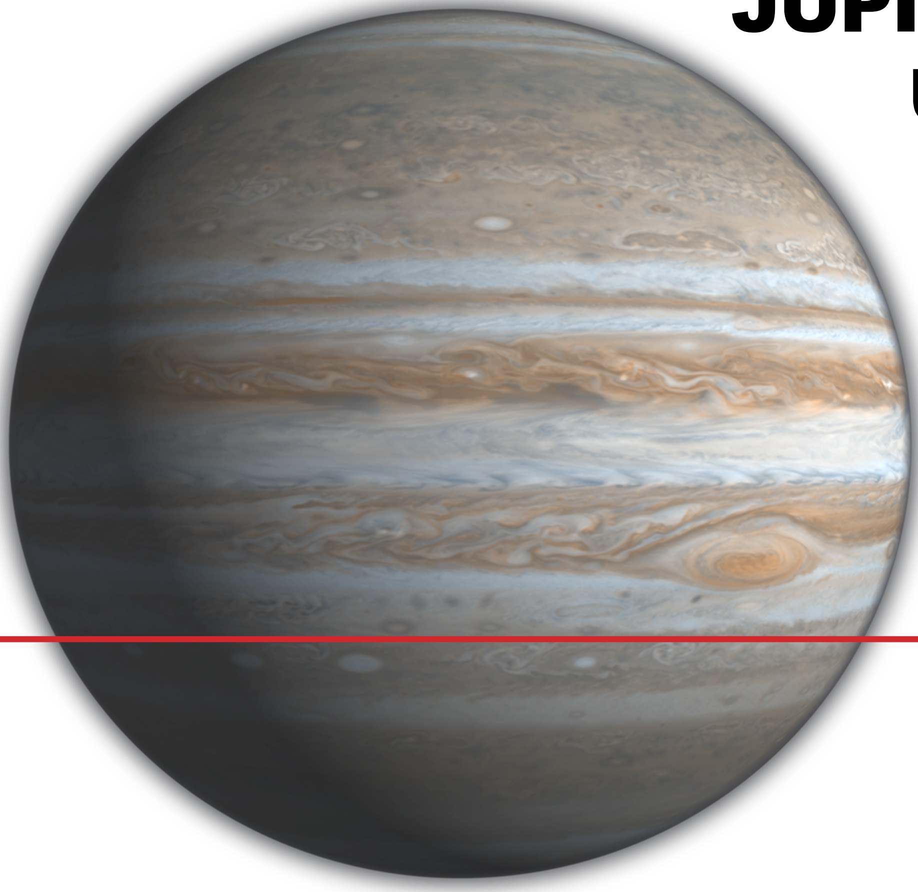


JUPITER'S GRAVITY FIELD UPDATES FROM JUNO

D. Durante[1,*], M. Parisi[2], D. Serra[3], M. Zannoni[4], V. Notaro[1], P. Racioppa[1], D. Buccino[2], G. Lari[3], L. Gomez Casajus[4], L. Iess[1], W. Folkner[2], G. Tommei[3], P. Tortora[4], S. Bolton[5]

EGU2020: Sharing Geoscience Online

(*) daniele.durante@uniroma1.it
(1) Sapienza University of Rome
(2) Jet Propulsion Laboratory
(3) University of Pisa
(4) University of Bologna
(5) Soutwest Research Institute

INTRODUCTION

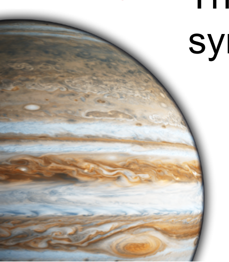
- Juno has been orbiting Jupiter since July, 2016. It completed 26 perijove passes (from PJ01 to PJ26), 15 dedicated to Jupiter's gravity field determination.

- The data collected during PJ01+PJ02 have been explained through the presence of a diluted core expanded to 0.3–0.5 times Jupiter's radius, with a mass of 7–25 Earth masses.

- The analysis of the first two gravity-dedicated perijove passes (PJ03+PJ06) allowed us to further constrain Jupiter's internal structure and surface winds' behavior:

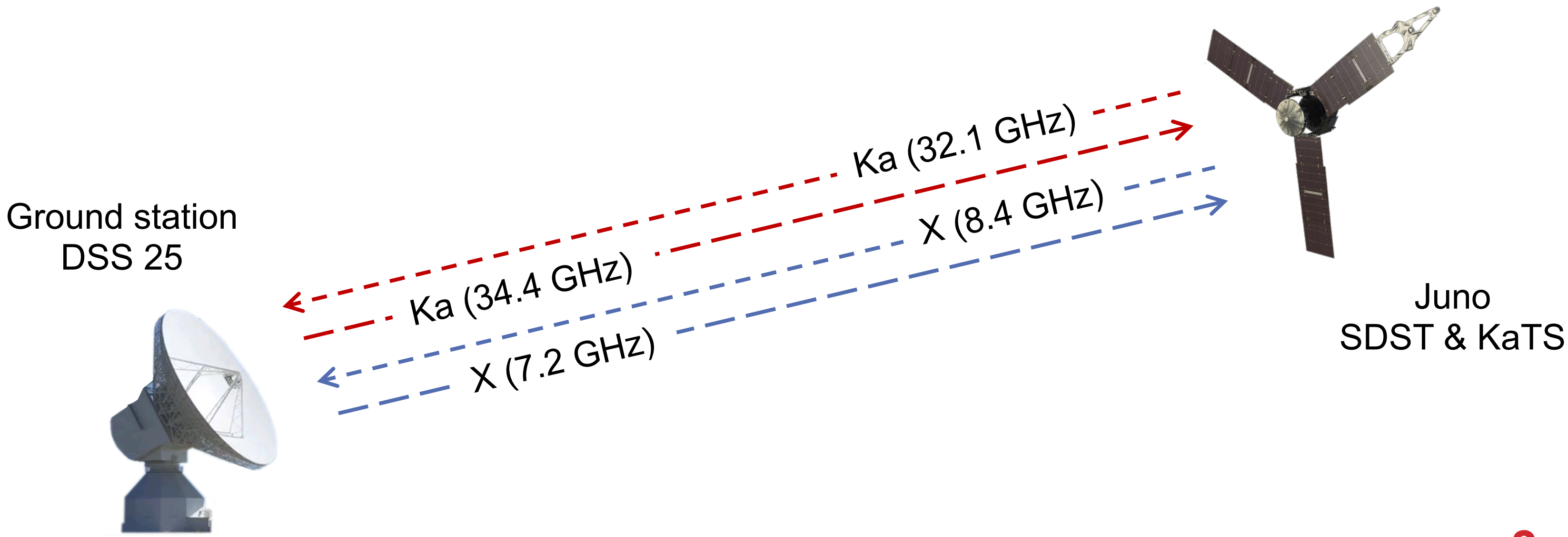
    - The surface winds, by penetrating deep into the planet, perturb the density profile and affect the gravity field. The north-south asymmetry of Jupiter's gravity field constrains the depth of the flow (H_1~2–3000 km), while the symmetric components revealed that Jupiter's deep interior is rotating as a rigid body.

- The current Juno's dataset can be explained to large extent by a purely zonal field (axial-symmetry). However, small scale structures started to appear in the data!



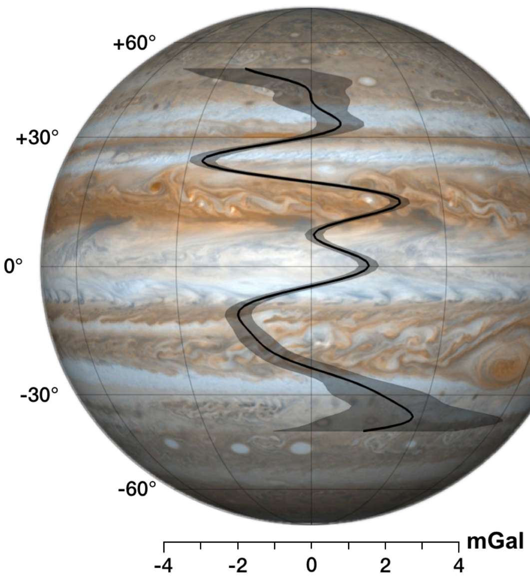
RADIO SCIENCE EXPERIMENT

- The Juno gravity investigation exploits the Doppler shift of a microwave signal to precisely determine the Earth-Juno radial velocity and to estimate Jupiter's gravity field coefficients.
- Juno is the first mission to exploit a Ka-band radio link for the determination of a planetary field.
- The gravity determination is obtained by fitting the two-way radial velocity of the spacecraft down to accuracies as low as 0.01 mm/s (at 60 s).

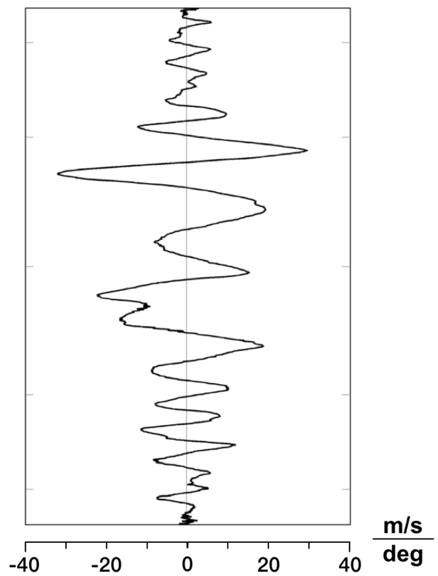


ASYMMETRY OF JUPITER'S GRAVITY

- Gravity disturbances:

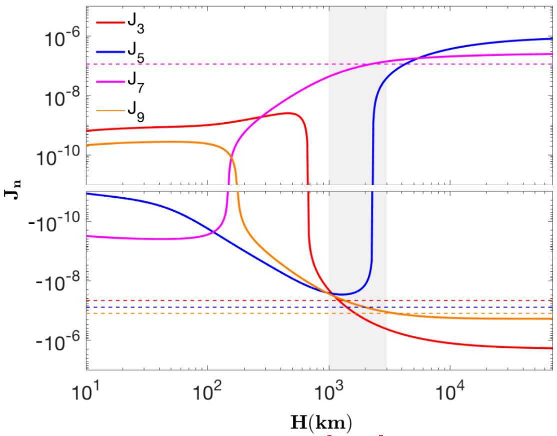


- Latitudinal wind gradient:



- Thermal wind model:

$$(2\Omega \cdot \nabla)[\tilde{\rho}\boldsymbol{u}] = \nabla\rho' \times \boldsymbol{g_0}$$



H ~ 2–3000 km

L. Iess, *et al.* (2018). *The measurement of Jupiter's asymmetric gravity field*, Nature 555, pp. 220-222

Y. Kaspi, *et al.* (2018). *The extension of Jupiter's jets to a depth of thousands of kilometres*, Nature 555, pp. 223-226

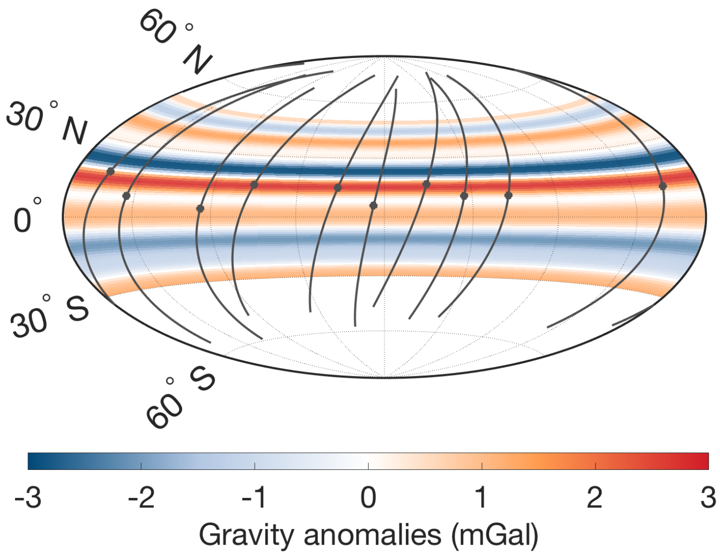
JUNO'S DYNAMICAL MODEL

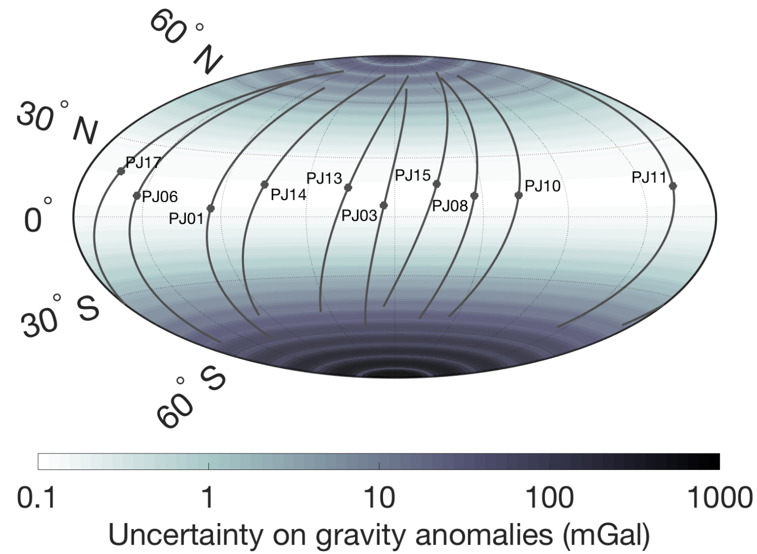
- Juno's dynamical model accounts for:
  - Gravity (solar system bodies and Galilean satellites) in a relativistic context
  - Jupiter's gravity field (spherical harmonics expansion)
  - Tides raised on Jupiter from Galilean satellites
  - Lense-Thirring effect (with fixed Moment of Inertia, NMoI=0.26)
  - Solar radiation pressure on Juno's large solar panels
  - Jupiter's albedo and IR emission

- Multi-arc least square estimation filter solves for:
  - Spacecraft state (position and velocity) at the beginning of each pass
  - **Empirical accelerations (at the level of 2×10^{-8} m/s^2)**
  - Jupiter's zonal harmonics (J_2 to J_{30}) and degree 2 tesseral coefficients
  - Jupiter's Love numbers up to degree 4
  - Spin axis inertial orientation (RA and Dec) and rate

GRAVITY ANOMALIES

- Juno's sampling is very broad in longitude. Still, the recovered gravity anomalies is largely axially-symmetric, and correlates with Jupiter's well-known banded structure.
- Uncertainties vary from 0.1 mGal (equatorial regions) to ~1 Gal (at the poles).





D. Durante, *et al.* (2020). *Jupiter's gravity field halfway through the Juno mission*, GRL 47, 4

JUPITER'S TIDAL MODEL

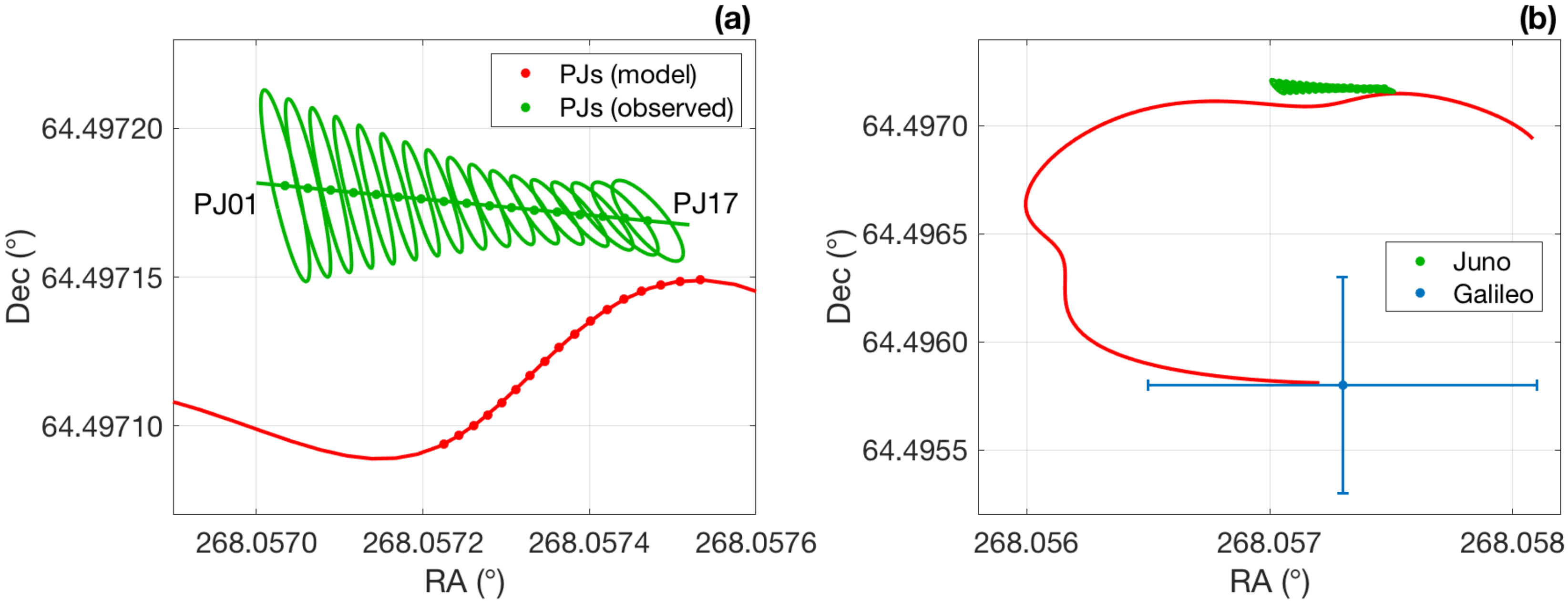
- We explored two different tidal models, and compared with static model predictions:
  - Standard tidal model (assumes the same k_{nm} for all the satellites)
  - Satellite-dependent tidal model (each satellite, i.e., forcing frequency, has a different k_{mn})
- Any deviation would be important to characterize the dynamical contribution to the tidal response.
- With the current data set, we still cannot separate the Love numbers (only k_{nm}^{Io} are determined).

	Model value for Io	Observed value ± 3-σ	
		Standard	Satellite-dependent
k_{22}	0.589	0.565 ± 0.018	0.566 ± 0.074
k_{31}	0.19	0.25 ± 0.05	0.30 ± 0.17
k_{33}	0.24	0.34 ± 0.12	0.42 ± 0.18
k_{42}	1.74	1.29 ± 0.19	1.15 ± 1.06
k_{44}	0.14	0.54 ± 0.41	0.89 ± 0.49

- Currently, the deviations from the static model values are below the satellite-dependent model uncertainties.

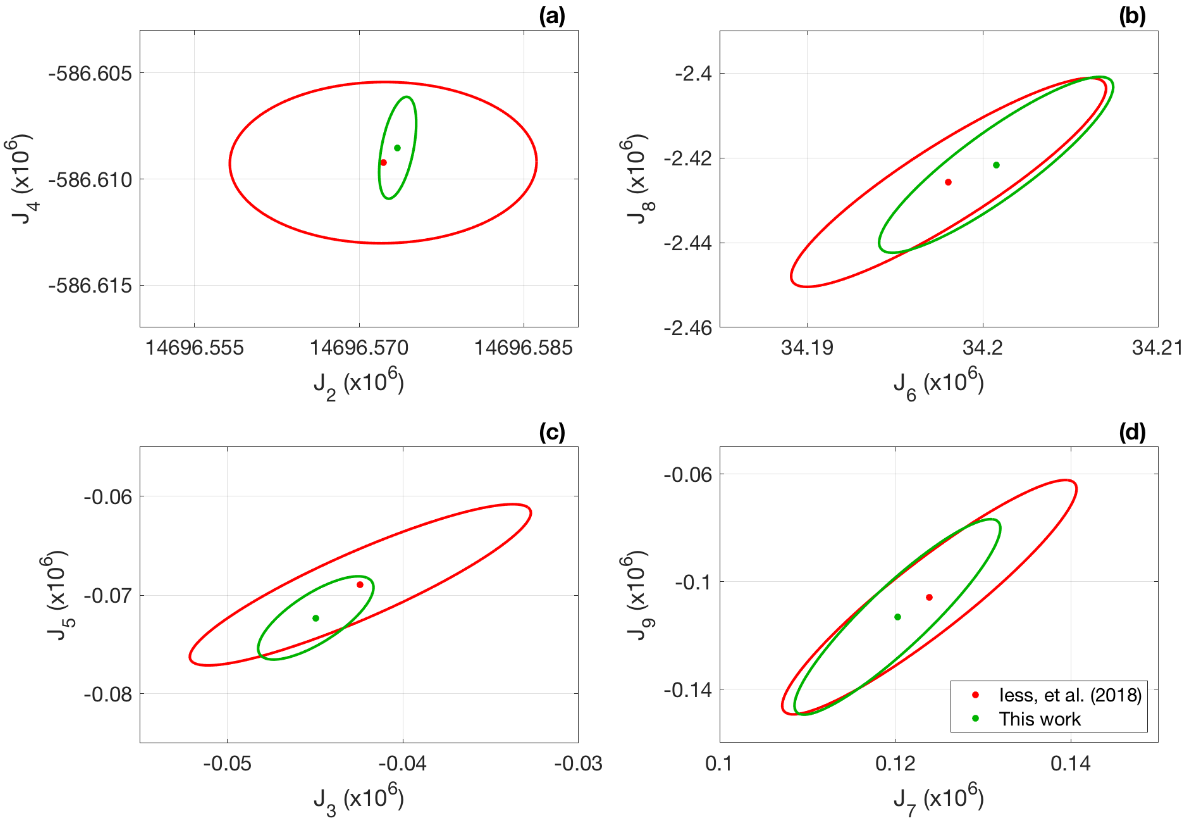
JUPITER'S SPIN POLE

- The motion of Jupiter's spin axis is reconstructed (green line with 3-σ uncertainties) and compared with IAU latest's model, based on integration of satellites and Sun's torques.
- The model (red line) is based on Galileo's data back in the 2000's.



D. Durante, *et al.* (2020). *Jupiter's gravity field halfway through the Juno mission*, GRL 47, 4

ERROR ELLIPSES (3-σ)

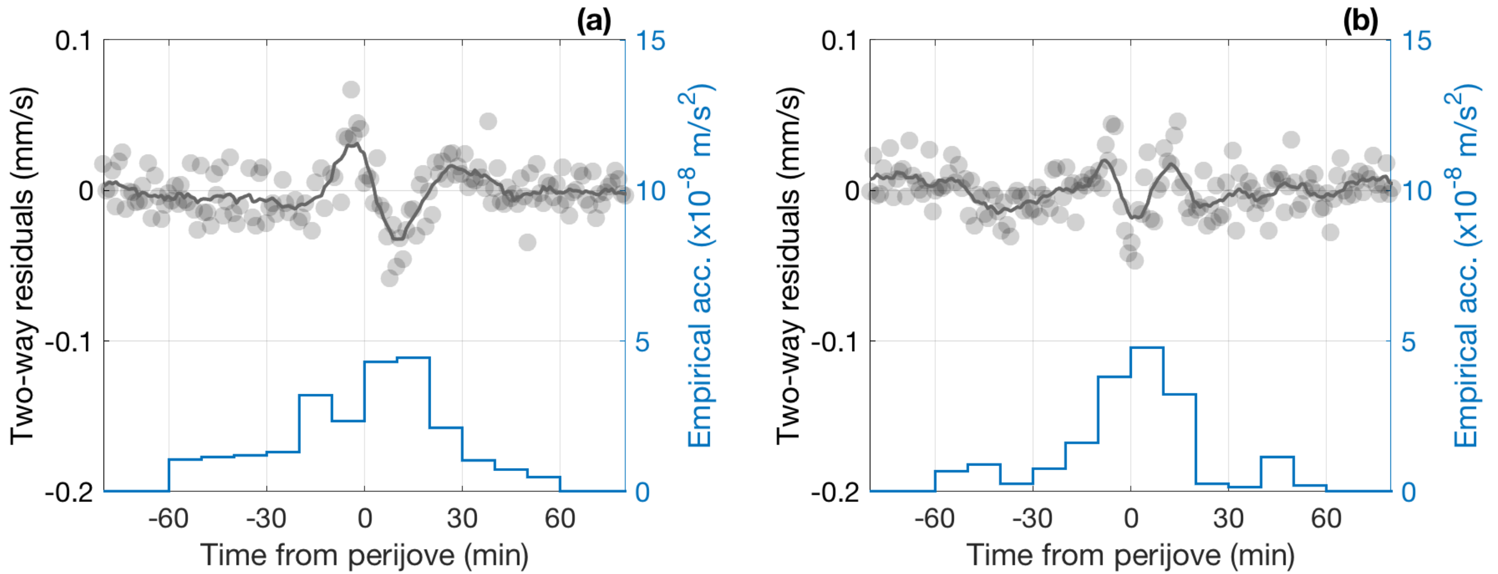


- This work
- Iess 2018

The zonal coefficients are stable with the inclusion of new data

D. Durante, *et al.* (2020). *Jupiter's gravity field halfway through the Juno mission*, GRL 47, 4

DOPPLER RESIDUALS AND EMPIRICAL ACCELERATIONS



- When empirical accelerations are not included, the residuals show <u>signatures</u> up to 0.1 mm/s at a time scale of ~15 minutes.
- The required empirical accelerations are of the order of 5×10^{-8} m/s^2, with larger magnitude close to the perijove: **indication of unmodelled gravity?**

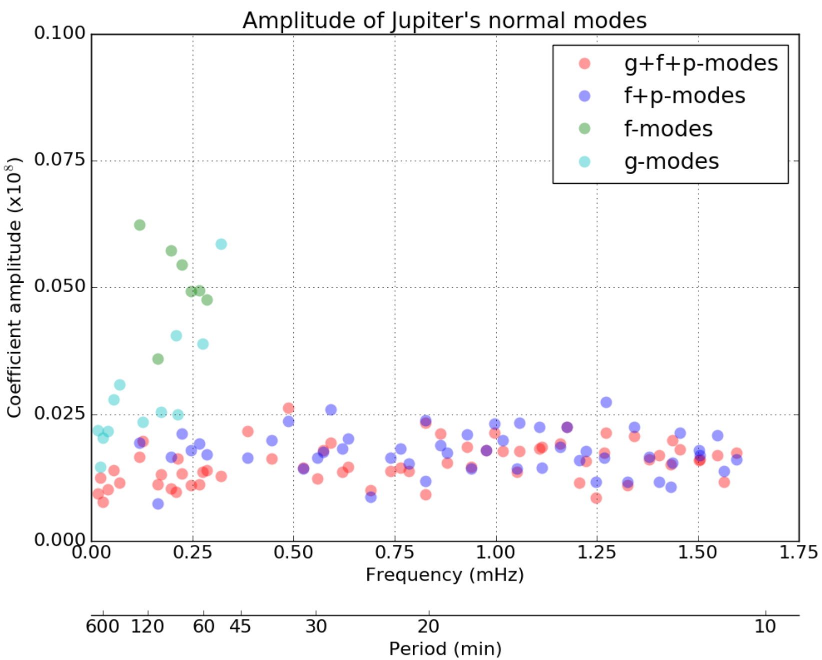
D. Durante, *et al.* (2020). *Jupiter's gravity field halfway through the Juno mission*, GRL 47, 4

STATUS OF GRAVITY ANALYSIS

- The root cause of these additional accelerations is actually unknown.
- All the instrumental effects we are aware of (Juno's spin, station delays, solar panels bending, etc.) cannot solve the issue.
- It is likely that those signals are due to Jupiter's gravity.
- Similar unexplained accelerations have been observed in Cassini's Doppler data during the Grand Finale orbits (but with ~20 times larger amplitudes!).
- Possible explanations:
  - Normal modes (acoustic or gravity)
  - Large-scale atmospheric vortices
  - Deep-rooted gravity anomalies, possibly related to the magnetic field

A POSSIBLE EXPLANATION: JUPITER'S NORMAL MODES

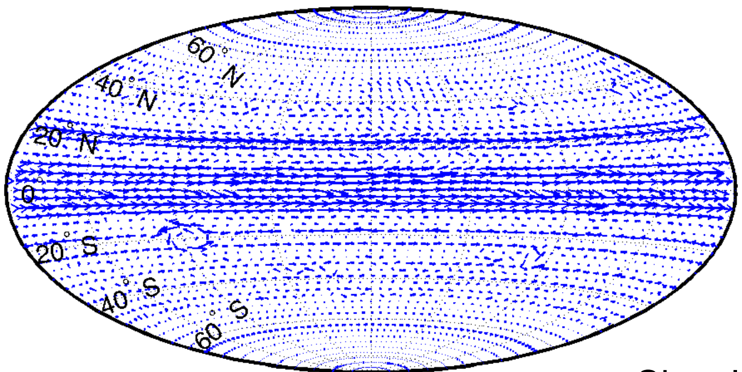
- Normal modes are a possible explanation of Juno's data.
- Ground-based SYMPA's measurements of Jupiter are compatible with amplitudes $10^{-10} – 10^{-9}$.



- Discriminating dominating modes with Juno is difficult because several subsets of those can fit the data (large parameter space and limited observations in space and time).
- Data can be explained by normal modes having amplitudes larger than $2x10^{-10}$.
- Slight preference for low-freq. modes: g- and f-modes have larger amplitudes when p-modes are not included.
- The p-modes' solution (large number of modes) does not prefer any frequency.

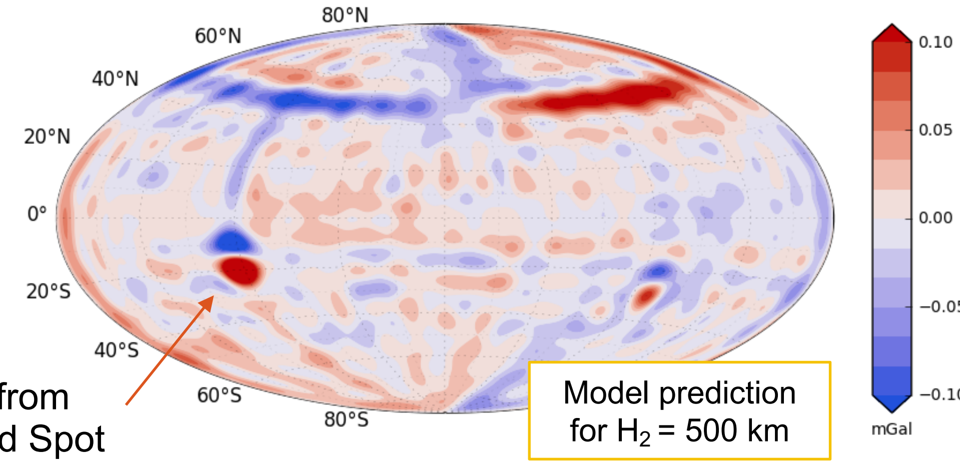
A POSSIBLE EXPLANATION: LARGE SCALE ATMOSPHERIC DYNAMICS

- Localized features of Jupiter’s surface winds (i.e., vortices) can provide non-zonal gravity anomalies (signal different in each arc).
- Predictions can be made through thermal-wind balance and an exponential decay (H_2).
- The data can be fitted with a 6x6 static field, compatible with non-zonal winds of $H_2 \gtrsim 500$ km.



Wind speed

Signal from
Great Red Spot



CONCLUSION

- We provided a mid-term update on Jupiter's gravity field. Our results are in good agreement with previous estimates and provide new clues about the gravity field of the gas giant planet.

- The gravity anomalies are largely symmetric about the rotation axis, and strongly north-south asymmetric after removing the effect of the uniform rotation.

- Smaller contributions from several, yet indiscernible, physical phenomena are possible. These include Jupiter's normal modes, localized atmospheric dynamics, or deeply-rooted density anomalies, possibly related to Jupiter's magnetic field.

- The empirical accelerations are ~2×10^{-8} m/s^2, or 0.1 mGal on the surface.

- Our improved determination of Jupiter's tidal response (Love numbers up to degree 4) is compatible with static tidal model predictions.