Research Statement

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I am interested in understanding how fundamental physics in the microscopic scales affects the formation and evolution of structure on the largest scales, such as galaxies and voids. Conversely, I am also interested in what physics in the cosmological scales can inform us about the standard model and its extensions. I perform simulation-based inference to investigate this interplay between scales at different epochs of the universe.

I have co-authored a paper with Dr Maria Giovanna Dainotti on compiling a new sample of Type Ia Supernovae to constrain the Hubble constant at different redshifts. This paper, titled "A New Master Supernovae Ia sample and the investigation of the H_0 tension", points to a time-varying trend of the Hubble constant, which might provide a plausible resolution to the Hubble Tension. Working on this project has been very illuminating, but with its fair share of memorable experiences. Initially, our aim was to identify a new parametrization for slowly evolving dark energy models, that could address existing parameter tensions. However, my analyses pointed out preference for no such hypothesis. Six months of hard work seemed to have been to waste. Intense reevaluation led to a new formalism for tracking the evolution of H_0 as a function of z, which yielded favourable results. The paper was finally accepted to the Journal of High Energy Physics in May, 2025.
I have recently undertaken multiple projects on using computational methods to probe how massive neutrinos affect large-scale structure formation. One such project I have been involved with for almost a year, aims at constraining the mass of neutrinos from galaxy $\times$ total matter field cross-correlations with k Nearest Neighbour Cumulative Distribution Functions (k NN CDFs). I am also exploring how one can break the $M_\nu - w$ degeneracy from kSZ $\times$ galaxy survey cross-correlations, using a novel method of calculating the halo bias. These projects have been deeply insightful, as they resonate with my broader aim of understanding the interplay between physics at different scales. These projects were of a more theoretical and computational flavor, which profoundly shaped my research direction. The transition was not easy, especially as these projects started along with my third year coursework. But the challenge of a new project motivated independent learning of a lot of new physics and statistics. The learning curve was steep, and after several office hours of communicating with Dr Arka Banerjee, my supervisor for these projects, I developed a more rigorous and intuitive approach to computational problem-solving. These projects, along with rigorous courses in cosmology and particle physics, have given me some valuable experience in the theory of large-scale structure formation and computational techniques, such as simulation-based inference, Fisher forecasts and MCMC inference to connect theory with surveys. Cumulatively, these projects have fostered a new interest and research direction: Exploring new formalisms for higher order summary statistics that can efficiently extract information beyond the two-point level.

To complement my research on extracting cosmological information beyond the two-point level, I have also worked on computational package development for faster calculation and interpretation of data. I am a core contributor in the development of a software package (kNNPy) that efficiently calculates k nearest neighbour (namely, k NN CDFs) statistics for higher order analyses of simulation data. This project has strengthened my skills in collaborative software development.

Building on these experiences, I envision a Master's and doctoral track in the same direction. These projects have not only built upon my interest in probing fundamental physics with cosmological simulations, but have given me valuable insight into theoretical and computational methods to approach newer research problems in novel and diverse directions. Ultimately, I hope to contribute to a deeper theoretical understanding of how the Universe encodes fundamental physics across its many scales with various computational approaches.