Correlations between triaxial shapes and formation history of dark matter haloes

Erwin T. Lau.et al.

https://ui.adsabs.harvard.edu/abs/2021MNRAS.500.1029L/abstract

Speaker:Shuo Xu

Outlines

- Background
- Data
- Method
- Results
- Model
- Summary

Background

- About 80% of the matter is made of dark matter.
- DM forms the skeleton on which galaxies form and evolve. DM halos with sufficient mass are natrual sites for galaxy formation
- The properties of galaxies are likely to connect with the properties of halos.

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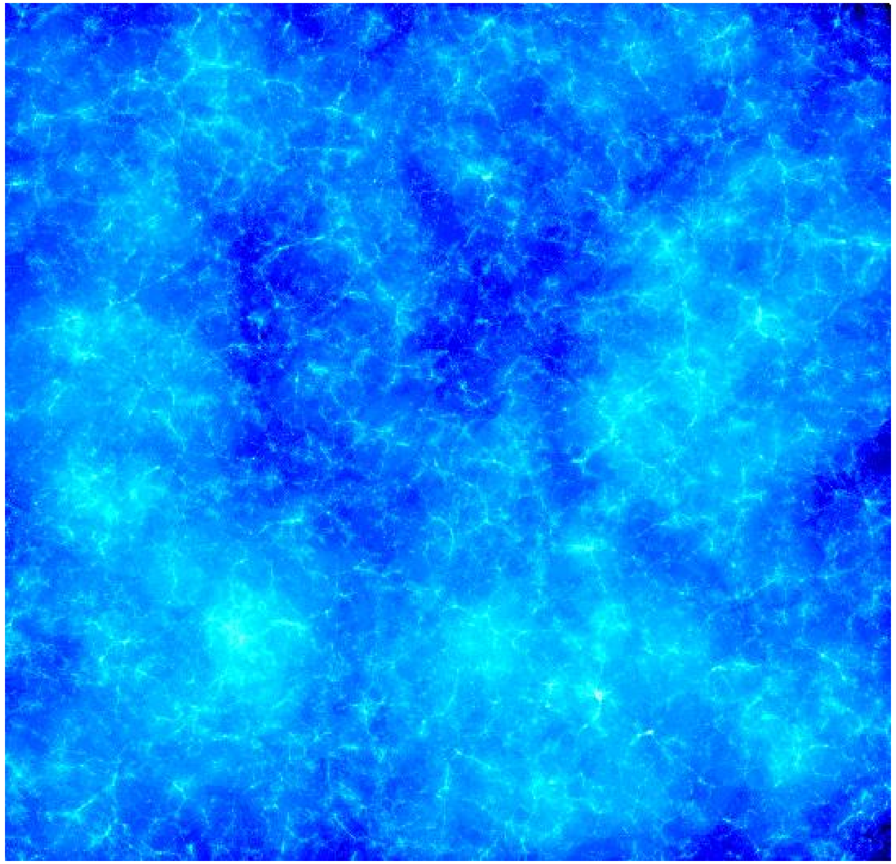
galaxy-halo connection



Background

- Galaxy-halo connection:

    scatter in stellar-halo mass relation

    assembly bias

    need to consider about halo secondary properties

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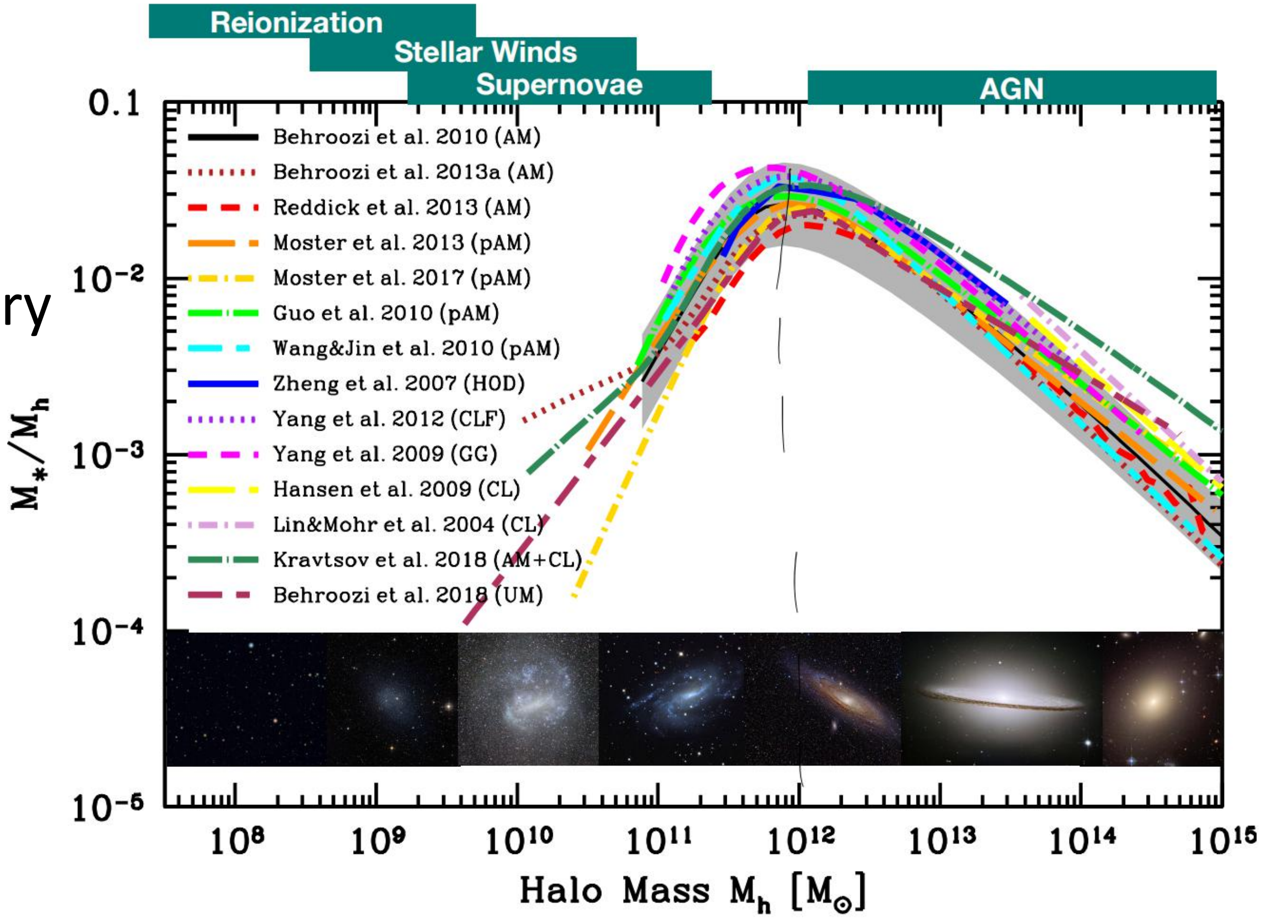
halo shape



Background

- Halo shape is expected to be non-spherical due to the primordial density field and assembly history

- The non-spherical shape affects the obsevations of galaxies clusters:

  orientation bias in gravitational lensing

- According to studies based on simulation, there is dependance on halo mass and redshifts but with scatter may come from halo formation history

Take-home message

- Highly elliptical halos tend to be preferentially prolate
- Halo ellipticity shows strong dependance on halo formation history
- Break the degeneracy between halo ellipticity and orientation bias by the scatter in excess surface mass density for global model

Halo shape

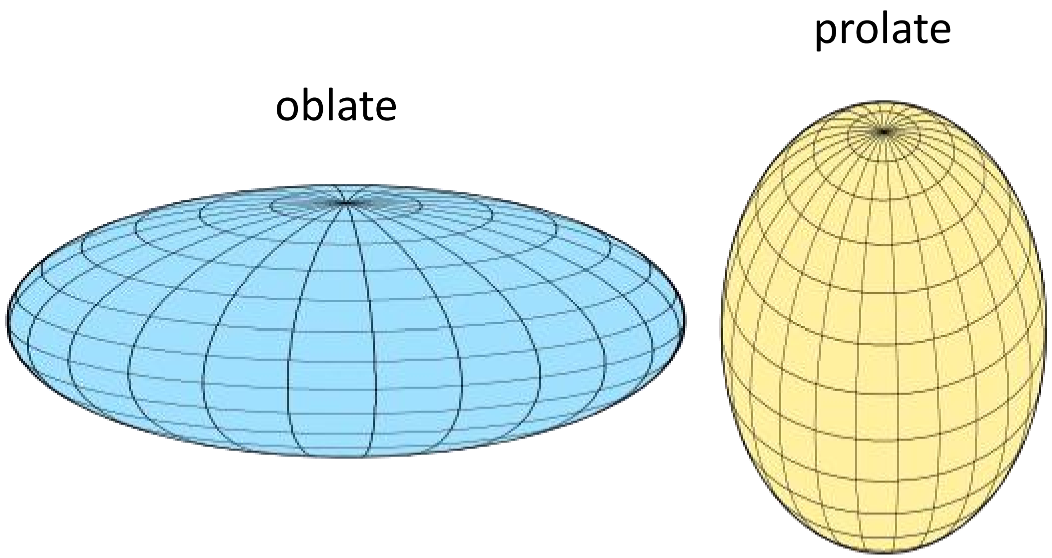
- For an ellipsoidal halo with axes $a \geq b \geq c$

ellipticity: $$e \equiv \frac{1-(c/a)^2}{2(1+(b/a)^2+(c/a)^2)}$$

prolaticity: $$p \equiv \frac{1-2(b/a)^2+(c/a)^2}{2(1+(b/a)^2+(c/a)^2)}$$

traxiality： $$T \equiv \frac{1-(b/a)^2}{1-(c/a)^2} = \frac{1}{2}\left(1+\frac{p}{e}\right)$$

parameters of shape: e and T



$T \lesssim \frac{1}{3}$ $T \gtrsim \frac{2}{3}$

Data

- A sample from gravity-only N-body simulation MultiDark Planck 2 (MDPL2):

  flat cosmology similar to Planck Collaboration VI

  host halos with mass $M_{\rm vir} \gtrsim 10^{13} h^{-1} {\rm M}_{\odot}$

  redshift: $z = 0.0, 0.5, 1.0, 1.5$

www.cosmosim.org

Shape measurement

- Iterative method of mass tensor:

$$I_{ij} \equiv \frac{1}{N}\sum_{n}^{N} x_{i,n}x_{j,n}$$

- Steps:
  1) start with all particles in $R_{\rm vir}$
  2) calculate the axes $(a,b,c) = (\sqrt{\lambda_a}, \sqrt{\lambda_b}, \sqrt{\lambda_c})$
  3) coordinate transformation to the frame of eigenvectors
  4) calculate new mass tensor with particles satisfiy

$$r_{ep} = a\sqrt{\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 + \left(\frac{z}{c}\right)^2} \le R_{\rm vir}$$

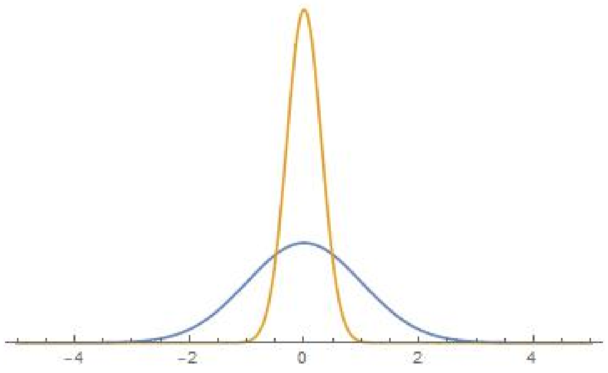
  5) repeat 2),3),4)

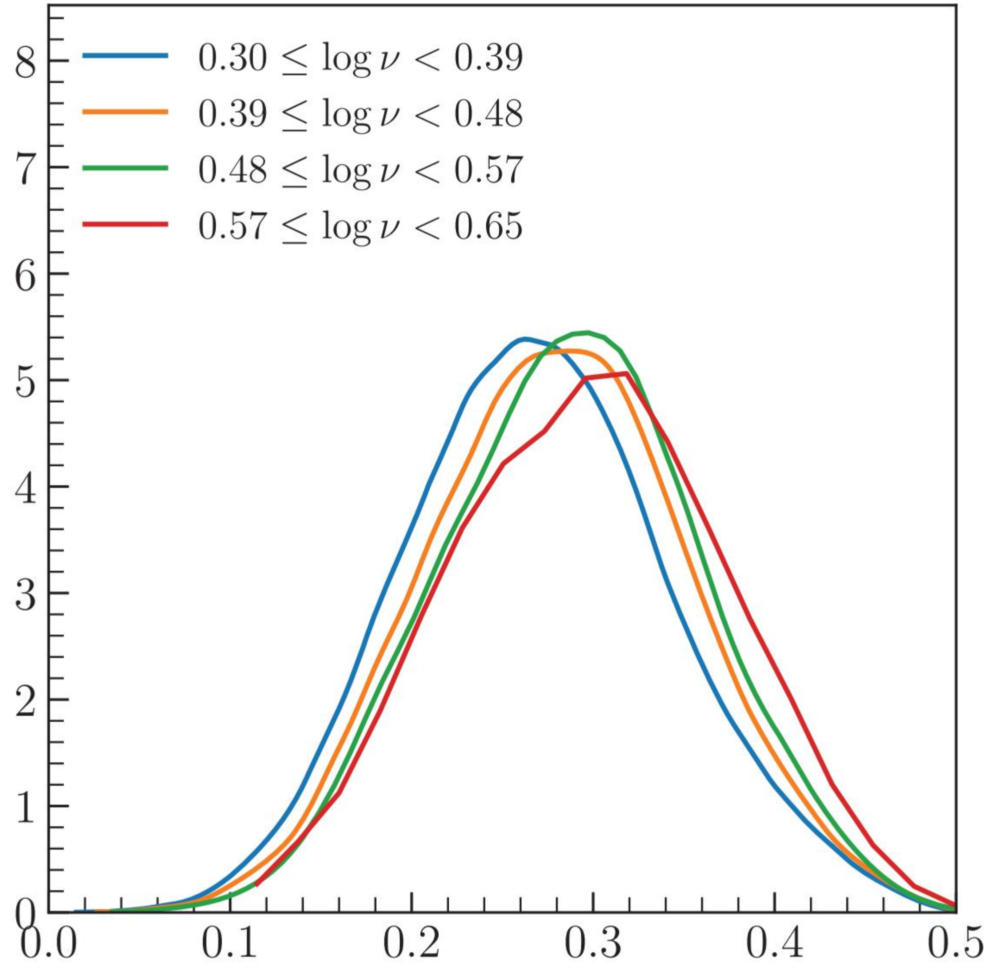
Results: ellipticity

- Halo density peak height to represent

halo mass $\nu = \frac{1.686}{\sigma(M_{\mathrm{vir}}, z)}$

- Gamma distribution
- Slight increase of ellipticity for larger peak height but significant overlap





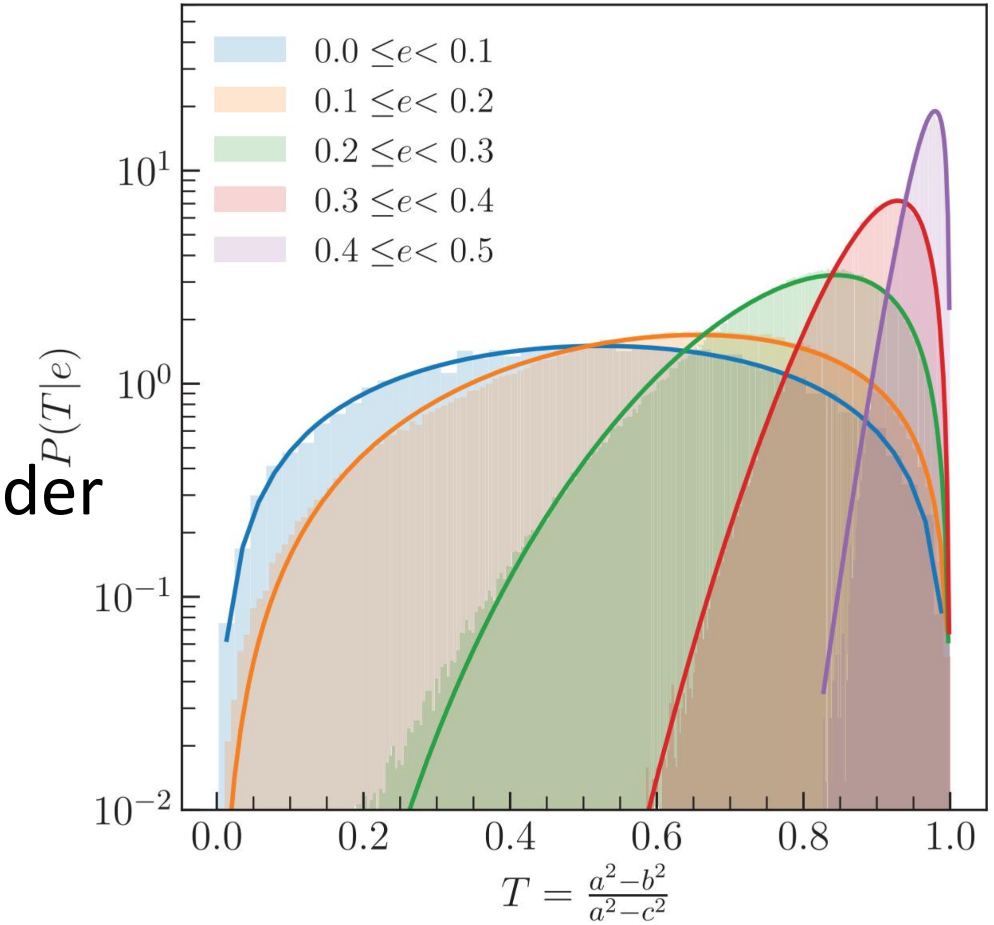
Results: triaxiality

- For triaxiality with fixed ellipticity：

  beta distribution

  highly elliptical halos tend to be more prolate

  less elliptical haloes tend to have a broader distribution of triaxiality



Results: correlations between ellipticity and proxies

- Six halo formation proxies shows the tightest correlation

halo concentration $c_{\rm vir} \equiv \frac{R_{\rm vir}}{R_s}$

virial ratio = ratio of kinetic to potential energy $T/|U|$

distance offset between mass centroid and densest peak normalized by the virial radius X_{off}

and 3 time-based proxies about the time halo reaches half of current mass

$$a_{1/2}, \Delta t_{1/2}, \Delta\omega_{1/2}$$

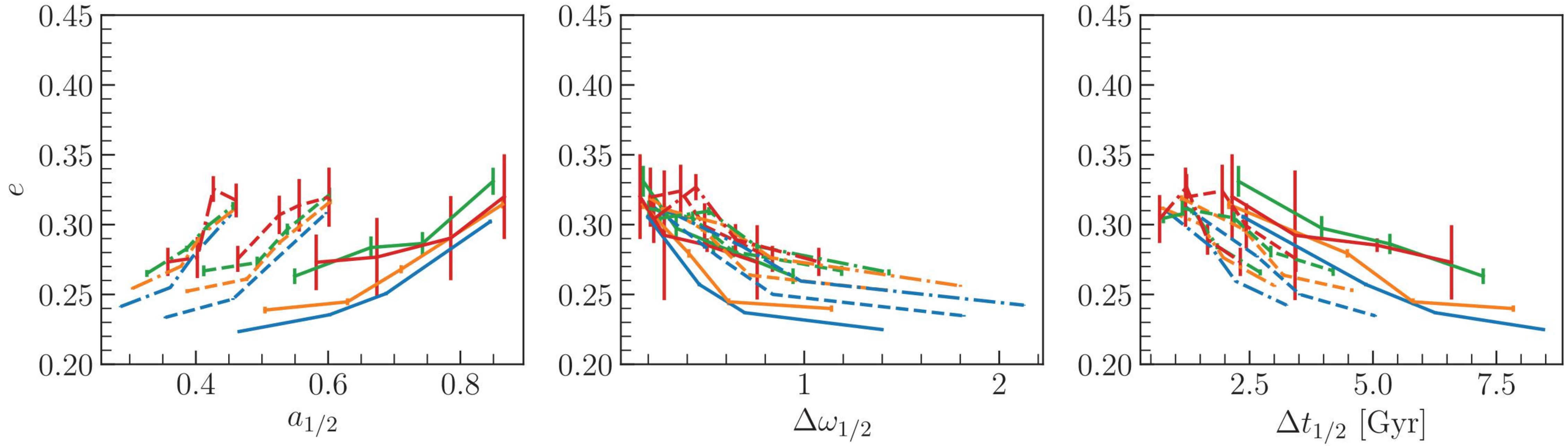
	$c_{\rm vir}$	$T/\|U\|$	$a_{\frac{1}{2}}$	$\Delta t_{\frac{1}{2}}$	$\Delta\omega_{\frac{1}{2}}$	a_{lmm}	$X_{\rm off}$	$V_{\rm off}$	$\dot{M}_{\rm vir}$	$\frac{\Delta M_{\rm vir}}{\Delta T_{\rm dyn}}$	e
$c_{\rm vir}$	1.00	-0.56	-0.68	0.68	0.68	-0.42	-0.66	-0.55	-0.08	-0.24	-0.42
$T/\|U\|$	-0.56	1.00	0.60	-0.60	-0.60	0.42	0.65	0.71	0.39	0.58	0.47
$a_{\frac{1}{2}}$	-0.68	0.60	1.00	-1.00	-1.00	0.63	0.56	0.55	0.06	0.23	0.46
$\Delta t_{\frac{1}{2}}$	0.68	-0.60	-1.00	1.00	1.00	-0.63	-0.56	-0.55	-0.06	-0.23	-0.46
$\Delta\omega_{\frac{1}{2}}$	0.68	-0.60	-1.00	1.00	1.00	-0.63	-0.56	-0.55	-0.06	-0.23	-0.46
a_{lmm}	-0.42	0.42	0.63	-0.63	-0.63	1.00	0.39	0.39	0.06	0.16	0.37
$X_{\rm off}$	-0.66	0.65	0.56	-0.56	-0.56	0.39	1.00	0.63	0.19	0.39	0.42
$V_{\rm off}$	-0.55	0.71	0.55	-0.55	-0.55	0.39	0.63	1.00	0.25	0.41	0.36
$\dot{M}_{\rm vir}$	-0.08	0.39	0.06	-0.06	-0.06	0.06	0.19	0.25	1.00	0.67	0.12
$\frac{\Delta M_{\rm vir}}{\Delta T_{\rm dyn}}$	-0.24	0.58	0.23	-0.23	-0.23	0.16	0.39	0.41	0.67	1.00	0.27
e	-0.42	0.47	0.46	-0.46	-0.46	0.37	0.42	0.36	0.12	0.27	1.00

$z = 0$

Results: correlations between ellipticity and proxies

- Dependance of mass and redshift:

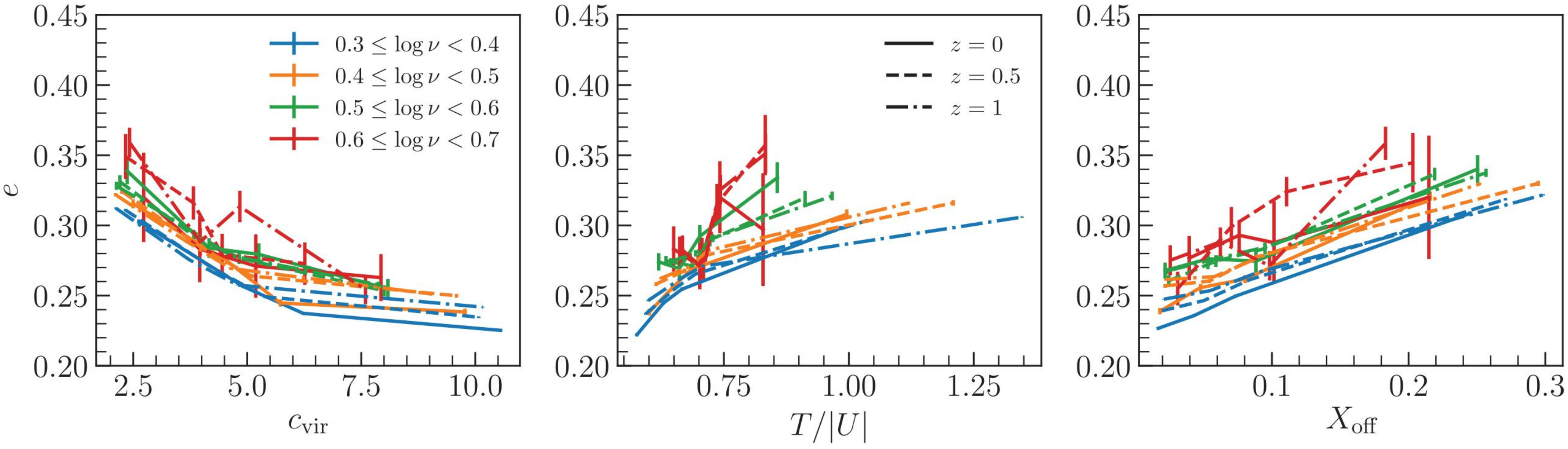
  time-based proxies show more dependance



Results: correlations between ellipticity and proxies

- Dependance of mass and redshift:

  space-based proxies show less dependance

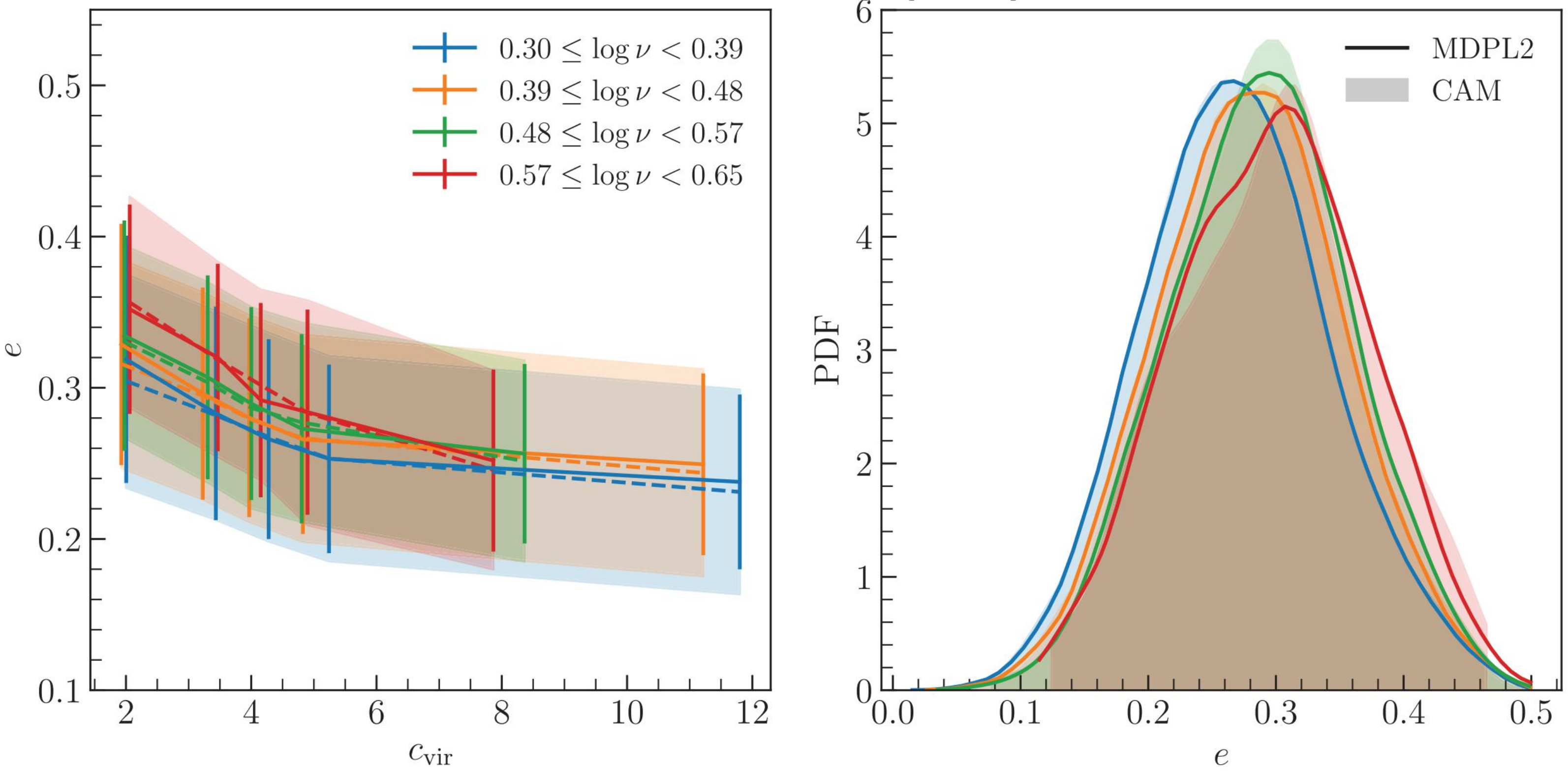


Model:Correlation between Halo ellipticity and Halo concentration

- Conditional abundance matching:

  ellipticity and concentration at different halo mass

  two-phase algorithm: 1) abudance matching main properties by CDF 2) analyse in divided bins of secondary properties



Connecting to observevation: orientation bias

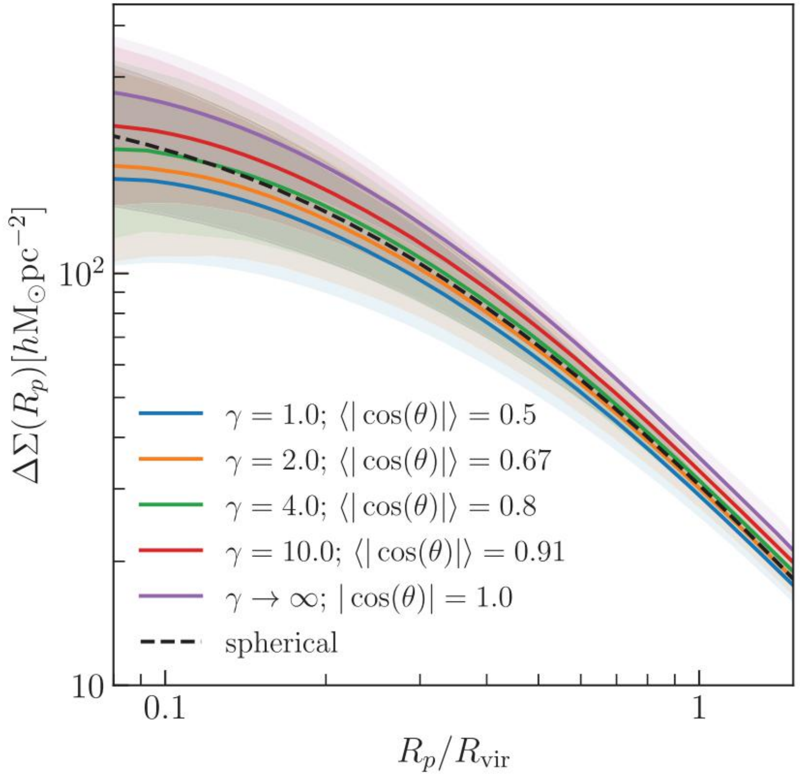
- Calculate the excess surface mass density profile with a sample of 8190 cluster-sized halos at z=0

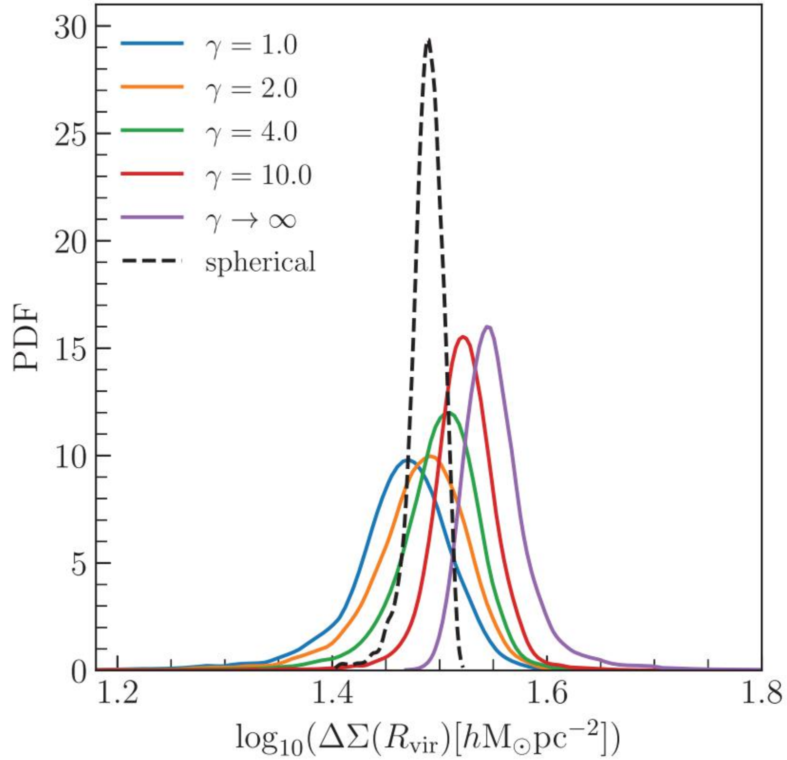
$$\Delta\Sigma(R_p) \equiv \bar{\Sigma}(< R_p) - \bar{\Sigma}(R_p)$$

- Orientation bias: halos' orientation draw from a random distribution
- Compared with spherical halos with same mass and concentration distributions

Connecting to obserevation: orientation bias

- Degeneracy between orientation bias and ellipticty in mean $\Delta\sum$
- For global model, the degeneracy can be broken by the scatter





Summary

- Highly elliptical halos tend to be preferentially prolate and less elliptical haloes tend to have a broader distribution of triaxiality.
- Halo ellipticity shows strong correlations with halo formation proxies such as halo concentration and viral ratios.
- A condition abundance matching model is made for correlation between halo ellipticity and concentration.
- For global model, the degeneracy between halo ellipticity and orientation bias can be broken.

Comments

- Lack of details about the conditional abundance matching model and the measurement of the formation proxies.
- Assume that halo internal structure is NFW profile and substructure effects can be neglected.

Quesitions

- How to measure the proxies?
- How to adapt the NFW profile to a triaxial halo?
- How to break the degeneracy between halo ellipticity and orientation bias for a single halo?
- How the baryonic effects influnce the real results?

Halo formation proxies

Parameter	Physical meaning
$c_{\rm vir}$	Halo concentration
$T/\|U\|$	Virial ratio = ratio of kinetic to potential energy of the halo = 0.5 for a completely virialized halo
$a_{1/2}$	Half-mass scale, which is the scale factor at which halo reaches a half of its current mass
$\Delta t_{1/2}$	Time difference in Gyr between now and when halo reaches a half of its current mass
$\Delta \omega_{1/2}$	Difference in re-scaled 'time' $\omega \equiv \delta_c(z)$ between now and when halo reaches a half of its current mass
$a_{\rm lmm}$	Scale factor at which halo experiences its last major merger
$X_{\rm off}$	Distance offset between mass centroid and densest peak normalized by the virial radius
$V_{\rm off}$	Velocity offset between mean halo velocity and velocity of the densest peak
$\dot{M}_{\rm vir}$	Instantaneous mass accretion rate
$\Delta M_{\rm vir}/\Delta T_{\rm dyn}$	Mass change over the past dynamical time

$$c_{\rm vir} \equiv \frac{R_{\rm vir}}{R_s}$$

parameter in NFW profile

Information of the simulation

- Box size: 1 Gpc/h
- Particles: 3840^3
- Cosmology:

h	0.6777
Ω_Λ	0.692885
Ω_m	0.307115
Ω_b	0.048206
n	0.96
σ_8	0.8228