Forward Modeling UV Luminosity Functions for Dwarf Galaxies in the JWST Era

THE UNIVERSITY OF CHICAGO

Zewei Wu[1] (advised by Andrey Kravtsov[2])

[1]*Department of Astronomy & Astrophysics, the University of Chicago,* [2]*Kavli Institute for Cosmological Physics, the University of Chicago*

Abstract

Our research aims to explore the reionization period of the universe, a phase transition in Big Bang Cosmology when neutral intergalactic matter was ionized by energetic photons. The origin of these photons is still a mystery, largely due to the faintness and high redshift characteristics of the galaxies that might be contributing.

This project explores the observational properties, mainly the ultraviolet luminosity function (UVLF), of high-redshift dwarf galaxies. The end goals of this project are to:

1. Test our model on existing measurements of UVLF over the range of redshift relevant to reionization (~5 to 10).
2. Predict how the UVLF behaves at fainter magnitudes, and compare to the observations by the James Webb Space Telescope (JWST) as they become available.
3. Compute the contribution of galaxies of different luminosities to the ionizing photon budget using the model UVLF.

Motivation & Methodology

In our study, we aim to enhance our understanding of the universe by predicting the evolution of the UVLF that will be observed by JWST. We employ a unique sampling method, allowing us to delve into the faint end of the luminosity function. This is achieved by integrating galactic halos, modeled to match the correct number density of masses at each redshift, backward over time. We achieve this by sampling galaxies in any given halo mass range with an analytical selection function, which is then applied later on the star formation history and UVLF.

Our method provides us with control over parameters such as box size and normalization. We then feed the resulting halo mass function into our star formation model GRUMPY, which has been tested to reproduce observed properties of nearby dwarf galaxies and their star formation histories, making it a reliable tool for predicting the luminosity distributions of dwarf galaxies that JWST will probe. To simulate the stochasticity often seen in real galaxies, we apply a numerical random walk. This results in a simulated star formation history, from which we compute incremental luminosity based on the age and metallicity of a stellar mass group, and integrate it over time.

The UVLF represents the relative frequencies of halos with varying luminosities, which is often limited by the parameters of our sampling method. To overcome this limitation and maximize the range of our results, we stitch together multiple boxes with different parameters for the UVLF in Figure 2.

Fractional flux

$$dF = \frac{dn}{d\log L} L \, d\log L$$

Luminosity density

$$\rho_{UV}(< M_{UV}) = \int_{-\inf}^{M_{UV}} dF$$

Fractional luminosity

$$f_{UV}(< M_{UV}) = \frac{\rho_{UV}(< M_{UV})}{\rho_{UV}}$$

LyC photon density

$$\dot{n}_{ion} = f_{esc} \xi_{ion} \rho_{UV}$$

Total photon budget

$$n_{ion}(> L) = \int_{t_z=12}^{t_z=6} \frac{n_{ion}(z)}{dt} \frac{dt}{dz} dz$$

Equations for the fractional contribution of UV flux and photon budgets.

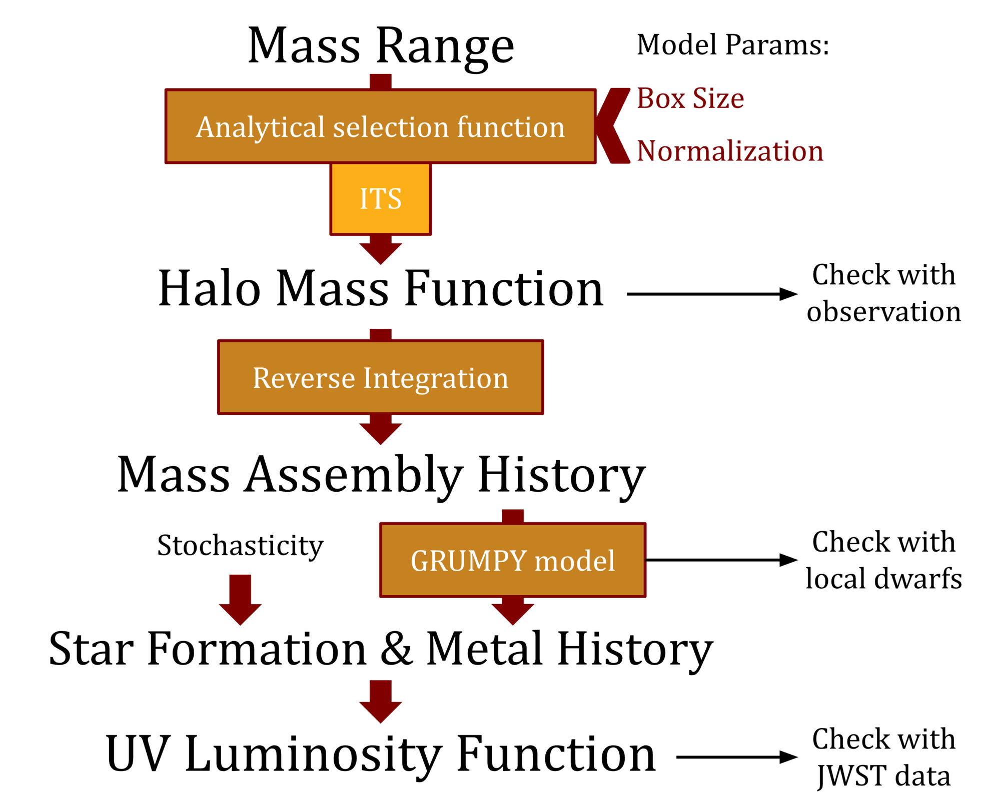

FIGURE 1. A schematic diagram of our methodology, showing the sampling, integration, and modeling of evolution.

UV Luminosity Function

Our UVLF shows agreement with observational data on the bright end, and makes predictions for the faint end distributions. Note how the plateau reflects quenching due to UV heating from reionization.

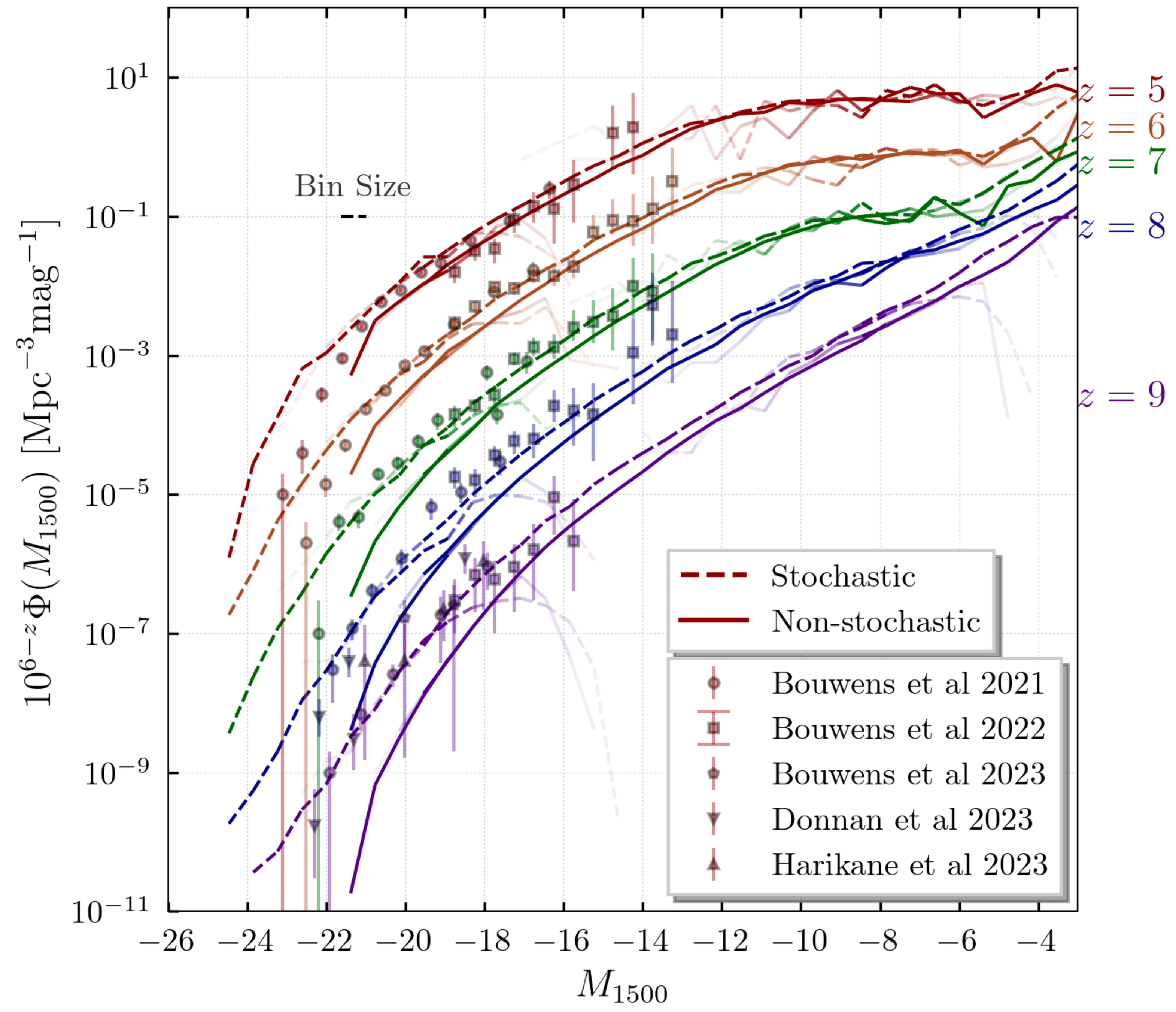

FIGURE 2. UVLF of the $z_{rei} = 8.5$ model across redshifts, stitched from three boxes of varying sizes. Dashed lines have stochasticity modeling. A redshift-based vertical shift is applied to distinguish the curves. Scattered points show JWST observation values and their errors.

Fractional UV Flux

With the UVLF, we integrated flux and computed fractional bins across different redshifts. The results show a significant contribution of UV flux from the faint end, up to 50% for higher redshifts corresponding to earlier cosmic times.

The model is run at two different reionization redshifts to test convergence and constraints: 6 is the fiducial value of global cosmic reionization, while 8.5 is the value for a local volume.

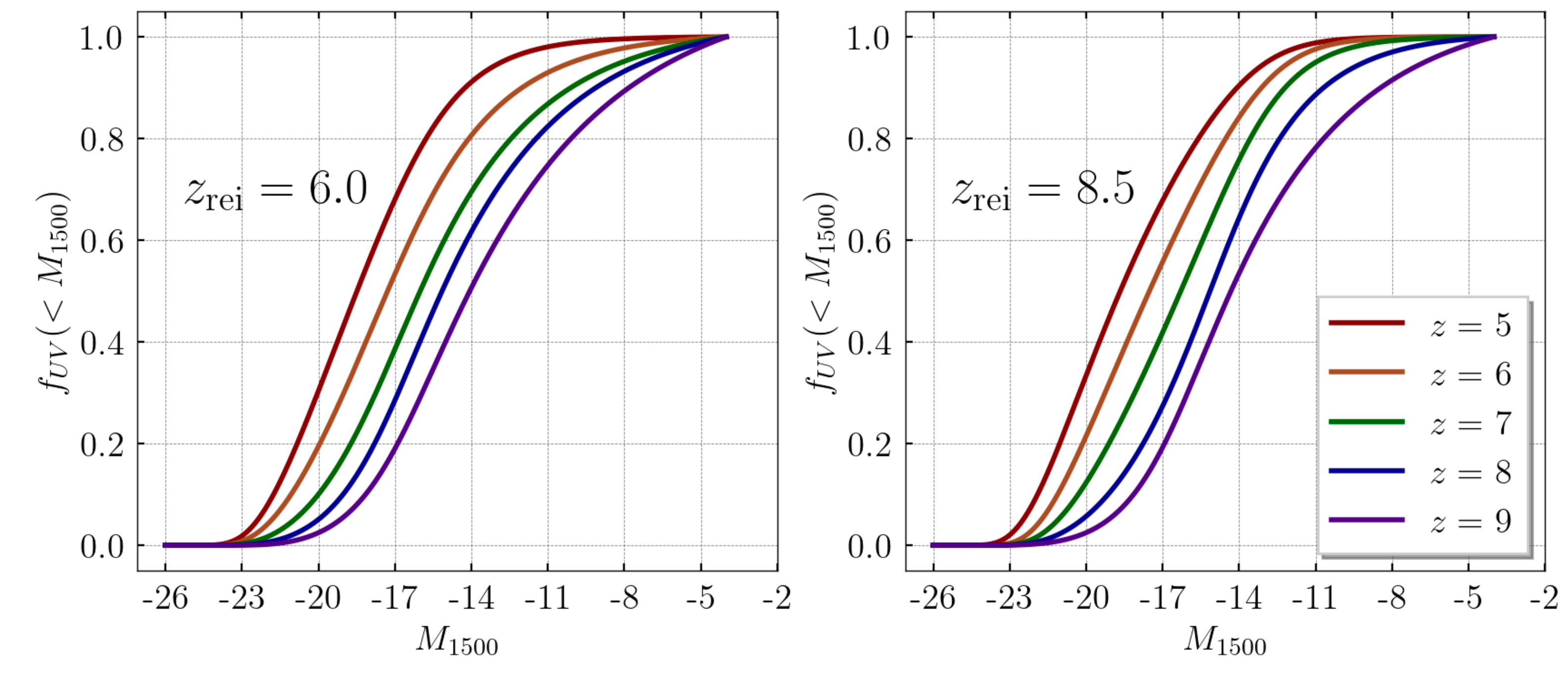

FIGURE 3. Cumulative fractional UV flux for two reionization models (6 and 8.5 respectively) across different redshifts. Both models are stochastic, and see a significant contribution (up to 50% at $M = -14$) from the faint end of the luminosity distribution.

Discussions & Conclusion

- We devised a novel pipeline to sample galactic halos and compute their properties and evolution. Our model produces bright-end UVLF in line with observation, and makes predictions on faint-end number densities.
- Dwarf galaxies contribute significantly to the galactic UV photon budget during cosmic reionization.

Next, we plan to model the ionizing photon budget. This is done for a continuum of frequencies instead of M_{1500} in the UV range, and would more accurately reflect contributions to reionization. This calculation would provide a better constraint on other quantities, such as the escape fraction and the ionizing photon production efficiency.

We also aim to model other factors that affect the UVLF, such as dust attenuation, but this should mainly affect the bright end, where our model has enough flexibility to fit observations. These works will be summarized in the paper Wu & Kravtsov, in prep.

Acknowledgments

Thanks to Prof. Andrey Kravtsov for his unwavering support and guidance. We are equally grateful to Prof. Gnedin and others in the group for their help. Last but not least, we thank CCRF's Quad Research Scholarship program for making this project possible.

wuz25@uchicago.edu