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Habitability of the giant icy moons: current knowledge and future insights from the JUICE mission

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Abstract

Large satellites of gas giants, at orbits beyond the snow-line, such as Jupiter or Saturn, can contain a large amount of water (almost 45% in mass). Hydrospheres are extremely thick, ~600 km for Ganymede and Callisto, and may possess liquid layers below the icy crust. Thus, the Galilean 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. The JUpiter Icy moons Explorer (JUICE) will greatly enhance our understanding of their potential habitability.

It is known, even at Earth where life mostly depends on solar energy, that habitats exist deep in the oceans in eternal darkness feeding on chemical energy. Aqueous layers are suspected below the icy crusts of the moons, which possess similar physical characteristics than Earth's deep oceans. Since they are certainly very stable through time, and because complex chemistry and energy sources may be available, life may have originated within such subsurface habitats despite the hostile surface conditions.

Liquid water reservoirs have been proposed on Ganymede, Europa and Callisto from geophysical models, based on Galileo observations. These oceans that are covered by ice shells exist independently of the input of stellar energy, and are located well outside the conventional habitable zone of the Sun. Considering the pressure range encountered within the icy moons, four different scenarios can be defined. These result from varying thicknesses of the water ice layers and the liquid ocean with respect to the silicate floor (Figure 1). Case 2 in Figure 1 is highly probable for the largest moons (Ganymede and Callisto), while case 3 is more probable for Europa and smaller icy moons if they host liquid reservoirs such as has been discovered at Enceladus. Europa's ocean is unique because it may be in contact with the rock layer. This substrate may be geologically active and affected by hydrothermal processes, similar to

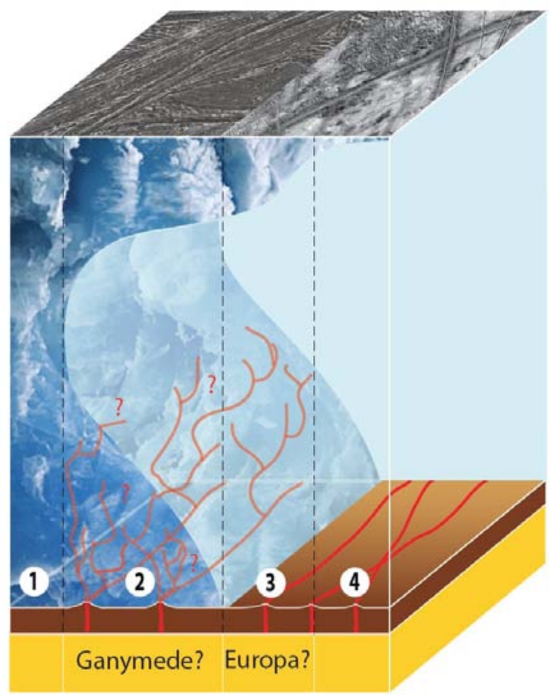

Figure 1: Possible locations of liquid layers in the icy moons of Jupiter are shown here as a function of depth:1) completely frozen; 2) three-layered structures impeding any contact between the liquid layer and the silicate floor; 3) thick upper icy layer (>10 km) and a deep ocean; 4) very thin upper icy layer (3-4 km). Cases 3 or 4 are the most probable for Europa. Case 2 is expected for Ganymede and Callisto.

the terrestrial sea floor. This may enhance habitability conditions since the rock layer could release chemical elements and energy to the surrounding water ocean. Differentiation of the rock could be responsible for the presence of salts and other essential elements in the ocean, and produce the low albedo terrains seen on the surface. An estimation of the minimal thickness of the icy crust over the most active regions of Europa is among the measurement goals of JUICE and this will provide important constraints on the subsurface structure of the moon.

On the larger icy moons, Ganymede and Callisto, where internal pressures are sufficient to allow for the formation of high pressure ice phases, the existence of an ocean suggests that it should be enclosed between thick ice layers. Chemical and energy exchanges between the rocky layer and the ocean, which are so important for habitability, cannot be ruled out but would imply efficient transport processes through the thick high pressure icy layer. Such processes are indeed possible but not as clear-cut as the exchanges that can be envisaged for Europa.

Icy and liquid layers are probably not solely constituted of pure H2O. Many other compounds such as salts, or CO_2 have been observed on the surfaces and may emerge from the deep interiors of the moons. Volatiles, organics and minerals solidified from the aqueous cryo-magmas, could be detected remotely from an orbiting spacecraft. Analysis of these materials will give great insight to the physico-chemistry and composition of the deep environments. But such organic matter and other surface compounds will experience a different radiation environment at Europa than at Ganymede (due to the difference in radial distance from Jupiter) and thus may suffer different alteration processes, influencing their detection on the surface. Measurements from terrains on both Europa and Ganymede will allow a comparison of different radiation doses and terrain ages from similar materials.

JUICE will address key areas that emerge in the study of habitable worlds around gas giants including constraints on the volume of liquid water in the Jovian system. The mission will also establish the inventory of biologically essential elements on the surfaces of the icy moons, and determine the magnitude of their transport among the moons which exchange material as a result of volcanism, sputtering, and impacts. The mission may also allow us to infer environmental properties such as the pH, salinity, and water activity of the oceans and will investigate the effects of radiation on the detectability of surface organics.