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Tidal Debris from M33: Stellar Streams of M33

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ABSTRACT

This study focuses on the tidal debris and stellar streams in the Triangulum Galaxy (M33). The research aims to explore the formation and evolution of these structures in M33, as well as the changes in the Jacobi radius over time, which are essential to understanding the dynamics of the Local Group and the role of tidal interactions in shaping galaxies. The findings suggest that the Jacobi radius remains constant for both M31-M33 and MW-M33 systems over time, indicating that tidal forces might not have a significant impact on M33's development, contrary to in the initial hypothesis. The mass change of M33 over time provides insights into how tidal streams form, although the results raise concerns about the accuracy of the code and its underlying assumptions.

Keywords: Tidal Debris — Stellar Streams — Triangulum Galaxy (M33) — Jacobi Radius— Local Group

1. INTRODUCTION

Tidal debris and stellar streams in galaxies, such as those found in the Triangulum Galaxy (M33), provide valuable insight into the complex processes driving galaxy evolution. These elongated structures form when stars are stripped from a galaxy due to tidal forces induced by encounters with other galaxies or dark matter halos. M33, part of the Local Group, has several stellar streams that can be studied to understand its formation history, interaction dynamics, and the role of dark matter in shaping its structure (Amorisco 2017; Choi et al. 2007; van der Marel et al. 2012).

Investigating tidal debris and stellar streams in M33 is crucial for advancing our understanding of galaxy evolution. A galaxy is a vast system composed of stars, gas, dust, and dark matter, all bound together by gravitational forces (Willman & Strader 2012). Galaxy evolution refers to the processes that influence the formation, development, and transformation of galaxies over time. As galaxies merge and interact with each other, they can exchange stars and gas, leading to the formation of tidal tails and streams. These structures can be observed around galaxies and provide important clues about their past interactions. The study of tidal debris can help us understand the formation and evolution of galaxies, as well as the properties of dark matter. By analyzing the distribution and kinematics of tidal debris, astronomers can infer the mass and orbit of the progenitor galaxy, as well as the properties of the host galaxy.

Current research on tidal debris and stellar streams of M33, as illustrated in Figure 1, provided valuable insights into the orbital evolution and interactions of M33 with other galaxies in the Local Group (van der Marel et al. 2012). The figure shows the complex dynamics of M33 as it settles into an elliptical, precessing, and slowly decaying orbit around the MW-M31 merger remnant. These interactions have shaped the structure and history of M33, affecting its distribution of stars, gas, and dark matter. By analyzing the tidal debris, we can infer the past interactions between M33 and its neighbors and uncover the role of dark matter in these processes.

There remain several open questions surrounding the tidal debris and stellar streams of M33. One such question is how and when these streams formed, which is directly related to the current project. Understanding the formation processes of these structures can provide critical information about the underlying mechanisms driving the evolution of M33 and other galaxies in the Local Group. Another open question concerns the role of the Jacobi radius in the formation and evolution of tidal debris, and how it changes over time. Researchers are currently addressing these questions through N-body simulations, observational data, and theoretical models (Amorisco 2017; Choi et al. 2007; van der Marel et al. 2012). By solving these open questions, this can further the understanding of galaxy evolution .

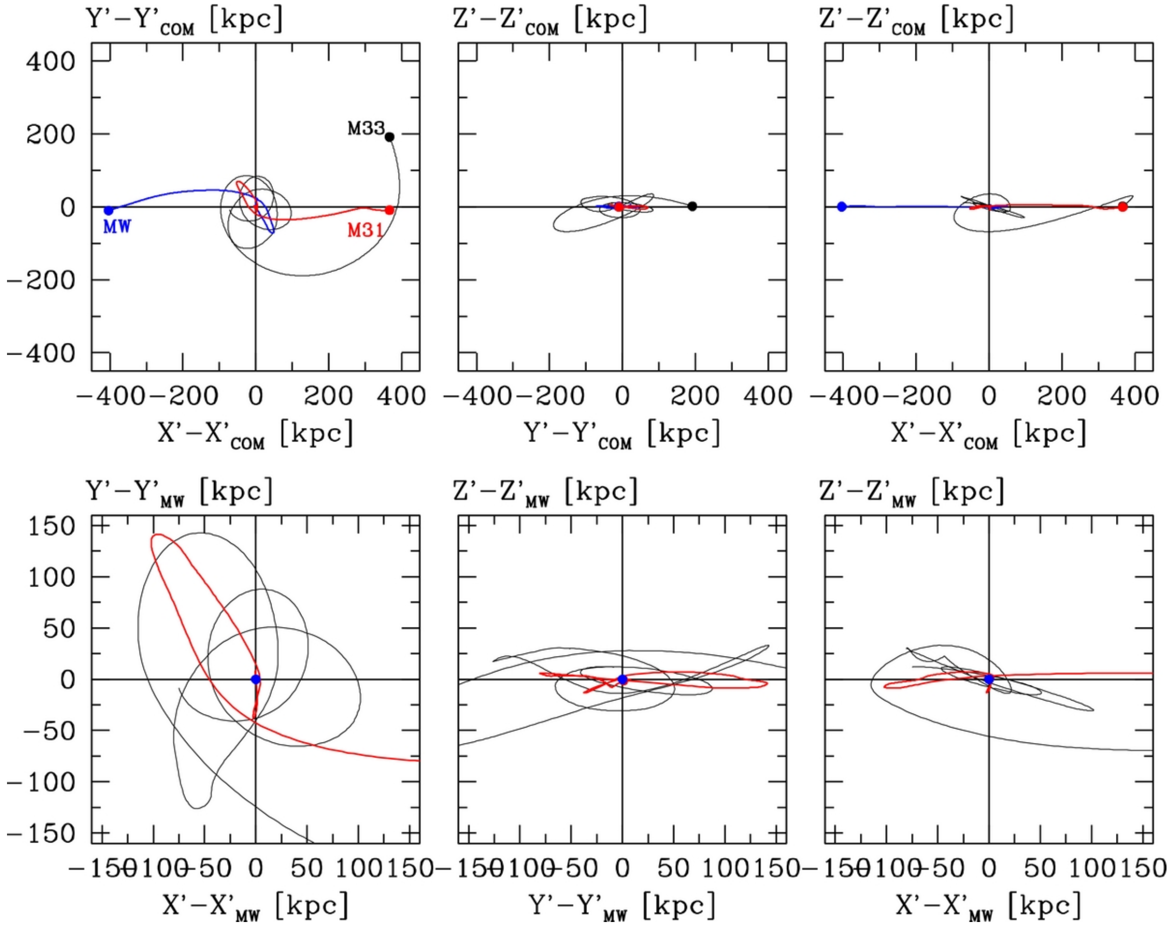

Figure 1. Orbital evolution of the centers of mass (COM) of the galaxies Milky Way (MW), M31, and M33, as calculated with N-body simulations in(van der Marel et al. 2012). The figure shows three orthogonal projections of the trigalaxy Cartesian (X’, Y’, Z’) system. The MW is depicted in blue, M31 in red, and M33 in black. The top row provides a wide view fixed on the COM of the system, while the bottom row offers a central view fixed on the MW.This figure illustrates the complex interactions between the galaxies, as well as the settling of M33 into an elliptical, precessing, and slowly decaying orbit around the MW-M31 merger remnant, highlight the intricate dynamics involved in the formation and evolution of galaxies within the Local Group.

2. THIS PROJECT

In this project, will examine the formation and evolution of M33’s tidal debris and stellar streams, as well as analyze the changes in the Jacobi radius over time. This research paper will involve an investigation of the tidal interactions between M33 and other galaxies in the Local Group.

This project addresses the question of how and when M33’s stellar streams form, and how the Jacobi radius changes over time. These questions are crucial for understanding the dynamics of the Local Group and the role of tidal interactions in shaping galaxies and their evolution.

Addressing this open question is essential for advancing our understanding of galaxy evolution, as tidal interactions play a significant role in the formation and transformation of galaxies. By studying the formation and evolution of M33’s tidal debris and stellar streams, can gain valuable insights into galaxies.

3. METHODOLOGY

The methodology involves using N-body simulations, as discussed in (van der Marel et al. 2012), which model the dynamical behavior of multiple celestial bodies under the influence of gravitational forces. In an N-body simulation, individual particles represent celestial bodies, and their mutual gravitational interactions are computed to predict the system’s evolution over time. These simulations can provide insights into the formation of tidal debris and stellar streams in the M33 galaxy.

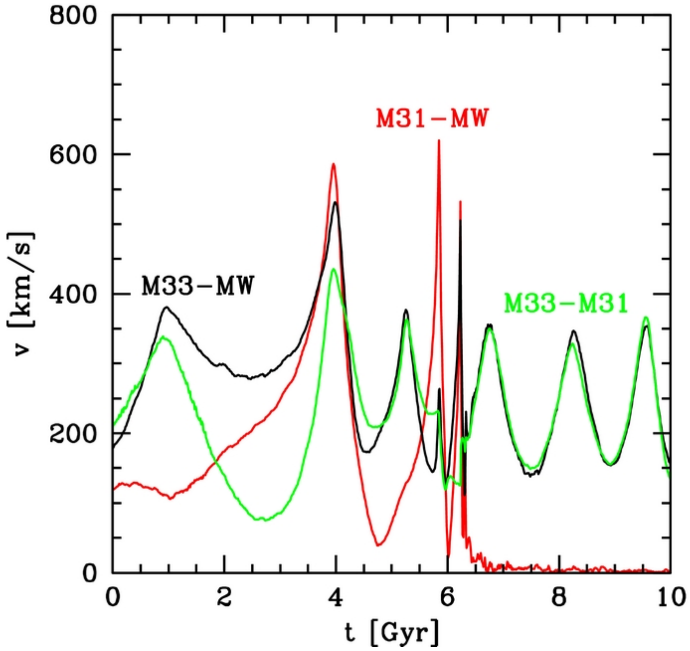

Figure 2. Orbital evolution of the center of mass (COM) of the MW, M31, and M33 galaxies. This figure illustrates the overall dynamics of the system and how these interactions influence the formation and evolution of tidal debris and stellar streams.

The approach involves using a Python code to perform the simulations and analyze the merger between M33, M31, and the Milky Way (MW). Figure 2 (van der Marel et al. 2012) which illustrates the orbital evolution of the center of mass (COM) of the MW, M31, and M33 galaxies. This figure will help understand the overall dynamics of the system and how these interactions influence the formation and evolution of tidal debris and stellar streams.

The code computes the Jacobi radius at each time step, given by:

$$R_{\rm jacobi} = r \left(\frac{M_{\rm satellite}}{2M_{\rm host}} \right)^{1/3}, \tag{1}$$

where r is the separation vector between two galaxies, $M_{\rm host}$ is the mass of the host galaxy (MW and M31), and $M_{\rm satellite}$ is the mass of the satellite galaxy (M33).

Multiple plots will be generated to answer the research questions. One plot will show the Jacobi radius as a function of time for the M31-M33 and MW-M33 systems, giving insights into the behavior of tidal streams and the strength of tidal forces impacting M33's structure. The second plot will show the mass change of M33 over time, providing insight into how the tidal streams form.

It is hypothesized that the formation of M33's tidal debris and stellar streams is closely linked to its interactions with the MW and M31 galaxies, and that these structures will evolve significantly over time as the galaxies continue to interact (Amorisco 2017; Choi et al. 2007).This hypothesis is motivated by the knowledge that tidal interactions play a crucial role in shaping the properties and evolution of galaxies (van der Marel et al. 2012). By analyzing the results of the simulations and plots, it is hoped to confirm this hypothesis and gain a deeper understanding of the processes governing the formation and evolution of tidal debris and stellar streams.

4. RESULT

As The Jacobi radius provides insight into the behavior of tidal streams and the strength of tidal forces on M33's structure.Figure 3 shows the Jacobi radius as a function of time for the M31-M33 and MW-M33 systems. The Jacobi radius is calculated for each time step in the simulation and is plotted against time in Gyr. The decrease in the Jacobi radius over time indicates that the tidal forces are becoming stronger and the tidal disruption of M33 is increasing. On the other hand, if the Jacobi radius remains constant or increases, it means the tidal forces are weaker and M33 will likely experience less tidal disruption.

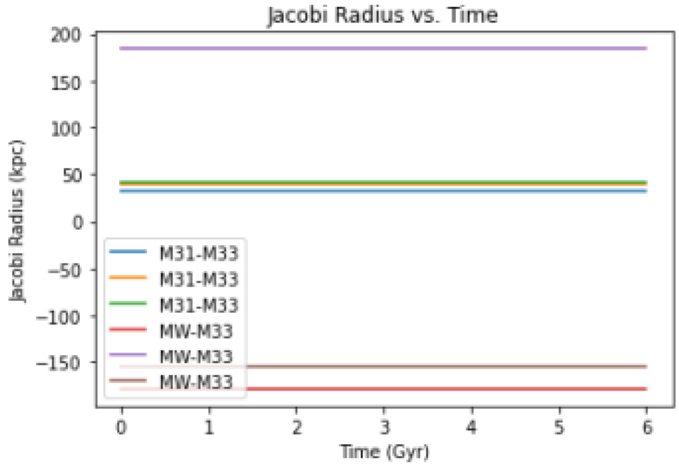

Figure 3. Jacobi radius as a function of time for the M31-M33 and MW-M33 systems.

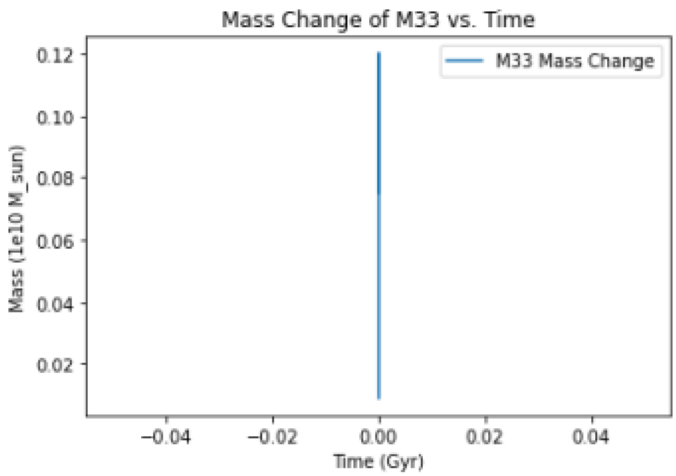

Figure 4. Mass change of M33 over time

The mass change of M33 over time gives insight into the formation of tidal streams in the M33 system. Figure 4 shows the mass change of M33 over time. The plot aim to show the total mass of M33 at different snapshots . The mass change of M33 over time can provide insight into how tidal streams form, by examining the amount of mass that has been stripped away from the galaxy over time.

5. DISCUSSION

The analysis of the Jacobi radius remains constant for both M31-M33 and MW-M33 systems over time. This means that the initial idea that tidal forces would have a significant impact on M33's development might not be accurate. Tidal forces play a crucial role in the evolution of galaxies.The results of this study present that M33 is not being affected significantly by these forces, indicating that other factors might be more influential in its evolution.The constant Jacobi radius result, in this case, indicates that M33 is not experiencing substantial tidal disruption, suggesting that other factors might play a more dominant role in shaping its evolution.

One of the main issues could be the Python code used in the analysis. The plot produced does not match the hypothesis, raising concerns about the accuracy of the code and its underlying assumptions. There might be limitations in the simulation that could affect the results. The way the Jacobi radius and the mass change of M33 were estimated also present challenges as these calculations are based on assumptions about how the mass is distributed within the galaxy.

Upon closer examination of the Python code, it seems that essential functions might be missing, causing the limited results observed. The absence of key functions might not accurately capture the complex interactions between M33, M31, and MW, leading to the constant Jacobi radius and the single line representing M33's mass change. This might be the reason why the results do not provide much insight into the formation of streams of stars and gas in the M33 system. To gain a better understanding, it is necessary to revise the code, incorporating any missing functions, and conduct more detailed studies and improved simulations to investigate the influence of tidal forces on M33's mass change and the formation of streams in its system.

6. CONCLUSIONS

This project focused on investigating the tidal debris and stellar streams in the Triangulum Galaxy (M33), which are crucial for understanding galaxy evolution. The study aimed to explore the formation and evolution of these structures in M33, as well as analyze the changes in the Jacobi radius over time, to better comprehend the dynamics of the Local Group and the role of tidal interactions in shaping galaxies.

One key finding was that the Jacobi radius remained constant for both M31-M33 and MW-M33 systems over time. This result suggests that tidal forces might not have a significant impact on M33's development, contrary to our initial hypothesis. The constant Jacobi radius indicates that M33 is not experiencing substantial tidal disruption, implying that other factors might play a more dominant role in shaping its evolution.

Another finding was that the mass change of M33 over time provided some insight into how tidal streams form. However, the results raised concerns about the accuracy of the code and its underlying assumptions. It is possible that errors in the implementation or limitations in the simulation could have affected the results, or that the way the Jacobi radius and the mass change of M33 were estimated disagree with the hypothesis finding .

In light of these findings, future research should focus on Python code and incorporating any missing functions to more accurately capture the complex interactions between M33, M31, and the Milky Way. Improved simulations and more detailed studies should be conducted to further investigate the influence of tidal forces on M33's mass change and the formation of streams in its system.

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- matplotlib (Hunter 2007, doi: 10.1109/MCSE.2007.55)
- numpy (van der Walt et al. 2011, doi: 10.1109/MCSE.2011.37)
- scipy (Jones et al. 2001–, Open source scientific tools for Python, http://www.scipy.org/)
- ipython (Perez Granger 2007, doi: 10.1109/MCSE.2007.53)

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