National Aeronautics and Space Administration

Postdoc Research

# A new pipeline to investigate the models of the evolution of the Universe

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## Background

The standard model of cosmology describes the evolution of the Universe. In this model, the Universe has three main components: dark energy, dark matter, and ordinary matter. The Euclid mission, launched on 1 July 2023, is a space telescope led by the European Space Agency (ESA) with NASA contributions to study the nature of dark energy and dark matter. Euclid will observe billions of galaxies across more than a third of the sky, measuring their shapes and distances to create a 3D map of the cosmic structure and history. This will allow us to better understand the evolution of the Universe including the expansion history, the growth of structure, and the laws of gravity with unprecedented precision and accuracy. To prepare for the scientific analysis of Euclid data, it is essential to generate realistic mock observables from cosmological simulations that explore non-standard models beyond the standard cosmological paradigm.

## Objectives

The goal of this project is to generate scientific results from a suite of non-standard cosmological dark matter only simulations, and to quantify observable signatures from non-standard cosmological models that could be used in the analysis of Euclid data to potentially rule out the standard model of cosmology. The insights gained from the mock observables have the potential to reshape our understanding of the cosmos, leading to breakthroughs in fundamental physics. The analyzed simulations include models with time-dependent dark energy, modified gravity models, massive neutrinos, and many other non-standard scenarios.

*Simulated Dark Matter Density Field in $w_0$CDM cosmology*

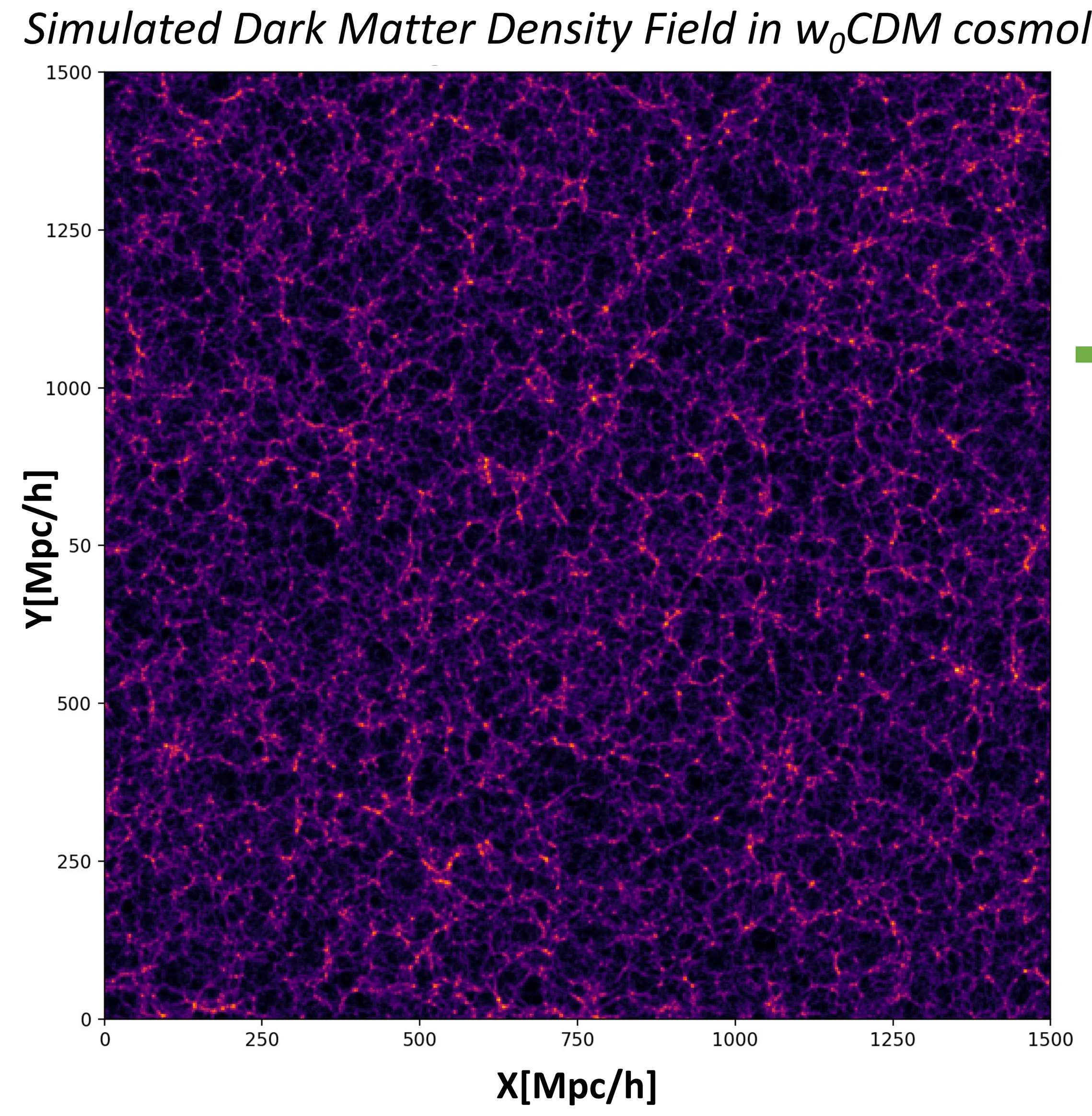


***Figure 1.*** *A 2D slice of the simulated dark matter density field of a non-standard $w_0$CDM cosmological simulation. This is the input of our pipeline. The simulation was run in a cubic region of the Universe over 4.6 billion light-years on a side.*

Statistical analysis

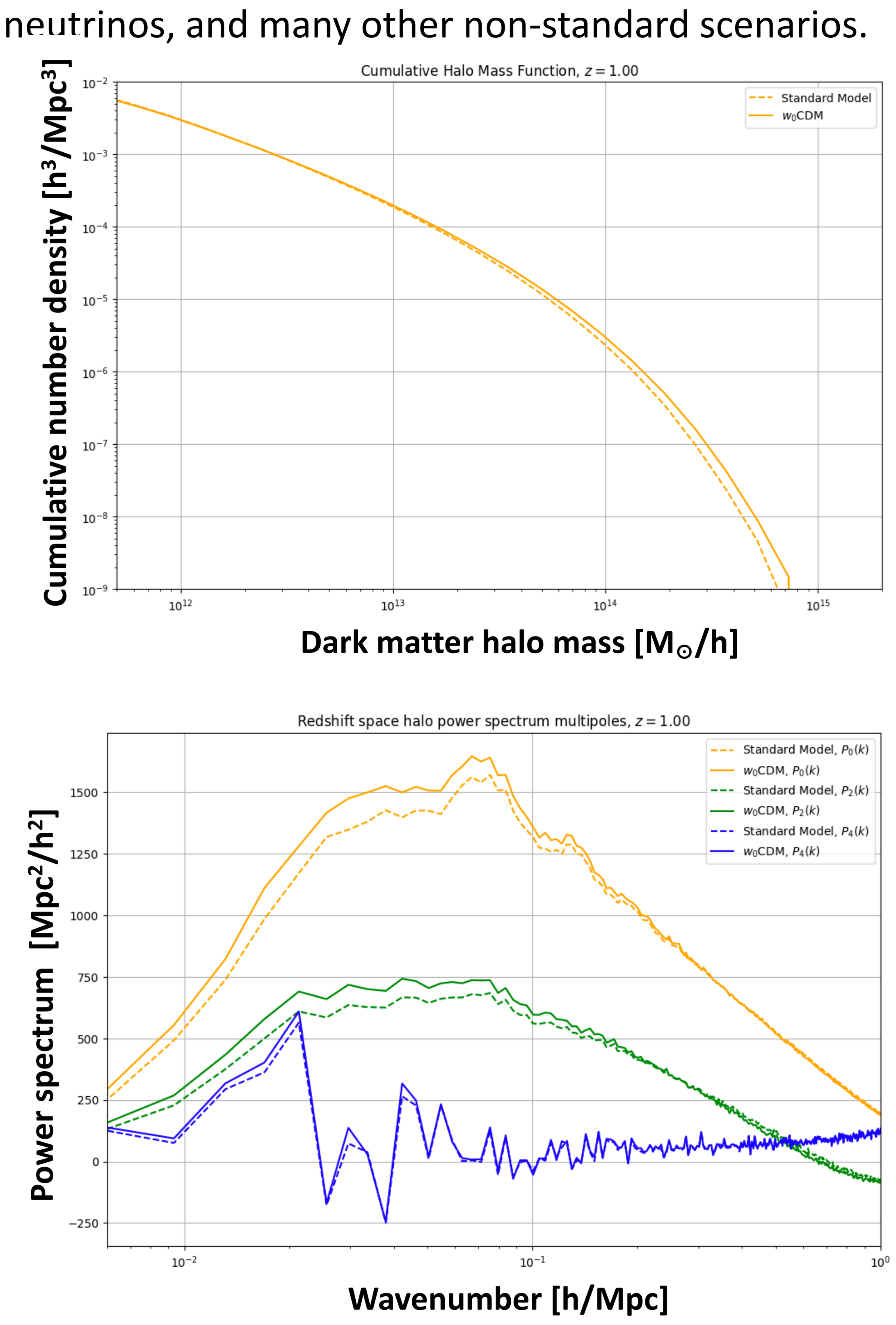


***Figure 2.*** *Example mock observables generated by our new pipeline. The solid lines represent the results from a non-standard model called $w_0$CDM, while the dashed lines show the results of the standard cosmological model.* ***Top:*** *Distribution of the different size dark matter halos in the non-standard cosmological model.* ***Bottom:*** *Calculated power spectra of the halo distribution of a non-standard model with a reference result from a standard-model simulation. This function shows how big are the density fluctuations on a given scale.*

## Approach and Results

We developed a new custom pipeline to analyze hundreds of simulations of non-standard cosmologies in a consistent and rapid way. In the first step, we identify compact, dense regions in the dark matter density field so called halos. In reality, these halos are hosting the galaxies what Euclid will observe. By analyzing the distribution these halos, we generate mock observables that can be used in the analysis of Euclid data to potentially rule out the standard model of cosmology.

## Significance of Results/Benefits to NASA/JPL

We find that non-standard cosmological models leave significant imprints on mock observables. Our results demonstrate that non-standard cosmological simulations provide valuable insights into the physics of dark energy and dark matter, and are crucial to maximizing the scientific return of Euclid. This project places JPL in the front line of scientific exploration.

## Future Work

These observables will be extended with mock galaxy catalogs, cluster catalogs and redshift cones. We will make our mock observables publicly available for the benefit of the Euclid Consortium and other interested researchers. Not just Euclid, but all other upcoming cosmological surveys such as Vera C. Rubin or the Nancy Grace Roman surveys will benefit from the new mock observables of non-standard models.

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## Publications:

Complementary Cosmological Simulations, 2023 G. Racz, A. Kiessling, I. Csabai, I. Szapudi, Astronomy & Astrophysics 672, A59
Euclid Preparation TBD: Results from non-standard simulations, 2023 G. Racz, et.al. (in prep.)

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