Literature Review:
Morphology and SEDs of Galaxies

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Abstract

This literature review aims to explore the study of galactic evolution through photometric measurements. From photometric measurements of galaxies, the physical properties of resolved and unresolved galaxies can be inferred from fitting the measurement to physical models for spectral energy distributions. The morphology of galaxies can also be quantified by looking at their isophotes and radial profiles. Combining these approaches to study galaxies of different ages allows for galactic evolution to be studied. This project aims to classify galaxies, investigate their structure, and measure their physical properties in order to compare galaxies of the same classification at different ages. This will be achieved through spectral energy distribution fitting and constructing the radial profiles of the galaxies from photometric data collected using a 1.2-meter telescope.

Contents

1 Introduction

The purpose of this project is to study the different properties and structures of galaxies at various ages, or redshift. This will be achieved by studying resolvable galaxies and unresolved galaxies which are candidates to be the same morphological type. The main goal of studying galactic evolution is to understand how galaxies produce their stars over time. The easiest way to study this is to measure star formation rates and stellar masses as a function of redshift for a sample of the galaxies (Leja et al. 2017). To study the properties of the galaxies spectral energy distribution fitting will be utilised. The morphology of the galaxies will be studied by constructing isophotes and radial profiles from the photometric data collected.

1.1 Spectral Energy Distribution

A spectral energy distribution (SED hereafter) of a galaxy is a plot of the energy emitted by the galaxy as a function of the wavelength. This distribution is a result of all the light being emitted from the objects contained within a galaxy, such as the different classes of stars, nebulae, and the active galactic nucleus. SEDs are the primary source of properties of unresolved galaxies (Walcher et al. 2010). The SED of a galaxy tells us about the star formation rate (SFR), redshift, metallicity, star formation history (SFH), stellar initial mass function (IMF), and dust masses. The SFR of a galaxy is the total mass of stars formed per year. The redshift is a measure of how the wavelength of the light has been shifted due to the expansion of the universe. This gives information on approximately how far away the galaxy is and therefore how old it is. This will allow us to compare the approximate ages of the galaxies being studied. The metallicity of a galaxy is a measure of the amount of elements heavier than hydrogen and helium in a galaxy relative to the total mass of the galaxy. The metallicity of a galaxy also gives information on its age. Heavier elements must be formed over time through nucleosynthesis, this means older star populations tend to have lower metallicity. SFH tells how stars are formed over the history of the galaxy, such as whether the rate was constant over a long time or did star formation occurred in short bursts. The IMF describes the distribution of masses for a stellar population during star formation. SEDs also allow for an estimation of dust mass within a galaxy, giving information about the galaxy's interstellar medium.

1.2 Morphology

The morphology of a galaxy refers to its structural properties. Galaxies are often categorised by common morphology. One popular classification scheme is the Hubble classification, also called the tuning fork, this can be seen in Figure 1. This system divides galaxies into roughly three categories, spiral, lenticular, and elliptical. A fourth classification, irregular, is also often used for galaxies that do not fit the other groups. Other, more nuanced classification systems also exist (Sandage and Bedke 1994), but Hubble's scheme will be sufficient for the purposes of this project.

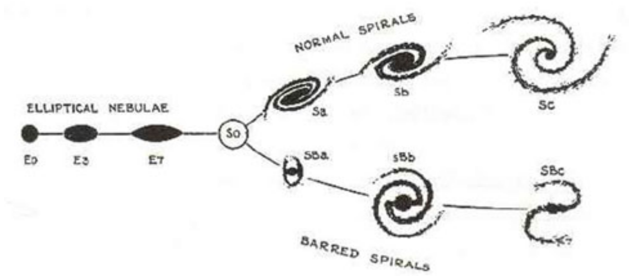

Figure 1: Hubble's tuning fork diagram for the classification of galaxies (Hubble 1982)

The main structures used to classify galaxies are disks, bulges, pseudobulges, bars, spiral arms, and dust lanes (Buta 2011). A galactic disk is a a thin circular distribution of gas, dust, and stars which are mostly orbiting the galactic centre in the same plane. Disks are a feature present in spiral and lenticular galaxies. Bulges are regions of densely packed stars near the centre of a galaxy. There are two types of bulges, classical and pseudobulges. Classical bulges consist of mostly older stars, with random orbits compared to the galactic plane. They are thought to be formed by major mergers. Pseudobulges, which are flatter and more disk-like, are believed to have evolved slowly over long periods (Fisher and Drory 2008). Bars are long regions which cross the centre of a galaxy. Bars can act as funnels bringing gas and dust into the centre of the galaxy leading to star formation. Bars can be found in barred spiral galaxies and some lenticular galaxies. Spiral arms are long thin regions of stars that extend out from the centre of a galaxy in a spiral pattern. The arms are regions of star formation, this causes the spiral arms to appear bright as they contain young, massive, bright stars. Finally, dust lanes are regions in the galaxy that contain dense interstellar dust and thus appear darker than their surroundings.

2 Research Methods

2.1 Spectral Energy Distribution Fitting

SED fitting is the process used to convert photometric and/or spectroscopic observations of a galaxy into inferred physical properties of the galaxy (Johnson et al. 2021). This involves using some statistical method to connect the observations of a galaxy to a physical model.

In the case of this project, the observations will be a series of optical photometry measurements. By fitting these optical measurements to a SED using software, a full SED for the galaxies can be obtained. This allows for properties otherwise limited to observations outside the visible band to be inferred. The software that will be used in this project is *Prospector*. *Prospector* is a Python package specially designed to perform SED fitting and inferring stellar population parameters from photometric and/or spectroscopic data (Johnson et al. 2021). It allows for the connection of observed data with the physical characteristics of galaxies. Figure 2 shows a sample SED fitted with *Prospector* using 5 optical photometric measurements.

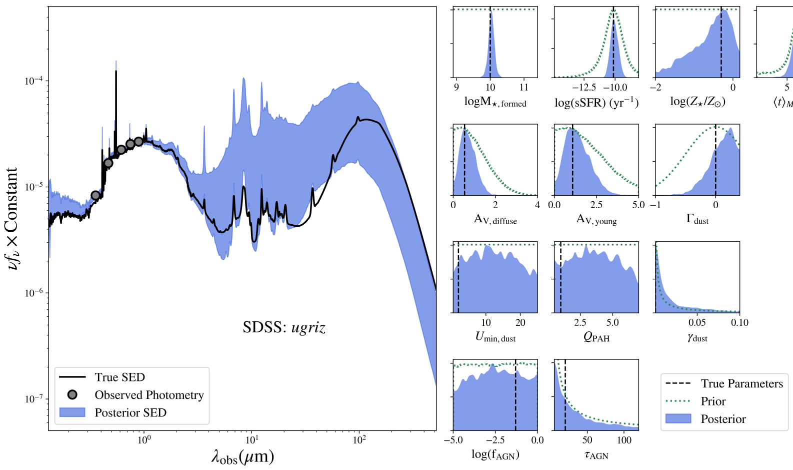

Figure 2: Example of inference of model parameters from 5 mock optical photometric bands (Johnson et al. 2021).

2.2 Radial Profile

One method of studying the morphology of a galaxy is to look at its radial profile. The radial profile of a galaxy is the change in intensity of a galaxy as a function of the distance from its centre. This data is fitted using the Sérsic function which is given by Equation 1.

$$\mu_b(r) = \mu_e + c_n \left[\left(\frac{r}{r_e} \right)^{1/n} - 1 \right] \tag{1}$$

Where μ_e is the bulge surface brightness at r_e, r_e is the radius containing half the light of the bulge, n is the Sérsic index, and c_n is given by $2.5(0.868n - 0.142)$ (Gadotti 2012). Using the Sérsic index a classical bulge can be identified as having an index value of $n \geq 2$, whereas a pseudobulge has an index value of $n < 2$. This method is not always correct and has been found to have a failure probability of 10-20% (Kormendy 2016). A classical bulge can be identified with complete confidence if the bulge-to-total flux ratio (B/T) is greater than 0.5. Bars can also be identified by the Sérsic index, they typically have a n value of 0.5-1. For spiral galaxies, the Sérsic index shows the balance between the bulge and the disk which are two separate elements. For elliptical galaxies, n typically shows the overall structure (Blanton and Moustakas 2009). A sample radial profile for a spiral galaxy with a bulge can be seen in Figure 3.

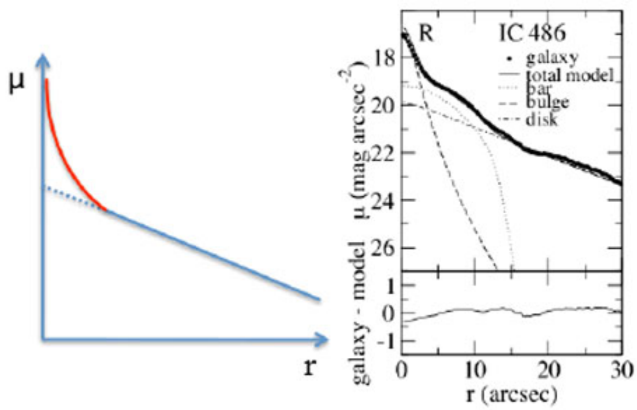

Figure 3: Sample radial profile for a spiral galaxy with a bulge (Gadotti 2012).

2.3 Isophotes

Isophotes are regions of constant surface brightness. These regions can be constructed by analysing photometric observation of a galaxy. By finding the ratio of the semi-major axis to the semi-minor axis we can see how far the isophote deviates from a circle. The shapes of isophotes in elliptical and lenticular galaxies are correlated with the physical properties of the galaxies and are influenced by galaxy formation processes (Chaware et al. 2014; Hao et al. 2006).

3 Research Question

This project aims to address the question of how galaxies of the same morphological type differ at various ages. This will involve a study of both the structural characteristics and the physical properties of galaxies through studying radial profiles, isophotes, and SED fitting. By examining galaxies of different ages and comparing their structural and physical attributes, the project seeks to gain insights into the process of galactic evolution.

This project will also explore the feasibility of classifying unresolved galaxies based on their physical properties derived from SED fitting. The SED fitting process will involve using photometric measurements at multiple optical wavelengths for each galaxy, facilitating not only the fitting of SEDs but also the construction of radial profiles and isophotes to understand each galaxy's structure.

In summary, this research project aims to understand the evolution of galaxies with the same morphological type at different ages. It will involve photometric measurements, SED fitting, and radial profiles to examine both their morphological and physical characteristics, contributing to our understanding of galactic evolution.

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