Effect of Baryons and Dissipation on the Matter Power Spectrum

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November 28, 2006

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Talk Outline

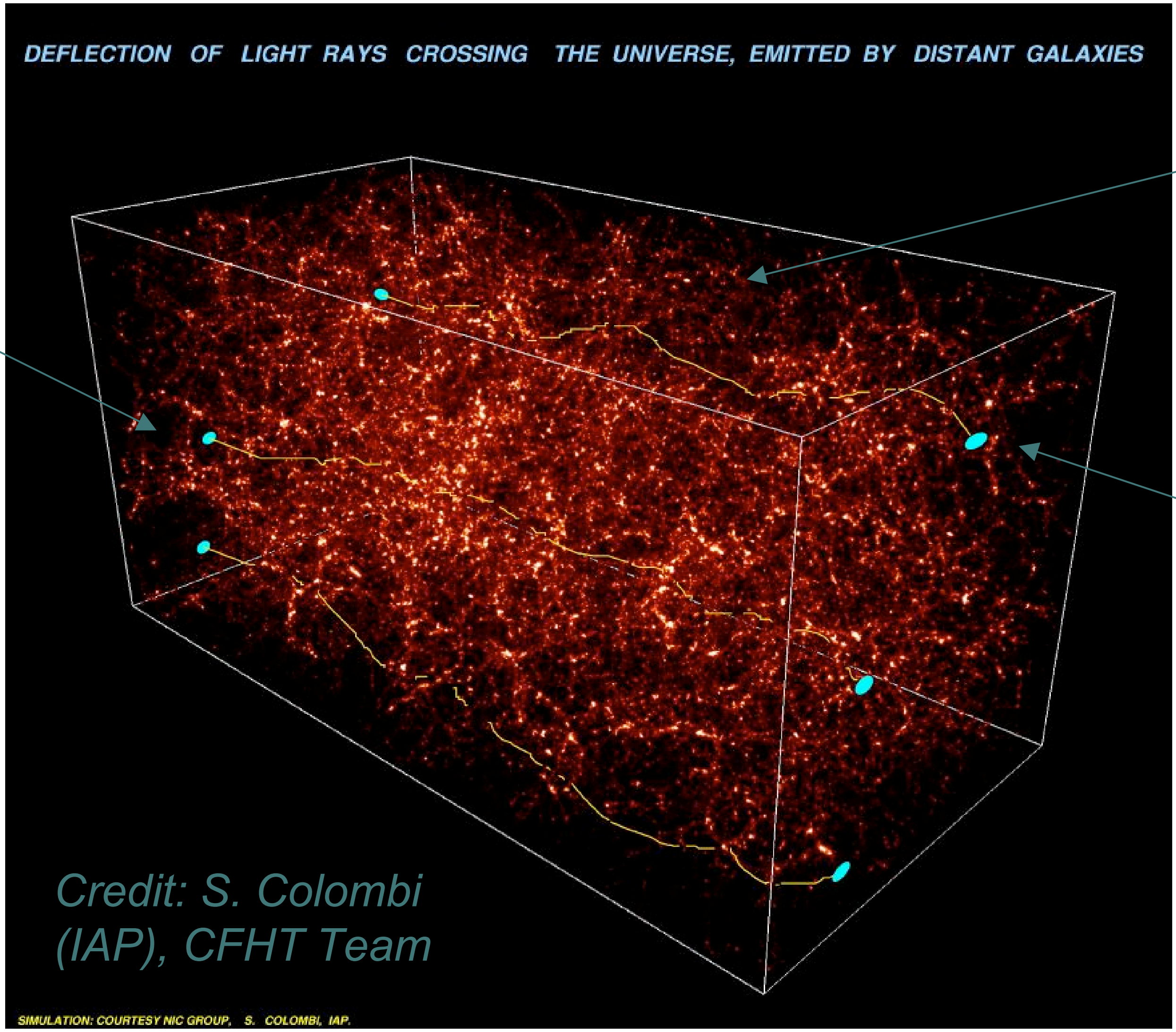
- Introduction to weak lensing
- Baryon Effects
- Simulation Results
- Interpreting Simulations with the Halo Model
- Large Cluster Simulations

Weak Lensing (weak introduction)

nitial image
hapes

e review articles by
tlemann &
neider (1999) and
regier (2004)

references therin



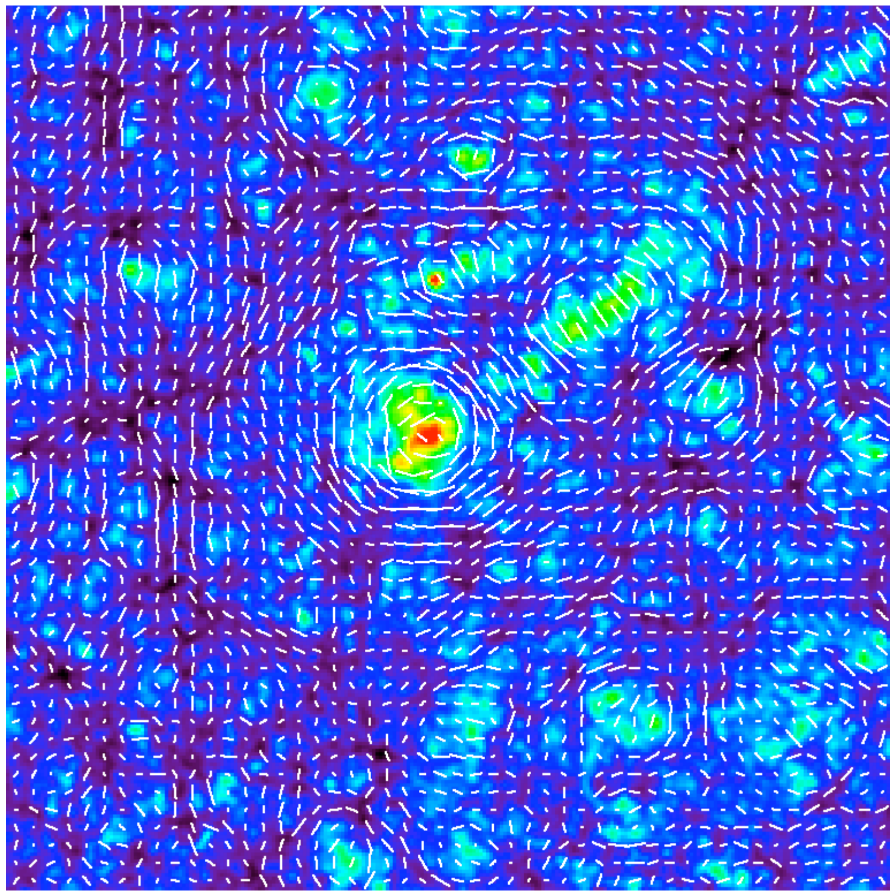
Large
scale
structure

Final image
shapes slight
distorted by
gravitational
lensing

Weak Lensing

Gravitational lensing causes tangential distortions (or shear)

Very weak effect and degenerate with already elliptical sources (galaxies)



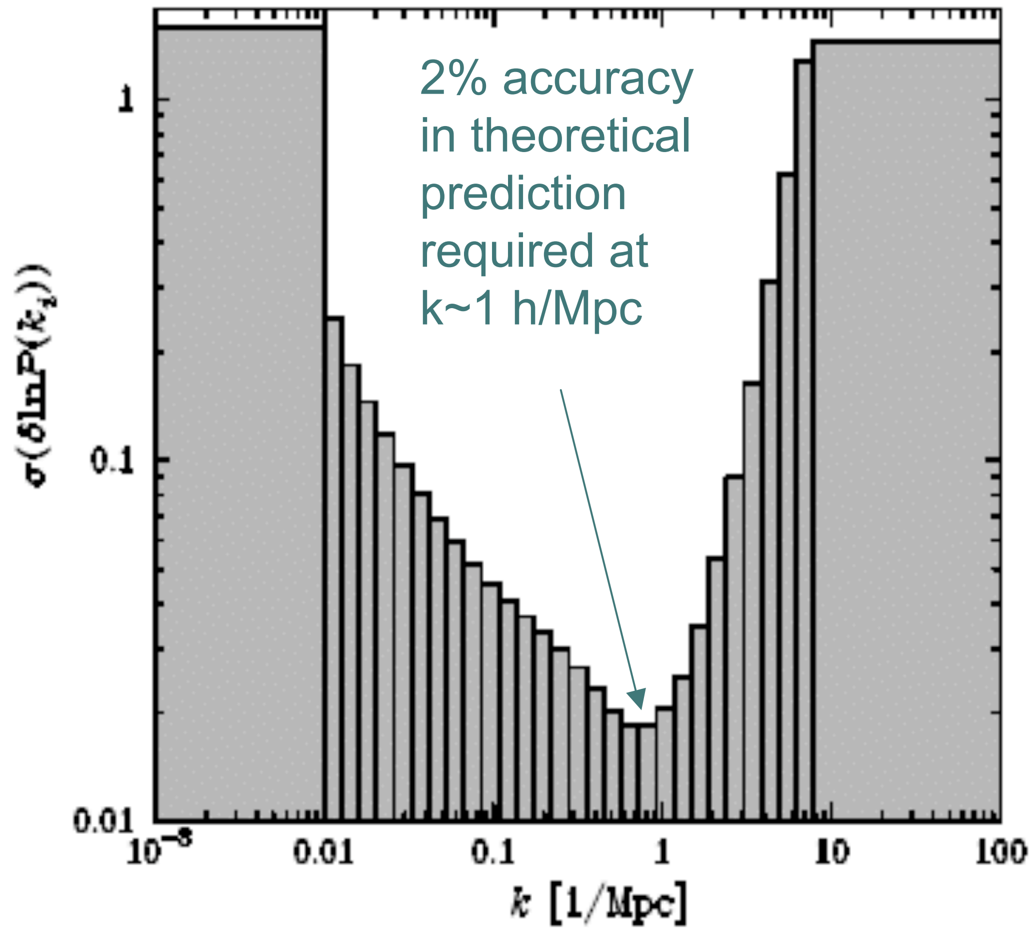
stolen from Henk Hoekstra
(http://www.cita.utoronto.ca/~hoekstra/lensing.html)

Detected statistically using many galaxies (sources) whose ellipticities become correlated

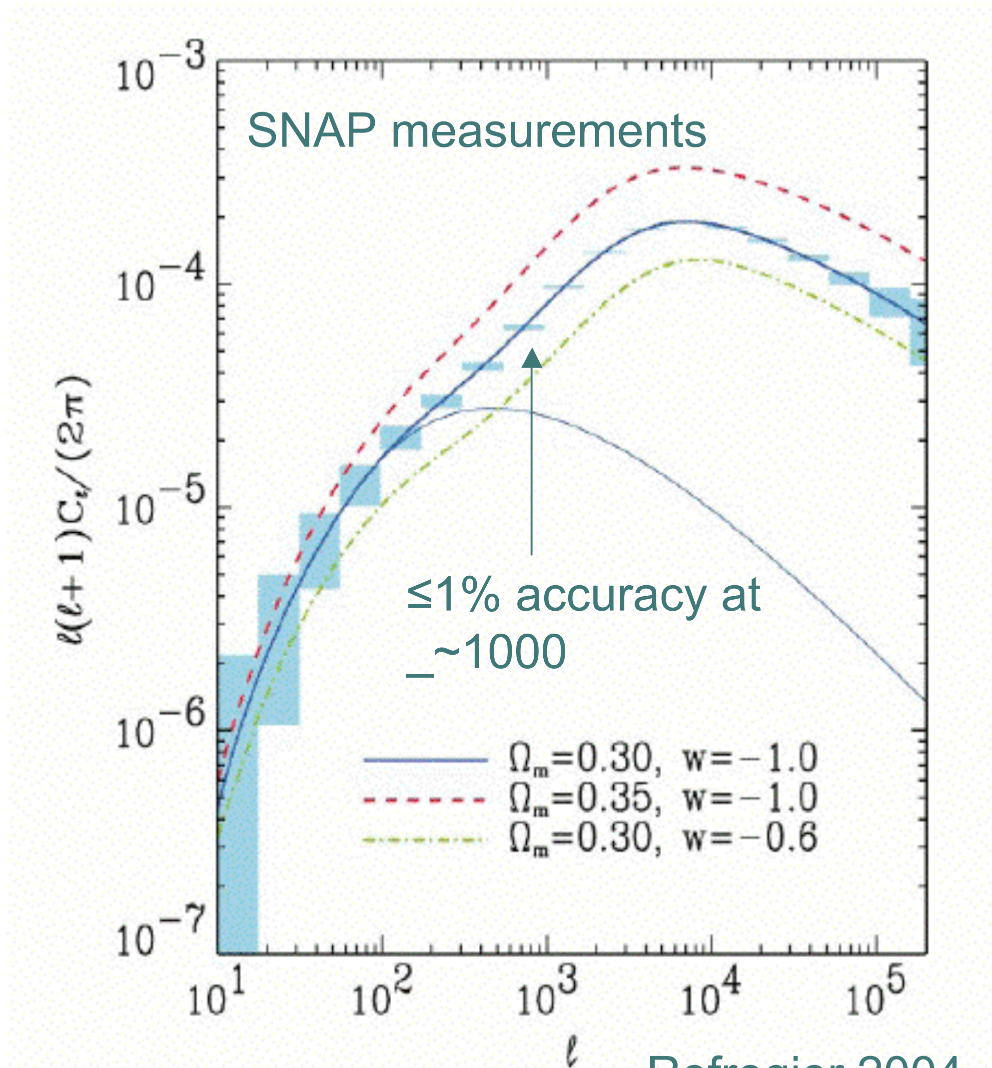
For cosmology, pow spectrum of the measured shear field is a direct probe of th underlying matter distribution (modulo theory)

Cosmology with Weak Lensing

Place constraints on _8, _m, w



Huterer & Takada 2005

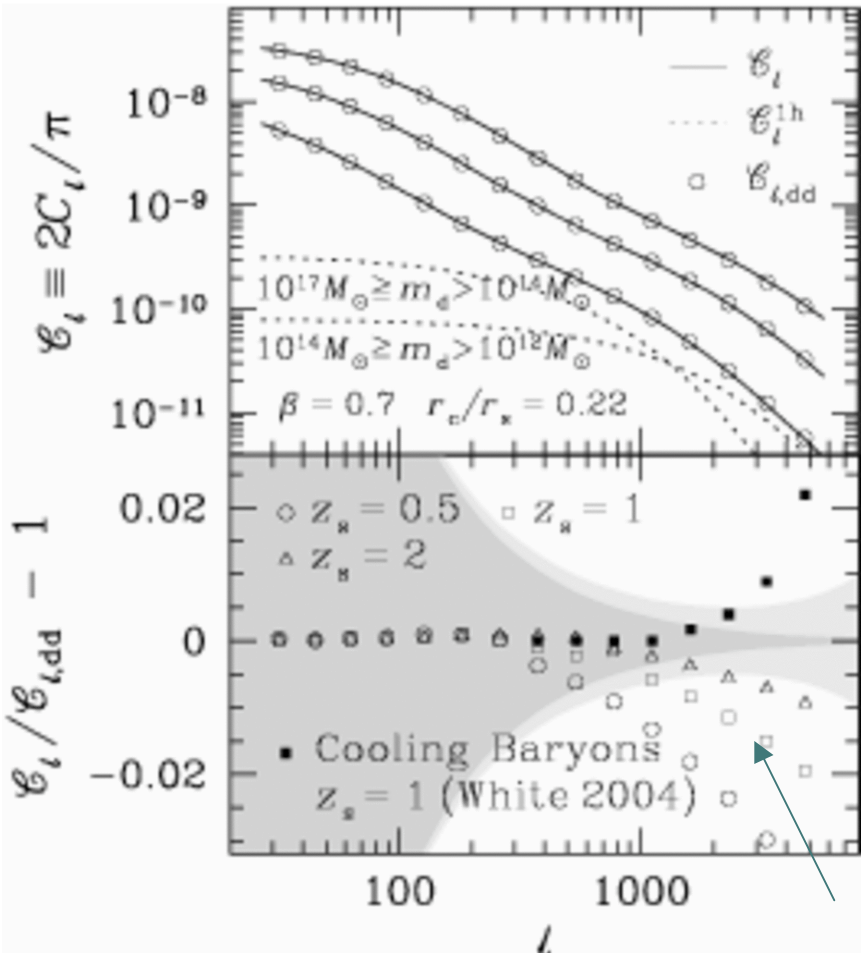


Refregier 2004

Predicting Non-linear P(k)

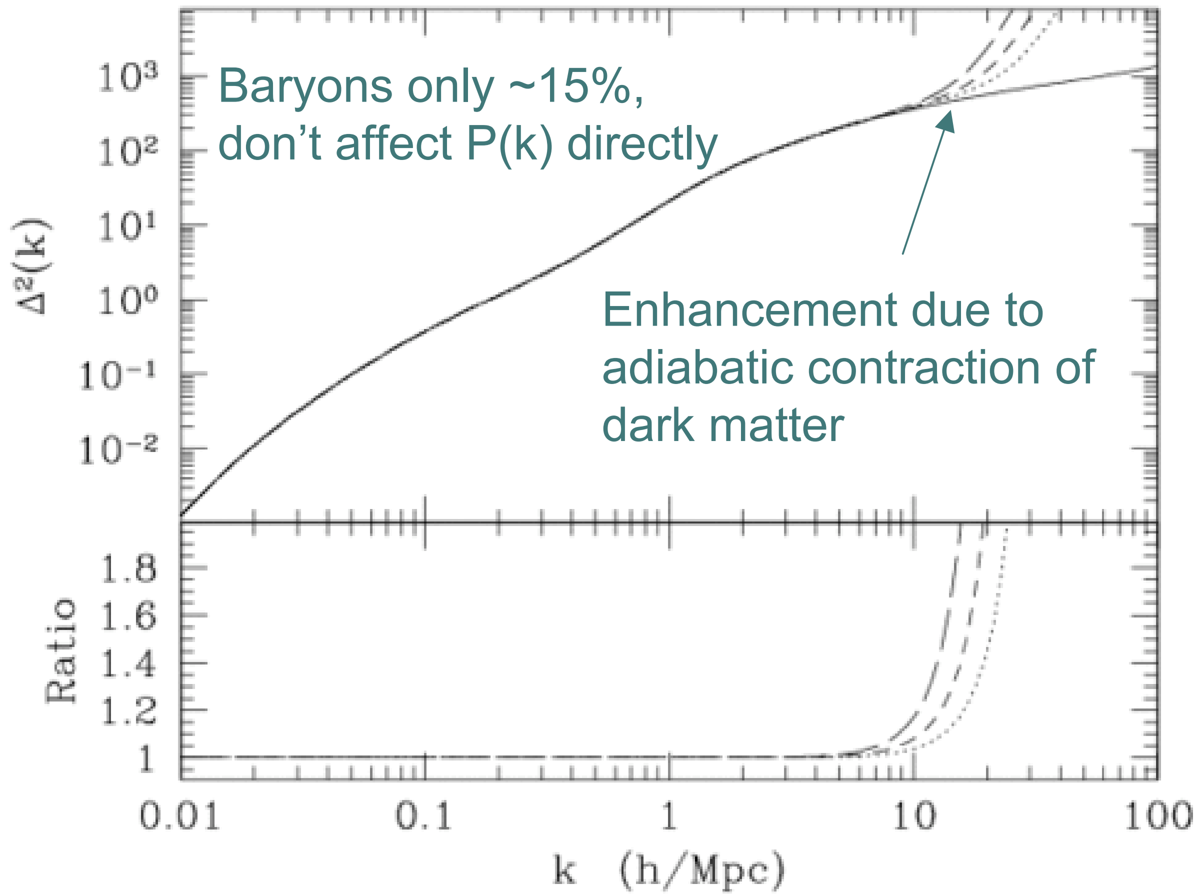
- Current fitting formula (Peacock & Dodds 1994, Smith et al 2003) only accurate to ~10%
- Can measure P(k) directly from numerical simulations
  - Now cheap enough to do N-body simulations for range of cosmological parameters
  - Question: do baryons trace dark matter well enough at large scales to use dissipationless simulations?

Semi-analytic Treatments



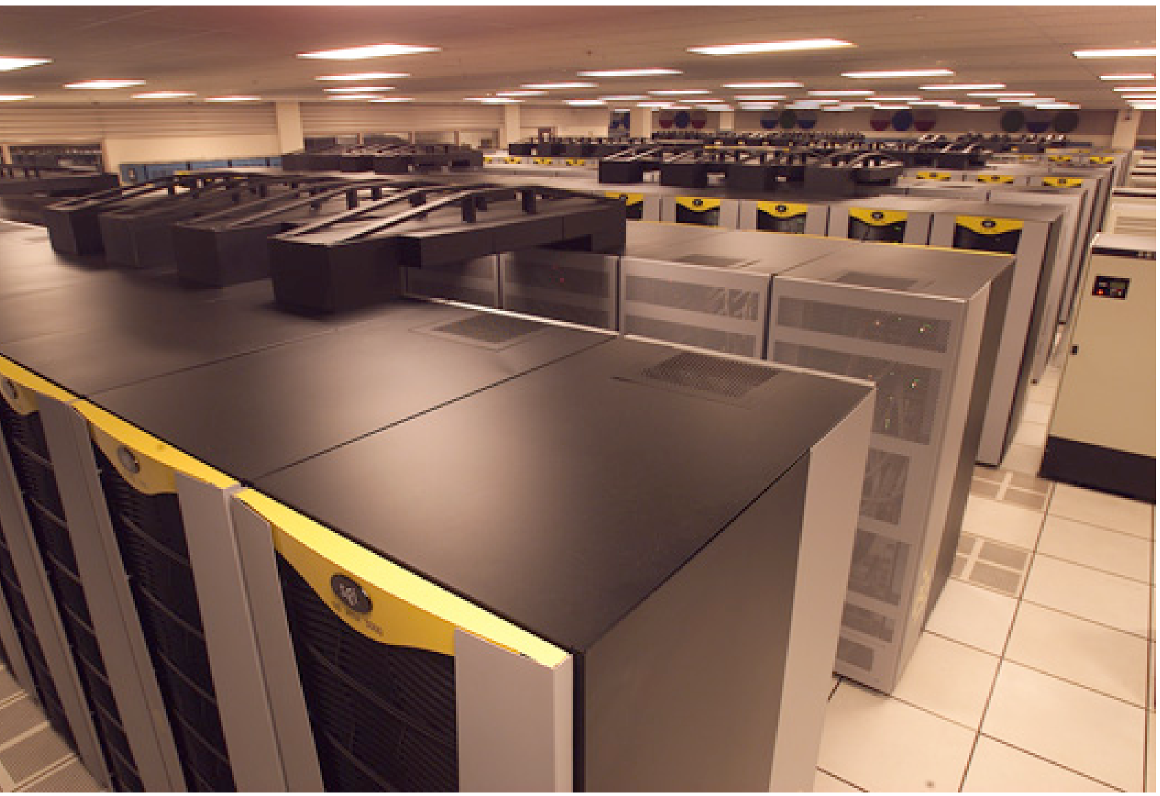
Zhan & Knox 2004

Suppression due to hot baryons



M. White 2004

Distributed ART Code



Columbia Supercomputer, NASA Ames

- Reimplementation of algorithms developed by Andrey Kravtsov and Anatoly Klypin (1998)
- Distributed parallel (MPI) to take advantage of modern supercomputers
- Necessary to add baryons to large-box simulations already probed by N-body simulations

Measuring Effect in Simulations

simulations
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itial conditions

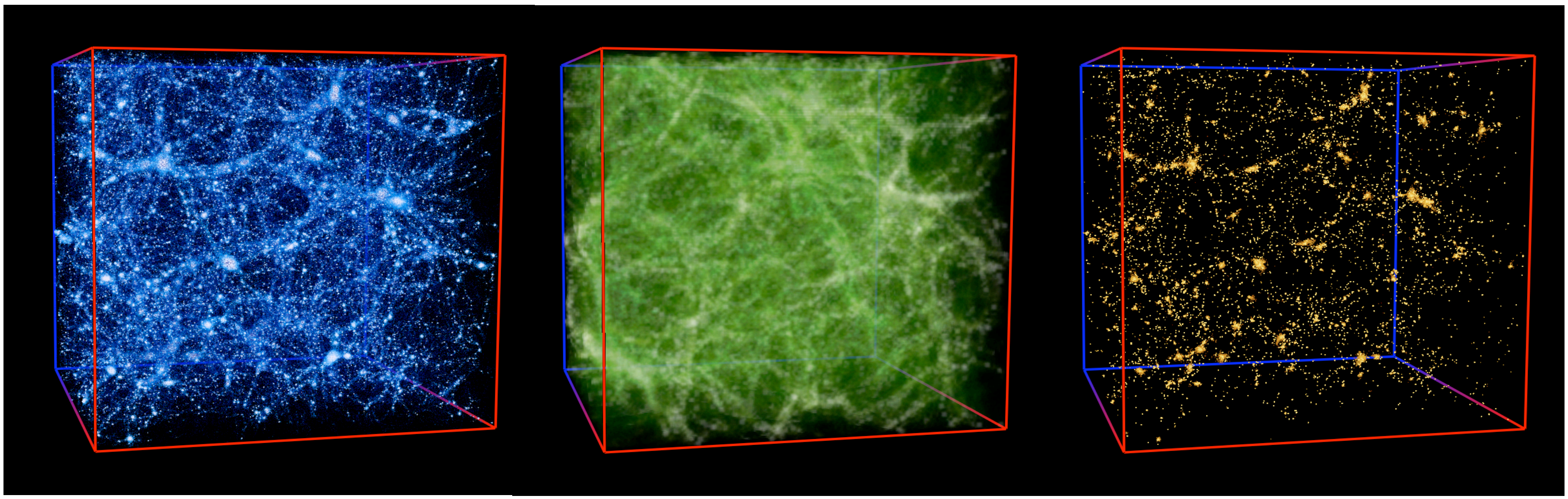
oncordance
osmology

_m = 0.3

__ =0.7

_8 = 0.9

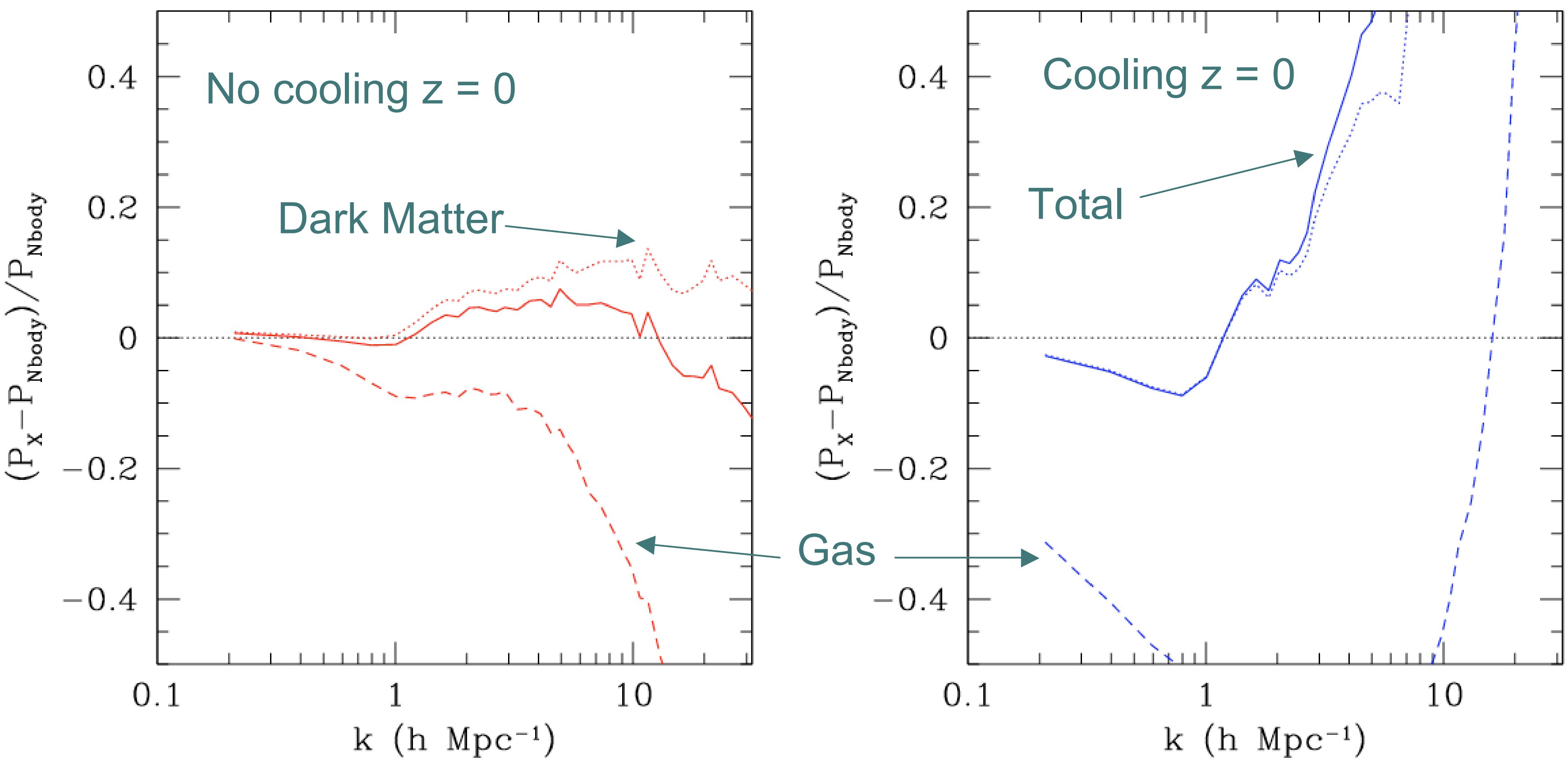
Dark Matter only | Non-radiative Gas & DM | Cooling and Starformation



60 h^{-1} Mpc box, 256^3 particles, 1 billion cells, ~30,000 CPU hours on 64 processors (cooling simulation), 1-3 kpc resolution: dynamic range of $O(10^5)$

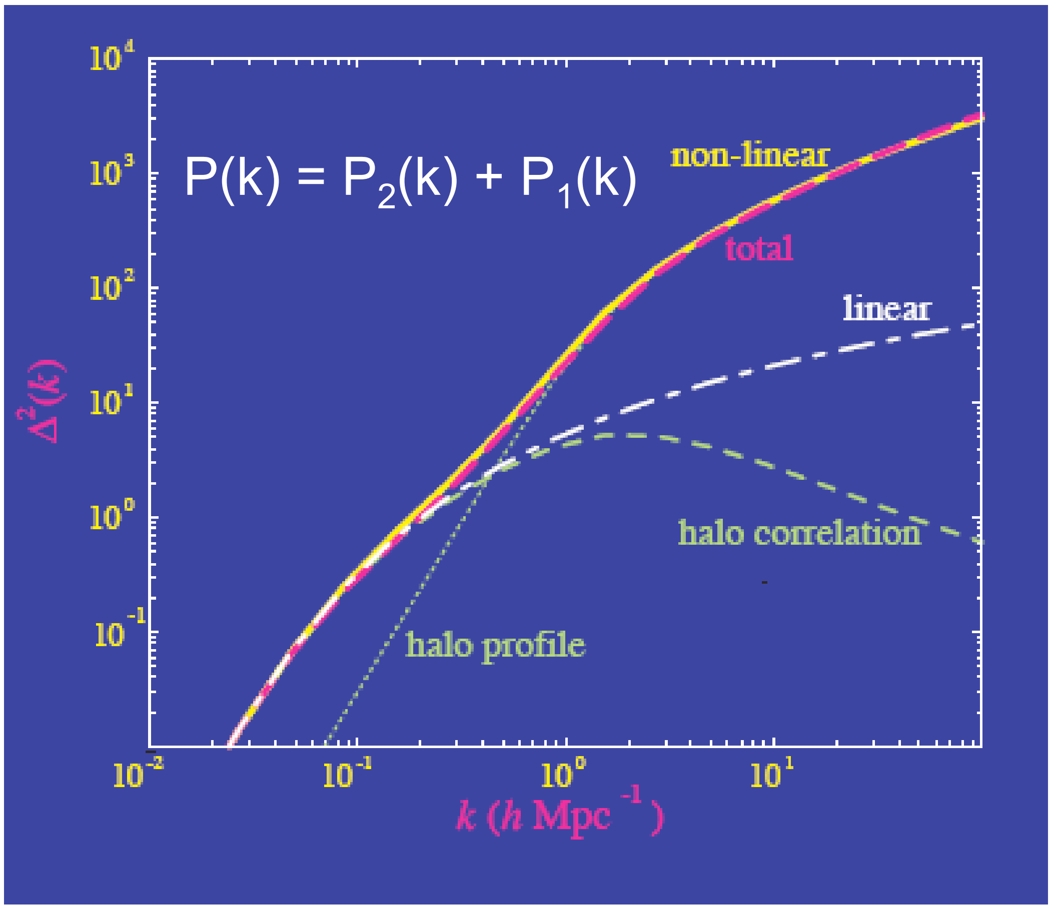
Simulated Power Spectra

Fractional difference in Power Spectrum



Qualitatively similar result found by Jing, et al. 2006

Halo Model Introduction



- Analytic method for predicting matter (or galaxy) power spectrum given input linear power spectrum
- Divides non-linear power spectrum into 2 pieces
  - Contribution from correlation of halos (linear on large scales)
  - Contribution from correlation within halos themselves

Credit: Wayne Hu   See review article Cooray & Sheth (2002) for more details

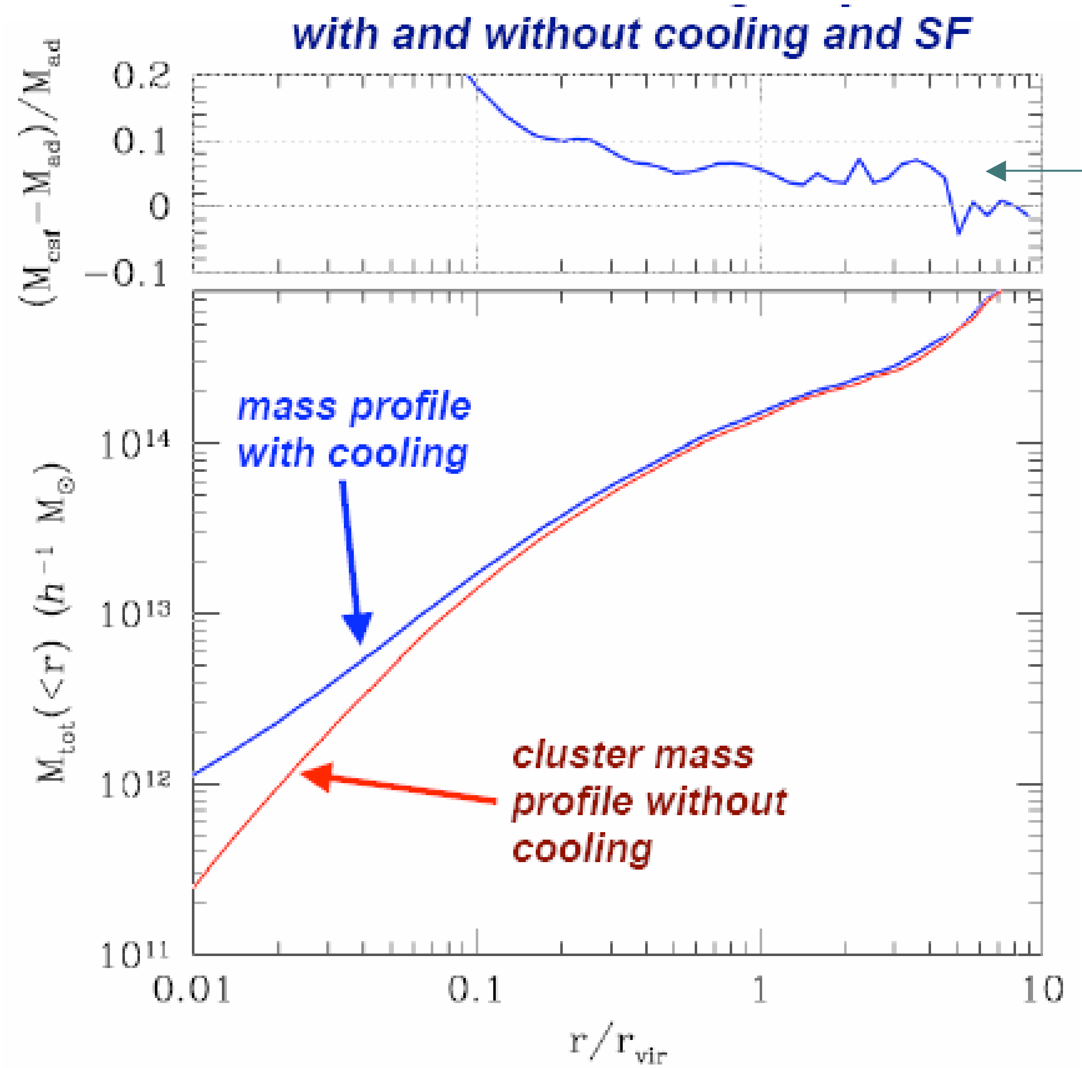
Effect of Cooling on Halo Profiles

Condensation of baryons at center causes contraction of dark halo

(inside 0.1 r_{vir})

“Adiabatic Contraction”

Blumenthal et al (1986), Gnedin (2004)

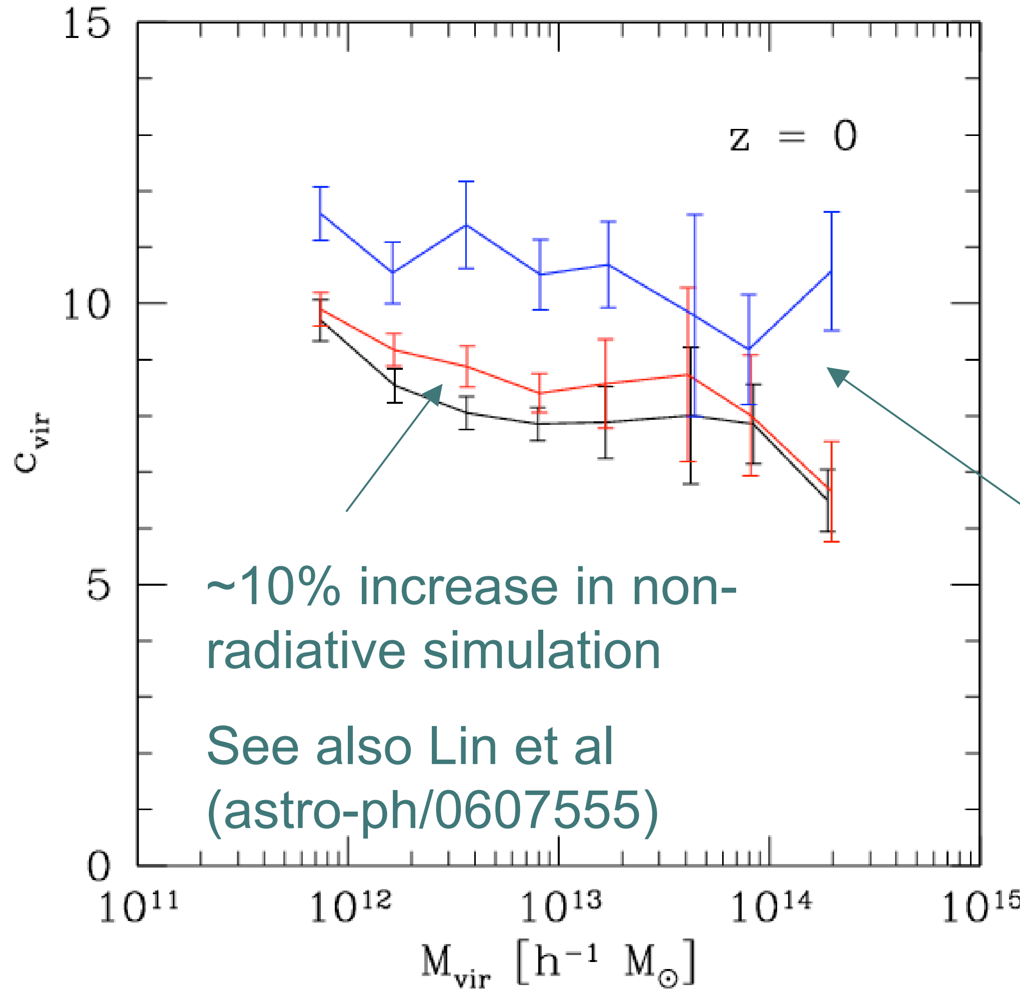


~5% effect all th way to the virial radius

(larger effect in r simulations)

High resolution cluster simulations by Nagai (2005,2006)

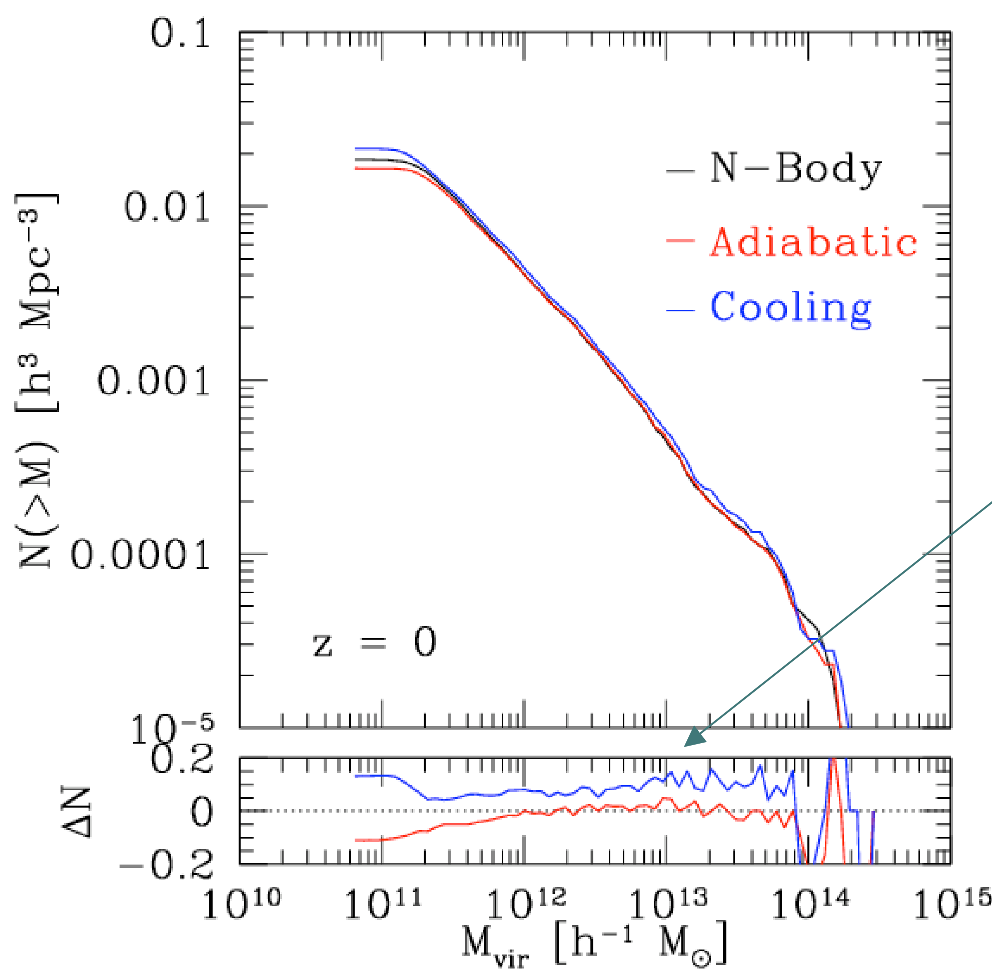
Dark Matter Halo Concentrations



Halo Mass Function

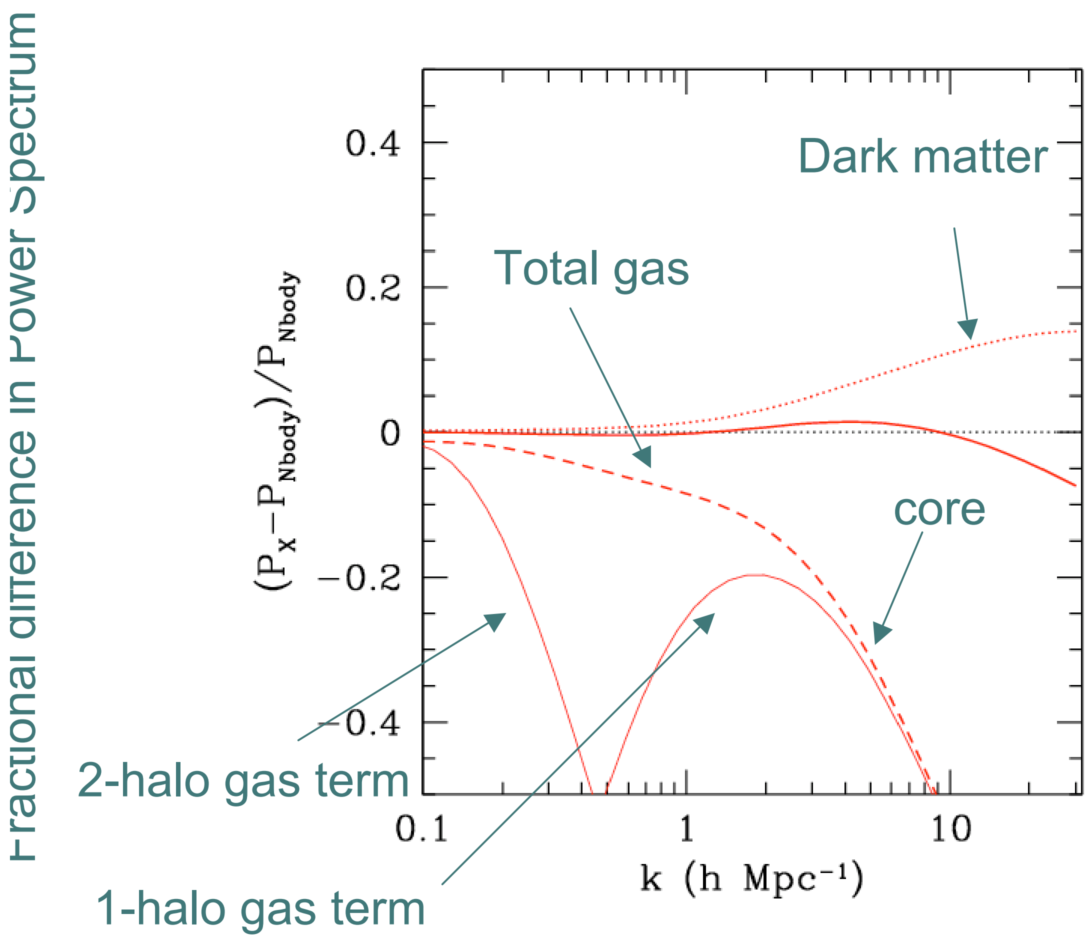
Caution:
definition of halo mass depends on profile when using fixed overdensities

Halo clustering unaffected by cooling



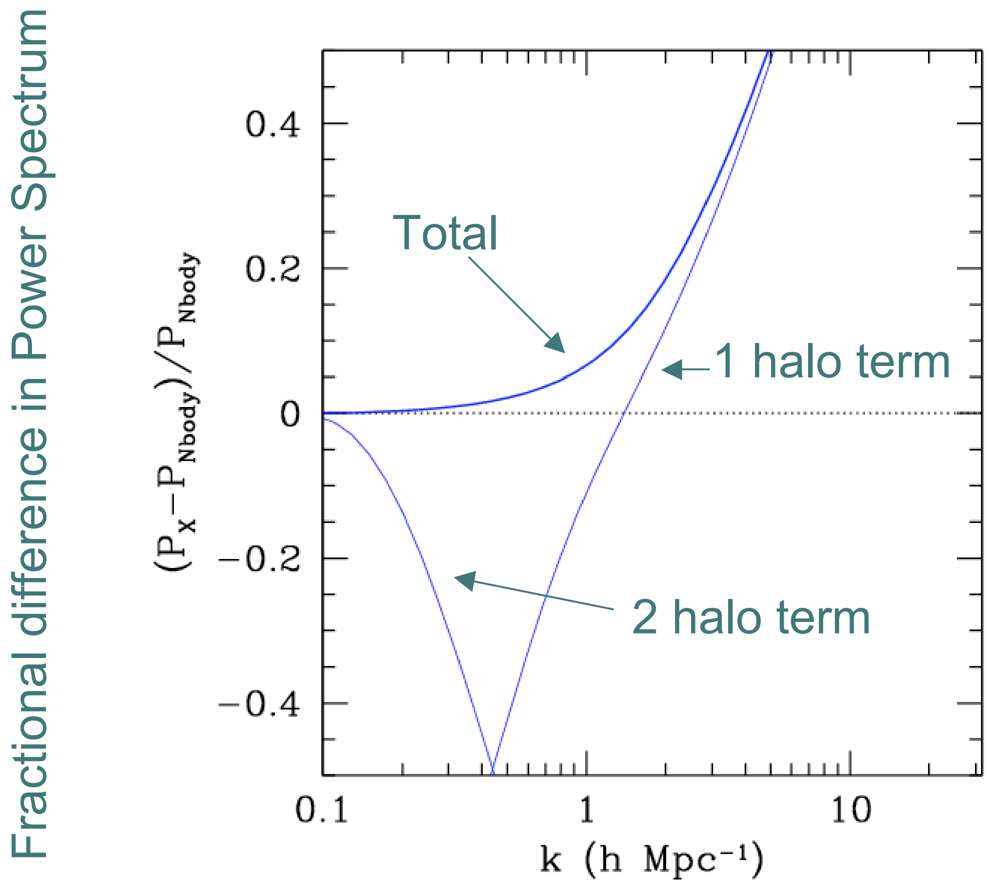
Mass function in cooling simulation 10
higher then N-body and non-radiative simulations (due to condensed baryons)

Non-Radiative Halo Model



- Gas treated as separate component, fit with a Burkert (cored) profile
- NFW profile concentrations of dark matter halos increased by ~10% (Lin et al 2006)

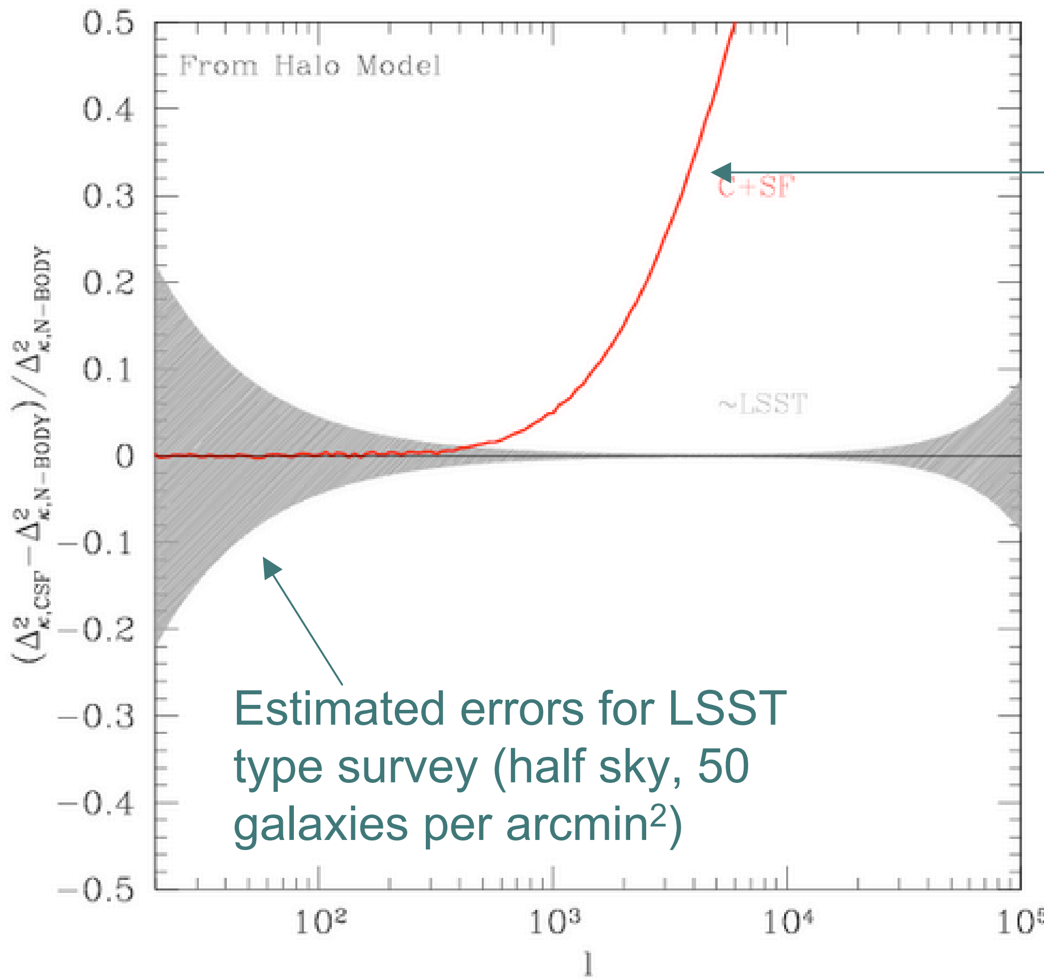
Cooling Simulation Halo Model



- Total mass (gas + stars + dark matter) well fit by single NFW profile
- Power spectrum starts to change at transition between 1 and 2-halo terms (due to 1-halo term)

Convergence Power Spectrum

Fractional difference in Power Spectrum



Estimated errors for LSST type survey (half sky, 50 galaxies per arcmin^2)

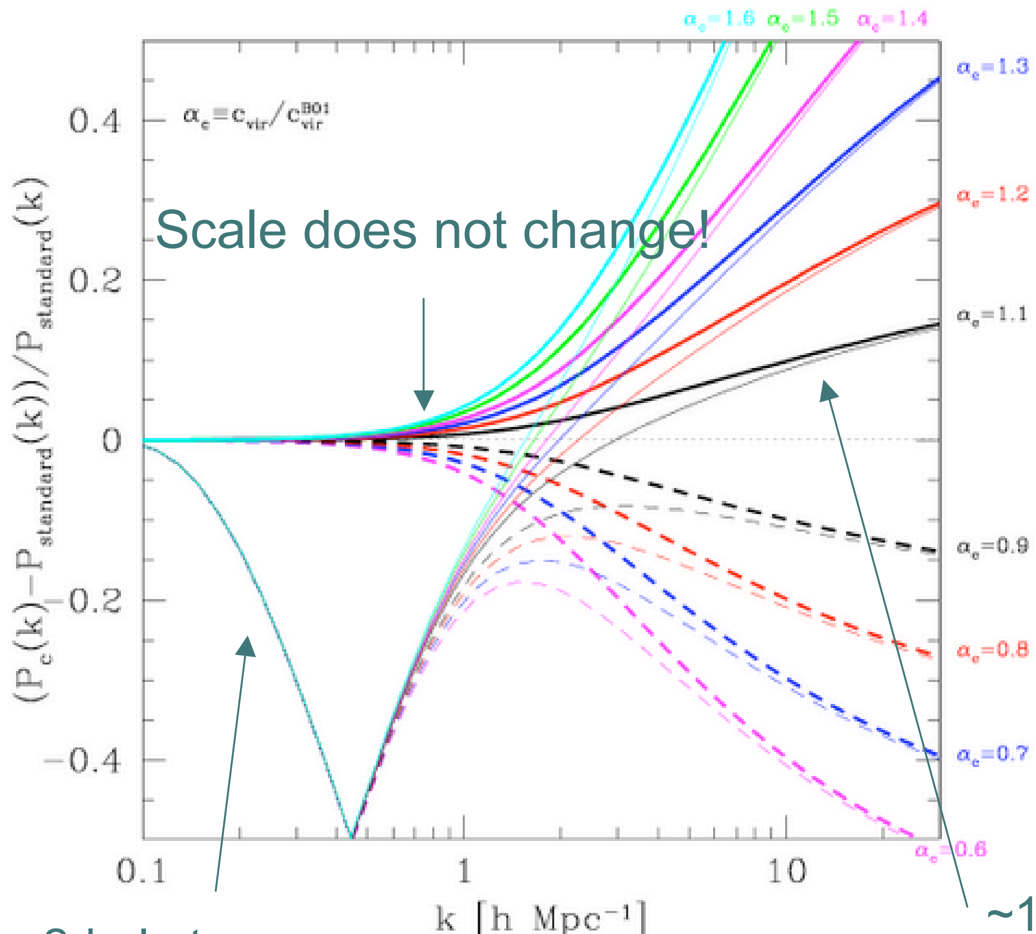
Halo model prediction given properties in simulation

Halo model predi given halo prope in simulation

Magnitude is affe by numerical overcooling in simulation

Halo Concentration Connection

Fractional difference in Power Spectrum



Scale does not change!

2-halo term

Halo model predictions concentrations are va (increasing and decre factors of 10%)

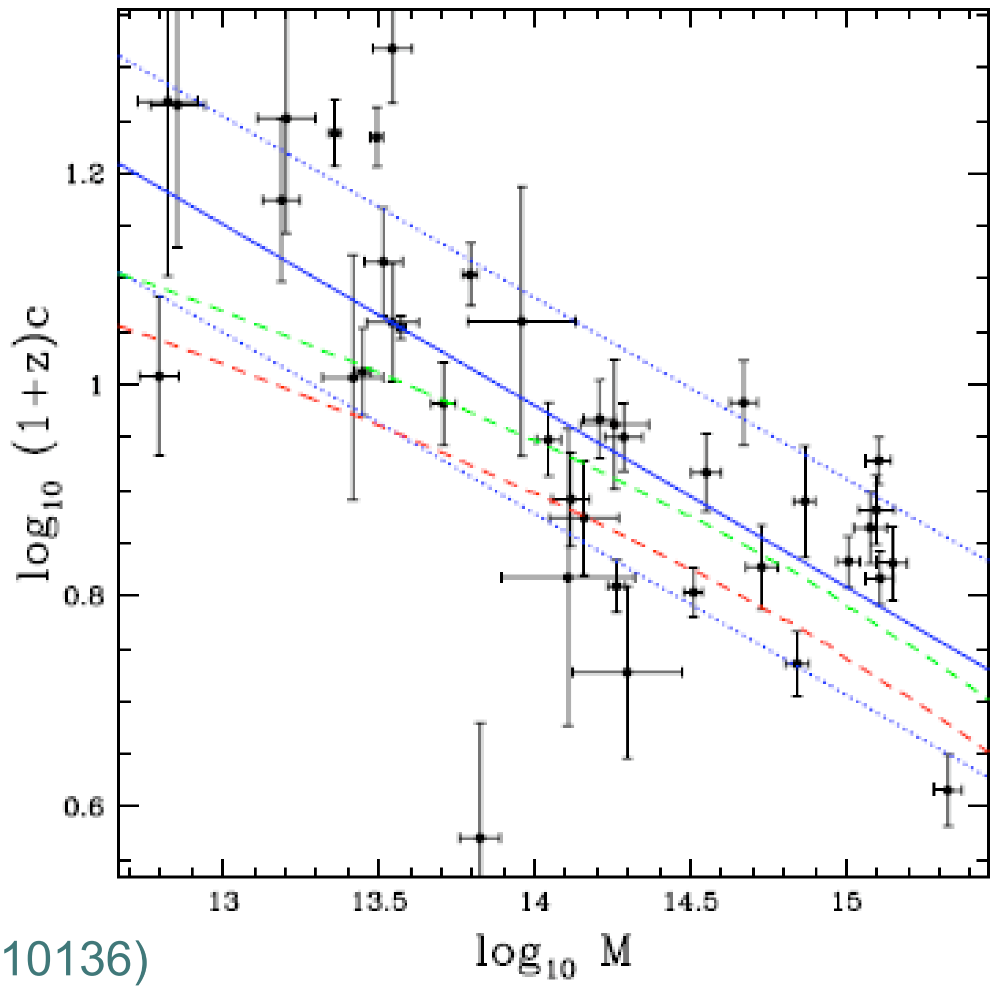
~10% boost in concentra expected from high resolu cluster simulations

Problems with Simulations

- Limited dynamic range (need ~10^6-10^7)
  - Box too small
  - Insufficient resolution leads to overcooling
- Missing important physics
  - AGN Feedback
  - May only be important for cluster core, outside 0.1 R_{vir} properties match X-ray observations (Nagai 2005, 2006)

X-Ray Cluster Concentrations

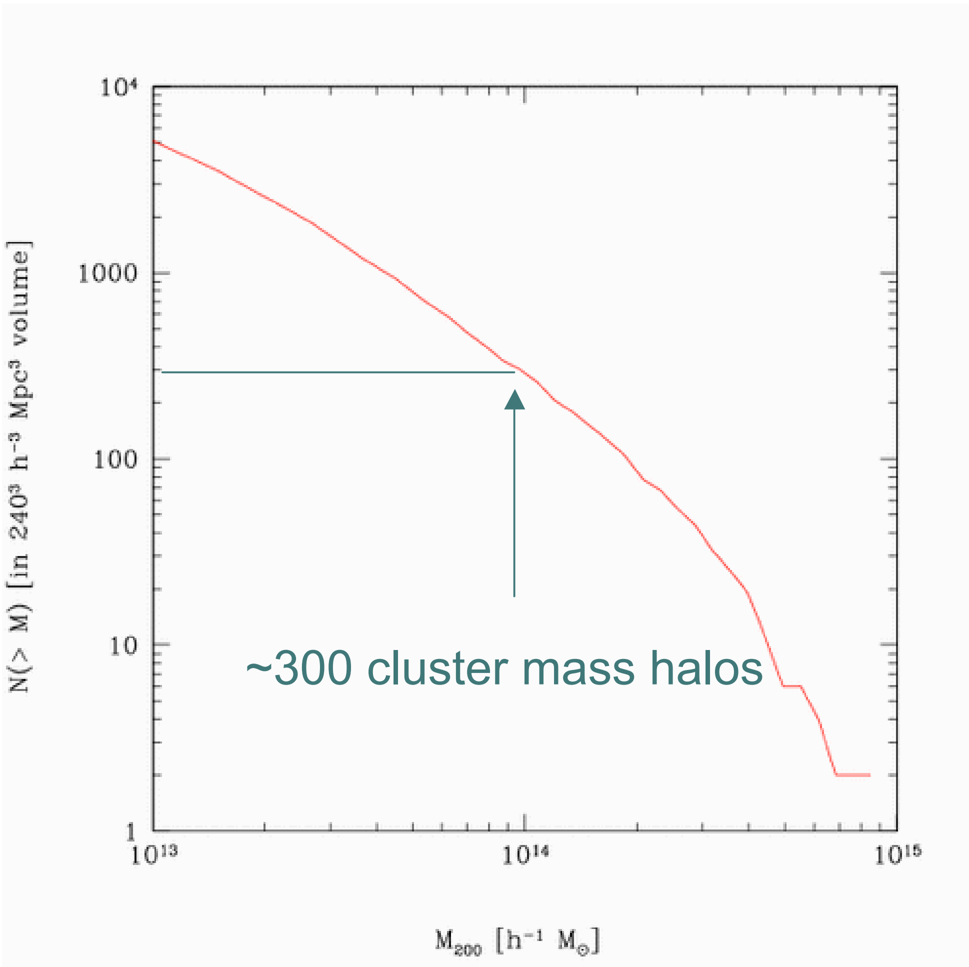
- Cluster concentrations can be independently measured using X-ray temperature and density profiles
- (and assumption of hydrostatic equilibrium)



Buote et al (astro-ph/0610136)

- Large boost in concentrations seen in X-ray measurements (compared to models based on dimensionless simulations, dashed lines)
- Degenerate with cosmology

Simulated Cluster Sample



- 240 h^{-1} Mpc box
- Generated 2048^3 initial conditions with WMAP3 cosmology
- simulated at low resolution (512^3), 20 h^{-1} kpc peak resolution to pick out clusters
- Sample of ~300 clusters with M ≥ 10^{14} M_ to re-simulate at higher resolution

Summary

- Simulations show that baryons affect the power spectrum on larger scales than previously thought ($k \sim 1$ h/Mpc)
- Magnitude of effect still uncertain, but already several percent effect in non-radiative simulations (should be lower bound)
- Halo model useful tool for understanding effect but not yet accurate to percent level
- We need more/better simulations which accurately reproduce baryon properties in large clusters
- Doing anything to 1% is hard!