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Science goals and concepts of a Saturn probe for the future L2/L3 ESA call

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Abstract

A Saturn probe is the next natural step beyond Galileo's in situ exploration of Jupiter, and the Cassini spacecraft's orbital reconnaissance of Saturn in order to understand the origin of giant planets. Here we describe the science goals and concepts of a Saturn probe that could be submitted to the future L2/L3 ESA call.

1. Introduction

The Galileo probe provided a step-change in our understanding of Jupiter, but one can wonder if these measurements are really representative or not of the whole set of giant planets (hereafter GPs) of the Solar System. Here we argue that a Saturn probe is the next natural step beyond Galileo's in situ exploration of Jupiter, and the Cassini spacecraft's orbital reconnaissance of Saturn. We briefly depict the broad scientific themes that can be addressed by an in situ exploration of Saturn. We finally describe the two possible mission scenarios that could be submitted to the future L2/L3 ESA call.

2. Planet Formation

In order to understand the formation of GPs and the origin of our Solar System, statistical data obtained from the observation of exoplanetary systems must be supplemented by direct measurements of the compositions of our planets. A GP'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 GP's chemical inventory, and contrasting these with measurements of (i) other GPs, (ii) primitive materials found in small bodies, and (iii) the abundance of our parent star and the local interstellar medium one, can reveal much about the conditions at work during the formation of our planetary system.

To date, the Galileo probe at Jupiter (1995) remains our only data point for interpreting the bulk composition of the GPs. 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, may be due to meteorological processes at the probe entry site; and neon was depleted, possibly due to rainout to deeper levels [1]. Explaining the high abundance of noble gases requires either condensing these elements directly at low-temperature in the form of amorphous ices [2], trapping them as clathrates [3–6] or photoevaporating the hydrogen and helium in the protoplanetary disk during the planet's formation [7]. The Galileo measurements at Jupiter also include a highly precise determination of the planet's helium abundance, crucial for calculations of the structure and evolution of the planet.

Because of the absence of in situ measurements, the noble gas abundances are unknown in Saturn and their determination is indispensable to understand its formation conditions. There is however some indication for a non uniform enrichment in C, N and S. [4] 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 nebula. Alternatively,

[5] finds that it is possible to account for these enrichments in a way consistent with those measured at Jupiter 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/H_2 ratio in Saturn is also necessary for properly modeling its interior.

3. Planetary Atmospheric Processes

Planetary atmospheres are our only accessible gateway to the processes at work within the deep interiors of the giant planets, and yet 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. 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 understand. 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 that are at work in planetary atmospheres, shaping the dynamics and circulation from the thermosphere to the deep troposphere, and ii) the properties and conditions for cloud formation as a function of depth and temperature in planetary atmospheres. In order to address these important points, the key measurements that could be performed by a Saturn probe are the following:

1. Determination of the thermal and density profile from thermosphere to troposphere, and the balance between different energy sources controlling atmospheric dynamics and structure;

2. Measurement of the strength of the winds as a function of altitude and the importance of wave perturbations on atmospheric structure;

3. Sampling and determination of the properties of cloud and haze layers as a function of depth;

4. Measurement of the vertical profiles of chemical products, disequilibrium species and ions to understand vertical mixing and atmospheric chemistry.

4. Mission Scenarios

Two mission architectures can be envisaged: (1) a single entry probe (with pre-entry science package) only with direct-to-Earth communication from the probe under parachute or during approach phase and pre-entry science. (2) An entry probe + carrier (derived from JUICE) that will accomplish additional science during approach and during its flyby leg above Saturn, including some magnetosphere and ring science. In this case, the probe's data communication can be envisaged in two different ways: direct-to-Earth and probe-to-carrier that will relay the data to Earth.

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