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The Interior Structure of Ganymede and Callisto: Implications from Gravity Data

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Abstract. Only a limited amount of gravity field data was collected during close satellite encounters of the *Galileo* spacecraft in the Jupiter system. The interpretation of these data in terms of interior structure is based on the widely held but unproven assumption of hydrostatic equilibrium. We will discuss physical constraints imposed on present-day interior structure models of Ganymede and Callisto and possible future refinement, as envisaged for the planned EJSM mission to the Jovian system. This should be accomplished by more complete recovery of the static and time-variable parts of the gravitational fields, using complementary observations from JGO and JEO spacecraft, combined with altimetry data of regional topography and global shape, and, possibly, in-situ monitoring of tidally-induced surface distortion.

Interiors of Ganymede and Callisto.

Ganymede is the largest planetary satellite with a radius of (2631.2 ± 1.7) km. Gravitational and magnetic field observations by the Galileo spacecraft together with spectral data of the surface suggest that Ganymede's interior is composed of water ice and rock-metal components in nearly equal amounts by mass and strongly differentiated [1]. Its intrinsic magnetic field is most likely maintained by dynamo action in a liquid Fe-FeS core. Shown in Fig. 1 are model density distributions that satisfy Ganymede's mean density and moment-of-inertia constraints of (1942.0 ± 4.8) kg m^{-3} and 0.3115 ± 0.0028, respectively. The models suggest Ganymede's interior to be composed of an iron-rich core surrounded by a silicate rock mantle and overlain by an ice shell. The latter may contain a briny subsurface water ocean sandwiched between a high-pressure water ice layer and the outermost ice layer [2,3].

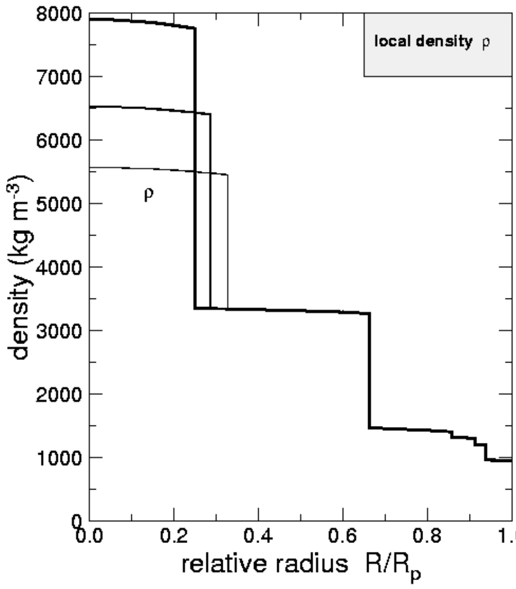

Fig. 1: Radial density distribution for three core compositions of Ganymede. From top to bottom: pure Fe; Fe-FeS (50:50 by wt.); pure FeS core. Adapted from [3].

Callisto is (2410 ± 1.7) km in radius and less massive than Ganymede but similarly composed. The gravity data collected during several close Galileo flybys suggest only partial internal differentiation [4,5], augmented by a density increase with depth due to pressure-induced water ice phase transitions [6]. The magnetic data are consistent with a briny subsurface water ocean present at around 150 km depth [7,8]. Incomplete separation of ice and rock component may have resulted in deviation of Callisto's interior from hydrostaticity. Depending on the timescale of satellite formation [9], the primordial rock concentration may have been retained at shallow depth, followed by a rock-depleted water ice/liquid shell and a mixture of rock and ice below, with the rock concentration increasing with depth up to the close-pack limit [10].

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Deep interior. More reliable constraints on the radial density distribution of the interiors of Ganymede and Callisto are urgently needed. Those would be imposed by a better knowledge of the satellite mean density, mean moment of inertia factor, and low-degree gravity field coefficients together with the composition and density of the outer ice shells.. In particular, the validity of the widely held assumption of hydrostatic equilibrium needs to be critically evaluated by separate determination of the static components of the gravitational field coefficients J_2 and C_{22} from independent orbits (polar) and flybys (inclined and equatorial). These coefficients are required to be determined at an accuracy that would facilitate separating tidally-induced contributions to J_2 and C_{22} and high-order static gravity anomalies [11]. Global shapes and rotational states and orientations in space would be obtained from combining imaging and laser altimetry data [12].

Crust and lithosphere. Important new constraints on the geologic history and thermal evolution of Ganymede and Callisto could be inferred from accurate higher-degree gravity data [11] combined with laser altimetry [12]. Coherence and admittance between spectral gravity and the subdued topography of the satellites as a function of spherical harmonic degree can be used to infer the depth of compensation of topography. Those are due to variations in crustal thickness and subsurface density and the elastic response of the lithosphere to loading. This would provide indirect constraints on flexural rigidity, tectonic stress distribution, and early thermal state of the lithosphere and crust of the outer ice shells.

Subsurface water oceans. The detection of a global subsurface water ocean and further characterization of the water-ice/liquid shell require monitoring of the dynamic response of the ice shell to tidal forces exerted by Jupiter at different true anomalies along the satellites' eccentric orbits. The tidal Love numbers k_2 and h_2 measure the variation of the gravitational potential due to tidally-induced internal redistribution of mass and the corresponding radial surface displacement, respectively. Whereas k_2 can be inferred from time-variable contributions to the low-degree coefficients J_2 and C_{22} of the gravitational field [11], h_2 can be constrained by additionally conducting laser altimetry on global shape variations [12]. Furthermore, monitoring of tidally-induced surface displacement and tilt using a well-suited in-situ mission component [13,14] would help constrain other tidal parameters, involving combinations of k_2 and h_2, thereby improving the overall measurement accuracy of each. In combination with measured induced magnetic fields, those data will help constrain the thickness of the ice shell and the depth of the water ocean below. Measurements of forced physical libration and spin-axis obliquity would provide additional information on the existence of a subsurface ocean, the ice shell thickness, and the coupling between the outer ice shell and the deep satellite interior [15].

Conclusions. Gravitational field sounding from low-altitude orbit and close flyby, combined with altimetry data and in-situ monitoring of tidally-induced surface distortion, would impose most reliable constraints on the low-degree coefficients of the gravitational fields of Ganymede and Callisto. Future recovery of their static and time-variable parts by using JGO and JEO observations in parallel would provide entirely new information on the gravitational signature of intrinsic density anomalies and regional topographic features as well as on the existence and radial extent of liquid subsurface water reservoirs on large icy satellites. This has important implications for bulk chemical composition and degree of internal differentiation. The latter are tied to the origin and early evolution of the entire Jovian satellite system.

References

[1] Schubert, G. et al. (2004) In *Jupiter: the planet, satellites and magnetosphere*, Cambridge Univ. Press., 281 – 306. [2] Anderson, J.D. et al. (1996) *Nature*, 384, 541–543. [3] Sohl, F. et al. (2002) *Icarus*, 157, 104-119. [4] Anderson, J.D. et al. (1998) *Science*, 280, 1573-1576. [5] Anderson, J.D. et al. (2001) *Icarus*, 153, 157-161. [6] McKinnon, W.B. (1997) *Icarus*., 130, 540-543. [7] Khurana, K.K. et al. (1998) *Nature*, 395, 777-780. [8] Zimmer, C. et al. (2000) *Icarus*, 147, 329-347. [9] Barr, A.C. & Canup, R.M. (2008) *Icarus*, 198, 163-177. [10] Nagel, K. et al. (2004) *Icarus*, 169, 402-412. [11] Iess, L. (2009) *this vol.* [12] Hussmann, H. et al. (2009) *this vol.* [13] Gowen, R. et al. (2009) *this vol.* [14] Richter, L. et al. (2009) *this vol.* [15] Van Hoolst, T. et al. (2008) *Icarus*, 195, 386-399.