On the evolution of the primordial hydrosphere of Titan

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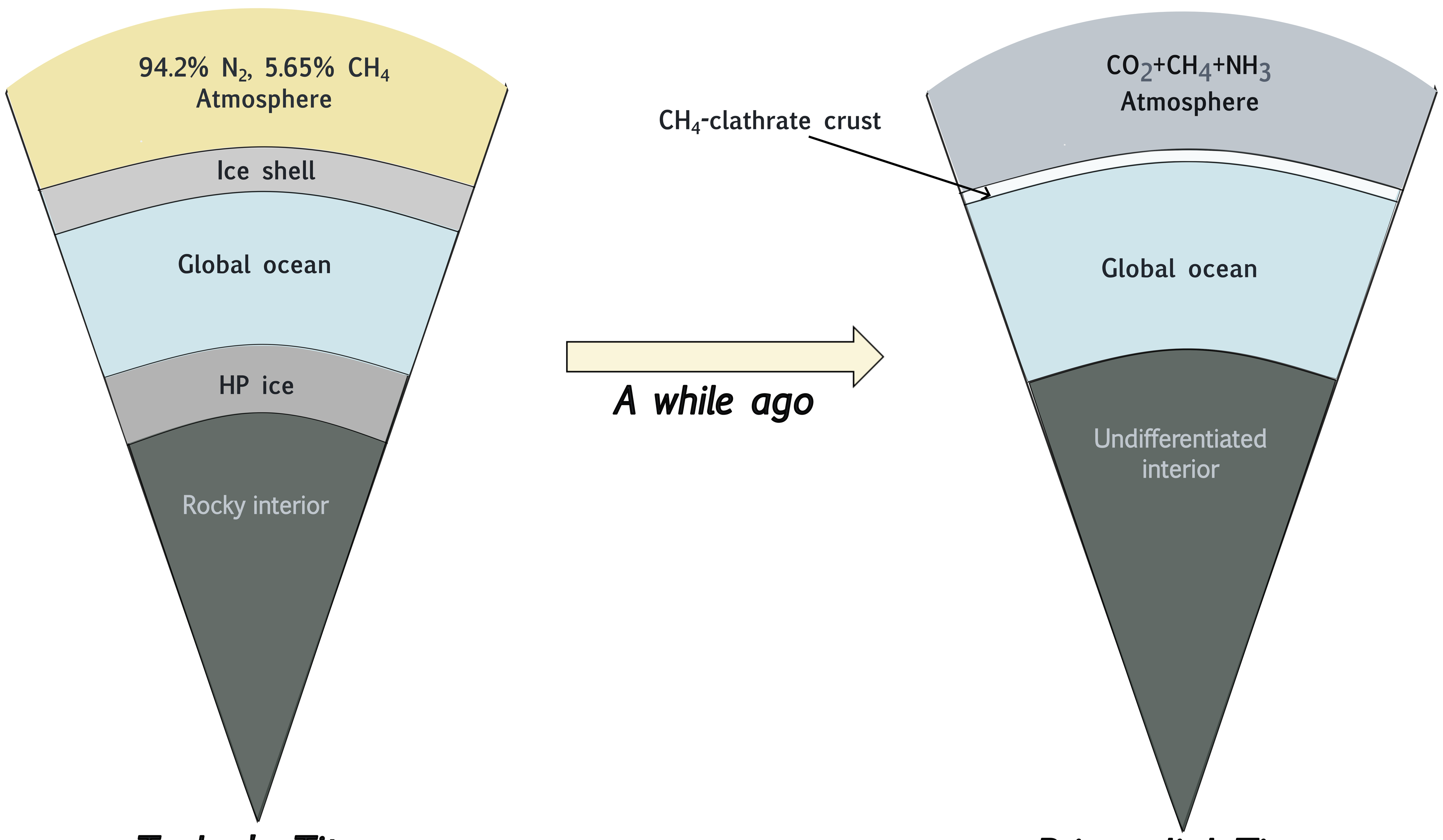
Abstract

Titan is the only moon of the solar system harboring a thick N_2-rich atmosphere, as well as a subsurface global ocean covered by an ice crust. To explore the origins and evolution of Titan's present hydrosphere volatile inventory, it is necessary to retrace the influence of the moons' formation scenarios on this inventory. To do so, we need to explore the post-accretion processes that could impact the distribution of volatiles in the hydrosphere. Especially, we investigate the evolution of the early "open-ocean" phase of Titan, which took place shortly after accretion before the ice crust formation.



Today's Titan — *Primordial Titan*

CH_4 is known to be destroyed by photochemistry irreversibly. Hence its lifetime in the atmosphere is between 10 and 100 Myr. [1]
Assuming Titan formed 4.55 Gyr ago [2], more than 10^{17} kg of methane should have been stored in Titan's interior, sustaining the atmosphere throughout years to explain nowadays' Titan atmospheric methane concentration.

Could the primordial hydrosphere have enabled the formation of a CH4-clathrate rich crust, thick enough to store such amount of methane ?

Atmosphere

$CH_4(g)$ $CO_2(g)$ $NH_3(g)$

Vapor-liquid equilibria

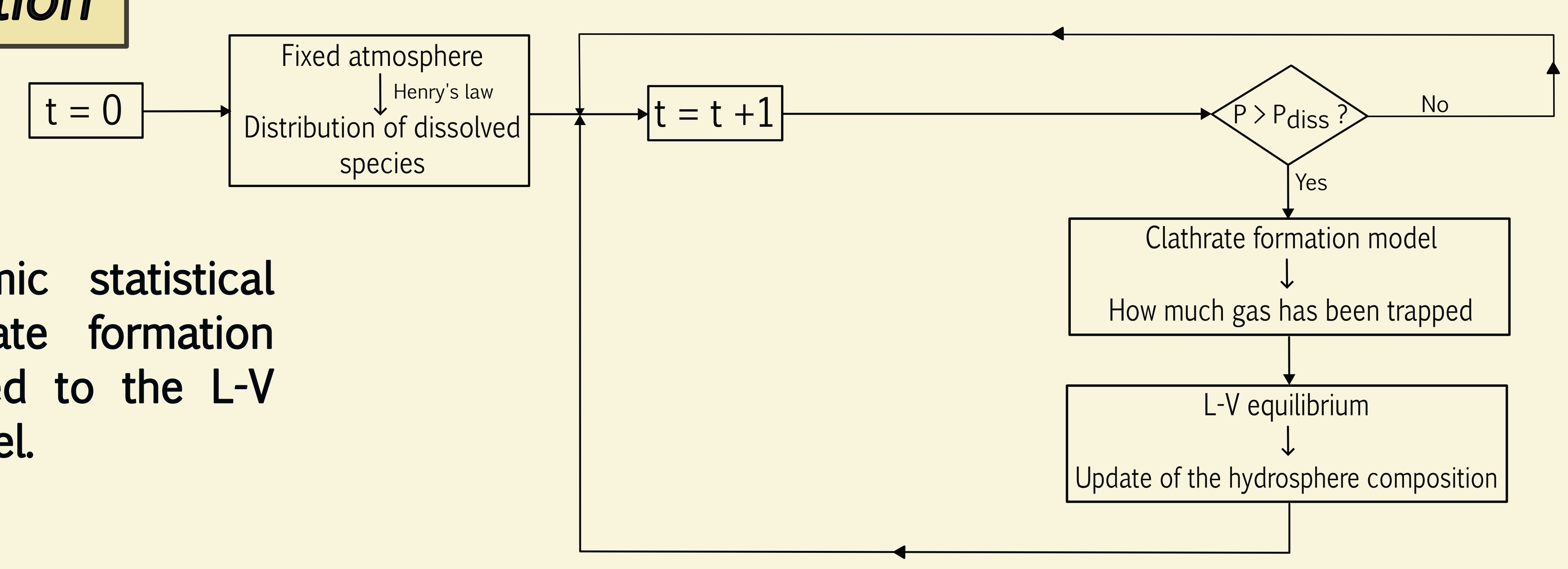
$CH_4(aq)$ $CO_2(aq)$ $NH_3(aq)$

Chemical equilibrium

Ocean

Clathrate formation

A thermodynamic statistical model of clathrate formation [3],[4] is coupled to the L-V equilibrium model.



Observables

- Ammonia is expected to be present in large quantities (min 2-3 %wt H_2O) in Titan's ocean to explain N_2% in today's atmosphere [2].

- CO_2-NH_3 chemical equilibrium in the ocean is affecting the distribution of partial pressures in the atmosphere. The values of P_{CO2} and P_{NH3} are dictated by the value of m_{CO2}/m_{NH3} in the ocean (fig 1).

- Figure 2 shows the required pressure to form clathrates as a function of CH_4/CO_2 ratio.

- To have sustain Titan's atmosphere with nowadays methane content, the pure methane clathrate crust must be at least ~40m thick.

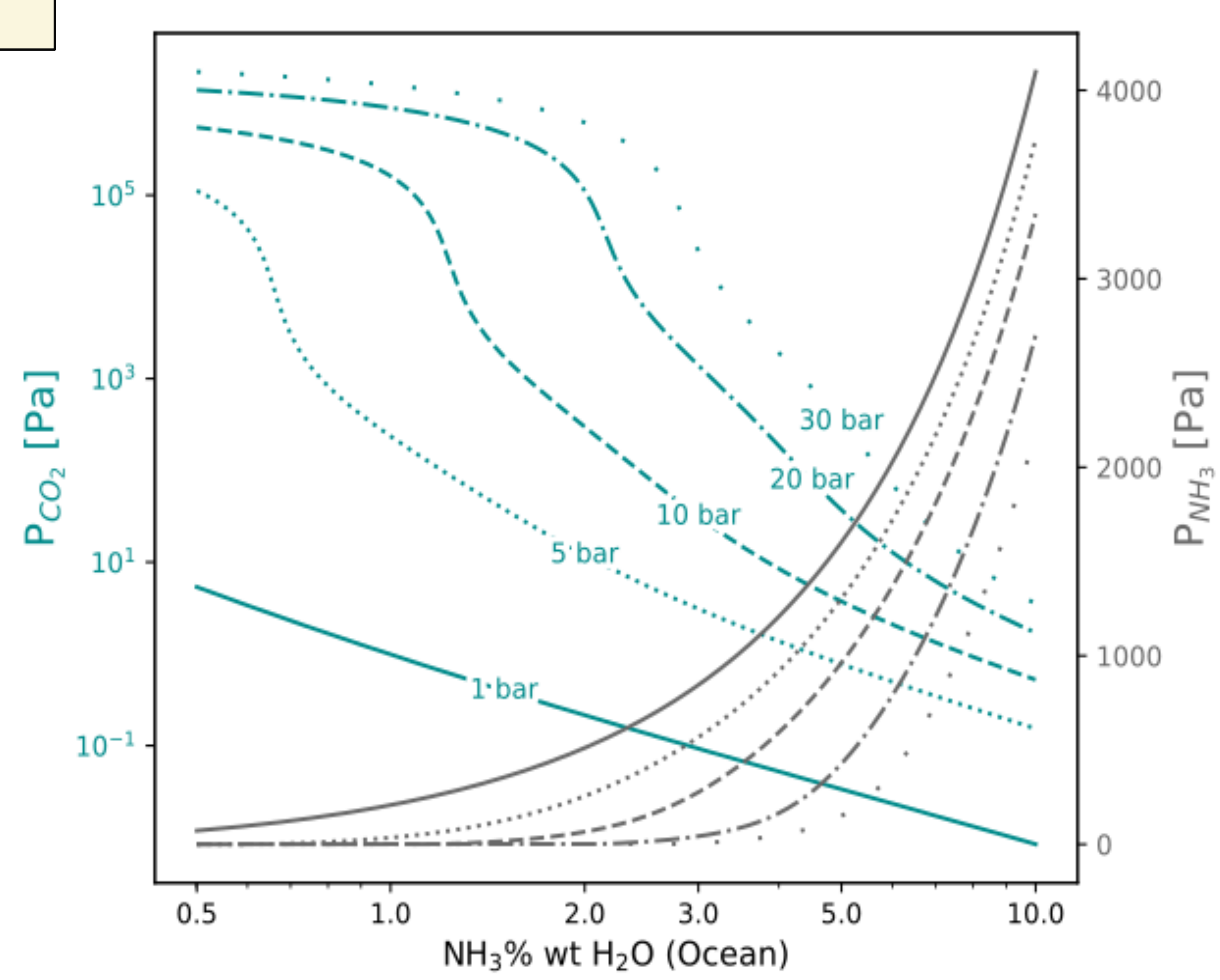


Fig 1. Partial pressures of CO_2 and NH_3 as a function of the percentage of NH_3 present in the ocean. Each curve corresponds to the amount of CO_2 incorporated in the system, which would have led to the indicated partial pressure without chemistry.

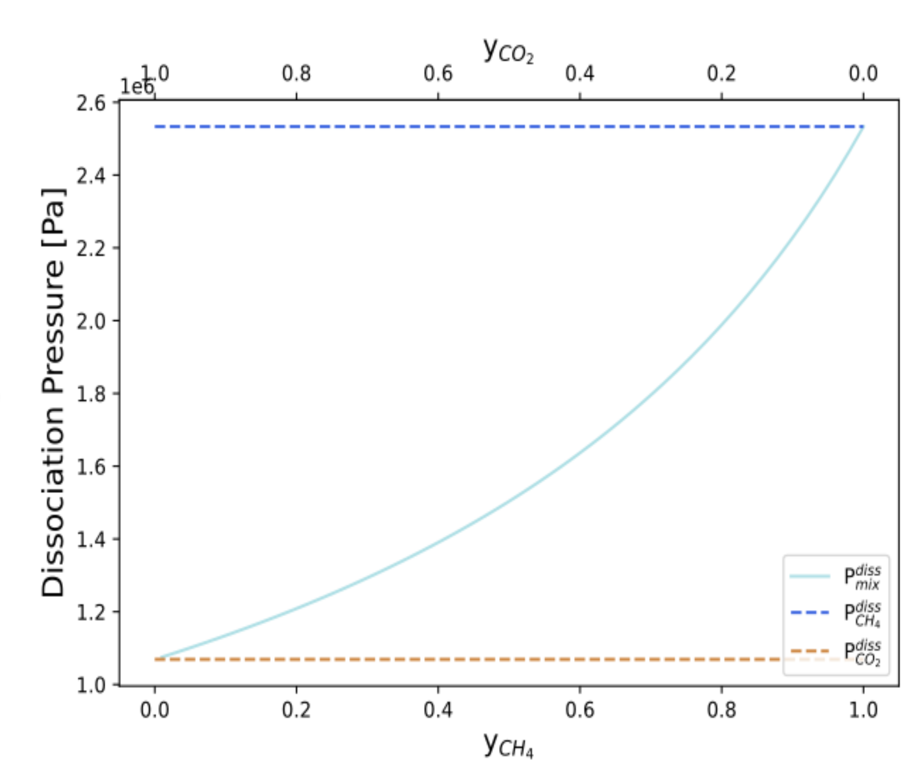


Fig 2. Dissociation pressure of clathrate as a function of CH_4/CO_2 ratio. The red and blue line show respectively the pressure of dissociation of pure CO_2 and CH_4 clathrate.

Prospects

- The formation of the clathrate crust is driven by the water ice crust's formation rate.

- Computation of the clathrates' composition, and how their formation affect the atmospheric composition.

- Computation of how noble gas trapping in clathrates could explain their depletion in nowadays' atmosphere.

References :

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