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An upper limit on Enceladus' obliquity

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Abstract

Control point calculations using *Cassini* images reveal that Enceladus' obliquity is limited to less than 0.05° (95% confidence level). This definitely rules out models explaining Enceladus' activity and anomalously high surface heat flows on the basis of obliquity-related tidal heating (OTH).

1. Introduction

The obliquity of Enceladus (angle between the normal to the orbital plane and the spin pole axis) is an important issue as it was suggested to be responsible for the enigmatic high surface heat flows observed by the *Cassini* spacecraft [1]. However, for the model to be applicable, a minimum obliquity of 0.1° is required. On the other side, Enceladus' obliquity has not been measured so far, which leaves the question regarding the applicability of the model open. An upper limit of 0.0015° has been obtained on theoretical grounds but this value relies on the assumption that dissipation has driven the spin pole to a Cassini state [2]. The same holds for the conclusion that OTH cannot be the source of the high heat flows [2]. This study presents an upper limit on Enceladus' obliquity that equally rules out the OTH model but does not take any assumption concerning a Cassini state. The limit is based on (i) observations of the orientation of the spin pole axis as provided by imaging of the body and (ii) observations of the orbit pole given by the ephemeris of Enceladus.

2. Method

Images of a rotating body can be considered as instantaneous samples of its rotational state. Accordingly, a time-series of images provides a record of the rotational motion that can be used to determine the parameters of the rotational model. Here manually measured image tie-points (control points) are used to determine the J2000 spin pole orientation (right ascension (RA) and declination (DEC)) of Enceladus within control point calculations [3]. These calculations show that the residual errors of the point measurements and the camera pointing angles depend on the applied rotational model parameters RA and DEC. The most likely RA and DEC are those where the total residual error is smallest.

3. Data base

The control point calculations involved 62 Cassini-images acquired over the period 2005-2012 with resolutions ranging from 112 m/pixel to 1217 m/pixel. A total of 232 control points were measured (1407 individual point measurements). Spacecraft-positions and pointing angles as well as camera alignment- and calibration parameters were gathered from NAIF-SPICE kernels.

4. Spin pole orientation

The control point calculations revealed an absolute minimum of the residuals at RA=40.59° and DEC=83.54° (Fig. 1), which is different from the currently valid values (40.66°, 83.52°) [4] but still lies within the error bars.

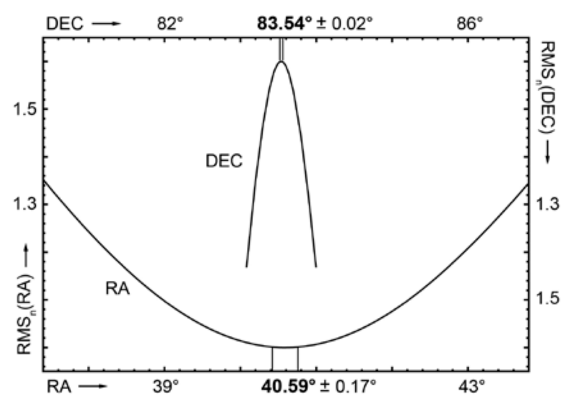

Figure 1: Root Mean Square (RMS) of the residuals returned within the control point calculations in dependence on RA (bottom) and DEC (top, mirrored vertically), normalized to the minimum value. The given error limits refer to the 95% confidence level.

To get an estimate of the accuracy of RA and DEC simulation studies using synthetic data close to the given ones have been carried out. The goal was to determine the extent to which it is possible within control point calculations to recover RA and DEC from the existing data if they have random errors. Out of 900 different distributions of tie-point measurement errors and 700 different distributions of spacecraft pointing errors it was found that RA can be recovered with an accuracy of 0.17° and DEC with an accuracy of 0.02°, both denoting the 2σ level.

5. Orbit pole orientation

The orientation of the orbit pole was determined from the ephemeris of Enceladus by fitting planes to the data each over one orbit cycle (pericenter to pericenter, 36 points included). Figure 2 shows the dynamics of RA and DEC of the planes' normal. Both RA and DEC exhibit periodicities of ~ 2.3 years with amplitudes of ~ 0.1° (RA) and ~ 0.01° (DEC) (actually 2 types of periodicities seem to be present which are not much different in frequency and amplitude though). However, the mean values of 40.58° (RA) and 83.54° (DEC) are very close to the orientation of the spin pole 40.59° (RA) and 83.54° (DEC).

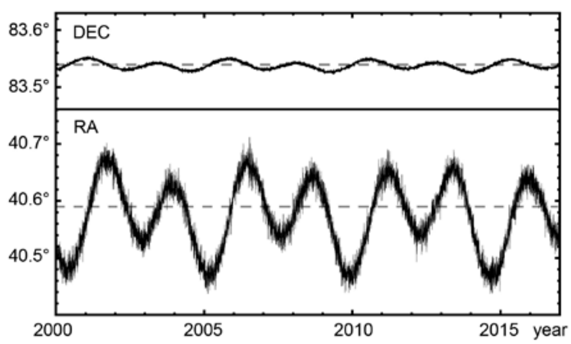

Figure 2: J2000 orientation of Enceladus orbit pole over 17 years. The thickness of the lines (top and bottom) is due to oscillations over an orbital period. The dashed lines mark the orientation of the spin pole as obtained from the control point calculations. Used ephemeris data: sat359l.bsp (Jacobson, R.A., 2013).

6. Discussion & Conclusion

The orientation of the orbit pole oscillates with periods of ~ 2.3 years and amplitudes of ~ 0.1° (RA) and ~ 0.01° (DEC), respectively. It is, however, not likely that the spin pole follows these movements as the obliquity damping timescale [2] at current values of Q/k_2 ~ 0.01 [5] is about 11 years. Therefore, keeping the spin pole orientation fixed over the period modelled within the control point calculations appears to be reasonable. With a fixed spin pole but oscillating orbit pole, the obliquity of Enceladus must also oscillate. At the nominal spin pole direction (RA=40.59°, DEC=83.54°), the amplitude of these oscillations is always less than 0.02°. Even if the 2σ uncertainty of the spin pole solution is taken into account the obliquity does not exceed values of 0.05°. As a consequence, OTH cannot be the source of the enigmatic heat flows observed on Enceladus irrespective of whether or not it is in a Cassini state.

References

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