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Wind Induced Instabilities in Accretion Flow Around Black Holes

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Abstract. We identify a new type of instability of the accretion flow which is formed due to interaction of the outgoing winds with the incoming flow. Mainly due to shear instability, the flow oscillates aronud the equatorial plane. We show that in the shocks are formed in accretion flows, this new type of oscillation persists along with the usual radial oscillation.

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

1. Introduction

Accretion onto a black hole in a binary system takes place in the plane of the companion orbit. In the case of supermassive black holes at the galactic centre, matter still accretes on a plane, since it is likely that it will have some angular momentum. Close to a black hole, matter has little time to loss angular momentum due to viscous forces and therefore accretes with almost constant angular momentum. Since close to a black hole, the centrifugal force becomes very prominent, it slows down matter and if conditions are satisfied, a standing shock is formed (Chakrabarti, 1990). Time dependent numerical simulation indicates that these shocks are stable (Chakrabarti & Molteni, 1993; Molteni, Ryu & Chakrabarti, 1996) and in presence of cooling, they exhibit radial oscillation with time-scales comparable to the cooling time-scale (Molteni, Sponholz and Lanzafame, 1996). Meanwhile, Pringle (1996) and Maloney, Begelman and Pringle (1996) showed that in presence of outgoing radiation force, a disk may develop warping instability. Recently, Molteni et al. (2001ab) pointed out that in presence of strong winds, the accretion flows may also develop a bending wave instability and argued that this may be due to a strong shear generated at the interface between the disk and the outflowing wind. Here we present an example of such an instability. We also present a new result that when the flow contains a shock, it exhibits both vertical (shear effect) and horizontal (cooling effect) oscillations.

2. Solution Procedure

We assume a central black hole with a mass $M_{BH} = 10^8 M_\odot$. We use Smoothed Particle Hydrodynamics (SPH) for the time dependent simulation. We inject sub-Keplerian matter at a radial distance of $x = 50 r_g$ with $r_g = 2GM_{BH}/c^2$, where G is the gravitational constant and c is the velocity of light. We measure lengths, velocity and time in units r_g, c and r_g/c respectively. We include cooling due to bremsstrahlung.

In the first simulation, matter is assumed to have a specific angular momentum $\lambda = 1.95$, polytropic index $\gamma = 5/3$, radial velocity (at $r = 50$) $v = 0.1240$ and sound speed $a = 0.0249$. These input parameters correspond to a smooth flow without a shock in the vertical equilibrium model (see, Chakrabarti, 1990). Figure 1 shows the velocity field at times $T = 3000$ and $T = 13000$ (marked). For clarity we plot one arrow out of three. In the upper panel, the disk is bent in the upper half and in the lower panel the disk is bent in the lower half. On the top of this, there are evidences of shear instability on the surface with an wavelength of about $3 - 5h(r)$. The global bending is due to lift of the disk from the plane because of Bernoulli's effect and the surface instability is due to the Kelvin-Helmholz instability. The simulation also shows asymmetric outflows.

In Fig. 2, we plot results of another simulation when a standing shock is not expected in the flow (Chakrabarti, 1990), but in presence of turbulence it forms (see, Molteni, Ryu & Chakrabarti, 1996). The input parameters at $r = 50$ are $a = 0.06146$ and $v = -0.06821$ and specific angular momentum is $\lambda = 1.65$. We add cooling due to bremsstrahlung as before. In two panels, we present the nature of oscillation at two different times ($T = 16485$ on left and $T = 16811$ on right). The velocity vectors only within $r = 20$ are plotted for clarity. The times are so chosen that the shock locations are at the extreme points ($r_s \sim 12$ on left and ~ 14 on right) during its radial oscillation. Vertical oscillation also takes place and as a result some asymmetry is observed. However, it does not disrupt the shock.

In Fig. 3, we show oscillations in this case more clearly. Open boxes are drawn for $T = 16485$ and filled boxes are drawn for $T = 16811$. Mach number (v_x/a along y-axis) vs. radial distance (x-axis) is plotted. In the upper panel, paricles have $|z| \leq 4$. These are close to the equatorial plane. Two locations of the shock at two times roughly correspond to the extreme values of shock location. Notice that because of cooling, the shock location is closer to the black hole ($r \sim 12 - 14$) compared to that ($r \sim 25$) presented in Molteni, Ryu and Chakrabarti (1996). In the middle panel particles have $15 < z < 20$ and in the lower panel particles have $-15 > z > -20$. Note the asymmetry of the results in the upper and the lower half. These shocks are weaker, as they are oblique.

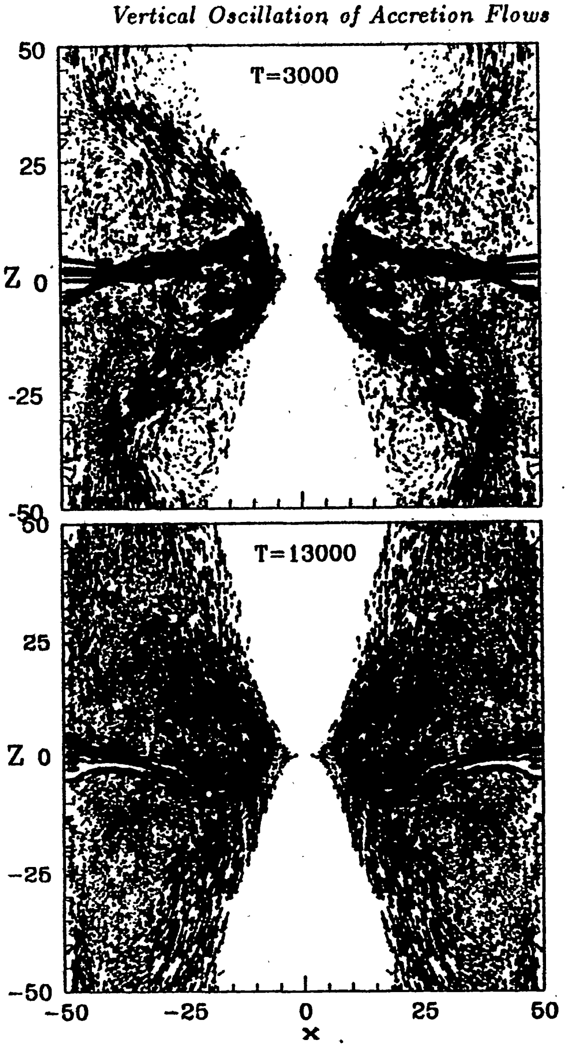

Figure 1. Bending wave instability of the accretion flow in presence of strong outgoing winds at $T = 3000$ and $T = 13000$. For every three velocity vectors, only one is plotted for clarity.

3. Conclusion

In this paper, we demonstrated that in the presence of strong outflows the disk develops a vertical oscillation. However though for thin flows without shocks, the disk is totally bent, in presence of accretion shocks, the deformity is less. The shock exhibits both radial and vertical oscillations. Observationally these oscillations are expected to modulate hard photons from the post-shock region and produce quasi-periodic oscillations. Details would be discussed else where.

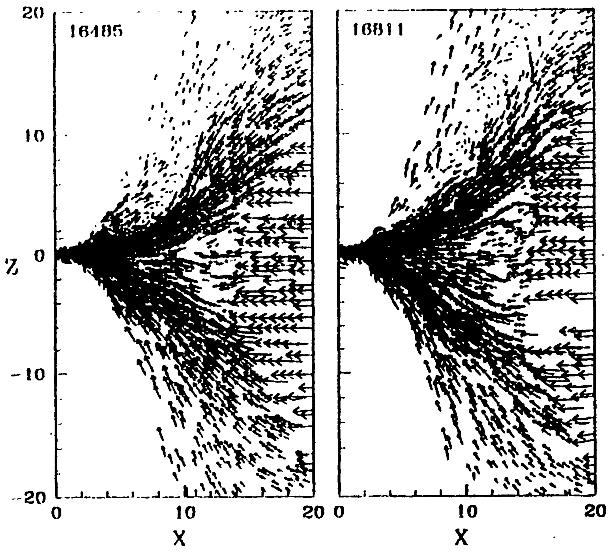

Figure 2. Vertical and radial oscillation of the shock front in an accretion flow at two different times (marked). Time scale of radial oscillation is about 700.

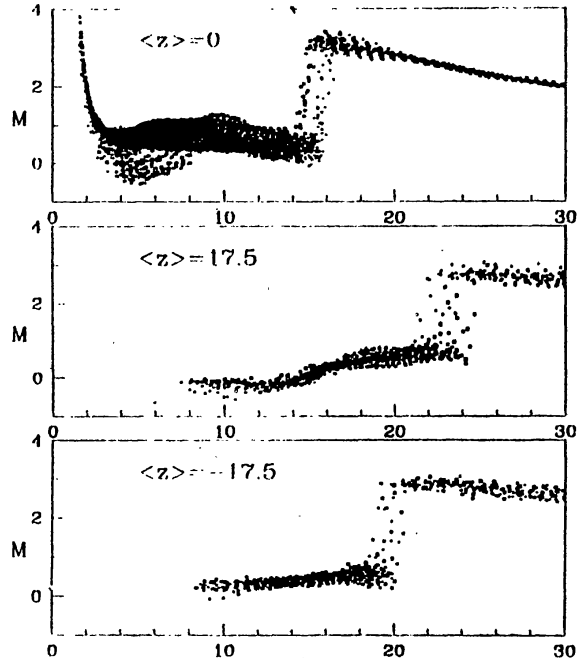

Figure 3. Mach number vs. radial distance is plotted for matter close to the equatorial plane (upper panel), above the equatorial plane (middle panel) and below the equatorial plane (lower panel). Open boxes are for $T = 16485$ and filled boxes are for $T = 16811$. Both horizontal/vertical oscilations are seen.

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