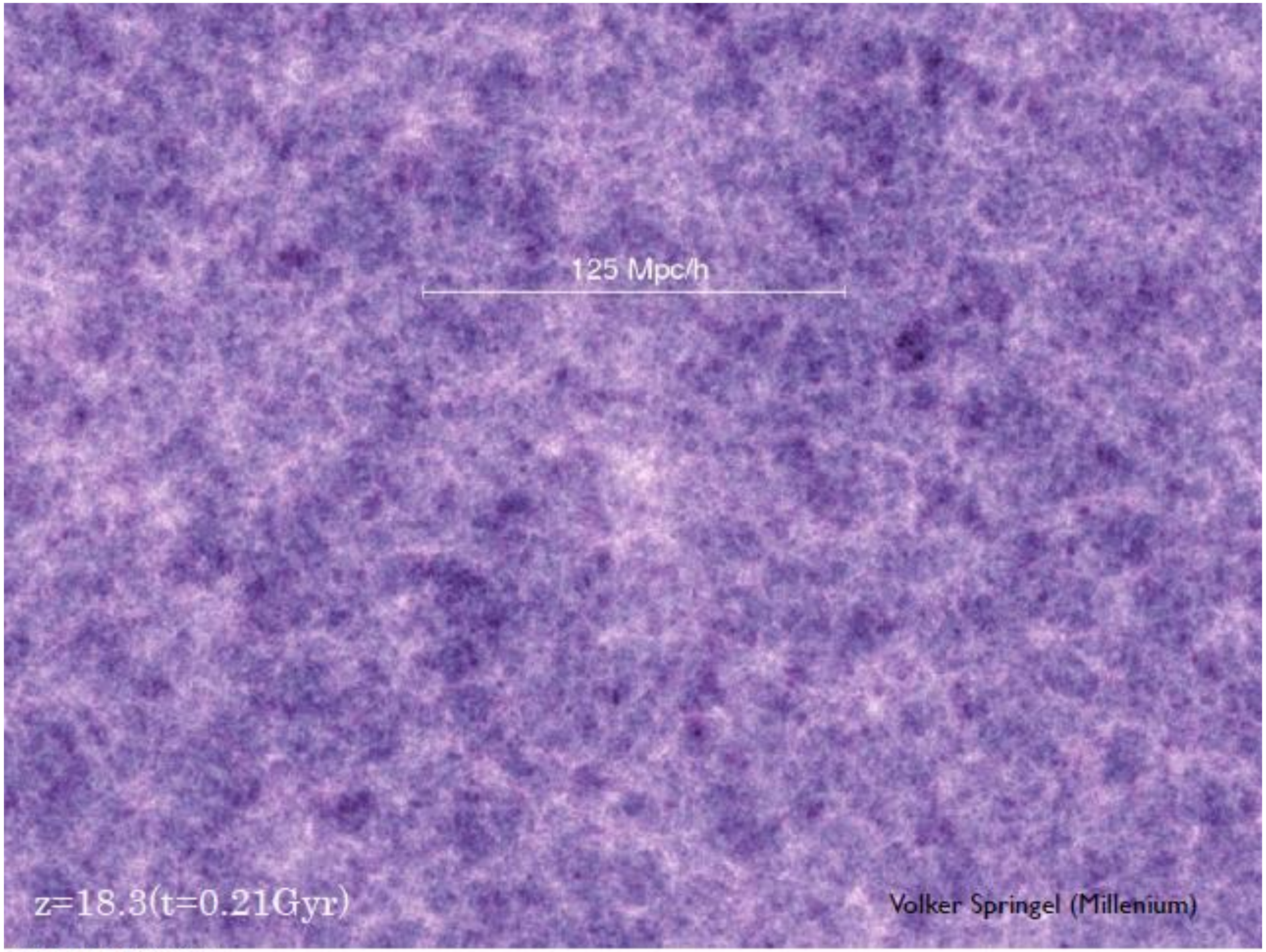
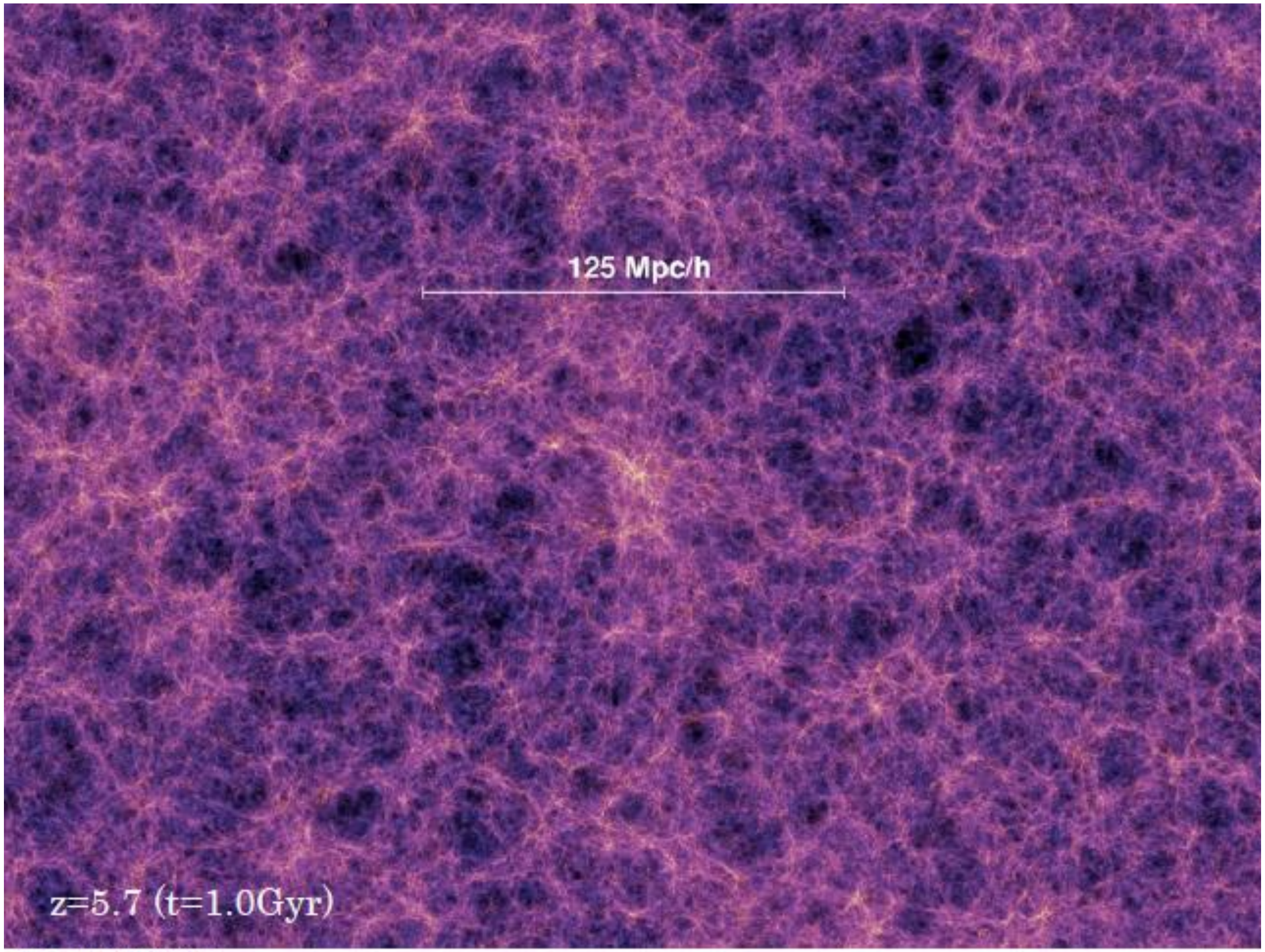
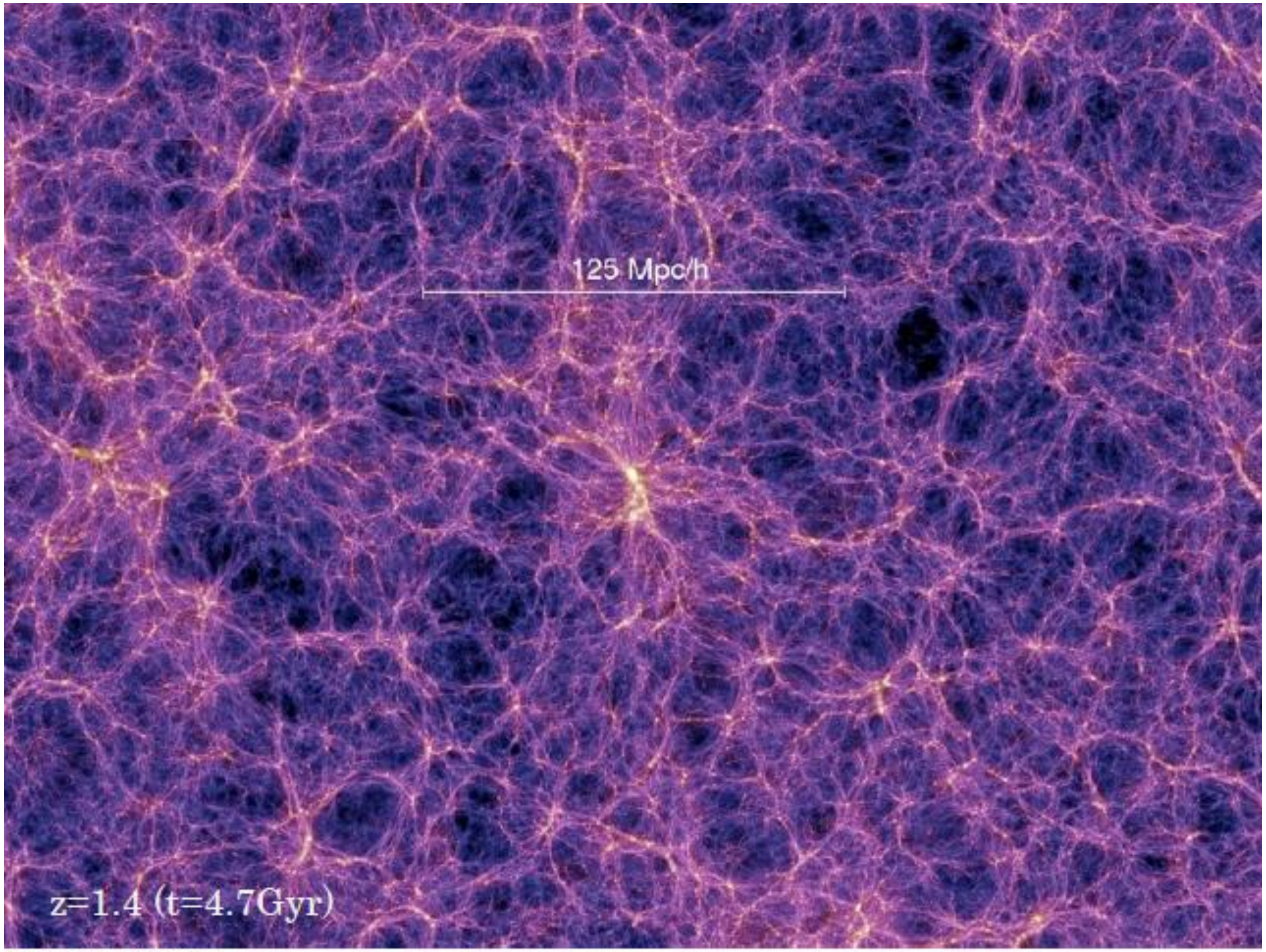
The excursion set approach

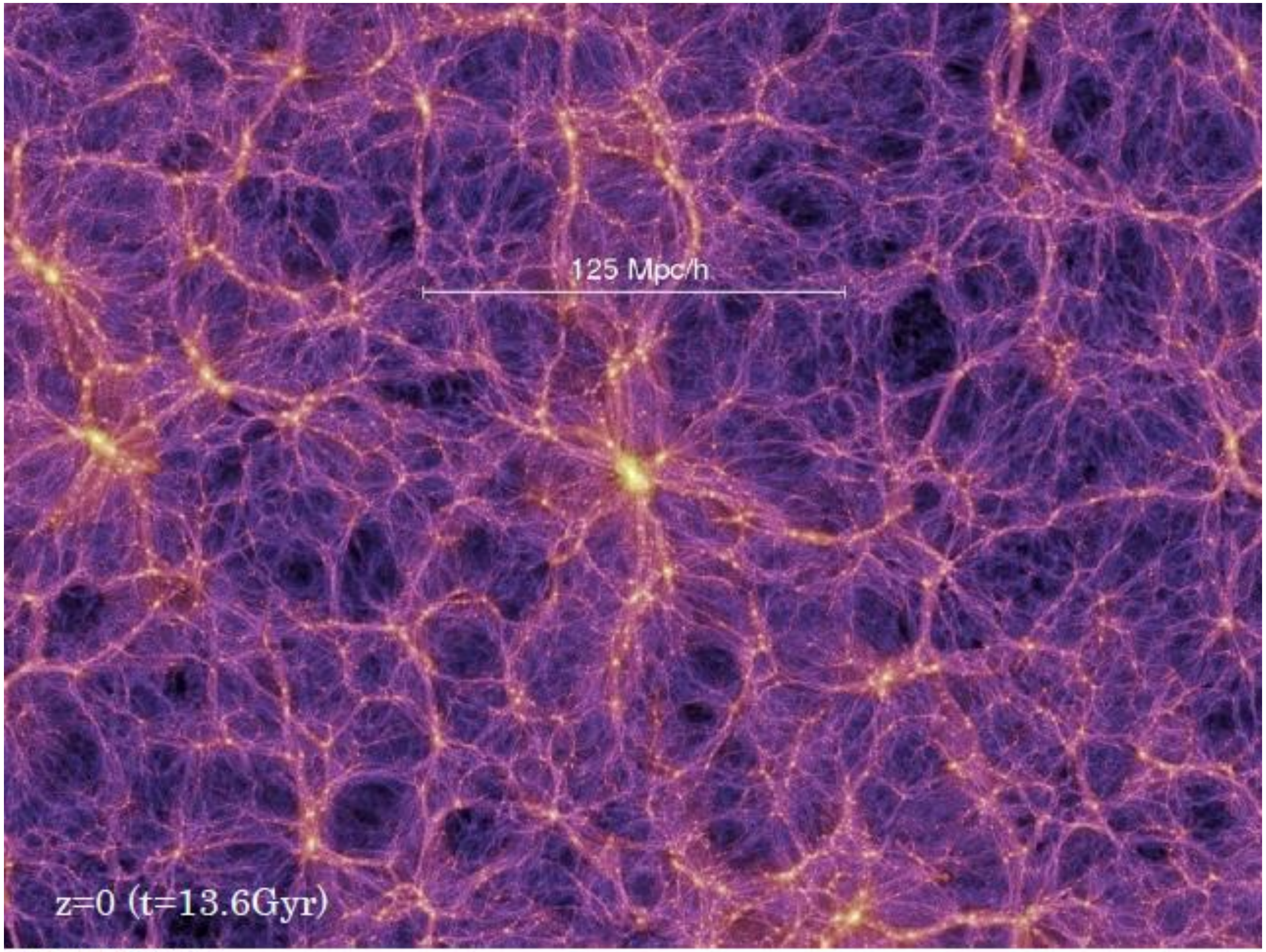
Halo abundances

Halo clustering/bias


125 Mpc/h
z=18.3(t=0.21Gyr)
Volker Springel (Millenium)


125 Mpc/h
z=5.7 (t=1.0Gyr)


125 Mpc/h
z=1.4 (t=4.7Gyr)


125 Mpc/h
z=0 (t=13.6Gyr)

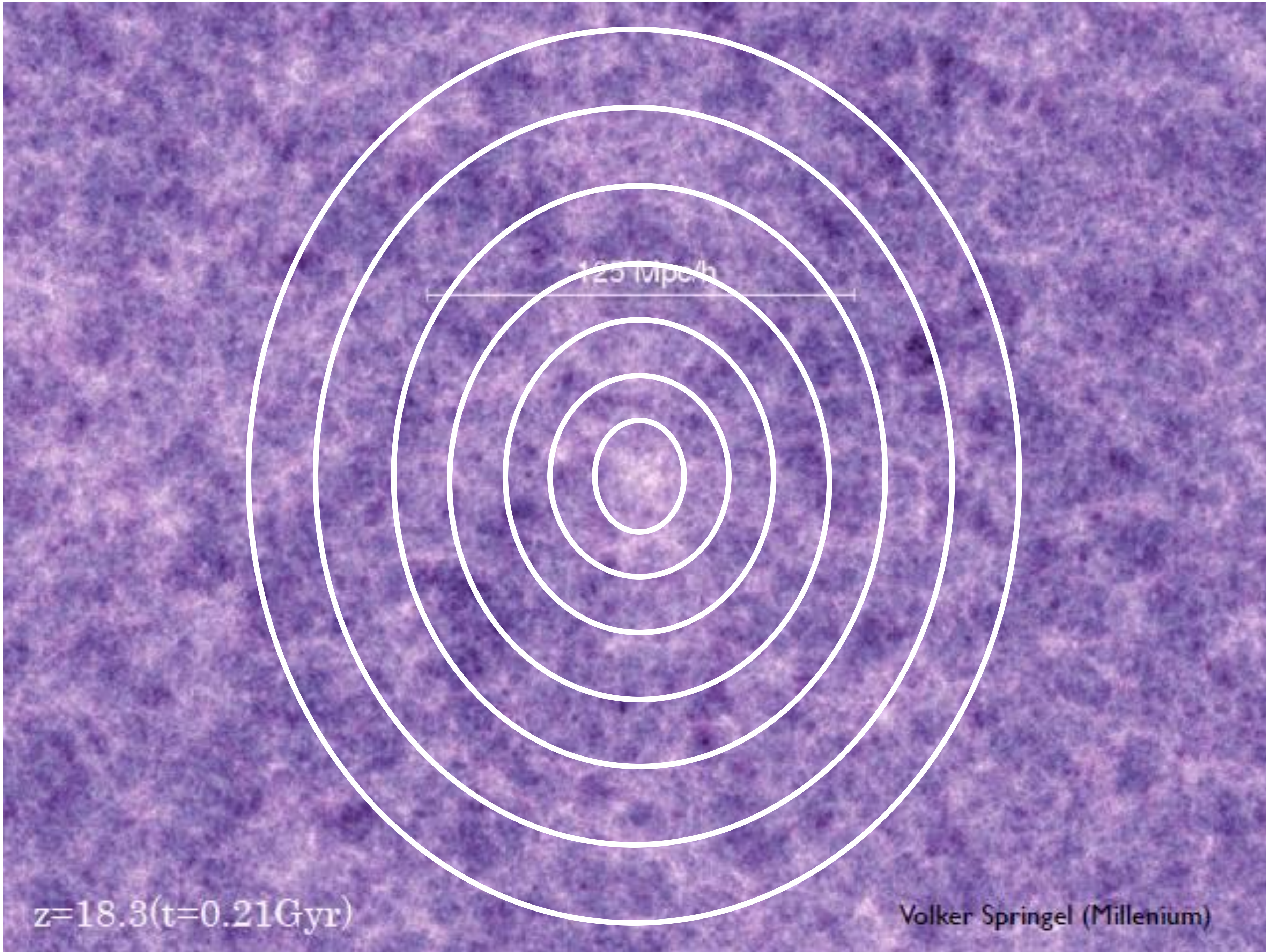
Why study halos?

- Cluster counts contain information about volume and about how gravity won/lost compared to expansion
- Probe geometry and expansion history of Universe, and nature of gravity

Massive halo = Galaxy cluster

(Simpler than studying galaxies? Less gastrophysics?)


But wait …
We should be doing
this in the INITIAL
fluctuation field!

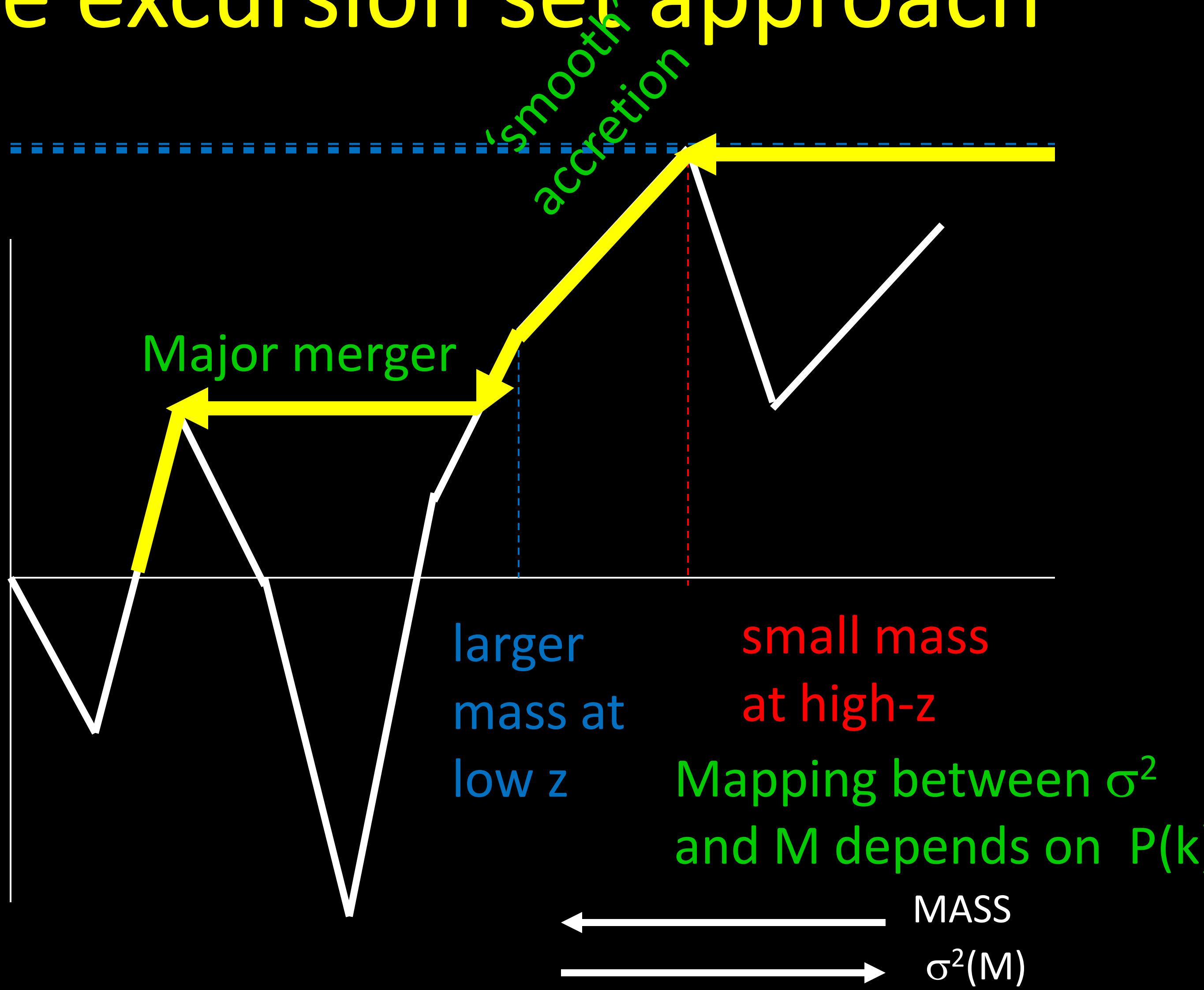

125 Mpc/h
z=18.3(t=0.21Gyr)
Volker Springel (Millenium)

The excursion set approach

High-z

Low-z

over-density



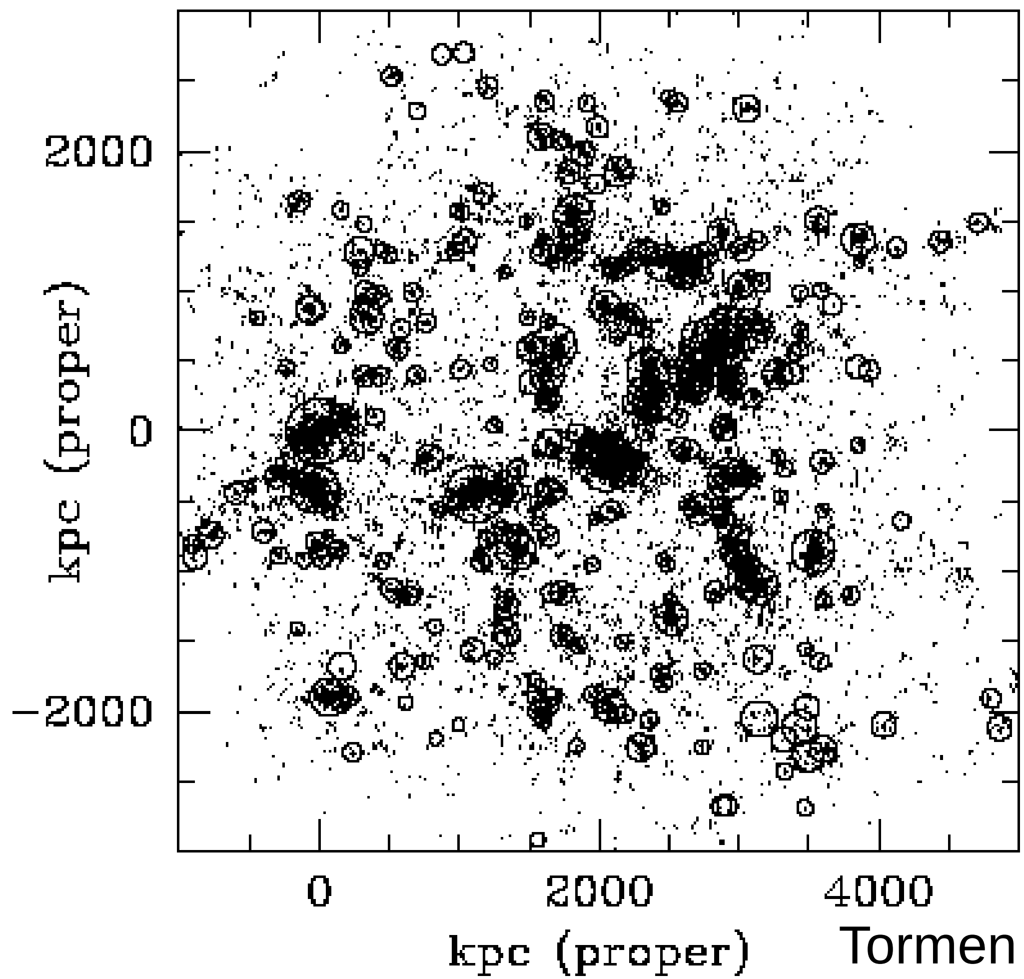
Time evolution of barrier depends on cosmology

Simplification because…

- Everything local
- Evolution determined by cosmology (competition between gravity and expansion)
- Statistics determined by initial fluctuation field: for Gaussian, specified by initial power-spectrum $P(k)$
- Nearly universal in scaled units: $\delta_c(z)/\sigma(m)$ where $\sigma^2(m) = \langle\delta_m^{\ 2}\rangle = \int dk/k\ \ k^3P(k)/2\pi^2\ W^2(kR_m)$ $\quad m \propto R_m^{\ 3}$
- Fact that only very fat cows are spherical is a detail (*crucial* for precision cosmology); in excursion set approach, mass-dependent barrier height increases with distance along walk

Spherical evolution model

- ‘Collapse’ depends on initial over-density Δ_i; same for all initial sizes
- Critical density depends on cosmology
- Final objects all have same density, whatever their initial sizes
- Collapsed objects called halos are ~ 200× denser than critical (background?!),



Tormen 1997

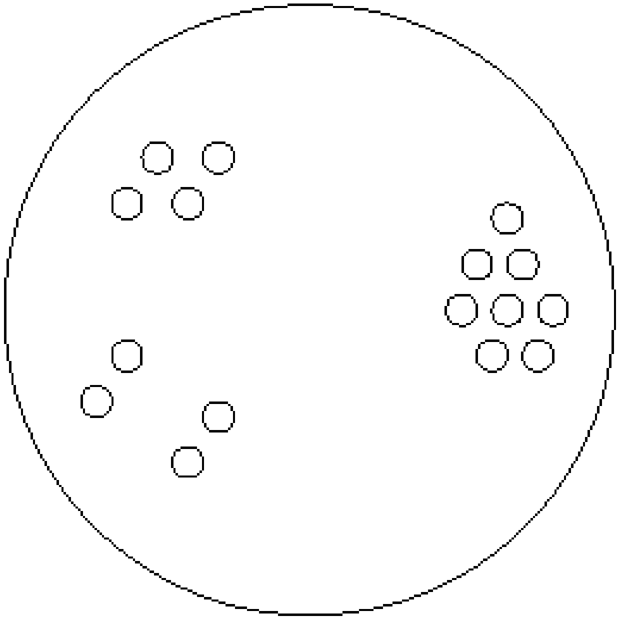


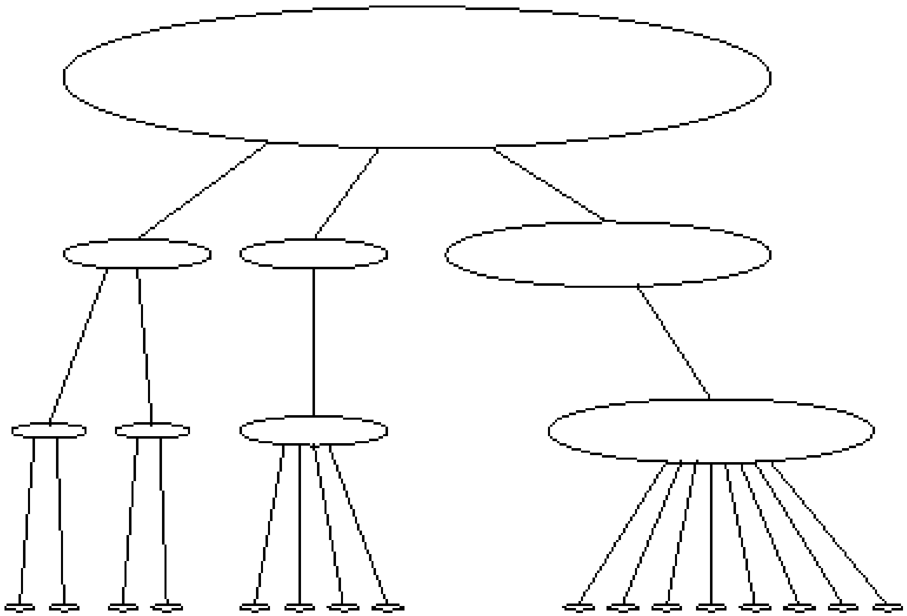




Assume a spherical herd of spherical cows…

Initial spatial distribution within patch (at z~1000)





…stochastic (initial conditions Gaussian random field); study 'forest' of merger history 'trees'.

…encodes information about subsequent 'merger history' of object

(Mo & White 1996; Sheth 1996)

Spherical evolution mapping …

$(R_{\text{initial}}/R)^3 = \text{Mass}/(\rho_{\text{com}}\text{Volume}) =$

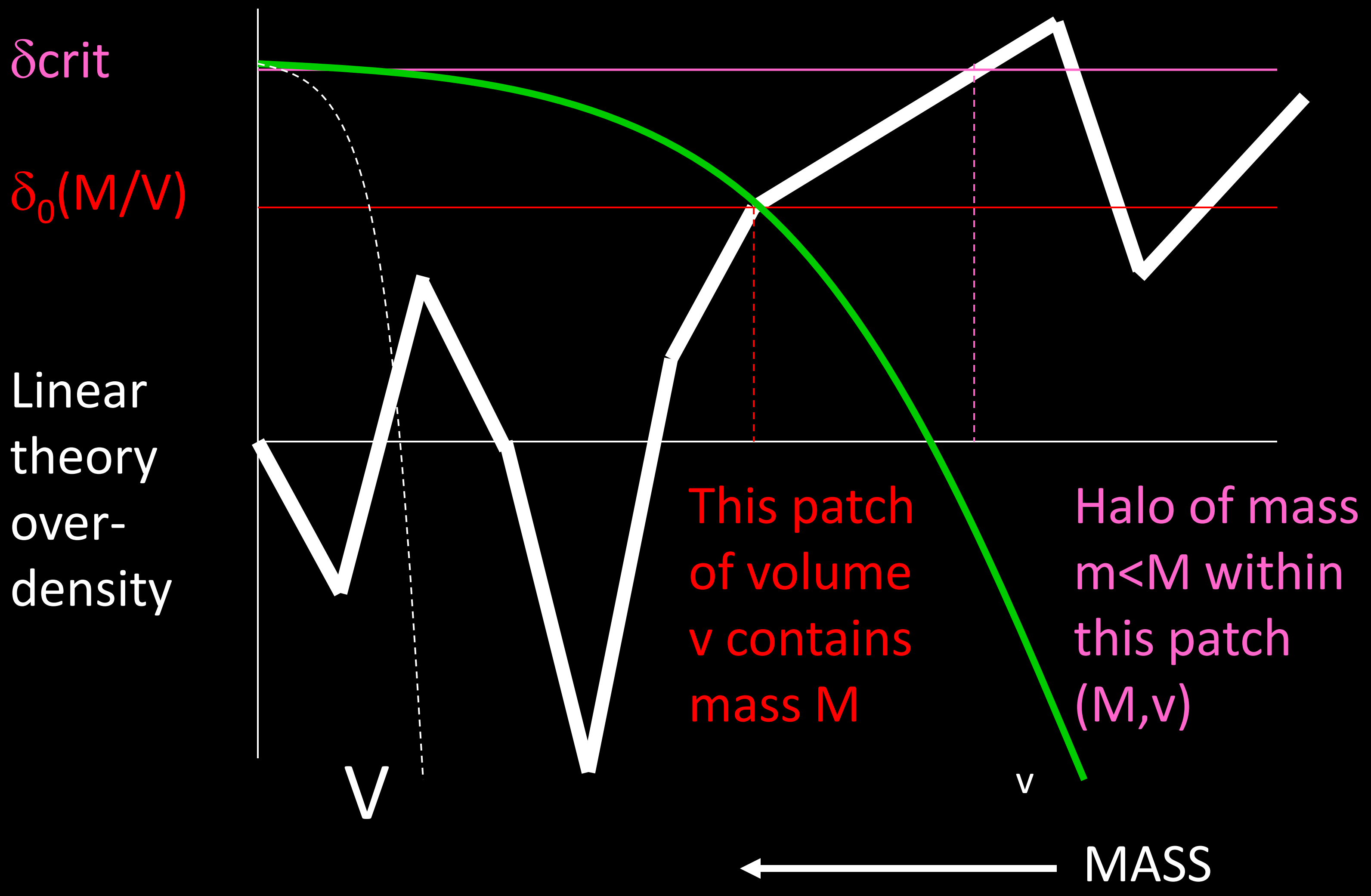
$$1 + \delta \approx (1 - \delta_0/\delta_{sc})^{-\delta sc}$$

… can be inverted:

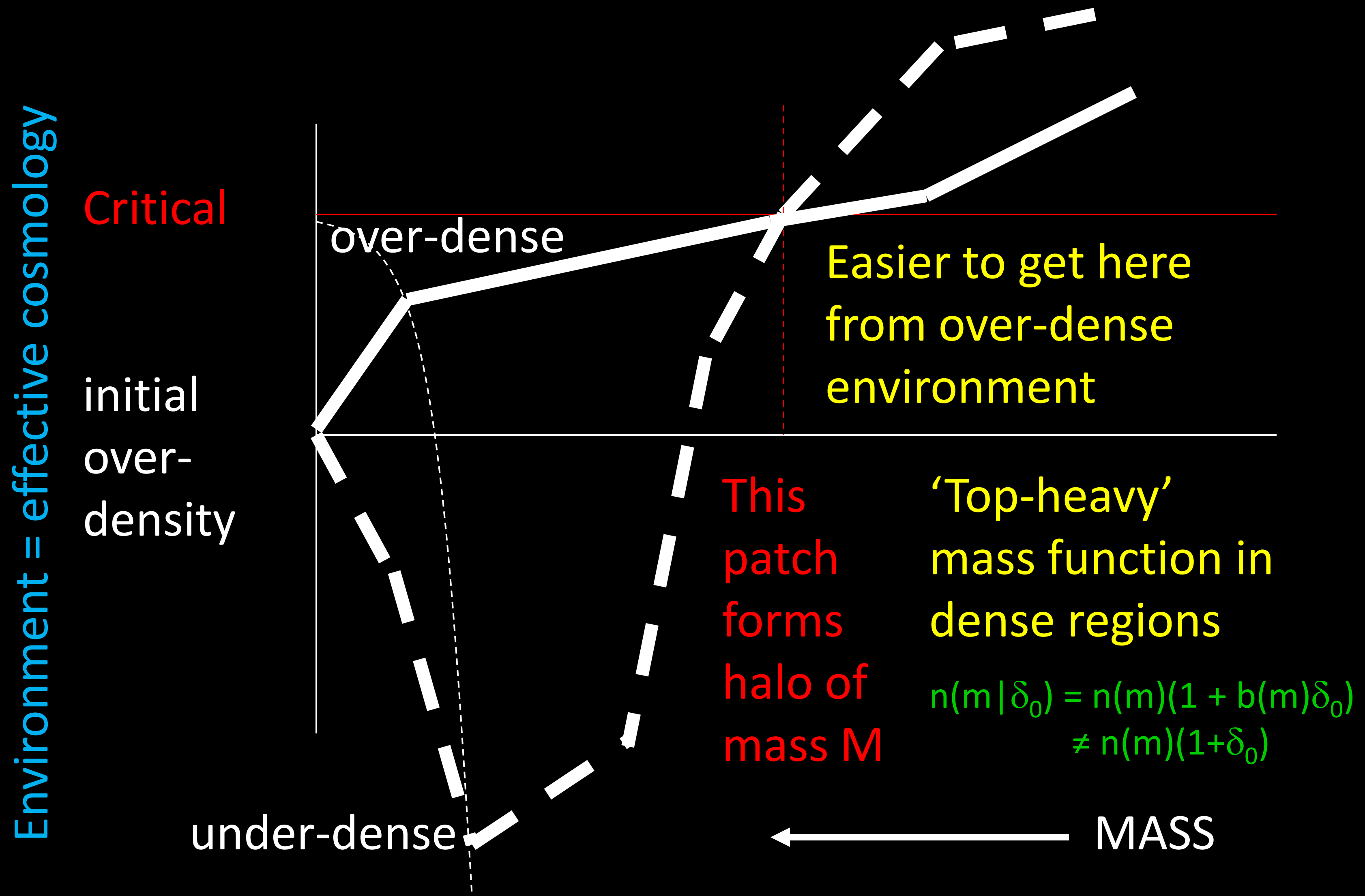
$$(\delta_0/\delta_{sc}) \approx 1 - (M/\rho_{\text{com}}V)^{-1/\delta sc}$$

N.B. For any V, there is a curve $\delta_0(M|V)$.

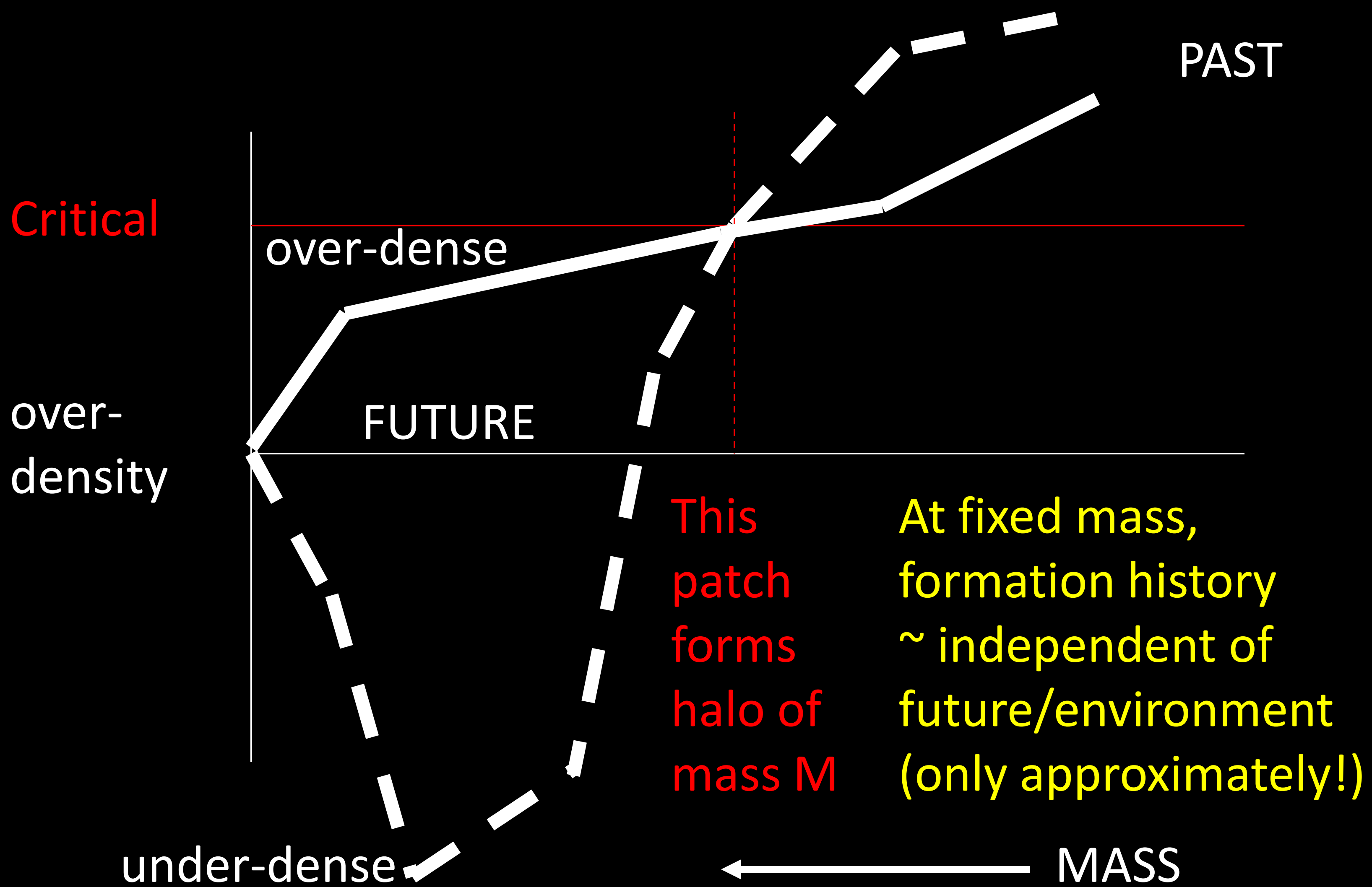
Moving barriers: The Nonlinear PDF



Correlations with environment



Correlations with environment



Large scale clustering/bias (from the peak-background split)

$$1 + \delta_h(\nu|\delta_0,S_0) = f(\nu|\delta_0,S_0)\,/f(\nu)$$

$$= 1 + b_1(\nu)\delta_0 + \ldots$$

- $b(\nu)$ directly from (derivatives of) $f(\nu)$ means halo abundances predict halo clustering
- $b(\nu)$ increases with ν

→ top-heavy mass function in dense regions:

$$n(m|\delta_0) = n(m)(1 + b(m)\delta_0 + \ldots) \neq n(m)(1+\delta_0)$$

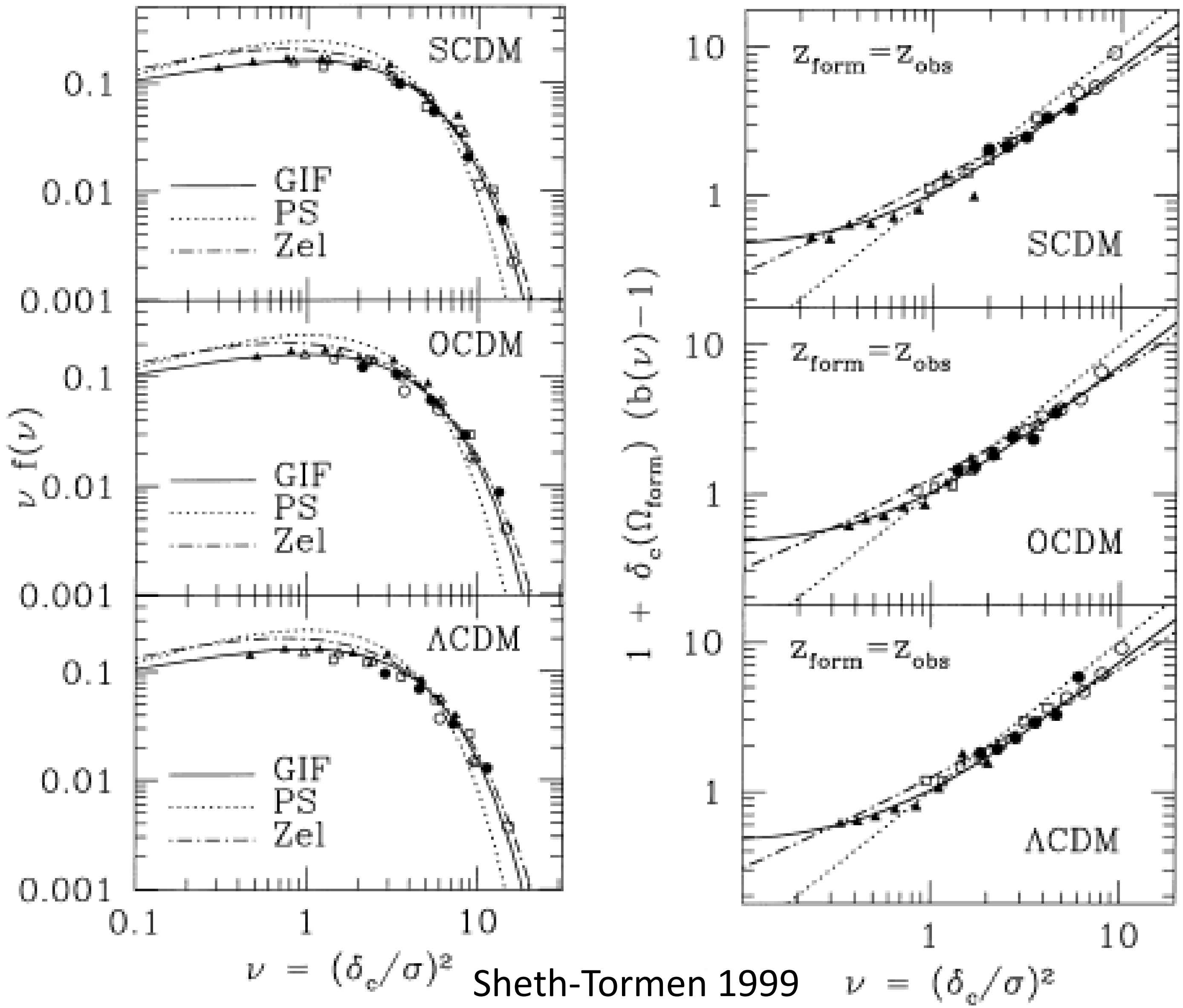
→ massive halos (i.e. larger ν) more clustered:

$$<\delta_h\delta_0> = b_1(\nu)\, <\delta_0^2> + \ldots$$

(Almost) universal mass function and halo bias

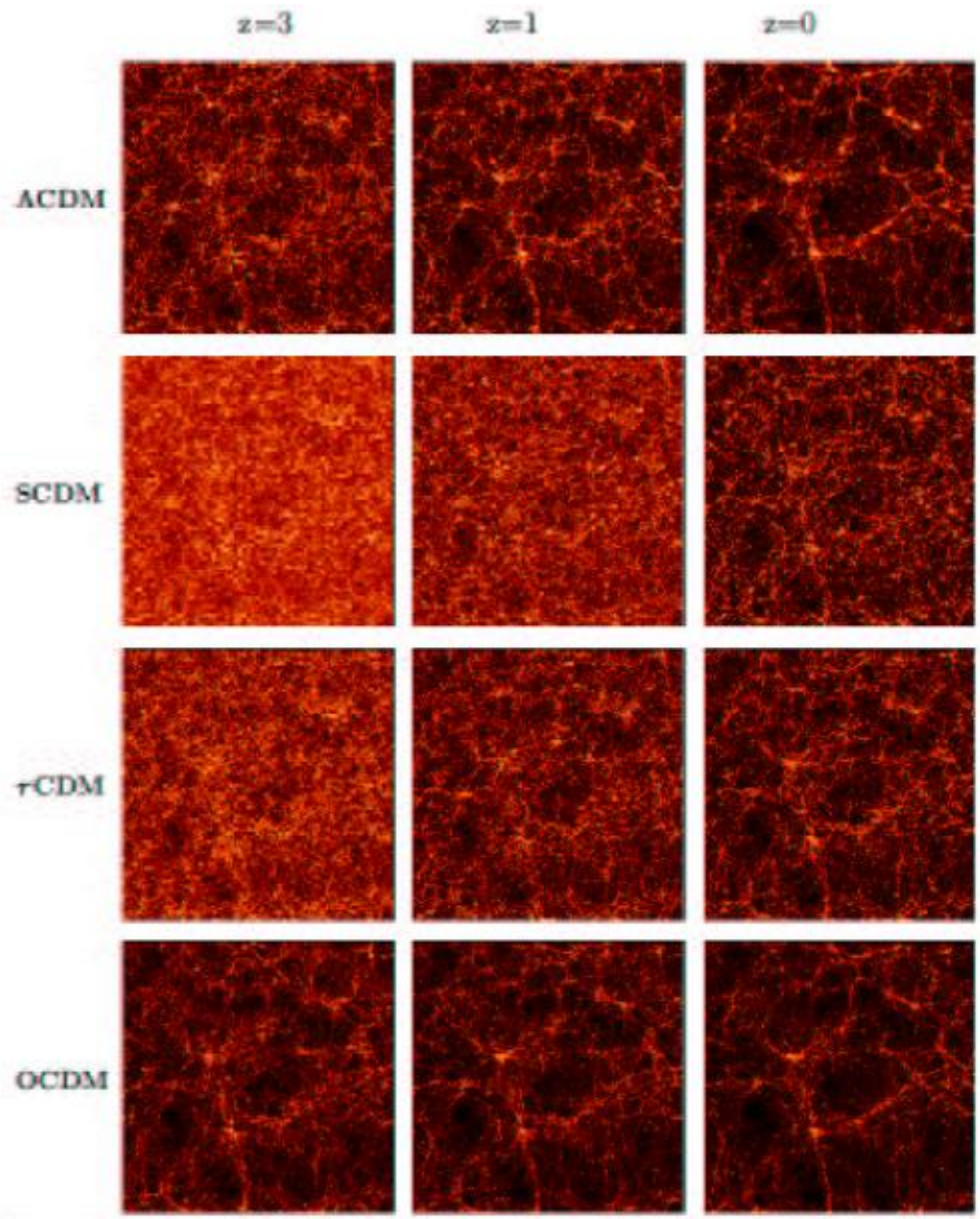
See Paranjape et al (2013) for recent progress in modeling this from first principles

See Castorina et al. (2014) for ν's



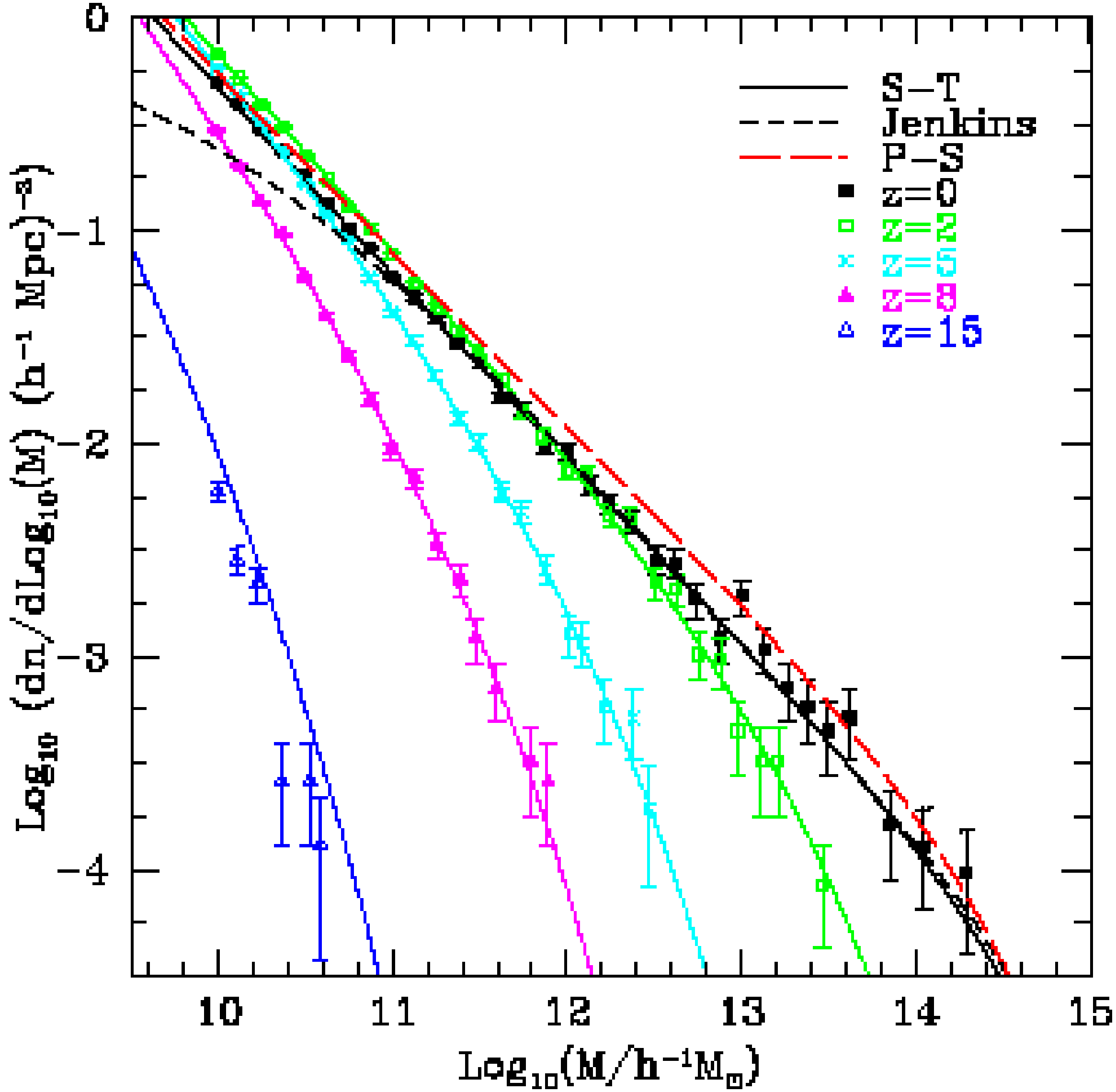
Sheth-Tormen 1999

- Structure at a given time, and, more importantly, growth of structure, provides sharp constraints on models

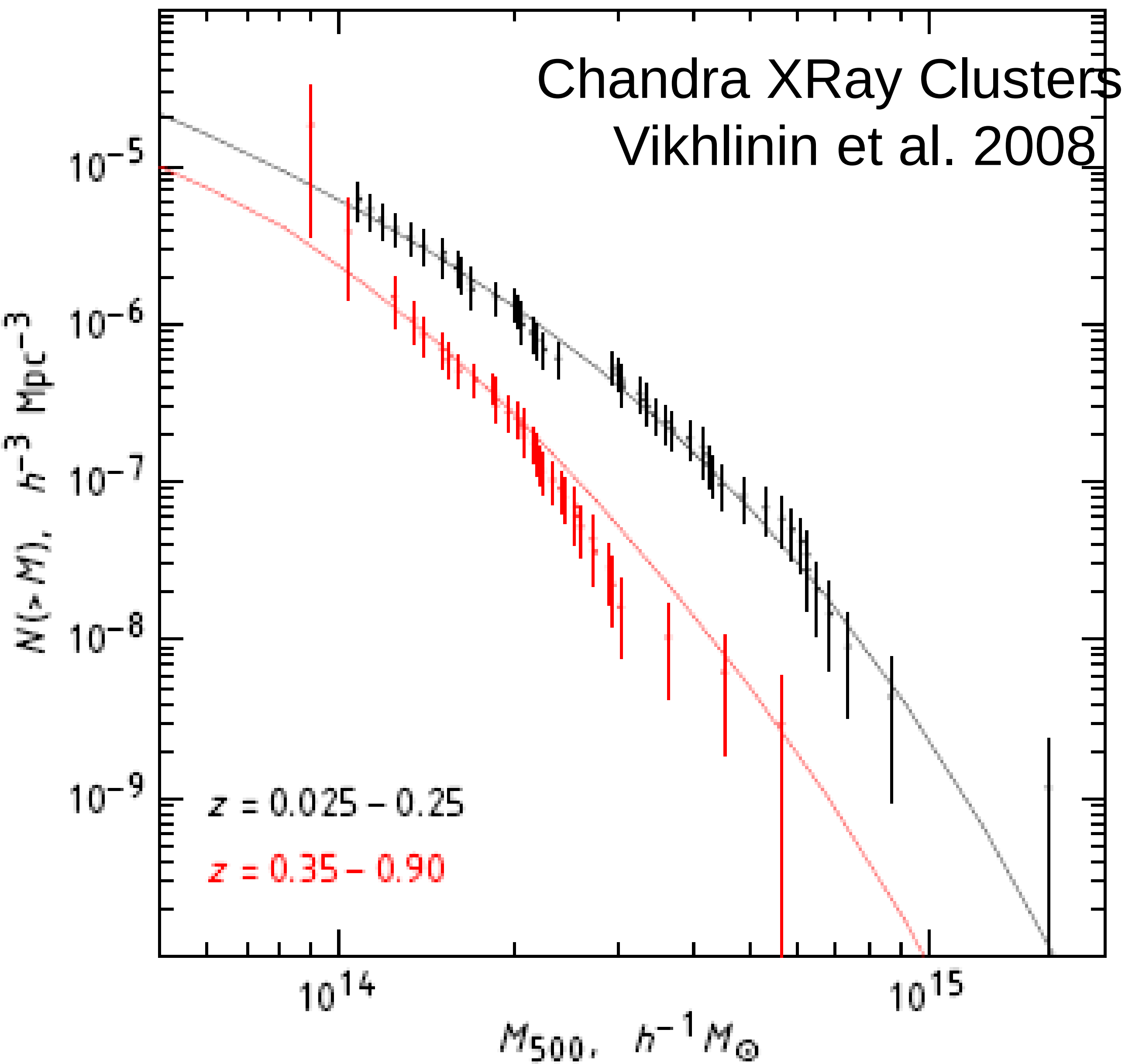


The Halo Mass Function

(Reed et al. 2003)



- Small halos collapse/virialize first
- Can also model halo spatial distribution
- Massive halos more strongly clustered



Chandra XRay Clusters
Vikhlinin et al. 2008
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
$N(>M)$, h^{-3} Mpc^{-3}
$z = 0.025 - 0.25$
$z = 0.35 - 0.90$
10^{14}
10^{15}
M_{500}, $h^{-1} M_{\odot}$

Study of random walks with correlated steps

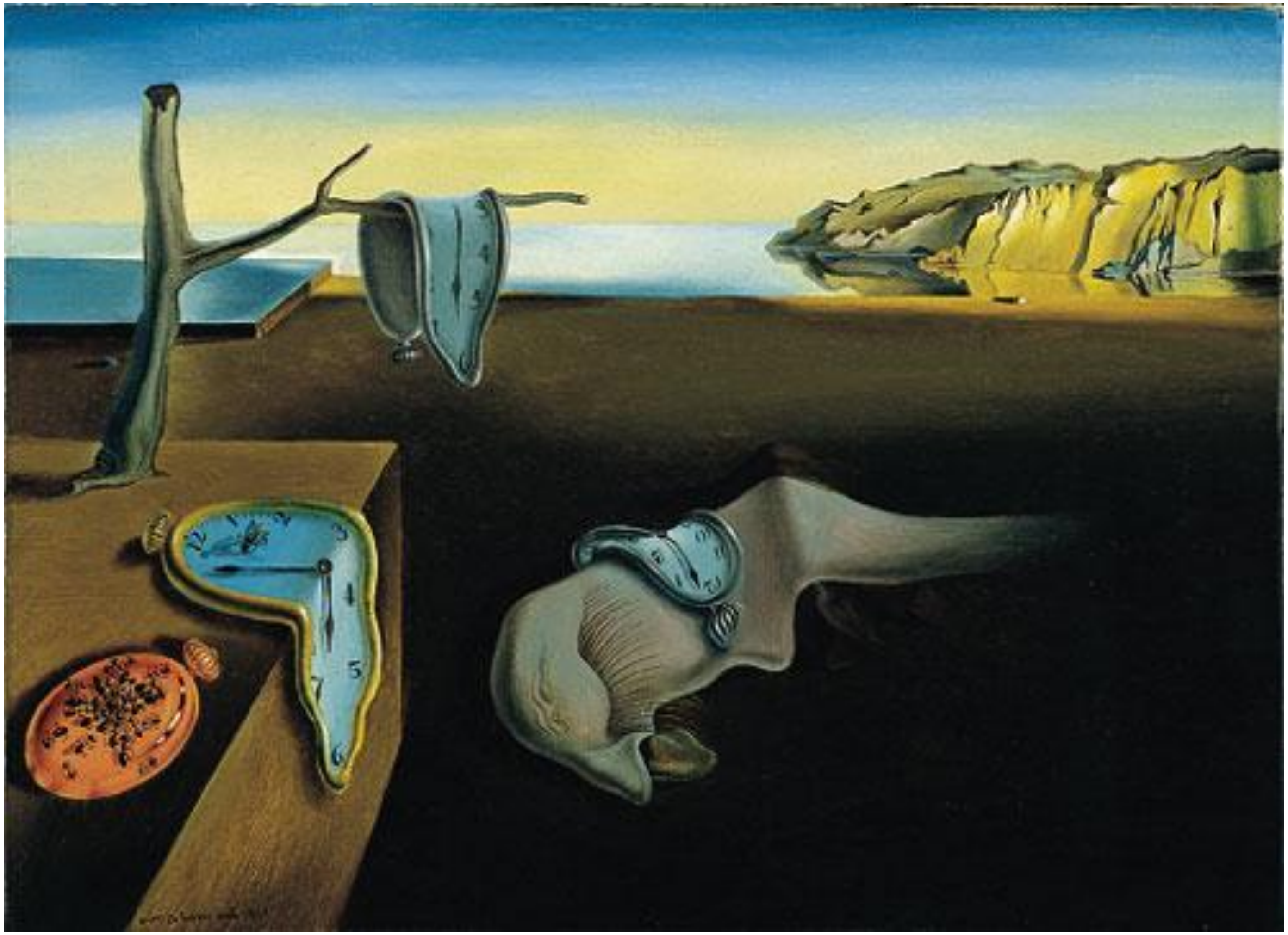
=

Cosmological constraints from large scale structures

Models of halo abundances
and clustering:
Gravity in an expanding universe

Use knowledge of initial conditions
(CMB) to make inferences about
late-time, nonlinear structures

Hierarchical clustering in GR



= the persistence of memory