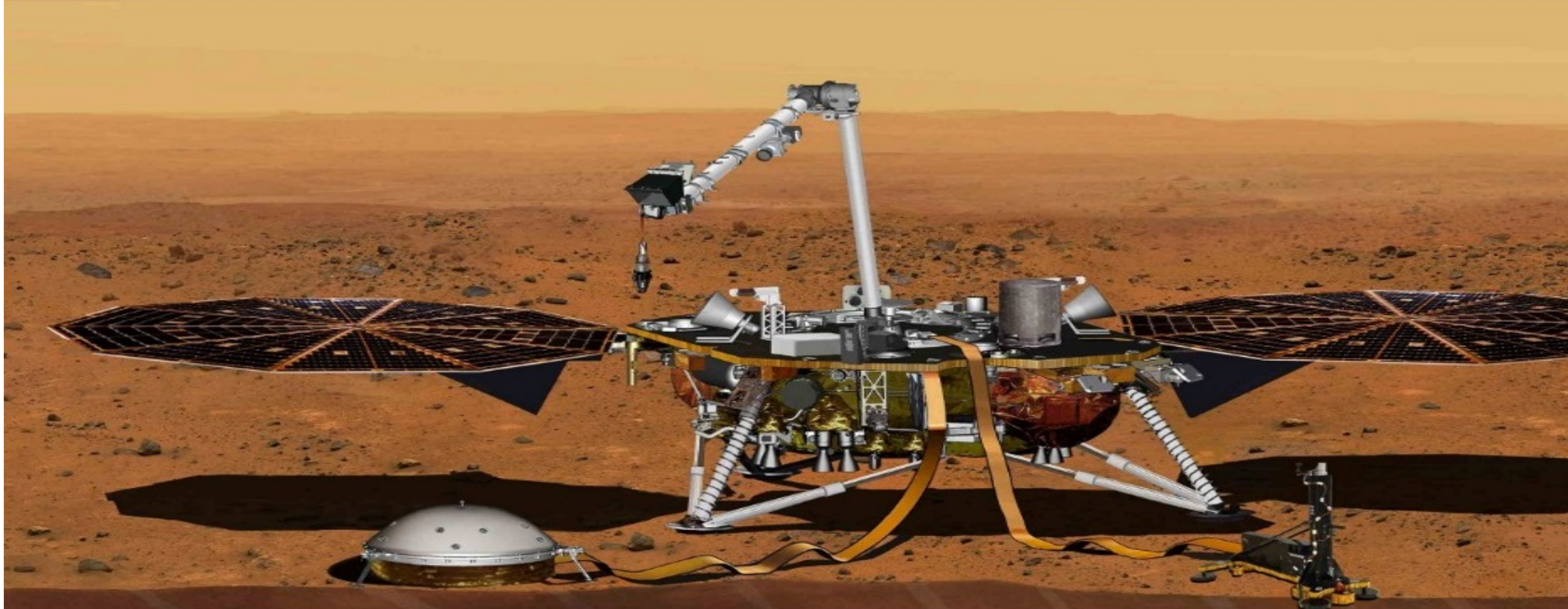

ROYAL OBSERVATORY OF BELGIUM

The structure of the martian core revealed by RISE

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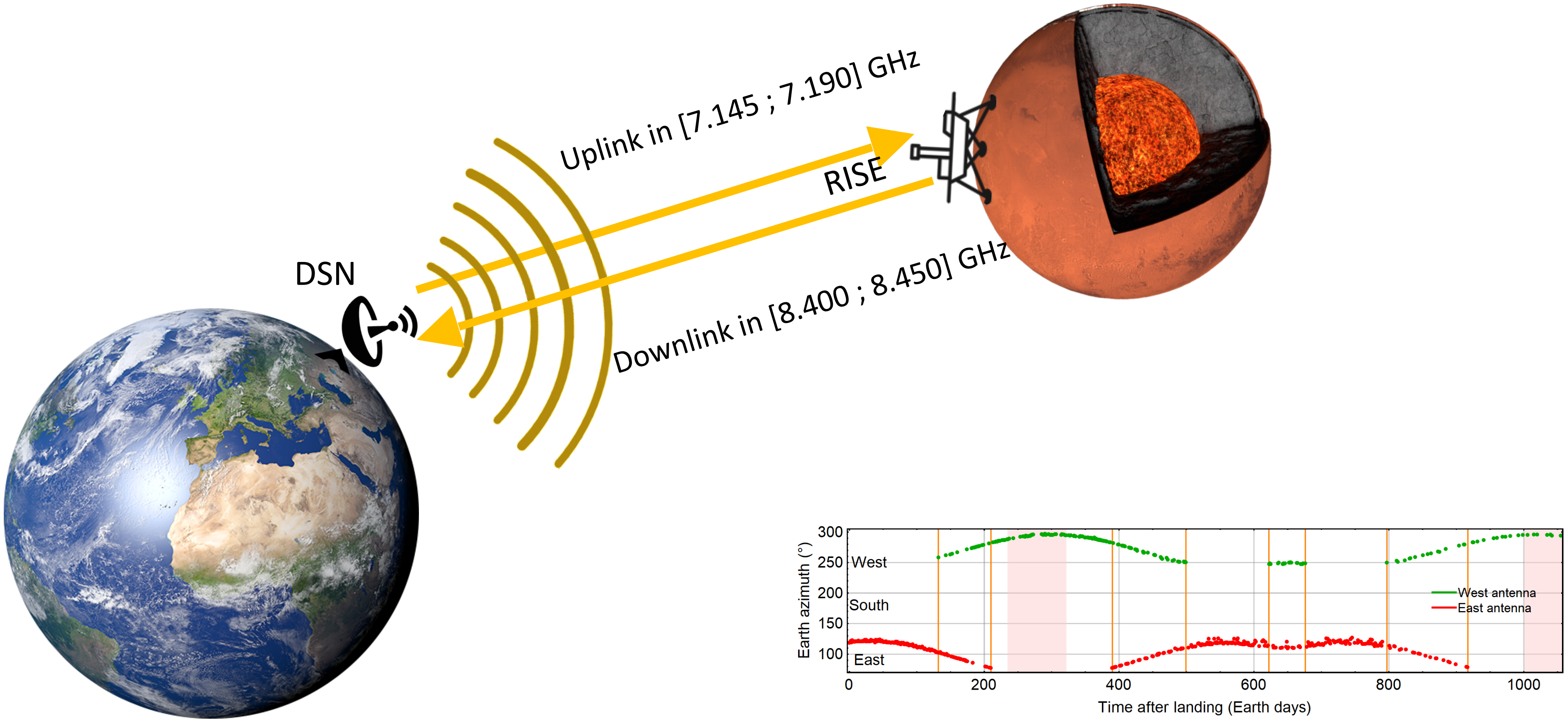
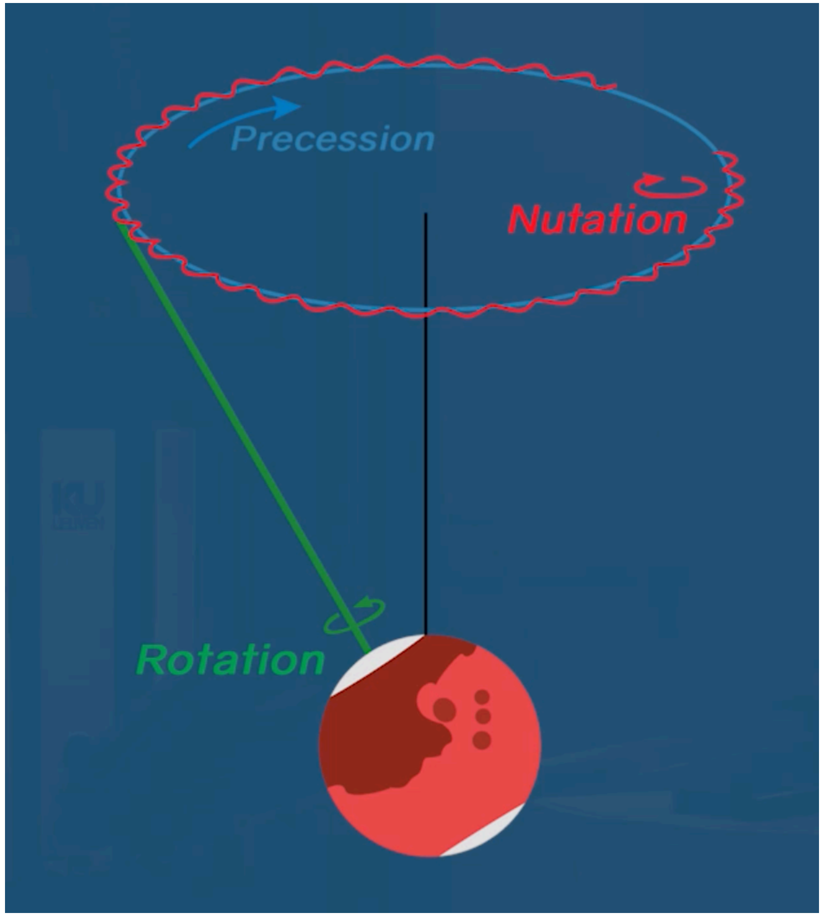
The Rotation and Interior Structure Experiment

- Use of radio-links between Earth-bound antennas and lander on the surface of Mars to determine its motion in space and reconstruct the rotation of Mars

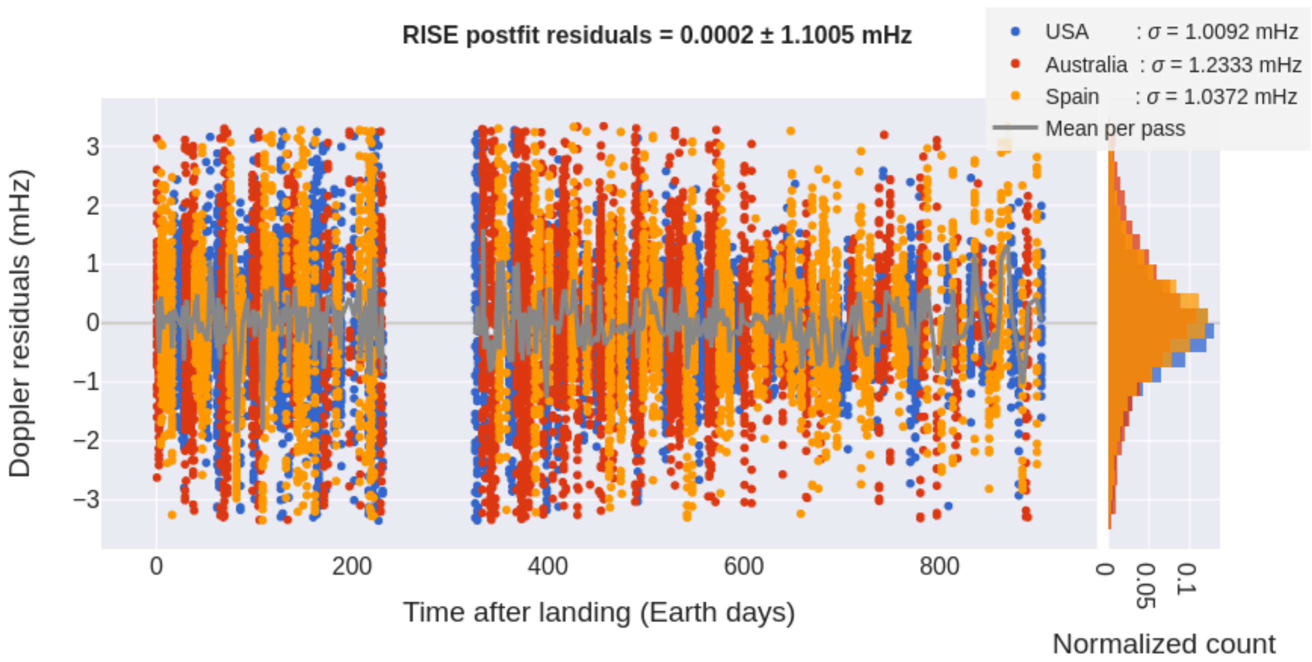


RISE goals

- determination of the time evolution of the **rotation** of Mars
  - ➢constrain the dynamics of the atmosphere (seasonal redistribution of CO_2 between ice-caps and atmosphere)
- determination of the time evolution of the **orientation** of Mars in space
  - ➢secular: precession → polar moment of inertia
  - ➢periodic short term: nutation → core state, core radius and composition



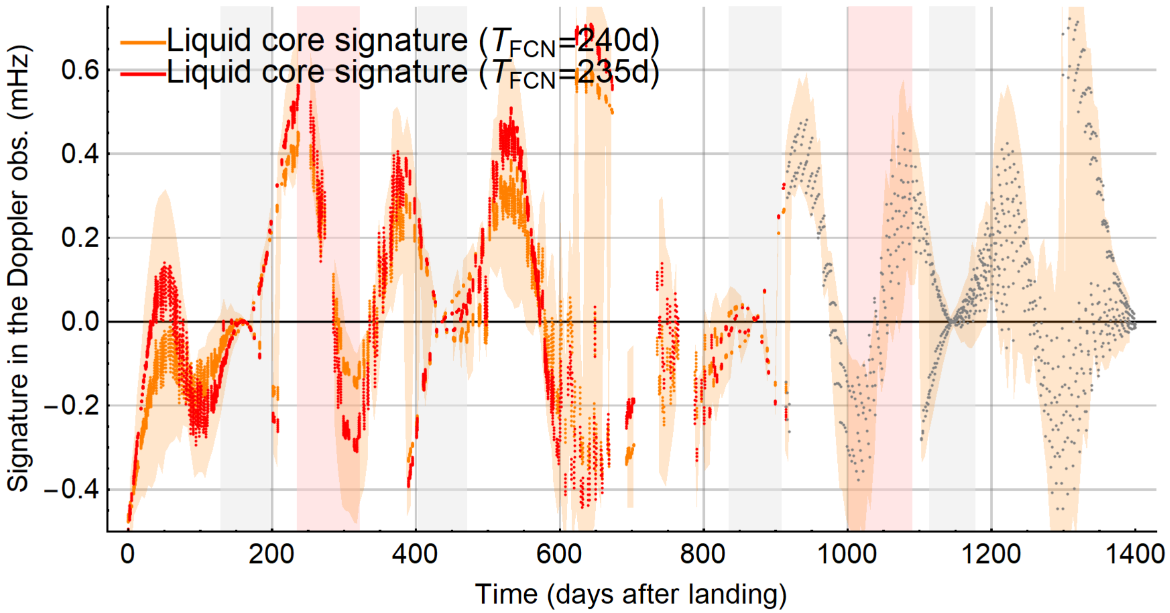
Doppler residuals and data accuracy



RISE 60s data accuracy ~1 mHz

Liquid core signature in RISE data

- Predicted signatures are ~2 times smaller than the accuracy of RISE 60s data



- Envelopes are ranges of predicted signal for an FCN period ranging

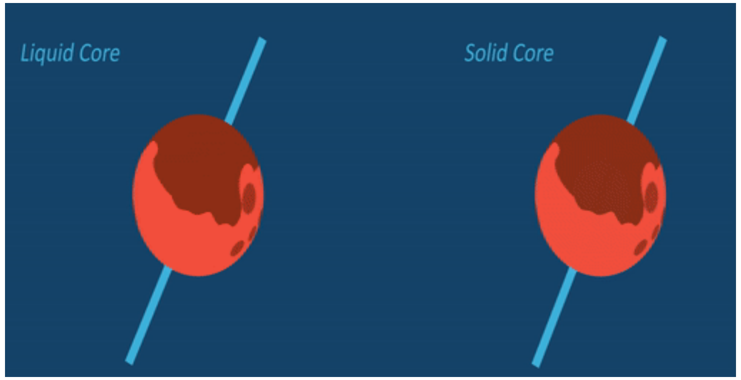
  from T_{FCN} = -280 days

  to T_{FCN} = -233 days (assuming F=0.07)

Nutations

- periodic variations of the spin axes in space due to the gravitational forcing of the Sun, Martian moons, and other the planets
- amplitude mainly determined by the liquid core

  (moment of inertia *Af*, dynamic flattening e_f, compliance: γ, β)
- characterized by the **core amplification factor F**



$$F = \frac{A_f}{A - A_f}\left(1 - \frac{\gamma}{e}\right)$$

and **Free Core Nutation** rotation normal mode
(relative rotation of core with respect to the mantle)

$$\Omega_{\mathbf{FCN}} = -\Omega \frac{A}{A - A_f}\left(e_f - \beta\right)$$

RISE

F=0.061± 0.006

Ω_{FCN}=-2π/(242.3±2.7 days)

Modeling assumptions

- two mantle compositions (Sanloup,1999 Yoshizaki 2020) that agree with the MOI from RISE and crust structure deduced by InSight (Knapmeyer-Endrun 2021), representative for the range of FeO in the mantle of Mars

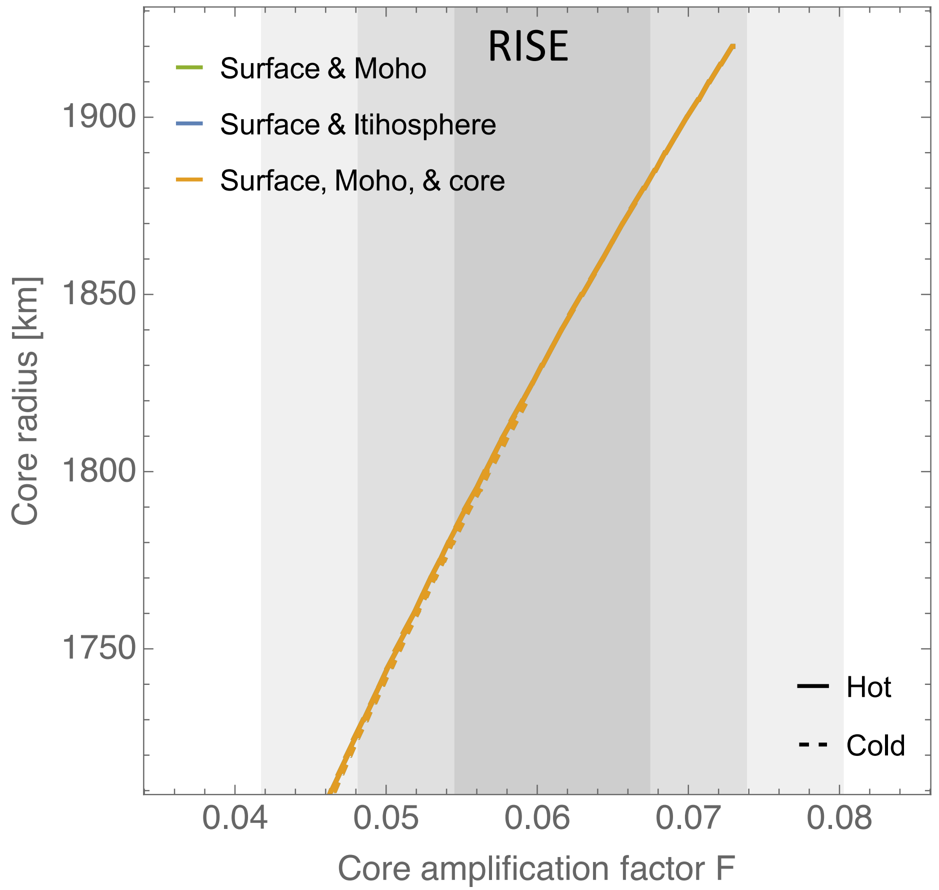
- mantle rheology constrained by Chandler Wobble period Love number, and secular acceleration of Phobos (Konopliv 2020)

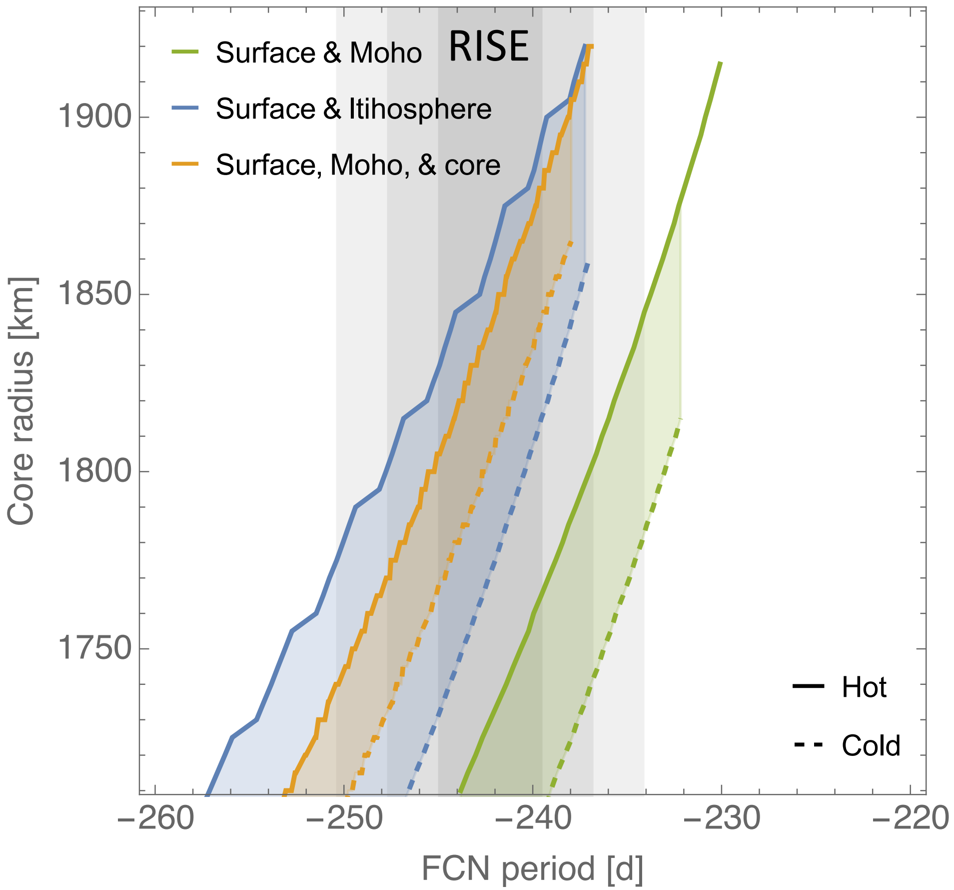
- hot and cold mantle end-member temperature profiles deduced from 3d thermal evolution studies (Knapmeyer-Endrun 2021, Plesa 2016)

- core is convecting liquid Fe-O-S-C-H alloy (amount of O is dependent on the #Fe of the mantle and bulk S content; C is assumed below solubility limit in Fe-O-S (~1wt%); H ≦1wt%)

- shape of models agree with observed non-hydrostatic geometric and dynamic flattening of Mars
→ shape model assumes a rotating fluid interior overlain by solid shell and loads generated by the crust and by 1 or 2 mass anomalies placed at depth (Moho, bottom of the lithosphere, core mantle boundary)

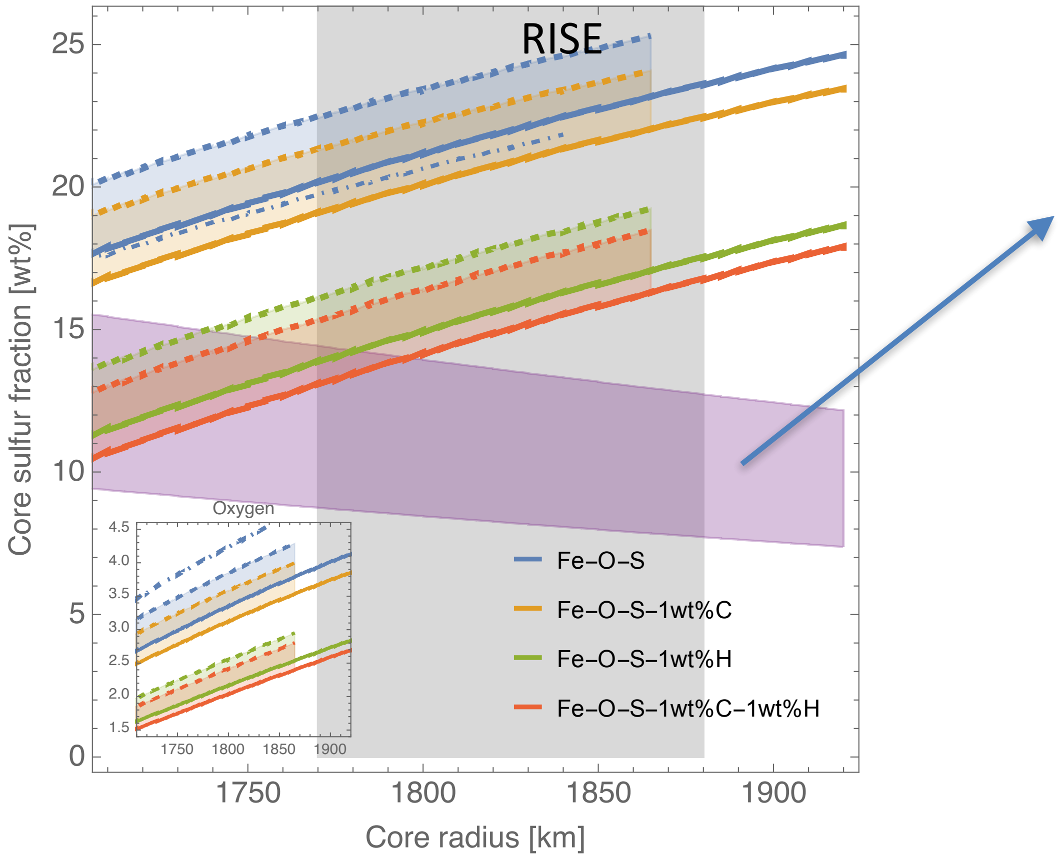
Results





- *F* almost not dependent on mantle composition and temperature
- FCN period strongly dependent on thermal state and placement depth of loads
- core range deduced form *F* in excellent agreement with tides and seismic observations (Stähler 2021)
- FCN period and *F* require a load placed at the bottom of a thick lithosphere (600km) or a shallow load together with a load at the bottom of the mantle

Core composition



Plausible range for core S concentration if S content in ordinary chondrites is representative for Martian core. Lowest S values slightly above max. S estimation based on volatility arguments.

- the large core radius inferred by RISE requires a substantial amount of light elements to match the core density
- the entailed low temperature core liquidus makes the presence of an inner core highly unlikely
- Fe-O-S-(C) models require an unrealistic large amount of S
- an appreciable amount of H is required to decrease S in the core to within acceptable bounds
- the amount of light elements can be reduced if the mantle has a lower density

Conclusions

- RISE observations confirm the presence of a liquid core inside Mars
- the inferred core range is in excellent agreement with estimations deduced from tides and seismic observations
- the FCN period requires either a mass anomaly at the bottom of a thick lithosphere (~600km) or a shallower load together with a load at the CMB
- the inferred core radius implies a relative low core density and a substantial amount of light elements
- RISE did not detect the signature of an inner core and the very low core liquidus entailed by the large amount of light elements makes the presence of an inner extremely unlikely
- Fe-O-S-(C) models require an unrealistic large amount of S that is not in agreement with cosmo-chemical constraints and formation models
- an appreciable amount of H is required to decrease S in the core to within acceptable bounds
- the amount of light elements can be reduced if the mantle has a lower density (less iron or a higher temperature)