Testing the near-far approach with FIRE simulations

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Reionization may have been caused by light from early low-mass galaxies. Many of the relevant galaxies are too faint to directly observe, so a technique known as the near-far approach has been developed as an alternative. The near-far approach uses present day (z = 0) Local Group low-mass galaxies as 'fossils' to reconstruct their histories all the way back to reionization ($20 < z < 6$). Here, we used data from FIRE simulations of Milky-Way like galaxies to investigate the legitimacy of the near-far approach. We created mass functions for galaxies within various radial distances from their hosts, and ultimately determined that mass function does not significantly depend on distance from the host. This supports the near-far approach.

Introduction

The Epoch of Reionization was a time period approximately 13 billion years ago when light from the first stars ionized the neutral hydrogen in the universe. This process resulted in the universe becoming transparent for the first time, allowing light from the first stars and young galaxies to propagate through space.

Many major questions about reionization remain unanswered. For instance, what drove the process of reionization? Many believe that it was photons from the low-mass galaxies, since they were far more plentiful than the higher-mass galaxies at that time. However, studying these high redshift low-mass galaxies is difficult because many of them are too faint to directly observe even with powerful instruments such as the Hubble Space Telescope and the James Webb Space Telescope [1].

An observational method that circumvents this problem is the "near-far" approach, a technique that uses Local Group low-mass galaxies as "fossils" to reconstruct what they might have looked like during reionization. This approach is not limited by the brightness of galaxies, so it can be used to study the faint low-mass galaxies that existed during reionization [2] [3].

Including all the low-mass Local Group galaxies when using the near-far approach can be practically difficult. Often only galaxies within a certain distance, or 'radial cut', from the host galaxy are used with the technique. Here, I investigate whether this downsampling of galaxies is representative of the entire group using mass functions. Mass functions display the number of objects (here, low-mass galaxies) with mass greater than a given x value where x is a logarithmic mass scale. The shape of a mass function can provide valuable information about the mass distribution of the galaxies in a system. In this work, I look at mass functions of low-mass galaxies at various radial cuts from the host for a variety of redshifts to examine the integrity of the near-far approach.

Methods

Since many of the low-mass galaxies of interest are so faint, I used FIRE (Feedback in Realistic Environments) simulations for this project. FIRE simulations are high-resolution cosmological simulations that model the formation of Milky Way-mass galaxies. They consist of dark matter, gas, and star particles. These particles each have a mass of 3500 - 7100 $M_{\odot}$, depending on the simulation. In this work, I used eight single-host simulations and three double-host simulations. In each of these simulations, the host(s) are surrounded by satellite low-mass galaxies [4] [5]. I analyzed these low-mass galaxies for redshifts 0 and 7 in order to investigate the plausibility of the near-far approach.

Results and Discussion

Using the FIRE simulations discussed above, I created mass function plots for various radial cuts from the host galaxy. Figure 1 illustrates how these radial cuts were measured. All galaxies within a given radius r are included in a radial cut. For simulations with two hosts, the radial distance was taken as the distance from the geometric center of the hosts. I selected visible galaxies within each radial cut, galaxies with stellar mass greater than $3.5 * 10^4$ $M_{\odot}$ at redshift 0. Then I created mass functions for these groups of galaxies excluding the host or hosts. I calculated the mass functions for various radial cuts from the host galaxy.

Figure 2 shows cumulative mass functions for a single simulation, m12m, at redshift 0. The upper plot shows the cumulative mass function for galaxies within various radial cuts of the host galaxy. The x-axis indicates the mass in solar masses on a log scale, and the y-axis represents the number of galaxies with a mass greater than the corresponding x value. The slopes of each curve appear to be roughly equal, but their relationship is illustrated more clearly in the lower plot.

The lower plot shows the ratio of each radial cut mass function to the overall mass function. The slopes of these curves appear to be roughly zero, indicating that the mass function does not significantly depend on the distance from the host for this simulation.

To improve the statistics of our analysis, I calculated mass functions for 10 other simulations. The upper two plots in Figure 3 show the median and mean of the ratio plots for the 11 total simulations. Here, the overall mass function was defined as the mass function for all galaxies within 2000 kpc of the host, so the ratio of the 0 to 2000 kpc section is one. I fitted each curve in these ratio plots to a line, which Figure 3 indicates with dashed lines. The bottom plot in Figure 3 shows the slopes of these lines as a function of distance from the host. The shaded regions around each curve indicate the uncertainty in the fits.

The slopes vary by about 10%; in other words, the mass function for a given radial cut differs from the overall mass function by at most about 10%. Since 10% is within the uncertainty of an observed mass function, this indicates that mass function does not significantly change for different distances from the host.

Figure 4 shows analogous plots to Figure 3, but at z = 7 rather than z = 0. For these plots, galaxies were selected that were within 2000 kpc of the host or hosts at redshift 0 and had a stellar mass of at least 10^4 solar masses. Once again, the slopes of the ratio plots varied by about 10%. I similarly analyzed galaxies at redshift 2 - 10, and these data showed the same trend.

These results indicate that mass function does not change as a function of distance from host, supporting the legitimacy of the near-far approach.

Future Work

Another potential issue of the near-far approach is that it assumes a 1:1 mapping between modern day galaxies and high redshift galaxies. In reality, there may have been more galaxies at high redshift than there are now. Future work extending this project could include using the FIRE simulations to track individual star particles from z = 0 to high redshift, to figure out whether star particles within one galaxy at z = 0 are in multiple galaxies at high redshift (which would imply a 1:n mapping where $n > 1$). This would further test the legitimacy of the near-far approach.

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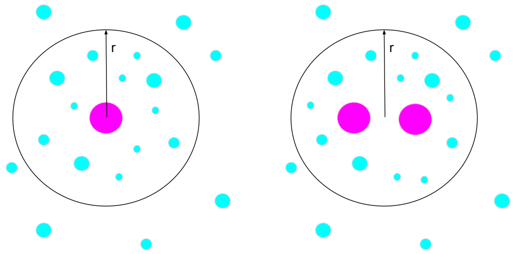

FIG. 1: Diagram illustrating how radial cuts were measured. The pink circles represent host galaxies and the blue circles represent low mass satellite galaxies. The right image shows a radial cut, r, for a simulation with a single host galaxy. All galaxies within r are included in the radial cut. The left image shows a radial cut for a simulation with two host galaxies, where the cut is measured from the geometric center of the hosts.

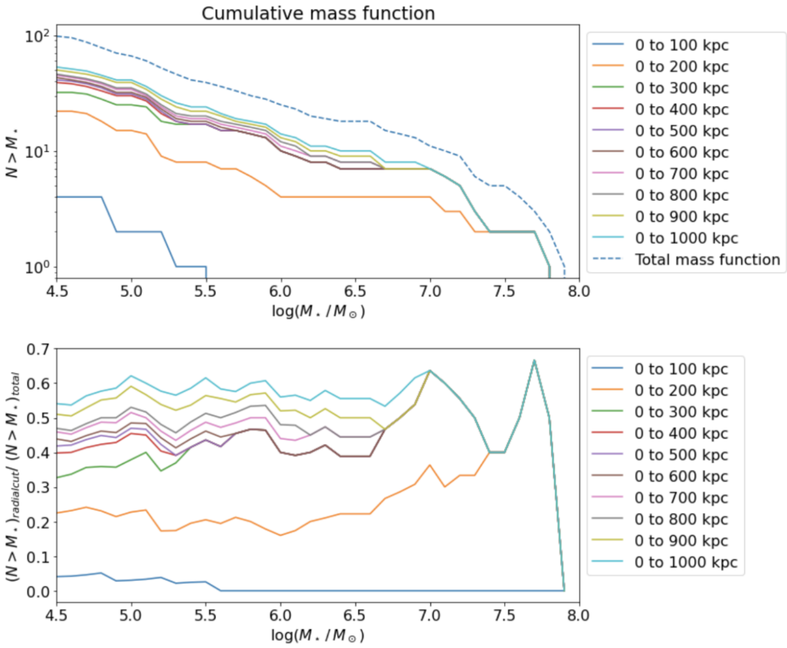

FIG. 2: The upper plot shows the cumulative mass function for galaxies within various radial cuts of the host galaxy in the m12m simulation at z = 0. The x-axis indicates the mass in solar masses on a log scale, and the y-axis represents the number of galaxies with a mass greater than the corresponding y value. The lower plot shows the ratio of each radial cut mass function to the overall mass function. The slopes of these curves appear to be roughly zero, indicating that the mass function does not significantly depend on the distance from the host for this simulation.

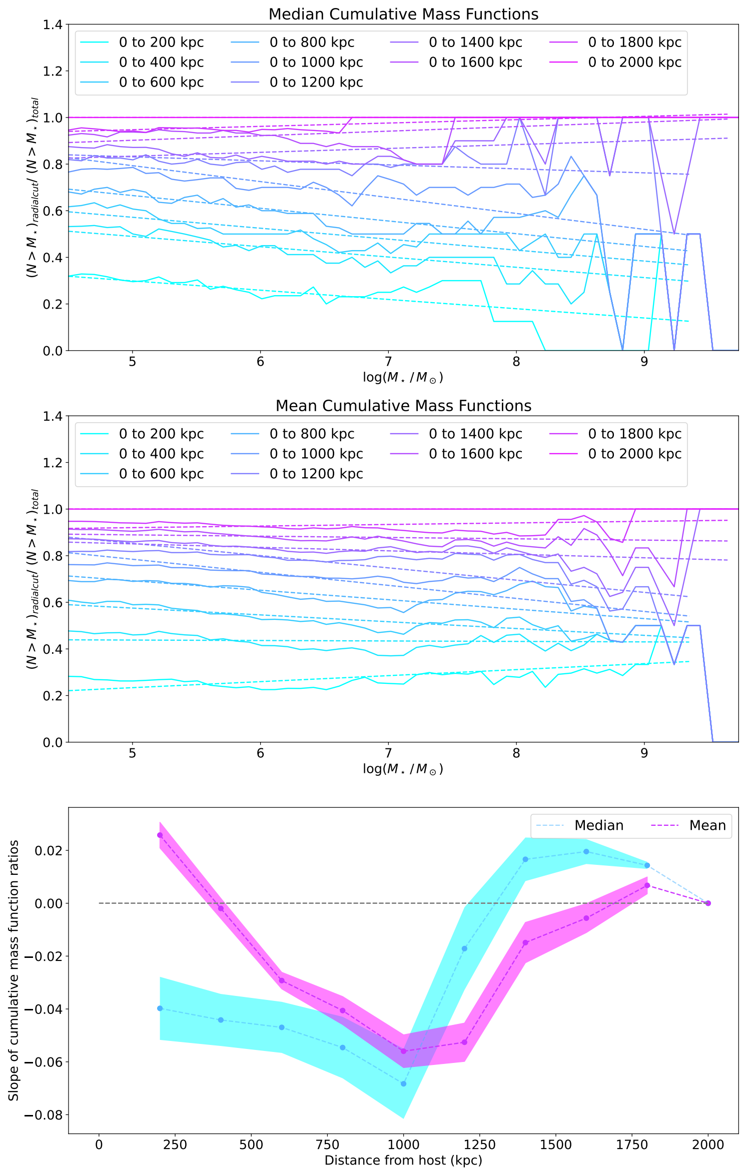

FIG. 3: The upper and middle plots show the median and mean of the cumulative mass functions at various radial cuts for eleven simulations at z = 0. The dashed lines show linear fits to the ratio curves for each radial cut. The slopes of these fits are plotted in the bottom figure as a function of distance from the host. The shaded regions around the curves indicate uncertainty in the fit. The range of each curve is about 10%, showing that the mass function does not significantly depend on the distance from the host.

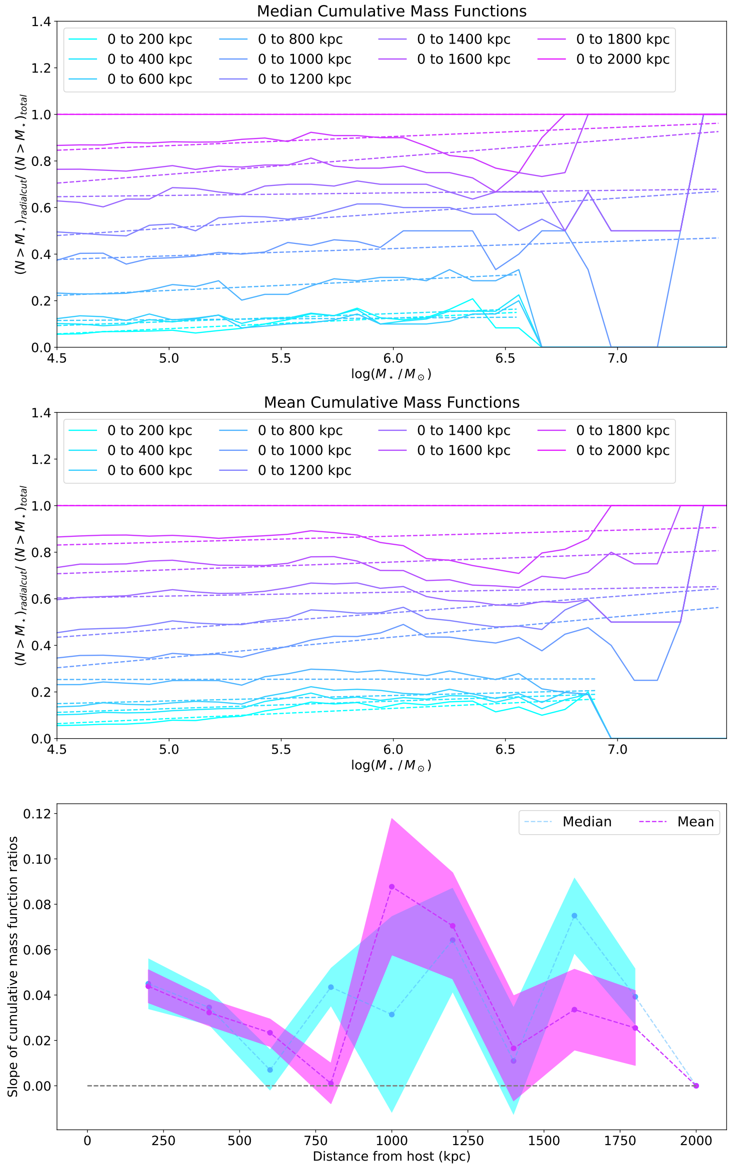

FIG. 4: This figure contains the same plots as Figure 3, but for z = 7. Once again, the range of each curve is about 10%. This indicates that the mass function does not significantly depend on the distance from the host.