Simulating the joint evolution of quasars, galaxies and their large-scale distribution

Springel et al., 2005

Presented by Eve LoCastro

October 1, 2009

Introduction

- Astronomers are still seeking answer(s) to how galaxies form and explanations for large-scale distribution of structure
- Observational surveys (2dFGRS, SDSS; Hubble) have substantially improved knowledge of nearby clustering patterns and physical properties of galaxies
- CDM predicts hierarchical growth of structure via gravitational instability, largely confirmed by observations but more rigorous confirmation requires detailed calculated predictions for comparison
- The authors and members of the Virgo Consortium contrived the *Millennium Run* to reproduce formation and evolution of structure starting at earliest seed perturbations

Outline

- New galaxy surveys are giving new, insights into clustering patterns and physical properties of galaxies
- Necessary to have robust prediction of CDM for comparison; made difficult by non-linear behavior of DM at early, small scales
- The *Millennium Simulation* is the largest, most-intricate attempt to model evolution of dark and baryonic matter into large-scale structure

The Millennium Run

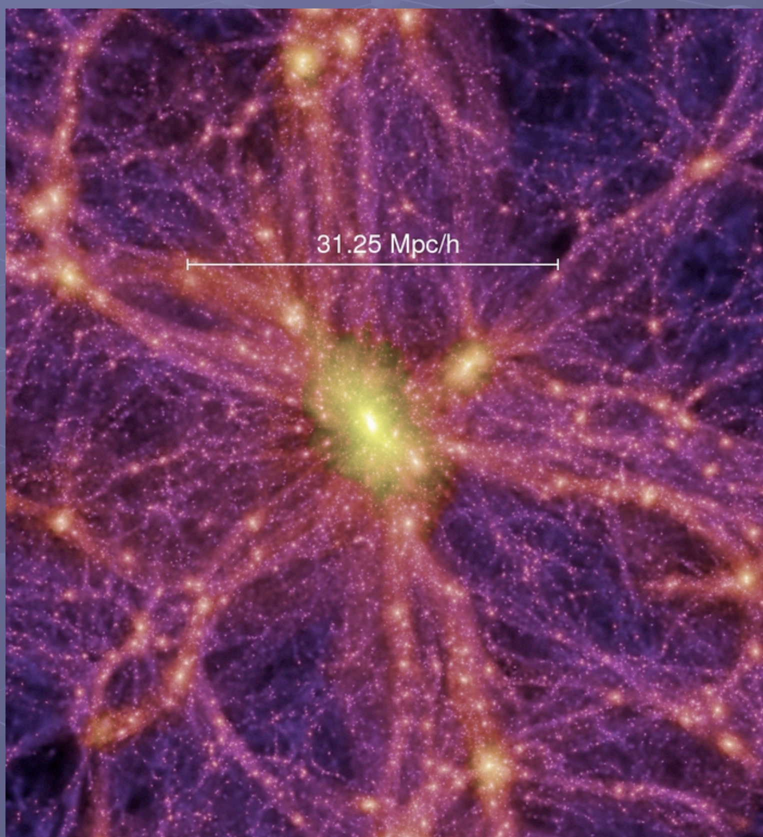


Image credit: the Virgo Consortium

- Completed 2004 after a month of processing
- *N*-body simulation evolved 2160^3 particles of baryonic and dark matter from z=126 through present epoch
- Cubic region measuring $500h^{-1}$Mpc per side; mass approx by $10^8 M_\odot$ particles
- Periodic boundary conditions

Dark Matter: Halo History

- Results of this and prior simulations show dark matter with complex filamentary structure, stretching in all directions through space
- Exceptionally-concentrated nodes of dark matter contain many halos that have gravitationally accumulated over time
- The formation of structure is detailed by merger-tree history of objects

Image credit: the Virgo Consortium

Dark Matter Halos & Galaxies

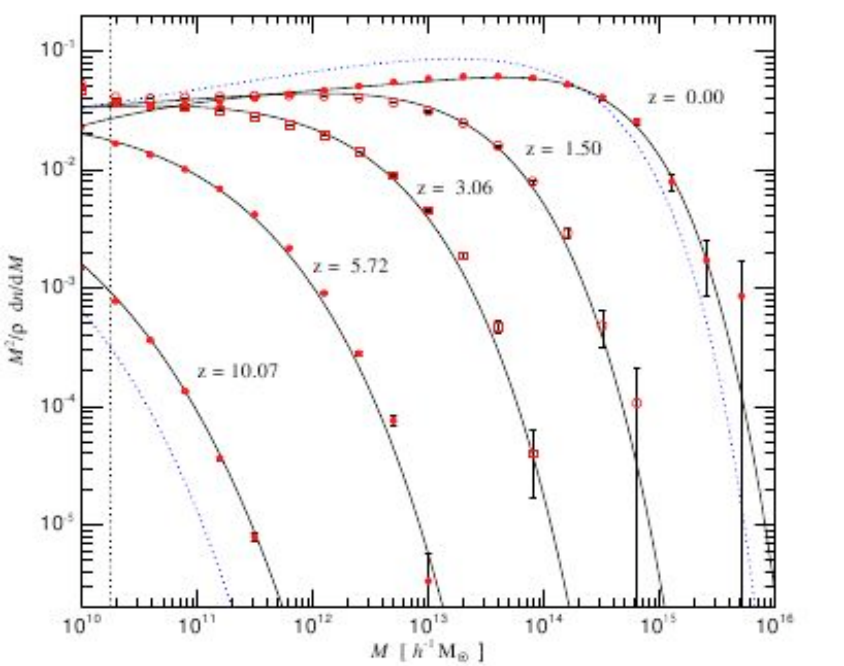


Figure 2: Differential halo number density as a function of mass and epoch. The function $n(M,z)$ gives the comoving number density of halos less massive than M. We plot it as the halo multiplicity function $M^2\rho^{-1}\mathrm{d}n/\mathrm{d}M$, where ρ is the mean density of the universe. Groups of particles were found using

- Snapshots of differential halo number density by mass
- Weighted by ρ, mean density of universe (ρ was greater at earlier times)
- *Dotted lines* are Press-Schecter predictions at z=10.07 and z=0

From Springel et al., 2005

The Earliest Quasars

- Furthest quasars lie near z=6.43, housing extremely massive black holes (~10^6 $M_\odot$)
- Such early, massive bodies extremely rare co-moving density $2.20\{\pm.73\}\times10^{-9}$ $h^3\mathrm{Mpc}^{-3}$
- Should be ~<1 in volume of M.S.

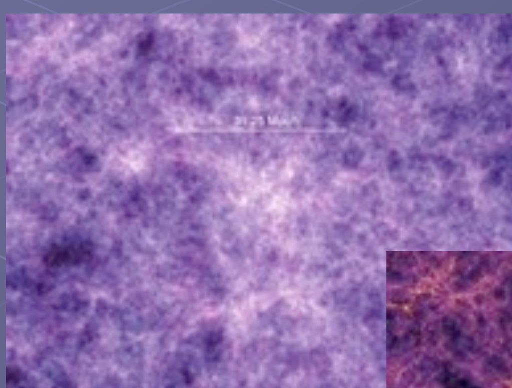



Image credit: the Virgo Consortium

Fate of the quasars?

- Three methods of combing through results to classify massive objects: halo mass, stellar mass, or instantaneous S.F.
- Environment of quasar candidate: sits on highly prominent dark matter filament flanked by a large number of smaller, fainter "galaxies"
- M.S. data, can trace the evolution of quasar from earliest progenitor at z=16.7, one of only 18 collapsed objects in entire volume
- Simulating into future, quasars become central objects in massive galaxy clusters

Clustering evolution of dark matter & galaxies

- Large volume and mass content of M.S. allows significant statistical calculations on clustering of galaxies, i.e. a 2-point correlation function
- Galaxy clustering in simulation reproduces dependence of slope on magnitude and color, but a difference in amplitude—unaccounted physics process?
- Modes of dark matter power spectrum grow linearly at earliest times; nonlinear evolution first affects smallest scales

Galaxy 2-point correlation function

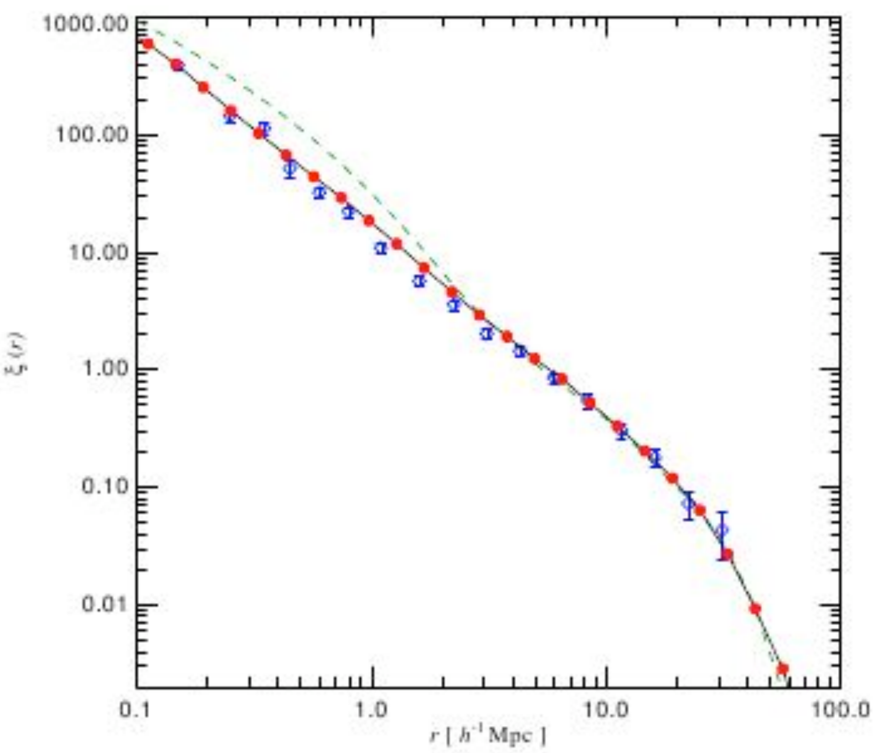


Figure 4: Galaxy 2-point correlation function at the present epoch. Red symbols (with vanishingly small Poisson error-bars) show measurements for model galaxies brighter than $M_K = -23$. Data for the large spectroscopic redshift survey 2dFGRS[28] are shown as blue diamonds. The SDSS[34] and APM[31] surveys give similar results. Both, for the observational data and for the simulated galaxies, the correlation function is very close to a power-law for $r \leq 20\,h^{-1}$ Mpc. By contrast the correlation function for the dark matter (dashed line) deviates strongly from a power-law.

Galaxy clustering

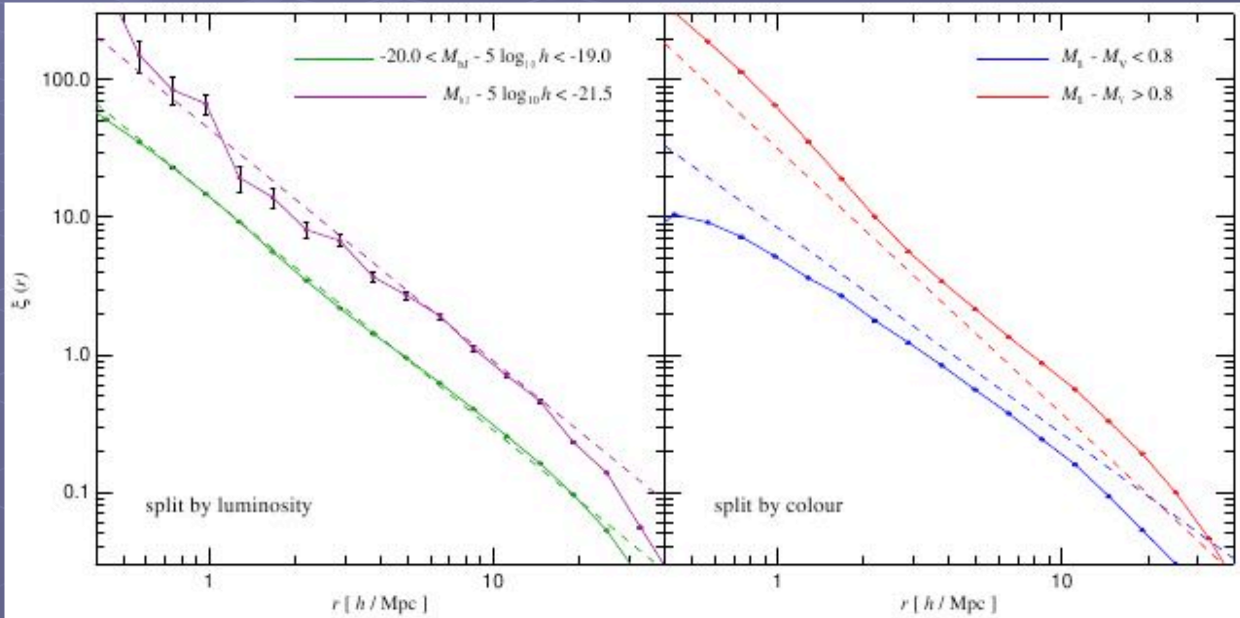
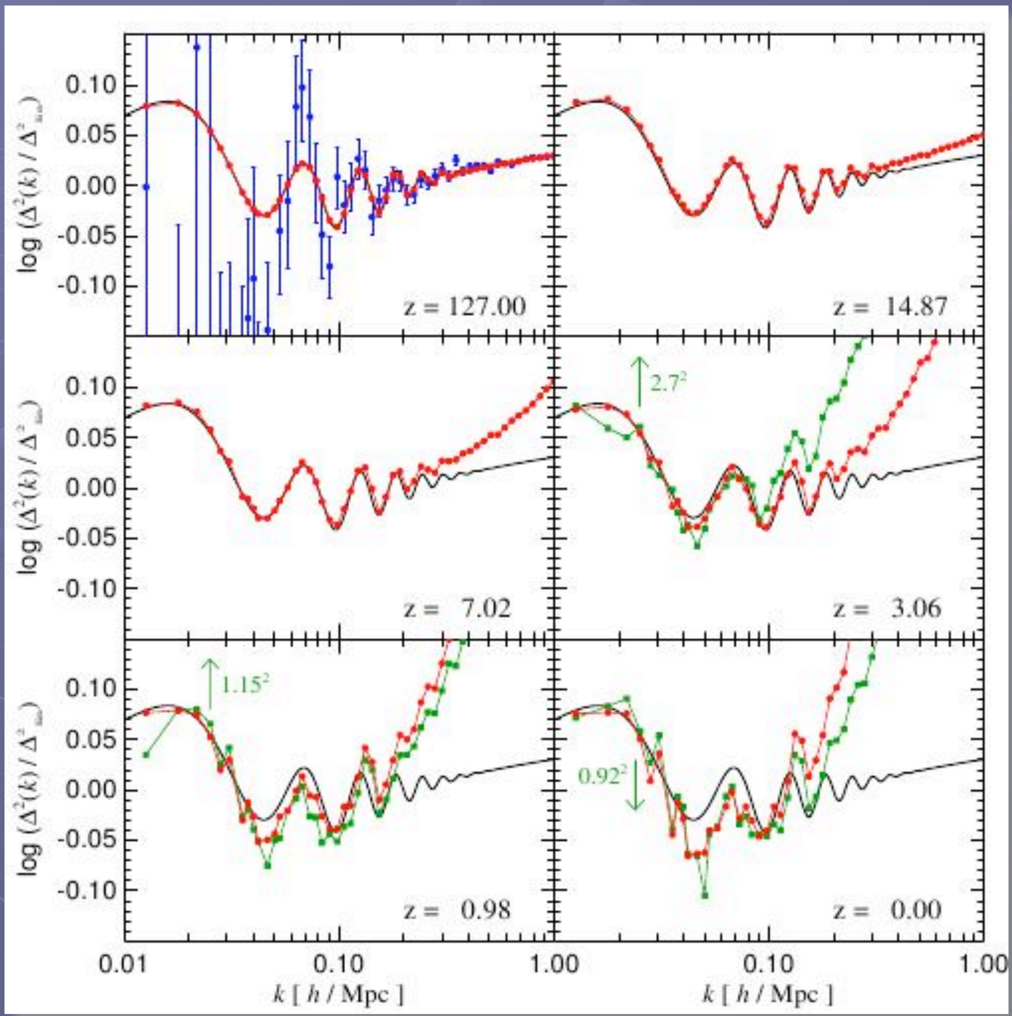


Figure 5: Galaxy clustering as a function of luminosity and colour. In the panel on the left, we show the 2-point correlation function of our galaxy catalogue at $z = 0$ split by luminosity in the bJ-band (symbols). Brighter galaxies are more strongly clustered, in quantitative agreement with observations[33] (dashed lines). Splitting galaxies according to colour (right panel), we find that red galaxies are more strongly clustered with a steeper correlation slope than blue galaxies. Observations[35] (dashed lines) show a similar trend, although the difference in clustering amplitude is smaller than in this particular semi-analytic model.

From Springel et al., 2005

"Wiggle" Room



- Evolution of the power spectrum from sim start, divided out by CDM spectrum to leave signature ripples
- Black curve traces same initial conditions for comparison as structure develops
- Red is dark matter
- Green is galaxies

From Springel et al., 2005

Conclusions

- Dark matter:
  - *Predicts hierarchical growth of structure*
  - *Results of M.S. disagree with Press-Schecter by order of magnitude, agree with obs. surveys*
- Quasars:
  - *Formed at locations of earliest collapsed objects; now believed to be enjoying retirement at centers of massive clusters*
- Large Scale Structure
  - *Baryon acoustic oscillations of CMB should be detectable in power spectra of galaxy distribution at z<3 and low-z NL dark matter power spectrum*
  - *Will put constraints on dark energy*