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The Fate of Baryonic Matter in the Tidal Streams of the MW-M31 Merger

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1. INTRODUCTION

Observations of galaxies revealed long streaming tails of stellar material, or bridges of stellar material between galaxies, extended out beyond the disk or perpendicular to it. These tails and bridges are created by interactions between two or more galaxies experiencing a tidal/gravitational interaction.

The existence of tidal features can indicate that a now isolated galaxy once interacted with a another galaxy and/or merged, which may not be obvious from its appearance. The history of a galaxy and any possible mergers can in turn indicate the history of the galaxy's formation (in a cluster, outside, etc.) and explain the galaxy's history of star formation and gas exchange. Many structures in elliptical or lenticular galaxies such as stellar shells are attributed to mergers Ji et al. (2014). The shape and length of a tidal tail can be used to determine the shape of the dark matter halo. Finally, some dwarf galaxies (tidal dwarf galaxies) may be generated from stellar tails Kroupa et al. (2010).

The current understating of the topic places tidal tails/bridges as a result of gravitational/kinematic interactions with another galaxy of any size. Tails tend to form in any interaction but seem more pronounced in flybys, while bridges are more common when the masses of the objects are about the same, and if they are merging, though exceptions exist Toomre & Toomre (1972). Tidal features last far longer further away from the center of the galaxy, because of the fewer particles to interact with at greater distances. The material in the tidal tails tends to be older stars, and while mergers can trigger star formation, it appears the new stars stay in the resultant galaxy's central regions Ji et al. (2014). The stellar tails tend to intersect or be completely subsumed by the dark matter halo, and as such the length and prominence of the tails are inversely proportional to the depth of the halo's mass. Generally, tidal tails remain gravitationally bound after a merger, although a few stars may escape.

One current question in the field is exactly how long these tidal features survive and what effects their lifespan. The initial rotation of the galaxy compared to the incoming galaxy's trajectory, initial angular momentum and the contributions of star formation and supernovae have been included in simulations calculating the lifespan of large features, but the effect of ram pressure, AGN, harassment, and nearby clusters of galaxies have not. Early galaxies are expected to have far more gas, and the addition of this gaseous material may alter the nature, shape, and lifespan of an tidal features compared to the gas poor galaxies and features that we observe Ji et al. (2014). The types of galaxies that create tidal features, particularly around the Milky Way, is also open for debate. for example, the Sagittarius stream may have been a spiral galaxy instead of a dwarf Peñarrubia et al. (2010).

2. PROPOSAL

2.1. *Questions*

The questions I intend to address are the following:

- When will tidal bridges/tail begin to form in M31/the Milky Way?
- What is the ultimate fate of these features? Do they escape, or do they remain bound and spiral back in? How much escapes, if any?
- What is the orientation of the tails relative to the disks of the merging galaxies? How "high" out of the (original) plane of the galaxy do they get?

2.2. *Methods*

To answer these questions, a qualitative method to start out may be appropriate. If tidal bridges or tails start to form, then they should be visible in a density map of the galaxy. The first code that should be written or adapted is the code that colormaps the galaxy based on density. This can give a good first approximation of when the galaxy first forms tidal features, and also approximately what happens to them at the end. Initial tests suggest that the galactic disk is too dense compared to any stellar tails, and I need to find some way to only map lower density areas for the tails to show up.

To develop a more quantitative analysis, I will have to rely on the geometry of the problem and determine some way to differentiate the tidal structure from the rest of the disk. The tidal structures will probably not be in the plane of the disk (difference in position), will probably be orbiting the galactic COM with a velocity vector that is easy to differentiate from the disk (difference in velocity), and also possibly be further from the COM than most of the disk. My task is to write code that goes through all the particles in the simulation and physically picks any particles that have peculiar positions, velocities, or distances (or some combination) and use that to exactly identify my tidal structure particles, possibly with the aid of the animation/images. However, I may need to adapt the code to Lab 7 to show both galaxies at once, by choosing one center of mass and converting the stored coordinates to the new center of mass frame. This is because the difference between a stellar tail, a stellar bridge, and the new merged galaxy may not be obvious from looking at just one galaxy. Also, it will probably be necessary to figure out where exactly the plane of the galaxies lie during each step, since the merger will disrupt them.

From that point, it should be fairly trivial to map out what happens to the tidal tail- both in image form and quantitatively. I'll already have the code to graph the density, and only need to modify it to only show the tails for the sake of clarity. I can also look at particle velocities to see if any diverge (suggesting they escape), and find the times (and average time) when particles cross into or out of the disk to figure out how long the structures last.

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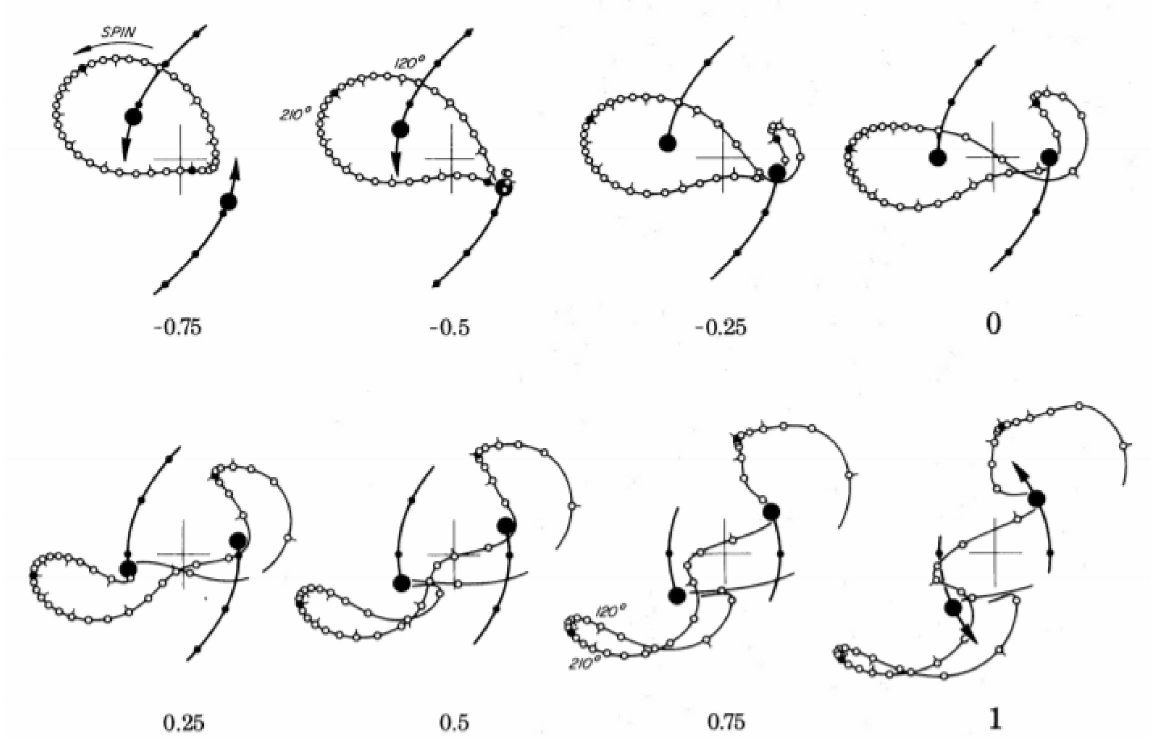

FIG. 3.—A slow-motion study of the distortion of the $0.6R_{\min}$ ring during the direct passage of the equal-mass companion. Originally spaced 30° apart in longitude, the tick marks on every third test particle help identify the "inside" of the curve in the later frames.

Figure 1. Image taken from Toomre 1971 showing a flyby interaction's ability to form tidal tails. Even though MW and M31 are expected to merge, the disruptions they experience as the approach may lead to similar structures. Toomre & Toomre (1972)

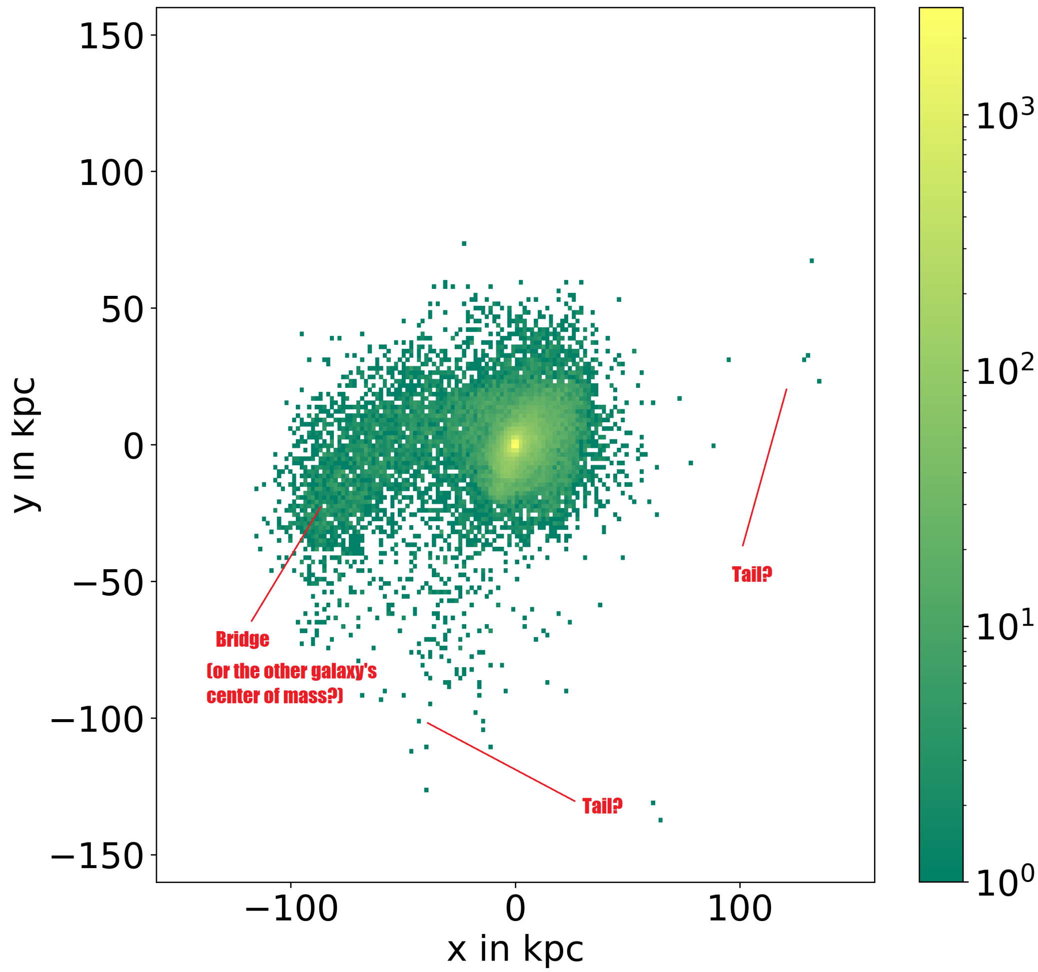

Figure 2. First test taken from MW_450 to see if any obvious features fall out of the density plot.