Toward Accurate Modeling of Galaxy Clustering on Small Scales: Halo Model Extensions & Lingering Tension

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Constraining Cosmology with Small-Scale Clustering

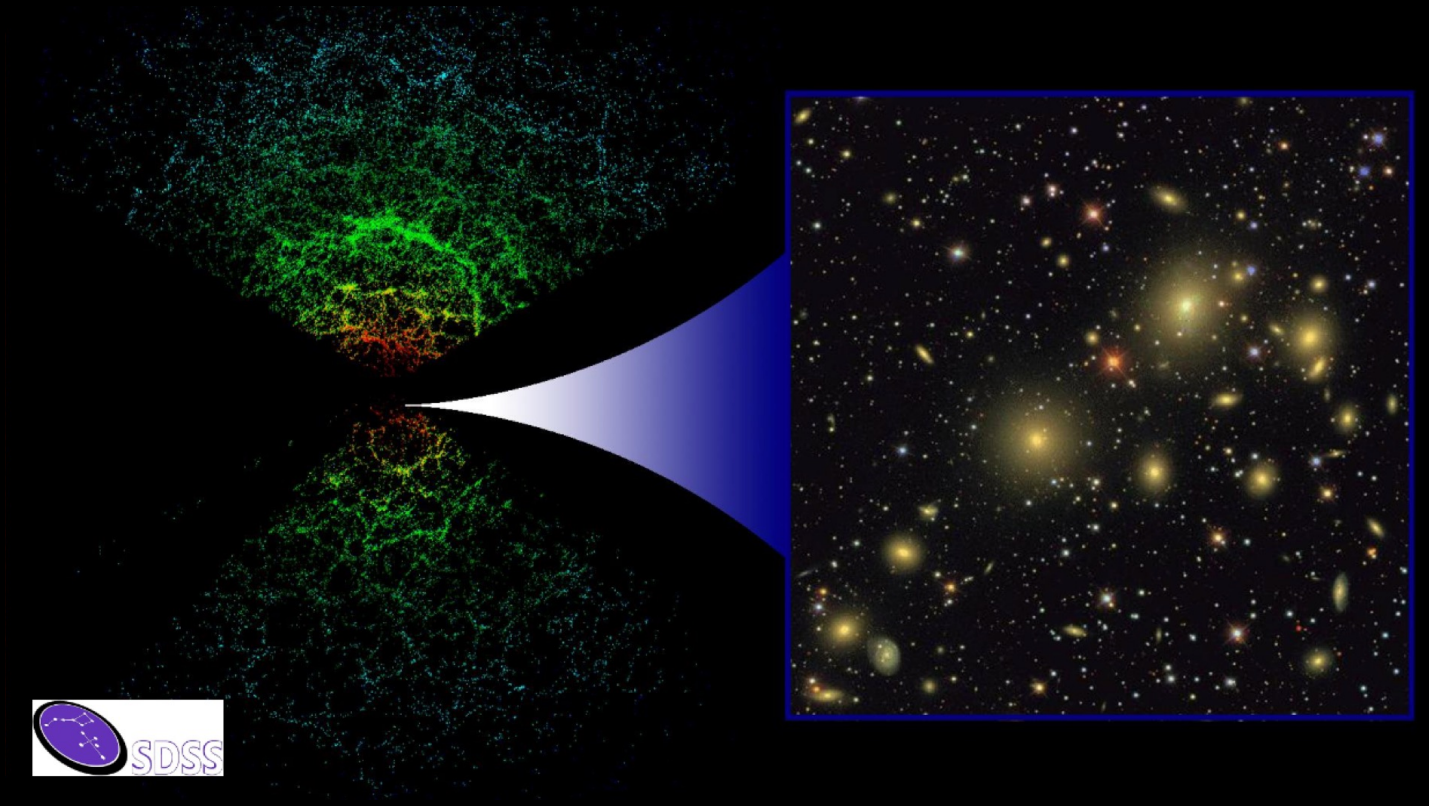
Run DMO simulation & identify halos

Apply halo model to DMO halos

Construct realistic mock galaxy catalogs

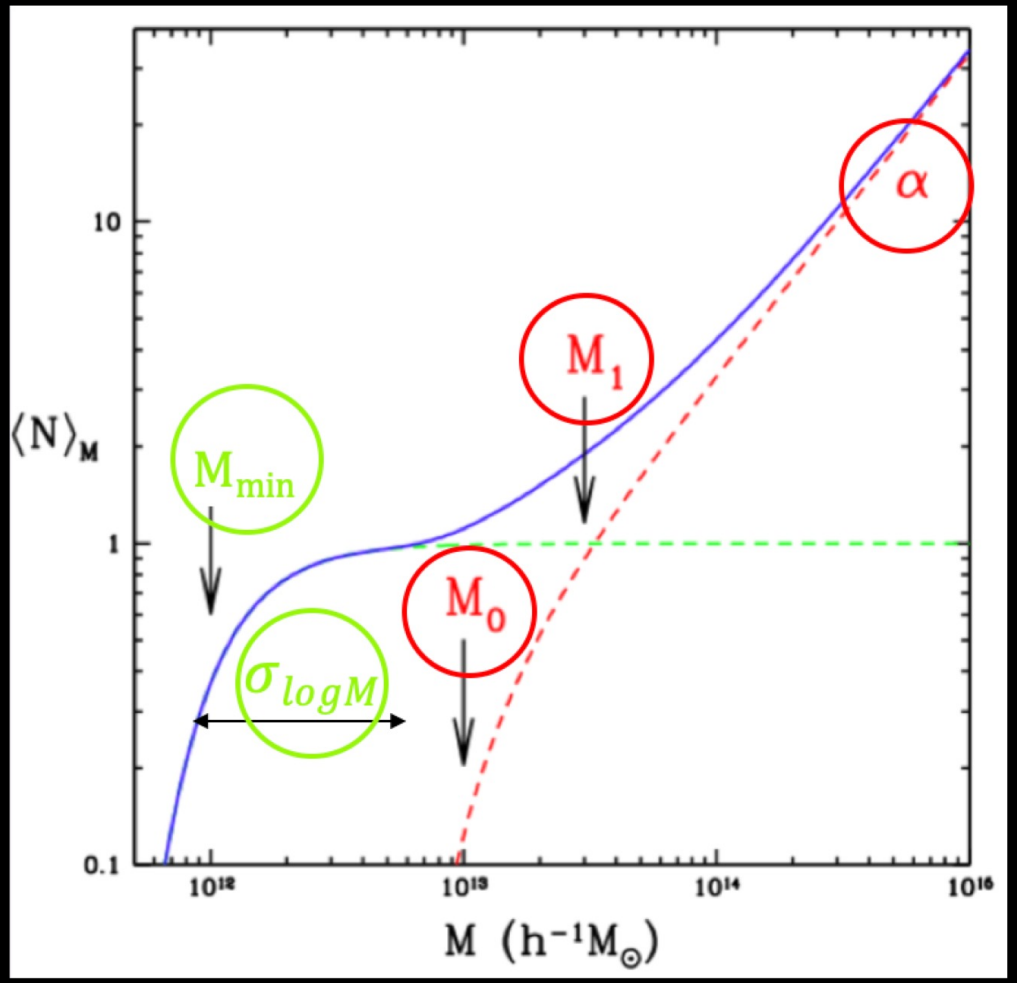
Measure clustering statistics and compare to data

Constrain halo model & cosmological parameters



Standard Halo Occupation Distribution Model

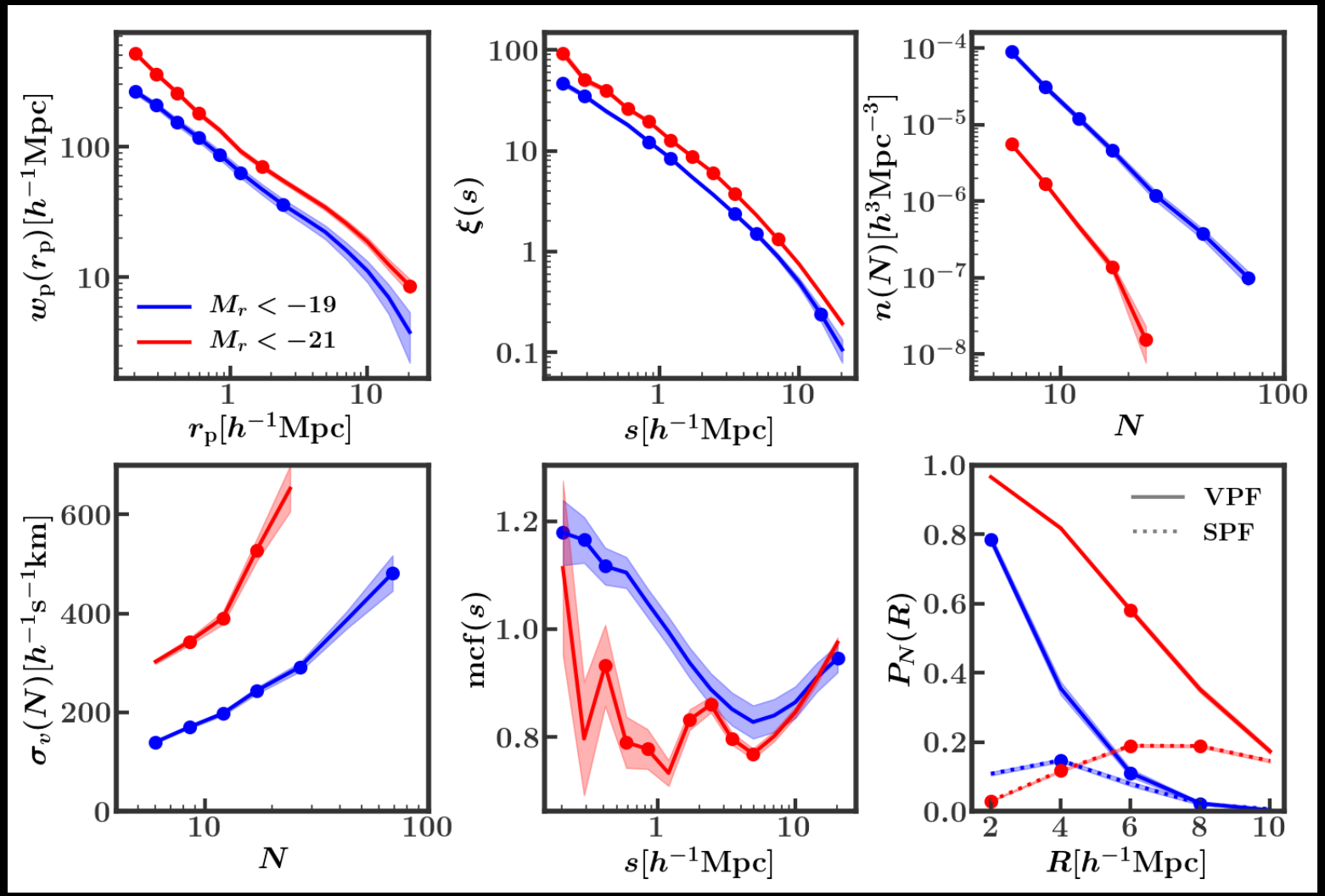
- Assign a number of central and satellite galaxies to a halo of mass M using 5 parameters
  - Central parameters: M_{min} and σ_{logM}
  - Satellite parameters: M_0, M_1, and α
  - Number of galaxies assigned to halo is based only on halo mass (no galaxy assembly bias)
- Central galaxy is placed at the center of the halo and is at rest with respect to the halo
- Satellite galaxies are given the positions and velocities of random dark matter particles within the halo (no spatial or velocity bias)



Berlind & Weinberg (2002), Kravtsov et al. (2004), Zheng et al. (2005), Zheng et al. (2007)

Optimal Clustering Measurements

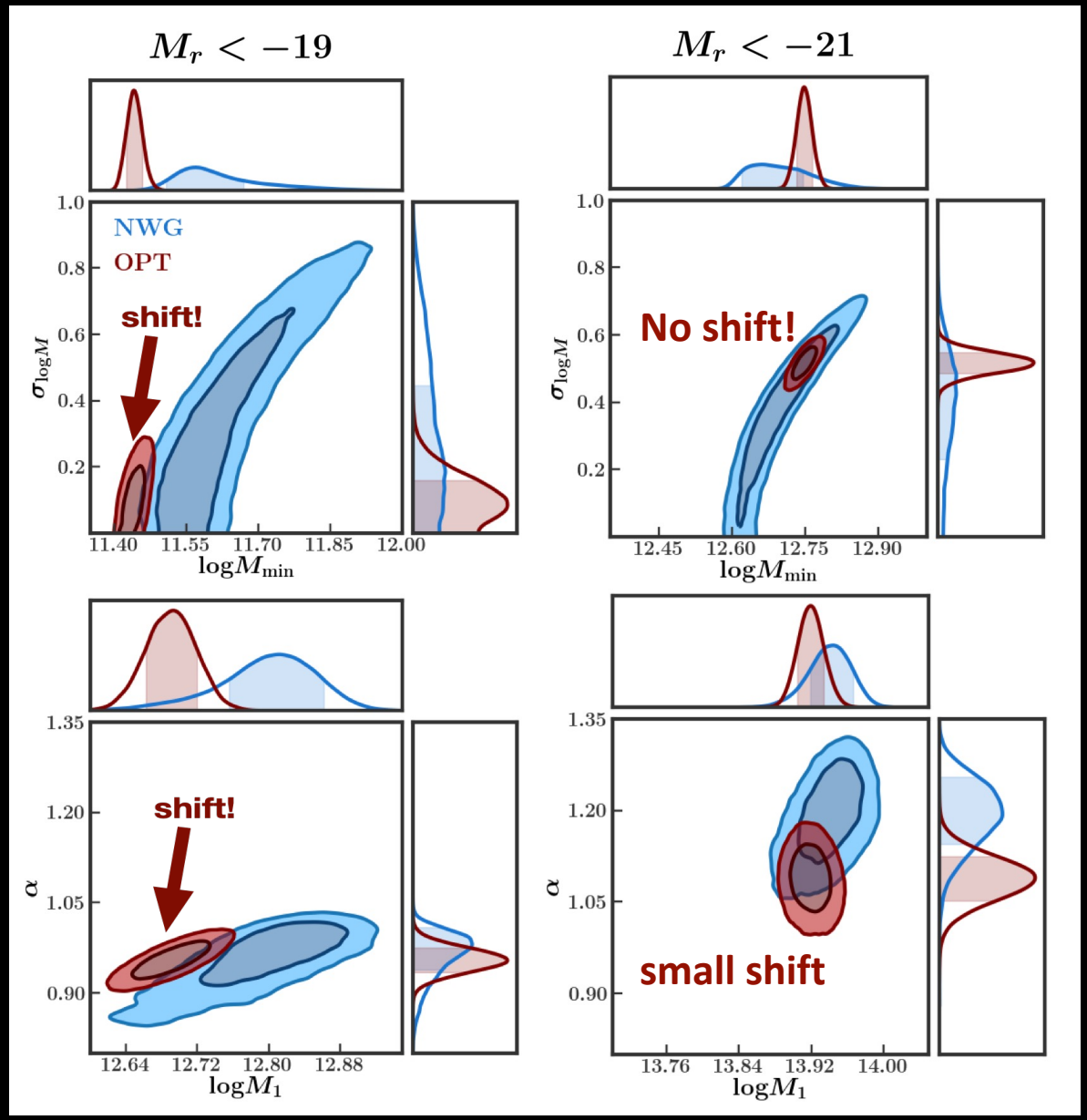
- Sinha et al. (2018)
  - Galaxy number density
  - Projected Correlation Function
  - Group Multiplicity Function
- Szewciw et al. (2022)
  - **Redshift-space Correlation Function**
  - **Average group velocity dispersion function**
  - **Mark Correlation Function**
  - **Counts-in-cells statistics**
- Designed an algorithm to select a combination of different scales of each clustering statistic that yields optimal constraining power



Szewciw et al. (2022)

Constraining the Galaxy-Halo Connection with Optimal Statistics

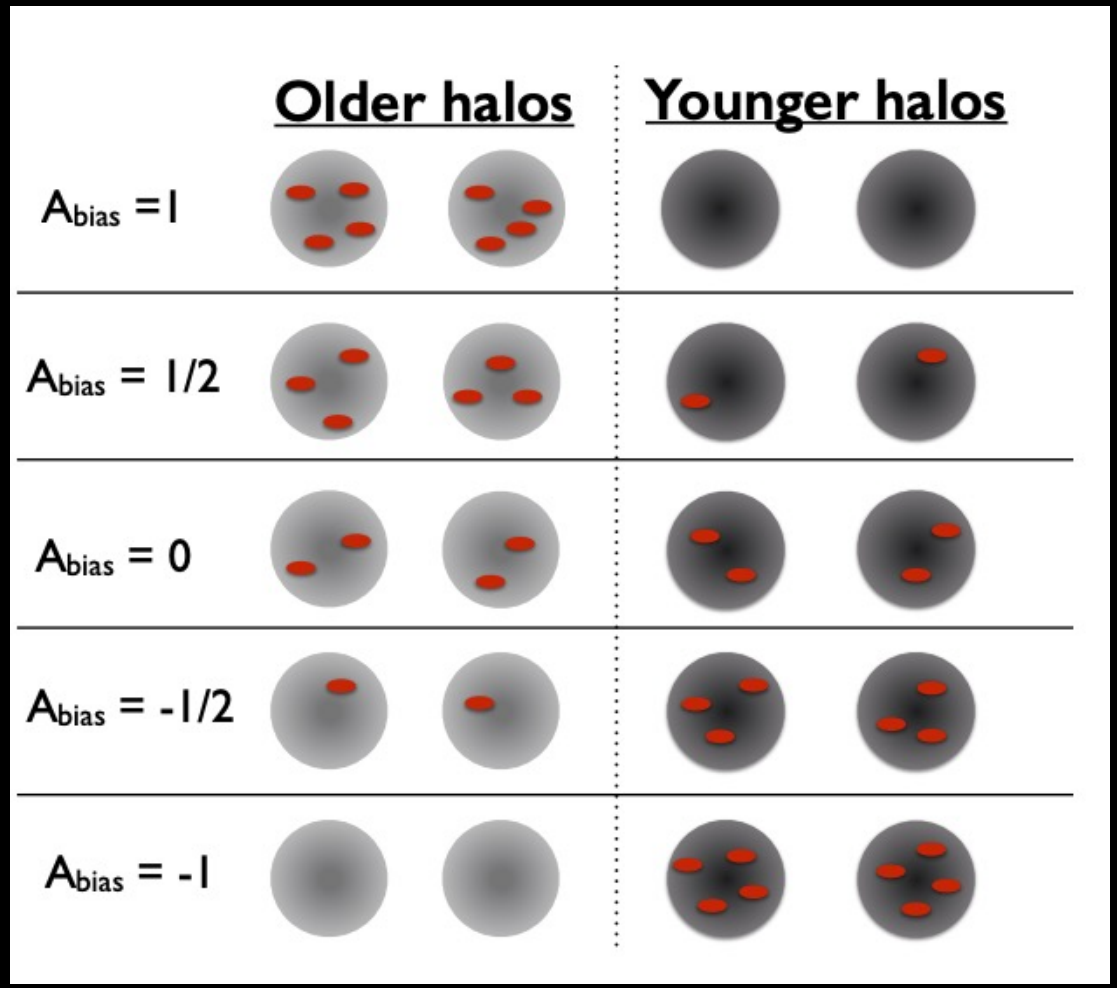
- Major shifts seen in best-fit parameter values compared to previous results
  - Shifts probably due to the inclusion of clustering statistics that are sensitive to non-standard effects (e.g. assembly bias)
  - Comparisons with hydro simulations indicate presence of these effects, particularly among low-luminosity galaxies
- Major increase in constraining power
  - >4σ tension for both samples



Szewciw et al. (2022)

Decorated HOD Model

- Expanded standard HOD model from to include parameters for **central and satellite galaxy assembly bias (A_{cen} & A_{sat})**
- "Decorated HOD" model from Hearin et al. (2016)
- Galaxies are assigned to halos based on both halo mass and a secondary halo property
  - e.g. age, **concentration, environment**
- Identify a new set of optimal clustering measurements to constrain this model

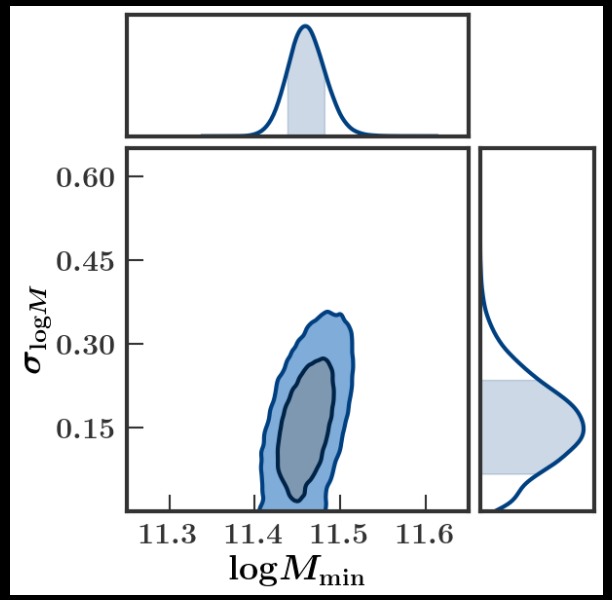


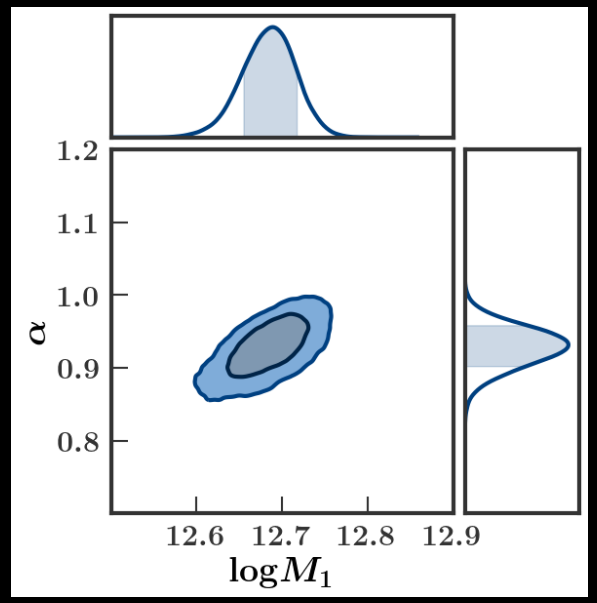
Hearin et al. (2016)

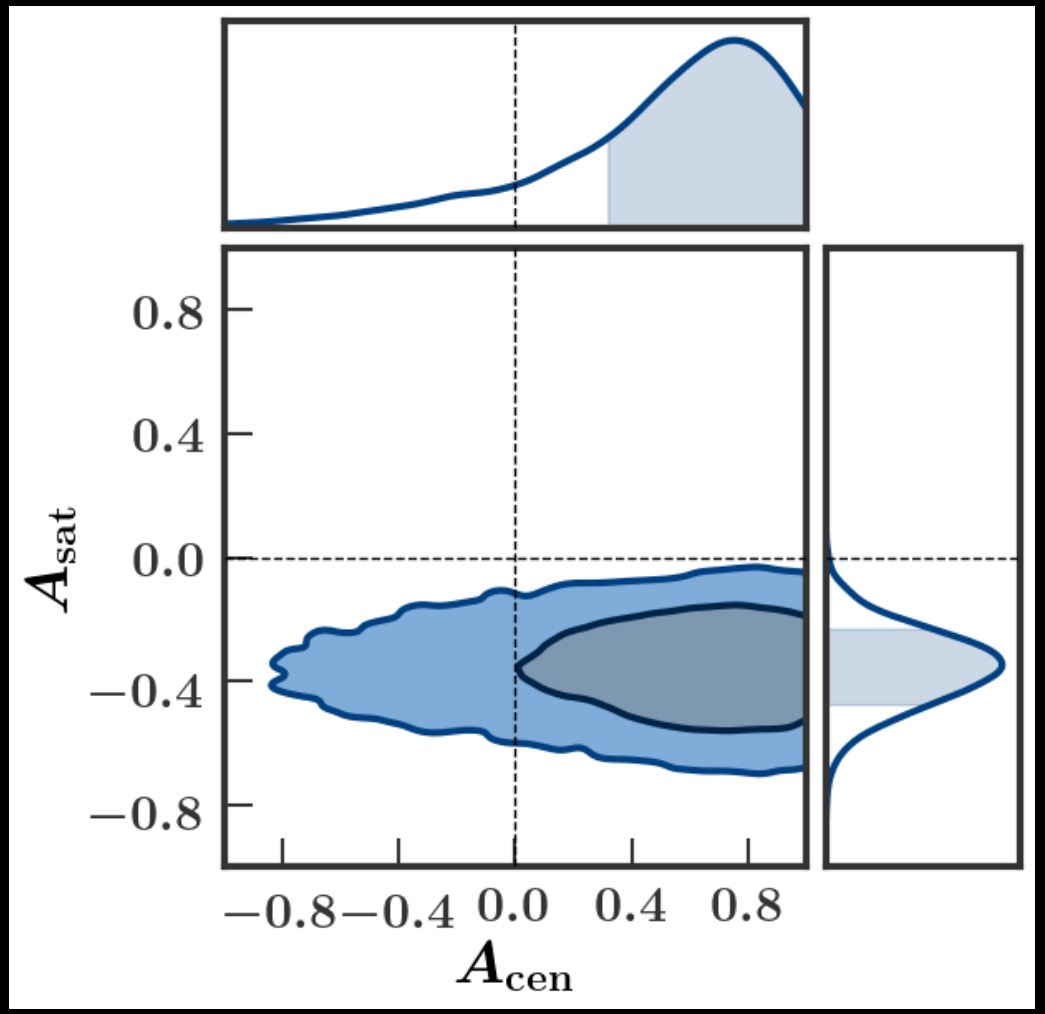
Results: Assembly Bias (Concentration)

-19 sample:

- Can rule out a model with zero assembly bias
- Evidence for negative satellite assembly bias at the 99.8% confidence level
- Improvement in tension with SDSS (4σ to 2σ)





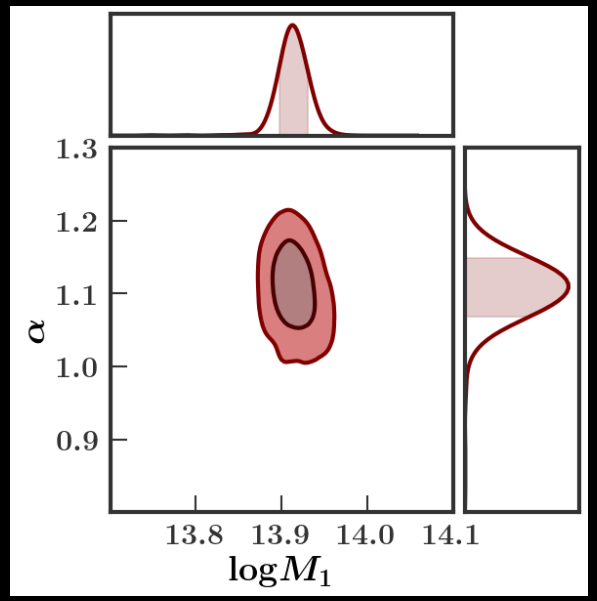


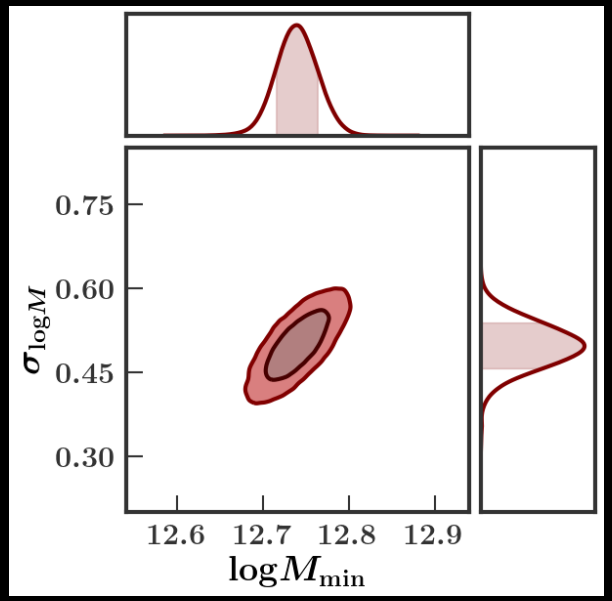
Beltz-Mohrmann et al. (2022)

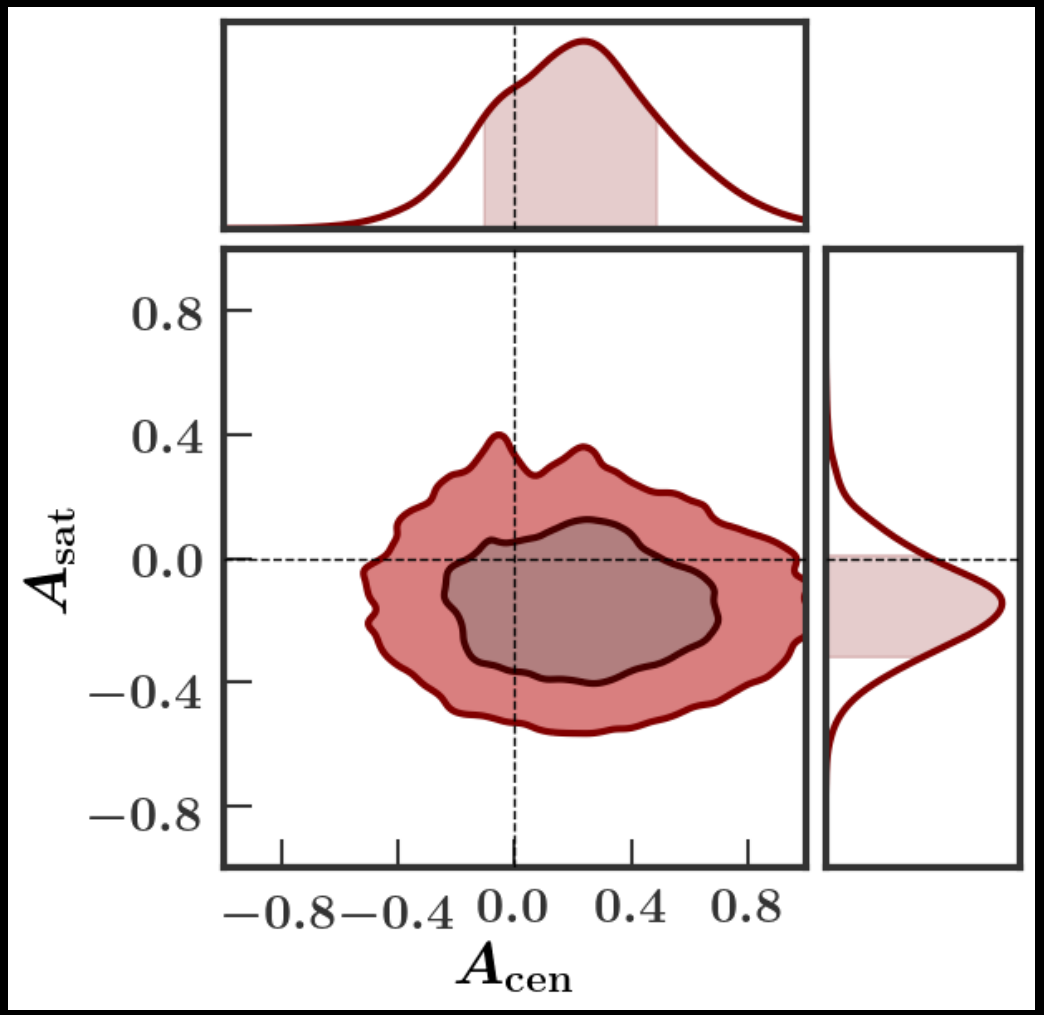
Results: Assembly Bias (Concentration)

-21 sample:

- No detection of central or satellite assembly bias
- No improvement in tension with SDSS (4.5σ)



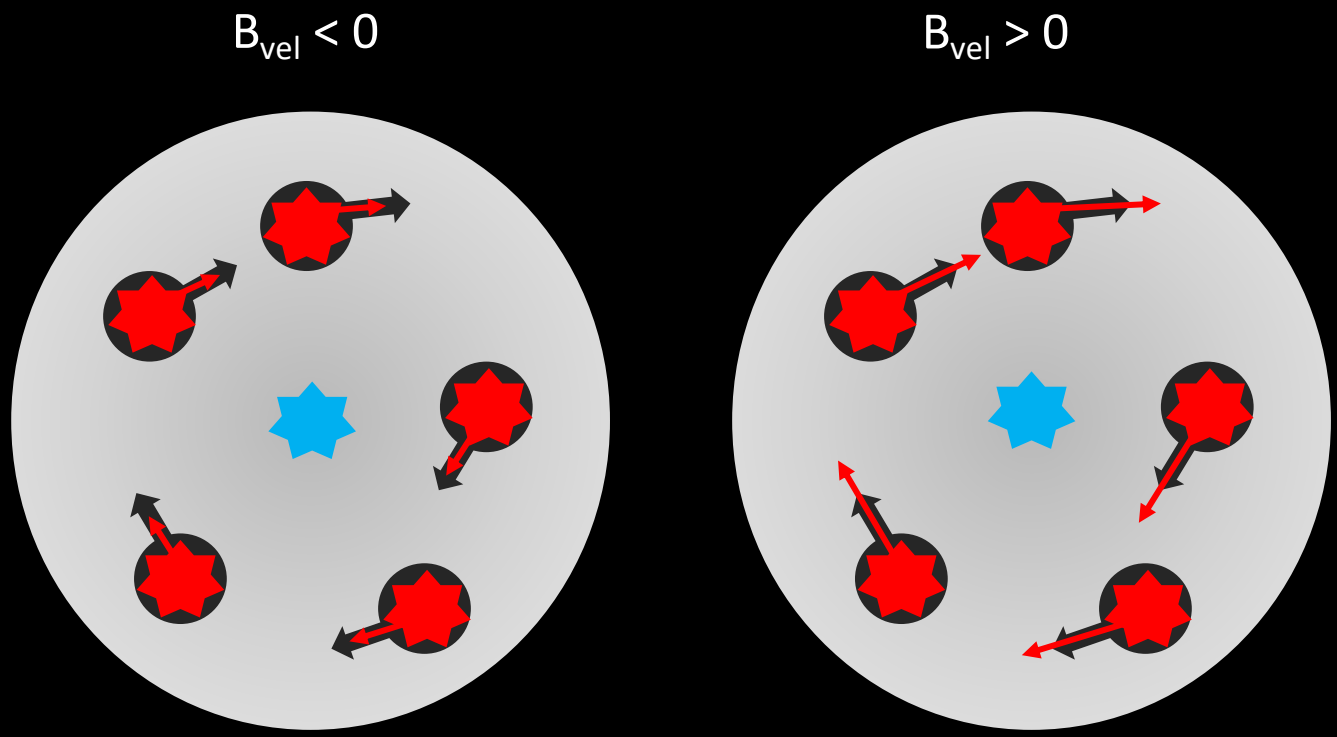




Beltz-Mohrmann et al. (2022)

Satellite Galaxy Velocity Bias

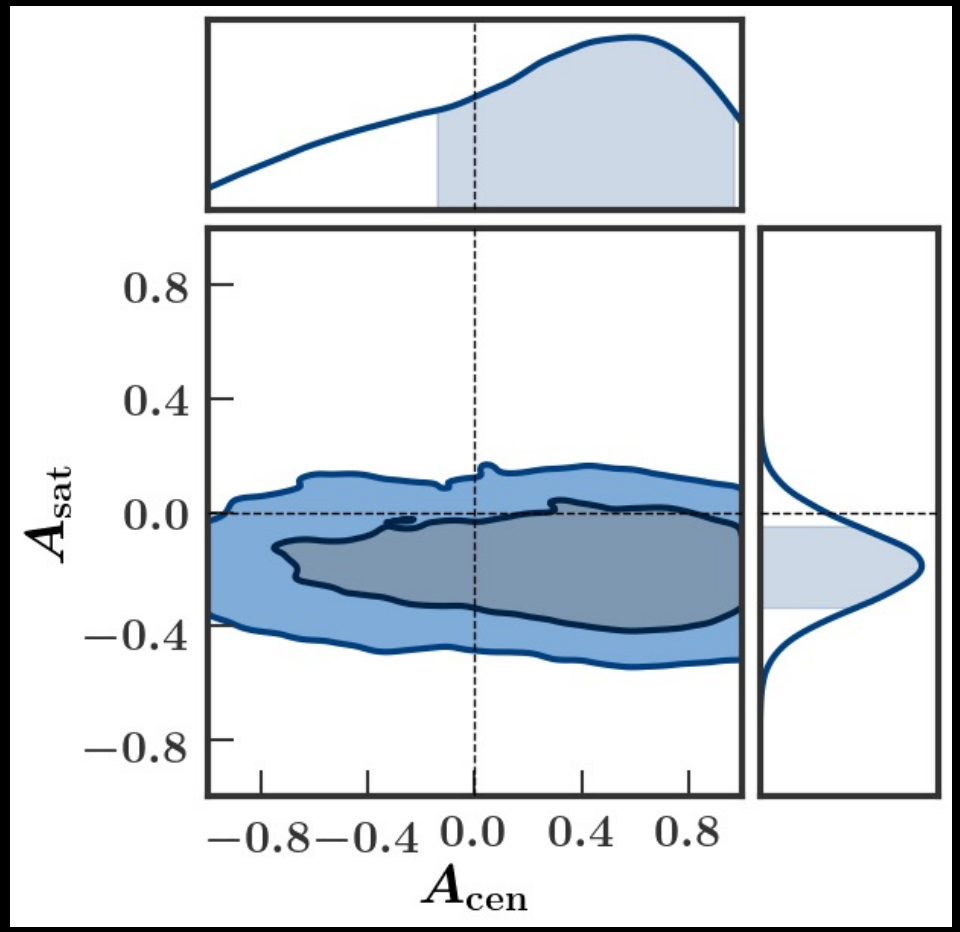
- Added parameter for **satellite galaxy velocity bias**, B_{vel}
- Indicates how much faster or slower galaxies move relative to dark matter
- Central galaxy still at rest with respect to halo (no central velocity bias)
- No spatial bias
- Did not identify new optimal clustering statistics

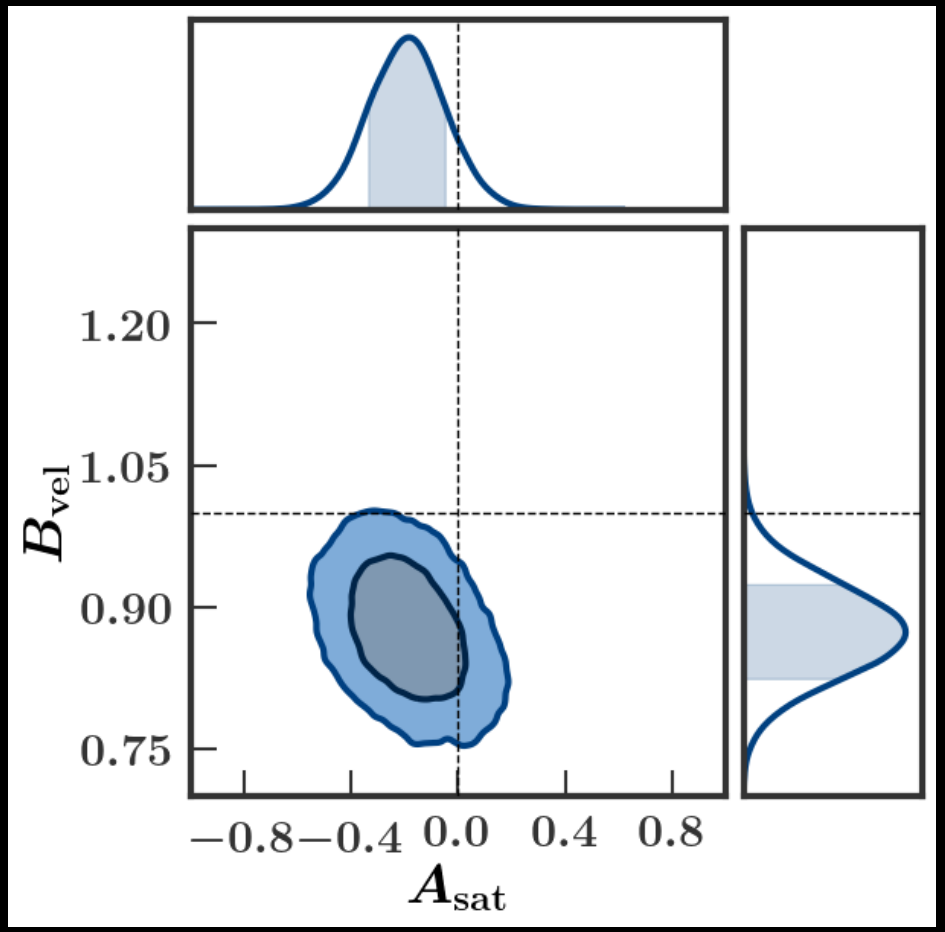


Results: Assembly Bias (Concentration) + Velocity Bias

-19 sample:

- Weaker constraints on A_{cen} & A_{sat}
- Detect moderate satellite velocity bias at the 99.8% confidence level
- Further improvement in tension with SDSS (< 2σ)



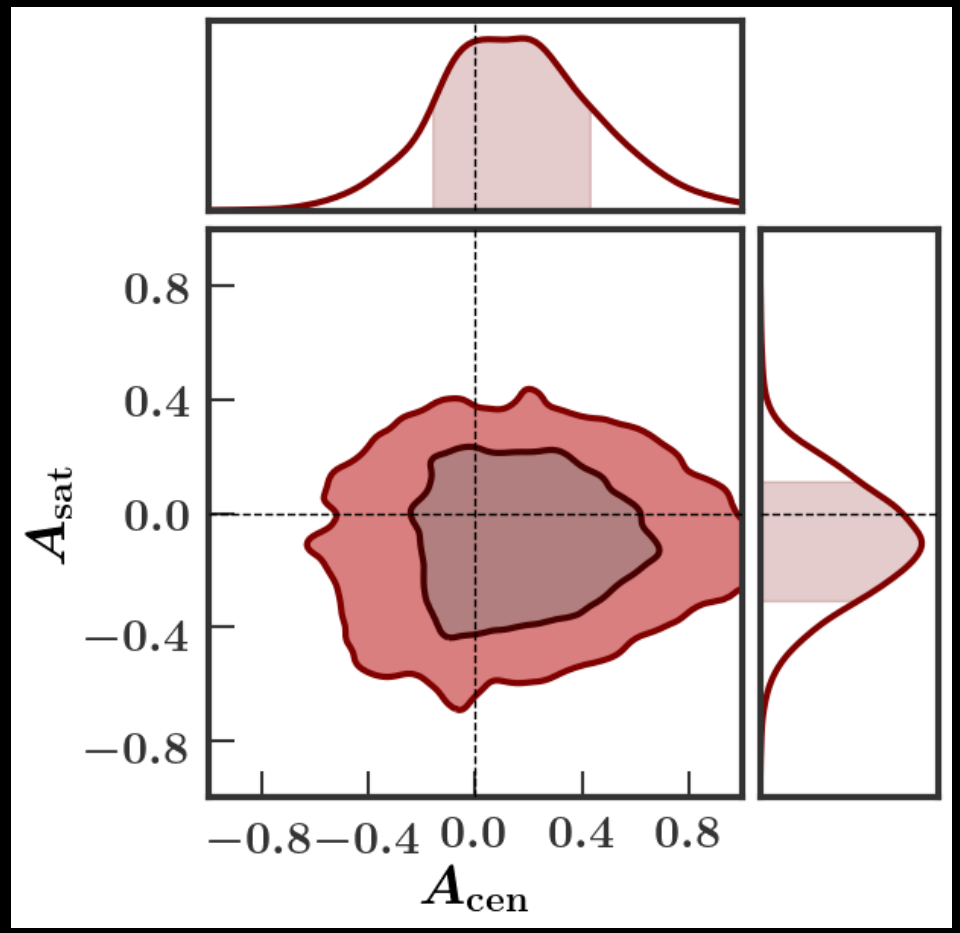


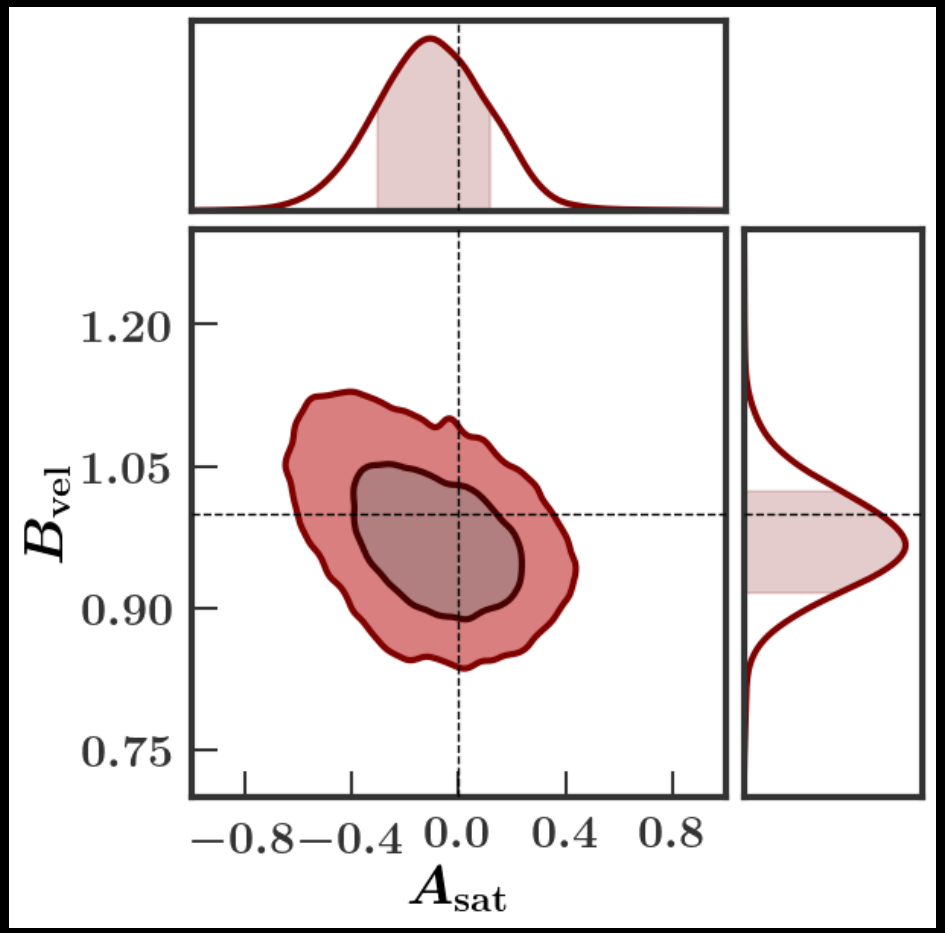
Beltz-Mohrmann et al. (2022)

Results: Assembly Bias (Concentration) + Velocity Bias

-21 sample:

- No detection of assembly bias or velocity bias
- No relief of tension with SDSS (still 4.5σ)

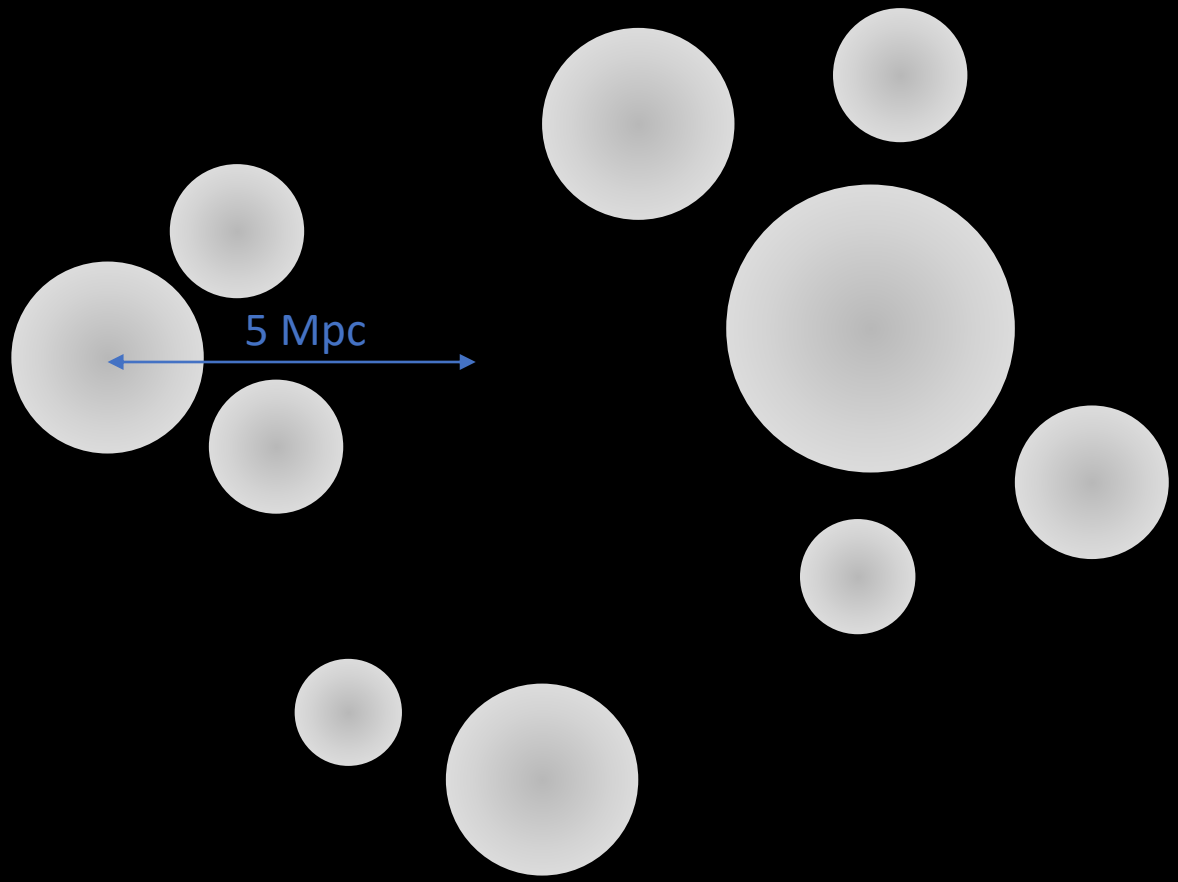




Beltz-Mohrmann et al. (2022)

Assembly Bias – Local Halo Environment

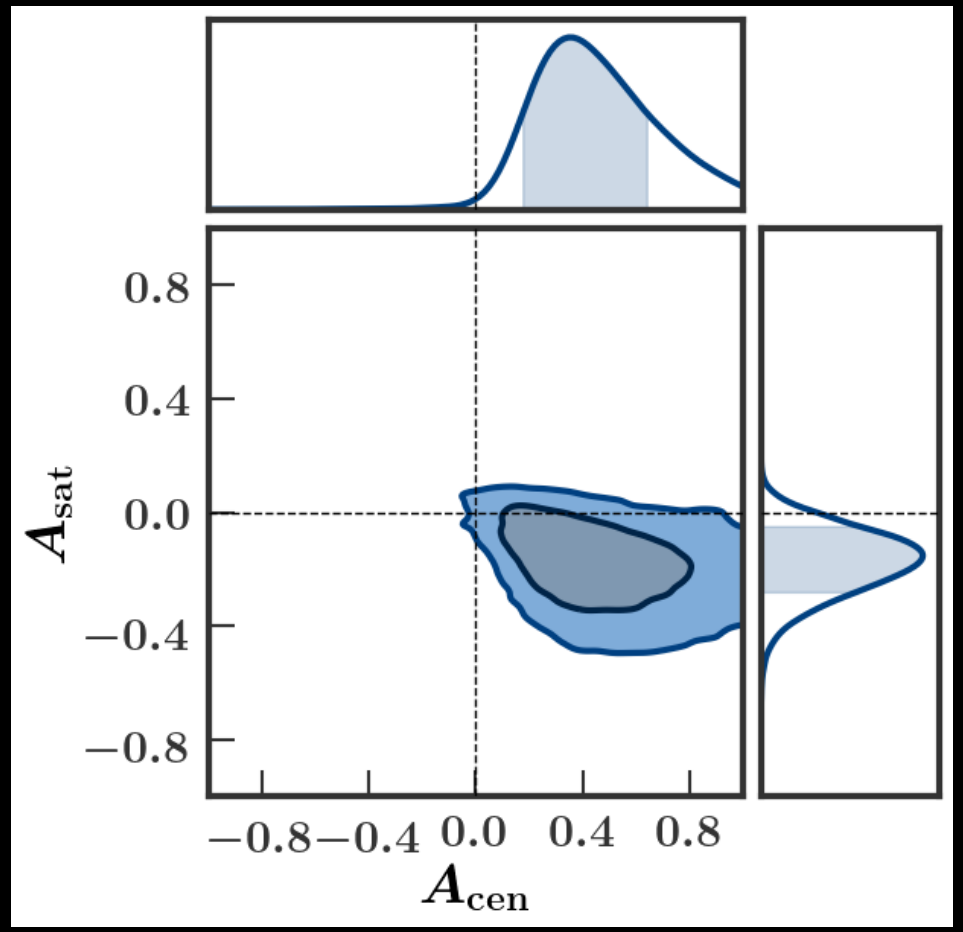
- New assembly bias property: **local halo environment**
- Note: we are not claiming that environment is the *cause* of assembly bias, but rather that the *true* assembly bias property correlates strongly with environment
- Mass (in halos) in 5 Mpc/h region around halo
- Did not identify new optimal clustering statistics

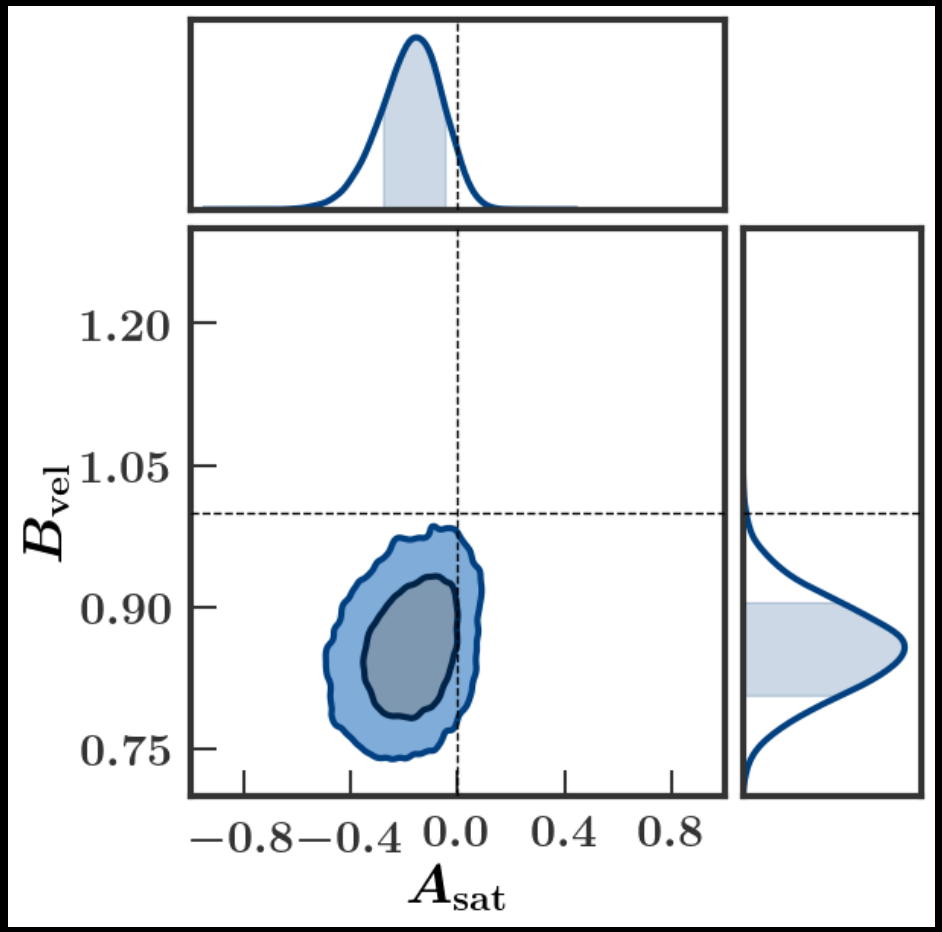


Results: Assembly Bias (Environment) + Velocity Bias

-19 sample:

- Tight constraints on A_{cen}, A_{sat}, & B_{vel}
- Detect central and satellite assembly bias at the 99% and 95% confidence levels
- Detect satellite velocity bias at the 99.9% confidence level
- No remaining tension with SDSS





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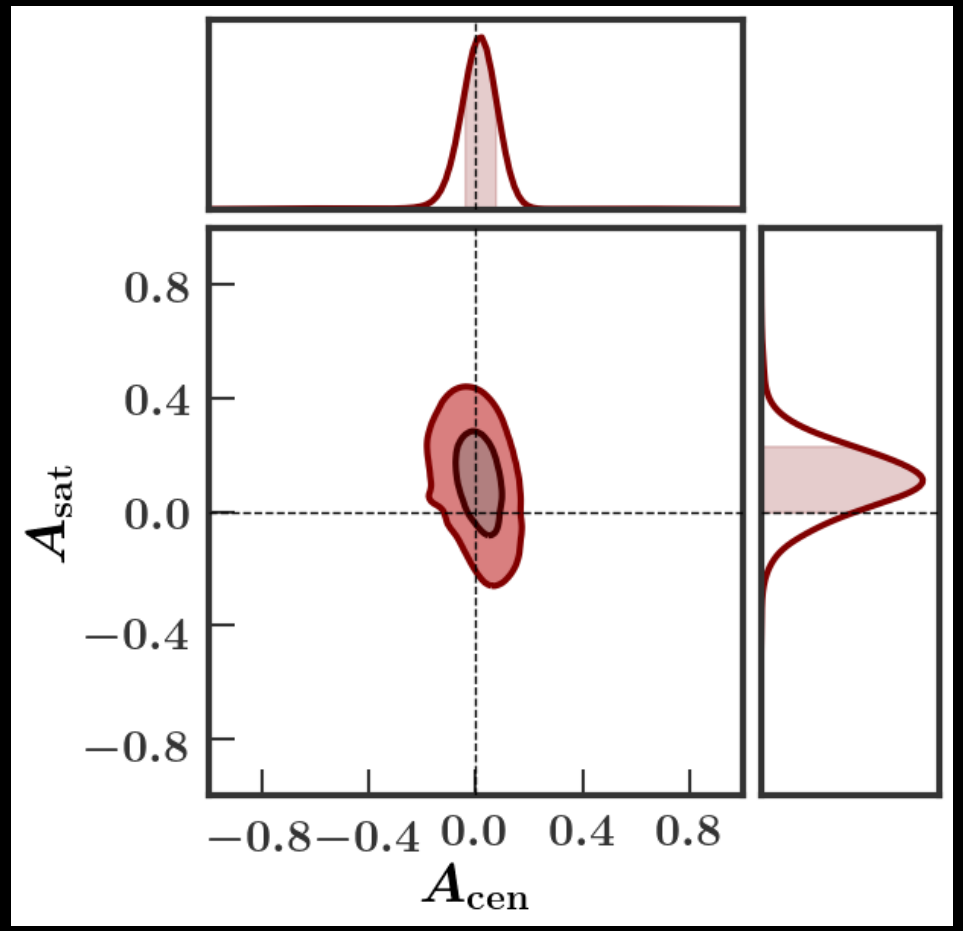

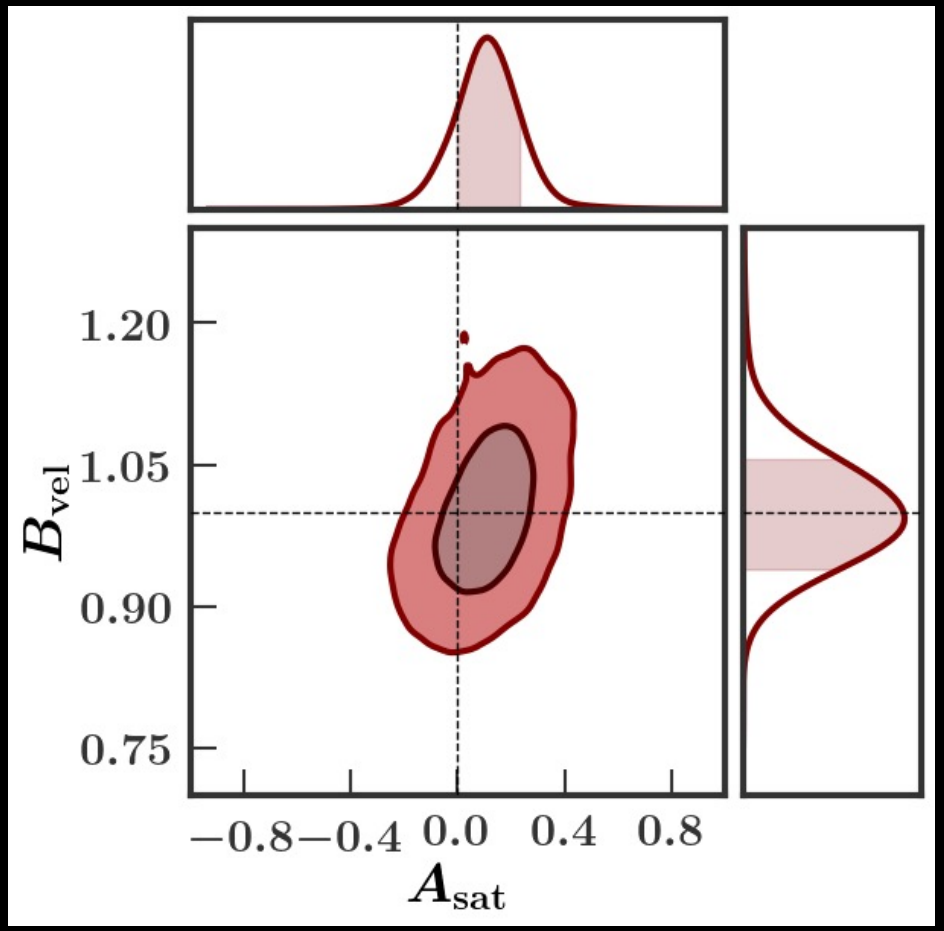

Beltz-Mohrmann et al. (2022)

Conclusions

- Low-luminosity galaxies in SDSS exhibit central and satellite galaxy assembly bias, as well as satellite velocity bias
  - Best fitting model uses environment-based assembly bias
  - Satellite galaxies preferentially reside in less dense environments (95%)
  - Central galaxies preferentially reside in denser environments (99%)
  - Satellite galaxies move 10-15% slower than the dark matter (99.9%)
  - Essentially no remaining tension with SDSS
- High-luminosity galaxies exhibit negligible assembly bias when using either concentration or local environment as the assembly bias property
  - They also exhibit negligible satellite velocity bias
  - None of these models yield good agreement with SDSS (4.5σ tension)
- These results are consistent with comparisons to hydrodynamic simulations (e.g., Beltz-Mohrmann et. al 2020)
- Tension in -21 sample is potentially indicative of an issue with our cosmological model
  - This would be consistent with several recent works that have found tension between their best-fit cosmological parameters and Planck (e.g. Zhai et al. 2022, Lange et al. 2022)