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# A new rotational model of Titan from Cassini SAR data

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## Abstract

The Cassini mission provided repeated SAR observations the surface of Titan, the biggest of Saturn satellites. The RADAR imaging allowed to determine the rotational state (spin pole, precession, length of day) of Titan by means of landmark tracking. We report on the latest findings.

## 1. Introduction

Repeated observations of the surface can be used to determine the rotational state of a body. If the body-fixed reference frame used for georeferencing is not perfectly aligned with the rotation axis an apparent shift on the surface of evident features (*registration error*) can be observed. Registration errors can be computed by means of image correlation. The mismatching is mainly due to errors in the rotational model, with smaller contributions from the spacecraft ephemerides and attitude, radar calibration and image processing. The pole location and the spin rate can then be estimated by applying a weighted least squares method to minimize the registration errors.

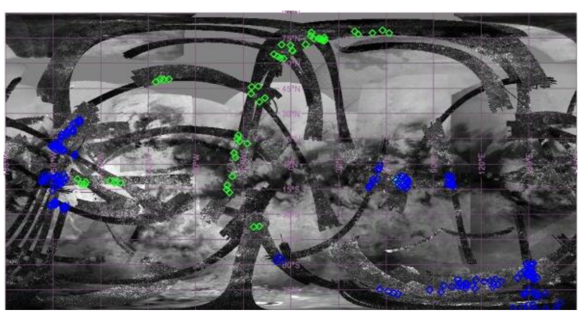

Figure 1: selected features for the Prime (green) and the Extended (blue) mission.

## 2. Data processing

Between 2004 and 2009 the Cassini RADAR provided 31 georeferenced SAR images of Titan's surface. 44 crossovers and 243 evident features were detected. Registration errors vary from 400 m up to 42 km (IAU model used for georeferencing), depending on the crossover location and temporal separation. Both systematic and random errors amount to about 1 km. Large georeferencing errors (up to 5 km) can occur if a spherical Titan is assumed, due to the mismodeled surface shape. For this reason surface height corrections were provided by JPL (B.W. Stiles, private communication) and applied to the observables. The obtained residuals vary from 700 m up to 1.7 km.

## 4. Estimate at observation epoch

We used a simplified model in order to compare the results with the previous estimate [4]. In this case the model refers to the spin pole location (α, δ) and to the prime meridian *W* (eq. 1) approximately at the center of the observation time span (11 March 2007).

$$\begin{aligned} \alpha &= \alpha_0 \\ \delta &= \delta_0 \\ W &= W_0 + \omega d \end{aligned} \tag{1}$$

*W* is the sum of the prime meridian longitude at epoch J2000.0 ($W_0$) and the contribution due to the spin rate ω. Time drift and precession terms are not included. Estimated parameters are the pole location at the observation epoch (α, δ) and the spin rate ω. $W_0$ was assumed as known and inferred from the IAU model [3]. The observed pole location (OBS) is compatible with the previous available estimate [4]. The estimated value (22.57693 deg/day) of spin rate is compatible at a 3σ level with the synchronous rotation value provided by [3].

Table 1: estimated pole location and spin rate at the observation epoch (11 March 2007)

| Parameter | Value |
|---|---|
| RA | 39.45° ± 0.042° |
| DEC | 83.451° ± 0.005° |
| Obliquity | 0.31° ± 0.005° |
| Spin rate | 22.57693°/day |
| Residual NSR | +0.02°/year ÷ - 0.02°/year |

The residual non-synchronous rotation (NSR) varies from + 0.02 deg/year to - 0.02 deg/year, depending on the observation epoch (prime mission, 2004 – 2007, or extended mission data, 2007 - 2009).

## 5. A new rotation model

The model proposed for the data fit is:

$$\left.\begin{aligned} \alpha &= \alpha_0 + \dot{\alpha}_0 t + \sum_{i=1}^{N} A_i^{\alpha} \sin(\gamma_i + \chi_i t) \\ \delta &= \delta_0 + \dot{\delta}_0 t + \sum_{i=1}^{N} A_i^{\delta} \cos(\gamma_i + \chi_i t) \\ W &= W_0 + \omega t + \sum_{i=1}^{N} A_i^{W} \sin(\gamma_i + \chi_i t) \end{aligned}\right\} \quad (2)$$

It is an extension of the IAU model, with updated coefficients, that includes precession ($i$=1 in the series) and nutation (trigonometric terms with $i \geq 2$). Linear drifts ($\dot{\alpha}_0, \dot{\delta}_0$), as well as the precession phase ($\gamma_1$) and frequency ($\chi_1$) are not estimated and set to the IAU values [3]. $A_i$ are the amplitudes of the precession – nutation terms. The prime meridian at epoch J2000 ($W_0$) has been updated assuming Titan's long axis pointing to Saturn at the pericenter with the new pole location.

New values of $\alpha_0$ and $\delta_0$ (RA and DEC at J2000 epoch of the precession axis) have been estimated and found to be compatible with the currently adopted Laplace pole. The amplitudes ($A_1$) of the precession terms have also been estimated. The estimated obliquity inferred from the model is equal to 0.31 deg and the new pole location is compatible with the occupancy of a Cassini state 1. Weak deviations (< 2 deg) from the Cassini state are still observed on long time scales. The deviations may be be ascribed to an imperfect knowledge of $\dot{\alpha}_0$ and $\dot{\delta}_0$. (Those parameters cannot be observed with sufficient accuracy within the time span of the Cassini observations).

## 6. Geophysical implications

The Moment of Inertia factor (MoI) inferred from the estimated obliquity is not compatible with the MoI (0.34) inferred from gravity measurements [1]. This incompatibility points to the failure of one or more assumptions required by the theory. In particular it may suggest a differentiated structure of the interior where the core and the outer icy shell are decoupled.

The estimated spin rate is in agreement at a 3$\sigma$ level with the predicted 1:1 spin-orbit coupling. At 1$\sigma$ level the observed periodic component of NSR is compatible with those predicted by [2], where the atmospheric torque acting on an icy shell gravitationally decoupled from the core produces deviations from synchronicity.


## Acknowledgements

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## References


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