Dark Matter and Galaxy Formation

(Section 3: Galaxy Data vs. Simulations)

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Overview

Creation of halos and the infall of baryonic matter

Success of modern hydrodynamical simulations

HOD formalism and the abundance matching model

Star formation rate

Galaxy “main sequence”

Galaxy mergers

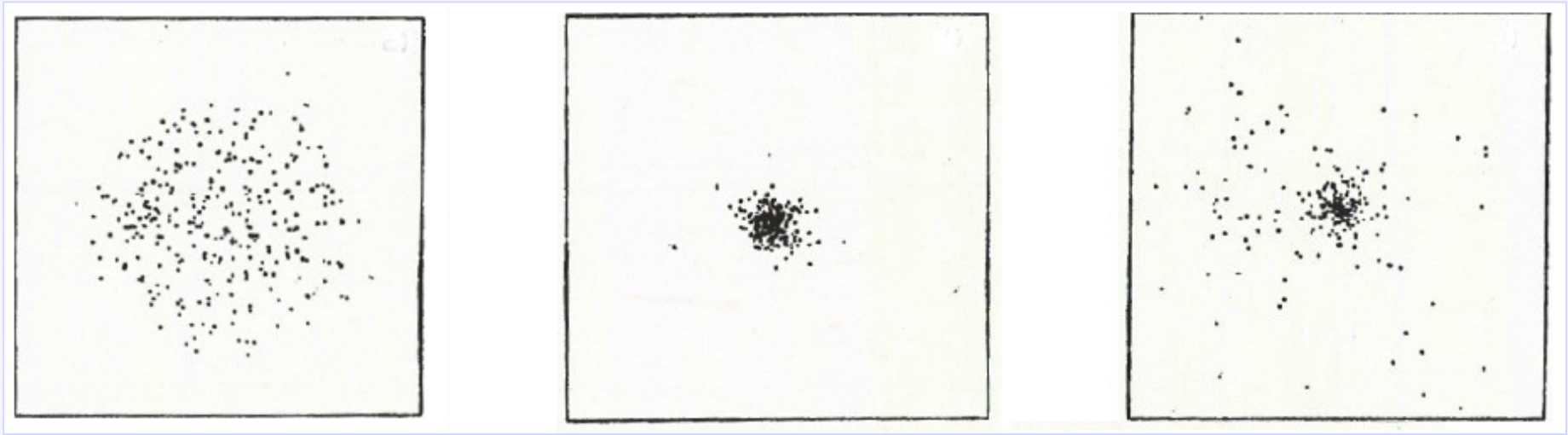
Positive Fluctuations

Initial inhomogeneities:

$$P(k) = A\,k^n$$

roughly scale-invariant $(n \approx 1)$, Gaussian

Collapse of positive fluctuations:



stable configuration: about ½ the maximum radius

density falls as r^{-2}

Baryonic Matter

Baryons radiate energy and fall toward the halo center

Less than 20% form stars and become galaxies

If the baryonic AM distribution was like that of DM

baryons would have: large central density peak

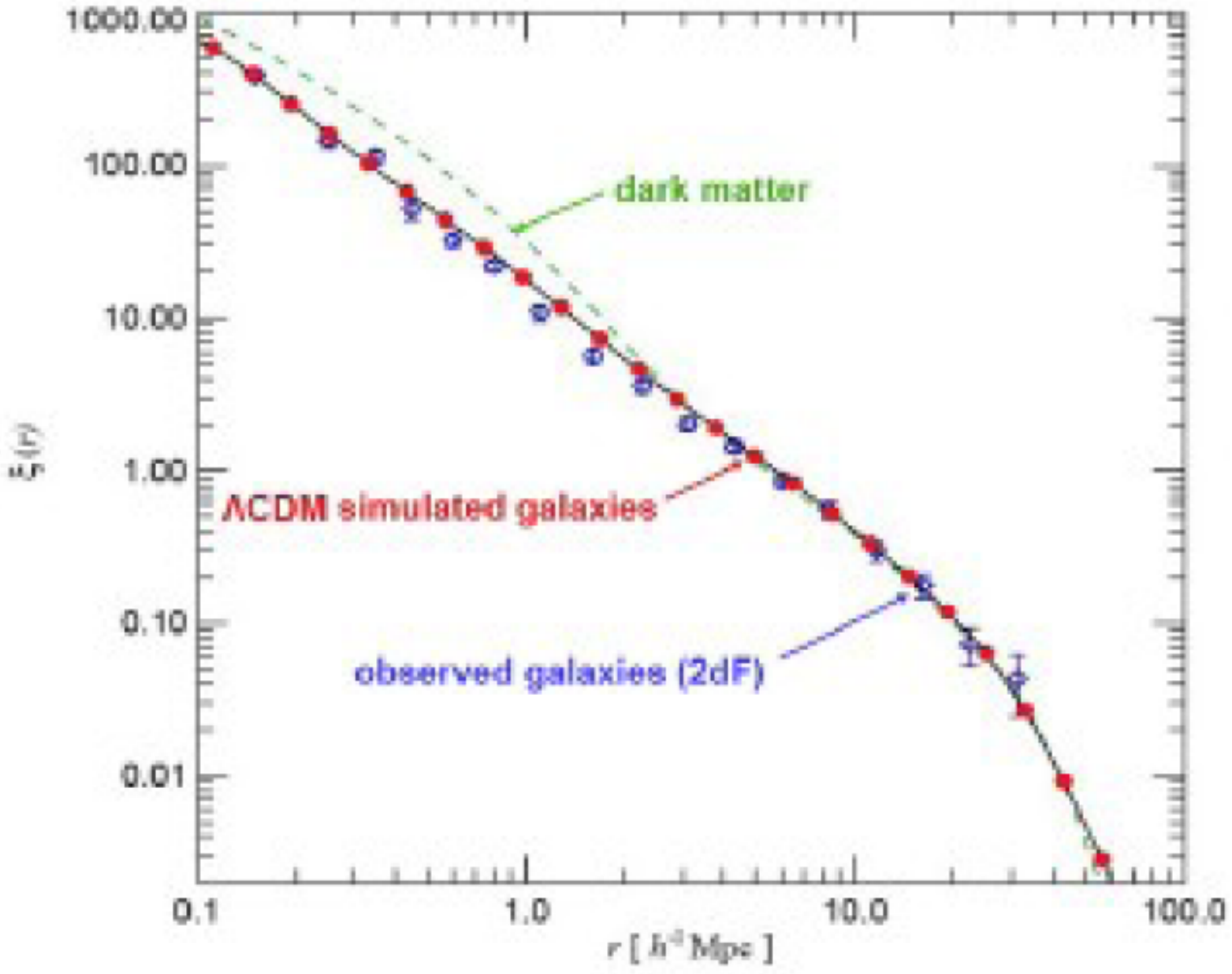
very extended disk

But the baryonic AM is not like that of the DM:

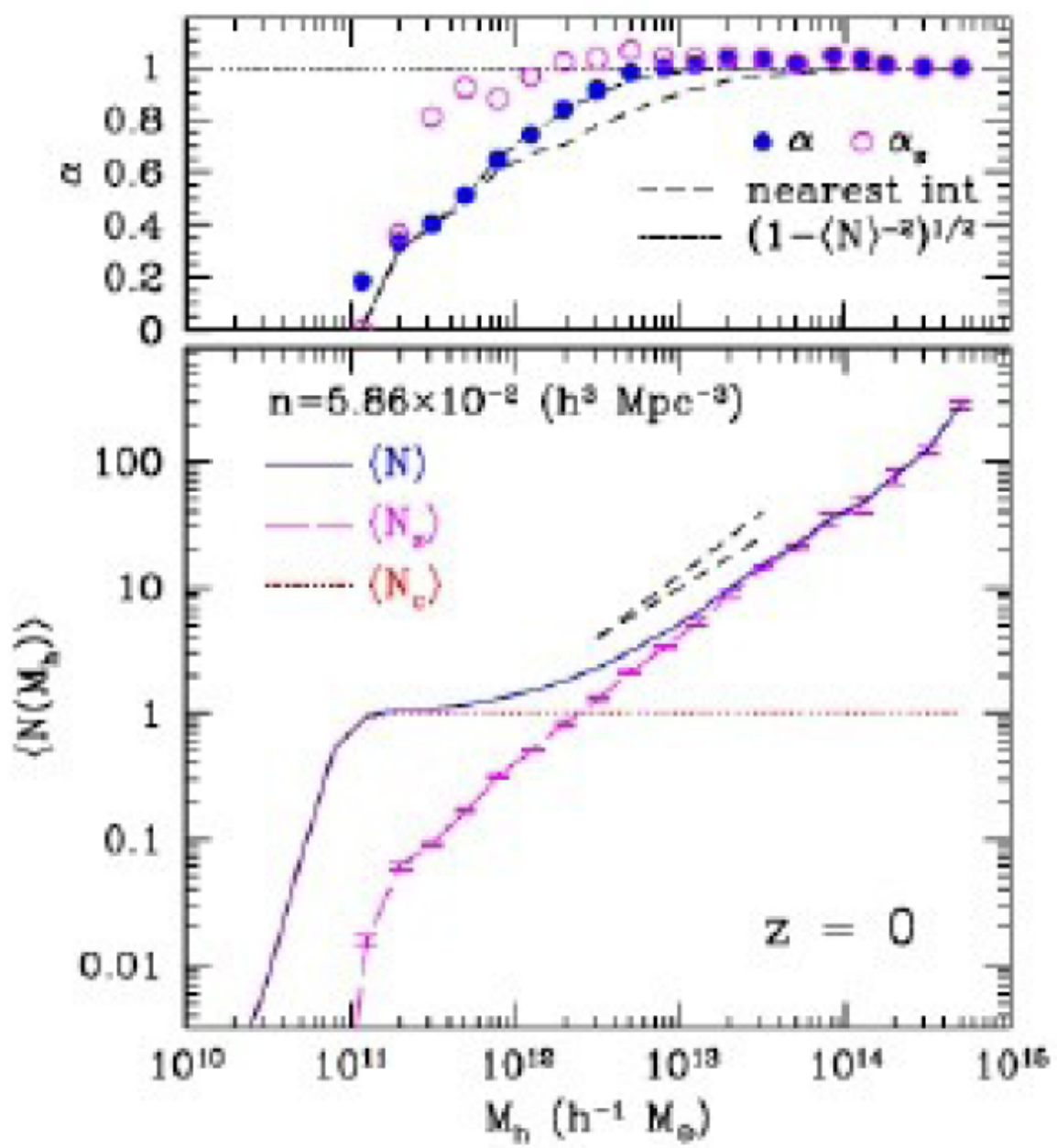
baryons interact hydrodynamically

clumps shock when they encounter each other

Galaxy 2-Point Correlation Function



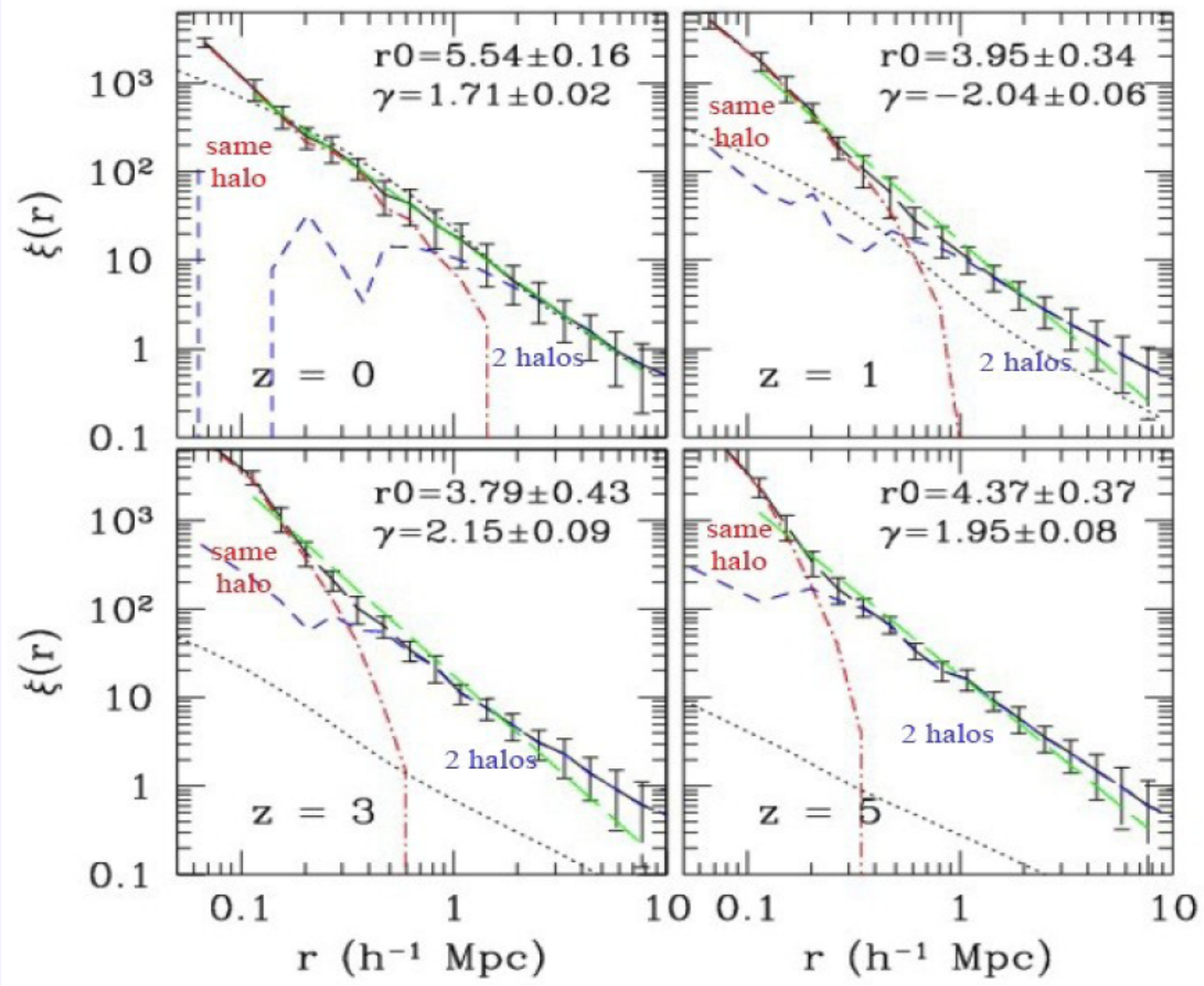
Halo Occupation Distribution Formalism



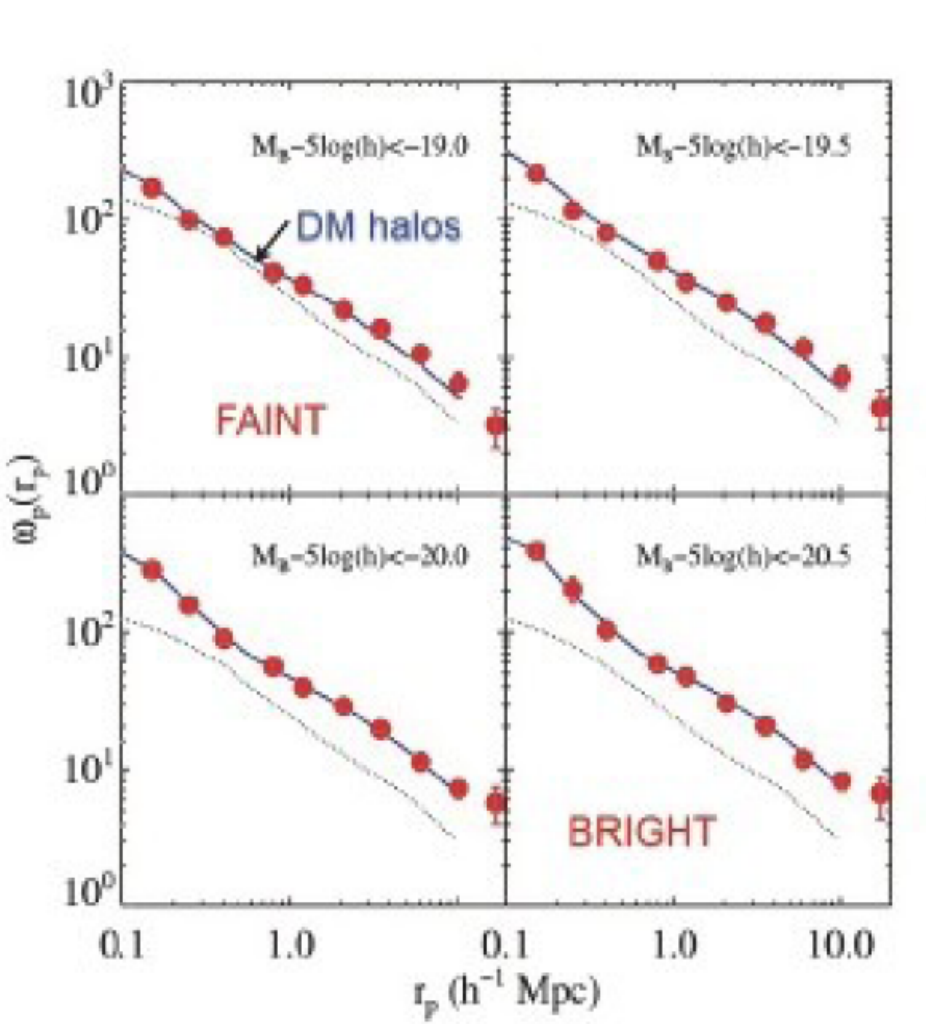
$\alpha = < N(N-1) >^{1/2} / N$

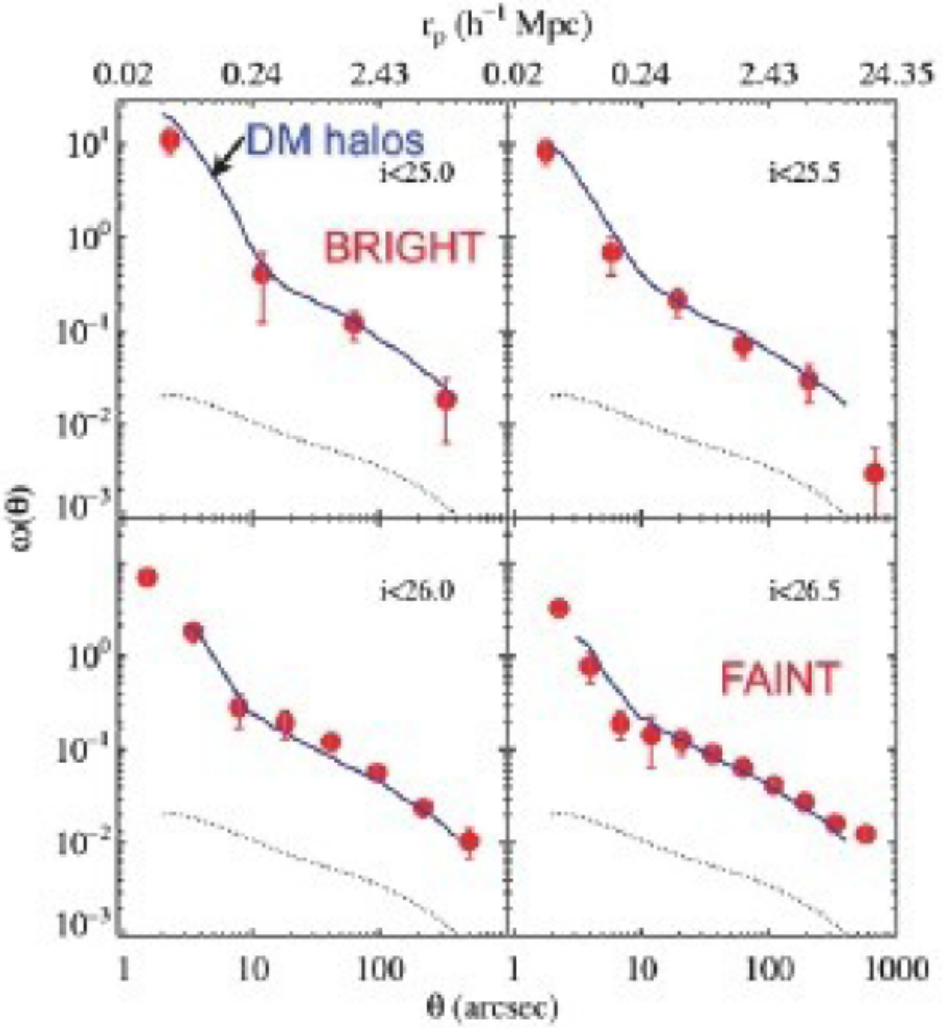
- All galaxies occupy dark matter halos
- How many galaxies, brighter than a given luminosity, occupy a halo depends only on the halo mass
- The brightest galaxies in a halo occupy the subhalos with the largest V_{max}

Evolution of the 2-Point Correlation Function



Galaxy Clustering

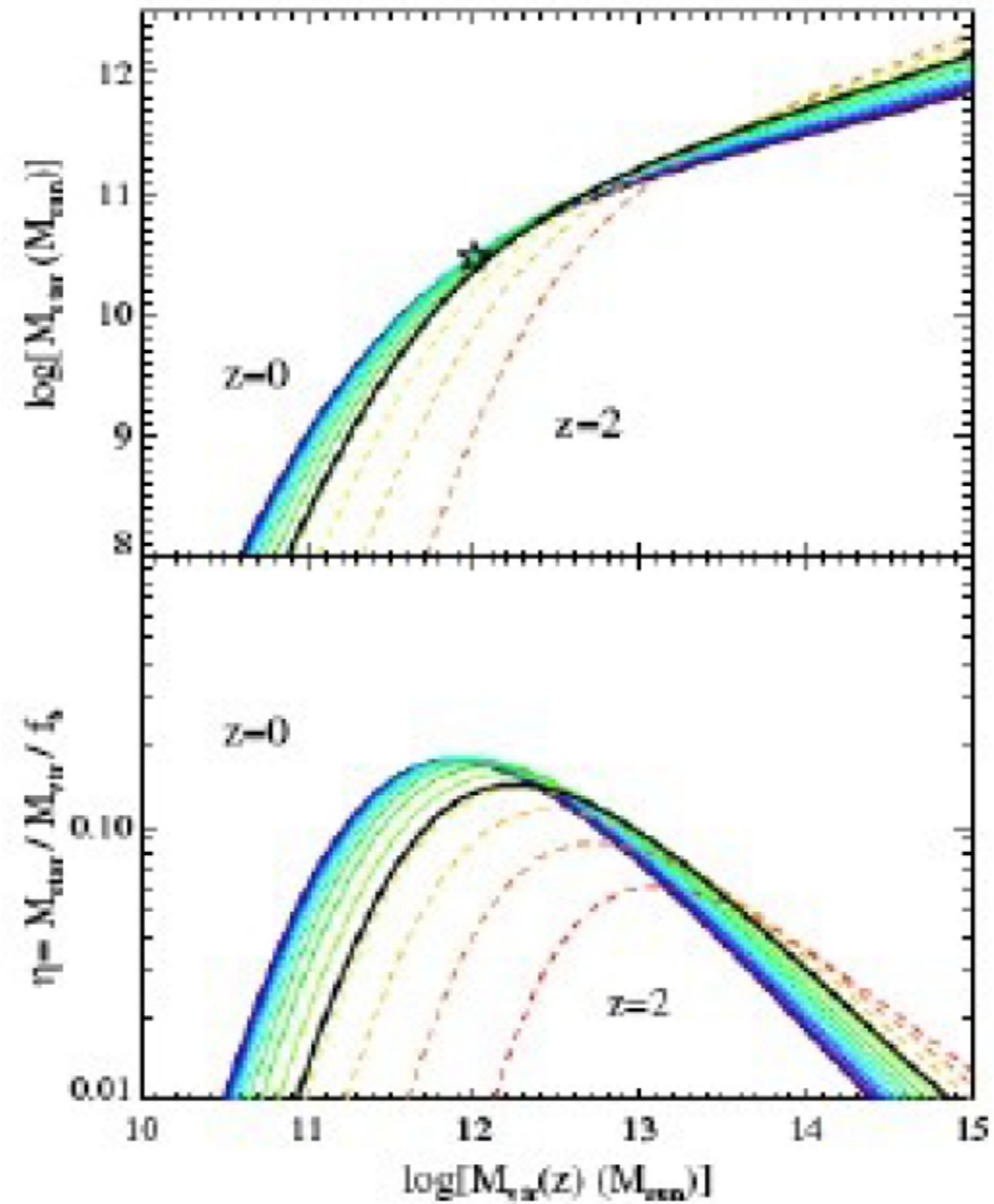




z ~ 1

z ~ 4

Stellar Mass Properties vs. Halo Mass



Crossover at $M_{vir} \approx 10^{12.5}\, M_{\odot}$:

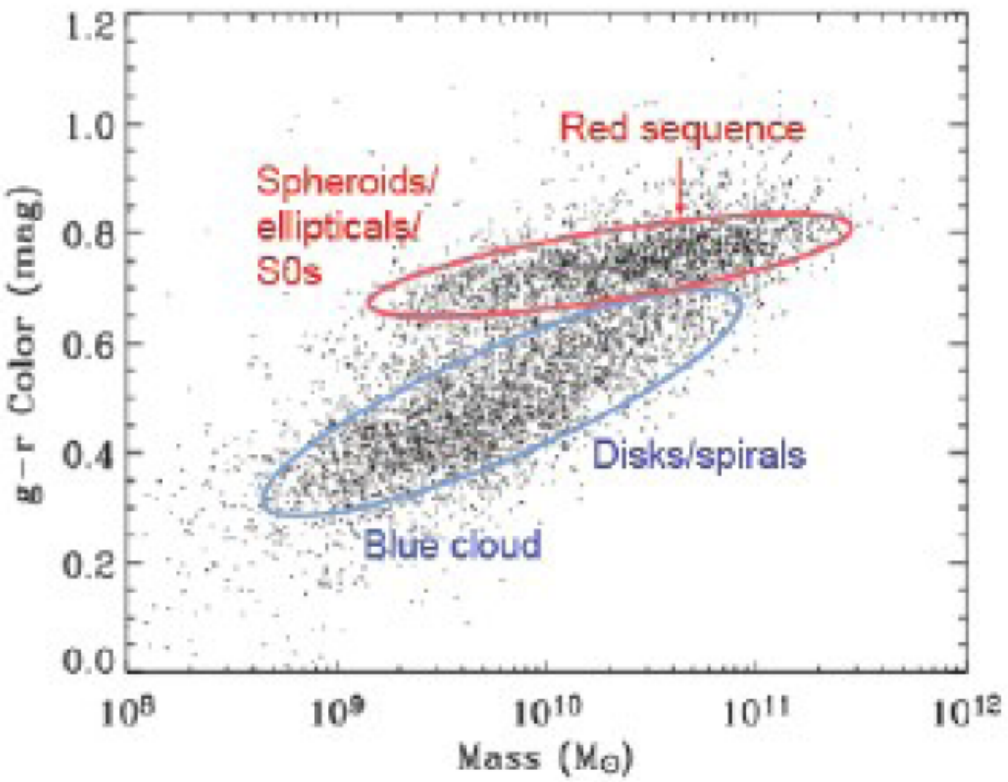
- halos of this mass host nearly constant stellar mass $M_{star} \sim 10^{11}\, M_{\odot}$
- above this halo mass, halos grow faster than their stellar content
- and slower below it

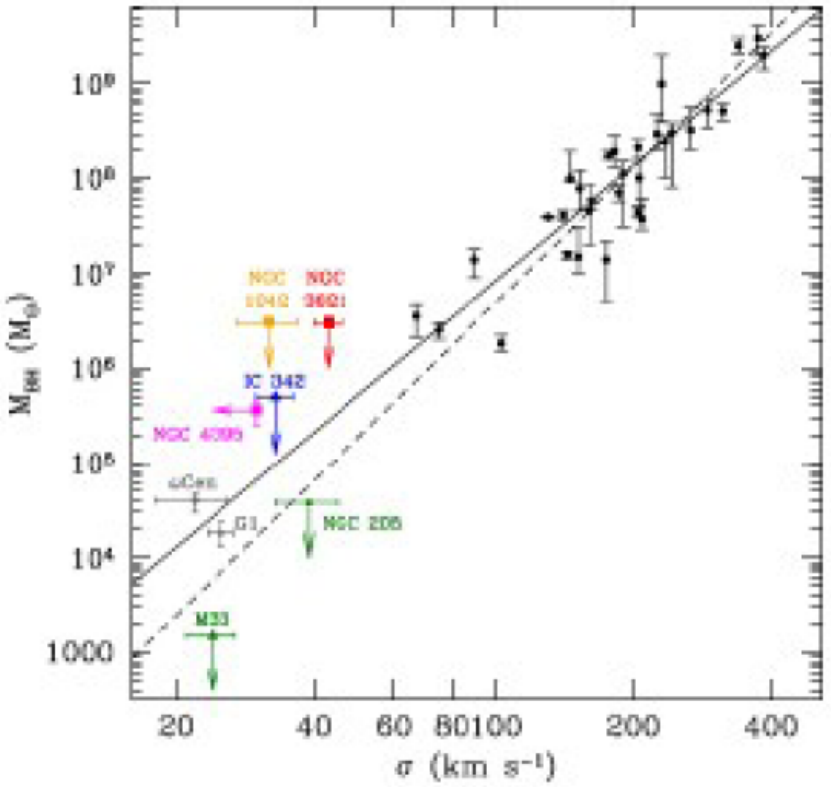
Low star formation efficiency:

~ 20% peak at $M_{vir} \sim 10^{12}\, M_{\odot}$

consistent with Milky Way estimates

“Main Sequence” of Star Forming Galaxies



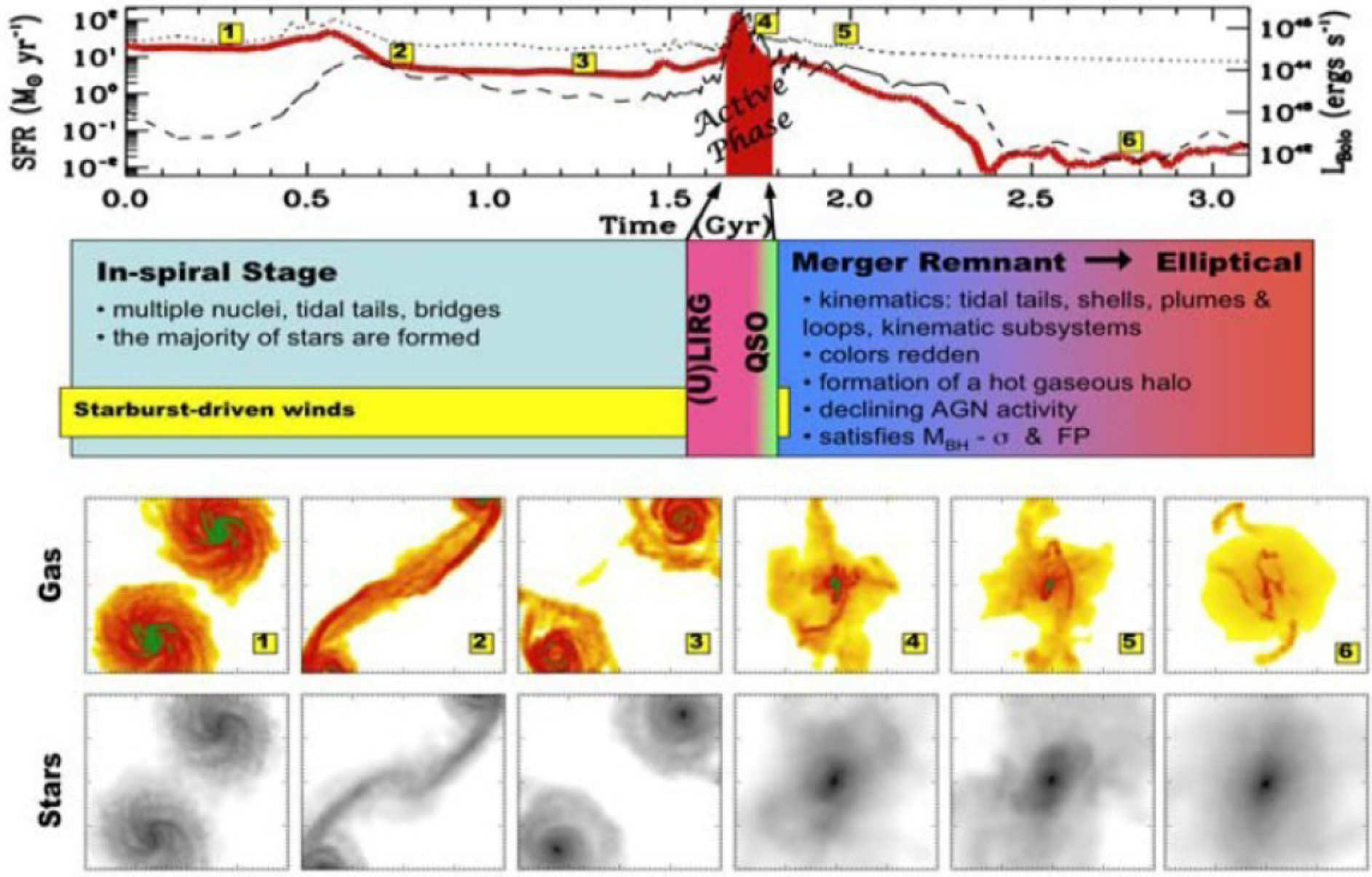


Massive galaxies form stars early and fast, and are red today

Lower mass galaxies form stars later and more slowly

Transformation from disks to spheroids must also grow massive BHs

Chronology of a Gas-Rich Major Merger



Summary

- Recent high-resolution hydrodynamic simulations generate realistic galaxies
- The abundance matching model predicts galaxy population observations
  - Halo occupation distribution formalism
  - Galaxies ranked by luminosity match to halos ranked by V_{max}
- Simulations agree with observations that the star formation efficiency is low (< 20%)
- We are only beginning to understand how massive BHs can grow and star formation can stop in disk mergers that produce spheroids.

Halo Properties

NFW halos: $\rho_{NFW}(r) = 4\,\rho_s\, x^{-1}\,(1+x)^{-2}$

$x = r / r_s$ $\quad$ r_s is a scale radius $\quad$ $\rho_s = \rho(r_s)$

The inner r^{-1} part of the halo forms early

then r_s stays nearly constant

$c_{vir} = r_{vir}/r_s$ grows linearly with a

average mass accretion history is exponential in z

$$\lambda \equiv \frac{J|E|^{1/2}}{GM^{5/2}}$$

grows significantly in major halo mergers

decreases when mass is accreted in minor mergers

Triaxiality: more elongated at

smaller radii, larger redshifts, higher masses