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Stellar Disk Remnant Distribution in the Milky Way M31 Merger Event

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1. INTRODUCTION

Over long enough periods of time, galaxies that are gravitationally bound will eventually merge, this is known as a galactic merger. A galactic merger is defined as the merging of two or more galaxies. This can occur with multiple parameters and classifications, but for the sake of this project we will only be looking at a major, dry merger. When the merging galaxies are roughly the same mass, the merger is considered to be a major merger. A merger is described as dry if there is a low amount of gas within each of the merging galaxies. Each of the merging galaxies is made up of multiple regions; the stellar bulge, the stellar disk, and the dark matter halo. For the sake of studying the stellar remnant of a merger we will be looking at just the bulge and disk matter. The stellar bulge refers to the area of a galaxy that is concentrated in the center of the galaxy. The stellar disk refers to stars that orbit along the axis of rotation. The bulge of a galaxy will be have a much higher surface area to brightness ratio, since the stars in the bulge are much more tightly packed. A galactic merger that is of great interest to us is the future merger of the Milky Way (MW) and the Andromeda (M31) galaxies. This merger is considered to be a major merger with the galaxies having roughly the same masses, $M_{MW} = 1x10^{12}M_{\odot}$ and $M_{M31} = 1.6x10^{12}M_{\odot}$ (van der Marel et al. 2012). One aspect of this merger is the stellar distribution and dynamics of the galaxies as they merge, and those of the new merged galaxy. It is possible to describe the distribution of the stellar material of a galaxy with a Sersic profile. A Sersic profile models the distribution of stars by relating the distance from the center to the intensity of the light. In order to study the dynamics of the merging galaxies, it could be useful to keep track of the number of stars that are ejected from their host galaxy. This will occur when the velocity of the star has exceeded the escape velocity for the host galaxy.

In order to talk about galaxies merging, we must first define what is meant by the term galaxy. A galaxy is a gravitationally bound set of stars whose properties cannot be explained by a combination of baryons and Newton's Laws of gravity(Willman, Strader 2012). According to this definition if the dynamics of a collection of stars can be explained from just directly observable mass and Newton's Laws, then it would not be considered a galaxy. In order for a cluster of stars to be considered a galaxy, there must be something else influencing the properties of the stars. This something else is known as Dark Matter. While we do not yet know what Dark Matter is, we do know that is essential in describing the properties we see when observing galaxies. Galaxies themselves are not static objects, but also evolve through internal and external interaction. The term galactic evolution refers to the total combined effect of internal and external factors on the galaxy. This can take the form of the Super Massive Black Hole at the center causing an outflow that removes gas from otherwise star forming regions, to the gravitational stripping of stars through interactions with another galaxy. It is important to study how the distribution of the stars is effected by the merger since it might give us a better understanding of how larger galaxies may have come to be. If we can study the dynamics of star distributions found within galaxies, we may be able to determine whether or not that galaxy was the product of a merger. By studying the stars that are ejected from a galaxy during a merger, it may be possible to determine the fates of individual stars, such as the fate of the Sun during the M31/MW merger.

Based on our current understanding of the remnants of galactic mergers, it is possible that S0, lenticular, galaxies may be the result of galactic mergers. When undergoing a major merger, it is not likely that any of the properties of the stars will be preserved directly, but may be recreated in the new merged galaxy. The simulated data for the distribution of disk-bulge material is consistent with that observed in actual S0 galaxies (Querejeta et al. 2015).

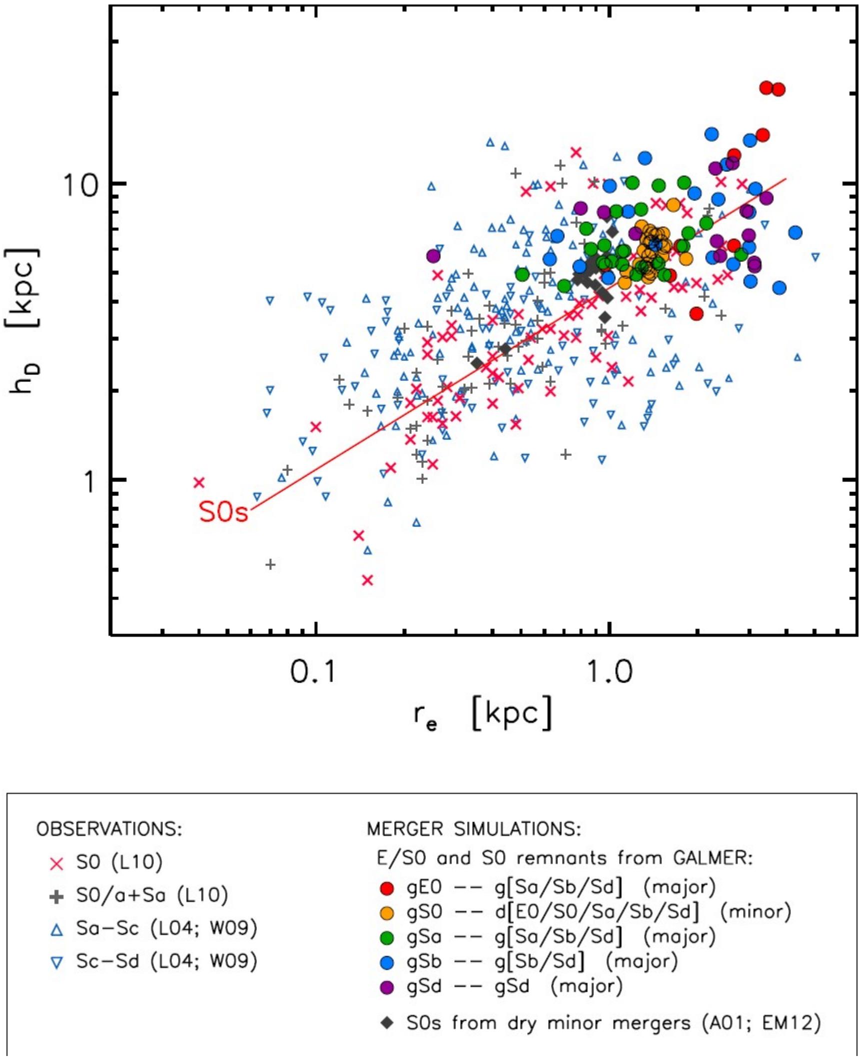

Figure 1. Distribution of the remnants from both simulated and observational data. Observational data was collected for S0 and S0-like galaxies. The red line is a linear fit to the observational data. The data is plotted in the $log(h_d) - log(r_e)$ plane, where h_d is the disk scale length, r_e is the effective radius. The plot contains both minor and major dry mergers.

One of the open questions in the study of galactic merger remnants, is what is the range of remnant dynamics and orbital structures are permitted by the merger process? (Barnes, Hernquist 1992) This question is about what the possible distribution of stellar matter might be after a merger, and also what are the possible kinematics of the remnant stellar material.

2. MW-M31 MERGER STELLAR REMNANT

In this paper we will study the distribution and dynamics of the stellar remnant of the MW-M31 merger event. This will be done by examining the Sersic profile for the stellar material, disk+bulge, for both M31 and MW separately. At each time snapshot, I will be looking for what percentage of stars will be ejected from their host galaxy.

I look to answer the question concerning the distribution and dynamics of the stellar remnant. By studying the Sersic profile, I hope to be able to determine if there are limitations to where the stars from the disk and the bulge are able to be found. I hope to be able to determine a range for the velocities of bound stars within the new merged galaxy.

This in an important question to solve in the study of galactic evolution since, it can give us some useful insight into the possible origins of some of the galaxies we see. We still do not have a complete understanding of the origins of some of the largest galaxies. If we can determine that the kinematics and distribution of the stars within them, we may be able to use models and simulations similar to this one in order to generate a model that could produce a history for any galaxy.

3. METHODOLOGY

The simulation we are using is presented in van der Marel et al. 2012, and uses an N-Body model to simulate the merger. This simulation assumes collisionless particles. It deals with the evolution of not just M31 and MW but also the smaller satellite to M31, M33. An N-body simulation is done when the number of particles in a system exceeds what is reasonable to do by hand. This is done by calculating some interaction between each particle individually. In this simulation the only force considered is gravity, since the particles are considered collisionless. These N-body simulations used both the stellar mass and the dark matter mass.

In order to model the Sersic profile for I will be modifying Lab 6 in order to calculate the profile for both the disk mass and the bulge mass. In order to get the time evolution nature of the simulation, I am fitting a model for the bulge and stellar masses separately at only specific time snapshots. The snapshots have been chosen to show times before, during, and after the merger. The chosen snapshots represent the present day, 4Gyr, 6Gyr, and 11.4429Gyr in the future. The bulge and stellar disk stars will have different Sersic profiles, and therefore must be calculated separately.

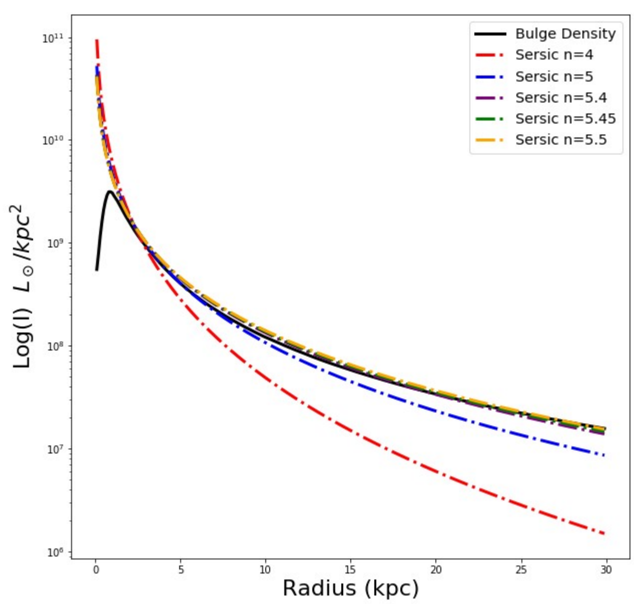

Figure 2. This is a Sersic profile for the bulge particles calculated using the foundation for the code. Using this I will decide on which Sersic index is most appropriate to use.

The Sersic profile is the most important equation in this paper, as it relates the intensity to the radius. The profile for the bulge is calculated using;

$$I = I_e exp^{(-7.67((r/R_e)^{1/n}-1)}$$

Where I is the intensity of the light for a given radius, L is the luminosity, and D is the radius from the center. This is a special case of the Sersic profile in that we are assuming a mass to light ratio of one, that is $\frac{M}{L}$, this lets us calculate using the luminosity, which is useful since we can get the half-mass radius, or the radius at which the mass has decreased by 0.5. This is calculated by setting boundary conditions for the mass, as $Low = \frac{TotalMass}{2}$ and $High = Low + 0.01Low$. Indices are then set by looking for the range of mass values so that either Mass > Low or Mass < High. A different form of the profile must be used when calculating the distribution of the stellar disk.

$$I = I_e exp^{(-7.67((r/R_e)^{1/n})}$$

The plots I plan to produce will show the Sersic profile for both of the galaxies at each time evolution snapshot. This will be done in four separate plots to show how the different components change over time.

I predict that the distribution of stars from each galaxy will be roughly similar in the remnant. This is due to the fact that during a major merger the disk and bulge components are not preserved. If this is the case, then we would expect to see a mixing of the material. If the simulation was to run for a longer time span, then it might be possible that the distributions could return to pre-merger conditions.

4. RESULTS

The surface density profile for the different components of each galaxy, show a decrease with increasing distance. Figure 3 shows how the surface brightness profile for the bulge material in M31 falls off as the distance from the center increases. Peaking near the center, the density drops by a factor of approximately a hundred by the edge of the galaxy, from a peak of roughly $10^{8.3}$ to a minimum of roughly $10^{7.3}$. We can see that the distribution of stars is not consistent throughout the evolution of the galaxy. This is most likely the result of the growing impact that the Milky Way will have as the two galaxies merge. Looking at the orange line, representing the present day, and comparing it to a time roughly around the first encounter, we can see that the two profiles are nearly identical. It is only when looking farther into the future do we see any real impact. The green line, representing the second encounter at roughly 6Gyr, shows a drastic shift in the surface brightness profile. This is most likely due to the massive disturbance that would have occurred as the two galaxies passed through each other. The stars in the bulge have become more diffuse with a peak nearly twice as far from the center as the present day. By looking at a time after the merger has completed, the red line representing this period at 11.4429Gyr, we can see that the bulge stars have resettled near the center, but with an overall lower density.

Figure 4 shows the evolution of the stellar disk of the Milky Way before, during and after the merger with M31. If we compare this to the brightness profile for the bulge of M31, we can see that the overall density is much lower. This matches our expectations, as the center of a galaxy is far more compact than the stellar disk. We can also see that, while the density is lower overall, it falls off at a much slow pace, dropping by less than a factor of 10. A similar pattern as in Figure 3 appears in the brightness profile for the stellar disk. We see that not much changes when looking at the profile for the present day and around the time of the first encounter. Although there is a more noticeable impact of M31. The density actually increases towards the center and drops more quickly in order to match that of the present day by roughly 10kpc. The brightness profile at 6Gyr has some interesting properties. The profile peaks farther away from the center, as with the bulge of M31, but it does not have a continuous drop with distance. There is a rise at roughly 17kpc. The profile after the merger shows that, like the bulge stars of M31, the stellar disk of the Milky Way, also seems to settle back into a distribution closer to that of the present day. Both of these plots show that while the merger event may disrupt the distribution of stars within the two galaxies, in the end they will settle into distributions that are close to their current distributions.

Figure 5 and Figure 6 show the stellar disk and the bulge surface brightness profiles for M31 and the Milky Way, respectively. They follow the same patterns as we can see in Figure 3 and Figure 4. All plots show a large disturbance in the profile at some time around 6Gyr. This is most likely due to the impact that each galaxy would have on the other as they merge, since 6Gyr is roughly the time of the second encounter. All of the plots also show the same settling down of the profiles after the merger.

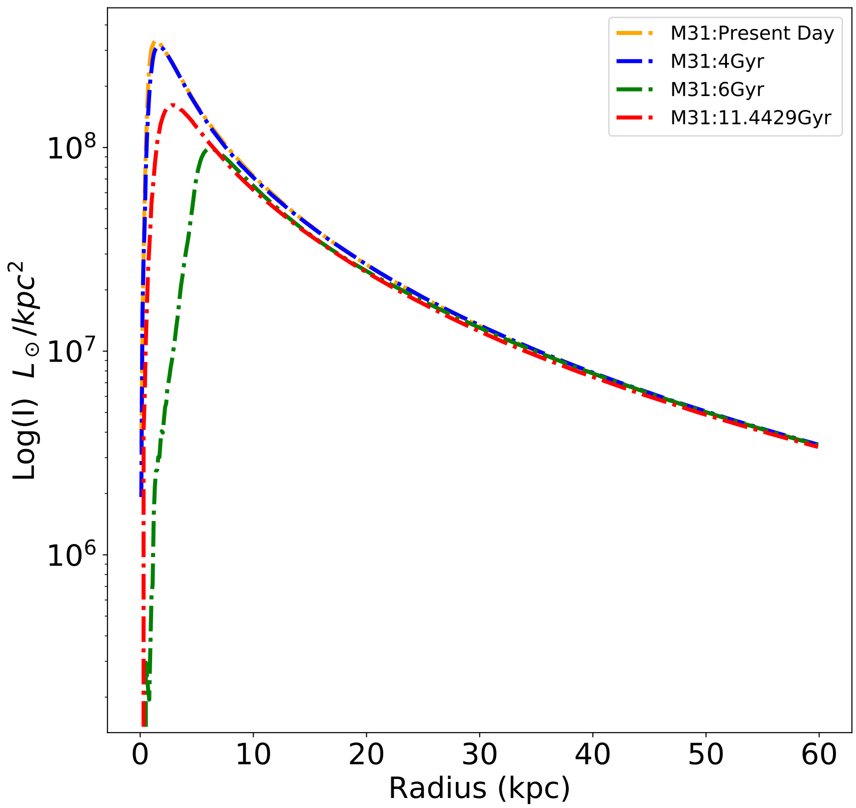

Figure 3. Density profile for the bulge stellar material in M31. The horizontal axis shows the radius from the center of the galaxy in units of kilo-parsecs (kpc). The vertical axis shows the log of the surface brightness in units of solar luminosities per square kilo-parsec. The different lines represent different time periods, with the earliest representing the present day, and the latest 11.4429Gyr into the future.

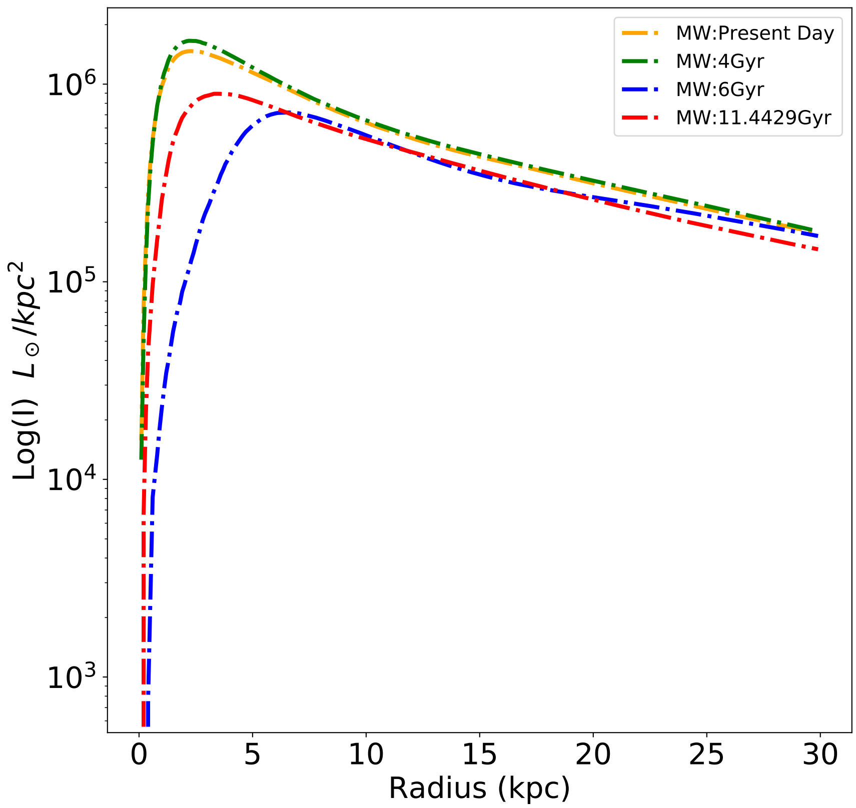

Figure 4. Density profile for the stellar disk in the Milky Way. As with Figure 3, the horizontal axis shows the radius from the center of the galaxy in units of kilo-parsecs (kpc). The vertical axis, again, shows the surface brightness of the stellar disk in units of solar luminosities per square kilo-parsec. The different lines represent different time periods, with the earliest representing the present day, and the latest 11.4429Gyr into the future.

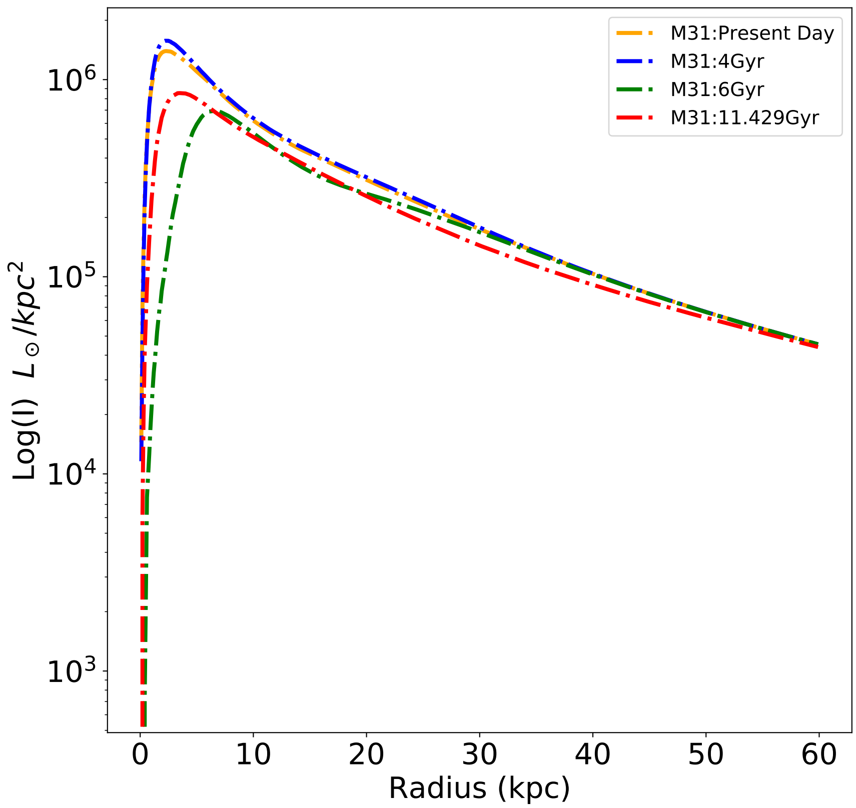

Figure 5. The surface brightness profile of the stellar disk of M31. The horizontal axis gives distance from the center, and the vertical axis gives the surface brightness. The profile at 6Gyr, shows a similar fall and rise as the disk of the Milky Way.

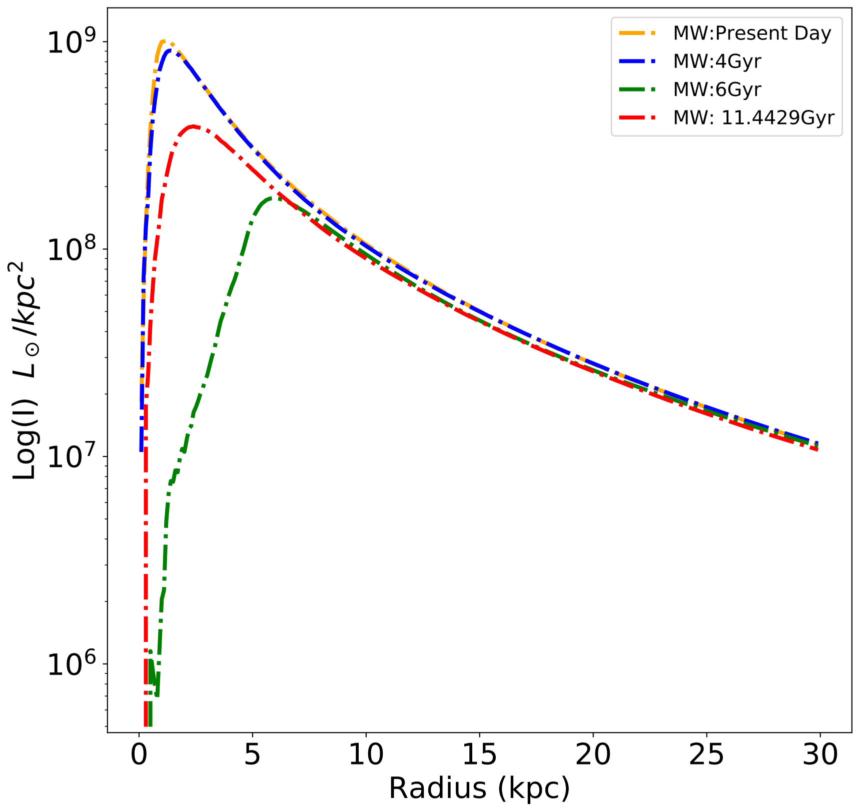

Figure 6. The surface brightness profile of the bulge of Milky Way, with the horizontal axis showing the distance from the center in kpc and the vertical axis giving the surface brightness. The disturbance of the bulge in the Milky Way at 6Gyr shows the greatest disturbance.

5. DISCUSSION

The results agree with my hypothesis that, while there will be some disturbances during the merger, the stars will settle down back into their original orbits after the merger. After the merger, the new stellar disk will contain stellar disk stars from both the Milky Way and M31, and a similar distribution occurs in the bulge of the galaxy. This disturbance and recombination can be most clearly seen when comparing the profiles for 6Gyr and 11.4429Gyr. The profiles will also follow a Sersic profile throughout the entire evolution of the merger, with the only noticeable deviation occurring in the stellar disks of both galaxies at 6Gyr. This matches the current understanding of galactic mergers, in that we expect the remnant of a major merger to be have an even distribution of the stellar material of the component galaxies. The results are important since they confirm the prediction that when a major merger occurs, the stars will be evenly distributed and evenly mixed. Since the results match expectations, we can potentially say some things about major mergers. If we want to study minor merger events, we could observe the evolution of M33 during the merger event. Overall, the results support the hypothesis that, during a major merger, the stellar material is heavily disturbed and then settles back into similar distributions once the merger has concluded.

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