PROPERTIES OF ICE-RICH PLANETS

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As is becoming more and more apparent, the galaxy contains an immense variety of planets and planetary bodies. From terrestrial (Earth-like) planets to gas (Jupiter-like) giants, from icy dwarfs to super-Earths, from hot Neptunes to super-Jupiters, and more. The structure and evolution of these worlds depends on 3 fundamental factors: how big (or massive) they are (which controls mineralogy, material properties, including temperature, and the degree of mixing or blending), what they are made of – the proportions of the 4 main cosmically abundant materials: metals (principally iron), rock (mainly silicates), ice (principally water ice), and gas (hydrogen and helium), and where they "orbit" (that is, are they "planets," "satellites," or "free-floaters," and for the first two categories how close they orbit to their parent star or planet).

In our own Solar System there are some clear planetary size/compositional categories that correlate with location, but there do not appear to be any fundamental reasons why super-sized Earths, or Earths with massive, thick oceans, or slimmed-down sub-Neptunes cannot exist (elsewhere). Regarding "ice-rich planets" closer to home, and by ice-rich I mean bodies for whom ice is an important component (say 10% by mass or more), we look mainly to the satellites of the outer Solar System. I also take ice to mean not just water ice, but all the ices formed from the most common volatile elements O, C, and N, whether chemically reduced by hydrogen or not: these include methane (CH_4), ammonia (NH_3), CO, CO_2, N_2, and more. This variety of com-ponents, and their interactions, imply a potentially rich, icy "geology" on the icy satellites, and on their free cousins in solar orbit: the dwarf planets Ceres, Pluto, and Eris, as well as numerous slightly smaller Kuiper Belt objects (all bodies we know relatively little about…at the moment).

Planets separate into distinct layers according to density (i.e., crust, mantle, and core). This process of differentiation occurs in ice-rich planets as well, but in such cases the outermost major layer is a mantle of ice, not rock. The Earth's rocky mantle is mostly solid, but the hottest portions are partially molten. Molten rock (lava) is less dense than solid rock, and thus relatively buoyant, which is why we have volcanoes and volcanic eruptions on bodies like the Earth. On ice-rich planets the opposite is true, molten ice (water) is denser than ice, so "cryolavas" tend to sink downward. Because these aqueous melts cannot escape, they can accumulate and form internal liquid layers or "oceans." Magnetic field evidence from the Galileo mission to Jupiter implies that Europa, Ganymede, and Callisto all possess such internal oceans. Less direct evidence from the Cassini mission implies that Titan and Enceladus may possess oceans as well. For the largest of these worlds, Ganymede, Titan, and Callisto, the oceans are sandwiched between a layer of ordinary ice I above, and a thicker layer of denser ice phases below. For less ice-rich Europa and diminutive Enceladus the oceans are probably in direct contact with rock mantles underneath. For Europa in particular, the possible interaction between the ocean and a potentially volcanically active rock interior is of deep astrobiological interest.

Although it isn't easy being cryovolcanic, ice-rich planets may form chemically distinct crusts if sufficient less dense ices (i.e., CH_4, N_2) are available. In the deep outer Solar System these ices can be found, on Pluto, Triton, and Eris, for example, and even as liquid on the surface and in the massive atmosphere of Titan. Titan's methane-powered "hydrologic" cycle brings us full circle, to a world whose eroded and sculpted surface is remarkably Earth-like. It is unique among the icy satellites in our Solar System, but certainly not among those in the galaxy, and as with all the bodies mentioned above, is (from a geophysical perspective) a planet in all but name.