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Explorer of Enceladus and Titan (E²T): Investigating ocean worlds' evolution and habitability in the solar system

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ABSTRACT

Titan, with its organically rich and dynamic atmosphere and geology, and Enceladus, with its active plume, both harbouring global subsurface oceans, are prime environments in which to investigate the habitability of ocean worlds and the conditions for the emergence of life. We present a space mission concept, the Explorer of Enceladus and Titan (E²T), which is dedicated to investigating the evolution and habitability of these Saturnian satellites. E²T is proposed as a medium-class mission led by ESA in collaboration with NASA in response to ESA's M5 Cosmic Vision Call. E²T proposes a focused payload that would provide in-situ composition investigations and high-resolution imaging during multiple flybys of Enceladus and Titan using a solar-electric powered spacecraft in orbit around Saturn. The E²T mission would provide high-resolution mass spectrometry of the plume currently emanating from Enceladus' south polar terrain and of Titan's changing upper atmosphere. In addition, high-resolution infrared (IR) imaging would detail Titan's geomorphology at 50–100 m resolution and the temperature of the fractures on Enceladus' south polar terrain at meter resolution. These combined measurements of both Titan and Enceladus would enable the E²T mission scenario to achieve two major scientific goals: 1) Study the

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origin and evolution of volatile-rich ocean worlds; and 2) Explore the habitability and potential for life in ocean worlds. E²T's two high-resolution time-of-flight mass spectrometers would enable resolution of the ambiguities in chemical analysis left by the NASA/ESA/ASI Cassini-Huygens mission regarding the identification of low-mass organic species, detect high-mass organic species for the first time, further constrain trace species such as the noble gases, and clarify the evolution of solid and volatile species. The high-resolution IR camera would reveal the geology of Titan's surface and the energy dissipated by Enceladus' fractured south polar terrain and plume in detail unattainable by the Cassini mission.

1. Introduction

The NASA/ESA/ASI Cassini-Huygens mission has revealed Titan and Enceladus to be two unique worlds in the Solar System during its thirteen years of observations in the Saturnian system (July 2004–September 2017). Titan, with its organically rich and dynamic atmosphere and geology, and Enceladus, with its active plume system composed of multiple jets (Waite et al., 2006a; Spahn et al., 2006; Porco et al., 2006), both harbouring global subsurface oceans (Iess et al., 2010, 2012, 2014; see also discussion in Sotin et al., 2010), are ideal environments in which to investigate the conditions for the emergence of life and the habitability of ocean worlds as well as the origin and evolution of complex planetary systems. The prime criteria of habitability include energy sources, liquid water habitats, nutrients and a liquid transport cycle to move nutrients and waste (McKay et al., 2008, 2016; Lammer et al., 2009). The best-known candidates in the Solar System for habitability at present meeting these criteria are the ocean worlds in the outer Solar System, which include: Enceladus, Titan, Europa, and Ganymede (Lunine, 2017; Nimmo and Pappalardo, 2016). While the Jovian moons will be thoroughly investigated by the ESA Jupiter Icy moon Explorer (JUICE), Enceladus and Titan, which provide environments that can be easily sampled from orbit in a single mission, are currently not targeted by any future exploration. The joint exploration of these two fascinating objects will allow us to better understand the origin of their organic-rich environments and will give access to planetary processes that have long been thought unique to the Earth.

Titan is an intriguing world that is similar to the Earth in many ways, with its dense nitrogen-methane atmosphere and familiar geological features, including dunes, mountains, seas, lakes and rivers (e.g., Stofan et al., 2007; Lorenz et al., 2006, 2009; Lopes et al., 2007a; Mitri et al., 2010). Titan undergoes seasonal changes similar to Earth, driven by its orbital inclination of 27° and Saturn's approximately 30 year orbit. Exploring Titan then offers the possibility to study physical processes analogous to those shaping the Earth's landscape, where methane takes on water's role of erosion and formation of a distinct geomorphological surface structure.

Enceladus is an enigma; it is a tiny moon (252 km radius) that harbours a subsurface liquid-water ocean (Iess et al., 2014; McKinnon, 2015; Thomas et al., 2016; Cadec et al., 2016), which jets material into space. The eruption activity of Enceladus offers a unique possibility to sample fresh material ejected from subsurface liquid water and understand how exchanges with the interior controls surface activity, as well as to constrain the geochemistry and astrobiological potential of internal oceans on ocean worlds (e.g., Porco et al., 2006). Since the 1997 launch of the Cassini-Huygens mission, there has been great technological advancement in instrumentation that would enable answering key questions that still remain about the Saturnian ocean worlds.

The scientific appeal of Titan and Enceladus has stimulated many previous mission studies (e.g. see reviews by Lorenz, 2000, 2009), which have articulated detailed scientific objectives for post-Cassini scientific exploration (e.g. Mitri et al., 2014a; Tobie et al., 2014). At Titan, in particular, the diversity of scientific disciplines (Dougherty et al., 2009) has prompted the study of a variety of observing platforms from orbiters ("Titan Explorer", Leary et al., 2007; Mitri et al., 2014a), landers for the seas ("Titan-Saturn System Mission – TSSM", Strange et al., 2009; "Titan Mare Explorer – TiME", Stofan et al., 2013; Mitri et al., 2014a), landers for

land (Titan Explorer), fixed-wing aircraft ("AVIATR", Barnes et al., 2012), to balloons (Titan Explorer, TSSM and others). Additionally, Enceladus' plume has attracted designs of spacecraft to sample it: "Titan and Enceladus Mission TANDEM" (Coustenis et al., 2009a, b), "Journey to Enceladus and Titan – JET" and "Enceladus Life Finder – ELF" (Reh et al., 2016).

We present a space mission concept, the Explorer of Enceladus and Titan (E²T), which is dedicated to investigating the evolution and habitability of these Saturnian satellites and is proposed as a medium-class mission led by ESA in collaboration with NASA in response to ESA's M5 Cosmic Vision Call. In Section 2 we present the science case for the future exploration of Enceladus and Titan as proposed by the E²T mission, and Section 3 the science goals for the E²T mission. In Sections 4 and 5 we discuss the proposed payload and mission and spacecraft configuration necessary to achieve E²T mission goals.

2. Science case for the exploration of Enceladus and Titan

Titan, Saturn's largest satellite, is unique in the Solar System with its dense, extensive atmosphere composed primarily of nitrogen (97%) and methane (1.4%) (e.g., Bézard, 2014), and a long list of organic compounds resulting from multifaceted photochemistry that occurs in the upper atmosphere down to the surface (e.g., Israël et al., 2005; Waite et al., 2007; Gudipati et al., 2013; Bézard, 2014). As methane is close to its triple point on Titan, it gives rise to a methane cycle analogous to the terrestrial hydrological cycle, characterized by cloud activity, precipitation, river networks, lakes and seas covering a large fraction of the northern terrain (Fig. 1) (e.g., Tomasko et al., 2005; Stofan et al., 2007; Mitri et al., 2007; Lopes et al., 2007a; Hayes et al., 2008).

With an environment that changes on a 29.5 year cycle, it is crucial to study Titan during an entire orbital period. Cassini has investigated Titan over only two seasons: from Northern winter solstice to summer solstice. While ground-based observations, have observed Titan in other seasons, these data are not sufficient to address many of the outstanding questions. Current measurements with Cassini/CIRS show that the chemical content of Titan's atmosphere has significant seasonal and latitudinal

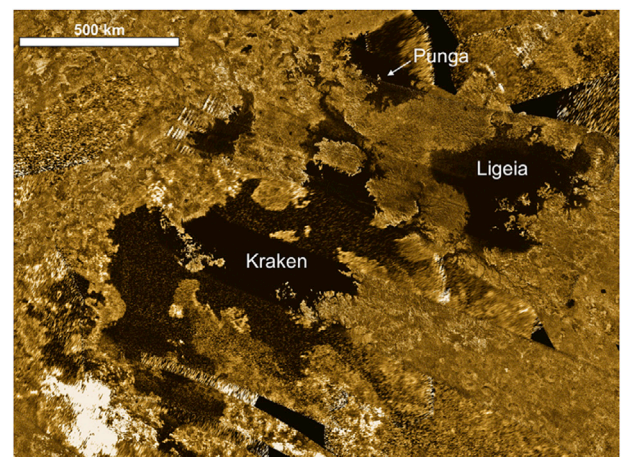


Fig. 1. Cassini SAR mosaic images of the north polar region showing Kraken, Ligeia and Punga Maria (from Mitri et al., 2014a).

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