Is the Near Power-Law Galaxy Correlation Function A Coincidence?

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Collaborators

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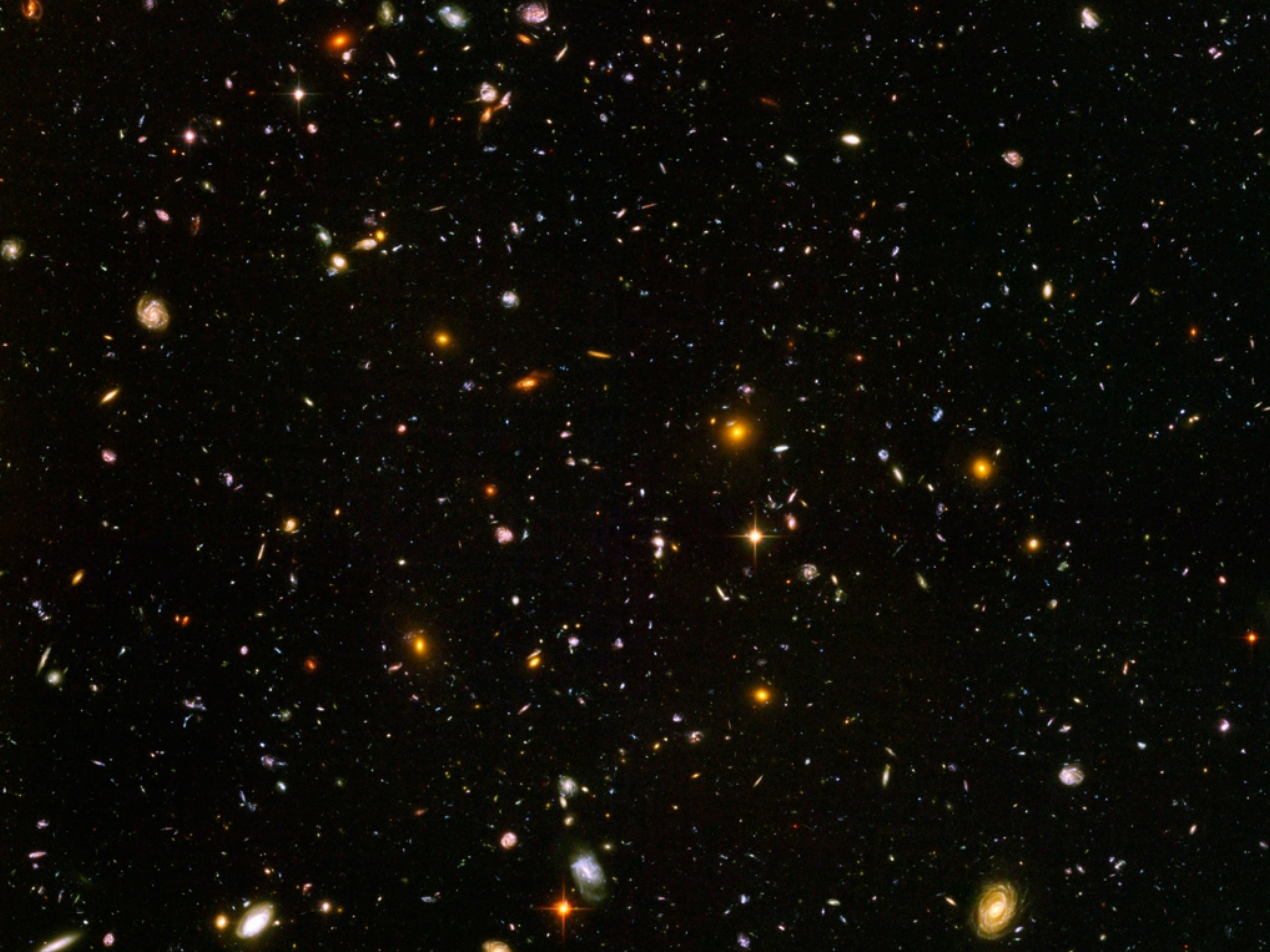
Based on:

Zentner et al. 2005

Watson et al. (in prep., 2010?)

Outline

1. The Galaxy Correlation Function vs. the Matter Correlation Function
2. The Halo Model for Correlation Statistics
3. Mapping Galaxies to Halos
4. The Physical Processes that Drive the low-redshift Galaxy Correlation Function to be a Power Law
5. The Past & Future of the Correlation Function
6. Conclusions



The Correlation Function

- Excess probability of finding a galaxy a distance r, from another:

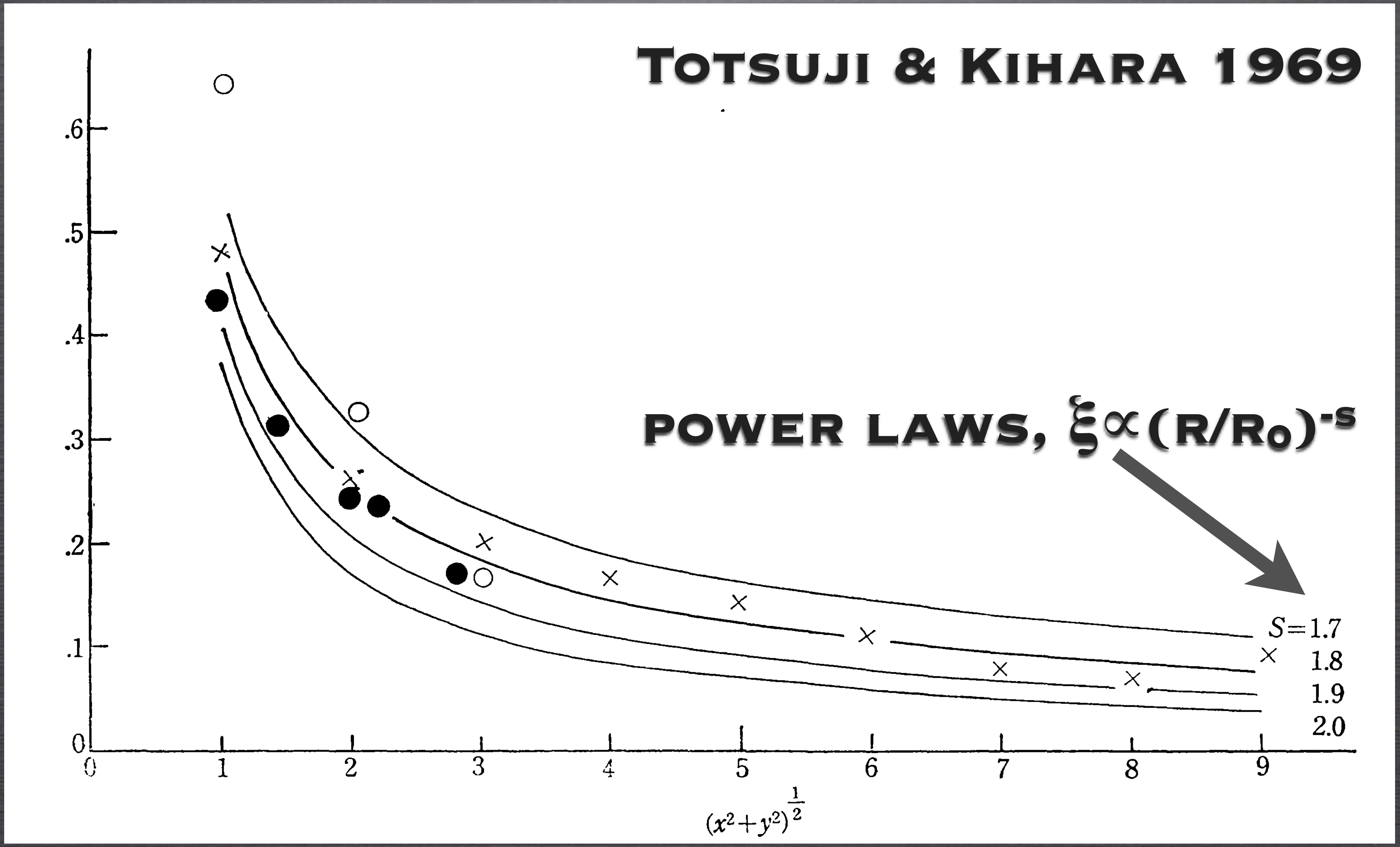
$$\mathrm{d}P = \bar{n}_\mathrm{g}\mathrm{d}V_1 \times \bar{n}_\mathrm{g}[1+\xi(r)]\mathrm{d}V_2$$

- If the local galaxy density is $n_g = \bar{n}_g\,[1+\delta(x)]$, then:

$$\mathrm{d}P = \bar{n}_\mathrm{g}^2 \langle[1+\delta(\vec{x}_1)][1+\delta(\vec{x}_1+\vec{r})]\rangle\,\mathrm{d}V_1\mathrm{d}V_2$$
$$= \bar{n}_\mathrm{g}^2[1+\langle\delta(\vec{x}_1)\delta(\vec{x}_1+\vec{r})\rangle]\mathrm{d}V_1\mathrm{d}V_2$$

- and: $$\xi(r) = \langle\delta(\vec{x}_1)\delta(\vec{x}_1+\vec{r})\rangle$$

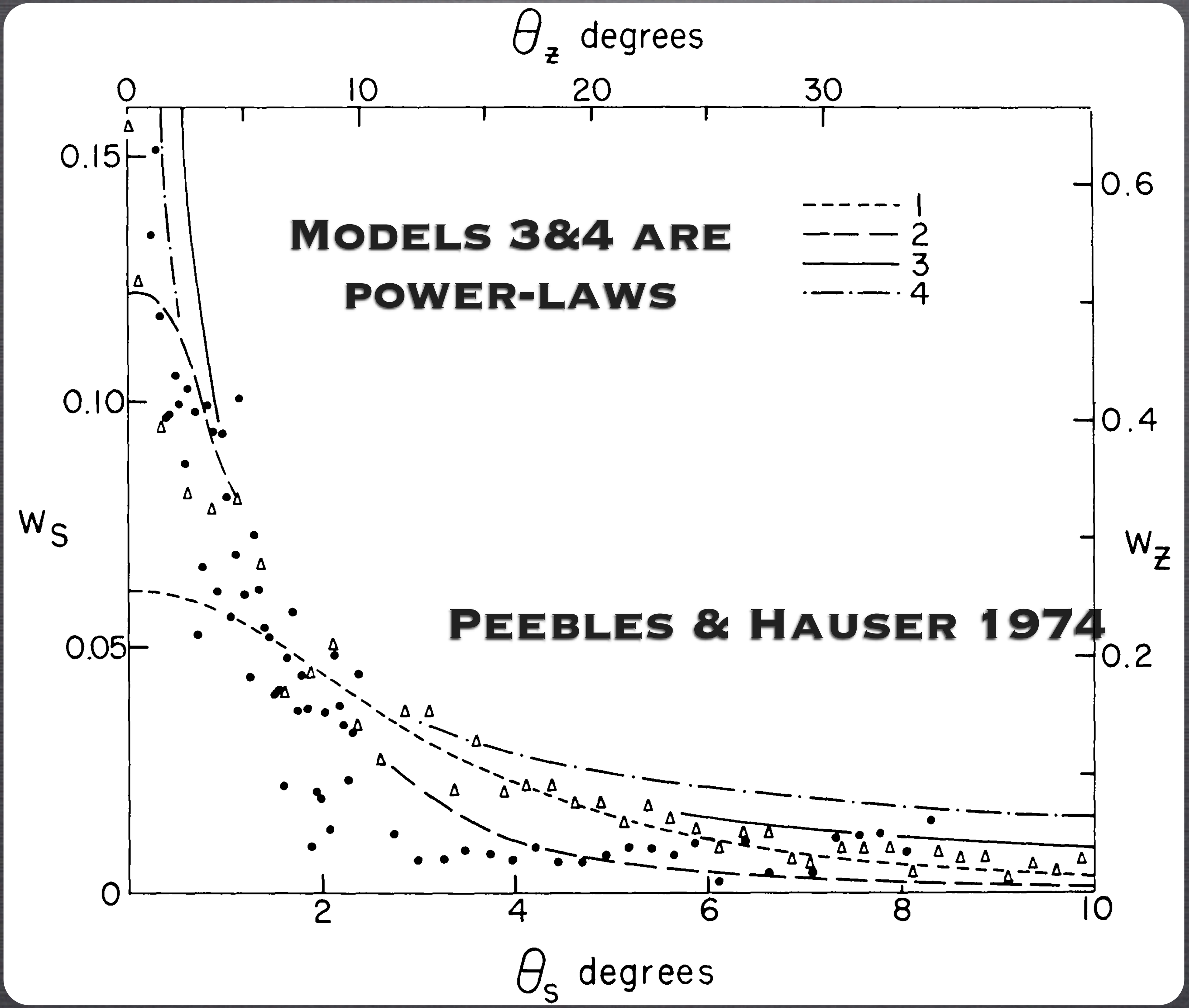
Correlation Function



Correlation function

Angular separation

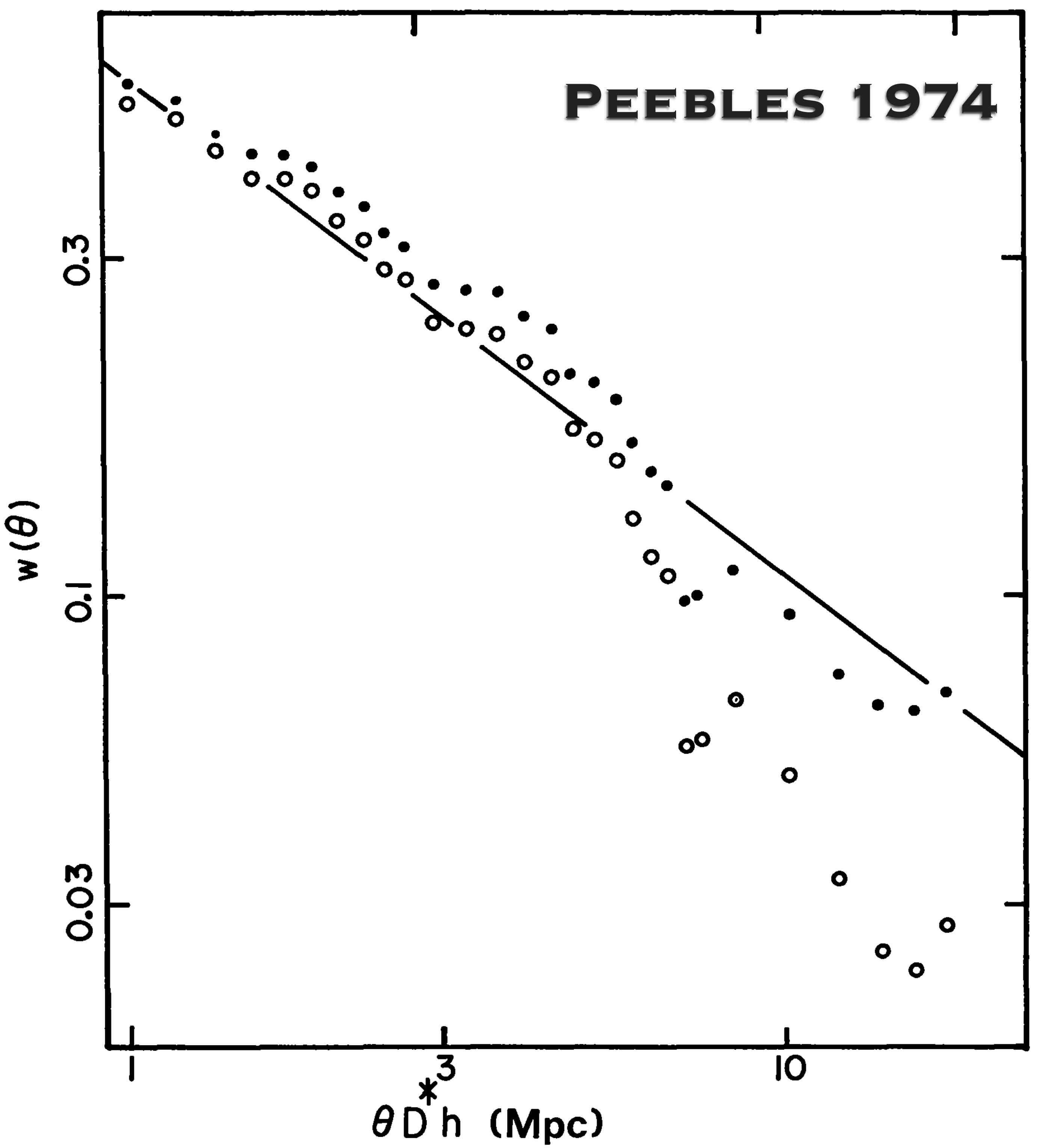
Correlation Function



Correlation function

Angular separation

Correlation Function



Correlation function

Perpendicular separation

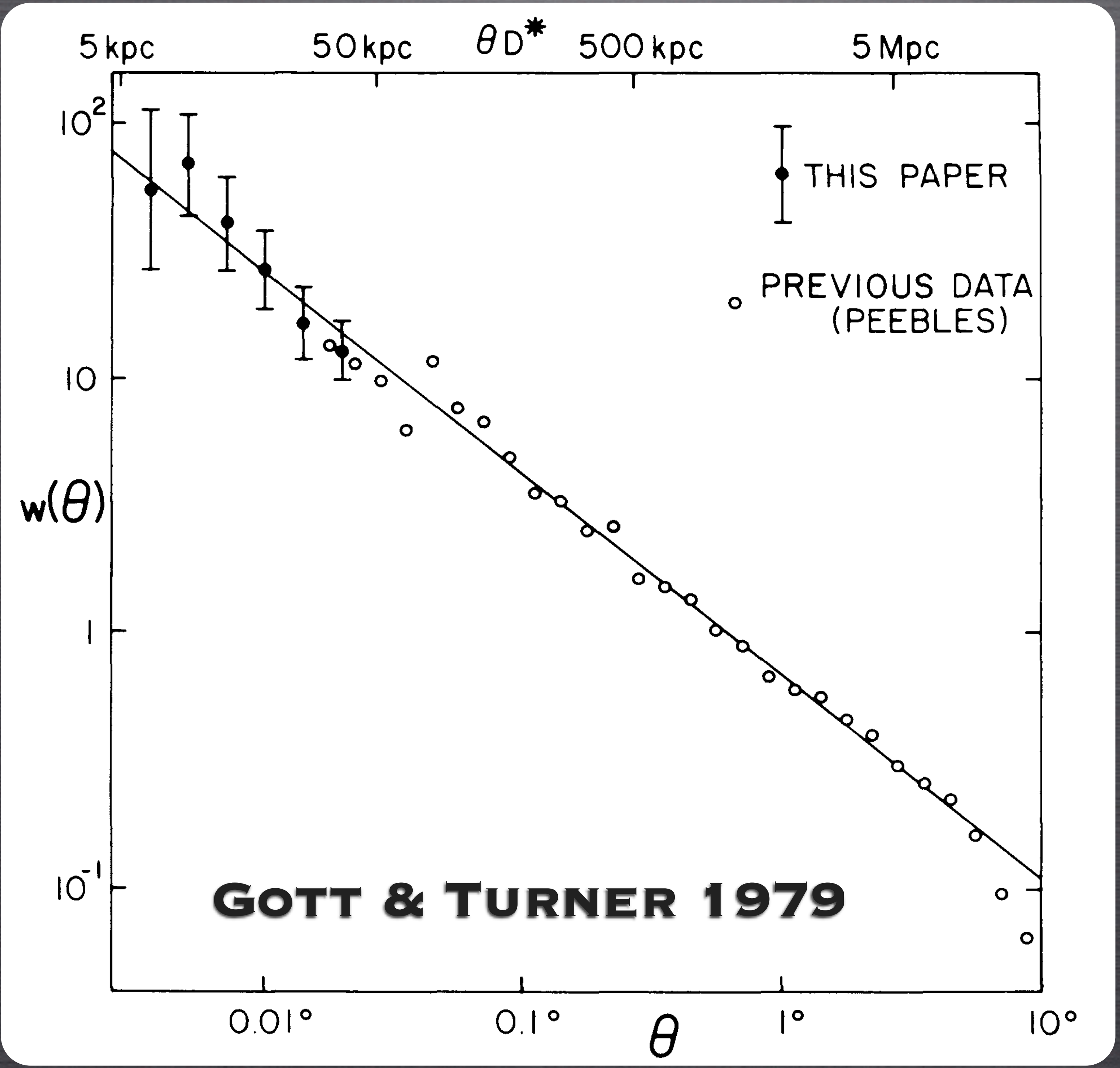
Correlation Function

I conclude from this discussion that the three classes of objects, compact groups, Abell clusters and super-clusters, have appreciable effects on the covariance function for scales $\sim 0.1\,h^{-1}$ Mpc, $1\,h^{-1}$ Mpc, and $10\,h^{-1}$ Mpc respectively. The interesting and surprising thing is that the contributions were such as to leave no clear features in the covariance function.

Correlation Function

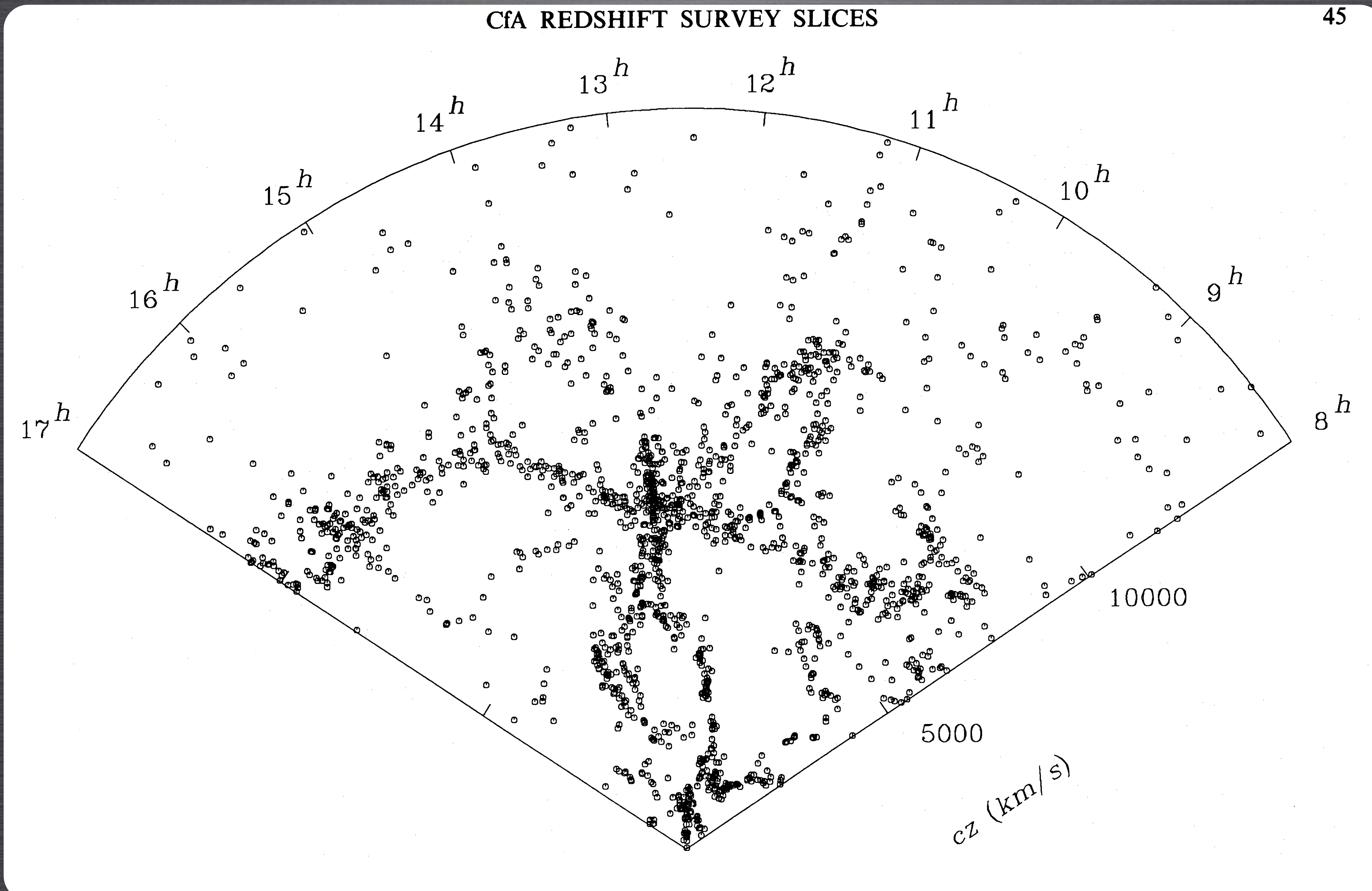
Projected Separation

Correlation function



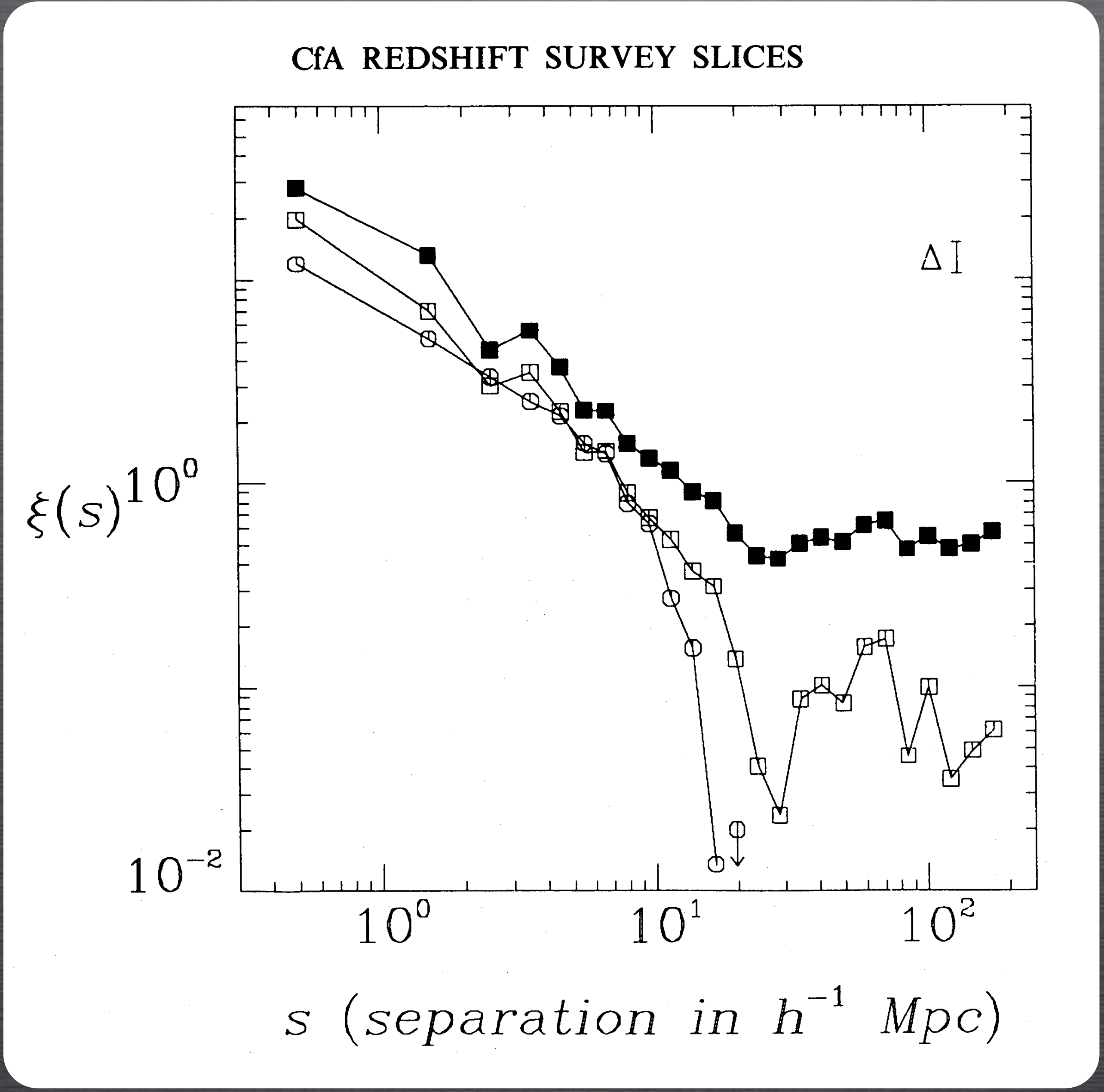
Angular separation

Correlation Function



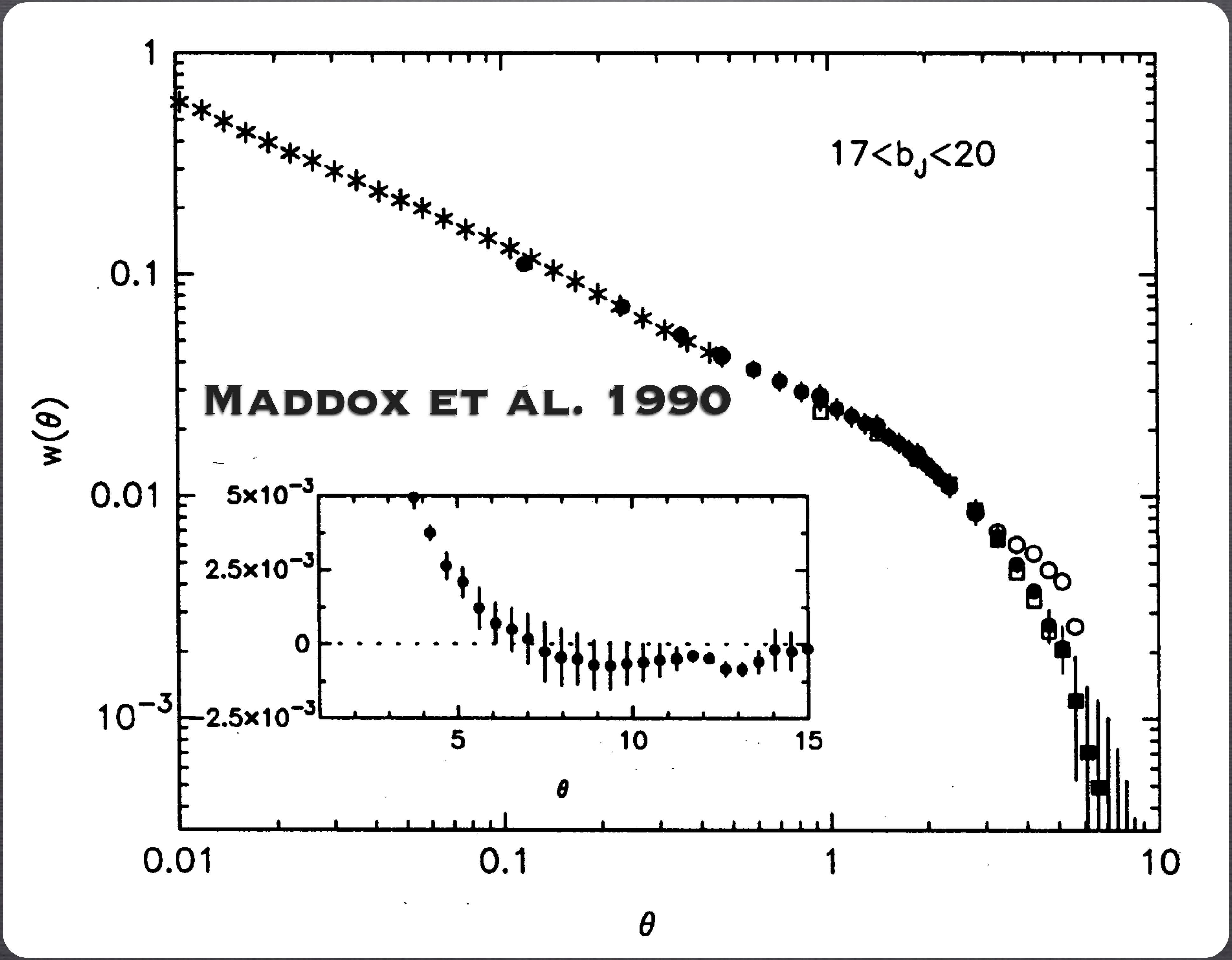
de Lapparent et al. 1987

Correlation Function



de Lapparent et al. 1987

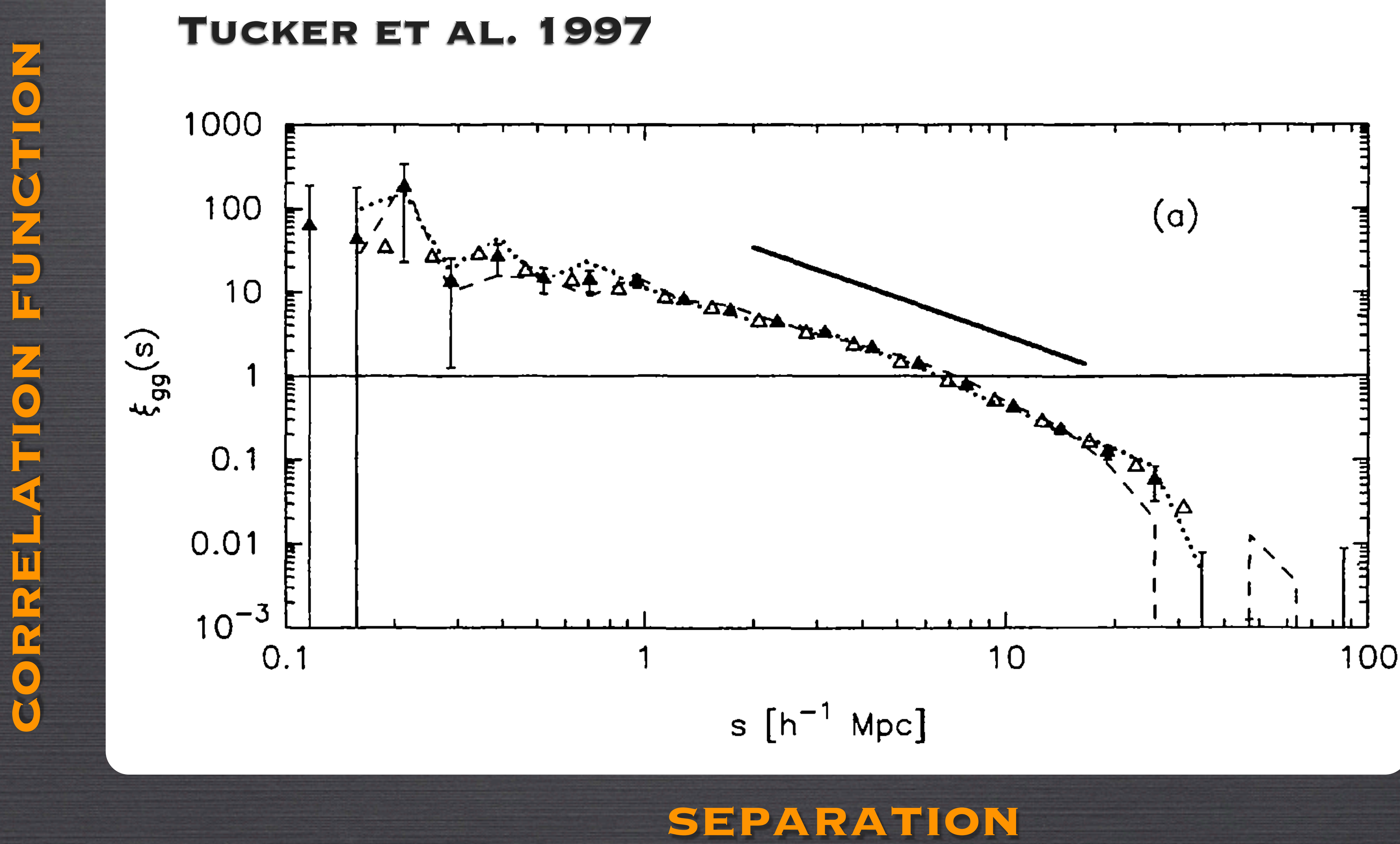
Correlation Function



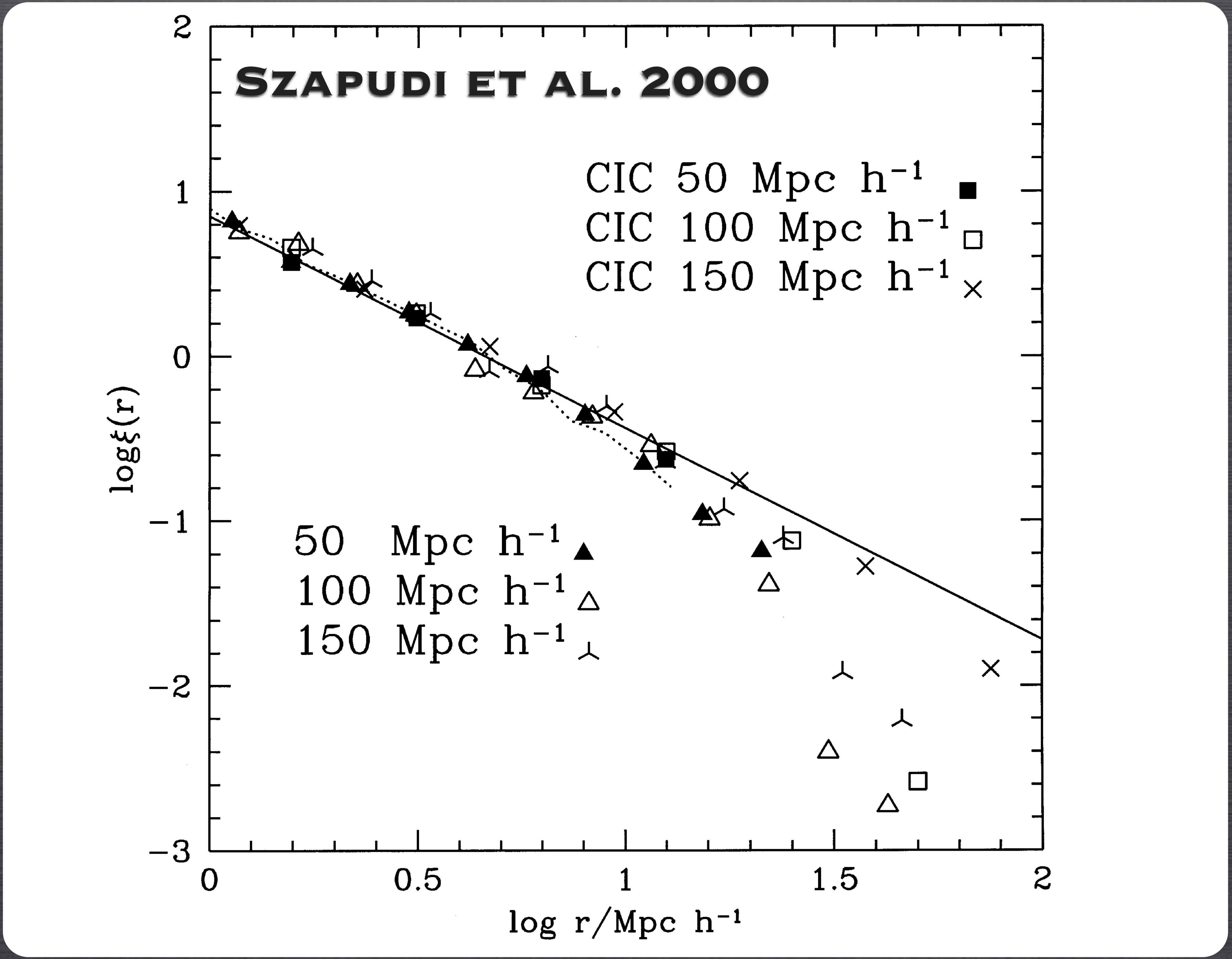
Correlation function

Angular separation

Correlation Function



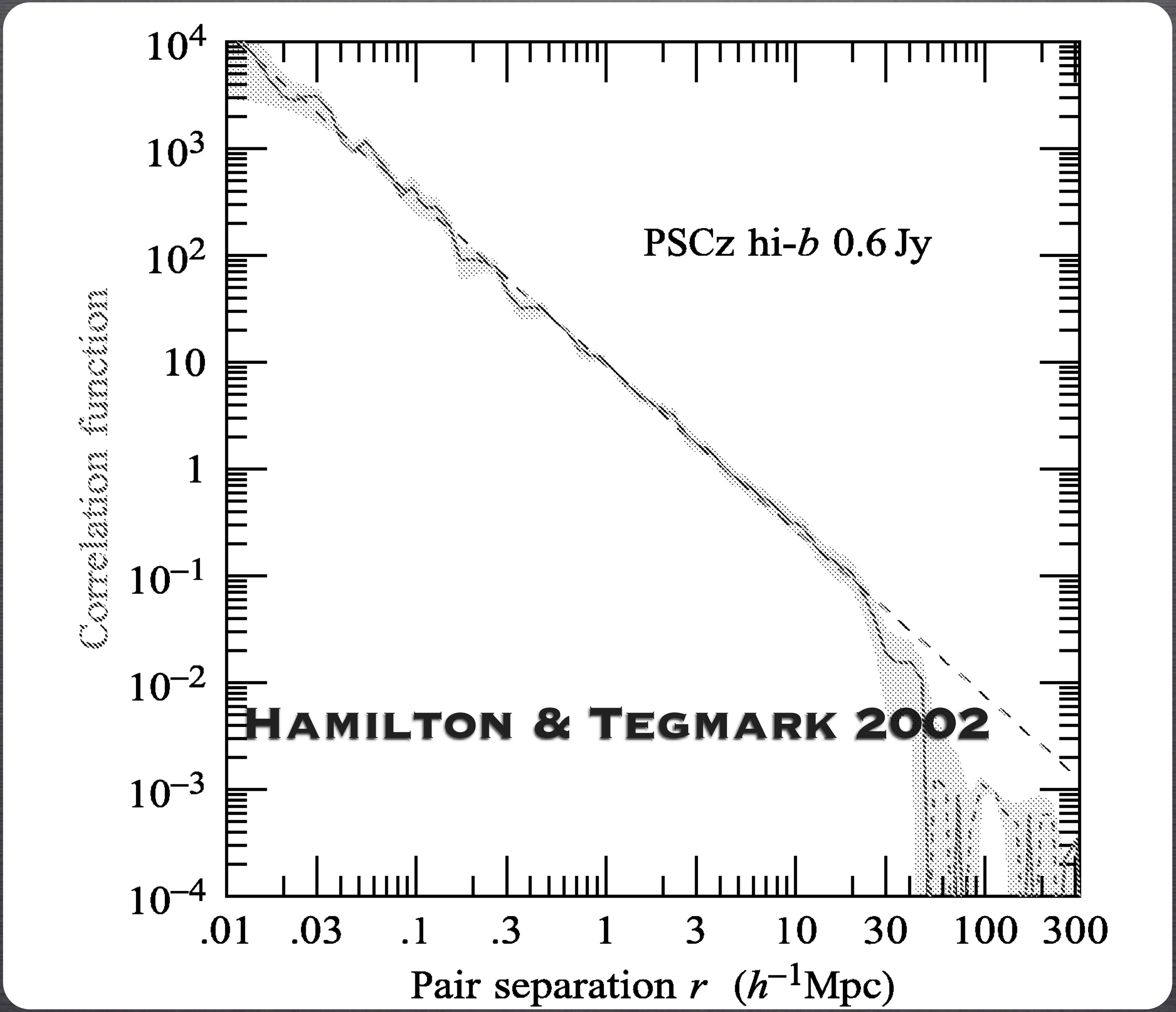
Correlation Function



CORRELATION FUNCTION

SEPARATION

Correlation Function

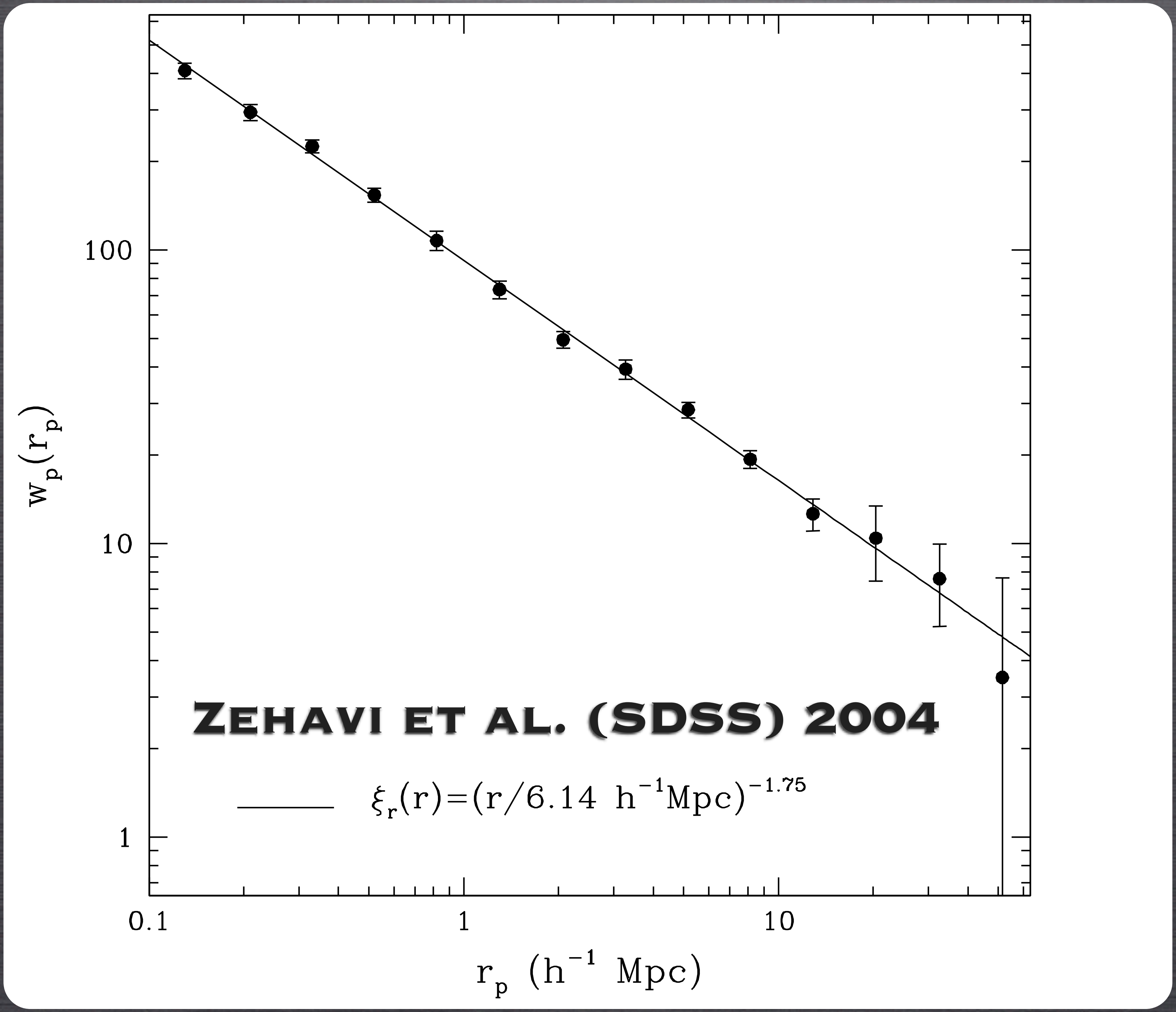


Correlation function

separation

Correlation Function

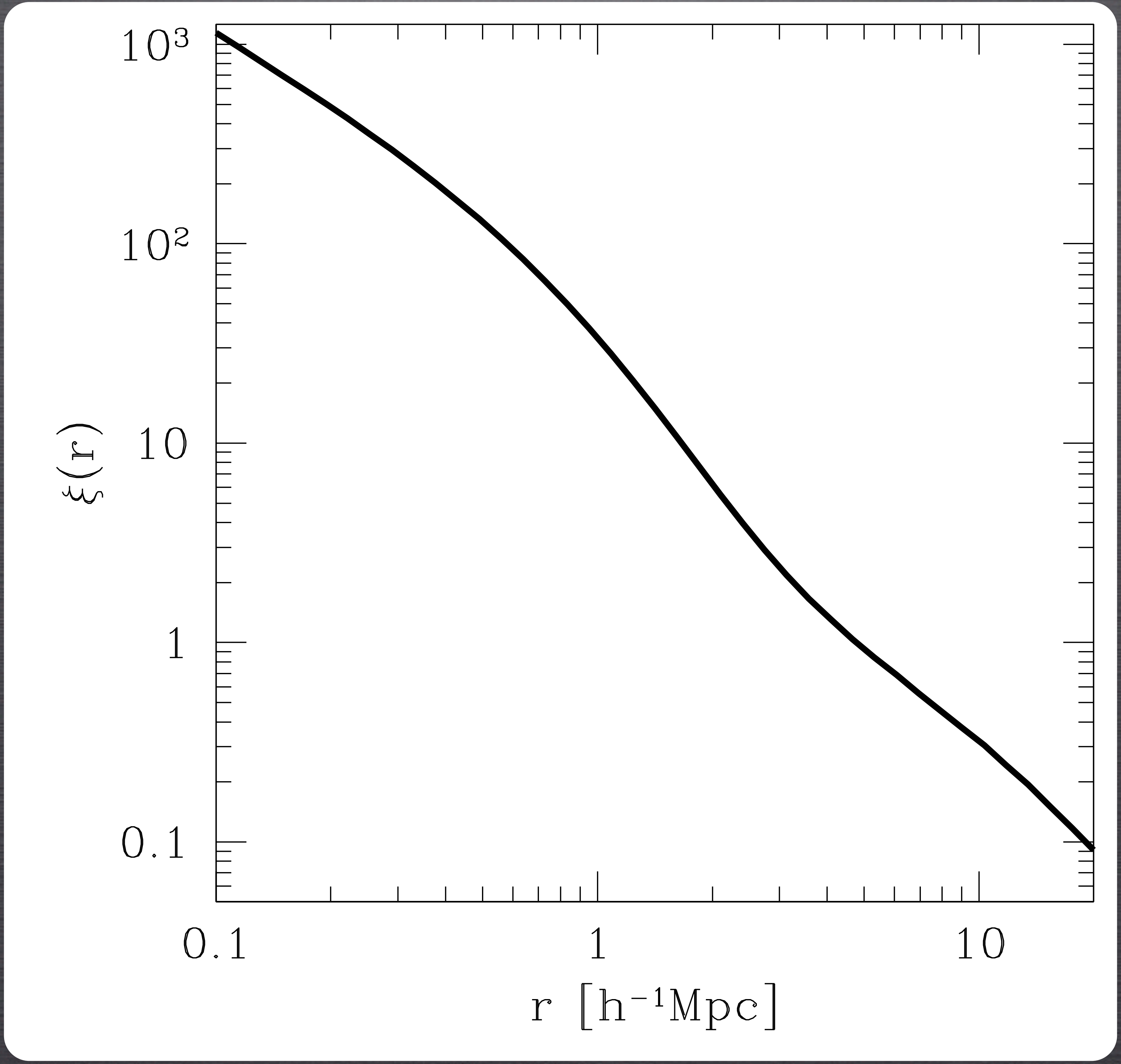
Correlation function



Projected separation

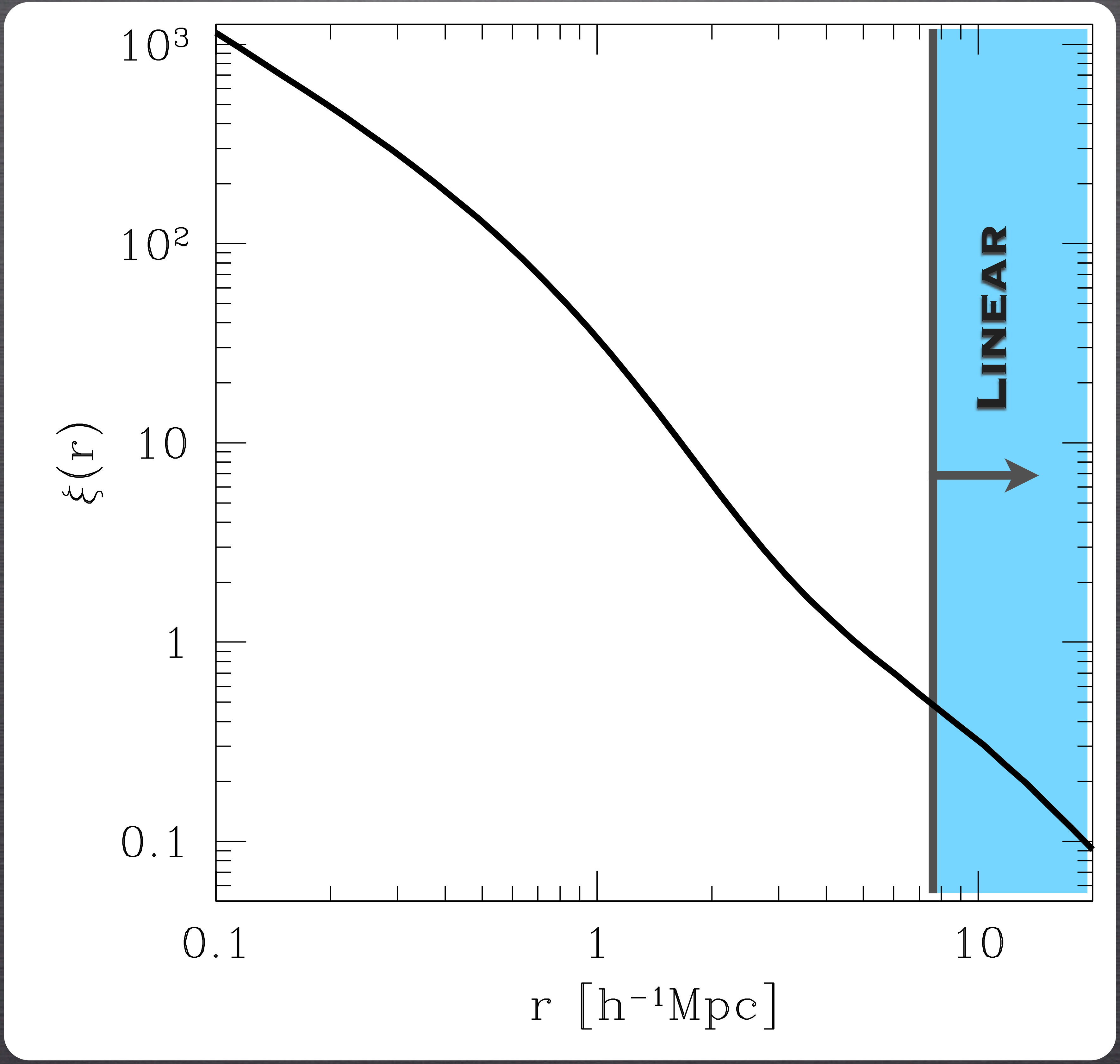
Matter Correlation

Matter Correlation Function

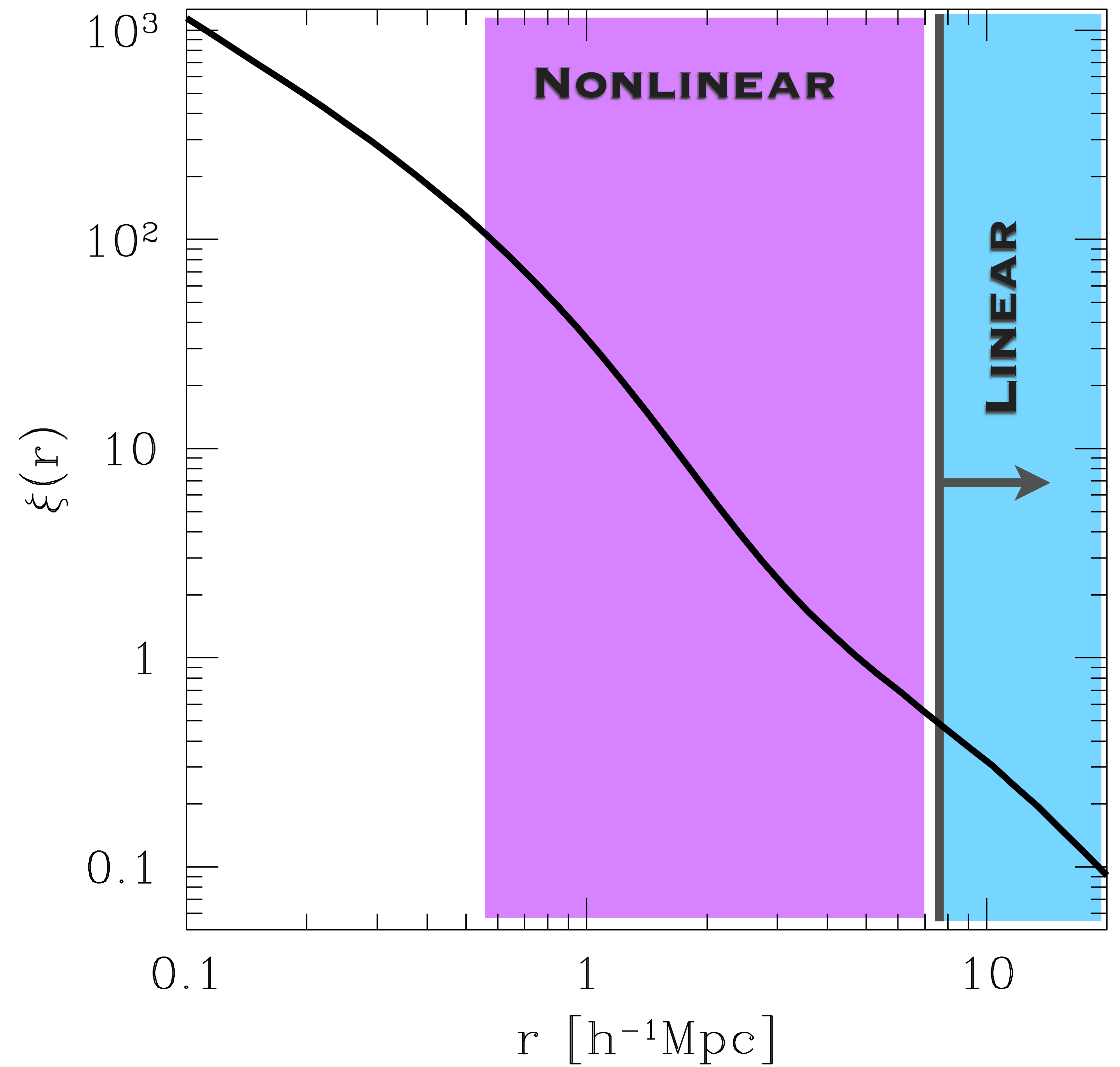


Matter Correlation

Matter Correlation Function



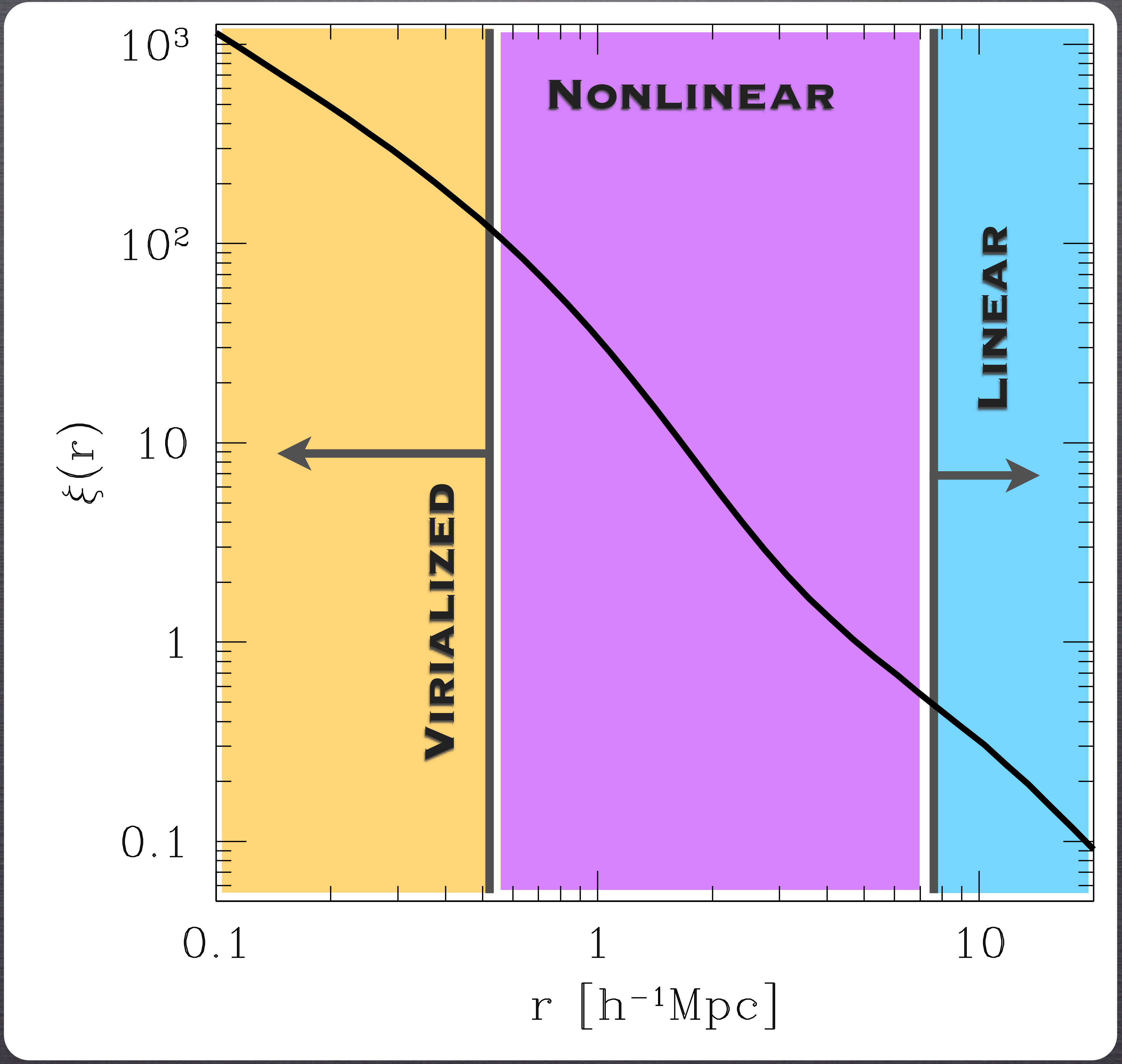
Matter Correlation



Matter Correlation Function

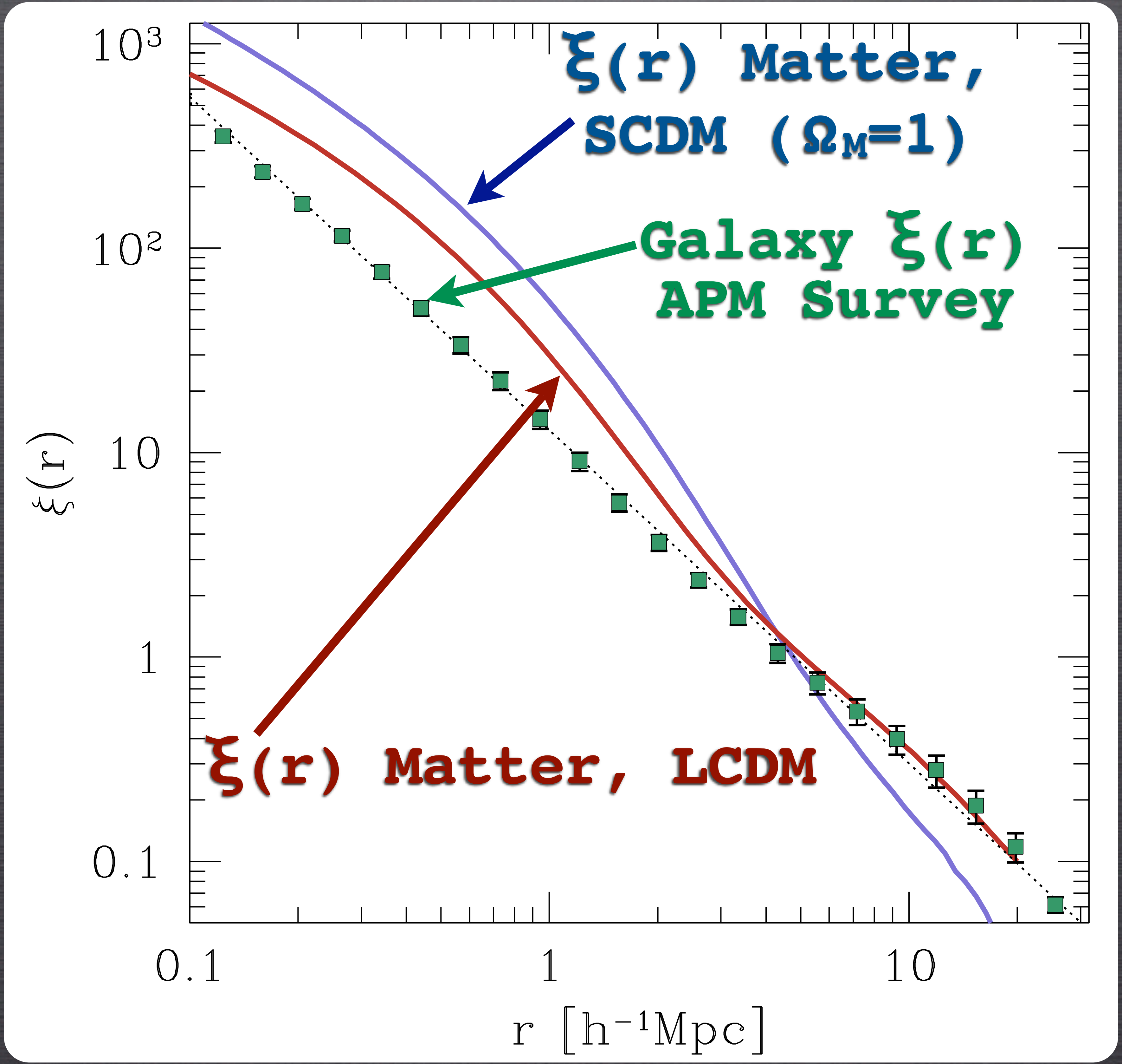
Matter Correlation

Matter Correlation Function

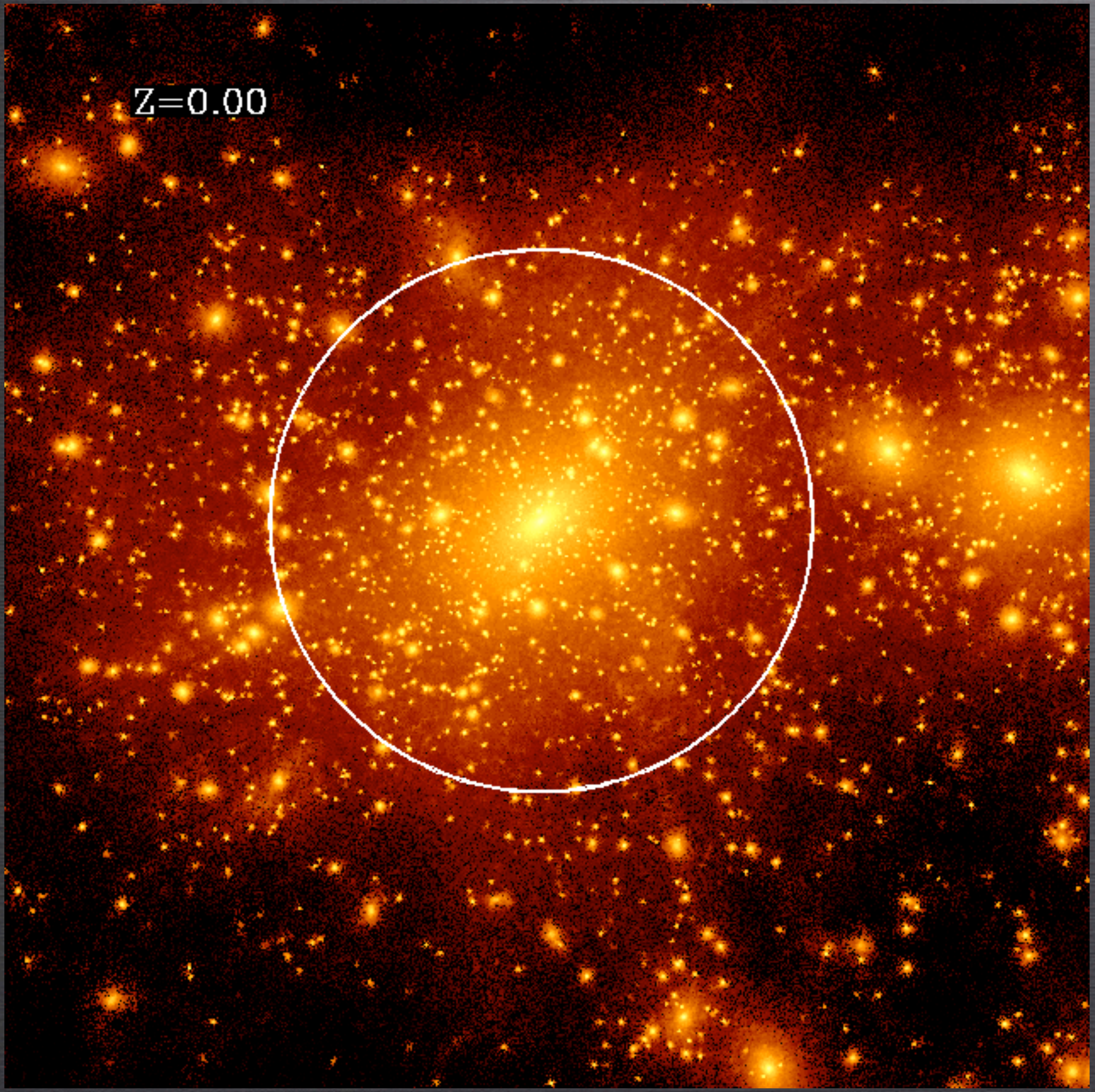


Matter Correlation

Correlation Functions



Dark Matter Halos

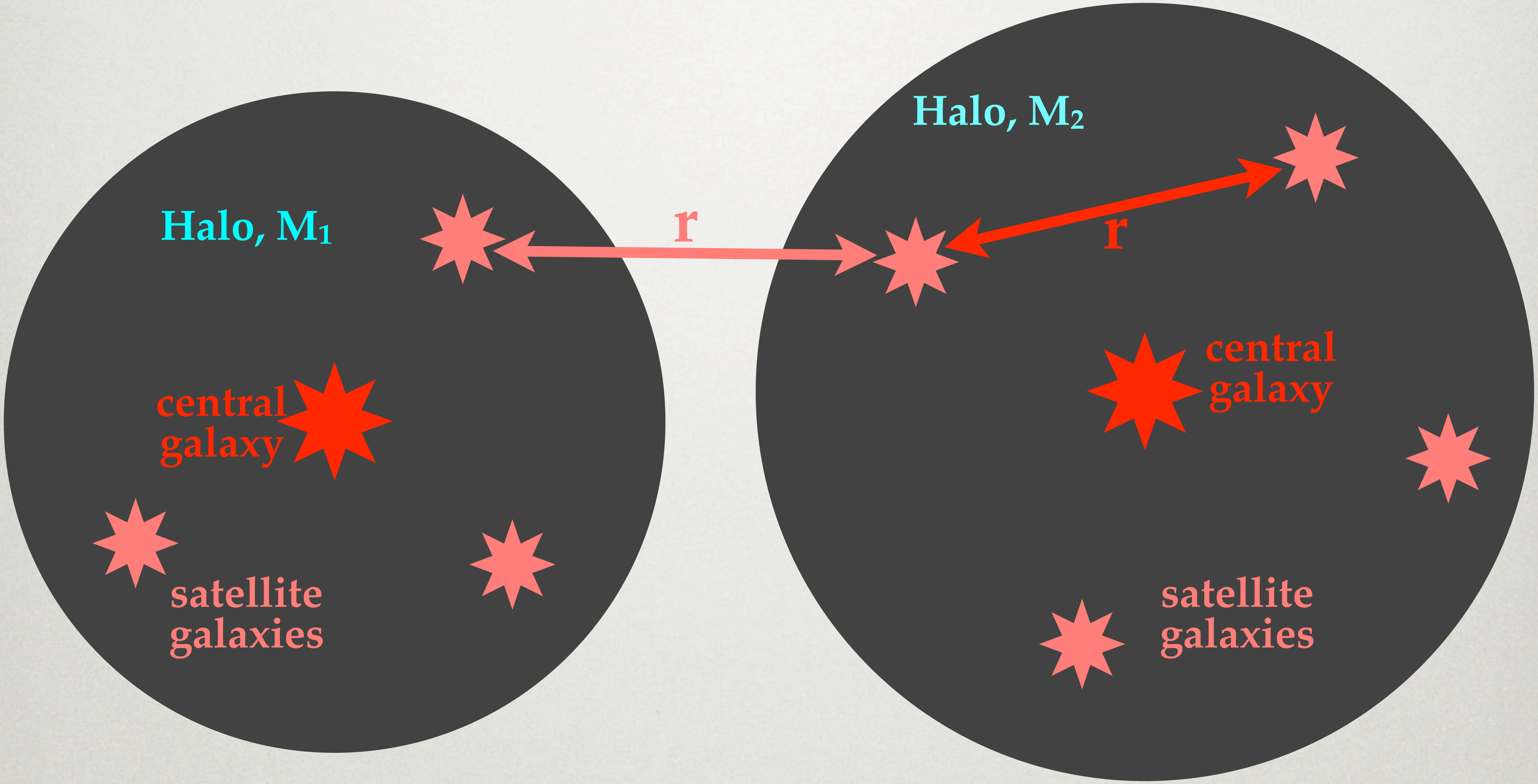


- Halos are "building blocks" of Nonlinear structure

- Virialized regions have typical average densities $\rho_{vir} \sim 10^2 \langle \rho \rangle = \Omega_m \rho_{crit}$

- Halo abundances and clustering are well understood in simulations

The Halo Model



- Compute correlation statistics using halos as the fundamental unit of structure: $\xi(r)=\xi^{1H}(r)+\xi^{2H}(r)$

The Halo Model

$$\xi(r) = \xi^{1\mathrm{h}}(r) + \xi^{2\mathrm{h}}(r)$$

- **Count pairs in individual halos...**

$$\xi^{1\mathrm{h}}(r) = \frac{1}{\bar{n}_g^2} \int \langle N_{\mathrm{gal}}(N_{\mathrm{gal}} - 1)\rangle \; \Lambda(r, M) \; \frac{\mathrm{d}n}{\mathrm{d}M} \mathrm{d}M$$

- **Λ(r,M) is the convolution of a halo profile with itself, and $\Lambda \propto R_{vir}^{-3} \propto M^{-1}$ at $r/R_{vir} \ll 1$**

The Halo Model

$$\xi(r) = \xi^{1\mathrm{h}}(r) + \xi^{2\mathrm{h}}(r)$$

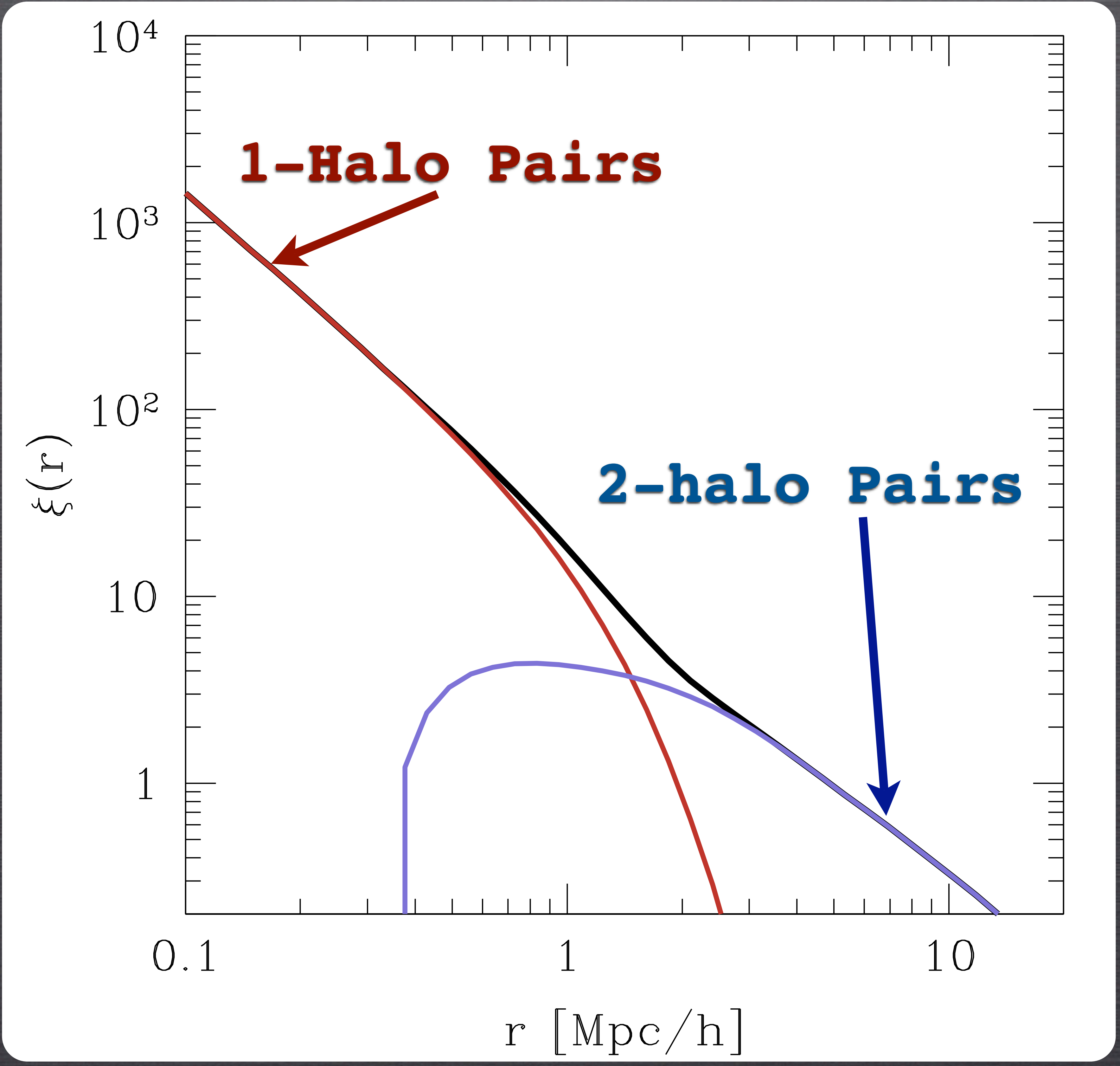
- **On large scales, pair counts reflect the galaxy number-weighted halo pair count**

$$\xi^{2\mathrm{h}}(r) = \frac{\xi_{\mathrm{mm}}(r)}{\bar{n}_{\mathrm{g}}^2} \left[\int b_{\mathrm{h}}(M) \left\langle N_{\mathrm{gal}} \right\rangle \frac{\mathrm{d}n}{\mathrm{d}M} \mathrm{d}M \right]^2$$

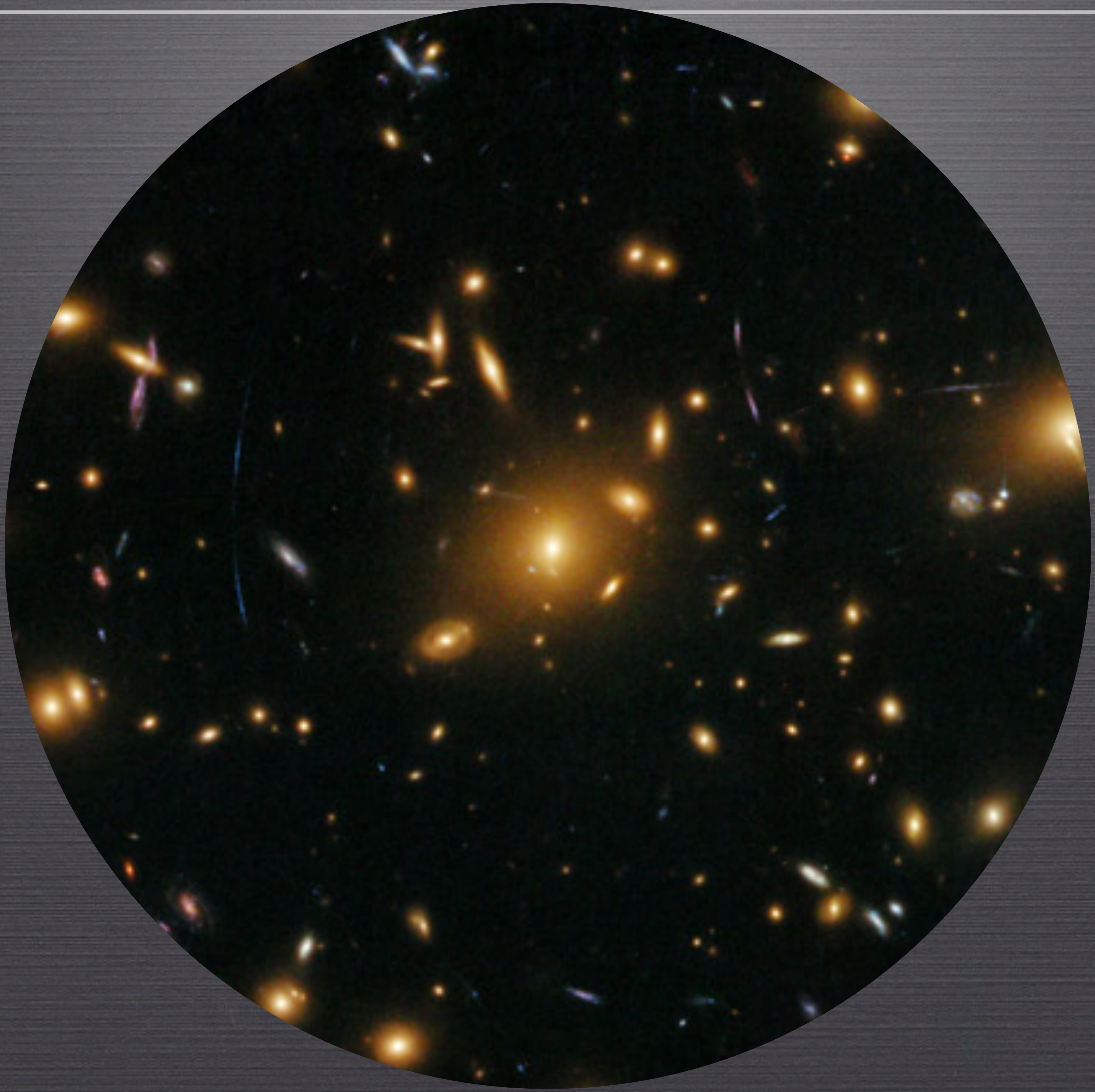
- **b_h(M) is the "halo bias" and $\langle N_{gal}$(M)$\rangle$ is the average number of galaxies in halo of mass M**

Restatement

Correlation Functions



Central & Satellites



Central & Satellites

- Halos with masses above some minimum mass M_{min} contain $N_{gal} = 1 + N_s$ galaxies with N_s a Poisson-distributed random variable...

$$\xi^{1h}(r) = \frac{1}{\bar{n}_{\rm g}^2} \int_{M_{\rm min}} \left[\langle N_s \rangle^2 + 2 \langle N_s \rangle \right] \Lambda(M) \frac{{\rm d}n}{{\rm d}M} {\rm d}M$$

$$\xi^{2h}(r) = \frac{\xi_{\rm mm}(r)}{\bar{n}_g^2} \left[\int_{M_{\rm min}} b_{\rm h}(M) \left[1 + \langle N_s \rangle \right] \frac{{\rm d}n}{{\rm d}M} {\rm d}M \right]^2$$

Toy Model: One Mass

- Consider a Universe where galaxies are in halos of only one mass, $dn/dM \rightarrow N_H \delta(M-M_H)$

$$\bar{n}_{\rm g} = (1 + \langle N_s \rangle) N_H$$: galaxy density

$$\xi^{\rm 2h} = b_{\rm h}^2 \xi_{\rm mm}$$: average halo bias

$$\xi^{\rm 1h} = \frac{\left[\langle N_s \rangle^2 + 2 \langle N_s \rangle\right]}{\left[1 + \langle N_s \rangle\right]^2} \frac{\Lambda}{N_H}$$

Toy Model: One Mass

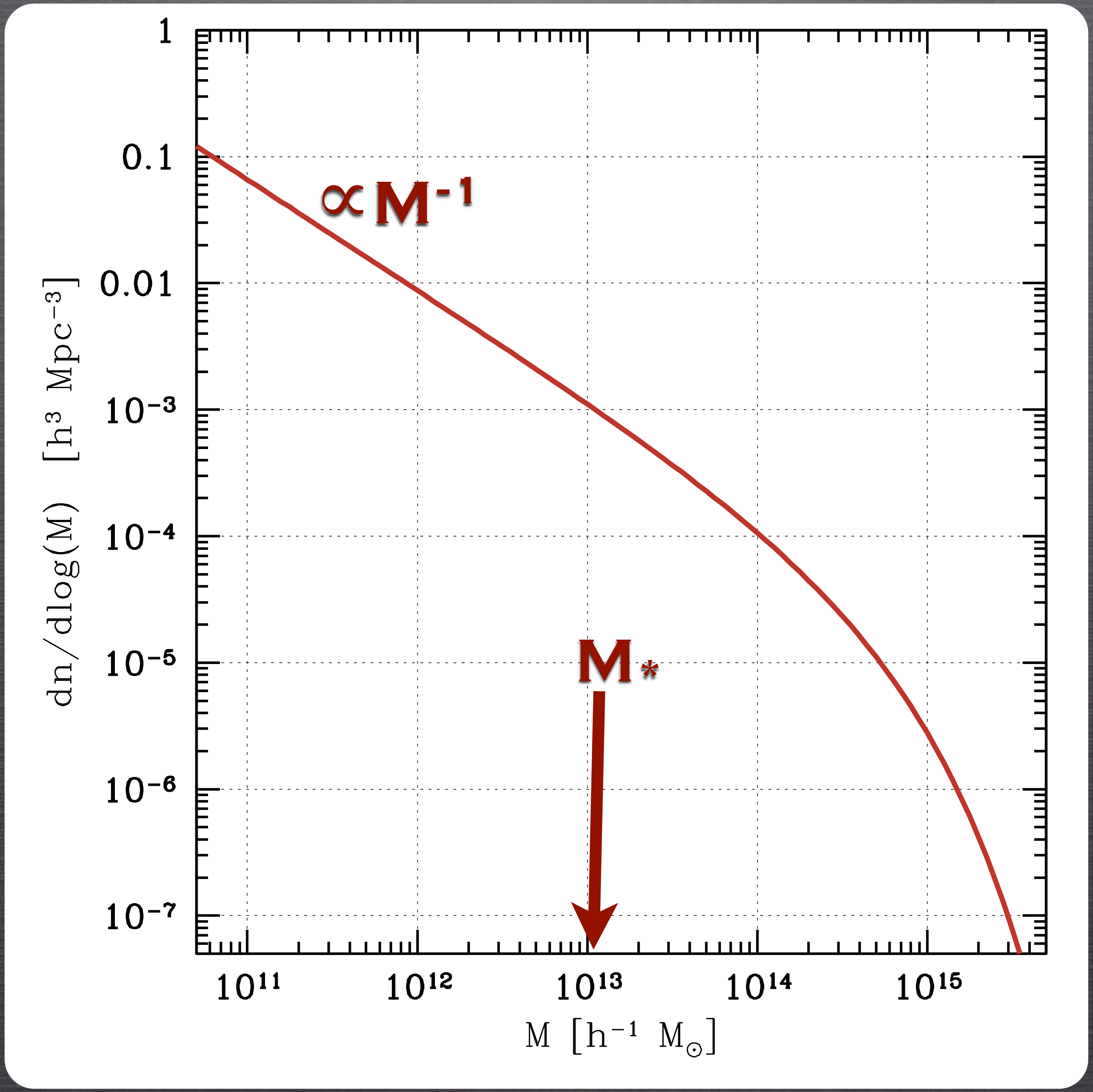
- If the satellite number is large

$$\xi^{1h} \xrightarrow{\langle N_s \rangle \gg 1} \frac{\Lambda}{N_H}$$

- If the satellite number is small

$$\xi^{1h} \xrightarrow{\langle N_s \rangle \ll 1} 2 \langle N_s \rangle \frac{\Lambda}{N_H}$$

Mass Function



Toy Model: One Mass

- If the satellite number is large (M<M*),

$$\xi^{1h} \xrightarrow{\langle N_s \rangle \gg 1} \frac{\Lambda}{N_H}$$

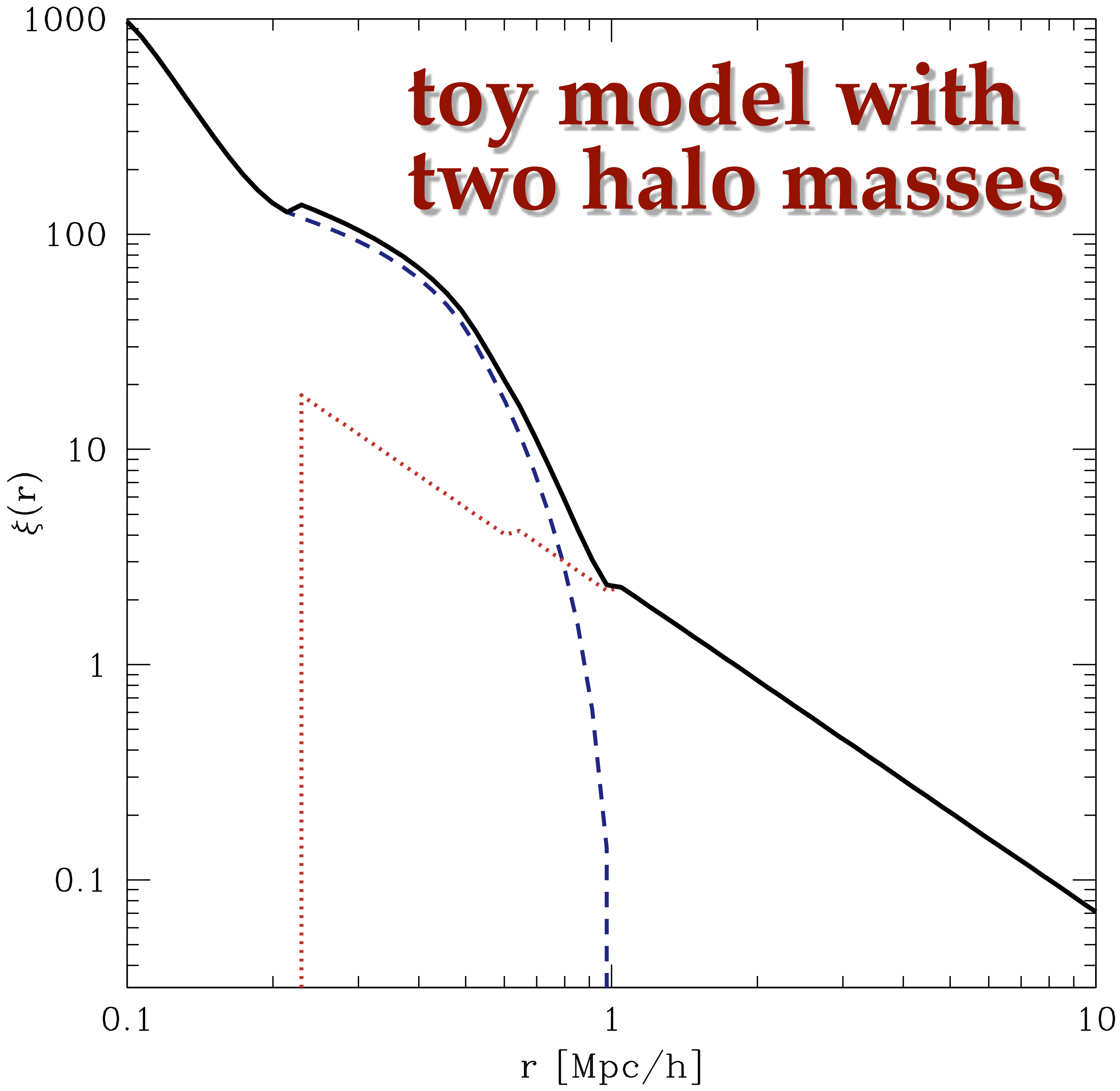
: mass independent number at $r \ll R_{vir}$

- If the satellite number is small and M<M*

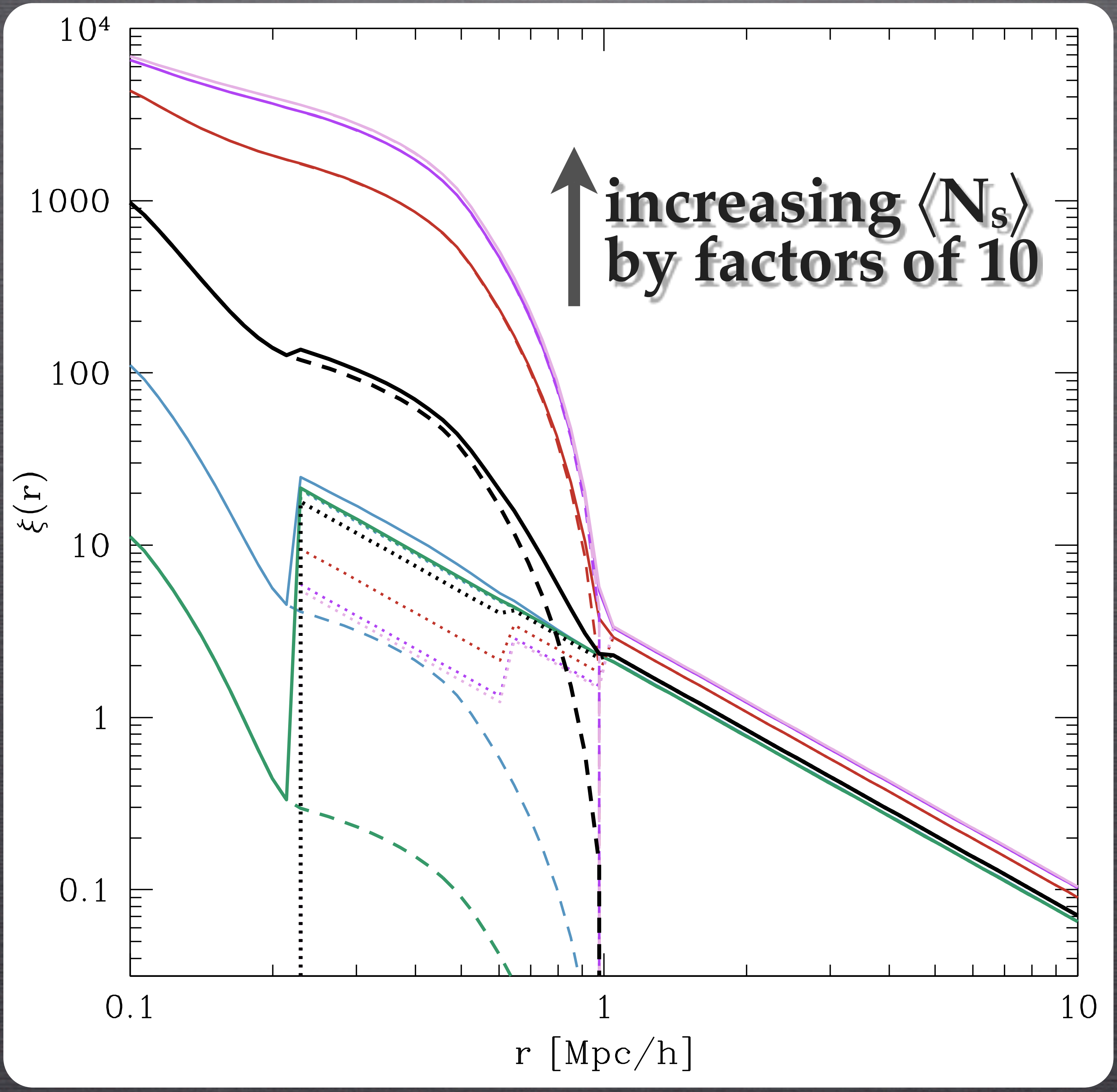
$$\xi^{1h} \xrightarrow{\langle N_s \rangle \ll 1} 2 \langle N_s \rangle \frac{\Lambda}{N_H}$$

$\propto \langle N_s \rangle$

Toy Model

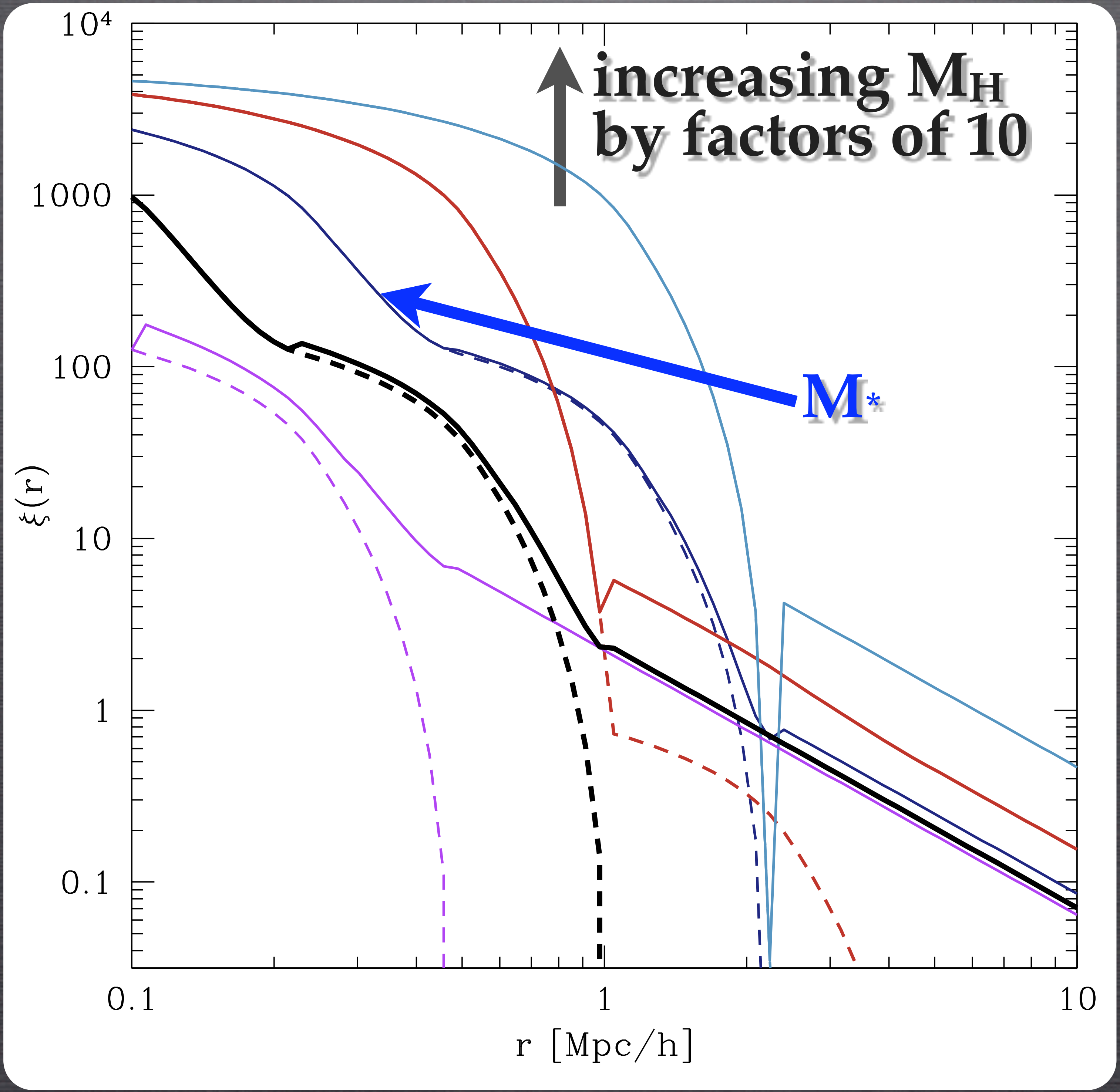


Toy Model



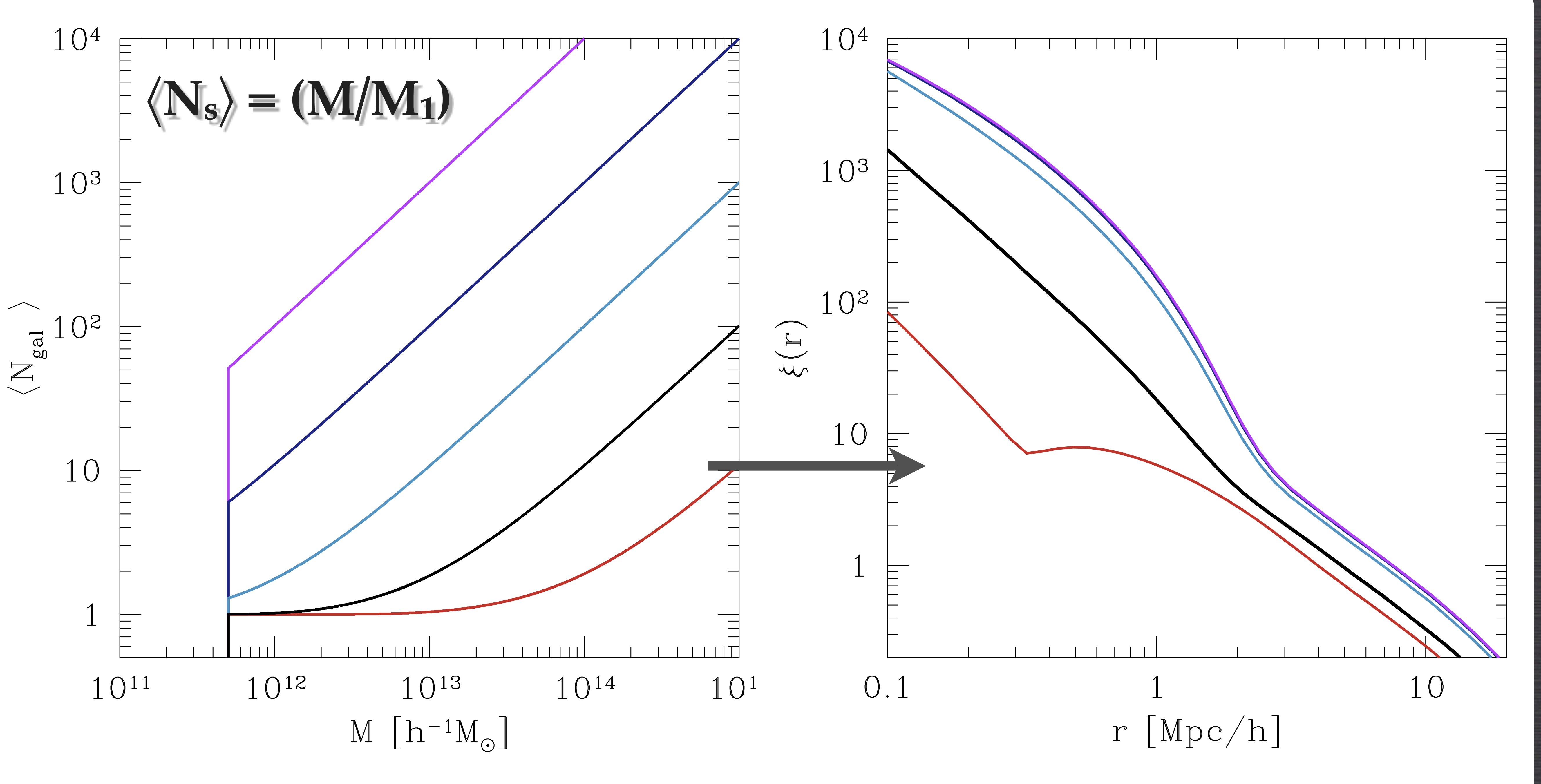
increasing ⟨N_s⟩
by factors of 10
10^4
1000
100
10
1
0.1
$\xi(r)$
0.1
1
10
r [Mpc/h]

Toy Model

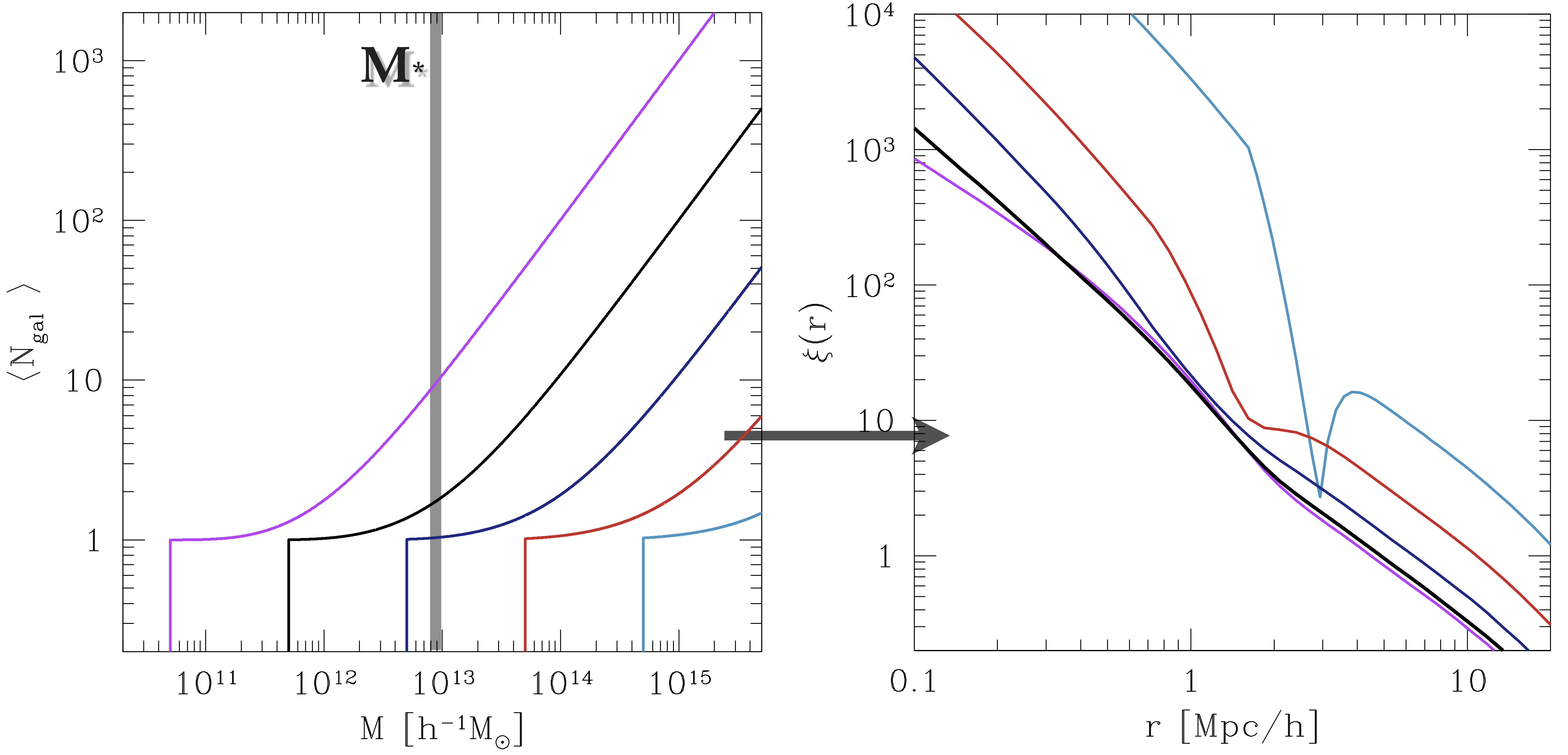


increasing M_H
by factors of 10
M*
ξ(r)
r [Mpc/h]
10⁴
1000
100
10
1
0.1
0.1
1
10

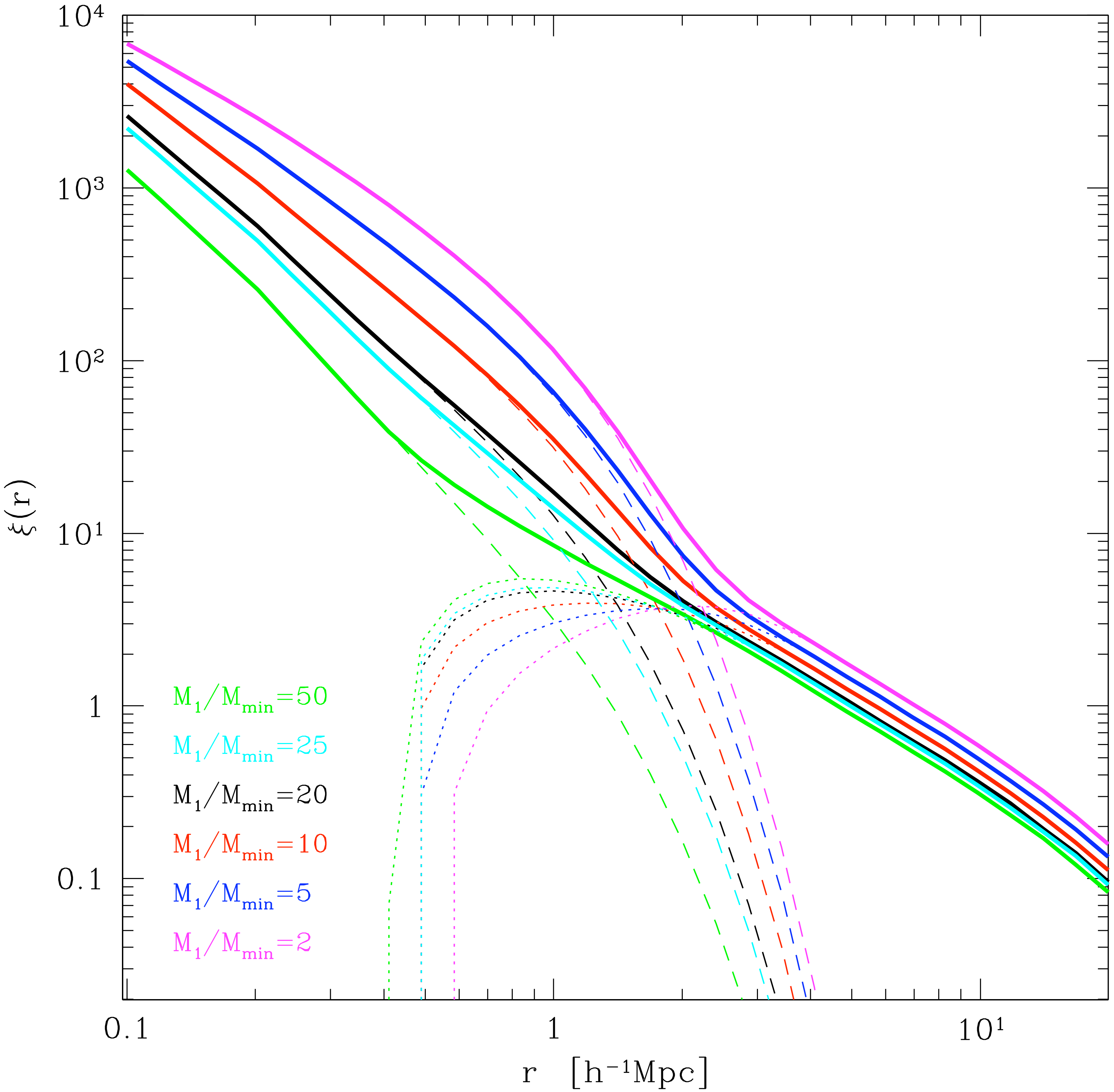
Full Halo Model



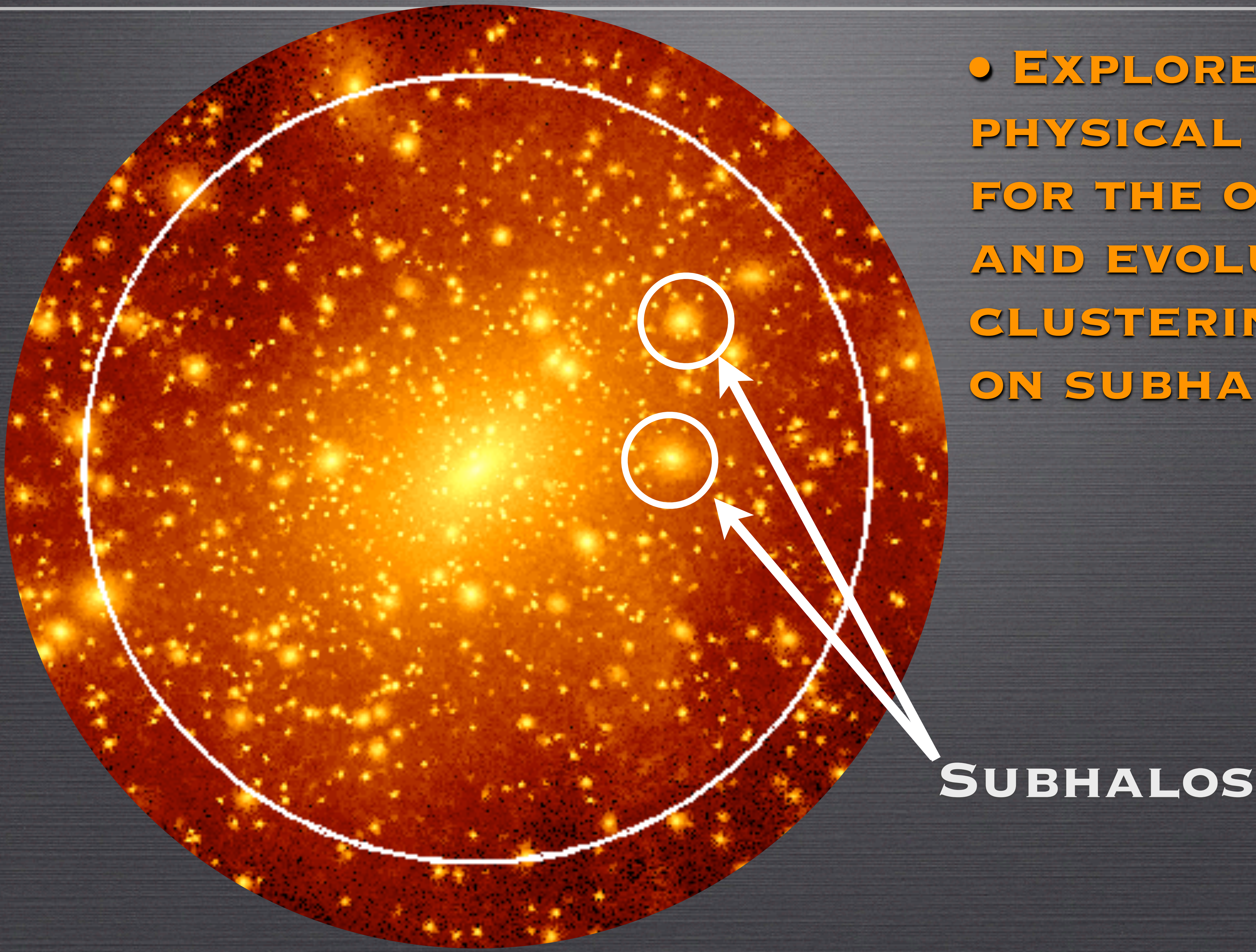
Full Halo Model



Full Halo Model

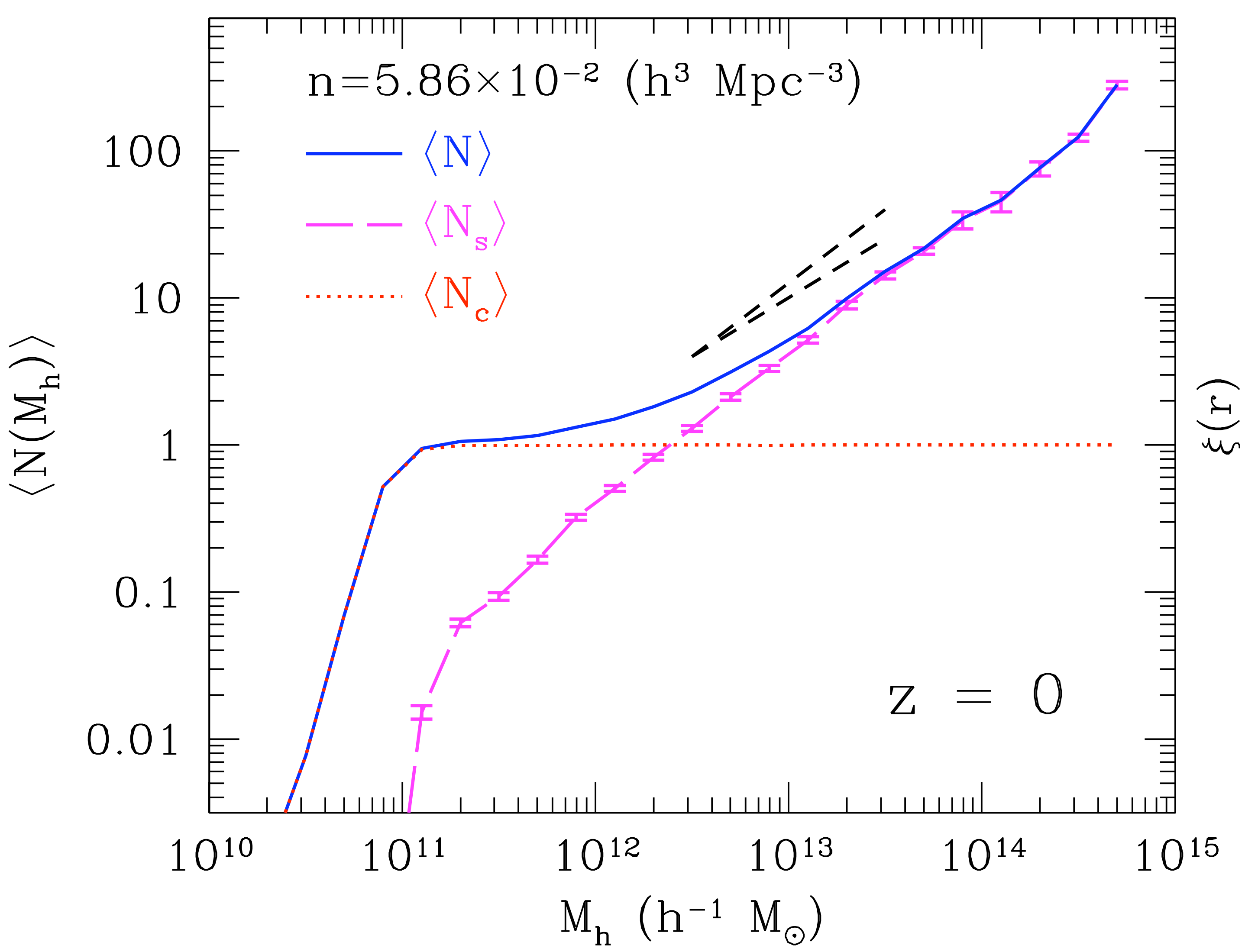


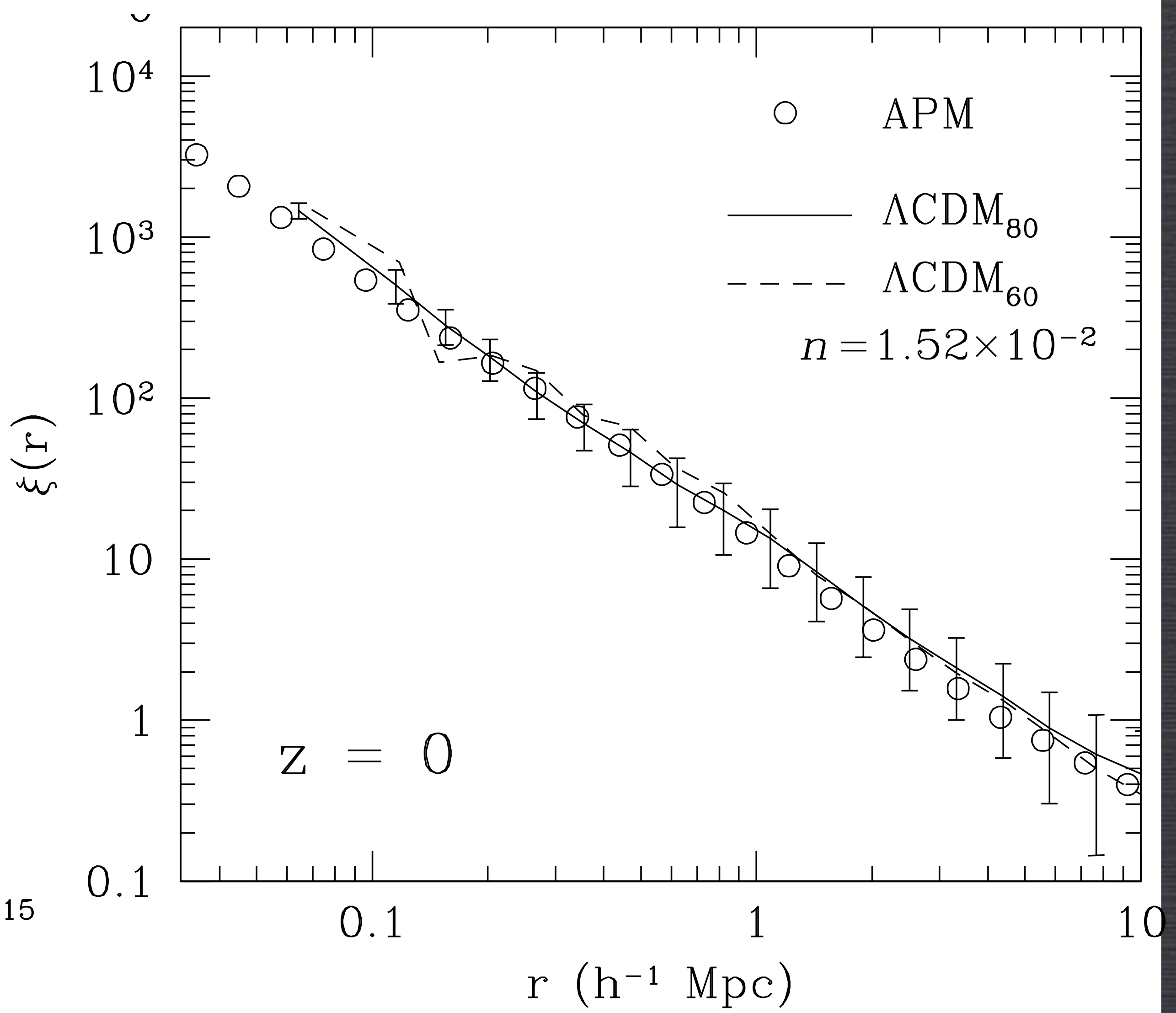
Physical Model



- Explore a physical model for the origin and evolution of clustering based on subhalos

(Sub)Halo Clustering

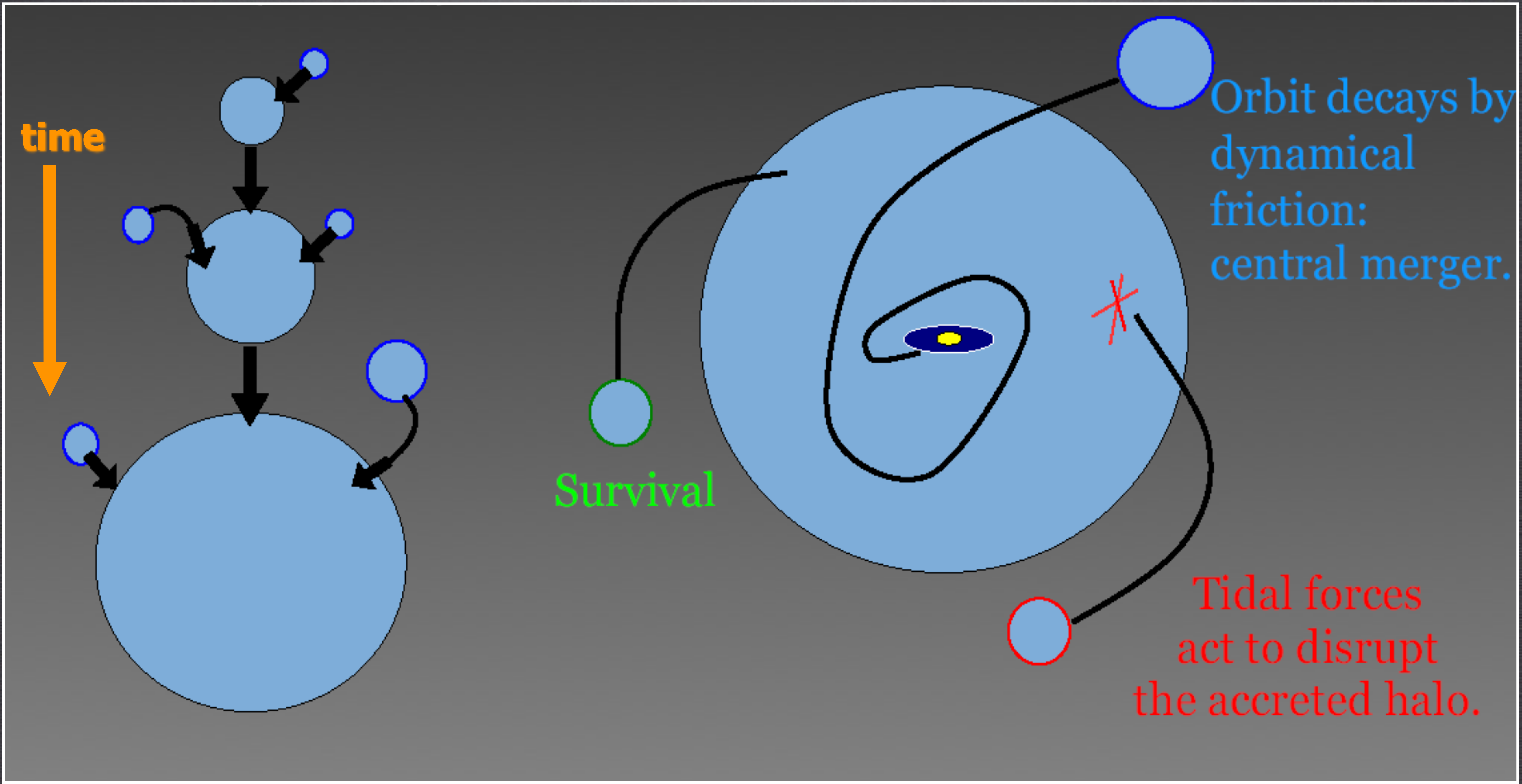




Kravtsov et al. 2004: also see Kravtsov & Klypin '99, Colin et al. '99, Conroy et al. 2006, many others

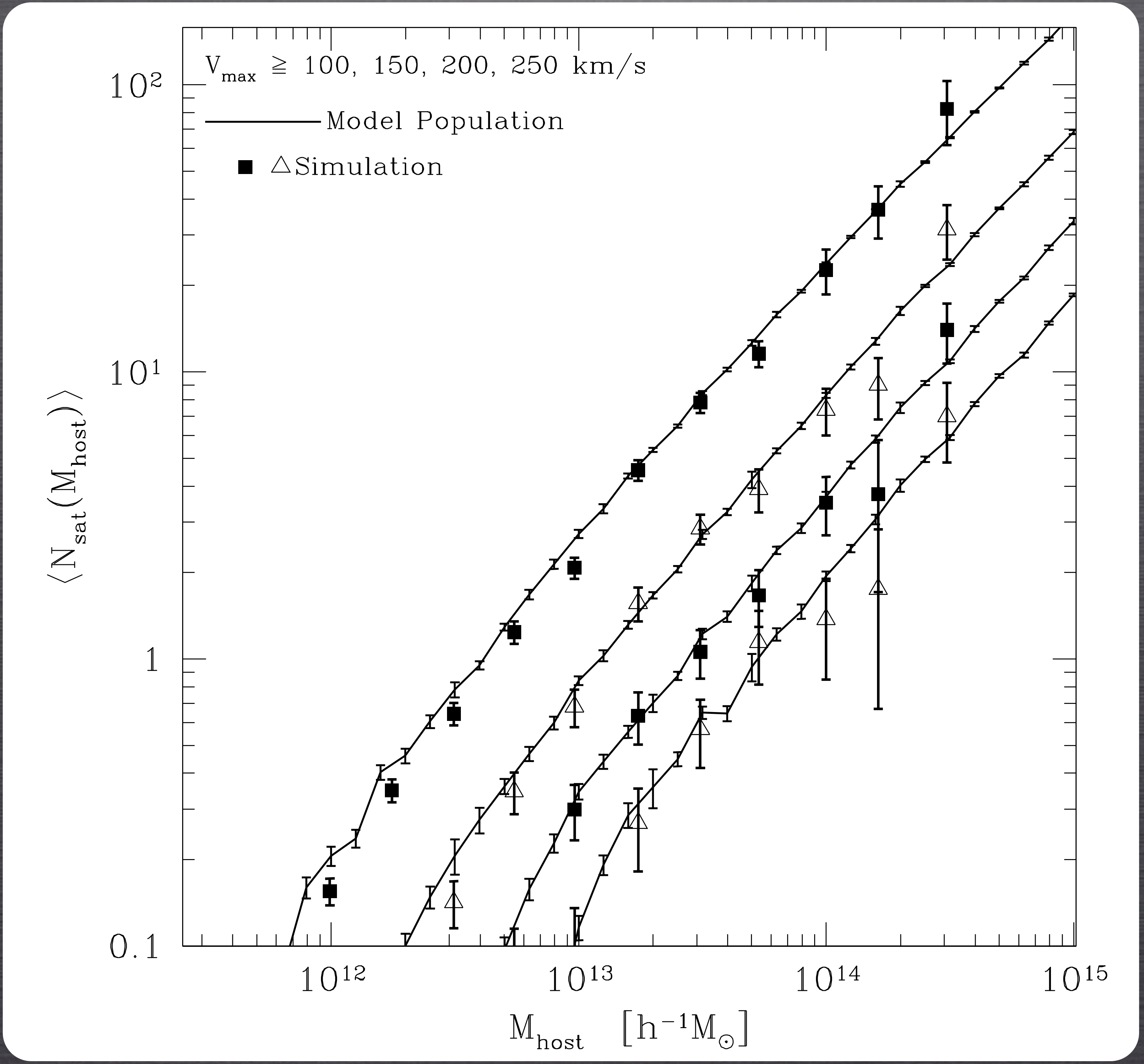
Analytic Method

Modeling Framework



Gnedin & Ostriker 1999; Gnedin, Ostriker, & Hernquist 2000; Taffoni et al. 2002;
Taylor & Babul 2002; **Zentner & Bullock 2003; Zentner et al. 2005a,2005b**

Modeling Framework



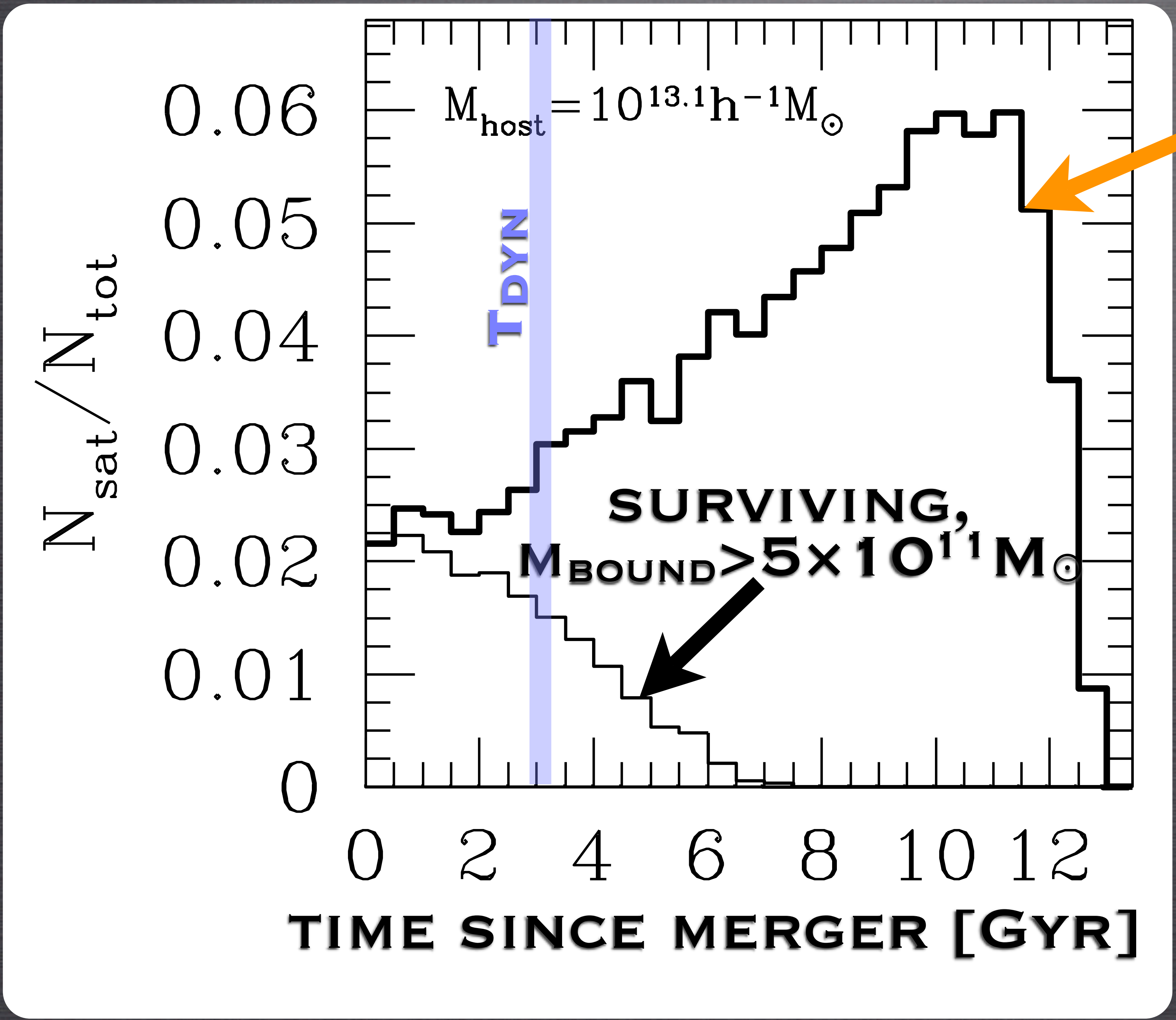
Timescales

orbital timescales: $$t_{\rm dyn} \sim \frac{1}{\sqrt{G\rho_{\rm vir}}} \sim \frac{1}{10}\frac{1}{H}$$

dynamical friction timescales: $$t_{\rm df} \sim t_{\rm dyn}\left(\frac{M_{\rm halo}}{10M_{\rm sub}}\right)$$

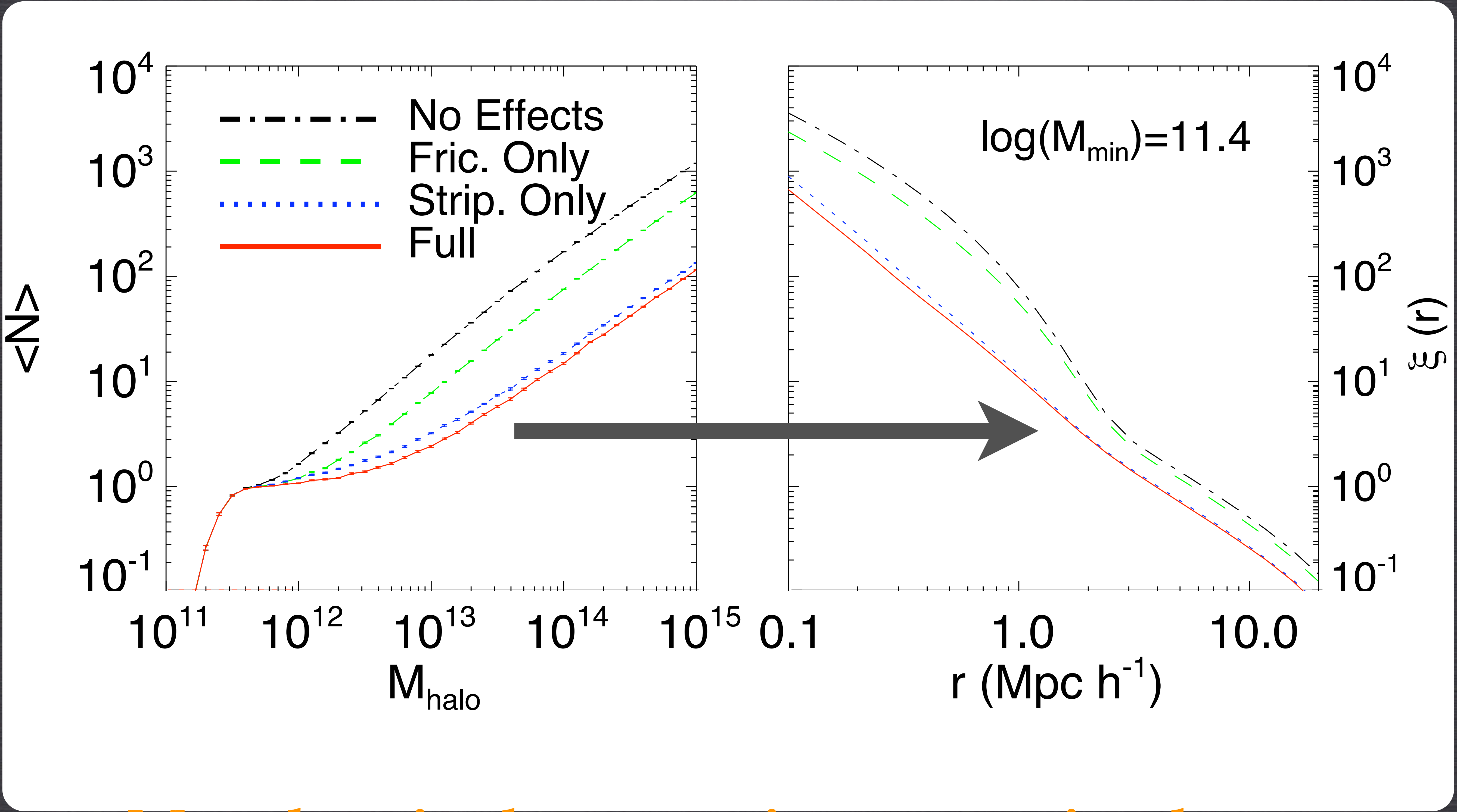
major merger timescales: (ΔM/M > 10%) $$t_{\rm merge} \sim \frac{{\rm d}\ln D(a)}{{\rm d}\ln a}\frac{1}{H}$$

Satellite "Destruction"



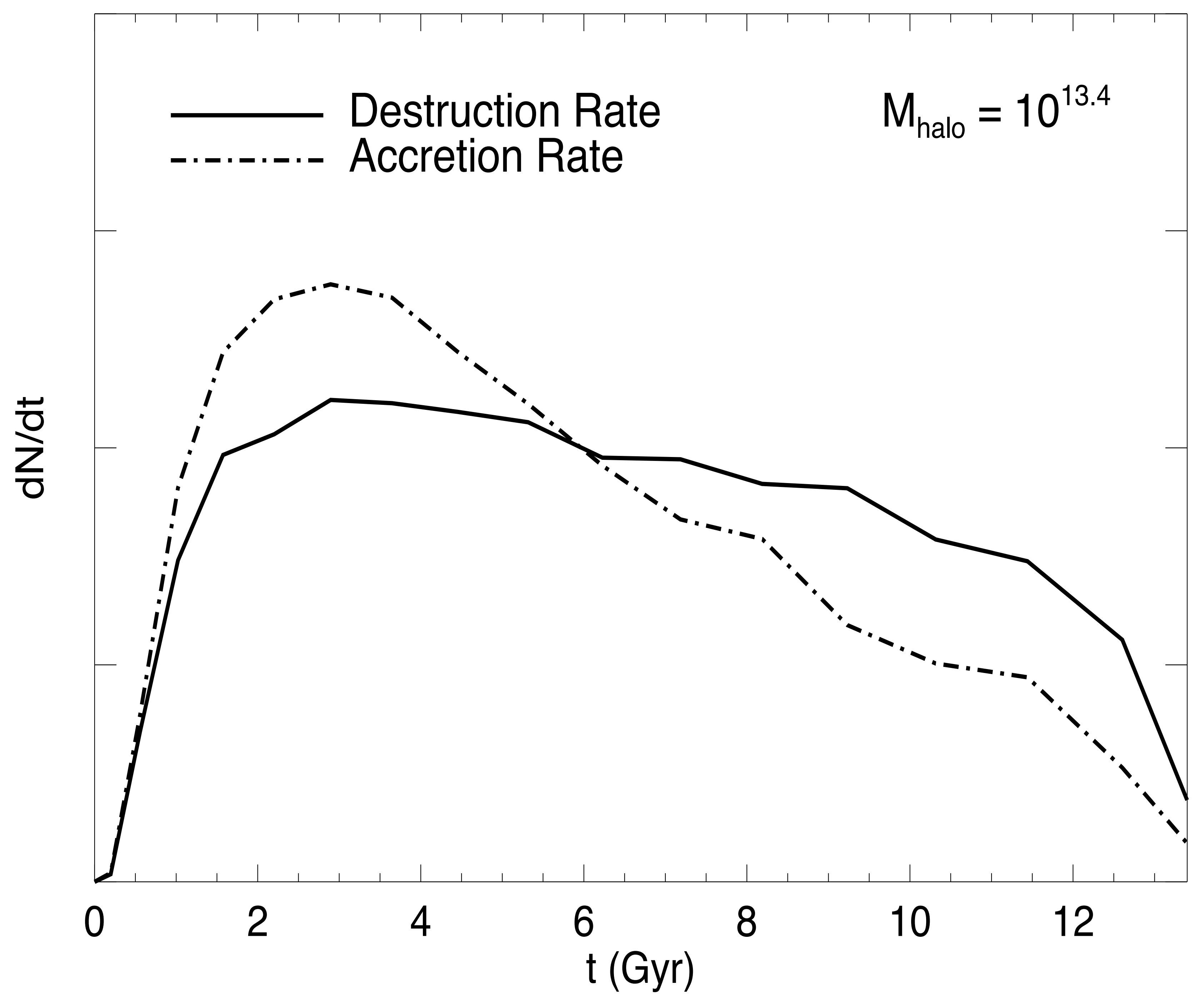
All In-Falling Subhalos with $M_{BOUND}>5\times10^{11}M_{\odot}$

Building ξ(r)

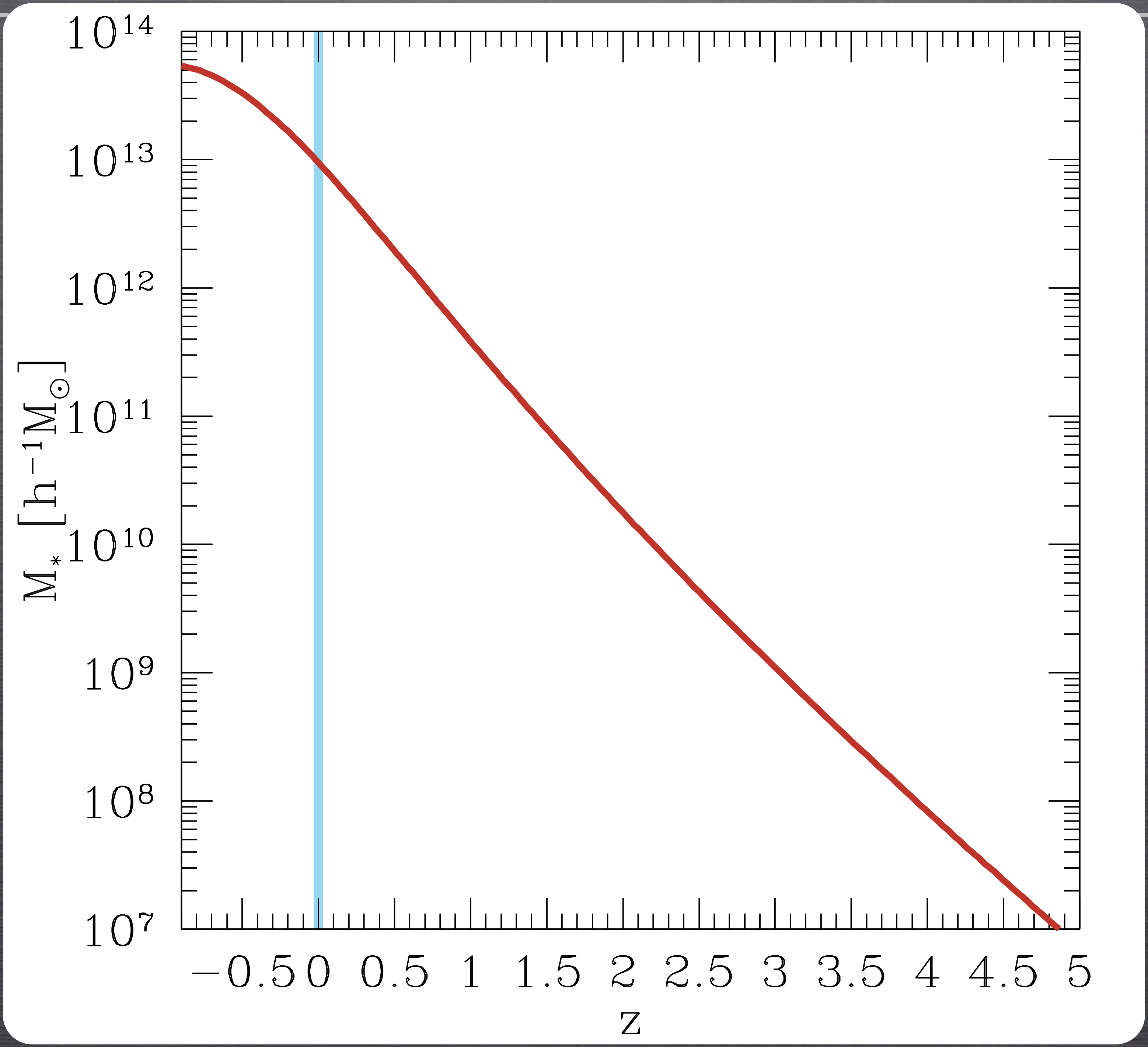


- Mass loss in dense environments is a key ingredient to building a power-law ξ

Accretion vs. Destruction

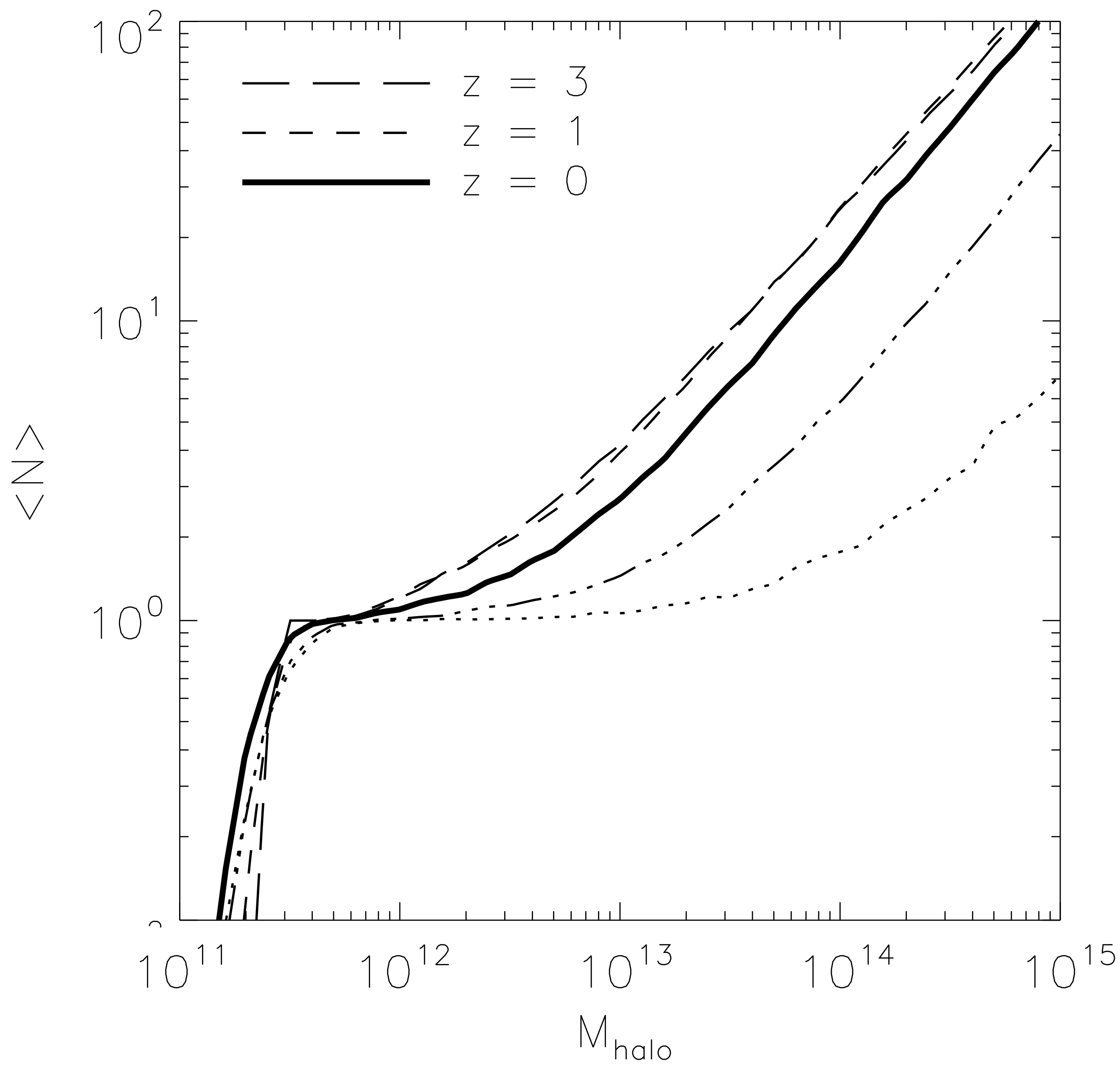


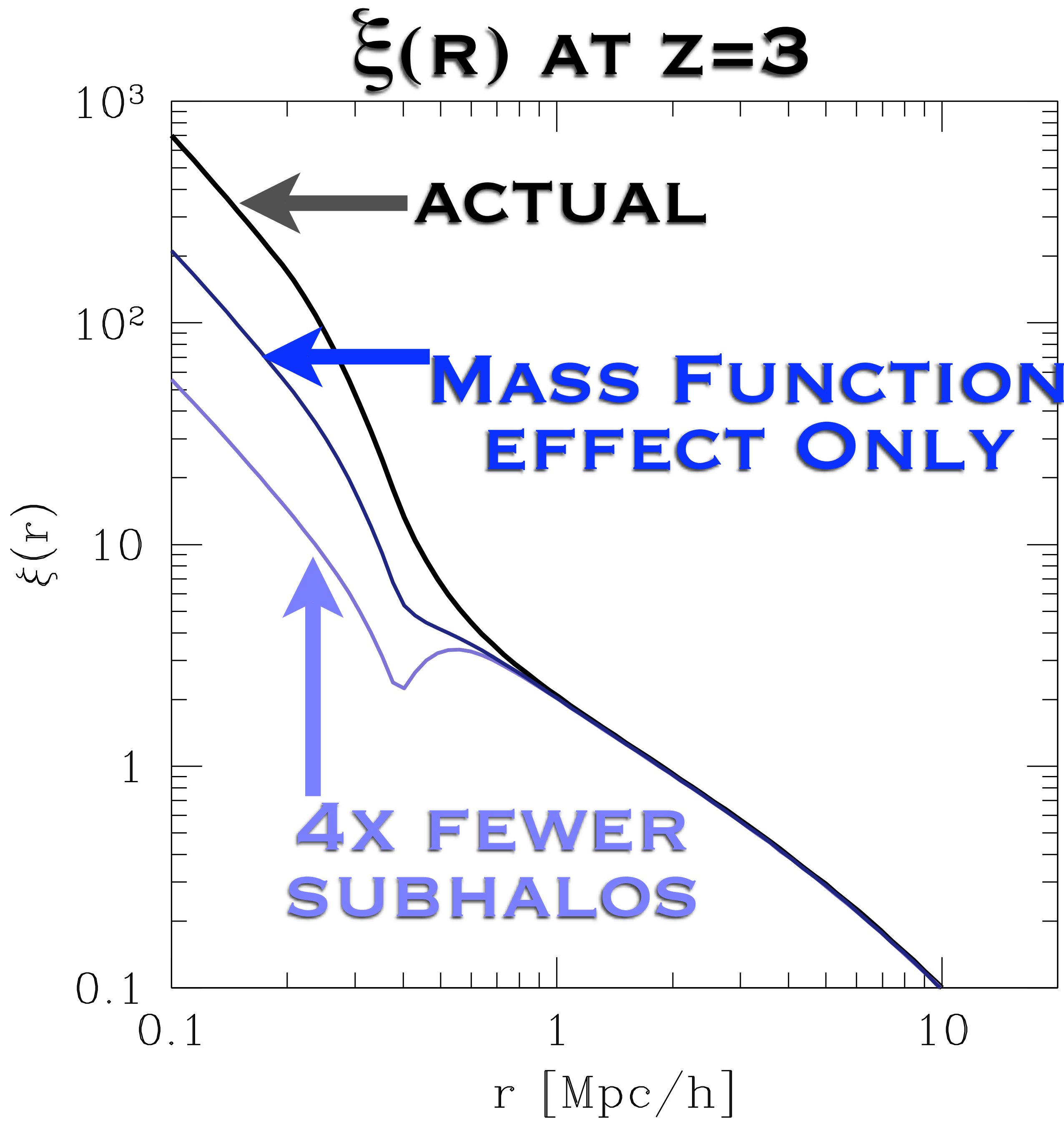
High Redshift



- M_* evolves significantly with redshift, until z~0
- Large halos are much more rare at high z

High Redshift





- As observed, Coil et al. 05, Ouchi et al. 06, Lee et al. 06, ...
- Similarly for SCDM (Ω_M=1) cosmology, etc.

(Very) Low Redshift

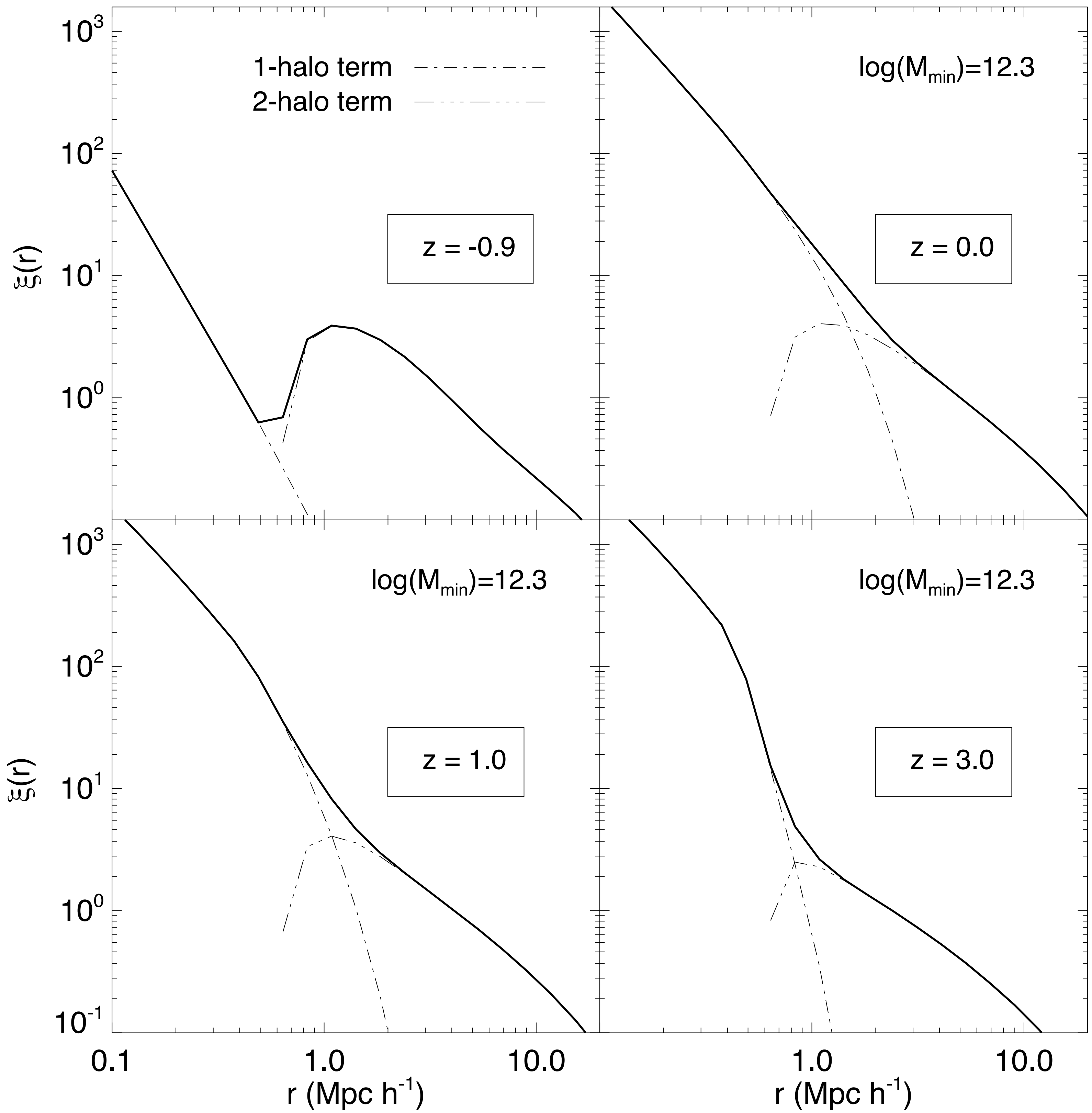
- Recall the timescale for mergers goes roughly like

$$t_{\mathrm{merge}} \sim \frac{\mathrm{d}\ln D(a)}{\mathrm{d}\ln a}\frac{1}{H}$$

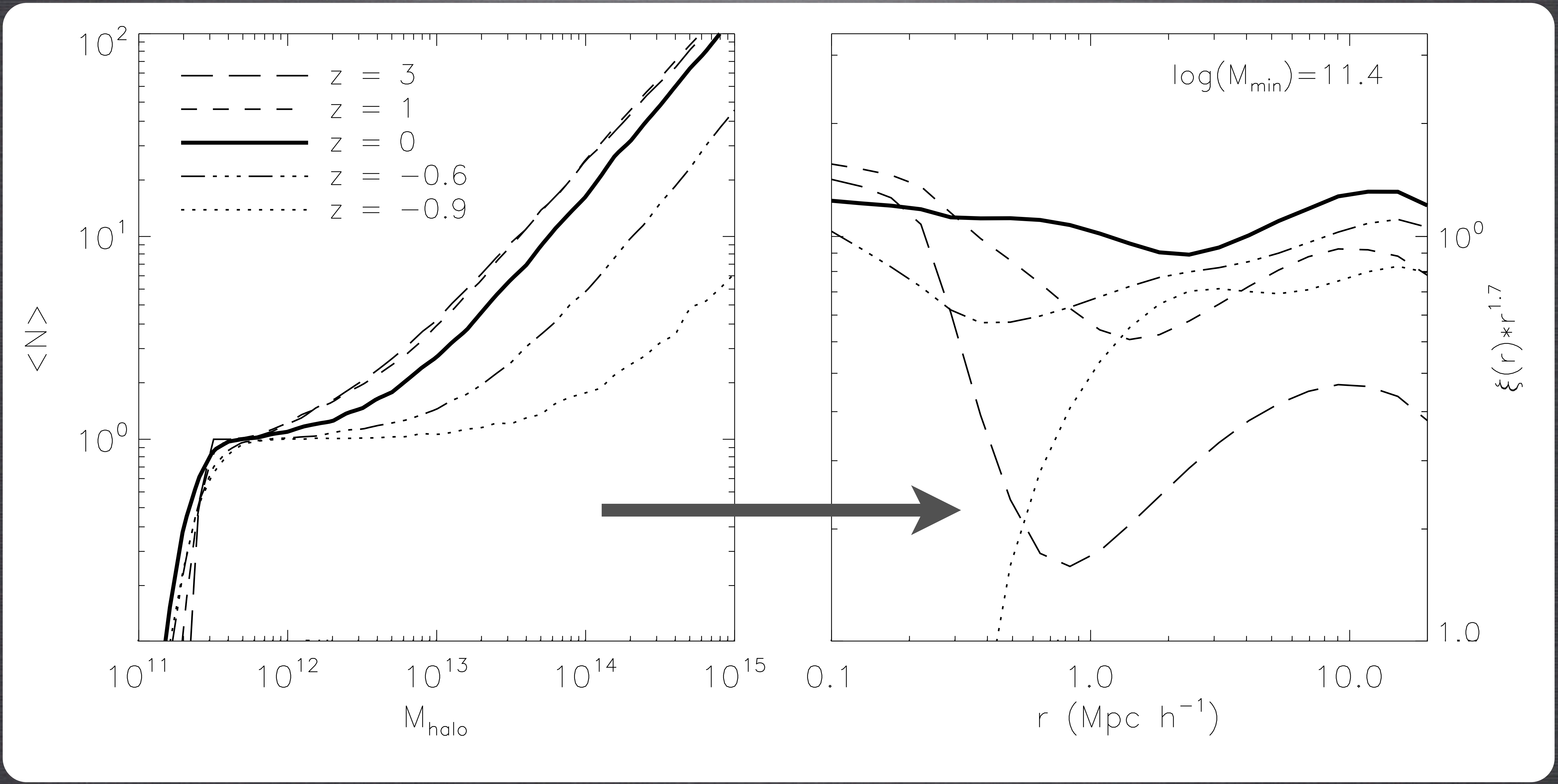
- When $\Omega_\Lambda \sim \Omega_M$ the growth of structure slows due to the dark energy and

$$\frac{\mathrm{d}\ln D(a)}{\mathrm{d}\ln a} < 1$$

Evolution of ξ



Evolution of ξ



- At any mass ("luminosity") threshold, the correlation function evolves through a power-law

Conclusion

1. The near power-law correlation function of galaxies appears to be a coincidence
   1.1. It relies on several conspiracies
   1.2. It depends upon luminosity (mass)
   1.3. Each luminosity threshold will evolve through a nearly power law stage
   1.4. Strong deviations from power laws should prevail in the past and in the future