Dynamics of the Oldest Stars in FIRE-2 Simulations

Emma Tasso, CAS 2025

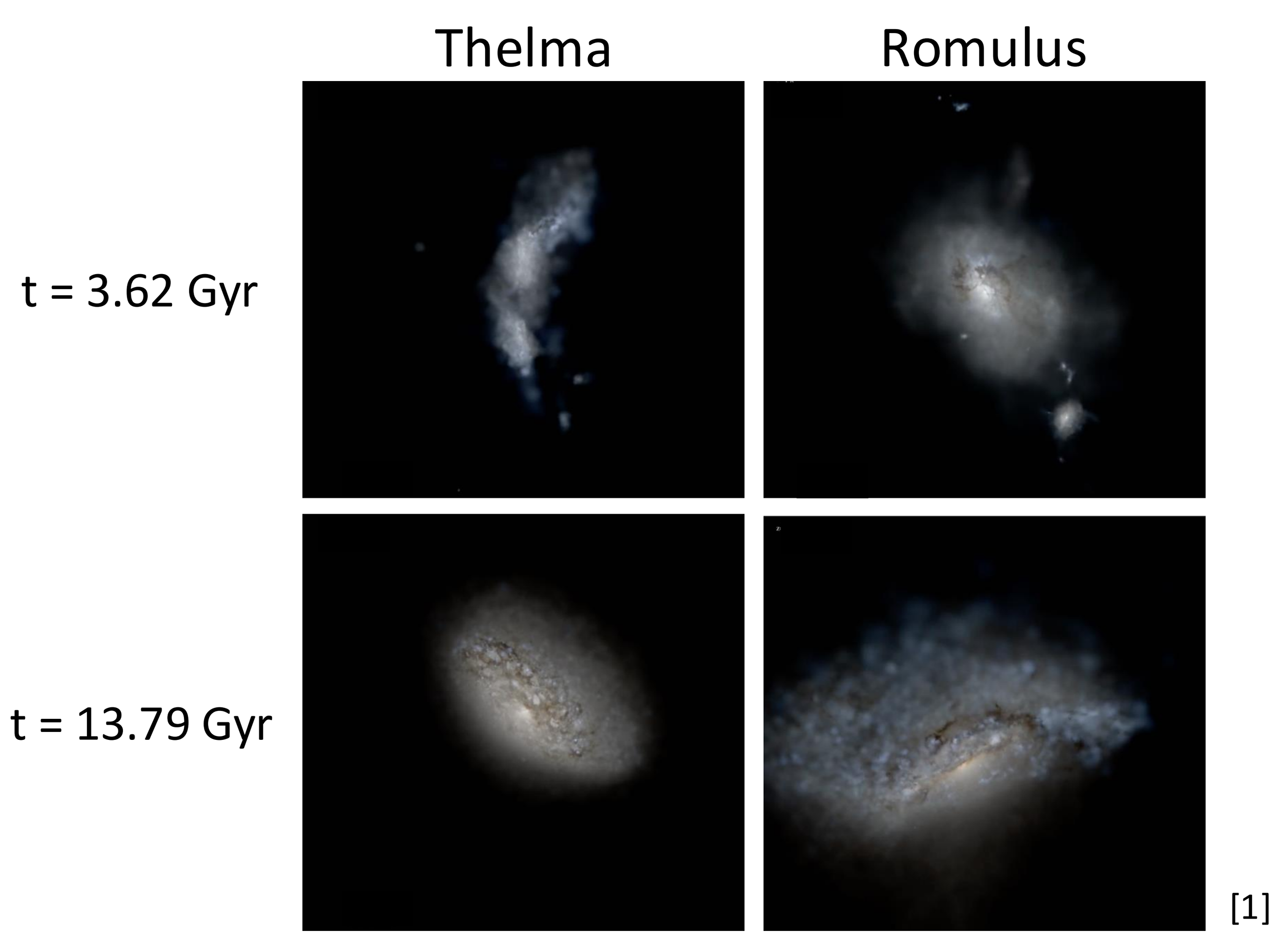
Madeline Lucey, CAS Department of Physics and Astronomy

Penn CURF
CENTER for UNDERGRADUATE RESEARCH & FELLOWSHIPS

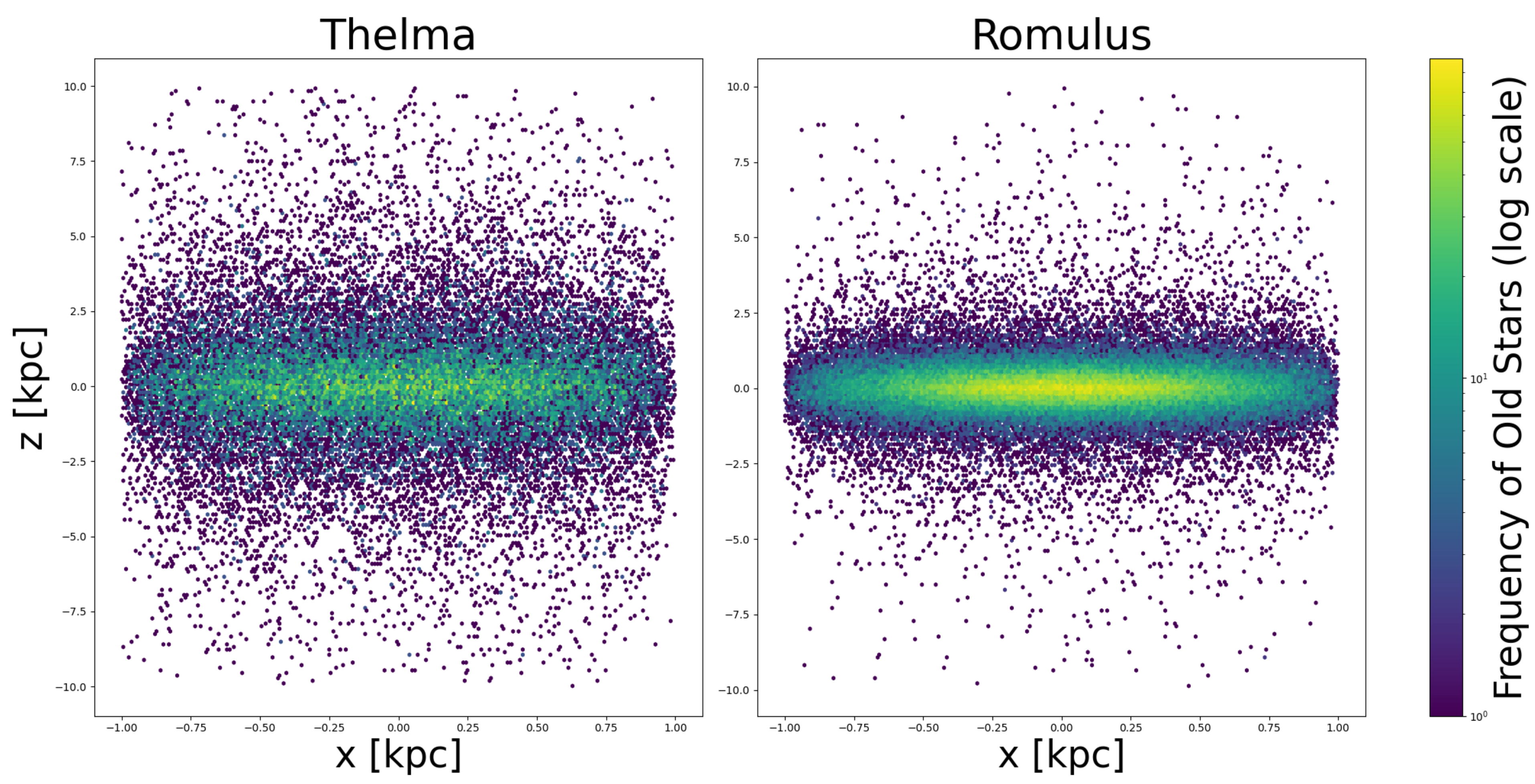
One goal of modern astrophysics is to understand the formation and evolution of galaxies. Cosmological zoom-in simulations are a tool we can use to test our theories. Using the **FIRE-2** (Feedback in Realistic Environments) high-resolution simulations that track star, gas, and dark matter particles over the course of billions of years, I examine **Milky Way-like galaxies.**

What is a galaxy? A galaxy is a massive collection of gas, dust, stars, and dark matter held together by gravity.

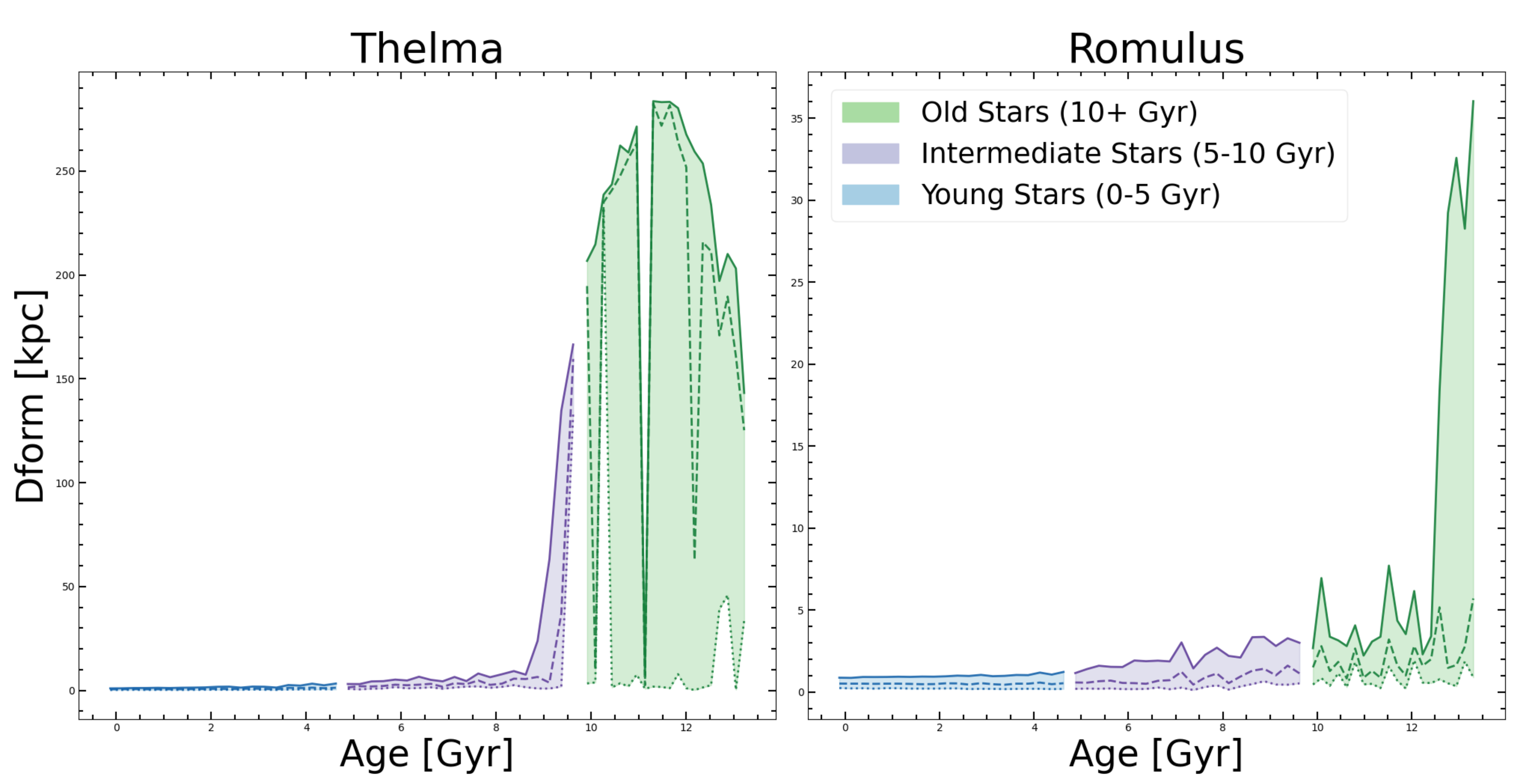
I study the most ancient stars in both isolated and paired galaxies and compare the dynamics and properties of their stars. In my study, I categorize stars into three age groups, each **measured in billions of years**: Young (0-5 Gyr), Intermediate (5-10 Gyr), and **Old (10+ Gyr)**. This research will allow us to make predictions about the ages, dynamics, and distribution of stars, as well as for the Milky Way as a whole. The more we can learn about our own galaxy, the more we will understand the dynamics of the universe that we are a part of.

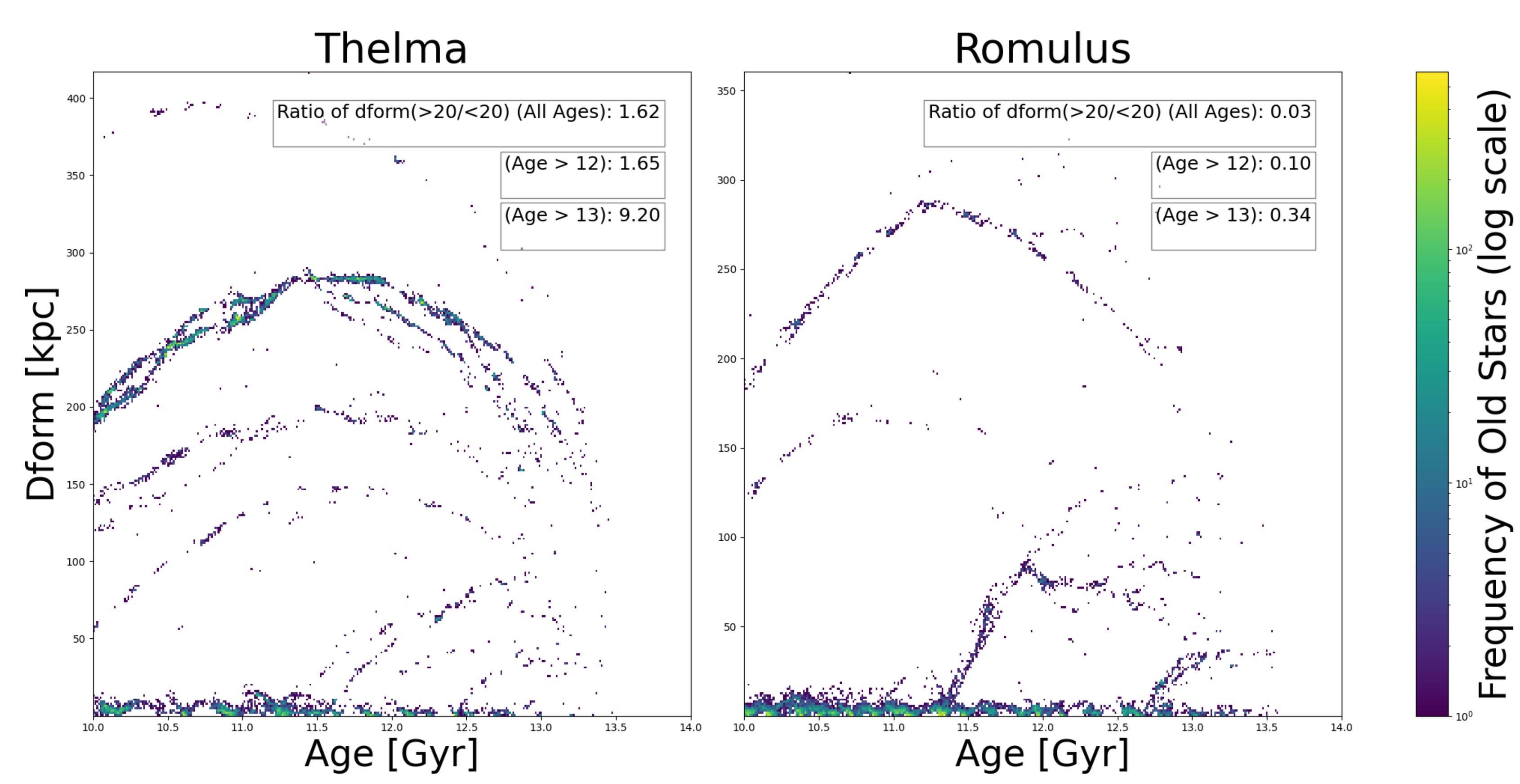


[1]



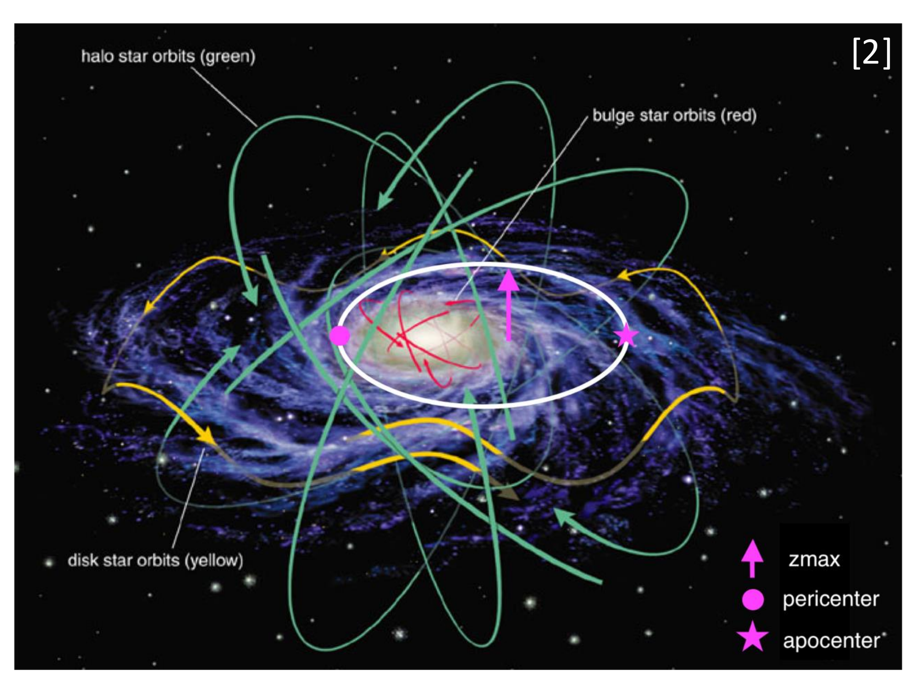
Old stars are more likely to have been formed ex-situ than young stars. The parameter for **ex-situ** formation in my research is that a star formed **more than 20 kiloparsecs away from where the center of the galaxy** is at the snapshot moment. The data suggests that a major component of early growth in Milky Way-like galaxies is hierarchical formation, or **accretion**. The calculated ratios of ex-situ to in-situ stars suggests that early accretion was supplemented by secular growth as well. This provides evidence for how our own galaxy likely formed billions of years ago. The trends in the data for galaxies Thelma and Romulus are consistent with the remaining simulated galaxies used in this study.

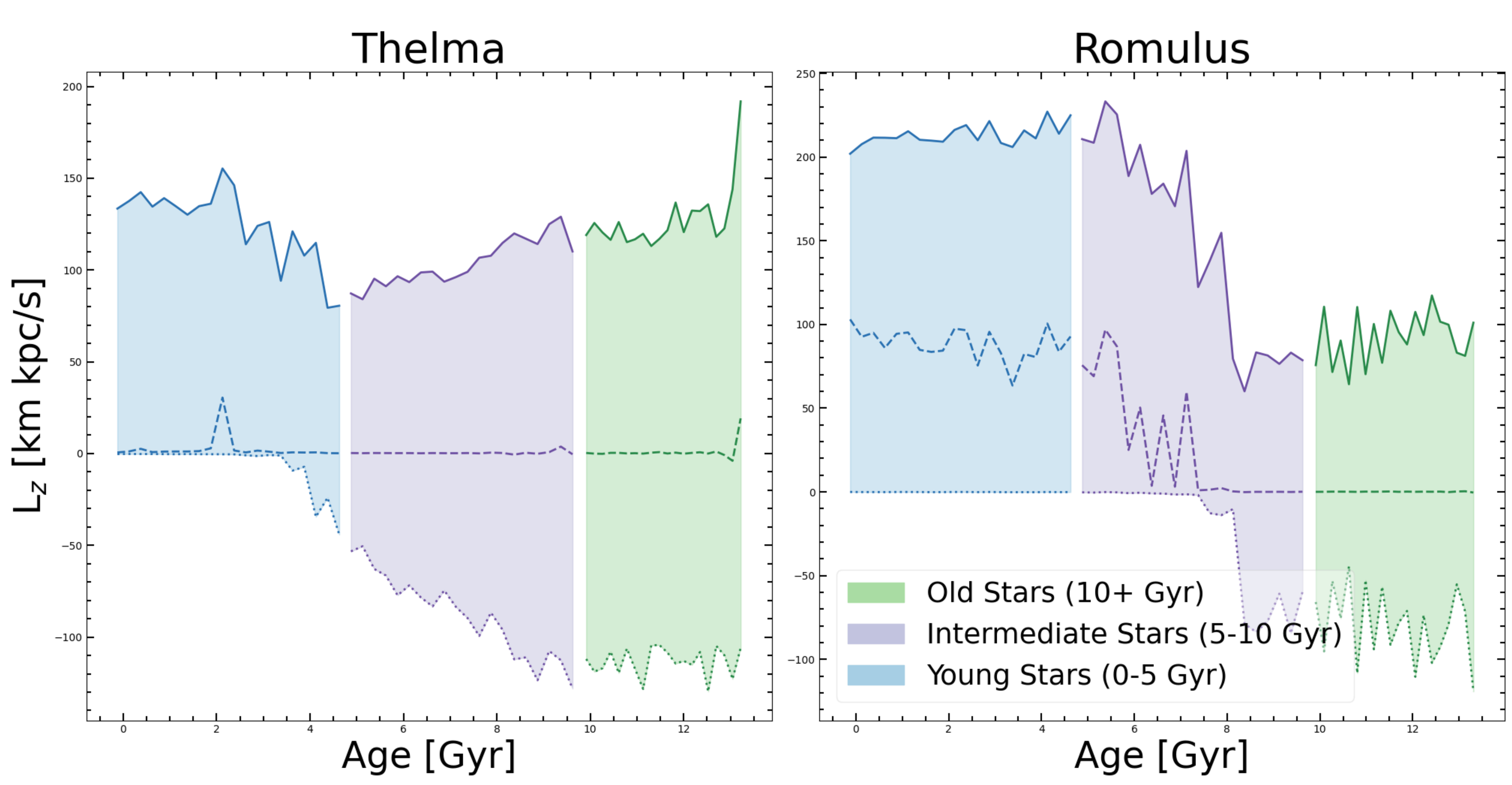


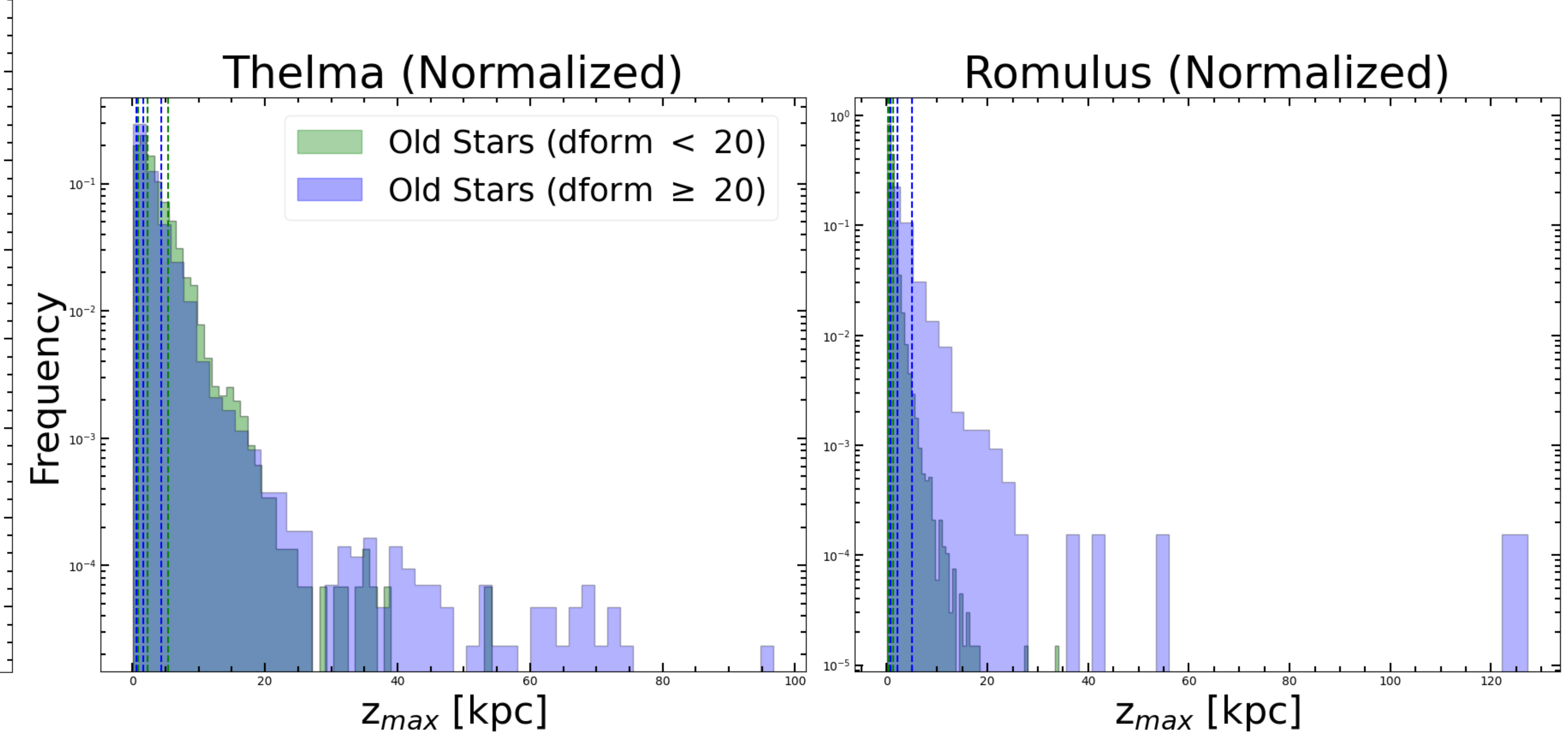


Old stars are largely halo stars as well as disk stars. Disk stars follow the main rotation of stars in the most populated region of the galaxies, while halo stars tend to follow more irregular orbital paths. The number of old stars with negative angular momentum compared to young stars, along with the frequency of properties like z max, apocenter, and pericenter further suggests that many stars are accreted during early growth in Milky Way-like galaxies. This can be compared to the Milky Way, and based on the orbits of stars in our galaxy and their properties we can predict their ages, and vice versa. Ultimately, these predictions allow us to better understand the dynamics of stars within the inner halo of the Milky Way Galaxy.

The diagram to the right differentiates between halo and disk star orbital paths, as well as the properties mentioned above.







[1] FIRE-2 Galaxy Visualizations, Caltech.edu. [2] Bennett et al., *The Cosmic Perspective* (2017).