Bridging Observations and Theory: Synthetic Star Cluster Observations from Numerical Simulations

Stellar clusters are the birthplaces of most stars in the Universe. These stellar nurseries, particularly dense ones like globular clusters and nuclear star clusters, are environments where stars are packed up to a million times more tightly than in regions like our Solar neighborhood. In these crowded environments, frequent gravitational encounters between stars and binary systems give rise to a wide array of fascinating astrophysical phenomena, including gravitational wave sources, high-energy transients like tidal disruption events, and exotic objects such as black holes, neutron stars, and unusual types of binary systems. These dense stellar environments are either studied observationally or are theoretically modeled using computer simulations.

With cutting-edge telescopes like the Hubble Space Telescope (HST), the James Webb Space Telescope (JWST), and Gaia, astronomers are now able to observe star clusters in extraordinary detail. These observations reveal the clusters' structure, kinematics, and multiple generations of stars, providing crucial insights into their formation and evolution. Ground-based facilities, such as the Very Large Telescope (VLT), equipped with state-of-the-art spectrographs, complement these space-based observations by enabling high-resolution spectroscopy and adaptive optics imaging of star clusters. The upcoming Extremely Large Telescope (ELT), with its unprecedented collecting area and advanced instrumentation, will further revolutionize our ability to study clusters, allowing us to probe their faintest stars and resolve their internal kinematics with exceptional precision. Together, these observational capabilities are uncovering the complexities of star clusters and advancing our understanding of their role in the broader context of galaxy evolution.

At the same time, computer simulations of star clusters have become increasingly sophisticated, providing detailed and thorough data on the evolution of individual stars, binaries, and cluster-wide dynamics over billions of years. These simulations capture processes such as mass segregation, stellar mergers, and the formation of compact objects, making them the best theoretical method available for modeling and understanding the complex evolution of star clusters. By complementing observational discoveries, these simulations offer unparalleled insights into the physical processes shaping these systems.

This project aims to bridge the gap between simulations and observations by creating synthetic observations of star clusters from numerical simulations. Synthetic observations allow us to “observe” simulated clusters as if they were real, incorporating the limitations of telescopes, such as noise, resolution, and observational biases. By mimicking how clusters appear in telescopic images and spectroscopic data, we can validate theoretical models, identify discrepancies, and refine both simulations and observational techniques.

Using advanced computer codes for simulating star clusters, this project will model the evolution of thousands of star clusters under a variety of initial conditions. We will then develop tools to transform the simulation outputs into realistic synthetic observations, generating photometric images, color-magnitude diagrams, and spectroscopic data cubes. These synthetic observations will be analyzed using the same techniques and pipelines employed by astronomers, enabling a direct comparison between theory and observation. The project addresses critical scientific questions, including the properties of binary stars in clusters, the impact of black holes on cluster dynamics, and the signatures of multiple stellar populations. It also explores how stars escaping from clusters contribute to the galactic field and halo, shedding light on the formation history of our Milky Way. Moreover, it will result in the creation of a publicly available suite of tools that researchers can use to create synthetic observations of their own simulated star cluster models.

By uniting advanced simulations with state-of-the-art observations, this project will not only improve our understanding of star clusters but also provide tools that benefit the broader astronomical community. These tools will help researchers unlock the secrets of some of the oldest and most enigmatic structures in the universe, paving the way for new discoveries about the cosmos.