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# Dynamically induced shock oscillation in the accretion disc around black holes

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**Abstract.** We investigate the global accretion solution around a stationary black hole using the smooth particle hydrodynamics (SPH) method. With the suitable choice of the input parameters, accretion flow undergoes shock transition that are oscillatory in nature. Such unstable solutions exhibit the modulation of the inner part of the disk, such as post-shock corona (PSC) and perhaps be responsible as the source of Quasi Periodic Oscillations (QPOs) of emergent high energy radiation commonly observed in black hole sources.

*Keywords* : black hole physics – accretion, accretion disc – methods: numerical

## 1. Introduction

It has been observed that transient black hole candidates often exhibits modulation of their emergent radiation which are Quasi Periodic in nature. Several attempts were made by numerous authors to explain the origin of the such QPOs. In an earlier effort, Kato and Fukue (1980) prescribed a trapped oscillation model considering the gaseous disk while demonstrating the long term variability of the super-massive black holes. Latter, Molteni, Ryu, Chakrabarti (1996) suggested that for an advective accretion flow, when the infall time scale of PSC roughly matches with the cooling time scale, resonance oscillation of PSC takes place. Due to shock-compression, PSC becomes hot and dens and therefore, it becomes the source of high energy radiation. When PSC modulates quasi periodically due to the resonance oscillation, the emergent radiations from PSC carry the imprint of QPO activity to us. Meanwhile, Das et al. (2014) claimed that PSC exhibits regular oscillation when the viscosity of an

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**Table 1.** Input parameters for SPH simulation.

| | $r_{inj}(r_g)$ | $v_{inj}(c)$ | $a_{inj}(c)$ | $\lambda\ (cr_g)$ | $\mathcal{E}(c^2)$ |
|---|---|---|---|---|---|
| (a) | 80 | -0.05203 | 0.05091 | 1.60 | 0.0030 |
| (b) | 100 | -0.05061 | 0.04330 | 1.64 | 0.0020 |
| (c) | 50 | -0.06820 | 0.06146 | 1.65 | 0.0040 |
| (d) | 50 | -0.07171 | 0.05936 | 1.67 | 0.0035 |

advective accretion flow is chosen equal to its critical value. Very recently, Okuda and Das (2015) pointed out that the unstable nature of the inner part of the advective accretion disk is inevitable for low angular momentum flow around black holes. Being motivated with this, we intend to study the dynamically induced shock oscillation for a time dependent inviscid advective accretion flow around a stationary black hole. While doing this, we adopt the pseudo-Newtonian potential to mimic the space-time geometry around the black hole (Paczyński and Wiita 1980). We employ the Lagrangian formulation of the two-dimensional fluid dynamics equations for SPH in cylindrical coordinates (Lanzafame, Molteni, Chakrabarti 1998) and study the dynamics of PSC. In this work, we use $2G = M_{BH} = c$, where $G$, $M_{BH}$ and $c$ are the gravitational constant, mass of the black hole and speed of light, respectively. In this unit system, distance, velocity and times are measured in units of $r_g = 2GM_{BH}/c^2$, $c$ and $r_g/c$, respectively.

## 2. Results and Discussions

In the SHP scheme, we inject SPH particles from an injection radius $r_{\rm inj}$ with supersonic radial velocity $v_{\rm inj}$, sound speed $a_{\rm inj}$ and angular momentum $\lambda$. The disc height at $r_{\rm inj}$ is approximated assuming the flow to be in local hydrostatic equilibrium. With the appropriate choice of above input parameters, the accretion flow may experience instability in the form of centrifugal pressure supported shock oscillation. In Fig. 1, we plot the variation of shock location with time for four different sets of input parameters. Here, we consider mass of the black hole $M_{BH} = 10M_\odot$ and adiabatic index $\gamma = 4/3$. Input parameters for all the panels are listed in Table 1 where the last column represents the Bernoulli parameters of the flow. Note that in all the cases, accretion flow exhibits persistent shock oscillation. This happens due to the fact that the chosen set of input parameters represents an accretion flow that possesses multiple sonic points (Das et al. 2001) where the entropy corresponding to the solution passing through the inner sonic point is higher than that passing through the outer sonic point. Since the high entropy solution is always preferred, it is natural for flows to pass through the inner sonic point before entering into the black hole. This is possible provided a discontinuous transition of flow variables occur within the accretion disc in the form of shock wave. However, when the input parameters of the flow are chosen in such a way that the flow contains multiple sonic points but the conditions for

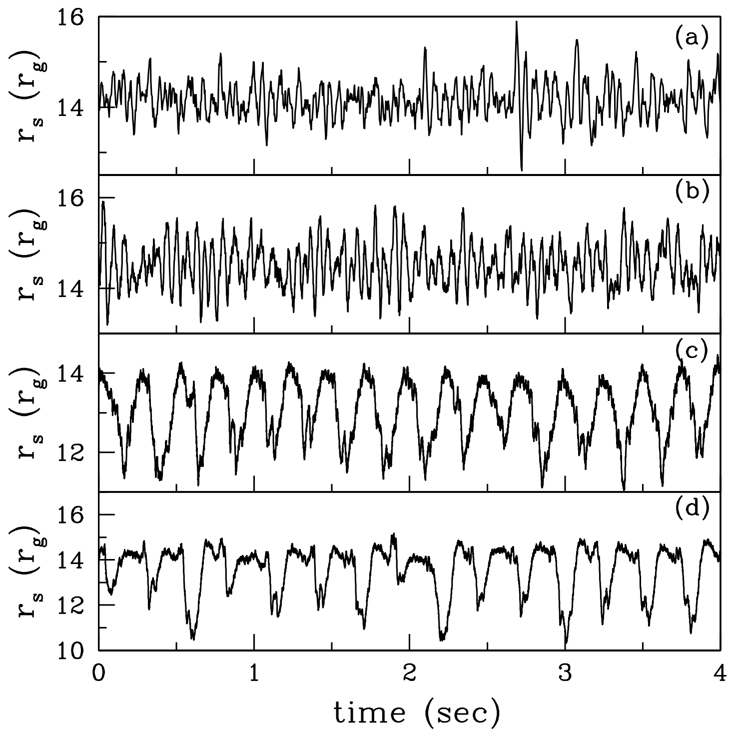


**Figure 1.** Variation of shock location ($r_s$) in the disk equatorial plane with time. Input parameters for panels (a), (b), (c) and (d) are depicted in Table 1. Persistent oscillations are observed in all the cases.

stationary shock transitions are not favorable (Landau and Lifshitz 1959), flow looks for a stable shock solution, but fails and hence starts oscillating.

We further extend our study to identify the range of the input parameters, namely the Bernoulli parameter ($\mathcal{E}$) and the angular momentum of the flow ($\lambda$) that provides the unstable shock solutions. While doing this, we carry out numerous numerical calculations considering various sets of input parameters and plot the corresponding $\lambda$ and $\mathcal{E}$ in Fig. 2 using asterisks and filled circles. In the plot, asterisks are marked that denote the results depicted in Fig. 1. Meanwhile, we theoretically identify the various regions in $(\lambda, \mathcal{E})$ plane for steady shock, oscillating shock and no shock, respectively considering a 1.5 dimension accretion disc around black hole (Das et al. 2001). Note that all the asterisks and filled circles belong to the region that provides shock solutions. Interestingly, some filled circles lie in the region of steady shock. The origin of this disagreement perhaps due to the fact that the numerical calculation is performed in 2D while the theoretical calculation is carried out in 1.5D. However, the theoretical results cater an important role of finding the input parameters for nu-

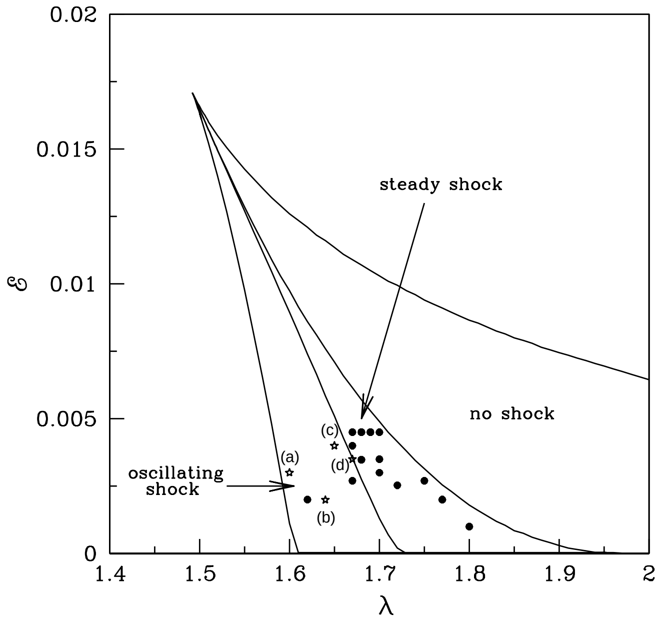


**Figure 2.** Range of angular momentum ($\lambda$) and Bernoulli parameter ($\mathcal{E}$) of the flow that provide global accretion solutions including and/or excluding shock waves. Various regions are identified and marked for steady shock, oscillating shock and no shock, respectively based on the theoretical study. Filled circles and asterisks denote the set ($\lambda$, $\mathcal{E}$) that provides unstable shock solutions obtained numerically.

merical calculations that provide the unstable shock oscillations which seem to be the source of QPOs around black holes. Since the variation of shock location is computed with respect to time, it is straight forward to calculate the frequency of quasi periodic variation of PSC which we plan to report elsewhere.

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