

Exploring Active Galactic Nuclei (AGN) – The Bright Hearts of Galaxies

Murph Lu

Murphjun@gmail.com

International Department of No. 2 High School Affiliated to East China Normal University

Abstract Active Galactic Nuclei (AGNs) are extremely energetic regions at the centers of galaxies and are vital for studying black holes. This paper focuses on physical mechanisms of AGN, including the energy dissipation and the formation of jets and radiation. In addition, this paper steps beyond formulas, aimed to provide a broader understanding of the fundamental physical world.

Keywords Active Galactic Nucleus; energy dissipation; electromagnetic field; detection techniques

1 INTRODUCTION

1.1 What is an AGN?

An Active Galactic Nucleus (AGN) is an extremely bright region at the center of a galaxy that harbors an active supermassive black hole and is accreting matter. When gas and dust spiral towards a black hole, they form an accretion disc around the black hole which emits massive amounts of energy from radio waves to X-rays.

Discovery of AGN is when 20 mid-century Astronomy

began. In 1943, Carl Seyfert reported galaxies containing very wide emission lines at the nuclei of these galaxies and named them Seyfert galaxies. In 1963, when Maarten Schmidt identified quasar 3C 273, it was found not to be a star but a faraway and bright galactic core. These results were the start of AGN astrophysics.

Nowadays, AGNs are understood as manifestations of accretion onto supermassive black holes, typically with masses ranging from 10^6 to 10^{10} solar masses.



<https://www.nature.com/collections/dttrsdkjww>

Figure 1.1 A depiction by an artist of a AGN. The picture shows a super massive black hole and its accretion disk and two outer relativistic jets. This picture show the major parts of the AGN structure: central black holes, inflowing materials, large scale outflows.

1.2 Why are AGNs important in astronomy?

1. **Powerful Energy Sources:** AGNs are some of the most powerful things in our universe, often brighter than entire galaxies.

2. **A major way into black hole studies:** Since black holes themselves are not visible, so AGNs give astronomers a means to study them via studying the radiation which comes from falling matter.

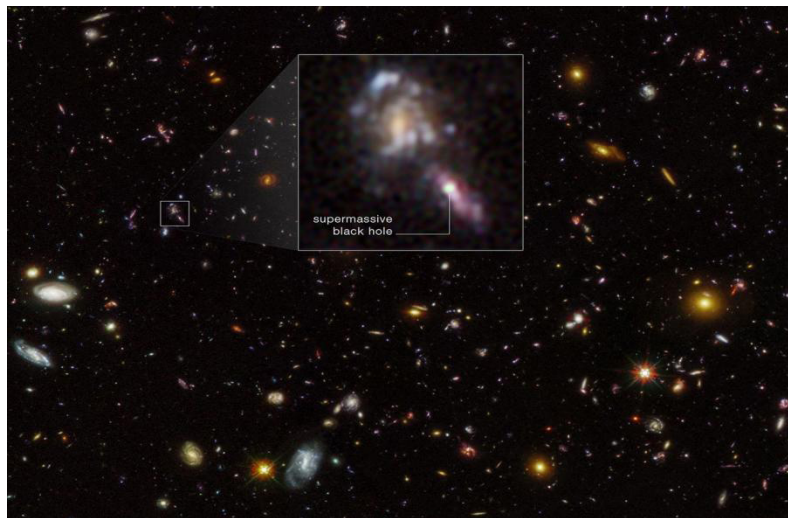
3. **Important observational probes for studying the early universe :** Because it is very bright, AGNs can be

observed in the distant universe, which helps us study the structure and evolution of the early universe.

4. **Drivers of galaxy Evolution :** AGNs are involved in the process of galaxy evolution. Their energetic outputs can regulate star formation in their host galaxies, which is known as “AGN feedback” .

2 STRUCTURE

2.1 Supermassive Black Holes



<https://science.nasa.gov/asset/hubble/supermassive-black-holes-in-hubble-ultra-deep-field/>

Figure 2.1 Annotated Image from the Hubble Ultra Deep Field Showing A Galaxy with A Supermassive Black Hole At Its Center. Although there is no black hole itself, there is a black hole through the surrounding bright core and gravitational effect.

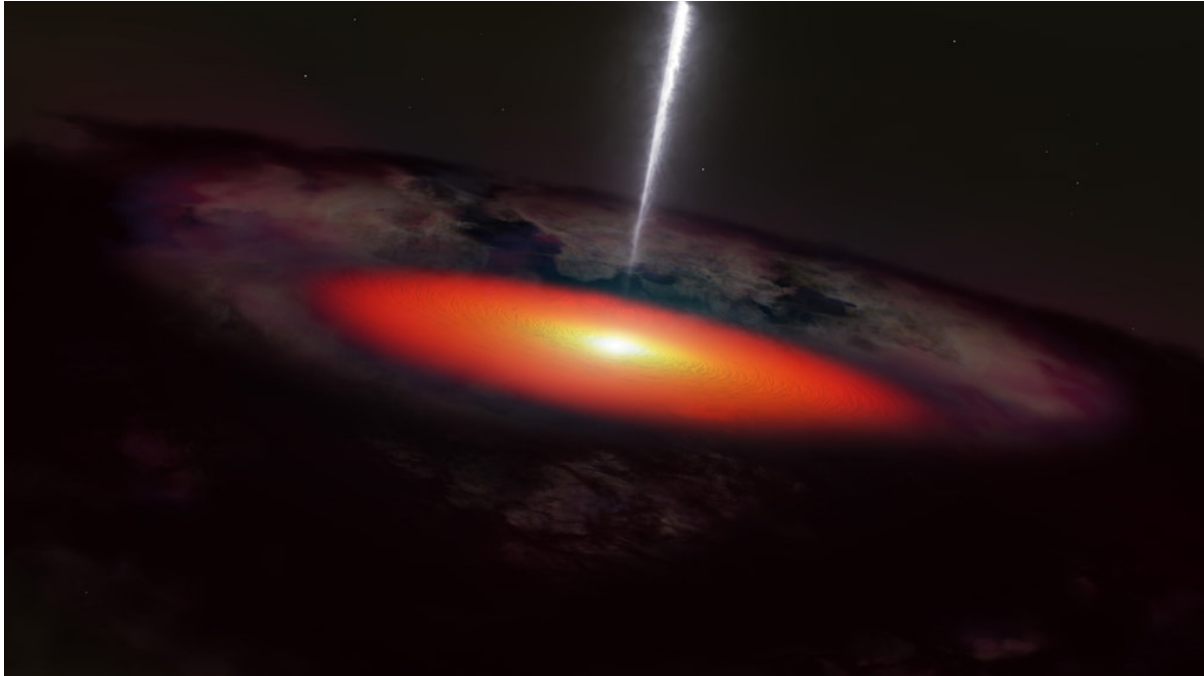
The core of any Active Galactic Nuclei (AGN) is a super massive black hole with a mass between 10^6 and 10^{10} solar masses, that’s millions to billions times bigger than our sun.

Although these giant black holes themselves cannot be observed, they are extremely strong gravitational forces

that attract gas and dust. What falls in gets very rapidly spun up in an accretion disk. Because of the great friction and compression in the disk, a huge amount of energy is released as electromagnetic radiation, and therefore an AGN is one of the brightest objects in the universe.

Component	Typical Mass Range (M_{\odot})	Role/Function
Supermassive Black Hole	$10^6 - 10^{10}$	Central gravitational source
Accretion Disk	$10^2 - 10^4$	Main radiation source
Broad Line Region (BLR)	$10^3 - 10^5$	Produces broad emission lines
Narrow Line Region (NLR)	$10^5 - 10^6$ (or higher)	Produces narrow emission lines

2.2 Accretion Disk



<https://svs.gsfc.nasa.gov/14584/>

Figure 2.2 Illustration of an accretion disk of a supermassive black hole. The hot, rotating disk radiates EM and relativistic jets are launched perp to the disk along B field lines.

The accretion disk is not a flat storage of matter orbiting around the black hole, but a dynamically coupled dissipative system, and angular momentum needs to be continuously released in the process of materials flowing inward. This process shows the complex network of energy conversion among different scales.

Material falling towards a supermassive black hole has inherent angular momentum and cannot fall directly. Instead, it is in a rotating disk state and the inward migration speed is determined by the gradual release of angular momentum. This energy redistribution is not an individual phenomenon, but the composite result of:

- Shear slip: In a rotating disk, the material at different orbiting radii have different tangential speed. Differential motion forms a velocity gradient, that is, the speed difference of the adjacent layer, and consequently generates shearing stress on the disk. Shear stress start carrying the momentum of rotation; And by doing a lot of insides talking, it slowly passes its energy outwards.
- Inelastic collisions: Interaction of particles in the dense plasma deflects the directed kinetic energy into thermal energy.
- Turbulent cascades: Local instabilities produces a Non-

linear turbulence and this is distributed by Space Hierarchy.

Together these all give us the feeling or macroscopic friction, however its pretty much not like solid friction. The dissipation don't destroy the energy; they merely transform organized kinetic order into unorderable heat and radiate that.

Magnetorotational Instability (MRI)

One reason for angular momentum transport is the MRI (magneto rotational instabilities) in an ionized accretion disc. Magnetized disk is MRI if it has weak vertical magnetic field and differently rotating where angular velocity, $\Omega(r)$, decreases with radius.

Under this condition linear instability emerges to boost the small disturbance for an immediate and sustained outwards moving of the angular momentum.

MRI Condition : is satisfied when:

$$\frac{d\Omega^2}{d \ln r} < 0$$

It also holds in Keplerian rotation profiles.

Mri synergistically combines magnetic field perturbation, differential shear and turbulence as the main mechanism for accreting in ionised discs.

When the accretion disk approaches the Eddington limit, The radiation pressure inside can no longer be reduced and then electromagnetic wave emission is produced throughout the electromagnetic spectrum. And then it occurs to us to wonder speculatively.

If the local energy dissipation leads to high-energy radiation, could dark energy be a large-scale residue of cosmological dissipation, an echo of entropy production in the expansion of the universe?

Eddington Luminosity & Eddington Accretion

During the disk accretion, its inner radiation pressure increases. When radiation pressure balances gravitational infall, the system reaches its Eddington limit, i.e., the maximum luminosity of the theory, below which inflow stops:

$$L_{\text{Edd}} = \frac{4\pi GMm_p c}{\sigma_T}$$

- L_{Edd} : Eddington luminosity
- G : gravitational constant
- M : mass of the black hole
- m_p : proton mass
- c : speed of light
- σ_T : Thomson scattering cross-section

The corresponding Eddington accretion rate then provides the upper bound for how fast matter can be accreted without reaching the Eddington luminosity. It is approximate to

$$\dot{M}_{\text{Edd}} \approx \frac{LE_{\text{Edd}}}{\eta c^2}$$

- \dot{M}_{Edd} : Eddington accretion rate
- η : radiative efficiency (typically ≈ 0.1)
- c : speed of light

Speculative Thought

Near to the eddington limit system has strong radiation all over its spectra. This causes the problem where:

If there is visible radiation from local energy dissipation, then can the phenomenon of dark energy be rethought to represent the macroscopic manifestation of the continuous dissipation throughout the development process of the universe?

2.3 Broad and Narrow Line Regions

Around the super massive black hole in center of galaxies is Active Galactic Nuclei and it has Broad line region (BLR) and Narrow line region (NLR).

BLR is inside of the light-days or -months from the black hole and has dense fast moving clouds of ionized gas. These clouds are Doppler-broadened spectral lines due to the high velocity and temperature. They are visible only when not hidden by the dusty torus. The NLR is farther away, spanning tens to hundreds of light-years, composed of low-temperature gas moving slowly, forming narrow emission lines that can be observed in most directions.

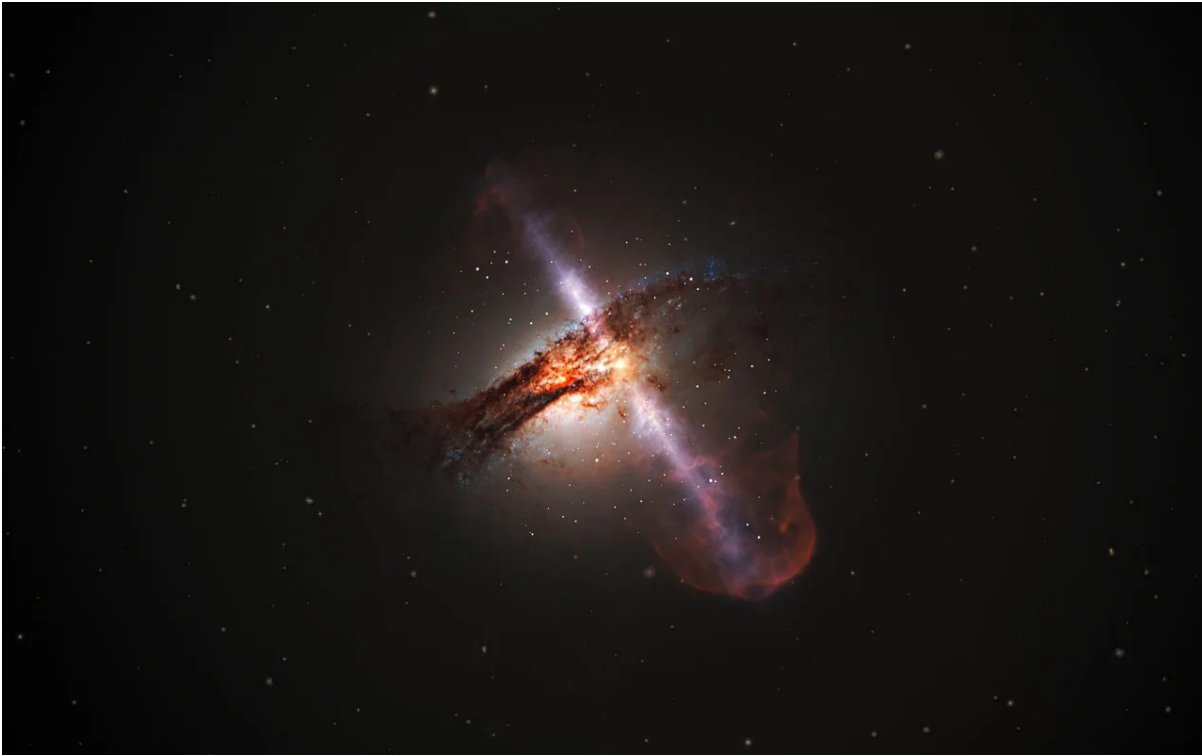
As well as their structures, they are both part of a thermodynamic process driven by the accretion disc. The disk dissipates energy through shear, turbulence and magnetic instabilities, and the photons are emitted outwards. Photons in the form of packets of energy absorbed by nearby gas clouds. Absorption result in electronic excitation or full ionization and release a free electron. The system briefly increases in order when electrons recombine with ions due to Coulombic attraction.

But this recombination releases excess energy in the form of photons with different frequencies. Running-away photons that takes it's entropy with them, converting locally structured energy into globally dissipated current. Emission lines there will be either broad or narrow depending upon how much by density, velocity and locally interacion. This way both the BLR and NLR work as spectral feature but also as thermodynamic structures that mediates the out ward flow of entropy.

BLR is concentrated and dissipates rapidly; the NLR plays the role of a slow channel and extends slowly. Here, ionization and recombination still take place, but at a lower rate because of fewer particles and weaker radiation fields. Energy redistribution is slower and the lines are narrower but more stable. And so the NLR contains the AGN's long range thermodynamic effects working with the same mechanism, local excitation for large scale entropy diffusion.

2.4 Jets and Radiation

Active Galactic Nuclei (AGN) often have powerful, collimated jets of relativistic particles that extend outwards from the central black hole for thousands or even millions of light-years. They are due to the black hole as well as it's accretion disc and the surroundings electromagnetic field. Partices run away along magnetic filed lines under some conditions in this framework.



<https://science.nasa.gov/missions/hubble/large-hubble-survey-confirms-link-between-mergers-and-supermassive-black-holes-with-relativistic-jets/>

Figure 2.3 A picture of relativistic jets fired off of a supermassive black hole encircled by an accretion disk. Very strong and collimated outflows exist that align along a magnetically field line over intergalactic distances.

Radiative Processes in AGN:

And then we have the Blandford-Znajek process, this one extracts rotational energy of a spinning black hole using magnetic field lines, and so as well we do have Blandford-Payne junctions in which magnetic fields linked to an accretion disc guide outflows through open magnetic field lines. And then explain that the rotational energy is becoming enormous groups of large particles.

Jet formation does not happen equally in all parts of the disk. It relies upon a structure in space of magnetic field lines, just ones that have an advantageous slant (“ \sim ” 30° according to the B-P model) can drive particles out from the disk rather than drawing them back into the gravitational well. The inclination threshold is not an absolute line, but rather the result of geometric stress - frame dragging has stretched the field lines to near-radial alignment and thus forms direction-specific escape channels. Particles in that region move along the magnetic trajectories, then are accelerated to a relativistic state.

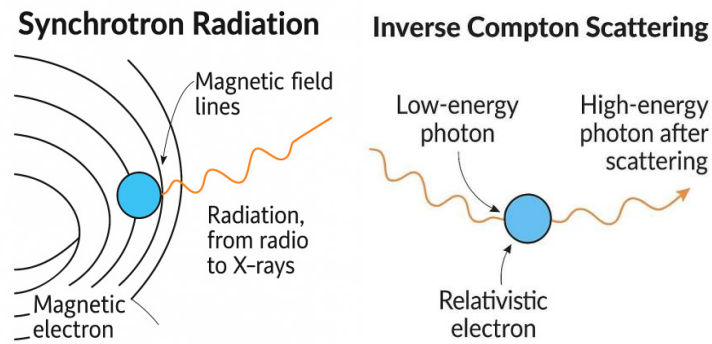
Although generally described as force-driven mechanisms, such jets may also be manifestations of some deeper properties of the fields themselves. Em field may have an internal dir that give large scale acts to follow even if only internally force.

In electromagnetic systems, Electric and magnetic components have opposite direction tendency, electric field line is linear outward, the magnetic field is in a closed rotation of the trend. These tendencies may represent different Spatial Modes of the same underlying field, rather than separate phenomena.

This unified structure is given in classical electrodynamics in the form of the electromagnetic field tensor, which behaves according to the Lagrangian density:

$$\mathcal{L}_{em} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

According to such a picture, we can understand jets and synchrotron radiation both as a result of magnetic interaction, but also as large-scale traces of directional tension in the electromagnetic field.



Synchrotron Radiation and Inverse Compton Scattering:

Synchrotron radiation and inverse compton scattering are the two main types of non-thermal emission responsible for most of what we see from AGN jets.

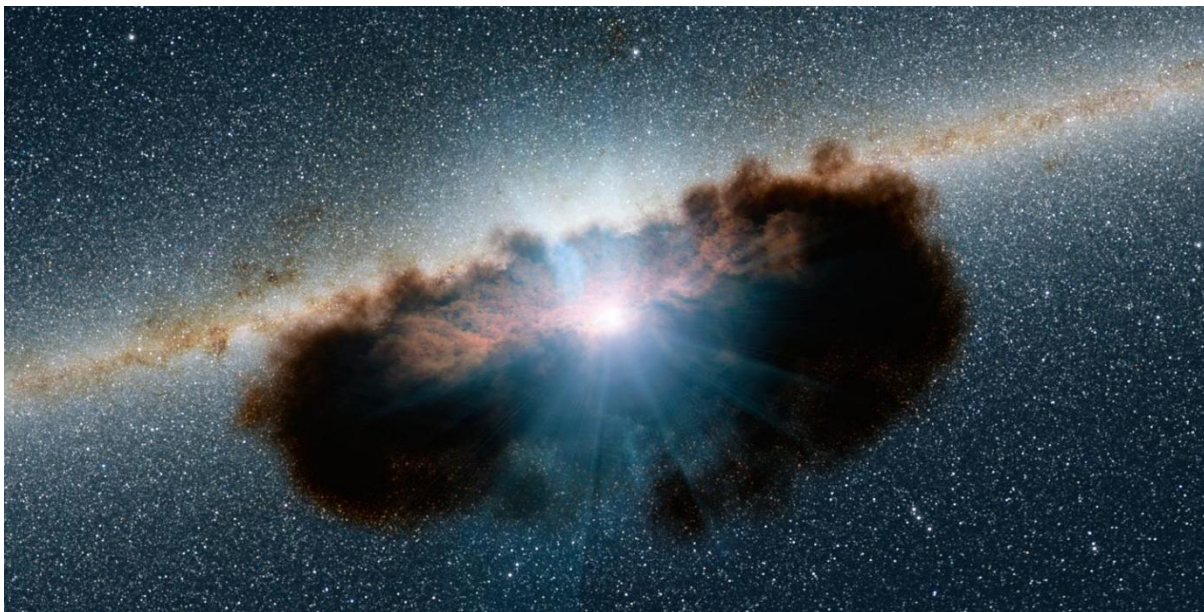
Relativistic electron moving around magnetic field line and accelerate transversally, then emit synchrotron radiation. This acceleration is non-linear: When the electron is emitting radiation and losing its energy, Magnetic field gives back the rotational energy which has been stolen from the black hole. The surrounding electromagnetic field breaks down and the field fluctuation that is capable of propagating is called wide spectrum radiation from radio waves to x-rays. The emitted spectrum depend sensitively on the electron energy distribution and local magnetic fields.

Inverse Compton scattering is when ambient low-ener-

gy photons, which could come from the accretion disk, cosmic microwave background, or even the synchrotron radiation itself, interact with these high-energy electrons. In the collision, Photon get the energy which is taken from electron's kinetic ,so that's why the photon shift towards the high frequency sometime in x-ray,gamma ray band. And this process is important to build up the high energy part of spectrum in AGN.

Though synchrotron radiation is due to the interaction of relativistic electrons and magnetic fields, yet in inverse Compton scattering, relativistic electrons are colliding with ambient photons. The first one convert magnetic into radiation using electrons and the other one transfer kinetic energy from electron to photon releasing high energy emission.

2.5 Dusty torus



https://www.eurekalert.org/multimedia/903805?utm_.com

Figure 2.5 Dusty torus around central supermassive black hole and accretion disk Figure 2.5 Absorbs high energy radiation and re-emits in the infrared. It is important for the AGN unification model as it hides or reveals the core depending on how we are looking at it.

Around the main engine of many AGNs is a geometric and optically thick system made up of gas and dust, which is called a dusty torus. Unlike the highly dissipative accretion disk, this torus is a quasi-stable configuration of matter that does not fall inwards or fly outwards. This is due to the material inside the torus having insufficient angular momentum relative to escape, but too high not to enter the inner accretion flow. There is no significant internal angular momentum removal process (such as shear-driven turbulence, magnetorotation stability, etc.), so the torus cannot further release its angular momentum. As such, the stuff stays up as though suspended in orbit several light-years away from the hole, floating in a gravitationally distorted but thermodynamically dead portion of space.

Although the torus does not directly feed the black hole, it is crucial for producing observable features of AGNs. Its dense, clumpy nature absorbs high-frequency ultraviolet and X-rays from the accretion disc and re-emits them as lower-energy infrared. This redshifts a large fraction of the central structure out of view at short wavelengths, but

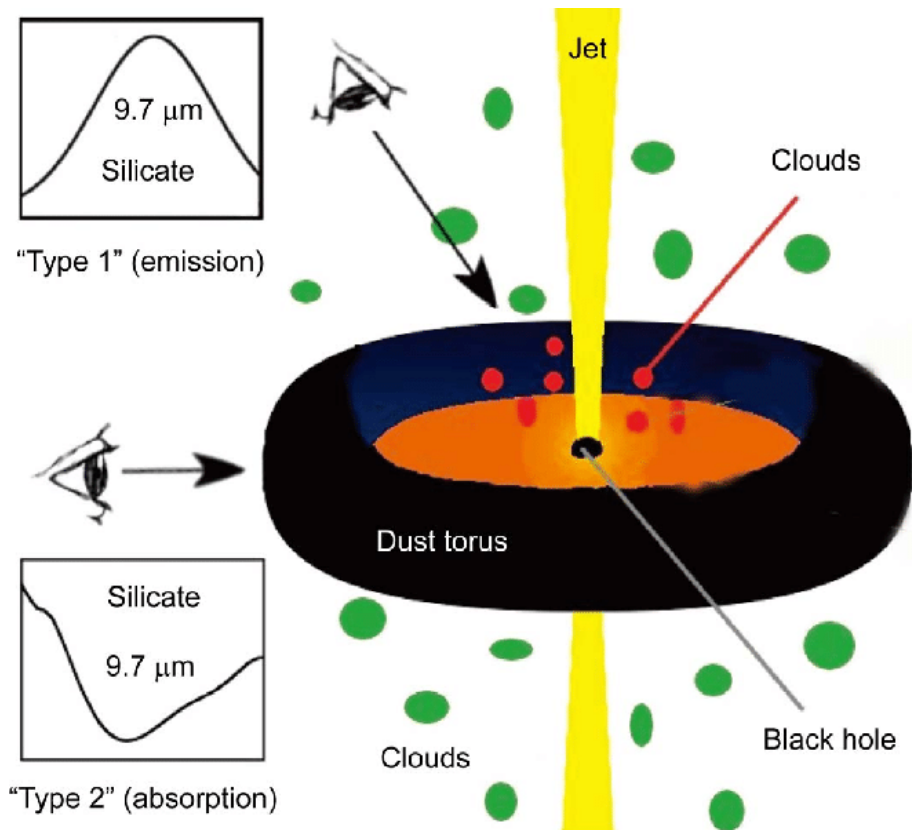
not at infrared wavelengths.

The torus works from a thermodynamic perspective as a radiative buffer. Isotropizes the outgoing directed radiation so that there can be no energetic feedback in a collimated form. Cold gas also prevents dust from evaporating due to heat so the dust would still be around for more extended periods.

The torus could then be considered as a sort of long-lived entropy holder which prevents dissipative collapse thereby delaying energy decay, containing radiation and modulating how an AGN influences its host galaxy.

3 TYPES OF AGN

Although Active Galactic Nuclei (AGN) have many different forms of manifestation in observations, their origins are actually all the same - a supermassive black hole accreting surrounding gas and dust. According to the variations of brightness, Spectral lines, Radio emission and Orientation, AGNs can be divided into several main categories.



https://www.researchgate.net/figure/Color-online-A-schematic-illustration-of-the-dust-torus-around-AGNs-See-Kochler-Li_fig4_274232743

Figure 3. A schematic diagram of the AGN unification model.

There is a central black hole with an accretion disk (orange) and a dusty torus (dark ring). Type 1 AGNs are observed from a small angle and show broad emission lines and silicate emission features; Type 2 AGNs are observed from the edge, with the dusty torus obscuring the inner Region and showing silicate absorption features. Relativistic jets are perpendicular to the plane of the torus, and surrounding clouds produce narrow emission lines.

3.1 Quasars

Quasars are the brightest type of AGN that emit across the entire spectrum. They have a higher luminosity than their host galaxies and are located far away in the universe. For that reason, quasars are useful for looking at the early universe.

3.2 Seyfert galaxies

Seyfert galaxies are low luminosity AGN in the nearby Universe. They can be subdivided into two subtypes: Seyfert Type I have both broad and narrow emission lines; Seyfert Type II only show narrow lines as result of the obscuration of the broad line region by a dusty torus.

3.3 Blazars

Blazars are AGNs with relativistic jets pointing almost directly at the earth. Their emission is very unstable and strongly polarized, mainly due to the non-thermal processes of synchrotron radiation and inverse Compton scattering.

3.4 Radio galaxies

Radio galaxies have prominent radio emissions and are often accompanied by large-scale jets and lobes that extend far beyond the host galaxy. Radio morphology based classification are known as FR I (edge dark) and FR II (edge bright).

Although these Types have different appearances, they all fall into a unified framework based on the concepts of viewing angle, obscuration and whether there is a jet to understand their observed properties.

3.5 Brief Comparison

All AGNs have the same central black hole and accretion process, but their observed characteristics vary greatly. Quasars are the brightest and farthest away; Seyfert galaxies have less energy and can be found nearby. Blazars and Radio Galaxies are both jet dominated systems, but Blazars are oriented along our line of sight so that they

exhibit strong relativistic effects, whereas Radio Galaxies are oriented off-axis. Seyferts and Quasars are referred to as “radio - quiet”, whereas Blazars and Radio Galaxies are classified as “Radio-loud”. Mostly these are due to the AGN unification model, where the difference is because of the angle we observe it from and any matter in between.

4 How AGN Are Detected

AGN found by Electromagnetic radiation at every wave length ranging from very long radio waves to incredibly short gamma rays. Each band shows different physical structures and processes in the AGN system. Radio observations show there are big scale Jets and lobes, and X-rays track the high energy interactions near the event horizon.

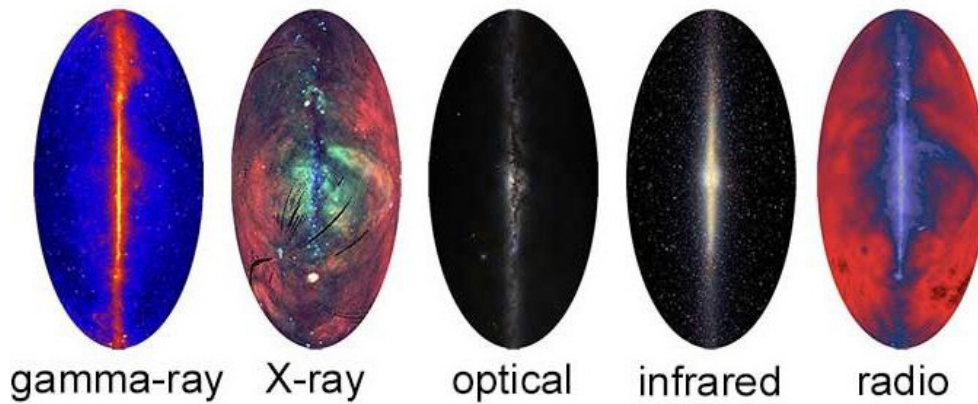
4.1 Different Types of Radiation (Radio, X-ray, etc.)

Each Region of the EM spectrum is probing a different Physical regime within an AGN.

- Radio waves trace relativistic jets and extended radio lobes;
- Infrared detects reprocessed radiation by dust-enshrouded regions;
- Optical observations resolve stars and ionized gas in the nucleus;
- X-rays and gamma rays reveal extreme-energy processes such as plasma heating and particle acceleration by the black hole.

They map the spatial energy distribution and structural changes of AGNs at different scales together.

4.2 Telescopes and Observations



<https://imagine.gsfc.nasa.gov/science/toolbox/multiwavelength1.html>

Figure 4.2 AGNs can be observed at different wavelengths by various telescopes, each revealing different components of the structure and emissions of AGNs.

Given the cosmological distances of many AGNs, multi-wavelength observations are needed to rebuild their internal structures. Key Instruments Includes:

- The Very Large Array (VLA) for mapping radio jets and lobes;
- Hubble Space Telescope (HST) for high resolution optical imaging;
- The Chandra X-ray Observatory for obtaining the high-energy plasma near the accretion zone;
- Fermi Gamma-ray Space Telescope to detect the high-frequency emission of non-thermal process;
- Event Horizon Telescope (EHT) to directly observe the black hole shadow, verify the prediction of general relativity.

Each telescope has a certain space of resolution and energy; By combining all these kinds, we can see the whole structure and development process of agn.

Process of analyzing radio waves

Although AGNs emit from radio waves to gamma rays, this part mainly discusses the radio wave band. Among all the wavelengths, radio observations need the most complicated technical processing, and are especially important for tracing relativistic jets and lobe structures. The following sub-sections describe the entire signal path of radio wave reception and analysis.

1. Reception of Radio Waves:

Radio waves are a kind of electromagnetic waves , its wavelength is usually much bigger compared with the one for visible light, say it's around 0.1m~hundreds/thousands

m. A radio telescope, which is used to receive such long wavelength electromagnetic waves and convert them into a signal for analysis.

a. Antenna

At the core of a radio telescope is the main parabolic antenna, and it resembles a big bowl. And it's chief job would be catching those long wave radio waves released by like an AHN Jet/Lobes. Parabolic Geometry: Incoming plane wavefronts (from very far away) are reflected and converge at one focal point, which is the location of the feed receiver. It will increase the received signal and also improve space resolution this focus.

The Size of an antenna, i.e. aperture for observing quality is the determining factor here. The larger aperture can get weak signals from far away, and the smaller angle resolution is due to the diffraction limit.

$$\theta \propto \frac{\lambda}{D}$$

θ being the angular resolution, λ the wavelength and D the dish diameter. Increase the size of an antenna basically increases the telescope's ability to separate close by source of a sky.

This way the antenna is first translator from the sky to our equipment gathering those faint low frequency whispers of radio galaxies & AGNs readying them for further processing.

b. Receiver

Handle the Antennas so that the Radio waves are aimed at the receiving system and It's that systems job to take Elec-

tromagnetic waves and turn them into a stream of Digital Electricity.

However, the incoming signal is usually very weak - at the level of nanovolts, and a low-noise amplifier must be used to boost it while minimizing additional background interference. Such amplifiers are transistor circuits, where the small input signal controls a much larger flow of energy. Physically this means to activate the release of the built up potential energy into a kinetic flow and cause an exponential increase in output power but maintaining the waveform structure.

That is to say, the signal itself does not bring energy, but acts as a gate to control the speed and time of releasing energy from the transistor. This is what makes good, low-noise amplifying in radioastronomy possible.

After amplification, it is still located at the original high frequency, usually hundreds of MHz to several GHz, which is not suitable for digitization. So we apply the technique of frequency conversion (heterodyning). The signal is mixed with a reference frequency from a local oscillator to generate a new signal of intermediate frequency (IF), which has the structure of the original signal but is easier to process digitally. Prepare the signal for analog-to-digital conversion (ADC) and Fourier analysis below.

c. Interferometry and Radio Arrays

Many modern radio telescopes like the VLA work in the manner of interferometric arrays. Through the signal received by multiple antennas at different locations, astronomers synthesize rebuild the resolution of a much larger “virtual telescope”, and this method can significantly improve the angular resolution, which allows us to obtain high-resolution images of AGN jets, radio lobes, and even the shadow of black holes through the Event Horizon Telescope.

2. Signal Processing and Analysis:

Further processing and analysis of the electrical signals received are required for electronic devices and computers.

a. Data Conversion and Processing:

The signal will be sent to a computer and go through ADC(analog-to-digital conversion),the analog signal change to digital information.

Then professional software will use these digital signal to find out the physical information of celestial body, such as

structure, movement speed, temperature and so on.

b. Fourier Transform:

What is Fourier Transform?

Fourier transform is a mathematical method to change the signal from time domain which can be seen as voltage changing with time into frequency domain where its hidden structure can be observed. The idea of this transformation is that any complex signal can be represented by the sum of some simple sine or cosine signals with different frequencies. In radio astronomy, it helps us reveal the frequency components contained in the signals received by the telescope.

Application in Radio Astronomy

The signals received by a radio telescope often seem chaotic in time, but they carry rich frequency information. Fourier Transform takes this frequency information, and it reveals the physical processes that created those signals: synchrotron emission, molecular transitions, thermal radiation of an AGN jet.

Most importantly they have different peaks on the following spectrum showing spectral lines where photons are emitted or absorbed as atoms and molecules change their energy quantization state. When a particle gets exactly the right energy from the surroundings due to temperature, collision, radiation and so on, it will cause an internal change. For example, an electron gains energy ΔE , and jumps to a higher orbital; Then drop to a lower state and emit a photon of frequency:

$$f = \frac{\Delta E}{h}$$

Atoms or Molecules have particular energy level and the corresponding frequency every one of them has specific sign that help to determine the composition and physical condition of remote cosmic object.

Information Extracted Through Fourier Transform

Frequency Components and Spectral Line Features.

- Frequency components: There are many different waves overlapping in radio signals. Fourier analysis takes it all apart and tells us the power at each frequency.
- Spectral lines: These are narrow frequency bands in which the signal is significantly stronger, corresponding to radiation by certain atomic or molecular transitions. Based on these features we could know the physical properties of emitting region, e.g. temperature, density, chemical component and so on.

Motion and Doppler Shift.

- The motion of the source with respect to the observer changes their frequency in this way. Doppler effect for the measurement of velocities -both inflow & outflow. Redshift means it is moving away from us, blueshift means it is moving toward us.

Thermal & Kinematic Properties.

- Bloating spectrum Broadening indicates the movement inside such as turbulence or rotational velocity, Thermal agitation.

- Energy distribution in all frequency ranges is conducive to distinguishing thermal and non-thermal radiation processes, thereby judging whether it is a jet, lobe or accretion region.

Chemical Composition.

- By spotting which ones are there and how strongly, scientists can tell what element or molecule is making the source emit, sometimes even rare species only in radio.

Fourier transform alone isn't enough - Fourier transform, that is how the astronomer looks on every EM noise and get it out of the noise informations quantitatively. To convert the feeble, time-varying voltage into an abundance of physical truths about the motion, structure and makeup of some of the most distant and energetic phenomena in our universe.

5 The Role of AGN in Galaxy Evolution

5.1 AGN Feedback

AGN feedback has importance effect in the regulation of galaxy evolution. AGN emit light and energy as radiation and also as relativistic jets, these jet interact with the surrounding ISM in two main ways:

- Radiative feedback: short energy photons can heat an ionized gas; sometimes these prevent collapse and stop star formation.
- Mechanical (Jet-Driven) Feedback, when Outflows drive gas away from the Galactic Center and limit Cold Material from Inflowing.

These mechanisms reduce the supply of cold, dense gas needed for star formation, so the galaxy cannot form stars at a high rate. This way the AGN can create a self-regulating loop among the activity of the central black hole and the growth of the host galaxy.

5.2 Impact on Star Formation

Simulations show that without AGN feedback, galaxies—particularly massive ones—would convert gas into stars at rates far exceeding observational limits. AGN release energy and momentum, which interferes with this process by heating the interstellar medium, removing star-forming materials, and preventing further cooling.

This regulation could modify the inner gas structure of a galaxy and then modify when and where stars are formed, thus resulting in an interval of inhibition and subsequent revival. Some studies have proposed that AGN feedback may act differently on different types of galaxies and masses, thereby introducing diversity among galaxy populations.

By controlling the supply of cold gas, AGNs becomes[.] the main actor(s) deciding on how quickly & to which extend do[?]galaxies evolve.

Fourier Transform & The Physical Interpretation Of Radio Signals.

Radio telescope receives the signals which are time-varying voltage wave containing all sorts of frequency from AGN like astronomical sources. These signals often exhibit disorderliness in the time domain and are difficult to determine the hidden physical laws. The mathematic tool used is called fourier transforms: it can take complex timedomain signal and break it down mathematically to be in summation form of sinusoid of different frequency.

The corresponding frequency spectrum will show spectral lines, that is, narrow frequency peaks corresponding to certain energy transitions of atoms and molecules. Transitions is when atoms hands over energy and moves an electron around particular amounts of it. In AGNs, this is caused by strong environmental interaction, such as collision, radiation, magnetic turbulence and other internal energy perturbation of the particles. An electron jumping up to a higher orbital (excited state), and later dropping down to a lower orbital by emitting a photon. For photons with frequencies f , they should satisfy the energy conservation relationship:

$$E = h f.$$

Where E is the difference in energy between two levels, h stands for Plancks constant.

Hence each peak in the frequency domain can correspond to well-defined atom or molecular process by which astronomers know what's being emitted, measure locally moving velocity through doppler shift ,estimate tempera-

tures and infer chemicals. Fourier Transform serves as the link between the original electric signal and the physical attributes of the AGN environment.

That is to say, it transforms radio waves into decipherable language in which every spectral feature contains a structure, heat or dynamics of the universe.

6 Interesting Facts and Recent Discoveries

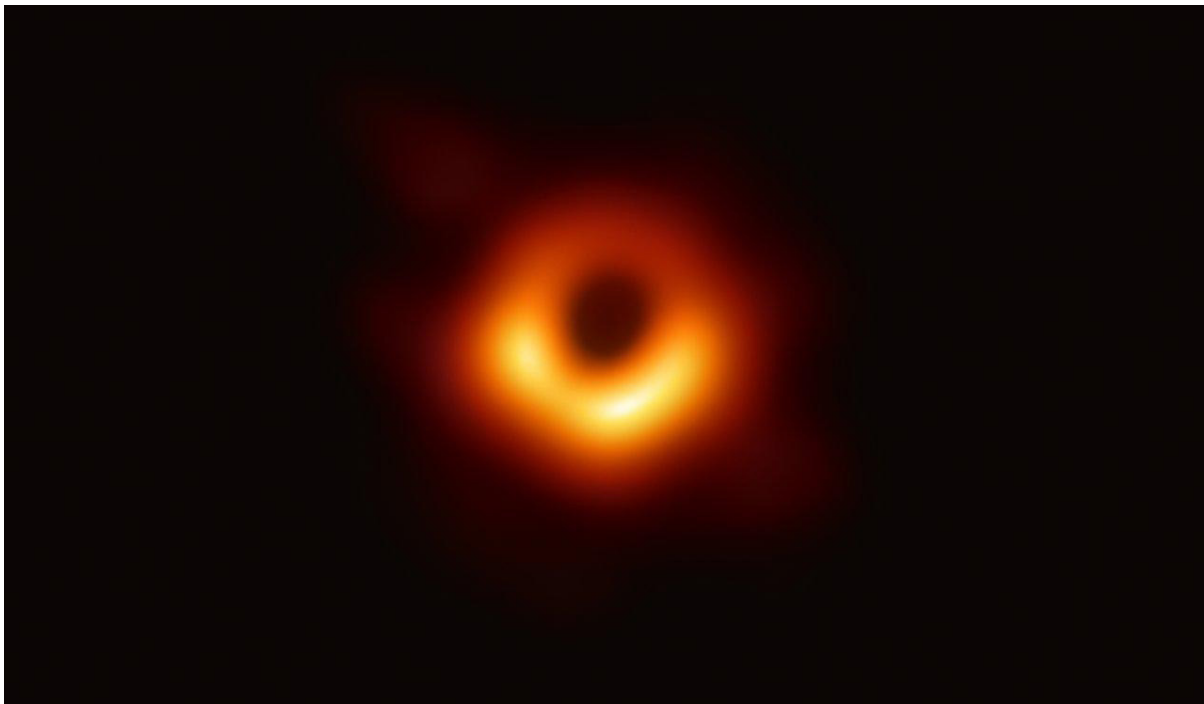
6.1 Brightness and Distance

Among the most distant and luminous in the observable

universe are AGNs. Since the light of these sources takes billions of years to reach us, studying AGNs allows us to see the early stages of cosmic evolution directly.

Some quasars that are currently detectable emitted light less than one billion years after the Big Bang, and they are key tracers of large-scale structure formation and early black hole growth. As they are very bright at so many wavelengths that they can illuminate things which was previously invisible in the high redshift universe.

6.2 Famous AGN: M87 and Beyond



<https://www.eso.org/public/images/eso1907a/>

Figure 6.2 First image ever of a black hole's event horizon was taken by EHT, it shows the AGN in the center of galaxy M87. Confirm the existence of black hole shadows predicted by general relativity.

One of the most prominent achievements of AGN research in recent years is the imaging of the supermassive black hole at the center of galaxy M87. Such great achievement by EHT, it helped us got our first ever picture of an event horizon so we confirmed one of its main predictions – general relativity.

The image showed the shadow of the black hole as well as the bright emission ring of accretion flows, thus confirming key parts of theoretical models of black hole environments.

Beyond M87, AGNs continue to defy expectations. Some, called “changing-look” AGNs, have sudden changes in brightness and spectra on time-scales of years to even

months, which implies dynamic and non-stationary interiors that do not conform to old ideas about their temporal constancy.

7 Conclusion

Started from the process of finding AGN, then according to its spectrum property and orient dependency to do the classification. Friction, the collision of particles and magnetic forces and turbulent flow are described as ways that matter in a circle around an supermassive black hole loses rotational energy so it can fall in (accrete). Relativistic jets formation was studied with respect to magnetic field con-

figurations as well as Blandford - Payne angles etc. It was considered radiative process like synchrotron radiation, inverse Compton scattering etc. to explain the emitted signal, also magnetic field was studied in how it directed charged particle and determined energy flux. Lagrangian mechanical concepts were referred to in establishing the framework for describing those internal energy-flow structures. AGNs are still central in astrophysics as they are extreme physical environments, expose processes close to event horizons, probe general relativity in the strong field regime, and illustrate co-evolution of galaxies and their central black holes. In the course of my study on Active Galactic Nuclei (AGNs), I was constantly reminded of how deeply energy flows is related to geometry. That which seemed just like “mechanical” affairs – like frictions in an accretion disc – were shown quickly to be much trickier. When I wrote on shear slip and magnetic feedback and angular momentum dissipation I started seeing those as states the system goes through: from ordered to disordered. When I was studying the formation of relativistic jets and radiation mechanisms, I felt that electric and magnetic fields are not only interacting but also co-evolution in curved space-time affected by the strong gravitational field of black holes. In this process, I was introduced to and studied deeper concepts such as Lagrangian density, electromagnetic field tensor, etc. I had never formally studied them, but I was looking for them in order to explain those that I was just beginning to understand. I

had used my own words, and more and more the language of physics itself to explain a system that was at once complex and beautiful for the very first time. And that was a little taste of how the physical laws and the language in which we write them down are intimately, and beautifully connected.

Reference

- [1] Blandford, R. D., Meier, D. L., & Readhead, A. C. S. (2019). Relativistic jets from active galactic nuclei. *Annual Review of Astronomy and Astrophysics*, 57, 467–509. <https://doi.org/10.1146/annurev-astro-081817-051948>
- [2] Carroll, S. (2004). *Spacetime and geometry: An introduction to general relativity*. Addison-Wesley.
- [3] Frank, J., King, A., & Raine, D. (2002). *Accretion power in astrophysics* (3rd ed.). Cambridge University Press.
- [4] Jackson, J. D. (1999). *Classical electrodynamics* (3rd ed.). Wiley.
- [5] NASA. (n.d.). Types of black holes. NASA Science. <https://science.nasa.gov/universe/black-holes/types/>
- [6] NASA Goddard Space Flight Center. (2021). Accretion disks around black holes. <https://svs.gsfc.nasa.gov/14584/>
- [7] Netzer, H. (2015). Revisiting the unified model of active galactic nuclei. *Annual Review of Astronomy and Astrophysics*, 53, 365–408. <https://doi.org/10.1146/annurev-astro-082214-122302>
- [8] Shakura, N. I., & Sunyaev, R. A. (1973). Black holes in binary systems: Observational appearance. *Astronomy and Astrophysics*, 24, 337–355. <https://ui.adsabs.harvard.edu/abs/1973A%26A....24..337S>