Constraining on the Massive Neutrino Mass from the Galaxy Power Spectrum of the HETDEX

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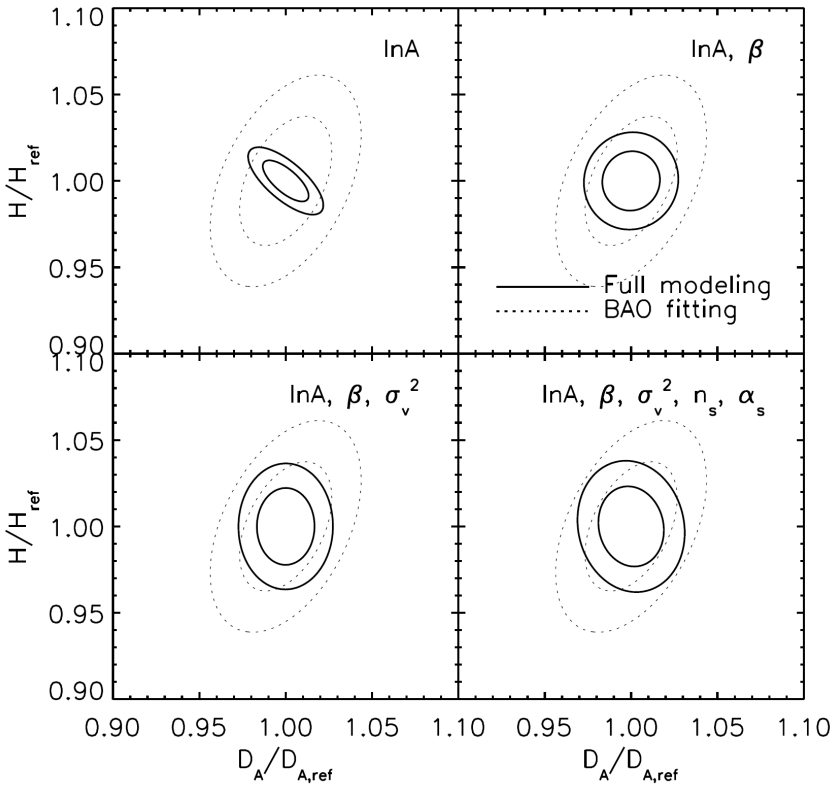
BAO vs GPS (shoji et al. 2009)

- Baryon Acoustic Oscillation gives robust measure of the $D_A(z)$ and $H(z)$
- Galaxy Power Spectrum better constrains $D_A(z)$ and $H(z)$ with the non-linearities (NL) under control
  - NL Structure Growth
  - NL Galaxy Bias
  - NL Redshift Space Distortion
  - NL Suppression by Massive Neutrino ←*NEW!*



Massive Neutrino and Cosmology

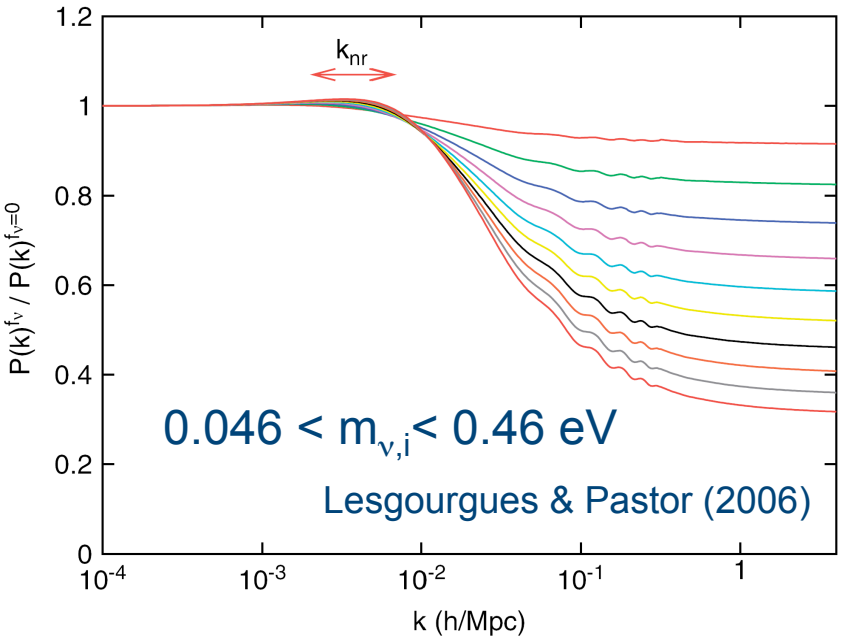
- How massive is neutrino?
  - Oscillation Experiments (both solar and reactor)
    - $\Sigma m_{\nu,i} > 0.056$ (0.095) eV
  - In flat ΛCDM model
    - $\Omega_\nu = \Sigma m_{\nu,i} / 93.14 h^2 \text{eV} < 0.27 \rightarrow \Sigma m_{\nu,i} < 12$ eV
  - Other Constraints from LSS and CMB
    (i.e., 2dF-gal, SDSS, Ly-α, WMAP, SN-Ia)
    - $\Sigma m_{\nu,i} < 0.6$ eV

- How can we put a constraint on the mass of neutrino from the power spectrum?

Massive Neutrino Suppresses Power Spectrum

~Effect on Linear Power Spectrum~

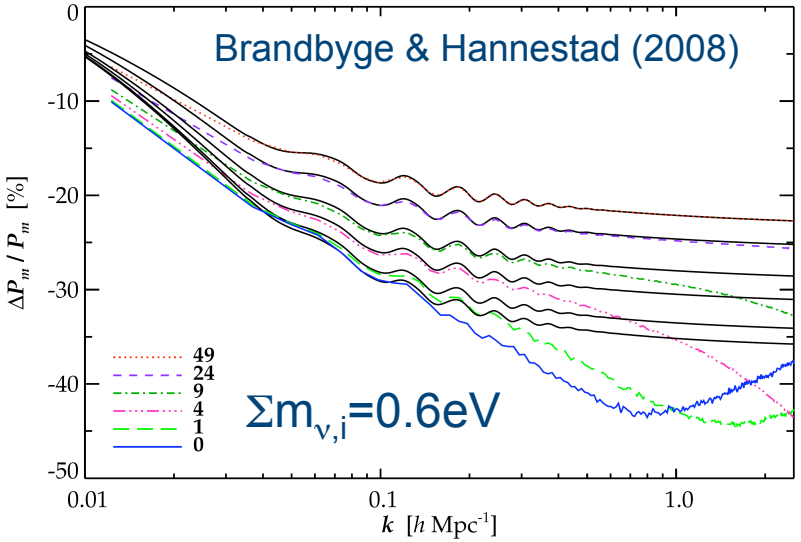
- Massive neutrino acquires velocity dispersion ($0 << \sigma_\nu < 1$) upon the transition to the non-relativistic particle at $z_{nr}(m_{\nu,i})$
- Within the free-streaming scale, $k > k_{FS}$, structure growth is suppressed : analogous to the Jeans scale if we replace k_{FS} with k_J
- At $k >> k_{FS}$, power spectrum is suppressed by a fixed amount: $P_{\Lambda MDM}/P_{\Lambda CDM} = 1-8[\Omega_\nu/\Omega_m]$



— Linear power spectrum with degenerate massive neutrino divided by the linear power spectrum with mass-less neutrino (N_ν=3.04)

Non-linear Suppression by Massive Neutrino

- Calculate the density contrast up to 3rd order solving perturbed continuity, Poisson and Euler equation
- The suppression effect can be understood by the two step processes
  - Density contrast of the neutrino is suppre… …ndent way: $g_n(\mathbf{k},\tau) \equiv \frac{\delta_{n,b}(\mathbf{k},\tau)}{\delta_{n,c}(\mathbf{k},\tau)}$
  - Reduced gravitational potential within the filtering scale (i.e., $k_{FS} < k$) results suppression of the growth rate:



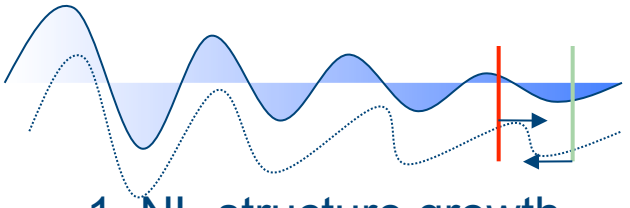
$$D_1^{(1)}(k,\tau) \propto \tau^{n(k)}$$

$$n(k) = \frac{1}{2}\left[-1 \pm 5\sqrt{1 - \frac{24}{25} f_b (1 - g_1^{(0)}(k))}\right]$$

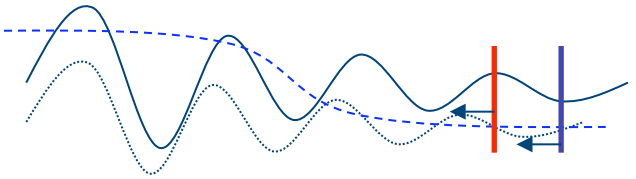
$$\simeq \begin{pmatrix} 2 \\ -3 \end{pmatrix} \mp \frac{6}{5} f_b (1 - g_1^{(0)}(k)),$$

Phase Shift of the BAO by Massive Neutrino

1. Mode mixing due to non-linear structure growth (power transfer from low *k* to high *k*)
2. Distort the BAO shape by filtering function
3. Weaken the non-linearity by suppressing power spectrum at $k >> k_{FS}$



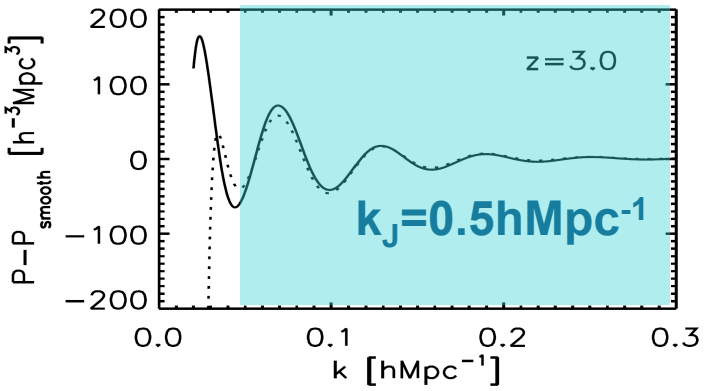
1. NL-structure growth



2. Filtering by free-streaming

Phase shift [%]	z=2.0	3.0	4.0
f_ν=0 (reference)	-1.2	-0.7	-0.3
k_{FS}=0.1 hMpc^{-1}	0.4	0.3	0.0
k_{FS}=0.5 hMpc^{-1}	0.8	0.9	0.3

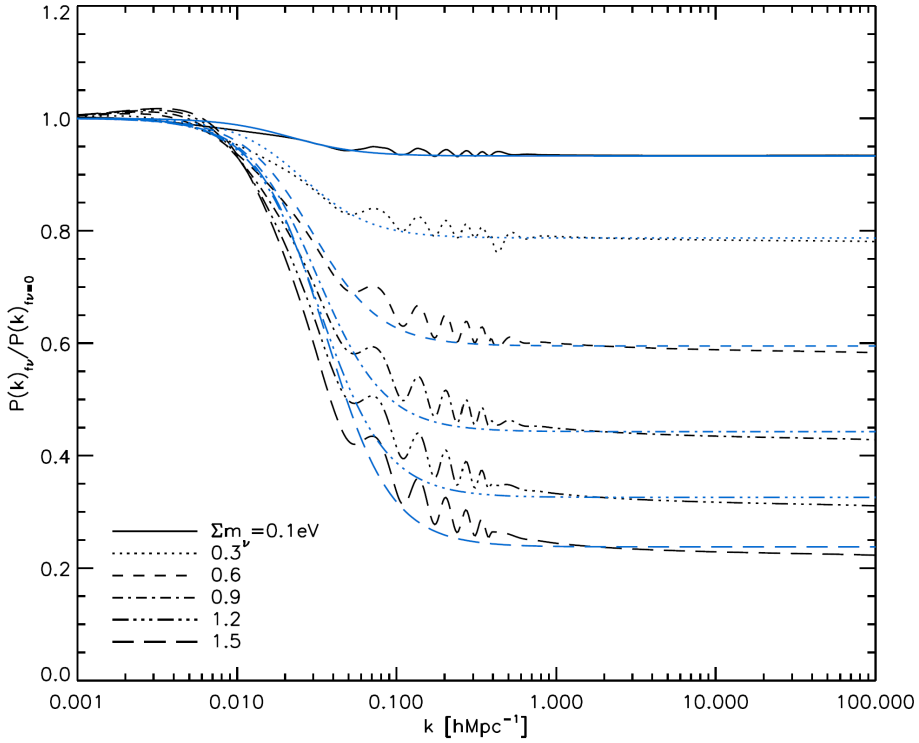
Linear BAO vs. Non-linear BAO phases



Conclusions

- Free-streaming of the massive neutrino distorts the power spectrum around the relevant scale as the BAO (0.05~0.3 $hMpc^{-1}$)
  - Potentially degenerate with the FoG effect
- NL behavior of the massive neutrino free-streaming suppresses the power spectrum in non-trivial way ← under control (Shoji & Komatsu 2009 in prep)
- BAO shape and phase is distorted in the presence of the massive neutrino. Its extent depends on the mass of the massive neutrino
- Understanding the effect of the massive neutrino on the power spectrum brings extra constraints on $\Sigma m_{\nu,i}$ and potentially $m_{\nu,i}$ for non-degenerate massive neutrino

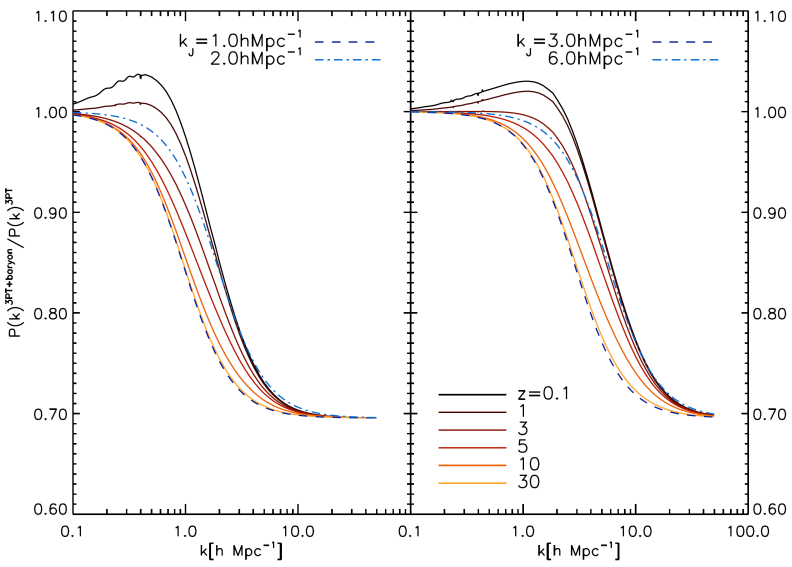
Supplements



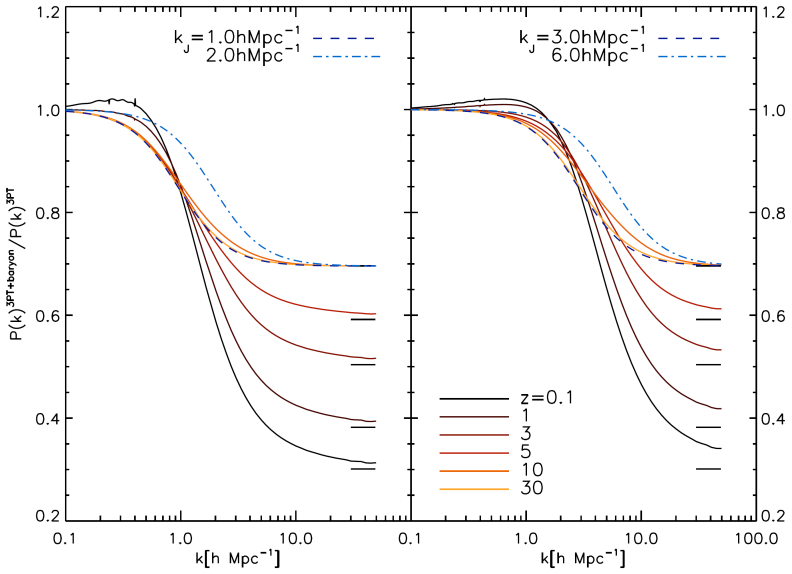
$$g_1(k) = \frac{1}{1 + (k / \tilde{k}_{FS})^2}$$

$$\tilde{k}_{FS} = \lambda(m_{\nu,i}, \Omega_m, \Omega_\Lambda, z) k_{FS}$$

Linear vs. Non-linear



Filtering function



Filtering function

+ Suppression of growth rate