



## Uranus Stellar Occultation 2025: Report and Preliminary Results from the Largest Uranus Stellar Occultation Campaign

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**Background:** UV occultations measured by Voyager 2 (V2) during its flyby of Uranus in 1986 detected a warm stratosphere and extremely hot thermosphere [1,2], far in excess of solar irradiance [3,4] or internal heating [5]. These measurements imply that Uranus has the coldest lower stratosphere and yet the hottest thermosphere of any Solar System planet [6] (Figure 1, dotted line). Uranus also has the weakest vertical mixing of any giant planet [5]. The fundamental lack of understanding about the energy balance of Uranus' atmosphere is an example of the "giant planet energy crisis" [7].

Furthermore, the V2 UV occultation measurements and models were in stark tension with Earth-based stellar occultations observed 1977-1996. In [8,9], we presented the results of processing 26 archival occultations using modern techniques, showing decreased stratospheric discrepancies, but thermospheric discrepancies remain. In [9], we presented a new 1-D atmospheric model based on the most reliable of these results, which shows a thermal structure similar to that of the other giant planets, and in contrast to some V2 measurements.

**Motivation:** Measurements of  $H_3^+$  emissions indicate that Uranus' thermosphere has cooled from 725K in 1992 to 425K in 2019 [7] and continues to cool to the present [10]. New stellar occultations have the potential to identify the present-day thermal structure and allow for comparison between different atmospheric layers to better understand energy transport in Uranus' atmosphere.

**Aims:** On 2025 April 08 UT, Uranus occulted a bright star, creating the best stellar occultation opportunity in decades. We observed the occultation using 18 professional telescopes in the US and Mexico, involving over 35 astronomers and observers. Details about the campaign and team can be found at <https://science.larc.nasa.gov/URANUS2025/>. To our knowledge, this was the largest Uranus stellar occultation campaign ever organized, and the largest simultaneous observation of Uranus since the 1986 V2 flyby campaign. We will report on the execution of the campaign, as well as preliminary results on atmospheric and ring measurements. We will discuss anticipated results and their implications for the understanding of Uranus' thermal structure, long-term variations, and potential use of aerocapture for orbital insertion of a spacecraft around Uranus.

**Background on Stellar Occultations:** An Earth-based stellar occultation occurs when a solar system body appears to pass in front of a distant star. By observing the differential refraction of starlight through the atmosphere of the occulting body, we can determine the pressure, temperature, and density vs. altitude with high accuracy and vertical resolution in the stratosphere and lower thermosphere ( $\square 0.1$ –100 microbar pressures). Observations of Uranus ring occultations are used to study the rings in detail and improve Uranus' ephemeris [11].

**Occultation Details:** This stellar occultation was initially predicted and reported in [12]. The star

has designations BD+18 489, SAO 93455, Gaia DR3 57460310166762752, and is an F5 white dwarf in a physical binary system with a parallax of 8.08 mas. Its magnitude is reported as  $V=9.05$ ,  $R=9.70$ ,  $K=7.95$ . The occultation occurred between approximately 02 and 03 UT on 2025 April 08; the view of Earth from the occultation at the mid-point is shown in Figure 2. All observations (with the exception of the IRTF) had to begin immediately after sunset and observe low in the Western horizon, creating a challenging observation.

**Occultation Campaign:** Figure 3 is a map showing the locations of each site involved in the campaign. In preparation, each telescope's team tested different combinations of filters, cadences, sub-frame windows, and/or modes to achieve the best possible signal-to-noise without any risk of saturating. Infrared or methane absorption band filters were used where available and achieved the best signal-to-noise. Of the 18 telescopes that attempted the observation, 14 had good weather and we anticipate 4-7 will produce high quality atmospheric light curves.

**Preliminary Results:** We will present preliminary results in (1) atmospheric temperature structure, (2) long-term stratospheric variations, and (3) ring occultation measurements. We will report the thermal structure of Uranus' stratosphere and lower thermosphere from inverting these light curves and the resulting vertically averaged stratospheric temperatures in 2025. We will compare these to past occultations from 1977-1996 as well as  $H_3^+$  measurements of the thermosphere. We will report on the many detected ring occultations and how they are being used to improve Uranus' ephemeris

**Implications for Aerocapture:** Aerocapture is a maneuver for orbital insertion in which a spacecraft passes through the stratosphere of a planet to decelerate. If used for a mission to the ice giants, it would enable a much shorter cruise and larger science payload than a propulsive orbital insertion [13], but it is impeded primarily by large uncertainties in Uranus' stratospheric densities [14]. We will discuss how our results may improve density measurements in support of aerocapture.

**Future Work:** We are exploring how airborne and/or space-based observations of future occultations (especially a 2031 Uranus occultation of a 4th magnitude star) may improve upon the ground-based observations from 2025, based on initial work from [12]. We will discuss science and technology motivations as well as the instrument needs for the 2031 occultation. We will also report on critical lessons learned that may help with future occultation campaigns.

**References:** [1] Herbert et al. (1987). [2] Stevens et al. (1993). [3] Marley & McKay (1999). [4] Li et al. (2018). [5] Pearl et al. (1990). [6] Young et al. (2001). [7] Melin (2020). [8] Saunders et al. (2023). [9] Saunders et al. (2024). [10] Luke Moore, personal communication. [11] French et al. 2024. [12] Saunders et al. (2022). [13] Soumyo et al. (2021). *BAAS*. [14] Report of the Aerocapture Demonstration Relevance Assessment Team 2023. [15] Mueller-Wodarg et al. (2008). [16] Orton et al. (2014).

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**Figure 1.** Comparison of temperature-pressure profiles for atmospheres in the solar system. The V2 profile (dotted) [15] is compared to the Spitzer IR model (dot-dash) [16] and the Earth-based occultation model (dashed) [9]. Figure 14 in [9].

**Figure 2.** Globe of Earth showing the geometry of the occultation. Gray indicates after sunset.

**Figure 3.** Map of all observing sites that attempted observations.

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