Effects of adiabatic index on shock oscillations around black hole

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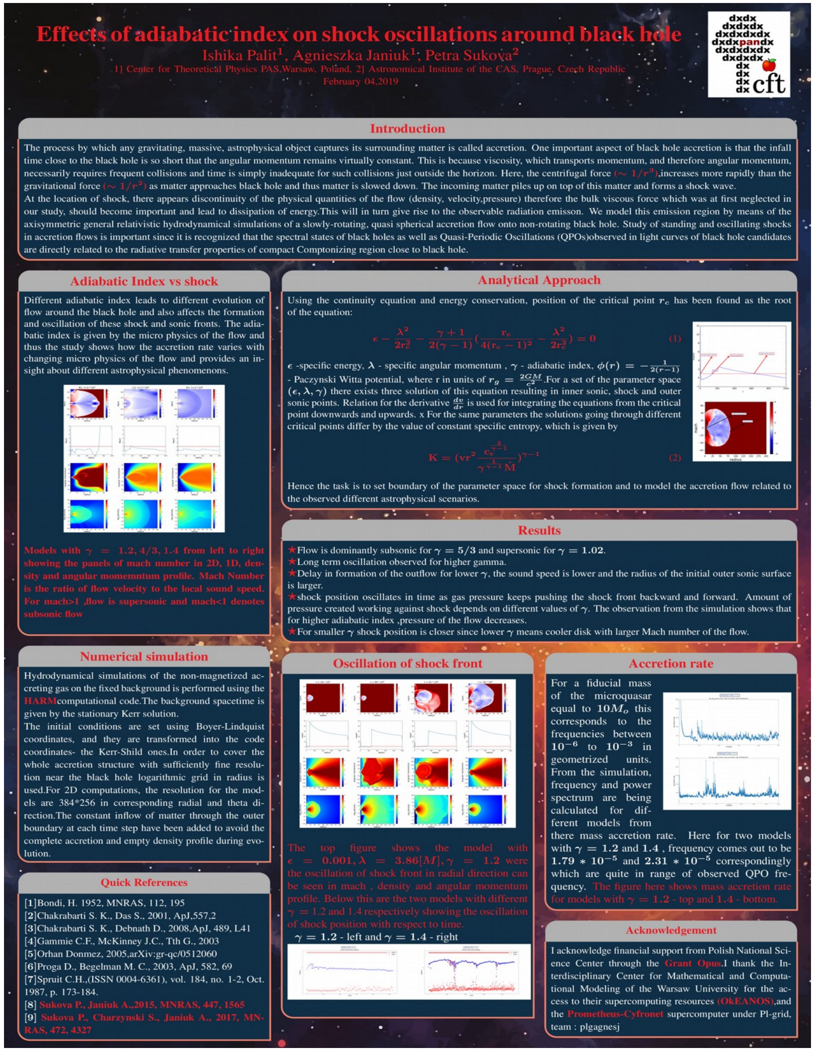

Effects of adiabatic index on shock oscillations around black hole

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February 04,2019

Introduction

The process by which any gravitating, massive, astrophysical object captures its surrounding matter is called accretion. One important aspect of black hole accretion is that the infall time close to the black hole is so short that the angular momentum remains virtually constant. This is because viscosity, which transports momentum, and therefore angular momentum, necessarily requires frequent collisions and time is simply inadequate for such collisions just outside the horizon. Here, the centrifugal force $(\sim 1/r^3)$,increases more rapidly than the gravitational force $(\sim 1/r^2)$ as matter approaches black hole and thus matter is slowed down. The incoming matter piles up on top of this matter and forms a shock wave.

At the location of shock, there appears discontinuity of the physical quantities of the flow (density, velocity,pressure) therefore the bulk viscous force which was 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. We model this emission region by means of the axisymmetric general relativistic hydrodynamical simulations of a slowly-rotating, quasi spherical accretion flow onto non-rotating black hole. 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 compact Comptonizing region close to black hole.

Adiabatic Index vs shock

Different adiabatic index leads to different evolution of flow around the black hole and also affects the formation and oscillation of these shock and sonic fronts. The adiabatic index is given by the micro physics of the flow and thus the study shows how the accretion rate varies with changing micro physics of the flow and provides an insight about different astrophysical phenomenons.

Models with $\gamma = 1.2, 4/3, 1.4$ from left to right showing the panels of mach number in 2D, 1D, density and angular momemntum profile. Mach Number is the ratio of flow velocity to the local sound speed. For mach>1 ,flow is supersonic and mach<1 denotes subsonic flow

Numerical simulation

Hydrodynamical simulations of the non-magnetized accreting gas on the fixed background is performed using the HARMcomputational 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.For 2D computations, the resolution for the models are 384*256 in corresponding radial and theta direction.The constant inflow of matter through the outer boundary at each time step have been added to avoid the complete accretion and empty density profile during evolution.

Quick References

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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:

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

ϵ -specific energy, λ - specific angular momentum , γ - adiabatic index, $\phi(r) = -\frac{1}{2(r-1)}$ - Paczynski Witta potential, where r in units of $r_g = \frac{2GM}{c^2}$.For a set of the parameter space $(\epsilon, \lambda, \gamma)$ there exists three solution of this equation resulting in inner sonic, shock and outer sonic points. Relation for the derivative $\frac{dv}{dr}$ is used for integrating the equations from the critical point downwards and upwards. x For the same parameters the solutions going through different critical points differ by the value of constant specific entropy, which is given by

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

Hence the task is to set boundary of the parameter space for shock formation and to model the accretion flow related to the observed different astrophysical scenarios.

Results

- ★Flow is dominantly subsonic for $\gamma = 5/3$ and supersonic for $\gamma = 1.02$.
- ★Long term oscillation observed for higher gamma.
- ★Delay in formation of the outflow for lower γ, the sound speed is lower and the radius of the initial outer sonic surface is larger.
- ★shock position oscillates in time as gas pressure keeps pushing the shock front backward and forward. Amount of pressure created working against shock depends on different values of γ. The observation from the simulation shows that for higher adiabatic index ,pressure of the flow decreases.
- ★For smaller γ shock position is closer since lower γ means cooler disk with larger Mach number of the flow.

Oscillation of shock front

The top figure shows the model with $\epsilon = 0.001, \lambda = 3.86[M], \gamma = 1.2$ were the oscillation of shock front in radial direction can be seen in mach , density and angular momentum profile. Below this are the two models with different $\gamma = 1.2$ and 1.4 respectively showing the oscillation of shock position with respect to time.

$\gamma = 1.2$ - left and $\gamma = 1.4$ - right

Accretion rate

For a fiducial mass of the microquasar equal to $10M_o$ this corresponds to the frequencies between 10^{-6} to 10^{-3} in geometrized units. From the simulation, frequency and power spectrum are being calculated for different models from there mass accretion rate. Here for two models with $\gamma = 1.2$ and 1.4 , frequency comes out to be $1.79 * 10^{-5}$ and $2.31 * 10^{-5}$ correspondingly which are quite in range of observed QPO frequency. The figure here shows mass accretion rate for models with $\gamma = 1.2$ - top and 1.4 - bottom.

Acknowledgement

I acknowledge financial support from Polish National Science Center through the Grant Opus.I thank the Interdisciplinary Center for Mathematical and Computational Modeling of the Warsaw University for the access to their supercomputing resources (OkEANOS),and the Prometheus-Cyfronet supercomputer under Pl-grid, team : plgagnesj

Quasi periodic oscillations. (QPO's)

Transonic accretion onto black hole: Shock and sonic points.

Adiabatic Index and shock oscillation.

Numerical simulation: GRMHD code – HARM.

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