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# Proto-atmosphere of a giant icy satellite accreted in a gas-starved circumplanetary disk

Hidetaka Okada[1*], Kiyoshi Kuramoto[1]

[1]Hokkaido Univ.

The interiors of Ganymede, Callisto and Titan are differentiated, but the mechanism and timing of their differentiation remain an open question.

For this problem, there are two types of theories; one assumes the differentiation during satellite accretion and another assumes that after the satellite formation.

The major heat source during satellite accretion is the accretional energy by planetesimal collision. If ice compornent supplied from planetesimal evaporates by the accretional energy, it is possible that a proto-atmosphere form. In that case, the blanketing effect of proto-atmosphere raises the satellite surface temperature higher than that of the case without proto-atmosphere. If the blanketing effect is so strong as to melt ice component, the internal differentiation is possibly induced.

Pioneering studies about the proto-atmosphere of giant icy satellite during accretion are Lunine and Stevenson (1982) and Kuramoto and Matsui (1994). For environment of satellite accretion, the former assumed satellite formation in a thick circumplanetary disk, and the latter assumed that in vacuum. According to the most recent theory widely accepted, satellite may have accreted in a gas-starved circumplanetary disk (Canup and Ward, 2002, 2006). This model points out the internal differentiation of giant icy satellite does not take place during accretion because the accretion timescale is estimated to be longer than that in previous studies. However, this diagnostic is based on the model analysis of a steam proto-atmosphere assuming gas-free accretion and neglects the effect of surrounding disk gas. The properties of proto-atmosphere composed of mixed gas from the disk and ice evaporant may be significantly different from those of previous atmospheric models.

In this study, we have estimated the radiative-convective equilibrium structure of a proto-atmosphere connected with a thin gas disk hydrostatically, and calculated the satellite surface temperature as a function of satellite size and accretional energy flux. We then attempt to clarify the condition for internal differentiation of giant icy satellite accreted in a gas-starved circumplanetary disk.

As a preliminary calculation, radiative-convective equilibrium structures are solved for the present sized Ganymede embedded within the disk gas with temperature and pressure of 180 K and 12 Pa, respectively, given thermal energy fluxes at the satellites surface. When the thermal energy flux exceeds 300 W / $m^2$, the total optical depth for infrared radiation exceeds 1 mainly because of absorption by $H_2O$ vapor in the proto-atmosphere. In this case, strong blanketing effect emerges and thereby the surface temperature becomes higher than the melting point of $H_2O$. Such value of thermal energy flux is equivalent to that of the accretional energy flux when Ganymede is accreted for time slightly shorter than $10^6$ yr.

As the thermal energy flux is larger than about 600 W / $m^2$, the position of tropopause locates beyond the radius of the gravitational sphere of satellite. In this case, it is expected that proto-atmosphere enriched in $H_2O$ vapor flows out into surrounding disk. The similar result is obtained by Kuramoto and Matsui (1994) for gas-free accretion model, however, this study confirms that atmospheric outflow is possible even when surrounding nebula gas exists.