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New Instabilities in Accretion Flows onto Black Holes

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ABSTRACT

The accretion disks are usually supposed symmetric to reflection on the Z=0 plane. Asymmetries in the flow are be very small in the vicinity of the compact accretor. However their existence can have a important role in the case of subkeplerian accretion flows onto black holes.These flows lead to strong heating and even to the formation of shocks close to the centrifugal barrier. Large asymmetries are due to the development of the KH instability triggered by the small turbulences at the layer separating the incoming flow from the outcoming shocked flow. The consequence of this phenomenon is the production of asymmetric outflows of matter and quasi periodic oscillations of the inner disk regions up and down the Z=0 plane.

Key Words : accretion, accretion disks — black hole physics — hydrodynamics — Instabilities — shock waves

I. Shocks in sub-keplerian flows

The theory of shock formation in accretion flows onto black holes is now well developed. The fact that a shock can be formed in a sub-keplerian accretion flow is straightforward and well known from the work of Hawley et al. 1984: gaseous matter possessing low angular momentum at large distances from a gravitational source will fall down untill the eventual centrifugal barrier stops and shocks it. However in this plain scenario the shock, so produced, is not steady and it expands outwards and therefore it reduces its efficiency to convert gravitational energy into radiation. Shock stability is therefore important: only its stability or permanence in some constrained spatial range, can offer a process producing high energy radiation emission from black holes. Since 1990 Chakrabarti formulated the analytical theory of the transonic rotating flows, leading to the prediction of the possible shocks locations. At that time it was not clear which position nature would chose among the different shock positions, allowed by the Rankine-Hugoniot relations, and it was also speculated that some form of cyclic behaviour would be possible. In 1993 Chakrabarti and Molteni performed numerical simulations showing that a steady shock can be formed, confirming analytical prediction of Nakayama, 1992. It is now clear that it exist a wide range of initial values of temperature and angular momentum (per unit mass) producing steady shocks around black holes typically at radii ranging from few R_g (R_g be the Schwarzschild radius) up to hundreds R_g. Analytical theory has been supplemented by numerical experiments and viceversa numerical simulations disclosed new scenarios: matter outflows from post shock region, nuclear enrichment, time variability. For a review of the subject see Chakrabarti 1998.

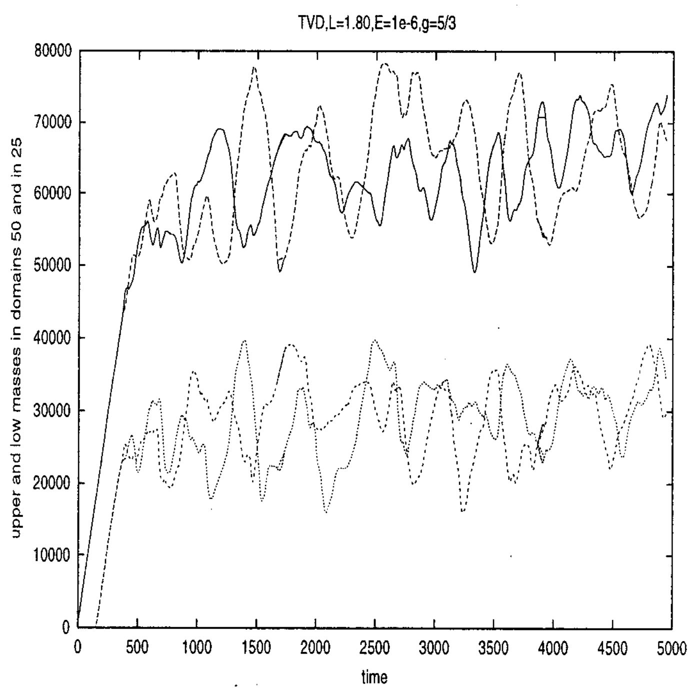

Fig. 1 : Up and down masses of the disk (within R=50 and R=25) versus time

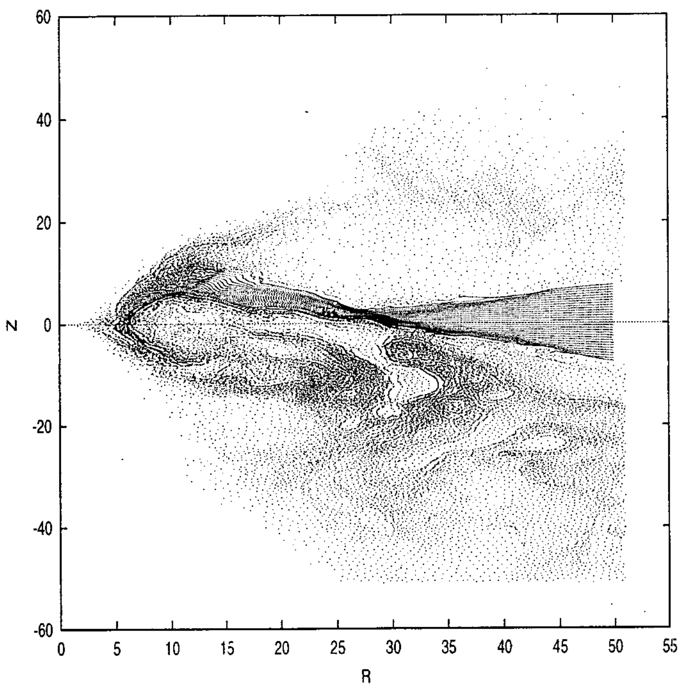

Fig. 2 : R-Z distribution of the SPH interpolation points

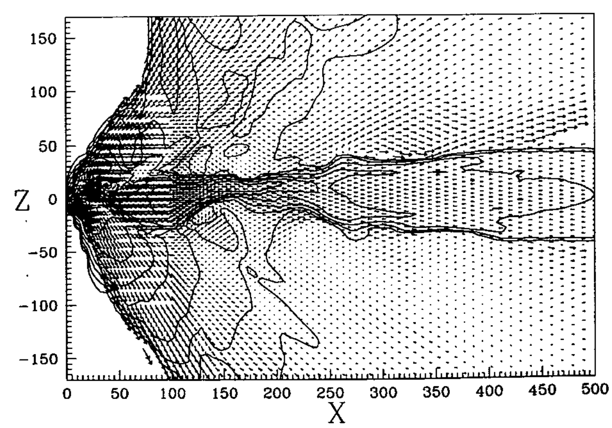

Fig. 3 : Isodensity contour and velocity field of the accretion flow

(a) Shocks variability

Numerical simulations have shown that different kinds of oscillations may occur in the shocked flow. The study of the time variability is still in its beginning. Even in the very simple case of no real cooling and no viscosity it is possible to have quasi periodic axis symmetric oscillations if the initial temperature at the far inflow position is very low (Ryu et al. 1997). In the same physical conditions it has been shown that azimuthal oscillations of the shock are possible if a break of the initially circular symmetry of the shock occurs (Molteni et al. 1999). It has been explored also the effect cooling and of viscosity. In the case of very plain cooling, e.g. bremsstrhalung, quasi periodic oscillations are produced like in the accretion column in White Dwarfs (Molteni, Sponholz 1995). The centrifugal barrier is strong enough to act as a 'hard' surface and triggers the oscillations. The time scale for these oscillations is typically of the order of the cooling time. The role of viscosity, in the typical form of Shakura Sunyaev (1973), has been studied both analytically (Chakrabarti 1990) and numerically (Chakrabarti and Molteni 1995, Lanzafame et. al 1998). The viscosity may damp out the shock and make it to disappear for large α, while for smaller values oscillations are again exhibited.

(b) Breaking of the Z = 0 symmetry

In this communication we examine a new scenario: the breaking of the Z=0 symmetry. It is quite common to assume that the flow is symmetric under reflections on the Z=0 plane. This is usually reasonable if the inflow condition are simmetric to the equator. All previous studies have been done with this hypothesis. This fact is also particularly convenient for numerical simulations since it allows reducing by half the integration domain. Small asymmetries are quite posible on account of natural inhomogeneities and fluctuations. It is therefore believed that the asymmetries should remain small. We started to make full disk simulations stimulated by an unsatisfactory behaviour (later successfully compensated) of the boundary condition at Z=0 in the numerical algorithm. The full disk simulations revelead that sometimes strong departure from symmetry was produced. We are now starting a more detailed study. We observe that for low temperatures and moderate angular momentum the asymmetry is strong and an oscillating quasi periodic behaviour of the disk part close to the BH occurs. Typical input values are evaluated from the analytical solutions due to Chakrabarti (1990). The disk oscillates above and below the Z=0 plane, producing also asymmetric outflows of matter. This behaviour is shown in Figures 1 where the masses of the disk within radii 50 and 25 above and below Z=0 are shown versus time. Figure 2 shows the interpolation points (SPH particles) in the r-z plane. Figure 3 shows the isodensity contours and the velocity field resulting from simulation with the TVD code. The deformed structure of the disk appears clear. We suggest the following explantion of the instability. The flow we consider has two components with opposite speeds: one inflowing supersonic disk and one outflowing subsonic hot wind generated at the shock. Kelving Helmotz instability may easily be triggered in this opposite flowing currents. The bremstrahlung cooling, proportional to squared density, enhances the initially small inomogeneities.

The phenomenon disappears for large angular momenta and for large initial temperatures. In the case of large angular momentum values the shock region (if it exist) is very far from the black hole and large amount of matter accumulates. In the case of large initial temperature the disk is geometrically thicker and suffers less distortions from the outflowing matter.

We suggest that this asymmetric phenomenon may provide a physical support to the model of QPO activity in black holes candidates proposed by Titarchuk L. and Osherovich V., 2000.

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