MODELING SATURN'S TURBULENT ACCRETION DISK AND FORMATION OF TITAN

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Key words: Saturn's protosatellite disk, Titan

Two-dimensional numerical model of the circumplanetary protosatellite disk of Saturn (Saturn's subnebula) has been constructed. This work is substantially based on methods of modelling circumstellar accretion disk (solar nebula) [1, 2] and develops our preceding studies concerning conditions of formation of Galilean satellites in the Jovian subnebula [3].

The model should satisfy the restrictions from the mean density of Titan and Cassini-Huygens observations of Saturn system, including the present-day data on the chemical composition of Titan's atmosphere [4]. The temperatures in the outer part of the subnebula (beginning from the Titan distance) should be sufficiently low for survival of clathrate hydrates [5], whereas formation of these compounds probably occurred not in the subnebula, but in the solar nebula, as was earlier suggested by other workers [6].

The model includes accretion of gas as well as accretion of solid particles and bodies from the surrounding region of the solar nebula on the Saturn's subnebula. Gas-dust accretion from the subnebula onto Saturn is also included. The above accretion processes suggest the subnebula to be turbulent and heated by dissipation of turbulence inside the disk. Three more mechanisms of disk heating are included: infall of gas and solids onto the disk, radiation of young Saturn and radiation of the surrounding solar nebula. . It is shown that the main mechanism of energy transport in the subnebula is radiation. Composition and size of the solid grains define the opacity of the gas-dust medium of the subnebula. We take into account temperature dependence of opacity below the water ice condensation temperature as well as at higher temperatures where organic compounds are responsible for opacity. Input parameters of the model (accretion rate, turbulent viscosity, opacity) vary for a 1-2 orders, according to the modern data on viscous protoplanetary disks and giant-planet formation. The constructed models are tested for fitting the cosmochemical constraints [5].

The radial and vertical distributions of temperature, pressure and density in the disk of Saturn and position of the water-ice sublimation front are calculated for the period of formation of Titan and other regular satellites. The model satisfies the above experimental restrictions in the following cases that are end-members among acceptable models: (1) a tenfold decrease of gas abundance in the solar nebula due to gas dispersal; (2) a decrease by 1-3 orders of magnitude of abundance of small dust grains in the subnebula due to accumulation of large dust aggregates and solid bodies (of millimetre or larger sizes).

The rate of replenishment of Saturn's protosatellite disk by solid material due to the capture of planetesimals from the surrounding region of the solar nebula is evaluated. It is shown that in cosmogonically short time intervals 10^5 yr several large (10-100 km) bodies could be captured into the subnebula from heliocentric orbits by two-body collisions, independently on gas inflow. The bodies play the role of seeds (embryos) in the process of satellite formation which proceeds by accretion of subnebula's solid material onto these seeds. The main income of solid matter into the subnebula from the feeding zones of the planets presumably resulted from the capture of dust particles and minor planetesimals (< 20 m in size) through gas drag.

We conclude that regular satellites obtained most of their solid material as small bodies from the subnebula, where it appeared from the solar nebula and after moderate heating in the subnebula it lost some volatiles. Nevertheless, satellite formation is impossible without capture of several large planetesimals that played role of embryos (seeds).

The work was supported by the Russian Foundation for Basic Research (Grant 04-05-64867)

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Electronic Scientific Information Journal "Herald of the Department of Earth Sciences RAS" № 1(24)'2006
ISSN 1819 – 6586
Informational Bulletin of the Annual Seminar of Experimental Mineralogy, Petrology and Geochemistry – 2006
URL: http://www.scgis.ru/russian/cp1251/h_dgggms/1-2006/informbul-1_2006/planet-2e.pdf

Published on July, 1, 2006
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