DOCTORAL DEFENSE

On Dark Matter Halos and their Connection to Galaxies

Kuan Wang

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Non-department members:
Contact the **doctoral candidate** or the **Undergraduate Coordinator** (paugrad@pitt.edu) for password.

Research Advisor:

Dr. Andrew Zentner

Abstract: In the concordance model of modern cosmology, dark matter is five times as abundant as the ordinary baryonic matter. While its nature remains one of the most challenging questions in today's physics, dark matter has been established as a defining factor in the large-scale structure we observe. Visible galaxies form in the potential wells of dark matter density peaks, known as halos. Empirical galaxy–halo connection models, which reconstruct the observable components of the Universe from our theoretical knowledge of the dark sector, are broadly used for their simplicity and effectiveness. The fundamental premise of such empirical models is the statistical dependence of galaxy properties on halo properties, the latter of which are easily accessible through gravitational N-body simulations.

With tremendous amounts of observational data being produced by new generations of surveys, theoretical tools need also be further developed to exploit the full potential of data. In particular, observables on small, non-linear scales are a promising source of statistical information for constraining both cosmology and galaxy physics. These observables require detailed knowledge of dark matter halos, which are the basic units of non-linear structure, and a connection between galaxies and halos. Improving the modeling of halos and their connection to galaxies is therefore an urgent and important task in the new era of precision cosmology.

This thesis aims to improve our understanding of the evolution of dark matter halos and the statistical dependence of galaxy properties on the properties of halos in which they reside. In the first part of this thesis, we investigate how the present-day halo structure emerges from the halo mass assembly history, and characterize the respective contribution from the two modes of halo assembly: pseudo-evolution and physical merger events. We uncover the significant impact of mergers on the evolution of halo structure, and recognize universal patterns in merger events. These findings will also shed light on the galaxy evolution in halos. In the second part of this thesis, we test the validity of the simplifying assumptions adopted in galaxy–halo connection models. We identify the optimal combination of observable statistics that contain the most information on the galaxy–halo connection, and obtain tighter observational constraints on the model using these statistics. These results inform the physics of galaxy formation and evolution and cosmological inferences.