Central American - Caribbean Bridge in Astrophysics

Credit: Kate (Kunyoung) Kim

Study of spiral galaxies and their environment

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To my friends, my partner and my family for all their love.

Abstract

Of the multi-arm spiral galaxies that are observed in the local universe, a majority of them have either two or four spiral arms. Rare are spirals with three spiral arms. The reason for this scarcity of odd-numbered spiral modes has been a source of speculation for some time now. This problem leads us to study the environment in which spiral galaxies develop according to their number of arms. In this study, we investigated how densely populated a galaxy's environment was according to the number of arms. We used the Galaxy And Mass Assembly (GAMA) survey and the Galaxy Zoo project data to plot the histogram of a galaxy's fifth nearest neighbour, surface density and number of galaxies within a cylinder vs their number of arms. We then applied the Kolmogorov-Smirnov test to see how similar these distributions were. We found that spiral galaxies, regardless of their number of arms, seem to live in a similarly dense environment. However, there seem to be some suggestions that the bigger the number of arms, the less dense the environment. All spiral galaxies seem to live in a group in similar proportion except for 4-arm spiral galaxies.

1 Introduction

A galaxy is a gravitationally bound system of stars, stellar remnants, interstellar gas, dust, and dark matter (Sparke & Gallagher (2000)). Galaxies are categorized according to their visual morphology as elliptical, spiral (Figure 1), or irregular (Jarrett (2000)). Initially described by Edwin Hubble (Hubble (1982)), spiral galaxies are named by their spiral structures that extend from the centre into the galactic disc. Together with irregular galaxies, spiral galaxies make up approximately 60% of galaxies in today's universe (Loveday (1996)).

Figure 1: An example of a spiral galaxy is the Pinwheel Galaxy (also known as Messier 101 or NGC 5457 (NASA (2006)).

Of the multi-arm spiral galaxies that are observed in the local universe, a majority of them have either two or four spiral arms (Hancock (2019)). Rare are spirals with three spiral arms. The reason for this scarcity of odd-numbered spiral modes has been a source of speculation for some time now. This problem leads us to study the environment in which spiral galaxies develop according to their number of arms.

Galaxies are not distributed evenly throughout the universe but tend to congregate in groups and clusters. The 'environment' of a galaxy is described by how other galaxies are distributed in its immediate neighbourhood. Evidence suggests that interactions between galaxies and their environments play an important role in galaxy formation and evolution (Dressler (1980)).

In this study, we investigated how densely populated a galaxy's environment was according to their number of arms.

2 Methods

We used the Galaxy And Mass Assembly (GAMA) survey (Driver et al. (2011)) for this study. GAMA brings together data from several world-class instruments: The Anglo-Australian Telescope (AAT), The VLT Survey Telescope (VST), The Visible and Infrared Survey Telescope for Astronomy (VISTA), The Australian Square Kilometre Array Pathfinder (ASKAP), The Herschel Space Observatory and The Galaxy Evolution Explorer (GALEX).

From the third GAMA data release (Baldry et al. (2018)), we used the `EnvironmentMeasures` data, which provides several different metrics of the local environment of galaxies. We also used the `MAGPHYS`, which computes the stellar masses. We joined the GAMA dataset with the Galaxy Zoo citizen science project (`www.galaxyzoo.org`) (Raddick et al. (2009)). From Galaxy Zoo 4, we got information on the galaxies' morphology.

Each spiral galaxy is defined by its spiral arm number, voted by Galaxy Zoo participants classified as m = 1, m = 2, ..., m = 5+. The full decision tree for the Galaxy Zoo project is shown in Figure 2. Joining the datasets, we selected our sample of galaxies based on their redshift, stellar mass and number of arms. To be part of the sample, a galaxy must have a stellar mass larger than $M_* > 10^9$ and a redshift less or equal to $z \leq 0.08$. This is to avoid those galaxies whose spiral arms are not correctly represented by Galaxy Zoo votes because of unclear imaging or lack of distinction between arms. To fall into m = n, a galaxy must have received at least 50% of votes in favour of having n spiral arms. Second, the galaxy must have less than 100% votes in favour of having n spiral arms. This eliminates some galaxies that have a very low number of votes. Our sample can be seen in Figure 3.

After this selection, we made a histogram of galaxies m = 1, m = 2, ..., m = 5+ and their distance to their fifth nearest neighbour to see how densely populated their environments are. The closer a fifth nearest neighbour is, the more densely populated the galaxy's environment. We also made histograms for the galaxies' surface density and the number of galaxies within a cylinder (CountInCyl).

We then applied the Kolmogorov-Smirnov test. The K-S test statistic indicates how similar one distribution is to another, with smaller values being more similar and larger values being less similar, where a statistic of 0.0 indicates two identical distributions. The p-value associated with each K-S statistic dictates the significance of the K-S statistic, and we considered a p-value of 0.05 or lower to be significant. We applied the test to the distribution of one-arm spiral galaxies and their distance to their fifth nearest neighbour vs the distribution of all spiral galaxies (without one-arm spiral galaxies being accounted for) and their distance to their fifth nearest neighbour. We did this to all n-arm spiral galaxies and also for their surface density and CountInCyl distributions.

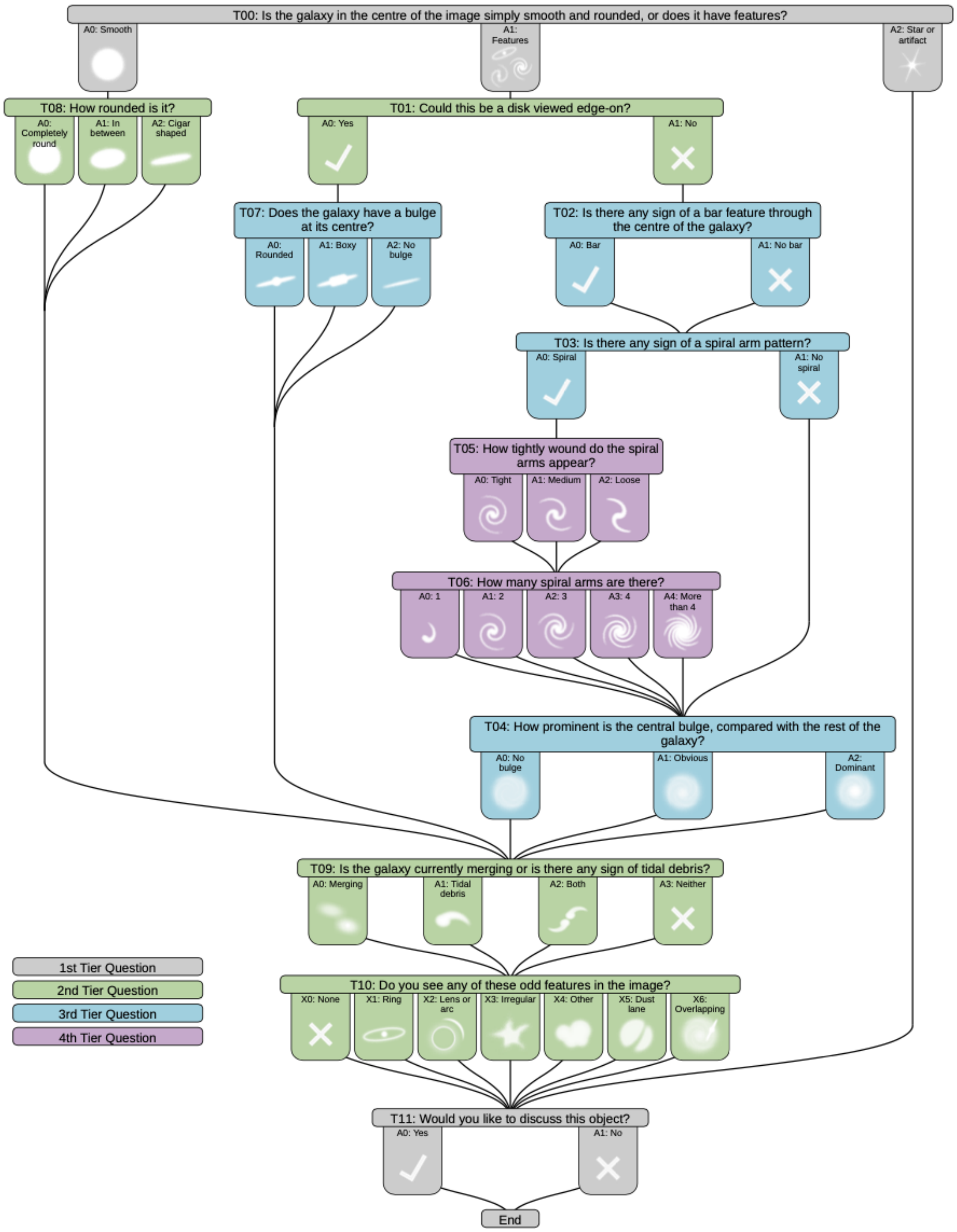

Figure 2: Galaxy Zoo 4 decision tree. Porter-Temple et al. (2022)

After this, we decided to study galaxies that were part of a group and see whether there was any difference according to the number of arms. We used the `G3CGalv10` data from GAMA. We calculated the fraction of each corresponding arm of galaxies that were part of a group and galaxies that were not part of a group.

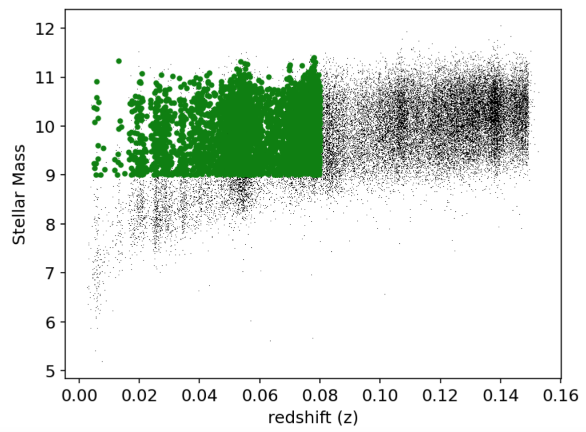

Figure 3: Stellar Mass vs Redshift from our data. The green dots indicate our sample. We have about 3000 spiral galaxies.

3 Results and discussion

Our results can be summarised in Table 1.

3.1 Fifth nearest neighbor

Figure 4 shows the histograms for the fifth nearest neighbour parameter. For this parameter, we found two significant results for m = 2 and m = 5+ with small K-S test statistic values suggesting that their distribution does not differ much from the other spiral galaxies. An interesting thing to note is that m = 4 and m = 5+ have the highest K-S test statistic, with the distribution of 4-arms spiral galaxies looking more dissimilar than the others.

3.2 Surface density

Figure 5 shows the histograms for the surface density parameter. For this parameter, we did not find any statistically significant result. The smaller significance is for m = 2, suggesting a similar distribution. The highest K-S test statistic is for m = 4.

3.3 CountInCyl

The histograms for the CountInCyl parameter can be found in Figure 6. For this parameter, we have one statistically significant result indicating that m = 2 galaxies have a similar distribution to the rest. We found again that m = 4 has the highest K-S test statistic. An interesting thing to note is that contrary to the other two parameters, CountInCyl is not continuous, so the K-S test may not be the best statistical test for its evaluation.

		2-Sample K-S Test	
		Statistic	Significance
DistanceTo5nn	m = 1	0.081	0.497
	m = 2	0.062	**0.017**
	m = 3	0.059	0.624
	m = 4	0.168	0.463
	m = 5+	0.172	**0.044**
SurfaceDensity	m = 1	0.108	0.175
	m = 2	0.050	0.08
	m = 3	0.043	0.919
	m = 4	0.185	0.345
	m = 5+	0.120	0.298
CountInCyl	m = 1	0.033	0.999
	m = 2	0.063	**0.014**
	m = 3	0.072	0.368
	m = 4	0.195	0.289
	m = 5+	0.119	0.312

Table 1: Spiral arm number (m), Kolmogorov-Smirnov test statistic and significance for distance to the fifth nearest neighbour, surface density, and the number of galaxies in a cylinder are shown under the header 2-sample K-S Test. Bold values for the K-S test significance are the statistically significant values discussed.

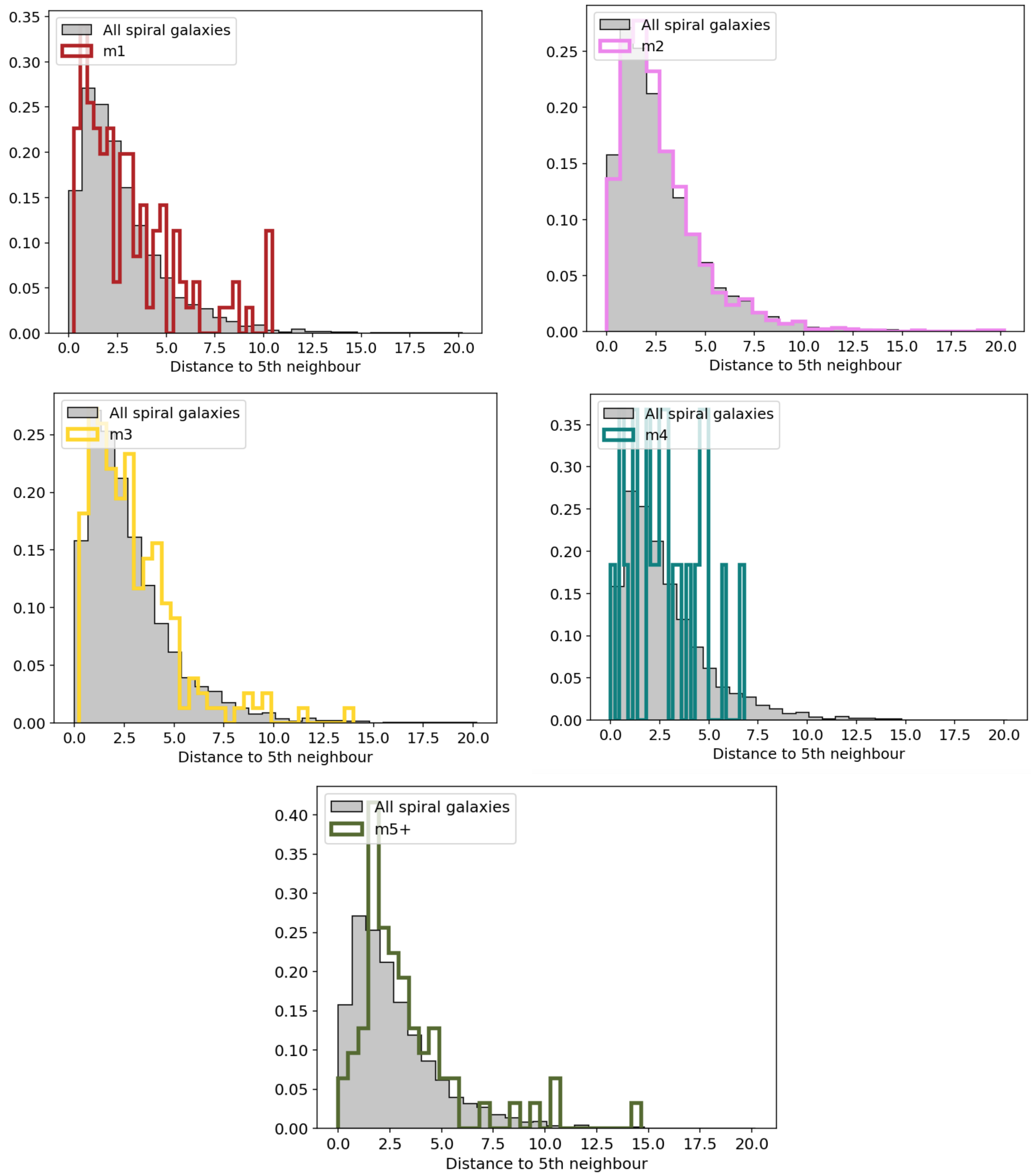

Figure 4: fifth nearest neighbour histograms for each type of spiral galaxies selected. The grey-filled histogram shows the distributions of the entire sample, while the coloured outlines show the distribution for the individual spiral arm number.

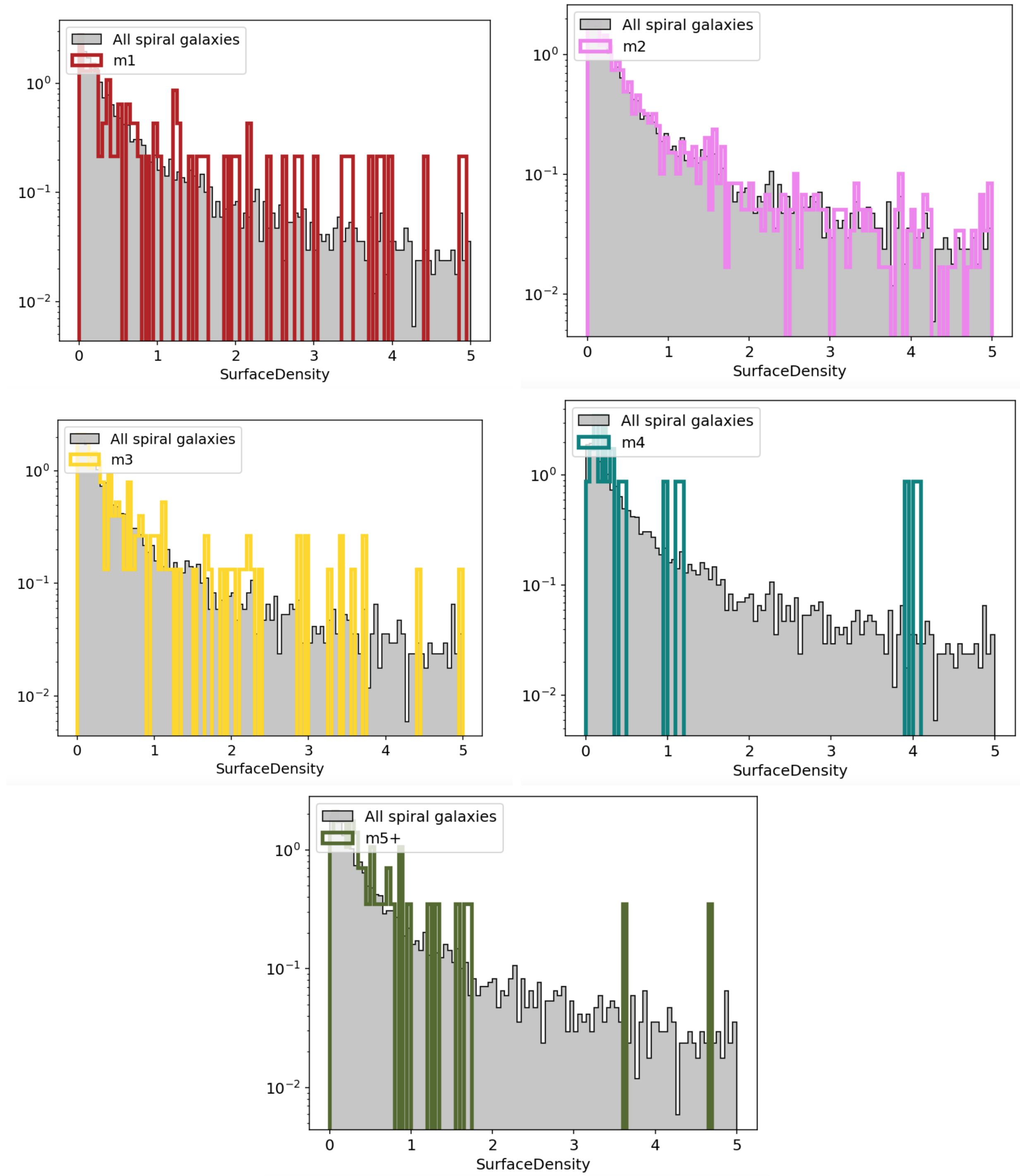

Figure 5: Surface density histograms for each type of spiral galaxies selected. The grey-filled histogram shows the distributions of the entire sample, while the coloured outlines show the distribution for the individual spiral arm number.

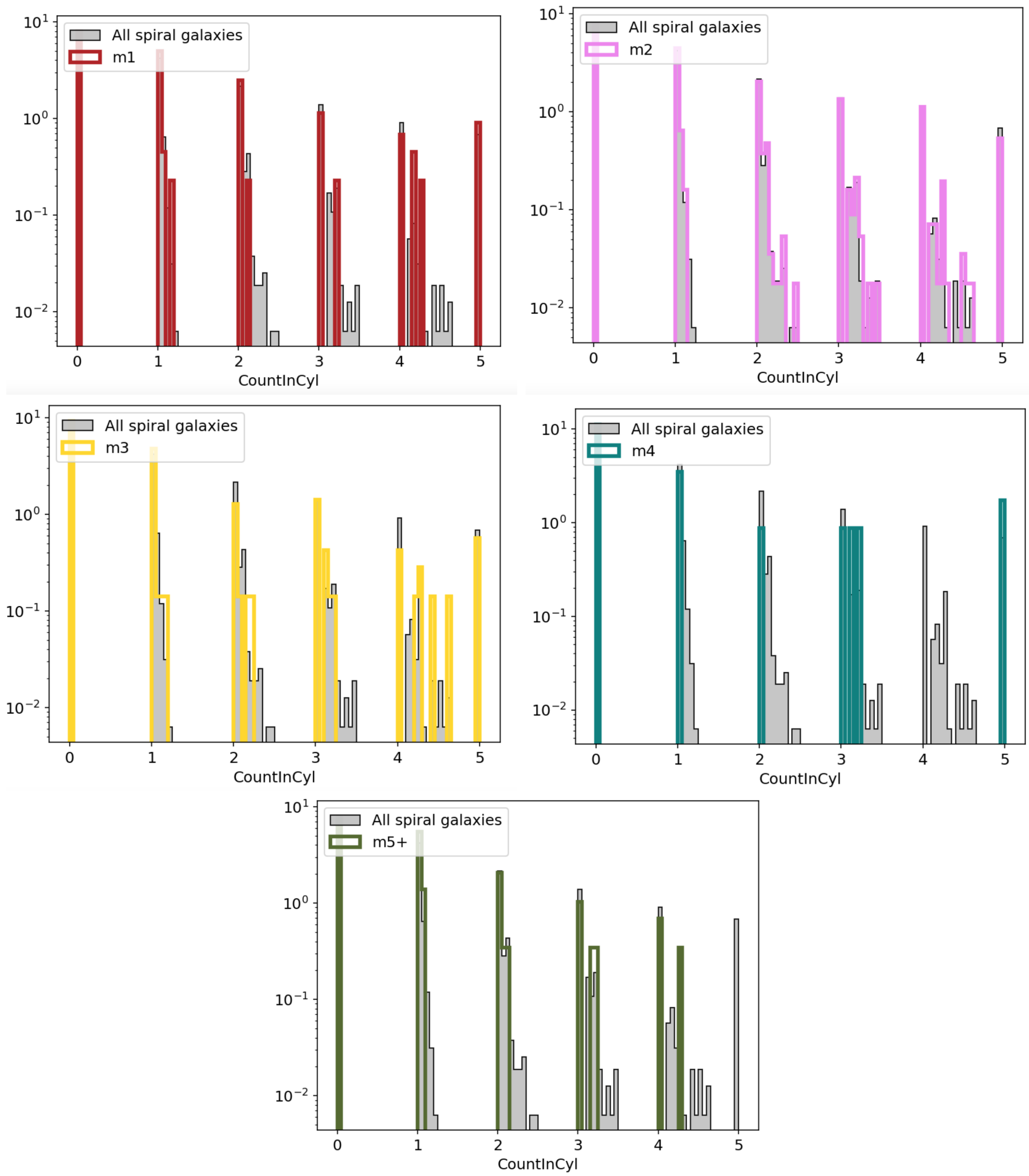

Figure 6: CountInCyl histograms for each type of spiral galaxies selected. The grey-filled histogram shows the distributions of the entire sample, while the coloured outlines show the distribution for the individual spiral arm number.

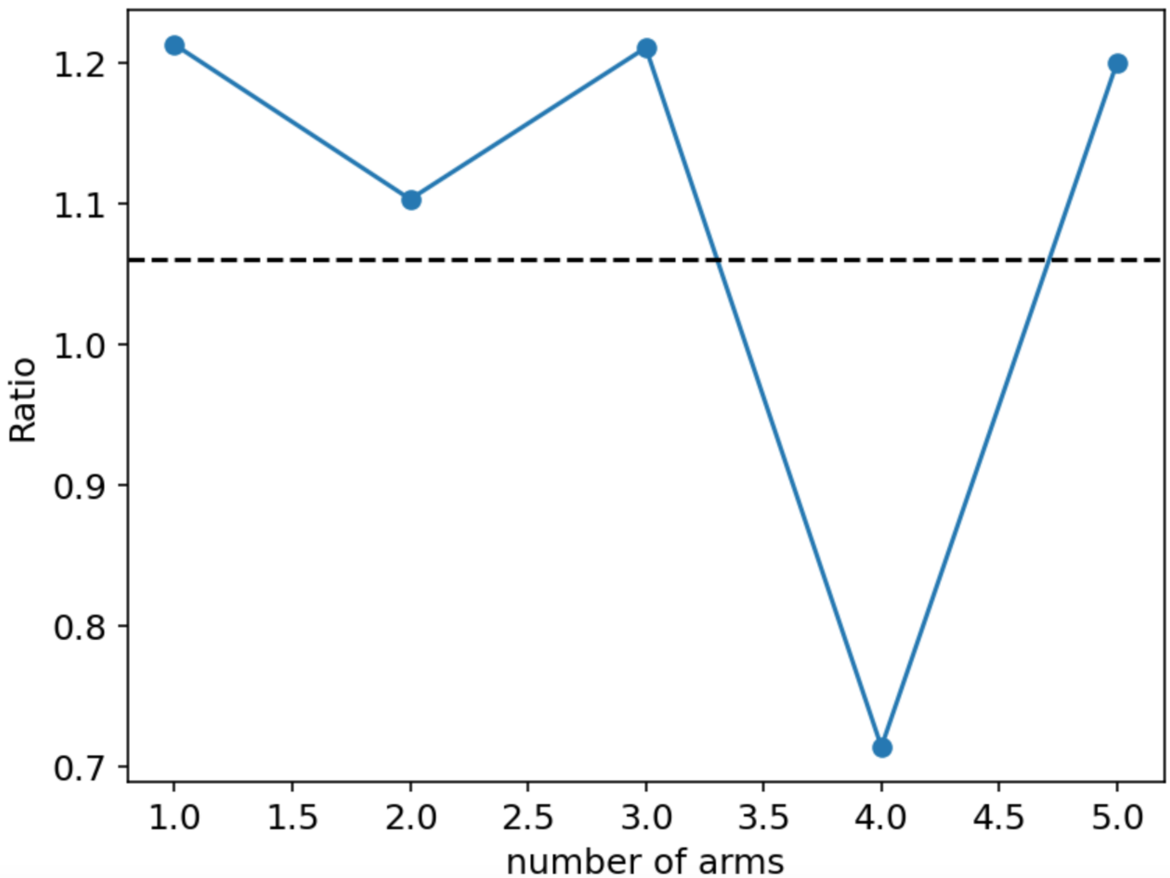

Figure 7: Ratio of galaxies in a group and not in a group according to their number of arms. The solid, dashed black line is the ratio of all spiral galaxies.

3.4 Fraction of galaxies in a group

A plot with the ratio between galaxies in a group and galaxies not in a group can be found in Figure 7. Most spiral galaxies seem to have a similar group and not in a group ratio, except for 4-arm spiral galaxies. The difference in 4-arm spiral galaxies may be because 4-arm spiral galaxies tend to be bigger and need more space to themselves. This is interesting combined with the result that 4-arm spiral galaxies also had the highest K-S test statistic in each parameter, although those results were not significant enough.

4 Conclusions and recommendations

In this study, we found:

- Spiral arm galaxies seem to live in similarly dense environments.
- All spiral galaxies seem to prefer to live in a group environment except for 4-arm spiral galaxies.

We also see hints that the more arms a galaxy has, there is a slight preference for a less dense environment.

4-arm spiral galaxies and their environments merit further study with a larger sample, for example, the future Galaxy Zoo 5.

References

Baldry, I. K. et al. 2018, MNRAS, 474, 3875

Dressler, A. 1980, ApJ, 236, 351

Driver, S. P. et al. 2011, MNRAS, 413, 971

Hancock, C. 2019, Master's thesis, University of Alabama, Tuscaloosa

Hubble, E. 1982, The Realm of the Nebulae, The Silliman Memorial Lectures Series (Yale University Press)

Jarrett, T. 2000, Publications of the Astronomical Society of the Pacific, 112, 1008

Loveday, J. 1996, Monthly Notices of the Royal Astronomical Society, 278, 1025

NASA, E. S. A. . 2006, Largest ever Hubble galaxy portrait - stunning HD image of Pinwheel Galaxy

Porter-Temple, R. et al. 2022, Monthly Notices of the Royal Astronomical Society, 515, 3875

Raddick, M. J. et al. 2009, arXiv preprint arXiv:0909.2925

Sparke, L., & Gallagher, J. 2000, Galaxies in the Universe: An Introduction, Galaxies in the Universe: An Introduction (Cambridge University Press)