Abundances of Rare Objects and primordial non-Gaussianity

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Benasque 2010 - August 17th

IPMU = Institute for Physics and Mathematics of the Universe

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Host Institute: U of Tokyo

Location: Kashiwa (Chiba)

New building open in Jan10

21 Full-time faculty members

40+ postdocs

OUTLINE

- Excursion set approach -- moving barrier in non-Gaussian models
- Doroshkevich's formula in local f_{nl} model
- First crossing problem -- path integral or Edgeworth expansion?
- Abundances of another extremes

Signatures of primordial non-Gaussianity on LSS

- ✳Bispectrum
- ✳Halo mass function
- ✳Scale dependent halo bias
- ✳peculiar velocity (redshift-space distortion)

(TYL, Desjacques & Sheth 2010; Schmdit 2010; TYL, Nishimichi & Yoshida 2010)

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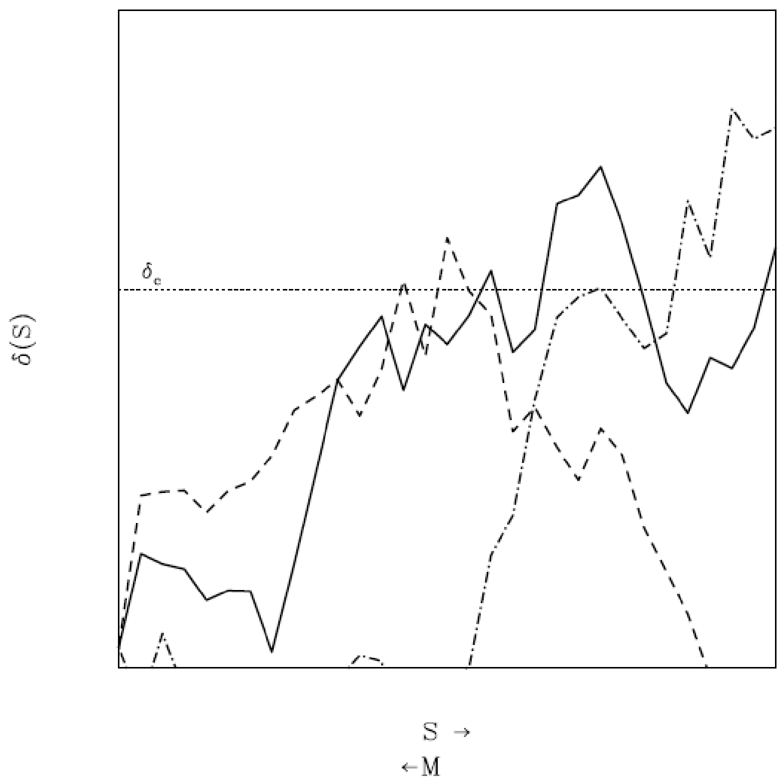
Need a good description of the halo mass function

Excursion set approach

Excursion set theory

Bond, Cole, Efstathiou and Kaiser (1991)
Peacock and Heavens (1990)

- study the evolution of $\delta(R)$ as a function of R
  - at $R=\infty$, $\delta(R)=0$. Lowering R, $\delta(R)$ evolves stochastically
  - use $S=\sigma^2(R)$ as "time". At $R=\infty$, $S=0$. As R decreases, S increases



First-passage time problem

slide from Maggiore's talk

Ingredients of excursion set approach

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ii. first-crossing probability across the barrier - correlated or uncorrelated walk

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Assumption: halo formation depends only on the smoothed density field

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OR

Full calculations of first crossing barrier based on path-integral (Maggiore & Riotto 2009+; D' Amico et al. 2010; De Simone et al. 2010) or bivariate Edgeworth expansion (TYL & Sheth 2009)

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ST mass function (moving barrier) describes the mass function from simulations (N-body, Gaussian initial conditions) better than the PS mass function (constant barrier).

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ST moving barrier: take the most probable values of e and p

$B(\sigma) = \sqrt{a}\delta_c[1 + \beta(\sigma/\sqrt{a}\delta_c)^{2\gamma}]$ where a=0.7, β= 0.4, γ=0.6

Question: Is the moving barrier the same for non-Gaussian models?

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OR

$$g(e, p|\delta; f_{nl}) = g(e, p|\delta; f_{nl} = 0)?$$

Method: Look at the eigenvalues of the shear field tensor

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Define:

$$\begin{aligned} x &= \Phi_{11} + \Phi_{22} + \Phi_{33} \\ y &= \frac{1}{2}(\Phi_{11} - \Phi_{22}) \\ z &= \frac{1}{2}(\Phi_{11} + \Phi_{22} - 2\Phi_{33}) \end{aligned}$$

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$\{x, y, z, \Phi_{12}, \Phi_{23}, \Phi_{31}\}$ is an independent set of components of the shear tensor

Important: $\langle y^3 \rangle = \langle z^3 \rangle = \langle \Phi_{ij}^3 \rangle_{i \neq j} = 0$

up to 1st order of f_{nl} and local f_{nl} ONLY

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$$\begin{aligned} p(\vec{\lambda}) &= p(\vec{\lambda}|\delta_l)p(\delta_l) = p_0(\vec{\lambda}|\delta_l)p_0(\delta_l)\left[1+\frac{\sigma S_3}{6}H_3(\nu)\right] \\ &= p_0(\vec{\lambda})\left[1+\frac{\sigma S_3}{6}H_3(\nu)\right] \end{aligned}$$

TYL, Sheth & Desjacques 2009

Generation of Doroshkevich's formula to the local fnl model

Tuesday, 17 August 2010

Applications

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- Redshift space distortion in f_{nl} model (TYL, Desjacques & Sheth 2010)

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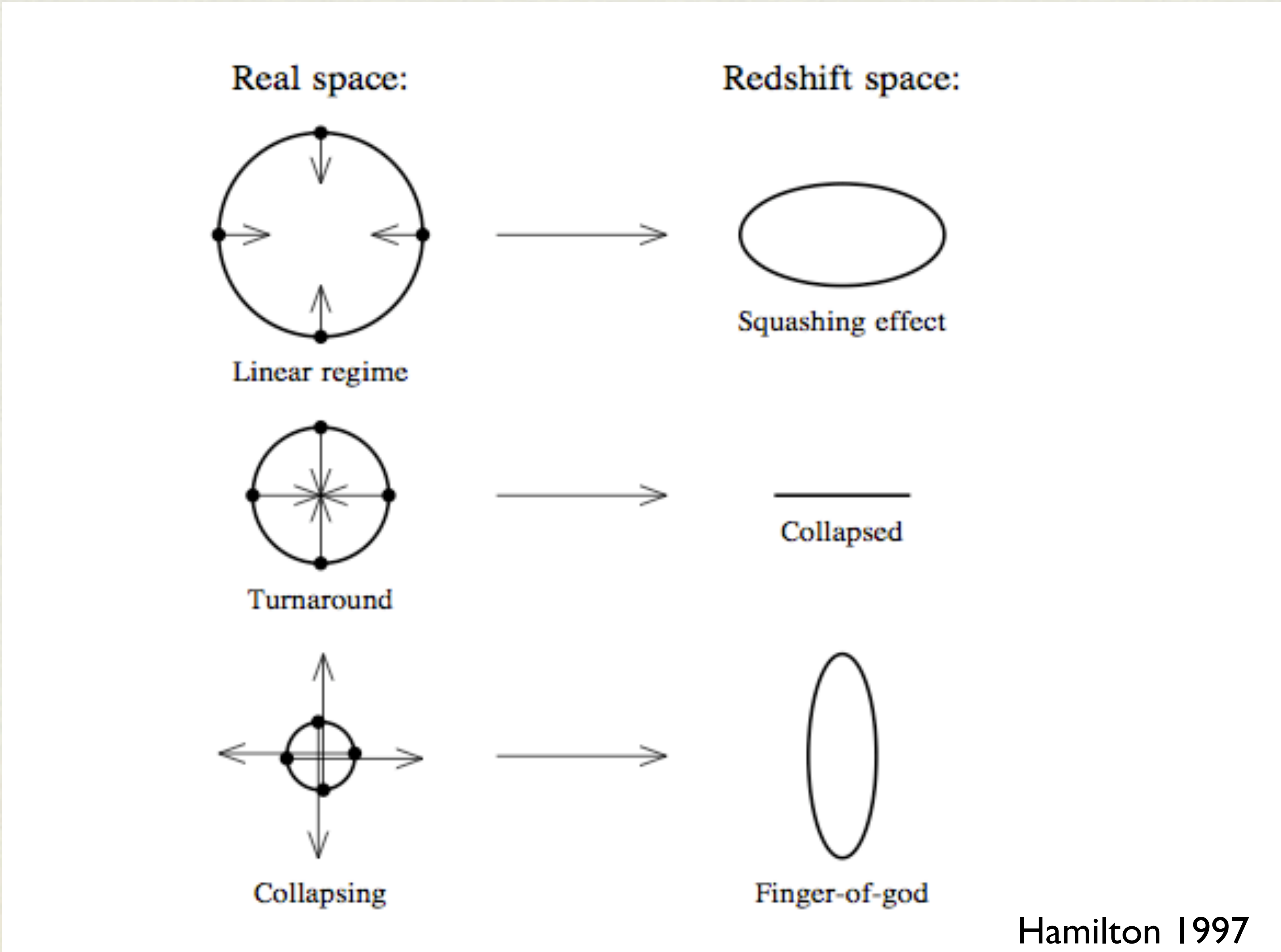

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- ✓ spherical collapse does not result the correct Kasier factor (Ohta et al. 2004)
- ✓ ellipsoidal collapse model gets the correct answer (Ohta et al. 2004; TYL & Sheth 2008)
- ✓ The Generalized Doroshkevich's formula in local f_{nl} type can apply to compute the effect on redshift space distortion (TYL, Desjacques & Sheth 2010)

- The zeroth order gives the original Kaiser factor:

$$\langle \delta_s^2 \rangle \approx \langle (\delta_r^{(1)})^2 \rangle = \left(1 + \frac{2}{3} f_1 + \frac{1}{5} f_1^2\right) \sigma^2$$

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- The first order has the effect of f_{nl}

$$\langle \delta_s^2 \rangle^{(2)} = 2 \underbrace{\frac{\sigma S_3}{6}}_{\propto f_{nl}} \sigma^3 \left[3\nu_2 + (\nu_2 + \frac{2}{3}) f_1 - \frac{44}{45} f_1^2 + \frac{4}{9} f_1^3 + \frac{\nu_2}{3} f_1 f_2 + \nu_2 f_2\right]$$

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- first crossing probability across moving barrier (height depends on smoothing scale/mass)

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analogy to n-point path integral neglecting correlation walk

Iterative solution (TYL & Sheth 2009):

$$s f_0(s,b) = \left[b - s\frac{\partial b}{\partial s}\right]\frac{\mathrm{e}^{-b^2/2s}}{\sqrt{2\pi s}} - \sum_{i=2}^{\infty}\frac{s^i}{i!}\frac{\partial^i b}{\partial s^i}\int_0^s dS\, f_0(S,B)\,\frac{\mathrm{e}^{-(b-B)^2/2(s-S)}}{\sqrt{2\pi(s-S)}}\,(S/s-1)^{i-1}$$

Path Integral (neglecting correlation) (De Simone et al. 2010):

$$\mathcal{F}^{(0)}(S) = \frac{B(S)}{\sqrt{2\pi}S^{3/2}}e^{-B^2(S)/(2S)}\,, \qquad (68)$$

while the higher orders give

$$\mathcal{F}^{(a)}(S) = -\frac{B'(S)}{\sqrt{2\pi S}}e^{-B(S)^2/(2S)}\,, \qquad (69)$$

$$\mathcal{F}^{(b)}(S) = \frac{B''(S)}{4\pi} \times\left\{\sqrt{2\pi S}e^{-B(S)^2/(2S)} - \pi B(S)\mathrm{Erfc}\left[\frac{B(S)}{2S}\right]\right\}. \qquad (70)$$

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Monte-Carlo:

Easy for Gaussian initial conditions with no correlation between steps.

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(TYL & Sheth, in preparation)

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e. Advantages: fast, no need to rerun for different barriers

Monte-Carlo simulation on correlated walk

Characteristic function:

$$\mathcal{M}(\vec{t}) = \exp\langle \exp(i\vec{t}\cdot\vec{x})\rangle_c$$

$\vec{x}$ is a N-dim vector, x_i is the height of the (uncorrelated) random walk at step i, whose variance is s_i

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Gaussian, uncorrelated walk (sharp k-space filter):

$$\mathcal{M}_g(\vec{t}) = \exp\left[\sum_{m=1}^{n} \underbrace{\frac{\langle x_m^2\rangle}{2}}_{=1}(it_m)^2 + \sum_{m<l} \underbrace{\langle x_m x_l\rangle}_{=\sigma_m/\sigma_l}(it_m)(it_l)\right]$$

Its Fourier transform is the multivariate normal distribution

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Write $\quad \mathcal{M}(t) = \mathcal{G}(t,x)\mathcal{M}_g(t)$

correction due to correlated walk

$$\begin{aligned}\mathcal{G}(t,x) \quad &= \quad \exp\Bigg[\sum_{m<l} \left(\langle x_m x_l\rangle - \sigma_m/\sigma_l\right)(it_m)(it_l) + \sum_{m=0}^{n} \frac{\langle x_m^3\rangle}{3!}(it_m^3) \\ &\qquad + \sum_{m<l} \frac{\langle x_m^2 x_l\rangle}{2}(it_m)^2(it_l) + \sum_{m<l<k} \langle x_m x_l x_k\rangle(it_m)(it_l)(it_k) + \dots\Bigg]\end{aligned}$$

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$$\left. + \sum_{m<l} \frac{\langle x_m^2 x_l \rangle}{2} (it_m)^2 (it_l) + \sum_{m<l<k} \langle x_m x_l x_k \rangle (it_m)(it_l)(it_k) + \ldots \right]$$

Fourier transform is derivative operator on $F_g(x)$

Expression of nth order derivative of F_g:

$$\frac{\partial^n}{\partial x_{i_1} \ldots \partial x_{i_k}} \mathcal{F}_g(x) = (-1)^k \mathcal{F}_g(x) \times \text{correction}$$

Path-integral: compute the cumulative probability and calculate first cross probability

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i. Correlated steps with moving barrier
ii. Moving barrier with other types of primordial non-Gaussianity
iii. Another type of moving barrier

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- Void-in-cloud: two barriers problem δ_c and δ_v

Two barriers problem (TYL, Sheth & Desjacques)

Ordinary first crossing prob.

conditional first crossing prob.

$$\mathcal{F}(s,\delta_v,\delta_c) = f(s,\delta_v) - \int_0^s \mathrm{d}S_1 \mathcal{F}(S_1,\delta_c,\delta_v) f(s,\delta_v|S_1,\delta_c)$$

first crossing prob. of δ_c at S, without crossing δ_v for all $S' < S$

first crossing prob. of δ_v at s, without crossing δ_c for all $s' < s$

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Swapping δ_v and δ_c ➡

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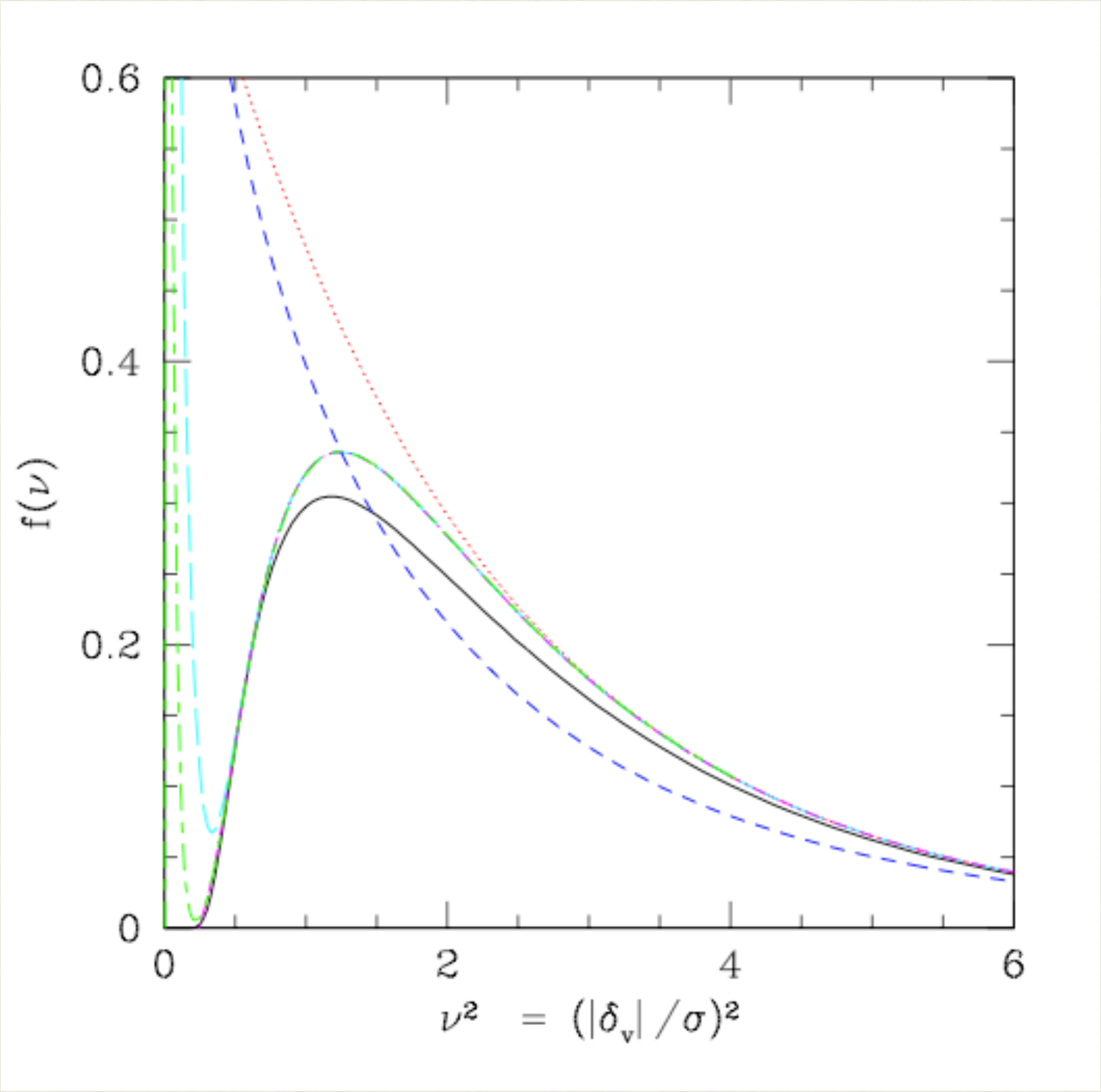
$$\mathcal{F}(s,\delta_v,\delta_c) = f(s,\delta_v)$$
$$+ \sum_{n=1}^{\infty}(-1)^n \int_0^{S_0} \mathrm{d}S_1 \ldots \int_0^{S_{n-1}} \mathrm{d}S_n \prod_{m=0}^{n-1} f(S_m,\delta_m|S_{m+1},\delta_{m+1}) f(S_n,\delta_n)$$

where $S_0 \equiv s$, $\delta_n = \delta_v$ (n even) or δ_c (n odd)

Void abundances



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Effect of f_{nl}

$$f(\delta_n, s) = f_0(\delta_n, s)\left[1 + \frac{\sigma S_3}{6} H_3\left(\frac{\delta_n}{\sigma}\right)\right]$$

$$f(s, \delta_v | S, \delta_c) = f_0(s, \delta_v | S, \delta_c)\left[1 + \frac{\sigma S_3}{6}\zeta(s, \delta_v, S, \delta_c)\right]$$

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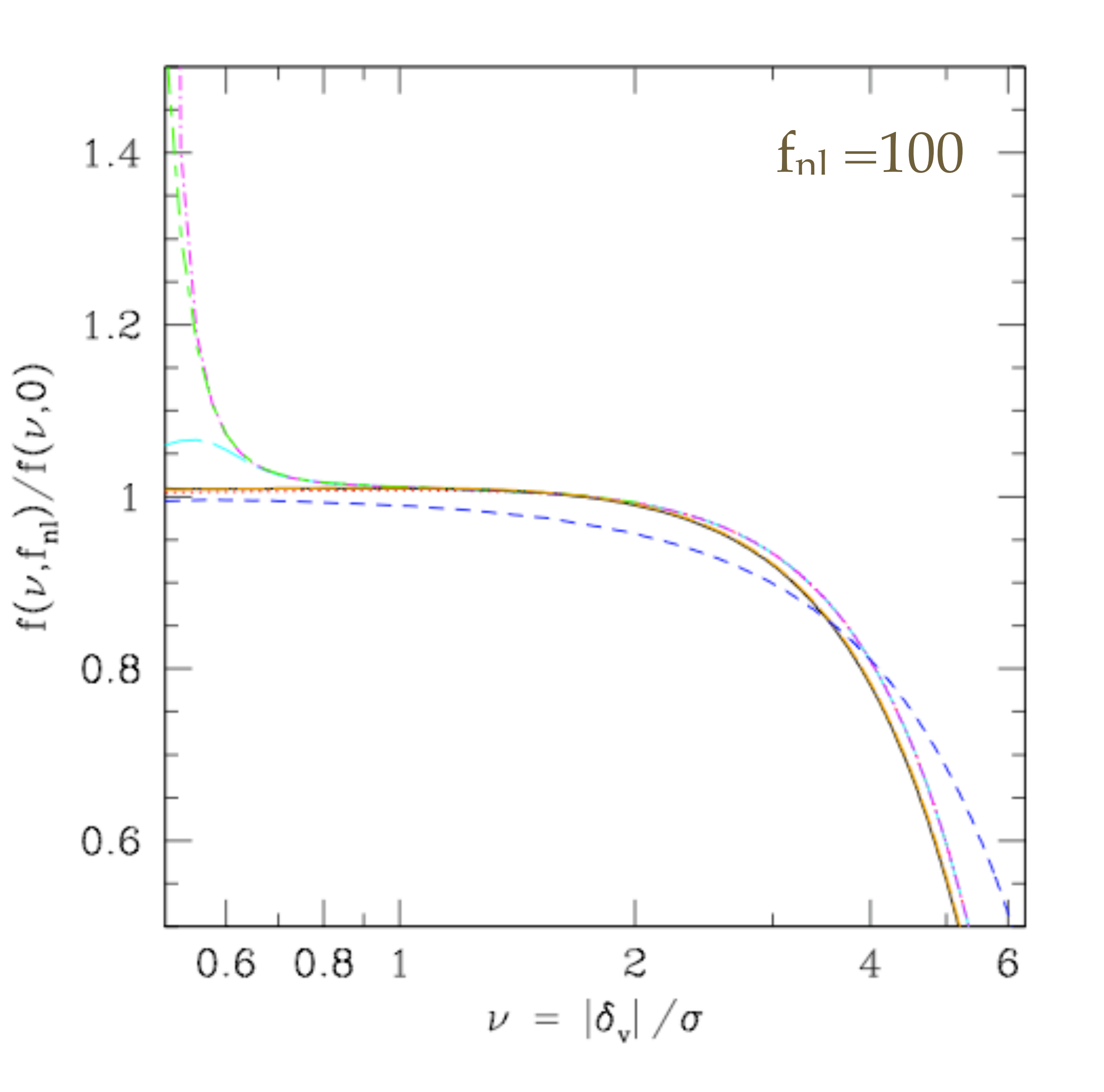
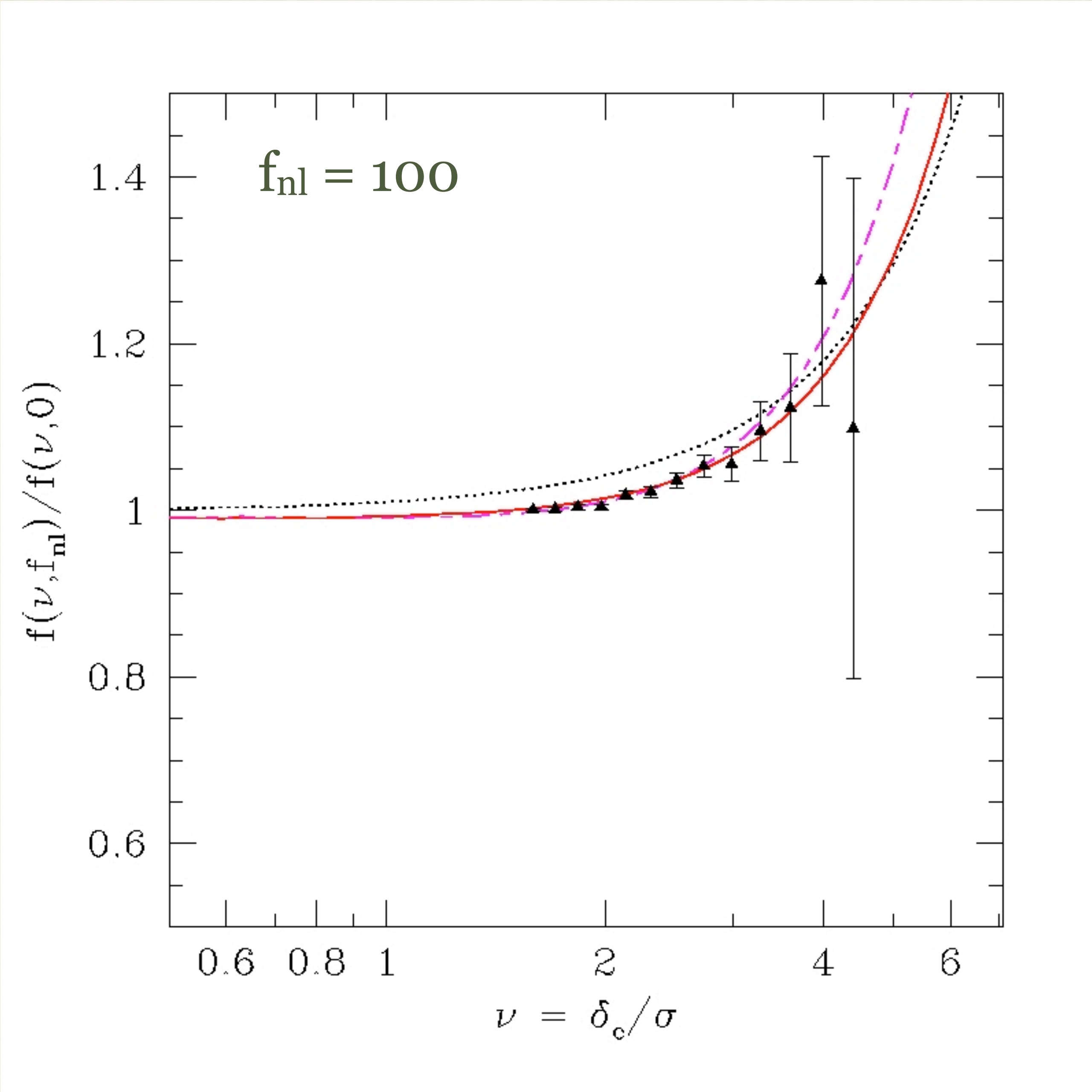
$$\mathcal{F}(s, \delta_v, \delta_c) = \mathcal{F}_0(s, \delta_v, \delta_c) + \frac{\sigma S_3}{6}\left\{ f_0(s, \delta_v) H_3\left(\frac{\delta_v}{\sqrt{s}}\right)\right.$$
$$\left. + \sum_{n=1}^{\infty}(-1)^n \int_0^{S_0} \mathrm{d}S_1 \ldots \int_0^{S_{n-1}} \mathrm{d}S_n \left[\prod_{m=0}^{n-1} f_0(S_m, \delta_m | S_{m+1}, \delta_{m+1})\right] f_0(S_n, \delta_n)\left[\sum_{m=0}^{n-1}\zeta(S_m, \delta_m, S_{m+1}, \delta_{m+1}) + H_3\left(\frac{\delta_n}{\sqrt{S_n}}\right)\right]\right\}. \quad (54)$$

Void Abundance



Halo Abundance



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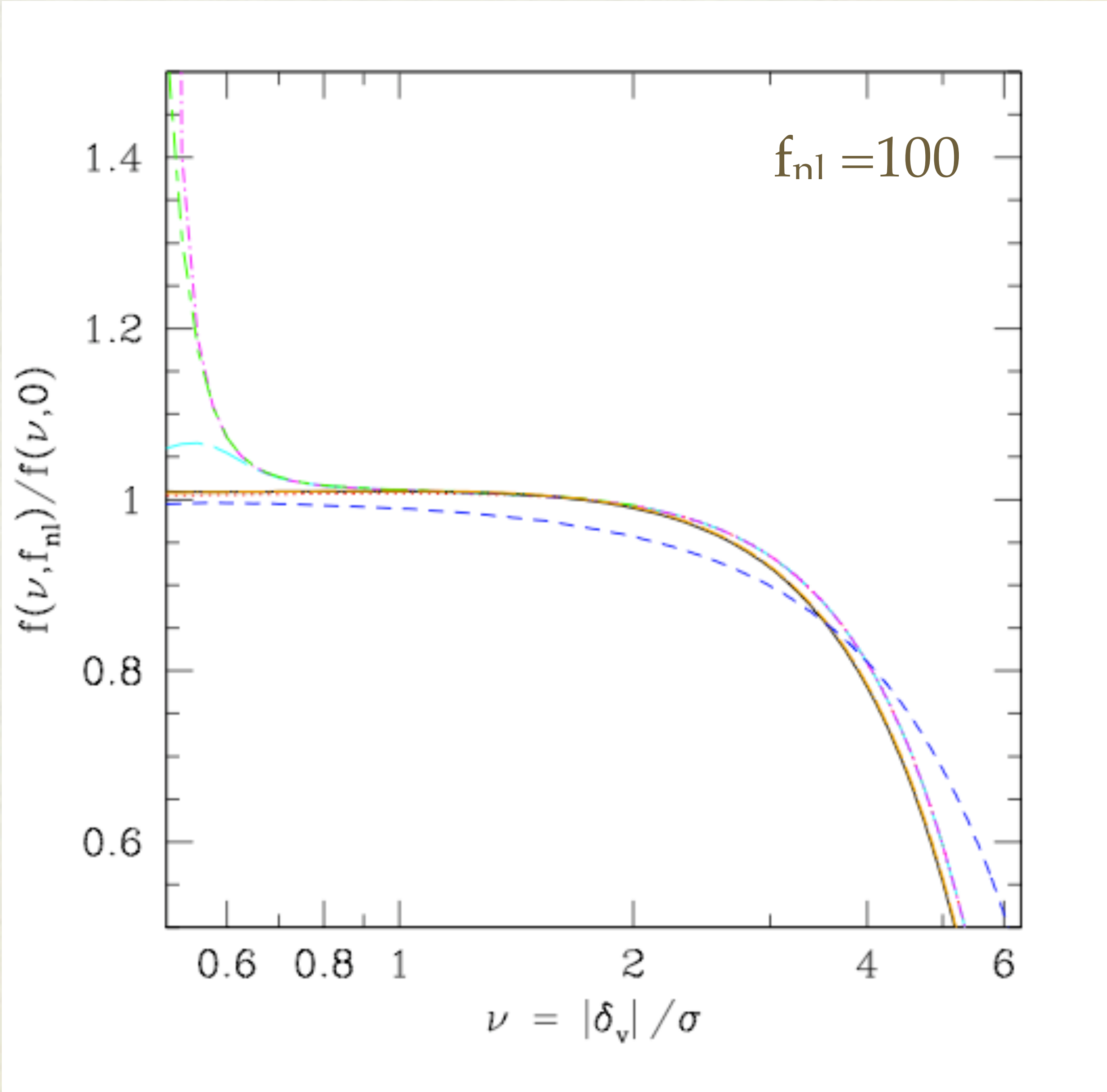

SUMMARY

- Excursion set theory two ingredients: barrier and first crossing probability
- Distribution of e and p does not change given δ for local type
- Moving barrier (ST02) is unchanged in local type; not necessarily true for other types
- First crossing probability for correlated walk and moving barrier is rough to solve analytically: but easy to implement Monte-Carlo simulations
- Void abundances is also sensitive to f_{nl} and the excursion set approach provides a method to solve the two-barrier problem

PECULIAR VELOCITY

- peculiar velocity field & redshift space distortions also affected by primordial non-Gaussianity
- The idea was proposed almost 20 years ago (Scherrer 1992; Catelan & Scherrer 1995; Schmidt 2010) -- all used linear theory
- TYL, Nishimichi & Naoki: Pairwise Vel PDF & evolution included
- Non-vanishing three-point functions:
- Induces correlation between velocities in parallel and perp directions

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- TYL, Nishimichi & Naoki: Pairwise Vel PDF & evolution included
- Non-vanishing three-point functions: $\langle v_{\parallel}^3 \rangle$ and $\langle v_{\parallel} v_{\perp}^2 \rangle$
- Induces correlation between velocities in parallel and perp directions

Evolution of PDF

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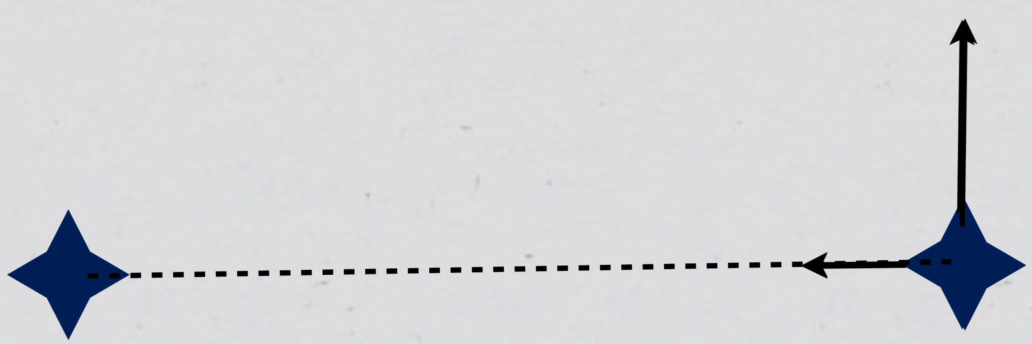

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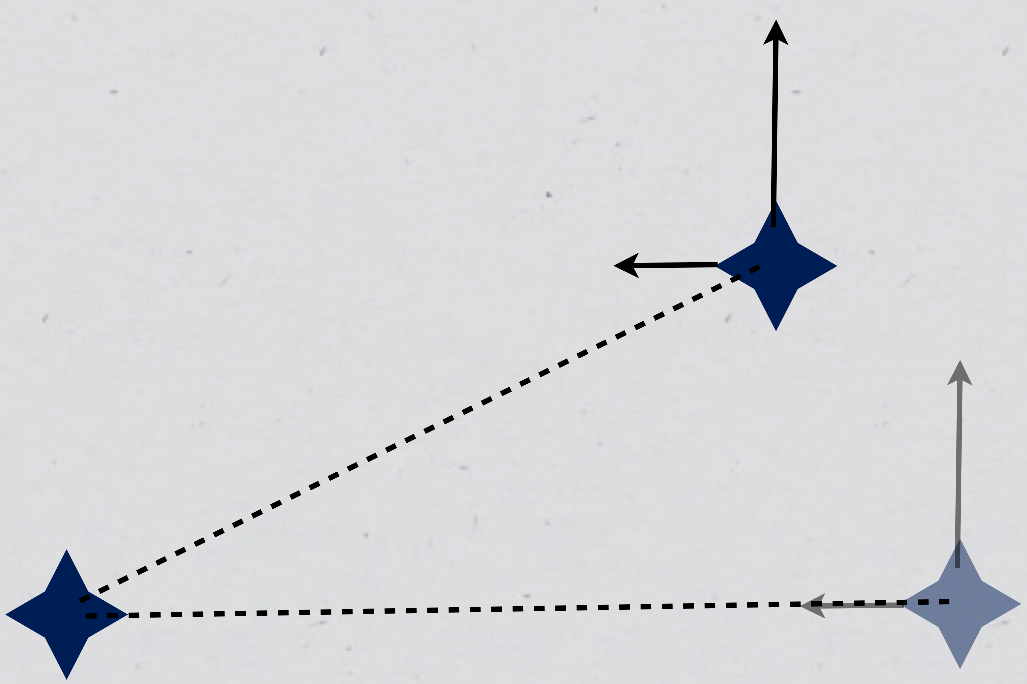


$$r^2 = \left(r_i + \frac{D_0}{\dot{D}_i} v^i_\parallel\right)^2 + \left(\frac{D_0}{\dot{D}_i}\right)^2 \left({v^i_{\perp_a}}^2 + {v^i_{\perp_b}}^2\right)$$

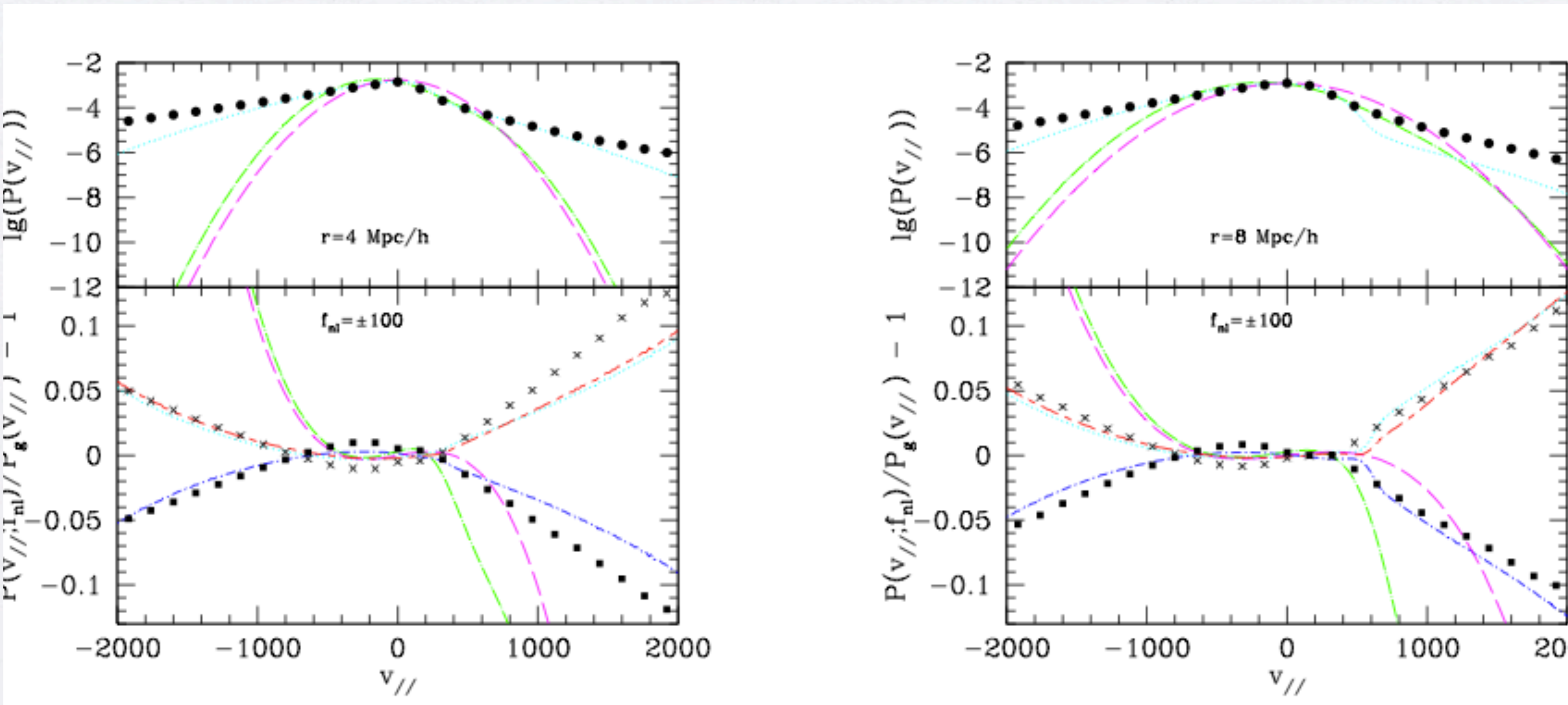
$$v_\parallel = \frac{\dot{D}_0}{r}\left(\frac{r_i v^i_\parallel}{\dot{D}_i} + \frac{D_0}{\dot{D}_i^2} v^{i2}\right)$$

$$|v_\perp|^2 = v_{\perp_a}^2 + v_{\perp_b}^2 = \left(\frac{\dot{D}_0}{\dot{D}_i} v^i\right)^2 - v_\parallel^2$$

RESULTS

parallel to the line of separation direction

★ ★ ★ ★ ★ ★ ★ ★



RESULTS

perpendicular to the line of separation direction