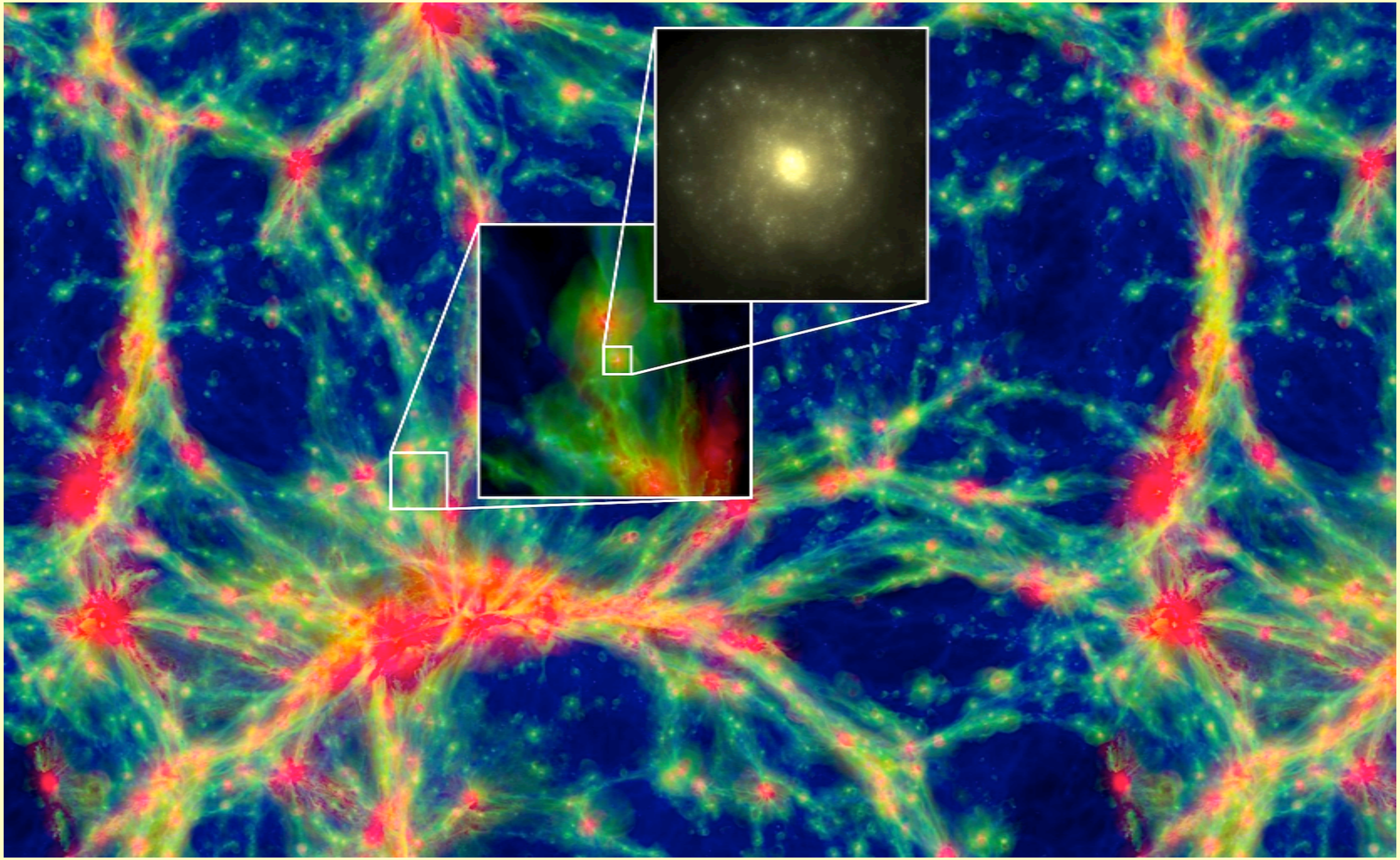
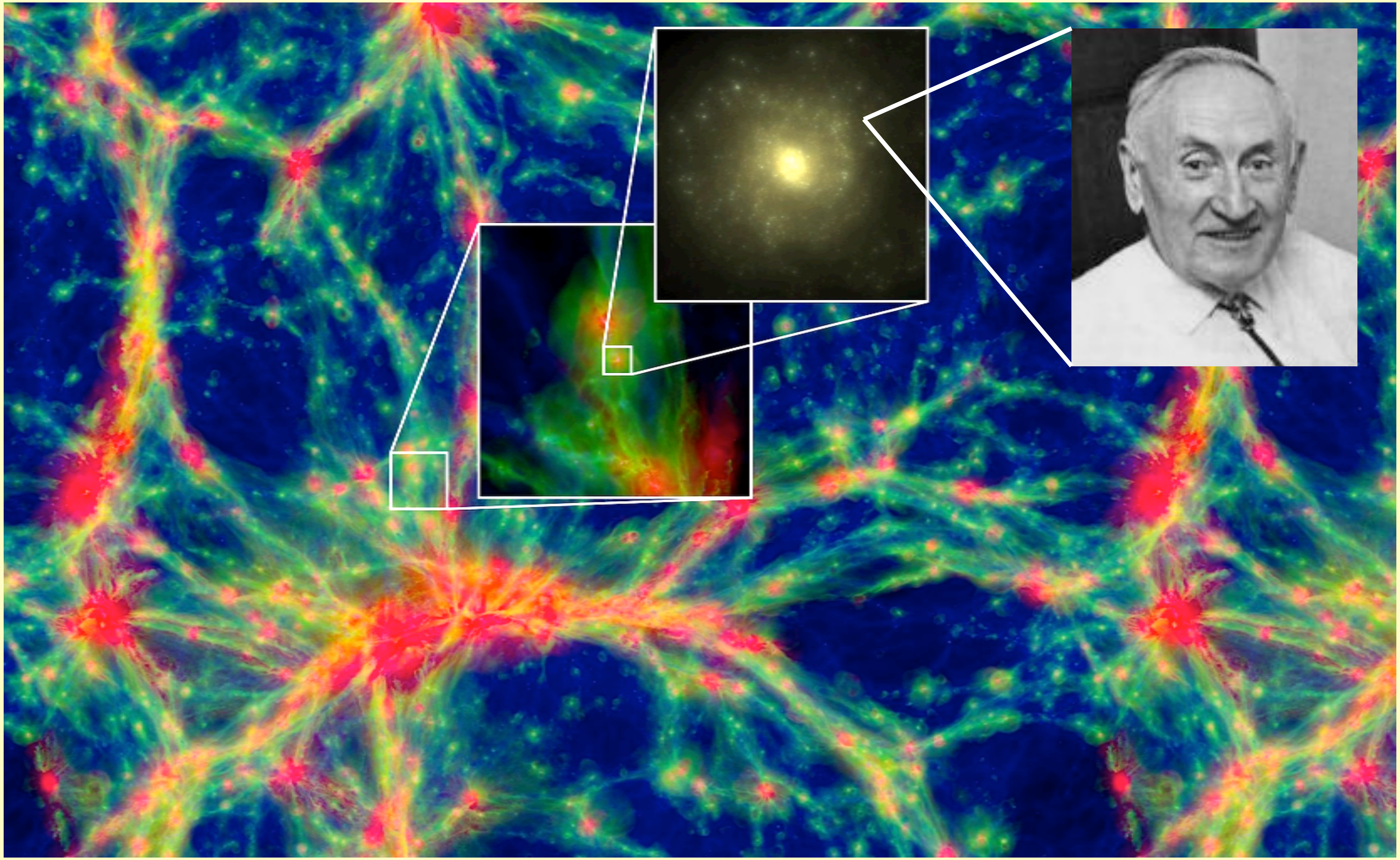
Galaxies in their cosmological setting



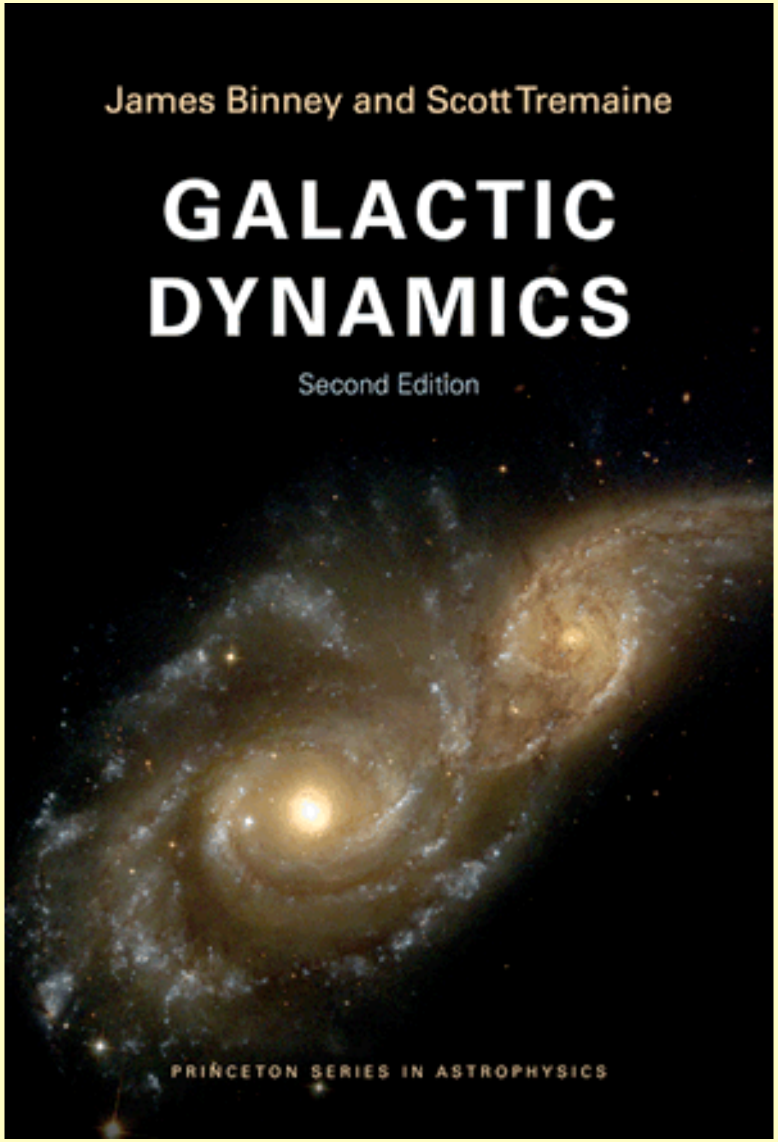
John Peacock | Zwicky @ Braunwald | 3 Sept 2015

Galaxies in their cosmological setting



John Peacock Zwicky @ Braunwald 5 Sept 2015

Q: Are galaxies ultimately simple manifestations of cosmic structure formation?



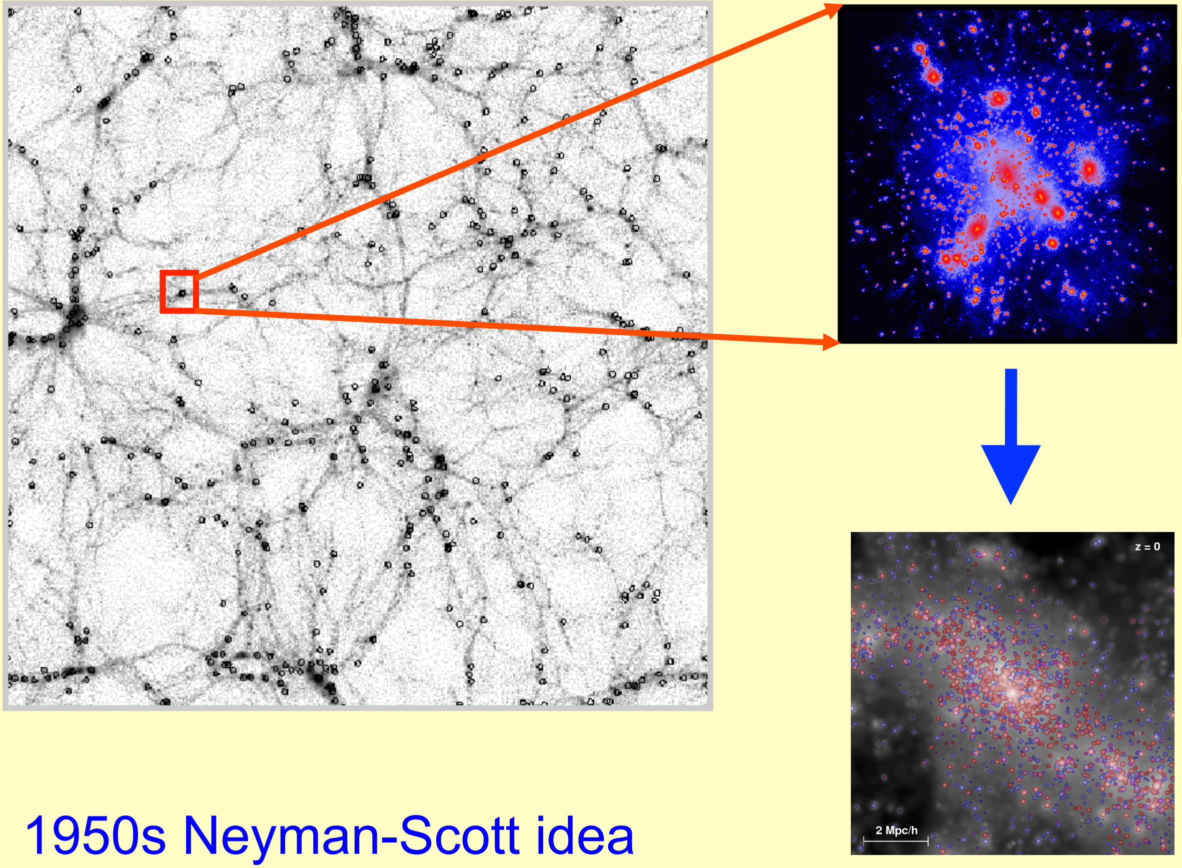
Tremaine ~ 1995:

“ Give up studying galaxies: you can’t get away from the cosmological initial conditions ”

Outline

- Three aspects of the coupling of galaxies to their larger-scale cosmological context:
  - I: Haloes, subhaloes
  - II: The cosmic web
  - III: Λ and structure formation

The Halo Model framework



1950s Neyman-Scott idea reborn with simulation results on DM haloes


METAL EARTH
3D METAL MODEL KITS
HALO
MASTER CHIEF HELMET
UNSC WARTHOG
UNSC
MANTIS
UNSC
PELICAN
wonders created by physicists
Fascinations
COMING SOON!
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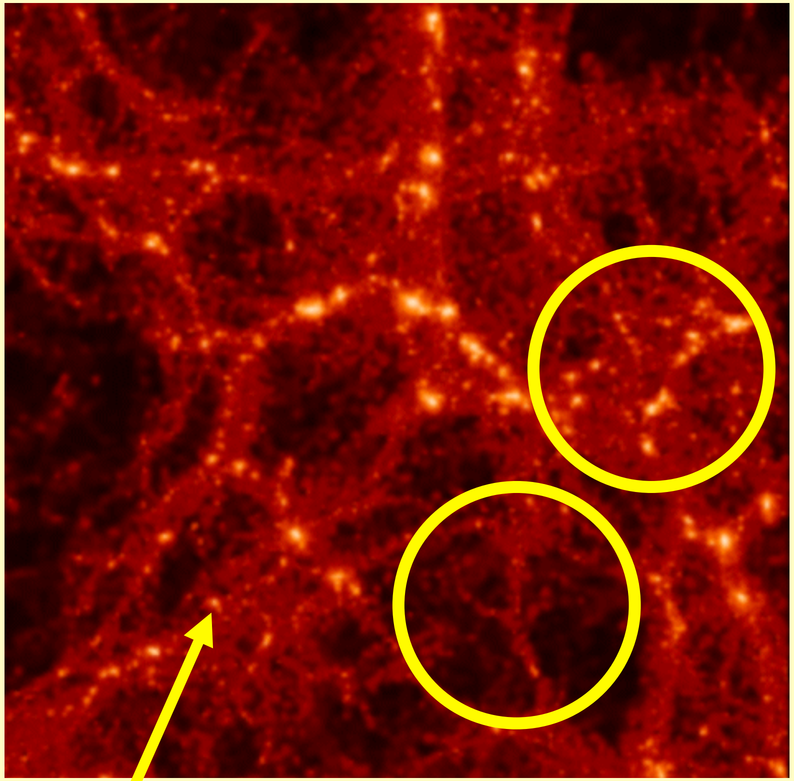
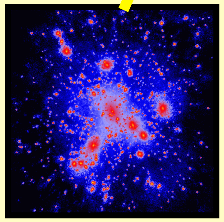
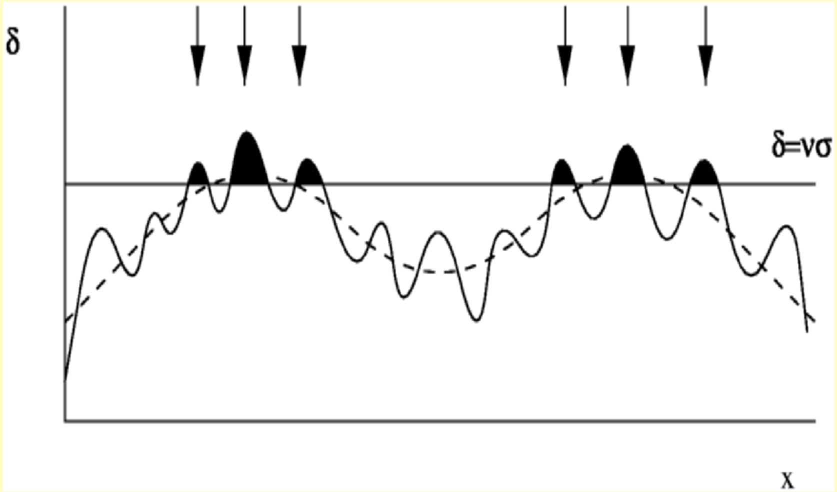
Environment perturbs halo formation







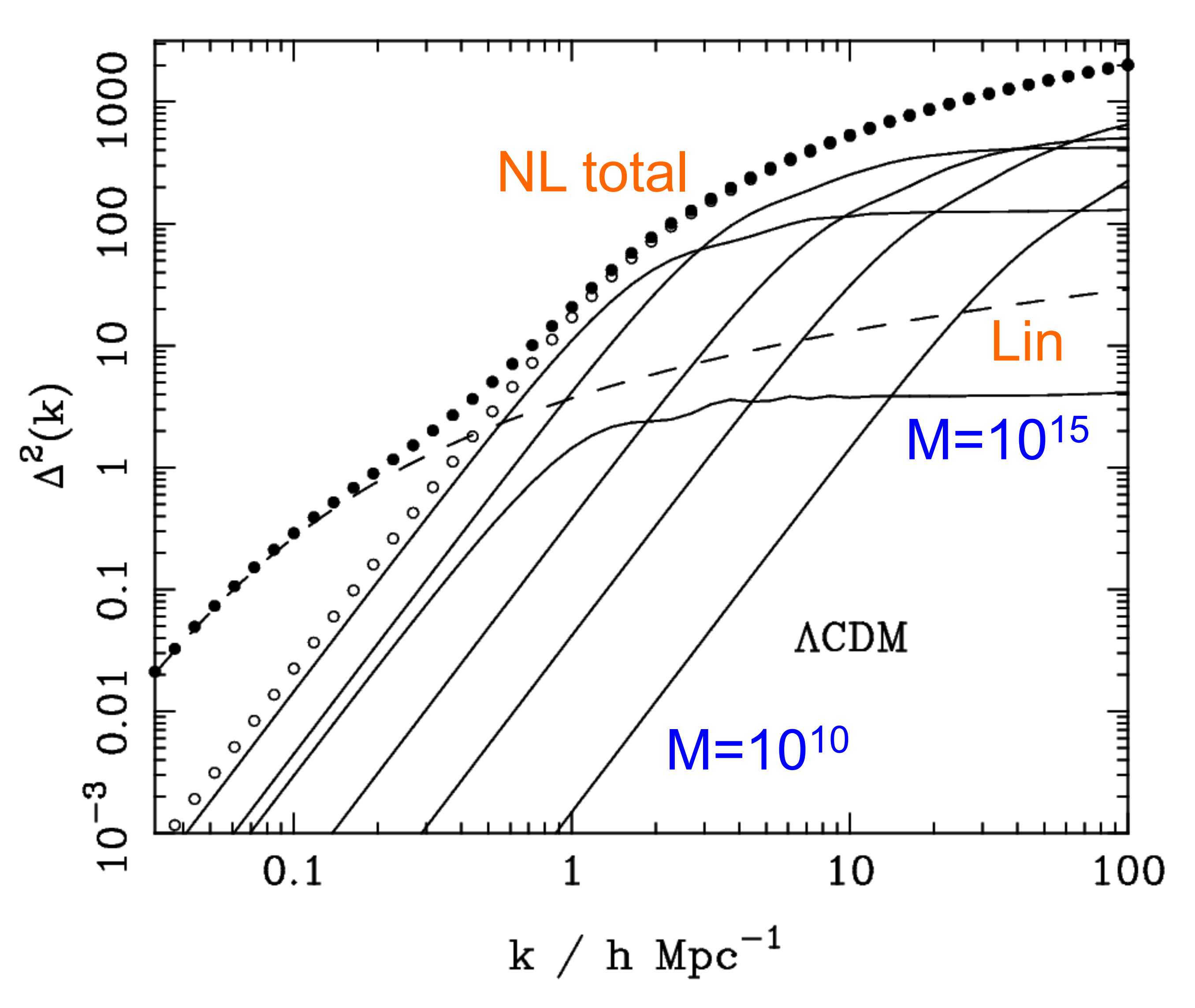
DM halo: group of

Galaxies in practice

- Kaiser (1984): shift in halo mass function in regions of different large-scale density

- Hence biased halo clustering: $\delta_{halo}=b(M)\ \delta_{mass}$

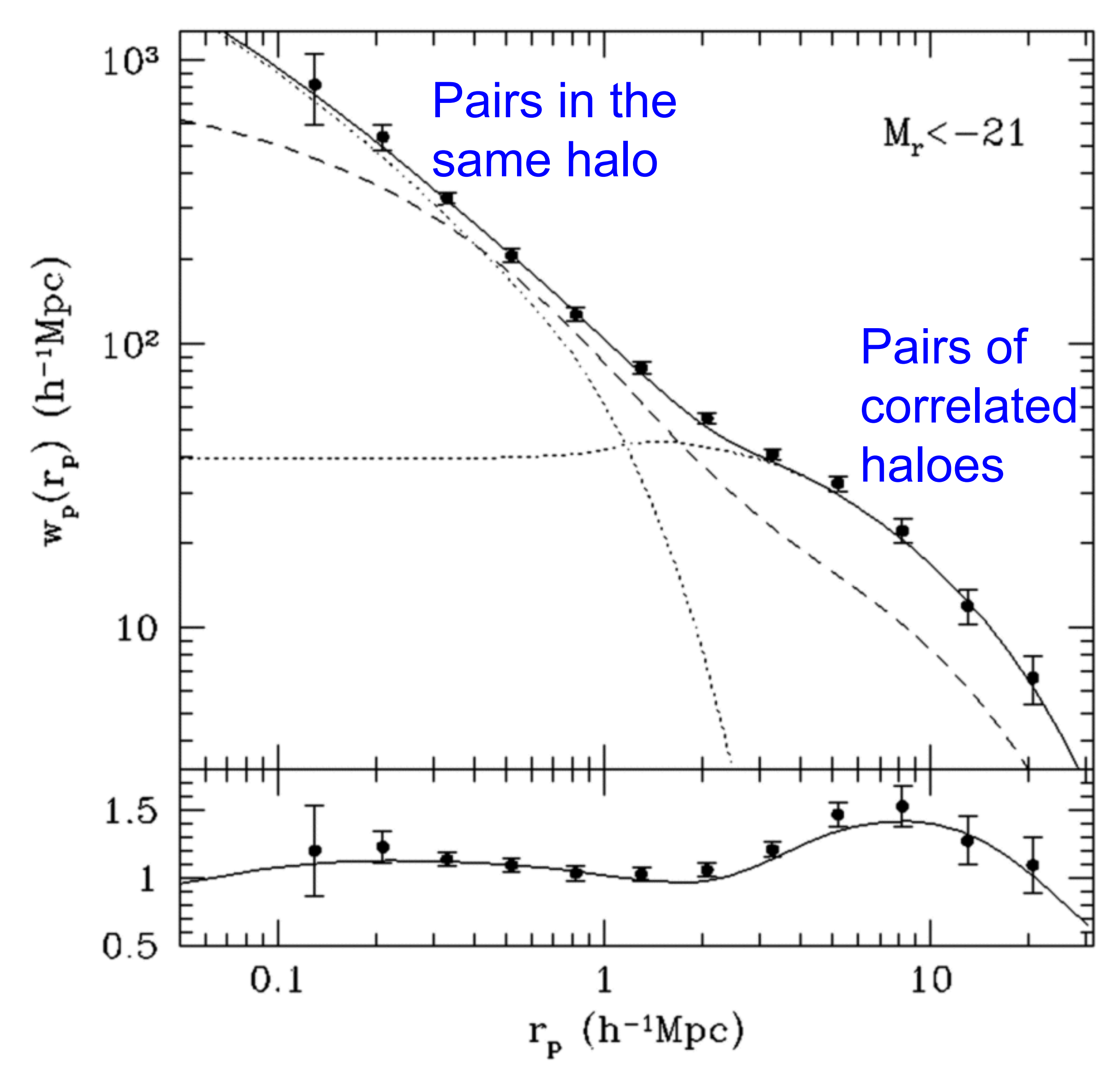
Power from haloes of different mass



PS++ mass function and NFW++ halo profile gives correct small-scale clustering from random haloes.

Add linear large-scale power for complete model.

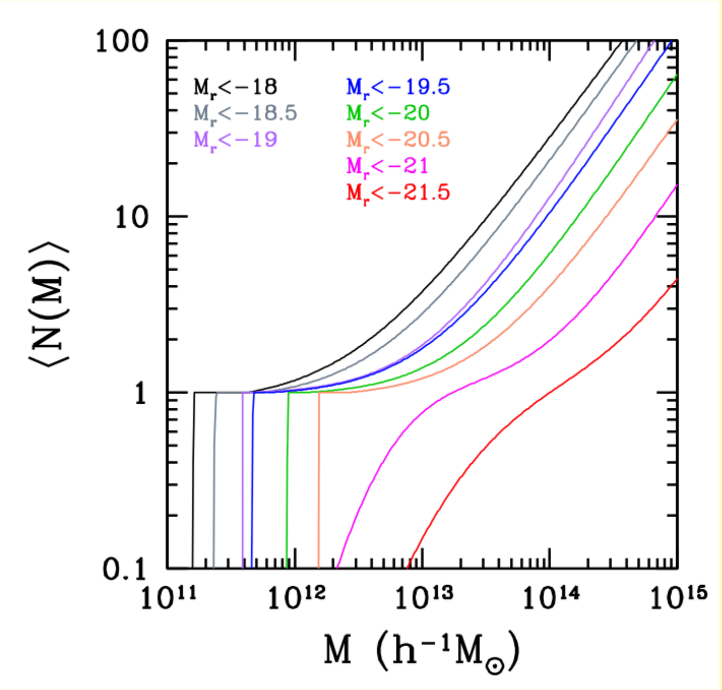
1-halo to 2-halo transition seen



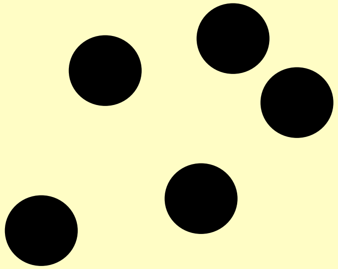
Zehavi et al. 2003

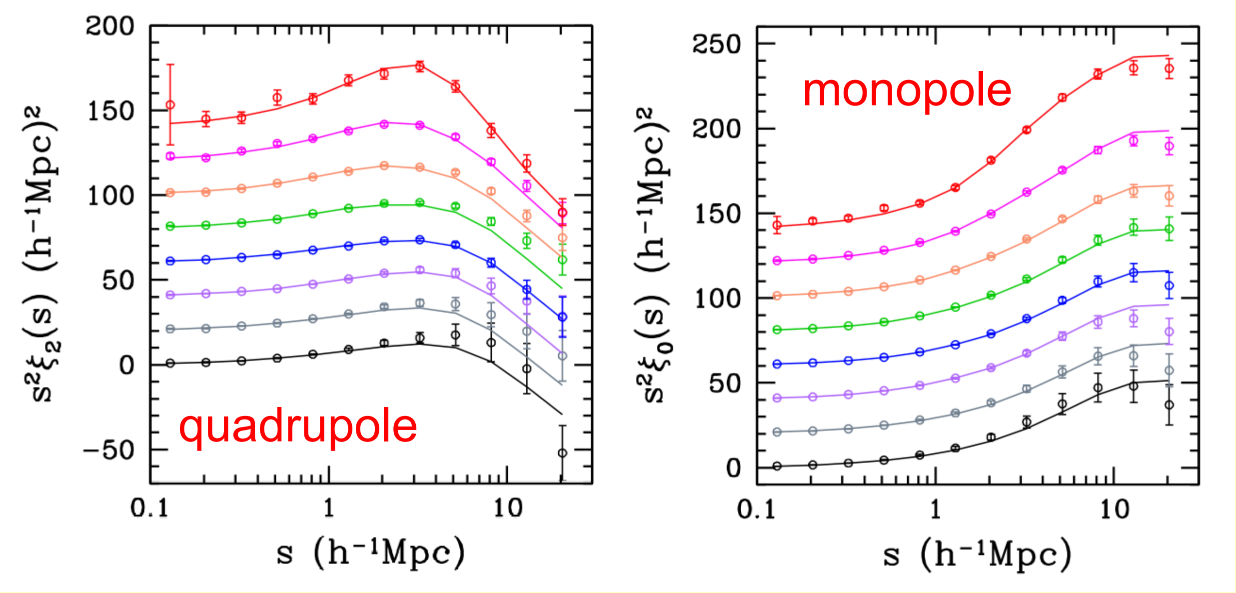
Luminous SDSS galaxies need weight $M^{-0.11}$ for $M > M_{min} = 10^{13.6}$

Occupying the haloes



Fitting SDSS:
Guo et al.
1505.07861

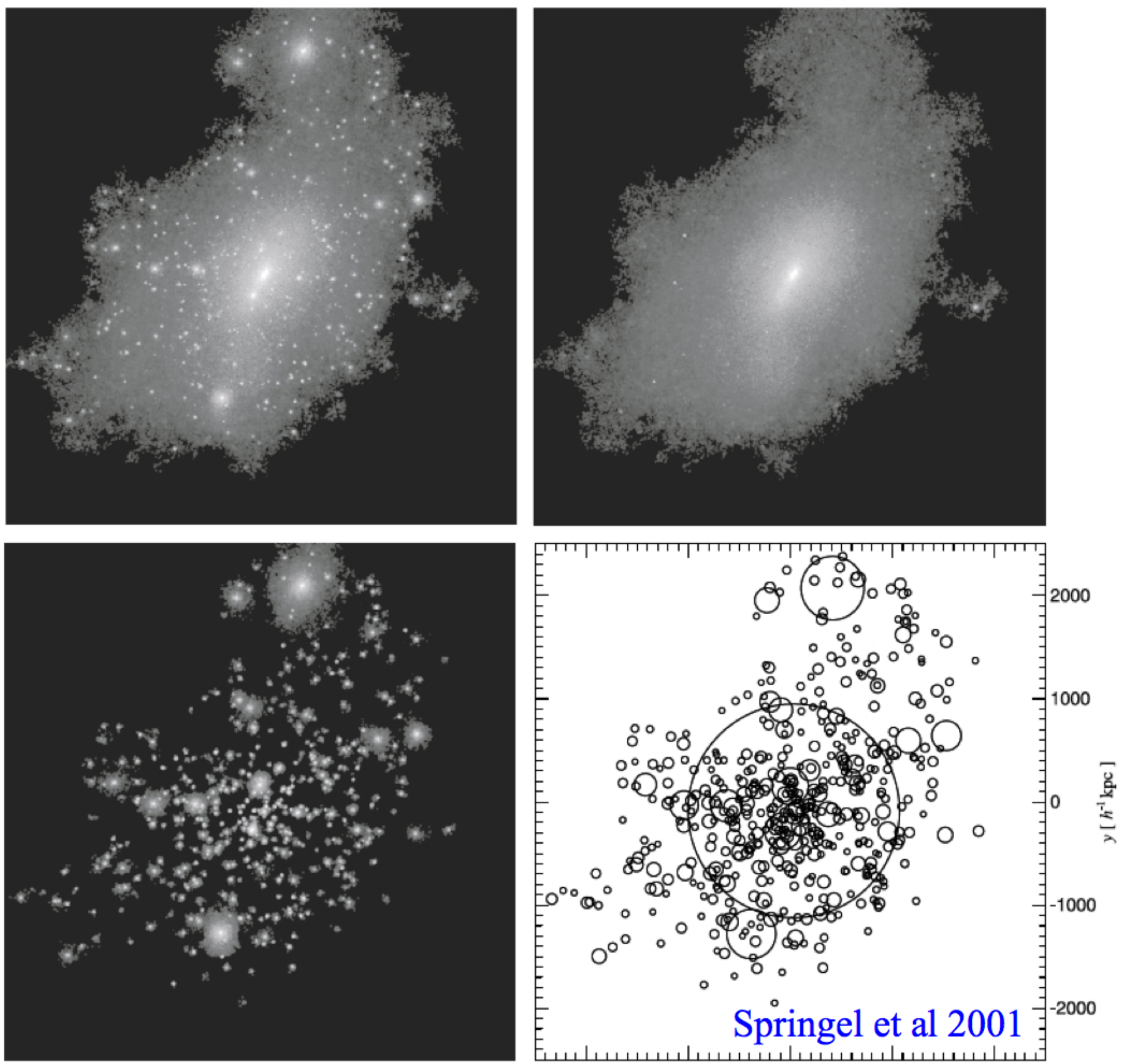




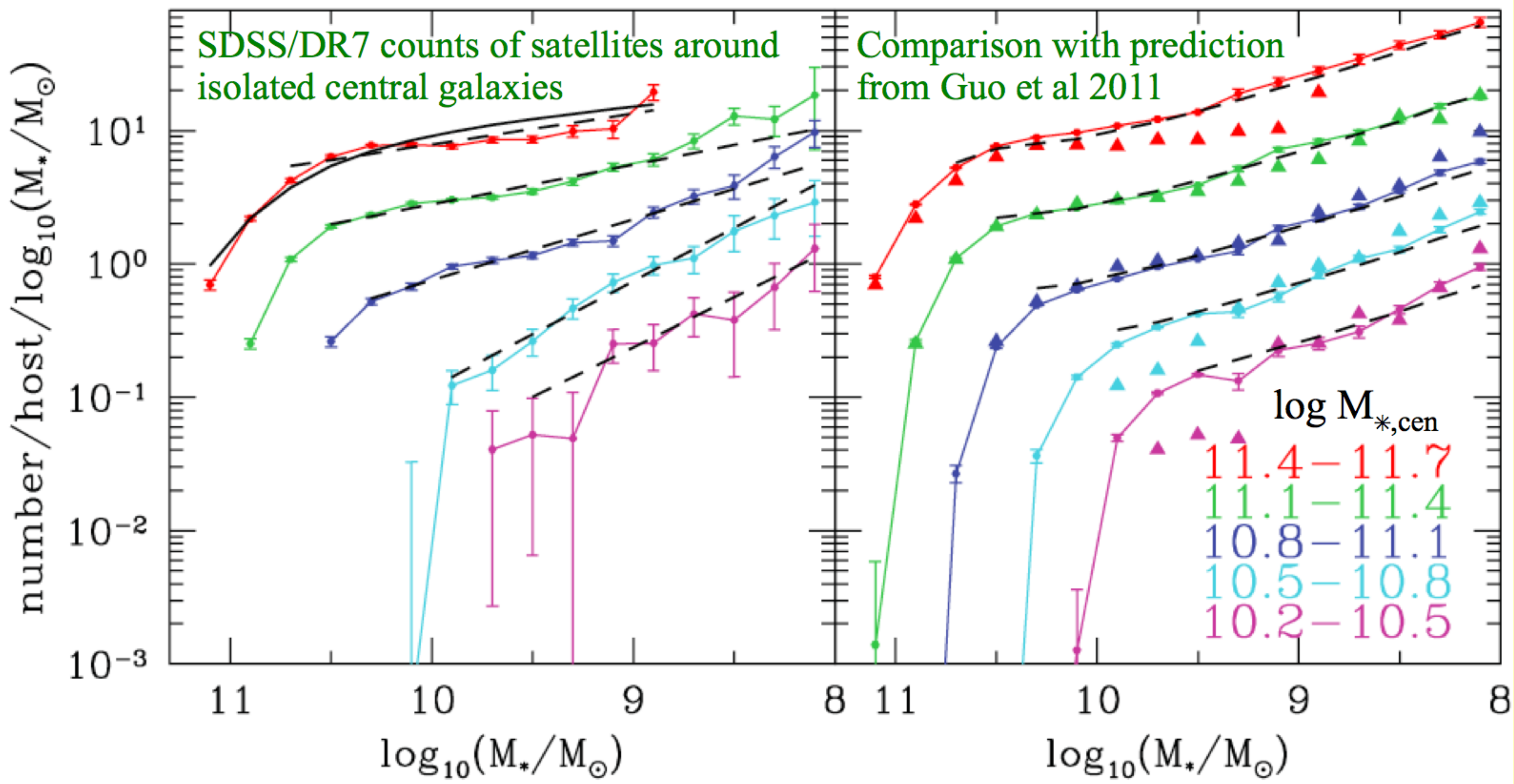
Halo model:

ρ = ● + ●

But halo contents should be predictable



Semianalytics & satellites

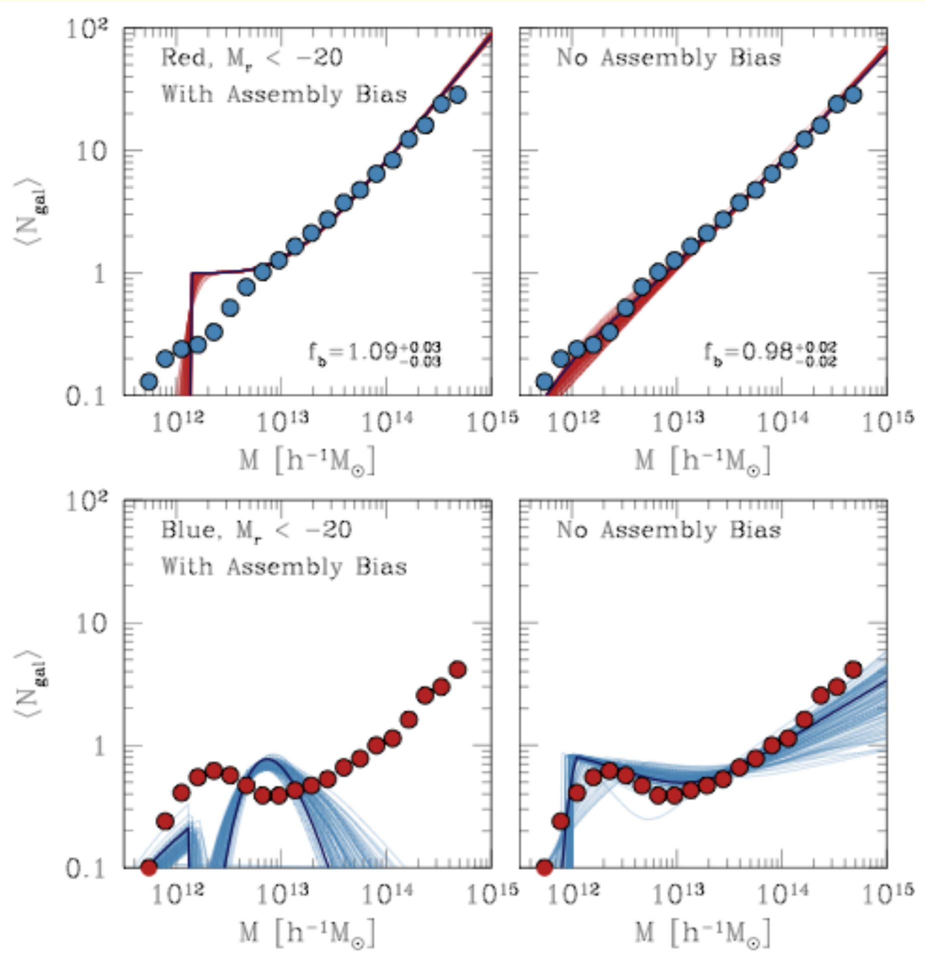


Works well for numbers: Wang & White 1203.0009

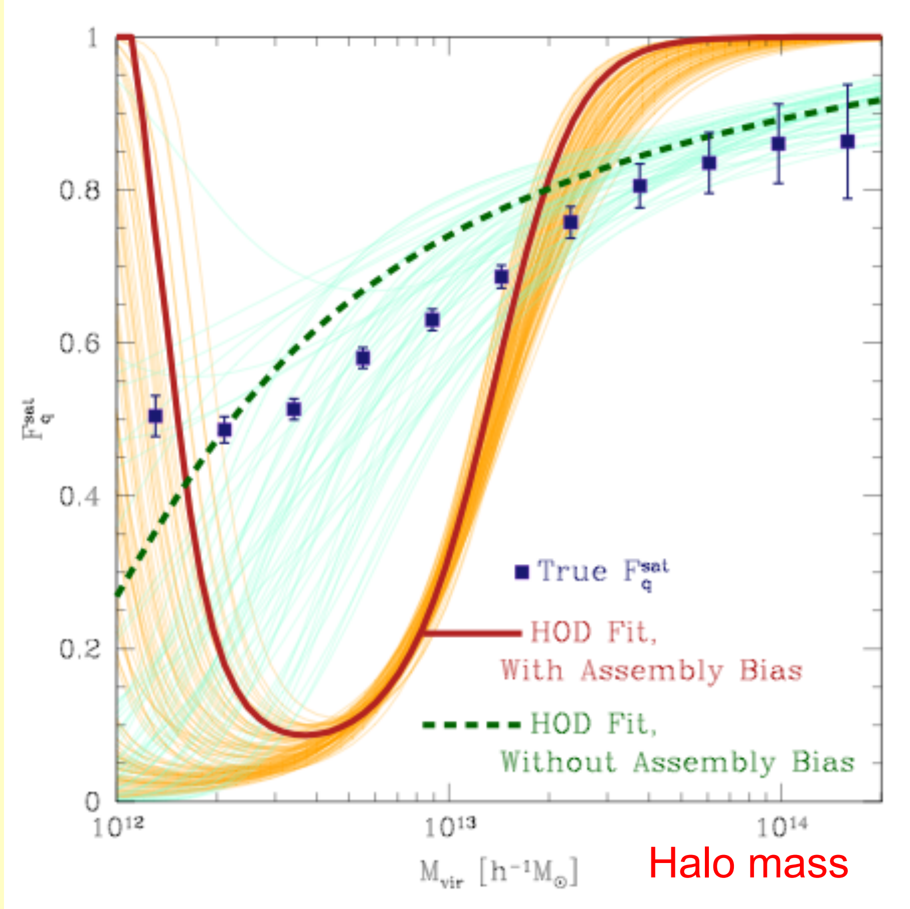
N(M+++)? Assembly bias

- Not just that haloes collapsing early are more clustered
  - Always present in Kaiser (1984)
  - Halo model averages over such effects
- But galaxy contents(M) can couple to formation z:
  - Early formation yields older stars
  - But deeper potential: harder to quench?
  - Early formation gives fewer subhaloes (= satellites)

Assembly bias and red fraction



Red satellite fraction

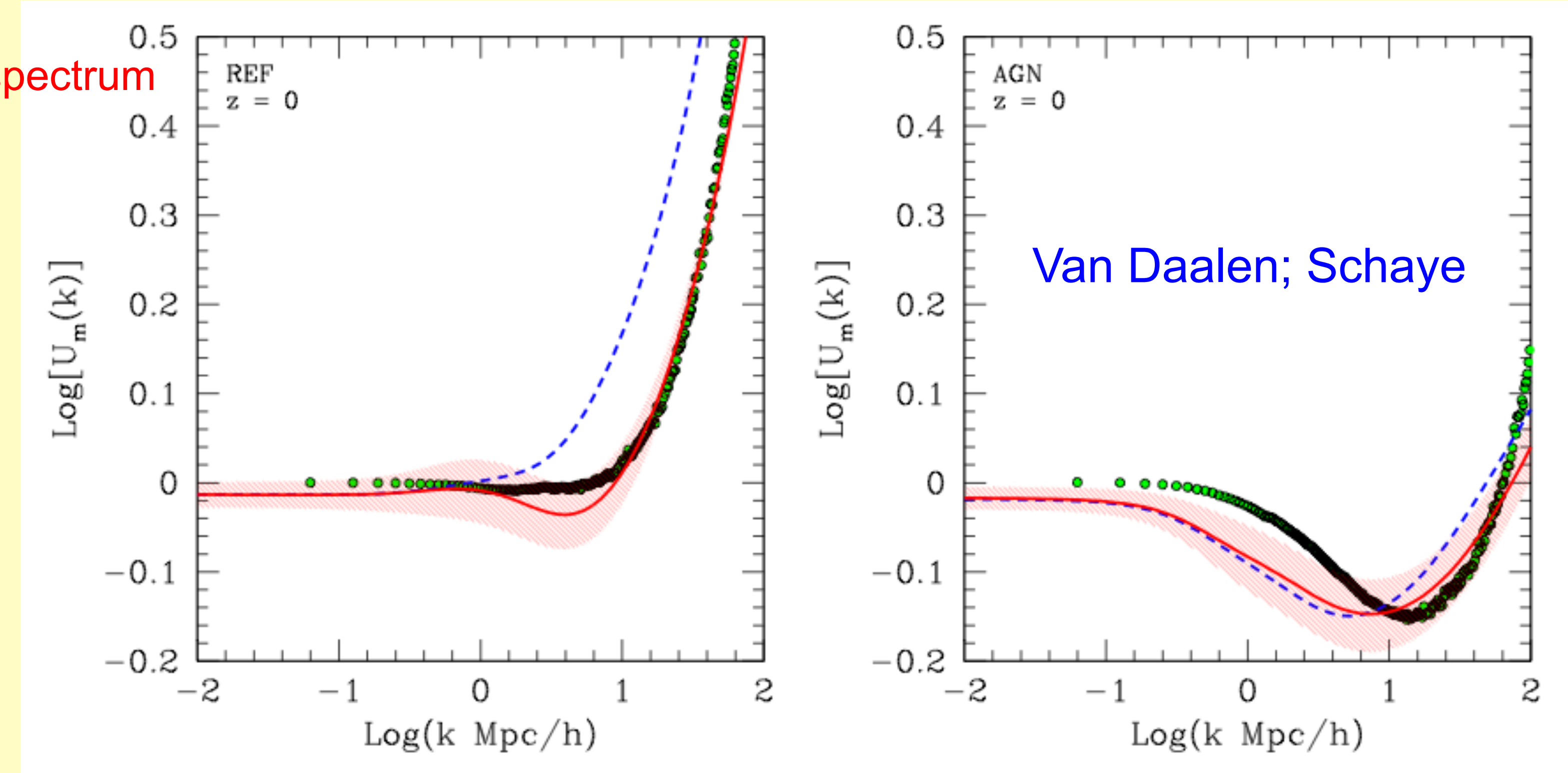


Halo mass

Zentner et al. 1311.1818: MC reassignment of semianalytic galaxies shows big effect

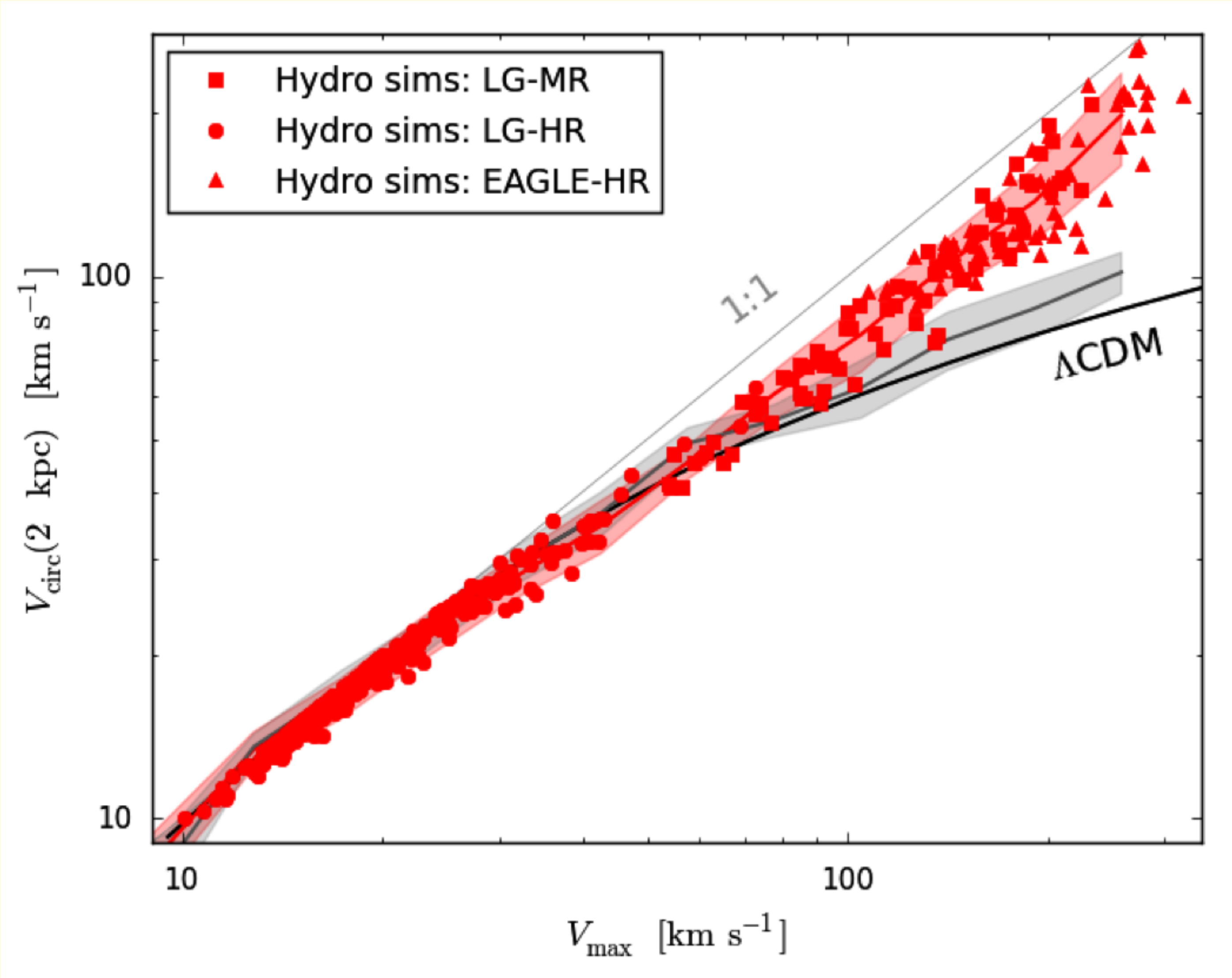
Haloes are not passive spectators

Power spectrum ratio



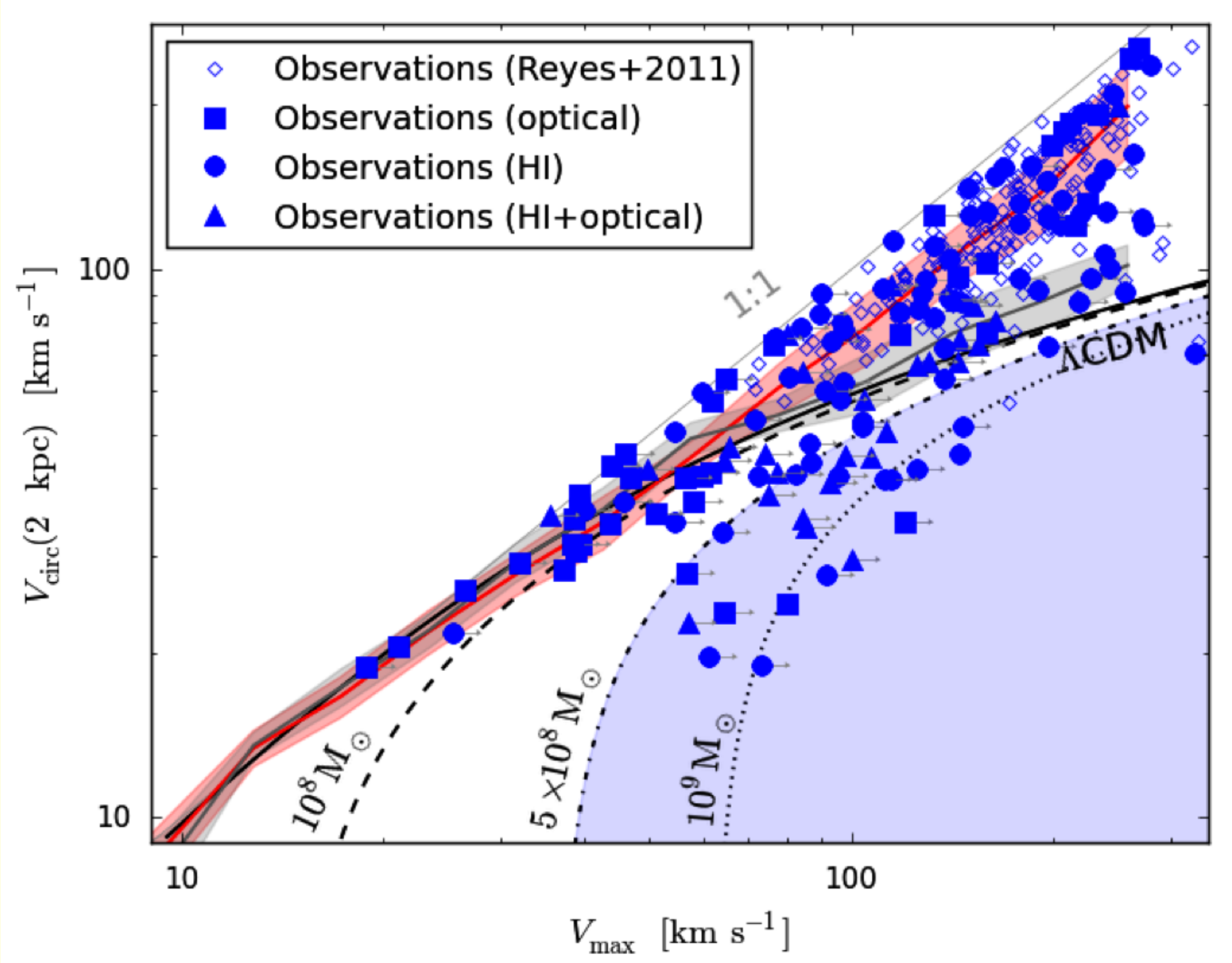
- Large potential effects on mass profile from feedback
  - Major problem for gravitational lensing
    - Can plausibly fit empirically with few parameters (1505.07833)
  - But lensing's headache is good news for galaxy formation

Cusps or cores?



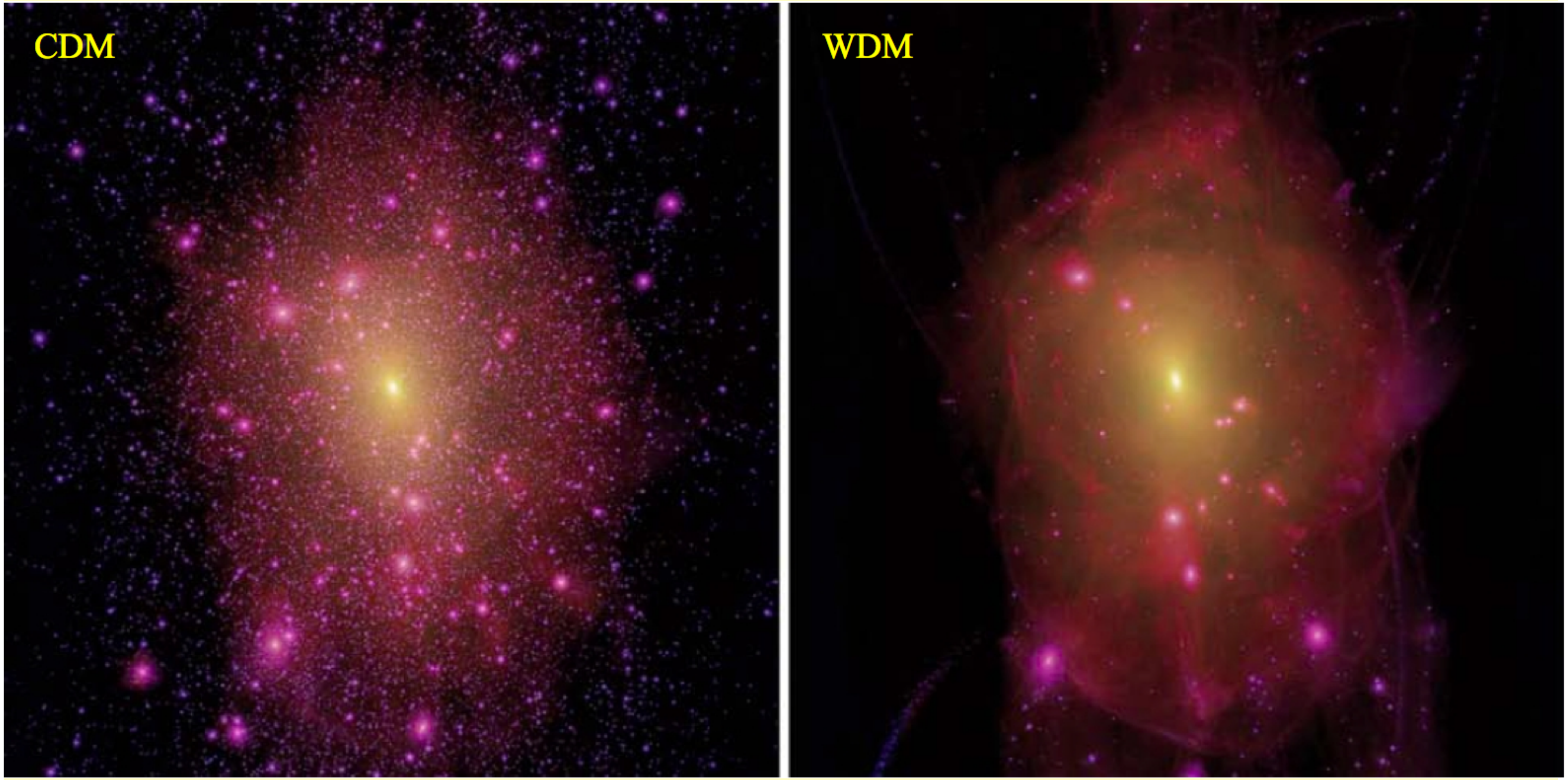
Oman et al. 1504.01437

Cusps or cores?



Oman et al. 1504.01437

WDM is not the answer



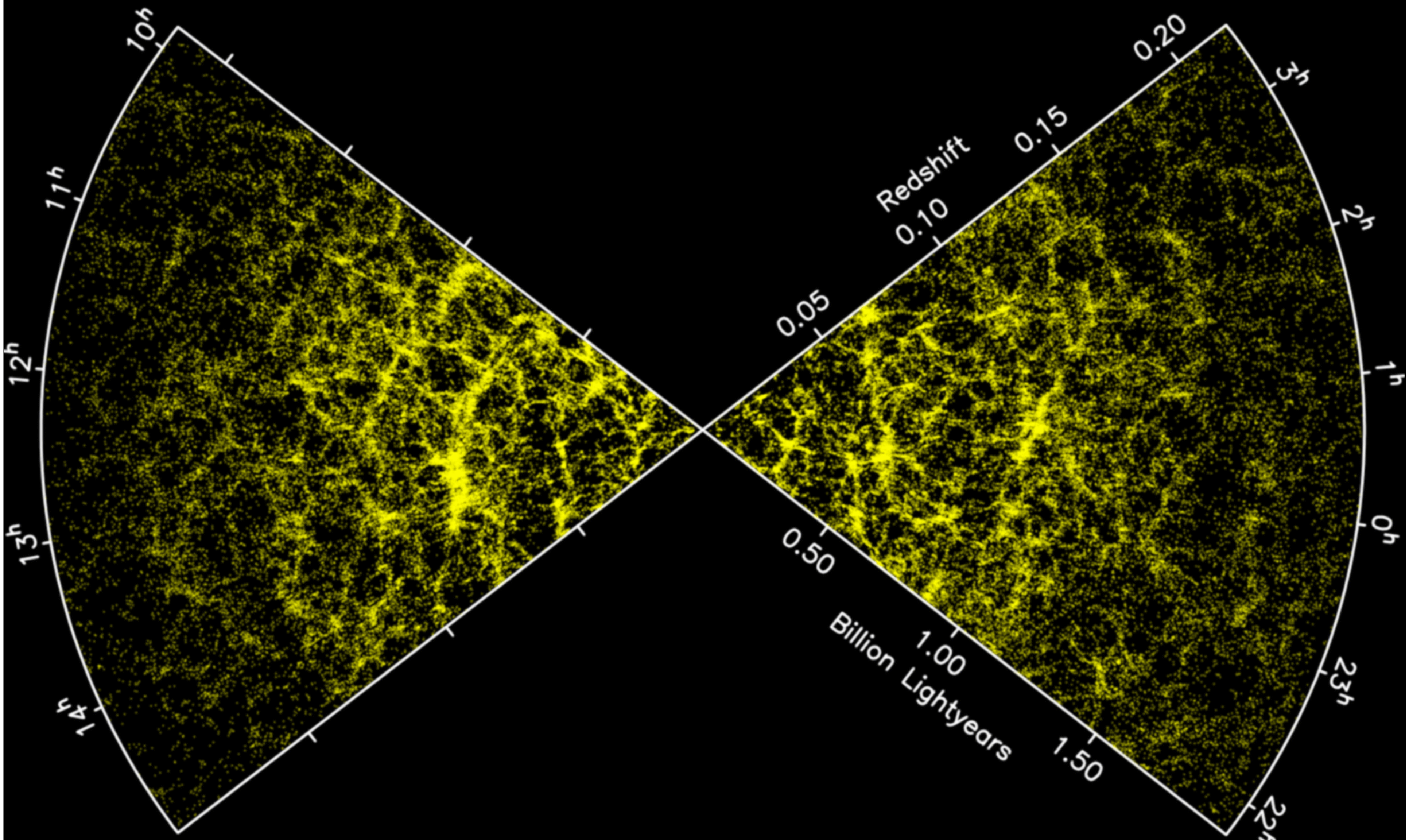
Lovell et al. 2012 2keV (too low)

Summary – I

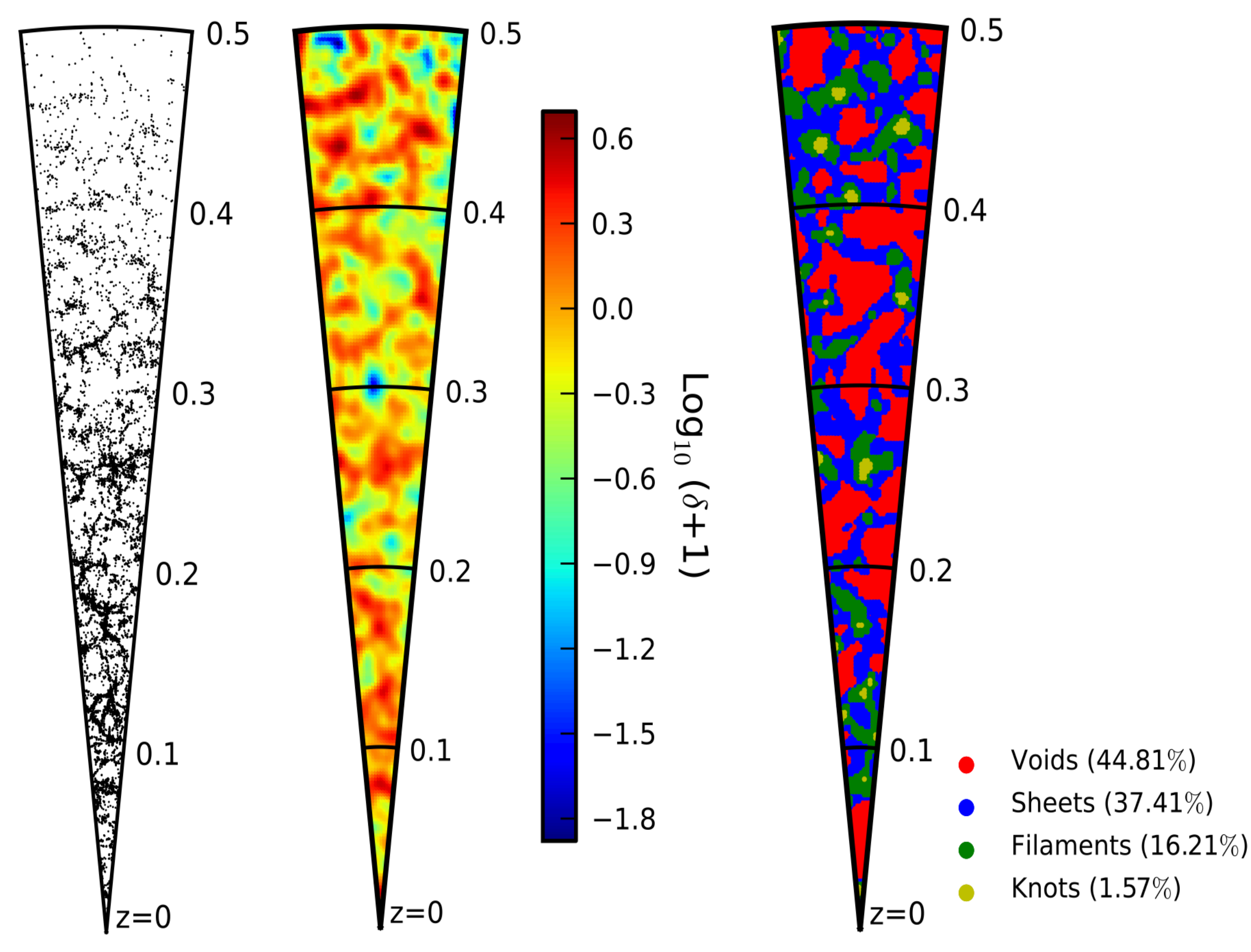
- Halo Model remains a helpful low-order framework
  - Despite deviations, understanding mass-dependent systematics is a big advance

- CDM haloes seem to work for ~80% of dwarfs

Galaxies and the Cosmic Web



Environment & geometry

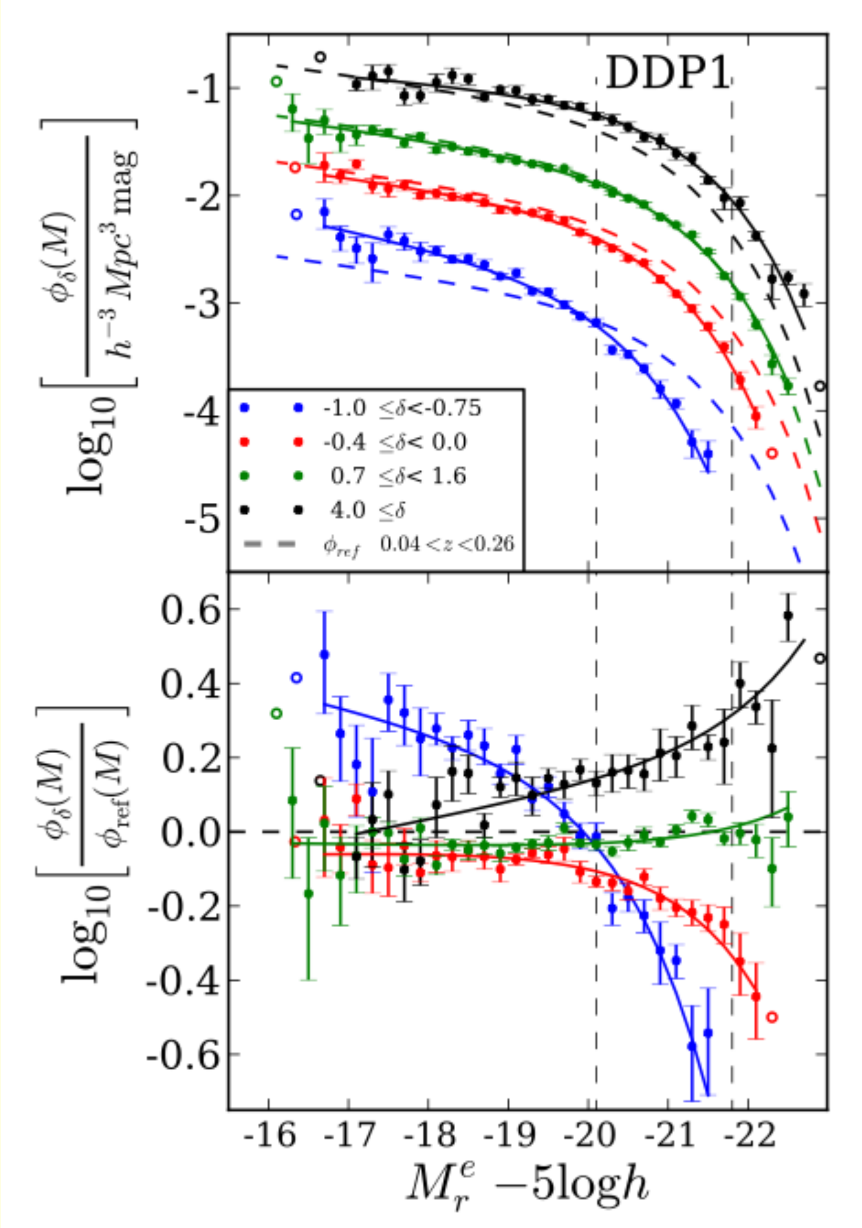


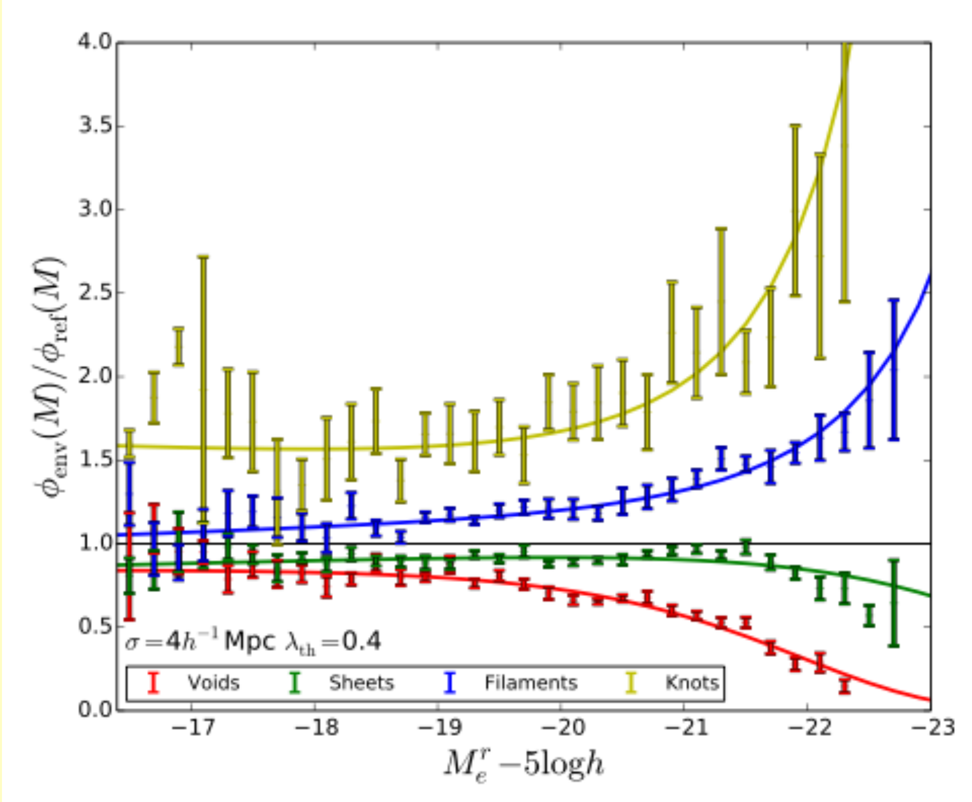
Eardley et al.
GAMA:
1412.2141

Filter to get overdensity

Or classify web from Hessian of potential, based on eigenvalues above threshold ~1

Density-dependent LF

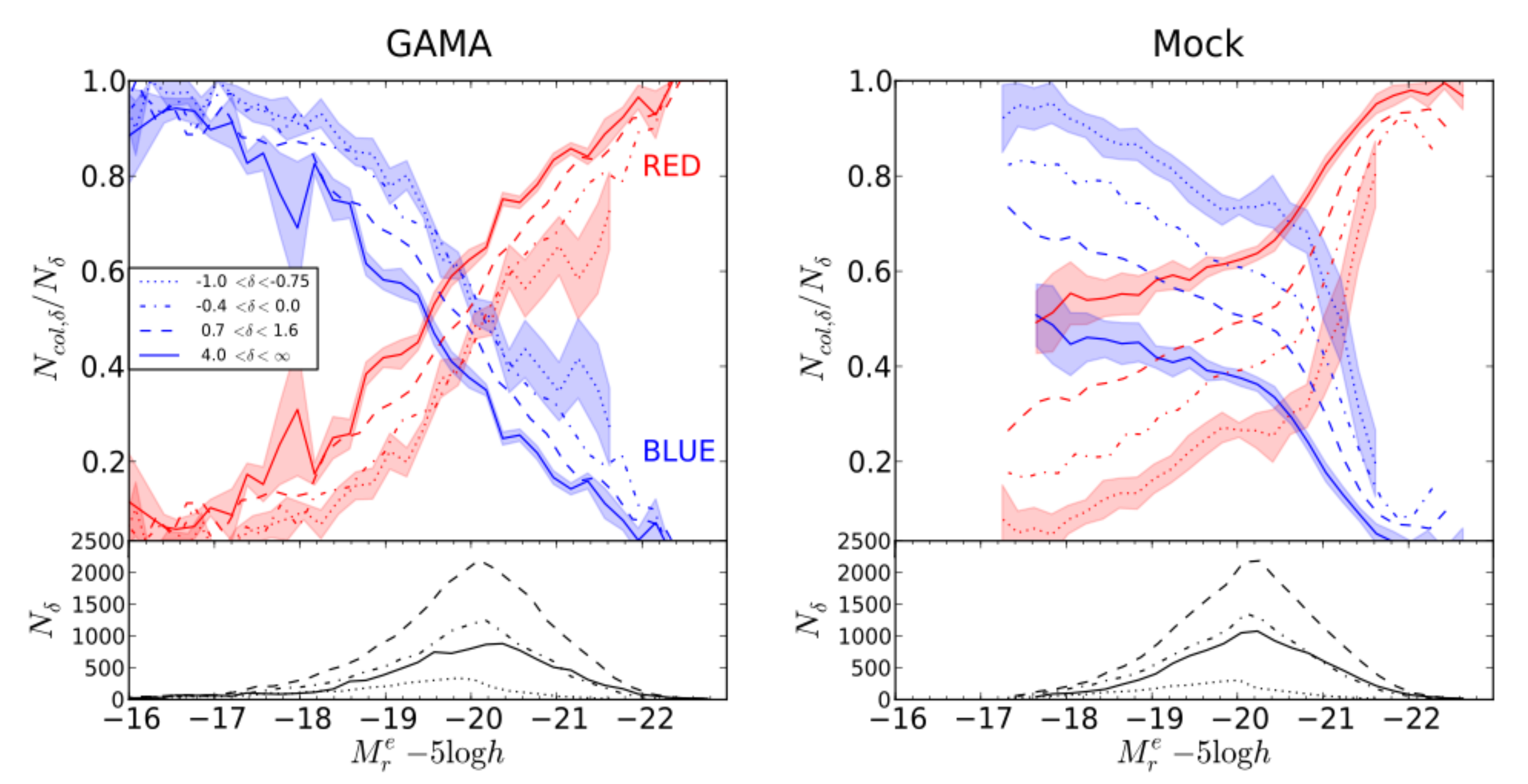




GAMA 1409.4681:

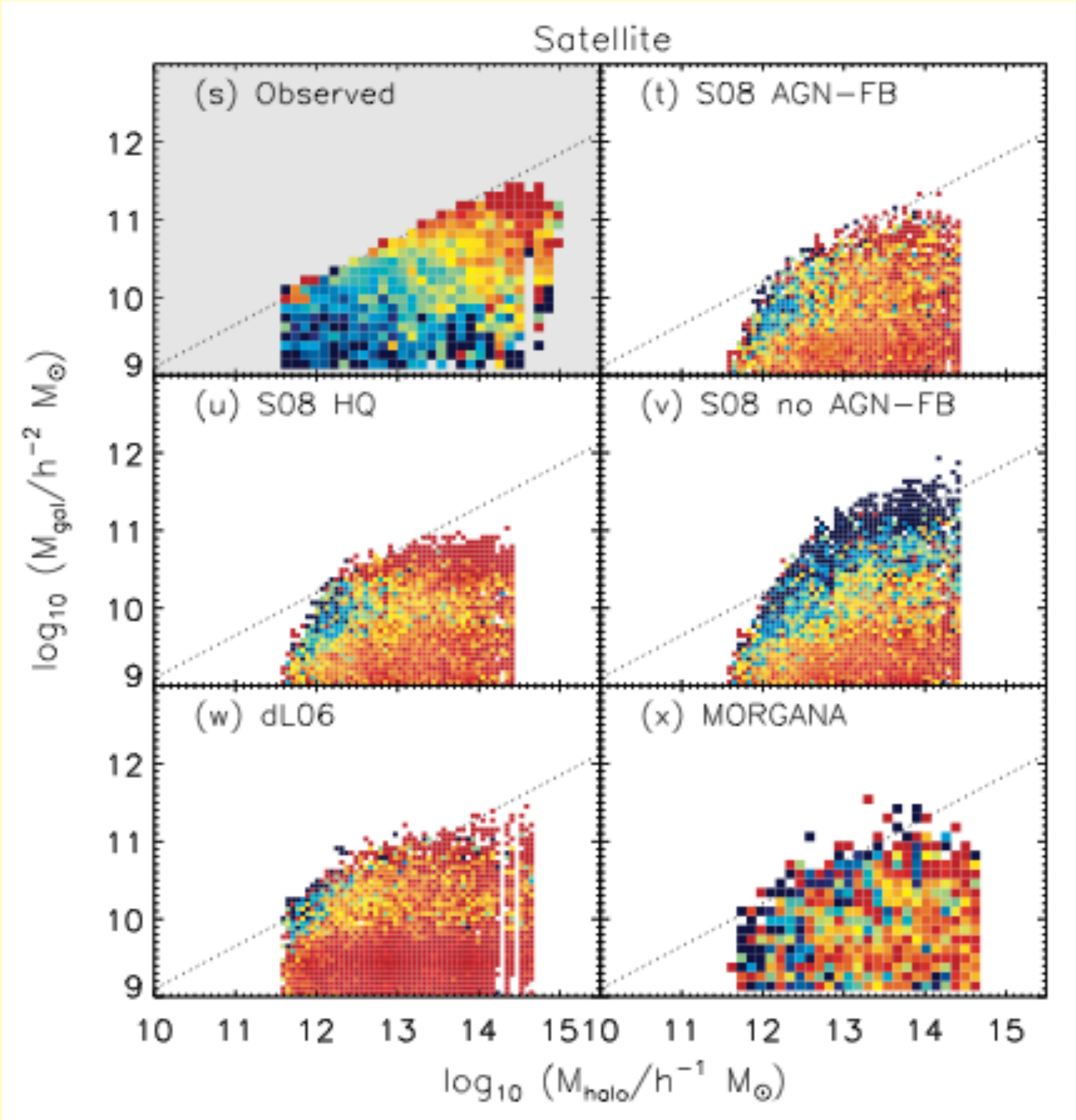
Define overdensity in 8 Mpc/h spheres

Problems with faint reds



Denser regions more blue-dominated than predicted

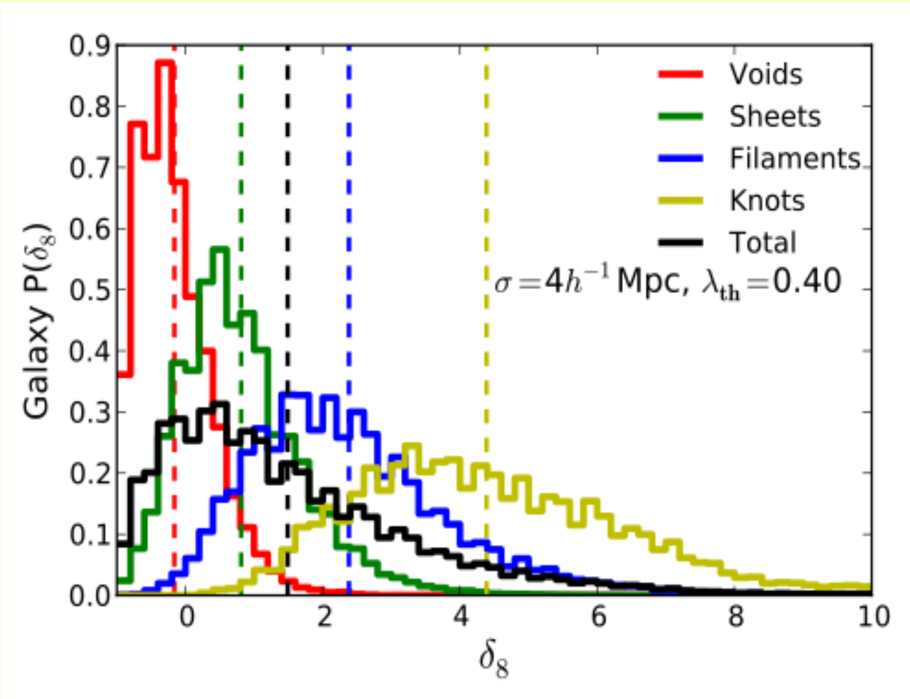
The passive satellite problem

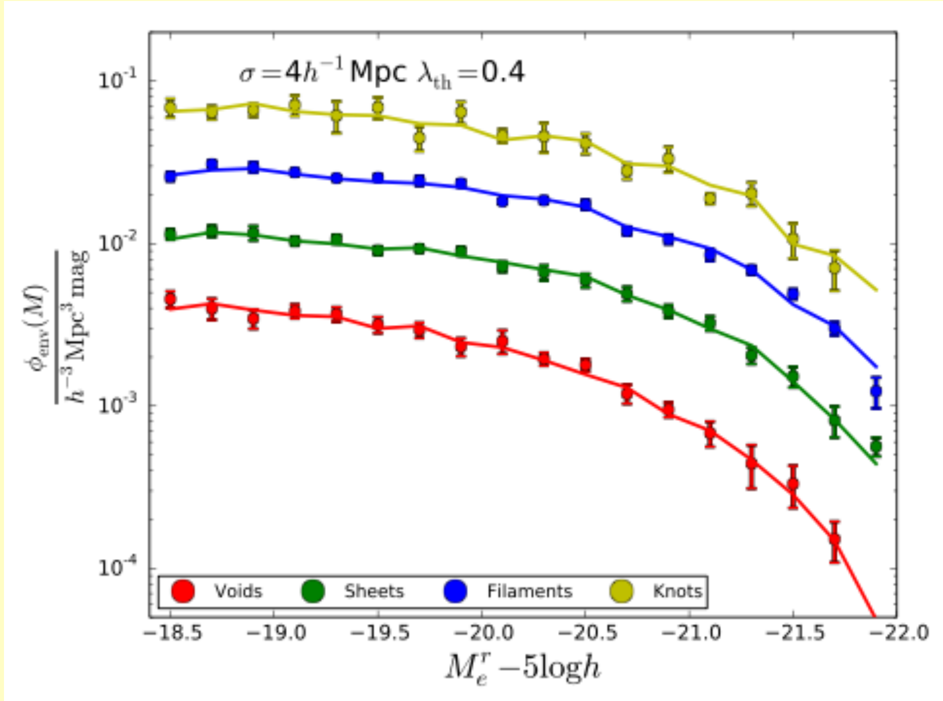


Kimm et al. 2009: SDSS groups vs semianalytics

− a balancing act?

Evidence of tidal effects?

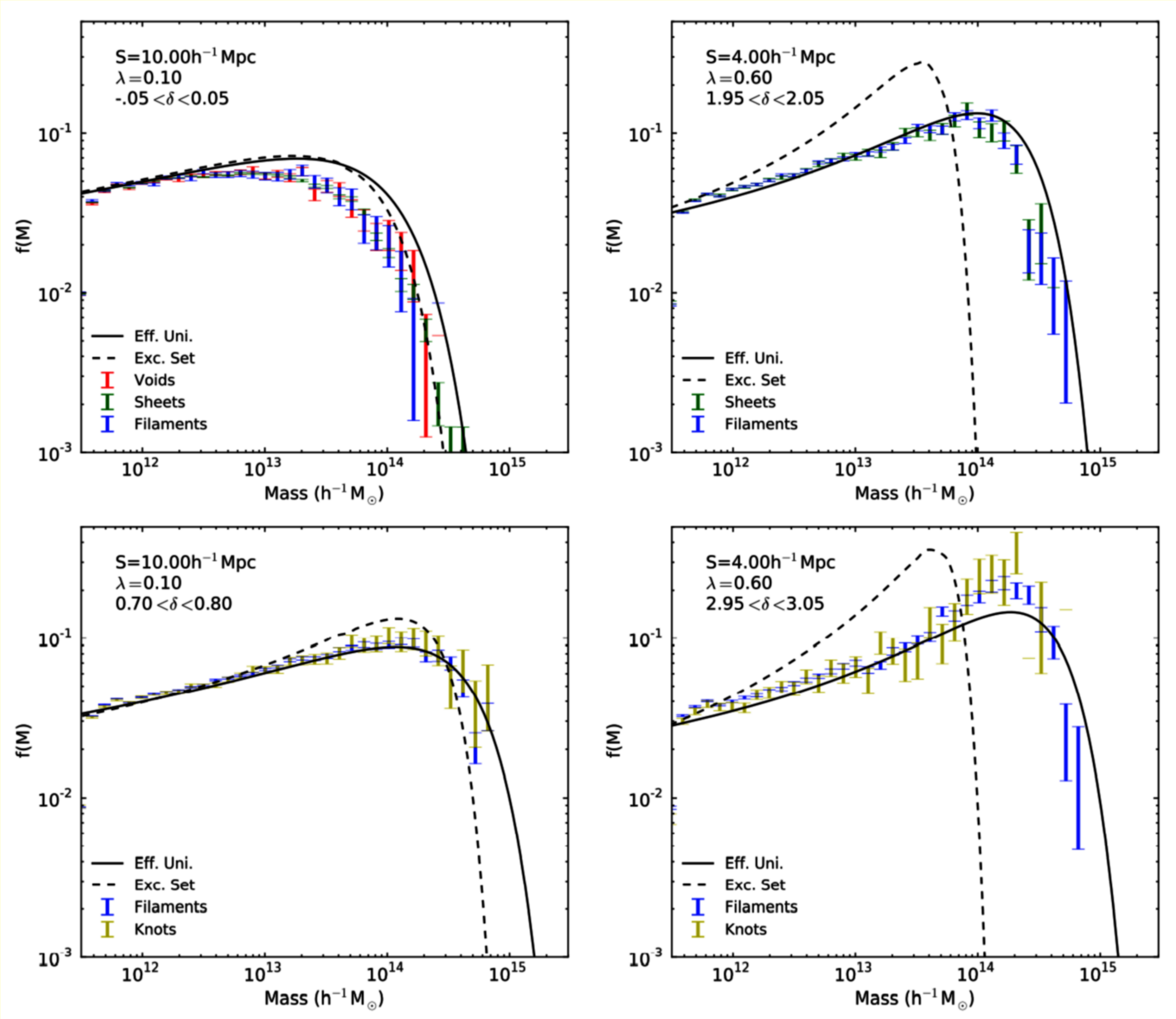




1412.2141: MC shuffling of cells according to density

− lack of any explicit effect

Effect of geometry on haloes



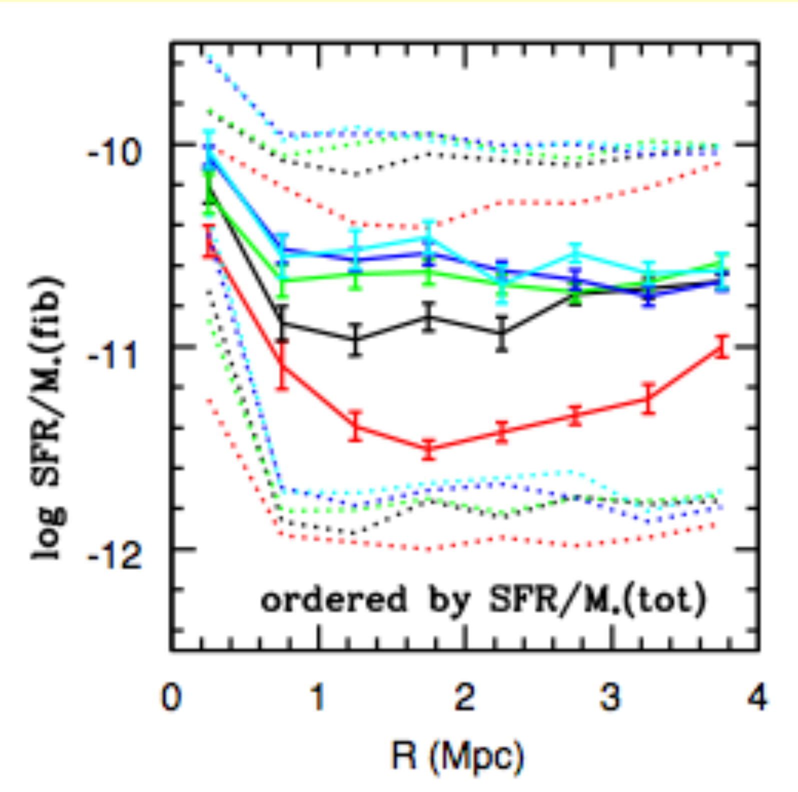
Narrow overdensity slices

Alonso et al. 1406.4159:

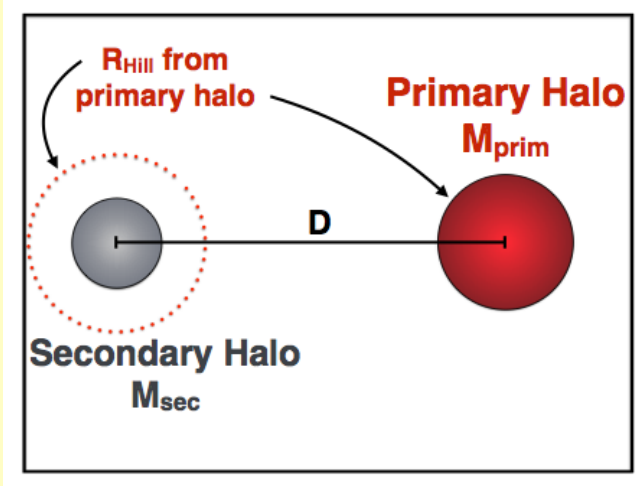
Gaussian theory suggests should be no dependence of conditional mass function on geometry at given overdensity

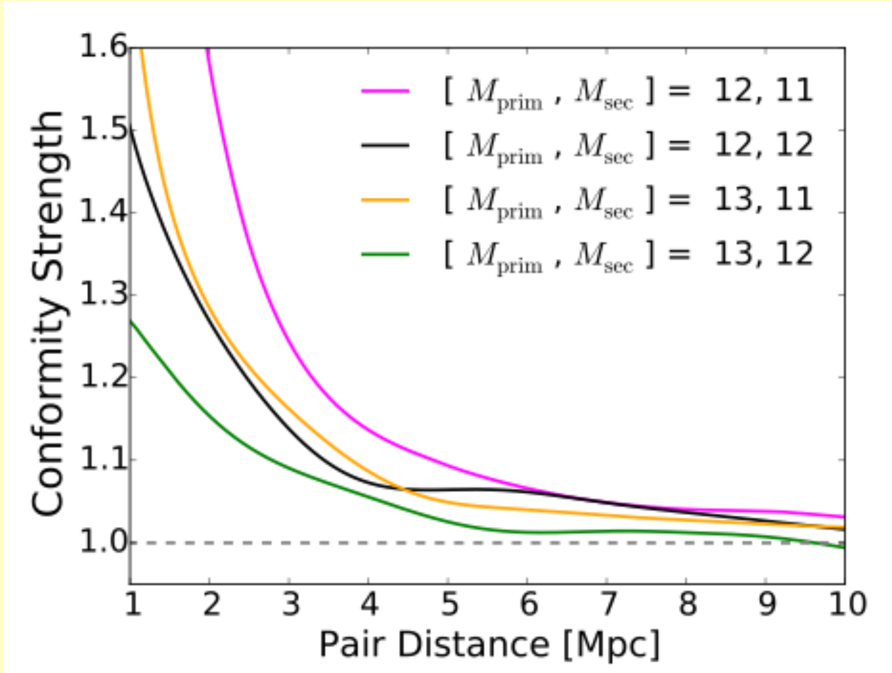
− seems to hold in MultiDark simulations

Galactic conformity



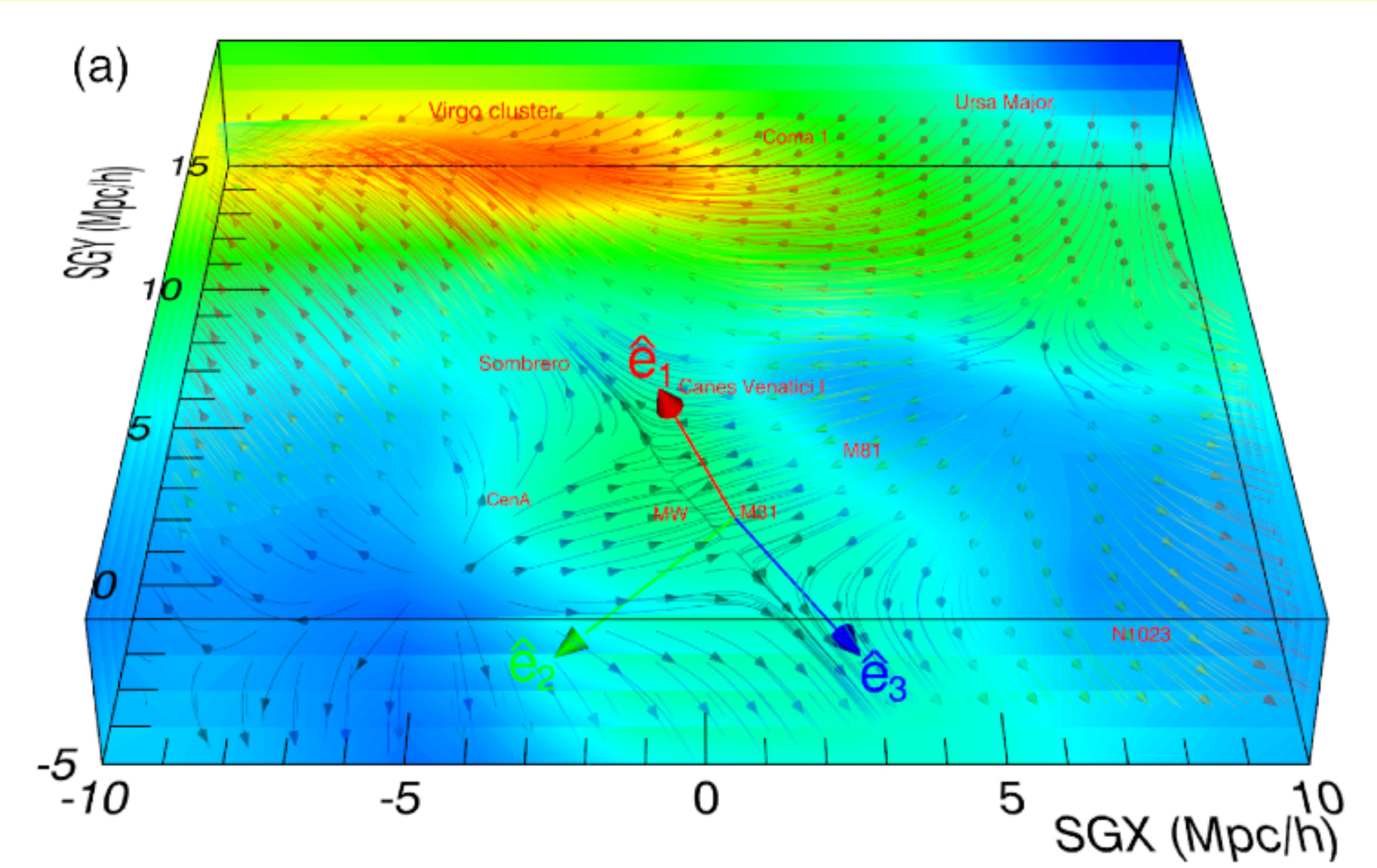
SFRs correlated within and between haloes (Kauffmann et al. 1209.3306)





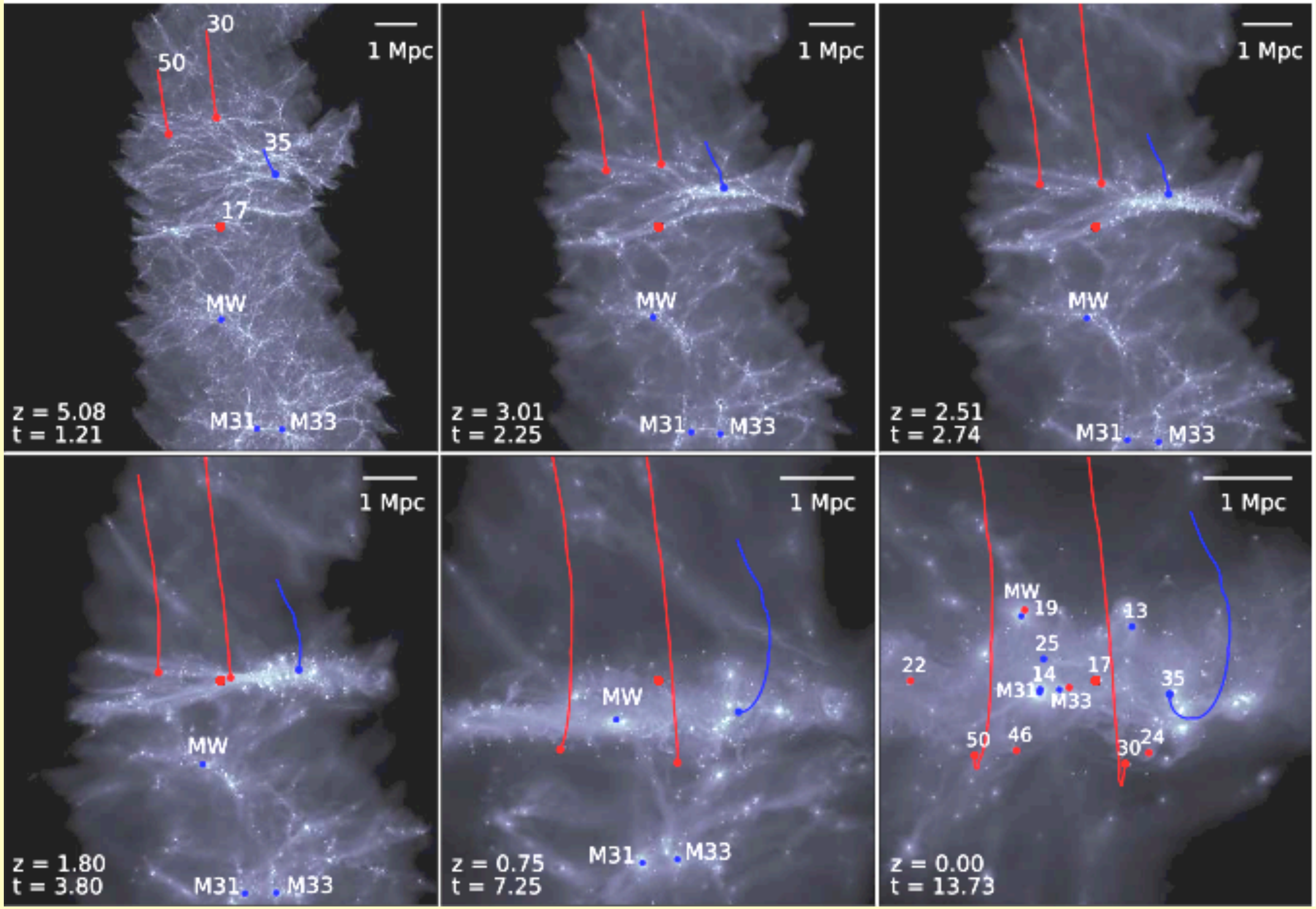
Tidal forces correlate halo accretion rates (Hearin et al. 1504.05578)

Satellite pancakes and the web



Tidal forces align with planes of satellites
(Libeskind et al. 1503.05915)

Non-tidal influence of the web?



Benitez-Llambay et al. 1211.0536: supersonic ram-pressure stripping in caustics as a means of baryon removal

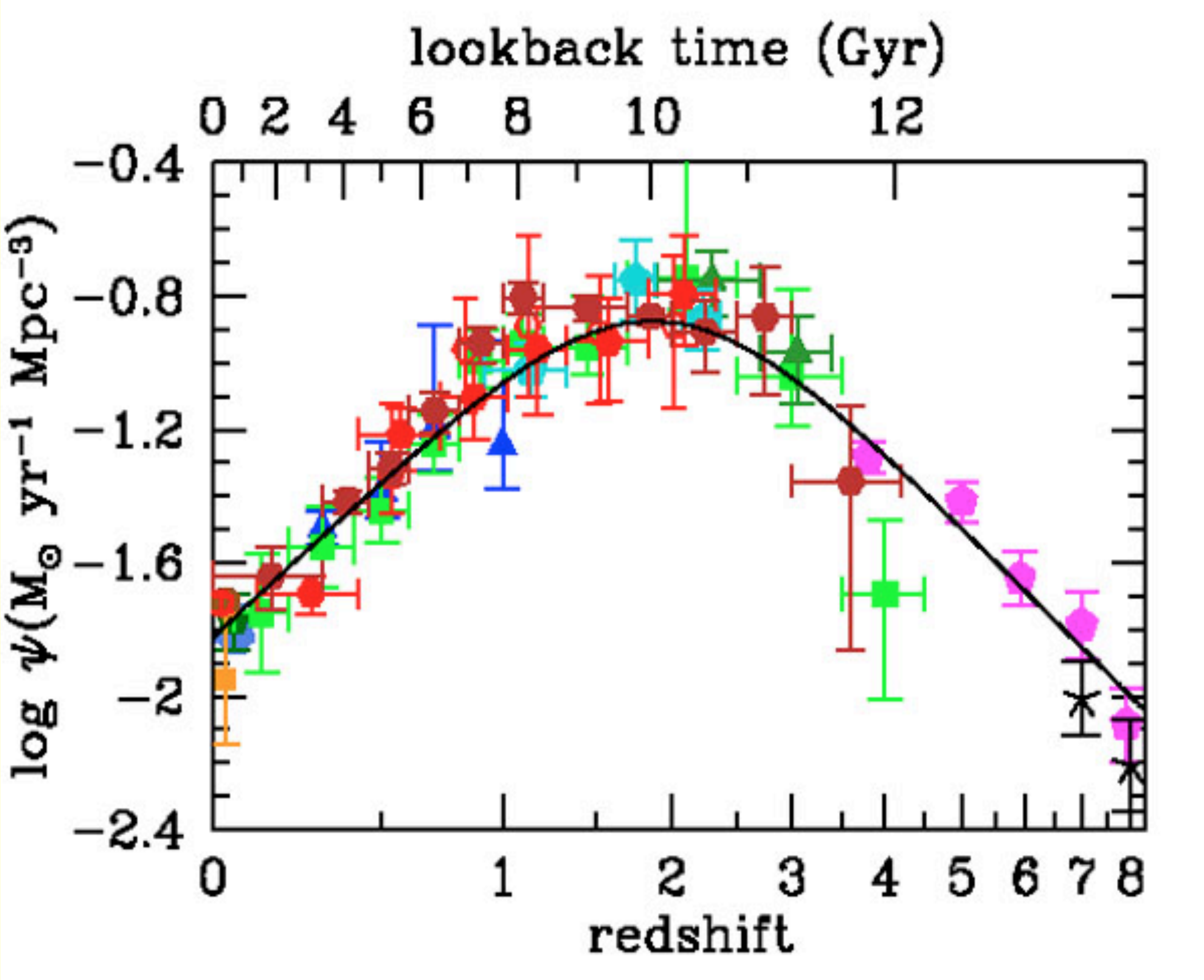
Summary – II

- Tidal forces have effects – not a surprise

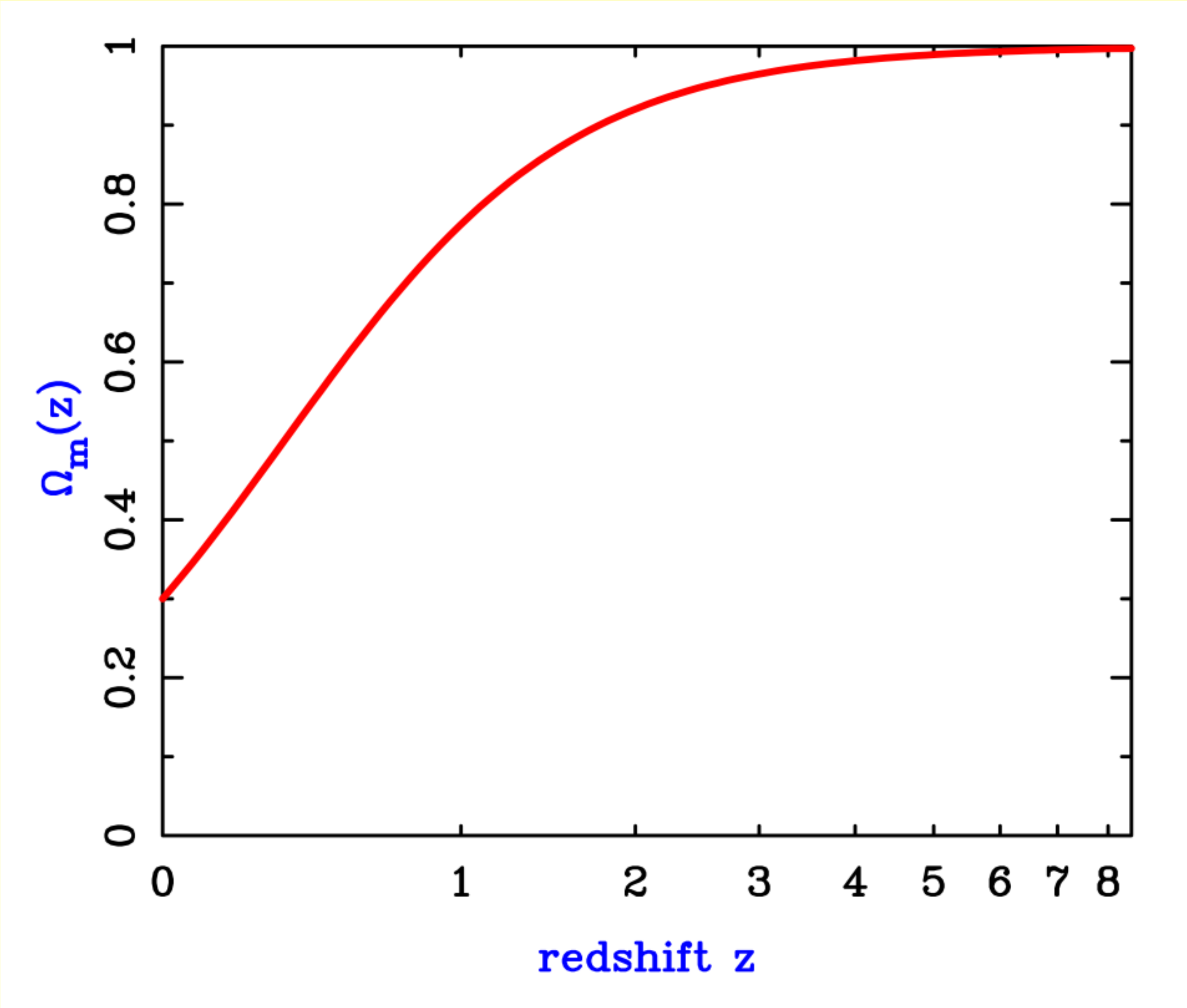
- Small, but measurable, and probably increasingly important in precision studies

[redacted]

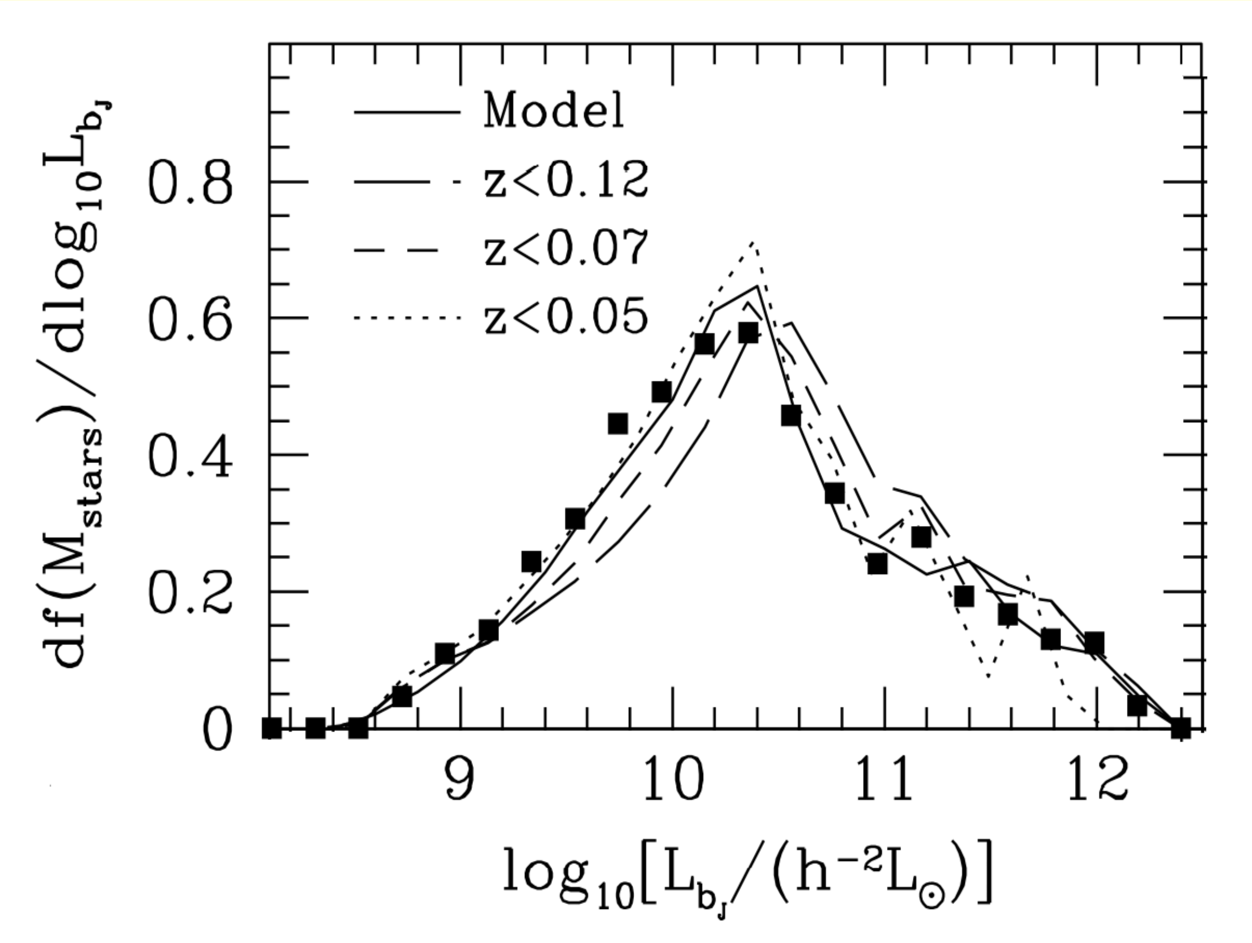
Turning off star formation



Turning off structure formation



Where are the stars?

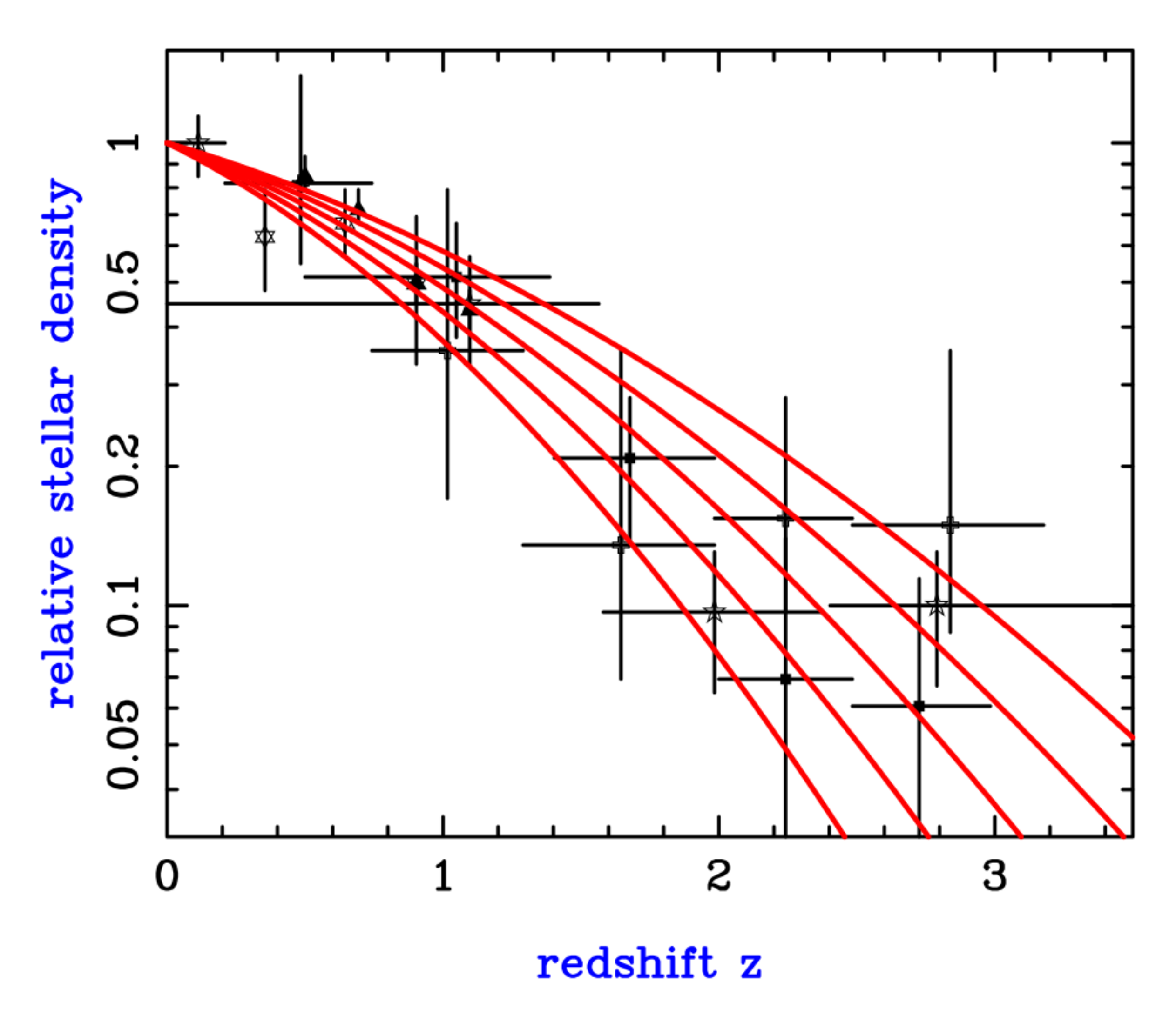


Eke et al. 2004

2PIGG groups

− optimal halo:
~ $10^{12.5}$ M_{sun}

Just-so halo approach

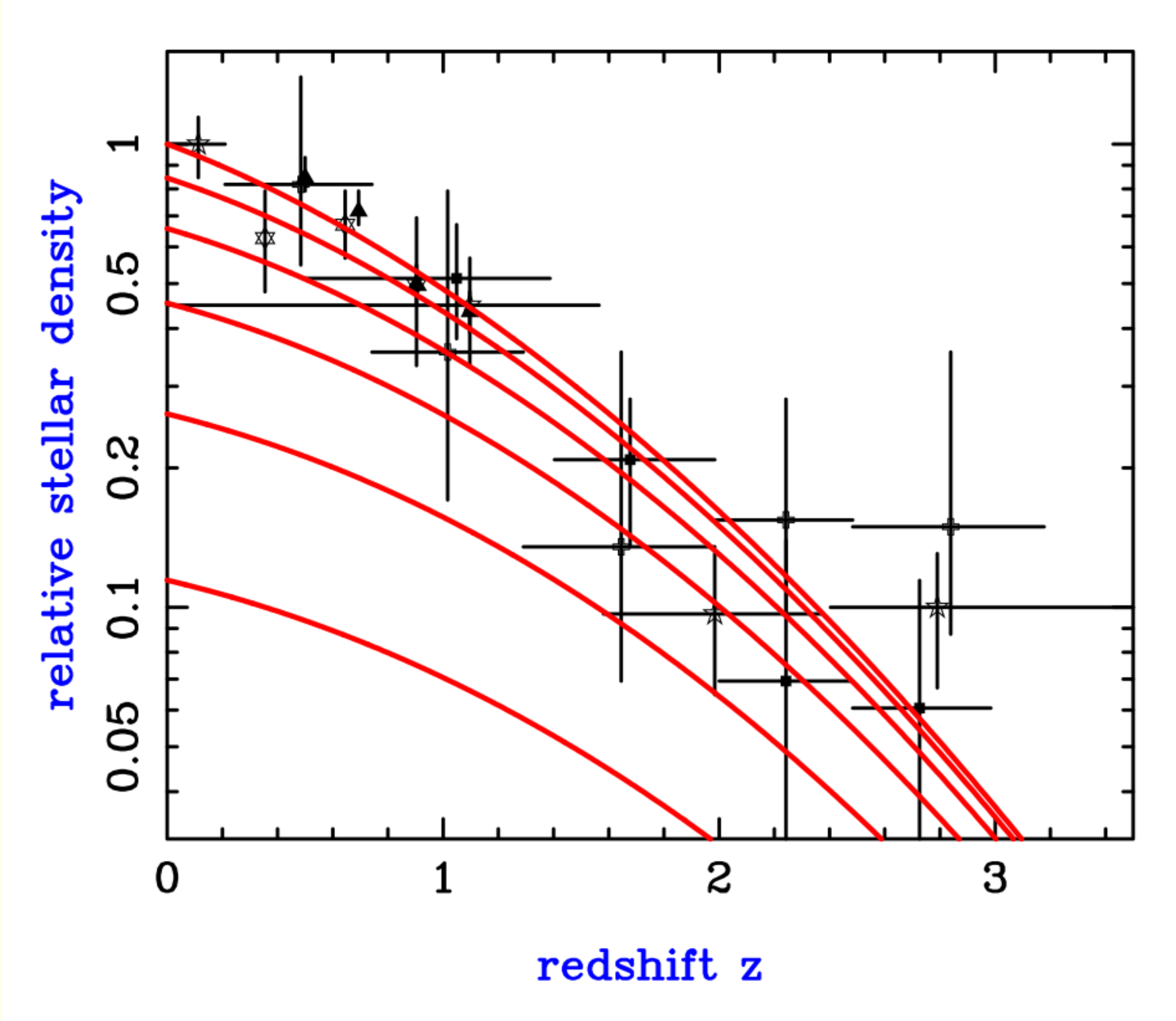


JAP (2007):

Predict stellar density as proportional to collapse fraction in peak efficiency haloes

~ 50% of all stars we will ever get are now in place

What if Λ had been larger?



Asymptotic stellar density exponentially suppressed

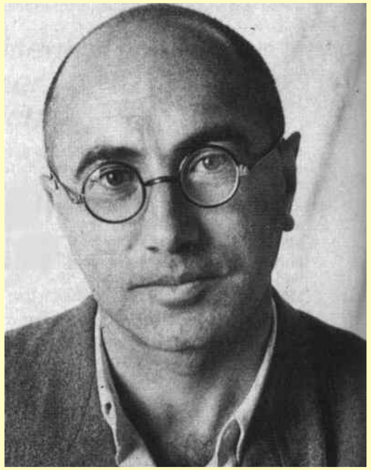
Λ and the vacuum energy problem

Renormalized vacuum density for particle of mass m and cutoff scale M:

$$\rho_{\rm vac} = \left[\frac{c^3}{\hbar^3}\right] \ \frac{m^4}{32\pi^2}\ln(m/M):\ \text{cf.}\ \ \frac{M^4}{16\pi^2}$$

(Koksma & Prokopec 1105.6296)

Real vacuum problem is that observed energy scale is at meV level, not TeV: discrepancy of 15 powers of 10, not 120



Zeldovich 1968

Sakharov 1968

$$\rho_{\rm vac}^{\rm eff} = \rho_{\rm vac} + \Lambda/8\pi G$$

− un-natural?

Weinberg's prediction

The cosmological constant problem*

Steven Weinberg

Theory Group, Department of Physics, University of Texas, Austin, Texas 78712

Astronomical observations indicate that the cosmological constant is many orders of magnitude smaller than estimated in modern theories of elementary particles. After a brief review of the history of this problem, five different approaches to its solution are described.

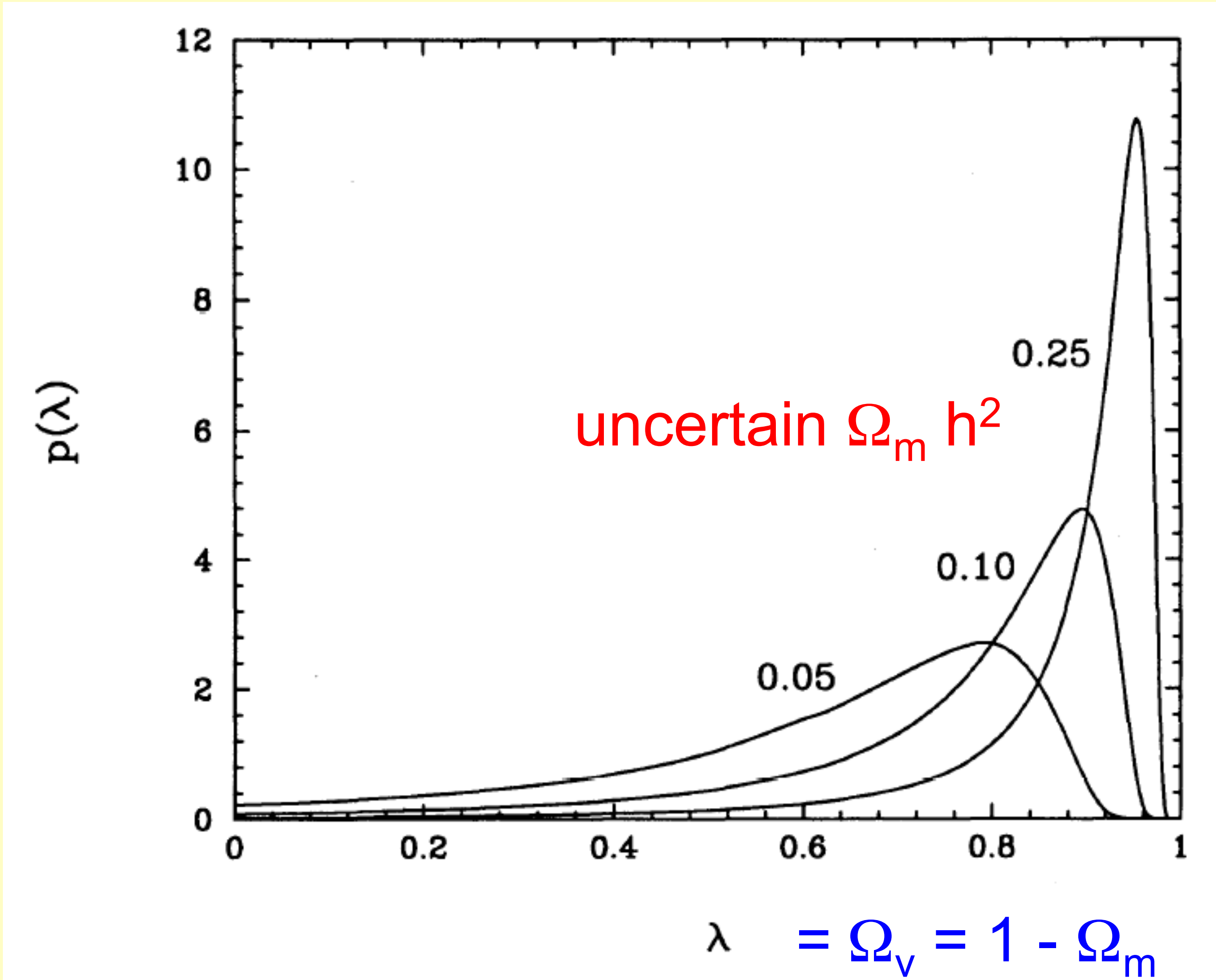
Reviews of Modern Physics, Vol. 61, No. 1, January 1989

A large cosmological constant would interfere with the appearance of life in different ways, depending on the sign of λ_{eff}. For a large *positive* λ_{eff}, the universe very early enters an exponentially expanding de Sitter phase, which then lasts forever. The exponential expansion interferes with the formation of gravitational condensations, but once a clump of matter becomes gravitationally bound, its subsequent evolution is unaffected by the cosmological constant. Now, we do not know what weird forms life may take, but it is hard to imagine that it could develop at all without gravitational condensations out of an initially smooth universe. Therefore the anthropic principle makes a rather crisp prediction: λ_{eff} must be small enough to allow the formation of sufficiently large gravitational condensations (Weinberg, 1987).

This result suggests strongly that if it is the anthropic principle that accounts for the smallness of the cosmological constant, then we would expect a vacuum energy density $\rho_V \sim (10-100)\rho_{M_0}$, because there is no anthropic reason for it to be any smaller.

Is such a large vacuum energy density observationally allowed? There are a number of different types of astronomical data that indicate differing answers to this question.

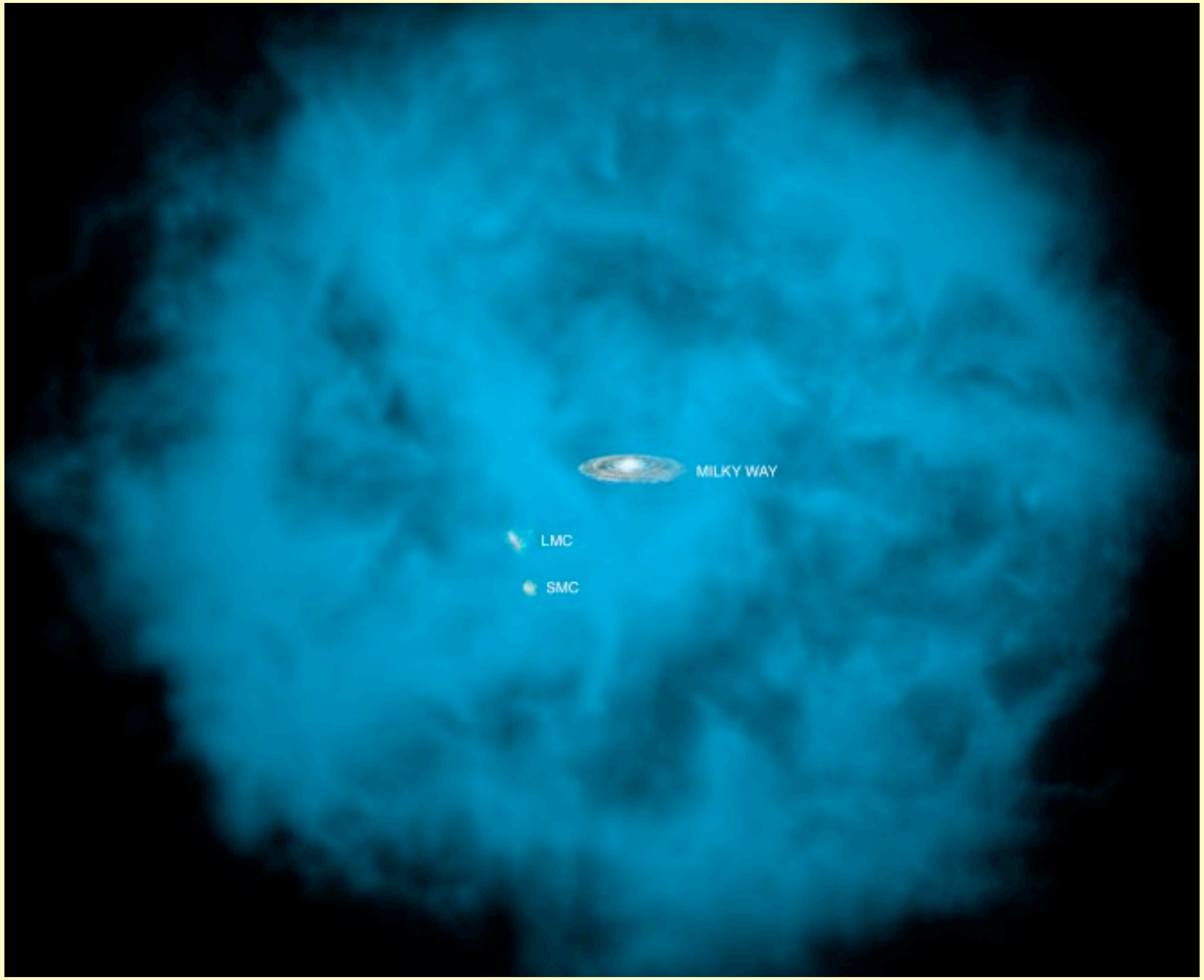
Efstathiou 1995



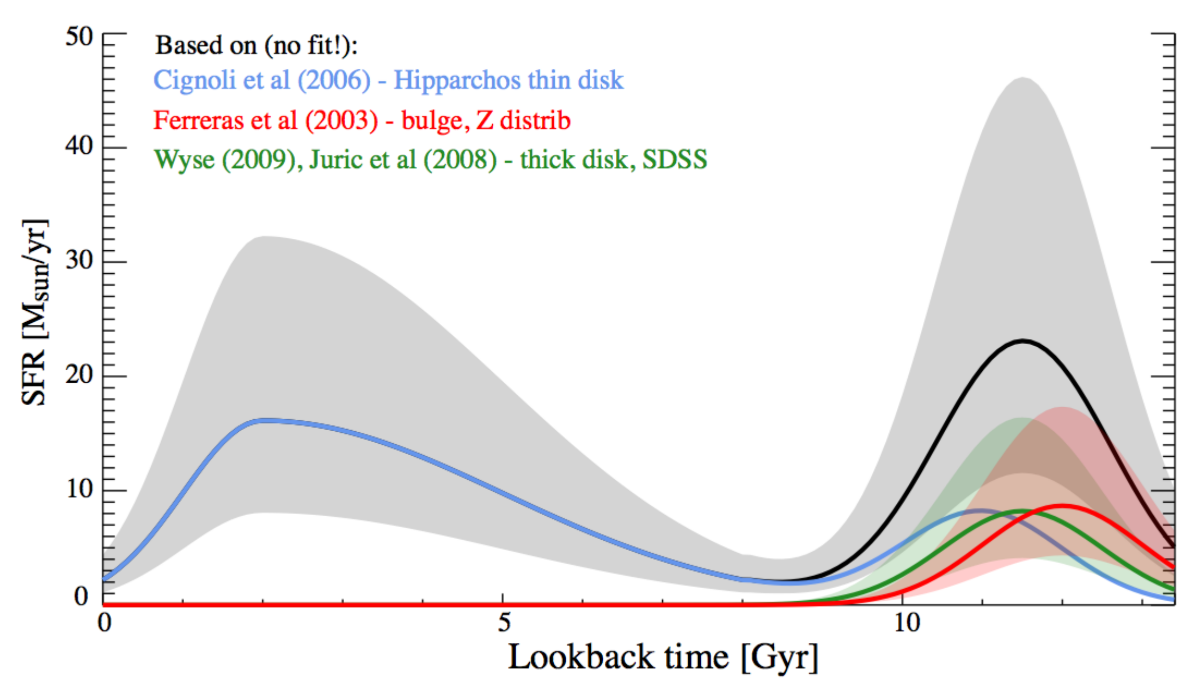
Refined version of Weinberg: simple halo collapse models work

“ Eternity is very long, especially towards the end ”

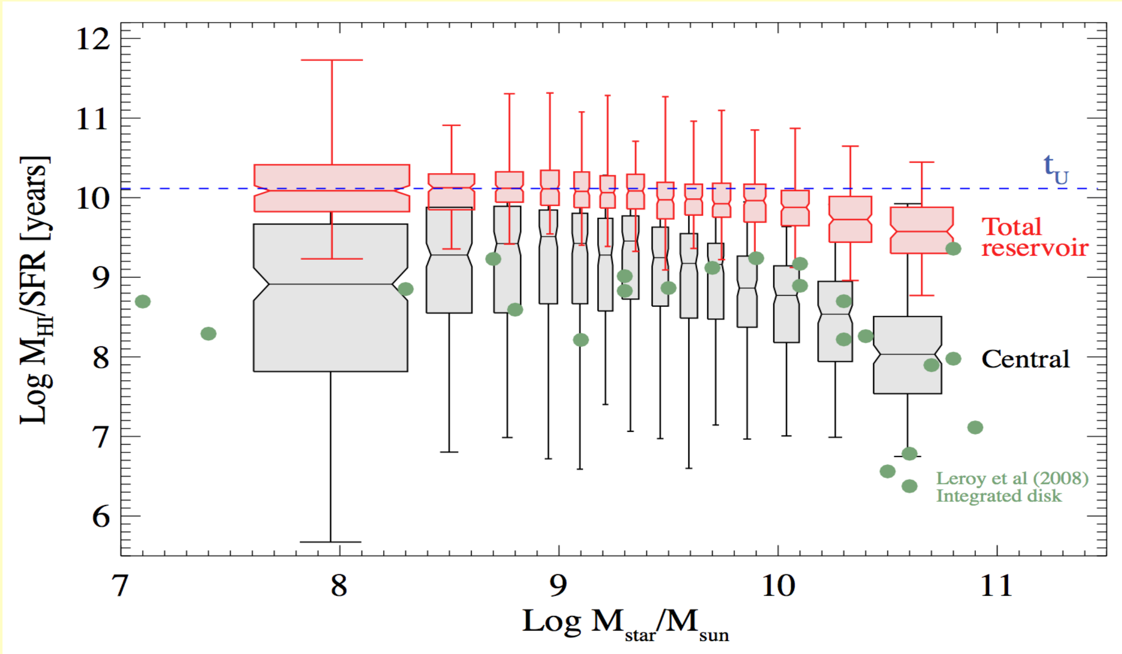
Cooling of extended gaseous haloes



Chandra’s vision of the Local Group



Once and future SF?



Summary – III

- Need to think more about star formation in the very very very long term

- But if Weinberg doesn't explain Λ, what does?