Title: Precision reconstruction of the cold dark matter-neutrino relative velocity.

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Abstract: Neutrinos occur in great number throughout the Universe, yet remain poorly understood due to their weak interactions with other matter. In particular, individual neutrino masses remain an elusive property for particle physicists and cosmologists abound. Recently, it has been proposed that individual neutrino masses may be constrained from observations of neutrino wakes that result from the relative flow between cold dark matter (CDM) and neutrinos. The only required knowledge for such a detection is the relative velocity field between CDM and neutrinos. However, since neither CDM nor neutrinos are directly observable, their relative flow must be obtained by indirect means. We modify the cosmology code, CUBEP3M, to simulate neutrino N-body particles alongside CDM. We find the result that the relative velocity field can be obtained accurately by applying linear transformations to the halo density field. Assuming prior knowledge of the halo bias, we find that the reconstructed relative velocities are highly correlated with the simulated ones, with correlation coefficients of 0.94, 0.93, 0.92 and 0.88 for neutrinos of mass 0.05, 0.1, 0.2 and 0.4 eV, respectively. We confirm that the relative velocity field reconstructed from large-scale structure observations, such as galaxy or 21 cm surveys, can be accurate in direction and, with appropriate scaling, magnitude.

Precision reconstruction of the cold dark matter-neutrino relative velocity.

JD Emberson

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Outline

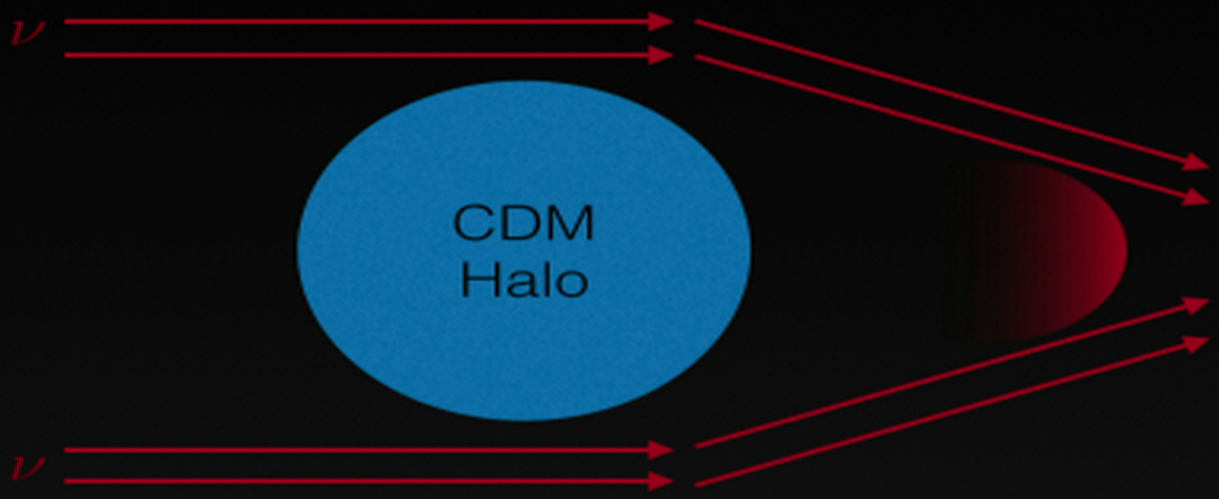
1. Introduction and motivation.
   Cosmological probe of neutrino mass.
2. Relative velocity reconstruction.
   The role of non-linear structure formation.
3. Observable quantities
   Dipole, Halo mass
4. Summary

Cosmological Neutrinos

- The cosmic neutrino background (CNB) contains relic neutrinos from the early Universe.
- Decoupled $t_{\rm dec} \sim 1\ {\rm s}$ after the Big Bang.
- Contribute an energy density $\Omega_\nu = \dfrac{\sum m_\nu}{93.14\ h^2\ [{\rm eV}]}$.
- Current constraints on neutrino mass are in the form of mass differences, $m_j^2 - m_i^2$, or total mass, $\sum m_\nu$.
- Individual masses are still unknown.

Measuring Neutrino Mass

- Neutrinos can be gravitationally focused by CDM into wakes.



- Downstream excess can be seen as a dipole distortion in weak lensing surveys that depends sensitively on neutrino mass.
- Requires knowledge of dark matter-neutrino relative velocity.

Neutrino N-body Simulations

- Modified the cosmology code, CUBEP^{3}M, to simulate collisionless neutrino point particles alongside dark matter.

- Dark matter initial conditions are generated at $z_c = 100$ and evolve independently to $z_\nu = 10$ at which point neutrinos are added to the mixture.

- Initial neutrino velocities composed of two components:
  1) Linear Zel'dovich velocity.
  2) Random thermal component drawn from the relativistic Fermi-Dirac distribution.

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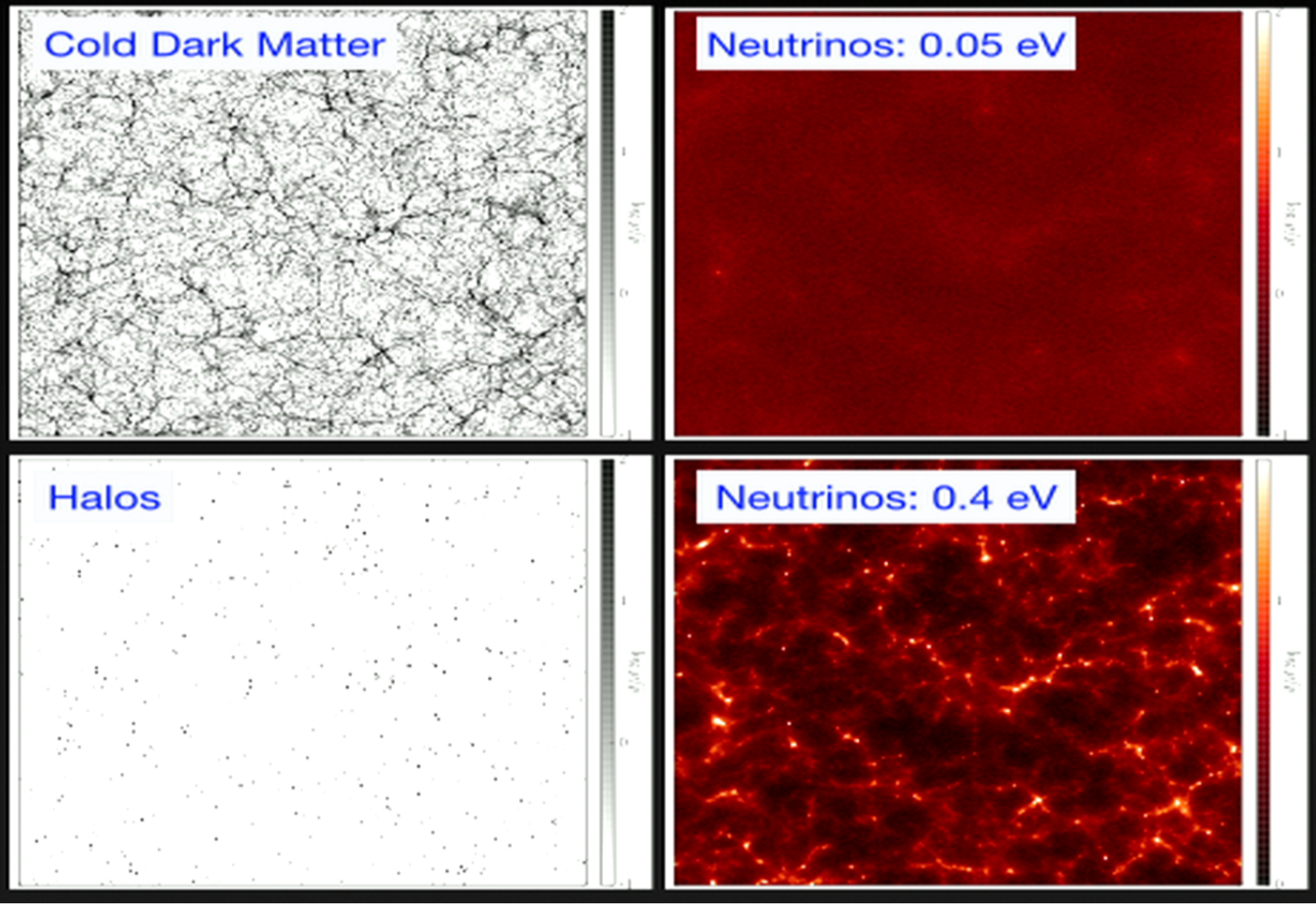
$$m_\nu = [0.05, 0.1, 0.2, 0.4] \text{ eV}$$
$$n_c = 1536^3$$
$$n_\nu = 3072^3$$
$$L = 500 \text{ Mpc}/h$$

Density Fields



Velocity Fields

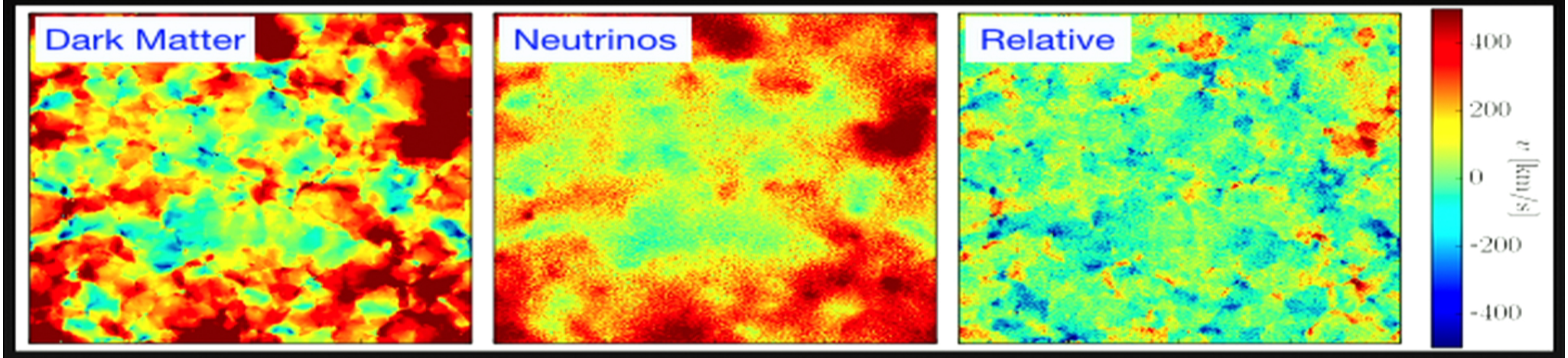
- Neutrinos: Divide the momentum density field by the density field.

$$\vec{v}_c = \frac{\sum_c m\vec{v}_i}{\sum_c m}$$

- Dark matter: Take average of the N nearest particles about the grid centre.

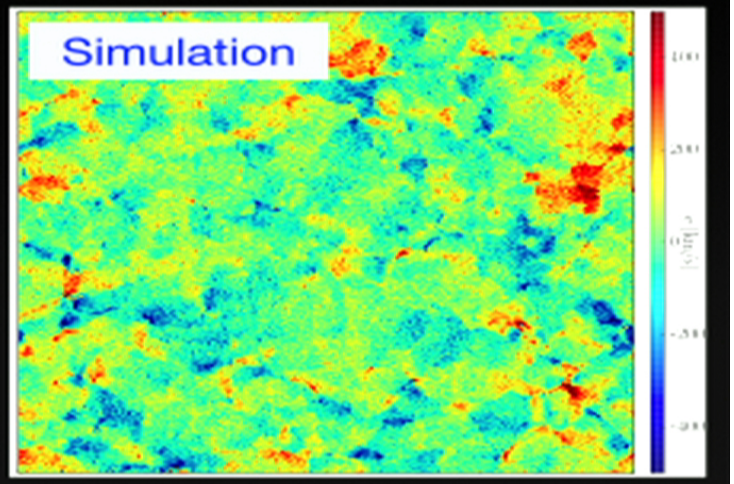
$$\vec{v}_c = \frac{1}{N}\sum_N \vec{v}_i$$

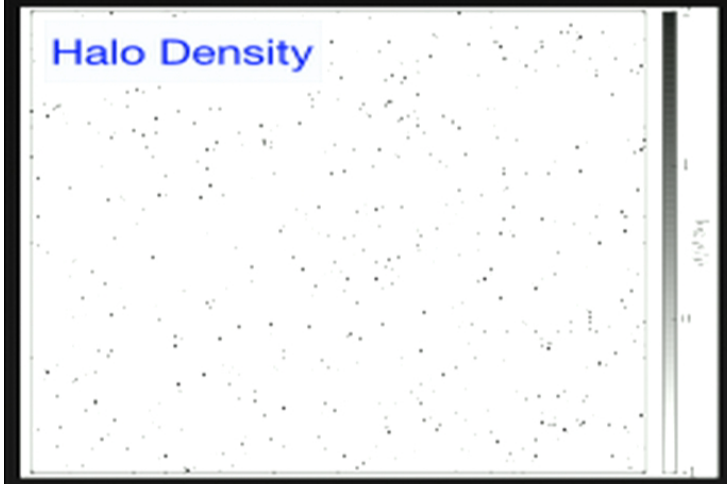
Velocity Fields



$m_\nu = 0.2$ eV

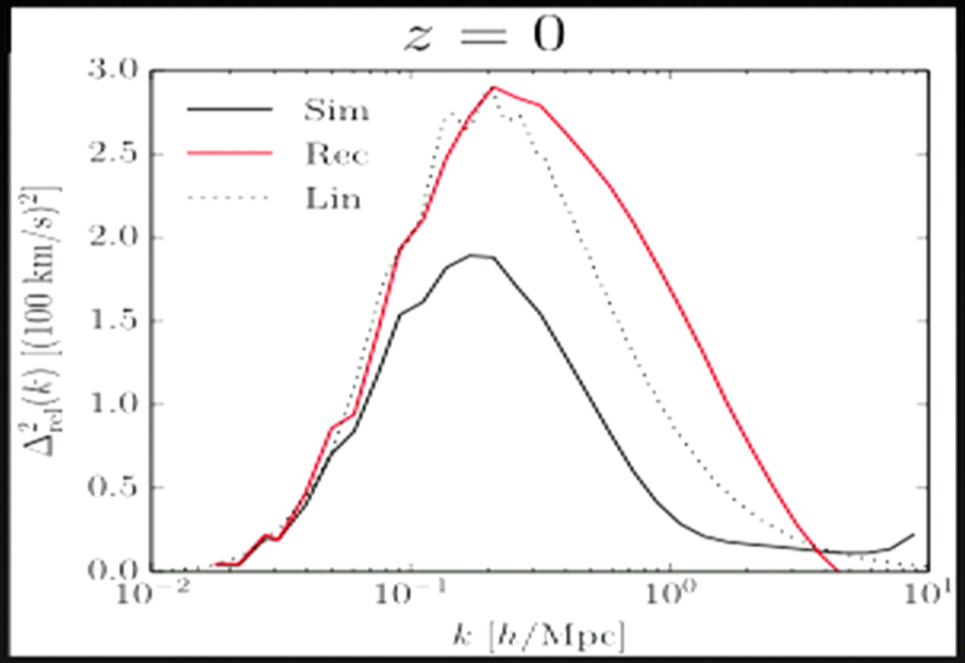
Velocity Reconstruction





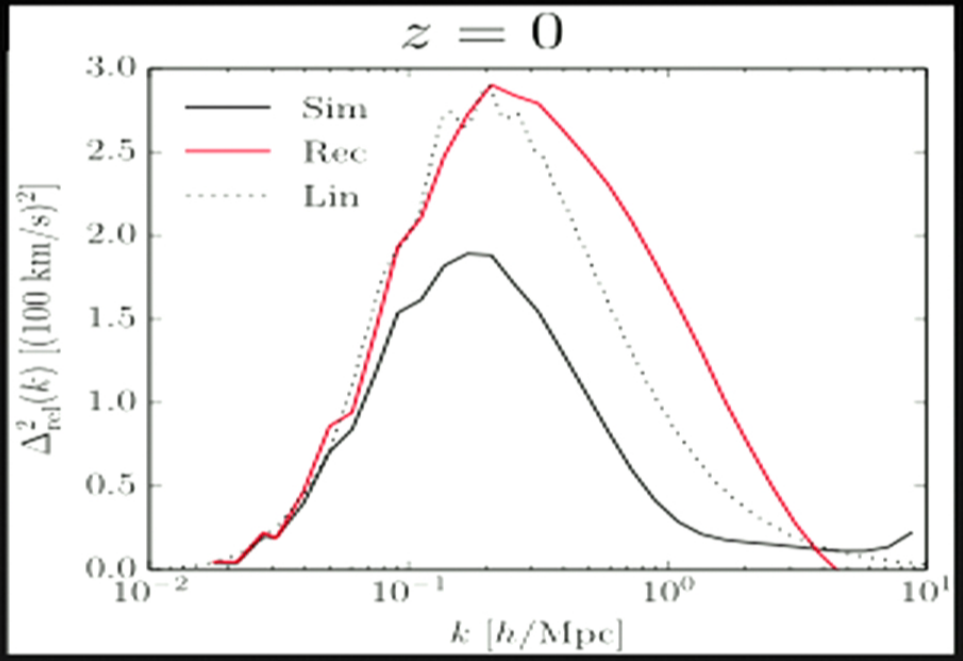
$$\vec{v} = \frac{T_v(k)}{T_\delta(k)} \frac{\vec{k}}{k} \frac{\delta_g(k)}{b}$$

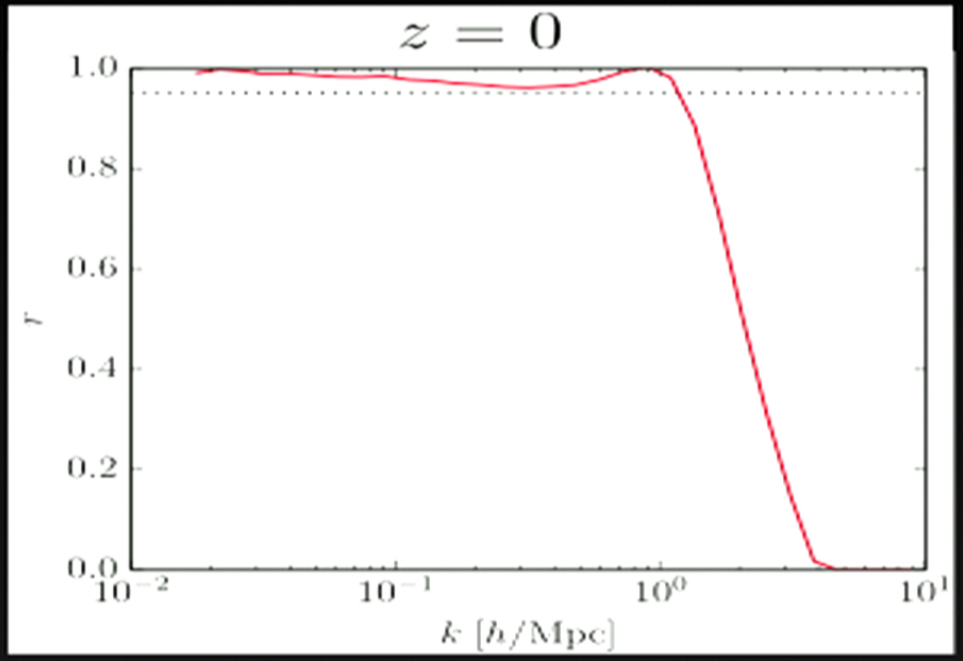
Velocity Reconstruction



$m_\nu = 0.2$ eV

Velocity Reconstruction





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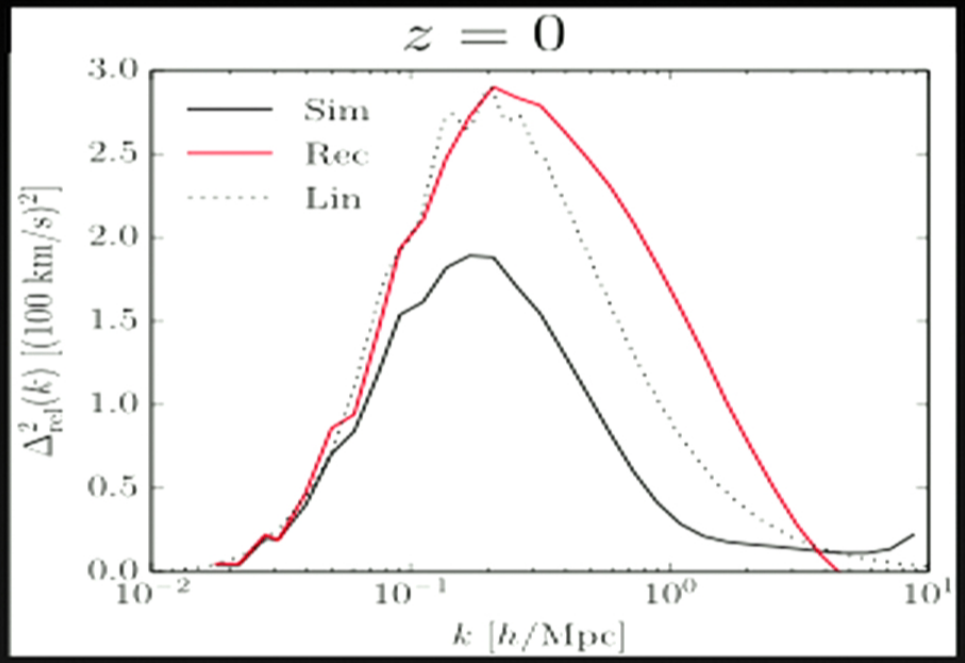
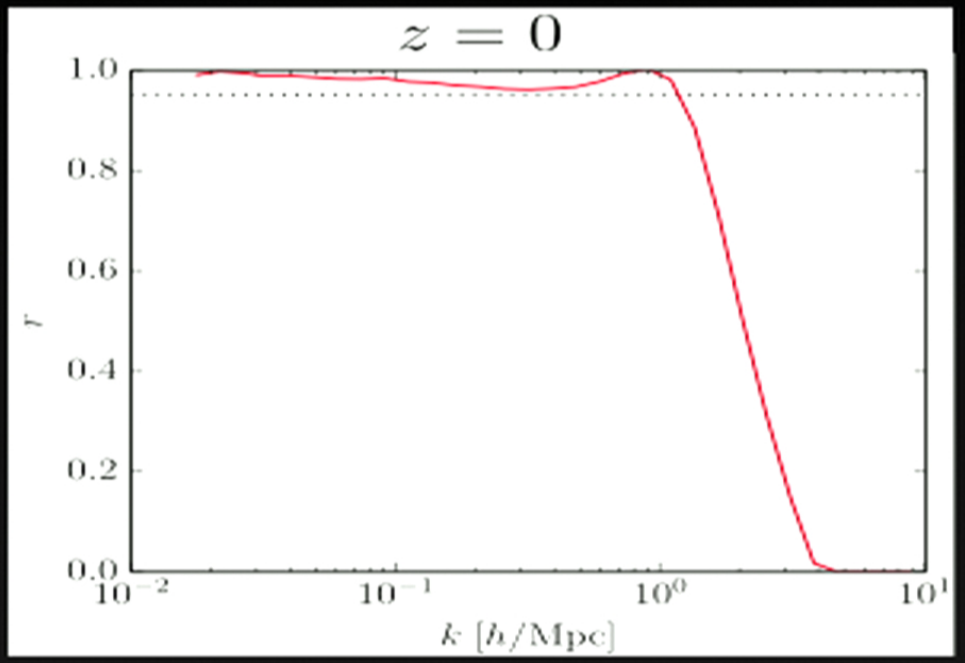
$$r = \frac{\Delta^2_{\rm sim,rec}}{\sqrt{\Delta^2_{\rm sim}\Delta^2_{\rm rec}}}$$

Velocity Reconstruction





The direction of the relative velocity field can be reconstructed accurately using the galaxy density field.

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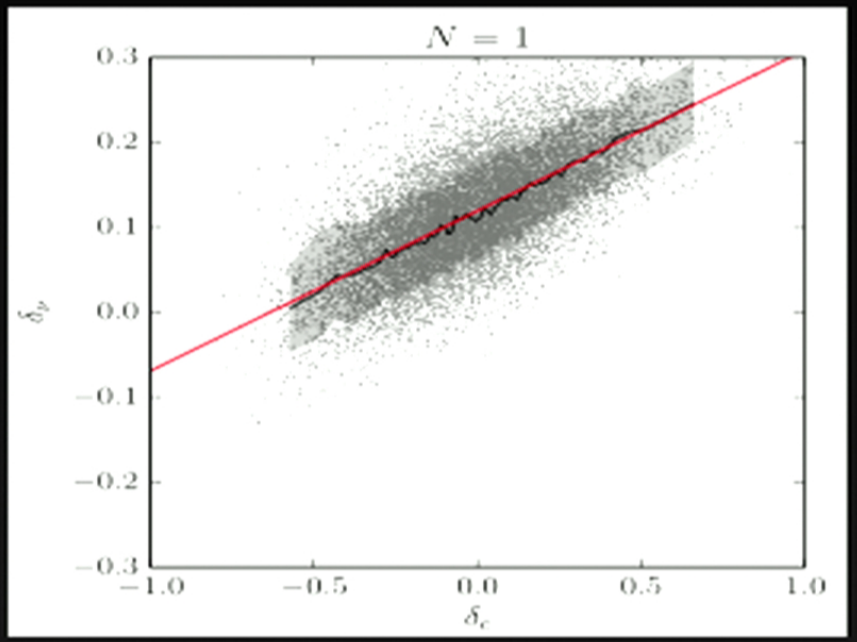
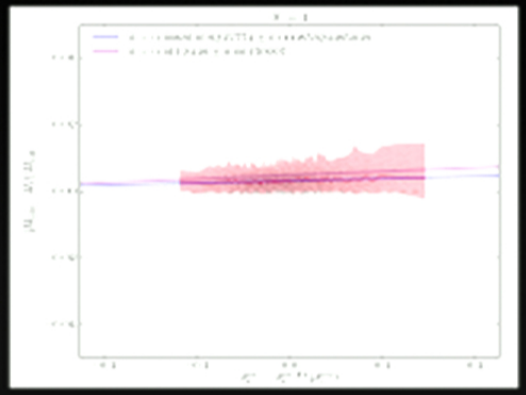
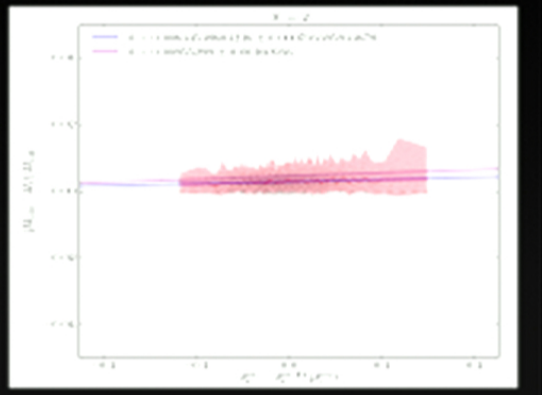
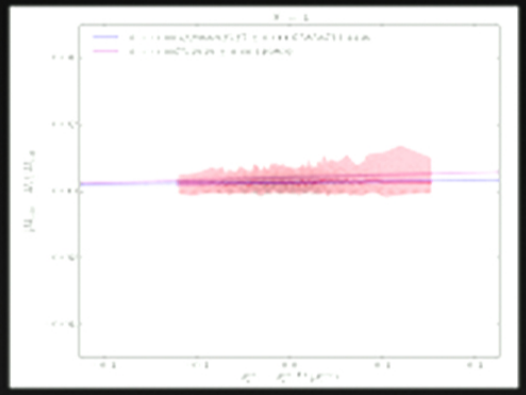
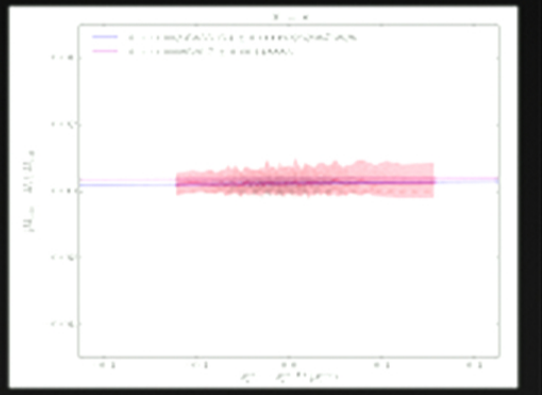
Halo masses
(Preliminary)







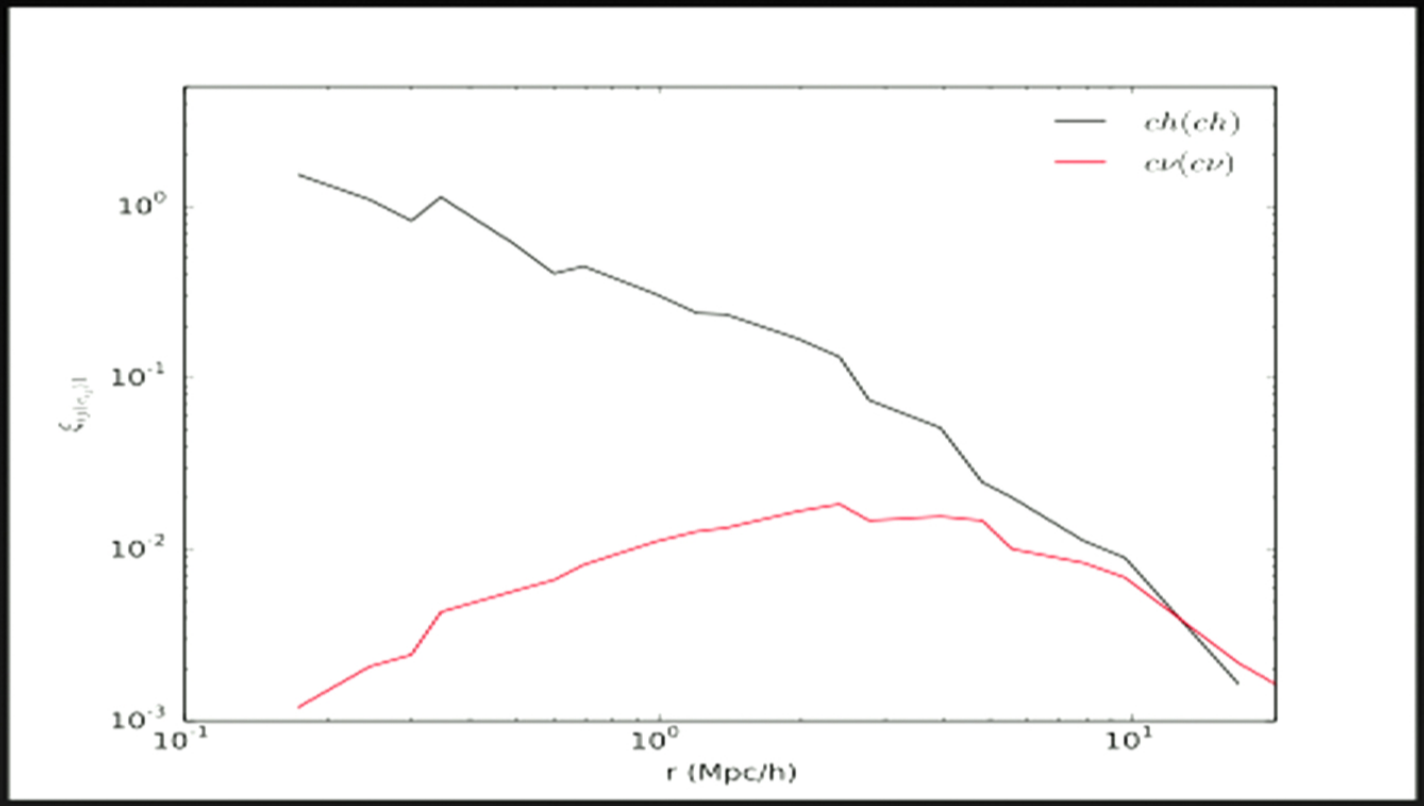




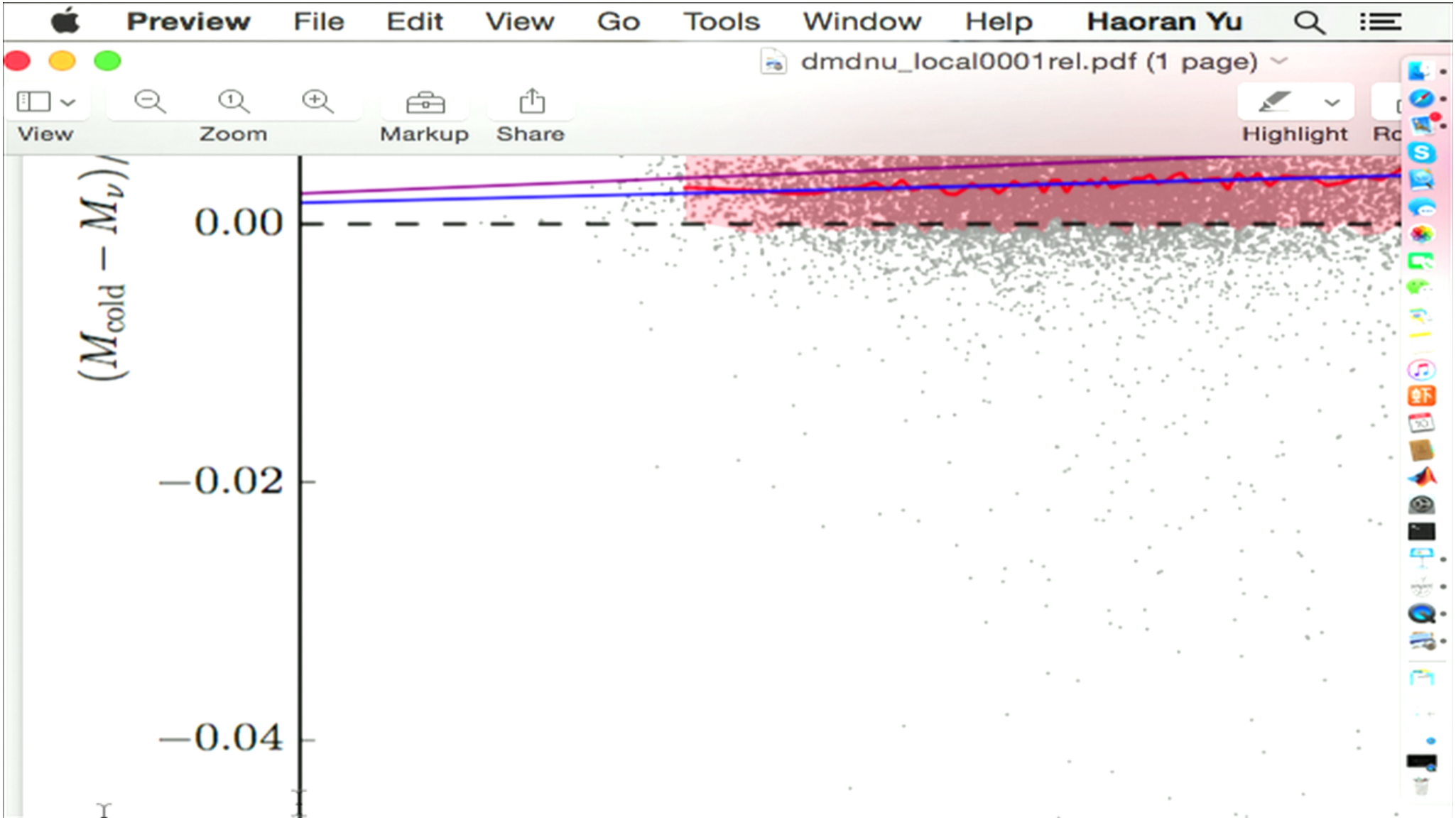
Even small neutrino masses can affect large scale structure

Dipole distortion (preliminary!)

$$\xi_{ij}(r) = \langle (\delta_i \delta_j - \delta_j \delta_i) \hat{v}_{ij} \cdot \hat{r} \rangle$$



See Hong-Ming's talk for more information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dmdnu_local0001rel.pdf (1 page)
View
Zoom
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Share
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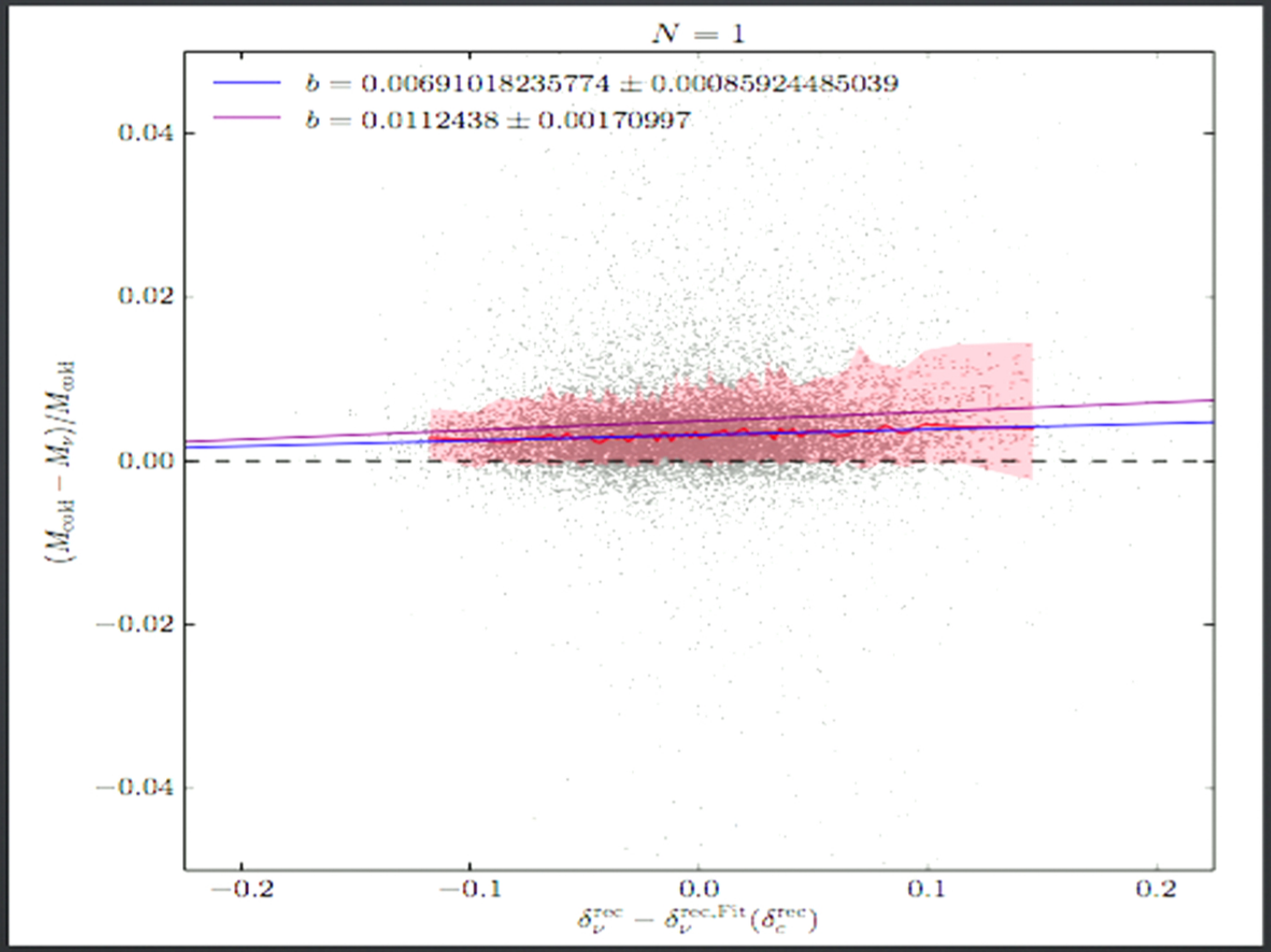
$(M_{\rm cold} - M_\nu)$
0.00
−0.02
−0.04


$N = 1$
$b = 0.00691018235774 \pm 0.00085924485039$
$b = 0.0112438 \pm 0.00170997$
0.04
0.02
0.00
−0.02
−0.04
$(M_{\rm coH} - M_\nu)/M_{\rm coH}$
−0.2
−0.1
0.0
0.1
0.2
$\delta_\nu^{\rm rec} - \delta_\nu^{\rm rec,Fit}(\delta_c^{\rm rec})$