Simulating intrinsic alignments without hydrodynamics

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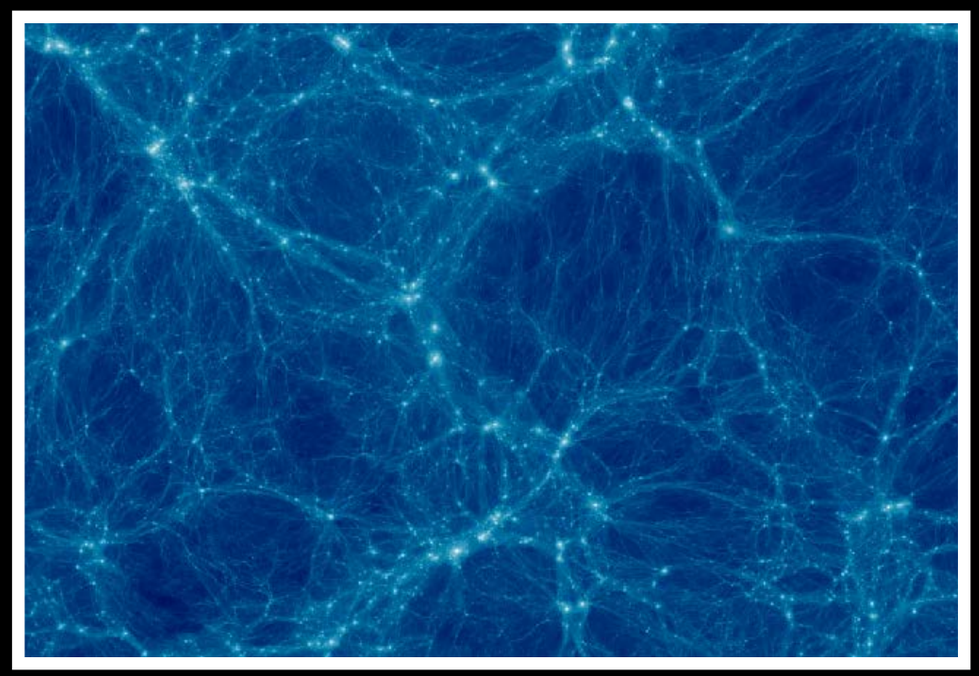
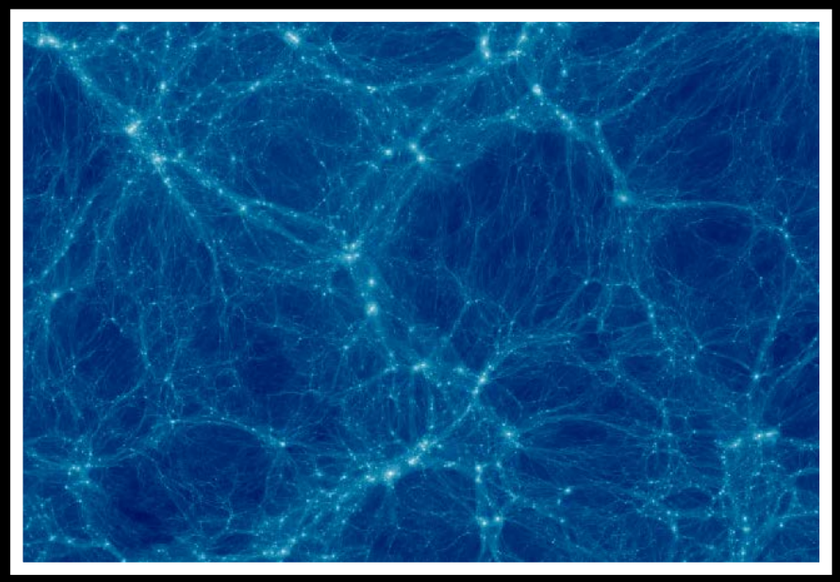
YITP: Intrinsic alignments
December 2022

Modeling galaxy observables



Modeling galaxy observables



nonlinear galaxy biasing

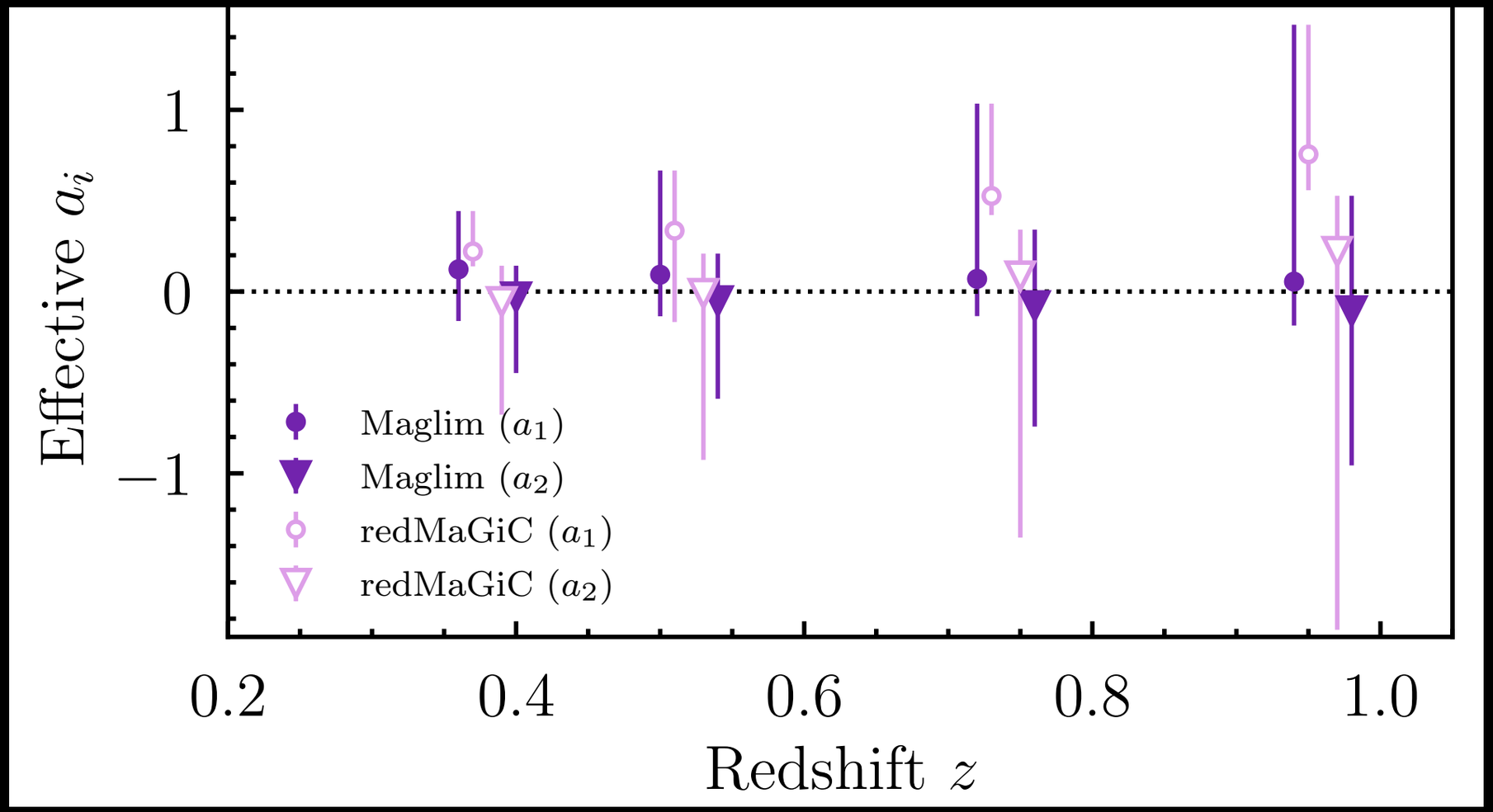
$$\delta_g = b_1\delta_m + b_2\delta_m^2 + b_s s^2 + b_{\rm 3NL}\psi + \cdots$$

$$\gamma_{ij}^I = C_1 s_{ij} + C_2(s_{ik}s_{kj}) + C_\delta(\delta s_{ij}) + C_t t_{ij} + \cdots$$

TATT or EFT model for intrinsic alignments

e.g. McDonald & Roy 2009; Baldauf+2012; JB+ 2015; 2019;
Schmitz, Hirata, JB+ 2019; Vlah+ 2020

IA parameters



(DES Collaboration 2022)

DES Y3 Amplitude consistent with Y1 results, but notably lower.

How do we proceed?

- Observations on real data (direct and inferred)
- Analytic studies
- Hydrodynamic simulations

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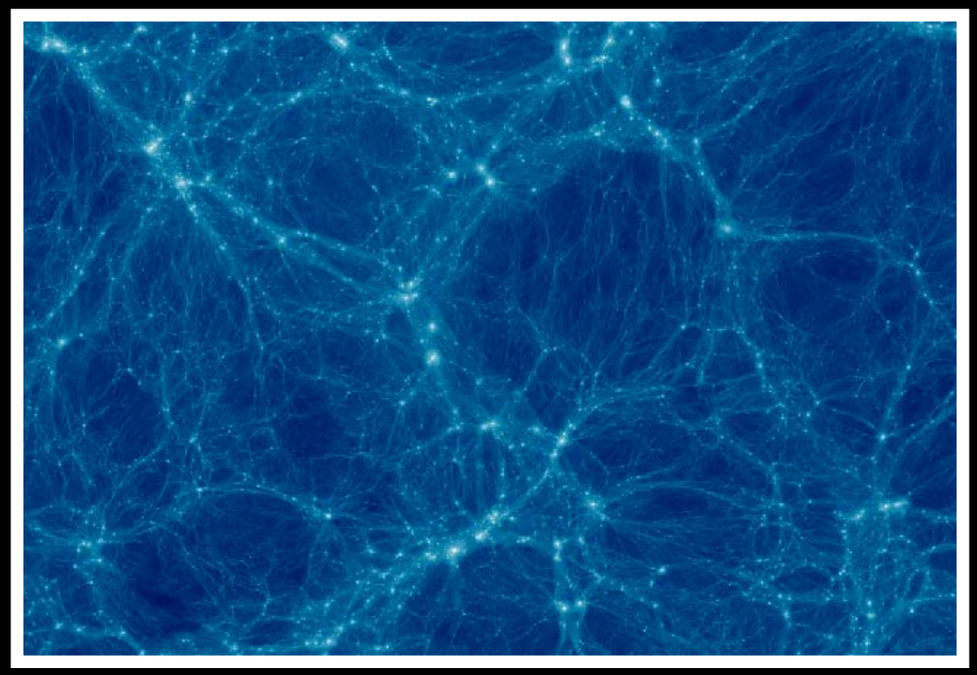
- **Gravity-only simulations with an additional IA "model"**

Simulating IA with gravity-only information

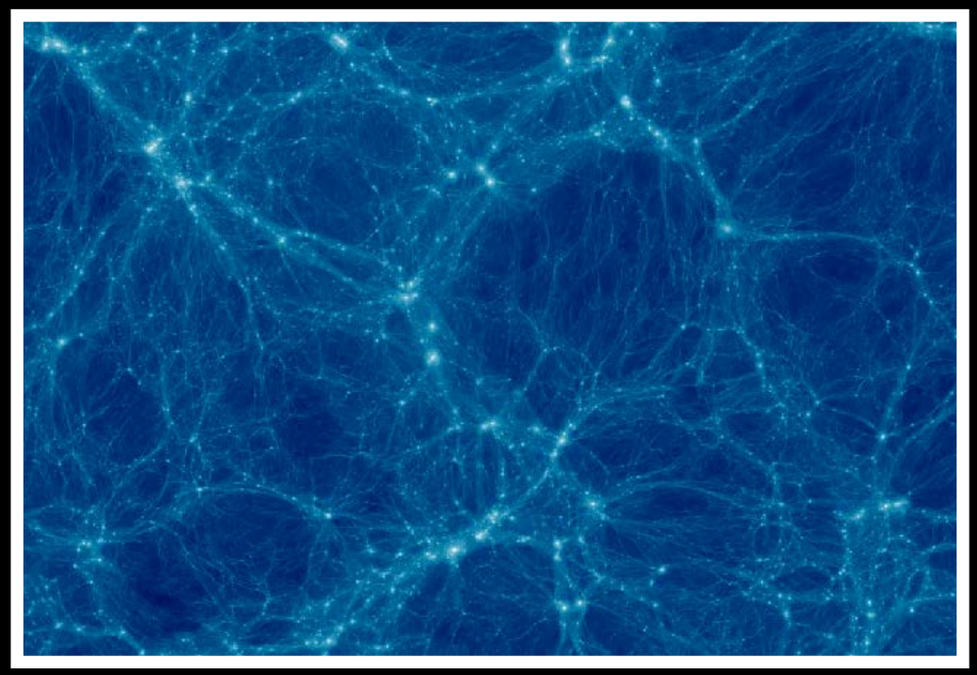


- **Semi-analytic modeling with halo information (e.g. Joachimi+ 2013)**
- IA infusion based on simulated tidal fields and an analytic model (e.g. Harnois-Déraps+ 2022, Singh+ in prep)
- AI/ML model trained on hydro sims (e.g. Jagvaral+ 2022)

Why use gravity-only sims with added IA modeling?

- **Complementary approach!**
- Hydro sims are computationally expensive; IA behavior can depend on sub-grid assumptions
- Nonlinear model with physically-motivated parameters
- Can rapidly produce large volumes: realistic mock catalogs, modeling, covariances
- Compare to observations, hydro sims, and analytic modeling

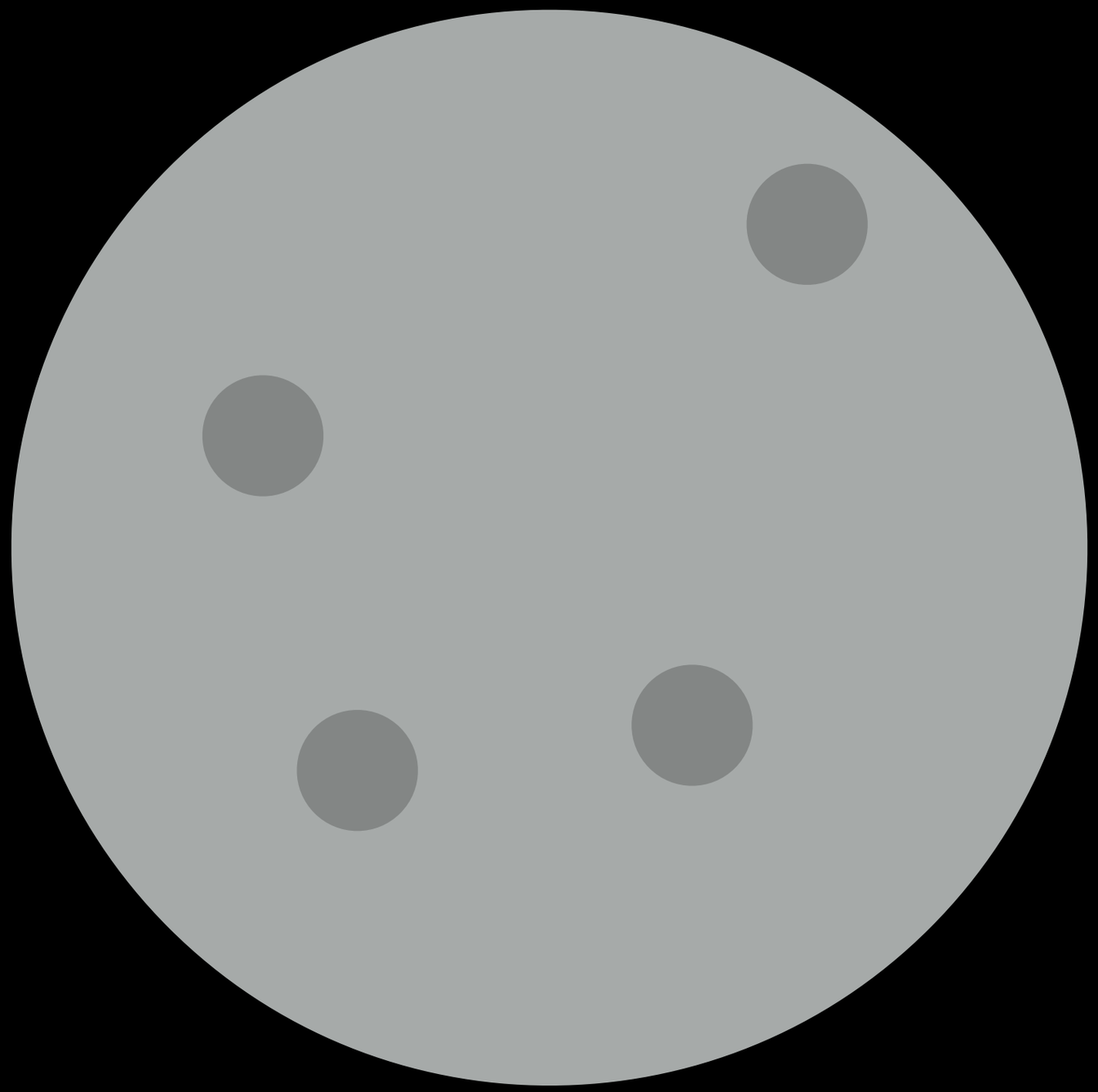
Simulating IA with gravity-only information



Method 1 (genIAL):
Kai Hoffman developer
K. Hoffman, M. Crocce, JB+ 2022
- Realistic galaxy properties
- Based on MICE and Euclid Flagship
- Relatively slow: designed for highly realistic mocks

Method 2 (Halotools-IA):
N. Van Alfen, JB, D. Campbell, F. Lanusse, D. Leonard, A. Hearin+
- Fewer galaxy properties (right now)
- Modular, flexible. Applying to DESC SkySim5000
- Fast: can make mocks or models

Halo Occupation Distribution (HOD) and Subhalo Abundance Matching (SHAM)



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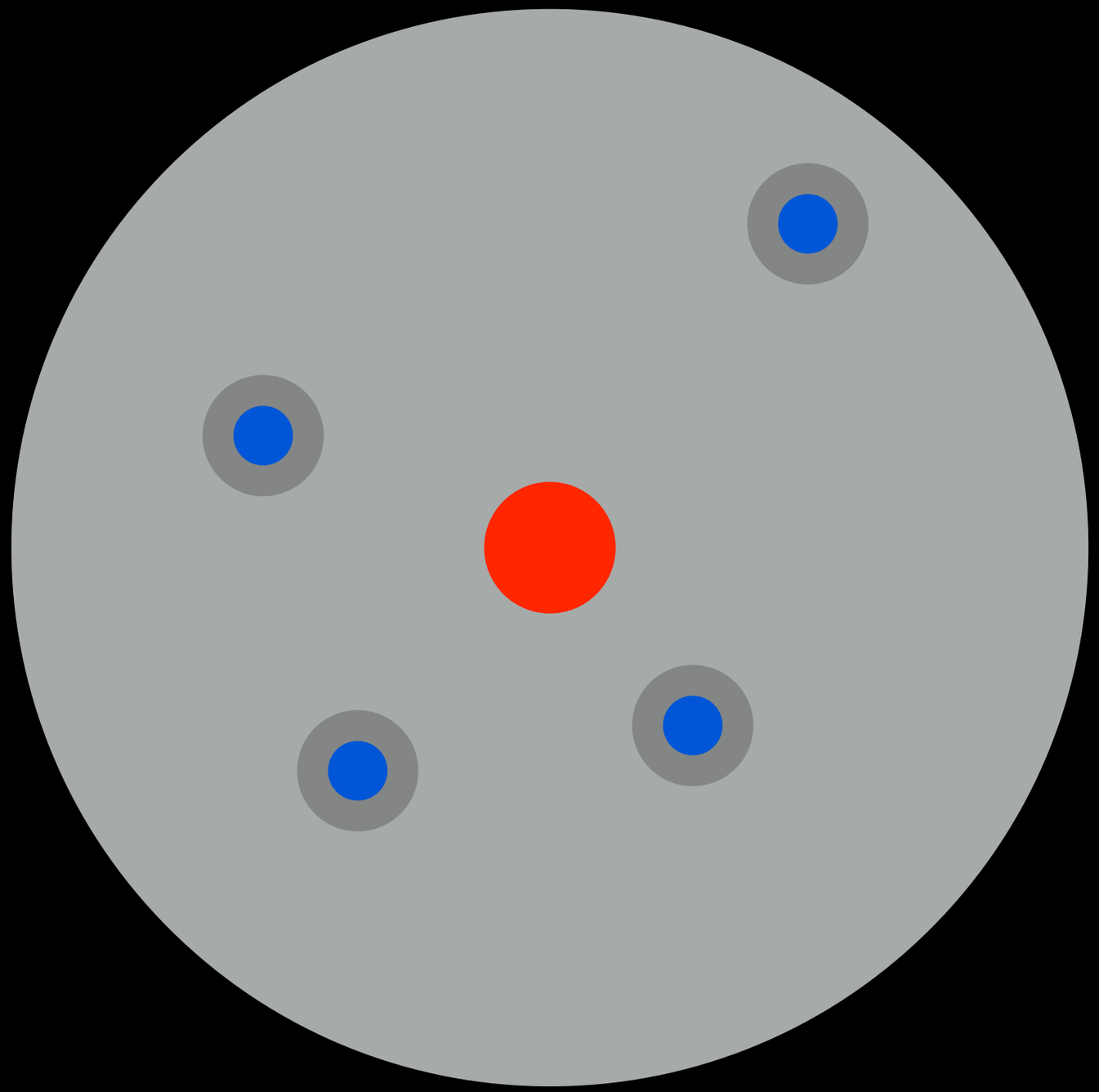

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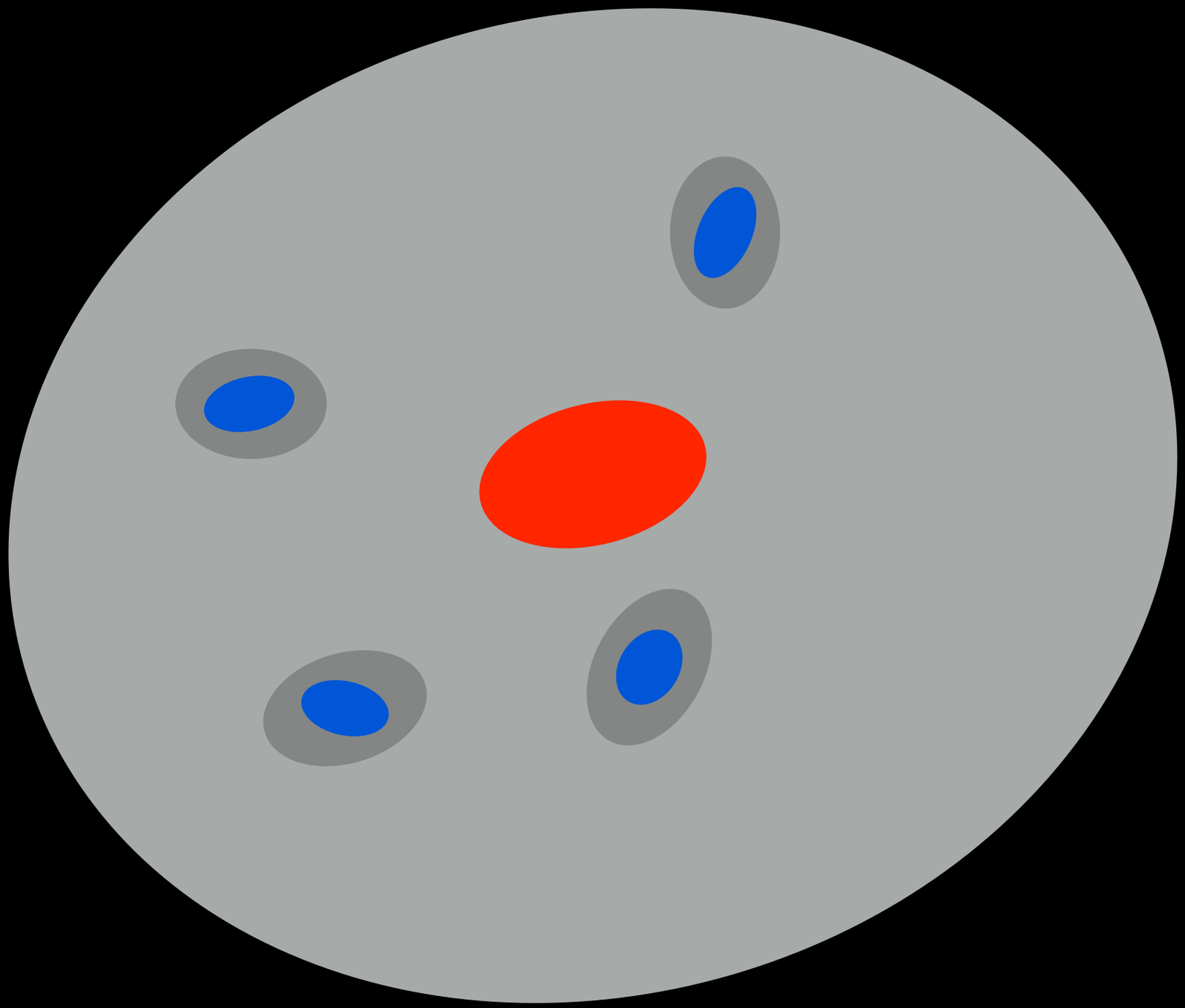
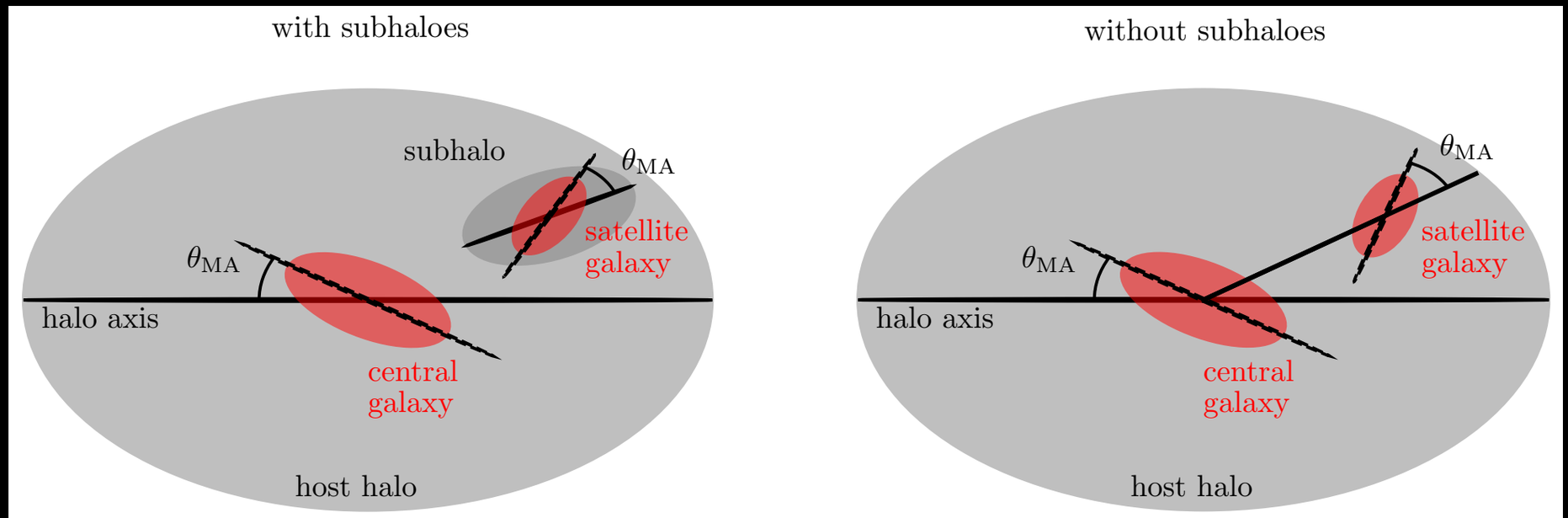
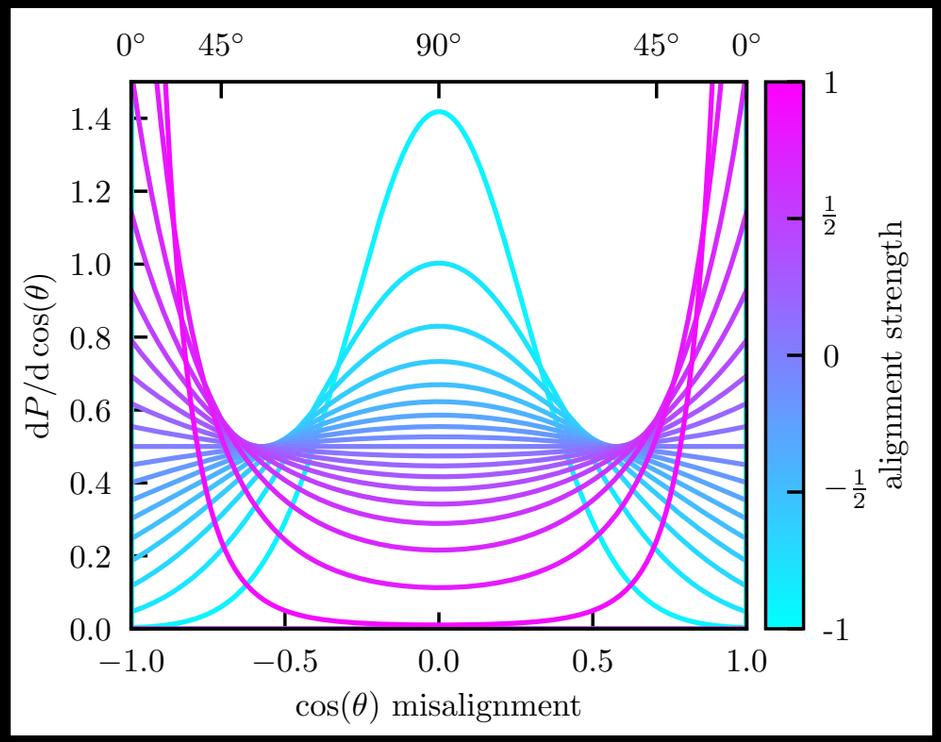


Halotools-IA



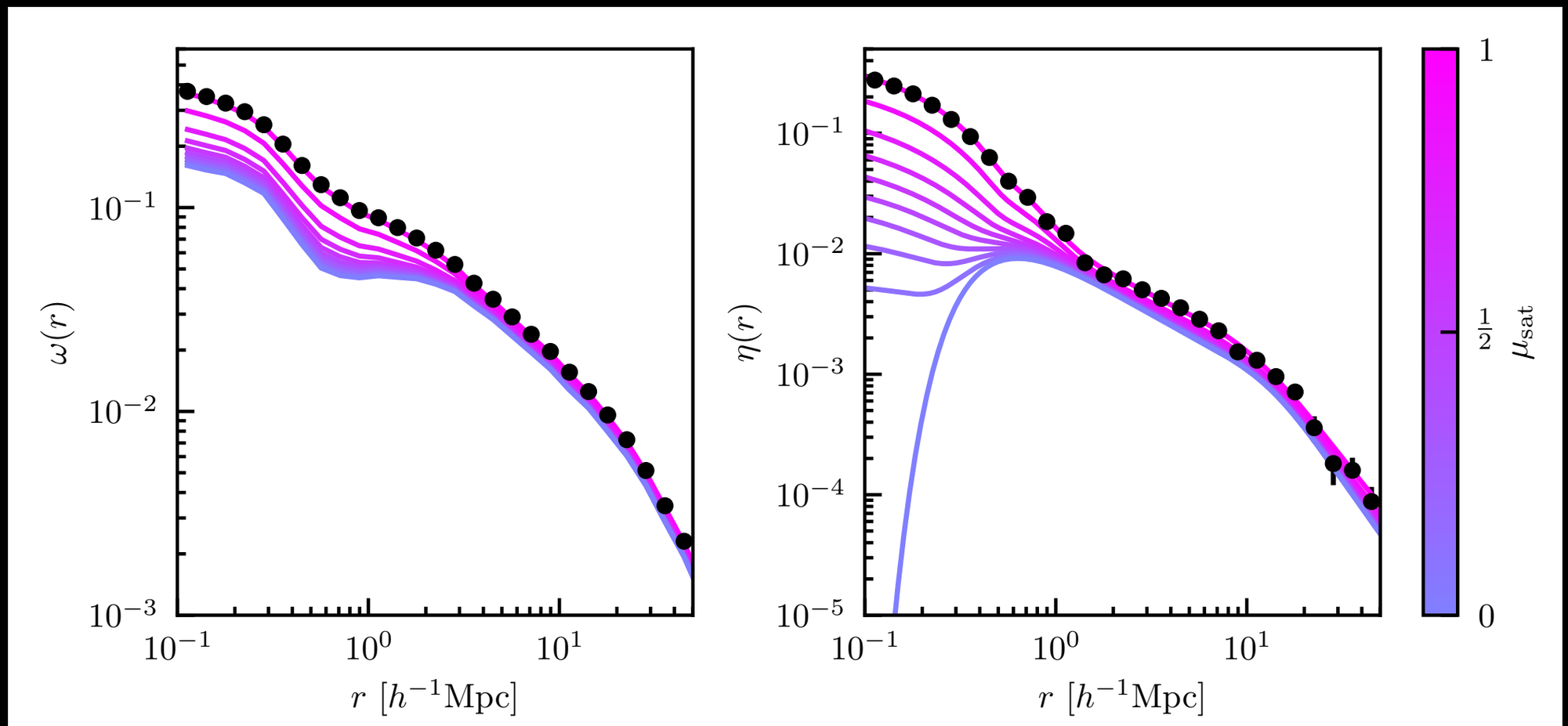
Nick Van Alfen

- Start with any dark matter halo catalog (with or without subhalos)
- Apply HOD/SHAM
- Choose galaxy shape and alignment based on halo and/or galaxy properties
- Calculate desired statistics



Van Alfen, **Campbell**, JB, Lanusse, Leonard, Hearin+ in prep

Halotools-IA



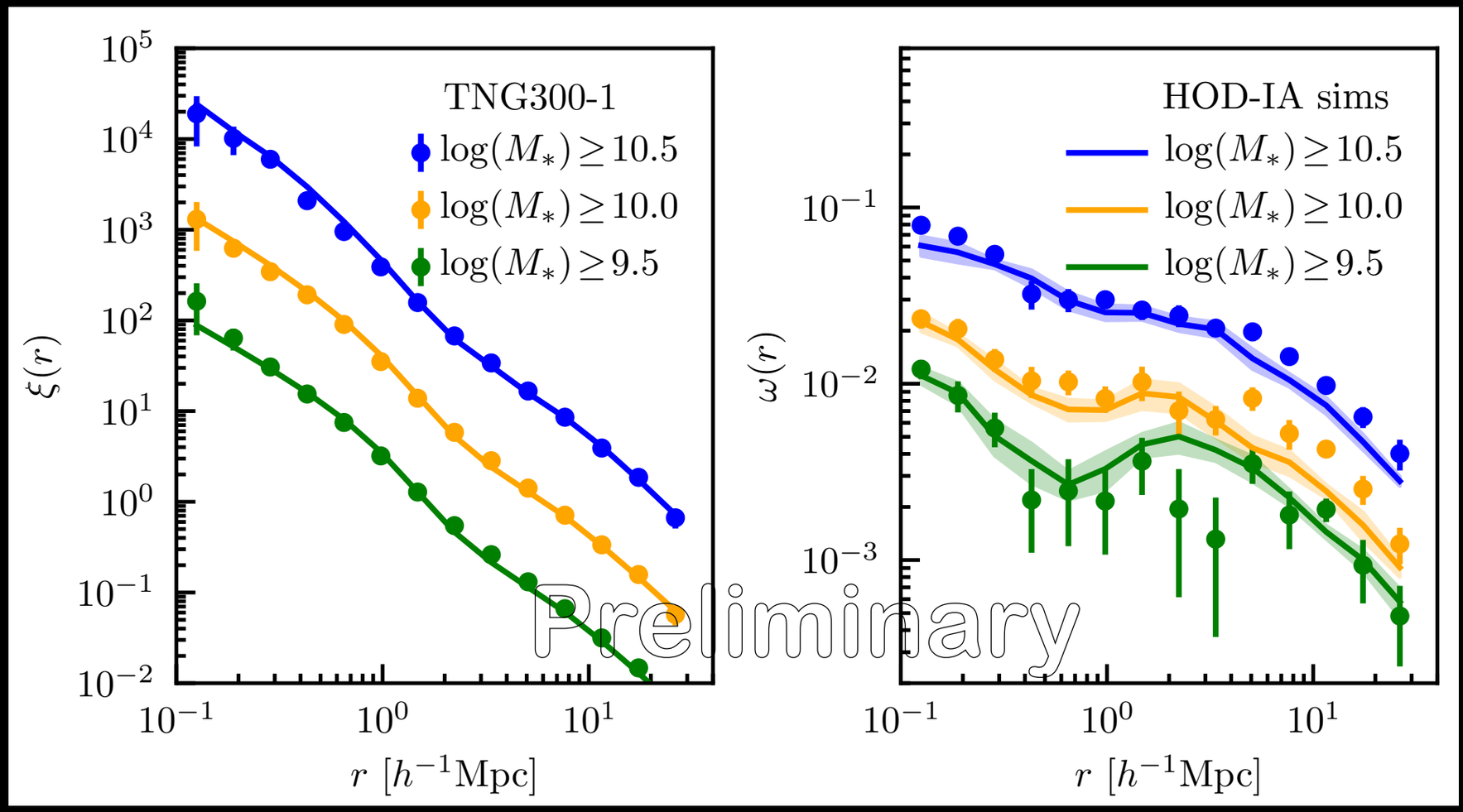
Example: changing satellite alignment strength impacts position-orientation and orientation-orientation correlation functions.

Halotools-IA

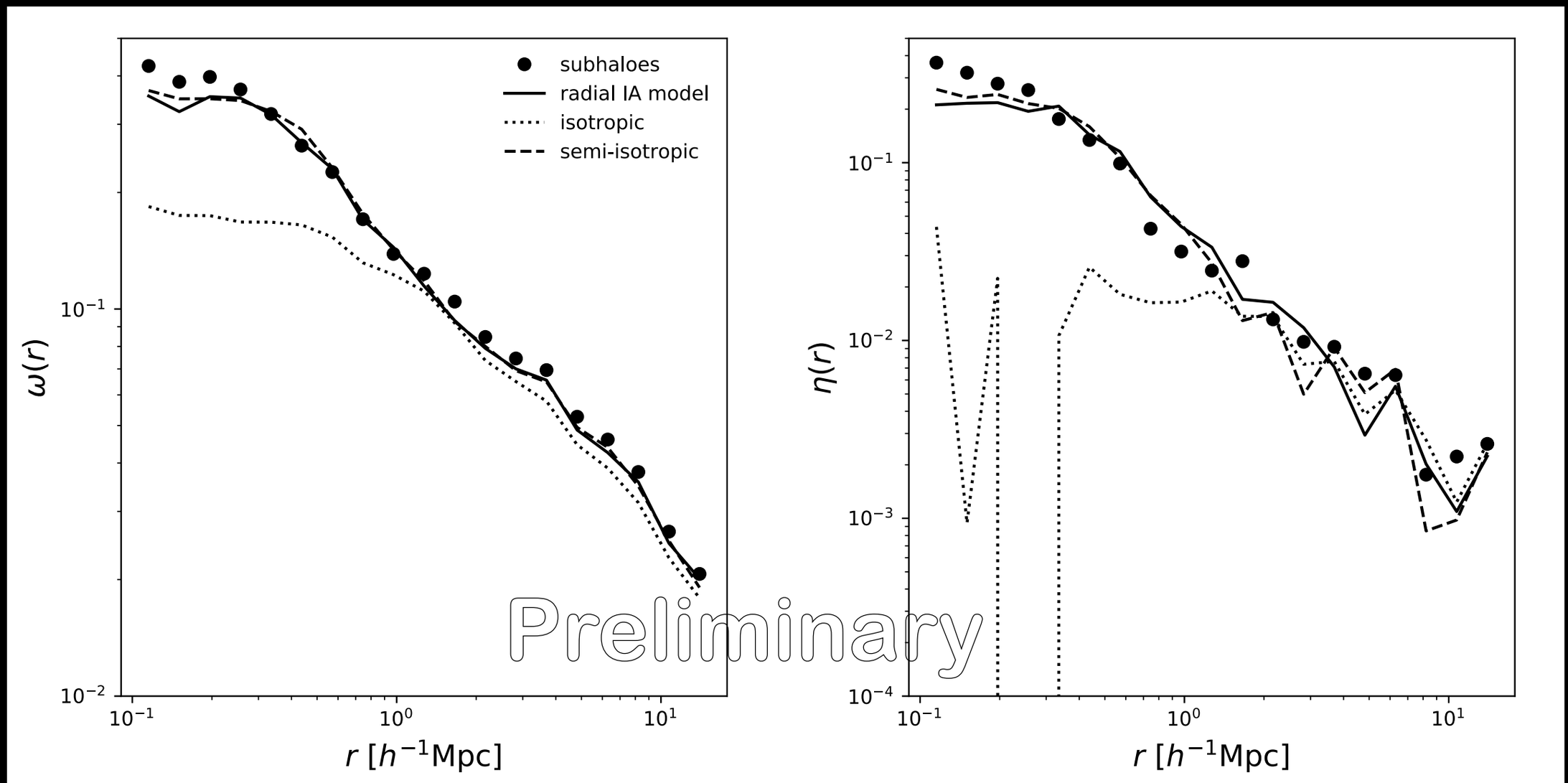
- Built on `Halotools` (Hearin+ 2015; part of `Astropy`)
- Modular, flexible, extendable
- Fast! ~10 seconds to create a galaxy catalog (~100k galaxies)
- ~few seconds to apply galaxy orientations
- ~few seconds to calculate correlation functions
- Can generate mock catalogs for model tests (e.g. LSST-DESC project)
- Can be directly used to make model predictions or to train an emulator

Van Alfen, JB, Campbell, Lanusse,
Leonard, Hearin+ in prep

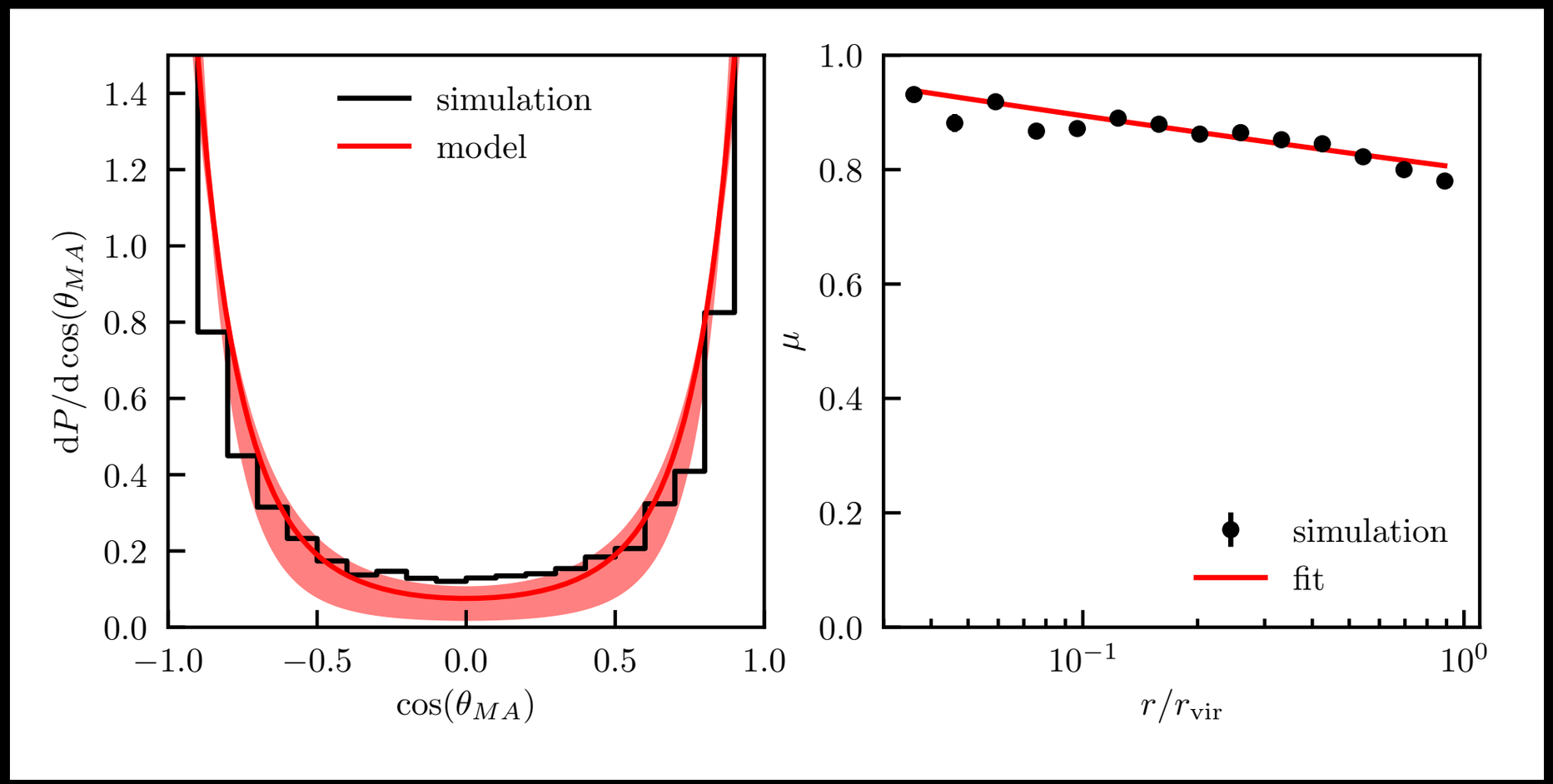
Consistent with Hydro Sims



Importance of halo ellipticity

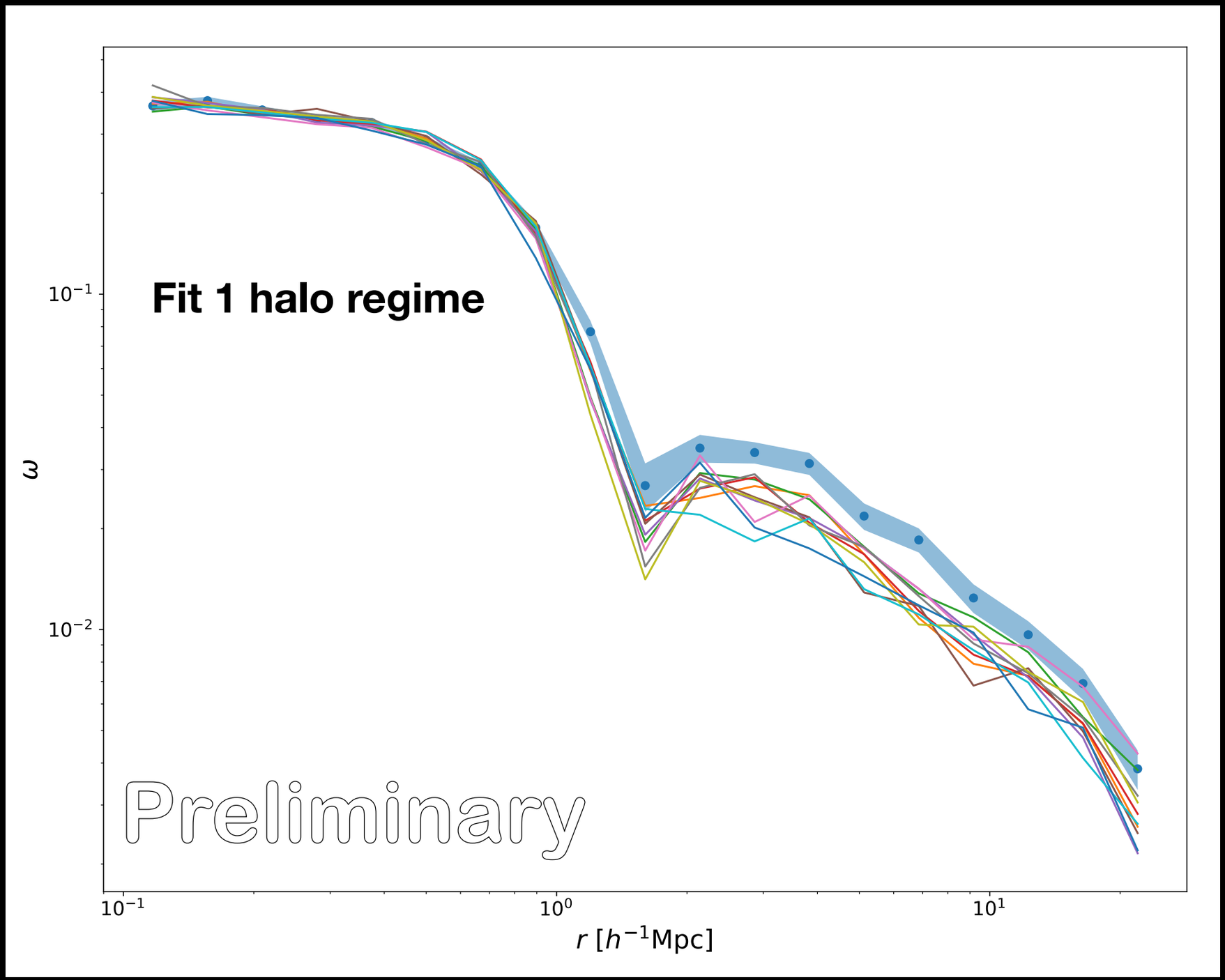


Need for environmental dependence?



radial alignment to match subhalos

Need for environmental dependence?



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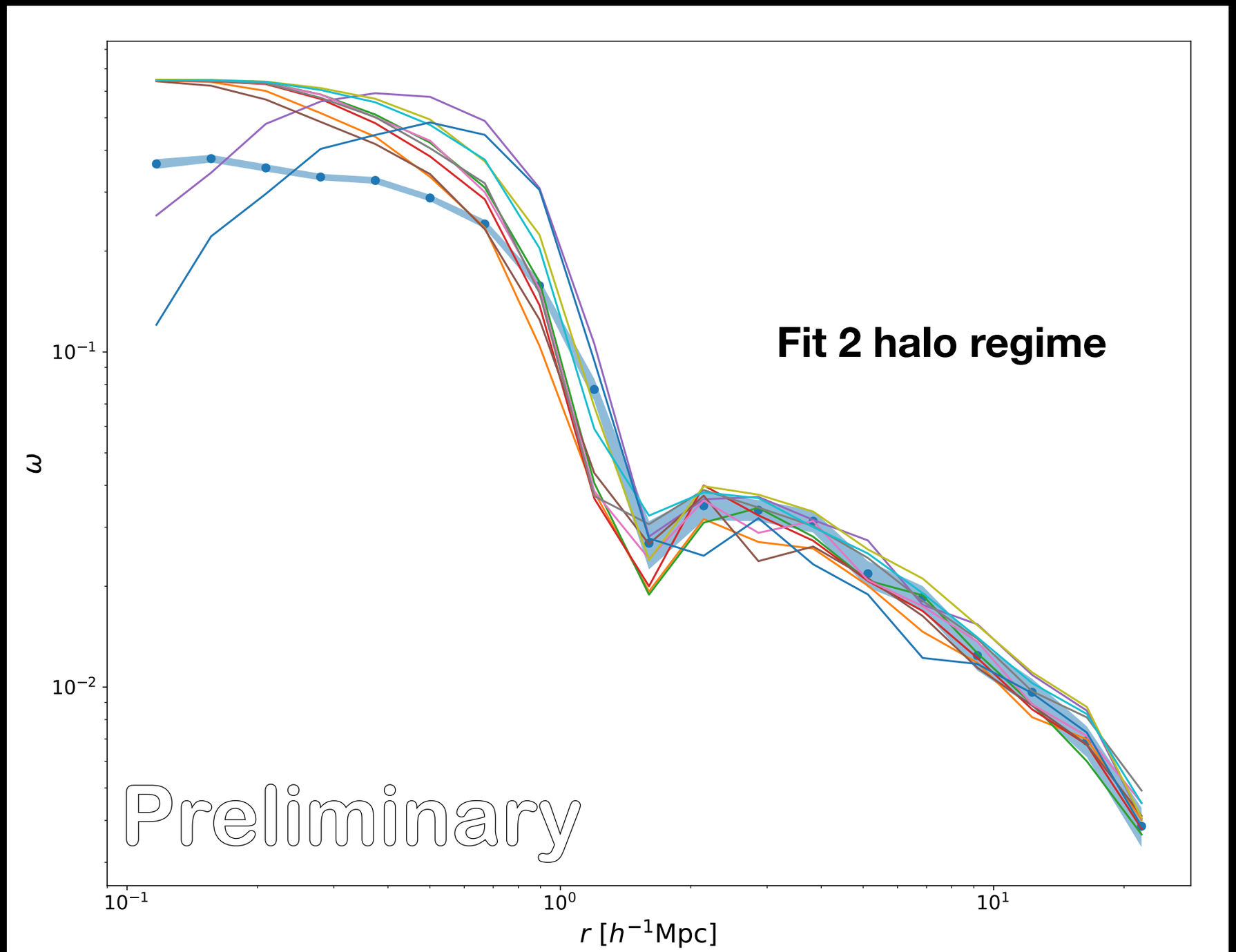
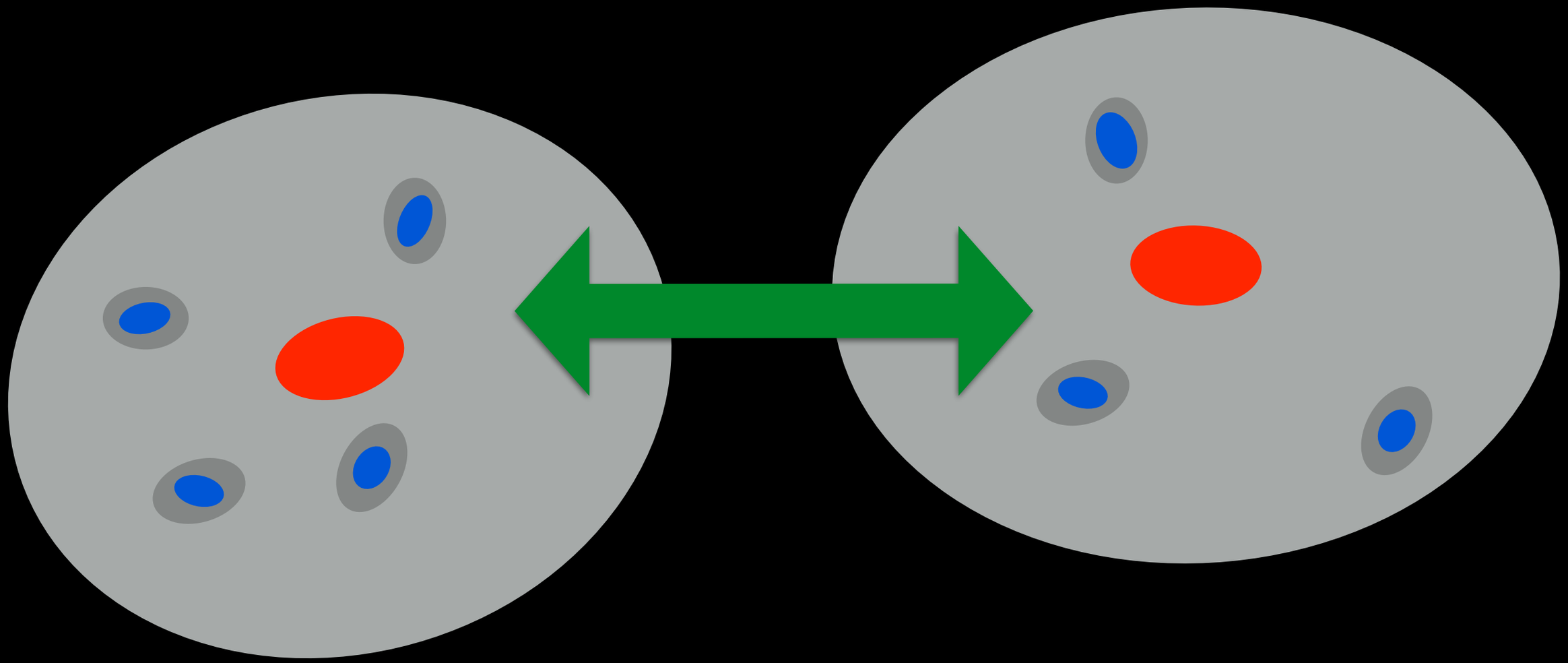
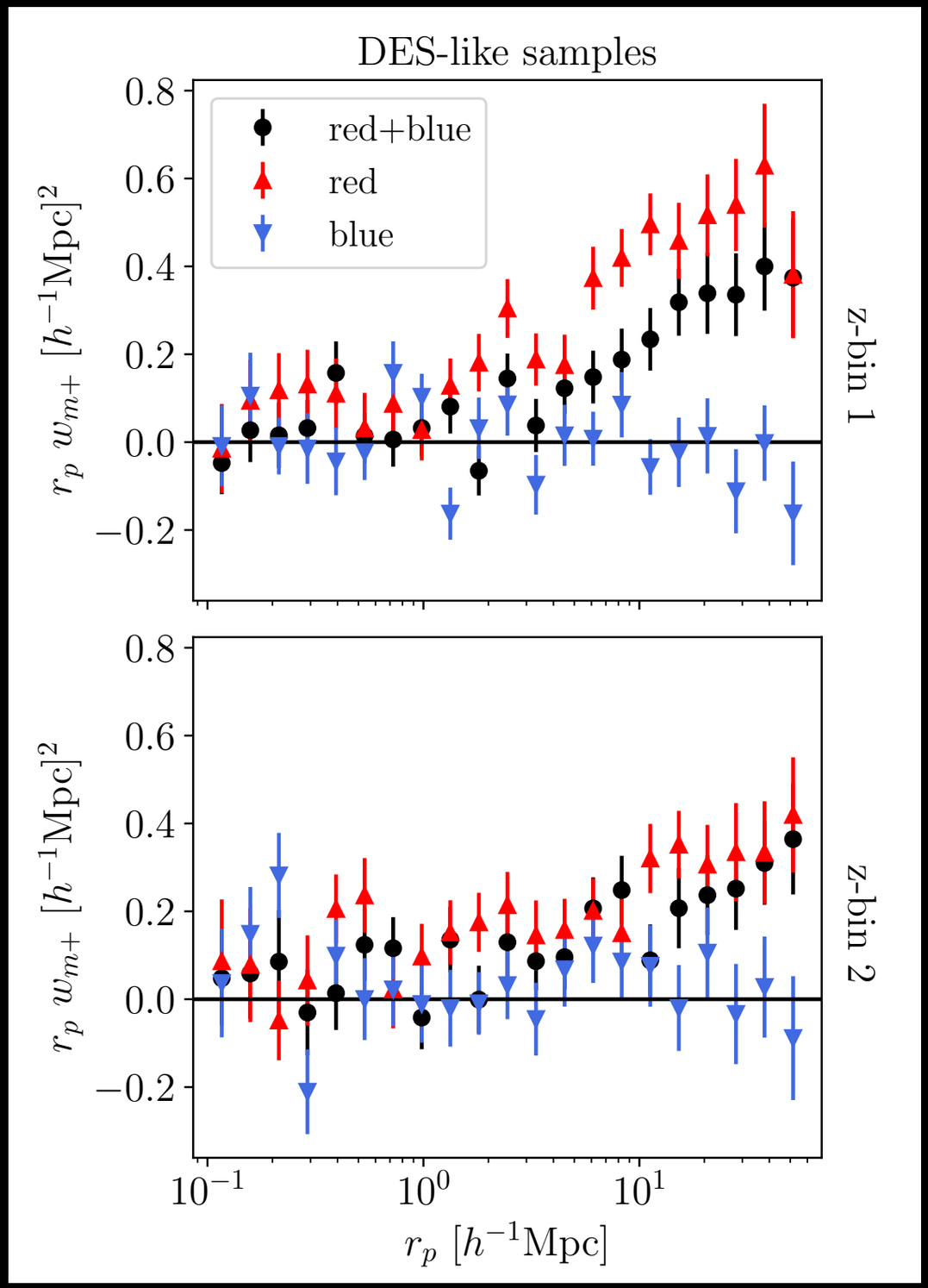


Developing the model (in progress)



- include information on environment and merger history.
  c.f. “decorated HOD” (Hearin+ 2016)
- operate with limited halo/subhalo information
- tidal field information
- merge with ML model (e.g. graph NN: Jagvaral+ 2022)

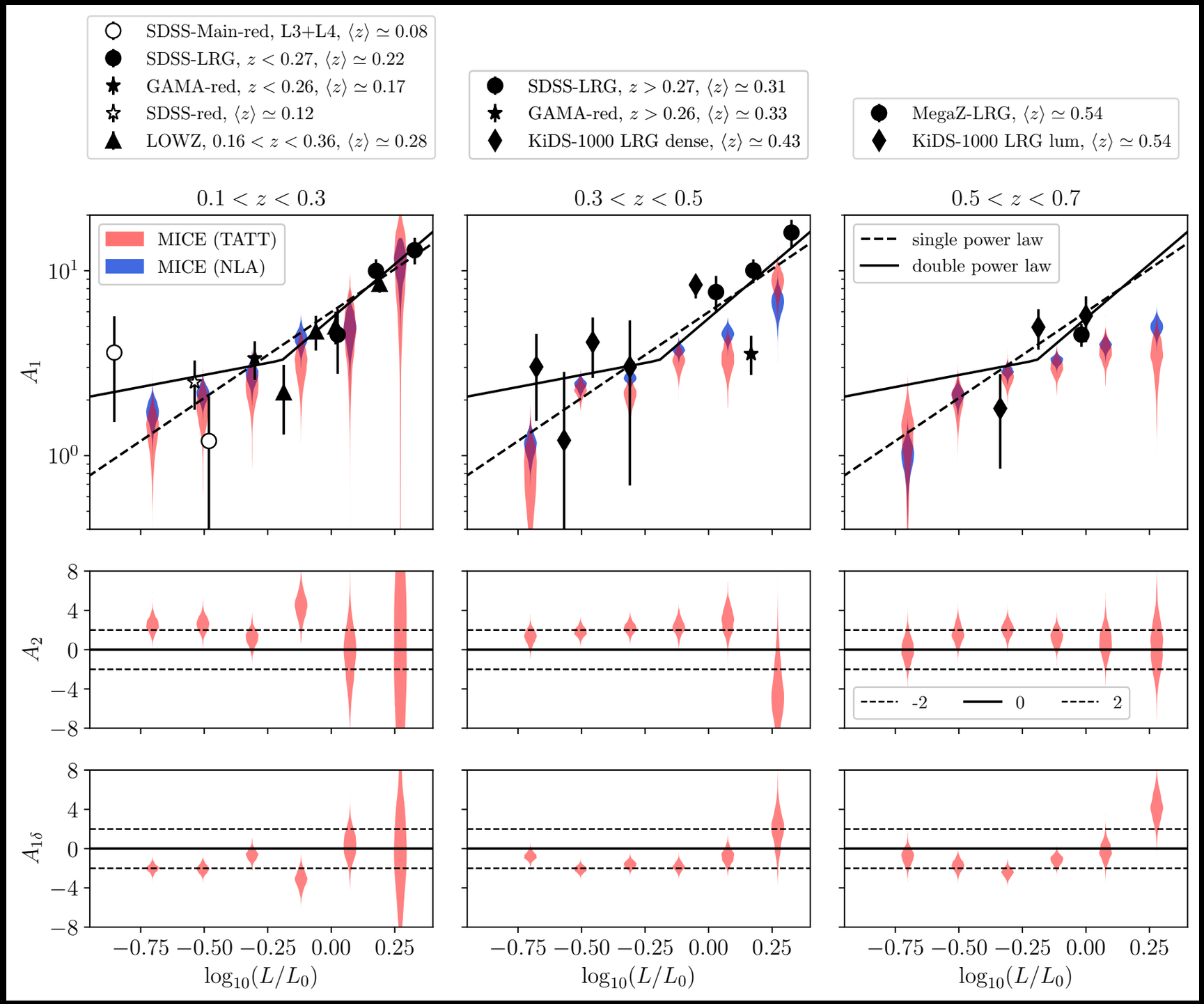
genIAL: Testing IA in MICE



Hoffman, Crocce, JB, Secco+ (2022)

- Incorporate observational constraints (and DES galaxy properties)
- Produce realistic IA catalogs
- Measure IA parameters and impact of analysis choices

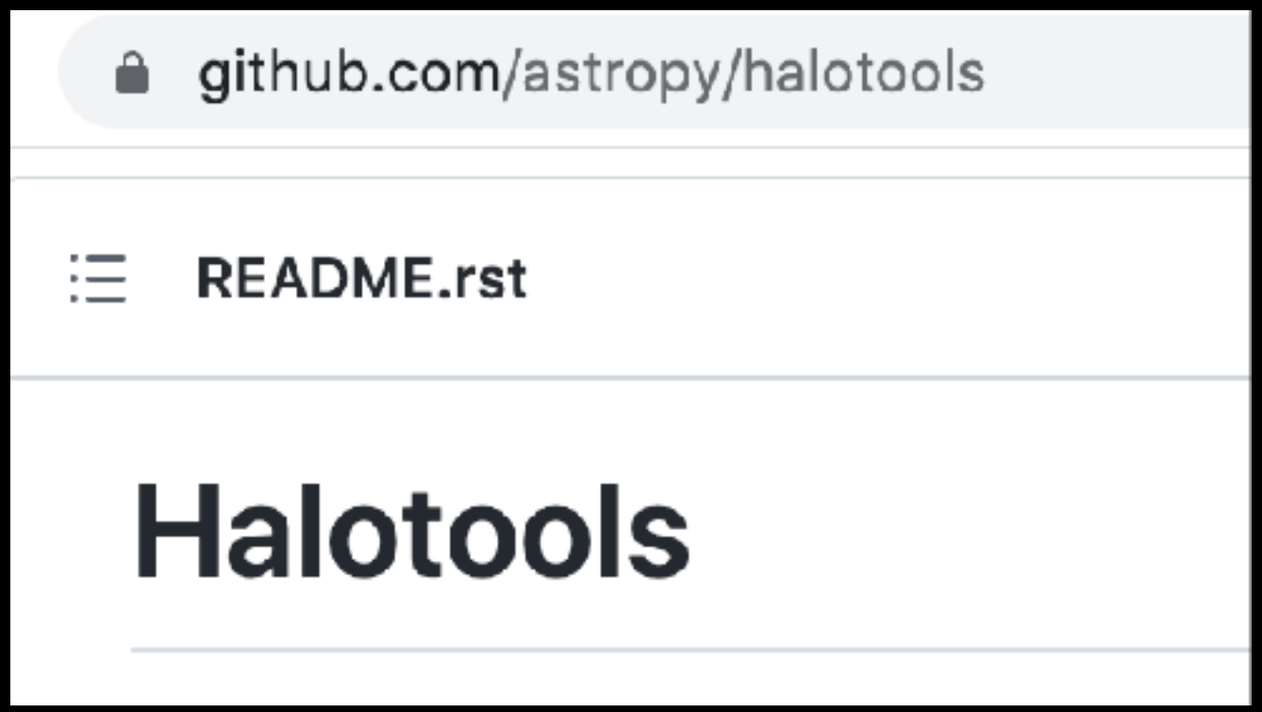
genIAL: Testing IA in MICE



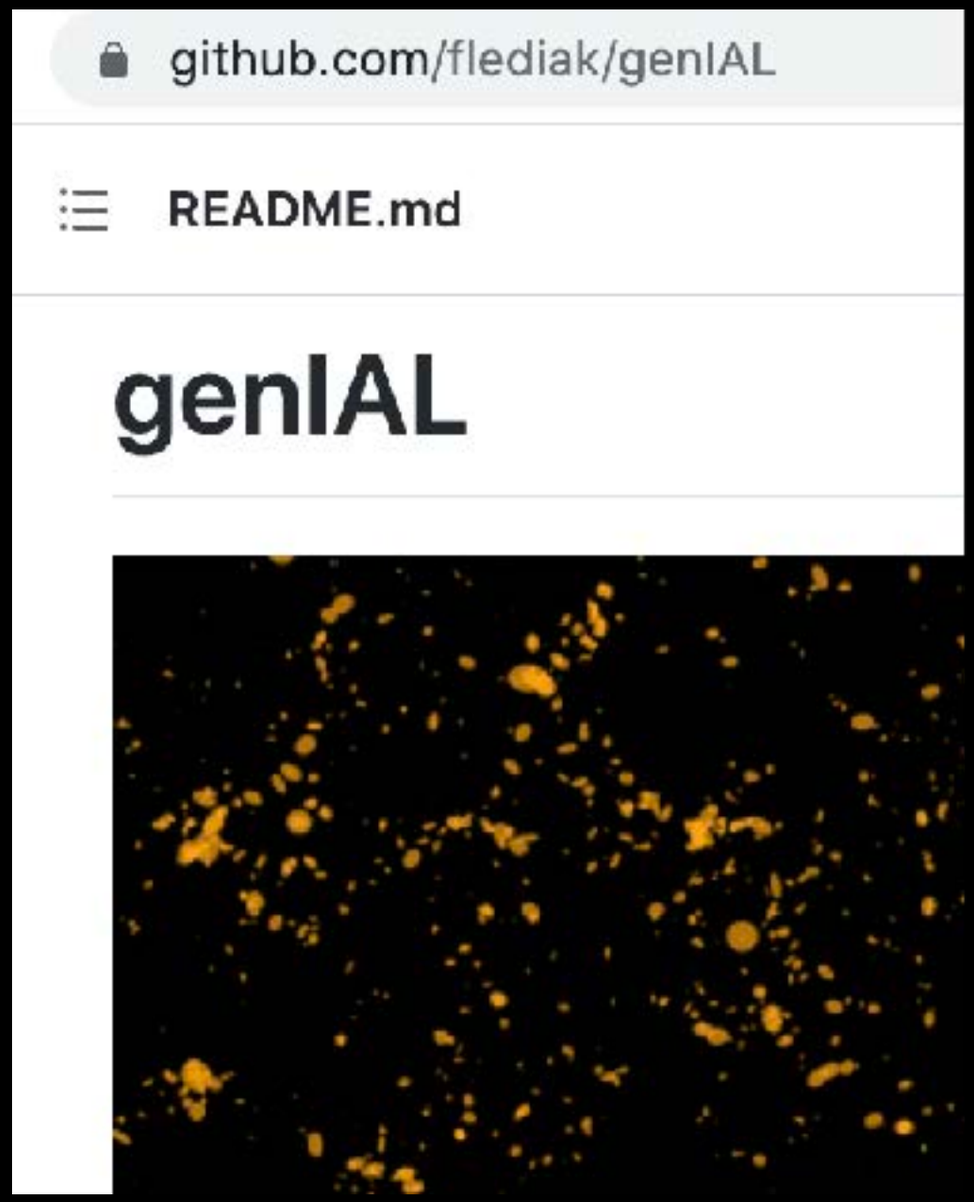
Hoffman, Crocce, JB, Secco+ (2022)

Publicly available tools and catalogs

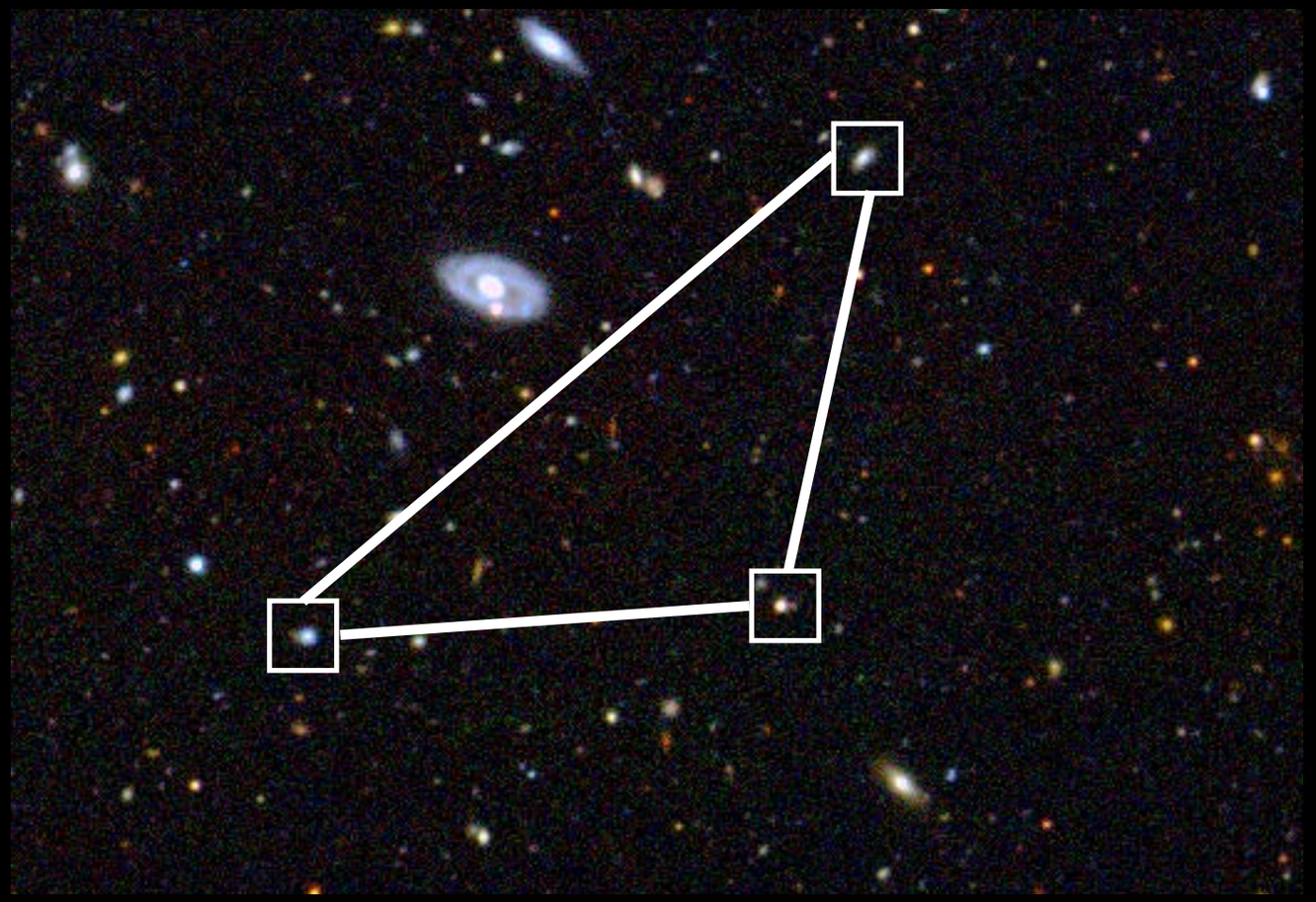
MICE IA catalogs: cosmohub.pic.es



[IA modules coming soon!]

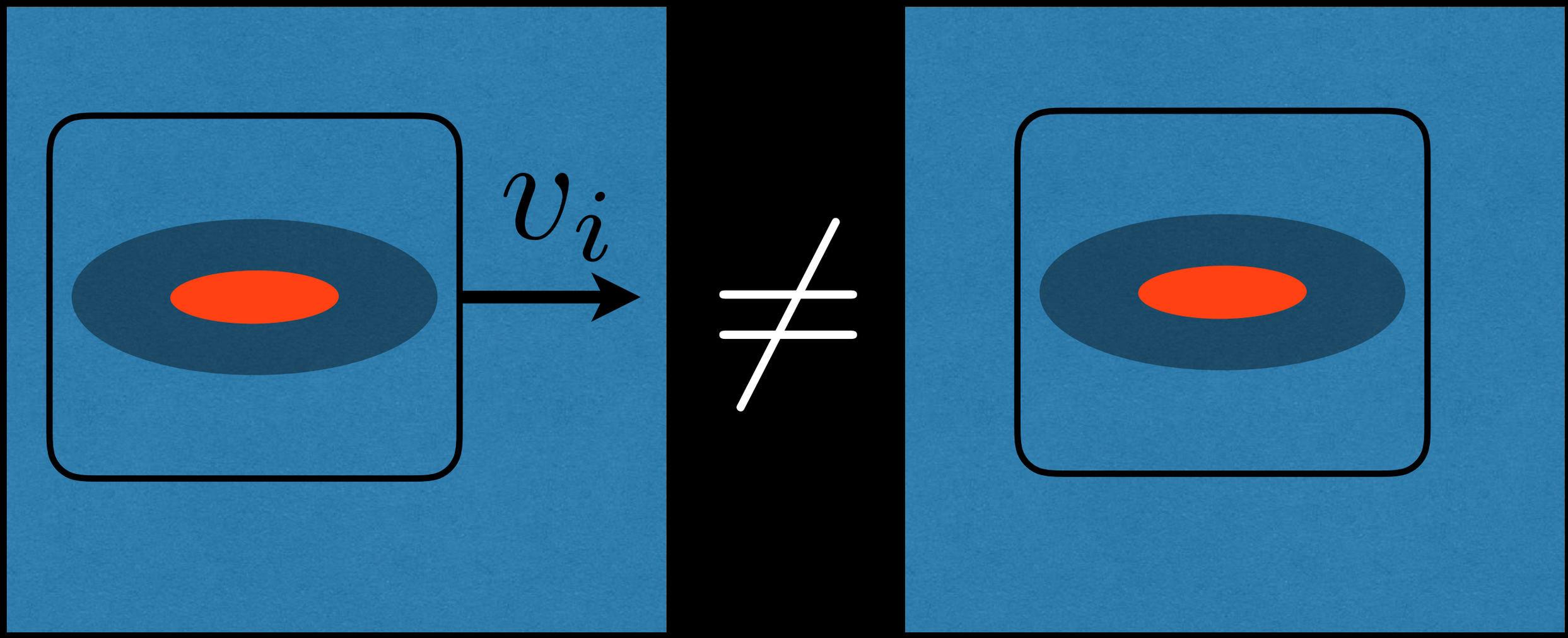


Beyond “nx2”



- Higher n-point correlations
- Treat IA and biasing as probes of physics rather than contaminants

Testing the Equivalence Principle



e.g. **Dark matter - aether interaction** (Blas+ 2012)
Horava-Lifshitz Quantum Gravity (Horava 2009)
Einstein-aether model (Jacobsen & Mattingly 2001)

Testing the EP with galaxy shapes

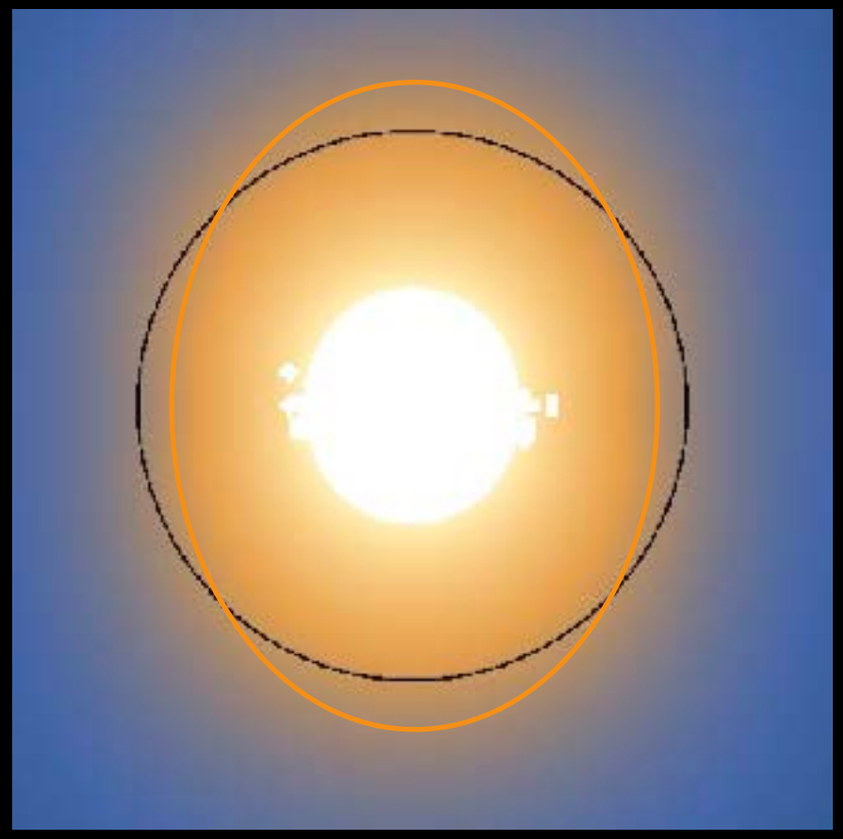
P. Martens, JB, S. Sibiryakov in prep.

$$\gamma_{ij}^I = C_{\rm EPV}(v_i v_j) + C_1 s_{ij} + C_2(s_{ik}s_{kj}) + C_\delta(\delta s_{ij}) + C_t t_{ij} + \cdots$$

$$\nabla_i \Phi \sim v_i$$

Preliminary results

- C_{EPV} can be well-constrained with future data sets (e.g. ggl bispectrum)
- Can be related to range of models with EP violation
- Complementary information to gravitational waves
- **Future work: Simulate this effect using `Halotools-IA`.**



Conclusions

- We need multiple approaches to understand and model intrinsic alignments.
- Generating realistic IA with gravity-only simulations is an important tool, and there are several promising methods.
- `Halotools-IA` and `genIAL` allow us to test IA modeling and are able to match hydro and observational results.
- These simulation tools can be adapted to include new physics to use IA as a powerful new probe.