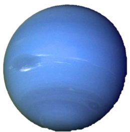

The Atmospheric Structure Instrument (ASI)
for the in situ exploration of the Ice Giants

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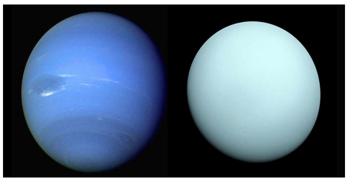
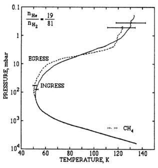
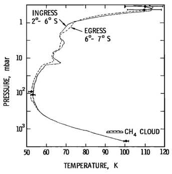


Uranus and Neptune: the Ice Giants

- Uranus' and Neptune's atmosphere probed by Voyager 2 flyby on 1986 and 1989.
- Atmospheric temperature profile retrieved primarily from Voyager radio occultation (RSS) [Lindal et al. 1987, Lindal et al 1990]
- Ground based and Voyager thermal infrared, solar and stellar occultation observations further constrained the atmospheric thermal structure [e.g. Marley & McKay 1999].

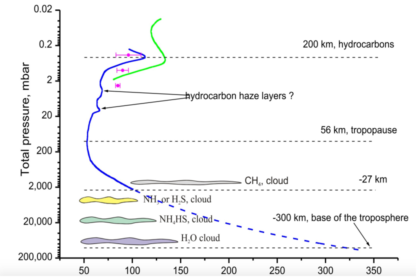


[Lindal 1992]



[Lindal et al. 1987]

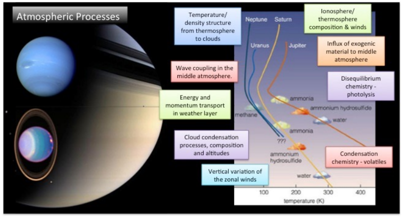
Atmospheric thermal structure



- **Voyager UVS occultation** [Herbert *et al.* 1987, Bishop *et al.* 1990, Stevens *et al.* 1993]
- **Voyager PPS stellar occultation** [Lane *et al.* 1986, West *et al.* 1987]
- **Voyager RSS occultation** [Lindal *et al.* 1987]

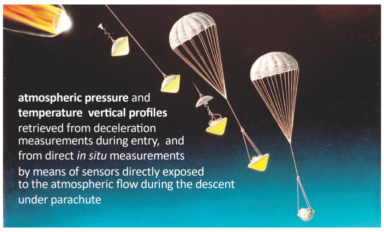
In situ measurements

In situ measurements by an atmospheric entry probe allow for sounding atmospheric regions not reachable from remote sensing observations and for investigating of the atmospheric composition, structure and dynamics down deep into the atmosphere (e.g. Galileo probe at Jupiter [Seiff et al. 1996], Huygens probe at Titan [Lebreton et al. 2005].



In situ studies allow studying the **chemical, dynamical, and aerosol-forming processes** at work **from the thermosphere down to the troposphere, below the cloud decks**

EDL *in situ* science



atmospheric pressure and **temperature vertical profiles** retrieved from deceleration measurements during entry, and from direct *in situ* measurements by means of sensors directly exposed to the atmospheric flow during the descent under parachute

Atmospheric Structure Instrument (ASI)

***In situ* measurements** during entry and descent into Uranus/Neptune's atmosphere to investigate the **atmospheric structure**, **dynamics** and **electricity**

ASI Scientific Objectives:

- to determine atmospheric profiles of **pressure** and **temperature**;
- to evaluate **density** and **mean molecular weight** profiles;
- to determine tropospheric **conductivity** profile, detect the atmospheric **AC/DC electric field** and discharges (e.g. lightning) along the probe trajectory

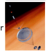
Primary engineering function: to establish entry trajectory and probe altitude and vertical velocity for correlating all Probe experiment data

Atmospheric entry probes

Viking

Pioneer Venus

Galileo



Mars Pathfinder

Huygens

Entry probes allow for *in situ* measurements over a wide altitude range and with spatial resolution not achievable by remote sensing observations.

- Few robotic probes have successfully entered the atmosphere on planetary bodies:
  - **Mars** (USSR Mars 6, NASA Viking 1&2, Pathfinder, MER1&2, Phoenix, MSL, ExoMars2016 Schiaparelli, InSight, Perseverance)
  - **Venus** (NASA Pioneer Venus probes, USSR Venera probes and Vega lander/balloons)
  - **Jupiter** (NASA Galileo probe)
  - **Titan** (ESA/NASA Huygens probe)

Atmospheric Structure instrument (ASI) for ***in situ* measurements** during Entry, Descent and Landing (EDL) phases of an atmospheric probe/lander.

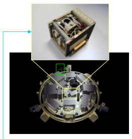
***Experience** and **lessons** learned with **Huygens** put into perspectives for future opportunities, with particular focus to the in situ exploration of the **Ice Giants**.*

ESA Huygens probe at Titan heritage

The Ice Giant ASI will be a multi sensor package designed to measure the physical quantities characterizing Uranus' or Neptune's atmosphere during the entry and descent of the probe into the planet. The key measurements will be **acceleration**, **pressure**, **temperature** and **electrical properties** all along the probe descent down deep into the atmosphere in order to investigate the **atmospheric structure**, **dynamics** and **electricity**.

ASI sensors and measurements

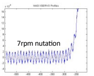
Entry

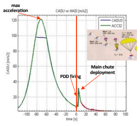


HASI ACC

- **Most accurate accelerometer ever flown in a planetary probe**
- **Sensitivity threshold (3x10^{-06} m/s^2) allowed measurement of Probe coning motion before atmospheric entry.**

HASI ACC X-Servo
Sundstrand (now Honeywell)
QA2000





[Fulchignoni et al., 2005]

- **During entry, atmospheric physical properties from acceleration data.**

Density profile from the inversion of the drag equation

probe mass (kg)
acceleration component in the direction of descent (m/s^2)

$$\rho = \frac{2\,m\,a}{v^2\,C_d\,A}$$

velocity relative to atmosphere in the direction of descent (m/ s)
aerodynamic drag coefficient
probe cross-sectional area (m^2)

Indirect **temperature** and **pressure** measurements

Hydrostatic equilibrium $dp=-g\rho dz$ ➡ $p(z)$

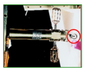
Equation of state of gas $\rho = \mu p/RT$ ➡ $T(z)$, $T=\mu p/\rho R$

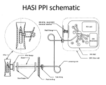
[Fulchignoni et al., 2002]

Descent

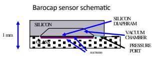
HASI TEM & PPI

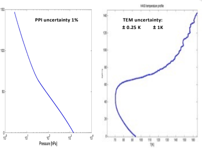
Direct **pressure** and **temperature** measurements during descent phase under parachute.

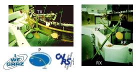




HASI PPI Kiel probe



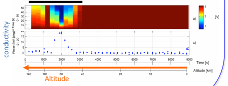




HASI PWA booms deployed:
direct measurements of **electrical properties** & **acoustic recording**, radar altimetry

Permittivity Wave Altimetry (PWA)

signature of the ionosphere



[Fulchignoni et al., 2002]

[Fulchignoni et al., 2005]

Ice Giant ASI sensors/measurements

ASI-ACC Triaxial science accelerometer or/&
GNC data from IMU: acceleration and derived velocity, rotation rates

ASI-TEM similar sensor already flown in Pioneer Venus & Galileo probes
Fast response (e.g. very short response time)
Temperature range 40-300 K resolution: 0.05 K accuracy: 0.1 K

ASI-PPI → silicon capacitive transducer (Vaisala Barocaps)
range 0.0001-10 hPa 1% accuracy, resolution 1mPa

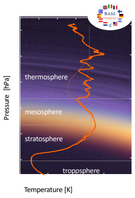
ASI AEP → ≈ relaxation probe, mutual impedance probe and passive E-field sensor for atmospheric conductivity, AC/DC electric fields and Schumann resonance measurements.

[Ferri et al., 2020]

Expected results

Atmospheric structure and dynamics

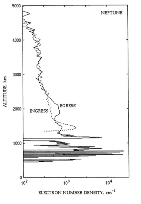
- Vertical structure of the planet's atmospheric temperature and stability
- Atmospheric winds and wave phenomena as function of depth
- Vertical structure of eventual clouds and haze layers
- Vertical distribution of chemical species by convective motions and vertical mixing



HASI at Titan [Fulchignoni et al. Nature, 2005]

Atmospheric electricity

- Tropospheric electric conductivity profile
- Measurements of natural DC electric field
- Detection of possible electrical discharges, i.e. lightnings
- Spectral analysis in the 1-200 kHz range to determine unknown lightning spectrum and detect potential Schumann resonance



Vertical distribution of free electron in the lower Neptune's ionosphere [Lindal 1992]

Conclusions

In the framework of the opportunity for a **NASA- ESA joint mission to Uranus, Neptune and their moons**, we are proposing an **Atmospheric Structure Instrument (ASI)** for an **entry probe at the Ice Giant planets**.

ASI instrument at the Ice Giants

- The temperature and density profiles inferred by IG-ASI will provide
  a) an accurate determination of the atmosphere (from the exobase down deep into the troposphere) sounding altitude range never reached
  b) the only new and independent definition of the stratosphere and tropospheric thermal structure
  c) atmospheric parameters for a very precise characterization of the chemical structure
- The characterization of the atmospheric electrical properties and possible detection of lightning

IG-ASI data will provide a 'ground thruth' for the remote sensing and groundbased observations.

Information gathered from IG-ASI will pertain to one site along the probe descent trajectory, but combined with measurements from the spacecraft will contribute to improve the knowledge of the global atmospheric structure and dynamics.

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