

# Inferring 3D shapes and measuring intrinsic alignments with UNIONS

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**Supervisors:** Calum Murray, Martin Kilbinger, Sandrine Codis

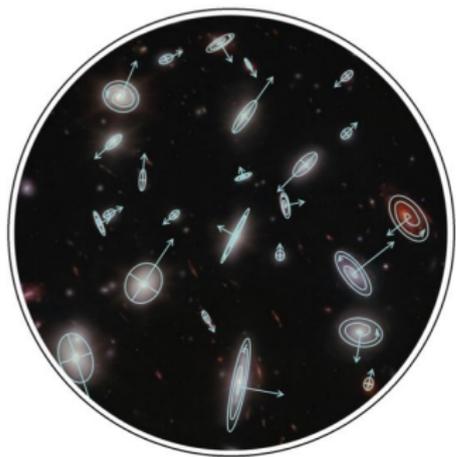
**Laboratory:** CEA, Paris-Saclay, CosmoStat



**Deep CosmoStat Days, CEA Paris-Saclay / DAp**

February 12<sup>th</sup>, 2026

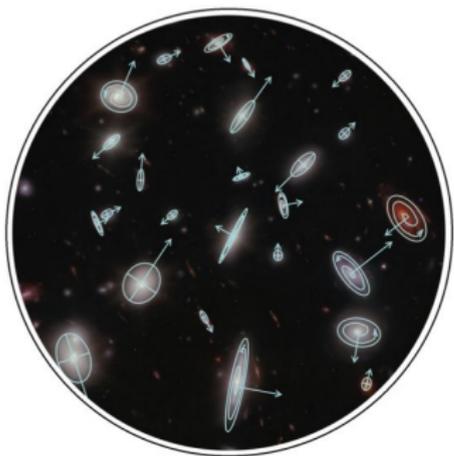
## Context: intrinsic alignments of galaxies



*Lamman et al. 2024*

- **Preferential orientations** of the galaxies due to local interactions with the **tidal field** of dark matter across the **large-scale structure** of the Universe (*Chisari 2025*)

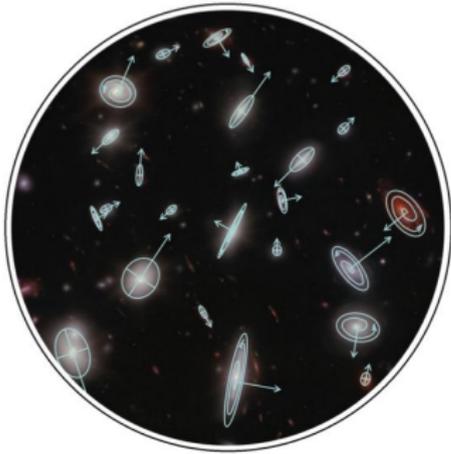
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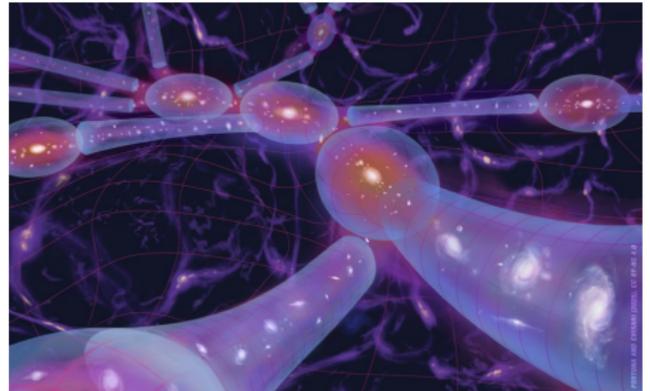
# Context: intrinsic alignments of galaxies



*Lamman et al. 2024*

- **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**

- **Preferential orientations** of the galaxies due to local interactions with the **tidal field** of dark matter across the **large-scale structure** of the Universe (*Chisari 2025*)
- **Correlations** between the shapes of galaxies observed across the sky



*Credit: Fortuna & Chisari (2025)*

# Ultraviolet Near Infrared Optical Northern Survey

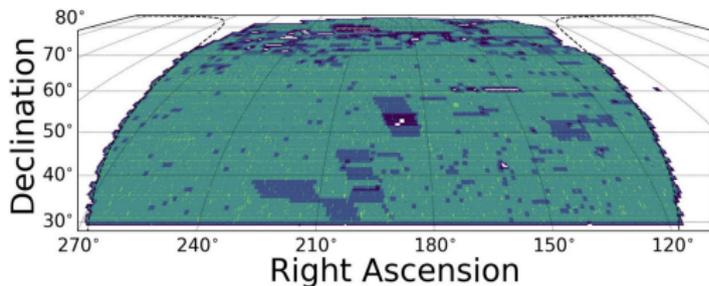


- CFHT, Pan-STARRS, Subaru Telescope (u,g,r,i,z-band)

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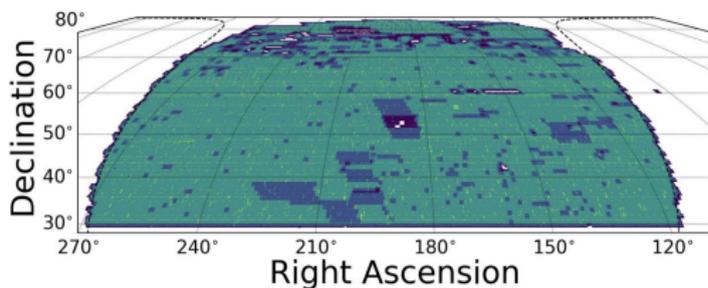


- **Photometric galaxy survey** in the northern hemisphere  
~340 millions of galaxy shapes  
4800 deg<sup>2</sup> (*Gwyn et al. 2025*)

# Ultraviolet Near Infrared Optical Northern Survey



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- **Photometric galaxy survey** in the northern hemisphere  
~340 millions of galaxy shapes  
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- Direct **measure of intrinsic alignments** by cross-matching UNIONS with **spectroscopic** surveys: cross-correlations between the 2D shapes of galaxies and the underlying galaxy density field (*Hervas Peters et al. 2025*)

## Project challenges and motivations

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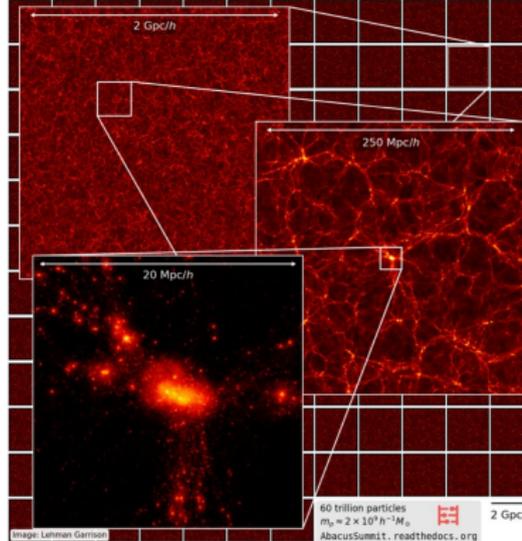
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- **Main issue:** we do not have access to the 3D shapes of galaxies directly in the data => we want to use simulations
- **Aims and challenges:**
  - 1) To develop a model of 3D morphology based on **simulated 3D halo shapes** to infer the distribution of the shapes of the galaxies in 3D from the distribution of their projected images
  - 2) To measure **2D intrinsic alignments** of galaxies and compare with the signal of projected halo shapes

*1) Measurement of the distribution of the 3D shapes of galaxies from the distribution of their projected images*

# Modelling (1): N-body simulations

## AbacusSummit

- Boxes of size 2 Gpc/h and halo light cones

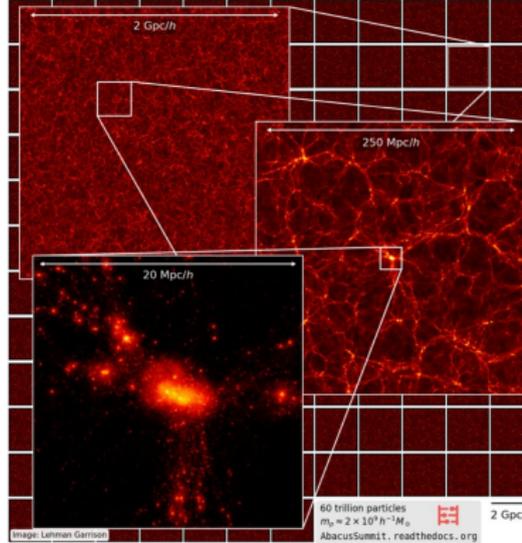


*Maksimova et al. 2021*

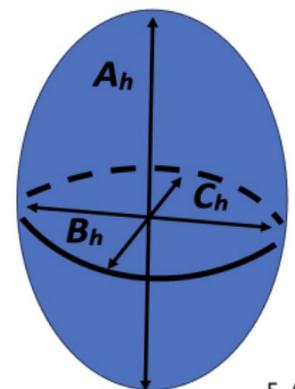
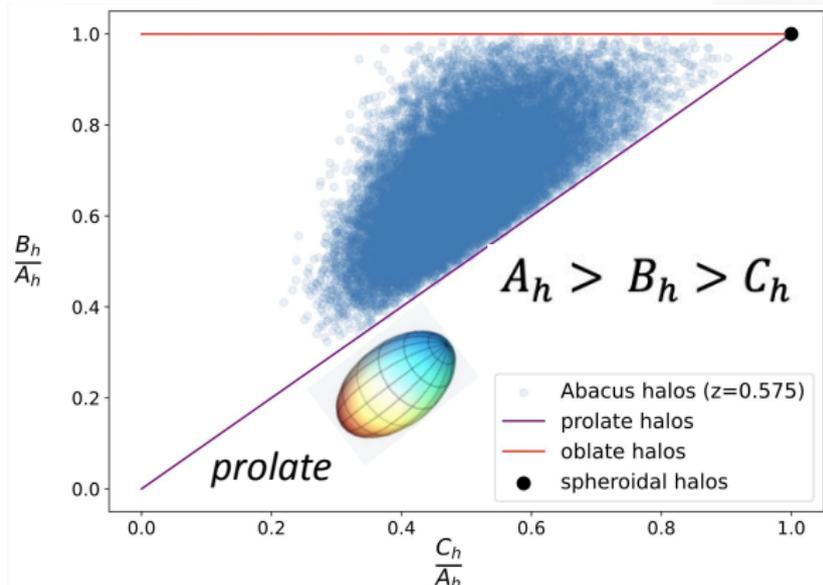
# Modelling (1): N-body simulations

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- **Boxes** of size 2 Gpc/h and **halo light cones**
- **Catalogs** of halos with 3D shapes and 3D orientations



*Maksimova et al. 2021*



## Modelling (2): 3D morphology of galaxies inside halos

- **Settlement** of each halo by a 3D **central galaxy** of shape  $A_g > B_g > C_g$  such that:

$$A_g = A_h \quad B_g = \tau_B B_h \quad C_g = \tau_C C_h$$

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

Host halo  
Galaxy



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$$\Sigma = \begin{pmatrix} \sigma_{\tau_B}^2 & r_{\tau} \sigma_{\tau_B} \sigma_{\tau_C} \\ r_{\tau} \sigma_{\tau_B} \sigma_{\tau_C} & \sigma_{\tau_C}^2 \end{pmatrix}$$

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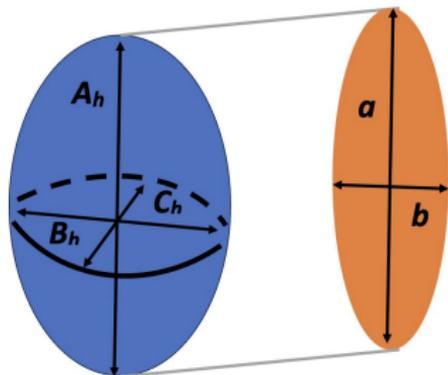
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- **Projection** in 2D ([Lamman et al. 2023](#)) for different  $\mu_{\tau_B}, \mu_{\tau_C}$  drawn uniformly in  $[0; 1]$

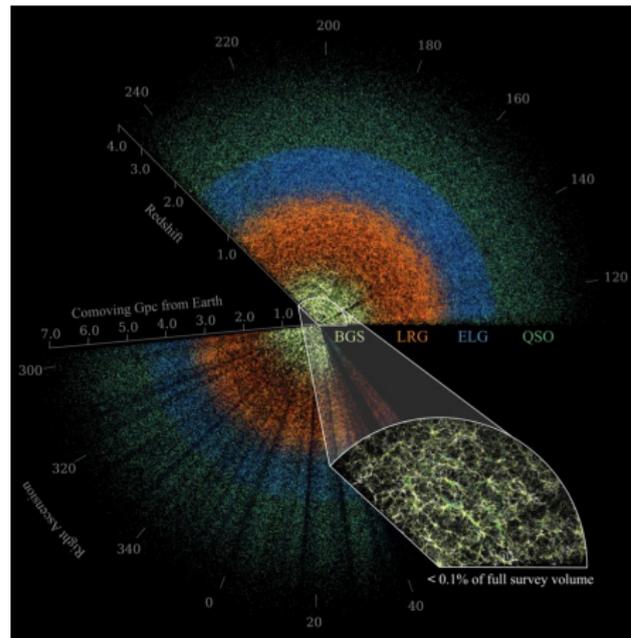


# Data

- Spectroscopic samples of galaxies:
  - **ELG**, **LRG** and **BGS**, Dark Energy Spectroscopic Instrument (DESI) DR1



*Credit: DESI Legacy Imaging Survey*



*DESI Collaboration 2025*

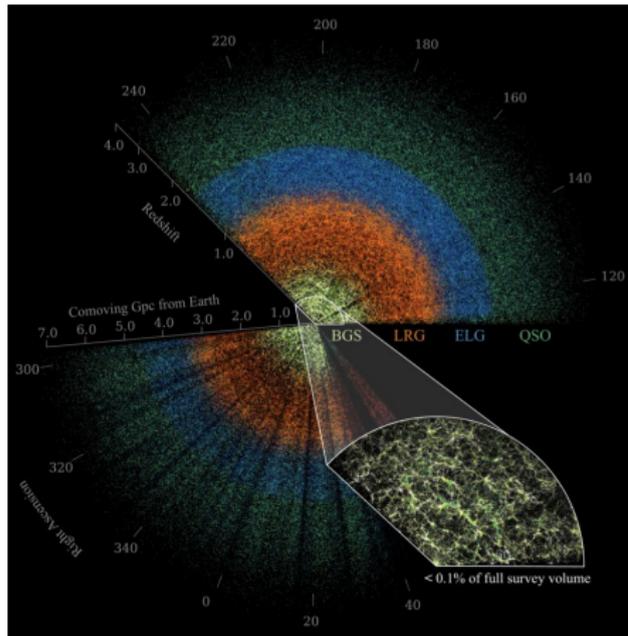
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- **Cross-match** with **UNIONS** forms
  - . **ELG-UNIONS**: ~360 000 galaxies
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*DESI Collaboration 2025*

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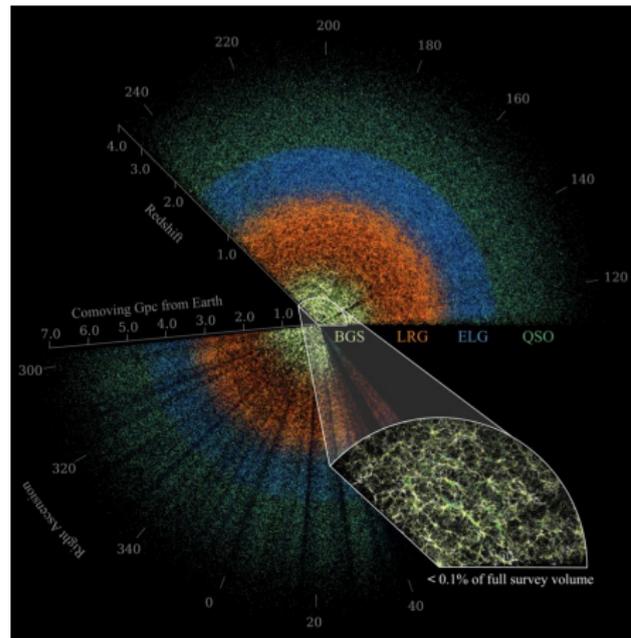
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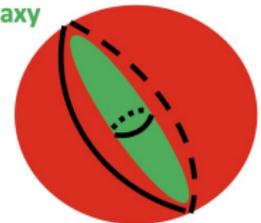
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- **Selection** of halos that host central galaxies using the **Halo Occupation Distribution (HOD)** model (*Zhang et al. 2025*)

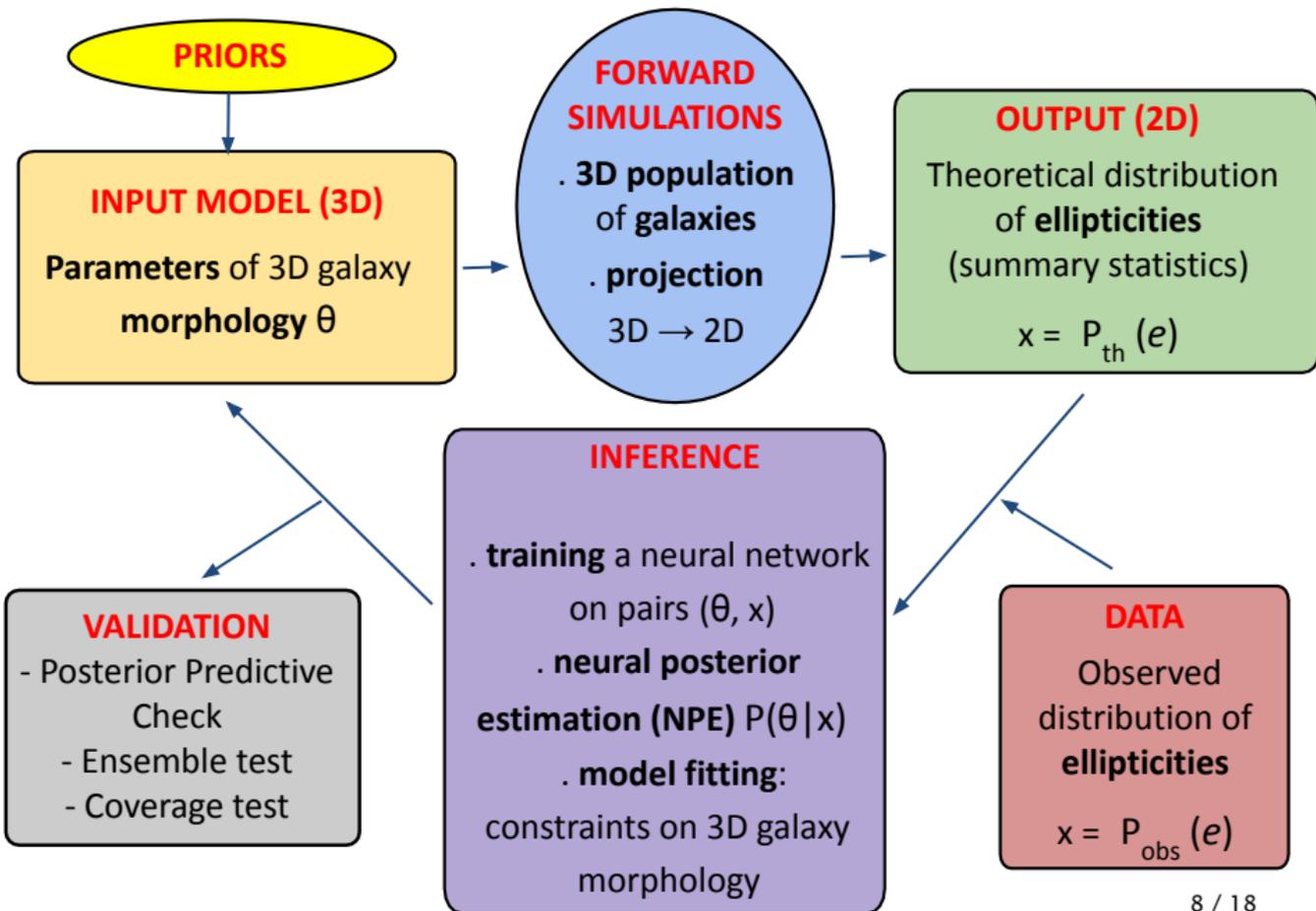


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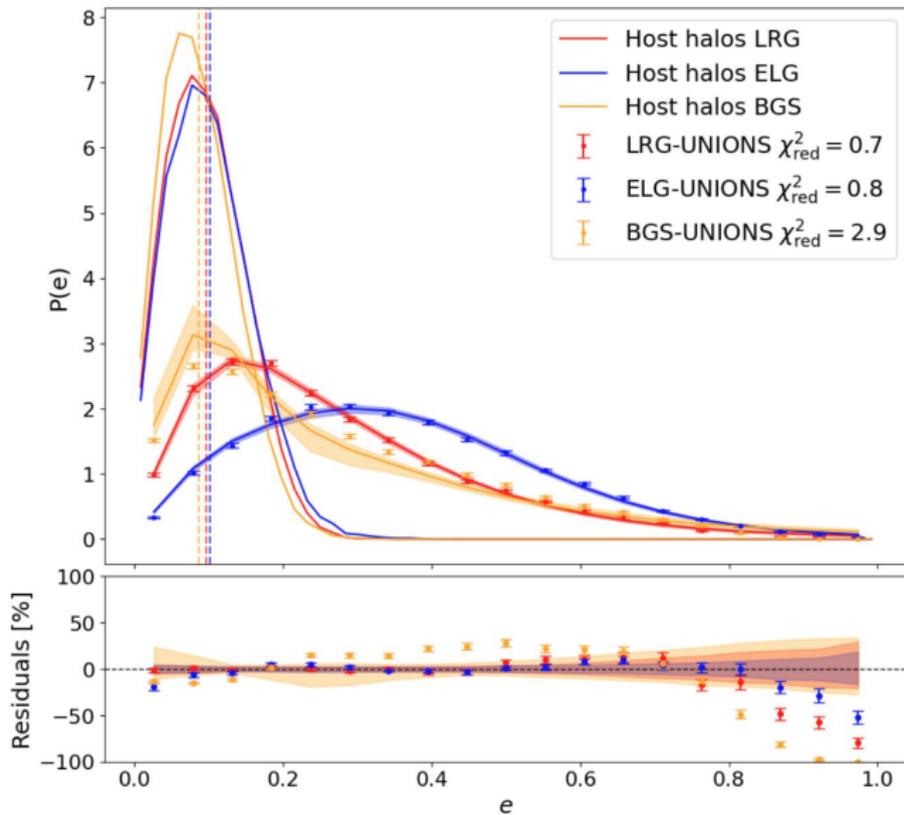
**Host halo**  
**Galaxy**



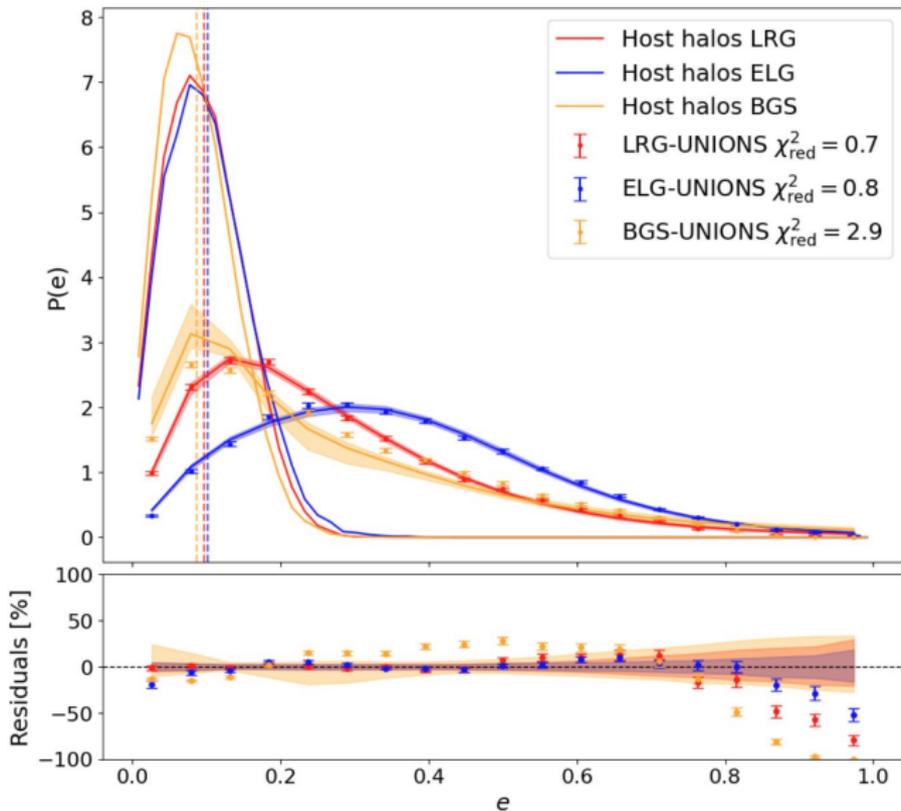
# Methodology: simulation-based inference (SBI)



# Results: distribution of ellipticities $P(e)$



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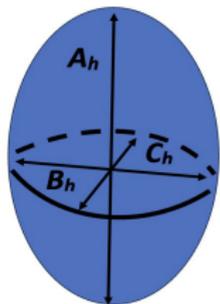
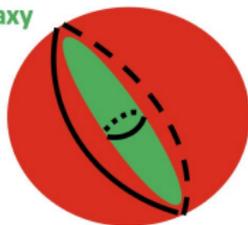


- **Conclusion:** we can constrain the distribution of the shapes of the galaxies in **3D** from the distribution of their **projected** images.

# Results: constraints on the 3D galaxy-halo connection

$\mu_{\tau_B}, \mu_{\tau_C}$ : means of  $\tau_B, \tau_C$   
for the whole population

Host halo  
Galaxy

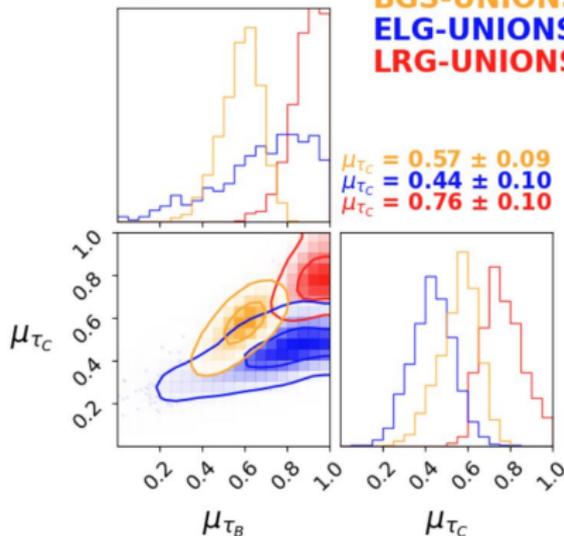


$$B_g = \tau_B B_h \quad C_g = \tau_C C_h$$

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

$$\begin{aligned} \mu_{\tau_B} &= 0.59 \pm 0.09 \\ \mu_{\tau_B} &= 0.74 \pm 0.23 \\ \mu_{\tau_B} &= 0.91 \pm 0.07 \end{aligned}$$

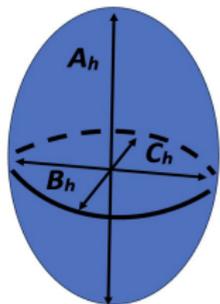
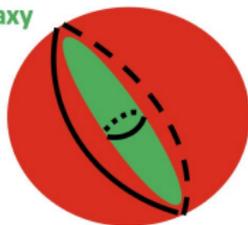
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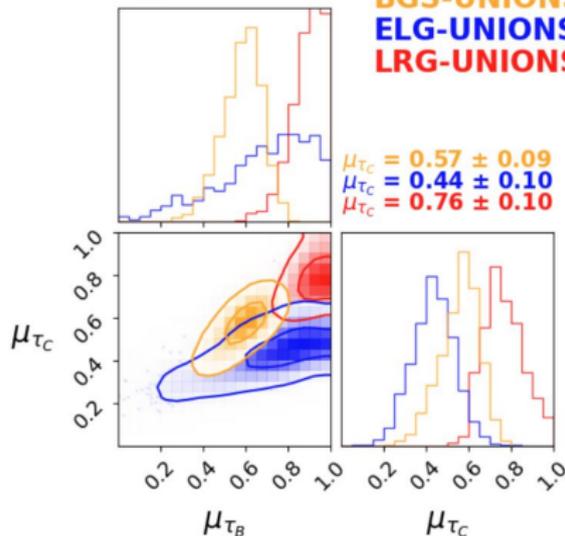


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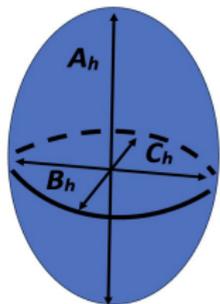
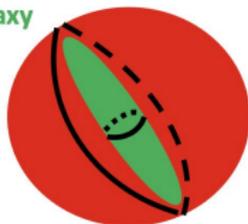


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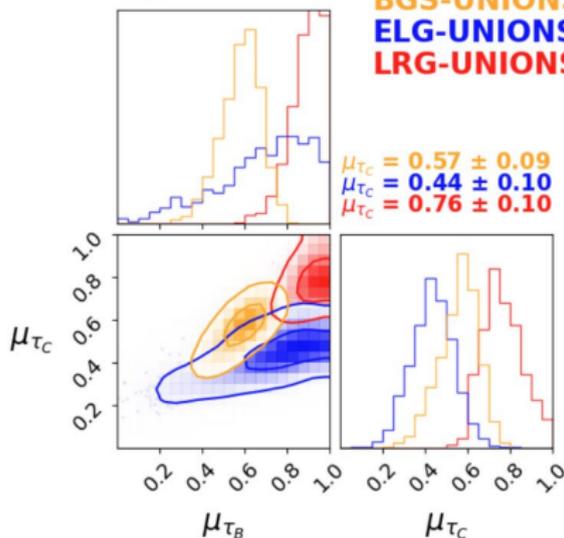


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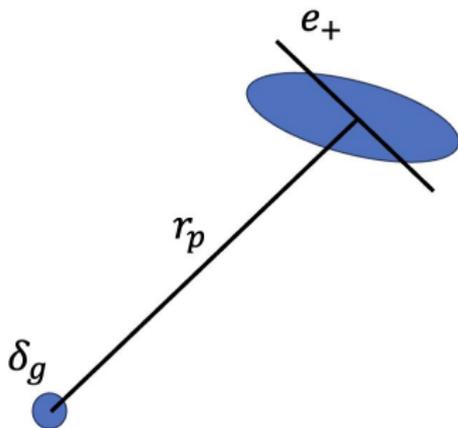
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- BGS 3D shapes are between ELG and LRG ones.

*II) Measurement of 2D intrinsic alignments of galaxies and comparison with the signal of projected halo shapes*

# Measurement of intrinsic alignments of galaxies

- Shape-density correlation function  $\xi_{g+}$ :

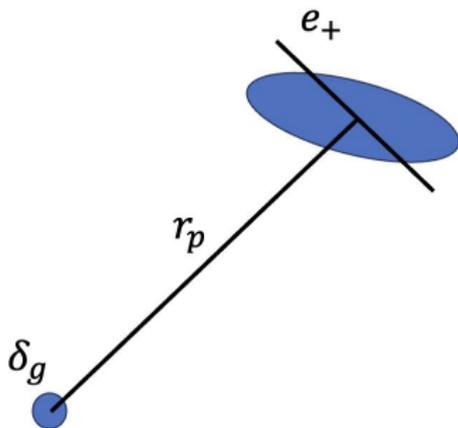
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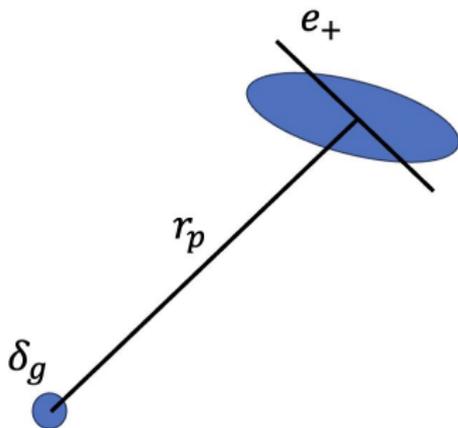
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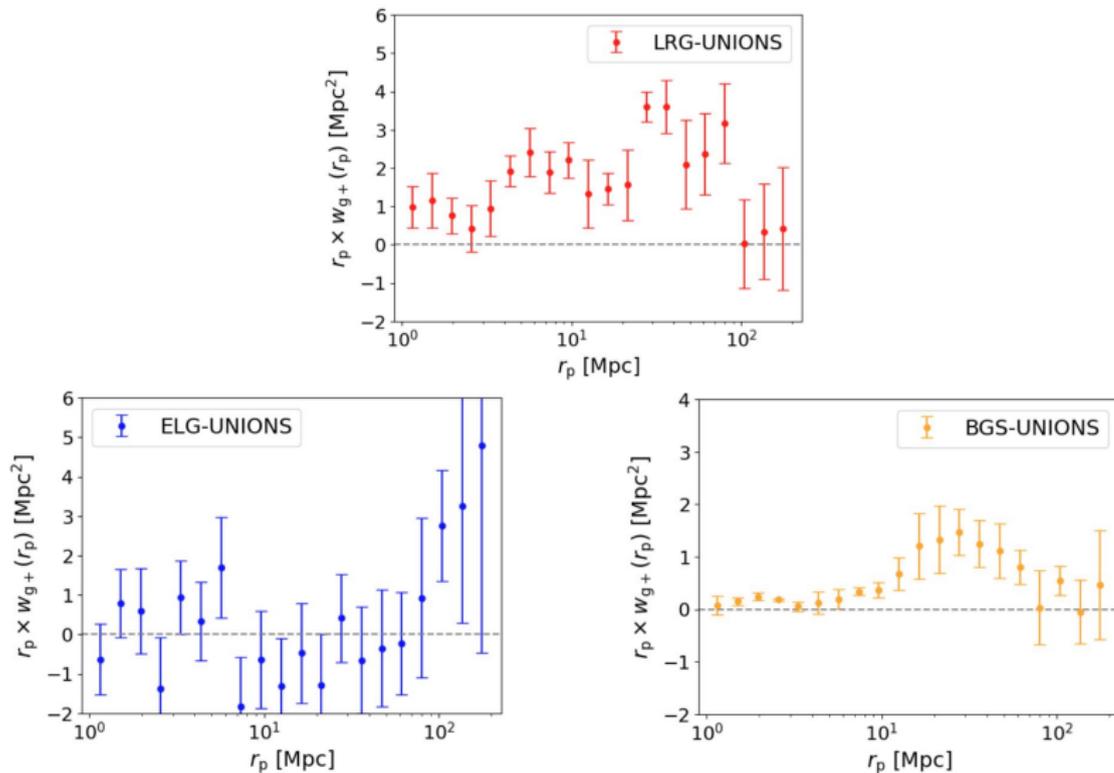
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- Projected estimator:  $w_{g+}(r_p) = \int_{-\Pi_{\max}}^{+\Pi_{\max}} d\Pi \xi_{g+}(r_p, \Pi)$

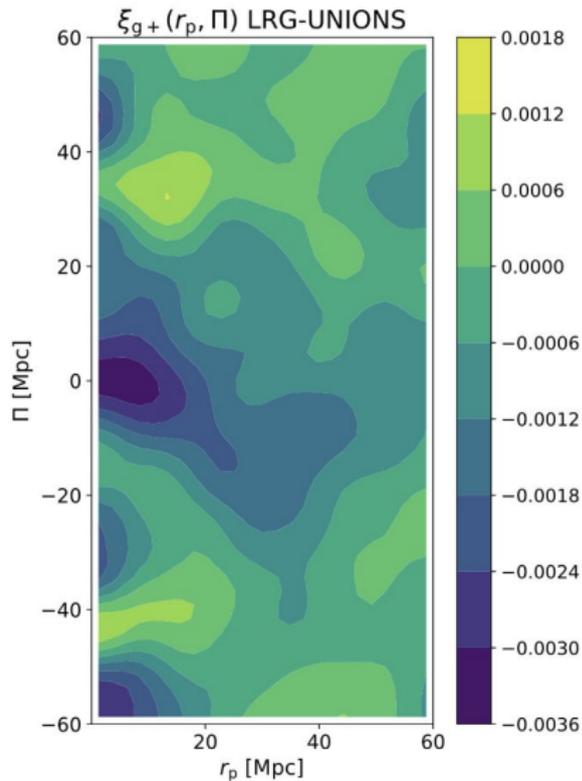
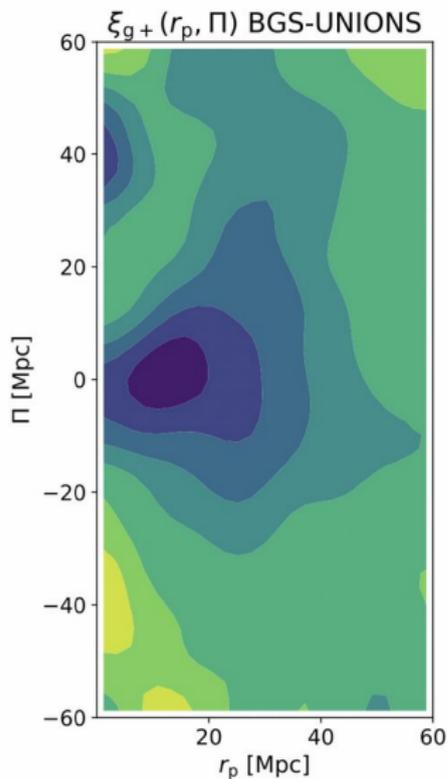
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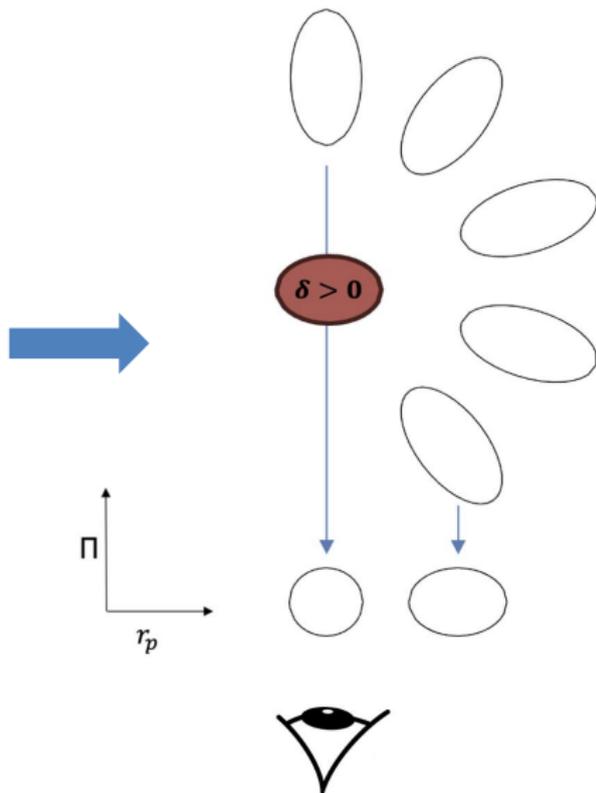
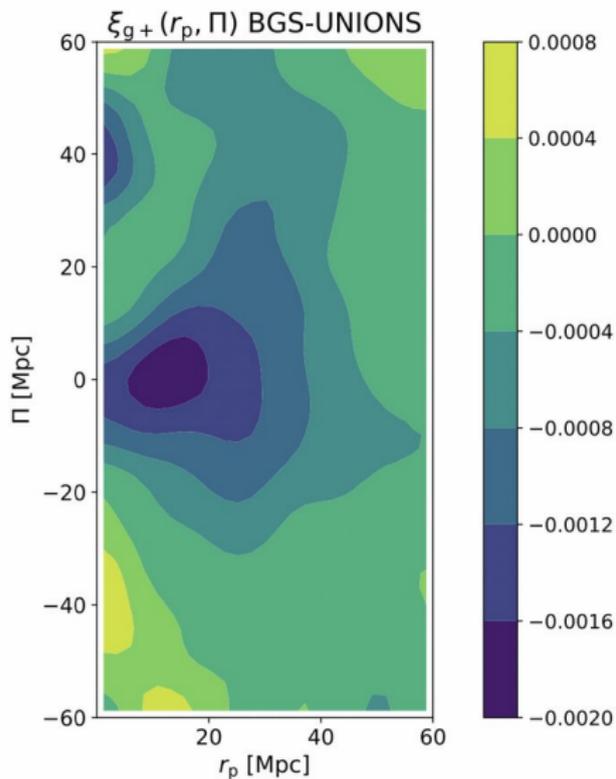
# Results: galaxy intrinsic alignment measurements (2)

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



# Projection effect

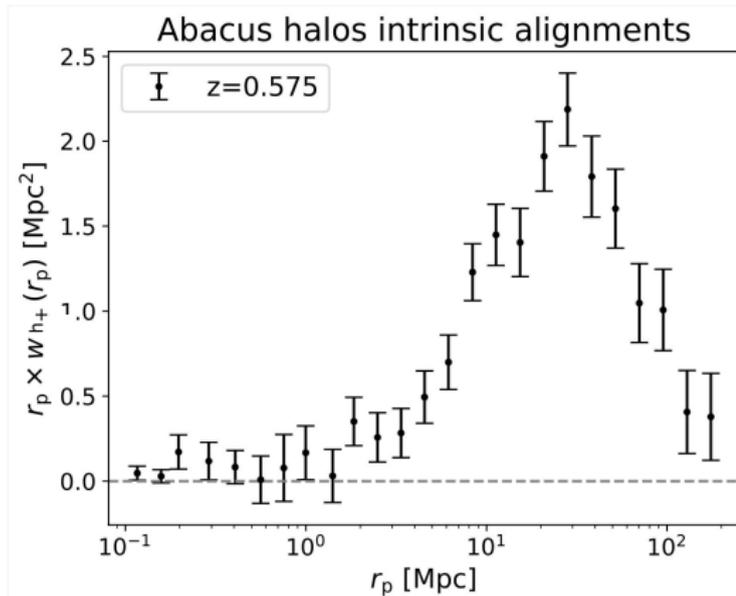
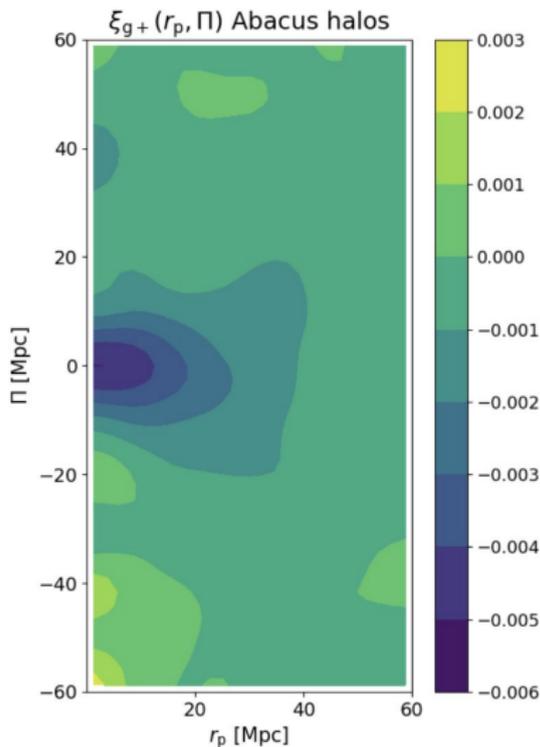
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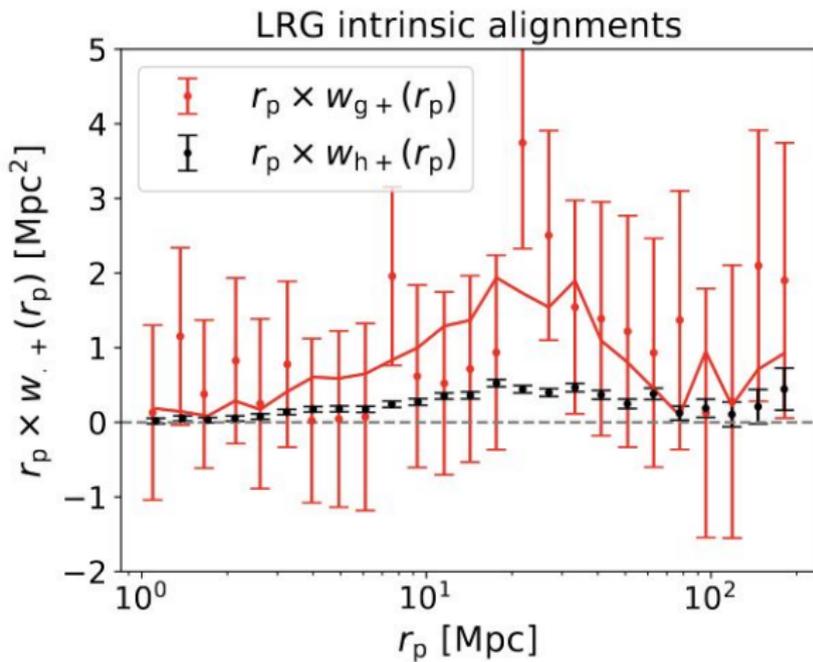
# Halo intrinsic alignment measurement

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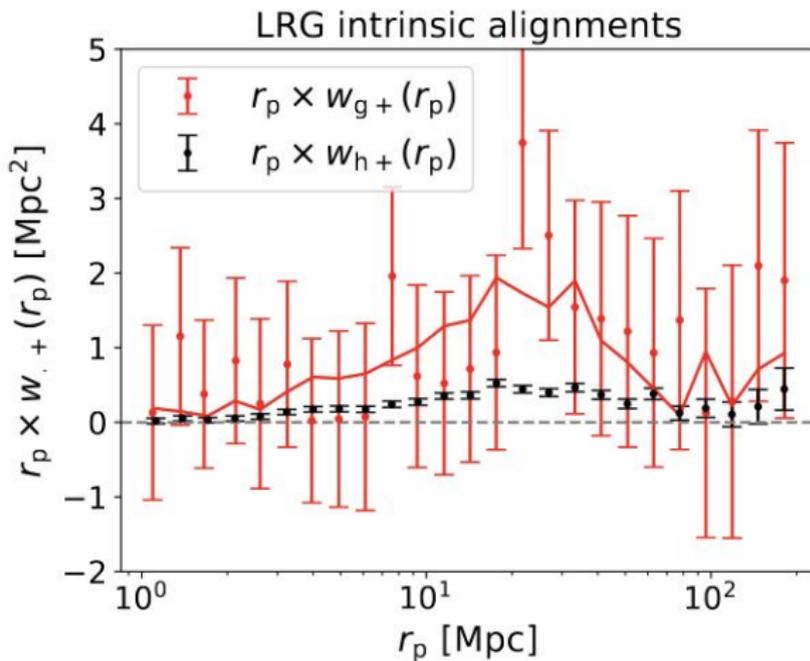


# Galaxy-halo intrinsic alignments measurements



*(Preliminary)*

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*(Preliminary)*

- In addition to the intrinsic alignments of galaxies, we can measure properties about the **distribution of 3D shapes** of galaxies.

## Conclusion

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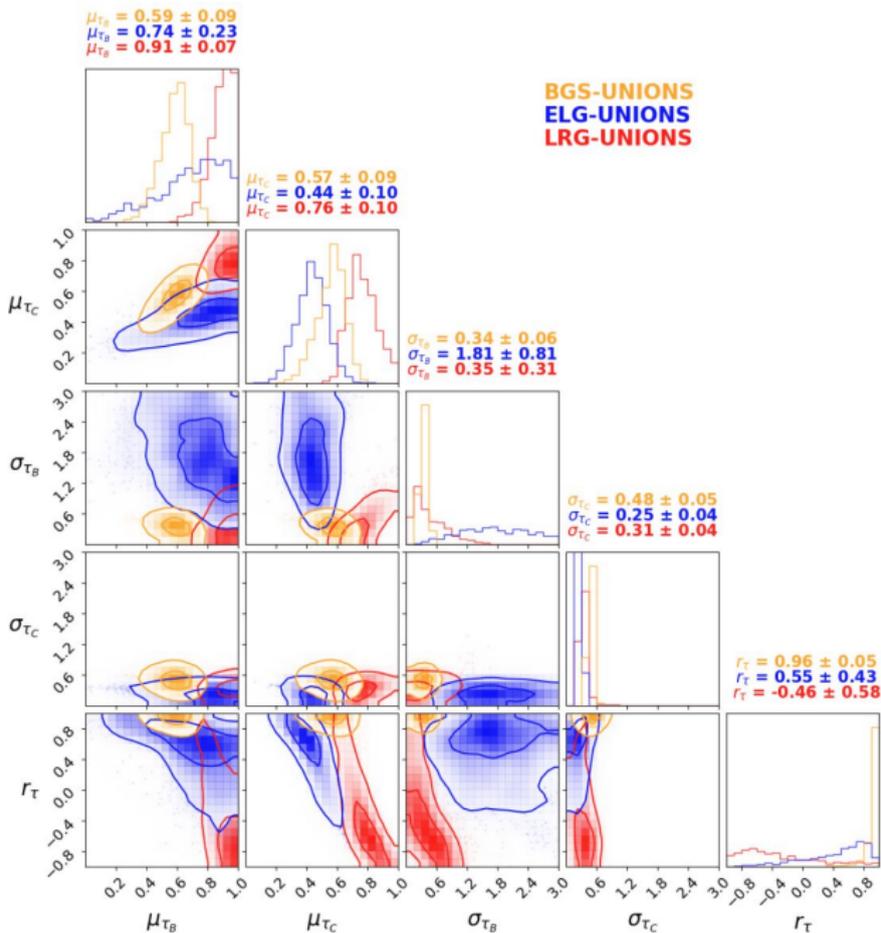
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- Measurement of **2D intrinsic alignments** of galaxies from UNIONS data and of halos from the AbacusSummit N-body simulation
- Ongoing work:
  - make a **theoretical prediction** for the alignment signal, using our model of 3D morphology
  - implementing a model of 3D morphology for satellite galaxies

**Thank you for your attention !**

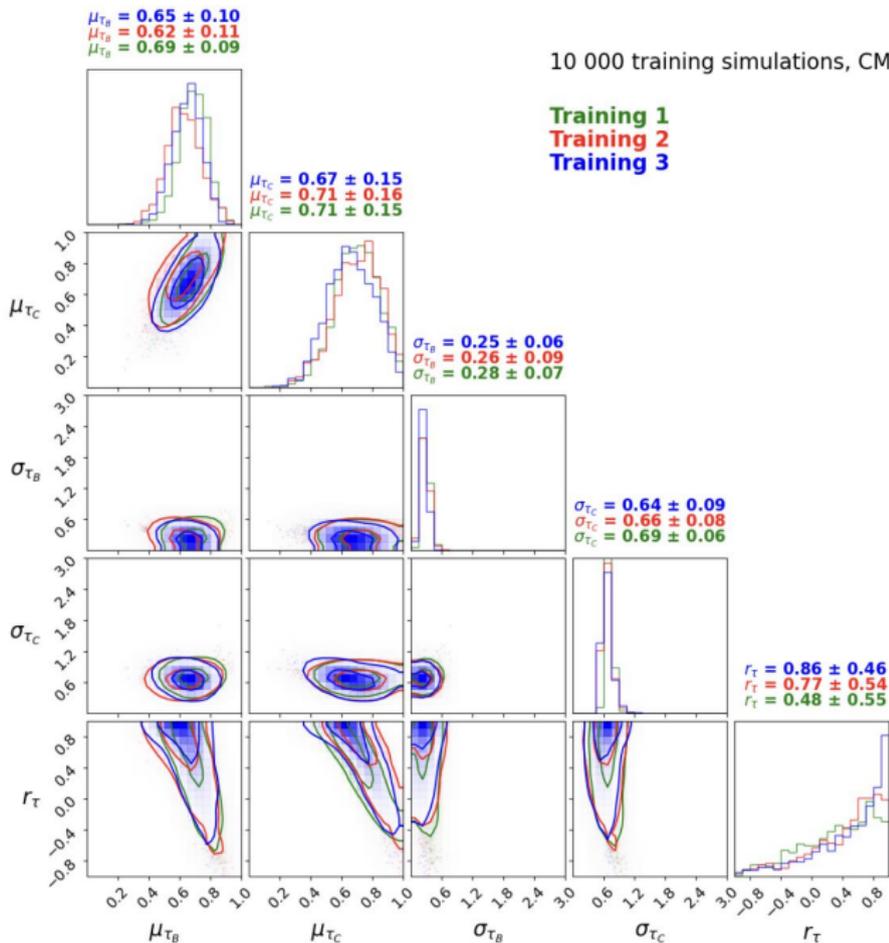
***Back up slides***

# Contours for other parameters

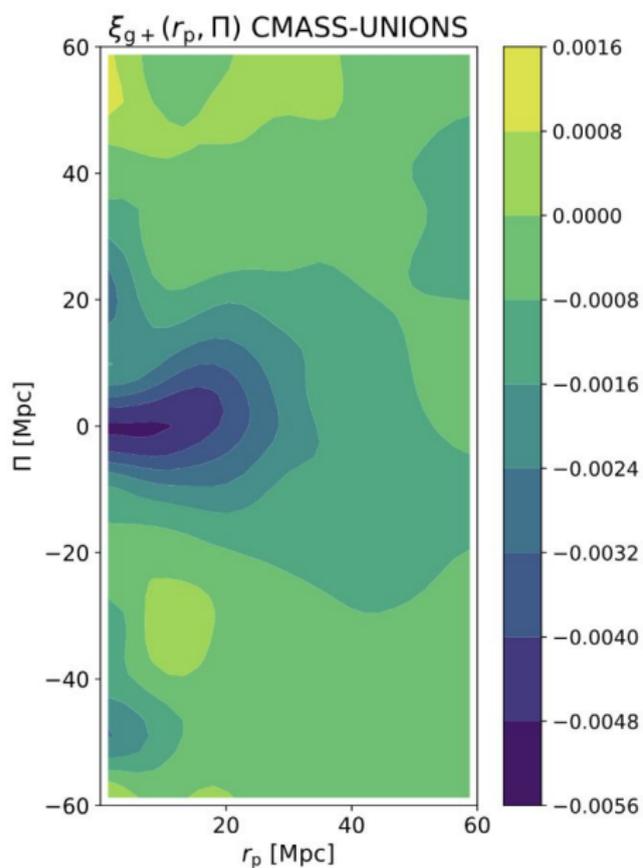
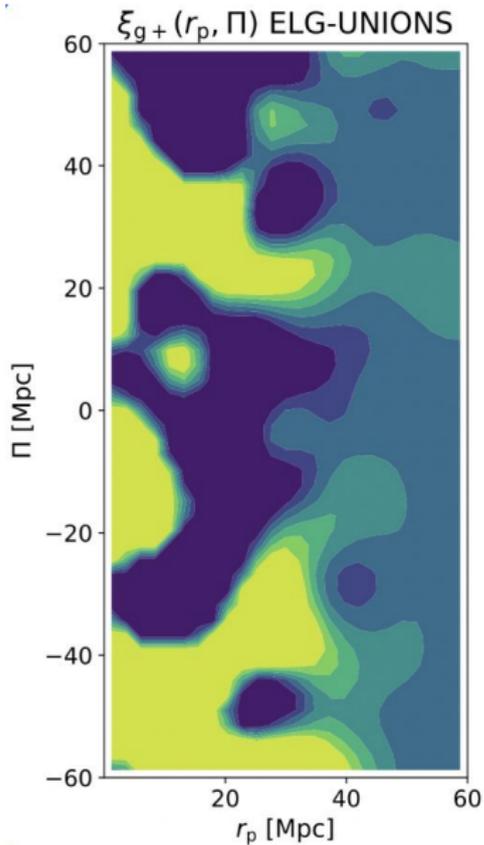


# Validation: ensemble test

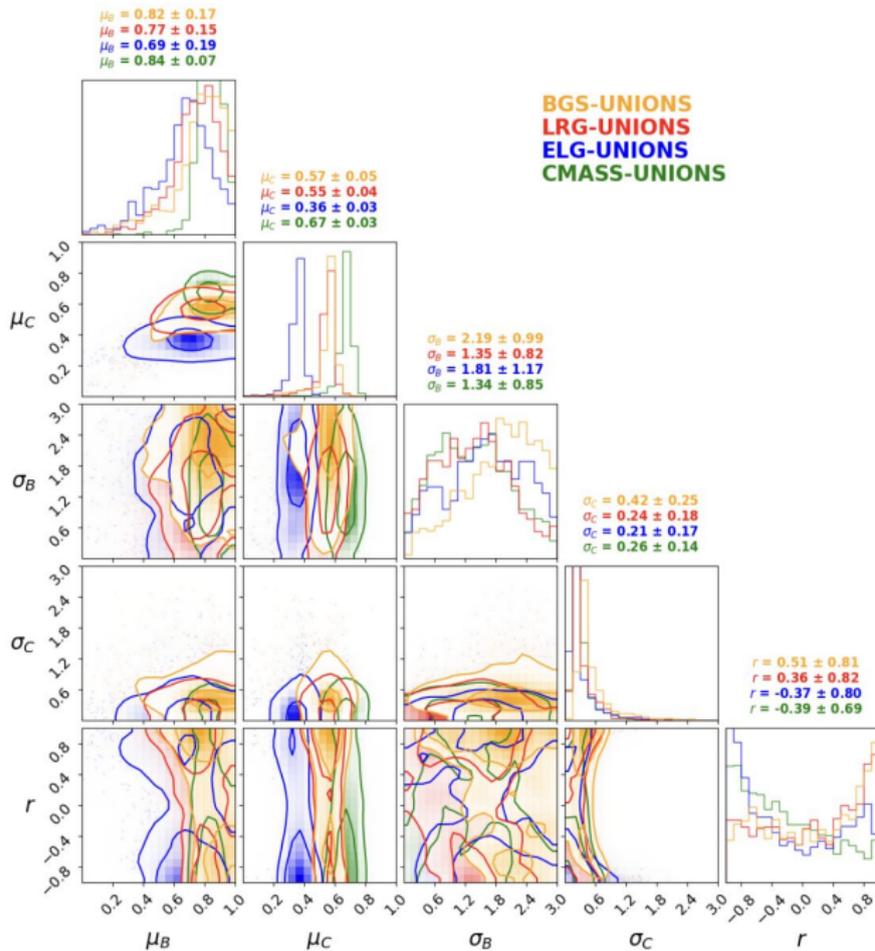
10 000 training simulations, CMASS-UNIONS



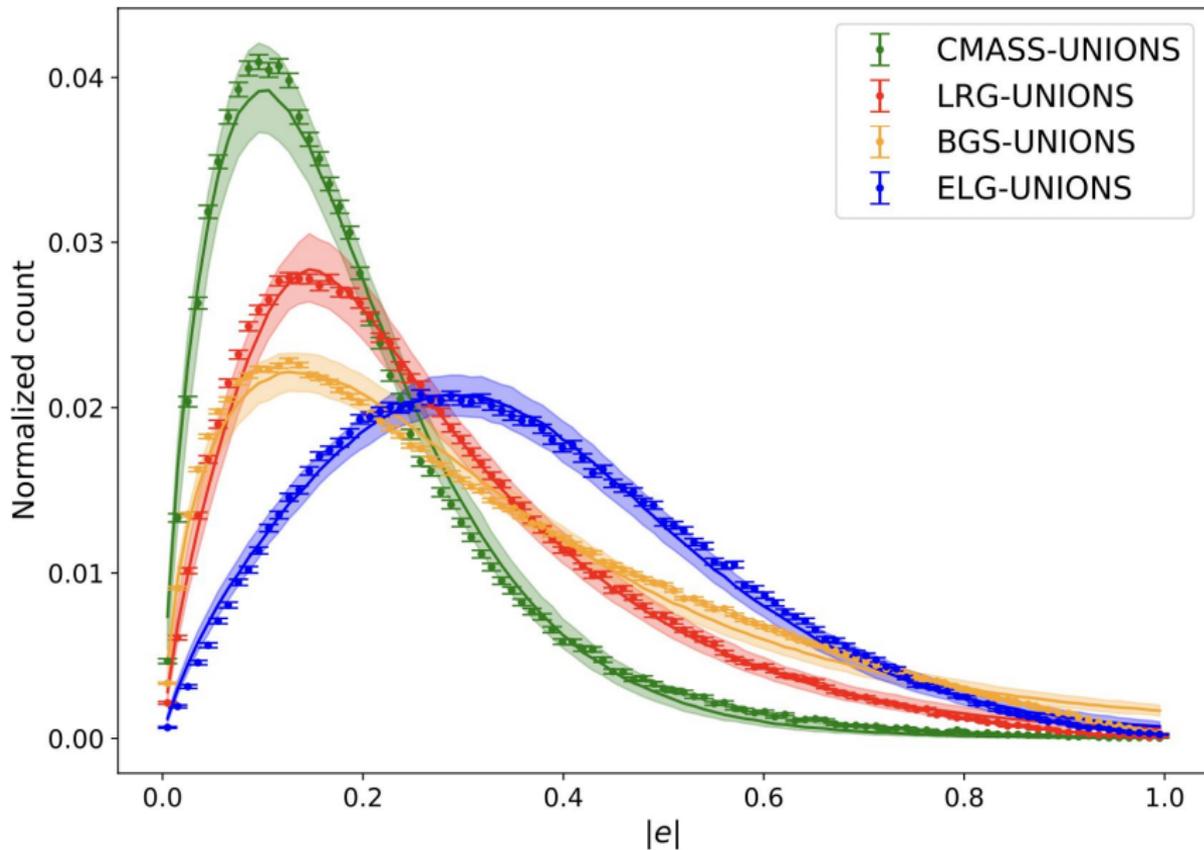
# Galaxy intrinsic alignment measurements for other galaxy samples



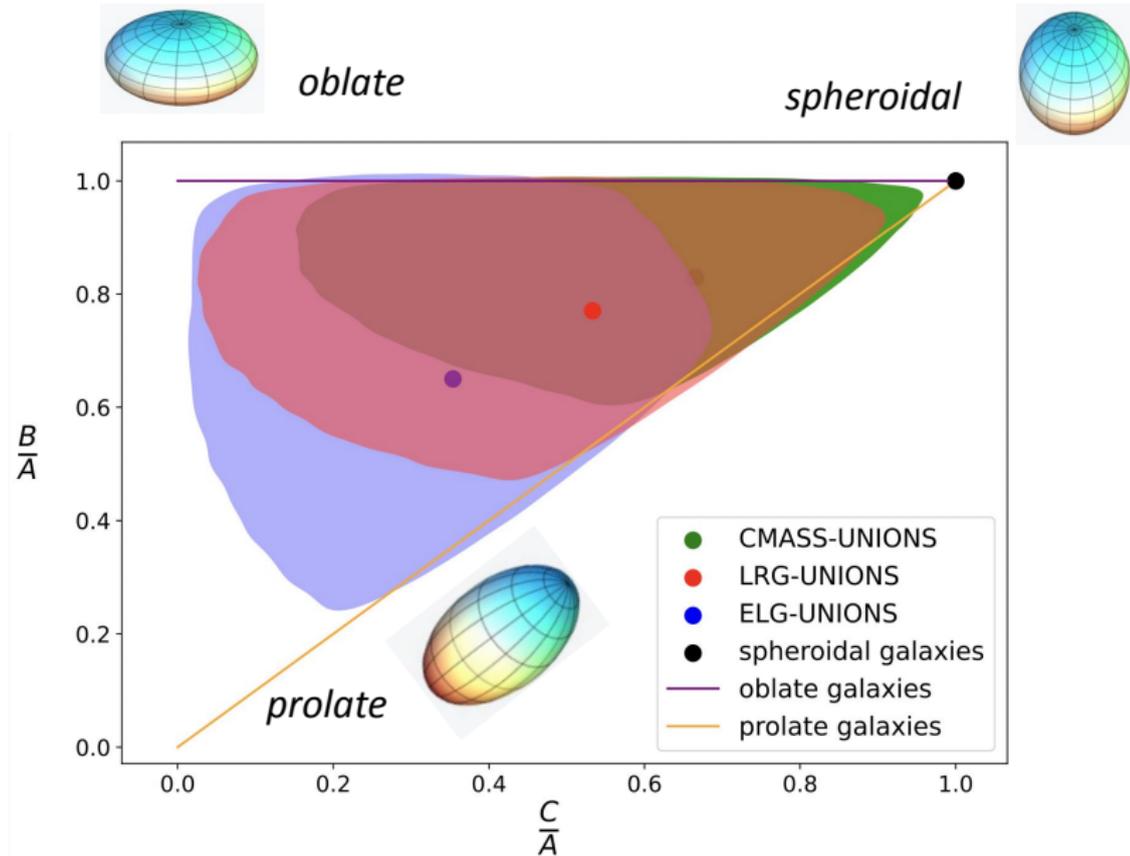
# Constraints on the parameters of 3D morphology



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



# Constraints on the 3D morphology of the galaxies



## Other interesting statistics

