The Science Case of Nautilus: A Multi-Flyby Mission to Triton

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References

[1] Hansen et al., 2021, *PSJ*. [2] Tyler et al., 1989, *Science*. [3] Hussman et al., 2006, *Icarus*. [4] Angor and Hamilton, 2006, *Nature*. [5] National Research Council, 2022, *The National Academies Press*. [6] Nimmo and Spencer, 2015, *Icarus*. [7] Trinh et al., 2023, *Science Advances*. [8] Anderson et al., 1998, *Science*. [9] Hofgartner et al., 2022, *Icarus*.

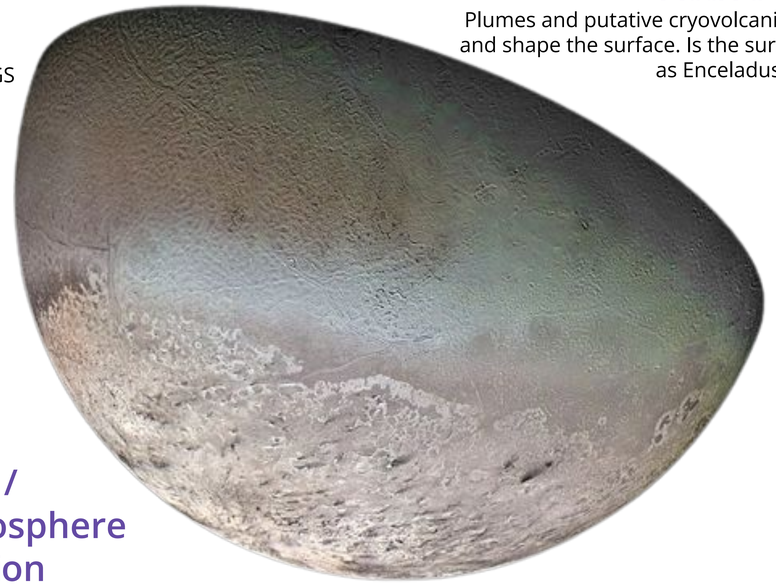
Background: Why Triton?

Neptune's largest moon, Triton, has puzzled scientists since Voyager II's flyby in 1989. Voyager II revealed an **active surface** with unusual geology [e.g., 1] and a unique atmosphere with a surprisingly **strong ionosphere** [2]. Triton is also a **candidate ocean world** [e.g., 3]. Given Triton's orbital characteristics, it has also been suggested that Triton was captured into orbit around Neptune, and could potentially even be a captured Kuiper Belt Object [4]. The combination of these features makes Triton an ideal place to study numerous questions set forth by the most recent Planetary Science Decadal Survey [5] (esp. Q2, Q5, and Q6). Additionally, despite observing ~60% of the moon's surface, Triton boasts the largest unmapped expanse in the solar system with an impressive ~40% (9.2×10^6 km^2) still unseen. **A new mission with instruments targeting specific scientific objectives could reveal the remainder of Triton's surface and answer the questions left in the wake of Voyager II.**

Active Surface

Plumes and putative cryovolcanism overwrite and shape the surface. Is the surface as active as Enceladus or Europa's?

Image Credit: NASA/JPL/USGS



Satellite / Magnetosphere Interaction

Triton's unusually strong ionosphere interacts with Neptune's tilted magnetosphere.

Ocean World / Captured KBO

A potential subsurface ocean enriched in C and N, given that Triton may have formed in the Kuiper Belt.

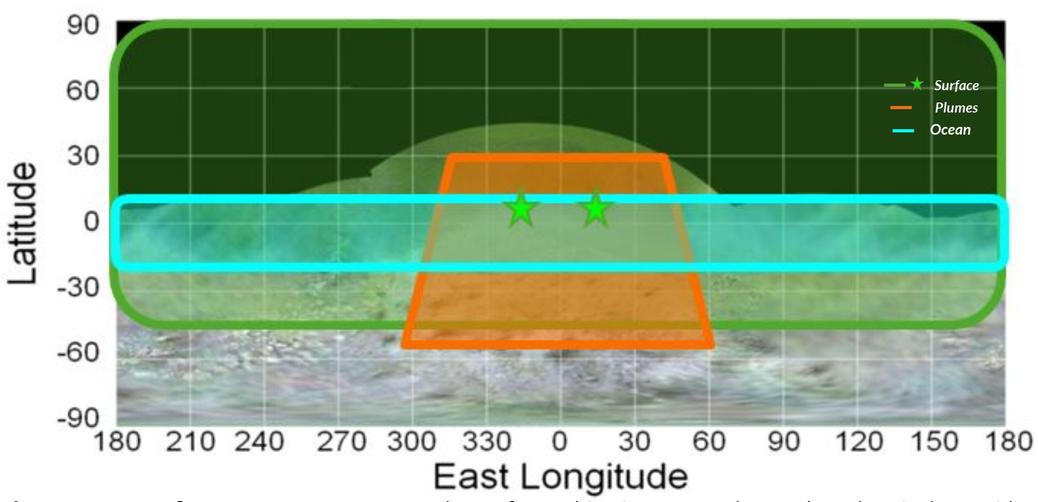


Figure 1) Areas of Measurement Interest. The surfaces objective targets the northern hemisphere with closest approach flybys starred targeting the details of the cantaloupe terrain and walled plains. The plumes objective targets the southern hemisphere terrain and the oceans objective targets equatorial landmarks for obliquity. Background image credit: NASA/JPL/USGS

Science Mission Objectives

1) Subsurface Ocean

Triton may host the only subsurface ocean sustained by obliquity tides. A conductive ice shell (<300 km thick) means radiogenic heating alone can sustain an ocean. A convective ice shell (>300 km thick) means obliquity tidal heating is needed [6]. To answer this objective we need to:

- Determine the spin axis obliquity
- Measure normalized moment of inertia
- Measure magnetic field strength

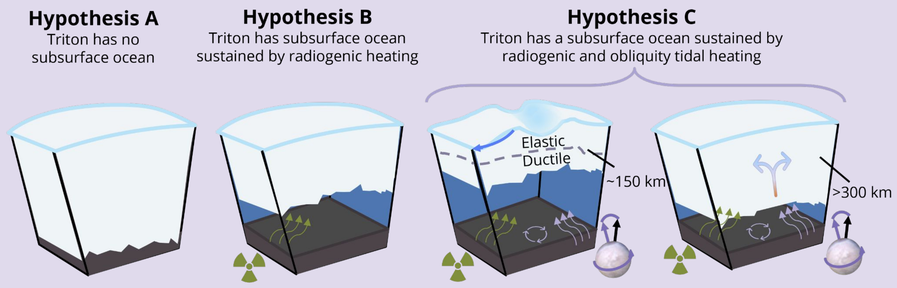


Figure 2) Hypotheses to **determine whether obliquity tidal heating contributes to sustaining a global subsurface ocean**. Credit: **SD, BGD.**

2) Atmosphere and Ionosphere

Determine whether ionization and escape processes in Triton's ionosphere are driven by precipitation of magnetospheric electrons or solar radiation. Between Neptune's unique strongly oblique magnetic field and Triton's retrograde orbit, this is a natural laboratory to study how changing planetary field lines (L-Shells) impact ionization. To answer this objective we need to:

- Measure field line strength
- Measure electron densities and energies
- Observe Triton's airglow emissions

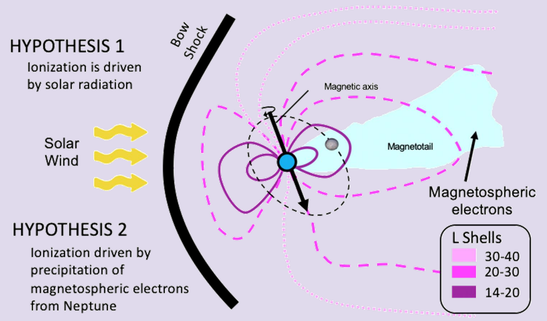


Figure 3) Schematic of Triton within Neptune's magnetic field. This objective considers two hypothesis for the source of Triton's strong ionosphere. Credit: **SD**

3) Surface Geology

Determine if geologic features (e.g. cantaloupe terrain and walled plains) are formed or shaped by internal or external processes. Triton's surface features are unique among known icy worlds. Are these features indicative of Triton's nature as a KBO (internal) or nurture as a tidally shaped icy moon (external)? To answer this objective we need to:

- Expand the observed area of Triton to the North.
- Increase image resolution to ~40 m/px.
- Determine whether surface features are endogenic or exogenic in origin.

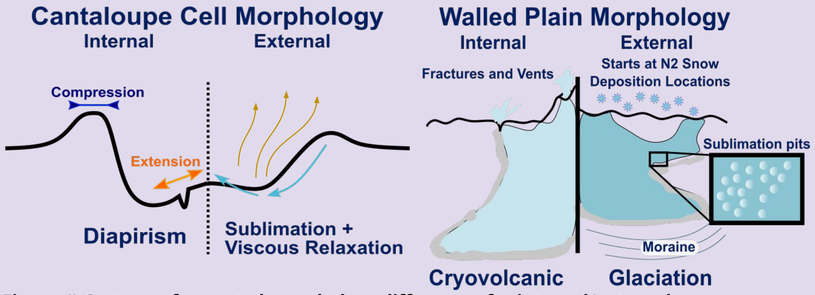


Figure 4) Cartoon of expected morphology differences for internal/external energy sources. Note highly detailed differences that fell under the V2 resolution limits. Credit: **JWC+CS**

4) Metallic Core

Determine whether Triton has a metallic core, which may be a consequence of capture. The capture process should generate ample heat to melt metal, which is a necessary condition for metallic core formation [6]. However, metallic core formation is also possible if Triton formed endogenously [7]. To answer this objective we need to:

- Measure Triton's normalized moment of inertia using gravity and radio science [e.g., 8]

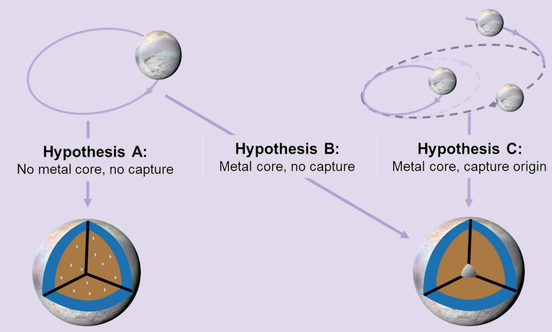


Figure 5) Triton's metallic core (if it exists) may be a relic of the capture process. Credit: **SD, BGD.**

5) Plumes

Determine whether Triton's plumes are the result of solar irradiation, melting volatiles caused by internal heat, or cryovolcanism. [9] lists the following tasks to identify plume mechanisms:

- Observe distribution of fan deposits on surface
  - Hypothesis 1: Subsolar latitude
  - Hypothesis 2: Southern Hemisphere Terrain
  - Hypothesis 3: No location dependance
- Measure fan composition
  - Hypothesis 1 & 2: Nitrogen ice dominant
  - Hypothesis 3: Water ice dominant

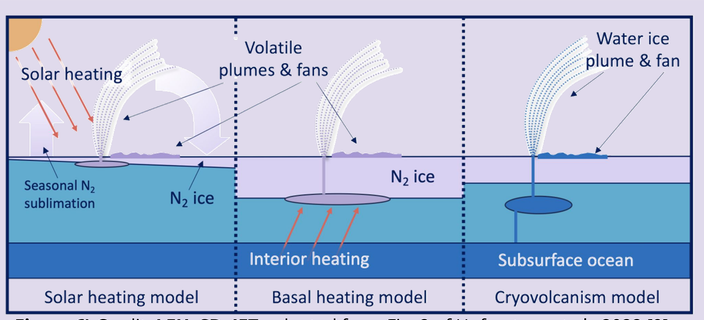


Figure 6) Credit: **LEH, SD, JET**, adapted from Fig. 2 of Hofgartner et al., 2022 [9]