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Rotational Motion of Ceres

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Abstract

Ceres is the most massive body of the asteroid belt and contains about 25 wt.% (weight percent) of water. Understanding its thermal evolution and assessing its current state are major goals of the *Dawn* Mission. Constraints on its internal structure can be inferred from various observations. Especially, detailed knowledge of the rotational motion can help constrain the mass distribution inside the body, which in turn can inform us on its geophysical history. Here, we compute the polar motion, precession-nutation, and length-of-day variations. We estimate the amplitudes of the rigid and non-rigid response for these various motions using a stratified model of Ceres interior constrained by recent shape data and surface properties.

1 Ceres' Pole Position

Ceres's pole position in space has been inferred from adaptive optics and *Hubble Space Telescope* images [1,2,3] and the orbital pole of Ceres at J2000 can be obtained from the Horizons ephemerides [4]. The obliquity, defined as the angle between the normal to the orbital plane and the figure axis, brings information on the moment of inertia only if it has reached an equilibrium position [5], the present value from observations is 4.01 degrees for [1], 0.23 deg for [2], and 3.91 deg for [3]. That is far from the $\sim$ 0.01 deg expected for the equilibrium position. In addition, the required timescale to fully damped the obliquity appears to be very long [6]. Thus, it appears that the obliquity of Ceres has not yet relaxed in its Cassini state.

2 Rotational motion

The figure of Ceres appears to be an oblate body (within the error bars) and the Sun exerts a non-zero torque and raises tides that perturb Ceres rotational velocity. By following the approach developed for the Earth [e.g. 7], we compute the polar motion of Ceres. It presents oscillations close to 9 hours whose main amplitude amounts to $\sim$ 0.5 millimeter (scaled by the mean radius of Ceres). Summing all the contributions regardless of the phase yields an amplitude no greater than 1 millimeter.

The precession time of the axis of Ceres is very long, about 220,000 years. The nutational motion of Ceres is dominated by the annual nutation (343 milliarcseconds or 0.79 m surface displacement) related to the obliquity of Ceres, and then terms related to Ceres' harmonics and also to Jupiter's mean longitude. Detecting such small displacements requires tracking of Ceres' surface for long periods of time, for example with a beacon.

The non-rigid contributions have a negligible effect on polar and nutational motions but generate a non-zero torque along the figure axis that would disturb the uniform rotational motion in the form of length of day (l.o.d) variations. The resulting oscillations of the m_3 variations are very small though, under 0.001 mas, largely below the expected accuracy for space-borne measurement techniques.

On top of this, Ceres should also present a Chandler wobble whose period expressed in the reference frame tied to the object is about 5.48 days, and the correction due to the deformation is between 3 and 5% of its value. In the inertial frame, this period is equal to 9h40 minutes i.e. an increase of 36 minutes with respect to the proper rotation of the body.

3 Geophysical constraints from space observations

In theory, the rotational motion of Ceres should be relatively uniform because the nutational oscillations, polar motion, and l.o.d variations show very small amplitudes. Therefore, if a sizeable departure from a quiet rotation is detected by the *Dawn* Mission at a period of about of 9h40, then we could assign this motion to the

Chandler Wobble. Indeed, the presence of a Chandler mode is expected as soon as any perturbation, exterior or interior to the body, shifts the figure axis from its equilibrium position. However, this mode is also damped due to internal dissipation.

On Earth, the Chandler wobble is in part excited by the atmosphere, but Ceres cannot retain a massive atmosphere. On the other hand, Ceres is in a rich dynamical environment, the asteroid belt, thus it is exposed to a constant meteoritic flux. Such meteoritic flux may involve impacts exciting the Chandler mode for Ceres. An excitation at 10 arcseconds may be achieved for a cometary projectile (heliocentric) with a diameter of 2.5 km, a density of 0.6 g/cm^3, and a velocity of 20 km/s; or by a neighbor asteroid of 4 km diameter with a density of 1.3 g/cm^3, colliding at 5 km/s.

Another source of excitation of the Chandler wobble may be an equatorial sea inside Ceres. The existence of such a water reservoir has been suggested by [8] based on the observation that Ceres' surface temperature at the equator is close to the eutectic temperature of salt impurities expected in the asteroid.

4 Conclusion

As a general result, the amplitudes of oscillations in the rotation appear to be small, and their characterization from spaceborne techniques will be challenging. Hence, the Chandler wobble's signature should stand out in a precise determination of the rotational motion. This offers the prospect to better constrain Ceres' thermal state, provided that the asteroid is excited by endogenic and/or exogenic processes. The potential role of a liquid reservoir in exciting that wobble remains to be modeled in preparation for the arrival of Dawn at Ceres in 2015.

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