Effect of massive neutrinos and dynamical dark energy on large scale structure

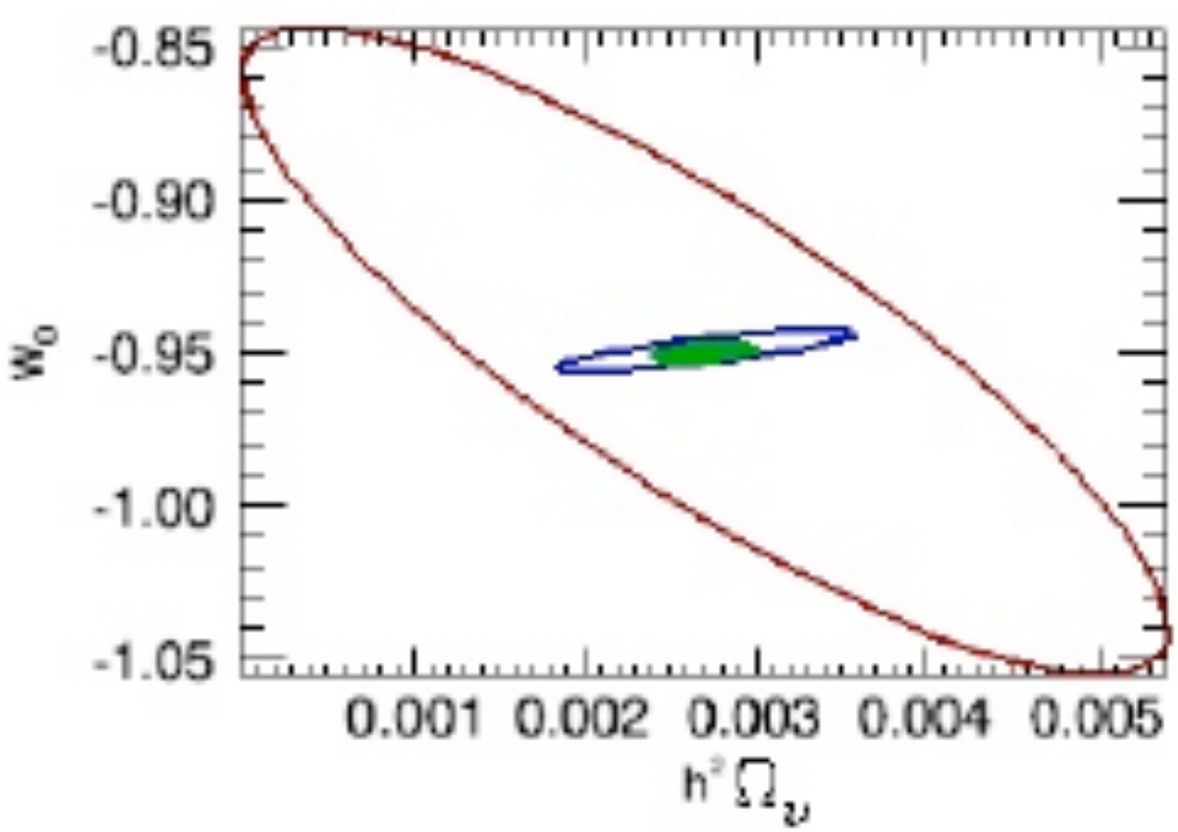
Based on arxiv:1309.5872

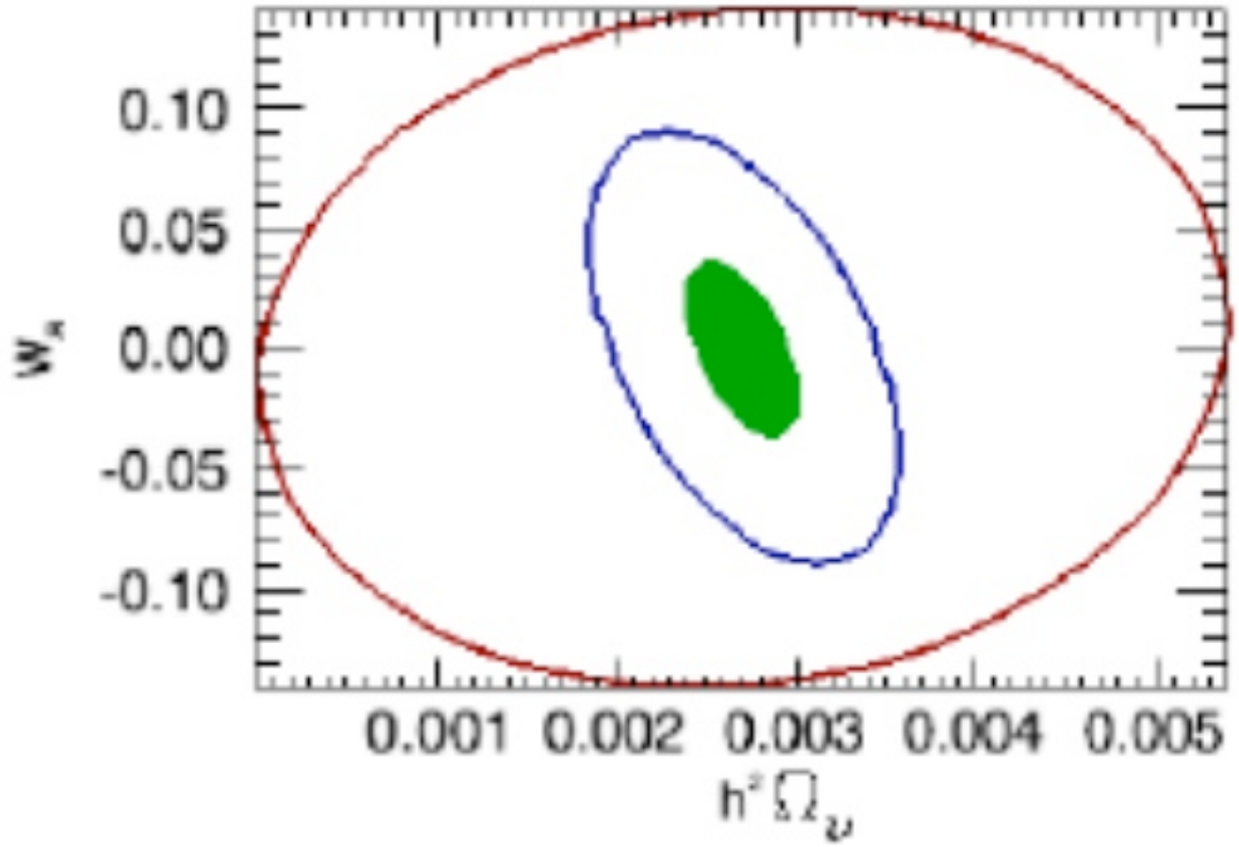
A. Upadhye, R. Biswas, A. Pope, K. Heitmann, S. Habib, H. Finkel, N. Frontiere

Argonne National Laboratory

Motivation

- Simultaneous study of w and neutrino mass needed: because effects on the power spectrum are degenerate



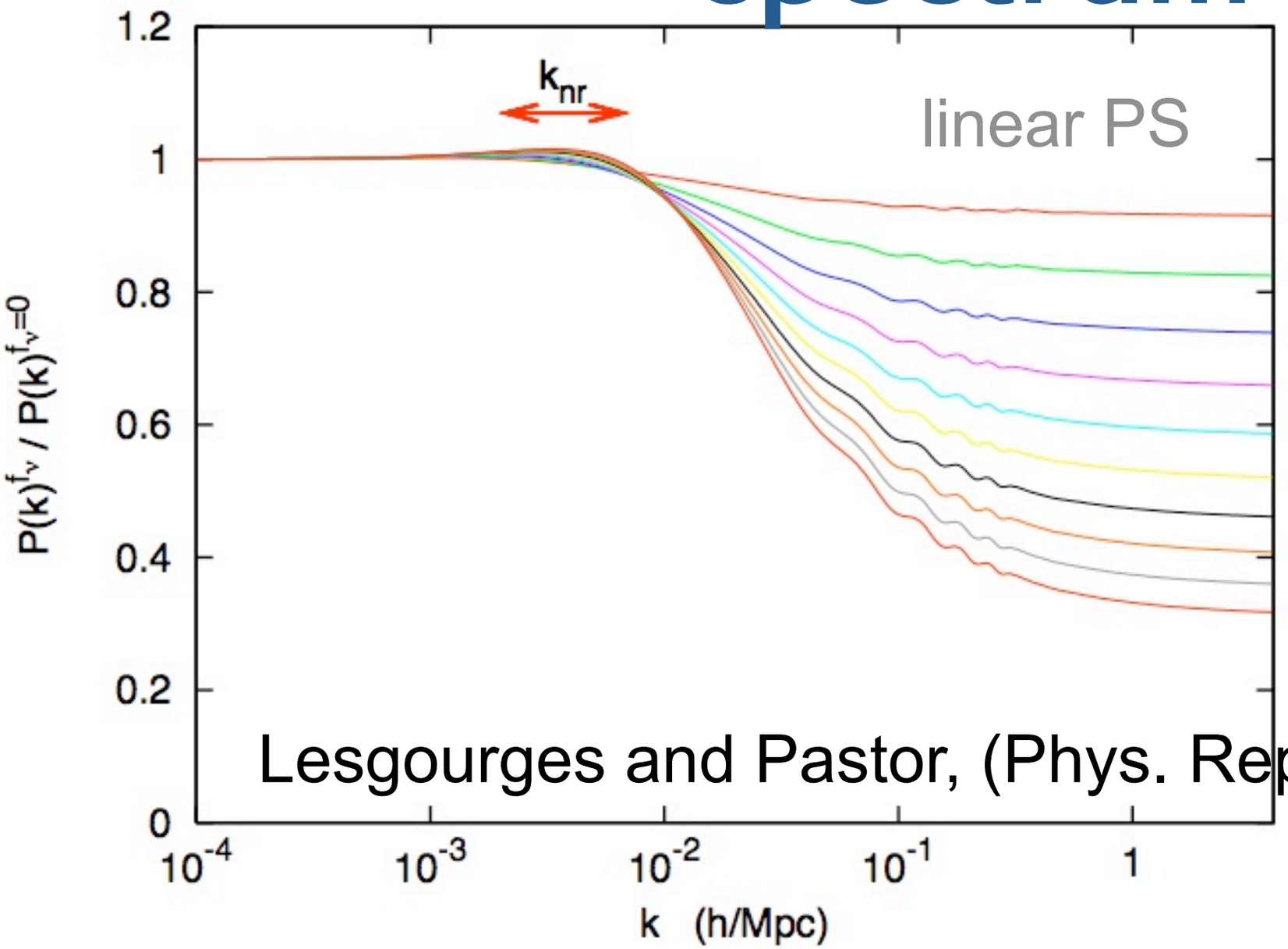


Forecasts: PLANCK + EUCLID gs, Santos et al , PRD 2013

Motivation

- Want to do MCMC with power spectra and Mass Function from simulations (which have to be sped up by emulators)
- Need to do simulations with both effects accurately: percent level in power spectrum at the mildly non-linear regime
- Task 5.2.1-H-2 on the DESC (https://confluence.slac.stanford.edu/display/LSSTDESC/5.2.1-H-2+Data+Analysis+and+Prediction+Tools)

Massive neutrinos have scale dependent effect on Power spectrum



Lesgourges and Pastor, (Phys. Repts. 2006)

- Neutrino velocity: free-streaming suppresses the growth of neutrino fluctuations at small scales
- At large scales neutrino fluctuations grow like dark matter fluctuations
- scale set by minimum of free streaming scale

$$k_{nr} = 0.018 \Omega_m^{1/2} h^{-1} Mpc$$

Modeling the effects of Neutrino Mass: Approximations

- Neutrino clustering : neutrino contribution to nonlinear power spectrum is small ($f_\nu < 0.1$), and $P_\nu(k)/P_{cb}(k)$ small at ($k > k_{nr} \sim 0.02\Omega_m^{1/2} h^{-1} Mpc$)
  - Neglect nonlinear contribution:

Approx 1: $P(k) = \left(f_{cb}^{NBODY} P_{cb}^{1/2} + f_\nu P_\nu^{lin} \right)^2$

- Neutrino clustering : sourcing growth in Poisson Equation?
  - Again Linear theory/spherical collapse indicate the clustering is small

Approx 2: source term from baryon/dark

Modeling the effects of Neutrino Mass:Changes to LCDM Simulations

- Scale Factor evolution: Calculated including massive neutrinos and dynamical dark energy in Hubble parameter evolution

- Initial Conditions: Use CAMB to generate power spectra at z=0 for desired model. Use growth function including massive neutrinos for H(z) to obtain power spectrum at initial z (~200). (Note: This is different from using the CAMB power spectrum z= 200)

Important: Hubble parameter evolution in growth and scale factor evolution in N-Body should be consistent to recover the z = 0 power spectrum in linear regime

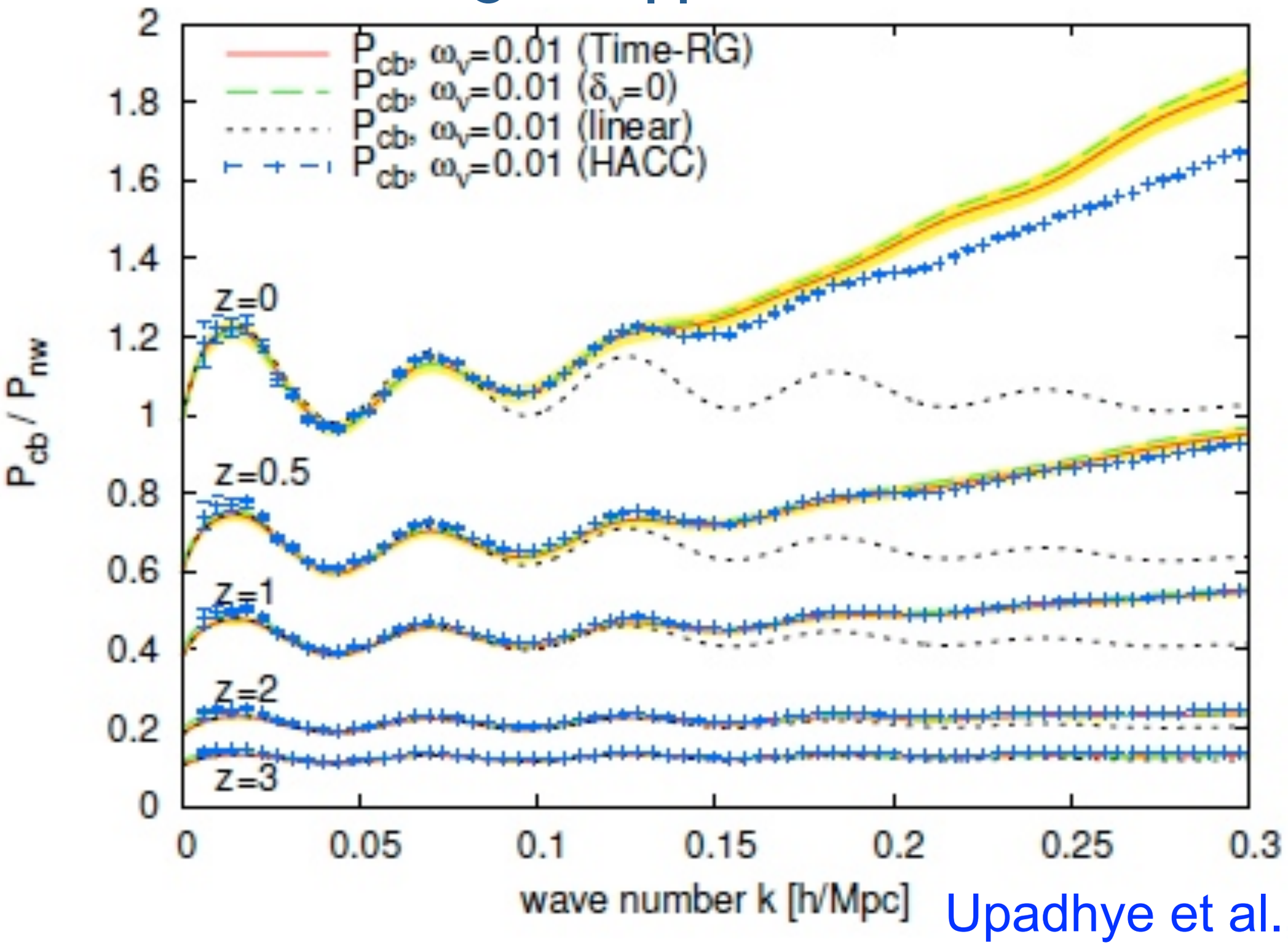
CAMB & Growth modifications

- Change background evolution for dark energy
- Dark energy perturbations treated as a dark energy fluid in CAMB (available at http://www.hep.anl.gov/cosmology/pert.html)
- Growth of perturbations small except at Hubble scales
- Growth Function solved with background evolved with neutrinos and dark energy

Compare Power spectrum to Perturbation Theory

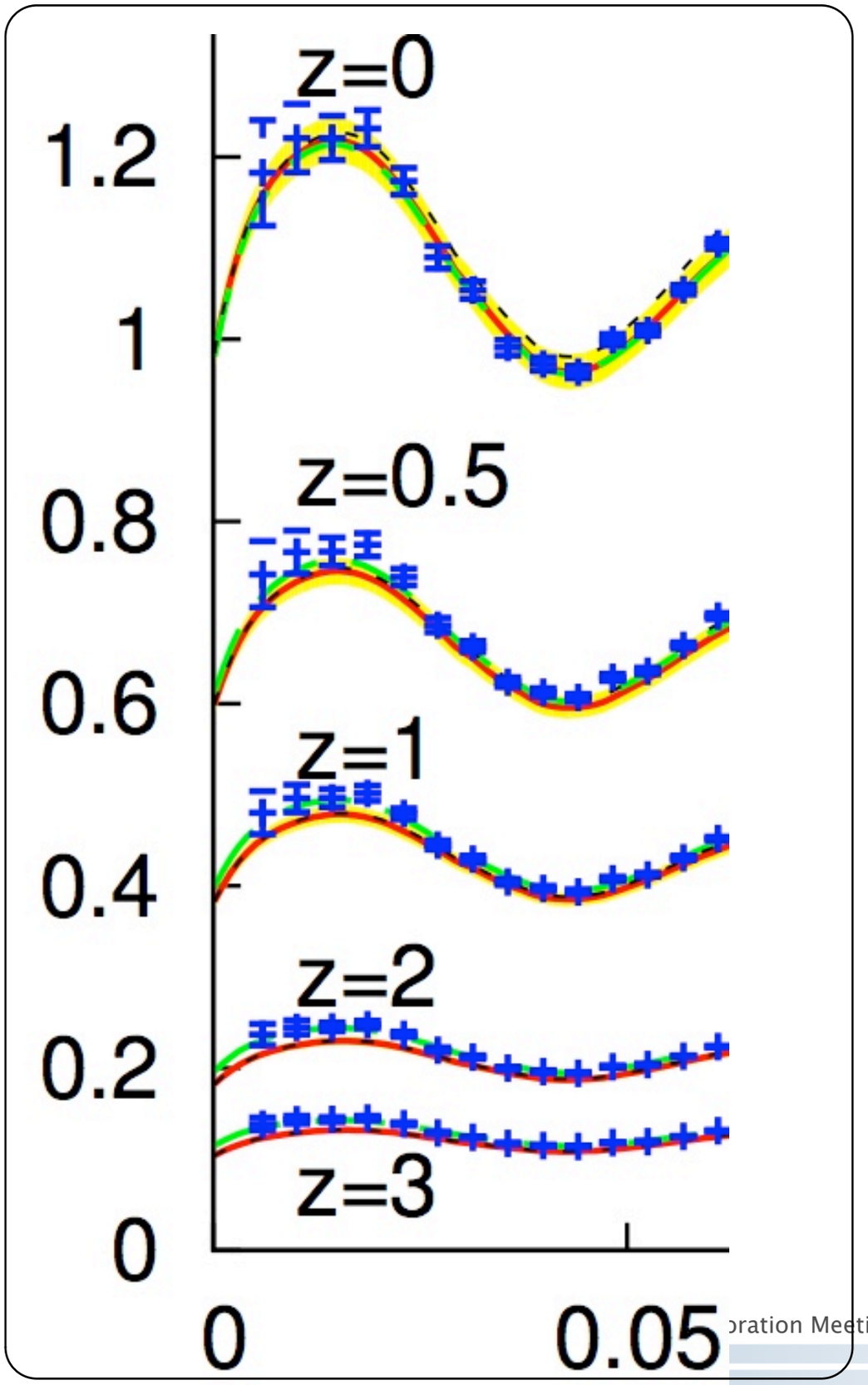
- Linear Theory should match at large scales zero redshift by design
- Higher Order Perturbation theory provides a check at mildly non-linear scales
- Extension of COPTER code (Carlson et al, 2009) for w0-wa dark energy and neutrinos (for Time-RG perturbation) available at http://www.hep.anl.gov/cosmology/pert.html
- Time-RG higher order perturbation theory allows the use of scale dependednt source term (from neutrinos)

Neglecting neutrino clustering in Poisson source is a good approximation



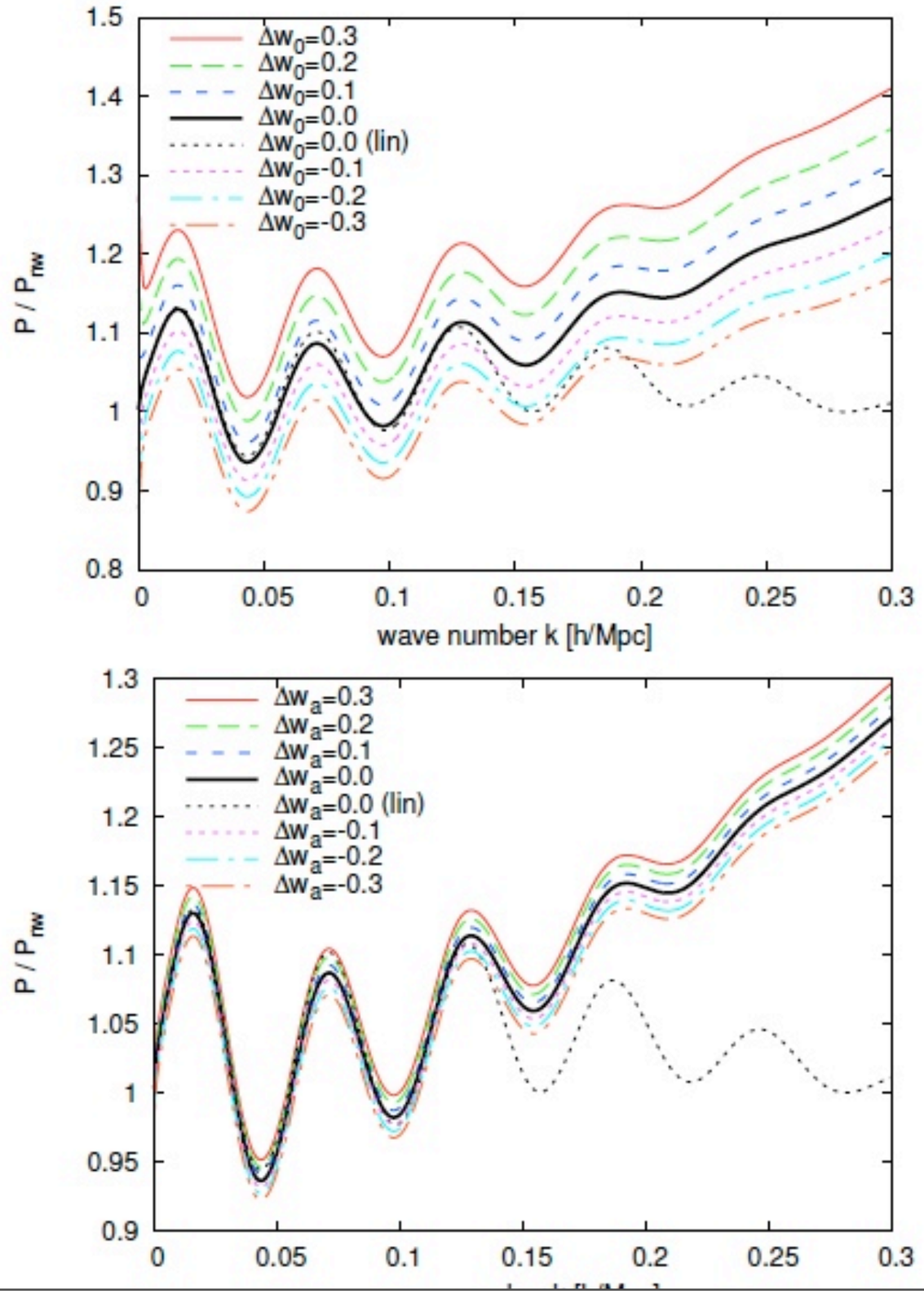
Upadhye et al., arXiv: 1309.5872

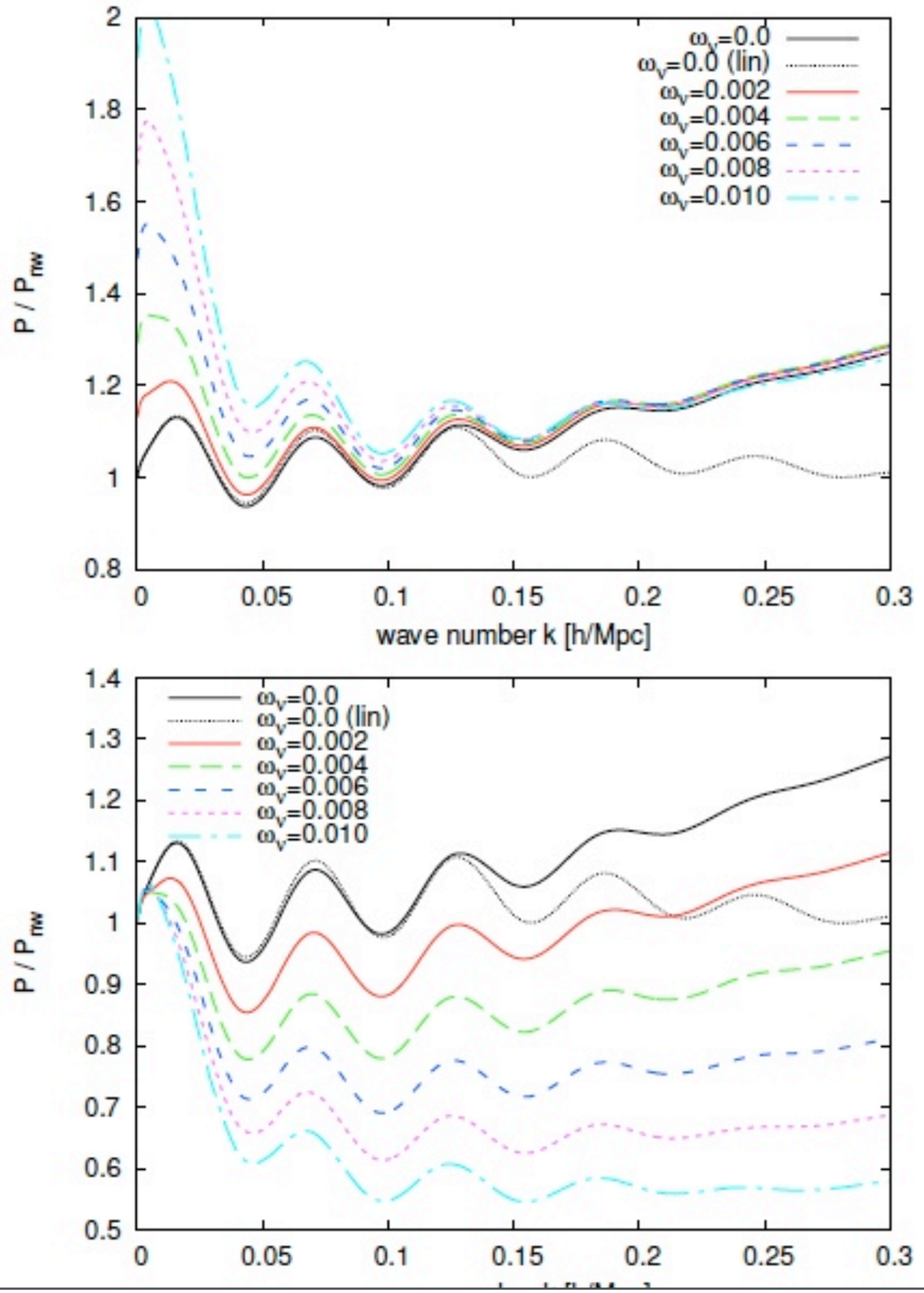
Tiny Simulation Perturbation Theory Discrepancy at Large scales Due to Sourcing Approximation



- z = 0: Match to everything by design
- Simulations (blue) match time RG with no neutrino source (green) better
- Higher z: Simulations (blue) / time-RG with no source (green) higher than time-RG (red) with scale dependent source

Effects of Dark Energy and Neutrinos on the matter Power spectrum (z =1)





Power Spectrum with massive neutrinos and w0-wa Dark Energy

- Combine linear Neutrino power spectrum from CAMB with non-linear baryon-CDM power spectrum from simulation
- Neglect effects of clustered neutrino as source: seems to be a good approximation
- Time-RG perturbation theory calculation allows extending comparison to mildly non-linear scales
- Details in arXiv:1309.5872, CAMB/higher order perturbation code available at http://www.hep.anl.gov/cosmology/pert.html

Effects of Dark Energy and Neutrinos on the Power spectrum