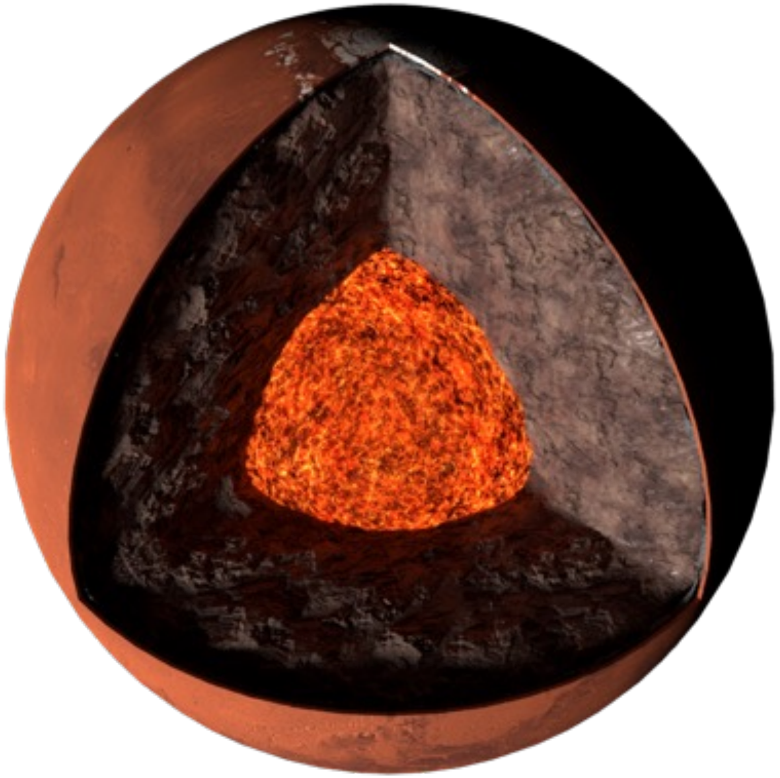
Understanding Mars from interior and rotation measurement

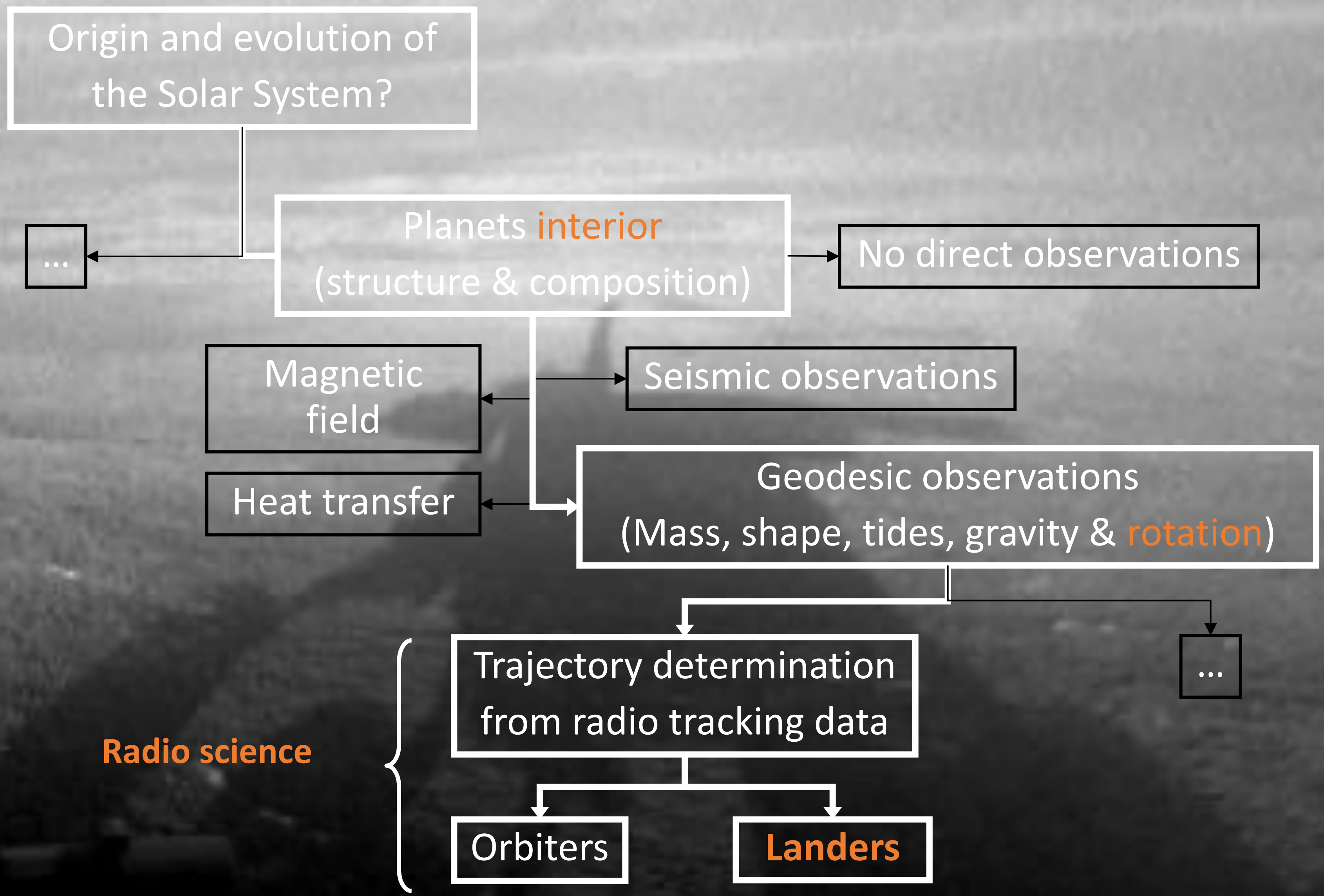
Sébastien Le Maistre

Switch to Space #3

Oct. 19th, 2022



Context


Origin and evolution of the Solar System?
…
Planets interior (structure & composition)
No direct observations
Magnetic field
Seismic observations
Heat transfer
Geodesic observations (Mass, shape, tides, gravity & rotation)
…
Radio science
Trajectory determination from radio tracking data
Orbiters
Landers

Royal Observatory of Belgium

- We have an internationally recognized leading expertise in interpreting spacecraft data in terms of planet/moon interior and rotation.

- Only institute in the world doing:
    - radio science instrument design
    - radio science data analysis
    - radio science data interpretation

- Expertise is reflected in many mission responsibilities (23 instruments on 10 accepted missions)

- PIship of several instruments (e.g. ExoMars-LaRa, Hera-GRASS)
    - Instrument lead of InSight-RISE

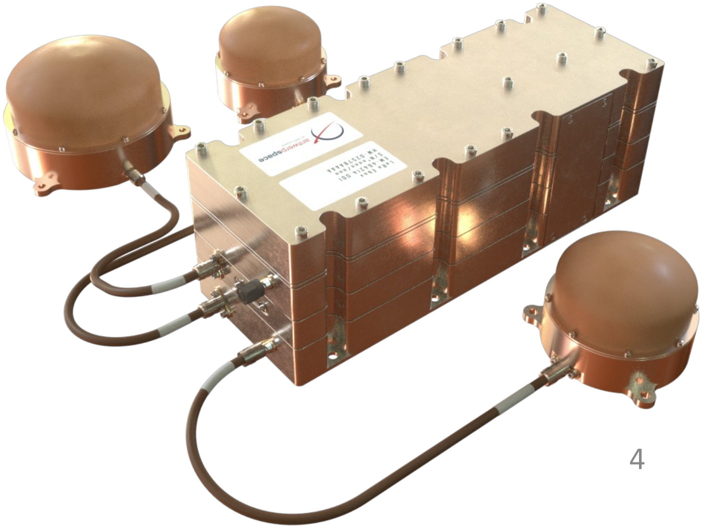
LaRa on ExoMars 202~~2~~

EXOMARS - LANDER RADIO SCIENCE

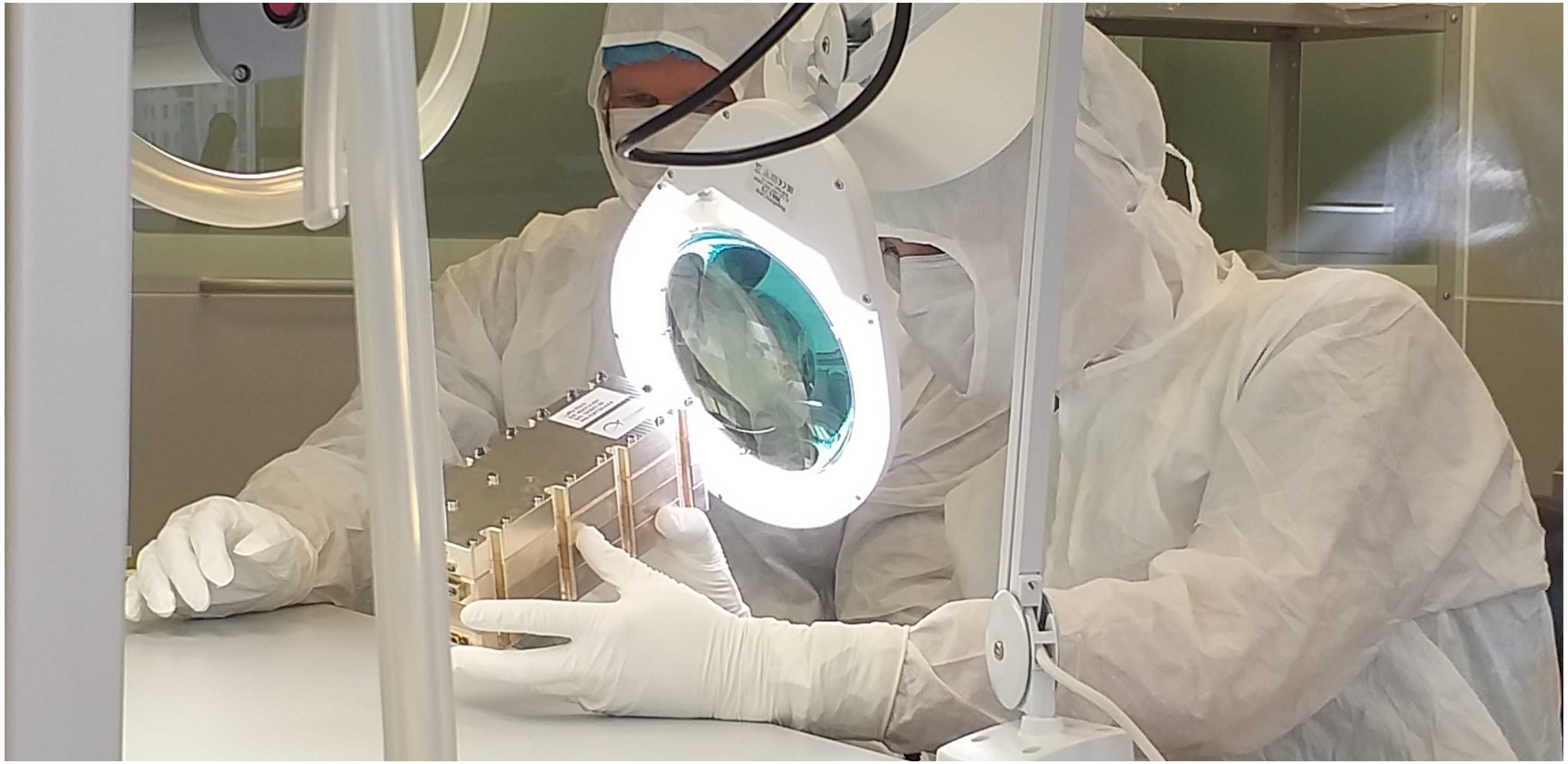
- Radio-science experiment under ROB lead
- Sept 2022 Launch cancelled because of War in Ukraine

- See www.lara.oma.be

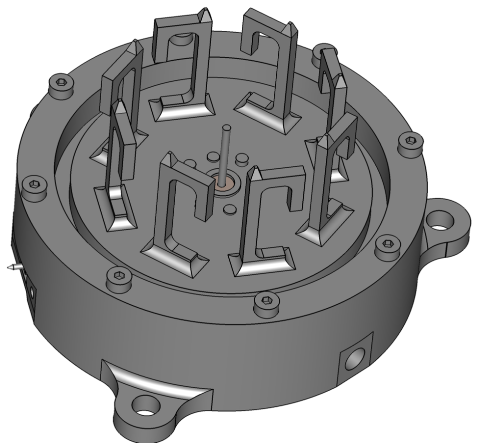
Credit: Thomas Marcos (Haute École Albert Jacquard)

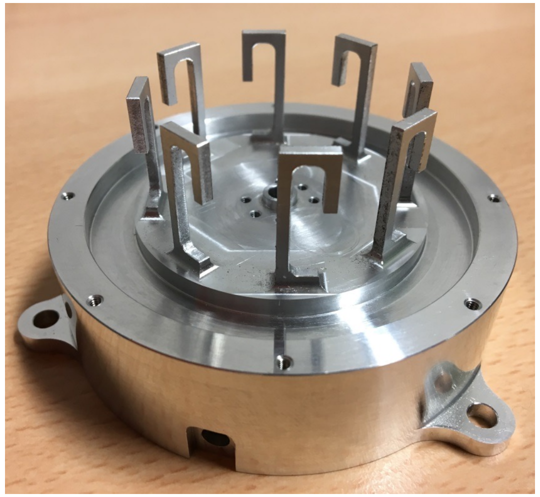


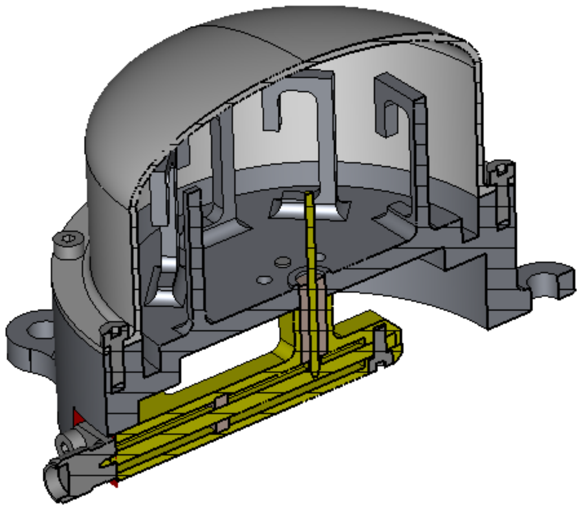
A coherent transponder designed for Mars by Antwerp Space

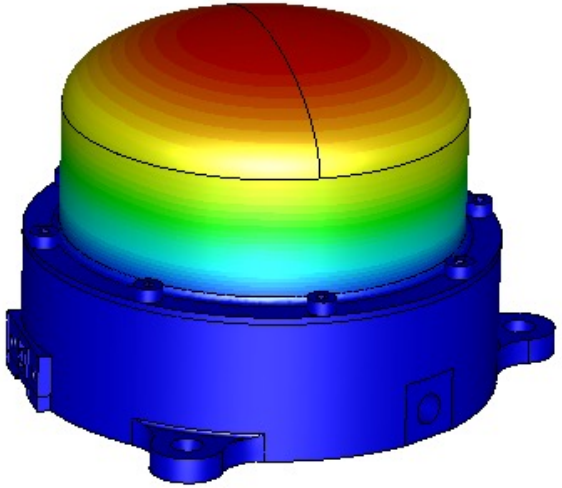


Antennas for Mars Surface designed by UCLouvain





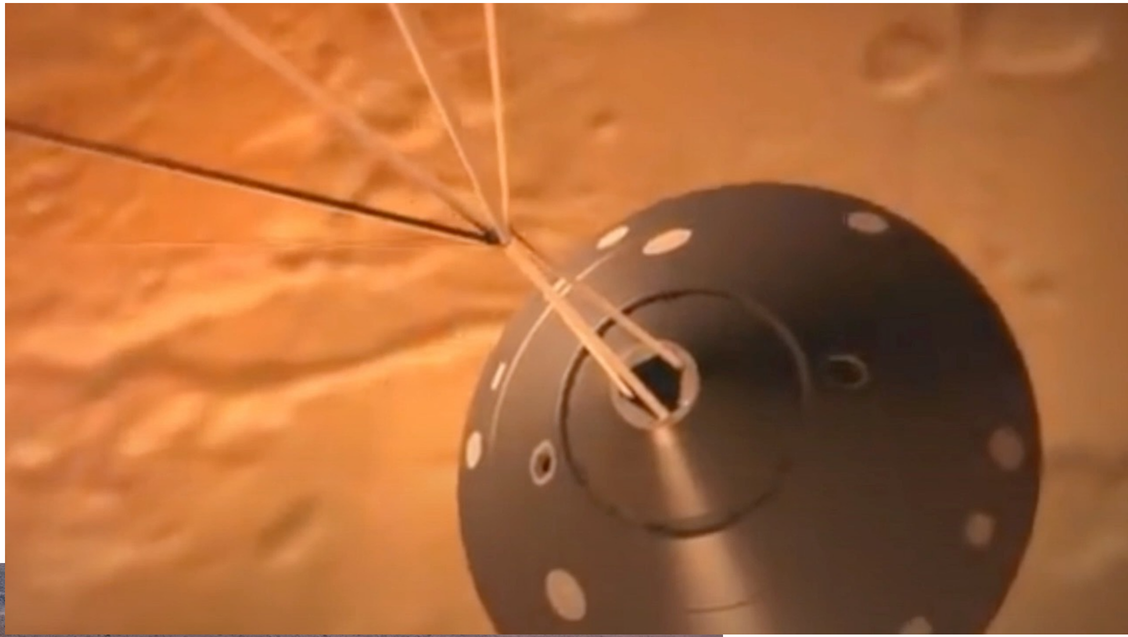


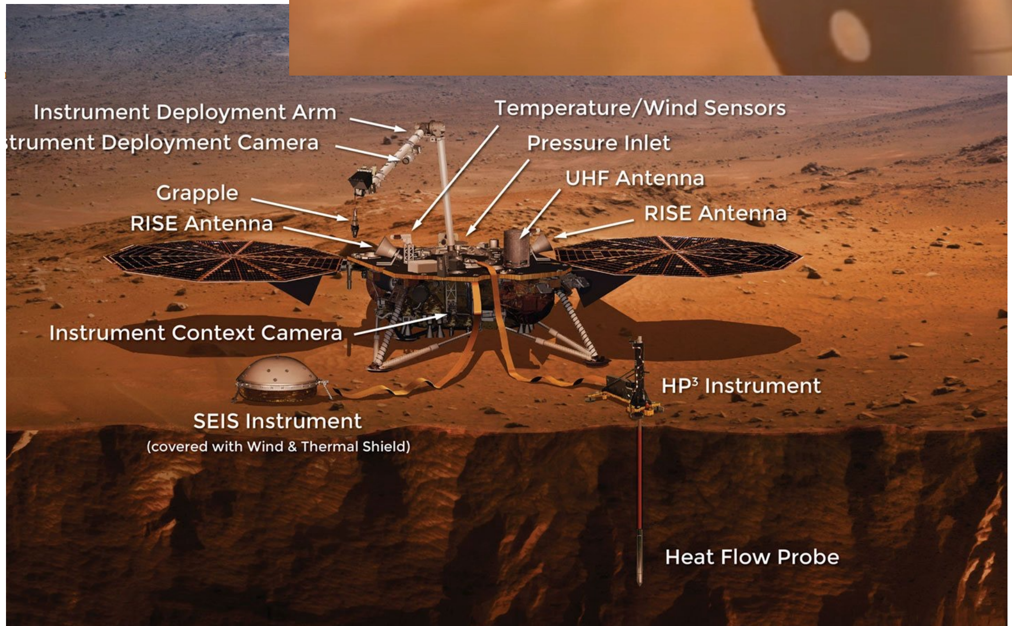


RISE on the InSight mission

The InSight mission

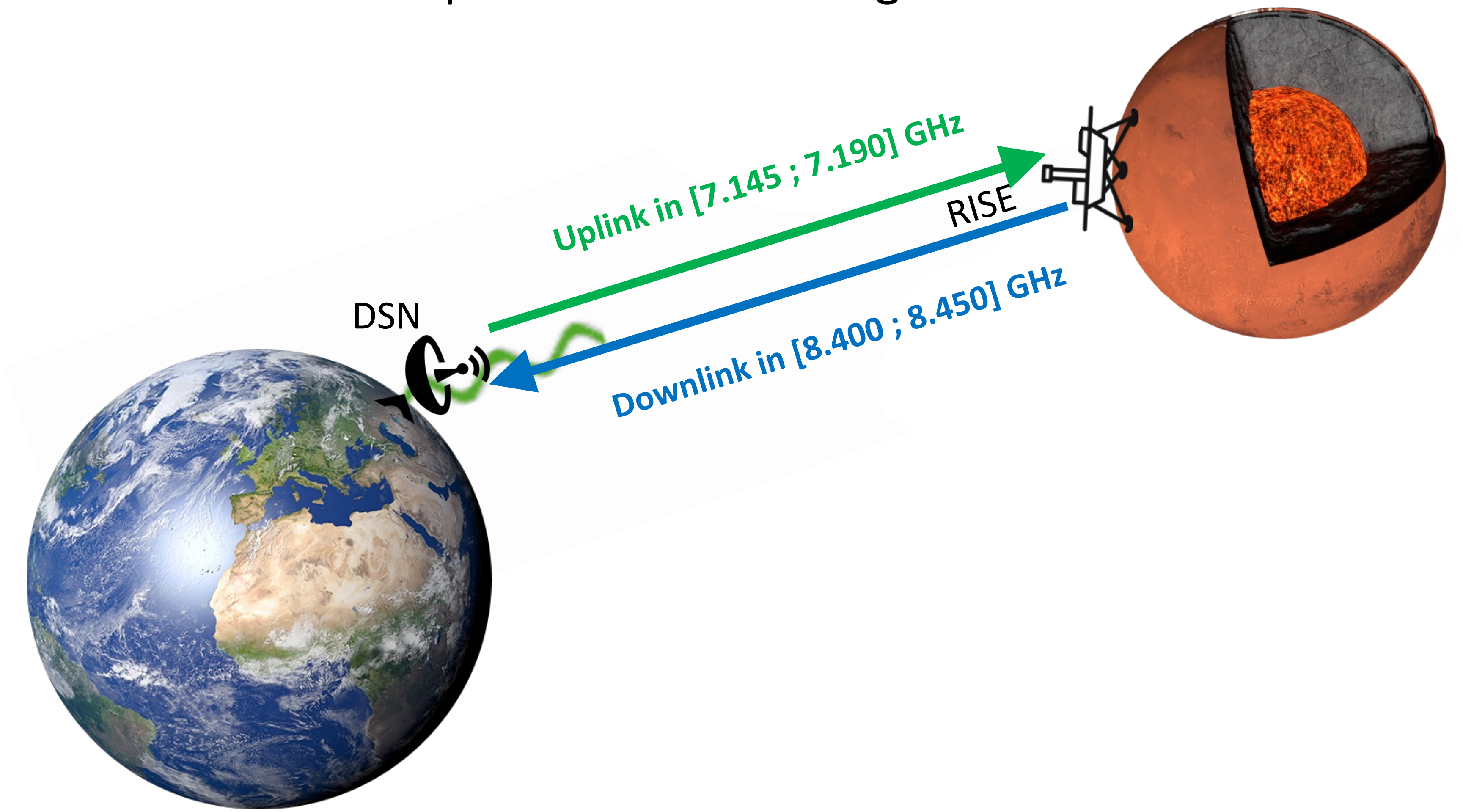
- NASA mission dedicated to Mars interior properties
- Landed on Mars' surface on Nov. 26th, 2018
- 3 scientific instruments
  - SEIS: Seismometer from CNES
  - HP^3 : Heat flow probe from DLR
  - RISE: Radio-Science from JPL
- Meteo sensors
- Cameras





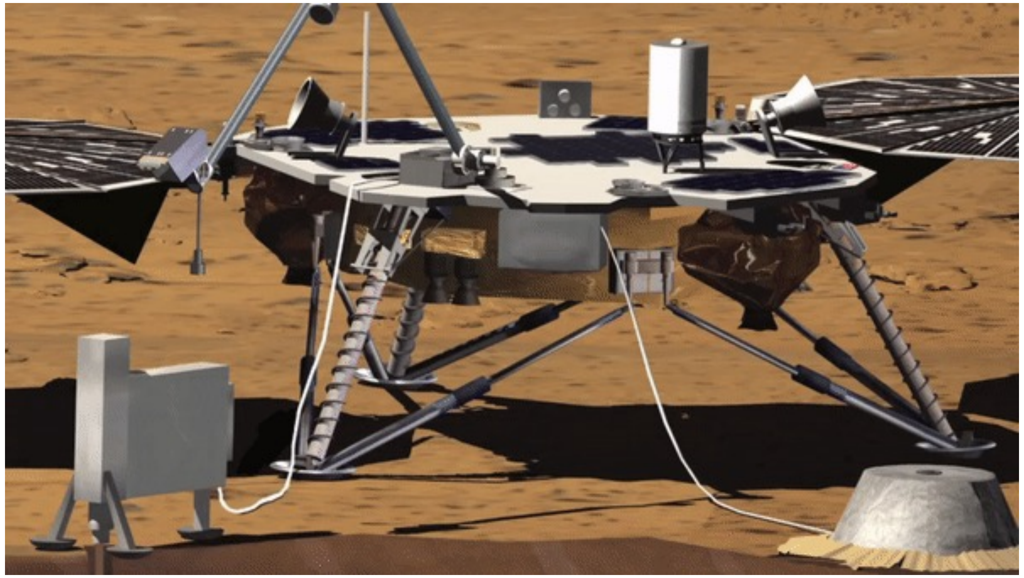
RISE/LaRa experiment principle

- Use of radio-links to reconstruct the motion of the lander in space
  - X-band Doppler measurements almost daily for RISE and twice a week for LaRa
  - ~45 min of observation per session in average



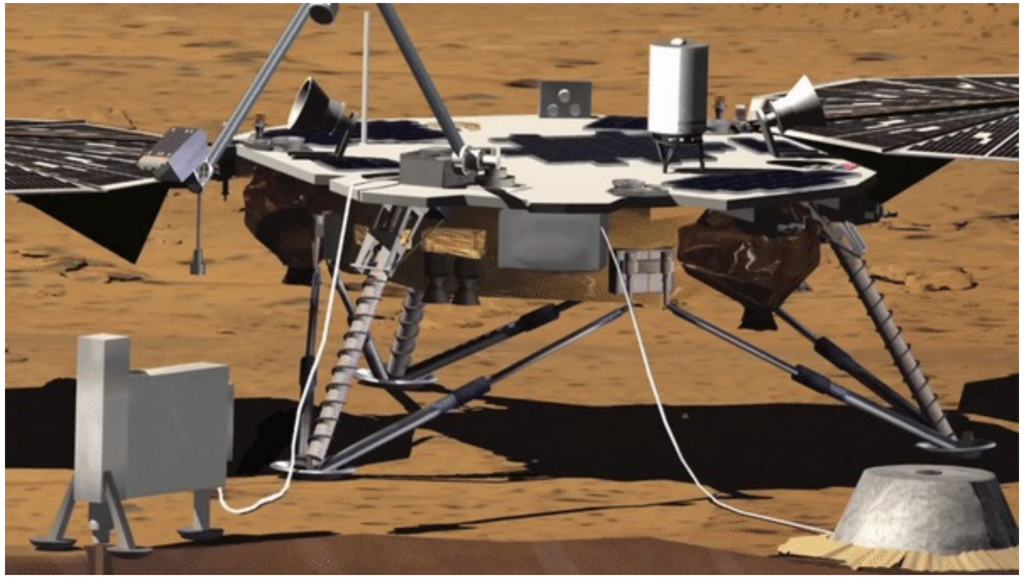
RISE/LaRa experiment principle

- Use of radio-links to reconstruct the motion of the lander in space
  - Coherent transponder and antennas fixed on the Mars surface



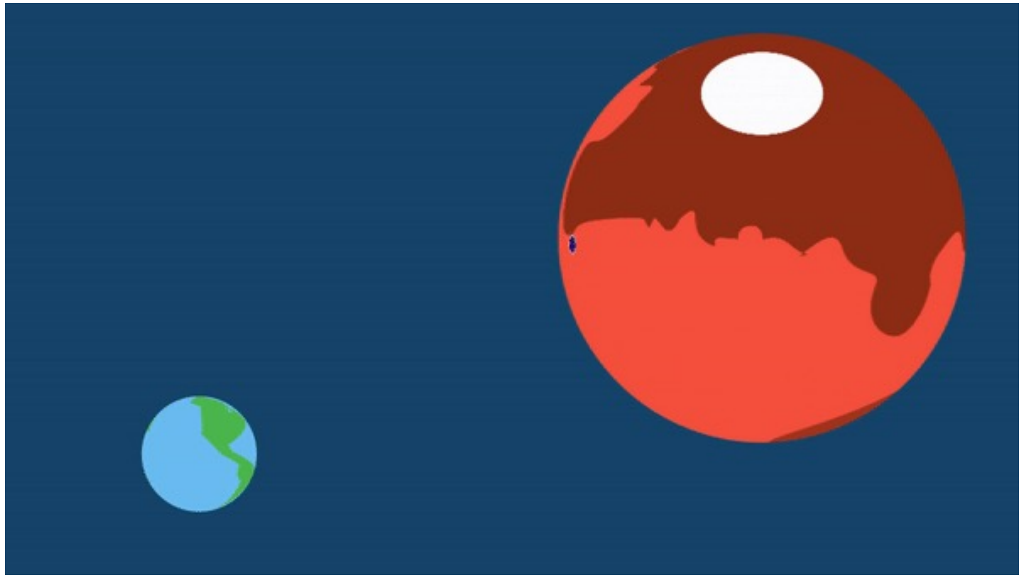
RISE/LaRa experiment principle

- Use of radio-links to reconstruct the motion of the lander in space
  - Coherent transponder and antennas fixed on the Mars surface
  - Deep-Space-Network antennas on Earth transmitting a highly stable frequency



RISE/LaRa experiment principle

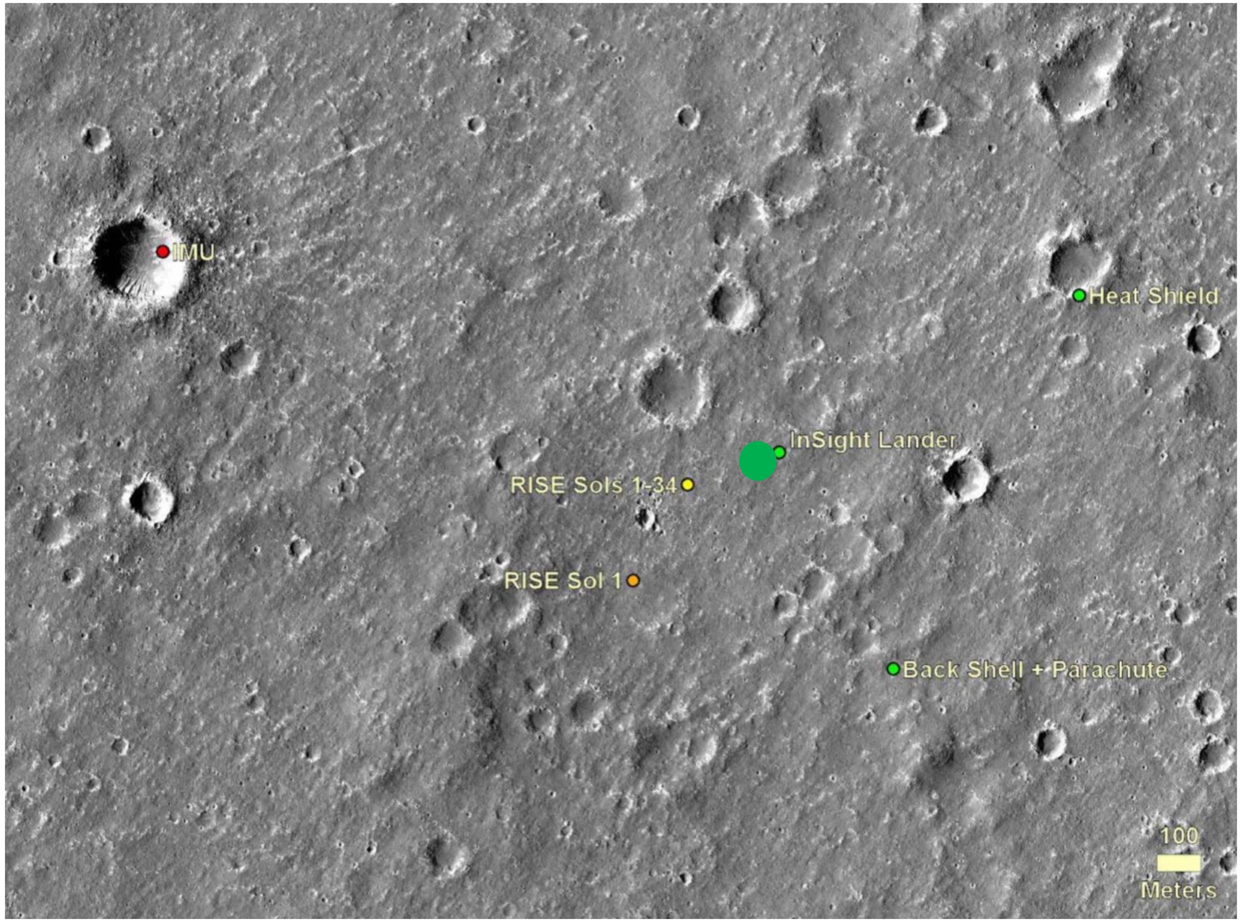
- Use of radio-links to reconstruct the motion of the lander in space
  - Coherent transponder and antennas fixed on the Mars surface
  - Deep-Space-Network antennas on Earth transmitting a highly stable frequency
  - Accurate measurement of Doppler shift (<1.5mHz level ⇔ <0.027 mm/s on relative velocity)



What do we do with RISE/LaRa?

- Accurate determination of the lander **location** on Mars

  - Early mission:
    - where is the lander ?
  - Late mission:
    - Quantify the topography map tie errors



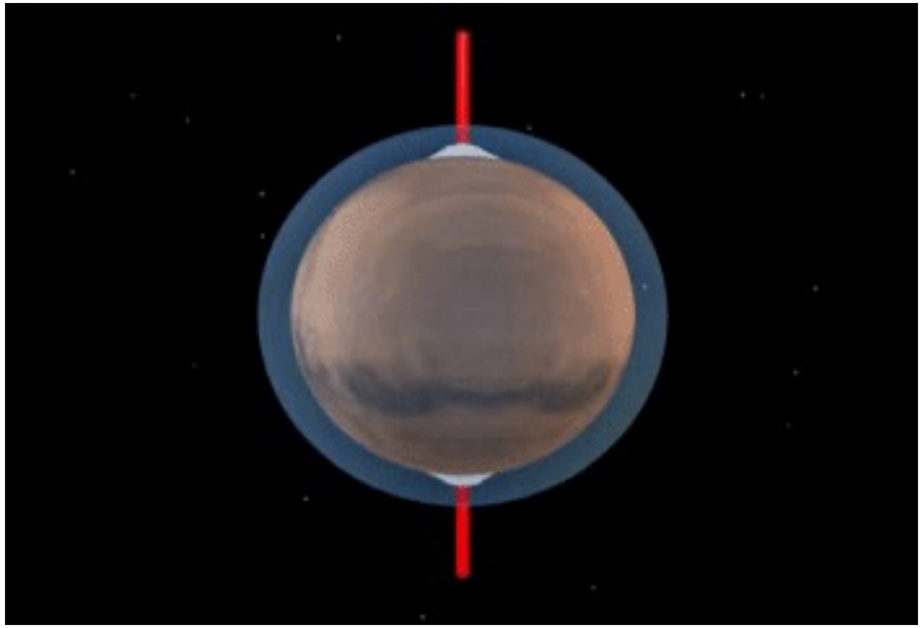
Golombek et al. (2020)

What do we do with RISE/LaRa?

- Accurate determination of the lander **location** on Mars

- Accurate determination of the time evolution of the **rotation** of Mars
  - ➢ Constrain Mars atmosphere dynamics

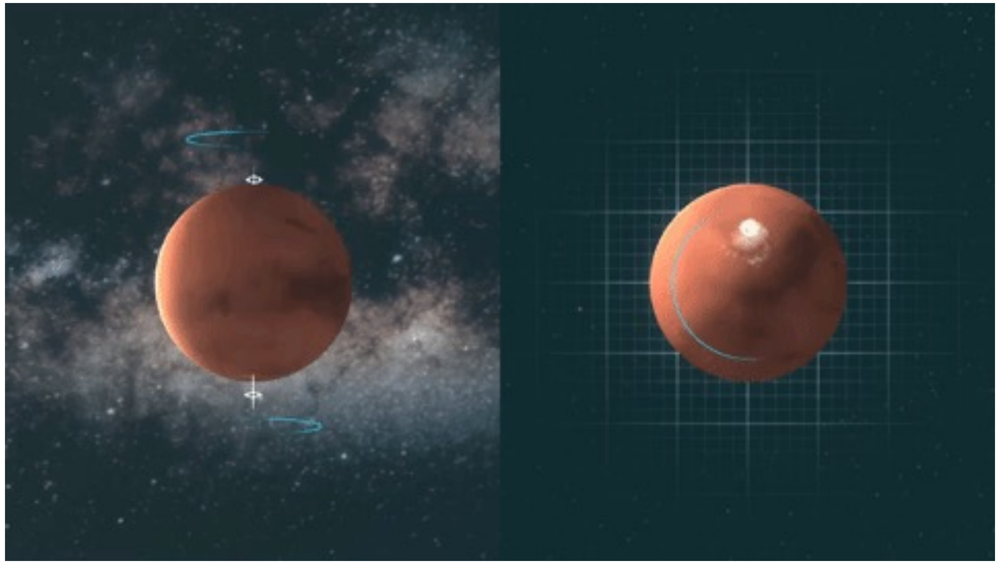
Length of day variations



What do we do with RISE/LaRa?

- Accurate determination of the lander **location** on Mars
- Accurate determination of the time evolution of the **rotation** of Mars
  - ➢Constrain Mars atmosphere dynamics
- Accurate determination of the time evolution of the **orientation** of Mars
  - ➢Constrain the moment of inertia of the planet

Precession

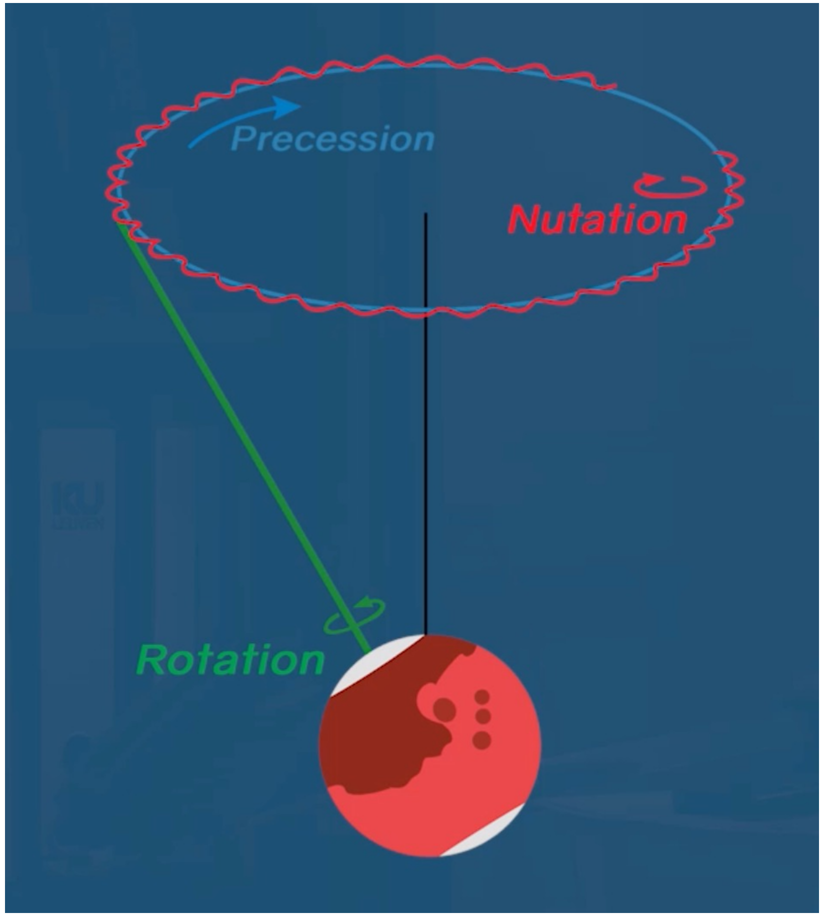


What do we do with RISE/LaRa?

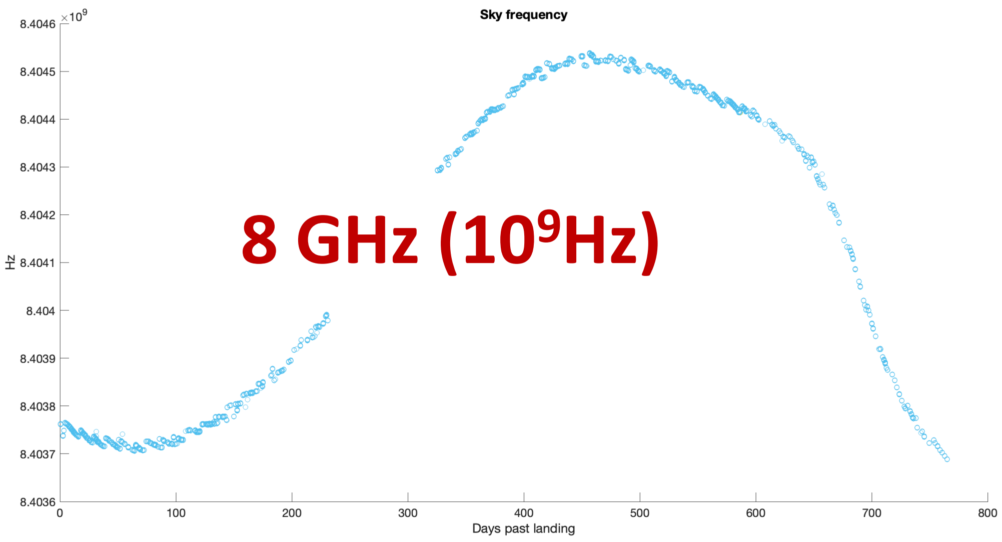
- Accurate determination of the lander **location** on Mars

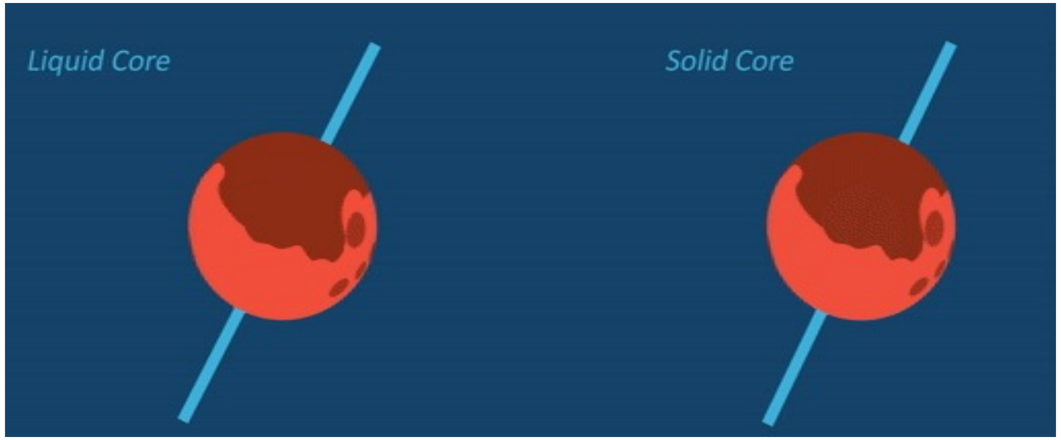
- Accurate determination of the time evolution of the **rotation** of Mars
  - Constrain Mars atmosphere dynamics

- Accurate determination of the time evolution of the **orientation** of Mars
  - Constrain the moment of inertia of the planet
  - Constrain Mars deep interior (core state, size, density, moment of inertia, composition)

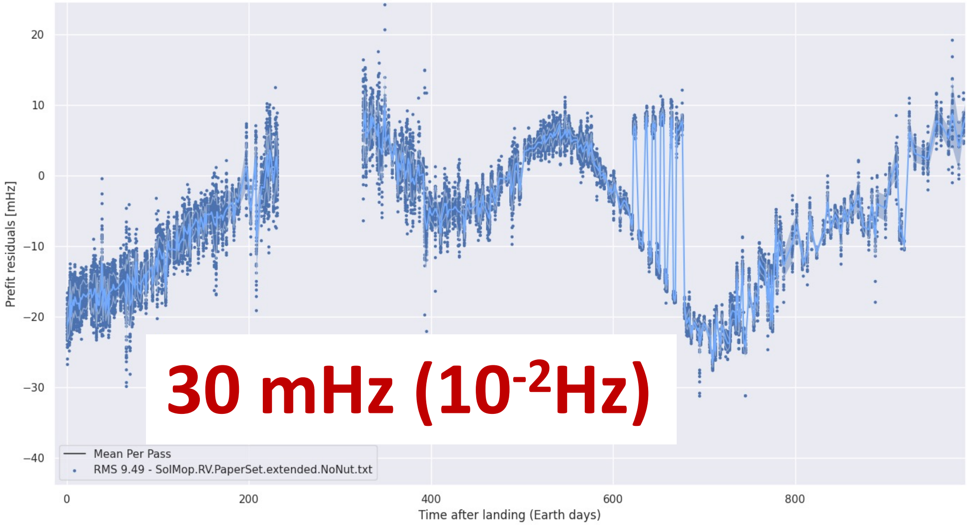


RISE/LaRa measurements and target signal level

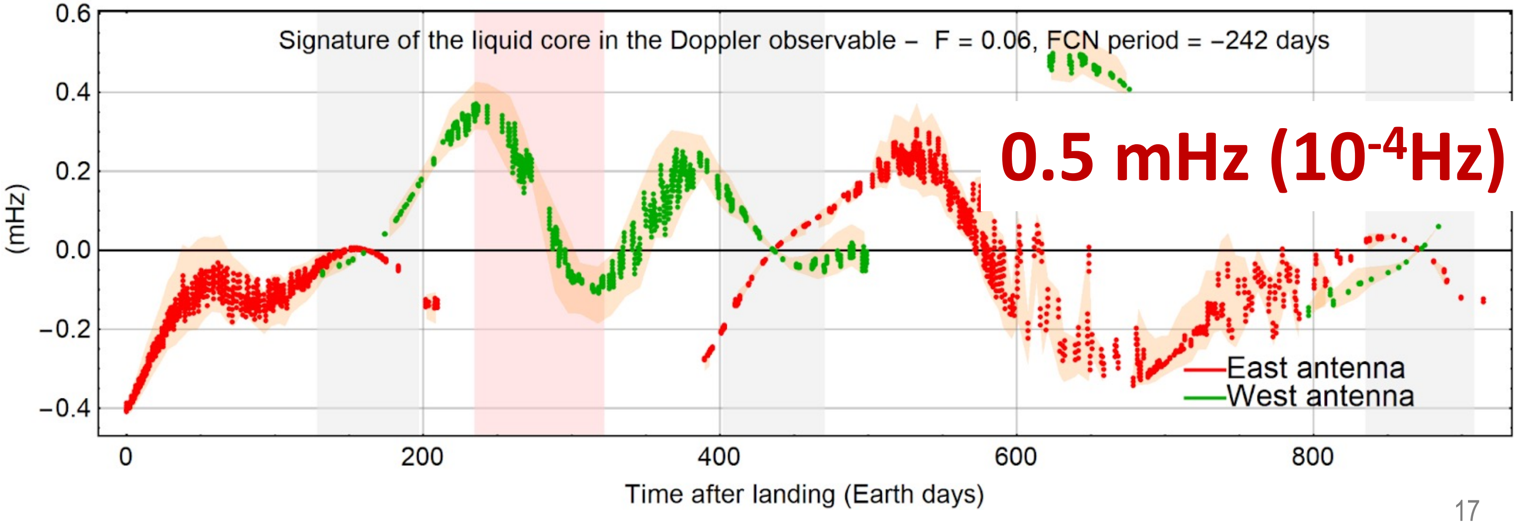




Full nutation contribution (N_{total})

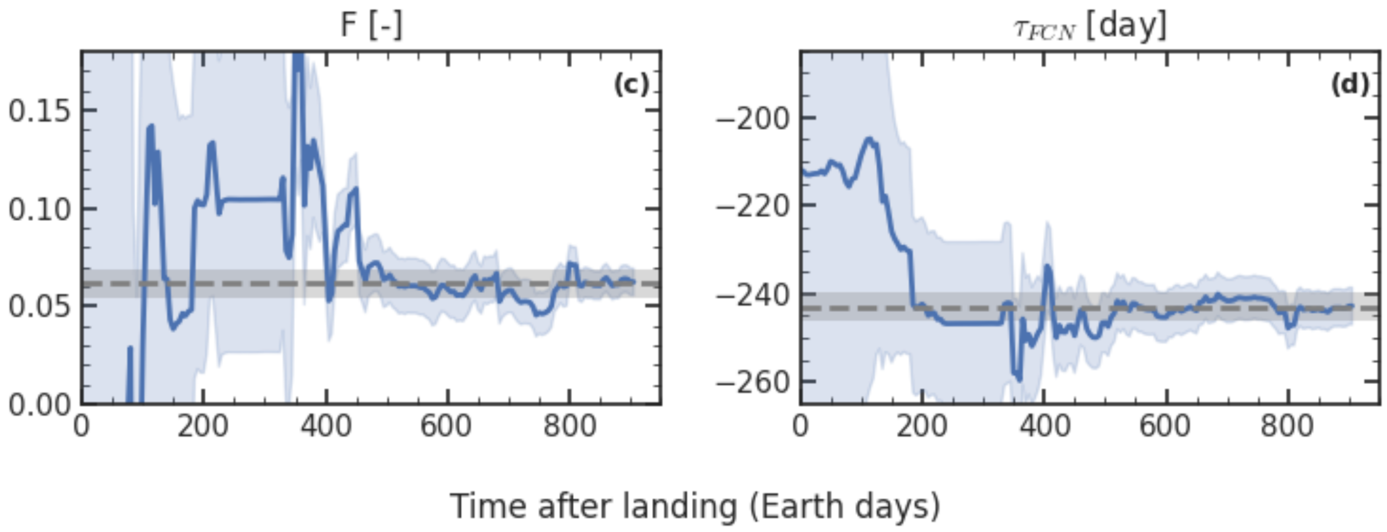


Liquid core contribution $\left(N_{total} - N_{rigid}\right)$



Some outcomes

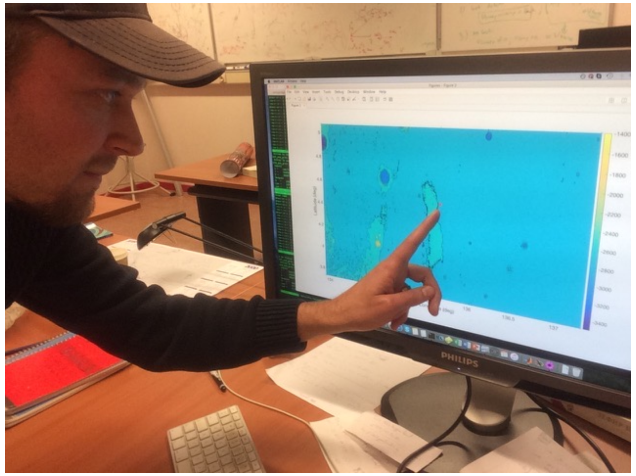
Recent results from RISE data analysis



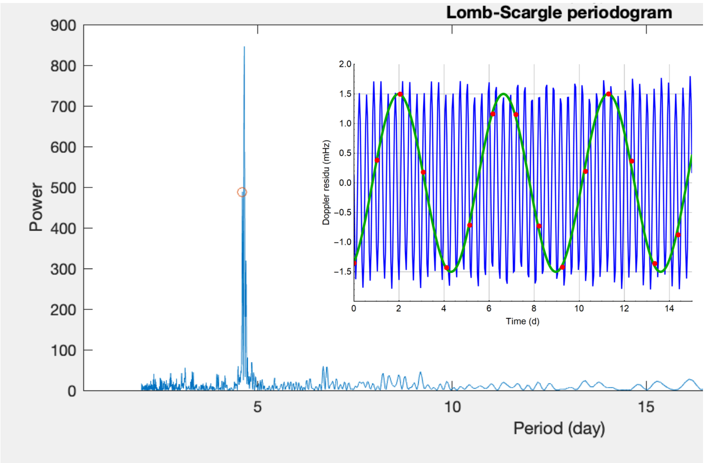
- Independent confirmation of
  - the liquid state of the core of Mars
  - the radius of the core of Mars
    - Constrain the amount and nature of the light elements in the core

- First time
  - we detect the Free-Core-Nutation normal mode for another planet than the Earth
  - we determine the shape of the core of Mars
    - suggest the existence of mass anomalies in the mantle
  - We observe an acceleration of the rotation rate of Mars – still unexplained

Funny facts and anecdotes



- InSight PI, Bruce Banerdt (JPL), ask ROB to provide the lander position few hours after landing, when nobody knows where it actually is.

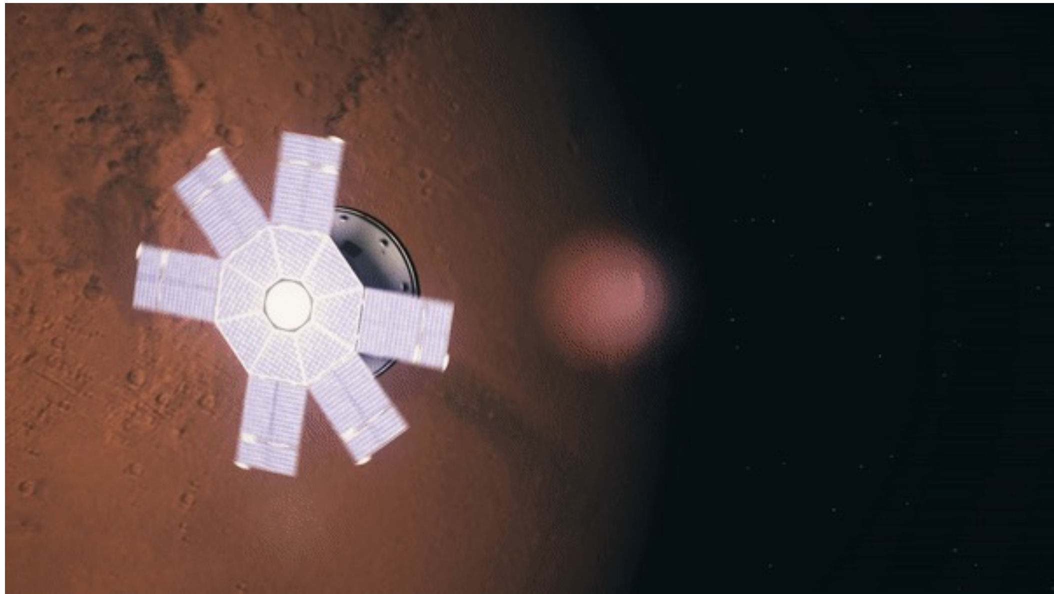


- RISE data are so accurate that the 10cm periodic motion of Mars center around the Martian system barycenter was quickly detected and tardily explained

- RISE provided its last data point in May 27th, 2022
- InSight should die very soon (~1-2 month from now)

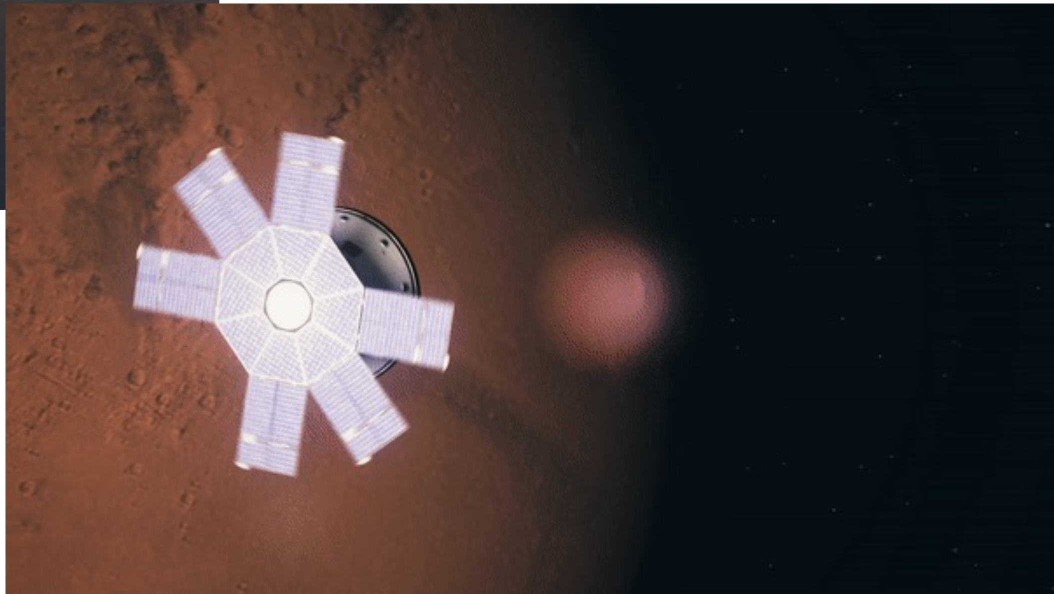
Conclusive remarks

- Involved in Planetary robotic exploration
- World leaders in Radio-science investigations from landers
- World experts in Terrestrial planet rotation determination
- World experts in planets interior science



Thanks for your attention

and let’s ~~pray~~ act for the future of LaRa



Every Mars Landing Attempt, Ever

Successes, *Failures*, and Future

Viking 2

NASA lander
Launched: 9 Sep 1975
Landed: 3 Sep 1976
Last contact: 11 Apr 1980
Utopia Planitia
47.643°N, 134.288°E, −4495m

Perseverance

NASA rover
Launch: expected 17 Jul 2020
Landing: expected 18 Feb 2021
Jezero Crater
18.4386°N, 77.5031° E, −2640m

Beagle 2

ESA lander
No contact since separation
Launched: 2 Jun 2003
Last contact: 25 Dec 2003
Isidis Planitia
11.5288°N, 90.4314° E, −3725m

InSight

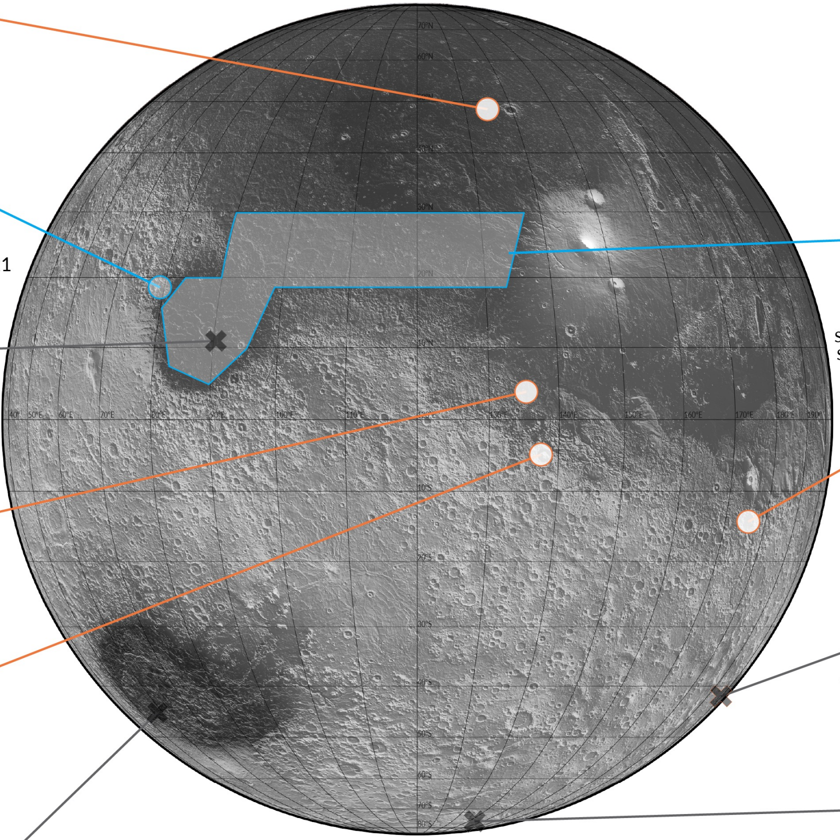
NASA lander
Launched: 5 May 2018
Landed: 26 Nov 2018
Elysium Planitia
4.502°N, 135.623°E, −2613m

Curiosity

NASA rover
Launched: 26 Nov 2011
Landed: 6 Aug 2012
Roved >22km
Gale Crater
4.5895°S, 137.4417°E, −4501m

Mars 2

Soviet lander and rover
Entered atmosphere too steeply
Launched: 19 May 1971
Crashed: 27 Nov 1971
Hellas Chaos
Near 45°S, 58°E, −5000m



−8000m | −6000m | −4000m | −2000m | 0m | +2000m | +4000m | +6000m | +8000m

Topography
Relative to Martian Datum

1 degree of latitude on Mars = 59.3 km

Phoenix

NASA lander
Launch 4 Aug 2007
Landing 25 May 2008
Last contact: 2 Nov 2008
Vastitas Borealis
68.2188°N, 234.2508°E, −4130m

Tianwen-1

Chinese rover
Launch: expected July 2020
Landing: expected early 2021
Site 1: Chryse Planitia 20–30°N, 310-330°E
Site 2: Elysium Planitia 19–30°N, 90–134°E
or within Isidis Planitia 4-20°N, 80-98°E

Spirit

NASA rover
Launched: 10 Jun 2003
Landed: 3 Jan 2004
Roved 7.73 km
Last contact: 22 Mar 2010
Gusev Crater
14.5692°S, 175.4729°E, −1936m

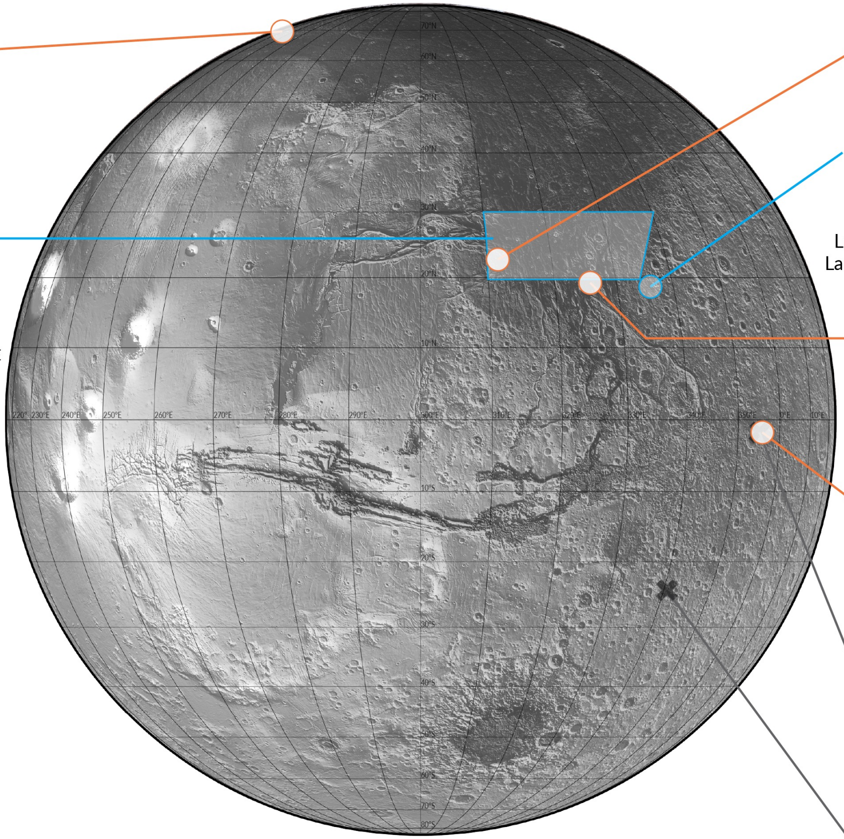
Mars 3

Soviet lander and rover
Contact lost after successful landing
Launched: 28 May 1971
Last contact: 2 Dec 1971
Terra Sirenum
45.044°S, 202.019°E, +1626m

Mars Polar Lander

NASA lander
No contact since entry
Launched: 3 Jan 1999
Last contact: 3 Dec 1999
Planum Australe
Near 76.57°S, 165.2°E, +3000m

THE PLANETARY SOCIETY



Viking 1

NASA lander
Launch 20 Aug 1975
Landing 20 Jul 1976
Last contact: 13 Nov 1982
Chryse Planitia
22.269°N, 312.048°E, −3637m

Rosalind Franklin & Kazachok

ESA rover & Russian lander
Launch expected Aug–Oct 2022
Landing expected Apr or Jul 2023
Oxia Planum
Near 18.14°N, 335.7°E, −3000m

Pathfinder & Sojourner

NASA lander & rover
Launch 4 Dec 1996
Landing 4 Jul 1997
Last contact: 27 Sep 1997
Ares Vallis
19.33°N, 326.47°E, −3681m

Opportunity

NASA rover
Launched: 8 Jul 2003
Landed: 24 Jan 2004
Roved 45.16km
Last contact: 10 Jun 2018
Meridiani Planum
1.9462°S, 354.4734°E, −1387m

Schiaparelli

ESA lander
Contact lost during descent
Launched: 14 Mar 2016
Crashed: 19 Oct 2016
Meridiani Planum
2.0524°S, 353.7924°E, −1444m

Mars 6

Soviet lander
Contact lost upon landing
Launched: 5 Aug 1973
Last contact: 12 Mar 1974
Margaritifer Sinus
Near 24°S, 340.5°E, −500m

References

Landing location data compiled by E. Lakdawalla for The Planetary Society in May 2020. For failed landers whose crash sites have not been identified, actual sites could be as far as 150 km (2.5 degrees) radially from given location.

Base map by P. McGovern from MOLA GTDR [P. Smith et al. (2001) DOI: 10.1029/2000JE001364].

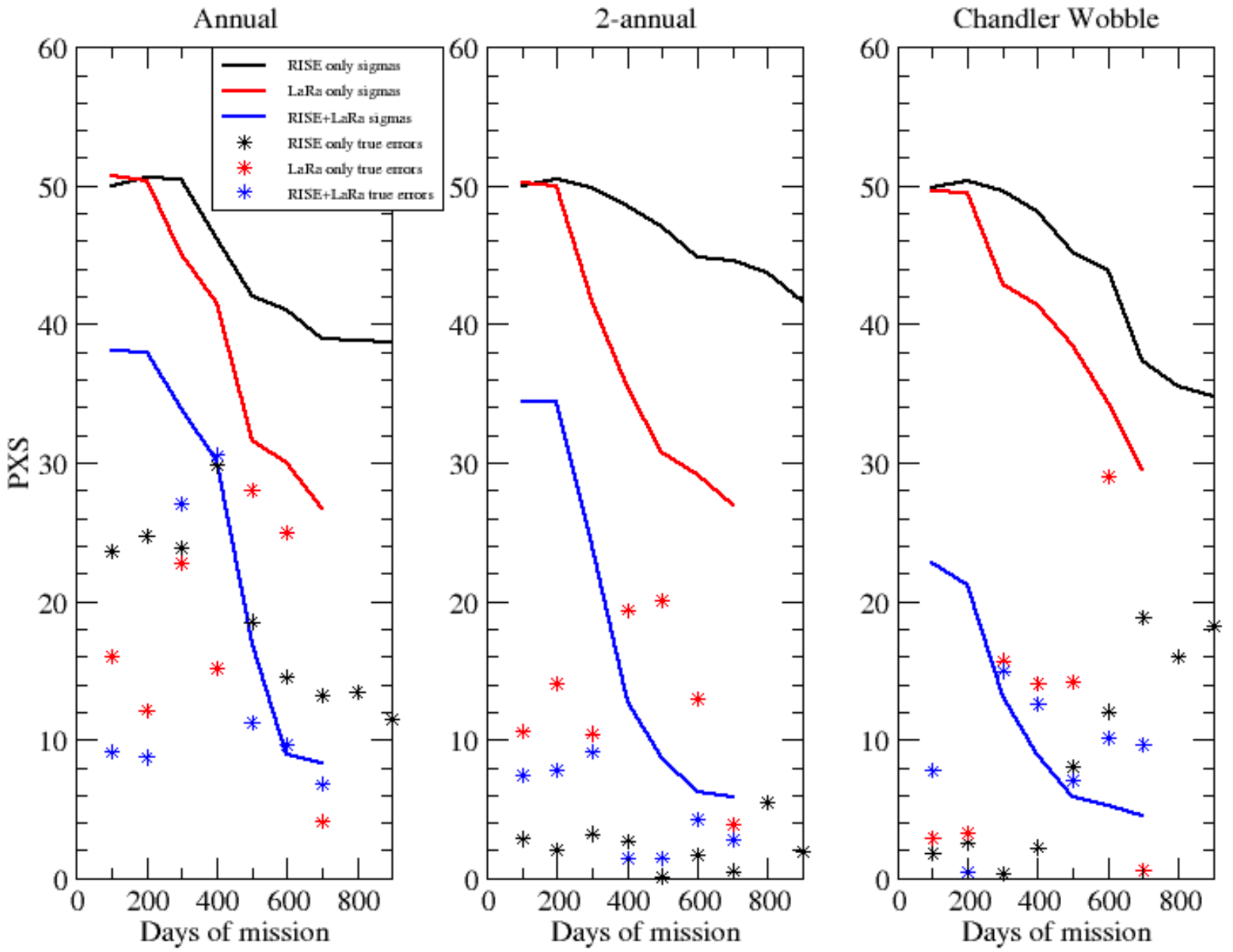
Beagle 2: Location: J.C. Bridges et al. (2017) DOI:10.1098/rsos.170785. Elevation: Peter Grindrod, personal communication.
Curiosity: E. Lakdawalla (2018) ISBN:978-3-319-68144-3
InSight: M. Golombek et al. (2020) DOI:10.1038/s41467-020-14679-1
Mars 2 & Mars 6: P. Stooke (2012) ISBN:978-0-521-76553-4. Landers have never been found.
Mars 3: Tom Stein and Feng Zhou, personal communication (hereinafter abbreviated SZpc).
Mars Pathfinder: Location: P. Stooke (2012). Elevation: SZpc.
Mars Polar Lander: P. Stooke (2012). Lander has never been found.
Opportunity: Location: Arvidson et al (2004) DOI: 10.1126/science.1104211. Elevation: SZpc.
Perseverance: J. A. Grant et al. (2018) DOI:10.1016/j.pss.2018.07.001
Phoenix: T. L. Heet et al. (2008) DOI:10.1029/2009JE003416
Rosalind Franklin: M. A. Ivanov et al. (2020) DOI:10.1134/S0038094620010050
Schaparelli: A. Aboudan et al. (2018) DOI:10.1007/s11214-018-0532-3
Spirit: Location: R. E. Arvidson et al (2004) DOI:10.1126/science.1099922. Elevation: SZpc
Tianwen-1: Possible landing regions read from map posted at planetary.org/blogs/guest-blogs/china-2020-rover-sites.html in November 2018, credited to a Chinese National Space Agency presentation to the United Nations Committee on the Peaceful Uses of Outer Space in June 2018.
Viking 1 & Viking 2: National Space Science Data Center, https://nssdc.gsfc.nasa.gov/nmc/spacecraft/displayTrajectory.action?id=1975-075C and id=1975-083C, accessed 11 May 2020.

Suggested citation: E. Lakdawalla (2020) "Every Mars Landing Attempt, Ever: Successes, Failures, and Future (version 1.3)." Poster published by The Planetary Society, Pasadena, CA, USA.

Version 1.3 (2020-06-03.2)

LaRa after RISE

- Refine Mars rotation model
- Refine interior properties
- Detect polar motion

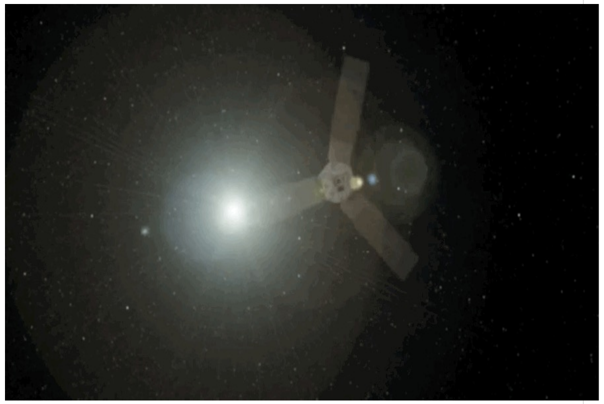


From MJ Péters

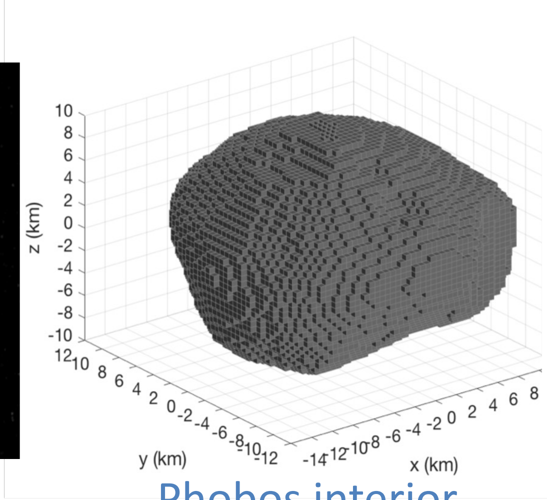
Some of my research topics

Numerical simulations

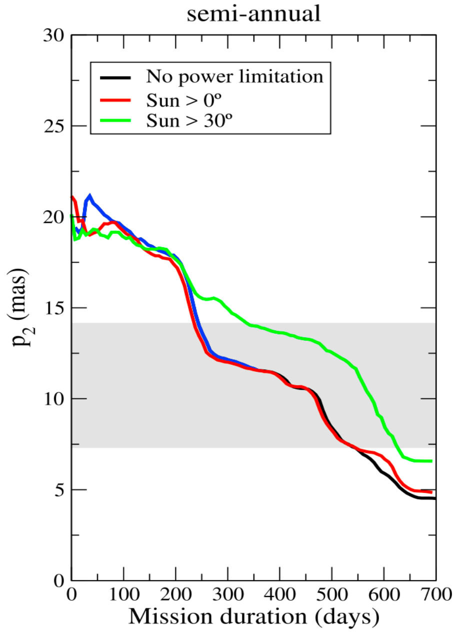
Phobos rotation determination



Jupiter gravity field determination

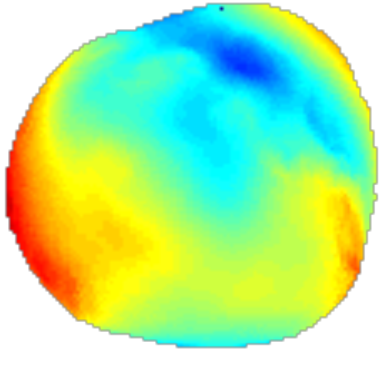


Phobos interior modeling



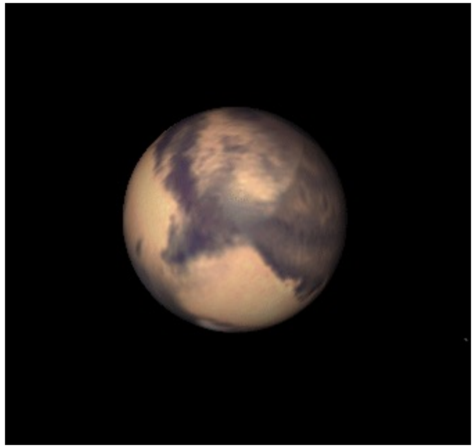
Mars nutation determination

Real data analysis



Mars gravity field determination

Phobos gravity field determination



Mars rotation determination