Inferring 3D shapes and measuring intrinsic alignments of galaxies from their projected images with UNIONS

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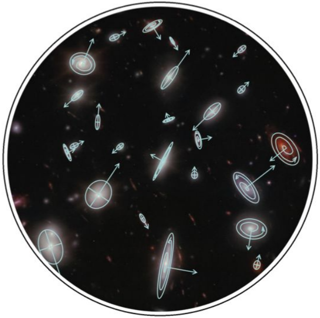
Laboratory: CEA, Paris-Saclay, CosmoStat

Elbereth conference 2026

April 8th, 2026

Scientific context: intrinsic alignments of galaxies



Lamman et al. 2024

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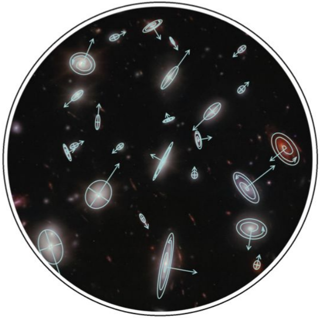

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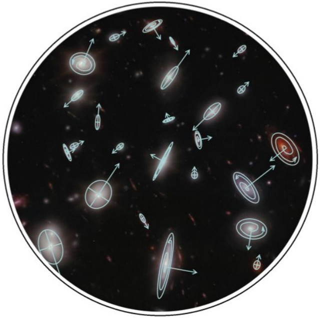

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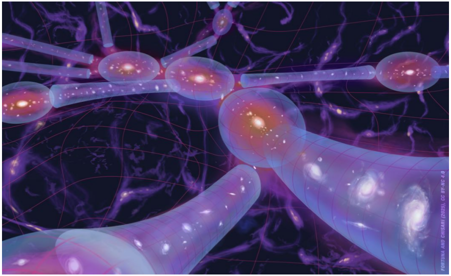
- **Effect** that can probe the **connection** between galaxies and their **dark matter halos** and the 3D properties of the large-scale structure in which the galaxies were **formed** and **evolved**



Credit: Fortuna & Chisari (2025)

Ultraviolet Near Infrared Optical Northern Survey

- CFHT, Pan-STARRS, Subaru Telescope (u,g,r,i,z-band)

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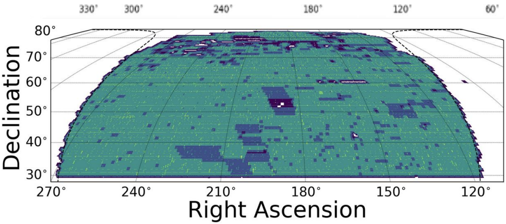

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  ~340 millions of galaxy shapes
  4800 deg^2 (*Gwyn et al. 2025*)

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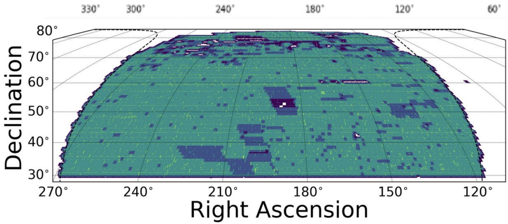

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- Direct **measure** of **intrinsic alignments** by cross-matching UNIONS 2D shapes of galaxies with **spectroscopic** surveys (*Hervas Peters et al. 2025*)

Motivations and challenges

- **Scope of this work:** investigating ways of analyzing intrinsic alignments of galaxies by using their **3D shapes** and **3D orientations**

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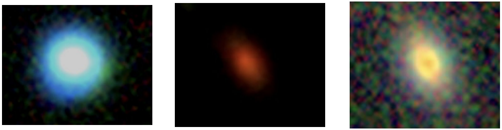
- **Aims and challenges:**
  1) To infer the distribution of the 3D shapes of galaxies from the distribution of their observed projected images by using a model of **3D morphology** of galaxies that live inside dark matter halos
  2) To measure **2D intrinsic alignments** of galaxies and halos and predict a signal by using our model of 3D morphology

I) Inferring the distribution of the 3D shapes of galaxies from the distribution of their observed projected images

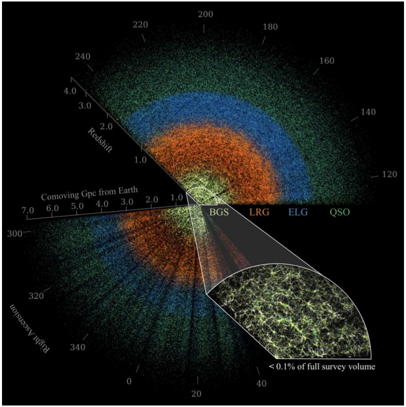
Data

- **Spectroscopic samples** of galaxies:

  Emission Line Galaxies (ELG), **Luminous Red Galaxies (LRG)** and **Bright Galaxy Survey (BGS)**, Dark Energy Spectroscopic Instrument (DESI)



Credit: DESI Legacy Imaging Survey



DESI Collaboration 2025

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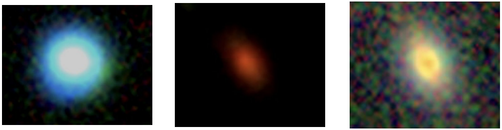

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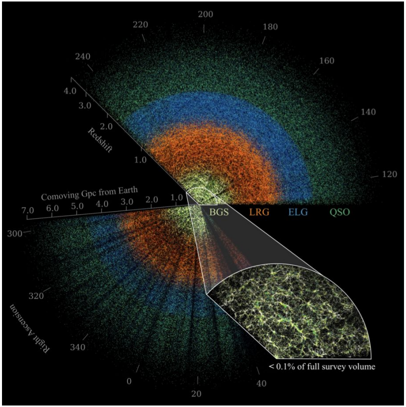

DESI Collaboration 2025

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  . **ELG-UNIONS**: ~360 000 galaxies
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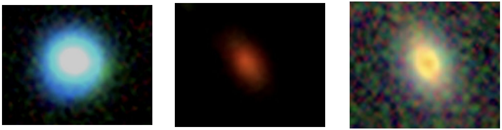

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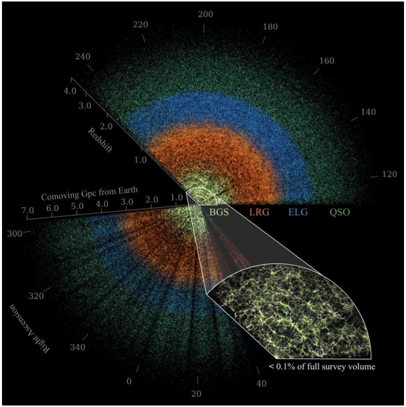

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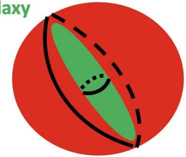
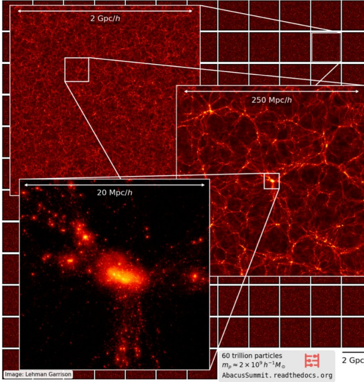
- **Selection** of halos that host central galaxies using the **Halo Occupation Distribution (HOD) model** (*Zhang et al. 2025*)



N-body simulations AbacusSummit

- **Boxes** of size 2 Gpc/h at different **snapshots**



Maksimova et al. 2021

N-body simulations AbacusSummit

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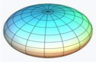
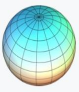
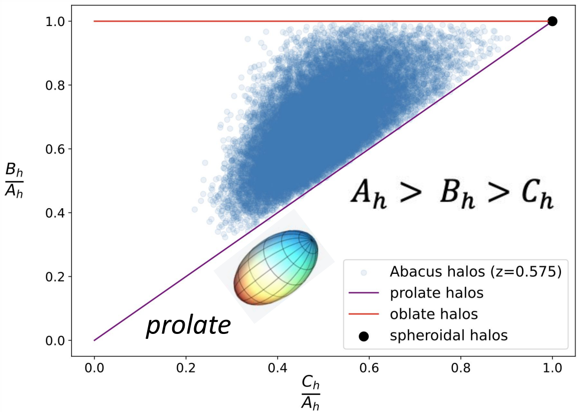
- **Halo catalogues** (CompaSO algorithm) with 3D shapes and 3D orientations

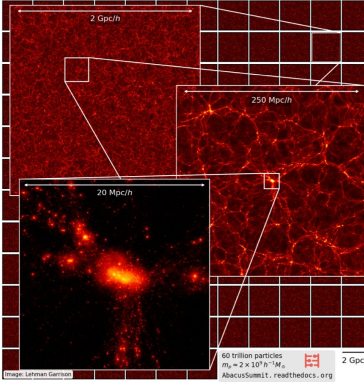


oblate

spheroidal







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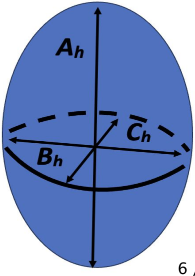

Model of 3D morphology of galaxies inside halos

- **Populating** halos with a 3D **central galaxy** whose shape follows the convention: $A_g > B_g > C_g$

$$A_g = \tau_A A_h \qquad B_g = \tau_A \tau_B B_h \qquad C_g = \tau_A \tau_C C_h$$

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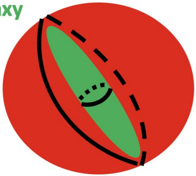

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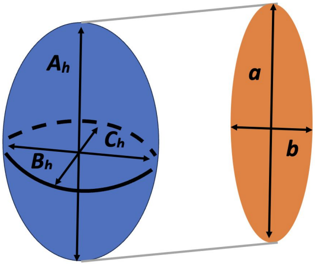
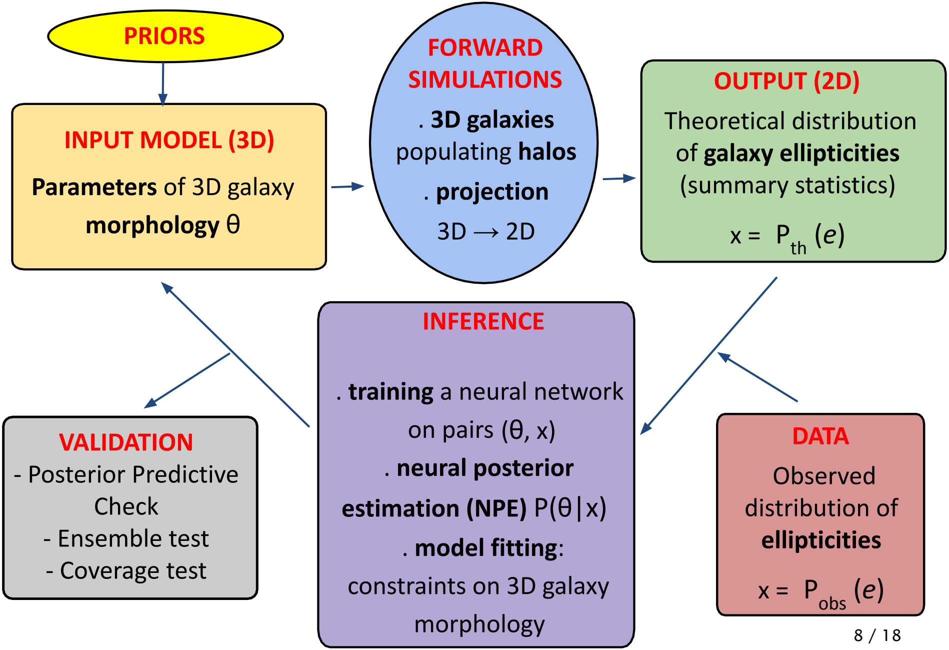
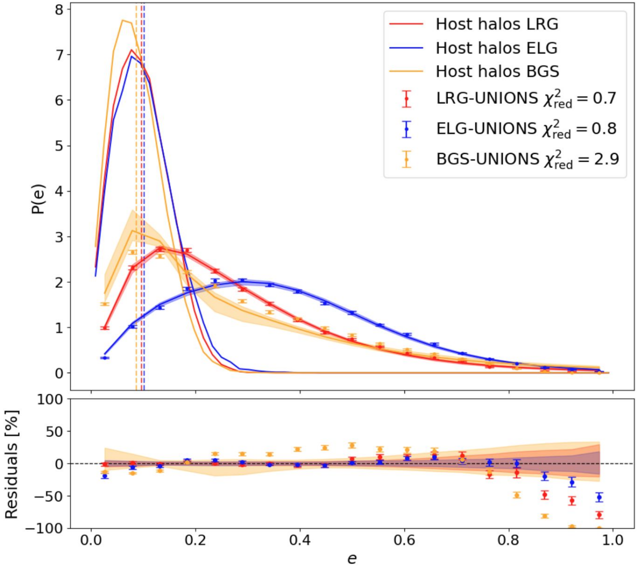
- **Projection** in 2D (*Lamman et al. 2023*) for different μ_{τ_B} , μ_{τ_C} drawn uniformly in [0;1]



Methodology: simulation-based inference (SBI)



Results: distribution of ellipticities P(*e*)



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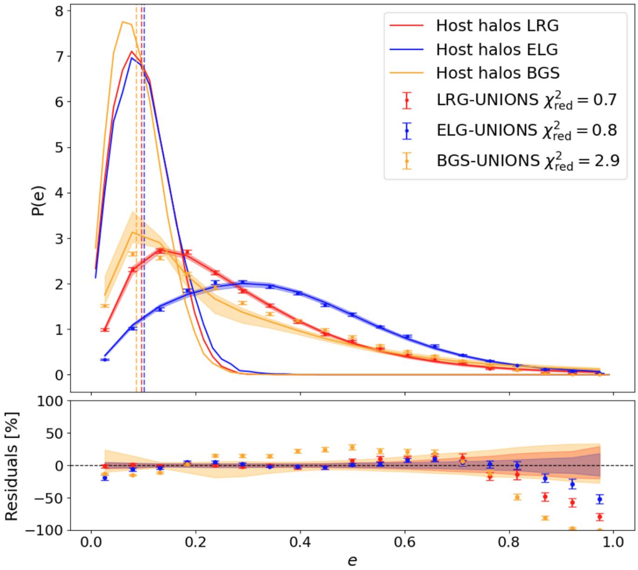
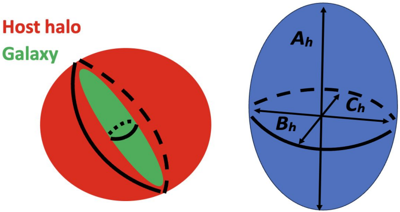


- **Conclusion:** we can constrain the distribution of the shapes of the galaxies **in 3D** from the distribution of their **projected images**.

Results: constraints on the 3D galaxy-halo connection

μ_{τ_B}, μ_{τ_C} : means of τ_B, τ_C
for the whole population



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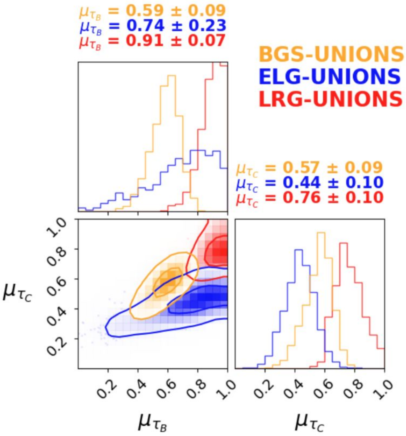

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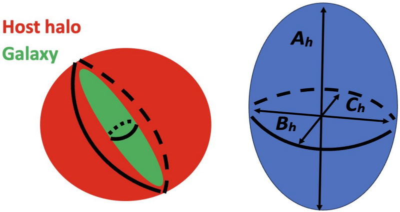

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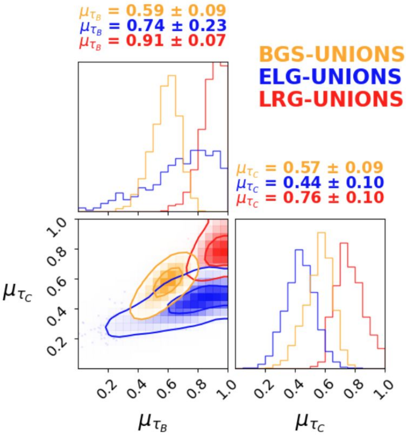

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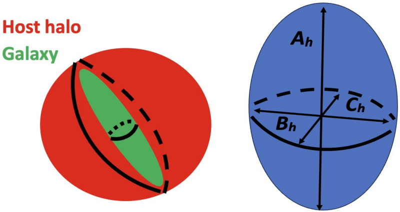

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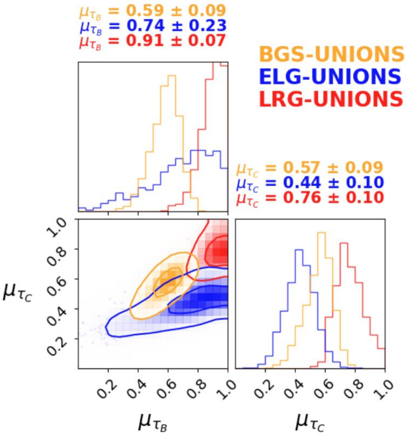

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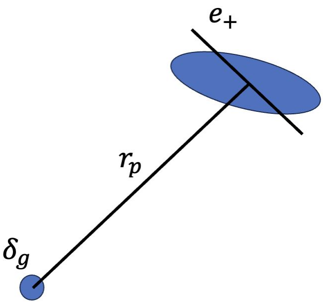
- BGS 3D shapes are between ELG and LRG ones.

II) Measuring 2D intrinsic alignments of galaxies and halos and predicting a signal thanks to our model of 3D morphology

Intrinsic alignments of galaxies: estimators

- Shape-density correlation function ξ_{g+}:

$$\xi_{g+}(r_\mathrm{p}, \Pi) = \langle \delta_g e_+ \rangle$$



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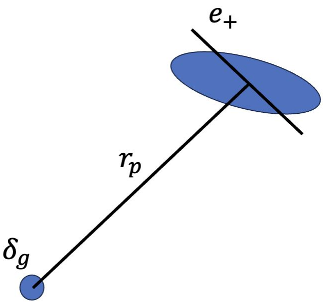

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$$\xi_{g+}(r_\mathrm{p}, \Pi) = \frac{S_+D - S_+R_D}{R_S R_D}$$

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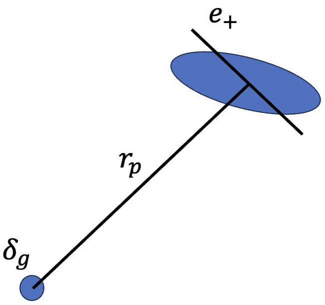

- Estimator of the shape-density correlation function (*Landy & Szalay 1993*):

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- Projected estimator: $$w_{g+}(r_\mathrm{p}) = \int_{-\Pi_\mathrm{max}}^{+\Pi_\mathrm{max}} \mathrm{d}\Pi \, \xi_{g+}(r_\mathrm{p}, \Pi)$$

Results: galaxy intrinsic alignment measurements (1)

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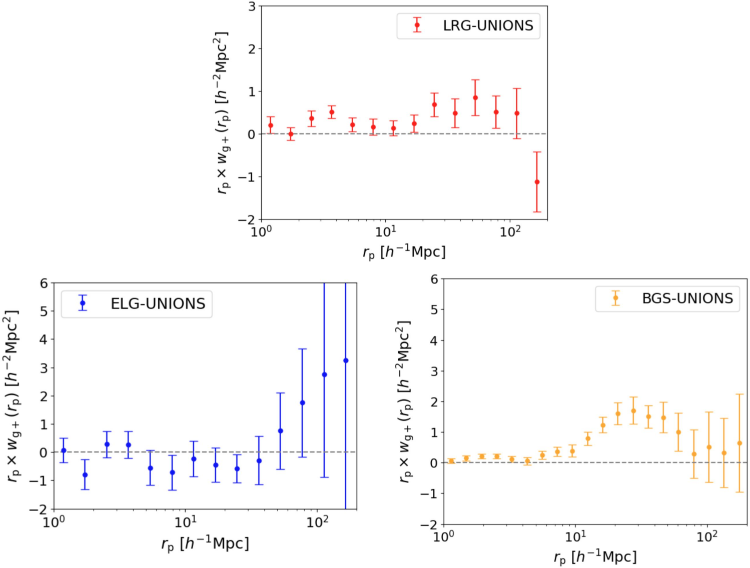

Results: galaxy intrinsic alignment measurements (2)

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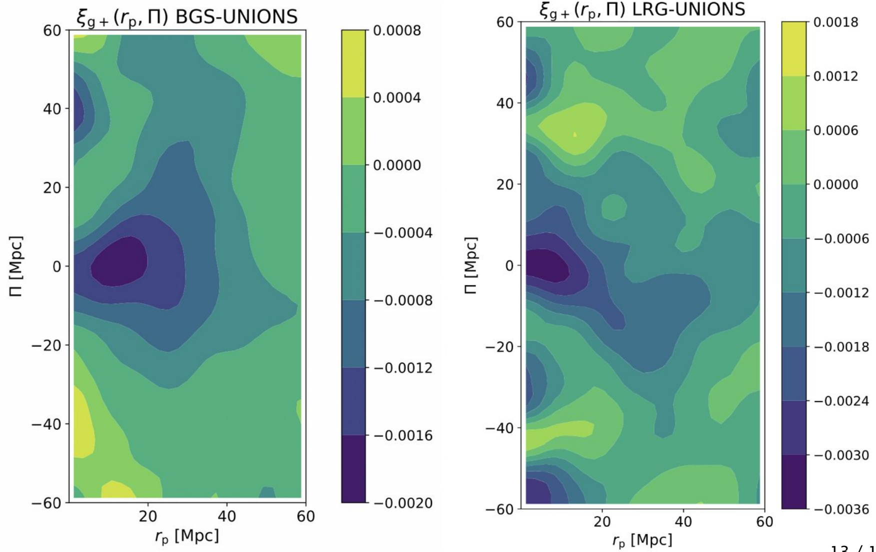

Projection effect

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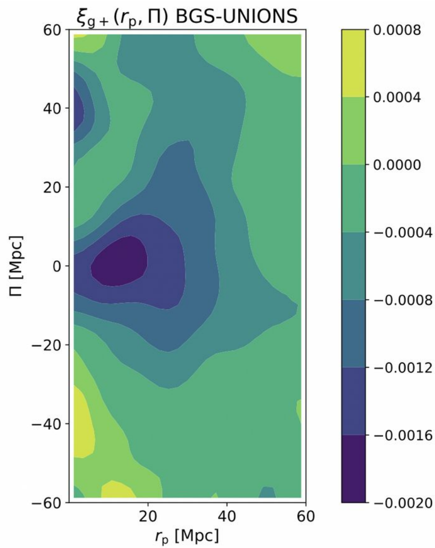
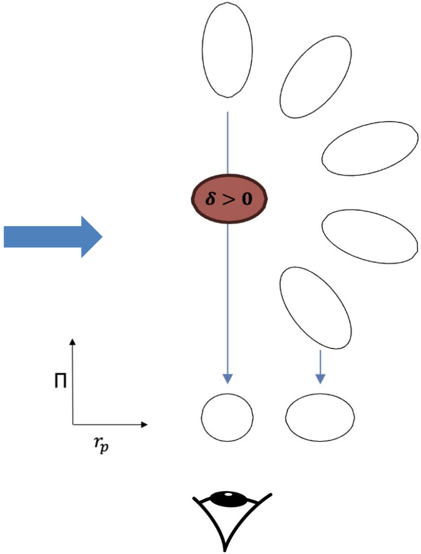
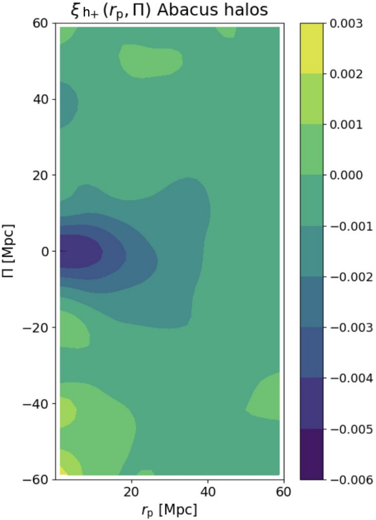
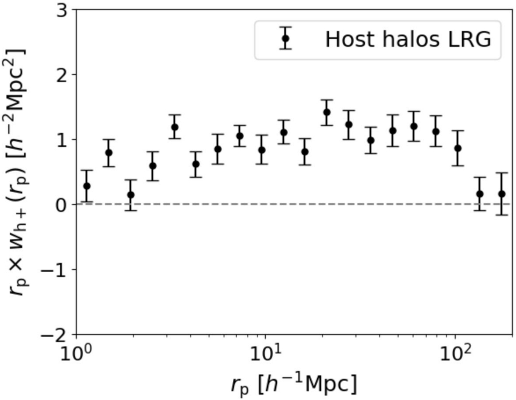




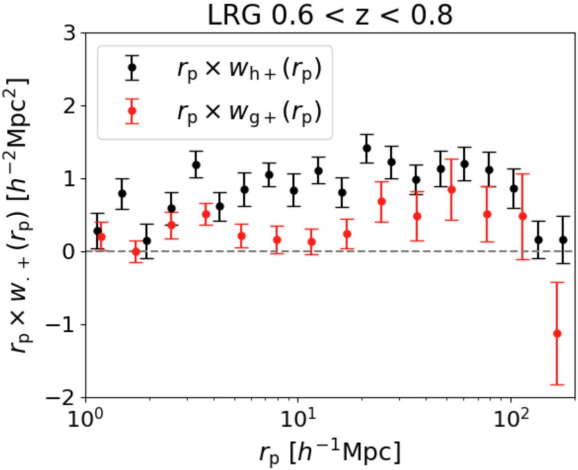
Halo intrinsic alignment measurements

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





Galaxy-halo intrinsic alignment measurements



(Preliminary)

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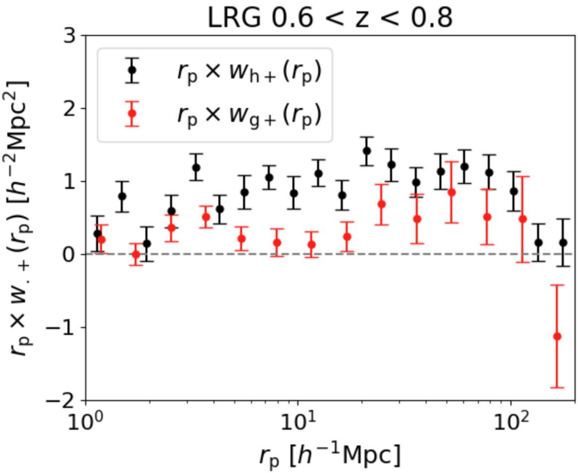

(Preliminary)

- Ongoing work: make a **theoretical prediction** of the galaxy intrinsic alignment signal, using our model of 3D morphology

Conclusion

- Development of a model of **3D morphology** for central galaxies that live inside dark matter halos

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- Development of a **simulation-based inference** method to measure the **distribution** of the 3D shapes of galaxies from the distribution of their **projected images** and found consistent results by testing our model on data and simulations

Conclusion

- Development of a model of **3D morphology** for central galaxies that live inside dark matter halos

- Development of a **simulation-based inference** method to measure the **distribution** of the 3D shapes of galaxies from the distribution of their **projected images** and found consistent results by testing our model on data and simulations

- Measurement of **2D intrinsic alignments** of galaxies from UNIONS data and of halos from the AbacusSummit N-body simulation

Conclusion

- Development of a model of **3D morphology** for central galaxies that live inside dark matter halos

- Development of a **simulation-based inference** method to measure the **distribution** of the 3D shapes of galaxies from the distribution of their **projected images** and found consistent results by testing our model on data and simulations

- Measurement of **2D intrinsic alignments** of galaxies from UNIONS data and of halos from the AbacusSummit N-body simulation

- Ongoing work / next steps:
  - adding a **misalignment** parameter for the central galaxies
  - develop a model of 3D morphology for **satellite galaxies**

Thank you for your attention !

Back up slides

HOD model for the LRG (*Zheng et al. 2007*)

- Mean occupation number of **central** galaxies:

$$\bar{n}_{\rm cent}^{\rm LRG}(M) = \frac{f_{\rm ic}}{2}\,{\rm erfc}\left[\frac{\log_{10}(M_{\rm cut}/M)}{\sqrt{2}\sigma}\right]$$

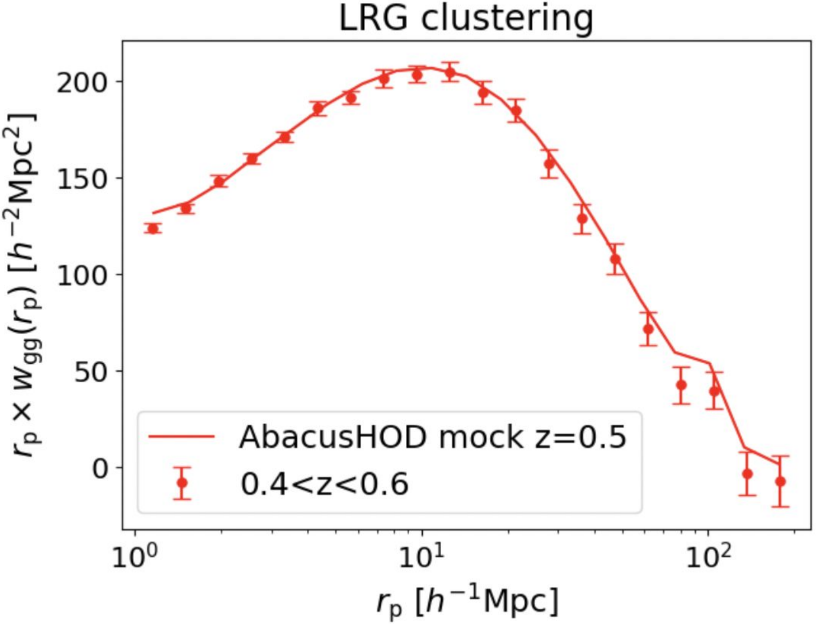
M mass of the host halo
$M_{\rm cut}$ minimum halo mass to set a central galaxy
$f_{\rm ic}$ incompleteness parameter (by definition: $0 < f_{\rm ic} \leq 1$)
σ steepness of the transition from 0 to 1 in the number of central

- Mean occupation number of **satellite** galaxies:

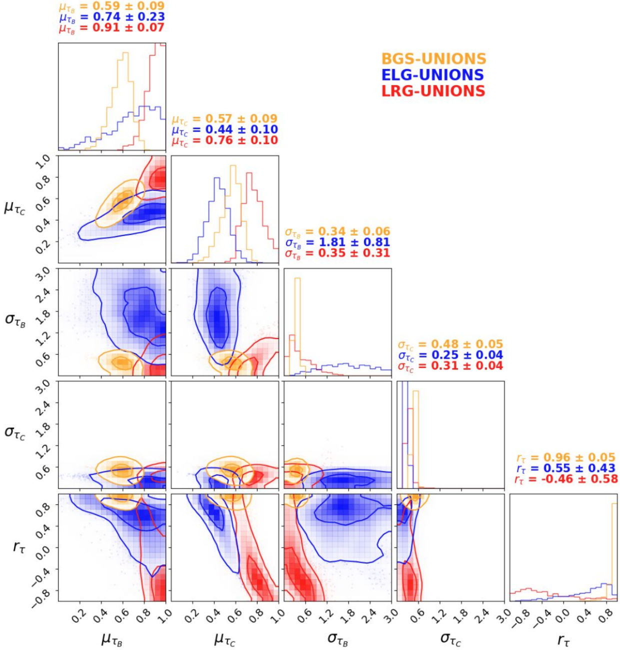
$$\bar{n}_{\rm sat}^{\rm LRG}(M) = \left[\frac{M - \kappa M_{\rm cut}}{M_1}\right]^{\alpha} \bar{n}_{\rm cent}^{\rm LRG}(M)$$

$\kappa M_{\rm cut}$ 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

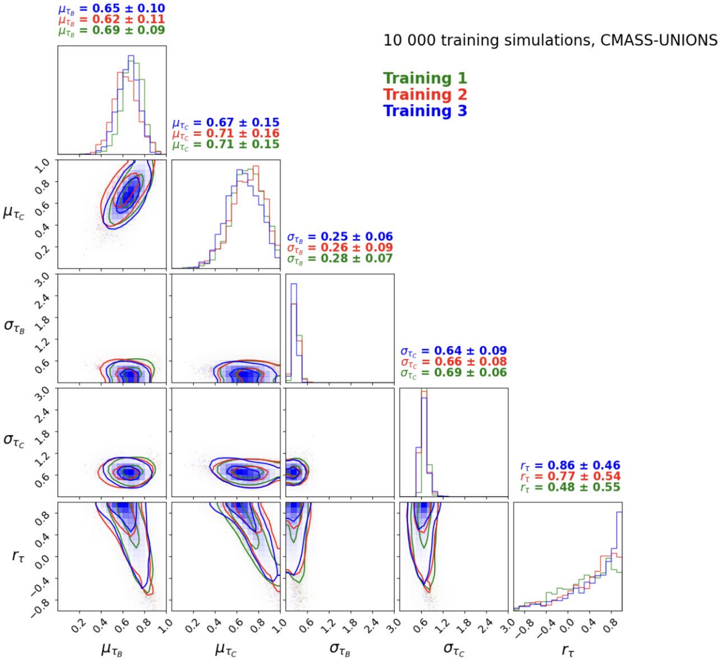
LRG clustering measurement



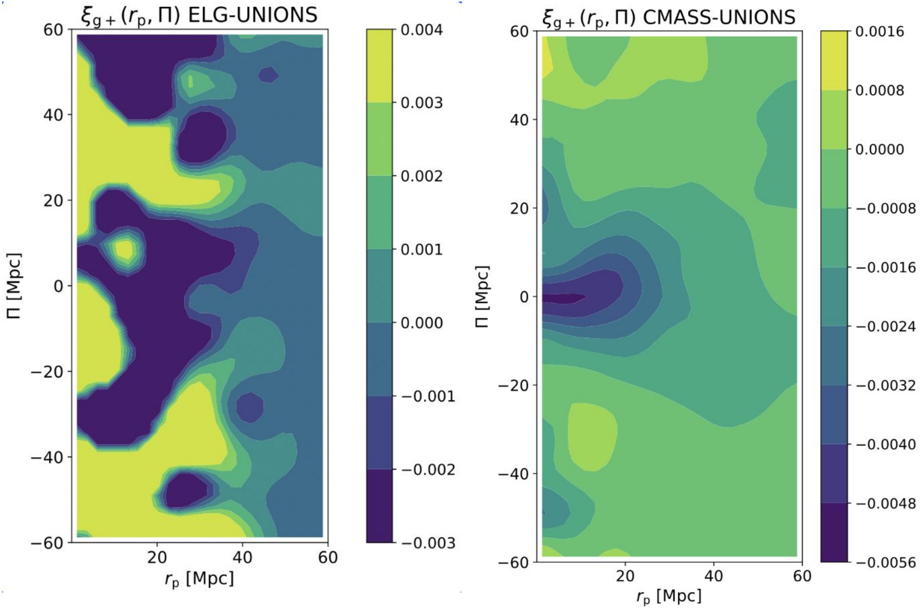
Contours for other parameters



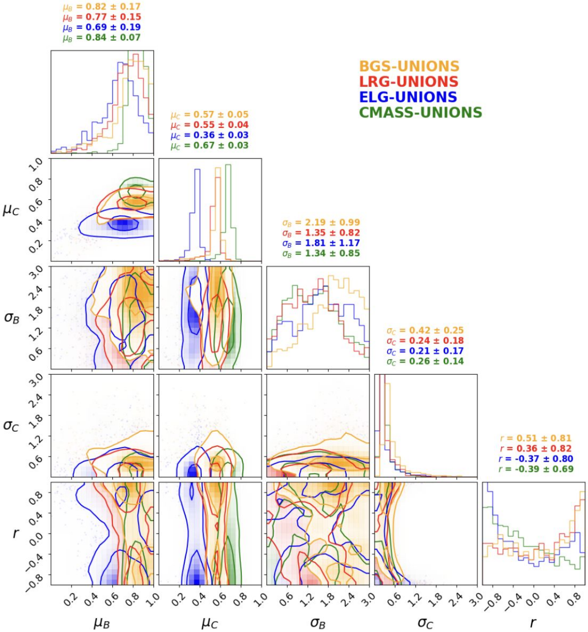
Validation: ensemble test



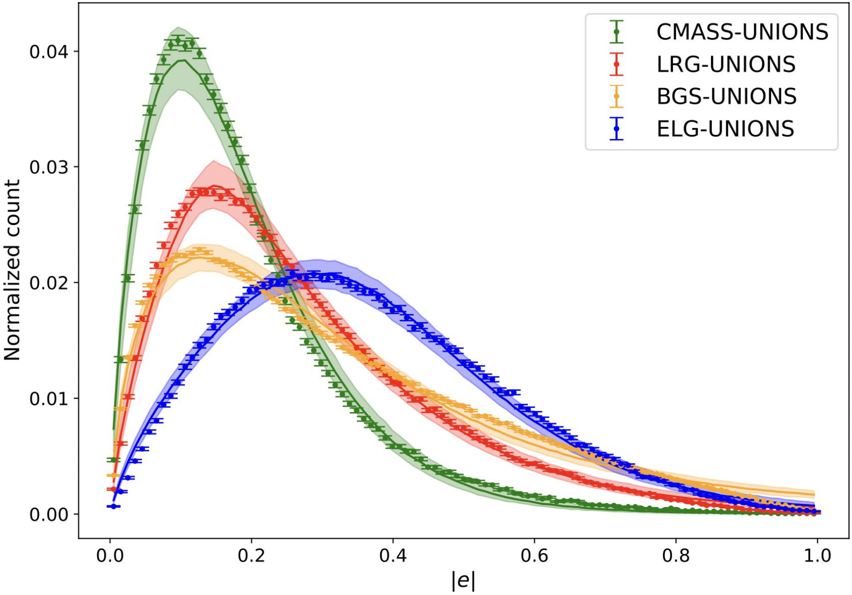
Galaxy intrinsic alignment measurements for other galaxy samples



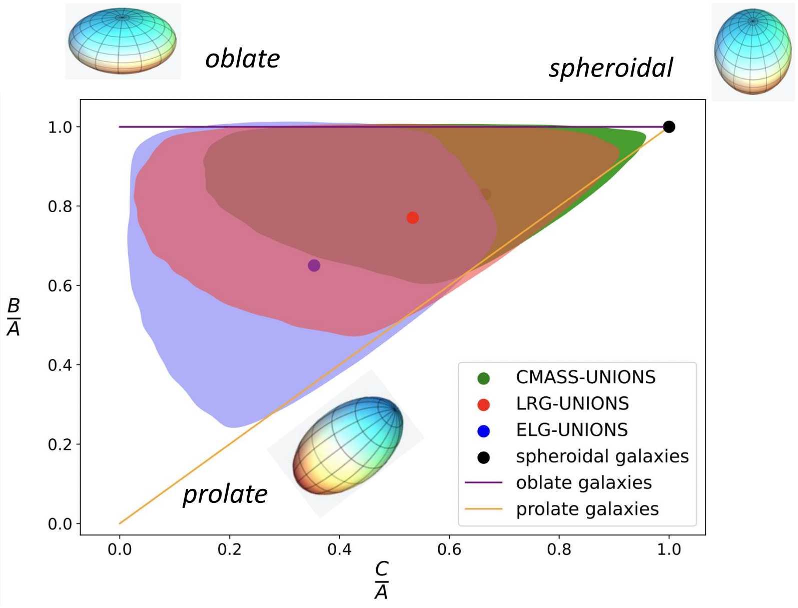
Constraints on the parameters of 3D morphology of galaxies with another simple model



Distribution of ellipticities P (e) with an other simple model



Constraints on the 3D morphology of the galaxies



Other interesting statistics