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## Science goals for future exploration of the habitability of the gaseous giant planets' satellites

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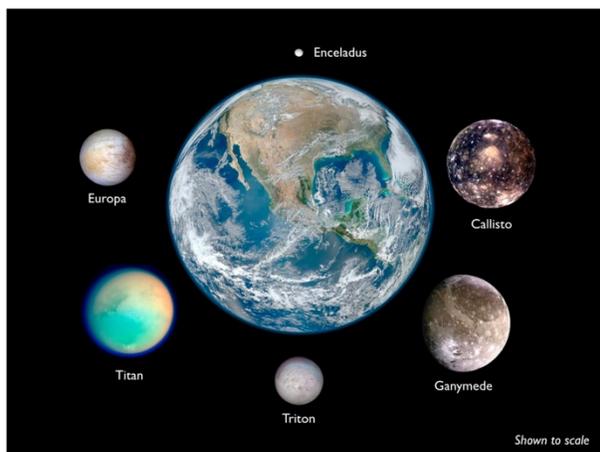
### Abstract

Large satellites of gas giants, at orbits beyond the snow-line and the traditional “habitability zone”, such as around Jupiter or Saturn, can contain a large amount of water (almost 45% in mass). Their hydrospheres are extremely thick (~600 km for Ganymede and Callisto for instance), and may possess liquid layers below the icy crust. Around Saturn, Enceladus and Titan have also been recognized as potentially having undersurface liquid water reservoirs. Thus, the icy satellites provide a conceptual basis within which new theories for understanding habitability can be constructed. Measurements from the Voyager and Galileo spacecraft revealed the potential of these satellites in this context. Future exploration towards the Galilean satellites include missions such as ESA’s JUPITER Icy moons Explorer (JUICE) or NASA’s Europa Clipper. For a return to Titan, NASA has recently selected the Dragonfly mission and other concepts are being studied. Such endeavors will greatly enhance our understanding of the icy moons, their potential habitability and the formation of the Solar System in general.

**Keywords:** (Icy moons, giant planets, space missions, JUICE)

### 1. Introduction

The satellites of Jupiter and Saturn have been revealed as extremely astrobiologically interesting bodies presenting promising conditions for habitability and the development and/or maintenance of life. Titan and Enceladus, Saturn’s satellites, were found by the Cassini-Huygens mission to possess active organic chemistries with seasonal variations, unique geological features and possibly internal liquid water oceans, among other. Additionally, Jupiter’s Europa and Ganymede show indications of harboring liquid water oceans under their icy crusts, which may be in direct contact with a silicate mantle floor and kept warm through time by tidally generated heat (Fig. 1).



All of these environments satisfy many of the “classical” criteria for habitability (liquid water, energy sources to

sustain metabolism and “nutrients” over a period of time long enough to allow the development of life). The oceans underneath these moons are of substantial size (Fig. 2).

In order to study the habitability of icy moons around giant planets, we look at the atmosphere-surface-interior connections with their similarities with the Earth as a starting point. The discovery of the water jets on Enceladus, the possibility for cryovolcanic processes on Titan and the hypothetically active mantle of Europa suggest that icy moons around giant planets may well contain subsurface oceans.

### 2. Science goals for future exploration

The science goals for future exploration of the icy moons are broad and cover a large range of aspects from formation and evolution to habitability. In the case of Titan for example, the science objectives can be summarized as follows.

#### *Goal A: Explore Titan, an Earth-like System*

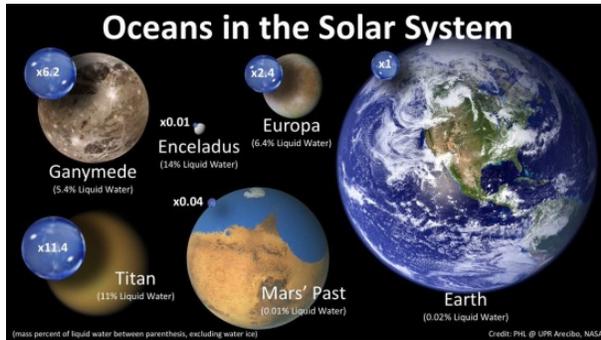
How does Titan function as a system? How are the similarities and differences with Earth, and other solar system bodies, a result of the interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system?

#### *Goal B: Examine Titan’s Organic Inventory – A Path to Prebiological Molecules*

What is the complexity of Titan’s organic chemistry in the atmosphere, within its lakes, on its surface, and in its putative subsurface water ocean? How does this inventory differ from known abiotic organic material in meteorites and contribute to our understanding of the origin of life in the Solar System?

*Goal C: Explore Enceladus and Saturn's Magnetosphere – Clues to Titan's Origin and Evolution*

What is the exchange of energy and material between the Saturn magnetosphere, solar wind and Titan? What is the source of geysers on Enceladus? Does complex chemistry occur in the geysers?



Similar goals are also aimed for in future missions exploring the icy moons around Jupiter. If the silicate mantles of Europa and Ganymede and the liquid sources of Titan and Enceladus are geologically active as on Earth, giving rise to the equivalent of hydrothermal systems, the simultaneous presence of water, geodynamic interactions, chemical energy sources and a diversity of key chemical elements may fulfill the basic conditions for habitability. In addition, Ganymede, the largest satellite in the Solar System presents unique features with its induced magnetic field, which can be connected to the presence of a liquid water undersurface ocean trapped between ice layers, as in the case of Europa, except that in the latter case the ocean is hypothesized to be in contact with the silicate core.

### 3. Future exploration

Small satellites as potential habitats can only be investigated with appropriate designed space missions, like ESA's L1 JUICE (whose main target is Ganymede and will be launched in 2022 for arrival in the jovian system in 2030) and NASA's Europa Clipper mission. More information on JUICE/ <https://sci.esa.int/web/juice>.

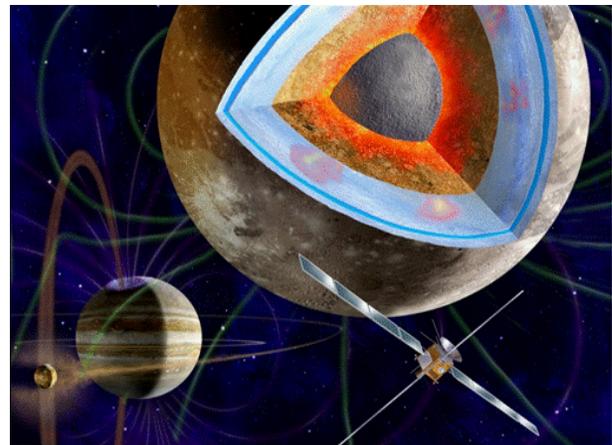
The overarching theme for JUICE is the emergence of habitable worlds around gas giants taking into account the requirements involving the presence of organic compounds, trace elements, water, energy sources and a relative stability of the environment over time.

Ganymede is identified for detailed investigation since it provides a natural laboratory for analysis of the potential habitability of icy worlds in general, but also because of the role it plays within the system of Galilean satellites, and its unique magnetic and plasma interactions with the surrounding Jovian environment. For Europa, two targeted flybys are planned, with a focus on the chemistry essential to life, including organic molecules, and on understanding

the formation of surface features and the composition of the non water-ice material, leading to the identification and characterisation of candidate sites for future in situ exploration. Furthermore, JUICE will determine the characteristics of liquid-water oceans below the icy surfaces of the moons. The mission will also focus on characterising the diversity of processes in the Jupiter system which may be required in order to provide a stable environment at Ganymede, Europa and Callisto on geologic time scales, including gravitational coupling between the Galilean satellites and their long term tidal influence on the system as a whole.

Focused studies of Jupiter's atmosphere, magnetosphere and their interaction with the Galilean satellites will further enhance our understanding of the evolution and dynamics of the Jovian system. The circulation, meteorology, chemistry and structure of Jupiter will be studied from the cloud tops to the thermosphere.

The mission scenario foresees arrival in the Jupiter system following orbit insertion, during which JUICE will perform a tour of the Jupiter system using gravity assists of the Galilean satellites to shape its trajectory. This tour will include continuous monitoring of Jupiter's magnetosphere and atmosphere, two targeted Europa flybys, a Callisto flyby phase reaching Jupiter latitudes of about 22°, culminating with the dedicated Ganymede orbital phase. The current end of mission scenario involves spacecraft impact on Ganymede. The JUICE mission will be launched in mid-2022, with a backup opportunity in August 2023. It will arrive at Jupiter in January 2030 after 7.6-years using an Earth-Venus-Earth-Earth gravity assist sequence and is foreseen to last for 3 and a half years.



**Fig. 3 : The Juice Mission**

Back to the Saturnian system, Dragonfly is a planned spacecraft and mission that will send a mobile robotic rotorcraft lander to Titan, the largest moon of Saturn, in order to study prebiotic chemistry and extraterrestrial habitability at various locations where it will perform

vertical-takeoffs and landings :  
<https://dragonfly.jhuapl.edu/>



chemistry with seasonal variations, unique geological features and possibly internal liquid water oceans. As revealed by Cassini, the liquid hydrocarbon lakes currently distributed mainly at polar latitudes on Titan are ideal isolated environments to look for biomarkers.

If the silicate mantles of Europa and Ganymede and the liquid sources of Titan and Enceladus are geologically active as on Earth, giving rise to the equivalent of hydrothermal systems, the simultaneous presence of water, geodynamic interactions, chemical energy sources and a diversity of key chemical elements may fulfil the basic conditions for habitability. All of these elements would be investigated with future space missions.

#### 4. Conclusions

Titan and Enceladus, Saturn's satellites, were found by the Cassini-Huygens mission to possess active organic