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Exploring the Dependence of Bulges in Spiral Galaxies on Their Environment

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EXPLORING THE DEPENDENCE OF BULGES IN SPIRAL GALAXIES ON THEIR ENVIRONMENT

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ABSTRACT

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Recent research has shown a relationship between spiral galaxy satellite populations and the size of spiral bulges. The modern cosmological model of our universe (ΛCDM), does not predict this. Instead, ΛCMD predicts that only the total dynamical mass of a host galaxy should be correlated with satellite populations. We investigate this relationship in regimes other than satellites. In this study we compare the bulge to total mass ratios of spiral galaxies to the number of nearby galaxies within "n" Mpc. We use four papers from literature that calculate bulge to total mass ratios of 189 spiral galaxies using different techniques. We reduce these 189 galaxies down 99 galaxies who all have heliocentric-corrected redshift values $0.005 \leq z \leq 0.03$. We use NASA Extra-galactic Database (NED hereafter) to determine the number of nearby galaxies within "n" Mpc of each of the selected spirals. We consider the relative luminosity completion in this database as well as the inaccuracies that are inherent in such large scale "crowd sourced" databases. From these considerations we make appropriate cuts. Finally we compare our results with recent literature and determine the effectiveness of using NED in this way. We find using NED is currently impractical for determining accurate nearby galaxy counts. For this reason, We find no obvious correlations between spiral galaxies bulge to total mass ratios and the number of nearby galaxies within "n" Mpc.

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CHAPTER 1

INTRODUCTION

Galaxies are some of the largest gravitationally bound objects in our universe. In this study we focus specifically on spiral galaxies. Spiral galaxies are notable for their disk shaped appearance and are regularly accompanied by spiral arms stretching throughout their disks. Spiral galaxies often contain an over abundance of stars near their centers. These over abundance's are referred to as bulges. Large spiral galaxies often have smaller galaxies orbiting them. These smaller galaxies are referred to as satellite galaxies. We attempt to find a relationship between the bulges of spiral galaxies and the number of nearby galaxies in a more general sense. In our case a galaxy is considered to be nearby if it is within some specified number of Mpc to the spiral galaxy in question. Instead of comparing the number of nearby galaxies to bulge mass, we compare the number of nearby galaxies to the mass of the bulge divided by the total mass of the galaxy (B/T hereafter). These B/T ratios are derived quantities. In particular, they are derived from computer models that use observed fluxes as input. Therefore, these B/T ratios are baryonic and do not directly include dark matter contributions. Previous literature has shown relationships between B/T ratio and the number of satellite galaxies up to the hosts viral radius ($\sim$ 300 kpc). Simply put, the virial radius is the distance at which it makes sense to consider a object to be gravitationally bound to another object. The major difference between our study and previous investigations is that we do not use surveys specifically designed for satellite population detection, nor do we only consider galaxies near the local group. For some of the closest galaxies outside the local group Javanmardi et al. (2020) [2] showed a positive correlation between the number of satellite galaxies and the B/T ratio of the corresponding host galaxies. The overall success of Javanmardi et al. can be attributed to modern deep field observations of the nearby universe. In an attempt to further this type of research Vudragovic et al. [3] used the second release of the satellites of galactic analog survey (SAGA hereafter) [1] to reproduce somewhat similar results. This type of relationship is important to study as the ΛCDM model of cosmology suggests the number of satellites a host galaxy contains should be correlated to the dynamical mass [4]. Other issues with ΛCDM at similar scales include the missing satellites problem [5], the too-big-to-fail problem [6], and the plane of satellite

problem [7]. Each of these papers and their associated problems call into question the efficacy of ΛCDM at these scales.

The relationship between B/T and satellite populations should be investigated further using complete and accurate data. However, we are limited by the lack of abundant deep field data for any meaningful sample of galaxies that has not already been analyzed in the aforementioned literature. In our present case, we opt instead to broaden our scope of observation to not only satellite galaxy distances, but group and cluster distances as well (1-3 Mpc). In our study we attempt to use NED instead of some dedicated satellite survey like SAGA. While this approach certainly decreases the completeness of our data, we may venture that larger galaxy populations will act as a proxy for satellite galaxy populations. We later comment on the effects this incompleteness has on our results and consider other non-obvious systematic errors in NED. Following this motivation we pull 189 spiral galaxies from literature whose B/T are already calculated. In chapter 2.2 this data is reduced further to 99 spiral galaxies. We then use NED to produce a galaxy catalog that fully encompasses the B/T galaxies range. Finally we calculate and compare the number of galaxies within "n" Mpc for each B/T galaxy. Magnitude cuts are also preformed selectively to facilitate comparison to previous literature.

1.1 MAKING ASTRONOMICAL OBSERVATIONS

Modern astronomical observations are carried out using a variety of telescopes and techniques. While astrophysicists often take astronomical data from literature and immediately apply it to their problem at hand, we should be more mindful and properly understand the techniques used to obtain such data. Although different methods of astronomical observations have appeared in recent years (gravitational wave astronomy), the majority of all current and historic observations of the cosmos have been conducted using telescopes. Telescopes are either ground-based or space-based. While each of these telescopes have their own advantages and shortcomings (accessibility, atmospheric interference etc) they often obtain similar information. The main function of a telescope is to identify objects in the night sky by their position and brightness. Depending on the telescope, these observations are done in what astronomers call, different bands. These bands describe which part of the electromagnetic spectrum was observed (radio, microwave, infrared, visible, ultraviolet, x-ray, and gamma).

The spectra of a galaxy can be used in a non-obvious way to obtain its distance from

Earth. This distance measurement comes from redshift. To understand how distances are derived from redshifts, we consider the expansion of the universe that was first explored by the American astronomer Edwin Hubble. In the late 1920s Hubble used the 100-inch Hooker telescope at Mount Wilson Observatory to measure the redshift of distant galaxies [8]. From these observations, Hubble used Cepheid Variable stars to determine the distances to different galaxies. Hubble determined that the redshift of these far away galaxies were linearly related to their distance from Earth. In modern astronomy, this relationship is known as Hubble's law and is given by Eq. (1):

$$D = \frac{zc}{H_0}, \tag{1}$$

where D is the distance in Mpc, z is the redshift, c is the speed of light in km/s, and H_0 is Hubble's constant which we set to 67.8 km/sec/Mpc. The equation used in determining a galaxies redshift can be found in any modern astronomy textbook. However, we write it here as Eq.(2) for convenience:

$$1 + z = \frac{\lambda_{observed}}{\lambda_{rest}}, \tag{2}$$

where z is the object's redshift, $\lambda_{observed}$ is the wavelength observed by our telescopes and λ_{rest} is the wavelength of the object if it were at rest relative to Earth. The reason farther galaxies have larger redshift is due to the expansion of the universe. We note that using redshift to determine distances to close galaxies may not always be effective as the dominate motion comes from close-by galaxy interactions. Using these Eqs. (1) and (2), astronomers have a reliable way to determine the distance to far away galaxies in the universe. We note this method breaks down at distances on the order of $z = 1$ due to the acceleration of the expansion of the universe. However, due to the motions of Earth and the Milky Way, some corrections still have to be made. For the purposes of our study, we correct redshift values to the frame defined by the 3 K cosmic microwave background radiation (CMB). This conversion is well understood and is given by equation (3).

$$V_{con} = V_{apex}[\sin(b)\sin(b_{apex}) + \cos(b)\cos(b_{apex})\cos(l - l_{apex})], \tag{3}$$

where l and b are the object's galactic longitude and latitude respectively, and V is its unconverted velocity. The apex values are dependent on the frames of reference between which the conversion is carried out. In our research we convert from the heliocentric frame to the 3 K CMB frame where $l_{apex} = 264.14°$, $b_{apex} = 48.26°$, and $V_{apex} = 371.0$ km/sec. We apply these conversions frequently in our research. With the information accumulated thus

far, we have the basic tools to understand how astronomers determine the 3D positions of galaxies in the night sky.

1.2 NED DATA BASE AND ITS LIMITATIONS

NED is the largest catalog of galaxies we have available. This database is the aggregate of modern astronomical observations and is widely utilized for its accessibility and relative completeness. NED takes data from both large and small surveys and compiles them into their database. Data can be queried using a multitude of search parameters. We note that utilizing NED as a data mining/discovery engine has proved fruitful, for example, in the discovery of super luminous spiral galaxies [9]. This recent success gives reason to believe that NED can be utilized in a large scale manner to produce further scientific insight. Table access protocols are frequently utilized in querying astronomical databases. In our research we use table access protocols and built in "search by parameter" functions.

We note that previous studies of the environment versus B/T correlation have not relied on NED in any substantial way [2, 3]. Instead, they either used particular galaxy surveys like SAGA [1], or they strictly focused on nearby galaxies whose satellite populations where extremely well understood. As mentioned before, we expect that using a larger data set will enable us to use the galaxies that are present in the database as a proxy for satellite galaxies. Therefore, we make the assumption that large and luminous galaxies nearby corresponds to an increased number of less luminous satellites that are not accounted for in the database. We justify this assumption as it is reasonable to expect that primordial density clusters also produce a relatively larger number of galaxy satellites. While we are not sure of the effectiveness of this approach, we consider it worth pursuing. Using NED, we conduct three separate queries over a total helio corrected redshift range of $0 \leq z \leq 0.03$. This range yields approximately 142000 objects classified as galaxies in NED. While we go into detail later on some nuanced difficulties that come with using NED, we briefly summarize some of its obvious issues now.

The first aspect of NED to keep in mind is its incompleteness. Luminosity functions are often employed to quantify a databases relative completeness. These function are used to determine how well cataloged databases are in different luminosity bands and intensities. In general its expected that galaxies of greater luminosity are better represented in surveys realative to less luminous galaxies. Blanto et al. [10] goes into detail on the the

luminosity functions associated with one of the largest sky surveys, the Sloan Digital Sky Survey (SDSS). Determining luminosity function is not a straightforward task, and it becomes increasingly difficult when comparing the multiple different catalogs that are present in NED. Many galaxies in NED do not have associated magnitudes (which are used to determine luminosity). This results in a high degree of impracticality when attempting to quantify NED's luminosity completeness. In the case of NED one must abandon the use of luminosity completeness and instead only consider galaxy counts. From NED's website we obtain Figure 1. This figure demonstrates the completion of NED compared to a simple cosmological model. The specifics of this particular model are of no direct interest in our research however we note the difference between the model's expectation and NED actual galaxy count. In particular, we see at low redhift values ($z \sim 0.03$) NED has a steep drop in completion compared to the expected differential galaxy count.

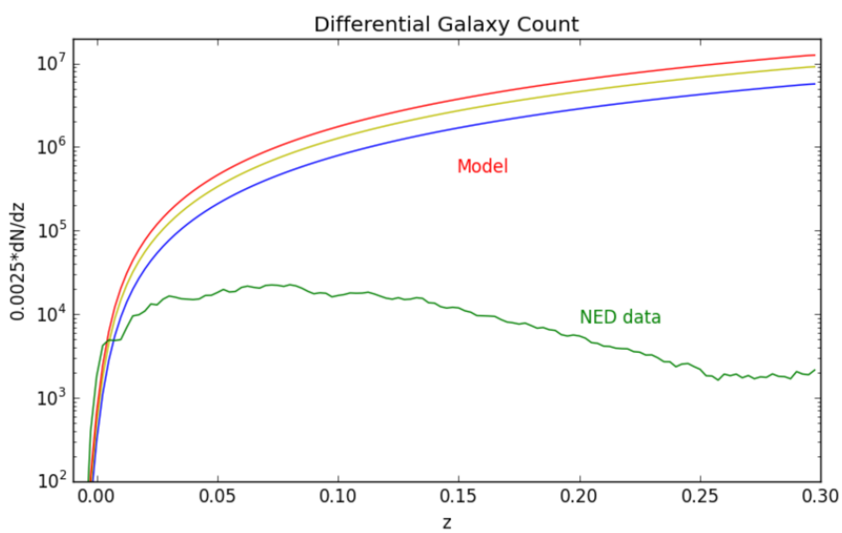

FIGURE 1. Differential counts of galaxies with spectroscopic redshifts in NED. This data is compared to model predictions of the galaxy redshift distribution, obtained by multiplying the co-moving volume element by an empirical estimate of the galaxy number density. Its assumed that the galaxy number density is redshift-independent at these low Redshift's. The three model curves show the median and 1-sigma variation in published estimates of the average galaxy density in this redshift range. This figure is from the NED holdings website.

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The cause of this incomplete data comes from the nature of astronomical observation. The luminosity of a galaxy is independent of its distance from Earth, however we do not observe luminosity directly. Instead, we observe apparent magnitude, which is dependent on the distance from earth (see chapter 1.3 for more detail). This results in more distant galaxies being harder to observe and catalog. We keep this in mind as we continue this research to be careful not to bias our results.

The second aspect of NED to keep in mind is that NED is essentially a crowd-sourced catalog. NED does not preform any particular sky surveys. Instead, the NED team takes other surveys and observations from literature and compiles them into their database. This process is prone to contamination. Fake objects find there way into the NED catalog and in some cases overpopulate real objects (see chapter 3.2 for more detail).

1.3 ATTEMPTING ABSOLUTE MAGNITUDE CUTS

As mentioned in section 1.2 the brightness of an object as seen on Earth is not exactly representative of the objects absolute brightness. In astronomy and astrophysics brightness values are referred to as relative magnitude and absolute magnitude respectively. We note that due to historical quirks, brighter objects have smaller (often negative) magnitudes. Astronomical surveys like SDSS publish the relative magnitudes of galaxies in particular bands of the electromagnetic spectrum. Using the magnitudes from these surveys one can use Eq. 4 to determine how bright an object would be if it were 10 parsecs away (absolute magnitude):

$$M = m - 5\log_{10}(D/10), \tag{4}$$

where M is the absolute magnitude, m is the apparent magnitude, and D is the distance in parsecs. Calculating absolute magnitudes gives astronomers a way to compare different objects at different distances as if they were all the same distance away. This transformation is a straight-forward task. However, before one compares different galaxies magnitudes, one must consider which part of the electromagnetic spectrum those magnitude values were observed in. This is to say, while one galaxy or star may be very bright in the infrared, it may be fairly dim in the visible spectra. To compare our results to previous literature [2], we will only consider NED galaxies with $M_V \leq -8.2$ (less than or equal because brighter objects have lower magnitude values). M_V signifies that this magnitude band is the Johnsons-Cousins V band. This restriction/cut requires us to determine our NED galaxies magnitude in this particular band. NED magnitude data is given in 23 different bands/surveys. Unfortunately, not every galaxy has a published magnitude and not all galaxies which are published have

magnitudes published in all 23 bands/surveys. Our goal is to compare these magnitude values and cut all the galaxies from our sample that do not have $M_V \leq -8.2$. However, converting these bands to Johnsons-Cousins V band is not straight-forward. Usually, these conversion equations only convert between the difference between bands (also know as color index). We strive to make conversions when possible, but admit that many conversions can not be preformed. In fact, the only practical transformation is that of SDSS to Johnson-cousins. All other surveys/bands do not have general transformation equations. We use Eq. (5) to transform SDSS g and r band magnitudes to Johnson-Cousins V band [11]. Furthermore, we use C-model data (a particular model SDSS uses to extract magnitudes from images) as it is recommended for galaxies by the SDSS team. With this transformation equation we can directly compare our results to those found in previous literature:

$$V = g - 0.5784(g - r) - 0.0038, \tag{5}$$

TABLE 1

Demonstrates how many galaxies in our NED sample have published magnitudes in particular surveys or bands. Approximately 86% of galaxies in our NED sample have a published magnitude in at least one band or survey.

Survey/Band	N
GALEX ASC FUV Kron	34359
GALEX ASC NUV Kron	44216
GALEX ASC FUV 7.5”	42405
GALEX ASC NUV 7.5”	44216
GALEX MSC FUV Kron	11462
GALEX MSC NUV Kron	16036
GALEX MSC FUV 7.5”	13723
GALEX MSC NUV 7.5”	16036
SDSS-DR6 u PSF	40714
SDSS-DR6 g PSF	40714
SDSS-DR6 r PSF	40714
SDSS-DR6 i PSF	40714
SDSS-DR6 z PSF	40714
SDSS-DR6 u Cmodel	39280
SDSS-DR6 g Cmodel	39280
SDSS-DR6 r Cmodel	39280
SDSS-DR6 i Cmodel	39280
SDSS-DR6 z Cmodel	39280
RC3 (m_B)	13108
APM b(J)	14711
2MASS J	56234
2MASS H	56234
2MASS K_s	56234

1.4 PYTHON CODE

We use a python code to determine the number of nearby galaxies to each of our spirals. This code determines which galaxies from the NED data have redshift values that are accurate to at least 4 decimal points and have redshift values greater than $z = 0.005$. Galaxies that do not meet this criteria, are considered ”unreliable” and are marked as such in the

data. We go over the reasoning for these cuts in chapter 3.

The code then converts all galaxies' redshifts to 3K CMB corrected distances in Mpc, using Eq.(3). Finally the code finds the number of neighbors within a specific number of Mpc for each of our spiral galaxies. If any of the neighboring galaxies are part of the "unreliable" group, the code no longer considers that spiral galaxy in any further analysis. Plots are the produced showing the bulge to total ratios against the number of neighbors within "n" Mpc. Another version of this code also makes magnitude cuts for SDSS magnitudes. Plots with these cuts are given in Appendix C. Figure 2 and Figure 3 show the processes described above.

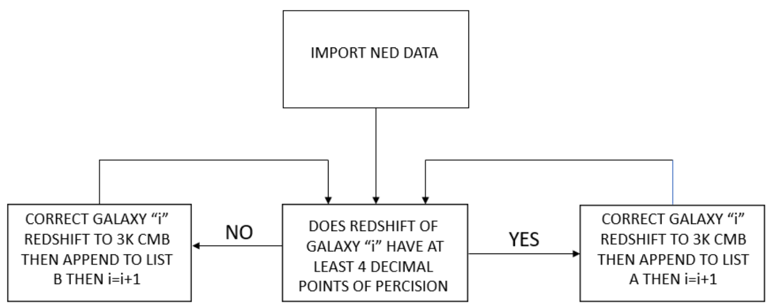


FIGURE 2. Flow chart demonstrating how the python code determines which NED galaxies are unreliable. This process halts when all "i" galaxies have been appended to a list.

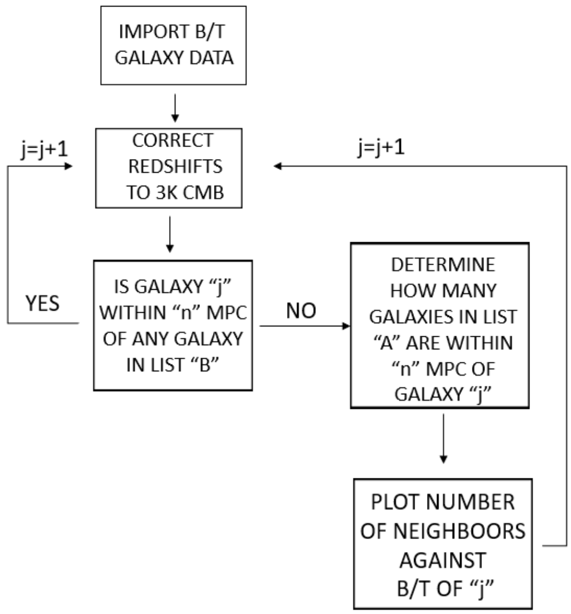


FIGURE 3. Flow chart demonstrating how the python code determines which B/T spirals are used in final analysis. This process halts when all eligible "i" galaxies have been plotted.

CHAPTER 2

BULGE TO TOTAL RATIOS FROM LITERATURE

2.1 LITERATURE SOURCES

In our research we utilize four papers that calculated bulge to total mass ratios of different galaxies. In this section we will go over the context of these papers as well as the models they used to determine M/L. Although the results from these papers do not directly impact our research, we believe that understanding the context of their calculations is valuable. We note that the Vudragovic [3] paper very closely resembles the focus of our research. We consider the results of this paper in more detail and compare it to our own results in chapter 4.2.

2.1.1 LAURIKAINEN ET AL. 2010

The authors of Laurikainen et al. [12] performed a visual multi-component decomposition (decomposing galaxies into their bulges, disks, and bars), using the decomposition tool BDBAR [13], on deep Ks-band images of 122 early-type disk galaxies and combined them with previous results to form a sample of 175 galaxies. The authors compared their results with the Ohio State University Bright Spiral Galaxy Survey (OSUBSGS) of nearly 200 spiral galaxies and found scaling relations between the parameters of bulges and disks in S0 galaxies and spirals. The main results of the study found coupling between the formative processes of bulges and disks in S0s. The authors concluded that spiral galaxies with bulges brighter than -20 mag in the K-band can evolve directly into S0s due to stripping of gas followed by suppressed star formation.

2.1.2 LIN ET AL. 2018

In this paper, Lin et al. [14] studied the spatially resolved stellar kinematics and luminosity distributions of a sample of 13 galaxies, which included 8 active galactic (AGN) picked from the 58-month Swift-BAT catalogue and 5 inactive galaxies selected from the local luminous AGN with matched analogs survey (llama). These inactive galaxies were selected as specific pairs to the AGN. Throughout their research they utilized the decomposition

tool GALFIT [15] to decompose their sample galaxies into bulges and disks. The authors eventually concluded with discussions on the kinematics and photometry between the two galaxy samples.

2.1.3 WEINZIRL ET AL. 2009

The authors Weinzirl et al. [16] used Sersic index's as well as B/T ratios to better understand how bulges form. This research utilized GALFIT to preform 2D bulge-disk and bulge-disk-bar decomposition's of 143 spirals from OSUBSGS. In this study the authors found that it was necessary to include the bar component when preforming 2D decomposition of barred galaxies. They found that when the bar was not included the bulge-to-total ratio was overestimated. They also note: "The overall picture that emerges is that the observed large frequency ($\tilde{6}6\%$) of high mass ($M_* \geq 10^{10} M_\odot$) spirals with low present-day bule to total ratios, $B/T \leq 0.2$, can be accounted for in our hierarchical models by high mass spirals, which have not undergone a major merger since $z \leq 2$, and most of which have not even experienced a major merger since $z \leq 4$. Most of these present-day low $B/T \leq 0.2$ bulges are likely to have been built by a combination of minor mergers and/or secular processes since $z \leq 4$." The insight from this quote is relevant when attempting to better understand the relationship between near neighbors and the B/T of spirals. Mergers by nature, reduce the number of nearby galaxies to the spiral in question. While we do not directly take into account galaxy masses in this paper, we recognize the benefit that accounting for galaxy mass could yield in this type to research.

2.1.4 VUDRAGOVIĆ ET AL. 2022

Vudragović et al. [3] investigated correlations between the number of satellites around spiral galaxies and fundamental properties of Milky Way-like host galaxies. The Satellites of Galactic Analogs survey (SAGA) was used to obtain spectroscopic observations of 36 Milky Way-like spiral galaxies along with their corresponding satellite populations. The results of the study showed no significant correlation between the number of satellites and other galactic properties. However, when the authors considered the expected number of satellites based on previous calculations, they found a strong correlation between the mass of a galaxies bulge and the total specific angular momentum. The authors also compared their results to the 2020 paper by Javanmardi et al. [2]. We later compare our results to the Javanmardi and Vudragovic. The exact details of this comparison are given in section 4.2.

2.2 DATA REDUCTION

We reduce the data from these 4 referenced papers. We only include spiral galaxies whose bulge to total ratios are given. A also preform data reduction in regards to redshift. In particular, we only consider galaxies with redshifts $z \geq 0.005$. We discuss our reasoning for this reduction in section 3.2. Figure **??** gives detail on the statistics associated with each of these cuts. We note that 13 galaxies are cited in two different papers while 2 galaxies are cited in three papers. These galaxies are given in Figure **??**. To decide which B/T ratios are to be used we prioritize data by the following procedure. Sources that utilize GALFIT are used instead of others as this decomposition tool is very robust and popular in the field. In all other cases we use data from Weinzirl et al. as this paper goes into much more detail about its calculations of B/T ratios (the paper is on the formation of bulges). After this data reduction we are left with 99 unique spiral galaxies.

TABLE 2

Data reduction preformed on all 4 Sources. The total column represents the total number of galaxies gathered from each source.

Source	Total	Spiral	B/T	$z \geq 0.005$
Laurikainen	158	33	30	20
Lin	14	13	12	7
Weinzirl	143	133	125	53
Vudragović	29	22	22	19

TABLE 3

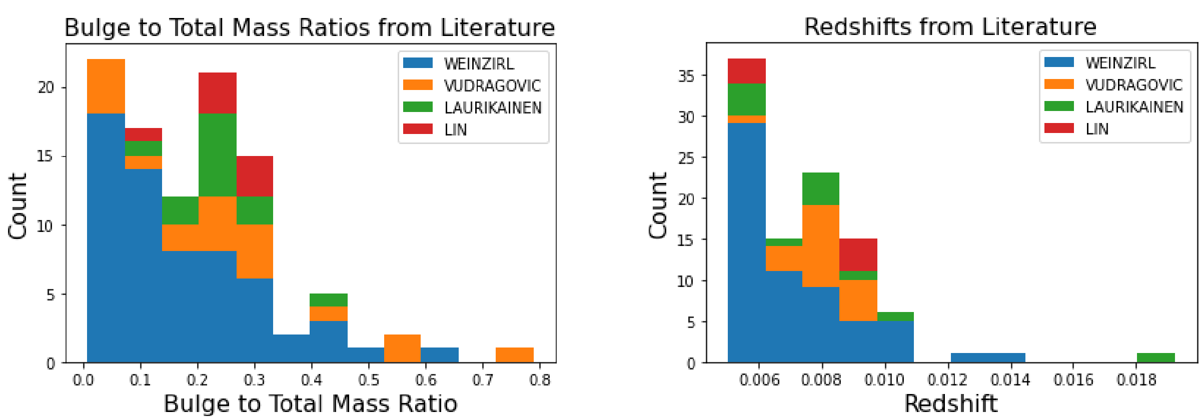
Table Showing which galaxies have their B/T calculated in more than one paper. Galaxy numbers are with respect to the New Galactic Catalog (NGC).

Galaxy	Morphology	Laurikainen	Lin	Weinzirl	Vudragović	B/T Used
718	SAB(s)a	0.21	0.28	-	-	0.28
1350	(R')SB(r)ab	0.25	-	0.1952	-	0.1952
1317	SAB(rs)a	0.35	-	0.1386	-	0.1386
2196	(R')SA(s)a	0.3	-	0.4638	-	0.4638
5728	SAB(r)a?	0.17	0.23	-	-	0.23
6782	(R)SAB(r)a	0.2	-	0.2627	-	.2627
7213	SA(s)a?	0.17	0.7	0.6574	-	0.6574
7727	SAB(s)apec	0.38	0.36	0.4177	-	.4177
4593	(R)SB(rs)b	-	0.41	0.2513	-	0.2513
4254	SA(s)c	-	0.19	0.3898	-	0.3898
1309	SA(s)bc?	-	-	0.2707	0.062	0.2707

2.3 DATA ANALYSIS

In this section we analyze the galaxy data gathered from our literature sources. After our data reduction, we are left with 99 unique spiral galaxies whose B/T ratios are known and whose redshifts are greater than or equal to 0.005. To begin we look at the redshift distribution of our sample in Figure 4b. We note that our galaxy sample is relatively nearby in redshift space, with 91 galaxies having a redshift less than 0.01. This distribution is somewhat expected as quantifying morphological structure like bulges and bars is most often preformed on closer galaxies where finely detailed imagery is abundant. We kept this distribution in mind throughout our research.

We also find it helpful to look at our B/T ratio distribution in Figure 4a. We note the large population of small B/T in our sample. This distribution is expected as galaxies are, in general, more likely to be categorized spiral if they have smaller bulges. After all, if a galaxy has a bulge to total ratio close to 1 then there is little merit in classifying such a galaxy as a spiral. Rather, this type of morphology would more closely resemble an elliptical or lenticular galaxy. We accept this distribution and keep it in mind when looking at data in future sections. We limit ourselves to strictly consider spiral galaxies, even though we expect the morphology versus environment discussion to reach far beyond the bounds of spiral galaxies.



(a) . **(b)** .

FIGURE 4. Spiral galaxy distributions. Figure (a) is a histogram showing the bulge-to-total ratio distribution of the 99 spiral galaxies taken from literature. Figure (b) is a histogram showing the redshift distribution of the 99 spiral galaxies from literature. 2.1.

Finally we observe Figure 5. This plot shows no apparent correlation between the redshift of a galaxy and its bulge-to-total ratio. We do, however, observe a slight over-density at the bottom left of Figure 5. This is expected as our sample is healthfully represented at low redshift and low bulge-to-total ratios. While we have not done any quantitative analysis of these plots thus far, we keep in mind these distributions to better understand results in later chapters.

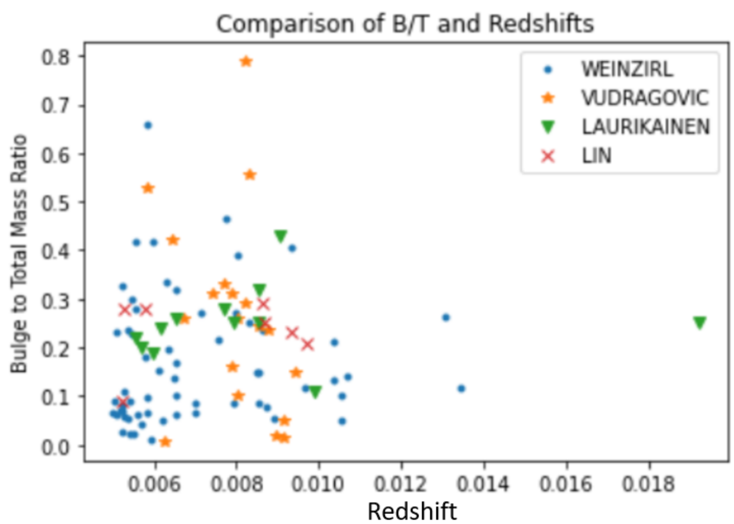


FIGURE 5. Bulge to total ratio of 99 spiral galaxies compared to their redshift values.

CHAPTER 3

NASA EXTRA GALACTIC DATABASE

The largest catalog of extra galactic objects is NASA's Extra-galactic Database (NED). This database is the aggregate of modern astronomical observation and is widely utilized for its accessibility and relative completeness. Data can be easily queried using a multitude of search parameters. Table access protocols are also available for the NED website. A table access protocol was utilized in this research. We note that previous studies into the environment versus B/T problem have not relied on NED. Instead they either use particular galaxy surveys like SAGA, or they only focus on nearby galaxies whose satellite populations are extremely well understood. By using these techniques, previous studies have tried to find relationships between the number of satellites a galaxy has and its bulge-to-total mass ratio. In our approach, we look at not only satellite galaxies, but instead larger neighborhoods as a whole. By this method, we expect that if a spiral galaxy is in a cluttered environment, whether that be a galaxy group or cluster, we use the results as a sort of proxy for satellite galaxy populations (as the presence of satellite galaxies increases the likelihood of recent minor mergers, resulting in larger bulges).

3.1 ACQUIRING NED DATA

In this section discuss we discuss the methods used to obtain data from NED. We largely relied on a table access protocol (TAP). TAP is a protocol for retrieving data tables from astronomical archives and allows for the efficient retrieval of data based on search criteria. TAP is particularly useful for searching through large datasets, such as those found in NED. In our study, we use TAP to output a data table containing all galaxies within a redshift range of $z = 0.0$ to $z = 0.03$. We select this redshift range as it fully encompasses our 99 spiral galaxies from literature (in fact, this range extends past what is necessary) . This was done in order to observe any irregularities in the NED data. The TAP query was conducted in December 2022. The search criteria was inputted manually.

We retrieved the following information for each galaxy: galaxy name, galactic longitude/latitude, and heliocentric corrected redshift. Unfortunately, complete photometric data on galaxies could not be accessed through TAP. Therefore, a web scraping code was employed

to find photometric data. This yielded information on the apparent magnitudes of galaxy across various wavelengths.

3.2 NED DATA ANALYSIS

From our NED TAP query, we obtain 142,014 galaxies within our defined redshift range. However, before calculating the number of nearby neighbors, we choose to analyze this data in more detail. We note that while NED is the most complete catalog of galaxies, this completeness falls off with distance. We investigate the redshift distribution of our NED data as reflected in Figure 6.

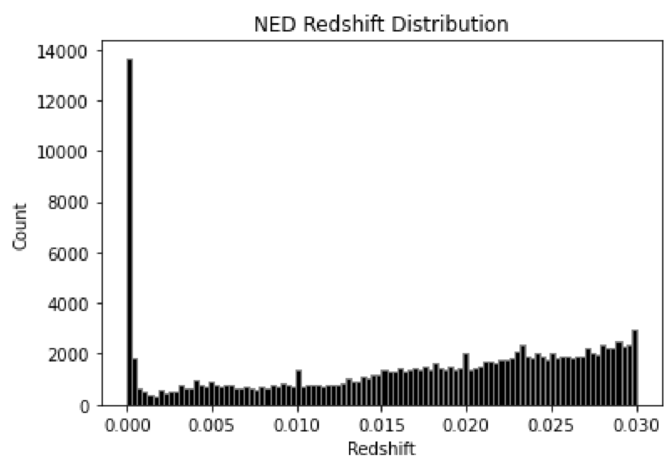


FIGURE 6. Helio redshift values of 142,014 NED galaxies between redshift range $0 \leq z \leq 0.03$

We acknowledge an irregularity in Figure 6 at low redshift values. Upon closer inspection we find more than 16,000 galaxies are cataloged in NED as having $z \leq 0.001$ (≈ 4 Mpc). This data is non-physical. Using such data in our research would obviously yield unrealistic results. We also note the regular smaller spikes at intervals of 0.01.

After an exchange with NED personnel, we conclude this over-density at low redshift

values is mainly attributed to galactic stars whose redshifts are being classified as galaxies in various large survey catalogs. While we expected a small amount of unreliable redshift data in NED, we had not anticipated such a gross overpopulation of fictitious galaxies. This is, of course, undesirable for our greater study. Our solution to this problem is to not include any of our 99 spiral galaxies from literature that have a redshift less than $z = 0.005$. This is why we made this cut earlier on in chapter 2.2. While one could attempt to go through these 16,000 galaxies and determine which are more likely to be real, the effort of such a task hardly justifies the end result. We should note for clarity that we are not cutting out the fictitious galaxies; instead we are only including the spiral galaxies from literature that have redshift values $z > .005$. We also have statistical anomalies at redshift values 0.01, 0.02, and 0.03. The frequency plot in Figure 7 is used to better visualize these anomalies.

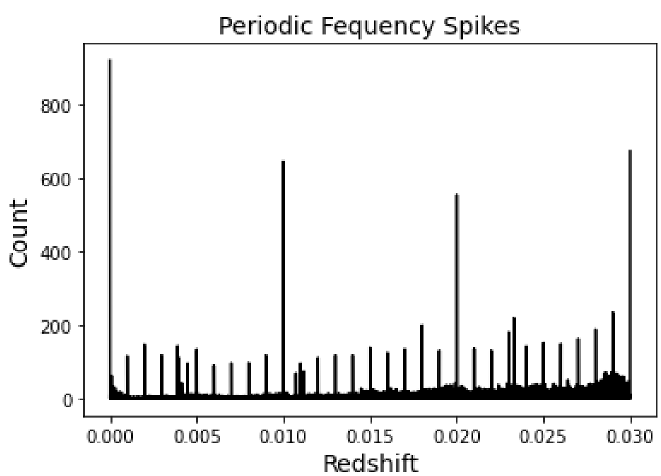
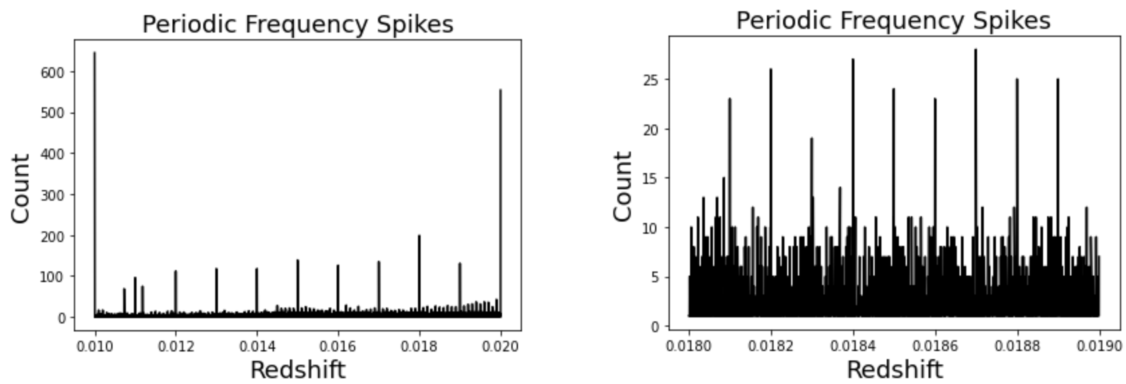


FIGURE 7. Galaxy redshift frequency plot. Count represents the number of NED galaxies that have the exact same published redshift values. Large spikes are found at intervals of 0.01 and smaller spikes are found at intervals of 0.001.

We find our NED data has periodic frequency spikes at regular intervals of 0.01, with smaller spikes occurring at intervals of 0.001. These spikes are peculiar and not expected. After another correspondence the NEDs team they noted that they had traced this issue to 2-3 publications that derived redshifts based on unreliable photometry. While many photometric redshifts (especially newer ones) can provide good redshifts, they flagged the redshifts occurring with regular intervals from these publications as unreliable. However, the periodic nature of these spikes suggests a more systematic effect is at play as well. One explanation could be that older surveys and telescopes published data to only 2 or 3 decimal points of accuracy, causing an over-density at the corresponding spikes. These spikes present an issue for our greater study. We find the best solution to this problem is to cut out any of our 99 spiral galaxies who are within "n" Mpc of a galaxy whose published redshift does not go to at least 4 decimal points of accuracy.

For example, if a NED galaxy has a published redshift of exactly 0.01, its actual redshift value likely lies between 0.005 and 0.015. This uncertainty corresponds to a range ± 22 Mpc. Likewise, if a galaxy has a redshift of exactly 0.005 then its true redshift values lies somewhere between 0.0045 and 0.0055 with a corresponding uncertainty of ± 2.2 Mpc. For our purposes, an uncertainty of ± 2.2 Mpc is unsatisfactory. To reiterate, we determine how many NED galaxies are within "n" Mpc 99 spiral galaxies. If one of these neighbors has a redshift that does not go to at least 4 decimal points of accuracy, then we no longer consider that spiral galaxy in the rest of the study. See Figure 3 for a visualization of this process.

We find that this periodic overpopulation extends to even finer detail. Figure 8a shows "fine" periodic nature, meanwhile Figure 8b shows "super fine" periodic nature. Compared to the background noise these super fine spikes are not as dramatic and correspond to a redshift uncertainty that is acceptable in our study.

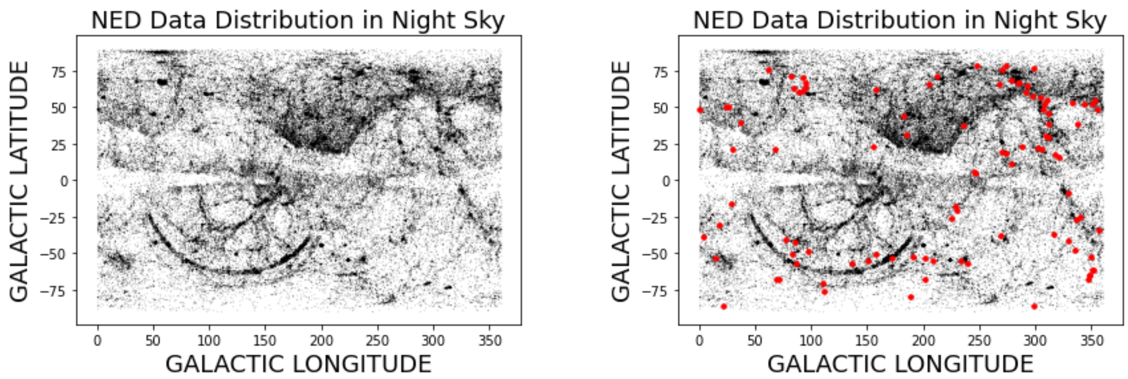


(a) **(b)**

FIGURE 8. Redshift spikes at different scales. Figure (a) shows frequency spikes over redshift range 0.01 - 0.02 while figure (b) shows frequency spikes over range 0.018 - 0.019.

We note the interesting case of the dwarf galaxy NGC 6744A. This dwarf is cataloged as having a redshift of exactly 0 with a corresponding uncertainty of 0 as well. However, in the classification section for this galaxy we find that it is described as being a dwarf galaxy in the disk of the large spiral galaxy NGC 6744. This parent galaxy has a published redshift of $z = 0.00281$ and an uncertainty of 0.00001. This is just one example of the many peculiarities that NED contains at low redshift values. We note that the NED team notified us that they have been investigating these issues and would be publishing a paper on it soon. The paper is currently in the process of being published and is not yet available online.

It is also worth investigating the positional parameters of our NED data. Figure 9a shows the positions of our NED galaxy data in the night sky. These positions are given in galactic longitude/latitude. Interestingly, one can infer from these plots where the center of the Milky Way is, where the abundance of dust and stars makes it difficult to observe galaxies (around longitude 0°, latitude 0°).



(a) (b)

FIGURE 9. Comparing positions of our two galaxy samples. Black dots in both figure (a) and (b) represent NED galaxies. Red dots in figure (b) represent the 99 spiral galaxies from literature.

We note the large swaths of the night sky that have been heavily observed by large sky surveys. We compare this data to the positional data of our 99 spiral galaxies in figure 9b. We find that some of our spirals fall into relatively well cataloged parts of the night sky while other galaxies do not. While this could be a cause for alarm, we find that our final results show no dependence on positions in the night sky.

CHAPTER 4

RESULTS

In this chapter we present results from our investigations and compare them with similar studies from literature. We do not find any significant relationship between a galaxies bulge-to-total ratio of spirals and the number of nearby galaxies with "n" Mpc. We do however conclude that NED can not be used effectively to determine group densities at these scales. Our results are given in bulk by Figures 10a - 11c.

4.1 BULGE-TO-TOTAL MASS RATIO AND NUMBER OF NEAR NEIGHBORS

The first impressions of these figures are not compelling. We do not see any obvious correlation between the number of neighbors and bulge to total mass ratios. The lack of a relationship is indicative of two different conclusions. The first explanation is that this relationship is not present in nature. The current ΛCDM model of the universe predicts these results. The Millennium-II Simulation [17], a very large N-body simulation of dark matter evolution in accordance with ΛCDM cosmology, did not show any relationship between our two variables [18].

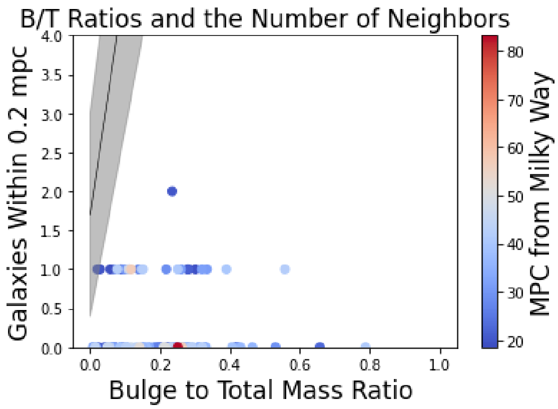
The second explanation is that many galaxies that are actually nearby neighbors are not cataloged in NED. This would result in the distribution seen in Figure 10c and Figure 10d, where many galaxies do not have all of their neighbors accounted for and therefore fall below the linear distribution that they actually exhibit. Data sets including galaxies with larger B/T ratios could help clarify if this triangular distribution is actually present. Regardless, we consider the second explanation as more likely when considering previous literature on the topic. This explanation does not suggest that ΛCDM is wrong, but rather that the model could benefit from some nuanced scale factor or variable being introduced to account for a relationship between B/T and the number of nearby neighbors. We should remind ourselves that the initial motivation for this research was not only to determine if their is a relationship between B/T and the number of near neighbors, but also to determine the efficacy of using NED as large data mining tool. The overall conclusion from this study is that NED is not currently an effective tool for this type of research. The incompleteness

of the catalog, as well as the lack of magnitude data on a large portion of our catalog is difficult to work around. We talk more about these issues in detail in the Section 2.1.4.

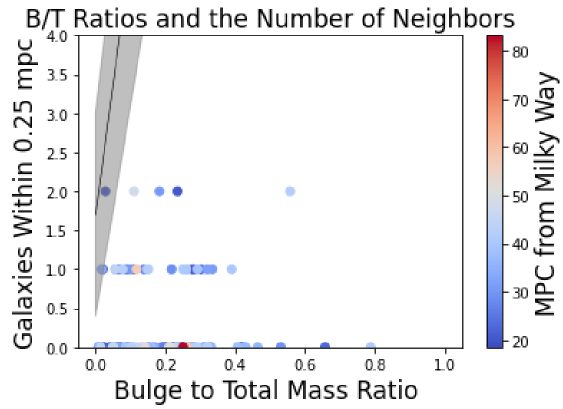
We note that we have thus far not included any error bars for the number of near neighbors or bulge-to-total ratios. Vudragović et al. is the only paper that gave errors for bulge-to-total ratios [3] This is understandable as this papers focus was directly related to galaxies bulge to total mass ratios and their relationship to their satellite populations. The other three papers calculated bulge-to-total ratios along with other galaxy components to understand galaxy properties and evolution. The results of these studies were not as sensitive to B/T errors and thus they did not include them in there final tables [14, 16, 12] To determine the error in the number of neighbors within "n" MPC we use a familiar technique used in [3] and [2]. This common technique is given by Eq. (6) :

$$N_{error} = \sqrt{N}. \tag{6}$$

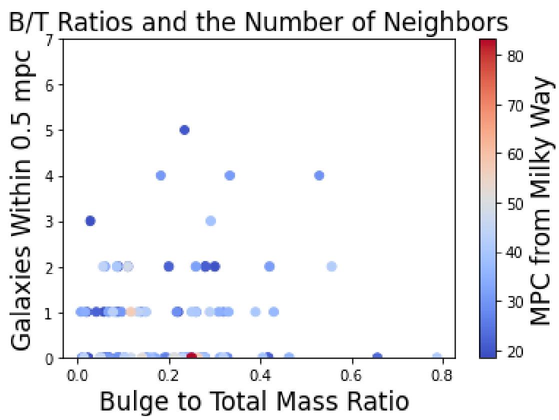
We do not include this error in this chapter as is does not add (or subtract) any value to our research. We never set out to define any correlation equation, but rather to show a general trend. We do however include error in Appendix A. We also note that if a sample had no fictitious galaxies present, there would be little merit to introduce equal plus and minus vertical errors. While this method of error is certainly justified in many regimes of research, it seems inappropriate in our particular case.



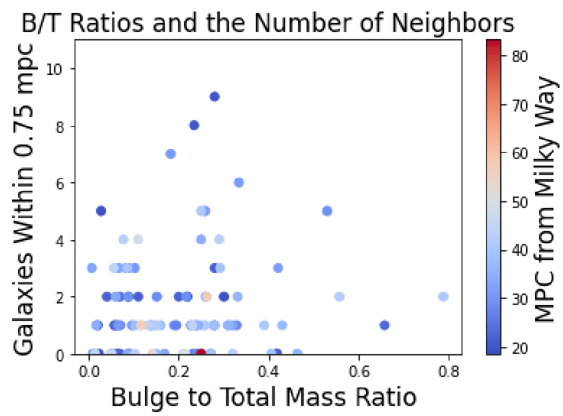
(a)



(b)

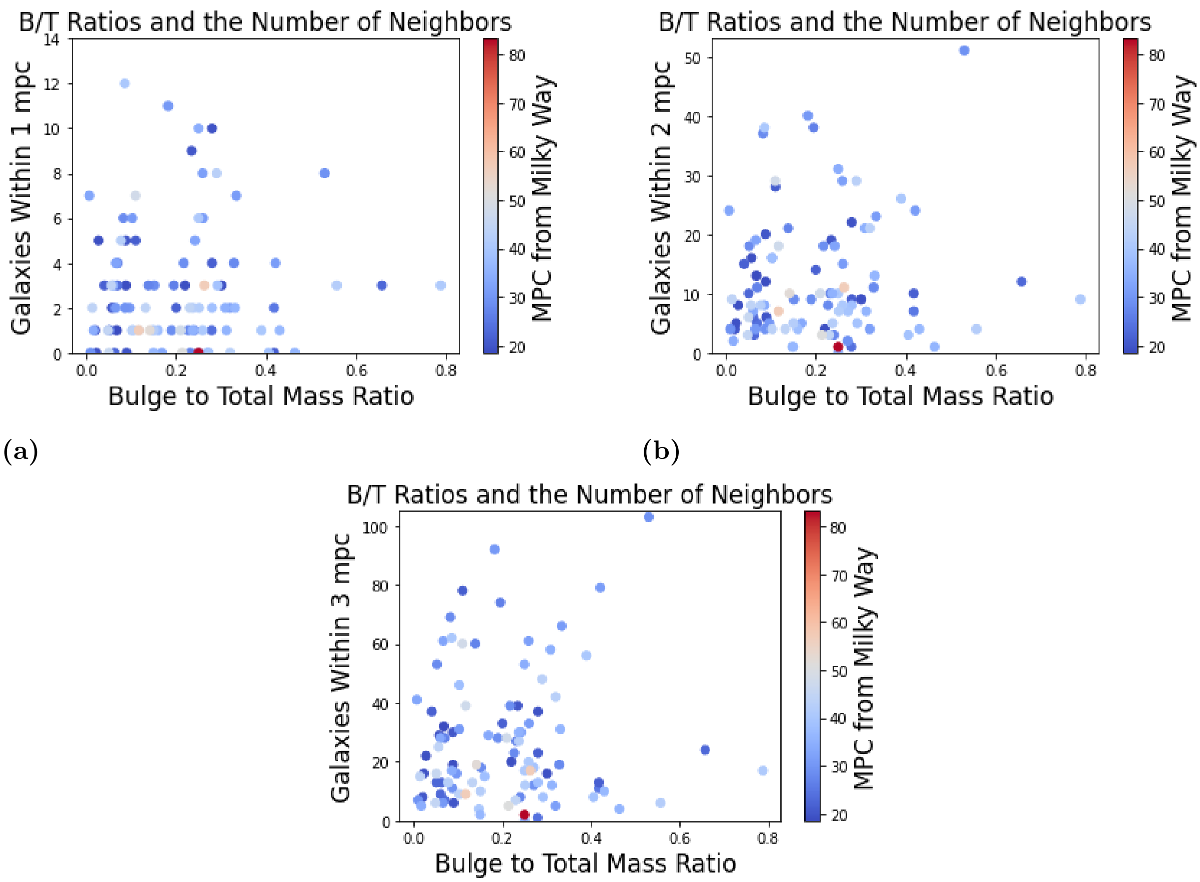


(c)



(d)

FIGURE 10. Plots showing little correlation between multiple spiral galaxies bulge-to-total mass ratio and the number of near neighbors within different mega-parsec ranges.



(a) **(b)** **(c)**

FIGURE 11. Plots showing little correlation between multiple spiral galaxies bulge-to-total mass ratio and the number of near neighbors within different mega-parsec ranges.

4.2 COMPARISON TO LITERATURE

We now compare our results with previous literature, some of which we have already considered. First we should note the difficulty and lack of consensuses in the astronomical community on how objects like groups and clusters are defined. ΛCDM, groups and clusters can be defined as such if the galaxies in question share a viralized dark mater halo [19]. The most popular schemes for identifying groups and clusters are friend of friend algorithms and hierarchical algorithms. In this study we prioritize friend of friend algorithms. In particular we create the simplest model as possible by determining how many galaxies are within "n" Mpc of the parent galaxy in question. We do not necessarily attempt to define groups using

this method. This approach is not without its draw backs. For instance we dont take into account any galaxies proximity in radial velocity space, which is done because of the lack of radial velocity data on our over 140,000 galaxies. With this in mind, we still consider our approach to be valid, even if more crude compared to more sophisticated methods. We see similar FOF algorithms to our own employed in both Javanmardi et al. and Vudragović et al. [2, 3].

Javanmardi et al [2] and Vudragović et al [3] are good comparisons to our own. while we have already dedicated a subsection to vudragović et al, we will go over both briefly. Javanmardi et al used accurate satellite data of 7 nearby galaxies (including the Milky Way) to find a correlation between satellites at distances of 200 kpc and 250 kpc and their bulge-to-total mass ratios. They also made a magnitude cut at $M_V \leq 8.2$. Fig 12 shows their results. The shaded region represents a 1σ spread. It should be noted that in both cases the galaxy M94 was left out of the fit because only satellites up to 150 Kpc had been surveyed. They considered a vertical uncertainty of $\sqrt{N}$. Galaxy masses were also taken into account in this study.

The linear correlation coefficient was given to be $r = 0.94$, or in other words, the data yielded a 99.5 percent (around 3σ) significant correlation between N_{sat} and B/T. The two fits are given by Eqs. (7) - (8) for 200 Kpc and 250 Kpc respectively:

$$N_{sat} = 30.2(\pm 6.2)B/T + 1.7(\pm 1.3), \tag{7}$$

$$N_{sat} = 33.6(\pm 6.5)B/T + 1.7(\pm 1.3). \tag{8}$$

It is noted by the authors that they do not attempt to give a formula for this relationship, but rather the general trend. We make comparisons between our results and theirs in Figures 10a and 10b. In particular we observe where our data for $n = 0.2$ Mpc and n=0.25 mpc lie in respect to the 1σ spread for both cases. We also make a cuts at $M_V \leq 8.2$. However we give the results from these cuts in appendix C

As for Vudragović et al., their study utilizes the second release of SAGA. They also used the decomposition tool GALFIT to calculate their B/T ratios [3]. They used this data and

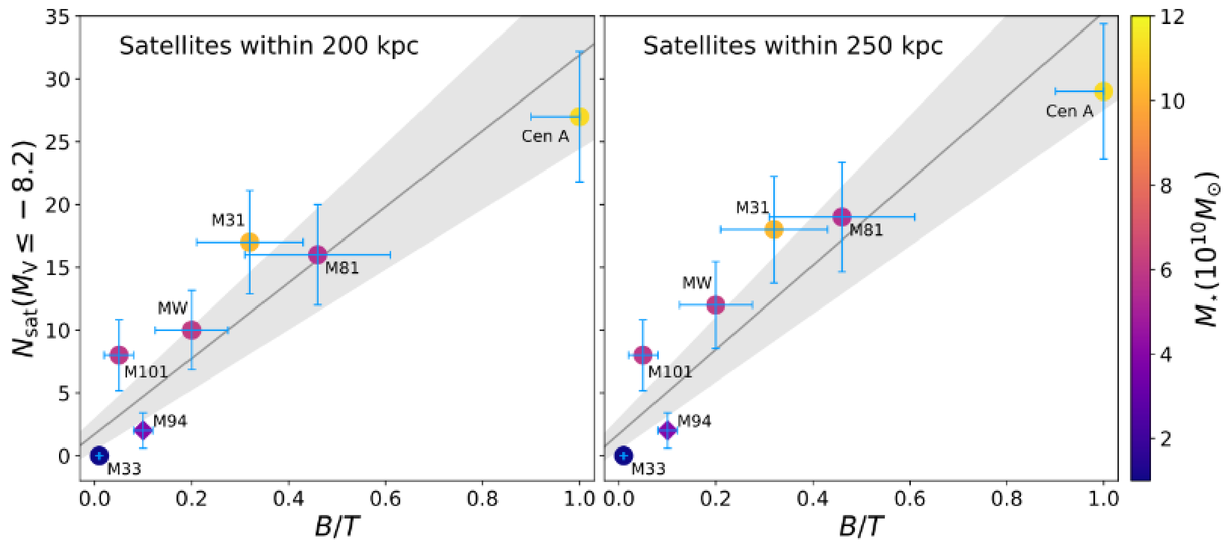


FIGURE 12. Results from Javanmardi et al. [2]. The shaded region represents a 1σ spread. M94 was left out of the fit. Including M94 would have improved the correlation. Only satellites up to $M_V \leq 8.2$ were included.

compared it to Javanmardi et al. The specifics of this paper have already been touched on in Section 2.1.4. We give the results from Vudragović et al. in Figure 13. The red data points and the green shaded region are from Javanmardi et al. The authors of Vudragović et al. point out that a likely explanation as to why so many of their data points fall below the shaded region is that they have satellites that are currently undocumented. This is a reasonable explanation as no galaxies sit above the green shaded region. These results represent the difficulty in preforming this type of research with incomplete data (which we are using as well).

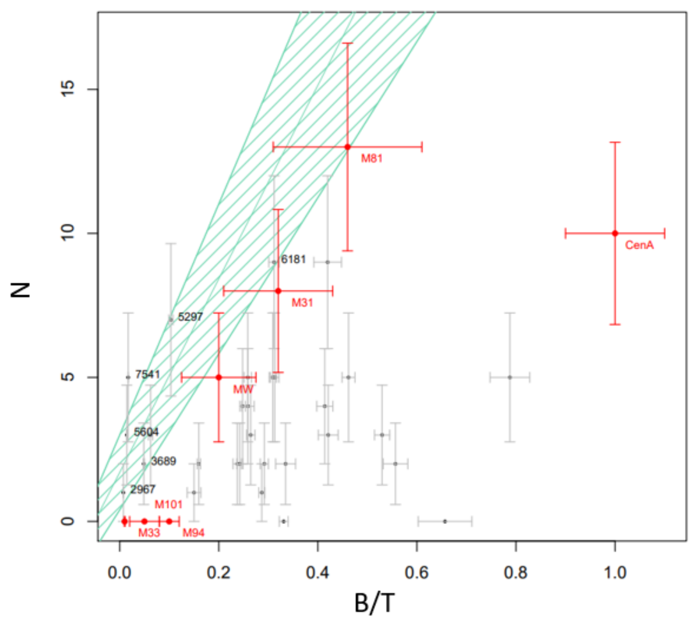


FIGURE 13. Results from Vudragović et al. The shaded region represents a 1σ spread from Javanmardi et al. Red data points represent galaxy data from Javanmardi et al. The authors believe that data points that fall below the shaded region have satellites that are as of yet unaccounted for.

Figure 13 labels six galaxies from Vudragović et al. that fall into the 1σ spread from Javanmardi et al. This yields a unique opportunity to directly compare our satellite populations to theirs for these particular galaxies. This comparison if given by Figure 14. We see that the number of calculated nearby neighbors from our study is less than the number of neighbors found from the SAGA survey used in Vudragović et al. In all but one case (NGC 7541), we found zero neighbors within 0.25 Mpc.

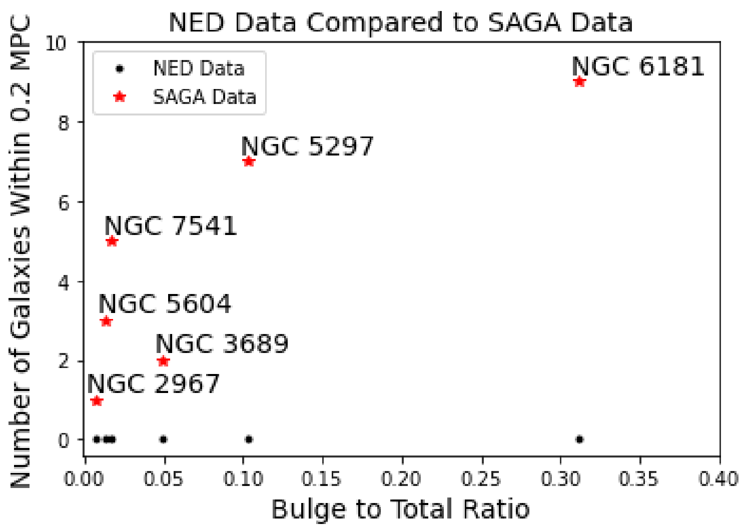


FIGURE 14. Comparison between SAGA [1] satellite populations and NED populations for the galaxies labeled. Our data falls directly below the SAGA data because we use the B/T ratios from that survey. The number of galaxies within 0.25 Mpc as calculated from NED data falls short compared to the SAGA survey.

We find that the lone satellite around NGC 7541 is NGC 7537. In the SAGA catalog there is a galaxy that is very similar in location and night sky position identified as NSA-637123 (NSA is the identifier of NASA Sloan Atlas). It is very likely that this NSA galaxy is the same galaxy as NGC 7537. However, NED has not cross-identified it as such. This further demonstrates the inherent incompleteness in NED. Not only have many galaxies not

been identified in large surveys, but many galaxies that have been identified in large surveys have not been registered or cross identified NED.

CHAPTER 5

FINAL REMARKS AND FUTURE INVESTIGATIONS

While this research did not produce a specific formula correlating the number of neighboring galaxies to the bulge-to-total mass ratio of their parent galaxies, it did provide valuable insights into the feasibility of employing NED as a research instrument at such scales. In this chapter, we discuss our findings regarding both NED's effectiveness and the inconclusive outcome of our investigation.

5.1 FINAL REMARKS ON NED

- NED is known to exhibit an incompleteness issue at high redshift values [10]. We found that NED is also overwhelmed by spurious galaxies at extremely low redshifts. The universe at very low redshifts is thoroughly studied and cataloged, but NED's usefulness at these nearby distances is hindered by the prevalence of implausible objects. More concerning is the fact that NED is aware of these spurious galaxies but has yet to address these challenges to the broader NED community. It was only after multiple email exchanges that the NED help desk admitted their knowledge of this erroneous data and mentioned a paper in preparation that would identify these spurious galaxies. Enhancing NED's transparency with their community could aid researchers in avoiding the issues caused by not disclosing such problems as soon as they are detected.

- A periodic overabundance is found in NED redshift data. While NED attributes this issue to a few unreliable publications, it seems unlikely that this is the only culprit. The periodic nature of these anomalies suggests that many astronomical observations cataloged in NED have inherent uncertainties that are larger than their associated published values. For example, a large number of galaxies have published redshift's of exactly $Z = 0.02$. The overabundance of galaxies with this exact redshift suggests that many of the telescope used to survey these galaxies only had precision up to two decimal points. Therefore, the uncertainty of those observations would be at

least ±0.005. However, most of the galaxies with redshift's of exactly $z = 0.02$ have published uncertainties less than ±0.005. Even more concerning is that many of these galaxies have no published uncertainties at all. This is obviously an issue that needs to be investigated further and should needs to be relayed to the NED community as soon as they determine the general culprit of these issues.

- NED does not allow for easy extraction of large amounts of magnitude data in different bands/surveys. In fact, the viability of the web scrapper used to determine magnitude values was completely dependent on an older tool which NED has promised it will soon discontinue. With this tool discontinued it will be very difficult, if not impossible, to create all sky catalogues from NED that include magnitude data. The only way to create this catalog would be to individually query data on each galaxy in question. This would overwhelm NED'S servers and decrease the effectiveness of the already inefficient website.

- As mentioned above, NED is discontinuing its service for querying basic data on "large" amounts of galaxies (the max query at one time is only 200 galaxies). If NED follows through and discontinues this service, it will effectively regulate NED the status of a galaxy search engine. In this scenario one would be able to efficiently find information on particular galaxies, but they would not be able to query data on multiple galaxies at one time. This would prevent future utilization of NED in research like our own. While using NED in this way was not entirely practical in our case, it has been in use full in other data mining research attempts [9].

5.2 FINAL REMARKS ON B/T VERSUS N

Even with the difficulties surrounding NED, it proved to be a valuable tool in our research. We found results somewhat similar to those from Vudragovic et al. [3]. We find that using a survey specifically designed to find satellites of spirals (SAGA) does not yield much better results than using NED. In both cases the data is fairly incomplete and can not be used to find any quantifiable correlation like that found in Javanmardi et al. [2]. However our results for distances of 0.20 Mpc and 0.25 Mpc obeyed the correlation found in Javanmardi et al. Research concerning the correlation between satellites populations and galactic morphology, while simple to preform in theory, is currently limited by incomplete data. While the nearby universe is fairly well documented and cataloged, the completeness of any catalog

will certainly decline as redshift increases. In addition, the question of how to define galaxy cluster/groups is an ongoing issue in astrophysics. Different schemes and algorithms need be employed in order to better understand and quantify satellite populations.

5.3 FUTURE INVESTIGATIONS

The initial motivation for this research came from the build up of difficulties ΛCDM has in explaining satellite populations [7, 6, 5]. To better understand these problems and the effect they have on the dominance of ΛCDM, future research needs to be conducted into satellite populations and distributions. Currently, the only low-luminosity complete catalogs are of the nearby universe. While these catalogs are certainly indispensable tools in astronomy and astrophysics, more SAGA like surveys should be preformed in detail to specifically identify satellites. In addition, research concerning morphological dependence on environment needs to be conducted in regimes other than spiral galaxies. Other morphological types should be investigated. For example, the ellipticity of elliptical galaxies could be investigated along side bulge to total mass ratios. Recent studies have shown relationships between galaxy morphology and the amount of dark matter [20]. Many more studies need to be preformed to better understand the nuanced correlations between galaxy morphology, satellite populations, and the modern ΛCDM explanations of these respective correlations.

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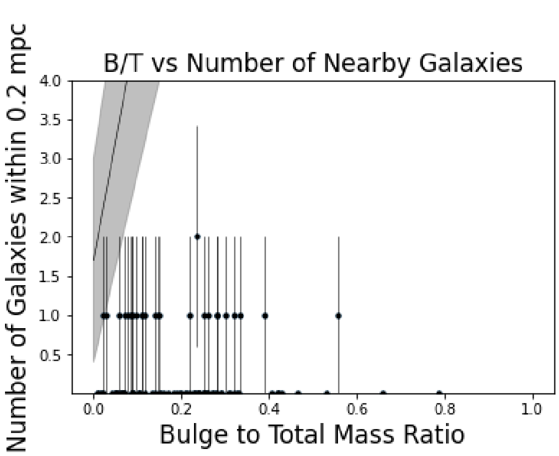
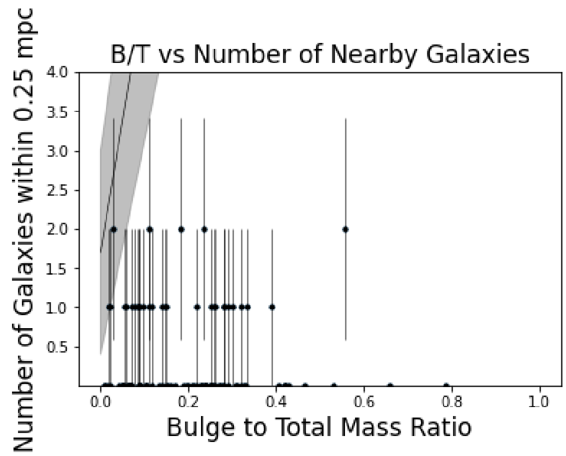
APPENDIX A

PLOTS WITH ERROR INCLUDED

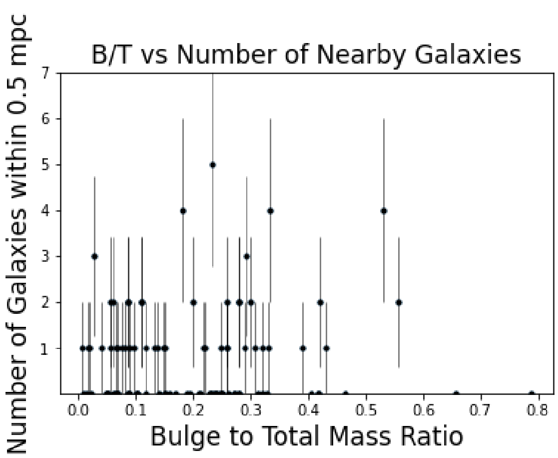
In this Appendix we display the same plots from Chapter 4 but with their associated errors in the number of nearby galaxies from Eq. (3). As we noted earlier, these error bars add little information to our results.



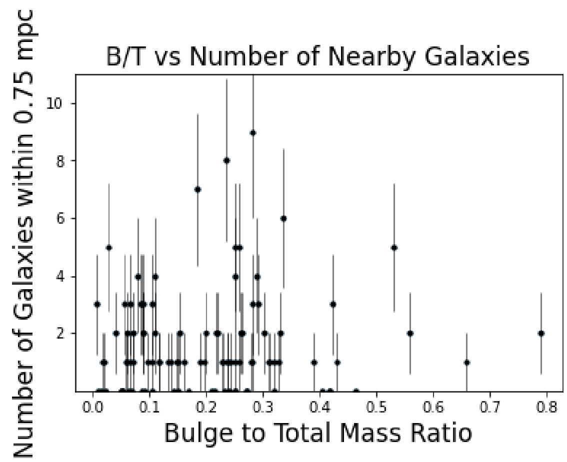
(a) Spiral galaxies B/T ratios vs the number of neighboring galaxies within 0.2 Mpc.



(b) Spiral galaxies B/T ratios vs the number of neighboring galaxies within 0.25 Mpc.

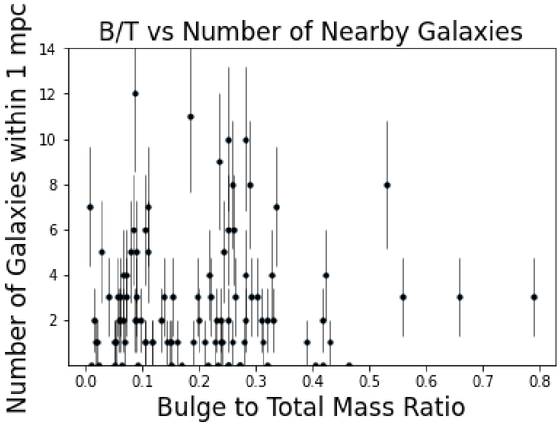


(c) Spiral galaxies B/T ratios vs the number of neighboring galaxies within 0.5 Mpc.

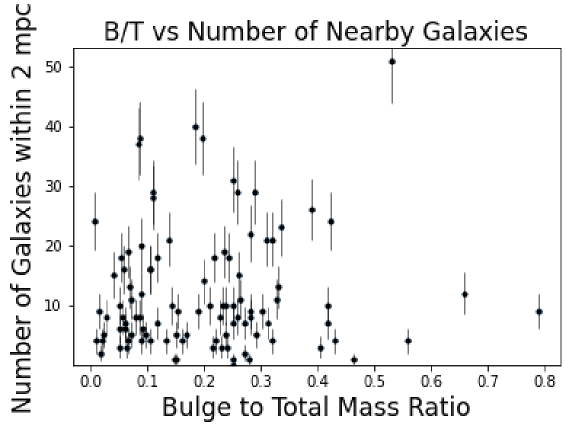


(d) Spiral galaxies B/T ratios vs the number of neighboring galaxies within 0.75 Mpc.

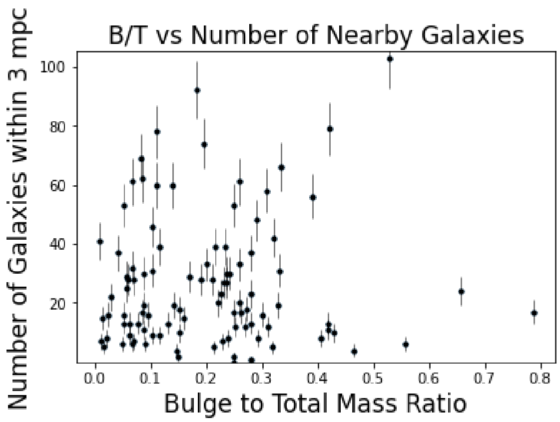
FIGURE 15. Plots showing little correlation between spiral galaxies bulge to total mass ratio and the number of near neighbors within 0.2 Mpc to 0.75 Mpc. Vertical errors are given.



(a) Spiral galaxies B/T ratios vs the number of neighboring galaxies within 1 Mpc.



(b) Spiral galaxies B/T ratios vs the number of neighboring galaxies within 2 Mpc.



(c) Spiral galaxies B/T ratios vs the number of neighboring galaxies within 3 Mpc.

FIGURE 16. Plots showing little correlation between spiral galaxies bulge to total mass ratio and the number of near neighbors within 1 Mpc to 3 Mpc. Vertical errors are given.

APPENDIX B

SDSS MAGNITUDE CUTS

In this appendix we give figures produced by only including C-model Sloan Digital Sky Survey data and cutting all galaxies with $M_V > -8.2$. We find this cut makes little difference to our final results.

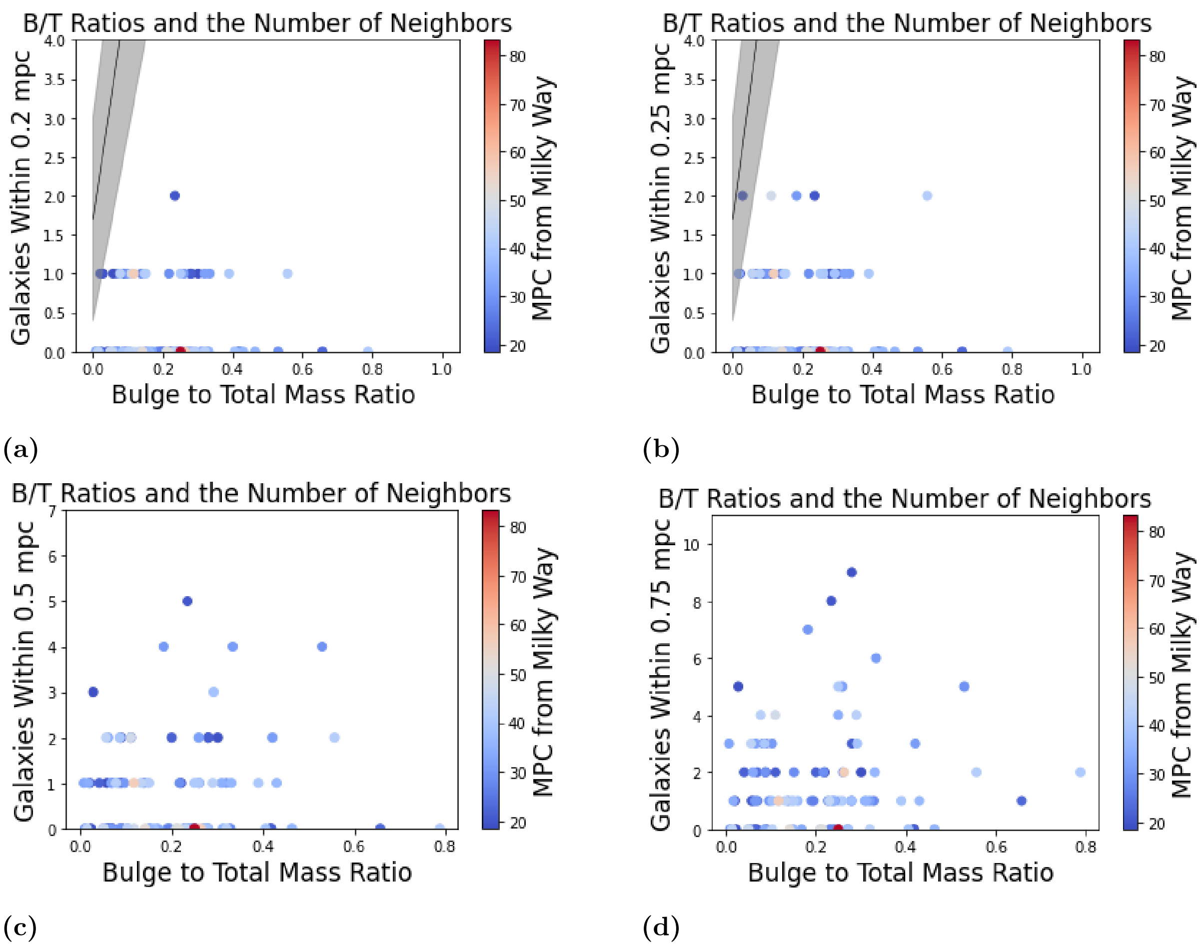
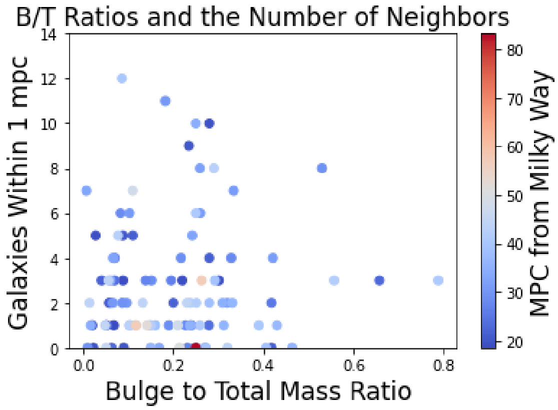
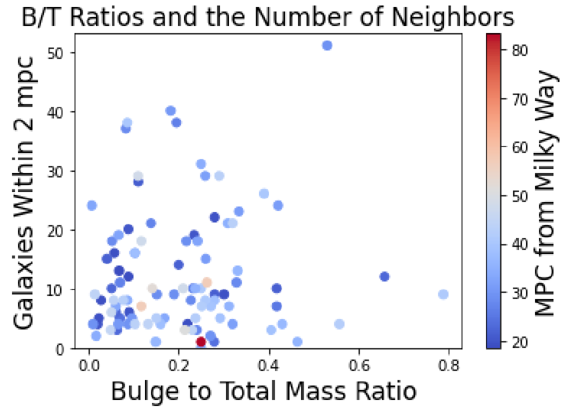


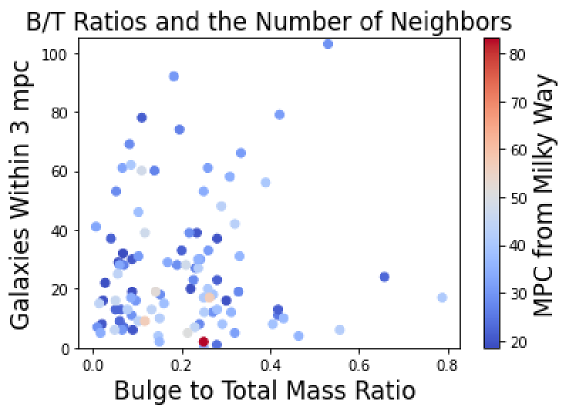
FIGURE 17. Plots showing little correlation between spiral galaxies bulge to total mass ratios and the number of near neighbors within 0.2 to 0.75 Mpc. All galaxies in this sample have $M_V \leq -8.2$.



(a)



(b)



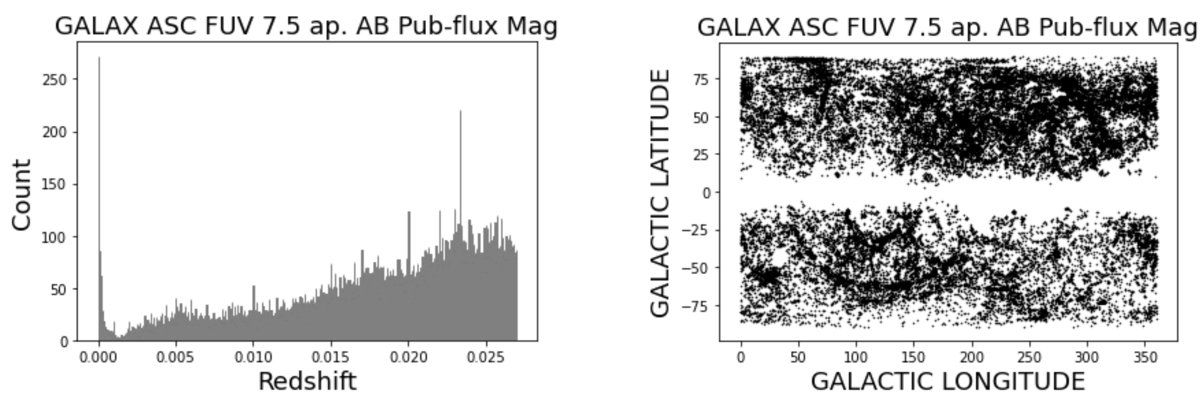
(c)

FIGURE 18. Plots showing little correlation between spiral galaxies bulge to total mass ratios and the number of near neighbors within 1 to 3 Mpc. All galaxies in this sample have $M_V \leq -8.2$.

APPENDIX C

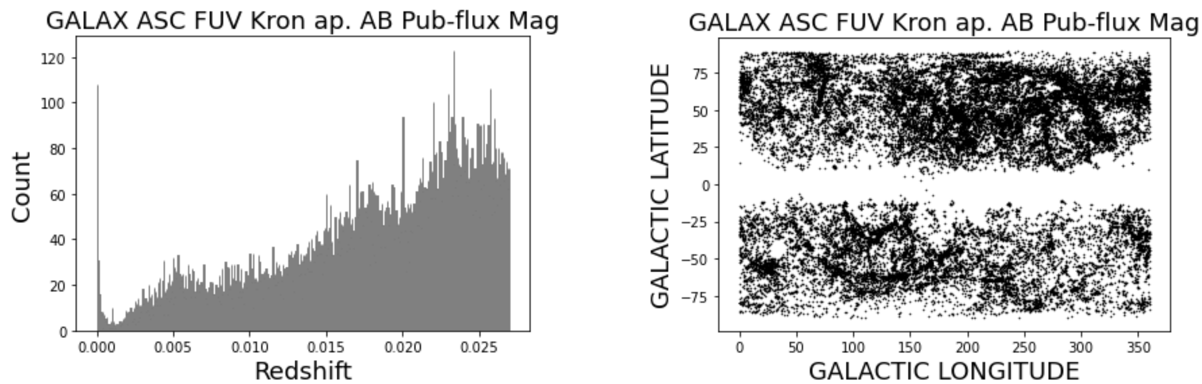
MAGNITUDE DISTRIBUTIONS

In this appendix we plot the distributions of each survey/band that is given in NED. We find the each survey observes different parts of the night sky and encompasses different redshift ranges. Not all the SSDS band are given as the distributions are identical. However SDSS C-model and PSF are have slightly different distributions so we plot each separately. While all the surveys have an over density of objects near $z = 0$ (except the RC3 survey), SDSS has a more extreme over-density of these objects. This suggests that the SDSS catalog has contributed to these fictions objects more so than other surveys.



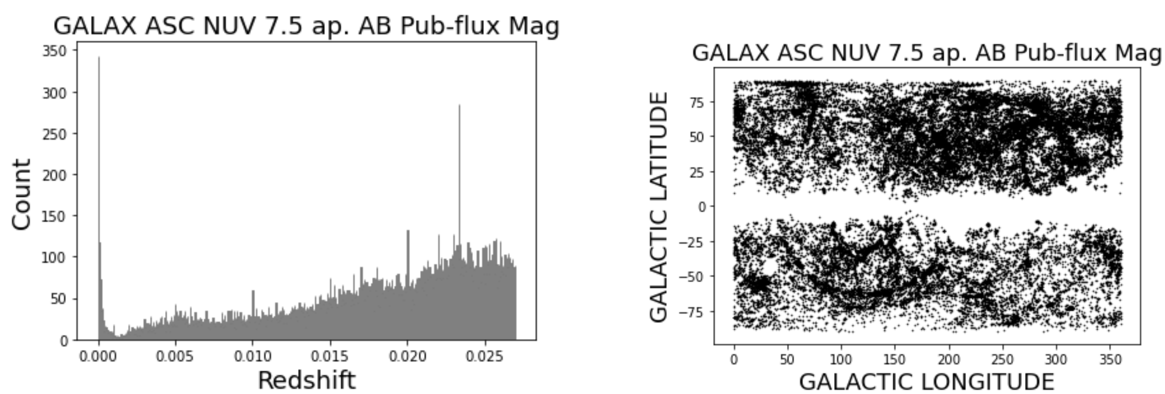
(a) **(b)**

FIGURE 19. ASC FUV 7.5 aperture positional data from NED. This survey observes most of the night sky uniformly and has a large spike near $z = 0$.



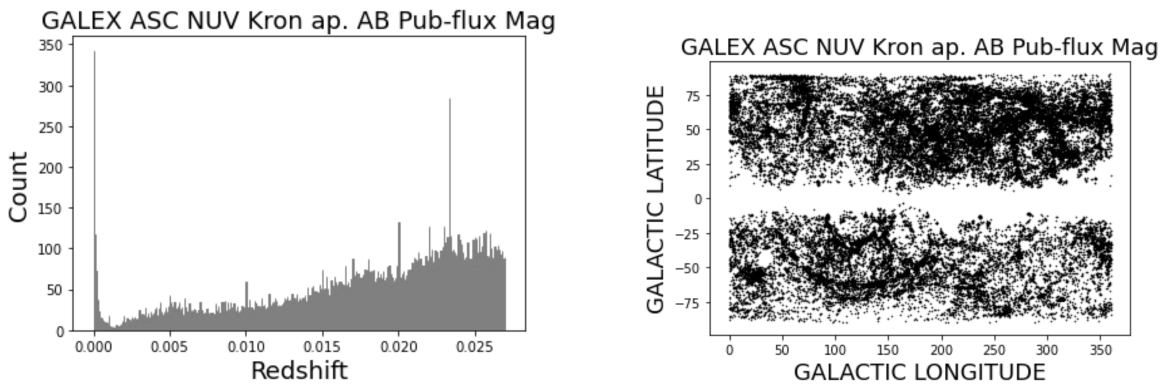
(a) **(b)**

FIGURE 20. ASC FUV Kron aperture positional data from NED. This survey observes most of the night sky uniformly and has a large spike near $z = 0$.



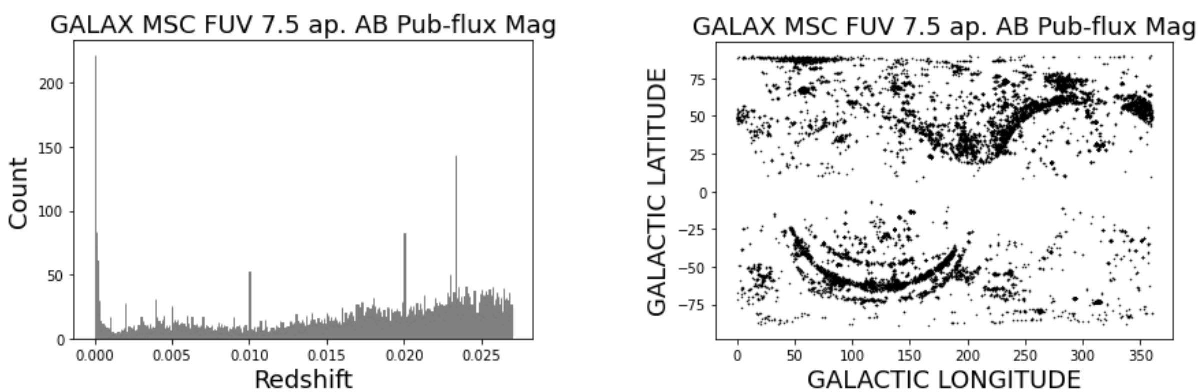
(a) **(b)**

FIGURE 21. ASC NUV 7.5 aperture positional data from NED. This survey observes most of the night sky uniformly and has a large spike near $z = 0$.



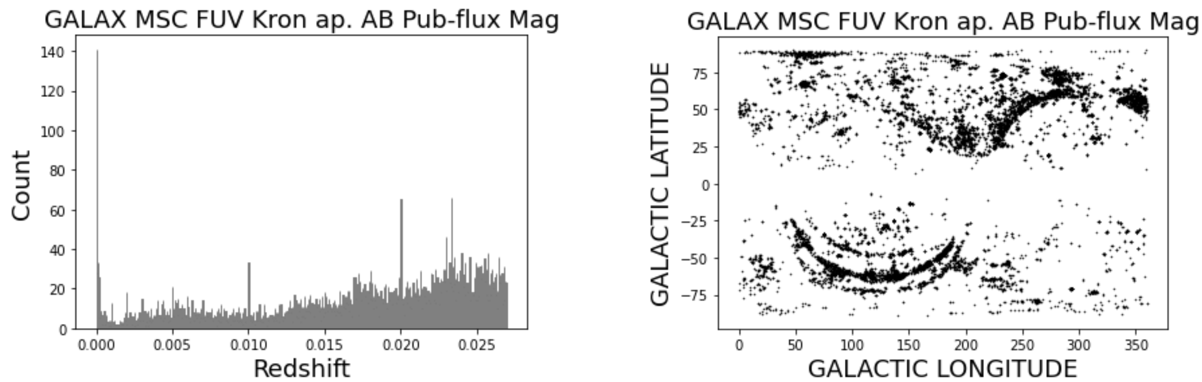
(a) **(b)**

FIGURE 22. ASC NUV Kron aperture positional data from NED. This survey observes most of the night sky uniformly and has a large spike near $z = 0$.



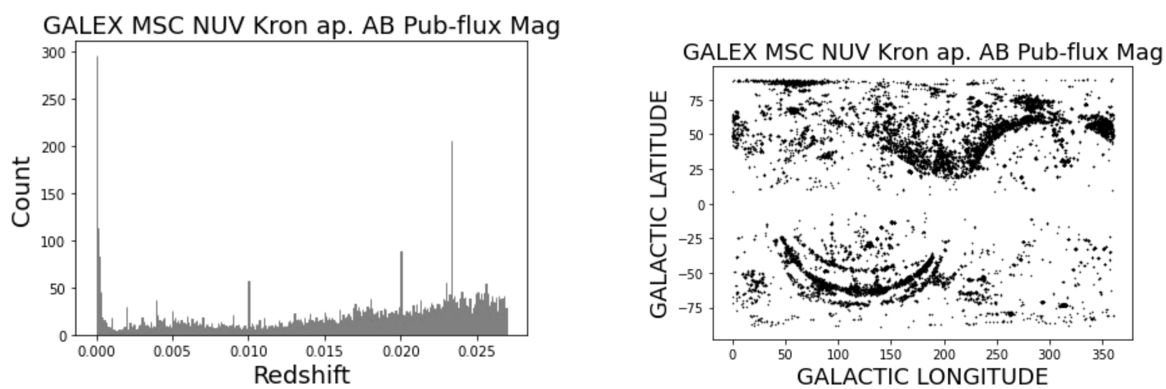
(a) **(b)**

FIGURE 23. MSC FUV 7.5 aperture positional data from NED. This survey does not include as much of the night sky as its ASC counterpart however there is still a large spike near $z = 0$.



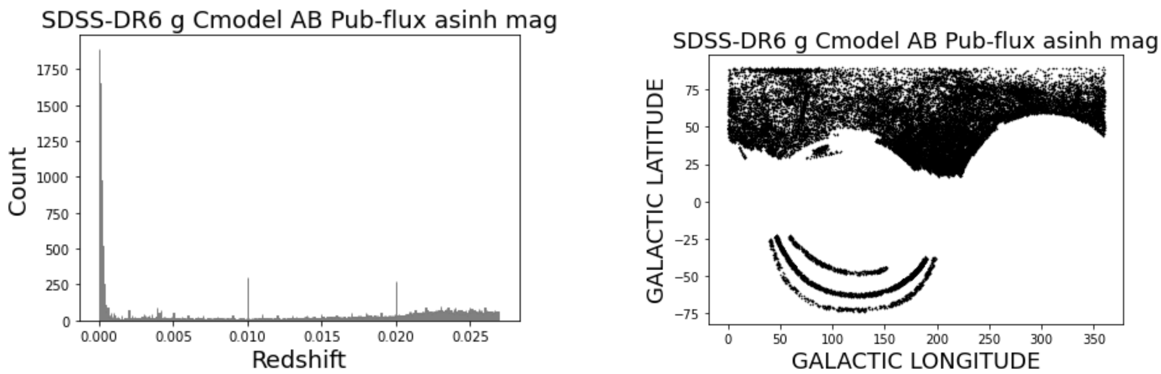
(a) **(b)**

FIGURE 24. MSC FUV Kron aperture positional data from NED. This survey does not include as much of the night sky as its ASC counterpart however there is still a large spike near $z = 0$.



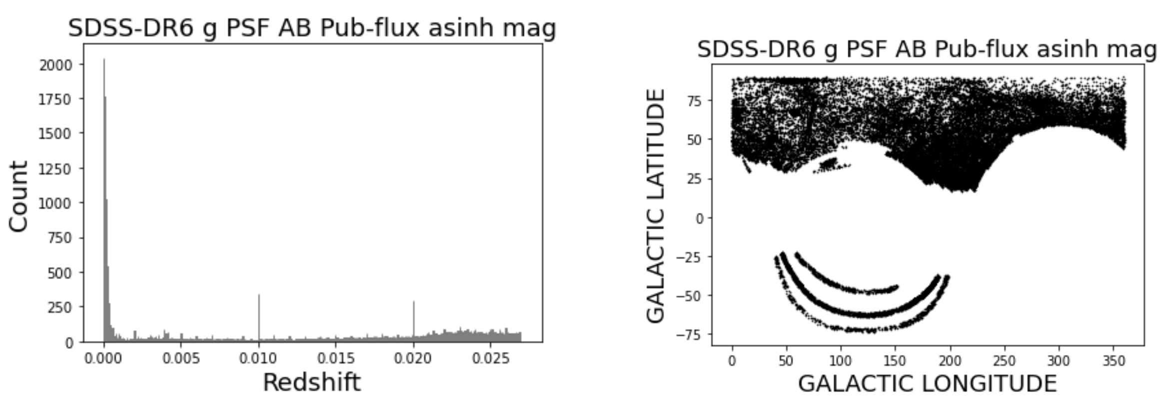
(a) **(b)**

FIGURE 25. MSC NUV Kron aperture positional data from NED. This survey does not include as much of the night sky as its ASC counterpart however there is still a large spike near $z = 0$.



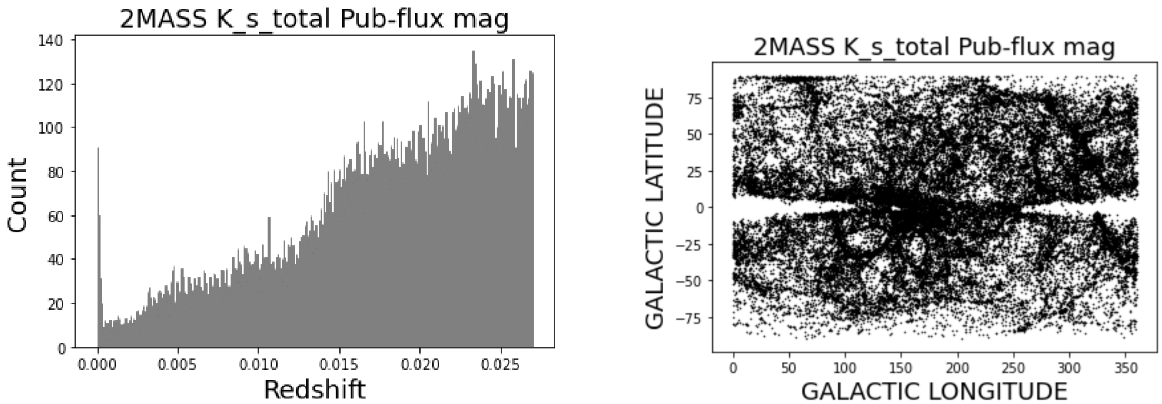
(a) **(b)**

FIGURE 26. Sloan Digital Sky Survey C-model positional data from NED. While this plot is labeled as g band we note that all other C-model bands have the same distribution. We find an extremely large spike near $z = 0$. Spikes are also present at 0.01 and 0.02. This suggests that much of the fictitious data in our NED sample is coming from SDSS.



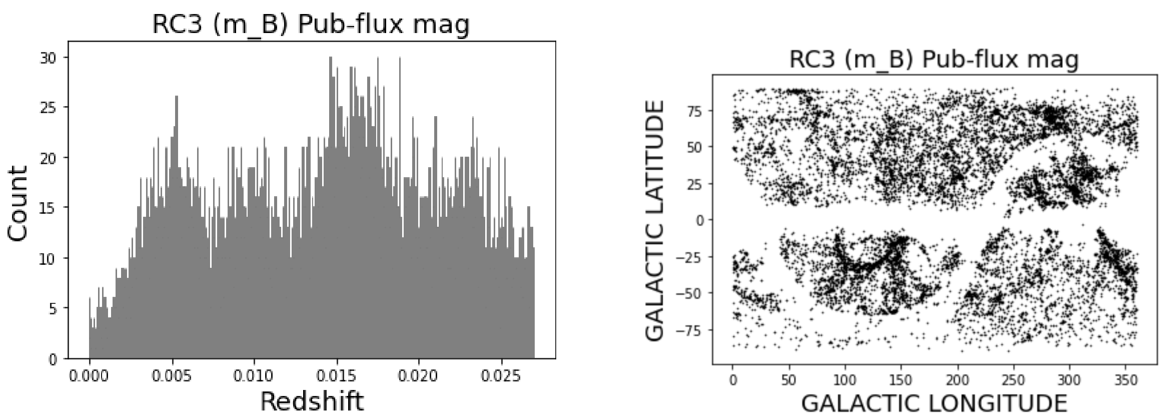
(a) **(b)**

FIGURE 27. Sloan Digital Sky Survey PSF positional data from NED. While this plot is labeled as g band we note that all other PSF bands have the same distribution. We find an extremely large spike near $z = 0$. Spikes are also present at 0.01 and 0.02. This suggests that much of the fictitious data in our NED sample comes from Sloan Digital Sky Survey.



(a) **(b)**

FIGURE 28. 2MASS positional data from NED. While this plot is labeled K_s, we note that all other 2Mass bands have the same distribution. This survey observed the night sky fairly uniformly. A slight spike is found near $z = 0$.



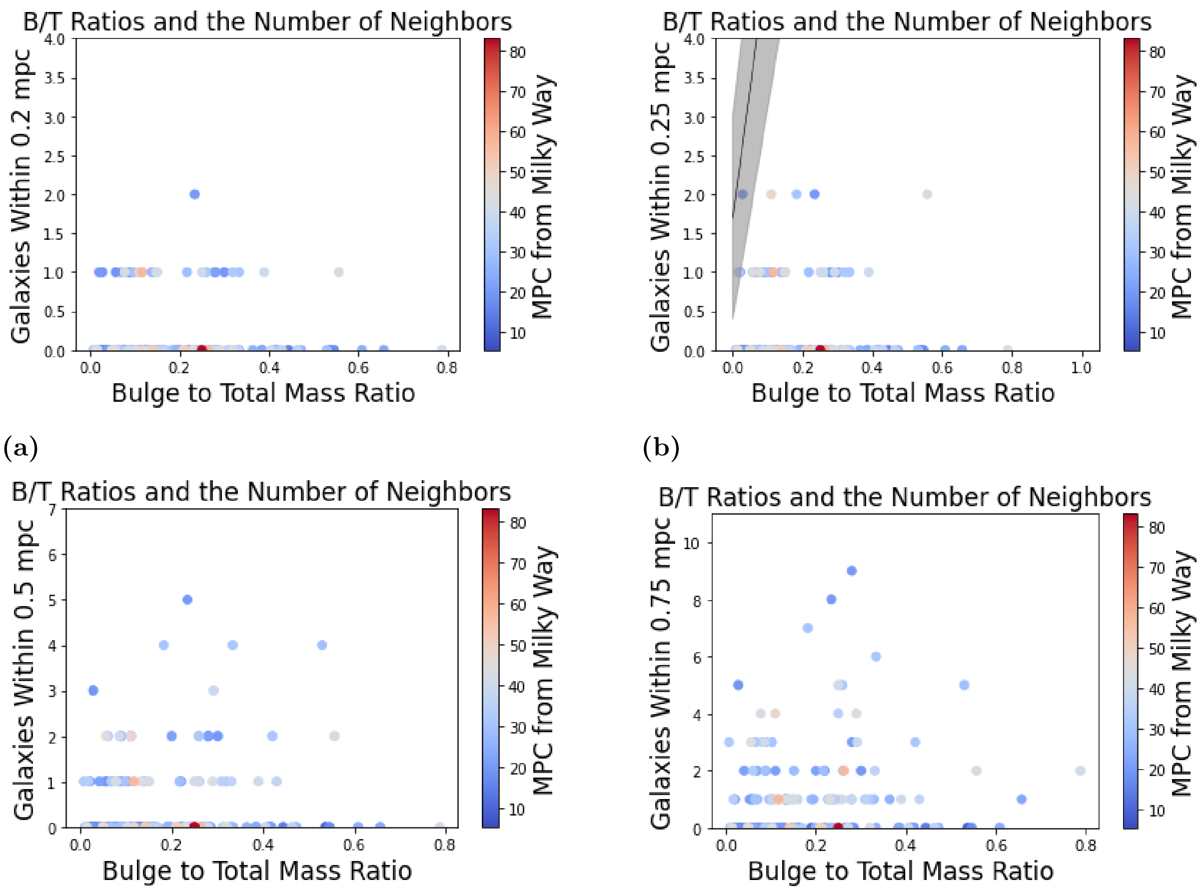
(a) **(b)**

FIGURE 29. RC3 positional data from NED. This redshift data is the most realistic when compared to others as there is no spike near $z = 0$. No periodic spikes are present.

APPENDIX D

SMALLER REDSHIFT CUT: 167 BULGE-TO-TOTAL GALAXIES

In this appendix we consider final results from a data reduction that is smaller than the initial reduction preformed in chapter 2.2. We cut any B/T galaxies whose redshift values are smaller than 0.0015. Making cuts smaller than this results in interference from the over-populated region near $z = 0$. With this smaller cut we are left with 166 spiral galaxies whose bulge to total ratios are known. We Include our results in figures 30 - 31. In figure 30a and figure 30b we find that our results still fall below the expected shaded region. While the shaded regions from javanmardi et al. are only truly valid for their respective distances of 0.20 Mpc and 0.25 Mpc we apply them more generally. In particular we apply the spread from equation 8 to distances greater than 0.20 Mpc. While this is not entirely appropriate we think it is qualitatively useful. From these plots we take away that galaxies should not be considered neighbors if they are at distances greater than 0.5 Mpc.



(a) **(b)** **(c)** **(d)**

FIGURE 30. Plots showing final results after making a B/T galaxy redshift cut at 0.0015. Shaded region is from javanmardi et al. [2]. We find in the cases of distances greater than 0.5 galaxies start extending past the shaded region. We find it is inappropriate to consider galaxies this far away as neighbors.

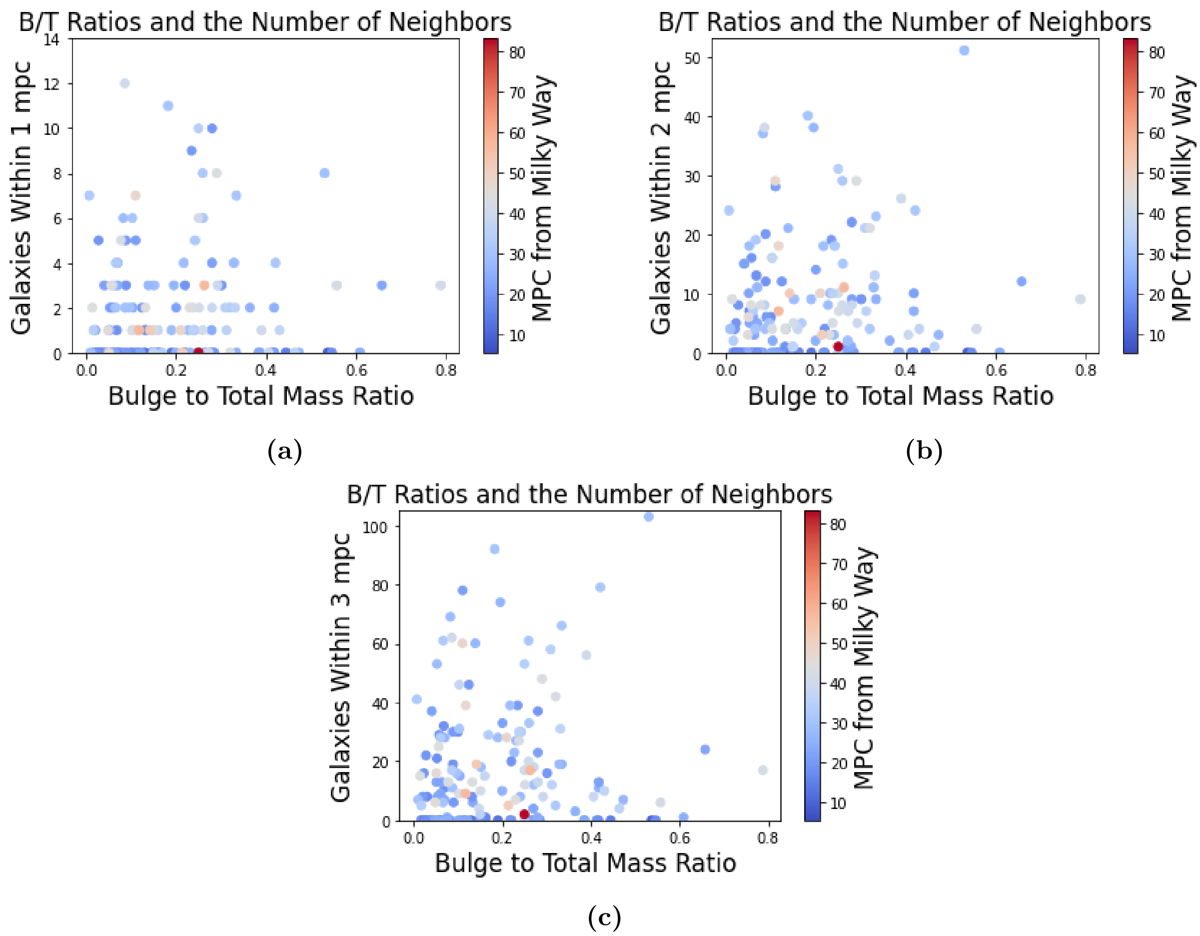


FIGURE 31. Plots showing final results after making a B/T galaxy redshift cut at 0.0015. The shaded region is from javanmardi et al. [2]. We find it is inappropriate to consider galaxies this far away as neighbors.

VITA

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