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EMPLOYING MORPHOLOGY TO MAP OUT GALAXY EVOLUTION

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BACKGROUND: EXPLORATION OF GALAXY MORPHOLOGY & EVOLUTION

Morphology and evolution are two closely intertwined properties of galaxies. In analyzing galaxy morphology, vital information is revealed regarding galaxy evolution. With the release of many deep space fields and numerous surveys and the anticipation of the James Webb Space Telescope (JWST), galaxy morphology is an increasingly popular field of research.

Recent observational studies on galaxies review evolution merely in terms of light profiles or physical properties (i.e. stellar mass, star formation rate (SFR), etc.), without delving into how the two compare (some examples of such studies: Bouwens et al. 2015; Kurczynski et al. 2016; Bouwens et al. 2017; Huang et al. 2017; Holwerda et al. 2020). Thus, the majority of observational research being conducted on galaxy morphology is done on a subset of the available data. Conversely, there are numerous studies on simulated galaxy structure and properties, which include their evolutionary implications (see the following for some of such studies: Vogelsberger et al. 2014; Genel et al. 2014; Duffy et al. 2017; Côté et al. 2018; Ma 2018; de Graaff et al. 2021; Robson & Davé 2021). In addition to these, there is also research being done to compare simulated and observed measurements (more information on these studies: Bouwens et al. 2017; Huang et al. 2017; Adams et al. 2021; Fontanot et al. 2021; Zheng et al. 2021). However, these studies merely analyze the light-weighted morphology of the simulations and observations, or their physical properties without comparing the two. Furthermore, the use of mock observations has recently started booming with the soon launch of JWST. Many studies use these mock observations as a means to predict the data of JWST and anticipate their results (some papers doing this: Endsley et al. 2020; Hainline et al. 2020; Kauffmann et al. 2020). Very little research, however, is being done to compare mock to real galaxy observations.

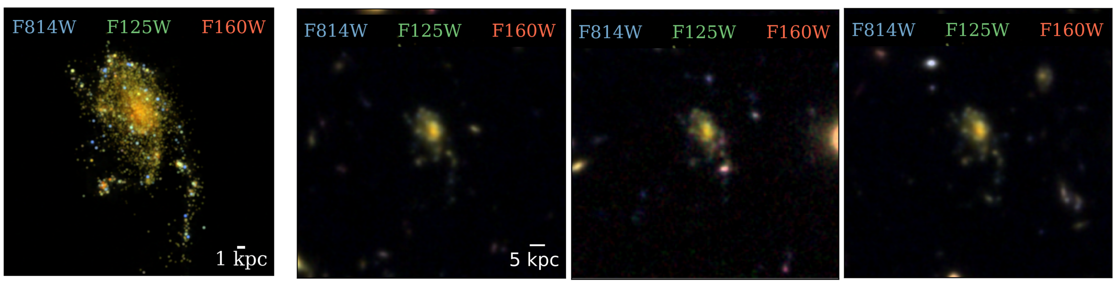
THE PROBLEM: INCOMPLETE PICTURE OF GALAXY EVOLUTION

Research on galaxy morphology is mostly constrained to studying either light profiles or physical properties. Thus follows that galaxy evolution is also constrained as such, leaving an incomplete picture of galaxy evolution. This is amplified even more-so in the lack of comparisons to the measurements of simulated galaxies. **Thus, we present two current gaps in this field of research: (i) the use of both light- and mass-weighted morphology to study galaxy evolution in simulations and real observations, and (ii) the use of mock observations to better understand real observations.** Mapping out galaxy evolution is not only the next step towards understanding the history and evolution of more local galaxies, such as our very own Milky Way, but it can also reveal vital information that is helpful to decode the evolution of the universe itself.

THE SOLUTION: MEASURE MASS- AND LIGHT-WEIGHTED GALAXY MORPHOLOGY IN THE XDF & SIMBA SIMULATIONS

To fill the two aforementioned gaps in this field, we will find the relationship between mass, light and star formation rate of galaxy observations and simulations.

We will use the Hubble eXtreme Deep Field (XDF)(Illingworth et al. 2013) for our observations. The XDF is a compilation of 10 years of HST data from the HST Advanced Camera for Surveys (ACS) and the Wide-Field Camera 3 Infra-Red (WFC3/IR). It is one of, if not the deepest sky image in the optical/near-IR. The data spans 9 different HST filters: F435W, F606W, F775W, F814W, F850LP, F105W, F125W, F140W, F160W. To find the mass maps and star formation histories of galaxies in this field, we will use `dense_basis` (Iyer et al. 2019); this package takes visible light from an image and fits each pixel individually, to convert the light from the galaxy into physical properties.



(a) Simulated galaxy. (b) Mock galaxy observations.

Figure 1: (a) SIMBA simulated and (b) mock galaxy at redshift z=2 through 3 HST filters: F814W, F125W, F160W. Credit: Dr. Lamiya Mowla

We will also use the SIMBA suite of cosmological hydrodynamical simulations (Davé et al. 2019), which outputs both physical property and light distributions of galaxies. SIMBA is the next generation of MUFASA simulations, now including better dust accretion and attenuation processes and introduces a new model of black hole growth (Anglés-Alcázar et al. 2017). Thus, SIMBA presents new additions of physical processes that drive galaxy evolution. Mock observations will be used alongside these simulations and compared to the real observations. These mock observations are generated via `noor` (Mowla et al. in prep); this software takes the simulation output, applies the `POWDERDAY` radiative transfer package (Narayanan et al. 2021) and outputs mock images as seen through different observational instruments. Figure 1 shows the same galaxy as outputted from the simulation and from mock observations.

A pipeline I developed this past summer (May-August 2021) will be used to measure the morphological parameters of these galaxies, namely the radii of the apertures containing half their light, mass and SFR. Simulations and mass-weighted morphology are analyzed using aperture photometry via the `astropy` python package (Astropy Collaboration et al. 2013, 2018). Observations, both mock and real, are PSF convolved and must be measured using different software; we use the `photutils` package to perform segmentation of the observation (Bradley et al. 2020) and the `statmorph` package to measure the properties of an individual galaxy (Rodriguez-Gomez et al. 2019). Figure 2 shows the output measurements of this pipeline for a simulated galaxy at z=2. Using these tools, we will study the morphology of galaxies across a wide range of redshifts ($0.25<z<6.0$) and stellar masses ($M_*>10^9 M_\odot$) in both simulations and observations.

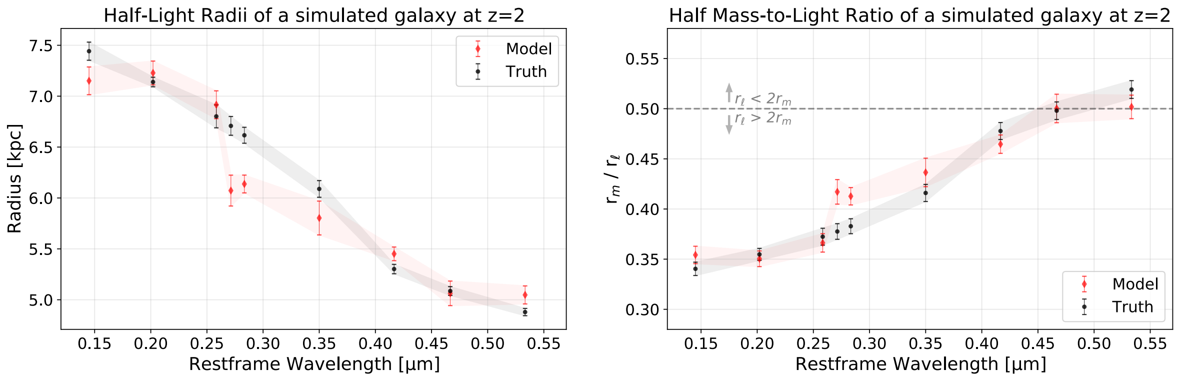


Figure 2: The half-light radii measurements (Left) and half-mass-to-light relation (Right) for a galaxy at redshift z=2 through simulations (Truth) and mock observations (Model) at 9 HST filters.

THIS PROPOSAL: STEPS TOWARD MAPPING GALAXY EVOLUTION

The steps we will take in order to map out galaxy evolution are as follows. First, the pipeline will be applied on simulated galaxies and their mock observations. This will yield their light- and mass-weighted sizes through measurements of half-light, half-mass and half-SFR radii. Next, we will study how these size measurements evolve as a function of stellar mass, SFR and redshift, and how the simulated and mock galaxies compare to each other. After these analyses on simulations, the same process will be performed to the $\sim$ 9000 galaxies in the XDF and their respective mass maps. Finally, we will compare the size evolution of galaxy populations in the observation and simulation. Figure 3 shows the schematic layout of the steps of this proposal. Two prospective goals to further this project and the study of galaxy evolution are (i) analyzing morphology through structural differences (i.e. mergers, dark matter distribution, etc.), and (ii) using size-galaxy property relations to forecast JWST observations. After these steps, a final report will be compiled explaining our results, and hopefully developed into a paper.

Figure 3: Schematic layout of the steps of this proposal.

Facilities: XDF: HST(WFC3/IR, ACS) (Illingworth et al. 2013)

Software: `astropy` (Astropy Collaboration et al. 2013, 2018), `dense_basis` (Iyer et al. 2019), `noor` (Mowla et al. in prep), `photutils` (Bradley et al. 2020), `POWDERDAY` (Narayanan et al. 2021), `statmorph` (Rodriguez-Gomez et al. 2019)

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