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S0 type galaxy formation

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ABSTRACT
In this project, the formation of S0-type galaxies was investigated. In about 3 Gyr the Milky Way and the Andromeda galaxy will merge. This will be the major merger of two similar mass galaxies. It may be possible that the remnant of this merger could be an S0-type galaxy. This possibility was investigated using N-body simulations.

Key words: Local Group – Spiral Galaxy – Galaxy Merger – Merger Remnant – Sersic Profiles

1 INTRODUCTION

Lenticular galaxies (S0-type) are an unusual class of galaxies that seem to incorporate structures of both spiral and elliptical galaxies. A spiral galaxy has a small bulge or bar in the center that is surrounded by arms rich in gas and dust, and with active star formation. An elliptical in contrast has a velocity dispersion-supported structure of stars with little cool gas or dust and no visible finer structure. A Lenticular galaxy has a large elliptical-like bulge in the center but is surrounded by a gas disk. This project aims to determine if the collision of two major spiral galaxies like the Milky Way and M31 can result in an S0-type galaxy.

A galaxy is defined to be a collection of stars, gas, and dust that are gravitationally bound together in such a way that gravity from the observed mass is not enough to keep the system bound (Willman & Strader 2012). This definition inherently includes dark matter as part of it since dark matter must be invoked to explain why the system is still bound. It is clear from the study of galaxies that dark matter is usually the dominant component of the mass thus its role in the system is undeniable. A galaxy merger is when two or more galaxies combine to form one larger galaxy.

Because a lenticular galaxy morphologically appears to be an intermediate between spirals and elliptical galaxies, and elliptical galaxies are thought to form as the result of mergers of spiral galaxies, perhaps the lenticular galaxy is an intermediate stage in time after the spirals have merged but before they form a fully elliptical galaxy(Cox et al. 2006). Elliptical galaxies have little to no cool gas, suggesting that the gas ring of a lenticular galaxy could be left over cool gas of the spirals that hasn't been heated and ionized yet. The exact formation of elliptical galaxies through mergers is still not well understood. A spiral galaxy has considerable angular momentum while ellipticals generally due not and are dispersion supported(Cox et al. 2006). How the merger product evolves from being rotationally supported to dispersion supported is of interest. An S0-type galaxy's light profile can be described using a Sersic profile of about n=1.0 for the bulge area(Querejeta, M. et al. 2015a). A Sersic profile is a function that describes the intensity of a galaxy as a function of the radial distance from the center. The light profiles of the bulge and disk can be fitted separately as seen in a figure provided by Querejeta et al (Querejeta, M. et al. 2015a). From observational evidence, one formation mechanism for S0 galaxies is ram-pressure stripping in galaxy clusters(Querejeta, M. et al. 2015a). However, there are many S0 galaxies observed outside the confines of clusters, indicating that the ram-pressure stripping can't be the only formation mechanism and hence indicating mergers may be able to result in S0 galaxies.

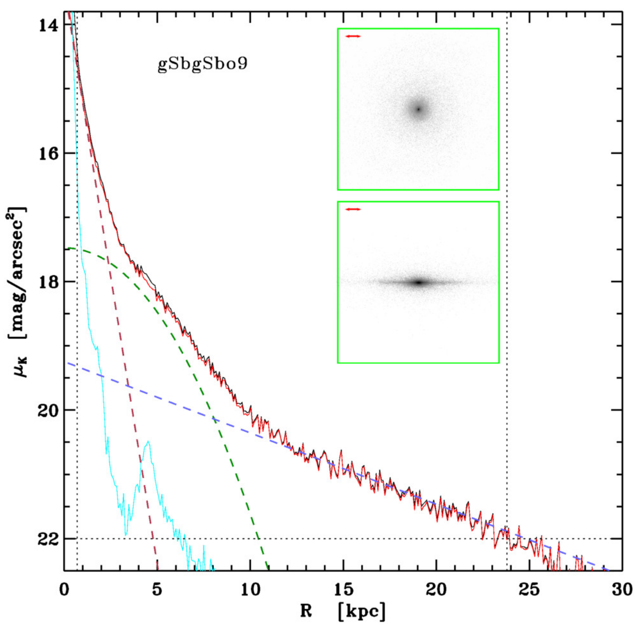

Figure 1. Image of the light profile of a simulated S0 type galaxy. It shows how the intensity of light for the lenticular galaxy depends on the radius from the center. Querejeta et al 2015

In this project, we intend to answer the question if a lenticular galaxy can be the result of a major merger between spiral galaxies. Currently, the full origin of Lenticular galaxies is not well known. From observations in galaxy surveys it is known S0-type galaxies are present inside and outside galaxy clusters. Thus their formation

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is not tied only to galaxy clsuters(van den Bergh 2009) There may be more than one formation pathway to form S0 galaxies. Currently ,a number of research teams are studying the formation of S0-type galaxies using numerical simulations(Querejeta, M. et al. 2015b). Simulations are about the only way this is possible because one needs to see the entire merger process.

2 THIS PROJECT

This research project intends to explore if the merger remnant of the Milky Way and Andromeda galaxies could be an S0-type galaxy. The origin of the S0 galaxies is interesting since they are an unusual type of galaxy. In connection to this question, I will also explore if the remnant of the merger is a slow or fast rotator. This could be a sign of an S0-type galaxy. If there is significant rotation in the merger remnant, it could be a sign that it is S0-type since an elliptical galaxy would not have significant net rotation.

A lead research question this study aims to address is if the S0-type galaxies could be the result of a major merger outside an environment of a galaxy cluster. One hypothesis for the lenticular galaxy formation is that they could be spirals whose gas was ram-pressure striped as they passed through a cluster. However lenticular galaxies are also observed far from clusters as well. Using the merger of the Milky Way and Andromeda galaxies as an example of a major merger between spiral galaxies, the remnant will be probed to determine if it is of type S0.

This study addresses the open question of lenticular galaxy formation outside galaxy cluster environments. Since the final product of a major merger is expected to be an elliptical galaxy, this study may show that a lenticular is merely an intermediate stage in the merger process as the merger remnant evolves into a true elliptical galaxy. However, the possibility of a lenticular galaxy evolving into an elliptical will not be answered since this would rely on a study of how the gas in the disk is heated up and/or dissipates.

3 METHODOLOGY

In this project, the merger between the Milky Way and the Andromeda Galaxy is explored using N-body simulations. The N-body simulations used were created by van der Marel et. al. van der Marel et al. (2012b,a) Of the Local Group galaxies in only the Milky Way, M31 and M33 are present in the simulation. Each galaxy is divided into three components, disk stars, bulge stars, and dark matter. The gravitational forces between each particle of mass are calculated according to Newton's theory of gravity. Then, due to the acceleration of gravity, the positions and velocities of each particle are updated. In the simulation, this process is run for 800 Myrs of simulation time.

The goal of this project is to determine if the merger remnant of the Milky Way and Andromeda is a lenticular galaxy. In order to do this Sersic profiles will be fit to merger remnant. For the sake of simplicity, the mass-to-light ratio will be taken as one. Then a combination of Sersic profiles of different indices will be fit to the remnant. From this fitted profile it will be examined to see if there is a distinct contribution from a disk and bulge. As a sanity check the rotational velocity as a function of the radius will be plotted. If appreciable rotation is observed then this indicates that there may be a rotating disk.

The main task of the code that is being written is to fit Sersic profiles to the merger remnant of the Milky Way and Andromeda. I will take the mass-to-light ratio to be unity to simplify the project.

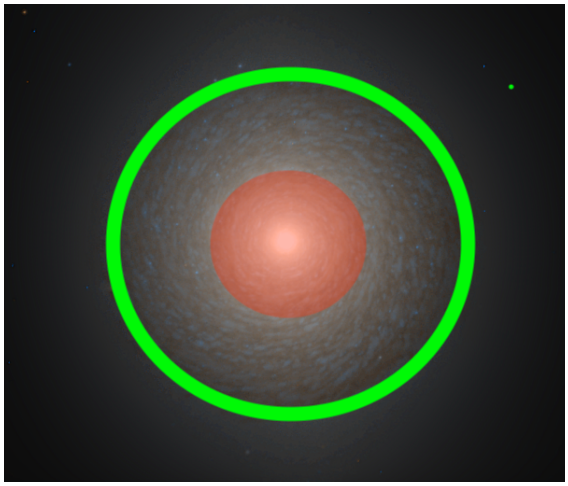

Figure 2. This is an image of an S0 galaxy with color overlays indicating the bulge and disk components. A Sersic profile will be fitted to both components to determine if it is a lenticular galaxy.

The method used to fit the profiles relies on the fact that disks and elliptical bulges have different profile functions. The sum of a disk and bulge profile will be fit and if the contribution from the disk is negligible than the remnant is likely elliptical and not lenticular. The equation for a Sersic profile is:

$$I(r) = I_0 e^{-(r/h)^{1/n}}, \tag{1}$$

where I is the intensity, I_0 is the central brightness, r is the radius, h is the scale length, and n is the index. For an elliptical galaxy the index is 4 and for a spiral disk the index is 1. A sum of these profiles will be fit to see if the galaxy has both a bulge and disk.

The first plot made by this project will be a graph of intensity vs radius. This graph will show the intensity vs radius for the galaxy from the data and the fitted Sersic profiles. Since a numpy fitting function will be used, the profile should match the data very closely. The second plot will be of circular speed as a function of radius. This will be a sanity check to see if there is an appreciable rotation in the merger remnant.

Since a lenticular galaxy is a fairly rare type of galaxy I would be surprised if the remnant is actually a lenticular galaxy. I suspect that remnant will be best described by a single Sersic profile of an index of about four. This would mean that the remnant is an elliptical galaxy. However if the result is of type S0 there will be a contribution to the light profile from a Sersic profile of index 1.

4 RESULTS

paragraph 1

paragraph 2

5 DISCUSSION

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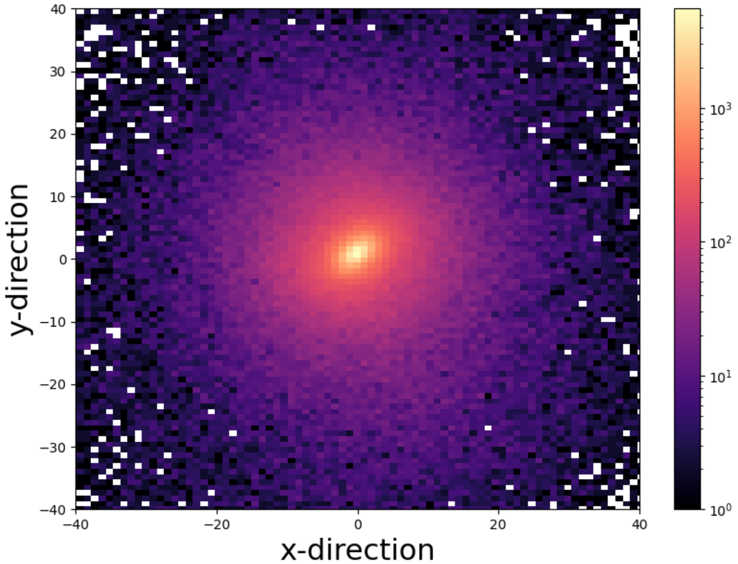

Figure 3. Caption

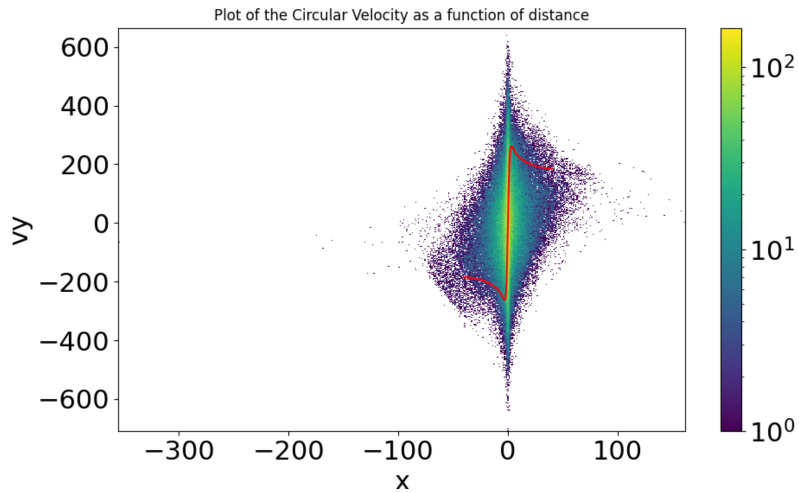

Figure 4. Caption

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APPENDIX A: SOME EXTRA MATERIAL

If you want to present additional material which would interrupt the flow of the main paper, it can be placed in an Appendix which appears after the list of references.

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