Theoretical and observational studies of the central engines of active galactic nuclei
by Ran Sivron

A thesis submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Physics
Montana State University

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In Active Galactic Nuclei (AGN) the luminosity is so intense that the effect of radiation pressure on a particle may exceed the gravitational attraction. It was shown that when such luminosities are reached, relatively cold (not completely ionized) thermal matter clouds may form in the central engines of AGN, where most of the luminosity originates.

We show that the spectrum of emission from cold clouds embedded in hot relativistic matter is similar to the observed spectrum. We also show that within the hot relativistic matter, cold matter moves faster than the speed of sound or the Alfven speed, and shocks form. The shocks provide a mechanism by which a localized perturbation can propagate throughout the central engine. The shocked matter can emit the observed luminosity, and can explain the flux and spectral variability. It may also provide an efficient mechanism for the outward transfer of angular momentum and the outward flow of winds.

With observations from X-ray satellites, emission features from the cold and hot matter may be revealed. Our analysis of X-ray data from the Seyfert 1 galaxy MCG -6-30-15 over five years using detectors on the Ginga and Rosat satellites, revealed some interesting variable features. A source with hot matter emits non-thermal radiation which is Compton reflected from cold matter and then absorbed by warm (partially ionized) absorbing matter in the first model, which can be fit to the data if both the cold and warm absorbers are near the central engine. An alternative model in which the emission from the hot matter is partially covered by very warm matter (in which all elements except Iron are mostly ionized) is also successful. In this model the cold and warm matter may be at distances of up to 100 times the size of the central engine, well within the region where broad optical lines are produced. The flux variability is more naturally explained by the second model. Our results support the existence of cold matter in, or near, the central engine of MCG -6-30-15. Cold matter in the central engine, and evidence of the effects of shocks, is probably forthcoming with future X-ray satellites.

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Montana State University

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APPROVAL

of a thesis submitted by

Ran Sivron

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Date 4/13/95 — Chairperson, Graduate Committee

Approved for the Major Department

Date 4-17-95 — Head, Major Department

Approved for the College of Graduate Studies

Date 4/15/95 — Graduate Dean

STATEMENT OF PERMISSION TO USE

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TABLE OF CONTENTS

TABLE OF CONTENTS — Continued

TABLE OF CONTENTS — Continued

LIST OF TABLES

LIST OF FIGURES

Figure | Page

LIST OF FIGURES — Continued

Figure Page

LIST OF FIGURES — Continued

ABSTRACT

In Active Galactic Nuclei (AGN) the luminosity is so intense that the effect of radiation pressure on a particle may exceed the gravitational attraction. It was shown that when such luminosities are reached, relatively cold (not completely ionized) thermal matter clouds may form in the central engines of AGN, where most of the luminosity originates.

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Chapter 1

INTRODUCTION

In this chapter we introduce the current theories and observations of the central engines of AGN. In the first section partially successful models of the central engines of AGN are presented. The second section is devoted to observations of AGN in the X-ray waveband, in which most of the radiation from the central engines is probably emitted. In the third section some of the problems in theoretically modeling the central engines of AGN are presented, possible solutions suggested in this thesis are outlined and our analysis of X-ray data from an AGN is discussed.

1.1 INTRODUCTION TO THEORY OF AGN

1.1.1 What are AGN?

Active galactic nuclei (AGN), which are the extraordinarily luminous centers of some galaxies, are among the most enigmatic phenomena in astrophysics. AGN may be as small as the solar system, but have energy outputs which, in some cases, rival the luminosity of the entire host galaxy. Approximately 10% of all galaxies are AGN, and at least 50% of galaxies show some evidence of activity in their nucleus. As of this date there is no one cohesive explanation to the source of this phenomenon that can be directly corroborated by observations. AGN are therefore characterized by observations.

In table 1 some of the observable properties of AGN are presented. Only properties related to the galactic nucleus are included. Other basic properties can be found in Woltjer 1990, Netzer 1990, Mushotzky, Done and Pounds 1993 and references therein. A partial list of AGN and host galaxies types is presented in the first two columns: Seyferts are optically resolved spiral galaxies with an AGN. Seyferts of type 1 have both broad and narrow emission lines in the infra-red (IR) - ultraviolet (UV) wavebands, and Seyfert 2s have only narrow emission lines. Seyferts comprise about 5% of all galaxies. AGN which could not be optically resolved when they were first observed are usually referred to as quasars. (In the past few years some quasars were optically resolved and shown to be AGN.) The radio quiet quasars are called quasi-stellar objects (QSO). In optically resolved elliptical galaxies AGN are usually radio galaxies and BL LAC objects (whose spectrum resembles the spectrum of strong radio galaxies, but lack emission lines and are highly variable). The radio loud quasars are quasi stellar radio sources (QSR) and quasars which exhibit strong optical variability are called optically violent variables (OVV, mostly a subgroup of QSR). Increased activity in the nuclear region may also be in the form of increased rate of star formation (in star burst galaxies), strong emission lines (in LINERS and nuclear H II regions) and increased IR emission (strong IRAS galaxies).

AGN morphology is based primarily on luminosity and spectrum, although the property which distinguishes AGN from most other astrophysical objects is their high luminosity per volume. We therefore included in the next four columns of table 1 some information on observed properties which are directly related to the luminosity and size. The estimated total luminosity in column 3, L_{tot}, includes emission in all wavelengths, whereas in column 4 we only include L_X, the emission in the dominant x-ray waveband. In column 5 the estimated doubling time scale Δt (the minimum time the X-ray flux takes to double in magnitude) is presented. Using columns 4 and 5 the compactness of the source can be defined as $l = L_X \sigma_T / (\Delta t m_e c^4)$ (Guilbert Fabian and Rees 1983), where σ_T is the Thompson cross section, m_e is the electron mass and $R = c\Delta t$ is usually referred to as the size of the central engine (see sections §1.3 for a more precise physical definition of the central engine). The compactness parameter is only appropriate for the first three categories of AGN. In Seyfert 2s the nucleus is most probably obscured, and the compactness parameter is meaningless.

Table 1. AGN: Observations That Can be Related to Central Engines

AGN type	Host Galaxy[a]	L_{tot}[b]	L_X[c]	Δt[d]	l[e]
Seyfert 1s	spiral	10^{42-45}	10^{41-44}	10^{3-5}	$10^{-2} - 10^{3}$
Seyfert 2s	spiral	10^{42-45}	10^{40-42}	$\sim 10^{7}$[f]	?
QSO	spiral(?)	10^{44-47}	10^{43-46}	10^{5-7}	$10^{-2} - 10^{3}$
Radio	elliptical	$\sim 10^{42-45}$[g]	[g]	10^{4-7}?	?
Strong Radio	elliptical	$\sim 10^{42-44}$[g]	[g]	?	?
QSR	elliptical(?)	$\sim 10^{43-47}$[g]	[g]	?	?
BL Lac	elliptical	[h]	[h]	$\sim 10^{4}$	?
OVV	all?	[h]	[h]	10^{4}	?
LINER	spiral	[i]	[i]	?	?
HII regions	spiral[i]	[i]	?	?	
IRAS		$\sim 10^{45}$[j]	?	?	?

[a]QSO and QSR are mostly unresolved.

[b]in erg sec^{-1}, estimated for the galactic nuclei.

[c]in erg sec^{-1} in the 2 – 10Kev range, estimated for the galactic nuclei.

[d]in seconds. Upper limit is an estimate.

[e]Compactness of central engine, lower limit: $l \sim L_x \sigma_T / R m_e c^3$.

[f]Some evidence for variability between x-ray observations

[g]Most of the observed flux is not from the central engine

[h]Most of the observed flux is probably from an observer oriented jet.

[i]Galactic nuclei emission can only be estimated in LINER and HII regions.

[j]Most emission in IR.

1.1.2 The Importance of AGN

Better understanding of AGN may help answer a number of questions. Among them:

1. Galactic morphology: AGN may help us understand how galaxies form and evolve. A large fraction of all galaxies have at least some AGN features, which implies that most galaxies may have had AGN in their centers at some point in their history (Blandford 1990, and references therein). Emission from highly red shifted quasars imply the existence of nuclear galactic activity at an epoch in which galaxies were not even supposed to have formed, according to many scenarios of galaxy formation. Understanding AGN will therefore help in understanding galactic evolution.

2. Cosmology: If we can understand AGN, quasars may become the perfect 'standard candles', which can be used to determine the geometry of the universe . Using a standard candle of known luminosity L_Q at a 'luminosity distance' $d_L = (L_Q/4\pi F)^{1/2}$, the cosmological parameters can be determined by observations using $H_0 d_L = z + 0.5(1 - q_0)z^2 + ...$, the approximate solution of Einstein equations for an expanding matter dominated universe. Here F and z are the observed flux and redshift, respectively. The Hubble constant H_0 and deceleration parameter q_0 may be found by using quasars, the highest redshift objects in the universe. These

parameters, if determined, may reveal the geometry of the universe (Woltjer 1990, Schutz 1985).

3. High energy physics: AGN may serve as high energy labs with which one can enhance our understanding of high energy phenomena. There are reasons to believe that very efficient particle acceleration mechanisms are present in AGN centers, and that plasmas with temperatures unaccessible in labs are present near their centers (Blandford 1990, Blandford and Eichler 1987).

4. General relativity: Understanding AGN may allow us a look into the very nature of the general theory of relativity. Some effects that may be observed in the future are the Lense-Thirring precession, energy extracted from a rotating black hole or, possibly, gravitational radiation from binary black holes in the central engine of an AGN (Blandford 1990 and references therein). These effects, when observed, will consolidate our understanding of general relativity.

5. The large scale structure of the universe: The spectrum and isotropy of the X-ray background are probably the signature of a period less than a billion years after the big bang. In that period more galaxies had active nuclei. It was shown that AGN may account for most of the X-ray background. An early evidence of the large scale structure may therefore be available (Fabian and Barcons 1992, and references

therein).

In order to advance towards a solution to these questions better understanding of AGN must be developed. In particular, emission of light and particles from the vicinity of the AGN center must be understood. These processes can only be explained in the context of a model for the central driving force of an AGN, the central engine.

1.1.3 Possible Candidates for the Central Engines of AGN

It is now generally accepted that super massive compact objects lurk at the centers of AGN (see Blandford 1990, appendix 1). Gravitational potential energy of matter which falls onto these objects is released in the form of radiation. Although the gravitational behavior of the massive objects is yet unknown, and the mechanisms by which these objects generate the incredible observed phenomena are not yet fully explained, the matter accreting super massive compact object model is the most successful in describing the phenomena.

Traditional candidates for the AGN central engines, such as dense clusters of normal luminous stars and clusters of neutron stars are probably rejected by the recent observations with the Hubble Space Telescope (HST) of a single central super massive object (see Ford et al. 1994). The Chandrasekar limit on masses of stars makes it impossible to construct a super massive compact object made of baryonic matter. Another alternative model is the star-burst model (Terlevich et al. 1992, and references therein), in which the energy is generated by violent star formation activity in the innermost regions of AGN. Although the spectra of AGN may be explained in this manner the variability is almost impossible to explain (Green 1993, and references therein). It's also hard to reconcile star-burst models with HST observations.

The compact objects are assumed to be super massive black holes (SMBH) in the so called 'best bet' model for AGN (Salpeter 1964, Lynden-Bell 1969, Rees 1984, Blandford 1990). We hereafter refer to the central compact objects as SMBH, as is often done in the professional literature. SMBH are the central objects in the models described in the following sections. (But note the quote from Blandford 1990: "...various observational discoveries are increasingly hard to interpret in terms of alternative models... however... the evidence [for black holes] is weaker than for stellar mass black holes in X-ray binaries...)

Black holes are vacuum solutions of Einstein equations with an event horizon, from which light and particle cannot escape (Wald 1984). Schwarzschild and Kerr family of solutions span all possible solutions for vacuum stationary axisymmetric spacetimes with a regular event horizon (Misner, Thorne and Wheeler 1972, Robinson 1975, Mazur 1982). The spherically symmetric Schwarzschild solution is a special case of the axisymmetric Kerr solution. A positive change in the mass of the central compact object, $\Delta M > 0$, is required in both of the Schwarzschild and Kerr solutions, if the efficiency of the accretion process is less than 100 %.

Black holes are more efficient in conversion of the mass to energy than other astrophysical processes. For example, nuclear fusion of hydrogen to helium can convert up to 0.7% of the rest mass to energy. Near Kerr SMBH up to 40% of the rest mass of the gas accreted onto the black hole can be converted into energy.

The release of gravitational energy from matter that falls onto the SMBH is via viscous processes in either accretion disks or semi-spherically accreted matter (see Frank, King and Raine 1992; Guilbert and Rees 1987; chapters §2 and §5 of this thesis). In accretion onto black holes most of the gravitational energy is released within the inner $10R_g$ where $R_g = GM/c^2$ and M is the mass of the SMBH. This can easily be seen if the Newtonian potential energy becomes kinetic energy which is radiated away, such that $GMm_H/(6R_g) - GMm_H/(10R_g) \sim 0.06 m_H c^2$, or 6% of the rest mass is converted into energy, where m_H is the mass of hydrogen. The inner boundary is chosen to be the last stable orbit in a Schwarzschild geometry. Accurate calculations of the total energy which can be radiated by an accreted particle yield a similar number. The efficiency of the accretion process is not only higher than that of hydrogen fusion, for example, but is also more stable than fusion when limited to a size $10R_g$. We hereafter refer to the inner $10R_g$ as the 'the central engine' as is often done in the professional literature. Accretion processes are assumed to be the main source of the energy emitted from the central engine.

The limited supply of mass to be accreted onto the SMBH in the center of AGN poses some problems for the best bet model. For a thorough discussion of this problem the reader is referred to Rees 1990.

Direct emission from the central engine may give us evidence of a SMBH. However, the spatial resolution of present day telescopes cannot tell us whether most of the radiation originates in the central engine or elsewhere, even in the nearest AGN. Redshifted emission lines may indicate emission from the vicinity of a SMBH, if observed. Variability may be observed which could be explained by gravitational lensing modification of emission from matter that follows geodesics in the central engine (Rauch and Blandford 1994).

A combination of observations of the spectrum, flux variability and spectral variability can be used for reconstruction of the possible geometrical configuration of the central engine. The results of such observations are described in the next three sections. A way to distinguish the central engine radiation from competing emissions regions may be found in the near future.

1.1.4 Spectra of Emission from the Central Engines of AGN

The overall continuum spectra of most AGN can be characterized as power-law with bumps super-imposed in the IR and UV, or extreme UV (EUV) and X-ray wavebands. (The IR bump probably does not originate in the central engines of AGN. See Blandford 1990.) Emission and absorption features are also present at photon energies of up to ~ 10keV.

In figure 1-1 we show the spectrum in wavebands from radio to γ rays of the quasar 3C273. The abscissa has units of ν and the ordinate has units of $\log \nu F_\nu$, where ν is the photon frequency and F_ν is the flux per frequency. The reason for this choice of coordinates is that for a power-law spectrum, of the form $F_\nu \propto \nu^{-\Gamma}$, the integrated flux between two frequencies, ν_1 and ν_2, is $F = C \log(\nu_2/\nu_1)$ when $\Gamma = 1$, where C is a constant. The total emission in each photon frequency decade is therefore the same, and a 'flat' curve appears on a graph of the above format. It is evident that the AGN flux in figure 1-1 has an almost flat spectrum. Black body stellar emission of a galaxy appears as a reference for comparison.

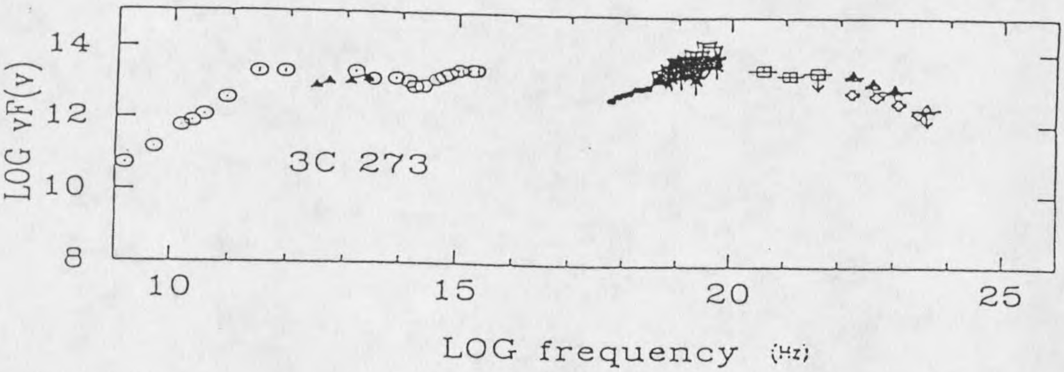

Figure 1.1: The spectrum quasar 3C273. AGN emit similar integrated power in the IR γ-ray wavebands (see text). (Adapted from Green 1993.)

If a SMBH is at the center of the AGN then most of the radiation originates in the central engine, as demonstrated in section 3 and chapter 2. The radiative processes responsible for the radiation that emerges from the central engine probably include synchrotron radiation, Compton scattering, radiative reprocessing in pair plasmas, and may include atomic radiative transitions and black body emission.

Synchrotron radiation emitted from relativistic electrons in magnetic fields should affect the spectrum if the synchrotron cooling time is shorter than the typical accretion time. Synchrotron emission, which should result in radio polarization, was proven to be important in most AGN by measurements of polarization. Measurements of magnetic fields in galactic centers yield values which require that synchrotron radiation be an important radiation mechanism on all scales. These magnetic fields which probably originate in stars which are being disrupted by the SMBH are increased as the accreting plasma becomes denser. Near the central engine the magnetic fields are strong enough to result in cooling time scales which are much shorter than the accretion time scales.

Synchrotron radiation in astrophysics usually results in an almost flat power law spectrum, similar to the underlying spectrum of most AGN. The synchrotron radiation in astrophysics usually comes from a power-law distribution of electrons velocities, which may result from acceleration mechanisms such as the Fermi-shock process in shocks. The resultant spectrum is an almost flat power-law spectrum, with a low frequency cutoff due to synchrotron self absorption. This self absorption may be associated with the radio-quietness of some compact AGN.

The effects of Compton scattering on the spectrum are noticeable when the cooling time of photons of energies comparable to $m_e c^2$ is shorter than the time in which a photon is crossing the emission region, $t_x = R/c$. The spectrum may also be affected by Compton scattering of low energy photons by relativistic electrons when the time scale for that process is shorter than t_x. Compton heating and cooling are important if the overall Thompson (or Klein Nishina) optical depth is large, which happens when the source is sufficiently compact ($l > 1$, see table 1). Compton cooling, usually referred to as 'reflection', is important if the Thompson optical depth of cold matter in the photon's path is larger than 1. The result of Compton cooling on a power-law spectrum is a decrease of the γ-ray photon flux and an increase in hard X-ray photon flux. Compton processes may, therefore, be responsible for the high energy cutoff and hard X-ray bump in the spectra of radio quiet AGN (Mushotzky, Done and Pounds 1993).

Pair processes affect the spectrum when the compactness parameter l is larger than ~ 10 (Lightman 1982, Svennson 1987). When this condition is met pair creation usually exceeds annihilation. Pairs lose most of their energy through Coulombic collisions. In some cases pair cascades, in which the relativistic pairs collide with the ubiquitous photons creating more pairs with less energy in the process and depleting the radiation field. If pair annihilation becomes important the 511keV pair annihilation line may be present in the spectrum. The effects of pairs on the spectrum are a decrease of the (negative) spectral slope in the UV waveband due to loss of soft photons, and an increase in the hard X-ray - *gamma*-ray wavebands, due to the loss of pair producing hard photons. Pair production is traditionally calculated in the presence of relativistic electrons and UV photons of relative compactness l_h for the electrons and l_s for the photons. It should be noted that although pair production can happen without synchrotron or Compton processes, an input power-law spectrum is generally assumed for the electrons, mainly because most processes that produce enough highly relativistic electrons also result in a power-law photon spectrum.

The atomic radiative free-free, bound-free, bound-bound and black body processes usually take place in 'cold'(not completely ionized) plasmas. The features superimposed on the continuum spectrum as a result are lines, edges and bumps in the IR through medium X-ray wavebands. The feature with highest photon energy is the iron line-edge system near 7keV, which may have an absorption effect at up to 10keV. (Absorption and emission features in the optical and UV regime are believed to be coming from regions which are far beyond the central engine. See Netzer 1990 and section 1.5.)

Matter in local thermal equilibrium (LTE) may be present in the central engine of AGN, and may be responsible for the UV bump superimposed on the flat spectrum. This UV bump is thought to be black body emission from optically thick LTE plasmas with different temperatures.

We shall limit our discussion to radio quiet AGN throughout the rest of the chapter. In radio quiet AGN most of the radiation is emitted in the EUV – X-ray wavebands, and the X-ray emission is believed to originate in the central engine (see the following section). Radio loud quasars may emit significant amounts of radiation from their jets due to relativistic beaming effects (see appendix 1). As a result it is very hard to distinguish central engine emission from jet emission. x

1.1.5 Variability of Emission from the Central Engines of AGN

More than 50% of radio quiet AGN exhibit large amplitude flux variability in the X-ray waveband. Spectral variability is also present in many of these AGN

(Mushotzky, Done and Pounds 1993). Long term variability (years) is present in most sources, whereas at least half of the sources exhibit short term large amplitude variability (Green 1993, McHardy 1988).

The flux variability (generally referred to as the light curve) is shown in figure 1-2 for three AGN. In the upper panel (1-2a) the light curve of NGC 4051 is shown. In the middle panel (1-2b) the light curve of NGC 5506. The light curve of MCG -6-30-15, a Seyfert galaxy which is extensively discussed in chapter 6, is shown in the lower panel (1-2c). It is evident that, in the first and last cases, the total flux doubles on timescales of thousands of seconds. This change in flux is believed to originate in the central engine.

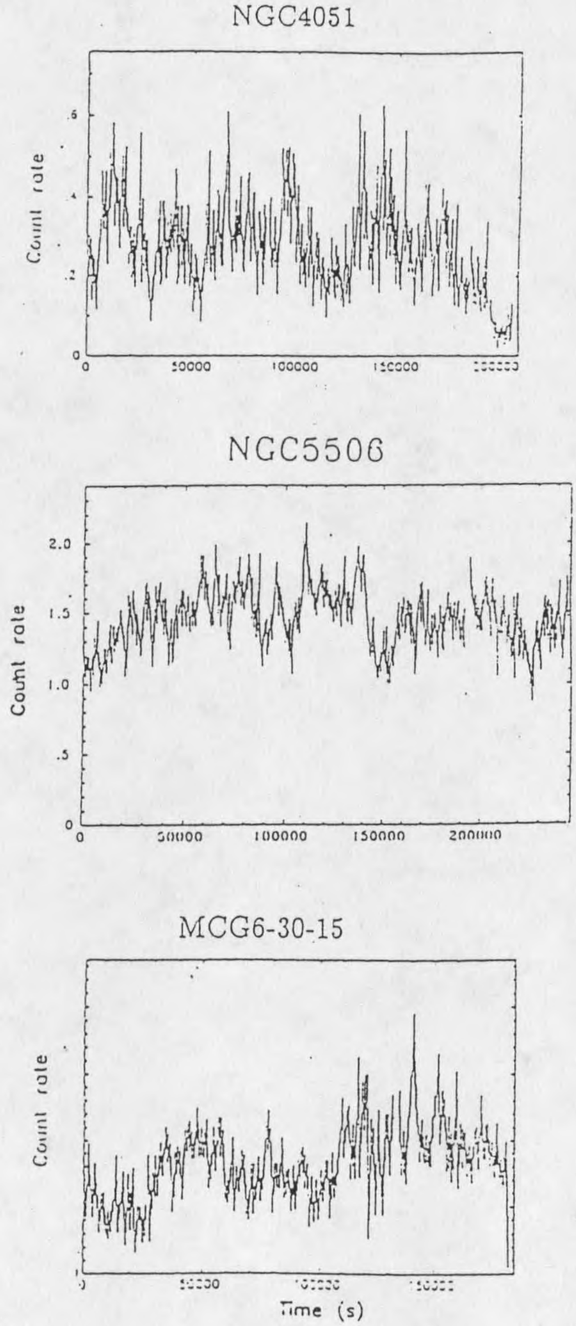

Figure 1.2: Typical flux for two types of variability: a. NGC 4051 exhibits large amplitude 'shot-noise' time variability ; b. NGC 5506 exhibits an almost 'chaotic' time variability. c. MCG -6-30-15 has time variability which is in between a. and b. (see text). Most AGN have time variability which is similar to a. or c. (Adapted from McHardy 1988.)

The size of the emitting region is usually assumed to be smaller than $R_e = \Delta t c$, where Δt is time in which the source is observed to double in flux. For incoherent radiation this condition is necessitated by causality. Events in a region of size R_e cannot be correlated by perturbations that move faster than light. Since most of the energy is emitted in the variable part of the spectrum R_e is the maximum possible size of the central engine. Since the shortest observed doubling timescale goes to hours in Seyfert 1 galaxies (see table 1) the emission region can be assumed to be of order 10^{13}cm in radius. The emission from this region is larger than $\sim 10^{42}$erg sec^{-1}. As a result models that try to explain the light curve need to account for the enormous production of energy per volume, which is quantified by the compactness parameter in table 1.

The Fourier transform of the light curves $P = \sqrt{1/2\pi} \int_0^\infty exp(i\omega t) f(t) dt$ (usually referred to as the power spectrum) can be used to categorize the different types of variabilities. In the upper panel of figure 1-3 the power spectrum of NGC 4051 is shown, the power spectrum of NGC 5506 is shown in the middle panel and the power spectrum of MCG -6-30-15 is shown in the lower panel. Unlike many sources inside our galaxy, there are no periodic components, which would appear as prominent spikes, in the power spectrum of AGN. The logarithm of the Fourier transform of a light curve with random flux level (white noise) can be fit by a constant. The Fourier transform of flux from regions of random sizes and random flux levels is usually referred to as a 'random shot noise'. In this case the power spectrum $\log L(f) \propto \log(-1/(f^2))$, where f is the frequency of variability, and the slope is -2. The flux of NGC 4051 is nearly a random shot noise. An almost chaotic intermediate $\log L(f) \propto \log(-1/(f))$ power spectrum slope fits the Fourier transform of the light curve of NGC 5506. MCG -6-30-15 has an intermediate power spectrum slope of ~ -1.4.

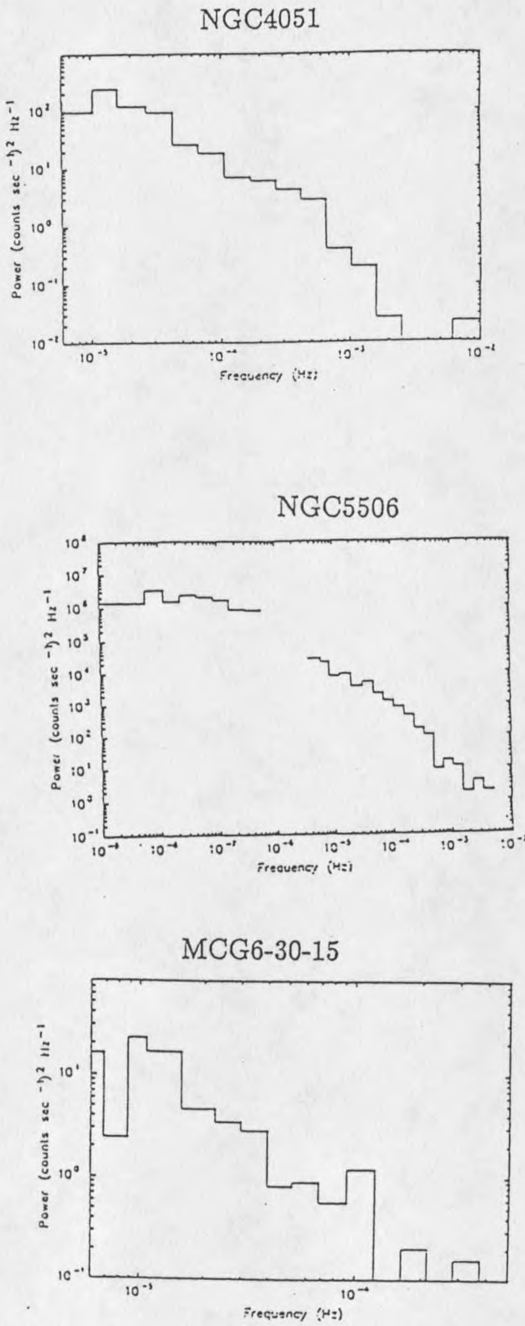

Figure 1.3: The Power spectrum of the AGN in figure 1-2: a. NGC 4051 b. NGC 5506 c. MCG -6-30-15 (adapted from McHardy 1988)

Some models of the variability assume white noise which is filtered by matter in the line of sight. For example, when variable white noise flux is incident on matter with moderate optical depth the higher frequencies are filtered out. Spherical extended regions of size R_e yield random shot noise from the original flat power spectrum (Sunyaev and Titarchuk 1980). This spectrum may be modified if pairs are present, as is expected in high luminosity to size ratio sources (Done and Fabian 1989, Lightman and Zdziarski 1987). Chaotic processes may also explain the observed power spectrum (Vio et al 1991), but no physical mechanism is yet known that may explain such processes.

1.1.6 Geometrical Models of the Central Engines of AGN

The most successful models of AGN include an accretion disk which channels accreted matter from the surrounding gas and stars onto a central super massive compact object in the central engine. In order to understand the observational success of this model one must look at models of the 'outer regions' (regions outside the central engine) of AGN.

In figure 1-4 we see a simplistic, schematic description of the current geometrical model of the outer regions of radio quiet AGN.

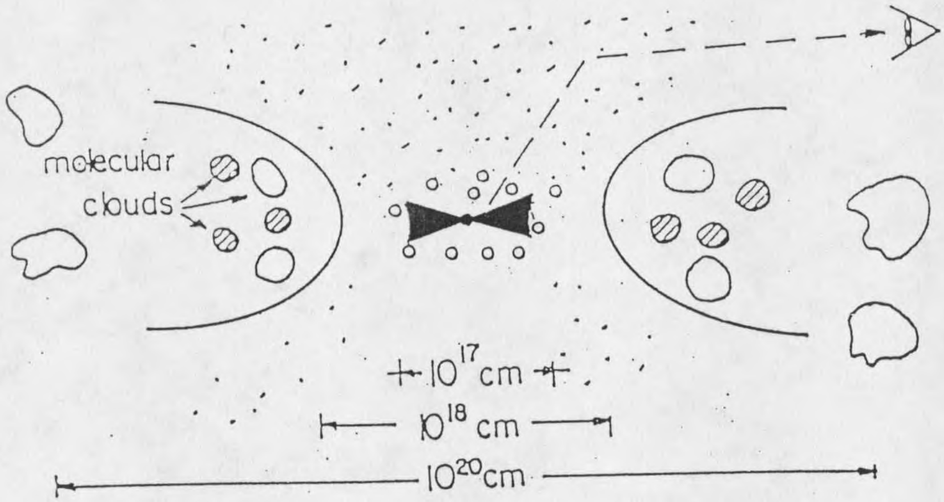

Figure 1.4: This picture of AGN has an axial symmetry about the vertical center of the page. Radio quiet AGN are presumed to have molecular clouds in a torus configuration, electron scattering region, broad line region (the small open circles) and an inner accretion disk (the X shape in the middle). The observed emission therefore depends on the orientation of the observer with respect to the AGN axis. (Adapted from Mushotzky, Done and Fabian 1993.)

Our current picture of the outer regions of radio quiet AGN is: In the outermost regions lies the source of matter to be accreted onto the SMBH. This matter may originate in rich stellar clusters, the inter stellar medium (ISM), or may be the result of cooling flows in clusters of galaxies (Blandford 1990, Rees 1990). We hereafter assume this matter to contain the usual cosmic abundance. Strong narrow lines are emitted by an unknown geometrical configuration of material with atomic number density $10^5 - 10^7 \mathrm{cm}^{-3}$, slightly more dense than the ISM, at distances of order 1 Kpc from the central engine. This material is usually referred to as the narrow line region (NLR, see Netzer 1990). A little closer to the central engine molecular clouds form an axisymmetric 'molecular torus'. The molecular torus may be responsible for the obscuring of parts of the more energetic parts of the spectrum, and is probably responsible for most IR emission. Closer to the center is the Broad Line Region (BLR), the geometry of which is uncertain. The broad line region clouds are the open circles near the center of figure 1-4. From the observed width of the optical lines we know that the BLR matter is moving fast. Other observations reveal the filling factor is small, and the number density of matter is $10^8 - 10^{10} \mathrm{cm}^{-3}$ in the BLR (Netzer 1990). Evidences for a super massive compact object and a superluminous central engine are mostly found from observations of NLR and BLR emission lines

(Netzer 1990).

Closer to the central engine a geometrically thin accretion disk, which is optically thick, is usually considered to be present. In figure 1-4 the disk is represented by the central dark bow-tie shaped region. Matter in this disk is accreted onto the SMBH. This disk is generally considered to emit a significant portion of the total luminosity emitted by AGN in the UV band (the so called 'UV bump'), and may also be responsible for the ionization of clouds in the BLR. The disk configuration is most efficient in the outwards transfer of angular momentum, which allows for high accretion rates. Angular momentum is viscously transferred from accreted matter to outflowing particles and radiation.

Since the model for the outer regions cannot explain the X-ray emission and variability a different, more elaborate, model is needed for the central engine. The model of the central engine must take the accretion disk into account.

Calculations show that the thin accretion disk is thermally unstable near the central engine because the heating due to viscosity exceeds the radiative cooling (see Lightman and Eardley 1974, Thorne and Price 1975). As a result, a geometrically thick disk which can be optically thick (if supported by radiation pressure) or optically thin (if supported by ion pressure in a two-temperature plasma, see Shapiro, Lightman