

Properties of accretion shock waves in viscous flows with cooling effects

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We study the properties of the shock waves for a viscous accretion flow having low angular momentum in presence of synchrotron cooling. We present all possible accretion solutions in terms of flow parameters. We identify the region of the parameter space for steady and oscillating shocks and show the effect of various energy dissipation processes on it. We discuss the role of the shock waves while explaining the observations from black hole candidates.

Keywords: accretion, accretion disc – black hole physics–shock waves.

1. Introduction

The shock induced accretion flow is currently one of the most promising self-consistent hydrodynamical accretion disk model, since it explains the spectral states of black holes as well as quasi-periodic oscillations (QPOs) most satisfactorily (^{3,4} and references therein). Since then, various groups of workers extensively studied the properties of the shock waves (e.g.,^{1,2}) in different astrophysical contexts. A fully self-consistent solutions of isothermal, viscous transonic flows was obtained by Chakrabarti³ considering sub-Keplerian flow at the inner part of the disc. In a rotating accretion flow, centrifugal force acts as a barrier^{4,5,7} that triggers the flow to undergo shock transition at a location where the Rankine-Hugoniot shock conditions (hereafter RHCs) are satisfied. However, so far, the study of viscous flows in presence of Synchrotron cooling has not been done. In the present paper, we concentrate on the study of a stationary, axisymmetric, viscous accretion solutions around a Schwarzschild black hole in presence of Synchrotron cooling. The space-time geometry around a non-rotating black hole is approximated by the pseudo-Newtonian potential.¹⁰ We study all the relevant dynamical flow variables in terms of the in-flow parameters. We identify the solution topologies which are essential for shock formation. The effects of viscosity and cooling are expected to be different while deciding the dynamical structure of the accretion flow since cooling reduces the flow energy while viscosity not only tends to heat the flow but transports the angular momentum from inner edge to the outer edge. We find that shock waves, standing or oscillating, can form even at a very high dissipation limit. The hot and dense post shock flow is the natural site of the hot radiation in the accretion disc and is believed to be a powerful tool in understanding the spectral properties of black holes,⁶ QPOs of the hard X-rays^{9,11} and the formation of the accretion-powered relativistic bipolar outflows/jets.⁸ In this paper, we discuss these issues.

2. Results and Discussions

A set of classical shock solutions are presented in Fig. 1a in terms of viscosity (α) and/or cooling parameter (β). We inject matter sub-sonically at the outer edge of the disc $x_{inj} = 145$ with local energy $\mathcal{E}_{inj} = 3.3663 \times 10^{-3}$ and angular momentum $\lambda_{inj} = 1.725$. Solid vertical line represents the shock location for non-dissipative ($\alpha = 0$ and $\beta = 0$) flow. When $\alpha \neq 0$, the shock front moves inward depicted by the dashed vertical line. In an accretion flow, viscosity transports angular momentum outwards causing the reduction of the centrifugal pressure and at the same time, the viscous heating increases flow energy. Since the shock moves forward as $\lambda(x)$ get reduced, we can conclude that the centrifugal force is the primary cause for shock formation. When $\beta \neq 0$, the shock location again proceeds towards the horizon. In the hot and dense post-shock flow cooling is more efficient which reduces the post-shock pressure causing the shock to move forward further. When both $\alpha \neq 0$ and $\beta \neq 0$, shock location is predicted at $x_s = 18.62$ and is indicated by vertical dot-dashed line. Here, the shock front is shifted significantly due to the combined effects of viscosity and cooling.

In Fig. 1b, we separate the regions of the parameter space spanned by the specific energy (\mathcal{E}_{in}) and specific angular momentum (λ_{in}) at the inner sonic point (x_{ci}) according to the flow topologies for $\beta = 0.00787$ in inviscid limit. Solid boundary represents the region for closed topologies passing through x_{ci} . At the inset, all possible solutions [Mach number vs. $\log(x)$] with parameters chosen from different region of the parameter space are presented. The box S represents the shock solution. The box OS shows an accretion solution having oscillating shock. For higher cooling, we obtain a new solution topology as shown in box CIM. We draw this solution with dotted curve as it is obtained for higher cooling parameter. The solution I passes directly through the x_{ci} before entering into the black hole. The solution O represents a flow which passes through the outer sonic point (x_{co}) only. The box

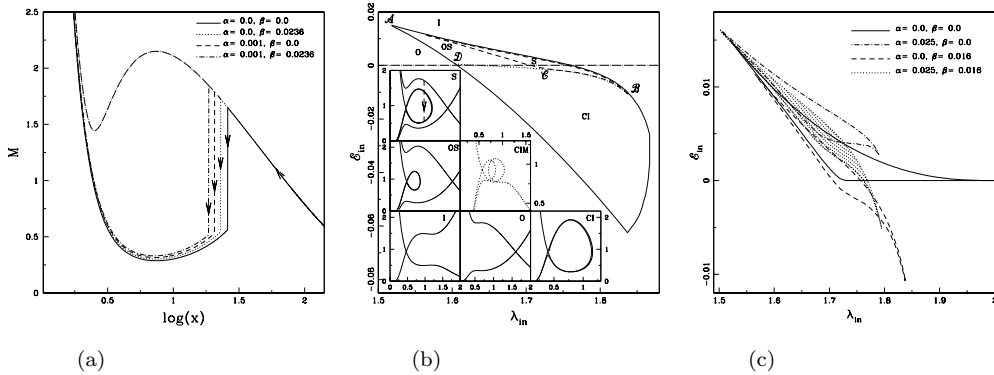


Fig. 1. (a) Variation of Mach number with the logarithmic radial distance. Dissipation parameters and corresponding shock locations are marked. (b) Sub-division of parameter space in the $\mathcal{E}_{in} - \lambda_{in}$ plane according to the nature of solutions. (c) Variation of the parameter space for standing shocks for different dissipation parameters (marked).

CI shows a closed flow solution passing through x_{ci} . This type of solution does not extend to the outer edge to join smoothly with any Keplerian disc and flow is expected to be unstable.

In Fig. 1c, we compare solutions with different dissipation parameters. Solid boundary is the parameter space for standing shock for $\alpha = 0$ and $\beta = 0$. For $\alpha \neq 0$, the effective region of the parameter space for standing shock separated by dot-dashed curve shrinks and moves towards the higher \mathcal{E}_{in} and the lower λ_{in} regime.⁵ When $\beta \neq 0$, the parameter space is reduced and shifts to the lower energy sides.⁷ For flows with $\alpha \neq 0$ and $\beta \neq 0$, the parameter space for the shock settles down at an intermediate region (shaded part). This shows that the viscosity and the synchrotron cooling act in opposite directions in deciding the parameter space.

3. Conclusion

We studied the properties of viscous accretion flow around a non-rotating BH in presence of synchrotron cooling. We found that the flow can have shock waves even when the viscosity and synchrotron cooling are high. The standing shocks form closer to the BH when dissipation is increased and these shocks are centrifugal pressure supported. We obtained the parameter space for the standing shocks for various dissipation parameters and showed that the effective region of the parameter space shrinks as dissipation rises. The parameter space for oscillating shock where RHCs are not satisfied but the flow is likely to pass through a shock has been identified. We also pointed out that the viscosity and the cooling have opposite effects in deciding the parameter space for stationary shock waves. Moreover, since the shocks form closer to the BH, QPO frequency increases with the enhancement of accretion rate as observed in several BH candidates.

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