LESSONS LEARNED FROM SCIENCE IMPLEMENTATION OF THE PROPOSED TRIDENT DISCOVERY MISSION TO TRITON. K. L. Mitchell[1], W. Frazier[1], D. Bearden[1], L. M. Prockter[2], and the Trident Team, [1]JPL, Caltech, Pasadena, CA 91109, USA <karl.l.mitchell@jpl.nasa.gov>, [2]JHU APL, Laurel, MD.

Introduction: Of all Solar System icy worlds, Triton has the youngest and most active surface. Voyager 2's sole encounter revealed the Solar System's first icy plumes, unique and enigmatic terrains, a dynamic atmosphere, and a surprisingly energetic ionosphere. As a captured KBO, likely ocean world and compelling habitability target at 30 AU, it is a tantalizing and challenging exploration target. In 2017 an opportunity was found to reach Triton under a modest NASA Discovery Program budget, delivering a powerful suite of instruments capable of major scientific advances (fig. 1). The Trident concept was down-selected for Phase A studies in 2020 along with three strong competitors, with a final evaluation of "selectable but not selected", with "Excellent" science and science implementation and "Medium" risk. Lessons learned by the team are presented below.

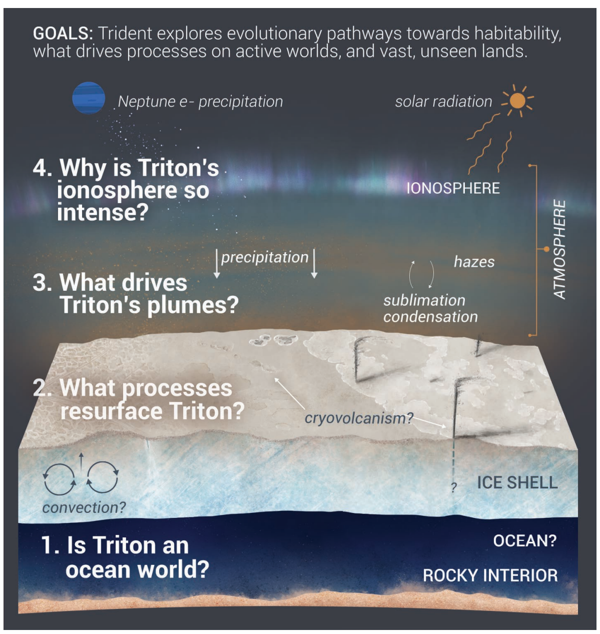

Figure 1 – Trident was designed to investigate the processes responsible for Triton's unusual landforms and plumes, determine the energy source for the intense ionosphere, and establish whether there is a subsurface ocean.

Pursue bold ideas: Despite initial skepticism that a comprehensive mission to Triton at 30 AU could be achieved within the Discovery cost cap, it was enabled by several critical elements: (i) a Jupiter gravity assist, permitting a simple, low-mass spacecraft design, and a 13-year ballistic trajectory, (ii) a radioisotope power system, which was successfully advocated for inclusion after being excluded from the draft AO, (iii) a higher-than-typical cost fraction for a mature payload – Magnetometer, Infrared Spectrometer and Narrow-Angle Camera, Wide-Angle Camera, Plasma Spectrometer, and Radio Science – including a remote sensing suite with excellent optical throughput, supporting the ~20 km/s flyby even at ~1/900th terrestrial light levels. The timely 2038-2042 arrival capitalized on a valuable observational window – closing in the mid-2040s for a century – to reveal changes in Triton's plume activity and surface characteristics one Triton season since the 1989 Voyager 2 encounter. Trident's instruments were integrated into a flight system provided by Ball Aerospace, with JPL leadership and expertise in key specialty areas (e.g., MMRTGs), providing a robust and capable mission within the Discovery cost cap [1].

Develop science traceability early to ensure robust requirement tracking and development: A science traceability matrix featuring hypothesis-based objectives was developed early in proposal development, not just to reflect the mission design but also as a tool to inform trades and allow tracking and negotiation of requirements. This streamlined interactions between science and engineering teams, improving communication and saving work effort.

Don't fear the flyby!: Despite the successful New Horizons mission, which demonstrated the utility of a flyby approach to planetary exploration using modern technology, a concern was identified that the constrained nature of the encounter could mean that data quality and quantity would be limited, and increased the perceived risk. This greater anticipated scrutiny led the Trident team to make observation planning and sequencing a core element of the team right from the formulation (or pre-Phase A) stage, in contrast with other missions that commonly wait until Phases A or B [2]. A 10-day science campaign (fig. 2) was planned to explore four targeted and interrelated objectives, from interior to exterior, and in doing so reveal with unprecedented richness the rest of Triton's unexplored surface. Thus, we were able to support robust remote sensing data sufficiency and develop and test redundant approaches to data collection and return. This contrasts with most other NASA flight project teams, which do not include mission planners or detailed sequencing until around project lifecyle phase A or B.

Model data sufficiency early: Among the many challenges faced by the project was the discovery that existing magnetometric methods for ocean detection were insufficient to demonstrate compelling ocean detection on a single flyby with sufficient margins. As a result, we had to devise a novel approach rapidly, which was breathtaking in terms of both multi-disciplinarity and scope (person-years of effort). While ultimately successful and productive, leading to multiple papers [3, and references therein], it was a time-consuming and costly distraction. Similar but lesser challenges were tackled for the other mission science objectives.

Turn challenges into strengths: COVID-19 impacted the entire science community, and might have had devastating consequences for the Discovery portfolio efforts. As initially the last mature mission concept in the competition, due to a lack of participation in prior competitions, there were fears that lockdowns would adversely impact the development effort. However, an unanticipated benefit was that shifting to an entirely virtual model allowed for improved engagement and collaboration with partners beyond JPL. Those experiencing lockdown conditions around the world worked enthusiastically with the JPL-centered team, feeling closer to the heart of the project than under other circumstances, despite distance and isolation. This allowed us to build a strong sense of community and utilize partnerships more effectively, which contributed in part to a successful and energetic virtual site visit.

Looking forward: While not ultimately selected, Trident's development spurred considerable advances to Triton science, even with the limited existing dataset available, and has led to a more engaged and productive community. Unfortunately, the Jupiter gravity assist window only comes along once every 13 years, and will almost certainly close too soon to allow a competitive proposal to be submitted to Discovery 2023, so we will now have to wait for another decade before re-proposing a similar approach. By this time, of course, the entire launch paradigm may have shifted. As a result, the Trident team will turn their attention to other mission opportunities to explore Triton as part of broader initiatives, including Ice Giant orbiters.

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References: [1] Frazier, W. et al. (2020) IEEE Aerospace Conf., Big Sky MT, pp. 1-12. [2] Frazier, W. et al. (2019) AAS 19-037; [3] Cochrane, C. J. et al. (in review) Single- and Multi-Pass Magnetometric Subsurface Ocean Detection and Characterization in Icy Worlds Using Principal Component Analysis (PCA): Application to Triton, submitted to *Earth Space Sci.*

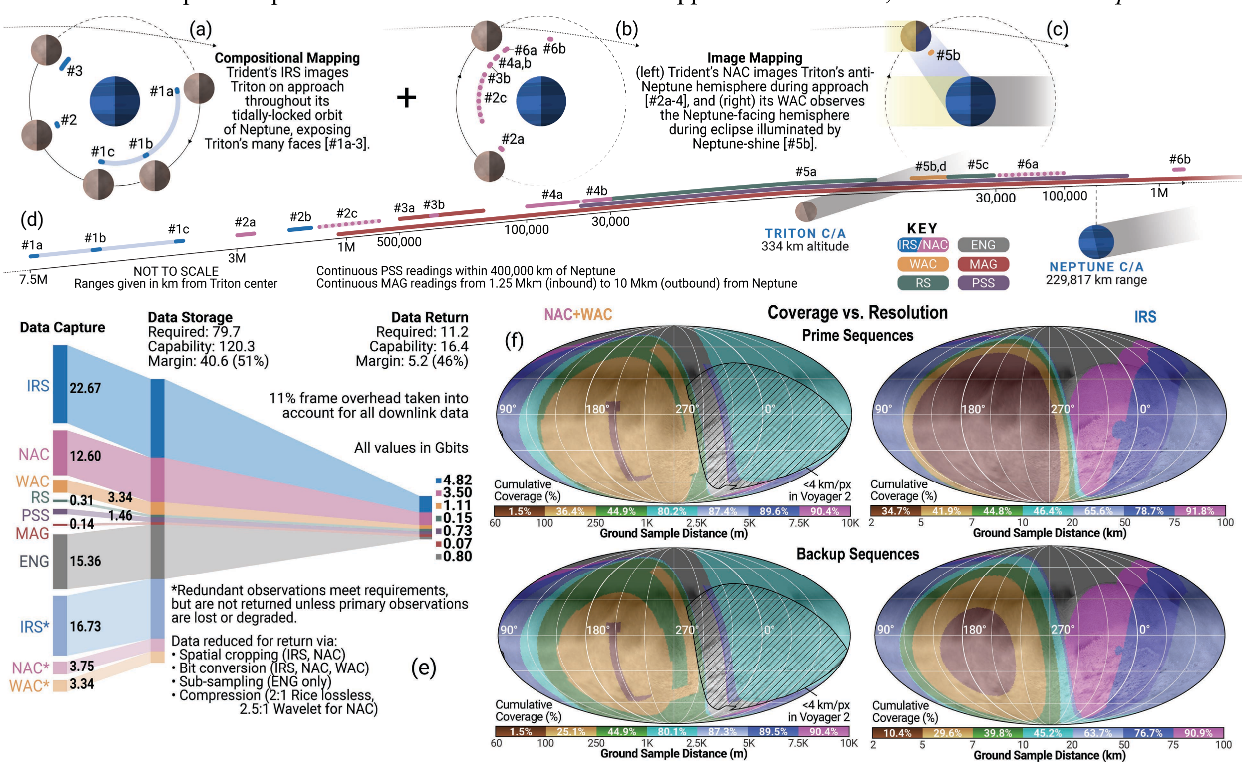

Figure 2 – Trident would have performed (a) compositional mapping and (b) imaging, using high-resolution sensors observing over ~2/3 of tidally-locked Triton's orbit of Neptune, combined with (c) innovative, stacked eclipse imaging exploiting Neptune-shine illumination. The sequence was broken down into successive segments (d), #1a-6b, with different observation characteristics. Trident data capacity provided margins allowing science enhancement (e). (f) The combined products ensured (f) high-quality, near-global mapping on a single encounter, exceeding expectations from a single pass.