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Tidal Transformation of M33: Evolution of the Internal Stellar Structure of M33

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1. INTRODUCTION

The Triangulum Galaxy (M33) is the third largest galaxy within the Local Group. The Local Group is the system of galaxies that include the Milky Way, Andromeda Galaxy (M31), Triangulum Galaxy (M33) and their constituents (smaller galaxies, clouds, masses that are bound to or are within the vicinity of these galaxies). M33 is a spiral galaxy that is currently gravitationally bound to the Andromeda Galaxy (M31); M33 is a satellite galaxy. These effects tidally morph (when the gravitational influence of Object 1 is enough to take mass from Object 2 with important parameters being density and radius) the shape and density of M33. By modeling the gravitational forces acting on M33 from M31 and the MW, we can examine how M33 will evolve over time.

A galaxy is a massive collection of dust, gas, and stars but are unique in that they include dark matter. Typically the galaxies have a dark matter halo, which is The evolution of a galaxy (Galaxy Evolution) is not a straight path to refer to. There are many different reasons for a galaxy to appear the way it does as these massive formations are on equally massive timescales. One common complexity is tidal transference or disruption, where the gravity of one galaxy/object affects the mass of another and can take matter from the other object and visa versa. In combination with the fact that smaller objects and galaxies can be commonly seen orbiting a larger galaxy such as our own Milky Way, we can visualize how tidal interference looks like. M33 is such a galaxy that orbits M31. Studying the tidal effects on M33 will help us better to properly visualize how smaller galaxies interact with larger ones and the morphological effects on both can help us to see what an orbital merger can look like.

A galaxy's disk (our focus) contains two parts: thin disk and thick disk. The thick disk is composed of older stars that are more spread and have lower metalicities. The thin disk makes up most of the disk's star population, and has higher metalicities and is younger that the thick disk. When introducing tidal disruption the disk will become distorted. There are two things to note: the dark matter halo and the thick disk. The thickness of the disk is somewhat affected by the gravitational pressure the halo wile put on the disk (like layers of sand). If the dark matter halo is tidally affected then the density of the disk is sure to change as well. In the same way the thick disk is less dense and is further in radius, so it will be more easily influenced by an external gravitational source.

M33's evolutionary history is not well understood. There is current speculation whether M33 had a recent close flyby with M31 (Semczuk et al. (2018)) (Sellwood et al. (2019)) which can be seen by the HI bridge between M33 and M31 (this plays a role in deciphering early M33 star formation)(Chang et al. (2019)). In Semczuk et al. (2018) there is discussion of M33's distorted disk and the probable causes of such an abnormality; the structure (such as the spiral arms and tidal bridge) was previously favored to be due to "primordial" attributes (not because of M31). The study sought to reproduce these abnormalities with a simulation but instead of M33 in a close encounter. Their conclusion was that it is possible that warps can exist from such encounters.

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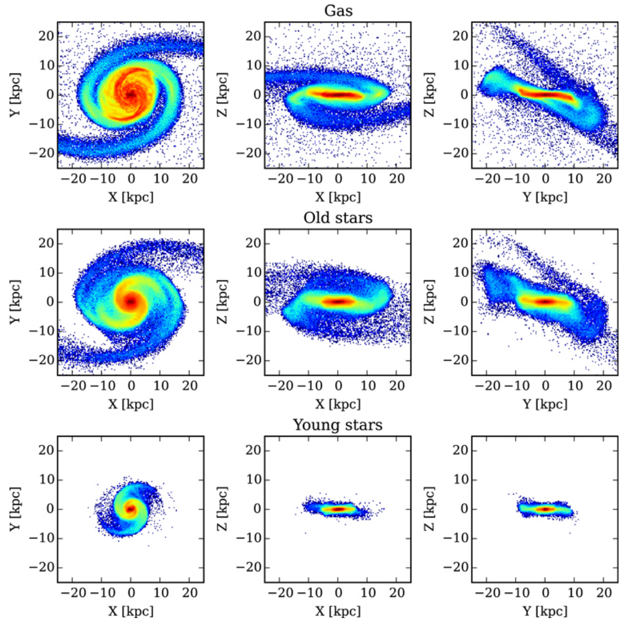

Figure 1. (Semczuk et al. (2018)) Surface density distributions seen from three different directions for the gas and —the old and young stellar particles for the simulated M33 at the time of the best match.

Galaxy evolution is tough to navigate due to a few factors. One such factor is because of perspective (which we have the luxury of due to simulation data rather than observational) the shape of a galaxy can change with the inclination. An elliptical galaxy could very well be a spiral galaxy, but is viewed more edge on, therefore muddying the view of the spirals. Also, time is not a helpful factor as the timescale of these massive objects are also large, so relative velocities must be observed, simulated, and hopefully we have matching data.

Another factor is that again the timescale is very large, so any number of things could of happened to these objects way before our existence to make them the way they are. It is assumed to be a very common thing for galaxies to be disrupted, have flybys, collide, and even merge. The best we can do is look for clues and hints that can narrow down some possibilities, but again some of those are just speculation. Luckily however, it is a very obvious thing to see that M33 can be and is being tidally affected by M31.

Again, M33 has been simulated to reproduce its distortions (Semczuk et al. (2018)) so we can reasonably assume that future close encounters will produce more distortions. With simulation data we can model how future flybys will look.

2. THIS PROJECT

In this paper we will be analyzing the Morphology of M33's disk as it orbits M31, and as M31 merges with the Milky Way. This can be observed visually by looking at the density map of M33's disk at different snapshots. Contours can be used as a visual aid to see the density change as well. As mentioned, before we have the luxury of being able to see M33 at any angle we choose, so we will be able to properly see M33 edge-on (perpendicular to the angular/orbital axis) and face-on (Parallel to the angular/orbital axis). This is useful to see the shape and thickness of M33.

In order to attempt to make some sort of guess as to what happened previously in M33's past, we have to look at what will happen to M33 now. We will not be focusing on clues or hints as to what made M33 what it is today. We will be focusing on what M33's future will be. We believe that this will be useful information as the simulations we use will address close encounters, tidal disruption, and mass loss.

We can find clues in other observed galaxies (including our own Milky Way) of mergers but cannot provide solid evidence. Our situation with M33 is flipped around. We do not know exactly what will happen, but we can make helpful simulations to visualize what a merger looks like with real observable galaxies. The Milky Way and M31 are already set to collide, but M33 is a slower process. We will be able to see how exactly tidal disruption effects the properties of a galaxy. We are looking at shape in particular to help our understanding of galactic morphological evolution. We look at the thickness of the disk because of its implications of the entire galaxy (other mass). The thickness of a galaxy's disk can be correlated to the pressure and density of all of the galaxy's mass; the dark matter

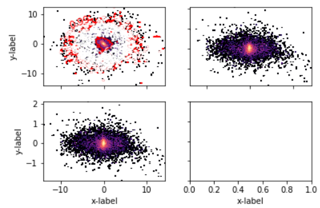

Figure 2. An example plot created from our code. These are the disk's density maps of M33 at snapshot 0 (today) with it being face-on (top left) and edge-on (bottom left and top right). The face-on plot will have contours to see the spread of mass.

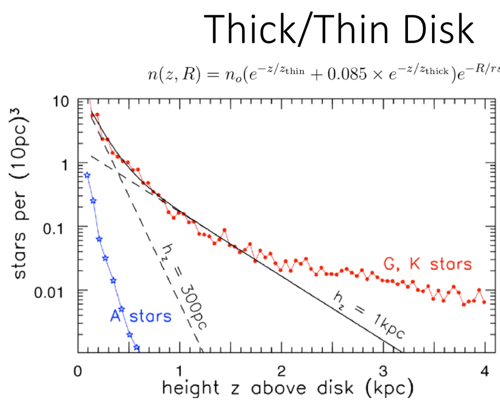

Figure 3. Picture taken from Lecture 2. From Sparke & Gallagher (2006) a plot made by Reid, Knude for a fit of the thin and thick disk approximation of the Milky way. Looking toward the south Galactic pole, filled circles show the density of stars with 5 ¡ Mv¡ 6; these are late G and early K dwarfs. Sloping dashed lines show n(z) exp(-z / 300 pc) (thin disk) And n(z) exp(-z/1 kpc) (thick disk); the solid curve is their sum. At z ¿ 2 kpc, most stars belong to the metal poor halo. A dwarfs (star symbols) lie in a very thin layer.

halo exudes a sort of gravitational pressure to "squeeze" the disk. If we see a change in the thickness, we can directly see the tidal effects of another object's gravity on the density of the galaxy and possibly assume the tidal effects of the dark matter halo.

3. METHODOLOGY

We will be using an N-body simulation from van der Marel et al. (2012) that provides information for the disk, bulge, and dark matter halo of M33, M31 and the Milky Way. An N-body simulation is a dynamic simulation of a set of particles that can be assigned to real physical objects that are affected by physical forces (ie gravity). For example, a star such as the Sun can be set as a single particle with assigned corresponding physical characteristics. Particles are not assigned to individual particulates of a complex body such as a gas. The gas itself would consider one body and therefore one particle. In the simulation we use the Milky Way, M31, and M33 are modeled with three sets of particles: Disk, Bulge and Dark Matter Halo particles. These galaxies are modeled with mass, position and velocity which change over the course of the simulation. The Simulation goes for 800 snapshots, from today to 10 Myr from today.

What we will do is to focus in on the disk particles of M33. We will be looking at the disk's density map from different axes for important snapshots: closest and furthest approaches. Our figures would look like Figure 2. We can do other snapshots in between but those are the main ones. From there we can make contours and see visually the changes over time. We can also try to find the average disk thickness over time through contours looking edge-on and try to plot a thickness vs time plot and compare it with the position of M33's center of mass with respect to M31. If there is enough time, we can make a movie from Figure 2 from each snapshot to help visually see what is happening. Alternatively, to finding the contour and using the contour to find a height, we can use a fit like Figure 3 to find the thin and thick disk approximation (Sparke & Gallagher (2006)). In the expression z is the height above the disk, adjustable zthin and zthick are scale heights, R is the radius, and rs is the scale radius.

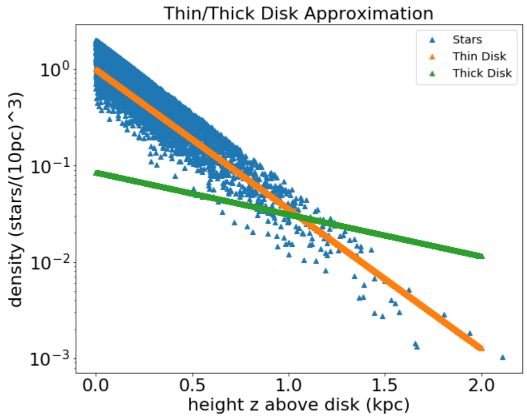

Figure 4. This is our attempt to replicate the picture (Figure 3) taken from Lecture 2 from Sparke & Gallagher (2006) a plot made by Reid, Knude. It seems there is some similarities but there some overflow due to lack of limitations. ALL data is presented here as opposed to the other plot where specific stellar classification types are used.

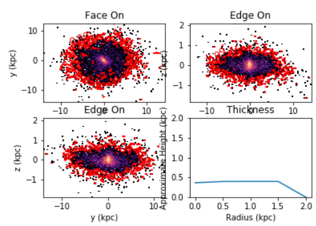

Figure 5. This plot visualizes the disk with face on (top left) and edge on (bottom left and top right). The contours in red on the three visual plots represent the 3 sigma lines for the mass density of the particles according to the perspectives. Using the idea of 3 sigma lines, the average height as a function of radius was used to visualize the disk's thickness in that snapshot. This is for snapshot 000.

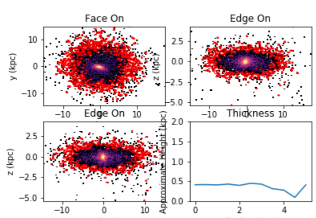

Figure 6. This is for snapshot 209. The disk seems to squish, but really if we note the height plots on Figures 5-7 we can see that its stretching in the radial direction rather than up or down.

Since M33 will be tidally disrupted by M31 and eventually the Milky Way, matter from M33 will be transferred to the other galaxies. Due to this the mass and density of M33 will change; the dark matter will be the first to be transferred. As a result, the disk will become thicker as the gravitational pressure of the halo is what makes the disk thinner. M33 will also have flyby's, so the disk itself will be heavily morphed but not yet transferred.

4. RESULTS

—————DISCLAIMER——————— For Assignment 6 The following will be over what is currently had as that is as much as I can actually discuss. I will be mentioning what could be better and what is planned to be shown in the final. This discussion will be the barebones for the final paper and as a result is being used in this assignment. Thank you

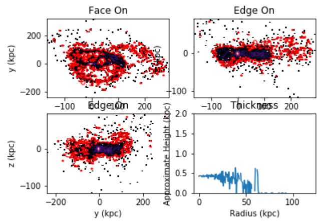

Figure 7. This is for snapshot 799. Note the drastic increase from Figure 5 6's radii. The scale here is much larger, but it seems the height plot stays steady at 0.5 kpc.

The attempt on reproducing Figure 3 and its basic concepts were unfortunately a failure (Figure 4). The issue came with the units and therefore a lack of information on our side. The units called for "stars" but unfortunately the N-Body simulation disk particles we used for our analysis were ambiguous clumps of mass rather than specified stars with classifications and such. From Figure 3 we can see that they are able to pinpoint the metallicities and comment on the ace of the populations, and therefore able to approximate scale lengths according to those populations. We did not have such luck; the disk particles were all the same in mass but different in location. As a result there was a flood of data points with a simple trend. Nothing about the plot seems to follow the logic of Figure 3.

We did, however manage to visualize the transformation of M33 over each snapshot. Figures 5-7. There is a single contour shown on the plots to visualize where most of the mass is (which is trivial) but is mostly used to help visualize the are which our disk height approximation (bottom right plot) uses. The way this was made was by calculation the standard deviation of the heights of the particles as a function of radius (in small bin intervals). The only issue we have at the moment is changing the limits to accommodate the radical morphing we can see on the disk length and height (the radius goes from 10kpc to 200kpc). The important snapshots can be shown (closest approach and furthest orbit). We just have to find the snapshots for those importance occurences. Also, a proper gif will be linked here for the entire animation of all snapshots with these plots: [insert link here]

5. DISCUSSION

The hypothesis of the disk thickness increasing is both true and false. It is false because the average height stays around 0.5 kpc consistently. The hypothesis is true because the mass spreads over a further radius, and that thickness increases till it is about par with the 0.5 kpc at the shorter radii. The thing that was criminally underestimated was the effect of tidal disruption. It looks like the effect was so large (due to the many very close calls that M33 has) that instead of becoming thicker, instead the disk became larger (though very distorted): from 10kpc to 200kpc! Though the idea of the reduction in density affecting the dimensions of the disk was sound, the idea of the disk increasing in radius was not considered. Further analysis on the morphology of the radius of the disk (and all of its aberrations) would be an interesting path to look forward to, particularly in terms of tidal effects on the development and morphology of spiral galaxies. These close approaches (and possible previous ones) can tell us a lot on how the bars, arms, and old/young populations settle on a galaxy.

Though the discussion on morphology may have been piqued, the analysis on metallicities was unsuccessful. It would have been intriguing to know the approximations of thick disk vs thin disk dimensions over time. Unfortunately this requires different information from the particles we use. It would be very useful to at least know the classifications of the stars in M33 and use those in another simulation (but that would be a VERY tedious task). It would at least be nice to have an idea as to where the older and younger star lie now in order to maybe incorporate them into this simulation and see the results (this may very well be a naive thought as the task may not be as easy as just adding that information on a few small particles).

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