National Aeronautics and Space Administration

FY24 R&TD Innovative Spontaneous Concepts (ISC)

Enceladus's gravity field and moment of inertia: using advanced calibration techniques to reanalyze Cassini Radio Science Subsystem (RSS) data

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Strategic Focus Area: Innovative Spontaneous Concepts

Objectives: The main objective of this Spontaneous Initiative was to carry out a comprehensive reanalysis of the Cassini Radio Science Subsystem (RSS) data collected during three close flybys of Saturn's moon Enceladus, labeled as E9, E12, and E19 (conducted between 2010 and 2012). Using advanced data processing methods and improved calibration techniques, we aimed to enhance the precision in determining critical parameters, such as Enceladus's 2x2 gravity field, degree-3 coefficient J_3, and the moon's moment of inertia factor. By analyzing open-loop radio science data and applying sophisticated compression algorithms, we were able to achieve a significant improvement of ~40% (on average) in the Doppler data noise level compared to previous analyses [1,2].

Background: Enceladus has emerged as one of the leading candidate for future NASA missions, particularly in the search for habitability within our solar system. The Cassini mission delivered compelling evidence of a global subsurface ocean beneath Enceladus's icy, geologically active surface, revealed through gravity and libration data [1,3].

Approach and Results: Due to three key factors - utilization of open-loop data, implementation of advanced compression techniques, and application of plasma and troposphere noise calibrations - we were able to achieve a 54% reduction in noise levels on the Doppler data for E09, a 17% reduction for E12, and a 51% reduction for E19. This reduction in noise directly correlates with improved accuracy in parameter estimation across the board. The estimated values for Enceladus's quadrupole field and degree-3 zonal harmonic, along with the moment of inertia factor (MOIF), are shown in Table 1.

Parameter	Central Value	1-σ Uncertainty
J_2	5538.4	29.1
C_{21}	-32.0	7.5
S_{21}	78.9	11.1
C_{22}	1584.0	23.6
S_{22}	-181.1	6.7
J_3	-172.5	19.6
J_2/C_{22}	3.50	0.06
MOIF	0.338	0.0014

Table 1. Enceladus gravity field solution.

Significance/Benefits to JPL and NASA: The refined estimates of Enceladus's gravity field aim to enhance our understanding of the moon's interior structure. These improved parameters will lead to more accurate models of Enceladus's interior, particularly its hydrosphere thickness. Comparisons with libration measurements will further refine our knowledge of the moon's subsurface ocean and its interactions with the icy shell, crucial for understanding its geological activity and habitability. Beyond scientific gains, this reanalysis promises benefits for future missions by improving spacecraft navigation and potentially reducing fuel costs, making exploration of Enceladus more feasible and cost-effective.

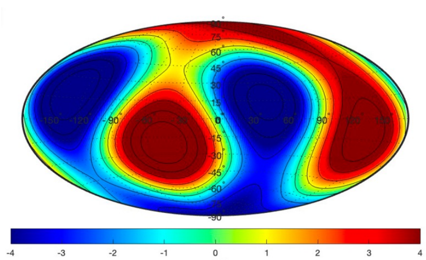

Figure 1. Enceladus's gravity anomalies from the recent solution.

References:

[1] Iess et al. 2014, Science, 344, 6179, 78-80.

[2] Park et al. 2024, JGR Planets, 129, 1, e2023JE008054.

[3] Thomas et al. 2016, Icarus, 264, 34.47.

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