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The origin and evolution of Titans thick nitrogen atmosphere

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Abstract

Titan is the only satellite in the solar system with a significant atmosphere consisting mainly of N_2. Its origin, however, is yet a matter of debate. Within this presentation we will present simulations of thermal atmospheric nitrogen escape at Titan through time and discuss its implications for the origin and evolution of the atmosphere of Saturn's biggest moon.

1. Atmosphere structure and thermal escape

For the simulation of nitrogen loss at Titan we applied a time-dependent 1-D hydrodynamic upper atmosphere model that solves the system of the fluid equations for mass, momentum, and energy conservation (see [1]). An important input into this model is the evolution of the solar EUV-flux over time, which is strongly depending on the rotational evolution of the Sun [2]. Figure 1 shows the temperature profile of Titan's nitrogen atmosphere for different insulating EUV fluxes as retrieved by our model. The simulated total thermal escape of nitrogen from Titan strongly varies in dependence of the initial rotation rate of the Sun, i.e. from ~0.3 (slow rotator) to ~1.1 (moderate) and up to ~11 times the present-day atmospheric mass for a fast rotator. As an example, Figure 2 shows the loss rates in case the Sun originated as a slow rotator.

1.1 The origin and evolution of the atmosphere

An insight into the origin and evolution of Titan's nitrogen atmosphere can be gained by the isotopic fractionation of $^{14}N/^{15}N$, which can be significantly modified by atmospheric loss, since escape preferentially removes the lighter isotope from the atmosphere. Cassini measured the atmospheric value at Titan to presently be at about 168 [3] which is in the range of cometary ammonia [4,5]. This might suggest NH_3 to be a potential source of Titan's nitrogen. If escape, however, modified this value over time, its origin might be a different one, e.g. N_2 from the solar nebula or chondrites (as for the Earth).

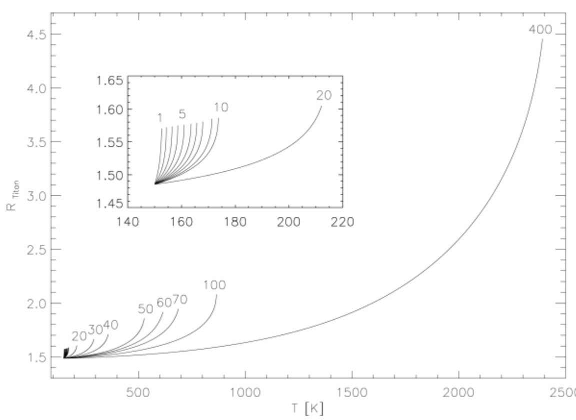

Figure 1: Temperature profiles for different EUV fluxes.

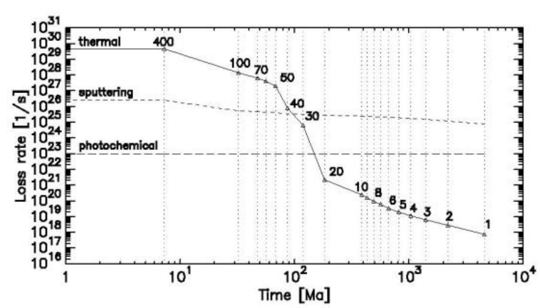

Figure 2: Atmospheric nitrogen loss rates over time (slow rotating Sun).

Our simulations show that atmospheric escape cannot alter $^{14}N/^{15}N$ significantly. Taking into account fractionation by thermal escape, sputtering and photochemistry, the original fractionation in Titan's atmosphere could not have been higher than ~161 for a slow, ~168 for a moderate and ~208 for a fast rotating Sun, indicating that the origin of Titan's atmosphere might have been indeed protosolar ammonia which is in agreement with a recent study by Mandt et al. [6]. Moreover, if Titan's atmosphere originated endogenically through decomposition of NH_3 and subsequent outgassing as N_2 as suggested by Glein (2015) [7], then our study further suggests that either for a moderate to fast rotating young Sun Titan's atmosphere originated not before ~4.3 billion years ago or the young Sun was a slow to moderate rotating young G-type star, which is also suggested by another recent study [8].

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