21aD2-5

Time Variation of Accretion Rate and Magnetic Fields via Interaction of Black Hole Accretion Flows with Gas Clouds

ブラックホール降着流とガス雲の相互作用による質量降着率と磁場の時間変化

Tomohisa Kawashima[1)] and Ryoji Matsumoto[2)]
川島朋尚, 松元亮治

1) Center for Computational Astrophysics, National Astronomical Society of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
国立天文台 天文シミュレーションプロジェクト 〒181-8588 東京都三鷹市大沢2-21-1
2) Department of Physics, Graduate School of Science, Chiba University 1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan
千葉大学大学院 理学研究科 〒263-8522 千葉県千葉市稲毛区弥生町1-33

We have carried out three-dimensional (3D) resistive MHD simulations of a gas cloud passing through a hot accretion flow onto the supermassive black hole at the Galactic center, taking into account the effects of radiative cooling. We found that larger the inclination angle of the gas cloud, the more gently the mass accretion rate increase. We also found that the magnetic fields are amplified after the gas cloud pass through the accretion flow.

1. Introduction

Gillessen et al. (2012)[1] reported that the gas cloud G2 with ~3M⊕ is approaching to the Galactic Center Sagittarius A* (hereafter Sgr A*). G2 is estimated to pass the pericenter located at ~2400 Schwarzshild radius from the supermassive black hole in the Galactic center on A.D. 2014.25 (Gillessen et al. 2013)[2]. G2 has attracted astronomers because G2 may supply the accreting gas to Sgr A*.

It has not yet been clear how much the mass accretion rate and the magnetic energy at Sgr A* will change, although some simulations have been done by some research groups. Therefore, we have carried out three dimensional MHD simulations of interaction of a black hole accretion flows with a gas cloud.

2. Numerical Method

We solve a set of three-dimensional (3D) resistive MHD equations in cylindrical coordinates (ϖ, φ, z), where ϖ denotes the cylindrical radius. We take into account the effects of radiative cooling. The effects of the general relativities are incorporated approximately by adopting a pseudo-Newtonian potential (Paczyńsky & Wiita 1980)[3].

We carry out global 3D simulations by using a newly-developed MHD code CANS+ (Matsumoto et al. in prep.)[4]. The code is based on the HLLD scheme, which is an approximate Rieamann solver proposed by Miyoshi & Kusano (2005)[5]. In order to preserve monotonicity and high-order accuracy in space, we employ MP5, which is a monotonicity preserving, fifth-order accurate interface value reconstruction method (Suresh & Huynh 1997)[6]. The third-order TVD Runge-Kutta method is applied to advance the solution in time. We choose the generalized Lagrange multiplier (GLM) scheme proposed by Dedner et al. (2002)[7] in order to satisfy the divergence-free constraint of the magnetic field.

The computational domain is $0 \lesssim \varpi \lesssim 4.3\times 10^4 r_s$, $0 \lesssim \varphi \lesssim 2\pi$, and $|z| \lesssim 2.8\times 10^4 r_s$. A spherical absorbing inner boundary is imposed at $r = 450 r_s$. Here, r denotes the spherical radius, and r_s is the Schwarzschild radius. The number of grid points is $(N_\varpi, N_\varphi, N_z) = (256, 64, 320)$.

At first, we perform the simulations of hot accretion flows without G2 until the accretion flow is achieved to be quasi-steady. We set the a rotating, equilibrium torus with the pressure maximum at $3\times 10^3 r_s$. A weak, purely toroidal, initial magnetic field is set inside the torus, by using the equilibrium solution of magnetized tori proposed by Okada et al. (1989)[8]. The torus is embedded in a hot, isothermal, non-rotating, coronal atmosphere in an equilibrium state. After the growth of the non-axisymmetric mode of the magnetic rotational instability, quasi-steady accretion flows are formed. After 30 orbital-time at the pressure maximum, we set a gas cloud in the computational domain to simulate the interaction between the hot accretion flow and the gas cloud We assume the orbital inclination I= 0, π/6, and π/3 rad, the longitude of

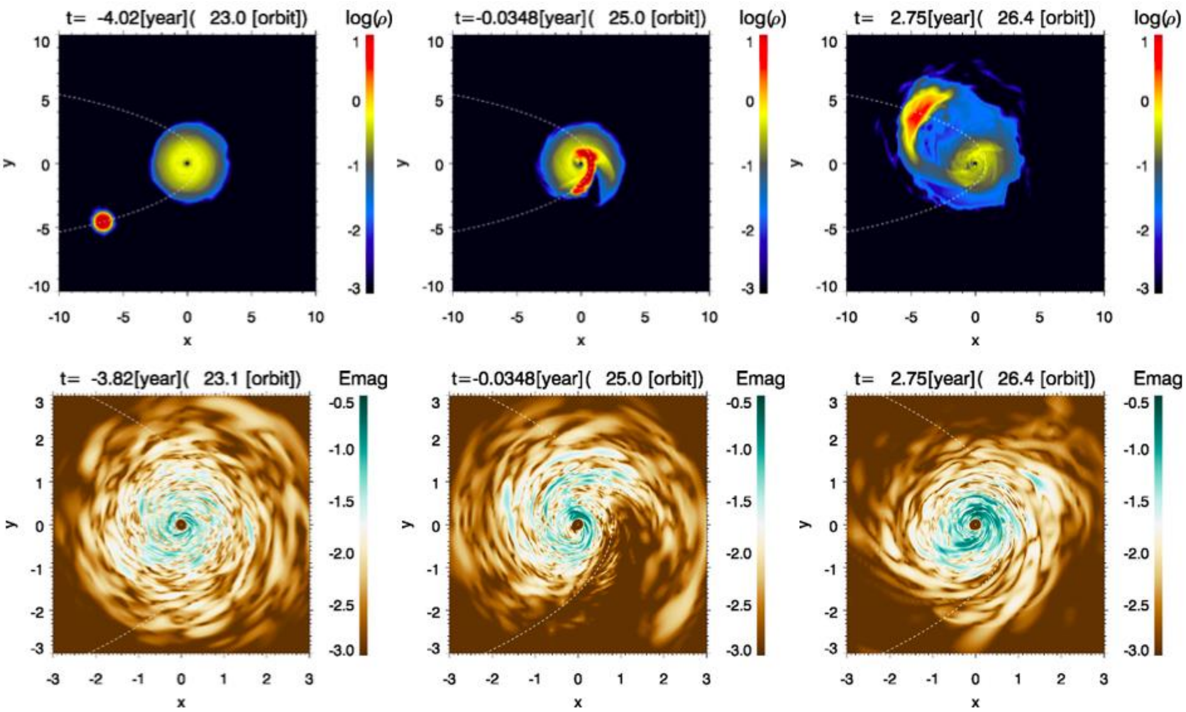

Fig. 1 Snapshots of the simulations. Upper panels represent the distributions of mass density on the equatorial plane. Lower panels are the enlarged figures representing the magnetic energy density distribution. White dashed curves represent the orbit of the gas cloud G2.

the ascending node $\Omega=0$, the argument of the pericenter $\omega=0$, the eccentricity e=0.9762, the pericenter radius $r_{\rm p} = 2.4\times 10^3 r_{\rm s}$.

3. Results

Fig. 1 shows the snapshots of the hot accretion flow and the gas cloud. The gas cloud is tidally disrupted before its pericenter passage. Shocks are formed when the gas cloud is passing through the hot accretion flow. After the pericenter passage of the gas cloud, we found that a gas stream accreting onto the edge of the accretion flow is formed, because a part of the gas cloud lost its angular momentum via the ram pressure. The magnetic energy density increase in the inner disk after the passage of the gas cloud.

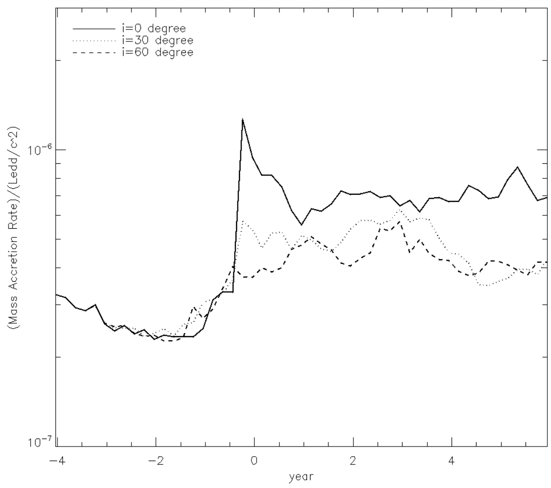

Fig. 2 The time-evolution of mass accretion rate.

Fig. 2 represents the time-evolution of the mass accretion rate. We found that the mass accretion rate increases more gently and the peak mass accretion appears later when the inclination I is larger. This is because the timescale for the interaction of the gas cloud with the accretion flow is shorter and also the interaction starts later when the inclination angle is larger.

Acknowledgments

The numerical simulations were carried out on the XC30 at the Center for Computational Astrophysics, National Astronomical Society of Japan. This work was supported by the JSPS Grants in Aid for Scientific Research (23340040, R.M.).

References

[1] S. Gillessen, R. Genzel, T.K. Fritz, et al.: Nature **481** (2012) 51.

[2] S. Gillessen, R. Genzel, T.K. Fritz, et al.: ApJ **774** (2013) 44.

[3] B. Paczyński, and P.J. Wiita: A&A **88** (1980) 23.

[4] Y. Matsumoto et al. in prep.

[5] T. Miyoshi, and K. Kusano: J. Comput. Phys. **208** (2005) 315.

[6] A. Suresh, and H.T. Huynh: J. Comput. Phys. **136** (1997) 83.

[7] A. Dedner, F. Kemm, D. Kröner, et al.: J. Comput. Phys. **175** (2002) 645

[8] R. Okada, J. Fukue, and R. Matsumoto: PASJ **41** (1989) 133