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The Pole Orientation, Pole Precession, and Moment of Inertia Factor of Saturn

R. A. Jacobson (1), R. G. French (2), P. D. Nicholson (3), M. Hedman (3), J. E. Colwell (4), E. Marouf (5), N. Rappaport (1), C. McGhee (2), T. Sepersky (2), and K. Lonergan (2)
(1) Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA, USA(robert.jacobson@jpl.nasa.gov/Fax:1-818-354-5904), (2) Wellesley College, Wellesley, MA, USA, (3) Cornell U., Ithaca, NY, USA, (4) U. of Central Florida, Orlando, FL, USA, (5) San Jose State U., San Jose, CA, USA

Abstract

This paper discusses our determination of the Saturn's pole orientation and precession using a combination of Earthbased and spacecraft based observational data. From our model of the polar motion and the observed precession rate we obtain a value for Saturn's polar moment of inertia.

1. Introduction

There are three major reasons for our interest in the direction and precession of Saturn's pole: (1) to orient the Saturn gravity field for satellite and spacecraft orbit modelling, (2) to orient the ring plane for studies of ring structure and dynamics (the ring plane is assumed to coincide with the planet equator), (3) to determine Saturn's polar moment of inertia for studies of Saturn's interior (the precession rate depends upon that moment of inertia).

2. Previous Work

Some of the earliest work on the pole was done as part of the development of Struve's Saturn satellite theory [11]. He included the pole precession due to torques exerted by the Sun and Titan. More recently, the modern satellite theory of Vienne and Duriez [12] extended the pole precession model by adding the torque from Iapetus. Boué and Laskar [3] published an informative general theoretical discussion of polar motion which is applicable to Saturn.

Jacobson [8] presented a pole model in the standard IAU trigonometric series representation based on the rigid body rotational equations of motion with couples exerted by the Sun, Titan, and Iapetus. The series coefficients are explicit functions of Saturn's J_2, spin rate, and moment of inertia, and the masses and orbital elements of Saturn and its satellites. He determined the orientation and precession by fitting Saturn ring occultation measurements, in particular: the radio occultation of Voyager 1, the occultation of the star δSco seen with the Voyager 2 Ultraviolet Spectrometer, the 1989 occultation of the star 28 Sgr seen from the Earth, the 1991 occultation of the star GSC 6323-01396 seen from *HST*, and ring plane crossing times [10]. Jacobson and French [9] updated that work by adding measurements from the 1995 occultation of the star GSC 5249-01240 seen from *HST* and a revised reduction of measurements of the 1991 occultation [5].

Figure 1 shows the pole precession during the 1000 year time period from 1600 to 2600. The large periodic signature is the effect of Titan; the period is that of Titan's orbital precession. The mean rate is $-0\overset{''}{.}87\,\mathrm{yr}^{-1}$, but the rate at the year 2000 is only $-0\overset{''}{.}56\,\mathrm{yr}^{-1}$. The normalized moment of inertia associated with the precession is 0.18. The rate at 2000 compares favorably with the previous estimates of the precession given in Table 1 which, with the exception of Struve's and Vienne's theoretical values, were obtained from ring occultation and ring plane crossing data. The moment of inertia lies between the theoretical bounds of 0.16 to 0.22 [4]; the lower bound is set by the point-core model for Saturn, and the upper bound is from the Radau-Darwin relationship for a fluid planet in hydrostatic equilibrium. Current thinking is that the upper bound may be too high by as much as 50% [7].

3. Current Work

In this paper we present our latest results. We have replaced the original 1989 occultation data with an improved data set which takes into account the finite size of the occulted star, and we have added the radio and stellar occultation measurements obtained with the Cassini spacecraft. We have also improved our pole model to include the previously neglected effect of the precession of the Saturn orbit.

4. Figures

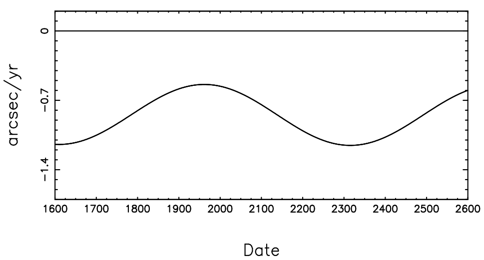

Figure 1: Pole Precession Rate.

5. Tables

Table 1: Annual Precession Rates.

Value	Source
$-0\rlap{.}''46$	Struve [11]
$-0\rlap{.}''50^{\dagger}$	Vienne and Duriez [12]
$-0\rlap{.}''63 \pm 0\rlap{.}''23$	French et al. [6]
$-0\rlap{.}''41 \pm 0\rlap{.}''19$	Bosh [1]
$-0\rlap{.}''52 \pm 0\rlap{.}''07$	Bosh et al. [2]
$-0\rlap{.}''51 \pm 0\rlap{.}''14$	Nicholson et al. [10]

†at J2000

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