

Shadow-Chaser: A Small Satellite Concept to Probe Ice Giant Atmospheres Using Stellar Occultations

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One of the major challenges in planetary atmospheric sciences is to understand the structure and temporal evolution in the upper atmospheres of Uranus and Neptune, the distant-most planets in our solar system. The most detailed measurements were made by the Voyager flybys of Uranus and Neptune in the 1980's using the stellar occultation technique. In a stellar occultation measurement, the target planet occults a distant star. 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. Voyager UV occultation measurements revealed that the atmospheres of Uranus and Neptune are very hot, despite the relatively small amounts of solar radiation these planets receive given their great distances from the Sun [1,2]. This disparity between the cold temperatures that would be expected based on the orbital placement of these planets and the warm 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 Earth by relying on serendipitous alignment of distant stars and these planets. However, ground-based measurements suffer from photometric fluctuations caused by atmospheric scintillation which negatively impacts the signal-to-noise ratio (SNR), unreliable weather, and are dependent upon time of day. 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 present a small satellite mission concept that will make stellar occultation measurements from Earth orbit. 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. An orbital observation will also create a potential to measure multiple locations on the target planets by simultaneously observing an occultation event from telescopes separated by a long distance. 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. Multiple telescopes on Earth could at most be separated by the ~12,000 km Earth diameter, which is much smaller than the ~90,000 km diameter of Uranus and Neptune; however, simultaneous measurements from the ground and an orbital platform (or multiple orbital platforms) could greatly increase this separation distance and will multiply the value of an occultation event by measuring multiple locations on the occulting planet, helping to uncover the latitudinal structure and seasonal variability.

We show that high-quality measurements of the upper atmospheres of Uranus and Neptune are possible

from satellites in Earth orbit. From 2025 through 2035, as many as 56 Uranus and 14 Neptune occultations could be observed from orbit, compared to 20 Uranus and 6 Neptune events from the ground [3]. We believe that placing a telescope in Earth orbit is a viable way to take advantage of these occultation events to monitor the temporal evolution of these distant planets that have had only a single visiting mission.

[1] Herbert et al. (1987). JGR, 92, 93-109.

[2] Broadfoot et al. (1989). Science, 246, 59-66.

[3] Saunders et al. (2022). Planetary and Space Science, <https://doi.org/10.1016/j.pss.2022.105431>

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