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
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 $Q_{\text{Phobos}} = 96 \pm 21$ (Lainey 2007)
liquid convecting Fe-S core (Rivoldini and Van Hoolst, 2013)
models agree with mean moment of inertia: $\text{MOI} = 0.3638 \pm 0.0001$ (Konopliv 2016)
• 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 ($\tau_{\text{FCN}} \sim -1/\alpha_c$)
- expected precision on core radius by RISE is comparable to present-day precision from $k_2$ Love number ($2\sigma$)
- 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

- the effect of the non-hydrostatic shape on the semi- and ter-annual retrograde nutations can be detected by RISE ($\sigma(R_3) \leq 3\text{mas} \sim 5\text{cm}$), 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 ($\sim 1.6\text{m}$) → 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 ($\sim 16\text{cm}$)
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