Galaxy Cluster Mergers

Alexia Schulz

Institute for Advanced Study

Andrew Wetzel

Daniel Holz

Mike Warren

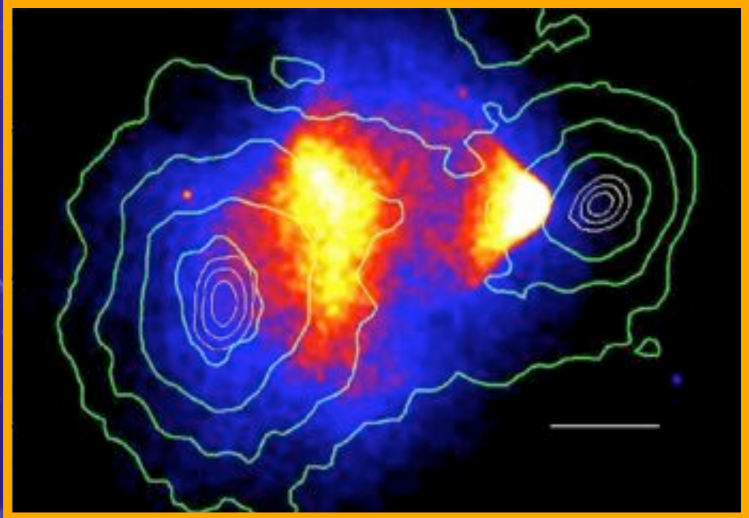
2 Nov 07 - Rutgers University Astrophysics Seminar

Talk Overview

- **Introduction**
  - Why are cluster mergers of interest?
  - Where will mergers complicate life?
- **Methods**
  - N-body Simulations
  - Merger Trees
  - Close pairs as a merger proxy
- **Results**
  - Merger rates and the fate of close pairs
  - Redshift space distortions
  - The merger kernel (coagulation)
  - Environmental dependence
- **Conclusions**
  - Implications
  - Questions

Why are Cluster Mergers Important?

- **Cluster formation processes are important for understanding structure growth**
- **Mergers contaminate galaxy cluster scaling relations**
- **Mergers may contaminate probes of cosmology**
- **Merger events exhibit environmental dependence**
  - Inherited by their galactic inhabitants



Structure Growth and Cosmology

- **Galaxy clusters are the largest virialized objects in the universe**
  - big, bright, easy to see
  - simple compared to galaxies
- **Galaxy clusters appear to have a roughly representative baryon fraction**
- **Galaxy clusters are the most recently formed objects in the universe**
  - Formation is being halted by accelerated expansion
  - probe recent expansion history
- **Cluster formation processes are sensitive to the cosmological parameters, esp. dark energy**

$$\frac{dn}{dM} = -\frac{\rho_m}{M^2}\frac{d\ln\sigma}{d\ln M}\left[0.315\exp\left[-(-\ln\sigma+0.61)^{3.8}\right]\right]$$

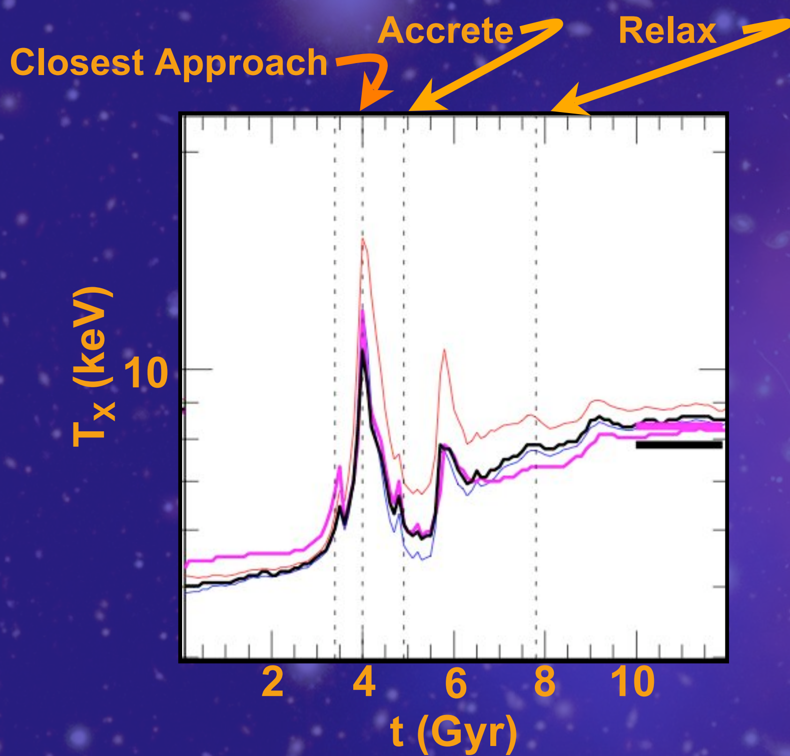
We need cluster masses

- **The key to tapping the number-count game is calibrating the cluster mass -- calibrate scaling relations**

Mergers Impact Scaling Relations

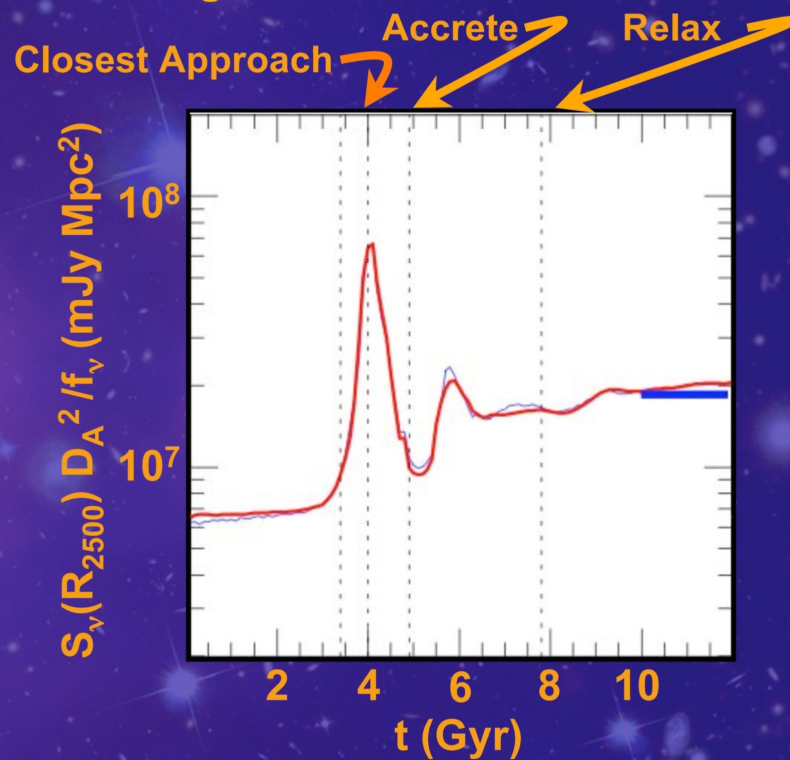
- **X-ray M-T relation**

3:1 Merger, off axis



- **Sunyaev Zel'dovich M-Y relation**

3:1 merger, off axis

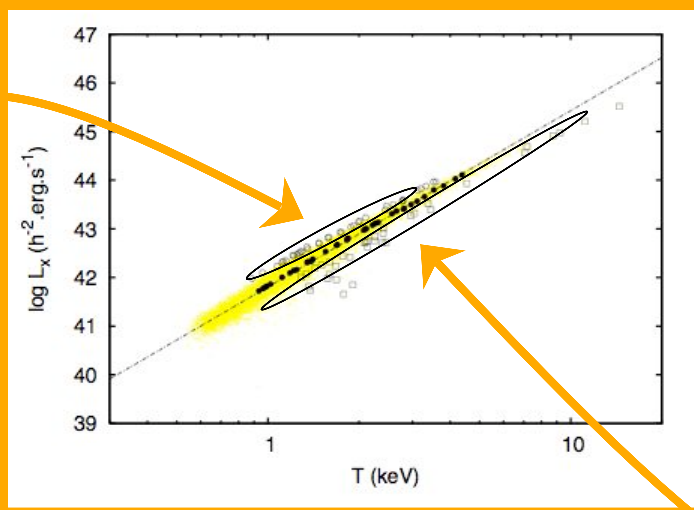


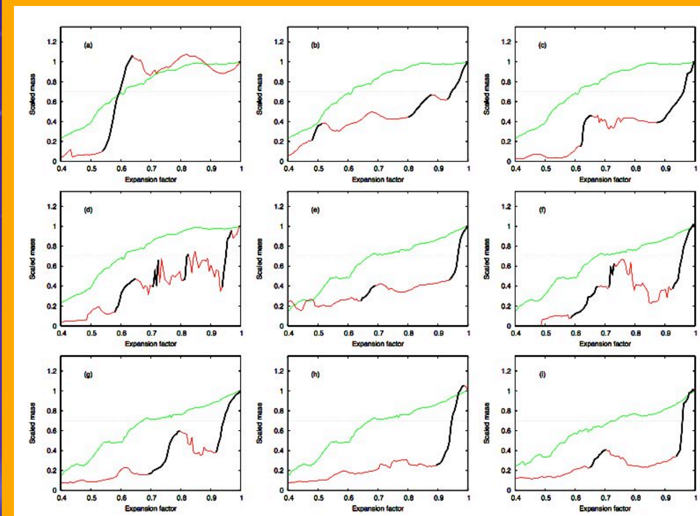
Credits: Poole et al. astro-ph/0701586

N.B.: Mergers alone are not sufficient to account for all the scatter in the observed scaling relations, but these results help illuminate how individual events can impact the scaling relation calibration.

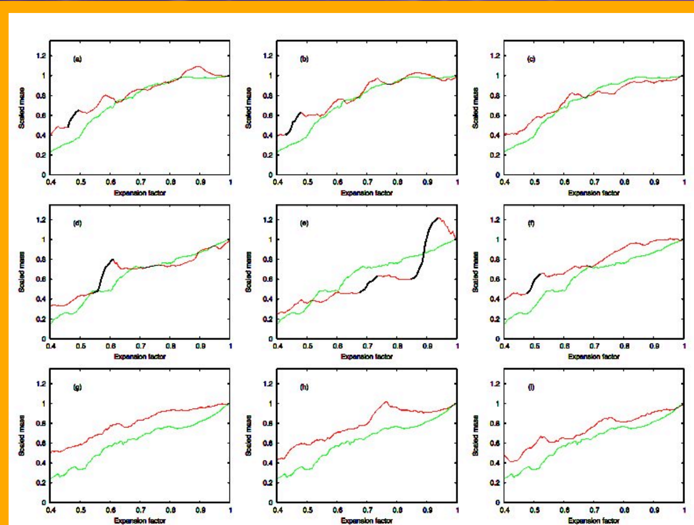
Mergers Impact Scaling Relations

- **Example: X-ray Luminosity-Temperature relation**





Merger dominated growth

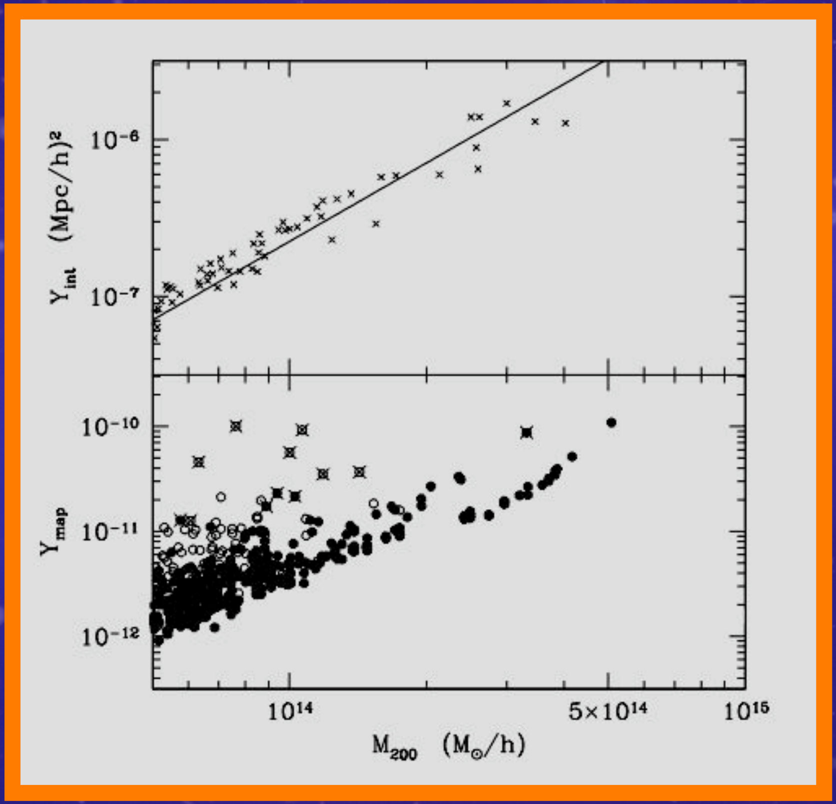


Slow Accretion

Credits: plots from (Hartley et al. 0710.3698)

Mergers Contaminate Cosmological Probes

- Cosmological constraints sensitive not only to scaling relations, but to the theoretical knowledge of the scatter about the relations

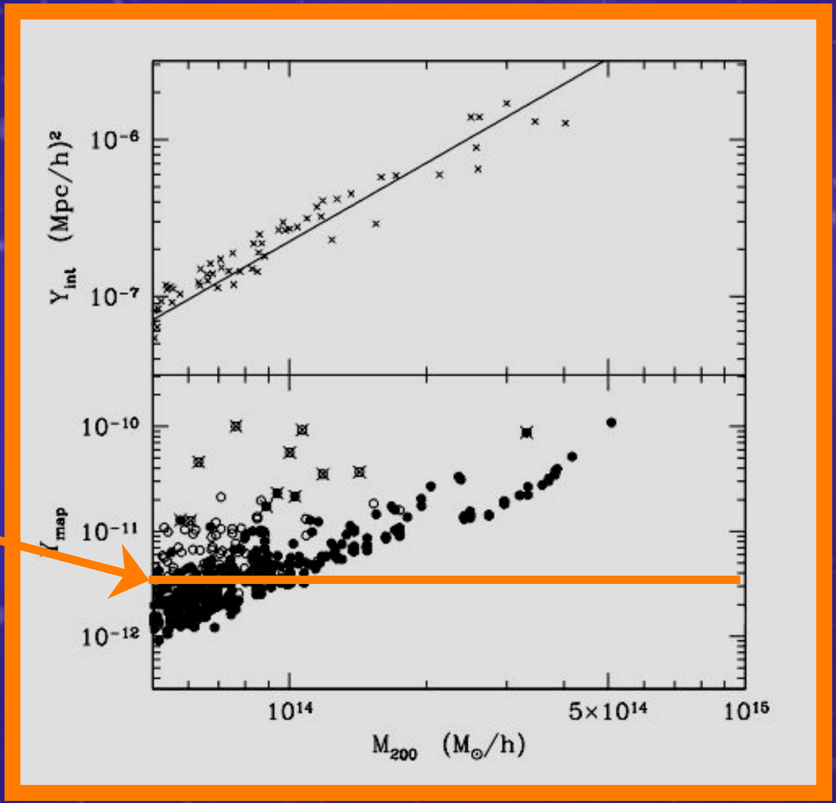


Credits:White & Hernquist astro-ph/0205437

Mergers Contaminate Cosmological Probes

- Cosmological constraints sensitive not only to scaling relations, but to the theoretical knowledge of the scatter about the relations

You have to define your threshold in terms of the observable

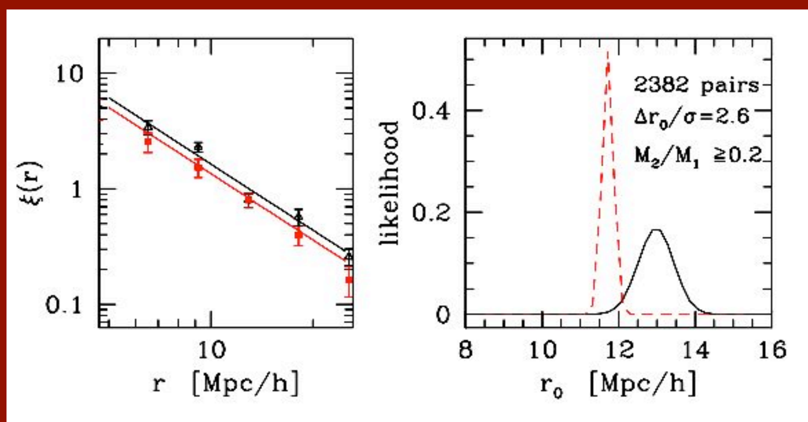


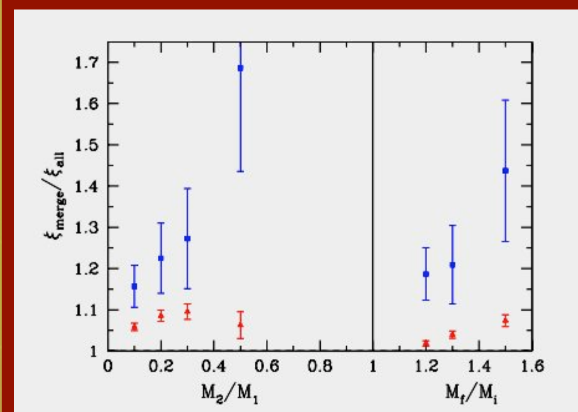
To understand the distribution of object masses in the sample, the shape of the scatter needs to be characterized

Credits:White & Hernquist astro-ph/0205437

Mergers Contaminate Cosmological Probes

- **Calibration via clustering**
  - Recently merged halos are more biased
  - Self calibration relies on clustering to calibrate mass-observable relations





$M > 5 \times 10^{13}\, M_\odot/h$

Credits:Wetzel et al
astro-ph/060699

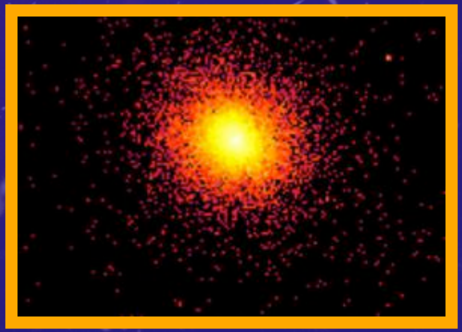
Mergers Contaminate Cosmological Probes

- Cluster gas mass fraction can be used with CMB or BBN value of Ω_b to constrain Ω_m

$$f_{\rm gas} = \frac{\rm Xray\ gas\ mass}{\rm total\ mass\ in\ cluster} \qquad f_{\rm gal} = 0.19\, h^{0.5} f_{\rm gas}$$

$$f_{\rm baryon} = f_{\rm gal} + f_{\rm gas} \qquad \Omega_m = \frac{\Omega_b}{f_{\rm baryon}}$$

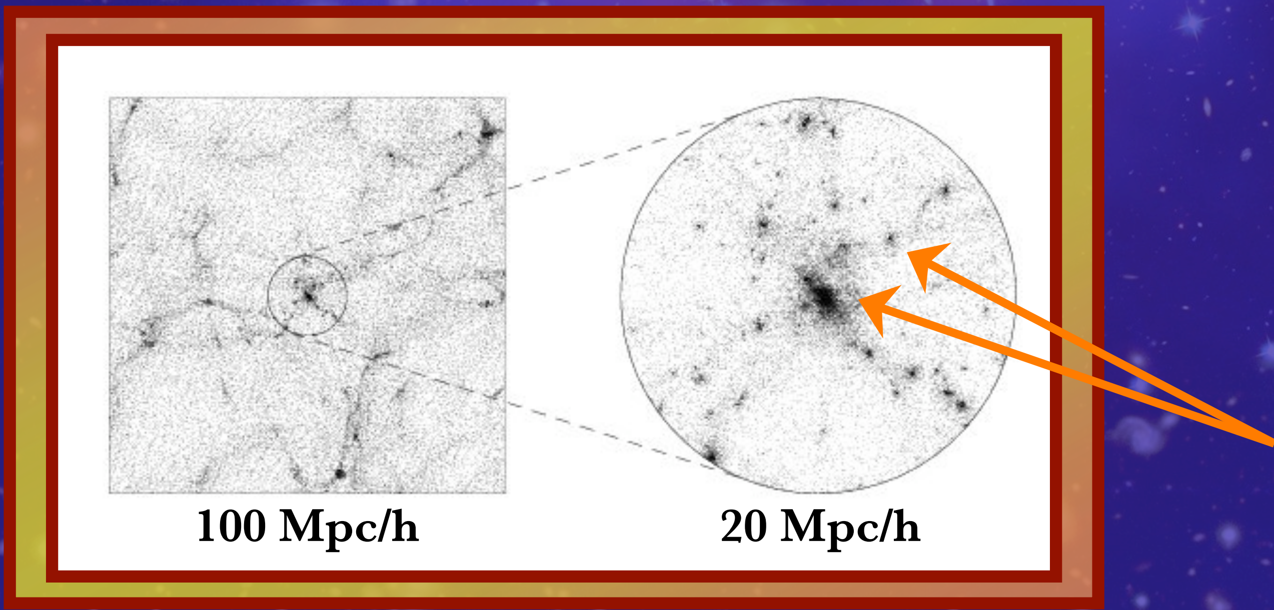
- Relies on weak lensing masses, and X-ray properties of ***RELAXED*** clusters
- Use X-rays to determine relaxedness



Credits: Steve Allen

Methods

- **Mergers are observationally difficult to identify**
  - Relies principally on the object appearing "disturbed"
  - May depend on alignment with respect to line of sight
  - Difficult to quantify completeness and contamination of an observed merger sample
- ***GOAL: Determine if close spatial pairs of clusters can be used as an observational proxy***



Credits: Martin White

For all pairs we ask:

Do these guys merge in Δt?

Methods

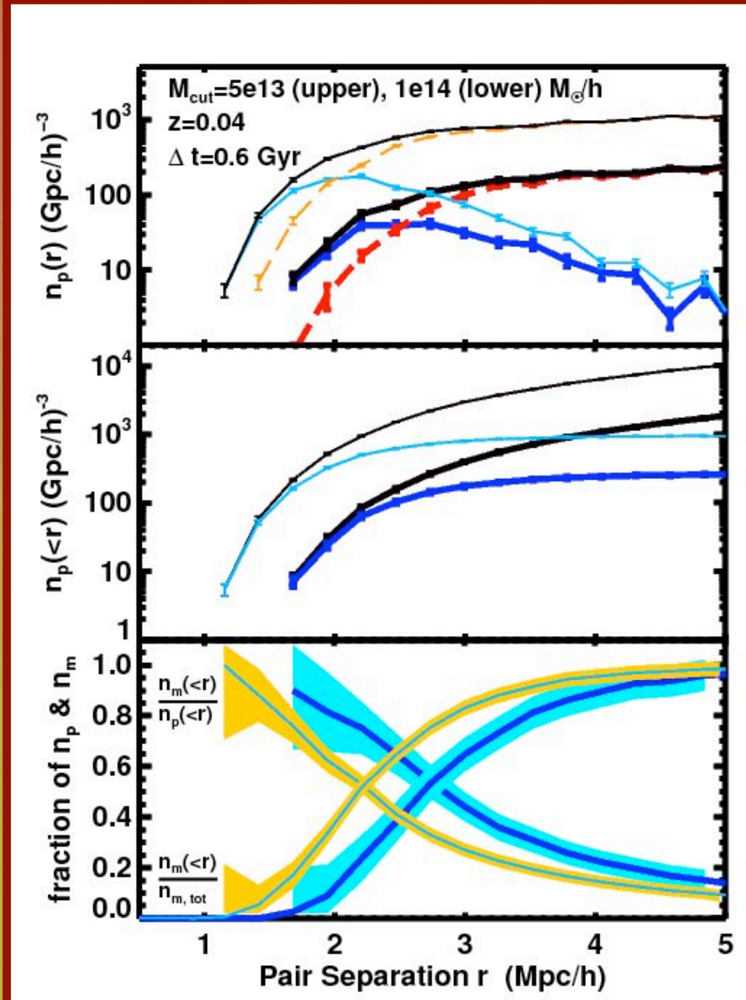
- **N-body Dark Matter Simulations with HOT**
  - 1.1 Mpc/h and 2.2 Mpc/h
  - 1024^3 Particles at 1×10^{11} $M_{\odot}$/h and 8×10^{11} $M_{\odot}$/h
  - Outputs in 1 Gyr intervals over 1 > z > 0
  - Halo catalogs with FoF with b=0.15
  - Halo catalogs have M > 5 $\times10^{12}$ $M_{\odot}$/h and 4 $\times10^{13}$ $M_{\odot}$/h
  - ~75,000 halos with M>5 $\times10^{13}$ $M_{\odot}$/h in smaller simulation

- **Merger trees specify a parent-child relationship**
  - Progenitor is a parent that contributes >50% of its mass
  - All parents (not just progenitors) are stored for each child
  - A merger is a child with more than one progenitor
  - 2 largest progenitors used for most of the merger statistics

Results - Mergers and Pairs

- **In 0.6 Gyr only pairs at smallest separations reliably merge**
- **Large separations**
  - Contamination: most pairs do not merge
- **Small separations**
  - Incompleteness: many mergers are missed
- **True for all mass scales resolved in our simulation**

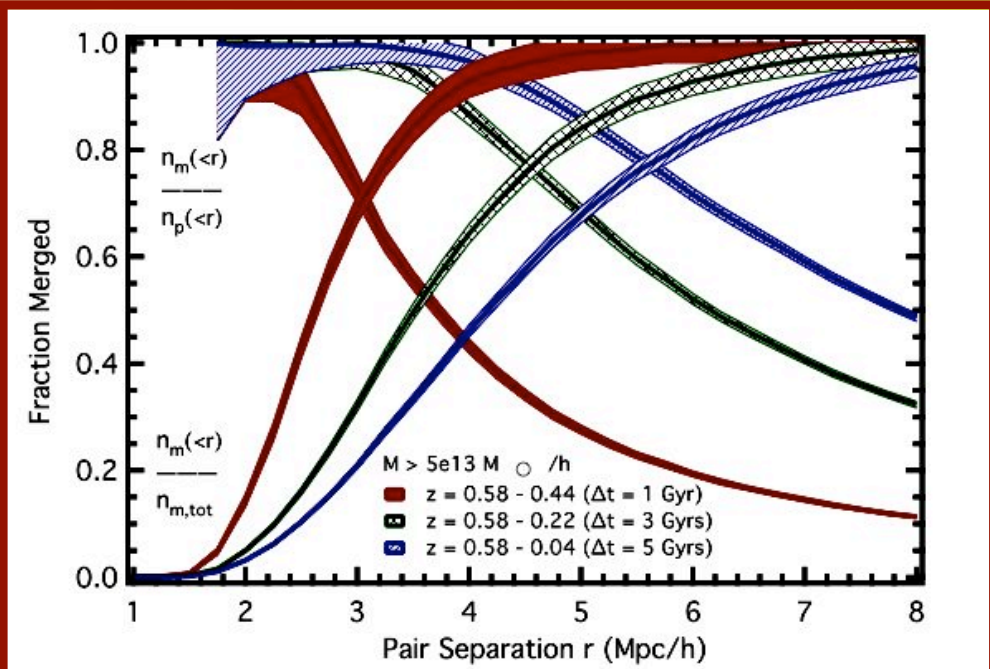
- **Pairs are not good merger indicators for this redshift and time interval**



Results - Mergers and Pairs

➢ **Is it just because halo mergers take longer than that?**

NO!

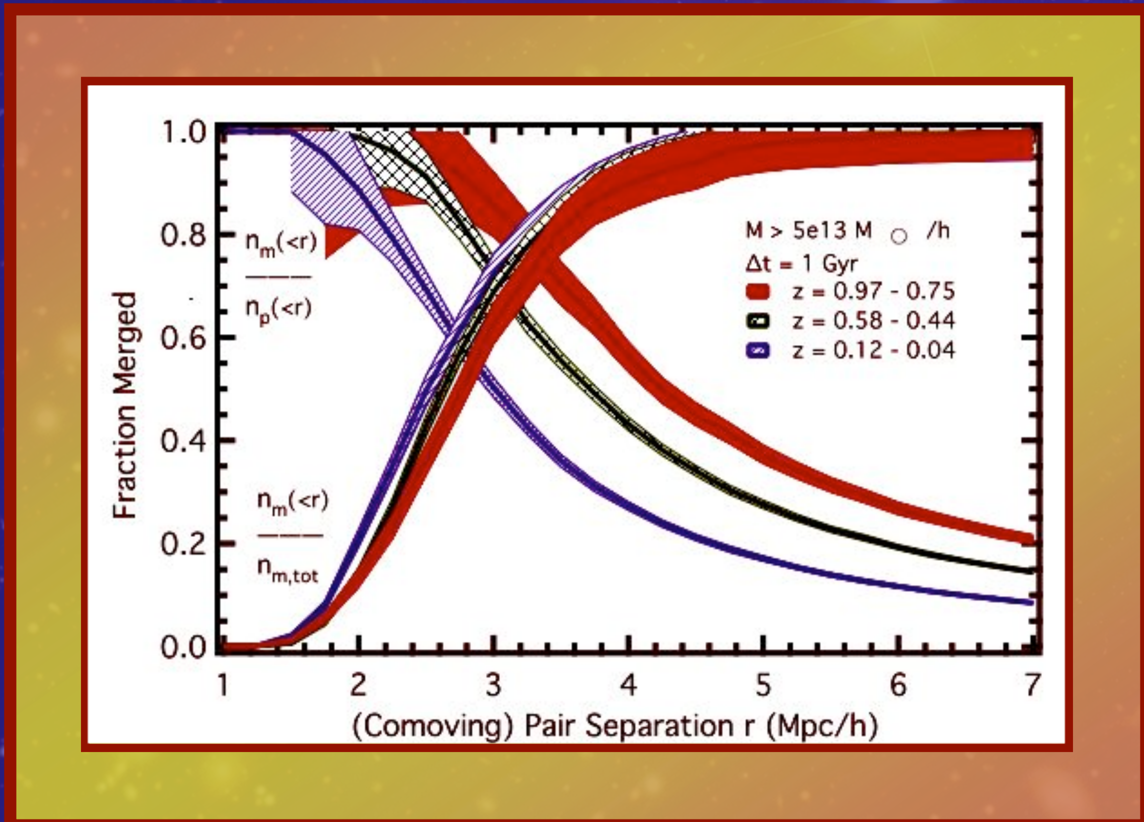


Different Merger Timescales

Results - Mergers and Pairs

- Maybe things improve at high redshift compared to z=0?

NO!



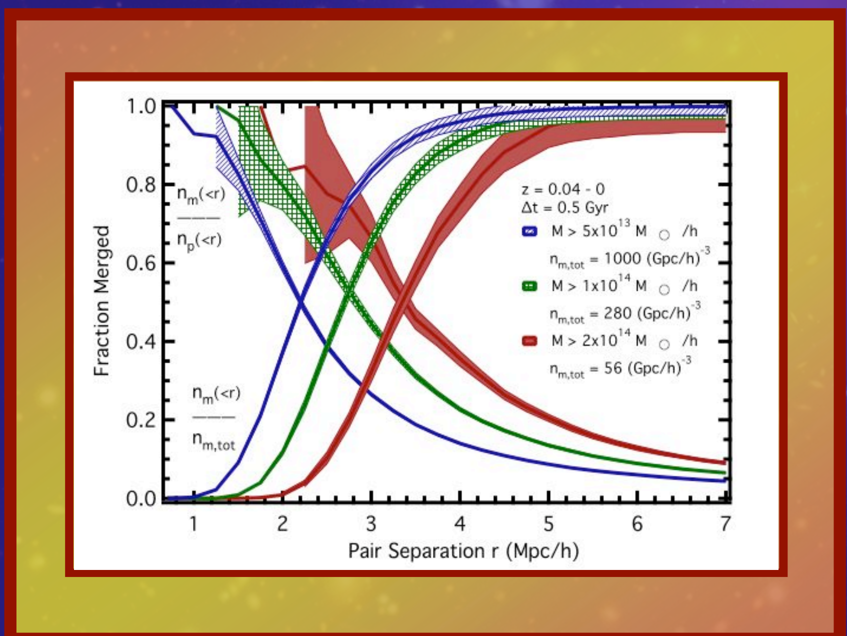
Different Merger Redshifts

Results - Mergers and Pairs

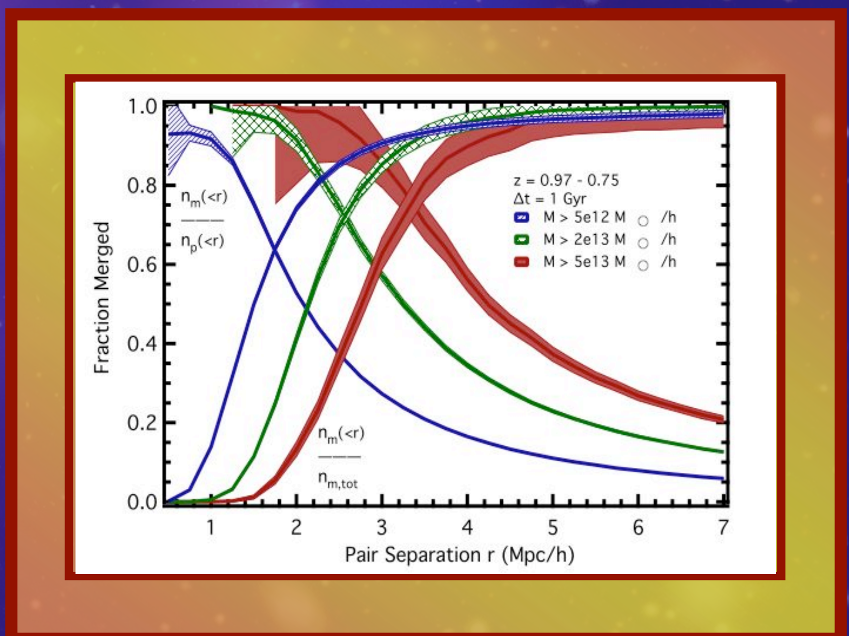
- Does the situation improve at higher or lower masses?

NOPE!

- High mass - contamination gets worse
- Low mass - pair approximation gets increasingly unreliable for low (galaxy) mass halos



$z=0$ ▣ $\Delta t=0.6$ Gyr ▣ Masses up to 2×10^{14}

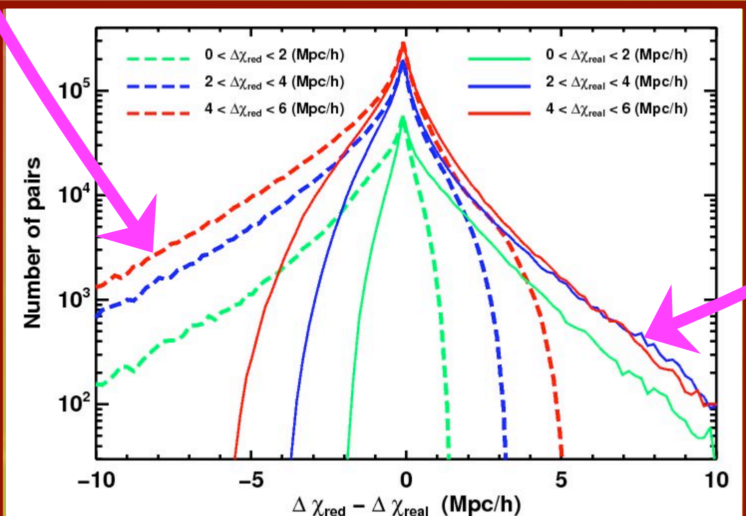


$z=1$ ▣ $\Delta t=1$ Gyr ▣ Masses down to 5×10^{12}

Results - Redshift Space

Distant pairs that appear close in redspace

Genuine pairs that get removed



- **We can only actually measure close halo pairs in redshift space**
- **Distortions are in the Kaiser infall regime**
- **Redspace distortions alter the merger candidate list**
  - Genuine close pairs get separated
  - Pairs separated by ~10 Mpc are mapped artificially close together
- **There is an asymmetry leading to a vast increase in the number of candidates**

Prognosis: Not So Good

- **Halo pairs are of limited value in assessing halo merger rates for all**
  - Timescales
  - Redshifts
  - Masses
- **For any reasonable level of completeness, merger candidate sample is quite contaminated (contains pairs that do not merge)**
- **Redshift space distortions vastly increase contamination and decrease completeness of the candidate sample**
- **Results hold true for halos hosting a single galaxy**

Galaxy Rates

- Can we trust galaxy merger rates computed with close galaxy pairs?

- No, not unless the population of galaxy pairs is dominated by pairs living in the same halo

Results - Merger Efficiency

- Is all hope lost? Can the merger population ever be characterized?
- Simulations can calibrate the merger kernel relating the merger rate to the mass function

$$Q(m_1, m_2, z) = \frac{n_m(m_1, m_2, z)}{n(m_1, z)\, n(m_2, z)\, \Delta t}$$

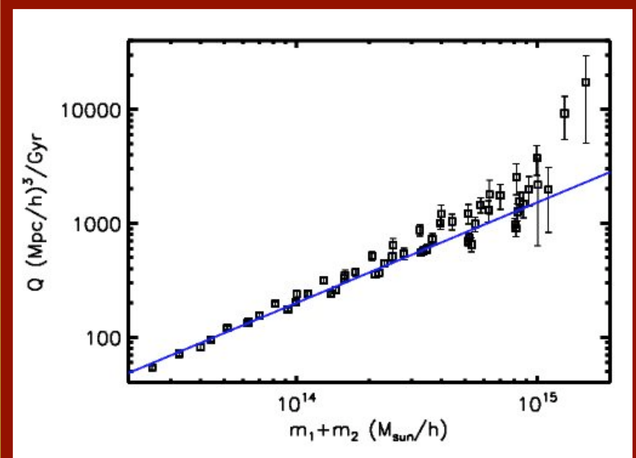
- From simulations:

$$Q(m_1, m_2, 0) = 0.088 \left(\frac{m_1 + m_2}{h^{-1} M_\odot} \right)^{0.88}$$

- But the fit is bad:

$$\chi^2_{\rm red} = 3.09$$

- Lots of scatter!

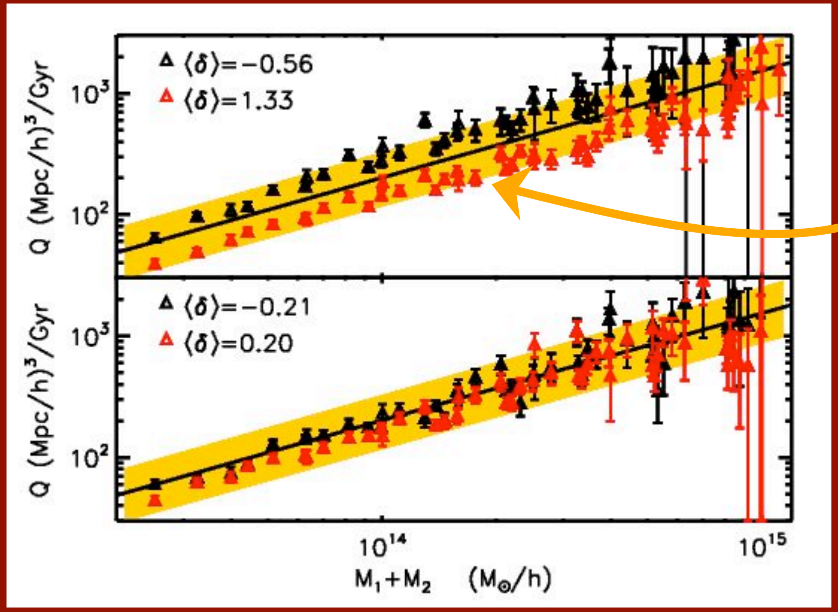


Results - Merger Environment

- What is driving the scatter?
- Environment clearly plays a role!

Merging is less efficient in high density environments

4 Environment Quartiles ~17 Mpc/h

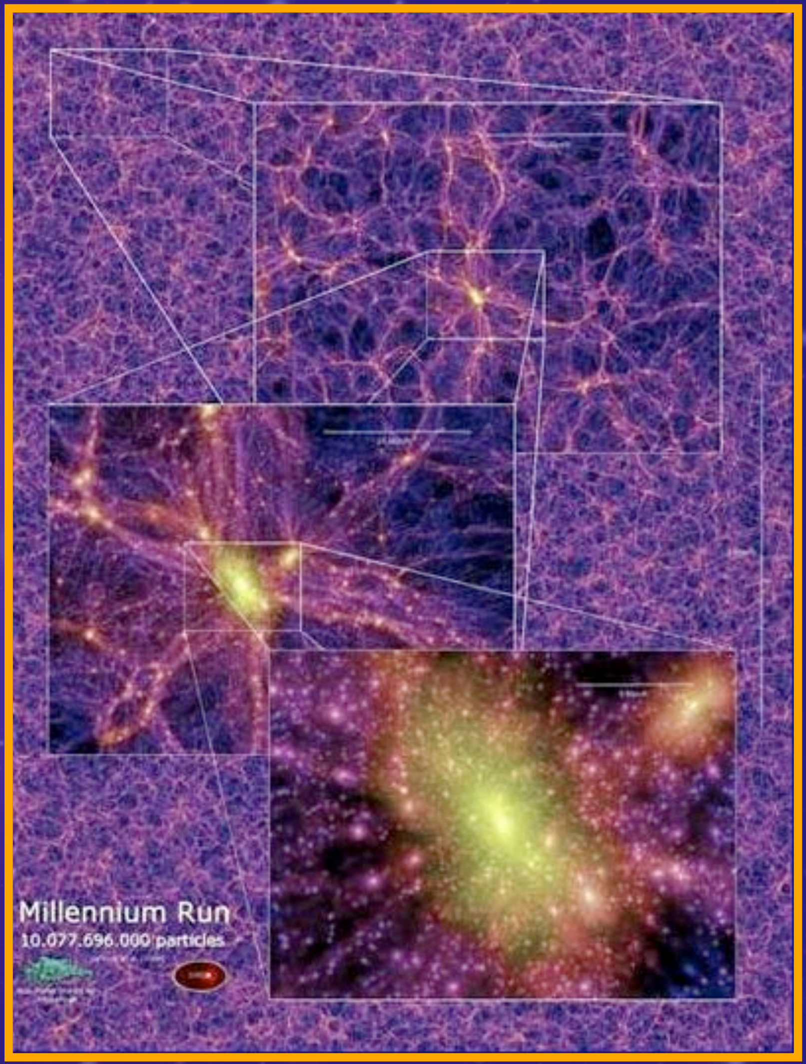


Density Extrema

Inner Quartiles

Results - Merger Environments

- **What is inhibiting mergers in high density environs?**
  - Larger velocities
  - Tidal fields
  - Angular momenta
- **Environmental trend depends on mass**
  - More pronounced at high mass
  - Potential reversal of trend at low mass suggested
    - Smaller (distinct) halos may merge more efficiently at high densities.
    - Smaller relative velocities among small halos in a filament, experiencing bulk flow toward large central object
- **Need different simulations to investigate**



Conclusions

- **Pairs of distinct halos are not a reliable proxy for halo merger rates at any redshift, time interval, or mass**
  - High contamination of merger candidate sample
  - Incomplete candidate sample
  - Highly degraded by redshift space distortions
- **In the absence of an observable proxy, merger rates will need to be inferred from the mass function via the merger kernel**
  - We have calibrated this at high halo mass
  - Significant scatter in the relation is driven primarily by environmental dependence
  - High mass pairs are less efficient mergers in overdense environments
- **Desirable to find a reliable observable halo merger signature**