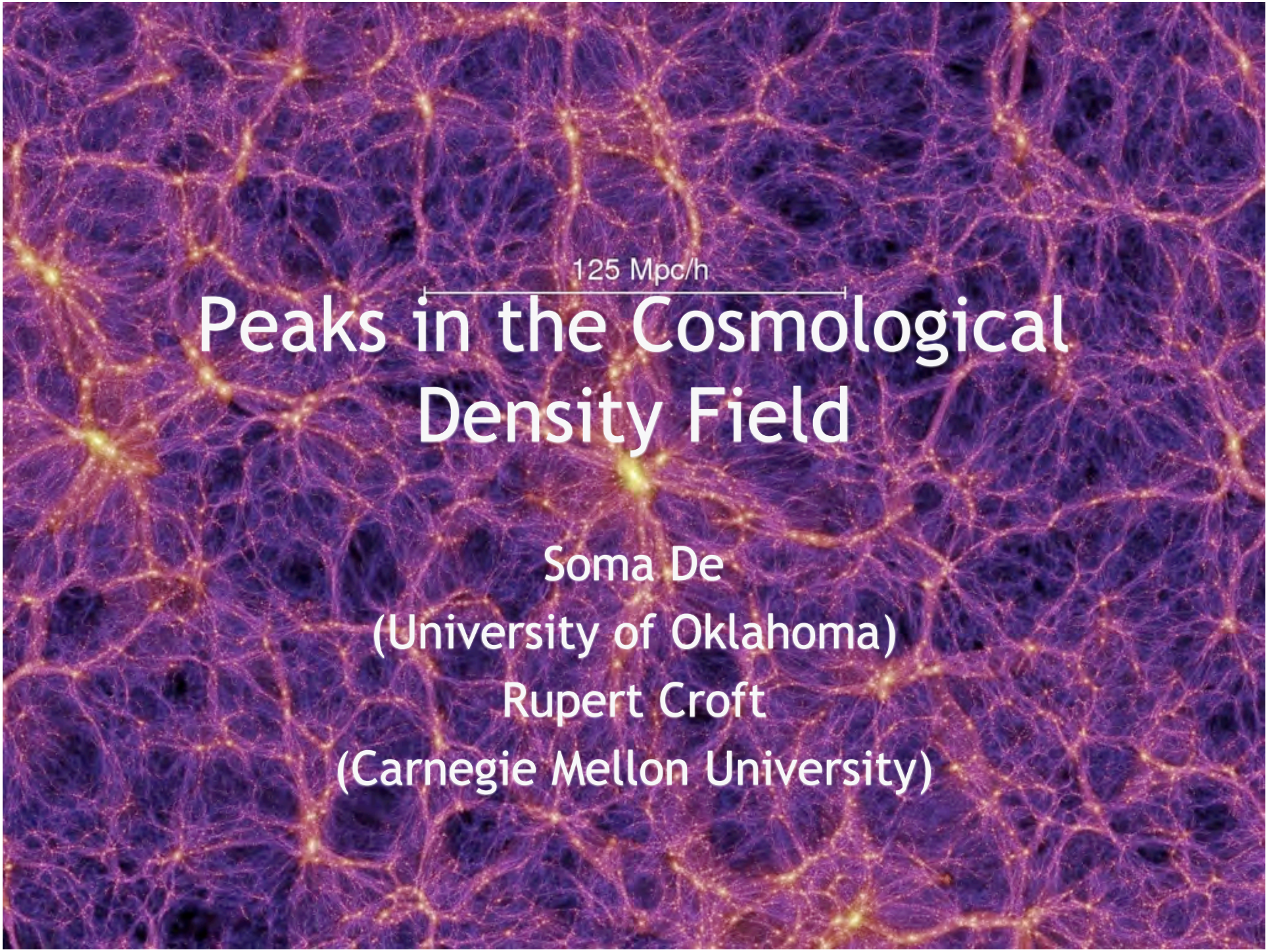

Peaks in the Cosmological Density Field

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Peaks from theory

- For a homogeneous Gaussian random field ensemble average of peak density is given as (Bardeen et al 1986)

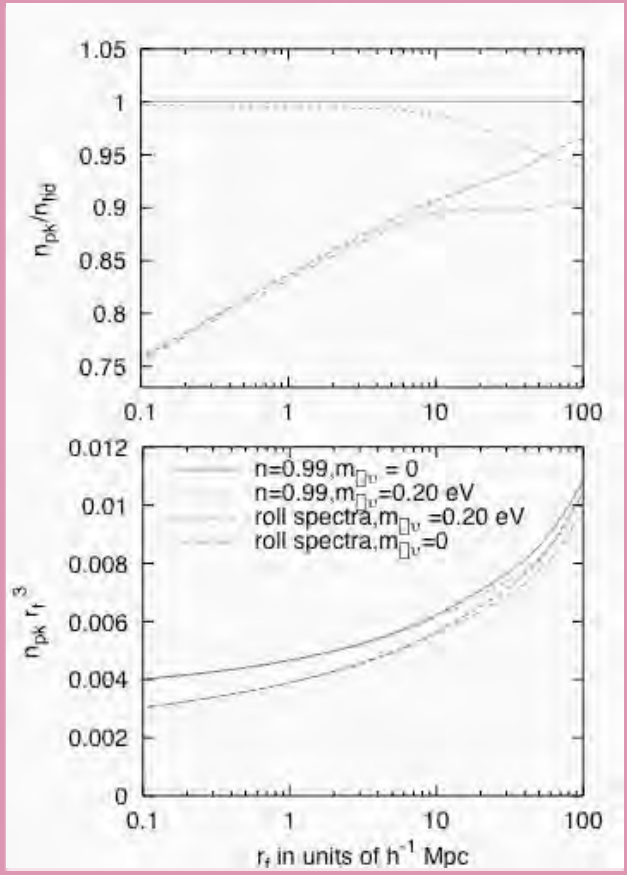
$$n_{pk} = 0.0277(\sigma_1/\sigma_2)^{-3}$$

- For a power spectrum $\sigma_j^2 = \int P(k,t)k^{2(j+1)}dk/(2\pi^2)$

- For a rolling spectral index $P(k) = P(k_0)(k/k_0)^{n(k_0)+0.5\ln(k/k_0)dn/d\ln k}$

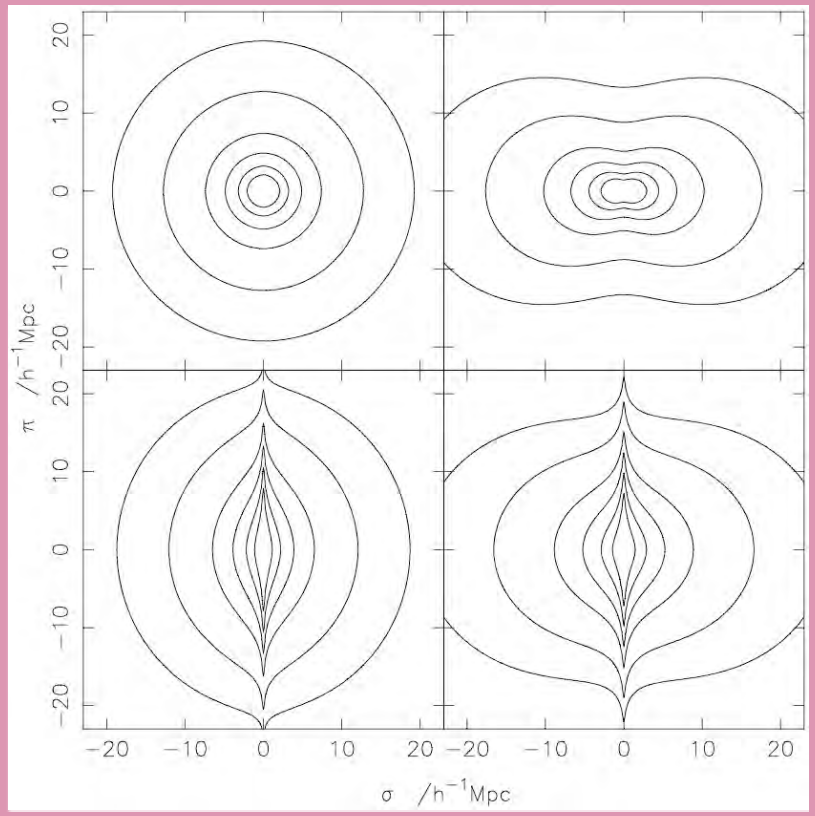
- In order to smooth the density field we multiply the spectrum with $\exp(-(kr_f)^2)$

Comparison between rolling and scale invariant spectra



- Rolling in spectral index of primordial power spectrum affects the peak density most on smaller scales. N_{pk} decreases by 15% around $r_f = 10h^{-1}Mpc$ when dn/dlnk varies from 0.0 to -0.1
- Massive neutrinos suppress the perturbation in smaller scales due to free streaming causing a lack of gravitating object.
- 0.6eV neutrinos suppress peak density by 5% around filter scale of $10h^{-1}Mpc$

Redshift Distortion

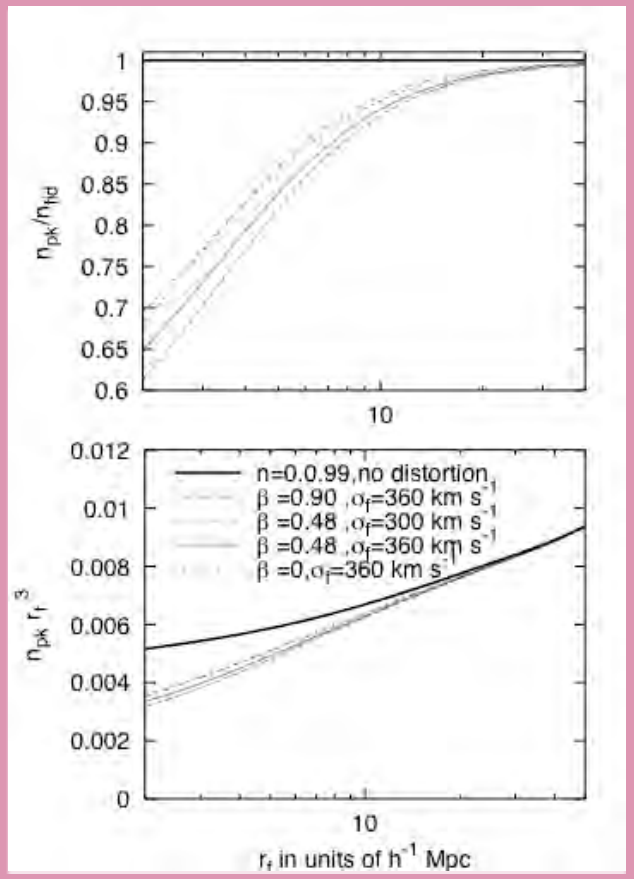


- Redshift distortion is the change in the density profile in space due to inclusion of peculiar velocities of galaxies into their Hubble velocities.
- Denser regions appear stretched along line of sight on small scales and squashed on large scales.
- Power spectrum gets modified as

$$P(k,\mu,\sigma_F) = P(k)\frac{(1+\beta\mu^2)^2}{(1+0.5(k\sigma_F\mu)^2)}$$

  where μ is the angle between line of sight and wave vector k.
- Correction to redshift is given by $\vec{v}(\vec{r}).\hat{r}/c$, $\hat{r}$ being the line of sight.
- Power spectrum now becomes anisotropic.

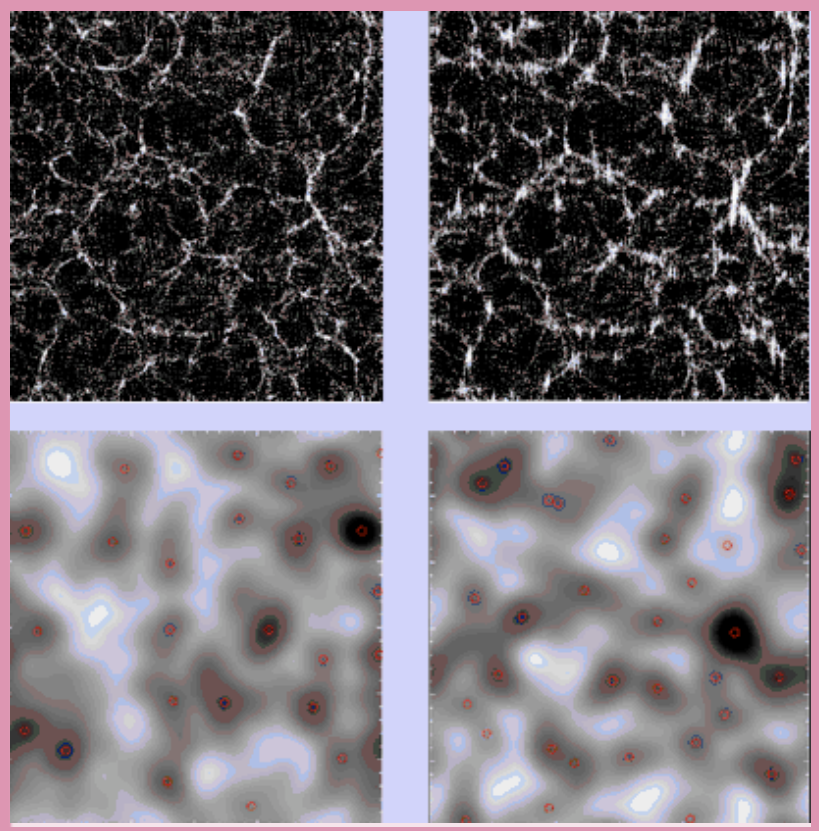
Peak theory under redshift distortion



- Effect of redshift distortion is to decrease the number of peaks. This effect is found to be strongest at filter radii where $r_f \leq \sigma/\mathrm{H}$
- On large scales β distortion is most effective.
- On large scales there is no suppression due to Fingers of God effect.

Simulation details

Real space Redshift space



Smoothed over $r_f = 10h^{-1}Mpc$

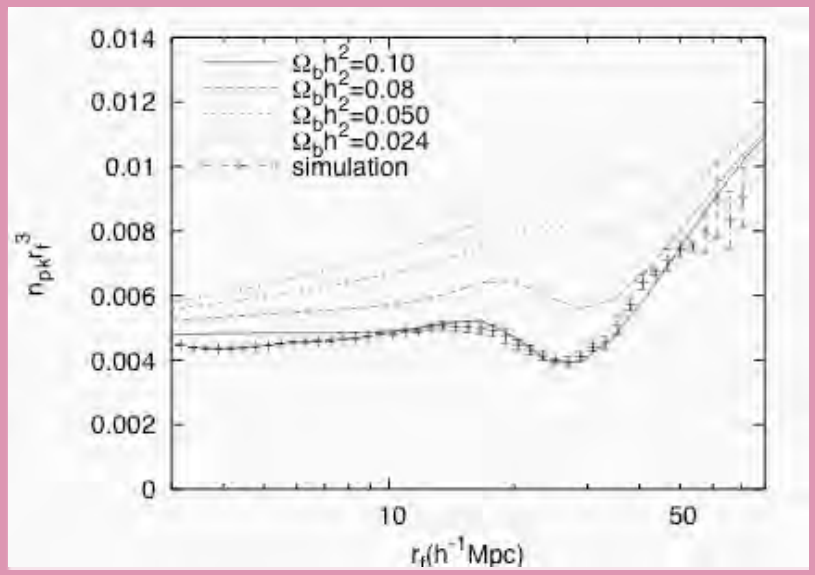
- Simulations present a model universe which is an output obtained by solving N-body equations.
- Parameters

$$n = 1$$
$$dn/d\ln k = 0.0, -0.020$$
$$\Omega_m = 0.3$$
$$\Omega_\Lambda = 0.7$$
$$\Omega_b h^2 = 0.024$$
$$\Omega_\nu = 0.0$$

- Simulation details

$$N_{particles} = 3.375 \times 10^6$$
$$grid = 256^3$$
$$M_{particle} = 6.86 \times 10^{10} h^{-1} M_{sum}$$

Baryonic Acoustic Oscillations



- Baryons suppress the growth rate of perturbations between matter-radiation equality and drag epoch. Baryons are trapped in acoustic oscillation until they are freed by recombination.
- K-space location of peaks and troughs are given by
  $k_{peak} = m\pi/(2s)$
  where m=3,7..(troughs) and 5,9 ..(peak) and s being the sound horizon at drag epoch.
- We calculated N_{pk} using output at z=0 from 5 simulations generated using $600h^{-1}Mpc$ box and 150^3 particles and it agrees well with theory.

Simulation results (LCDM+ROLL)

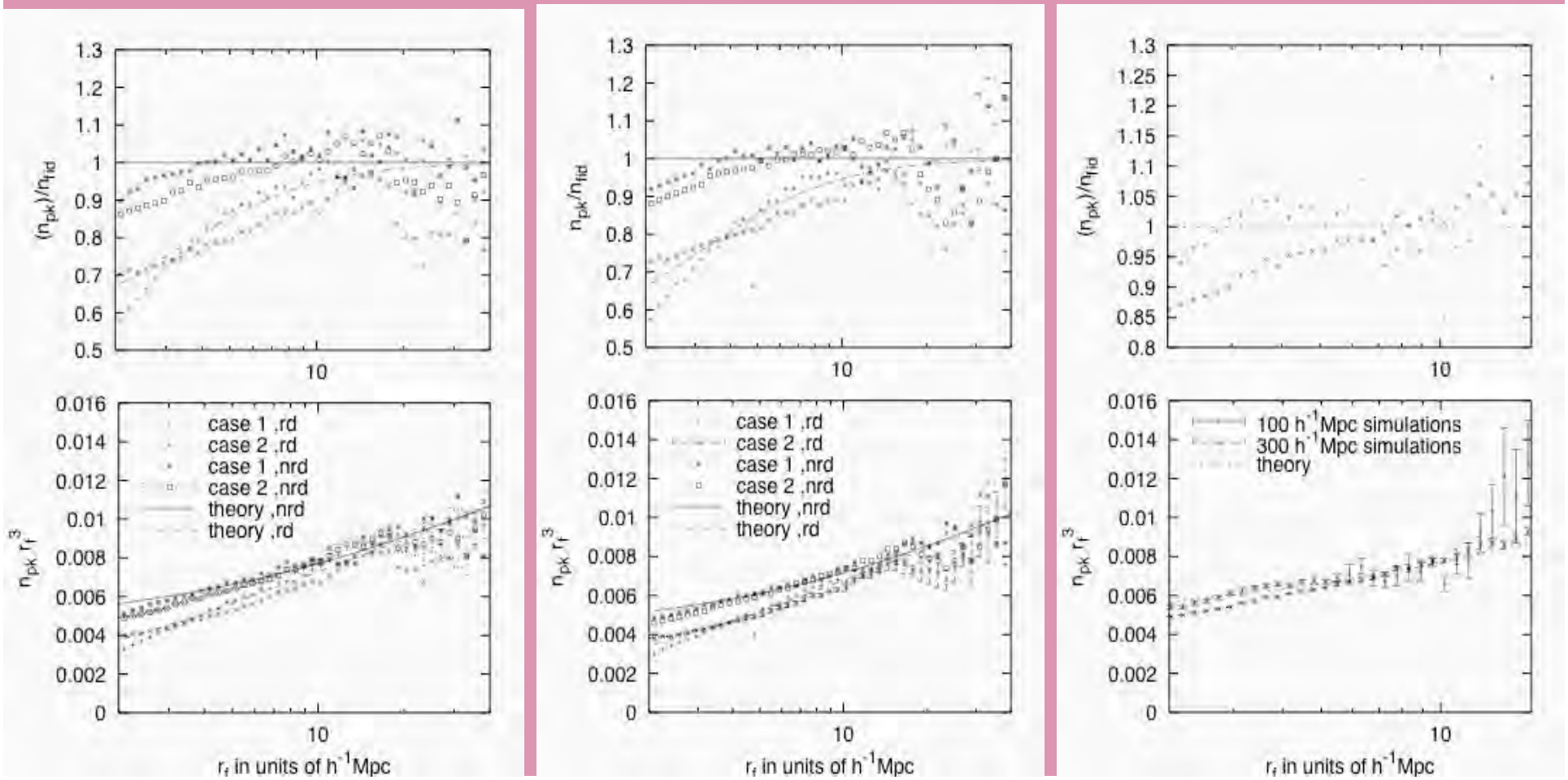
- We add correction to redshift by adding peculiar velocity to line of sight distance. We denote case 1 as when we input an anisotropic power spectrum to calculate the growth factor for perturbations. In case 2 we distort the output from N-body simulation (under distance observer approximation) generated using an isotropic primordial power spectrum.
- In length scale $4-20h^{-1}Mpc$ error bars are small and theory predictions are within 5% of the simulation results. For $r_f = 20h^{-1}Mpc$ random fluctuations in mean peak density grow due to limited number of independent volumes. Mean deviation from theory over all filter scales is 3.2% for LCDM and 2.1% for rolling spectral models.
- Assuming small grid cell size compared to mean particle separation, a mean particle separation less than $0.5r_f$ is needed to avoid discreteness effect. This occurs below $4h^{-1}Mpc$ in $300h^{-1}Mpc$ simulations which is tested by running a few $100h^{-1}Mpc$ boxsized simulation and we recover agreement with theory within 5% in those scales.

Results from simulation

$n = 1$

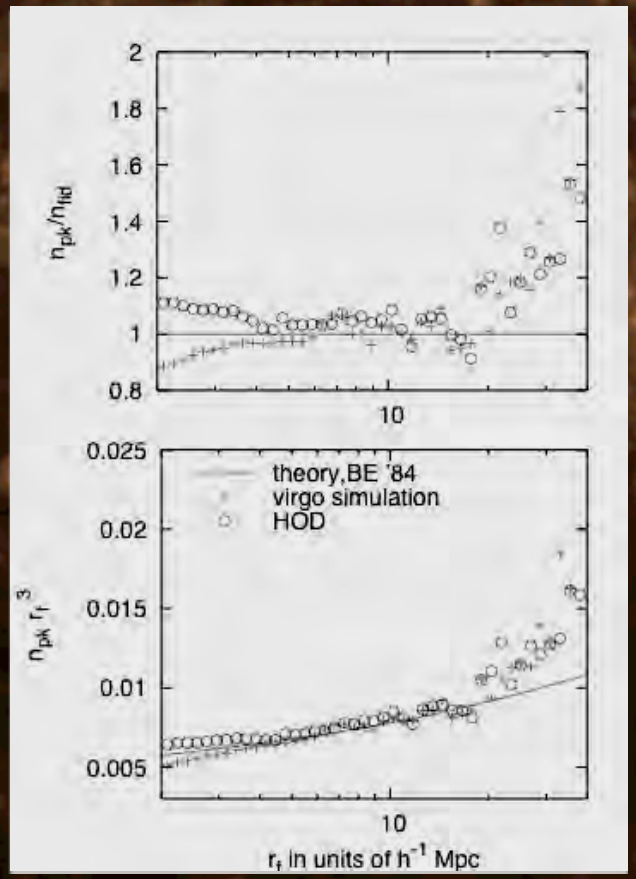
$n = 1, dn/d\ln k = -0.020$

Resolution test



z=10.6

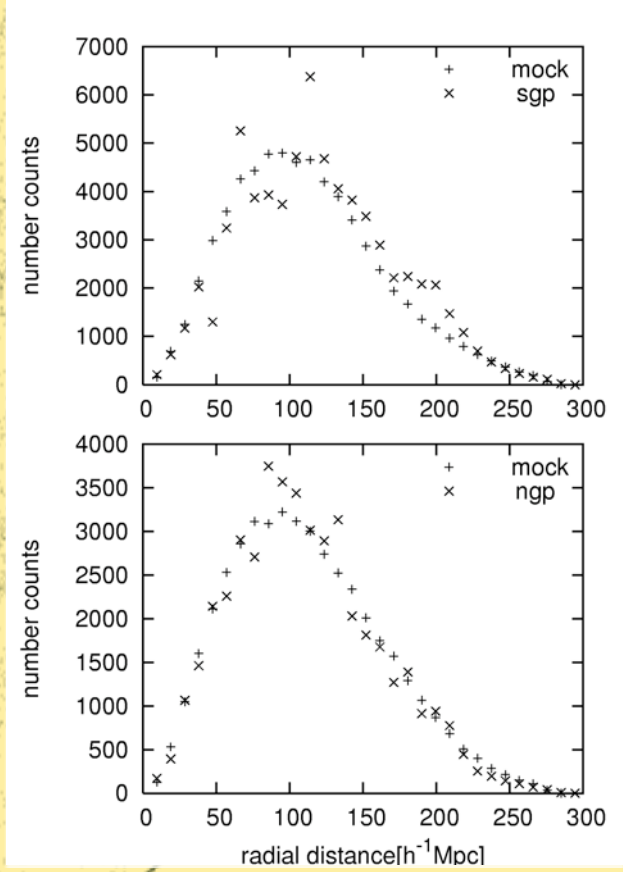
Halo Occupation Distribution



- We check if galaxy density distribution could be used as a proxy for dark matter density. In other words we test if linear peak theory could be recovered from galaxy distribution.
- Dark matter Halo distribution is generated using Virgo simulation by picking CDM particles with standard Friends of Friends algorithm. HOD is used to yield the number of central and satellite galaxies inside each halo.
- Above $r_f = 6h^{-1}Mpc$, peaks from dark matter and galaxy distribution agree well. Below this length scale deviation occurs due to resolution effects.

8 kpc

Applying peak theory on 2dF galaxy redshift survey data (Colless et al 2005):Constructing mock catalogs

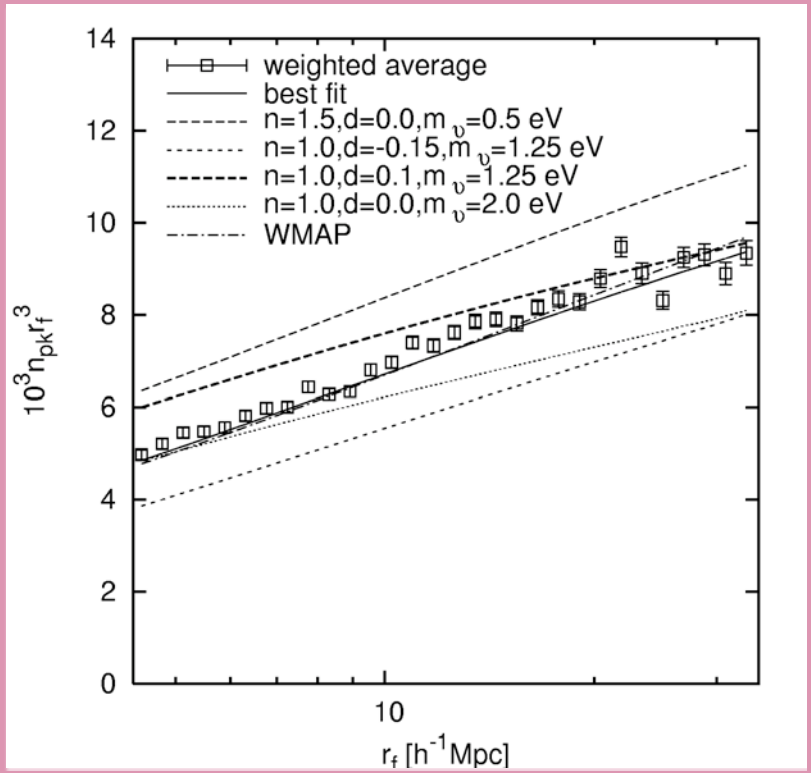


- Replicate $300h^{-1}Mpc$ box simulation to produce survey volume.
- Construct the radial selection function using a Schechter function for luminosity as

$$\phi(r) = \frac{\int_{L_{\min}}^{\infty} \Phi(L)dL}{\int_{L_{0(\theta,\varphi)}}^{\infty} \Phi(L)dL}$$

- Solve for luminosity assuming a random value for selection function.
- Calculate apparent magnitude using $L_{\min} = (d_L(1+z))^2(1+z)10^{10.0-0.4(m-M_*)}$
- Apply redshift and magnitude limit mask and geometrical constraints of the survey into simulation volume to generate the mock catalogs.

Results: the peak density measured in 2dF galaxy redshift survey



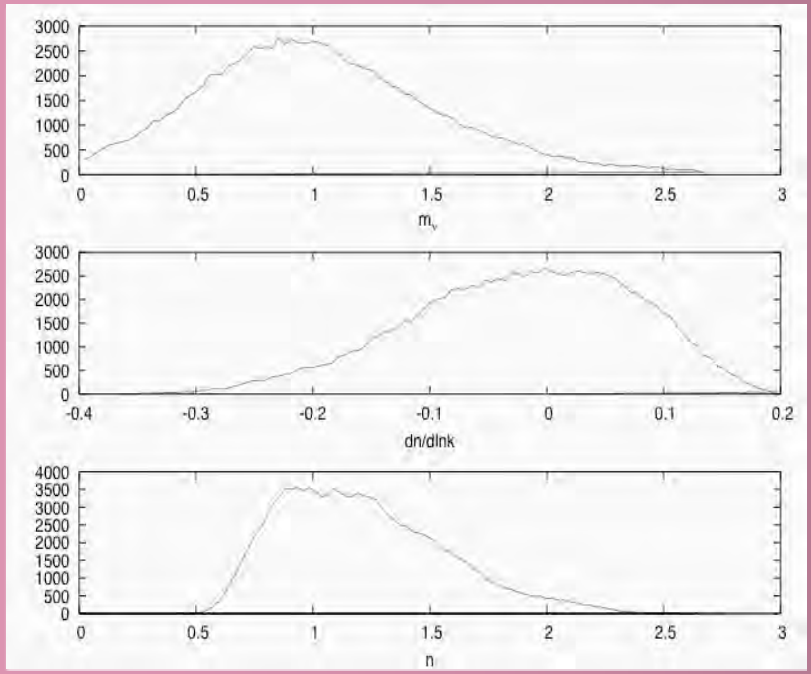
(Points with error bars: 2dF peak density)

- We generated 20 mock catalogs and calculated completeness function by comparing number of peaks in different spatial bins between mocks and complete simulations which have only same geometrical shape of the survey. We then correct the observed peak density (taking into account edge effects, for example) from 2dF survey using this completeness function.
- Error bars were calculated using covariance between mock catalogs which were then scaled with observed peak density to yield the errors relevant to the observed 2dF survey data.

Advantages to our approach

- Our approach is not biased by nonlinear clustering or dynamics which is required to know in case of evaluating galaxy power spectrum.
- Peak density is relatively insensitive to exact relation between galaxy and dark matter density.

Results:Cosmological parameter constraints from fitting 2dF measured peak density



- We use maximum likelihood analysis with Markov chains, and take neutrino mass, n, dn/dlnk as variables.
- Most probable cosmological parameters and their error are

$$n = 0.93^{+0.40}_{-0.31}$$

$$dn/d\ln k = -0.002^{-0.102}_{+0.091}$$

$$m_\nu < 1.211eV(1\sigma), 2.39eV(3\sigma)$$