EPSC Abstracts
Vol. 7 EPSC2012-610 2012
European Planetary Science Congress 2012

Formation of Circumplanetary Disks: High-Resolution Hydrodynamic Simulations

T. Tanigawa (1,2), M. Machida (3) and K. Ohtsuki (1,4)
(1) Center for Planetary Science, Japan, (tanigawa@cps-jp.org / Fax: +81-11-706-7142), (2) Hokkaido University, Japan, (3) Kyushu University, Japan, (4) Kobe University, Japan

Abstract

We investigate gas accretion flow onto a circumplanetary disk from a protoplanetary disk in detail by using high-resolution three-dimensional nested-grid hydrodynamic simulations, in order to provide a basis of formation processes of satellites around giant planets. Based on detailed analyses of gas accretion flow, we find that most of gas accretion onto circumplanetary disks occurs nearly vertically toward the disk surface from high altitude, which generates a shock surface at several scale heights of the circumplanetary disk. We also analyze fluxes of accreting mass and angular momentum in detail and determine the distributions of the mass and angular momentum fluxes onto the disk surface, which is necessary for evolution of circumplanetary disk and satellite formation.

1. Introduction

Satellite systems around gas giant planets are thought to be formed in circum-planetary disks, which are believed to exist at the gas capturing growing phase of the giant planets[1, 2, 3]. The disk structure is thus crucially important for the formation process of the satellite systems.

There are several studies that show gas accretion flow onto circum-planetary disks by using hydrodynamic simulations[4, 5, 6]. However, results of the previous studies were not adequately analyzed and did not give us detailed information necessary for the study of the formation process of satellite systems[7]. In order to understand the formation process of satellite systems, we carry out high-resolution hydrodynamic simulations of circum-planetary disks around proto giant planets embedded in proto-planetary disks and analyze the accretion flow structure and circum-planetary disk structure in detail.

2. Methods

We consider a situation in which a protoplanet embedded in a protoplanetary disk has induced the nucleated instability and the gas of the disk accretes dynamically onto the planet. We take local Cartesian coordinates rotating with the planet, which is located at the origin. We adopt Hill's approximation. The orbit of the planet is assumed to be fixed circular and co-planar with the disk midplane. We use inviscid and isothermal gas. Magnetic field and self gravity of the gas is neglected. Basic equations of the system are accordingly given and basically the same as [5].

We employ a three-dimensional nested-grid hydrodynamic simulation code [8]. Size of the whole computational domain $(\tilde{L}_x, \tilde{L}_y, \tilde{L}_z)$ is (24,24,6) and the covered region is $\tilde{x} = [-12, 12]$, $\tilde{y} = [-12, 12]$, and $\tilde{z} = [0, 6]$, where there is a symmetry about $\tilde{z} = 0$ plane. We set 11 levels for the nested-grid system and the number of grids for each level has $(n_x, n_y, n_z) = (64, 64, 16)$. The size of the finest grid created around the planet is thus $\tilde{L}_x/64/2^{11-1} = 0.000366$, which corresponds to about 1/4 of the present Jovian radius at 5.2 AU. We examine the case where planet's Hill radius equals to the scale height of protoplanetary disk.

3. Results

Figure 1 shows the accretion flow onto the circum-planetary disk from the protoplanetary disk. On the midplane, gas cannot enter the Hill sphere and either accrete onto the circumplanetary disk. Gas in the Hill sphere is rotating in prograde direction and can exit through the two Laglangian points L_1 and L_2. Off-midplane gas in the protoplanetary disk jumped into the inner region ($\tilde{r} \lesssim 0.1$) of the disk surface nearly from the vertical direction.

Figure 2 shows the distribution of the gas directly accreted onto the circum-planetary disk. The solid line, $\tilde{f}_s(\tilde{r})$, is mass accretion flux onto a circum-planetary disk with radius $\tilde{r}$. This shows that the flux is

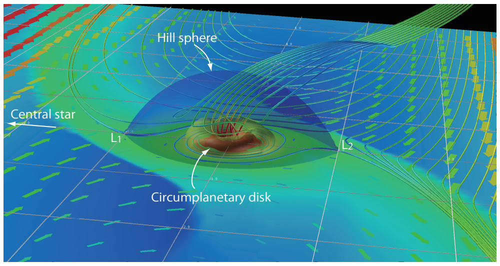

Figure 1: Structure of gas accretion flow. Colored plane is the midplane and the color shows density on the midplane. Colored lines show streamlines and the color indicates velocity of the flow. Most of the streamlines drawn in the figure are on the midplane and some are started from $\tilde{z} = 1$. Blue translucent surface shows the Hill sphere and the other surfaces show isodensity surfaces.

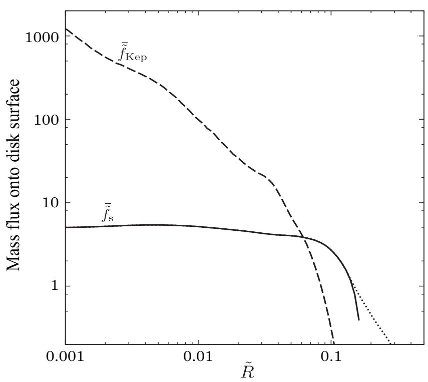

Figure 2: Mass accretion rate onto the surface of a circum-planetary disk with a given radius $\tilde{r}$. Solid line shows the distribution of the accreting mass, and dashed line shows the distribution modified by taking account of the re-distribution of the gas after accretion due to angular momentum conservation.

almost constant from the planet to ~ 0.1, which means that large fraction of gas is supplied to the outer region ($\tilde{r} \sim 0.1$). However, if angular momentum of the falling gas is considered in calculating the final position of the gas elements, the distribution should be changed to $\tilde{f}_{\rm Kep}(\tilde{r})$, which is approximately inversely proportional to $\tilde{r}$, meaning that the gas accretion in the outer region is still dominant.

Acknowledgements

This work was supported by Center for Planetary Science running under the auspices of the MEXT Global COE Program entitled “Foundation of International Center for Planetary Science”, and by Grant-in-Aid for Young Scientists (B) from JSPS (23740326). We are also grateful for the support by NASA’s Origin of Solar Systems Program. Numerical calculations were carried out on NEC SX-9 at Center for Computational Astrophysics, CfCA, of National Astronomical Observatory of Japan.

References

[1] Lunine, J. I., & Stevenson, D. J. 1982, Icarus, 52, 14

[2] Canup, R. M., & Ward, W. R. 2002, Astronomical Journal, 124, 3404

[3] Estrada, P. R., Mosqueira, I., Lissauer, J. J., D’Angelo, G., & Cruikshank, D. P. 2009, Europa, University of Arizona Press, Tucson, p27

[4] Bate, M. R., Lubow, S. H., Ogilvie, G. I., & Miller, K. A. 2003, MNRAS, 341, 213

[5] Machida, M. N., Kokubo, E., Inutsuka, S., & Matsumoto, T. 2008, Astrophysical Journal, 685, 1220

[6] Ayliffe, B. A., & Bate, M. R. 2009, MNRAS, 397, 657

[7] Ward, W. R., & Canup, R. M. 2010, Astronomical Journal, 140, 1168

[8] Machida, M. N., Tomisaka, K., & Matsumoto, T. 2004, MNRAS, 348, L1