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The kinematics of the stellar disk particles in the MW/M31 galaxy major merger remnant

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1. INTRODUCTION

As is well known throughout the astronomy community, The Milky Way (MW) and Andromeda (M31) are set on a course to collide in a spectacular galaxy merger event ∼4-5 billion years from now (van der Marel et al. 2012). This galaxy merger is classified as a major merger given that the colliding spiral galaxies have approximately the same mass. Luckily, we can determine what this collision will look like and how the aftermath (i.e. the merger remnant) will behave dynamically through simulations. Specifically, they allow for the analysis of the stellar kinematics of the remnant. The stellar remnant's kinematical properties such as its velocity dispersion σ, the spread of velocities around the average velocity of the stars, can allow for the determination of whether the remnant will be a fast or slow rotator. A fast rotator is defined as a system where velocity and dispersion are quite similar (V/$\sigma \rightarrow 1$), whereas a slow rotator is a system that is dispersion dominated (V/σ <0.6).

Analyzing the stellar kinematics of a major merger remnant is incredibly important to our understanding of galaxies and galaxy evolution. A galaxy is defined by Willman & Strader (2012) as: *A gravitationally bound set of stars whose properties cannot be explained by the combination of baryons and Newton's laws of gravity.* Galaxy evolution is the study of how galactic properties (such as the stars, morphology, internal kinematics, black hole, gas content etc.) change over time. A major merger event of two spiral (late-type) galaxies such as that of the MW and M31 will drastically alter the galactic properties of both galaxies, especially their internal kinematics. Generally, early-type galaxies (ellipticals) have more random stellar motions whereas the stars of late-type galaxies (spirals) have more structured rotational motions. Depending on the type of binary merger event, like whether it is a "wet" merger (the coalescence of two gas-rich spiral galaxies) or "dry" merger (the coalescence of two gas-poor galaxies), the kinematics of the merger remnant can have numerous possibilities. A wet merger can supply the amount of gas needed to conserve the angular momentum of the system for the remnant to have a significant amount of rotation. It also is currently believed to lead to the formation of low luminosity ellipticals. However, the kinematics of a dry merger event (such as the MW/M31 collision) are not believed to be the same.

Since the MW/M31 merger will be "dry", it is theorized that the collision will increase the velocity dispersion of the system and the remnant will not have the gas needed to conserve angular momentum. A current dominating theory for wet mergers is referred to as the "merger hypothesis", which states that the merging of two equal-mass, gas rich spiral galaxies forms an elliptical galaxy (Toomre & Toomre 1972). This is supported by Cox et al. (2006) who used numerical simulations to study the kinematics of major merger events between gas-rich and gas-poor mergers (referred to as dissipational and dissipationless respectively in the paper). As shown in Figure 1, they found that the simulations of gas-rich major mergers with masses 20 times smaller or 30 times larger than $\sim 10^{12} M_\odot$ successfully replicated the observed kinematic properties of more massive ellipticals. As shown in Figure 1, they found that the simulations of gas-rich remnants successfully replicated the observed kinematic properties elliptical galaxies, while gas-poor remnants did not.

Many of the open questions in this field have to do with the accuracy of the "merger hypothesis" predicting the correct formation of ellipticals. For example, one thing it does not account for is the apparent lack of a dark matter halo observed in certain ellipticals (Romanowsky et al. 2003). *What happens to a galaxy's dark matter halo during a merger event?*. For this project, some major open questions I hope to help answer are: *What will the Milky Way and M31 remnant look like?* and *How will the merger remnant behave kinematically?* Currently, astrophysicists attempt to answer these ques-

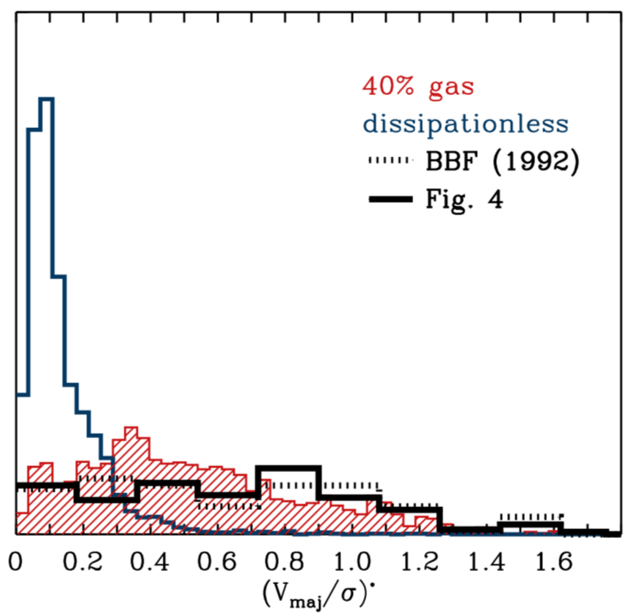

Figure 1. Histogram of (V/σ) for both gas-poor (blue) and gas-rich (red) remnant simulations overplotted with data from observed ellipticals and spheroids (black). The red and black histograms are much more similar than the blue one, thus supporting that the simulations of the gas-rich mergers better emulated the stellar motions of ellipticals. (Cox et al. 2006).

tions through numerical integration simulations to allow us to "see" into the future of the system after the collision. These simulations include assumptions of physics that follow Newton's laws of gravity as well as Cold Dark Matter Theory (the theory that dark matter only interacts with matter gravitationally).

2. THIS PROJECT

This paper will be focusing on some specific aspects of the stellar kinematics after the MW and M31 have coalesced, specifically at Snapshot 575 which is ~8.5 Gyr from now. I plan on using simulation data to determine the velocity dispersion as a function of radius in the remnant, whether the remnant is rotating, as well as whether the remnant will be a fast or slow rotator. The stellar kinematics to be analyzed will be the velocity of particles and the dispersion of the velocities.

Following the description above, I plan to address how the stellar merger remnant will behave kinematically in this project. Specifically in terms of velocity dispersion and rotation.

In terms of galaxy evolution, studying how the merger remnant behaves kinematically after the galaxies have become one allows us to take into account that the interactions of galaxies with each other can drastically change the morphology and dynamics of each. It can also give us insight into why the kinematics of large ellipticals look the way they do.

3. METHODOLOGY

The simulation data used in this paper was generated by van der Marel et al. (2012) who used it to determine the velocity vector of M31 with respect to the Milky Way. One part of their project was using an N-body model, a simulation of the motions of N particles under the influence of gravity in this case, to simulate the internal mechanics of M31. They used their simulation to determine the trajectory and behaviors of the MW, M31, and M33.

I will create a phase diagram of velocity dispersion vs. radius for a given axis at Snapshot 575. I will also determine whether the remnant is rotating as well as whether it is a fast or slow rotator by calculating the (V/σ) ratio along a given axis for the remnant, where V is the average velocity along that axis. Figure 2 shows a phase diagram of the velocity component oriented out of the page vs. a position axis, after reorienting the remnant so that the angular momentum vector is aligned with the z-axis, I will make a plot like this for each velocity and position component to determine the mean velocity and dispersion along each axis.

I believe that the MW/M31 remnant will be rotating since both the MW and M31 have their own angular momentum, then there is no possible way it will be devoid of angular momentum. For the velocity dispersion of the remnant as a function of radius, I believe that it will decrease at further radii as seen in Romanowsky et al. (2003). As for the classification of whether the remnant will be a fast or slow rotator, I believe that it will be a slow rotator since the merger between M31 and the MW will have very little gas.

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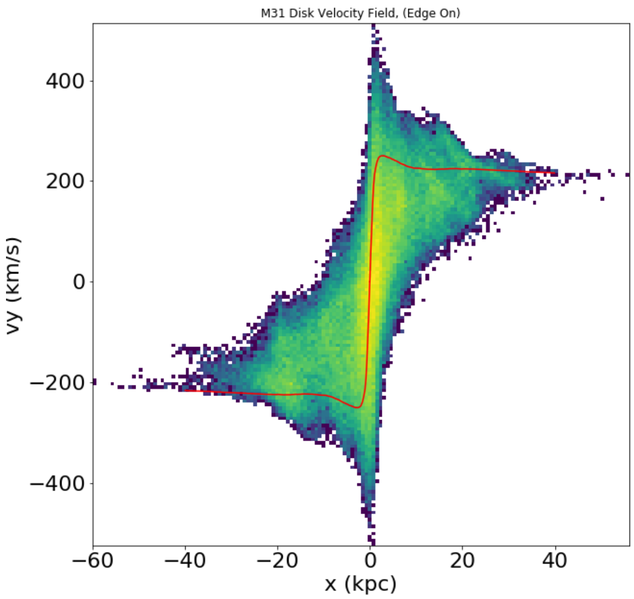

Figure 2. Phase diagram of M31's y-component of velocity vs. x-component of position. You can determine the mean velocity along the axis (as well as the velocity dispersion) using a diagram like this.

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