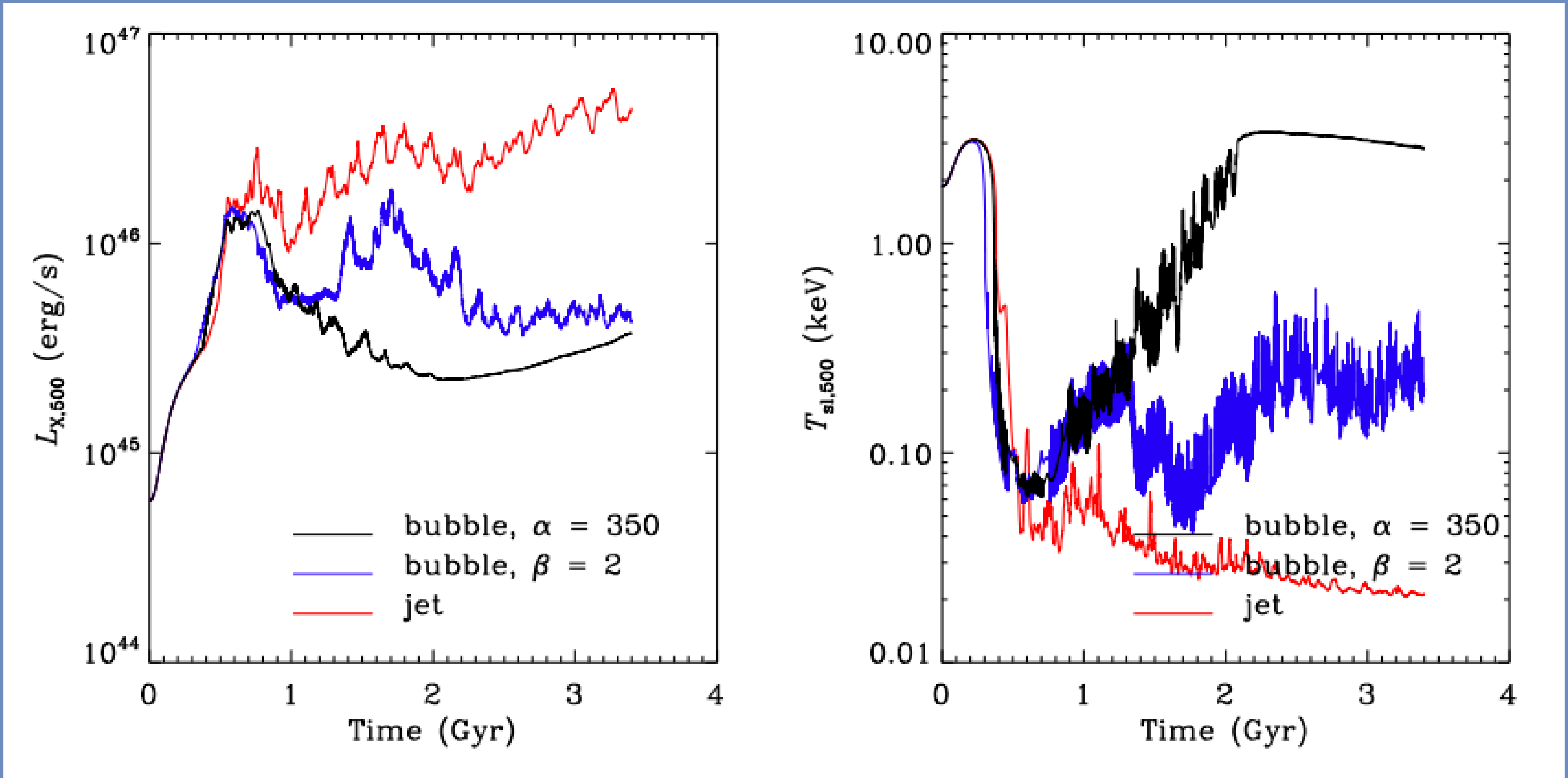
AGN accretion in single-cluster simulations

Yang, Ricker, & Sutter (2009, 2010 in prep.)



Effects of AGN in single-cluster simulations

Yang, Ricker, & Sutter (2009, 2010 in prep.)



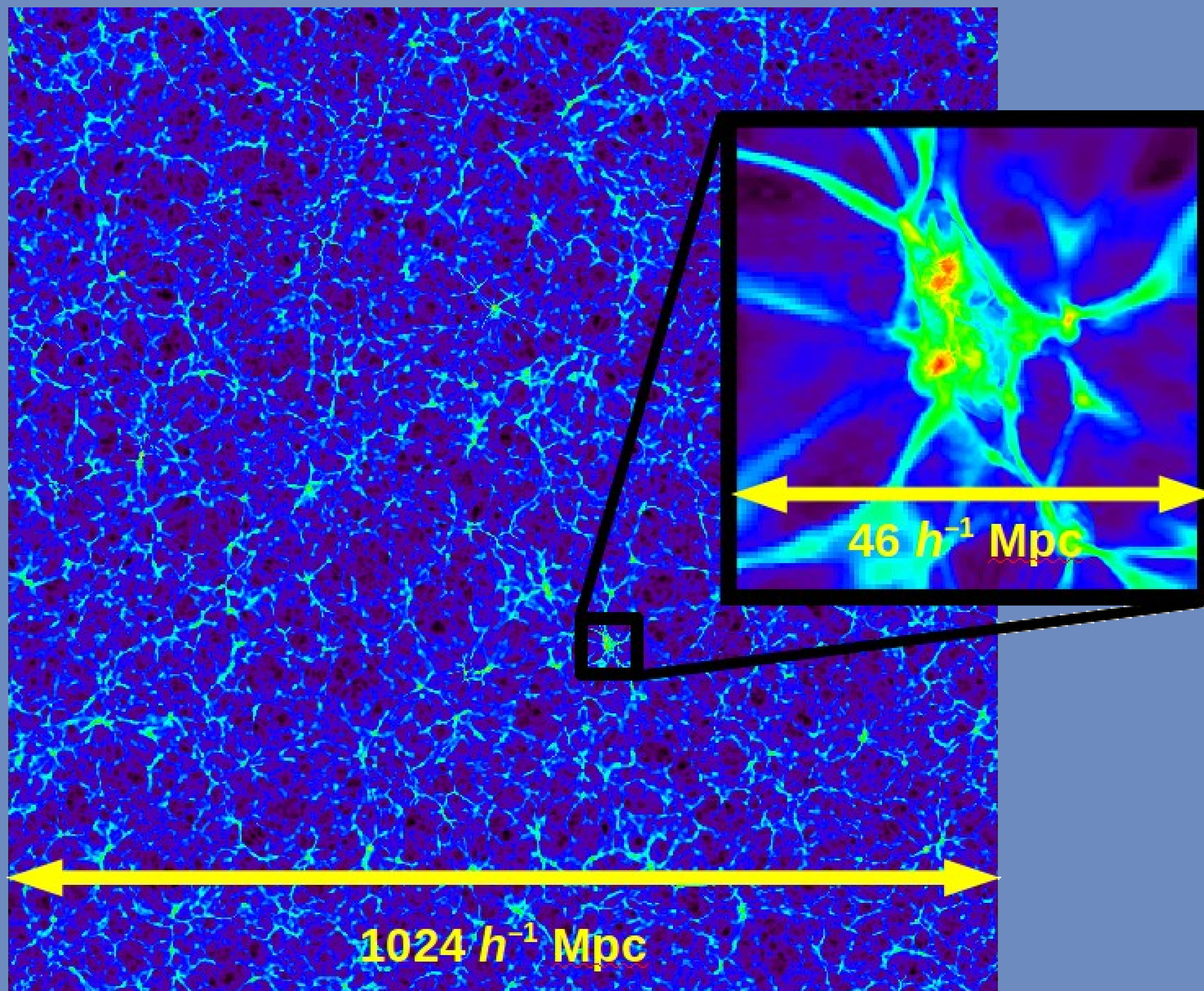
In the can

Sutter & Ricker (2010)

FLASH 3.2
Jaguar 14k cores
700k core-hr

Refined 100 randomly selected 50 Mpc regions about clusters

$L = 1024h^{-1}$ Mpc
$\Delta x_{min} = 31h^{-1}$ kpc



Conclusions

- Merging can skew observables that are sensitive to cluster cores
- However, integrated history and non-gravitational physics appear to be more important than recent mergers in driving mass-observable scatter
- Range of currently considered AGN subgrid models yields significant theoretical uncertainty in mass-observable scatter