Examining The Role of AGN in Galactic Morphology

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Abstract

Active Galactic Nuclei (AGN), though only comprising a small percentage of the total galaxy mass, are believed to play an integral role in star formation, as suggested by theories developed in recent years. Furthermore, a galaxy's star formation likely contributes to its overall shape. After all, disk galaxies tend to be younger and more gas-rich than their elliptical counterparts, so they are likely to have higher star formation rates. We hypothesize that AGN hosts tend to be disk galaxies. By cross-matching morphology data with AGN data, this study aims to examine the relationship between AGN host galaxies, their star formation rates, black hole accretion rates, and their morphologies.

Introduction

Supermassive black holes (SMBHs), though only reaching up to ~0.5% of the host galaxy mass once fully evolved to present day, may play an important role in shaping the overall structure of their host galaxy. Galactic morphology remains at the forefront of modern astronomical research because it could provide insight on the history of the universe and map out the properties of our own galaxy, the Milky Way. Models and classification schemes of AGN are currently under development, but all AGN share the same basic anatomy. Although relatively small and compact when compared with the rest of the galaxy, it is reasonable to assume that AGN may be linked to the greater galactic structure due to its immense energy. AGN can reach up to 10^{15} solar luminosities, which makes them more luminous than their host galaxies.

The purpose of this study is to explore the relationship between the presence of AGN and other processes that happen around the galaxy through the use of computational data analysis. A galaxy's star formation rate and black hole accretion rate both depend on the presence of a sufficient gas reservoir within the galaxy. These two phenomena are likely linked with each other and may also influence a galaxy's morphology, as that too also depends on how gas-rich a galaxy is.

General Methodology

Galaxies in the past were not only more active in forming stars and growing their black holes, but they were also heavily dust obscured. Therefore, star formation rates (SFR) and black hole accretion rates (BHAR) must be derived from a galaxy's infrared data to more accurately describe these processes in dusty galaxies. Although SFR values are usually derived from UV or optical data, infrared data serves as a better proxy for star formation in this case because radiation emitted at shorter wavelengths, especially in dusty galaxies, are absorbed by dust particles. The radiation is re-emitted by the dust as infrared waves, which telescopes can accurately detect. Star formation occurs in molecular regions of gas, which are kept cold by surrounding dust. Because dust is a good indicator of star formation, tracking the dust via infrared data is also optimal for obtaining SFR. To calculate SFR, data from the CANDELS survey was used. The CANDELS survey was comprised of data for galaxies in COSMOS (COS), GOODS (GDS), Extended Groth Strip (EGS), and Ultra Deep Survey (UDS). Initially, the CANDELS data table included only total infrared luminosity (8 µm– 1000 µm) and fraction of the luminosity emitted by the AGN in the mid infrared spectrum (5 µm – 15 µm). These two quantities were used to deduce the SFR and BHAR through other values, namely, total AGN fraction in the infrared, total luminosity emitted by the AGN in the infrared, total luminosity emitted by star formation in the infrared, and finally, SFR and BHAR.

Calculations

To calculate SFR and BHAR for each of the galaxies in the CANDELS data table, several conversions were made from the original infrared data. The equations used to obtain the final quantities are shown.

The calculation for SFR is the equation below and is from Kennicutt *et al*.

$$SFR\left[M_{\odot}\ yr^{-1}\right] = 4.5 \times 10^{-44} L_{sf}$$

Kennicutt's equation is an empirical relationship and may differ from the relationships used by other scientists. However, Kennicutt's formula is considered to be one of the most authoritative.

The formula below shows the standard calculation for BHAR. It is essentially a rate-based rearrangement of Einstein's equation, $E = mc^2$. In the formula, $\dot{M}$ represents the BHAR, η represents the efficiency at which matter is accreted (generally assumed to be 10%), L_{bol} is the bolometric luminosity, and c is the speed of light in vacuum.

$$\dot{M} = \frac{(1-\eta)L_{bol}}{\eta c^2}$$

Relationship between BHAR and SFR

In the end, SFR and BHAR data was obtained for approximately 2000 galaxies in CANDELS. The data were then conjoined with FITS files containing more information on the respective CANDELS galaxies. Several plots were made to compare the properties of each galaxy within this sample.

Testing the correlation between a galaxy's stellar mass, SFR, and BHAR was a particular point of interest in this study. Graphs of Mstar (a galaxy's stellar mass) vs. SFR are shown in Figure 1. The graphs are sorted into three redshift bins. Cosmological redshift refers to an object's recession velocity or distance from our point of view. It could also describe specific cosmological epochs. For example, a redshift of $z = 0.1$ would be considered the "local" universe and a redshift of $z = 5$ would be considered the "early" universe. The CANDELS data were sorted into redshift bins to account for differences between different cosmological eras.

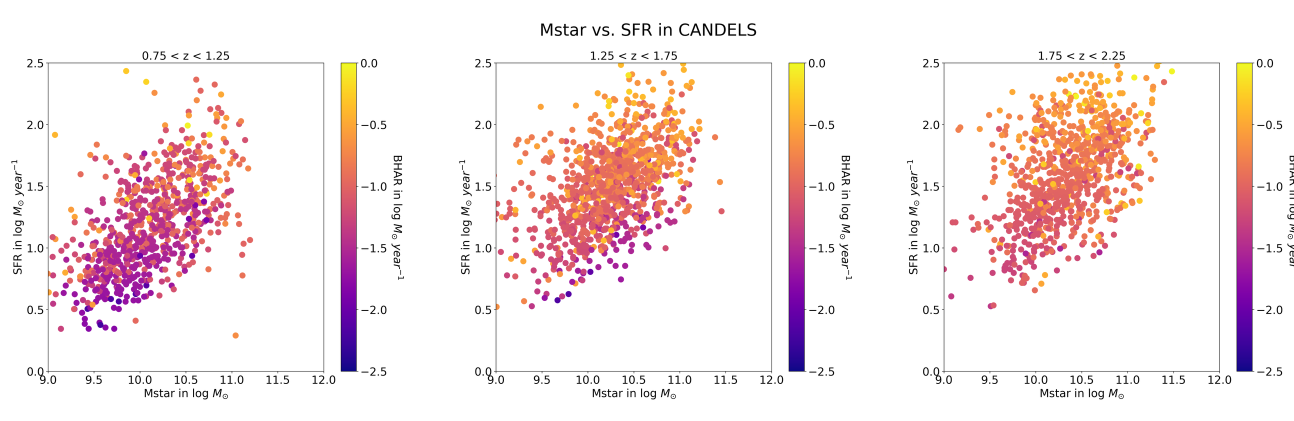

Figure 1. – Plots of Mstar (stellar mass) vs. SFR for all CANDELS galaxies. The galaxies are sorted into three redshift bins: 0.75 to 1.25, 1.25 to 1.75, and 1.75 to 2.25. On all the plots, the stellar mass of the galaxy is graphed on the x-axis in units log solar masses, and the SFR is graphed on the y-axis in units log solar masses per year. The data is shaded by BHAR in units log solar masses per year. The plots seem to show that as stellar mass increases, so does SFR and BHAR. BHAR is also higher at higher redshifts, given the progressively yellower color.

Relationship with Stellar Main Sequence

SFR plots with the stellar main sequence were created to further examine the correlation between potential AGN host galaxies and their star formation rates. The stellar main sequence represents the average star formation rate for a galaxy of a given mass and redshift range. Figure 2 shows plots of stellar mass vs. SFR and is essentially Figure 1 with the main sequence included. Figure 2 does show that lower BHAR (shown as darker, purple points) tend to fall below both main sequence curves, which strengthens the initial claim that if a galaxy has a lower SFR, it would likely have a lower BHAR, and vice versa for higher values of each variable.

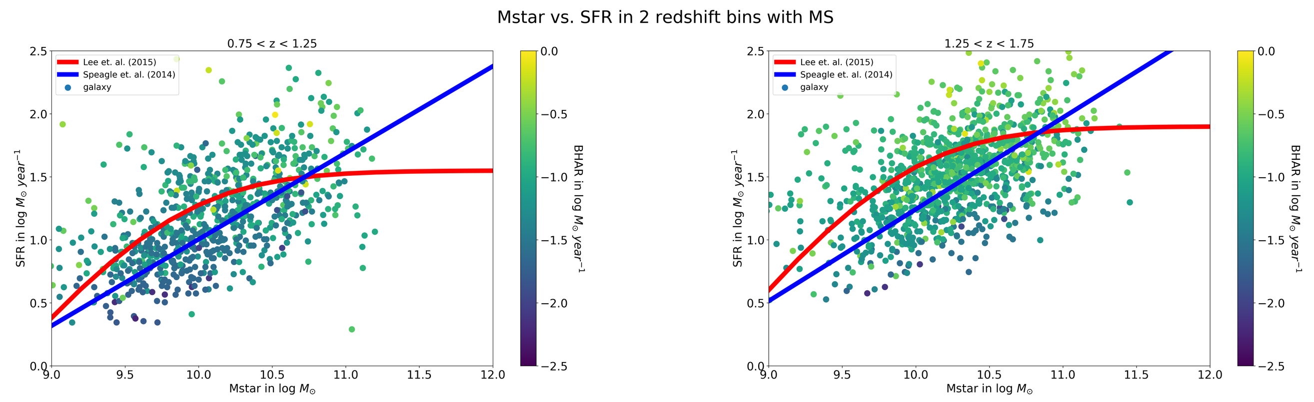

Figure 2. – Plots of Mstar vs. SFR, shaded by BHAR. Mstar is in log solar masses, SFR is in log solar masses per year, and BHAR is in log solar masses per year. Main sequence star formation rate curves were also included. The red curve represents the main sequence projected by Lee et. al. (2015)[1], and the blue line represents the main sequence projected by Speagle et. al. (2014)[2]. The third redshift bin from Figure 1 was omitted in Figure 2 due to the fact that the Main Sequence formulas lose accuracy at higher redshifts.

In both Figure 2, two different projections of the main sequence are graphed to address a controversy. Using the linear relationship produced by Speagle *et al*. at $z = 1$ is incorrect, but the equation produced by Lee *et al*., which exhibits a turnover at $z = 1.5$, may also be incorrect since the stellar main sequence has not been measured at that redshift. Although a turnover at $z = 1.5$ has not been confirmed, the relationship between stellar mass and SFR should plateau as stellar mass increases because higher stellar mass means that more of the gas supply within a galaxy has been consumed to fuel star formation.

Relationship with Galactic Morphology

Overall, the positive correlation between SFR and BHAR was expected they are fueled by the same phenomena: the presence of a sufficient gas reservoir within the galaxy. The amount of gas in a galaxy begs the question of galactic structure. Whereas elliptical galaxies are gas-poor and old, spiral galaxies, on the other hand, are gas-rich and young. It is likely that the galaxies that host AGN are spiral galaxies since that explains their black hole fueling mechanism. To determine if this was indeed the case, galaxies in the overlap between the GOODS-S field and CANDELS survey were plotted to see if their morphologies were linked with their BHAR. Figure 3 below shows examples of elliptical and spiral galaxies for visual purposes, and Figure 4 on the next section shows the results of this test.

Figure 3. – Two main morphological galaxy types used in Figure 4. Left: an elliptical galaxy.[3] Right: a spiral galaxy.[4]

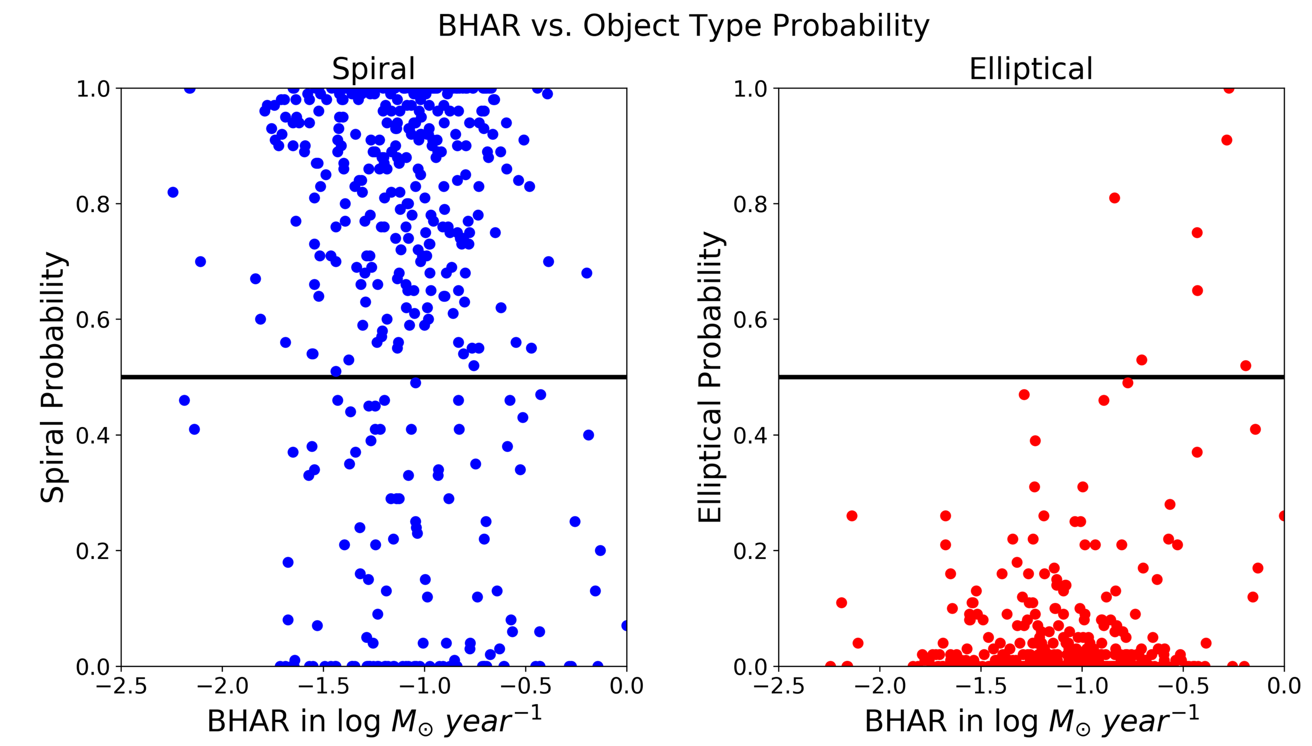

Figure 4. – Graphs of BHAR vs. Object Type Probability, which is how likely the galaxies' morphologies are to be a certain shape. BHAR is graphed on the x-axis in units log solar masses per year. The left-hand graph has the probability that the object in question is a spiral on the y-axis, on a scale of 0 to 1. 0 refers to a probability of 0%, and 1 refers to a probability of 100%. The right-hand graph has the probability that the object is an elliptical on the y-axis using the same scale. The horizontal black line represents a 50% probability and is drawn for data interpretation.

The data points in Figure 4 come from approximately 400 galaxies, with morphology data taken directly from the Rainbow Navigator database. The probabilities were calculated via machine-learning. Surprisingly, the graphs seen in Figure 4 do not match the original hypothesis. No tangible correlation exists between BHAR and spiral probability. The graph does show that most galaxies in the sample exhibit spiral-like features, as shown by the number of data points above the 50% probability line. This makes sense because most galaxies are spirals. Likewise, the same objects have a low probability of being ellipticals. On the other hand, elliptical probability loosely rises with BHAR. This result contradicts the classical picture of galaxy evolution and as such should be taken with a caveat. It is likely that the galaxies exhibiting a high probability of being ellipticals are actually spiral galaxies because the brightness of the AGN may obscure the galaxy's morphology and prevent accurate classification. Star formation is present in spirals and virtually absent in ellipticals, and recent theory also supports that the majority of black hole growth occurs alongside star formation. It is still possible that a galaxy's morphology is connected with its BHAR, but other means of experimentation must be used to confirm the relationship. The morphology graphs shown in Figure 4 seem to disprove any connection between a galaxy's shape and its BHAR, but the data likely appears this way due to instrumental limitations of the telescope from which it was collected, as the extraordinary brightness of an AGN could easily obscure the true shape of its host galaxy. In summary, future work remains to be done on this subject.

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