# Dark Matter Distributions Across Different Galaxy Types

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## Abstract

Dark Matter has been a focal point of attention, ever since the observation that the outer parts of galaxies were moving at the same speed or faster than the inner parts. In this study, we aim to investigate the distribution of dark matter in galaxies based on the radius and compare the distributions among different galaxy types. We utilize the Spitzer Photometry & Accurate Rotation Curves (SPARC) database, focusing on late-type and early-type galaxies, including Blue Compact Dwarf (BCD), Lenticular (S0), Small Magellanic (Im), Tight Spirals (Sa), Loose Spirals (Sc), Irregular Spirals (Sm), and Elliptical (E0-E7) galaxies. First, we start by graphing the relationship between dark matter halo mass and rotational velocity at a radius where the dark matter density is 200 times the critical density of the Universe. This data is given in the SPARC database. From this analysis, we are able to derive an equation for the mass of the galaxy in its entirety. Next, we also calculated the luminosity within a given radius using a luminosity formula derived from the rotational velocity and effective surface brightness again given by the SPARC database. Our results indicate that the mass-luminosity (M/L) ratio generally increases with radius, and that the M/L ratio follows a similar trend across all galaxy types. Additionally, we can use our data to predict that the dark matter distribution decreases as we move further away from the center of a galaxy.


Keywords: dark matter, galaxy, distribution, SPARC database, mass, luminosity, mass-to-luminosity ratio.

## Research Question

The mystery of dark matter has been puzzling scientists for a long time. Ever since the discovery that the outer parts of galaxies were moving at the same speed or faster than the inner parts of galaxies, scientists have been searching for what dark matter could be made of.

Our study aims to find the distribution of dark matter in a galaxy based on the radius, and then compare the distributions for spiral, elliptical, lenticular, and irregular galaxies. We also want to compare the dark matter distributions in field galaxies to those in a cluster.

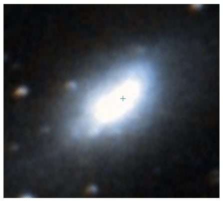
## Methodology and Approach

### Data Source: SPARC Database

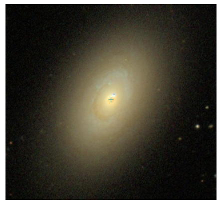
We are using the Spitzer Photometry & Accurate Rotation Curves (SPARC) database of galaxies. We specifically focus on the Basic SPARC Data (Late-Type Galaxies) and the Early-Type Galaxies Data for our analysis. Our sample encompasses various galaxy types, including Blue Compact Dwarf (BCD), Lenticular (S0), Small Magellanic (Im), Tight Spirals (Sa), Loose Spirals (Sc), Irregular Spirals (Sm), and Elliptical (E0-E7). By including galaxies across different classifications, the goal was to capture a wide range of dark matter distribution patterns.

### Highlighted Galaxies

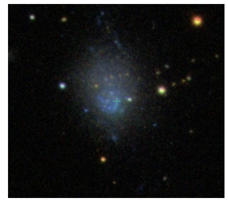
We have chosen these specific galaxies based on their classification and characteristics in order to capture a diverse range of dark matter distribution patterns.



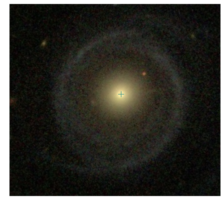
NGC2915 (BCD)



NGC4138 (S0)

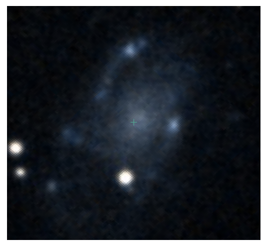


NGC3741 (Im)

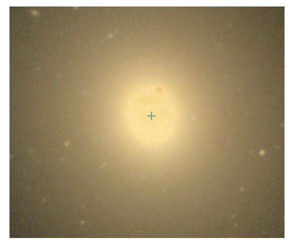


UGC6614 (Sa)

NGC2998 (Sc)



UGC191 (Sm)

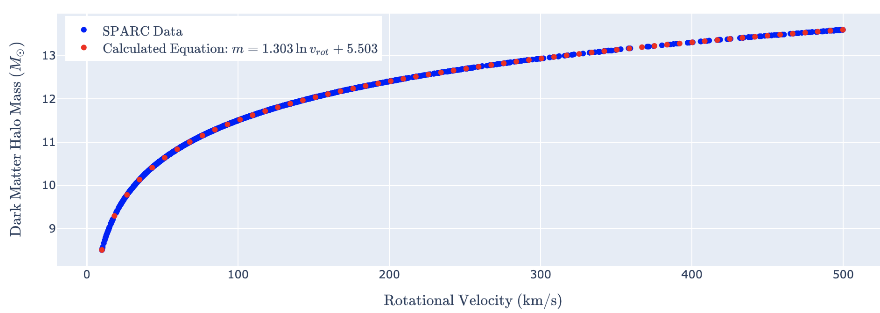


NGC4278 (E0-E7)

## Preliminary data analysis

In order to do some preliminary data analysis, the first thing we did was graph the following:

Figure 1: Dark Matter Halo Mass vs. Rotational Velocity at a radius where the Dark Matter Density is 200 times the critical density of the Universe.




We found the following equation for the dark matter halo mass:

$$m = 1.303 \ln v_{rot} + 5.503$$

where $m$ is the dark matter halo mass in solar masses ($M_\odot$) and $v_{rot}$ is the rotational velocity of the galaxy in km/s.

From this graph, we were able to understand that there is a relationship between the mass of dark matter in a galaxy and rotational velocity.
Then, using this equation:

$$M(r) = \frac{v_{rot}^2 r}{G} \tag{1}$$

where $M(r)$ is the mass of the galaxy within the radius $r$, $v_{rot}$ is the rotational velocity of the galaxy, and $G$ is the universal gravitational constant, we can find the mass of the galaxy within a certain radius. We assume that the galaxy is circular so that analysis will be simplified.

As part of the process of finding the dark matter mass distributions, we found the luminosity of the galaxy to be approximately represented by

$$L = \frac{\pi R^2 S}{500} \tag{2}$$

where $L$ is the luminosity contained within the radius $R$ and $S$ is the effective surface brightness. We originally used the effective radius of the galaxy to find derive this model, which had a mean error of 1.25% for late-type galaxies and a mean error of 2.50% for early-type galaxies.

We then used equations (1) and (2) to calculate both the mass and luminosity of the galaxy contained within a given radius. Doing this gave us the following graphs:

Figure 2: Mass Contained within a Radius vs. Given Radius

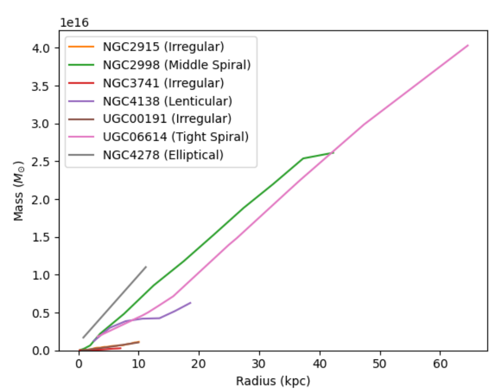


Figure 3: Luminosity within a Radius vs. Given Radius

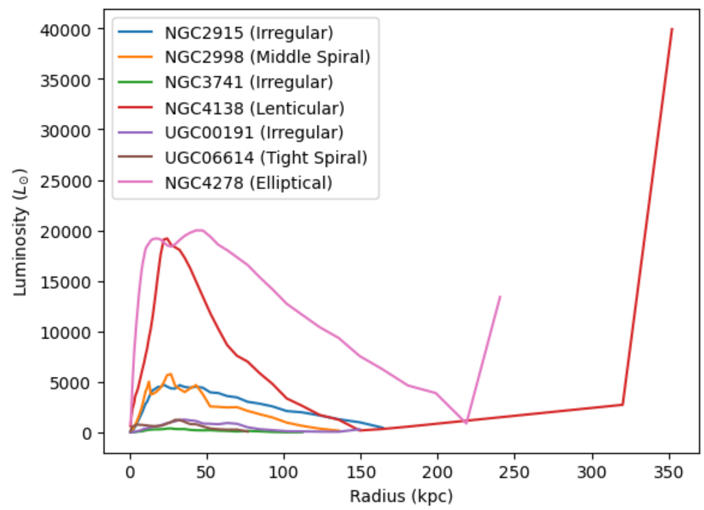
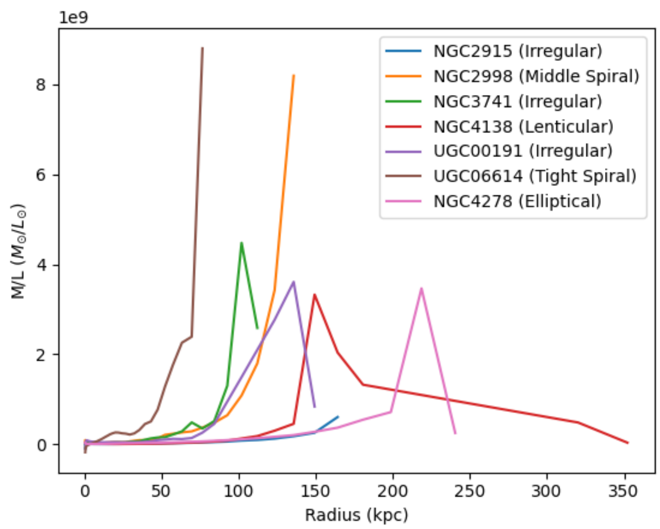



Figure 4: Mass-to-Luminosity Ratio within a Radius vs. Given Radius




# Results and Implications

In Figure 3, it can be seen that certain curves spike up towards the end. We are not completely sure about the underlying cause, but we have identified a few patterns from graphing other galaxies than the ones listed:

1. The spikes only happen in elliptical or lenticular galaxies.

2. They all occur after the radius reaches 200 kpc.

As can be seen from the graphs, both mass and luminosity increase for any galaxy as the radius in which both are measured increases. It seems that mass has an approximately linear relationship with the radius, while luminosity seems to have an exponential or power relationship with the radius. Interestingly, the mass-to-luminosity ratio follows a similar general trend for all the galaxies: it spikes and then decreases. Depending on how much data we had for a given galaxy, it could spike up and not come down or fully come down and flatten out.

A higher mass-to-luminosity ratio represents more mass for a given luminosity. The mass in a galaxy is composed of normal matter (stars, planets, black holes, etc.) and dark matter. However, only normal matter has luminosity as dark matter does not give off light. For a given luminosity, a higher mass would mean more dark matter (as dark matter cannot shine) and less mass means less dark matter. Thus, a higher mass-to-luminosity ratio indicates more dark matter. Spikes in the mass-to-luminosity ratio graph could indicate more dark matter at that radius in the galaxy.

**Hypothesis:** *We predict that the dark matter concentration in a galaxy increases, peaks, and then decreases as we move further out from the center of the galaxy in accordance with the mass-to-luminosity ratio graph.*

## References

[1] Federico Lelli et al 2016 AJ 152 157

[2] Special thanks to Professor Shyamal Mitra, Ph.D. at the University of Texas at Austin.