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Scientific Rationale of a Saturn Probe Mission

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Remote sensing observations meet some limitations when used to study the bulk atmospheric composition of the giant planets of our solar system. A remarkable example of the unicity of in situ probe measurements is illustrated by the exploration of Jupiter, where key measurements such as noble gases abundances and the precise measurement of the helium mixing ratio have only been made available through in situ measurements by the Galileo probe. Here we describe the main scientific goals to be addressed by future in situ exploration of Saturn.

Planet 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 a giant planet's chemical inventory, and contrasting these with measurements of (i) other giant planets, (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 [1].

To date, the Galileo probe at Jupiter (1995) remains our only data point for interpreting the bulk composition of the giant planets. Galileo found that Jupiter exhibited an enrichment in C, N, S, Ar, Kr and Xe compared to the solar photospheric abundances, with some notable exceptions - water was found depleted, possibly due to meteorological processes at the probe entry site; and neon was also found depleted, possibly due to rain-out to deeper levels [2]. Explaining the high abundance of noble gases requires either condensing these elements directly at low-temperature in the form of amorphous ices [3], trapping them as clathrates [4-7] or photoevaporating the hydrogen and helium in the protoplanetary disk during the planet's formation [8]. The in situ Galileo measurements at Jupiter also include a highly precise determination of the planet's helium abundance, crucial for studies of the structure and evolution of the planet.

Because of the lack of in situ measurements, Saturn noble gas abundances are unknown and their determination is missing to properly understand its formation conditions. There is however some indication for a non-uniform enrichment in C, N and S. [5] suggests that observations are well fitted if the atmospheric C and N of the planet were initially mainly in reduced forms at 10 AU in the protosolar nebula. Alternatively, [6] finds that it is possible to account for these enrich-ments in a way consistent with those measured at Jupi-ter if the building blocks of the two planets shared a common origin. As in Jupiter, the missing piece of the puzzle remains the measurement of the oxygen abundance. Precisely measuring in situ the He/H2 ratio in Saturn is also needed for properly modeling its interior and thermal evolution.

Planetary Atmospheric Processes: Saturn's complex and cloud-dominated weather-layer is our principle gateway to the processes at work within the deep interior of this giant planet. We must extrapolate from this thin, dynamic region over many orders of magnitude in pressure, temperature and density to infer the planetary properties deep below the clouds [1]. Remote sensing provides insights into the complexity of the transitional zone between the external environment and the fluid interior, but there is much that we still do not under-stand. In situ measurements are the only method providing ground-truth to connect the remote sensing inferences with physical reality, and yet this has only been achieved twice in the history of outer solar system exploration, via the Galileo probe for Jupiter and the Huygens probe for Titan.

In situ studies provide access to atmospheric regions that are beyond the reach of remote sensing, enabling us to study the dynamical, chemical and aerosol-forming processes at work from the thermosphere to the troposphere below the cloud decks. Two crucial questions in this theme remain i) the nature of the processes at work in planetary atmospheres, shaping the dynamics and circulation from the thermosphere to the deep troposphere (e.g., [9]) , and ii) the chemical properties and conditions for cloud formation as a function of depth and temperature in planetary atmospheres (e.g., [10]).

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