Investigating the Relationship Between Bulge Growth and X-ray Emission in Luminous AGN

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ABSTRACT

To investigate the influence of AGN on host galaxy bulge growth as well as if AGN are responsible for the quenching of star formation, we look at the bulge to total (B/T) fractions and their dependence on X-ray luminosity. We use GALFIT to model X-ray selected galaxies in COSMOS with a single Sérsic profile. After finding a large number of sources at Sérsic index of 20 due to prominent point sources in our sample, we expanded our model to have three components: two Sérsic profiles for galaxy bulge and disk respectively, and a nuclear point source model. B/T shows no significant correlation with properties such as X-ray luminosity ($L_X$), Stellar Mass ($M_\star$), star formation rate (SFR), and offset from the main sequence ($\Delta SFR_{MS}$). However, luminosity in the nucleus is strongly correlated with $L_X$, $M_\star$, SFR, $\Delta SFR_{MS}$, and flux ratios sensitive to emission from the Big Blue Bump (BBB) and Torus.

Keywords: AGN, Galaxy Structure, Galaxy Morphology, X-ray Sources

1. INTRODUCTION

Active Galactic Nuclei (AGN) are supermassive black-holes (SMBHs) with mass $M_\bullet > 10^6 M_\odot$ that are currently accreting matter. A common threshold for AGN is sources with X-ray luminosity $> 10^{42}$ erg s$^{-1}$. Most AGN include components such as: an accretion disk, a dusty torus which may obscure the AGN, broad line regions (BLR), narrow line regions (NLR), and occasionally central radio jets (Elvis et al. 1994; Sanders et al. 1989; Netzer 2015; Calistro Rivera et al. 2016).

AGN are thought to co-evolve – i.e. interact and grow – with their host galaxies. One example is the established relationship between SMBH mass ($M_\bullet$) and velocity dispersion ($\sigma$) within the bulge component of the galaxy, known as the $M_\bullet-\sigma$ relation (McConnell & Ma 2013). In addition, it is predicted that SMBH growth regulates star formation of the host galaxy through negative feedback (Kormendy & Ho 2013).

The star formation rates (SFR) of star forming galaxies are highly correlated with their stellar masses ($M_\star$). This roughly linear SFR–$M_\star$ relation is known as the galaxy Main Sequence (MS). Hung et al. (2013) finds that a large fraction of galaxies above the main sequence are mergers. Mergers are thought to induce AGN activity (Sanders et al. 1988) and drive bulge growth in the host galaxy (Kormendy & Ho 2013).

Active star-forming galaxies populate the MS, and quenched galaxies reside below the MS. While the classic MS shows a linear relationship when exclusively using purely star forming galaxies, the inclusion of all galaxy types yields a MS turnover (Whitaker et al. 2014; Lee et al. 2015). Moreover, various studies show that AGN inhabit the region between the MS and quenched population, and that there is an increased bulge to total ($B/T$) fraction in galaxies with higher SFRs (Salim et al. 2007; Leslie et al. 2016; McPartland et al. 2019). To determine if AGN produce MS turnovers and if they quench star formation, we examine the change in X-ray luminosity in the intermediate region of the SFR–$M_\star$ diagram.

We investigate the bulge to total ($B/T$) fractions of X-ray selected galaxies from The Cosmic Evolution Survey (COSMOS) and compare to X-ray luminosity to see how AGN influence bulge growth as well as how AGN relate to their host galaxy’s position on the MS and if AGN are responsible for the quenching process.

Multi-wavelength data facilitates studies of AGN since obscuration by gas and dust biases selection in any given band (Hickox & Alexander 2018). However, selection of luminous X-ray sources results in the most complete sample. The Accretion History of AGN (AHA) project aims to gain a comprehensive understanding of the evo-
Figure 1. Examples of HST F814W cutouts of (a) a pure disk, (b) a disk with bulge, (c) a spheroid, and (d) an example of a prominent point source. Panels (a), (b), and (c) are shown in increasing order of $B/T$. All images have a size of 70 kpc proper at the source redshift.

Figure 2. An example of the masks used to remove extra sources in the fitting procedure. The yellow contours show the masked regions of the image. The red circle has a diameter of 2 arcseconds surrounding the X-ray source. The example galaxy Laigle ID is 0197038.
3.2. GALFIT

The Sérsic profile is commonly used to quantify galaxy morphology (Sérsic 1963). Here, we use GALFIT (Peng et al. 2002, 2010), a two-dimensional parametric fitting algorithm, to decompose galaxies into bulge and disk components, thus measuring the bulge to total fraction ($B/T$). Examples of galaxies with varying $B/T$ are shown in Figure 1.

The Sérsic profile has the following functional form:

$$\Sigma(r) = \Sigma_e e^{-\kappa \left( \frac{r}{r_e} \right)^{1/n} - 1}$$

where $r_e$ is the effective radius of the galaxy, $\Sigma_e$ is the surface brightness at $r_e$, $n$ is the power-law/Sérsic index, and $\kappa$ is coupled to $n$ such that half of the total flux is always within $r_e$ (Peng et al. 2002). Initial parameters are estimated using the python package photutils (Bradley et al. 2019; Astropy Collaboration et al. 2013). These parameters include position, magnitude, $r_e$, $n$, axis ratio, position angle, and sky background.

A Sérsic index of 1 corresponds to a pure disk galaxy, and a Sérsic index of 4 corresponds to a spheroidal bulge dominated galaxy, with a range of $B/T$ values in between. Sérsic indices greater than 4 typically correspond to point sources.

It is essential to mask extra sources in the cutout images to ensure that GALFIT is only fitting the source of interest. Photutils is used to define a detection threshold and a normalized Gaussian 2D kernel is used to create a segmentation map of all the sources in an image. In addition, since our sample contains galaxies in various merger stages, the sources are de-blended using a watershed segmentation technique. Moreover, since the central source is not always located at the center pixel of the cutout, the central source was identified using the nonzero mode of a small area in the center of the segmentation map. Before removing the central targeted source from the mask for the purpose of fitting, the other sources are dilated without infringing on the central source in order to ensure the residual flux around masked sources is excluded. Figure 2 shows the result of the masking process for an example galaxy (Laigle ID 0197038) with a contour map overlayed onto the data (yellow), and a 2 arcsecond diameter circle (red) to indicate the central source.

The output of the GALFIT modeling process is a FITS image block containing all the inputs, values and estimated errors of fit parameters in the headers, and images of the data, model, and residuals. Figure 3 displays the output images for an example galaxy (Laigle ID 0828975). The first panel is the original data formatted similar to Figure 2 with mask contours (yellow) and a 2 arcseconds diameter central circle (red). The second panel is a synthetic image of the model galaxy created from the parameters fit by GALFIT with the same identifying circle. The third panel is the residual, subtracting the model from the original data, and formatted identically to the data panel.

4. RESULTS

4.1. Single Sérsic Profile

We initially use GALFIT to fit the image cutouts with single Sérsic profiles. Figure 4 shows a histogram with 10 bins of Sérsic index for various modeling approaches. The first method solely utilizes a single Sérsic (1n) profile, and yields a significant number of galaxies with Sérsic index of around 20 indicative of a strong nuclear point source.

When the sample is split by spectral classifications, the majority of Type 1 AGN have a Sérsic index of 20,
and tend to have a higher X-ray luminosities. Type 2 AGN also have a significant number of sources with a Sérsic index of 20, but extend to lower Sérsic indices and X-ray luminosities as well. Further probing the distinction in Sérsic index between AGN spectral type classifications shows there is a greater population and larger spread in the distribution of Type 2 AGN when the Sérsic index is less than 17.5. While both Type 1 and Type 2 AGN display a peak at a Sérsic Index of 20, the peak is dominated by Type 1 AGN both in number and fraction of galaxies.

In addition, splitting the sample into morphological classes using the visual classifications described in section 3.1 reveals that while many of the galaxies classified as spheroids were also classified as having prominent point nuclei, sources with a Sérsic index of 20 are dominated by spheroidal galaxies and galaxies containing central point sources. As a result, the high concentration of galaxies at Sérsic index of 20 is most likely due to prominent point nuclei in the respective galaxies.

Typically, Type 1 AGN are unobscured and more luminous than their Type 2 counterparts; as a result there are more point nuclei in Type 1 galaxies than Type 2. Therefore, the higher concentration with a Sérsic index of ∼20 for Type 1 AGN supports that these sources feature strong point sources in their nuclei. Furthermore, the randomly selected subset of 1400 visually classified galaxies shows that point sources and spheroidal galaxies are common in sources with a Sérsic index of ∼20. While we do not see a clear correlation between Sérsic index and X-ray Luminosity, we are able to determine that contamination by point sources in the nuclei of our sample can greatly increase the Sérsic index of our model and skew any underlying correlation.

To reduce the congregation of sources at Sérsic index of ∼20 and improve the model, a point source function (PSF) component is added to the model to be included in the fitting process. Figure 4 shows that models including the additional point source component (+psf) have a reduced concentration of high Sérsic index sources, and a corresponding excess of sources in the anticipated region of 0 < Sérsic index < 4 relative to models without a PSF component.

In addition, while we originally left the sky background as a free parameter to allow the sky background to be fit and the errors to propagate to the other parameters, Figure 4 shows that models with a fixed sky background (fix sky) have less sources with high Sérsic indices as well as a greater number of sources due to fewer failures in the fitting process. Consequently, we chose to follow the standard procedure (Meert et al. 2013) and use a fixed sky background.

4.2. Three Component Model

Our final galaxy model consists of three components: two Sérsic profiles for the galaxy bulge and disk respectively, and a PSF model component. Adding a component for the point source removes the effect on Sérsic index and allows us to better investigate the correlation between X-ray luminosity and morphology. This model is much more physically meaningful and allows us to plot B/T instead of Sérsic index as a function of X-ray luminosity. In addition, throughout the rest of this paper we use a fixed sky background. 2308 galaxies were successfully model fit with this three component method.

Figure 5 shows a 2D histogram with 30 bins of B/T and 30 bins of log X-ray luminosity. The color scale indicates the log number of galaxies within a bin, where empty bins are set to white. An X-ray luminosity ($L_X$) cut is made, retaining only sources with $L_X > 10^{42.5}$ erg s$^{-1}$, to ensure all sources are X-ray selected AGN. Galaxies are split into bins of 0.5 log X-ray luminosity from 42.5 to 45 erg s$^{-1}$. The red points with error bars in each bin indicates the median B/T and quantiles.

Despite a broad distribution of galaxies with seemingly little correlation to X-ray Luminosity in the 2D histogram, the median values show a weak but noticeable positive trend between B/T and X-ray luminosity; however, any correlation is not statistically significant. It is also apparent that there are a significant number of galaxies with $B/T = 0$ or $B/T = 1$ meaning there are is a large population of pure disk and pure bulge galaxies respectively. Removing galaxies with a reduced

![Figure 4](image_url)
χ² greater than 10 did not significantly change the distribution of the plot; therefore, we decided to include all sources.

We find that galaxies with higher X-ray luminosities have slightly higher $B/T$, and thus a slightly more developed bulge. This correlation is statistically weak but shows that host galaxy bulge growth and AGN activity are related.

Comparing the optical PSF luminosity of the nucleus to the X-ray luminosity reveals a stronger correlation. Figure 6 displays a 2D histogram with 30 bins of log luminosity of the nuclear emission ($L_{Nuc}$) and 30 bins of log X-ray luminosity. The same formatting, luminosity cut, and median over-plotting methods found in Figure 5 are used.

This correlation is stronger and more statistically significant than the previous result. We expect this relationship since both $L_{Nuc}$ and $L_X$ correspond to AGN activity and increased AGN activity results in increased $L_{Nuc}$ and $L_X$, although the optical emission from the nucleus is more subject to obscuration, especially in Type 2 AGN.

4.3. Morphology of Type 1 and Type 2 AGN

To investigate the relationship between AGN activity and galaxy morphology, the sample is separated by spectral classifications into Type 1 and and Type 2 AGN. Figure 7 shows the distribution of $B/T$ as a function of X-ray Luminosity for Type 1 (left) and Type 2 AGN (right) formatted consistently with Figures 5. Note that 57% of successfully fit sources have spectral classifications.

The majority of Type 1 AGN have a $B/T$ near 1, meaning they tend to be more bulge dominated. Type 1 AGN also have a higher average X-ray luminosity, which is to be expected of optical quasars. Type 2 AGN also have a significant number of sources with a $B/T$ near 1, but have a greater population of sources in the widespread distribution of middle $B/T$ value sand a stronger concentration at $B/T$ near 0 of disk dominated galaxies. Type 2 AGN reach lower X-ray luminosities as well. Type 1 AGN tend to have higher X-ray luminosities than their Type 2 counterparts; probably since Type 1 AGN are relatively unobscured.

The median values from Figure 7 suggest that Type 1 AGN tend to reside in host galaxies with higher $B/T$ values. However, this offset we find could be in part due to any residual PSF in the images causing GALFIT to think the galaxies are more bulge dominated than they actually are. When high luminosity optical quasars aren’t fully point source subtracted, the remaining light may be applied to the bulge component of the model skewing the $B/T$ of Type 1 AGN.

To further probe the distinction in $B/T$ between AGN spectral type classifications, Figure 8 shows a histogram of $B/T$ values of all sources as well as sources split into Type 1 and Type 2 AGN. Again, there is a greater population of Type 2 AGN when $B/T$ is less than 0.9. While both Type 1 and Type 2 AGN display a peak at $B/T$ of 1, the peak is more prominent in Type 1 AGN both in number and fraction of galaxies.

This slight offset may suggest that Type 1 AGN reside in more bulge dominated host galaxies; however, since we do not expect a difference between Type 1 and Type 2 AGN, it is more likely that it is an artificial offset caused by undermodeling of the PSF and residual light being attributed to the bulge component of the model.
Figure 7. 2D histogram comparison of $B/T$ as a function of X-ray luminosity for Type 1 vs Type 2 AGN, colored by log number of sources in each bin. Red points with error bars show the median and quantiles in bins of log X-ray luminosity.

Figure 8. histogram of $B/T$ broken down by spectral classification of Type 1 vs Type 2 AGN.

Breaking the sample into a different set of classes, Figure 9 shows the histogram of $B/T$ split by morphological classes using the visual classifications described in section 3.1. While many of the galaxies classified as spheroids were also classified as having prominent point nuclei, Figure 9 shows that sources with a $B/T$ of 1 are dominated by spheroidal galaxies and galaxies containing central point sources. Disk classified galaxies tend towards lower $B/T$, and spheroid classified galaxies tend towards higher $B/T$ values and spike at $B/T \sim 1$ supporting the match of visual qualitative classifications and modeling quantitative classifications.

Despite this, there is still a spread in the distribution of sources visually classified as disk and spheroid that would be consistent with the $B/T$ of the opposite classification. This may be caused by indistinguishable differences between spheroidal galaxies and face on disk galaxies with no resolvable disk features such as spiral arms or bars, especially at higher redshifts. In addition, the images used for visual classifications contained point sources, and even though there was a column to identify point sources, their extra light may disguise disky galaxies as being bulge dominated.

5. DISCUSSIONS

We find a wide distribution of $B/T$ values with a concentration of sources with $B/T = 0$ and an even sharper concentration with $B/T = 1$. The median values show
Figure 10. A 2D histogram showing log luminosity of the nucleus ($L_{NUC}$) as a function of 0.25µm excess ($L_{0.25\mu m}/L_{1\mu m}$) from the big blue bump (BBB) in the first row, and as a function of 5µm excess ($L_{5\mu m}/L_{1\mu m}$) from dusty torus emission in the second row. The first column contains all galaxies, while the second and third columns contain Type 1 and Type 2 AGN respectively. The histograms are colored by log number of sources in each bin. Red points with error bars show the median and quantiles in bins of log X-ray luminosity.

There is a slight trend between $B/T$ and X-ray luminosity. Even after removing poorly fit galaxies with large reduced $\chi^2$ values, we still see the polarized concentrations of bulge dominated sources and pure disk galaxies, as well as the weak positive correlation of the median values. There is, however, a strong correlation between nuclear point source luminosity and X-ray luminosity.

Type 1 AGN seem to display a higher $B/T$ than their Type 2 counterparts, but this could be an artificial offset caused by undermodeled PSFs (n=4) contributing residual light to the bulge component (n=4) of the galaxy model since the bulge is closer in Sérsic index to the PSF than the disk (n=1).

In addition, while the peaks of distributions for visually classified morphologies are consistent with their identifications, the spread suggests there could be discrepancies between spheroid and face on disk galaxies as well as the possibility that point sources bias visual classifications towards spheroidal galaxies.

5.1. Correlations with AGN Emission Features

To further discuss the implications of AGN on host galaxy morphology, we investigate the dependence of log luminosity in the nucleus on the spectral energy distribution (SED) components of the host galaxy. SEDs show energy as a function of wavelength of light emitted from the galaxy. Spectral energy distributions rely on multiwavelength coverage of a survey for completeness. The SEDs are normalized at the 1µm values in order to account for redshift effects. The 0.25µm excess ($L_{0.25\mu m}/L_{1\mu m}$) is big blue bump (BBB) emission at ultra-violet (UV) wavelengths from the accretion disk. The 5µm excess ($L_{5\mu m}/L_{1\mu m}$) is dusty torus emission in near infrared (NIR) wavelengths. The 100µm excess ($L_{100\mu m}/L_{1\mu m}$) is diffuse emission often linked to star formation in far infrared (FIR) wavelengths.

Figure 10 shows 2D histograms of log luminosity of the nucleus vs log big blue bump emission in the first row, and log luminosity of the nucleus vs log dusty torus emission in the second row. The first column displays all of
the galaxies, while the second and third columns contain Type 1 and Type 2 AGN respectively. There were fewer 100\(\mu m\) detections, and the statistics were too low to investigate the dependence of \(L_{NUC}\) on \(L_{100\mu m}/L_{1\mu m}\). The color scale corresponds to the number of sources in each bin, and the medians with quartiles are plotted in similar fashion as the previous figures.

In the first row there is a clear positive trend between nuclear luminosity and 0.25\(\mu m\) excess. This trend is shared between the total sample as well as Type 1 and Type 2 AGN individually. Furthermore, separating the sample into spectral classifications reveals that Type 1 AGN make up the higher nucleus and higher \(L_{0.25\mu m}/L_{1\mu m}\) regime and Type 2 AGN make up the lower nucleus luminosity and lower \(L_{0.25\mu m}/L_{1\mu m}\) regime.

This trend is supported physically by the fact that the optical PSF luminosity of the nucleus and the UV big blue bump emission from the accretion disk both radiate from the innermost region of the galaxy. Both \(L_{NUC}\) and \(L_{0.25\mu m}/L_{1\mu m}\) are direct results of AGN activity. In addition, the Type 2 AGN are lower in nucleus luminosity and BBB excess due to obscuration effects from the torus.

The second row displays what appears to be a distribution of \(L_{NUC}\) centered at \(L_{5\mu m}/L_{1\mu m} = 0\) in the first column with all galaxies. However, after splitting into spectral types, it becomes clear that both Type 1 and Type 2 AGN show a correlation with similar slopes both centered around \(L_{5\mu m}/L_{1\mu m} = 0\). Type 1 AGN have a higher \(L_{NUC}\) and a narrower spread in \(L_{5\mu m}/L_{1\mu m}\), while Type 2 AGN have a lower \(L_{NUC}\) and a wider spread in \(L_{5\mu m}/L_{1\mu m}\). Combining the narrower and higher Type 1 AGN with the broader and lower Type 2 AGN gives the illusion that the overall distribution is bell curve shaped. In reality, nucleus luminosity in both spectral types are individually correlated with dusty torus emission.

The correlation of luminosity in the nucleus with the 5\(\mu m\) excess shows that AGN activity influences emission beyond the accretion disk. While both spectral types are centered at \(L_{5\mu m}/L_{1\mu m} = 0\) and show a similar dependence on dusty torus emission, Type 1 AGN show a higher \(L_{NUC}\) likely due to their relatively unobscured nature.

5.2. Correlations with Stellar Masses

To see if the bulge to total fraction of a galaxy is related to the galaxy’s stellar mass, we analyze a 2D histogram of \(B/T\) vs log stellar mass. Figure 11 shows the plot in the same format as the previous Figures, with the exception of the x-axis being stellar mass. There is a dispersion of sources centered around \(10^{10.75}\) \(M_\odot\) with concentrations at \(B/T = 0\) and \(B/T = 1\). The median values show contrasting slopes below (negative) and above (positive) \(10^{11}\) \(M_\odot\). Any correlation is likely not statistically significant.

On the contrary, comparing log nuclear point source luminosity (\(L_{NUC}\)) to log yields a strong correlation. Figure 12 shows the 2D histogram of \(L_{NUC}\) vs \(M_\odot\) colored by number per bin and with the medians and quartiles overplotted. We find that galaxies with higher stellar masses have more luminous nuclear point sources in their centers.

In order to further investigate the relationship with mass, Figure 13 shows histograms of \(B/T\) for all galaxies, Type 1 AGN, and Type 2 AGN, each broken down into 3 bins of stellar mass as well as the full sample.
Figure 13. Histograms of B/T with labels for all sources and bins of log stellar mass ($M_\star$), separated into panels for all galaxies, Type 1 AGN, and Type 2 AGN.

Figure 14. A 2D histogram showing B/T as a function of log star formation rate ($M_\odot/yr$), colored by log number of sources in each bin. Red points with error bars show the median and quantiles in bins of log $M_\star$/yr.

For the most part, there seems to be no correlation with stellar mass. However, when the data is separated into spectral types, it is interesting that for pure bulge galaxies with $B/T \sim 1$ the mass bins are in opposite order of abundance for the two spectral classifications. Type 1 AGN with high $B/T$, in order of increasing abundance, go from low mass ($10^{10} < M_\star < 10^{10.5}$), to medium mass ($10^{10.5} < M_\star < 10^{11}$), to high mass ($10^{11} < M_\star < 10^{11.5}$); Type 2 AGN display the opposite order of abundance for high $B/T$ sources. In addition, Type 2 AGN have relatively low percentage of high mass ($10^{11} < M_\star < 10^{11.5}$) compared to the other mass bins.

Figure 13 also highlights that Type 1 AGN display a systematic skew towards bulge dominated ($B/T = 1$) galaxies. Once again, it is possible that this is due to undermodelling of the PSF luminosity. In some optical quasars, GALFIT likely contributes the extra light towards the bulge since the fixed Sérsic index ($n = 4$) of the bulge is closer to the PSF ($n > 4$) than the fixed Sérsic index ($n = 1$) of the disk, thus biasing $B/T$.

5.3. Correlations with Star Formation

To determine if bulge growth and morphology are directly linked to the quenching of star formation in AGN host galaxies, we examine a 2D histogram of $B/T$ as a function of log star formation rate (SFR) in $M_\odot/yr$. Figure 14 shows the plot, colored by the number of sources per bin with the medians and quartiles plotted in red. Galaxies with star formation rates from 1 to 10 $M_\odot/yr$ seem to have a downward trend implying that galaxies with higher SFRs tend to be more disky. However, there is no evidence of significant correlation between $B/T$ and SFR due to the large quartile error bars.

Instead of exploring SFR directly, we also look for any dependence on the offset from the main sequence in log SFR ($\Delta SFR_{MS}$). Main sequence sequence offset is the deviation in star formation rate (Suh et al. 2019) from...
Figure 16. A 2D histogram showing log luminosity of the nucleus ($L_{NUC}$) as a function of star formation rate (M$_{⊙}$/yr), colored by log number of sources in each bin. Red points with error bars show the median and quantiles in bins of SFR.

Figure 17. A 2D histogram showing log luminosity of the nucleus ($L_{NUC}$) as a function of main sequence offset ($\Delta SFR_{MS}$), colored by log number of sources in each bin. Red points with error bars show the median and quantiles in bins of $\Delta SFR_{MS}$.

The median $L_{NUC}$ values are consistent with a linear correlation between point source luminosity and star formation rate. However, the quartile error bars increase with SFR, especially below the median values. As a result, the data in Figure 16 is also consistent, within the error bars, of semi-parabolic turnover in the relationship between $L_{NUC}$ and SFR.

Finally, we investigate nuclear point source luminosity as a function of main sequence offset. Figure 17 is a 2D histogram showing $L_{NUC}$ vs $\Delta SFR_{MS}$ with the colors scaled by abundance of sources in each bin, and the medians and quartiles plotted in red. There is a correlation between $L_{NUC}$ and $\Delta SFR_{MS}$. The relationship is linear for galaxies far below the main sequence ($\Delta SFR_{MS} < -0.5$). At $\Delta SFR_{MS} = -0.5$, there is a turnover and the nuclear point source luminosity flattens out at 10$^{11}$ L$_{⊙}$.

If AGN truly are responsible for quenching star formation in their host galaxies, the linear decrease in log $L_{NUC}$ as galaxies deviate below the main sequence could reflect diminishing AGN activity while feedback mechanisms quench star formation.

6. CONCLUSIONS

To probe AGN involvement in producing MS turnovers and the quenching of their host galaxy’s star formation, we examine the morphology dependence on X-ray luminosity in the intermediate region of the SFR–M$_{*}$ diagram. Using GALFIT’s two-dimensional parametric fitting algorithm, we model X-ray selected COSMOS galaxies with two Sérsic profiles for bulge and disk components and a PSF model.

The bulge to total fraction has a weak trend with X-ray luminosity, but the correlation is not statistically significant. B/T does not show a significant correlation with stellar mass (M$_{*}$), star formation rate (SFR), or main sequence offset ($\Delta SFR_{MS}$) either. However, the luminosity of the nuclear point source ($L_{NUC}$) strongly corresponds with $L_X$, M$_{*}$, SFR, $\Delta SFR_{MS}$, as well as $L_{0.25\mu m}/L_{1\mu m}$ and $L_{5\mu m}/L_{1\mu m}$ flux ratios corresponding to Big Blue Bump (BBB) and Torus emission respectively.

When separating the sample into spectral type classifications, Type 1 AGN show a higher median B/T as well as a higher concentration of galaxies with B/T ~ 1. This could be a result of some optical quasars having underfit PSFs, and the residual light saturating the bulge component of the GALFIT model, thus skewing the B/T for Type 1 AGN.

the corresponding main sequence value for a particular stellar mass and redshift as defined in Tomczak et al. (2016). Figure 15 shows a 2D histogram of B/T vs $\Delta SFR_{MS}$ colored by the number of sources per bin and with medians and quartiles plotted in red. There is still no evidence of correlation between B/T and offset from the main sequence.

Instead of looking at B/T, Figure 16 shows $L_{NUC}$ vs star formation rate. The color bar represents the number of galaxies in each bin, and the red points with error bars are the median nuclear point source luminosity values and quartiles for bins of SFR. There is a strong correlation between $L_{NUC}$ and star formation rate, showing that galaxies with higher SFRs also have high point source luminosities in their centers.
While we were able to fit a PSF model to the data, the point source function fits were not perfect and left residual light to saturate the bulge component of the galaxy model. An improved PSF model, and perhaps a more sophisticated galaxy model, would reduce skew in $B/T$, improving results and possibly revealing any underlying correlations.

Collaborators in the AHA project at Yale University are using a point spread function generative adversarial network (PSFGAN) (Stark et al. 2018) to remove the point source from an image of a galaxy. Future work could include running GALFIT on these point source subtracted images to compare the results when the point nucleus is modeled in GALFIT vs removed with machine learning algorithms.

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