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# Long-term rotation of Ceres and Vesta

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## Abstract

The Dawn space mission studied Ceres and Vesta, the two heaviest bodies of the main asteroid belt and notably determined precisely some physical characteristics that are necessary to the computation of their long-term rotation. In a recent paper [1], we perform a long-term integration of the rotation of Ceres and Vesta by using the physical parameters obtained by the Dawn space mission and we obtain obliquity variations over $[-20 : 0]$ Myr between $2^\circ$ and $20^\circ$ for Ceres and between $21^\circ$ and $45^\circ$ for Vesta. We investigate the stability of their rotations by using secular equations and obtain that the spin axes of Ceres and Vesta are relatively stable.

## 1. Introduction

The study of the two heaviest bodies of the main asteroid belt, Ceres and Vesta, by the Dawn space mission has allowed one to know precisely some physical characteristics necessary to the computation of their long-term rotation [2, 3, 4].

The study of the long-term rotation of a celestial body can give the variations of its obliquity, which is the angle between its equator and the plane of its orbit. For Ceres, it is an important parameter to put constraints on the ice distribution on and under the surface [5, 6, 7].

The Dawn space mission observed that Vesta suffered two giant impacts [8, 9]. These two impacts can have modified its long-term rotation.

In a recent work [1], we have determined the obliquity variations of Ceres and Vesta and studied the stability of their spin axes.

## 2. Methods

The orbital motions of Ceres and Vesta are obtained from the symplectic integration of the complete equations [10]. To obtain their rotational motions, we average the rotational equations over the fast proper rotation which can be then integrated with the integrator of [10] in a symplectic way with the method of [11].

We use the initial conditions for the spin axes and the physical parameters (gravitational flattening, spin rate) obtained by the Dawn space mission [2, 3]. However the polar moments of inertia of Ceres and Vesta have not could be obtained [2, 4]. We then estimate the polar moments of inertia of Ceres and Vesta by using models of internal structure proposed from the results of the Dawn space mission [12, 13, 3].

To study the stability of the rotation, we use secular equations averaged over the fast orbital motion [14]. We verify that the secular equations give similar results to those of the symplectic integration of the complete equations. We use the secular equations, whose the integration is faster, to obtain the long-term rotation for a large number of parameters and initial conditions. The stability of the rotation is then estimated by frequency analysis [15].

## 3. Results

The obliquity variations over $[-20 : 0]$ Myr are between $2^\circ$ and $20^\circ$ for Ceres and between $21^\circ$ and $45^\circ$ for Vesta. The results for Ceres are similar to those of [7] and [16]. These large variations of obliquity result from the high inclinations of the orbits of Ceres and Vesta as indicated by [17]. As [17, 7], we observe that the secular orbital dynamics of Ceres and Vesta is dominated by the perturbations of Jupiter and Saturn.

The spin axes of Ceres and Vesta are relatively stable although their precession frequencies are close to the secular orbital frequencies of the inner planets. It can be explained by the fact that the secular orbital dynamics of Ceres and Vesta is dominated by the perturbations of the giant planets and that the perturbations of the inner planets are much weaker. The widths of the secular resonances due to the inner planets are then shorter and these resonances do not then overlap contrary to the case of the inner planets where the overlap of secular resonances leads to a large chaotic area [15].

From the supposed shape and spin rate of Vesta before the two giant impacts [18, 12], we estimate the polar moment of inertia and then the precession constant of the early Vesta. The two giant impacts could then bring Vesta closer to the secular resonance $2s_6 - s_V$. The present Vesta could then be in this resonance where the obliquity variations are between $17°$ and $48°$.

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