Uncovering the 3D cosmological tidal field of dark matter with UNIONS

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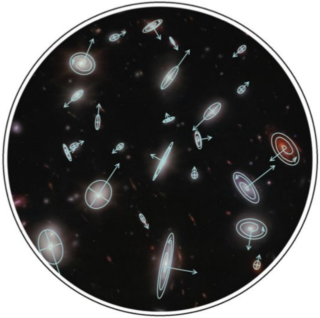
Laboratory: CEA, Paris-Saclay, CosmoStat

Euclid France meeting, Strasbourg

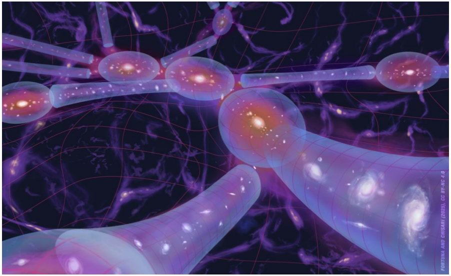
November 18th, 2025

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*)



Credit: Fortuna & Chisari (2025)

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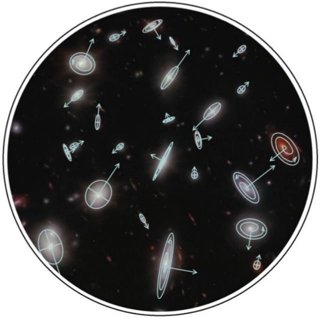

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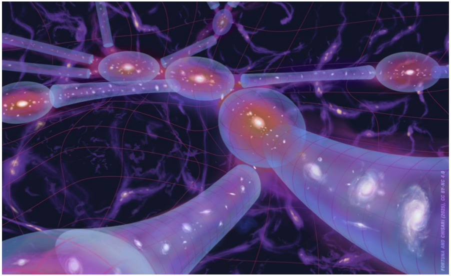

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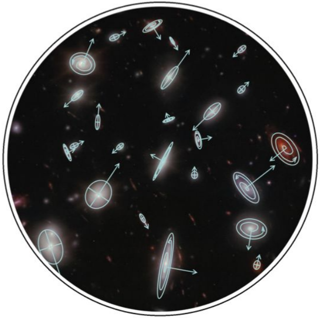

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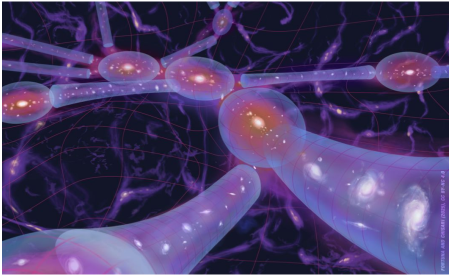
- **Effect** that can probe the **connection** between galaxies and their **dark matter halos** and the 3D properties of the large-scale structure in which the galaxies were **formed** and **evolved**



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Ultraviolet Near Infrared Optical Northern Survey *(see S. Guerrini's talk)*

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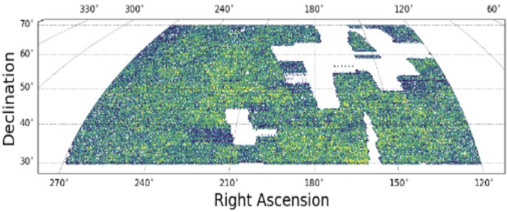

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  ~140 millions of galaxy shapes
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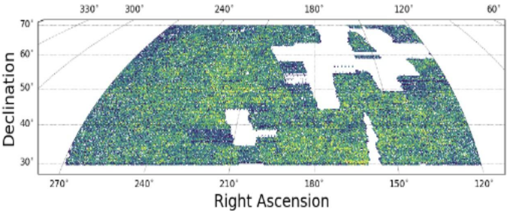

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- Direct **measure** of **intrinsic alignments** by cross-matching UNIONS with **spectroscopic** surveys: cross-correlations between the 2D shapes of galaxies and the underlying galaxy density field (*Hervas Peters et al. 2024*)

Project challenges and motivations

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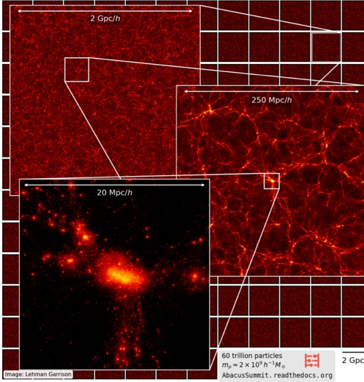
- **Aims and challenges:**
  1) To develop a model of 3D morphology based on **simulated 3D halo shapes** to infer the distribution of the shapes of the galaxies in 3D from the distribution of their projected images
  2) To measure **2D intrinsic alignments** of galaxies and compare with the signal of projected halo shapes

I) 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

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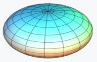
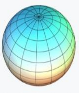
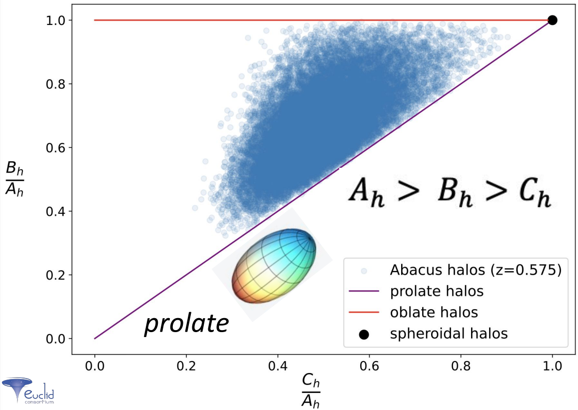
- **Catalogs** of **halos** with 3D shapes and 3D orientations

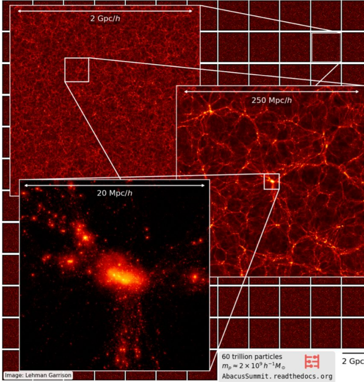


oblate

spheroidal







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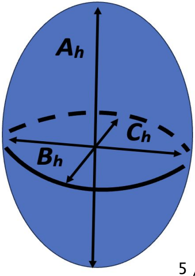

Modelling (2): 3D morphology of galaxies inside halos

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

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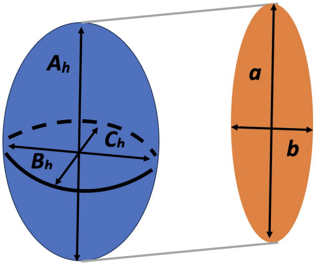
- **Projection** in 2D (*Lamman et al. 2023*) for different $\mu_{\tau_B}, \mu_{\tau_C}$ drawn uniformly in [0;1]



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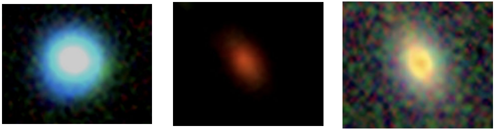
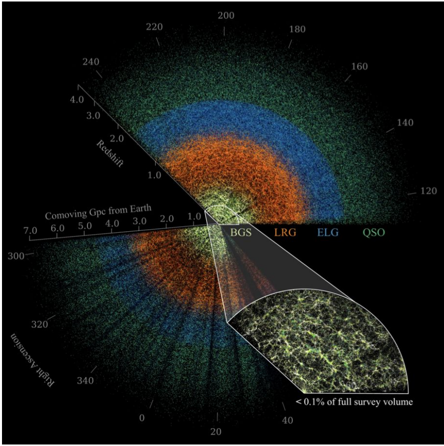


Credit: DESI Legacy Imaging Survey



DESI Collaboration 2025

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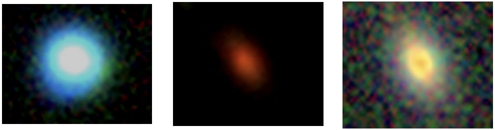

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- **Cross-match** with **UNIONS** forms
  . **CMASS-UNIONS**: ~210 000 galaxies
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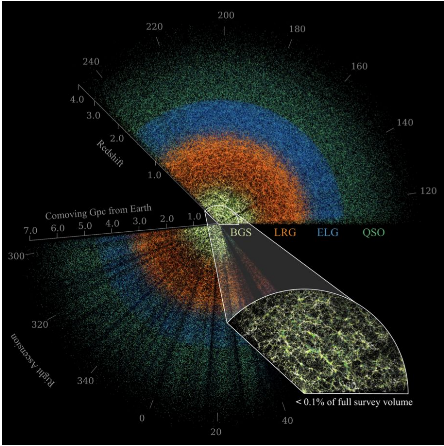

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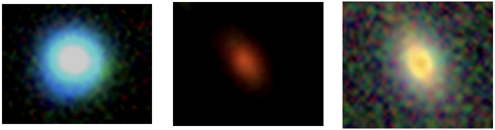

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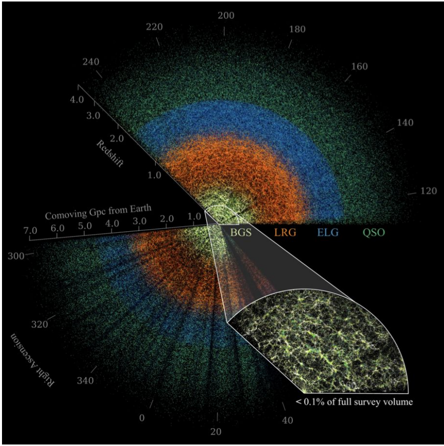

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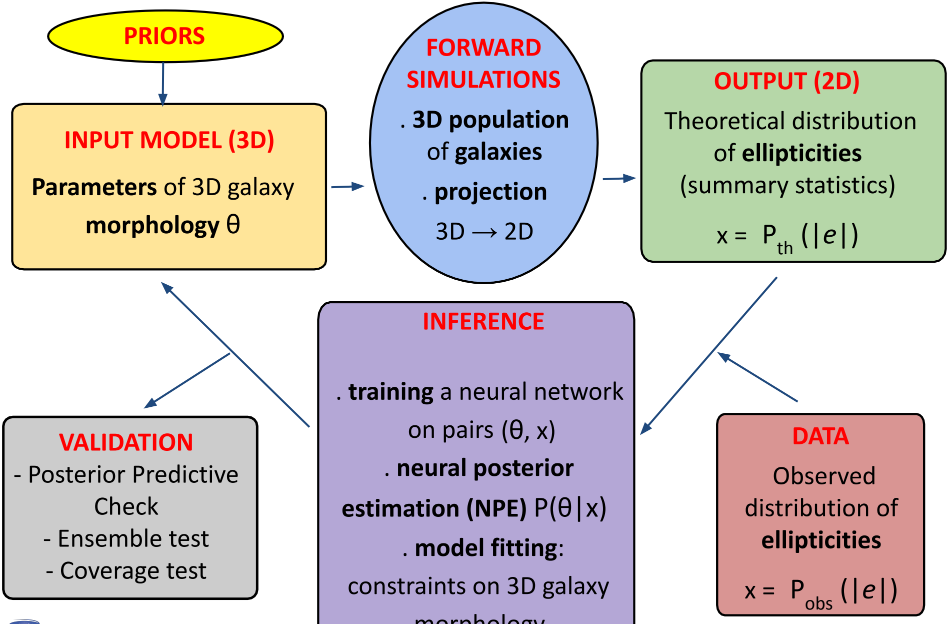
- **Selection** of host halos by ranges of **mass** and **redshift** to match with the samples of galaxies (*Zhang et al. 2025*)

Methodology: simulation-based inference (SBI)



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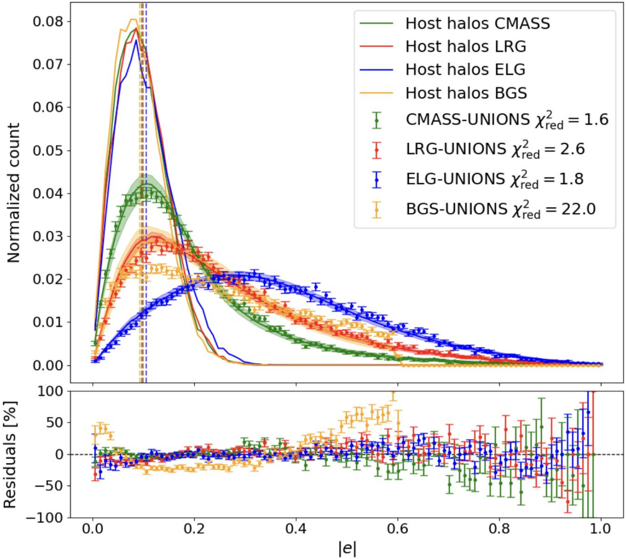

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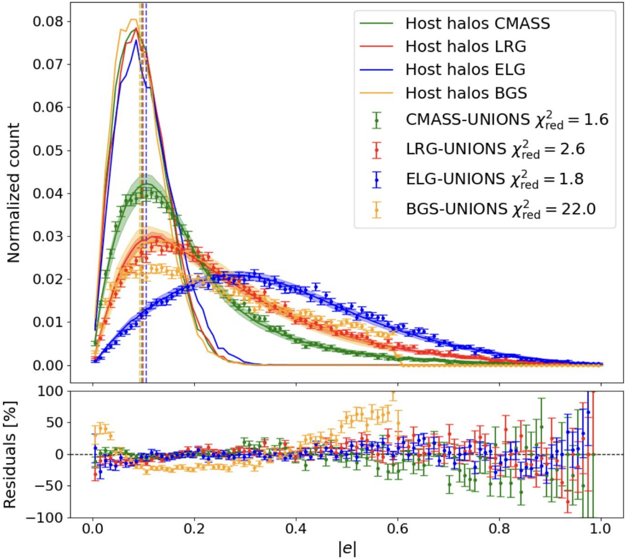
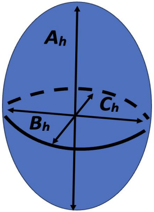


- **Conclusion:** we can constrain the distribution of the shapes of the galaxies **in 3D** from the distribution of their **projected images**

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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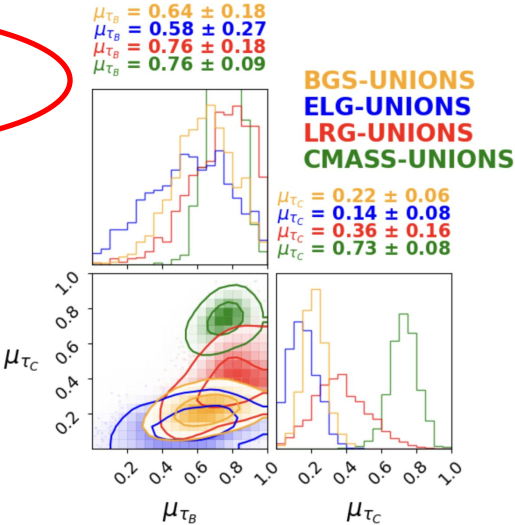

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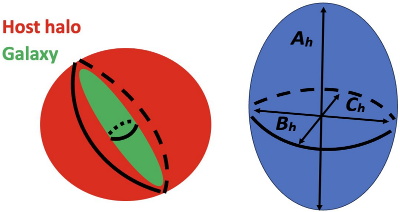

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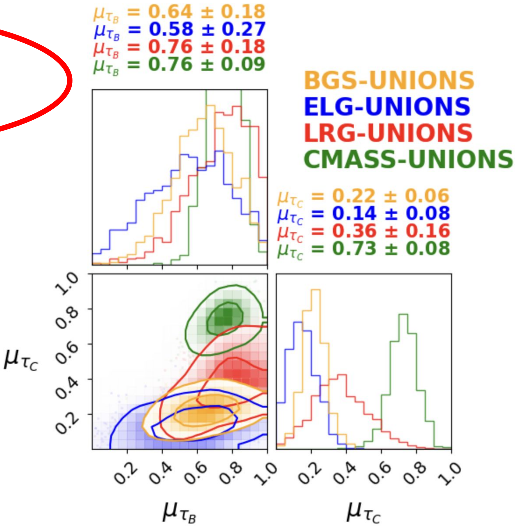

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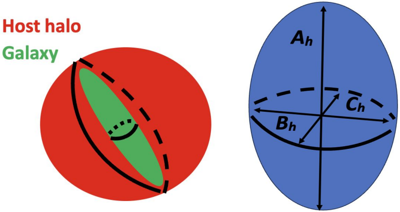

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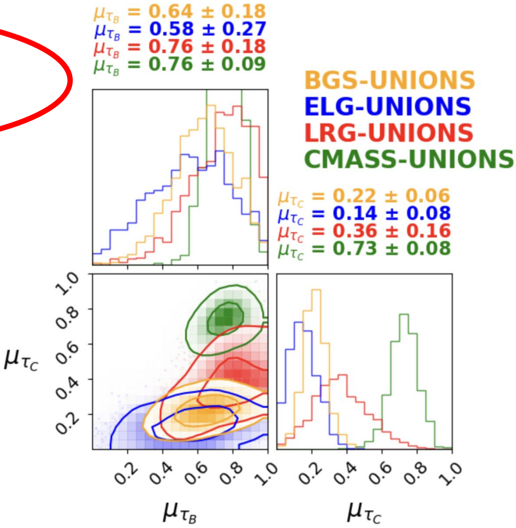
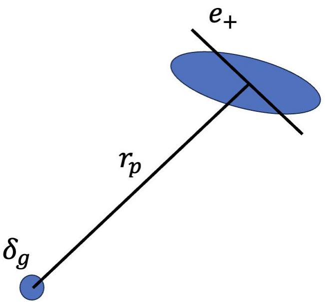


- ELG (disk-like galaxies) are more **flattened** inside their host halo
- CMASS galaxies are more **spheroidal** than LRG, BGS,...

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 ξ_{g+}



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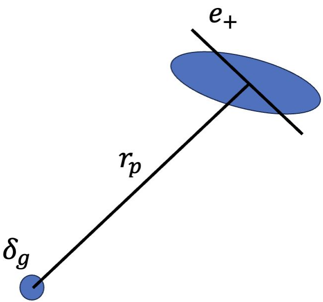

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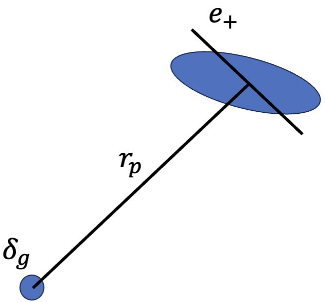

- Estimator of the shape-density correlation function (*Landy & Szalay 1993*):

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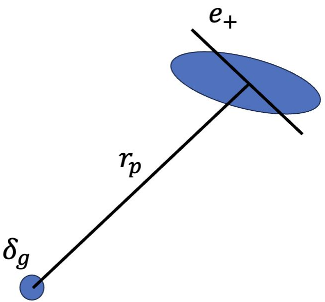

- Estimator of the shape-density correlation function (*Landy & Szalay 1993*):

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

- 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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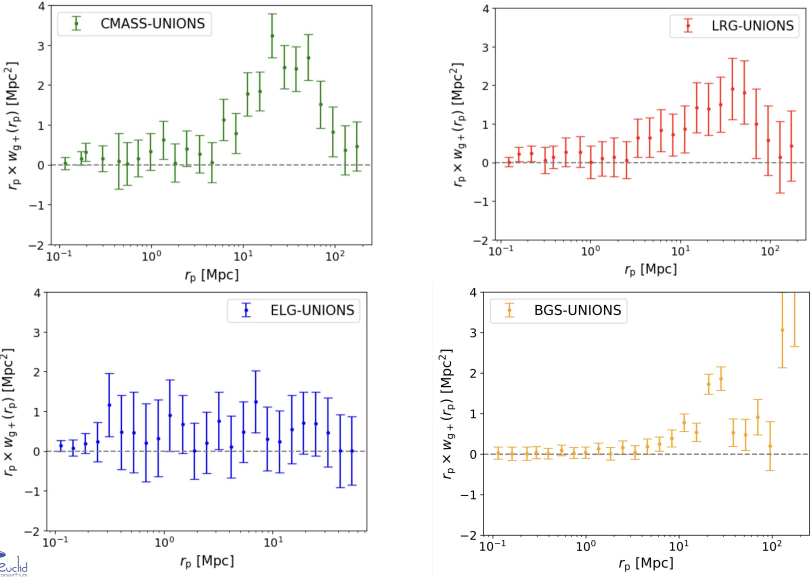

Results: galaxy intrinsic alignment measurements (2)

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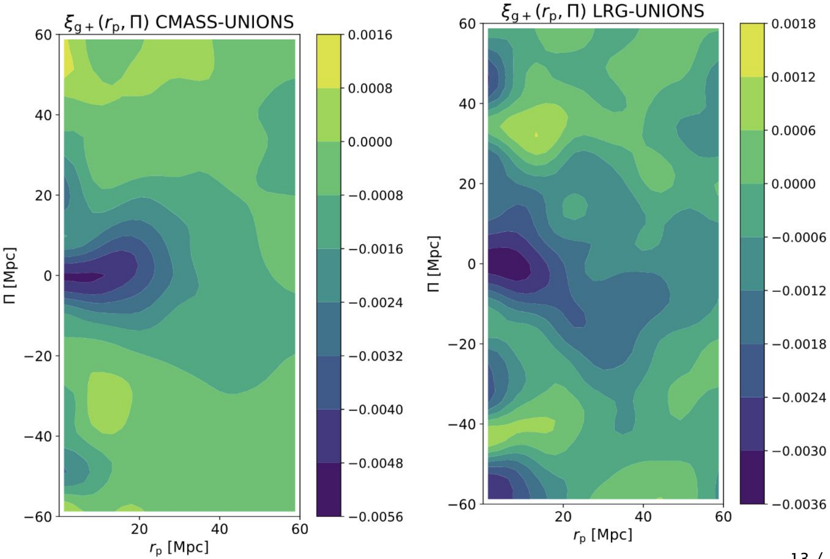

Projection effect

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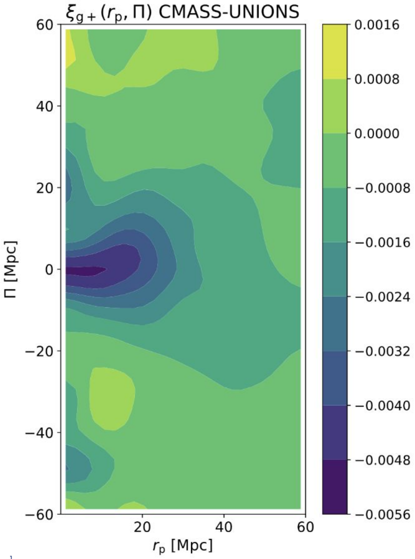

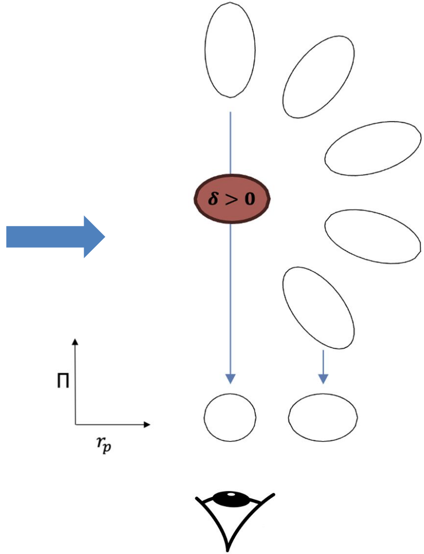

Halo intrinsic alignment measurement

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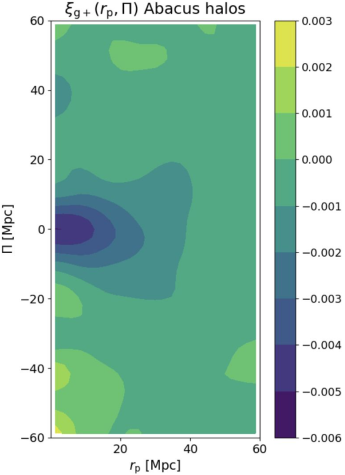
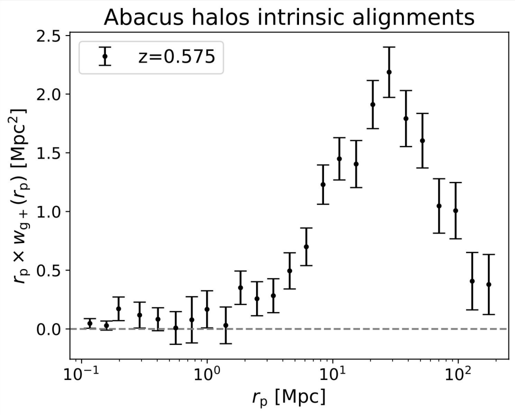
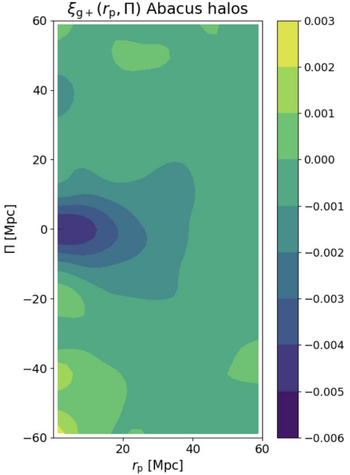
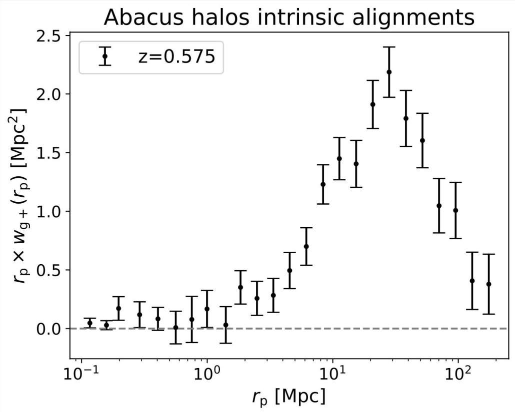




Halo intrinsic alignment measurement

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





- **Next step** (ongoing work): populating these halos with galaxies, measuring an intrinsic alignment signal and comparing it with the data

Conclusion

- Development of a **SBI** 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

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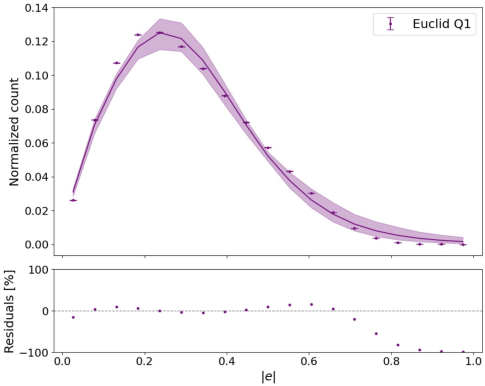
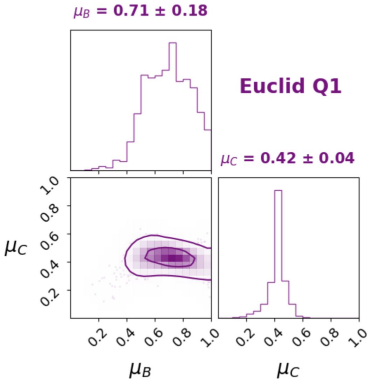
  => preliminary results on 3D morphology measurement with **Euclid Q1 data**



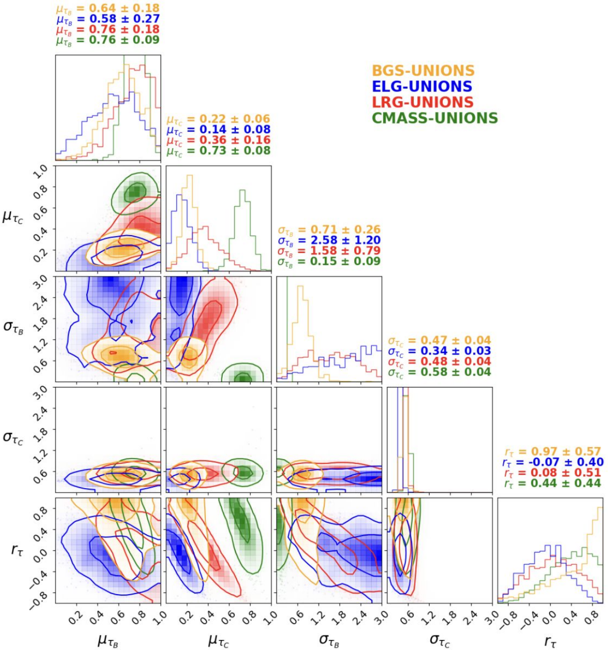


(Preliminary)

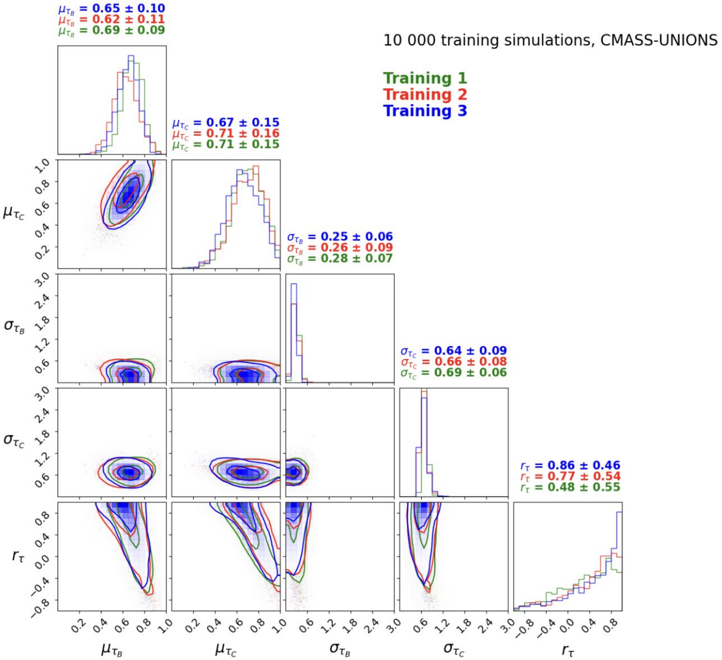
Thank you for your attention !

Back up slides

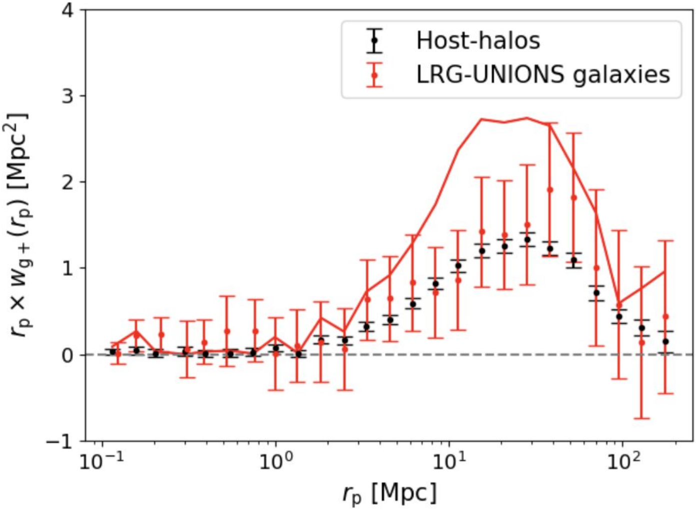
Contours for other parameters



Validation: ensemble test



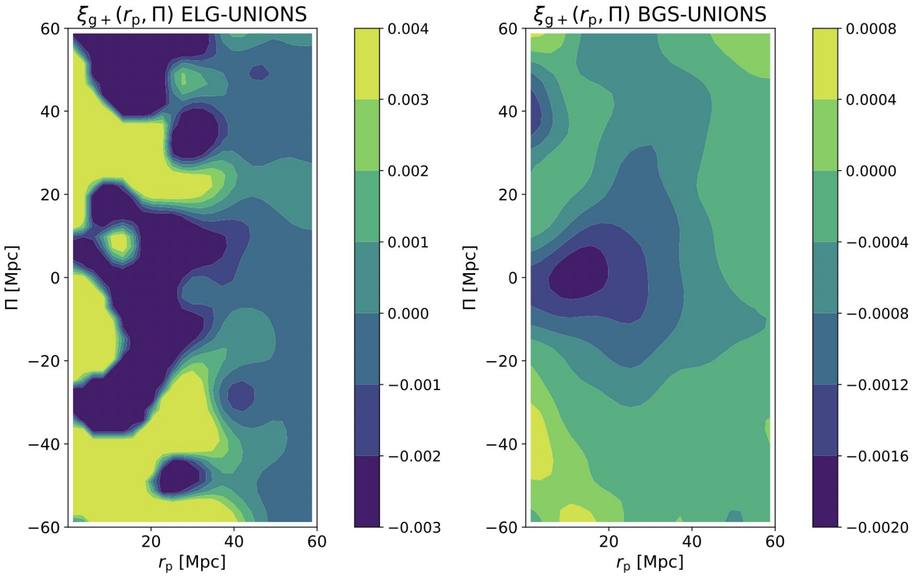
Galaxy-halo intrinsic alignments measurements



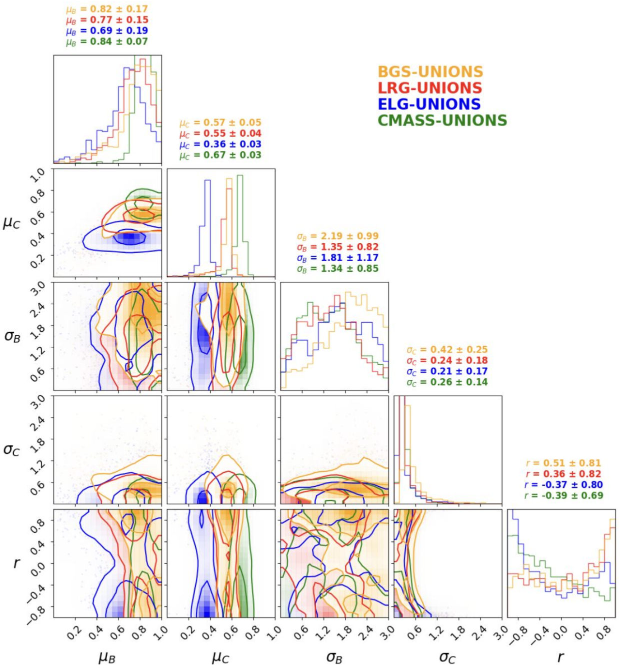
(Preliminary)

- A potential way of measuring **galaxy misalignment**

Galaxy intrinsic alignment measurements for other galaxy samples

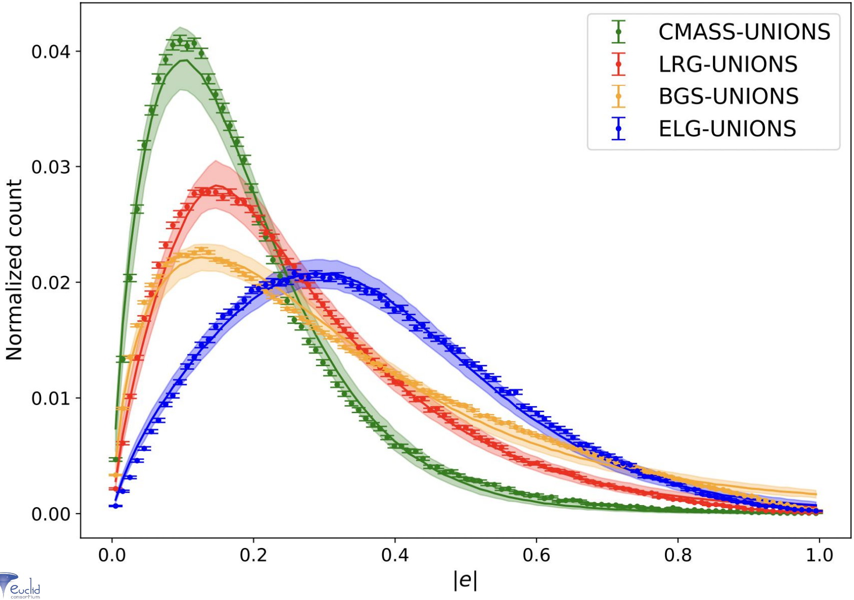


Constraints on the parameters of 3D morphology

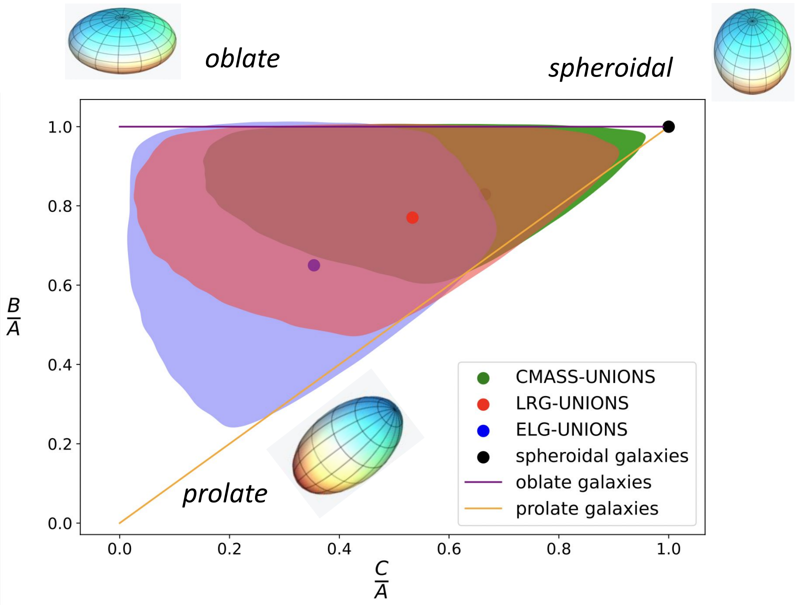


euclid consortium

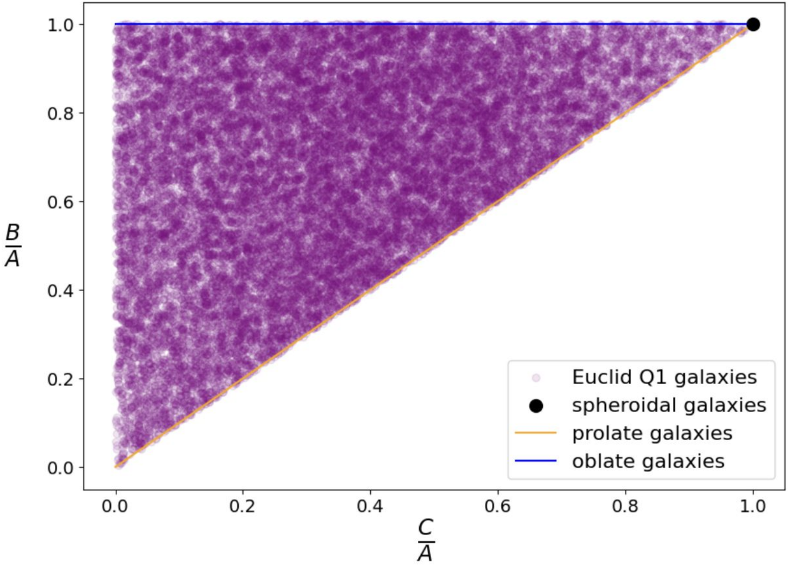
Distribution of ellipticities P (|*e*|) with an other simple model



Constraints on the 3D morphology of the galaxies



Constraints on the 3D morphology of the galaxies with Euclid Q1 data



(Preliminary)

Other interesting statistics