CERES: JAWBREAKER OR CREAMY NOUGAT CENTER?

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Introduction: While we now know much about the volatile-rich world of Ceres from the Dawn mission [1], the deep interior of Ceres remains something of an enigma, shrouded by a crust composed of carbonates, salts, serpentines, water ice, and organic material. Ceres' largest craters appear to have gravitationally relaxed, yet smaller craters appear to be relatively unrelaxed [2], indicating that the mechanically strong lithosphere overlies a weaker interior. Viscoelastic modeling of the relaxation of Ceres topographic spectrum and modeling the relaxation of the largest craters only constrains the strength of the outer 70-100 km shell [2,3]. Using the global gravity and shape models from Dawn, admittance modeling indicates the crust is approximately 40-km thick and has a density of 1,200-1,300 kg m^{-3} [4], while matching the hydrostatic flattening requires a thinner, denser crust [5].

Shape and gravity models show that Ceres is a partially differentiated body [4-6], yet it is difficult to determine whether differentiation proceeded to the point that Ceres has a core [5]. Solving for the density structure consistent with hydrostatic equilibrium, the probability of a dense core is greater than 1-σ. However, there is little constraint on the density of the core, with acceptable core densities ranging from hydrous and/or anhydrous silicates that can even include a denser (than silicate) component [5].

Previous Heat and Mass Transport Modeling: Modeling the heat and mass transport through time within Ceres leads to two different views of the evolution and present day internal structure of Ceres. In one set of models, decay of radiogenic elements heats the interior to the point that a degree-one convective instability forms, transporting most of the heat from the deep interior to the surface where it escapes through a thin conductive lid [7]. The instability occurs within the first one to two billion years of solar system evolution. This set of models predicts that present-day Ceres is cold and rigid throughout its interior. This is the jawbreaker model.

Another set of models starts with a frozen mixture of ice and silica grains in a permeable silicate core, with a mud ocean mantle beneath an ice shell. Hydrothermal activity in the rocky, permeable core is coupled to flow in the ocean mantle that then transfers heat in an evolving ice shell [8]. In this set of models, present day Ceres has a thick, strong, conducting outer shell and a significant amount of heat remains trapped deep within Ceres. This set of models predicts that the present-day deep interior of Ceres is a convecting, viscous, mush of water, clay, and suspended particles. This is the creamy nougat model.

An Approach to Bridge the Difference: A limitation/assumption of the jawbreaker model is that the rheology is dominated by a strong silicate phase such as serpentine, and as the internal temperature approaches (or even in some models exceeds) the melting point of water ice, the rheology of the interior is controlled by the temperature-dependence of serpentine. This is appropriate if all the water within the interior is bound in hydrous phases and there is no free water-ice phase present. Here we relax the assumption that serpentine (or a similar hydrous silicate phase) controls the rheology of the interior by using homologous temperature creep to allow the rheology of the interior of Ceres to weaken as the temperature approaches (or exceeds) the melting point of water ice.

Homologous temperature. The homologous temperature is defined as the ratio of the temperature of a material to its melting point temperature in Kelvin. Homologous temperature creep has been used in convection modeling in the terrestrial planets in cases where the temperature approaches the melting temperature, as is the case in Earth's asthenosphere.

We construct a rheology based on an exponential dependence of the homologous temperature such that near the surface of Ceres, the present-day rheology is consistent with the viscosities constrained by the viscous relaxation studies [2-3]. As the temperature of the interior approaches (or exceeds) the melting point of water ice, the viscosity approaches the viscosity of the mud mixture used in the creamy nougat models [8].

Numerical Method. We use CitcomS [9], the 3D spherical creeping convection code that we used in the jawbreaker models. We also use the distribution of radiogenic heating and surface temperature that we used in the original jawbreaker models. We will systematically vary the viscosity of the deep interior, from the stronger values based on serpentine used in the jawbreaker models to the weaker values used in the creamy nougat models. We will determine whether the degree-1 convective instability from the jawbreaker models forms with the homologous creep law, rapidly cooling the interior of Ceres and leaving a strong, cold interior. Alternatively, a strong, conductive outer shell may form trapping heat deep within the weak, convecting interior of Ceres.

Anticipated Results: By comparing the predicted gravity and topography from these models we hope to identify systematic differences between the models that may allow Dawn observations to confirm one or the other model.

References: [1] Russell, C. T., et al. (2016) *Science, 353,* 1008–1010. [2] Fu, R. R., et al. (2016) *EPLS, 476,* 153-164. [3] Bland M. T. et al. (2016) *Nat. Geosci.* 9, *538–543*. [4] Ermakov, A. I. et al. (2017) *JGR, 122,* 2267–2293. [5] King, S. D. (in revision) *MAPS*. [6] Park et al. (2016), *Nature, 537,* 516-518. [7] King et al. (2016), *LPSC XLVII*, abstract 1699. [8] Bland, P. A. & Travis, B. J. (2017) *Sci. Adv.,3*, e1602514. [9] Zhong, S., et al. (2000) *JGR, 105*, 11,063-11,082.