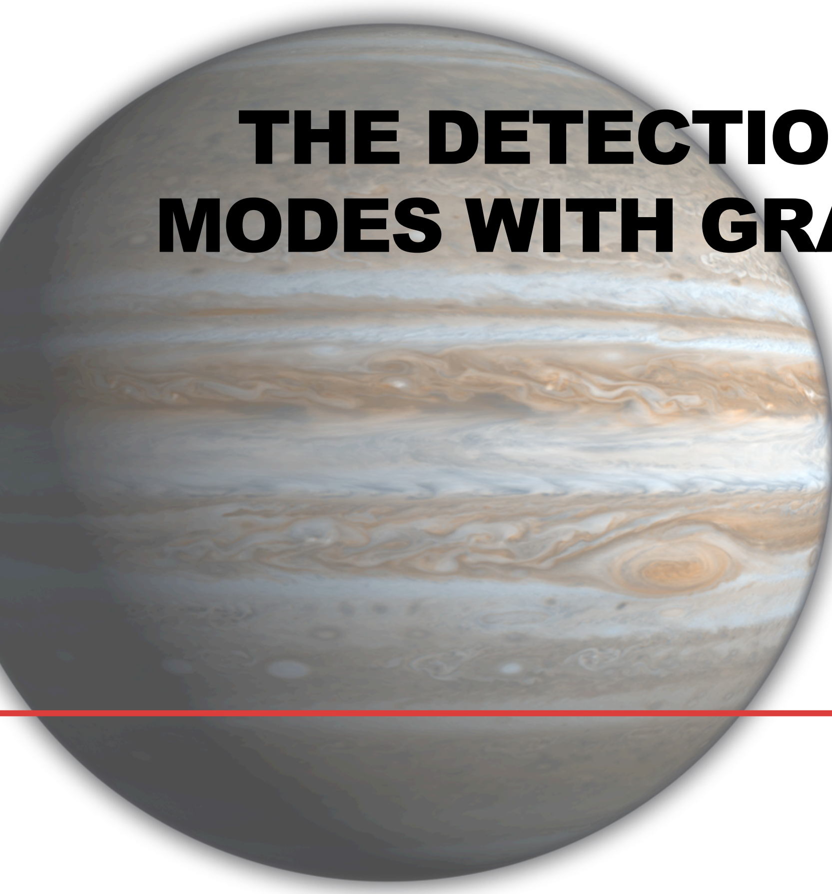


THE DETECTION OF JUPITER NORMAL MODES WITH GRAVITY MEASUREMENTS OF THE MISSION JUNO

Daniele Durante and Luciano Iess

29 September 2015

EPSC 2015 – Nantes, France

Radio Science Laboratory – Dept. of Mechanical and Aerospace Engineering

Sapienza University of Rome

TABLE OF CONTENTS

JUPITER OSCILLATION MODES

- Recent detection of Jupiter global modes suggests that pressure waves cause a significant redistribution of Jupiter's internal masses:
  - Jupiter acoustic modes (p-modes).
- The energy source sustaining the acoustic modes is unknown, but internal dissipation must be small (very high *Q*).
- These modes may displace a large amount of mass, causing time-variable perturbations in the gravitational field, to levels that may be detectable by Juno's high accuracy radio tracking system.
- Jupiter normal modes are both an unique opportunity to probe Jupiter's interior, and a source of noise that may threaten Juno gravity experiment.
- Juno's radio science experiment may in principle be used to probe Jupiter's acoustic modes. We address the following questions:
  - Are normal modes detectable by Juno?
  - How do normal modes affect the determination of the static gravity field and Love numbers?

MATHEMATICAL MODEL

- Static harmonic coefficients of gravitational field are perturbed by Jupiter's oscillations:

$$U_{l,m} = U_{l,m}^{STATIC} + \sum_{n\geq 0} \widetilde{U}_{l,m,n} \cos(\omega_{l,m,n}\, t + \varphi_{l,m,n})$$

- The perturbation on harmonic coefficients is computed as:

$$\widetilde{U}_{l,m,n} = \frac{\iiint_V r'^{l}\, Y_{l,m}(\vartheta', \varphi')\ \widetilde{\Delta\rho}_{l,m,n}(P')\, dV}{M\, R^{l}}$$

- The associated density perturbation is:

$$\widetilde{\Delta\rho}_{l,m,n}(r', \vartheta', \varphi') = \left(\frac{\partial\rho}{\partial r'}\right)\bigg|_{r'} \left[A_0\, f_{l,m,n}(r')\right] Y_{l,m}(\vartheta', \varphi')$$

Density gradient

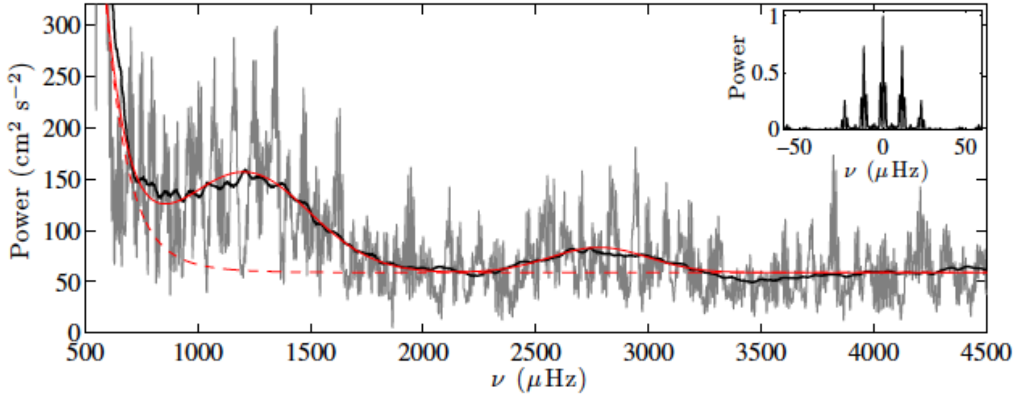
Surface displacement (unknown)

Radial eigenfunctions

- It depends on Jupiter's interior (modeled as a polytrope with *n=1*).
- Oscillation spectrum has been computed with GYRE software.

AMPLITUDE OF ACOUSTIC MODES

- Recently, Gaulme, *et al.* (2011) analyzed a data set of radial velocity maps of Jupiter surface (as seen from Earth), retrieved with their instrumentation. They founded an excess of power between 800 and 2100 μHz, evidence of Jupiter global modes. The maximum radial velocity is about 50 cm/s, peaking at about 1200 μHz.



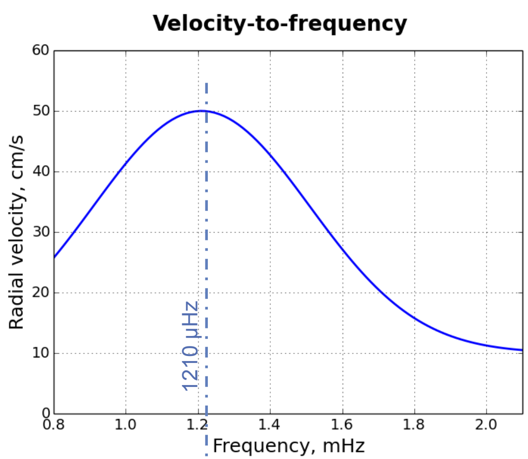
- Results by SYMPA instrument.

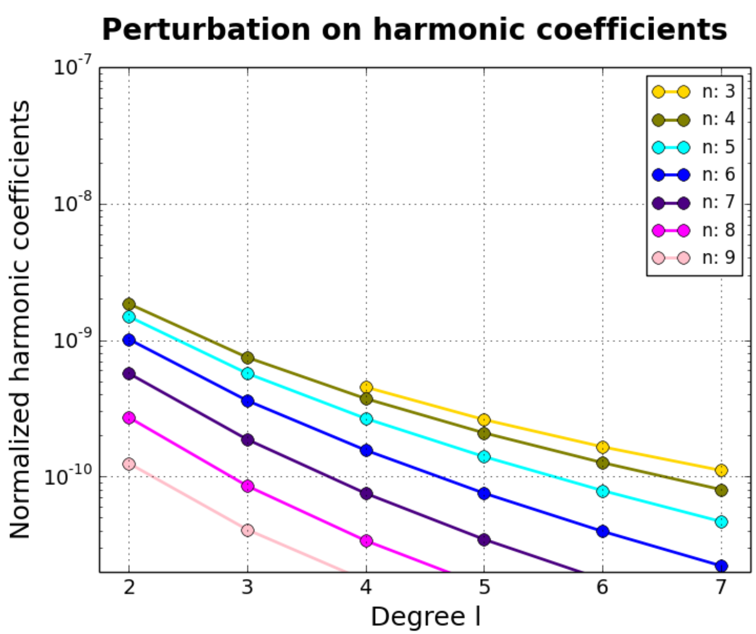
- However, the velocity maps are not associated to a specific harmonic (degree and order), thus we cannot predict each mode's amplitude, neither we know which modes dominate.

ACOUSTIC MODE AMPLITUDES AND HARMONIC COEFFICIENTS

- In our simulations, we assume the same radial velocity in all modes at a given frequency and a Gaussian velocity-to-frequency mapping.
- We simulated two different cases:
  1. Modes within observed frequencies (800 to 2100 μHz);
  2. All acoustic modes (also f-modes) are included.

Case (1)



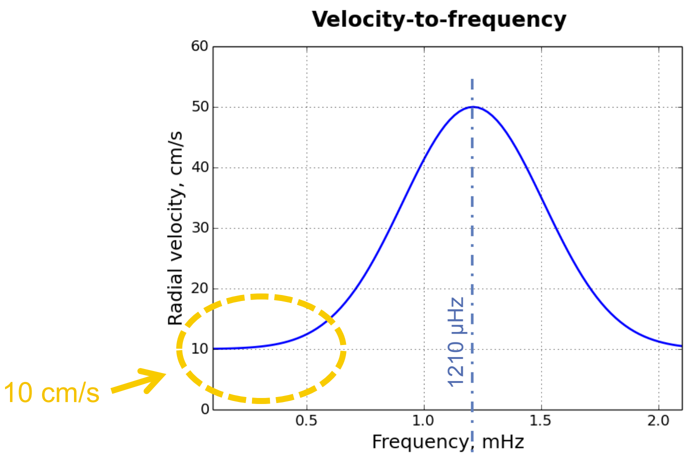


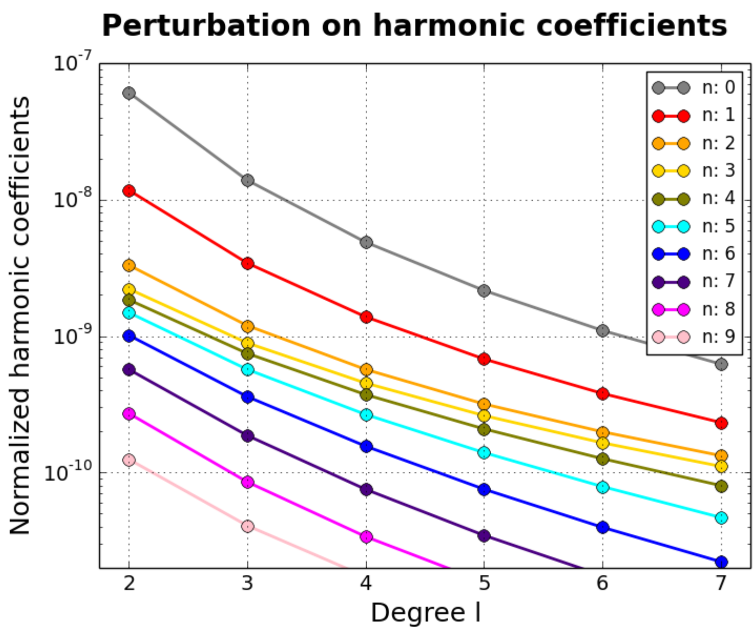
Velocity, frequency → Amplitude

ACOUSTIC MODE AMPLITUDES AND HARMONIC COEFFICIENTS

- In our simulations, we assume the same radial velocity in all modes at a given frequency and a Gaussian velocity-to-frequency mapping.
- We simulated two different cases:
  1. Modes within observed frequencies (800 to 2100 μHz);
  2. All acoustic modes (also f-modes) are included.

Case (2)





Velocity, frequency → Amplitude

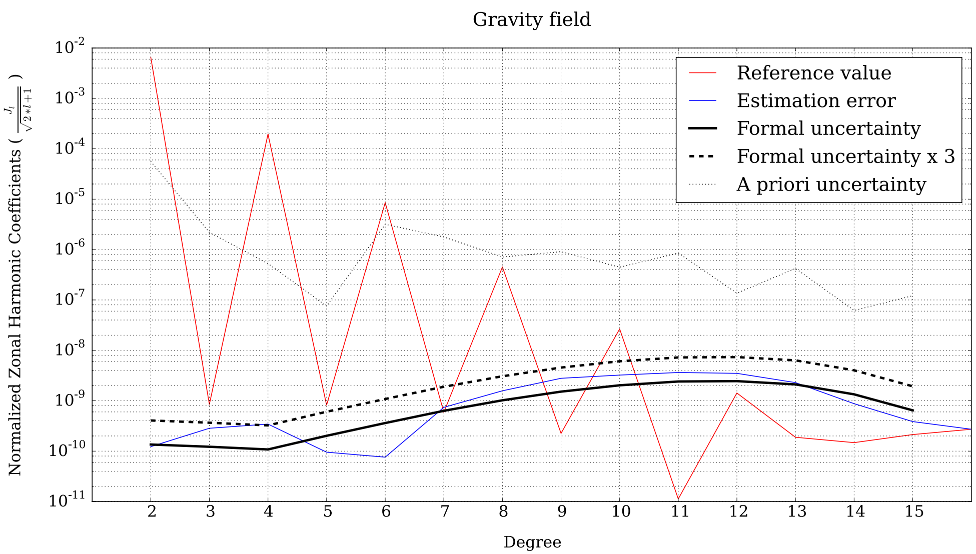
JUNO SIMULATIONS SETUP

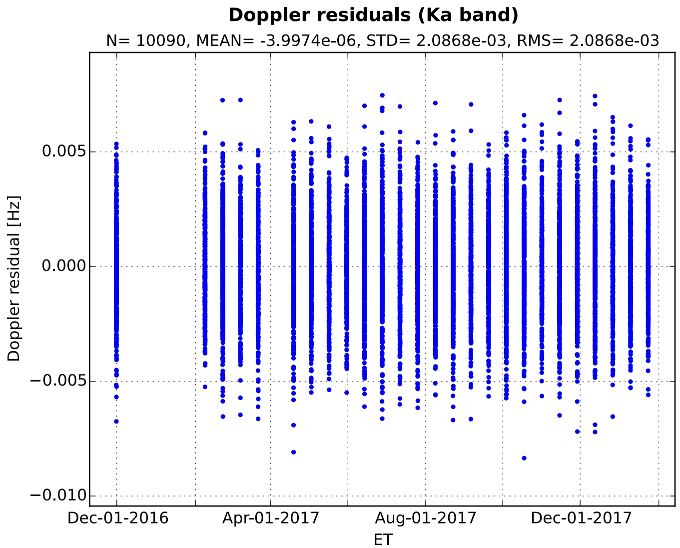
- Our simulations aim to *assess the effect of oscillations on static gravity field estimation*, i.e. to evaluate at what level the acoustic modes begin affecting the estimation of the static part of Jupiter's gravitational field.
- In the estimation process, acoustic modes are not estimated, but only the static gravity coefficients are.

- Our simulations for Juno mission are performed using JPL's latest orbit determination code (Monte). Simulated dynamical model for Juno spacecraft includes:
  - Gravity (also relativity) from all the solar system bodies;
  - Jupiter's gravitational moments (shallow winds case);
  - Effects of tides raised by Galilean satellites;
  - Solar pressure;
  - Gravity perturbations due to the acoustic modes.

CASE (1) - SIMULATION RESULTS

- When high frequency acoustic modes (peak amplitude: 50 cm/s) are included, Doppler data are easily fitted to noise level by using only static gravity field parameters.

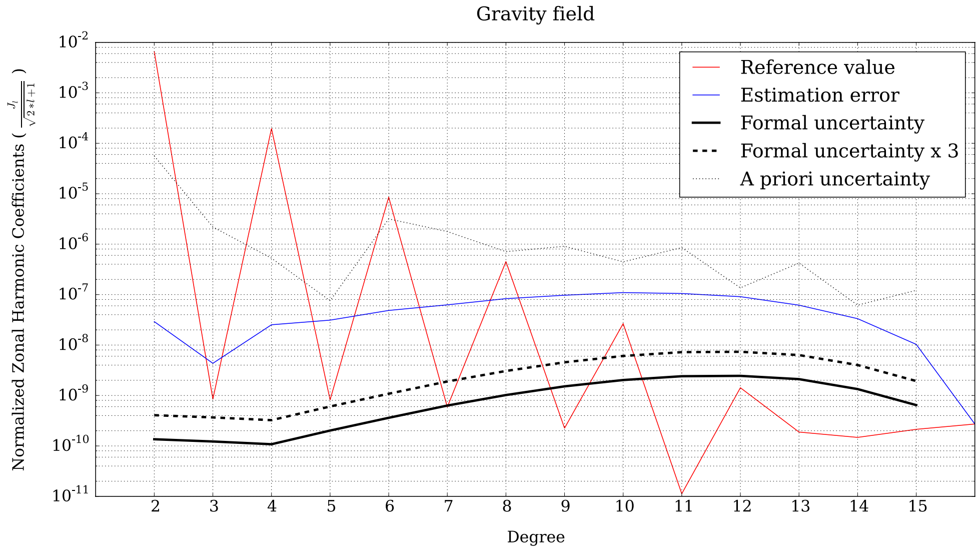


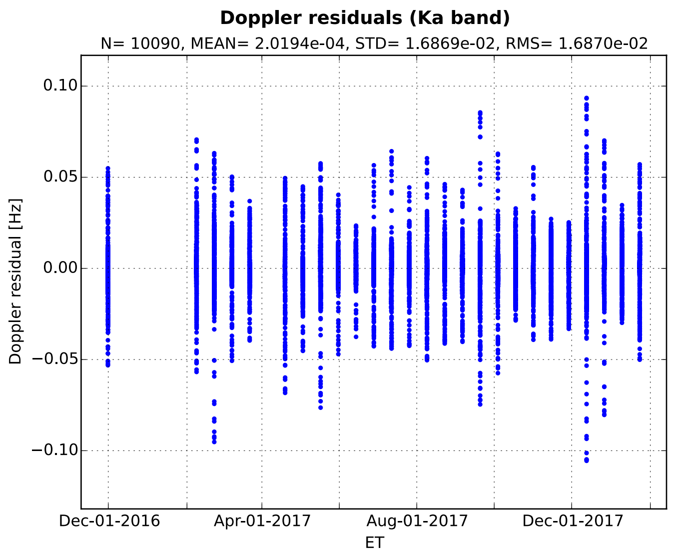


- We conclude that acoustic modes (with SYMPA amplitudes/freq.):
  - ✓ do not produce signatures in our data;
  - ✓ do not bias the solution of the static gravity field.

CASE (2) - SIMULATION RESULTS

- When fundamental modes are included (amplitude of 10 cm/s), Doppler data cannot be fitted by a static gravity field.





- We conclude that:
  - ✓ Acoustic modes may produce signatures in the Doppler residuals;
  - ✓ Acoustic modes <u>must</u> be estimated in order to obtain an unbiased solution, also for static gravity field coefficients.

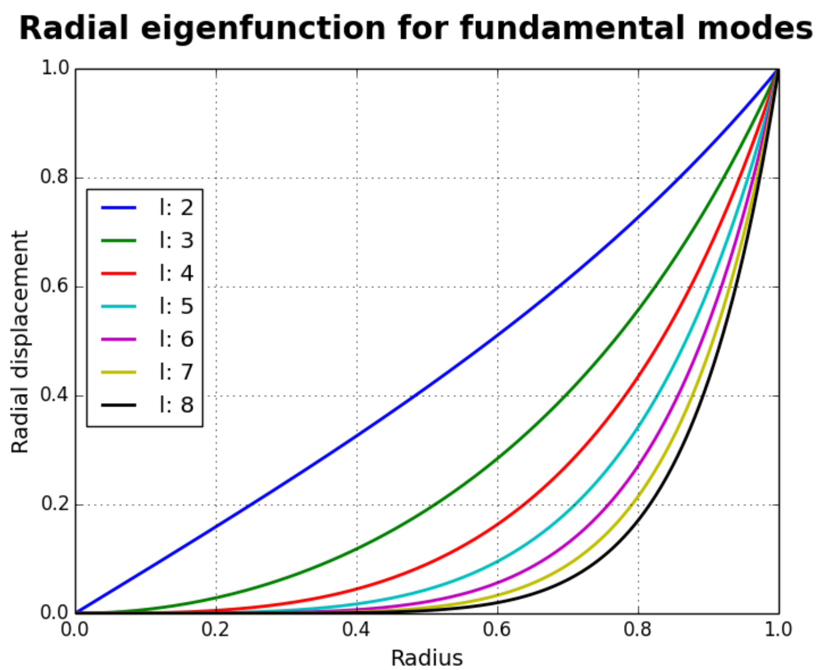
CONCLUSIONS

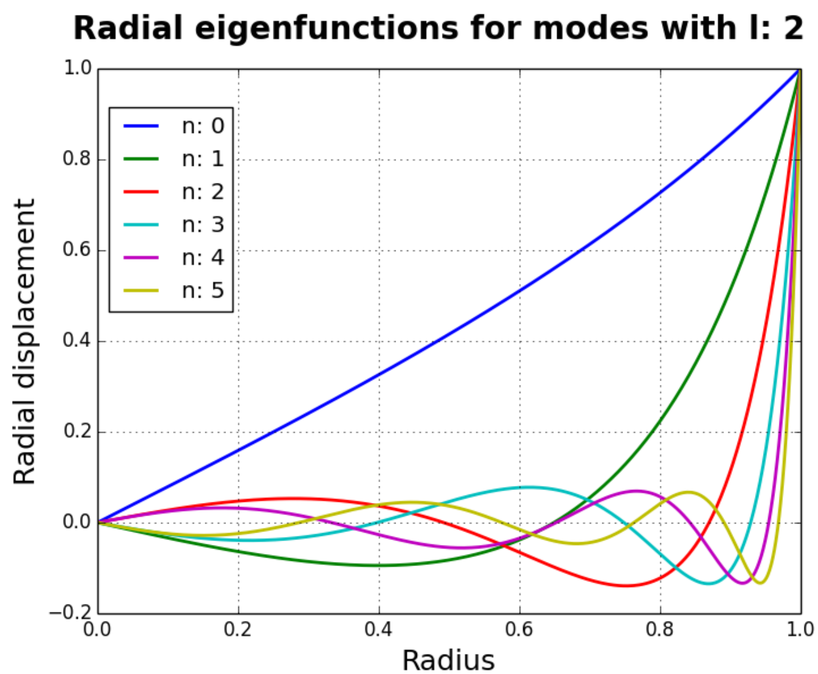
- We developed a simple mathematical model able to compute the dynamic harmonic coefficients due to acoustic normal modes assuming a reasonable velocity-to-frequency profile.
- At this time, no reliable indication on each mode amplitudes is available. Our results depend strongly on mode amplitudes and, to a lesser extent, on the dominating modes.
- With high frequency modes only (≤ 50 cm/s), no signature on Juno Doppler data was found.
- When low-order modes are included (~ 10 cm/s), Juno Doppler observables show signatures due to acoustic oscillations.
- Low-order modes below 1 cm/s do not produce sufficient perturbation on gravity coefficients to be observed by Juno Doppler data.
- Juno gravity experiment is potentially able to detect acoustic modes, if large enough. However, the discrimination of dominating modes and the estimation of modes frequencies will certainly be challenging.

BACKUP SLIDES

MODES EIGENFUNCTIONS

- Radial eigenfunctions for the Jupiter model adopted are:

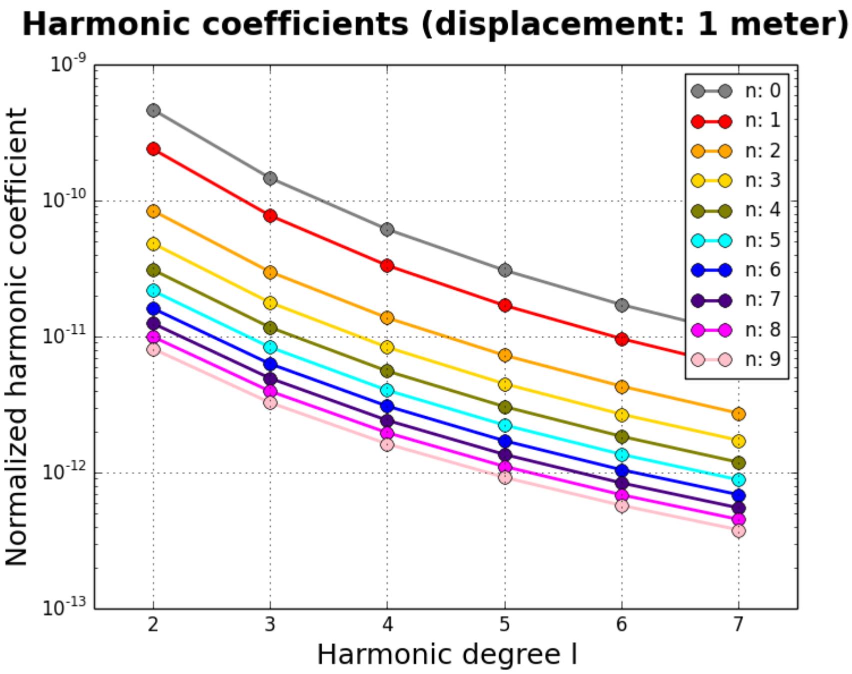




- As the radial order increase, eigenfunctions move toward the surface. High radial-order modes influence Jupiter upper layers, whereas low radial-order modes penetrate deeper in the planet.

HARMONIC COEFFICIENTS PERTURBATION (FIXED)

- The perturbations on harmonic coefficients can be computed for a fixed surface displacement, i.e. 1 meter:



- At constant displacement, low-degree low-order modes produce the higher perturbations on harmonic coefficients.

ESTIMATING THE MODES – PRELIMINARY RESULTS

- A second set of simulations has been performed to analyze the possibility to estimate the acoustic mode parameters, i.e. dynamic harmonic coefficients and associated frequencies have been estimated.
- A global solution cannot be obtained, because the filter is not able to estimate correctly the frequencies, thus phase coherency is not maintained through time (as expected if no dumping is assumed, high Q).
- A local solution can be researched, in order to do not maintain phase coherency and facilitate the convergence of the filter to the solution. The drawback is an increase in the number of estimated parameters, thus an increase of uncertainties. In fact, in our simulations, when Doppler data are fitted estimating also dynamic coefficients, the formal uncertainties on static gravity field coefficients increase up to *an order of magnitude* for low degree harmonics.