Fruitful information beyond 1D-BAOs through galaxy surveys

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Introduction

- Baryon Acoustic Oscillations (BAOs)

- standard ruler (~150Mpc) precisely determined by CMB

- imprinted in late-time matter distribution: galaxy surveys, Ly-alpha forest

- one of main targets to determine the cosmic expansion history

- Clustering of galaxies in redshift-space

- so far angle-averaged (1D) BAO scale is simply measured

BUT

- shape information in galaxy P(k): **Neutrino Mass**, Inflation parameters

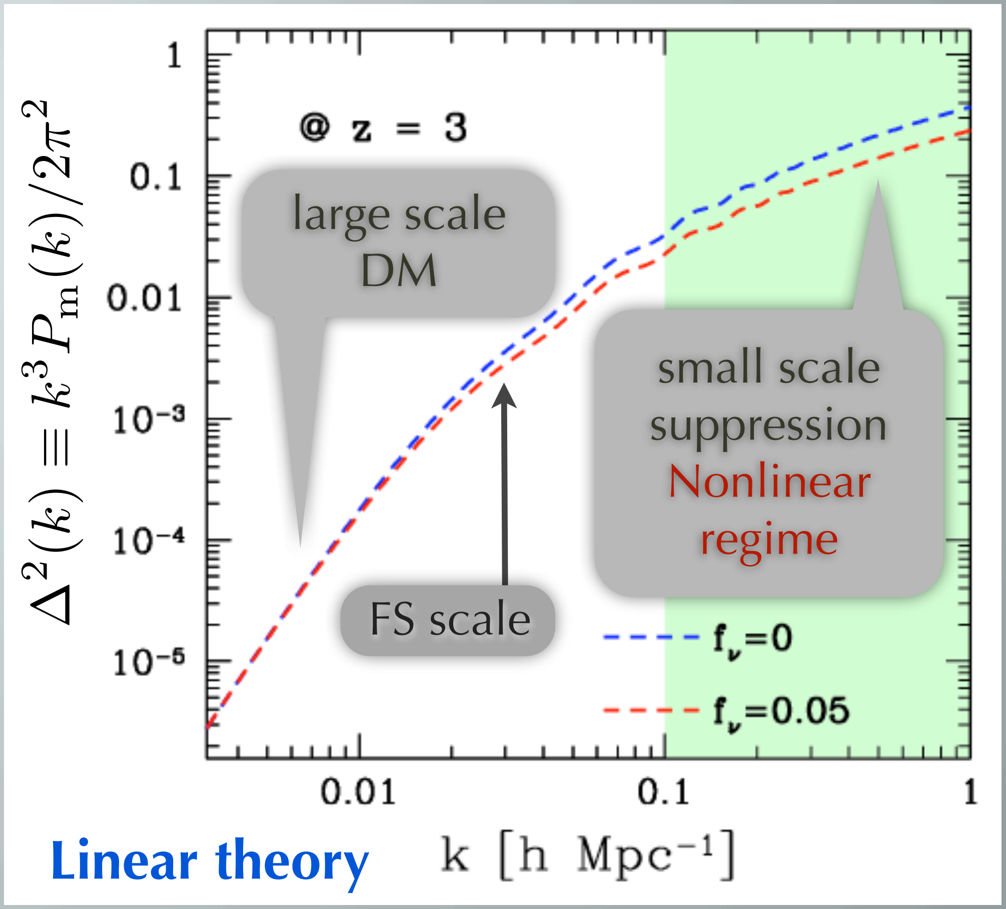
- **2D BAOs** in redshift-space distortion

Neutrino Mass & Galaxy survey

- A experimental proof that SM of particle physics is not sufficient
- Cosmology: ***complementary & powerful*** to constrain total mass

- cosmology: $\Sigma m_\nu < \sim 1$ eV
- terrestrial: $0.05\text{eV} < \Sigma m_\nu < 2\text{eV}$
- suppression effects due to neutrino's free-streaming
- comparable to BAO scale
- Neutrino effect cannot be negligible

$$\delta P/P \approx -8 f_\nu \geq -4\%$$

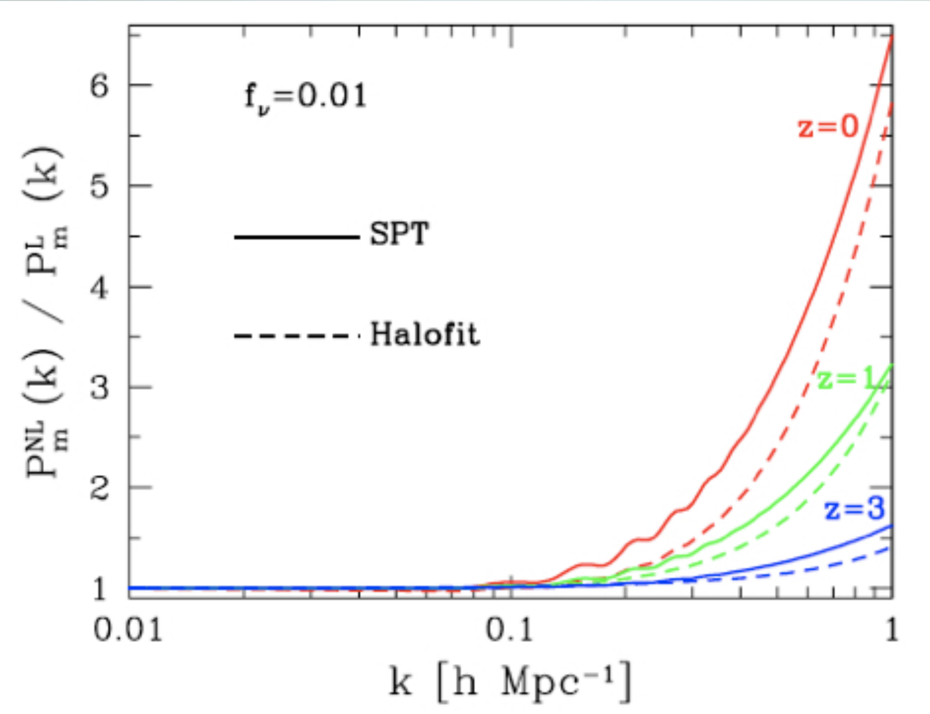


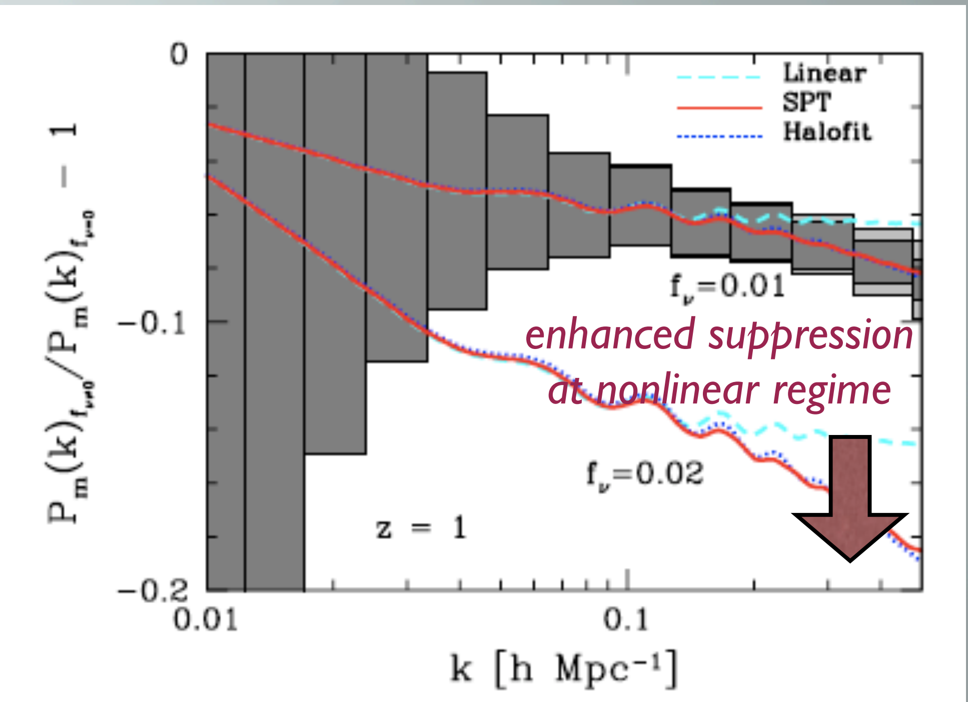
Shape of galaxy P(k)

- To use info of galaxy P(k) shape, we need to model nonlinear issues

  - nonlinear gravitational evolution
  - nonlinear galaxy biasing
  (- nonlinear redshift-distortion)

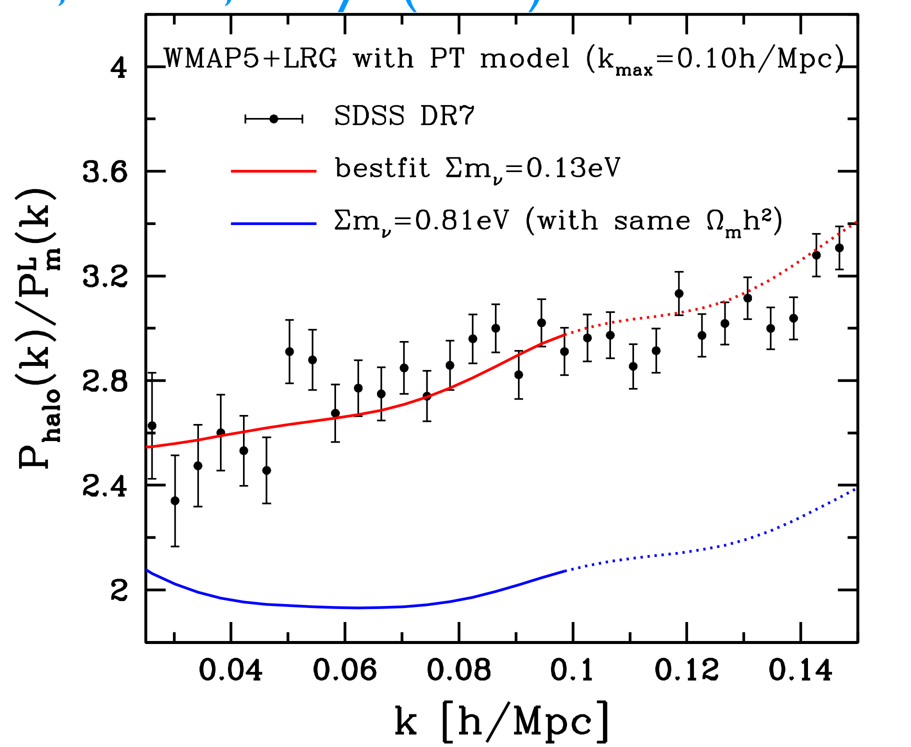
  Modeling based on perturbation theory
  S.S, Takada, Taruya (2008,2009)

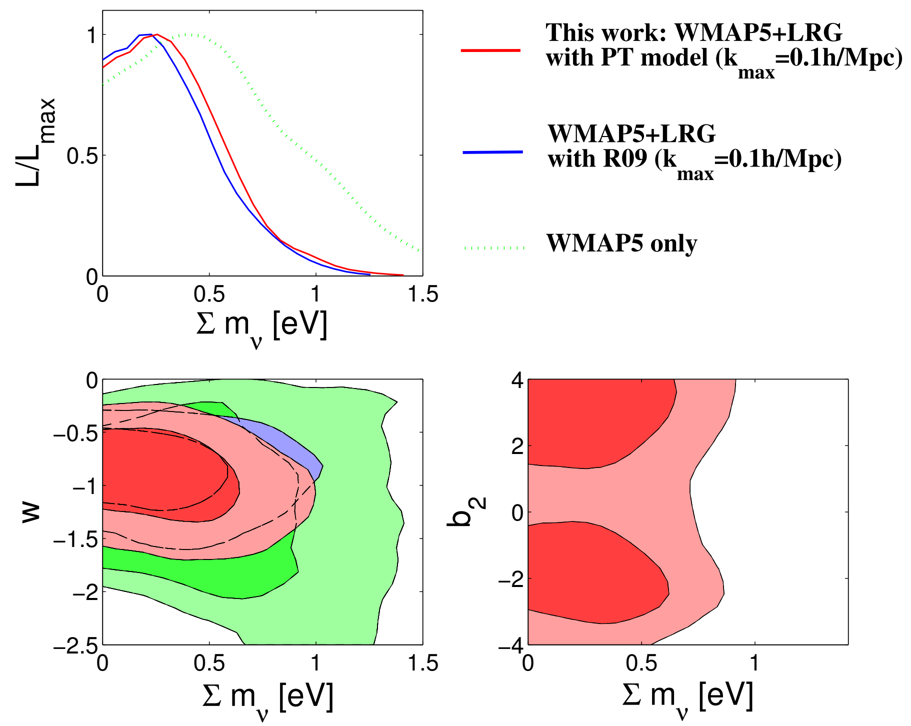




Neutrino Mass constraint with SDSS DR7 'halo' P(k)

S.S, Takada, Taruya (2010)





- WMAP5 + 'reconstructed halo' P(k) measured by B.Reid et al (2009)
- obtain a conservative bound, $\Sigma m_\nu < 0.81$eV (95% C.L.)
- Going beyond k_{max}=0.1h/Mpc is still challenging...

2D BAOs in redshift-space

- Redshift Space Distortion (RSD) Kaiser (1987)

- peculiar velocity of galaxies along l.o.s should be contaminated in measured-z

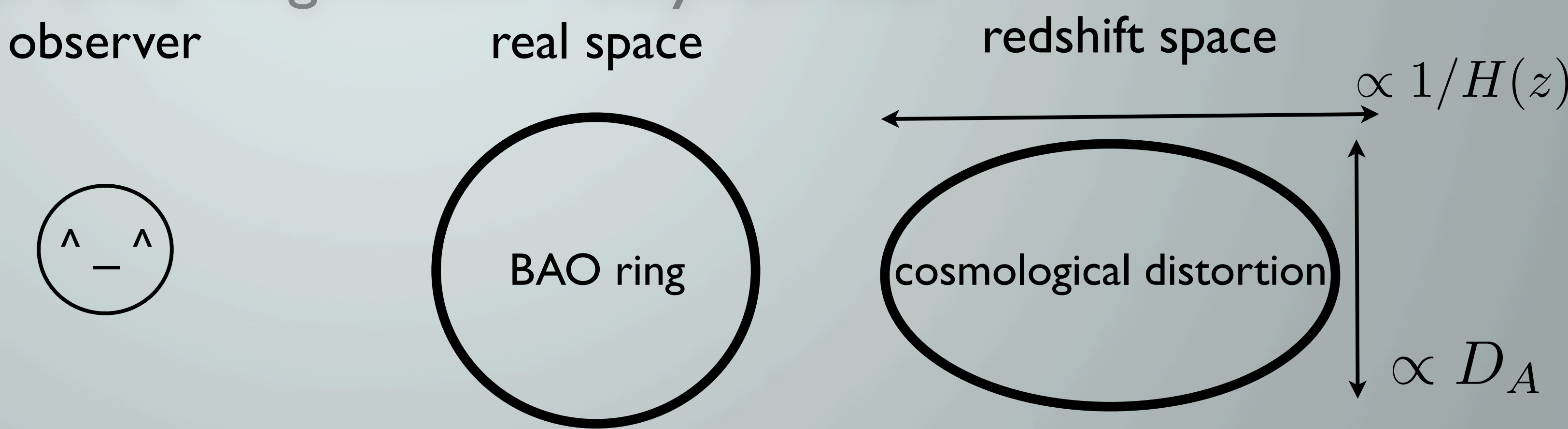
$$\vec{s} = \vec{r} + \frac{\vec{v}\cdot\hat{z}}{aH(z)}\hat{z}$$

redshift space ($\vec{s}$), real space ($\vec{r}$), line of sight direction ($\hat{z}$)

- Linear Kaiser formula depends on growth parameter "f": **modified gravity**

$$P^S(k,\mu) = b^2\left(1+\frac{f}{b}\mu^2\right)^2 P_{\rm m}(k)$$

- 2D BAO ring: Alcock Paczynski test Alcock & Paczynski (1979)



- Note: spherically averaged BAO scale $\propto D_V \propto [(1+z)^2 D_A^2 \cdot z/H(z)]^{1/3}$

Percival et al (2009) etc

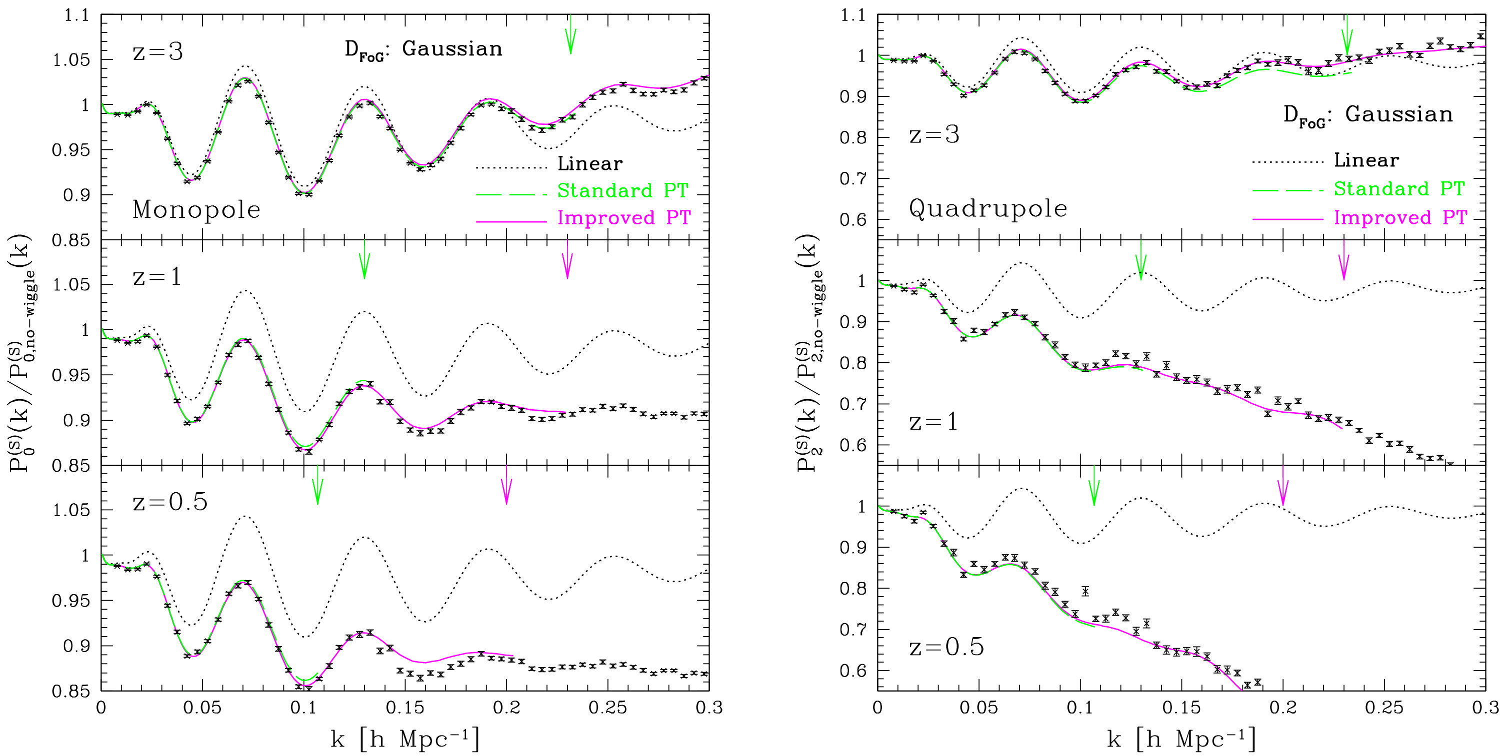
Modeling of RSD

Taruya, Nishimichi, S.S. (2010)

We found a perturbation-theory motivated formula in which nonlinear matter power spectrum can successfully recover the N-body results.

$$P^S(k,\mu) = e^{-k^2 f^2 \sigma_V^2 \mu^2}\left[P_{\delta\delta}(k) + 2f\mu^2 P_{\delta\theta}(k) + f^2\mu^4 P_{\delta\theta}(k) + \underline{A(k,\mu) + B(k,\mu)}\right]$$

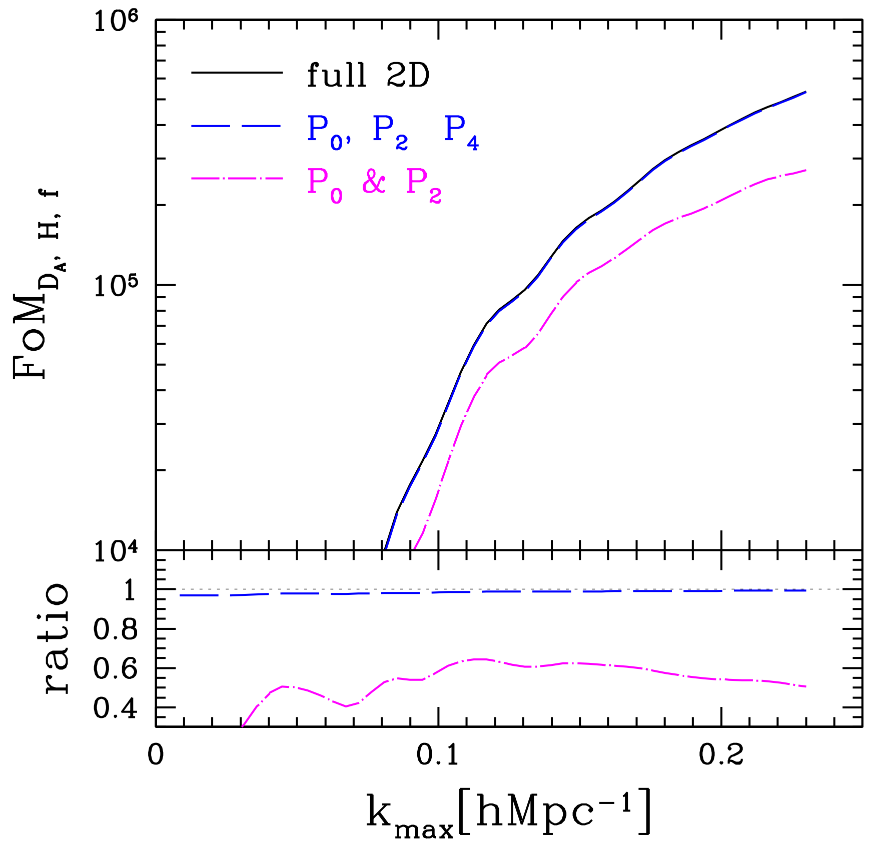
correction terms originating from higher-order correlation



Multipole vs full-2D?

Multipole expansion

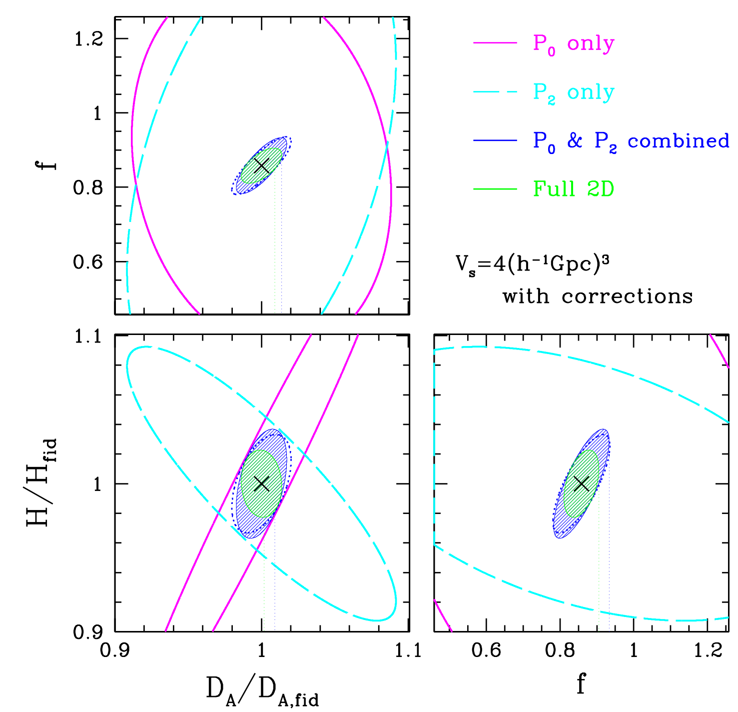
$$P(k,\mu) = \sum_{\ell=0}^{\text{even}} P_\ell(k)\,\mathcal{P}_\ell(\mu)$$



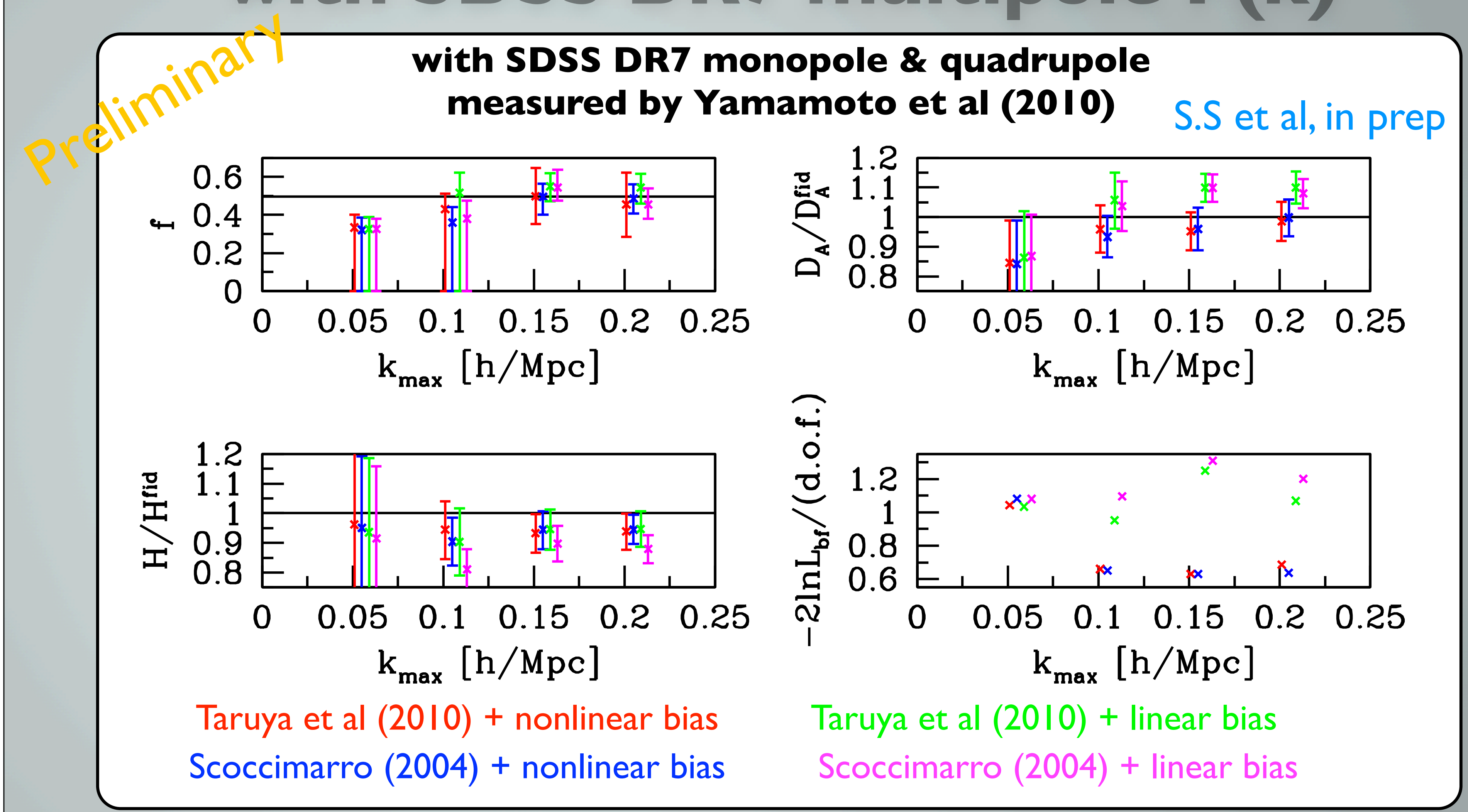
Padbanabhan & White (2008)
Taruya, S.S., Nishimichi, in prep

- Even if including nonlinear effects, nearly full 2D information can be obtained with multipoles up to l=4.

- With monopole & quadrupole, roughly 50% information can be gained



Two distances measurement with SDSS DR7 multipole P(k)



- need precise modeling especially at k > 0.1h/Mpc

- constraint on D_A seems to depend on modeling of galaxy biasing

Conclusion

- Full shape of galaxy power spectrum in redshift space potentially contains fruitful information on fundamental physics
Key: **modeling of nonlinear issues**

- Neutrino Mass
  - obtained a "conservative" bound, $\Sigma m_\nu < 0.81$ eV (95% C.L.) with SDSS DR7 combined with WMAP5

- 2D BAOs
  - preliminary results: we should carefully constrain D_A & H
  - first step to use 2D BAO information