MULTIPLE PROBE MEASUREMENTS AT URANUS MOTIVATED BY SPATIAL VARIABILITY

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Motivation: Spatial variations in the temperature field and composition of Uranus' atmosphere demonstrate a need for multiple entry probes to characterize vertical profiles in multiple locations. We will review variation of composition and temperature, which are produced by dynamical processes on a range of scales from global (polar anomalies, zonal bands) to regional (vortices, storms) [1–2]. In particular, the spatial variation of convective activity is not well understood based on existing remote sensing observations [3]. Understanding how these processes operate, and how they modulate variable composition, is key to constraining bulk atmospheric abundances. Abundances in turn provide cosmochemical constraints on planetary origins.

Secondary probes at Uranus: Key measurements for secondary probes are temperature-pressure profiles, along with compositional profiles. Radio occultations are limited to shallow levels less than ~2 bar [4]. *In situ* temperature-pressure measurements (or atmospheric structure measurements) can unambiguously extend these results to deeper levels. Measurements with vertical resolution of at least 2 km are needed to characterize anomalies like the 1.2-bar feature from the Voyager 2 occultation at 2–6° S [4], which supports a range of temperature gradients depending on assumptions of composition. Simultaneous measurements of temperature, pressure, and composition are key to understanding this class of features. Species such as methane, hydrogen sulfide, and ammonia must be measured along a probe descent profile because they vary over several orders of magnitude due to the strong temperature dependence of their saturation vapor pressures [e.g., 5]. Results of these measurements can be interpreted to understand the potential for moist convective activity in the atmosphere.

Lessons from the other giant planets: On Jupiter, the Galileo Probe's entry into a meteorologically distinct five-micron hot spot led many to interpret the local composition as column-stretched, so that well-mixed abundances were reached at deeper levels than in surrounding, unperturbed regions [6–8]. Ground-based microwave measurements and Juno data now indicate that the deep depletion of ammonia is a very widespread atmospheric characteristic not limited to 5-µm hot spots [9–11]. But in the absence of multiple probes, we do not know if the other volatiles H_2S and H_2O behave in the same way. The open questions for the Jupiter case strongly motivate sending multiple probes to Uranus. On Saturn, retrievals of NH_3 and PH_3 abundances at shallow levels vary with latitude [12], but it is unknown how deep these differences extend, which is why a Saturn probe (or probes) was a mission theme for NASA's New Frontiers 4 and 5 opportunities [13].

Challenges for secondary probes: Cost is an issue due to the perception that it involves sacrifices to other mission elements. Spacecraft trajectories may be constrained by needs for orbit insertion that limit probe deliveries to different latitudes, and additional limitations may be placed on communication windows for probe descent phases (particularly if multiple probes are released from the orbiter simultaneously) [14]. Finally, composition sensors for miniature secondary probes are not at the required technological maturity [15]. Mass spectrometers are typically too large, massive, and power-hungry, while smaller nanosensors are only beginning to be developed for planetary missions. Finally, the need for probe survival heating is most easily met by radioisotope heat sources, but these require regulatory approvals that are even more difficult to satisfy compared to standard environmental reviews [16], unless the secondary probe is designed as a core element of a mission.

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