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

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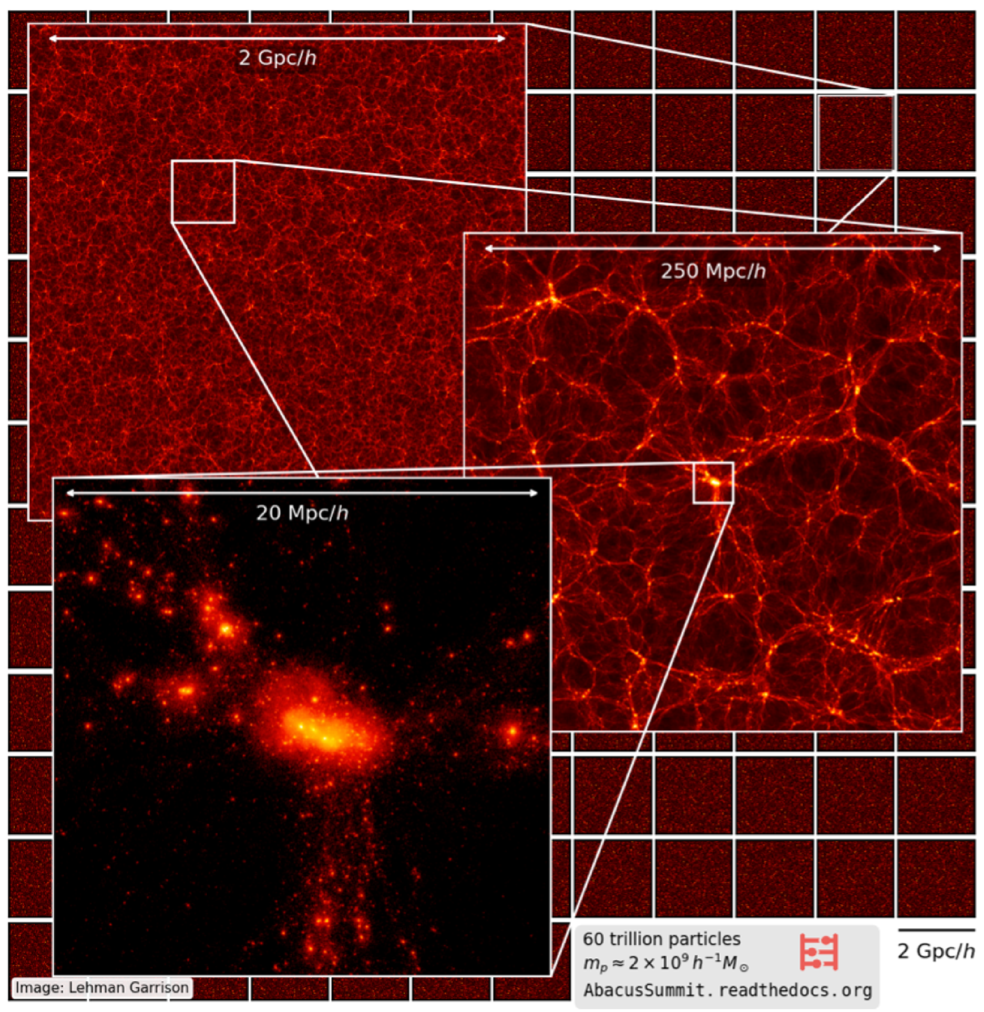
Introduction

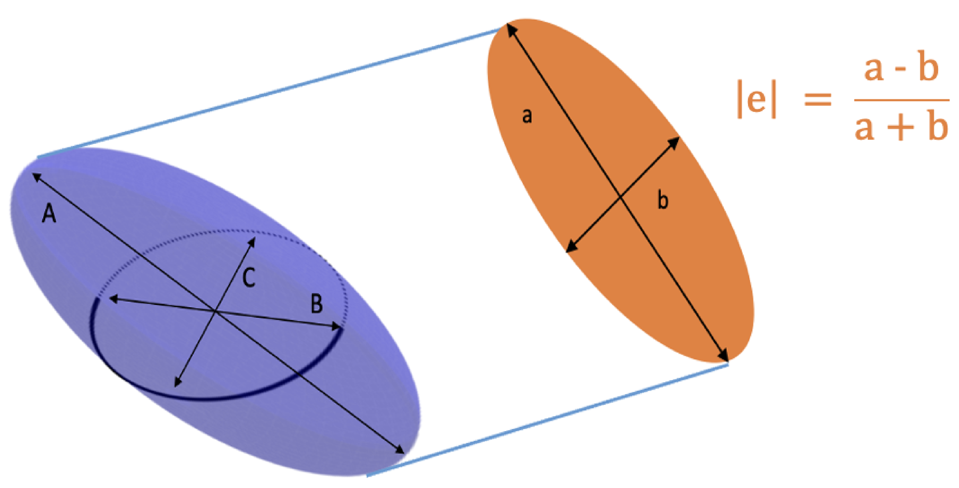
- **Galaxies** within their host **dark matter halos** are subject to **intrinsic alignments** which correspond to the correlations between the 3D galaxy shapes and orientations and the underlying **tidal field** of dark matter. This intrinsic galaxy alignment is traditionally analyzed with **2D estimators** that measure the projected galaxy shape correlations in the sky plane. This projection, however, leads to a **loss of information** [1]. In this work, I present some investigations I did during my master's project to find ways of recovering the **full intrinsic galaxy alignment** by inferring their 3D shapes and 3D correlations from the projected images of the galaxies observed in the **Ultraviolet Near-Infrared Optical Northern Survey (UNIONS)**. The scientific motivation is to better understand how galaxies respond to the **3D cosmological tidal field** of dark matter in the **large-scale structures** of the Universe.
- We present :
  1. A simple model for 3D galaxies that populate dark matter halos whose shapes are extracted from the **AbacusSummit N-body simulation**, as we can't directly observe 3D shapes of galaxies in the data
  2. Constraints on the **3D shapes** of the galaxies of UNIONS measured from their projected images using a method based on **simulation-based inference**
  3. Measurements of **2D intrinsic alignment correlations** of galaxies and halos using their projected shapes

Model for 3D galaxies within simulated dark matter halos



AbacusSummit N-body simulation [2]

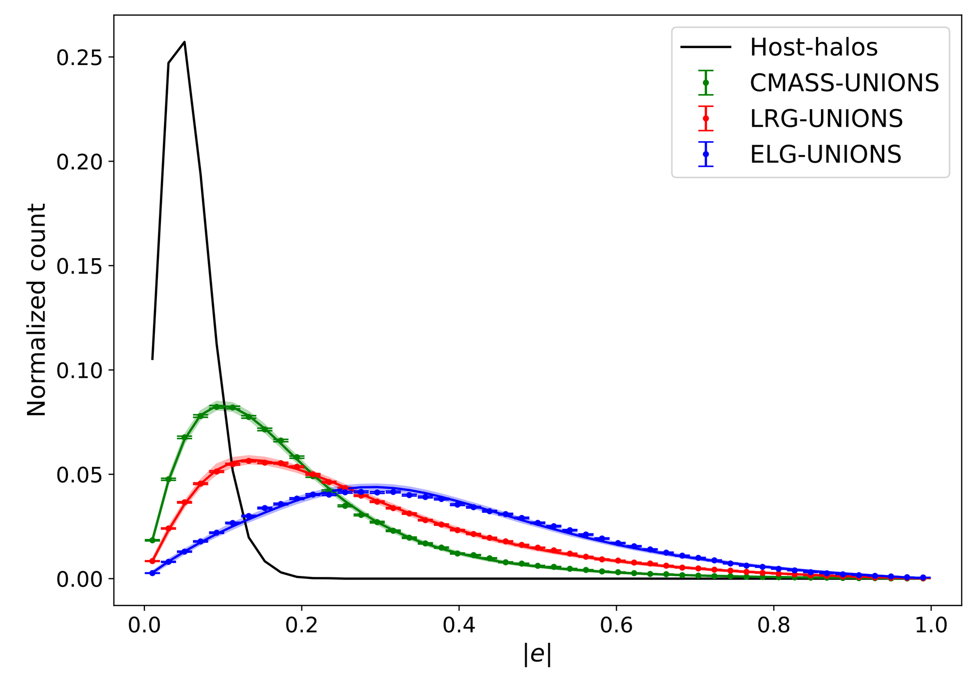
1. Extraction of the **3D shapes** A_h, B_h, C_h and **3D orientations** of the dark matter halos from the AbacusSummit N-body simulation
2. **Settlement** of them by 3D galaxies with 3D orientations inherited from the host-halos ones and of shape A_g, B_g, C_g such that : $A_g = \tau_A A_h$, $B_g = \tau_B B_h$ and $C_g = \tau_C C_h$ ($\tau_A, \tau_B, \tau_C \in [0;1]$)
3. **Projection** in 2D [3] for different τ_A, τ_B, τ_C drawn uniformly in $[0;1]$



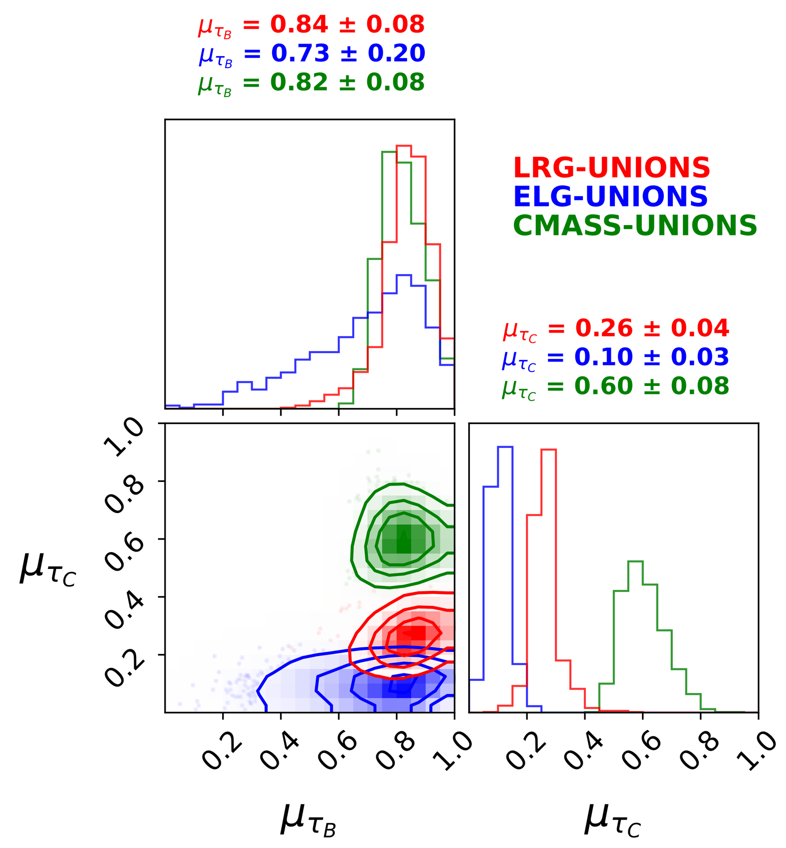
Data : UNIONS, SDSS and DESI surveys

- **UNIONS** : multi-band optical survey, 4800 deg^2, **shape sample**
- **SDSS** (Sloan Digital Sky Survey) and **DESI** (Dark Energy Spectroscopic Instrument) : redshift information, **density sample**
  - CMASS (Constant Mass) galaxies
  - LRG (Luminous Red Galaxies) and ELG (Emission Line Galaxies)
- **Cross-match** between UNIONS shapes and SDSS/DESI positions

Results : constraints on 3D shapes of galaxies from 2D images



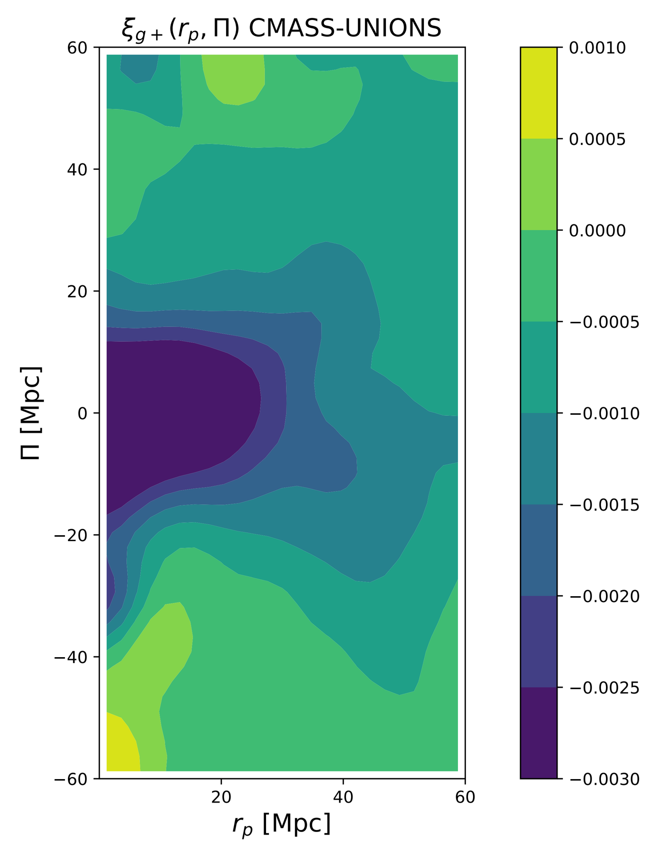
Histogram of projected shapes $P(|e|)$: model fitting with UNIONS, SDSS and DESI data

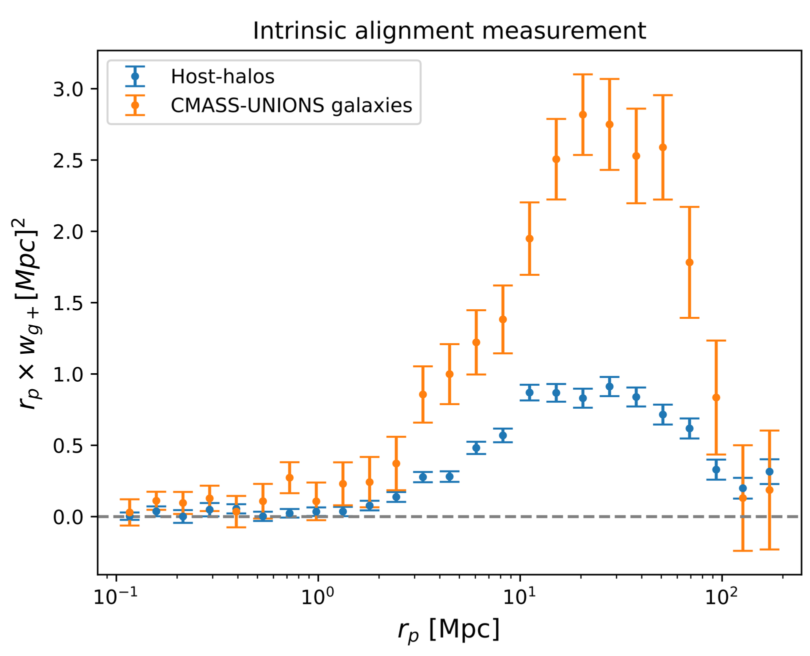


Constraints on the parameters of 3D galaxy-halo connection ; $\mu_{\tau_B}, \mu_{\tau_C}$: means of τ_B, τ_C for the whole population of galaxies and halos

Signal of intrinsic alignment ξ_{g+} with traditional 2D estimators

$$\xi_{g+}(r_p, \Pi) = \frac{\mathrm{Shape}_+\mathrm{Density} - \mathrm{Shape}_+\mathrm{Random}_D}{\mathrm{Random}_D\mathrm{Random}_S} \qquad w_{g+}(r_p) = \int_{-\Pi_{max}}^{\Pi_{max}} \xi_{g+}(r_p, \Pi)\, d\Pi \quad [4]$$





Conclusion and perspectives

- We have an **innovative method** centered on simulation-based inference to infer the **3D shapes** of SDSS and DESI galaxies from their projected images measured with UNIONS, and their **3D connection** with their host dark matter halos. We can also analyze correlations between their projected images to measure **2D intrinsic alignment** of galaxies.
- Next step (work in progress) : development of **new estimators** to measure correlations between the **3D shapes and 3D orientations** of the galaxies and application of this research to the future **Euclid VIS data**

References

[1] S. Singh and R. Mandelbaum, "Intrinsic alignments of boss lowz galaxies – ii. impact of shape measurement methods", *Monthly Notices of the Royal Astronomical Society*, vol. 457, no. 3, pp. 2301–2317, Feb. 2016, ISSN: 1365-2966. DOI: 10.1093/mnras/stw144. [Online]. Available: http://dx.doi.org/10.1093/mnras/stw144.

[2] N. A. Maksimova, L. H. Garrison, D. J. Eisenstein, *et al.*, "¡scp¿abacussummit¡/scp¿: A massive set of high-accuracy, high-resolution n-body simulations", *Monthly Notices of the Royal Astronomical Society*, vol. 508, no. 3, pp. 4017–4037, Sep. 2021, ISSN: 1365-2966. DOI: 10.1093/mnras/stab2484. [Online]. Available: http://dx.doi.org/10.1093/mnras/stab2484.

[3] C. Lamman, D. Eisenstein, J. N. Aguilar, *et al.*, "Intrinsic alignment as an rsd contaminant in the desi survey", *Monthly Notices of the Royal Astronomical Society*, vol. 522, no. 1, pp. 117–129, Apr. 2023, ISSN: 1365-2966. DOI: 10.1093/mnras/stad950. [Online]. Available: http://dx.doi.org/10.1093/mnras/stad950.

[4] F. Hervas Peters, M. Kilbinger, R. Paviot, *et al.*, "Unions: A direct measurement of intrinsic alignment with boss/eboss spectroscopy", *Astronomy amp; Astrophysics*, vol. 699, A201, Jul. 2025, ISSN: 1432-0746. DOI: 10.1051/0004-6361/202453442. [Online]. Available: http://dx.doi.org/10.1051/0004-6361/202453442.

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