Inferring the 3D shapes of galaxies inside halos with UNIONS and DESI

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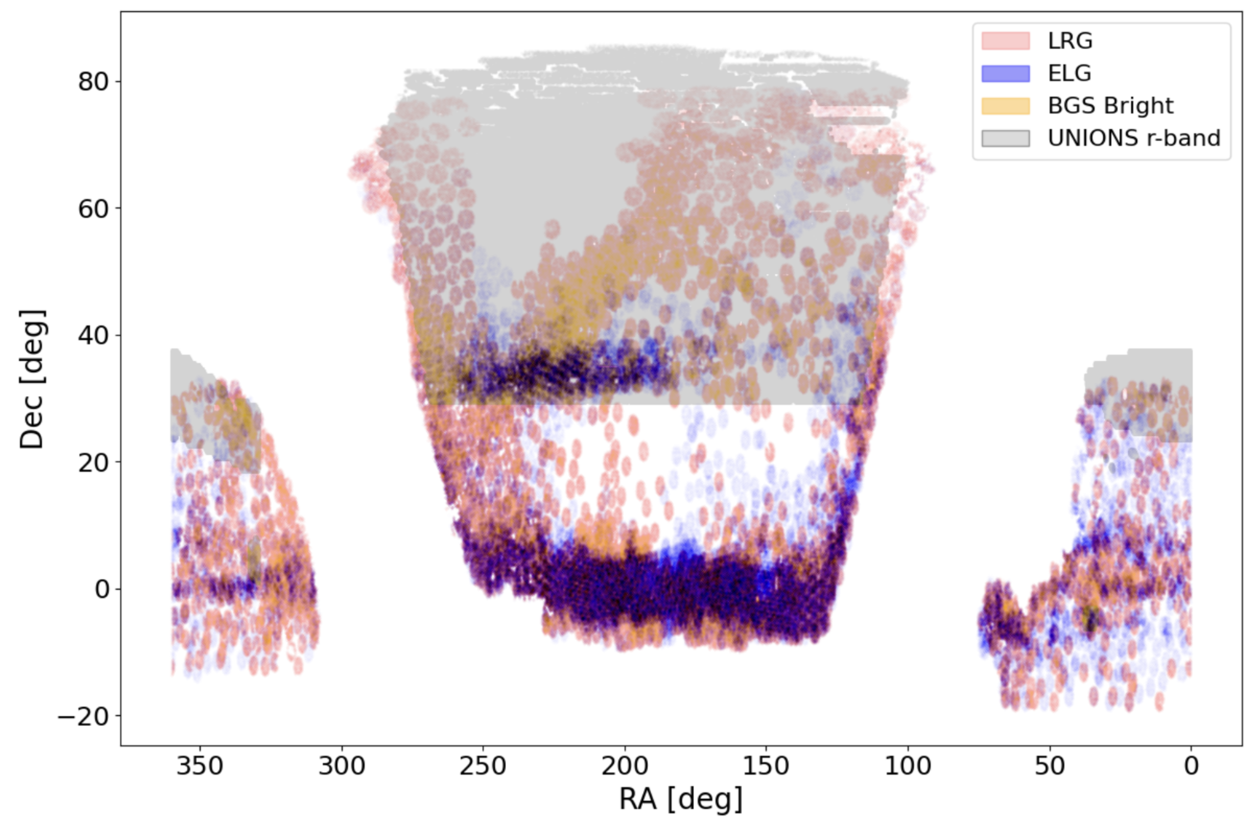
Introduction

- Understanding the **galaxy-halo connection** [1] — how the properties of galaxies relate to those of their host **dark matter halos** — is a key ingredient for cosmology, in particular to interpret **intrinsic alignments**: the correlations between galaxy shapes and orientations and the underlying **tidal field** of dark matter. In this work, I present a model relating the **3D morphology** of galaxies to that of their host halos, to constrain the **3D shapes** of galaxies from their projected images observed in the **Ultra-violet Near-Infrared Optical Northern Survey (UNIONS)**, cross-matched with density tracers from the **Dark Energy Spectroscopic Instrument (DESI)**.
- We present :
  1. A model for the 3D shape of central galaxies populating dark matter halos, whose 3D shapes are extracted from the **AbacusSummit N-body simulation** and which are occupied using a **Halo Occupation Distribution (HOD)** model
  2. Constraints on the distribution of **3D shapes** of Luminous Red Galaxies (LRG), Emission Line Galaxies (ELG) and Bright Galaxy Survey (BGS) from their projected images using **simulation-based inference**

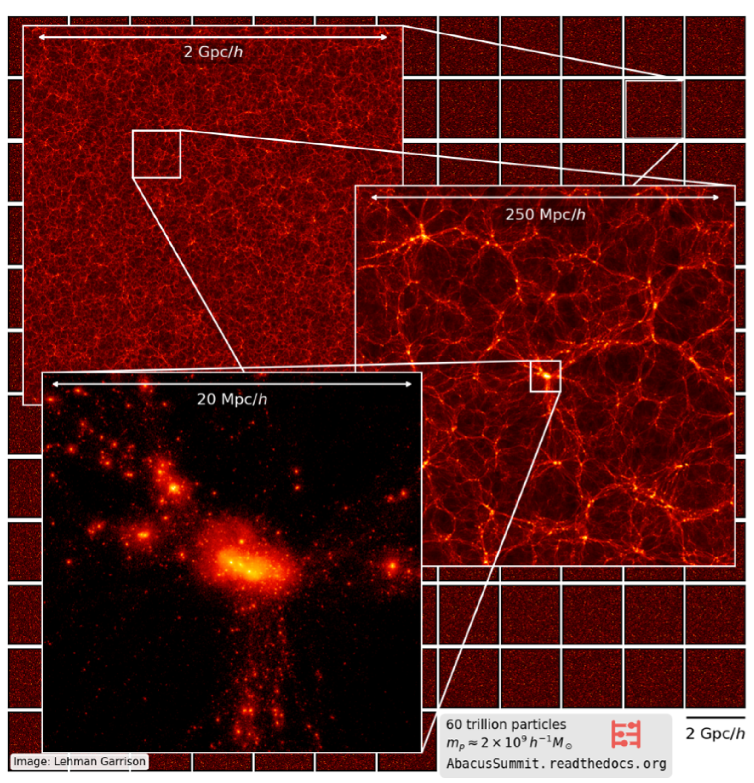
Galaxies: UNIONS and DESI data



Survey footprints of UNIONS and DESI

- **UNIONS** [2] : multi-band optical survey, 5800 deg^2, **shape sample**
- **DESI** (Dark Energy Spectroscopic Instrument) : redshift information, **density sample**: LRG, ELG and BGS
- **Cross-match** between UNIONS shapes and DESI

Halos: AbacusSummit N-body simulations



AbacusSummit N-body simulation

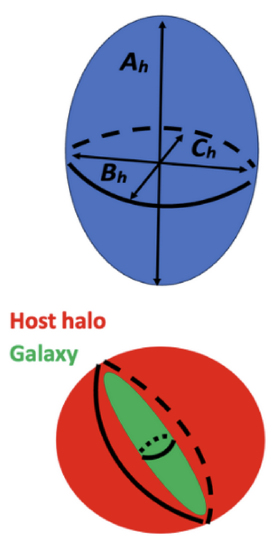
- **Simulation suite** designed for DESI [3] with 60 trillion particles:
  - Box size: $2\,h^{-1}\,\mathrm{Gpc}$.
  - 139 simulations with particle mass $2 \times 10^9\,h^{-1}\mathrm{M}_\odot$.
- Catalogues of halos identified using the **CompaSO algorithm**:
  - axis lengths $A_h > B_h > C_h$ and 3D orientations
  - match with each galaxy sample using a HOD model and galaxy clustering

Modelling the 3D shapes of galaxies inside dark matter halos

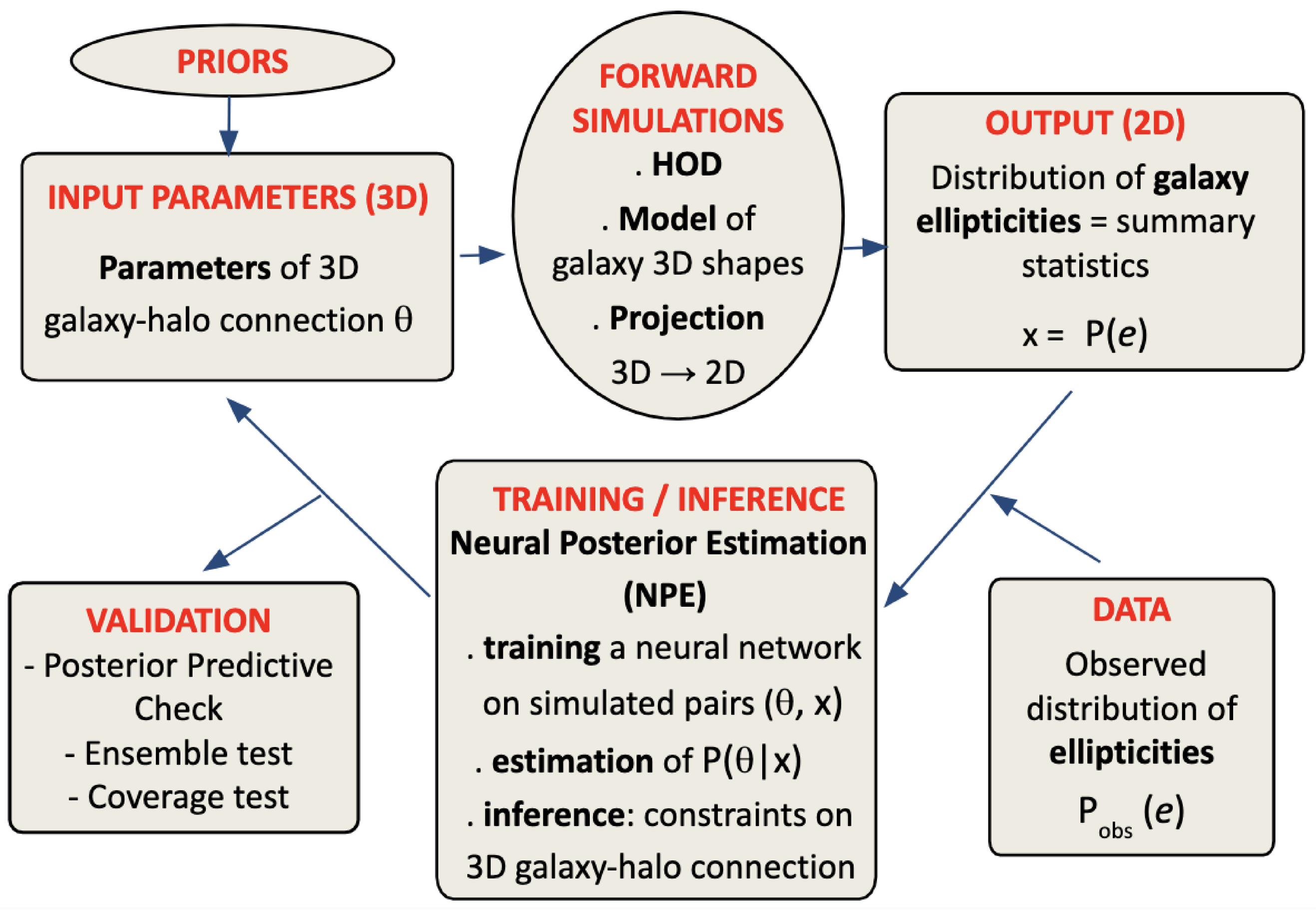
- Settlement of the host halos by **3D central galaxies** with axis ratios B_g/A_g, C_g/A_g such that:

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

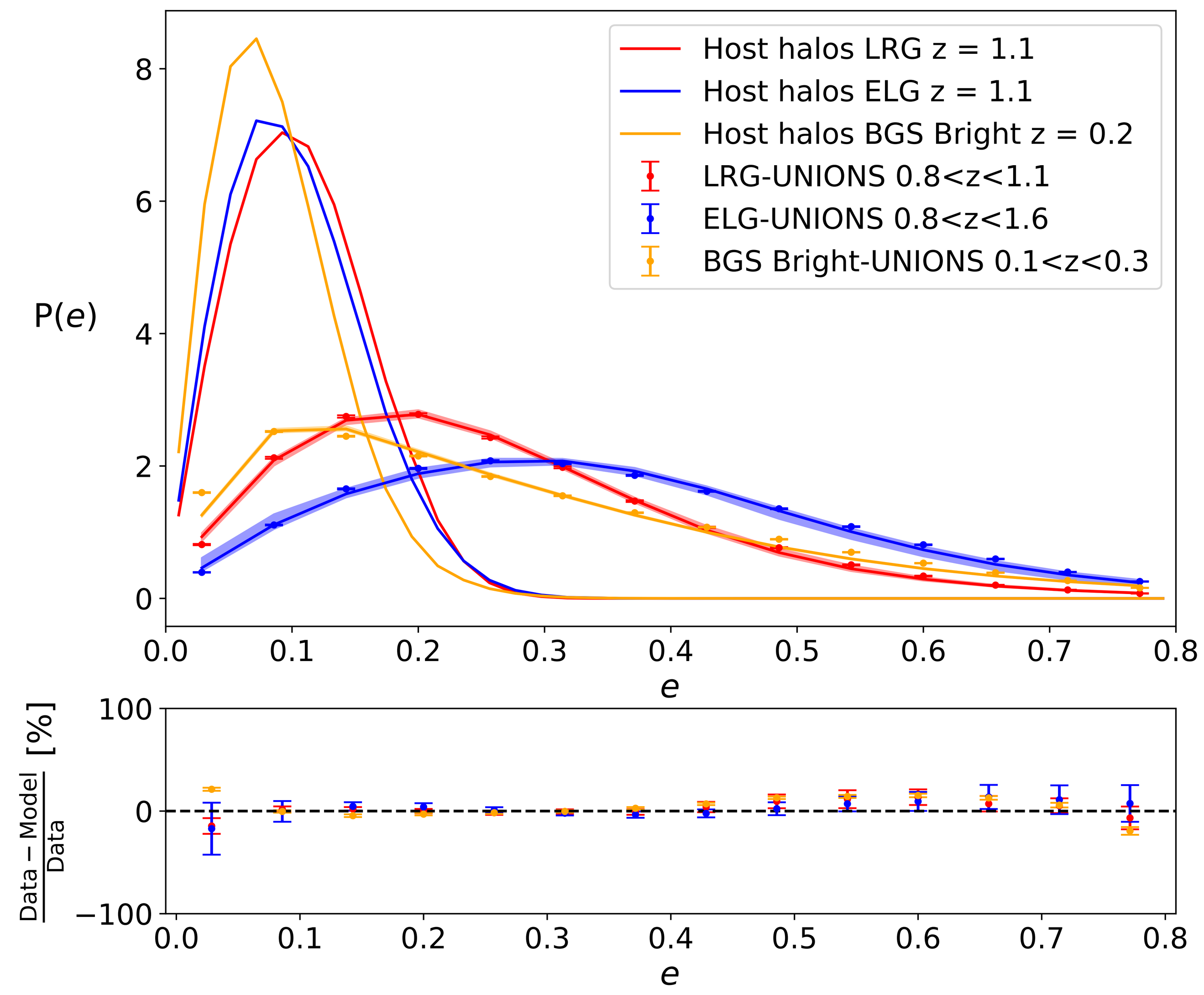
- 3D population = **gaussian draw** of τ_B and τ_C around mean values μ_{τ_B}, μ_{τ_C}



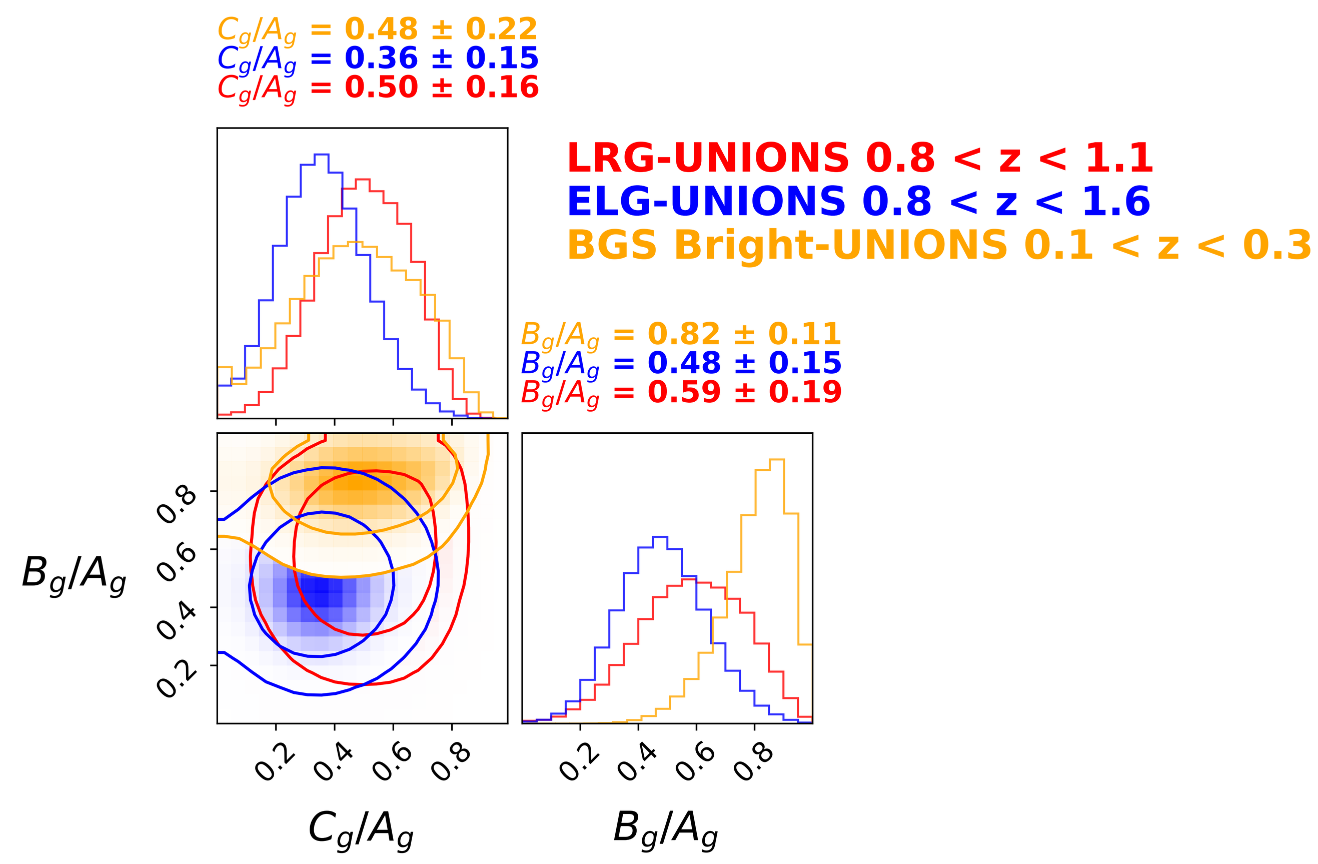
Simulation-based inference to constrain 3D shapes from data



Results : 3D morphology of LRG, ELG and BGS



Distributions of ellipticities $P(e)$ of galaxies and halos



Constraints on the 3D shapes of galaxies inside halos

Conclusion and perspectives

- **New method** centered on simulation-based inference to infer the distribution of the 3D shapes of galaxies inside halos
- Our simulation-based model of morphology **fits well** with observations
- **Future work**: predict an intrinsic alignment signal using this model

References

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