ASTR 400B Homework 3

Stellar and Dark Matter Mass Fractions in Galaxies: A Brief Analysis

My python code entitled GalaxyMass generated the data used in the following table.

Galaxy	Halo Mass (10^12 M☉)	Disk Mass (10^12 M☉)	Bulge Mass (10^12 M☉)	Total Mass (10^12 M☉)	Baryon Fraction
Milky Way	1.975	0.075	0.01	2.060	4.13 %
Andromeda (M 31)	1.921	0.12	0.019	2.060	6.75%
Triangulum (M 33)	0.187	0.009	0.000	0.196	4.59%

Table- Mass Distribution and Baryon Fractions of Key Galaxy Components: Milky Way, Andromeda (M31), and Triangulum (M33)

1. <u>Total Mass Comparison and Dominant Galaxy Component</u>

The total mass of the Milky Way (MW) and Andromeda (M31) in this simulation is found to be nearly identical, each measuring 2.060 x 10^12 solar masses. This result suggests that both galaxies possess comparable dark matter halo masses within the modeled framework.

The dominant contributor to the total mass in both galaxies is the dark matter halo, which constitutes over 95 percent of the total mass budget. The stellar components, including the disk and bulge, contribute only a minor fraction. This is consistent with Lambda Cold Dark Matter cosmology, wherein galaxies form within extended dark matter halos that far exceed the stellar mass content.

2. <u>Stellar Mass and Luminosity Expectation</u>

Despite their nearly identical total masses, M31 exhibits a significantly higher stellar mass, 0.139 x 10^12 solar masses, compared to the MW, 0.085 x 10^12 solar masses. This difference is primarily due to M31's more massive disk and bulge, which are approximately 1.6 times more massive than their MW counterparts.

Given that galaxy luminosity is directly correlated with stellar mass, it is reasonable to expect M31 to be intrinsically more luminous than the MW. This expectation aligns with observational data, which indicate that M31 is indeed one of the most luminous galaxies in the Local Group, marginally outshining the MW. Estimates suggest that M31's luminosity is about 25% higher than that of our own galaxy.

3. Dark Matter Mass Ratio and Stellar Mass Discrepancy

The dark matter masses of the MW and M31 are remarkably similar, with values of 1.975 x 10^12 solar masses and 1.921 x 10^12 solar masses, respectively. The ratio of their dark matter content is therefore:

MW to M31 dark matter mass ratio = 1.975 / 1.921 = 1.03

This three percent difference is relatively minor, suggesting that both galaxies formed within halos of comparable mass. However, given that M31 has a significantly higher stellar mass than the MW, this result is nontrivial. If the efficiency of stellar mass conversion from gas were uniform, one would expect M31's dark matter content to exceed that of the MW. The fact that this is not the case suggests either:

a. Differences in Star Formation Histories: M31 may have undergone more efficient gas accretion and conversion into stars, leading to a higher stellar-to-dark-matter ratio. This is merely a hypothesis.

b. Variations in Feedback Processes: The MW might have experienced stronger stellar and active galactic nucleus feedback, reducing its final stellar mass.

c. Different Assembly Histories: M31 may have undergone a greater number of minor mergers, increasing its stellar mass without significantly increasing its dark matter halo mass.

4. Baryon Fraction and Comparison to Cosmic Mean

The stellar mass fraction, often referred to as the baryon fraction, is computed as:

baryon fraction = stellar mass / total mass

for each galaxy:

Galaxy	**Total Mass (10^12 M☉)**	**Stellar Mass (10^12 M☉)**	**Baryon Fraction (10^12 M☉)**
Milky Way	2.060	0.085	4.13%
Andromeda (M 31)	2.060	0.139	6.75%
Triangulum (M 33)	0.196	0.009	4.59%

Table 2-Baryon Fractions

These baryon fractions are significantly lower than the cosmic mean baryon fraction, which is approximately 16 percent. The discrepancy is expected and can be attributed to several astrophysical processes:

a. Gas Ejection from Feedback Mechanisms: Stellar and active galactic nucleus driven winds can expel baryonic gas from galaxies, particularly during active star formation phases. This process removes gas while leaving the dark matter halo largely unaffected.

b. Inefficient Star Formation: Not all baryons within a galaxy's halo collapse into stars. A substantial fraction remains in a diffuse gaseous state or is ejected due to supernova-driven outflows.

c. Dark Matter Halo Overdensity: Galaxies reside in regions of the universe where the dark matter density is higher than average. Consequently, the local baryon fraction in these halos may be systematically lower than the universal mean.

Given that the gas mass in the MW and M31 disks is negligible compared to the stellar component, these mechanisms provide an explanation for why the baryon fraction in galaxies is lower than the cosmic value.

Discussion

This analysis confirms that the MW and M31 possess comparable total masses, though M31 has a significantly higher stellar mass. Dark matter dominates the total mass budget in both galaxies, with baryon fractions well below the cosmic average.

The results suggest that feedback-driven gas loss and inefficient star formation play a fundamental role in shaping the baryon content of large galaxies.