Multi-Wavelength and Morphological Properties of X-ray Luminous AGN in the GOODS Fields

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**ABSTRACT**

Active Galactic Nuclei (AGN) are supermassive black holes (SMBH) that are in the process of accreting new material located at the center of most galaxies. They emit across the entire electromagnetic spectrum from the X-ray to the radio. We present an analysis of spectral energy distributions (SED) and morphological classifications for 140 X-ray luminous AGN (intrinsic $\log L_X > 42.5$) in the Great Observatories Origins Deep Survey (GOODS) North and South field from $0.5 < z < 1.5$. We sort our sources by four characteristic SED shapes dependent on the ultraviolet (UV) and mid-infrared (MIR) emission to better understand how AGN emission correlates to galaxy morphology and evolution. Strong MIR (defined here as $1 - 6 \mu m$) emission appears to be linked with bulge growth as sources with low MIR emission tend to be preferentially classified as disks, while sources with strong MIR emission are more likely to be classified as spheroids. All sources with strong UV emission are classified as point sources and are dominated by the AGN.

1. **INTRODUCTION**

When a supermassive black hole (SMBH) at the center a galaxy accretes large amounts of new material, it becomes an active galactic nucleus (AGN). When such accretion occurs, a disk of material is generated around the SMBH. The disk radiates thermal energy across the electromagnetic spectrum due to the cooling of the disk as the distance from the SMBH increases and temperatures decrease (Shakura & Sunyaev 1973). Active accretion generates emission in the X-ray to optical wavelengths and is often greatest in the ultraviolet (UV) (Koratkar & Blaes 1999). In turn, dust and gas farther away from the SMBH and the accretion disk absorb this radiation and reprocess it to the infrared (IR). The strength of the multi-wavelength emission can be measured through a spectral energy distribution (SED). The shape of the SED is strongly dependent on the environment immediately around the SMBH. This creates features such as the Big Blue Bump (BBB) in the UV and optical or increased infrared radiation (Sanders et al. 1989; Elvis et al. 1994; Richards et al. 2006). The UV emission is physically generated in or near the accretion disk of the SMBH where material is moving at high velocities with high temperatures. Infrared emission comes the dusty torus, which absorbs and reemits the energy in the infrared (Suh et al. 2019).

Through improvements in data processing methodologies and cataloguing, analyzing aggregated data from numerous observatories is now much more straightforward than in the past due to online repositories and widely available catalogues, opening many new opportunities for analysis (Xue et al. 2016). Recent studies have used this wealth of data to conduct in depth analyses of the SEDs for AGN (e.g., Li et al. (2020); Suh et al. (2019); Hickox et al. (2017); Kirkpatrick et al. (2020). By utilizing some of the deepest observations of the universe, we can learn much more about the growth and evolution of both AGN and their host galaxies across multiple epochs.

Understanding how an AGN impacts the host galaxy and the inverse is crucial in explaining galactic evolution (Kormendy & Ho 2013). SMBHs are already known to be connected to their host galaxies through a linear mass relationship between the mass of the SMBH and the total mass of the host galaxy (Bandara et al. 2009). Identifying further relationships can provide vital information concerning topics ranging from AGN feedback to galaxy morphological evolution.
This paper contributes to the Accretion History of AGN (AHA) project\(^1\). AHA utilizes a wedding cake style survey with three observational fields, each with a different area and flux limits, therefore covering a different luminosity and redshift range. This wedding cake is comprised of sources from four principle fields sorted from deepest to most shallow: Great Observatories Origins Deep Survey (GOODS)-North (GOODS-N) and GOODS-South (GOODS-S), COSMOS, and Stripe 82x (Guo et al. 2013; Grogin et al. 2011; Koekemoer et al. 2011; Scoville et al. 2007; LaMassa et al. 2013). The GOODS fields were designed to probe for many faint sources such as Compton-thick AGN (Grogin et al. 2011; Giavalisco et al. 2004). COSMOS is utilized as the medium depth-field, providing access to both some luminous and dim X-ray sources, and more importantly allows reasonable depth over a 2 square degree region of the sky (Scoville et al. 2007). Stripe 82x focuses on widefield imaging that will detect the rarest and most luminous X-ray sources over approximately 31 square degrees (LaMassa et al. 2013).

In this paper, we generate SEDs for AGN sources in the GOODS fields and analyze the morphologies of the host galaxies. We show a relationship between increased mid-infrared emission and bulge growth in our sample.

2. DATA

GOODS combines data from the Hubble Space Telescope, Chandra X-ray Observatory, Spitzer Space Telescope (SST), XMM-Newton, and Herschel Space Telescope, as well as many ground facilities in order to provide deep, multi-wavelength observations on the twin 10’ x 16’ GOODS-N and GOODS-S fields (Giavalisco et al. 2004).

Both the GOODS-N and GOODS-S fields overlap with the Chandra Deep Fields. These fields include the X-ray data from the 2Ms Chandra Deep Field - North (CDF-N) Survey and the 7Ms Chandra Deep Field - South (CDF-S) Survey. The CDF-N survey has 683 X-ray sources and CDF-S has 1055 sources. Both the CDF-N and CDF-S were imaged from 0.5 to 7keV (Xue et al. 2016; Luo et al. 2017). Deep X-ray observations are fundamental to selecting the AGN to be analyzed by allowing larger numbers of sources and more accurate data. It has been shown that star-burst galaxies only produce X-ray luminosities up to \(10^{39}\) erg s\(^{-1}\) while AGN can produce X-ray luminosities up to \(10^{46}\) erg s\(^{-1}\) (Persic et al. 2004). This allows us to easily identify

\(^{1}\) For more information on AHA, reference the AHA website: https://project.ifa.hawaii.edu/aha

Figure 1. X-Ray luminosities for sources in the CDF-N (blue) and CDF-S (red) catalogues plotted against the best-available redshift measurements. These are all the X-ray sources in the fields. However, we only utilize sources from 0.5 < z < 1.0 and 1.0 < z < 1.5. Vertical lines demarcate all X-ray sources within our upper and lower redshift bins.

Figure 2. The Number of X-ray sources in the CDF-N (red) and CDF-S (blue) fields as a function of X-ray luminosity in bins with a width of 0.25 erg s\(^{-1}\). The vertical lines represent the median values of the the CDF-N and CDF-S surveys in erg s\(^{-1}\).
the AGN and remove star-forming galaxies within each field.

X-ray luminosities and best-available redshifts for the CDF-N and CDF-S fields were taken from catalogues published by Xue et al. (2016) and Luo et al. (2017), respectively.

Photometric data for SED construction was taken primarily using the Rainbow Cosmological Surveys Database which in turn utilizes data from Guo et al. (2013). The following filters and instruments were used in our analysis: The Blanco 4m - telescope’s DECam instrument, U - filter. The Hubble Space Telescope Advanced Camera for Surveys with B, V, I, and Z filters. The HST Wide-field Camera 3 and the F105W, F125W, and F160W filters. We utilized the VLT’s Ks filter with a central wavelength of 2.18µm. For mid and far-IR (MIR and FIR) data, we relied on the Spitzer and Herschel telescopes. From Spitzer, we utilized the IRAC camera and the 3.6µm, 4.5µm, 5.8µm, 8.0µm filters. We also used the MIPS 24µm detector from Spitzer. From Herschel, we utilized the PACS and SPIRE instruments. We selected sources that have detections at 1µm filter with the central wavelength of 2.18µm. This effectively removes non-AGN sources with low X-ray luminosity such as X-ray binaries and supernovae, ensuring a clean sample of luminous AGN.

We initially characterized sources into two different redshift ranges, 0.5 < z < 1.0 and 1.0 < z < 1.5, to analyze differences between the bins. However, there were no significant differences in SEDs or morphologies between them, so we have combined them into a single 0.5 < z < 1.5 bin. This redshift range is necessary as the most accurate multi-wavelength data are available for this range. At higher or lower redshifts, emission may be shifted to different wavelengths and out of view.

Finally, we matched our sources between the Rainbow catalogues and X-ray catalogues based on the reported coordinates with a maximum of 1 arcsecond disagreement between the X-ray and photometric catalogues. This removes sources erroneously categorized as being the same source that are either two distinct objects or have inaccurate location information.

After these cuts were made, we were left with 136 sources for which both X-ray data and photometry necessary to construct the SEDs were available.

3. RESULTS

3.1. SEDs

We selected sources that have detections at 1µm with fractional flux error in each filter with ∆f_{\text{flux}} < 0.2. The rest frame wavelength is given as (\lambda = \frac{\lambda_{\text{rest}}}{1 + z}) where \lambda is the observed wavelength and z is the AGN’s redshift. Sources were normalized to the 1µm flux to emphasize AGN attributes, especially differences in the UV and IR.

Figure 3 shows SEDs for the 136 sources with 0.5 < z < 1.5 normalized at 1µm. These sources show data from the X-ray to the MIR as we expect. We also see FIR detections for roughly half the sources. While we see AGN emitting from 10^{42.5} \text{ erg s}^{-1} to 10^{45} \text{ erg s}^{-1}, the majority of sources have luminosities towards the lower end of that scale with less than 10^7 greater than 10^{44} \text{ erg s}^{-1}. Considering the small field of view and deep observations on the fields, we would not expect to see many high-luminosity sources. As high X-ray luminosity AGN are rare, it is reasonable that there are few in the small GOODS fields.

3.2. Morphology

As noted in section 2, we use morphological classifications computed using neural networks by Huertas-Company et al. (2015). They produce the fractional likelihood that a source contains features of a disk (f_{\text{disk}}), spheroid (f_{\text{sph}}), irregular (f_{\text{irr}}), point source (f_{\text{ps}}), or unclassifiable (f_{\text{unc}}). They also provide a basic method of determining which type any individual galaxy is.
They establish five classifications, and we add a sixth for point sources following their method.

- Disk: \( f_{\text{disk}} > 2/3 \) and \( f_{\text{sph}} < 2/3 \) and \( f_{\text{irr}} < 1/10 \)
- Bulge: \( f_{\text{sph}} > 2/3 \) and \( f_{\text{disk}} < 2/3 \) and \( f_{\text{irr}} < 1/10 \)
- Disk-Spheroidal: \( f_{\text{sph}} > 2/3 \) and \( f_{\text{disk}} > 2/3 \) and \( f_{\text{irr}} < 1/10 \)
- Disk-Irregular: \( f_{\text{disk}} > 2/3 \) and \( f_{\text{sph}} < 2/3 \) and \( f_{\text{irr}} > 1/10 \)
- Irregular/Merger: \( f_{\text{disk}} < 2/3 \) and \( f_{\text{sph}} < 2/3 \) and \( f_{\text{irr}} > 1/10 \)
- Point sources: \( f_{\text{ps}} > 2/3 \) and \( f_{\text{disk}} < 2/3 \) and \( f_{\text{sph}} < 2/3 \) and \( f_{\text{irr}} < 1/10 \)

Figure 4 shows example cutouts for the classifications. Disks are traditional disk-type galaxies with no dominant bulge. Disk-spheroids show a disk as well as a bright spheroidal source. Irregular-disks show some tidal features while still retaining an overall disk morphology. Irregulars are composed of primarily major mergers or sources with no distinct morphological type. Spheroids are what could be called elliptical galaxies. Point sources are typically small and the AGN dominates emission, so we see very little or no emission from the host galaxy.

We then manually classified 69 sources with available galaxy cutouts using the same classification categories as Huertas-Company et al. (2015). Figure 5 shows a comparison of the fraction of sources per morphological class for Huertas-Company et al. (2015) and for our classifications. Note that Huertas-Company encompasses a broader redshift range from \( 0.5 < z < 1.5 \), while we focus on a sub-sample from \( 0.7 < z < 1.3 \) that we had cutouts available for.

For Huertas-Company, 20% of sources are classified as a disk, 38% as spheroid, and 33% being a disk with a spheroid component (disk-spheroid). Less than 10% in Huertas-Company are point sources as is expected at relatively low redshifts. There are 18 missing Huertas-Company sources compared to the number of SEDs in figure 3. This is due to some sources lacking either sufficient classification confidence or sufficient data to be classified. Our classifications show more than double (15% of total) point sources compared to Huertas-Company, probably due to differing stretch levels making some bulges appear as point sources. Our major distinction is in irregulars and disk irregulars, with over 30% of sources in our sub-sample showing some irregularities.

To further investigate how well our classifications match with those from Huertas-Company et al. (2015), we directly compare the classifications for individual sources in figure 6. It shows that while there is disagreement between source classifications, we typically agree that a source has a disk component or a spheroid component, only disagreeing on how dominant said components are. For example, if we classify a source as a disk and Huertas-Company et al. (2015) classifies that source as a disk-spheroid, we still agree that that object fundamentally has a disk. For this reason, we acknowledge that discrepancies may arise from factors such as different types of stretches and differing criteria for what constitutes each morphological class, but that these discrepancies primarily pertain to sub-classes (e.g. disk-spheroid, disk-irregular). For example, over 80% of sources are classified by Huertas-Company et al. (2015) as one of three classes: disk, disk-spheroid, or spheroid. Thus, we can utilize their classifications for broad trends.

Our visual classifications, however, are much better at detecting faint tidal features from ongoing or past mergers that were missed by Huertas-Company et al. (2015). In figure 5, our classifications of a sub-sample of sources from Huertas-Company detects much higher fractions of irregular-disk and irregular (merging) galaxies. We believe this may be due in part to Huertas-Company smoothing the data to a lower resolution which may have hidden some of the fainter features. In addition, differing stretches may have made faint features more or less visible, meaning that if they did not sufficiently stretch the data, they may have missed these irregularities.
Figure 4. Images of six characteristic classes of galaxy morphologies utilized by both ourselves and Huertas-Company et al. (2015). From left to right, we see disks, disk-spheroids, irregular-disks, irregulars/mergers, spheroids, and point sources.

Figure 5. Bar graph showing the fraction of sources classified as a disk, disk-irregular, irregular, disk-spheroid, bulge, point-source, unclear for sources classified by Huertas-Company et al. (2015) using neural networks and by ourselves visually. Immediately different are the numbers of irregulars and disk-irregular sources, with our classifications seeing many more of them relative to Huertas-Company et al. (2015).

Despite these issues, we repeat that the classifications from Huertas-Company et al. (2015) are useful for discussing broad trends between morphological classifications. However, future authors should note that visual identification is necessary to find more subtle trends.

4. DISCUSSION

4.1. Characteristic SED Shapes

We separated the sources in figure 3 into four panels dependent on the calculated slope between three wavelength ranges: 0.25 – 1μm, 1 – 6μm, and 6 – 10μm. The parameters were established by Auge et al. (2021, in prep.) based on the SEDs of X-ray selected AGN from all three AHA fields. These four panels capture the full range of SED shapes of X-ray luminous AGN that are present within the AHA survey. The sorting criteria for the four panels are found in table 1.

Figure 7 shows the 116 sources in the 0.5 < z < 1.5 redshift bin separated into the five panels. There are 44 fewer sources than in figure 3 due to some SEDs lacking sufficient data to be sorted into one of the four panels.

<table>
<thead>
<tr>
<th>Panel</th>
<th>(0.15 - 1.0μm)</th>
<th>(1.0 - 6.5μm)</th>
<th>(6.5 - 10μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>α &lt; −0.2</td>
<td>−0.2 &lt; α</td>
<td>−</td>
</tr>
<tr>
<td>2</td>
<td>0.2 &lt; α</td>
<td>−0.2 &lt; α</td>
<td>−</td>
</tr>
<tr>
<td>3</td>
<td>−0.3 &lt; α</td>
<td>α &lt; −0.2</td>
<td>0.0 &lt; α</td>
</tr>
<tr>
<td>4</td>
<td>−0.3 &lt; α</td>
<td>α &lt; −0.2</td>
<td>α &lt; 0.0</td>
</tr>
</tbody>
</table>

Table 1. Criteria to separate SEDs into the 4 panels seen in Figure 7. Each column is the region of the SED that is used to determine the slope α.
Figure 7. Four characteristic shapes of SEDs with $0.5 < z < 1.5$ grouped by slope values in the UV and MIR.

There are seven sources in panel 1. However, a low number is expected as these panels contain only high luminosity unobscured AGN that emit broadly across the entire electromagnetic spectrum and dominate emission from the host galaxy. These sources are rare within the GOODS fields. $5/7$ panel 1 sources have high X-ray luminosities greater than $10^{44}$ erg s$^{-1}$ with the median being $10^{44.2}$ erg s$^{-1}$.

Panel 2 shows 30 sources with typically low UV emission but higher emission in the IR. This is likely caused by the reemission of light generated within the accretion disk in the UV, which is then reprocessed to the IR within the dusty torus. Median X-ray luminosity also drops to $10^{43.5}$ erg s$^{-1}$.

Panel 3 has a much sharper drop-off in the $1 - 6 \mu m$ IR. The 57 sources in this panel are almost entirely low-to-mid X-ray luminosity objects, with the median X-ray luminosity being $10^{43.2}$ erg s$^{-1}$. Panel 4 is differentiated from Panel 3 by the IR emission continuing to decrease out to $10 \mu m$. It also has a median X-ray luminosity of $10^{43.2}$ erg s$^{-1}$.

These plots demonstrate the validity of the AHA project’s wedding cake methodology. The panel 3 and 4 sources especially are often missed because of their lower X-ray luminosities in the shallower Stripe-82X and COSMOS surveys. By utilizing deep observations of the GOODS fields, we can better understand low X-ray luminosity AGN and their host galaxies in a way that the other two surveys cannot. Simultaneously, while this study finds many panel 3 and 4 sources, the limited field of view restricts the number of bright AGN that we see. By actively studying these different sized and differently-observed fields, we can better understand AGN of different types and stages in a way that no individual survey can.

4.2. Morphologies Sorted by SED Shape

Figure 8 shows 101 sources classified by Huertas-Company et al. (2015) that were able to be separated into four panels in the same manner as figure 7. The decrease in objects between figures 5 and 8 is possibly due to a lack of accurate classifications for some of the sources in figure 7. As noted in section 3.2, Huertas-Company used neural networks to classify objects in the GOODS fields. Their identifications are useful for showing broad trends, but miss faint features.

Panel 1 of figure 8 contains the brightest X-ray sources (median intrinsic X-ray luminosity of $10^{44.2}$ erg s$^{-1}$) as well as sources with strong multi-wavelength emission. UV emission is generated directly from the central accretion disk, though it is susceptible to extinction by dust in the torus. Thus, the strong UV emission of the sources in panel 1 imply that the AGN in unobscured and the morphologies for the panel 1 host galaxies are all point sources.

Panel 2 shows a higher fraction (45%) of spheroids than disks(15%). Spheroids appear most common, with irregular disks, irregular, and point sources each comprising 10% of host morphologies.

Panel 3 is disk dominated, with 75% of hosts classified as disks or disk-spheroids. These sources have the lowest median X-ray luminosity of any of the panels and also show extinction in both the UV and $1 - 6 \mu m$ IR. Panels 2
Figure 8. Four panels of bar graphs classified by Huertas-Company et al. (2015) showing the fraction of sources per panel for each morphology type for 101 sources in the GOODS-N and GOODS-S fields with $0.5 < z < 1.5$. 25 sources compared to figure 7 either lack fractional classification values from Huertas-Company et al. (2015) or have associated SEDs without sufficient to be separated into a panel.

and 3 show a broader range of host galaxy morphologies and low UV emission, consistent with obscuration from dust of the central accretion disk.

In panel 4, around 60% of sources are classified as disks or disk-spheroids, with some disks and a single point source. Emission from the AGN is tightly constrained to the X-rays, and what little emission is left between the UV and MIR likely comes from the host galaxy.

In general, from panel 3 to panel 1, the sources tend to move from being disks to being spheroids, ultimately culminating in the point sources of panel 1. A broader discussion of this trend will occur in figure 4.3.

We also separated our own morphological identifications for with $0.7 < z < 1.3$ into four panels matched with the SEDs. Here, more distinct differences are visible compared to figure 8. There are many more sources with irregularities as discussed in 3.2, especially in panels 2 and 3 which were almost entirely absent of these classifications in the Huertas-Company identifications.

Even with significantly fewer pure-disk sources, the trend noticed in figure 8 from disk-like sources to bulges still exists. The primary difference is that we have identified many more irregular galaxies that had previously been identified by Huertas-Company as disks, consistent with figure 6. A more in depth discussion of this follows.

4.3. Bulge to Disk Transition and Associated Increased AGN Emission

A trait of figure 7 is increased AGN emission from the bottom to the top panel. X-ray luminosity increases from panel 4 to panel 1, and there are hints that UV emission increases between panels 3, 2, and 1. Especially of note, MIR luminosity increases by half to a whole order of magnitude between panels 3 and 2. MIR luminosity has been directly linked to AGN activity in Stern (2015), so the difference in MIR luminosities between panels 2 and 3 are driven by either the AGN itself or its environment. Specifically, dust in the torus heated between 500K and 1800K by the AGN is likely the cause of this emission. Panel 3 sources have normalized $1-6\mu m$ relative luminosities almost an order of magnitude smaller than panel 2, indicating stronger emission in panel 2 from this heated dust.

This increase in MIR emission is correlated with the changes in the morphology classifications between panels 3 and 2. Figure 8, the classifications by Huertas-Company separated into four panels based on characteristic SED shape, show an increase in the fraction of bulges between panels 3 and 2, with the combined proportion of bulges and point sources increasing by greater than 20% coupled with an increase in irregular disks and irregulars by 10% each.
Thus, we see a link between bulge-growth as well as X-ray and MIR luminosity, with the proportion of spheroids and point-sources increasing with both X-ray and MIR luminosity. This implies that as X-ray and MIR luminosity increase, so too does the source’s likelihood of being a bulge. However, while this trend is appreciable using the Huertas-Company classifications, our visual classifications provide crucial evidence that an actual evolutionary process is ongoing.

Our increased classification of mergers, as seen in figure 9, allows us to see these differing stages. Panel 3 shows more galaxies with disk-like morphologies, with the highest proportion of disk-irregulars. There are also around 18% more irregular/merging galaxies compared to figure 8.

It is possible that the act of merging may be causing an inflow of material into the cores of the galaxies, spurring AGN activity that is visible in the X-rays and especially in the MIR, where the emission from the dusty-torus increases between panels 3 and 2 of figure 9. By the time sources reach panel 1, they are in their most luminous phase and would likely be categorized as Type I AGN or quasar-like sources. However, this leaves the question of what happens after these AGN exhaust their fuel?

Panel 4 of figure 9 shows 40% of sources classified as spheroids. However, it is possible that these spheroids represent a population of post-quasar sources that have fed upon, blown away, or sublimated away the majority of the dust from around them, leaving little material left to accrete and cause emission. This is supported by the weak emission present in panel 4 of figure 7.

4.4. Possible X-ray/FIR Anti-Correlation

In figure 7, there appears to be an anti-correlation between X-ray luminosity and FIR luminosity. For example, in panel 1, the sources have the highest median X-ray luminosity, but no high-levels of FIR emission relative to $1\mu m$ emission. Compared to panels 2 and 3 where the median X-ray luminosity is lower but the FIR emission is much higher for some sources. Interestingly, the highest luminosity sources of panel 2 look very similar to all the sources in panel 1, perhaps implying that the AGN are impacting the overall shape of the SED.

This possible anti-correlation could be explained by a more powerful AGN sublimating or blowing away the cooler dust that would emit in the FIR. A low X-ray luminosity AGN may simply not be powerful enough to remove the cooler dust leading to an increase in emission at the FIR.

While intriguing, we must caution that due to the small sample size of this paper, further analysis is needed to confirm these results. The presence of the possible

Figure 9. Four panels of bar graphs for 45 sources visually classified by ourselves, with $0.7 < z < 1.3$. These show significantly more irregular-type sources than in figure 8 classified by Huertas-Company et al. (2015) due to our ability to distinguish faint tidal features missed by their neural networks.
anti-correlation between X-ray and FIR luminosity lends credence to the FIR component being influenced by the AGN, but it is impossible to verify these without understanding exactly what components of the galaxies are causing the FIR emission.

To discern this, we propose sampling the 150µm emission of galaxies at $z = 2$ using the Atacama Large Millimeter/submillimeter Array and the 35µm emission using the soon-to-launch James Webb Space Telescope to determine if the FIR emission is localized to the central AGN or if it is extended throughout the host galaxy. A bright core point source with limited detection of the host galaxy would show that the FIR emission in the sources is driven by the AGN and not by star formation. It could also be possible for a combination of both star formation and AGN activity to be present in the FIR. Detections of a bright point source but also strong FIR emission from the rest of the host galaxy would tend to support this hypothesis.

5. SUMMARY AND CONCLUSIONS

We study the spectral energy distributions and host galaxy morphologies of X-ray selected AGN in the GOODS fields. We constructed SEDs for 136 X-ray selected AGN and separated them into four characteristic shapes based on the UV and MIR emission. Using host galaxy morphology classifications from Huertas-Company et al. (2015) and visual classifications for a subsample of sources, we looked for trends between morphological classification and SED shape. We present four primary findings:

- The deep observations of the GOODS fields are best optimized for detecting lower-luminosity and obscured AGN. There are very few of the highest X-ray luminosity sources that would be considered quasars compared to lower X-ray luminosity sources. This is a result of the small size of the GOODS fields. The lack of bright sources indicates the success of the AHA Collaboration’s wedding cake survey, as many faint AGN are added to the overall AHA sample by GOODS.

- Neural networks used by Huertas-Company et al. (2015) are adept at identifying sources into broad classifications, especially whether they are a disk-type object or a spheroidal object. However, we find many faint features such as tidal streams that are not represented in the classification scheme presented by Huertas-Company et al. (2015).

- The incidence of spheroidal galaxies increases with emission increases, the fraction of sources classified as spheroidal also increases. This is likely caused by merger events spurring AGN activity by funnelling more material to the galactic core, increasing AGN accretion rates and emission.

- Panel 4 sources from figure 7 and 8 appear to include a mixture of late-stage AGN nearing the end of their duty cycles residing inside of spheroidal galaxies, as well as younger galaxies whose AGN are only beginning to emit brightly in the X-rays.

In addition to these main results, we tentatively hypothesize that far-infrared emission present in figures 3 and 7 could be due to cold dust far away from the core that is experiencing residual heating from the AGN. However, more observations in the far-infrared using the JWST and ALMA to localize the source of the emission there to the AGN, star formation, or some mixture of both.

While exciting, these results and hypotheses must be viewed cautiously due to the small sample size of the GOODS fields. Further studies must be conducted on larger fields with more sources to improve upon our findings.

6. ACKNOWLEDGEMENTS

Will Jarvis acknowledges support from Research Experience for Undergraduate program at the Institute for Astronomy, University of Hawaii-Manoa funded through NSF grant #2050710. We would like to thank the Institute for Astronomy for their hospitality during the course of this project. This work is based on observations made by the W.M. Keck Observatory. We wish to extend our special thanks to those of Hawaiian ancestry on whose sacred mountain of Maunakea we are privileged to be guests. The observations presented herein would not have been possible without their generosity. This research made use of Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration et al. 2013, 2018). This work has made use of the Rainbow Cosmological Surveys Database, which is operated by the Centro de Astrobiología (CAB/INTA), partnered with the University of California Observatories at Santa Cruz (UCO/Lick,UCSC). We acknowledge the use of the NumPy Package and would like to thank the NumPy team for their hardwork in creating such an invaluable tool (Harris et al. 2020). We acknowledge the usage of Matplotlib for plotting and would like to thank the

2 http://www.astropy.org
Matplotlib team for their efforts in creating such a wonderful package (Hunter 2007). Finally, Will would like to thank the other members of his REU cohort for continually encouraging and supporting him through this project, and for the friendships built over this summer.

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