Abstract Submitted to NASA SMD Technology Showcase Call for Mission Concept and Technology Needs

**Shadow Chaser: a smallsat concept to determine the middle and upper atmospheric structures of Uranus and Neptune through stellar-occultation measurements from Earth orbit**

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**Science Goals and Objectives:** The Shadow Chaser smallsat mission will measure the middle and upper atmospheric temperature and density of Uranus and Neptune through stellar occultation (SO) technique from Earth orbit. By achieving its scientific objectives, the mission will address the Decadal Survey Priority Question "Q7. Giant planet structure and evolution: What processes influence the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres?"

The key transformative advancement to be enabled by Shadow Chaser over Voyager 2 and ground-based SO measurements is the vastly improved data quality to be returned by our mission concept. The mission's main scientific objectives include investigating the surprisingly hot thermospheres of Uranus and Neptune found by Voyager 2. The Voyager 2 UV occultation measurements revealed that the atmospheres of Uranus and Neptune are unexpectedly hot; explaining the high temperatures would require an unknown source of heat. This disparity between the cold temperatures that would be expected based on the distance from the sun of these planets and the high temperatures that are observed is often referred to as the "giant planet energy crisis." Understanding the energy balance in the upper atmospheres of Uranus and Neptune requires further atmospheric observations, and such measurements would help to inform a flagship mission to either Ice Giant.

Stellar occultation measurements are possible from (near) Earth by relying on serendipitous alignment of distant stars and these planets. However, these time-critical SO events are often not visible from a ground-based observatory due to unreliable weather and Earth's rotation. Even when an event is visible, ground-based measurements suffer from and photometric fluctuations caused by atmospheric scintillation which negatively impacts the signal-to-noise ratio (SNR). Consequently, the high-precision photometry required for SO measurements are possible only using telescopes with 1-meter aperture or larger, which preclude placing mobile telescopes at sites with favorable observing conditions as typically done to observe asteroid occultations. Thus, a vast majority of these occultations are left unobserved primarily because the occultations are not observable from ground-based observatories with the appropriate equipment. We have determined that SO measurements performed using a 20-cm telescope in Earth orbit can return an SNR comparable to those using a 4-meter aperture on the ground (Saunders et al. 2022). Thus, the Shadow Chaser concept will overcome these difficulties by performing reliable high-quality observations of Uranus and Neptune by making SO measurements in Earth orbit.

**Target Destination:** The Shadow Chaser mission's scientific targets are Uranus and Neptune, which will be observed from Earth orbit through the stellar occultation technique. Shadow Chaser will tour a select subset of the shadows cast toward Earth by the 56 Uranus and 14 Neptune stellar occultation events that are observable from Earth orbit between 2025-2035 (Saunders et al. 2022). These SO events are valuable opportunities that enable unique access to Uranus and Neptune to advance our understanding of the middle and upper atmospheres of the Ice Giant planets with unprecedented precision using modern instrumentation.

**Mission Architecture:** Shadow Chaser is envisioned as a smallsat in Earth orbit. We are currently studying the feasibility of making the proposed stellar occultation measurements from an orbit similar to a Geostationary Transfer Orbit (GTO). Orbital SO measurements require a mid/high-Earth or GTO-like orbit because each SO event lasts for up to an hour; thus, spacecraft in a 90-minute low-Earth orbit cannot remain on the Uranus/Neptune-facing phase of the orbit for the full duration of an SO event. We currently envision that the satellite will reach GTO on a rideshare opportunity offered by a geostationary satellite launch. Subsequently, Shadow Chaser will raise its periapsis to stabilize its orbit from where its tour of the SO shadows will commence. Once the spacecraft reaches its science orbit, it will adjust its orbital phase through delta-V maneuvers so that SO measurements are performed near the orbit's apoapsis, which will ensure that the full duration of each SO event is observable from the spacecraft.

**Platform:** Shadow Chaser is envisioned as an ESPA-class smallsat carrying a >20-cm aperture telescope in Earth orbit.

**Expected Measurements:** Shadow Chaser will make stellar occultation measurements from Earth orbit. Detailed photometric measurements of the star as it goes behind the planet reveal the refractivity as a function of altitude, which can be converted to temperature, pressure, and density as function of altitude when hydrostatic equilibrium and the ideal gas law are assumed. A telescope with an aperture of tens of cm will provide a sufficient SNR to reveal the vertical upper atmospheric structure with enough vertical resolution to resolve a scale height. As the distant star appears much smaller than the occulting planet, an occultation measurement senses a small region of the atmosphere that occults the star. We are currently exploring orbital configurations that will target a set of SO events and measure at least 5 latitudes including the south polar region, southern mid-latitude, equatorial region, northern mid-latitude, and near the north pole. In addition, in combination with ground-based observations, an orbital observation will also create a potential to measure multiple latitudes during a single SO event by simultaneously observing from telescopes on the ground and from orbit separated by a long distance.

**Target Solicitation:** The Shadow Chaser concept targets the next SIMPLEx solicitation assuming a 50% increase in the cost cap over the previous opportunity as recommended by the recent Decadal Survey.

**Technology Challenges/Opportunities:** Shadow Chaser will advance science, and also benefit future atmospheric entry missions to Uranus and Neptune. In particular, improved measurements by Shadow Chaser will reduce the risk in an aerocapture orbit insertion maneuver, which is a NASA technology of strategic importance for future missions to the Ice Giant Planets, the last class of planets to be explored by an orbiter.

**Reference:**

Saunders, W. R., Person, M. J. Withers, P. Sayanagi, K. M. Young, C. L. Randall, C. and Valle, T. (2022) "Assessment of the feasibility of space-based stellar occultation observations of Uranus and Neptune" Planetary and Space Science 213, 105431, https://doi.org/10.1016/j.pss.2022.105431