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Simulated Velocity Dispersion of Bar Stars in the Milky Way–M31 Merger

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1. INTRODUCTION

Galactic evolution is one of the most dynamic fields in cosmology. My proposed topic focuses on the influence of major galactic mergers on the bar structures in spiral galaxies. This subject encapsulates a broader area of galaxy structure and dynamics, as it examines how the galactic bar structure responds to dramatic changes induced by mergers. By analyzing the evolution of these bars, we gain insight into the mechanisms that drive the overall transformation of galaxies (e.g., van der Marel 2001).

This topic is central to our understanding of galaxy evolution because the disruption or alteration of the bar structure plays a critical role in the transformation of galactic geometry (Wu et al. 2018). The presence and nature of bars significantly affects star formation and the secular evolution of galaxies (Schönrich & McMillan 2017). Understanding how mergers affect these structures helps elucidate the processes that cause barred spiral galaxies to transition into elliptical galaxies, ultimately shaping the observable characteristics of galaxies in the universe.

Current research indicates that major galactic mergers prompt significant changes in spiral galaxies, frequently leading to an evolution towards an elliptical shape (e.g., Mutch et al. 2011). Although simulations have successfully replicated some aspects of this transformation, the details of the intermediate stages remain poorly understood (Berentzen et al. 2003). The prevailing view is that the bar structure, characteristic of many spiral galaxies, is significantly disrupted during mergers (e.g., Mutch et al. 2011). The dynamics of stars within the bar are disturbed, leading to a chaotic dispersal throughout the merged galaxy. Despite a qualitative understanding of the overall process, there exists gaps in our knowledge of the precise mechanisms at work.

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Despite progress in simulating and observing galactic mergers, several open questions persist. The exact physical measurements and propoerties of bar structures in spiral galaxies are the subject of an ongoing debate, which greatly influences the evolution of galactic centers during a merger (Rathore et al. 2024). Furthermore, It is partially unclear how individual perturbations during a merger contribute to the overall disruption of the bar, and how we can predict the detailed dynamics of these events (Berentzen et al. 2003). Addressing these uncertainties is vital for developing a more comprehensive model of galaxy evolution post-merger, ultimately enhancing our understanding of the lifecycle of galaxies.

2. PROPOSAL

2.1. *This Proposal*

For stars ejected from the bars of the Milky Way and Andromeda (M31) galaxies during their merger as simulated in van der Marel et al. (2012), how does a star's initial distance from the galactic center influence its post-merger velocity?

2.2. *Methods*

Considering sing the high-resolution simulation data from van der Marel et al. (2012), I will write a python script that identifies the bar of the Milky Way and M31 and tracks these stars through carefully selected snapshots that highlight close encounters between the galaxies. This data will then be summarized and analyzed as position-velocity phase plots and contour maps.

To perform any analysis on the barred region of a spiral galaxy, one must first define the bar. As previously discussed, this remains an active area of research (Berentzen et al. 2003). For this project, I employ the method depicted in Fig. 1 from Dehnen et al. (2023) due to our analogous methodologies. This approach requires an input parameter θ that I obtain from the location of high-density regions in Fig. 2.

After identifying the stars located in their host galaxy's bar, I write a function that identifies close encounters between the Milky Way and M33 and generates a list of snapshots with an interval of 16 at "quiet" inter-

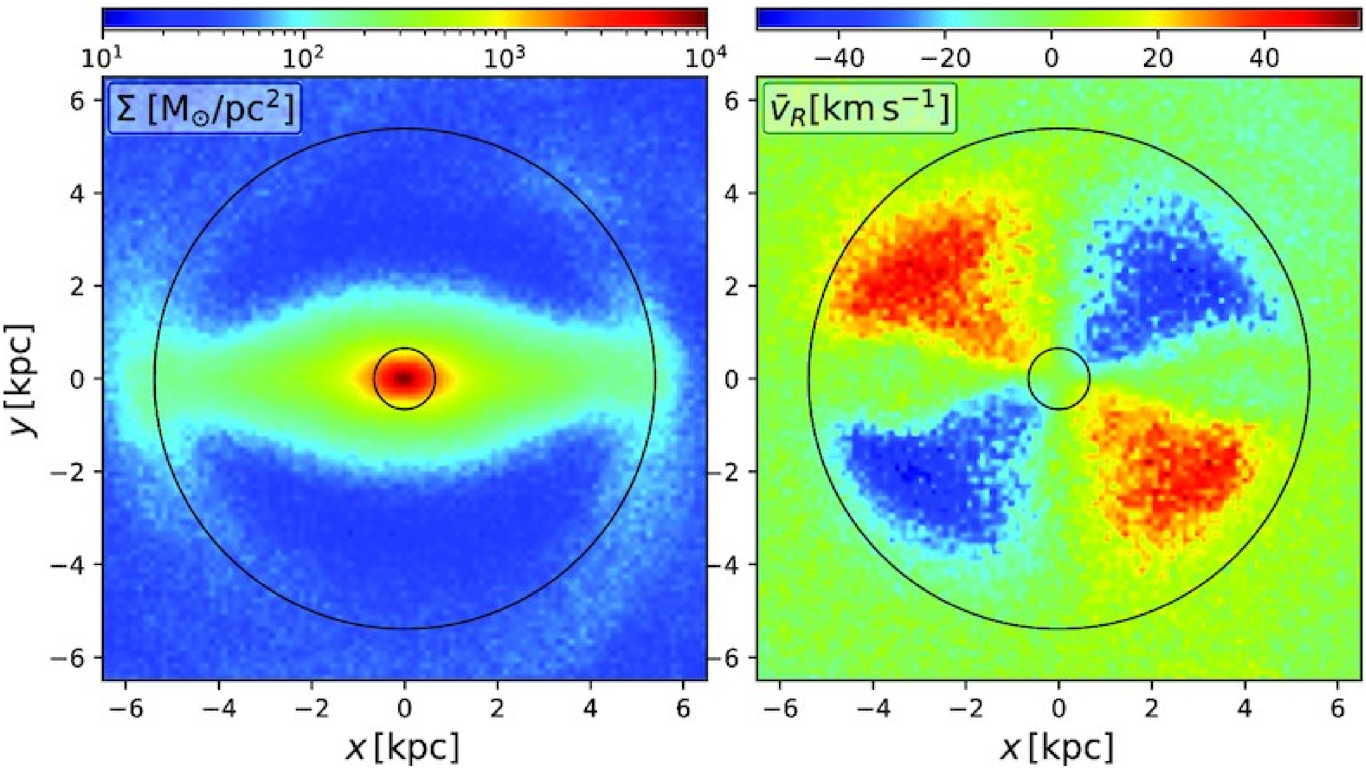

Figure 1. Figure 7 from Dehnen et al. (2023). The visual demonstrates one method used to determine the bar size and shape. This figure is generated from simulation snapshots, which mirrors the method I discuss later in the proposal.

vals, an interval of 1 surrounding close encounters and interval sizes of 2, 4, and 8 to provide smooth transitions.

At each screenshot for each star located in a bar, I will generate a scatter plot comparing the distance to the galactic center on the x-axis to rotational velocity on the y-axis. At special snapshots depicting the initial state, final state, and states halfway between close encounters, I generate density contour plots from a face-down and cylindrical perspective that portray the bar structure of the Milky Way and M31 as well as their merger product. These plots show allow me to address my proposal.

2.3. *Hypothesis*

I expect that stars initially located further from the galactic center will exhibit higher velocities after dispersion.

Software: This work made use of the following software packages: `matplotlib` (Hunter 2007) and `python` (Van Rossum & Drake 2009). Software citation information aggregated using `The Software Citation Station` (Wagg & Broekgaarden 2024; Wagg et al. 2024).

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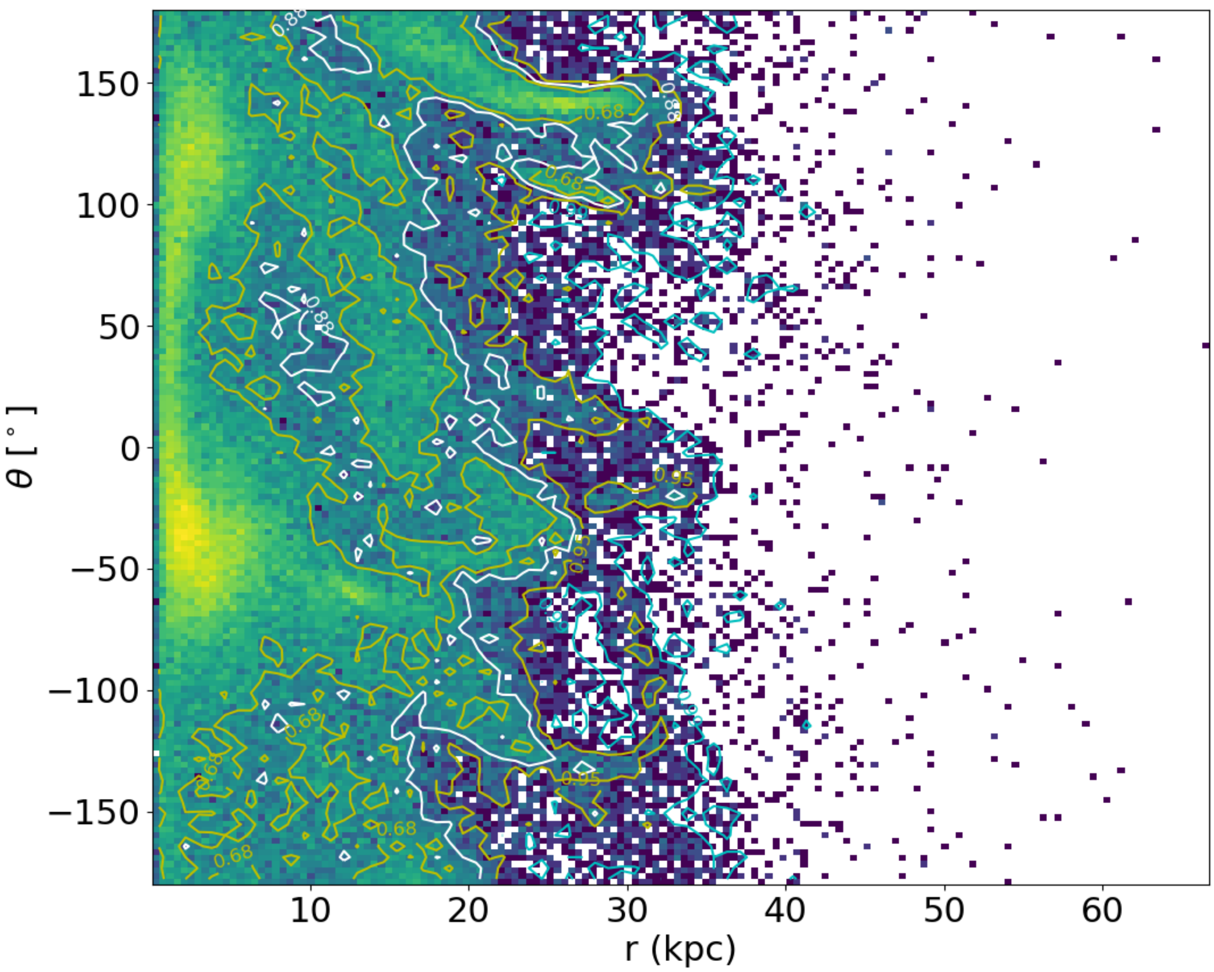

Figure 2. A histogram of M31 in polar coordinates (r, θ) onto $\mathbb{R}^2$ from Lab 7 from ASTR 400B Spring 2025 taught by Dr. G. Besla. This graph discretizes the stellar distribution, enabling us to identify the radius and principal angle of the bar. This analysis is used to determine the bar geometry for this project. By examining the density of the histogram, one can see that the bar appears most prominently at $\theta \approx -45^\circ$ and $\theta \approx 135^\circ$ Credit to G. Besla, R. Hoffman, R. Li, E. Patel, and myself for developing the code used to generate this figure.

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