Advanced Lab 2: Final Project Report

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Abstract

In astrophysics, the mass-to-light ratio is a helpful measure to categorize galaxies and other celestial objects based on their total mass and luminosity. This ratio can be used to analyze a galaxy's dark matter content and gain insight into various other galactic properties.

The mass-to-light ratio of dwarf galaxies and globular clusters surrounding the Milky Way can be calculated from the dynamics of their system, including virialized stellar mass, half-light radius, and line-of-sight velocity dispersion. Additionally, these observed values can be compared to simulated dwarf galaxies from the EDGE Simulation suite. By analyzing ratios of both observational and simulation data, we can see trends in the dark matter content of small, low-mass galactic objects, and apply this analysis to subsequent data releases.

1 Introduction and Background

In astrophysics, the mass-to-light ratio Υ is a quotient between the total mass of a large spatial volume (usually a galaxy) and its luminosity. Like many astrophysical measurements, this is calculated relative to the Sun as a standard baseline given by the equation below.

$$\Upsilon_{\odot} = \frac{M_{\odot}}{L_{\odot}} \tag{1}$$

The mass-to-light ratios of galaxies are much greater than $\Upsilon_{\odot}$ due to the fact that most matter in these objects do not reside within stars. These ratios are helpful measures of dark matter content and confirm with other observational data that a large fraction of a galaxy's mass is from dark matter. A higher mass-to-light ratio suggests a larger dark matter domination within the galaxy.

The EDGE (Engineering Dwarfs at Galaxy's Edge) Simulation suite is a cosmological hydrodynamical simulation that selects dark matter halos in the early universe to resolve at a high resolution once they evolve to the present day (see Figure 1). These low-mass dark matter halos host traditional dwarf galaxies as well as globular clusters. At the tail end of the galaxy formation spectrum, low-mass dwarfs are particularly sensitive to galaxy formation physics, including the process by which dark matter seeds structure development in the early universe

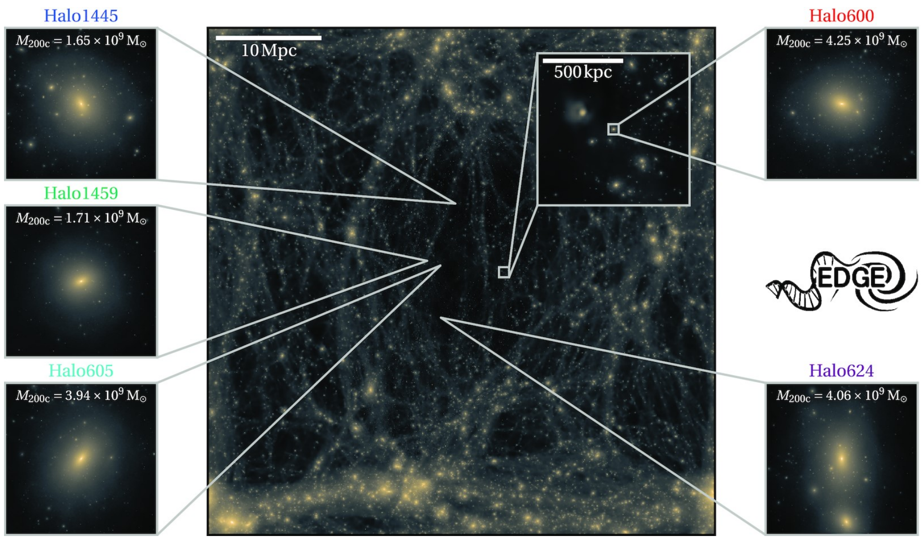

Figure 1: Depiction of EDGE Simulation selection of dark matter halo databases within a cosmological void. Halo databases are selected for higher resolution re-simulation at a redshift of zero.[2]

[1]. The EDGE Simulation evolves dwarf galaxies from their initial formation through to the present day, as well as takes into account the impact of gas and stellar physics on the interstellar environment [4]. Additionally, advances in galactic formation physics within the EDGE suite such as non-equilibrium cooling and heating models, radiative transfer and supernovae feedback, and an updated element enrichment model provide a highly beneficial environment with which to study the nature of dwarf galaxies and their halos [4].

2 Data Parameters

Parameter	**Source**
Stellar Mass	Local Volume Database/Simulation Data
Luminosity	Local Volume Database/Simulation Data
Half Light Radius	Local Volume Database/Simulation Data
Line of Sight Velocity Dispersion	Local Volume Database/Simulation Data
Dynamical Mass	Calculated from Half Light Radius and Velocity Dispersion
Mass-to-Light Ratio	Calculated from Dynamical Mass and Luminosity

3 Methods

In order to analyze mass-to-light ratios of dwarf galaxies and star clusters surrounding the Milky Way, data is pulled from the publicly available LVDB (Local Volume Database) repository on Github compiled by researchers from the University of Virginia. [3] This data catalogs objects within roughly 3Mpc of our galaxy.

Mass-to-light ratios of observed local volume are calculated according to the parameters of dynamical mass [$log_{10}M_{\odot}$], azimuthally-averaged spherical half light radius [parsec], line-of-sight velocity dispersion [km/s], and stellar mass [$log_{10}M_{\odot}$]. The calculation of an object's dynamical mass is given by

$$M_{dyn} = \frac{log_{10}(R_{half}\sigma_{los}^2)}{G} \tag{2}$$

using the method employed by Wolf et al.[5] The calculation of mass-to-light ratio Υ_{dyn} is as follows, with the widely-used assumption that a galaxy's luminosity is approximately equal to half of its stellar mass.

$$\Upsilon_{dyn} = \frac{M_{dyn}}{L} = \frac{M_{dyn}}{(M_*/2)} \tag{3}$$

The values of these parameters for the simulated EDGE dwarf galaxies are produced by the Python script used for data analysis on simulated halo databases (see Python notebook in Github repository). Two halo databases are analyzed: Halo 339 and Halo 261. Each database is created within a cosmological void containing baryonic matter and cold dark matter. In order to obtain useful data, various cuts are made to the halos within the database. These filters include excluding all halos with zero stellar mass, halos with a contamination fraction > 0.1, and visually determining viable subhalos within a larger parent halo. Finally, the needed parameters for each galaxy within a valid halo are calculated and compiled into csv files.

4 Results

The mass-to-light ratios for each local volume dwarf galaxy and globular cluster were calculated, analyzed, and compared with EDGE ratios as shown in the plots below.

Mass-to-light ratio is visually represented as slope lines on the dynamical mass versus stellar mass plot (in log_{10} units). The grey dashed lines denote reference values of Υ_{dyn} = 1, 50, and 1000. A standard dwarf galaxy has a typical mass-to-light ratio of 1000, whereas globular clusters tend to have ratios of around 1. The Milky Way galaxy itself has a ratio of approximately 100. The local volume dwarfs and globular clusters both have roughly log-linear relationships, with a higher stellar mass corresponding to a higher dynamical mass. This correlation also matches the linear slope of mass-to-light ratio. As expected, local volume globular clusters have a significantly lower trend towards

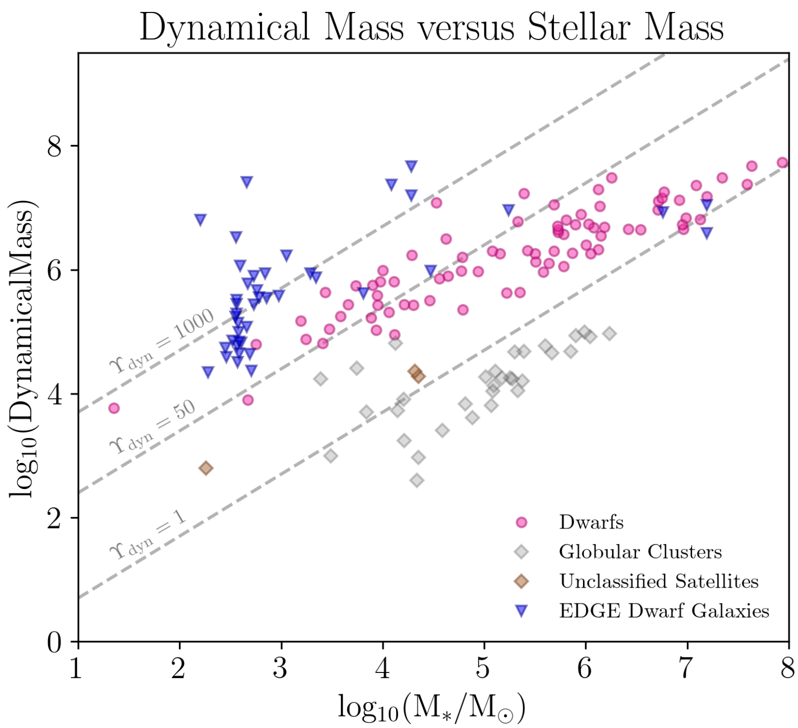

Figure 2: Dynamical mass of local volume dwarfs, globular clusters, and unclassified satellites with EDGE dwarf galaxies plotted against stellar mass. Mass-to-light ratio values are denoted by grey dashed lines with values of 1, 50, and 100.

a mass-to-light ratio $<$ 50, as they are thought not to be very dark matter dominated.

The simulated EDGE dwarf galaxies, however, do not show a noticeable log-linear relationship between dynamical mass and stellar mass. There is notable clumping of dwarfs towards the lower end of the stellar mass scale, between around $10^2 - 10^3 M_\odot$. This is consistent for the average size of dwarfs being simulated with updated EDGE2 parameters, as modeling extremely low-mass galaxies is crucial in order to examine galaxy formation physics and consequences of alternative dark matter models. However, there is a similar distribution in EDGE dynamical mass spread compared to local volume dwarfs.

Further data analysis was conducted on the local volume dwarfs in the form of linear regression. A linear best fit was calculated using SciPy curve fit, as shown in Figure 3.

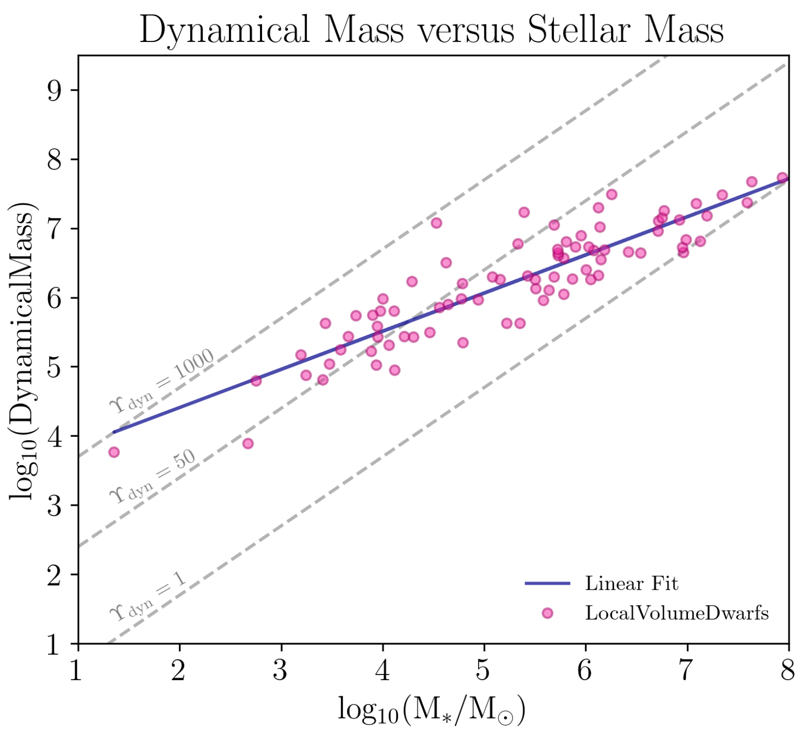

Figure 3: Log-linear fit of local volume dwarfs galaxy data with mass-to-light ratio lines for reference.

5 Conclusion

Overall, mass-to-light ratio is a helpful tool in analyzing both observational and simulation data. When applied to faint, low-mass dwarf galaxies, is it easier to see the total contribution of dark matter mass compared to stellar mass.

References

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