Determination of Jupiter's gravity field by Juno

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A The Juno mission

Juno is currently orbiting Jupiter in a highly eccentric, 53.5-day orbit, with a perijove altitude of about 4000 km. Radio science measurements are acquired during selected perijove passes for about eight hours across the closest approach to determine the gravity field and the interior structure of Jupiter. The gravity determination is obtained by fitting precise range-rate measurements (3 μm/s over a time scale of 1000 s) through predictions obtained from a dynamical model of the spacecraft.

So far, Juno has completed eleven perijove passes, of which five have been devoted to gravity field determination (see table 1).

Perijove	PJ Epoch	Type of pass	Doppler data available	Sun-Earth-Probe angle (degree)
PJ01	27 August 2016	Generic	X/X + X/Ka	22.6
PJ02	19 October 2016	Safe mode	X/X	18.2
PJ03	11 December 2016	Gravity	X/X + Ka/Ka	61.6
PJ04	2 February 2017	MWR	X/X	110.8
PJ05	27 March 2017	MWR	X/X	167.1
PJ06	19 May 2017	Gravity	X/X + Ka/Ka	135.4
PJ07	10 July 2017	MWR	X/X	85.7
PJ08	1 September 2017	Gravity	X/X + Ka/Ka	42.5
PJ09	24 October 2017	MWR	X/X	1.9
PJ10	16 December 2017	Gravity	X/X + Ka/Ka	40.8
PJ11	7 February 2018	Gravity	X/X + Ka/Ka	86.8

Table 1: Details of first eleven Juno closest/approach with Jupiter.

B Juno data analysis

The most recent results about Jupiter's gravity field are based on the analysis carried out by Iess, *et al.* (2018) with PJ03 and PJ06 data only. This work exploits a larger dataset: Doppler data acquired by DSN during PJ01 and the gravity orbits (PJ03, PJ06, PJ08, PJ10, and PJ11) are combined in a multi-arc least square estimation filter in order to obtain a new solution. The other passes are not included because the tracking configuration (X-band only) does not allow the calibration of the Io Plasma Torus effect. Note that Doppler measurements have been integrated over 60 s before processing to enable adequate sampling of the gravity signal. The range data, acquired at X-band, have been included to better estimate Jupiter's ephemeris, improving the gravity field solution.

The dataset have been analysed with JPL's operational software MONTE. Concerning the dynamical model of the spacecraft, all the main effects able to produce an acceleration large enough to perturb Juno trajectory to a level that can be probed by Juno radio science system, have been taken into account. These include Jupiter's gravity field (which is expanded into spherical harmonics), the gravitational acceleration of Galilean satellites and Solar System planets in a relativistic context, the tidal perturbations induced on Jupiter by its satellites, the Lense-Thirring precession due to Jupiter's fast rotation, and the non-gravitational accelerations acting on Juno due to solar radiation pressure, and Jupiter's albedo and infrared emission.

Concerning the estimation setup, we solved for Jupiter's zonal gravity field coefficients to degree 30, plus a small tesseral field of degree 3 (estimated to be lower than 10^{-8}). The tidal response is estimated, by means of the Love number k_{22}. Jupiter's spin axis motion and ephemerides are updated as well.

C Solution stability

The new solution is compared to the solution presented by Iess, *et al.* (2018), which exploits only measurements acquired during PJ03 and PJ06 gravity passes. The error ellipses at 3-sigma are reported for J_3 vs J_5 and J_7 vs J_9, for both the solutions.

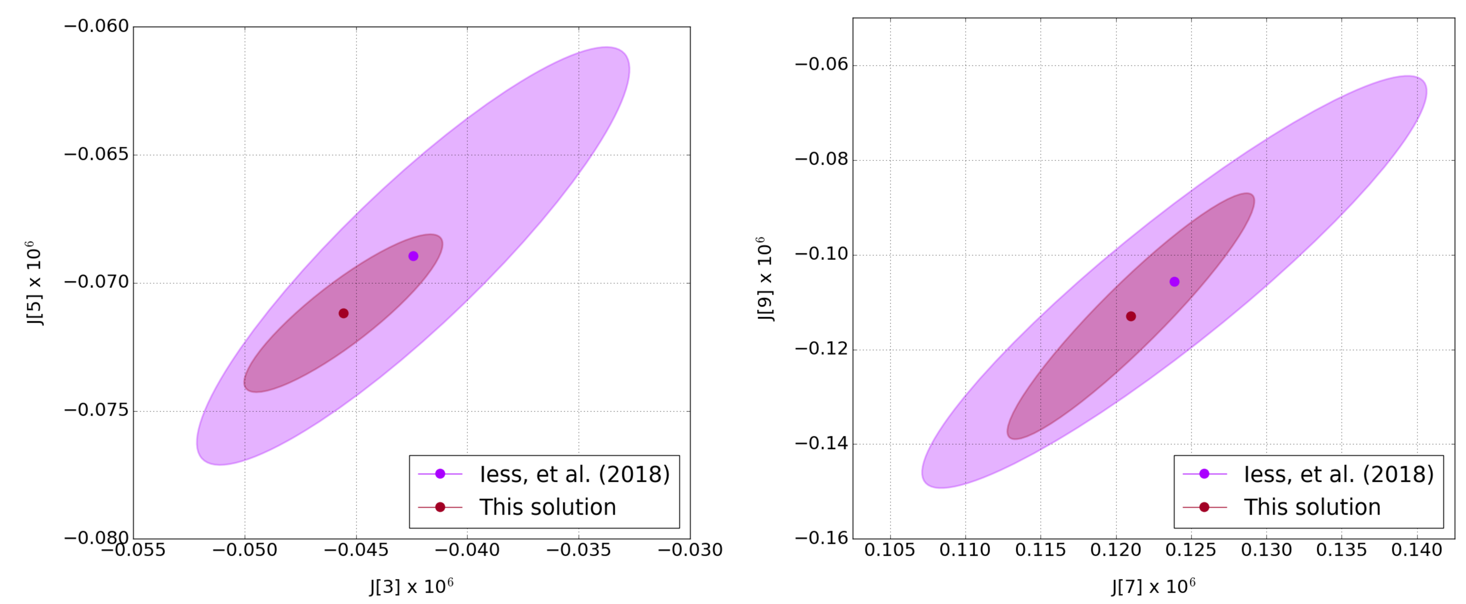

Figure 1: Error ellipses (3-sigma) for low-degree odd harmonics.

The error ellipses show a remarkable agreement between the two solutions for all the gravity harmonics (here only the low-degree odd harmonics are reported for the sake of brevity). The error ellipses of the new solution is contained within the error ellipses from Iess, *et al.* (2018). In addition, the solution shows smaller ellipses due to the larger dataset analyzed.

D Jupiter's zonal gravity field

The gravity field of Jupiter is largely axially symmetric, thus described only by zonal harmonics (Hubbard, 1999). The values and uncertainties for J_{2-12} is reported in figure 2.

The even harmonics are related to solid body rotation, whereas odd harmonics may arise from wind dynamics (Kaspi, *et al.*, 2018).

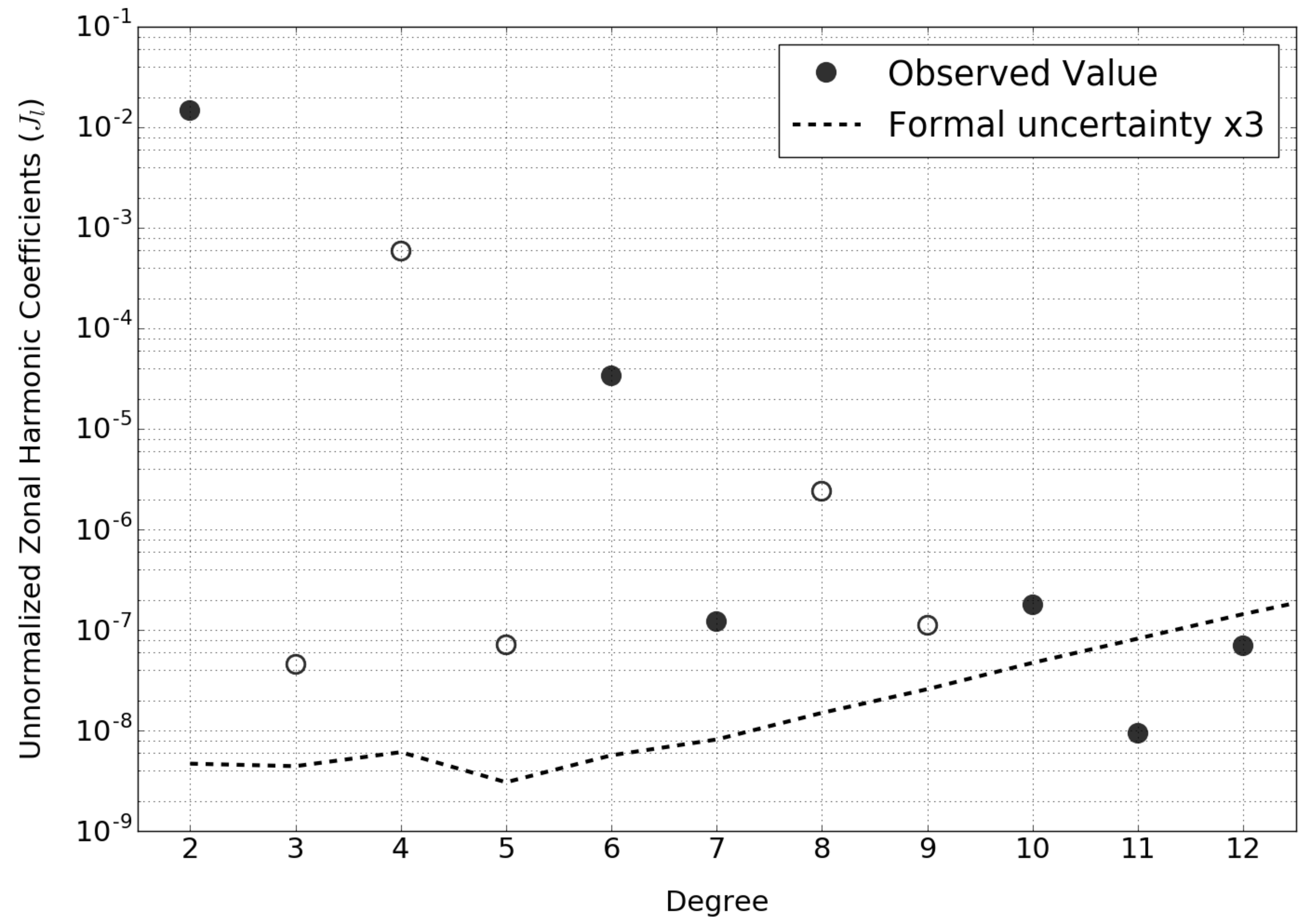

Figure 2: Jupiter's unnormalized zonal gravity coefficients.

E Wind-induced asymmetric gravity field

The radial component of the acceleration (gravity disturbances), after the removal of the large contribution from the low-degree even harmonics (J_{2-8}), is clearly North-South asymmetric, and correlates with the latitudinal wind profile, especially in the equatorial region, as expected from the thermal wind model (Kaspi, 2013). The largest value of -3.4 mGal is found at 24-degree North, where the wind speed is very large.

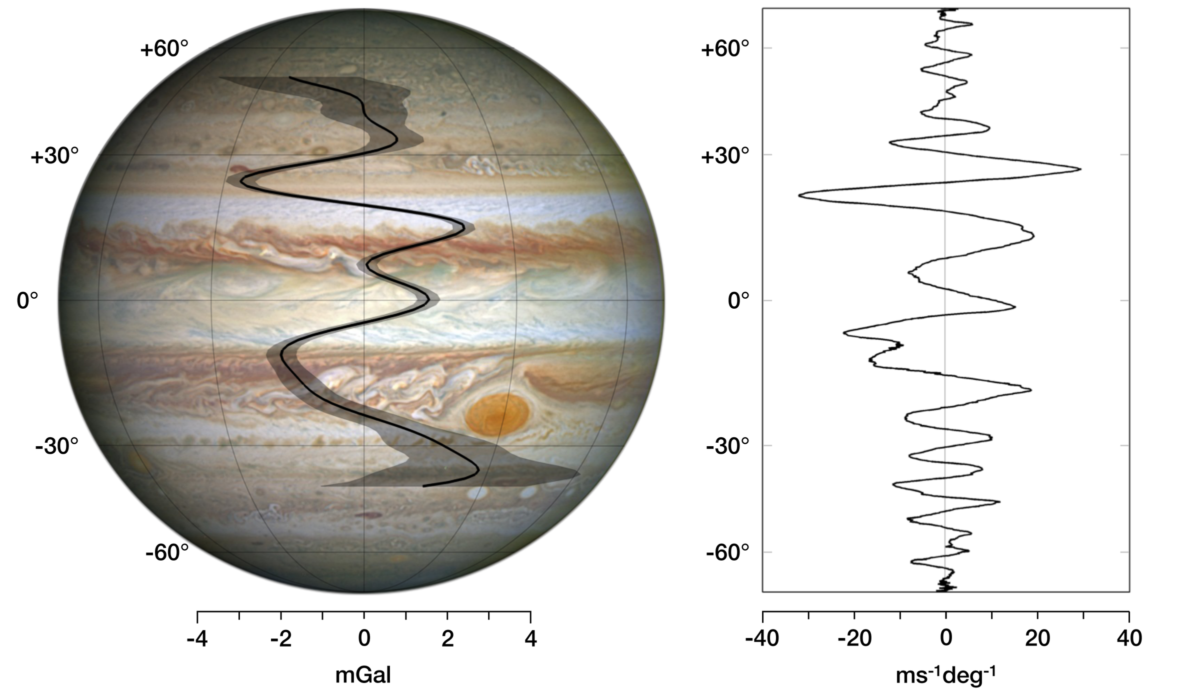

Figure 3: Gravity disturbances due to atmospheric dynamics and latitudinal wind gradient.

F Jupiter's spin axis direction

The motion of Jupiter's spin axis has been recovered (assuming a linear model). The figure reports the estimated value and corresponding uncertainty for each of the Juno's passes (in green), to be compared with the IAU2006 model (in red).

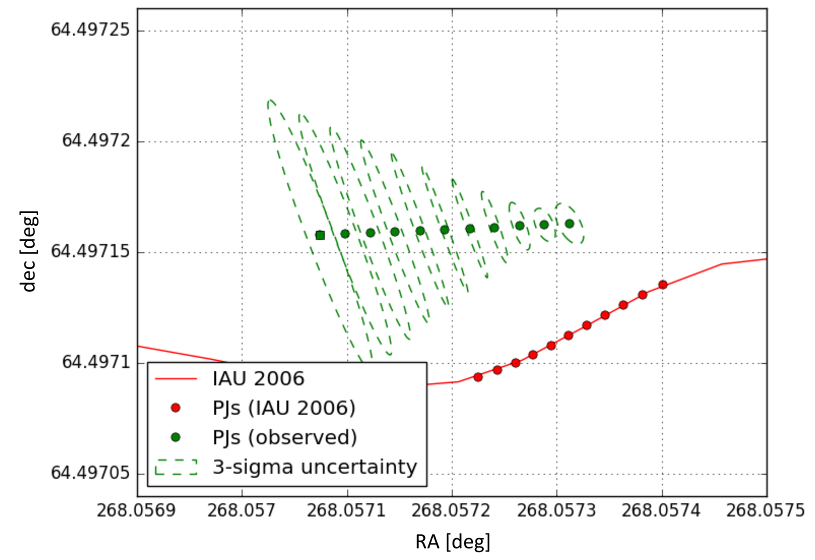

Figure 4: Jupiter's estimated spin axis location versus model.

Pole position at J2017.0	
RA	268.057132° ± 0.000036°
dec	64.497159° ± 0.000045°
dRA/dt	(0.0164 ± 0.0013) deg/century
dDec/dt	(0.0004 ± 0.0015) deg/century

Table 2: Jupiter's spin axis location at J2017.0 (1 January 2017 12:00).

G Conclusion

To conclude, the new solution, which exploits data from five gravity passes and PJ01, shows consistent results with those published in Iess, *et al.* (2018). Jupiter's gravity field coefficients are very stable, as reported in figure 1 with the error ellipses. In addition, the larger number of passes allows us to further improve the gravity harmonics' uncertainties.

The new solution also allows a more accurate determination of Jupiter's spin axis motion to be obtained, and the estimated positions are close to the IAU2006 model predictions.

References

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