SMALL NEXT-GENERATION ATMOSPHERIC PROBE (SNAP) CONCEPT FOR ICE GIANT MISSIONS.

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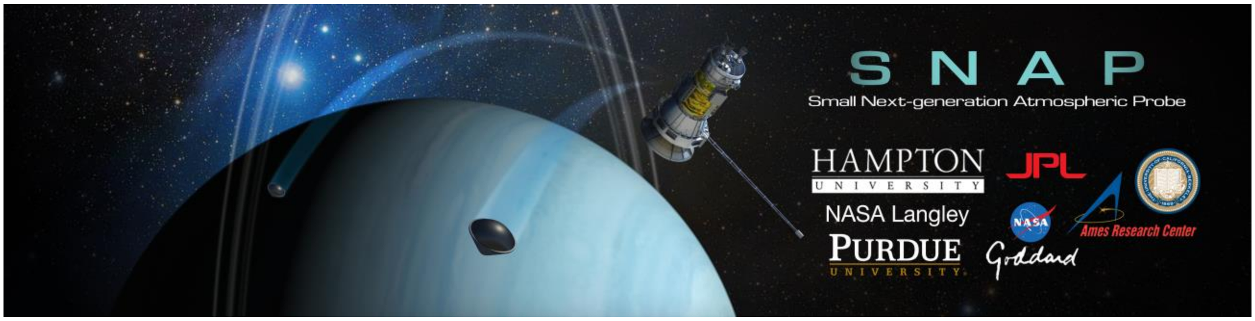

Introduction: We present the results of a mission concept study, funded by NASA's Planetary Science Deep Space SmallSat Studies Program, for a small atmospheric entry probe designed to be added to future giant planet missions. The primary scientific objectives of SNAP are to perform in-situ measurements of atmospheric composition, stratification, and dynamics as a function of altitude at the probe descent location. The 30-kg SNAP design will enable future multi-probe missions. Specifically, we examined the advantages of adding SNAP as a second atmospheric entry probe to a future Uranus Orbiter and Probe flagship mission. In combination with a primary entry probe, SNAP would explore a second location, and thus enable and enhance the scientific objectives to determine atmospheric spatial variabilities as recommended by the 2013-2012 Planetary Science Decadal Survey and the 2014 NASA Science Plan.

Scientific Objectives: The main scientific objective to be advanced by a second atmospheric entry probe is the measurement of spatial variabilities within a planetary atmosphere. Horizontal spatial variability cannot be revealed by a single probe that explores a single location. SNAP's measurement objectives are to determine: (1) Vertical distribution of cloud-forming molecules (CH_4, H_2S, and NH_3); (2) Thermal stratification; and (3) Wind speed as a function of depth at a location significantly separated from the primary probe entry location. The SNAP entry location can be selected to examine spatial variabilities of different climatic zones, hemispheric seasonal differences, localized meteorological features, or temporally transient phenomena.

Noble gas abundance and elemental isotopic ratios are not expected to vary spatially and thus are not prioritized in the scientific objectives of the second probe. Noble gases and isotopic ratios are assumed to be measured by a larger primary probe equipped with a mass spectrometer.

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 [1]. 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 hemisphere will reveal the effects of seasonal forcing on the clouds, thermal stratification, and winds. Furthermore, as the winter hemisphere of Uranus always faces away from Earth, the winter side of the planet can be observed only by visiting spacecraft; this valuable remote-sensing opportunity can be significantly enhanced by an in-situ probe that establishes the ground-truth.

A second in-situ probe can help resolve the vertical structures of Uranian clouds that exist at different latitudes. While models of Uranus predict that CH_4 and H_2S ice clouds condense between 1 and 5 bars [2], remote-sensing retrievals do not agree on the vertical structure of the observed clouds. Karkoschka and Tomasko [3] present a diffuse cloud layer across 1-2 bars, while Sromovsky et al. [4] show three compact layers at around 1, 1.5, and 5 bars, which is consistent with the Voyager 2 radio occultation data [5]. Furthermore, retrieved thermal stratification of Uranus depends on the poorly known CH_4 concentration [6]. A multi-probe mission could resolve these open issues regardining the atmospheric vertical structure and spatial variability.

In addition to enhancing the scientific value of remote-sensing observations, a multi-probe mission also mitigates the risk of sampling an unrepresentative site. In 1995, the Galileo probe measured an unexpectedly low concentration of cloud particles as well as cloud-forming molecules at Jupiter [7]. When remote sensing observation provided the context, it was revealed that the probe entered a previously known transient region with unusually clear atmosphere called the 5-micron hotspot [8], which covered approximately 0.1% of the surface of Jupiter. As a result, the volatile (especially water) abundances at Jupiter remain uncertain to date. The Galileo Probe results in part influenced the 2003 Planetary Decadal Survey to recommend a Jupiter Multi-Probe mission to mitigate such risks.

Instruments: The baseline instrument payload comprises an Atmospheric Structure Instrument (ASI) to measure entry and descent accelerations and the altitude profile of temperature and pressure, a carbon nanotube-based NanoChem atmospheric composition sensor, and UltraStable Oscillators (USO) on both the probe and the Carrier spacecraft to enable retrieval of atmospheric dynamics using Doppler Wind techniques. The adaptation of a low-mass, low-power atmospheric composition sensor, NanoChem, is the primary enabling factor that realizes the SNAP design with a 30-kg atmospheric entry mass. A primary advantage of solid-state sensors like NanoChem is that the sensor heads can operate over a range of atmospheric pressures. To make atmospheric composition measurements, a traditional probe design employs a mass spectrometer, which weighs 10 kg or more due to the necessity for a vacuum pump. Assuming an instrument mass fraction of 10%, a probe with a mass spectrometer would weigh 100+ kg. One tradeoff is that solid-state sensors cannot sense isotopic ratios, which is not expected to be dependent on the probe entry location, and assumed to be carried out by a mass spectrometer on the primary probe.

Mission Architecture: We present a point-design that adds SNAP to a notional mission architecture included in the recently concluded Ice Giant Flagship Science Definition Team study for a future Uranus mission. In our point design, the carrier spacecraft will deliver both the primary probe and SNAP to Uranus, and each of the probes will first send data to the carrier spacecraft, which in turn will relay the data to Earth. We assumed that the carrier spacecraft has a single receiver, and the two probes cannot return data to the carrier spacecraft simultaneously. With these constraints, we examined numerous Uranus arrival trajectory options to evaluate the feasibility of delivering two probes at two significantly different locations (e.g., autumn and spring hemispheres), and send data to the Carrier spacecraft. We identified unique challenges inherent in multi-probe missions, and present viable solutions. In almost all scenarios, the atmospheric depth explored by the probe is limited by the short temporal window while the carrier spacecraft is above the horizon from the point of view of the descent probe.

Technology Needs: Two enabling technologies of a 30-kg SNAP design are (1) A solid-state atmospheric composition sensor such as NanoChem (under development at NASA Ames) that can operate under atmospheric pressure, and (2) Low-density Thermal Protection System material such as the Heat-shield for Extreme Entry Environment (HEEET, under development at NASA Ames). In addition, we identified other low-mass instrument technologies that would further enhance the value of future small atmospheric entry probes. A helium-abundance detector would significantly increase the mission value without significant mass growth; any future technology that can sense additional noble gases would further enhance the mission. Ortho-Para Hydrogen Ratio could be measured with a relatively low-mass package, and should be considered for future missions.

Mission Cost: We estimate that the cost of adding SNAP to a host mission that already includes a 300-kg primary probe is $30M-$50M (not including margins). The cost includes development and construction of a SNAP probe, periodic tests and monitoring of the probe during the 10-year cruise to Uranus, and science operations after arrival at Uranus as well as any modification to the carrier spacecraft.

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