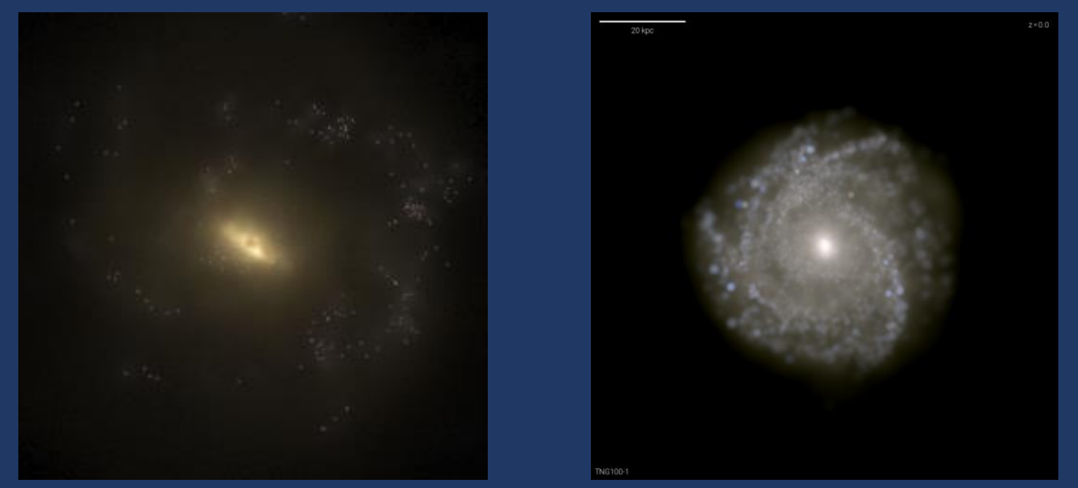

False-colour images of #1 MWAs in EAGLE (left) and TNG-100 (right).

Characterizing Milky Way Analogues in Cosmological Simulations

Alicia Savelli[1,2,3], Prof. Josh Speagle[1,4], Dr. Ted Mackereth[5]

[1]David A. Dunlap Department of Astronomy & Astrophysics, University of Toronto [2]Dunlap Institute for Astronomy and Astrophysics, University of Toronto [3]Department of Physics, Brock University [4]Department of Statistical Sciences, University of Toronto [5]Ocean Mind, UK

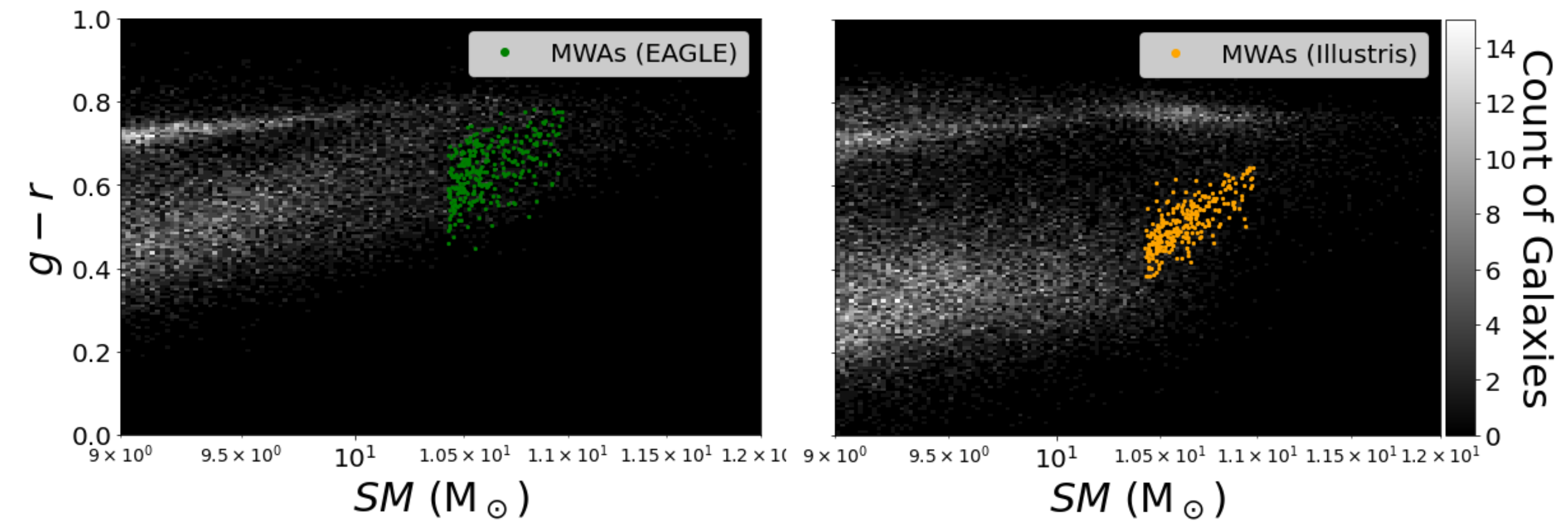
Introduction

The Milky Way (MW) is of great interest to astronomers, as it is our home galaxy and the galaxy we can study in the greatest detail. We wish to study galaxies similar to our MW, "**Milky Way Analogues**" (**MWAs**), to help us make predictions for properties that can't be directly measured, and improve our sense of the MW in an extragalactic context.

Simulations allow us to study of the evolution of MWAs, thus aiding us to more easily identify MWAs observationally at higher redshifts.

In our project, we aim to answer the question: **Is the Milky Way a typical galaxy, or is it special?**

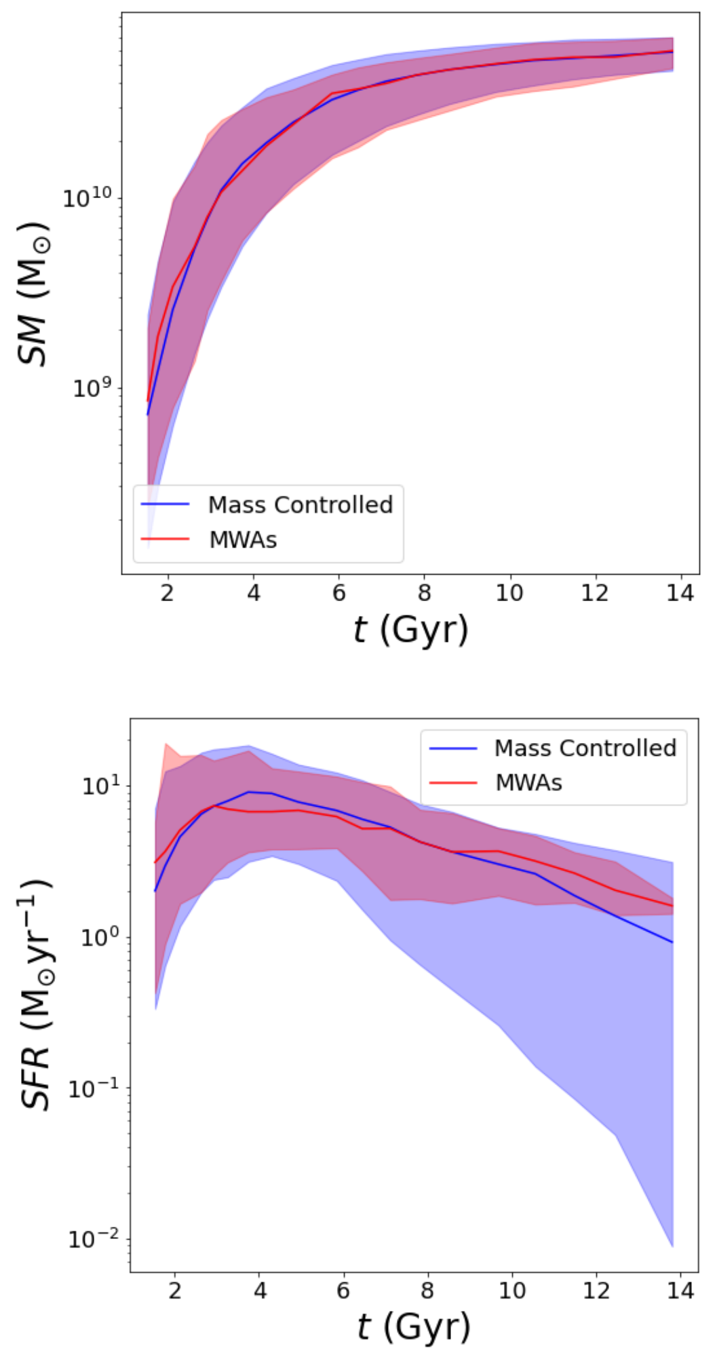
Key Properties at $z = 0$



Various properties of MWAs were analyzed at redshift $z = 0$, including SM, SFR, chemical enrichment, and B/T ratio. Of these, only matching on **SM** and **SFR** appear to affect MW assembly histories. Additionally, MWAs in both EAGLE (above, left) and TNG-100 (above, right) were found to be **red spirals**.

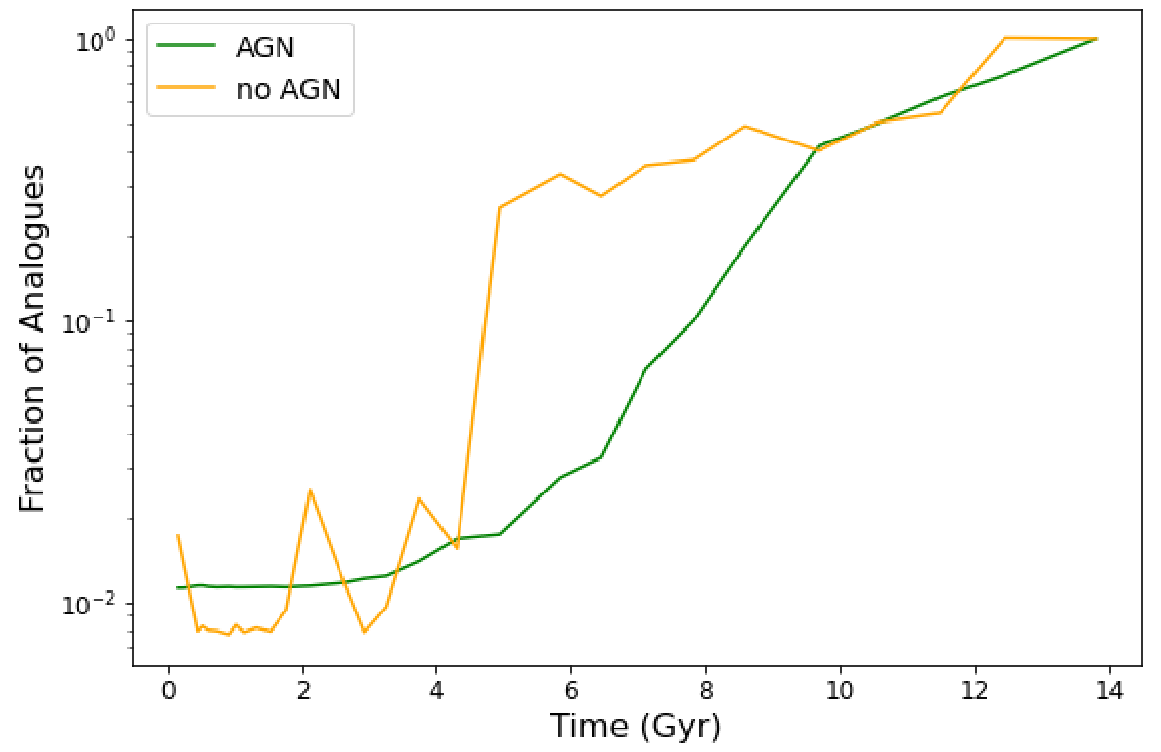
Stellar Mass is Driving Factor

Comparing the assembly histories of our MWAs (red) to galaxies of similar mass (blue) in EAGLE, we find that SFR (right, bottom) plays a role in determining MWAs at early times, but **SM** (right, top) **is overall most significant.** In later times, SFR has little effect on MW-ness, as **galaxies have already assembled majority of their SM**.



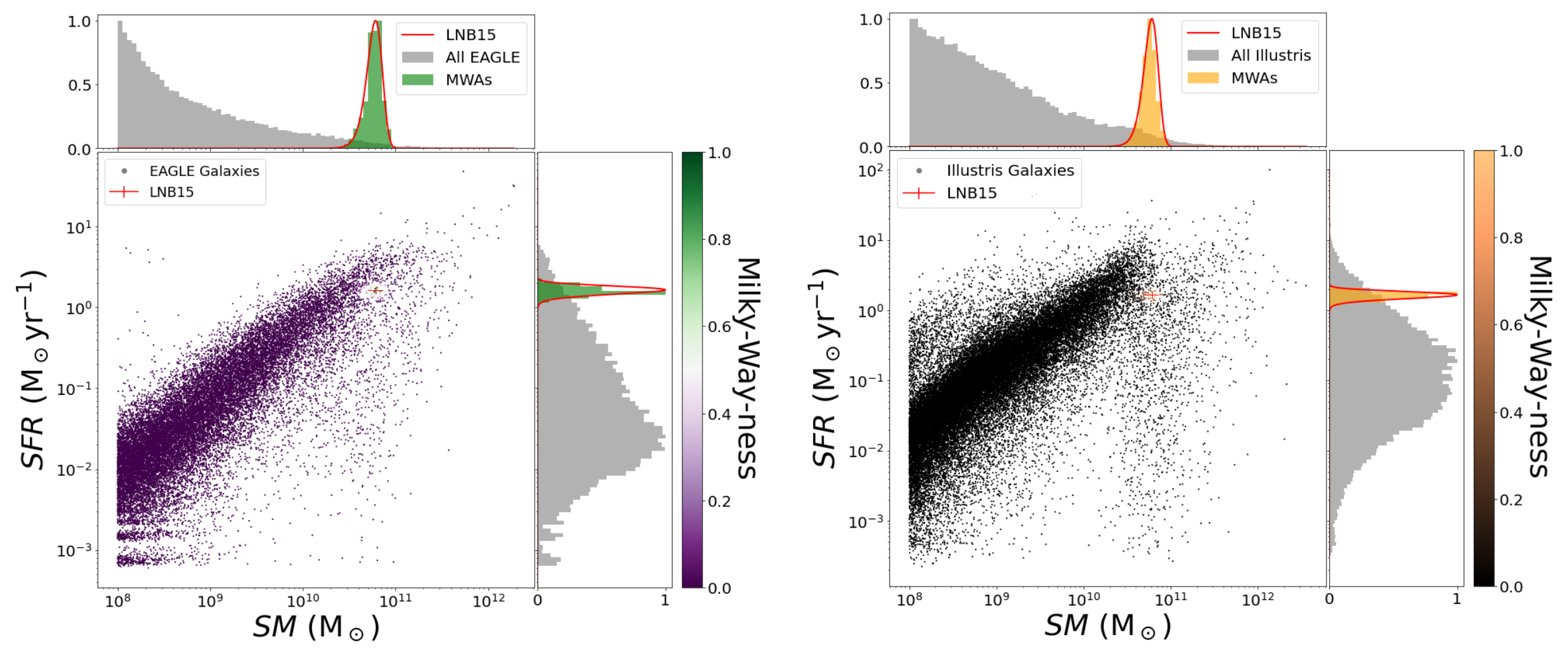
Influence of AGN in EAGLE

In EAGLE, users can analyze simulations with or without AGN. Comparing the fraction (as defined in *Tracing Milky Way Analogues through Time*) of analogues of galaxies with similar SM and SFR to the MW shows longer coherence across SFR histories with **no AGN**. **With AGN**, feedback kicks in ~4 Gyr ago, before which it is much more difficult to select MWAs successfully.



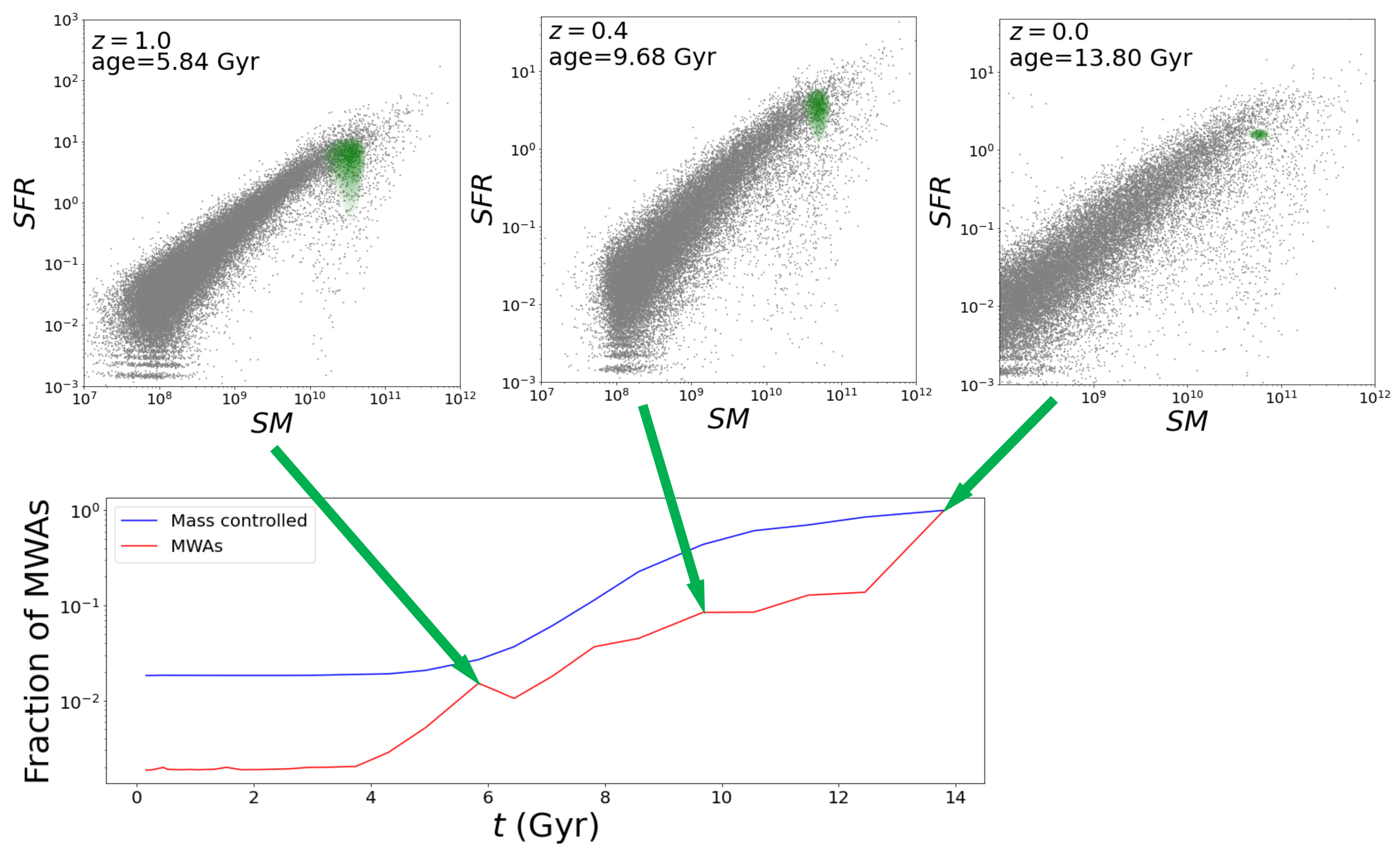
Data Selection

This project uses the **EAGLE suite of cosmological simulations** [1] and **IllustrisTNG-100** [2-7] – both large-scale hydrodynamical simulations in ΛCDM. MWAs were selected based on the MW's stellar mass (SM, $6.08 \pm 1.14 \times 10^{10}\ \mathrm{M}_\odot$) and star formation rate (SFR, $1.65 \pm 0.3\ \mathrm{M}_\odot \mathrm{yr}^{-1}$) [8], weighted by a χ^2 distribution scaled by a Gaussian KDE pdf.



MWAs in EAGLE (left) and TNG-100 (right) on a plot of SFR vs. SM.

Tracing Milky Way Analogues Through Time



The **fraction of MWAs** (left, bottom) is the ratio of the effective sample size of MWAs at redshift $z = 0$ to that at each previous time step. This ratio generally decreases going back in time, meaning that there is some **contamination** with galaxies behaving as MWAs at higher redshifts that do not end up as MWAs today. The **snapshots** (left, top) also show this through the increased "selection boxes/ellipses" that determine MWAs. Thus, studies trying to observe MWAs at higher redshifts may be investigating galaxies that are not similar to the MW today.

Conclusions & Next Steps

Our results agree with those of [9] – that SM and SFR are the most important properties in determining MWAs, and that the MW is a red spiral; however, we also find that SM is far more significant in determining an early galaxy's likeness to the MW today. Are we being too restrictive in selecting MWAs?

Additionally, galaxies selected as MWAs at higher redshifts are likely not similar to the MW today, according to EAGLE. In this sense, **the MW does not appear to be special**.

To complete the project, the history analysis will be repeated with TNG-100. Future works should look at more parameters and observed data.

References

[1] Joop Shaye et al. (2014). The EAGLE project: Simulating the evolution and assembly of galaxies and their environments. *arXiv: Astrophysics of Galaxies*.
[2] Dylan Nelson et al. (2019). The IllustrisTNG simulations: Public data release. *arXiv: Astrophysics of Galaxies.*
[3] Annalisa Pillepich et al. (2018). First results from the IllustrisTNG simulations: The stellar mass content of groups and clusters of galaxies. *arXiv: Astrophysics of Galaxies*.
[4] Volker Springel et al. (2018). First results from the IllustrisTNG simulations: Matter and galaxy clustering. *arXiv: Astrophysics of Galaxies*.
[5] Dylan Nelson et al. (2018). First results from the IllustrisTNG simulations: The galaxy color bimodality. *arXiv: Astrophysics of Galaxies*.
[6] Jill P. Naiman et al. (2018). First results from the IllustrisTNG simulations: A tale of two elements – chemical evolution of magnesium and europium. *arXiv: Astrophysics of Galaxies*.
[7] Federico Marinacci et al. (2018). First results from the IllusrisTNG simulations: Radio haloes and magnetic fields. *arXiv: Astrophysics of Galaxies*.
[8] Timothy C. Licquia, J. Newman, & J. Brinchmann (2015). Unveiling the Milky Way: A New Technique for Determining the Optical Color and Luminosity of our Galaxy. *arXiv: Astrophysics of Galaxies*.
[9] Catherine E. Fielder, Jeffrey A. Newman, Brett H. Andrews, Gail Zasowski, Nicholas F. Boardman, Tim Licquia, Karen L. Masters, & Samir Salim. (2021). Constraining the Milky Way's Ultraviolet to Infrared SED with Gaussian Process Regression. *arXiv: Astrophysics of Galaxies*