Rotation and Interior of Terrestrial Planets

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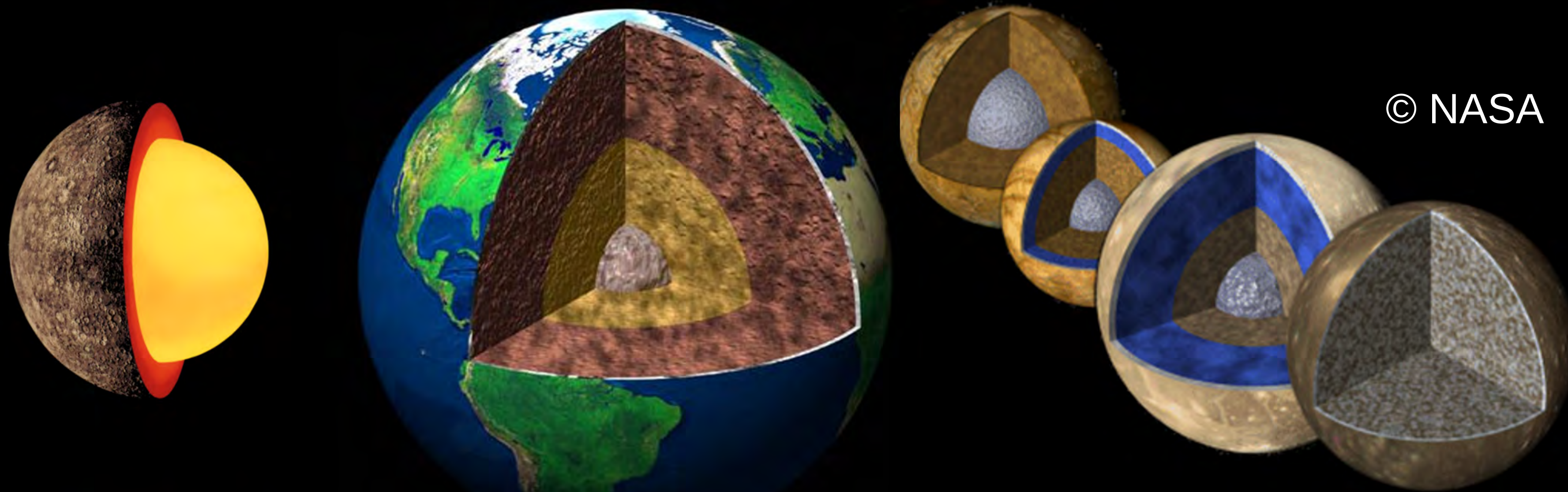
introduction

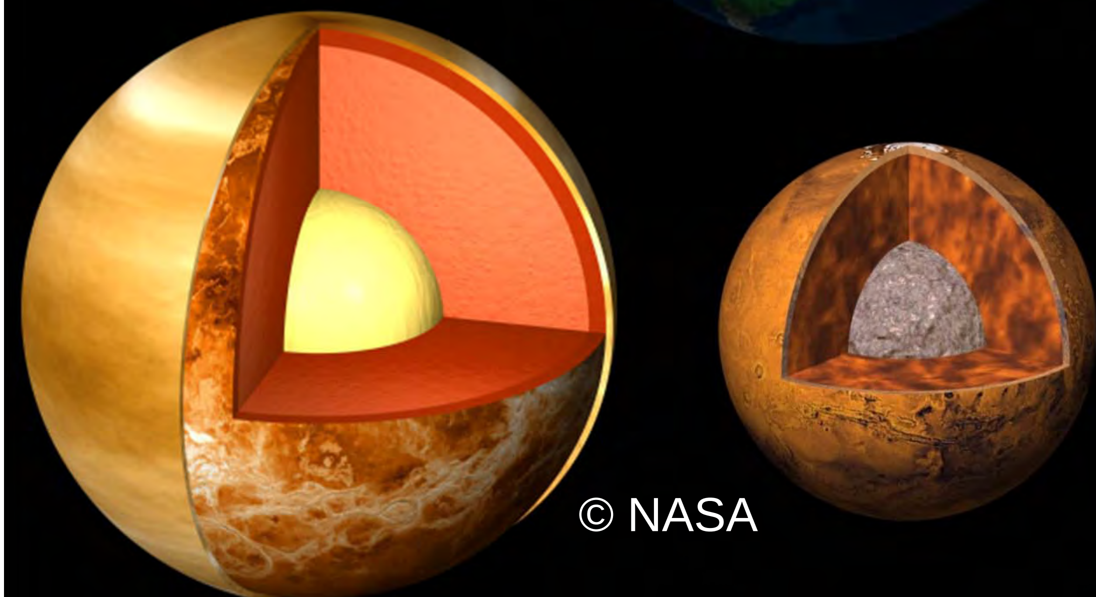
WHAT DO WE KNOW ABOUT THE MEAN ROTATION AND INTERIOR OF THE PLANETS?

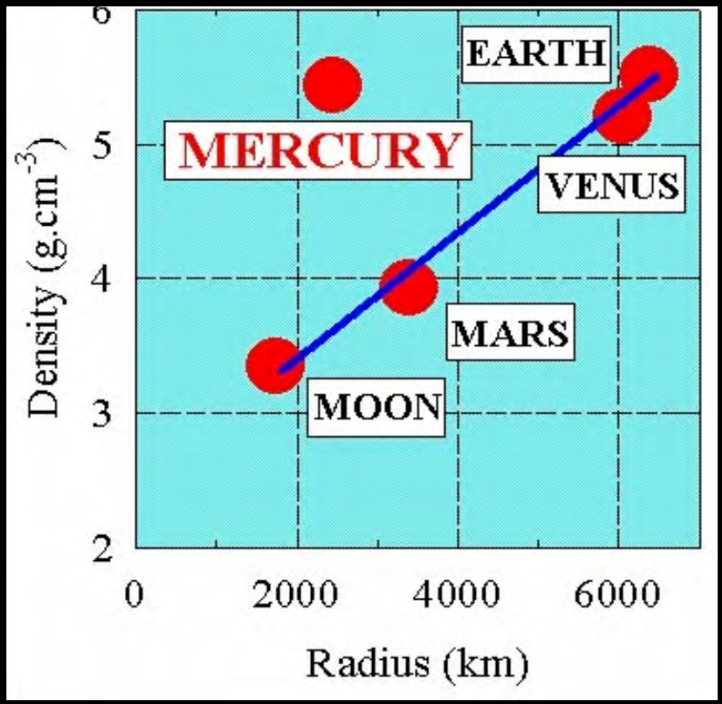
Orbit, rotation and orientation characteristics of the 8 planets of the Solar System at present

Planets	Orbital periods (Earth days or years)	Rotation periods (Earth hours or days or years)	Obliquity
Mercury	87.97 days	58.65 days	2.0 arcmin
Venus	224.70 days	−243.02 days (retrograde)	177.36°
Earth	365.256 days or 1 year	23h56m04s	23.439°
Mars	686.98 days or ~2 years	24h37min23s or 1.026 days	25.19°
Jupiter	11.86 years	9.55h	3.1°
Saturn	29.46 years	10.32h	26.7°
Uranus	84.02 years	−17.24h	97.8°
Neptune	164.79 years	16.11h	28.3°

slow (Mercury, Venus)
rapid (Earth, Mars)
extremely rapid (Jupiter, Saturn, Uranus, Neptune)







Interior Structure

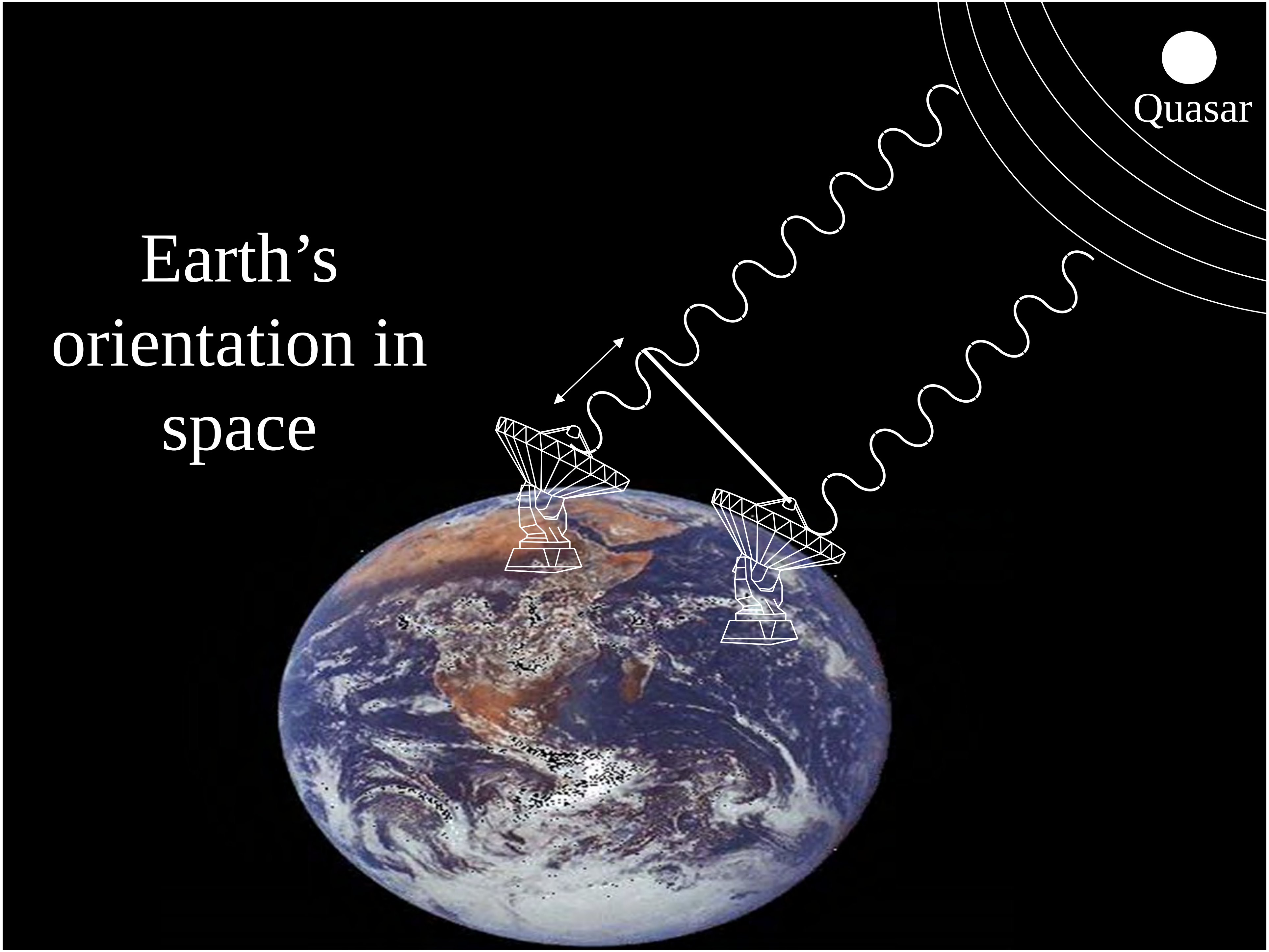
[Courtesy: BepiColombo Study Report]

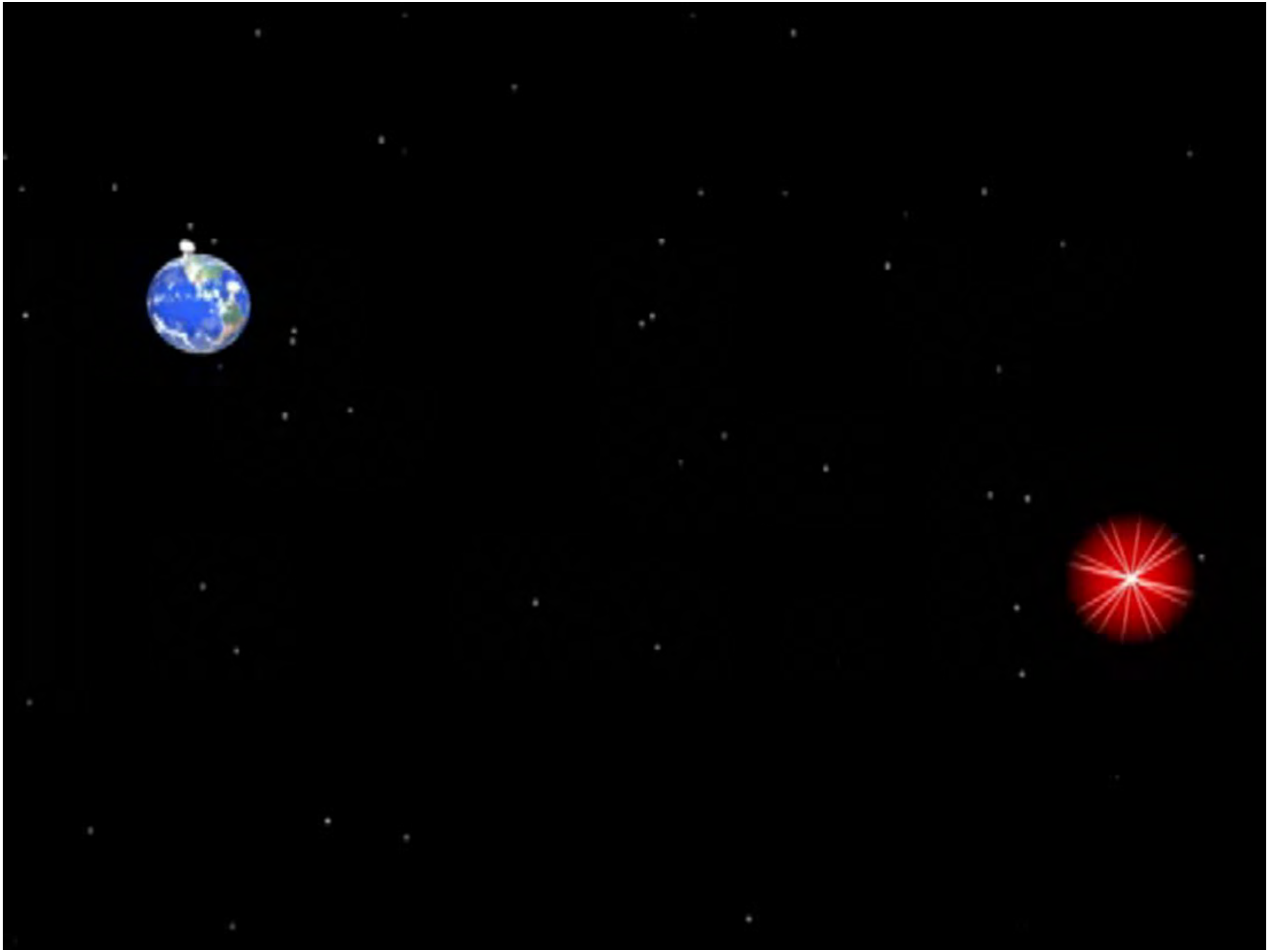
Terrestrial planets

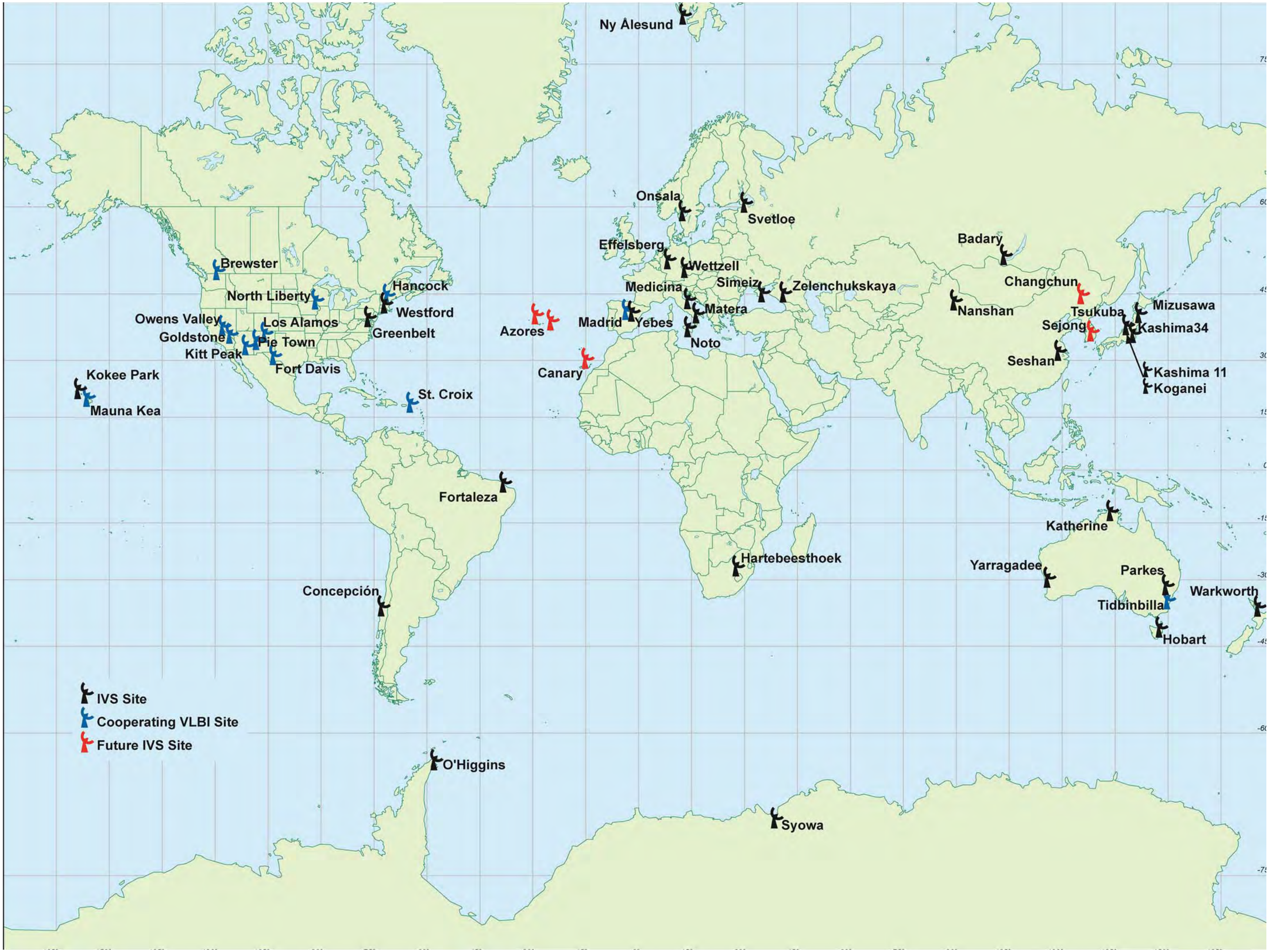
OBSERVATION OF THE ROTATION OF PLANETS?

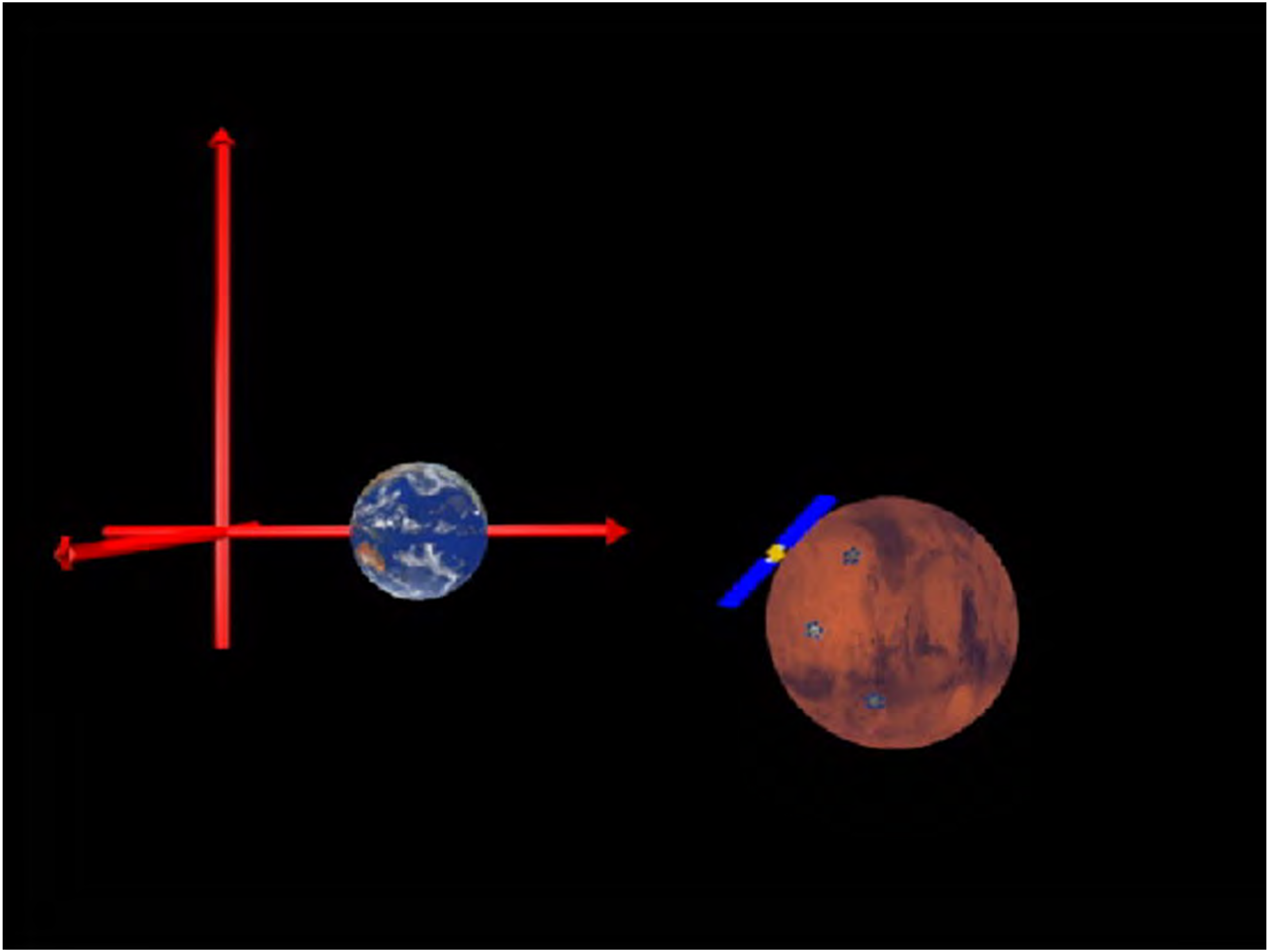
Nutation measured by VLBI

Very Long Baseline Interferometry

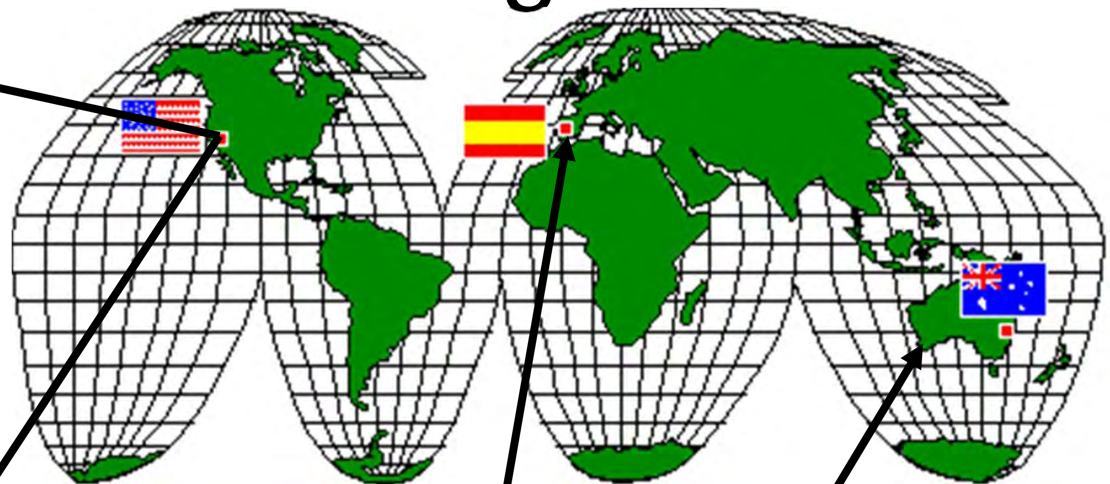

Earth's orientation in space
Quasar




Ny Ålesund
Onsala
Svetloe
Badary
Effelsberg
Wettzell
Brewster
Hancock
North Liberty
Westford
Medicina
Simeiz
Zelenchukskaya
Changchun
Owens Valley
Los Alamos
Greenbelt
Azores
Madrid
Yebes
Matera
Nanshan
Mizusawa
Tsukuba
Goldstone
Pie Town
Kitt Peak
Noto
Sejong
Kashima34
Fort Davis
Seshan
Canary
Kokee Park
Kashima 11
Koganei
St. Croix
Mauna Kea
Fortaleza
Katherine
Hartebeesthoek
Yarragadee
Parkes
Concepción
Warkworth
Tidbinbilla
Hobart
IVS Site
Cooperating VLBI Site
Future IVS Site
O'Higgins
Syowa



NASA's DSN and ESA's ESTRACK networks of tracking stations



ESA's 34 m. antenna at New Norcia
& Cebreros (Mars Express, Venus Express)

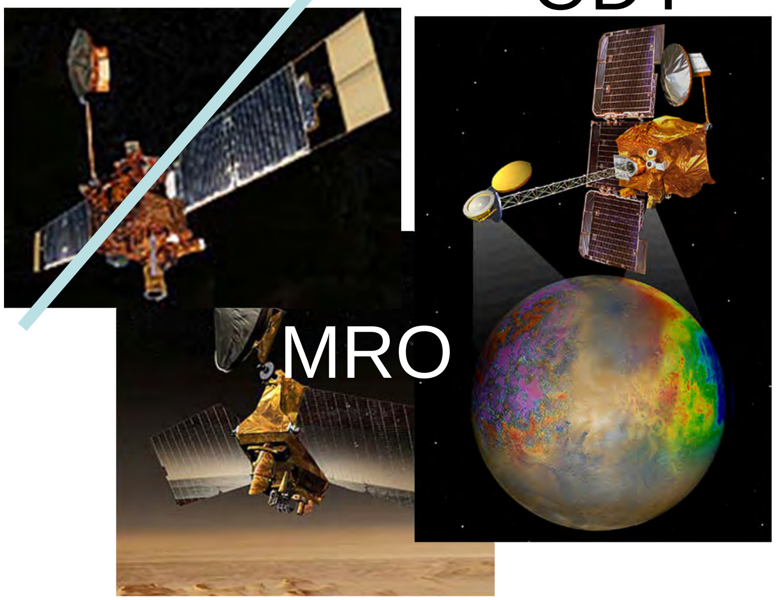
- Radio-link for data & telemetry
- Doppler & range radio-tracking mainly at frequencies of around 8 Ghz (X band) (dual-frequency X/S bands to correct ionospheric and interplanetary plasma perturbations)

Mars missions

future

MGS

ODY



MEX

TGO

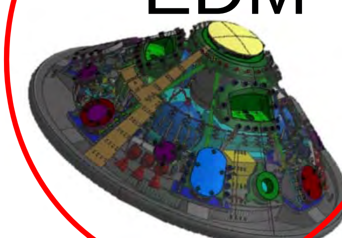
MAVEN

MERs

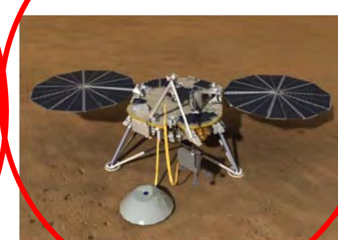
MSL

Phoenix

ExoMars
EDM

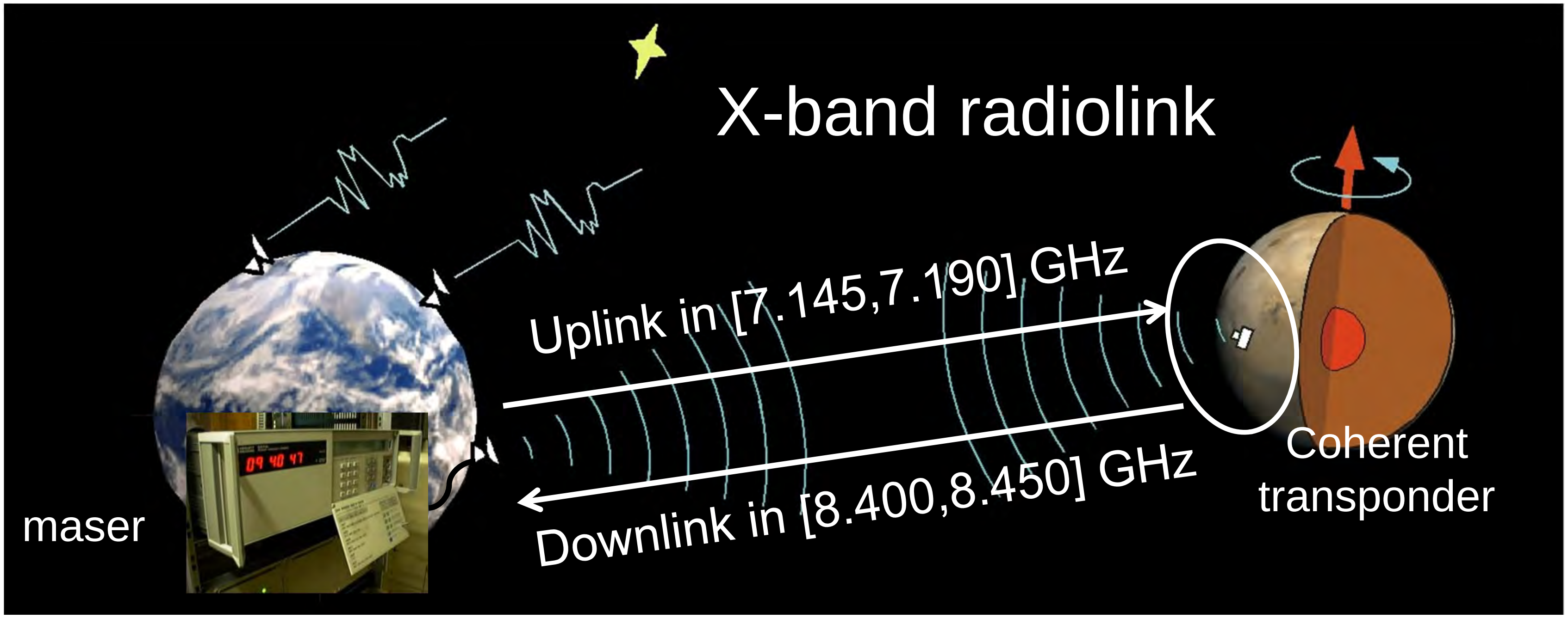


InSIGHT

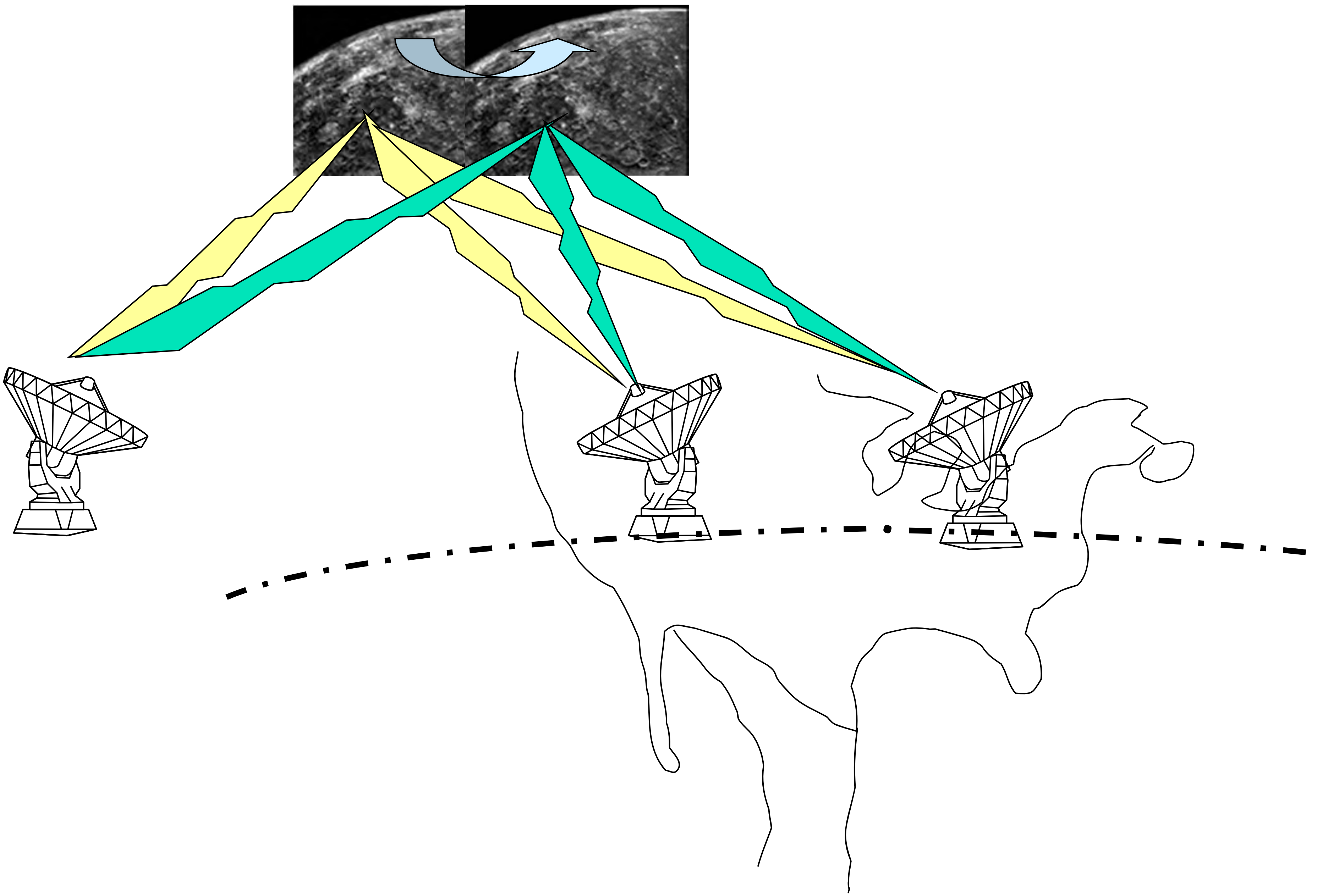


Lander driving science requirements

- **Doppler measurements between the lander on Mars and the ground station on Earth in X-band.**



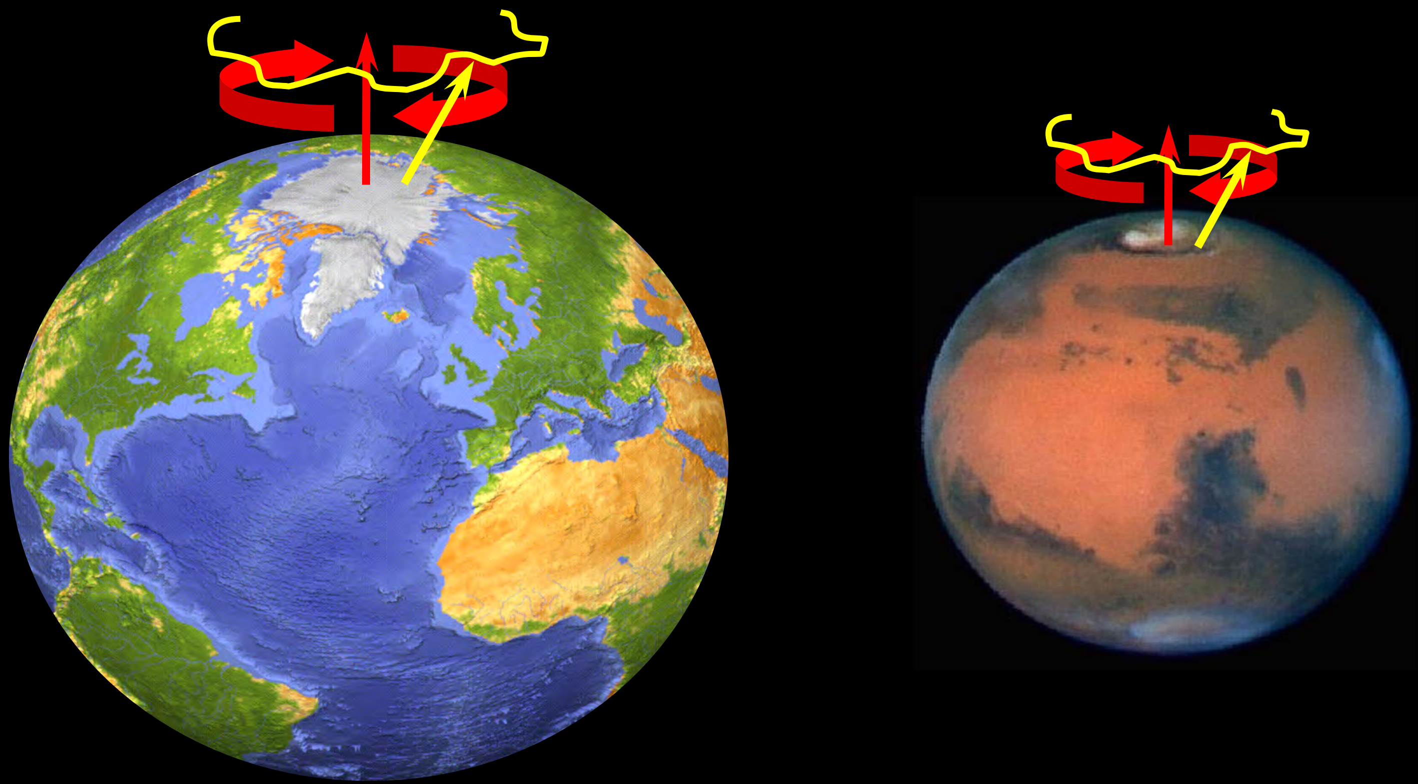
InSIGHT: A Geophysical Mission to Mars
Interior exploration using **S**eismic **I**nvestigations, **G**eodesy, and **H**eat **T**ransport



Terrestrial planets

VARIATIONS WITH RESPECT TO THE MEAN ROTATION AND INTERIOR OF THE PLANETS?

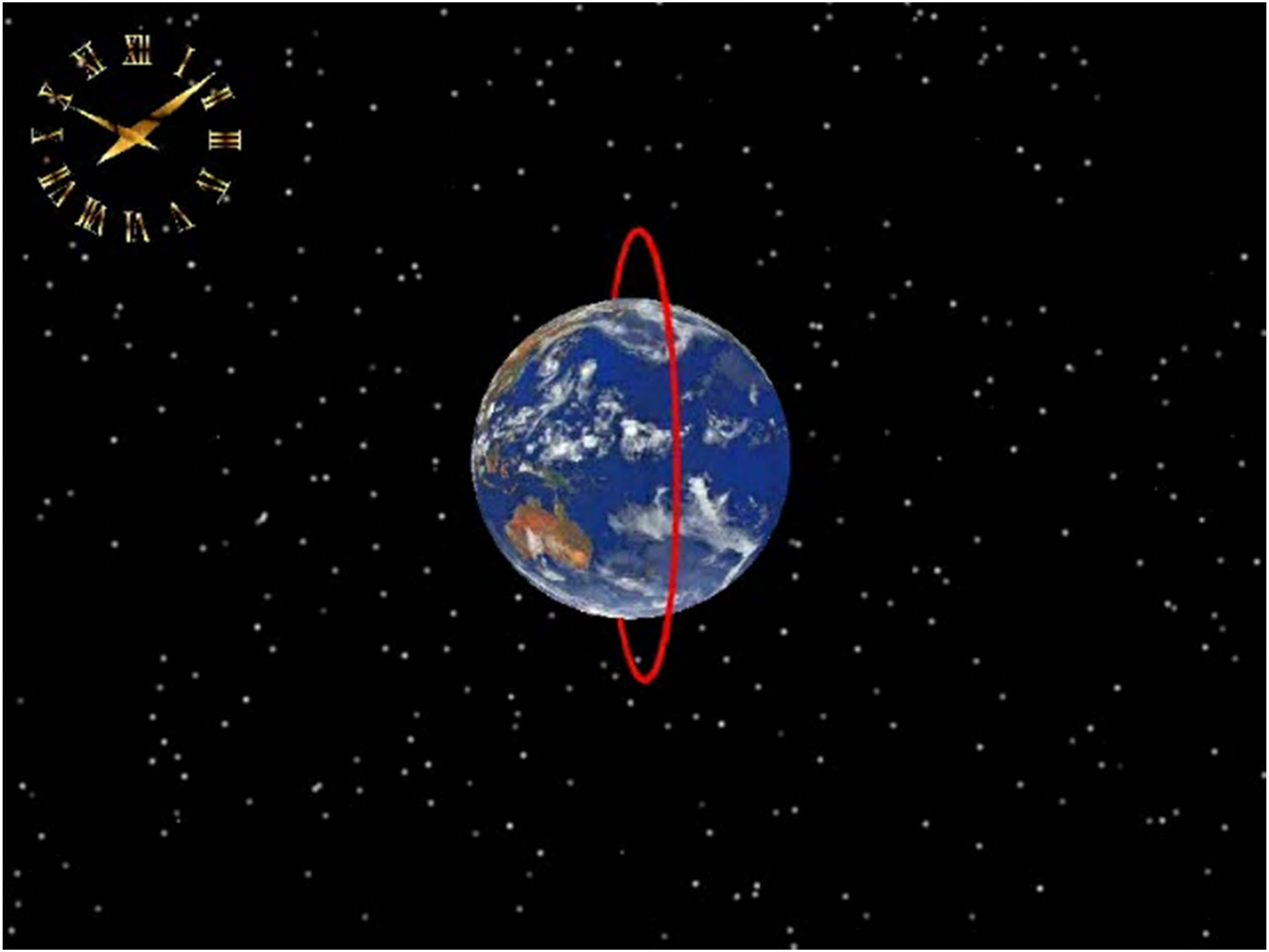
Two terrestrial planets rapidly rotating → flattened, inclined, thus large precession and nutation



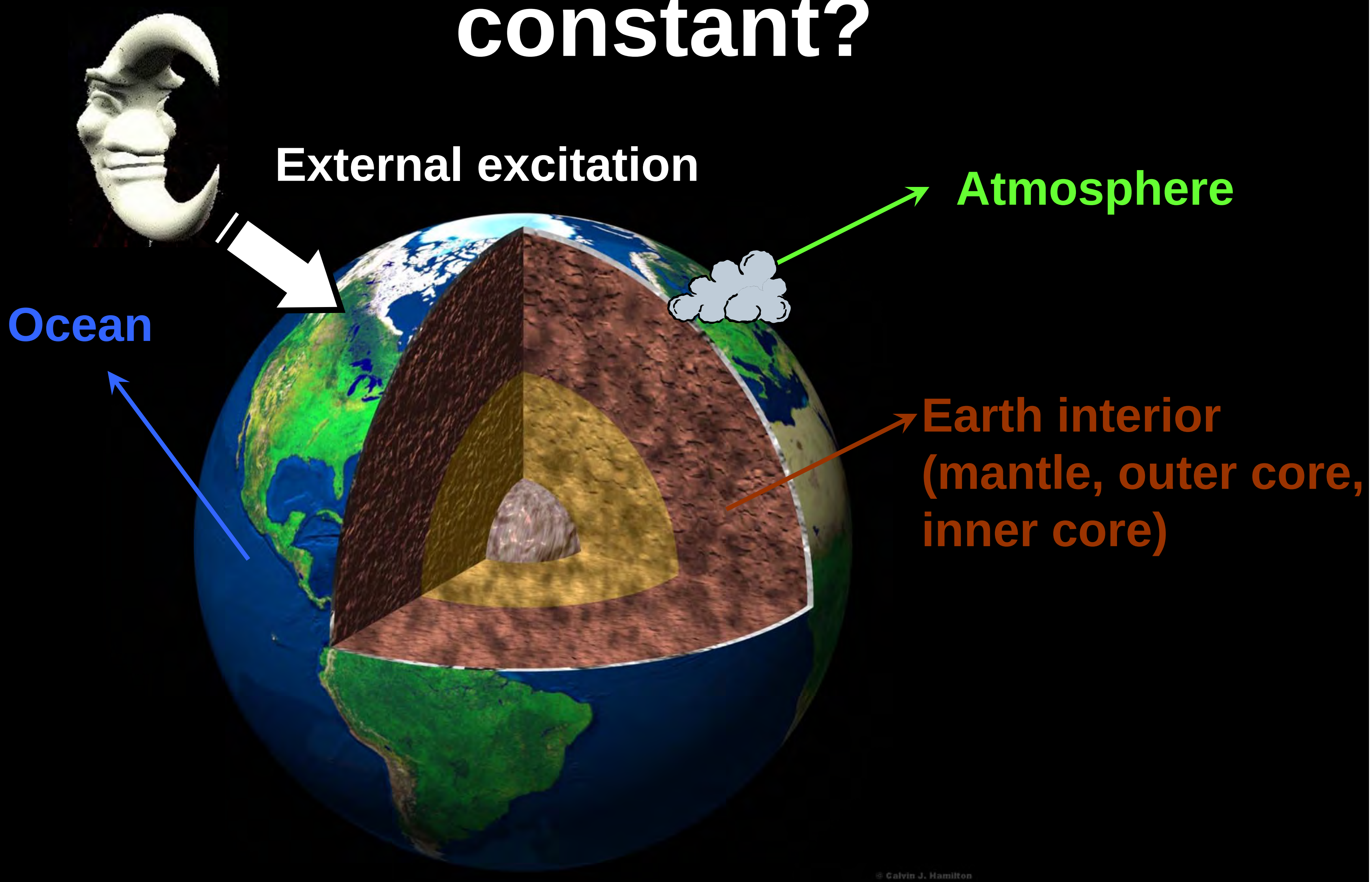
ROB

Terrestrial planets

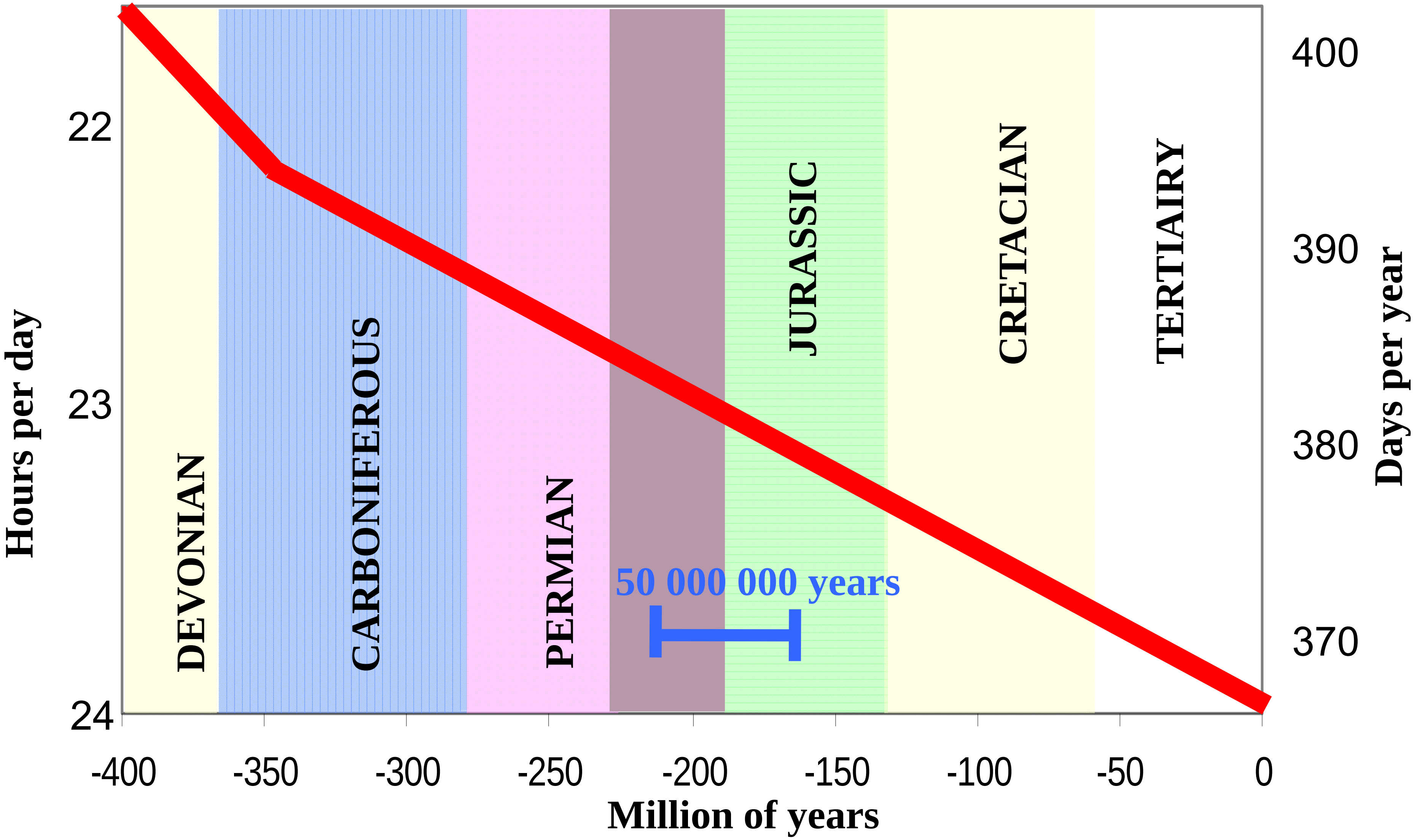
VARIATIONS WITH RESPECT TO THE MEAN ROTATION AND INTERIOR OF THE EARTH ?

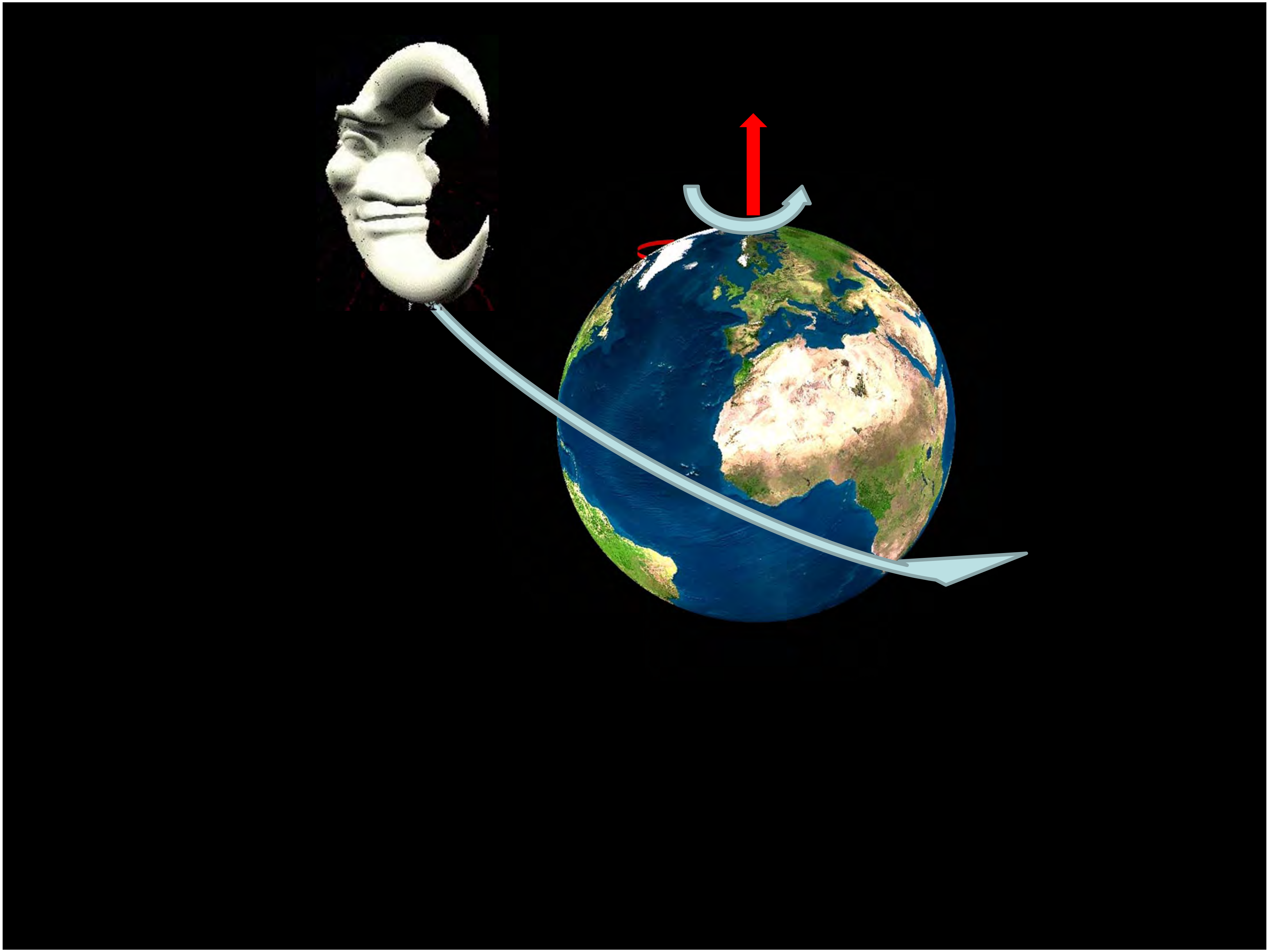


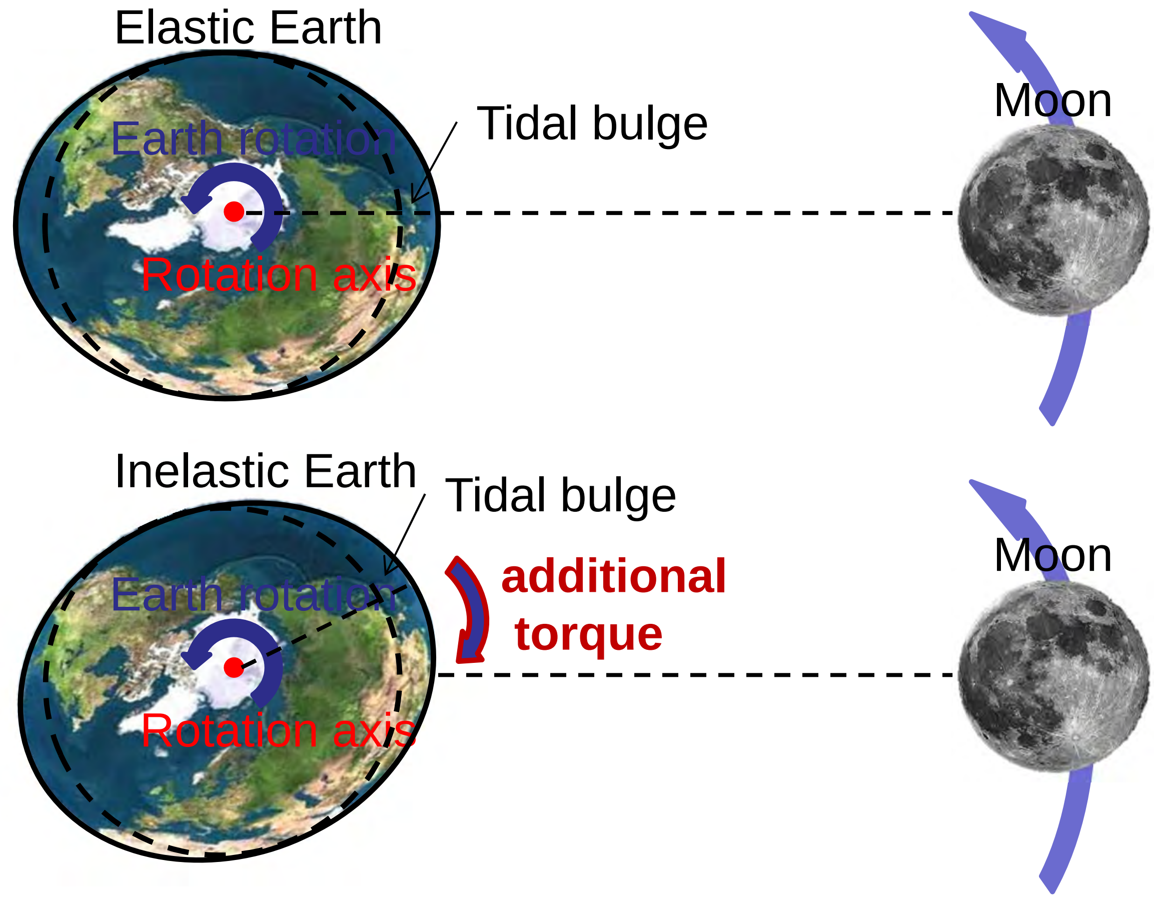
Why is the length-of-day not constant?

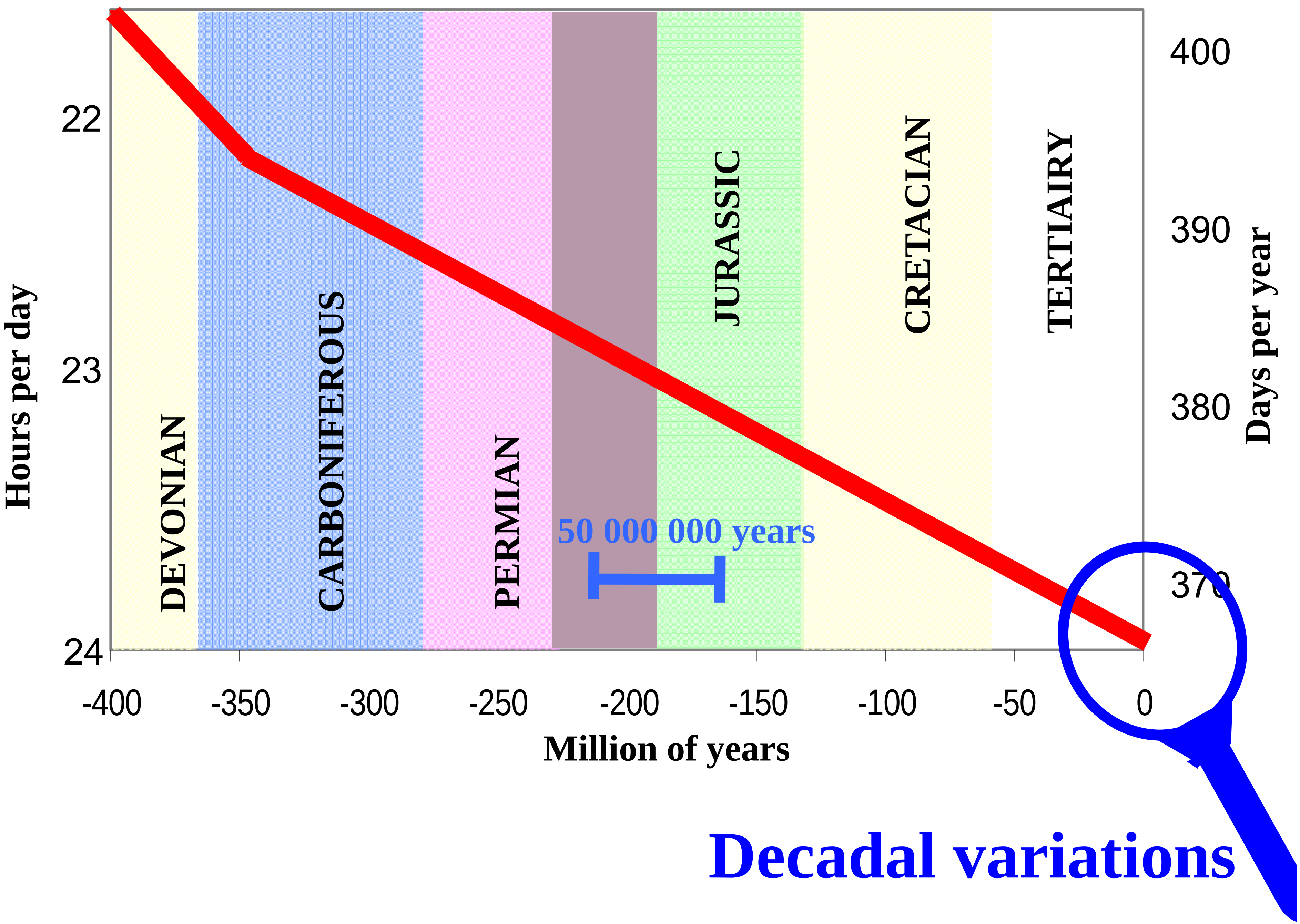


Long-term Earth rotation variations

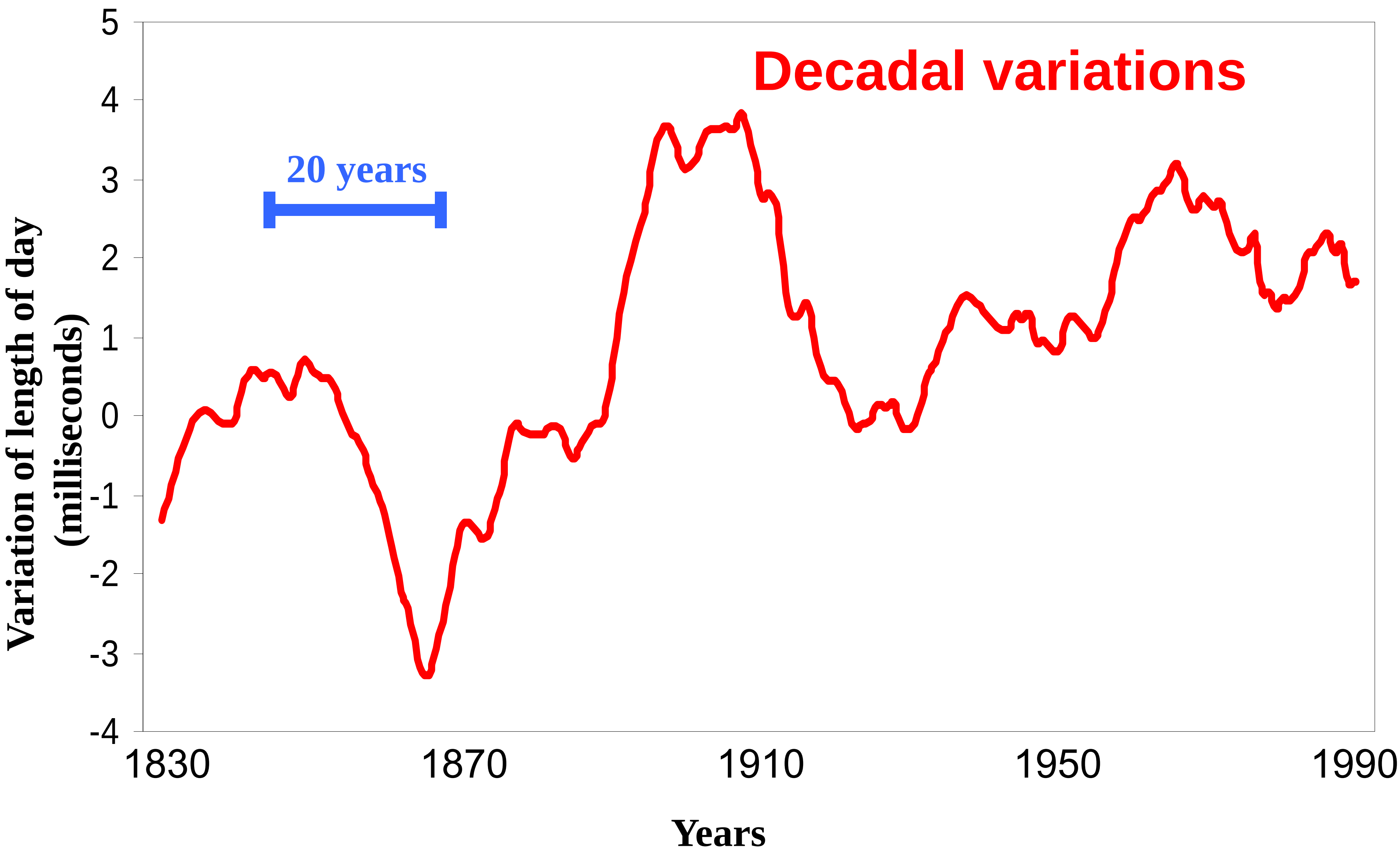




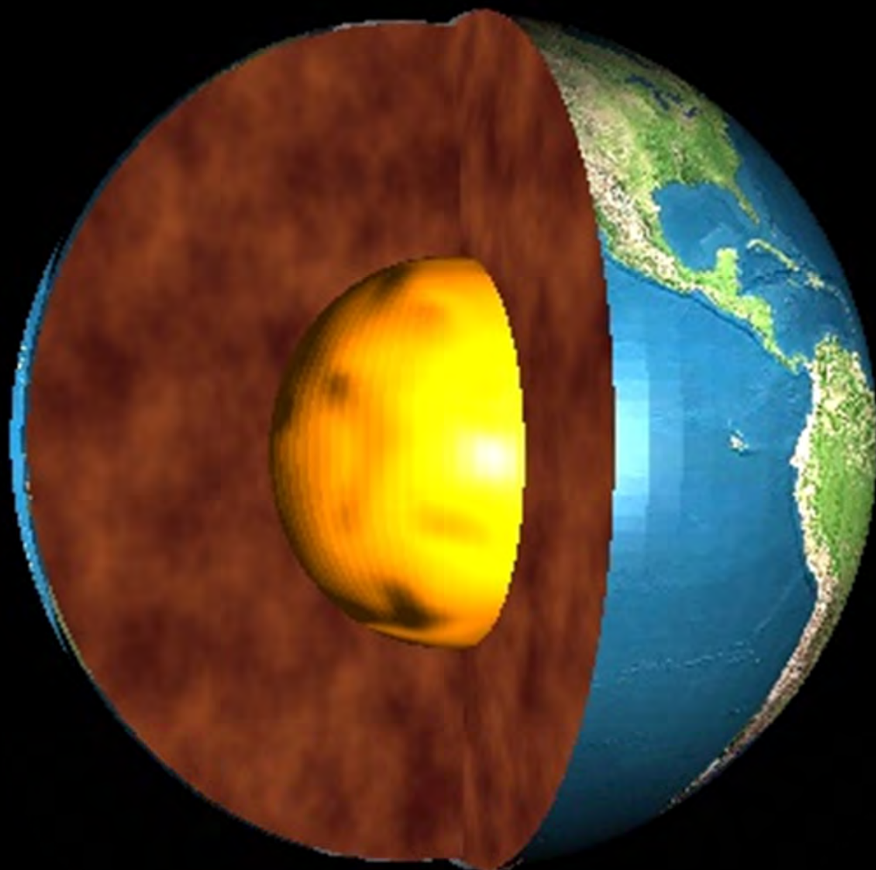

Elastic Earth
Tidal bulge
Moon
Earth rotation
Rotation axis
Inelastic Earth
Tidal bulge
additional
torque
Moon
Earth rotation
Rotation axis



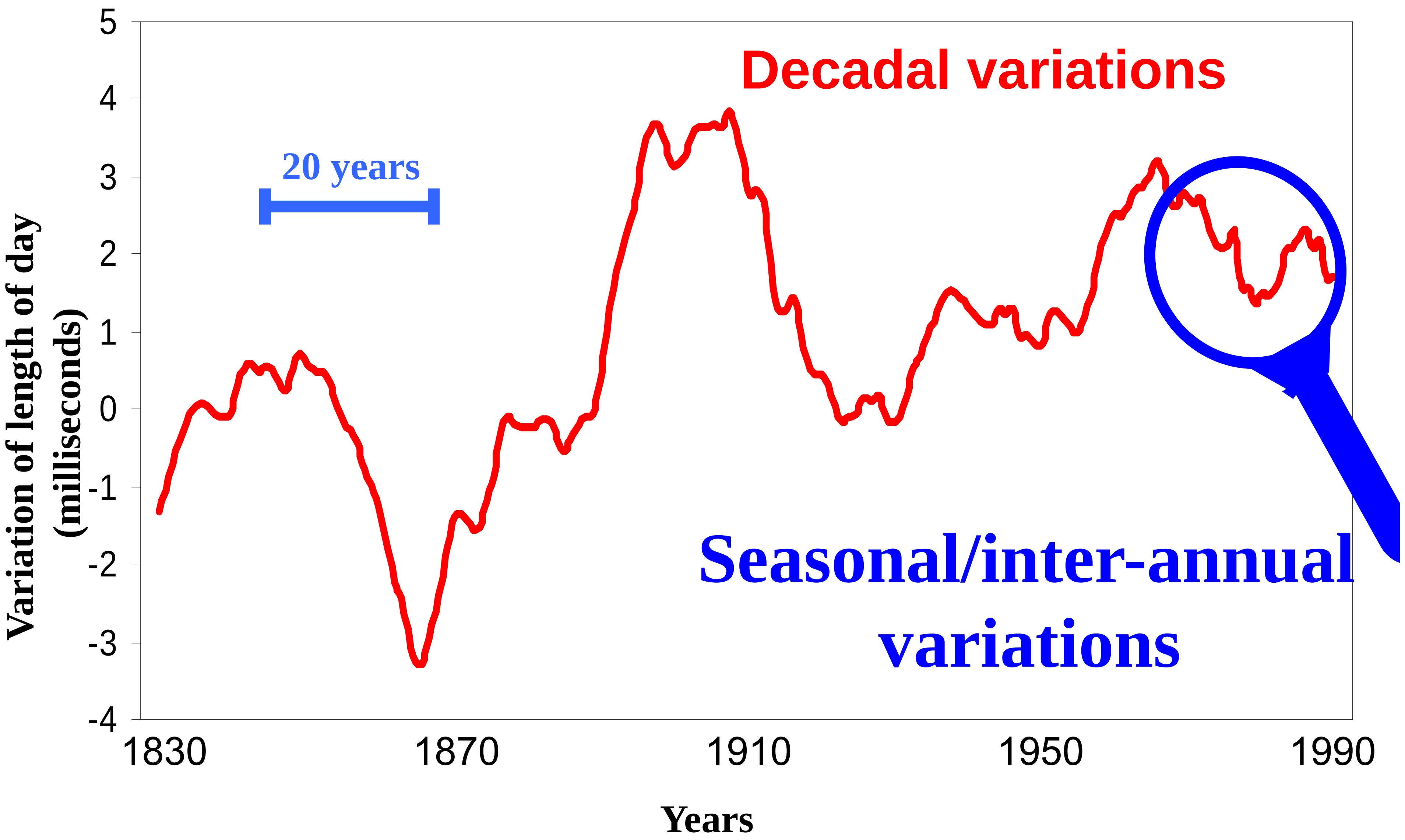
Hours per day
22
23
24
Days per year
400
390
380
370
DEVONIAN
CARBONIFEROUS
PERMIAN
JURASSIC
CRETACIAN
TERTIAIRY
50 000 000 years
-400
-350
-300
-250
-200
-150
-100
-50
0
Million of years
Decadal variations



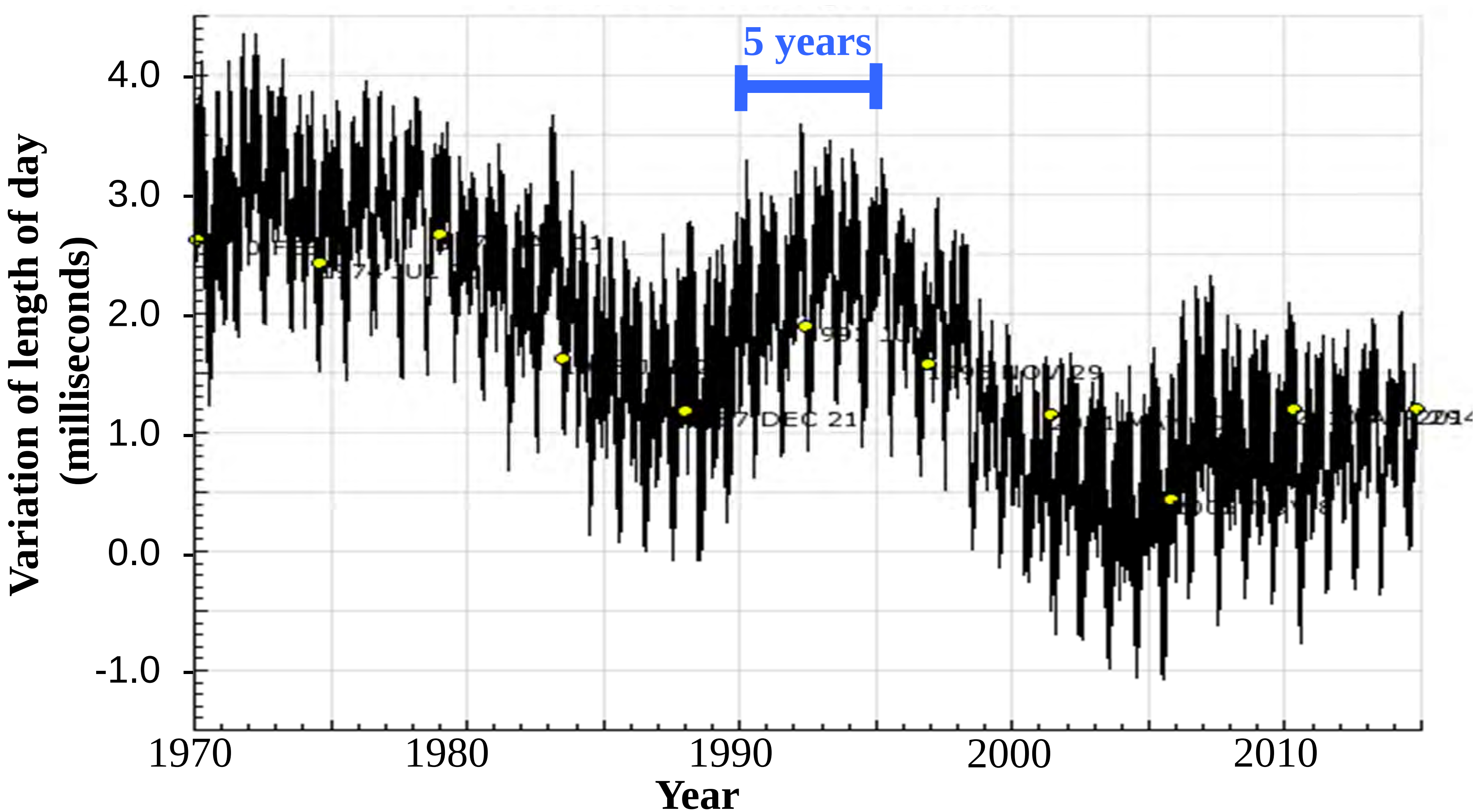
Decadal variations
20 years
Variation of length of day
(milliseconds)
5
4
3
2
1
0
-1
-2
-3
-4
1830
1870
1910
1950
1990
Years



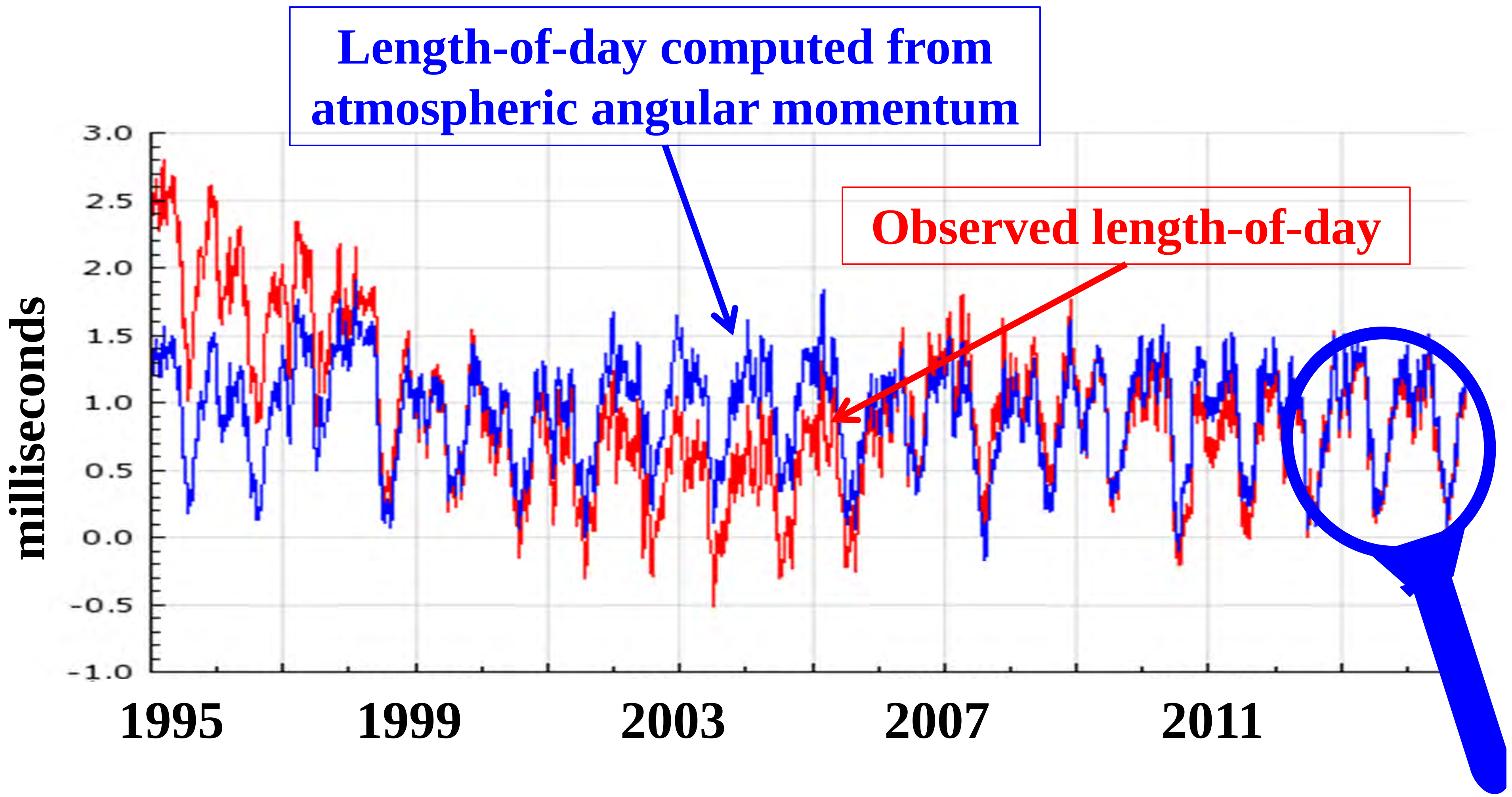
Coupling at core-mantle boundary


Decadal variations
20 years
Seasonal/inter-annual variations
Variation of length of day (milliseconds)
5
4
3
2
1
0
-1
-2
-3
-4
1830
1870
1910
1950
1990
Years

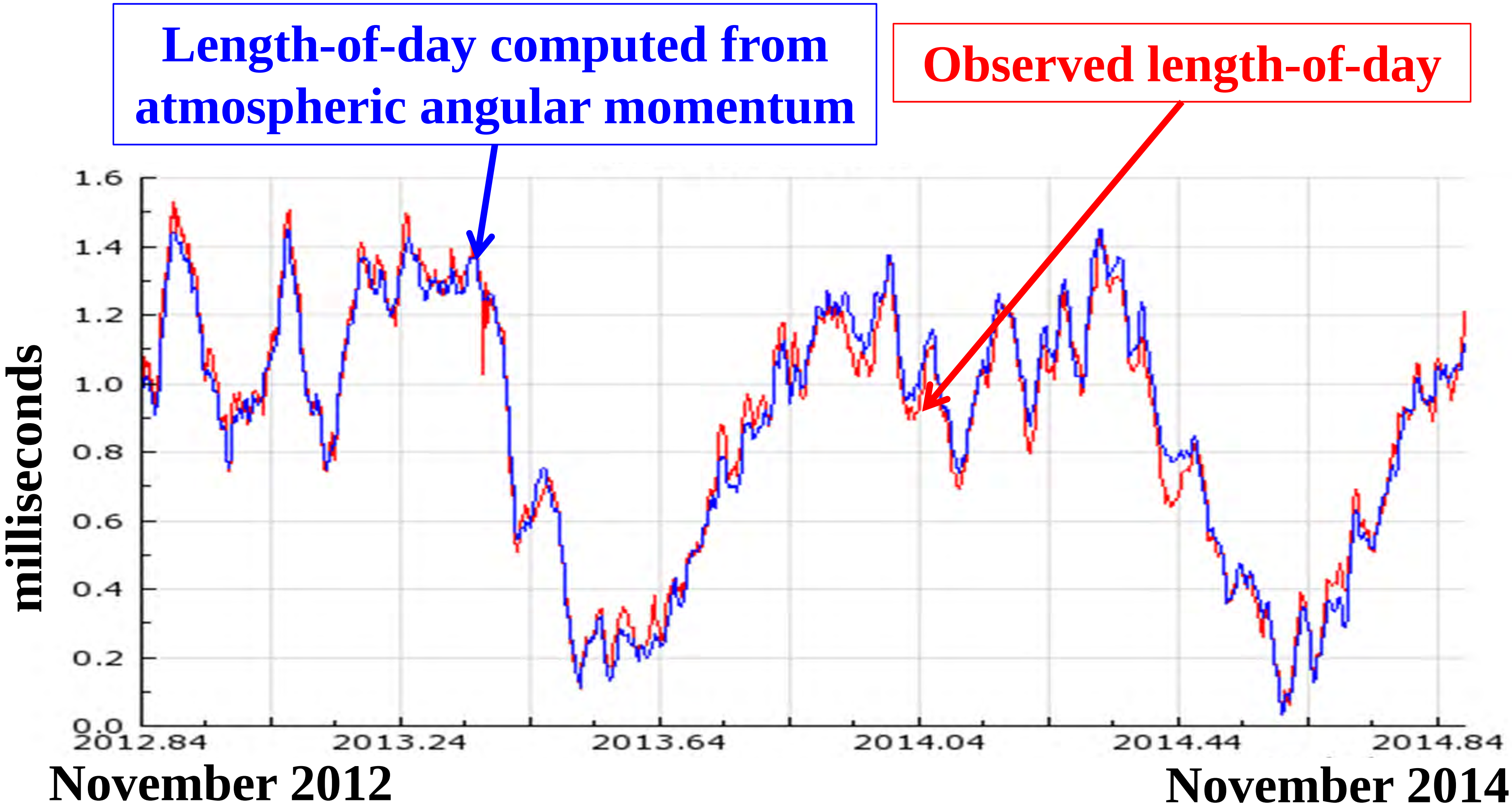
Seasonal variations



Drawn from http://hpiers.obspm.fr/eop-pc/

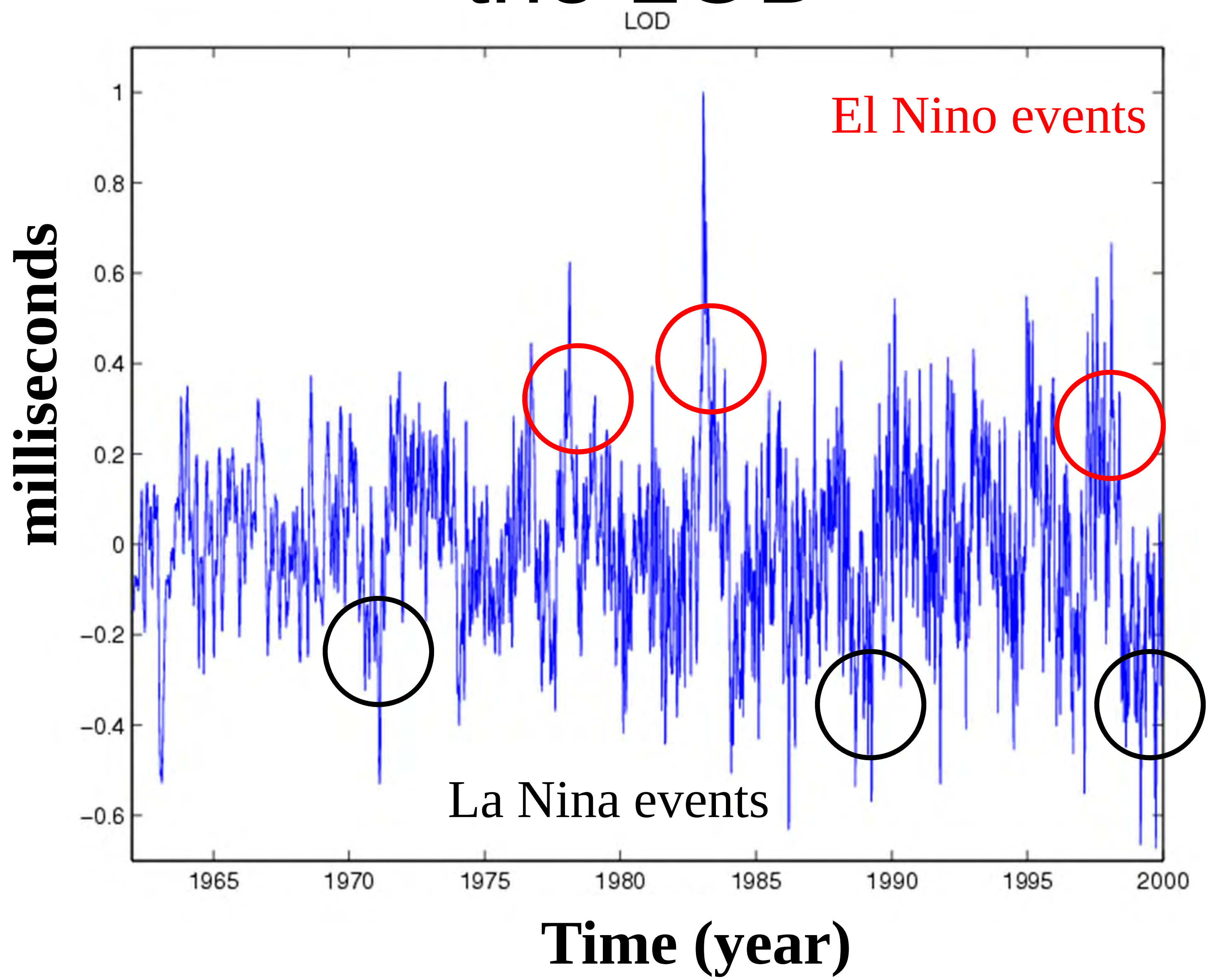


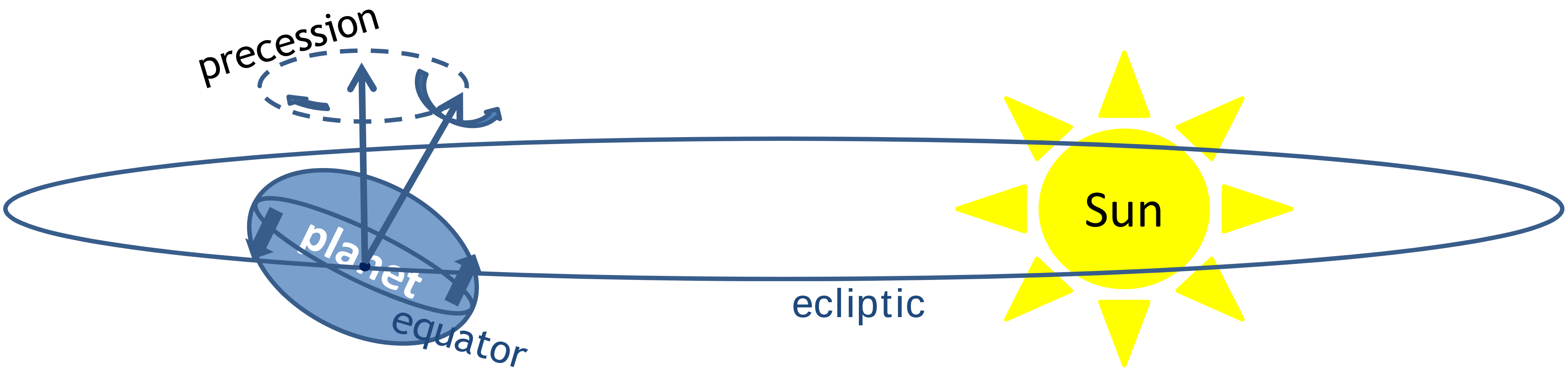
Drawn from http://hpiers.obspm.fr/eop-pc/

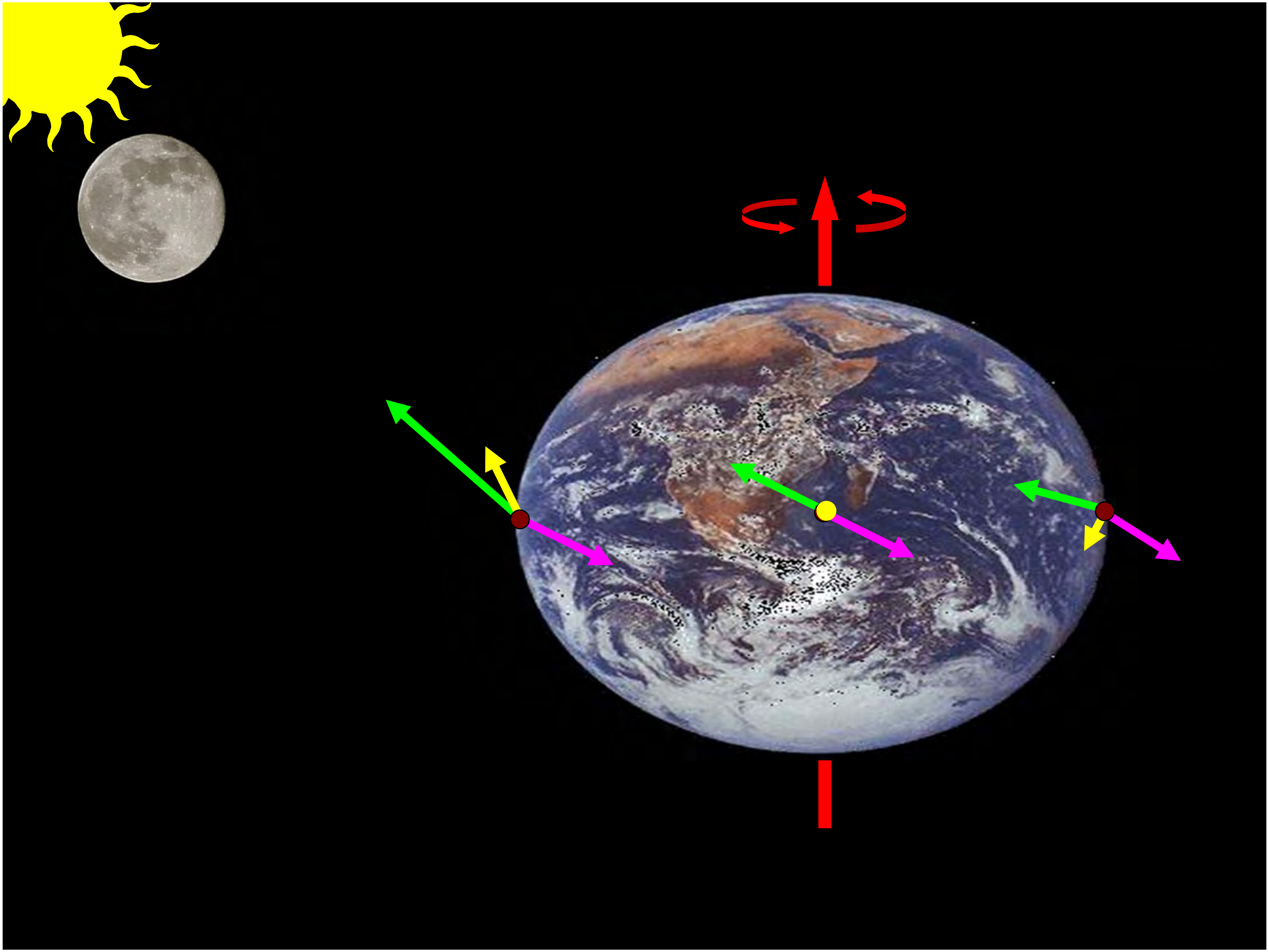


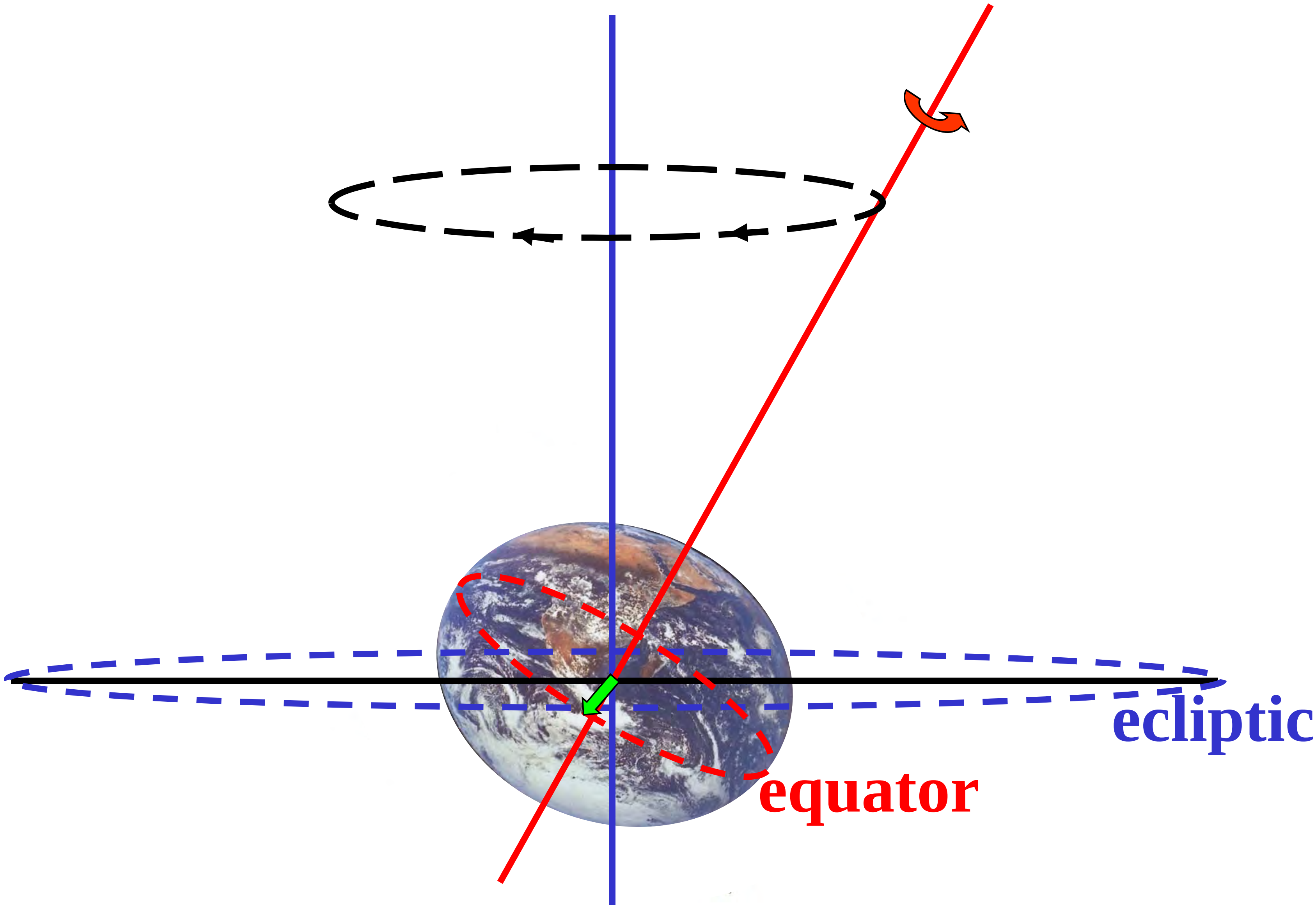
Drawn from http://hpiers.obspm.fr/eop-pc/

Effect of the ENSO cycle on the LOD

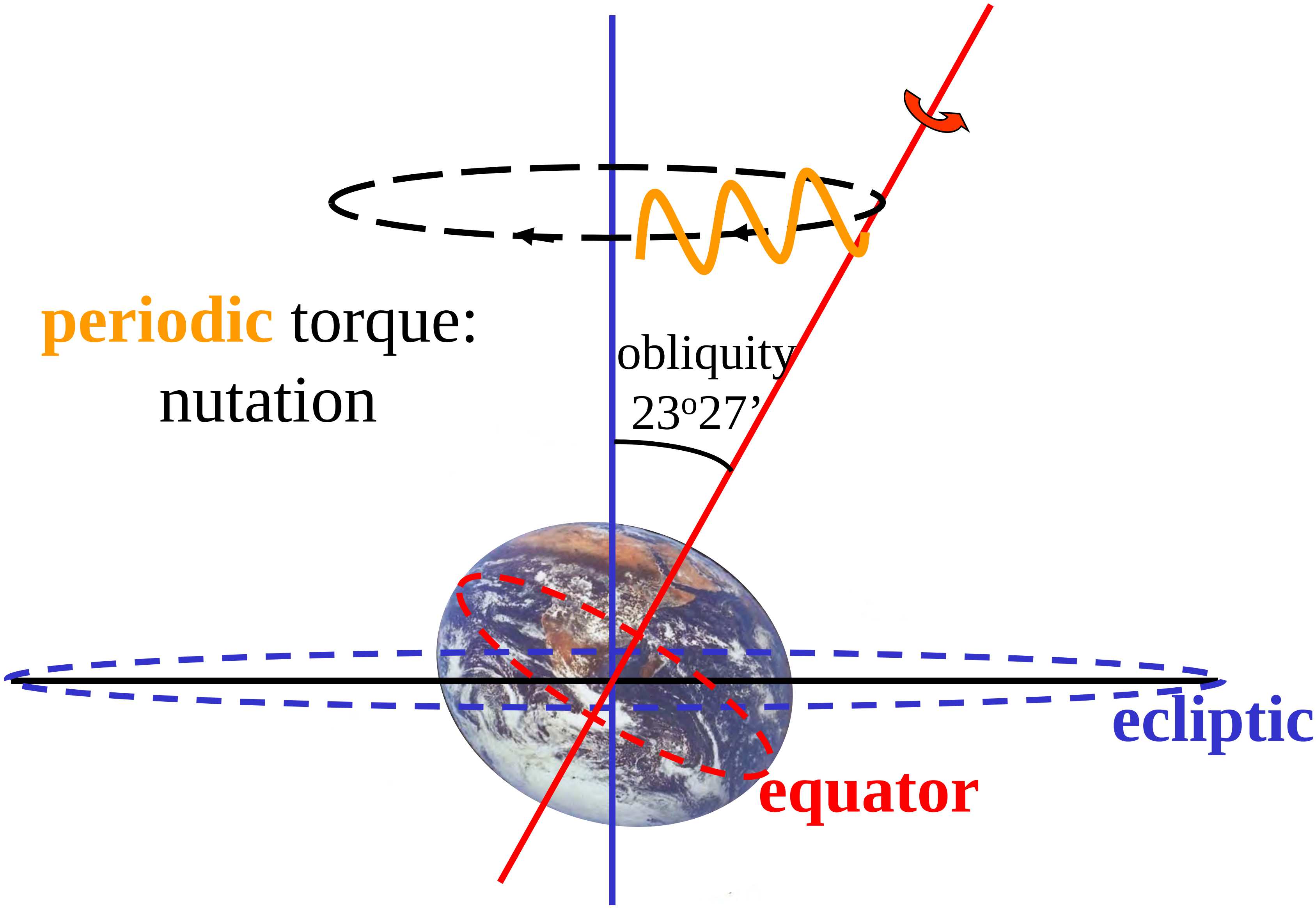


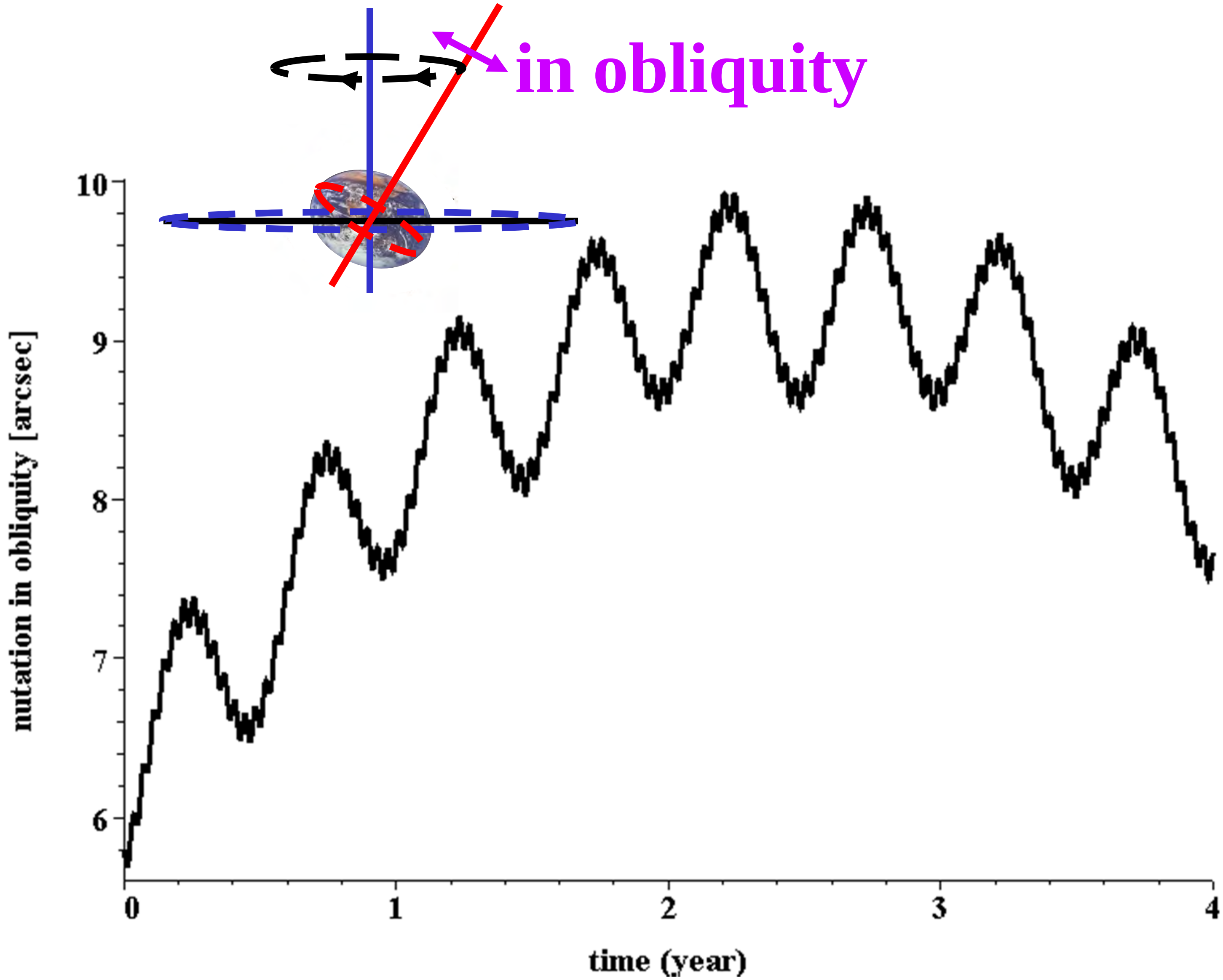

precession
planet
equator
ecliptic
Sun



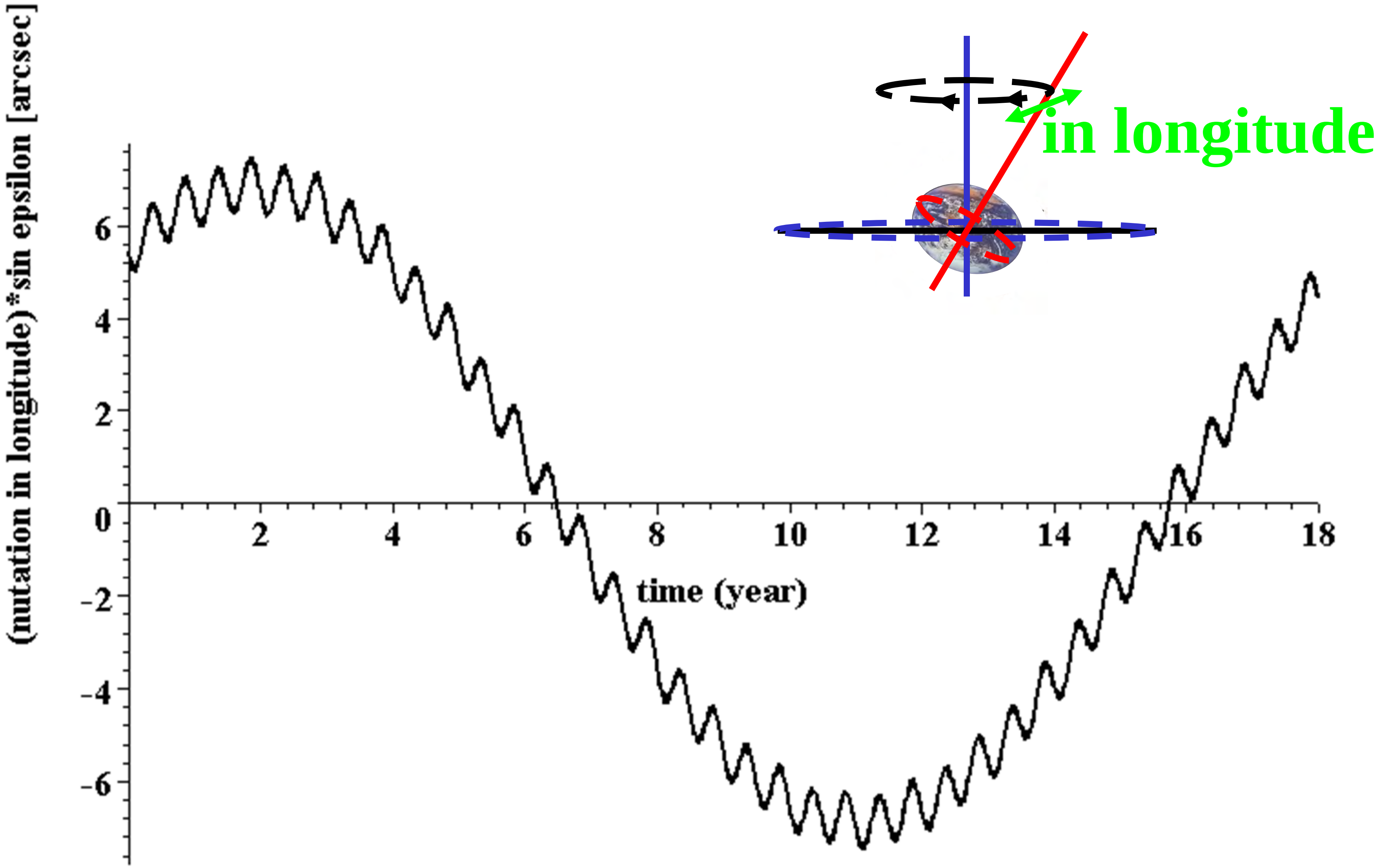


Constant torque (time averaged): precession, similar to motion of a top

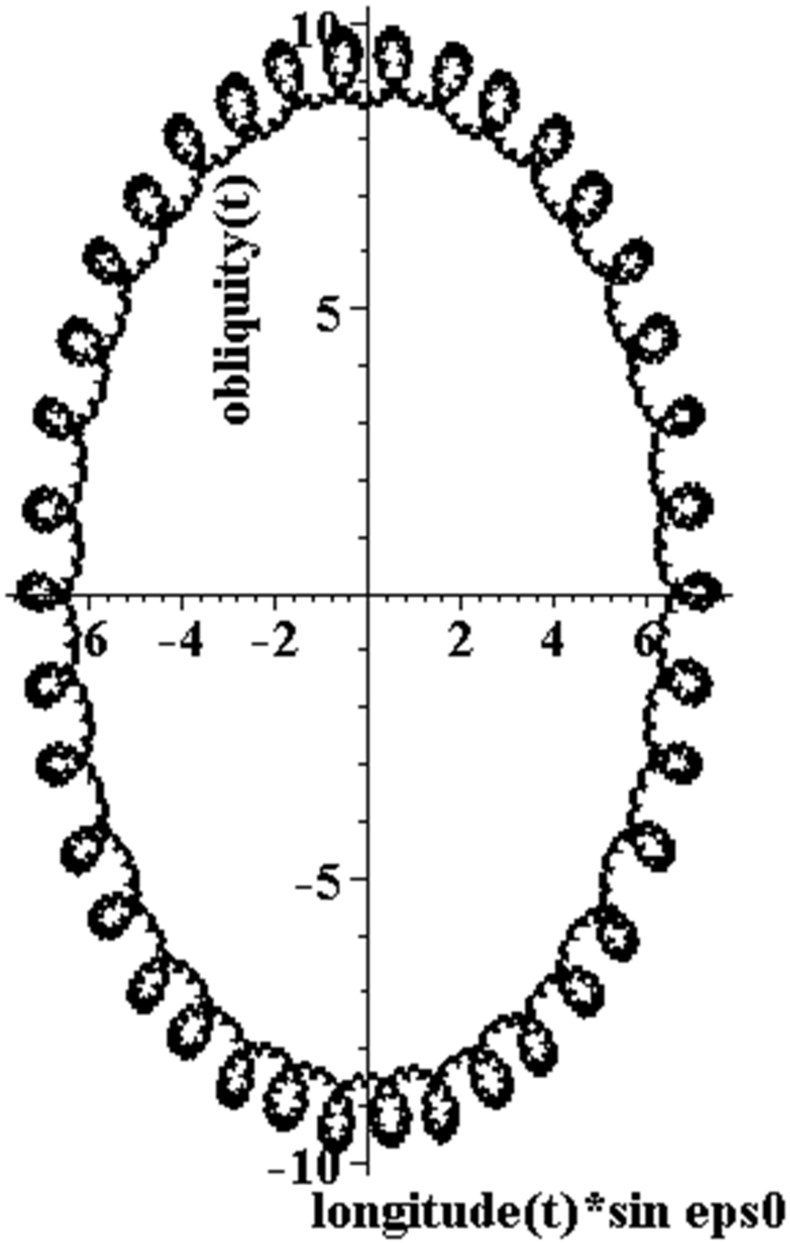

periodic torque:
nutation
obliquity
23º27'
ecliptic
equator

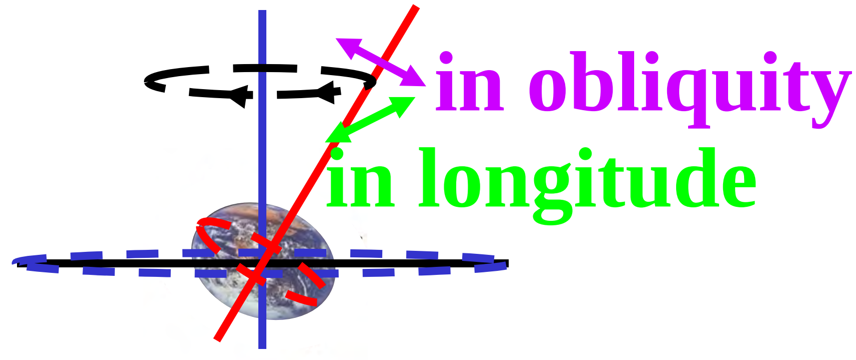


Nutation in obliquity as a function of time, starting at J2000.



Nutation in longitude as a function of time, starting at J2000

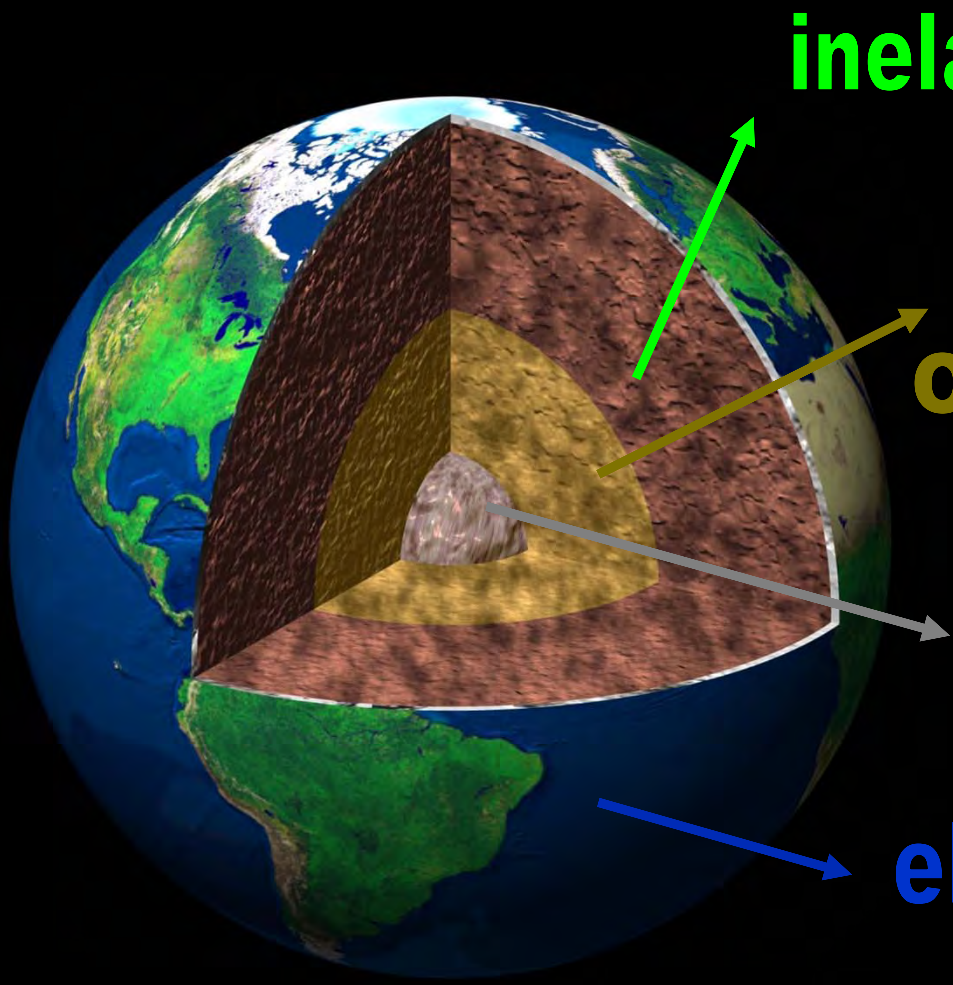




Nutations for 18.6 yrs, starting from J2000

structure of the Earth's interior for its response

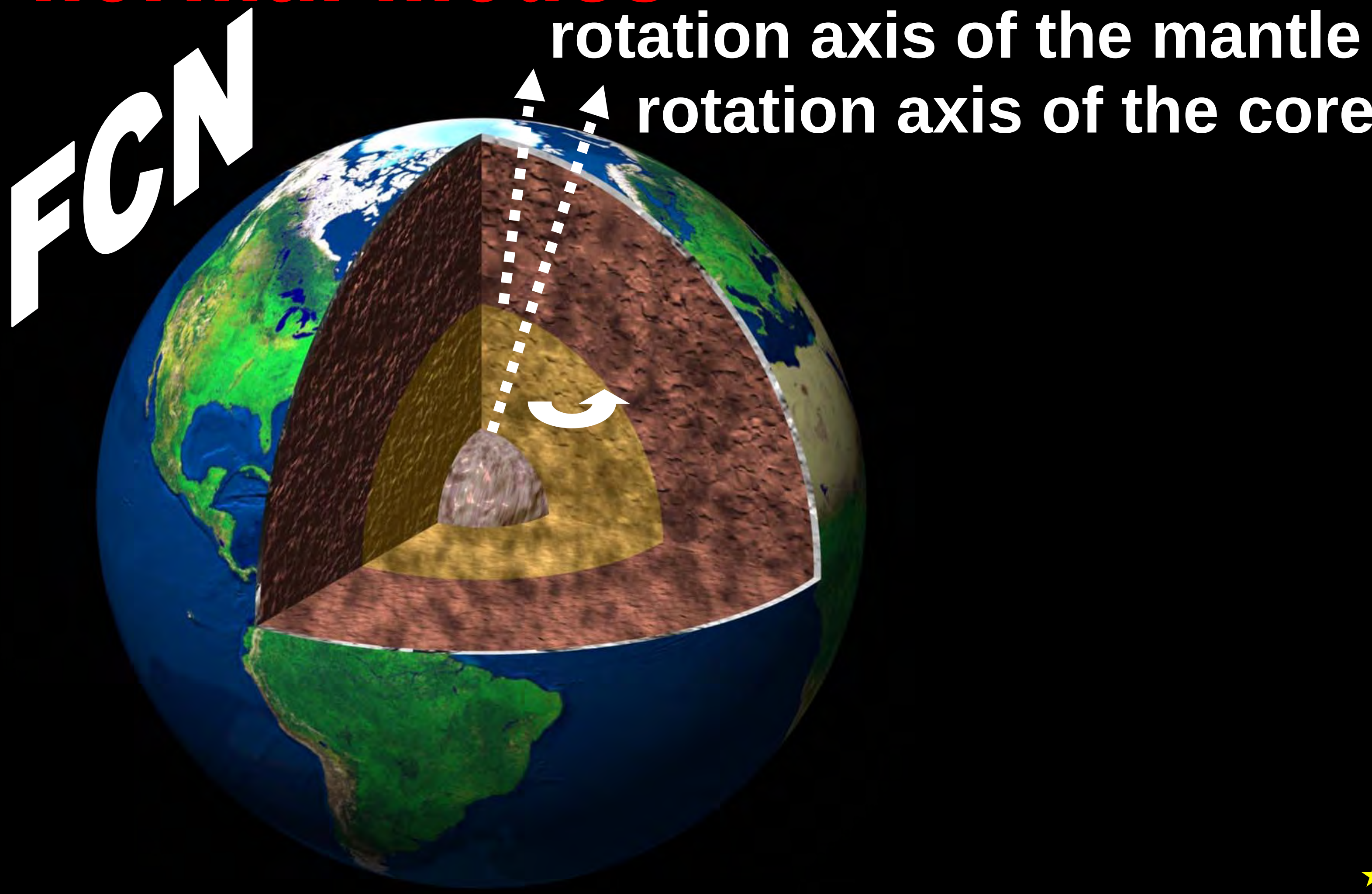
+ normal modes



ROB

structure of the Earth's interior for its response

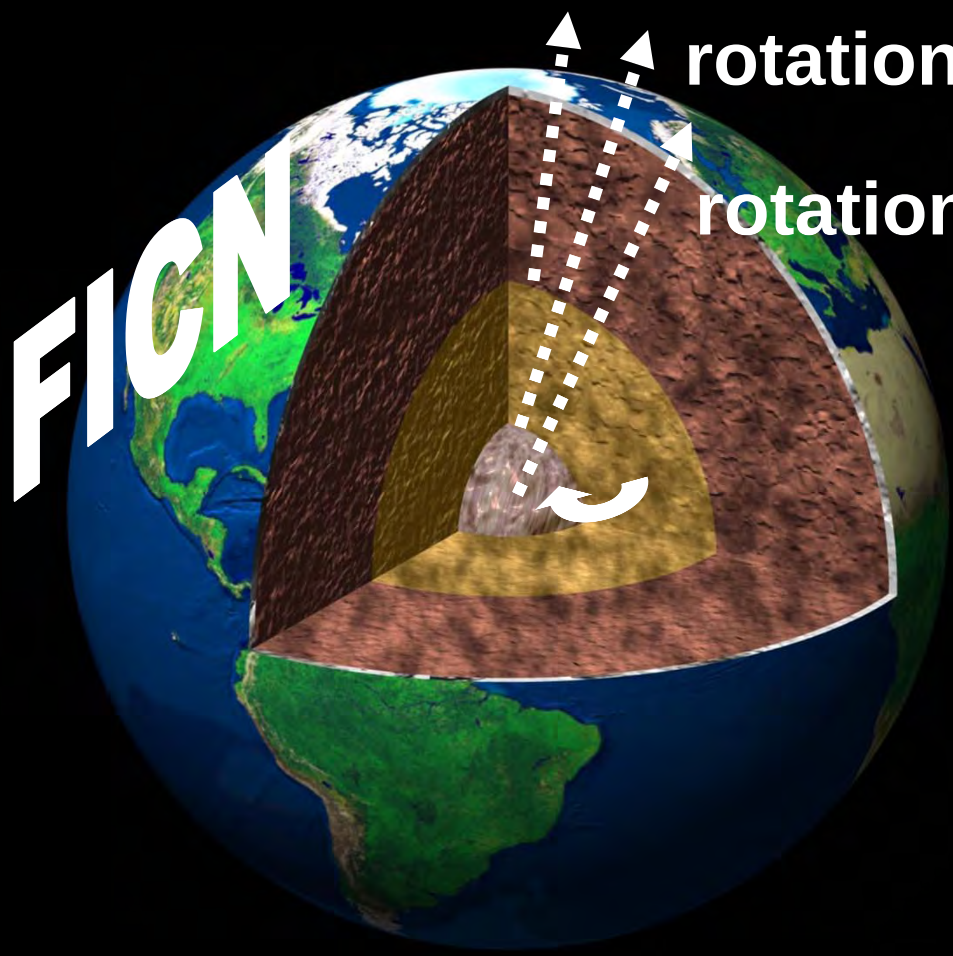
+ normal modes



ROB

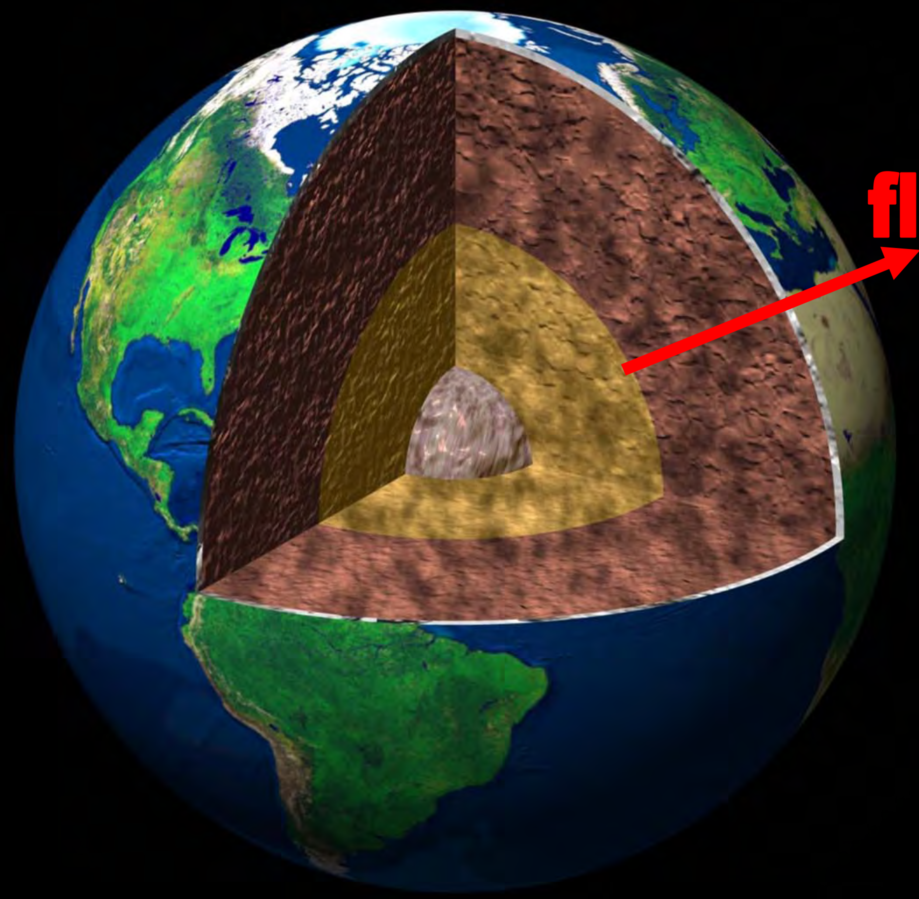
structure of the Earth's interior for its response

+ normal modes



ROB

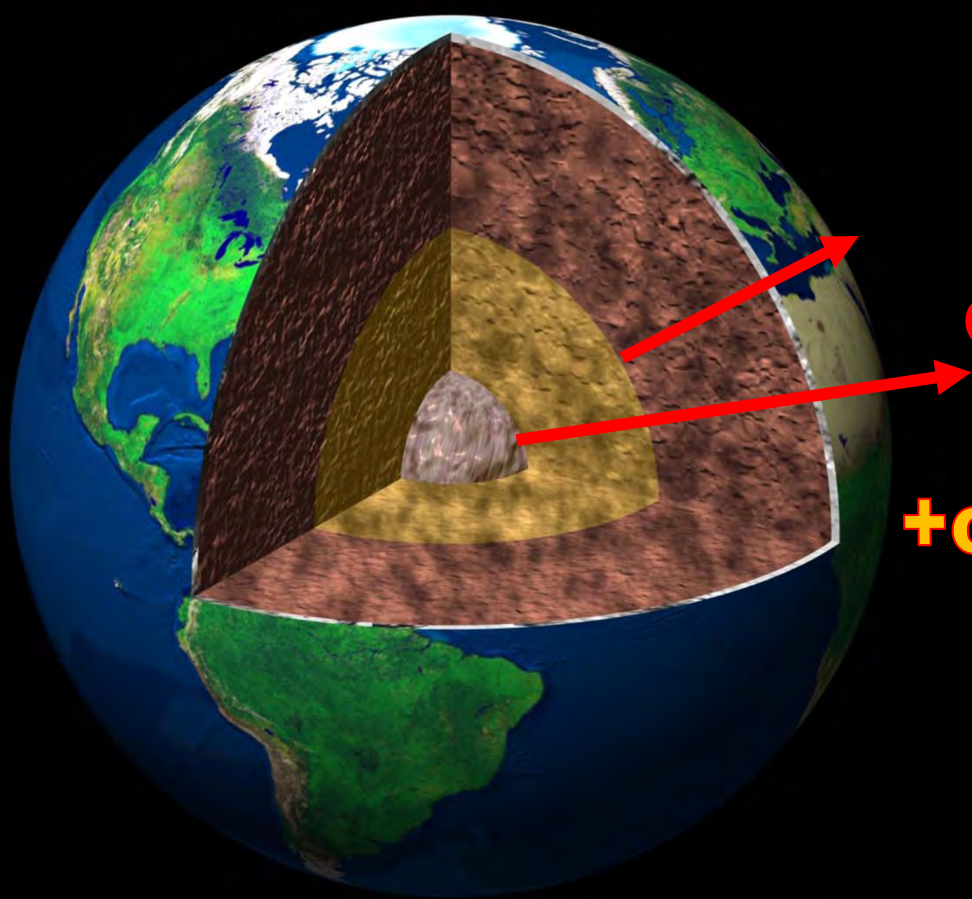
structure of the Earth's interior for its response



Change in the CMB flattening/topography

ROB

structure of the Earth's interior for its response



Flattening & electromagnetic Coupling

+other mechanisms

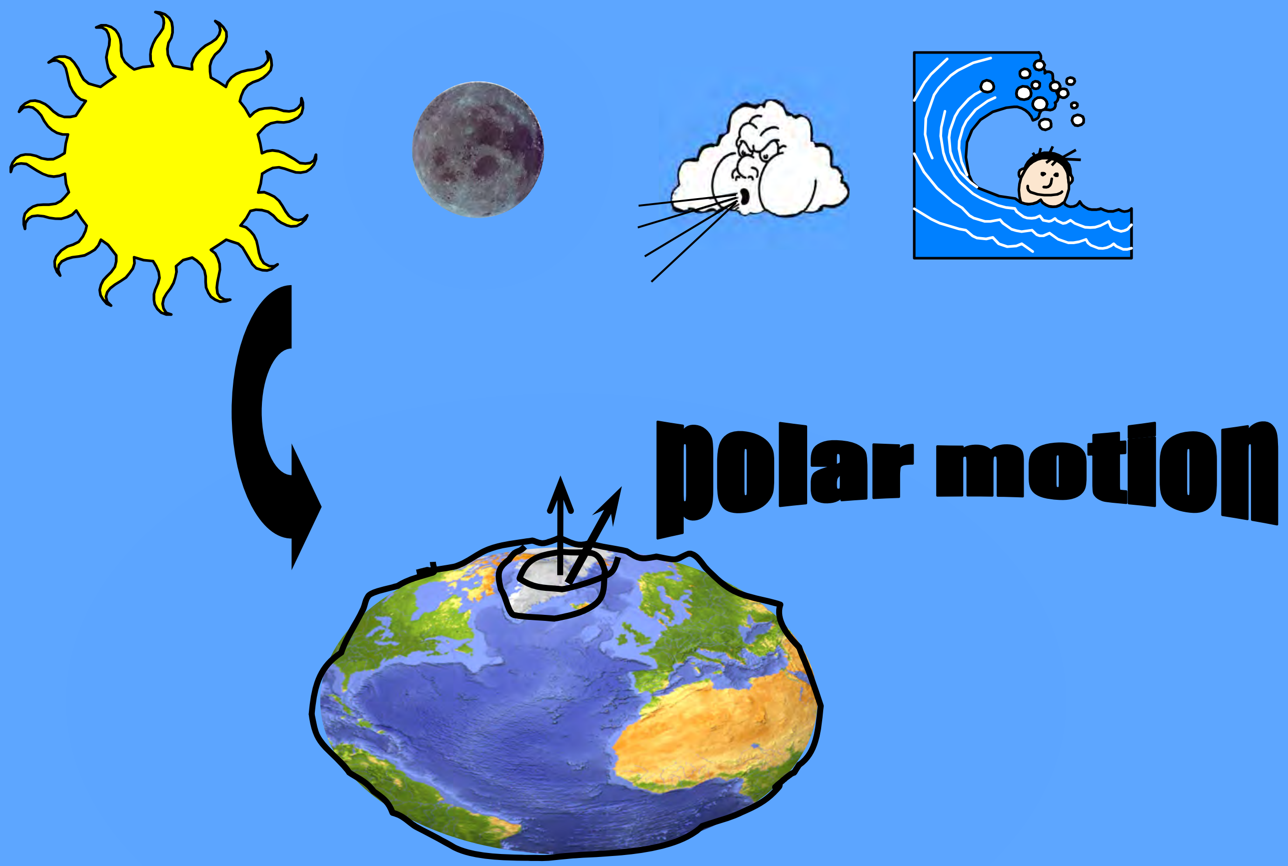
ROB

Some results concerning Earth interior

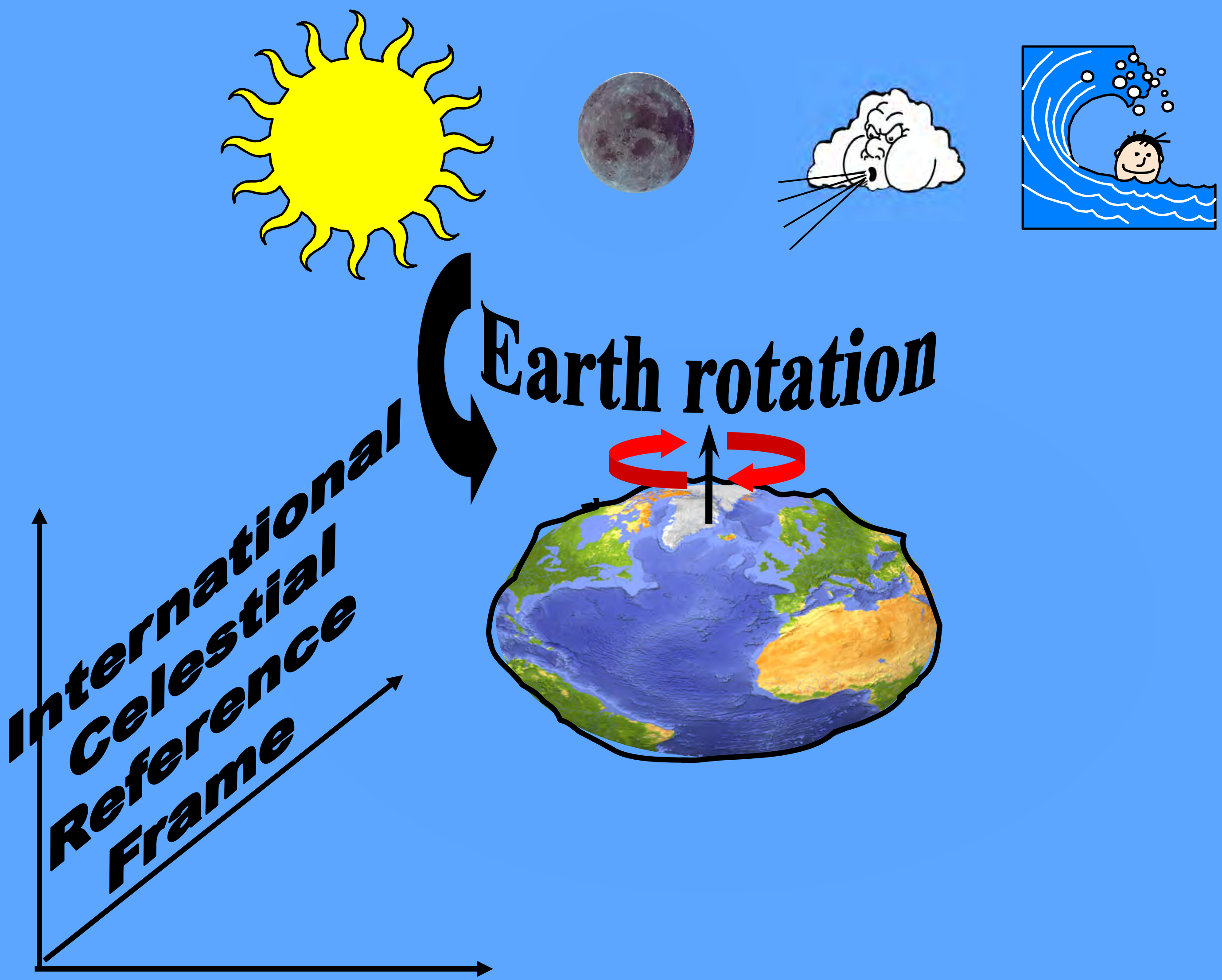
- From nutations: flattened core is not in hydrostatic equilibrium: increase of equatorial radius of about 350m
- From nutations: electromagnetic field is important at CMB if ignoring viscous and topographic torques, more important than downward continuation of surface field
- From LOD: inner core gravitational coupling, torsional oscillations, explain decadal timescale fluctiations.

Earth's response to external forcing

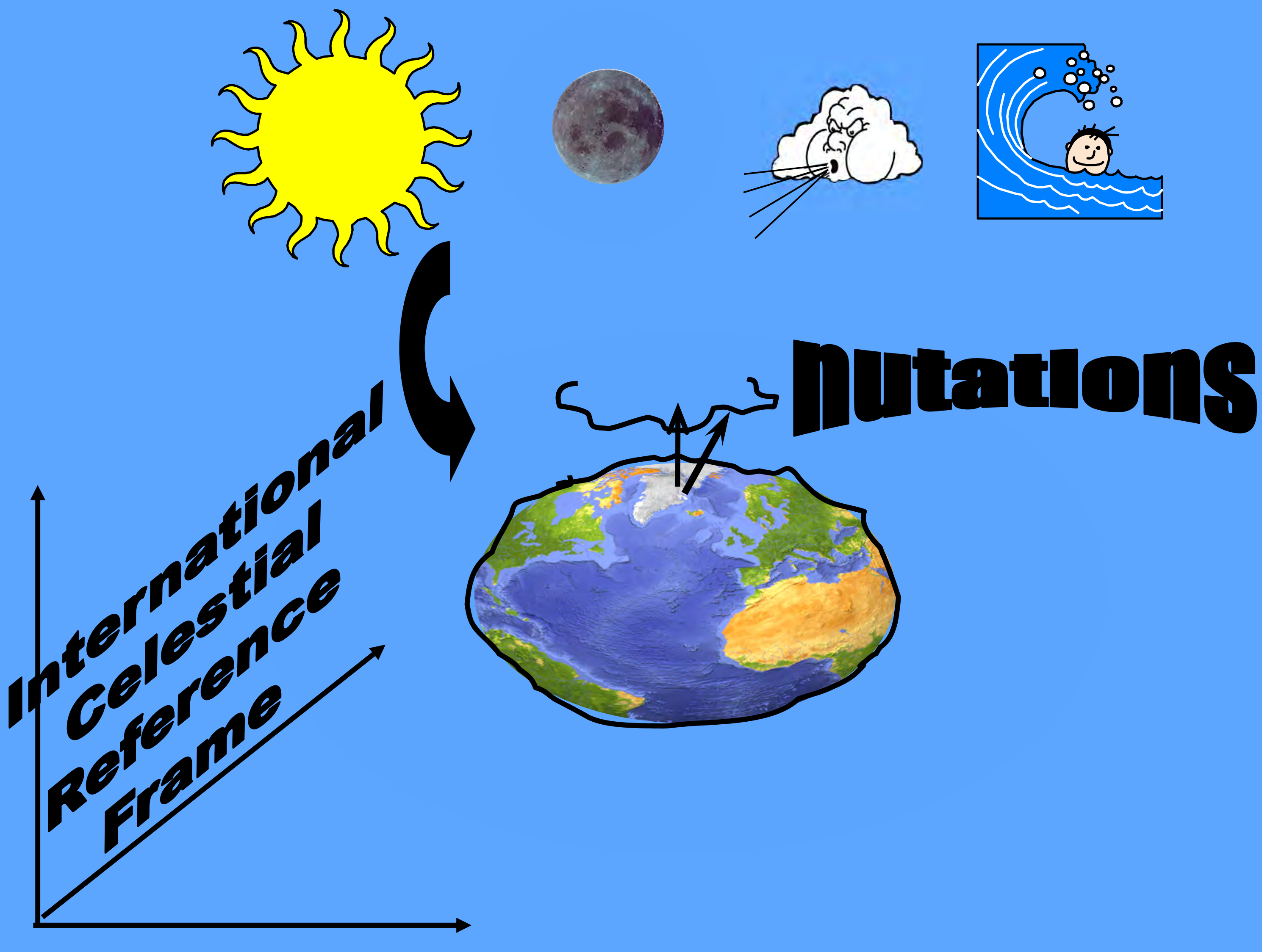
Earth’s response to external forcing



Earth's response to external forcing



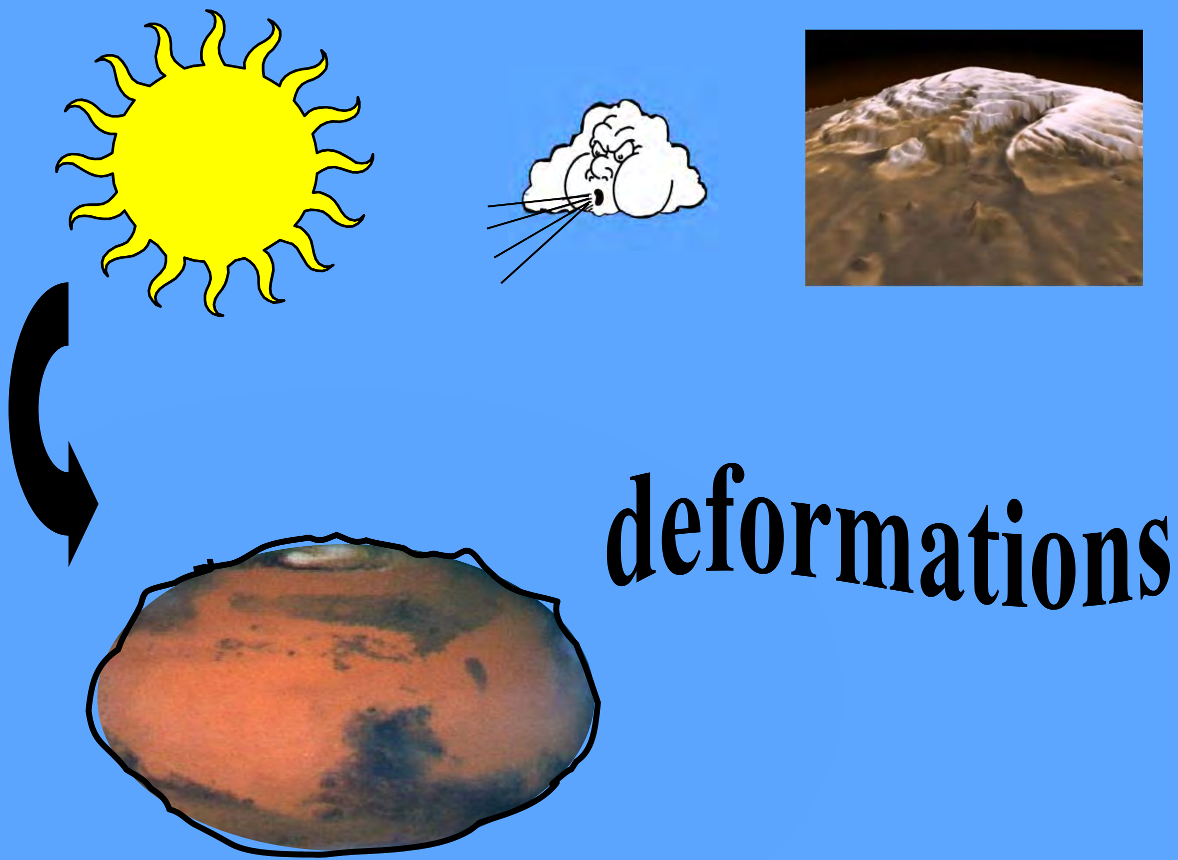
Earth's response to external forcing



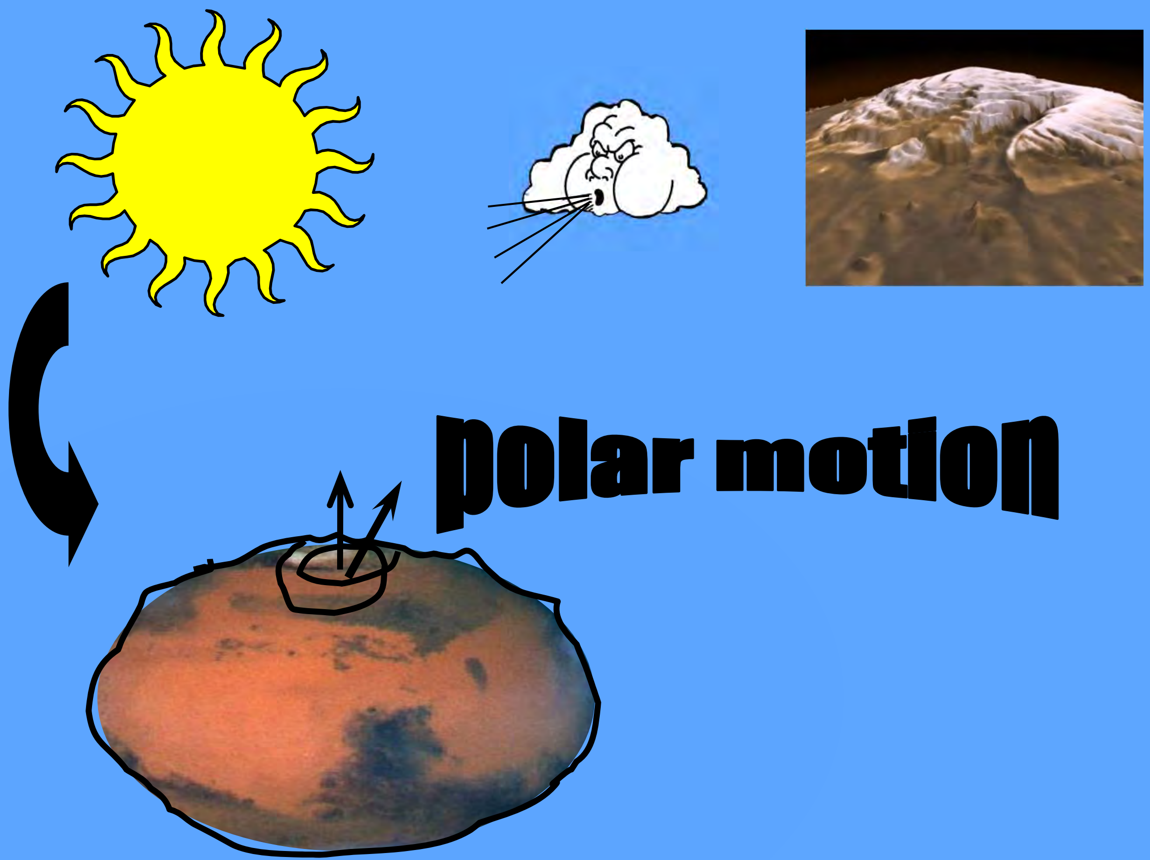
Terrestrial planets

VARIATIONS WITH RESPECT TO THE MEAN ROTATION AND INTERIOR OF MARS?

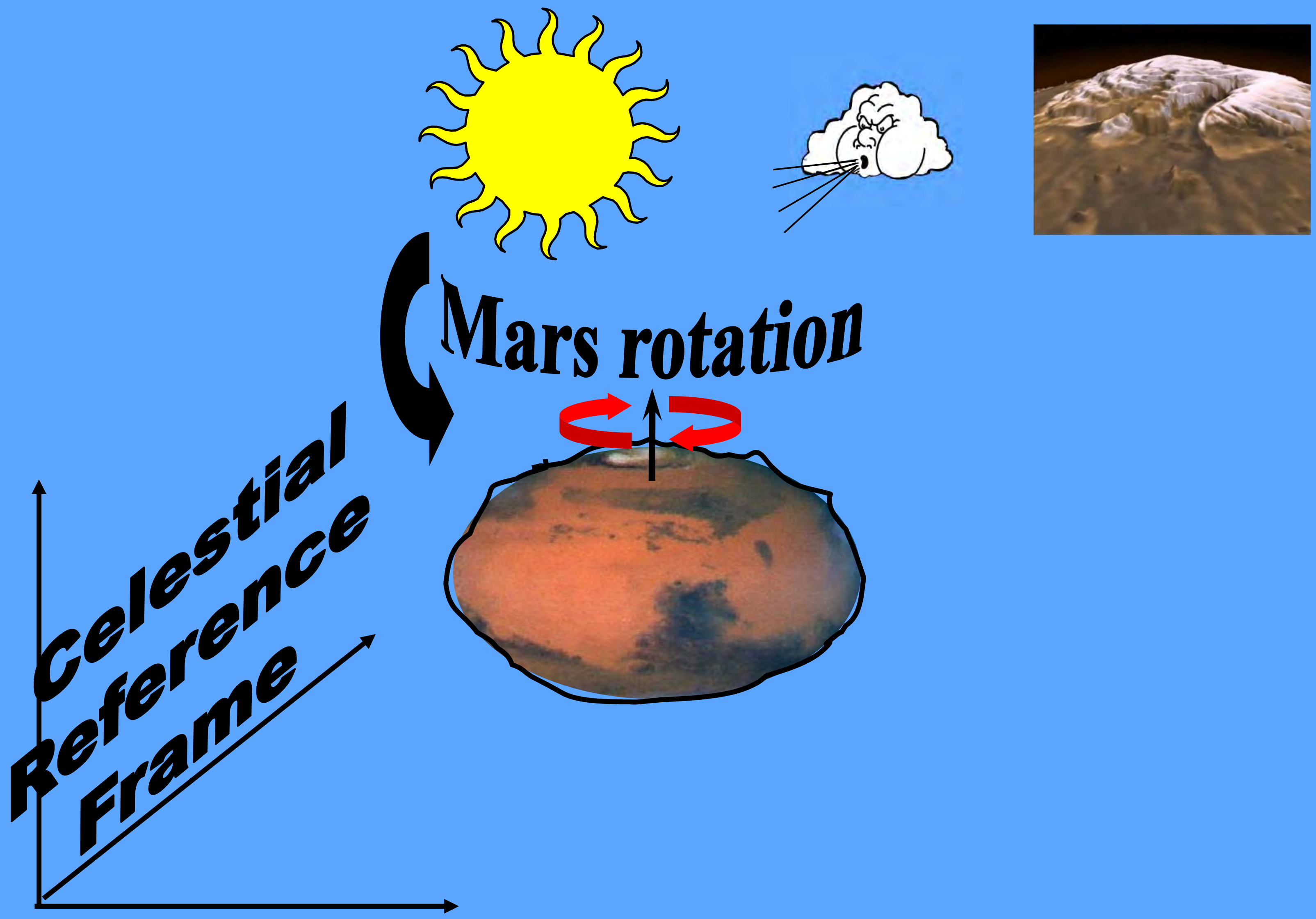
Mars' response to external forcing



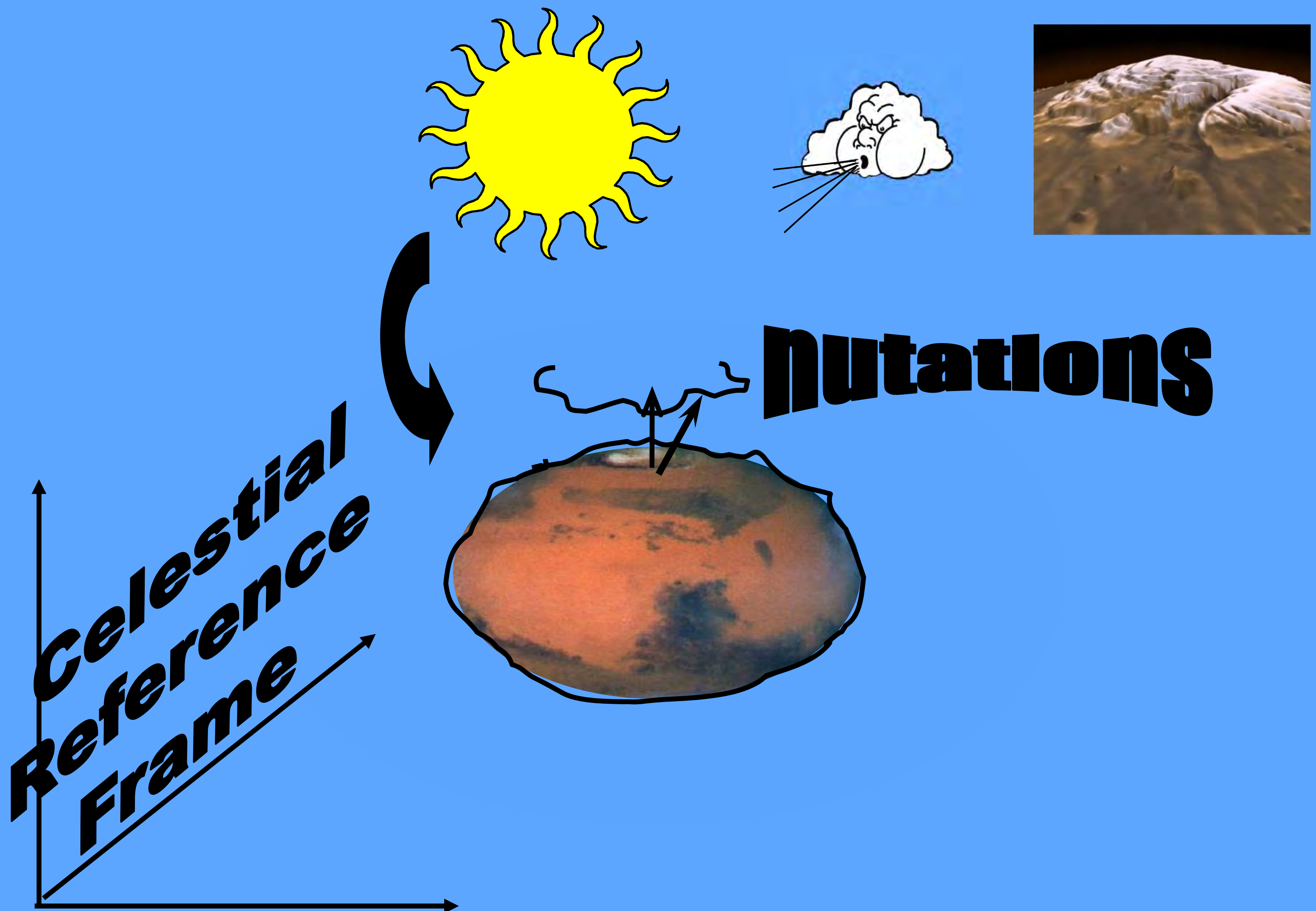
Mars' response to external forcing



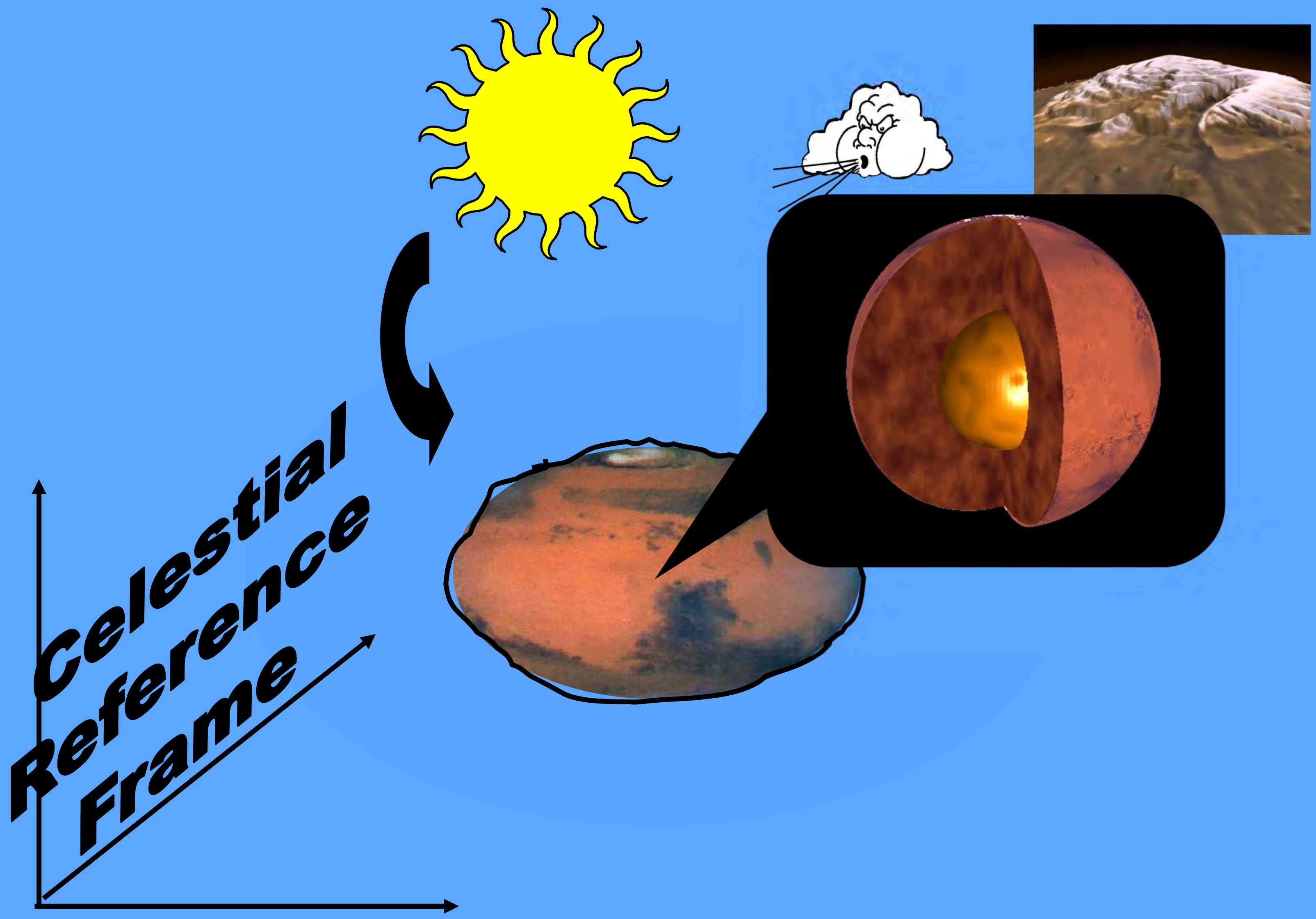
Mars' response to external forcing



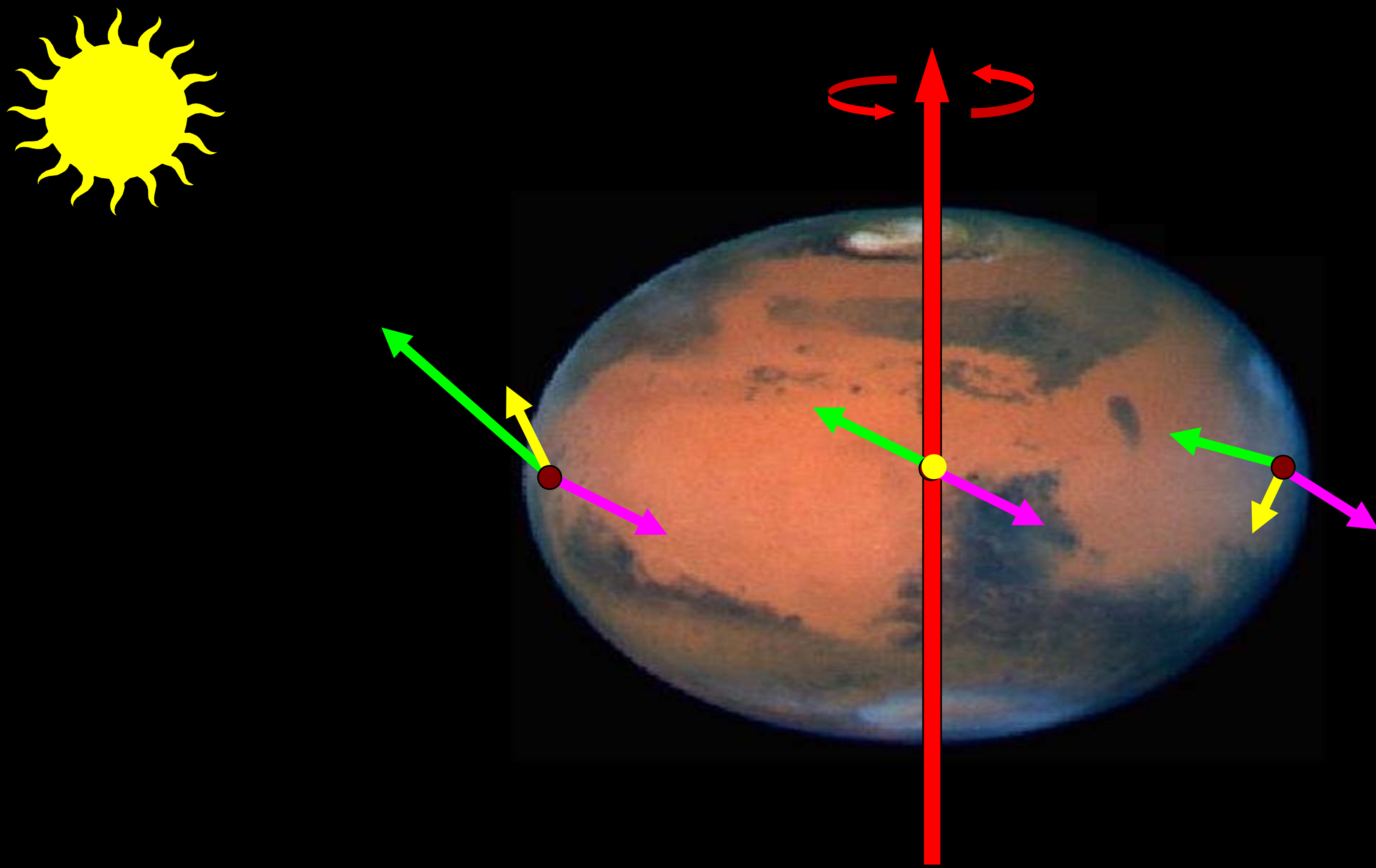
Mars' response to external forcing

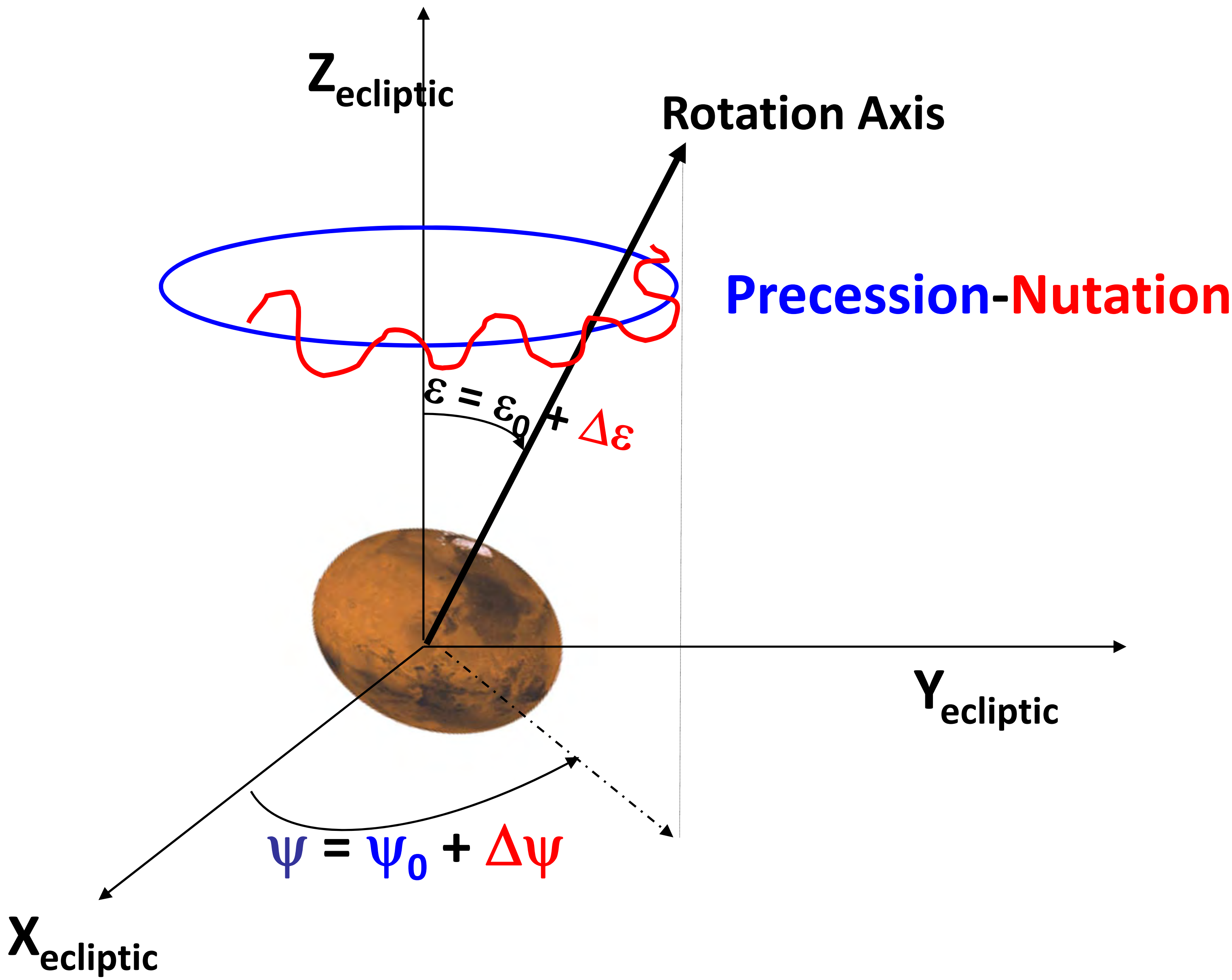


Mars' response to external forcing

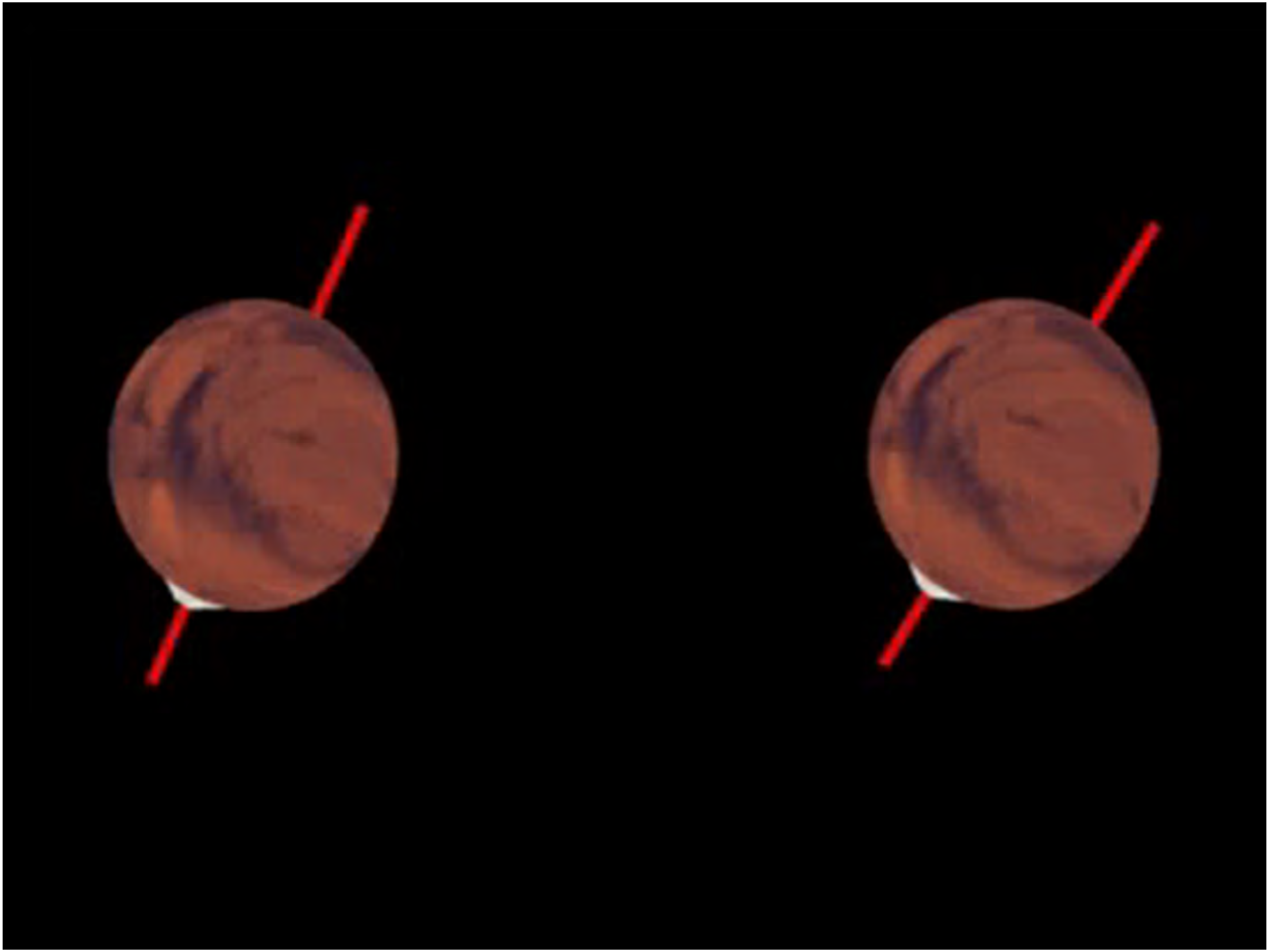


Precession and nutation of Mars



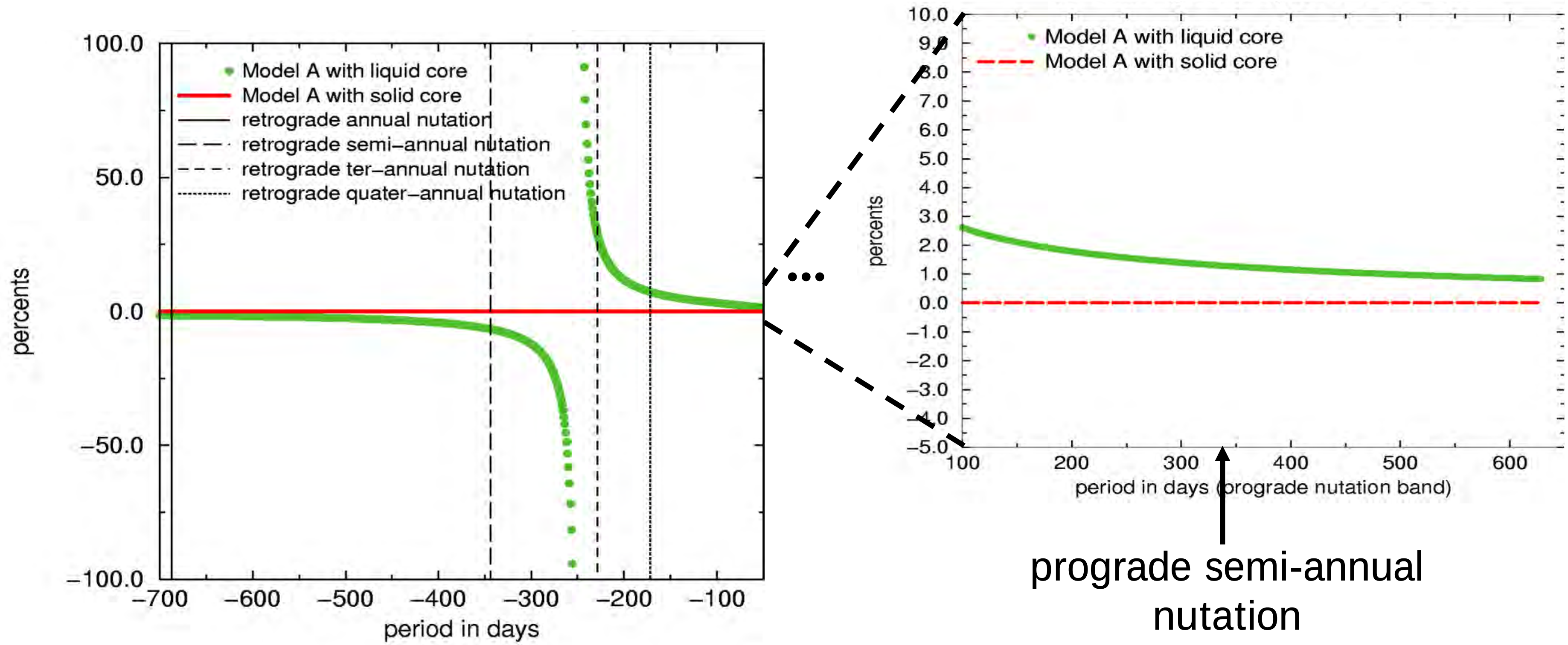


Z ecliptic
Rotation Axis
Precession-Nutation
ε = ε0 + Δε
Y ecliptic
ψ = ψ0 + Δψ
X ecliptic



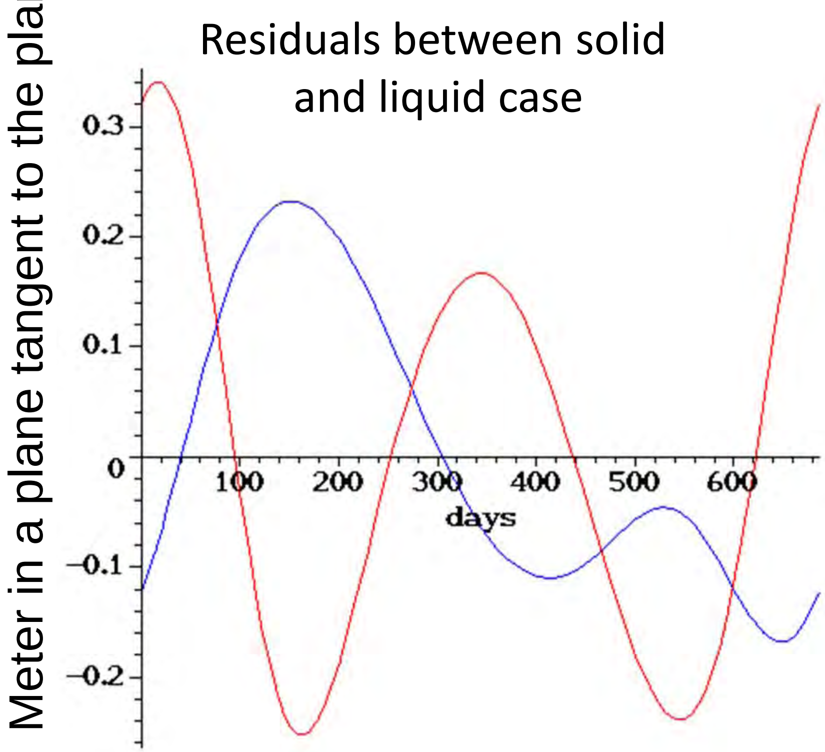
Bratio for the nutation of Mars; FCN

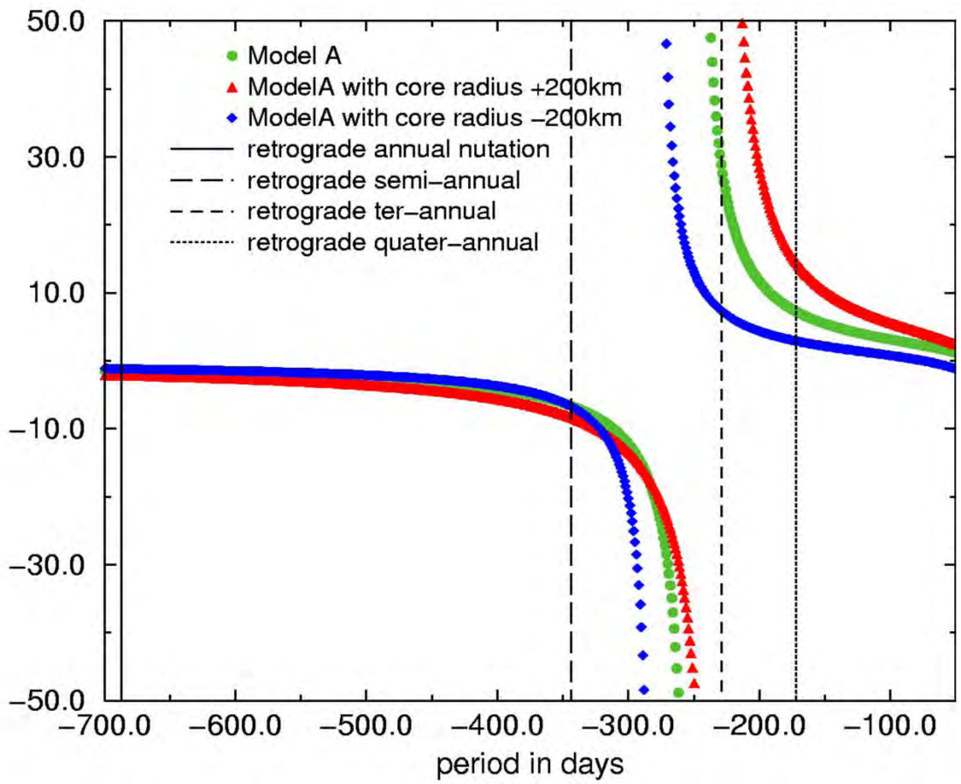
- Measurement of nutation



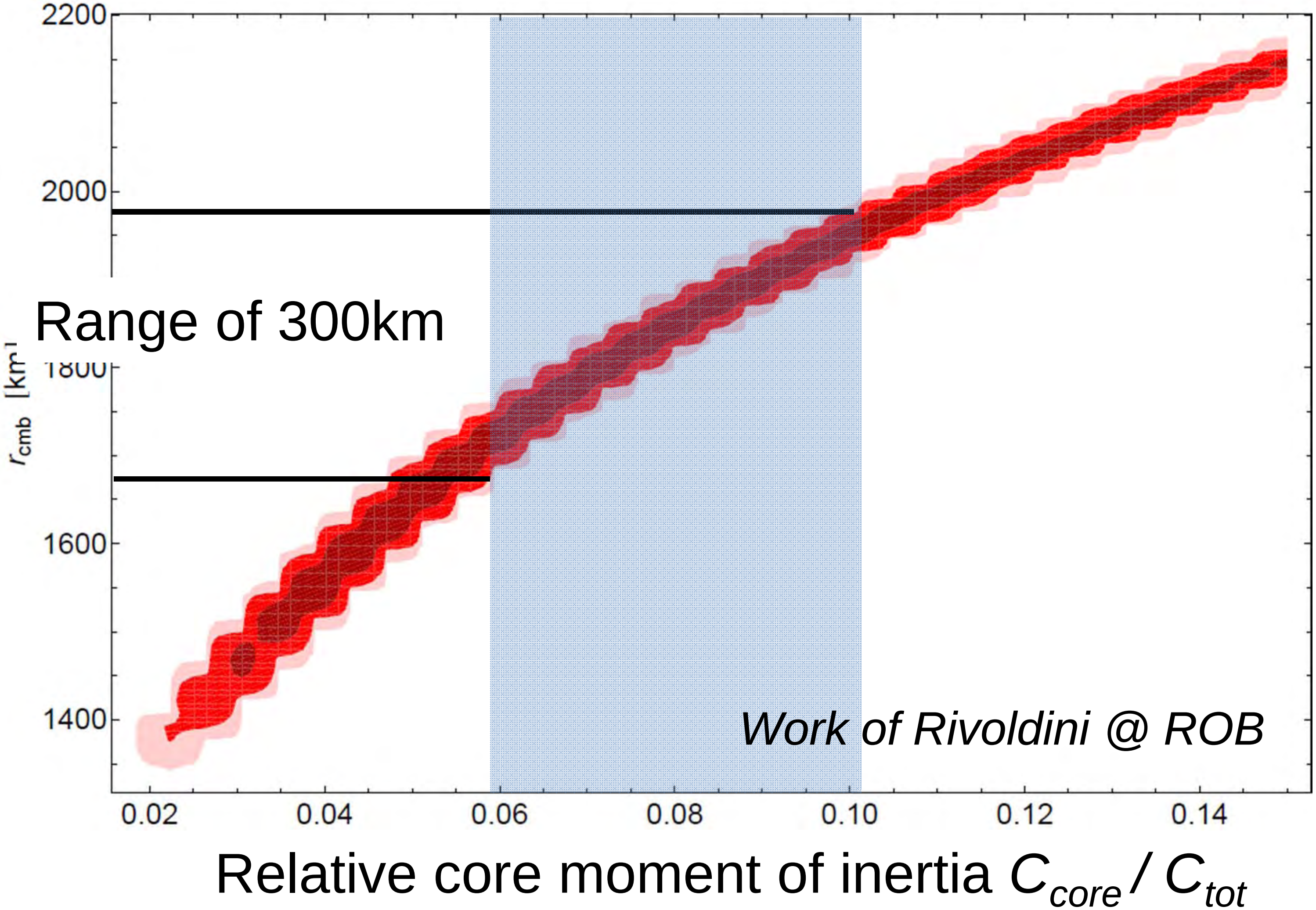
Nutation for different core dimensions

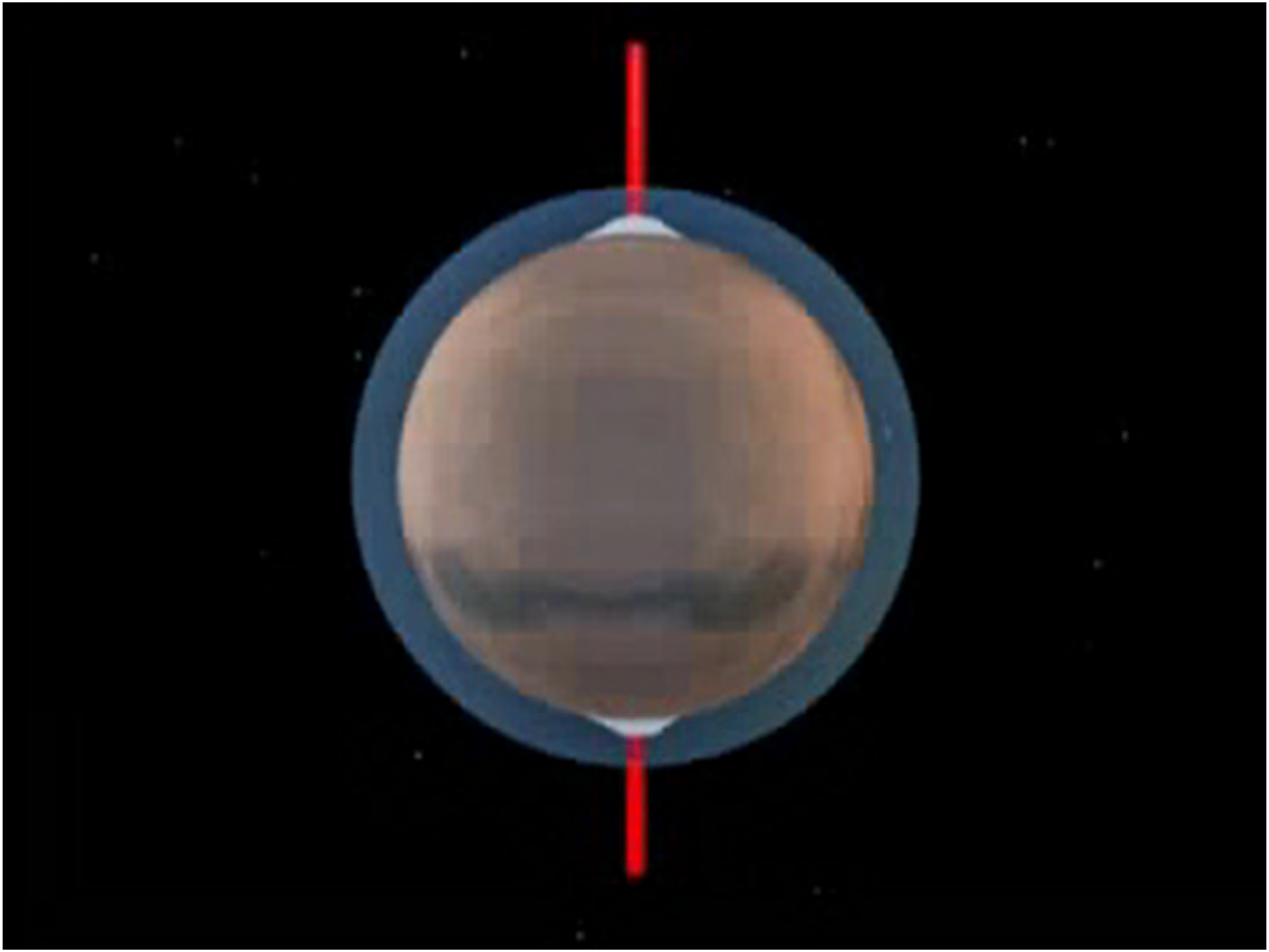
Measurement of nutation





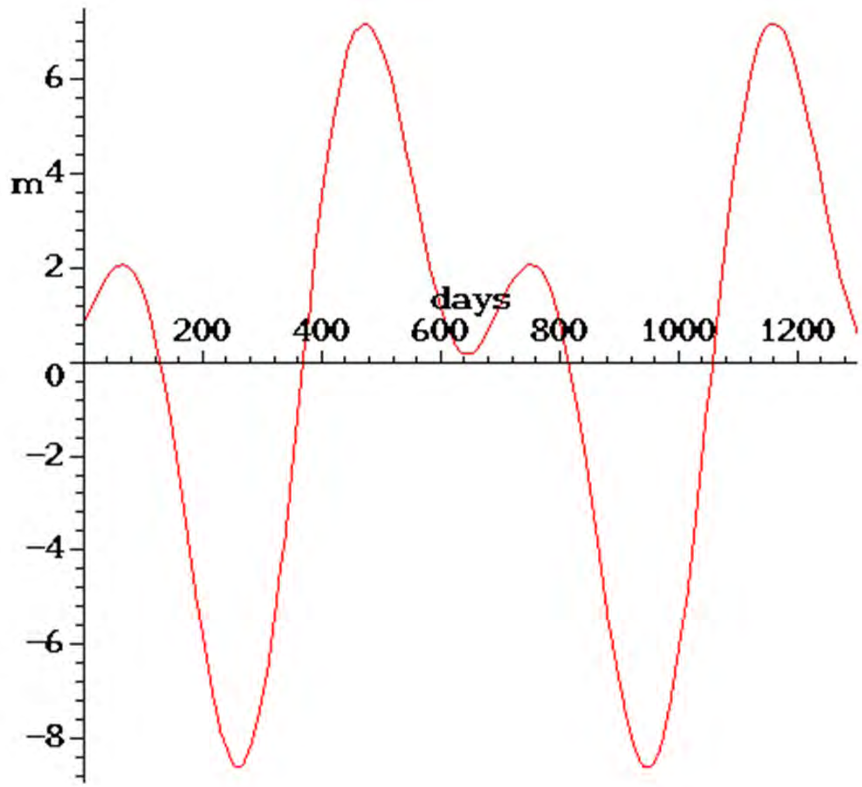
Retrieving the core radius from the core moment of inertia

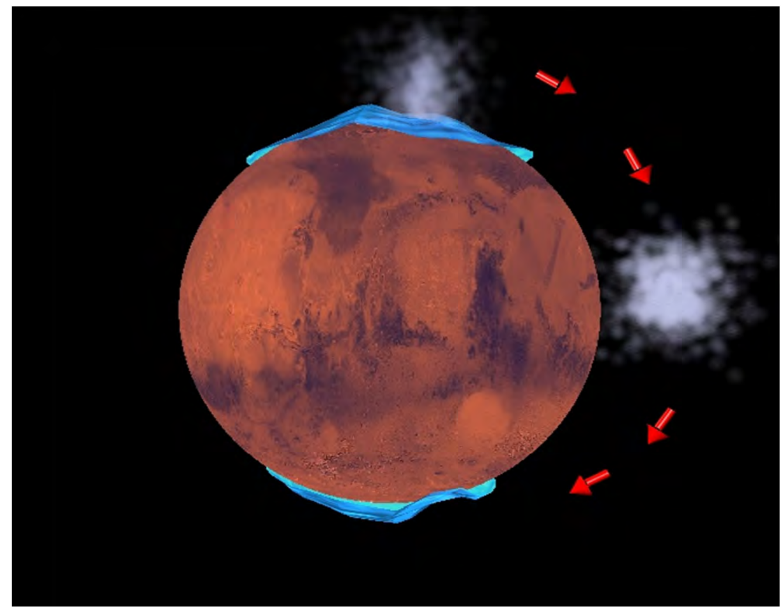




Mars radioscience objectives

- Measurement of Length-of-day variations





Some results concerning Mars interior

- Tides and Precession allow to conclude that core is at least partially liquid
- Tides and Precession allow to constrain liquid core dimension at 1800km ±150km
- If the light element in the core is Sulfur, there is no inner core.
- More to come soon… InSIGHT 2016!

Terrestrial planets

VARIATIONS WITH RESPECT TO THE MEAN ROTATION AND INTERIOR OF VENUS?

The twin sister of Earth? ...
Not for the rotation!

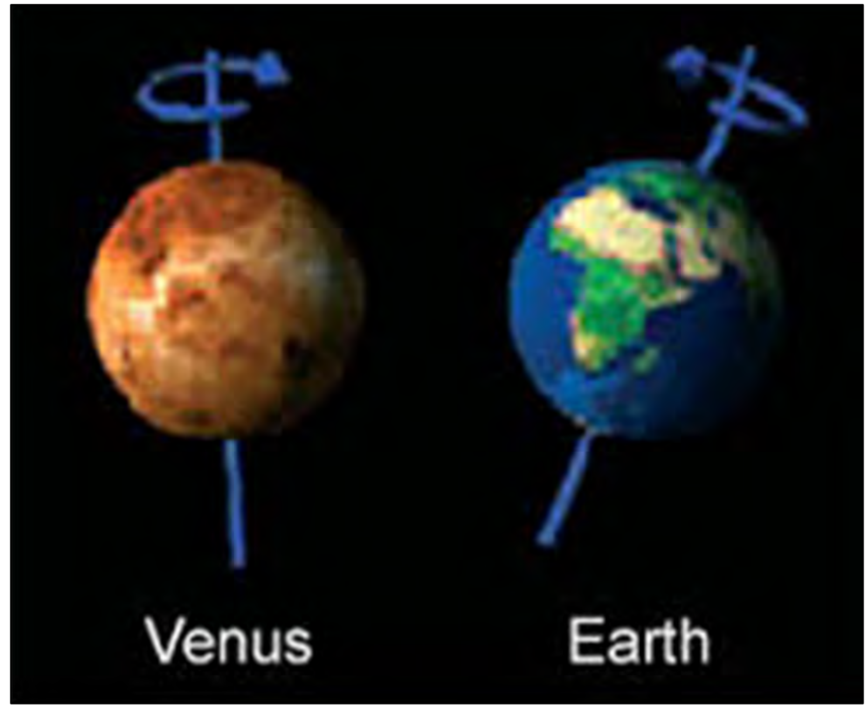
Venus

Terre

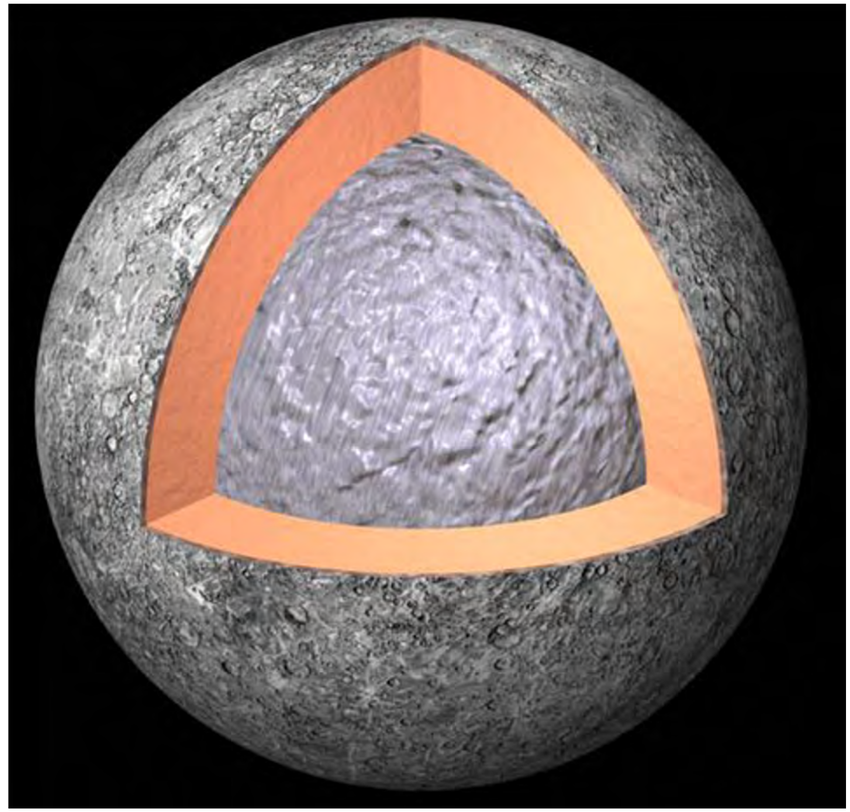
Retrograde rotation of Venus

- Possible causes?
  - Original collision/state
  - Slow down of the rotation until developing a retrograde rotation
  - Slow down of the rotation and flip of the rotation axis
- What slows down the rotation?
  - Tidal friction
  - Internal friction (tends to favor 0 or 180 degree inclination)

  See Laskar's talk

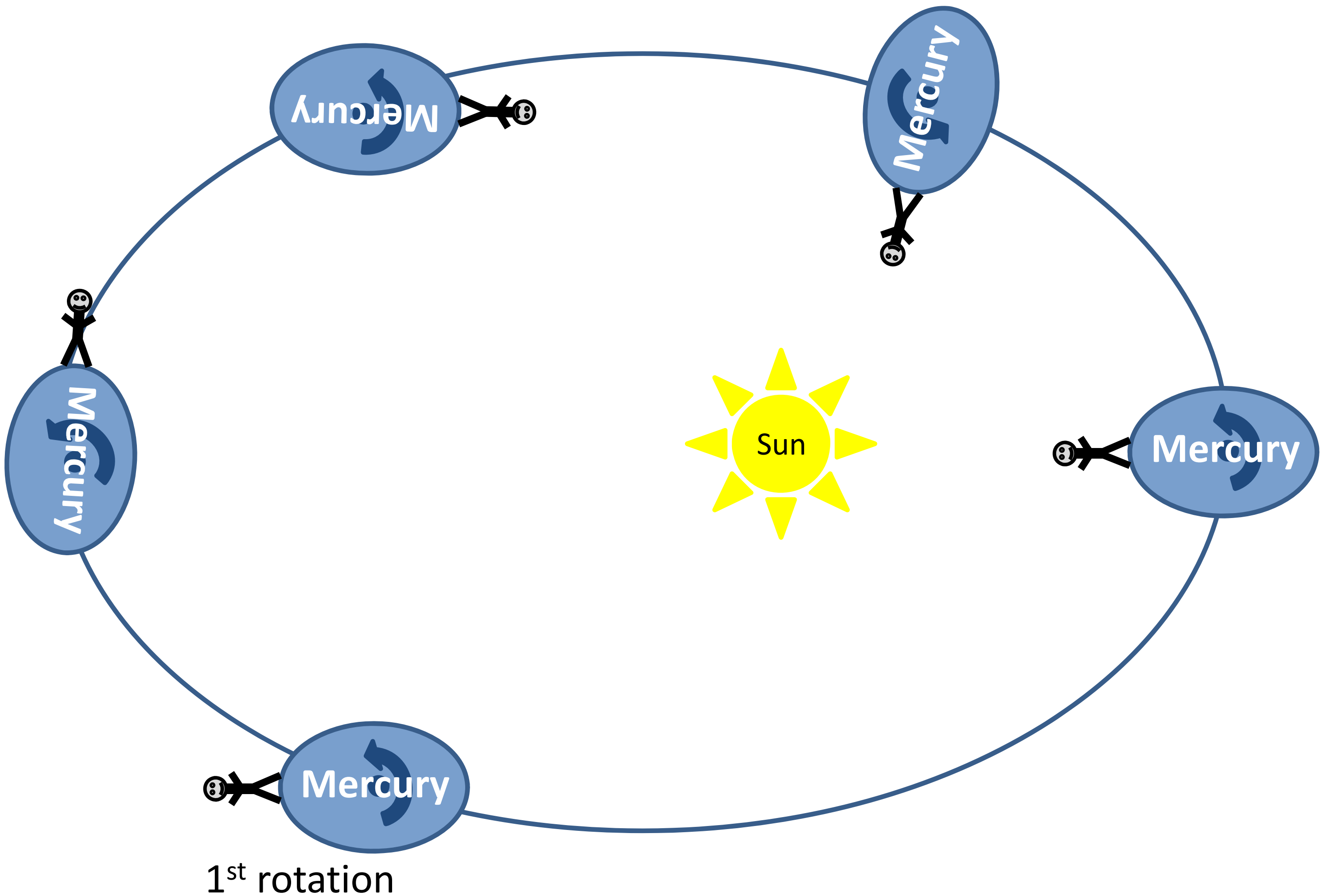


- Interior?
  - From tidal Love number: liquid core

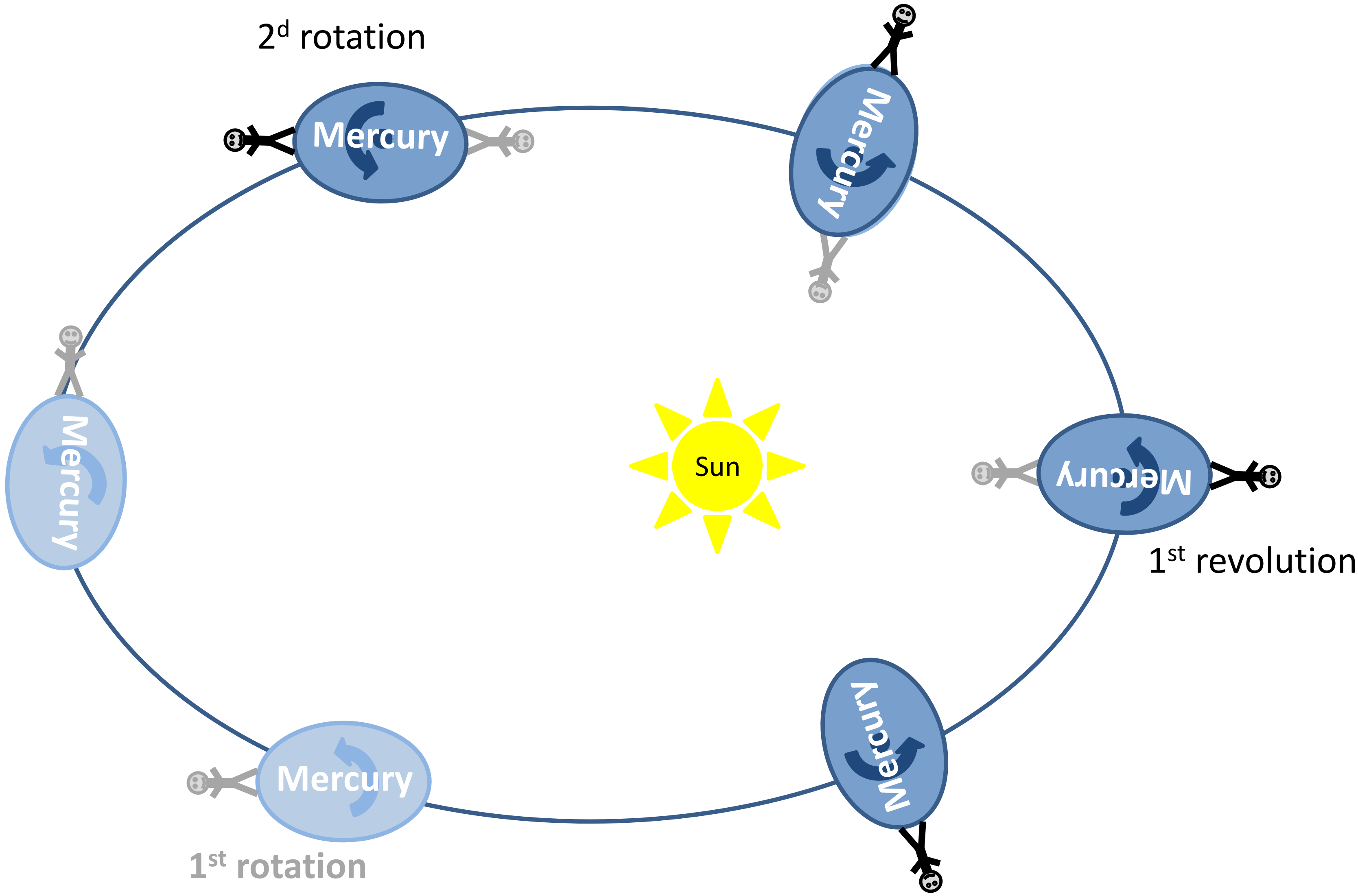


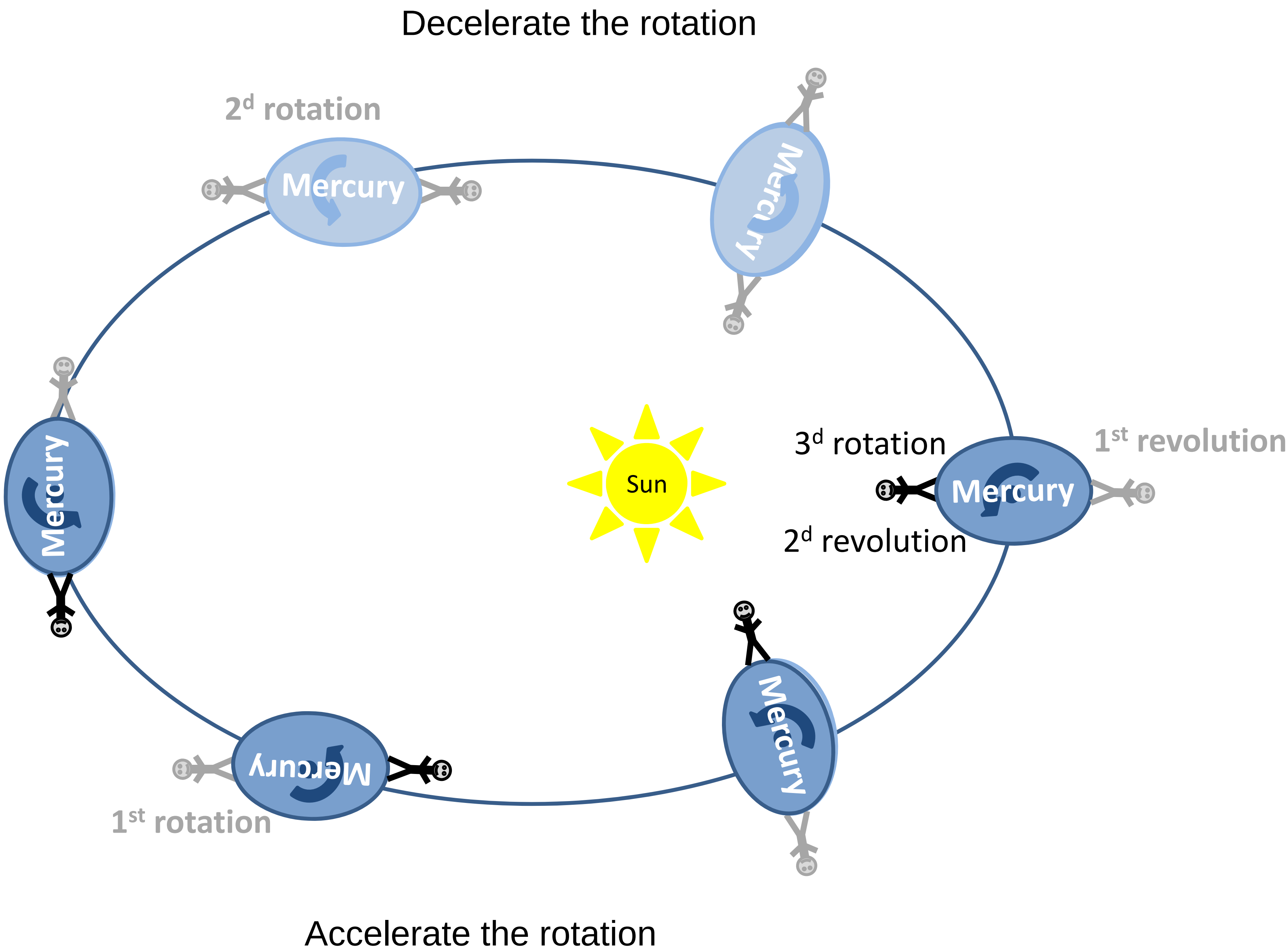
Terrestrial planets

VARIATIONS WITH RESPECT TO THE MEAN ROTATION AND INTERIOR OF MERCURY?



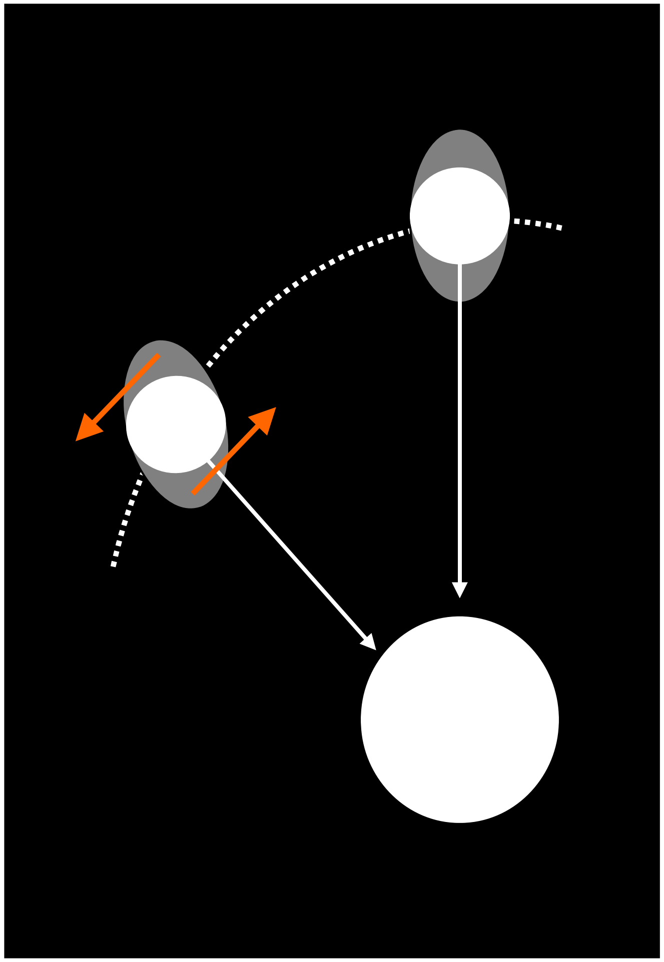
Mercury
Mercury
Mercury
Sun
Mercury
Mercury
1st rotation

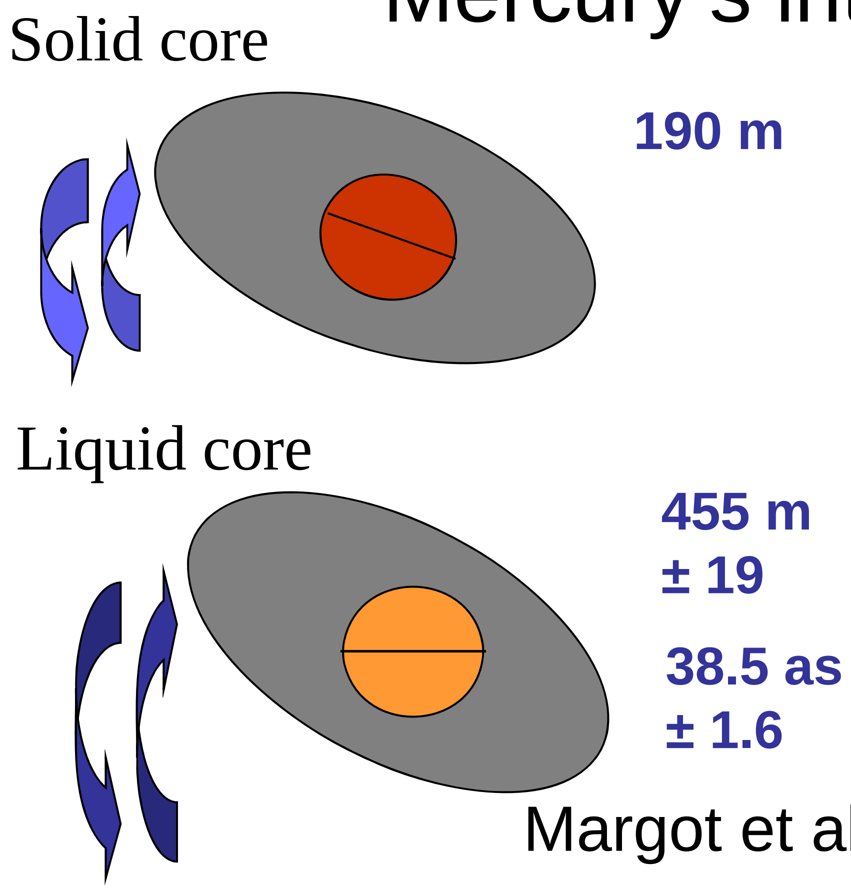

2d rotation
Mercury
Mercury
Mercury
Sun
Mercury
1st revolution
Mercury
Mercury
1st rotation



Decelerate the rotation
2d rotation
Mercury
Mercury
Mercury
Sun
3d rotation
Mercury
1st revolution
2d revolution
Mercury
Mercury
1st rotation
Accelerate the rotation

Some results for Mercury's interior





Margot et al., 2012

- The radius of the core is 2000 km ± 40km

  (Rivoldini and Van Hoolst, 2013)

using Messenger (Smith et al. 2012) gravity field and libration and obliquity (Margot et al., 2012)

Conclusions

- Planetary geodesy is a very helpful for studying planets or moons of the solar system.
- In particular (this talk), for obtaining their rotation and orientation,
- and therewith for obtaining properties of the interior of these planets or moons.