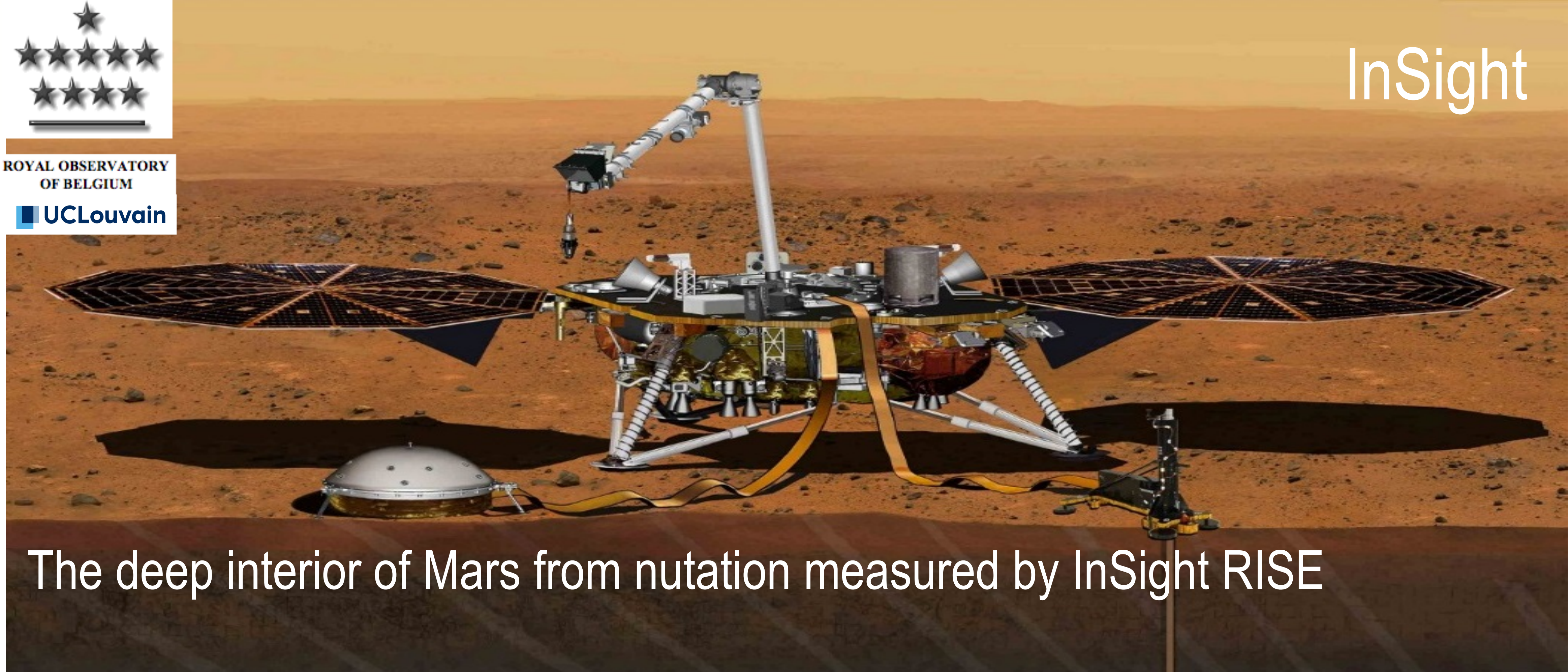


InSight

The deep interior of Mars from nutation measured by InSight RISE

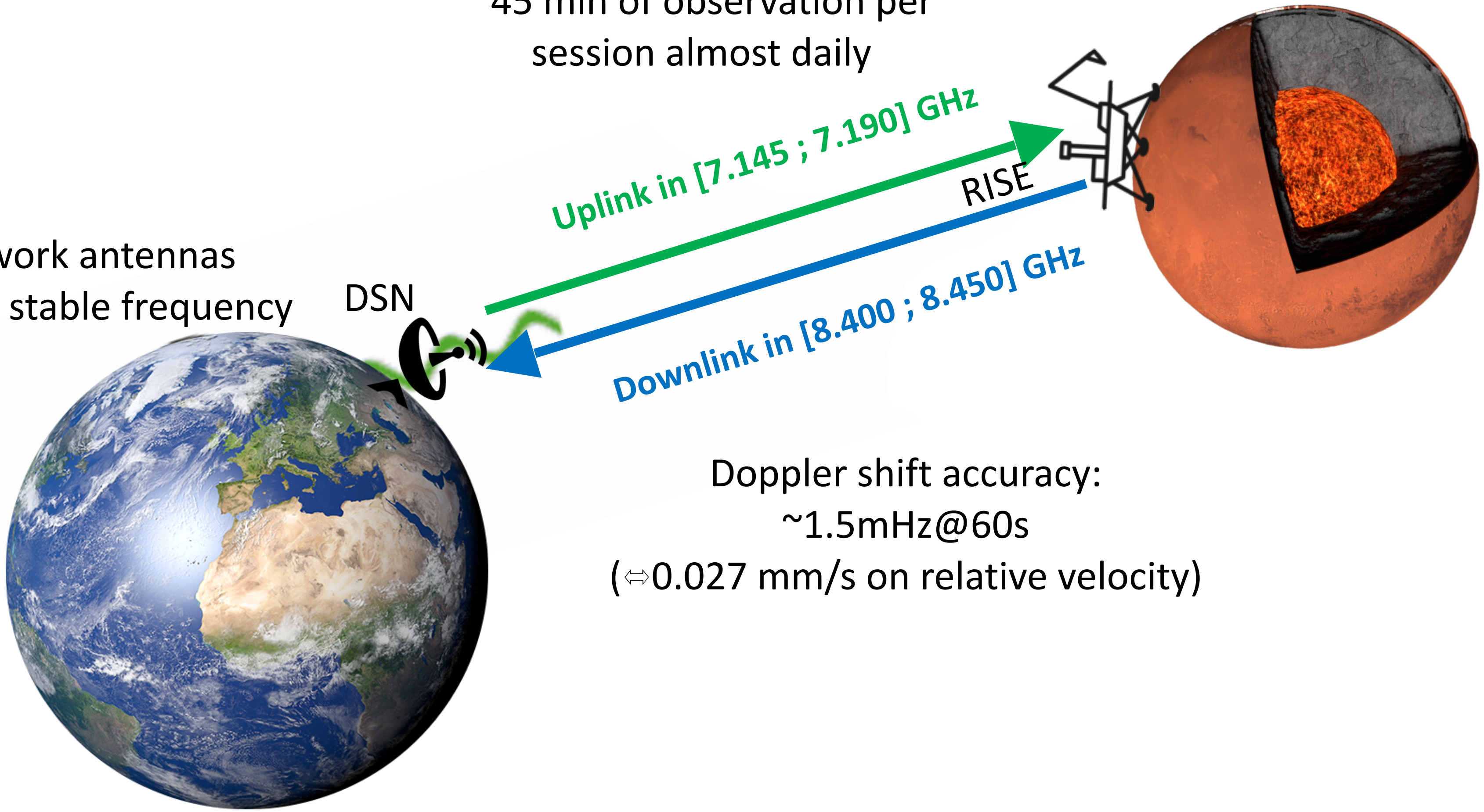
Sébastien Le Maistre[1,2*], Attilio Rivoldini[1], Alfonso Caldiero[1,2], Marie Yseboodt[1], Rose-Marie Baland[1], Mikael Beuthe[1], Tim Van Hoolst[1,3], Véronique Dehant[1,2], William Folkner[4], Dustin Buccino[4], Daniel Kahan[4], Jean-Charles Marty[5], Daniele Antonangeli[6], James Badro[7], Mélanie Drilleau[8], Alex Konopliv[4], Marie-Julie Péters[1], Ana-Catalina Plesa[9], Henri Samuel[7], Nicola Tosi[9], Mark Wieczorek[10], Philippe Lognonné[7], Mark Panning[4], Suzanne Smrekar[4], W. Bruce Banerdt[4].

[1] Royal Observatory of Belgium, Brussels, Belgium. [2] UCLouvain, Louvain-la-Neuve, Belgium. ,[3] Institute of Astronomy, KU Leuven, Leuven, Belgium. [4] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA. [5] Centre national d'Études Spatiales, Toulouse, France. [6] IMPMC, Sorbonne Université, MNHN, CNRS, Paris, France. [7] Université de Paris, Institut de Physique du Globe de Paris, CNRS, Paris, France. [8] Institut Supérieur de l'Aéronautique et de l'Espace SUPAERO, Toulouse, France. [9] DLR Institute of Planetary Research, Berlin, Germany. [10] Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France.

May 24, 2022

RISE: the InSight radio science experiment

It uses radio-links to reconstruct the motion of the lander in space



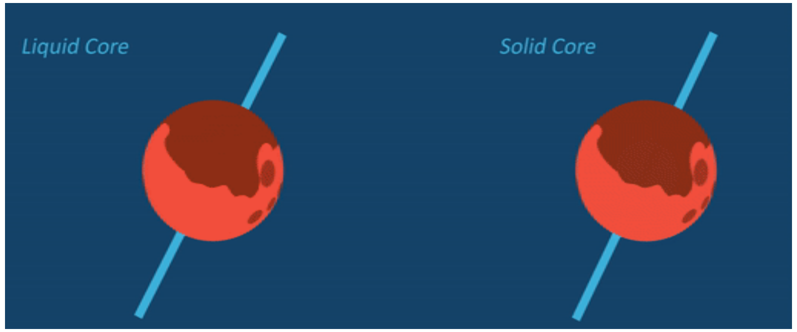
Coherent transponder
and 2 horn-antennas
fixed on the Mars surface

~45 min of observation per
session almost daily

Deep-Space-Network antennas
transmitting a highly stable frequency

Doppler shift accuracy:
~1.5mHz@60s
(⇔0.027 mm/s on relative velocity)

RISE measures the nutation of Mars



$$N_m = N_m^r\left(1 + F\frac{\sigma_m}{\sigma_m - \sigma_{FCN}}\right)$$

Nutation constrains the interior:

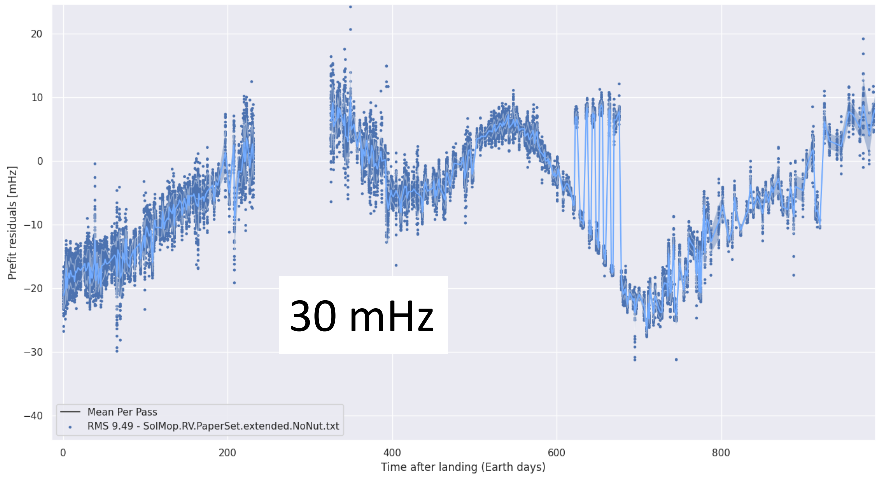
F and σ_{FCN} depend on

- moments of inertia of the fluid core
- Tidal and rotational deformation of the core

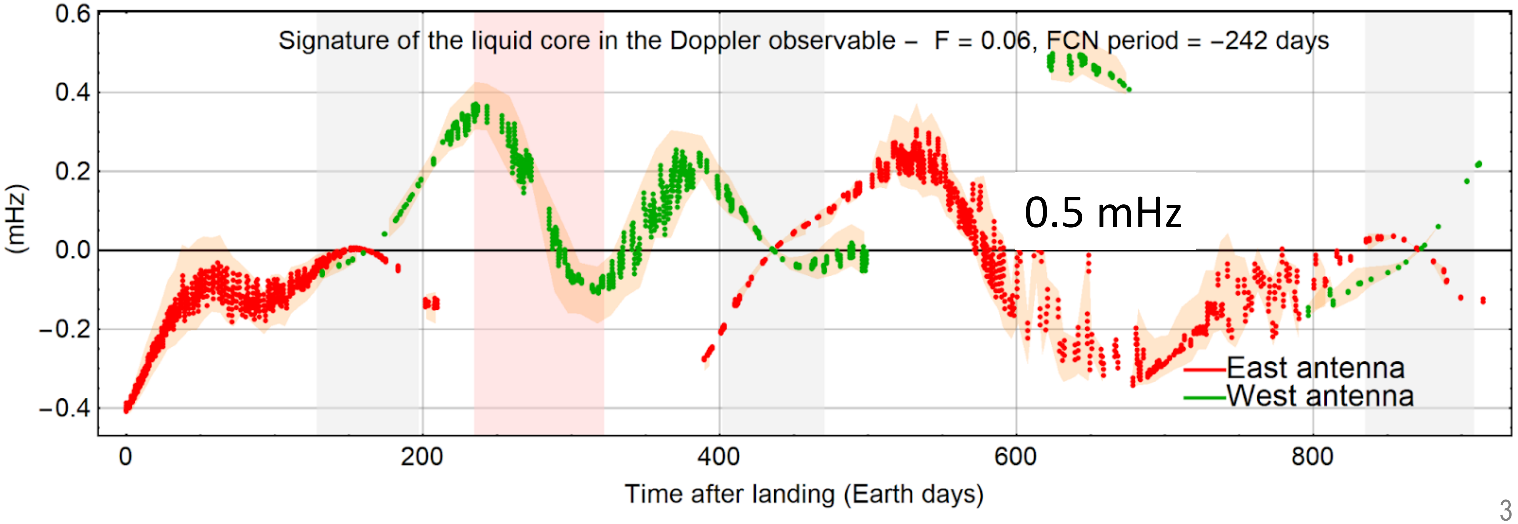
σ_{FCN} also depends on

- shape of the core

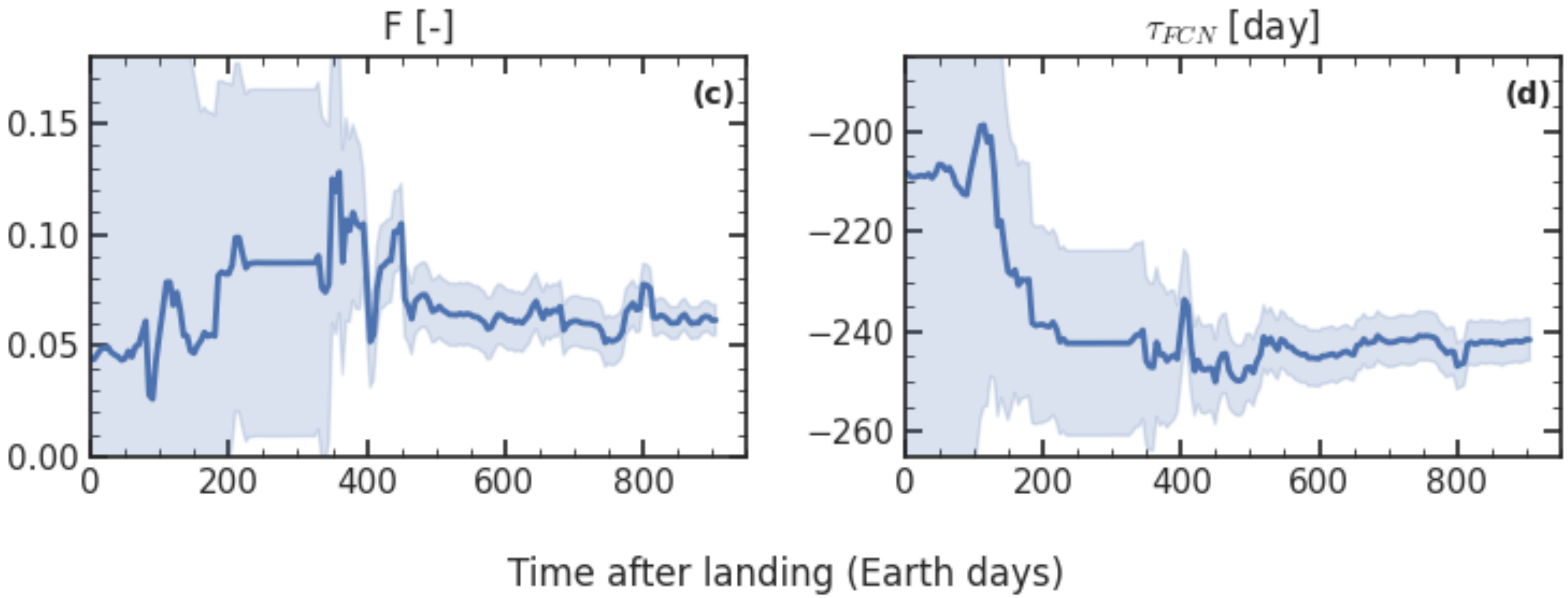
Full nutation contribution (N_m)



Liquid core contribution $\left(N_m - N_m^r\right)$



RISE nutation parameters estimate

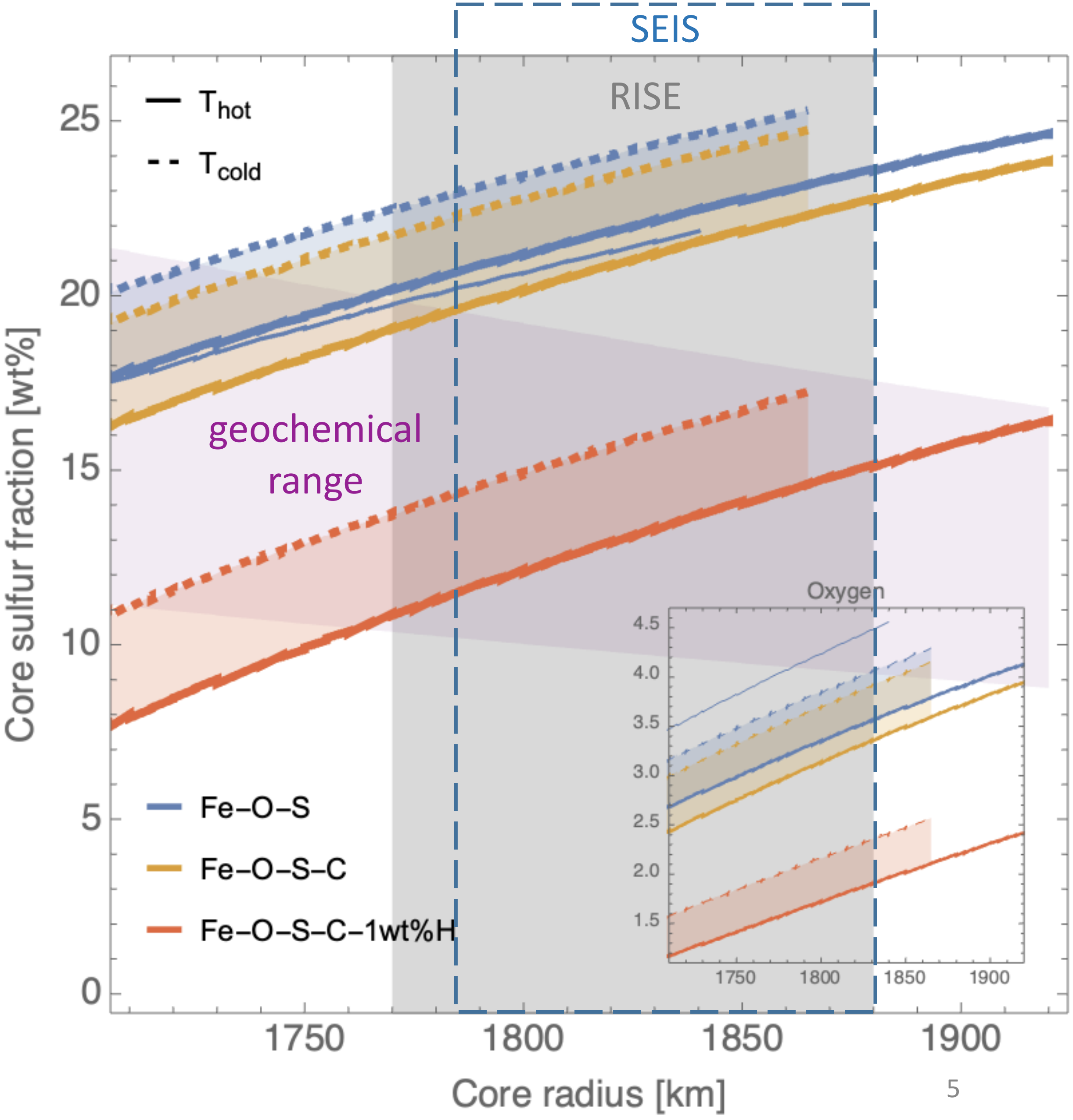


- >600 days of data are required to obtain robust estimates for the core amplification factor F and FCN period $\tau_{FCN} = 2\pi/\sigma_{FCN}$

- $F \simeq 0.06$ and $\tau_{FCN} \simeq -242$ days

Core radius and composition

- Inferred core range in excellent agreement with tidal measurements (e.g. Rivoldini et al. 2011) and seismic data (Stähler et al. 2021)
- Candidate light elements that are siderophile at core forming conditions: S, O, C, H
- RISE compatible models require >0.6wt% of H if S is in agreement with geochemical constraints



Core shape and internal mass anomalies

- FCN frequency proportional to core shape

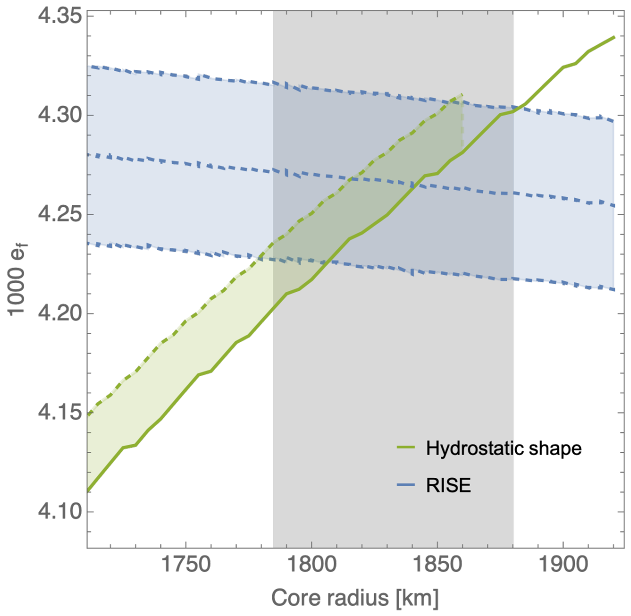
$$e_f = \frac{C_f - A_f}{A_f}$$

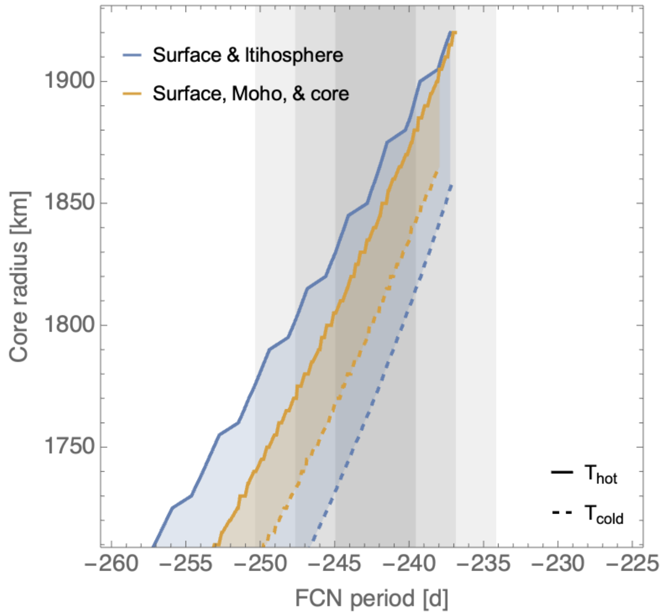
- RISE data implies a quasi-hydrostatic core shape, but the shape of Mars is not hydrostatic

  ➔ In order to match the shape of Mars and the shape of the core, we place

    either one load at the bottom of a thick lithosphere (>550km)

    or two loads at shallow depth and at the core-mantle boundary





Conclusions

- Detection of FCN normal mode
- Confirmation of the liquid state of the core
- Core radius in good agreement with tides and seismic data
- Quasi-hydrostatic shape of the core
- Shape of Mars and its core explained by mass anomalies within the mantle originating from thermal or chemical anomalies