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Enceladus' long-period physical librations

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Abstract

The predicted long-period librational response of Saturn's moon Enceladus [1] proceeds on the assumption that the spin pole is inertially fixed. Actually, the spin pole is expected to occupy a Cassini state [2] where it tracks the motion of the precessing orbit pole [3]. Here we show that this would result in additional long-period libration frequencies with appreciable amplitudes.

1. Orbit pole orientation

Enceladus' orbit pole precesses about the spin pole of Saturn at an average inclination of 0.0086° (Fig. 1). A frequency analysis reveals periodicities of 2.36 and 4.98 years suggesting that the precession is non-uniform.

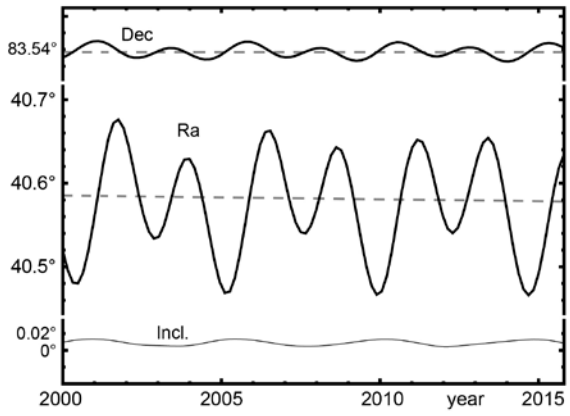

Figure 1: J2000 declination (Dec) and right ascension (Ra) of Enceladus' orbit pole determined from JPL ephemeris data [4]. Dashed lines indicate the orientation of Saturn's spin pole which averages the oscillating orbit pole orientation. The lower curve shows the inclination of the orbit pole to Saturn's spin pole. It varies between 0.0032° and 0.0139° at a mean value of 0.0086°.

2. Spin pole orientation

While uniform precession would, under stationary conditions, result in a coplanar configuration between Saturn's spin pole, Enceladus' orbit pole and its spin pole, non-uniform precession when fully damped drives the spin pole to a generalized Cassini state where each mode of the orbit pole precession has a corresponding mode of spin pole precession with rate and phase identical to the orbit modes but with different amplitudes [5]. However, as the spin precession rate parameter (see [5]) for Enceladus is ~9°/day and thus much higher than each orbit pole precession rate shown in Fig. 1, the resulting spin pole amplitudes must be close to those of the orbit pole and any obliquities thus must be close to zero, at least much smaller than the orbital inclination. Consequently, we have neglected any obliquities and assumed that the spin pole has the same dynamics as the orbit pole.

3. The librational response

With a perfect elliptical orbit and synchronous rotation Enceladus' long axis would, on a diurnal average, always point to Saturn. As Enceladus' orbit experiences strong perturbations notably by Dione this is no longer the case and torques by Saturn result which try to rotate Enceladus to compensate the misalignment. The degree of compensation (response) depends on the ratio of the free libration frequency to the frequencies of perturbation (forcing). For Enceladus, this ratio is on the order of 10^{-3} which implies that the (librational) response is in phase with the forcing and has the same amplitude. Thus to calculate the librational response of Enceladus we simply calculated the forcing under different conditions.

4. Results and discussion

In calculating the librational response we considered two rotational models: (i) the model of uniform rotation about a (inertially) fixed spin pole and (ii) the model of uniform rotation about a spin pole identical to the orbit pole (dynamic spin pole). Figure 2 shows the differences in the results: As expected, the librational response in case (ii) now includes the orbital periodicities of 2.36 and 4.98 years (§1), respectively. This leads to differences in the libration amplitudes of up to 0.1° as compared to case (i).

However, we note that our result here is based on the assumption that Enceladus' spin pole is fully damped. Only in that case a generalized Cassini state will be acquired [5]. Control point calculations as performed earlier [3, 6] may be used to verify the new results.

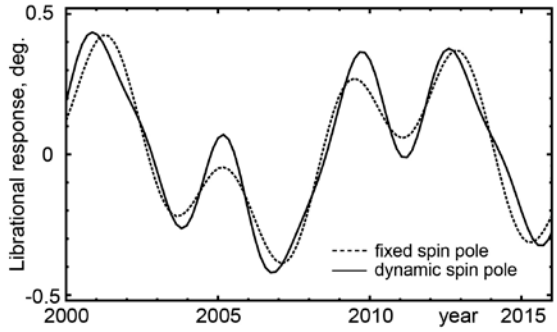

Figure 2: Predicted long period physical librations of Enceladus. The "fixed spin pole" result fully agrees with the results given in [1] (however with corrected parameter values [6] only).

References

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