High Energy Processes and Phenomena in Astrophysics
IAU Symposium, Vol. 214, 2003
X. D. Li, V. Trimble, and Z. R. Wang, eds.

Non-axisymmetric Instabilities in Shocked Accretion Flows

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Abstract. We investigate the stability of shocked inviscid isothermal accretion flows onto a black hole. Of the two possible shock positions, the outer one is known to be stable to axisymmetric perturbations, while the inner one is unstable. Our recent work, however, shows that the outer shock is generally linearly unstable to non-axisymmetric perturbations. Eigenmodes and growth rates are obtained by numerical integration of the linearized equations. These results offer new perspectives to interpret the variability of X-ray binaries.

Accretion flows generally suffer from local and global instabilities. Nakayama (1992) and Nobuta & Hanawa (1994) studied shocked inviscid isothermal accretion flows around black holes and concluded that post-shock acceleration should cause instability. Of the two possible shock positions, the inner one is thus unstable while the outer one is stable. This conclusion, however, is based on axisymmetric perturbations.

Foglizzo & Tagger (2000) considered non-axisymmetric perturbations and found a new instability between a stationary shock and a sonic surface, which is based on a cycle of entropy/vorticity and acoustic waves in this subsonic region. Foglizzo (2001,2002) studied shocked Bondi accretion flows and found that: (i) the vortical-acoustic instability occurs when the post-shock Mach number is very small, $M_{sh} \ll 1$ (e.g. strongly shocked isothermal flow), (ii) the entropic-acoustic instability occurs when the temperature of the sonic point is much higher than that of the shock, $T_{sonic} \gg T_{shock}$ (e.g. adiabatic Bondi flow).

Looking for similar instabilities in shocked flows with angular momentum, we first considered an inviscid and isothermal flow for the sake of simplicity. The most unstable eigenmode was found using a standard linear stability analysis (perturbations proportional to $e^{-i\omega t+im\varphi}$) and a Runge-Kutta numerical method. In our calculation, the azimuthal wave number m was set to 1. To our surprise, we found that the outer shock is generally unstable to non-axisymmetric perturbations even for a very weak shock. An example is shown in Fig.1, which is stable to axisymmetric perturbations (Nobuta & Hanawa, 1994), but unstable to non-axisymmetric perturbations.

What is the mechanism for such instability? In the above example, there is no entropy perturbations since the flow is isothermal. Besides, the vortical-acoustic instability should not be strong because the post-shock Mach number is not very low, $M_{sh} = 0.39$. We argue that the mechanism is based on the purely acoustic cycle between the sonic point and the shock, resulting from the

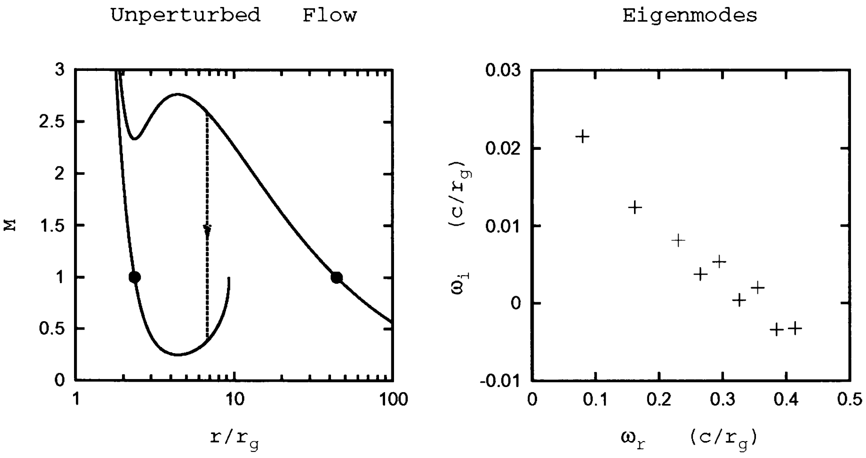

Figure 1. Left: Radial profile of the Mach number in the unperturbed flow, for which the sound speed $c_s = 0.1c$, the angular momentum $l = 1.87cr_g$, and the shock position $r_{sh} = 6.8r_g$. Right: Real and imaginary parts of the eigenfrequencies in this shocked flow. The positive values of ω_i correspond to unstable modes, while the negative ones correspond to stable modes. The eigenfrequency of the most unstable mode is $\omega = (0.0796 + 0.0215i)c/r_g$.

corotation resonance. It is thus a form of the Papaloizou-Pringle instability (1984), modified by advection and particular boundary conditions.

Our linear calculation supports the results of Molteni et al. (1999) who did numerical simulations of adiabatic accretion flows and found that the outer shock is generally unstable to non-axisymmetric perturbations. The instability saturates at a low level, and a new asymmetric configuration develops, with a strongly deformed shock rotating steadily. They also pointed out that this effect may have relevant observational consequences, such as quasi-periodic oscillation (QPO).

Conclusion: *Despite the post-shock deceleration, the outer shock is generally unstable to non-axisymmetric perturbations.*

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