The Relationships Between Morphology, Luminosity, and Redshift in Active Galactic Nuclei

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Abstract

Active galactic nuclei (AGN) are an area of astronomy research with many questions still unanswered. This paper uses x-ray data taken from XMM-Newton to correlate different properties of AGN. In particular, we correlate morphology, luminosity, and redshift. We attempt to explain the trends we see, drawing on insight from the current scientific literature on AGN. We find trends consistent with a classification scheme based primarily on line of sight obscuration. Among other trends, obscured AGN have lower redshifts and luminosities, while unobscured AGN have higher redshifts and luminosities.

Keywords: physics, astronomy, active galactic nuclei, morphology, luminosity, redshift, obscuration

I. INTRODUCTION

Carl Seyfert found the first spectral evidence for strong emission in the center of a galaxy in the 1940s. Since then, active galactic nuclei have been at the forefront of astronomy research. Although we have made much progress in recent years, there are still lots of unanswered questions. The goal of this paper is to correlate different properties of AGN and see what relationships we can glean from the data. We will specifically examine morphology, luminosity, and redshift. We then analyze trends based on scientific readings.

II. BACKGROUND

Galaxies are a collection of gas, dust, and billions of stars bound to each other by gravity. Galaxies can be broken up into different classifications, or morphologies, depending on their characteristics. At the most basic level, there are spiral and elliptical galaxies. Spiral galaxies are brighter, have more gas, and have arm-like structures. Elliptical galaxies tend to be larger, older, fainter, and have very little gas. At the center of a galaxy—the nucleus one could say—resides a super massive black hole (SMBH). This is both the technical term and an apt descriptor. If this SMBH at the center of a galaxy is accreting matter from its surroundings, we call it an active galactic nucleus.

AGN have some unique features that allow us to categorize them into different morphologies. A general model of these features is shown in Fig. 1. AGN accrete gas and dust along a disc. Perpendicular to this disc are relativistic jets. Our SMBH and accretion disc are surrounded by a dusty torus, which serves as our central obscurer. The torus also encompasses a region of broad emission line spectra, while the narrow emission line region is elevated outside of the torus and around the relativistic jets. Depending on the angle one is viewing the AGN, the torus can often block one’s line of sight to the broad emission line region. If this region is obscured, it can be generally classified as a Type II AGN, while if it is visible, it is considered Type I. Our AGN is placed in the center of its host galaxy with radio lobes extending outside of the galaxy.

Fig. 2 shows more specific AGN morphologies, divided into radio loud on the top and radio quiet on the bottom. Two of the more noteworthy morphologies are Seyferts and QSOs. Seyfert galaxies are bright spirals with large central bulges. They also can be divided into Type I and Type II depending on their line of sight obscuration and the presence of broad emission line regions. As the angle of inclination relative to the accretion disk increases, Seyferts become Quasi Stellar Objects, or QSOs. The difference between these two can be arbitrary, as they lie along a continuum. QSOs that are radio loud are classified as QSRs, a name from which has derived the term Quasar. Quasars are some of the most luminous objects in our universe and are found at high redshift.
Fig. 1. This diagram shows the basic model of an active galactic nucleus. It includes an accretion disc, relativistic jets, a torus of gas and dust, broad line and narrow line emission regions, and radio lobes extending from the host galaxy.

Fig. 2. Grand Unification of AGN morphology. Classification can be divided into radio loud and radio quiet, and from there it largely depends on the line of sight viewing angle and obscuration from the central torus.

The next important concept to understand is redshift. One of the things redshift can tell us is how far away an object is. Because the universe is expanding, objects are moving away from us. As light travels towards us, its wavelength expands and is hence redshifted, see Fig 3. We can measure this shift in wavelength to tell us distance.

Redshift can also tell us how old an object is. Because the universe is expanding, objects that are farther away are also older. We can convert redshift to lookback time using a functional fit, Fig. 4. By varying the parameters of our universe, we will get different functions for lookback time.

From previous coursework, we expect to see luminosity generally increase with redshift. Additionally, Seyfert galaxies should have high luminosity and low redshift, while QSOs should have high luminosity and high redshift.
III. METHODS

AGN can be observed in different wavelengths. The famous photo of the AGN in M87, Sagittarius A*, published by the Event Horizon Telescope, was created using data in the radio wavelength. The data used in this paper is primarily from the European Space Agency’s X-Ray Multi-Mirror Mission, or XMM-Newton. XMM-Newton is a satellite carrying three x-ray telescopes. This paper uses data specifically from the COSMOS field, which is an approximately two square degree area of the sky that has been extensively observed. While observing AGN in different wavelengths can have different advantages, the benefit of using x-ray data is that this wavelength range presents the least amount of bias.

After identifying AGN based on x-ray observation, the researchers used Spectral Energy Distributions (SEDs) to classify AGN by their morphology. Different morphologies have different spectra, with unique features based on their individual characteristics. One can match an observed spectrum to a commonly found SED template, resulting in a matching morphology, seen in Fig. 5. This method of classification is used extensively by the researchers.

The first COSMOS data set comes from Salvato et. al. 2009. It specifically includes AGN and host galaxy morphologies as well as their redshifts. The SED template library for identifying morphologies comes from Ilbert et. al. 2009. The second COSMOS data set was further selected for the hard x-ray as a subset of the original data and is provided by Poletta et. al. 2007. It was then supplemented with data in the infrared and optical wavelengths, and specifically includes AGN morphology, redshift, and luminosity in both the x-ray and infrared.

IV. RESULTS AND ANALYSIS

The first properties correlated are host galaxy morphology and redshift, see Fig. 6 for this distribution. Interestingly, elliptical galaxies appear significantly less than spirals, and at lower redshifts. This is not something we expect. This result is not indicative of the actual distribution of AGN, but rather a systematic error in the method of data collection. What these histograms really tell us about elliptical galaxies is that they are not remarkable in the x-ray wavelength—recall that XMM-Newton is an x-ray telescope—and when we do see activity, it is at lower redshift.
Next we look at AGN morphology as a function of redshift, shown in Fig. 7. There is a stark contrast between Broad Emission Line AGN (Type I) and Narrow Emission Line AGN (Type II). Recall that by definition, Type II AGN are obscured by the dusty torus, whereas Type I AGN are not. Because of this, we see in Fig. 7 that Type II AGN have lower redshifts. They are more difficult to see farther away. Likewise, Type I AGN are easier to see farther away and hence have higher median redshifts.

The next step is to break down AGN morphologies into further classifications. Fig. 8 shows the distribution of different SED templates as functions of redshift. Several of the templates that were similar in characteristics, but lacking in sufficient data, were combined to help draw conclusions. Two main takeaways from these histograms are that AGN with Seyfert, Starburst, and S0 SED fittings all have lower redshifts, while QSOs have higher redshifts. These results align with our current understanding of these particular morphologies.
Fig. 8. These histograms show the distribution of AGN as a function of redshift for different AGN classifications. Seyferts, Starbursts, and S0s all have lower redshifts, whereas QSOs have higher redshifts.

Fig. 9. The distribution of AGN morphology as a function of the log of x-ray luminosity.

Fig. 10. The distribution of AGN morphology as a function of the log of infrared luminosity.
Fig. 11. These plots show the log of x-ray luminosity versus redshift for different AGN morphologies.

Fig. 12. These plots show the log of infrared luminosity versus redshift for different AGN morphologies.
The remainder of the analysis is done using data from Polletta et al. 2007. We first create histograms of AGN as a function of x-ray luminosity, Fig. 9. We see that Broad Emission Line AGN are more luminous than Narrow Emission Line AGN. If we again relate this trend back to their definitions, it makes sense that our unobscured AGN are more luminous than obscured ones. In addition, low luminosity Type I AGN are rare when observed in x-ray because they experience a special kind of obscuration due to highly ionized gas (HIG) from the opening of the torus. We see similar results in the infrared as well, Fig. 10.

Not only does luminosity change with morphology, but it also changes with redshift. Fig. 11 plots the log of x-ray luminosity versus redshift for different AGN morphologies. The curves fit onto the plot are the same functional form as mapping redshift to lookback time, Fig. 4. If our curves match the function, it would mean the log of luminosity increases linearly with look back time. Because our luminosity is logarithmic, it would increase exponentially. We again see similar trends with infrared luminosity, Fig. 12.

As the trends would suggest, luminosity increases with redshift. On one hand, there was more gas and dust at higher redshifts, enabling higher luminosity AGN. This gas is used up over the history of the universe and there simply isn’t as much now as there was before. However, there is another factor we have to look at to understand this correlation. As we look at higher redshifts, it becomes harder to observe low luminosities. Although the number density of these lower luminosity AGN is more consistent throughout time, they are more difficult to observe. This is another factor contributing to an overall increase in AGN luminosity with increased redshift.

**CONCLUSION**

Active galactic nuclei are a key topic of research in the astronomy community. This paper used data from XMM-Newton to correlate morphology, luminosity, and redshift of AGN. There are several conclusions we have drawn from our analysis. First, elliptical galaxies do not exhibit particularly notable x-ray activity, and hence are harder to detect using x-ray telescopes. Activity that we do see is seen at lower redshift. Second, obscuration from the central torus limits what redshift AGN can be seen at. This is why we see less Type II AGN at higher redshifts compared to Type I AGN. Similarly, Type I are more luminous than Type II AGN. This again can be traced back to central obscuration. The data also supports our hypotheses that QSOs are found at higher redshifts with higher luminosities, and that Seyferts, while also luminous, are found at lower redshifts. In addition, we find that AGN luminosity increases exponentially with redshift. This is because there was more gas to fuel AGN back in the early universe. However, it is also difficult to observe low luminosity AGN at higher redshifts, which is a selection bias that would increase our overall luminosity.

While we may have identified several trends in AGN, there are many other questions that would be good to investigate. How do these properties correlate with AGN mass? Because gas was more abundant in the early universe, we hypothesize mass will increase with redshift and luminosity. QSOs in particular should be massive. How do these properties correlate with galaxy mass? How do these correlations change at different wavelengths? We may have looked at AGN in the x-ray, but they have many other characteristics visible in other wavelengths. In the future, technologies enabling us to observe lower luminosities will also be important to us understanding AGN. There is simply a bias when it comes to observing anything at large enough redshifts. In the meantime, this research contributes to our overall understanding of how AGN properties relate to each other.

**REFERENCES**


