INTERIOR STRUCTURE MODELS SUGGEST A COMETARY ORIGIN FOR THE LARGE ICY MOONS. C. Sotin[1], B. Reynard[2], F. Guyot[3], and A. Neri[4], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [2]University of Lyon, ENS de Lyon, CNRS, Lyon, France, [3]Sorbonne Université, IMPMC, UMR CNRS 7590, IRD, UMR206, Museum National d'Histoire Naturelle, Paris, France, [4]IRAP, Université de Toulouse, CNRS, CNES, UPS, Toulouse, France.

Introduction: Information on the composition of the icy moons of Jupiter and Saturn would provide insights on their formation and evolution. Their inner structure comprises an hydrosphere made of ices, liquid water and potentially high-pressure (HP) ice, a silicate rocky core, and an inner metallic core depending on thermal evolution and differentiation. The density profile inside these moons is poorly known. The values of the degree 2 gravity coefficients provide information on the moment of inertia (MoI) which is a measure of the degree of differentiation. But it cannot provide a unique solution for the density profile. In this study, we have investigated the density profiles that would be consistent with a CI carbonaceous chondrite elementary composition for the silicate fraction and pure water for the hydrosphere. We find that a light component is needed in the silicate fraction in order to explain mass and MoI. This light component could be insoluble organic matter (IOM) [1].

Models: Ganymede and Titan have very different MoI values although very similar in mass and radius. The low value of Ganymede's MoI of 0.311 [2] together with the presence of an intrinsic dynamo [3] suggest a very differentiated interior with an iron-rich liquid core and a mostly dehydrated silicate shell. On the other hand, Titan's MoI of 0.341 [4] suggests a much less differentiated moon with an hydrated silicate core [5]. However, the density inferred for the hydrated silicate core requires a low Fe/Si ratio, much smaller than chondritic. Instead of leaving the iron (and other elements) content as a free parameter, we assume a CI carbonaceous chondrite composition for the interiors of icy satellites [6].

The interior structure models are constructed using equations of state to calculate the density of the different phases along a (P,T) profile. The temperature profile is conductive in the ice crust and the silicate core. It is adiabatic in the water ocean and the iron-rich liquid core when present. If a layer of HP ice is present, the temperature profile is close enough to the melting curve [7] that the melting curve of HP ice is a good approximation. The pressure profile is consistent with the density of the phases, implying an iterative process for the calculation of the density profile [1]. In the hydrosphere, a pure H_2O composition is assumed although salts and volatiles may be present. However their effect is small compared to that of iron in the silicate fraction. For the silicate fraction, we use the thermodynamic software Perple_X [8] at relevant pressures and temperatures. Preliminary high pressure experiments are used to check the reliability of the thermodynamic calculations in iron-rich chondritic compositions of hydrous silicates [1].

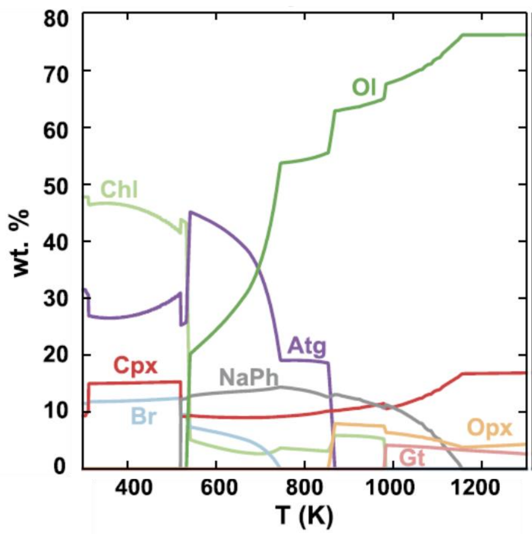

Figure 1: mineralogy of the silicate fraction as a function of temperature from Perple-X applied to a CI chondritic composition at P=3.0 GPa.

Two models are built for the silicates: the first one applicable to Titan assumes an hydrated silicate core. The second one, applicable to Ganymede, assumes dehydrated silicates with a low Fe number (Fe/(Fe+Mg)) because a large fraction of the iron was segregated to the liquid core where a dynamo operates. In the Titan model, FeS (23 wt%) is mixed with silicates. The differences in the silicate iron content modifies the phases predicted by the thermodynamic software. Lookup tables are built for each model, with mineralogy and density for a range of pressures and temperatures consistent with the probable (P,T) conditions inside the icy moons. As an example, the mineralogy at P=3 GPa and temperatures between 300 and 1300 K is displayed in Figure 1. At temperatures lower 500 K, chlorite is the main component. Above, it is replaced by antigorite and olivine. As temperature increases, olivine becomes the major phase at the expense of antigorite. Above 900 K, antigorite disappears and orthopyroxene forms. For the Ganymede-like model where sulfur is in the core forming an Fe-FeS mixture, the lower amount of iron in the silicates changes the mineralogy. In addition, dehydration happens within a smaller temperature range.

Several models are built for different water/rock fractions, which is equivalent to determining the radius of the interface between the silicates and the hydrosphere. For each model, the mass and MoI are calculated. They provide the two curves shown in Figure 2, in blue for Ganymede and orange for Titan. The observed values of mass and MoI do not lie on these curves pointing to the necessity of a low density component. Note that for Titan, a non-hydrostatic (NH) component may be present [4], which would lead to a lower value of the MoI. Nonetheless, this NH component is not large enough to bring the Titan point on the orange curve.

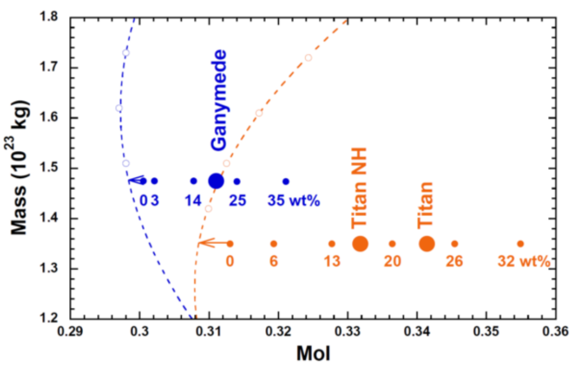

Figure 2: The points (MoI, mass) for Ganymede and Titan don't fall on the curves for CI chondrites composition. A low density component is needed. It could be IOM.

The necessity of a low density component has led us to investigate the possibility of insoluble organic matter (IOM) that comprises 45 weight % of cometary dust observed by the Rosetta mission [9]. The nature of this IOM is poorly constrained. In addition, there is a limited amount of data on the density of this material in the pressure range (1 to 5 GPa) relevant to the interior of Titan and Ganymede. We use values on carbonized coals [10] showing a sharp increase in density around 900 K due to the release of hydrogen. Below that temperature, the density is on the order of 1400 kg/m^3. It reaches 1800 kg/m^3 above that temperature. Interestingly, this density jump is in the temperature range of the dehydration zone of the silicates. With these values, we find that about 20 weight% of IOM is necessary to shift the (Mass, MoI) curves onto the observed values for Titan and Ganymede (Figure 2).

The resulting favored interior models for Titan and Ganymede are displayed in Figure 3. For Ganymede, the outer part of the silicate shell is hydrated because the temperature is below the dehydration curve. Although the figure shows very different thicknesses for the water ocean, the models are not sensitive to this parameter. In both cases, the IOM would correspond to a large mass fraction of the core, much more than the 4% IOM present in carbonaceous chondrites. It therefore suggests that part of the icy moons building blocks are comets.

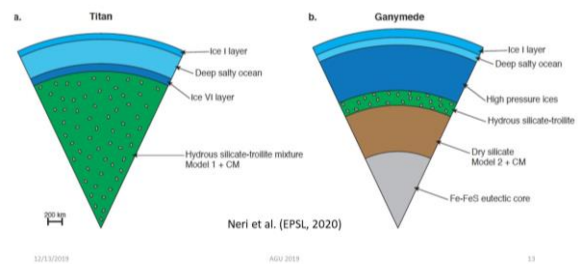

Figure 3: Suggested interior models of Titan and Ganymede

Discussion and conclusion: The density profiles of the icy moons is poorly known. The information provided by the gravity coefficients (MoI) cannot provide a unique solution. The models presented here are consistent with EoS for water and silicates. Further work should investigate the potential reaction between the IOM and the silicate fraction during the evolution of these icy moons. It has been suggested that up to 50% of the nitrogen in Titan's atmosphere could come from the destabilization of IOM contained in its interior [11]. This conclusion is consistent with the present models.

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