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GAMMA-RAY FLARES IN AGN

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I. INTRODUCTION

Active galactic nuclei have long been suspected as being sources of gamma-rays. For example, 3C 273 was observed by *COS B* (Swanenburg *et al.* 1978) to be a strong source of gamma-rays in the range 50-500 MeV. The small number of gamma-rays involved even in the strongest extragalactic gamma-ray sources prevented astronomers from determining if gamma-rays were highly variable.

The inner regions of accretion disks onto supermassive black holes can become unstable when the existing temperatures are sufficiently high (Shapiro, Lightman, and Eardley 1976; Eilek and Kafatos 1983). This naturally occurs for two-temperature disks in the case of rapidly spinning (Kerr) black holes. Physical effects in the hot, inner regions are such that non-steady flows can result. We here focus on three such effects which would be relevant in producing variability in intense gamma-ray sources (MeV to GeV range), such as the recent discovery of strong gamma-ray emission in 3C 279 discovered by the EGRET instrument on board the *Compton Telescope* (Hartman *et al.* 1991).

II. VARIABILITY IN THE INNER ACCRETION DISK

Theoretically predicted effects may have relevant observational consequences. The first effect relates to the production of the most energetic (GeV) e^+e^- pairs in a hot disk scenario via Penrose pair production (Kafatos and Leiter, 1979; Kafatos 1980). Such a production is intrinsically a gravitational effect. Order of magnitude estimates are easy to obtain because the natural timescales associated with it would be the light travel time in the ergosphere, 8000 M_8 sec where M_8 is the central mass in 10^8 solar masses. Penrose pair production (PPP) would yield pairs up to $\sim 4\ m_p c^2$ or ~ 4 GeV with an approximately exponential distribution that over a limited energy range would fit a power law. The pairs would be emitted in bursts as long as a source of copious gamma-ray emission existed close to the horizon. An ion-dominated inner accretion disk could be the source of seed gamma-rays needed to produce the pairs via scattering with the protons.

The second relates to the existence of an intrinsic dynamical effect that operates even when the disk is assumed to, initially, be steady-state. Instabilities of standard disks, two temperature disks and ion-supported tori have been extensively discussed in the literature (e.g. Lightman and Eardley 1974; Shapiro, Lightman and and Eardley 1976). Eilek and Kafatos (1983) assumed that a steady flow occurs. It is likely, however, that the dynamic (Coulomb) viscosity is very large when the temperatures are sufficiently high. Both the two-temperature model with $T_i \sim 10^{12}$ - 10^{13} °K (Eilek and Kafatos 1983) and the hot corona model with $T \sim 10^{11}$ °K (Liang and Thompson 1980) would be subject to large viscosities,

$\alpha \sim 37\ (\dot{M}_*/M_8)^{3/7}\ r_*^{-9/28}\ y^{-3/7}$ and

$\alpha \sim 1.2\text{x}10^4\ (\dot{M}_*/M_8)^{12/7}\ r_*^{-18/7}\ b^{6/7}$,

respectively, when the accretion rate is sufficiently close to the Eddington limit, $0.01 \lesssim \dot{M}_*/M_8 \lesssim 1$. Here $\dot{M}_*$ is the accretion rate in $M_\odot\ yr^{-1}$, y is the Comptonization parameter and r_* is the radial distance in units of gravitational radii.

When the viscosity parameter α exceeds unity, the disk will collapse over dynamical timescales (Shakura and Sunyaev 1973). Such a collapse would trigger a flare in an AGN. The gas would then return to a quasi-steady accretion until the temperature in the inner disk or hot corona builds up again. It is clear that these provide for time-dependent conditions where Comptonization is an important process in the accreting/collapsing gas. Since high viscosities imply copious production of gamma-rays (MeV - several 100 MeV) and energetic (70 MeV) pairs, this mechanism would be relevant to AGNs observed both by OSSE and EGRET.

These ideas provide the possibility of, at least, a variable accretion flow.

On the topic of steady-flows, the requirement of steady accretion flow in real astrophysical sources is probably an oversimplification. Accretion into black holes may actually not follow the usual steady inflow process assumed in standard disks. Accretion onto black holes may always be a transonic phenomenon with the transonic radius close to the black hole if the accretion occurs in a thin disk configuration (Liang and Thompson 1980).

At George Mason University, we have have developed the relativistically correct continuity and Euler's equations in the Kerr metric ignoring viscosity terms. We have numerically solved the resulting inflow assuming a polytropic equation relating the pressure to the density for the special case of Schwarzschild metric. For a variety of initial conditions in the

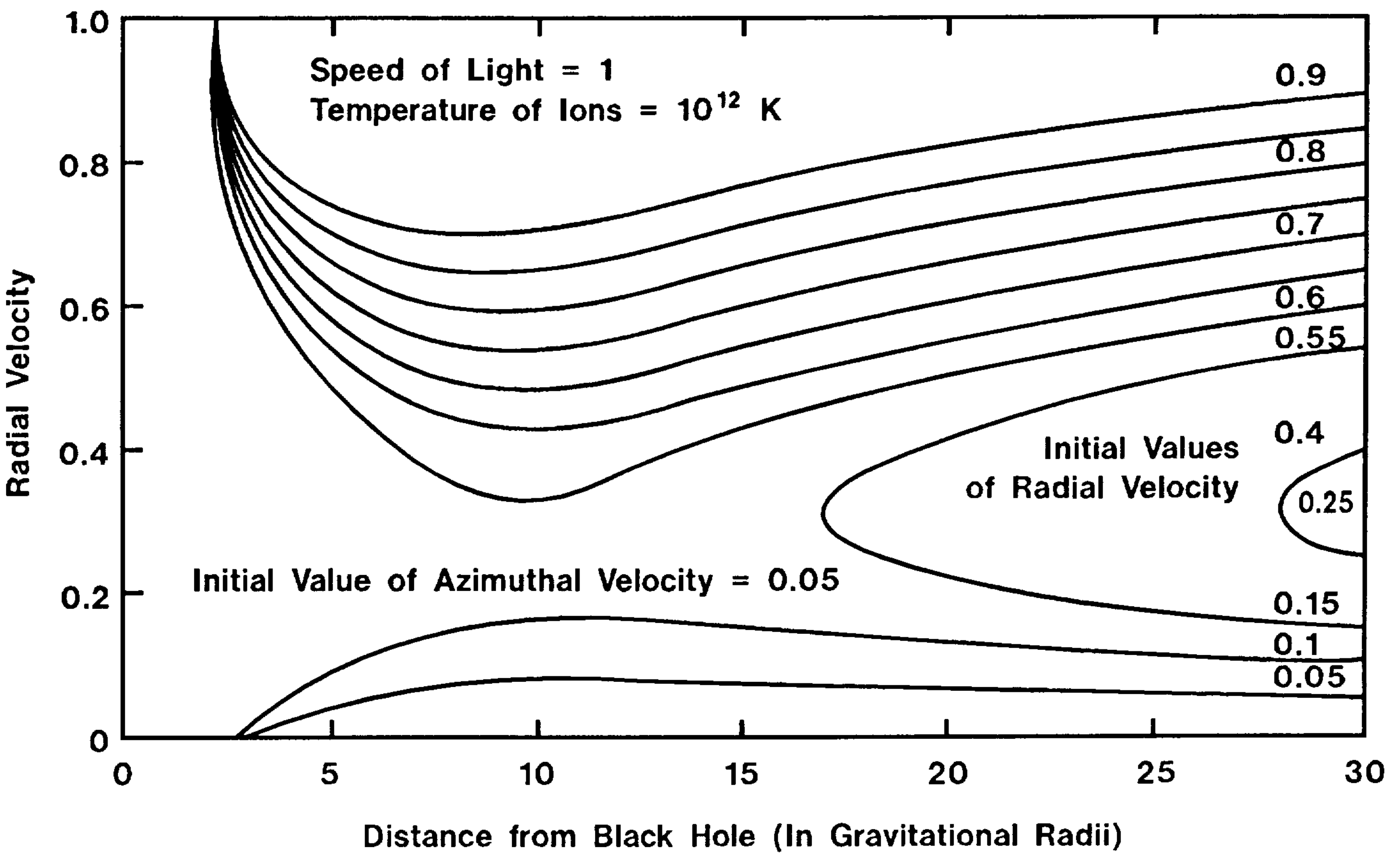

Figure 1: Steady transonic flow in the Schwarzschild metric (in units of c = 1)

isothermal case, we find that the velocity of the flow becomes supersonic and rapidly approaches the speed of light for radii closer than about 30 r_g (see Figure 1). We are presently in the process of examining the case of isentropic flow in the Schwarzschild metric.

We emphasize that that the inclusion of viscosity would enhance the effect of transonic solutions since angular momentum would be lost and the inflow would be even more rapid. The existence of these effects will result in the collapse of the inner disk whenever the ion temperatures become sufficiently high and would, therefore, also be relevant to strong gamma-ray AGN sources, and specifically 3C 279. It follows that considerations of whether accretion disks in the centers of AGNs exist or not cannot ignore the flow of the gas close to the horizon and the associated instabilities. The *Compton Telescope* could provide important insights in our understanding of inner accretion disk flows.

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