UNIONS: constraining the galaxy-halo shape connection in 3D for intrinsic alignments

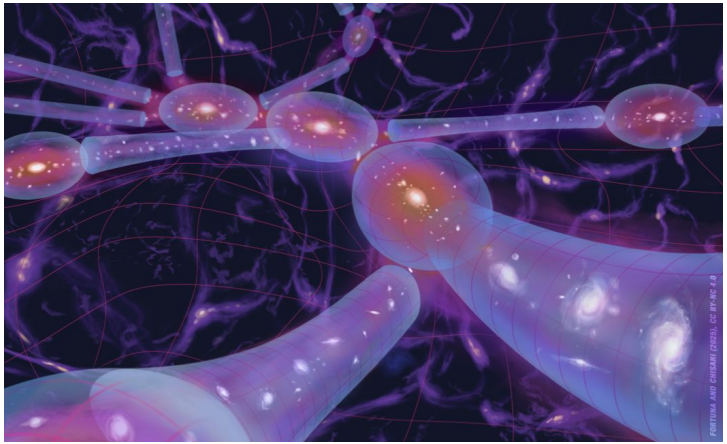
Antonin Corinaldi, 2nd year PhD student at CEA Paris-Saclay

Supervisors: Martin Kilbinger, Sandrine Codis, Calum Murray, Romain Paviot

Action Dark Energy 2026 – November 3rd, 2026

Context and motivations

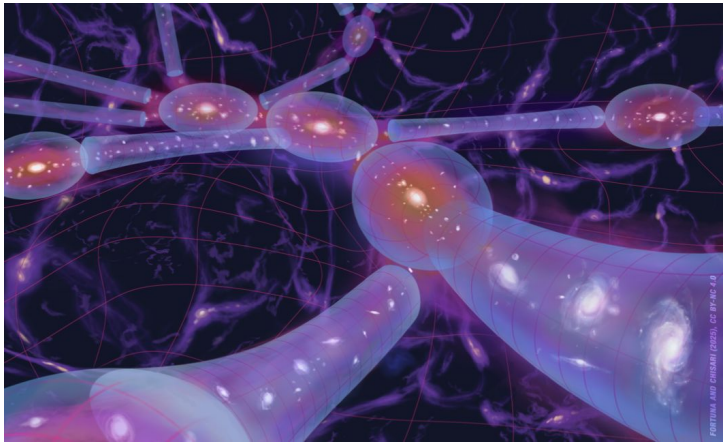
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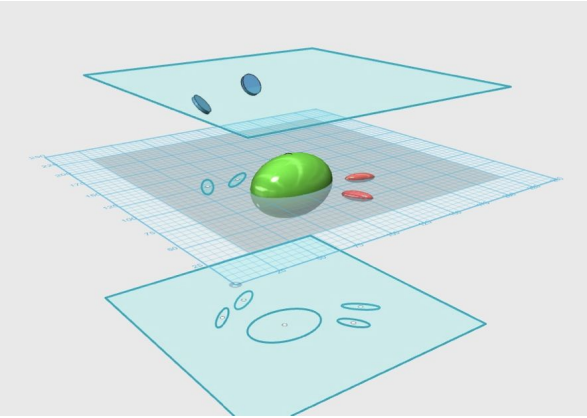
Fortuna & Chisari (2025)

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- **Galaxy 3D morphology**: it encodes fundamental information about processes governing galaxy formation and evolution within the cosmic web.
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Fortuna & Chisari (2025)

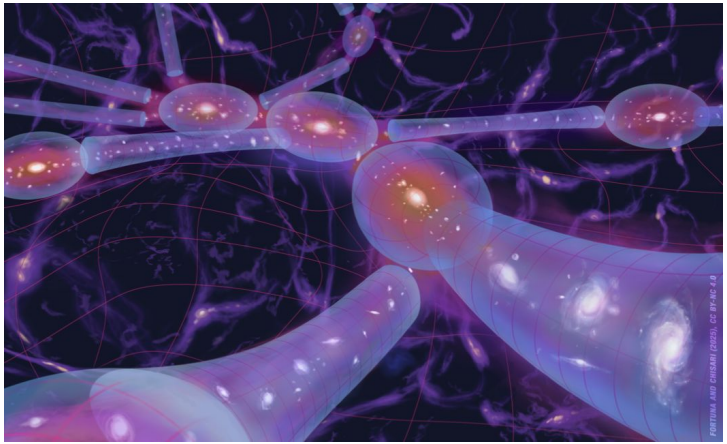


Joachimi et al. 2026

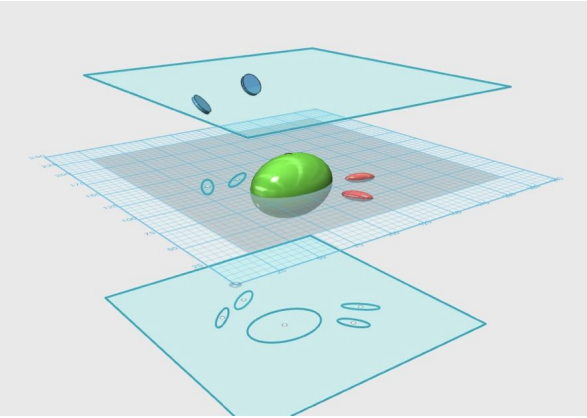
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Joachimi et al. 2026

- **This work: galaxy-halo connection for IA.** The IA signal depends on the morphology of galaxies and the way their shapes evolved in 3D inside halos among the large-scale structures of the Universe

Objectives

- **Aims:**

  1) Developing a forward model for the 3D morphology of central galaxies inside dark matter halos using N-body simulations

  2) Inferring the galaxy-halo connection and the distribution of the shapes of galaxies in 3D from their observed projected images

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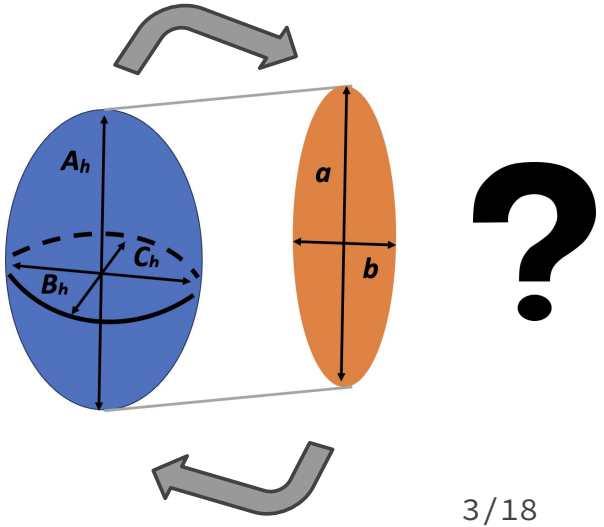
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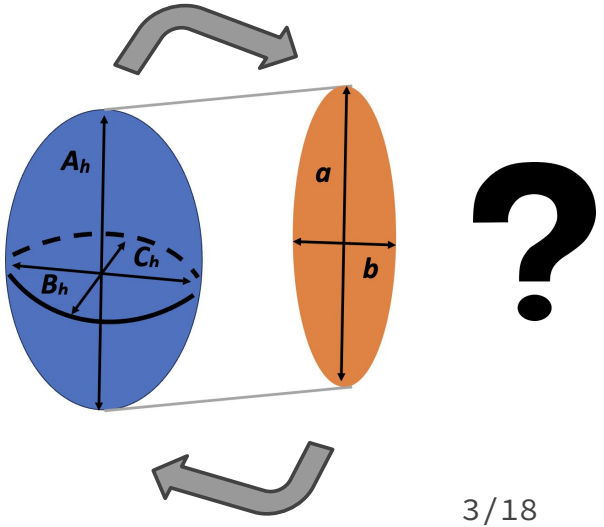
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- **Solution:** simulation-based inference !



UNIONS (Ultraviolet Near-Infrared Optical Northern Survey)

(see Cail and Calum's talk)



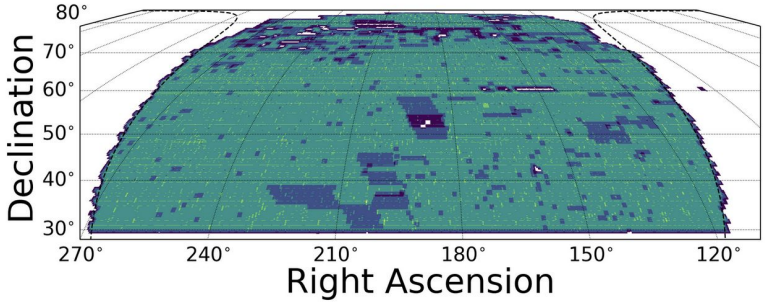
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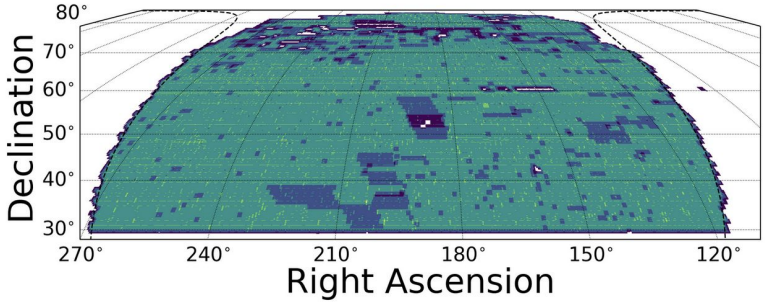
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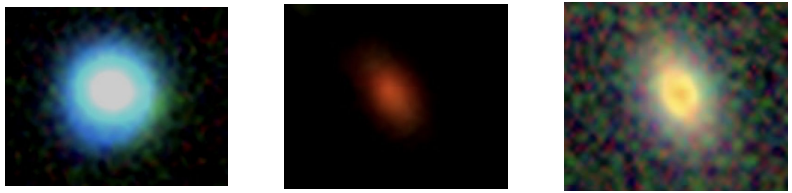


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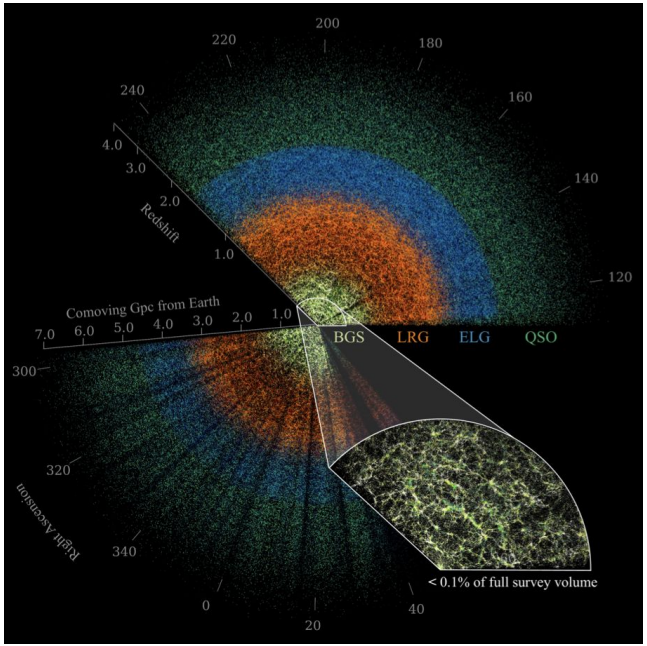
- Measurement of IA by cross-matching UNIONS shapes of galaxies with spectroscopic surveys (*Hervas Peters et al. 2025, Paviot et al. 2026*)

UNIONS x DESI

- **Spectroscopic samples** of galaxies:
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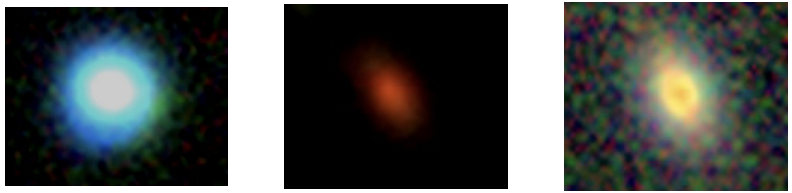
Credit: DESI Legacy Imaging Survey



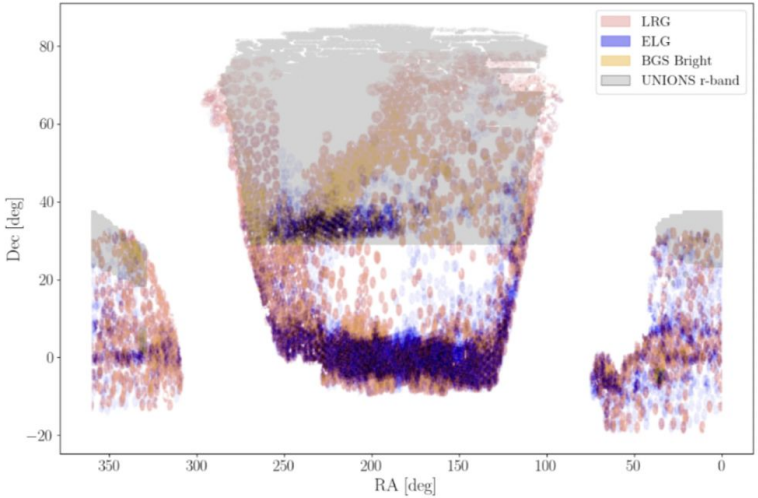
DESI Collaboration 2025

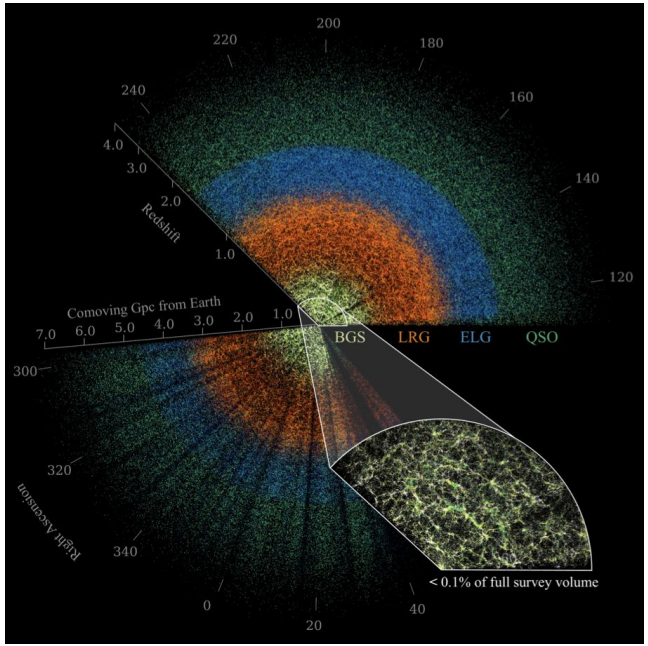
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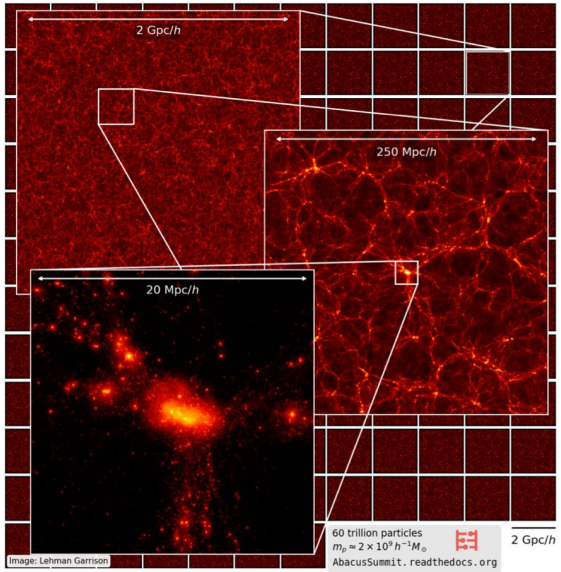


DESI Collaboration 2025

- **Cross-match** with **UNIONS** shapes
  . **ELG-UNIONS**: ~360 000 galaxies
  . **LRG-UNIONS**: ~360 000 galaxies
  . **BGS Bright-UNIONS**: ~1 300 000 galaxies

N-body simulations AbacusSummit

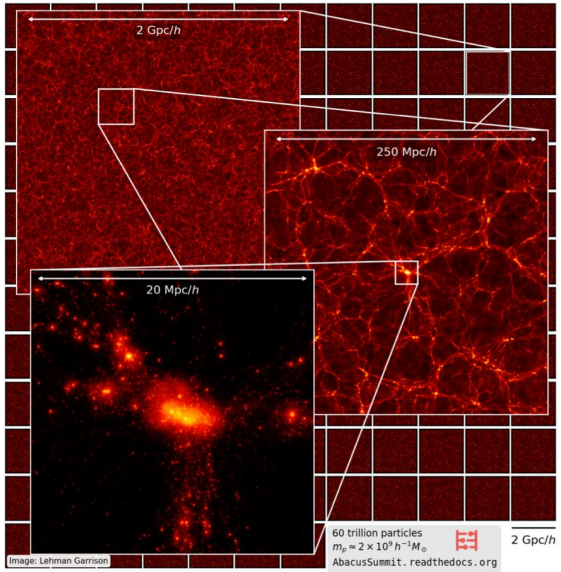
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Maksimova et al. 2021

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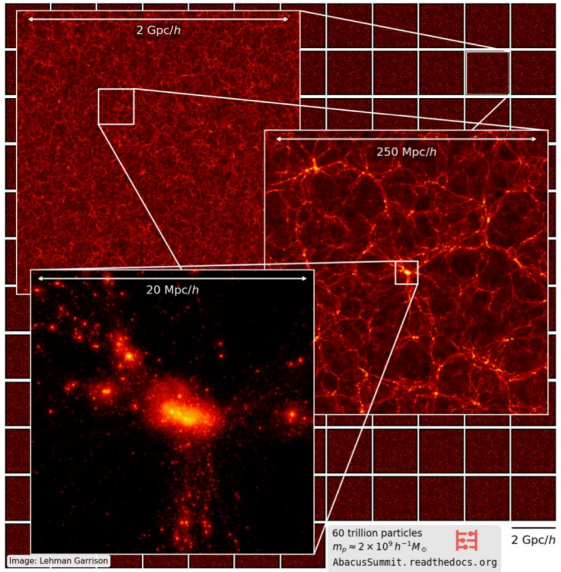
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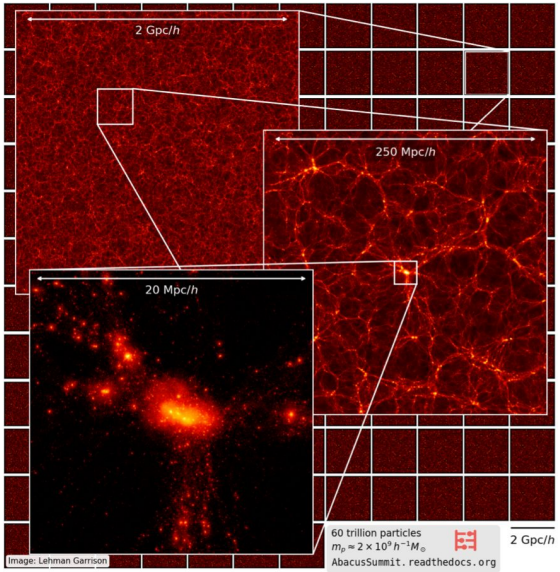
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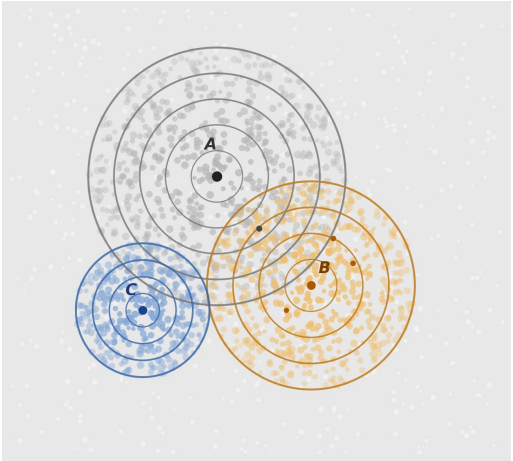
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Maksimova et al. 2021



- Catalogues of halos identified with the CompaSO (Competitive Assignment to Spherical Overdensities) algorithm (*Hadzhiyska et al. 2021*)

Methodology

I) Getting a halo catalogue per galaxy sample

II) Modelling the 3D shapes of halos

III) Modelling the 3D shapes of central galaxies in their host halos

IV) Inferring galaxy-halo shape connection from observations using simulation-based inference (SBI)

I) Getting a halo catalogue per galaxy sample

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Example: HOD model for the LRG (*Yuan et al. 2023*)

Mean occupation number of **central** and **satellite** galaxies:

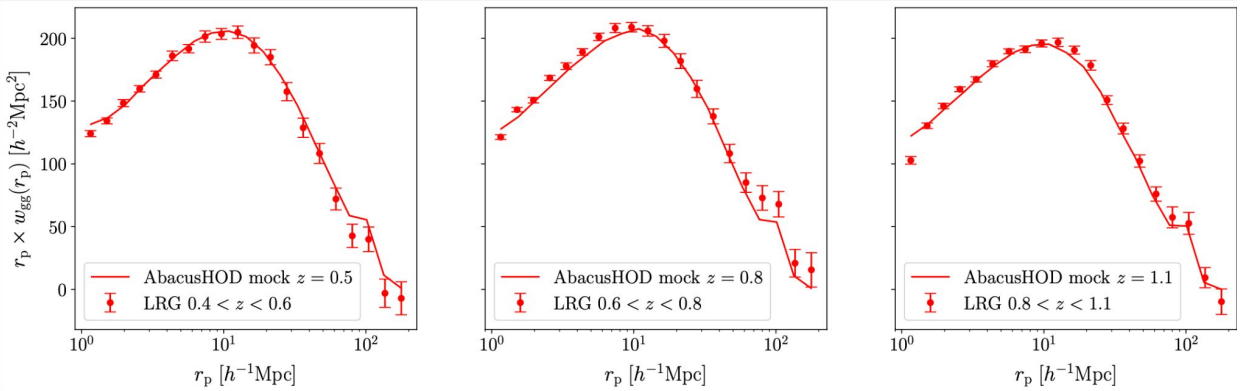
$$\bar{n}^{\mathrm{LRG}}_{\mathrm{cent}}(M) = \frac{f_{\mathrm{ic}}}{2}\mathrm{erfc}\left[\frac{\log_{10}(M_{\mathrm{cut}}/M)}{\sqrt{2}\sigma}\right] \qquad \bar{n}^{\mathrm{LRG}}_{\mathrm{sat}}(M) = \left[\frac{M-\kappa M_{\mathrm{cut}}}{M_1}\right]^{\alpha} \bar{n}^{\mathrm{LRG}}_{\mathrm{cent}}(M)$$

M	mass of the host halo
M_{cut}	minimum halo mass to set a central galaxy
f_{ic}	incompleteness parameter (by definition: $0 < f_{\mathrm{ic}} \leq 1$)
σ	steepness of the transition from 0 to 1 in the number of central
κM_{cut}	minimum halo mass to host a satellite galaxy
α	power law index on the number of satellite galaxies
M_1	typical halo mass that hosts one satellite galaxy

Code: *AbacusHOD* (*Yuan et al. 2021*), scripts here: antonincorinaldi

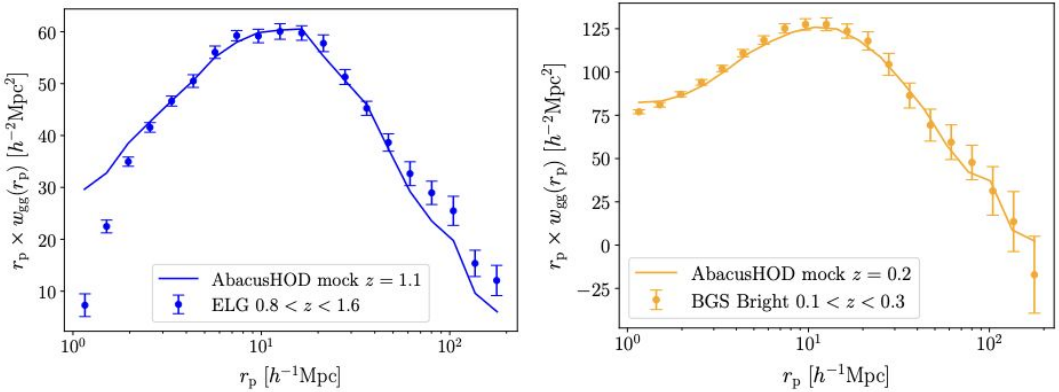
I) Getting a halo catalogue per galaxy sample

- *Step 2*: **clustering measurements** with the data and the mock and check the consistency between both (*Landy & Szalay 1993*)



$$\xi_{gg}(r_p, \Pi) = \frac{DD(r_p, \Pi) - 2\,DR(r_p, \Pi) + RR(r_p, \Pi)}{RR(r_p, \Pi)}$$

$$w_{gg}(r_p) = \int_{-\Pi_{max}}^{\Pi_{max}} d\Pi\, \xi_{gg}(r_p, \Pi)$$



- Best-fit HOD parameters:
  - LRG *Yuan et al. 2023*
  - ELG *Rocher et al. 2024*
  - BGS *Prada et al. 2025*

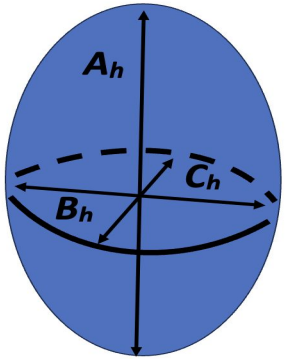
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$$A_h > B_h > C_h$$

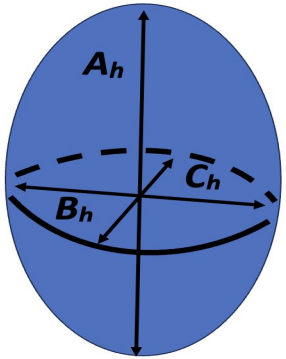


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- 3D orientation: eigenvectors of I_{ij}

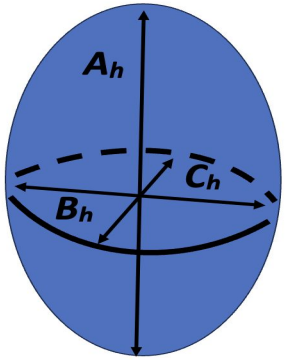


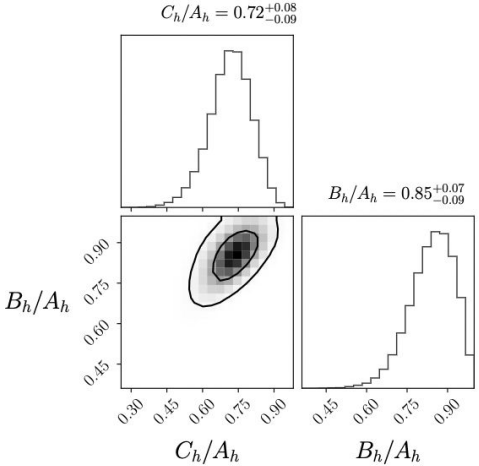
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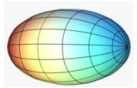
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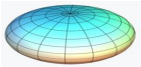




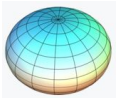
Example: Abacus halos at $z = 0.5$



prolate $A_h > B_h \approx C_h$



oblate $A_h \approx B_h > C_h$



spheroidal $A_h \approx B_h \approx C_h$

Pandya et al. 2024

III) Modelling the 3D shapes of central galaxies in their host halos

- Populating each halo with a 3D central galaxy with axis lengths $A_g > B_g > C_g$ such that:

$$\frac{B_g}{A_g} = \tau_B \frac{B_h}{A_h} \qquad \frac{C_g}{A_g} = \tau_C \frac{C_h}{A_h} \qquad \text{with} \quad \tau_B, \tau_C \in [0;1]$$



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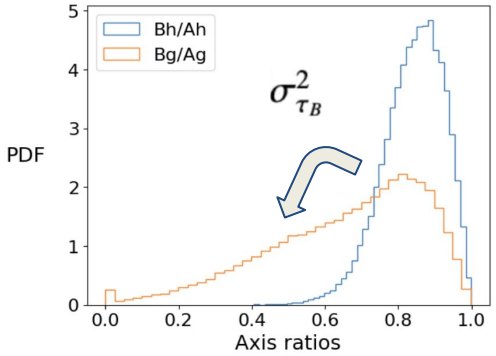


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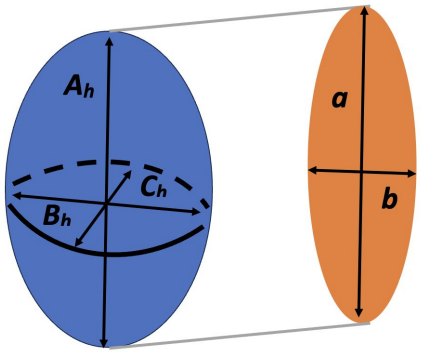
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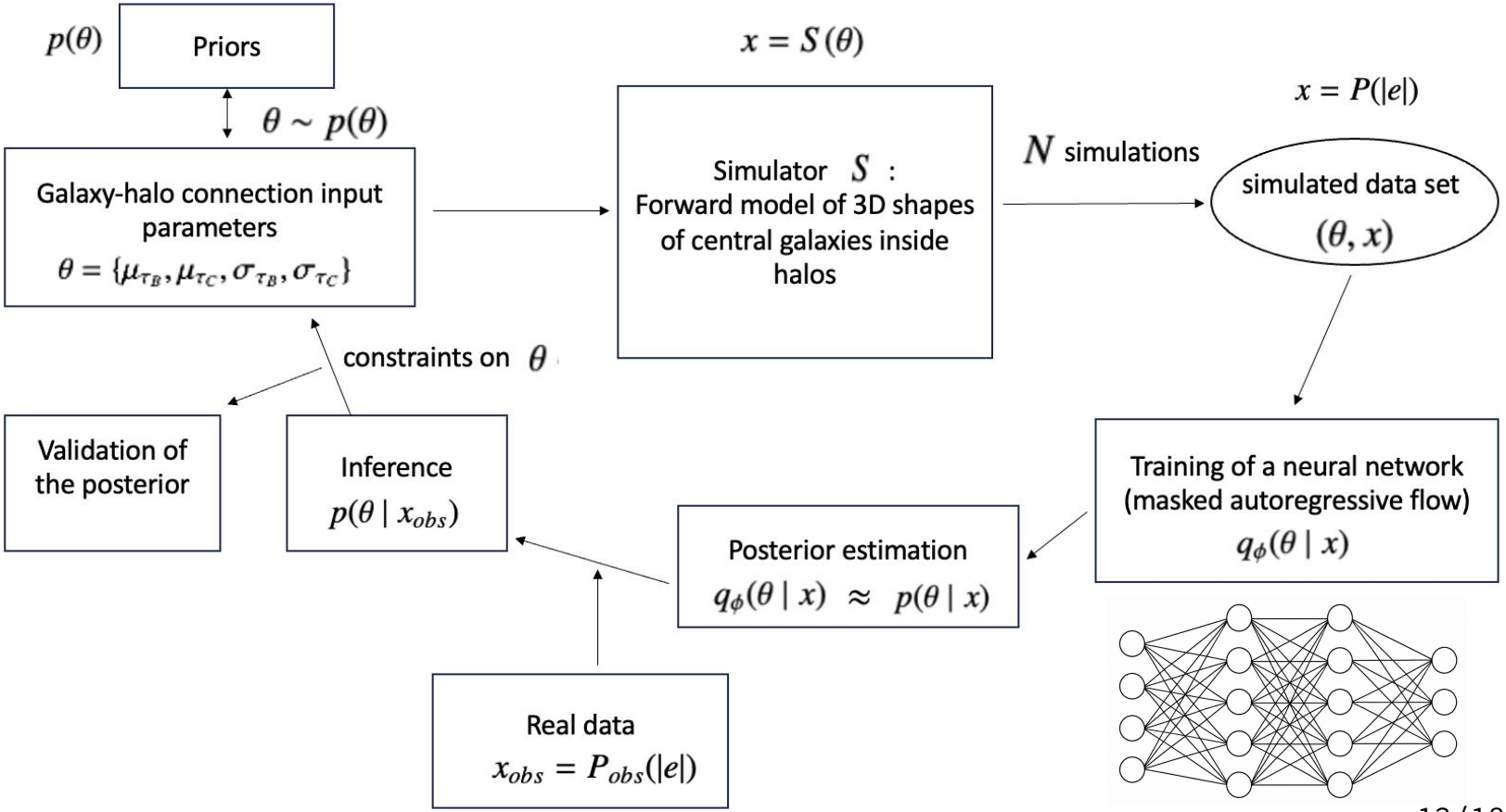
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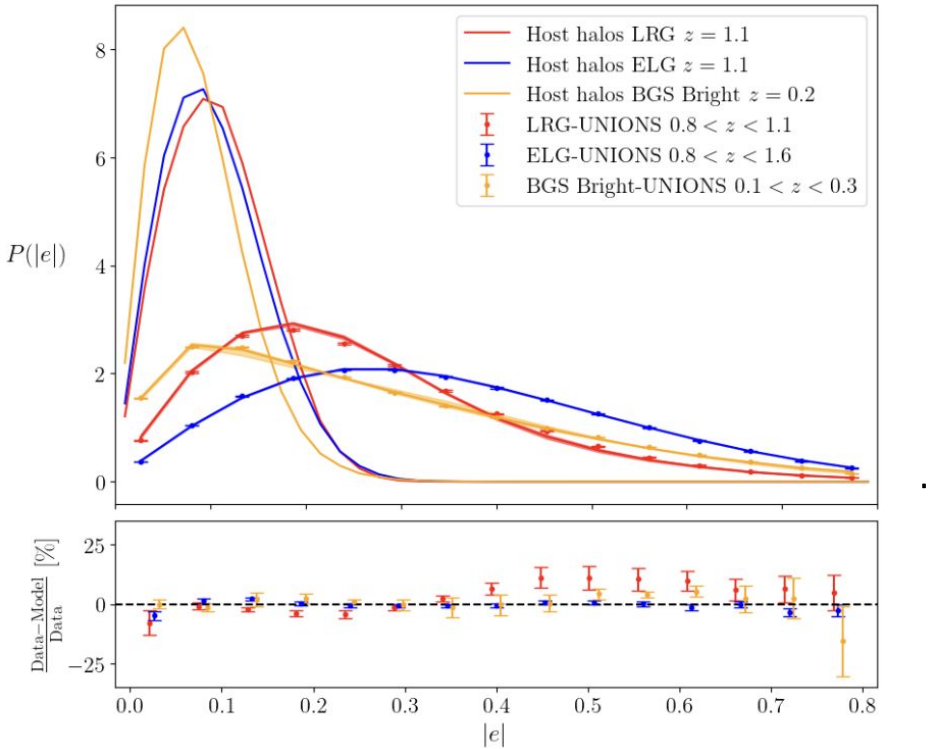
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- Projection in 2D (*Lamman et al. 2023*) for different $\mu_{\tau_B}, \mu_{\tau_C}$ drawn with a uniform prior over $[0;1]$.



IV) Inferring galaxy-halo connection with SBI



Results, ELG-LRG-BGS: distributions of ellipticities



ELG 2D shapes are more scattered than LRG.
BGS 2D shapes are rounder than ELG and LRG.

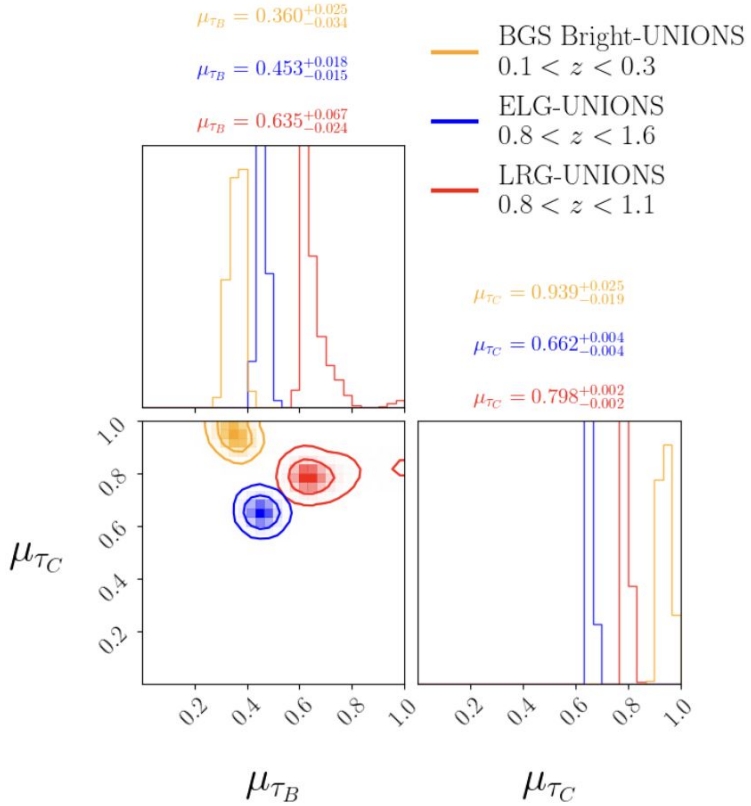
Results, ELG-LRG-BGS: galaxy-halo connection

$\mu_{\tau_B}, \mu_{\tau_C}$: means of τ_B, τ_C for a given halo sample



$$\frac{B_g}{A_g} = \tau_B \frac{B_h}{A_h} \qquad \frac{C_g}{A_g} = \tau_C \frac{C_h}{A_h}$$

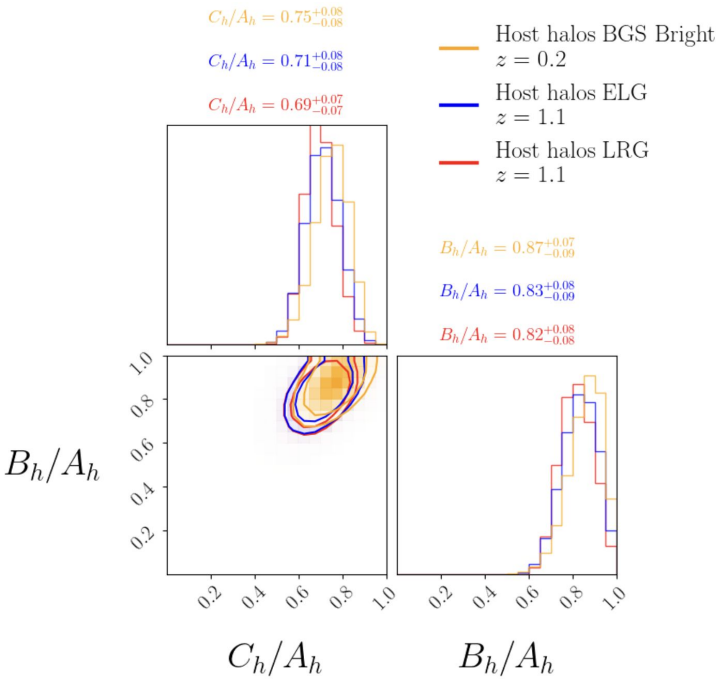
with $\tau_B, \tau_C \in [0; 1]$



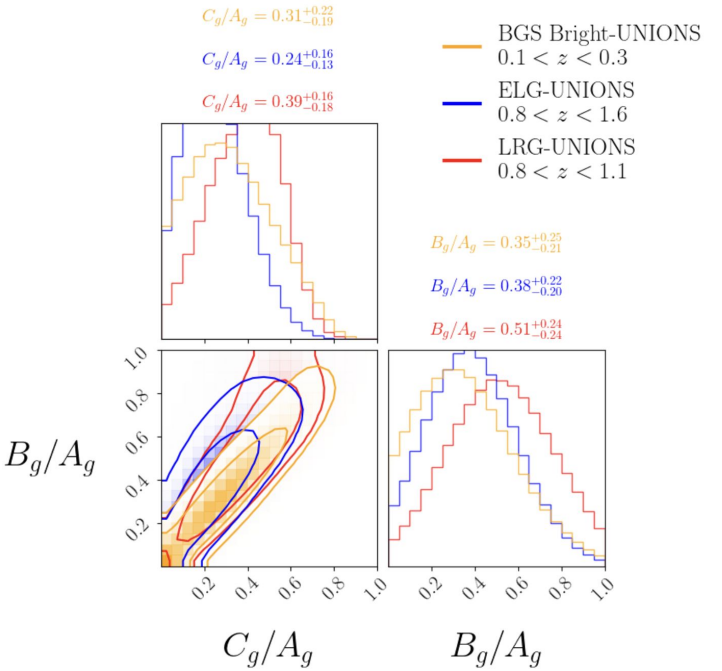
We probe different 3D galaxy-halo shape connections between LRG, ELG and BGS.

Results, ELG-LRG-BGS: constraints on 3D shapes

Halos



Galaxies

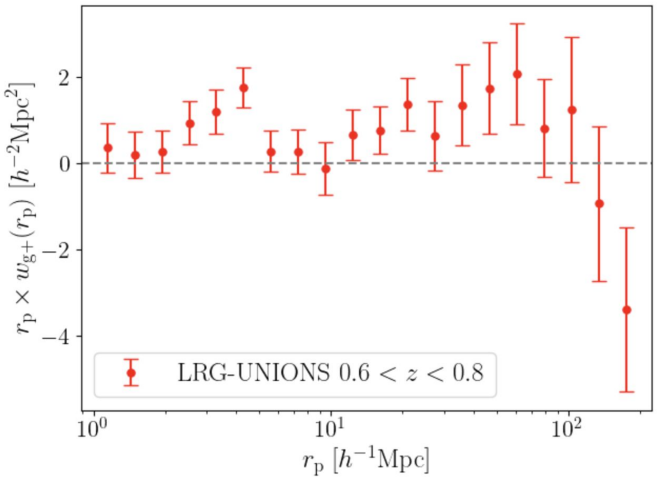


We estimate different 3D morphologies of galaxies depending on their types, from their observed projected images.

Towards IA prediction with galaxy 3D morphology model

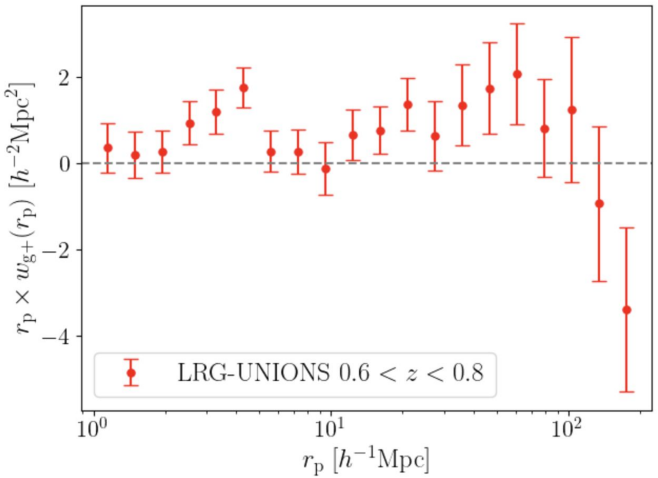
$$\xi_{g+}(r_p, \Pi) = \frac{S_+ D(r_p, \Pi) - S_+ R_D(r_p, \Pi)}{R_S R_D(r_p, \Pi)}$$

$$w_{g+}(r_p) = \int_{-\Pi_{max}}^{\Pi_{max}} d\Pi \, \xi_{g+}(r_p, \Pi)$$



Towards IA prediction with galaxy 3D morphology model

$$\xi_{g+}(r_p, \Pi) = \frac{S_+ D(r_p, \Pi) - S_+ R_D(r_p, \Pi)}{R_S R_D(r_p, \Pi)} \qquad w_{g+}(r_p) = \int_{-\Pi_{max}}^{\Pi_{max}} d\Pi \, \xi_{g+}(r_p, \Pi)$$



- **Future aim:** predict galaxy IA by using our halo-based model
  => **motivation:** to reveal extra informations to IA about the 3D morphology of galaxies

Conclusion and perspectives

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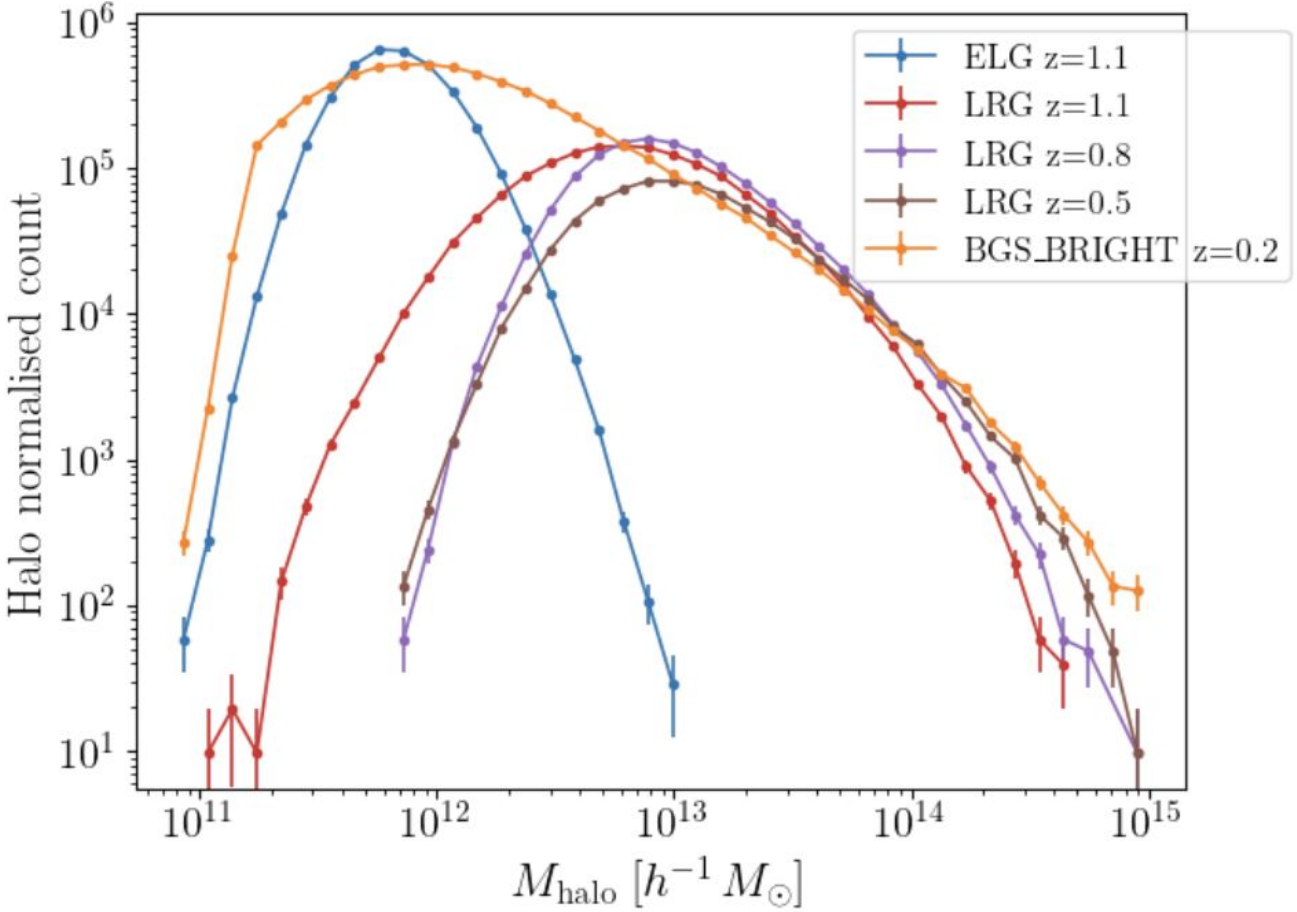
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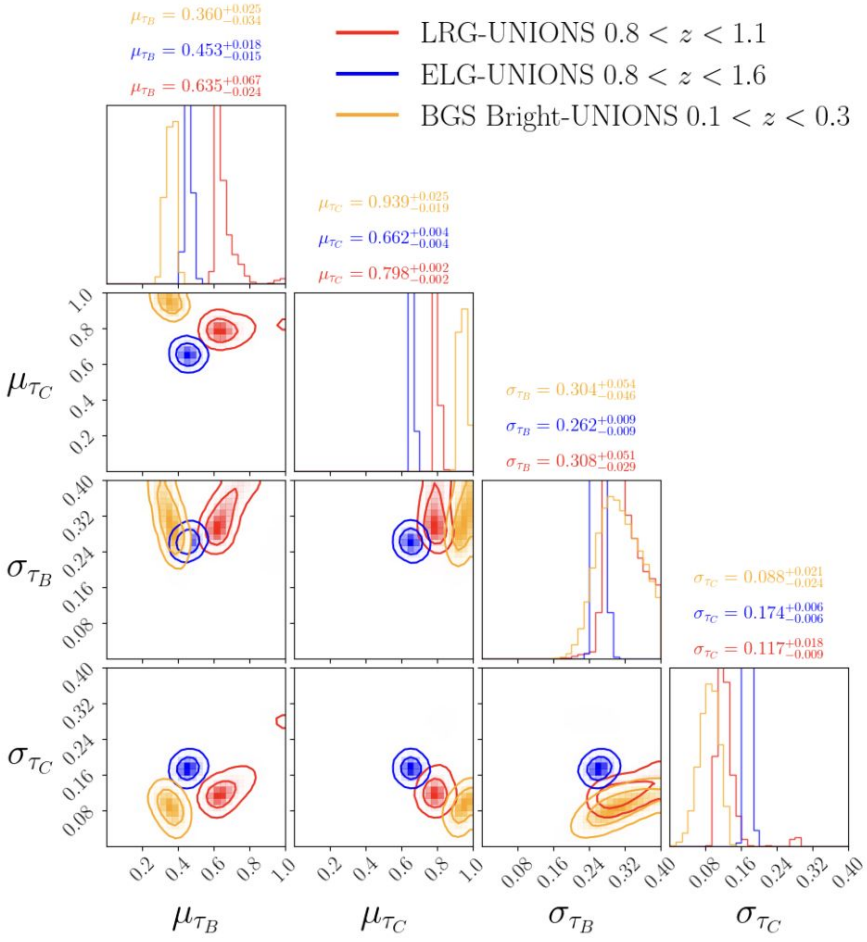
- This work will be published soon with associated codes. Stay tuned !

Back up slides

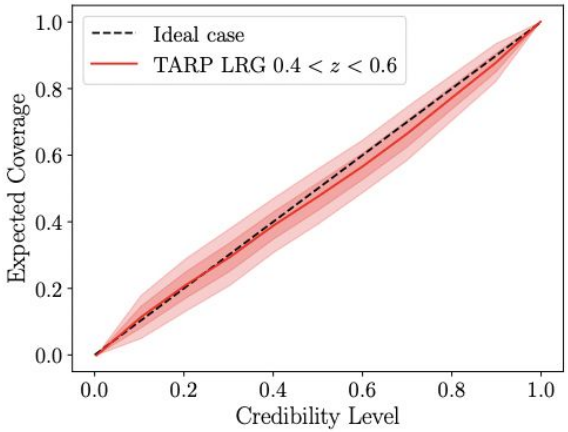
Halo mass distributions

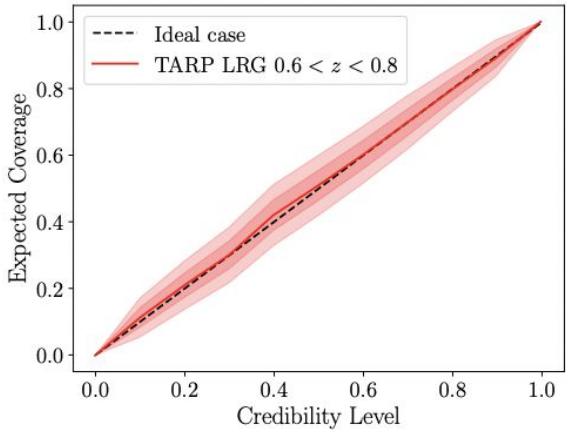


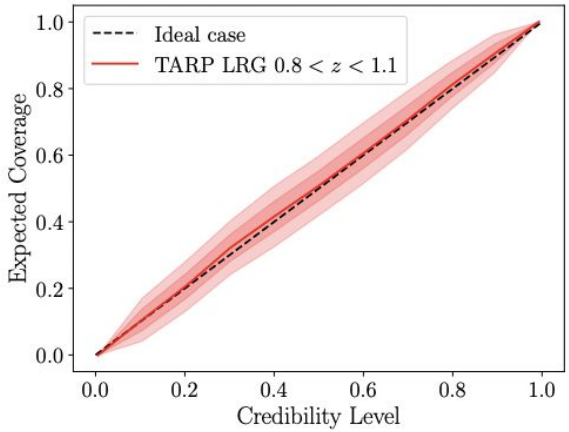
ELG-LRG-BGS: other parameter constraints

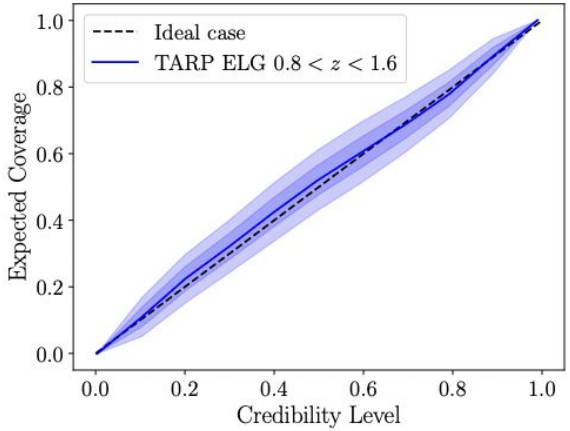


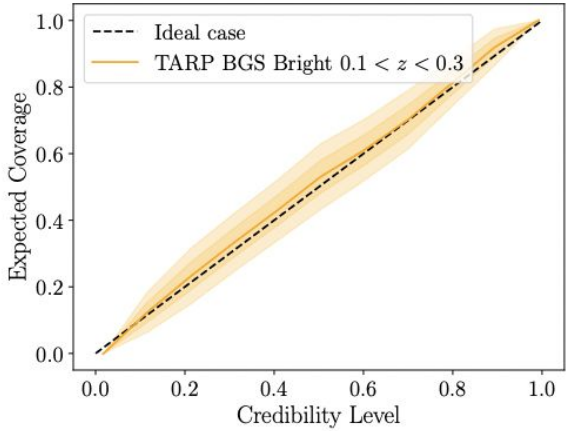
Validation: coverage tests



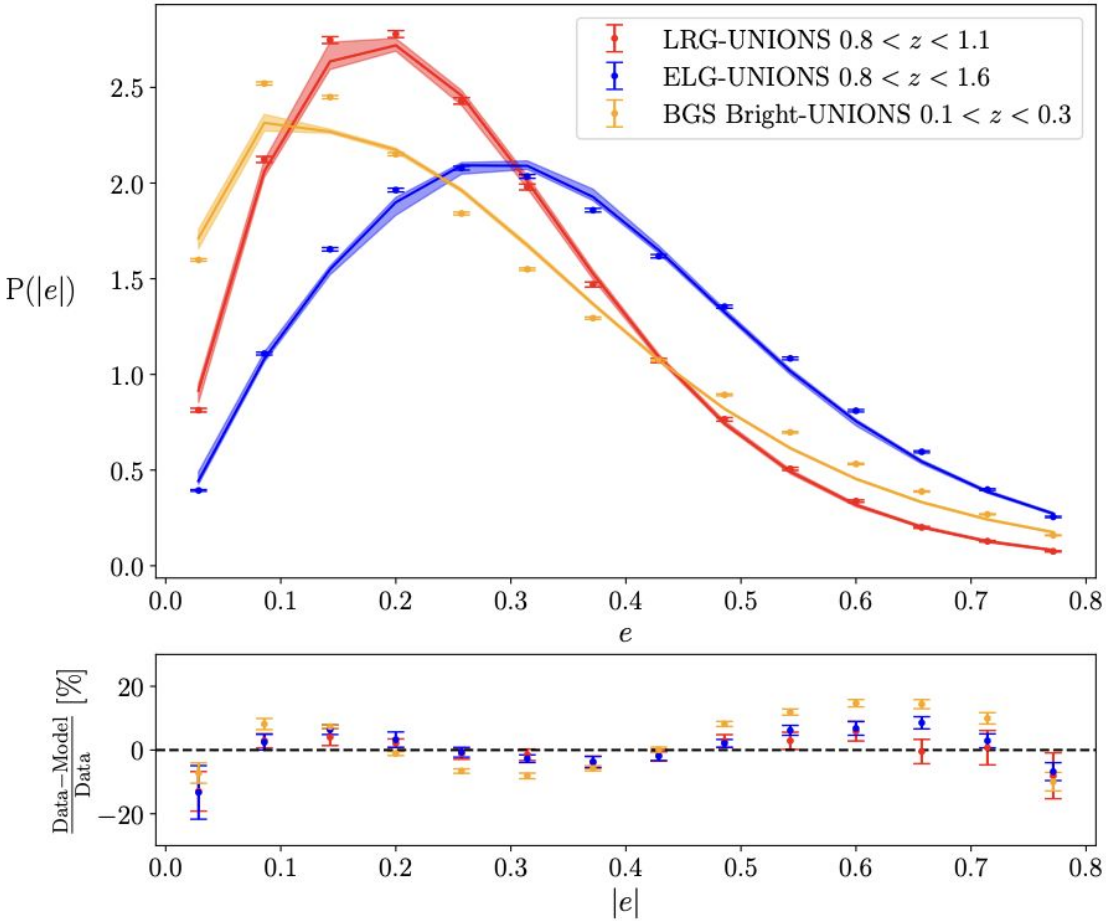








Toy-model for the 3D shapes of galaxies (1)



Toy-model for the 3D shapes of galaxies (2)

