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Modeling the Stellar Kinematics of the Thick Disk and Halo of the Andromeda Galaxy

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***Abstract*— In studying the Andromeda Galaxy to better grasp its physical components—particularly its northeastern region—we utilized Python code to simulate its halo and disk. Using previously observed data and various formulas, such as one that calculates the density distribution of stars, we closely modeled the real dimensions of Andromeda's halo and disk. Moreover, looking at different velocity dispersions along the height, radius, and angle axis helped us further understand Andromeda's actual dispersions. Comparing models with different percentages of stars in the thick disk and halo, we found that both the thick disk and the halo had minimal effect on the observed dispersion. Furthermore, we had difficulty observing overarching dispersion trends brought about by changing the dispersion coordinate variables. Based on these observations, a more natural and substantial dispersion of Andromeda can be concluded. As we continue, our analysis will assist us in fine-tuning the model, more accurately simulating the Andromeda Galaxy, and eventually adapting the code to forward model any galaxy.**

I. Introduction

As the brightest and largest galaxy within our own cluster of galaxies, the Andromeda Galaxy has its own unique attributes [1]. Yet, this huge collection of gas, dust, and billions of stars, along with their solar systems, is identical to every other galaxy in that it is held together by gravity. Andromeda has three main parts—the bulge, a dense ball of stars at its center; the disk, a thick and less dense disk of stars; the halo, a dimmer, sparsely populated cluster of stars surrounding it. Because Andromeda is nearby and frequently observed, it is often used as a starting point for galaxy models [4]. Specifically, previous research conducted by J. Veljanoski, among others, examined the velocity dispersion of Andromeda's outer halo globular cluster system and discusses various formation scenarios for Andromeda [3]. Therefore, there is a considerable amount of information available regarding Andromeda. However, we remain unsure about much of the details of its evolution. Understanding the dynamics of its stellar population could help us understand the history of Andromeda's formation, as well as the formation of other large galaxies, including our own. Likewise, there remains debate over the external and internal factors begetting dynamical heating of stellar disks, including the central bar, dwarf satellite bombardment, molecular clouds, and dark matter substructure. Hence, we are coding a model illustrating the stellar kinematics of the thick disk and halo of the Andromeda galaxy.

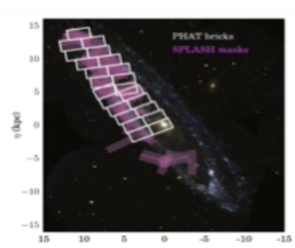

Figure 1. White outline indicates the observed (northeastern) region of Andromeda. [2]

II. Methods

By creating a simulation of Andromeda via Python code, we will eventually be able to forward model any galaxy, helping us better understand far off galaxies as well as our very own Milky Way. We fine-tuned the code of our model to Andromeda in particular because of its close proximity to us, similarity to the Milky Way, and familiarity to astronomers. Our model was created with Jupyter Notebook and implements the libraries NumPy, to perform operations on arrays, and Matplotlib.pyplot, to generate graphs of the galaxy. However, this model only includes the disk and halo. We also limited the code to Red Giant Branch Stars within the Northeastern part of Andromeda (Fig. 1) as they are larger, brighter, and therefore easier to observe than stars like our sun. Hence, we modeled the dispersion of velocities of Red Giant Branch Stars in Andromeda's Northeastern disk and halo. Both the simulated halo and disk are projected in cylindrical units. However, the spherical halo is modeled in two dimensions because it appears as a circle no matter what angle it is viewed at, whereas the disk is projected in three-dimensional space due to its thickness. To allow for direct comparison between the physical quantities generated by our simulation and the spectral line profiles shown by observations, we must create a model to generate data that can be closely compared with observed data. This technique is known as forward modeling [6]. Utilizing this approach, we built our code around known parameters and then adjusted the unknown parameters to match observed data. Initially, we had Andromeda's sky position and two velocity components as known parameters. These variables were included in existing code that modeled the distribution of Red Giant Branch Stars and the dispersion of their radial velocities in Andromeda's disk. But, the initial model only had one overall dispersion variable and did not include Andromeda's halo.

After subdividing the original dispersion variable into three different variables for dispersion along the phi angle (σ_ϕ), the z coordinate or height (σ_z), and the radius (σ_r), we used the equation seen in Equation 1: C being the expected total dispersion of Andromeda when observed. We input the variable we knew, σ_z; plugged in various possible numbers for one unknown, σ_ϕ; and solved for the other, σ_r. This resulted in various plausible data sets that we could plug into the model and then compare to Andromeda to help narrow down what Andromeda's actual σ_ϕ and σ_r are.

$$\sigma_r^2 + \sigma_\phi^2 + \sigma_z^2 = C^2$$

Equation 1. The formula for C or the expected total dispersion of Andromeda observed, where σ_ϕ describes dispersion along the phi angle, σ_r describes dispersion along the radius, and σ_z describes dispersion along the z coordinate or height.

We then modeled the halo in two-dimensional space. Equation 2 illustrates the power-law formula we used for determining the density of stars in relation to the radius. This formula accounts for how stars from the halo begin to dominate as the density of the stars from the disk falls off, as indicated from analysis of Andromeda's luminosity profile [4]. Thus, we simulated the stars in the halo according to the distribution defined by Equation 2. On the other hand, the velocity dispersion of the stars in the halo was generated randomly within the bounds of our observed data.

$$R' = R_c\sqrt{(1-w)^{\left(\frac{1}{1+\alpha}\right)} - 1}$$

Equation 2. The formula for the density of stars in relation to the radius, where *R'* is the observed projected radius, *Rc* is the halo core radius, α is the halo surface brightness profile power-law index, and *w* represents a random number uniformly distributed between zero and one.

Finally, we periodically adjusted the free parameters and compared the different simulations of Andromeda with the Andromeda observed in the sky. We primarily focused on how stars within the halo impacted the observed dispersion profile. This meant thoroughly analyzing the ratio of halo stars to disk stars and its effect on the simulated galaxy's velocity dispersion. Additionally, we looked for significant trends in dispersion as we altered the σ_ϕ and σ_r variables.

III. Results and Discussion

Overall, we discovered that the projection effects from the thickness of the disk were less pronounced than we previously thought. This suggested that there is an intrinsic dispersion unaffected by the halo. From these observations, the halo appears to be subdominant, having little to no effect on the dispersion within the surveyed region. Moreover, we found it extremely difficult to perceive overarching trends as σ_r and σ_ϕ changed. This implies that there is no observable dispersion contribution from the thick disk. However, based on our observations, the thick disk and halo do not account for much of Andromeda's overall dispersion. Ultimately, our findings were limited to what we could clearly discern with the human eye. Accurately and precisely observing such large amounts of data within a model displayed on a computer monitor would unavoidably prove difficult. However, unnoticed does not denote unnoticeable. In fact, existent and important trends could be uncovered with further research. By forward-modeling our observations of Andromeda, we are able to better understand the structural and kinematical properties of its thick disk and RGB stars, thereby helping to create a more realistic model which may be applicable to kinematical data of similar, nearby galaxies, such as the Triangulum galaxy. Additionally, future investigations could focus on determining the effect of Andromeda's bulge component on the galaxy's kinematics.

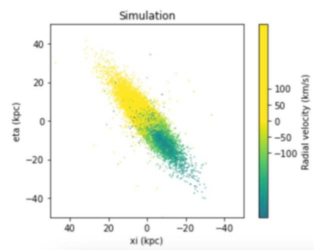

Figure 2. Model of the disk and halo of the Andromeda galaxy with 95% contribution of stars from the disk and 5% from the halo. The xi and eta axis labels are placeholders for coordinates.

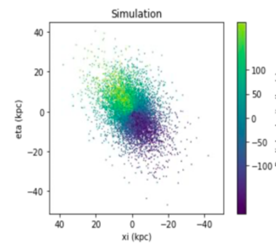

Figure 3. Illustrates the radial velocity within Andromeda's disk where σ_r equals 60, σ_ϕ equals 60.03, and σ_z equals 20. The xi and eta axis labels are placeholders for coordinates.

Our team has been awarded the most time of the Hubble Telescope's upcoming cycle 29, which will allow us to observe a broader area of Andromeda in greater detail. We will continue improving the model, broadening the parameters within Andromeda, and exploring the relationship between σ_r and σ_ϕ.

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