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Complete escape of the earliest atmosphere on Titan

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A Hydrodynamic escape of a dense earliest atmosphere which proto-Titan would capture from the saturnian subnebula is investigated with implications for the origin of the present Titan's atmosphere.

Titan, the largest satellite of Saturn, is a unique satellite covered with a thick N2 atmosphere.The surface pressure reaches 1.5 bar, and the atmosphere contains CH4, H2 and various organic compounds derived from CH4 photolysis as trace components. The major issues for understanding the origin and evolution of Titan's atmosphere are the origin of atmospheric N2 and the fate of carbon, which is expected to have been brought to this satellite more than nitrogen. Under P-T conditions of the minimum-mass saturnian subnebula (Mosqueira and Estrada, 2003; ME2003 below), major carbon- and nitrogen-bearing compounds are expected to be CH4 and NH3, respectively (Prinn and Fegley, 1989). The earliest atmosphere of Titan would be the mixture of H2-He rich gas gravitationally captured from the subunebula and heavier gas such as CH4 released from accreting satellitesimals. Since such earliest atmosphere is optically thick, its vertical structure is expected to be convective. Surface H2O ice likely becomes molten by the accretional heating and atmospheric blanketing effect during the course of accretion. Once a liquid H2O shell forms, accreting CH4 is almost entirely released to the atmosphere because of its low solubility into water. Giving the subnebula pressure and temperature at the boundary of the sphere of influence to be 0.01-0.1 bar and 100 K (ME2003), the mass of H2O-saturated adiabatic atmosphere is estimated to be 10^21-10^22 kg with surface pressure 10^3-10^4 bar and CH4 volume mixing ratio of 0.01-0.1. Here the CH4 mixing ratio is estimated from the abundance of CH4 in satellitesimals.

At the end of accretion, whole layer of atmosphere is opaque to the thermal radiation and the virtually no external radiation penetrates the sphere of influence. Such a proto-atmosphere outflows adiabatically associated with the dissipation of subnebula. This is because the estimated internal energy retained by the earliest atmosphere with moist adiabatic structure exceeds the gravitational potential energy at every atmospheric layer. If subnebula dissipates for 0.1 Myr, the adiabatic outflow of earliest atmosphere continues until the atmosphere becomes partially transparent to the thermal radiation (corresponding to the surface pressure of 0.1bar). Subsequently, the continuous atmospheric escape is driven by the IR radiation from the remnant subnebula and EUV radiation from the proto-Sun. According to one-dimensional numerical model, which takes into account H2-H2 and H2-He collision induced absorption (CIA, Brinbaum et al.,1996), CH4 band absorption for IR radiation and EUV absorption caused by the transition of electronic energy levels of H2 (Hudson,1971), the escape flux is mainly limited by external heating rate. Though, the cooling due to CIA might decrease the escape flux by an order of magnitude. Eventually the atmospheric pressure would drop below 10^-10 bar under which external EUV becomes to reach the surface. Thus, Titan is expected to have lost almost all the earliest atmosphere. This strongly suggests that the present atmosphere is derived from continuous degassing from its interior. Recently, the Cassini-Huygens mission reveals that the present Titan's atmosphere is depleted in non-radiogenic noble gases such as Kr and Xe but contains 40Ar derived from 40K decay. These data supports the entire loss of earliest atmosphere. The origin of CH4 in the present atmosphere is explained by the continuous CH4 degassing from the component originated from the undifferentiated core. Atmospheric N2 would be originally generated by conversion from NH3 in the hydrothermal system at the boundary of silicate core and H2O-NH3 ice mantle and subsequently degassed as proposed for Triton.