Large Scale Structure: What Have We Learned? What Will We Learn?

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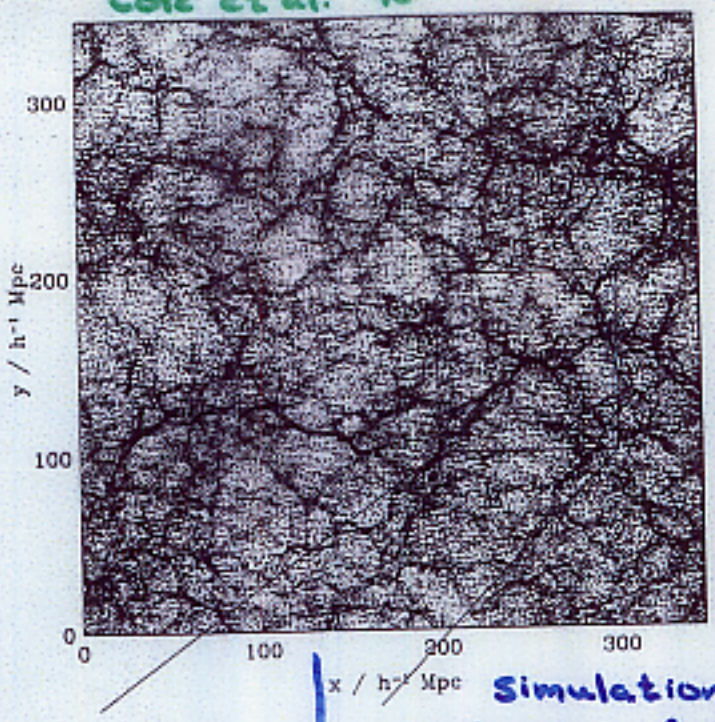
Observable Probes of Large Scale Structure

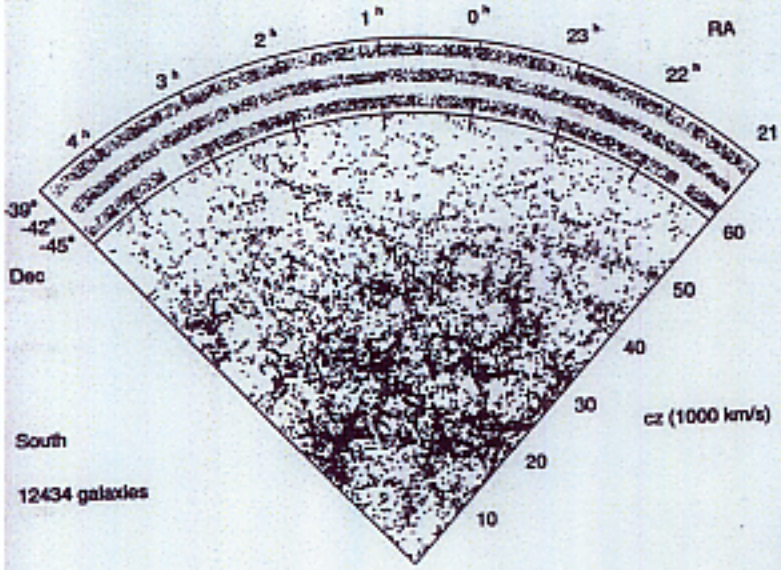
Galaxy clustering (redshift surveys)
Galaxy-galaxy lensing
Cosmic shear
Galaxy, X-ray, and S-Z clusters
Galaxy peculiar velocities
Quasar clustering
Lyman-alpha Forest
Cosmic microwave background

Large Scale Structure: A Dramatization

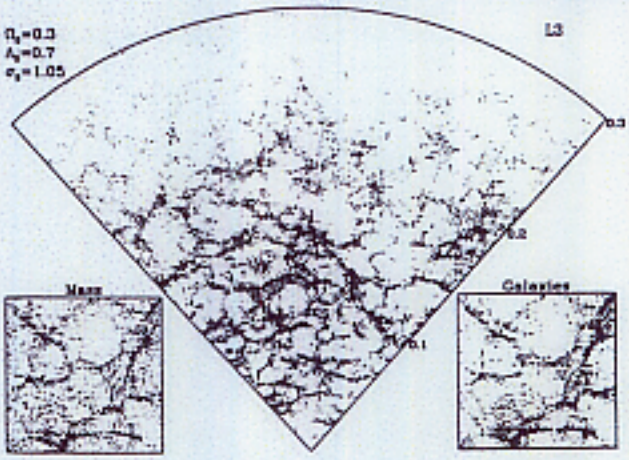
Cole et al. '98



Shectman et al. '96

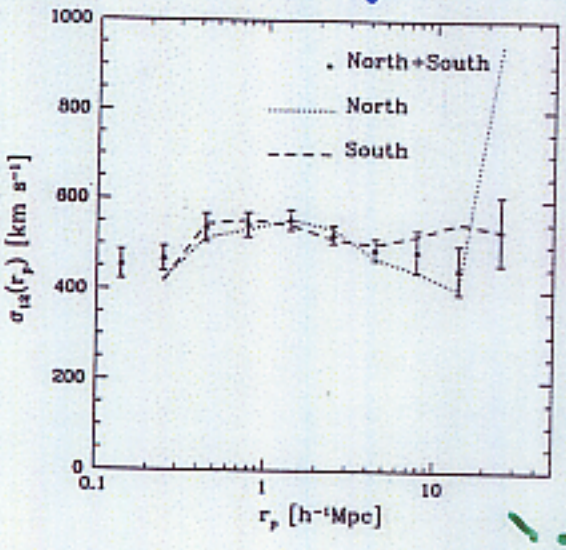


Simulation → mock data



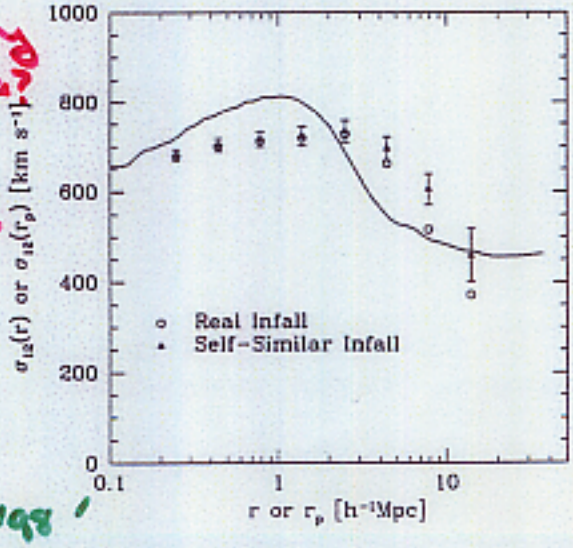
Data → statistics

mock data → statistics



Does theory match data?

→ ? ←



Jing et al. '98

What did we learn from the major redshift surveys of the 1990s?

CfA2 — 13,000 blue selected galaxies
PSCz — 15,000 far-infrared selected galaxies
LCRS — 24,000 red selected galaxies

Observed galaxy clustering is well described by an inflationary cold dark matter (CDM) model with $\Omega_m \sim 0.2 - 0.4$ and $h \sim 0.6 - 0.8$, with optically bright galaxies roughly tracing the dark matter.

BUT

Galaxy clustering varies with galaxy morphology, color, and luminosity.

Some scale-dependent "bias" is needed to explain observed clustering in detail; in particular, the power-law galaxy correlation function.

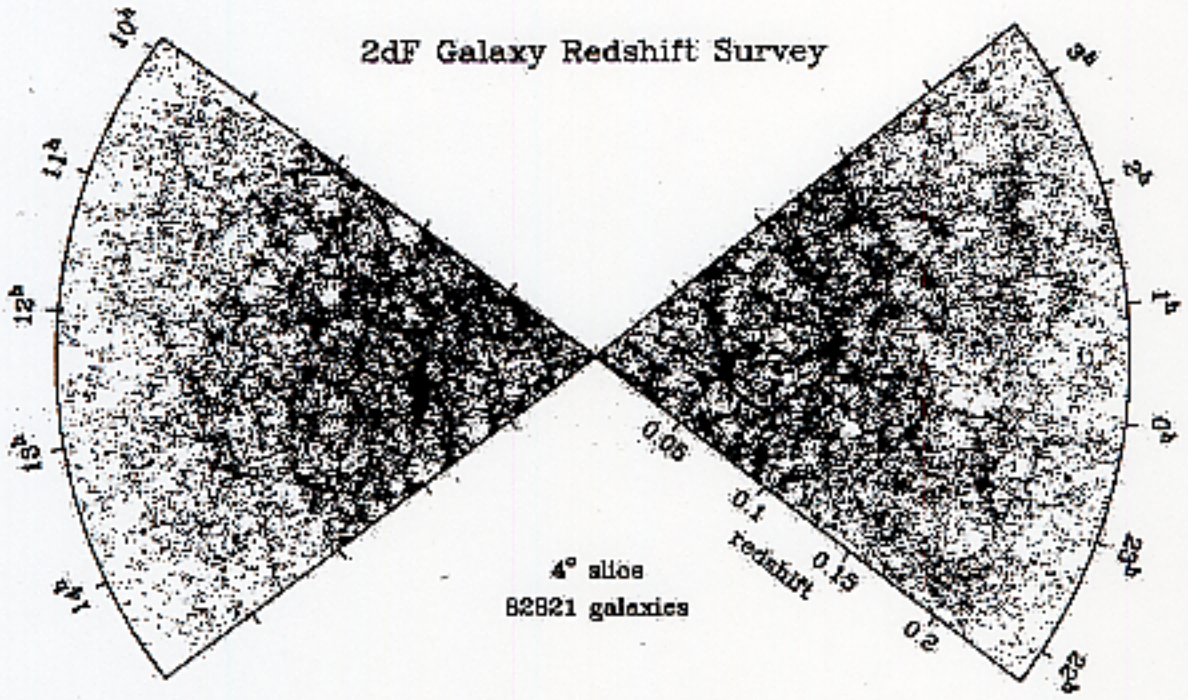
A working cosmological model has

- Gaussian initial conditions
- $P(k)$ shape like scale-invariant ($n = 1$) fluctuations modulated by a CDM transfer function with $\Omega_m h \sim 0.1 - 0.3$
- $\sigma_8 \times \Omega_m^{0.5} \approx 0.5$

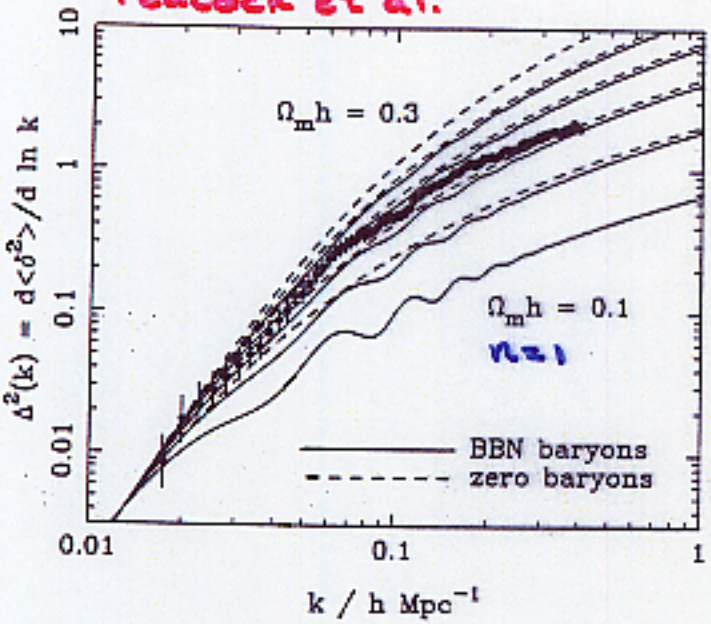
The predictions of any successful model cannot be too far from this.

What have we learned since 2000?

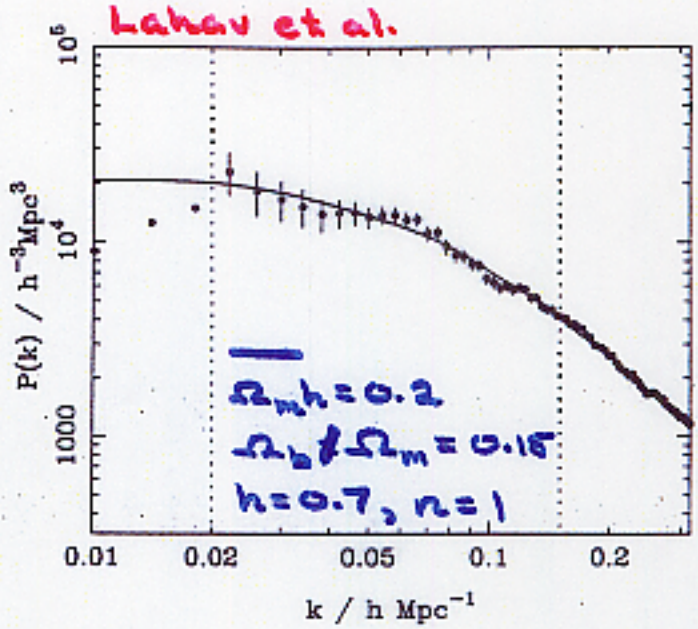
Essentially the same thing, but tests are much more stringent, and parameter constraints are much tighter.


2dF Galaxy Redshift Survey
10h
11h
12h
13h
14h
9h
2h
1h
0h
23h
22h
0.05
0.1
0.15
0.2
redshift
4° slice
82821 galaxies

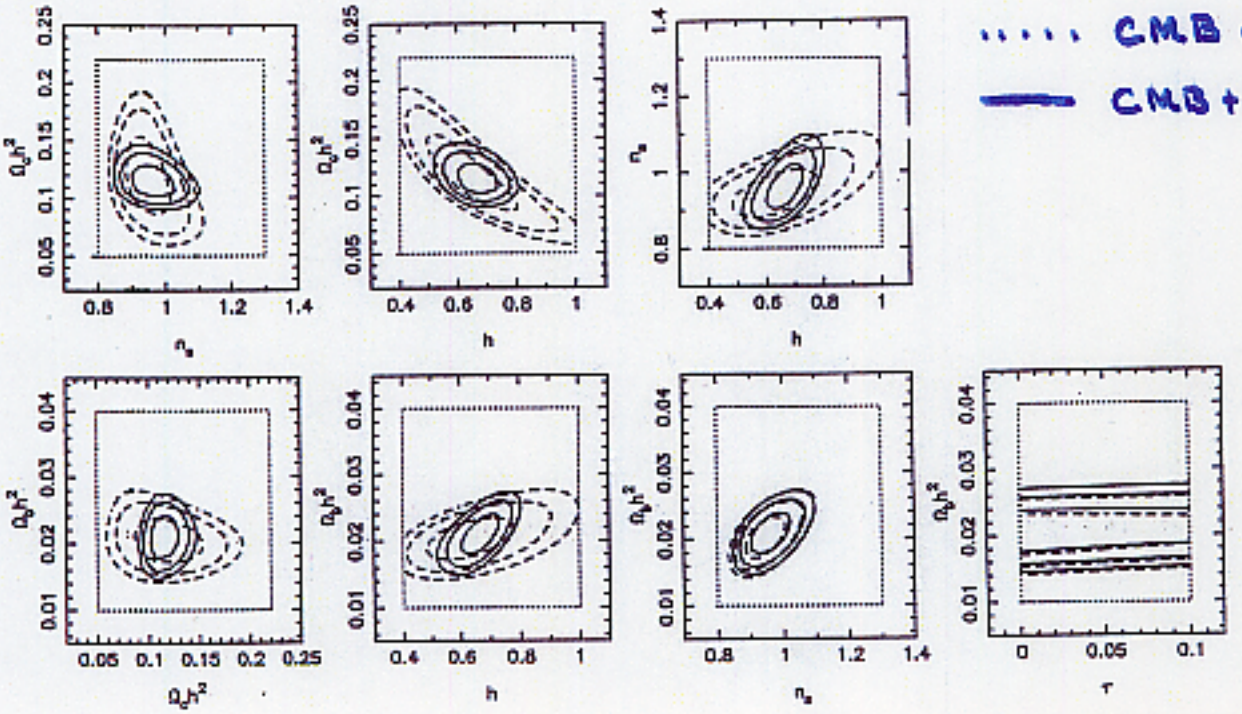
Peacock et al.



Lahav et al.

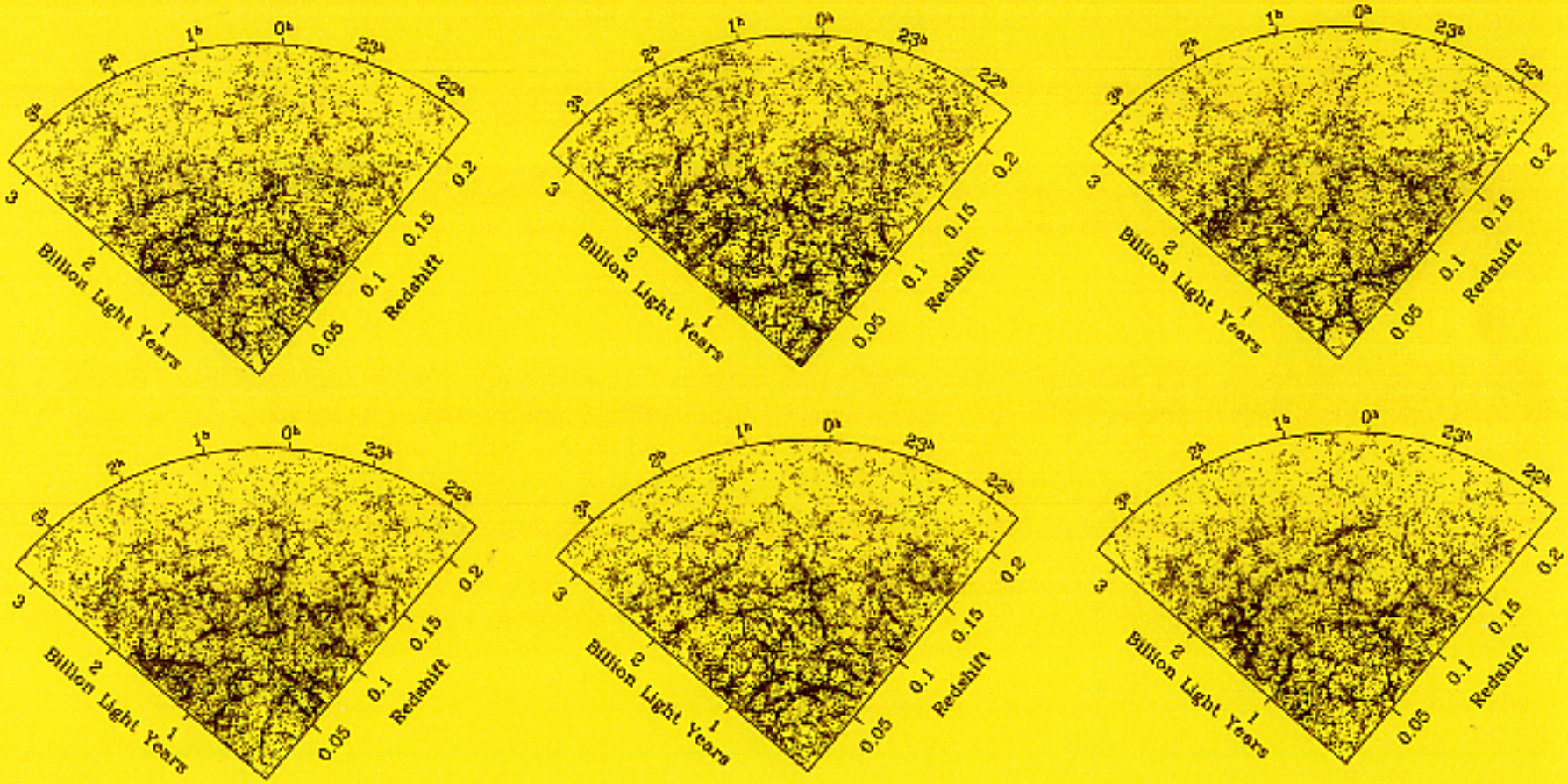


Percival et al.

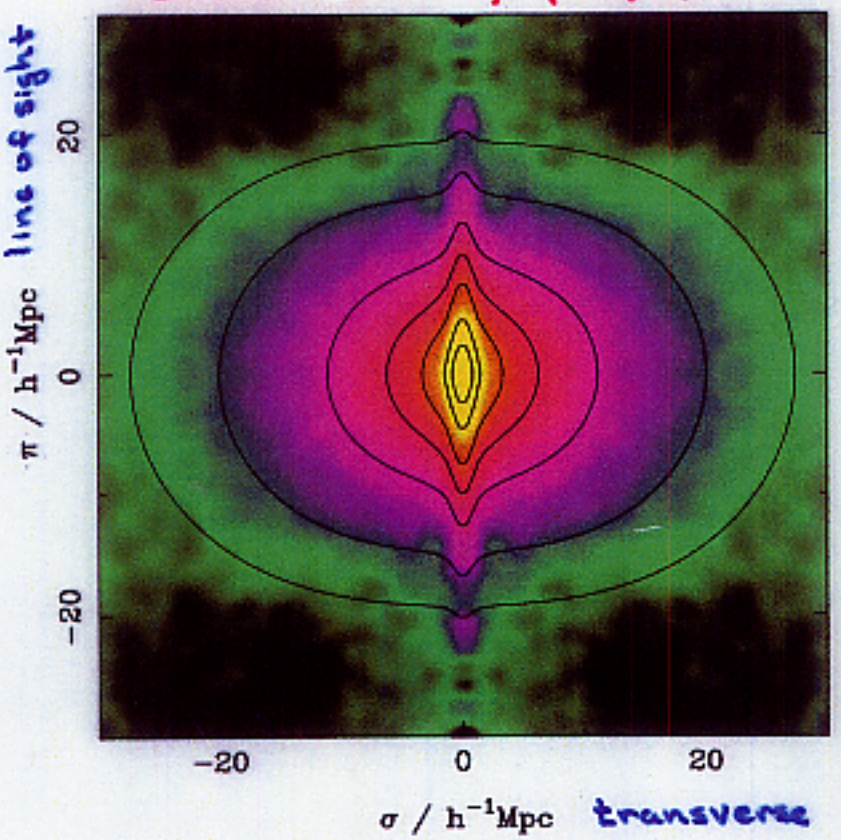


Norberg, Cole, + 2dFGRS

VIRTUAL vs REAL UNIVERSES II



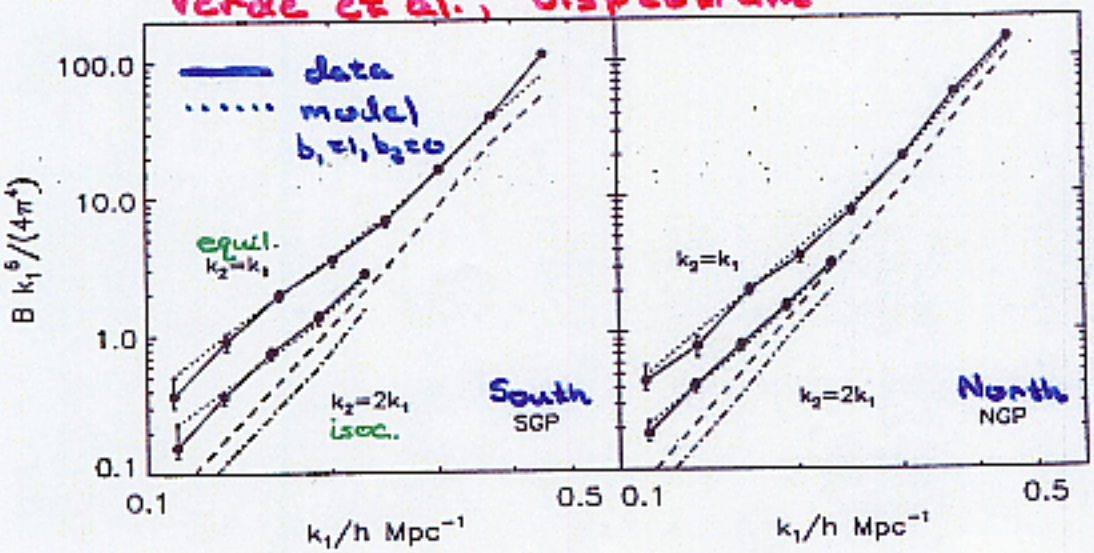
Peacock et al., $\xi(\sigma,\pi)$



$$\delta_{gal} = b\,\delta_\rho$$

$$\beta \equiv \frac{\Omega_m^{0.6}}{b} = 0.43 \pm 0.07$$

Verde et al., bispectrum



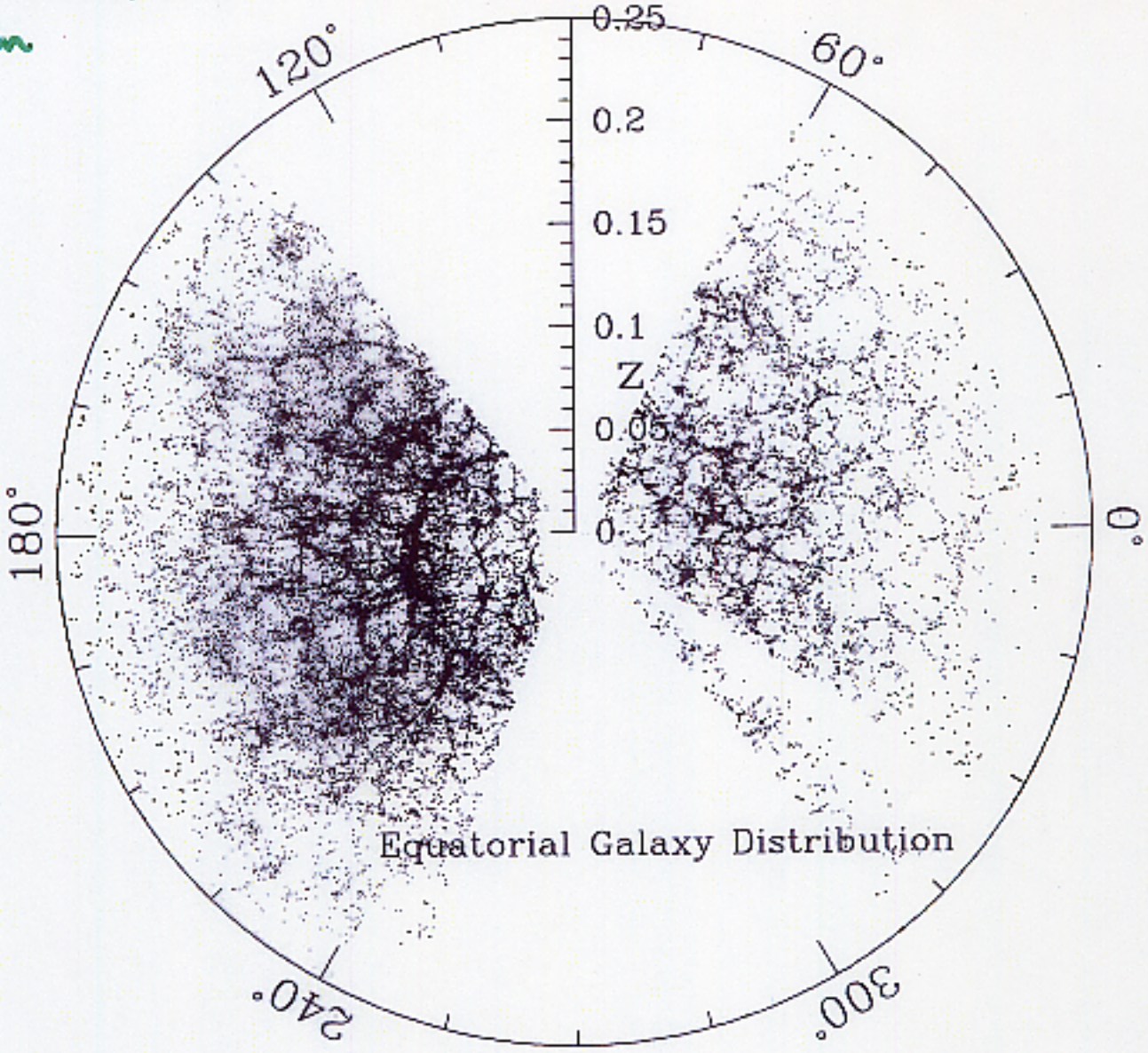
$$\delta_{gal} = b_1\delta_\rho + b_2\delta_\rho^2 + b_0$$

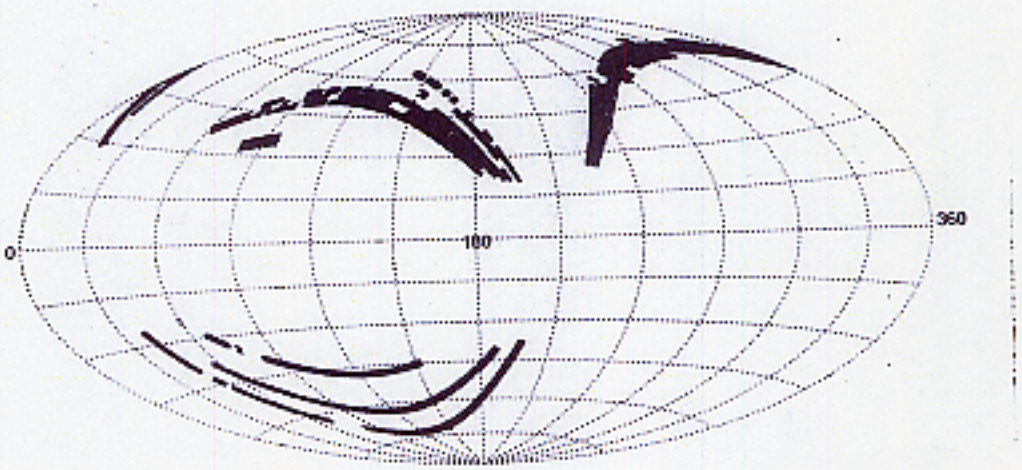
$$b_1 = 1.04 \pm 0.11$$

$$b_2 = -0.054 \pm 0.08$$

Smaller scales →

SDSS "Sample 10"
Blanton





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What have we learned since 2000?

Essentially the same thing, but tests are much more stringent, and parameter constraints are much tighter.

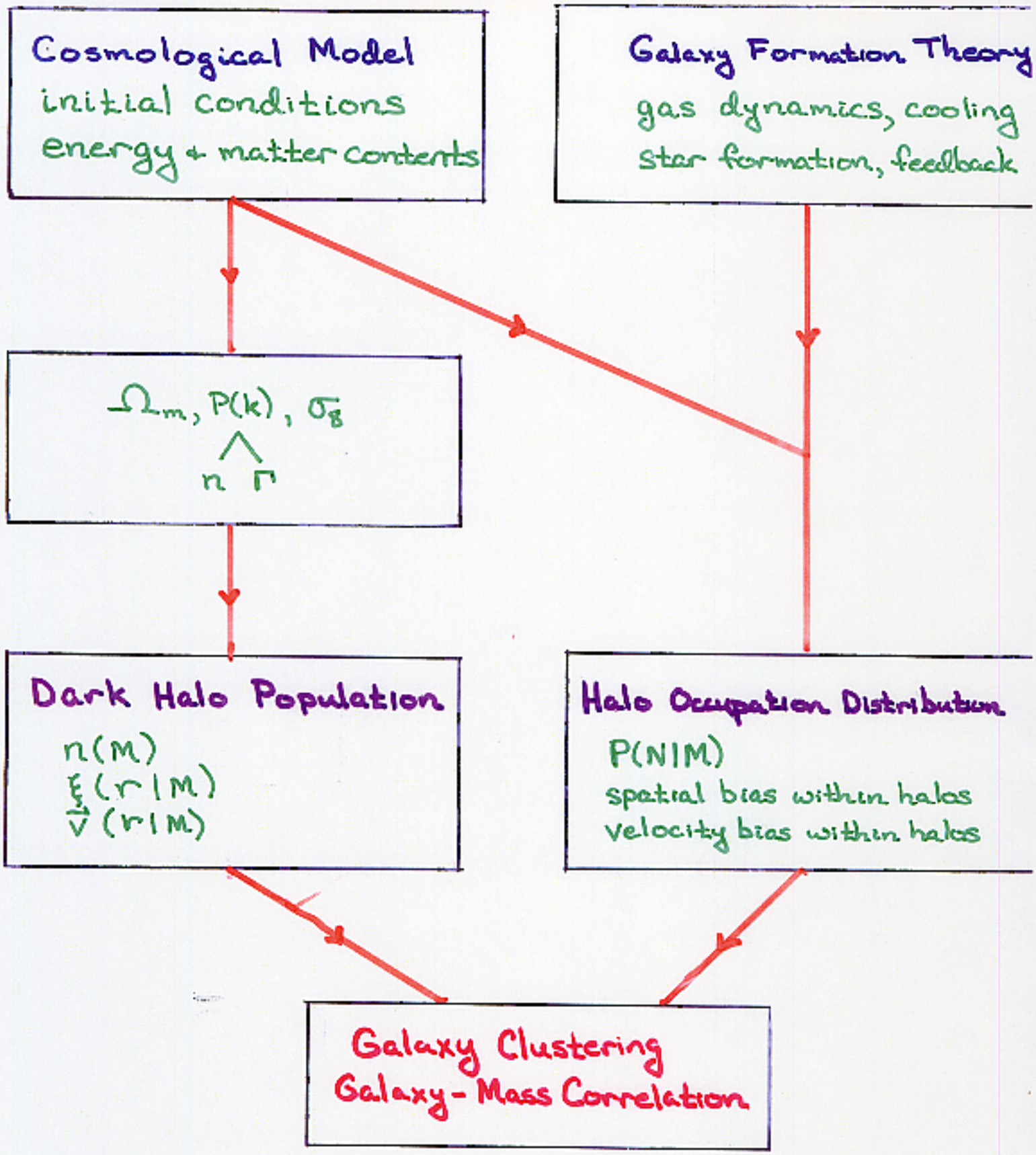
Large scale structure breaks degeneracies present in CMB data alone.

Cosmic shear and the Lyman-alpha forest give consistent results, independent of galaxy bias.

The large scale bias factor of L_* galaxies is not far from one.

What will we learn from the 2dFGRS and the SDSS?

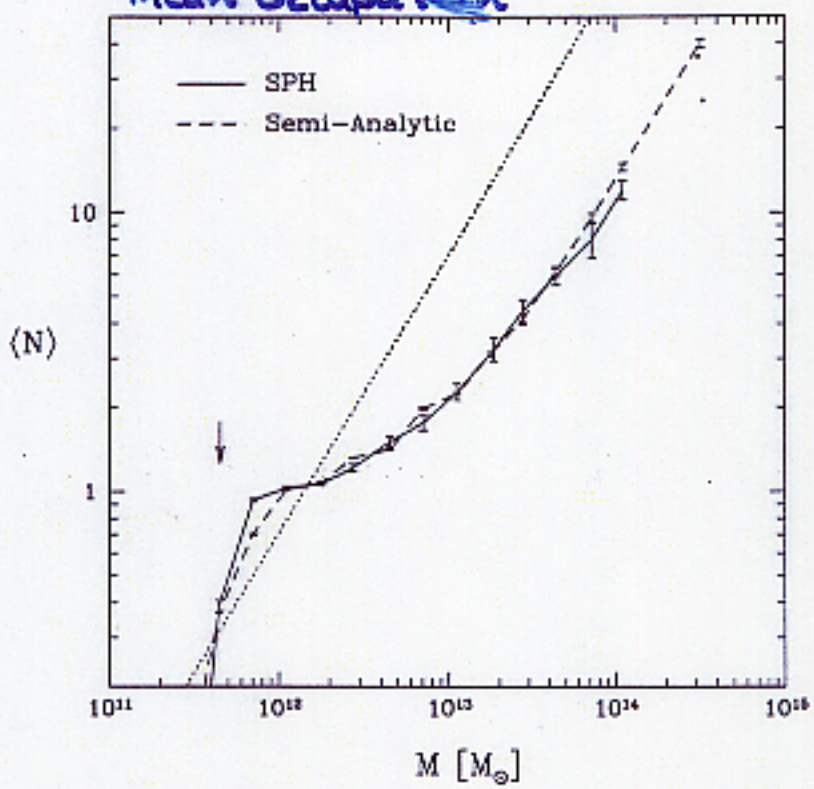
The challenge: understanding the relation between galaxies and mass.



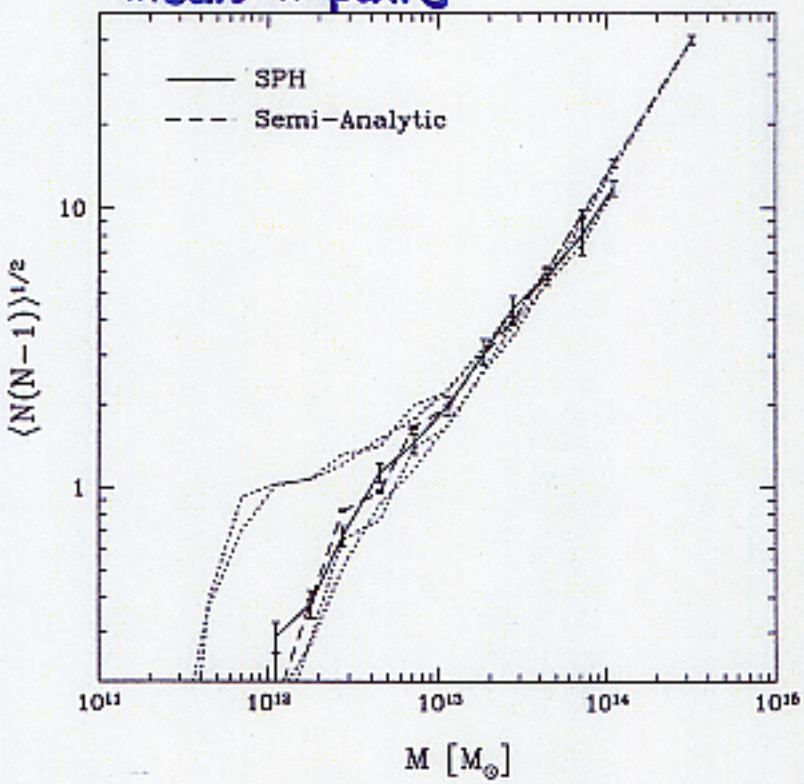
$P(N|M)$ = probability that a halo of virial mass M contains N galaxies

Berlind et al.

mean occupation



mean # pairs



Berlind + Weinberg

$$\langle N \rangle = \left(\frac{M}{M_1}\right)^{\alpha} \qquad M \geq M_{min}$$

$$= 0 \qquad M < M_{min}$$

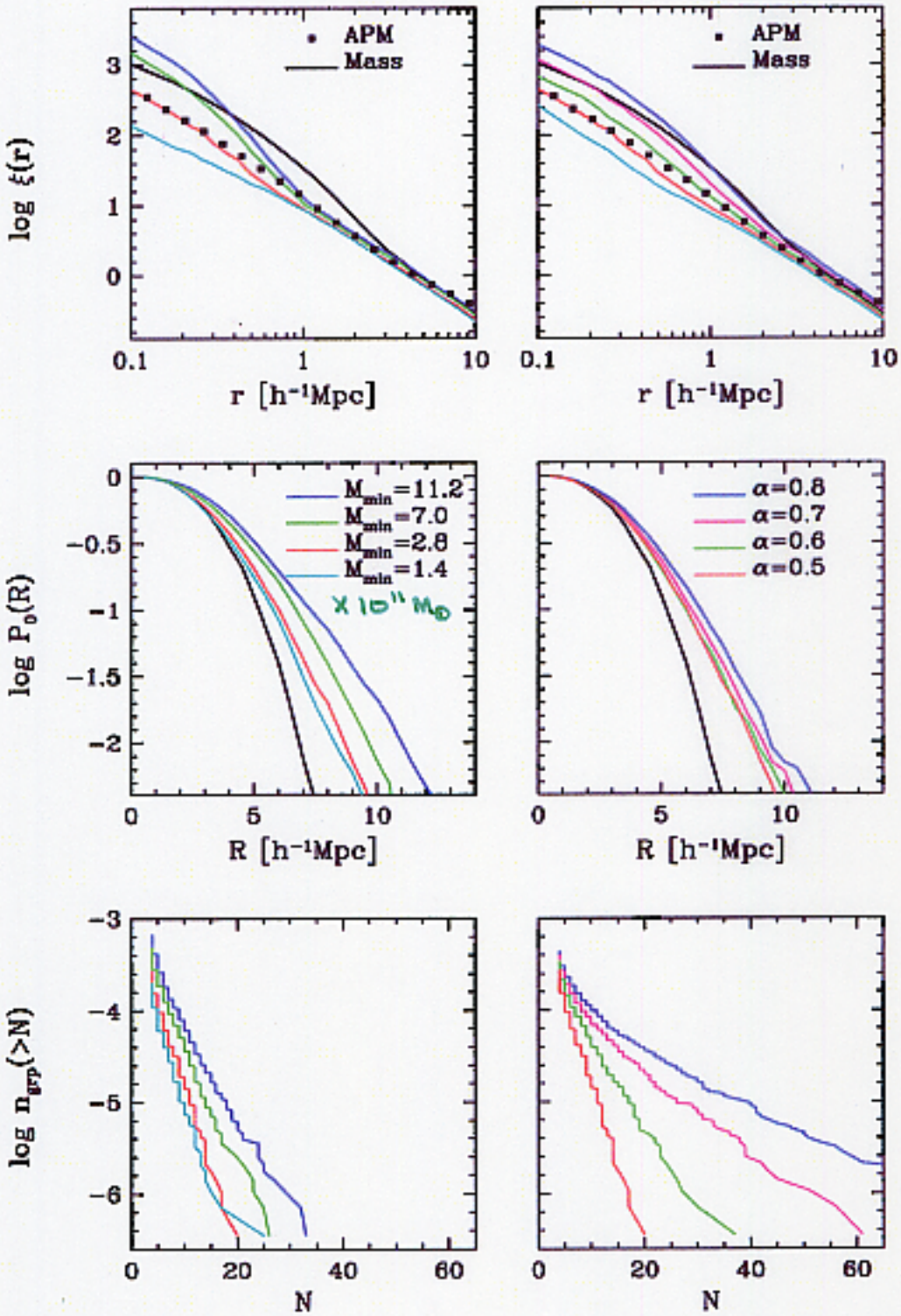
M_{min} variations

α variations

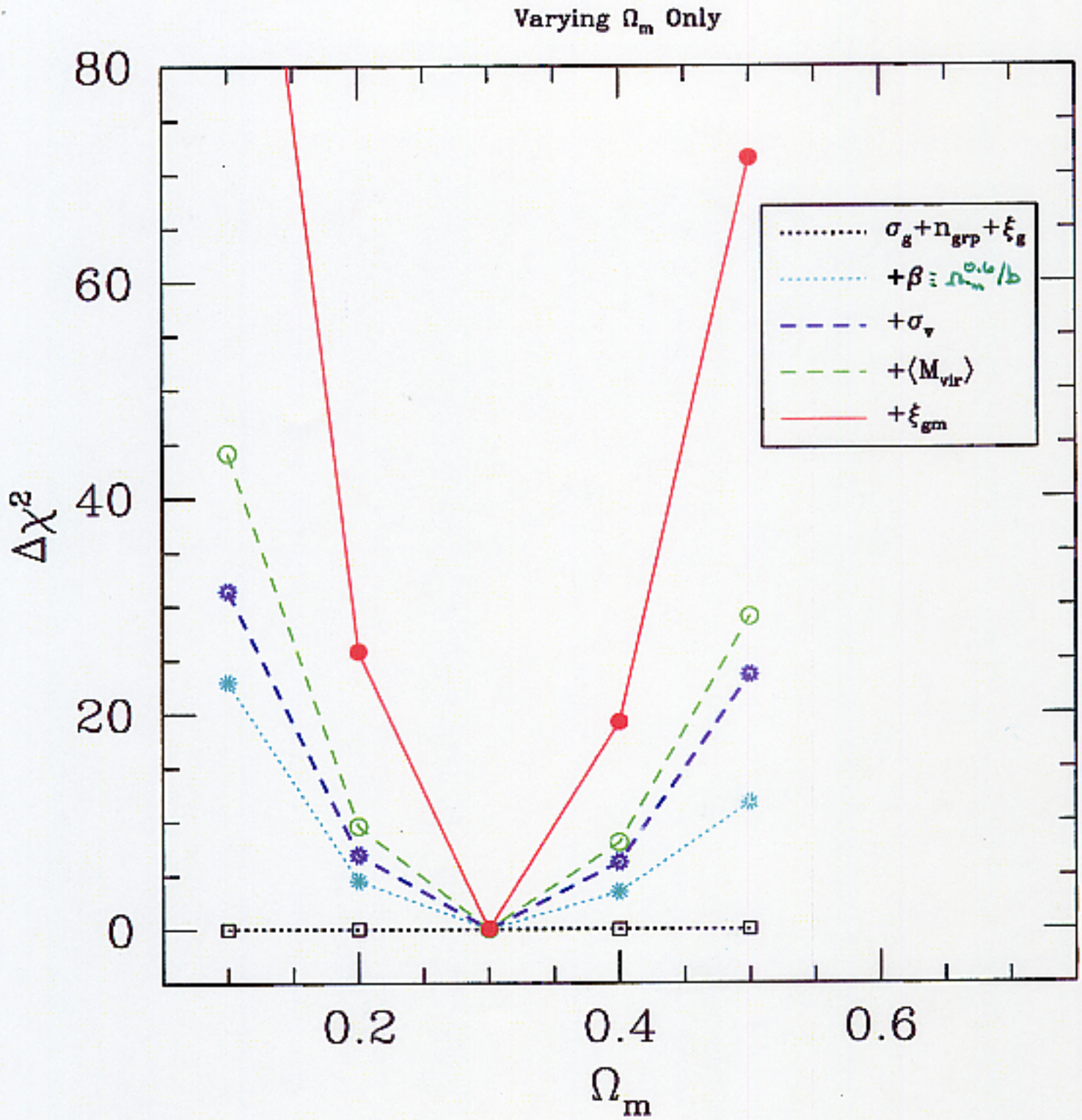
correlation function

void probability function

group multiplicity function



Zheng


Varying Ω_m Only
80
60
40
20
0
$\Delta\chi^2$
0.2
0.4
0.6
Ω_m
$\sigma_g + n_{grp} + \xi_g$
$+\beta \equiv \Omega_m^{0.6}/b$
$+\sigma_v$
$+\langle M_{vir} \rangle$
$+\xi_{gm}$

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What will we learn from the 2dFGRS and the SDSS?

The challenge: understanding the relation between galaxies and mass.

For specified cosmology, we will learn the halo occupation distributions of different galaxy types.

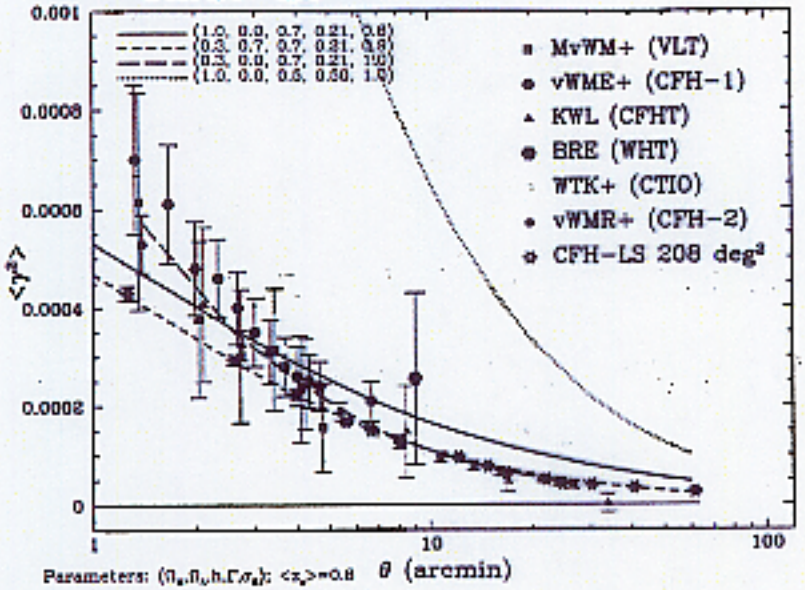
Using empirically derived constraints on the HOD, we will get tighter and more robust constraints on cosmology.

- High-precision measurements of $P(k)$ shape into the moderately non-linear regime.
- Reasonably good separation of Ω_m from $P(k)$ amplitude (σ_8).
- High-precision tests of Gaussian initial conditions.

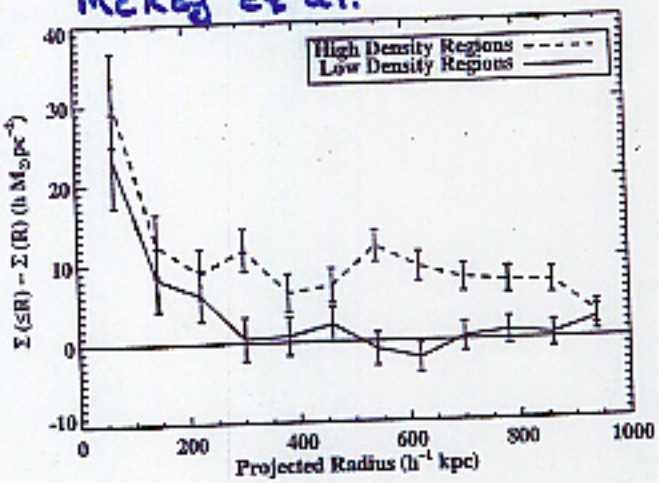
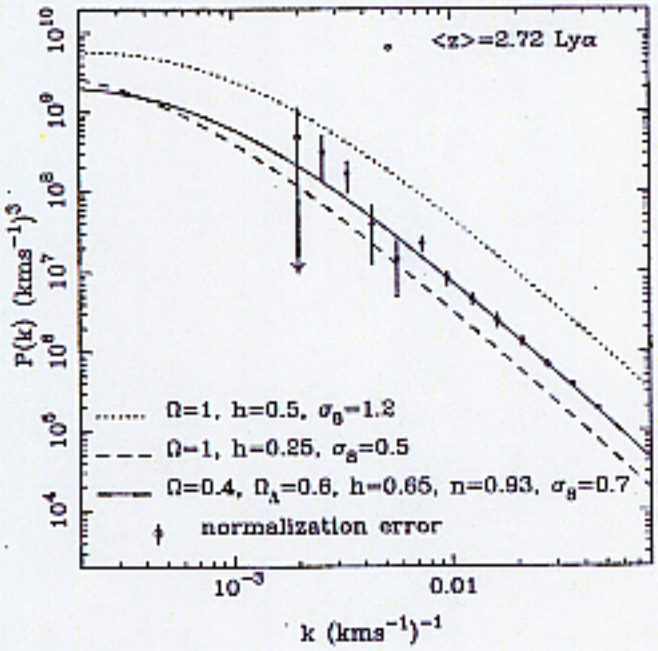
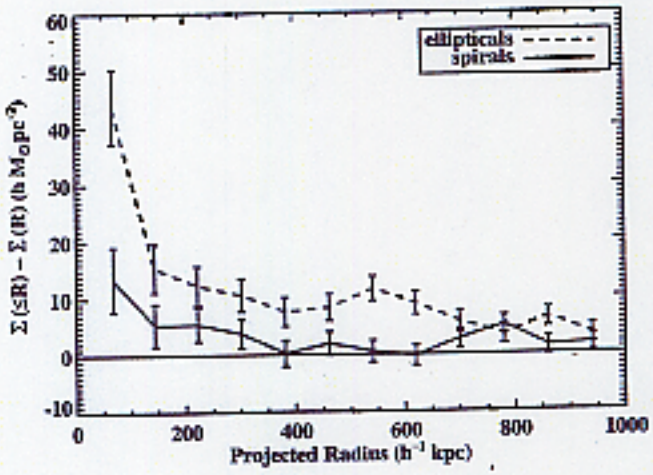
Applications:

- Test galaxy formation theories; learn how to modify them.
- Constrain tensor contribution to CMB anisotropy.
- Constrain dark energy properties.
- Constrain neutrino masses.
- Detect subtle departures from the simplest inflation models (non-scale-invariance, isocurvature component, non-Gaussian component)
- Detect subtle departures from standard matter content (non-BBN $\Omega_{\rm baryon}$, massive neutrinos, extra relativistic background)

Cosmic Shear
Mellier et al.



Galaxy-galaxy lensing
McKay et al.



Lyα Forest P(k)
Croft et al.