The Evolution and Growth of Nearby Galaxy Groups

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Abstract:

To determine how galaxy groups grow and individual galaxies evolve in the local universe, this project used 19 high richness, high-mass galaxy groups at z < 0.1 from the Berlind et al. 2006 paper to study the nearby group environment through its optical properties. Using position, g-r color, and r-band absolute magnitude data, the shapes, luminosities, and colors of each member galaxy were mapped in group combination plots and an inter-group color-magnitude diagram of all 477 sample galaxies. These figures show that members of the high-mass group environment trend towards redness where the most luminous members of each galaxy group are found to be red. Both findings are consistent with previous predictions of the group environment's bias towards red elliptical galaxies. Future work using optical properties and the galaxy sequence will be crucial to identify galaxies in groups undergoing evolutionary change as potential indicators of a changing group environment.

1. Introduction

Containing glowing structures of stars, gas, and dust, galaxy groups are some of the most interesting and important collections in the cosmos. Galaxy groups are gravitationally bound groupings of two to fifty member galaxies intrinsically tied to their group environments, which simply describe the matter contained in a galaxy group. Galaxy groups are important large-scale structures that holds the majority of galaxies in the local universe (Freeland et al., 2009), and dark matter is known to play an important role in their formation. Interactions between member galaxies or between member galaxies and gas in the group environment play an important role in determining properties such as color, morphology, and star formation rates (Freeland et al., 2009). However, while it is known that galaxy properties are impacted by their surrounding environment, the correlation between galaxy properties and their residing group's environment in the local universe is poorly understood (National Research Council & Panel on Galaxies Across Cosmic Time, 2011). Galaxy groups are postulated to be biased towards red and elliptical galaxies, but there is still much to be discovered about these complex environments (Cooray, 2005). Likewise, there are still many questions surrounding galaxy dynamics, specifically how galaxy groups grow and how their individual members evolve. This inquiry into the evolution of galaxies is built on a nearly 100yearold exploration designed to understand the visual differences and histories of these floating island universes.

The 1920's marked one of the first attempts to explain the evolution of galaxies with the Hubble Galaxy Classification Scheme or "Tuning Fork" that identified galaxies using their distinct morphologies (Hubble, 1926). This classification system was viewed as an evolutionary sequence where diffuse, round elliptical galaxies later became the rich, swirling arms of spiral galaxies through some process (Hubble, 1926). This idea permeates in galaxy nomenclature consisting of elliptical "early type" and spiral "late type" galaxies. However, the evolutionary sequence presented by the Hubble Tuning Fork is incorrect. Rather, the current leading theory of galaxy evolution is described in the galaxy sequence, where the star formation in blue galaxies with high star formation rates is quenched in the green valley to form red galaxies with low star formation rates (Eales et al., 2018). However, the crucial process that halts star formation in the green valley is still unknown, with theories spanning from violent collisions (Tempel et al., 2017) to more gradual, quiet processes (Eales et al., 2018). By working with optical galaxy properties such as color, luminosity, position, and stellar mass, this project has worked to unlock the galaxy evolution and the group environment through the study of its members.

2. Sample

The first step of this project was to assemble a sample of galaxy groups whose properties could be studied. One of the most important criteria was to find groups with member galaxies from the extensive Sloan Digital Sky Survey (SDSS) where a greater range of galaxy properties could be collected. Since assembling galaxy groups often requires difficult algorithms, the volume-limited group catalogs created by the Berlind et al. (2006) group using SDSS galaxies and a tested friends of friends group-finding algorithm proved perfect for the needs of this project. Electing for groups from the Mr18 Catalog with the faintest limiting magnitude of -18, a sample of 19 groups containing 33 to 20 members were chosen. For reference, the unique Mr18 catalog number for each of these galaxy groups is 388, 555, 1160, 2000, 2242, 2254, 2577, 2807, 3056, 3064, 3642, 3896, 4616, 7866, 8325, 8336, 9722, 9806, and 9950. It is important to note that these 19 groups are high in group mass and member richness and are not a representative sample of all possible group environments. Thus, it is important to regard any findings in this project as potential trends in the high-mass, high-richness group environment and not trends in the group environment as a whole. However, all methods conducted during the course of this project are applicable to galaxy groups with any number of members and allow for future sample expansion.

The Mr18 catalog provided complete position, redshift, color (g-r), and r-band luminosity (M_r) data for each member galaxy in the aforementioned 19 groups. While collecting this data, the original catalog creators encountered fiber collisions and survey edge cutoffs. These issues were addressed by adopting missing data from a galaxy's closest neighbor and only impacted, at most, five member galaxies from each group (Berlind et al., 2006). However, this process that corrected for missing spectroscopic data may have led to redundancies found in the luminosity, color, and redshift data. This sample contains many red galaxies with g-r > 0.8. This bias may be a trend, as the group environment is hypothesized to generally contain more red, elliptical galaxies (Cooray, 2005).

3. Methods

To collect member galaxy data, and study and visualize these 19 group environments, this project used a variety of computational and graphical methods described in the following sections.

3.1   SDSS Queries SDSS queries were made using data release seven (DR7) ObjIDs in a version of the Mr18 catalog linked to the Berlind et al. 2006 paper. Since SDSS replaced all object identifiers in their eighth data release, any query needed to be joined with the PhotoObjDR7 table to access the SDSS database. Some useful measures collected from SDSS for each member galaxy were best-fit stellar log masses, specific star formation rates, morphologies, and velocity dispersions. Since the stellar mass data for the majority of groups was incomplete, r-band luminosity was a more reliable inter-group measure for comparing sample g-r color.

3.2   Figures All project figures were created using Python's Matplotlib and NumPy data visualization and array libraries. Information pertinent to their scaling and axes can be found in the following sections.

3.3   Position Scaling In order to graph each member galaxy's position in terms of physical units, member right ascension and declination need to be converted to their distance from the group's center. First, the group center RA and Dec given by the Mr18 group catalog are subtracted from each member galaxy's RA and Dec. This gives a ΔRA or ΔDec value from the group's center in degrees. These ΔRA or ΔDec values be converted to arcminutes, and E.L. Wright's "A Cosmology Calculator for the World Wide Web" and group redshift can be used to produce an angular size distance factor in kpc/arcsec" at the group's given distance. Multiplying each ΔRA or ΔDec value by this factor and 0.001 gives the physical distance of each member galaxy from their group's center in Mpc. These ΔRA or ΔDec values can then be used to plot each member galaxy's position in space. This process was used to create Fig. 1-21.

3.4   Magnitude Scaling To incorporate absolute magnitude into Fig. 1-19, each galaxy's position marker was scaled for the member's r-band absolute magnitude. Since the r-band absolute magnitude of member galaxies only ranged between -17 and -23, this project instead utilized the rband absolute magnitude of each galaxy compared to the survey cut-off M_r = -18 to determine marker size. Each galaxy's luminosity was scaled using the formula $B = 10^{(-18-M_r)/2.512}$ where M_r is the member galaxy's absolute r-band magnitude and 2.512 is the factor difference in brightness between objects with a magnitude differing by one and B is marker size. These markers were then multiplied by a factor of 20 to make them visible. This scaling process was used to create Fig. 119.

3.5   Axes and Color Bars To accommodate all member data, Fig. 1-22 contain the same axes and color bar scaling to allow for intergroup comparison. The g-r scale used in the color bar is comparable to that in the Angthopo et al. (2019) for uncorrected g-r color.
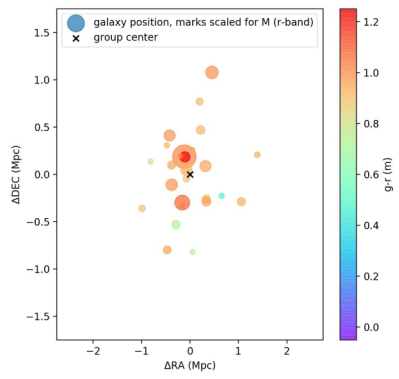
4. Key Results

As can be seen through Fig. 1-19, even when galaxy groups are selected for similar richness of members and mass, the makeup and arrangements of these groups can differ greatly. While some are more spatially diffuse, like group 4616, others are tightly condensed within the position axis scales, like group 2000. While each group has a large concentration of red galaxies as shown in Fig. 22, some groups contain relatively large populations of blue or green galaxies, like group 9806. Others, like group 9722, have exceptionally high concentrations of red members. These groups also differ in the intra-group dispersions of their luminosities, with some groups like 3056 containing one member notably brighter than its companions and others like group 2242 containing galaxies with similar luminosities. As can be seen in Fig. 1-19, the group environment for galaxy groups with similar richness and mass display a diverse array of characteristics. However, a few notable trends can be seen among these groups.
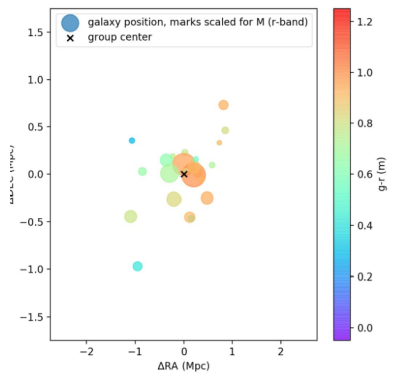
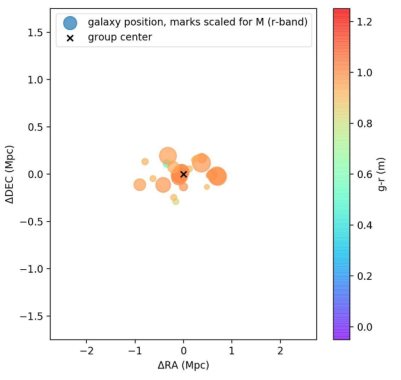Mr18 Group 388: ΔRA vs. ΔDec with Color and Abs. Magnitude
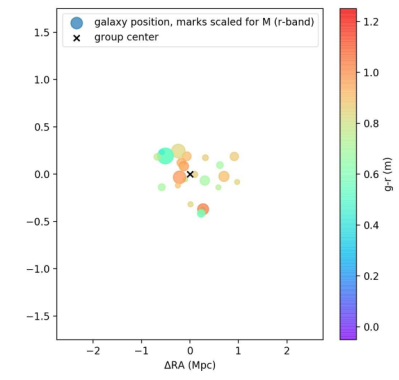Mr18 Group 555: RA vs. Dec with Color and Abs. Magnitude
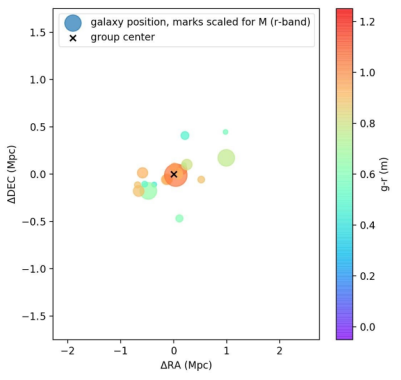Mr18 Group 1160:: ΔRA vs. ΔDec with Color and Abs. Magnitude
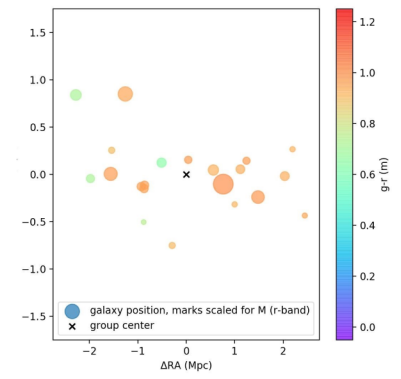
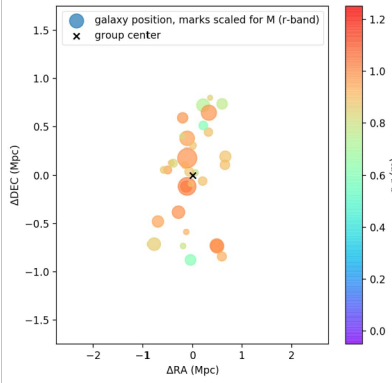Mr18 Group 2000: RA vs. Dec with Color and Abs. Magnitude
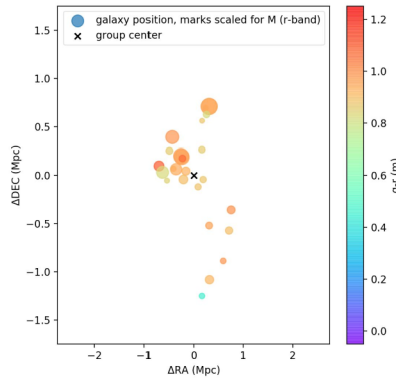Mr18 Group 2242:: ΔRA vs. ΔDec with Color and Abs. Magnitude
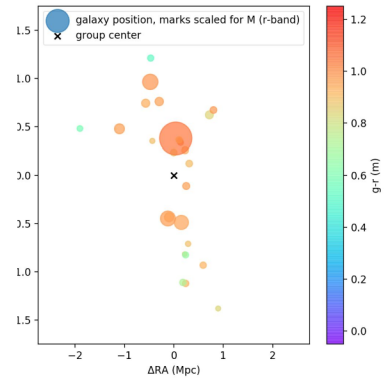Mr18 Group 2254:: ΔRA vs. ΔDec with Color and Abs. Magnitude

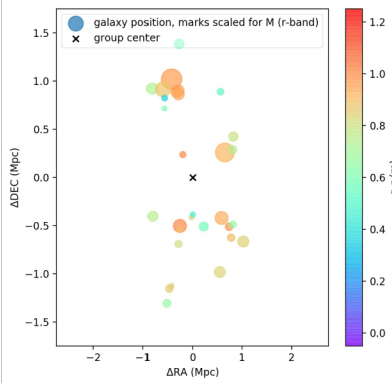Mr18 Group 2577: : ΔRA vs. ΔDec with Color and Abs. Magnitude
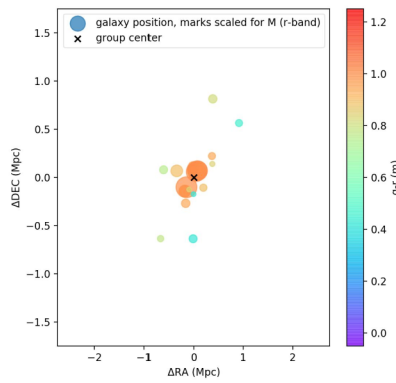Mr18 Group 2807: : ΔRA vs. ΔDec with Color and Abs. Magnitude
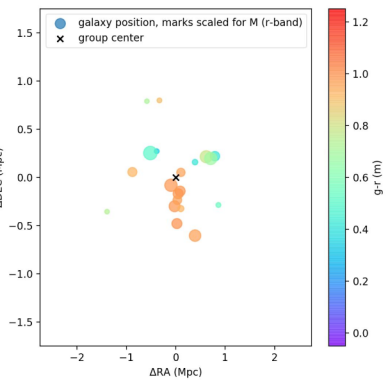Mr18 Group 3056: RA vs. Dec with Color and Abs. Magnitude
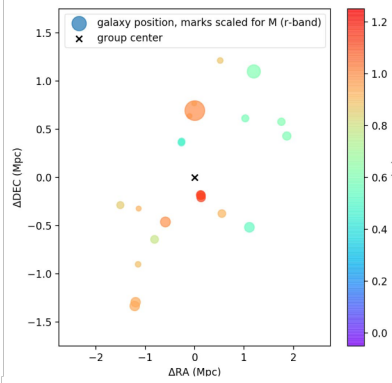Mr18 Group 3064: : ΔRA vs. ΔDec with Color and Abs. Magnitude
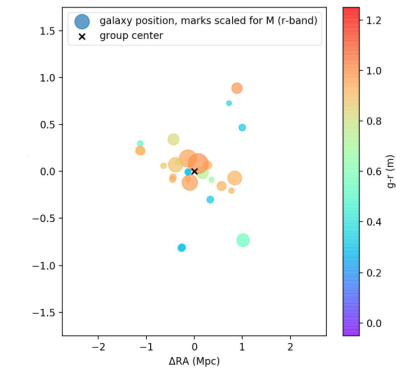Mr18 Group 3642: : ΔRA vs. ΔDec with Color and Abs. Magnitude
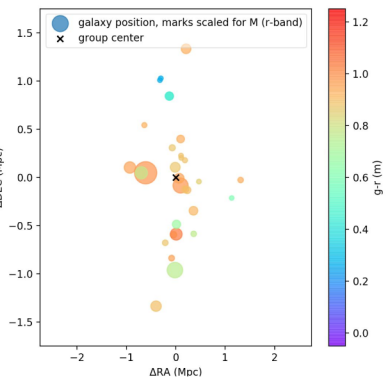Mr18 Group 3896: RA vs. Dec with Color and Abs. Magnitude
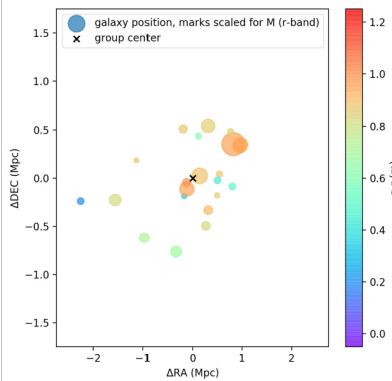Mr18 Group 4616: ΔRA vs. ΔDec with Color and Abs. Magnitude
Mr18 Group 7866: ΔRA vs. ΔDec with Color and Abs. Magnitude
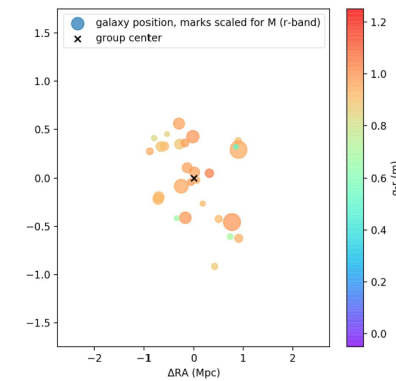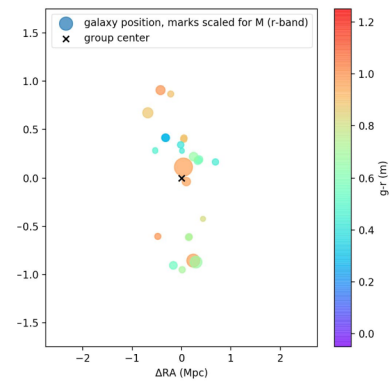Mr18 Group 8325: : ΔRA vs. ΔDec with Color and Abs. Magnitude
Mr18 Group 8336: RA vs. Dec with Color and Abs. Magnitude
Mr18 Group 9722: : ΔRA vs. ΔDec with Color and Abs. Magnitude
Mr18 Group 9806: : ΔRA vs. ΔDec with Color and Abs. Magnitude

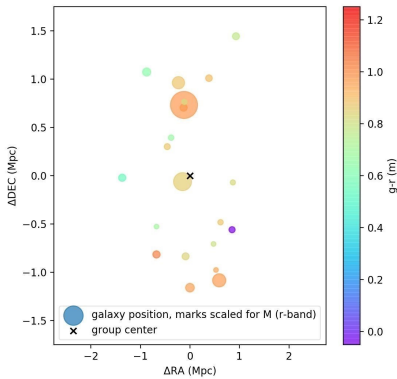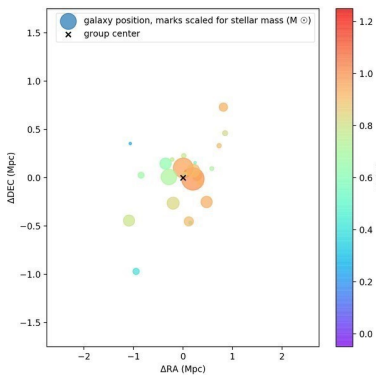Mr18 Group 9950: RA vs. Dec with Color and Abs. Magnitude

Fig. 1-19: Group ΔRA vs. ΔDec with Color and Absolute Magnitude. Scaled for absolute r-band magnitude and distance, these figures combine member galaxy position relative to the group center, luminosity and color to create a picture of each galaxy group in space. The group center is marked with a black "x" for reference. Fig. 1-19 contain ΔRA and ΔDec values plotted along the x and y axes with markers scaled in size for absolute magnitude using previously described methods. The color bar maps each of these markers for g-r galaxy color using a scale of -0.05 to 1.25. The position axes also include constant scales, with each x-axis spanning from -2.75 Mpc to 2.75 Mpc and each y-axis spanning from -1.75 Mpc to 1.75 Mpc. Thus, Fig. 1-19 are an important tool for qualitative and quantitative comparison between each of the sample's 19 groups.

One trend that can be seen in Fig. 1-19 is that each galaxy group's members tend towards redness with primarily positive g-r color values. Only one galaxy in 477 members contained a negative gr value of -0.044 indicative of very blue galaxies. This finding is substantiated by Fig. 22, where gr values in the red galaxy region between g-r = 0.85 and g-r = 1 contain the most galaxies across a wide variety of luminosities. Curiously, this dense region of galaxies isn't located at the reddest part of the g-r color bar, and this dense, red-orange region is rather surrounded by a few, very-red outlier galaxies (g-r > 1) that reflect the plot density of the bluest region of the color magnitude diagram (about g-r < 0.4). The most luminous galaxy in each group is also red. This is substantiated in Fig. 22, where any galaxy brighter than $M_r = -21.25$ is red. It is also important to notice the shape of the galaxy distribution in Fig. 22. At $M_r = -18$, the color-distribution forms an expected vertical cut-off at the sample's limiting magnitude. To the right of this distribution there is an interesting, negative correlation indicating that as a galaxy's g-r color decreases, the maximum luminosity of galaxies with the same g-r value decreases. Thus, there is a lower range in member luminosity as g-r color decreases. However, this sample contains fewer blue members overall, which may be the true cause of this trend, as there are more relatively dim galaxies than highlyluminous galaxies for any g-r color in Fig.22.

Mr18 Group 388: ΔRA vs. ΔDec with Color and Stellar Mass

Mr18 Group 555: ΔRA vs. ΔDec with Color and Stellar Mass
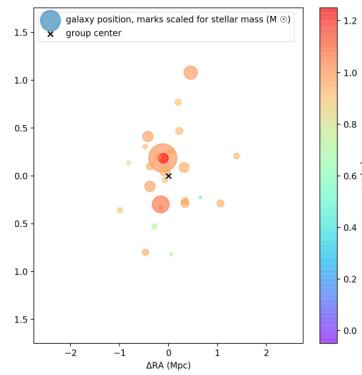
Fig. 20-21: Group ΔRA vs. ΔDec with Color and Stellar Mass. Fig 20-21 are identical to Fig. 1-2 except their markers are scaled for member stellar mass instead of r-band absolute magnitude. This scaling was done by exponentiating each SDSS stellarMassFSPSGranEarlyDust log stellar mass using a base value of 10. These large masses in terms of solar masses were then divided by a factor of 5×10^8 to ensure each marker fit within Fig. 20-21.

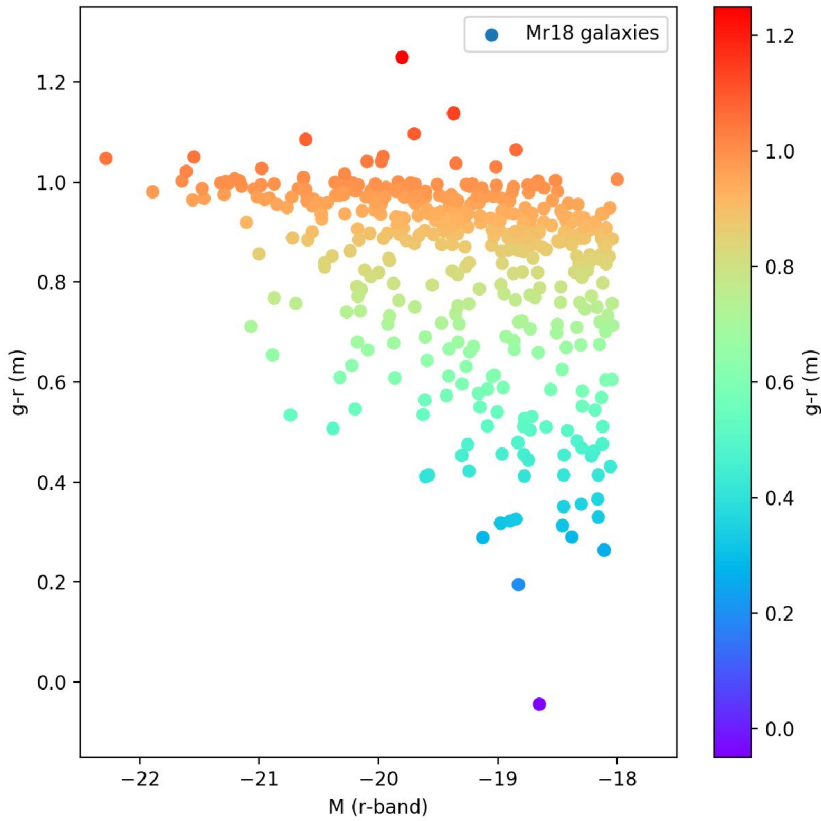Color-Magnitude Diagram of Galaxies in Mr18 Groups

Fig. 22: Color Magnitude Diagram of Galaxies in Mr18 Groups. Fig. 22 is a standard color-magnitude diagram with a gr mapping color bar.. Fig. 22 includes the 477 member galaxies contained within the sample's 19 Mr18 galaxy groups. As seen in the diagram, this survey contains a large number of red galaxies with varying luminosities.

Stellar mass data useful for studying a galaxy's stellar population and mass was incomplete for the majority of groups. One notable tangent about stellar population is seen when comparing Fig. 1-2 to their counterparts Fig. 20-21, where markers are scaled for stellar mass instead of luminosity. As can be seen in these mass-color diagrams, the stellar mass inside these groups isn't evenly dispersed.

Proportionally, figure markers for red galaxies grow or remain constant in Fig. 20-21, showing that a large mass of low-luminosity, older red stars contributing to galaxy luminosity when compared to Fig.1-2. The figure markers for blue galaxies shrink substantially when scaled for stellar mass, indicative of a smaller, newer population of highly luminous stars. Bright, massive, central galaxies are crucial fixtures in certain group growth scenarios such as accretion. Thus, color-mass diagrams provide important information qualifying a group's stellar population and potential evolutionary scenarios.

5. Discussion

As mentioned previously, the 19 galaxy groups studied in this project substantiate previous hypotheses about the group environment in the local universe. These groups were found to contain a large population of red members of all luminosities. The most luminous galaxy in each group and most luminous galaxies in the project sample were also red. These conjectures substantiate the hypothesis that the high-mass group environment is biased towards red galaxies, potentially ellipticals. To determine this, morphology information could be mapped onto each member galaxy, which would be exceptionally informative for galaxies with bright, massive, red, central members that could represent an accretion growth scenario with a central, cannibalizing elliptical galaxy. It is important to note that these results cannot be extended to the entire group environment. Thus, just as these results provide information about the high-mass, high-richness group environment, to learn

about the group environment in totality, the low-mass group environment should be studied for its optical properties. Future research could unlock trends in the properties of the full group environment in the local universe, especially with a large, diverse survey spanning all possible group richness and mass. Understanding the characteristics of the group environment robustly can help link individual galaxy properties to conditions within their galaxy groups, allowing for correlations between the group environment and galaxy properties to be studied and developed.

It is also crucial that these results and galaxy properties be interpreted in light of the current theory on galaxy evolution: the galaxy sequence. Through methods provided by Angthopo et al. (2019) and complete optical data, it is possible to map each group's member galaxies onto the galaxy sequence, revealing their evolutionary location in the blue cloud, green valley, or red sequence. Identifying a galaxy's location in the green valley, where star formation is halted through some unknown process, is imperative, as this process marks a galaxy undergoing drastic change in its properties. By understanding which galaxies in the group environment are evolving, the outwards group environment can be examined and studied for causation. Due to the link between galaxy properties and the group environment, member green valley galaxies in a group may indicate a growing or changing group environment, potentially driven by member interaction. This future extension would operate by using member galaxies' evolutionary properties to study their outwards environments. Morphology will be an important aspect of identifying known group change and growth scenarios as well. Complete stellar mass data will also be an important part of this project moving forward: to study stellar populations and group mass arrangement through the magnitude gap (Dariush et al., 2010). The magnitude gap can be used to study halo mass arrangement and the role of cold dark matter (CDM) in forming large-scale structures like galaxy groups (Dariush et al., 2010).

Acknowledgements

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