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The Unified Era: An understanding journey from observations to the Unified Model of Active Galactic Nuclei

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Abstract
The Unified Model of Active Galactic Nuclei (UMAGN) serves as a comprehensive theoretical framework designed to elucidate the myriad observations of AGN, encompassing both quasars and Seyfert galaxies. This model attributes observed variations to distinct orientations of a circumnuclear matter disk around a supermassive black hole (SMBH). The primary factor influencing the observational diversity lies in the alignment of the AGN with the observer's line of sight. We provide an exhaustive overview of observational evidence, empirical and theoretical research, tracing pivotal milestones that have led to a unified perspective. Our exposition encapsulates the scientific journey culminating in the proposal of UMAGN, delving into insights regarding the accretion disk, torus, and relativistic jet. We emphasize key properties of objects within the UMAGN framework. Furthermore, we underscore recent progress in multimessenger research involving electromagnetic waves, gravitational waves, astroparticles, and neutrinos. Noteworthy collaborations, such as the Event Horizon Telescope, LIGO/Virgo, IceCube, Pierre Auger, and KM3Net, have significantly advanced this field. We argue that these collaborative efforts present opportunities to enhance and refine UMAGN, thereby contributing to a profound understanding of AGNs and their implications for the formation and evolution of galaxies. The convergence of observational and theoretical research, coupled with emerging multimessenger techniques, paves the way for substantial strides in comprehending these enigmatic cosmic phenomena.

Keywords: Astrophysics, Unified Model of Active Galactic Nuclei, Black Holes.

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La Era Unificada: Una trayectoria de comprensión desde las observaciones hasta el Modelo Unificado de Núcleos Galácticos Activos

Resumen

El Modelo Unificado de Núcleos Galácticos Activos (UMAGN) sirve como un marco teórico integral diseñado para elucidar las numerosas observaciones de NAG, abarcando tanto cuásares como galaxias Seyfert. Este modelo atribuye las variaciones observadas a orientaciones distintas de un disco de materia circunnuclear alrededor de un agujero negro supermasivo (ANSM). El factor primario que influye en la diversidad observacional radica en la alineación del NAG con la línea de visión del observador. Proporcionamos una visión exhaustiva de la evidencia observacional, investigación empírica y teórica, rastreando hitos fundamentales que han llevado a una perspectiva unificada. Nuestra exposición encapsula el viaje científico que culmina en la propuesta de UMAGN, adentrándonos en perspicacias sobre el disco de acreción, el toro y el chorro relativista. Enfatizamos propiedades clave de los objetos dentro del marco UMAGN. Además, destacamos el progreso reciente en la investigación multimensajera que involucra ondas electromagnéticas, ondas gravitacionales, astropartículas y neutrinos. Colaboraciones destacadas, como el Telescopio del Horizonte de Eventos, LIGO/Virgo, IceCube, Pierre Auger y KM3Net, han avanzado significativamente en este campo. Argumentamos que estos esfuerzos colaborativos presentan oportunidades para mejorar y refinar UMAGN, contribuyendo así a una comprensión profunda de los NAG y sus implicaciones para la formación y evolución de galaxias. La convergencia de la investigación observacional y teórica, junto con las técnicas multimensajeras emergentes, allana el camino para avances sustanciales en la comprensión de estos enigmáticos fenómenos cósmicos.

Palabras clave: Astrofísica, Modelo Unificado de Núcleos Galácticos Activos, Agujeros Negros.

1 Introduction

The term "AGN" stands for Active Galactic Nucleus, a compact region at the center of a galaxy characterized by significant and unusual activity, such as the emission of large amounts of electromagnetic radiation, including X-rays and radio waves. This heightened activity is believed to result from the presence of a SMBH accreting mass from its surroundings [1, 2]. Presently, it is widely accepted that the central engine of AGN is an SMBH, an idea originally proposed in the mid-1960s by Salpeter [3], Zel'dovich and Novikov [4], and Lynden-Bell [5].

Since Seyfert's observations in the 1940s [6], through Schmidt's discovery of the radio source 3C 273 in 1963 [7], the number of seemingly distinct objects has increased, sharing only their peculiarities and unusual spectral behavior. It is reasonable to assume that with the gradual technological advancement of instruments and the improvement of astronomical observation techniques, the diversity of nomenclatures (Seyfert, quasar, blazar, BL Lacertae, radio galaxies, etc.) seemingly designating different astrophysical objects led to the advent of the "Unified Era" in the mid to late 1980s. Thus, despite the apparent dissimilarity among AGNs, a synthesis of empirical evidence gathered from systematic observations and theoretical studies emerged in the 1980s. Antonucci consolidated all known features of AGNs at the time into one model during this period, marking the inception of the Unified Era and the UMAGN [8]. The UMAGN posits the presence of a SMBH at the center, surrounded by an accretion disk and a torus, with two relativistic jets emitted perpendicular to the plane of the accretion disk. The diversity of objects observed from a terrestrial point of view is elucidated by varying the perspective of the components comprising UMAGN.

Our study aims to demonstrate that literature describing objects like quasars, Seyfert galaxies, BL Lacertae, and other AGNs provides evidence that has accumulated, enabling the synthesis proposed by Antonucci in the Unified Era [8–10]. We recognize that post-Unified Era articles have played a role in consolidating and refining UMAGN. We argue that the responsibility for corroborating or improving UMAGN in the contemporary moment lies with collaborations such as the Event Horizon Telescope (EHT), LIGO/Virgo, IceCube, Pierre Auger, and KM3Net, providing multimessenger information and contributing to ongoing AGN research.

The structure of this article is as follows: In Section 2, we describe characteristics and physical properties of AGNs influencing the observed variety of phenomena and explain how they are synthesized in UMAGN. In Section 3, we provide an overview, not claiming completeness, of the evidence, discoveries, and theoretical research in the Era of Unification that culminated in UMAGN. Section 5 explores possibilities offered by recent experiments and collaborations, discussing how they could contribute to improving UMAGN with multi-messenger data. Finally, in Section 6, we summarize our perspective and discuss its implications for understanding AGN evolution and the central black holes.

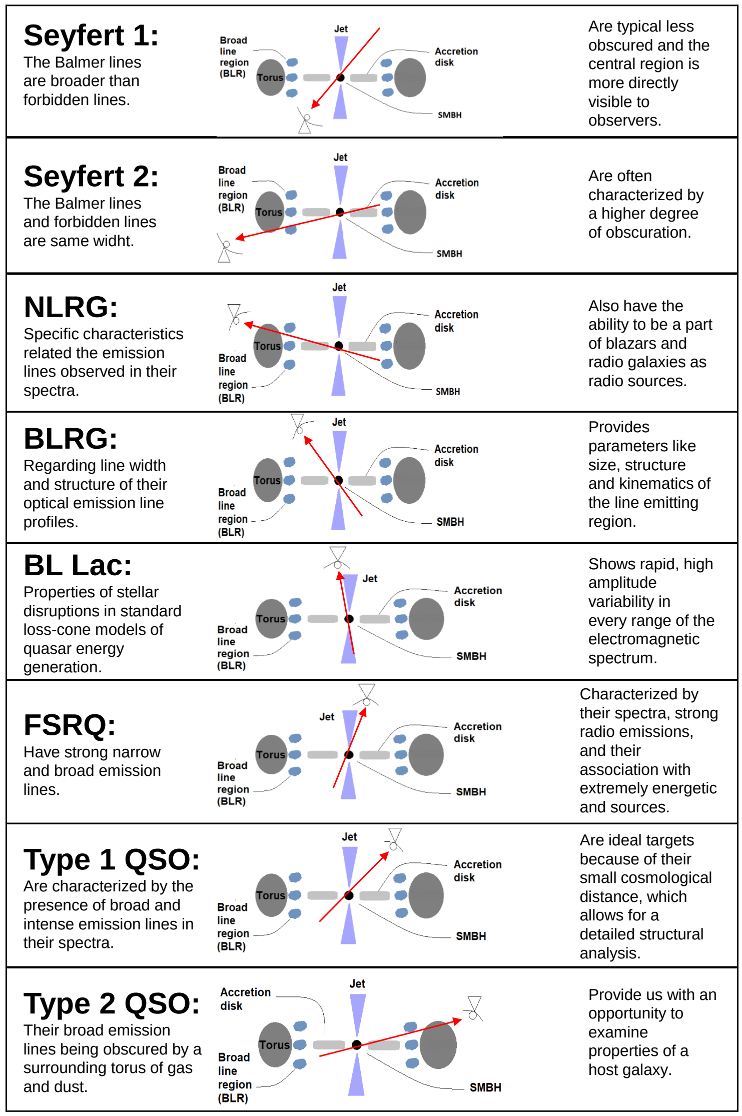

Figure 1: Variety of objects explained by UMAGN and some characteristics.

2 The Unified Model of Active Galactic Nuclei

The UMAGN (Figure 1), formulated by Antonucci in the mid-1990s, provides a comprehensive explanation for the diverse observed properties of AGNs [8]. These properties arise from orientation-dependent effects of a relativistic jet, an optically thick torus, and an accretion disk surrounding a central SMBH within the central regions of galaxies. This accretion process leads to the release of substantial energy through various radiative processes. Let's represent the luminosity of the accretion disk with the Eddington luminosity formula:

$$L_{\mathrm{Edd}} = 4\pi G M_{\mathrm{BH}} m_p c / \sigma_T \tag{1}$$

where L_{Edd} is the Eddington luminosity, G is the gravitational constant, M_{BH} is the mass of the black hole, m_p is the proton mass, c is the speed of light, and σ_T is the Thomson cross-section.

Observations from Earth cover a broad range of electromagnetic radiation, exhibiting strong variability on various timescales indicative of compact emission regions. The signatures also include relativistic jets, producing intense outbursts and flares across the optical, radio, and gamma-ray bands. The study of AGNs unveils physical processes, such as the emergence of flares due to the injection of high-energy particles by shock waves along relativistic jets [11, 12]. Let's represent the synchrotron emission from these jets using the synchrotron power formula:

$$P_{\text{syn}} = \frac{\sqrt{3}e^3 BR}{m_e c^2} \tag{2}$$

where P_{syn} is the synchrotron power, e is the elementary charge, B is the magnetic field strength, R is the characteristic size of the emitting region, m_e is the electron mass, and c is the speed of light.

The UMAGN encompasses various types of AGNs, each exhibiting distinctive observed characteristics and physical properties [8]. The differences among these AGN types arise from variations in accretion rates, orientation, and the presence of relativistic jets. For example, blazars exhibit rapid and large-amplitude flares attributed to magnetohydrodynamical instabilities near the base of the jets, while quasars are known for strong and broad emission lines (BELs), indicating the presence of highly ionized gas in their vicinity. Seyfert galaxies have less luminous nuclei [13].

2.1 Interpreting signatures received on Earth

The study of AGN radiative processes provides insights into the astrophysical phenomena occurring around SMBHs [14]. Distinct regions within these structures offer unique spectral signatures, each contributing to our understanding of AGN dynamics.

Starting with the Broad-Line Region (BLR) at the core, emissions from the vicinity of the SMBH produce broad spectral lines such as $H\alpha$, $H\beta$, and Mg II, revealing conditions near the central nucleus.

Moving outward, the accretion disk plays a pivotal role in AGN dynamics [15]. Material undergoing accretion generates thermal emissions, prominently featuring X-ray radiation from the hot disk. These radiative processes significantly contribute to the energetic output of AGNs. Let's represent the X-ray luminosity using the formula:

$$L_X = \eta \dot{M} c^2 \tag{3}$$

where L_X is the X-ray luminosity, η is the radiative efficiency, $\dot{M}$ is the accretion rate, and c is the speed of light as usual.

The Narrow-Line Region (NLR) lies on the periphery, extending beyond the accretion disk. Emissions in this region manifest as narrow spectral lines, including [O III] and [N II], resulting from ionization induced by ultraviolet radiation originating from the central disk.

Examining energetic regimes and observational effects, we find that X-ray emissions predominantly emanate from the Accretion Disk, detectable by observatories like Chandra [16] and XMM-Newton [17]. BLR, influenced by ionizing radiation from the central nucleus, exhibit broad spectral lines observable in optical and ultraviolet spectra.

Conversely, the Narrow-Line Region, ionized by radiation from the central disk, yields narrow spectral lines, including [O III] and [N II], detectable in optical spectra. Additionally, optical polarization arises from the scattering of light in the Molecular Torus, introducing variable optical polarization contingent on the observer's viewing angle [18, 19].

In the upcoming Section 3, we will trace a comprehensive view of the path from initial discoveries to the elaboration of the UMAGN, providing a context to our current understanding of AGNs.

3 From Initial Discoveries to Elaboration of the Unified Model

Antonucci [8] defines the so-called Unified Era as a diversity in AGN types, that can be attributed to varying orientations relative to the line of sight. One extreme hypothesis is the straw person model (SPM), which suggests that there are two fundamental types of AGN: radio quiets and radio louds. While this model is a simplified representation of the unification idea, it has been mostly ruled out on various grounds. The discussion revolves around convincing evidence that orientation effects are both important and widespread. The orientation of an object relative to the observer can significantly affect its classification and properties. The true situation likely falls somewhere between the SPM and the idea that orientation doesn't influence classification at all. Antonucci's conclusion suggests that the SPM represents significant progress in understanding orientation effects in AGN and quasars. While the strict SPM is not entirely accurate and may not fully describe the situation, it has laid the foundation for further refinement of our understanding of orientation-dependent classifications.

In 1943, Seyfert [6] observed the emission lines in the spectra of extra galactic nebulae, with a focus on a rare class of objects characterized by high-excitation emission lines superposed on typical spectra. Mostly intermediate type spirals with luminous or semi-stellar nuclei containing a significant portion of the total light, belong to this unusual category. Seyfert references early observations of these objects, that exhibit emission lines with significant width, and the highlights observation of the emission lines being small discs or bands several angstroms wide. Still on emission lines, two decades later another researcher identified similar lines.

In 1963, Schmidt [7] discussed observations of an object that show broad emission features on a blue continuum. The presence of certain emission lines suggests a Redshift, indicating a high apparent velocity. There are two possibilities as explanations: the object is either a star with a large gravitational Redshift or the nuclear region of a distant galaxy wit a cosmological Redshift. Schmidt explained that is favored due to the observed properties. In the same year, other work was carried out on observational properties.

In 1963, Matthews [20] explained that the position accuracy had significantly improved, enhancing the efficiency of the search for optical identifications compared to earlier searches. These identifications revealed that radio sources are associated with a variety of astronomical objects. The distribution of discrete radio sources above a certain declination has been found to be isotropic and is generally attributed to galaxies. Before these identifications, no star, had been associated with a radio source, except for the Sun. The radio source may originate from other objects.

In 1969, Lynden-Bell [5] debated the idea that Quasars evolve into powerful radio sources with two well-separated radio components. The energies involved in these outbursts are calculated to be enormous, and it is suggested that gravity may play a dominant role in providing the necessary energy. Discusses various astronomical observations related to different galaxies and their central regions. Lynden-Bell mentions observations in other galaxies, and provides estimates for nuclear masses and fluxes. Discusses Seyfert galaxies and their activity levels, a measure of flux, is high active Seyfert galaxies due to the presence of a significant amount of gas in their central regions. Explained the rapid buildup of mass is the Schwarzschild throat large values, suggests that during the formation of galaxies, there was a significant amount of gaseous material present. It also references recent observations of the galactic center and proposes a dust model to explain infrared observations. The discussion includes various astronomical observations related to different galaxies and their central regions.

In 1973, Shakura and Sunyaev [21] showed that a black hole capturing appropriate amounts of matter could emit electromagnetic radiation in the visible and X-ray ranges. The light production mechanism proposed by the authors involves successive energy transformations, such that a SMBH surrounded by gas, located at the center of a galaxy, has a huge gravitational potential energy gradient. Due to the gravitational potential energy gradient, the gas surrounding the black hole can be accelerated towards the singularity. As the gas plunges towards the black hole, it will convert its gravitational potential energy into kinetic energy. When the gas has angular momentum, it will not precipitate radially into the singularity, it will form a disk that will orbit around the black hole with different angular velocities, faster near the center and slower at the periphery of the disk. Orbits with different velocities create viscosity that heats the gas in the disk through friction. Through this mechanism, kinetic energy is converted into internal thermal energy in the gas. Shakura and Sunyaev [21] showed that this process can produce temperatures of the order of 100 million degrees Kelvin in the gas disk around the SMBH. Such photons escape from the disk before the gas precipitates into the black hole. Therefore, it is the gas spiraling into the singularity that emits the radiation captured by observation instruments, not the black hole. The emitted photons from the accretion disk can be observed, and the black holes can be studied by calculating their mass and angular momentum.

In 1977, Blandford and Rees [22] focused on the interpretative aspects of observations of strong radio sources in galactic nuclei. Provided insights and interpretations into the historical significance of strong radio sources as evidence of violent activity in galactic nuclei. Jets are indicative of some type of asymmetry in the collimation mechanism. There are two possibilities for jets: The emission can come from particles accelerated by dissipation processes; or the electrons in the beam itself may not have been completely cooled by radiative or adiabatic losses during exit from the nucleus. If it is the former, it would predict brightening of the limbs and a magnetic field along the jet; if it is the second case, it would predict a magnetic field perpendicular to the jet.

So far we have carried out research that resulted in discoveries and that provided an accumulation of evidence for the creation of UMAGN. The works presented below highlight the development of the model itself.

In 1982, Antonucci [23] studied the alignment of optical polarization position angles with the large-scale radio structure in low-polarization quasars. Such alignment implies a geometrical relationship between the inner, optically-emitting region and outermost, radio-emitting region. He still argues two possible causes for optical polarization: synchrotron emission and scattering. If polarization is due to synchrotron emission, it reveals the orientation of the magnetic field in the optically-emitting region. If scattering is the cause, the position angle reflects the distribution of scatterers. Antonucci mentions their observations of quasars in a sample and discusses a forthcoming study to distinguish between these possibilities. Emission-line polarizations suggest that polarizations in both groups are likely due to scattering or dust transmission rather than the emission process itself. Indicates their intention to discuss the implications of these results in more detail in a different context, where they will have access to the complete set of radio, optical spectroscopic, and optical spectropolarimetric data. There are other ways to carry out studies related to AGNs.

In 1985, Antonucci & Miller [9] study of broadband polarization in Seyfert nuclei, particularly NGC 1068, initially suggested optical synchrotron radiation. Polarization decreasing with wavelength was explained by wavelength-dependent dilution from unpolarized starlight. Subsequent higher-resolution spectropolarimetry, considering unpolarized starlight dominance, revealed high, wavelength-independent nuclear polarization. This conclusion, suggested synchrotron radiation or electron scattering as the likely causes. The paper presents detailed observations, including previously unshown data, resolving the continuum polarization cause. The study includes polarization measurements for various emission lines and discusses the wavelength-dependence of polarization.

In 1991, Roche [24] studied the infrared (IR) energy distributions of various classes of galaxies by combining photometric data from IRAS (Infrared Astronomical Satellite) mission with ground-bases observations at shorter wavelengths. The most luminous AGN with powerful non-thermal emissions tend to have IR SEDs that smoothly connect with optical and radio observations, implying continuity in the emission mechanism. In contrast, lower-luminosity AGN show evidence of an additional IR component, often peaking in the infrared, which is best explained as emission from dust grains. Galaxies with active nuclear star formation also exhibit strong thermal peaks in the infrared. Even normal spiral galaxies emit significantly in the IR, with a substantial portion of their output originating from their galactic discs. In contrast, active nuclei often exhibit less structure spectra, which can often be approximated by power-law distributions at these wavelengths.

In 1995, Urry [25] delves an enigmatic nature of AGN and their significance in understanding the universe. AGN are unique in that they generate extremely high luminosities in a concentrated volume, likely through processes other than nuclear fusion, which powers stars. The prevailing model of AGN's physical structure involves a supermassive black hole at the center, the gravitational potential energy of which is the source of AGN luminosity. Matter spiraling into the black hole emits radiation in the form of an accretion disk, primarily in the ultraviolet and soft X-ray wavelengths. The presence of strong optical and ultraviolet emission lines is attributed to rapidly moving clouds of gas in the gravitational potential of the black hole, known as broad-line clouds. These emissions, are obscured along certain lines of sight by a torus or warped disk of gas and dust. Energetic particles are expelled along the poles pf the disk or torus, forming collimated radio-emitting jets and sometimes giant radio sources. This inherently asymmetric model implies that AGN appear radically different at different viewing angles. To reconcile these differences in appearance, AGN of various orientations are assigned to different classes, and unification is essential to study the underlying physical properties.

It is presumed that the articles presented in this Section have compiled both empirical evidence and theoretical elaborations, leading to the inception of UMAGN during what has become recognized as the Unified Era. In the subsequent Section 4, we will elucidate works and discoveries post-Unified Era, which can be viewed as either corroborating or enhancing the model developed by Antonucci [8].

4 Post-Unified Era

The UMAGN has been a cornerstone in elucidating the mechanisms governing the phenomena of emissions and absorptions about AGNs. Subsequent to its inception, numerous endeavors within the scientific community have been undertaken to validate or refine the premises of UMAGN. Post-1993 literature reflects a diverse array of approaches, methodologies, and observations that can be viewed as aimed at enhancing and extending the original model. Researchers have employed a spectrum of observational and theoretical techniques to scrutinize UMAGN predictions against empirical evidence. This section endeavors to furnish of some of these recent efforts.

In 2000, Gebhardt [26] discusses the recognition of massive black holes as a common component in the centers of galaxies, including elliptical galaxies and spiral galaxy bulges. The mass of these black holes is found to be proportional to the galaxy mass or luminosity, despite significant scatter. The availability of black hole mass data, primarily from Hubble Space Telescope (HST) observations, has grown substantially, allowing for investigations into the correlation between line-of-sight velocity dispersion and black hole mass with minimal intrinsic scatter. The tight correlation between black hole mass and velocity dispersion suggests a connection between black hole formation and the evolution of the galactic bulge. The study raises questions about the correlation's extension to larger or smaller black hole masses and its potential applicability to stellar systems with lower dispersions, such as dwarf spheroidal galaxies and globular clusters. These components into the center of galaxies presents absorption and emission lines.

In 2000, Elvis [27] proposed a simple yet comprehensive structure to explain the inner regions of quasars, particularly focusing on their emission and absorption line phenomena. This model successfully accounts for both broad and narrow absorption lines and also provides explanations for other emission line and scattering effects. Quasars are a solvable problem, some coherent structure must be present. Quasars research results in a single simple scheme: he high-and-low-ionization parts of the BELR,the BAL and NAL regions, and the Compton-thick scattering regions can all be combined into the single funnel-shaped out-ow. All of these features come about simply by requiring a geometry and kinematics constructed only to explain the two types of absorption lines.

In 2001, Vollmer [28] provided information about the structure and characteristics of the Circumnuclear Disk (CND) surrounding the Galactic Center. The CND, consists of gas and dust clouds and was initially discovered as a tilted dust ring. It has a clumpy structure, low ionization, and is influenced by the radiation from the central Heistar cluster. A continuous, smooth molecular disk model is ruled out due to its clumpy nature. The CND rotates, has a sharply defined inner edge, and is inclined to the line of sight Presents an analytical model for the Galactic Center's Circumnuclear Disk, that consists of around 500 heavy clouds, creating a disk-like structure. The model successfully matches observations and identifies two stable cloud regimes: heavy molecular clouds and their stripped cores.

In 2008, Gaskell [29] discusses the examination of theory and observations related to the dominant thermal continuum emission in AGN. After correcting for reddening, the optical–UV spectral energy distributions (SEDs) of steady-state AGN are found to be very similar. The primary contributor to these SEDs is identified as the big blue bump (BBB), which contrasts with the predicted spectrum for a standard thin accretion disk. The size of the disk is described as large, with the region emitting the optical continuum being as extensive as the inner BLR. Optical variability is observed in all AGN on the light-crossing time of the BLR, suggesting that variations propagate close to the speed of light rather than on dynamical timescales. This leads to the inference that the energy-generation mechanism is electromagnetic rather than hydrodynamic. Also discusses the implications of large rapid variations in the BBB, suggesting that the magnetohydrodynamic energy generation is fundamentally unstable. Due to the radial temperature gradient in the accreting material, different spectral regions are associated with different radii, explaining the observed independence of X-ray and optical variations, the sequence of variability from lower to higher energies, and rapid changes in emission-line reverberation lags. In the same year there were two other studies related to AGNs.

In 2008, Papovic [30] discusses the presence of disk winds as an explanation for various observed phenomena in AGN, including X-ray and UV absorption, line emission, reverberation results, and differences among different types of AGN. The argument proposes that a BLR in AGN is composed of two dynamically distinct components: a disk and a wind. While a small fraction of AGN exhibit double-peaked BELs in their spectra, the majority of AGN with BELs display single-peaked profiles. However, having single-peaked profiles doesn't necessarily mean that the contribution of disk emission can be neglected, as a disk with a small inclination angle can also produce single-peaked broad lines. To explain the complexity of BELs, different geometrical models are discussed. Some BEL profiles can be properly explained only by considering two or more kinematically different emission regions contributing to the line profiles. The existence of the Very Broad Line Region (VBLR) with random velocities within an Intermediate Line Region (ILR) has been considered to explain BELs.

In the same year, in 2008, Storchi-Bergmann [31] provides an overview of the understanding, as of the last decade, that most galaxies with a stellar bulge contain a SMBH in their nuclei, and the mass of this SMBH is proportional to that of the bulge. The distinction between active and non-active galaxies lies in whether the SMBH is actively accreting mass or not. The key unresolved questions in nuclear activity in galaxies include the origin of the accreting mass that feeds the SMBH and the mechanisms that trigger nuclear activity, particularly the processes that bring gas from galactic scales to the galaxy's nucleus. Several proposed mechanisms for gas inflow on extragalactic scales involve interactions with other galaxies, while on galactic scales, non-axisymmetric structures like bars can bring gas from the disk to the nucleus. On smaller scales, nuclear bars and nuclear spirals are suggested as means to transport gas inward. Still on the classification of AGNs, there are other related articles.

In 2011, Dharam [32] discussed the classification of active galaxies, particularly Seyfert galaxies, into different types based on their appearance, luminosity and spectra. The unified scheme model is introduced, suggesting that Seyfert 2 galaxies are essentially Seyfert 1 galaxies with their nuclear emission attenuated in the observer's direction, typically due to an obscuring torus. Also mentions inconsistencies with the unified scheme, such as young stellar populations in Seyfert 2 galaxies, differences in morphological types, and the lack of detected broad-line regions in some Seyfert 2 galaxies. Is constructed a sample of Seyfert 1 and Seyfert 2 galaxies matched in orientation-independent parameters to test the unified scheme hypothesis. A study aimed at unifying Seyfert 1 and Seyfert 2 galaxies by examining their radio emissions at various scales is discussed. A sample of 20 Seyfert galaxies is carefully selected based on parameters related to the AGN and host galaxy properties. Key findings include the discovery that both Seyfert 1 and Seyfert 2 galaxies have an equal tendency to display compact radio structures, contrary to previous studies. Additionally, the distributions of radio luminosities at different scales are similar for both types, supporting the unification hypothesis. There is no evidence of relativistic beaming in Seyfert galaxies.

In 2013, Kormendy [33] provides an overview of the coevolution of SMBHs and host galaxies, particularly focusing on the early history of the universe, approximately 7 to 12 billion years ago. The metaphor of the universe's evolution as a fading display of fireworks is used to emphasize the different conditions prevalent during that time. The review acknowledges the role of the HST in advancing the study of SMBHs and mentions the transition to new tools as HST nears the end of its operational life. This discovery, along with subsequent findings of rapidly variable quasars, led to the acceptance of the idea that AGNs are powered by accretion onto SMBHs. The review emphasizes the lack of dynamical evidence for the existence of black holes with the required masses. The text introduces the challenges of finding dynamical evidence for black holes, considering their small sizes and the expected dominance of their gravity only within a limited sphere of influence.

In 2015, Podigachoski [34] wrote about the AGNs exhibit diverse observational characteristics despite being fundamentally drive by the accretion of matter onto supermassive black holes. Unification models for AGNs were developed to explain these differences based on the viewing angle, particularly considering the presence of an AGN torus, a structure filled with molecular gas and dust surrounding the active nucleus. The torus allows radiation to escape in some directions while obscuring it in others. This model suggests that powerful radio-loud AGNs can be either radio galaxies (RGs), viewed edge-on with the torus obscuring the active nucleus, or quasars (QSRs), viewed face-on, making the nuclear regions and BELs directly visible. The colors in the far to mid-infrared spectral range serve as valuable indicators of the orientation of powerful radio-loud AGNs, providing support for the unification model of these objects. These diagnostic tools hold promise for future investigations involving extensive samples of dusty star-forming galaxies and AGNs.

In 2015, Netzer [15] explored recent developments in the unified model of AGNs with a specific focus on new insights into the nature and characteristics of the central obscuring structure, known as the torus, and its connection to the surrounding environment. There are a emphasis that AGN torus are likely clumpy in nature, although uncertainties regarding their properties persist. Leading models propose the involvement of various types of disk winds and hydrodynamic simulations that connect the large-scale galactic disk to the inner accretion process. Infrared studies have significantly enhanced in the comprehension of the spectral energy distribution of AGNs, although they face limitations due to selection effects. One fundamental relationship that remains unexplained is the correlation between the covering factor of the torus and AGN luminosity. It is suggested that AGN unification may not be applicable to merging systems and might be restricted to galaxies undergoing secular evolution.

In 2016, Lusso [35] studied the distribution of X-ray and optical-UV properties in quasars, and their potential dependence on redshift, has been a subject of active research. Recently, this nonlinear correlation between X-ray and optical-UV luminosities has been utilized to derive cosmological parameters such as stellar mass and luminosity density and construct the first Hubble diagram for quasars, extending up to redshifts. In this study, a sample of optically selected AGNs from the Sloan Digital Sky Survey, he primary objective is to understand the sources of the observed dispersion and estimate the intrinsic dispersion of this relation. It also serves as a basis for estimating cosmological parameters, although sample size limitations apply.

In 2017, Padovani [36] discussed about the discovery of quasars in the 1960s, and how revolutionized astronomy and led to the development of a new branch of study. Quasars are much more powerful emitters compared to normal galaxies due to the presence of actively accreting supermassive black holes at their centers. Key properties of AGN include their extremely high luminosities, compact emitting regions, strong evolutionary trends in their luminosity functions, and emissions spanning the entire electromagnetic spectrum. AGN are observed in various wavelength regimes, each providing unique insights into AGN physics. Explored AGN selection and physics across all wavelength bands, discussed various AGN types, their similarities and differences, selection effects, and the underlying physical mechanisms.

In 2020, Kaaret [37] wrote about the Milky Way galaxy, that is surrounded by a circumgalactic medium (CGM), which is significant for galaxy evolution as it provides gas for star formation and serves as a reservoir of metals and energy generated by stars and nuclear processes. Utilizing a soft X-ray spectrometer optimized for diffuse emissions, observed that X-ray emissions are best described by a disc-like model, based on the radial distribution of molecular hydrogen density, a tracer of star formation. The study reveals significant variations in X-ray emissions on angular scales of about 10 degrees, indicating the clumpy nature of the CGM. It is proposed that an additional extended, and possibly massive, halo component is necessary to account for the overall halo density inferred from other observations.

In 2021, Spinoglio [38] explained about the discovered of Seyfert galaxies in 1943 and yours varied optical spectra. Their distinctions involve broad versus narrow spectral lines. AGN is linked to the luminosity of supermassive black holes. In the 1980s, the Unification Era aimed to explain diverse AGN spectra through a single object, observed from different angles. The unified model was devised to explain the diversity of AGN as a single physical object. While it works well for unifying Hidden BLRG with AGN type 1, it does not apply universally to all AGN types. Observational evidence supporting the presence of torus with the required characteristics to block BLR, channel radiation, and facilitate AGN feeding remains elusive. Many changing-look AGN transitions can be explained by the AGN's duty cycle.

In 2021, Ogawa [39] studied the structure of the torus that surrounds a SMBH in AGNs. The torus consists of dusty gas that absorbs radiation from the nucleus and re-emits it. With focus on the torus geometry, employ a self-consistent model for both X-ray and infrared data. The X-ray spectral model, allowing for a direct comparison with the clumpy model used for infrared data analysis. The clumps are distributed based on power-law and normal profiles in the radial and angular directions. Aiming to provide a unified view of AGN torus structure, particularly the distribution of gas and dust around SMBHs in AGNs. Confirmed prior observations that torus angular widths determined from infrared data tend to be systematically larger than those obtained from X-ray data . The model clarifies that optical and X-ray classifications, as well as observed torus properties in both the X-ray and infrared bands, are primarily determined by the inclination angle, enhancing the understanding of AGN structure.

After reviewing pertinent research during the "Post-Unified Era", the subsequent Section 5 will explore how collaborative initiatives and advanced multimessenger techniques can advance the field. Our goal is to gain insights into how synergies between observational collaborations and the burgeoning field of multimessenger astronomy can enhance our understanding of phenomena associated with AGNs and refine the UMAGN model, emphasizing progress made, identifying existing gaps, and proposing potential avenues for future inquiry.

5 Collaborations & Multimessenger Astronomy

Although we already have evidence of the existence of SMBHs in some cases, including in the Milky Way [40], and an image of Sagittarius A^* [41] and practically all other alternatives to SMBHs are currently ruled out, and Occam's razor strongly suggests that many, if not all, galaxies do in fact host SMBHs that can fuel AGN activity.

However, there are still questions that remain to be understood [14]. Even though the idea of unification is widely accepted, there are still many open questions that need to be understood. Some of the basic ideas related to the unification of the AGN require observational evidence as they are not yet conclusive. AGN formation can be understood within the framework of galaxy formation, but the two most important conditions for the production of an AGN are the existence of a central SMBH and a sufficient amount of gas to fuel the nucleus. Understanding how SMBHs form and the mechanisms responsible for transporting gas towards the center of the host galaxy to feed the black hole are key aspects that need to be further explored.

An important fact that any theory of AGN formation must take into account is that quasars are observed at high redshifts. The time scale for the formation of an SMBH must be less than cosmic time at these redshifts. The growth of SMBHs and the promotion of AGN are areas that require further investigation to fully understand the processes involved.

The kinematics of stars and gas in the central regions of spheroidal galaxies indicate the presence of massive dark objects, but further investigation is needed to determine whether these objects are SMBHs or other alternatives, such as dense clusters of stellar remnants or exotic objects such as fermion balls. heavy stars or bosons. Probing kinematics at smaller scales and detecting higher velocities will provide more information about the nature of these central massive objects. For this reason, the contribution of multimessager data from Collaborations is so essential.

The quest to unravel the mysteries of AGNs and the SMBHs residing at their cores has entered a new era with the advent of multimessenger astronomy. This transformative approach relies on combining information from different cosmic messengers, such as electromagnetic waves, gravitational waves, and neutrinos, to gain a comprehensive understanding of the most extreme astrophysical phenomena. One of the pioneering endeavors in this field is the Event Horizon Telescope [42] (EHT), a global collaboration that links radio telescopes across the planet to form a virtual Earth-sized telescope. The EHT's unprecedented resolution allows for the observation of the immediate vicinity of SMBHs, providing vital clues about their accretion processes and the dynamics of the surrounding regions.

Gravitational wave astronomy has emerged as another indispensable tool for probing the universe's most enigmatic phenomena, including AGNs and SMBHs. The Laser Interferometer Gravitational-Wave Observatory [43] (LIGO) and Virgo collaborations have significantly expanded our ability to detect gravitational waves, enabling the observation of cataclysmic events such as the merger of black holes. By combining gravitational wave signals with electromagnetic observations, we can glean insights into the formation, growth, and merger history of SMBHs. The synergy between EHT and LIGO/Virgo is particularly potent, as it offers a unique opportunity to study AGNs and their associated gravitational wave signatures simultaneously, opening new avenues for understanding the intricate interplay between matter, space, and time.

In the realm of neutrino astronomy, experiments like IceCube [44] have become instrumental in providing complementary information about the high-energy processes occurring in AGNs and the vicinity of SMBHs. Neutrinos, being elusive and nearly massless particles, can traverse vast cosmic distances without interaction, carrying information about the extreme environments where they originated. By combining IceCube's neutrino data with observations from other instruments, we can create a more comprehensive picture of the energetic processes associated with AGNs and gain insights into the nature of their central black holes.

Furthermore, the Pierre Auger Observatory [45] and the upcoming KM3NeT [46] project contribute crucial components to the multimessenger puzzle. Pierre Auger's focus on ultra-high-energy cosmic rays complements the information provided by other messengers, shedding light on the cosmic accelerators responsible for producing such particles in the vicinity of AGNs. Meanwhile, KM3NeT, designed to detect high-energy neutrinos in the deep sea, adds another layer to the multimessenger approach. The synergy between these experiments allows scientists to cross-validate and cross-correlate information from different messengers, enhancing the reliability and completeness of our understanding of AGNs and the SMBHs embedded within them.

The collaborative efforts of projects like the Event Horizon Telescope, LIGO/Virgo, IceCube, Pierre Auger, and KM3NeT are essential for advancing our knowledge of AGNs and the SMBHs residing at their cores. The combination of electromagnetic, gravitational wave, and neutrino observations provides a holistic view of these extreme astrophysical environments, allowing us to address fundamental questions about the formation, evolution, and behavior of AGNs and their central black holes. As we delve deeper into the multimessenger era, the synergy between these diverse observational techniques will undoubtedly propel us towards unprecedented discoveries and a more profound understanding of the cosmic phenomena that shape our universe.

6 Conclusion

In conclusion, this study has delved into the UMAGN, the Unified Era, and the era of Collaborations and Multimessenger Astronomy in an effort to comprehensively understand AGNs and the SMBHs at their cores. Through a synergistic approach encompassing empirical observations, theoretical advancements, and multimessenger data integration, significant strides have been made in unraveling the complexities of these cosmic phenomena.

UMAGN, formulated by Antonucci [8], serves as a unifying framework adept at explaining the diverse observational characteristics of AGNs. By incorporating orientation-dependent effects of relativistic jets, an optically thick torus, and an accretion disk surrounding a central SMBH, UMAGN not only consolidates features of quasars, blazars, BL Lacertae, and Seyfert galaxies but also enhances our understanding of the radiative processes and energetic regimes within AGNs.

The Unified Era, led by Antonucci [8], witnessed the convergence of empirical evidence and theoretical insights, laying the foundation for our contemporary understanding of AGNs. However, this unification remains a dynamic paradigm, with open questions prompting further exploration, particularly concerning SMBH formation and mechanisms governing gas transport toward the galactic center.

Collaborations and Multimessenger Astronomy have ushered in a new epoch in AGN studies. Initiatives such as the Event Horizon Telescope, LIGO/Virgo, IceCube, Pierre Auger, and KM3NeT have provided extensive data, offering a holistic view of AGNs through electromagnetic waves, gravitational waves, and neutrinos. Collaboration between these observatories allows cross-validation and cross-correlation, enhancing the reliability of our insights into AGNs and their central black holes.

As we stand on the cusp of the multimessenger era, the combination of groundbreaking observations and collaborative efforts promises unprecedented discoveries. The mysteries surrounding AGNs and their central black holes are gradually being unveiled, providing insight into the cosmic processes shaping our universe. This synthesis and perspective emphasize the ongoing importance of collaborative, multimessenger approaches to advance our knowledge of AGNs and their central black holes, paving the way for future investigations into the evolution and behavior of these cosmic phenomena.

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