GA

MP

# STAR FORMATION IN DWARF GALAXIES: USING SIMULATIONS TO IDENTIFY KEY OBSERVABLES TO TEST MODELS

**Elaad Applebaum, Rutgers, The State University of New Jersey**
2018–2019 Graduate Fellow

## EXECUTIVE SUMMARY

Modern cosmological hydrodynamic simulations self-consistently model the evolution of segments of the universe under the influence of gravity and hydrodynamics. To model how gas turns into stars, these codes use analytic prescriptions taking place below the resolution of the simulation. Though implementation details differ, in large galaxies the results tend to converge.

These prescriptions, however, have not been tested in the low-mass limit. In new simulations at cutting-edge resolution capable of resolving the faintest known galaxies, the PI tested how different star formation recipes affected the resulting galaxy distributions. These tests included running different models on Blue Waters and then comparing galaxies across simulations. The research found that the robustness of the models depends on the galaxy environment, with results being model-dependent in isolated regions but converged in dense environments. These results, paired with observations, can help constrain the underlying small-scale physics of how gas forms into stars. Additionally, they highlight the need for simulators to further investigate these trends to ensure accuracy in interpreting their results in faint galaxies.

## RESEARCH CHALLENGE

When running cosmological hydrodynamic simulations of galaxy formation, scientists simulate the evolution of galaxies within large volumes of space. Despite strategies to maximize the already enormous range of spatial and time scales relevant to galaxy formation, it is impossible to resolve the scales in which stars form. Including realistic star formation is crucial to modeling galaxies, however, since massive stars return energy to their surroundings and modulate future star formation. To incorporate star formation, therefore, simulators include "subresolution" recipes, which are analytic prescriptions that determine under what conditions gas turns into stars. These subresolution prescriptions have led to many successes in simulating realistic galaxies. However, many galaxy properties remain unchanged even when altering these star formation recipes, as shown in [1,2]. To probe the underlying physics, researchers must look at very small galaxies, called ultrafaint dwarf galaxies, which are expected to be sensitive to changes in cosmological models.

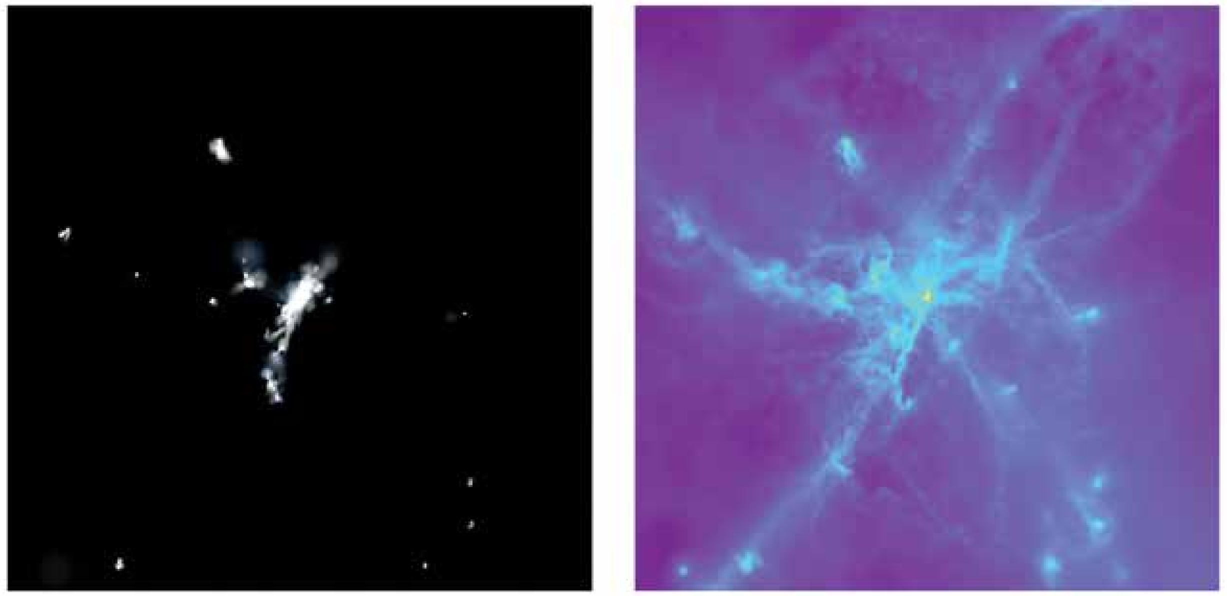

Figure 1: Mock stellar image (left) and projected gas density (right) of simulated galaxies in the very early universe. Of interest is the nontrivial relationship between local gas conditions and star formation.

## METHODS & CODES

Studying such small galaxies while still capturing large volumes of space requires incredibly high resolution. This project, therefore, uses simulations at cutting-edge resolution in two different environments to compare how stars form: one is an environment such as that far from the Milky Way or any other massive galaxy and the other is an environment similar to our own Milky Way. The latter simulations are the highest resolution of their type ever run. All simulations are run with an advanced code, ChaNGa [3,4], designed to handle the unique challenges of galaxy simulations.

## RESULTS & IMPACT

The results suggest that in the environment far from the Milky Way, changing the star formation model had a large impact on the resulting galaxies. In fact, changing from one model to the other led to the existence of half as many galaxies because of the greater difficulty of gas collapsing into stars, as shown in [5]. In a region such as the Milky Way, however, there is little difference because the environment is different and better able to form stars regardless of the subresolution recipe.

With upcoming large surveys such as the Legacy Survey of Space and Time, researchers expect the discovery of up to hundreds of new galaxies very close to the Milky Way. It is unknown what the properties of these galaxies will be, and theoretical work will be necessary to understand the upcoming observations. This project is a first step in constraining the uncertainty in simulation models. Furthermore, the differences among the star formation models present us with differences that are testable with future observations. Pairing the simulations with observations can therefore greatly increase the understanding of how the first star formation proceeded in the early universe.

## WHY BLUE WATERS

Cosmological galaxy simulations involve enormous dynamic ranges in both space and time, and include many different computationally intensive processes relevant to galaxy formation. Additionally, modeling the faintest galaxies requires incredibly high resolution, greatly increasing the computational requirements for running these simulations. Therefore, the advanced computational capabilities of Blue Waters make it the best machine for accomplishing this work.

## PUBLICATIONS & DATA SETS

F. Munshi *et al.*, "Dancing in the dark: uncertainty in ultrafaint dwarf galaxy predictions from cosmological simulations," *Astrophys. J.*, vol. 874, no. 1, p. 40, Mar. 2019, doi: 10.3847/1538-4357/ab0085.

Elaad Applebaum, a fourth-year Ph.D. student in physics at Rutgers University, is working under the supervision of Alyson Brooks. He expects to receive his degree in 2021.