Sismologie Planétaire Large Bande
Planetary Large-Band seismology

Philippe Lognonné and
the InSight Observation Service Team
the InSIght SEIS Science team

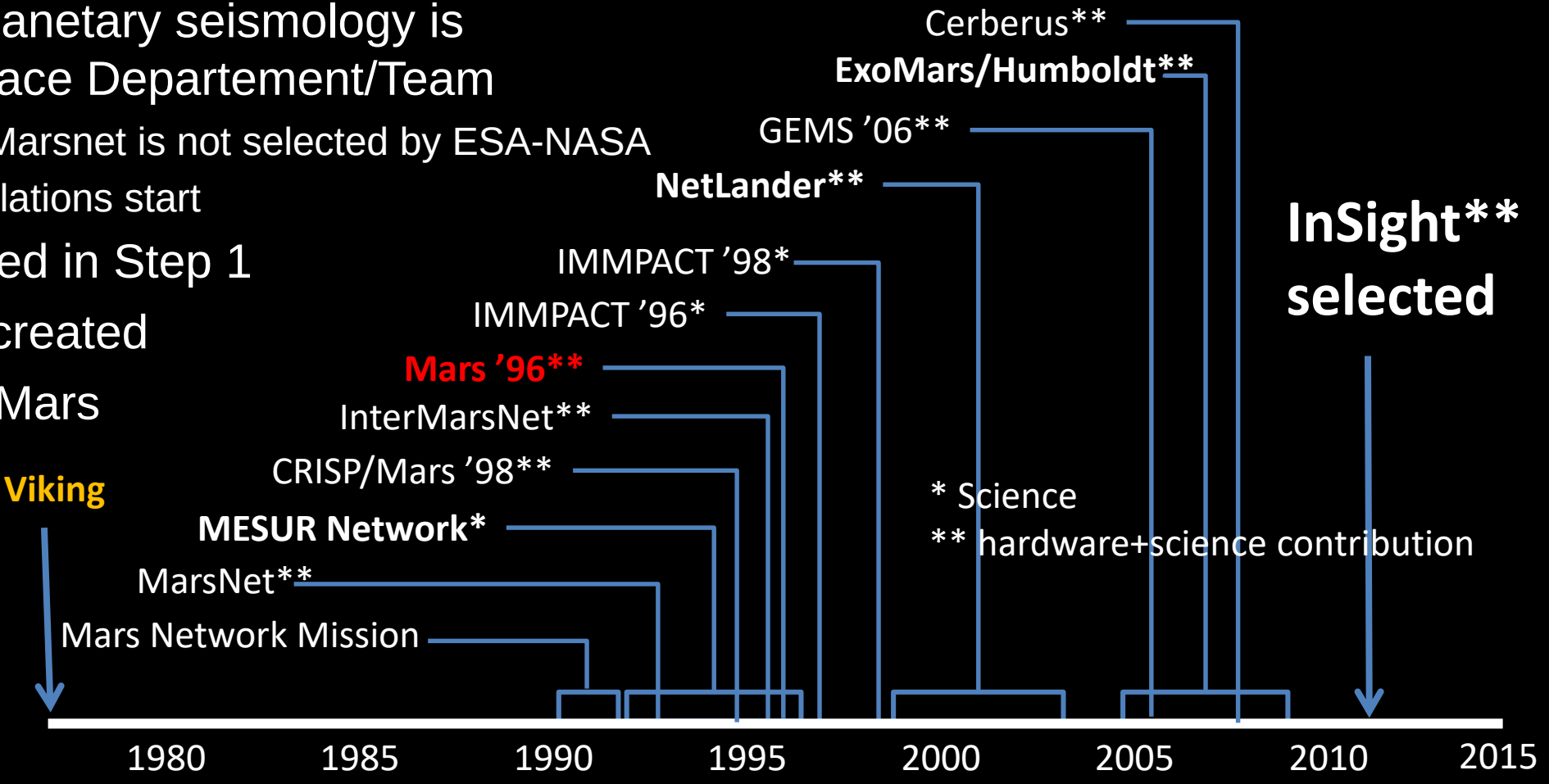
Colloque pour le 40ème anniversaire de l'Observatoire GEOSCOPE

29 et 30 juin 2022, à l'Institut de physique du globe de Paris

Planetary seismology in IPGP: from start to InSight

- From 1991 to 1996: Planetary seismology is part of Geoscope
  - 1st Flight Project with Mars96 and the OPTIMISM seismometer
  - Start in 1993 of the VBB Planetary seismometer project
- Starting 1996: Planetary seismology is transfered to IPGP Space Departement/Team
  - Mars 96 is lost and InterMarsnet is not selected by ESA-NASA
  - 14 years of project formulations start
- 2011: InSIght is selected in Step 1
- 2017: InSight SNO is created
- 2018: InSight land on Mars

Proposal/Phase A Study (Only Mars)
Approved Mission (temporarily…)
Lost mission

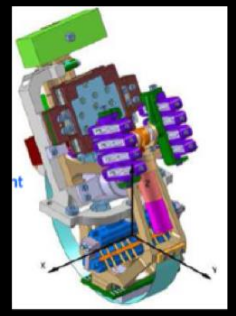


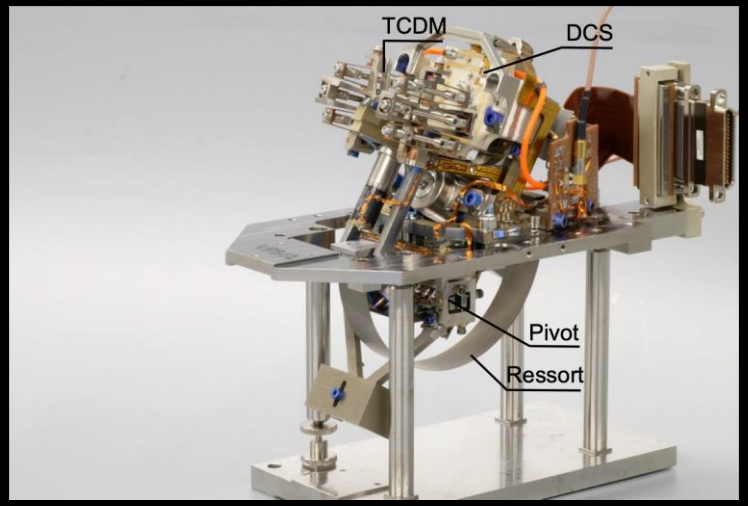
The first 30 years (from OPTIMISM to InSIght/FSS)

10^{-8} m/s^2/Hz$^{1/2}$
(0.3-5 Hz)

10^{-9} m/s^2/Hz$^{1/2}$
(0.1-5 Hz)

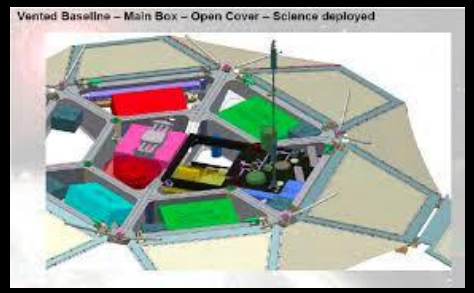
< 10^{-9} m/s^2/Hz$^{1/2}$
(0.01-5 Hz)

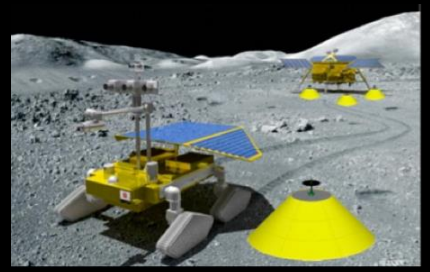




INSIGHT/FSS (2011-2023)

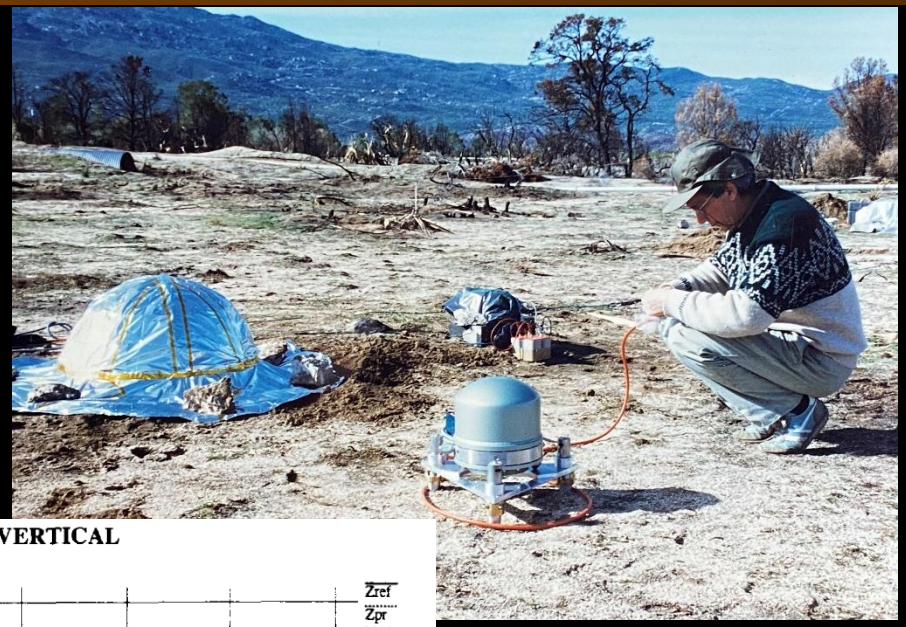
Optimism / Mars 96 → 2002/2005 : Netlander → 2008/ 2010 : ExoMars → 2012 : SE2/GEMS

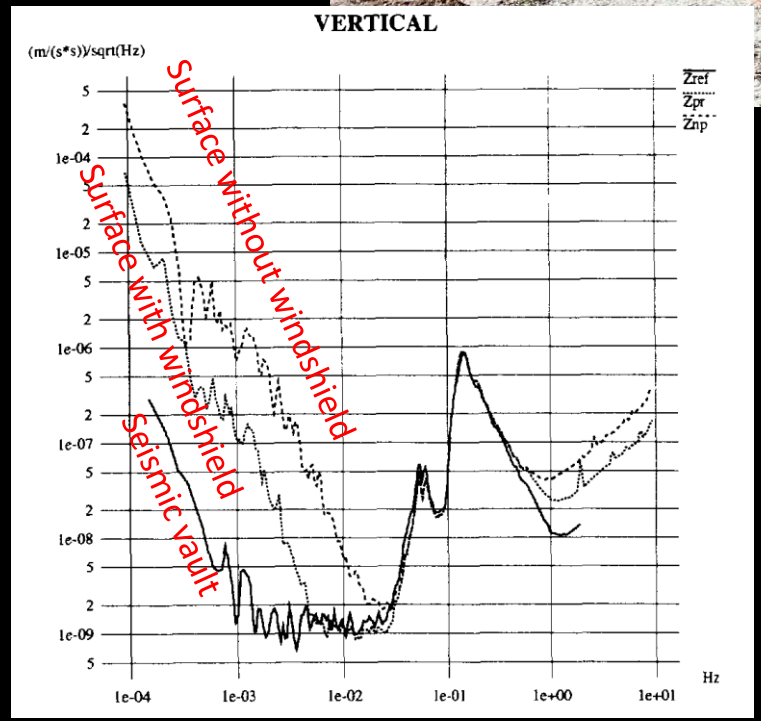




Large heritage: example of Pinion Flat test (February 1995)

- These tests, made in preparation of the InterMarsnet ESA-NASA project, validated the possibility to reach noise as good as 10^{-9} m/s^2/Hz$^{1/2}$ with surface deployment
- This noise level was later taken as the requirement for Mars mission, including InSight



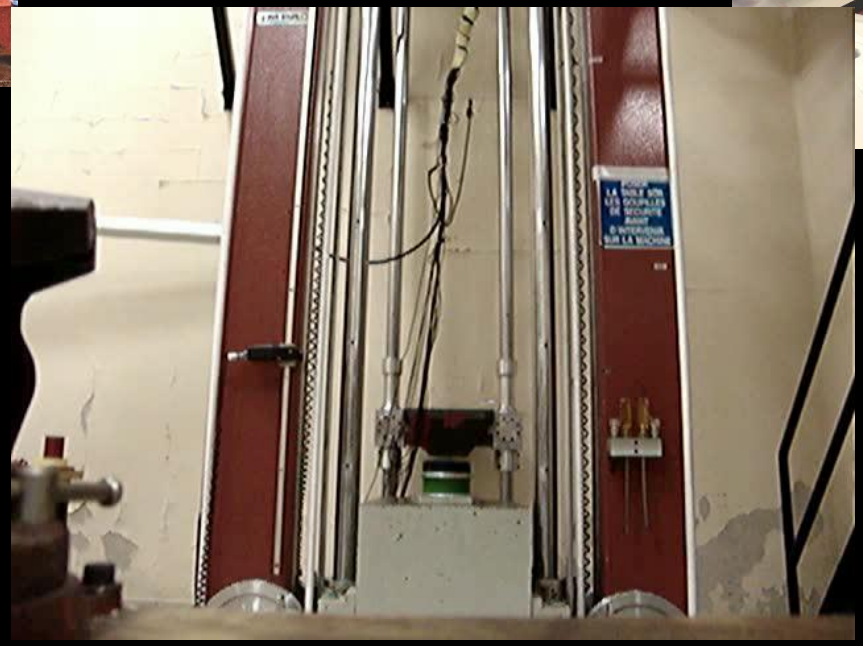


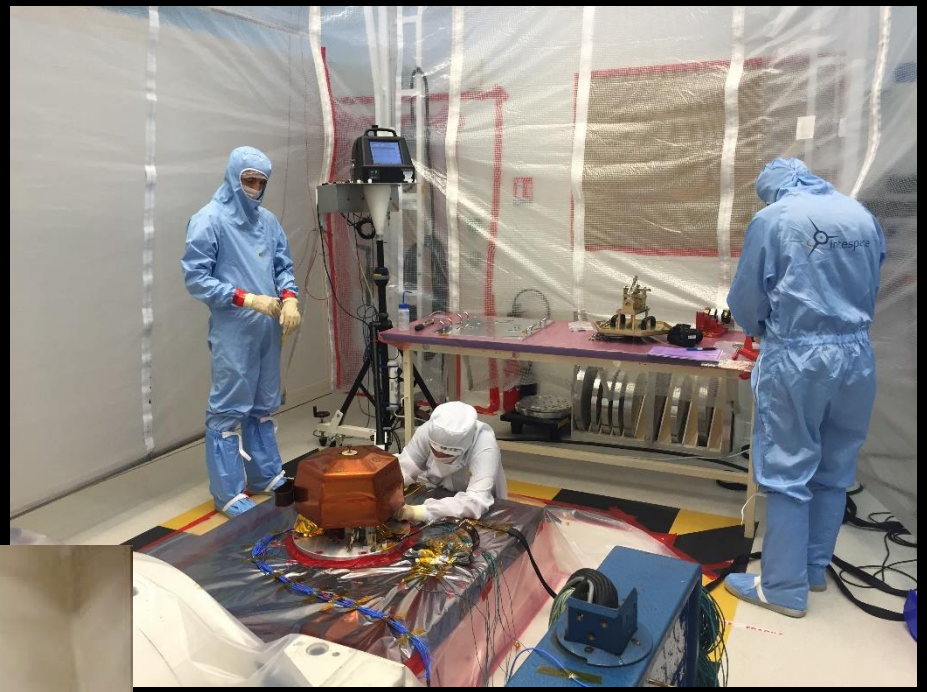
Lognonne et al. 1996

Tests: From early starts…. to state of the art….

Optimism choc tests Saint Maur
(1990-1994)

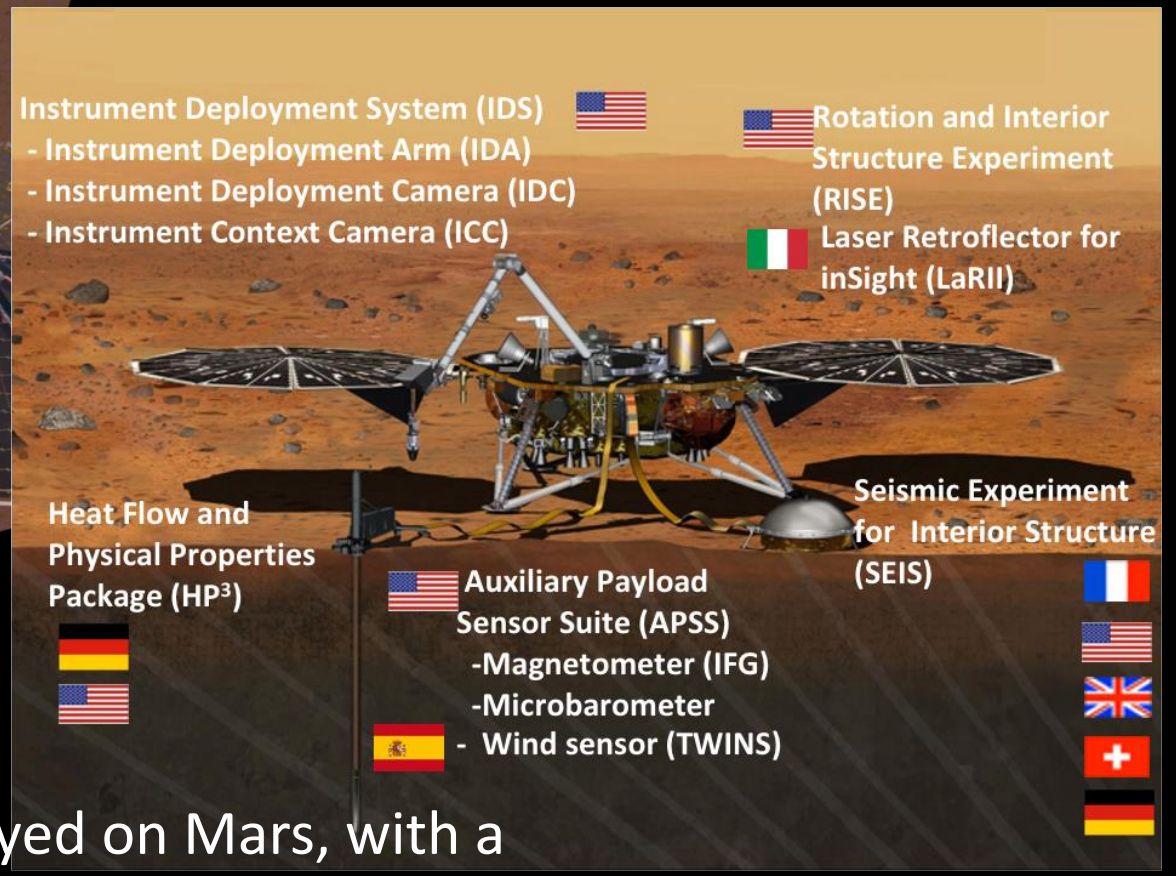
VBB choc tests
(2000-2005)





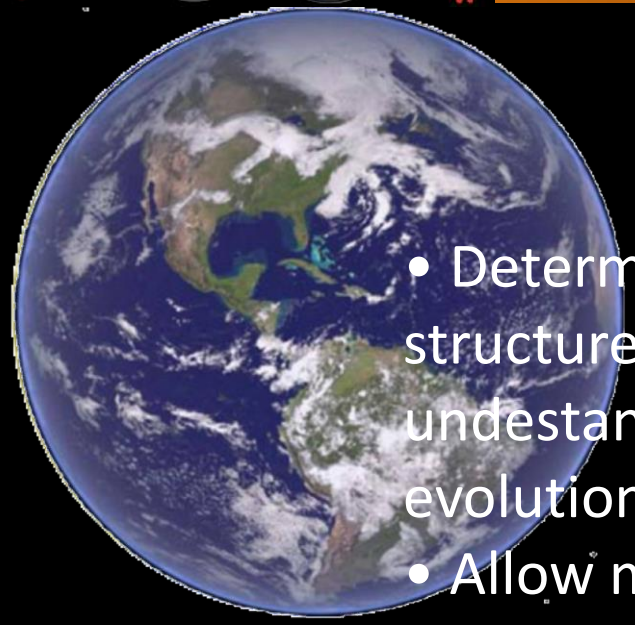
InSIght SEIS Flight Unit
Vibration tests
(2017)

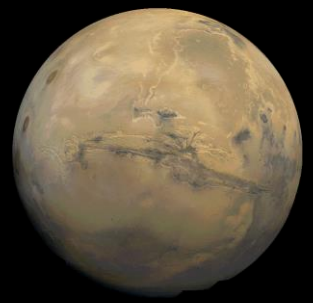
InSight : International start of Mars seismology



• InSight is the first geophysical observatory deployed on Mars, with a suite of instruments comparable to those deployed on the Moon by the Apollo Lunar Surface Packages (plus atmospheric sensors…)

InSight goals : Mission objectives





- Determine the interior structure of Mars for better undestanding its formation and evolution
- Allow much better comparative planetology for terrestrial planets (e.g. Mars/Earth) and bodies (Moon)
- initiate comparative seismology for terrestrial planets !

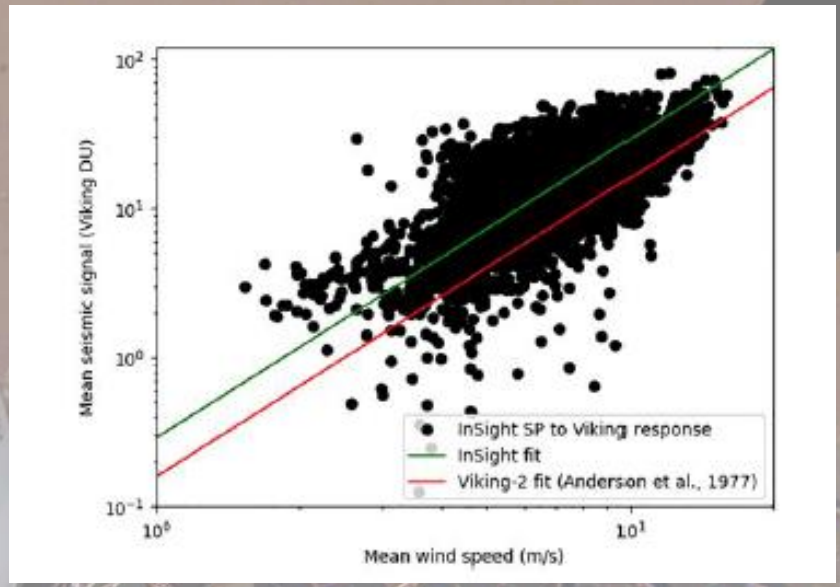
Mission objectives	Knowledge prior landing
Crustal thickness (SEIS)	65±35 km
Crustal stratification (SEIS)	No information for deep structure
Mantle seismic velocity (SEIS)	8±1 km/s (predicted)
Liquid/Solid core state (RISE)	Likely liquid
Core radius **(RISE)**	1700±300 km
Mass density (**RISE)**	6.4±1.0 gm/cc
Heat flow **(HP3)**	30±25 mW/m^2(predicted)
Seismic activity (SEIS)	Unknown by x100
Location of seismic zone (SEIS)	No information
Meteorites flux (SEIS)	Unknown by x6

MARS SEIS First data on the Deck

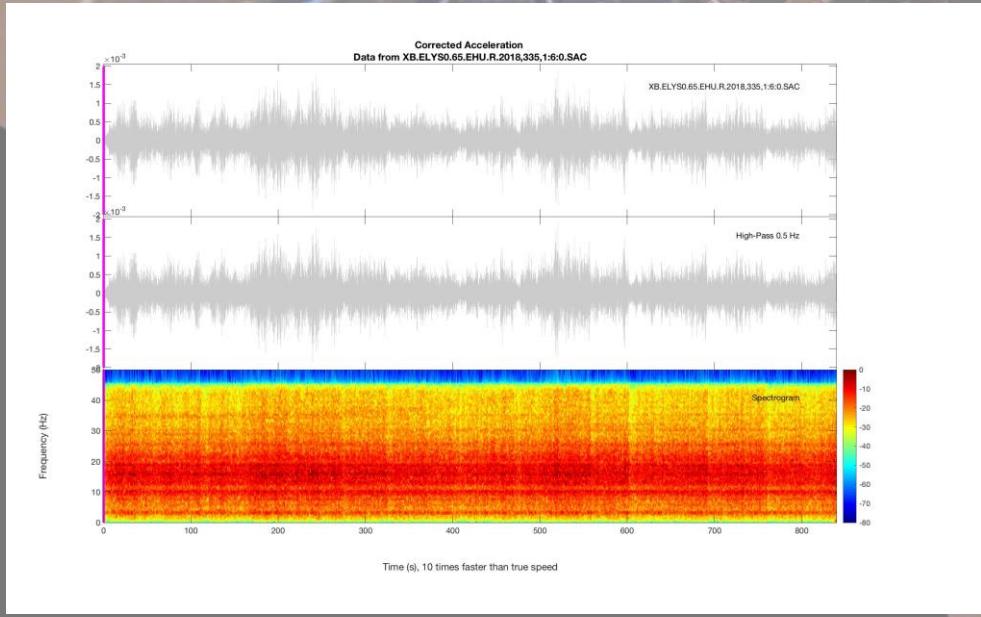
- **Very large high frequency signals driven by lander vibrations from Noise**

  Panning et al. 2020

- **Vibration in amplitude comparable to those of Viking.**



Panning et al. (2020)



Courtesy W.T.Pike and C.Charalambou

P.Lognonné © InSight SNO and SEIS Science Team

10^{-3} m/s^2

2×10^{-4} m/s^2

2×10^{-5} m/s^2

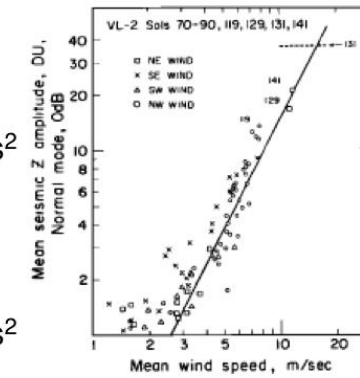
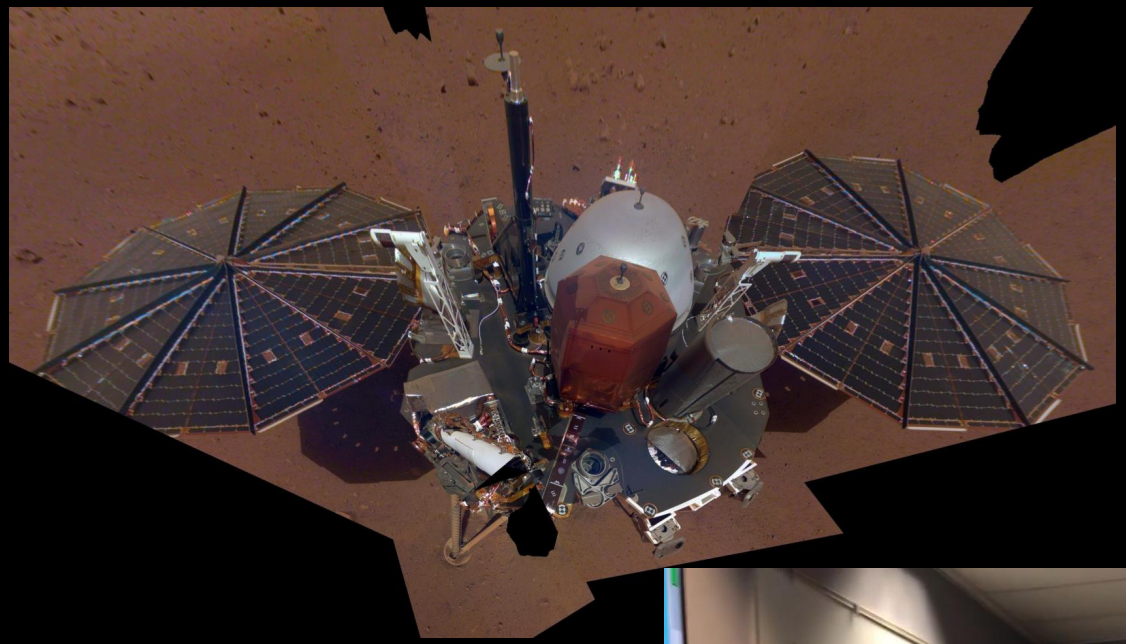
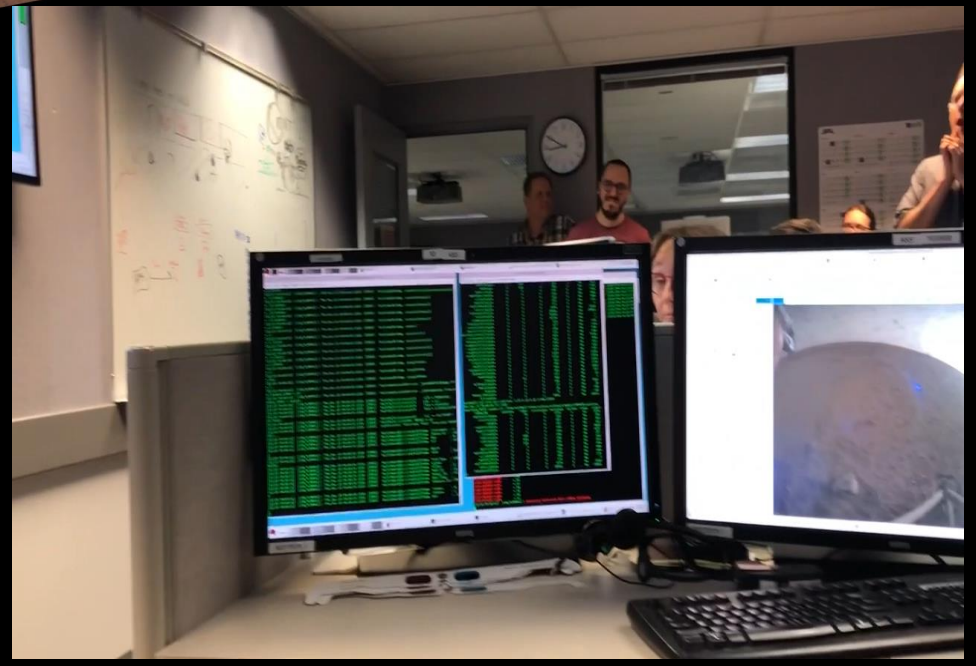


Fig. 17. Correlation between wind speed and norma
amplitude (Z component) for winds from different d
solid line corresponds to the slope expected if seismi
proportional to the square of the wind speed, as is a
turbulent flow. The scatter of points below wind speeds
to noise from other sources than wind

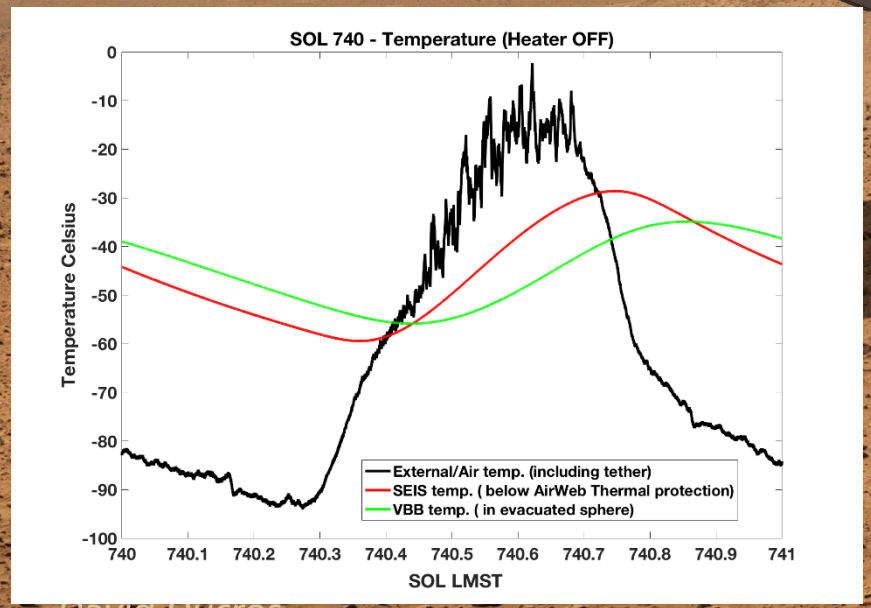
SEIS… the real landing…





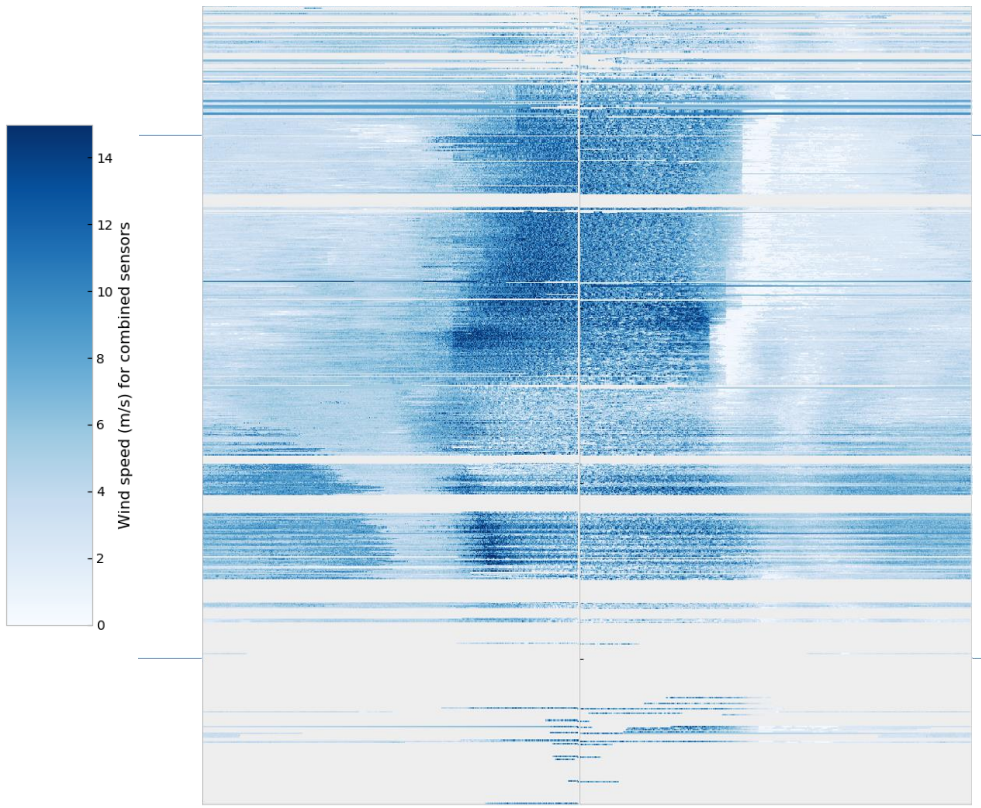
SEIS on the field

Lognonné et al. 2019 for all details (https://doi.org/10.1007/s11214-018-0574-6)



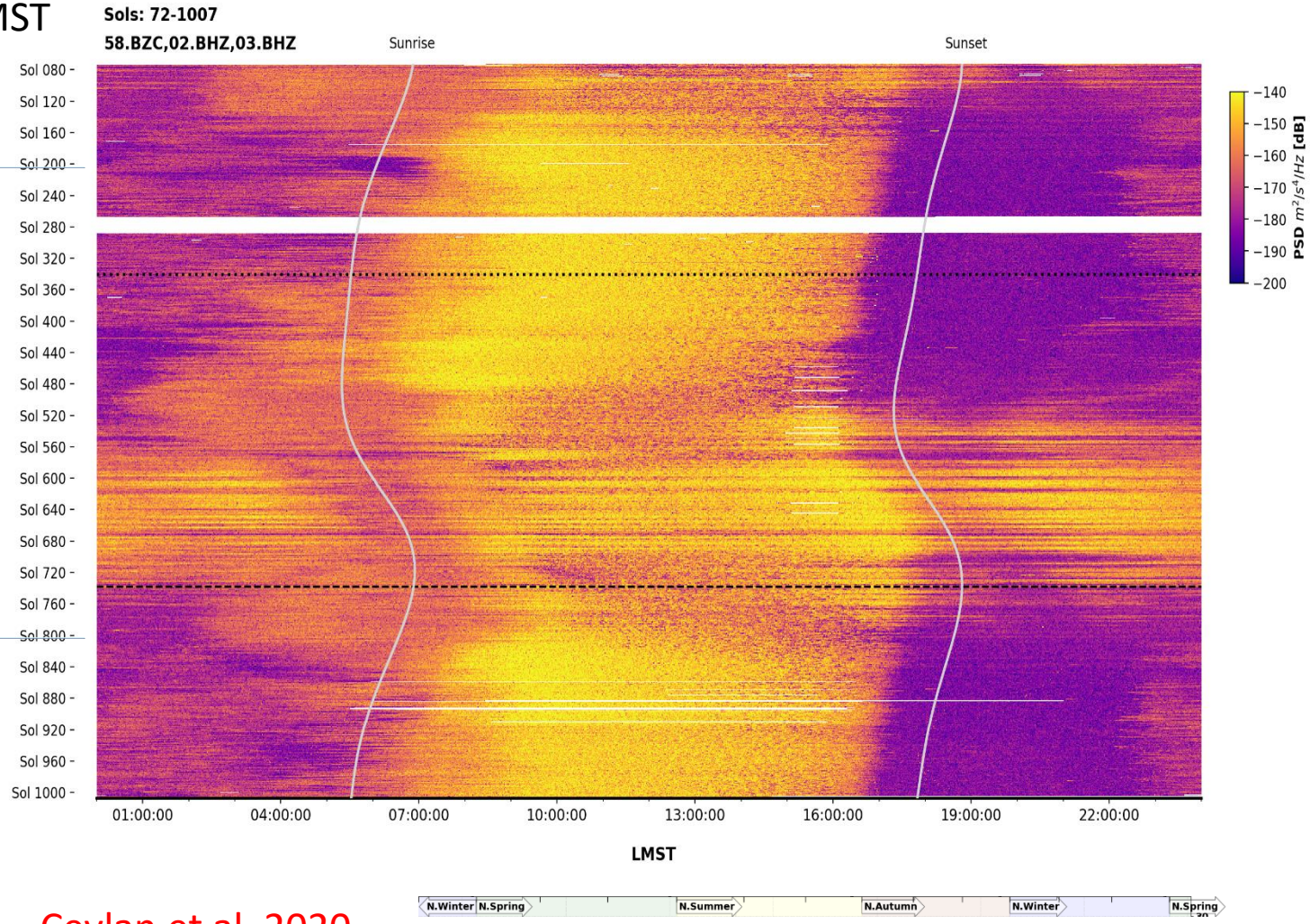
Noise and wind sensitivity

TWINS Wind measurement



M. Plasman

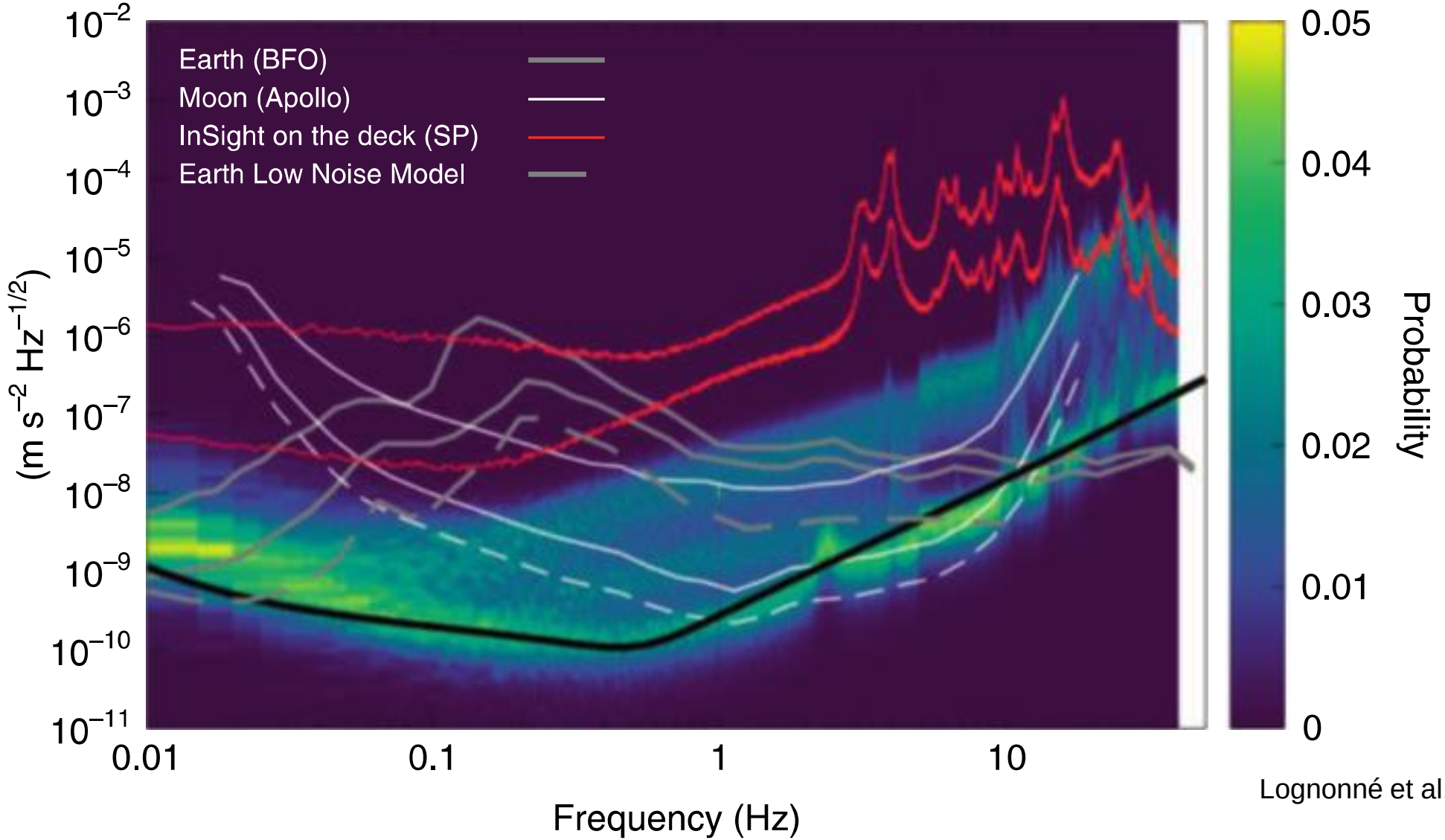
SEIS Ground acceleration measurement



Ceylan et al. 2020

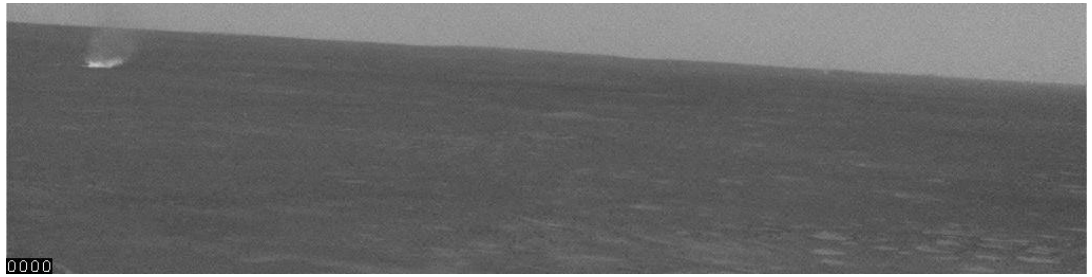
VBB noise : Mars, Earth, Noise comparison

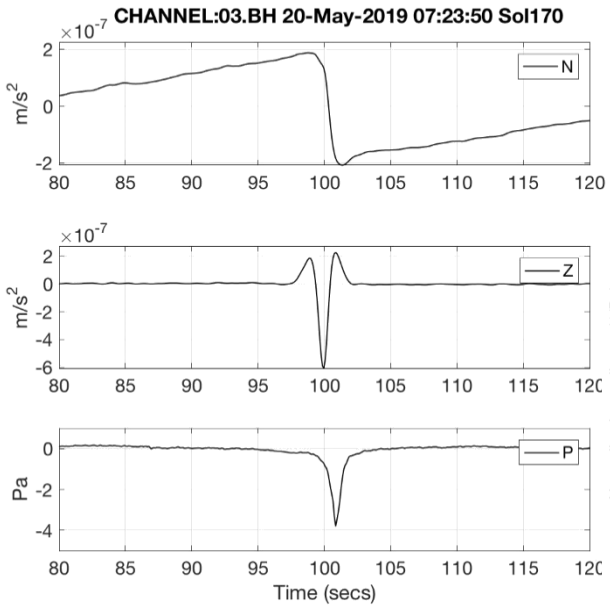
- In the first portion of the Night, the noise recorded by SEIS is the smallest never recorded by seismologists in the 0.1-1 Hz bandwidth

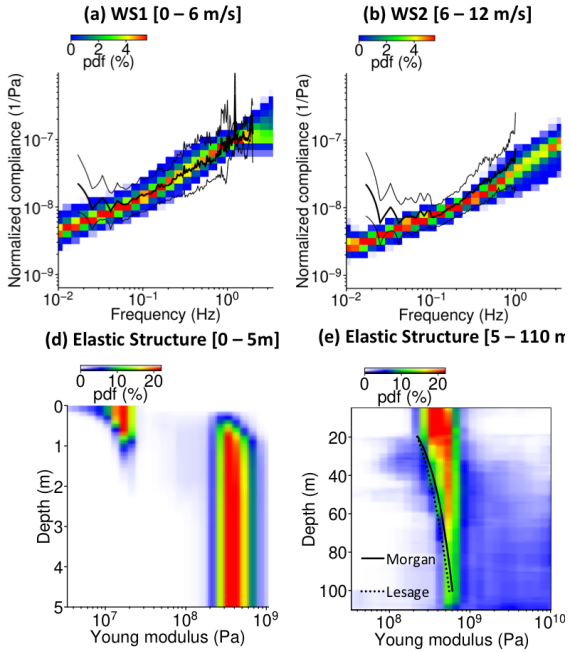


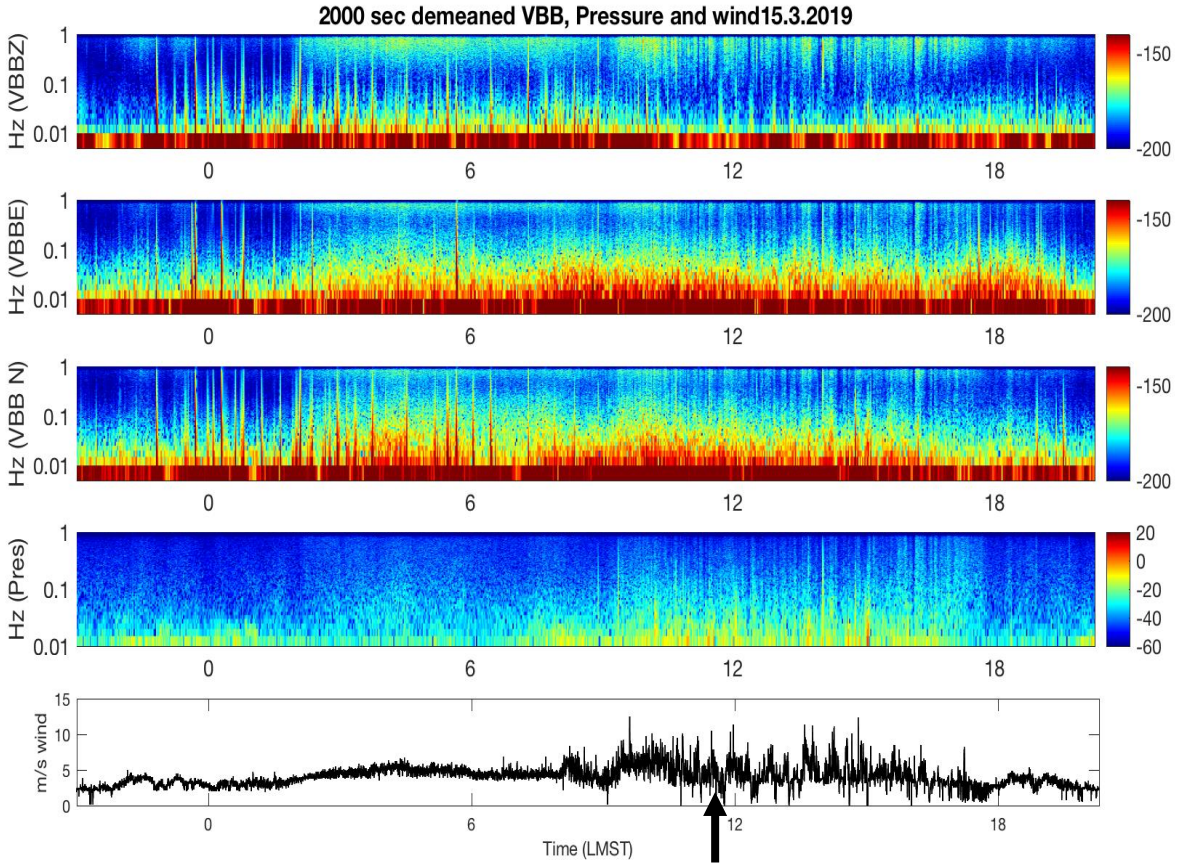
Lognonné et al. 2020

Typical VBB noise : Day time and pressure drops



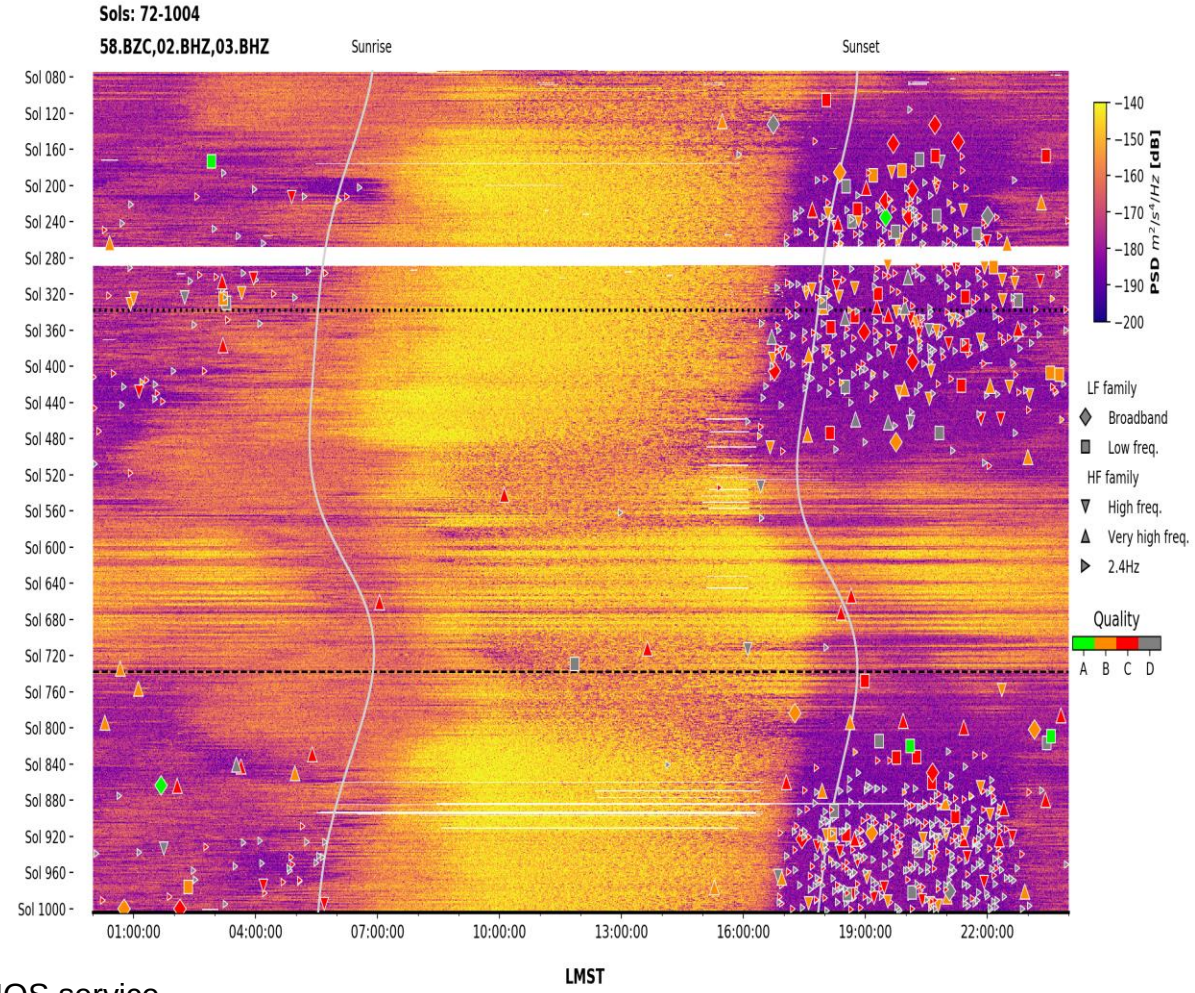


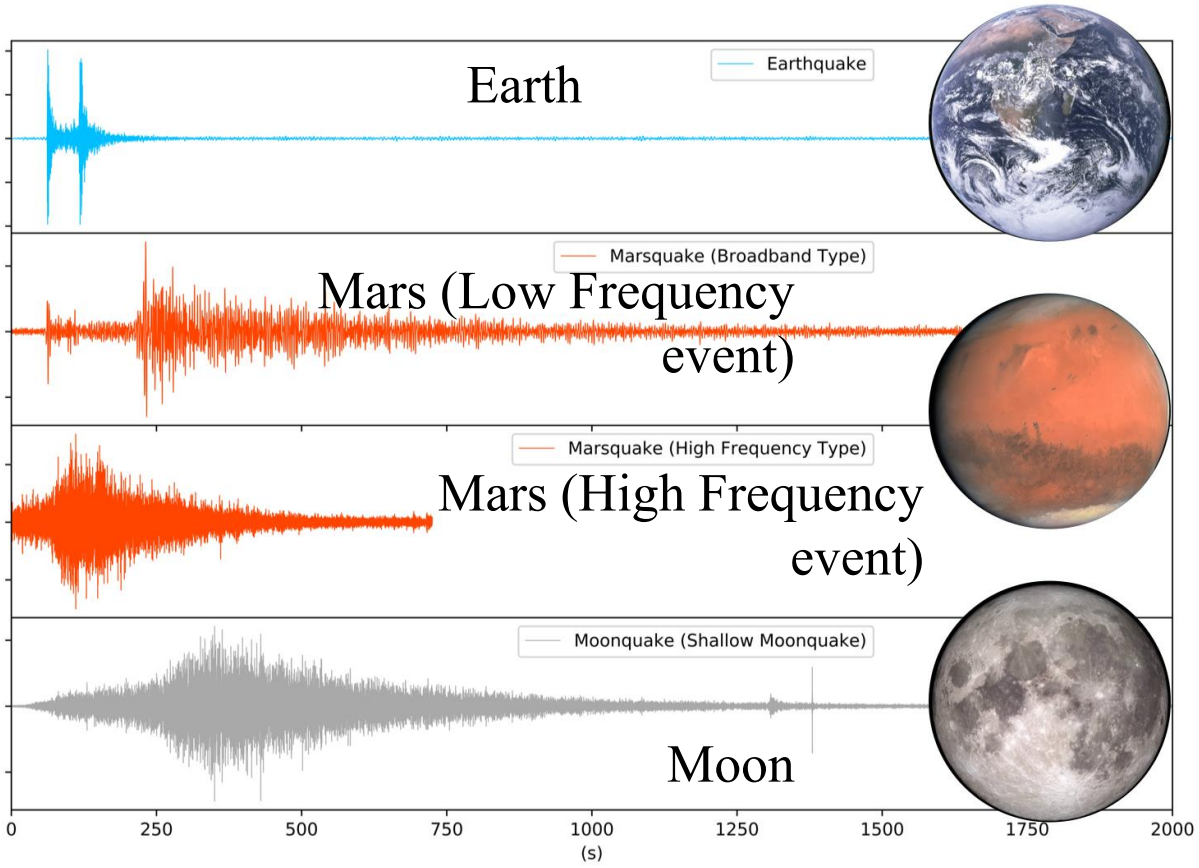




Mars Seismicity and seismograms (1/2)

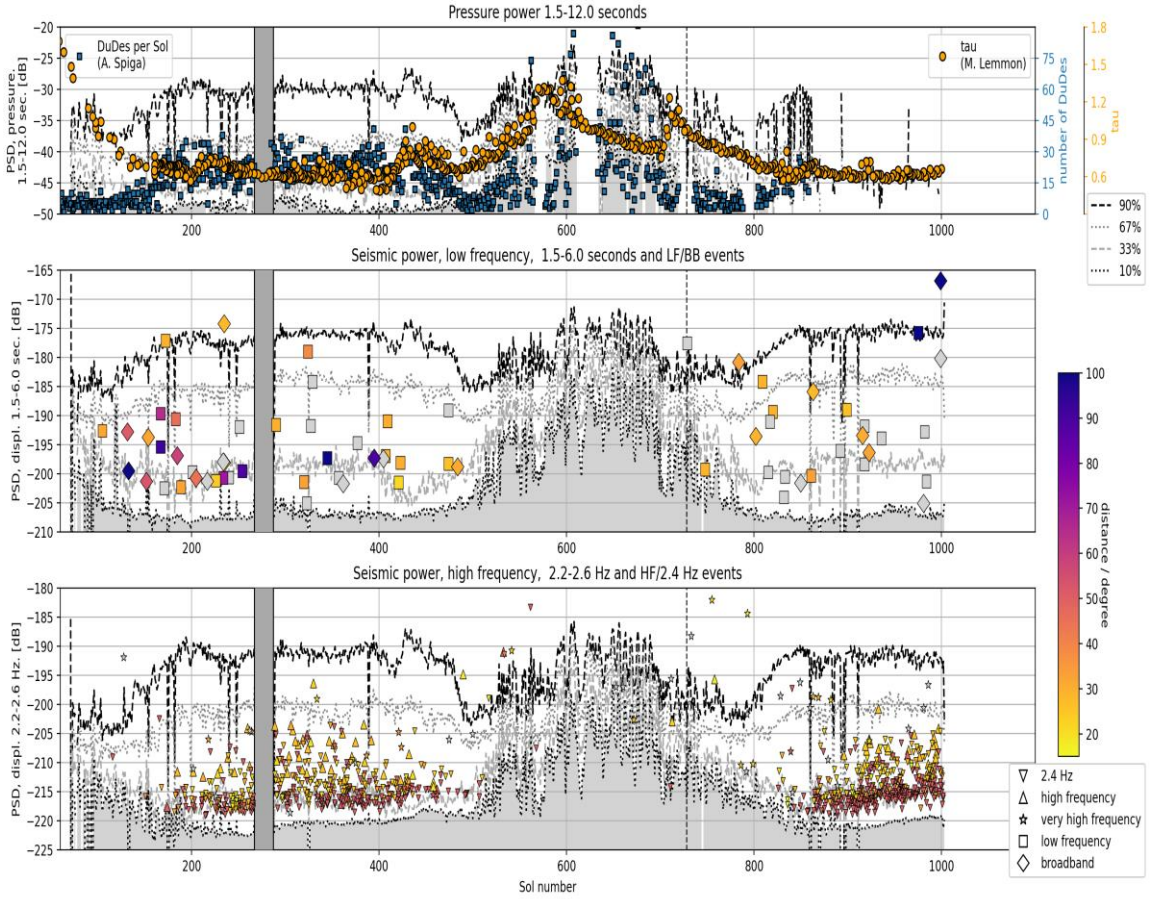
- More than 1300 events including ~100 with large low frequency (< 1 Hz) amplitudes
- A seismicity putting Mars between Earth and Moon
- The start of comparative seismology….

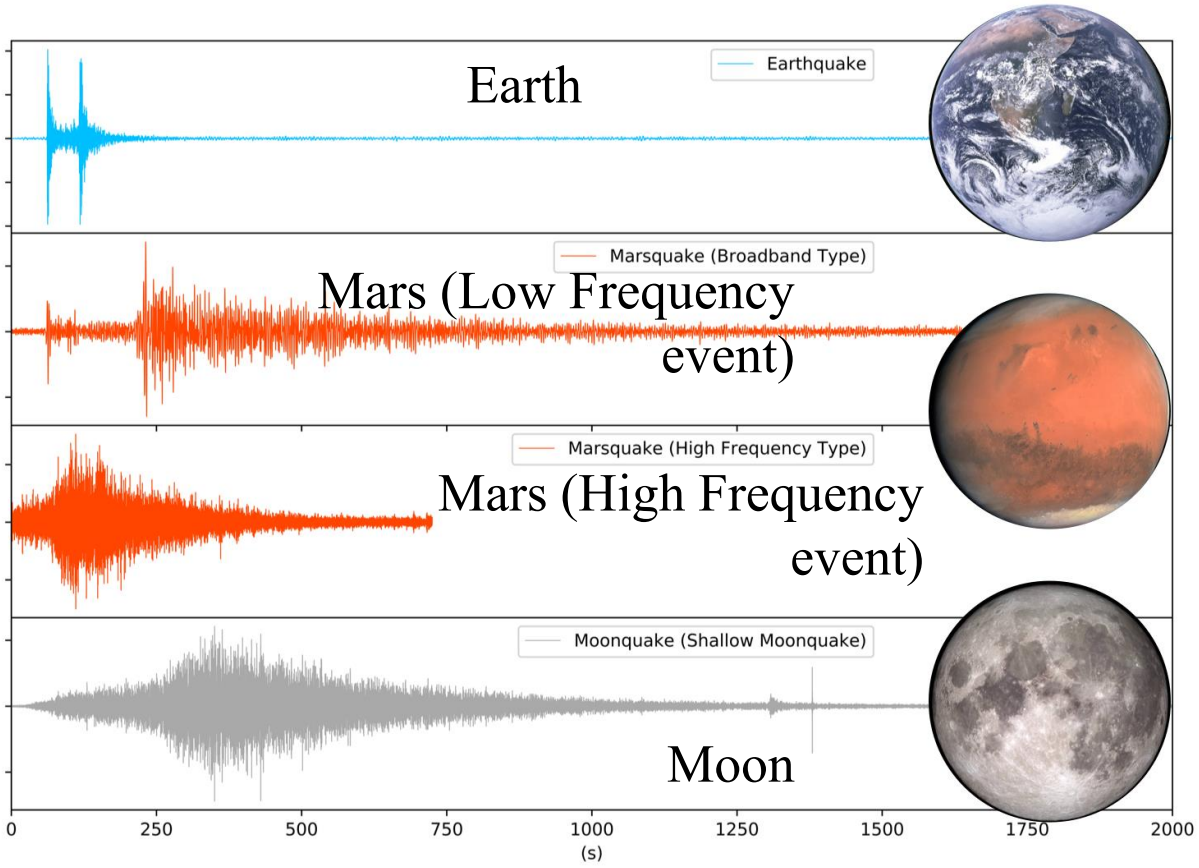




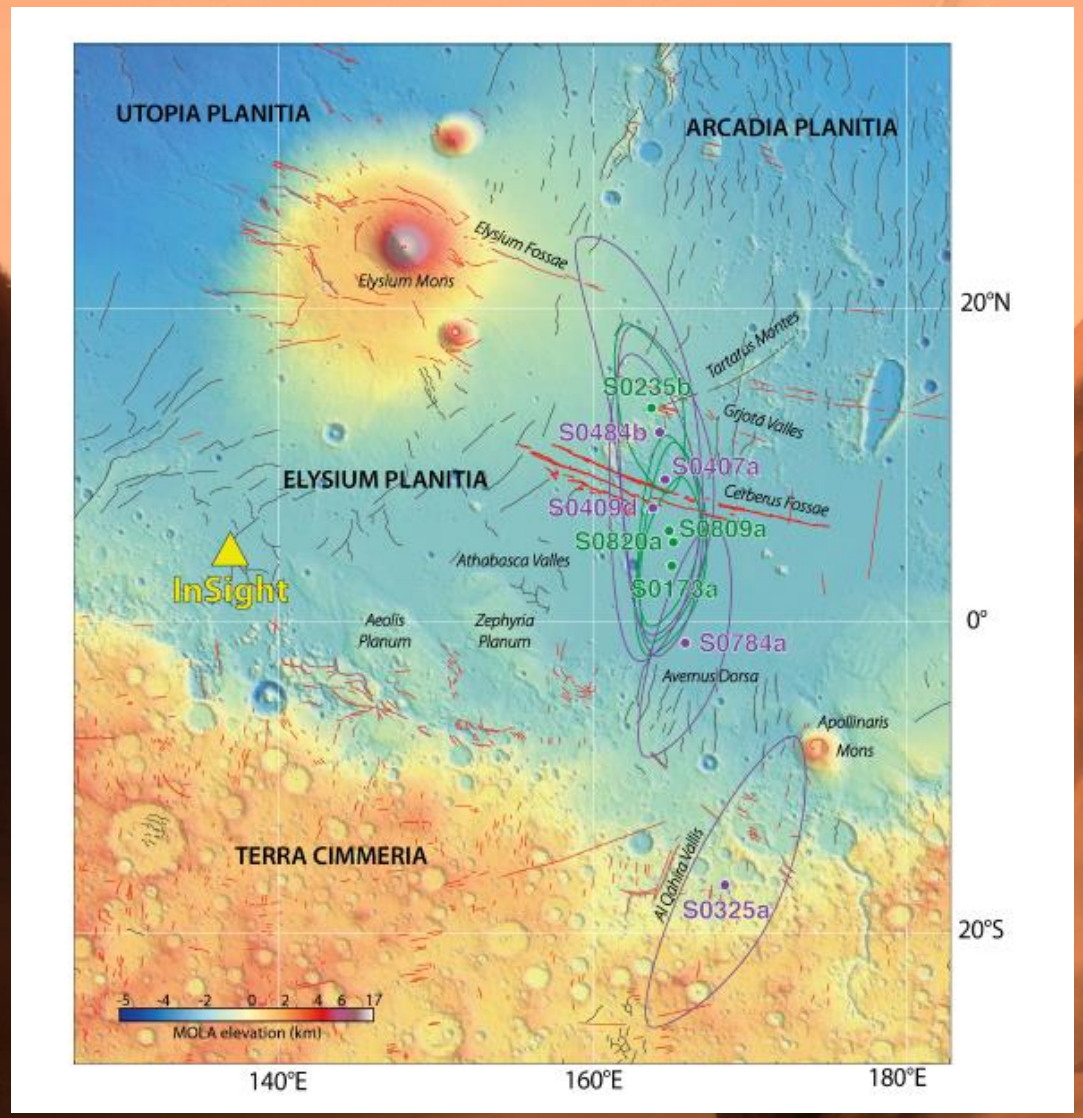
Mars Seismicity and seismograms (2/2)

- More than 1300 events including ~100 with large low frequency (< 1 Hz) amplitudes
- A seismicity putting Mars between Earth and Moon
- The start of comparative seismology….

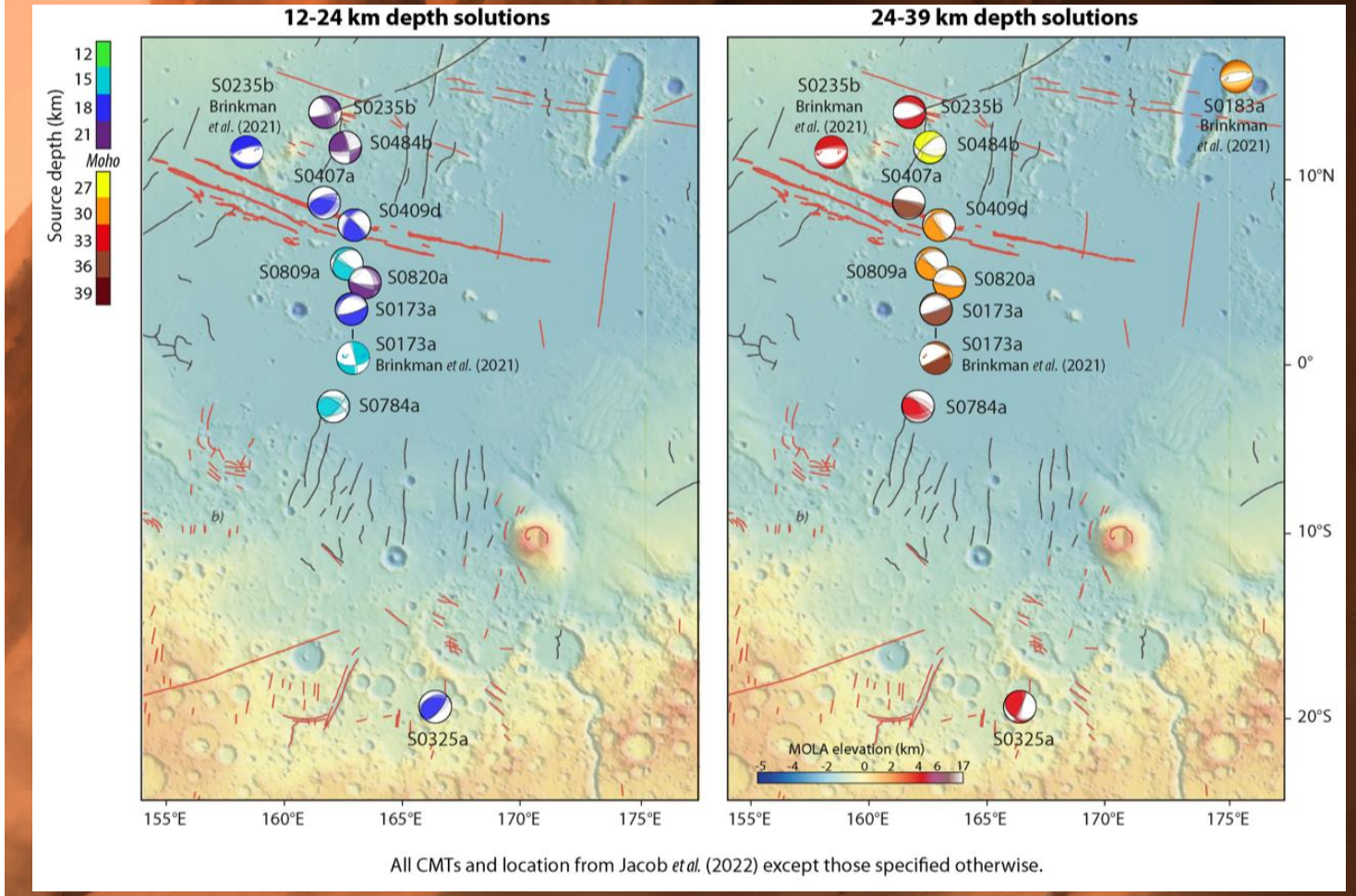




Cerberus Fossae seismicity, and CMT mechanisms



Clinton et al. 2021, Drilleau et al. 2022

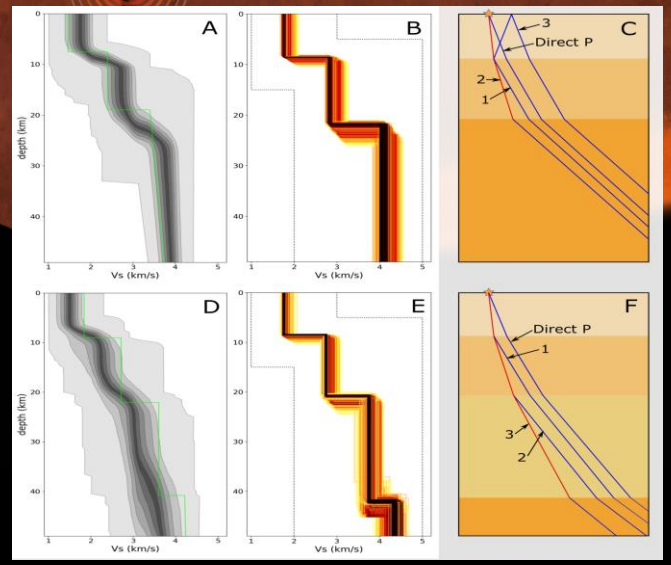


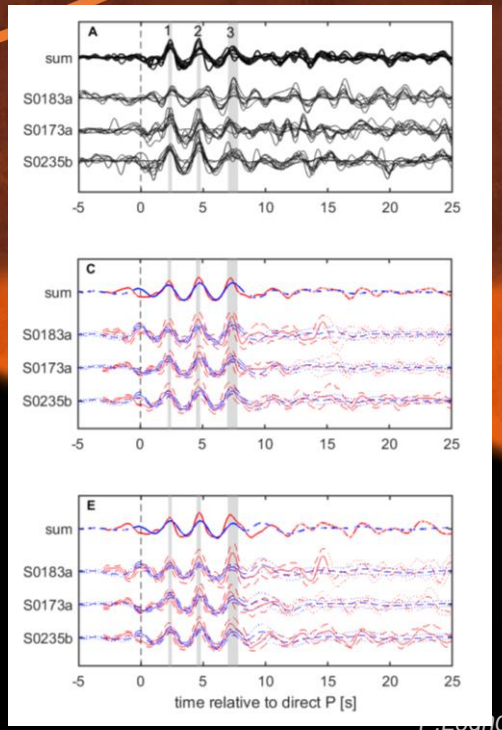
Brinkman et al. 2021, Jacob et al. 2022

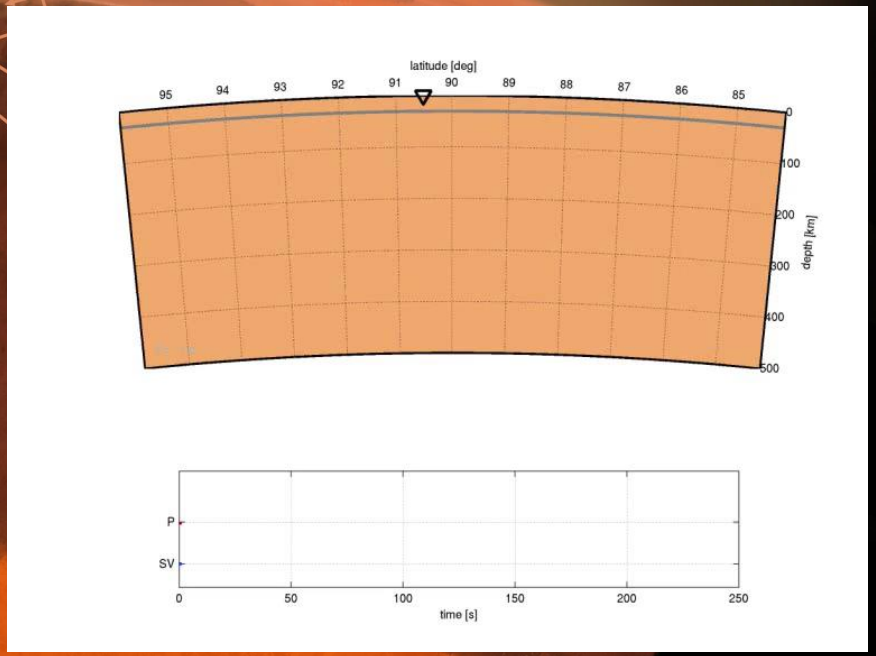
Crust layering, crustal thickness and crustal anisotropy

Lognonné et al. (2020)
Knapmeyer-Endrun et al. (2021)
Li et al. (2022)

Mars Elysium Planitia

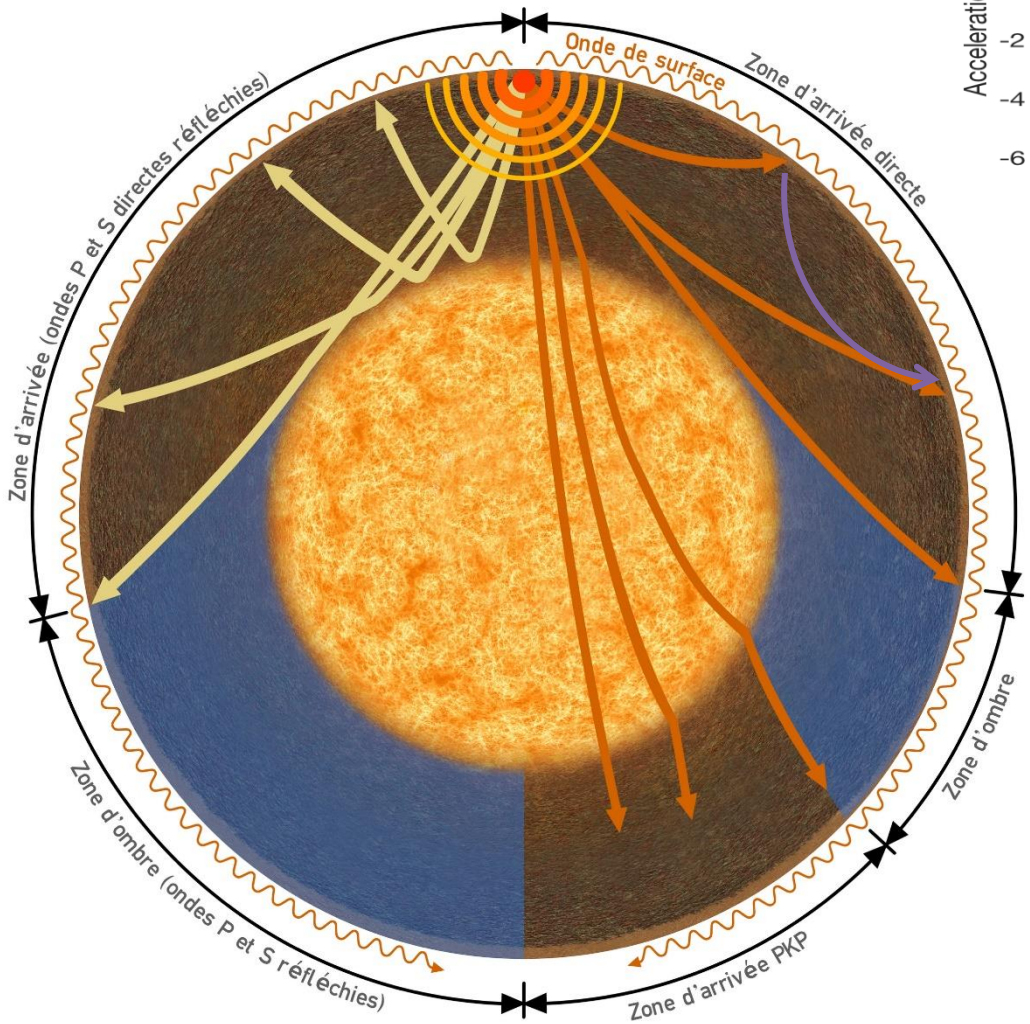


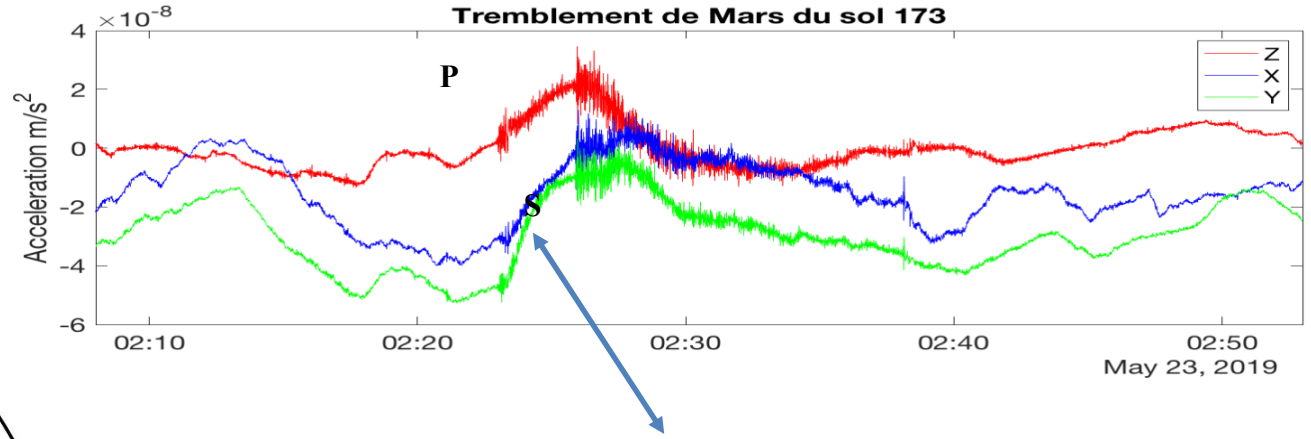




Mantle structure with one station: Multiple (SS+,PP+) travel times

S0173 Marsquake (M ~3.7}





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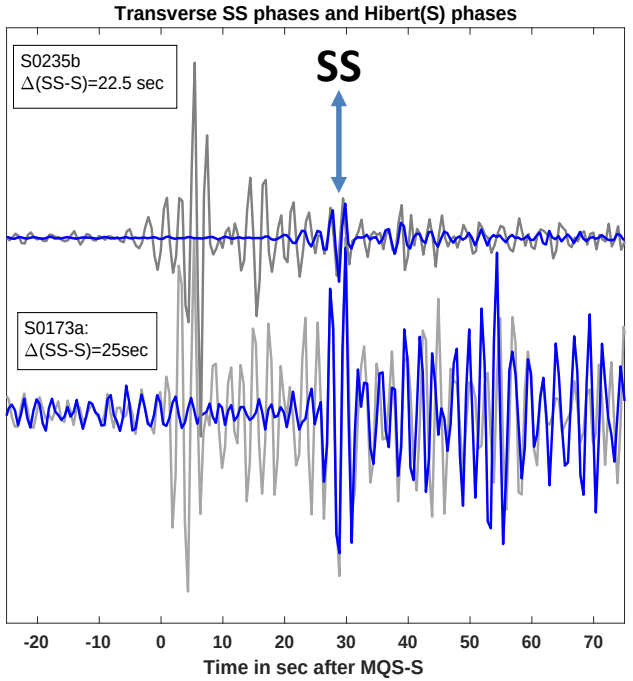
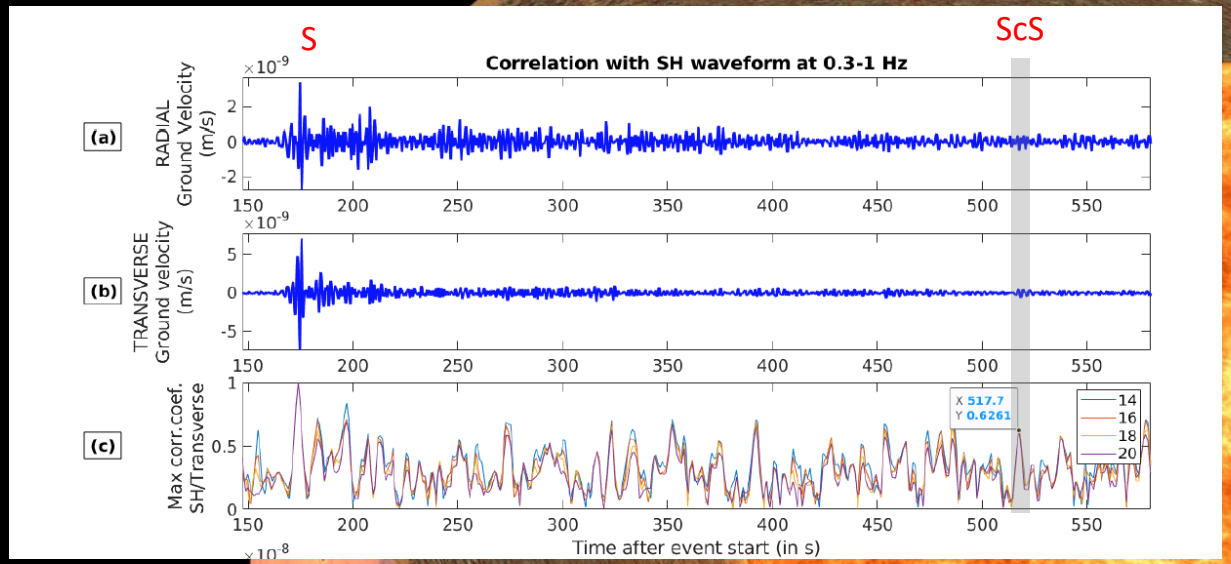
Analyze made on the 8 largest quakes with 3 different techniques

- **See more in Khan et al. 2021 and Drilleau et al. 2022**



Waveform matching: Lognonne et al. Contribution to Khan et al. 2021

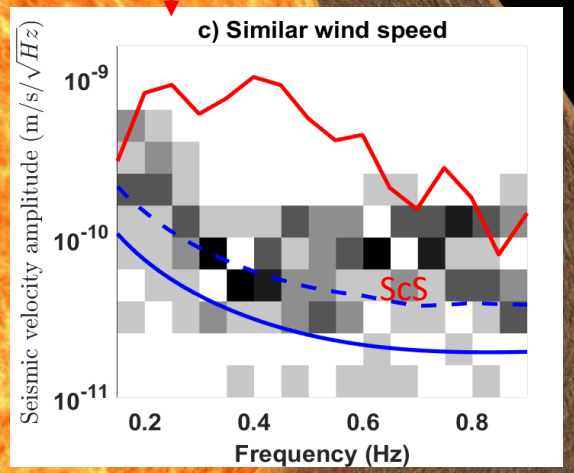
Core: challenge in data processing



Contribution: R.Garcia, E.Stutzmann

- Low amplitude phases
- 6 Different methods by several team
- wind noise carefully estimated by statistics and polarisation
- See more in Stähler et al. 2021

ScS

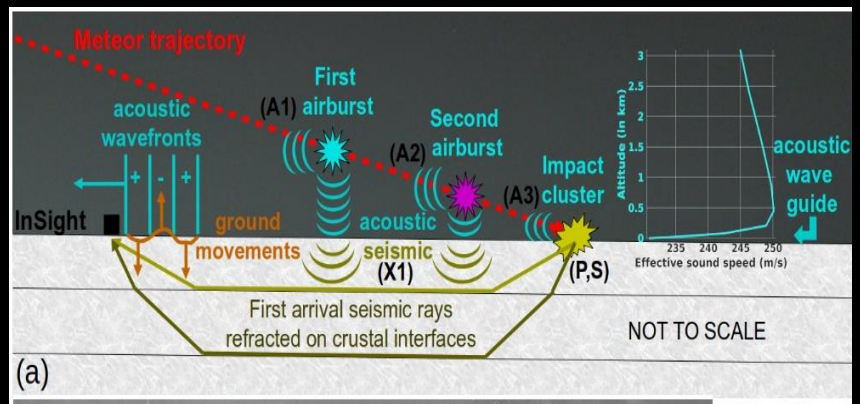


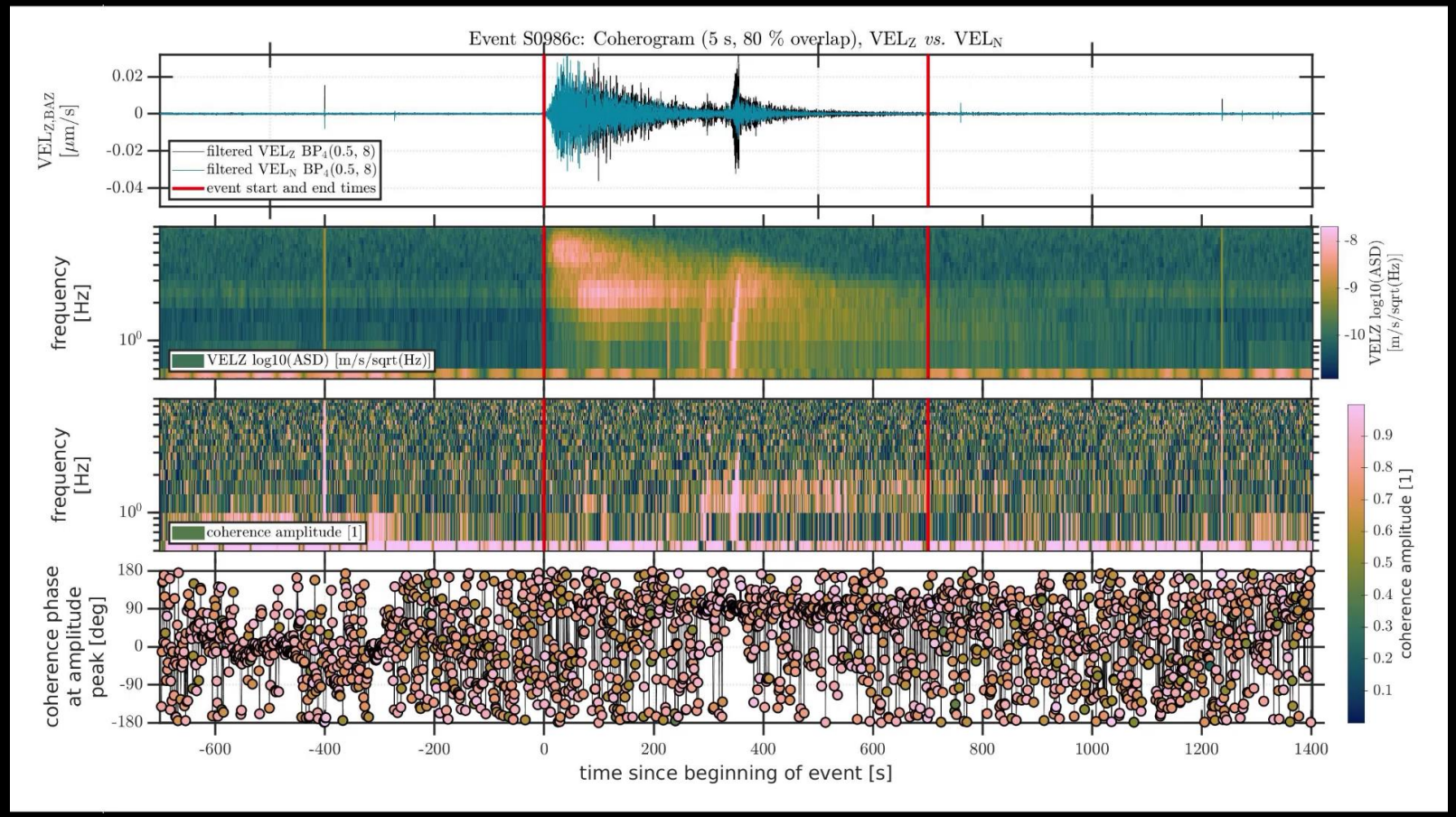
Contribution Z.Xu, P.Lognonné

Wind noise

Impacts

- Several impacts have been detected, including some close from InSigh
- These impacts are characterized by both a seismic signal and a ground induced acoustic signal (Garcia et al. 2022, in revision, Nature geoscience)





SEIS Goals achievement

Mission objectives	Mission results
Crustal thickness	20-35 km below InSight
Crustal stratification	Altered crust in the first 10 km
Mantle seismic velocity	7.8±0.2 km/s
Liquid/Solid core state	Liquid at the Mantle/core
Core radius (SEIS)	1830±40 km
Mass density (SEIS)	6±0.3 gm/cc
Heat flow (SEIS)	14-29 mW/m²
Seismic activity	Between Earth and Moon
Location of seismic zone	Large activity in Cerberus fosse
Meteorites flux	3+ since last STM

Knapmeyer-Endrun et al. 2021

Lognonné et al. 2020

Khan et al. 2021, Drilleau et al., 2022, Duran et al 2022, Khan et al., 2022

Stähler et al. 2021

Stähler et al. 2021, Duran et al., 2022

Stähler et al. 2021, Duran et al., 2022

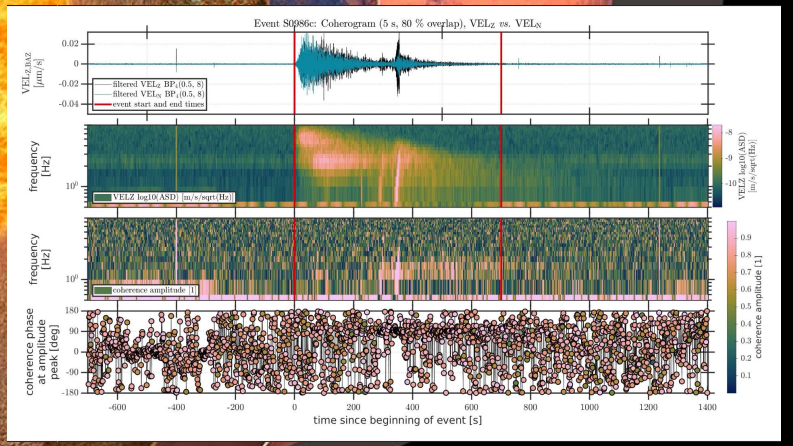
Khan et al. 2021, Drilleau et al. 2022

Giardini et al. 2020, Brikman et al. 2021,Jacob et al. 2022

Giardini et al. 2020, Clinton et al. 2021

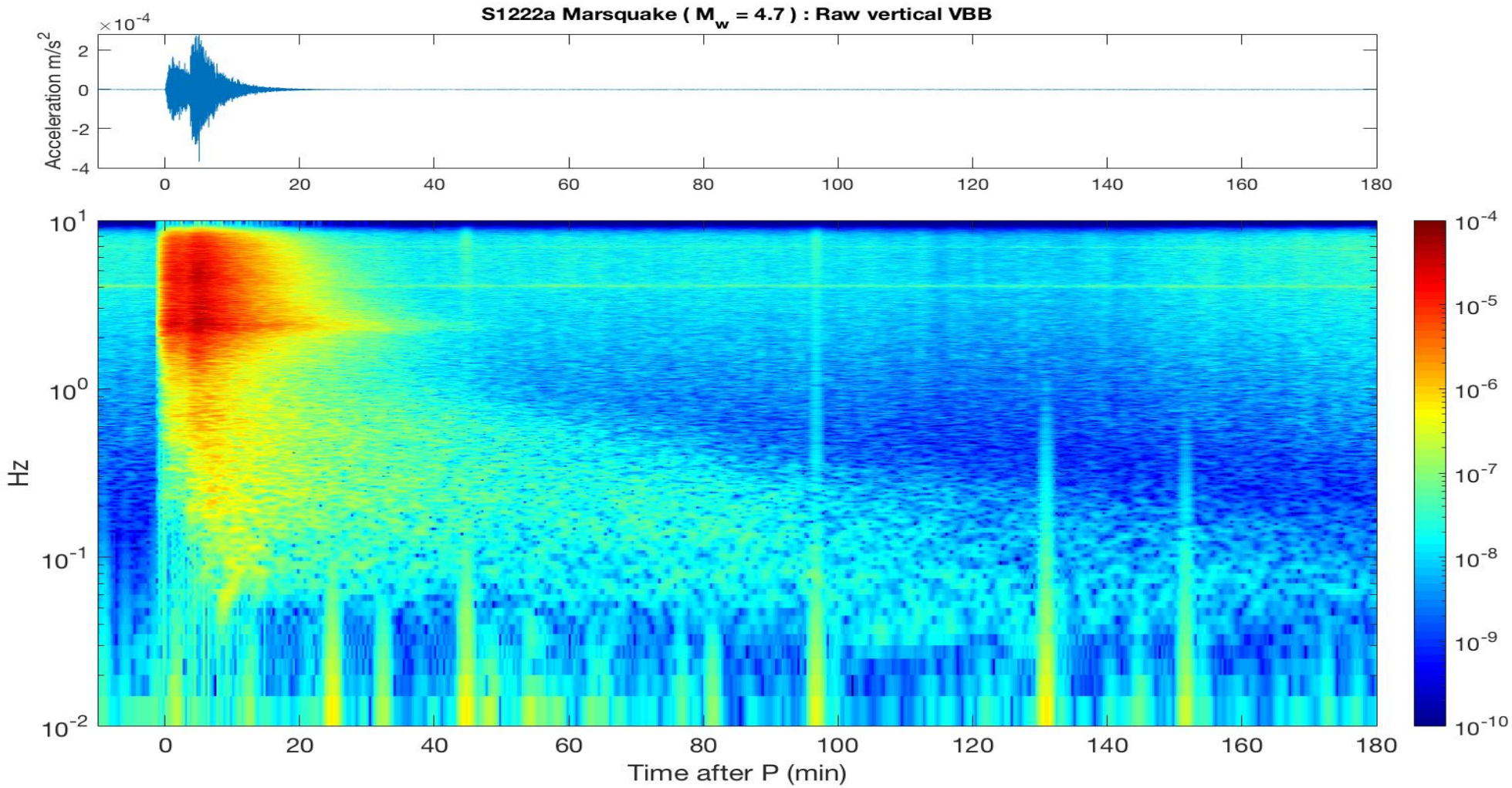
Garcia et al. (revised version in review) , Posiolova et al (in review)

And many more to come in 2022



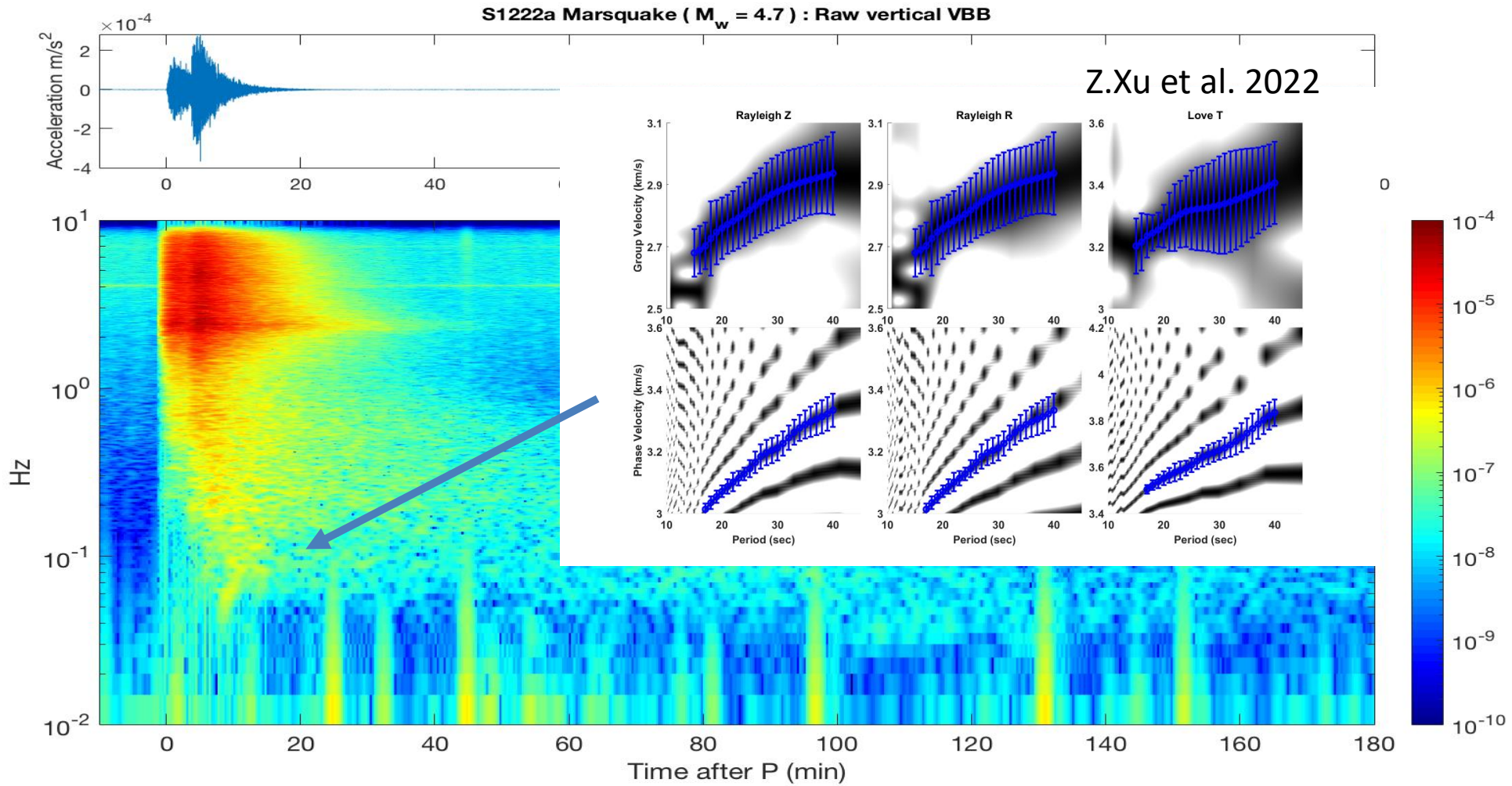
May 4… farewell gift with the S1222a event

- The high Gain output was only ~5 below the saturation..

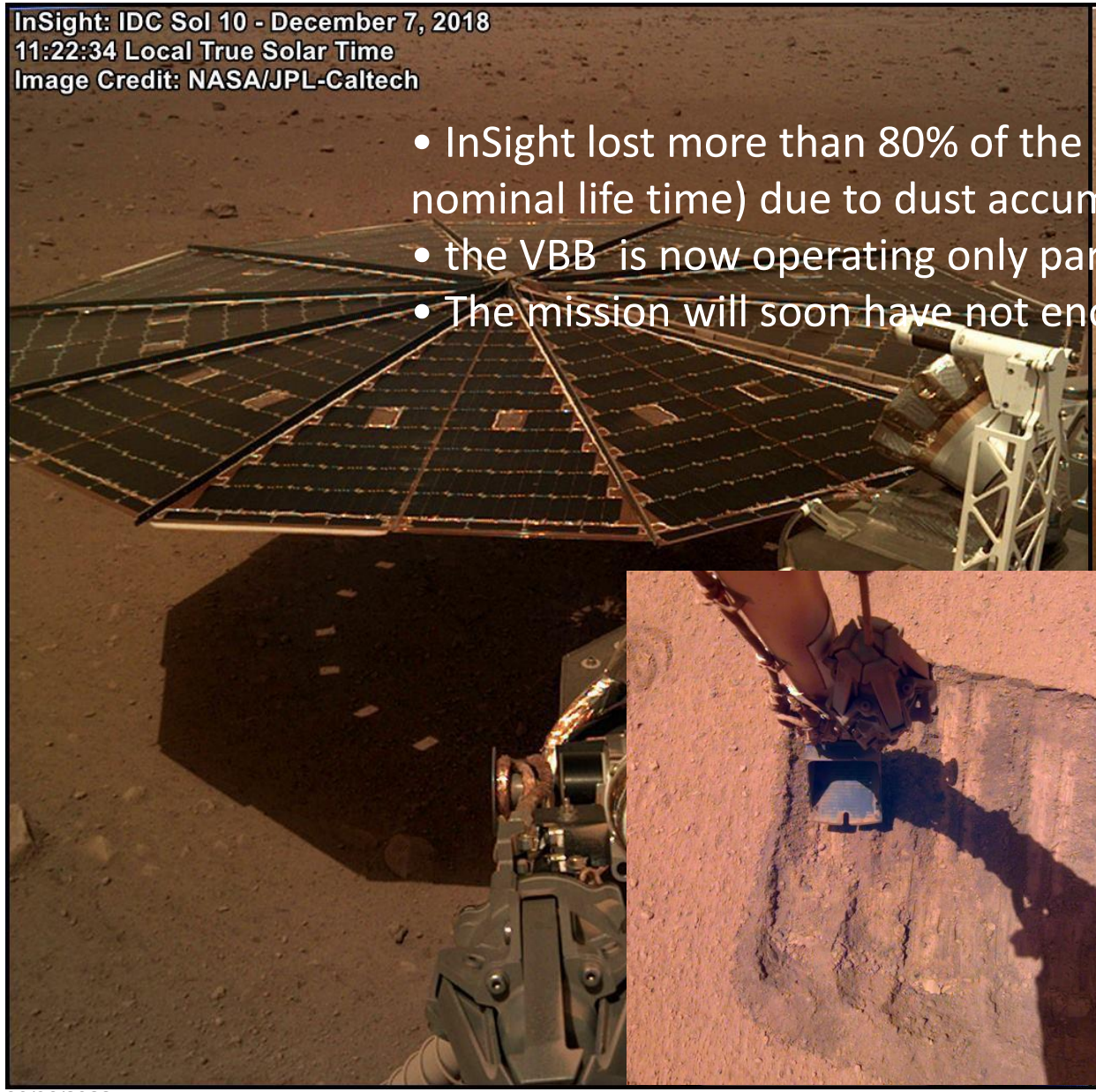


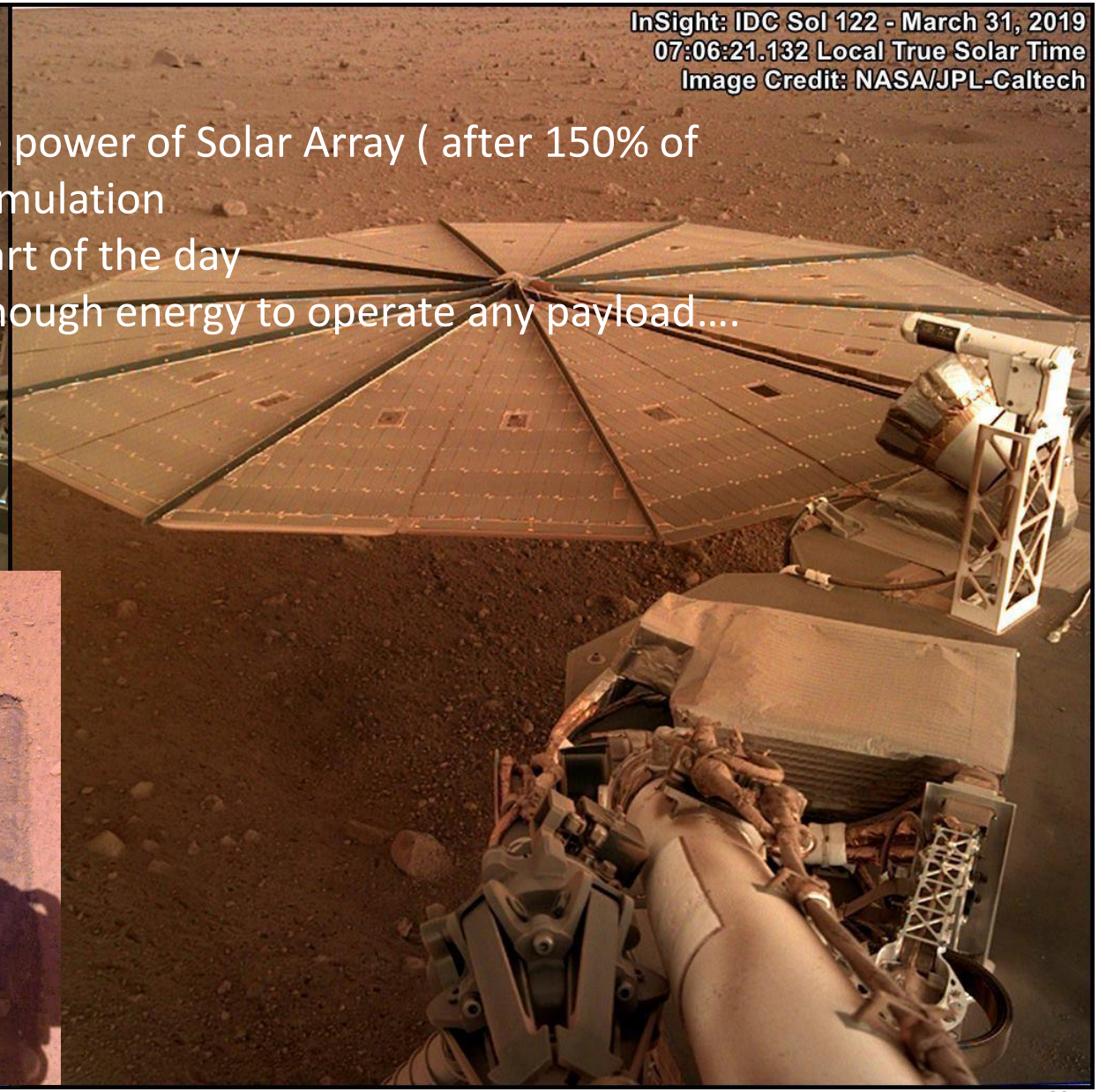
May 4… farewell gift with the S1222a event

- For the first time, detection of Rayleigh and Love surface waves…



Toward the end of mission….

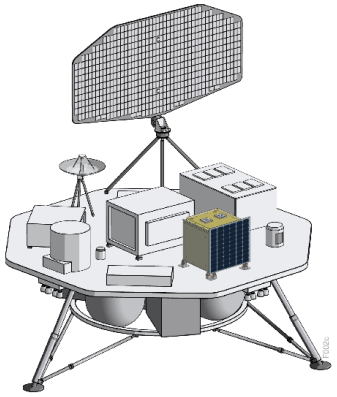


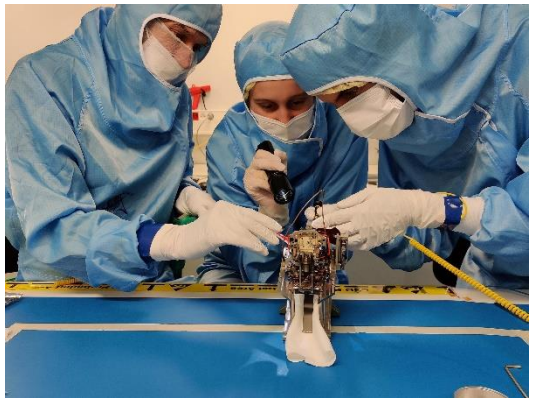


- InSight lost more than 80% of the power of Solar Array (after 150% of nominal life time) due to dust accumulation
- the VBB is now operating only part of the day
- The mission will soon have not enough energy to operate any payload….

The next 10+ years (starting FSS…)

- **Flight Projects with hardware**





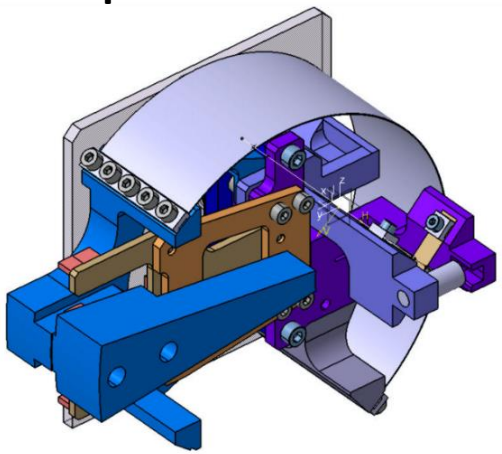
FSS : Use of the spare units of InSight VBB for lunar mission (NASA/JPL)
FSS-1 : To be launch in early 2025 on the Farside of the Moon (Shrödinger bassin)
FSS-2: under discussion with JPL and likely candidate for the Artemis-3 Geophysical payload AO

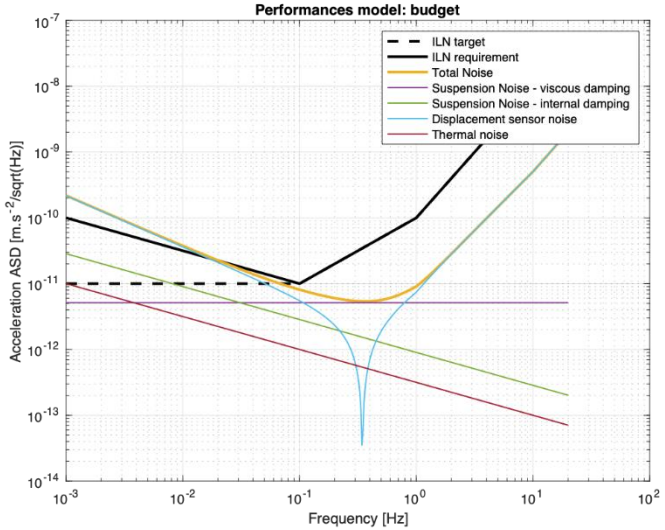
- **Flight Projects with science contribution**

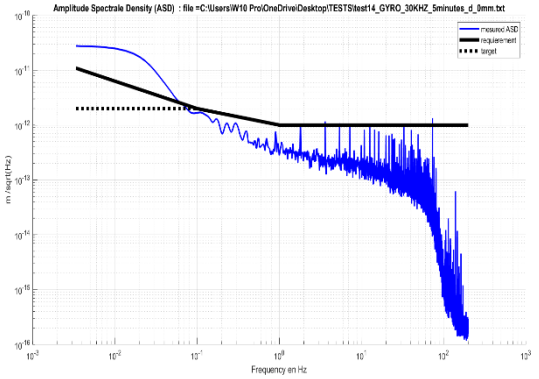
- Science coordination of the Titan DragonFly geophone (T.Kawamura)
- Science team members of the Chang'e 7 seismometer (P.Lognonné, T.Kawamura, S. de Raucourt)

- **Projects in development**

Optical VBB: > 20 db of sensitivity improvement
Will be candidate for Artemis 4+ and other Lunar opportunities after 2027







Extreme Displacement transducer sensitivity:
(1 pm/Hz$^{1/2}$ @ 10 sec to be soon improved…)