



DEPARTMENT OF PHYSICS
THE UNIVERSITY OF HONG KONG



香港天文與天體物理研究所
THE HONG KONG INSTITUTE FOR
ASTRONOMY AND ASTROPHYSICS

HKIAA SEMINAR

Galaxy Cluster Mass Distributions and Subhalo Properties Through Simulations and Machine Learning

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ABSTRACT

Galaxy clusters are powerful observational laboratories for investigating hierarchical structure formation, the nature of dark matter, and the evolution of cosmic structures. Understanding their mass distributions and subhalo properties is essential for connecting cosmological simulations with observations. In this seminar, I will discuss how zoom-in hydrodynamical simulations of galaxy clusters can be used to investigate dark matter substructure and how simulation-derived datasets and deep learning can be combined to reconstruct galaxy cluster total mass distributions, including their dark matter component.

First, I will discuss the discrepancy between observed and simulated galaxy-galaxy strong lensing (GGSL) in galaxy clusters, highlighted by Meneghetti et al. (2020). This tension is closely connected to the internal structure and compactness of cluster subhalos, particularly the relationship between subhalo mass and maximum circular velocity. Using clusters from The Three Hundred suite of hydrodynamical simulations (Cui et al., 2018), I investigate this discrepancy in both the Gadget-X and GIZMO-SIMBA models of The Three Hundred clusters. The analysis reveals a persistent offset between the simulated and observed $M_{\text{sub}}-V_{\text{circ}}$ relations. I will then also discuss the role of subhalo and galaxy size, galaxy stellar age, baryon fraction, and cluster-centric distance in understanding the origin of this tension. These findings highlight the ongoing challenges in reproducing observed subhalo properties within hydrodynamical simulations based on the standard Λ CDM cosmological framework.

Second, I will present a deep-learning approach to reconstructing galaxy cluster mass distributions and subhalo populations from optical observations. Traditional mass reconstruction techniques typically rely on strong and weak gravitational lensing or on assumptions about hydrostatic equilibrium when interpreting X-ray and Sunyaev-Zel'dovich observations. We demonstrate that optical imaging, combined with a U-Net-based deep convolutional neural network, can recover projected total mass distributions and substructure. The network is trained on realistic mock Hubble Space Telescope (HST) observations generated from The Three Hundred simulations, incorporating instrumental noise, observational systematics, and redshift-dependent effects, and is subsequently applied to real clusters observed by the Cluster Lensing And Supernova survey with Hubble (CLASH). The reconstructed mass maps recover the overall cluster morphology and radial mass profiles, with results consistent with independent strong- and weak-lensing reconstructions. The recovered subhalo mass functions are also consistent with lensing-based estimates and cosmological simulations. Together, these studies demonstrate how hydrodynamical simulations and machine learning can advance our understanding of galaxy cluster mass distributions and dark matter substructure.

BIOGRAPHY

Atulit Srivastava is a final year PhD student in astrophysics at the Universidad Autónoma de Madrid, Spain, working under the supervision of Dr. Weiguang Cui. His research focuses on galaxy clusters, dark matter substructure, and machine learning. Combining hydrodynamical cosmological simulations with deep-learning techniques, he investigates the physical properties of dark matter subhalos and develops methods to reconstruct galaxy cluster mass distributions by utilizing multi-wavelength observations. His work aims to bridge the gap between cosmological simulations and observations, advancing our understanding of dark matter and structure formation in the Universe.

30 October 2026 (Friday)

3:15 – 4:15 PM

Venue: KB132, 1/F · Knowles Building, HKU

Anyone interested is welcome to attend.



ZOOM FOR ONLINE PARTICIPANTS

Meeting ID 964 7297 1072

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