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

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ABSTRACT

The Triangulum Galaxy (Messier 33) is bound to the Andromeda Galaxy (Messier 31) and is being tidally affected in its orbit. Not much is known about the developmental effects of tidal disruption on smaller satellite galaxies. This paper explores the tidal effects on the thickness and morphology of the disk of M33. The thickness of the disk tells much about the distribution of mass among the disk of the galaxy and other parts of the galaxy as well as how external gravitational effects change such distributions. What has been found is that the disk indeed gets thicker and does so as a result of a close approach from its massive object of interest. The morphology also is visible distinct with aberration due to the same approaches and at a greater scale for each approach after. This would mean that the prediction of M33 having a close approach in the past might be hard to analyze as it will be a lot more subtle.

Keywords: Satellite Galaxy, Galaxy Interaction, Morphology, Local Group, Tidal Transfer, Dark Matter Halo

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 vice 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 metallicities. The thin disk makes up most of the disk's star population and has higher metallicities 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

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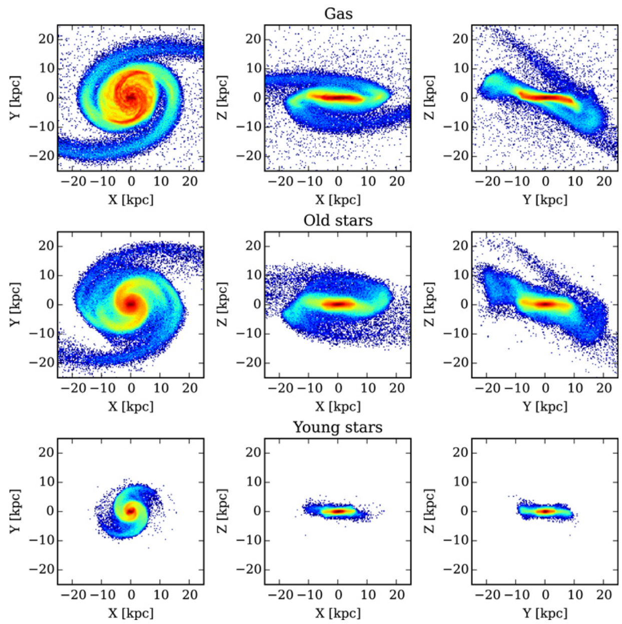

Figure 1. (Semczuk et al. (2018)) Surface density distributions seen from three different directions for the gas and —the old and young stellar particles for the simulated M33 at the time of the best match.

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.

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 have 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 an 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 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 the galaxy's mass; the dark matter 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.

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

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. The bottom right plot shows the average height of the particles within a standard deviation, so that we monitor the inner workings of the disk. This is important because we can see in the Figures 5-7 that the disk warps drastically, meaning the inner parts of the disk are more interesting to look at. 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), and the heights of the stars under a standard deviation are averaged.

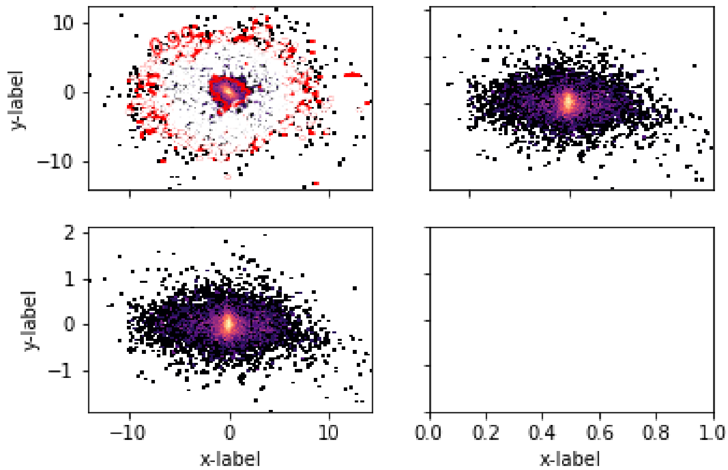

Figure 2. An example plot created from our code. These are the disk's density maps of M33 at snapshot 0 (today) with it being face-on (top left) and edge-on (bottom left and top right). The face-on plot will have contours to see the spread of mass.

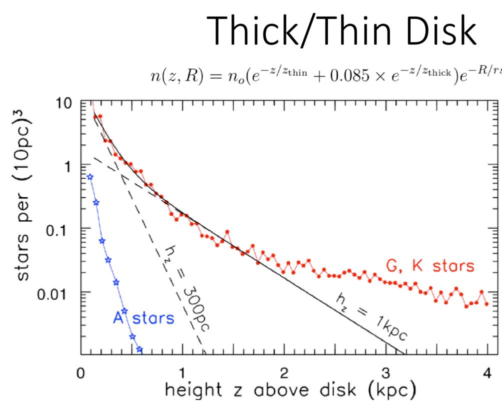

Figure 3. Picture taken from Lecture 2. From Sparke & Gallagher (2006) a plot made by Reid, Knude for a fit of the thin and thick disk approximation of the Milky way. Looking toward the south Galactic pole, filled circles show the density of stars with 5 ¡ Mv¡ 6; these are late G and early K dwarfs. 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.

The important snapshots can be shown (closest approach and furthest orbit). There is a total of 801 snapshots that go from now to about 12 Myr from now. A few snapshots can be seen above at certain events (such as close approach, furthest approach). The full animation can be seen at:

"https://github.com/barraganma/400B Barragan/blob/master/ResearchAssignment/M33Animation.gif"

Looking at Figures 8 and 9 we can see that at around the merger event (6 Myr) that the thickness spikes dramatically. A closer look and we can see two major events on our height plot: a small increase between 0 Myr and 2 Myr and a spike around 6 Myr. Both correspond to the first two close approaches seen on Figure 9 at the same time. Though a bit sporadic we can also note that there is a steady decline. It is not as clear as to whether the close approaches after 6 Myr have the same effect. Instead we can see a steady decline, and a few major dips.

5. DISCUSSION

The hypothesis of the disk thickness increasing is true, as we can see in Figure 8 that the furthest ones have y-axis (height) values that increase. It looks like the closer approaches (or at least the first two) had the greatest effects on M33's disk thickness. This is intriguing when considering that M33 has been predicted to have had another close approach in the past.

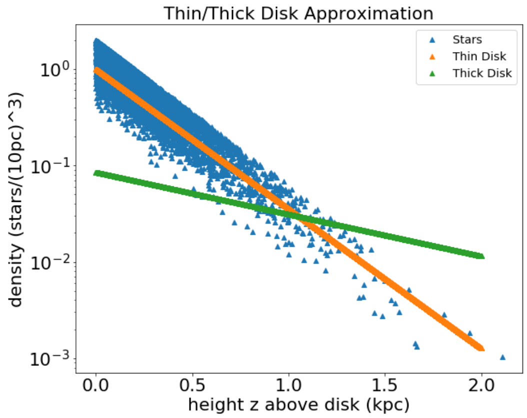

Figure 4. This is our attempt to replicate the picture (Figure 3) taken from Lecture 2 from Sparke & Gallagher (2006) a plot made by Reid, Knude. It seems there is some similarities but there some overflow due to lack of limitations. ALL data is presented here as opposed to the other plot where specific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

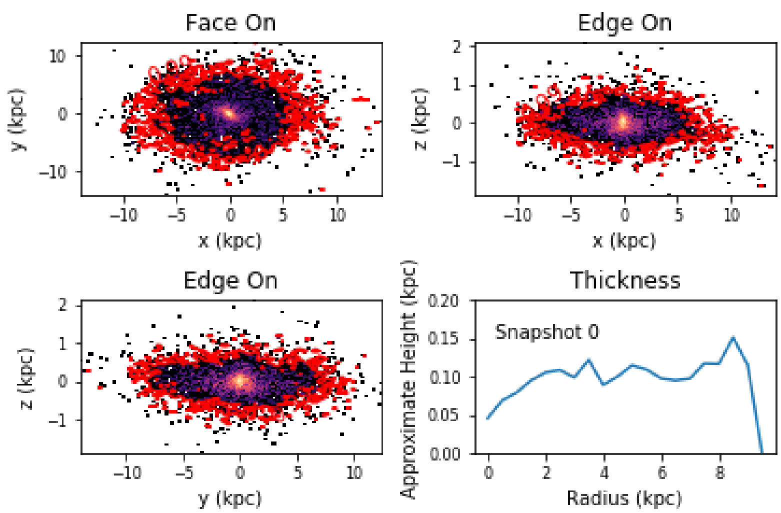

Figure 5. This is for snapshot 000 which represents current time. This plot visualizes the disk with face on (top left) and edge on (bottom left and top right). The contours in red on the three visual plots represent the 3 sigma lines for the mass density of the particles according to the perspectives. The bottom right shows a plot of the average height within one standard deviation all within a radius of 10 kpc in order to capture what is happening in the inner disk. This all might be due to the use of low resolution data (which is an issue on our side).

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 the disk became much larger than thicker (though it did indeed become thicker): 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 fully considered. Further analysis on the morphology of the radius of the disk (and all 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

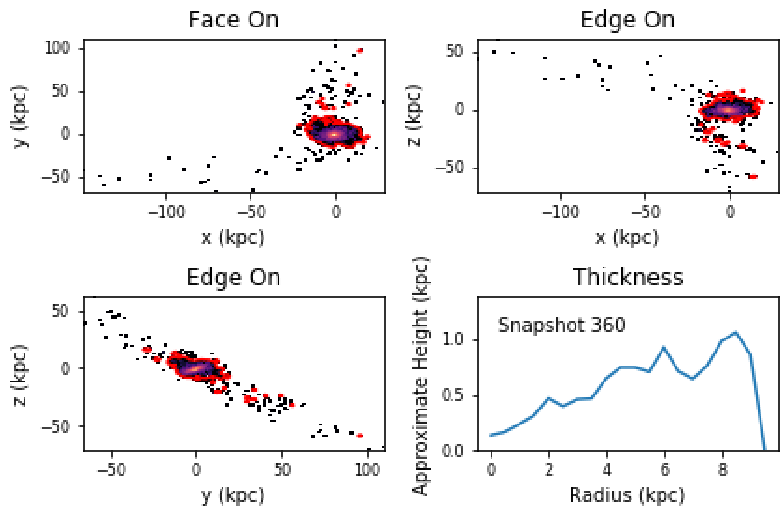

Figure 6. This is for snapshot 360 which is about more than 4 Myr from today. This snapshot is significant because it is around the second close approach since today (snap 000). This is around the spike in a plot seen below. Notice the increase in the height axis: from 0.1 to 0.5 kpc. The disk is getting thicker.

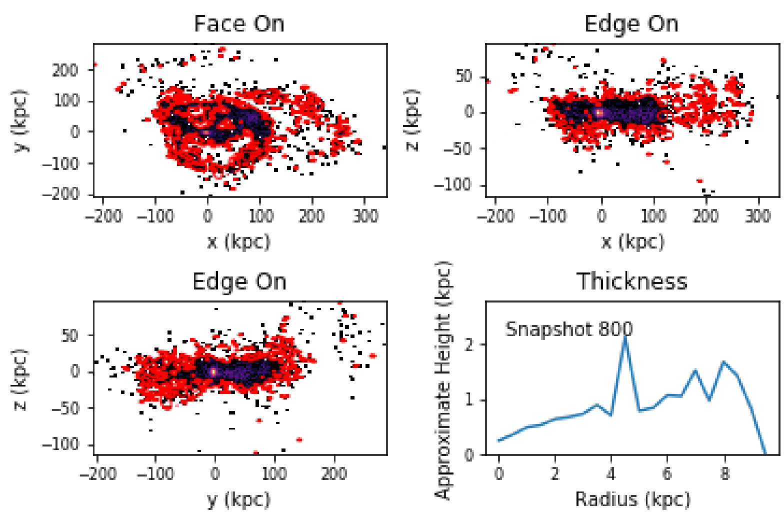

Figure 7. This is for snapshot 800 which is around 12 Myr from today. Note the drastic increase from Figure 5 6's radii. The scale here is much larger meaning that the disk is stretched quite a bit.

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). Though we can make some conclusions with our data now.

6. CONCLUSION

The tidal effects of the Milky Way and M31 effect the morphology of the M33 galaxy as M33 orbits M31. As M33 is a satellite galaxy, not a lot is well understood about its morphological evolution. Observing M33's motion and simulating its future positions can show us how satellites such as M33 develop over time under the effects of tidal disruption.

We found that on the seemingly unperturbed M33, upon close approach to M31 the disk of M33 became thicker. It even spiked as a result of the second approach. Indeed, as the satellite approaches M31 the gravitational effects become stronger and mass is pulled as a result. This allows the mass distribution of M33's disk to become less coherent. Whatever mass is not transferred is not in constant motion due to the well of M33 trying to pull it back, thus giving

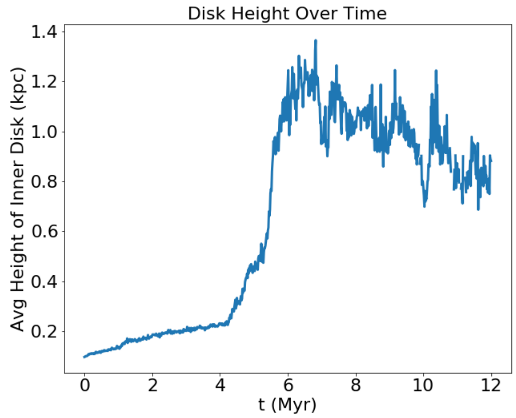

Figure 8. This plot shows the average value of the bottom right "height" values as a function of time/snapshot. We can see that the disk indeed thickens over time, but at around 6 Myr the height spikes with a steady decrease over time.

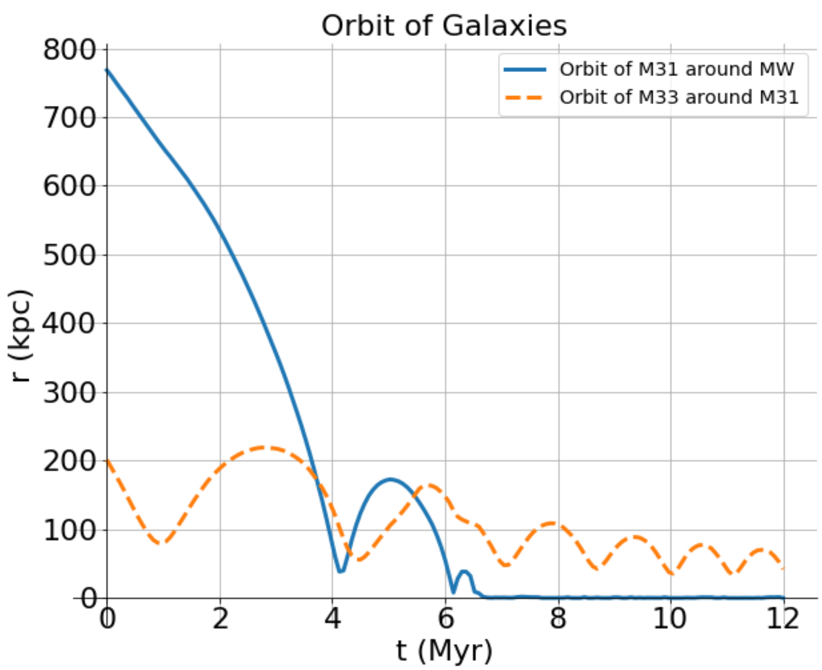

Figure 9. This plot uses the N-Body data to plot the position of M33's center of mass with respect to M31 (orange) and M31's center of mas position with respect to MW. We can see the significant event where M31 merges with MW around 6 Myr where both orbits have some "blip" in their oscillations.

the mass much more momentum. The disk became less dense as the thickness grew and the radius expanded. The close approaches contribute a lot of energy to the satellite galaxy and just like the electron of an atom, the position and kinematics of the mass change accordingly.

Two things can be done to further contribute to this discussion: an actual density analysis and a metallicity/spectral analysis. The latter can be helped if we used the high-resolution data and could assume limits of the mass of the disk particles to be able to classify them. This might not be very accurate, but we will be able to see what happens to the old (lower mass) and new (higher mass) stars on top of our code and results here. The former can easily be done by doing what we did for the height, but account for the volume. As a substitute, we could user the high-resolution data and take a count of particles within a volume at different heights so we would be able to see not just the density as a function of radius but a function of height.

7. ACKNOWLEDGEMENTS

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Astropy (Astropy Collaboration et al. 2013; Price-Whelan et al. 2018 doi: 10.3847/15383881/aabc4f)

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

FFmpeg Bellard, FFmpeg Team (2000), Open source. https://git.ffmpeg.org/ffmpeg.git

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