Research Assignment 2 - Proposal

Laura J. Mack

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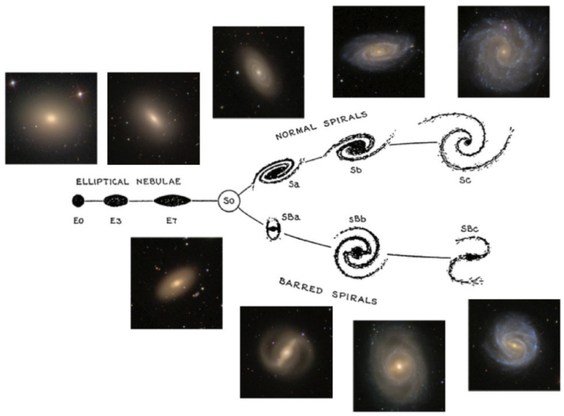

Figure 1. The Hubble tuning fork. This particular version is from Masters (2025) and also includes example galaxy images from the Sloan Digital Sky Survey.

1 INTRODUCTION

1.1 Define Proposed Topic

Galaxy morphology, which comes from typically visual description, correlates to stellar formation history and the history of the galaxy itself. This traditionally visual inspection done by a small number of astronomers while useful has some level of subjectivity. These classification are often derived from the classification scheme described by (Hubble 1926), which can be seen in Fig 1. Though recent developments of Large Survey Astronomy has led to crowd-sourced analysis (Masters 2025), with a large number of separate classifications, visual inspection has remained a very useful tool for classification.

Major galaxy mergers, which occur between two galaxies of similar mass, result in the development of early type galaxies (ETGs). In the Hubble tuning fork, ETGs are the left side strand encompassing elliptical and lenticular (S0) galaxies. ETGs can also be described as galaxies that have stellar formation rates below the mean. This encompasses elliptical, S0 and Sa galaxies. Elliptical galaxies in particular, are classified by their ellipticity.

$$n = 10[1 - \frac{a}{b}]. \quad (1)$$

Where n is the ellipticity, a is the major axis and b is the minor axis of the projected ellipse.

1.2 Why this Matters

Understanding and classifying galaxies can lead to understanding patterns in galaxy formation. This understanding can be used to connect the disparate snapshots gathered from observations into a complete picture of galaxy evolution. The formation of elliptical galaxies in particular is a result of major mergers which are difficult to explore how exactly they evolve.

1.3 Overview of Current Understanding

Major galaxy mergers cause dramatic disturbances in the stellar disk/bulge morphology. In general, galaxies will build up over time, through mergers, each associated with morphological changes. These changes will eventually lead to massive, elliptical galaxies (Duc et al. 2012). Specifically, dry (dust poor) mergers between spirals result in elliptical galaxies with highly altered structure from the parent galaxies. These final structures are dependent on the precise initial conditions of the parent galaxies (Querejeta et al. 2014).

These present-day galaxies can be studied through their surface density (brightness) profiles. For elliptical galaxies in particular, the Sérsic profile is used.

$$I(r) = I_0 \exp(-7.67[\frac{r}{R_e}^{\frac{1}{n}} - 1]) \quad (2)$$

Where I(r) is the intensity, I_0 is the central intensity, r is the radius in question, R_e is the effective radius (2D radius where half the light is contained), and n is the Sérsic index. This profile comes from the $I \propto R^{\frac{1}{n}}$ relationship. Here R is the radius in question. The de Vaucouleurs profile, which is typical for elliptical galaxies, uses n=4.

The Sérsic index can be used to analyze how well the merger remnant fits to the expected surface density of an elliptical galaxy. Sérsic profiles as a whole can be used to analyze a whole host of galaxies using objective profile fits rather than subjective visual classification.

1.4 Open Questions

In terms of the classification of galaxies as a whole there is, in some samples, a correlation between pitch angle and the bulge size. This correlation however, is missing in other samples, particularly for more massive spirals (Masters 2025). As surveys continue to improve in resolution and depth, more morphologies and patterns within them will be revealed (Masters 2025). For galaxy formation and merger history, the question of how high redshift ETGs would have formed given the traditional galaxy merger model is not resolved (Duc et al. 2012). Additionally, the level at which accretion history impacts galaxy mass growth is still an open question (Duc et al. 2012). This merger history and how it impacts the final remnant is still a question.

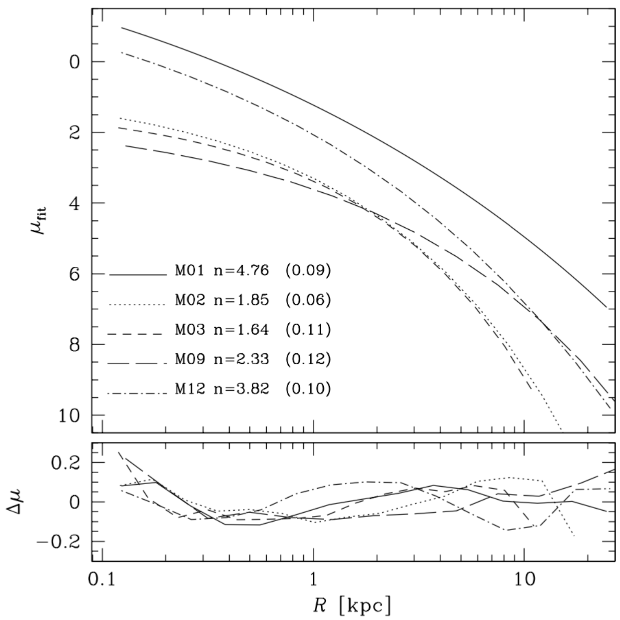

Figure 2. Figure from Aceves et al. (2006). Various Sérsic profiles with various indices. The root mean square of the fit is shown in parentheses. The bottom panel shows the change in surface density.

2 PROPOSAL

2.1 This Proposal

The remnant of the MW-M31 merger can be described as a classical elliptical galaxy. This proposal attempts to answer how well the Sérsic profile fits that classification.

2.2 Methods

In class (Lab 6) we have written code that will apply a Sérsic profile to a set of bulge particles. This can be applied to disk and bulge particles of the MW-M31 remnant. After the system has settled, at around 7Gyr, the surface density can be examined. This will fit a Sérsic profile but not necessarily one that has the ideal n=4. The best fit profile will need to be found by adjusting the Sérsic index. This can be done by measuring various Sérsic profiles and calculating the how the profile differs from the data itself. This can be done using the mean squared error.

$$\frac{1}{n}\sum_{i=1}^{N}(Y_i - \hat{Y}_i)^2 \tag{3}$$

Where N is the number of data points, Y_i is the observed values and $\hat{Y}_i$ is the expected values. A script can be written that by cycling through the Sérsic indices can find the best fit with minimizing the mean squared error. Fig 2 shows a series of Sérsic profiles with various indices. This should be more or less what the code will cycle through.

I will use the bulge and disk particles for the MW and M31 at a high-res snapshot at some point after the merger. Apply the code to loop over the Sérsic profiles and find the best fit. The best fit is the profile that is closest to the reality of the merger remnant.

2.3 Hypothesis

I expect that the final merger will fit quite will as a classical elliptical galaxy. This is supported by Aceves et al. (2006) who explicitly state that their simulations of disk galaxy mergers have led to Sérsic indices that match the observed indices for early type galaxies. Additional support is given by Hopkins et al. (2008) that found spheroidal merger remnants with masses $M_{sph} \geq 10^{11} M_{\odot}$ are overwhelmingly classical elliptical galaxies.

REFERENCES

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