上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

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A physical and concise halo model based on the depletion radius

Yifeng Zhou, Jiaxin Han

Department of astronomy, Shanghai Jiao Tong Univerity

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Background

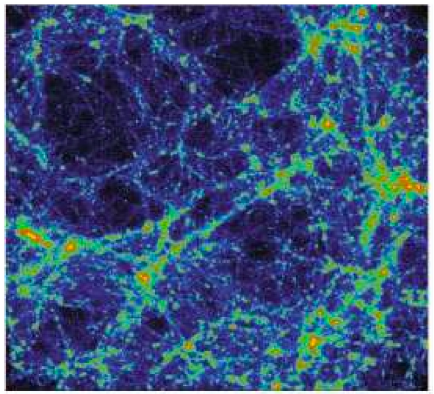
- Halo model of large-scale structure

Matter density field → **Halo model** →

- **Large scales:** Spatial distributions of haloes
- **Small scales:** Internal structure of haloes

Fully understand the dark matter halo in all aspect

matter distribution



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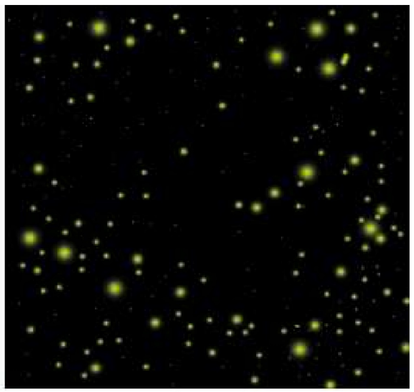
halo spatial distribution



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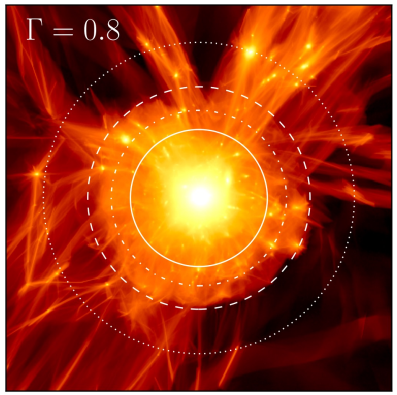
halo interior structure



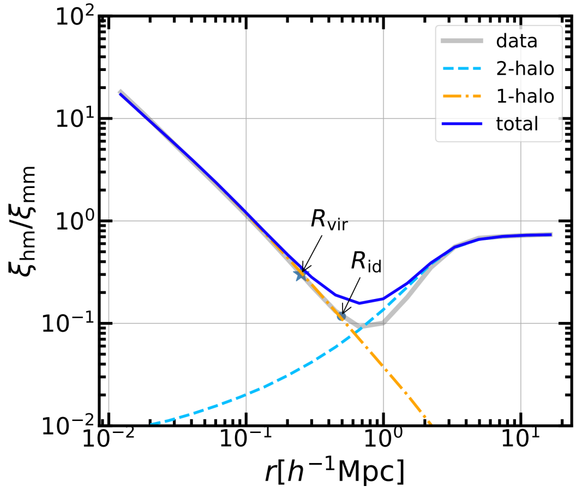
Cooray & Sheth (2002)

More et al. (2015)

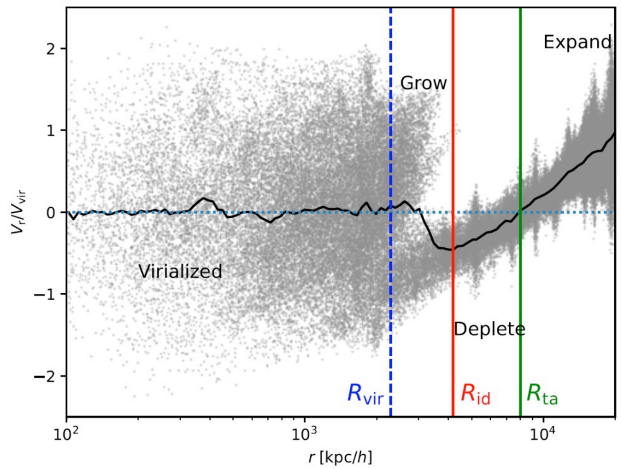
Background

- Halo boundary and exclusion

Halo exclusion



The depletion radius $R_{\rm id}$



- Mass should be partitioned into haloes **completely** and **without double counting** according to the halo boundary (exclusion radius);
- Haloes **can not overlap** with each other;

- Growth boundary: Grow vs. Deplete
- **Exclusion boundary: Halo vs. Environment**

Build a physical halo model based on a physical boundary $R_{\rm id}$

Depletion halo model

- A self-consistent halo catalogue

- **Exclusion scale:** $R_{\mathrm{ex}}(m_1, m_2) = R_{\mathrm{id}}(m_1)+R_{\mathrm{id}}(m_2)$

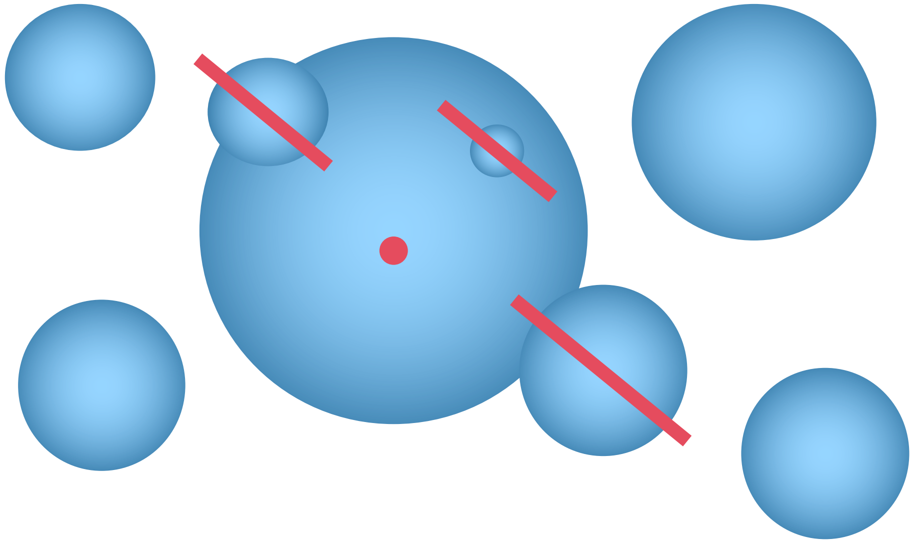
- **Depletion catalogue:**

  (FoF haloes - smaller overlapping haloes)

Statistics of new catalogue should be reconsidered

- *halo distribution*
- *bias*
- *halo profile*
- *halo mass function*

Exclusion criterion: $d > R_{id}(m_1) + R_{id}(m_2)$

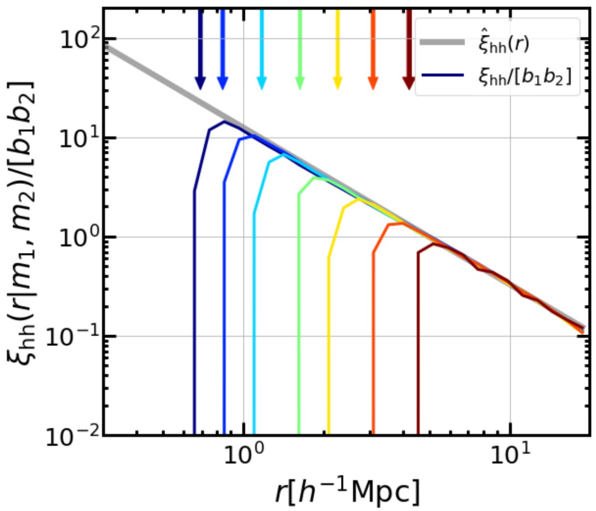


- Haloes overlapping with more massive neighbours are removed;
- The removed haloes are regarded as the substructure of the massive neighbour.

Depletion halo model

- Ingredients of depletion catalogue

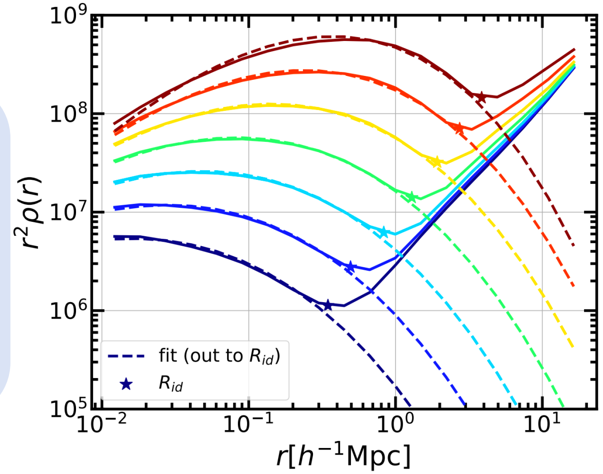
Unit halo correlation: $\hat{\xi}_{\rm hh}(r) = \dfrac{\xi_{\rm hh}(r|m_1, m_2)}{b(m_1)b(m_2)}$



Einasto profile: $\rho_{\rm EIN}(r) = \rho_s \exp\left(-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha} - 1\right]\right)$

- Halo profile

- Perform well inside $R_{\rm id}$;
- A gentle transition to model the outer substructure.



- Halo correlation function

- Self-similar for different halo masses
- Truncate at the exclusion scales

Exclusion scale: $R_{\rm ex}(m_1, m_2) = R_{\rm id}(m_1) + R_{\rm id}(m_2)$

- Other statistics of depletion catalogue:

- *halo bias*
- *halo mass function*
- ……

} Fit with the parametric formula

Depletion halo model

- Model framework

- A revised halo model

$$\xi_{\rm hm}(\vec{r}|m) = \langle \delta_h(\vec{x}|m)\delta_m(\vec{x}+\vec{r})\rangle$$

1-halo term → $\xi^{\rm 1h}_{\rm hm}$: Mass from the central halo

2-halo term:
- $\xi^{\rm res}_{\rm hm}$: Neighboring resolved haloes
- $\xi^{\rm unr}_{\rm hm}$: Unresolved haloes and mass → Free parameter: $b_{\rm unr}$

A self-consistent halo catalogue with physical boudaries → **Statistics of the new catalogue**
- *halo distribution*
- *bias*
- *halo profile*
- *halo mass function*

Results

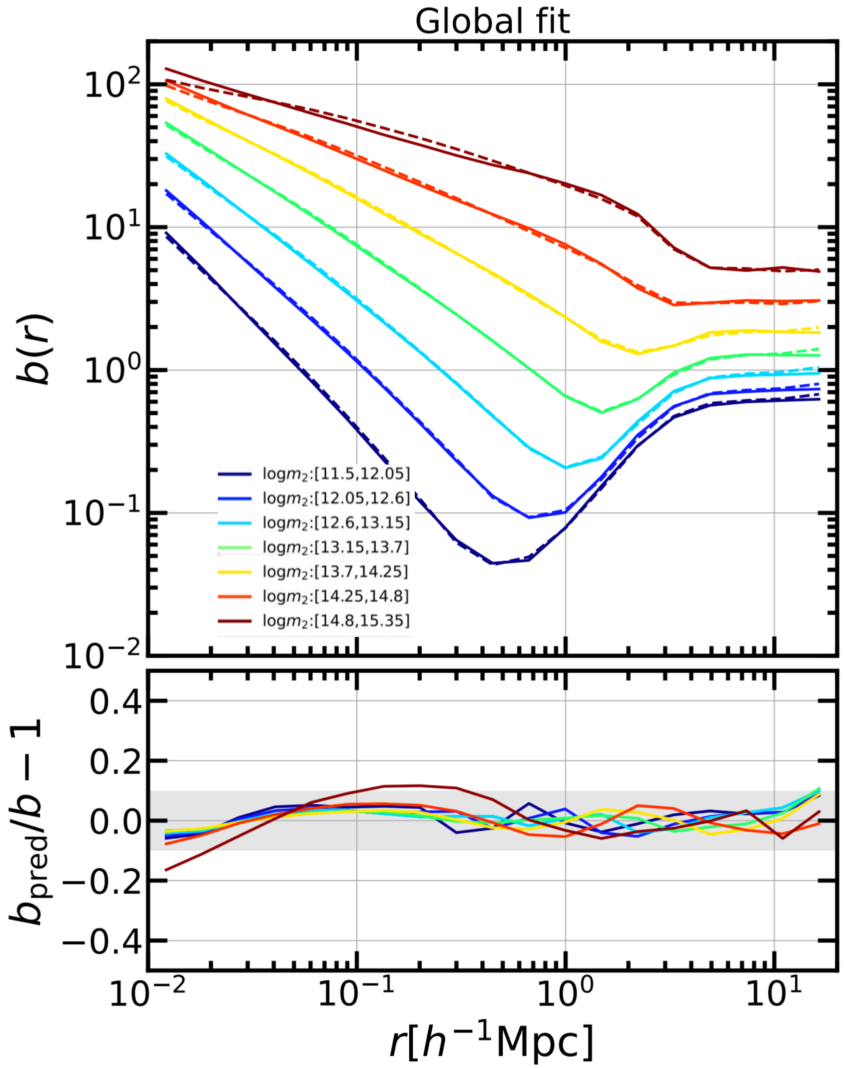
- Fits to bias profiles

Bias (relative density) profile: $$b(r) = \frac{\xi_{hm}(r)}{\xi_{mm}(r)} = \frac{\langle\delta(r)\rangle}{\xi_{mm}(r)}$$

Mass range: $10^{11.5}h^{-1}M_\odot < M_{vir} < 10^{15.35}h^{-1}M_\odot$

Radial range: $0.01h^{-1}\mathrm{Mpc} < r < 20h^{-1}\mathrm{Mpc}$

- $b\,(r)$ with accuracy $\lesssim 10\%$ across wide radial and mass range;
- The scale dependence of bias is reproduced without artificial fixes



Results

- Compare with other works

- **Hayashi & White (HW08):**

$$\xi_{\rm model}(r;M) = \begin{cases} \xi_{\rm 1h}(r) & \text{if } \xi_{\rm 1h}(r) \geq \xi_{\rm 2h}(r), \\ \xi_{\rm 2h}(r) & \text{if } \xi_{\rm 1h}(r) < \xi_{\rm 2h}(r), \end{cases}$$

$$\xi_{\rm 1h}(r) = \frac{\rho_{\rm halo}(r;M) - \overline{\rho}_{\rm m}}{\overline{\rho}_{\rm m}}$$

$$\xi_{\rm 2h}(r) = b(M)\xi_{\rm lin}(r),$$

- **Diemer & Kravtsov (DK14):**

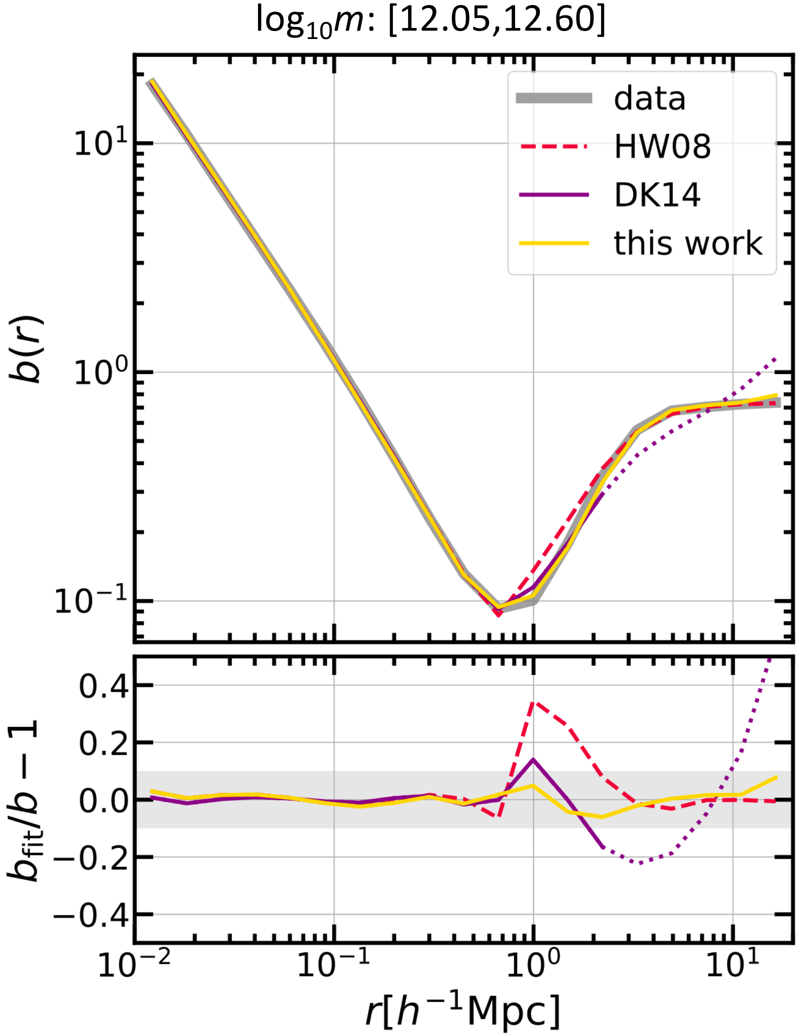
$$\rho(r) = \rho_{\rm inner} \times f_{\rm trans} + \rho_{\rm outer}$$

$$\rho_{\rm inner} = \rho_{\rm Einasto} = \rho_{\rm s} \exp\left(-\frac{2}{\alpha}\left[\left(\frac{r}{r_{\rm s}}\right)^{\alpha} - 1\right]\right)$$

$$f_{\rm trans} = \left[1 + \left(\frac{r}{r_{\rm t}}\right)^{\beta}\right]^{-\frac{\gamma}{\beta}}$$

$$\rho_{\rm outer} = \rho_{\rm m}\left[b_{\rm e}\left(\frac{r}{5\,R_{\rm 200m}}\right)^{-s_{\rm e}} + 1\right].$$

- **Our model:** performs well on both intermediate and large scales



Summary

- Summary of our model

The depletion catalogue →

1. More accurate and physical on transition scales;
2. The scale dependence of bias is reproduced without artificial fix;
3. Mass convesation is maintained due to the consideration of unresolved mass
4. More concise ingredients;

→ **A physical and concise halo mdoel**

- New insights into the halo model

This work:
(arXiv: 2303.10886)

Halo profiles: Eiansto profiles
Halo field: the depletion catalogue
} Infer → **Matter field**

Our future work:
(In Prep.)

Matter field
Halo field: the catalogue with other exclusion radius
} Constrain → **Halo profiles**

Future work

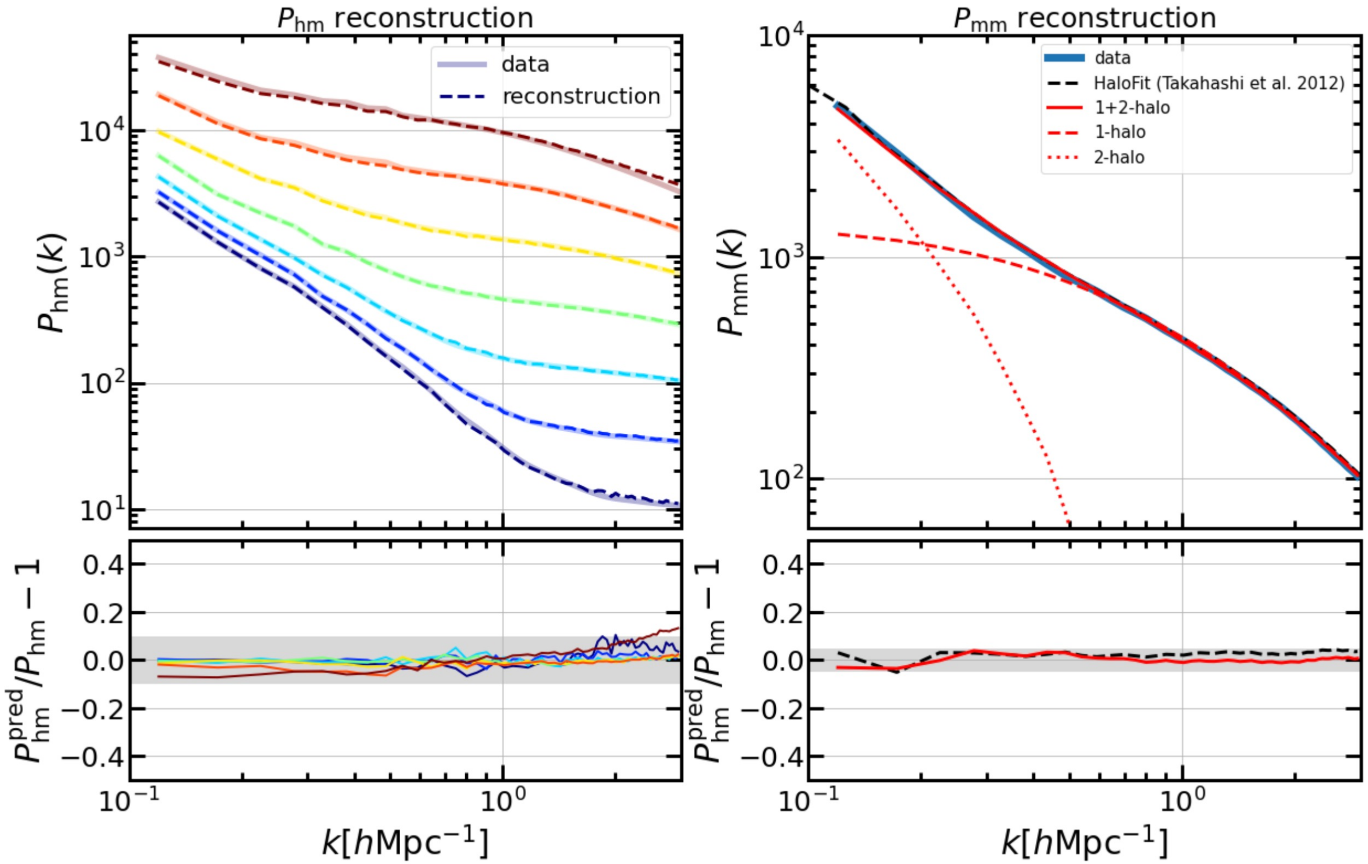
- Power spectra

Reconstruction of Power spectra:

- Depletion catalogue + Einasto profiles;
- Two parameters for unresolved mass

Performances:

- P_{hm} : $\lesssim$ 10% accuracy;
- P_{mm} : $\lesssim$ 5% accuracy



(In Prep.)