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

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

**Laboratory** : Department of Astrophysics of CEA, CosmoStat

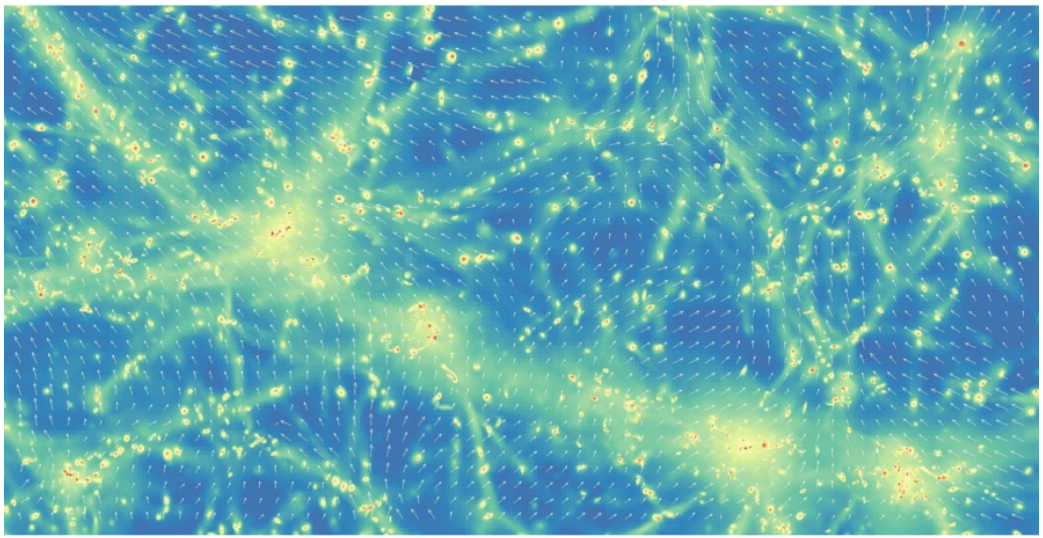

CosmoStat

UNIONS


**Euclid meeting** - Marseille

October $3^{rd}$ 2025

# Scientific context: intrinsic alignment of galaxies



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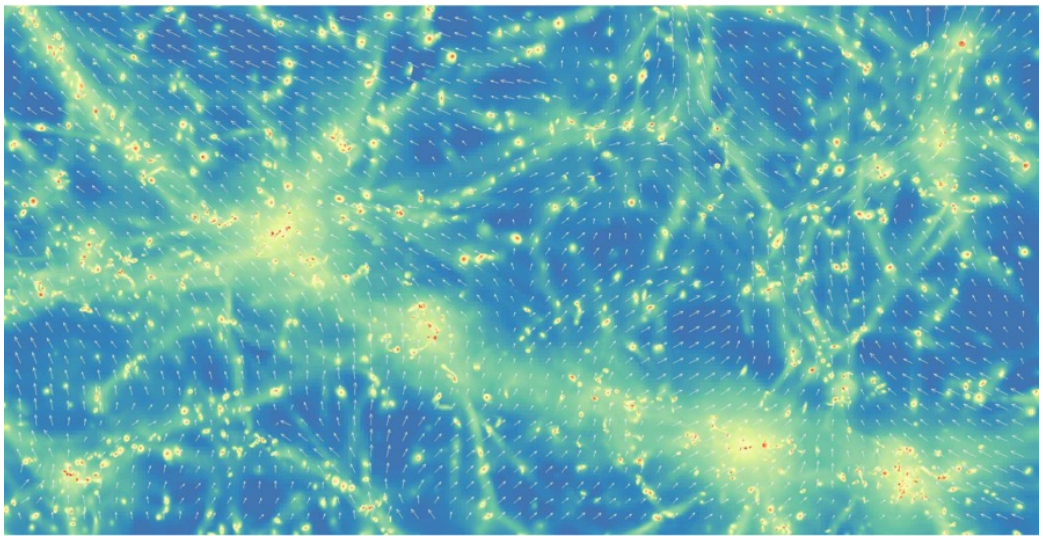

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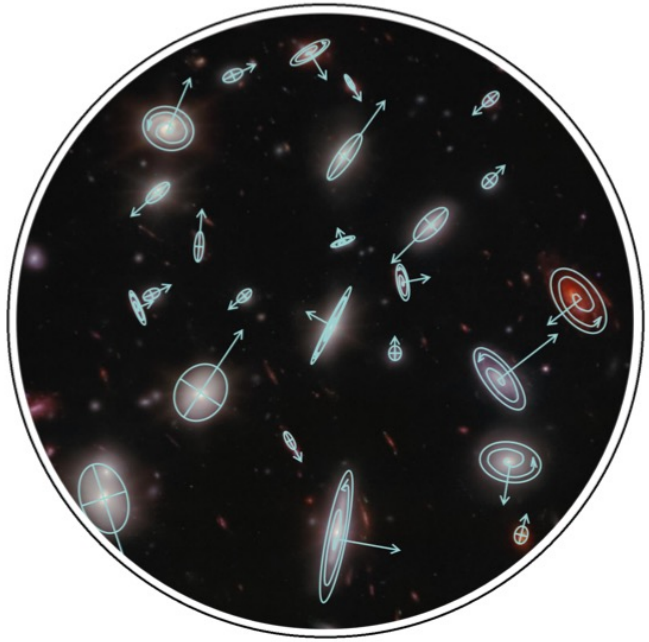

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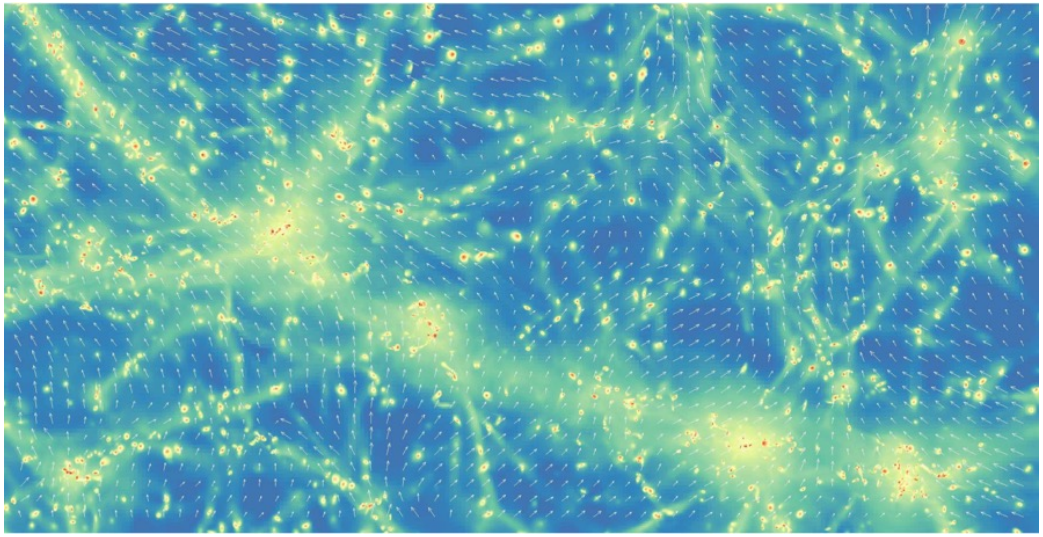

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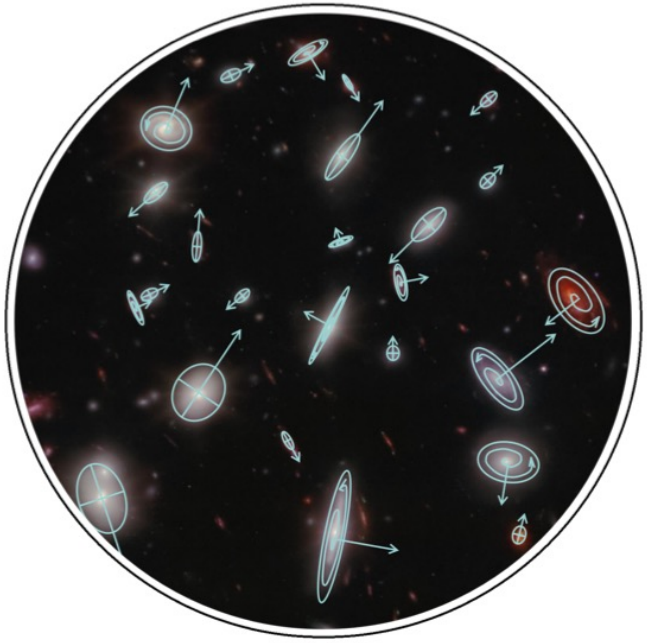

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- **Correlations** between the **shapes** of the galaxies observed in the sky and **the density field**
- Fundamental effect to probe the **3D properties** of the **large-scale structure** of the Universe in which the galaxies **were formed** and **evolved**

# UNIONS (Ultraviolet Near-Infrared Optical Northern Survey)

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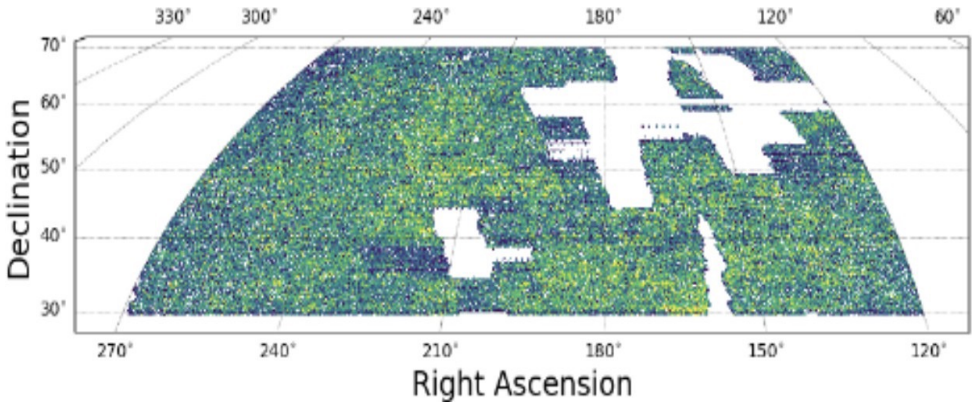


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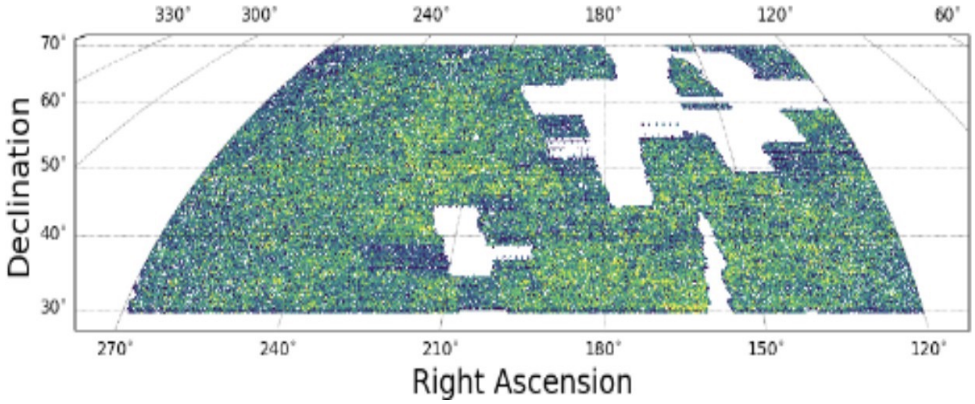


- **Galaxy survey** (r-band):
  ~100 millions of galaxy shapes
  4800 deg$^2$ *(Gwyn et al. 2025)*

- Direct **measure** of **intrinsic alignments** in the data **=** measure of correlations between 2D shapes of galaxies and the galaxy density field with traditional estimators of the shape-density correlation function (*Hervas Peters et al. 2024*):

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

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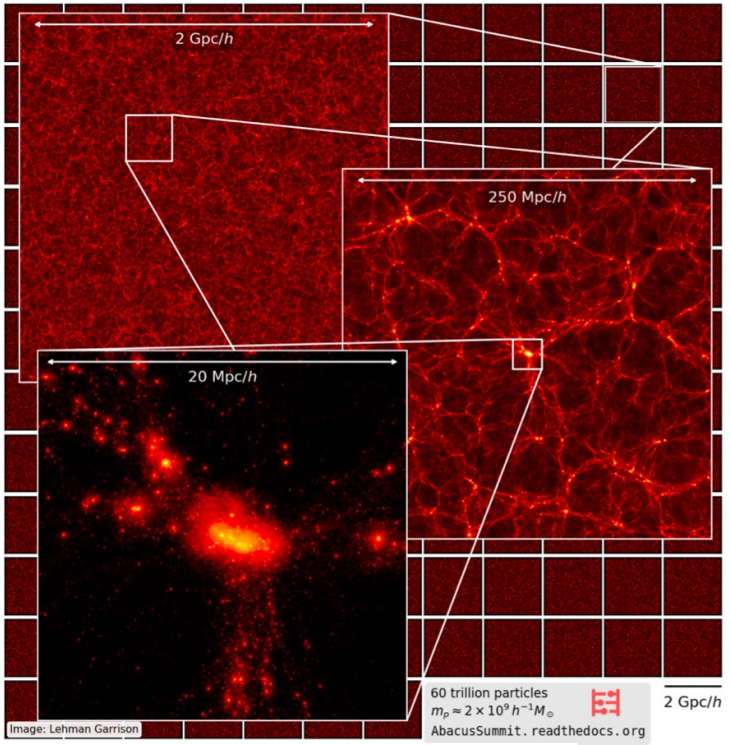
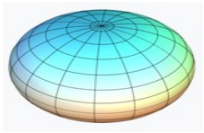
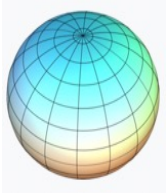
- **First aim and challenge of the project:** developing a method to constrain the **distribution of the 3D shapes** of galaxies from the **distribution of their 2D shapes**

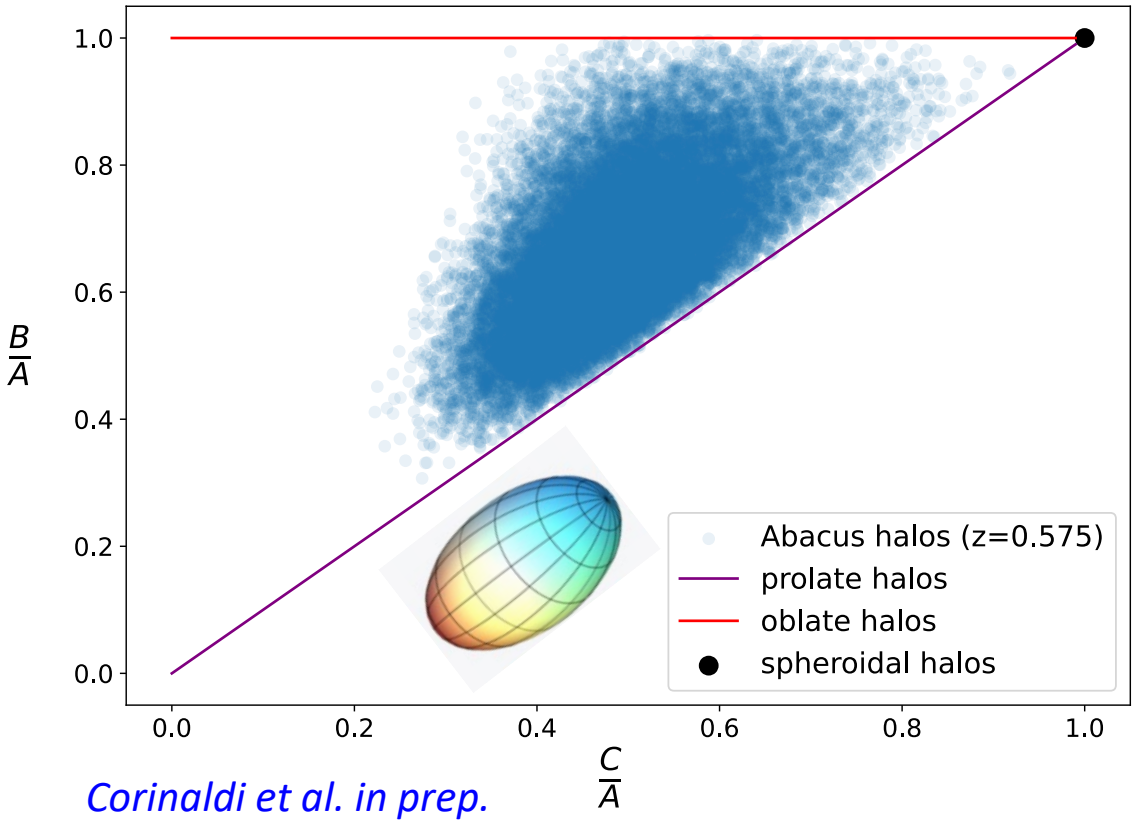
# Modelling (1): dark matter halos

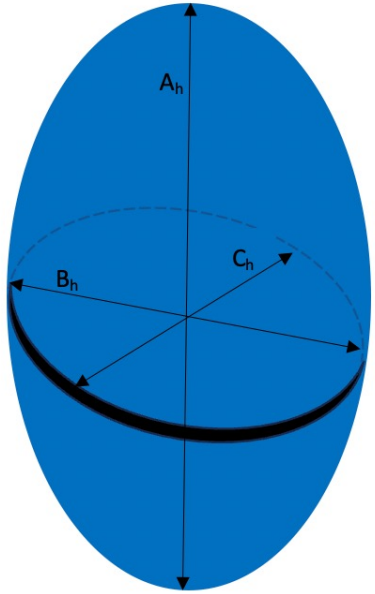
1) **Dark matter halo** 3D shapes $A_h > B_h > C_h$ and 3D orientations from the AbacusSummit N-body simulation (*Maskimova et al. 2024)*





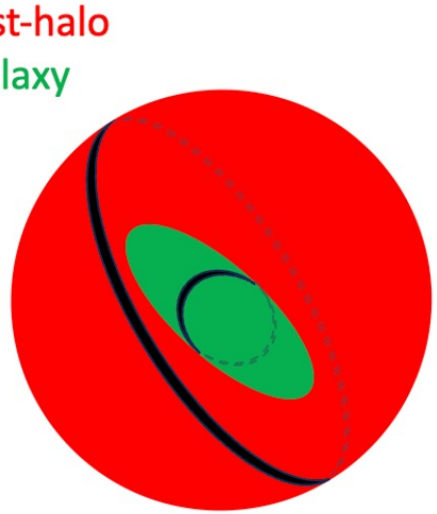



*Corinaldi et al. in prep.*

# Modelling (2): galaxy-halo connection

2) **Settlement** of the halos by 3D **central galaxies** with 3D orientations inherited from the host-halos ones and of shape $A_g > B_g > C_g$ such that:




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

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

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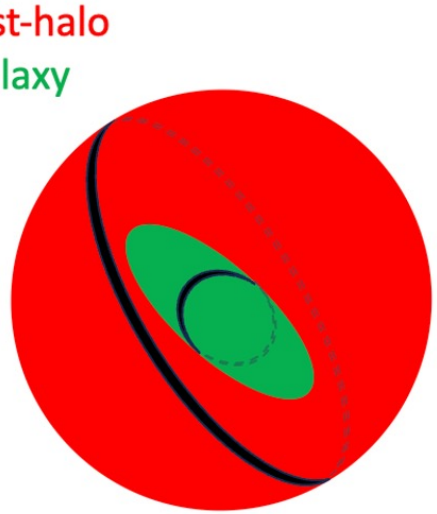


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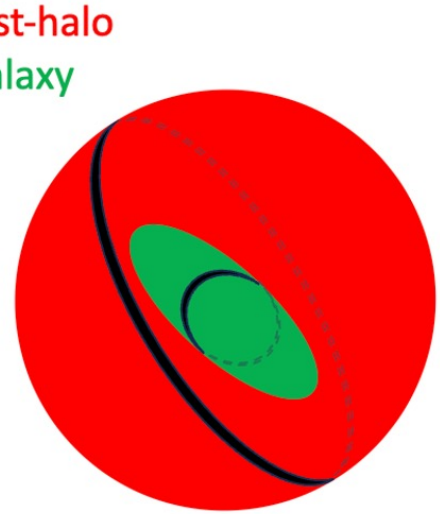


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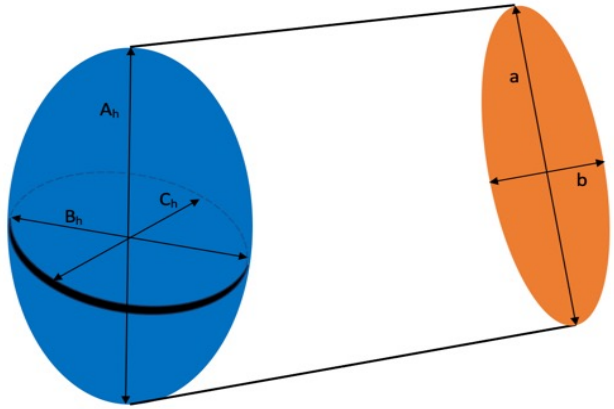
4) **Projection** in 2D (*Lamman et al. 2023*) for different $\mu_{\tau_A}, \mu_{\tau_B}, \mu_{\tau_C}$ drawn uniformly in $[0 ; 1]$



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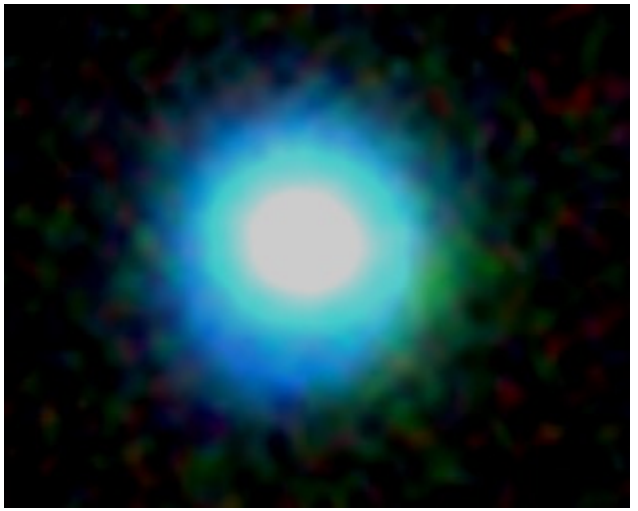
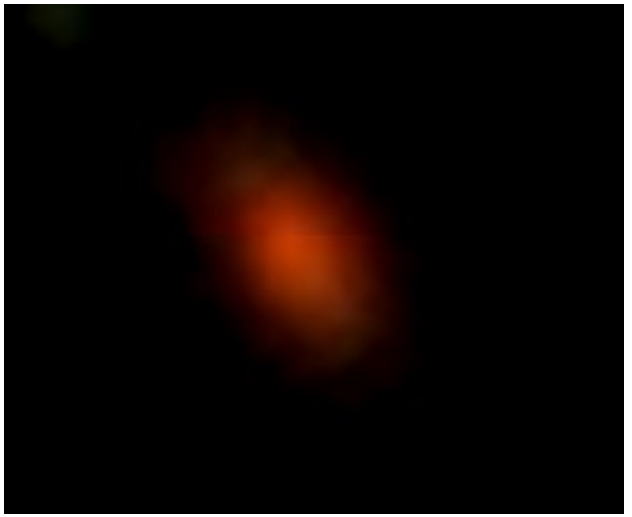
    . **LRG (Luminous Red Galaxies, red)**

  observed by DESI (Dark Energy Spectroscopic Instrument)

  => **positions** of identified galaxies



*Credit : DESI Legacy Imaging Survey*



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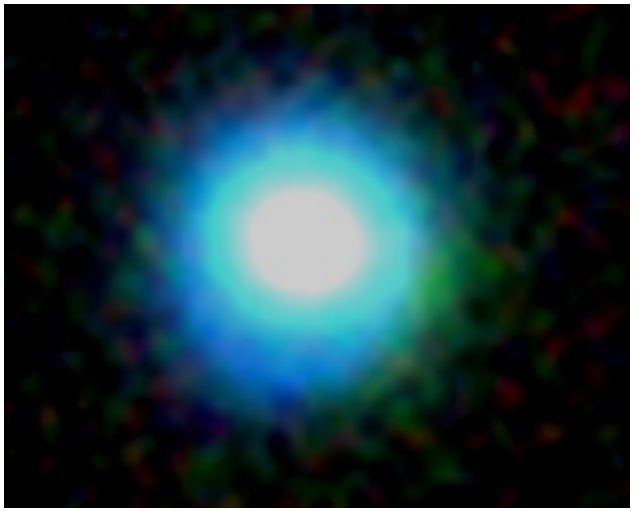

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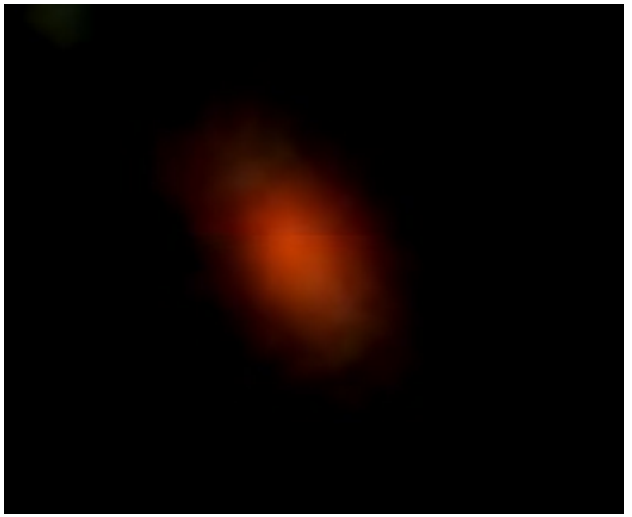

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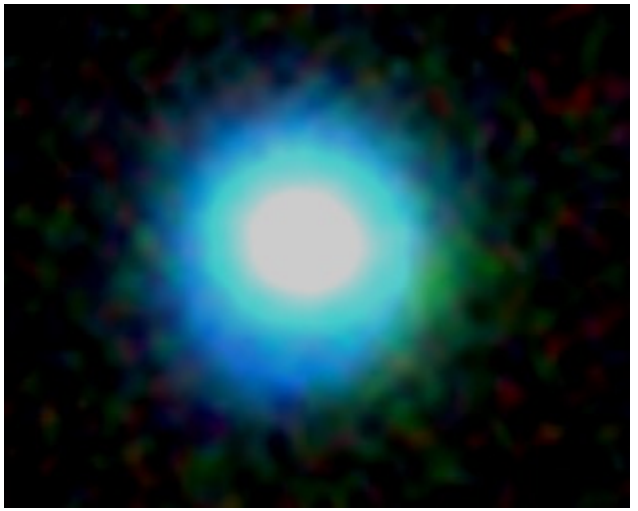

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  . **CMASS-UNIONS**: ~210 000 galaxies

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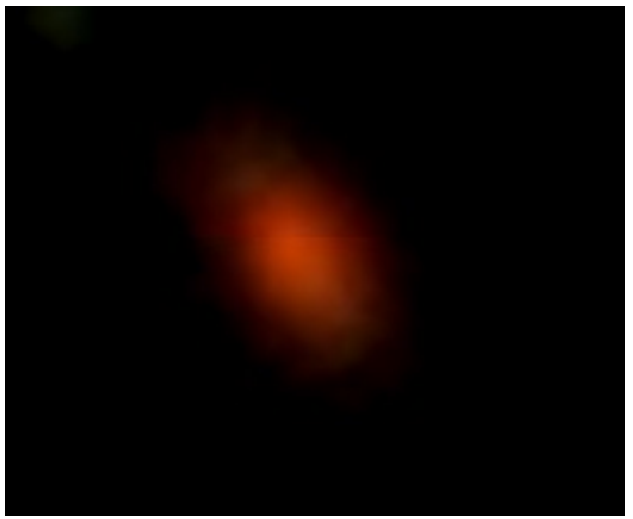

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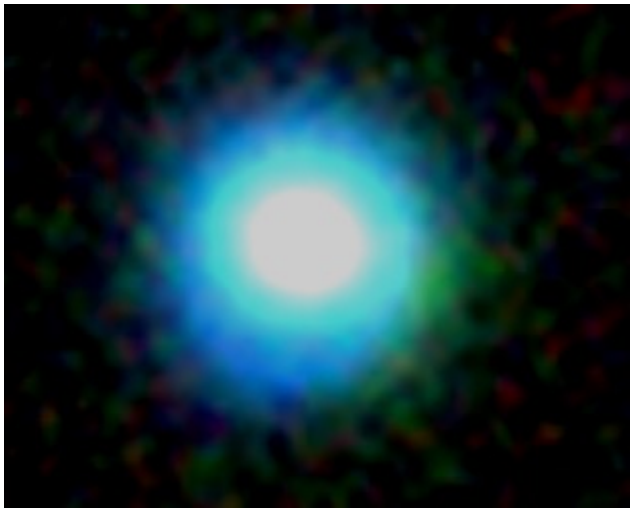

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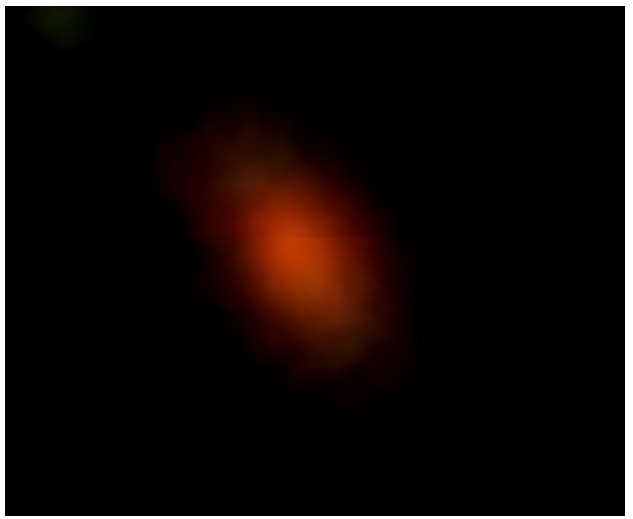
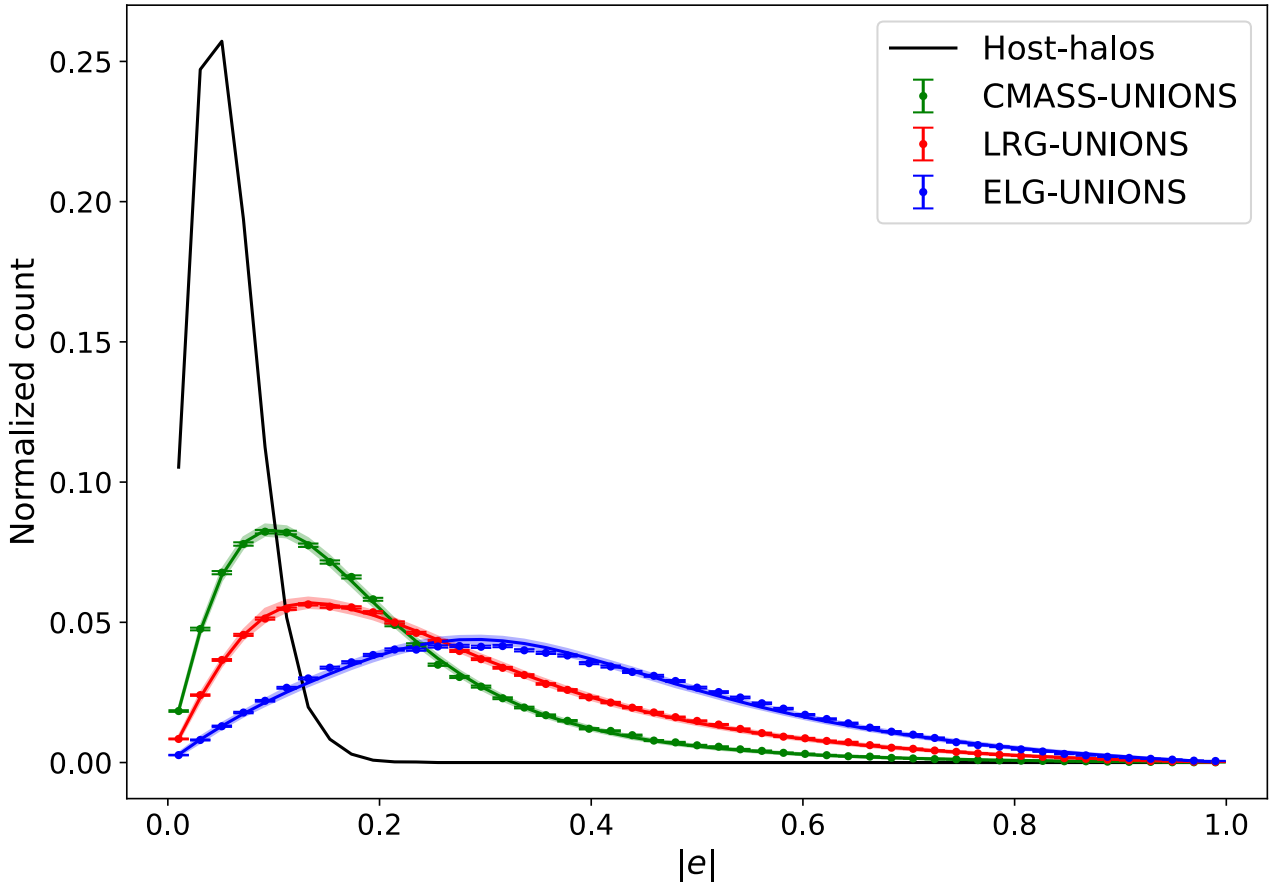


- **Motivation:** better **image quality** from UNIONS for measuring galaxy shapes

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

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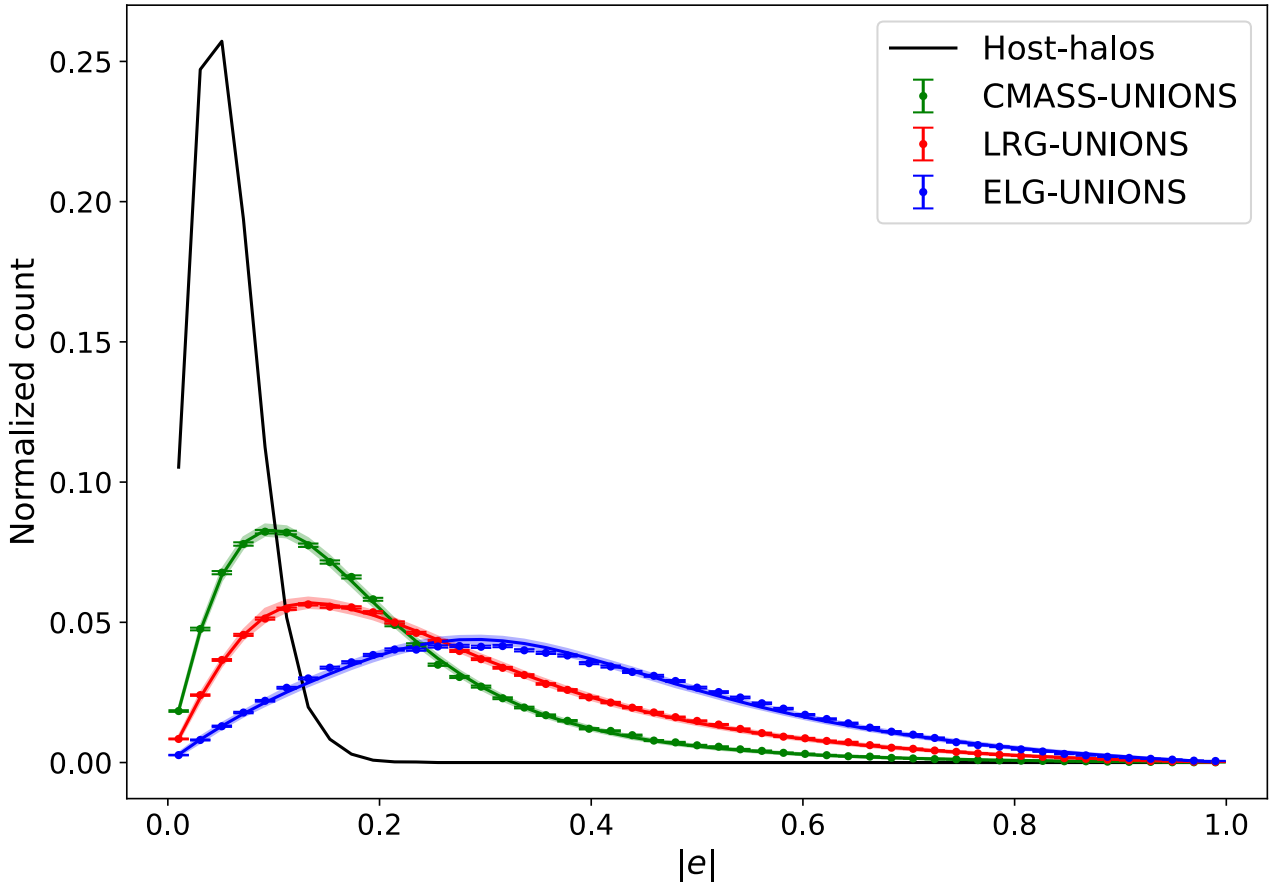


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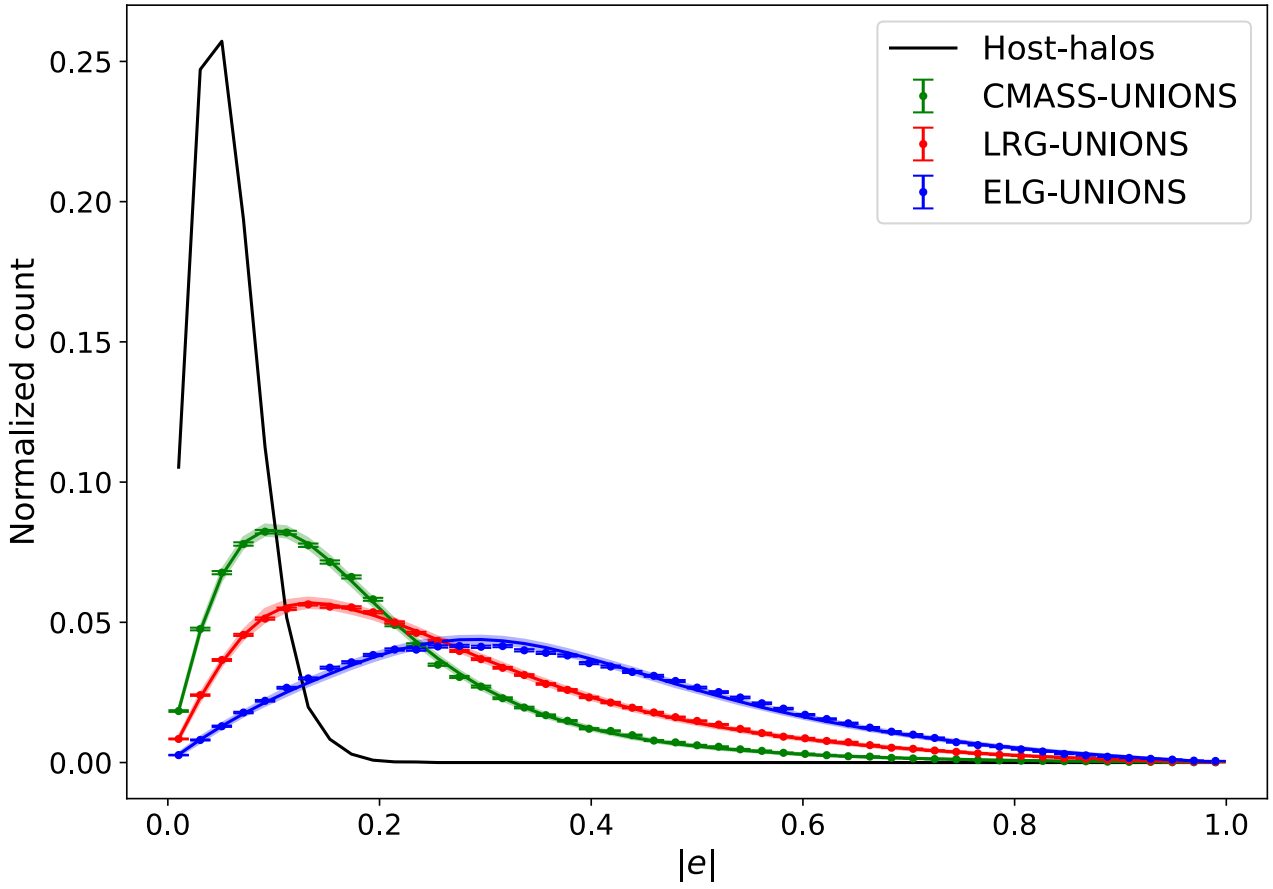


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- **2D shapes**:
  - LRG and ELG more elongated than CMASS
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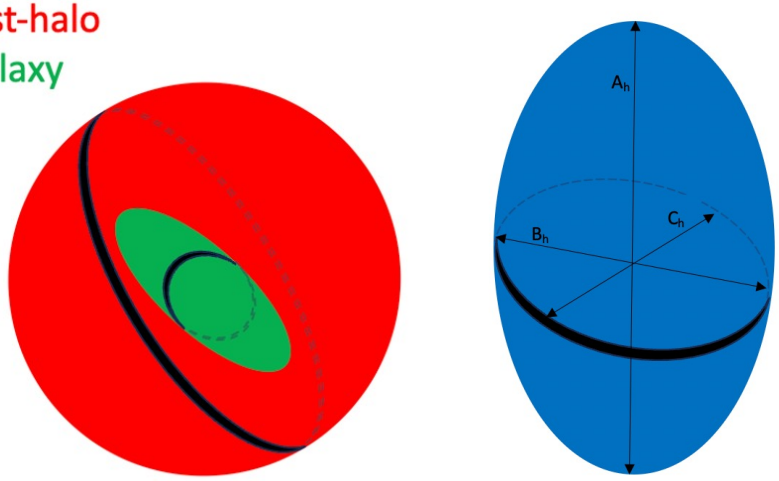
- We can constrain the distribution of the **3D shapes** of the galaxies from the distribution of their **2D shapes**

# 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

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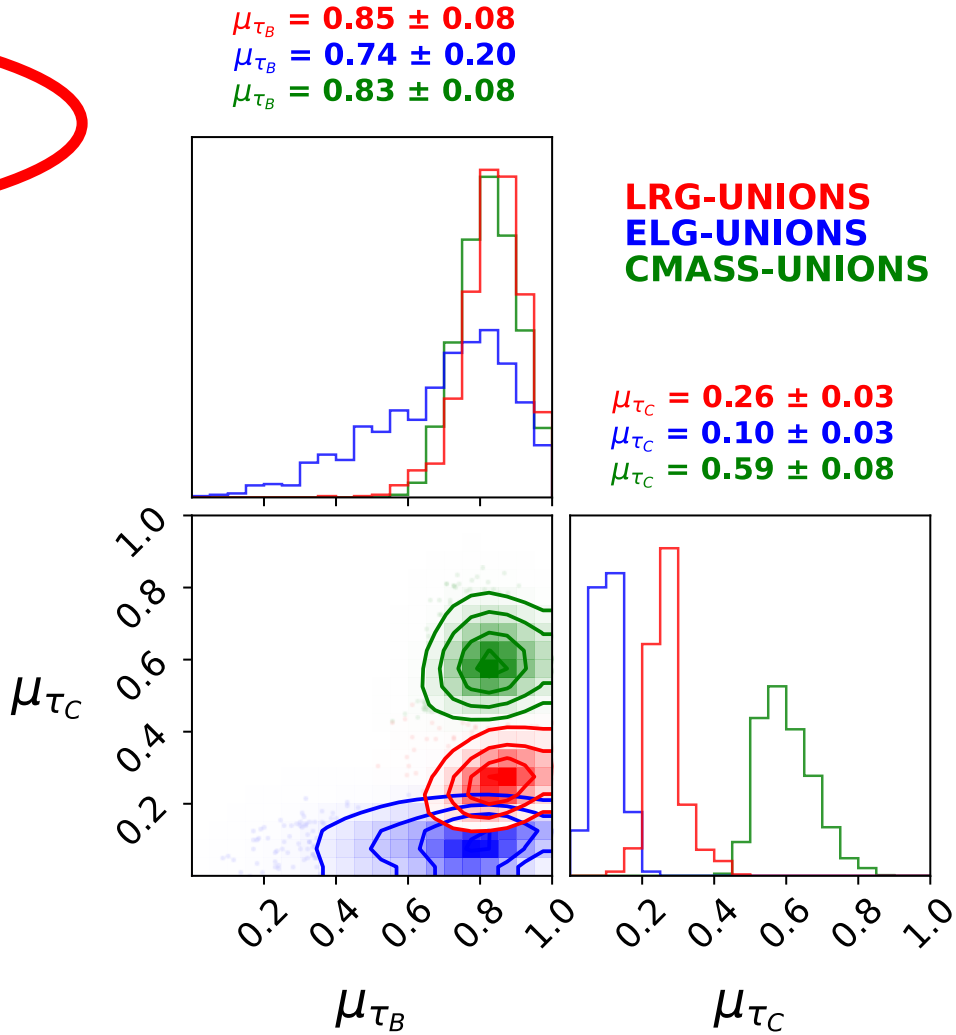


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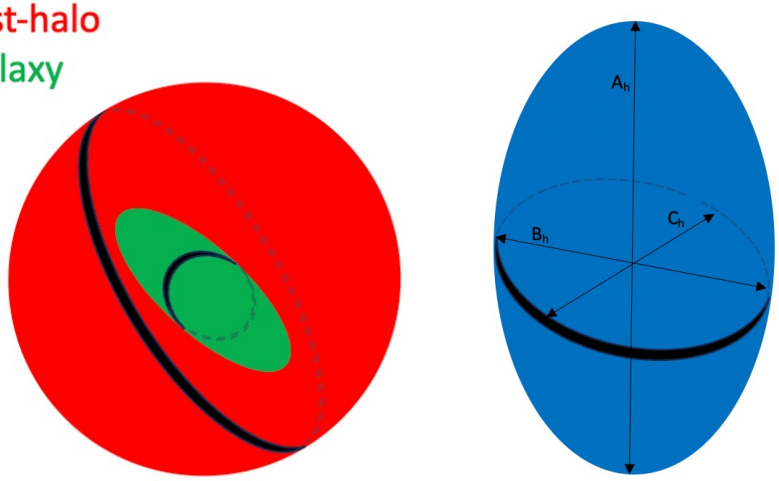


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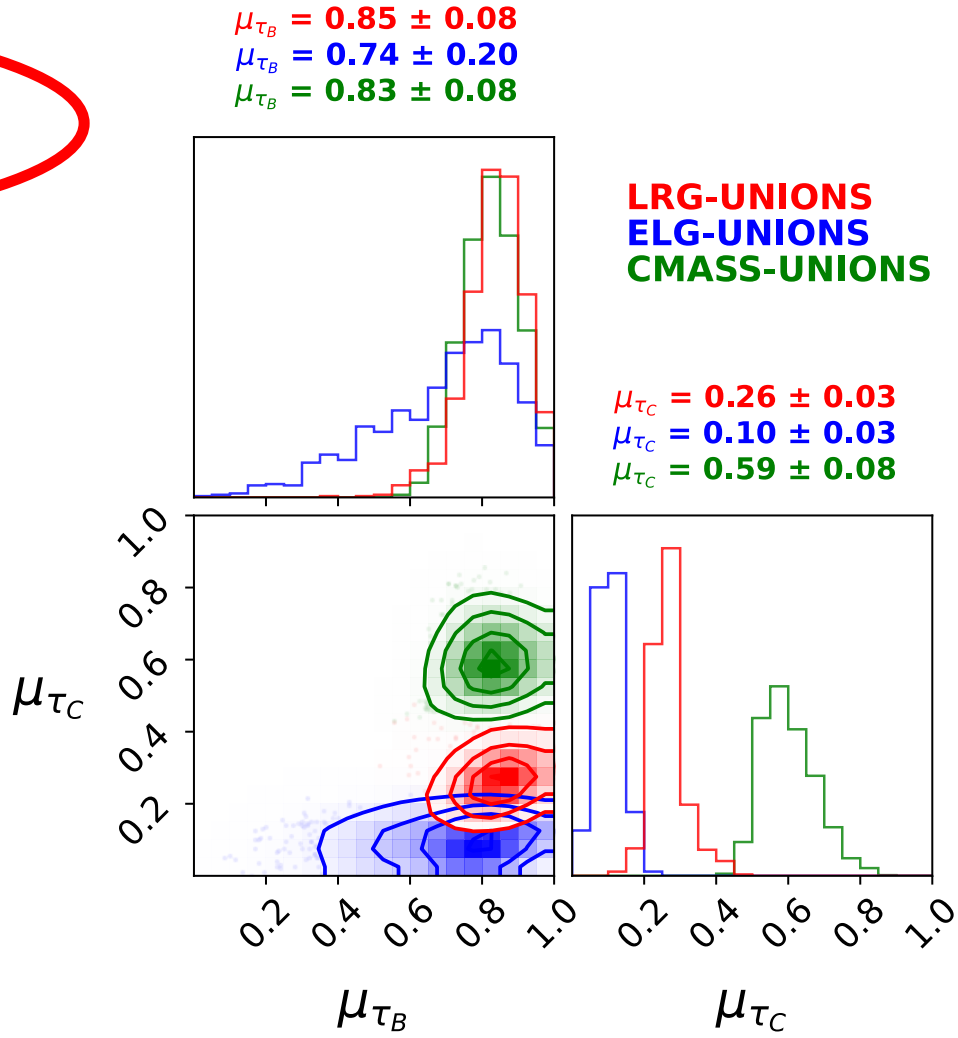


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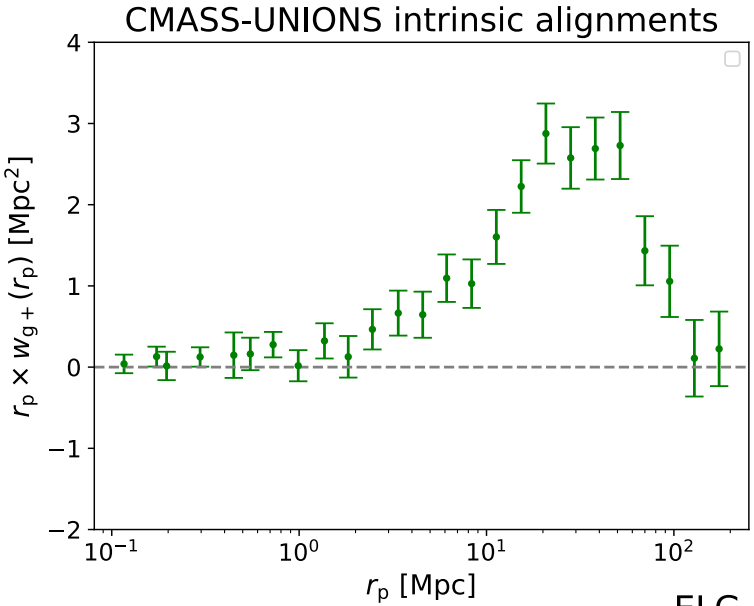
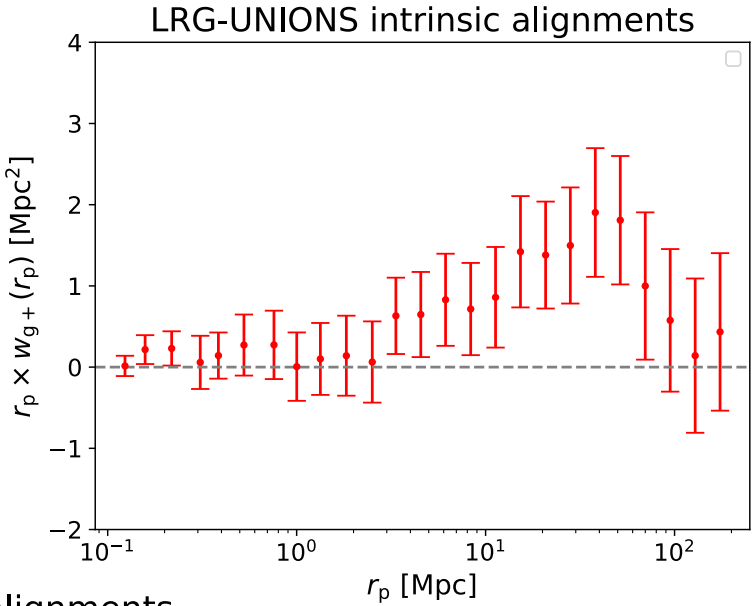
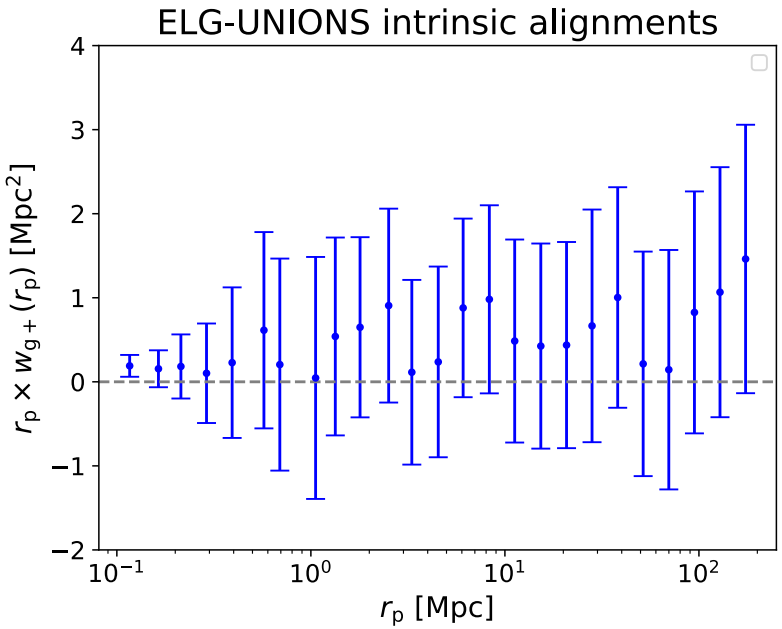
**Conclusions**: - CMASS are more **spheroïdal** than LRG and ELG.
- ELG (disk-like) are more **flattened** than LRG (prolate)

# Intrinsic alignment measurements (1)

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

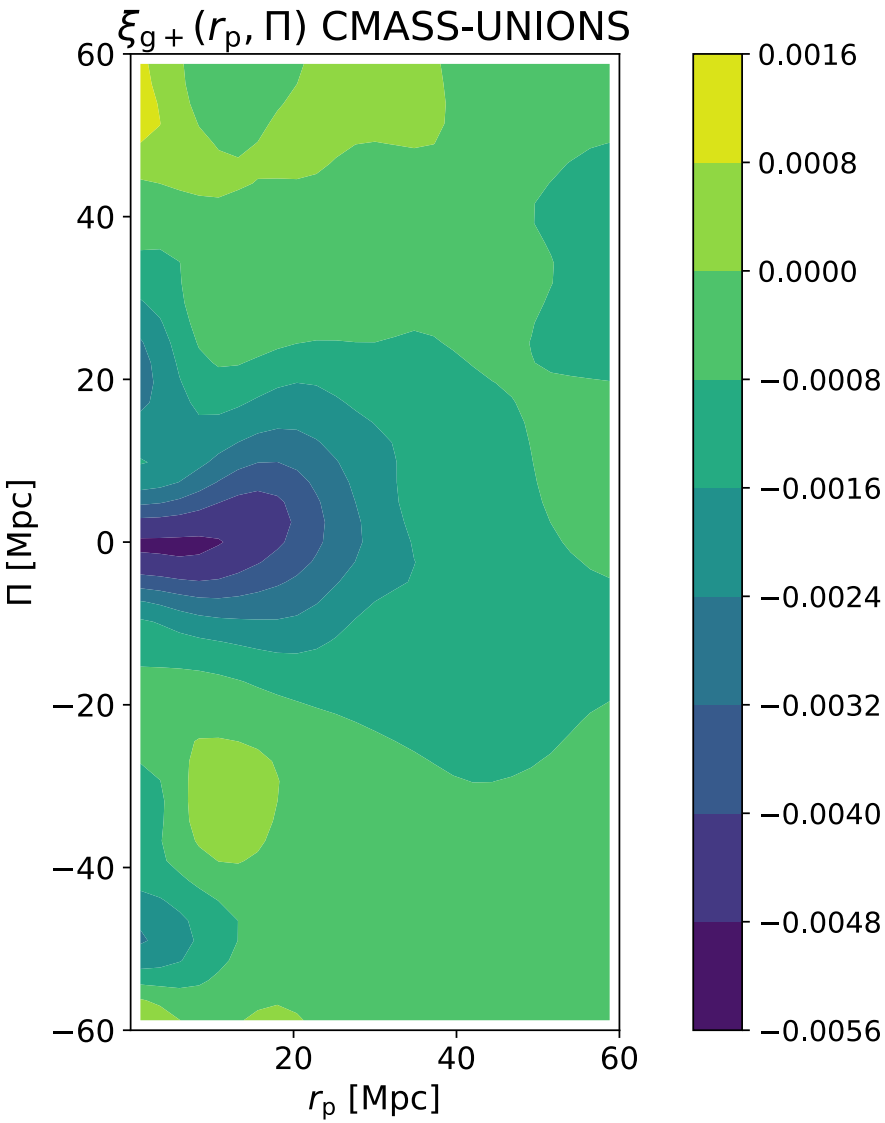


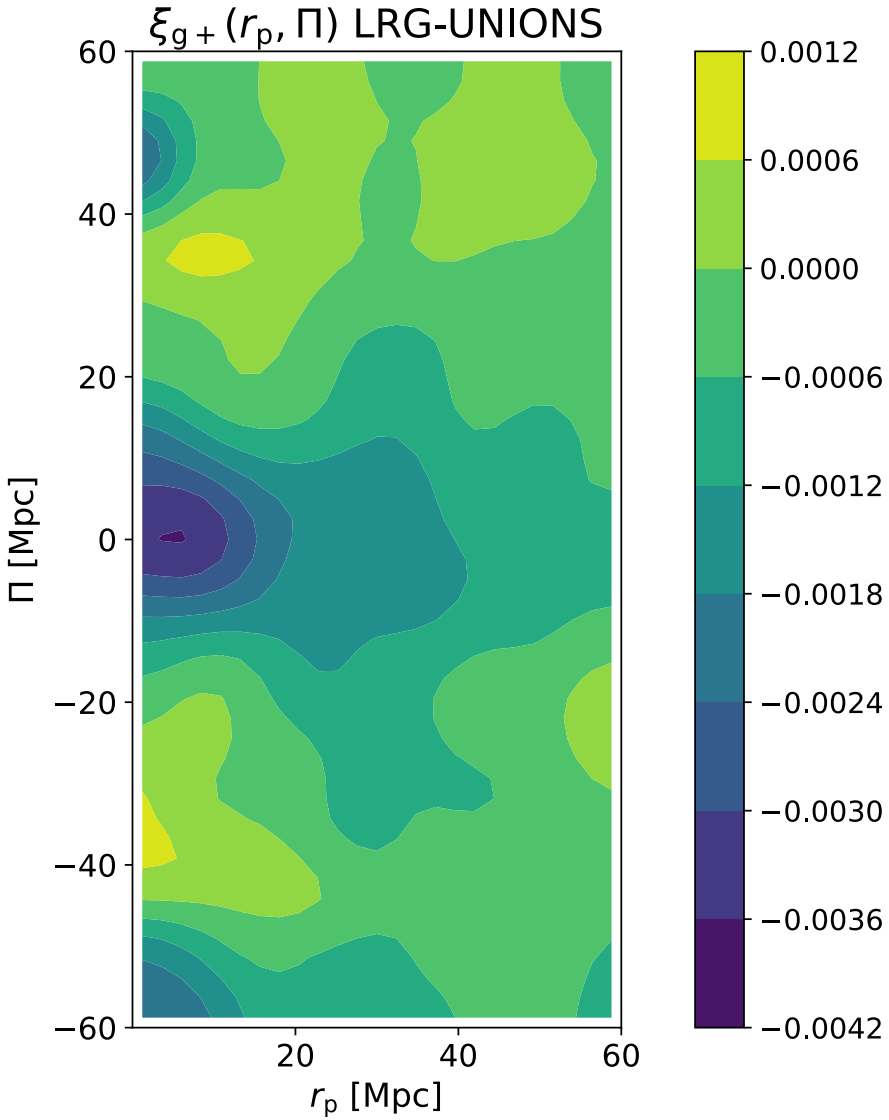



# Intrinsic alignment measurements (2)

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



# Projection effect

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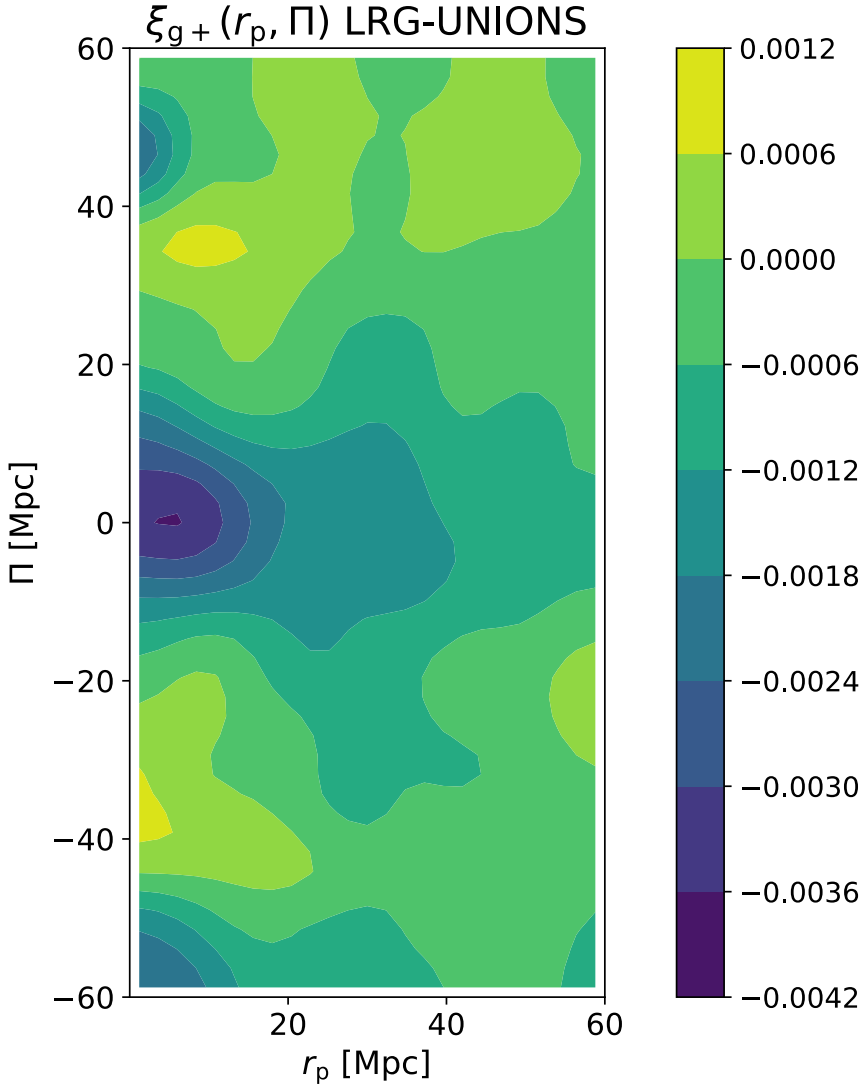
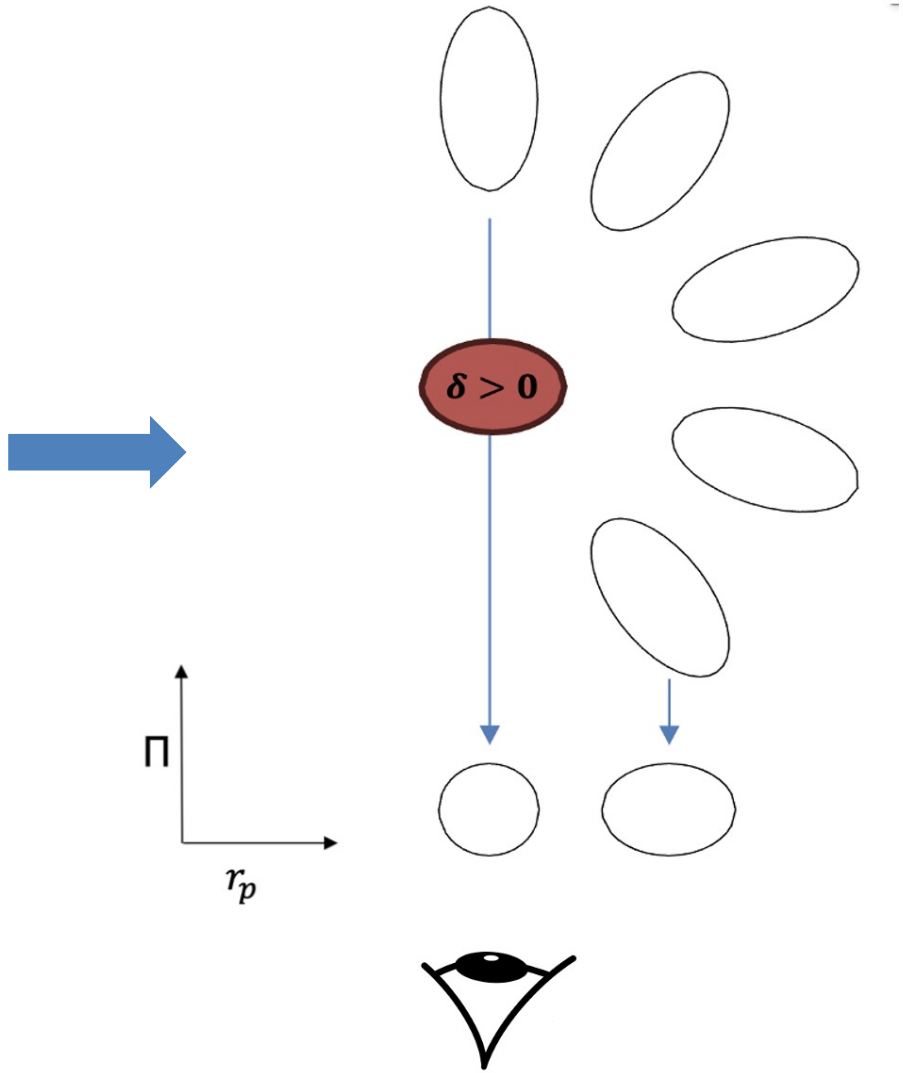


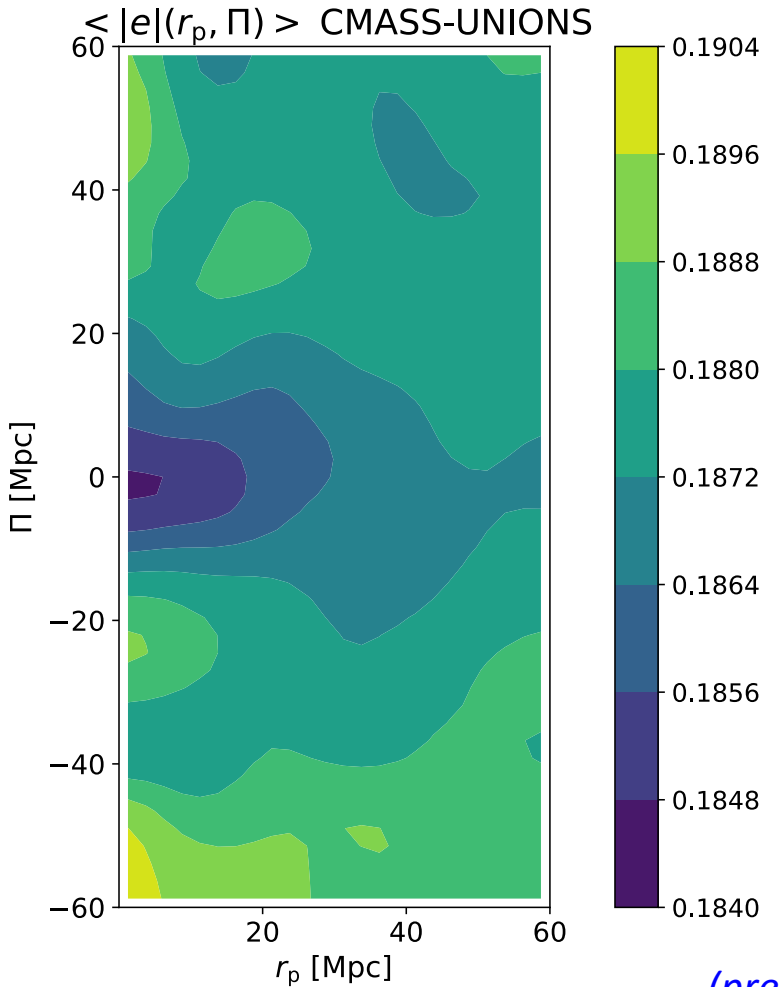



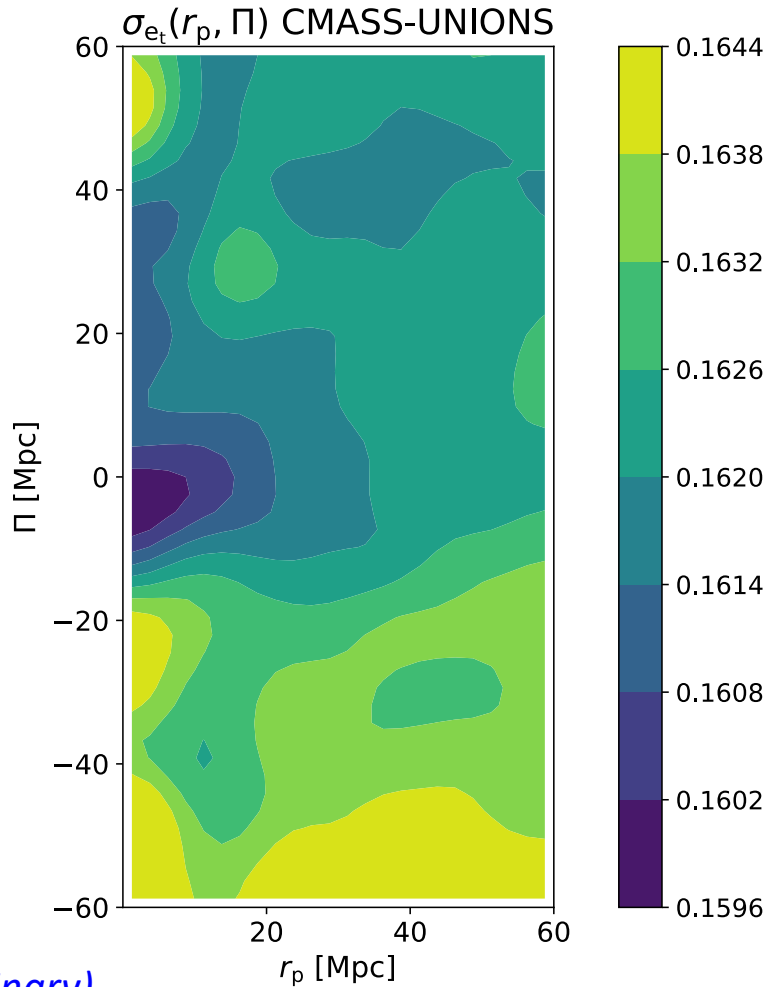
# Prospects

- **Next objective of the project:** to develop estimators **beyond traditional estimators** to measure an intrinsic alignment signal by analyzing correlations between the **3D shapes** of galaxies with **Euclid data**.

# Prospects

- **Next objective of the project:** to develop estimators **beyond traditional estimators** to measure an intrinsic alignment signal by analyzing correlations between the **3D shapes** of galaxies with **Euclid data**.
- **Prospects:** other interesting statistics...




*(preliminary)*

# Thank you for your attention !

# *Back up slides*

# 3D galaxy population: modelling

- Parameters: $\theta = \{\mu_{\tau_A}, \mu_{\tau_B}, \mu_{\tau_C}, \sigma_{\tau_A}, \sigma_{\tau_B}, \sigma_{\tau_C}, r_\tau\}$

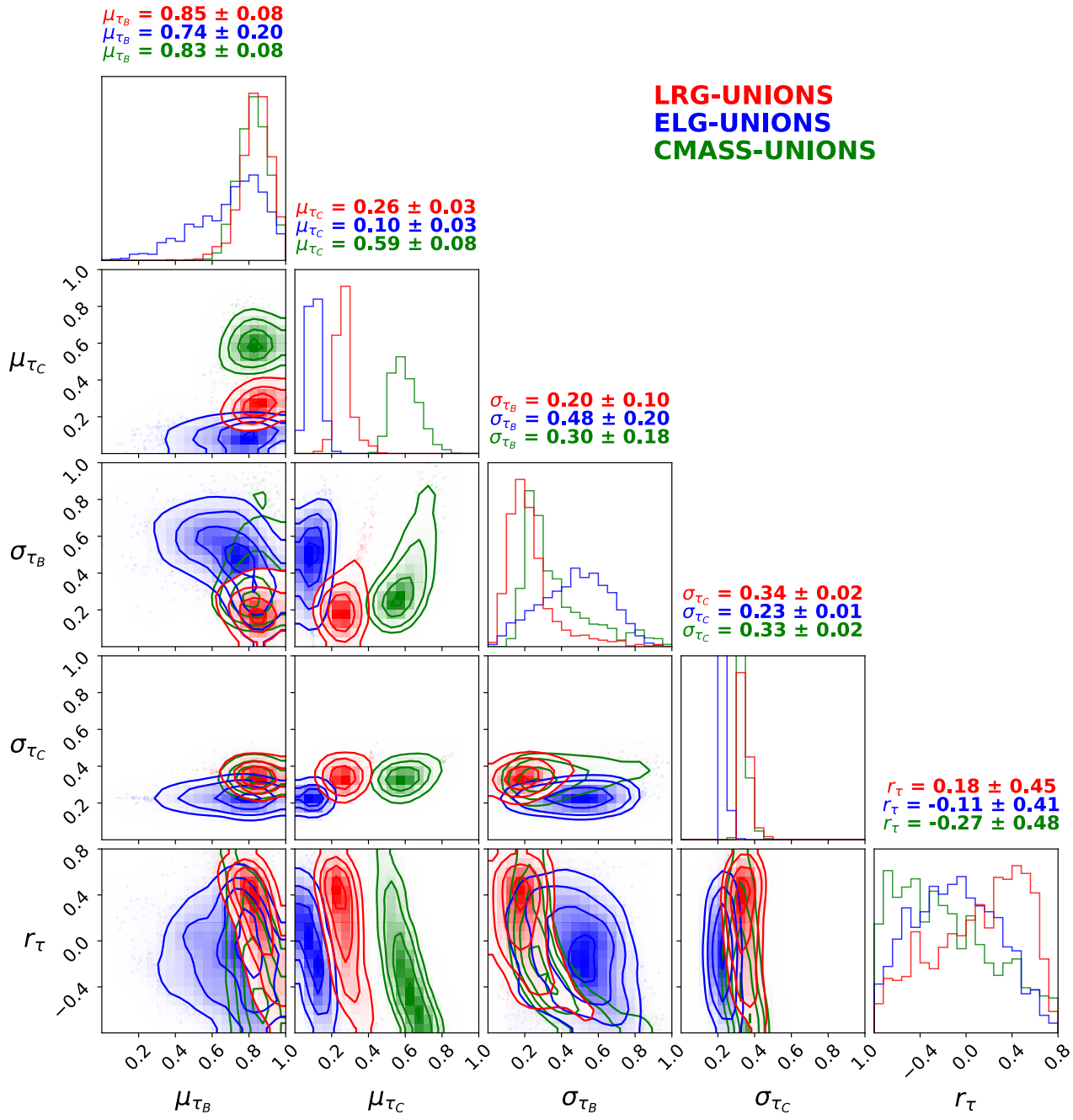
- Gaussian draw: $f(\boldsymbol{x}) = \frac{1}{(2\pi)^{\frac{3}{2}}|\Sigma|^{\frac{1}{2}}} \exp\left(-\frac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu})^T\Sigma^{-1}(\boldsymbol{x}-\boldsymbol{\mu})\right)$

with:

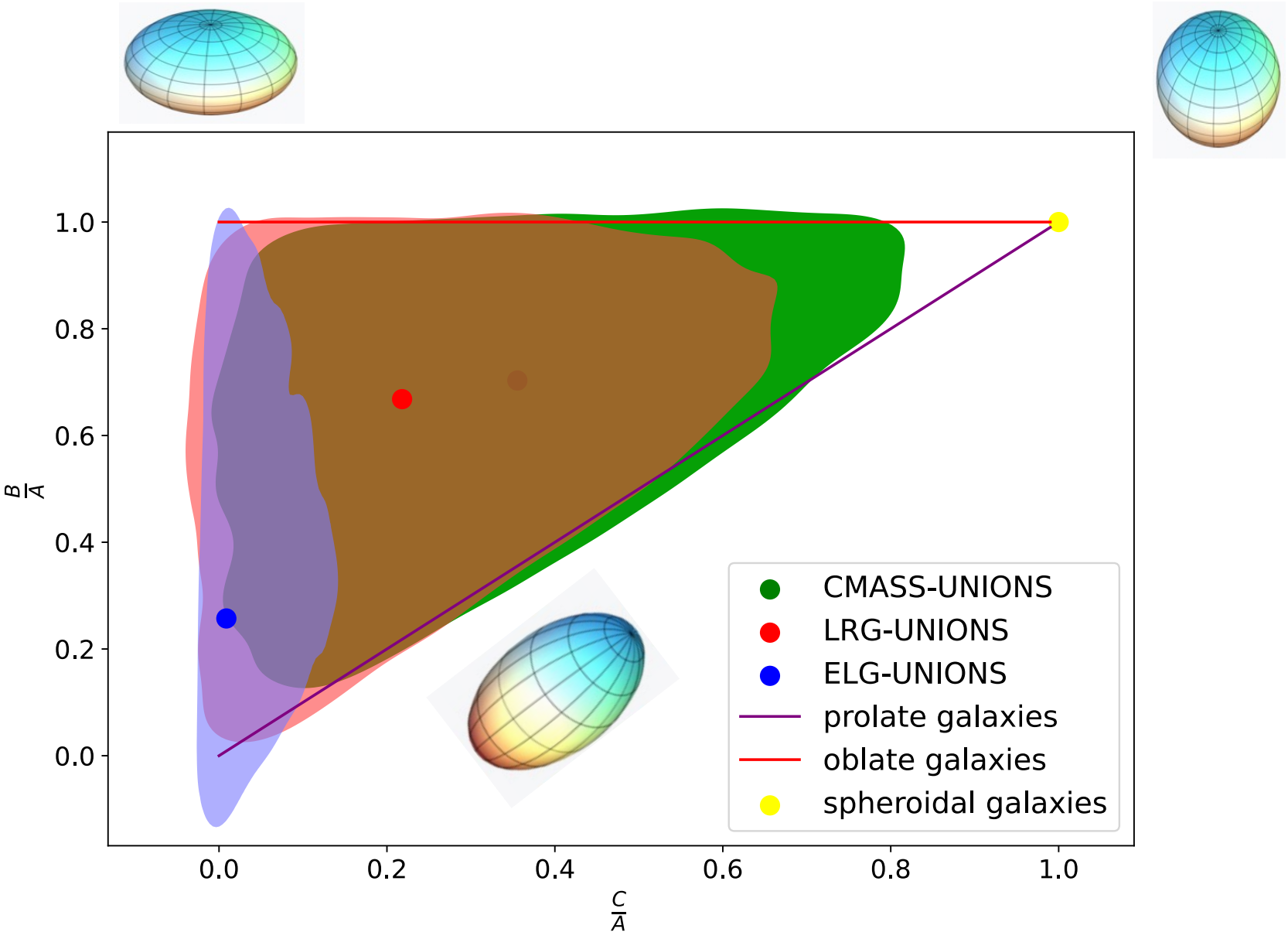
Mean vector: $\boldsymbol{\mu} = \begin{pmatrix} \mu_{\tau_A} \\ \mu_{\tau_B} \\ \mu_{\tau_C} \end{pmatrix}$

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

# Contours for other parameters

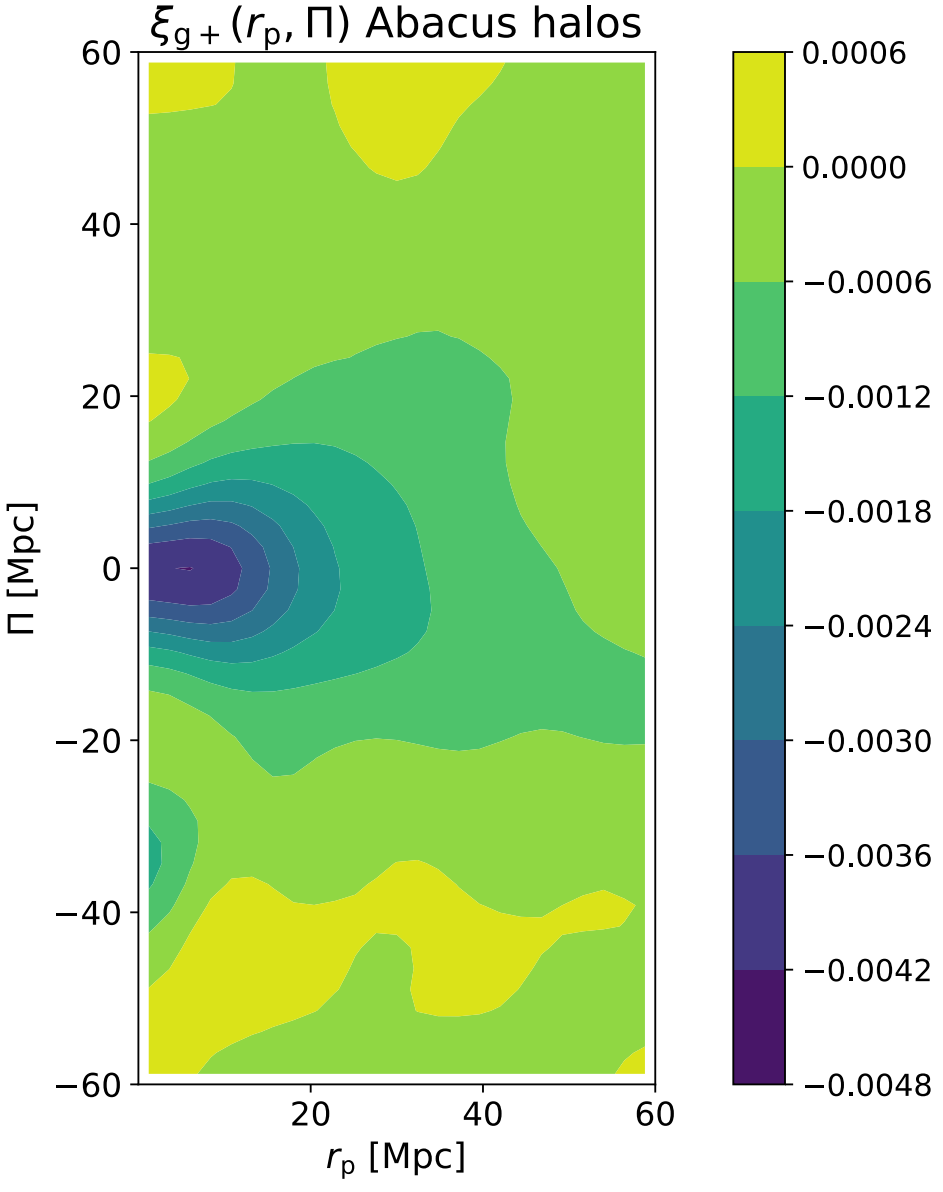


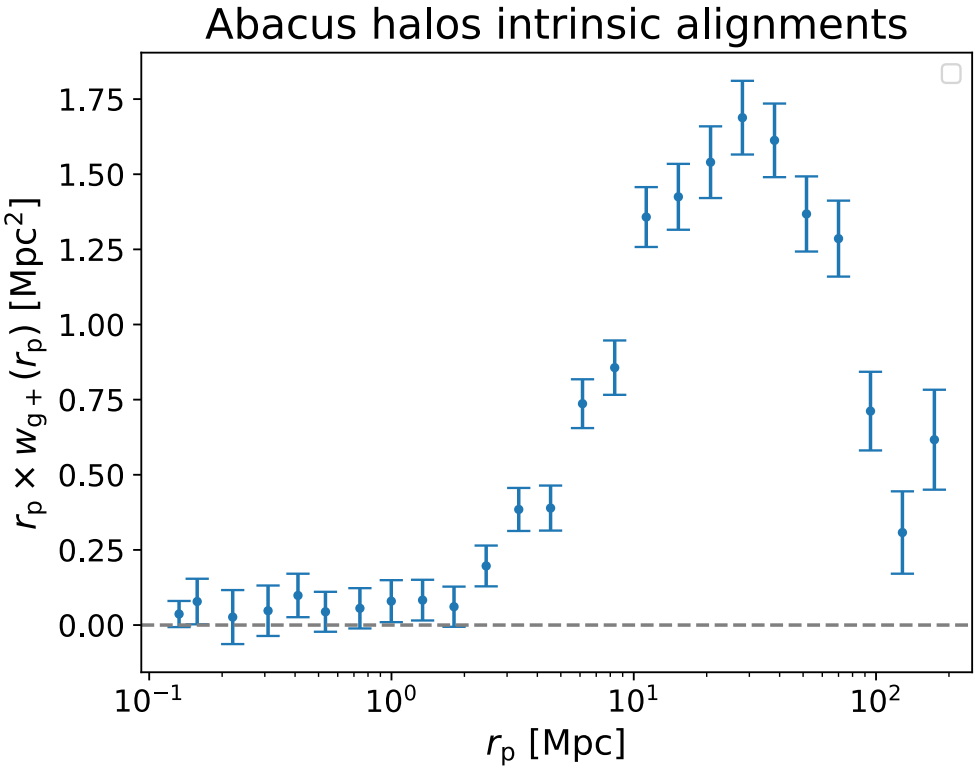
# Constraints on the 3D morphology of the galaxies



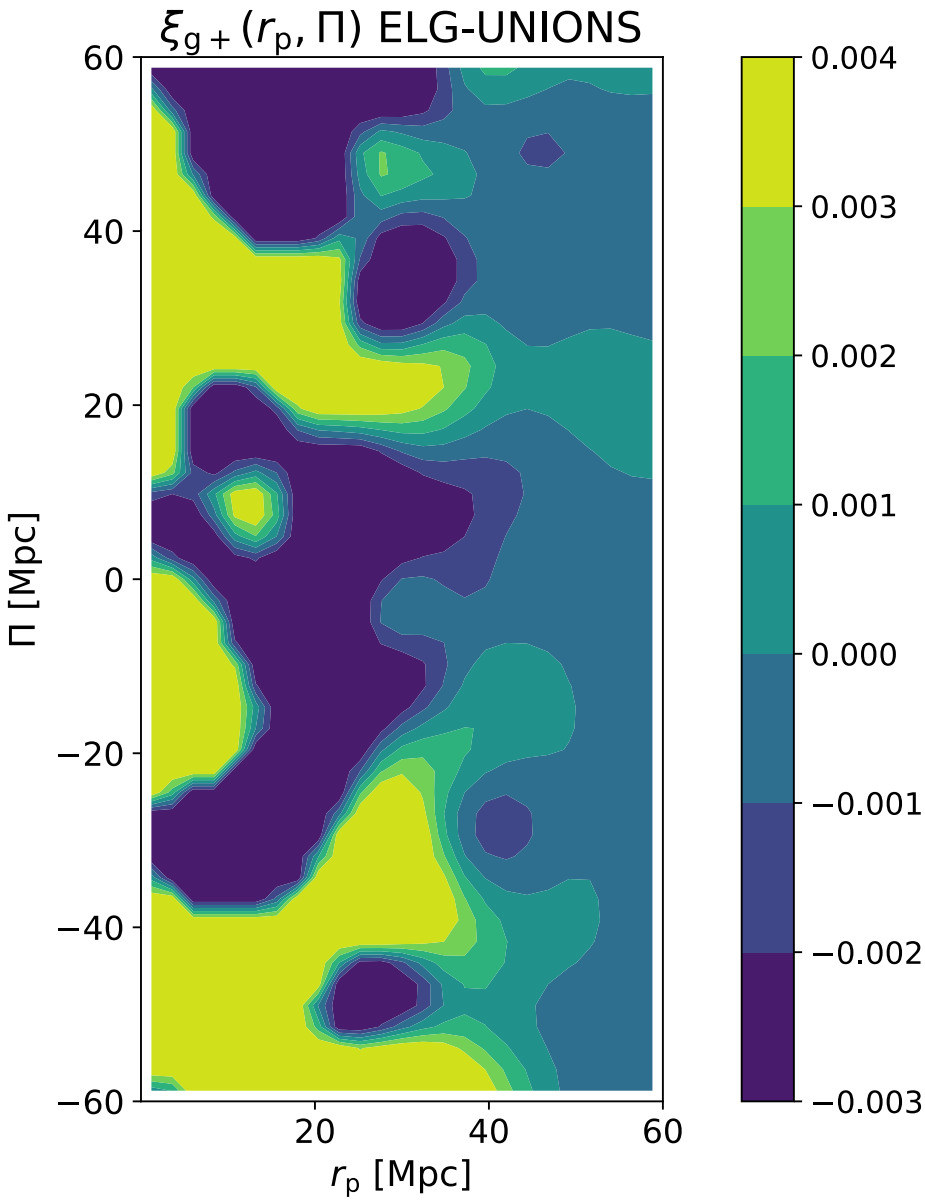

*(preliminary)*

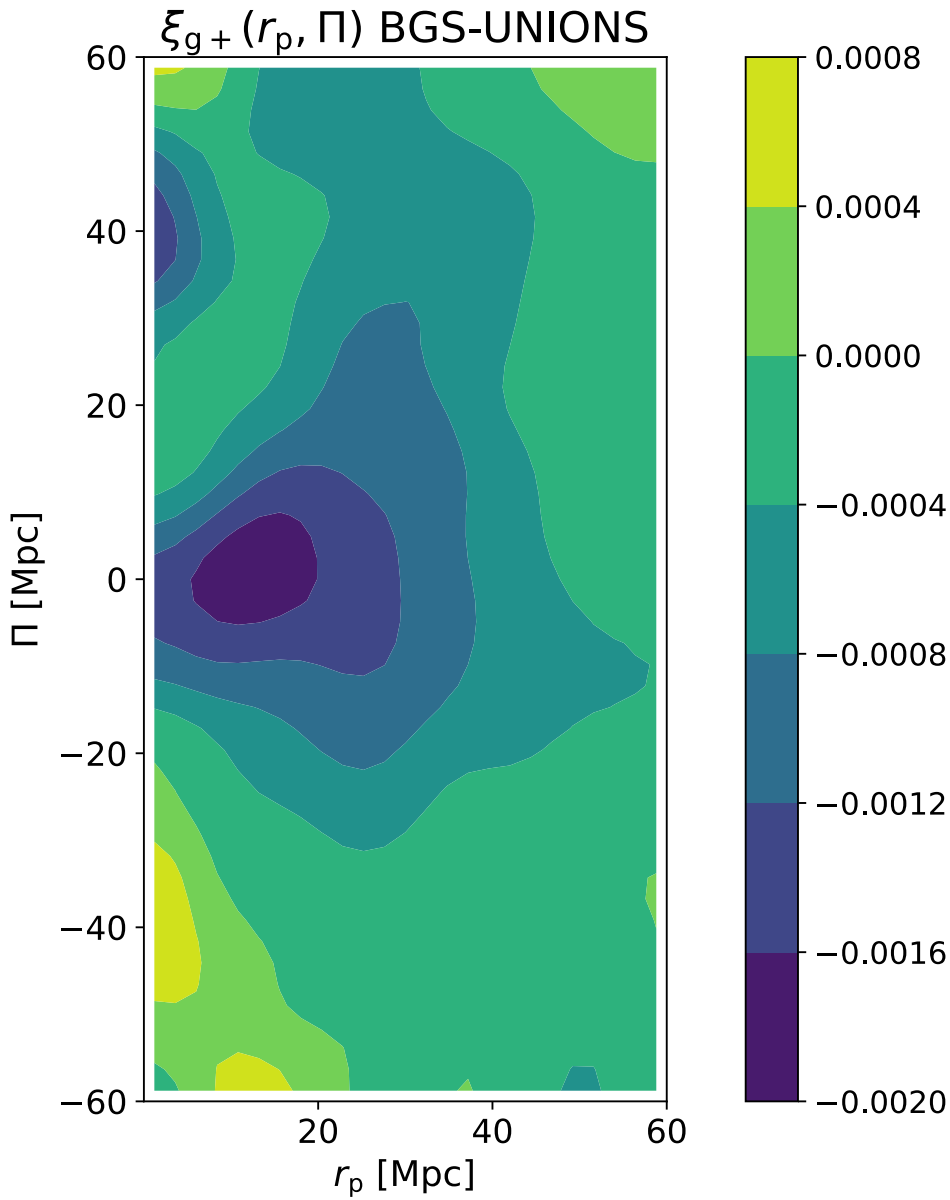
# Halo intrinsic alignment measurements



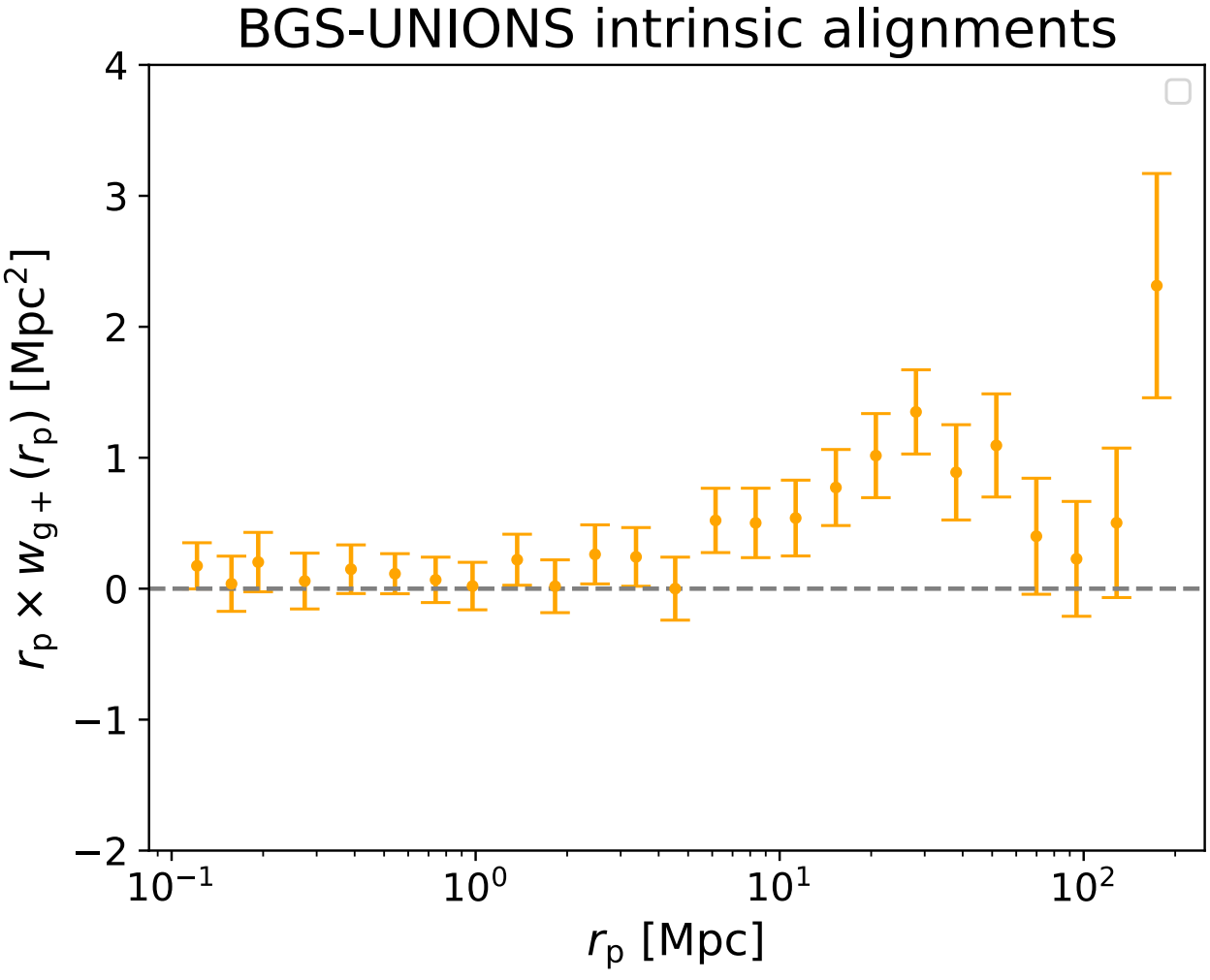



# Galaxy intrinsic alignment measurements for other galaxy samples



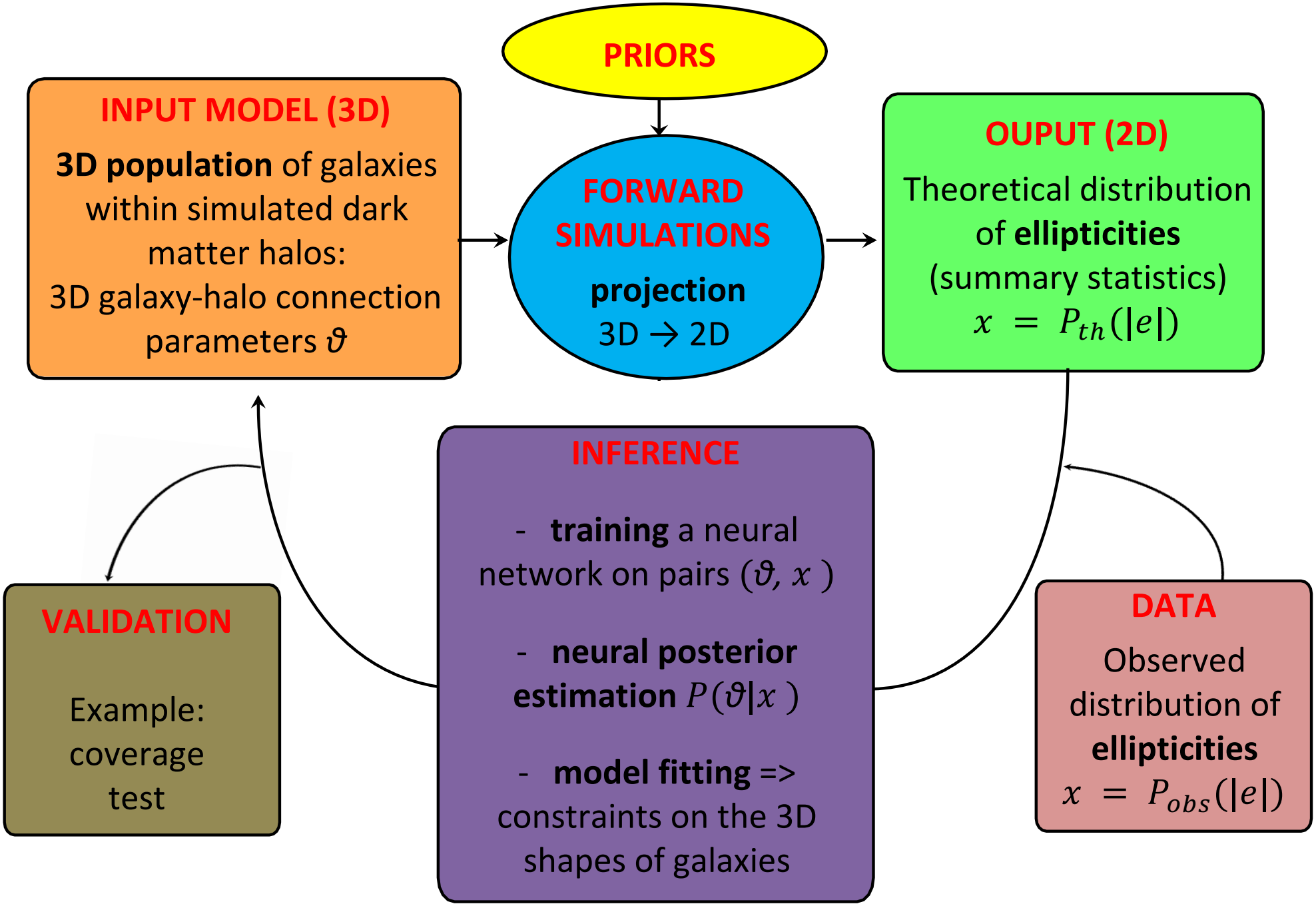



# Projected correlation function measurements for BGS-UNIONS

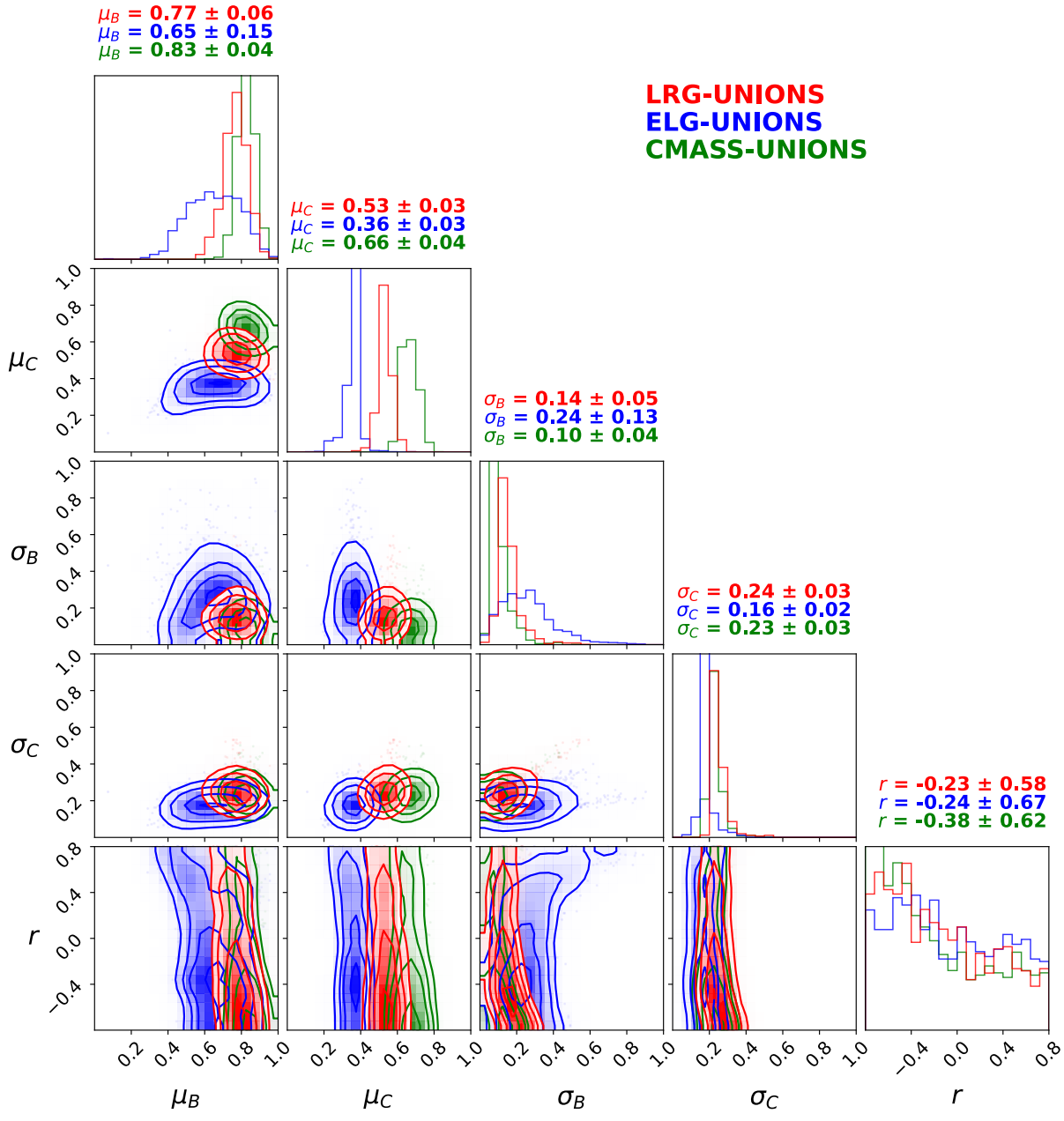



**BGS-UNIONS**: ~1 000 000 galaxies

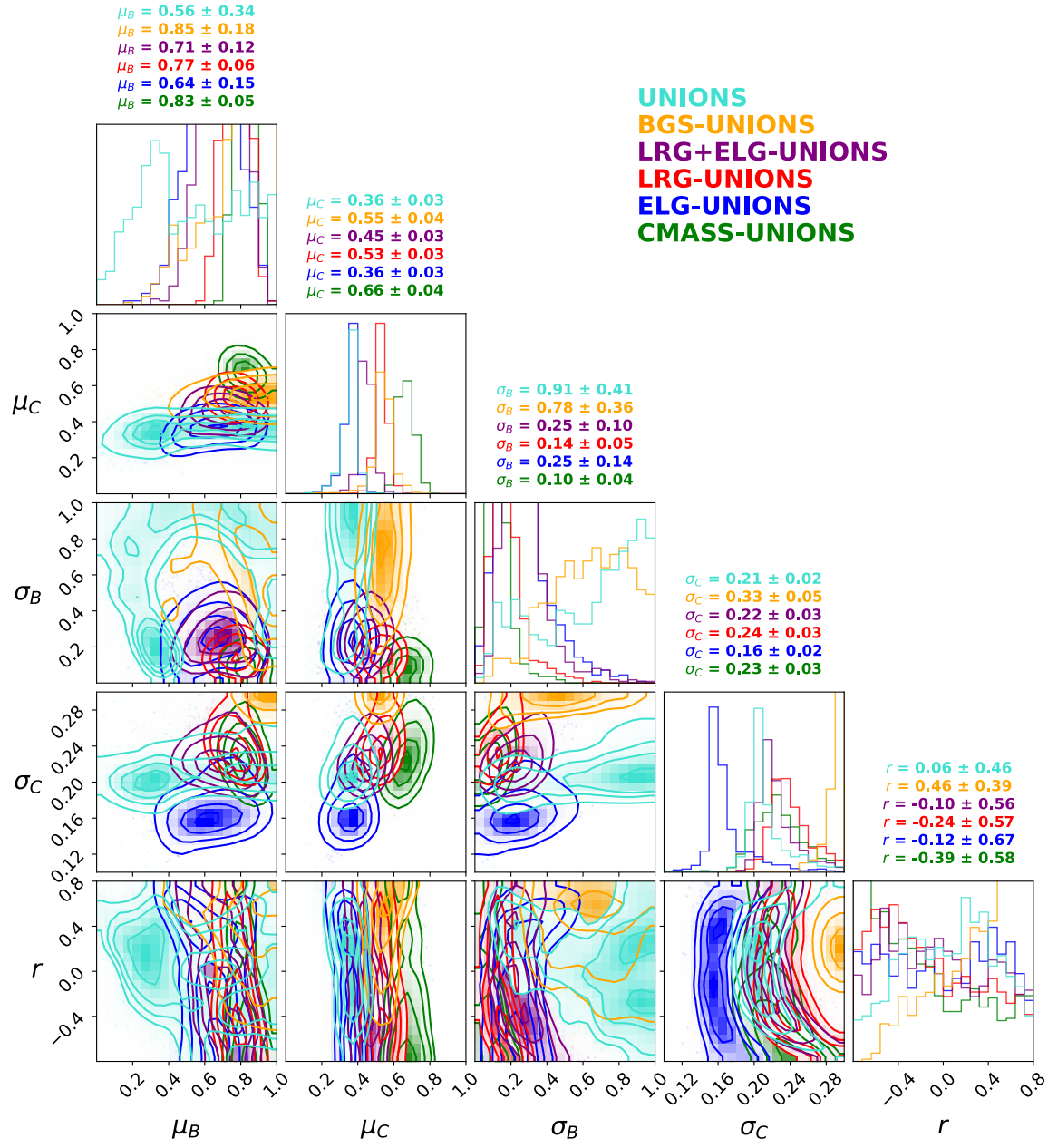
# Methodology: simulation-based inference



# Contraints on the parameters of 3D morphology of galaxies with an other simple model



# Contraints on the parameters of 3D morphology of galaxies for other samples



# Distribution of ellipticities $P(|e|)$ for other galaxy samples