Measurements of Martian rotational variations by space geodetic technique

（宇宙測地学的手法を用いた 火星回転変動計測）

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ABSTRACT

Variations of Mars' rotation provide us information concerning both the interior structure and the surface mass redistribution of Mars. Precession and nutation of Mars mainly reveal the core-mantle subsystem, besides length-of-day (LOD) variation and polar motion of Mars are generally referred to the atmosphere-cryosphere sub-system. As one of the missions of Mars Entry-Descent-Landing and Surface Exploration Technologies Demonstrator, we are proposing areodetic observations by space geodetic techniques using two-way Doppler measurements.

In the framework of this technology, ground tracking stations observe the Doppler-shifted signals transmitted from the lander on the mars. We analyzed that the estimated accuracy of precession will be improved by three times better than from InSight mission, and the LOD accuracy is enough to detect each factor of air pressure, wind, and polar ice cap. We also confirmed that the communication system for X-band two-way coherent relay is feasible for our mission.

Changes of Mars Exploration Project of Japan

Mars
火星

Former: Mars Exploration with Lander-Orbiter Synergy (MELOS)
- Orbiters: Global view of Mars
  - **1) Meteorology Orbiter**
  - **2) Atmospheric Escape Orbiter**

  \+

- Landers or airplane

↓

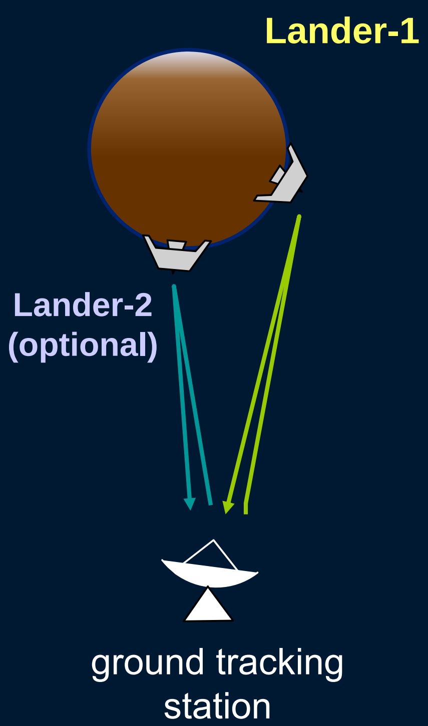
new: Mars Entry-Descent-Landing and Surface Exploration Technologies Demonstrator (△ early 2020s)

for
- Surface exploration for **chronology** by a rover
- **Biological experiments** by a **Rover**
- **Interior observation** by seismometer and rotation measurements using **Lander(-s)**

this study

2-way Doppler measurements (2w-DOPP)

Mars
Марс



Measurements of Martian Rotational Variations by Space Geodetic Techniques:
- 1 or 2 Lander(-s)
- observations for > 100 week
- observations for 1hr x 3 / week
- improvement of accuracy by combining data of InSight

Four categories of rotation variation and their scientific targets

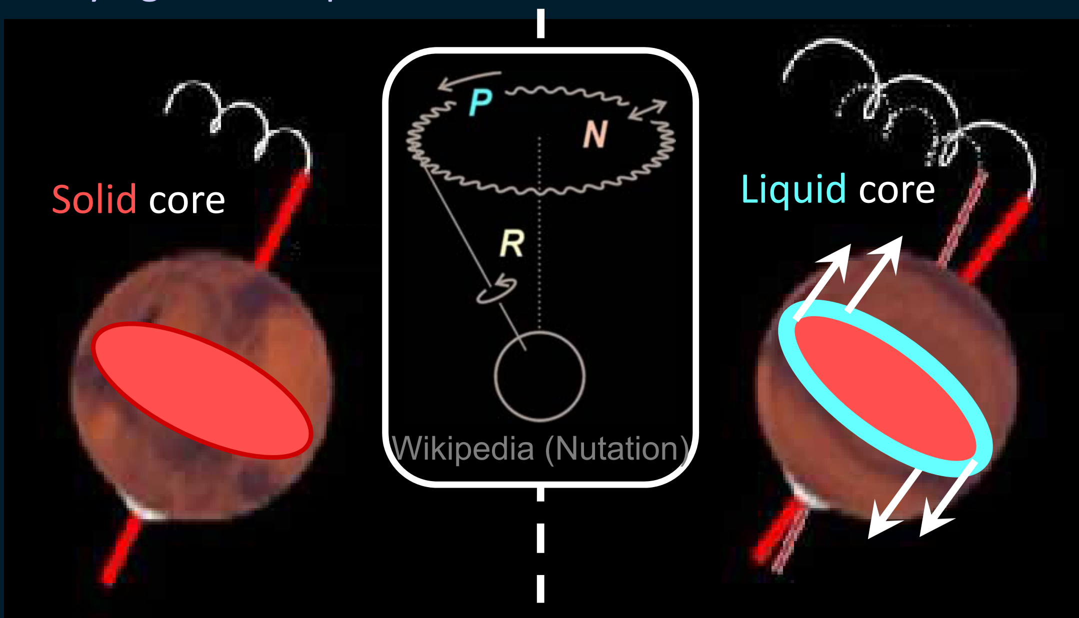
- **Precession (歳差)** → 3 times improved from InSight
  - MOI (momentum of inertia) → **density structure**
  - Obliquity → **climate change**
- **Nutation (章動)** → 1.5 - 2 times improved from InSight
  - Radius of core-mantle boundary
  - Presence of inner core

    → **thermal evolution model**
- **Polar motion (極運動)**
- **LOD variation (日長変動)**
  - Sublimation / condensation in atmosphere-cryosphere, activity of dust storm

    → **global circulation model**

Physical Origins of Nutation

Time-varying tidal torque with / without fluid core resonance ?



(angular momentum interaction between core and mantle)

Physical Origins of Nutation

Time-varying tidal torque with / without fluid core resonance ?

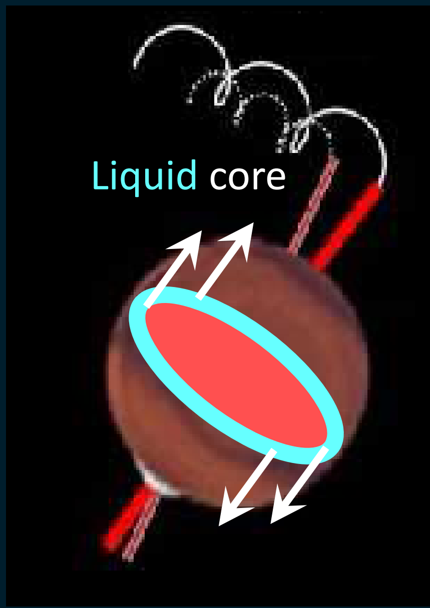
Tidal Love number
(by Mars Global Surveyor)

$k_2 = 0.153$;

- fluid core (Yoder *et al.*, 2003)
- marginal (van Hoolst *et al.*, 2003)

V

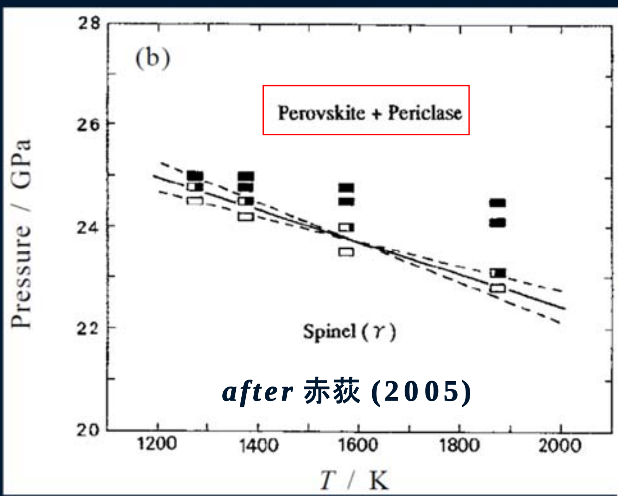
- needs more precise observation



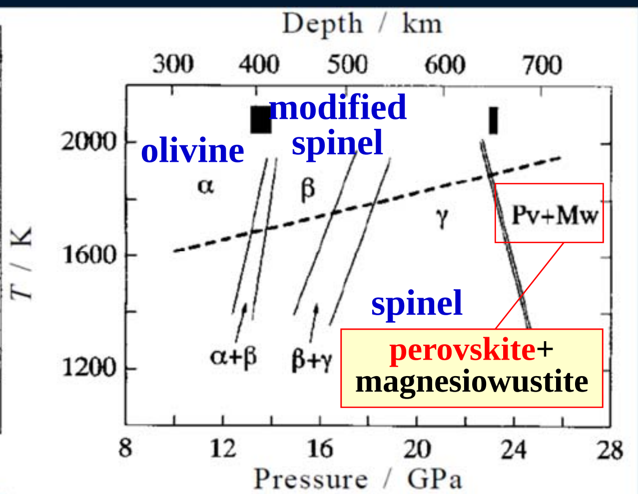
(angular momentum interaction between core and mantle)

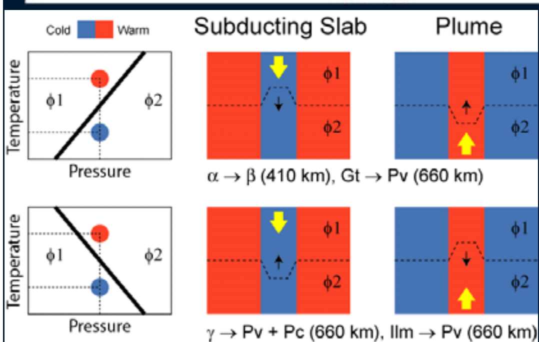
Spinel – Perovskite phase diagram

Mars
Mapc



after 赤荻 (2005)

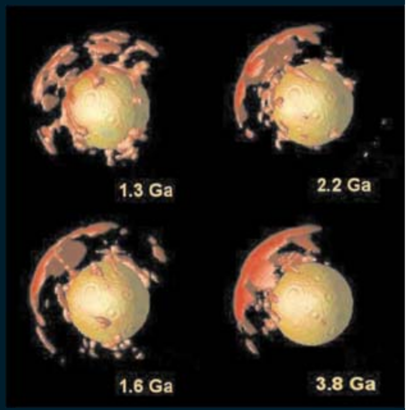




Spinel – Perovskite phase transition interferes with the convection

What Do We Know from Mars' nutation?

- Nutation
  - –> radius of core–mantle boundary
  - –> pressure under the mantle
    + temperature distribution model
  - –> presence of Spinel/Perovskite phase transition
  - –> * efficiency of thermal transfer,
    * pattern of convection
  - –> **thermal evolution model**



Spohn *et al.* (2001)

Estimation for liquid core radius

Mars
火星

If fluid core resonance exists:

- Observed nutation amplitudes in the retrograded case (r'_m) are increased from that of rigid body (r_m) as;

$$r'_m = r_m \left(1 + F \frac{\alpha_m}{\alpha_m + \sigma_0}\right)$$

Folkner *et al.* (1997)

Hereafter, we call this term as **"Nutation Amplification Term"**

F : "nutation transfer function" which is a coefficient depends on characteristics of the size and flattening of core.

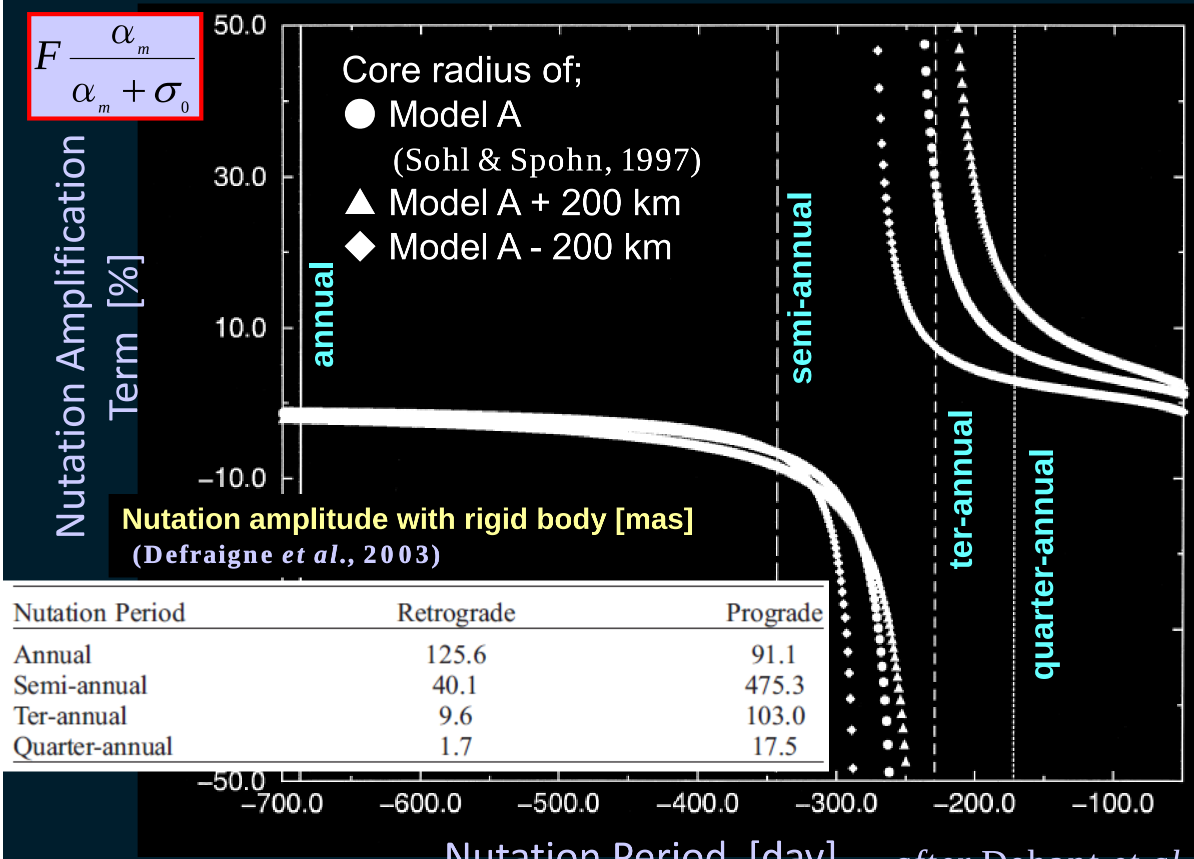
α_m : nutation frequency, σ_0 : free core nutation frequency

$$F = \frac{C_f}{C - C_f}\left(1 - \frac{\gamma}{e}\right), \quad \sigma_0 = -\Omega_0 \frac{C}{C - C_f}(e_f - \beta)$$

Yseboodt *et al.* (2003)

Analysis for errors of core radius estimation

$$F \frac{\alpha_m}{\alpha_m + \sigma_0}$$



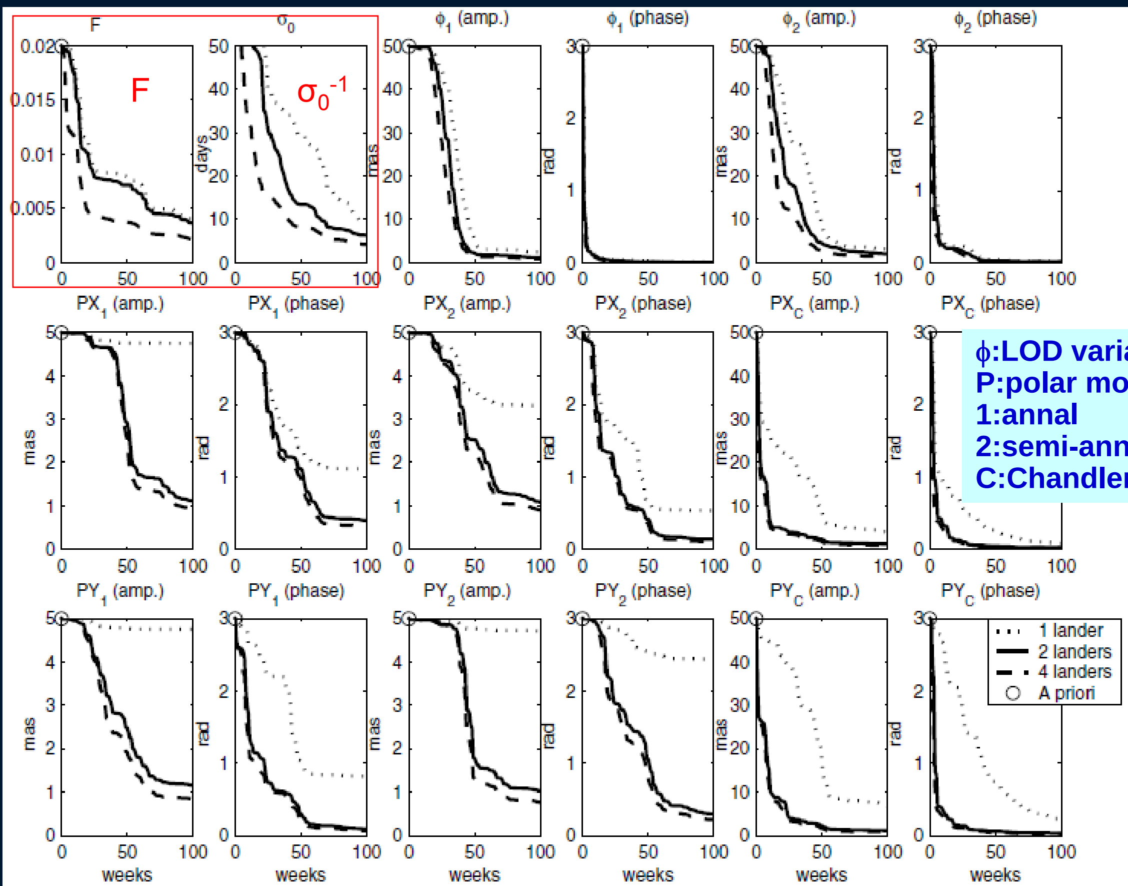
Nutation amplitude with rigid body [mas]
(Defraigne *et al.*, 2003)

Nutation Period	Retrograde	Prograde
Annual	125.6	91.1
Semi-annual	40.1	475.3
Ter-annual	9.6	103.0
Quarter-annual	1.7	17.5

after Dehant *et al.* (2000)

Mars 火星

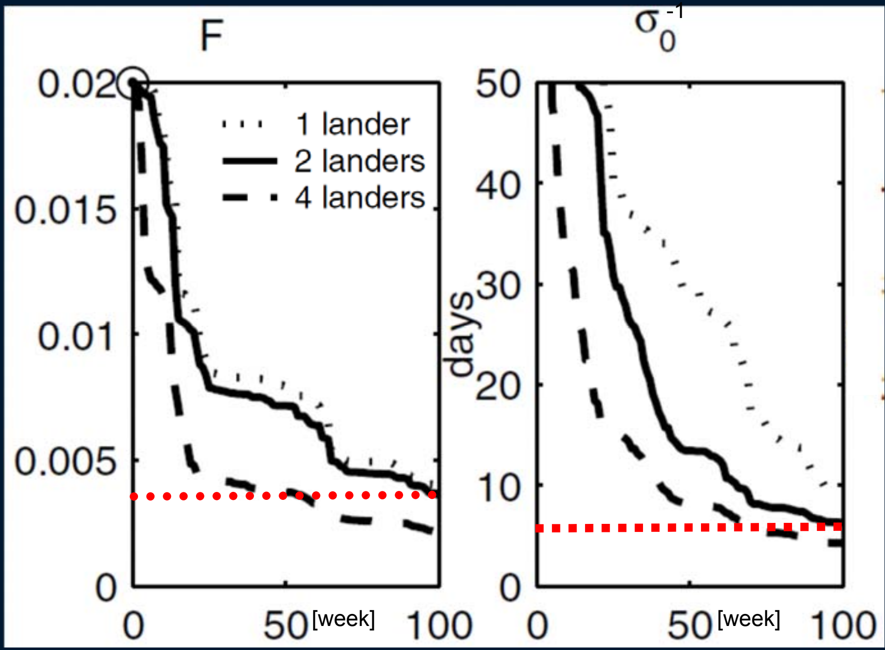
Evolution of standard deviation of areodetic parameters（Yseboodt et al., 2003）



φ:LOD variation
P:polar motion
1:annal
2:semi-annual
C:Chandler wobble

Evolution of standard deviation

Mars
火星



F : “nutation transfer function”

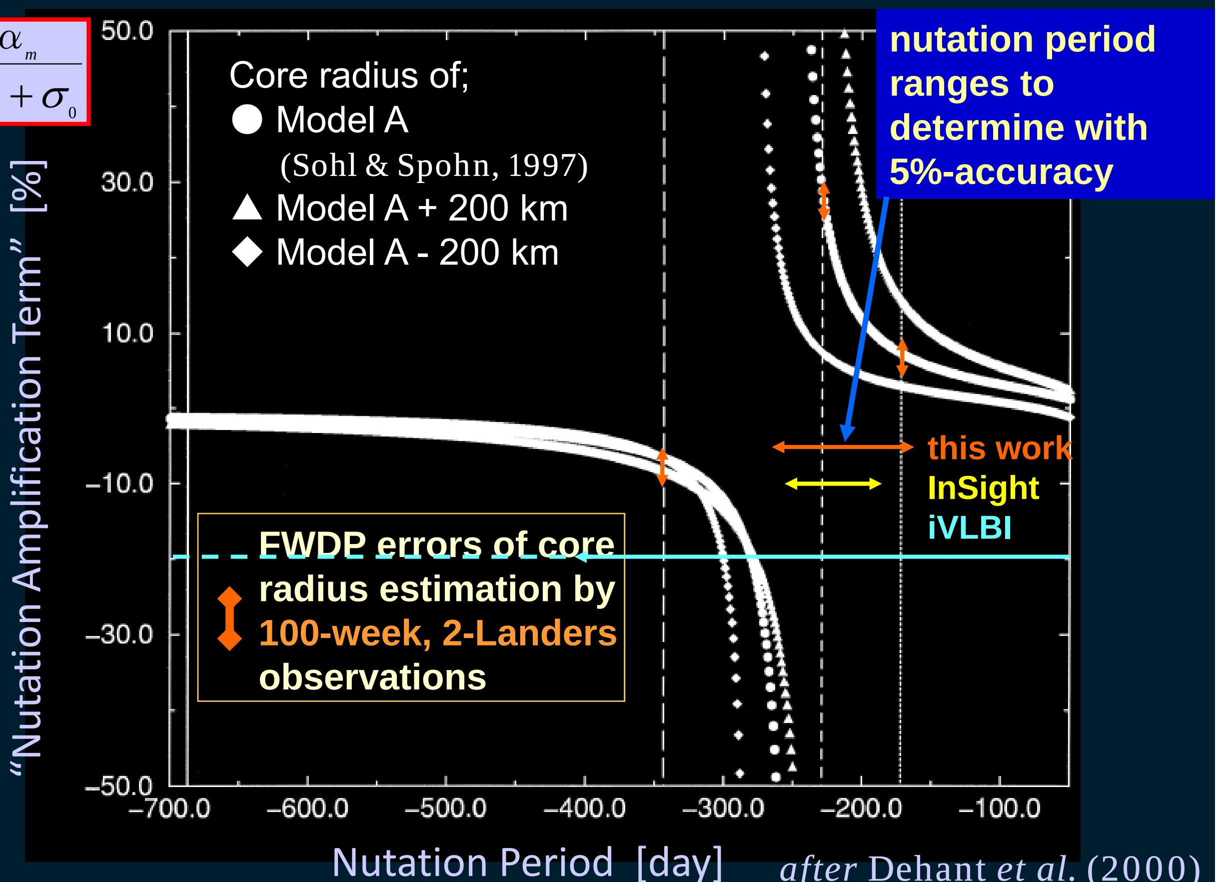
σ_0^{-1} : free core nutation period

σ_0 : free core nutation frequency

after Yseboodt *et al.* (2003)

Analysis for errors of core radius estimation

$$F \frac{\alpha_m}{\alpha_m + \sigma_0}$$



after Dehant *et al.* (2000)

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- **Nutation (章動)**
  - Radius of core-mantle boundary
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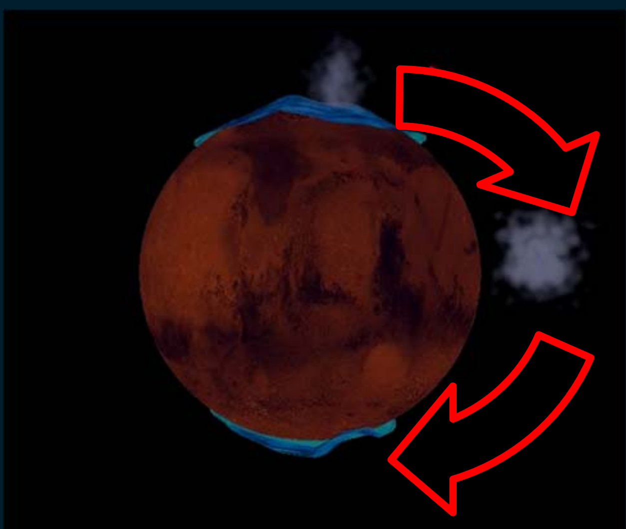
    → **thermal evolution model**
- **Polar motion** → 5 times improved from InSight
- **LOD variation** → 2 times improved from InSight
  - Sublimation / condensation in atmosphere-cryosphere, activity of dust storm
    → **global circulation model**

Mechanisms of Polar Motion & LOD Variation

Loading by atmosphere & ice

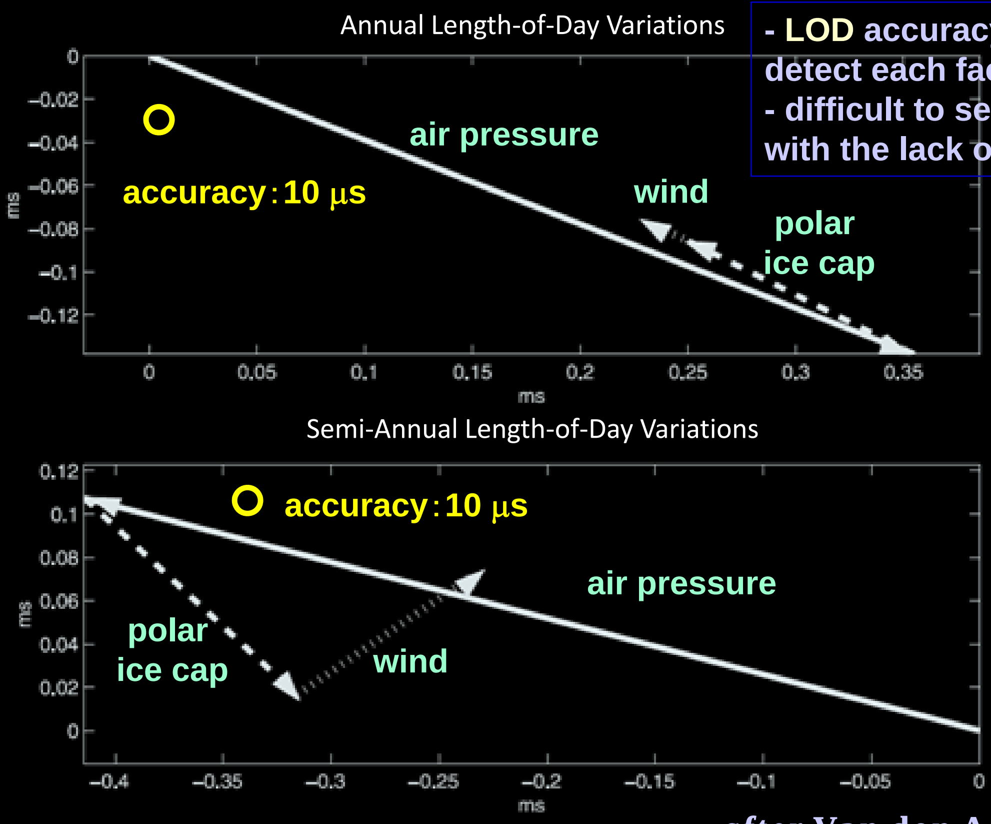


(MOI perturbation)

Shear stress by wind

(Angular momentum interaction)

amplitudes & phases of **LOD variation**



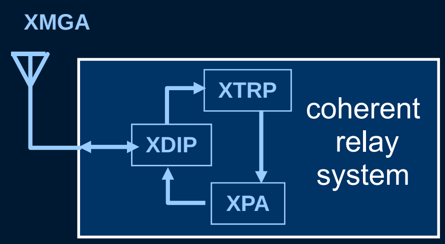
- LOD accuracy is enough to detect each factor.
- difficult to separate each factor with the lack of accurate J2.

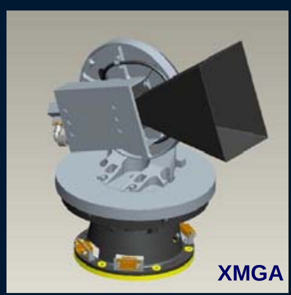
- 単位：ms（ミリ秒）
- 実線：大気圧
- 破線：極冠
- 点線：風

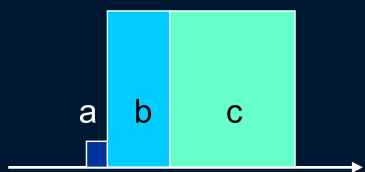
after Van den Acker *et al.* (2002)

X-band communication system for 2w-DOPP

Mars Mapc







power profile
a) pointing; 11 W
b) warm up; 123 W
c) observation; 123 W
-> 187 Whr x3 / week

name	function	power [w]
XMGA	middle gain	11
XDIP	diplexer	0
XTRP	transponder	23
XPA	power amp.	100

mission requirements
- pointing to the Earth
- transmission of 20 W
- 30 minutes warm up
- observation for >1 year
- duration for -40 degC

Summary

- We studied the design of system for Martian Rotational Variations using Mars Entry-Descent-Landing and Surface Exploration Technologies Demonstrator.
- Accuracy of precession will be improved by 3 times better than from InSight.
- LOD accuracy is enough to detect each factor of air pressure, wind, and polar ice cap. However, it is difficult to separate each factor with the lack of precise J2 measurements.
- Communication system for X-band two-way coherent relay is feasible for our mission.