EXPLORING TRITON WITH TRIDENT: A DISCOVERY-CLASS MISSION.

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Overview: Neptune's moon Triton was one of the most unusual and surprising bodies observed as part of the Voyager mission. During its distant flyby in 1989, Voyager 2 captured a series of images, mostly of the southern, sub-Neptune hemisphere, establishing Triton as one of a rare class of solar system bodies with a substantial atmosphere and active geology. Although Triton is, like many other bodies, subject to the tidal, radiolytic, and collisional environment of an icy satellite, its starting point and initial composition is that of a Dwarf Planet originating in the KBO. It is this duality as both captured dwarf planet and large icy satellite that has undergone extreme collisional and tidal processing that makes Triton a unique target for understanding two of the Solar System's principal constituencies and the fundamental processes that govern their evolution. Thus, comparisons between Triton and other icy objects will facilitate re-interpretation of existing data and maximize the return from prior NASA missions, including *Voyager, New Horizons*, *Galileo, Cassini* and *Dawn*. Triton was recently identified as the highest priority candidate ocean world in the recent "Roadmaps to Ocean Worlds" study [1].

Background: Triton has a remarkable but poorly understood surface and atmosphere that hint strongly at ongoing geological activity, suggesting an active interior and a possible subsurface ocean. Crater counts suggest a typical surface age of <10 Ma [2], with more conservative upper estimates of ~50 Ma on more heavily cratered terrains, and ~6 Ma for the Neptune-facing cantaloupe terrain. These results imply that Triton almost certainly has the youngest surface age of any planetary body in the solar system, with the exception of the violently volcanic world, Io. The lack of compositional constraints obtained during Voyager, largely due to the lack of an infrared spectrometer, means that many of Triton's surface features have been interpreted as possibly endogenic based on comparative photogeology alone. Candidate endogenic features include: a network of tectonic structures, including most notably long linear features which appear to be similar to Europa's double ridges [3]; several candidate cryovolcanic landforms [4], best explained by the same complex interaction among tidal dissipation, heat transfer, and tectonics that drives resurfacing on Europa, Ganymede, and Enceladus; widespread cantaloupe terrain, unique to Triton, is also suggested to be the result of vertical (diapiric) overturn of crustal materials [5]; and several particulate plumes and associated deposits. Despite an exogenic solar-driven solid-state greenhouse effect within nitrogen ices being the preferred formation mechanism initially [6], this paradigm is now being questioned [7] in the context of observations of regionally-confined eruptions on the much smaller Enceladus.

The possibility of an endogenic heat source is considered more likely over the past few years, given recent studies that have suggested sufficient heat to maintain an internal ocean. Radiogenic heating alone may play an important role, possibly providing sufficient heat to sustain an ocean over ~4.5 Ga [8]. Capture into orbit around Neptune [9, 10 and references therein] would have almost certainly resulted in substantial heating [11]; the time of capture is not constrained, but if sufficiently recent some of that heat may be preserved. Finally, despite having a highly circular orbit, Triton's high inclination also results in significant obliquity, which should be sufficient to maintain an internal ocean if sufficient "antifreeze" such as NH_3 is present [12]. Confirmation of the presence of an ocean would establish Triton as arguably the most exotic and probably the most distant ocean world in the solar system, potentially expanding the habitable zone to 30 AU.

Even without the presence of an ocean and endogenic activity, Triton remains one of the most compelling targets in the solar system for exploration. Triton's atmosphere is thin, ~1 Pa, 10^{-5} bar, but sufficiently substantial to be a major sink for volatiles, and sufficiently dynamic to play a role in movement of surface materials. Its youthful age implies a highly dynamic environment, with surface atmosphere volatile interchange, and potentially dramatic climate change happening over obliquity and/or season timescales. An extensive south polar cap, probably mostly consisting of nitrogen which can exchange with the atmosphere, was observed. No north polar cap was detected, in part due to a lack of high northern latitude image coverage, but even so we would have expected to have observed the outer limits of such a structure, implying a dichotomy. The presence of methane in the atmosphere, and possibly on the surface, makes possible a wide range of "hot atom" chemistry allowing higher order organic materials to be produced in a similar, albeit slower, manner to Titan. The presence of such materials is of potential importance to habitability, especially if conditions exist whereby they come into contact with liquid water.

Mission concept: We have identified an optimized solution to enable a New Horizons-like fast flyby of Triton in 2038 that appears at this preliminary stage to fit within the Discovery 2019 cost cap (see companion paper by Mitchell et al., this meeting [13]). The mission concept uses high heritage components and builds on the New Horizons concepts of operation. Our overarching science goals are to determine: (1) if Triton has a subsurface ocean; (2) why Triton has the youngest surface of any icy world in the solar system, and which processes are responsible for this; and (3) why Triton's ionosphere is so unusually intense. If an ocean is present, we seek to determine its properties and whether the ocean interacts with the surface environment. Trident will pass within 500 km of Triton, inside its atmosphere, imaging the surface, sampling its ionosphere, and getting sufficiently close as to permit highly detailed magnetic induction measurements. Passage through a total eclipse makes possible atmospheric occultations.

Trident's focus on the internal structure, surface geology, organic processes, and atmospheric characteristics of Triton closely align with key priorities established in the NRC 2013 Planetary Decadal Survey and the NASA 2018 Roadmaps to Ocean Worlds white paper.

Instrument suite: To address these questions, we propose a focused instrument suite consisting of: (1) a magnetometer, primarily for detection of the presence of an induced magnetic field which would indicate compellingly the presence of an ocean; (2) a high-resolution mapping and compositional infrared spectrometer with spectral range up to 5 um, suitable for detection and characterization of surface materials at the scales of Triton's features; (3) a narrow-angle camera, for imaging of the mostly unseen anti-Neptune hemisphere; (4) a wide-angle camera for repeat imaging of the sub-Neptune hemisphere to look primarily for signs of change; (5) a gravity and atmospheric occultation radio system; and (6) a plasma spectrometer to sample Triton's tenuous atmosphere.

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References

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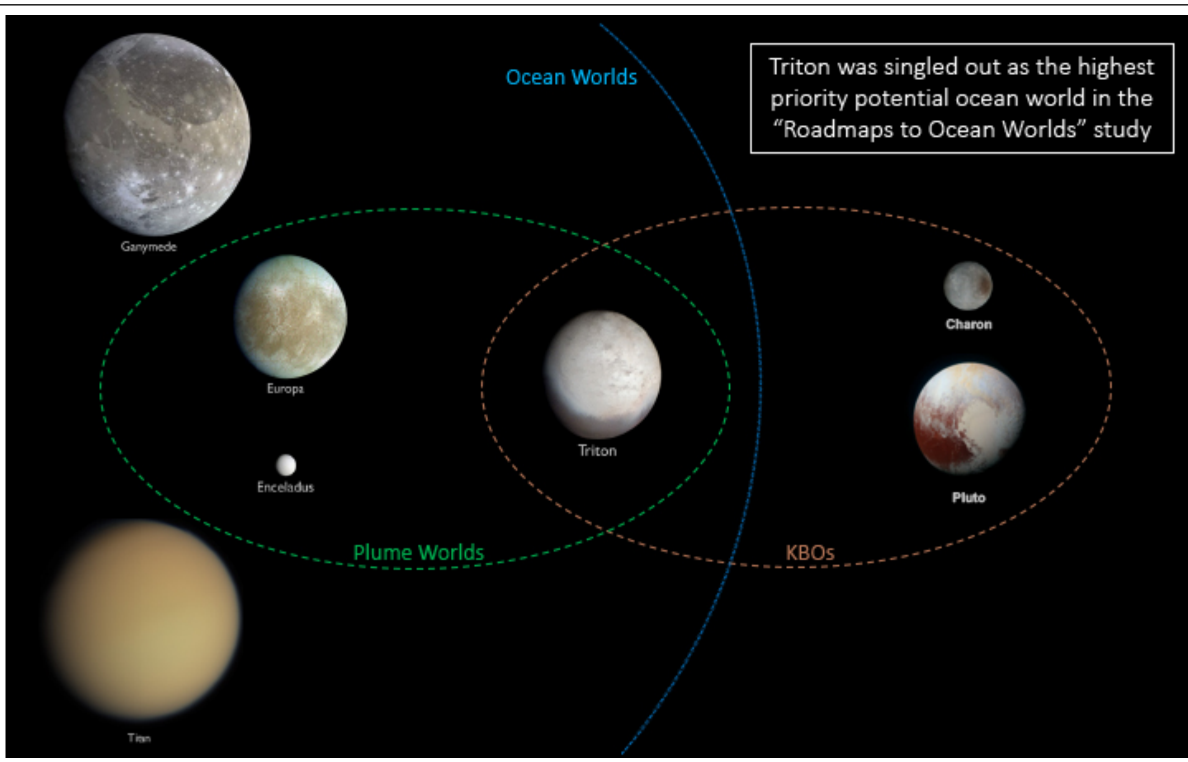

Figure 1: Triton is a captured, evolved KBO, and a candidate ocean world. It is also a member of the family of icy worlds thought to have plumes.