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Unified Models of AGN Accretion Disks and Blazars

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Abstract. Accretion disks around supermassive black holes are expected to be the power sources in all AGNs, including blazars. To date, though, little direct evidence for such disks exists in AGN observations. In blazars, the intense relativistic beaming would mask any underlying disk component. Here we present relevant work that our group at GMU is carrying out on unified aspects of disk accretion onto supermassive black holes and the possible coupling of thick disks to beams in the inner regions.

1. Introduction

The physical nature of the central power source in AGNs has remained one of the most challenging problems in modern astrophysics. At present the most favored model in all AGNs, including the special class of blazars, is the supermassive black hole hypothesis (Rees 1984). In this scenario, gas falling onto the central black hole radiates with a luminosity that can approach the Eddington limit. Despite the attractiveness of this picture, the discovery of the underlying disks still eludes us. Moreover, in blazars one has the additional problem that the brightness of the relativistic jet would obscure any disk contribution even if it were otherwise present. The discovery of powerful γ-ray emitting blazars by EGRET at the beginning of CGRO observations (Hartman et al. 1992) and in the years following, has presented challenges for any non-jet source mechanisms. The observed luminosity from 3C 279 implies a central mass close to $10^{10}\,M_\odot$ if the emission is unbeamed and the source is radiating near the Eddington limit (Becker, Kafatos, & Maisack 1994). The viability of disk models for blazar emission does not, however, imply that disks are not present. In fact, it is difficult to imagine any scenaria utilizing supermassive object where disks would not be present. As such, the issue of developing unified models which would involve both disks and relativistic beams is still a forefront problem in AGN astrophysics. At GMU, we are working on unified models.

2. Disk models

We are utilizing a particular disk model first developed by Shapiro, Lightman and Eardley (1976) and extended by Eilek and Kafatos (1983) to include full GR effects and γ-ray production. The advantage of these hot, ion-dominated disks is that they naturally produce copious amounts of gamma-rays, extending to $\sim$ GeV energies, as well as relativistic electrons and positrons (with Lorentz factors $\sim$ 300) and are, therefore of interest to γ-ray observations. The inner region of an ion-dominated disk is quasispherical, h/r $\sim$ 1 and $T_i \gg T_e \sim 10^9$ K. If Coulomb collisions is the only means of energy exchange between protons and electrons, protons do not have enough time to establish a common temperature with electrons, the latter radiate much more efficiently and consequently protons become very hot. Proton-proton collisions in the ion-dominated region produce pions which subsequently result in electron/positron production with positrons dominating the production outcome. Although the disk formalism is applied here as well (with the usual assumptions of slow infall velocities, small or zero vertical flow velocities and spatially-thin disk structure) it is obvious that the disk formalism is strained in these regions. For example, if h/r $\sim$ 1, one would expect appreciable flows in the z- and θ-directions which may take on the form of circulation patterns as revealed in numerical simulations. Finally, the material quickly falls onto the central object at radii close to the marginally stable radius, which occurs at 1.2 r_g for canonical Kerr black holes and 6 r_g for Schwarzschild black holes. A schematic diagram is shown in Figure 1.

The hot inner region eventually connects to a standard, radiation- dominated Shakura and Sunyaev region (Shapiro, Lightman, & Eardley 1976), expected to occur at $\sim$ 30-50 r_g (Eilek & Kafatos 1983). There, electrons and ions achieve a common temperature, $T \sim 10^7$ K or less.

A crucial element in many disk scenaria, including the ion-dominated disk, is the operation of Comptonization (Sunyaev & Titarchuk 1980). In the ion-dominated regions, Comptonization of softer, cool disk radiation by the hot electrons produces a power-law photon spectrum extending to hard X-rays/soft γ-rays, $\sim$ several 100 keV. Recently, Chakrabarti and Titarchuk (1995) have examined a variety of Comptonization scenaria in the inner accretion disk regions. They find that shocks may form in the transition region between the two-temperature, ion-dominated and cooler, standard disk. Recently, Becker (in progress) has been examining the physics of strongly radiating shocks. It is not immediately obvious where shocks could be located and the possible locations have been examined in idealized fully-relativistic inviscid flows (Kafatos & Yang 1994; Yang & Kafatos 1995). The existence of shocks may be an element to account for the mysterious QPO behavior seen in galactic black hole candidates (c.f., Yang & Kafatos 1995). In Chakrabarti and Titarchuk's picture, the shocks provide the requisite seed photons for Comptonization (Figure 1).

3. Viscosity mechanisms

Ever since the seminal work of Shakura and Sunyaev (1973), the precise physical mechanism for viscous angular momentum transfer and energy loss has remained a mystery. Fortunately, the emitted spectrum is not strongly dependent on the details or actual values of the viscosity parameter, α (c.f., Pringle 1981). It has been generally assumed that turbulent viscosity may be operating in the standard Shakura and Sunyaev scenaria with precise values being unknown, although $\alpha < 1$. Other viscosity mechanisms have been proposed, including ra-

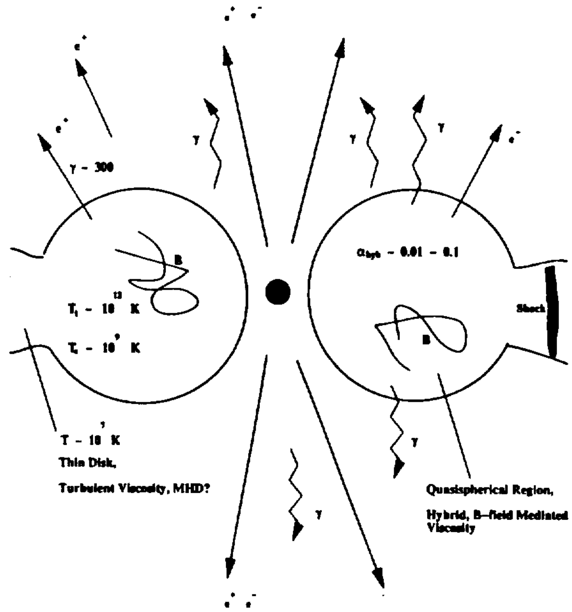

Figure 1. Unified disk/beam scenario in a blazar

diation viscosity (Loeb & Laor 1992) and MHD-driven viscosity (Eardley & Lightman 1975).

Recently, we have achieved a breakthrough in viscosity mechanism applicable to hot ion-dominated disks (Subramanian, Becker, & Kafatos 1996). We have examined the viscosity associated with the shear stress exerted by ions in the presence of a tangled magnetic field (Figure 1). We have taken a self-similar field with a coherence length that is a fixed fraction of the disk scaleheight h. We have arrived at a "hybrid" formulation for the viscosity in which the tangled magnetic field acts as an intermediary in the transfer of momentum between different layers in the shear flow. Consequently, the ions play a much larger role in the transfer of momentum in the presence of B-fields than was previously thought. The hybrid viscosity can dominate over conventional magnetic viscosity for fields that are tangled on sufficiently small scales.

4. Towards unified models of AGNs and Blazars

The observational situation with respect to blazars generally indicates the existence of synchrotron/self-Compton (SSC) mechanism (see articles in present volume). BL Lac spectra like that of Mk 421 (Macomb et al. 1995) indicate the presence of two broad components, centered in the microwave–optical and X-ray–γ-ray regions (synchrotron and self-Compton, respectively). One blazar, however, may be prototypical of the presence of both a jet and a disk, 3C 273 (Ramos, Kafatos, & Fruscione 1996). The UV/EUV peak seen in 3C 273 may be indicative of the presence of an underlying accretion disk.

If indeed this is the case, it may point to a path towards a unification of AGN models. Whereas relativistic beaming is probably operating in blazars, it is hard to see how just a beaming can explain the whole picture without invoking another component, the disk, which is the ultimate power source of the central engine and probably contains the majority of the energy. Becker and Kafatos (1995) have shown that the $\gamma - \gamma$ transparency constraints in extreme blazar sources like 3C 279 allow the EGRET γ-rays to be emitted close to the central black hole, within 45 GM/c^2, perhaps in the active plasma located above the central funnel of the accretion disk (Becker, Kafatos, & Maisack 1994). The steps towards unification in AGNs and specifically blazars involve the following:

- Comptonization/two-temperature disk $\longrightarrow$
- stochastic MHD acceleration in evacuated funnel $\longrightarrow$
- Lorentz factors $\sim$ 2,000 $\longrightarrow$
- γ-ray focusing along axis of rotation $\longrightarrow$
- pair escape in the high-radiation environment of the accretion disk $\longrightarrow$
- focusing of pairs along axis of rotation $\longrightarrow$
- boundary conditions at base of beam near thick accretion disk $\longrightarrow$
- observed properties?

In this prescription, one has an orderly progression to the phenomenology of jets based on principles and mechanisms that are reasonable.

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