Small Next-generation Atmospheric Probe (SNAP) Concept.
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Introduction: We present the Small Next-generation Atmospheric Probe (SNAP) as a secondary payload concept for future missions to giant planets. As a case study, we examine the advantages, cost and risk of adding SNAP to the future Uranus Orbiter and Probe flagship mission; in combination with the mission's main probe, SNAP would perform atmospheric in-situ measurements at a second location.

Scientific Objectives: The primary objectives to be addressed by the SNAP mission concept are:

- Vertical distribution of cloud-forming molecules.
- Thermal stratification.
- Wind speed as a function of depth.

These objectives originate from the recommendations in the 2013 Planetary Science Decadal Survey for the Uranus Orbiter and Probe flagship mission and the Saturn Probe New Frontiers mission. The decadal survey also prioritized noble gas abundance and isotopic ratios; our objectives assume that a future SNAP mission will be a secondary probe that accompanies a large probe mission; the noble gas and isotopic ratios are to be measured by the main probe.

The SNAP objectives represent the unique advances enabled by a SNAP mission: in-situ detection of spatial variabilities in the vertical structure of clouds, thermal stratification, and atmospheric dynamics. Planetary Science Decadal Surveys have expressed desires for multi-probe missions; the 2003 survey advocated for a Jupiter Multi-Probe mission; and the 2013 survey emphasized that a second probe that takes measurement at a separate location can significantly enhance the scientific value of the mission by providing data on atmospheric variability. Such missions have not been realized because their costs are perceived to be prohibitive. We advocate the SNAP concept as a path toward giant-planet multi-probe missions.

Design Goals: We envision that the science objectives can be achieved with a 30-kg entry probe ~0.5m in diameter (less than half the diameter of the Galileo probe) that reaches 5-bar pressure-altitude and returns data to Earth via the carrier spacecraft. As the baseline instruments, the probe will carry an Atmospheric Structure Instrument (ASI) that measures the temperature, pressure and acceleration, a carbon nanotube-based NanoChem atmospheric composition sensor, and an Ultra-Stable Oscillator (USO) to conduct a Doppler Wind Experiment (DWE). While SNAP is applicable to multiple planets, we will examine the feasibility, benefits and impacts of adding SNAP to the Uranus Orbiter and Probe flagship mission.

Science Targets: Although the current study targets the future Uranus Orbiter and Probe flagship mission, a probe that is built for Uranus should be viable at Neptune and Saturn with few changes, and enables missions such as;

- Adding SNAP as a second probe to a flagship mission with probe to Uranus or Neptune.
- Adding SNAP as a second probe to the Saturn Probe New Frontiers mission.
- Deploying SNAP at Saturn during a gravity-assist flyby en route to Uranus or Neptune.

Nature of Expected Science Advancement: The SNAP mission will reveal the physical and chemical processes governing the planetary energy balance by measuring the vertical cloud structure, stratification, and winds. Understanding these processes will reveal how the giant planets have evolved. The atmospheric composition measurements will constrain the abundance of volatile species on the target planets, which may clarify how, where, and when the giant planets formed [1, 2, 3].

A major source of spatial variability is seasonal forcing. We envision that the SNAP concept will explore a different location than the main probe, so the mission can examine two hemispheres in different seasons. Uranus represents an especially interesting target to study seasonal variability because the planet's rotation axis is tilted ~98º to the orbital plane, imposing a strong summer-winter hemispheric dichotomy [4]. 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.

Another source of spatial variability is atmospheric convection. Uranus has cumulus outbreaks that cause localized clouds that evolve rapidly [5], and meridional circulation that is predicted to vary with seasons [6]; however, the vertical structures of these clouds remain debated. While models of Uranus predict that CH4 and H2S ice clouds condense between 1 and 5 bars [7], remote-sensing retrievals do not agree on the vertical structure of the observed clouds. Karkoschka and Tomasko [8] present a diffuse cloud layer across 1-2 bars, while Sromovsky et al. [6] show three compact layers at around 1, 1.5, and 5 bars, which is consistent with Voyager 2 radio occultation data [10]. Furthermore, retrieved thermal stratification of Uranus depends on the poorly known CH4 concentration [11]. An atmospheric probe could resolve these open issues on the atmospheric vertical structure. SNAP exploration of a second location will provide data on spatial variability, and also reduce the risk of sampling an unrepresentative site.

The instruments that are available today for the determination of isotopic ratios and noble gas abundances are beyond the payload mass and power appropriate for the proposed SNAP concept. Our proposal will challenge the current state-of-the-art for atmospheric entry probe designs, enable new mission concepts, and identify new instrument and spacecraft systems technologies. By doing so, we will define the performance goals and technology development requirements to achieve decadal objectives with a small probe.

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