Primordial Non-Gaussianity and Bispectrum in N-Body Simulations

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collaborators:
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- Las Damas collaboration

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What to bring home: sneak peek at the conclusions:

1) We have a *fast* code to generate IC for Non-Local Primordial Non-Gaussian fluctuations

2) We have run a set of large N-Body simulations for the Local, Equilateral, and Orthogonal Primordial Bispectrum shapes.

3) We are currently analyzing the halo bias in these simulations.

Outline

- Local & Non-Local PNG models
- Generating IC for Non-Local Models
- Bispectrum Results from Simulations
- Halo biasing
- why use a 2LPT code?

notice: work still in progress, some plots are preliminary

Local Primordial NG model

- In local models of primordial non-Gaussianity (PNG) we have for the Bardeen potential,

$$\Phi = \phi + f_{\rm NL}(\phi^2 - <\phi^2>)$$

which implies for it a bispectrum,

$$B(k_1, k_2, k_3) = 2 f_{\rm NL} P(k_1) P(k_2) + \text{cyc.}$$

- Generating IC for local models is easy, we only need to Fourier transform the gaussian field back and forth to add the quadratic part.

- For biased tracers (galaxies, halos), this model leads to a scale-dependent bias at large scales (Dalal et al 2008), where $b_1 \sim 1/k^2$ at low-k

Non-local PNG

We are interested in single field inflationary models that correspond to non-local PNG. There are two shapes that we consider:

Equilateral shape (Creminelli 2006)

$$(6f_{\mathrm{NL}})^{-1}B_{\mathrm{equil}} = -P_1P_2 - 2(P_1P_2P_3)^{2/3} + P_1^{1/3}P_2^{2/3}P_3$$

Orthogonal shape (Senatore 2010)

" the parameter space of the most general single field models, where the inflaton fluctuations have an approximate shift symmetry, consists of a linear combination of two independent shapes: the equilateral one and one that we call orthogonal"

$$(6f_{\mathrm{NL}})^{-1}B_{\mathrm{ortho}} = -3P_1P_2 - 8(P_1P_2P_3)^{2/3} + 3P_1^{1/3}P_2^{2/3}P_3$$

(permutations are understood in the equations)

The EQ and ORT shapes are a basis of a theoretical bispectrum space from a single field effective theory inflation. They can have large Fnl because they have a non canonical kinetic term.

Non-local PNG

Another shape of the bispectrum in the literature:

<u>Folded shape</u> (Meerburg 2009)

$$(6f_{\rm NL})^{-1}B_{\rm folded} = P_1P_2 + 3(P_1P_2P_3)^{2/3} - P_1^{1/3}P_2^{2/3}P_3$$

The Folded shape however can be understood as a combination of the LOC, EQ, and ORT shapes.

Generating IC in Non-local PNG

We are interested generating IC for models with bispectra of the type

$$(6f_{\rm NL})^{-1}B_{\rm general} = c_1 P_1 P_2 + c_2 (P_1 P_2 P_3)^{2/3} + c_3 P_1^{1/3} P_2^{2/3} P_3$$

We want to generate such models from a quadratic (non-local) potential.

$$\Phi = \phi + f_{\rm NL}\ K[\phi, \phi] \qquad\qquad \delta_{\mathbf{k}} = \frac{2}{3}\frac{k^2 T(k) D(z)}{\Omega_m H_0^2}\Phi_{\mathbf{k}}$$

where we need to find the appropriate non-local quadratic kernel that generates the desired bispectrum. For simplicity we assume scale-invariance.

$$\Phi = \phi + f_{\rm NL}\phi^2, \qquad B = 2 f_{\rm NL} P_1 P_2 + \text{cyc.}$$

$$\Phi = \phi + f_{\rm NL}\nabla^{-2}(\partial\phi)^2, \qquad B = -6 f_{\rm NL}(P_1 P_2 P_3)^{2/3}$$

$$\Phi = \phi + f_{\rm NL}[(1-t)\partial^{-1}(\phi\partial\phi) + t\nabla^{-2}(\phi\partial^2\phi)] \qquad B = f_{\rm NL} P_1 P_2^{2/3} P_3^{1/3} + \text{cyc.}$$

$$\partial^{-1}A \equiv \sqrt{-\nabla^{-2}}A \equiv \int e^{-i\boldsymbol{k}\cdot\boldsymbol{x}}\left(\frac{1}{k}\right) A(\boldsymbol{k})\, d^3k$$

Recent Limits on Fnl

-29 < Local Fnl < 70 SDSS (Slosar et al. 2008)
-10 < Local Fnl < 74 WMAP (Komatsu et al. 2010)

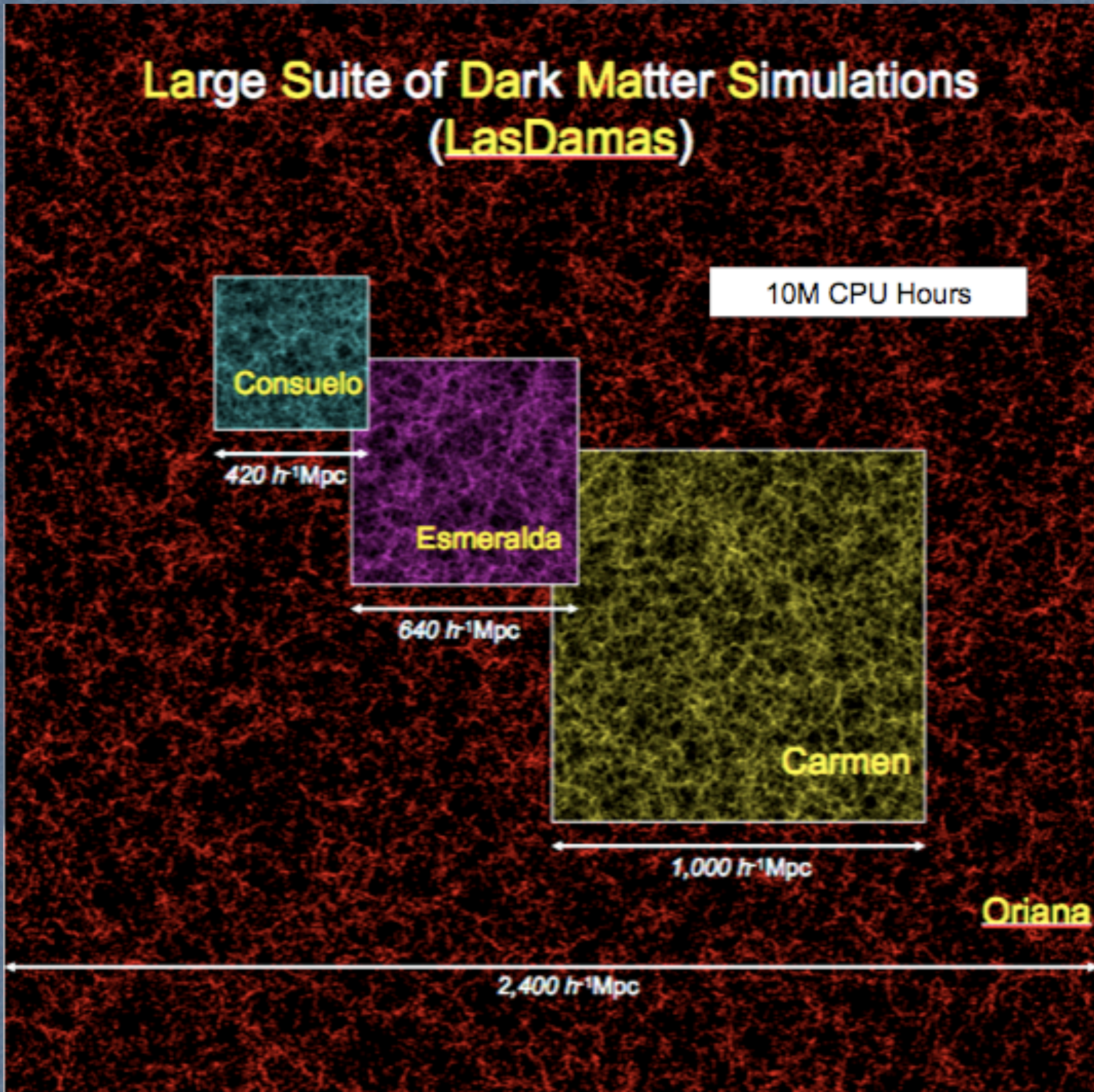
-214 < Equil Fnl < 266 WMAP7 (Komatsu et al. 2010)
-125 < Equil Fnl < 435 WMAP5 (Smith et al 2009)

-410 < Orthog Fnl < 6 WMAP7 (Komatsu et al. 2010)
-369 < Orthog Fnl < 71 WMAP5 (Senatore et al. 2009)

LasDamas Simulations

Name	Sample	Lbox	Npar	mpar	Nrealiz
Oriana (G)	LRG +Main -22	2400	1280^3	4.57E+11	42
Oriana (LOC)	LRG +Main -22	2400	1280^3	4.57E+11	12
Oriana (EQ)	LRG +Main -22	2400	1280^3	4.57E+11	12
Oriana (ORT)	LRG +Main -22	2400	1280^3	4.57E+11	12
Carmen (G+loc)	Main -21	1000	1120^3	4.98E+10	42
Esmeralda	Main -20	640	1250^3	9.31E+09	50
Consuelo	Main -19-18	420	1400^3	1.87E+09	50

Nmocks=4 x Nrealiz, 2LPT ICs, Gaussian Mocks available at http://lss.phy.vanderbilt.edu/lasdamas/

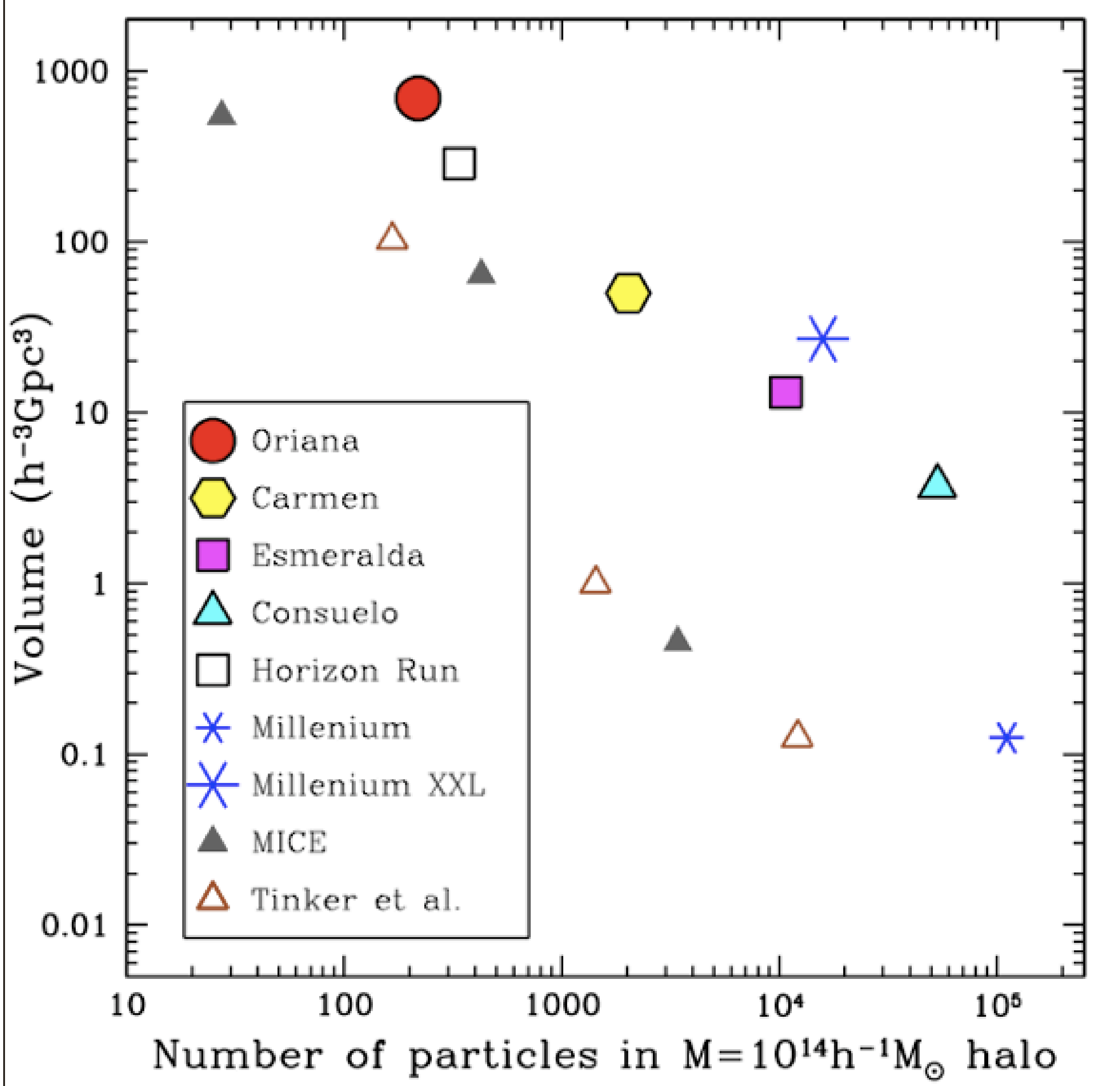


VANDERBILT U.
Andreas Berlind
Cameron McBride
-
SLAC
Michael Busha
Risa Wechsler
-
YALE
Frank van den Bosch
-
NYU
Roman Scoccimarro
Marc Manera

$\Omega_b = 0.04$ $n_s = 1$

$\Omega_\Lambda = 0.75$ $h = 0.7$

$\Omega_m = 0.25$ $\sigma_8 = 0.8$


1000
100
10
1
0.1
0.01
Volume (h^{-3}Gpc^3)
10
100
1000
10^4
10^5
Number of particles in $M=10^{14}h^{-1}M_\odot$ halo
Oriana
Carmen
Esmeralda
Consuelo
Horizon Run
Millenium
Millenium XXL
MICE
Tinker et al.

more details on PNG simulations

Initial conditions

- 2LPT IC at zi=49
- *FAST code* few minutes only

  60 cpu-hours / $Np=1280^3$

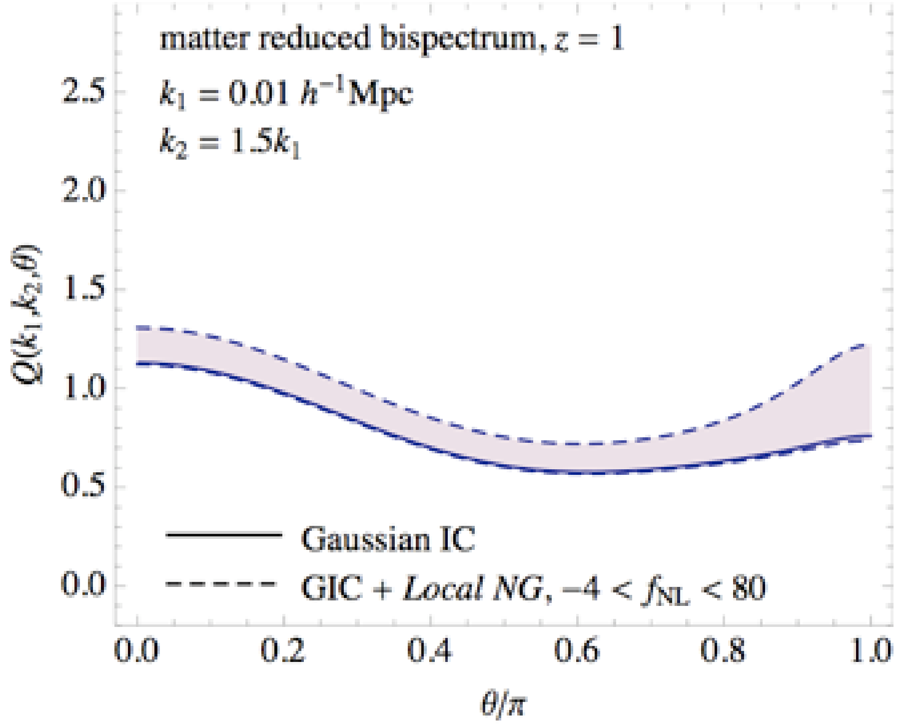
  EQ,ORT take only 20% longer than LOC

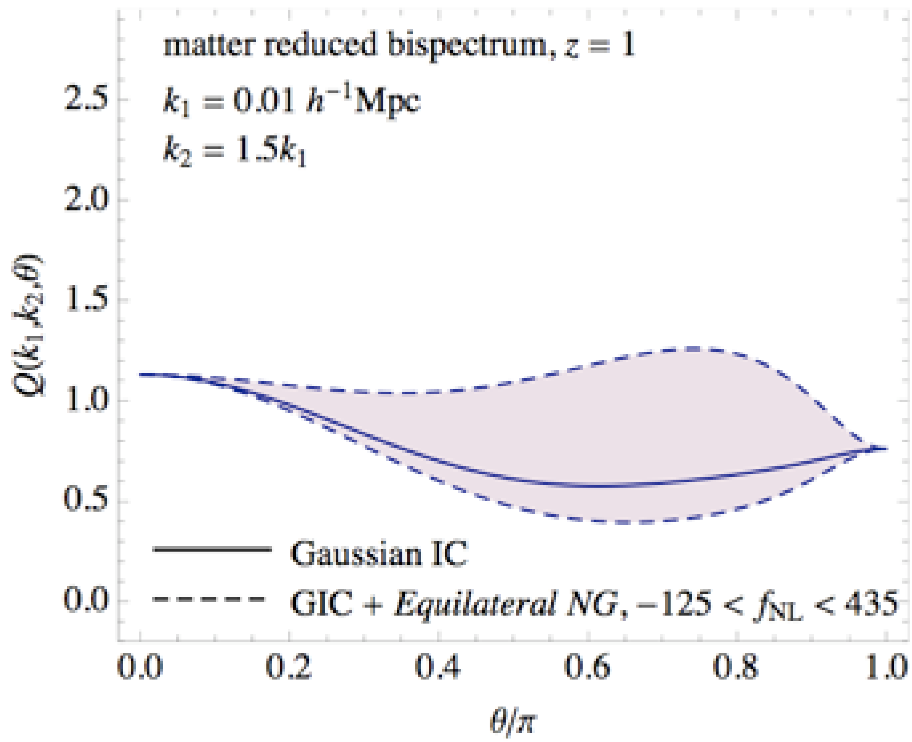
Simulations

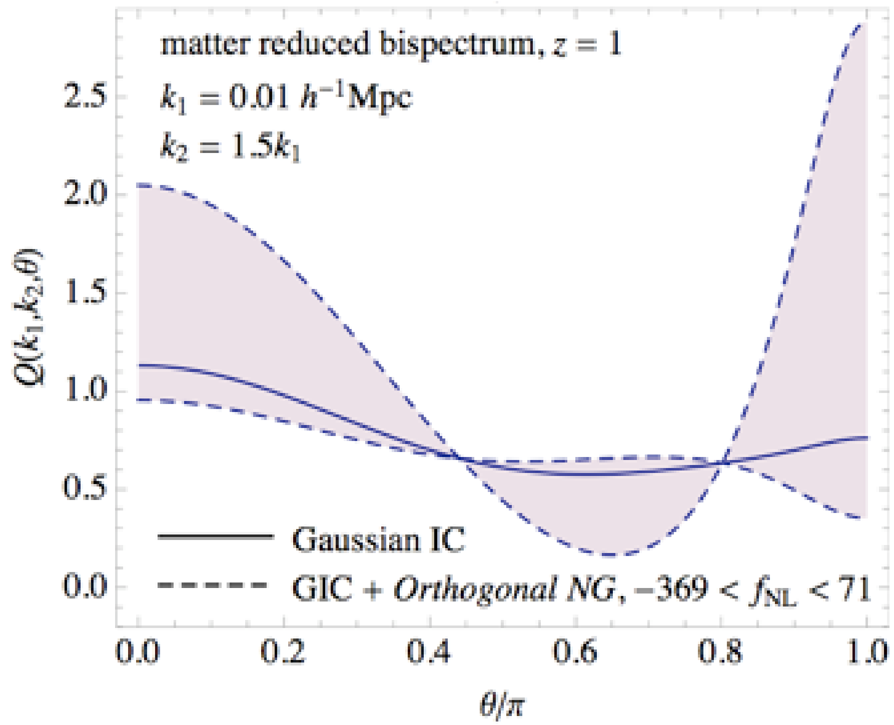
- Run at Kraken (Tennessee)
- ~ 27.000 cpu-hours, less than three days

Reduced Bispectrum

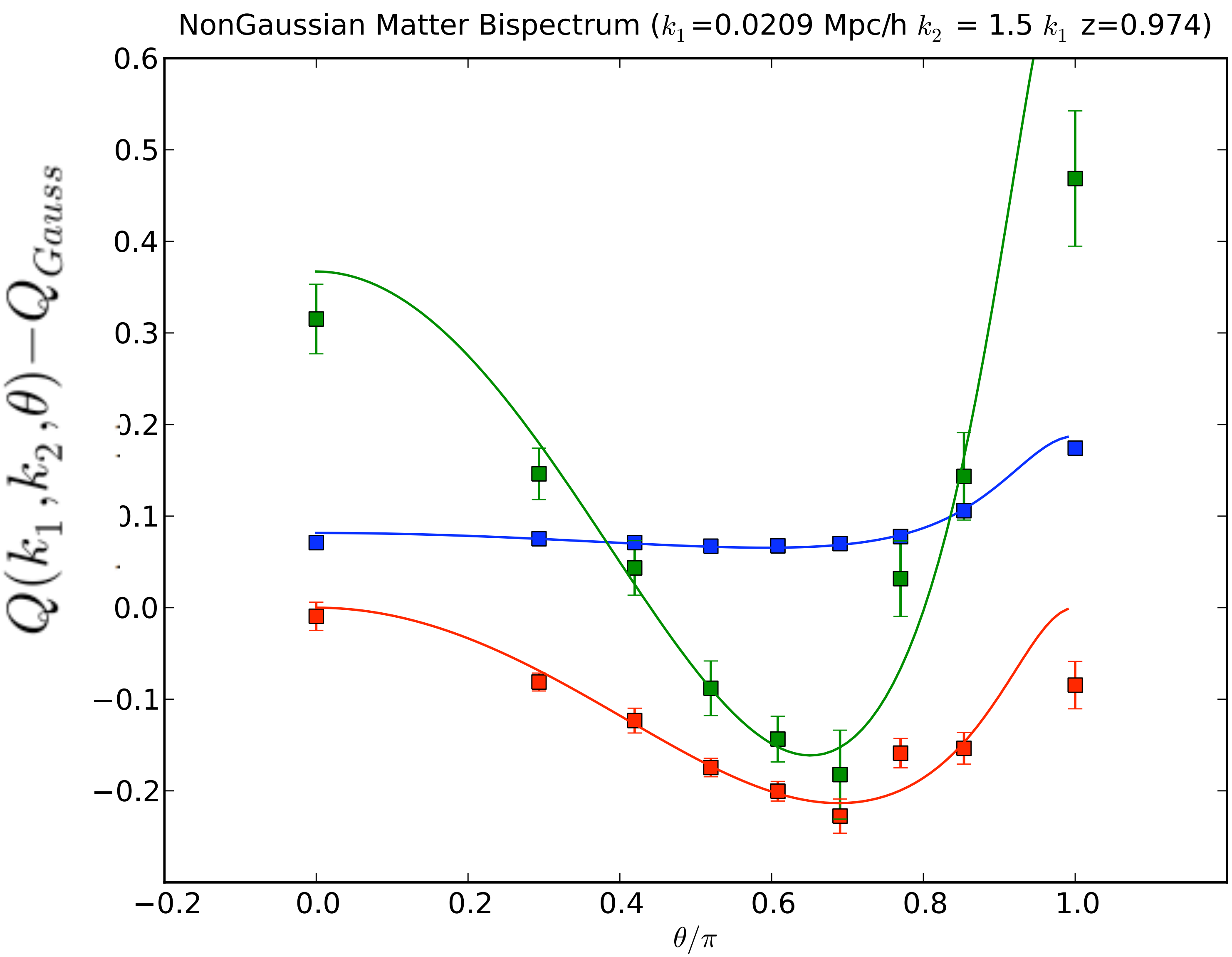
$$Q(k_1, k_2, k_3) = \frac{B(k_1, k_2, k_3)}{P(k_1)P(k_2) + 2\text{ perm.}},$$

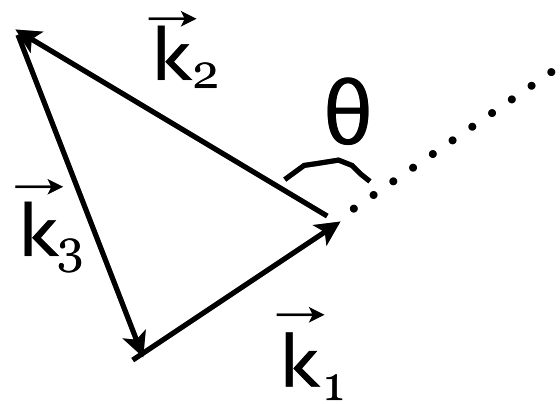




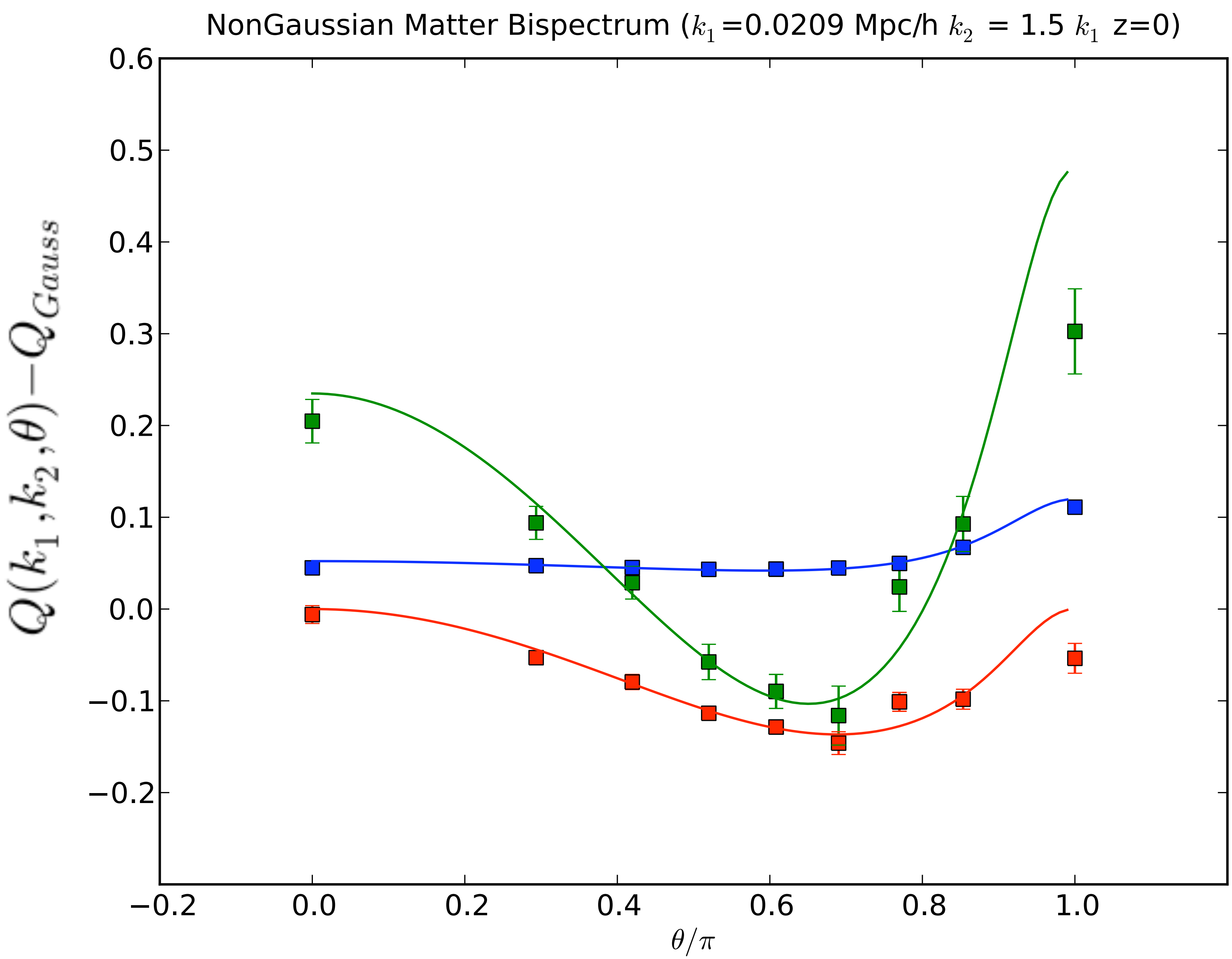


from Liguori, Sefussati, Fergusson, Shellard 2010

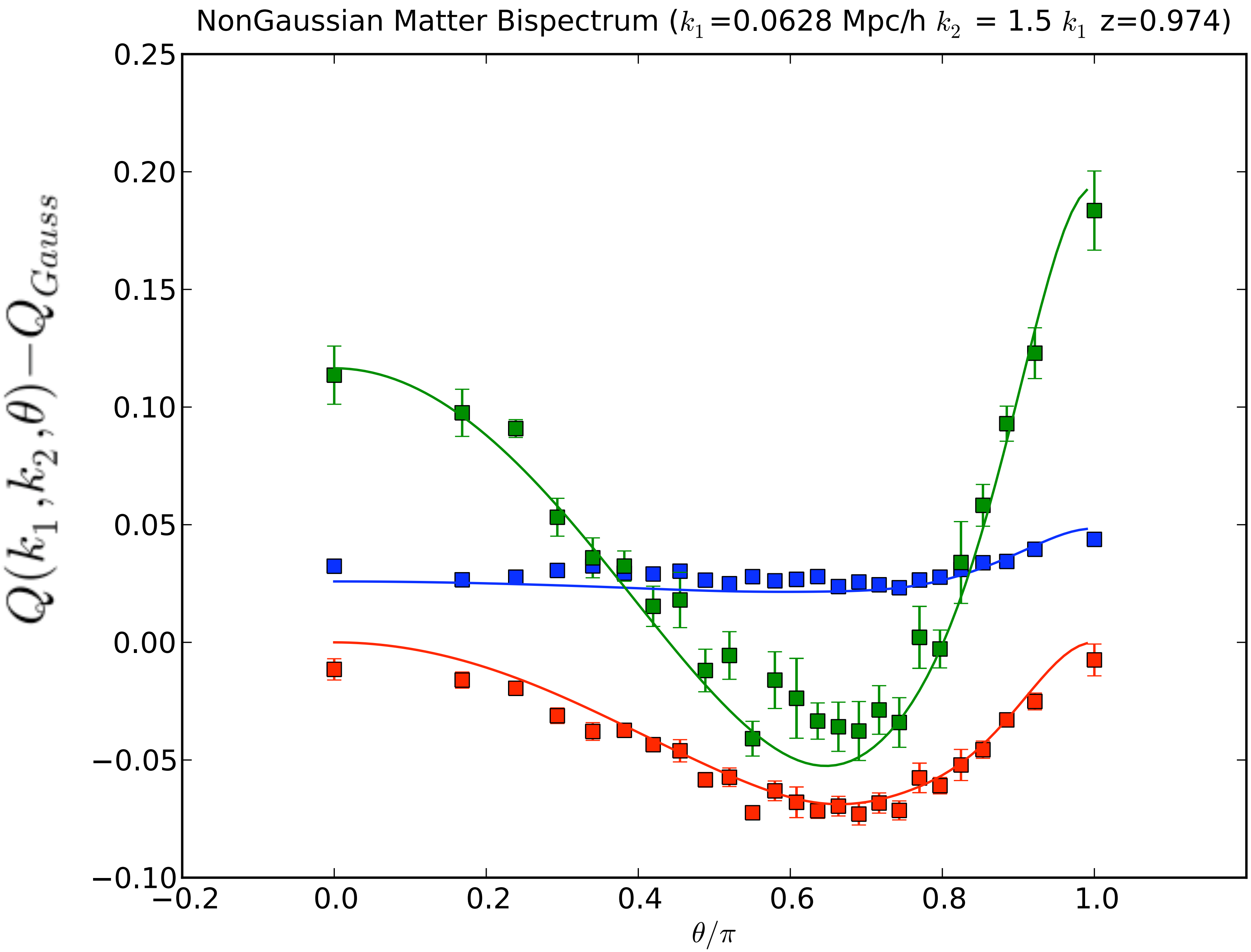




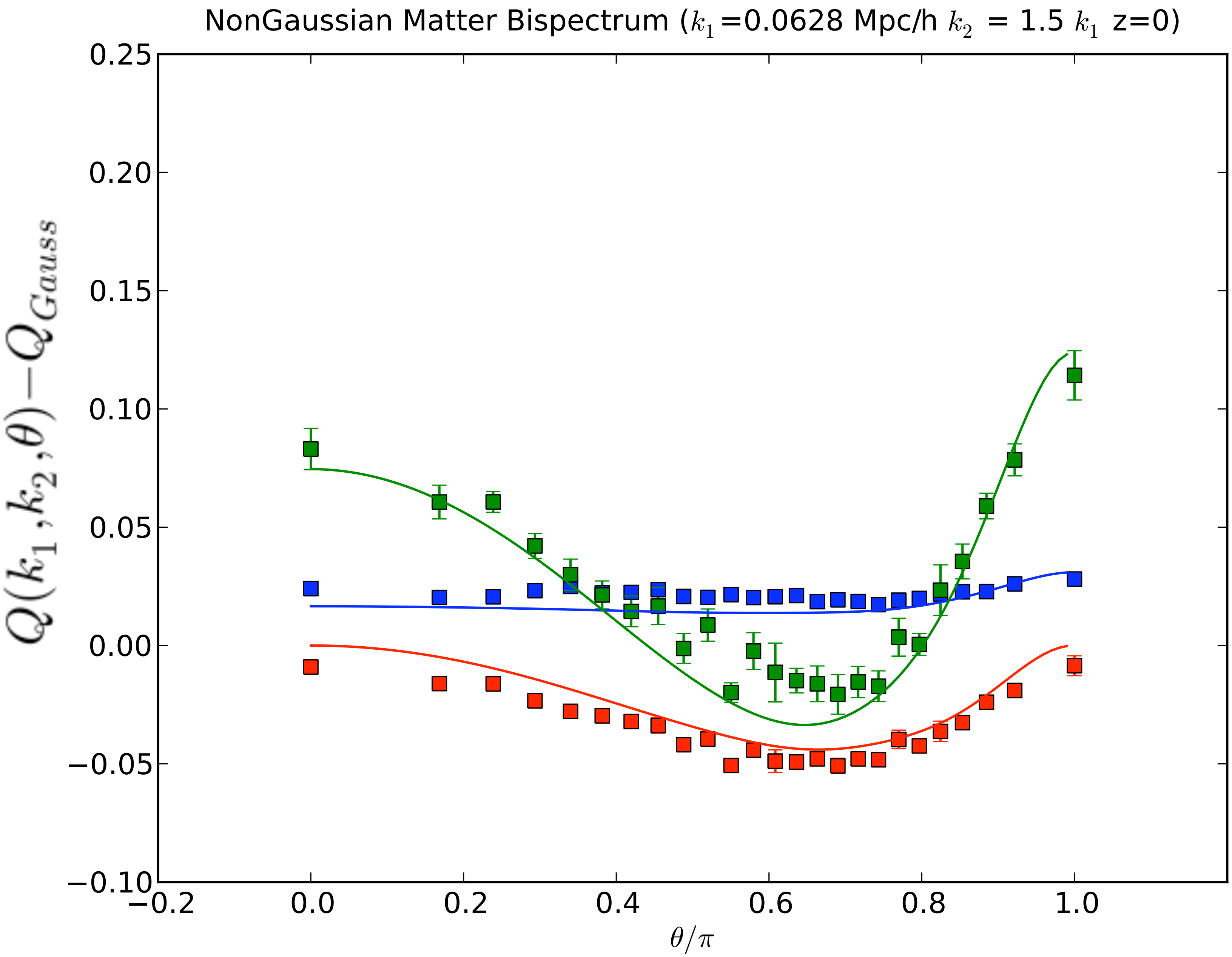
blue = LOC (fnl=100) , red = EQ (fnl=-400) , green = ORT(fnl=-400)



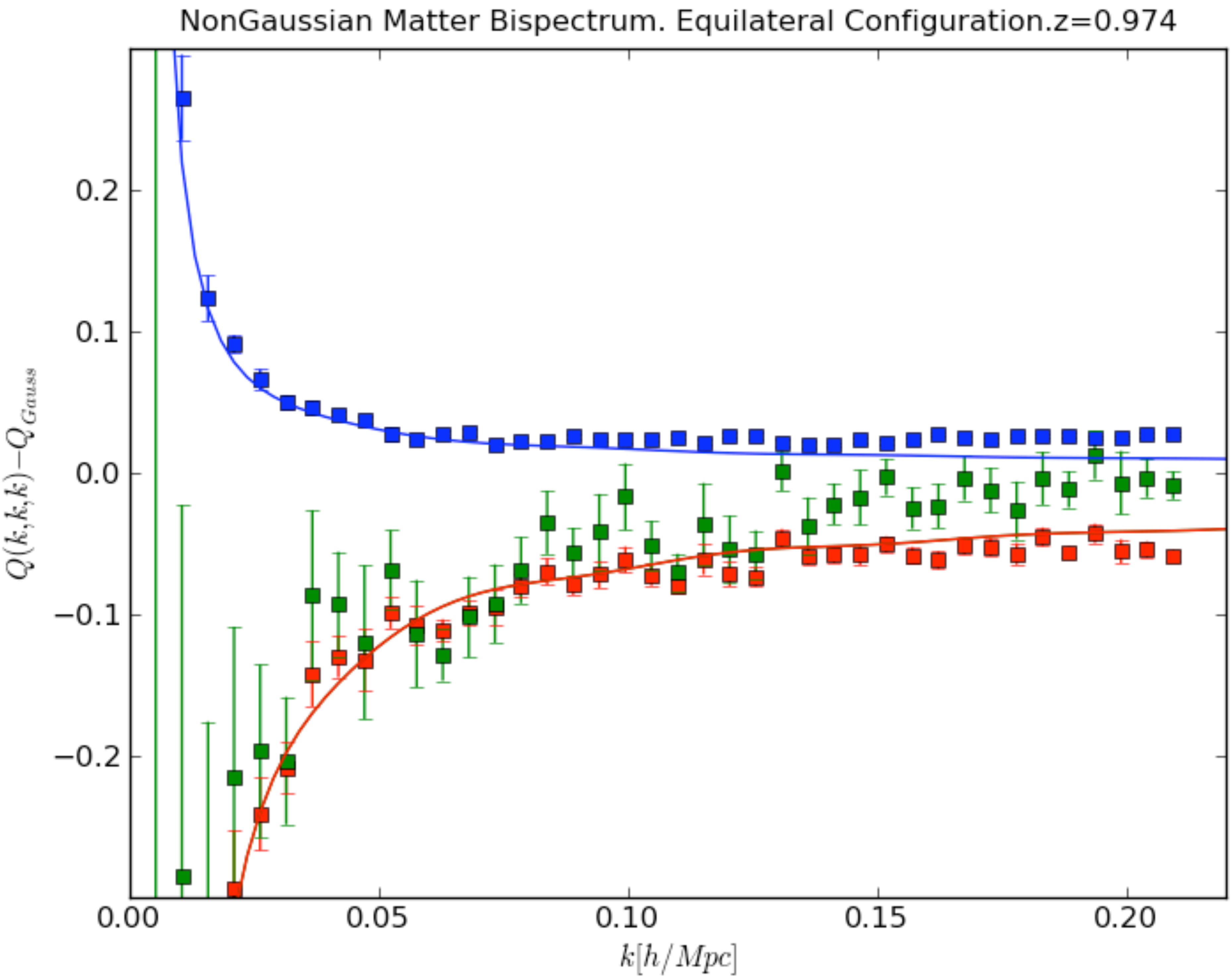
blue = LOC (fnl=100) , red = EQ (fnl=-400) , green = ORT(fnl=-400)



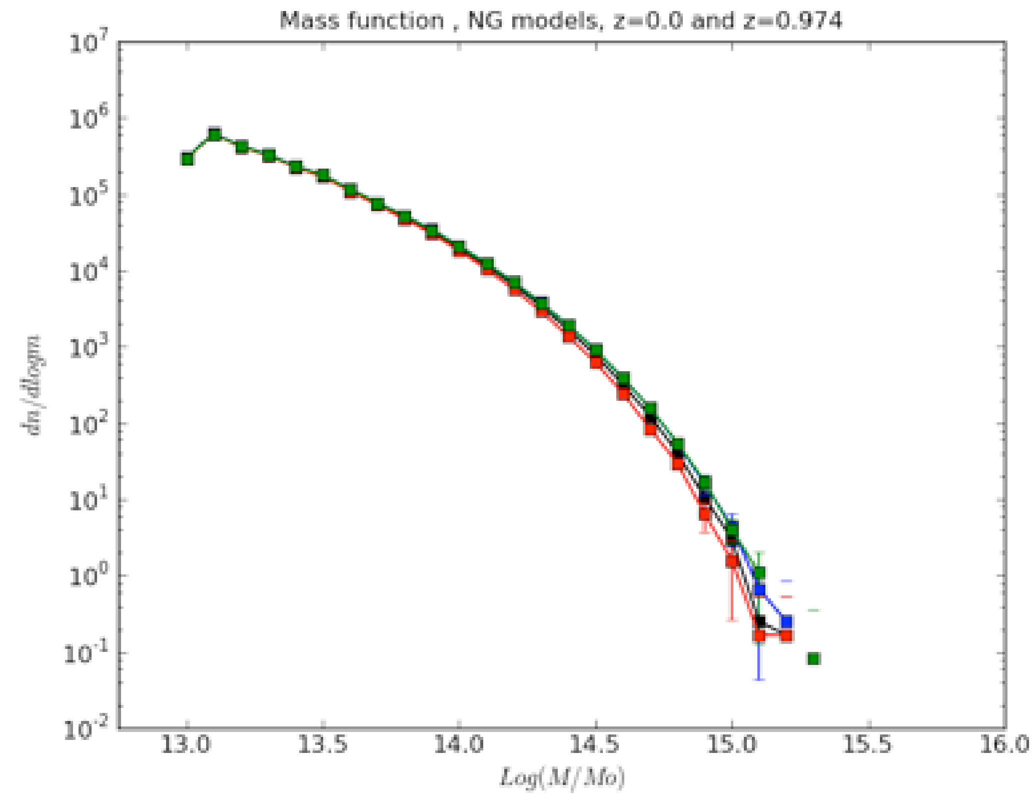
blue = LOC (fnl=100) , red = EQ (fnl=-400) , green = ORT(fnl=-400)

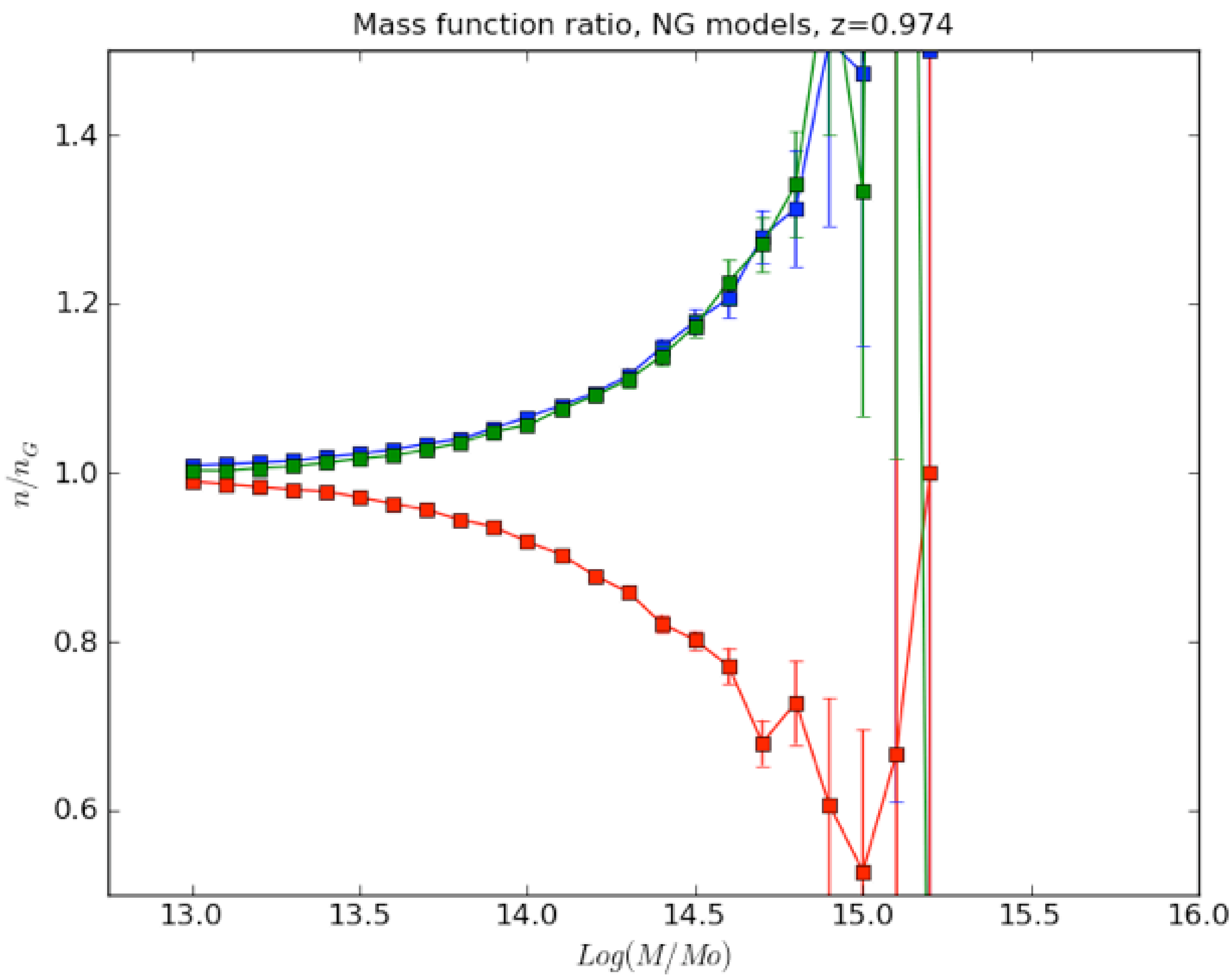


blue = LOC (fnl=100) , red = EQ (fnl=-400) , green = ORT(fnl=-400)


NonGaussian Matter Bispectrum. Equilateral Configuration.z=0.974
0.2
0.1
0.0
−0.1
−0.2
0.00
0.05
0.10
0.15
0.20
$Q(k,k,k) - Q_{Gauss}$
$k[h/Mpc]$

Matter is OK, now let's look at HALOS

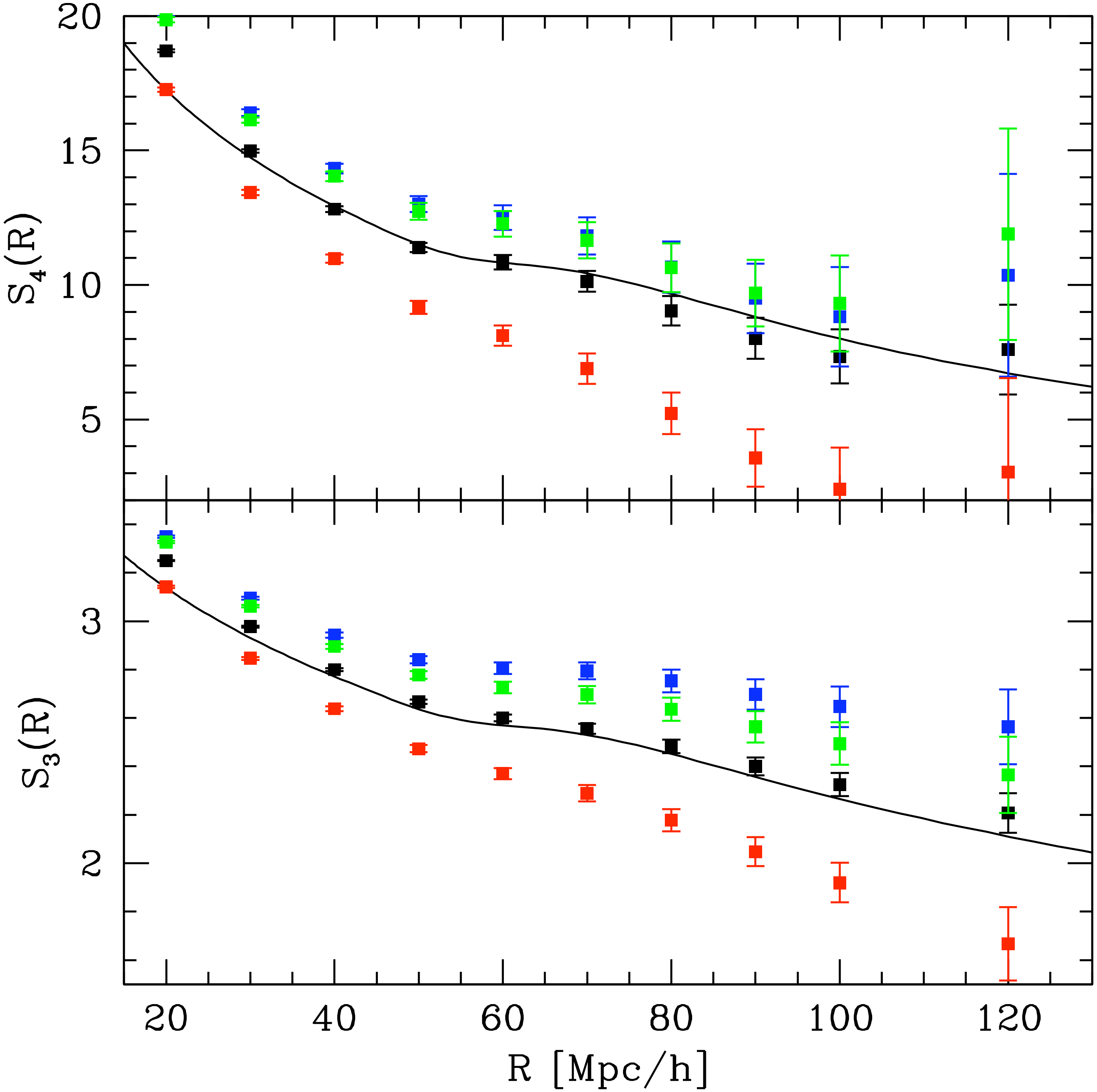


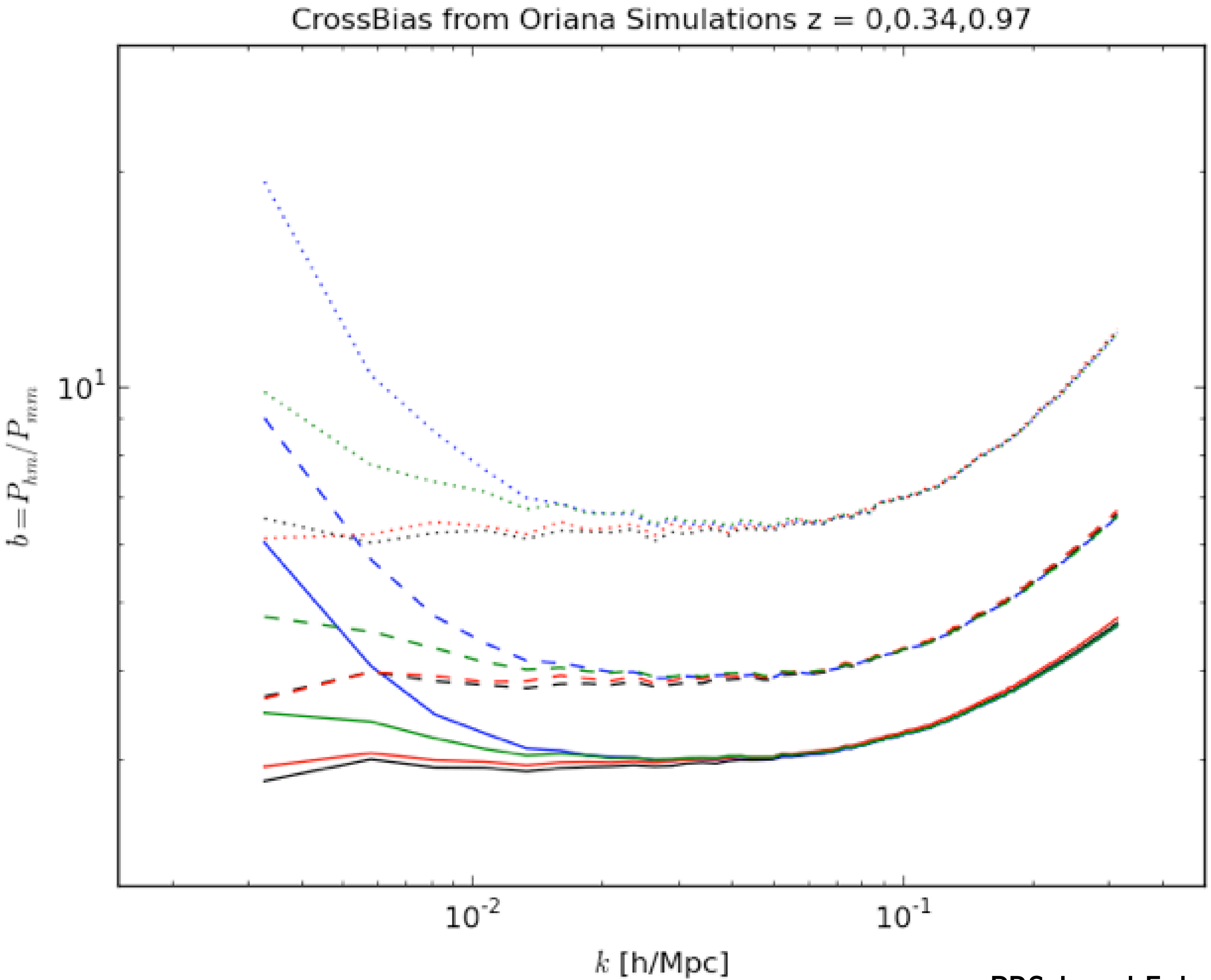


blue = LOC (fnl=100) , red = EQ (fnl=-400) , green = ORT(fnl=-400)

$$S_4 = \frac{<\delta^4>_c}{\sigma^6}$$

$$S_3 = \frac{<\delta^3>_c}{\sigma^4}$$



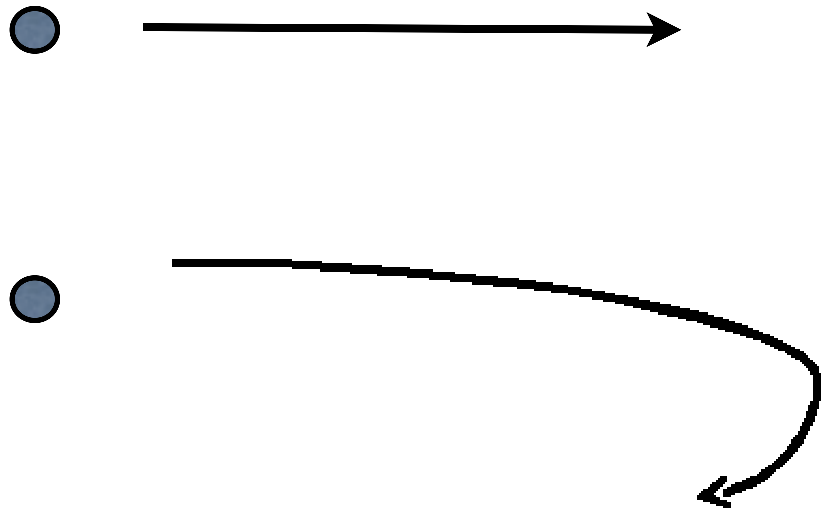


PBS, Local Fnl

$$b_1(k) = b_{10} + \Delta b_1(k, f_{\rm NL})$$

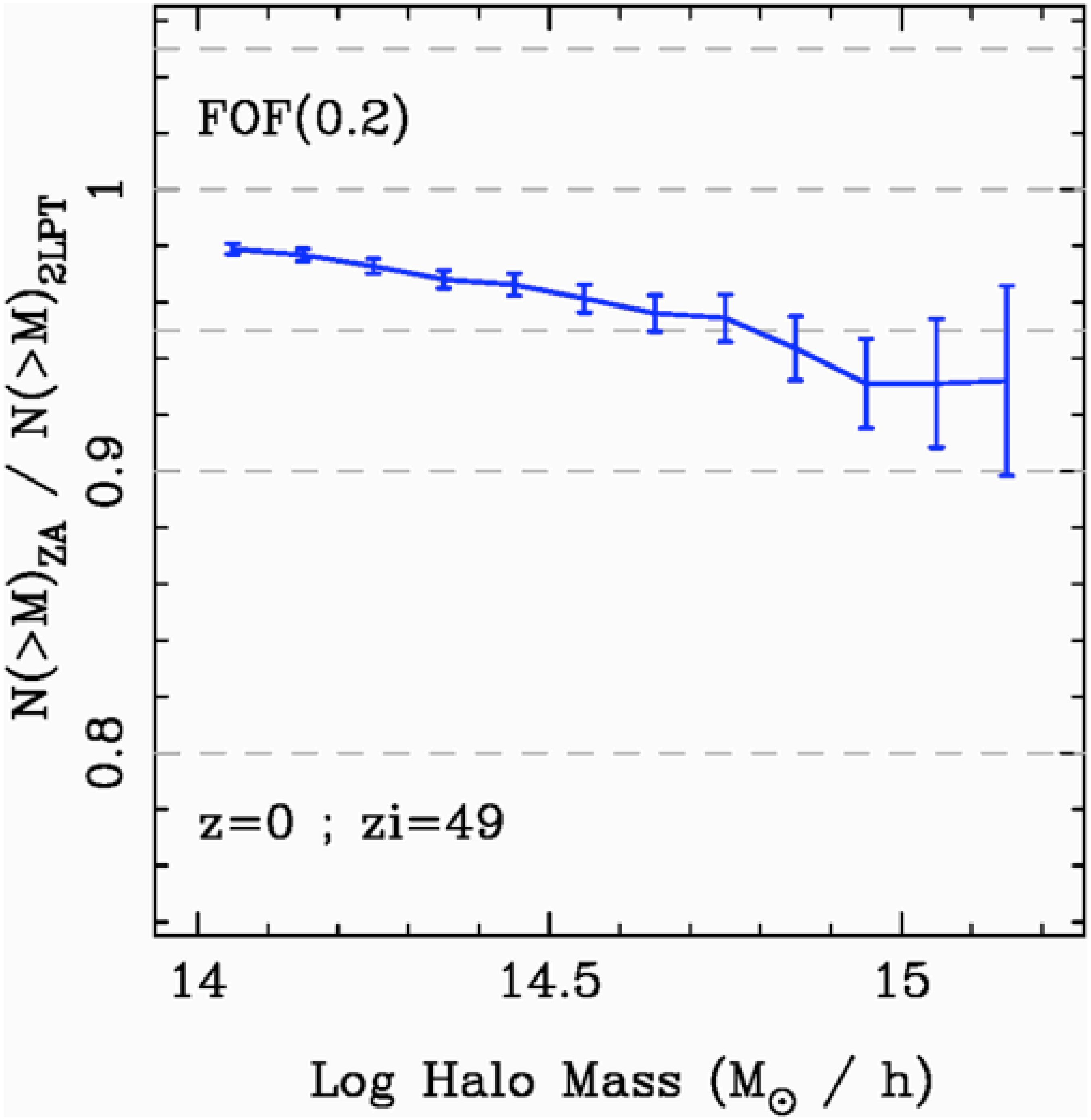
$$\delta_g = 2 f_{\rm NL}(b_1 - 1)\delta_c \phi + b_1\,\delta$$

comments on 2LPT IC

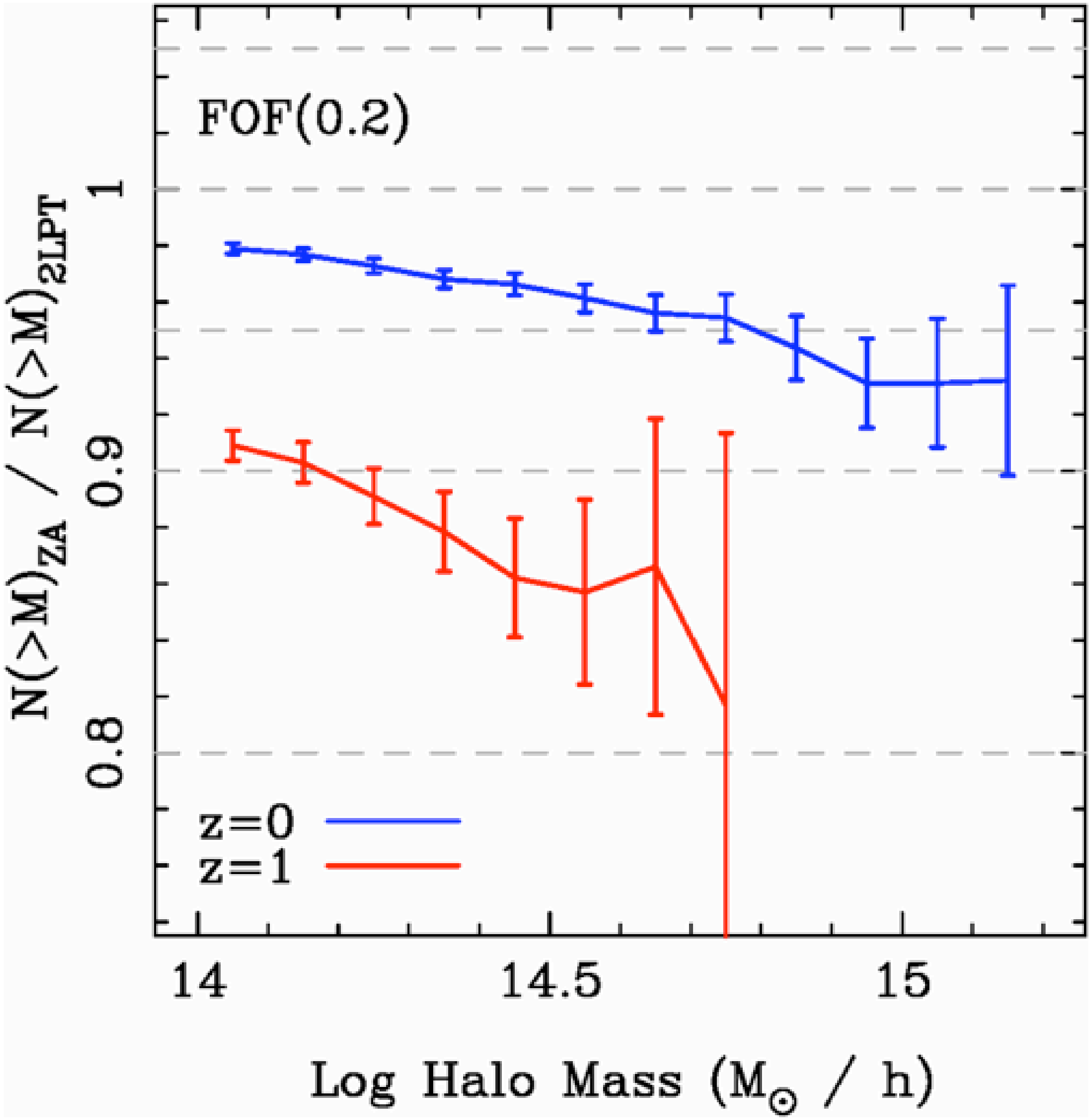


The Zeldovich approximation assumes that particles move in straight lines between t=0 and the starting redshift of a simulation.

This causes *transients* that affect the collapse of the most massive structures. Scoccimarro (1998), Crocce et al. (2006), Jenkins (2010)



plot from
LasDamas Collaboration,
(McBride et al in prep)



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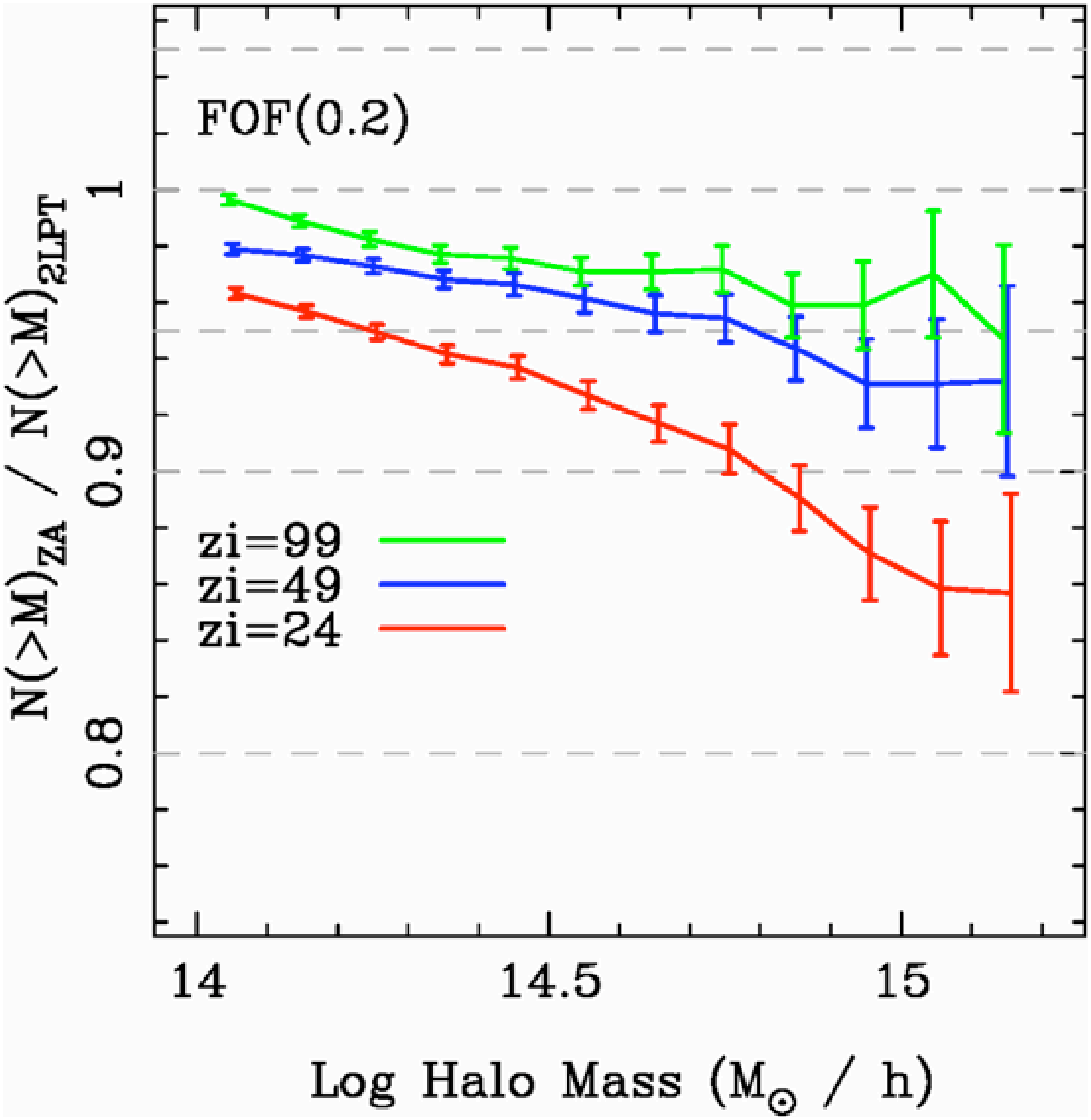
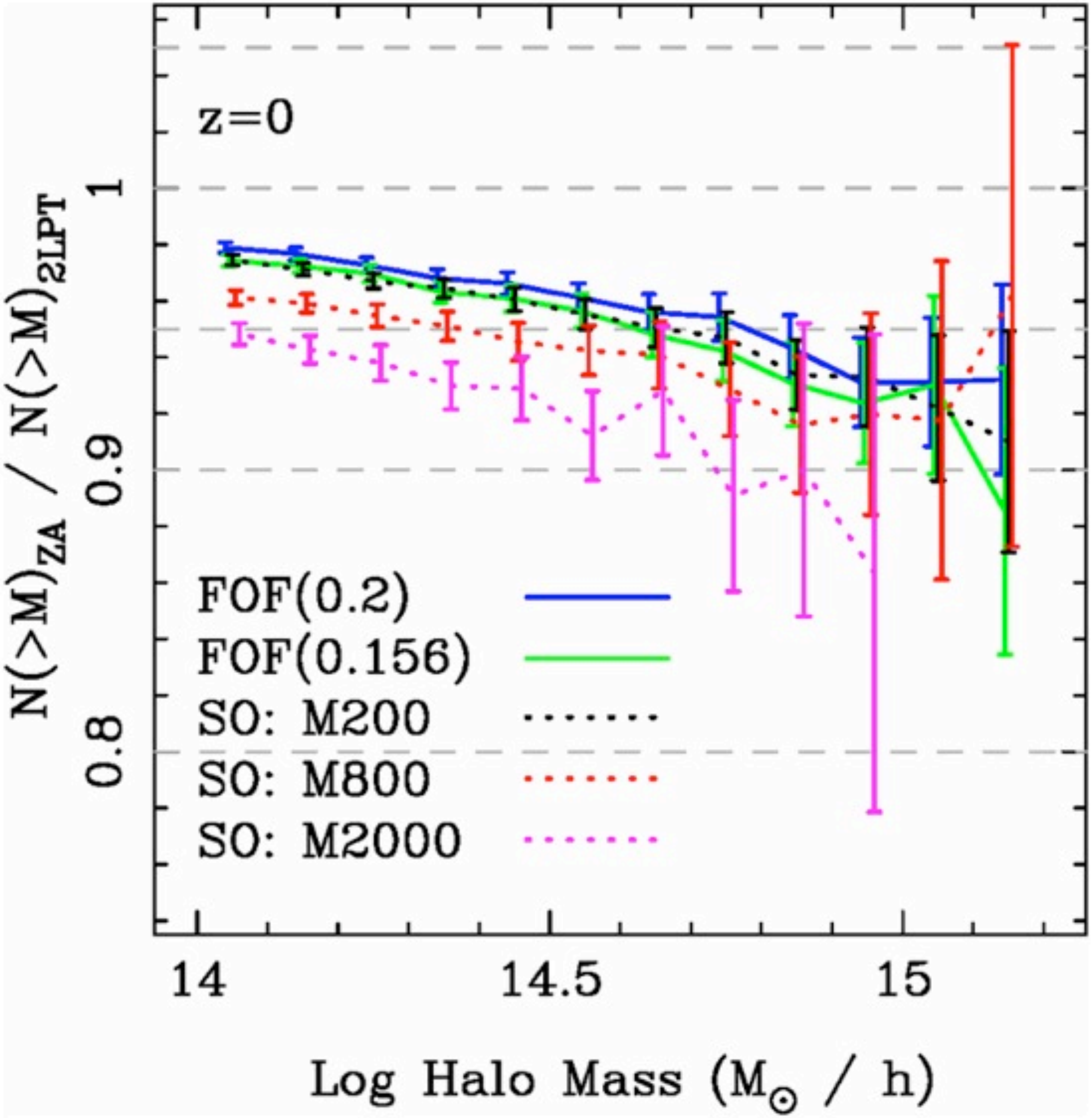


ZA initial conditions converge very slowly, use 2LPT always!!

This is true also for SO halos

plot from
LasDamas Collaboration,
(McBride et al in prep)



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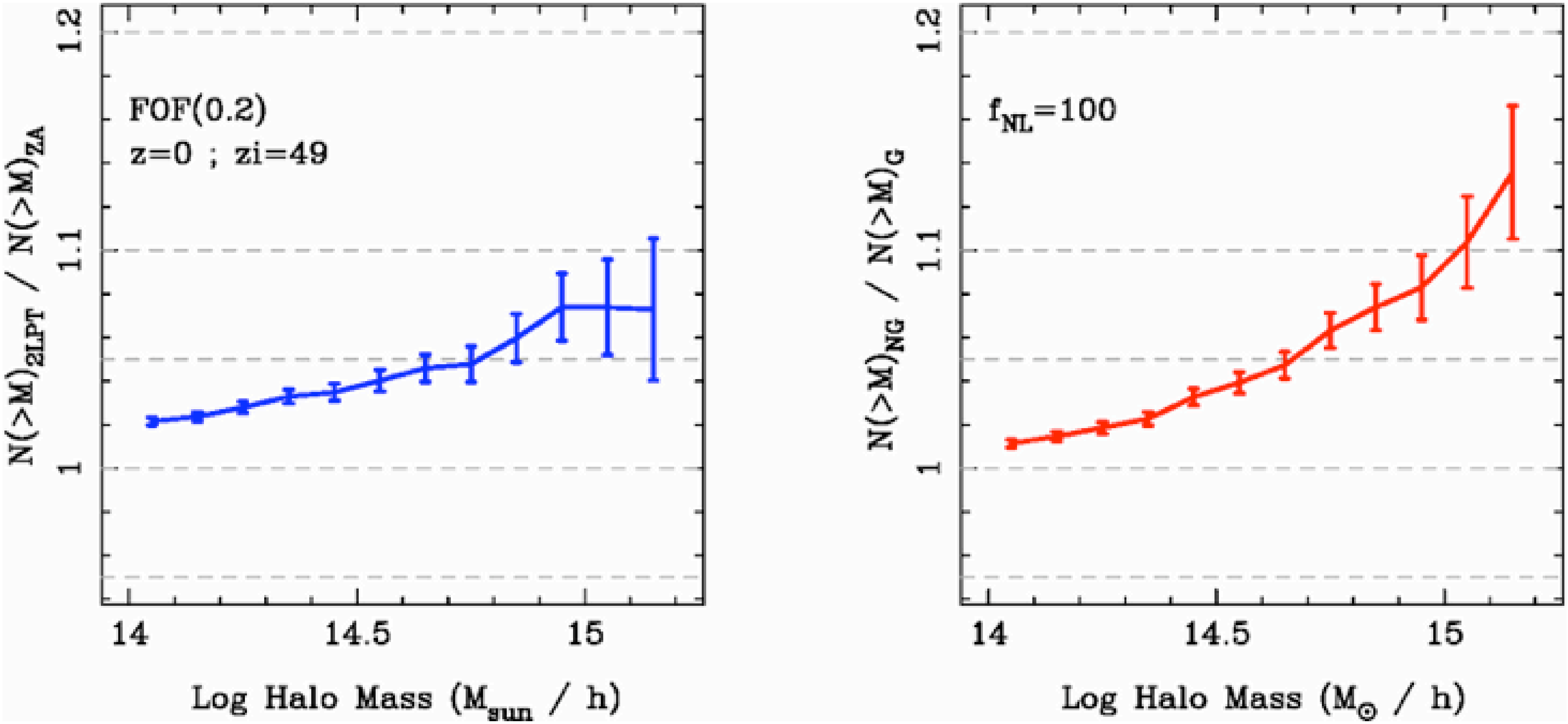
comment on 2LPT IC



ZA initial conditions can mimic primordial non-Gaussianities.

Conclusions

Simulations

- We have a set of N-Body simulations with PNG of the LOC, ORT, and EQ type. These simulations are part of LasDamas.

- We are currently analyzing halo biasing in these simulations. We have also mocks that match SDSS wp(rp). The Bispectrum adds significant S/N when all configurations are used.

Initial Conditions

- We have produced a code that generates IC for PNG models.
- This code:
  - *is fast and takes advantage of a factorizable kernel for the potential.*
  - *It will be made public.*
  - *Uses 2LPT, and it is implemented in parallel.*
- Using 2LPT is easy to use and avoids transients in the high mass end of the mass function. ZA takes long to converge.