Accretion disks modelling

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In astrophysics there are many cases of X-ray radiative outburst, caused by instabilities of hot gases. One of significant description is thin accretion disk surrounding a black hole. Our attempt is a hydrodynamical description of an accretion disk. We show the physics of the model, and try to compare the behaviour of the disk apparent luminosity with the observed light curve of microquasar IGR J17091.

1 Accretion and accretion disks

In astrophysics there are many examples of accretion. Every massive object can attract the surrounding matter, and when the matter has not sufficiently angular momentum to stay on the orbit or when energy of matter is dissipating it leads to accretion on the central object. The most common examples of the central object are the black holes, neutron stars or odwhite dwarfs. Accretion can have different geometry - we know also examples of the spherical accretion or the accretion in the form of disk. The geometry is determined moreover by the angular momentum. The aim of our model is the accretion disk around the black hole connected with the microquasar IGR J17091. The microquasar IGR J17091-3624 has showed its pronounced outburst in 2011. In some states, the source exhibited characteristic quasi-periodic oscillations (on timescales of tens of seconds), so called as the 'heartbeat state'. From a theoretical point of view, such oscillations may be modelled by the process of accretion disk instability, driven by the domination of radiation pressure and enhanced heating of the plasma. The mean accretion rate in this source is however probably well below the Eddington limit. As the observations show, the source exhibits also strong wind outflow in some states (Rao & Vadawale, 2012; King et al., 2012).

2 Thin disk

We consider a hydrodynamical model of thin disk (Shakura & Sunyaev, 1973) consists of the ideal gas. We assume that the disk rotates with the angular velocity Ω. The disk is axially symmetric and geometrically thin. To have the hydrostatic equilibrium pressure must balance the centrifugal force: $p = \rho\Omega^2 H^2$, where ρ is density and H - half of the disk thickness. Disk is radiating energy as the black body with power per square unit equal to $Q_- = \frac{4\sigma_B T^4}{3\kappa\rho H}$. Heat is produced by turbulence $Q_+ = \frac{3}{2}\alpha p H$. From the angular momentum conservation, we have following expression on the amount of heat produced at the given distance R from the central object of the mass M:

$$F_{tot} = \frac{3}{8\pi}\frac{GM\dot{M}}{R^3}f(R) = \frac{3}{8\pi}\frac{GM\dot{M}}{R^3}(1 - \sqrt{\frac{r}{6GM/c^2}}) \qquad (1)$$

where $\dot{M}$ is an accretion rate. Thermal equilibrium and fact that we assume a physical identity between heat production and viscous energy dissipation makes necessary the equality: $Q = Q_+ = F_{tot}$

To obtain a stationary solution, we assume that the disk is in pressure equilibrium. Full model includes gas and radiation pressure. We finally obtain fifth order polynomial equation for the equilibrium temperature, which can be solved only numerically. The model was solved in General Relativity approach, and stationary solution in huge radii limit lead to the set of power dependences of density, temperature and pressure on the assumed mass accretion rate. On Figures 1 and 2 the numerical solutions are shown. Non bijective dependence between Σ and T causes the unstable behaviour of the system.We should notice change of behaviour of the profiles of major physical values. Radiation pressure pulls the matter outwards. The accretion disk is thicker, more rarified and cooler unless we do not neglect the radiation pressure term.

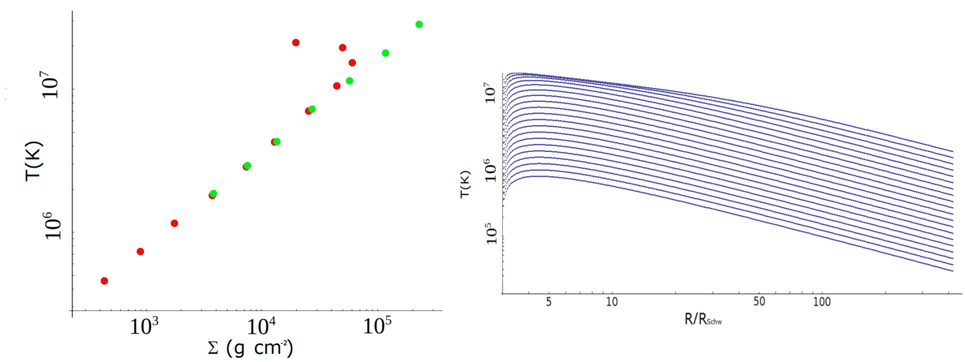


Fig. 1: Left panel presents temperature versus surface density dependence. Green dots - model without radiation pressure. Red dots - model with radiation pressure. Models are computed for luminosities $L = 10^{-5} - 1\ L_{\rm Edd}$. Right panel shows temperature profiles and their changes due to radiation pressure instability

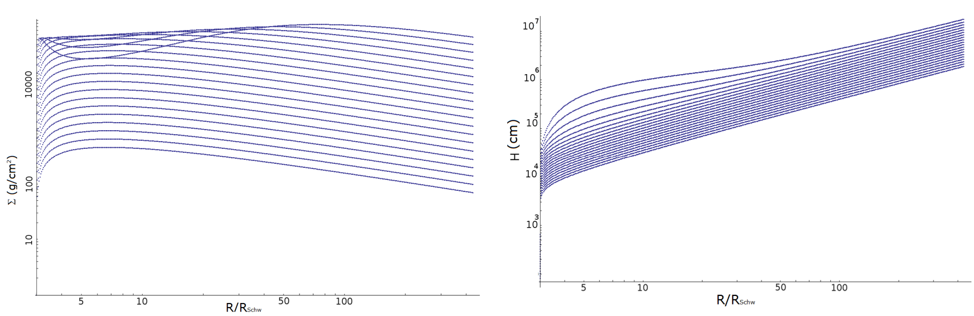
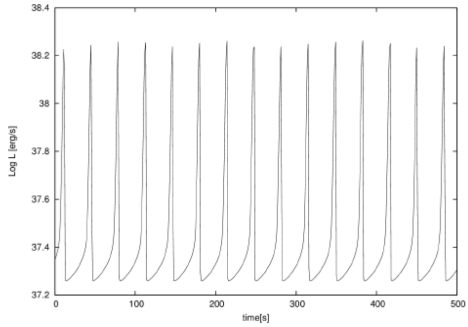


Fig. 2: Profiles of surface density (left panel) and geometrical thickness (right panel) and thier changes due to radiation pressure instability

3 Microquasar IGR J-17091 - 3624 - modeling

We assumed mass of the object as 6 $M_\odot$, viscosity coefficient $\alpha = 0.1$, accretion rate $\frac{dM}{dT} = 4.22 \cdot 10^{-8}\ M_\odot/y$, and advection coefficient $q_{adv} = 0.32$.

We try to model following observational X-Ray SWIFT XRT data (spectral range $0.3 - 10$ keV) (King et al., 2012). We solve numerically following set of equations for surface density Σ, radial velocity v_r, pressure p and temperature T. Equations 2, 3, 4



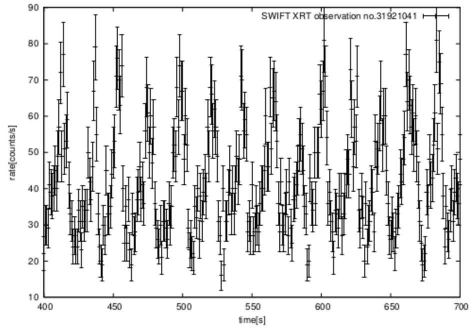


Fig. 3: Comparison of the model results with SWIFT XRT observational data of IGR J17091. On the left panel the modelled light curve in X-ray energy range is shown, while on the right panel observed count rate is presented.

are hydrodynamics equation, and Eq. 5 is equation of state which gives as the bound between pressure and temperature:

$$\frac{\partial \Sigma}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(3r^{1/2}\frac{\partial}{\partial r}(r^{1/2})\nu\Sigma\right) \tag{2}$$

$$v_r = -\frac{3}{\Sigma}r^{-1/2}\frac{\partial}{\partial r}(\nu\Sigma r^{1/2}) \tag{3}$$

$$\frac{\partial \ln T}{\partial t} + v_r\frac{\partial \ln T}{\partial \ln r} = \frac{4-3\beta}{12-10.5\beta}\left(\frac{\partial \ln \Sigma}{\partial \ln r} - \frac{\partial \ln H}{\partial \ln r} + v_r\frac{\partial \ln \Sigma}{\partial \ln r}\right) + \frac{Q_+ - Q_-}{(12-10.5\beta)PH} \tag{4}$$

$$p = \frac{\rho k_B T}{m_H} + \frac{4\sigma_B}{3c}T^4 \tag{5}$$

where ν is a kinematic viscosity connected by nondiagonal term of stress tensor by formula $T_{r\phi} = \alpha PH = (3/2)\Omega\nu\Sigma$. α is non-dimensional viscosity (Shakura & Sunyaev, 1973) (Janiuk et al., 2002). Total luminosity is obtained by formula 1. The comparison model vs. equation is visible on the Figure 3. We can see that the model describes the behaviour of the disk quite properly. X-ray outbursts occured at the comparable frequency and gain the amplitude with the same rate of magnitude.

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