<u>Reconstructing Morphologies of Distant Galaxies with the JWST Mock Catalog</u>

Keywords: Galaxy Evolution, Early Galaxy Structure, Near Infrared Imaging

Abstract:

In today's universe, galaxies have simple morphologies (i.e. shapes and structures). They are ellipsoidal and symmetrical, often with an additional spiral component like our own Milky Way. However, there is strong evidence to suggest that galaxies in the early universe were clumpy and distorted, possibly driven by their assembly. The question then arises: *how and why did galaxies change over time from asymmetrical structures to the objects we see today?* The *James Webb Space Telescope* (*JWST*), NASA's upcoming flagship space observatory, will revolutionize astronomers' ability probe from the formation of the first galaxies over time until today. As a member of the *JWST* NIRCam team at the University of Arizona, I propose to create an analysis framework for the extraction of morphological information from the unique shapes and structures present in young galaxies. **My proposed study will provide the necessary tools to understand the changing look of galaxies over cosmic time, fulfilling one of the primary aims of the *JWST* mission: understanding galaxy evolution from the first galaxies until today.**

Background and Motivation:

The morphologies of galaxies are tied to the overall evolution of galaxy populations over cosmic time. For example, in today's universe we use the shapes of galaxies to infer their recent histories; i.e. large spheroidal galaxies have undergone a merger with a galaxy of similar mass, whereas spirals have not (e.g. Mihos & Hernquist 1996). However, the deepest observations from the *Hubble Space Telescope* reveal that galaxies eleven billion years ago exhibit asymmetries and clumps in their images (e.g. Elmegreen et al. 2007, 2009). With few detections of distant galaxies, astronomers have been unable to fully characterize the evolution of galaxy morphology over cosmic time. Instead, the community has turned to complex hydrodynamical simulations, such as Illustris (Genel et al. 2014), to model galaxy evolution. While simulations can prove valuable for understanding certain astrophysical processes, they require tens of millions of CPU hours and can be difficult to compare to observations. Therefore, **there exists an opportunity to provide methods to generate images of early galaxies with physical shapes that can be used to develop tools to extract morphological information from upcoming *JWST* data.**

Methods:

The need to accurately simulate the data of the upcoming *JWST* Advanced Deep Extragalactic Survey (JADES) has led to the development of the JAdes extraGalactic Ultradeep Artificial Realizations (JAGUAR) mock catalog package (Williams et al. 2018). The package uses an empirical model for galaxy properties across cosmic time, including morphologies. However, the JAGUAR morphologies are modeled by simple symmetrical spheroids, an unrealistic assumption for early galaxies as shown in Figure 1. My first task will be to assign realistic morphologies to each mock galaxy. Here I will couple the results of hydrodynamical simulations, similar to Illustris, with existing observations of distant galaxies to inform the shape, structure, and composition of morphological components in each mock JAGUAR galaxy. By folding these in with *JWST* data simulation tools, *I will produce physically motivated images of early galaxies with colors and luminosities that agree with observations of the distant universe*. Following my creation of mock galaxy images, I will test techniques to extract morphological information from the data.

Astronomers have attempted to tackle the problem of accurate characterization of distinct features in images with an ever growing suite of machine learning techniques. I will robustly examine existing techniques and find the approach that is best suited for categorizing asymmetric and distorted morphologies of early galaxies. These include ensemble classifiers, such as a random forest decision trees employed in classifying galaxy mergers, e.g. Goulding et al. (2017), or deep learning algorithms trained on existing data sets, e.g. Sánchez et al. (2018). While both have been used to great effect, these procedures have only been tested in the local universe. I can therefore adapt and test candidate algorithms on my simulated images, measuring the method's ability to recover input parameters. *I will evaluate the efficacy of a broad set of techniques to find those that extract morphological parameters accurately for early galaxies over a wide range of cosmic times.*

The Steward Observatory at the University of Arizona is the ideal host institution for this endeavor, hosting the Principal Investigator of the NIRCam instrument on *JWST* (Professor Marcia J. Rieke) and the primary authors of the JAGUAR project (C. C. Williams and K. N. Hainline). I am therefore confident I can integrate my enhanced morphological modelling with current mock catalog efforts. **Ultimately, I will produce a data analysis framework optimized for extracting morphological information from early galaxies validated through observations and simulations which will help determine why galaxies look the way they do today.**

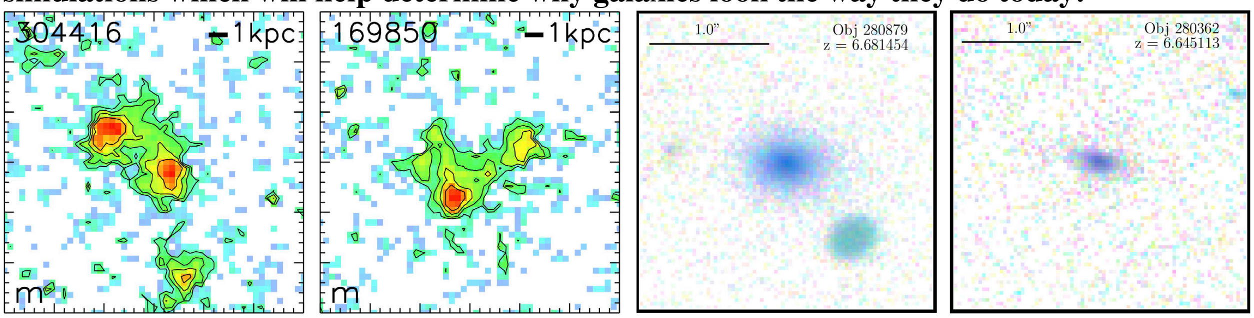

Fig. 1: Young galaxies from current observations on the left (Bowler et al. 2017) compared with current models in the JAGUAR mock catalog on the right (Williams et. al 2018). Note the discrepancy in the level of structure.

Conclusions and Broader Impact:

My simulations of early galaxies and corresponding extraction algorithms will have immediate implications for the characterization of complex morphologies of young galaxies. These will be useful for any large-scale extraction of galaxy parameters in the early universe and essential for the success of the extragalactic component of the *JWST* mission. My tools will be made publicly available to the astronomical community to further the understanding of galaxy evolution to one day understand the nature and fate of all galaxies.

In addition, I aim to bring the results of my research to the general public in Tucson. Given the intuitive nature of galaxy shapes, I aim to create lesson plans for the elementary school children I work with through Project ASTRO. By using my simulated images of galaxies, I will present a realistic view of the scientific capabilities of *JWST* in a fun and informative manner to inspire curiosity about extragalactic astronomy. Furthermore, simulated *JWST* observations of realistic images of galaxies are ideal for public lectures. By presenting a compelling visual narrative of watching galaxies change shape over time, I can communicate the main outcomes of my study that uniquely engages an audience. I plan to present my work at public talks that are held throughout Tucson, including the Steward Observatory weekly lectures and the Astronomy On Tap series.

With support from the NSF Graduate Research Fellowship, I can develop useful and relevant tools for the astronomical community while taking advantage of the intuitive nature of galaxy shapes to bring high level cutting edge science questions to the general public.

References:

Agertz+, 2009, MNRAS, 397, L64
Bowler+, 2017, MNRAS, 466, 3612
Elmegreen+, 2007, ApJ, 658, 763
Elmegreen+, 2009, ApJ, 692, 12
Genel+, 2014, MNRAS, 445, 175
Goulding+, 2017, PASJ, 70, S37
Mihos+, 1996, ApJ, 464, 641
Sánchez+, 2018, arXiv: 1807.00807
Williams+, 2018, ApJS, 236, 33