REPORTS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
ISSN 2224-5227
Volume 5, Number 309 (2016), 5 – 13

[1,2]B.T. Shukirgaliyev, [1,2]T.P. Panamarev, [4]A.Zh. Naurzbaeva, [1,4]M.T. Kalambay, [1]M.A. Makukov, [1]E.Y. Vilkoviskij, [3,1]Ch.T. Omarov, [2,5,6]P.P. Berczik, [2]A. Just, [2,5,7]R. Spurzem

[1] Fesenkov Astrophysical Institute, Kazakhstan;
[2] Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Germany;
[3] National Center of Space Research and Technology, Kazakhstan;
[4] Al-Farabi Kazakh National University, Kazakhstan;
[5] National Astronomical Observatories of China and Key Laboratory for Computational Astrophysics, China;
[6] Main Astronomical Observatory, National Academy of Sciences of Ukraine, Ukraine;
[7] Kavli Institute for Astronomy and Astrophysics at Peking University, China
bekdaulet.s@gmail.com, mukhagaly@gmail.com

EFFECT OF GAS ACCRETION DISC PROFILE ON ORBITAL PARAMETERS OF THE ACCRETED STARS

Abstract. The results of studies of the effect of the gas disk and its profile on the dynamics of active galactic nuclei are presented. The study was conducted with a numerical model of galactic nucleus based on phiGRAPE+GPU comprising three subsystems – a central supermassive black hole, gaseous accretion disc, and compact stellar cluster. The evolution of the compact stellar cluster is modeled with direct integration (N-body simulation), while the black hole and gaseous disc are represented phenomenologically: the black hole is introduced as an external potential (fixed in space but variable in time due to black hole mass growth), and the gaseous disc is introduced as spatial time-independent density distribution. We examined and compared with each other orbital parameters of accreting stars for model of the galactic nucleus with gas disc of constant and variable thickness, as well as without gas. It was found that in the presence of a gaseous disk almost half of the accreted particles interact strongly with the gas and are captured by the disc before accretion, while more than 85% of particles are affected to some extent by the disc prior to accretion. This suggests that interaction of the stellar cluster with the gas disk in the galactic nucleus might lead to the formation of stellar disk in the central part of the nucleus.

Key words: active galactic nuclei (AGN), supermassive black hole (SMBH), accretion gas disk(AGD), computational astrophysics, N-body simulations.

The physical nature of active galactic nuclei (AGN) our day is far from a complete understanding, that is why the development of AGN theory still remains one of the most urgent problems of astrophysics. According to modern concepts, activity of galactic nuclei is due to the accretion of matter onto supermassive (up to several trillion solar masses) black holes, which are, apparently, in all the centers of galaxies [1]. Released in the course of this accretion the gravitational energy is the source that lies at the heart of an extremely powerful radiation observed from the AGN.

Active galactic nuclei can be seen as consisting of three subsystems: the central supermassive black hole (SMBH), the accretion gas disk (AGD), which is formed due to the conservation of angular momentum of accreting matter, and compact spherically symmetric stellar clusters [2].

In previous studies [3-6] by means of numerical simulation we have been investigated the interaction of star cluster with an accretion disk and its impact on the dynamics and evolution of active galactic nuclei. Indeed, dissipative effects from the gas disk leads to loss of energy of stars in the central cluster and, under certain conditions, to the accretion of some stars onto the black hole.

In these studies, we used two phenomenological gas disk model. The first gas disk had Keplerian rotation, constant height and was defined in a constant in time density distribution:

$$\rho(R,z)=\frac{2-\alpha}{2\pi\sqrt{2\pi}}\frac{M_d}{hR_d^3}\left(\frac{R}{R_d}\right)^{-\alpha} exp\left[-\beta_s\left(\frac{R}{R_d}\right)^s\right]\exp\left(-\frac{z^2}{2h^2R_d^2}\right), \qquad (1)$$

where $\alpha = 3/4$ (corresponds to the outer boundary of the disk according to the Novikov-Thome model [6]), $R^2 = x^2 + y^2$, R_d - disk radius, $\beta_s = \left[\Gamma\left(1+\frac{2-\alpha}{s}\right)\right]$ ($\Gamma(x)$ - gamma function, s was taken to 4, then $\beta_s = 0.70$), M_d - disk mass, h defines the half-thickness of disk: $h_z = hR_d$.

The second, a more realistic model of the gas disk is a modification of the first model with the introduction of a linear increase of the half-thickness of disk in the domestic sector. This modification was based on the physical properties of the inner accretion disk, which are described by the Shakura-Syunyaev approach [8].

$$h_z = hR_d\left(\frac{R}{R_{crit}}\right). \qquad (2)$$

The transition point from linear half-thickness to the constant was determined by equating the expression for the velocity of sound in the case of self-gravity of disk $c_s^2 = 4\pi G h_z \Sigma$, and in case of its absence $c_s^2 = 2h_z^2 G M_{bh} R^{-3}$. Then $R_{crit} = 0.0257314$ in the dimensionless system of units N-body [8], which we use everywhere in the future.

Accretion disk properties were recorded with reduced mass μ_d with analytical density distribution according to equation (1) with the values of the parameters $\alpha = 3/4$ and $s = 4$ and $h = 10^{-3}$. There was an implication of Keplerian rotation of the disc in the potential of a supermassive black hole, neglecting the gravitational influence of the disc and pressure gradients inside the disc [3]. Read more about the gas disk models - [5].

The black hole was also defined phenomenologically as a Newtonian potential. Star cluster was modeled by direct integration of interaction of individual stars with each other (N-body simulations), as well as with the gas disk and black hole. If the star falls in a region with radius of less than R_{accr} (accretion radius), then it is considered as accreted - its mass is added to the mass of the black hole and the star itself is removed from the system. As the source code phiGRAPE+GPU [10] it was used for the numerical simulation, which uses parallel computation technologies (CUDA and MPI). This code was added to our module, describing dissipative interaction of stars with gas. Evolution of the system begins with the status given by Plummer model. A more detailed description of the numerical model can be found in [3,4,6].

In [5] there was a comparison of the results obtained using two gas disk models, i.e. we investigated the influence of the disk profile on the process of accretion of stars in the black hole (see. the dotted line in Fig. 2). There were considered stars that are accreting due to the effect of the gas disk, that is, stars with small eccentricity (it was believed that the stars, accreting when $e \approx 1$, that is, in orbits close to hyperbolic, fall into the capture area of the black hole as a result of random spans). It was found that in the first model accreting when rotated in one direction with disk the stars form on the diagram "eccentricity - orbit inclination angle to the plane of the disc" a close group with nearly circular orbits lying substantially in the disc plane and the counter-rotating stars have any inclination values and eccentricity when accretion. In the disk model with a variable thickness the co-and counter-rotating stars accrete at all angles of inclination of the orbit, but about 70% of all captured SMBH stars at the time of capture were very close to a circular orbit and were in the plane of the disk. Furthermore, in the second disk model impulse momentum is transferred to the black hole in a larger amount than in the first.

This paper presents the results of further studies of the effect of the gas disk on the dynamics of active galactic nuclei, namely, discussing the orbital parameters of accreting stars, which were captured by SMBH for two relaxation time (t=2t_{rel}), since initial time, for the three models: with "old" (with constant thickness) and the "new" (with variable thickness) gas disks, and also without the disc. In all launches rating system was 32 thousand, accretion radius was assumed to be $0.0003R_d$.

Results and discussion

Results of the study of orbit eccentricity of accreting stars are shown in Figures 1-3. Figure 1 shows the cumulative distribution of the particles on the eccentricities of their orbits at the time of accretion for the three models, the ordinate axis represents the ratio of the number of stars, accreting eccentric, less than given to the number of accreted stars.

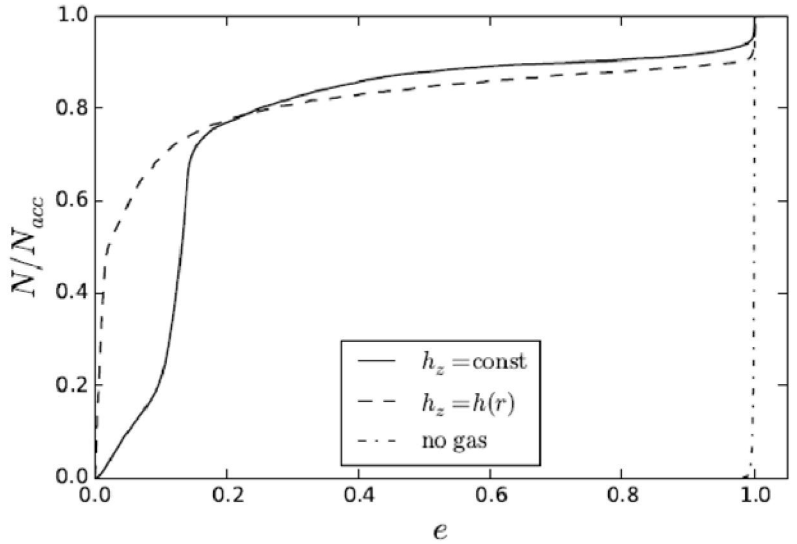

Figure 1 - The cumulative distribution of the particles on the eccentricities of their orbits at accretion time for the model without gas disk (dot-and-dash line), model with a disc of constant thickness (solid line) and model with disk of variable thickness (dashed line). On the vertical axis it is presented the ratio of the number of stars that accrete with an eccentricity of less than given, to all the accreted stars

Figures 2-3 show bar graphs of eccentricities of the orbits of accreted stars. To enable a more detailed analysis, the histogram are given in linear and logarithmic form, and separately there is a graph for the model without the gas disk with smaller intervals of the partition area of the eccentricity values. As can be seen from the figures, in the absence of the gas disk stars accrete in orbits close to hyperbolic, i.e., fall into the capture area of the black hole as a result of random spans. Gas disk greatly affects the distribution of eccentricities of accreted particles: in the model with the "new" disk about 50% of stars accrete in nearly circular orbits, in the model with the "old" disk the particles mainly accrete in more elongated orbits.

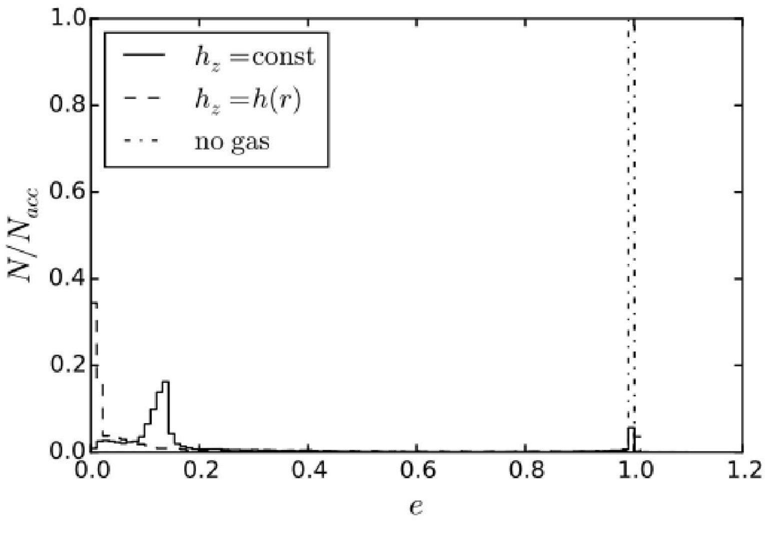

Figure 2 - Distribution of the eccentricities of the orbits of stars at the time of accretion for the three models in the linear (A) and logarithmic (B) scales. Designations are the same as in Figure 1.