Effects of Galactic Bar Properties in AGN Host Galaxies and Activity

Meti Kebede Getachew

A Thesis Submitted to

The Department of Applied Physics

School of Applied Natural Science

Presented in Partial Fulfillment of the Requirement for the Degree of

Master's in Applied Physics (Astrophysics)

Office of Graduate Studies

Adama Science and Technology University

June, 2024

Adama, Ethiopia

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Declaration

I declare that this Master Thesis entitled **"Effects of Galactic Bar Properties in AGN Host Galaxies and Activity"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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We, the advisor(s) of this thesis, at this moment certify that we have read the revised version of the thesis entitled **"Effects of Galactic Bar Properties in AGN Host Galaxies and Activity"** prepared under our guidance by Meti Kebede Getachew submitted in partial fulfillment of the requirements for the degree of Master's of Science in Applied Physics. Therefore, we recommend submitting the revised version of the thesis to the department following the applicable procedures.

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Approval Page

We, the advisors of the thesis entitled **“Effects of Galactic Bar Properties in AGN Host Galaxies and Activity”** and developed by Meti Kebede Getachew, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Meti Kebede Getachew have read and evaluated the thesis entitled **“Effects of Galactic Bar Properties in AGN Host Galaxies and Activity”** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Applied Physics (Astrophysics).

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List of Acronyms

AGN	Active galactic nuclei
BPT	Baldwin-Phillips-Terlevich diagram
JHU	Johns Hopkins University
KS	Kolmogorov-Smirnov test
$M_\odot$	Mass of the sun
MPA	Max plank institute for astrophysics
Rb	Bar length
Sb	Bar strength
SDSS	Sloan digital sky survey
SDSS-DR16	Sloan digital sky survey data release 16
SFR	Star formation rate
SMBH	Super massive black hole
UV	Ultraviolet spectrum
Z	Red shift
Ωb / Ωp	pattern speed (angular velocity of bar)

Abstract

In this study, we explored the effect of galactic bars on the nuclear activity, supermassive black hole mass, and accretion rate of AGN host galaxies, comparing these characteristics with those of unbarred AGN host galaxies. Utilizing a sample of AGN from the SDSS-DR16, which includes both spectroscopic and photometric data, we conducted a statistical analysis on 29,030 spiral face-on AGN host galaxies brighter than g-mag < 16.5, identifying 10,813 barred AGN hosts. To accurately assess the impact of bars, we constructed a control sample of unbarred AGN host galaxies matched in redshift, r-band magnitude, concentration index, bulge size parameter, and local environment distributions.Our findings indicate that barred active galaxies exhibit higher levels of nuclear activity compared to their unbarred counterparts. The barred sample also displayed a surplus of high Lum[OIII] values relative to unbarred spiral active galaxies in the control sample. Furthermore, the fraction of powerful AGN (with Lum[OIII] $> 10^{11} L_{\odot}$*) increases in more massive hosts with higher concentration indices (C values) and in denser environments. Barred AGN host galaxies consistently showed a higher fraction of powerful AGN across various galaxy property bins. Additionally, barred active galaxies were found to have higher black hole mass growth and elevated accretion rates compared to unbarred AGN hosts. Both barred and unbarred active galaxies displayed higher R values compared to the control sample.*

Keywords: *AGN host galaxies, galactic bars, nuclear activity, supermassive black holes, accretion rate, SDSS-DR16, Lum[OIII], galaxy properties, statistical analysis.*

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Active Galactic Nuclei (AGN) are highly energetic sources found in galaxies, driven by material falling into supermassive black holes. They exhibit unique features observable across the entire electromagnetic spectrum, from radio waves to gamma rays. AGN are among the most powerful phenomena and the brightest sources in the Universe, emitting strong radio, optical, and X-ray signals. They are fueled by the accretion of material onto supermassive black holes, which have masses of at least a million times that of the Sun, located at their centers (Masoura, 2021). Accretion, which involves the conversion of gravitational energy as matter falls onto a black hole, is the most efficient known way to convert mass into energy. The central engine of an AGN consists of this accretion disk and the black hole. Regardless of whether the accretion rate is high or low, a significant portion of the energy released in this process is emitted as thermal radiation from the disk's surface, mostly in the optical and ultraviolet (UV) bands (Maraschi & Haardt, 1997).

Several theories have been suggested to explain how black holes are fed, enabling mass to reach the innermost part of the central engine. Major galaxy interactions, minor mergers, tidal disruptions, gas dynamics involving multiple black holes, and gravitational instabilities in the disks of barred galaxies can all drive gas toward the centers of galaxies (M. Alonso & Coldwell, 2013). Many researchers agree that galactic bars and galaxy mergers or interactions are generally seen as the primary processes for funneling material to the centers of active galaxies (S. Alonso & Lambas, 2018). Galactic bars are elongated structures commonly seen in galaxy discs.These bars vary in shape and size, typically having an elasticity around $\varepsilon \approx 0.6$ and an average length Lbar $\approx$ 4.5 kiloparsecs. Galactic bars form naturally due to instabilities in the disc, either through gradual internal processes or triggered by interactions like close encounters or mergers with other galaxies. In the local Universe, about 70% to 80% of disc galaxies have bars. These bars play a crucial role in many internal processes, acting as drivers of gradual changes and dynamics within disc galaxies.

As the bar forms and spins, it applies a force on the surrounding material. This force removes angular momentum from the inner regions, causing the material to move toward the center. Consequently, the bar significantly influences the movement of angular momentum from the center to the outer parts of the disc, facilitating the movement of material within the disc (Athanassoula, 2003). Bars are crucial for moving gas from the outer disc to the center. According to a theoretical study by (Shlosman & Frank, 1989), bars can drive gas inward to fuel AGN activity. As the gas accumulates, it can trigger gravitational instabilities, forming structures like nuclear spirals, bars, rings, and clumpy discs. These structures then efficiently move gas further inward, maintaining the inflow needed for ongoing AGN activity (Sakamoto & NZ, 1999).

Observationally, (M. Alonso & Coldwell, 2013) and (S. Alonso & Lambas, 2018) compared the nuclear activity of barred galaxies with that of unbarred galaxies and AGN galaxies in paired systems, respectively. In both studies, barred galaxies showed excess nuclear activity and black hole accretion rate compared to the control samples.. However, (Cisternas & Gadotti, 2013) did not find any significant correlation between any of the bar strength indicators and the degree of nuclear activity (Kataria & Vivek, 2024).

The present work intends to contribute to a better understanding of the nature of bar and related with AGN host galaxy by investigating major structural properties of the bars and their AGN host galaxies in relation to its activity within the bar. In this work we studied in detail the properties of barred host galaxies and the effects that bars have on the AGN activity for a sample of AGN host galaxies, comparing the results with a carefully selected sample of unbarred AGN host.

This paper is structured as follows, in chapter one introduces about the context and information to orient readers to the topic without delving deeply into detailed research providing the background, the objective and state the statement of the problem with significance. Then in chapter two brief overview and explanation in the literature review, establishes the existing knowledge in the field. Then in chapter three describe in detail the methodology, detailing the data sources, sample selection, and software utilized, as well as control the sample and also describes the specific analysis method. In Chapter Four presents the results and discussion, highlighting the findings obtained from the analysis. Finally, Chapter Five concludes the thesis by summarizing the key findings, emphasizing their implications, and offering recommendations for further research in the field.

1.2 Statement of the Problem

The presence and influence of bars in galaxies hosting Active Galactic Nuclei (AGN) raise questions about the impact of these structures on the properties, evolution, and activity of AGN. Understanding the specific effects of bar properties on AGN host galaxies remains a complex and less explored area within galactic astrophysics.Earlier research on the effect of bars on AGN host galaxies encountered several limitations, such as limited sample sizes, image quality issues, and incomplete capture of evolutionary changes in bar fueling of AGN. Previous research by (M. Alonso & Coldwell, 2013), using data from SDSS-DR7, has examined the impact of bars on AGN host galaxies and black hole activity, uncovering notable insights into how bars affect AGN properties and nuclear activity. The study found that barred AGN host galaxies exhibit distinctive characteristics, including a higher fraction of powerful active nuclei and a shift towards higher Lum[OIII] values compared to unbarred AGN galaxies (Oh, Oh, & Sukyoung, 2011).

However, there remains a need to update these findings using more recent data. This study aims to fill this gap by utilizing the latest SDSS-DR16 data to reassess the effects of galactic bar properties on AGN host galaxies and their activity. With the advent of the Sloan Digital Sky Survey Data Release 16 (SDSS-DR16), there is an opportunity to delve deeper into this topic with a more comprehensive and updated dataset. Preliminary analysis using SDSS-DR16 data indicates a stronger correlation between the presence of bars in AGN host galaxies and black hole activity than previously reported.This discrepancy prompts the question: Could the larger sample size and enhanced data quality of SDSS-DR16 reveal more intricate relationships and trends that were not discernible in the SDSS-DR7 data? Moreover, how might the improved image quality of SDSS-DR16 affect the identification and characterization of bars in galaxies? And how might evolutionary changes in the role of bars in fueling AGN be captured more accurately with this new data? Therefore, the problem this research aims to address is to investigate this study using the SDSS-DR16 data, to elucidate the reasons behind the observed increase in correlation, and to understand the impact of improved image quality and evolutionary changes on these findings.

1.3 Objectives

1.3.1 General Objective

The general objective of this work is to investigate the properties of host galaxies and the effects that galactic bars have on the AGN host.

1.3.2 Specific Objectives

The specific objectives of this study:

- Analyze the effect of bar on AGN host galaxy correlated with nuclear activity.
- Analyze the effect of bar on AGN host galaxy correlated with Blackhole Mass.
- Analyze the effect of bar on AGN host galaxy correlated with Accretion rate.
- Comparing the results with a carefully selected sample of unbarred AGN host.

1.4 Significance of the Study

In light of the substantial gaps in academic research and practical understanding regarding the connection between active galactic nuclei (AGN) in their host galaxies and the formation of bars based on observational evidence, this study plays a crucial role in advancing scientific knowledge in this area The significance of studying the "Effect of Bar on AGN Host Galaxy" lies in several critical aspects:

- Understanding galactic evolution: Investigating the influence of bars on AGN hosts provides crucial insights into the mechanisms driving galaxy evolution. It sheds light on how internal structures impact the activity and development of galaxies over cosmic time.
- AGN phenomena: Understanding the role of bars in AGN behavior can unravel underlying factors triggering nuclear activities within galaxies. This knowledge is pivotal for comprehending the physics behind AGN and its variability.
- Cosmological relevance: The study's findings might contribute to a broader comprehension of the role of bars in galactic evolution within the context of broader cos-

mological theories, enhancing our knowledge of how these structures impact the universe's larger-scale dynamics.

- Astronomical observation: Insights into the influence of bars on AGN can guide observational strategies and help refine astronomical models, potentially aiding in the interpretation of observational data related to galaxies, their structures, and the presence of AGN.

CHAPTER 2

LITERATURE REVIEW

2.1 Active Galactic Nuclei (AGN)

2.1.1 Overview of AGN

AGNs are dynamic phenomena found at the cores of galaxies. They are fueled by supermassive black holes that draw in and consume nearby gas and stars, releasing immense amounts of energy in the process. AGNs emit radiation across the entire electromagnetic spectrum, ranging from radio waves, microwaves, and infrared to visible light, ultraviolet, X-rays, and gamma rays. This broad frequency coverage spans more than twenty orders of magnitude, demonstrating a wide spectrum from low to high frequencies. In comparison to the nuclei of ordinary galaxies, AGNs emit significantly greater amounts of energy and radiation, making them standout as exceptionally luminous and energetic sources in the universe (Zdziarski, 1998).

Active galactic Nuclei, which are characterized by having a supermassive black hole (SMBH) at their center. These black holes have masses greater than or equal to 10^6 times the mass of the Sun ($10^6 M_\odot$). The defining feature of these active galaxies is that their SMBHs are actively accreting matter, meaning they are pulling in surrounding gas and dust. This process releases energy that is emitted across the entire electromagnetic spectrum, from radio waves to gamma-rays. The accretion process, which involves the gravitational energy of the infalling matter being converted into radiation, is the most efficient way known to convert bulk mass into energy. As matter falls toward the black hole, it starts to orbit around it due to its angular momentum. Over time, the energy dissipation causes this matter to form a flattened structure known as an accretion disc. In this disc, magnetic viscosity plays a crucial role: it transfers angular momentum outward and allows mass to move inward toward the black hole.The combination of the accretion disc and the central black hole is referred to as the central engine of an Active Galactic Nucleus (AGN). This central engine is responsible for the significant energy output observed in active galaxies (Maraschi & Haardt, 1997). Whether the accretion rate is high or low, it is probable that the gravitational energy released by this process is primarily emitted locally, with a substantial portion being in the form of thermal radiation from the disc's surface, peaking in the optical/UV ranges. A significant fraction of these optical/UV photons is reprocessed: (a) by dust located beyond the sublimation radius, which emits them in the infrared band (IR); and (b) by a corona of hot electrons near the accretion disc, which up-scatters them via inverse Compton in the soft/hard X-ray bands. AGN emit a notable part of their luminosity in these X-ray bands. An AGN is surrounded by an accretion disc and a hot corona on scales ranging from 0.01 to 0.1 parsecs. Within this region, there exists high-velocity gas moving at speeds between 1000 and 5000 km/s, known as the Broad Line Region (BLR). The BLR is responsible for the broad emission lines seen in optical spectra and can cause ionized absorption, creating distinctive features in the UV and soft X-ray bands (referred to as the warm absorber).At distances greater than 100 parsecs up to kiloparsec scales, there is a structured region of lower velocity gas (less than 900 km/s), forming a biconical shape known as the Narrow Line Region (NLR). Radiation passing through this region produces permitted, intercombination, and forbidden narrow lines observed in the optical-UV bands (Padovani, 2017).

However, the disc and corona represent only the innermost part of an AGN's nucleus. Evidence of a complex environment surrounding this region includes significant radiation absorption by interstellar gas and dust near the accretion disc, which likely re-emits in different wavelengths. Additionally, the interaction between the supermassive black hole's rotating magnetic field and the accretion disc can generate powerful magnetic jets that eject material perpendicular to the disc at high speeds close to the speed of light, extending over distances ranging from hundreds to thousands of parsecs.Collectively, these elements have been instrumental in explaining the diverse range of AGN classes observed across all wavelengths. They have also contributed to the development of the Unified Theory of AGN, which suggests that much of the diversity in AGN can be attributed to different viewing angles, although accretion rate and efficiency also play significant roles (Zdziarski, 1998).

2.1.2 AGN host galaxy properties

The properties of host galaxies hosting active galactic nuclei (AGNs) at different redshifts offer valuable insights into the processes that initiate AGN activity across different epochs of the universe's history.

- Luminosity: There is a luminosity-dependent evolution in the population of AGNs, where low-luminosity AGNs achieve their peak space density at lower redshifts compared to higher luminosity AGNs. This pattern mirrors the downsizing trend observed in star-forming galaxies (Ueda, 2014).

- At low redshifts, (Laine & Peletier, 2002) discovered that AGNs exhibit a higher star formation rate (SFR) compared to a control sample of non-AGN galaxies. According to their findings, the SFR of AGNs demonstrates a slight correlation with AGN luminosity, without any indication of an increase at high luminosities used SDSS sources at $z < 0.1$ and classified them based on their emission line ratios.

- Accretion rate: Typically represented as a geometrically thin, optically thick structure, formed by material rotating near the SMBH. However, there are alternative models proposing slim or thick disks which reveal the nature of the accretion disk. Matter sheds angular momentum as it spirals inward and is accreted onto the SMBH, converting gravitational energy into thermal blackbody radiation. The accretion rate also indicates that AGNs in merging pairs are actively supplying their central black holes (M. S. Alonso & Lambas, 2007).

- Relativistic jet: Typically bi-polar and collimated, these are energetic outflows of particles moving at relativistic velocities perpendicular to the accretion disk. They are observed in some AGNs and can extend up to Mpc scales for particularly powerful jets. The jets emit non-thermal radiation through synchrotron and inverse-Compton scattering processes. All AGNs emit radio waves due to synchrotron radiation, which is generated by relativistic electrons interacting with a magnetic field (Padovani, 2017).

2.1.3 observational evidence

The discovery of AGN dates back to 1943 when Carl Seyfert identified excessive luminosity in the nuclei of twelve spiral galaxies[2]. Just twenty years later, it was recognized that some of the compact 3C radio sources not only had a relatively bright point-like optical counterpart (e.g., m_V (3C 273) $\sim$ 13m) but also exhibited highly redshifted spectra. These redshifts, attributed to the Hubble law describing the expansion of the Universe, placed these galaxies at cosmological distances and implied intrinsic luminosities of AGN up to $10^{15} L_{\odot}$. This led to the detection of the most powerful class of AGN known as Quasi-Stellar Radio Sources (Quasars) (Athanassoula, 2012).

2.2 Bar in AGN host galaxy

Galactic bars are elongated structures that extend from the center of galaxies and are a common and crucial component of disk galaxies. Bars are internal drivers that significantly influence the evolutionary processes of galaxies. They can efficiently redistribute gas and stars within galaxies through large-scale streaming motions, flatten the chemical distribution of the disk, enhance star formation activity in the central region, and contribute to the formation of (pseudo) bulges (Ellison, 2011). The characteristics of bars in galaxies can be described by three primary parameters: their radius, strength, and pattern speed. The radius and strength of a bar indicate the prominence of the non-axisymmetric component of the galactic disk potential, with larger and stronger bars suggesting more substantial changes in the disk structure. The pattern speed of the bar determines its dynamics and the location of bar resonances, which are crucial for the formation of various orbital families.

The presence of a bar in a disk galaxy strongly alters its dynamics by transferring angular momentum between different structures within the galaxy. It can also influence various properties of spirals over relatively short timescales. In this context, bar perturbations can change star formation activity, stellar populations, colors, chemical composition, and even galactic structure, promoting the evolution of their host galaxies (Cheung, 2013). Additionally, the gas inflow caused by bars towards the innermost regions of galaxies is a mechanism that can effectively trigger nuclear activity in the central zones of AGN galaxies. In galaxies, angular momentum is produced by interactions between gas clouds and the edges of the bar, driving a flow of material towards the central regions of barred galaxies (Jung, 2018).

Bars play a crucial role in the evolution, star formation, chemical composition, and nuclear activity of galaxies. They appear to facilitate radial gas flow, promoting an elevated star formation rate in galaxies, which may be more impactful than interactions between galaxies. Given the established link between star formation and galactic nuclear activity, it is reasonable to anticipate that bars also enhance AGN activity (Matteo, 2005).

2.2.1 Formation and Evolution of bar

Galactic bars are sturdy substructures found in barred galaxies. They are compact, dense collections of stars that orbit around the central core, with a pattern speed differing from that of the disk. Several theories exist regarding the origin of galactic bars (Padovani, 2017).

The formation of a bar is a complex process influenced by numerous internal and/or external properties of the galaxy (Athanassoula, 2012). To date, three primary scenarios for the formation of bars have been suggested.

- One prominent theory posits that galactic bars result from rotational instabilities caused by density waves emanating outward from the galactic core. These instabilities alter the trajectories of stars, leading to reshaped orbits that propagate outward, forming a self-stabilizing stellar structure known as a bar(Bovy, 2019). Galactic bars come in various shapes and sizes depending on the potential energy function. Several three-dimensional models of bar potentials, such as spherical, homoidal, triaxial, and ellipsoidal, have been extensively studied (Sellwood, 2016).

- In the second scenario, bars can form due to tidal interactions with another galaxy. These interactions can produce elongated, bar-like features in the disks of galaxies. Unlike bars that form internally from rotational instabilities, bars formed through tidal interactions evolve over longer timescales and grow slowly. This is because there is limited exchange of angular momentum between the interacting galaxies and other components of the galaxy (Martinez-Valpuesta, 2006).

- A third theory for bar formation, proposed recently by (Yoon & Gu, 2019), suggests that interactions between clusters of galaxies could be responsible for the formation of these structures in galaxies.

2.2.2 The Morphology of Galactic Bars

Bars are prevalent morphological characteristics found in disk-shaped galaxies. The fraction of galaxies with bars holds cosmological importance, and various estimates of the nearby galaxy bar fraction have been derived from optical and infrared studies. Bars are considered transient features that can potentially dissolve and reappear multiple times over the span of a Hubble time. Alternatively, bars may exist as long-lived density wave patterns that influence the secular evolution of both stellar and gaseous distributions. Additionally, bars are believed to drive spiral density waves (Buta, 2015).

Regular barred galaxies often feature an oval structure surrounded by an elongated inner ring. Deprojected blue light images of two examples are shown in Figure 1. NGC 1433 exhibits a robust classical bar and one of the most elongated inner rings known.

The inner ring is positioned at the periphery of an oval shape, which becomes more noticeable at longer wavelengths. In NGC 1433, the inner ring, oval, and bar are all aligned parallel to each other. The situation differs in ESO 565-11, where a bright oval is strongly misaligned with a prominent bar. However, similar to NGC 1433, the oval is enclosed by an inner pseudoring. The implication here is that the bar and the oval are distinct and independent structures (Buta, 2015).

2.3 Observed Properties of Bar

Galactic bars are found at the centers of approximately two-thirds of nearby spiral galaxies, as observed in the near-infrared. Bars are commonly characterized by their length (R_b), strength (s_b), and pattern speed (Ω_b) in various galactic environments (Buta, 2015).

- Bar length (R_b): The length of bars can be estimated visually, through structural decompositions of the galaxy surface brightness, by identifying the maximum in the isophotal ellipticity, variations in the isophotal position angle, or by analyzing variations in the phase angle of the Fourier modes of the galaxy light distribution. Bar lengths have been found to correlate with galaxy parameters such as galaxy mass, color, disc scale-length, and bulge size. Until approximately five years ago, the half-length of bars was thought to be well constrained to about $R_b \sim 3.5$ kpc (Padovani, 2017).

- Pattern speed (Ω_b): The rate of rotation of the bar is a critical parameter influencing its dynamical structure, but direct measurement is challenging. This method typically involves high signal-to-noise long-slit spectra and photometric light profiles taken along cuts offset from the nucleus and parallel to the major axis. In practice, inferred pattern speeds are sensitive to errors in centering, alignment, warps, and the presence of non-bisymmetric perturbations, leading to uncertainties. The bar angular velocity (or pattern speed, Ω_b or Ω_p) determines where resonances occur in the disk, crucial for understanding the bar's impact on disk dynamics. While bar length and strength can be directly measured from observations, estimating Ω_b typically requires kinematic information. Current estimates constrain its pattern speed to approximately $\Omega_b \sim 50-60$ km s^{-1} kpc^{-1} (Petersen, 2019).

- Bar strength (s_b): A bar's strength is not solely determined by its shape but also by its mass. Furthermore, the relative disturbance associated with the bar is influenced by the central gravitational field, such as the presence of a massive bulge. Therefore, bar strengths are more accurately assessed by the tangential forces normalized to the total axisymmetric force fields, as proposed by (Block & Freeman, 2004) and applied in galaxies by (Fahr, 2019).

2.3.1 Evolutionary Processes in a Barred galaxy

The presence of bar in the inner galaxy makes the number of evolutionary processes relevant for galactic evolution. Some are:

- Gas infall: Within the rotating Galactic bar potential, molecular gas moves inward through the cusped orbit shock. Rough estimates suggest the current mass inflow rate through the Inner Lindblad Resonance (ILR) is approximately $\sim 0.1\,M_{\odot}$ per year. Deeper into the galaxy, massive Galactic Center clouds on x2-orbits circulate at speeds greater than the bar's pattern velocity, losing angular momentum to bar stars through gravitational torques from the rotating quadrupole and dynamical friction. The latter process alone causes gas to flow inward to even smaller radii at a comparable rate. Consequently, the current population of Galactic Center clouds must be transient, with material accreting onto the Galactic Center at an average rate of $0.01-0.1\,M_{\odot}$ per year over the next billion years. The frequent observation of central gas concentrations with associated non-circular motions in nearby barred spirals indicates that radial gas inflow is a common phenomenon (Quillen, 1994).

- Angular momentum transfer: The infalling gas must transfer its angular momentum to the stars within the bar. For a hot stellar component, the significance of this angular momentum transfer is amplified by the fact that the typical circular velocity for gas in the bar region is approximately ~ 180 km s^{-1}. In a rapidly rotating stellar bar, dynamical friction calculations predict that the gas will drive angular momentum into the surrounding spheroid (Petersen, 2019).

- Build-up of the inner disk: If accretion rates of $0.1\,M_{\odot}$ per year can be sustained over extended periods and most of the material is converted into stars, significant mass additions to the inner disk will occur. The current star formation rate in the central few hundred parsecs is typical for the amount of gas present. It may currently be suppressed by pressure from very hot gas at 10^8 K, but it's difficult to maintain this hot medium over long timescales without converting a substantial fraction of the accreted material into stars, unless an unusually large number of massive stars are formed. This discusses the triggering of burst-like star formation by gas inflow in external barred galaxies (Quillen, 1994).

- Bar dissolution by a central mass concentration: By channeling material toward its center, the bar may trigger its own destruction. Studies have demonstrated that a central mass equivalent to a few percent of the bar's mass (approximately $10^8 M_\odot$ in our Galaxy) could disrupt the bar. At this mass level, the outer Inner Lindblad Resonance (ILR) moves outward sufficiently, eliminating the elongated x1-orbits that support the bar's shape. While the central point mass of our Galaxy currently does not significantly affect this bar evolution, research has shown that bar-driven gas inflow may form sufficiently concentrated gas disks or secondary bars, which can have similar disruptive effects (Maraschi & Haardt, 1997).

2.4 The role of Bar in AGN host galaxy

Bars play a crucial role in the evolution, star formation, and nuclear activity of galaxies. In this context, bar disturbances can alter star formation rates, stellar populations, colors, chemical compositions, and even the structure of galaxies, influencing the evolution of their host galaxies (Ellison, 2011).

- Stellar population: Simulations indicate that torques generated by the stellar bar potential disturb the interstellar medium (ISM), transporting gas and dust through the bar, where this material undergoes shocks and compression. Observations also suggest that bars serve as a mechanism for transporting gas to the central regions, enhancing the young stellar population in the bulge region (Laine & Peletier, 2002), modifying the gas content and N/O gas abundances, and establishing a correlation between the star formation rate (SFR) near the nucleus and certain bar properties.

- Star formation: Bars appear to be an effective mechanism for generating radial gas flow, which promotes an increased star formation rate in galaxies, potentially more effectively than galaxy interactions (Ellison, 2011). Gas clouds within galaxies experience shocks from interactions with the edges of bars, leading to losses in angular momentum and enabling a gas flow within the innermost regions of galaxies (Sellwood, 2016).

- Nuclear activity: Gas inflow driven by bars toward the innermost regions of galaxies is a mechanism that can effectively trigger nuclear activity in the central zones of active galactic nuclei (AGN) galaxies (Cheung, 2013). Numerical simulations indicate that interactions between gas clouds and the edges of bars lead to a loss of galaxy angular momentum, driving material flow towards the central regions of barred galaxies. The inflow of material driven by the bar towards the innermost regions has been identified as an efficient mechanism for triggering activity in AGN (S. Alonso & Lambas, 2018). (Price, 2021) proposed a model known as "bars within bar" as a mechanism for fueling AGN galaxies. In this scenario, external bars transport gas on scales of a few parsecs, where the material accumulates and exhibits gravitational instability, forming a secondary bar that allows gas to approach closer to a central black hole. There is still debate in observational analyses regarding the varied results on the effects of bars on central nuclear activity.

- Morphology: Several observational studies have indicated that the fraction of barred galaxies does not depend on the environment. However, Bloom & Reenen (2013) observed a higher fraction of barred galaxies in pair systems among their sample of spiral galaxies. Analyzing galaxies in the Shapley-Ames Catalog, (Masoura, 2021), found that the fraction of barred galaxies in cluster environments is higher compared to lower density regions. More recently, demonstrated that barred galaxies tend to be more common in denser environments than their unbarred counterparts across a large sample.

- Chemical Composition in AGN host Galaxy : Hydrogen, oxygen, helium, and small amounts of lithium, boron, and beryllium were synthesized in the early stages of the Big Bang. All other elements, collectively referred to as "metals," were produced through nucleosynthesis in stars. The abundance of these elements thus serves as a direct indicator of the history of star formation within a galaxy. Active galactic nuclei (AGNs) are crucial for studying the early stages of chemical enrichment in the universe (Matteo, 2005). Their luminosity enables us to observe chemically processed environments when the universe was less than 7% of its current age, providing insights into early star formation and galaxy evolution. The spectra of the highest redshift AGNs resemble those of AGNs in the local universe, indicating that chemical enrichment occurs rapidly on cosmological timescales (Ahumada & Prieto, 2020). This similarity makes local AGNs a valuable tool for studying chemical evolution in the early universe. There are two primary methods for determining abundances in AGNs:

Broad Emission Lines (BELs) are commonly observed in AGNs and originate in close proximity to the nucleus. Significant effort has been dedicated to determining AGN abundances by analyzing the relative strengths of BELs in both individual and composite spectra (Athanassoula, 2003). These studies indicate that the metallicity of the Broad Emission Line Region (BELR) is above solar. However, BEL abundance studies are inherently relative and do not directly measure heavy element-to-hydrogen ratios. The BELR exhibits spatial stratification with a wide range of densities and temperatures, leading to BELs originating from disparate regions. This spatial complexity complicates the use of BEL line-flux ratios as indicators of abundance. Furthermore, radiation transfer within the opaque BEL material poses challenges in interpreting observed BEL ratios (Jung, 2018).

Absorption lines associated with AGN outflows provide an opportunity for absolute abundance measurements, as the hydrogen Lyman series troughs can directly indicate ratios of hydrogen to heavy elements. Resonance line absorption troughs, which are blue-shifted relative to the systemic redshift of their emission counterparts, are clear indicators of AGN outflows. The distances of these outflows from the central source can vary, from smaller than the Broad Emission Line Region (BELR) distances to tens of parsecs or even 1000 parsecs. In most cases, these outflows are associated with material near the AGN and can serve as diagnostics for the chemically enriched environment at the centers of galaxies (Matteo, 2005).

CHAPTER 3

DATA SOURCE AND METHODOLOGY OF THE STUDY

3.1 Data Source

3.1.1 Sloan Digital Sky Survey

The selection of AGN host galaxies for this study was based on comprehensive spectroscopic and photometric data obtained from SDSS. The Sloan Digital Sky Survey (SDSS) is currently the most extensive galaxy survey. Utilizing a 2.5-meter telescope, it gathers photometric and spectroscopic data that will span roughly one-third of the entire night sky of the celestial sphere and obtain spectra for over million objects.

This study utilizes photometric and spectroscopic data sourced from the Sloan Digital Sky Survey's Data Release 16 (SDSS-DR16) galaxy catalog.Data Release 16 (DR16) represents the sixteenth installment of data from the fourth phase of the Sloan Digital Sky Survey (SDSS-IV). This release, which encompasses observations made up until August 2018, immediately succeeds DR15. As with all SDSS data releases, DR16 is cumulative, incorporating all prior data and expanding on it. To date, the SDSS has captured detailed images covering over one-third of the night sky (Yao, 2023).

3.2 Sample Selection

3.2.1 AGN Host Galaxy Selection

We utilized the primary galaxy sample from the fourth data release (DR16) of the SDSS-IV project. we accessed photometric and spectroscopic data from the Catalog Archive Server (CAS) for DR16. We conducted quick inspections of objects and wrote concise queries using the Sky Server web application (https://skyserver.sdss.org) (Ahumada & Prieto, 2020). We concentrated on galaxies with redshifts ranging from 0 to 0.25. The lower limit helps avoid saturated images, while the upper limit allows for precise morphology assessments. We included only those galaxies whose morphology we could classify reliabl. In the SDSS DR16, there are 62,606 galaxies within this redshift range.

We selected the active galaxy sample using the criteria established by (Kauffmann & Heckman, 2003). We employed a standard diagnostic diagram proposed by (Baldwin, Phillips, & Terlevich, 1981), and utilized publicly available emission-line fluxes. This diagram distinguishes type II AGN from normal star-forming galaxies based on their emission-line ratios and their position within the diagram. The Standard 'unified' model divides AGNs into two main categories. In this model, 'type 1' AGNs have a visible central black hole and its emissions, while 'type 2' AGNs have a dusty region that conceals these central features. This dusty region allows some radiation to escape, resulting in strong narrow emission lines. The non-thermal light in type 1 AGNs complicates the study of the surrounding galaxy and its stars. We included only galaxies with a signal-to-noise ratio (S/N) greater than 22 for all lines used in the diagnostic diagram to differentiate AGNs from HII galaxies. This S/N threshold was selected because the adjusted uncertainties nearly doubled the original errors (Paul, 2011). Using the BPT diagram, which includes the spectral lines [OIII]λ5006, Hβ, [NII]λ6583, and Hα, we applied the criteria from (Kauffmann & Heckman, 2003) to identify type II AGN,

$$\log\left(\frac{[\text{O III}]}{\text{H}\beta}\right) > \frac{0.61}{\log\left(\frac{[\text{N II}]}{\text{H}\alpha}\right) - 0.05} + 1.3 \tag{3.1}$$

In Fig. 3.1, we present the BPT diagram for all the emission-line galaxies in our sample. The plot shows the ratio of [O III] λ5006 to Hβ versus the ratio of [N II] λ6583 to Hα for galaxies where all four lines were detected with a signal-to-noise ratio (S/N) greater than 22. These ratios are nearly unaffected by reddening or spectrophotometry errors. The x-axis represents the logarithm of the [N II] to Hα ratio, labeled as "log([NII]/Hα)." The y-axis represents the logarithm of the [O III] to Hβ ratio, labeled as "log([OIII]/Hβ)." In the diagram, blue dots indicate star-forming galaxies, which typically appear on the left side due to their lower [NII]/Hα and [OIII]/Hβ ratios. Red dots represent galaxies with active galactic nuclei (AGN), usually located on the right side because of their higher [NII]/Hα and [OIII]/Hβ ratios. The green curve is the demarcation line derived from (Kauffmann & Heckman, 2003),which separates the two types of galaxies. Galaxies above this line are generally AGN, while those below it are usually star-forming galaxies.

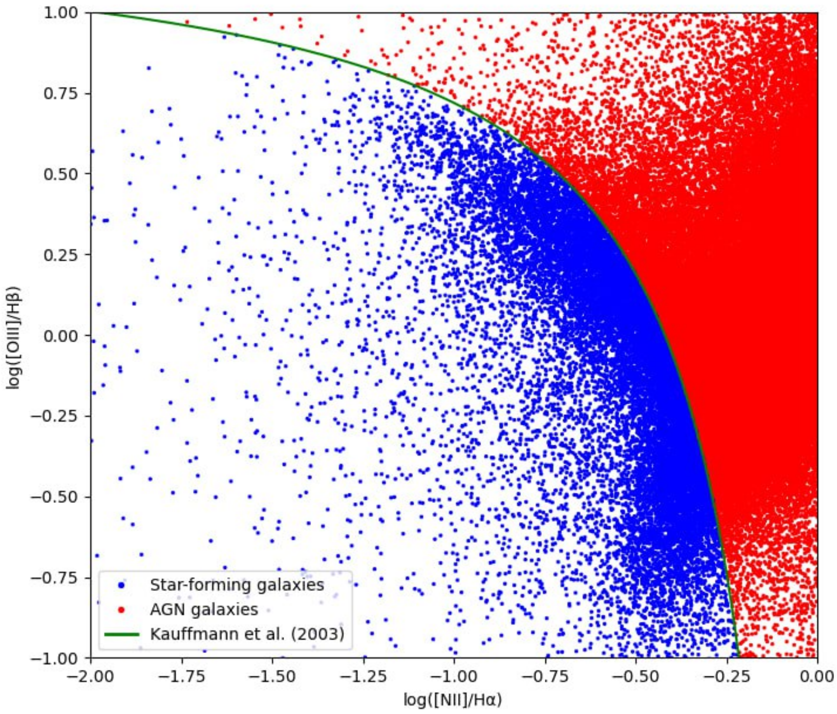

Figure 3.1: [BPT diagram]BPT (Baldwin et al., 1981) diagram in which we plot the emission-line flux ratio [O III]/Hβ versus the ratio [N II]/Hα for all the galaxies in our sample.

3.2.2 Selection of barred AGN host galaxies

Our selection of barred galaxies comes from the catalog by (Willett & Lintott, 2013). In summary, Willett and colleagues visually classified 29,030 galaxies with redshifts below 0.1 ($z < 0.1$) from the spectroscopic sample in the Sloan Digital Sky Survey Data Release 16 (SDSS DR16). They also applied a brightness limit, selecting galaxies with an SDSS g-band magnitude brighter than 16.5, corrected for extinction. Out of this, were identified as disc galaxies, with 10,813 classified as barred (indicated by `bar_flag = 1`) and 18,217 as unbarred (`bar_flag = 0`) (Willett & Lintott, 2013).

However,our barred sample is biased to more face-on galaxies, due to the difficulty of visually classifying bars in edge-on galaxies by adopted flag for combined spiral - 1 if debiased spiral fraction > 0.8. If the debiased spiral fraction is greater than 0.8, the value is 1 (indicating a spiral galaxy). in the context of galaxy classification, an axial ratio greater than 0.8 often indicates a spiral galaxy. The axial ratio is a measure of the galaxy's elongation, calculated as the ratio of the minor axis (shortest diameter) to the major axis (longest diameter).

For a perfect circle, the axial ratio is 1. As the shape becomes more elliptical, the axial ratio decreases. So, an axial ratio > 0.8 suggests a relatively circular shape, which is characteristic of spiral galaxies (Lintott & Schawinski, 2008).

Figure 3.2: Example of barred galaxy sample

3.3 Control Sample

In our study, we focused on investigating the impact of barred structures on AGN host galaxy. To ensure unbiased results regarding the effects of bars on AGNs, we constructed a sample of AGNs hosted by relatively isolated barred and unbarred galaxies. To achieve this, we applied a rigorous isolation criterion for barred galaxies. Specifically, we stipulated that any neighboring galaxy within a projected separation of 20 kpc h^{-1} and a radial velocity difference (Δv) greater than 10000 km/s must be fainter than the barred active galaxy. This criterion was designed to reduce the impact of nearby galaxies on the barred AGN, thereby isolating the effects of the bar structure itself.To execute this isolation criterion, we first calculated the comoving distance and projection separation for each galaxy based on its redshift and distance measurements. The comoving distance was computed using the Hubble constant and the speed of light, while the projection separation was derived from the comoving distance and angular separation. These calculations were performed to establish a robust spatial criterion for defining galaxy isolation.this process involved implementing strict isolation criteria to construct samples of barred and unbarred galaxies hosting AGNs, ensuring that our subsequent analyses are unbiased with respect to the influence of nearby galaxies on AGN activity linked to barred structures (M. S. Alonso & Lambas, 2007).

We generated a control sample of galaxies using a Monte Carlo algorithm. This algorithm selected objects previously identified as unbarred galaxies, ensuring they matched the barred galaxies in terms of redshifts, absolute r-band Petrosian magnitudes, concentration index (C) distributions, the fracdeV parameter (indicator of bulge sizes in galaxies with disk morphology), and the local density environment parameter ($\sum 5$) (Vera, Alonso, & Coldwell, 2016).

We examined the distribution of the local density environment and concentration index (C) in both barred and unbarred galaxies. To achieve this, we defined a projected local density parameter, $\sum 5$, for each isolated sample (barred and unbarred).The projected local density parameter, $\sum 5$, was calculated using the projected distance (d) to the fifth nearest neighbor:

$$\sum 5 = \frac{5}{\pi d^2} \tag{3.2}$$

This parameter quantifies the local galaxy density based on nearby galaxies within the specified distance.Additionally, we analyzed the concentration index (C), which is defined as the ratio of the Petrosian 90% to 50% r-band light radii: C= r50/r90. This index provides insight into the spatial distribution of light in galaxies, with higher values indicating more concentrated light profiles.By examining the distributions of $\sum 5$ and C in barred and unbarred galaxies, we aimed to understand how these structural properties differ between galaxies with and without bars. This analysis helps us explore potential correlations between bar presence and local environment density, as well as the spatial concentration of light within galaxies (M. Alonso & Coldwell, 2013).

3.4 Data Analysis

In our study, we seek to examine how barred structures influence the neuclear activity in galaxies hosting active galactic nuclei (AGN). We first calculated the dust correction factor based on the Balmer decrement. Using the measured fluxes of the Hα and Hβ lines, the observed Balmer decrement was determined by taking the ratio of these fluxes. The theoretical Balmer decrement for Case B recombination at a temperature of 10,000 K was set to 2.86. The dust correction factor was then obtained by dividing the observed Balmer decrement by the theoretical value (Kauffmann & Heckman, 2003). Next, we calculated the dust-corrected

[OIII]λ5006 line luminosity for each galaxy. The luminosity was computed using the measured flux of the [OIII]λ5006line, the distance to the galaxy, and the dust correction factor. The flux was converted to luminosity using the formula

$$L = 4\pi d^2 F$$

Where d is the distance in centimeters and F is the flux. The dust correction factor was then applied to obtain the corrected luminosity. Finally, the luminosity was converted from erg s^{-1} to solar luminosities (Carroll & Ostlie, 2017). After that, we seek to examine how barred structures influence the mass of supermassive black holes in galaxies hosting active galactic nuclei (AGN). It is well-established that supermassive black holes are commonly found in both elliptical galaxies and spiral bulges. The estimation of black hole masses has been facilitated by discovering correlations between galactic black hole mass and bulge luminosity, as well as a more precise correlation between central black hole mass and the line-of-sight velocity dispersion (Kormendy & Richstone, 1995). To estimate black hole mass, we used the M_{BH}–σ relation, expressed as:

$$\log\left(\frac{M_{\mathrm{BH}}}{M_{\odot}}\right) = \alpha + \beta \log\left(\frac{\sigma_e}{200\,\mathrm{km\ s^{-1}}}\right)$$

We applied different M_{BH}–σ relations for barred and unbarred galaxies. For barred galaxies, we used parameters $(\alpha, \beta) = (7.67 \pm 0.115, 4.08 \pm 0.751)$, while for unbarred galaxies, we used $(\alpha, \beta) = (8.19 \pm 0.087, 4.21 \pm 0.446)$, based on the findings of (Gültekin & Richstone, 2009). These differences arose because stellar motion along a bar increased the "measurable" central velocity dispersion. After calculating the black hole masses, we estimated the accretion rate onto the black holes by calculating the ratio of [OIII] luminosity to black hole mass. This ratio, denoted as R, is expressed as:

$$R = \log\left(\frac{\mathrm{Lum[OIII]}}{M_{\mathrm{BH}}}\right)$$

(Heckman & Kauffmann, 2004). Also Statistical analyses, including the Kolmogorov-Smirnov test, were conducted to compare the distributions of Lum[OIII] , black hole masses and accretion rates between barred and unbarred galaxies.

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, we present the results of our study on the effect of galactic bar properties in AGN host galaxy and activity. The study had specific goals, we analyzed the effect of bars on AGN hosts by looking at how the presence of galactic bars impacted various aspects of AGN host galaxies, such as their nuclear activity of central activity of the galaxy, the mass of the supermassive black hole at the galaxy's center, and the accretion rate at which the black hole was pulling in matter. Additionally, they compared the results from barred galaxies with those from a carefully chosen sample of unbarred AGN host galaxies to understand the differences and similarities. To achieve these objectives, we incorporated data from both barred and unbarred AGN host galaxies to gain a comprehensive understanding of barred AGN host galaxies. We utilized the ASTROPY code to estimate the luminosity, black hole mass, and accretion rate of the AGN host galaxies. This section presents the results of our analysis on how the presence of a bar correlates with Nuclear activity, Black hole mass, and Accretion rate in AGN host galaxies. Additionally, we compared the properties of barred AGN host galaxies with those of unbarred AGN host galaxies to gain insight into the unique features of bars in influencing galaxy properties.

4.1 Effect of bar on AGN host galaxy correlated with Nuclear activity

We perform an analysis of the impact of bars on the nuclear activity of AGN host galaxies driven by the feeding of the central black hole presented.Specifically, the objective is to understand how the presence of a bar structure within a galaxy influences the feeding mechanisms of the central black hole, consequently affecting the AGN's nuclear activity. To analyze the effect of galactic bars on the nuclear activity of AGN host galaxies, we focus on the dust-corrected luminosity of the [OIII] λ5006 line, Lum[OIII], which serves as a reliable tracer of AGN activity due to its minimal contamination from star formation processes.By comparing the distributions of Lum[OIII] between barred and unbarred AGN host galaxies, we aim to identify any significant differences that may indicate the role of bars in enhancing or suppressing nuclear activity.

Our approach involves categorizing the data based on the presence or absence of a bar and examining the corresponding Lum[OIII] distributions. This method allows us to assess how the structural properties of the host galaxy, specifically the existence of a bar, correlate with the AGN's luminosity and activity levels.The correction accounts for the effects of dust obscuration on the measured fluxes of Hα and Hβ emission lines. Next, we calculated the dust-corrected [OIII]λ5006 line luminosities (Lum[OIII]) for each galaxy in our sample using the flux measurements and distances provided in the data. To correct for dust extinction in emission line flux measurements, used the Balmer decrement method. The Balmer decrement method to correct for dust extinction in emission line flux measurements is based on the physics of hydrogen emission lines and the effects of interstellar dust on these lines. The Balmer lines, particularly Hα and Hβ, are strong emission lines emitted by hydrogen in the ionized state. These lines are prominent in the spectra of ionized gas, such as that found in H II regions surrounding young stars or in the ionized gas near active galactic nuclei (AGN). Dust grains in the interstellar medium can absorb and scatter light, preferentially affecting shorter wavelengths more than longer wavelengths (Kauffmann & Heckman, 2003). This results in the attenuation of the observed flux of emission lines, which makes the measured line fluxes lower than the true values.

The primary reason is that the [OIII] line is especially attractive on this work it's among the most intense and noticeable narrow emission lines found in AGNs, making it relatively straightforward to detect and measure even when other features may be faint or obscured. Many AGNs are shrouded by dust and gas, which can obscure optical light and make it difficult to observe certain features. However, the [OIII] line remains strong and detectable even in these conditions, providing valuable information about the AGN's properties.In galaxies, emission lines can arise from various processes, including star formation. However, the [OIII] line has minimal interference from the light emitted by stars forming in the host galaxy (Veilleux & Osterbrock, 1987). This means that the [OIII] emission primarily originates from the AGN itself, making it a cleaner and more reliable indicator of the AGN's activity.

The impact of bars on nuclear activity is evident in Fig.4.1 in the histogram of log(Lum[OIII]) depicts the distributions for both barred and unbarred AGN host galaxies.The graph is compares the frequency of barred and unbarred galaxies with respect to their luminosity, specifically log(Lum[OIII]). There are two sets of data represented by bars: one set in blue for unbarred galaxies and another outlined in black for barred galaxies.Barred galaxies demonstrate a clear inclination towards higher log(Lum[OIII]) values in comparison to the control sample of unbarred galaxies.This suggests that barred AGN host galaxies exhibit notably stronger nuclear activity as indicated by Lum[OIII]. A vertical dashed red line indicates the threshold for powerful Active Galactic Nuclei (AGN). The x-axis is labeled "log(Lum[OIII])" and ranges from 9.0 to 12.5, while the y-axis represents frequency ranging from 0 to 1200. The histogram shows that both barred and unbarred galaxies have similar frequencies across most luminosity values, but there is a noticeable difference around the threshold for powerful AGN, where the number of barred galaxies increases significantly compared to unbarred ones. This suggests a potential correlation between the presence of bars in galaxies and the activity level of their AGN. In other words, barred galaxies might have a higher likelihood of hosting powerful AGN compared to unbarred galaxies. This could be due to the bars providing a more efficient mechanism for gas inflow, which could result in higher AGN luminosity. The analysis shows that AGN host galaxies with bars exhibit higher levels of nuclear activ-

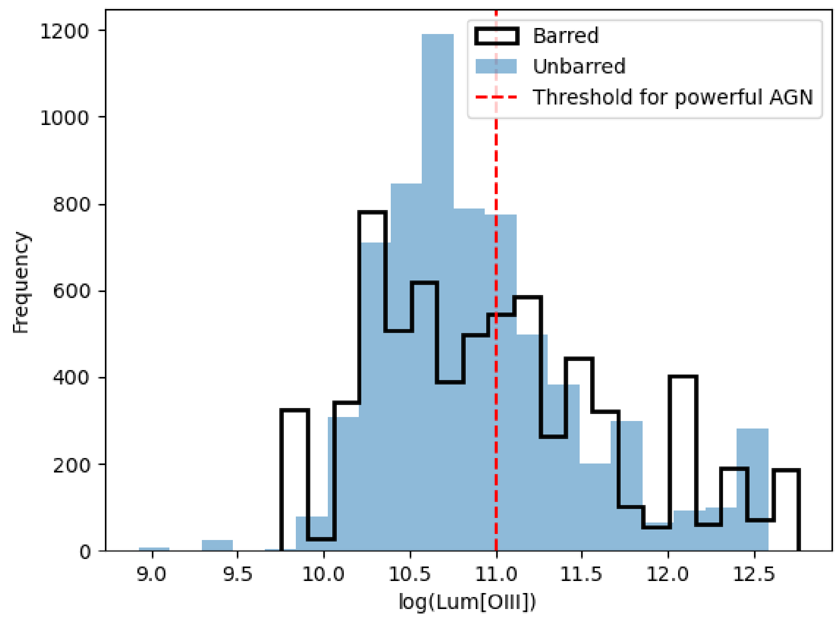

Figure 4.1: Distribution of log (Lum[OIII]) for barred active galaxies (solid black line) and unbarred AGN host (full shaded surfaces).

ity compared to those without bars and a control sample of unbarred galaxies. This finding aligns with earlier research (Kauffmann & Heckman, 2003) and (Heckman & Kauffmann, 2004), which proposes that bars in galaxies can facilitate the movement of gas towards the central black hole. This enhanced gas flow fuels the black hole, thereby boosting the AGN's activity. Galactic bars are elongated structures of stars and gas that extend from the central regions of some galaxies. Theoretical models and observational evidence suggest that these bars can channel gas from the outer regions of the galaxy towards its center. When this gas reaches the vicinity of the central supermassive black hole, it can be accreted, or pulled in, by the black hole's gravitational force. This process of accretion leads to an increase in the black hole's activity, which we observe as increased luminosity in certain emission lines, such as the [OIII]λ5006 line. Therefore, the presence of a bar can effectively enhance the nuclear activity of an AGN by providing a mechanism for efficiently transporting gas to the black hole.

The higher Lum[OIII] values observed in barred galaxies imply that bars provide a more effective means of channeling gas towards the central regions of these galaxies, thereby fueling AGN activity. In galaxies, bars act as a gravitational conduit, directing gas from the outer regions to the central nucleus. This influx of gas can be accreted by the central supermassive black hole, leading to enhanced AGN activity. The [OIII]λ5006 emission line is a strong indicator of such activity because it is emitted by ionized gas close to the black hole. When we see higher Lum[OIII] values in barred galaxies, it suggests that the bar structure is indeed effective in promoting this gas inflow and subsequent black hole feeding. The Kolmogorov-Smirnov (K-S) test supports this observation, showing a statistically significant difference between the distributions of Lum[OIII] in barred and unbarred galaxies, with a significance level of 99.99%. The Kolmogorov-Smirnov test is a statistical method used to compare two distributions (Berger & Zhou, 2014). In this case, it compares the distribution of Lum[OIII] values between barred and unbarred galaxies. A K-S statistic of 0.10729, along with a p-value of 4.4885×10^{-34}, shows that the difference between these distributions is not random but statistically significant. This supports the hypothesis that bars enhance the central black hole activity by providing a more efficient mechanism for gas inflow, resulting in higher AGN luminosity. We divided the samples into low- and high-luminosity subsamples based on a threshold $Lum[OIII] = 10^{11}L_{\odot}$, which corresponds to the mean Lum[OIII] of the control sample. This threshold helps in categorizing weak and powerful AGNs.

The study also analyzed the fraction of powerful active galaxies (log(Lum[OIII]) > 11) as a function of the concentration index (C) and local environmental density, log($\sum$5).In Fig. 4.2 shows provided to compare the nuclear activity distributions of barred and unbarred galax-

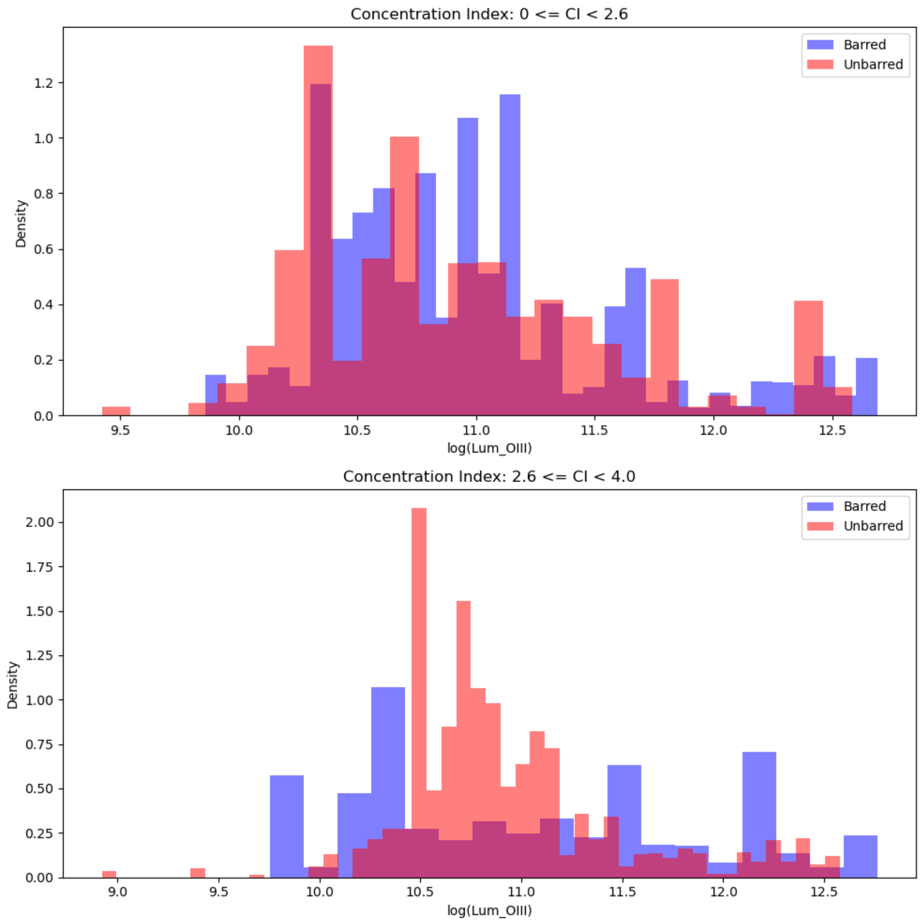

Figure 4.2: Distributions of log (Lum[OIII]) for barred and unbarred AGN host galaxies (blue and full orange) in different ranges of concentration index

ies within two different ranges of concentration index. It was found that the fraction of barred active galaxies with high Lum[OIII] values increases with higher C values, indicating that more concentrated barred galaxies tend to have more powerful AGN. We examined how nuclear activity varies in barred and unbarred AGN hosts with different concentration parameters. A key value of the concentration index, C = 2.6, was used to differentiate between more compact, bulge-like galaxies (C > 2.6) and more extended, disc-like galaxies (C < 2.6). In other words, we looked at how the nuclear activity of galaxies with and without bars differs depending on their structural characteristics and surroundings. By categorizing galaxies based on their concentration index, which indicates whether a galaxy is more bulge-dominated or disc-dominated, we can better understand the role of bars in influencing AGN activity (Gadotti, 2009). The concentration index threshold of 2.6 helps us distinguish between galaxies that are more centrally concentrated versus those that are more spread out. This analysis examines the intricate relationship between bars, bulges, and AGN activity in galaxies. Bars increase the central mass concentration (CMC) by funneling gas toward the galaxy's center, potentially enhancing AGN activity. However, this effect can be diminished in galaxies with well-developed classical bulges, which are often formed through major mergers and can disrupt the gas inflow driven by bars. The study differentiates classical bulges from pseudo-bulges using the Petrosian concentration index, where a value of C *ageq* 2.6 indicates classical bulges (Gadotti, 2009). It was found that pseudo-bulge galaxies, usually part of the main sequence of star-forming galaxies, show a stronger correlation between the bar fraction, velocity dispersion σ, and star formation rate within the fiber. Bars significantly impact the evolution of these galaxies. Conversely, classical bulge galaxies exhibit a weaker dependence on σ, with many having already quenched star formation without bar influence. This suggests alternative quenching mechanisms, such as major mergers (Hopkins et al., 2006).

Bars impact AGN activity in both bulge types, but this effect is more pronounced in pseudo-bulge galaxies, especially those with lower σ. This indicates that while bars can enhance AGN activity by channeling gas to the center, classical bulges may partly inhibit this process (Sellwood, 2016). Nonetheless, well-developed bulges still support AGN triggering in galaxies with lower σ. These findings indicate that the structural properties of the host galaxy, including the presence of a bar and the type of bulge, significantly influence AGN activity. This theoretical framework supports the observed correlation between bars and the concentration of AGN host galaxies (Athanassoula, 2003).

We also selected two different local environment density ranges, to explore differences in the nuclear activity distributions. Bars in galaxies play a crucial role in the dynamics of gas and the feeding of central black holes. Their non-axisymmetric gravitational potential tends to funnel gas towards the galactic center, which can enhance the feeding of black holes located there. Interestingly, the presence and structure of bars themselves can be influenced by the amount of gas present. The exchange of angular momentum between the bar and the gas depends on the gas content, which affects how strongly the bar is maintained or weakened. Several studies have explored these relationships. (Athanassoula, 2003) and (Athanassoula, 2012) highlighted that the redistribution of angular momentum within galaxies depends on the interaction between the bar and the gas. Observational evidence from (Davoust & Contini, 2004) and (Masters & Nichol, 2012) suggests that gas-rich galaxies tend to have fewer bars compared to gas-poor ones. Moreover, (Zhou, Ma, & Wu, 2021) found that bars in galaxies tend to be larger in physical size as the stellar mass increases and the gas fraction decreases. The presence of a significant amount of gas in galaxies appears to suppress the formation of bars through stabilizing the disc against bar-type instabilities. Therefore, understanding how gas mass influences the connection between bars and the growth of black holes is crucial for comprehending the broader evolution of galaxies and their central black holes.

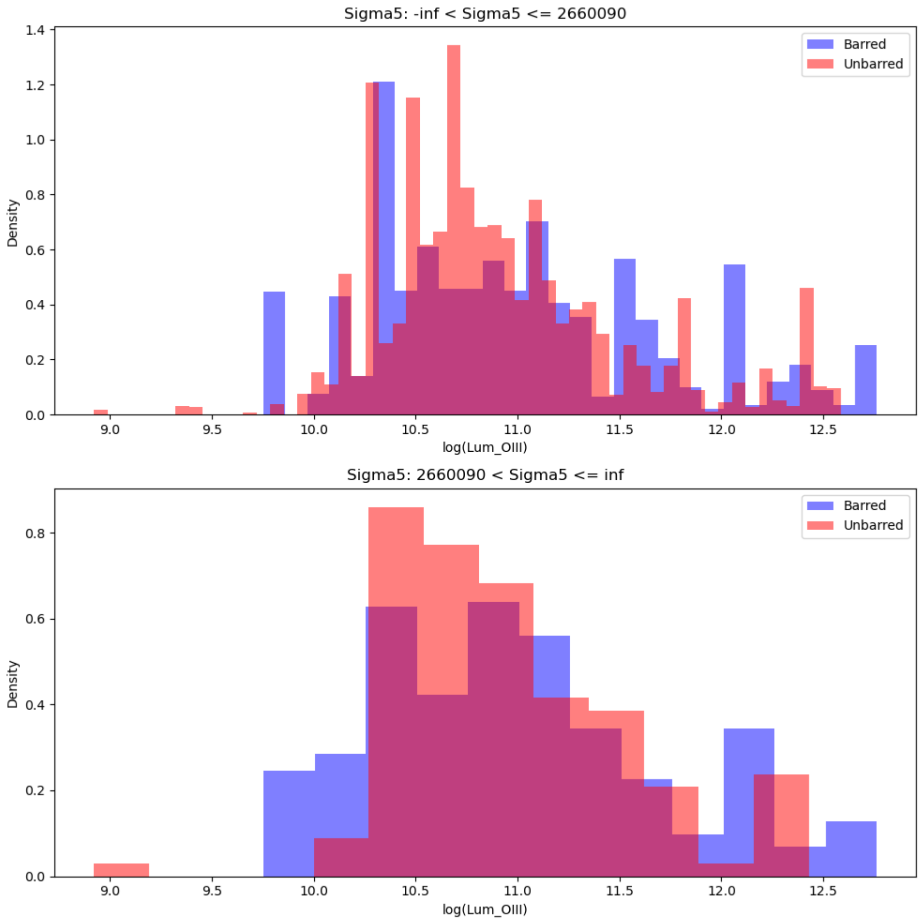

Figure 4.3: Distributions of log (Lum[OIII]) for barred and unbarred AGN host galaxies (blue and full orange) in different ranges of local environment density

In the Fig. 4.3 show provided compare the nuclear activity distributions of barred and unbarred galaxies within two different ranges of local environment density, represented by the parameter Sigma5.The Fig. 4.3 show provided comparesThe The nuclear activity is inferred from the value of log(Lum_OIII), a common proxy for nuclear activity in galaxies. In the Fig.4.3 upper graph , representing lower local environment density ("-inf < Sigma5 <= 266090"), the distribution of nuclear activity for barred galaxies is slightly higher than that for unbarred galaxies at certain intervals. This suggests that in lower-density environments, barred galaxies might exhibit slightly more nuclear activity. In contrast, the lower graph, representing higher local environment density ("266090 < Sigma5 <= inf"), shows a more noticeable difference in the distribution of nuclear activity between barred and unbarred galaxies. Here, barred galaxies have higher peaks at certain values of log(Lum_OIII), indicating increased nuclear activity in these galaxies in denser environments. These results suggest that local environment density plays a crucial role in influencing nuclear activity in galaxies. In low-density environments, the availability of cold gas might facilitate continuous AGN fueling, with bars enhancing this process by channeling gas toward the center. In high-density environments, frequent gravitational interactions could trigger gas inflows, leading to bursts of nuclear activity. Bars in these environments might be more effective in sustaining AGN activity by stabilizing gas inflow despite the disruptive interactions (Blake & Kazin, 2011).

4.2 Effect of bar on AGN host galaxy correlated with Blackhole Mass

In this section, we perform an analysis of the impact of bars on the mass of the supermassive black hole at the galaxy's center of AGN host galaxy presented.To analyze the effect of galactic bars on the mass of super massive Blackhole of AGN host galaxy. As mentioned in Section 3.2.2, this study examines 6,760 unbarred galaxies and 6,702 barred galaxies. The main goal is to explore how galactic bars contribute to the activity of active galactic nuclei (AGN). To investigate the effect of bars on the black hole mass (M_{BH}) in active galactic nucleus (AGN) host galaxies, we used a sample of barred and unbarred AGN host galaxies. The black hole masses were estimated using the correlation between M_{BH} and the bulge velocity dispersion (σ_*), as described by Tremaine et al. (2002)

In Fig.4.4 presents the mass distribution of black holes for all barred and unbarred galaxies. The distributions reveal a significant difference in black hole masses between barred and unbarred galaxies. Specifically, the peak mass of black holes in barred galaxies is twice as large as that in unbarred galaxies. This shows the distribution of M_{BH} for barred (solid line) and unbarred (filled area) AGN host galaxies. The barred galaxies exhibit a significant excess of high black hole masses compared to the control sample of unbarred galaxies. This finding suggests that the presence of a bar may influence the growth of the central black hole in AGN host galaxies.The presence of a bar in a galaxy can enhance the central velocity dispersion due to the stellar motion along the bar, which in turn can lead to an increased estimate of the

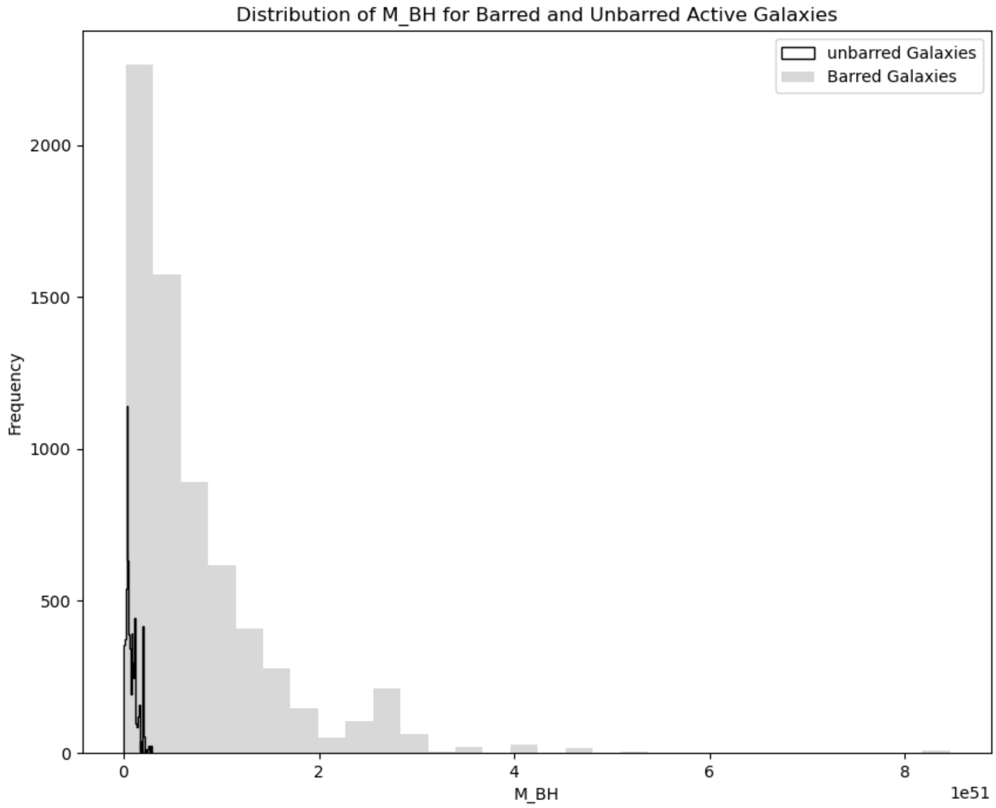

Figure 4.4: Distribution of Blackhole Mass for barred active galaxies (solid line) and unbarred active galaxies (full surfaces)

black hole mass.

The higher values of M_{BH} in barred galaxies support the idea of (Shlosman & Frank, 1989) that bars can facilitate the inflow of gas toward the central regions of the galaxy, potentially feeding the central black hole and leading to more rapid growth.

The Kolmogorov-Smirnov (K-S) test supports this observation, showing a statistically significant difference between the distributions of M_BH in barred and unbarred galaxies, with a significance level of 100%. In this case, it compares the distribution of M_BH values between barred and unbarred galaxies. A K-S statistic of 0.761, along with a p-value of 0.0, shows that the difference between these distributions is not random but statistically significant.This supports the hypothesis that bars enhance the growth of central black hole mass by providing a more efficient mechanism, resulting in higher Blakhole Mass.

4.3 Effect of bar on AGN host galaxy correlated with Acretion Rate

In this section, we perform an analysis of the impact of bars on the accretion rate at which the black hole was pulling in matter.To investigate the effect of bars on the accretion rate in active galactic nucleus (AGN) host galaxies, we used a sample of barred and unbarred AGN host galaxies. The accration rate were estimated using the ratio between the luminosity of the [OIII] emission line and the mass of the black hole (R = log (Lum[OIII]/MBH)).It is a valuable metric for estimating the rate at which material is falling onto a black hole.The ratio R = log (Lum[OIII]/MBH) provides insights into the accretion rate onto the black hole. Higher values of R indicate higher accretion rates, meaning that more material is falling into the black hole and generating [OIII] emission (Heckman & Kauffmann, 2004). Fig.4.5 provided compares the distribution of accretion rates, represented by R = log (Lum[OIII]/MBH), between barred (solid blue line) and unbarred (orange shaded region) active galaxies. The histogram indicates that both barred and unbarred galaxies have similar overall distributions of accretion rates, but there is a slight shift in the distribution for barred galaxies towards higher accretion rates compared to unbarred galaxies. This suggests that, on average, barred galaxies exhibit higher accretion rates onto their central supermassive black holes than unbarred galaxies. This finding implies that the presence of a bar in a galaxy may influence the accretion process onto the central black hole, potentially enhancing the gas inflow towards the nucleus.

Theoretically, the presence of a bar in a galaxy can enhance the accretion process onto the central black hole through several mechanisms. Bars are known to channel gas towards the central regions of galaxies more efficiently than in unbarred galaxies. This efficient gas transport can lead to increased gas density in the central regions, promoting higher accretion rates onto the black hole. For example, (Shlosman & Frank, 1989) discuss how bars can drive gas towards the nucleus, enhancing the fueling of AGNs. Additionally, simulations and observational studies demonstrate that bars can induce inflows of gas towards the center of galaxies, increasing the likelihood of fueling central black holes.

The Kolmogorov-Smirnov (K-S) test supports this observation, showing a statistically significant difference between the distributions of Accretion Rate in barred and unbarred galaxies, with a significance level of 100%. In this case, it compares the distribution of R values between barred and unbarred galaxies. A K-S statistic of 0.525 , along with a p-value of 0.0,

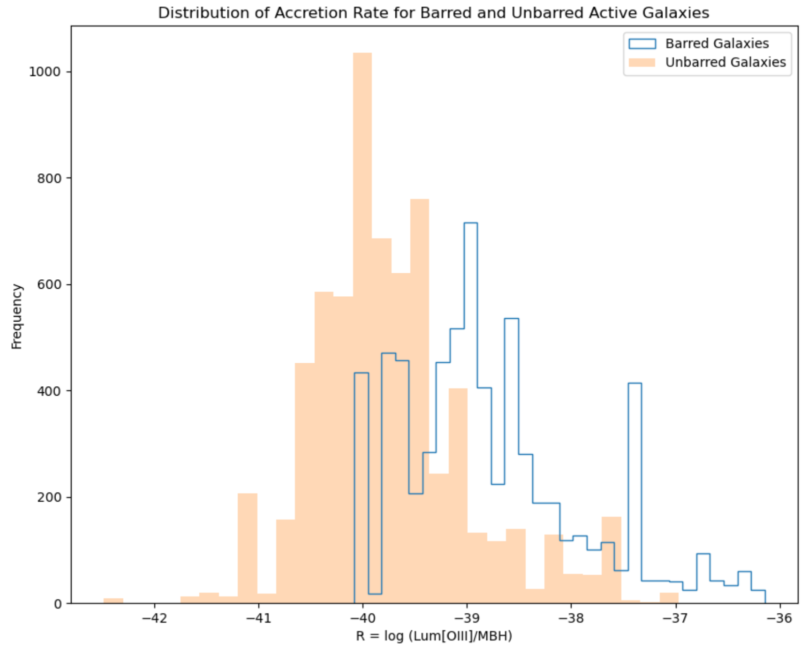

Figure 4.5: Distribution of Acretion Rate for barred active galaxies (solid blue line) and unbarred active galaxies (shaded orange full surface)

shows that the difference between these distributions is not random but statistically significant.This supports the hypothesis that bars enhance the accretion rate at which the black hole was pulling in matter by providing a more efficient mechanism, resulting in higher accretion rate.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In this study, we have explored the effect of galactic bar in nuclear activity, supermassive blackhole mass and accretion rate of AGN host galaxy while comparing them with unbarred AGN host galaxy. We conducted a statistical analysis of the host characteristics and nuclear activity of AGN host galaxies, both with and without bars. Our study utilized a sample of AGN from the SDSS-DR16, incorporating both spectroscopic and photometric data. From a total of 29,030 spiral face-on AGN host galaxies brighter than g-mag < 16.5, we identified 10,813 barred AGN hosts. To accurately quantify the effects of bars, we constructed a control sample of unbarred AGN host galaxies, matching them in redshift, r-band magnitude, concentration index, bulge size parameter, and local environment distributions.

The main results and conclusions of our analysis are as follows. We discovered that barred active galaxies exhibit higher levels of nuclear activity compared to AGN galaxies without bars. Additionally, the barred sample showed a surplus of high Lum[OIII] values relative to unbarred spiral active galaxies in the control sample.

We also investigated the proportion of powerful AGN (with Lum[OIII] $> 10^{11} L_{\odot}$) in relation to the properties of their host galaxies. Our findings indicate that the fraction of active galaxies with Lum[OIII] $> 10^{11} L_{\odot}$ increases in more massive hosts, those with higher concentration indices (C values), and in denser environments. Additionally, we observed that barred AGN host galaxies consistently exhibit a higher fraction of powerful AGN compared to the control sample, across various bins of galaxy properties.

We also examined the black hole mass and accretion rate onto the central black hole for AGN host galaxies across different samples. Our study concludes that barred active galaxies have a higher proportion of objects with elevated accretion rates and significant black hole mass growth compared to unbarred AGN hosts. Moreover, active galaxies in both samples display higher R values than those in the control sample of active galaxies.

Recommendations

Building on the findings and significance of this study, several recommendations emerge for future research in the field of AGN host galaxies and the influence of galactic bars. Firstly, it is recommended to expand the sample size of AGN host galaxies with and without bars to further validate the observed associations between nuclear activity, black hole mass, accretion rate, and host galaxy properties. This will enhance the statistical robustness of the results and provide a more comprehensive understanding of the impact of bars on AGN activity.Additionally, future studies should explore other host galaxy properties, such as morphology, gas content, and local environment, to uncover further insights into the unique nature of barred and unbarred AGN host galaxies. Incorporating these additional properties will contribute to a holistic understanding of the factors influencing AGN activity and the role of galactic bars.

Furthermore, it is recommended to investigate the evolutionary aspects of AGN host galaxies by studying their temporal variations and examining the connections between AGN activity, bar properties, and galaxy evolution processes. This will provide deeper insights into the co-evolution of AGNs, galactic bars, and their host galaxies. Lastly, the utilization of advanced observational facilities and techniques, such as upcoming space missions and next-generation telescopes, should be considered to enhance observational capabilities and resolution in studying AGN host galaxies and their bar structures. By addressing these recommendations, future studies will further advance our understanding of the effects of galactic bars on AGN activity, paving the way for more comprehensive analyses and breakthroughs in the field of astrophysics.

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