Evaluation of Ceres' compensation state. Anton I. Ermakov[1], Maria T. Zuber[1], David E. Smith[1,2], Roger R. Fu[1,3], Carol A. Raymond[4], Ryan S. Park[4], Christopher T. Russell[5]. [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA (eai@mit.edu); [2]NASA/Goddard Space Flight Center, Greenbelt, MD, 20771, USA; [3]Lamont-Doherty Earth Observatory, Earth Institute, Columbia University, Palisades, NY 10964, USA; [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, USA; [5]University of California Los Angeles, IGPP/EPSS, Los Angeles, CA, 90095, USA.

Introduction:

Ceres is the largest body in the asteroid belt with a radius of approximately 470 km. It is large enough to be much closer to hydrostatic equilibrium than other major asteroids. Pre-Dawn shape models of Ceres revealed that its shape is consistent with a hydrostatic ellipsoid of revolution [1,2,3]. However, the Dawn data suggests that Ceres is less physically differentiated than previously thought. Observed non-hydrostatic effects include a 2.0 km triaxiality as well as a center-of-mass – center-of-figure (COM–COF) offset of 1.0 km. Internal structure inferences based on the gravity and topography data are not unique. We use Ceres' topography power spectrum to constrain the dwarf planet's rheology. This work complements our previous gravity-topography analysis and helps reduce the parameter space of the internal structure model.

Evidence for viscous relaxation:

Ceres's topographic spectrum behaves as a power law. However, we observe a decrease of topographic power at low degrees with respect to the best-fit power law [4]. The spectrum deviation at low degrees is statistically significant, i.e., the spectrum lies outside of the 95% confidence interval of a power-law fit. We interpret this spectral characteristic as a consequence of viscous relaxation.

On the basis of Bland's prediction [5] of a significant latitude dependence of crater relaxation, we also investigated local variations of Ceres' topography power spectrum. Since Ceres has a low obliquity (≈4°), there is a strong systematic difference in insolation between the polar and equatorial regions. Equatorial regions are expected to have more relaxed topography due to higher temperatures. However, crater morphology might be affected by processes other than viscous relaxation, such as infilling with ejecta of subsequent impacts [6]. The localized topography power spectrum samples crater populations and can conceivably identify regional trends. To isolate subregions, we used a spectral-spatial localization algorithm [7] and localized Ceres topography in latitudinal bands. There is a correlation between the topographic power at low spherical harmonic degrees and latitude. The topography power is lower near the equator and increases poleward. This effect is evident only at the degrees $n < 30$. This observation is consistent with the viscous relaxation predictions [5], however, we observe that viscous relaxation is important only at large scales (over 100 km). It also implies that Ceres has not experienced a significant true polar wander in its history consistent with [8]. Finite element viscoelastoplasic modeling shows that a uniformly strong (rock- and/or salt-like) composition with a temperature gradient is the simplest structure that can explain the observed topography spectrum. Shell composition is likely a mixture of ice, rock and salts, with the ice component less than 40 vol% [9]. This result will be tested with the spectroscopic measurements by the Dawn's VIR and GRaND instruments. The thickness of the heavily contaminated shell is over 45 km with the upper bound essentially unconstrained from the gravity-topography data.

Compensation:

We evaluate the compensation state of Ceres topography based on the shape and gravity data. By repeating the analysis of [10] for Ceres, we compute the degree of compensation C_n [Eq. 27 in 11] that depends on such lithospheric properties as Young's modulus, effective elastic thickness, Poisson's ratio, as well as crustal and mantle densities. The effective elastic thickness depends on the petrological model of the Ceres' outer shell as well as on its thermal history [12]. Young's modulus is a function of the outer shell composition. Thus, evaluating the compensation state allows us to further reduce the parameter space of the internal structure and evolution models of Ceres.

Gravity-topography admittance and internal structure:

Admittance is the ratio of the gravity-topography cross-power to the power of topography. At the time of this writing, a degree-2 gravity model is available from Dawn's Survey orbit radio-tracking data (altitude of 4400 km). We observe a negative gravity-topography correlation in the sectorial degree-2 term. The admittance is therefore also negative (-46 mGal/km) A possible explanation of the negative admittance at degree 2 and order 2 could be a combination of a buoyant bottom loading and a thick/rigid shell (Figure 1). The load's contribution to the gravity is negative and the surface uplift contribution is positive. However, if the shell is rigid it would not bend enough to compensate the negative contribution of the load, and the total effect will be negative. Interestingly, the "bright-spot" crater Occator – hypothesized to be indicative of cryoactivity – lies in a strong negative Bouguer anomaly region. We model the effect of the buoyancy-driven gravity anomaly with a finite-element viscoelastoplastic code [13,14]. Our modeling is to be further tested with higher-degree gravity models from the lower Dawn orbits.

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Figure 1: Illustration of the effect of a buoyancy-driven gravitational anomaly