Origin of a Difference Between Jovian and Saturnian Satellite Systems

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Abstract. The difference between Jovian and Saturnian satellite systems has been a mystery. Here we introduce the formulations of growth and orbital evolution of proto-satellites in accreting proto-satellite disks for simulations of satellite formation to explain the origin of the difference.

Keywords: satellite formation, proto-satellite disk, Jovian satellites, Saturnian satellites
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SATELLITES FORMATION IN THE ACCRETIN DISK

The Jovian/Saturnian satellites are considered to form in actively-supplied gaseous accretion disks at the very end of the host planets' own accretion [1, 2]. Adding new ideas on diverse termination of infall to the disks and associated diverse inner disk boundary conditions to the accretion disk model, we will explain the difference in satellite systems between Jupiter and Saturn [3]. In this paper, we introduce the formulations of growth and orbital evolution of proto-satellites in the accretion disks.

Accretion Disk Model

We consider the accretion disk with relatively small mass with uniform infall onto the disk [1, 2]. The asymptotic disk gas surface density distribution at $r < r_c$, in which the gas from the Solar nebula inflows [1], is given by

$$\Sigma_g = \frac{F_p}{3\pi\nu}\left[1-\frac{4}{5}\sqrt{\frac{r_c}{r_d}}-\frac{1}{5}\left(\frac{r}{r_c}\right)^2\right] \approx 0.55\frac{F_p}{3\pi\nu}, \tag{1}$$

where F_p is the total infall rate to whole disk regions at $r < r_c$ defined with τ_G as $F_p = M_p/\tau_G$ for the steady accretion state, ν is disk gas viscosity, and r_d is the diffused-out disk outer edge. The temperature of the proto-satellite disk is determined by a balance between viscous heating and blackbody radiation from the photosurface [1],

$$T_d \approx 160\left(\frac{M_p}{M_J}\right)^{1/2}\left(\frac{\tau_G}{5\times 10^6 yrs}\right)^{-1/4}\left(\frac{r}{20R_J}\right)^{-3/4}. \tag{2}$$

Adopting the alpha prescription for viscosity [4], Eq. 1 becomes

$$\Sigma_g \approx 100 f_g \left(\frac{M_p}{M_J}\right)\left(\frac{r}{20R_J}\right)^{-3/4}, f_g \equiv \left(\frac{\alpha}{5\times 10^{-3}}\right)^{-1}\left(\frac{\tau_G}{5\times 10^{6} yrs}\right)^{-3/4}. \quad (3)$$

We scale the solid surface density with a scaling factor f_d as

$$\Sigma_d = \eta_{ice} f_d \left(\frac{M_p}{M_J}\right)\left(\frac{r}{20R_J}\right)^{-3/4}, \quad (4)$$

where η_{ice} is an enhancement factor due to condensation of icy grains. In the steady state, the increase rate of f_d due to infall is

$$\frac{d f_d}{dt} \approx 0.029 \left(\frac{M_p}{M_J}\right)^{-2/3}\left(\frac{f}{100}\right)^{-1}\left(\frac{\tau_G}{5\times 10^{6} yrs}\right)^{-1}\left(\frac{r}{20R_J}\right)^{3/4}. \quad (5)$$

Our calculation shows that asymptotic values of f_d are $\sim 10 f_g$.

Accretion and Migration Rates of Proto-Satellites

The growth and migration of satellites in circum-planetary proto-satellite disks proceed similarly to those of solid planets in circum-stellar proto-planetary disks that have been studied in detail [5, 6]. The accretion timescale [5] and the type I migration timescale [6] are

$$\tau_{acc} = \frac{M}{\dot{M}} \approx 10^6 f_d^{-1} \eta_{ice}^{-1} \left(\frac{\rho}{\rho_p}\right)^{1/3}\left(\frac{M}{10^{-4}M_p}\right)^{1/3}\left(\frac{M_p}{M_J}\right)^{-5/6}\left(\frac{\beta}{10}\right)^{2}\left(\frac{r}{20R_J}\right)^{5/4} \quad (6)$$

$$\tau_{mig} = \frac{r}{\dot{r}} \approx 10^5 \frac{1}{f_g}\left(\frac{M}{10^{-4}M_p}\right)^{-1}\left(\frac{M_p}{M_J}\right)^{-1}\left(\frac{r}{20R_J}\right)^{1/2}\left(\frac{\tau_G}{5\times 10^{6} yrs}\right)^{-1/4}. \quad (7)$$

$\beta \sim 10$ is a constant value.

Our 1D model reproduces the result of N-body simulation quite well [3].

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