Galactic Relations

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1 Introduction

We can use galactic relations to better understand and calculate various galactic parameters.

2 Background

2.1 Galaxy Classifications

Galaxies can be classified into three large classes based on their morphology: spiral, elliptical, and irregular.

Figure 1: A spiral galaxy, galaxy m101 (Source: Wikipedia)

Figure 2: An elliptical galaxy, galaxy NGC 4150 (Source: Wikipedia)

These classifications help us separate out which galactic relations apply to which galaxies. For more information on galaxy classes, see the galactic classification and AGN handout. Most galactic relations primarily apply to spiral galaxies, which are extremely common, and likely have significant physical similarities across the entire class. Ellipticals, on the other hand, tend to display significant variation across their many sub-categories.

2.2 Galactic Components

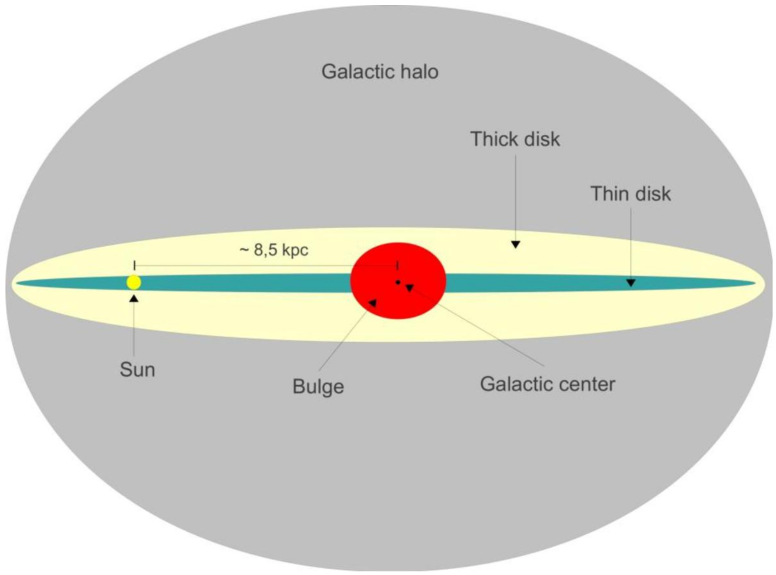

Figure 3: A diagram of galactic components (Source: Wikipedia)

Most galaxies are composed of a few key components:

- There is a bright, relatively dense **central bulge**, and possibly a bar or ring around that.
- There is a **thin disk** a few kiloparsecs thick composed of relatively younger stars. This includes most of the star formation and H II regions.
- There is a thicker disk on the order of tens of kiloparsecs thick, with relatively older, redder stars that is depleted in gas and dust.
- There is also a larger **halo** around that comprised of similar, old and red stars, as well as a significant number of globular clusters and dark matter. This halo is approximately spherically shaped.

2.3 Mass-to-Light Ratio

The mass to light ratio is a very important concept for galaxies. It is a marker of the amount of mass per brightness contained within a certain radius, R_{25} which is the disk radius corresponding to a surface brightness level of 25 magnitudes per arcsecond squared. This ratio is approximately constant for each class of spiral galaxy when integrated across the entire galaxy. For a Sa type galaxy, this ratio is approximately 6.2; for an Sb type galaxy, it is approximately 4.5; and for an Sc type galaxy, it is approximately 2.6.

The mass to light ratio values are important for understanding the amount of dark matter in galaxies, as the brightness can be directly measured, allowing for an order-of-magnitude calculation of the luminous mass, or mass that is capable of producing light. Since independent kinematic techniques can be used to calculate the total mass, the mismatch between the answers generated by these two approaches allows for an estimation of the amount of dark matter present in the galaxy.

3 de Vaucouleurs Profile

The **de Vaucouleurs profile** demonstrates the dependence of the surface brightness, or brightness per unit area, on the radius. This relies on the effective radius (r_e) or the projected radius that marks out a region where half the light of the galaxy is emitted within. With r as the radius, μ as the surface brightness, and μ_e as the surface brightness at the effective radius, the most common profile exhibited is

$$\mu(r) = \mu_e + 8.3268((\frac{r}{r_e})^{1/4} - 1)$$

A more generalized version is known as the **Sersic profile**, which replaces the 1/4 with 1/n where n is a free parameter.

4 Galactic Rotation Curves

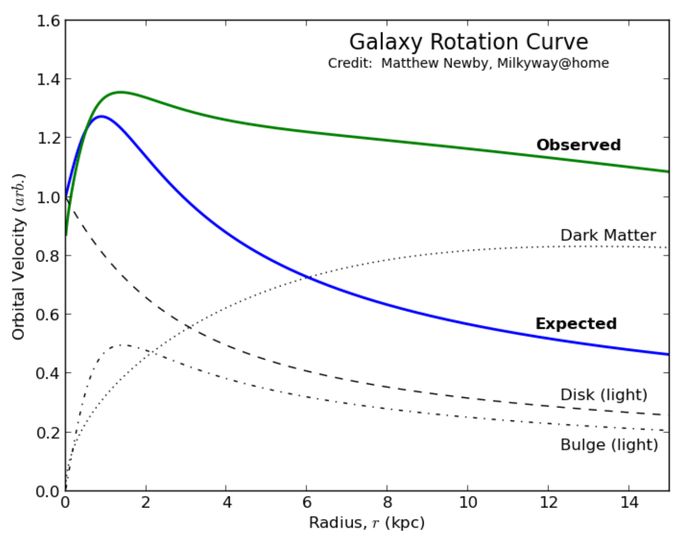

Figure 4: An example set of rotation curves (Source: Physics Stack Exchange)

Rotation curves, or a plot of the velocity of the gas in a galaxy against radius, are an important way to understand galactic kinematics. These are most commonly measured using the Doppler shift of the **21-cm hydrogen line**, an important type of emission caused by spin flip transitions in extremely cold and low density conditions of atomic hydrogen in interstellar space. Simple kinematic arguments allow for the relations of this to orbital period and mass using orbital mechanics techniques. The deviation of observed rotation curves from the predicting Keplerian set is also another key piece of evidence for dark matter.

5 Tully-Fisher Relation

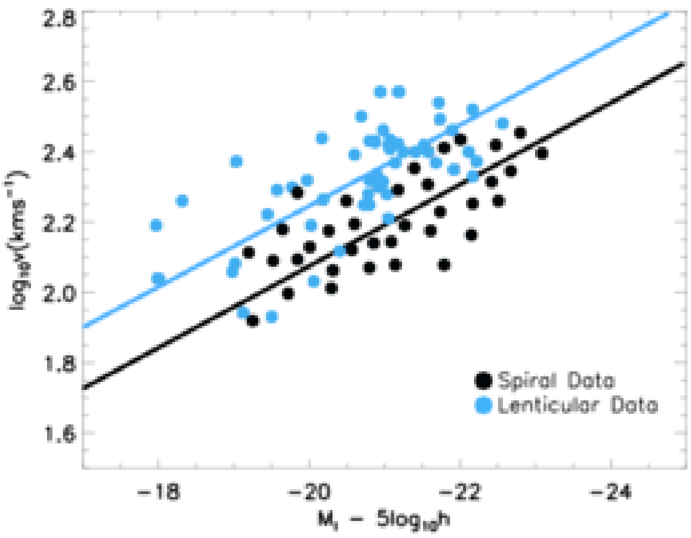

Figure 5: The Tully-Fisher Relation (Source: Wikipedia)

Based on the existence of known rotation curves and known mass-to-light ratios for spiral galaxies, a relationship between magnitude and maximum rotation velocity for each type of spiral can be generated, where M_B is the bolometric magnitude and V_{max} is the maximum velocity.

$$M_B = -9.95 \log V_{max} + 3.15$$

for Sa.

$$M_B = -10.2 \log V_{max} + 2.71$$

for Sb.

$$M_B = -11.0 \log V_{max} + 3.31$$

for Sc. Similar formulations in the infrared are often used as they are slightly more accurate.

6 Radius-Luminosity Relation

For spiral galaxies, a relationship between the brightness and the radius that matches a surface brightness of 25 magnitudes per square arcsecond. This relationship is independent of which class of spiral a galaxy is for early type spirals. For R_{25} in kpc,

$$\log R_{25} = -0.249 M_B - 4.00$$

7 Faber-Jackson Relation

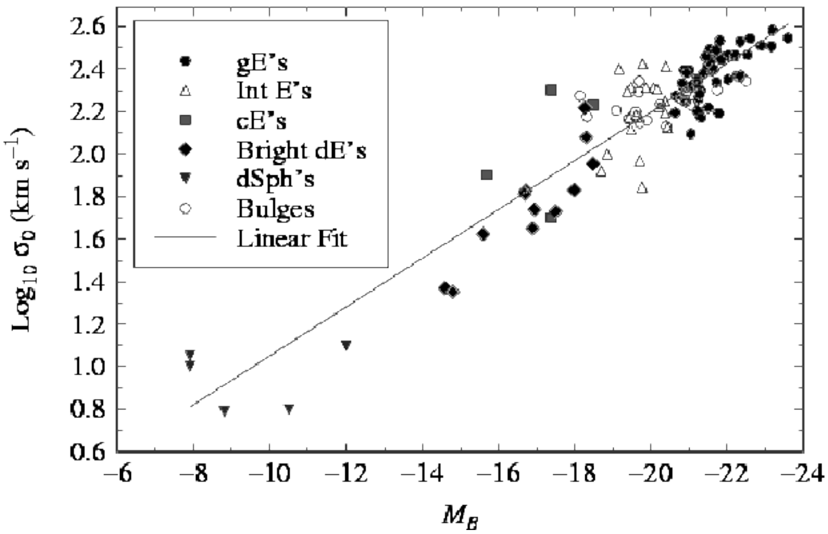

Figure 6: The Faber-Jackson Relation (Source: ICC)

Despite the wide variety among elliptical galaxies, they all share a common relationship that emerges from the virial theorem for a sphere and a constant the mass to light ratio,

$$L \propto \sigma_0^4$$

where L is the luminosity in solar units, and σ_0 is the central radial velocity dispersion. This can be re-written as

$$\log \sigma_0 = -0.1 M_B + c$$

where c is a generic constant.

8 Conclusion

Now, we can use the power of galactic relations to calculate a wide variety of information about galaxies!