Cosmic voids with Euclid

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Introduction and Motivations

Cosmology, the study of the universe's origin and evolution, has advanced significantly in recent decades. Observations, such as those from the cosmic microwave background radiation and distant supernovae, strongly suggest that the universe is expanding. This expansion began from a compact, warm, and dense state known as the **Big Bang**, approximately 13.8 billion years ago.

Recent evidence indicates that the universe has entered a phase of accelerated expansion, driven by an unknown force termed **dark energy**. Additionally, the presence of **dark matter**, which constitutes about 27% of the universe, plays a crucial role in the formation of cosmic structures, influencing the motion of galaxies and galaxy clusters through its gravitational effects. Together, these components challenge our understanding of gravity and the fundamental properties of the universe. As we gather more data and refine our models, cosmology continues to evolve, offering deeper insights into the cosmos and the forces that govern its dynamics.

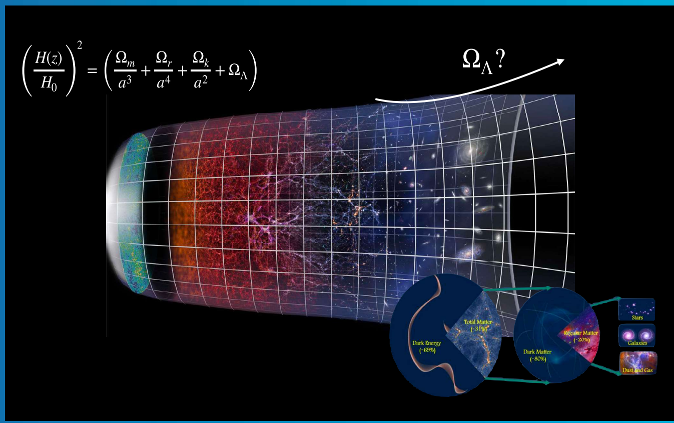

Figure 1: State of the art of the concordance model of cosmology

1) Euclid

The Euclid satellite [1] was launched in July 2023, and will observed about 1/3 of the sky after 5 years. Equipped with a visible-wavelength camera and a near-infrared spectrometer, Euclid will capture high-resolution images and spectra, allowing us to analyze the distribution and shape of billions of galaxies.

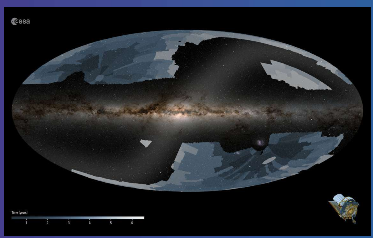

Figure 2: Area that Euclid will cover after 6 years of observations

Euclid main objective is to put cosmological constraints on Dark Energy and Dark matter, using the information contained in the position and shape of billions of galaxies.

2) Cosmic voids

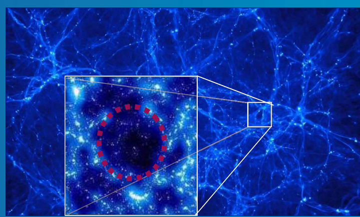

Figure 3: Exemple of a cosmic void identified in the cosmic web

Cosmic voids are large underdensities in the cosmic web, formed through gravitational interactions and the universe's expansion. As matter accumulates in denser regions, it leaves behind these relatively empty areas. While they may seem barren, cosmic voids play a crucial role in our understanding of cosmology, providing insights into dark energy, dark matter, and the overall dynamics of the universe.
Moreover, new-generation galaxy surveys, such as Euclid, will give the opportunity to cosmic voids to become a full cosmological probe and put constraints on cosmological parameters by increasing the total number of observed voids of about two degrees of magnitude, enhancing thus their statistical power.
In this project, we are using the algorithm described in [2] to identify voids in Euclid galaxy catalogues.

3) Gravitational lensing

Gravitational lensing is a powerful tool in cosmology, it occurs when the gravitational field of a massive object distorts the light from distant sources. In the context of weak lensing, the distortions manifest as slight elongations of galaxy shapes. This lensing effect allows astronomers to map the distribution of dark matter, as the amount of distortion correlates with the mass of the lensing object. By measuring the ellipticity of a large number of galaxies e_{obs}, it is possible to infer the amount of distortion of the galaxy field as:

$$e_{\text{obs}} = e_{\text{int}} + \gamma_t, \qquad \Delta\Sigma(r_p) \propto \gamma_t(r_p) \tag{1}$$

where e_{int} is the intrinsic ellipticity, that will average if the sample observed is large enough, and γ_t is the distortion of the galaxy shape due to gravitational lensing effects commonly called tangential shear. Information on the underlying matter field resides in the correlation between background galaxy for whom the shape has been distorted and foreground objects that will act as lenses, as pictured in fig.4. Since lensing is a projected effect, a common estimator of it is the Excess surface mass density $\Delta\Sigma(rp)$ defined in the right hand side of eq.1 that represent the projected mass crossed by the light as a function of the distance to the source r_p.

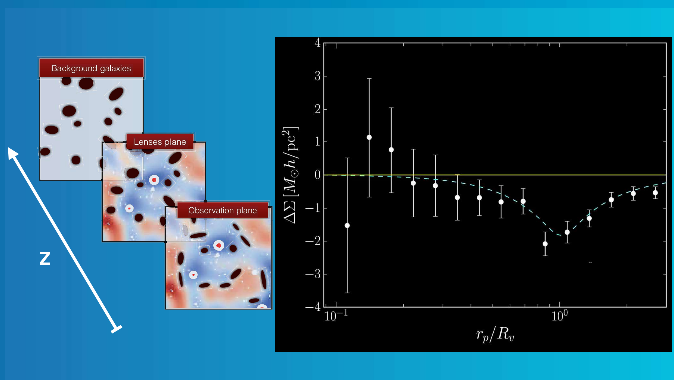

Figure 4: Left: Diagram explaining gravitational lensing caused by voids (red points), to background galaxies (brown ellipses). Right: Void lensing measurement by the Dark Energy Survey first year of observations [3]

4) Objectives

Using the lensing signal from cosmic voids, it's possible to extract cosmological information. Using cosmological simulations in a first time and Euclid first year of observation then the goal of this project is to modelize and optimised the measurement of lensing signal of cosmic voids and provide constraints on cosmological parameters from it.

References

(1) Euclid Collaboration, Y. Mellier et al., *arXiv e-prints*, 2024, arXiv:2405.13491.
(2) C. Sánchez, J. Clampitt et al., 2017, **465**, 746–759.
(3) Y. Fang, N. Hamaus et al., 2019, **490**, 3573–3587.