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THE ORIGIN OF THE JET IN THE ACTIVE GALACTIC NUCLEI

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Abstract. The most recent optical and radio observations of AGN and the discovery of the quasi-periodic oscillations in X-ray binaries reveal the importance of searching the inner edge of the accretion disk assumed to be essential for the formation of the jet in any kind of AGN (either radio galaxy, or radio-loud or radio-quiet quasars, or Seyfert or Blazar, etc.). The discovery of variability of GRS 1915+105 in X-ray and radio has led to interesting results concerning the jet/disk symbiosis at small scale (microquasar scale).

The correlation between radio and the disk luminosities suggests the fact that the inner region of the accretion disk is the foot of the jet and the emissions observed along the jet are consequences of the efficient feeding of the jet from the disk. Following the unified scheme of the AGN, we investigated the jet/disk symbiosis paying attention to the accretion disk structure and the inner geometry of the system. The symbiotic system contains: a black hole, an accretion disk and the jet.

In recent years it was found that the astrophysical jets are the most energetic phenomena in AGN. They are connected to the black holes which are generally assume to exist in any active galactic nuclei (AGN) and to be the main sources of energy for any galaxy.

The AGN show a large variety of objects from the powerful radio galaxies, radio-loud quasars, radio-quiet quasars to Seyfert galaxies, Blazars, LINERS, etc. People ask the question "Are jets in any class of AGN?". An overview of the evidence for astrophysical jets in different types of AGN have been done by Falcke (1998). The recent HST and VLA observations reveal new aspects of the plasma outflows structure in AGN.These observations add bricks to the model that an AGN powered by a black hole fed by an accretion disk *must have jets.*

It is now generally accepted that jets and accretion processes (relativistic accretion disks) are strongly related. The recent review Livio (1997) shows that the accretion disk systems produce outflows and that the budget energy of the jet is controlled by the accretion rate onto the central engine.

It is known that AGN can approximately be divided into two main classes: radio-loud (RL) objects and radio-quiet (RQ) objects. The RL are only 10 percent of the AGN population and they reside in elliptical galaxies, while RQ seems to reside in a mix of spiral and elliptical galaxies (Kukula *et al.* 1997). Despite the differences in radio-loudness, the optical-ultraviolet spectra of both RL and RQ objects are very similar. This is the first indicator that accretion conditions do not differ much in these classes of AGN, since the optical-UV radiation is produced by the accretion disk around a black hole. Therefore, the difference in the radio power of the jet for RL and RQ, comes from the way in which the jet gets energy from the black hole/disk system. This supports the idea that the parameters which determine the total power of the jet and the radio activity of the AGN are those of the inner geometry of the system, nearby the event horizon .

A first way in analyzing the jets and last, but not least the emissions in AGN is to start looking at the inner edge of the accretion disk, the place where now it is believed that the jet is formed.

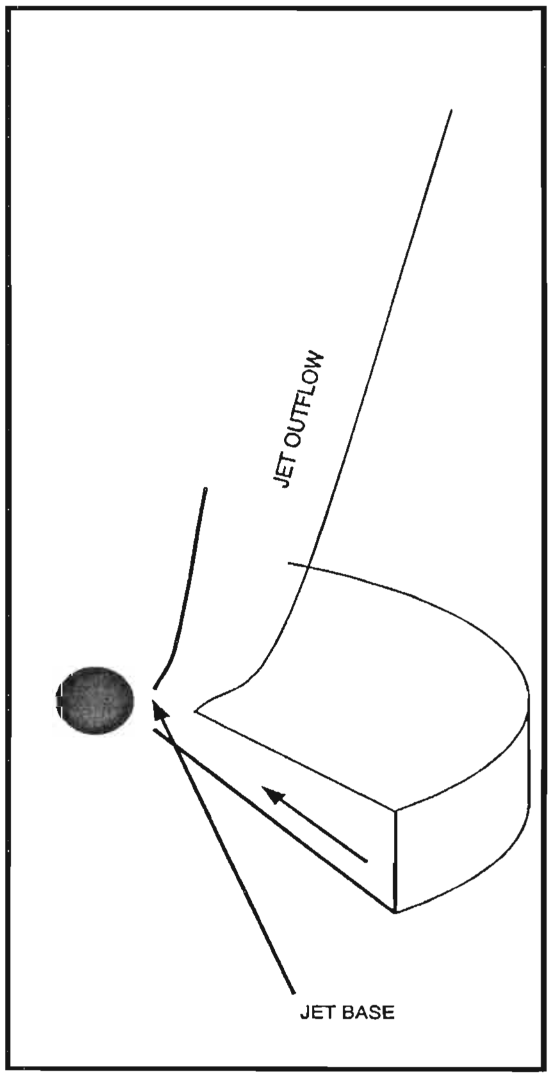

Fig. 1. Sketch of the inner region close to the compact object.

We are already familiar with the general adopted view of an AGN with the three essential constituents: the black hole, the jet and the accretion disk. The black hole may be rotating with the maximum angular momentum equal to $a_\star = 0.9981$, where $a_\star$ is its specific angular momentum divided by the mass of the black hole. The great observed luminosities observed in AGN require supermassive black holes with masses $M \in [10^8 M_\odot, 10^{10} M_\odot]$. The black holes possess deep gravitational potential wells and work like powerful engines. The second constituent is the accretion disk. One generally accepts that disk-like accretion is an efficient mechanism for converting the rest-mass energy into radiation. The jet completes the view of the central part of the quasars.

The notion that the jets and the accretion disks are symbiotically related originated since the first radio and optical observations revealed the parsec-scale of the AGN. Although, there are many uncertainties concerning the origin and the acceleration of the jets, many different types of mechanisms have been proposed for the formation of the jets. We note here the jet model driven by magnetic or radiation pressures (Lovelace *et al.*. (1994)) or the formation of the jet due to the magnetic activity of the accretion disks (Camenzind (1989)).

The standard theories for the emissions in quasars have been developed as results of the elaborated observations done over the whole range of energies of the spectra of quasars. Therefore, Blandford & Königl (1979) explained the emission from compact radio cores. Falcke *et al.*. (1995) add mass and energy conservation of the jet-disk system. The correlation between the accretion disk (UV) luminosity and the radio emission of the quasars (Falcke *et al.*. (1995a)) suggests that the compact core radio emission and the UV bump have a common energy source in all quasars. These elements have led Falcke *et al.*. (1995) to the concept of what we will refer to as jet-disk symbiosis. The standard disk model has been introduced in 1973 by Shakura & Sunyaev (1973) and Novikov & Thorne (1973). One needs to combine these models in order to provide a compact theory for the jet-disk symbiotic system. In the view of this point, we consider that the jet is fed by a geometrically thin disk and we assume that the inner part of the "standard" disk contains all energetic conditions necessary to form and to maintain a stable jet's configuration.

The presence of the jet changes the accretion disk boundary at the inner edge. Since this is the key in understanding the physics of powering the jet people have been looking deeply at the short variabilities in spectra, which may be connected to the inner regions of the accretion disks. The clues on the compact region in AGN may come from understanding at a little small scale of the similar phenomena happening in the stellar systems with black holes .

The most recent discoveries of the quasi periodic oscillations (QPOs) with the Rossi X-Ray Timing Explorer revealed that GRS 1915+105 is a galactic superluminal source having an accretion disk around a black hole of stellar mass. Mirabel *et al.*. (1998) find the correlation between the radio outbursts and the X-ray flares as being done by the fall of the material from the inner edge of the accretion disk into the black hole. Falcke & Biermann (1996) has included already in the unified model of the quasars this source which fits very well into the scheme, at the bottom of the distribution of black holes, jets and disk systems with low luminositites. This shows that, regardless the scale (big black holes or small black hole, core of the galaxies or stellar systems), the simple idea of a jet/disk coupling leds to insight of the origin of the jet.

Adopting the point of view that formation of jet is possible under all circumstances (Falcke 1998), whether there are AGN or stellar size systems, we investigate the effects of the presence of the jet on the structure of the accretion disk, and implicitly on the emission spectrum.

Important results concerning the base of the jet geometry are obtained. We estimate also the total energy delivered into the jet. The key point of the model is that the matter accreted towards a supermassive black hole is the primary source for mass outflows from the inner dense part of a disk and the fact that a large fraction of the energy from the inner disk is not radiated away but dissipated into the jet.

Because the kinetic energy in the jet has to be great enough in order to provide all sources of energy required by the nonthermal processes we stress the fact that a maximally rotating black hole is required. The rotating central object can supply through its gravitational potential well the energy necessary for driving and maintaining a stable jet in the AGN.

We assume that the jet starts between $R_{\rm ms}$, the last marginally stable orbit in the absence of a jet and the radius $R_{\rm jet}$ with $R_{\rm jet} > R_{\rm ms}$, extracting mass, energy and angular momentum from the disk (see Donea & Biermann (1996)). The presence of the jet will modify both the behaviour of the infalling matter across the radius $R_{\rm jet}$ and the structure of the relativistic disk. As we mentioned before, the gravitational potential energy released between the $R_{\rm ms}$ and the outer radius of the jet $R_{\rm jet}$ goes into the jet. Therefore, the total energy carried by the jet outside is strongly dependent on the mass and angular momentum of the black hole. Q_{jet} is the total power of the jet – including the rest energy of the expelled matter – and is expressed as:

$$Q_{jet} = L_{disk} - L_{disk}^{jet}$$

L_{disk}^{jet} is the total luminosity of a disk modified by the presence of the jet and L_{disk} is the total luminosity of the disk if there are no physical conditions to drive the jet. A large fraction of the total power of the jet is in magnetic fields and relativistic particles.

The conservation laws inside the disk are now modified by considering the presence of the jet. We work with two theoretical parameters: $R_{\rm jet}$ and q_m. We define q_m as the ratio between the mass loss rate due to the jet $\dot{M}_{\rm jet}$ and the disk accretion rate $\dot{M}_{\rm disk}$. The mass and angular momentum extraction from the disk makes it thinner and denser. The region between the radius of the last marginally stable circular orbit and the radius where we consider to be the outer radius of the jet no longer shows a disk-like structure.

The most important conclusion of our model is that the relativistic effects and the presence of the jet modify the locally emitted spectrum. In the optical UV range the general form of the spectra is not significantly changed. Most of the UV radiation originates from the inner region of disk outside $R_{\rm jet}$. Due to our theoretical assumption about the energy source of the jets, the shape of the spectrum coming from an "old" standard disk around a maximally rotating black hole is cut off at high frequencies, from extreme UV to soft X-ray range. We get also a small flattening of the spectra in the UV range if we take a thick base of the jet and a maximum ratio $q_m = 0.1$.

Emission lines of ionized helium are among the most important diagnostic indicators in the spectrum of the active galactic nuclei. The clouds surrounding the central active region of a quasar are ionized by the UV photons emitted by the disk. There are some arguments based on the width of the HeII lines emission and their correlation to the UV fluxes and soft X-ray fluxes in AGN. Netzer *et al.*. (1985) calculated the intensity of HeII lines and conclude that the UV continuum has to be approximately flat in νF_ν beyond the last measured point, from $3 \cdot 10^{15}$ Hz to 10^{16} Hz. Our model with a Kerr maximal rotating black hole and a relativistic disk driving the jet can explain the flatness of the spectrum in the UV range.

On the other hand, our disk model driving a jet in the innermost dense regions very close to a maximal Kerr black hole can replace all the simple models of the accretion thin disk surrounding a Schwarzschild black hole. Earlier attempts to fit UV data (Czerny & Elvis (1987)) need a few times the Eddington mass accretion limit, contradicting the geometrically thin disk approximation. We have interpreted the UV fluxes of the quasars working with sub-Eddington accretion rates and taking into account the presence of the jet.

We postulated that the jet and disk around a black hole are symbiotic features which can be found both in all types of active galactic nuclei and around the stellar mass black holes . Using the energy, mass and angular momentum conservation laws of the black hole-disk-jet system we can successfully model the UV "bump" of the quasars. Concerning the jet we conclude that the thickness of the base of the jet is limited by the necessity to have sufficient UV photon flux in order to explain the high luminosity of the disk. The total energy of the jet has the upper bound corresponding to the gravitational potential energy lost by the infalling gas between R_{ms} and R_{jet}.

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