In Situ Probe Science at Saturn

D.H. Atkinson[1,11], J.I. Lunine[2], A.A. Simon-Miller[3], S.K. Atreya[4], W. Brinckerhoff[3], A. Colaprete[5], A. Coustenis[6], L. Fletcher[7], T. Guillot[8], J.-P. Lebreton[6,9], P. Mahaffy[3], O. Mousis[10], G.S. Orton[11], K. Reh[11], L.J. Spilker[11], T.R. Spilker[12], C. Webster[11]

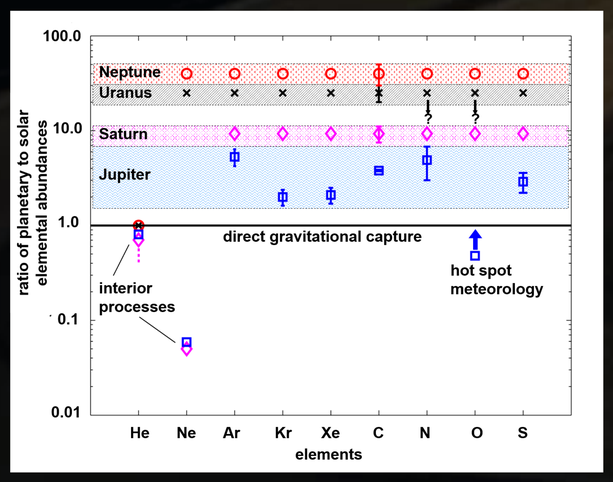
[1]Univ. Idaho (atkinson@uidaho.edu), [2]Cornell University, [3]NASA Goddard Space Flight Center, [4]Univ. Michigan, [5]NASA Ames Research Center, [6]LESIA Paris Observ., CNRS UPMC, Univ. Paris-Diderot, Meudon, France, [7]University of Oxford, [8]Observatoire de la Côte d'Azur, [9]LPC2E, CNRS –Université d'Orléans, [10]Université de Franche-Comté, [11]NASA Jet Propulsion Laboratory/California Institute of Technology, [12]SSSE

A fundamental goal of solar system exploration is to understand the origin of the solar system, the initial stages, conditions, and processes by which the solar system formed, how the formation process was initiated, and the nature of the interstellar seed material from which the solar system was born. Key to understanding solar system formation and subsequent dynamical and chemical evolution is the origin and evolution of the giant planets and their atmospheres.

The 2013 Planetary Sciences Decadal Survey "**New Frontiers in the Solar System, An Integrated Exploration Strategy**" defines three Overarching Goals for giant planet exploration, with specific Science Objectives and Science Questions to address the issues related to solar system origin and evolution. The PSDS Overarching Goals, and the Science Objectives and Science Questions most relevant to Saturn *in situ* exploration are listed below.

	Overarching Goal #1 **Giant Planets as Ground Truth for Exoplanets** *Explore the processes and properties that influence giant planets in the solar system in order to characterize and understand the observable planets in other planetary systems.*						**Overarching Goal #2** **Giant Planet's Roles in Promoting a Habitable Planetary System** *Test the hypothesis that the existence, location, and migration of the giant planets in the solar system has contributed directly to the evolution of terrestrial planets in the habitable zone.*		**Overarching Goal #3** **Giant Planets as Laboratories for Properties and Processes on Earth** *Establish the relevance of observable giant planet processes and activities as an aid to understanding similar processes and activities on Earth and other planets.*			
Science Objectives	**Understand Heat Flow and Radiation Balance in Giant Planets**				**Investigate the Chemistry of Giant Planet Atmospheres**		**Search for Chemical Evidence of Planetary Migration**		**Investigate Atmospheric Dynamical Processes in the Giant Planet Laboratory**			
Science Questions	What mechanism has prolonged Saturn's thermal evolution?	Does Helium rain play a role in reducing the H/He in Saturn's molecular envelope?	Why and how does the atmospheric temperature and cloud composition vary with depth and location on the planet?	Which processes influence the atmospheric thermal profile, and how do these vary with location?	How did the giant planet atmospheres form and evolve to their present state?	What are the current pressure-temperature profiles for these planets?	How and why do elemental and isotopic abundances vary as a function of distance from the Sun?	How & why do abundances of heavy elements and isotopes, the D/H and H/He ratios, and noble gases differ between the two classes of giant planets?	What processes drive the visible atmospheric flow and how do they couple to the interior structure and deep circulation?	What are sources of vertically propagating waves that drive upper atmosphere oscillations and do they play a role on all planets?	How does moist convection shape tropospheric stratification?	What are the natures of periodic outburst such as global upheaval on Jupiter and infrequent great white spots on Saturn?

Several theories have been put forward to explain the process of solar system formation, and the origin and evolution of the giant planets and their atmospheres. Each theory offers quantifiable predictions of the abundances of noble gases He, Ne, Ar, Kr, and Xe, and abundances of key isotopic ratios $^4He/^3He$, D/H, $^{15}N/^{14}N$, $^{18}O/^{16}O$, and $^{13}C/^{12}C$.



Only the Galileo probe has made *in situ* measurements of the composition of a giant planet atmosphere. Galileo arrived at Jupiter at a meteorologically anomalous location, found to be significantly depleted in water. Neon was also found to be depleted, likely due to rainout mixed with helium. Only carbon in the form of CH_4 has been measured by remote sensing in the atmospheres of Saturn, Uranus, and Neptune.

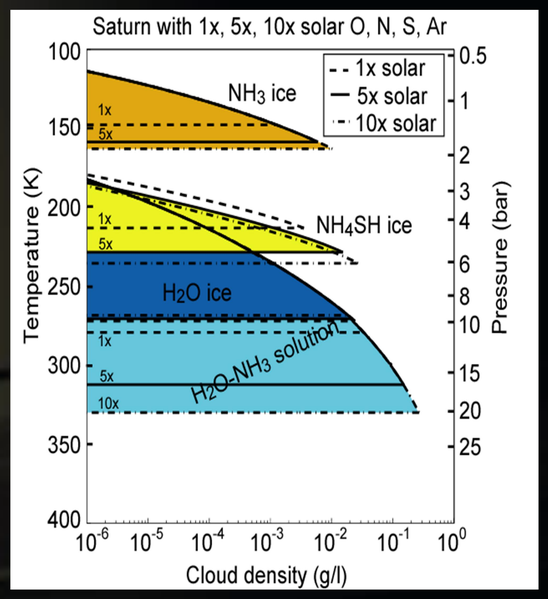
In the figure above, error bars on Jupiter abundances are based on Galileo NMS measurements. Symbols without error bars are based on the Core Accretion Model of giant planet formation. Note that N has been measured on Saturn. See Mousis, PSS (2014) for more information.

Many of the key atmospheric constituents needed to discriminate between alternative theories of giant planet formation and chemical evolution are either spectrally inactive or primarily located in the deeper atmosphere inaccessible to remote sensing. Abundance measurements of these key constituents, as well as the two major molecular carriers of carbon, methane and carbon monoxide (neither of which condense in Saturn's atmosphere), sulfur which is expected to be well-mixed below the 4 to 5-bar ammonium hydrosulfide (NH_4SH) cloud, and gradients of nitrogen below the NH_4SH cloud and oxygen in the upper layers of the H_2O and H_2O-NH_4 solution cloud, must be made *in situ* and can only be achieved by an entry probe descending through 10 bars.

Detection and measurement of the abundances of certain disequilibrium species such as CO, PH_3, AsH_3, and GeH_4 can be diagnostic of internal processes and dynamics including vertical mixing of the deep atmosphere, and would also help discriminate between competing theories.

Acknowledgements: This research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Copyright 2014 California Institute of Technology. U.S. Government sponsorship acknowledged. O. Mousis acknowledges support from CNES.

Measurements of elemental and isotopic abundances must be made in the well-mixed deep atmosphere, beneath multiple cloud layers. Dependent upon the abundances of nitrogen, sulfur, and oxygen, the base of the clouds are expected to be at 1-2bars/150-170K (NH_3 cloud), 4-6 bars/210-240K (NH_4SH cloud), and 10-20 bars/260-340K (H_2O/H_20-NH_3 cloud). See Mousis, poster#8094 and Mousis (2014).



Summary

The atmospheres of the giant planets serve as laboratories to better understand the atmospheric chemistries, dynamics, processes, and climates on all planets in the solar system including Earth, and offer a context and provide a ground truth for exoplanets and exoplanetary systems. Additionally, giant planets have long been thought to play a critical role in the development of potentially habitable planetary systems.

A small, relatively shallow Saturn probe capable of measuring abundances & isotopic ratios of key atmospheric constituents, atmospheric structure and dynamics, and cloud locations and properties not accessible by remote sensing can provide additional context to giant planet science provided by Galileo and Cassini and to be provided by Juno, and will help discriminate between competing theories of solar system and giant planet origin, chemical, and dynamical evolution.

For More Information

Atkinson, D.H., *et al.* "Entry Probe Missions to the Giant Planets," Nat. Acad. Sci. Planetary Science Decadal Survey 2013-2023.

Atreya, S.K., Proceedings of the 4th International Planetary Probe Workshop IPPW-4, 2006.

Atreya S.K. and A.S. Wong, Space Sci. Rev., 116, Nos. 1-2, pp 121-136, 2005.

Atreya, S.K., in *Galileo's Medicean Moons Their Impact on 400 Years of Discovery*, Ch. 16, p130, 2011, Cambridge Univ. Press.

Atreya S.K., *et al.*, Planet. Space Sci., 47, 1243, 1999.

Coustenis, A., *et al.*, "POSSIBLE CONCEPTS FOR AN IN SITU SATURN PROBE MISSION," LPSC, abstract#1244, 2014.

Fortney, J.J., *et al.*, "Planetary Formation and Evolution Revealed with a Saturn Entry Probe: The Importance of Noble Gases," Nat. Acad. Sci. Planetary Science Decadal Survey 2013-2023.

Mousis, O., *et al.*, "Scientific rationale of a Saturn probe mission," LPSC, abstract#1261, 2014.

Mousis, O., *et al.*, "Scientific rationale of Saturn's *in situ* exploration," Submitted to Planetary Space Sciences, 2014.

"Vision & Voyages for Planetary Science in the Decade 2013-2022," National Academies Press, Mar. 7, 2011.

IPPW-11 2014 / Abstract#8005