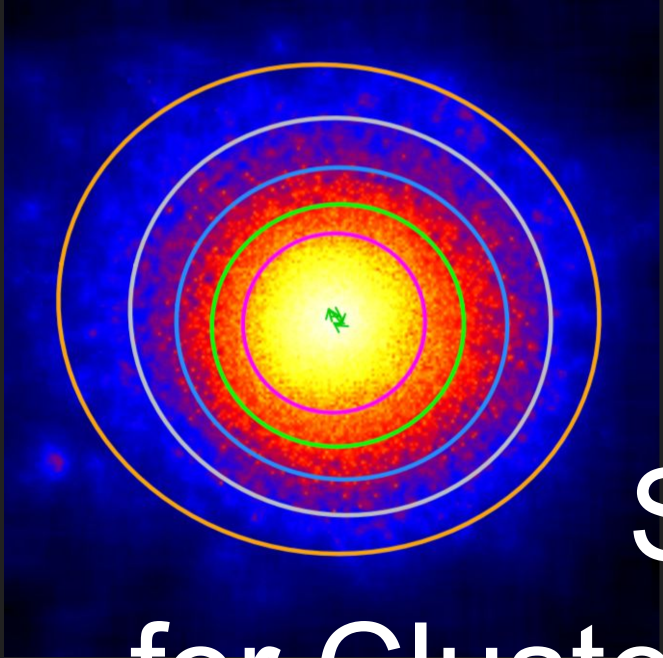
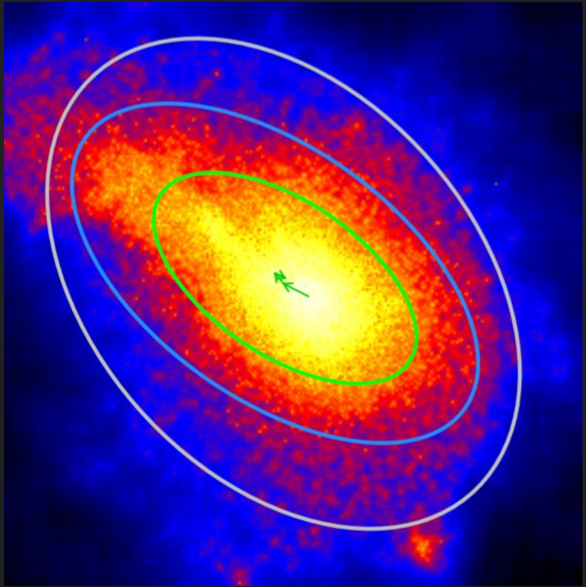




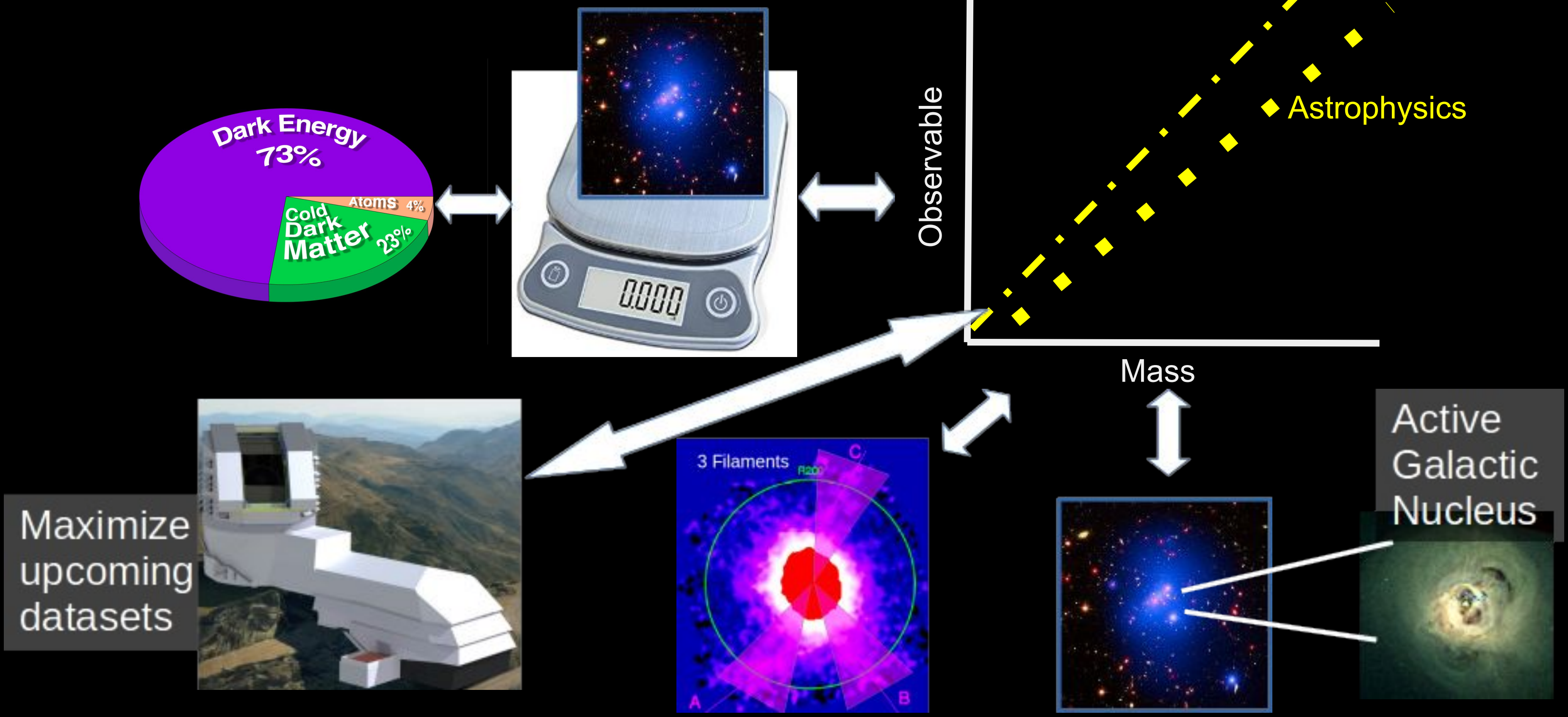
Simulations for Cluster-based Cosmology

Astronomy Colloquium
@LIneA, Webinar Colloquium

Camille Avestruz
U. Michigan, LSA Collegiate Fellow

UNIVERSITY OF MICHIGAN

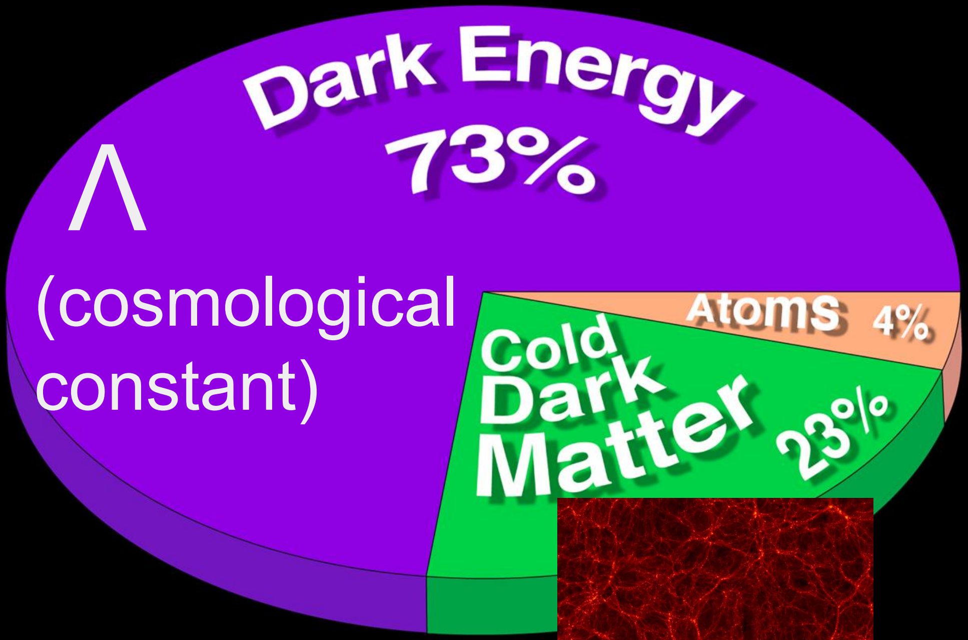
Upshot of talk in <3min

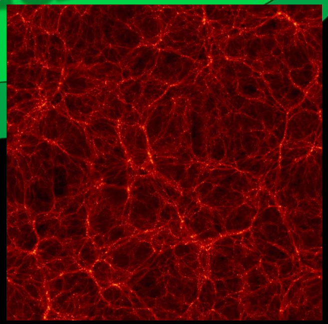


Energy budget of our universe (mostly unknown!)

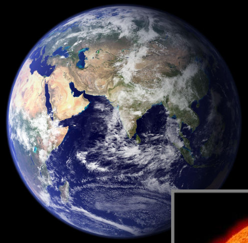
($E = mc^2$)

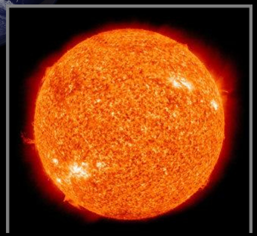
?



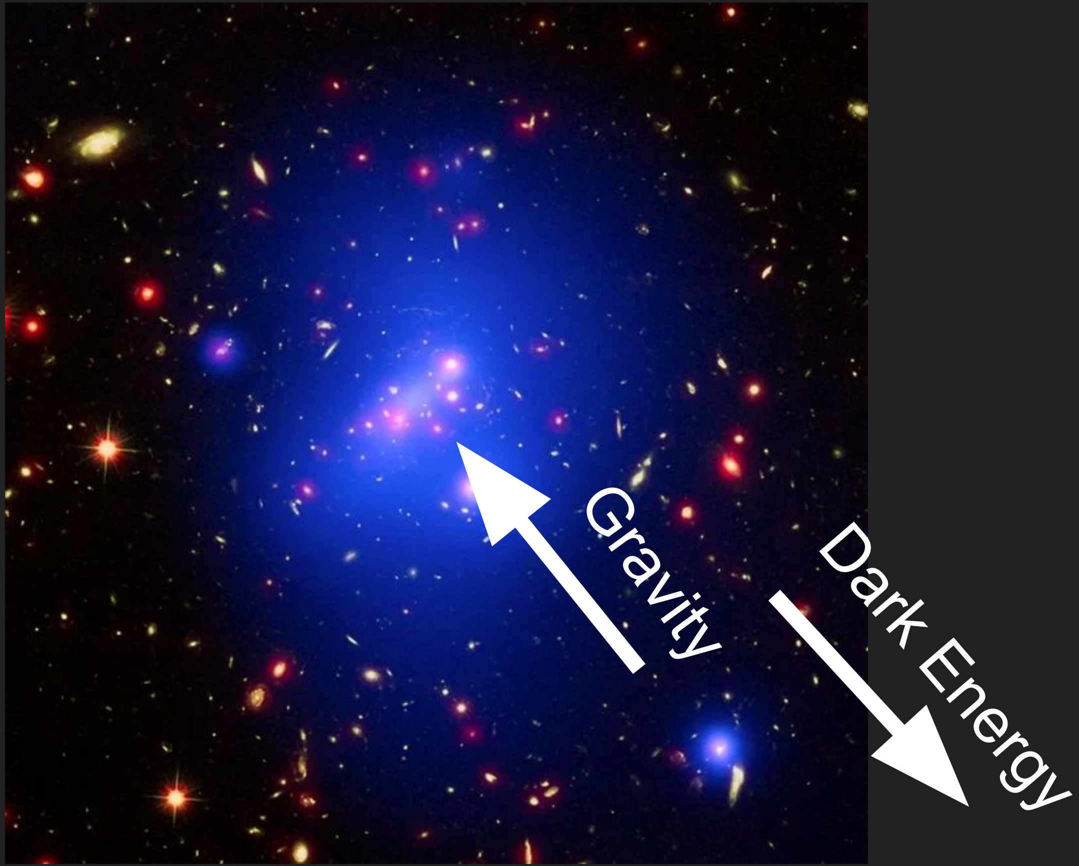


The earth, the sun, us...

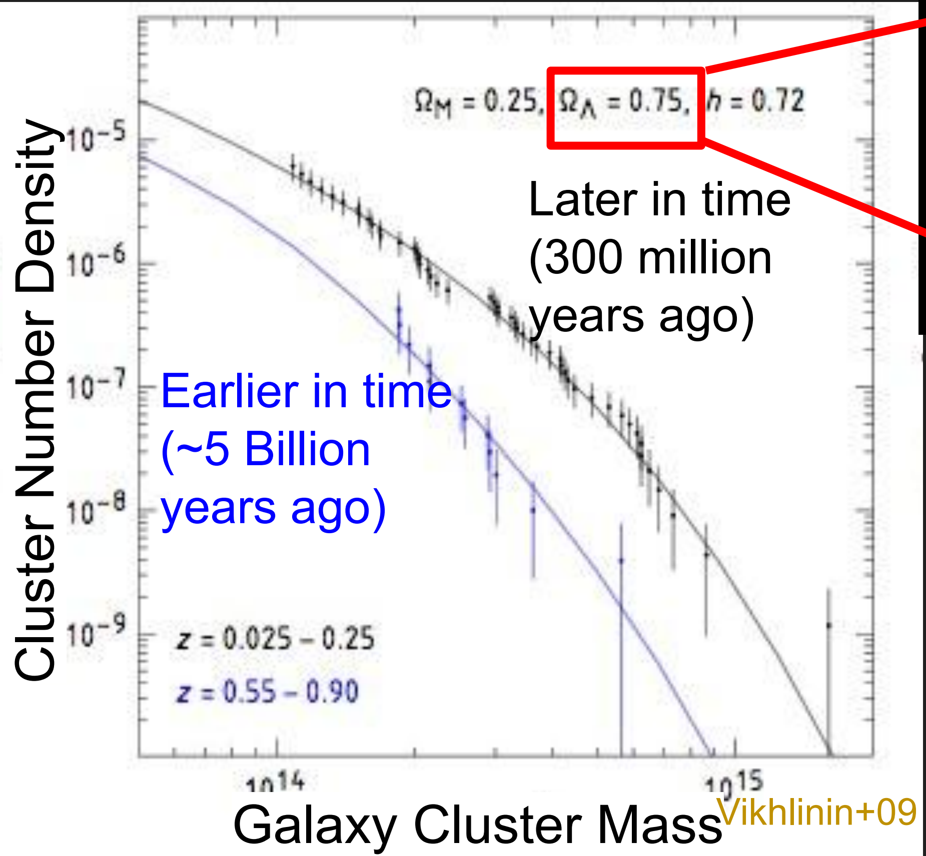


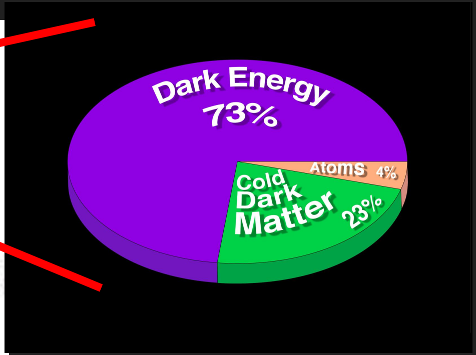


Galaxy clusters probe cosmology

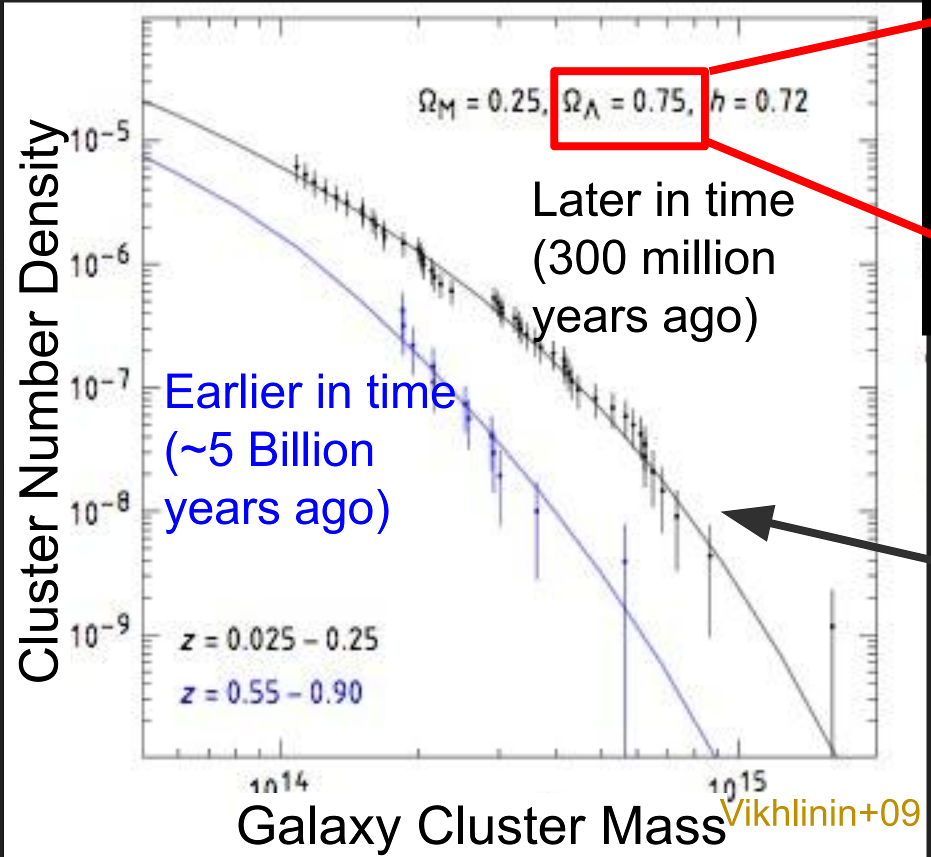


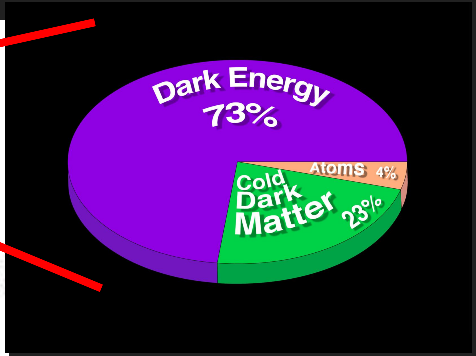
Number of galaxy clusters probe cosmology



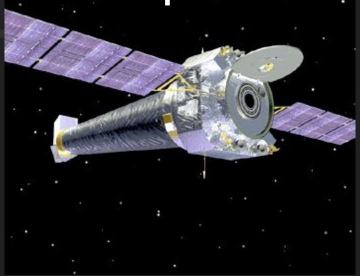


Number of galaxy clusters probe cosmology

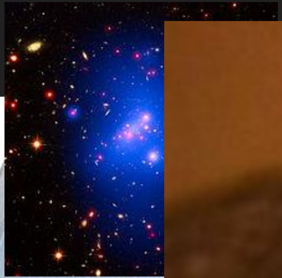




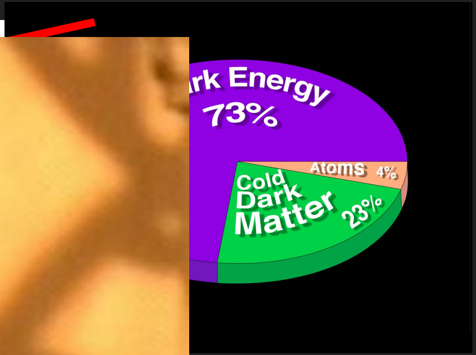
Masses from
Chandra X-ray
telescope



Number of galaxy clusters probe cosmology

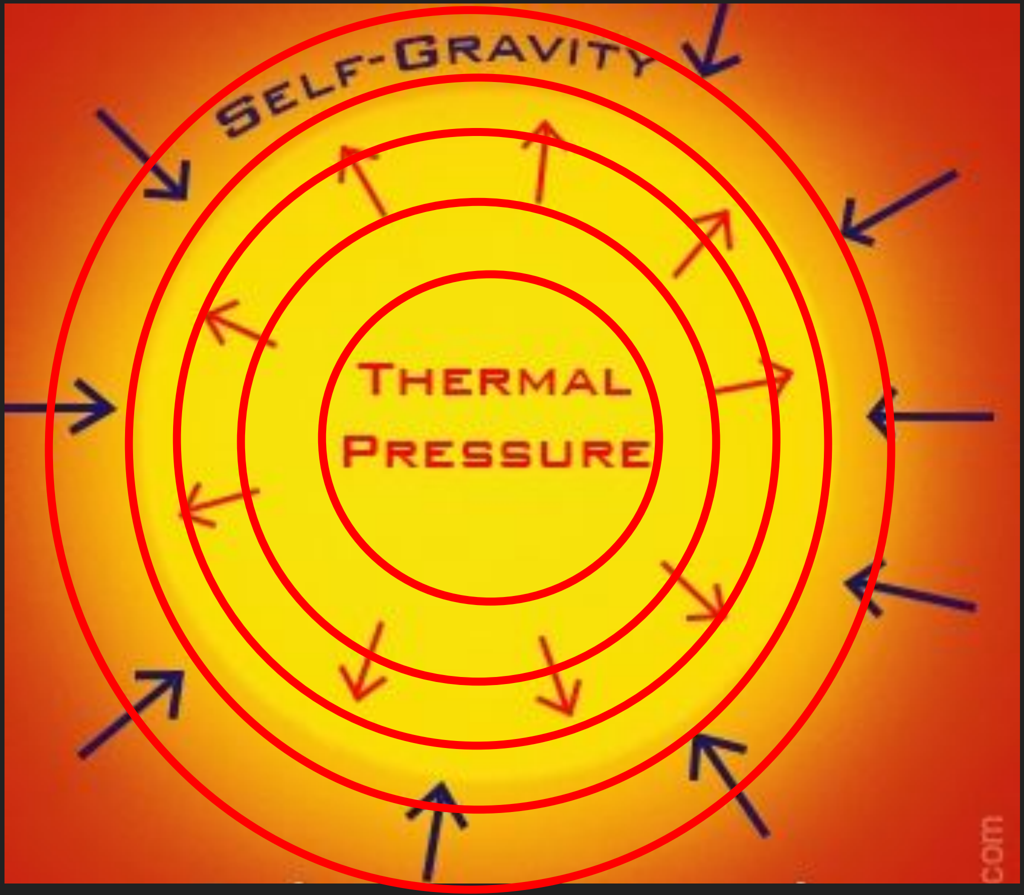


Galaxy Cluster Mass Vikhlinin+09

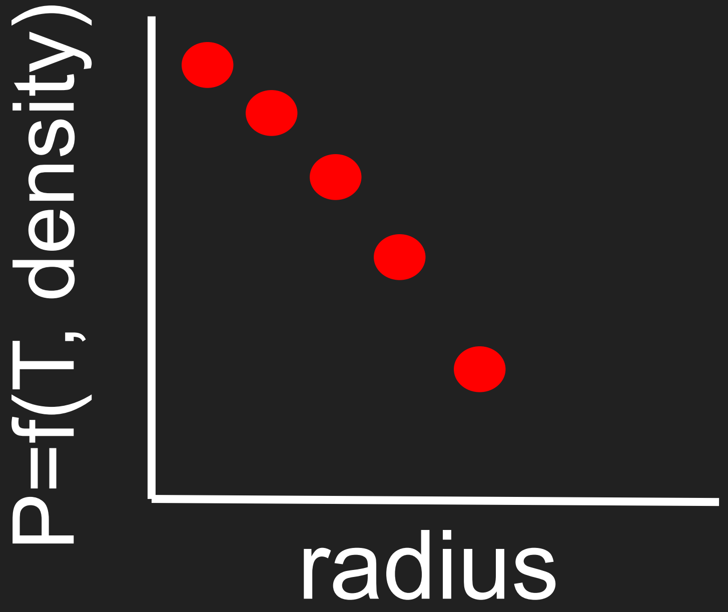


sses from
andra X-ray
escope

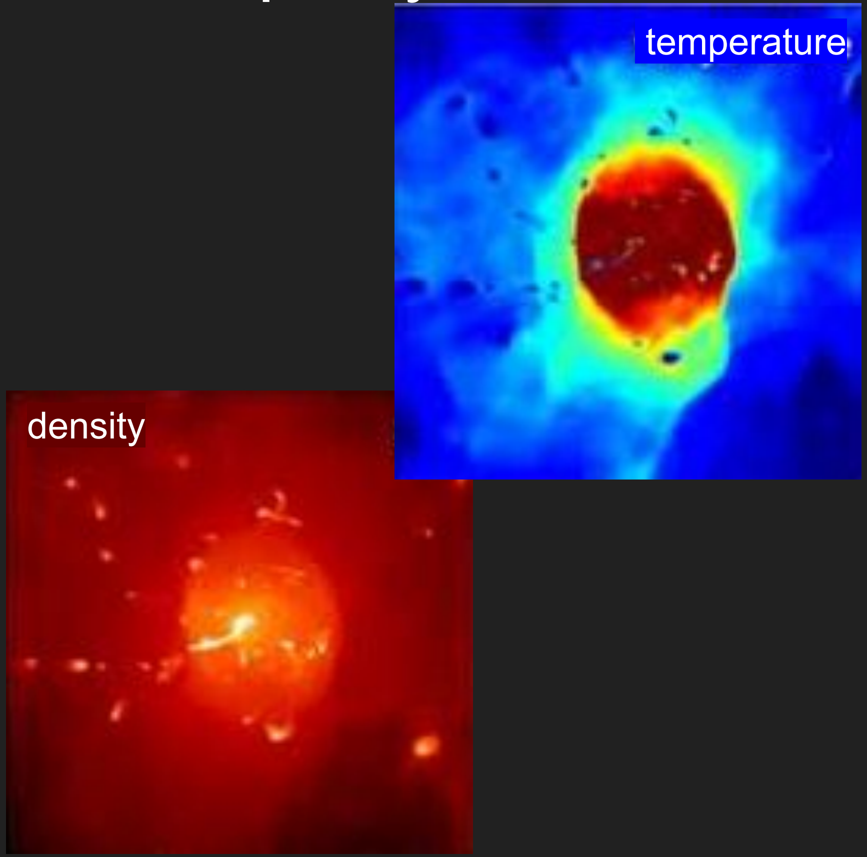
Proxy: Gas measurements tell us about the mass

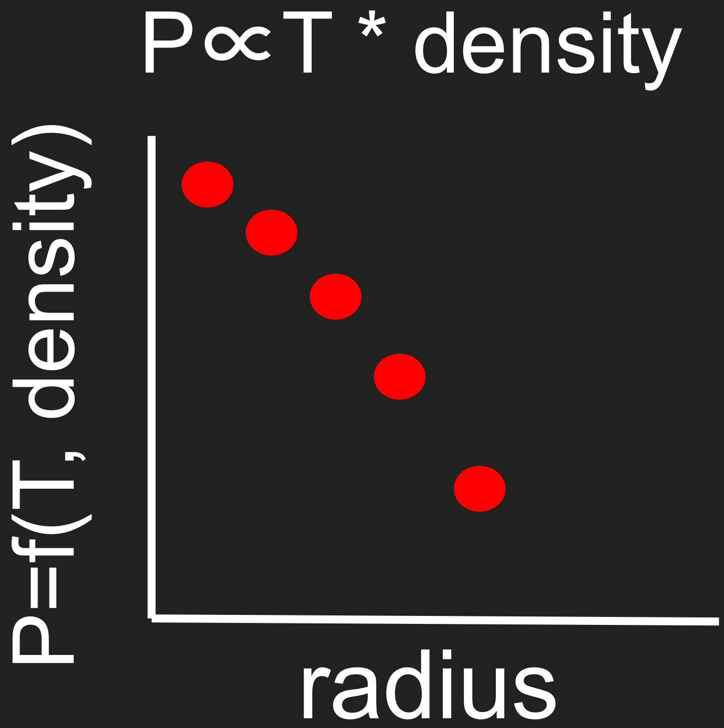


$P \propto T$ * density

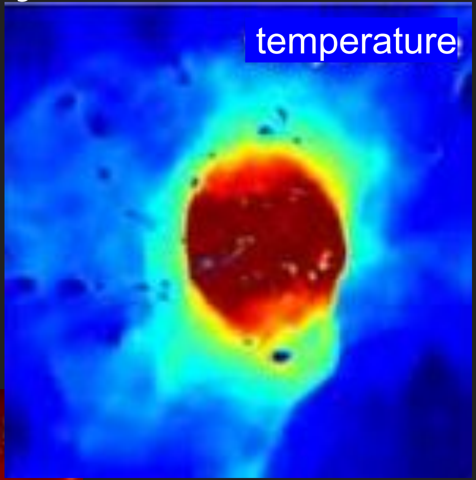


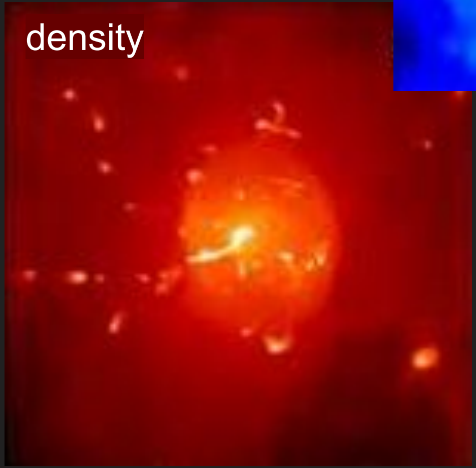
Test the proxy with simulations

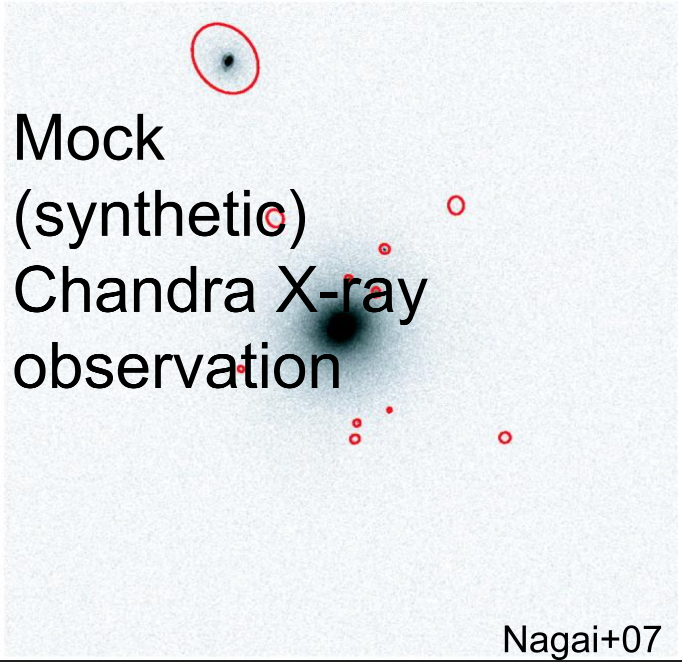




Test the proxy with simulations

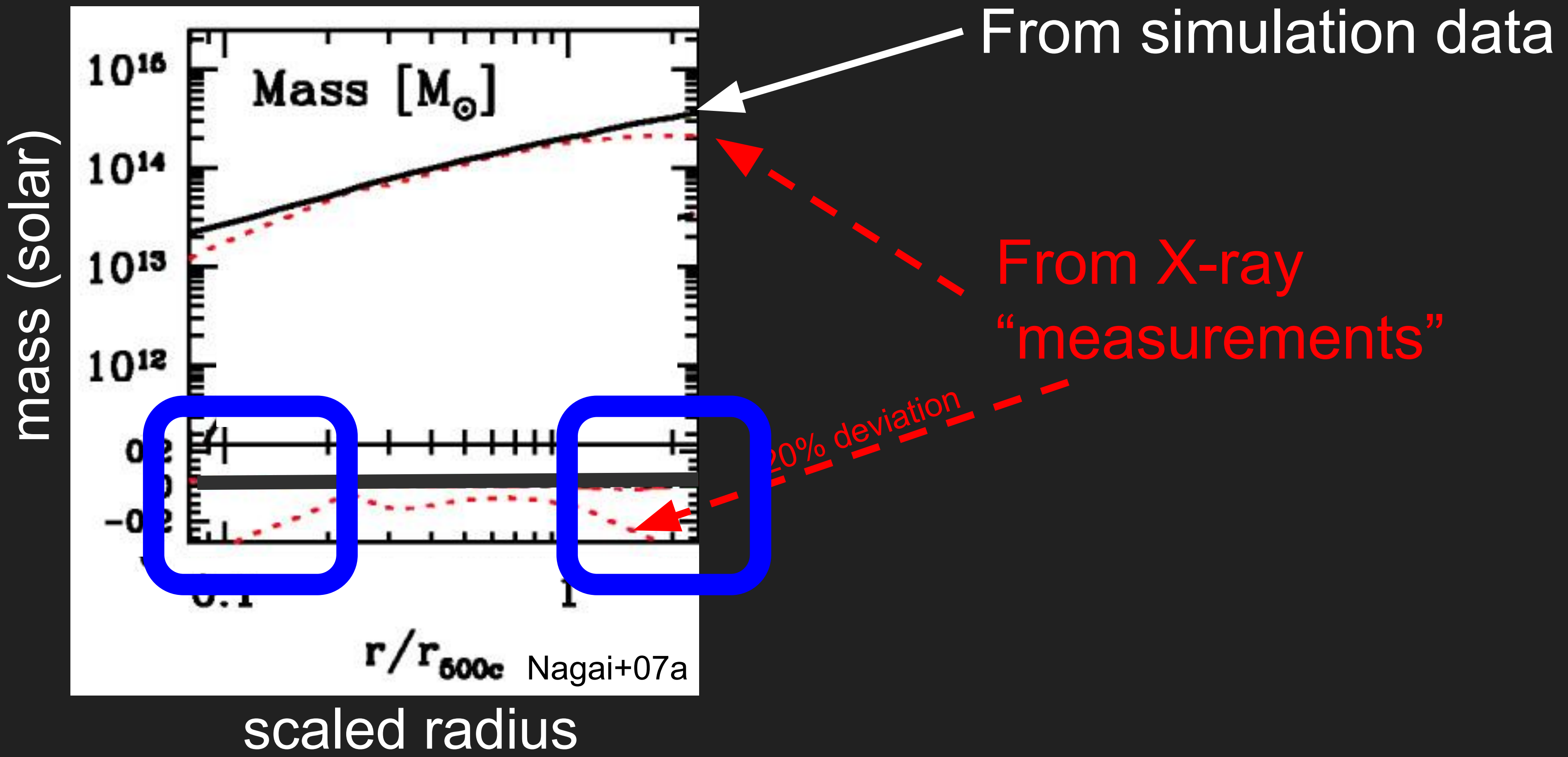






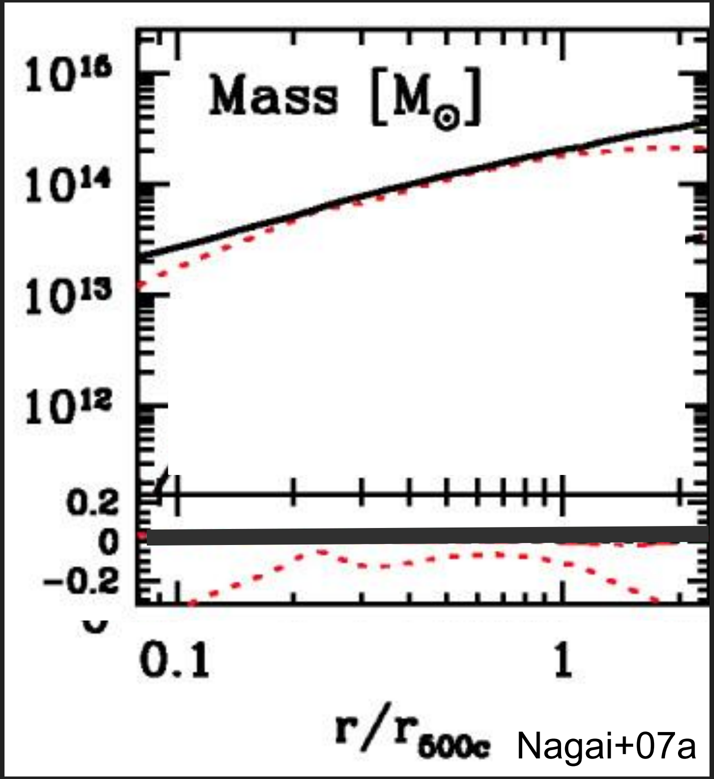
Nagai+07a

Test the proxy with simulations

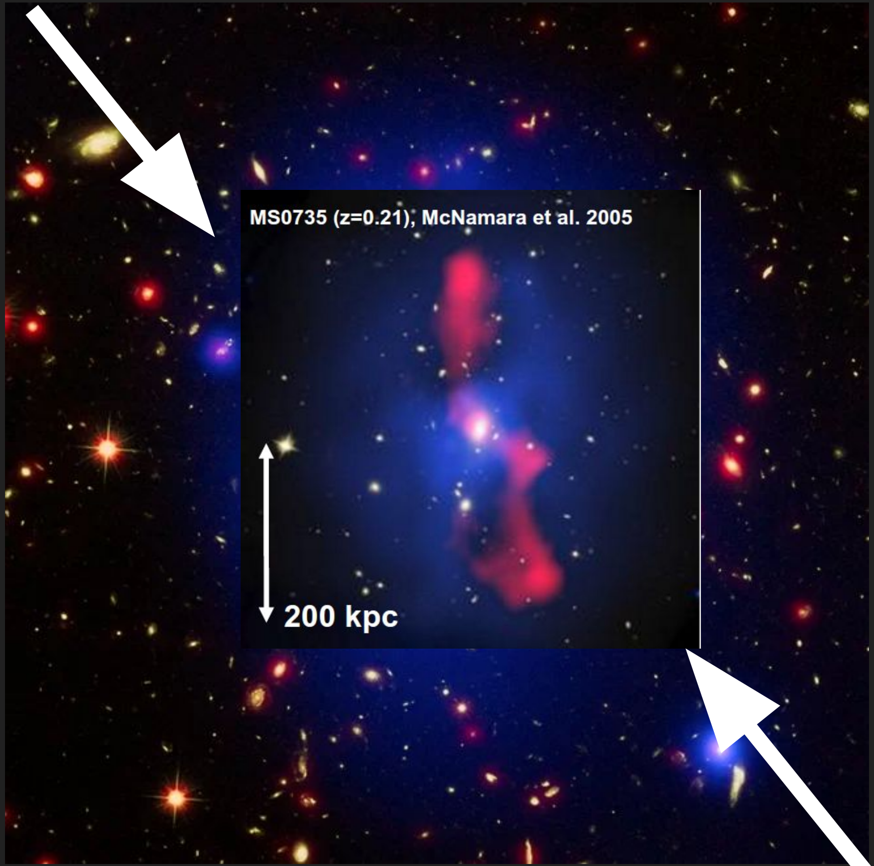


Problem: Mass proxies are proxies with assumptions

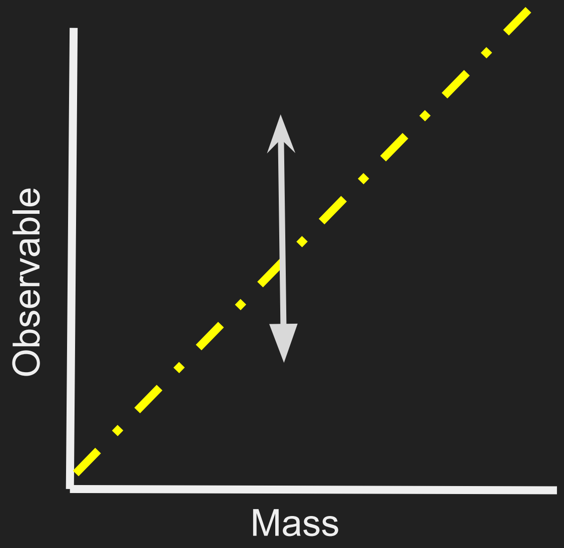
mass (solar)

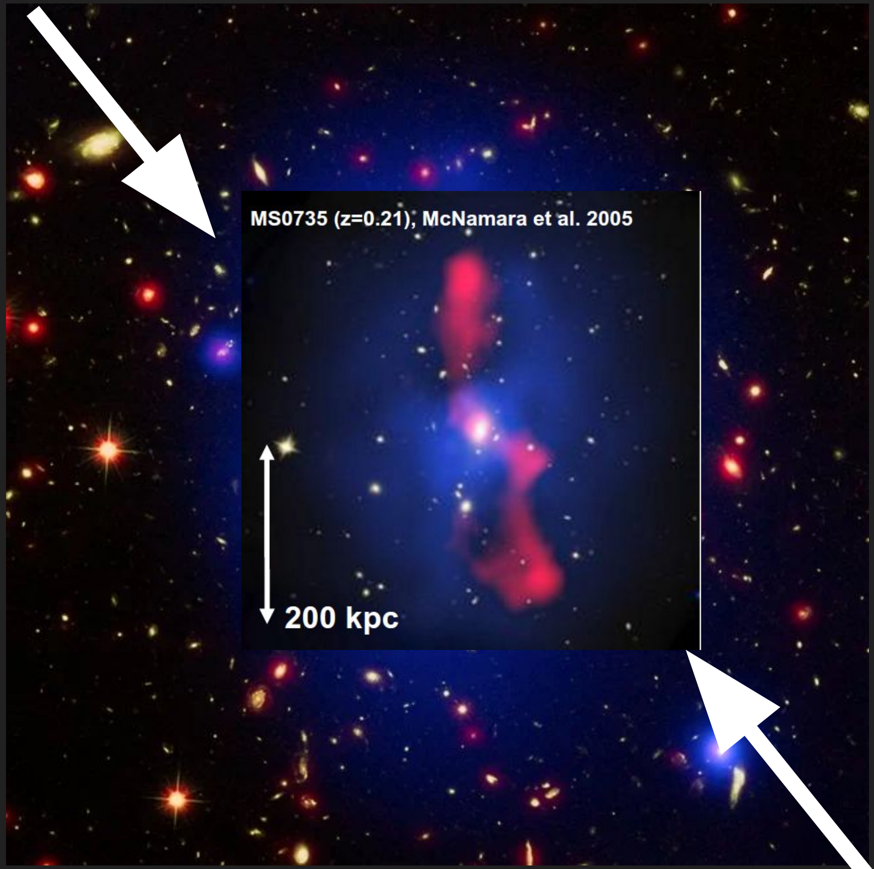


scaled radius

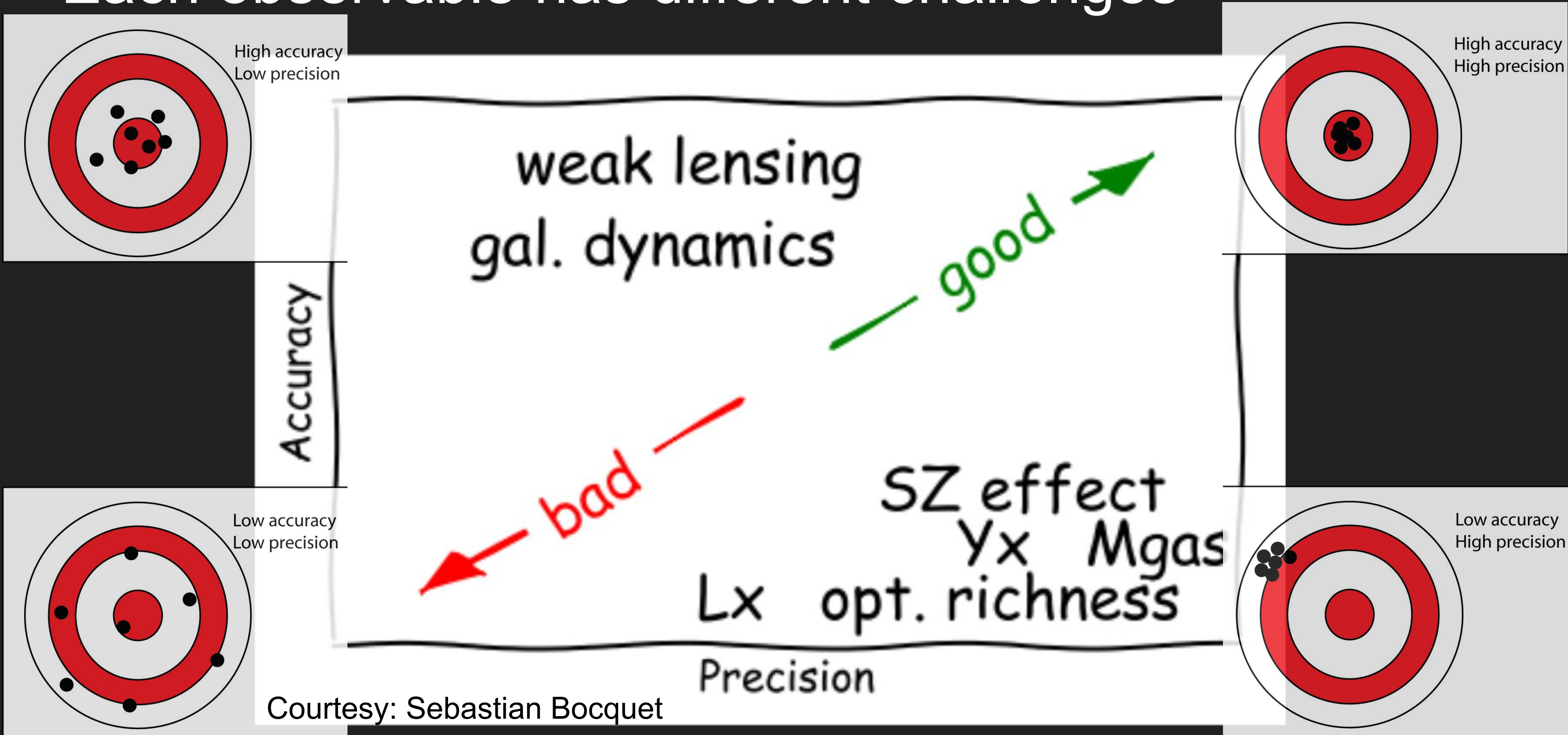


Problem: Mass proxies are proxies with assumptions

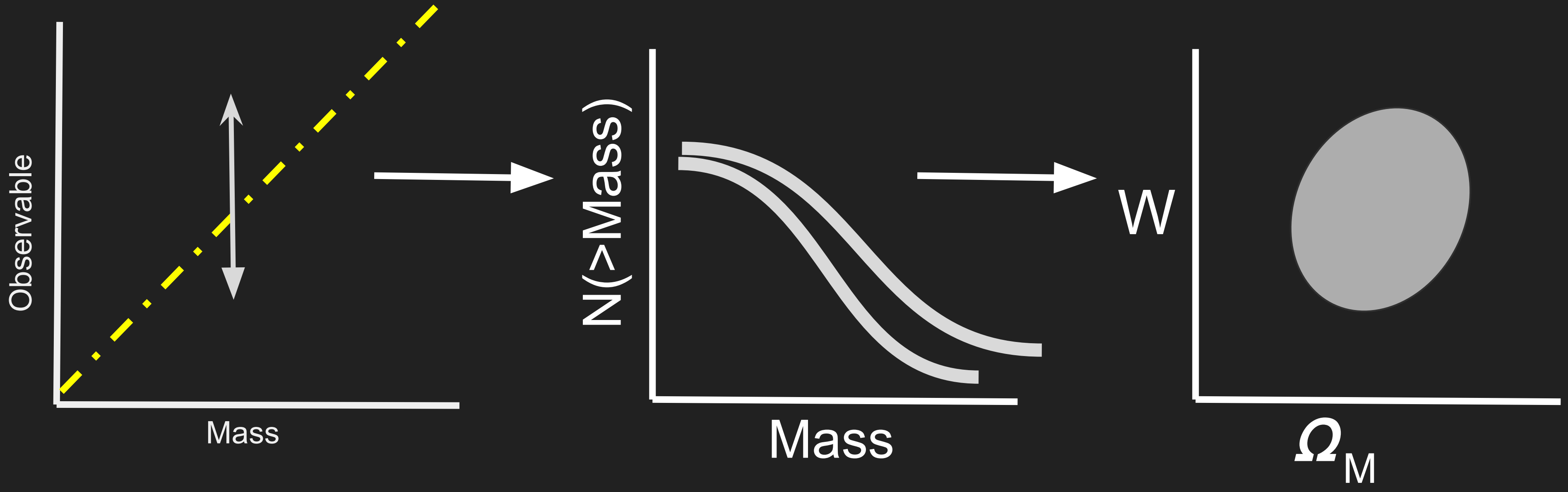




Each observable has different challenges

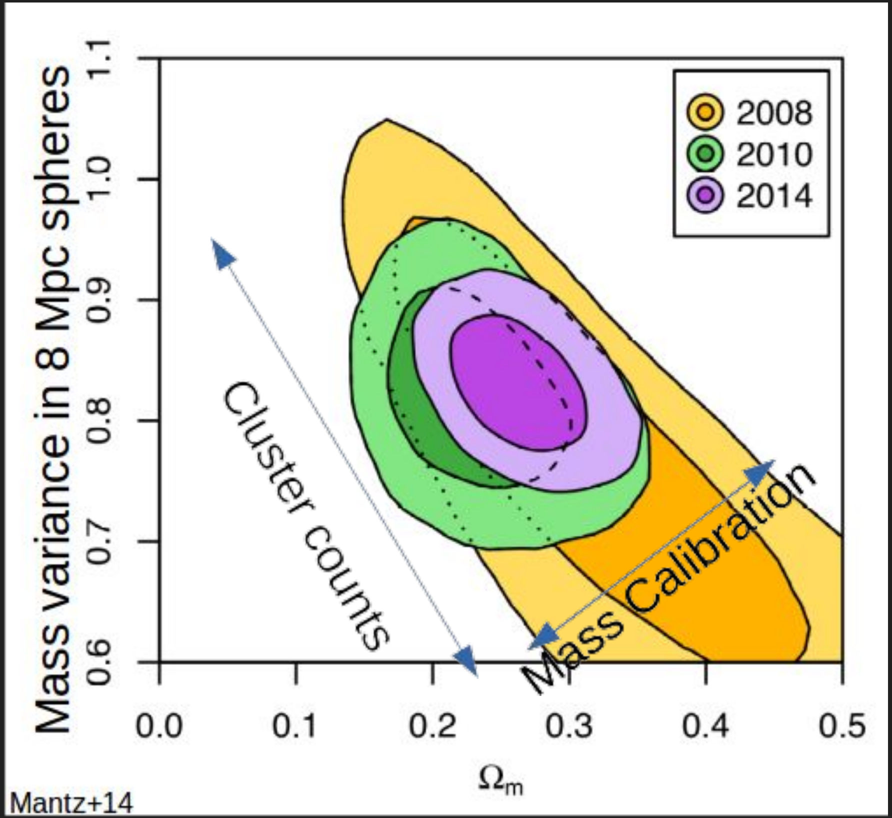


Courtesy: Sebastian Bocquet



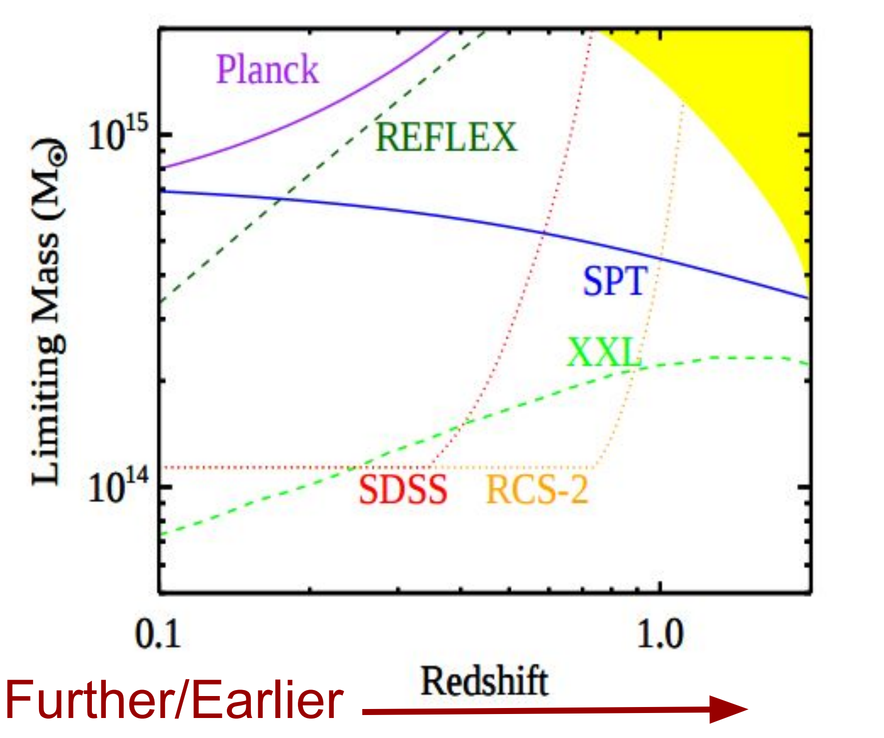
Galaxy clusters' dynamical state ties with systematics

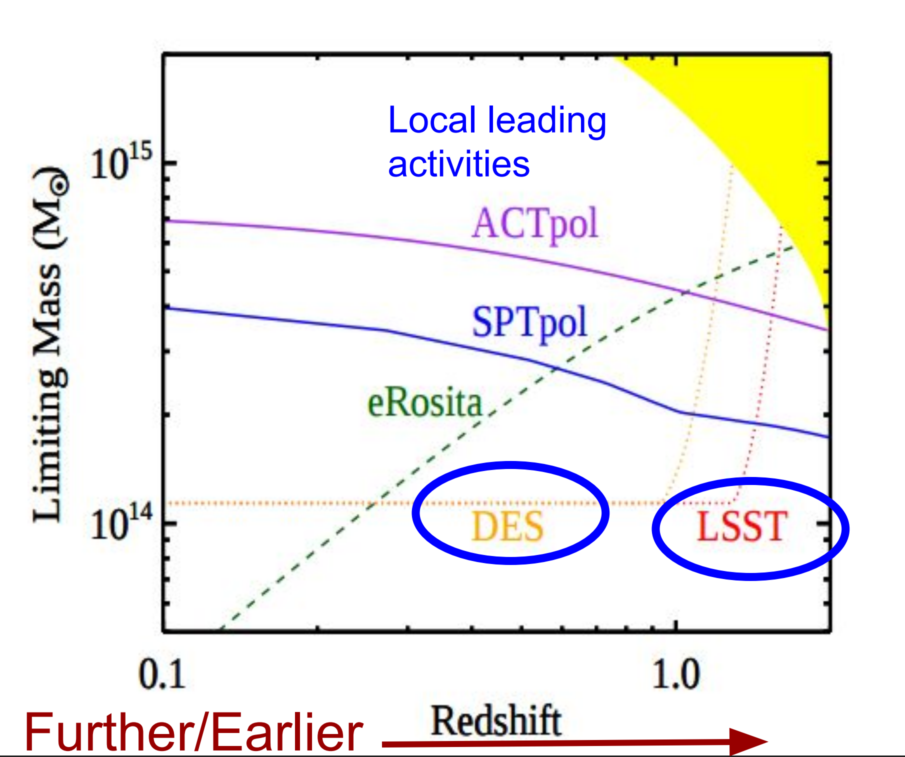
Combining observables can improve constraints



Larger datasets from surveys: Galaxy Clusters

… Getting lower masses and further objects



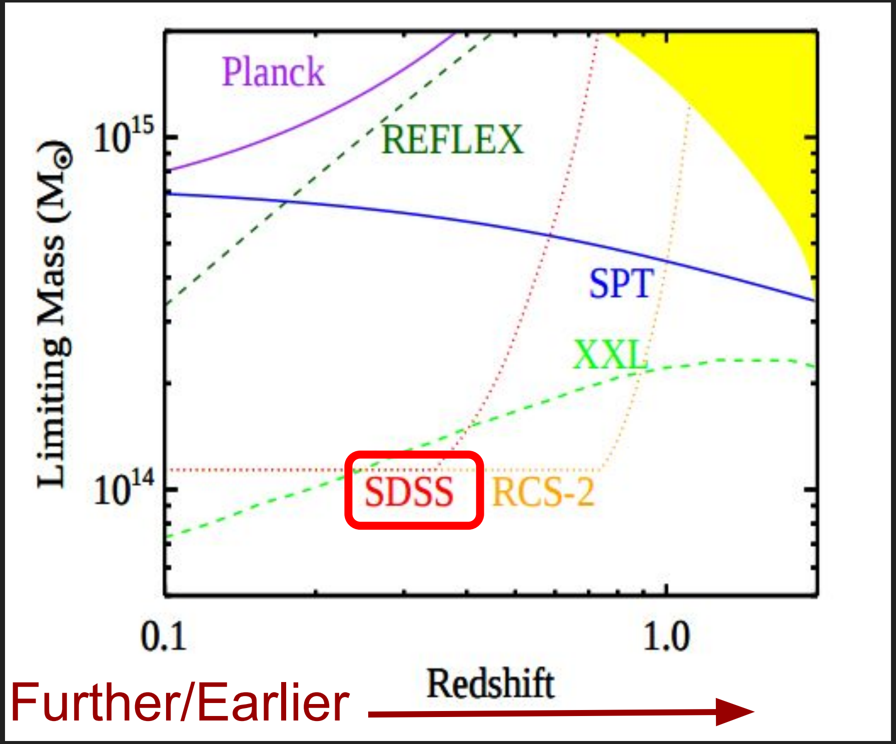


Past Surveys

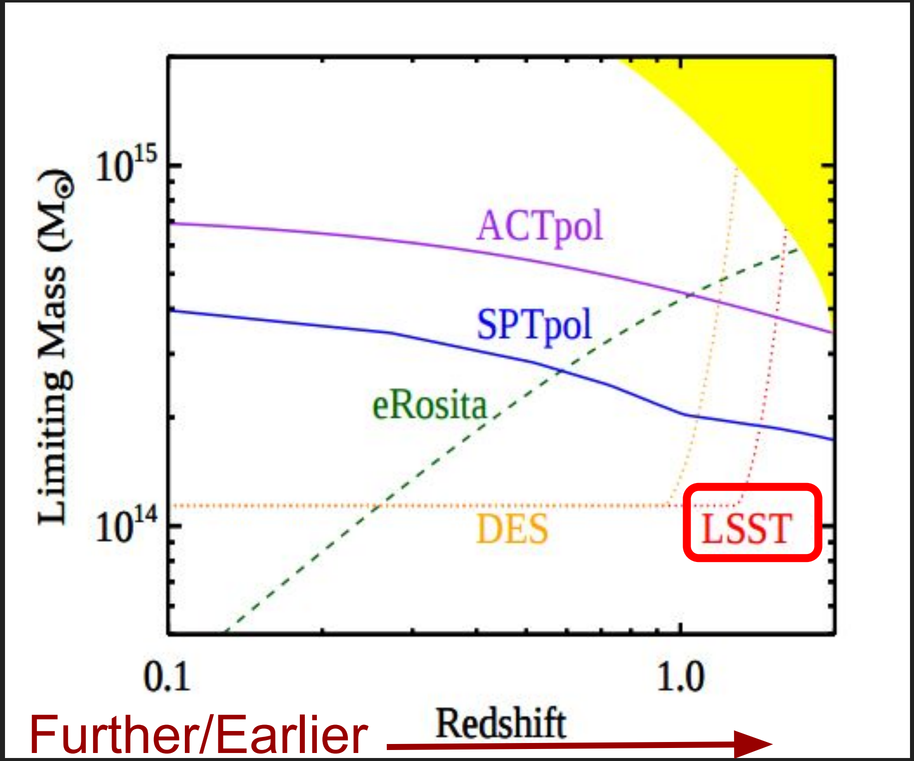
Current/Future Surveys

Larger datasets from surveys: Galaxy Clusters

… Getting lower masses and further objects



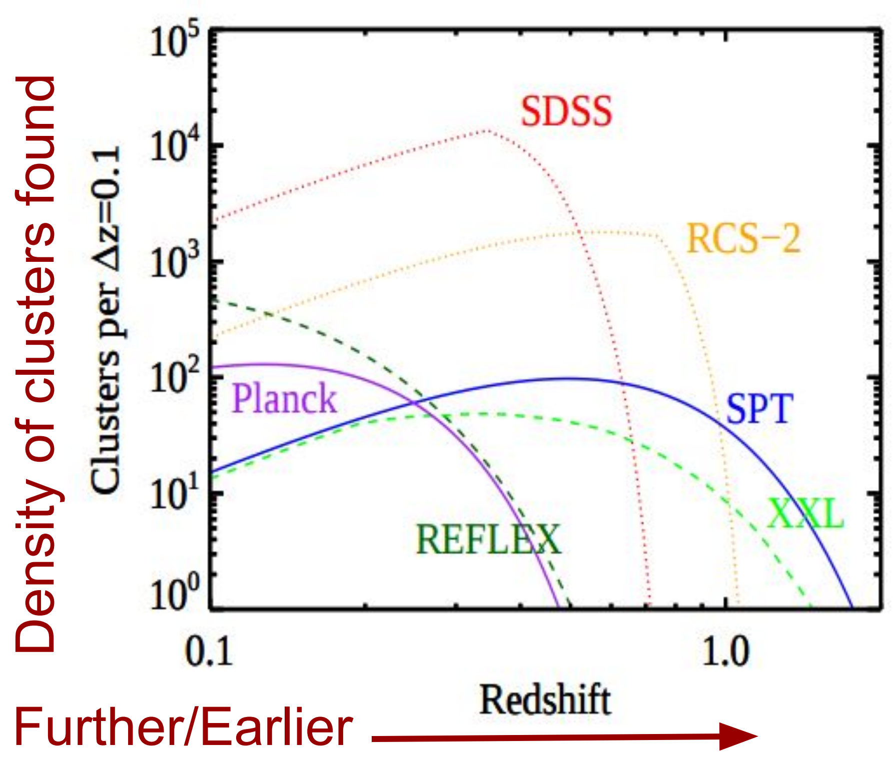
Past Surveys



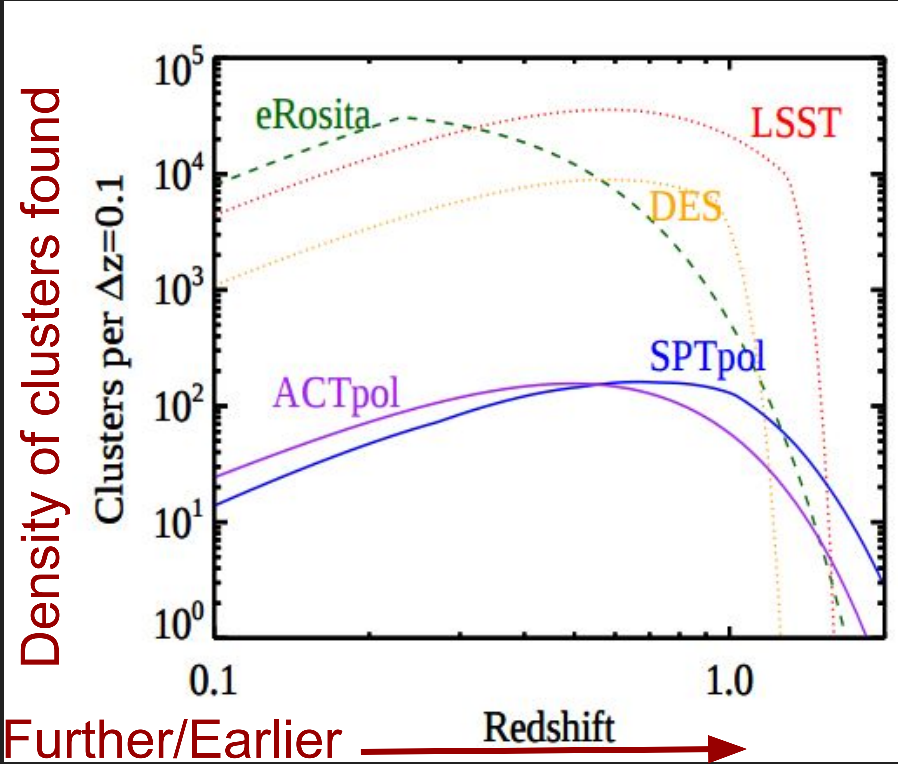
Current/Future Surveys

Larger datasets from surveys: Galaxy Clusters

… Getting more objects for better statistics



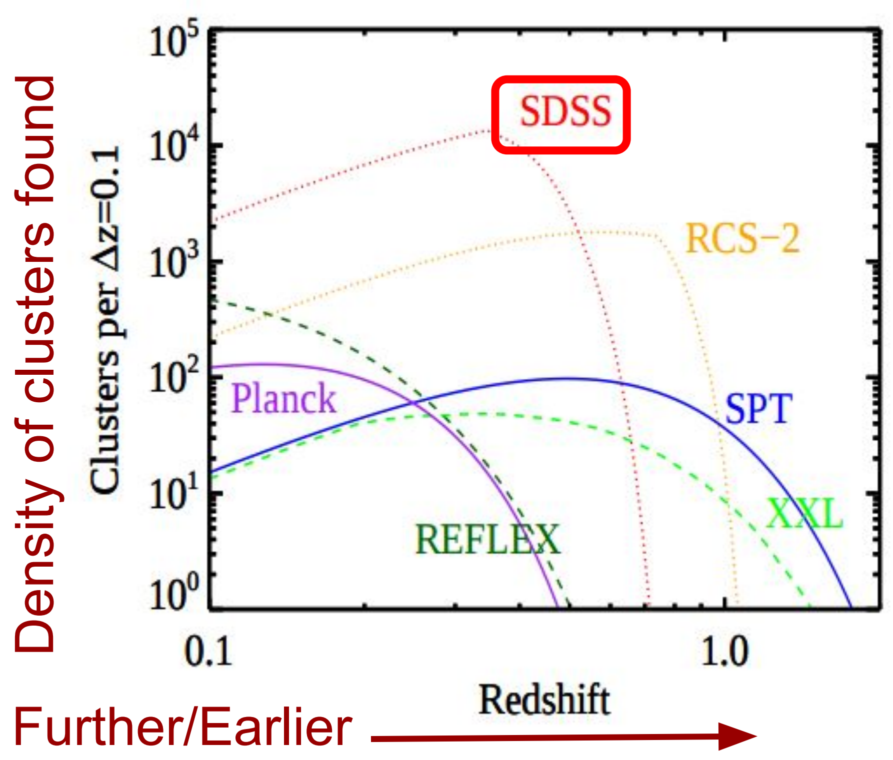
Past Surveys



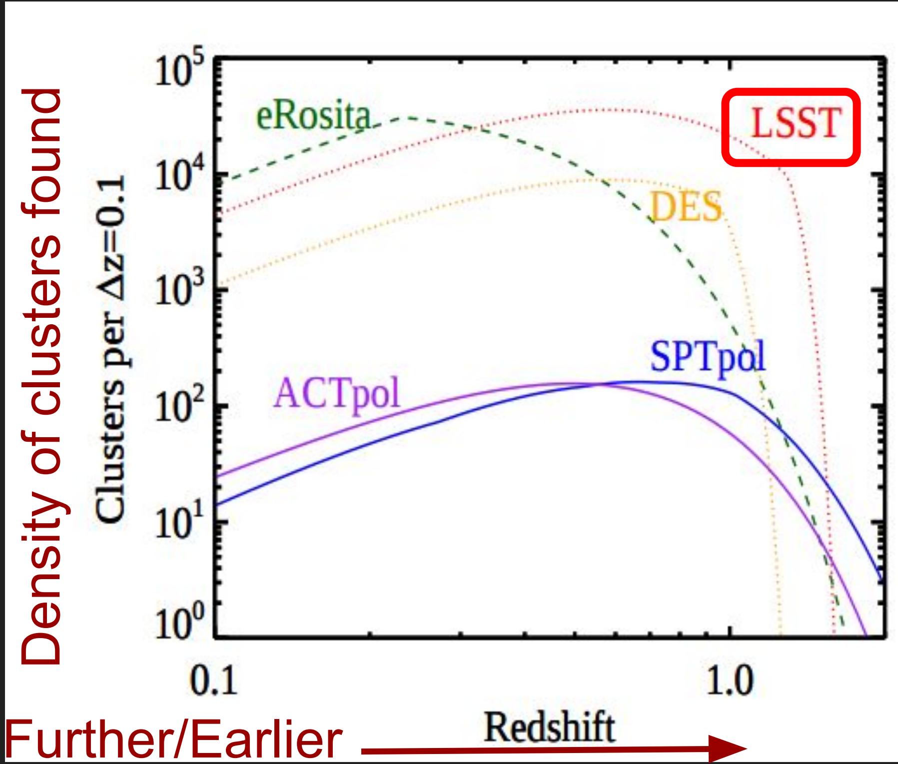
Current/Future Surveys

Larger datasets from surveys: Galaxy Clusters

… Getting more objects for better statistics

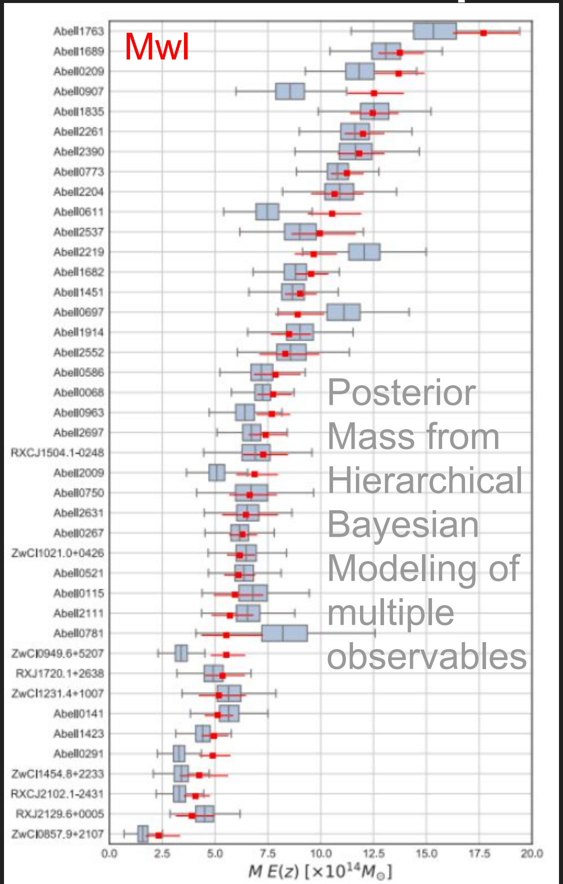


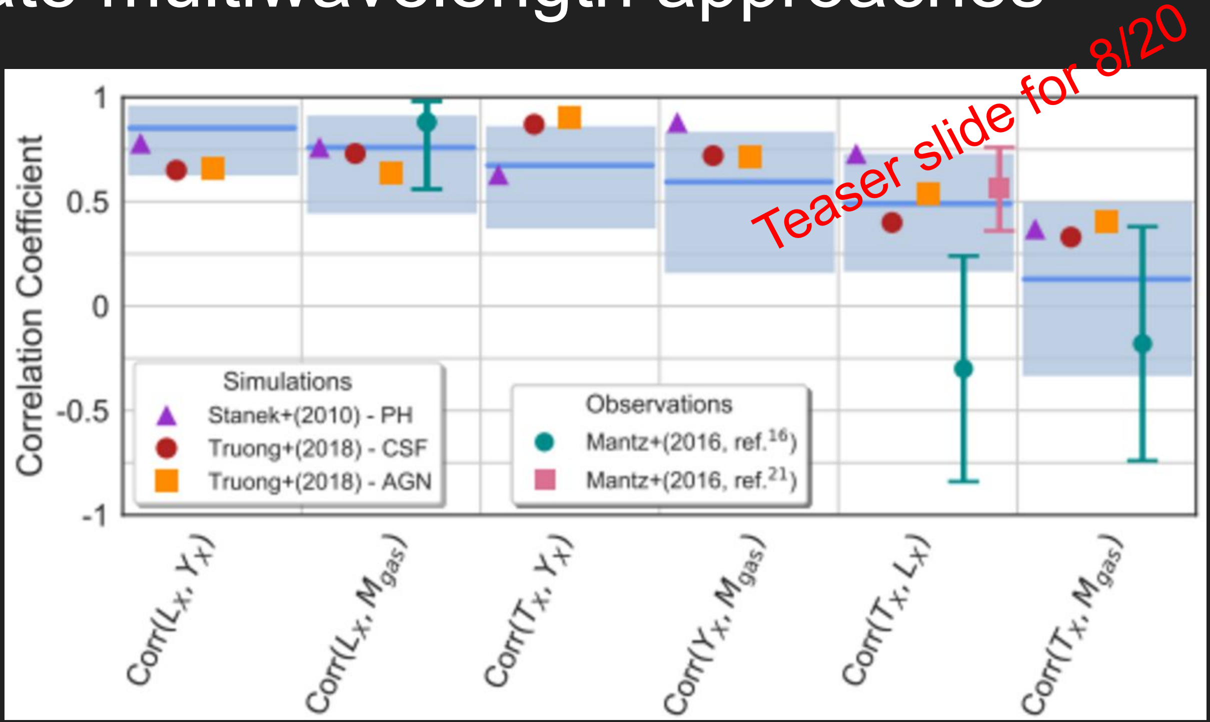
Past Surveys



Current/Future Surveys

Start to incorporate multiwavelength approaches



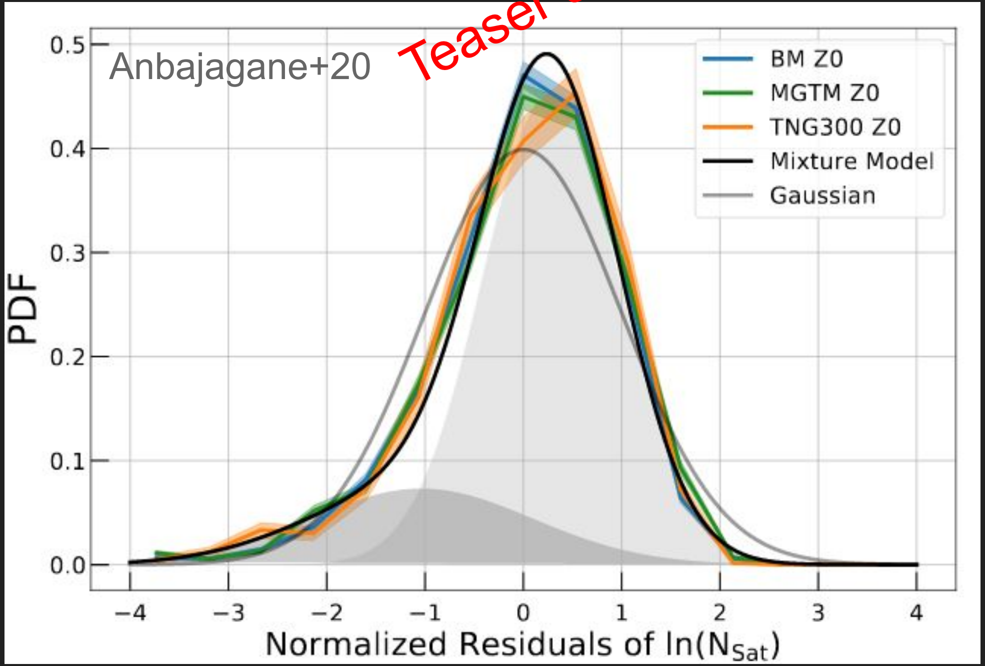


LoCuSS Clusters

Farahi+19
Mulroy+19

Each simulation has a (slightly) different approach

Teaser slide for 8/20

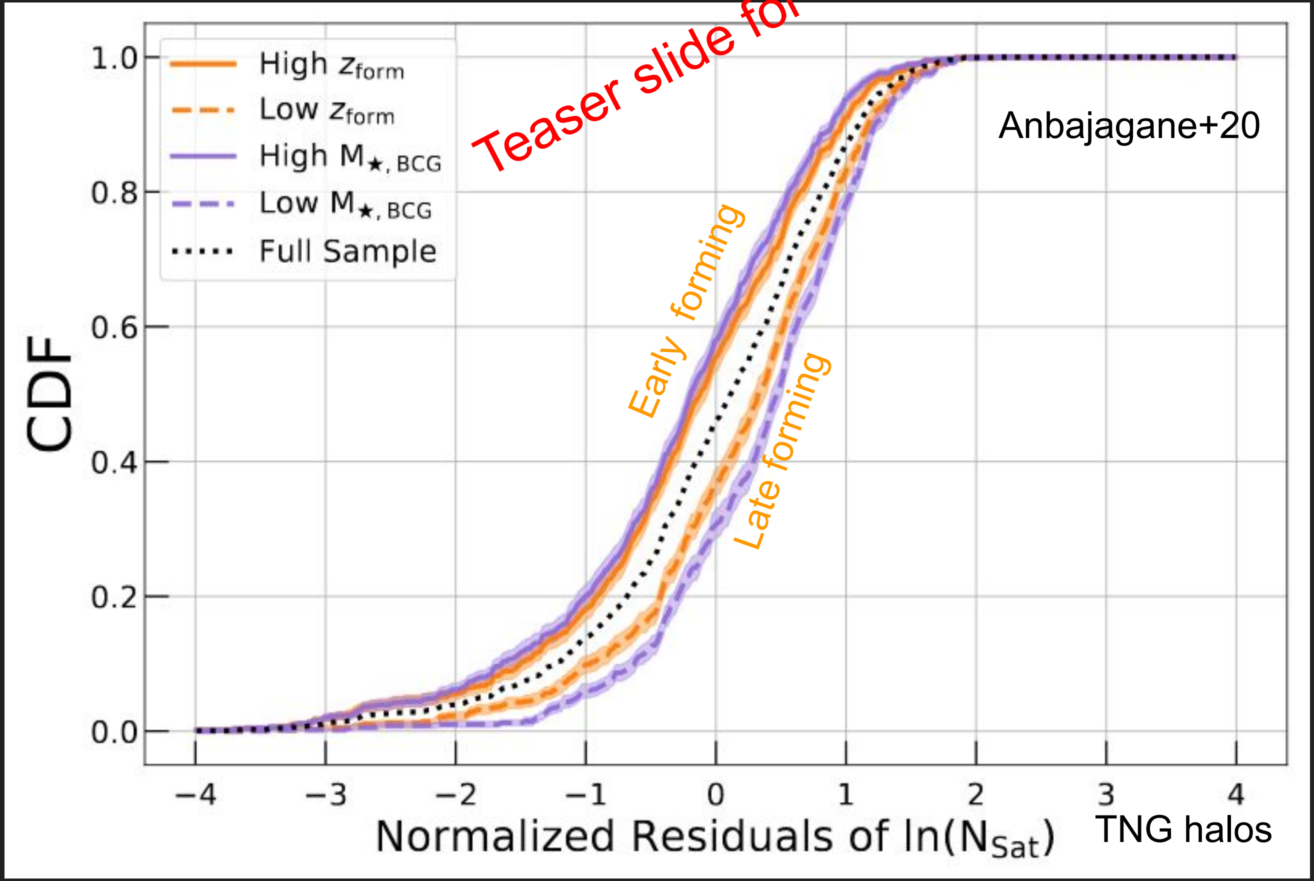


Quantify differences/robustness of models predictions with Local Linear Regression (Evrard14)

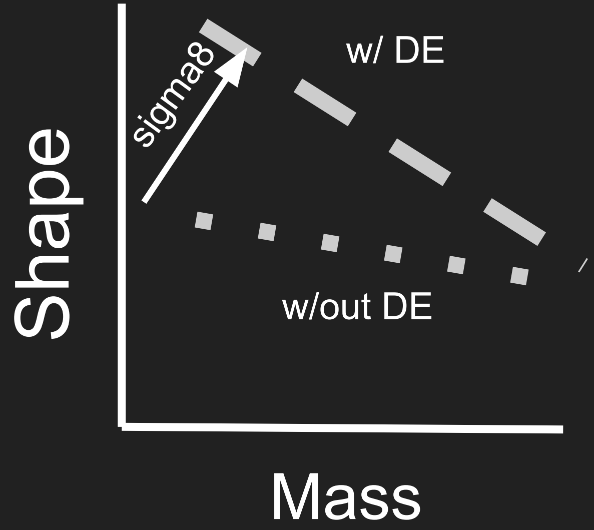
- Describe simulated galaxy cluster population: Mass conditioned estimates of slope, normalization and property covariance.

Example: Satellite Statistics to Inform Optically-Selected Cluster Counts

Early vs. Late forming halos split in the PDF



Shapes sensitive to accretion and cosmology, impacting mass-observable relations



Cosmology Sensitivity (e.g. Kasun+Evrard 05, Allgood+06)

Environmental Dependence (e.g. White, Cohn, Smit 10)

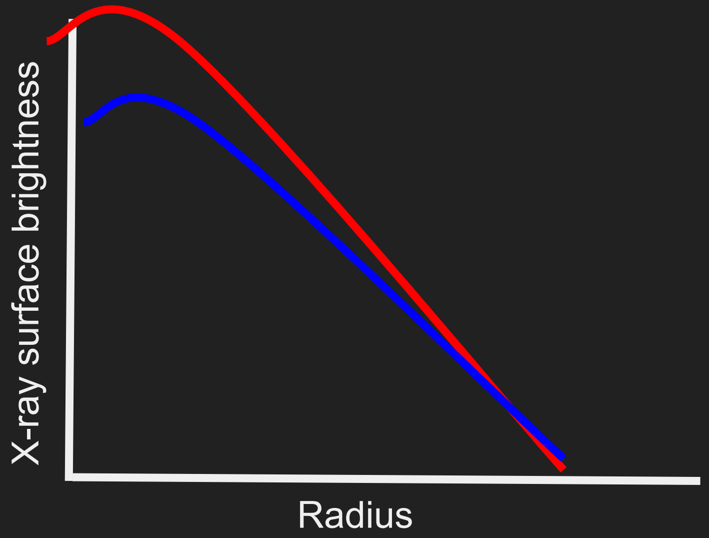
Shape/morphology as a key relaxedness criterion

Bulk asymmetry measures → unrelaxed

(e.g. Mohr+1993, Jeltema+05)

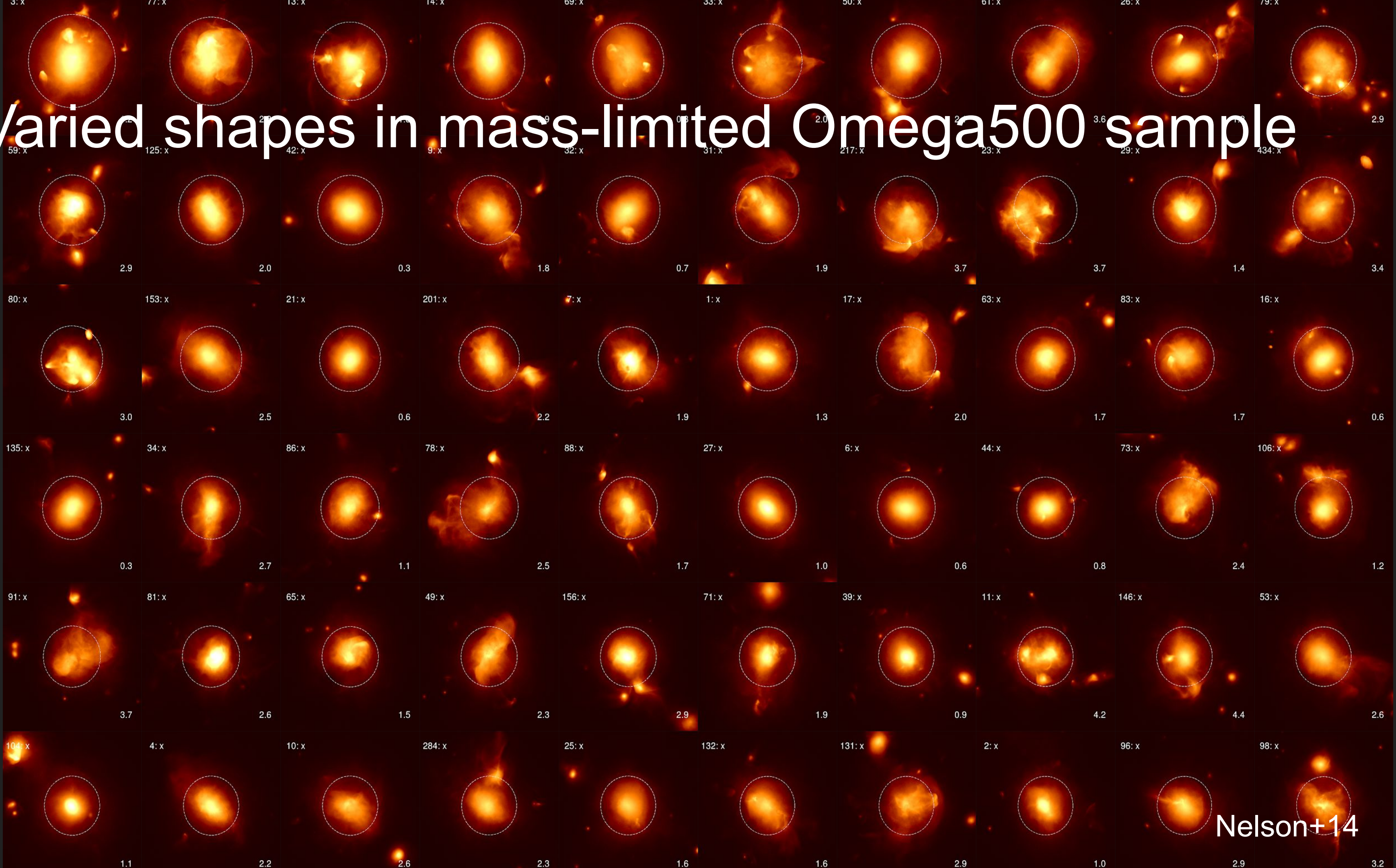
Peakedness/Cool-core → relaxed

(e.g. Vikhlinin+07, Bohringer+10)



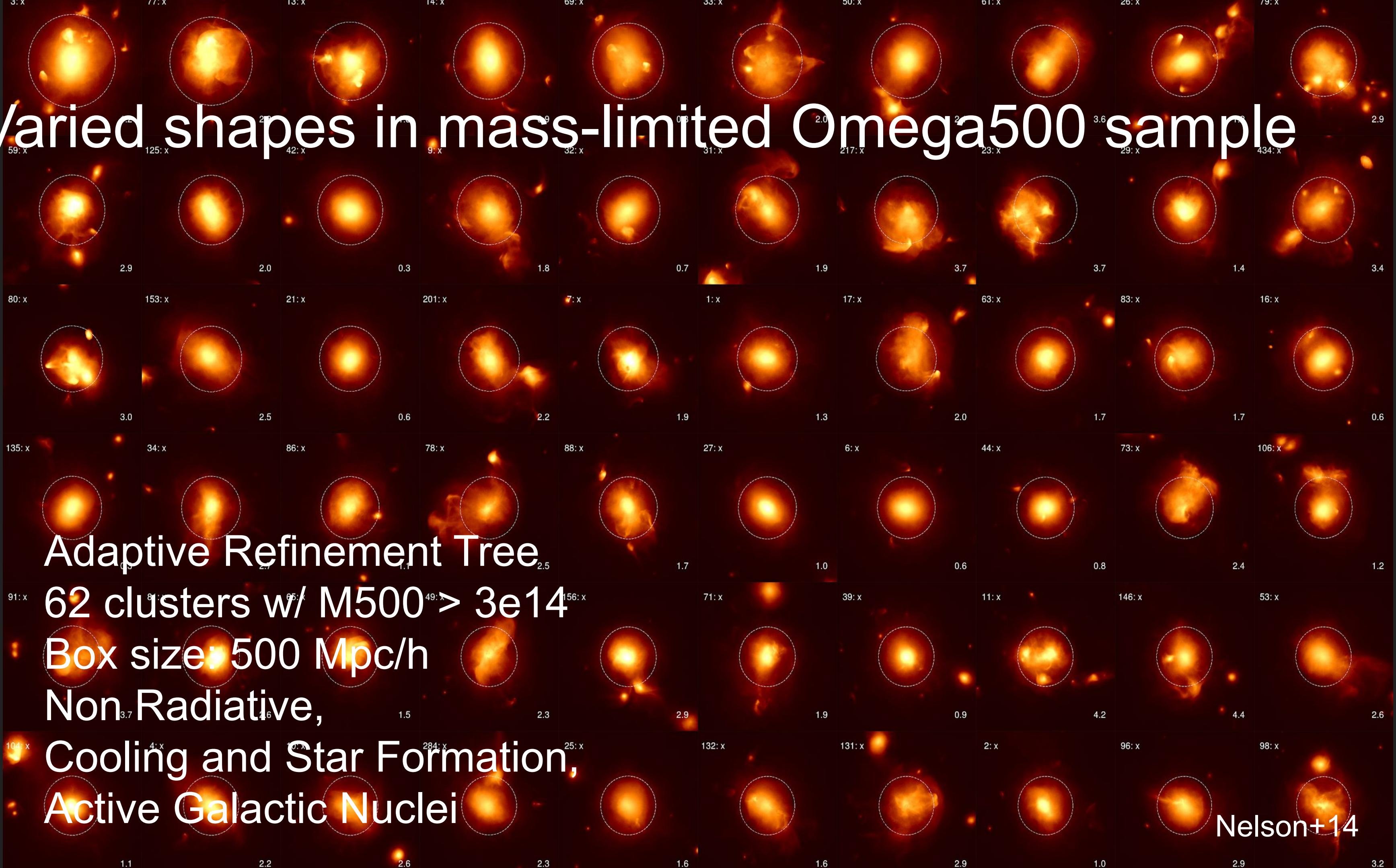
Combination of visual measures in X-ray (e.g. Rasia+13, Mantz+15)

Varied shapes in mass-limited Omega500 sample



Nelson+14

Varied shapes in mass-limited Omega500 sample



Adaptive Refinement Tree
62 clusters w/ M500 > 3e14
Box size: 500 Mpc/h
Non Radiative,
Cooling and Star Formation,
Active Galactic Nuclei

Nelson+14

Varied morphology in mass-limited Omega500 sample




Team work needed for
large scale simulations



Varied morphology in mass-limited Omega500 sample

Developed hydro code, halo finder

PI: Enabled science and resources for simulations

Ran the first NR box,Developed merger tree+db

Ran CSF, Developed tracer particle capability

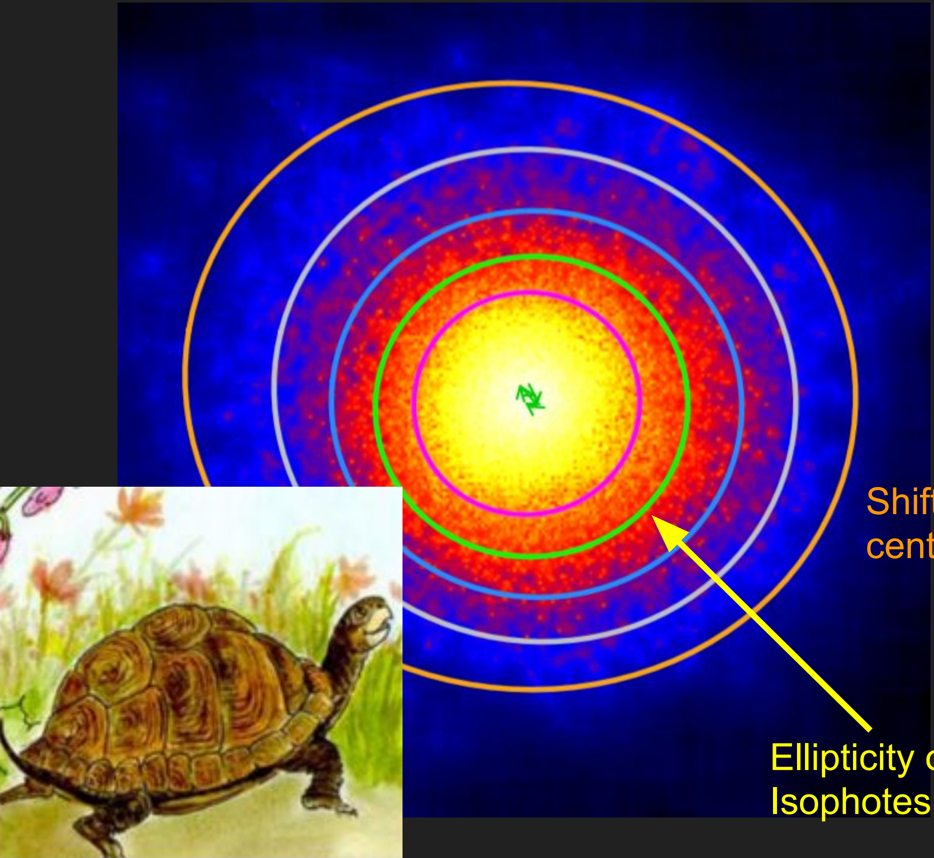
Ran later CSF, AGN boxes, database

Developed initial AGN module

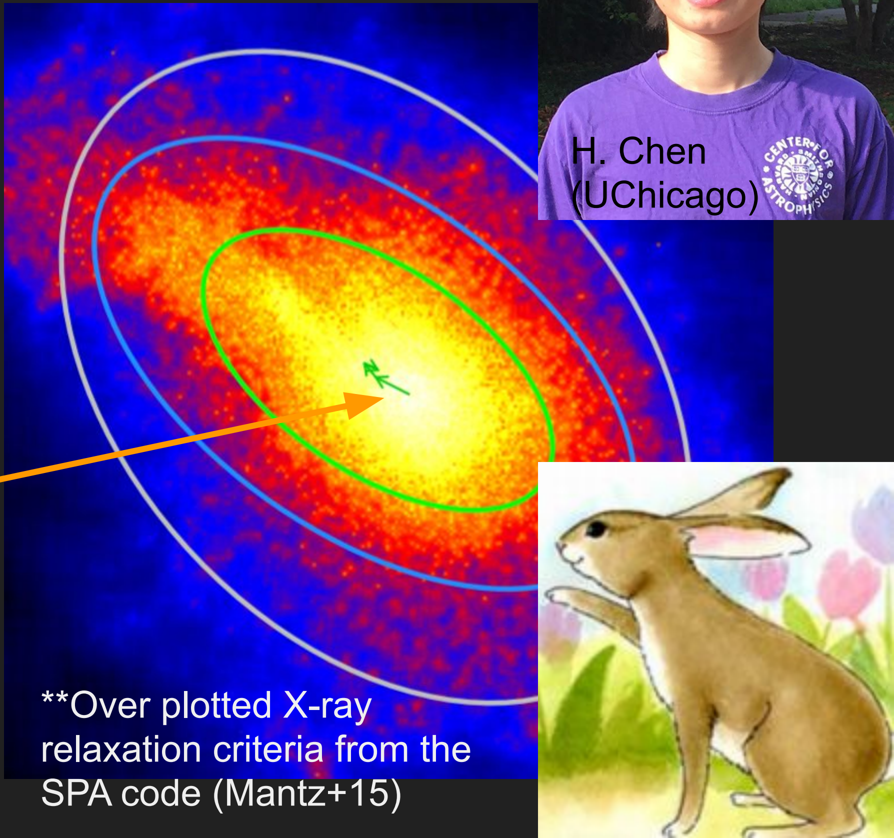
Developing state-of-art AGN

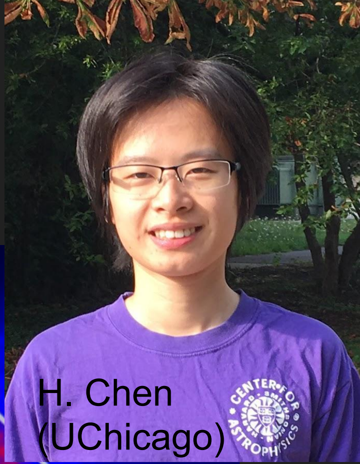
Recent accretion drives ICM shape

"Slow accretor"



"Fast accretor"





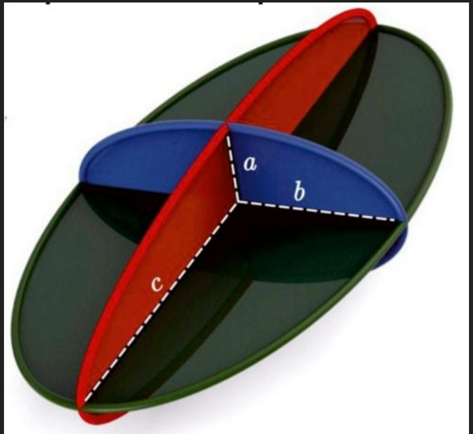
Shift of centroid

Ellipticity of Isophotes

**Over plotted X-ray relaxation criteria from the SPA code (Mantz+15)

Shape and accretion study of Omega500 clusters

Shape: Axis ratio

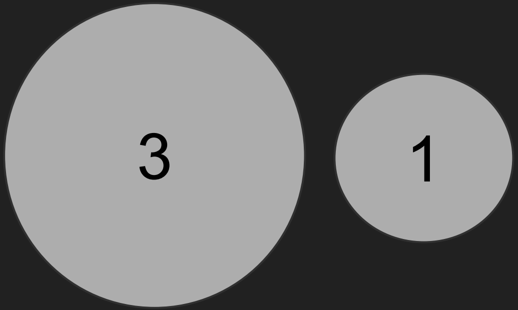


Accretion Rate (modified Diemer+Kravtsov14)

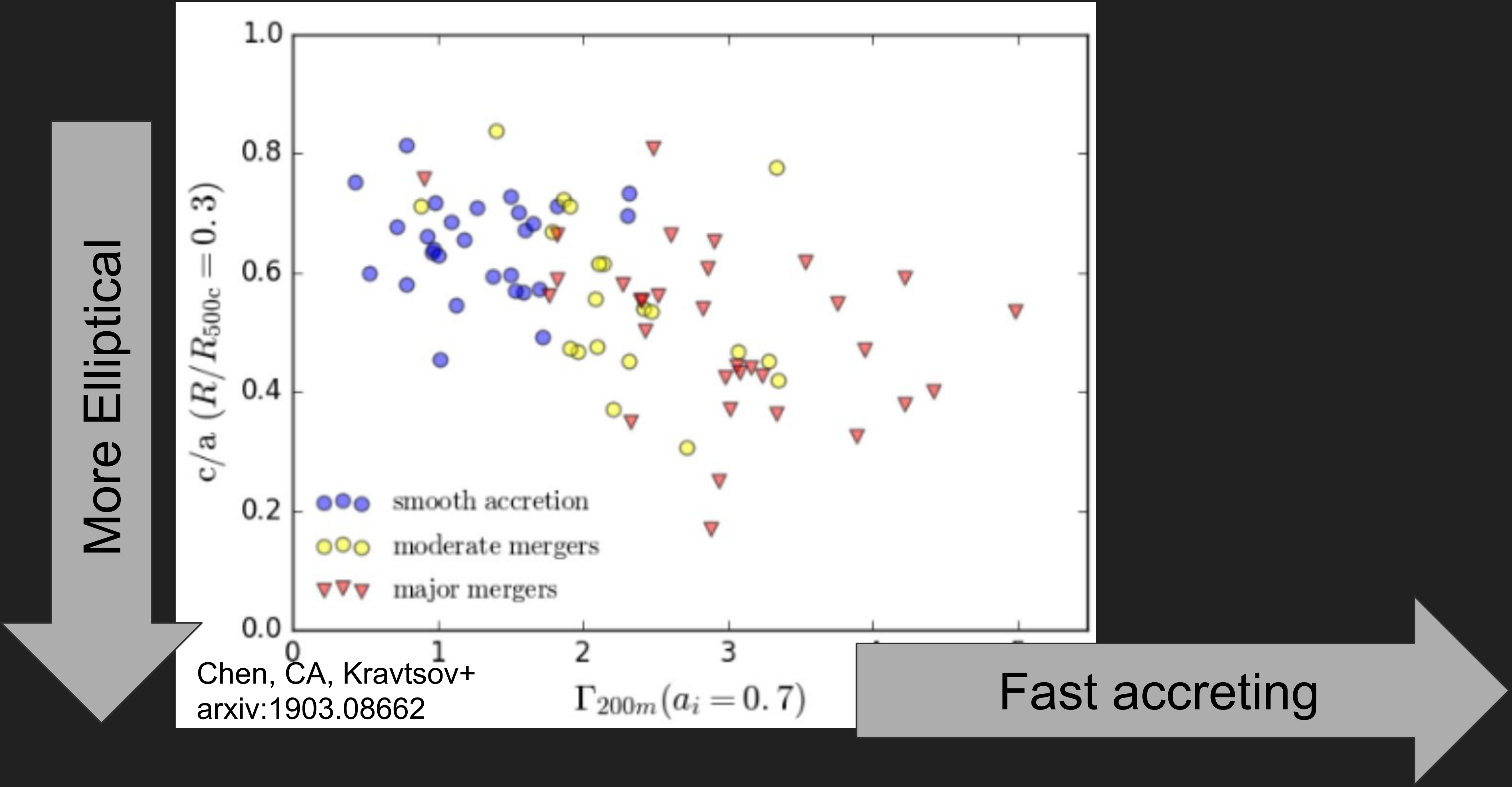
$$\Gamma_{200m}(a_i) = \frac{\log(M_{200m_i}) - \log(M_{200m_0})}{\log(a_i) - \log(a_0)}$$

timescale

Max Merger Ratio

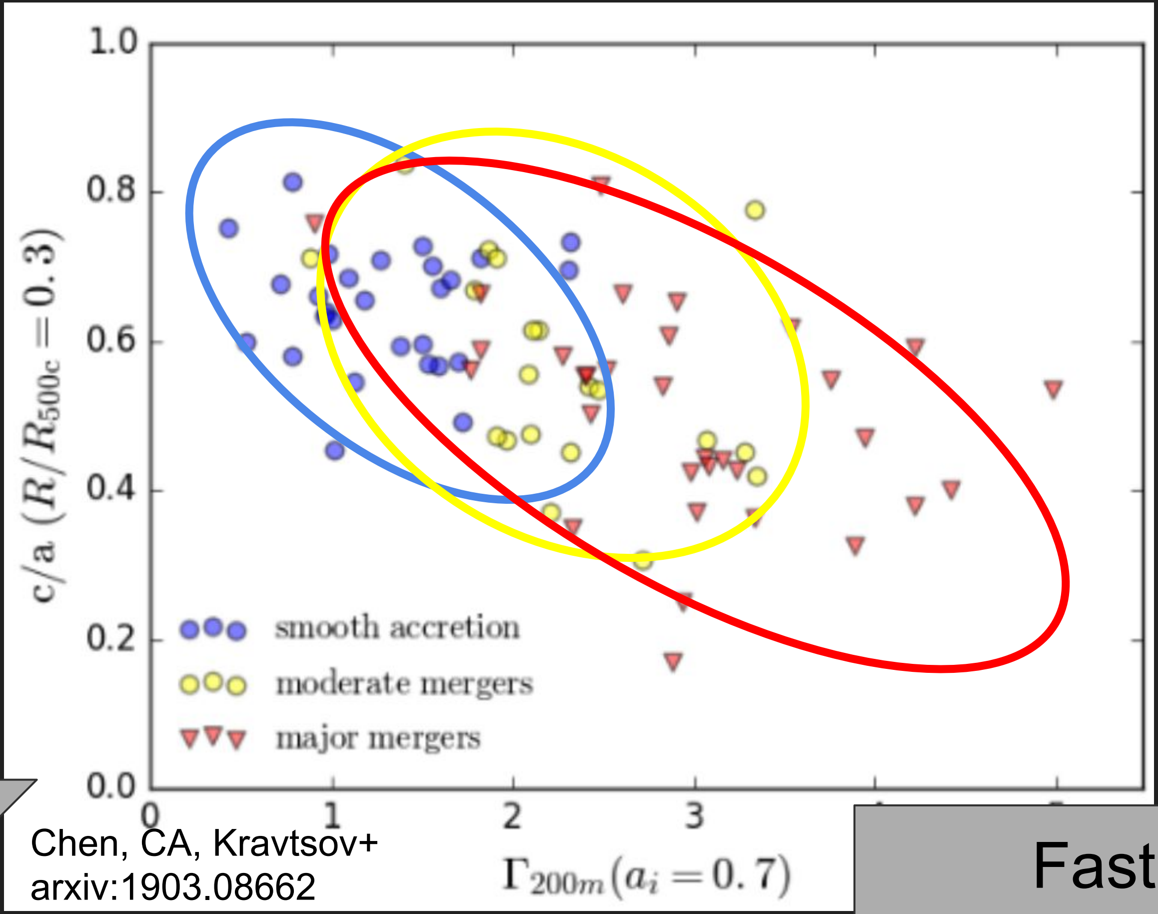


Accretion rate *and* accretion mode matter



Chen, CA, Kravtsov+
arxiv:1903.08662

Accretion rate *and* accretion mode matter



More Elliptical

Chen, CA, Kravtsov+
arxiv:1903.08662

Fast accreting

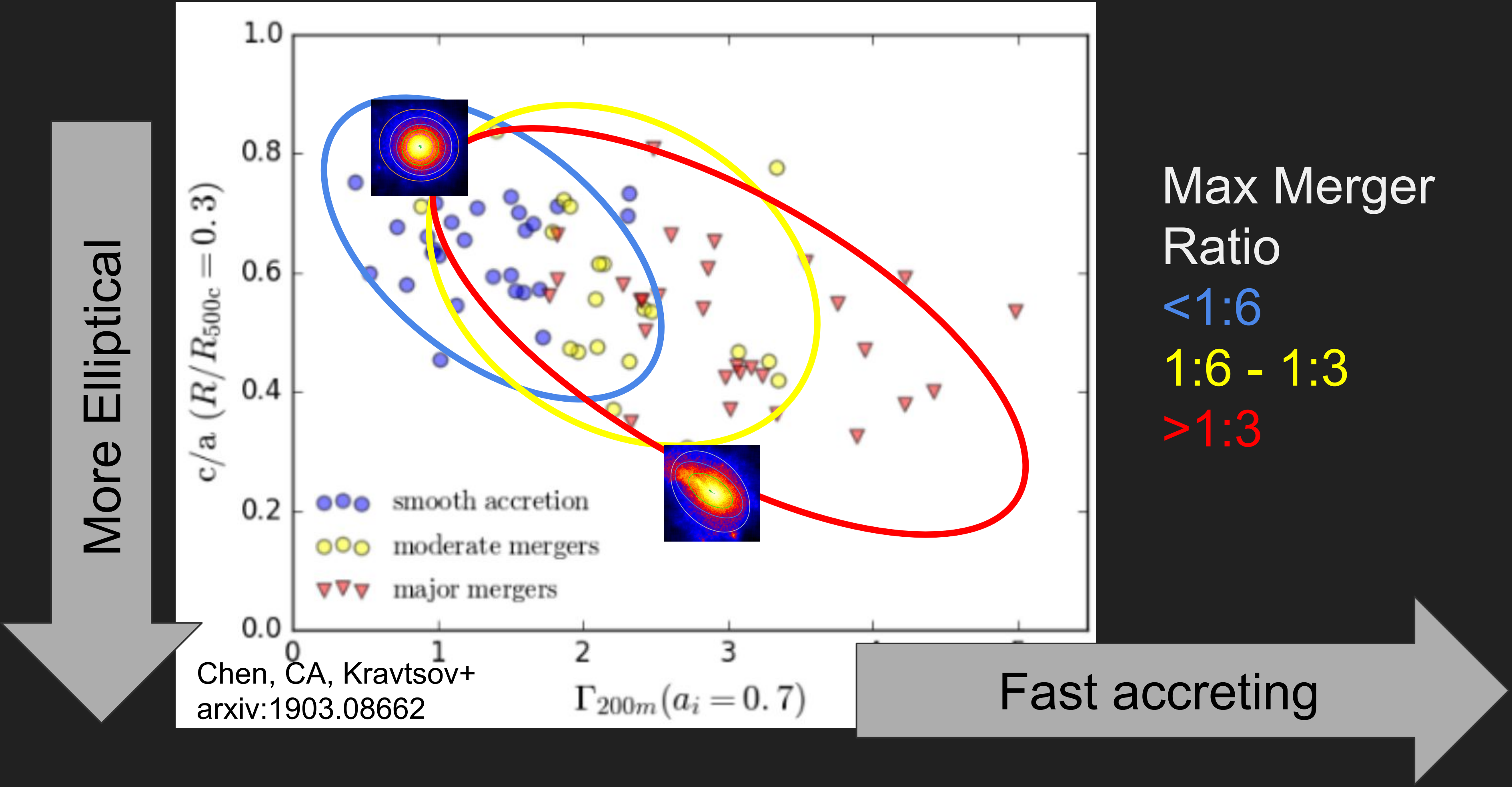
Max Merger Ratio

<1:6

1:6 - 1:3

>1:3

Accretion rate *and* accretion mode matter



Chen, CA, Kravtsov+
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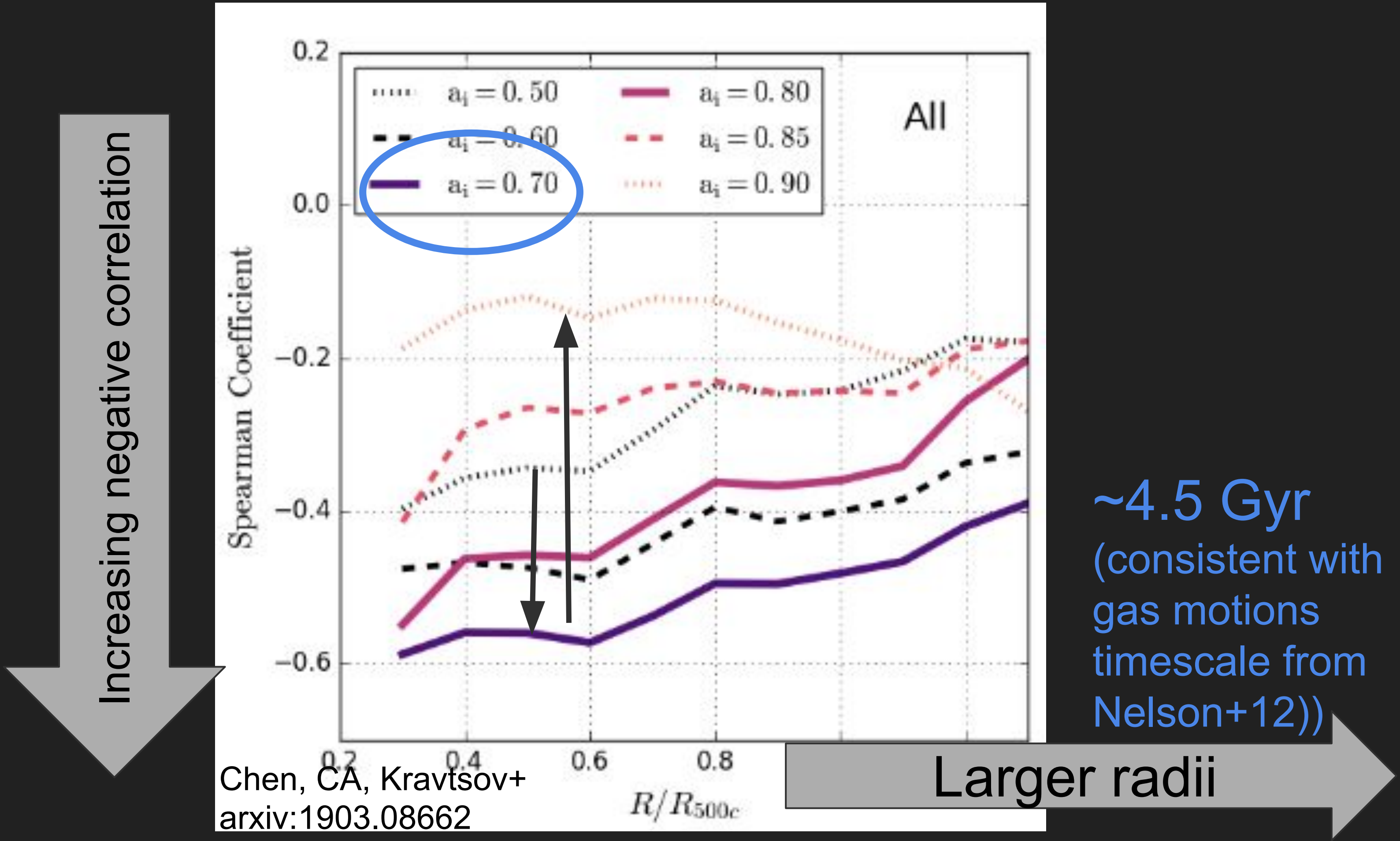
Max Merger Ratio
<1:6
1:6 - 1:3
>1:3

A characteristic timescale for shape relaxation

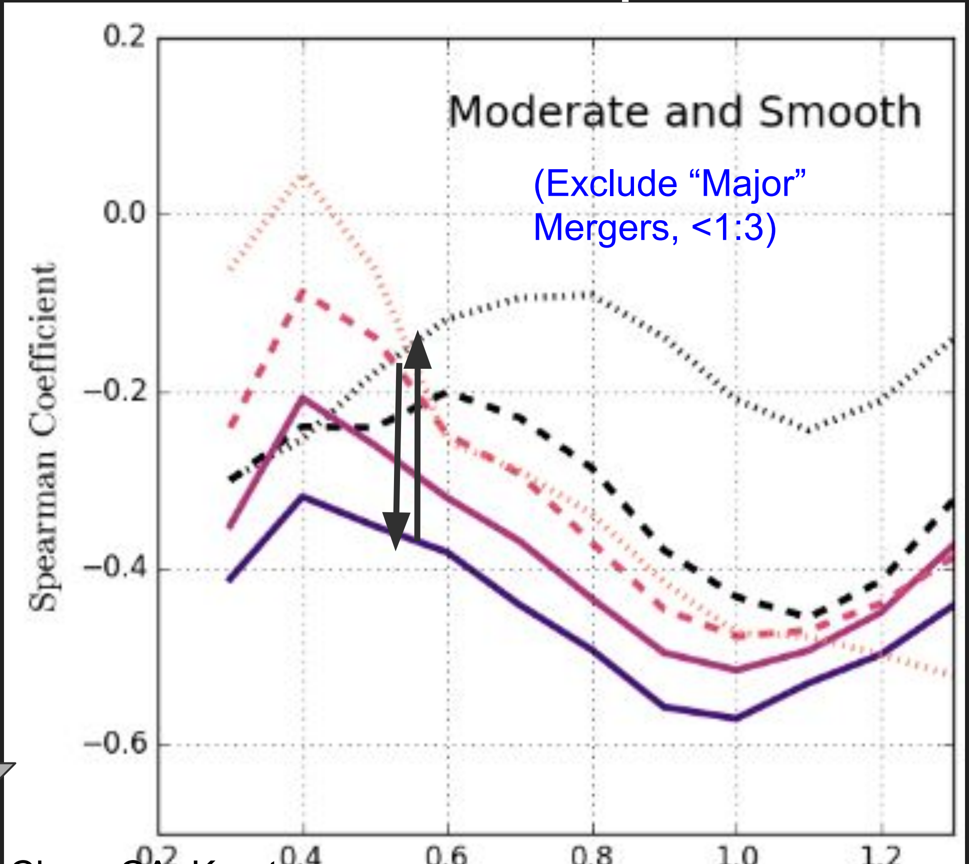


Chen, CA, Kravtsov+
arxiv:1903.08662

~4.5 Gyr
(consistent with gas motions timescale from Nelson+12))

A characteristic timescale for shape relaxation

Increasing negative correlation

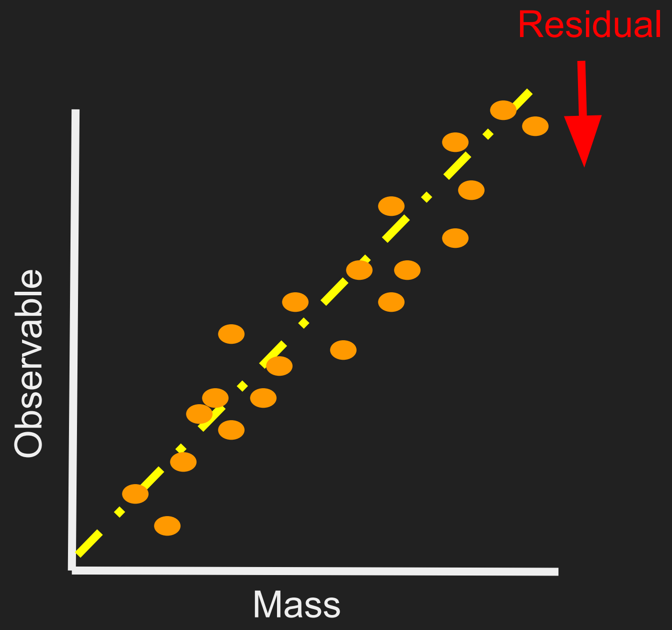


Chen, CA, Kravtsov+
arxiv:1903.08662

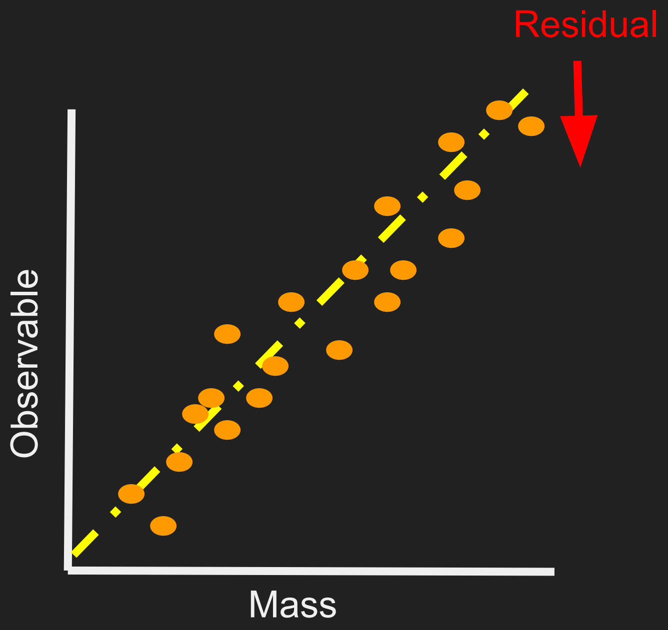
~4.5 Gyr
(consistent with gas motions timescale from Nelson+12))

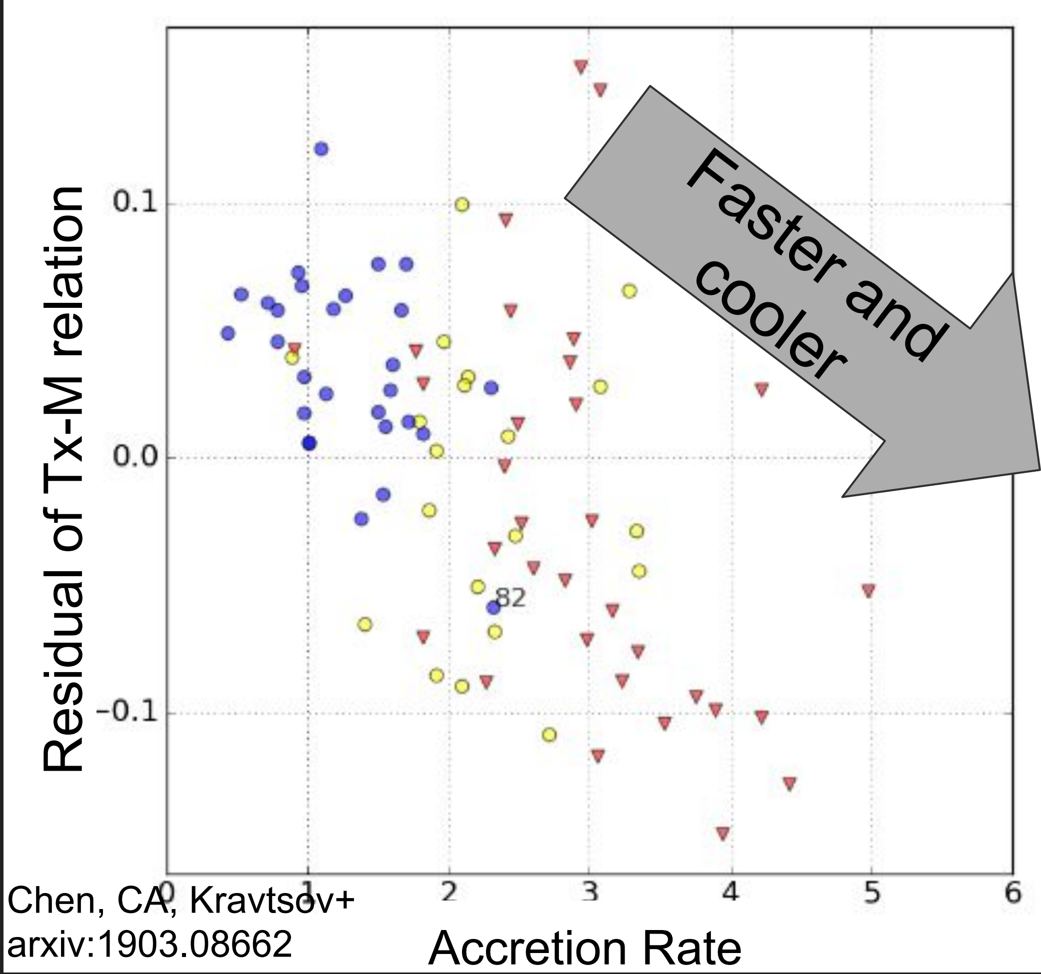
Larger radii

Connecting accretion and shape to scatter in MOR



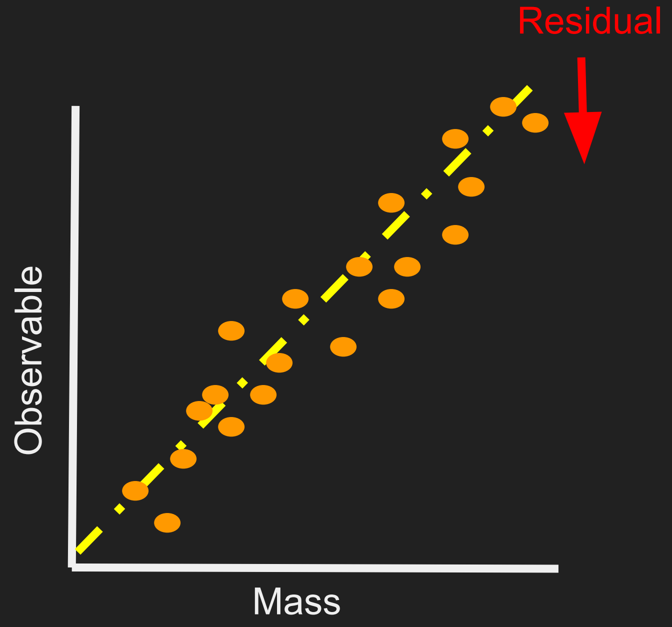
Residual varies monotonically with accretion rate

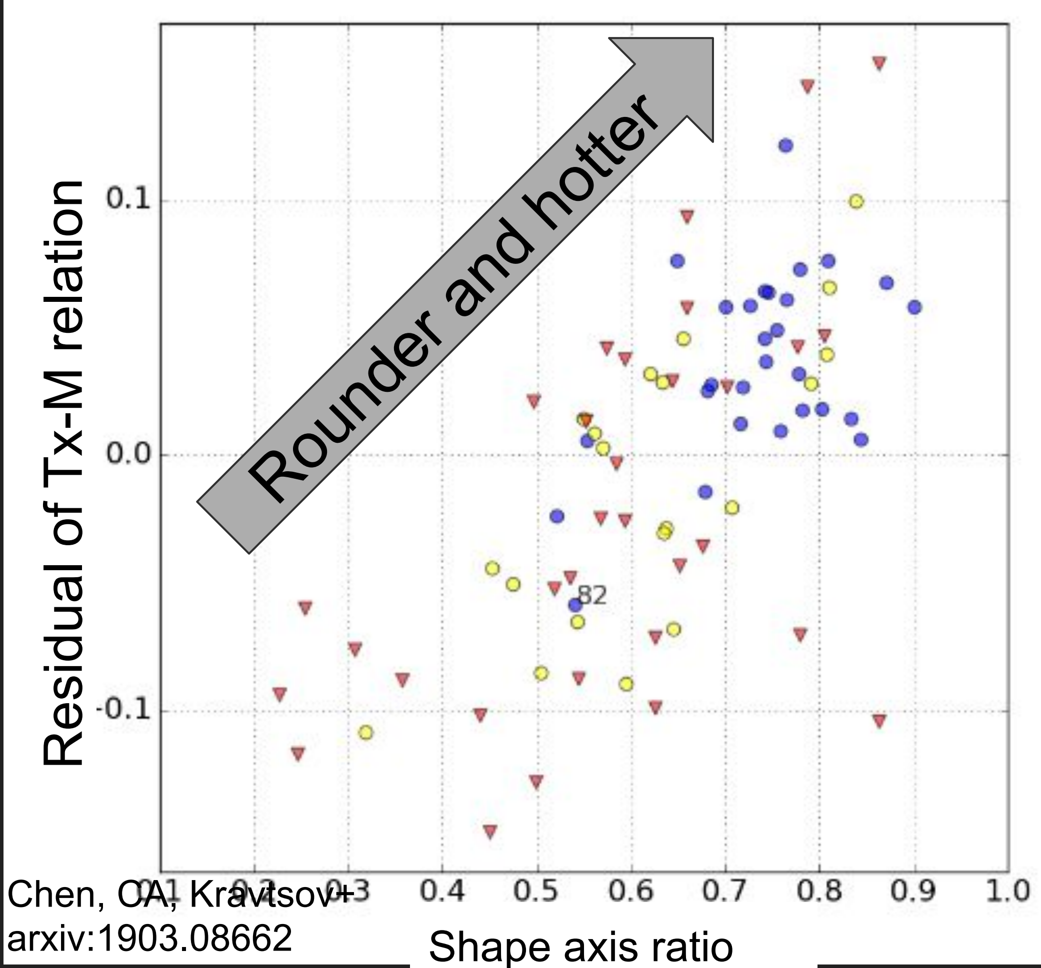




Chen, CA, Kravtsov+
arxiv:1903.08662

Rounder clusters are hotter with higher residuals





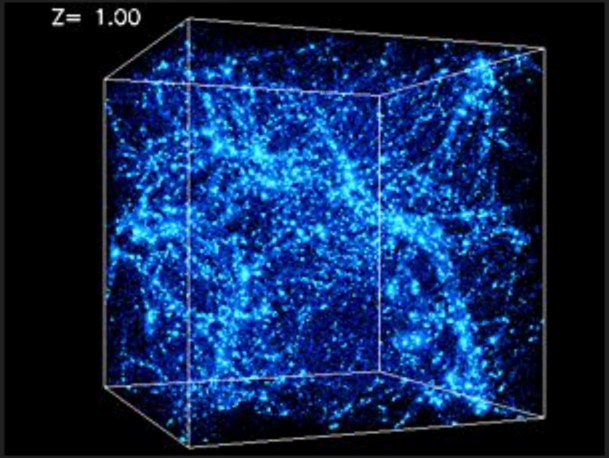
Chen, CA, Kravtsov+
arxiv:1903.08662

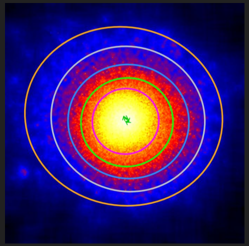
Groundwork for “baryon pasting” prescriptions

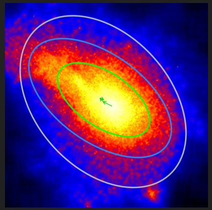
Halo property:
Mass,
accretion rate,
shape, etc.

↔

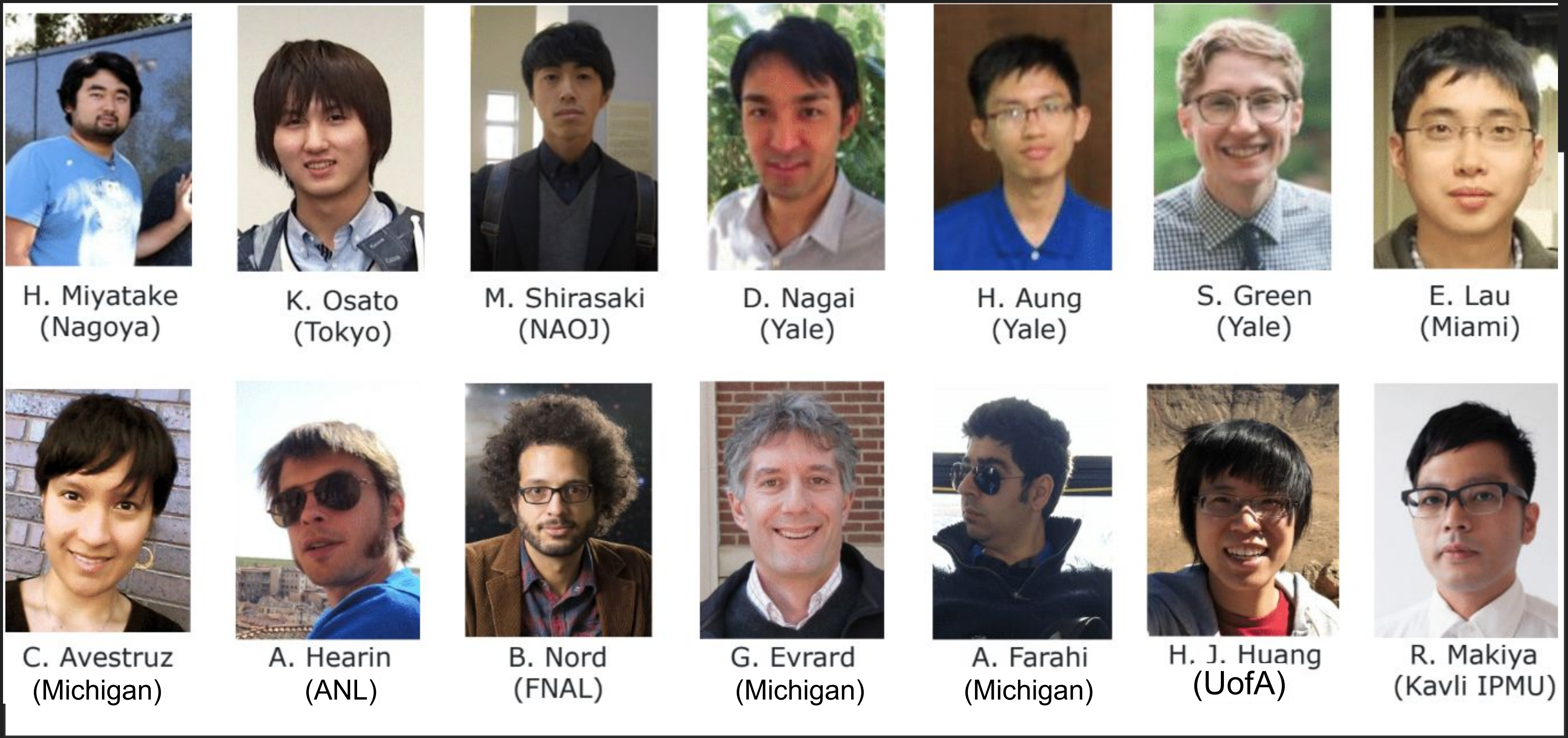
Observable:
Integrated
property,
profile, etc.





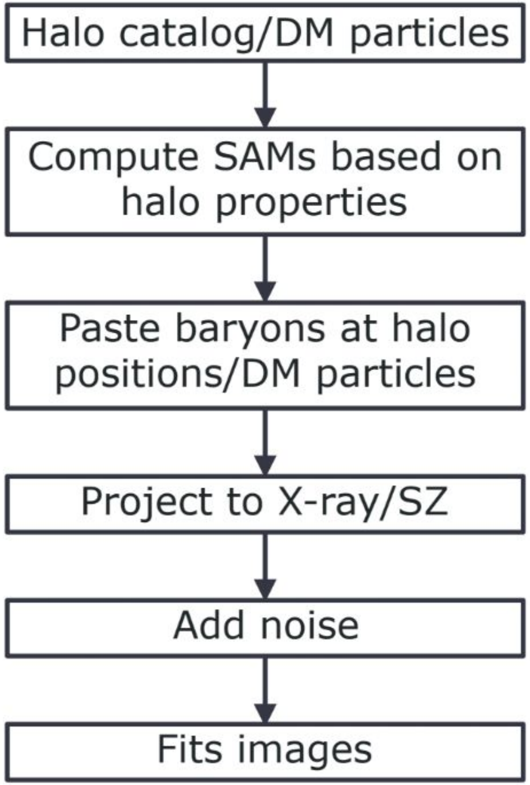


Baryon Pasters



Baryon Pasters

- Still under development, but we already have a prototype pipeline.
  - C++ with Python wrapper
  - MPI capability
- Modular code design
  - Interface to inputs/outputs
  - Different SAMs for pasting baryonic profiles
  - Instrumental-specific noise properties



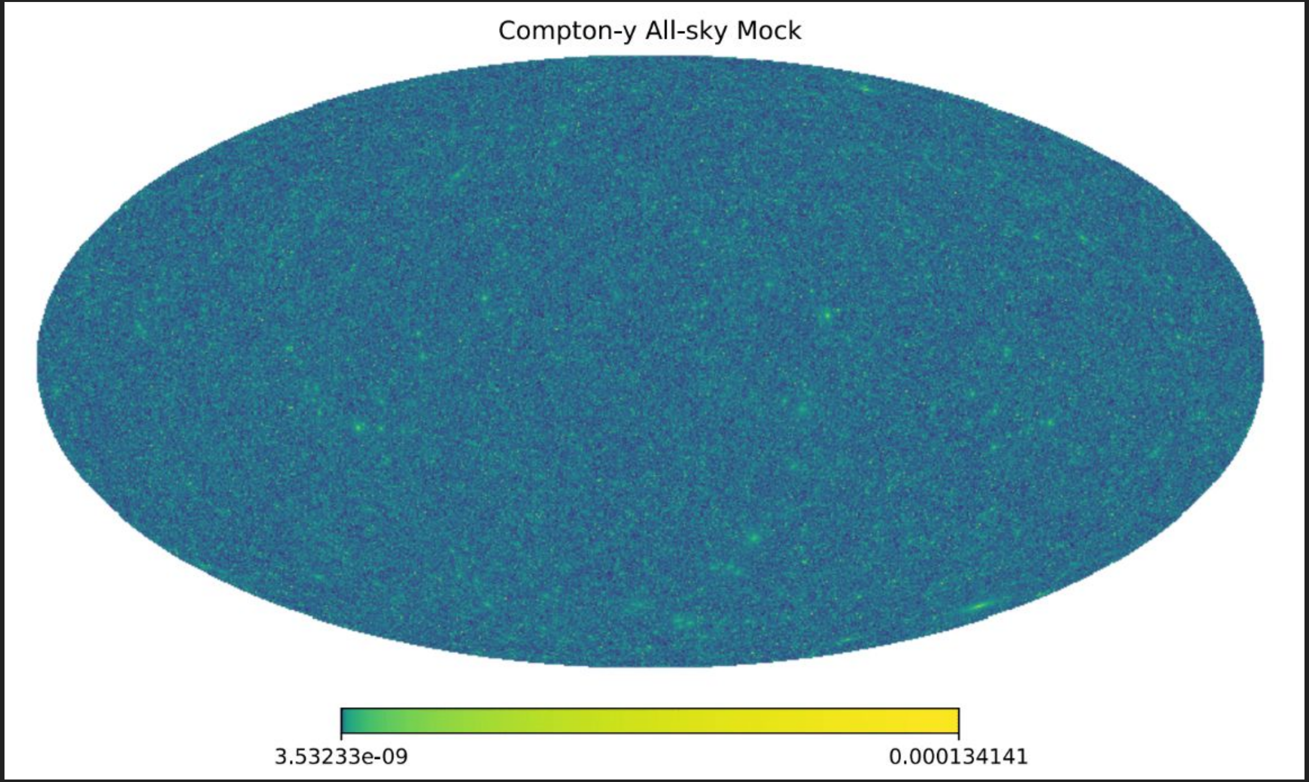
Baryon Pasters: Some Science Goals

- Accurate modeling of selection functions
- Seek for (physically) reasonable (multi-variate) mass-observable relations
- Modification to cosmic shear, cluster/galaxy lensing, galaxy clustering
- [Your area of interest here?]

Baryon Pasters: Planned Efforts

- Mass accretion rate and shape dependence (Machado, CA+)
- Calibrate SAM of gas down to CGM (Osato+)
- Modification of DM profile due to baryonic effects (Shirasaki, Huang+)
- Paint gas (and galaxies) onto filaments (Aung, Green+)
- Unified models of stars and gas (Hearin, Makiya+)
- Gaseous substructure (TBD)

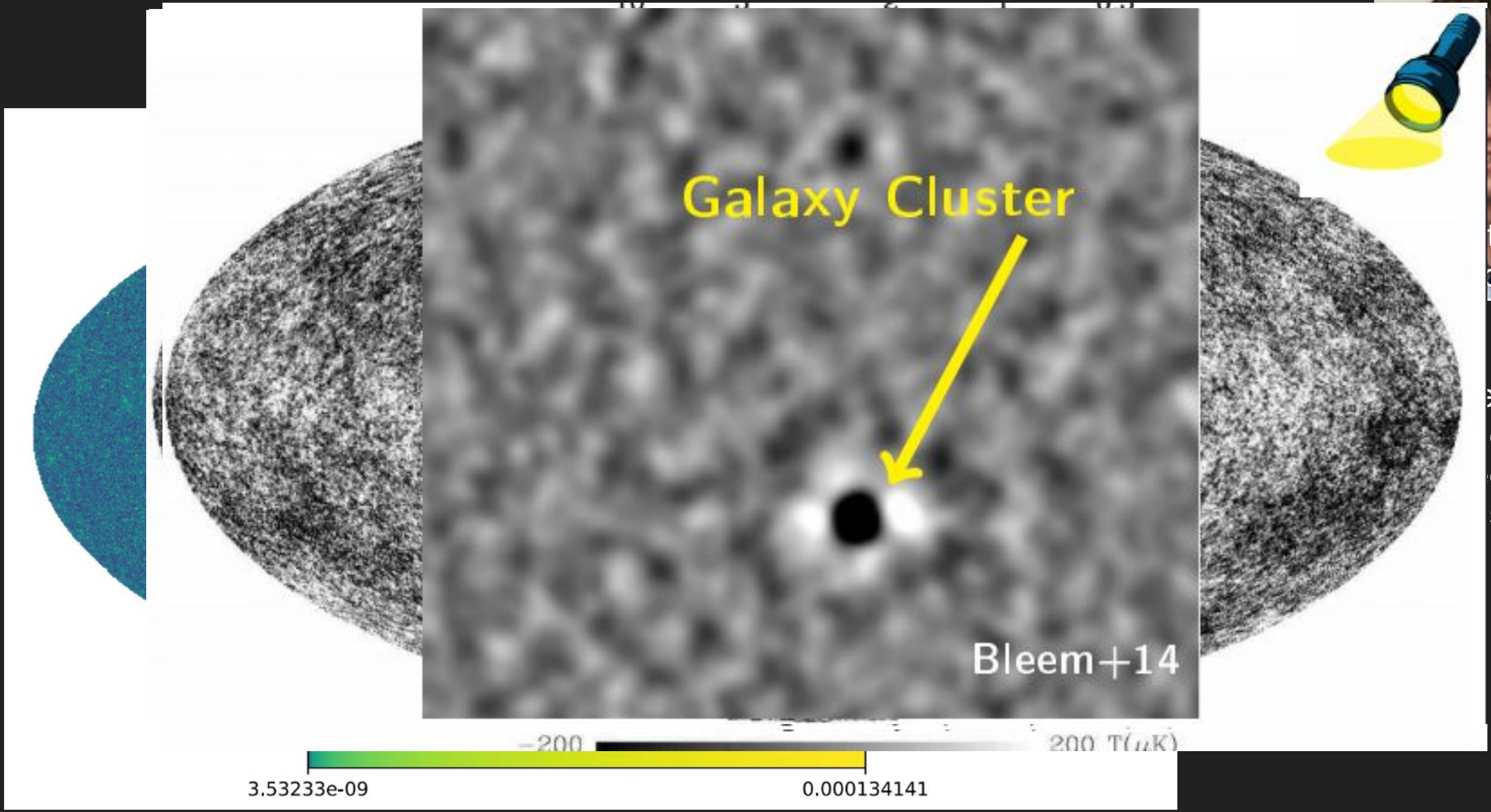
Baryon pasting example: SZ effect



Shaw+10 model (Pressure profile model calibrated from simulations)

Will be used in upcoming HSCxPlanck analysis

Baryon pasting example: SZ effect (backlight)



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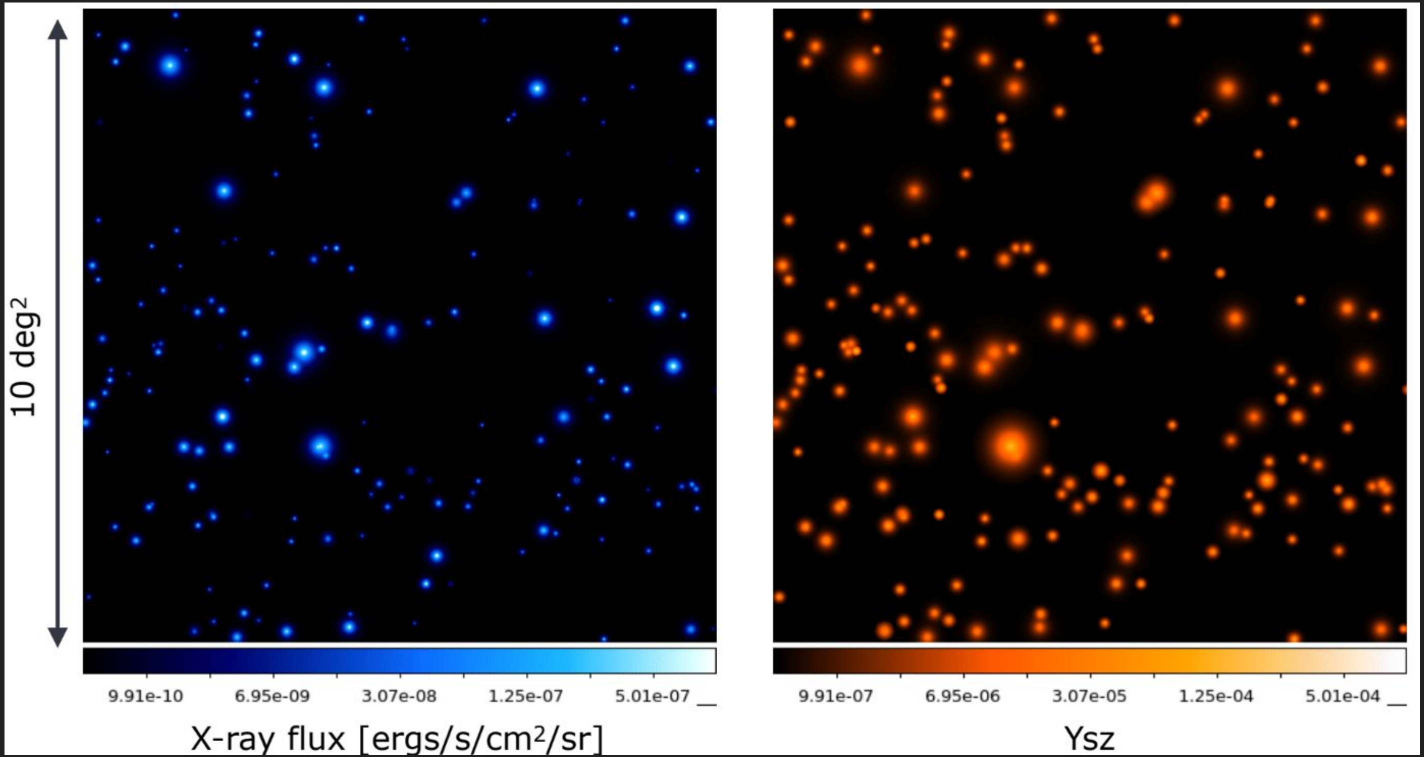
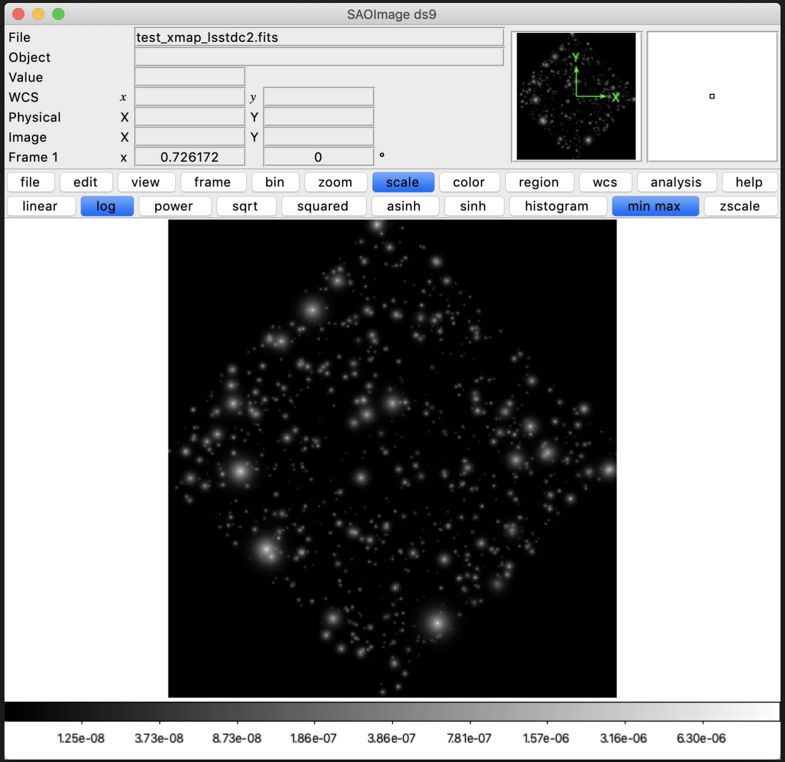
Baryon pasting example

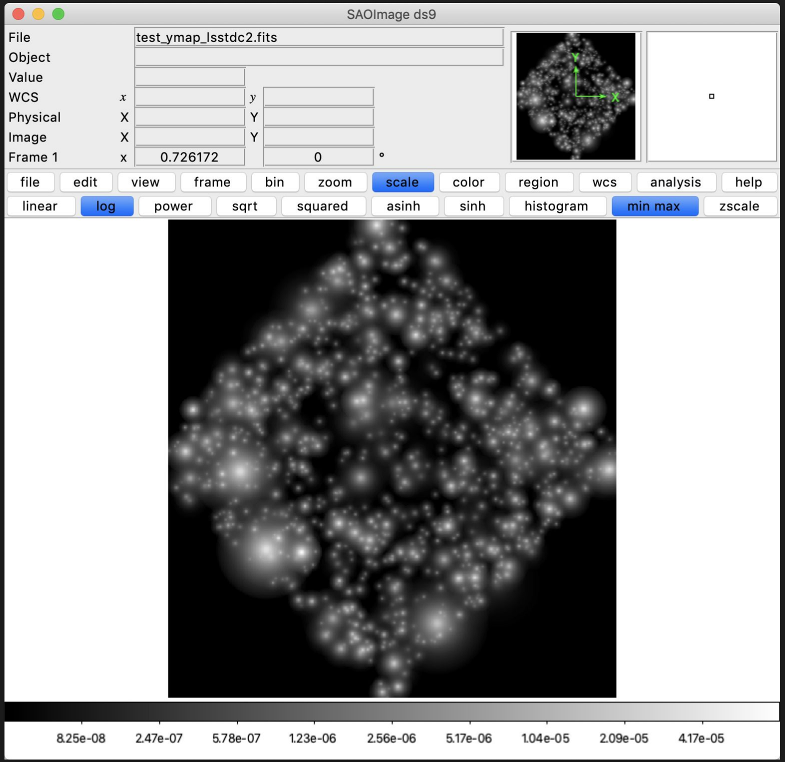


E. Lau
(Miami)

Input: Lightcone simulation

First X-ray and SZ maps from LSST Simulations





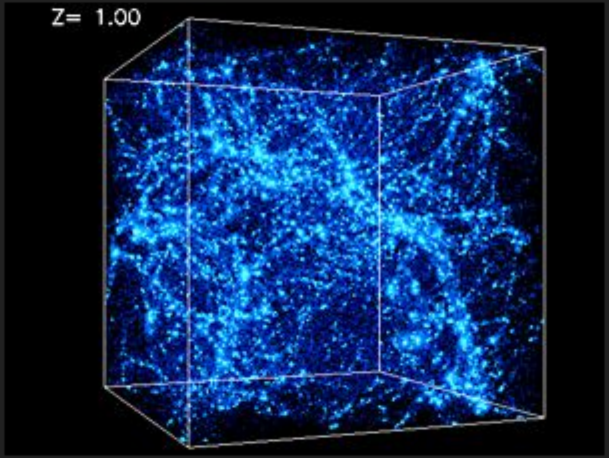
Courtesy: Hironao Miyatake, Andrew Hearin, Erwin Lau - Baryon Pasting efforts

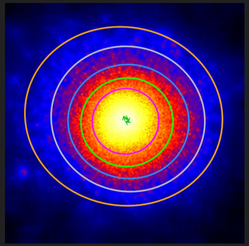
“Baryon pasting” application

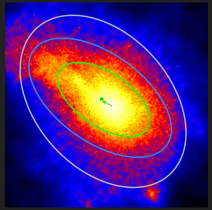
Halo property:
Mass,
accretion rate,
DM density

↔

Observable:
Tx, Ysz

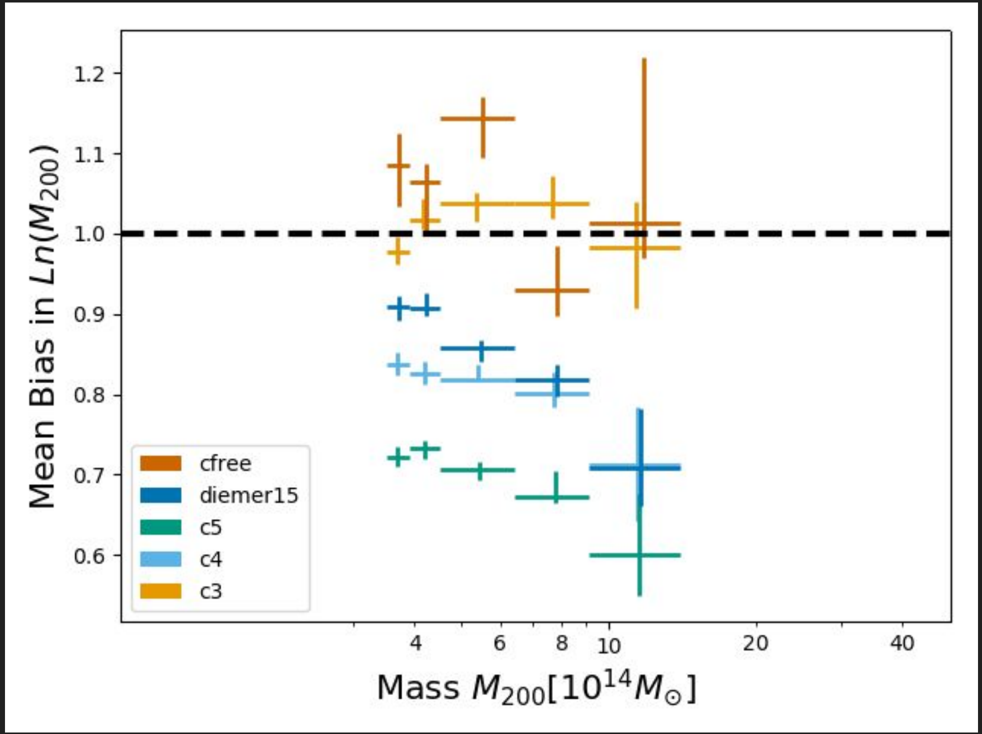


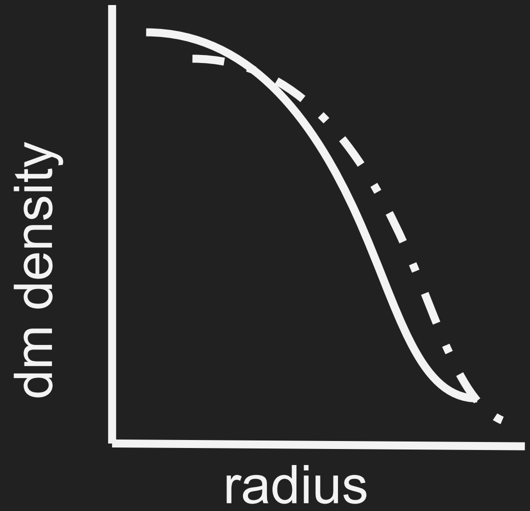




Compare with Shaw model

Weak lensing mass estimate has model dependence

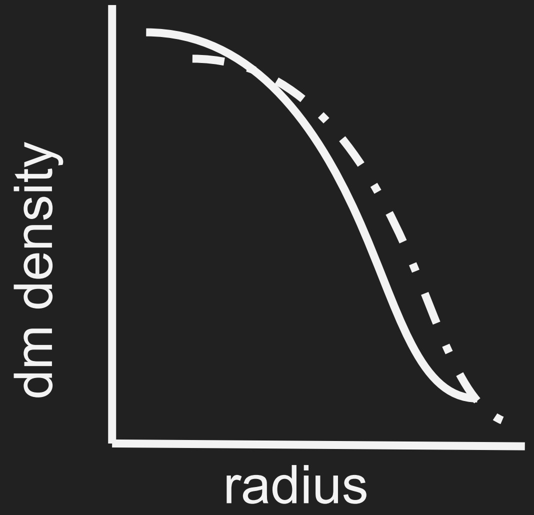




Example: Testing bias of z=1 MXXL halos with different concentration assumptions

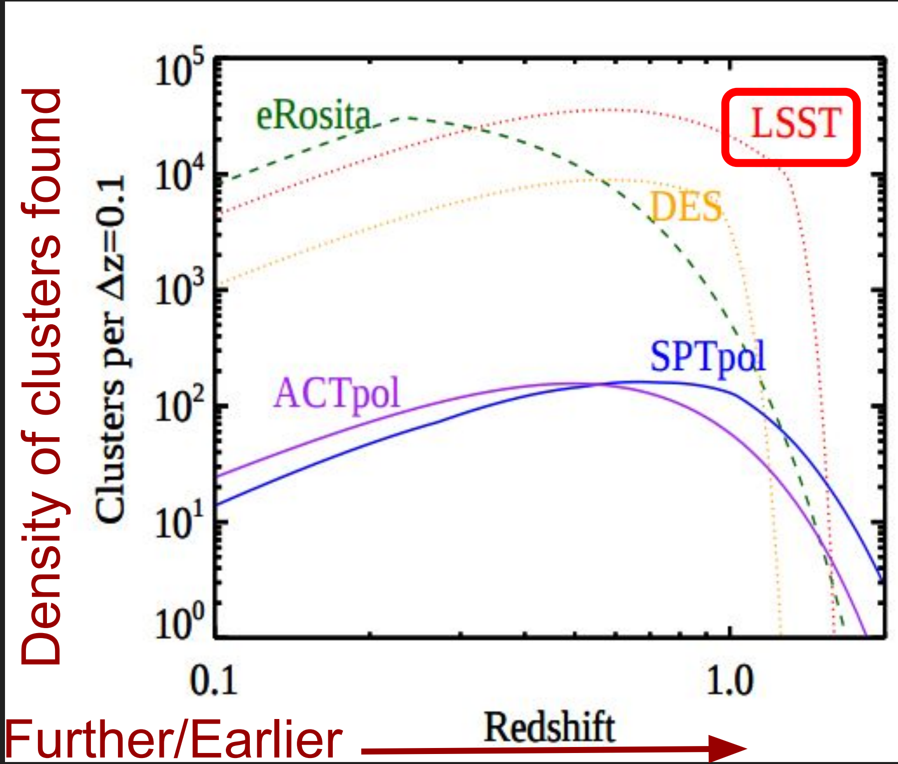
Weak lensing mass calibration

- Stacked mass fitting vs. individual fit in hierarchical framework
- Test observational effects, e.g. miscentering, selection…
- Model profile dependence, e.g. radial range, c-M assumptions…
- Profile independent measures, e.g. aperture mass



Larger datasets from surveys: Galaxy Clusters

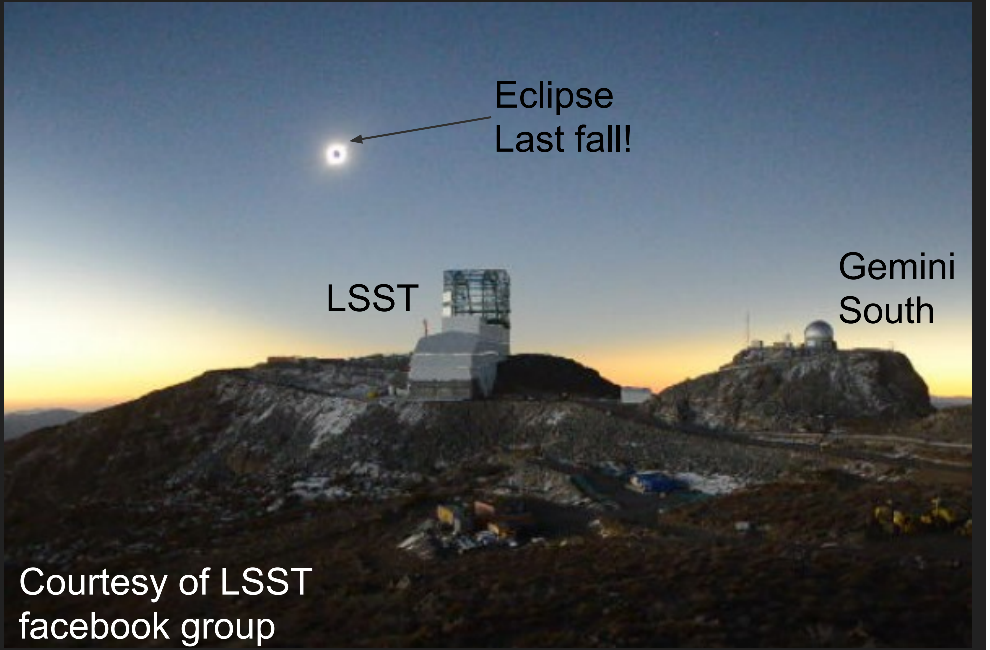
… Getting more objects for better statistics

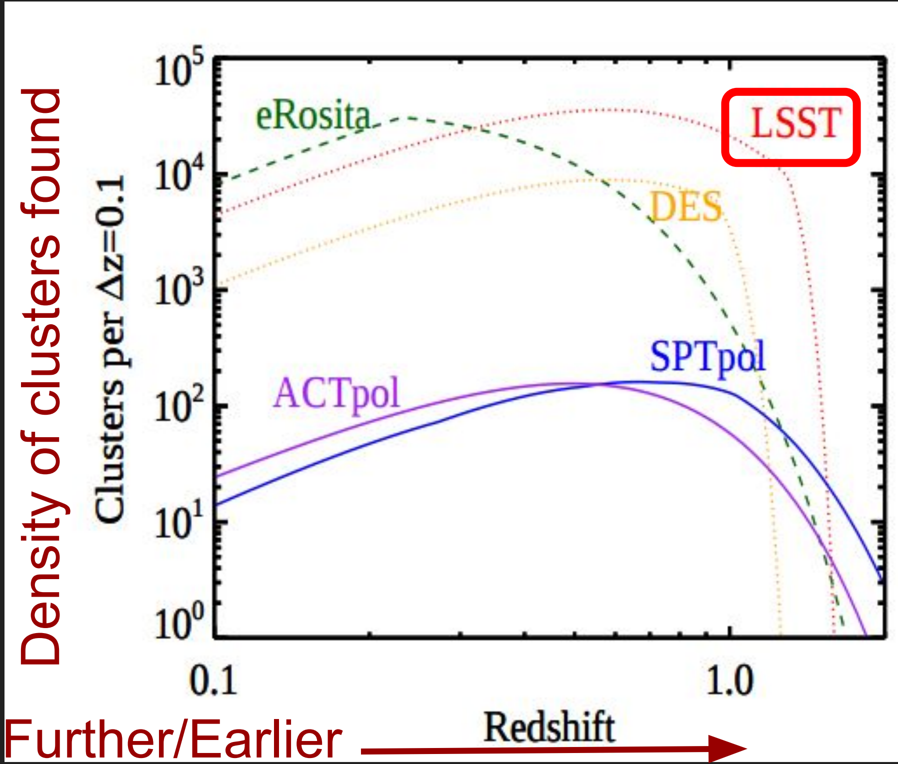


Current/Future Surveys

Larger datasets from surveys: Galaxy Clusters

… Getting more objects for better statistics





Current/Future Surveys

Hacking for LSST - Cluster Mass Calibration Pipeline

Training in data and computation

software carpentry

Teaching basic lab skills for research computing

Syllabus

The Unix Shell

- Files and Directories
- History and Tab Completion
- Pipes and Redirection
- Looping Over Files
- Creating and Running Shell Scripts
- Finding Things
- Reference...

Programming in Python

- Using Libraries
- Working with Arrays
- Reading and Plotting Data
- Creating and Using Functions
- Loops and Conditionals
- Defensive Programming
- Using Python from the Command Line
- Reference...

Version Control with Git

- Creating a Repository
- Recording Changes to Files: `add`, `commit`, ...
- Viewing Changes: `status`, `diff`, ...
- Ignoring Files
- Working on the Web: `clone`, `pull`, `push`, ...
- Resolving Conflicts
- Open Licenses
- Where to Host Work, and Why
- Reference...

**At your department

**At professional meetings (AAS, SACNAS, ...)

Summary

- We'll need a confluence of N-body, hydro and semi-analytic modeling to fully leverage the next generation of cosmology experiments
- A galaxy cluster's mass accretion history is a critical component in developing models that paint baryons onto DM only simulations
- Community code development will likely play a key role in the era of LSST