

Small Next-Generation Atmospheric Probe (SNAP) For Ice Giant Missions. K. M. Sayanagi¹, R. A. Dillman², D. H. Atkinson³, J. Li³, S. Saikia⁴, A. A. Simon⁵, T. R. Spilker⁶, M. H. Wong⁷, W. C. Edwards², D. Hope², C. Young², S. Dutta², A. Arora⁴, S. Bowen², A. Bowes², J. Brady², T. Clark², D. Goggin², T. Grondin², R. Fairbairn², S. Horan², S. Infeld², J. P. Leckey², L. Li², J. M. Longuski⁴, T. Marvel², R. M. McCabe¹, A. Parikh², D. Peterson², S. Primeaux², A. Scammell², K. Somervill², L. Taylor², C. Thames², H. Tosoc², L. Tran². ¹NASA Lagnely Research Center (kunio.m.sayanagi@nasa.gov), ²NASA LaRC, ³JPL, ⁴Purdue Univ., ⁵NASA GSFC, ⁶Indep. Contract, ⁷UC Berkeley.

Introduction: We present the Small Next-generation Atmospheric Probe (SNAP) concept for future Ice Giant missions. The primary scientific objectives of SNAP are to perform in-situ measurements of atmospheric composition, stratification, and dynamics as a function of altitude at the entry location. The 30-kg SNAP design could either enable a second probe that explores a separate location to determine atmospheric spatial variabilities, or serve as the only probe in a cost-constrained mission.

Science Goals and Objectives: By performing in-situ atmospheric measurements of Uranus, SNAP addresses the decadal Priority Science Question “Q7. Giant planet structure and evolution: What processes influence the structure, evolution, and dynamics of giant planet ... atmospheres ...?” SNAP’s objectives are to determine: (1) Vertical distribution of cloud-forming molecules (CH₄, H₂S, and NH₃); (2) Thermal stratification; and (3) Wind speed as a function of depth. Through these objectives, SNAP will resolve a major controversy in the atmospheric vertical structure; while models of Uranus predict that CH₄ and H₂S ice clouds condense between 1 and 5 bars, remote-sensing retrievals do not agree on the vertical structure of the observed clouds. SNAP measurements will conclusively resolve this important open question.

In addition, SNAP will enable a major new objective to determine the spatial variabilities when combined with another probe that explores a separate location. Entry locations for multiple probes can be selected to examine different climatic zones, hemispheric seasonal differences, localized meteorological features, or temporally transient phenomena.

Target Destination: Uranus represents an especially interesting target to study seasonal variability because the planet’s rotation axis is tilted ~98° to the orbital plane, imposing a strong summer-winter hemispheric dichotomy. If a Uranus mission launches around 2030, the spacecraft should arrive at Uranus around 2040; by then, the north pole will have been basking in continuous sunshine for over 30 years since the equinox of 2007, while the south pole will have been in winter darkness for the same period. Deploying an atmospheric probe into each of the hemispheres will reveal seasonal effects on the clouds, thermal stratification, and winds.

Mission Architecture: Our point-design adds SNAP to a notional Uranus Flagship mission presented

in the 2017 Ice Giant Flagship Science Definition Team study. In our design. The architecture retains the large 300-kg primary probe and adds SNAP to enable exploring a second location. The orbiter will deliver both the primary probe and SNAP to Uranus. The orbiter receives the data from the probes before relaying to Earth.

Platform: SNAP is an atmospheric entry probe to be carried to Uranus by a future Flagship mission. After delivery, SNAP will make in-situ atmospheric measurements and send data to the Flagship orbiter, which will relay data to Earth.

Expected Measurements: SNAP will make in-situ atmospheric measurements at a location spatially well-separated from the large primary probe. using the following baseline instruments. (1) Atmospheric Structure Instrument (ASI) is used to measure entry and descent accelerations and the altitude profile of temperature and pressure. (2) A carbon nanotube-based NanoChem vapor sensor makes the atmospheric composition measurements. (3) UltraStable Oscillators (USO) on both the probe and the Carrier spacecraft are used to retrieve atmospheric dynamics using Doppler Wind techniques. SNAP’s atmospheric composition measurements are enabled by the adaptation of a low-mass, low-power atmospheric composition sensor, NanoChem. A major advantage of solid-state sensors like NanoChem is that they do not require a massive vacuum pump unlike a mass spectrometer. Ortho-Para Hydrogen Ratio could be measured with a relatively low-mass package while adding significant scientific value, and should be considered for future designs.

Target Solicitation: The SNAP concept is targeted to be carried on an upcoming Flagship mission to Uranus to enable exploring a second atmospheric location alongside a large primary probe that makes more comprehensive measurements that will primarily address the “Origins” Decadal Survey questions. SNAP could be a directed component of the mission, or an element proposed to an anticipated instrument or a ride-share opportunity associated with the Flagship mission.

Technology Challenges/Opportunities: A major opportunity enabled by the SNAP design is that this small 30-kg atmospheric probe could be flexibly accommodated in a wide range of mission scenarios. A traditional design like the Galileo Probe weighs approximately 300 kg due to the need for a mass spectrometer

that typically weighs at least 10 kg while a typical instrument mass fraction of a probe is 10%. A mass spectrometer is required to measure noble gas abundances and isotopic ratios, which are high-priority scientific objectives but these quantities are not expected to vary spatially. Thus, we present SNAP as a low-mass probe option to (A) enable a second probe to determine spatial variabilities in a mission that has a separate probe carrying a mass spectrometer; and (B) add a probe to a cost-constrained mission that otherwise cannot afford a probe.

Two enabling technologies of a 30-kg SNAP design are (1) A low-mass low-power atmospheric composition sensor such as NanoChem (under development at NASA Ames); (2) Low-density Thermal Protection System material such as the Heat-shield for Extreme Entry Environment (HEEET). Mission performance is enhanced by Li-CFx batteries' high energy density by lowering the battery mass without sacrificing capacity.

Mission Cost: Addition of SNAP to a carrier mission is expected to cost \$80M including \$18M reserve, or 5% of the \$2.0B estimate for a Uranus mission studied by the 2017 Science Definition Team study.

Acknowledgement: Our study is supported by NASA Planetary Science Deep-Space SmallSat Studies grant NNX17AK31G.