The Orbital and Structural Evolution of Triton: Evidence for a Subsurface Ocean Beneath Triton's Icy Shell

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Abstract

Triton, Neptune's largest moon, is one of the coldest bodies in our solar system with a surface temperature of 38 K. Even so, Triton may have sustained an ammonia rich subsurface ocean underneath its outer icy shell throughout its history. The presence of such an ocean relies on Triton's structural and orbital evolution. After its capture from Neptune from a heliocentric binary, Triton's orbit was rapidly circularized and began to evolve to its current values. Due to Triton's retrograde orbit, its semi-major axis decays over time. Results from my simulation indicate that Triton's semi-major axis decays slowly by 6% over 3.5 G.y. This leads to an 8% increase in orbital frequency over this period and a 60% increase in tidal dissipation over this time. Tidal dissipation helps warm the ice shell and slow the rate of freezing of he subsurface ocean. As tidal dissipation increases due to spin-up, crystallization will slow. This tidal dissipation predominantly acts at the base of the ice shell and near polar regions. At eccentricities as low as 8 x 10^{-5} a global subsurface is sustained until present day. As eccentricities decrease, a polar subsurface ocean becomes more likely while a global surface ocean becomes less likely to have been sustained.

Hypothesis

H1: Triton's spin-up increases tidal dissipation enough to sustain a polar subsurface ocean.

H Null: Triton's spin-up and subsequent increase in tidal dissipation is not enough to sustain a polar subsurface ocean.

Background

•Triton is Neptune's largest moon with a radius of 1325 km. Half of Triton's surface is composed of N_2 in solido solution with carbon monoxide (CO) and (methane). The other half is composed of carbon dioxide and ice water.
•Triton likely contains a metal core and a silicate core with radioactive elements that may contribute to a subsurface ocean.
•Based on Triton's current orbital parameters, we can suggest Triton originated in a heliocentric binary and was captured by Neptune. The other planetary body in the binary was ejected.
• Triton's surface has recent geologic features, included quasi-linear ridges, dimples formed by diaprism, icy volcanism, and cantaloupe terrain.
•Crater counting suggests this features are less than 100 Ma years old.
•Rapid circularization of Triton contributed large amounts of energy into the system. Tidal blanketing may allow the subsurface ocean to remain over time.

Results

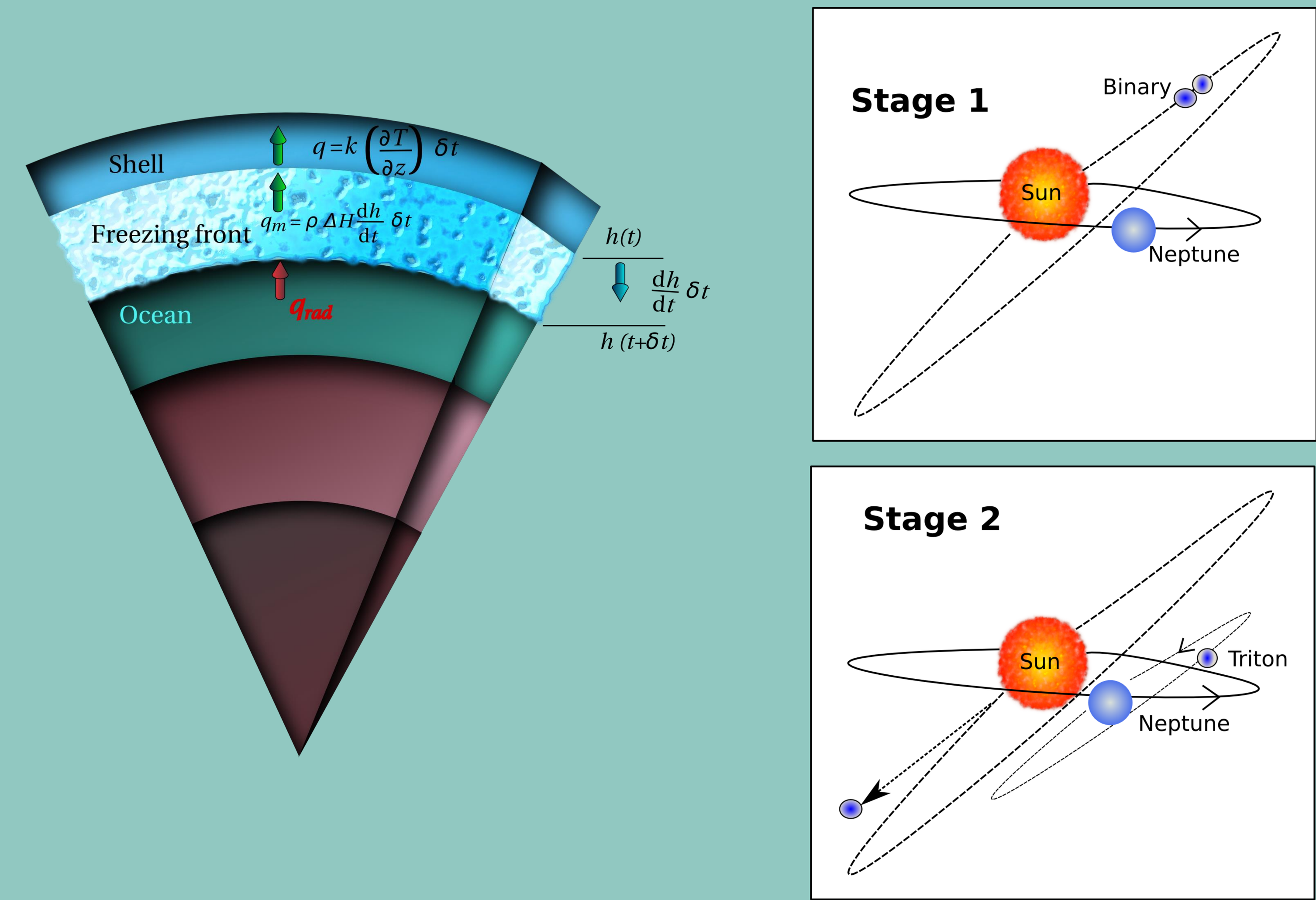


Figure 1: Left: A cross section of Triton. The interior of Triton contains a metallic core surrounded by a silicate mantle. This silicate mantle likely contains radiogenic elements which contribute heat to a potential subsurface ocean. Above this subsurface ocean we expect to see a freezing front of the outer subsurface ice shell. **Right:** Graphic of Triton's capture by Neptune. Early in our solar system's history, Triton orbited the sun in a heliocentric binary. This binary came into close proximity to Neptune and was captured, resulting in Triton's retrograde orbit.

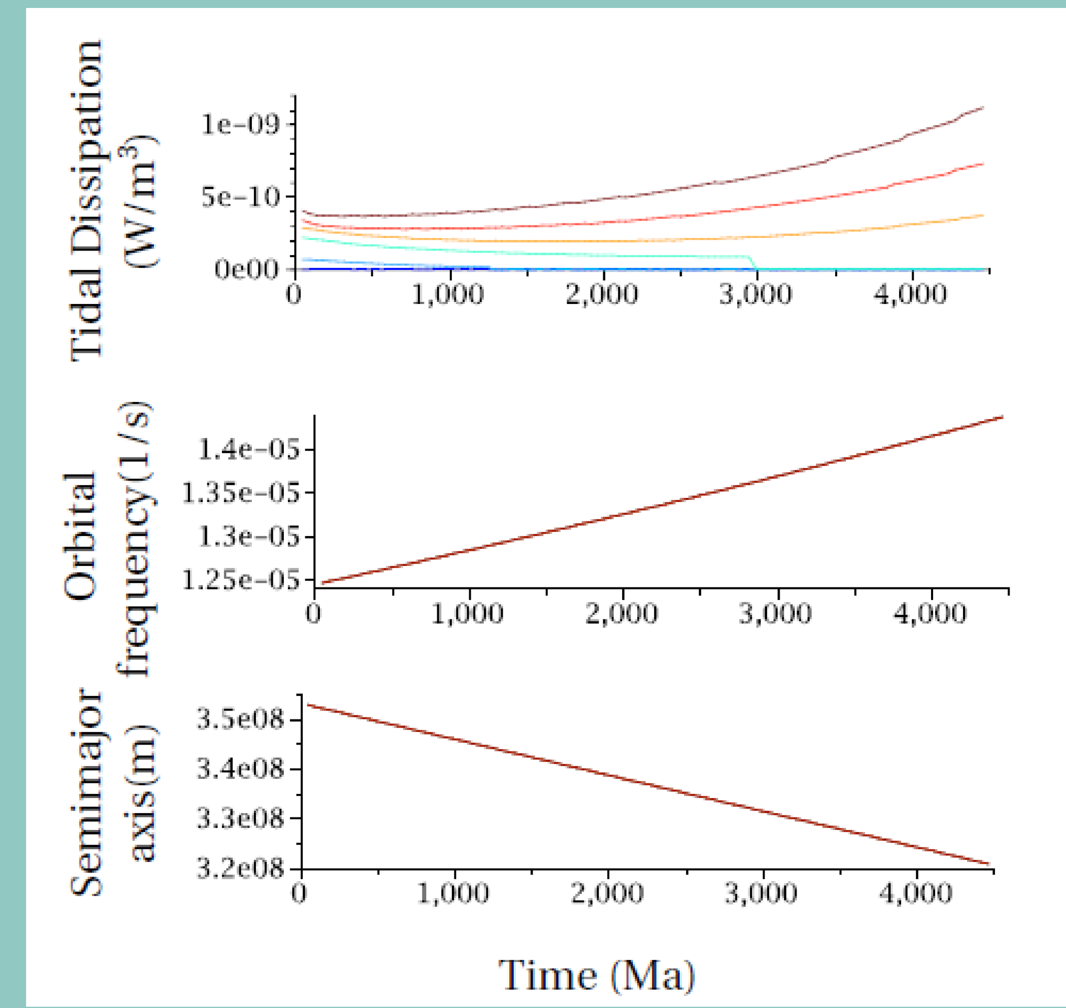


Figure 2: Orbital evolution of Triton. The top graph shows increases in tidal dissipation of Triton over time, except for the lowest eccentricities. At eccentricities of 8 x 10^{-5} or higher, tidal dissipation increases due to spin up. The middle graph shows the 8% increase in spin-up with time, while the bottom graph displays the 6% decrease in semi-major axis.

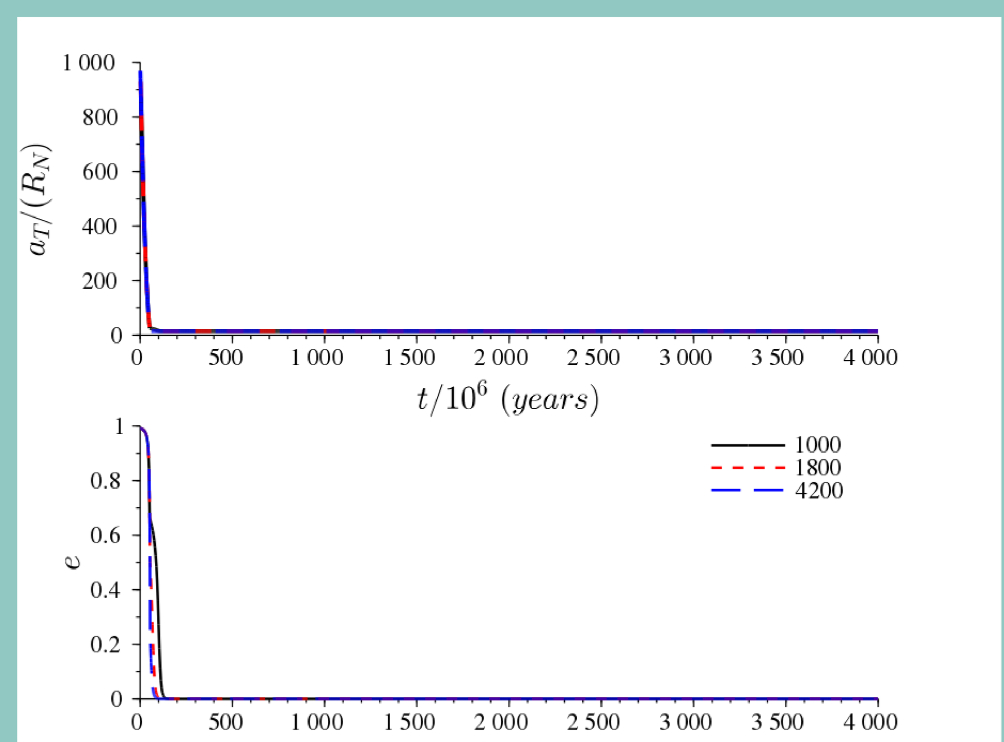
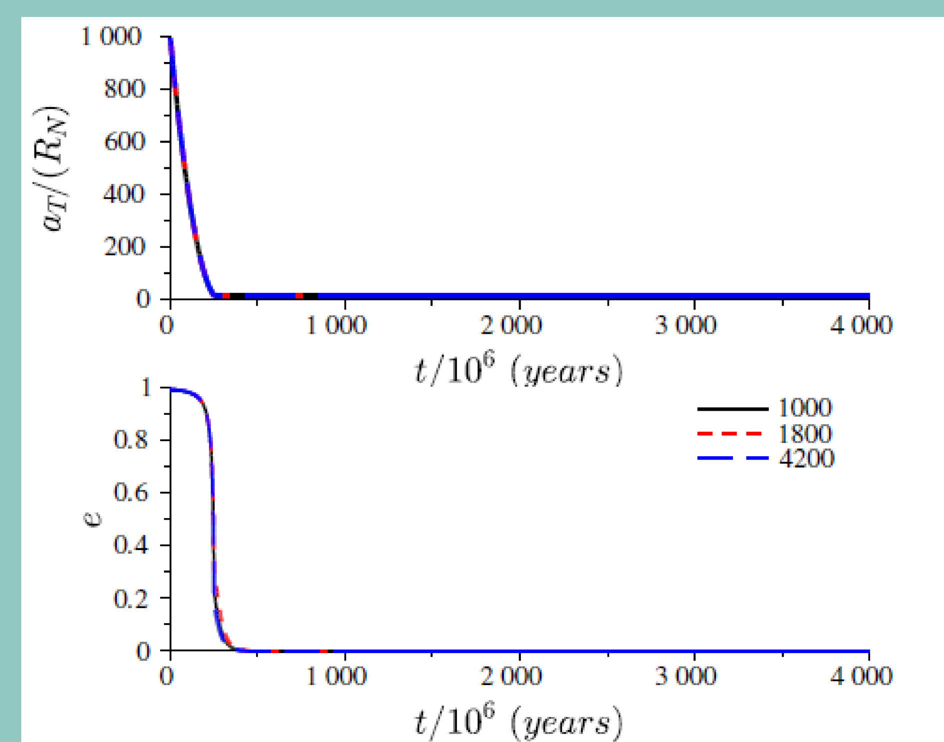
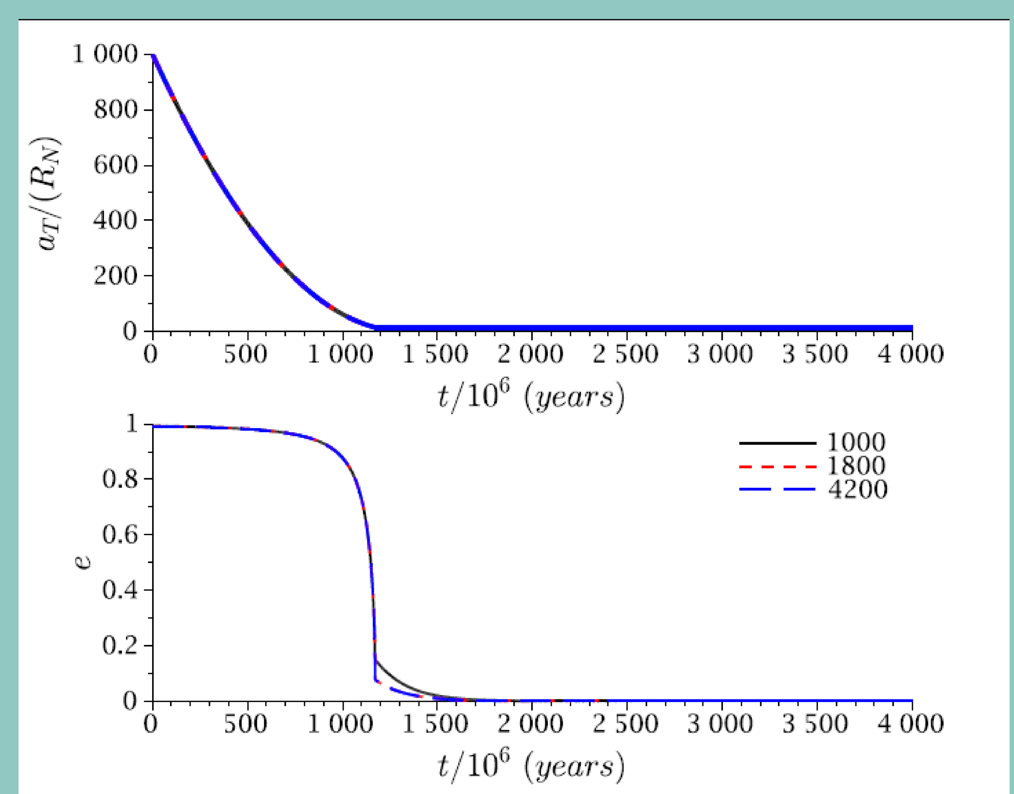
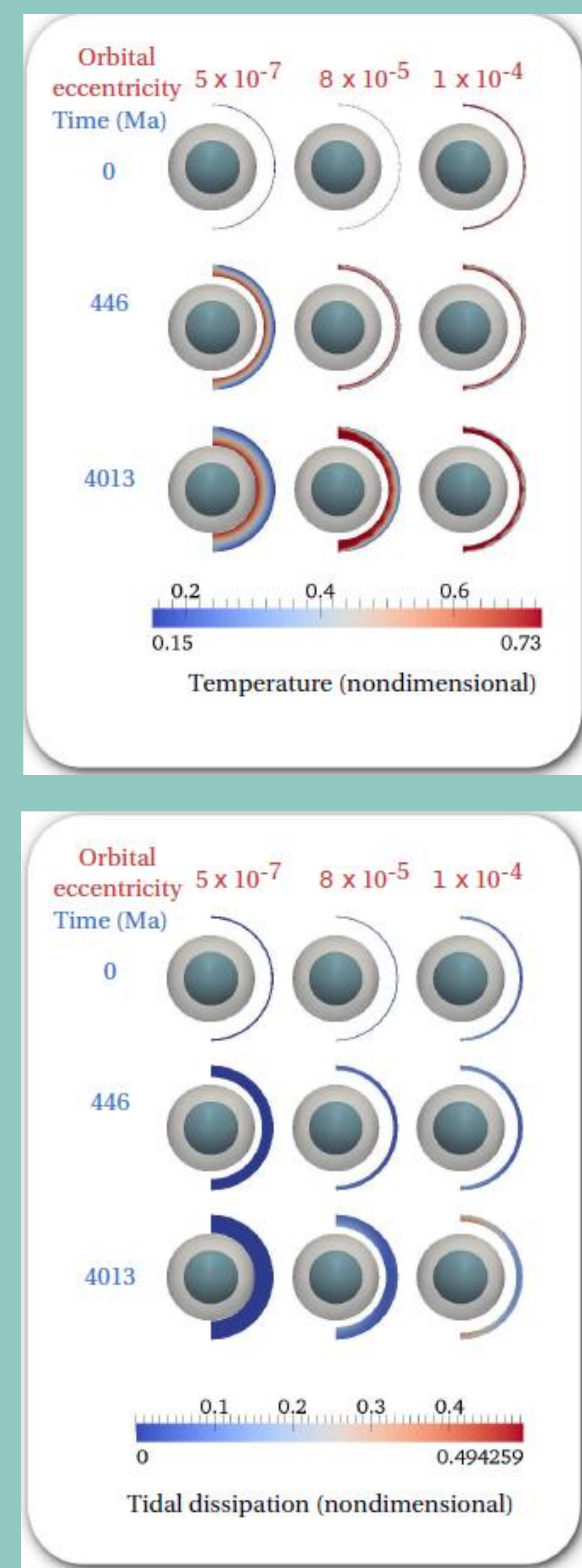




Figure 3: The three graphs (left and above) represent how changes in K_2/Q_n effect the evolution of eccentricity of semi-major axis and eccentricity with time. The top left graph is for a K_2/Q_n magnitude of 10^{-2}, the top right has a magnitude of 10^{-3}, and the bottom left graph has a magnitude of 10^{-4}..

Figure 4: The simulations to the right indicate changes in temperature (top) and tidal dissipation (bottom) for difference initial eccentricities over 4 G.y. At intial eccentricities at 8 x 10^{-5} or higher a subsurface ocean is sustained over time. **Top right :** higher temperatures are visible with higher eccentricities. Increased temperatures occur at poles, where tidal dissipation is strongest. **right:** the tidal blanketing mechanism is prominently visible., especially in polar regions



Methods

•**Orbital evolution**

$$\frac{da}{dt} = \left(-\frac{(3k_{2N})}{Q_N}\right)\left(\frac{M_N}{M_T}\right)\left(\frac{C_N}{a}\right)^5 (a)(n)$$

Triton's orbital evolution numerically modeled using the 4th order Runge Kutta Method. Provided an initial condition for the semi-major axis and used a grid size of 1000, which minimized analytical error. A seperate model was constructed to exam the effect changes in values of K_2 and Q_N would have on orbital evolution.

•**Thermal evolution**

$$\frac{\partial T}{dt} = \left(-\frac{(\kappa)}{\rho c_p}\right)\nabla^2 T + \dot{E}$$

Structural Evolution

$$\rho \Delta H \frac{dh(t)}{dt} = \kappa \nabla T \cdot \hat{r} \mid h(t) - q_r(t) \mid$$

•Structural and thermal evolution were numerically modeled using the finite element method model DyMMS (Dynamics of Melt Migration and Storage) and TiRADE**.** These models use finite element method discretization on a quadratic quadrilateral grid. Semi-major axis and orbital frequency are obtained from the orbital evolution model at each time step and are coupled with structural and thermal evolution.

Discussion

• The orbital evolution model shows that Triton's semi-major axis decays by approximately 6% over 3.5 G.y. Orbital frequency increases by approximately 8% over this time. The increase in orbital frequency causes a nearly 60% increase in tidal dissipation.
• In a coupled orbital-structural and thermal evolution model, the subsurface ocean fails to crystallize completely except at the low tested eccentricities.
• At eccentricities lower than 8 x 10^{-5} we saw full crystallization of the subsurface ocean. At lower eccentricities only partial crystallization occurred.
• Tidal blanketing predominantly acts in the polar regions and makes polar oceans more likely
• Changes in the K_2 and Q_n parameters lead to highly variable changes in the orbital evolution.
• I accept the hypothesis that a polar subsurface ocean may exist on Triton.

References

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