STRUCTURE FORMATION: SUMMARY

Model Ingredients

- Properties of primordial fluctuations
- Material contents of universe
- Cosmological parameters
- Galaxy/star formation assumptions

Observables

(1) "Direct" parameter measurements
(2) CMB anisotropies
(3) Galaxy properties
(4) Galaxy clustering
(5) Cluster properties
(6) Cluster clustering
(7) Intergalactic medium (IGM)
(8) Gravitational lensing

Items (3)-(7) can be studied at $z = 0$ and (in less detail) as a function of redshift.
Simulations play a major role in predictions for items (3)-(8).
The large obstacle in (3) and (4) is the complexity of the physics of galaxy formation.

Dual Role of Simulations

- *Given* a cosmological model, understand the physics of structure formation and interpret observations.
- Predict observables in order to test cosmological models against observational data.

Second goal puts much higher demands on accuracy of simulations.
Simpler physics $\Longrightarrow$ more robust cosmological tests.

Types of Simulations

LOW RESOLUTION N-BODY
- mass clustering
- + bias prescription $\longrightarrow$ galaxy clustering

HIGH RESOLUTION N-BODY
- halo clustering
- halo mass profiles

LOW RESOLUTION HYDRO
- diffuse IGM
- cluster gas (probably wrong)
- galaxy masses/luminosities and clustering (probably wrong)

MEDIUM RESOLUTION HYDRO
- diffuse IGM
- cluster gas
- galaxy masses/luminosities and clustering

HIGH RESOLUTION HYDRO
- galaxy properties and their evolution

What have we learned so far?

Observed structure in the universe is well explained by a model with
- Adiabatic, Gaussian initial fluctuations with
- A nearly scale-invariant primeval $P(k)$, $n_p = 1.0 \pm 0.3$
- Cold dark matter
- $\Omega_M h \times \exp\left[-\Omega_b\left(1+\frac{\sqrt{2h}}{\Omega_M}\right)\right] - 0.32\left(\frac{1}{n_p}-1\right) \approx 0.2$
- $\sigma_8 \Omega_M^{0.5} \approx 0.5$
- $H_0 \approx 70$ km s^{-1} Mpc^{-1}
- $\Omega_M = 0.4 \pm 0.2$
- $\Omega_{\rm VAC} \approx 1 - \Omega_M$
- Galaxies roughly tracing mass on large scales

BUT
- Galaxy bias depends on luminosity, type, redshift
- Galaxy bias is complicated on small scales ($r < 5h^{-1}$Mpc)
- Nagging problems remain with galaxy luminosities, disk sizes, rotation curves

Computing Our Universe, Structure Summary David Weinberg

Anticipated observational revolutions

- Greatly improved CMB measurements
- 2dF and Sloan redshift surveys
- Sloan and 2MASS galaxy properties
- Larger high redshift galaxy samples
- Evolution of galaxy clustering
- Weak lensing by large scale structure

also

- Lyα forest analysis
- Cluster data: weak lensing, Sunyaev-Zel'dovich, X-ray

Theoretical frontiers

Physics of galaxy formation, quasar formation

High precision, redundant tests of "standard model" (inflation + CDM)
Subtle departures from predictions of simplest model could give clues to

- nature of vacuum energy
- physics of inflation/early universe ($n_p \neq 1$, gravity waves, isocurvature contributions, small departures from Gaussianity, high Ω_b)
- properties of dark matter
- neutrino masses
- non-standard particle content