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Science goals and mission concept for the future exploration of Titan and Enceladus

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ABSTRACT

Saturn's moons, Titan and Enceladus, are two of the Solar System's most enigmatic bodies and are prime targets for future space exploration. Titan provides an analogue for many processes relevant to the Earth, more generally to outer Solar System bodies, and a growing host of newly discovered icy exoplanets. Processes represented include atmospheric dynamics, complex organic chemistry, meteorological cycles (with methane as a working fluid), astrobiology, surface liquids and lakes, geology, fluvial and aeolian erosion, and interactions with an external plasma environment. In addition, exploring Enceladus over multiple targeted flybys will give us a unique opportunity to further study the most active icy moon in our Solar System as revealed by Cassini and to analyse in situ its active plume with highly capable instrumentation addressing its complex chemistry and dynamics. Enceladus' plume likely represents the most accessible samples from an extra-terrestrial liquid water environment in the Solar system, which has far reaching implications for many areas of planetary and biological science. Titan with its massive atmosphere and Enceladus with its active plume are prime planetary objects in the Outer Solar System to perform in situ investigations. In the present paper, we describe the science goals and key measurements to be performed by a future exploration mission involving a Saturn–Titan orbiter and a

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Titan balloon, which was proposed to ESA in response to the call for definition of the science themes of the next Large-class mission in 2013. The mission scenario is built around three complementary science goals: (A) Titan as an Earth-like system; (B) Enceladus as an active cryovolcanic moon; and (C) Chemistry of Titan and Enceladus – clues for the origin of life. The proposed measurements would provide a step change in our understanding of planetary processes and evolution, with many orders of magnitude improvement in temporal, spatial, and chemical resolution over that which is possible with Cassini–Huygens. This mission concept builds upon the successes of Cassini–Huygens and takes advantage of previous mission heritage in both remote sensing and in situ measurement technologies.

1. Introduction

The Cassini–Huygens mission, which has been in orbit around Saturn since July 2004 and released the Huygens probe that landed on Titan's surface on January 14, 2005, has revealed Titan and Enceladus to be enigmatic objects – introducing extraordinary challenges for geologists, astrobiologists, organic chemists, and planetologists. Titan, Saturn's largest satellite, is unique in the Solar System with its extensive atmosphere made mostly of N_2, with a column density 10 times that of Earth's atmosphere. The presence of a few per cent methane provides the basis for rich organic chemistry, leading to production of complex CHON compounds from the upper atmosphere down to the surface (e.g. Israël et al., 2005; Waite et al., 2007; Bézard et al., 2014). Methane is close to its triple point on Titan, which gives rise to a methanological cycle analogous to the terrestrial hydrological cycle, characterized by cloud activity, precipitation, river networks and lakes (e.g. Tomasko et al., 2005; Stofan et al., 2007; Rodriguez et al., 2009). Exploring Titan in greater detail than ever possible with Cassini–Huygens offers the possibility to study physical processes analogous to those shaping the Earth's landscape, where methane takes on water's role, and to analyse complex chemical processes that may have prebiotic implications (e.g. Raulin et al., 2012).

The discovery of jets of water vapor and ice grains emanating from Enceladus' south pole in 2005 is one of the major highlights of the Cassini–Huygens mission (e.g. Dougherty et al., 2006; Porco et al., 2006; Spahn et al., 2006; Waite et al., 2006; Spencer et al., 2009). Despite its small size (10 times smaller than Titan), Enceladus is the most active moon of the Saturnian system. Although geyser-like plumes have been reported on Triton (Soderblom et al., 1990) and more recently transient water vapor activity around Europa (Roth et al., 2014), Enceladus is the only one proven to have current endogenic activity. The jets, which form a huge plume of vapor and ice grains above Enceladus' south pole, are associated with abnormally elevated heat flow along tectonic ridges, called ‘Tiger stripes’. Sampling of the plume by Cassini's instruments revealed the presence of water vapor, organics and salt-rich ice grains (Hansen et al., 2008; Waite et al., 2009; Postberg et al., 2009, 2011), suggesting that the jet sources are connected to subsurface salt-water reservoirs (e.g. Postberg et al., 2011). The surprising activity of Enceladus provides a unique opportunity to analyse materials coming from its water-rich interior, potentially containing compounds of prebiotic interest, and to study today aqueous processes that may have been important on many other icy worlds in the past.

The objectives of the present paper is to present the science goals and mission concept that were defined in response to the ESA call for the definition of the science theme of the next L-class (L2/L3) missions of the Cosmic Vision programme and to discuss the possible next step in the exploration of these two moons. Here we focus on science goals that could be achieved from the combination of a Saturn–Titan orbiter and a Titan balloon. The science goals and key measurements that may be achieved from the combination of a Titan orbiter and a lake probe are described in a companion paper (Mitri et al., this issue). The mission scenario described here is built around three major science goals, which were identified as the highest priority for such a mission:

- *Goal* A: Understand how Titan functions as a world, in the same way that one would ask this question about Venus, Mars, and the Earth.
- *Goal* B: Characterize the present-day activity of Enceladus, to understand what processes power it and how it affects the Saturnian environment.
- *Goal* C: Determine the degree of chemical complexity on the two moons, to analyse complex chemical processes that may haveprebiotic implications.

These goals are explained in detail in Sections 2–4. In Section 5, we briefly discuss a possible mission concept and key measurements, and consider the technological issues involved in return to the Saturn system. Section 6 provides a brief conclusion and some perspectives for the preparation of future exploration mission projects.

2. Science goal a: Titan as an earth-like system

Titan is a complex world more like the Earth than any other: it is the only place besides Earth known to have a dense, predominantly nitrogen, atmosphere; it has an active climate and meteorological cycle where the working fluid – methane – behaves under Titan's conditions the way that water does on Earth; and its geology – from lakes and seas to broad river valleys and mountains – while carved in ice is, in its vast range of processes, again most like Earth. Beneath this panoply of terrestrial processes an ice crust floats atop what appears to be a liquid water ocean. Science Goal A seeks to understand how Titan functions as a world, in the same way that one would ask this question about Venus, Mars, and the Earth. How are the distinctions between Titan and other worlds in the Solar System understandable in the context of the complex interplay between geology, hydrology, meteorology, and aeronomy? Is Titan an analogue for some aspect of the Earth's history, past or future? Why is Titan endowed with an atmosphere when, for example, Jupiter's moon Ganymede, virtually identical in size and mass, is not? Although the Cassini–Huygens mission provided major advances for understanding the atmospheric and geological processes at work on Titan, many questions remain unanswered – addressing these questions require future missions designed to explore these worlds.

2.1. Titan's atmosphere

2.1.1. Meteorology and methane cycle

Titan is the only body in the Solar System besides Earth with an active “hydrologic” cycle, featuring methane rather than water as the condensable fluid in clouds, rain, and surface reservoirs (lakes). Titan has an obliquity of 26.7° (similar to Earth) giving pronounced seasonal change during its 29.5-year orbit around the Sun. Cassini

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