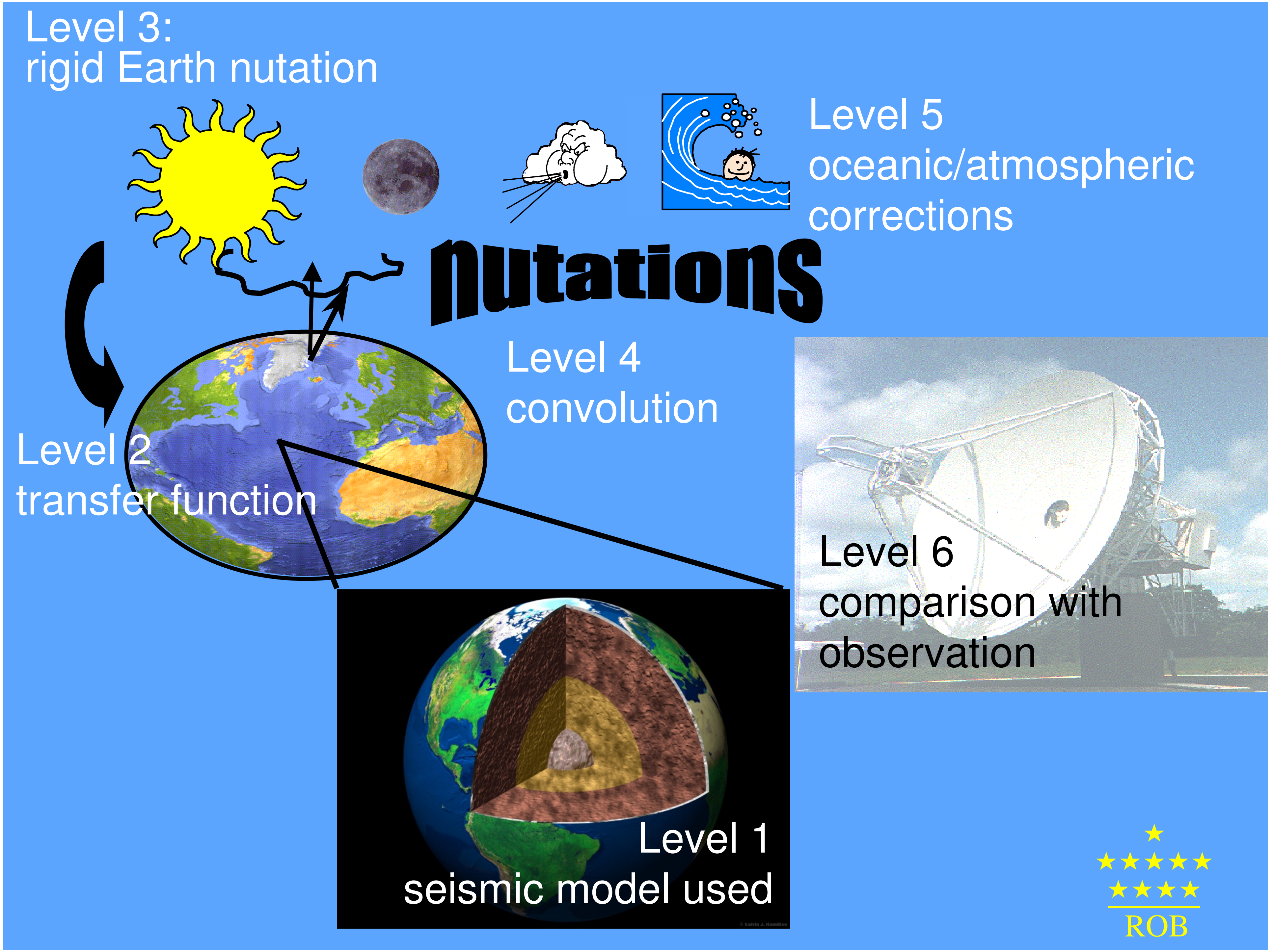
Recent advances in modeling precession-nutation

Véronique Dehant	ROB
Sébastien Lambert	OP
Nicolas Rambaux	ROB
Marta Folgueira	Madrid Univ
Laurence Koot	ROB

v.dehant@oma.be


Level 3:
rigid Earth nutation
Level 5
oceanic/atmospheric
corrections
nutations
Level 4
convolution
Level 2
transfer function
Level 6
comparison with
observation
Level 1
seismic model used
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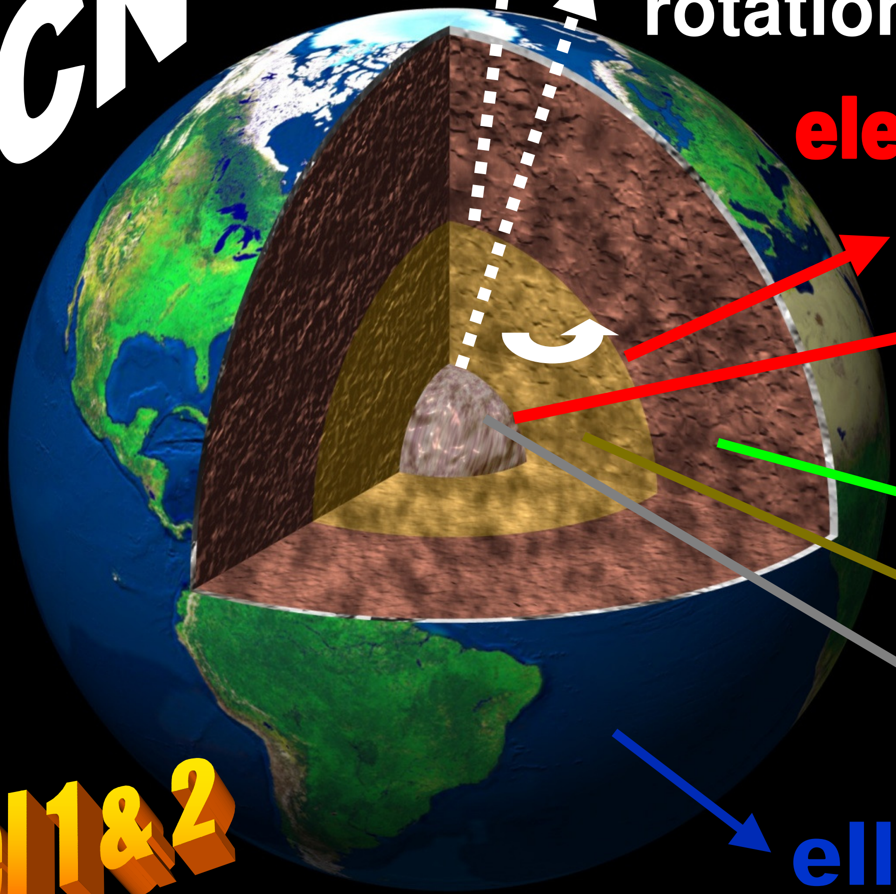
structure of the Earth's interior for its response

+ normal modes

FCN

rotation axis of the mantle

rotation axis of the core



electromagnetic coupling

non-hydrostatic CMB

flattening

(in)elastic mantle

liquid outer core

solid inner core

ellipsoidal Earth

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Level 1 & 2

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Descartes Fellows

- Laura Fernández
- Géraldine Bourda
- Yonghong Zhou
- Marta Folgueira
- Maciej Kalarus
- Sergei Bolotin
- Laurence Koot
- Kristyna Snajdrova
- Maria Kudryashova
- Sergei Bolotin
- Laurent Metivier
- Nicolas Rambaux
- Anna Korbacz
- Stefka Vojtech
- Alberto Escapa

• on FCN free mode observations,
• on combination of observations,
• on atmosphere angular momentum,
• on atmosphere effects on Earth orientation,
• on atmospheric and oceanic contributions to nutation
• relations between the Earth Orientation Parameters (EOP) and the variations of the Earth gravity field,
• on sub-diurnal Earth orientation and rotation variations,
• on finite method for coupling mechanisms,
• on dissipative and excitation mechanisms,
• on the expression of EOP in terms of CIP-*X* and *Y* rectangular coordinates,
• on influence of a non-barycentric frame on the Earth rotational motion

VLBI OBSERVATION STRATEGY

1. SOURCES STABILITY

from ICRF, stable sources, structure index, no rotation condition, sources observed in more than 40 sessions, sources considered with local/global parameters, elevation cutoff …

2. NETWORK CHOICE

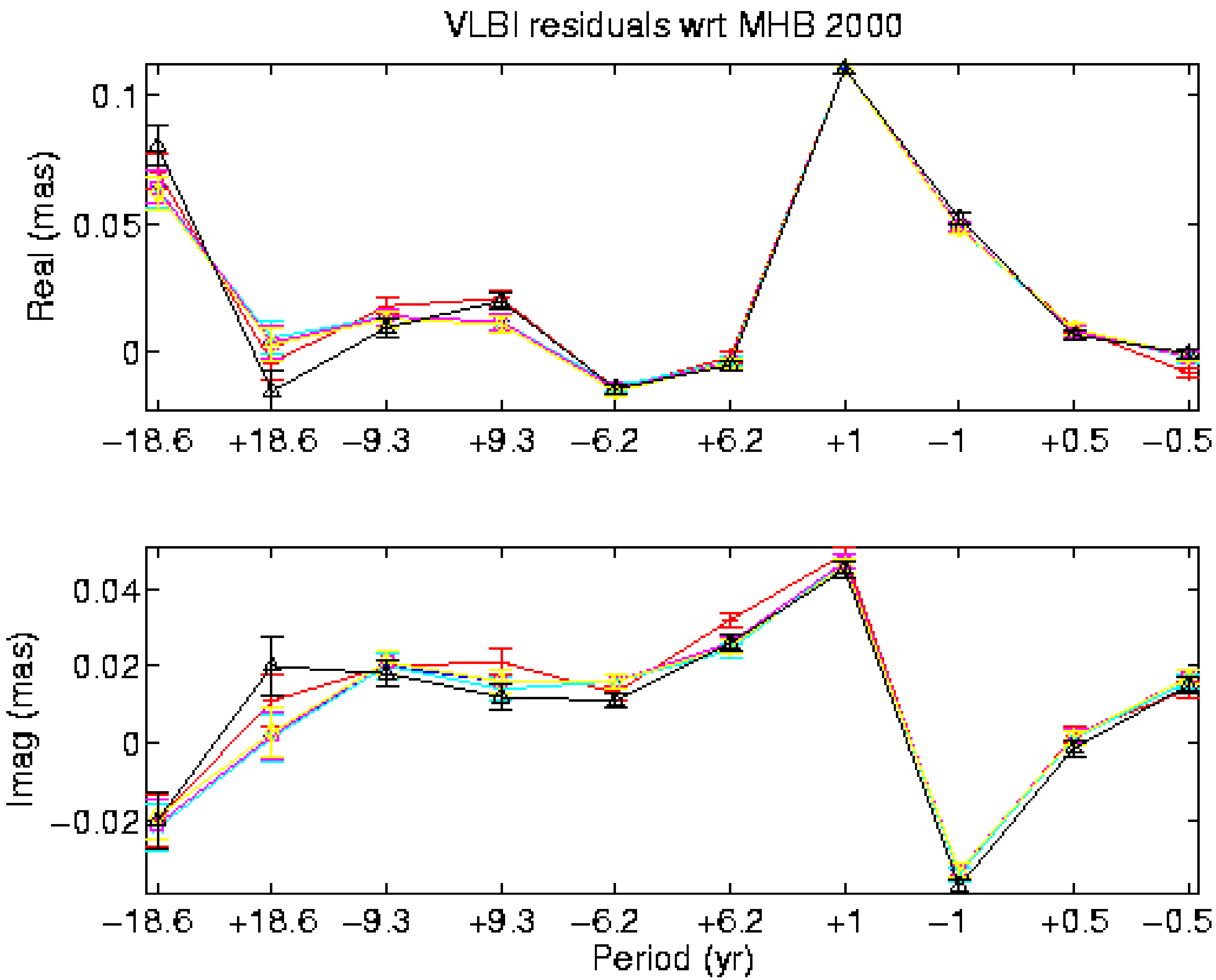
R1/R4 networks

See Lambert et al., this session

Also session from yesterday

What are the residuals?

- VLBI observations with the different strategies – MHB2000 model (without atmospheric corrections)
- What remains should be due to the atmosphere
- What do we see?

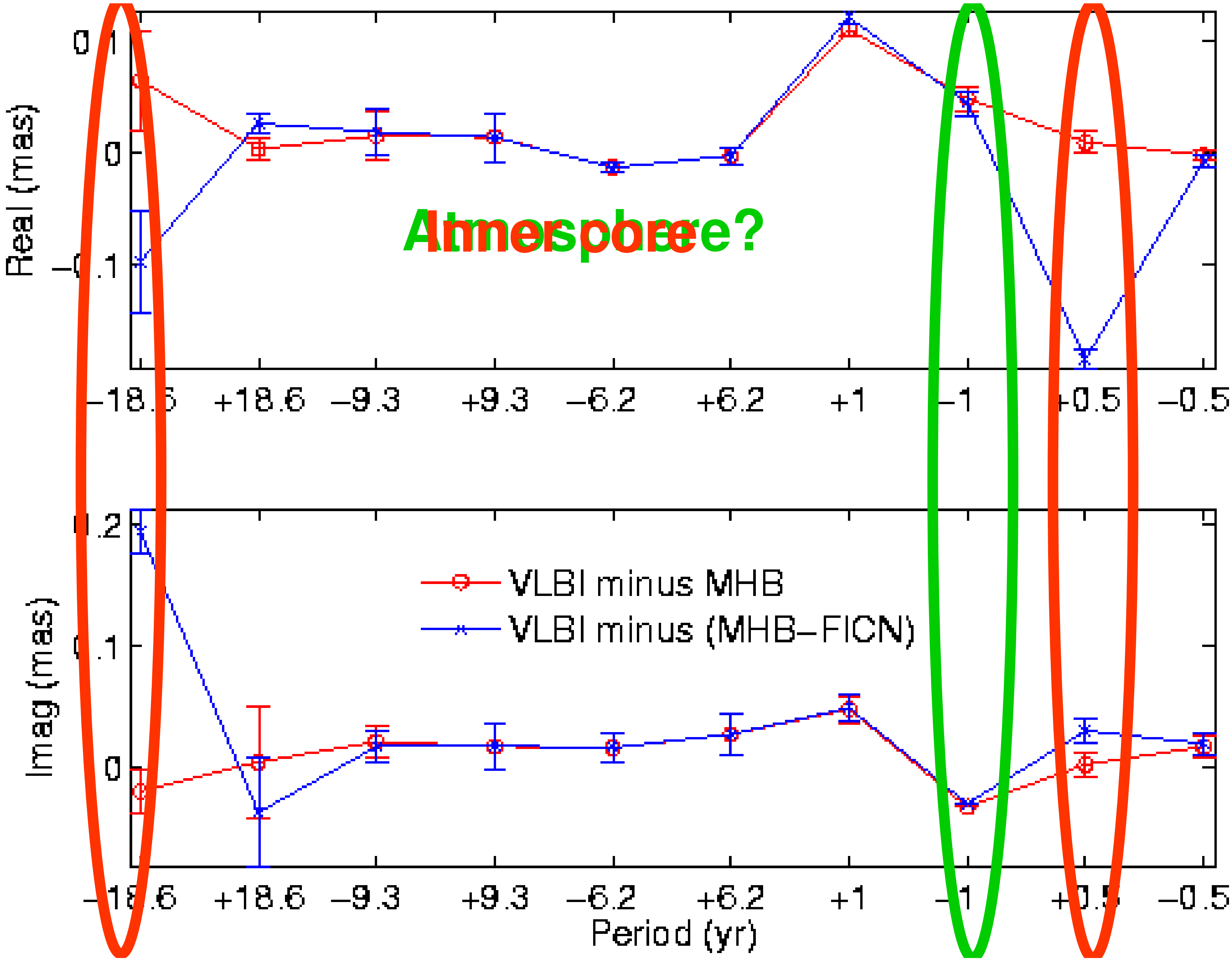

VLBI residuals wrt MHB 2000
Real (mas)
0.1
0.05
0
Imag (mas)
0.04
0.02
0
−0.02
−18.6
+18.6
−9.3
+9.3
−6.2
+6.2
+1
−1
+0.5
−0.5
Period (yr)

Now let us consider that the model used has no inner core

- VLBI observations with the different strategies – modified MHB2000 model (with atmospheric corrections at the prograde annual period and without inner core)

transfer function $= R_0 + R_1\sigma + \dfrac{R_{FCN}}{\sigma - \sigma_{FCN}} + \cancel{\dfrac{R_{FICN}}{\sigma - \sigma_{FICN}}} + \dfrac{R_{CW}}{\sigma - \sigma_{CW}}$

- What remains should be due to the atmosphere (except at prograde annual period) and inner core contributions
- What do we see?



Atmosphere?
Inner core
Real (mas)
0.1
0
−0.1
−18.6
+18.6
−9.3
+9.3
−6.2
+6.2
+1
−1
+0.5
−0.5
VLBI minus MHB
VLBI minus (MHB−FICN)
Imag (mas)
0.2
0.1
0
Period (yr)

Geophysial parameters (direct link)

- Link between the FCN frequency and the core flattening and electromagnetic coupling at the **CMB** and the **ICB**

$$\sigma_{FCN}^{\mathrm{Re}} = -\Omega\left(1+\frac{A}{A_m}\left[\alpha_f - \frac{q_0}{2}\bar{h}_f + K_{CMB}^{\mathrm{Re}} + \frac{A_s}{A_f}K_{ICB}^{\mathrm{Re}}\right]\right)$$

$$\sigma_{FCN}^{\mathrm{Im}} = -\Omega\frac{A}{A_m}\left(K_{CMB}^{\mathrm{Im}} + \frac{A_s}{A_f}K_{ICB}^{\mathrm{Im}}\right)$$

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Geophysial parameters (direct link)

- Link between the FICN frequency and the inner core flattening and electromagnetic coupling at the ICB

$$\sigma_{FICN}^{\mathrm{Re}} = -\Omega\left(1 - \left[\alpha_s e_s + \upsilon_s - K_{ICB}^{\mathrm{Re}}\right]\right)$$

$$\sigma_{FICN}^{\mathrm{Im}} = -\Omega K_{ICB}^{\mathrm{Im}}$$

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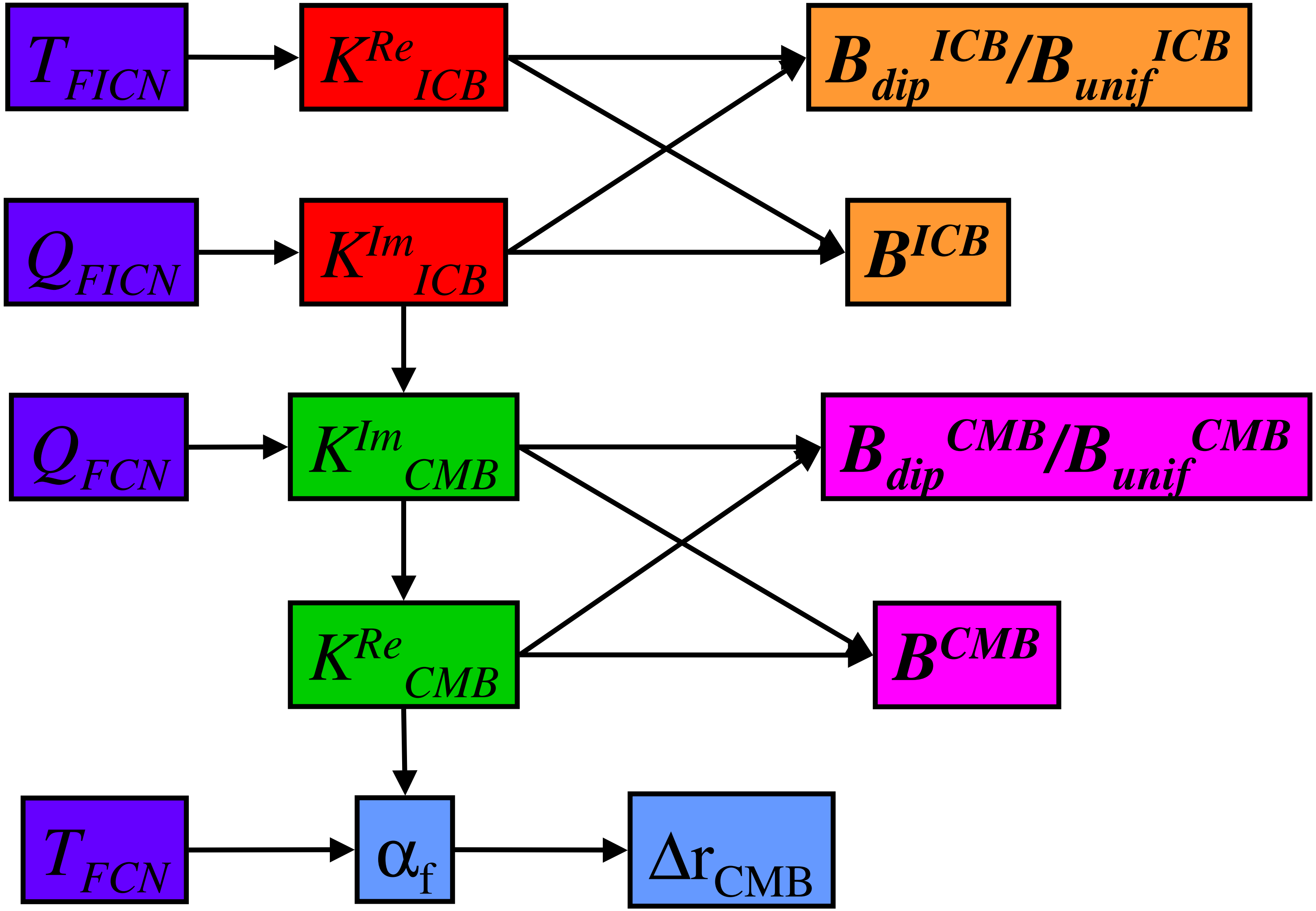

T_{FICN}
$K^{Re}{}_{ICB}$
$B_{dip}{}^{ICB}/B_{unif}{}^{ICB}$
Q_{FICN}
$K^{Im}{}_{ICB}$
B^{ICB}
Q_{FCN}
$K^{Im}{}_{CMB}$
$B_{dip}{}^{CMB}/B_{unif}{}^{CMB}$
$K^{Re}{}_{CMB}$
B^{CMB}
T_{FCN}
α_f
Δr_{CMB}

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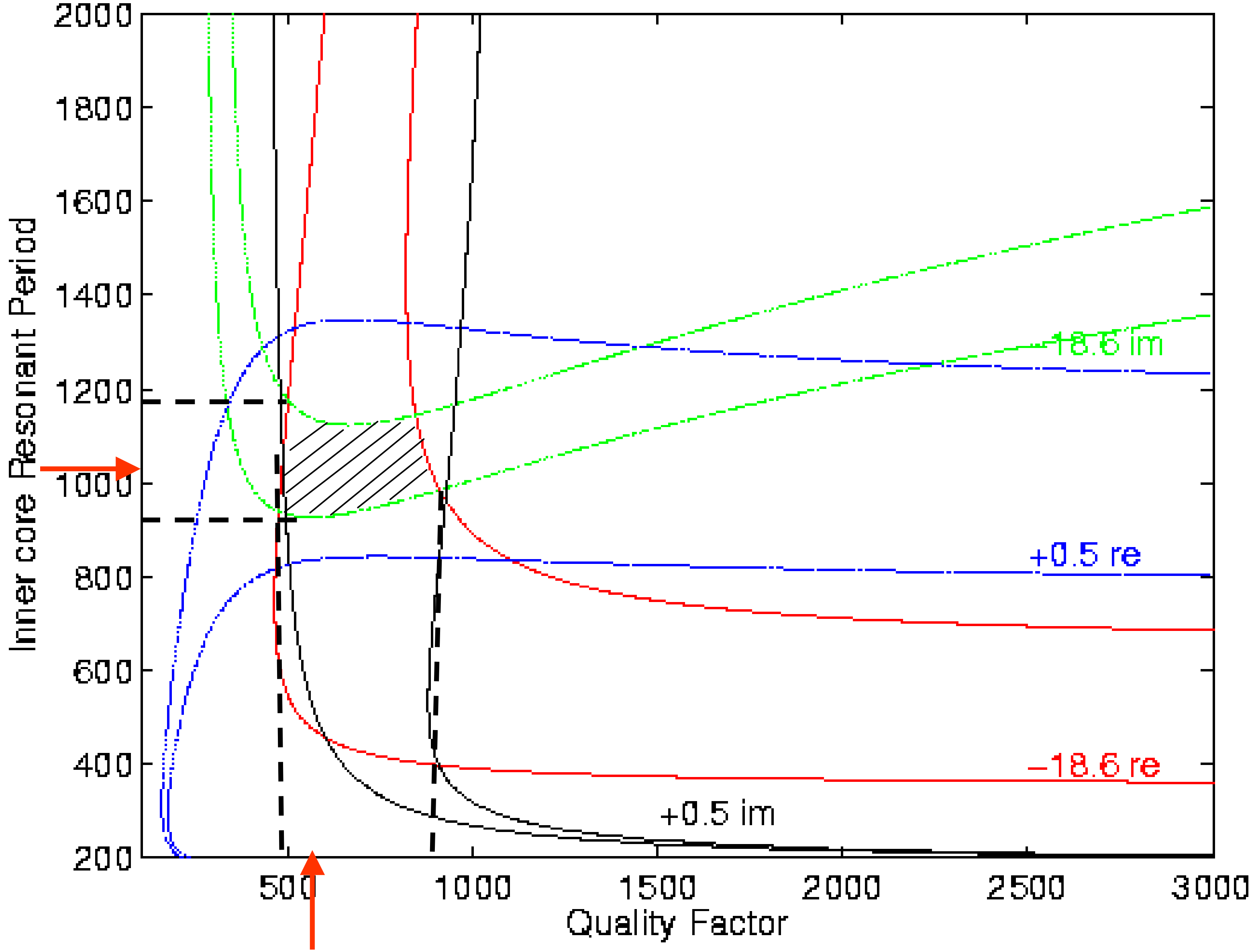
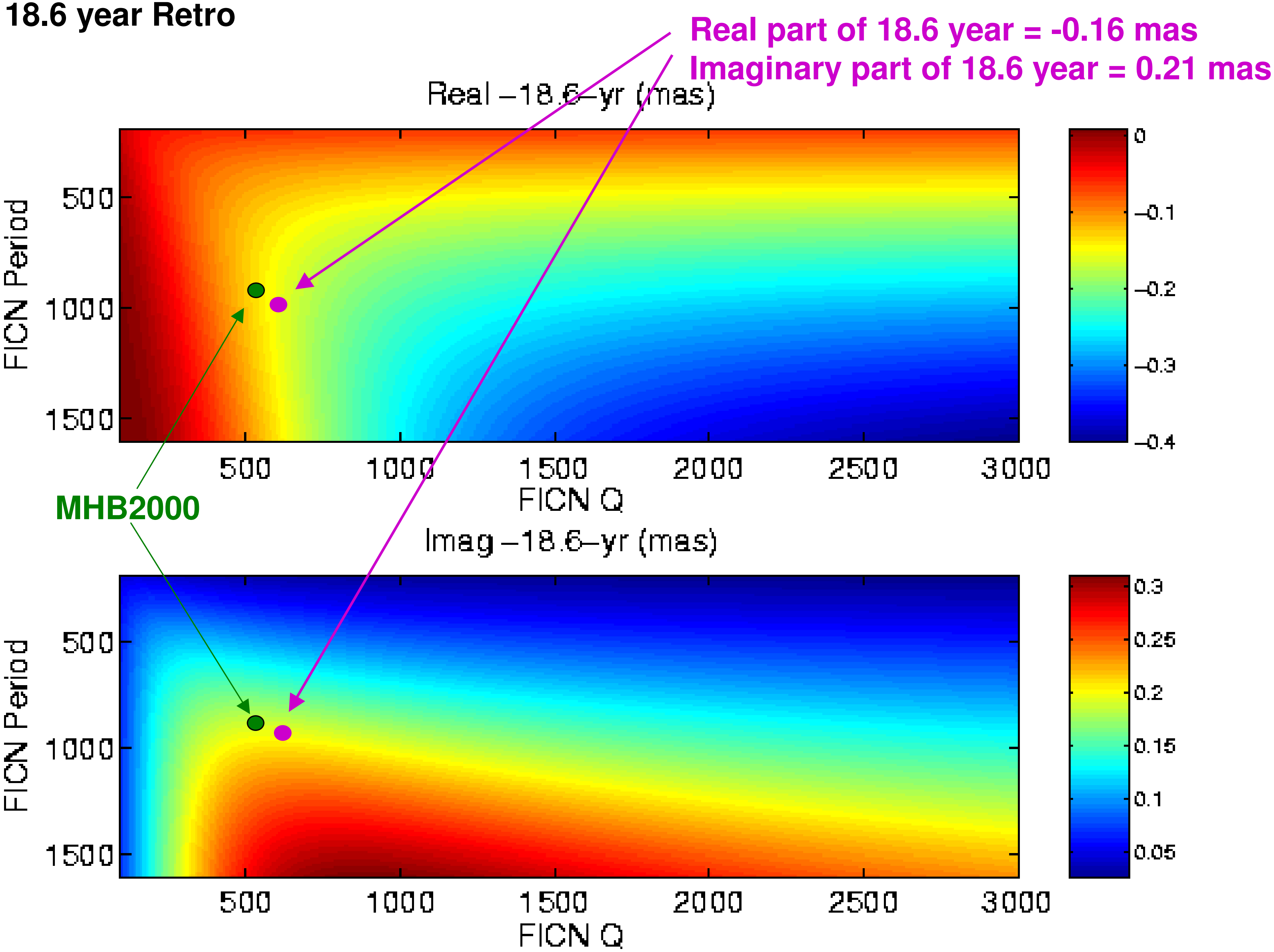
Within the residuals (all VLBI strategies), where can we find the inner core parameters?



Contribution of the FICN on the nutations

$$\textbf{transfer function} = R_0 + R_1\sigma + \frac{R_{FCN}}{\sigma - \sigma_{FCN}} + \frac{R_{FICN}}{\sigma - \sigma_{FICN}} + \frac{R_{CW}}{\sigma - \sigma_{CW}}$$

18.6 year Retro



VLBI OBSERVATION STRATEGY

3. NEW APPROACH

take the classical series or any other but fit the parameters in the time domain, and get probability distribution on the parameters…

See Koot et al., this session

Main results

- Bayesian approach in the time domain
- Almost all the same parameter values as MHB
- Particularly important changes for global flattening, inner core FICN frequency and quality factor
- Frequency approach: correlation between amplitudes of the nutations (ex: 9.3 and 18.6 years)
- Time approach: correlations between basic Earth parameters : probabilistic approach in which one uses the direct problem
- Lower uncertainties on the parameters related to a longer data set and the accounting of the error on the nutation in the time domain

THEORY

1. IMPROVEMENT IN RIGID NUTATION

consider all coupling mechanism between tides and nutation (Lambert & Mathews)

consider all coupling mechanism in the Poisson terms of the potential (Folgueira et al.)…

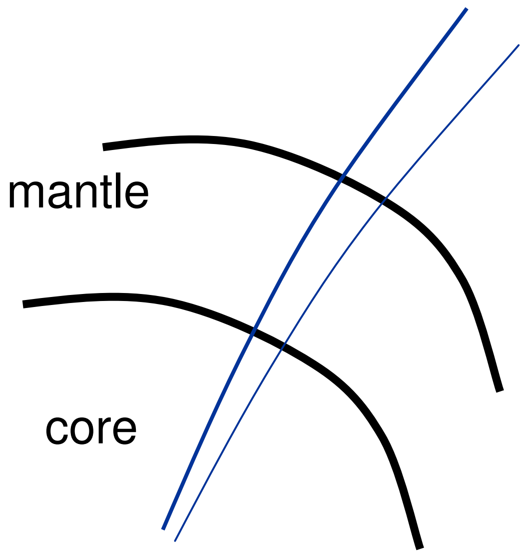
THEORY

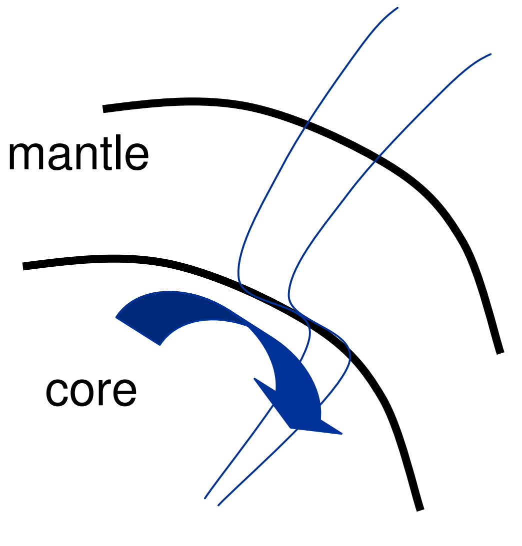
2. IMPROVEMENT IN NON-RIGID TRANSFER FUNCTION

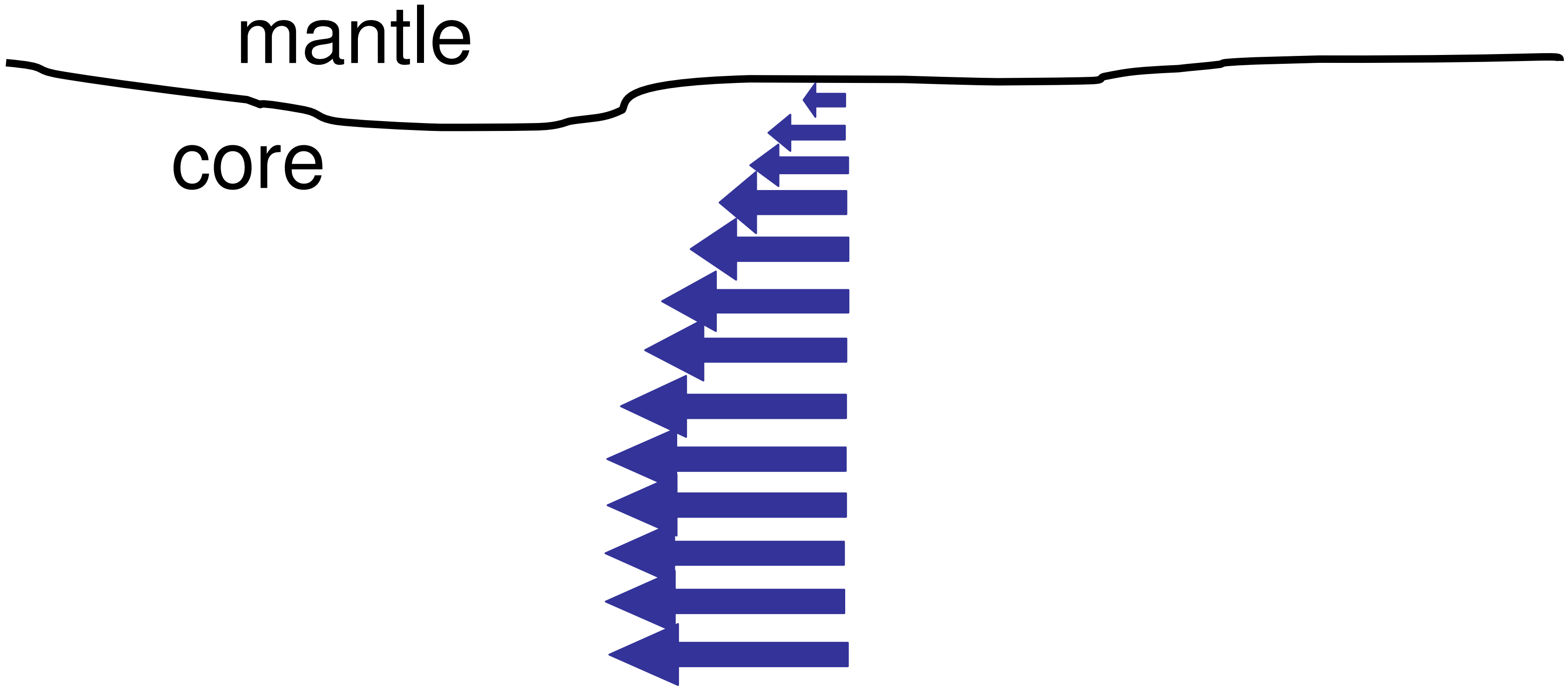
consider all possible coupling mechanisms at CMB and ICB:

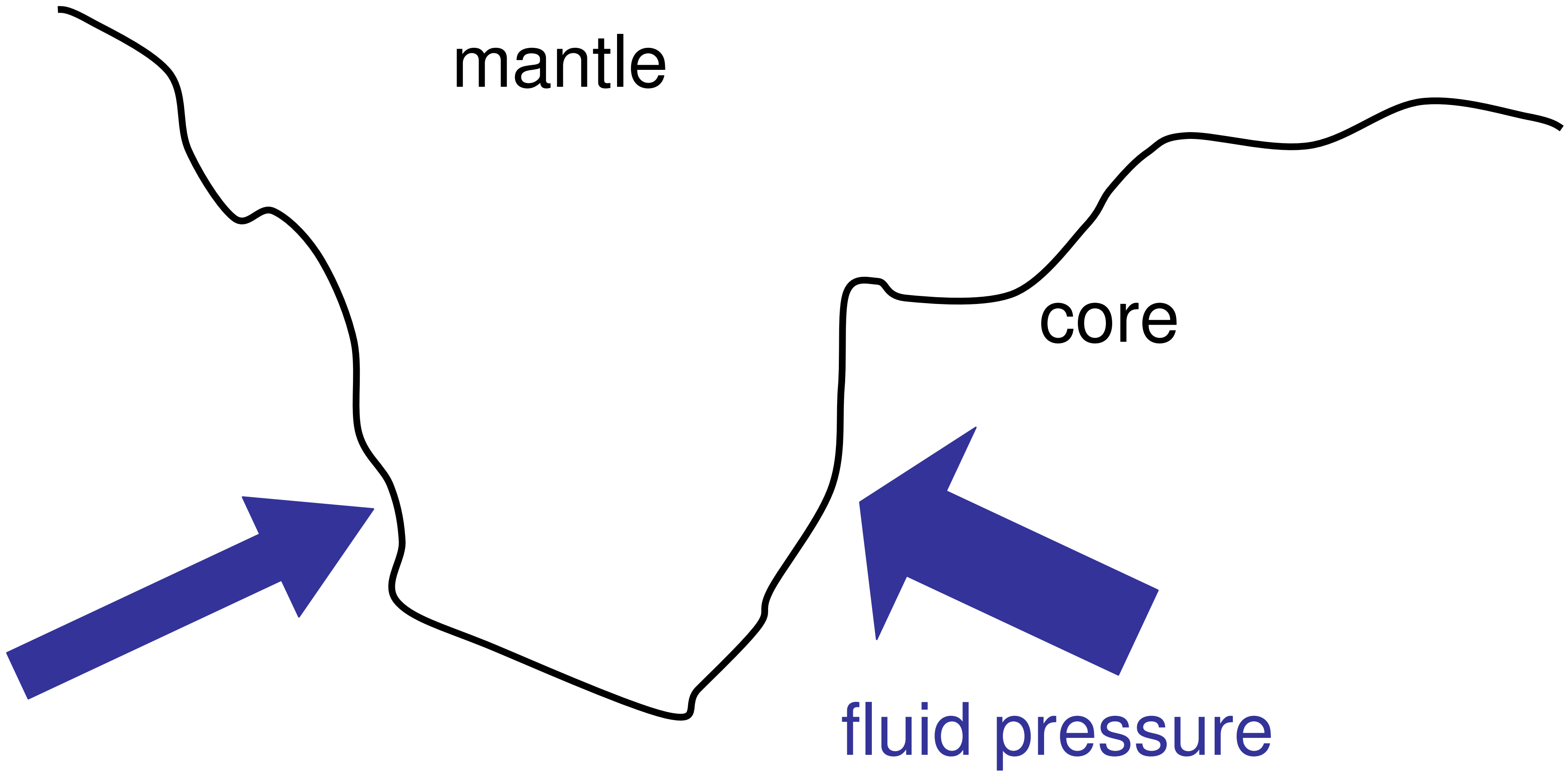
- electromagnetic
- viscous
- topographic

See Folgueira et al., poster of this session


mantle
core


mantle
core

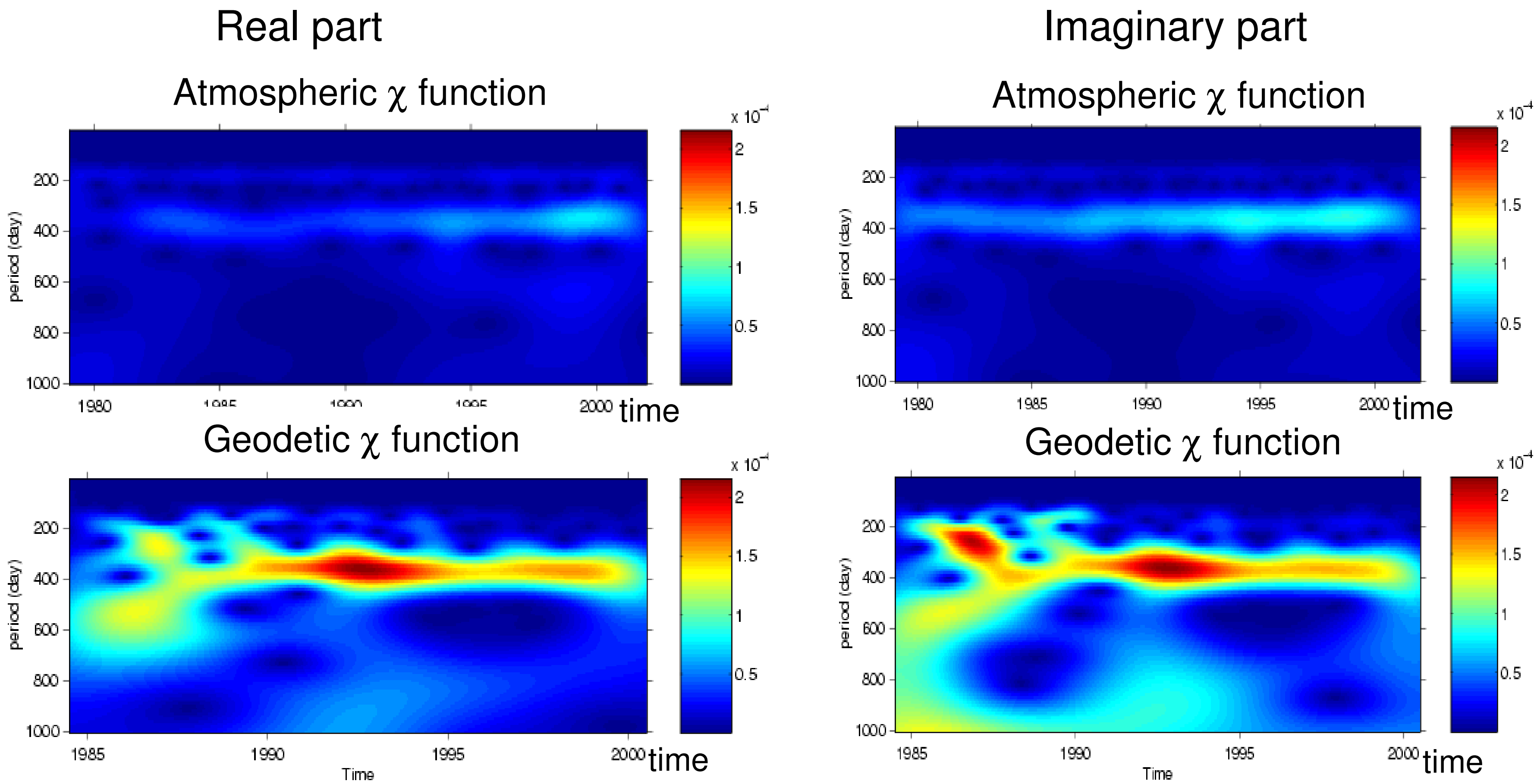

mantle
core


mantle
core
fluid pressure

OBSERVATION/THEORY

1. IMPROVEMENT IN ATMOSPHERIC CORRECTION

needs to have improvements in angular momentum of the atmosphere


Real part
Imaginary part
Atmospheric χ function
Geodetic χ function
period (day)
200
400
600
800
1000
1980
1985
1990
1995
2000
time
Time
x 10⁻⁴
2
1.5
1
0.5

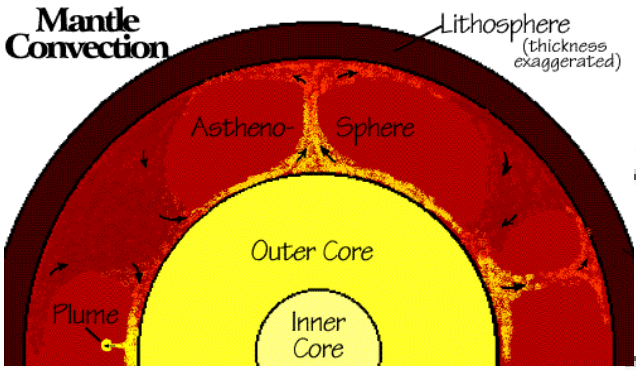
OBSERVATION/THEORY

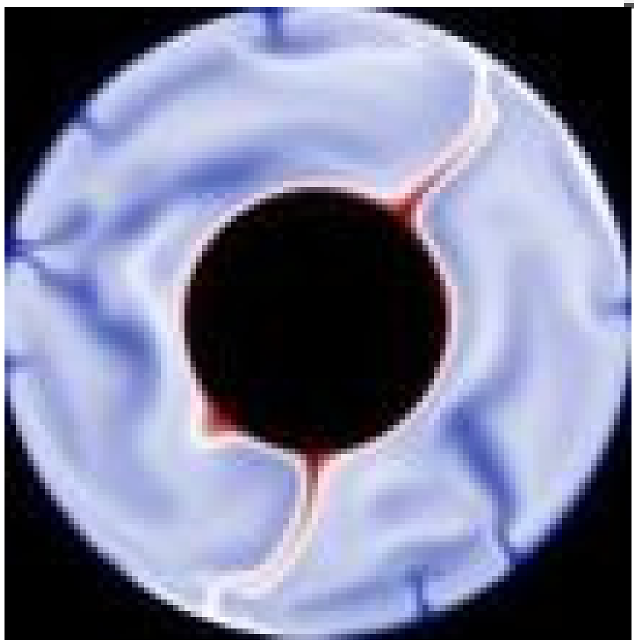
2. IMPROVEMENT IN MASS TRANSFER UNDERSTANDING

not only the atmosphere plays a direct role on the nutation but the J2 changes and the nutations may be related, via the dynamical flattening entering in nutation modeling

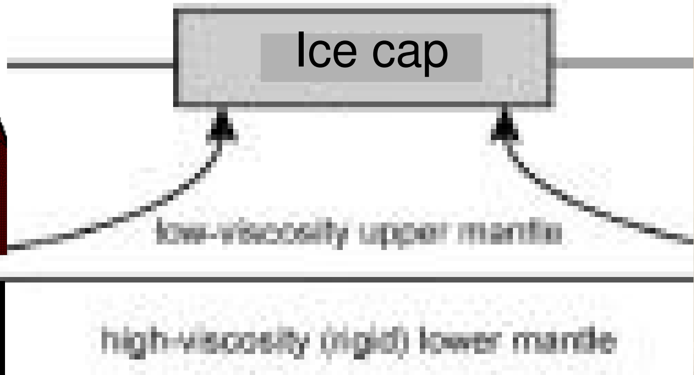
Mass changes (1)

Mantle convection

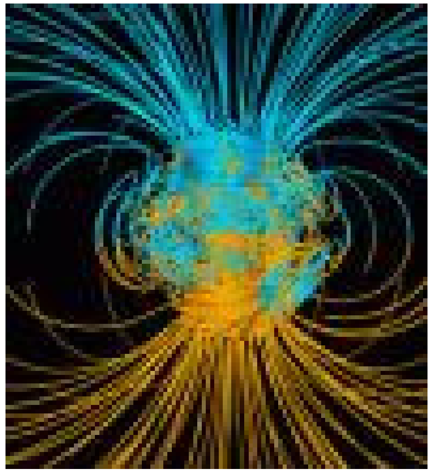




Post-glacial rebound

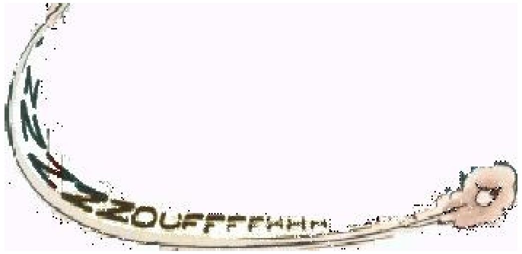


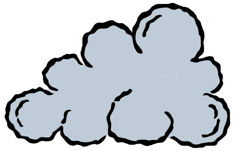
Core flow

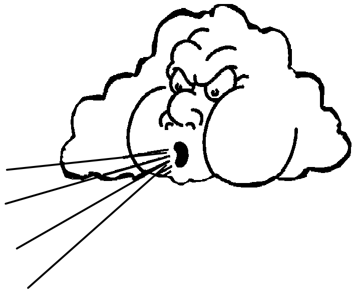


Mass changes (2)

Atmosphere







Ocean

hydrology

OBSERVATION/THEORY

2. IMPROVEMENT IN FREE MODE MODELING

can not be modeled,
needs to be estimated from epoch to epoch

See Lambert's work, IERS conventions
+ Descartes Fellows

Conclusions (1)

- Rigid nutations are well determined;
- The FCN frequency is quite well determined from VLBI observations, even if we consider different strategies for computing nutation series, or even considering atmospheric contamination of the amplitudes (not shown in this talk);
- The 18.6 year retrograde nutation is the key nutation for getting the right FICN parameters; the 0.5 year prograde nutation also helps;
- Different strategies for VLBI observations provide 18.6 year retrograde nutation amplitudes different with respect to MHB2000 at the level of 60-70 μas;
- The FICN frequency and quality factor are not very well constrained; VLBI observations still need improvement;

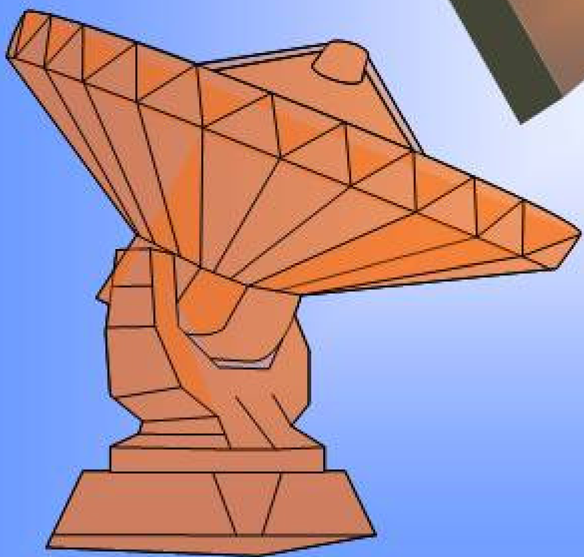
Conclusions (2)

- The time domain approach looks very promising;
- The FCN free mode needs to be observed and determined;
- The atmosphere effects may be large and needs to be improved; nutations need to be corrected for;
- Many possibilities for the magnetic field deduced when considering error bars on the observed value;
- Other coupling mechanisms need to be considered; we believe in particular that the topographic coupling might be important; the triaxiality must be considered at the present-day level of precision.

Perspectives for the planet Mars

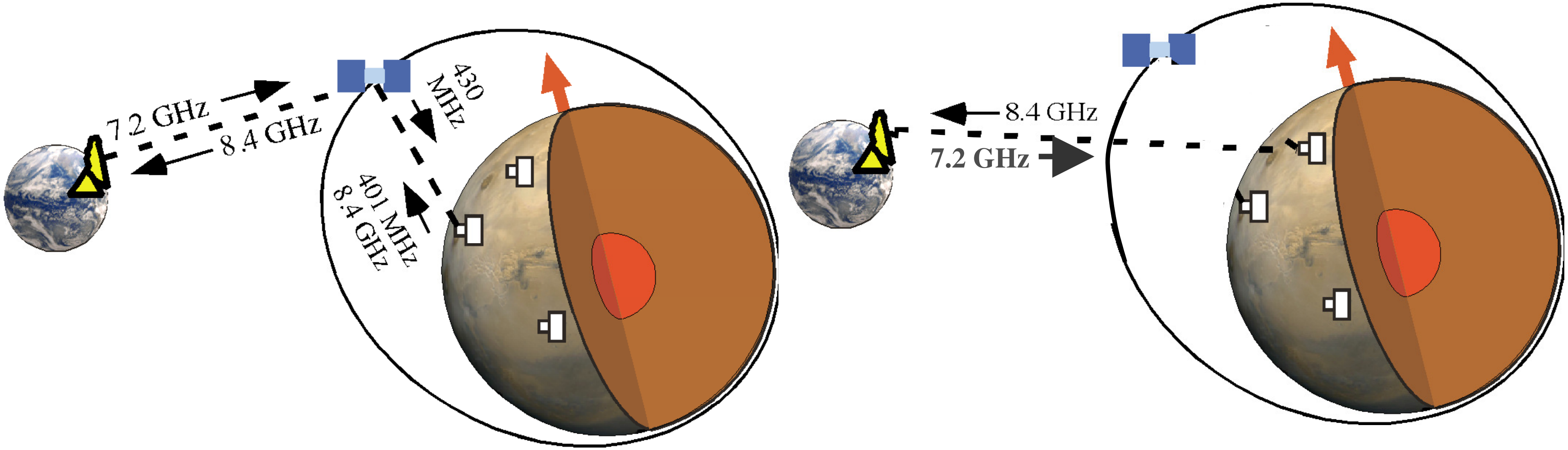
ExoMars/GEP Lander Radioscience LaRa, a Space Geodesy Experiment to Mars

Lander
Radioscience

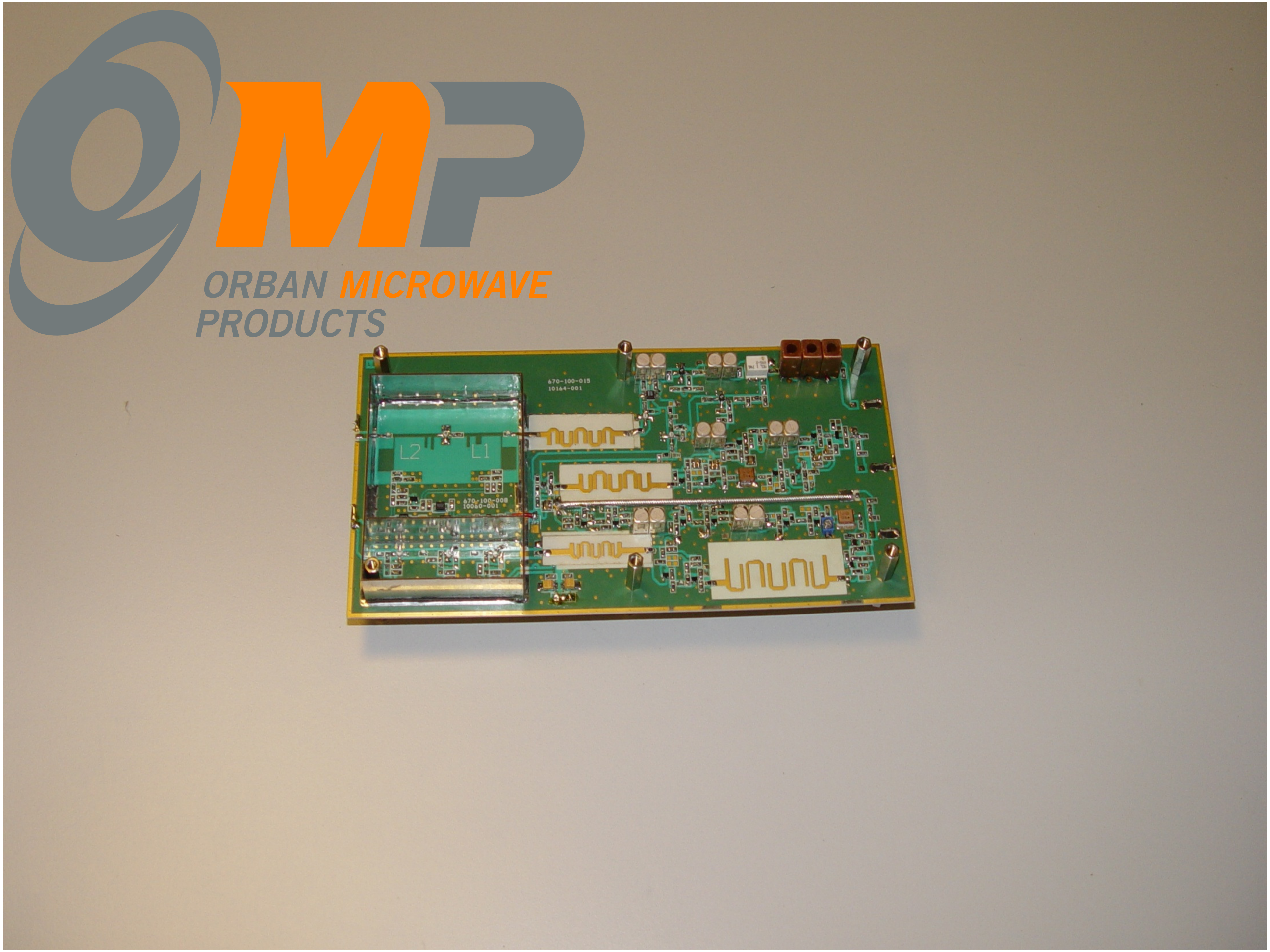


Dehant V., Folkner W., Renotte E., Orban D., Le Maistre S., and the LaRa Team

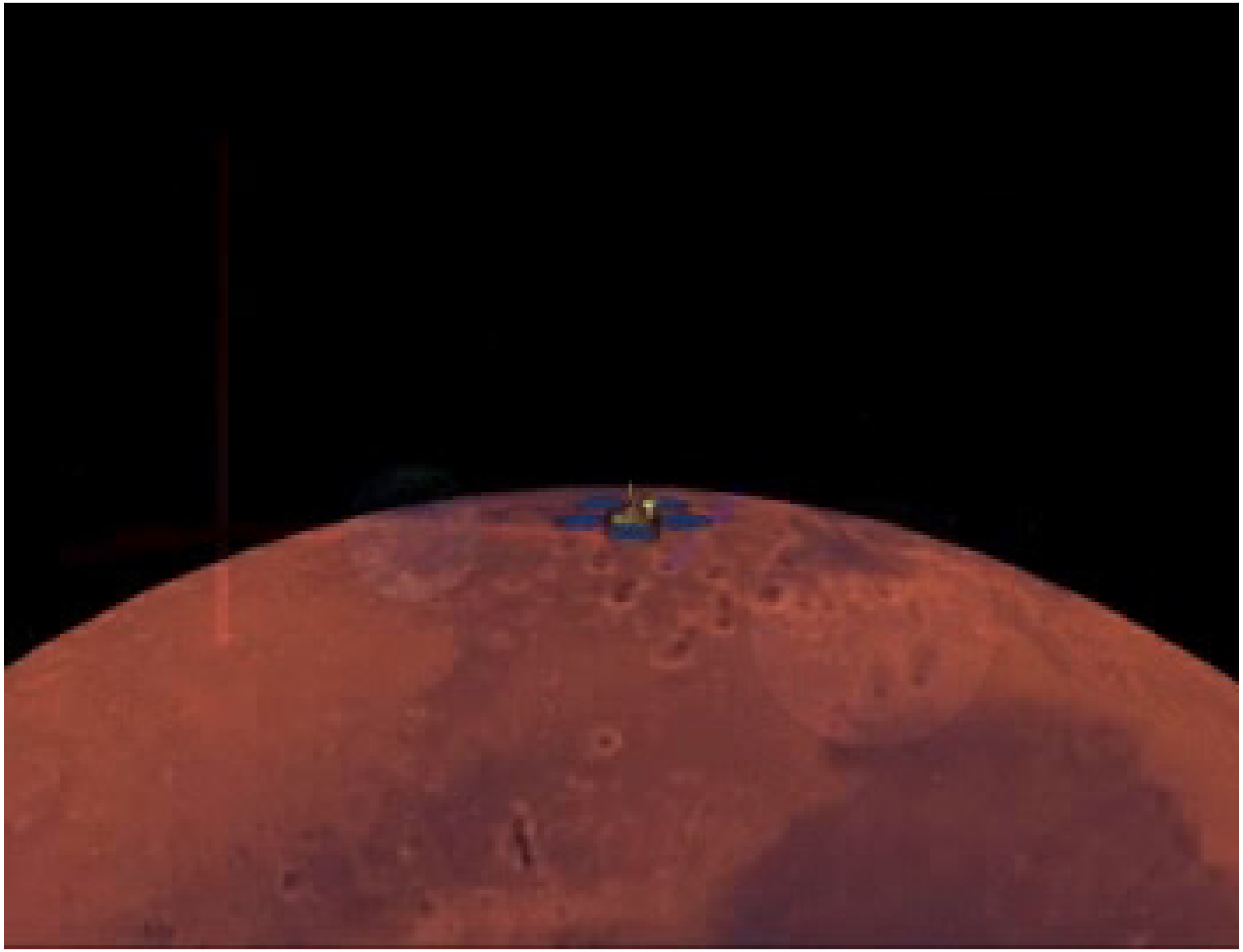
Also possible: a direct link with the Earth!



ORBAN MICROWAVE PRODUCTS



Measuring Doppler shifts on Lander-Orbiter link Lander-Earth link



≈ Projection of relative velocity on line-of-sight Lander-Orbiter

$$\text{Dop.} = \frac{\Delta \vec{V} \cdot \Delta \vec{R}}{\left|\Delta \vec{R}\right|}$$

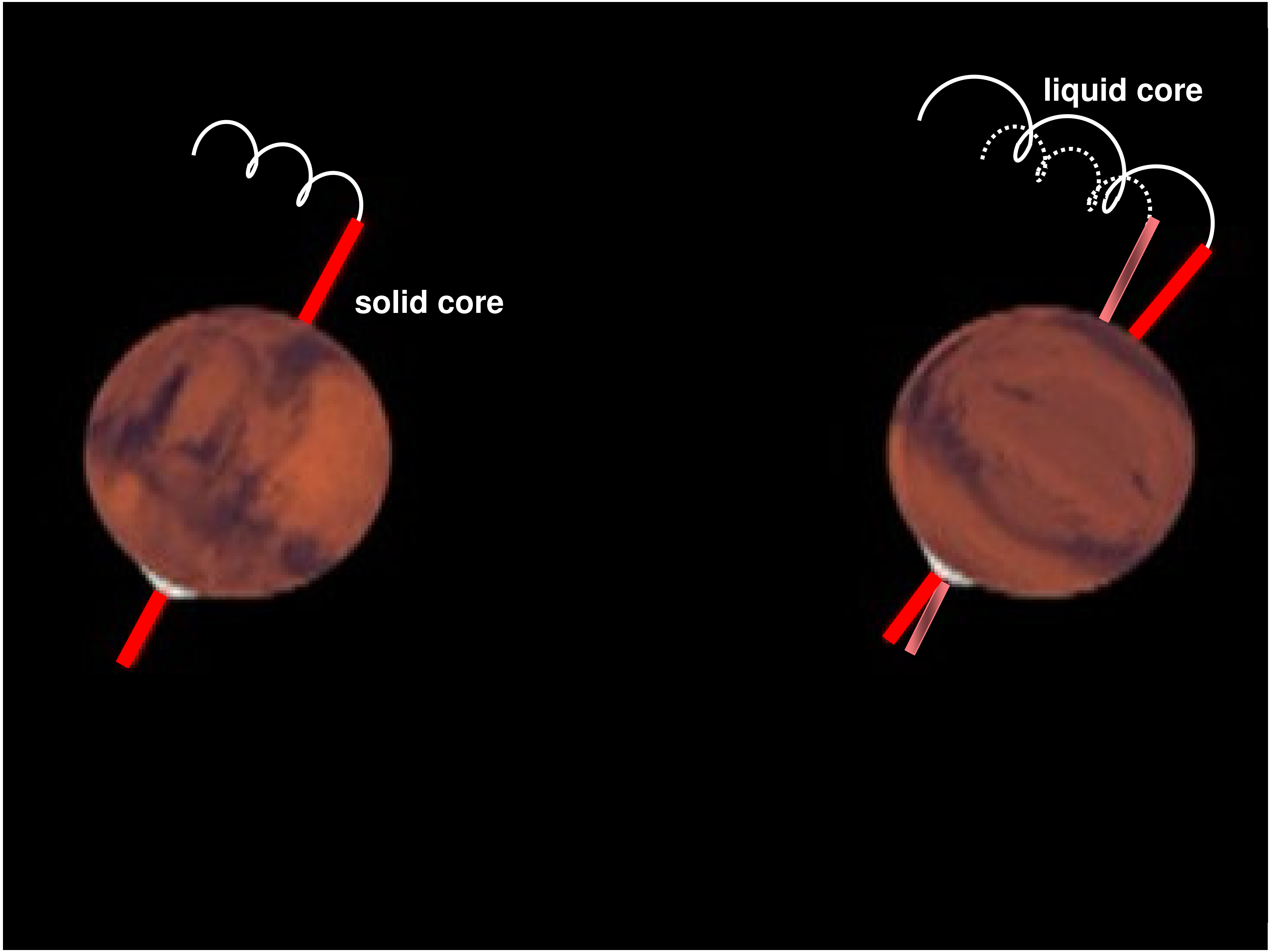
Objectives

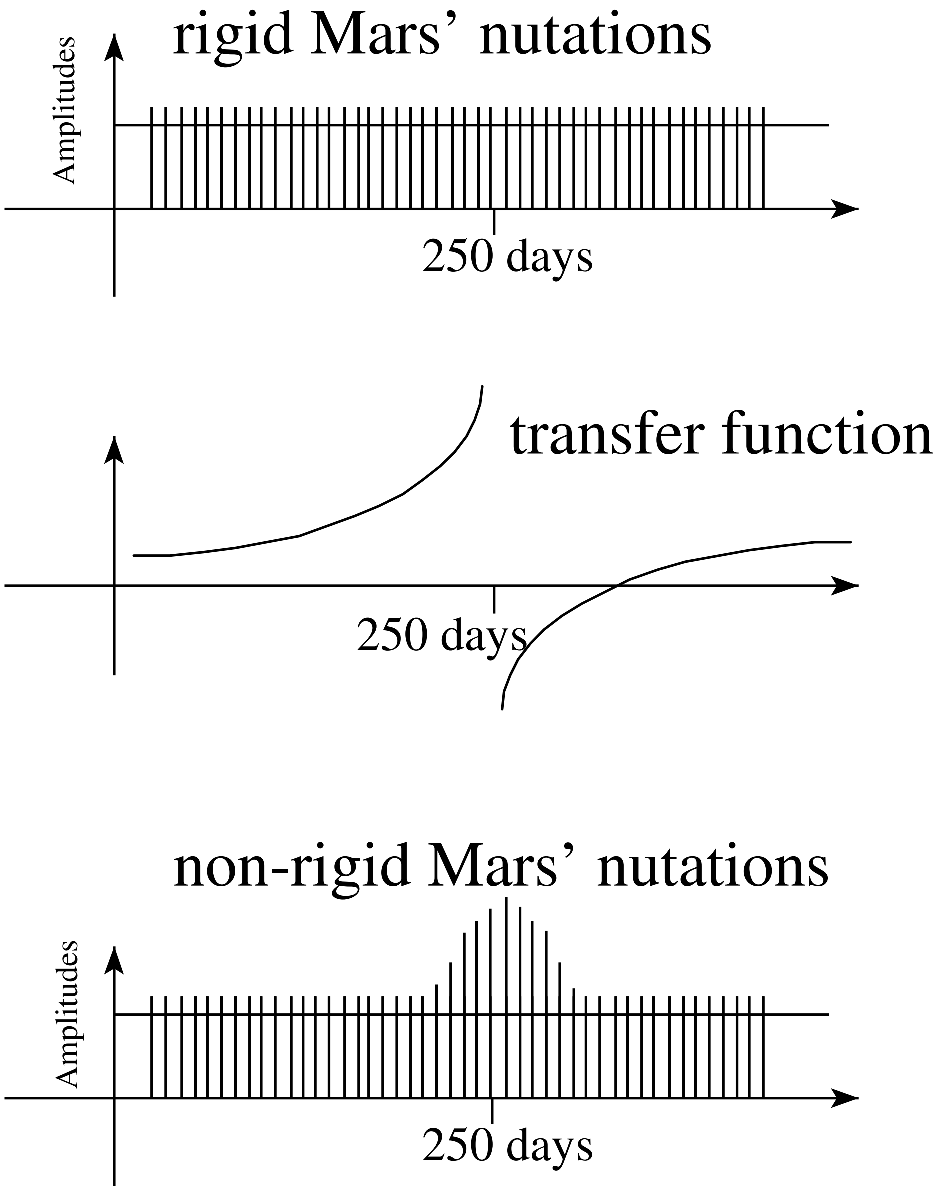
Rotation variations

- Orientation in space: precession/nutation
- Orientation in planet: polar motion
- Rotation speed: length-of-day variations

Þ Modeling of

- Interior of planets
- Atmosphere dynamics (CO_2 sublimation/ condensation process)


solid core
liquid core



IMPORTANT FOR:

- retrograde ter-annual nutation
- retrograde semi-annual nutation
- retrograde 1/4 year nutation
- prograde semi-annual nutation

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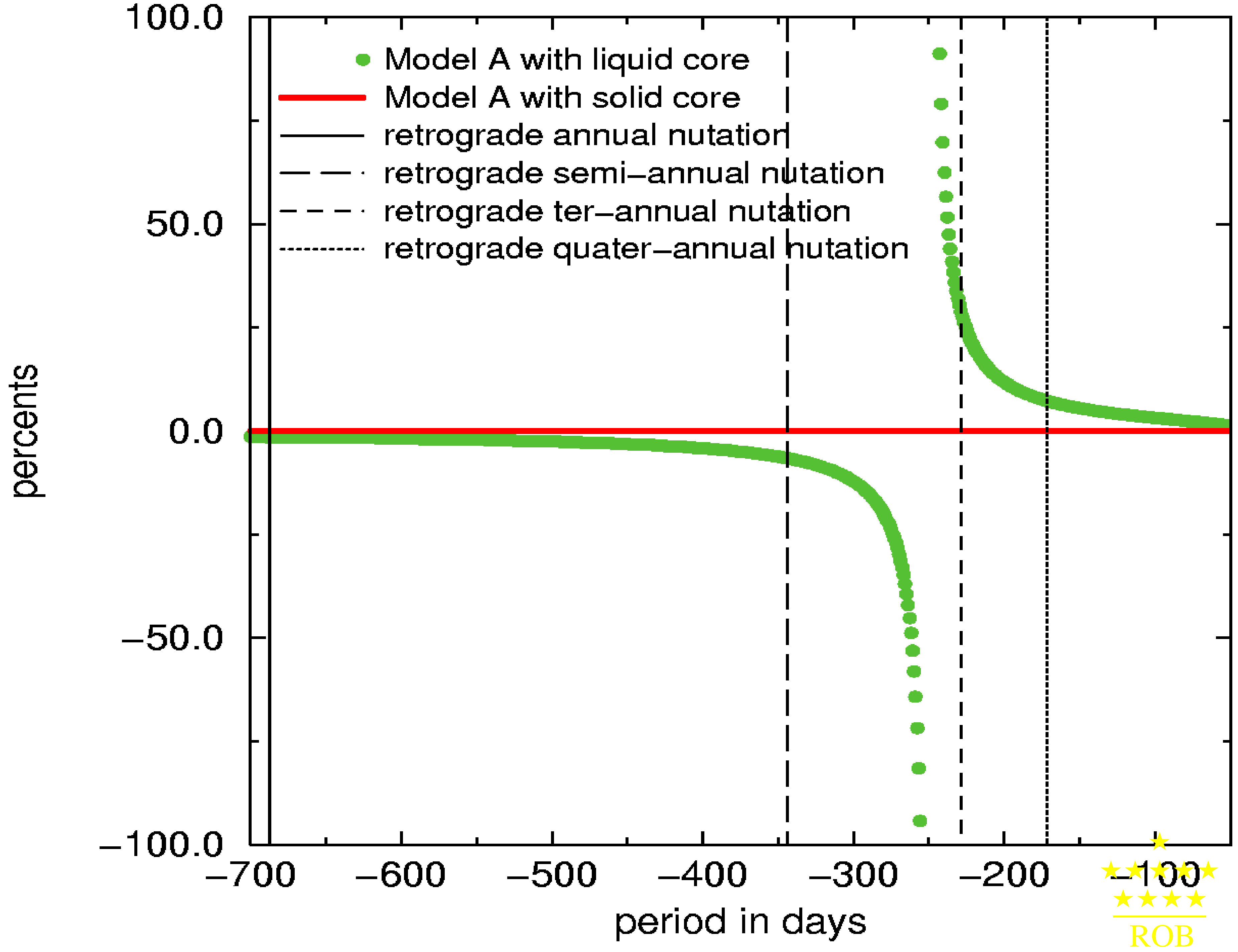
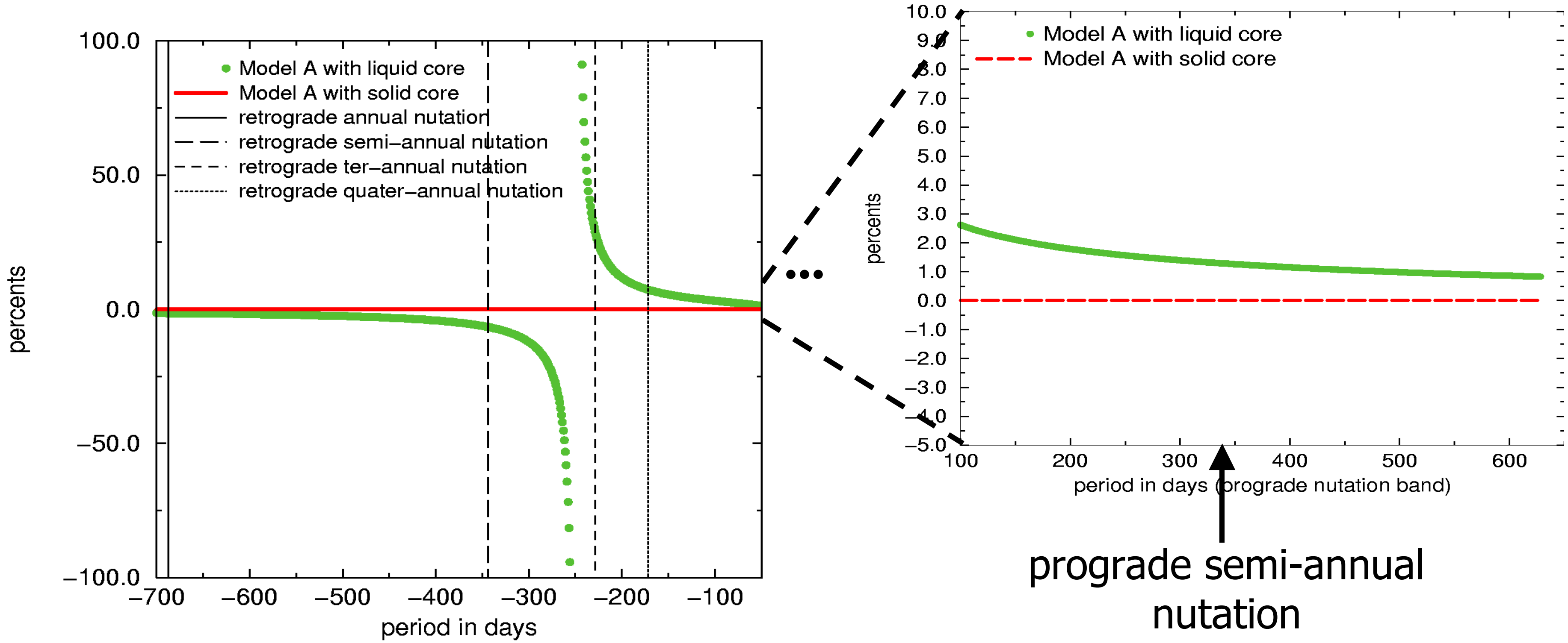
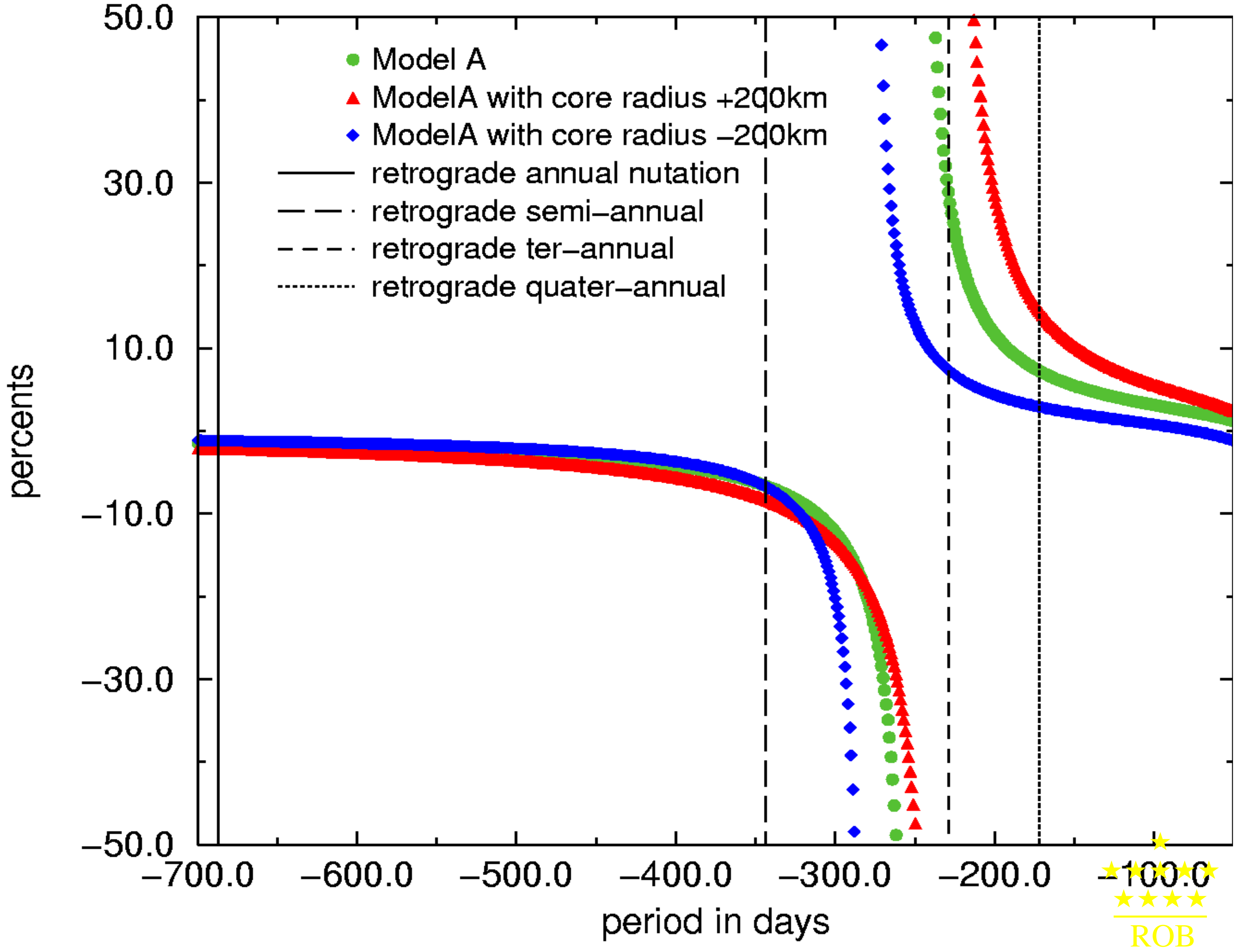


Model A with liquid core
Model A with solid core
retrograde annual nutation
retrograde semi–annual nutation
retrograde ter–annual nutation
retrograde quater–annual nutation
100.0
50.0
0.0
–50.0
–100.0
percents
–700
–600
–500
–400
–300
–200
–100
period in days
ROB



prograde semi-annual nutation



Model A
ModelA with core radius +200km
ModelA with core radius –200km
retrograde annual nutation
retrograde semi–annual
retrograde ter–annual
retrograde quater–annual
50.0
30.0
10.0
–10.0
–30.0
–50.0
percents
–700.0
–600.0
–500.0
–400.0
–300.0
–200.0
–100.0
period in days
ROB