The three causes of (low-mass) halo assembly bias

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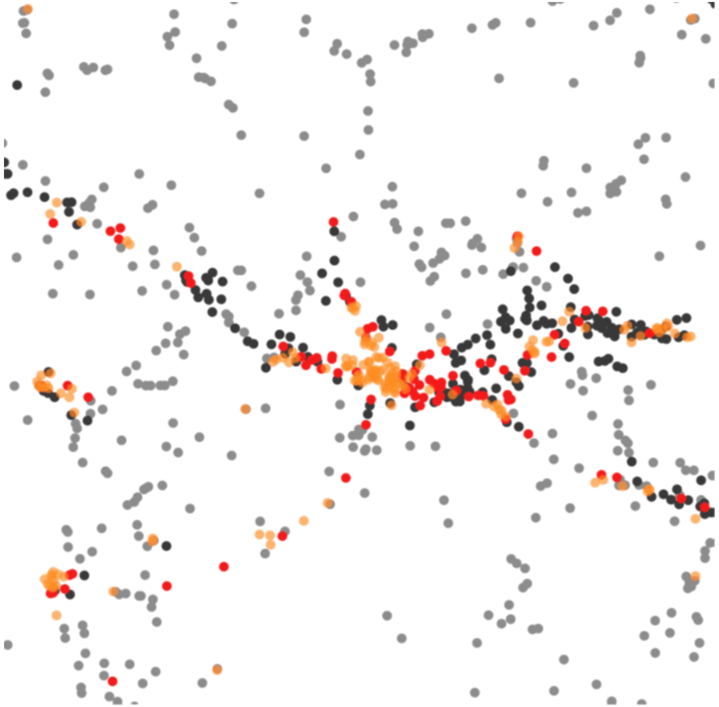
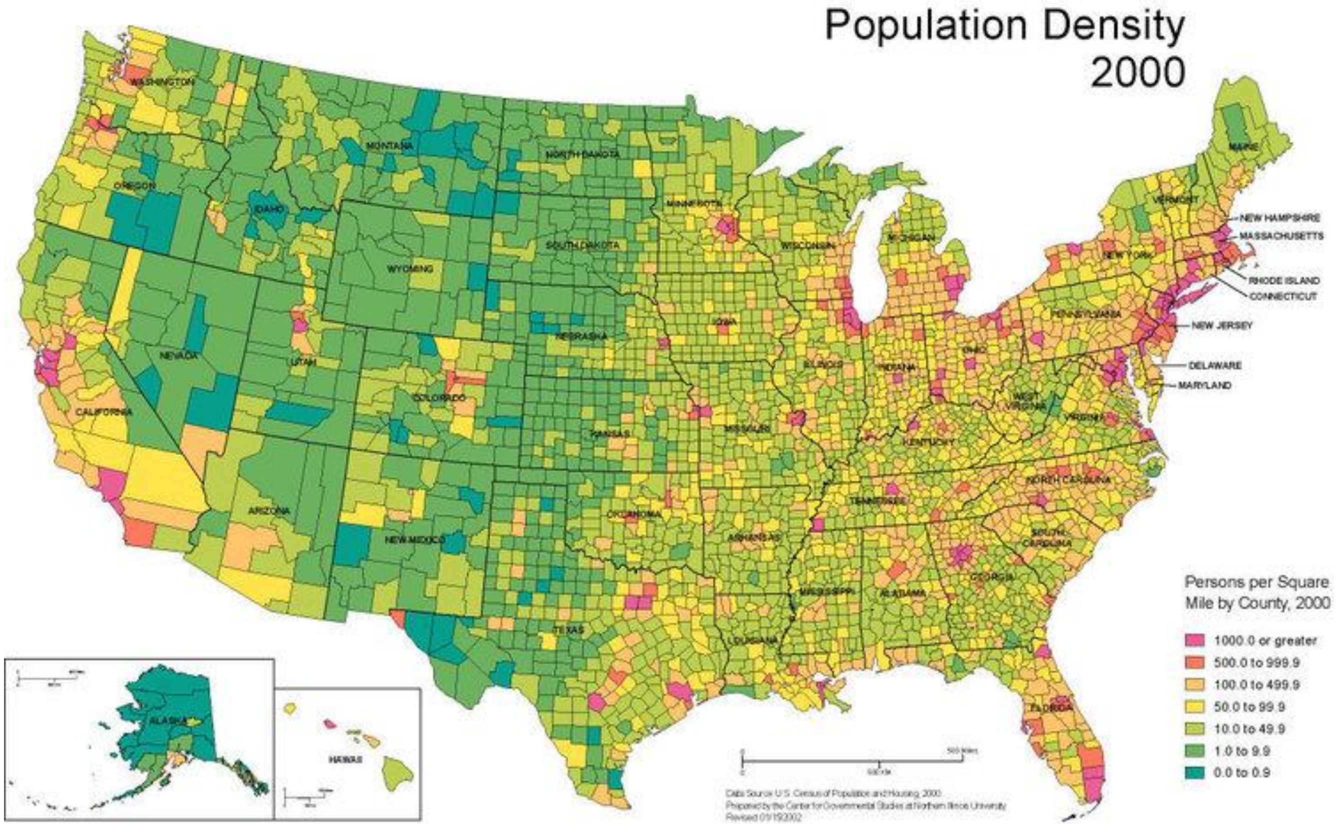


with

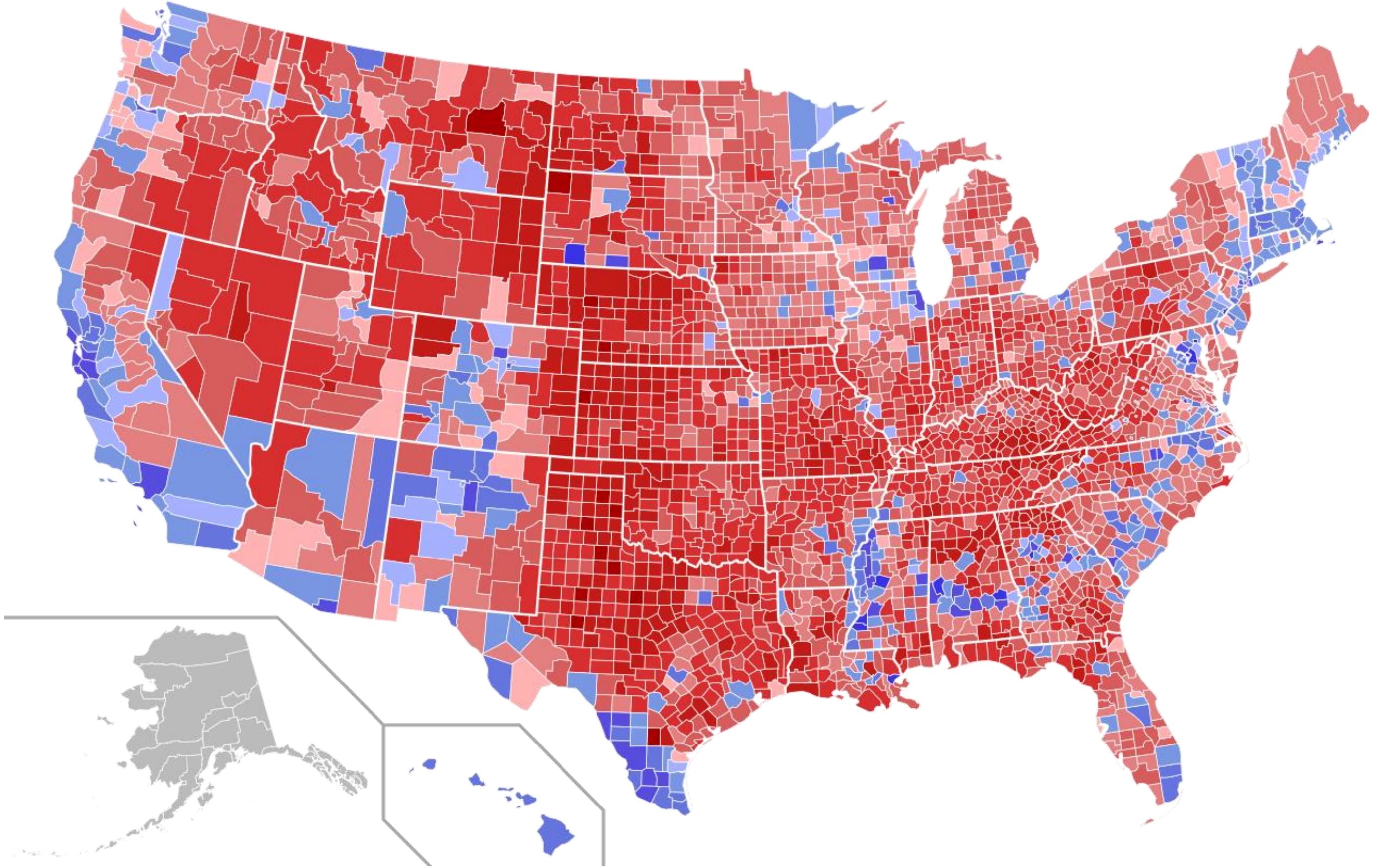
Phil Mansfield
(U. Chicago)

arXiv/1902.00030

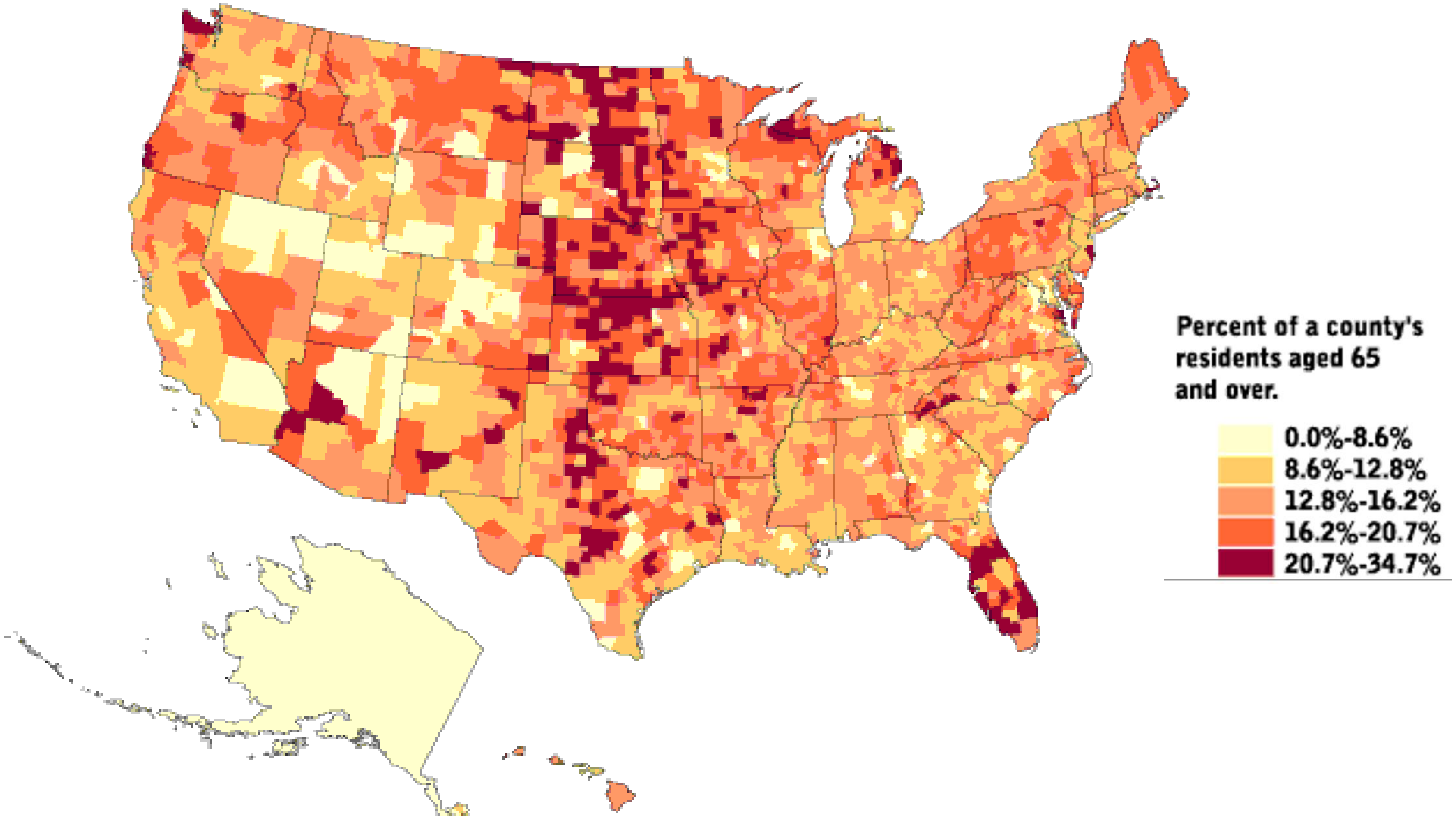
US map colored by population surface density



US map colored by 2016 presidential election voting results



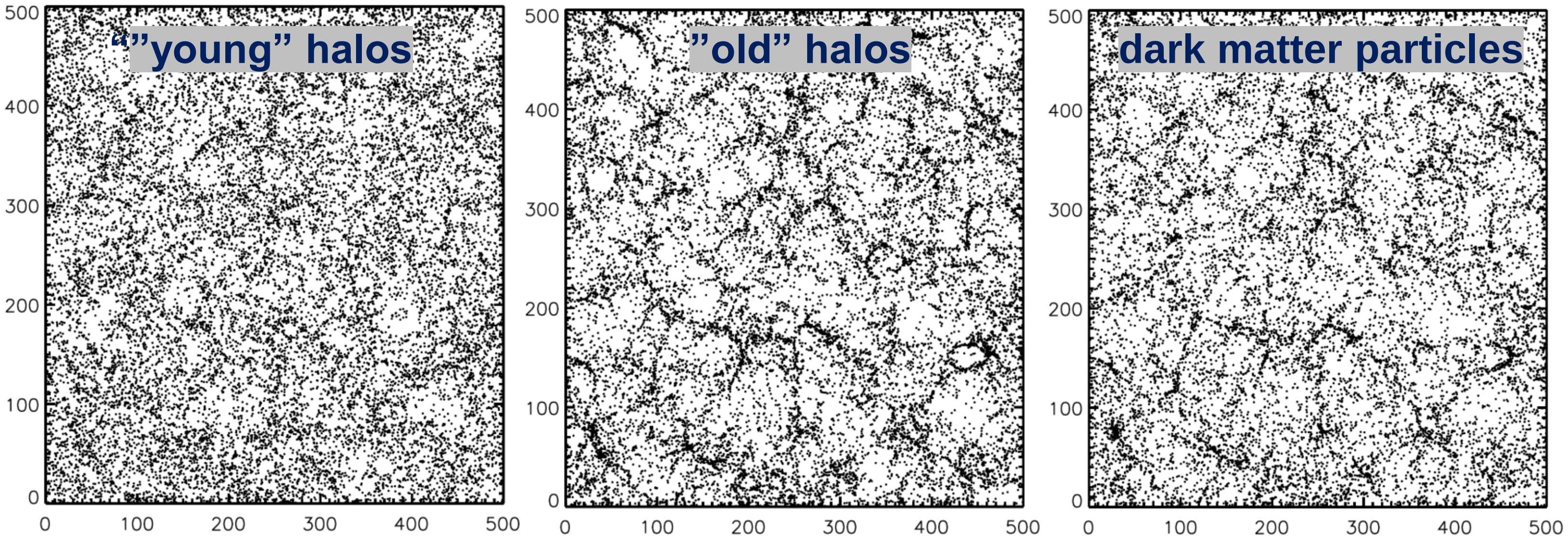
US map colored by surface density of >65 old population



Halo assembly bias

Gao, Springel & White 2005
Wechsler et al. 2006, Harker et al. 2006; Gao & White 2007; Croton et al. 2007; Jing et al. 2007, Dalal et al. 2008…

at a fixed virial mass
“younger” galaxy-scale halos cluster less strongly than “older” halos, both cluster differently from dark matter
(at cluster scales assembly bias effect is reverse and is much weaker)

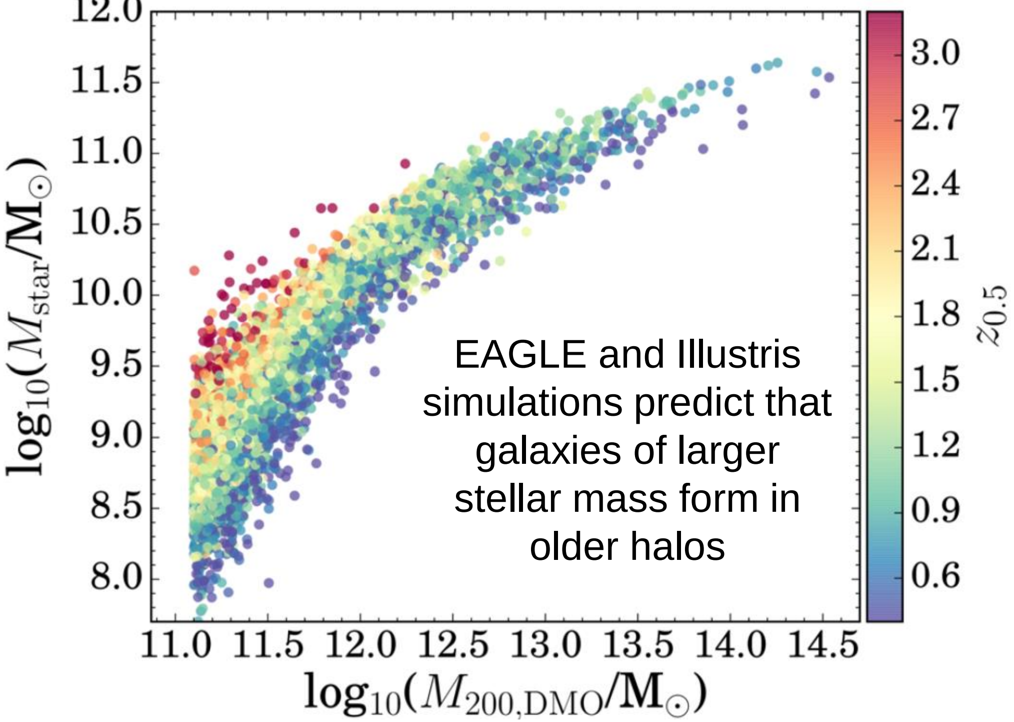


Halo “age” can be defined using a quantity parameterizing the assembly history of halo mass or epoch (redshift or expansion factor) when a given fraction of halo mass (e.g. 0.5) is assembled

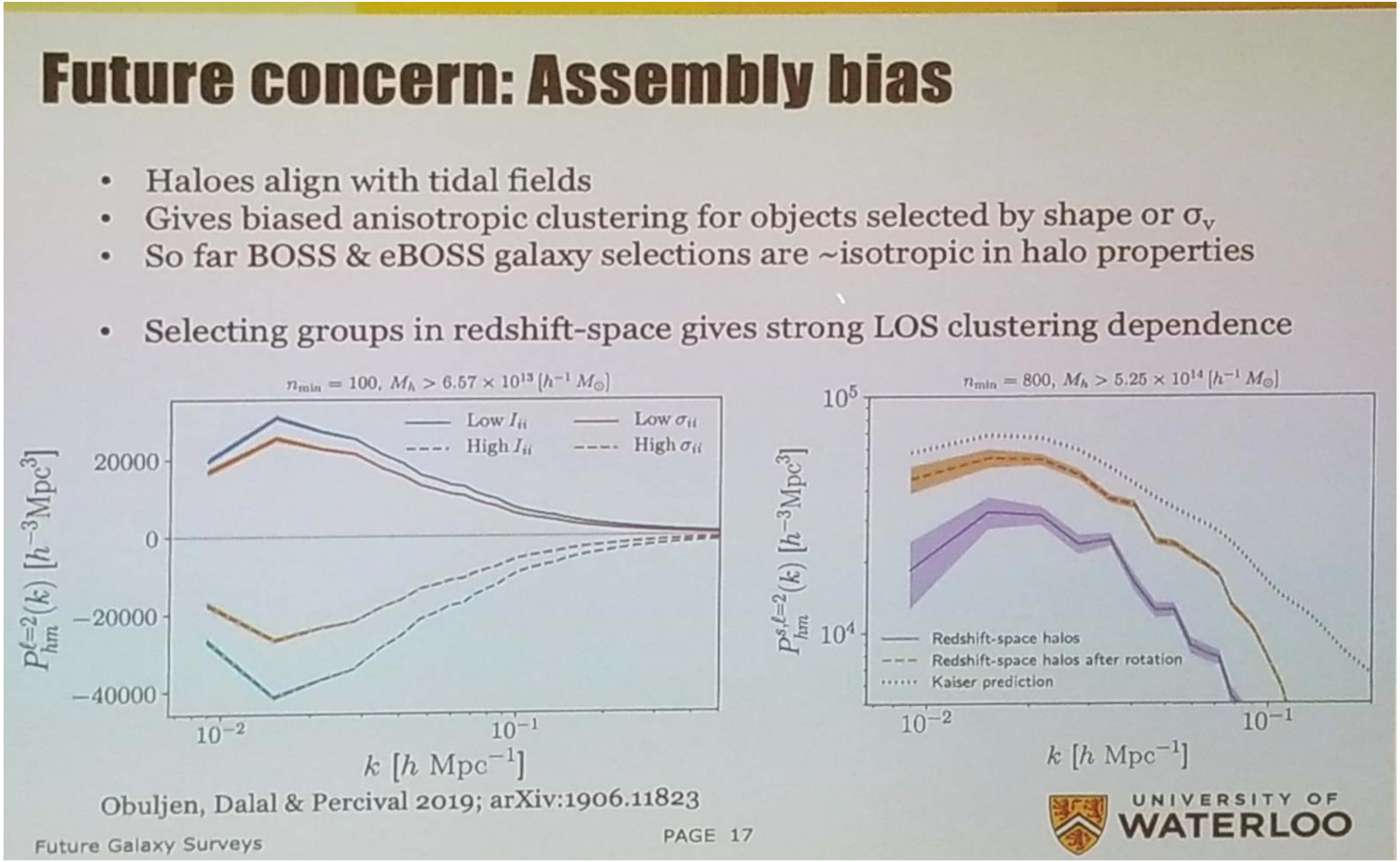
Why do we care about halo assembly bias?

it is likely that assembly bias of halos is imprinted in properties of galaxies that form in them and so needs to be modelled in cosmological analyses that use galaxy clustering

e.g., Matthee et al. 2017; Artale et al. 2018
Croton, Gao & White 2007; Contreras et al. 2019



A slide from Will Percival’s talk on Tuesday

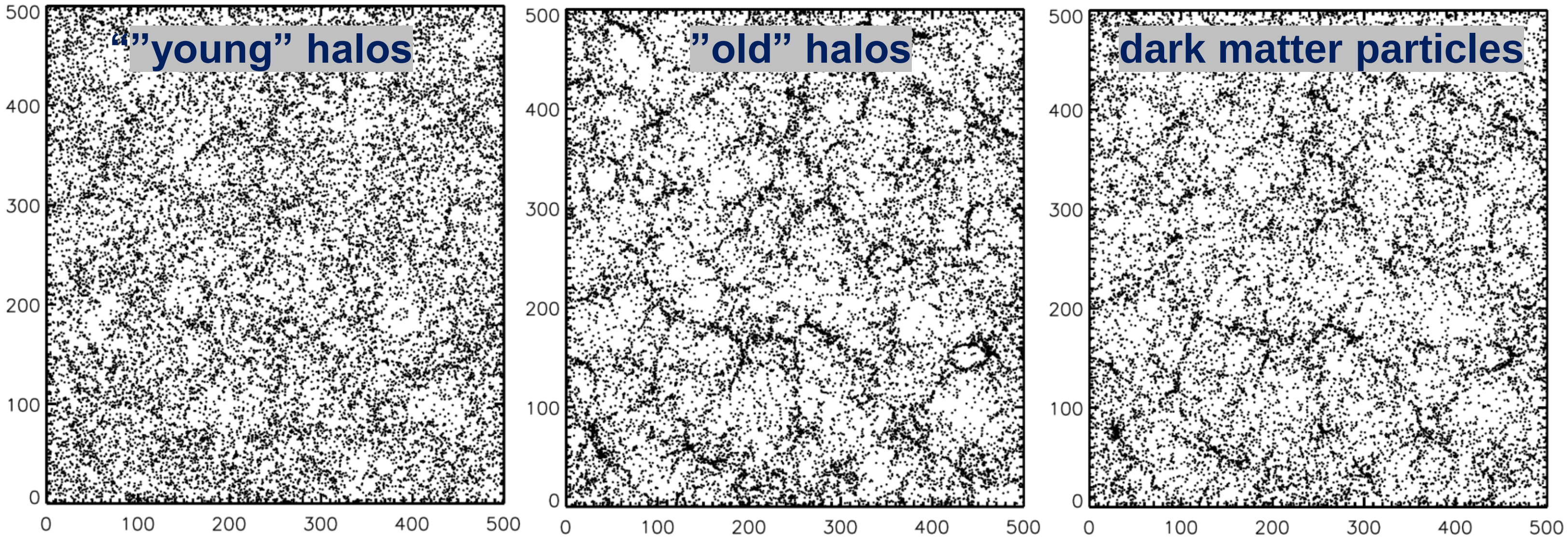


What is the origin of assembly bias?

Gao+ ’05; Wechsler+ ‘06, Harker+ ‘06; Gao & White ‘07; Croton+ ‘07; Jing+ ’07; Li+’08, ‘13; Wang+ ’08, 11; Hahn+ ’09; Faltenbacher & White ‘10; Lacerna & Padilla ‘11; Sunayama+ ’16; Sato-Polito+ ‘18; Paranjape+ ‘18; Mao+ ‘18; Villarreal+ ‘18; Han+ ’19…

Some processes that affect halo mass accretion history in a spatially correlated manner…

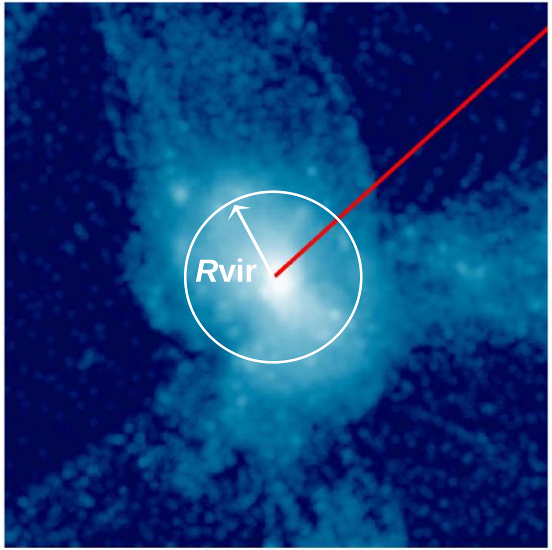
Interaction of satellites with their host systems?
Truncation of mass growth due to tidal forces from a massive neighbour? From overall matter distribution?
Gravitational heating of surrounding matter during its collapse into sheets and filaments?

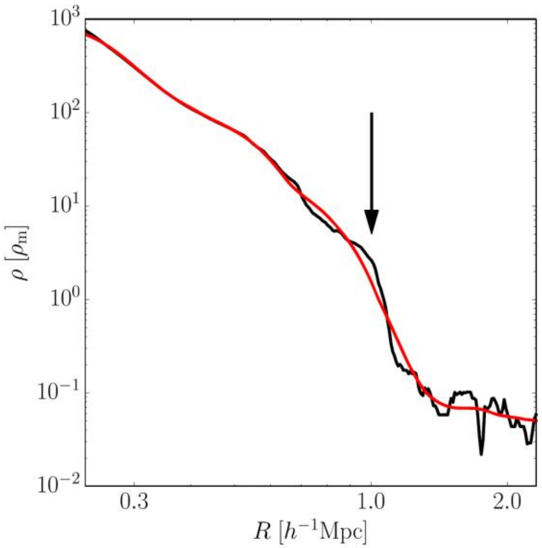


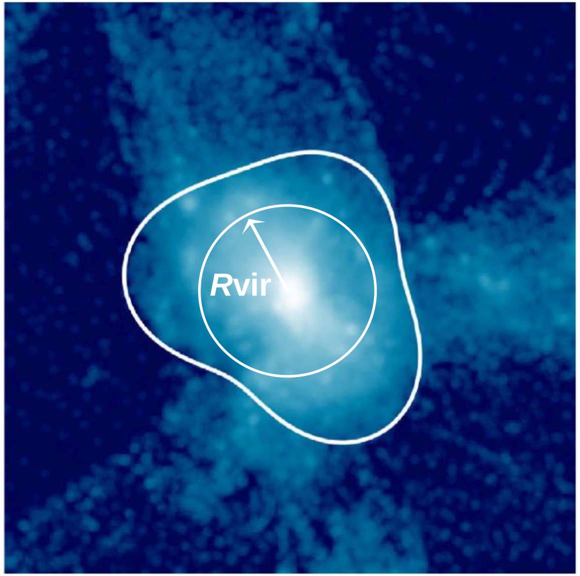
Initial motivation for our study

Estimate contribution of "splashback" halos to the assembly bias signal
using the new tool we developed to identify 3d "splashback shells" around halos in simulations
https://github.com/phil-mansfield/shellfish

Independently check results of Villarreal et al. 2017 (and Wang+ 09; Li+ 13; Sunayama+16),
who concluded that assembly bias is not due to just splashback haloes
and further explore implications

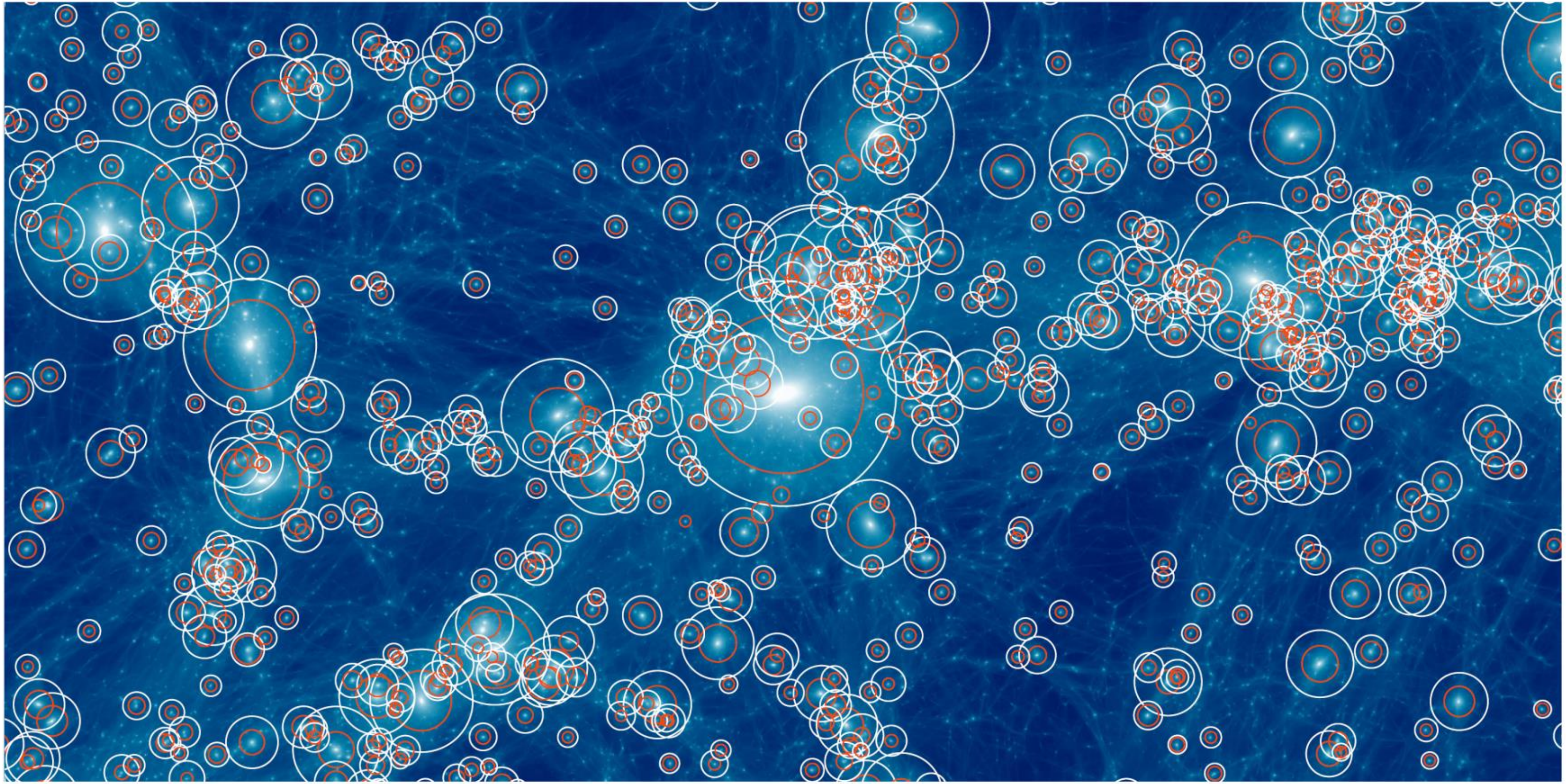






Mansfield, Kravtsov & Diemer 2017

Among all halos with 1.7×10^{11} Msun < Mvir < 1.2×10^{12} Msun (the focus mass range of our study):
27% are within Rvir of a larger halo,
but 37% are within splashback shell of a larger halo



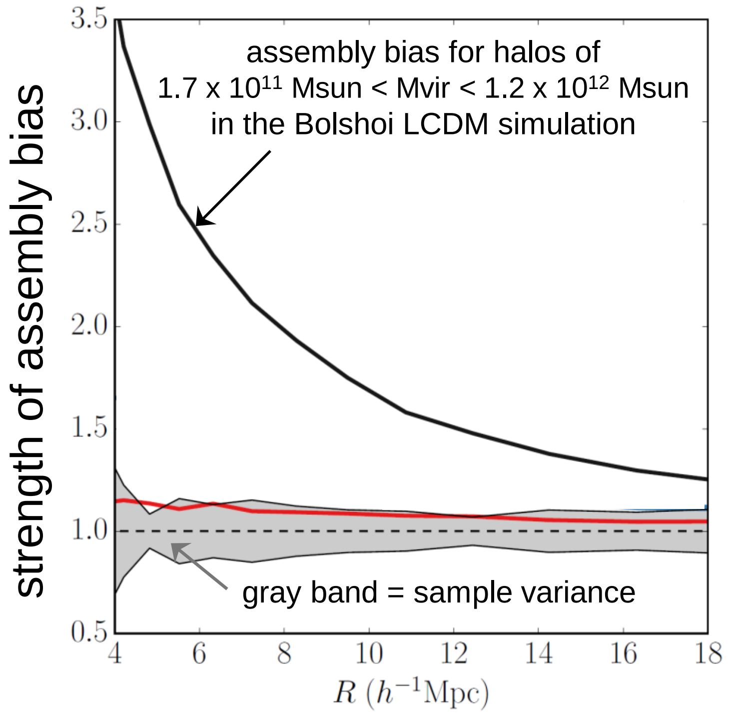
red circles = virial radii; white circles = splashback radii   figure from Diemer et al. 2017

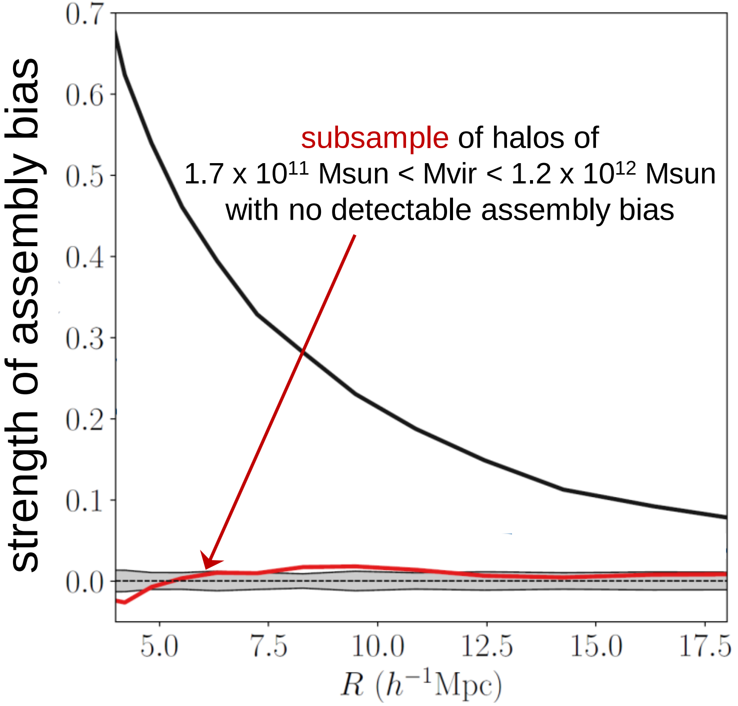
Quantifying assembly bias

Is usually done using either ratio of 2pt correlation functions of "old" and "young" subsamples of halos of a given mass or using marked correlation function (MCF)

$$\mathcal{M}(r) = \frac{\langle m_i m_j \rangle_{i,j\in P(r)} - \langle m \rangle^2}{\langle m^2 \rangle - \langle m \rangle^2}$$

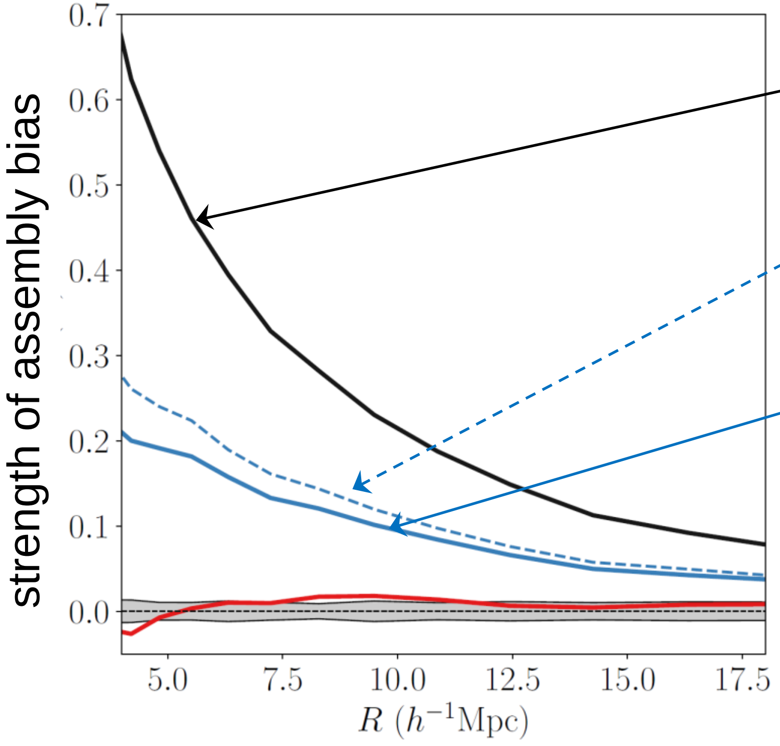
m = indicator of halo "age" or some other property. In this study we will use halo concentration and $z_{0.5}$





Effect of “splashback” subhaloes

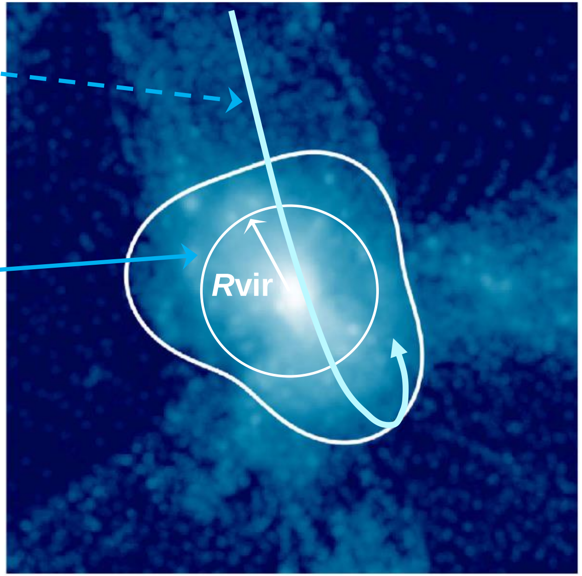
About 60% of the assembly bias is due to 10% of halos outside Rvir but within splashback shells of larger halos (roughly consistent with previous estimates, e.g. Wang+ 09; Li+ 13; Sunayama+16)



assembly bias for “distinct” halos (outside Rvir of larger halos) of 1.7×10^{11} Msun < Mvir < 1.2×10^{12} Msun in the Bolshoi LCDM simulation

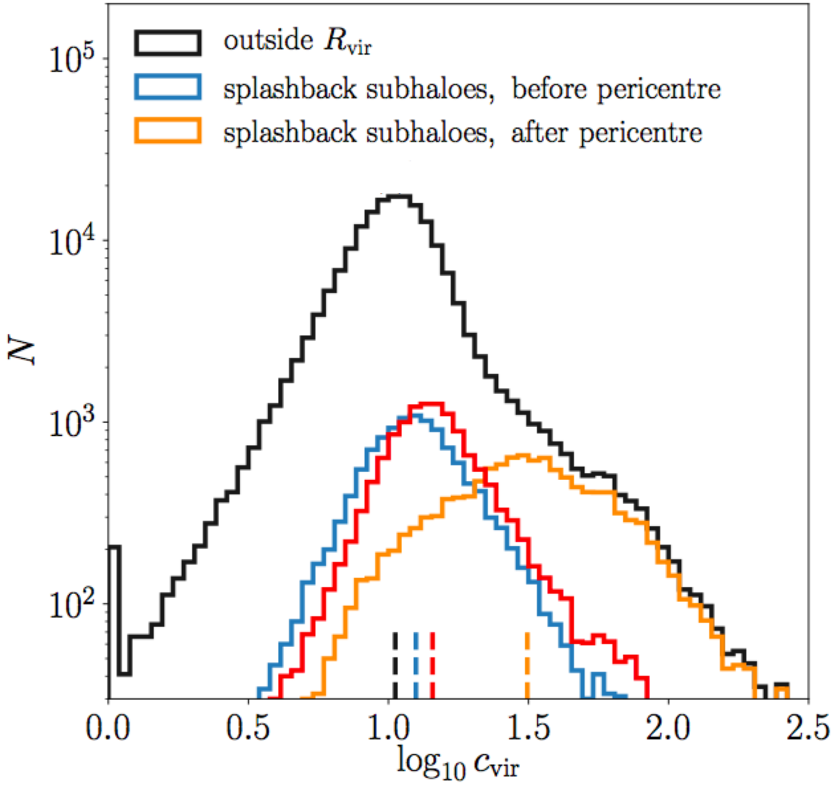
assembly bias after “flyby” haloes are excluded

assembly bias after haloes within splashback shells are excluded



Mass growth truncation and stripping due to tides from a larger host during pericenter passage is the 1st significant cause of assembly bias

Concentration of haloes is drastically affected after a halo passes through its orbit pericenter within splashback



Mansfield & Kravtsov 2019

What causes the remaining assembly bias?

a number of possible physical processes have been proposed to explain assembly bias

- Truncation of mass accretion by tidal forces (e.g., Hahn+ 09; Hearin+ 16)
  - from a single dominant neighbour: use minimum Hill radius as a proxy $R_{\mathrm{Hill},i} = \min_j d_{ij} \left(\frac{M_{\mathrm{vir},i}}{3M_{\mathrm{vir},j}} \right)^{1/3}$
  - from the overall mass distribution: use tidal radius or mass as proxy $R_{\mathrm{tidal}} = \left(\frac{GM_{\mathrm{vir}}}{\alpha_1} \right)^{1/3}$

or

$$M_{\mathrm{tidal}} = M(< R_{\mathrm{tidal}})$$

absolute value of the largest eigenvalue of the tidal tensor

- Truncation of mass accretion due to gravitational heating of surrounding mass (e.g., Wang+ 07; Dalal+ 08): use bound mass within $3R_{\mathrm{vir}}$ of halos as proxy

$$M_{3R_{\mathrm{vir}},\mathrm{b}} = M_{\mathrm{bound}}(< 3R_{\mathrm{vir}})$$

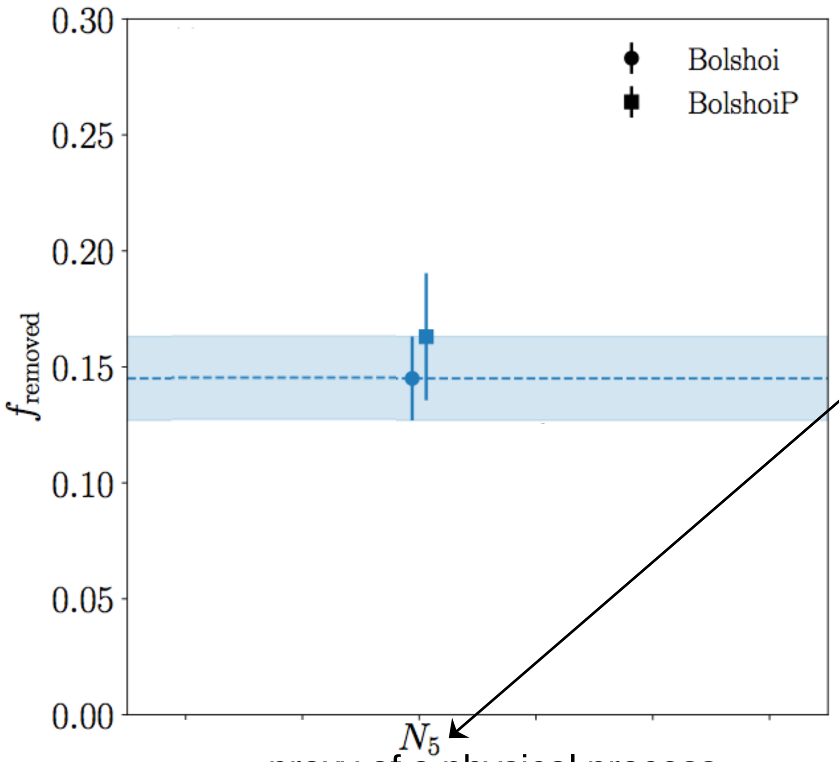
- Combination of the above: use bound mass within tidal radius as proxy

$$M_{\mathrm{tidal,b}} = M_{\mathrm{bound}}(< R_{\mathrm{tidal}})$$

establishing the baseline

All mass growth truncation processes are stronger in high-density regions.
Local density thus provides benchmark for proxies of the candidate processes

fraction of halos with largest (or smallest) proxy that needs to be removed to eliminate assembly bias



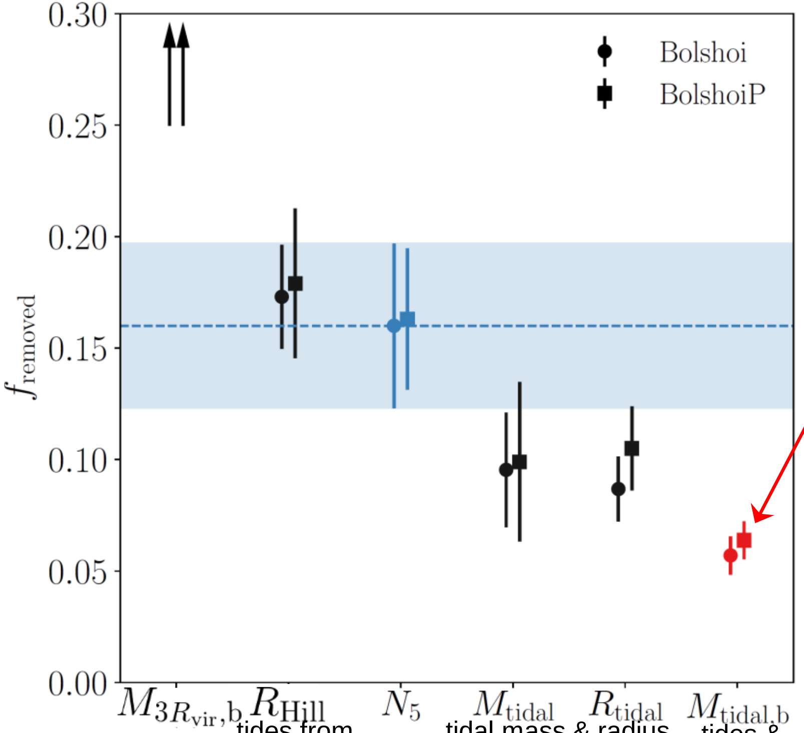
number of neighbour haloes in the sample within 5/h Mpc

proxy of a physical process

What causes the remaining assembly bias?

- The assembly bias is eliminated by excluding only 6% of haloes outside splashbacks
- The proxy that works best combined effects of tidal forces and gravitational heating)
- Tidal truncation is due to overall surrounding mass distribution, not a single dominant neighbour

fraction of halos with largest (or smallest) proxy that needs to be removed to eliminate assembly bias



heating

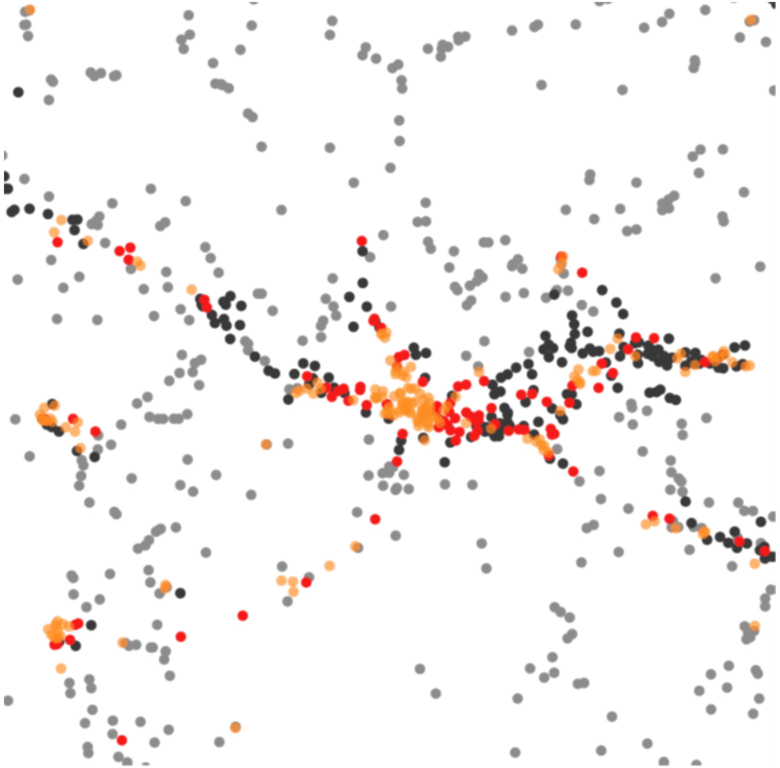
tides from 1 neighbor

tidal mass & radius from all mass

tides & heating

proxy of a physical process

Conclusions:
the three causes of low-mass halo assembly bias



1. ~60% of effect is due to *tidal interactions of haloes inside splashback shells with their host*

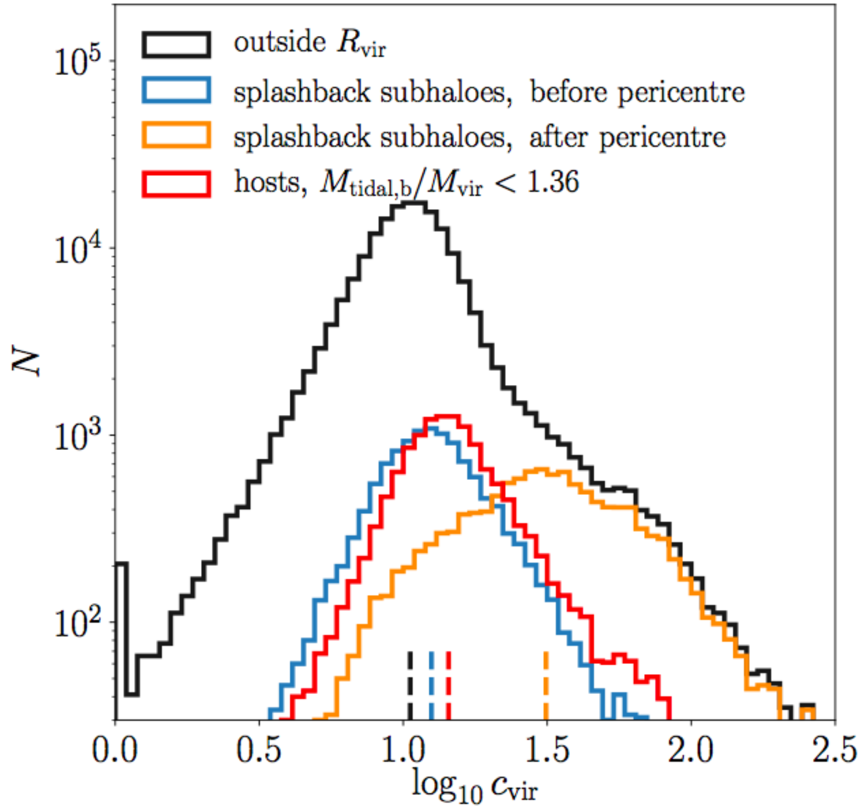
2. The second most important effect is *truncation of mass growth due to tidal forces from surrounding mass distribution* (not single dominant neighbour)

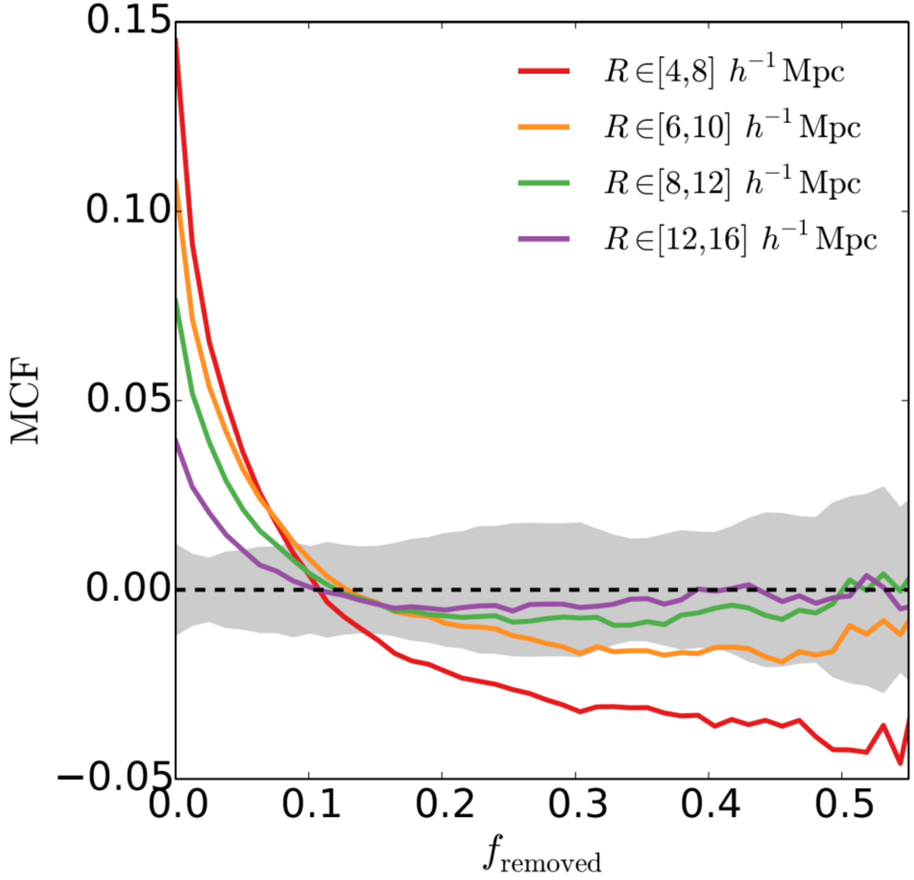
3. The third cause is *gravitational heating of matter during its collapse into sheets and filaments*.

overall, assembly bias arises due to only <16% of what is usually considered to be "distinct" haloes

Mansfield & Kravtsov arXiv/1902.00030

Distribution of concentrations of the halos affected by these processes are biased high by a small amount, compared to the overall distribution

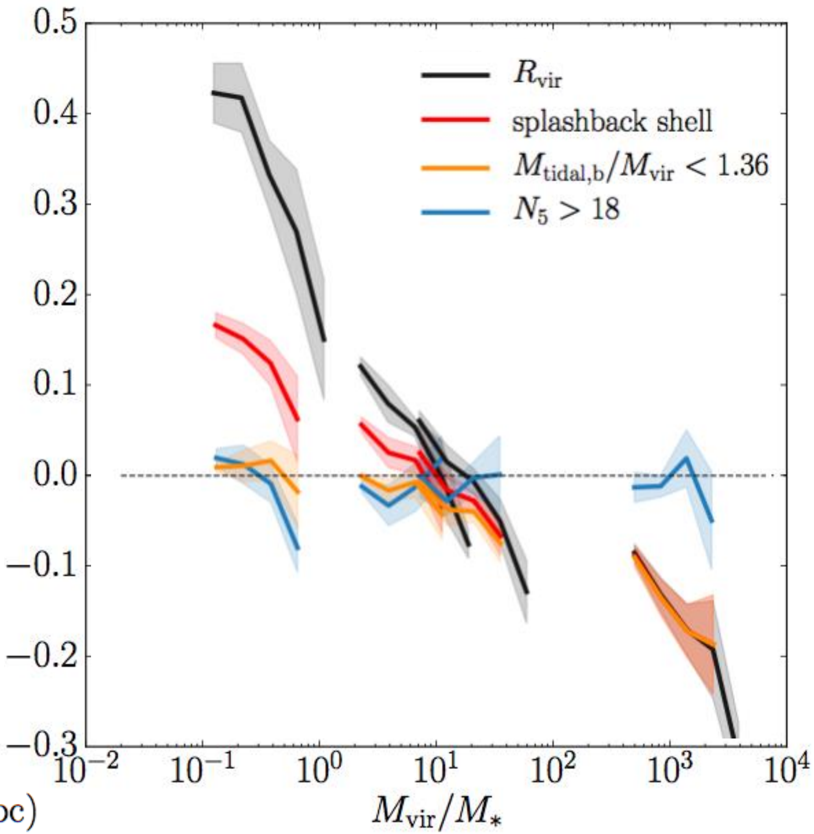




0.15
0.10
0.05
0.00
−0.05
0.0
0.1
0.2
0.3
0.4
0.5
MCF
$f_{\rm removed}$
$R \in [4,8]\ h^{-1}\,\mathrm{Mpc}$
$R \in [6,10]\ h^{-1}\,\mathrm{Mpc}$
$R \in [8,12]\ h^{-1}\,\mathrm{Mpc}$
$R \in [12,16]\ h^{-1}\,\mathrm{Mpc}$

How does this depend on mass?

Assembly Bias Strength*



Older haloes cluster more than younger haloes

No assembly bias

Younger haloes cluster more than older haloes

*$\mathrm{MCF}(4\ h^{-1}\ \mathrm{Mpc} < R < 8\ h^{-1}\ \mathrm{Mpc})$