

Precision measurements of the local bias of dark matter halos

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Contents

- 1 Introduction
- 2 Theory and measurements predictions
- 3 Results and discussion
- 4 Conclusions

Guidelines

- 1 Introduction
- 2 Theory and measurements predictions
- 3 Results and discussion
- 4 Conclusions

Motivation

Why are we interested in the large-scale local bias parameters of dark matter halos?

- essential to describe the statistics of halos on large scales, a key ingredient of the theoretical description of large-scale structure
- most observed tracers of LSS, such as galaxies, reside in halos
- essential for the halo model description of the non-linear matter density field

Halo bias

- ▷ Perturbation theory : statistics of halos written in terms of bias parameters multiplying operators constructed out of the matter density field (δ_m).
- ▷ Most important bias parameters on large scales are those multiplying powers of δ_m (*local bias parameters*) :

$$\delta_h(\mathbf{x}, \tau) \supset b_1(\tau)\delta_m(\mathbf{x}, \tau) + \frac{1}{2}b_2(\tau)\delta_m^2(\mathbf{x}, \tau) + \frac{1}{6}b_3(\tau)\delta_m^3(\mathbf{x}, \tau) + \dots$$

δ_h : fractional number density perturbation of halos

- ▷ This talk : precision measurements of b_1 , b_2 , b_3 using a novel technique, *separate universe simulations*.
- ▷ Comparison to biases determined by fitting to halo 2- and 3-point statistics and theoretical predictions from the excursion set-peaks (ESP).

Separate universe simulations

- Separate universe approach : **long-wavelength density perturbation is included in an N-body simulation**

$$\tilde{\rho}_m(t) = \rho_m(t) \cdot [1 + \delta_m(t)]$$

Sirko (2005), Baldauf+ (2011),
Sherwin+ (2012), Li+(2014), Wagner+ (2014)

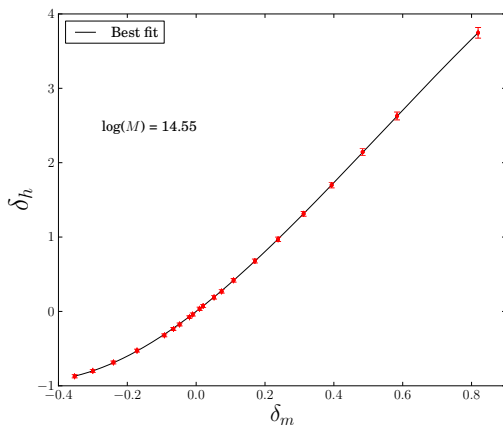
→ Ω_m , Ω_Λ , Ω_K and H_0 different from their fiducial values,
and simulation ran to a different scale factor.

- Wagner+ (2014) : full non-linear computation $\Rightarrow \delta_m$ can be large!

Halo bias from separate universe simulations

Local bias parameters = response of the halo abundance to a long-wavelength density perturbation

→ measure $\delta_h = [\tilde{N}(M) - N(M)]/N(M)$ in a suite of separate universe simulations and fit a polynomial in δ_m to find the b_i .



Guidelines

- 1 Introduction
- 2 Theory and measurements predictions**
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- 4 Conclusions

Bias from correlations

- ▷ Check of the validity of the method : **comparison of separate universe results with measurements from correlations**
- ▷ Compute P_{hm} and B_{mmh} in fiducial cosmology
 - $b_1 = \frac{P_{hm}}{P_{mm}}$
 - b_2 estimated from B_{mmh}
 - b_3 could be estimated from trispectrum but too complicated
→ we don't do it

Excursion set peaks (ESP)

ESP unifies the *peak model* of Bardeen et al. (1986) and the *excursion set formalism* of Bond et al. (1991) : **on a given smoothing scale R , consider only the peaks that have a smaller height $\nu \equiv \delta_c/\sigma$ at the next larger smoothing scale**

Paranjape & Sheth (2012), Paranjape+ (2013)

- Peak-background split (PBS) : effect of a long wavelength perturbation δ_L :

$$\delta_c \rightarrow \delta_c - \delta_L \Leftrightarrow \nu \rightarrow \nu(1 - \delta_L/\delta_c) \equiv \nu_1$$

Mo & White (1996)

- Bias parameters :

$$b_n(\nu) \equiv \frac{1}{n_h(\nu)} \left. \frac{\partial^n n_h(\nu_1)}{\partial \delta_L^n} \right|_{\delta_L=0}$$

→ n_h from ESP + moving barrier + top-hat filter

Other predictions

We also compare our results with other previous results from the literature :

- Tinker et al. (2010) best fit (b_1 only)
- PBS argument : $b_n(\nu) \equiv \frac{1}{n_h(\nu)} \frac{\partial^n n_h(\nu_1)}{\partial \delta_L^n} \Big|_{\delta_L=0}$ with n_h the Tinker et al. (2008) best fit mass function
- Sheth and Tormen (1999) prediction (PBS)

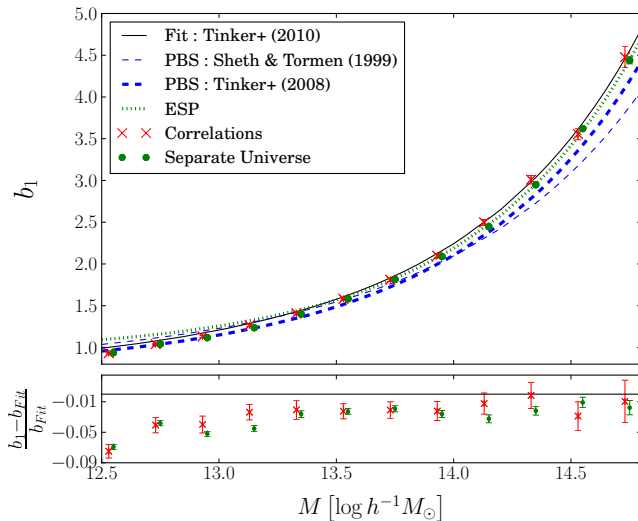
Guidelines

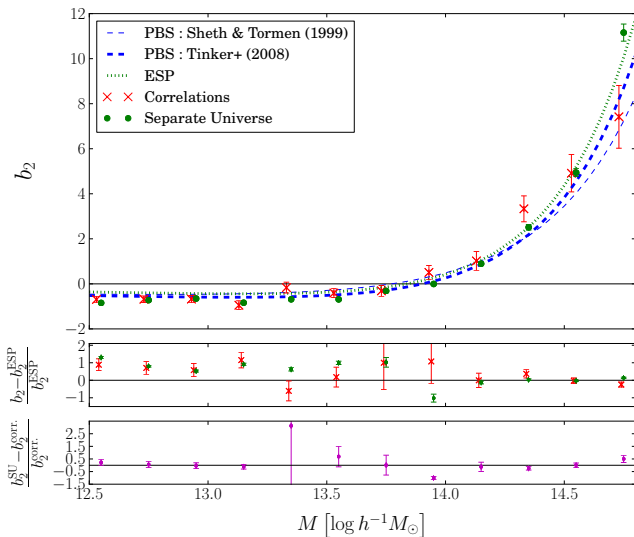
- 1 Introduction
- 2 Theory and measurements predictions
- 3 Results and discussion**
- 4 Conclusions

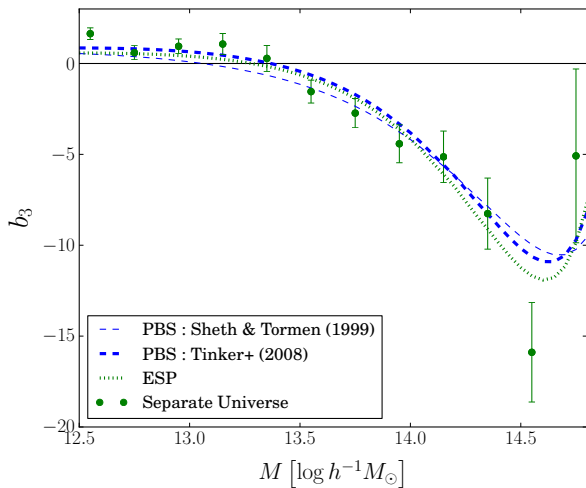
Simulations and halo catalogs

- Suite of separate universe simulations described in Wagner et al. (2014) ran with GADGET-2
- Fiducial cosmology : flat Λ CDM, $\Omega_m = 0.27$, $h = 0.7$, $\Omega_b h^2 = 0.023$, $n_s = 0.95$, $A_s = 2.2 \cdot 10^{-9}$
- δ_m corresponding to $\delta_L = \{\pm 0.5, \pm 0.4, \pm 0.3, \pm 0.2, \pm 0.1, \pm 0.07, \pm 0.05, \pm 0.02, \pm 0.01, 0.00, 0.15, 0.25, 0.35\}$
- Halos identified using AHF (SO halos) at $z_f = 0$
Gill+ (2004), Knollmann+ (2009)
- Key point : density threshold $\rightarrow \rho_h = 200\rho_m$. Simulations with a different background density, the threshold must be rescaled

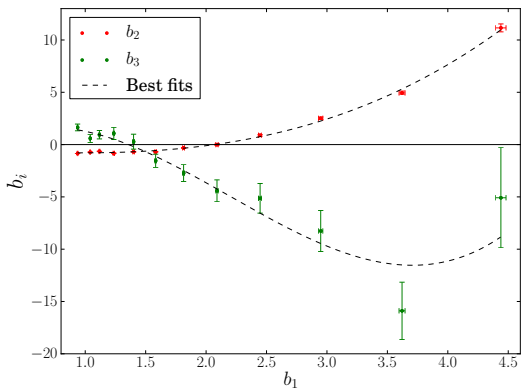
$$\Delta_{\text{SO}} = \frac{200}{1 + \delta_m}$$

b_1 

b_2 

b_3 

Fitting formulae



$$b_2(b_1) = -0.407 - 0.650 b_1 + 0.135 b_1^2 + 0.133 b_1^3$$

$$b_3(b_1) = -0.711 + 7.352 b_1 - 6.331 b_1^2 + 0.960 b_1^3$$

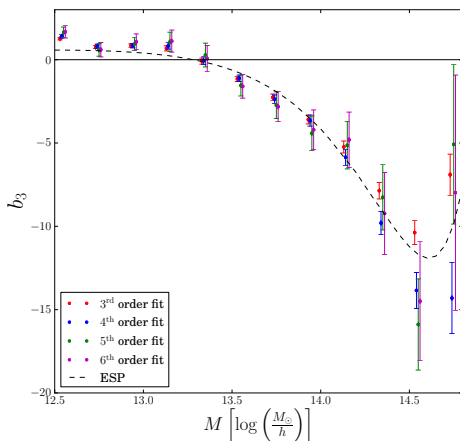
Guidelines

- 1 Introduction
- 2 Theory and measurements predictions
- 3 Results and discussion
- 4 Conclusions**

Conclusions

- Good agreement with correlation points, ESP prediction and other curves proves the validity of the method
- Easy to implement and physically motivated method
- Most precise measurements to date for b_2 and b_3 → efficient technique
- ESP performs very well at high mass but not at low mass → well known problem of the peak model that doesn't work for low peaks
- Tinker+ (2008) mass function very precise but the biases derived from it are not so good → fits to the halo mass function have limited range of application → have to go into the details of halo collapse to come up with something that agrees with $n_h(M)$ and b

Effect of the fitting polynomial degree



\Rightarrow need a fit of degree $n + 2$ to get unbiased b_n

b_4 