Focus Atmospheric Science Questions for Probing Uranus. E. Dahl[1], N. Rowe-Gurney[2], G. S. Orton[3], S. R. Brueshaber[3], R. Cosentino[4], C. Palotai[5], R. Sankar[6], K.M. Sayanagi[7]. [1]NASA Postdoctoral Fellow at JPL/Caltech (emma.k.dahl@jpl.nasa.gov), [2]NASA GSFC/Howard University, [3]JPL/Caltech, [4]Space Telescope Science Institute, [5]Florida Inst. Technology, [6]University of Minnesota, [7]Hampton University.

Introduction: The ice giants represent a unique and relatively poorly-characterized class of planets that remain unexplored by a visiting mission since the brief Voyager 2 flyby in the late 1980's. Uranus is particularly enigmatic, with an extreme axial tilt, offset magnetic field, apparent low internal heat flux, mysteriously cool stratosphere, and lack of well-defined, long-lived storm systems and distinct atmospheric features. All these characteristics make Uranus a scientifically intriguing target, particularly for in situ missions. The recently-published 2023-2032 Decadal Strategy for Planetary Science and Astrobiology prioritized a flagship orbiter and probe to Uranus with the intent to "...transform our knowledge of ice giants in general and the Uranian system in particular" [1].

Decadal Science Goals: An in situ mission to Uranus would be highly relevant to two of the three major overarching Scientific Themes spelled out by the decadal survey and several Priority Science Question Topics. In particular, an Ice Giant probe would address Q1, "Evolution of the protoplanetary disk," by unveiling the primordial materials collected during the formation of Uranus, as well as Q2, "Accretion in the outer solar system," by exploring how and when Uranus formed and migrated. A Uranian in situ mission would also significantly tackle Q7, "Giant planet structure and evolution," by examining the processes that shape their atmospheres today and drive their long-term evolution. Additionally, a Uranian probe would also contribute to the cross-cutting theme of the decadal survey by addressing Q12 "Exoplanets" priority question thereby improving our knowledge of the Ice Giants mass class of planets, the most prevalent type of exoplanets among those that have been discovered to date.

Focus Questions: In support of addressing these overarching science goals and priority questions recommended by the decadal survey, we present community-sourced and -supported science questions that can be best answered by a Uranian in situ mission.

1. Origins:

- What does Uranus' atmospheric composition reveal about its migration and formation history? How can those measurements inform our understanding of the origin of the solar system and Ice Giants in general?

2. Worlds and Processes:

- How has the atmospheres of Uranus regulated its long-term thermal evolution? Why does Uranus today exhibit negligible internal heat release?
- What is the role of moist convection in vertical heat transport in the Uranian atmosphere?
- How does atmospheric composition control the vertical atmospheric structure, and throttle the vertical thermal flux in the atmosphere?
- What drives the long- and short-term chemical and photochemical processes that affect Uranus' atmospheric composition?
- How are meridional and zonal circulation patterns coupled, and how do they transport material and energy? How are these patterns of circulation maintained?
- How does periodic seasonal forcing affect the state of the Ice Giant atmospheres, especially in the case of Uranus' extreme axial tilt?

Priority Measurements: Here, we identify key in situ measurements that best address the focus questions for Uranus, which in turn directly address the decadal overarching themes and priority questions:

1. Elemental abundances and isotopic ratios of noble gases as well as C, N, S, and O.
2. Atmospheric thermal structure
3. Horizontal wind speed as a function of altitude
4. Vertical distribution of Hydrogen Ortho-Para Ratio
5. Vertical distribution of condensable molecules (CH_4, H_2S, NH_3, H_2O)
6. Characterize distribution and properties of cloud/haze particles
7. Determine net atmospheric radiative energy balance

Note that one probe can perform these measurements at a single atmospheric entry site, but multiple probes would enable determination of horizontal variability in each of these quantities, except that the elemental abundance of noble gases and isotopic ratios are not expected to vary spatially, and those measurements do not need to be repeated by multiple probes.

These focus questions and priority measurements were originally published in three white papers, "Ice Giant Atmospheric Science" [2], "Science Return from In Situ Probes in the Atmospheres of the Ice Giants" [3], and "In Situ Probes in the Atmospheres of the Ice Giants" [4], in support of the 2023-2032 Decadal Survey.

References: [1] NASEM, DOI: 10.17226/26522; [2] Dahl et al. DOI: 10.3847/25c2cfeb.97316a54; [3] Orton et al. DOI: 10.3847/25c2cfeb.b804c71f; [4] Orton et al. DOI: 10.3847/25c2cfeb.4eb75332