

## Exploration of Extraterrestrial Ocean Worlds –results from Cassini and perspectives

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The Cassini mission, which has been in Saturn's system for more than a decade, has discovered two ocean worlds: Enceladus, a tiny moon 252 km in radius and Titan, a large moon 2575 km in radius which is the only moon in the solar system with a dense atmosphere. For each of these satellites of Saturn, the ocean is located beneath a thick icy crust. Enceladus is characterized by the presence of jets that eject samples of the deep ocean into space. The data gathered by the Cassini instruments suggest the presence of hydrothermal activity (Hsu et al., 2015). Recent measurements of Enceladus' librations are best explained by a decoupling between the icy crust and the inner core, suggesting the presence of a global ocean. Maintaining a global ocean during billions of years is a challenge for thermal evolution models of a tiny moon in a very cold environment. Titan is characterized by its dense atmosphere where large organic molecules are produced. These heavy molecules eventually form the organic haze that falls on Titan's surface and may constitute the sand of the equatorial dunes. Titan is also characterized by hydrocarbon seas at the North Pole making Titan, the only other object besides Earth with stable liquid bodies on its surface. Although the organic cycle has been studied by the Cassini missions, there are still major scientific questions such as the molecular and elementary composition of the heavy organics and the processes responsible for the replenishment in methane of Titan's atmosphere.

Enceladus can be compared with Europa in the sense that the global ocean is in contact with a rocky core where conditions are very similar to those existing on the terrestrial sea-floor. The fact that its ocean is being ejected into space makes measurements into the plume a science priority for future missions to Enceladus. Europa is the target of a planned NASA flagship mission for which the instruments to be mounted on the spacecraft have already been selected. This mission would characterize Europa's deep ocean. Although the presence of a plume (Roth et al., 2013) that would eject samples of Europa ocean into space is still debated, assets that would analyze this potential plume are being studied.

Titan can be compared to Callisto and Ganymede, Jupiter's largest moons, which have very similar mass and radius. Interpretation of the magnetic field measurements at Ganymede and Callisto by the Galileo mission suggests that they also have a deep ocean. Similarly, interpretation of (i) the electric signal recorded by the Huygens probe during its descent in Titan's atmosphere in January 2005 and (ii) the value of the tidal Love number  $k_2$ , suggest that an ocean is present beneath Titan's icy crust. On these three large moons, models based on the equation of state of H<sub>2</sub>O and values of the moment of inertia, a measure of mass repartition, suggest that this deep ocean would not be in contact with silicates because a high-pressure layer of ice would be present between the ocean and the rocky core. This paper will investigate the conditions under which the liquid water may have been in contact with the silicates in the past. This question is important to assess the habitability potential of these large icy moons. Ganymede and to a lesser degree Callisto will be the targets of the ESA JUICE mission, the first large mission of the ESA "Cosmic Vision" program. The primary goal of the JUICE mission is to characterize the oceans of Ganymede and Callisto. This work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

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