Titan rotation: Constraints from Cassini radar

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Introduction: We report on progress being made in using the Cassini mission radar data to better constrain the rotational dynamics of Titan. It has long been known that Titan is a synchronous rotator, with small obliquity, and moves in an orbit with small eccentricity, and low inclination to Saturn's equator plane. Thus, at lowest order, the rotation is quite simple. It can be well approximated by rotation at uniform rate about a fixed axis. However, at the level of accuracy of the radar measurements, small departures from this simple model become evident. Both the rate and axis of rotation are expected to change on a wide range of time scales. We have used 4.8 years of Cassini radar data to constrain those variations. We will first briefly describe some of the expected motions, and then note how the data have constrained these motions.

Expected modes: Because of its relative proximity to Saturn, Titan is expected to be a synchronous rotator, with small obliquity. As the orbital eccentricity is non-zero, there will be forced variations in rotation rate, known as forced librations, during each orbit. They are expected to be small, and the Cassini radar sampling interval is such that they would be hard to see, in any case.

The principal forced modes which we should be able to see are precession and nutation of the spin pole. The orbit pole will precess about Saturn's spin pole, with a period of roughly 700 years, and the spin pole will precess about the instantaneous orbit pole. There is a small solar torque, which will make the orbit pole precess about Saturn's orbit pole. That will induce fluctuations, or nutations, in the motion of the spin pole, with period equal to half of Saturn's orbital period, or 14.729 yr.

In addition to these forced modes of rotational change, there are also 3 distinct free modes, whose periods depend upon the principal moments of inertia. Using recent estimates of the moments from the degree-two gravity field and an assumption of hydrostatic equilibrium, the free modal periods are estimated to be 2.33 years, 15.942 days, and 294.2 years. The first of these is a libration in longitude, and the other two influence the pole directions.

Data: Much of the surface of Titan has been imaged by the Cassini mission, and some parts of the surface have been imaged more than once. In regions with multiple coverage, we can identify surface features in each image, and note the time of observation and position of the feature, in an inertially oriented reference frame, with origin at Titan's center of mass. Each such selected surface feature provides a tie-point, consisting of two times and two positions. The times are extremely accurate. In our analysis we round them to the nearest millisecond. The position errors are expected to be of order a few hundred meters in each component, and are mainly due to difficulty in locating the same feature in two different images, acquired from somewhat different viewing geometry.

We have used 1018 tie-point pairs, spanning the time interval from 7 September 2005 to 7 July 2010, to constrain the rotation of Titan. The chief limitation in the current data set is the sampling cadence of the tie-points. Due to the orbital geometry of the Cassini mission, most of the Titan fly-by encounters have been separated in time by very nearly integer multiples of half the Titan orbital period, or roughly 7.97 days. In the degenerate case of observations of a point, separated in time by an exact integer multiple of the rotation period, the inertial positions of the point should be identical. If the sample times are close to that situation, we can estimate the period, but the pole is still poorly constrained.

Results: Our simplest solution specifies that the rate and axis of rotation are both fixed. The best fitting solution of that type has a pole with right ascension (39.39905 ±0.00016) deg, and declination (83.43959 ± 0.00002) deg, with a rotation period of (15.94548714 ± 0.00000003) days. The mean-square misfit of that solution is 3.258 km^2.

The time span of our observations is too short to separate the Saturn-driven precession from the solar–driven nutation, but we do see a nearly steady motion of the spin pole, which we interpret as the sum of these motions.

If we allow the rate of rotation to vary periodically, we find solutions which better fit the data. The figure below shows the misfit as a function of modulation period, where we allowed the modulation period to take values between 10 days and 10^4 days. There are 5 distinct minima, with periods of 15.51, 16.08, 275.1, 648.4, and 1330.5 days. However, it appears that all of them are either pure artifacts of the sampling cadence, or at least badly biased.

A sampling function, which is the Fourier transform of sums of delta functions at the sample times, has a structure quite similar to that shown in the figure. This sampling function has pronounced minima at 1280, 550, and 16.1 days. We are developing an algorithm to deconvolve the imprint of the sampling cadence.

We anticipate that further analysis of the exisiting tie-points will yield improved models of the rotational variations of Titan. Those models will provide two types of benefit.

First, and most practical, is that it will facilitate mosaicking of the radar data, and ease construction of digital elevation models of the surface. Second is that it will provide insights into the internal structure. Both spin pole precession and forced librations have signatures which are diagnostic of the moments of inertia of the body. Current estimates of the moments of inertia of Titan assume hydrostatic equilibrium, which may not be a good enough approximation.