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Research Assignment 2

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1. INTRODUCTION

1.1. *Proposed Topic*

As M31 and the Milky Way (MW) approach and merge, the gravitational potential environment of M31's satellite galaxy M33 will change. What are the effects of this change on the internal structure of M33?

1.2. *Relevance to Galaxy Evolution*

M33 is a borderline case between dwarf and non-dwarf galaxies and can thus provide insight into both its larger and smaller cousins. Tidal forces during galactic close encounters are believed to have a major impact on the morphology of galaxies big and small, and M33 is one of the galaxies with the best-understood initial parameters in the universe.

1.3. *Current Understanding*

Elliptical galaxies are the result of repeated galactic mergers; spheroidal dwarf galaxies are believed to come from tidal interactions (Grebel et al. 2003). Taken together, these facts imply that galactic roundness is a consequence of tidal interactions. Simulations, such as the one shown in Figure 1, have shown that initially spiral dwarf galaxies can become more spherical as they continue to interact with their host galaxy (Łokas et al. 2015). Simulations of M33 in particular indicate that its current morphology has been heavily influenced by a past closer encounter with M31, indicating that M33 is likely to continue to be shaped by its larger neighbors (Semczuk et al. 2018).

1.4. *Open Questions*

The tidal evolution of M33 has been overlooked in the literature, with few attempts being made to simulate its evolution, and those that have been made focus on evolving it to its current state (Semczuk et al. 2018). Dwarf elliptical galaxies are generally associated with dense local environments, yet three mysteriously orbit Andromeda, implying that there might be something special about Andromeda to make its satellites particularly round. Given the overall lack of understanding of the Andromeda system, all aspects of the future of M33 are relatively poorly understood. Of particular interest to this paper is whether M33 will retain its current state following the merger of M31 and MW or become more spheroidal, lending credence to the dominant theory of spheroidal dwarf galaxy formation. Other questions not of relevance to this paper include the influence of tidal forces on the stellar population of M31 and the change in morphology of its small bar (Semczuk et al. 2018).

2. PROPOSAL

2.1. *Questions Addressed*

(1) How does the velocity dispersion of the stellar particles evolve? (2) What is the morphological evolution of the disk (use density contours)? (2a) Does the disk get thicker? (2b) Edge on: Does the disk become warped? (3) Is M33's disk turning into a spheroidal system? (e.g. (3a) more dispersion supported vs. rotation supported and (3b) morphologically less like a disk). (2b) is less central than the other questions. (3a) is an application of (1) and (3b) is an application of (2).

In sum, how is the disk of M33 changing with time, as revealed through its morphology and dispersion vs. rotation support, and is that change towards a more spherical galaxy?

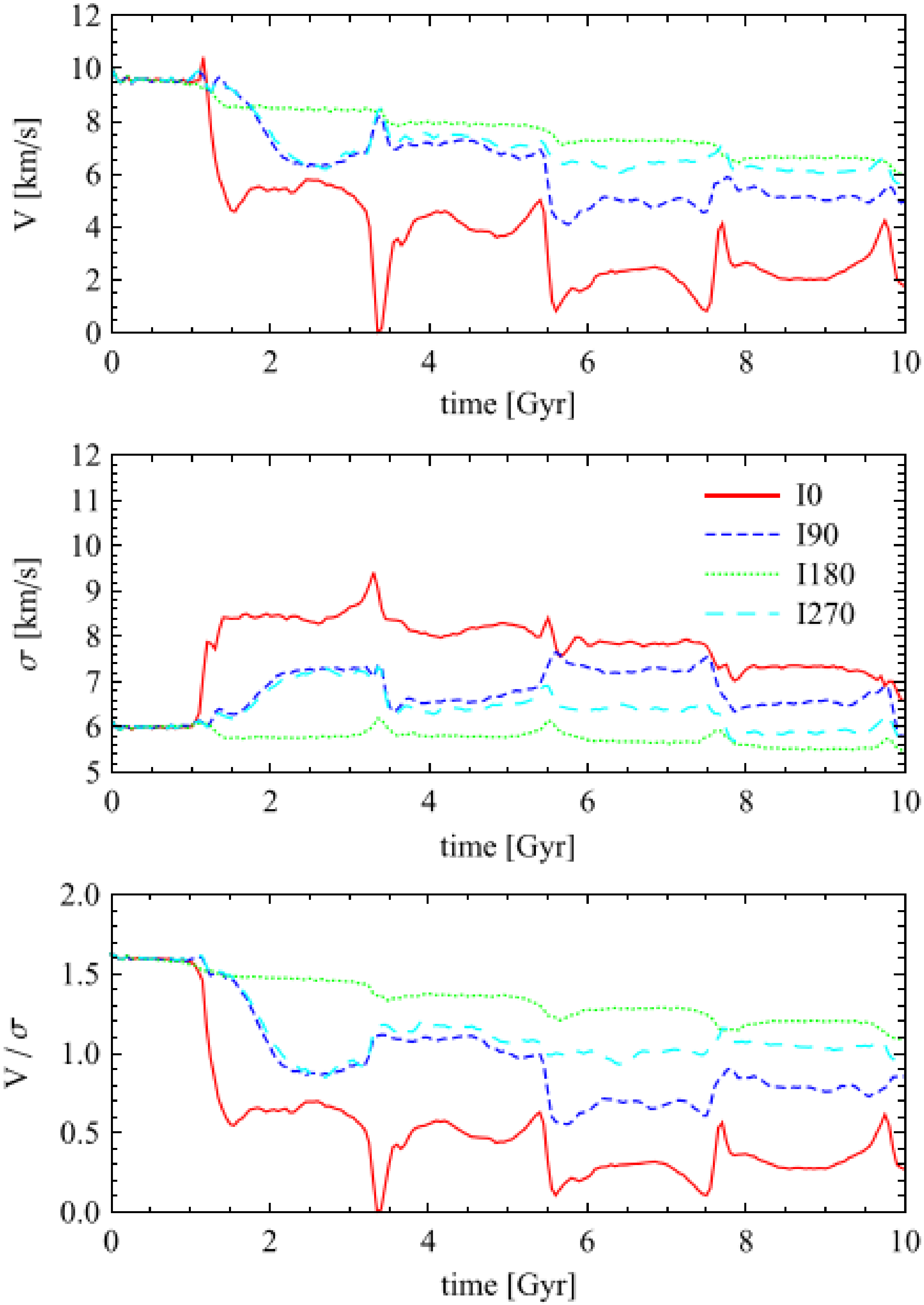

Figure 1. The simulated time evolution of the average rotational velocity, V and velocity dispersion, σ, of a dwarf galaxy interacting with a MW-like galaxy, from Łokas et al. (2015). The lines represent different initial inclinations.

2.2. *Codes Required*

Questions 1 and 3b would be solved in part by a new code that plots the kinetic energy of disk particles in various dimensions against each other to determine the spherical symmetry of M33 with time. As I am interested in the long-term secular evolution of M33 in response to its surroundings, I am interested in comparing M33 only at times when it is at the same relative position in its orbit, thus I select 1 Gyr as my timestep for this and all other plots. This has the additional benefit of reducing the number of timestamps per figure to a dozen, allowing all to be manually inspected.

If $KE_z << KE_x$, KE_y, M33 is still disk-dominated, if $KE_z \approx KE_x \approx KE_y$, M33 is becoming spheroidal. In creating this final project, I will identify a number to parameterize this balance on the galactic level. I suspect that a ratio between the sums of the individual kinetic energies of every disk particle along each component will perform well. The kinematic evolution of M33 can also be determined via the evolution of the graph from Lab 7 Part C with time. The closer the x v. v_y velocities adhere to the expected circular rotational velocity, the more rotationally supported the galaxy. The more spread the x v. v_y velocities, the more dispersion-supported the galaxy. Drawing contours on this graph would make the analysis of this increasing spheroidality more quantitative.

Questions 2 and 3a relate to the morphology of M33's disk in 2D projections, both edge- and face-on. To answer Question 2, I would simply feed the data for M33 at various times into Lab 7 Part B. (2a) is answered immediately, while (2b) requires that density contours are added to the edge-on plot as well as the face-on plot. (2bI) is a qualitative question that will require I track the deformation of M33 with time, while (2bII) can more quantitatively be answered by plotting the spacing between contours with time.

Question 3 overlaps heavily with question 2, especially (2bII). If M33's disk gets significantly thicker with time – and if the growth in thickness is greatest near the central axis of the galaxy – then it can be concluded that M33 is becoming morphologically spheroidal.

The relationship of the three codes to the central question (will M33 become more spheroidal) and its immediate implications as expressed in questions (1) and (2) are illustrated in Fig. 2.

2.3. *Hypothesis*

Dwarf spheroidals are generally located in denser environments, and the local group will become a denser environment as M31 and MW merge, thus I expect that M33, which is on the edge of being considered a dwarf, will follow this trend and become more round. Larger elliptical galaxies are generally the evolution of colliding spiral galaxies, so the evolution of M33 towards a rounder state as its surroundings become denser is expected when comparing it to its larger cousins as well.

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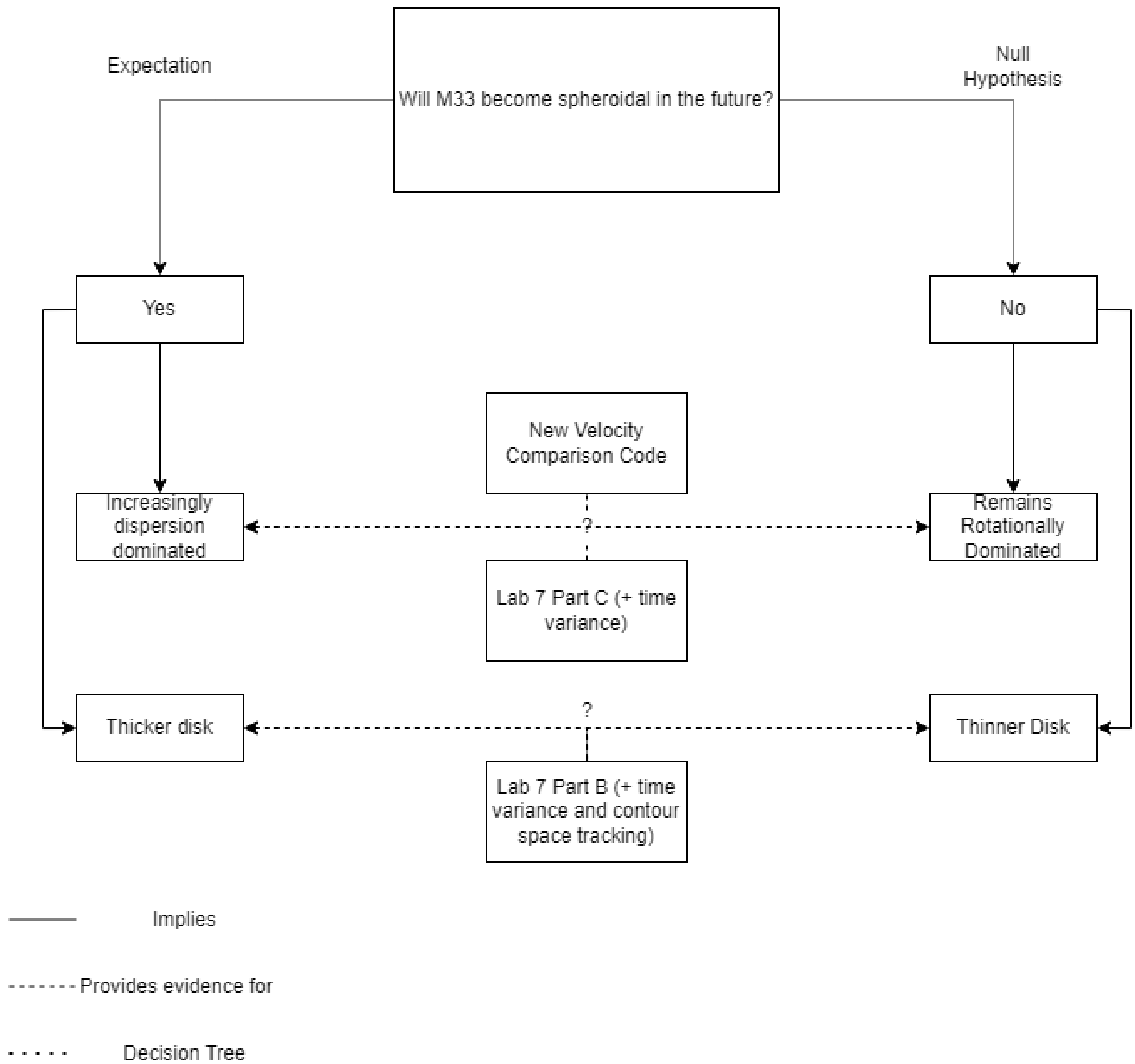

Figure 2. The relationship between the central question of this research project, the secondary questions of this rsearch project, and the codes developed in this research project.