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The Juno and Cassini gravity measurements: probing the interior dynamics of Jupiter and Saturn

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Abstract

During 2016-2017 both the Juno and Cassini spacecraft will enter into close-by polar orbits of Jupiter and Saturn, respectively. Using Doppler tracking from Earth these flybys will allow high precision gravity measurements of these planets [1]. These will include high order gravity harmonics (at least up to J_{10}), and the yet to be measured odd gravity spectrum. As the dynamics of deep flows relate to perturbations in the density of the planets, this data can be used to probe for the first time the atmospheric and interior flows on these planets [4, 5, 8]. Particularly, this may allow addressing one of the longest-standing questions in planetary atmospheric dynamics regarding the depth of the observed strong east-west jets-streams on Jupiter and Saturn. In this talk we review different approaches to analyze the gravity measurements, discuss the proposed models relating the gravity fields to the dynamics, and the implications of the results for understanding the mechanisms governing the interiors and atmospheres of Jupiter and Saturn.

1. Gravity field analysis

The measured gravity field can be decomposed to a contribution from the static planet, and a contribution due to dynamics. Several approaches can be taken for inferring the dynamics from the gravity data:

1. The high-order zonal gravity harmonics are dominated by the dynamics [5]. We find that if the flow is deep enough, $O(1000 \text{ km})$ beneath the cloud level, then the signal of deep dynamics is measurable by the high order gravity spectra [8].

2. The odd gravity harmonics have no contribution from the static planet, and therefore any measurement of odd harmonics (J_3, J_5, J_7, etc.) will likely be a pure signature of deep dynamics (Fig. 1). We find that even flows $O(100 \text{ km})$ below the cloud level should produce a measurable ($O(10^{-9})$, [2]) gravity signal [7, 11].

3. Upper limits on the depth of the dynamics can be obtained by comparing low order even harmonics from dynamical models to the difference between the measured low order even harmonics and the largest possible values of a static planet. Such analysis has proved to be useful for the cases of Uranus and Neptune [9], and with sufficient accuracy by Juno and Cassini of the low order even harmonics (J_2, J_4, J_6), may be applicable to Jupiter and Saturn as well.

4. Spatially varying measurements of the gravity field enable direct probing of spatially varying dynamical features such as the equatorial jets or the Great Red Spot [13]. We show under which conditions such gravity measurements give a detectable signal.

2. Models

To date, three different types of models have been suggested to relate the measurable gravity field and the dynamical induced density perturbations: potential theory models, thermal-wind models and general circulation models. We discuss the pros and cons of each, and show how they can be compared and checked against one another. The potential theory method allows accurate solutions of the gravity field, taking into account the planetary oblateness that dominates the low-order harmonics, but is limited to only purely barotropic flows (full differential rotation) [5, 6, 10]. On the other hand, the thermal wind model allows for any type of wind field but is limited to spherical symmetry, thus allowing us to calculate only the dynamically induced components of the spectrum and neglecting non-spherical effects [8, 7, 12]. Nonetheless, we show that approximate solutions using the thermal wind method can be obtained by incorporating the

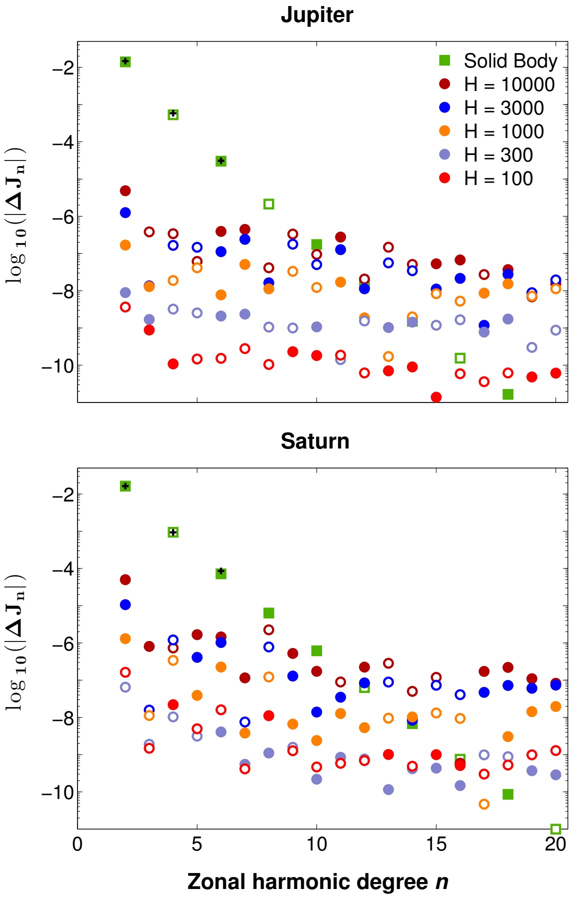

Figure 1: The static (squares) and dynamical (circles) gravity spectrum for Jupiter (top) and Saturn (bottom). The dynamical gravity harmonics are shown for five different decay depth values (H, in km) using the thermal wind model [8, 7]. Plus signs show the currently observed values of J_n. Taken from [7].

oblateness effects, and in the appropriate limits the two methods give nearly identical solutions. General circulation models contain more complete physics, but are limited to specific parameterizations and governing equations, and thus to specific types of flows that might not be representing well the exterior dynamics [8]. As eventually we would like to translate the measured gravity field into wind fields, we present also an adjoint based inversion technique to do so [3]. We show examples of how this adjoint model coupled with the thermal wind model can produce realizations of the interior flow given a measured gravity field. Finally, we discuss the implications of these measurements to understanding the mechanisms driving the dynamics on these planets.

3. Summary

The Juno and Cassini gravity measurements will provide an exciting opportunity to probe the dynamics of the atmospheres and interiors of Jupiter and Saturn. A combination of different models and methods is necessary for the data analysis. The results presented here show that it is likely that this upcoming data will provide new insights about the extent of the dynamics, and the mechanisms controlling the observed flows.

References

[1] S. J. Bolton. Juno final concept study report. Technical Report AO-03-OSS-03, New Frontiers, NASA, 2005.

[2] S. Finocchiaro and L. Iess. Numerical simulations of the gravity science experiment of the Juno mission to Jupiter. In *Spaceflight mechanics*, volume 136, pages 1417–1426. Amer. Astro. Soc., 2010.

[3] E. Galanti and Y. Kaspi. An adjoint based method for the inversion of the Juno and Cassini gravity measurements into wind fields. *Icarus*, 2015. submitted.

[4] W. B. Hubbard. Effects of differential rotation on the gravitational figures of Jupiter and Saturn. *Icarus*, 52:509–515, 1982.

[5] W. B. Hubbard. Note: Gravitational signature of Jupiter's deep zonal flows. *Icarus*, 137:357–359, 1999.

[6] W. B. Hubbard. High-precision Maclaurin-based models of rotating liquid planets. *Astrophys. J. Let.*, 756:L15, 2012.

[7] Y. Kaspi. Inferring the depth of the zonal jets on Jupiter and Saturn from odd gravity harmonics. *Geophys. Res. Lett.*, 40:676–680, 2013.

[8] Y. Kaspi, W. B. Hubbard, A. P. Showman, and G. R. Flierl. Gravitational signature of Jupiter's internal dynamics. *Geophys. Res. Lett.*, 37:L01204, 2010.

[9] Y. Kaspi, A. P. Showman, W. B. Hubbard, O. Aharonson, and R. Helled. Atmospheric confinement of jetstreams on Uranus and Neptune. *Nature*, 497:344–347, 2013.

[10] D. Kong, K. Zhang, and G. Schubert. On the variation of zonal gravity coefficients of a giant planet caused by its deep zonal flows. *Astrophys. J.*, 748, 2012.

[11] D. Kong, K. Zhang, and G. Schubert. Wind-induced odd gravitational harmonics of Jupiter. *Mon. Not. Roy. Astro. Soc.*, 450:L11–L15, 2015.

[12] J. Liu, T. Schneider, and Y. Kaspi. Predictions of thermal and gravitational signals of Jupiter's deep zonal winds. *Icarus*, 224:114–125, 2013.

[13] M. Parisi, E. Galanti, and Y Kaspi. Inferring the depth of Jupiter's Great Red Spot with the Juno gravity experiment. *Icarus*, 2015. in prep.