Charting M33's Stellar Stream Dynamics Following The Milky Way-M31 Merger

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1. INTRODUCTION

For the most prominent model on how galaxies evolve, the standard ΛCDM cosmology, galaxies form and evolve via a series of mergers with neighboring smaller star systems (K. V. Johnston et al. 2008). One of the predicted resulting factors in these mergers are coherent streams of stars that are stripped from their original host by the stronger tidal forces from the larger galaxy (J. Jensen et al. 2021). As such, the existence of such streams hints at the scenario in which galaxies evolve via merging, and the dynamics of such objects may reveal crucial information on the history of a given galaxy.

Considering the distance these streams generally are from the galactic center, their dynamical timescales are much longer, which allows us to peer into past conditions of this system, forming something akin to a "fossil record" for past mergers of a specific galaxy (K. V. Johnston et al. 1996). Thus, studying these streams' dynamics is deeply beneficial to understanding how galaxies evolve and can even provide insight on how different kinds of mergers affect the resulting galaxy, strengthening or weakening the ΛCDM framework. Furthermore, it has been discussed that measuring the amounts of stellar streams a galaxy has can put a lower limit to past merging events and also present indirect evidence for the existence of dark matter sub-haloes (K. Malhan et al. 2018).

At this point in time, as Jensen et al.(2021) evidences, we are getting access to revolutionary amounts of observational data concerning galactic structures, which includes cataloging Milky Way's stellar streams (K. Malhan et al. 2018)1. This revolution also comes in the form of deeply detailed simulations aiming at describing the behaviors of such streams and justifying the observations we are gathering (J.-H. Choi et al. 2007).
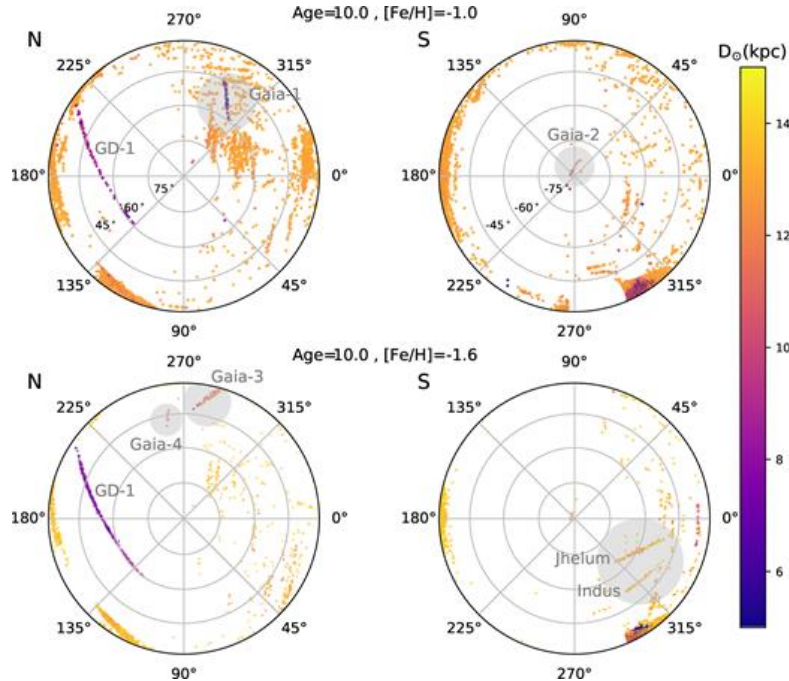

Figure 1. Chart demonstrating potential stream stars identified in (K. Malhan et al. 2018). This evidences the astounding capability we have to identify these objects, however this only accounts for a small portion of all stream stars.

Despite the huge advances and breakthroughs seen in recent years, big questions remain. Some which only depend on our observational technology advancing, such as what the total quantity of stellar streams would be for our own galaxy, as even at this point some remain to be found (N. Shipp et al. 2023). Others that, even with technological advancements, may still be impossible to answer completely, such as what the nature of Dark Matter is or how galaxies are created and evolve in a more detailed frame, given the presence of highly stochastic processes (N. C. Amorisco 2017).

2. PROPOSAL

2.1. *This Proposal*

The aim within this project is going to be to better describe the stellar streams that will originate from M33 during the Milky Way-M31 merger. More specifically I will be looking at the dynamic properties of such an event, including velocity gradients and dispersion in the stream. My final goal is to answer how these kinematics evolve throughout the merging process and whether or not we can draw any conclusions from its behavior that may advance current research.

2.2. *Methods*

In order to achieve such goals many of the functions devised during classes and labs will be used. First the relevant snap shots from the simulation will be selected. In this case snap shots before and after each MW-M31 interaction will be the most useful, so around 3.8 Gyr ("M33_260.txt"), 4.2 Gyr ("M33_300") and 5.9 Gyr ("M33_420"). Since stars are being addressed, only disk particles will be used.

Now we have to find which particles are not bound to M33 at each of these moments. In order to do that we will be using the "Jacobi Radius", which is defined as:

$$R_j = r * \left(\frac{M_{sat}}{2M_{host}(<r)} \right)^{\frac{1}{3}} \tag{1}$$

This equation takes in the mass of the satellite M33 (M_{sat}), the mass of the host MW+M31 (M_{host}) and r, which is the separation between these two.

Both masses can be easily obtained directly from the "GalaxyMass.py" function created in Homework 3. The separation, however, will require some extra steps. The base code will come from Homework 6, where we used the "CenterOfMass" class and created the "orbitCOM" function in order to plot the separation between each object in terms of time. For this project we will be using "orbitCOM" in order to obtain the separation for a given time and plugging that into the Jacobi Radius formula.

Then finally we will be able to use the code developed on Lab 7 to make contour plots of the velocity dispersion with the Jacobi radius being a condition, so only particles beyond the Jacobi radius will be shown in the plots, allowing us to clearly see the characteristics and how they change from time to time during the merging event. See Figure 2 for reference.

2.3. *Hyposthesis*

I believe that, as the merging event advances, M33 will lose a large amount of the particles localized in its edges, most of it being during the major encounters of MW and M31, since its Jacobi radius will decrease since now both MW and M31 masses are exerting tidal forces. This will probably also mean we will see more extreme velocities beyond the Jacobi radius during those timeframes. Another prediction we can make is that as time passes these streams will slwoly be accreted by the now merged MW-M31 system, since this is what the ΛCDM model predicts.
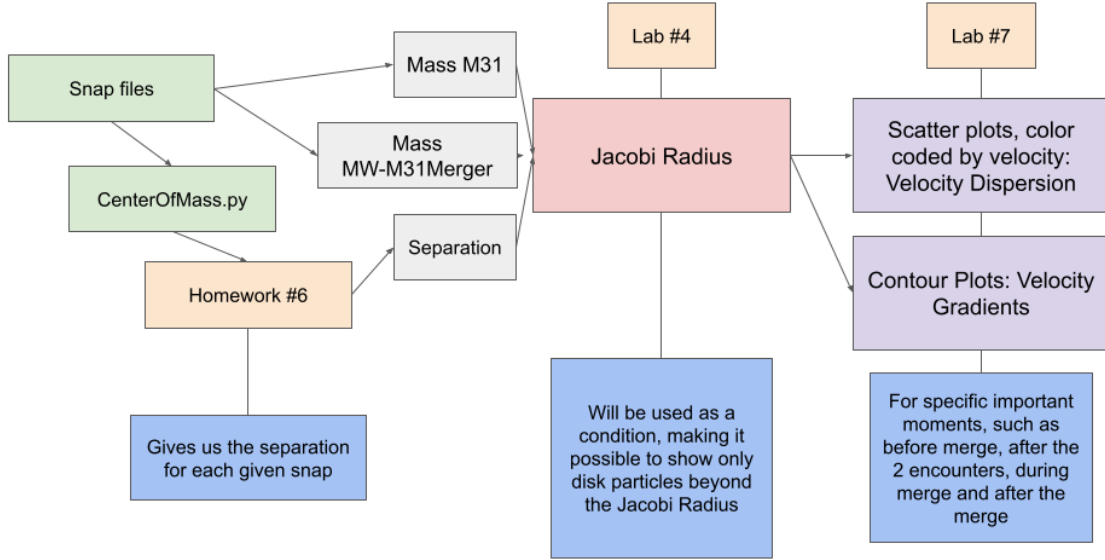
Figure 2. Diagram illustrating the steps that need to be taken in order to obtain velocity dispersion and gradient plots of particles located beyond the Jacobi radius (No longer bound by M33). In blue we can see more detailed explanations for how each function developed during an assignment will be used.

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