Shock front in Accretion disk

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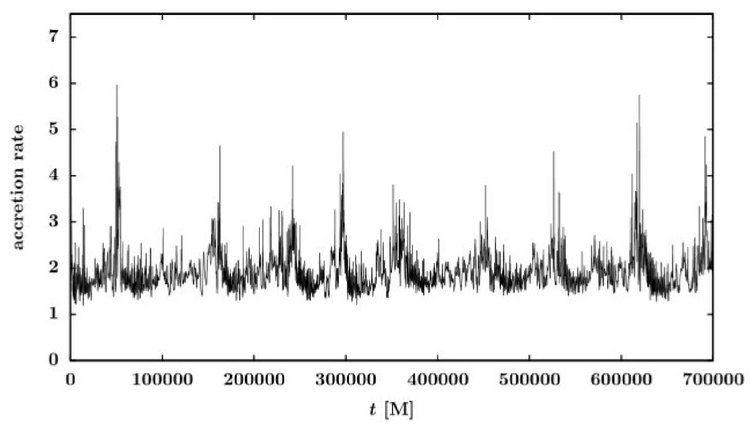
1. Introduction

The process by which any gravitating, massive, astrophysical object captures its surrounding matter is called accretion.Depending on rotational energy content of the infalling material, accretion flows onto black holes are broadly classified into two categories: nonrotating (spherical) and rotating (accretion disks) accretion.The gas velocity at BH must be equal to the speed of light, thus the accretion flow must make a transition between subsonic and supersonic speeds at some point before horizon.At the time of shock, there appears discontinuity of the physical quantities of the flow (density, velocity,pressure) therefore the bulk viscous force at first neglected in our study, should become important and lead to dissipation of energy.This will in turn give rise to the observable radiation emisson and it is the ultimate goal of our study to compare the simulation results with observed sources.

2. Description

Study of standing and oscillating shocks in accretion flows is important since it is recognized that the spectral states of black holes as well as Quasi-Periodic Oscillations (QPOs)observed in light curves of black hole candidates are directly related to the radiative transfer properties of a compact Comptonizing region close to a black hole.Thus shocks play a significant role in governing the overall dynamical and radiative processes taking place in accreting matter.



3.Analytical Approach

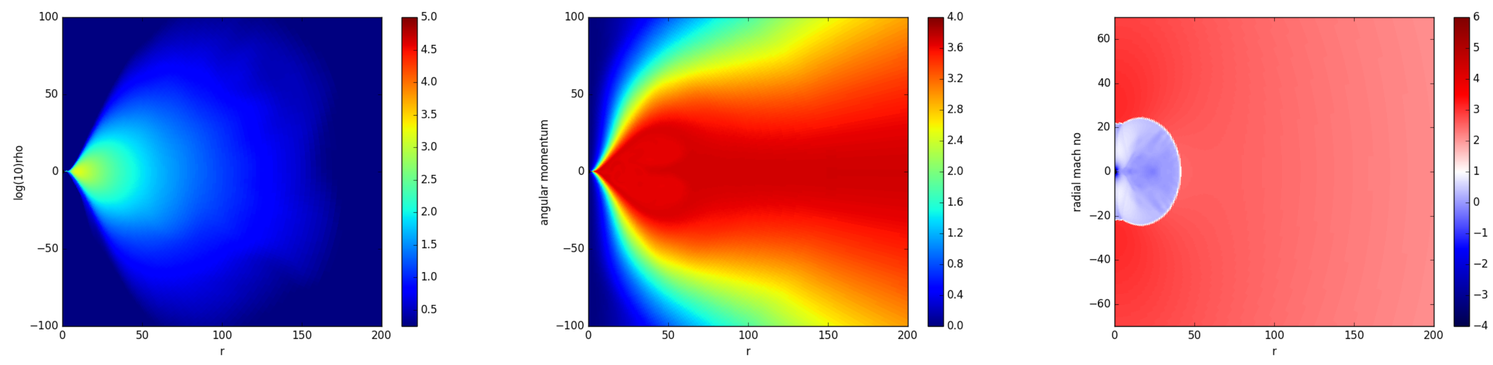
Using the continuity equation and energy conservation, position of the critical point r_c has been found as the root of the equation:

$$\epsilon - \frac{\lambda^2}{2r_c^2} - \frac{\gamma+1}{2(\gamma-1)}\left(\frac{r_c}{4(r_c-1)^2} - \frac{\lambda^2}{2r_c^2}\right) = 0 \quad (1)$$

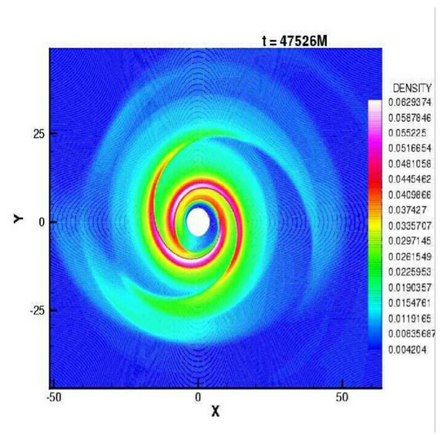
where ϵ stands for energy, λ stands for specific angular momentum and the Paczynski-Wiita gravitational potential in the form of $\phi(r) = -\frac{1}{2(r-1)}$ where r in units of $r_g = \frac{2GM}{c^2}$. Four critical points are found among which one is beyond hrizon hence imaginary, and rest three critical points are r_{in}, r_{mid}, r_{out}. where two of them are saddle type.For a subset of the parameter space $(\epsilon, \lambda, \gamma)$ there exists three solution of this equation.Relation for the derivative $\frac{dv}{dr}$ obtained by integrating the equations from the critical point downwards and upwards.For same parameters $(\epsilon, \lambda, \gamma)$, constant specific entropy K differ in value, which is given by

$$K = \left(vr^2 \frac{c_s^{\frac{2}{\gamma-1}}}{\gamma^{\frac{1}{\gamma-1}}\dot{M}}\right)^{\gamma-1} \quad (2)$$

Hence the boundary of the parameter space for shock formation is obtained by analytical means.



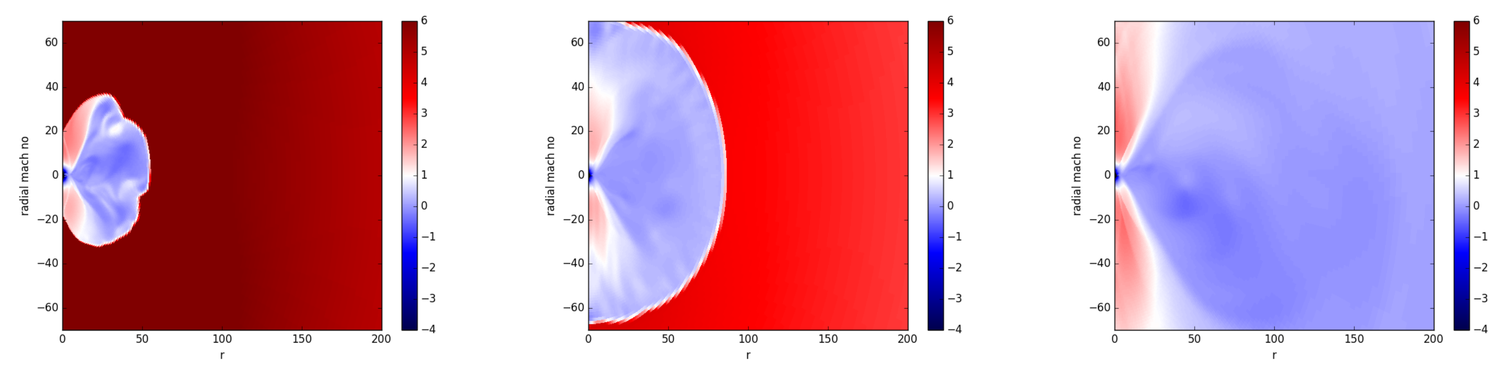
4.OKEANOS in shock



OKEANOS satisfies my need for doing large scale calculations which requires many computational cores and several tens of gigabytes of RAM to run for very long times say upto 10^6.I am able to run my simulation very comfortably using 11 or more nodes, with the help of parallel programming dividing my job over various nodes and hence I reach very high time of evolution which I need for my simulation in just 24 hrs which might take few months with a quadcore processor. I am very much looking forward to start my 3-D simulation on OKEANOS with grid resolution 256 x 128 x 96 cells. And hence I can move forward with the study of many shock fronts in the form of spiral waves in accretion disk.

5. Numerical simulation

Hydrodynamical simulations of the non-magnetized accreting gas on the fixed background is performed using the HARMPI computational code.The background spacetime is given by the stationary Kerr solution. The initial conditions are set using Boyer-Lindquist coordinates, and they are transformed into the code coordinates- the Kerr-Shild ones.
In order to cover the whole accretion structure with sufficiently fine resolution near the black hole logarithmic grid in radius is used with superexponential grid spacing in the outermost region, so that the outer region is covered with low resolution grid and provide the reservoir of gas for accretion.
For 2D computations, the resolution is in the range between 256 x 128, up to 384 x 256 and 576 x 192.The evolution of initially non-magnetized gas is simulated with the HARMPI package supplied with our own modifications. The code conserves the vanishing magnetic field and there is no spurious magnetic field generated during the evolution.
Here in right,three models shown with $(\epsilon = 0.0005, \lambda = 3.72)$ for different $\gamma = 1.2, 4/3, 1.4$ at $t = 10^4$ respectively showing different shock front and position with oscillation or expansion of shock bubble.



6.Results

1. shock waves are created for all the γ's except the case $\gamma = 5/3$.Among 4 critical points, For a gas with $\gamma = 5/3$,the only critical point is one found by Bondi which lies outside the event horizon. Hence shock not produced.
2. It appears that for smaller γ shock position is more closer since Lower γ means cooler disk with larger Mach number of the flow.
3. The oscillations of the shock front are connected with small oscillations of the value of angular momentum downward from the shock front.
4. with considerably higher angular momentum, the formation and propagation of the shock can be even higher than the sound speed in the post-shock medium

7. References

[1]Bondi, H. 1952, MNRAS, 112, 195
[2]Chakrabarti S. K., Das S., 2001, ApJ,557,2
[3]Chakrabarti S. K., Debnath D., Nandi A., Pal P. S., 2008,ApJ, 489, L41
[4]Gammie C.F., McKinney J.C., Tth G., 2003
[5]Orhan Dönmez, 2005,arXiv:gr-qc/0512060
[6]Proga D., Begelman M. C., 2003, ApJ, 582, 69
[7]Spruit C.H.,(ISSN 0004-6361), vol. 184, no. 1-2, Oct. 1987, p. 173-184.
[8]Suková P., Janiuk A., 2015, MNRAS, 447, 1565
[9]Suková P., Janiuk A., 2017, MNRAS, 447, 1565

8.Acknowledgement

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