Non-hydrostatic effects on Mars' nutation

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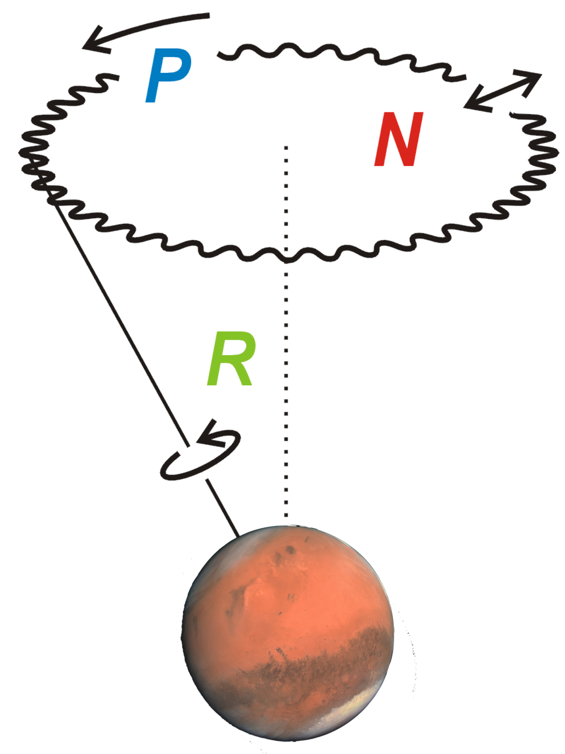
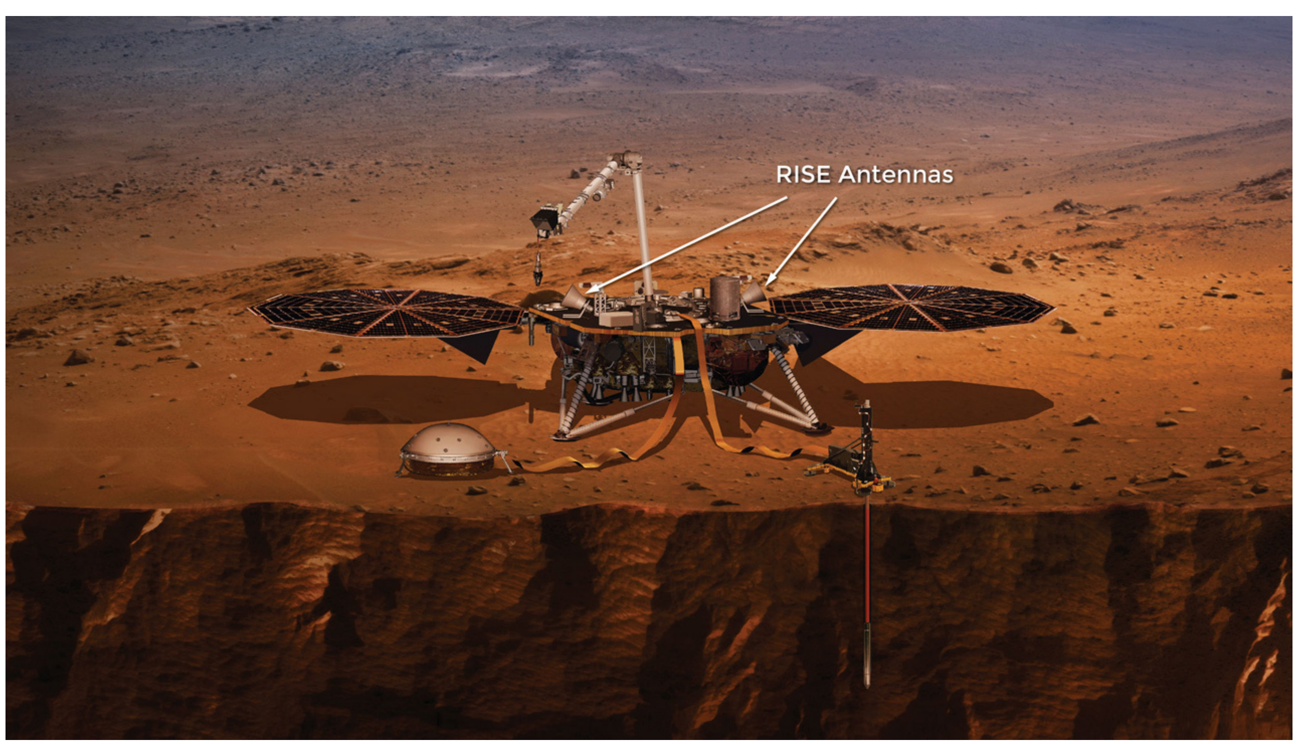
Introduction



Nutation:

time dependent tidal forcing exerted by the Sun and the planets on the **flattened** Mars induces periodic nutation of its rotation axes



Why study now:

ongoing: **RISE** on InSight is currently measuring the rotation of Mars and from it Mars' nutation will be determined
→ EPSC-DPS **1755** for first results

near future: **LaRa** on Exomars2020 will measure Mars rotation and nutation
→ EPSC-DPS **891** and **1681**

Why study nutation

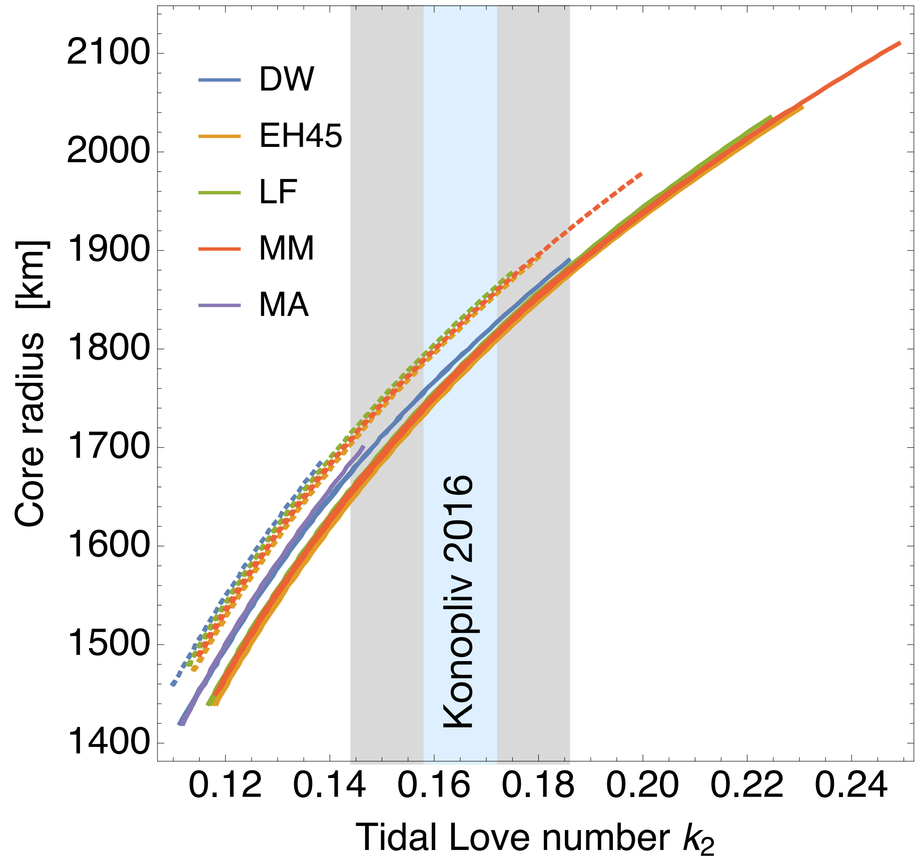
- Mars' liquid core can have a relative rotation with respect to that of the mantle
- one of the rotational normal modes of Mars is characterized by such a relative motion, the Free Core Nutation (FCN)
- because of the FCN the time-dependent tidal forcing exerted by the Sun and other planets on the flattened Mars can lead to resonantly amplified nutation if the forcing period is close to the FCN period
  → EPSC-DPS **488** for details about the relevant tidal forcings
- the period of the FCN and the nutation amplitude depend on the structure of the **core**: moment of inertia, **shape**, radius, and capacity to deform

  ⇒ studying and measuring nutation provides constraints on the structure of the core which are complementary to those obtained from measuring tides, precession, and seismic events

Scope

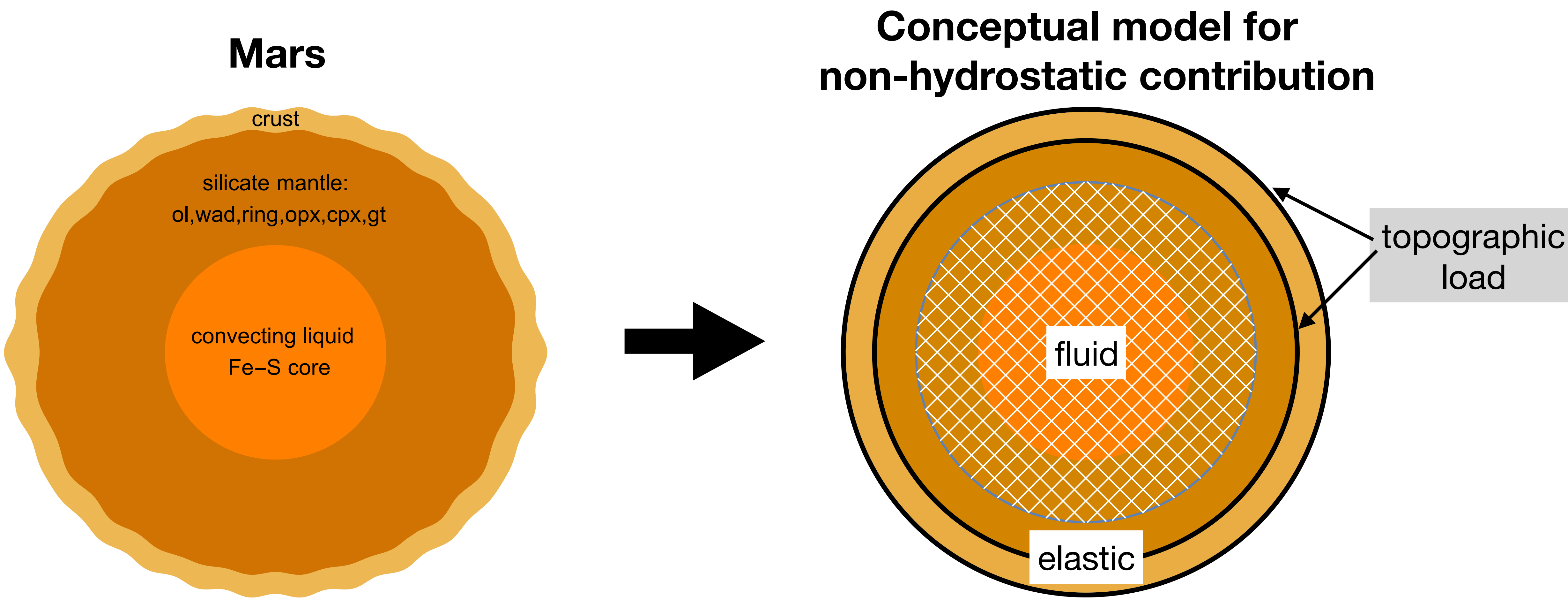
- study how the interior structure affects nutation: FCN period and principal pro- and retrograde nutations (annual, semi-annual, and ter-annual)
- construct a shape model that can explain the non-hydrostatic figure of Mars (**hydrostatic figure** → figure of an uniformly rotating fluid planet)
- assess how a non-hydrostatic core shape affects the FCN period and nutation amplitudes
- illustrate the constraints on the interior structure of the core that can be expected from RISE on InSight and LaRa on ExoMars2020

Interior Structure models



- crust density and thickness range in agreement with Wieczorek and Zuber, 2004
- hot and a cold end-member mantle temperature profiles from thermal evolution studies (Plesa et al. 2016)
- 5 plausible mantle compositions (DW, EH45, LF, MM, MA) (see Panning 2016)
- viscoelastic mantle rheology (Jackson and Faul, 2010) with grain size chosen such that $Q_{Phobos} = 96 \pm 21$ (Lainey 2007)
- liquid convecting Fe-S core (Rivoldini and Van Hoolst, 2013)
- models agree with mean moment of inertia: MOI = 0.3638 ± 0.0001 (Konopliv 2016)

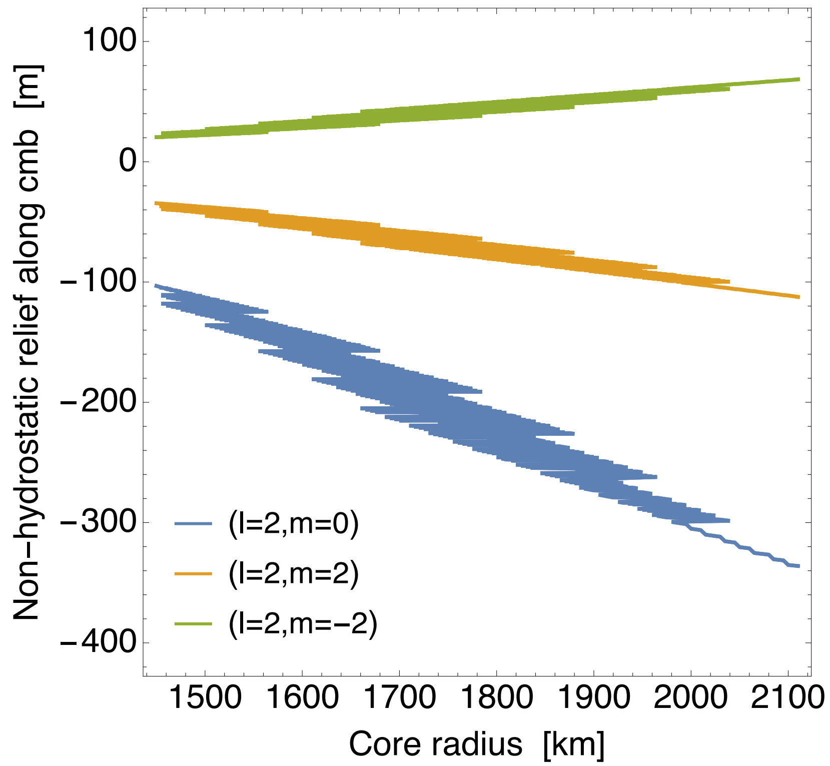
Shape model

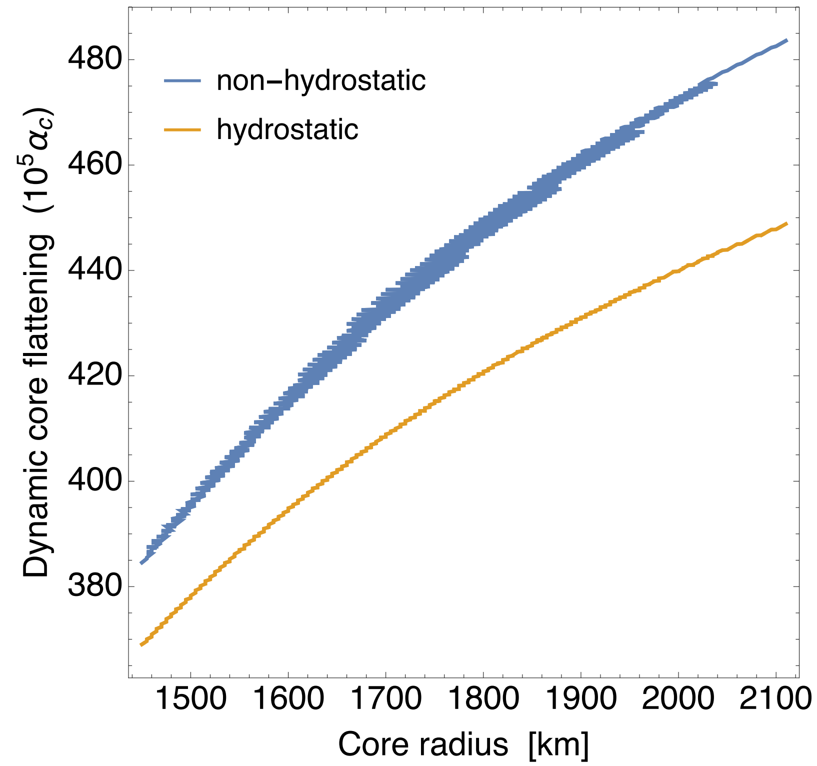


- assume shape and gravity field of planet and core result from surface topographic load, internal load at the crust-mantle interface, and planet rotation

- **model for non-hydrostatic contribution**
  ➞ assumes an elastic lithosphere overlying a fluid lower mantle and core
  ➞ non-hydrostatic degree-2 load at the surface is induced by non-hyd. topography
  ➞ non-hydrostatic degree-2 load at the crust-mantle interface is calculated by requiring that the non-hyd. gravity field coefficients are satisfied
  ➞ effect of surface and internal loading on internal shape is calculated with the load Love number formalism

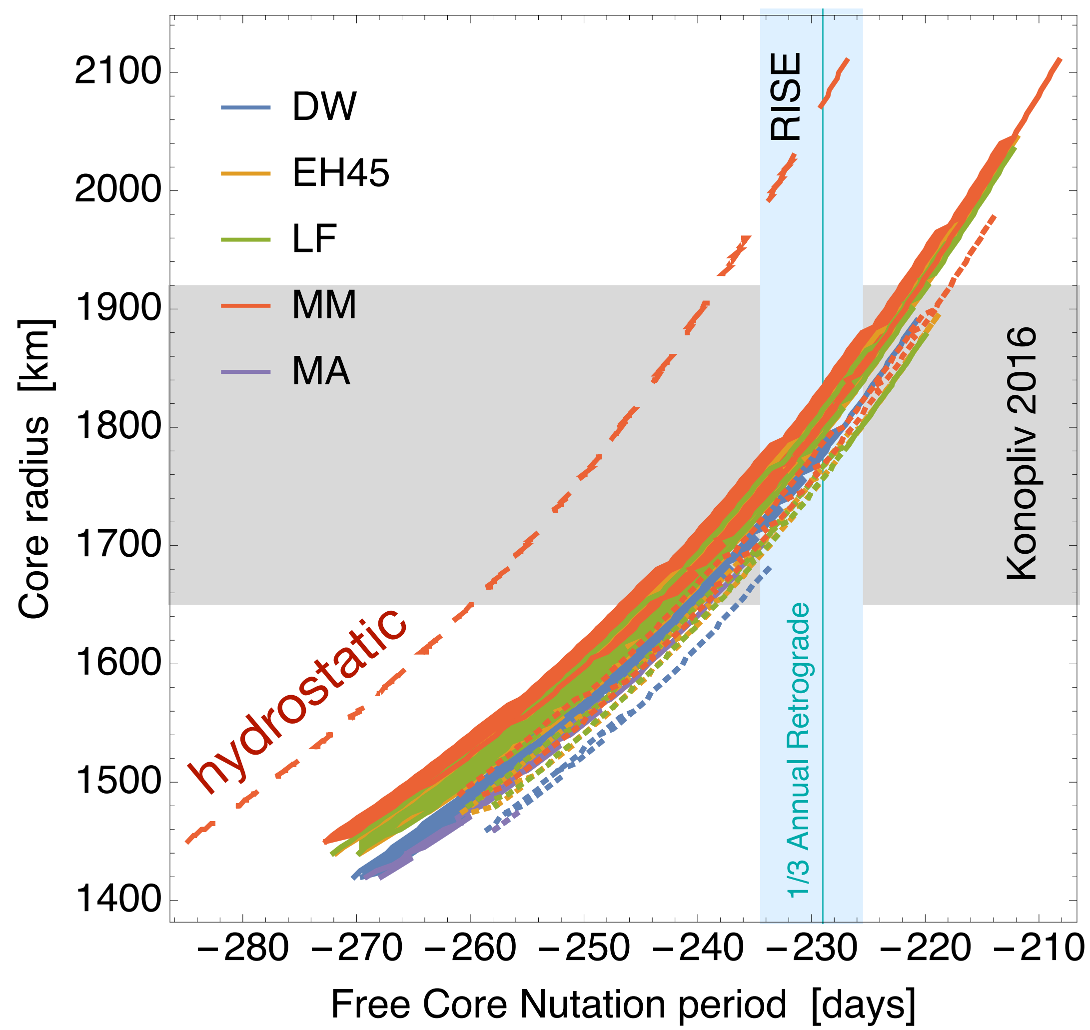
Non-hydrostatic effects





- the magnitude of the core-mantle boundary relief and $\alpha_c = (C_c - A_c)/A_c$ increase with decreasing density contrast at the crust mantle interface
(MOI constraint requires contrast to decrease with increasing core radius)
- and with increasing core radius because the magnitude of the load Love numbers increases with core radius and decreasing core density
- elastic lithosphere thickness (100-300 km) has a small effect on the dynamic core flattening
- results are in agreement with Wieczorek et. al 2019

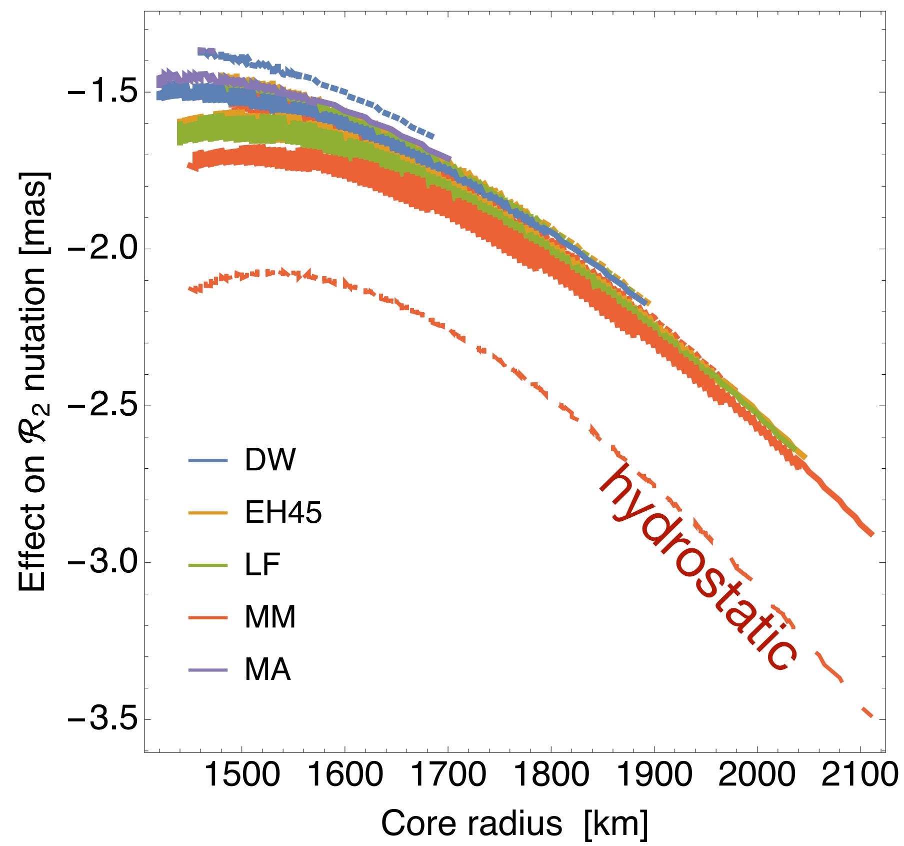
Effect on FCN period



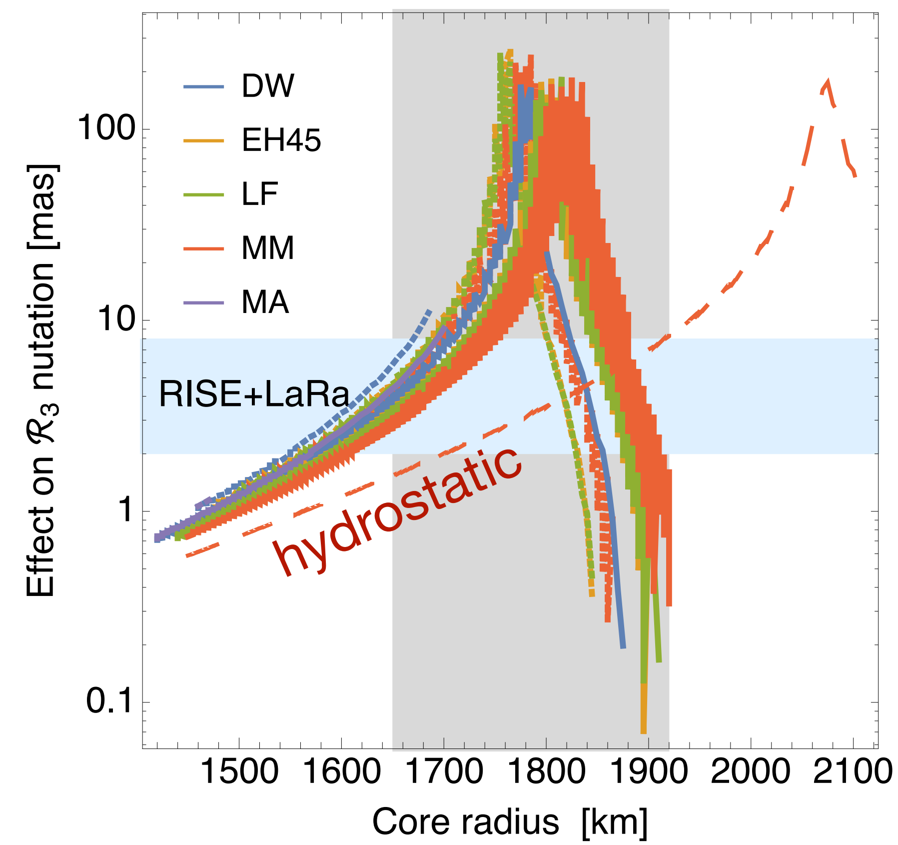
- FCN period increases with core radius because of decreasing mantle moment of inertia
- non hydrostatic core shape increases FCN period by about 10% FCN ($\tau_{FCN} \sim -1/\alpha_c$)
- expected precision on core radius by RISE is comparable to present-day precision from k_2 Love number (2σ)
- the shape of the core can be inferred from RISE data if combined with k_2
- our shape model predicts that the ter-annual retrograde nutation of models compatible with k_2 is resonantly amplified

Effect on nutation amplitudes

semi-annual retrograde



ter-annual retrograde



- the effect of the non-hydrostatic shape on the semi- and ter-annual retrograde nutations can be detected by RISE ($\sigma(R_3)\lesssim$3mas~5cm), but not on the other principal nutations
- models with a non-hydrostatic shape that are compatible with k_2 and with a FCN period close to the retrograde ter-annual forcing period can be amplified by more than 100mas (~1.6m)
  → EPSC-DPS **1223** for details about expected precision on core radius estimations
- hydrostatic models that agree with the k_2 Love number are amplified by less than 10mas (~16cm)

Conclusions

- non-hydrostatic models have an FCN period that is about 10% larger than hydrostatic models
- non-hydrostatic models compatible with k_2 are resonantly amplified (up to 100mas)
- a combination of RISE nutation measurements with tides will provide new inferences about the shape, composition, and elastic properties of the core and will further reduce the uncertainty on the core radius
- a combination of RISE and LaRa data will further reduce the uncertainties about the core radius