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Scientific rationale and concepts for in situ probe exploration of Uranus and Neptune

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Abstract

Uranus and Neptune, referred to as ice giants, are fundamentally different from the better-known gas giants (Jupiter and Saturn). Exploration of an ice giant system is a high-priority science objective, as these systems (including the magnetosphere, satellites, rings, atmosphere, and interior) challenge our understanding of planetary formation and evolution. The importance of the ice giants is reflected in NASA's 2011 Decadal Survey, comments from ESA's SSC in response to L2/L3 mission proposals and results of the 2017 NASA/ESA Ice Giants study. A crucial part of exploration of the ice giants is in situ sampling of the atmosphere via an atmospheric probe. A probe would bring insights in two broad themes: the formation history of our Solar System and the processes at play in planetary atmospheres. Here we summarize the science driver for in situ measurements at these two planets and discuss possible mission concepts that would be consistent with the constraints of ESA M-class missions.

Solar System formation

To understand the formation of giant planets and the origin of our Solar System, statistical data obtained from the observation of exoplanetary systems must be supplemented by direct measurements of the composition of the planets in our Solar System. A giant planet's bulk composition depends on the timing and location of planet formation, subsequent migration and the delivery mechanisms for the heavier elements. By measuring the chemical inventory in at least one of the ice giants, and contrasting these with measurements made (i) at Jupiter by the NASA *Galileo* probe and the Juno mission, (ii) primitive materials found in small bodies, and (iii) the composition of our parent star and the local interstellar medium, much can be revealed about the conditions at work during the formation of our planetary system.

Planetary Atmospheric Processes

Uranus and Neptune provide a tantalising opportunity to sample atmospheric processes in environments not found elsewhere in our Solar System – namely the complex, cloud-dominated weather layers of cold ice-rich giants. Remote sensing has revealed stark differences between these two worlds – sluggish Uranus, with its fine banding, extreme axial tilt and negligible internal heat source; and vigorous Neptune, with its episodic cloud outbursts and polar vortices. But remote sensing is challenging without in situ "ground-truth". A probe would (i) provide access to chemical species that have not been previously detected due to the low atmospheric temperatures; (ii) reveal the vertical temperature, chemical and aerosol structure down to at least 10 bar; (iii) determine the vertical changes to ice giant winds as a function of depth; and (iv) reveal how energy is transported upwards through an ice giant atmosphere. A probe to Uranus, Neptune, or both worlds would provide a vital counterpoint to our understanding of atmospheric processes on the H_2-dominated gas giants, Jupiter and Saturn.

Mission concepts

Different mission architectures are envisaged, all based on an entry probe that would descend through the stratosphere and troposphere under parachute down to a minimum of 10 bars. Future studies will focus on the trade-offs between science return and the added design complexity and cost of a probe that could operate at pressures greater than 10 bars. Three possible mission configurations can be envisaged (with different risk/cost trades):

- Configuration 1: Single Probe + Flyby Carrier/Relay. The probe would detach from the carrier several weeks to months prior to probe entry. The carrier trajectory would be designed to enable probe data relay during over-flight as well as performing approach and flyby science;
- Configuration 2: Two Probes + Flyby Carrier/Relay. Same as in Configuration 1 but in the case of a two-planet mission (Saturn/Uranus or Uranus/Neptune) that uses the same spacecraft and probe designs;
- Configuration 3: Single Probe + Orbiter (similar to the Galileo Orbiter/Probe). Following the probe descent mission and relay, the carrier spacecraft would transition to an orbit around Uranus or Neptune, and continue to perform orbital science.

In the three configurations, the carrier/orbiter would be equipped with a combination of Radioisotope Thermoelectric Generators (RTGs), secondary batteries and possibly a set of primary batteries for phases that require a high power demand, for example during the probe entry phase. Note that NASA and ESA agreed that a flyby with probe (Configuration 1) does not meet the science requirement for the next mission to the ice giants (NASA Ice Giants Science Definition Team Report, 2017).

Payload

To meet the mission science goals and measurement requirements, a model payload would include a Mass Spectrometer, an Atmospheric Structure Instrument (also dedicated to the measurement of the atmospheric electricity), a Doppler Wind Experiment, a Nephelometer, and a Net-Flux Radiometer. For budgetary and technological reasons, ESA does not have currently the capacity to prepare a standalone mission. However, in the context of NASA-ESA cooperation, ESA could provide an entry probe to a US ice giant flagship mission. Additional contributions could be also supplied by EU states independently from ESA. Such a probe, whose design would be very close to that of a Saturn entry probe, would fit well into the envelope of an ESA M-class mission.