Network Science on Mars

Philippe Lognonné

With many inputs and discussions from B.Banerdt and the NETSAG group

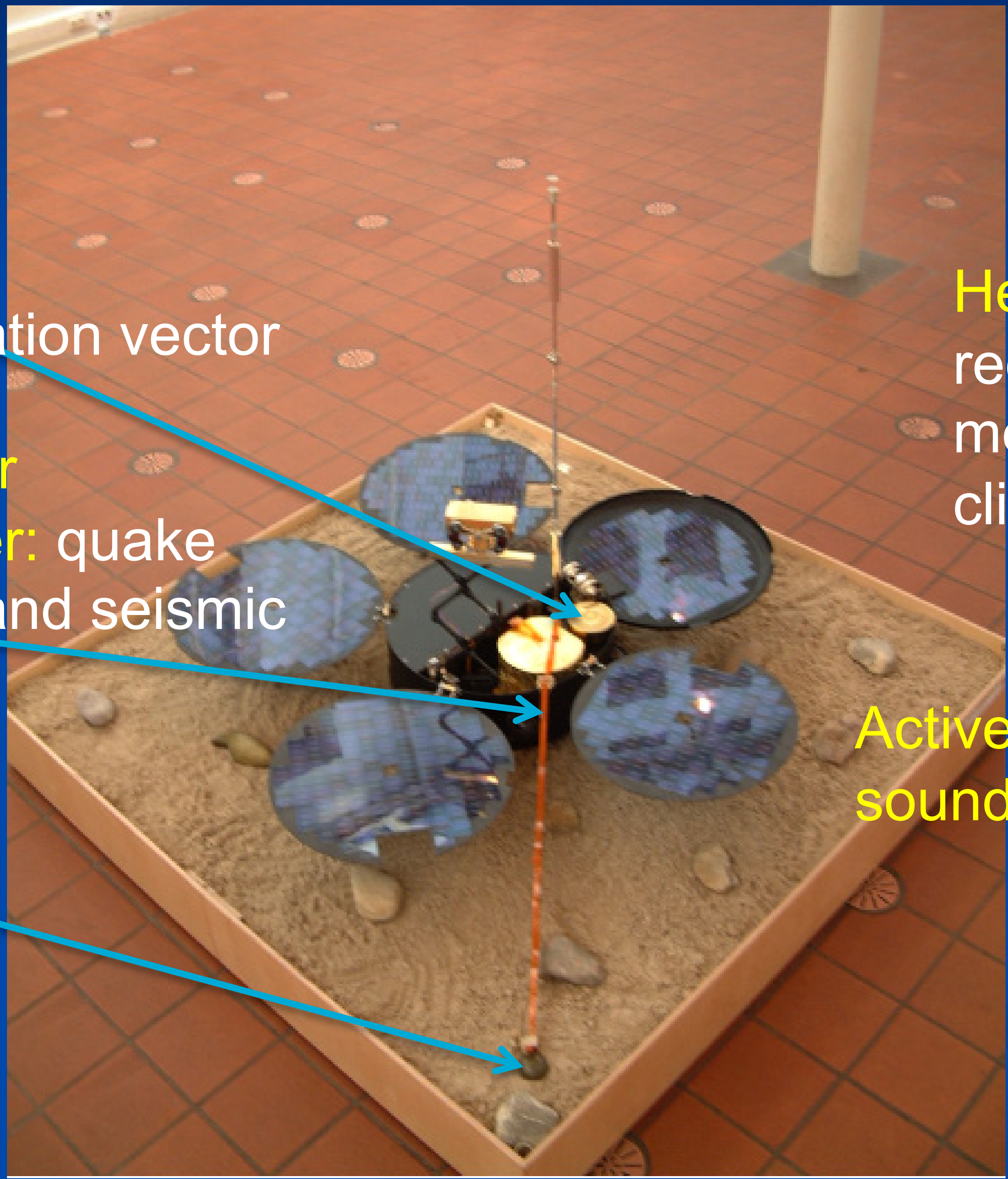
Geophysical network payload

Network payload

Geodesy experiment or DTE Radiosystem : rotation vector

3 axis LP seismometer
3 axis SP seismometer: quake location, mechanism and seismic velocities

3 axis Magnetometer : planet conductivity from magnetic field gradient measurements

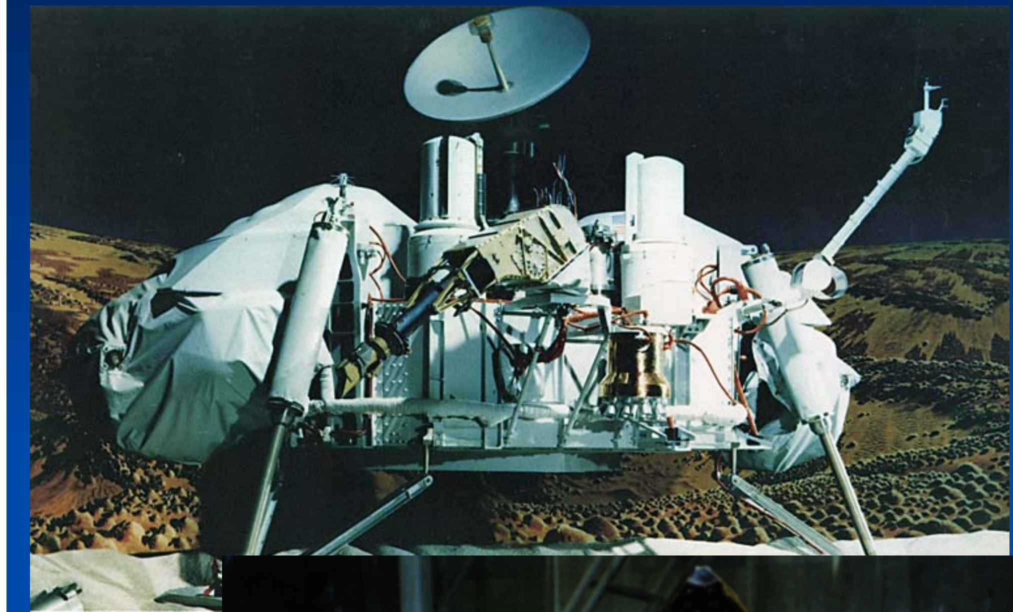


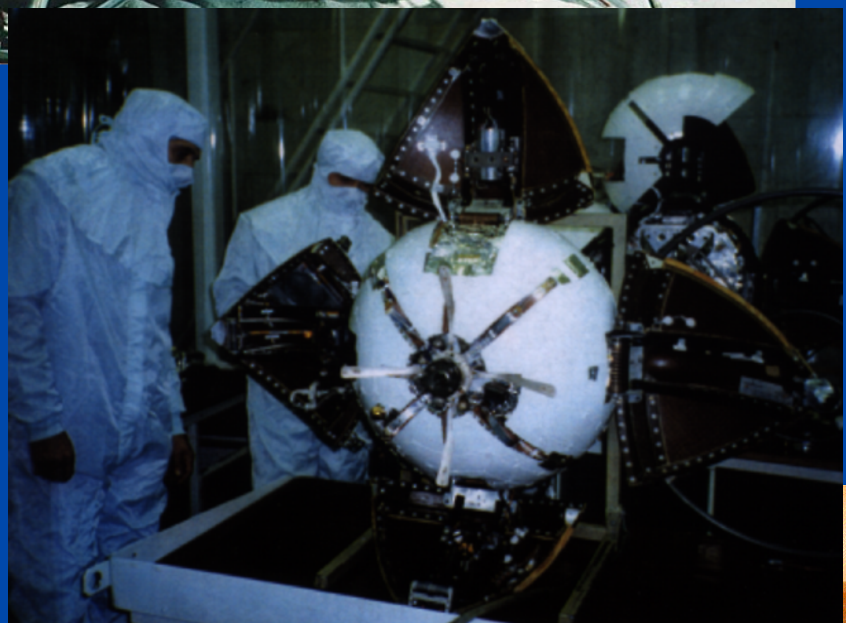
Other Geophysical payload

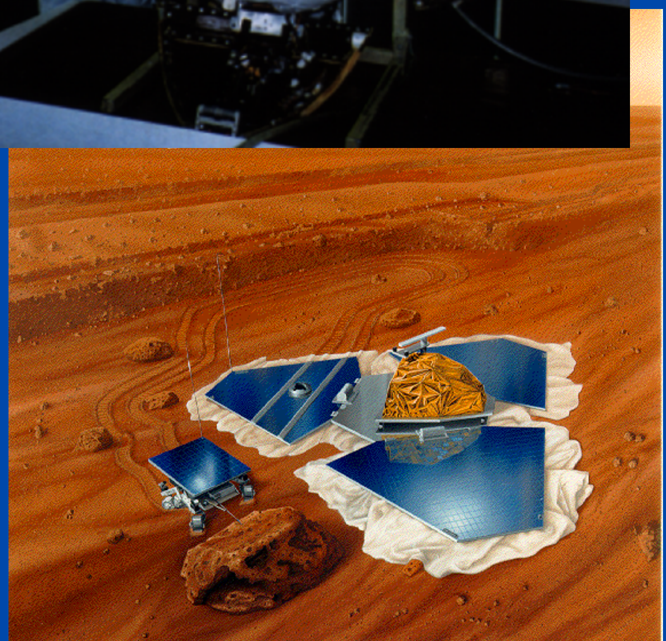
Heat flow experiment : may request multisite measurement to correct for climatic effects

Active or Passive EM sounding : crustal conductivity

Launched landed mission with Geophysics







- 1975-Viking: An exobiology driven mission with some (small) room for a seismometer. Claim for the detection of one quake on one lander.
- 1996: Failure of the launch of Mars96, with 2 surface stations equipped with BRB Z axis seismometers and 2 penetrators with SP geophones. Remains the best example of geophysical mission in the last 2 decade.
- 1996: (MESUR)-Pathfinder perform geodesy measurements. No seismometer in the payload however

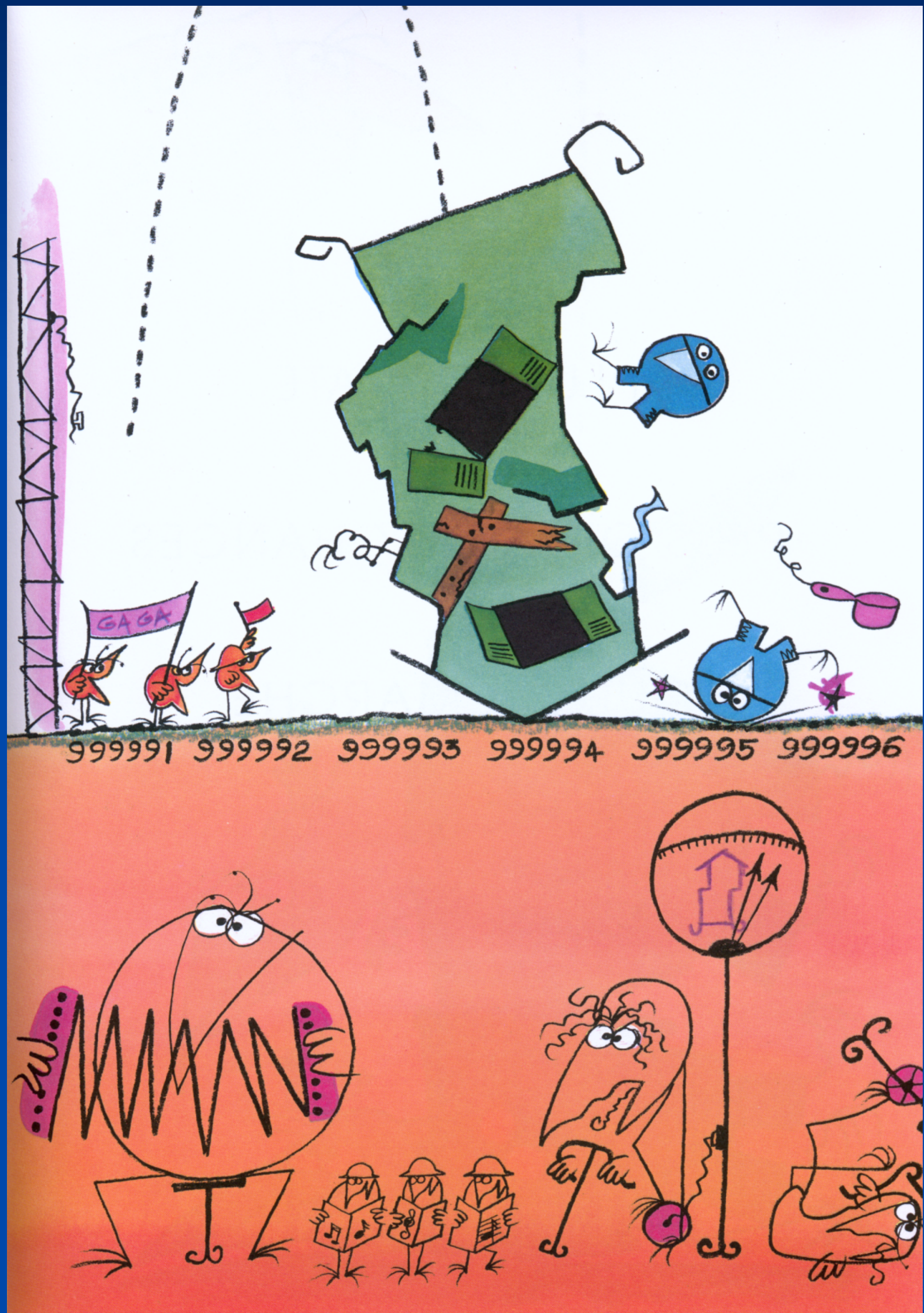
Canceled projects since 1990

- 1990-1995: ESA's MarsNet and InterMarsnet projects (4stations) lose competition against Astronomy missions
- 1990-1993: NASA's MESUR project (16 stations) is stopped after the loss of Mars Observer… only MESUR Pathfinder is launched in 1996
- 2001: The MASTER project, carrying one lander to Mars, is not selected by ESA

- 1997-2003: The NetLander project is stopped by CNES and NASA before phase B completion.

- 2005-2009: ESA cancel the Geophysical Package onboard the ExoMars lander (and transform later the lander into orbiter).

An impressive success story…

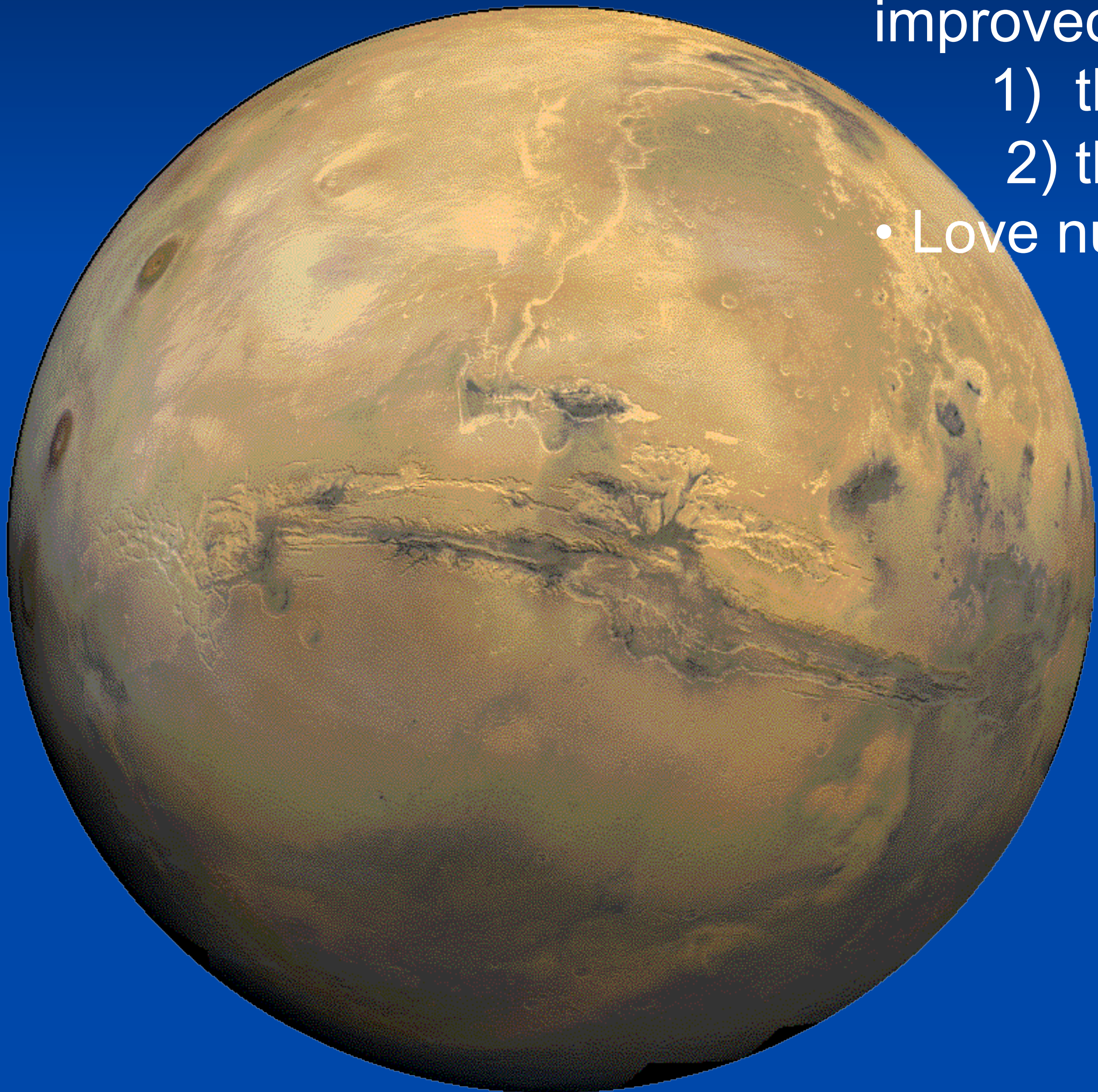


Mars interior remains widely unconstrained…

• The ONLY geophysical data constraining the interior improved in the last 20 years are

1) the mean density and Moment of Intertia
2) the gravity topography fields and ratio

• Love number measurements remain VERY noisy

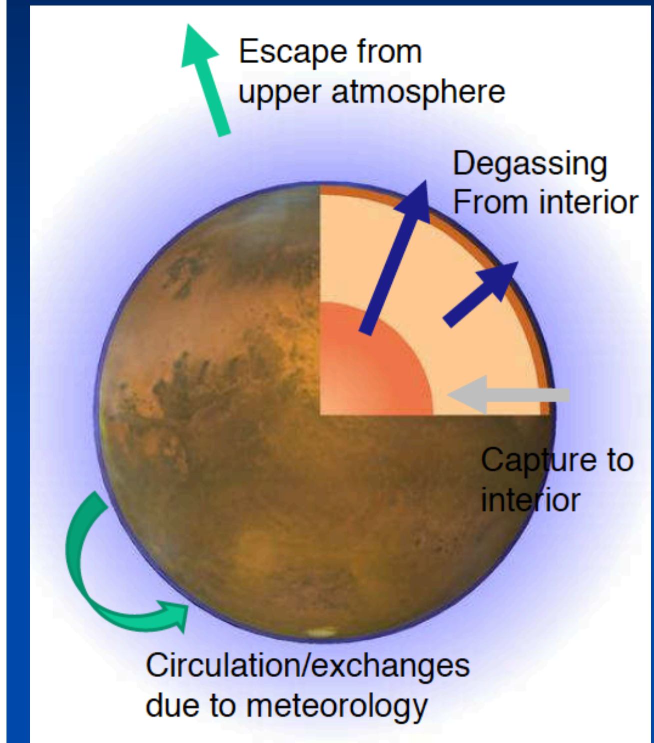


These data are NOT providing any constrains on the mean planetary structure (i.e. mean crustal thickness and core size and radius) nor on the detailed crustal thickness

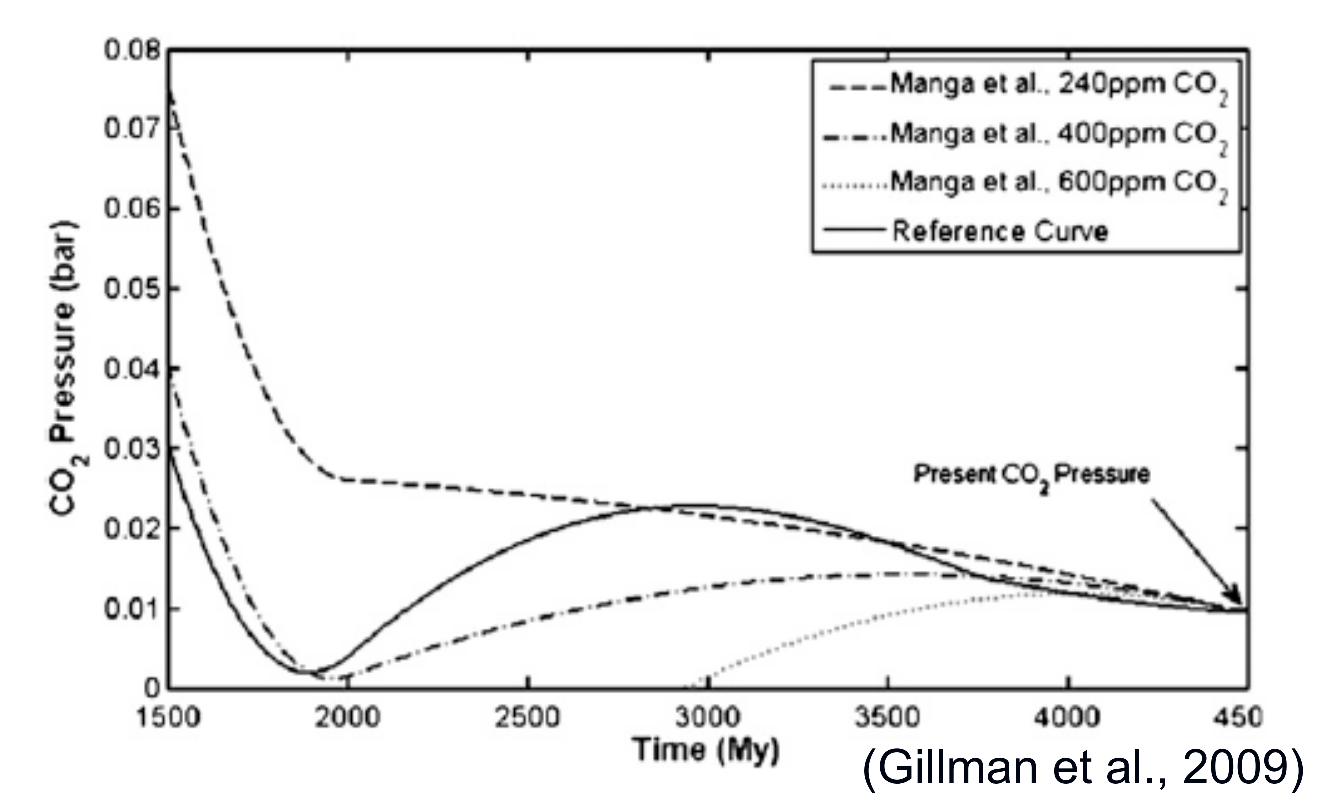
Due to SNC, 1st Sample Return mission will tell us little more on the deep interior (and planetary formation), unless its demonstrate that SNC are NOT from Mars

Mars interior is TODAY much less known than the Earth interior in 1910…

Can we therefore seriously understand the past habitability of Mars?



- Interior structure provide the characteristics of the planetary thermal engine
  - crustal thickness = thermal insulation and mantle depletion
  - Mantle exo/endo thermal discontinuities = efficiency of the mantle convection
- Volcanism and dynamo are the consequence of this engine and constrain the atmosphere on geologic time scales

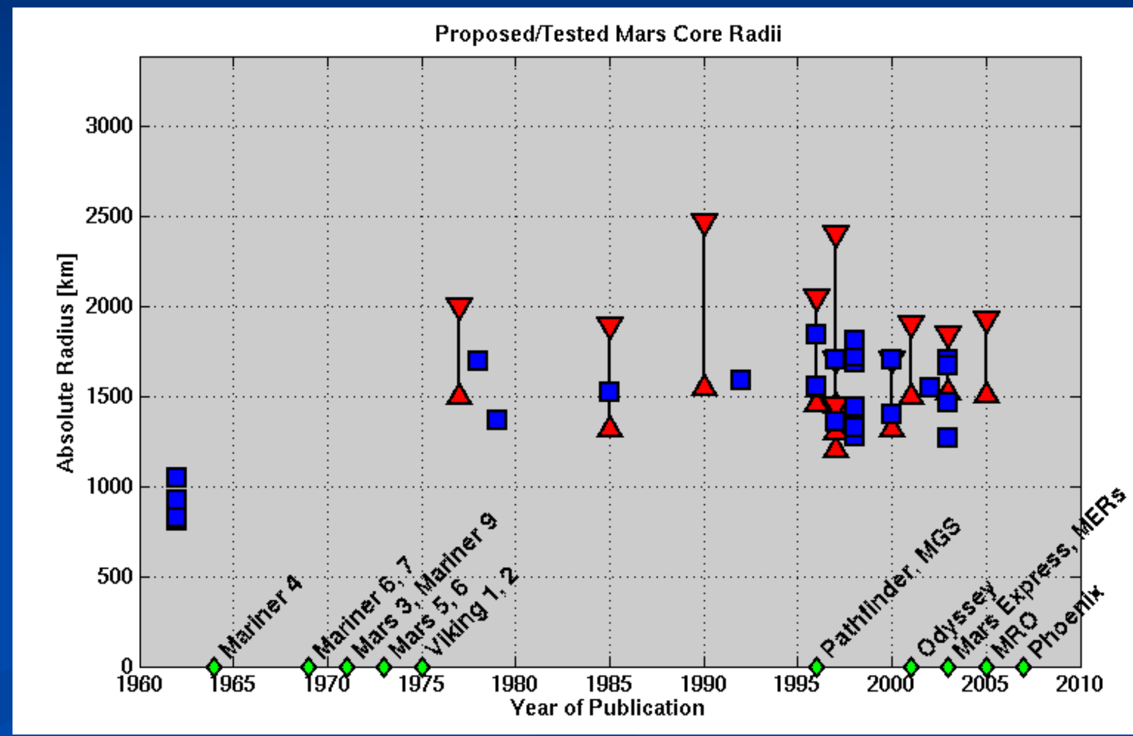


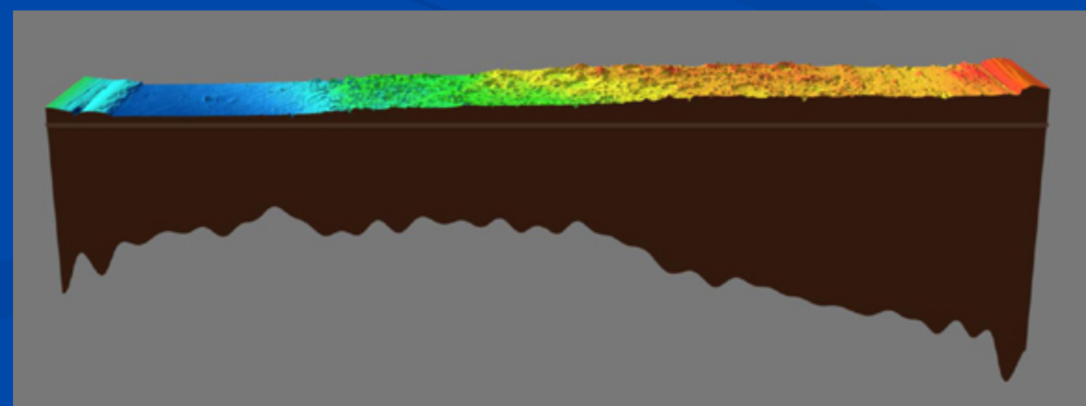
(Gillman et al., 2009)

- Maybe Mars has lost its past CO_2 atmosphere and what we see is a secondary volcanic atmosphere?
- Major impact on past climate
  - 1 km^3 of Earth lava = 0.06 km^3 of H_20 and 16 Mt of H_2SO_4 (Ph =2)
  - Tharsis might have generated 1.5 bar of CO_2 and 120 m of water

The new seismological challenges

- Our knowledge on the Mars interior has weakly progressed
  - Core is estimated within ±200 km since.. 30 yrs
  - Inner core is suspected
  - Maps of the lateral variations of the crust have been produced
  - High pressure mineralogy has narrowed the range of interior models of Mars
- Advance in Seismic instrumentation (challenged by Lunar projects) offers however better instruments
  - Comparable mass but better than MESUR(and close or better than Apollo) for VBB instruments
  - Comparable mass but better than Mars96
  - Comparable quality but lighter than Mars96 for micro-seismometer instruments
- Advance in seismic processing methods offers better perspectives than the simple travel time analysis
  - Receiver functions and single station analysis
  - Seismic hum at one station
  - Cross-correlation surface wave tomography without quakes
  - Environmental decorrelation from pressure noise





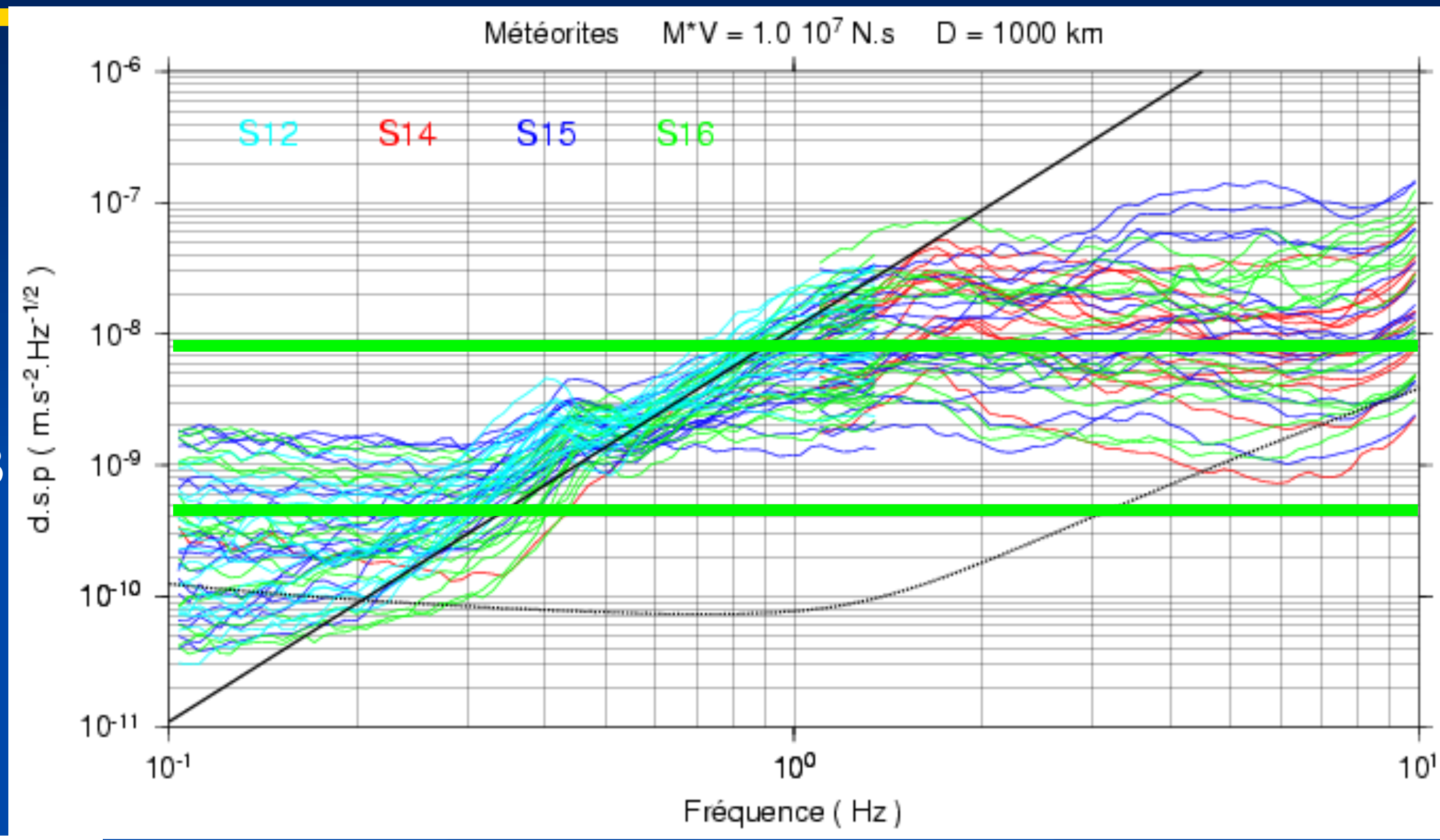
Typical signals : Moon data

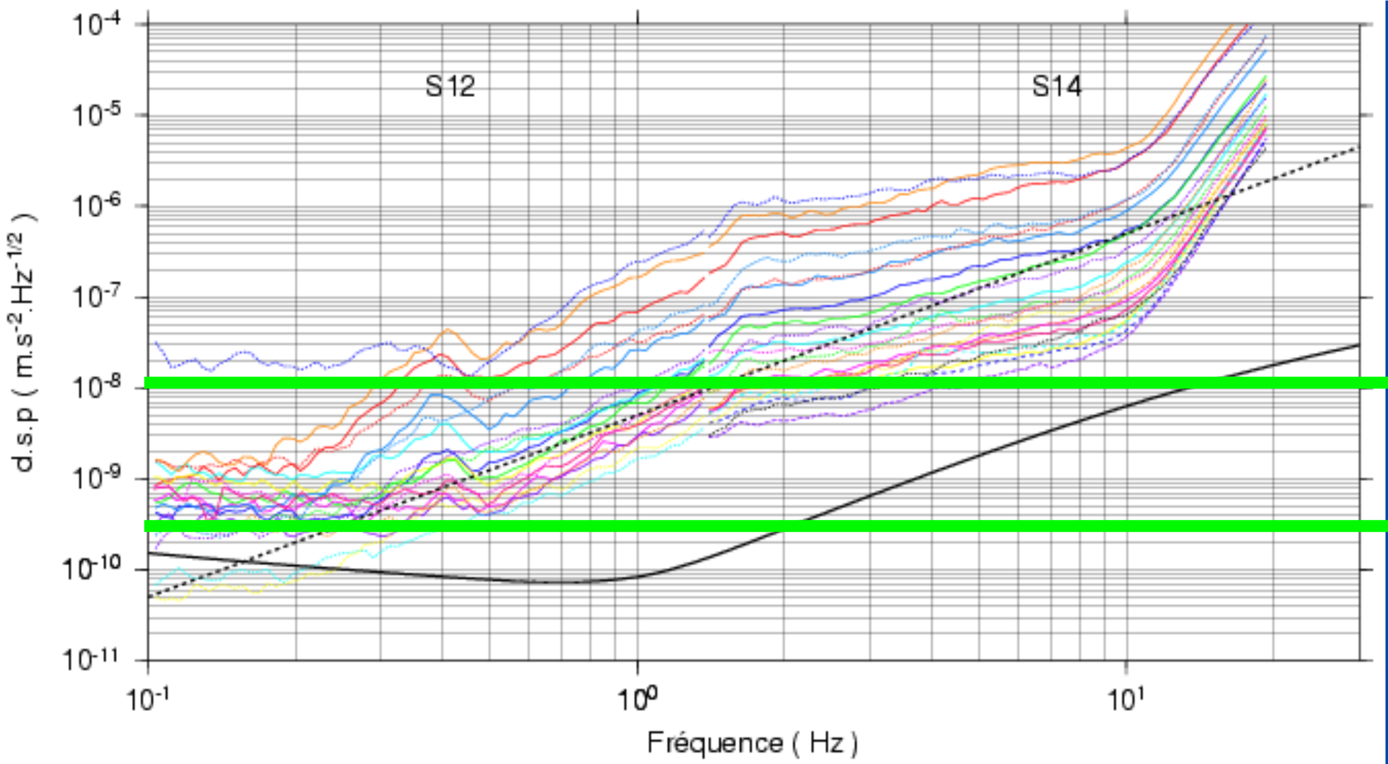
Meteoroids…

- **Acceleration at 1000 km - 650 kg mass sensitivity**
- **mv/D rule without attenuation**

SP

VBB





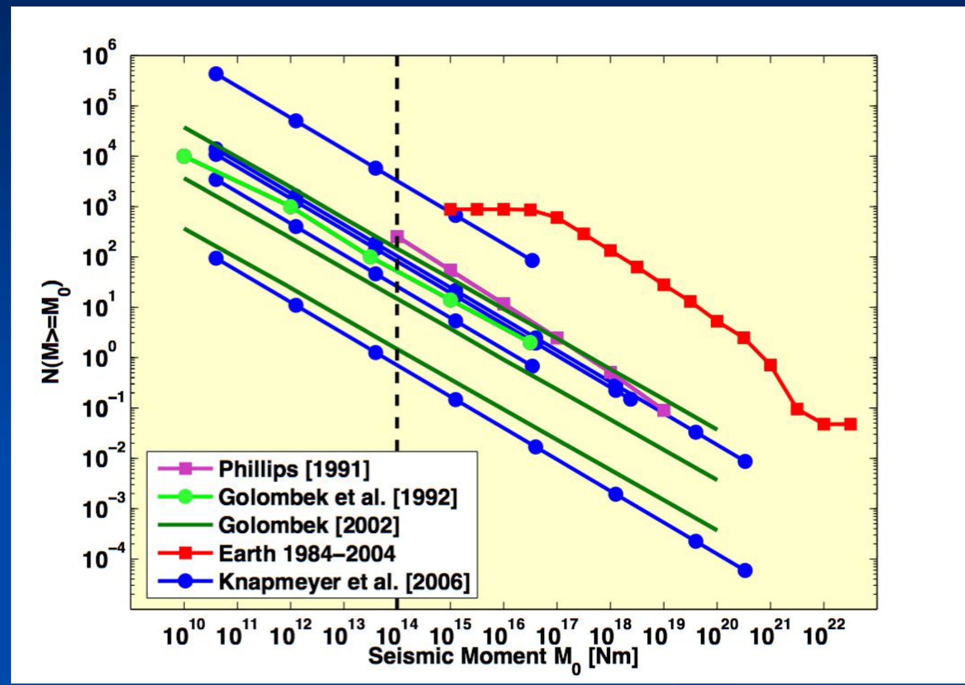
SP

VBB

Quakes….

- **Normalisation at D=1000 km**
- **Ms=3 in dotted line**
- **High frequency related to low attenuation**

Challenge #1: Dealing with the unknown

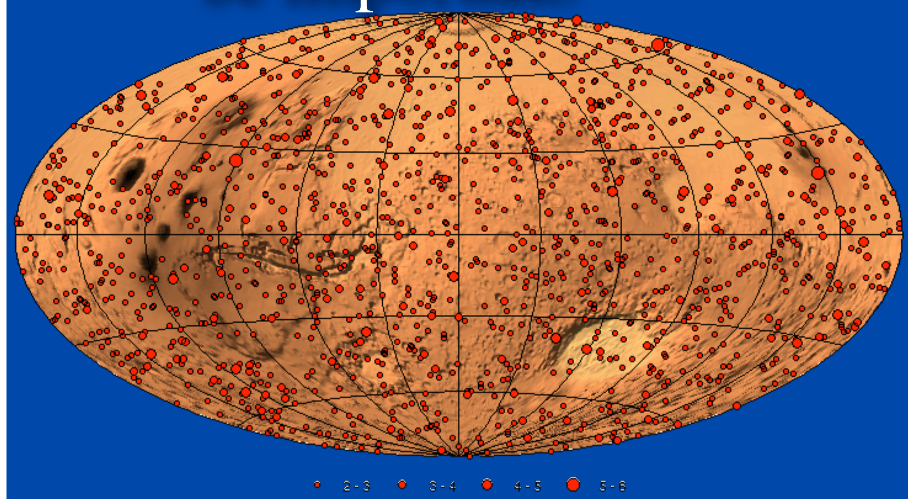


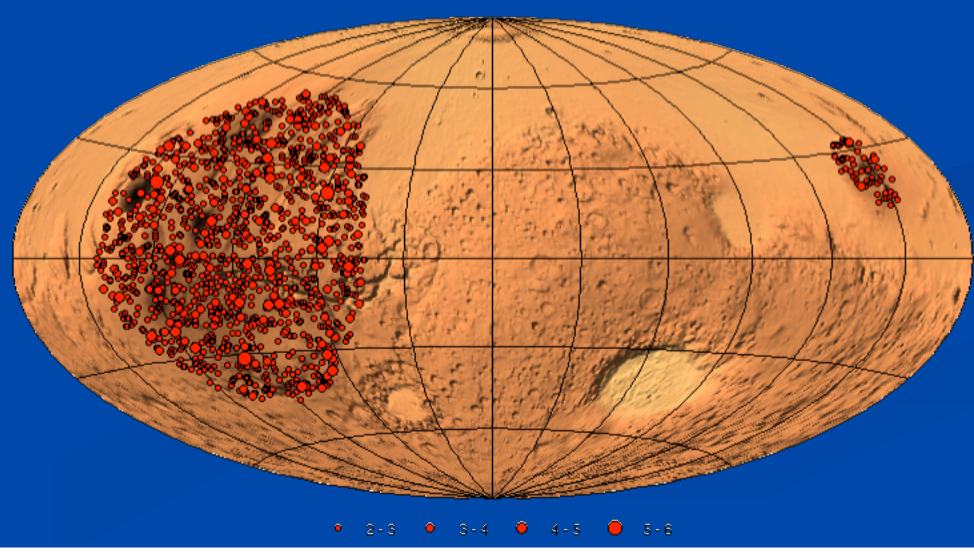
What is the Seismic activity of Mars and the seismic attenuation/scattering?

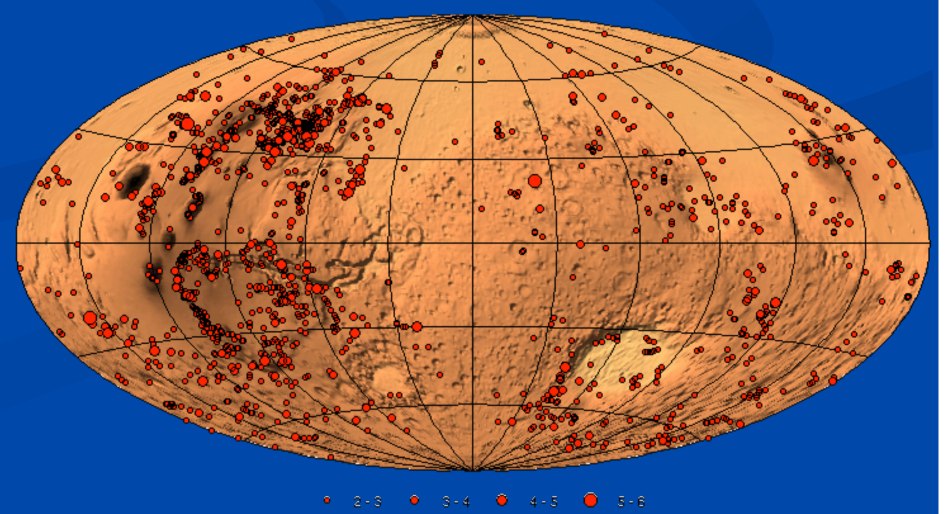
- Typically 2 orders of magnitude between Low and High Activity
- Typically 1 order of magnitude on the amplitude due to attenuation/scattering
- 3 orders of magnitude for the signal amplitude for events with same recurrence time

What is the geographical distribution of Marsquakes?

- Uniform, somehow concentrated at Tharsis/Elysisum, or along known tectonic faults?
- Might half/double the number of detected events for a 4 stations network
- After ESA's cancelation of the Humboldt precursor station, a Pathfinder mission might be important.

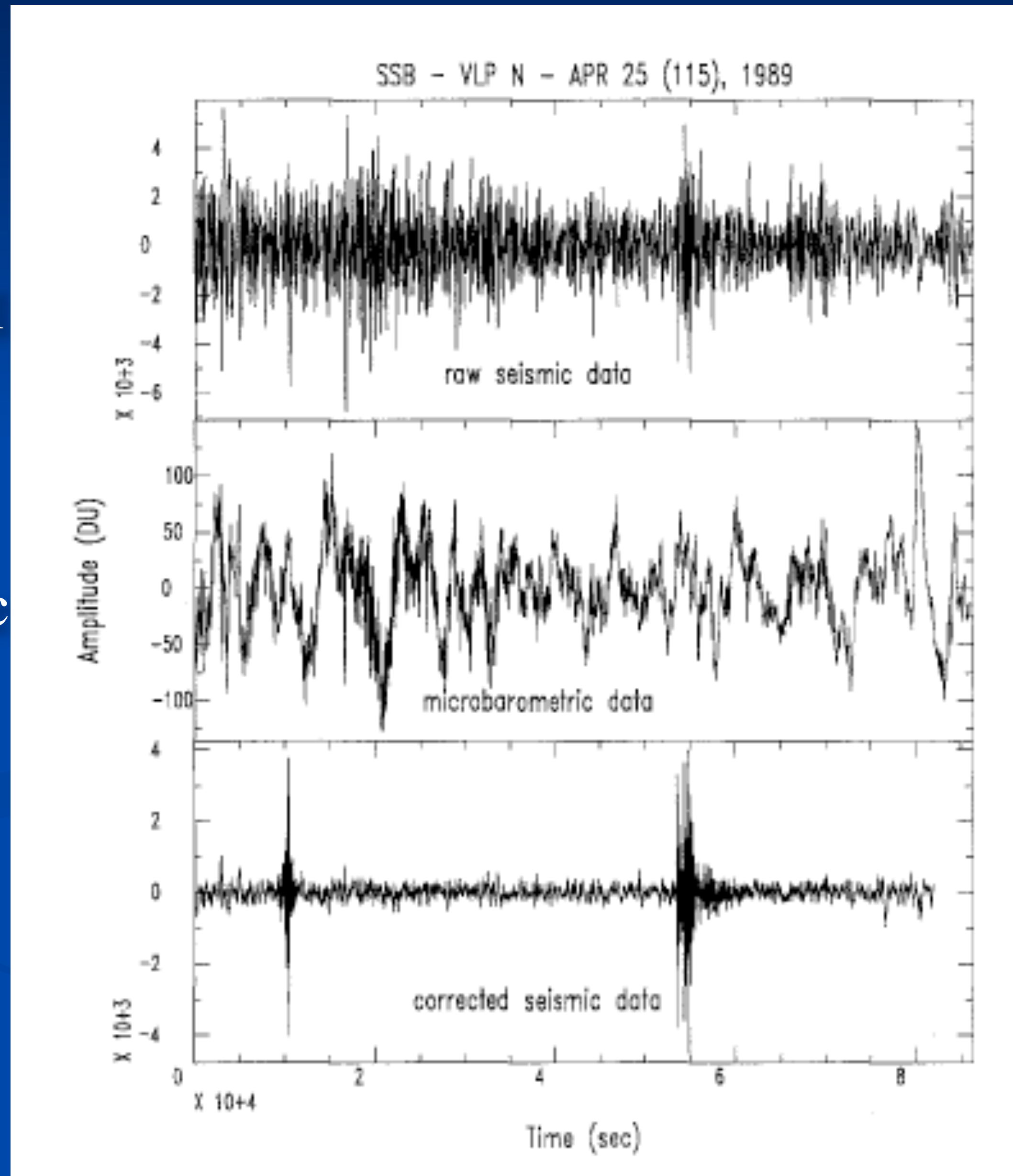


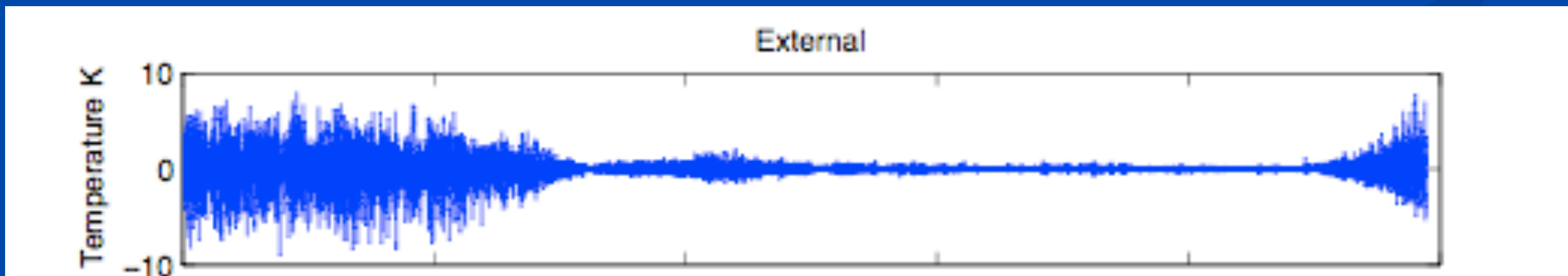




Challenge #2: Dealing with the known harsh environment

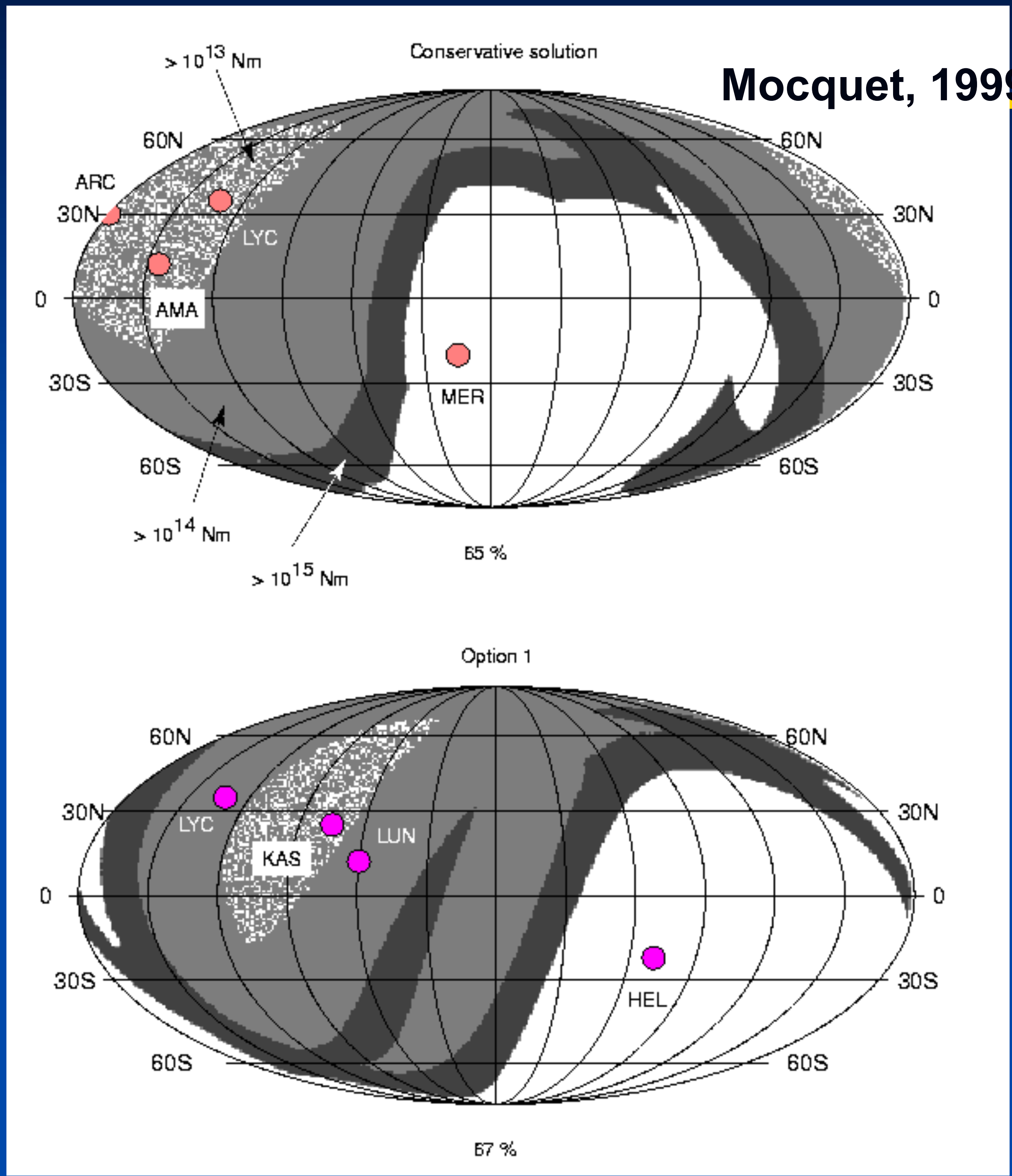
- Mars environment looks hard but…
  - Just put the seismometer on the ground unlike Viking
  - Protect the seismometer against temperature
  - Environmental de-correlation to correct for meteorological induced surface deformations (i.e. infrasounds sensor)
- Such optimized installation will have major impact on the efficiency of a seismic stations
  - Increase by 4-5 the number of events detected by a seismic station
  - Almost double the range for S waves detection at large distance (e.g cover Tharsis without landing on Tharsis…) and secure its detection for high attenuation/diffraction
  - Secure very long period measurements (surface waves/ normal modes)
  - Allow seismology without quakes!

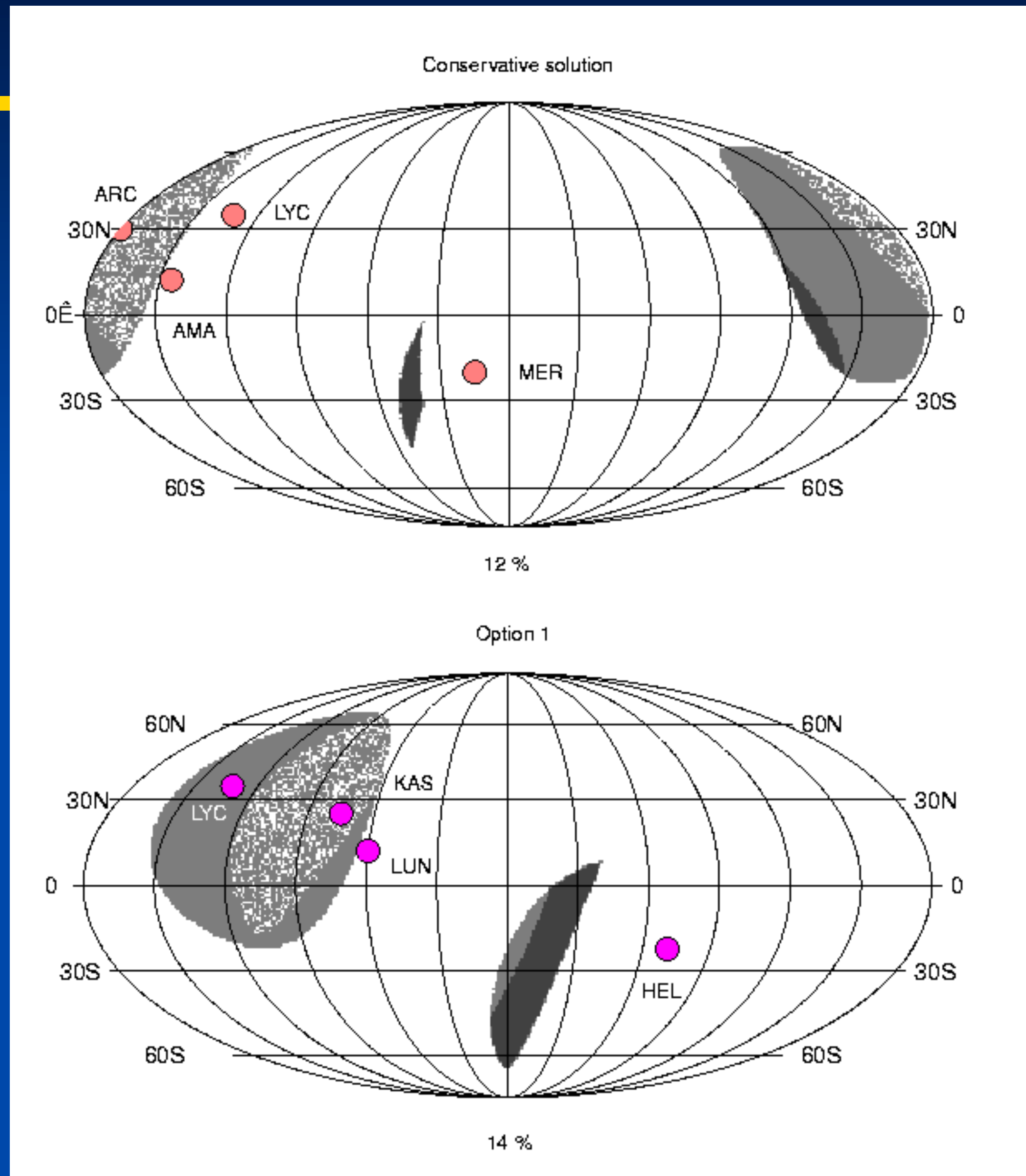




Night

Seismic Network efficiency for P and S waves detections





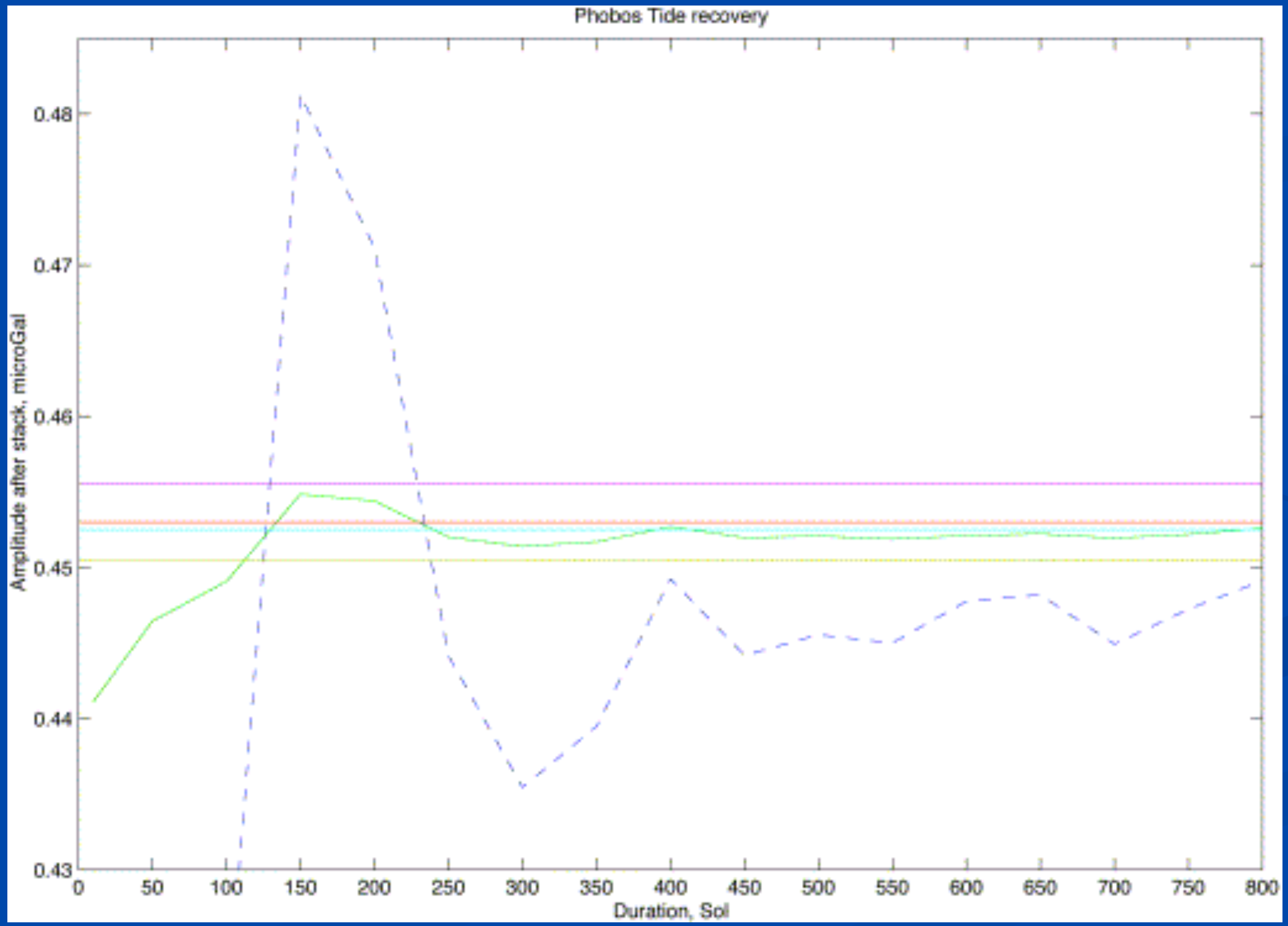
- Seismic activity, from thermoelastic cooling of the lithosphere indicate about 50 quakes with Moment > 10^{14} N.m per year (10 with Moment > 10^{15} N.m)
- For realistic noise level (10^{-9} $ms^{-2}/Hz^{1/2}$ in 0.1-1 Hz), 60 % of the quakes might be detected

Why a Network

- For seismology, the primary goal of a network is to locate the sources and to increase the number of observations for a single source
  - Example of Travel times: 2 per stations x 3 for locating events and getting the two seismic velocities
- Network is therefore NOT necessary if
  - Seismic sources have a known position
  - Seismic data are NOT sensitive to the seismic source location
  - Seismic sources are everywhere
- In these case, the observations are multi-site observations and start with the first lander
- How much science can then be done?

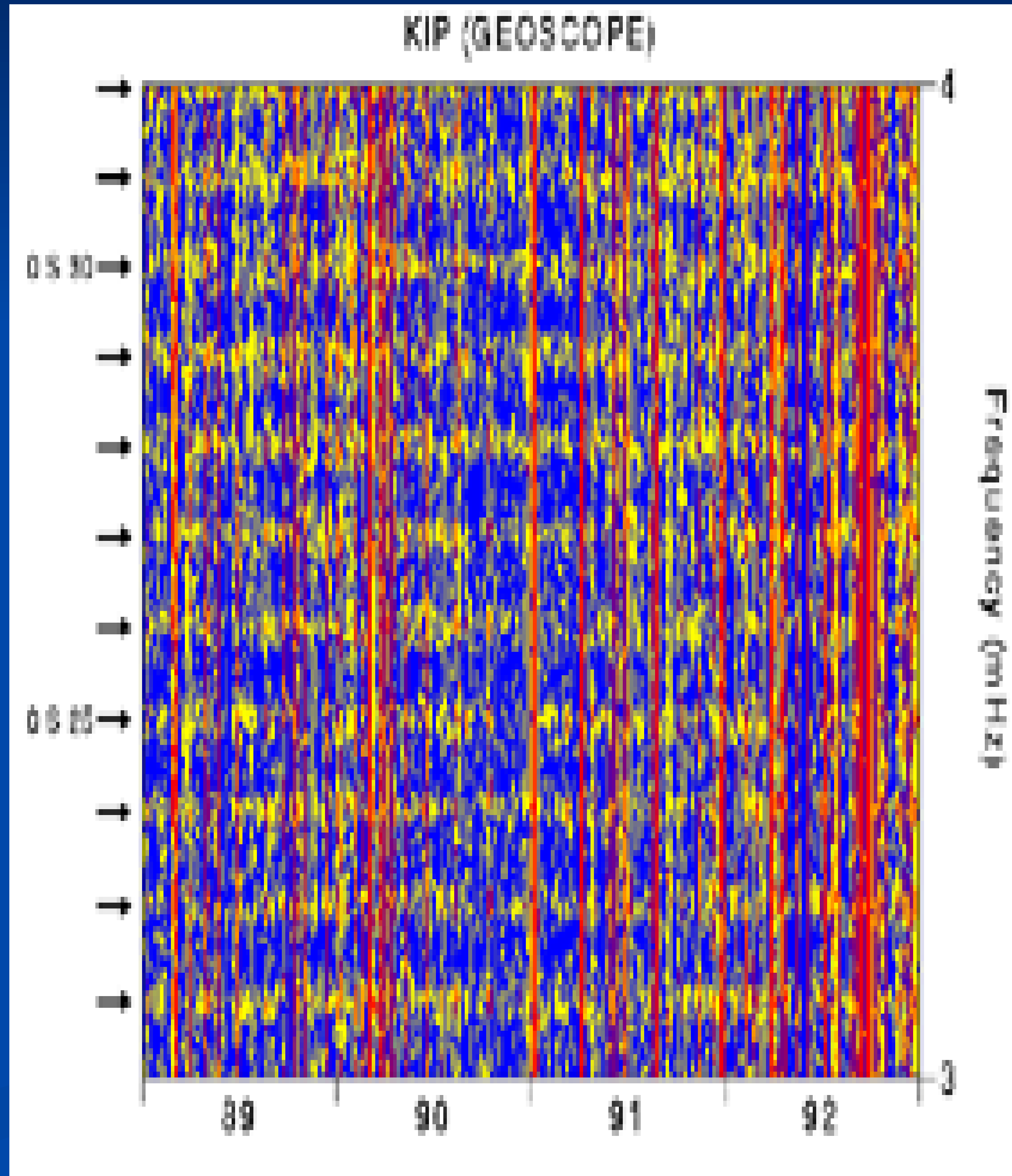
Seismology without quakes: one station

- Idea already proposed for InterMarsnet with the Phobos tide measurement
  - Phobos tidal signal ~0.4 10^{-8} ms^{-2}
  - Geophysical signal (i.e. difference between a solid core/liquid core) is 7.5 ngal and 1 ngal is 60 km in core radius (1ngal = 10^{-11} ms^{-2})



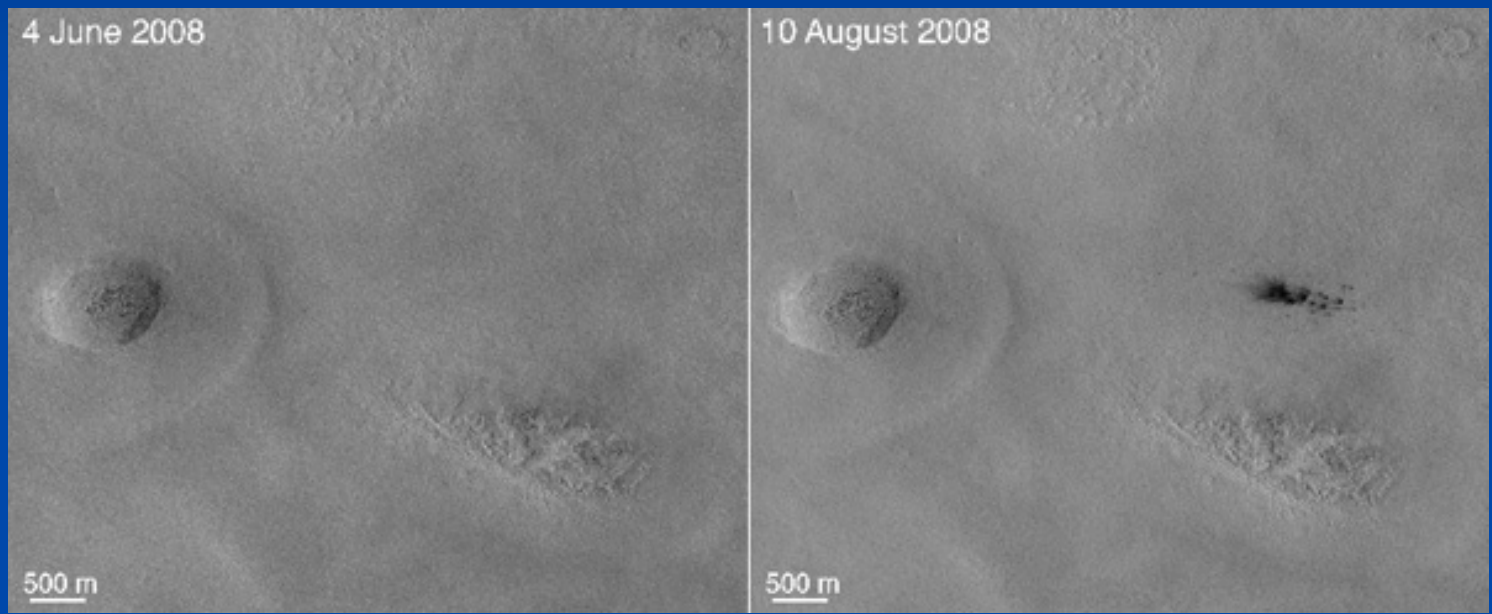
Seismology without quakes: one station

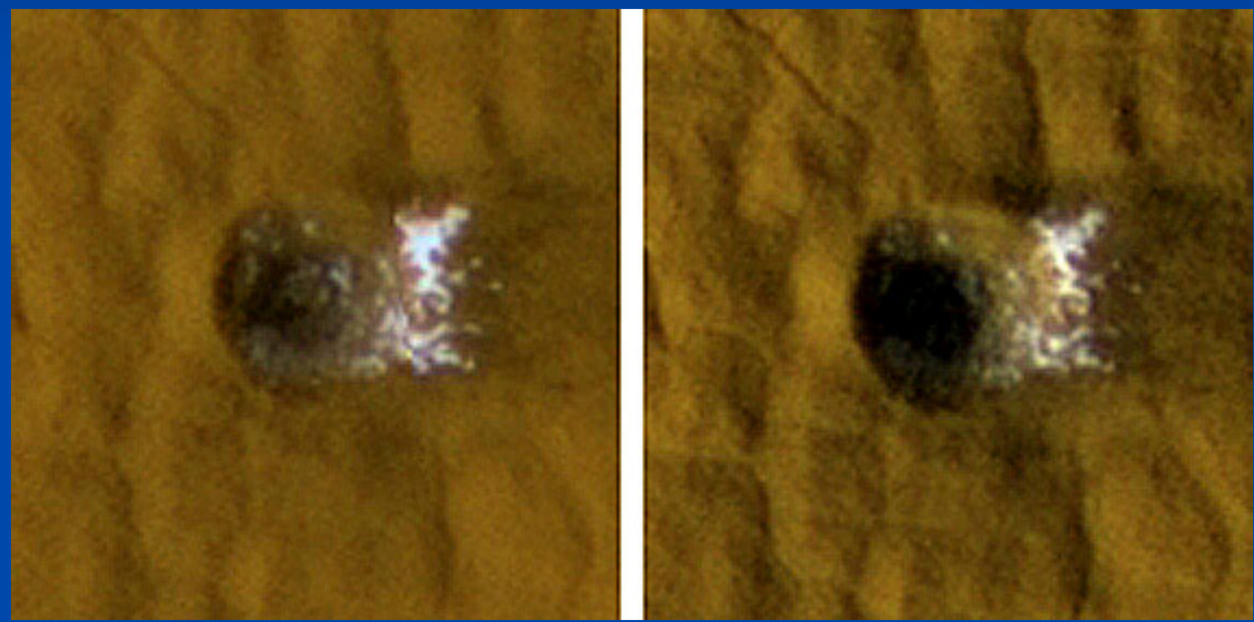
- Seismic Hum
  - New discoveries from Earth seismology
  - Use the fact that a planet with atmosphere is seismically excited by atmospheric turbulences and atmospheric dynamics
  - A single station is able on the Earth to detect the fundamental free oscillations and therefore to constrains the earth upper mantle WITHOUT quakes nor Network



Seismology with impacts: one/two stations

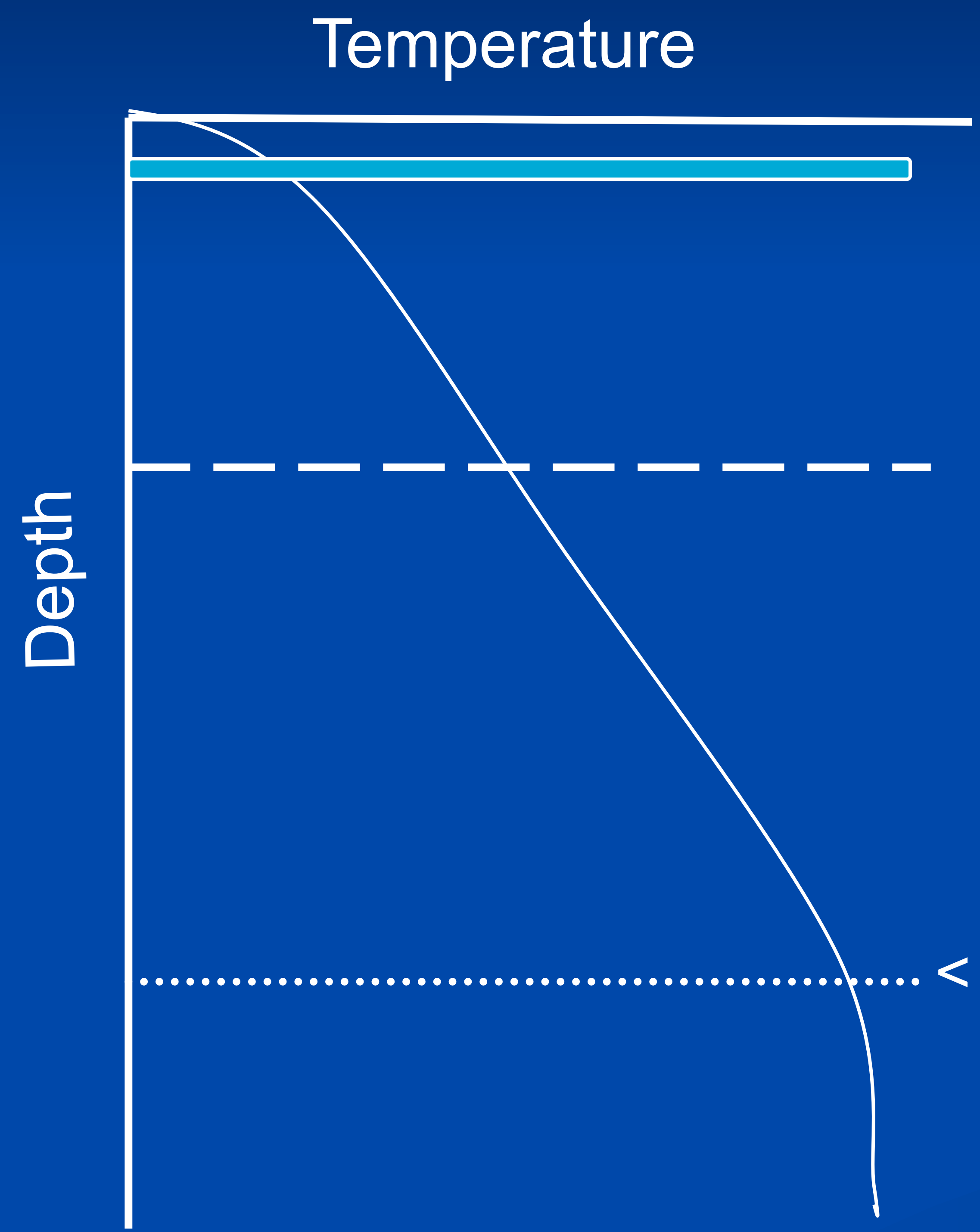
- MRO has detected almost 100 fresh craters since its MOI





- For each station, such impacts if detected by seismometers enable the direct use of the T_s-T_p arrival time as the location is known, and provide the differential T_{p1}-T_{p2} for each pair of stations
- Detailed models of the crustal thickness can then be achieved

Synergies Among Instruments: one station



Temperature and Water in the Crust

< Liquid water: EM sounding, & seismic attenuation; T constrained to ±10°C if water is detected

< Crustal thickness defined by seismology

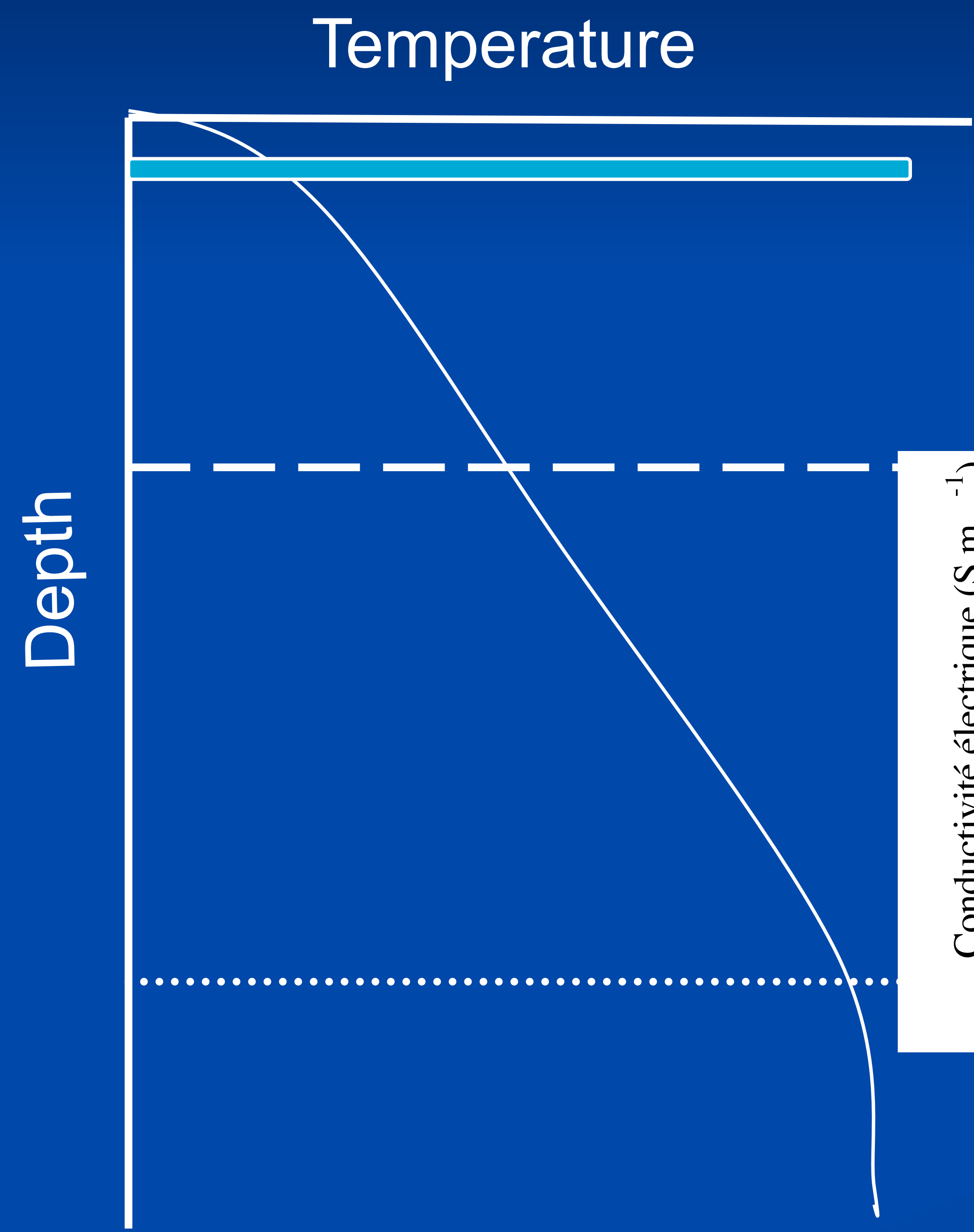
Heat flow determines thermal gradient and helps constrain distribution of radiogenic elements between crust and mantle

< Thermal lithosphere detected by gravity/topography, seismology and EM sounding

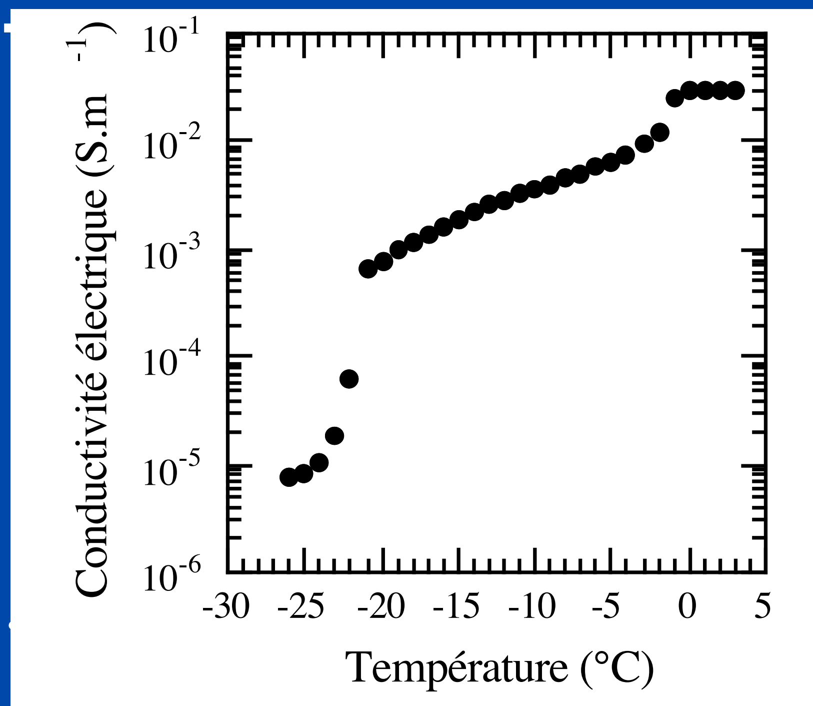
< Upper mantle T constrained by petrology and seismic velocity

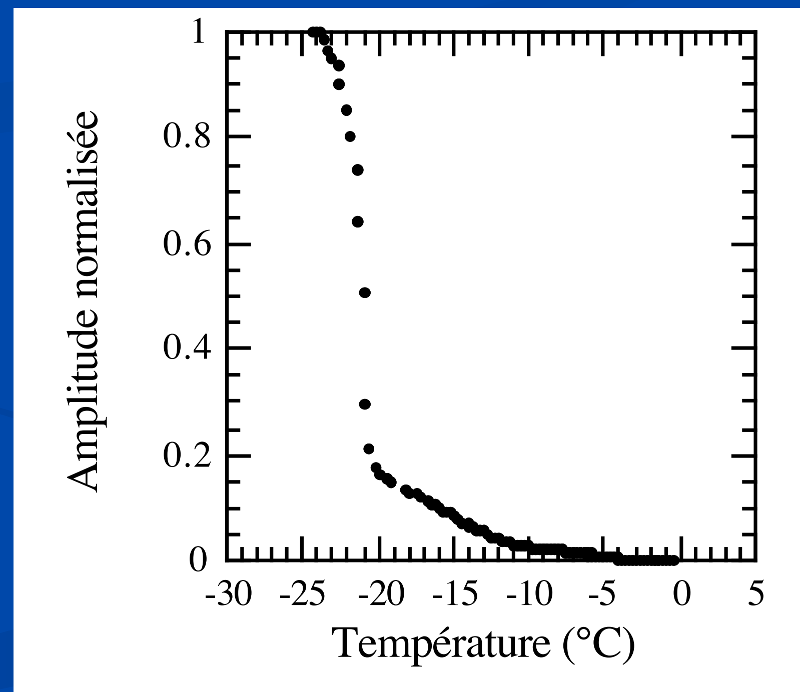
Synergies Among Instruments: one station

Temperature and Water in the Crust

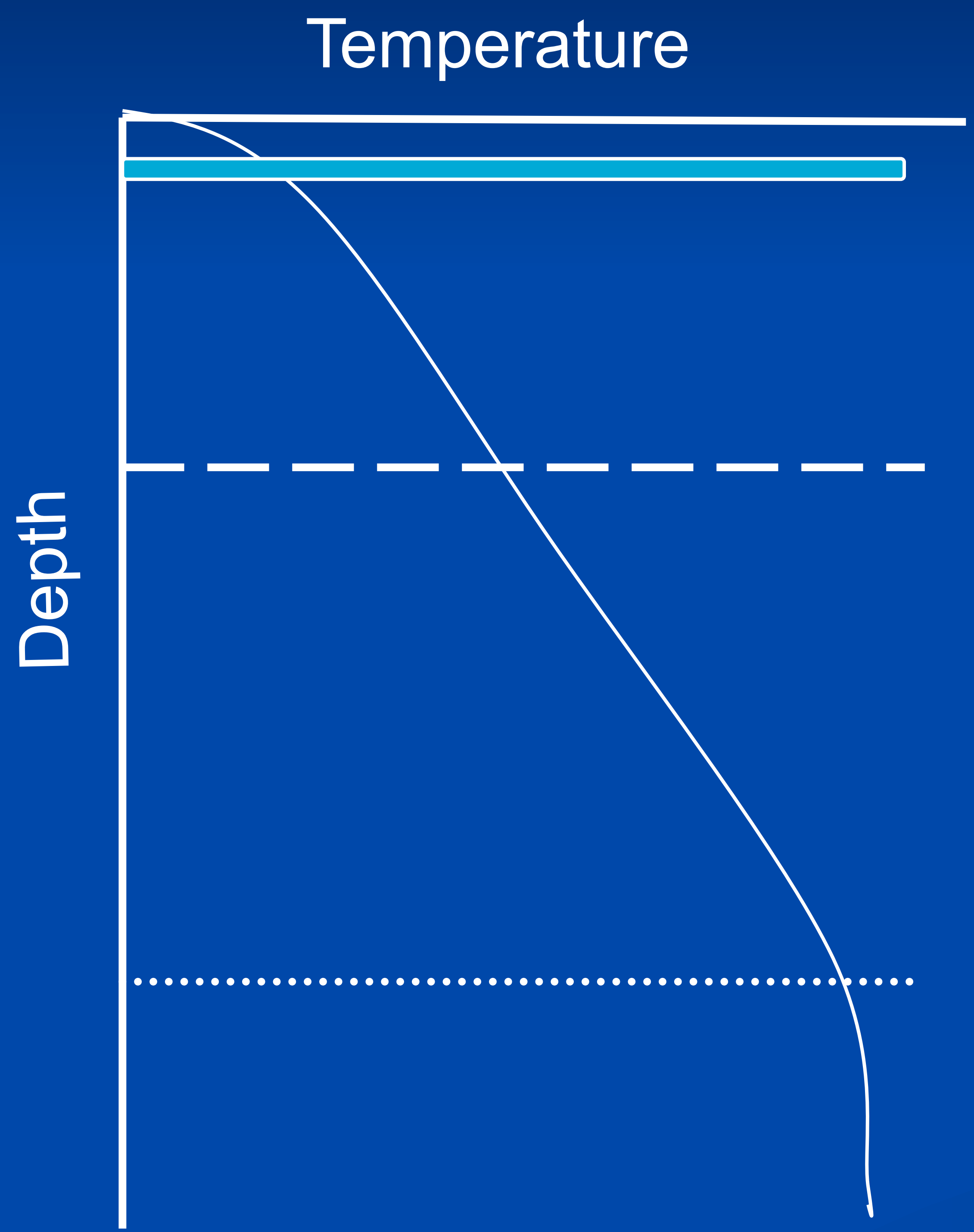


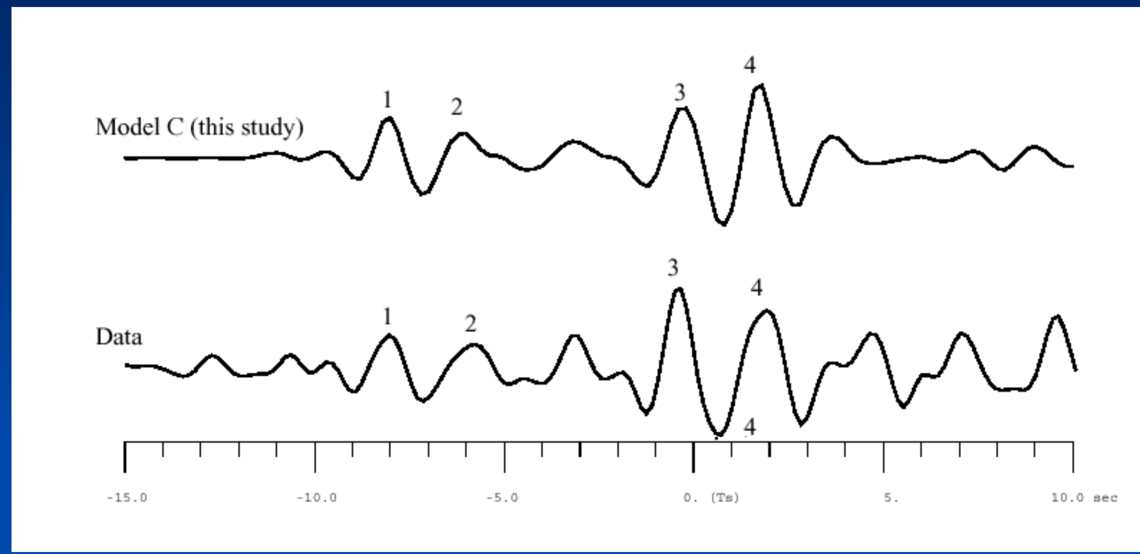
- Liquid water: EM sounding, & seismic attenuation; T constrained to ±10°C if water is detected



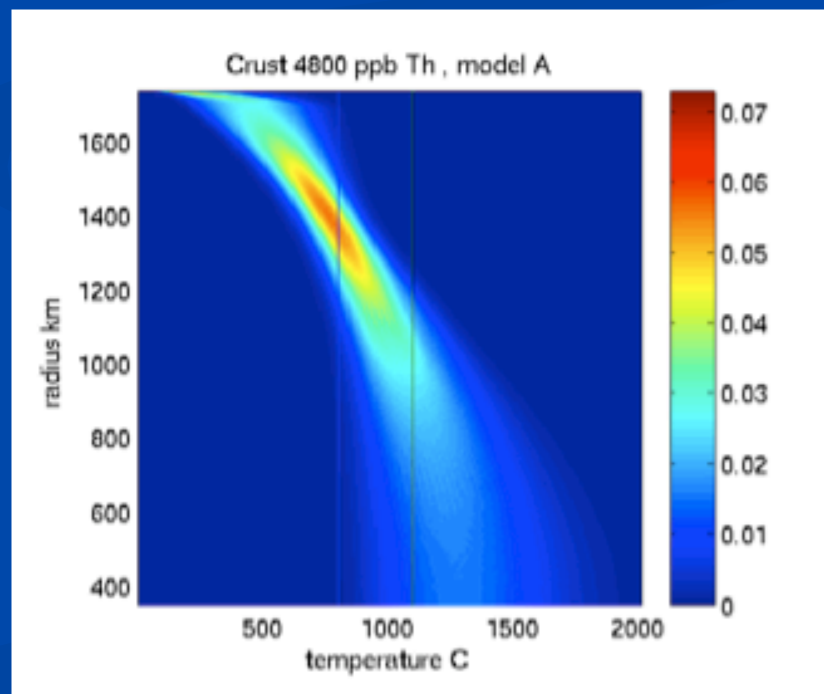


Synergies Among Instruments: one station





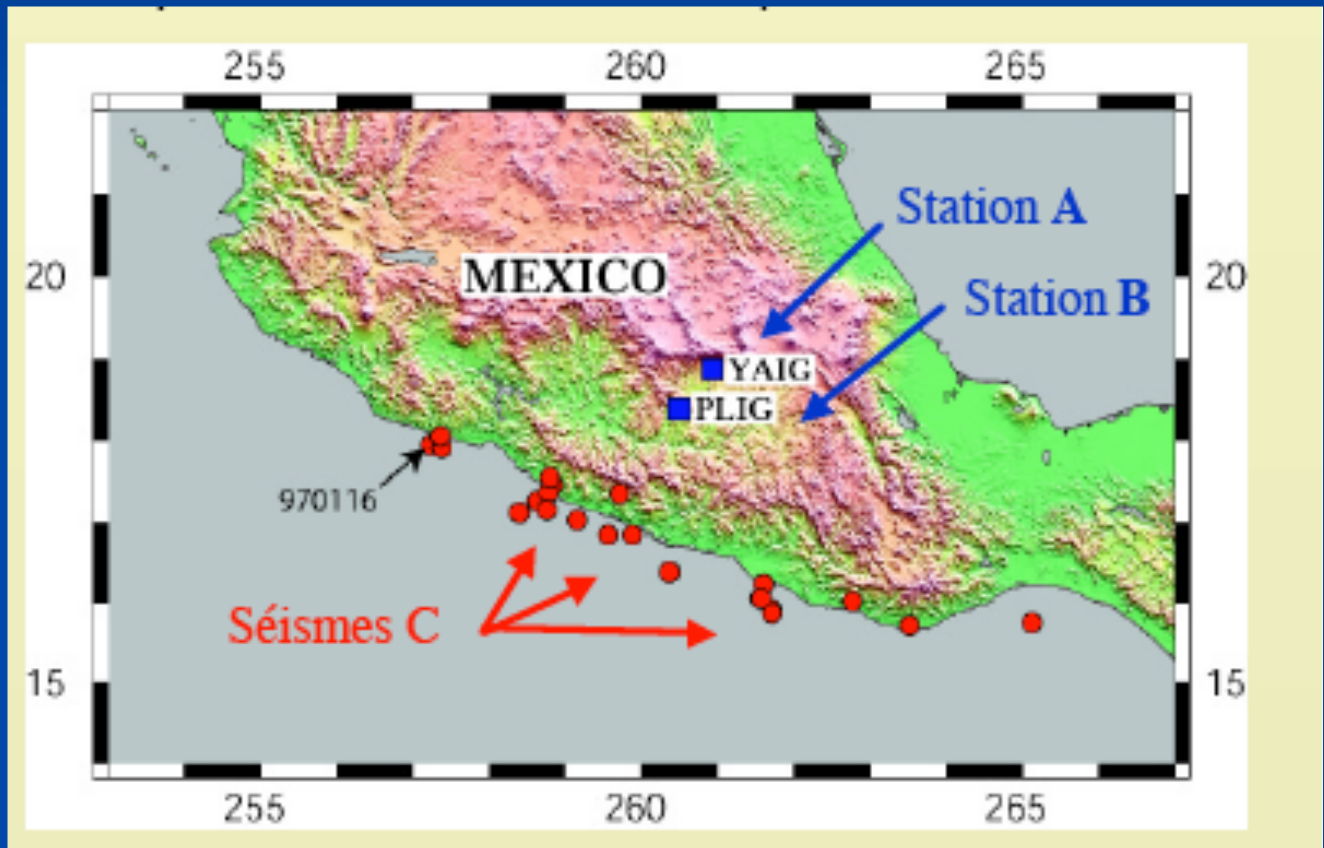
< Crustal thickness defined by seismology

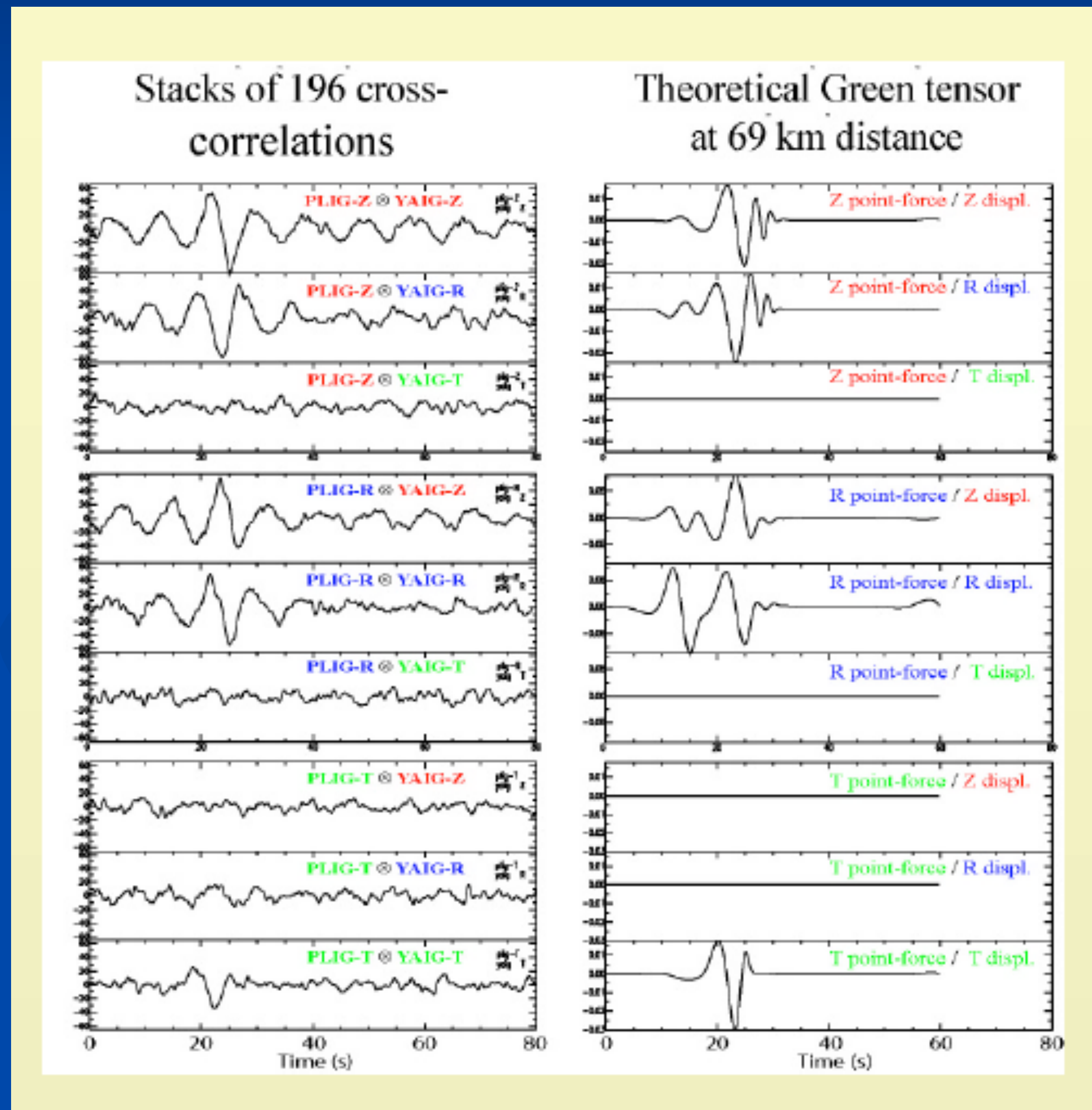


< Upper mantle T constrained by petrology and seismic velocity

Seismology without quakes : two stations

- On Earth, the measurement of seismic noise on two stations allows to retrieve the properties of surface waves propagating from one station to the other

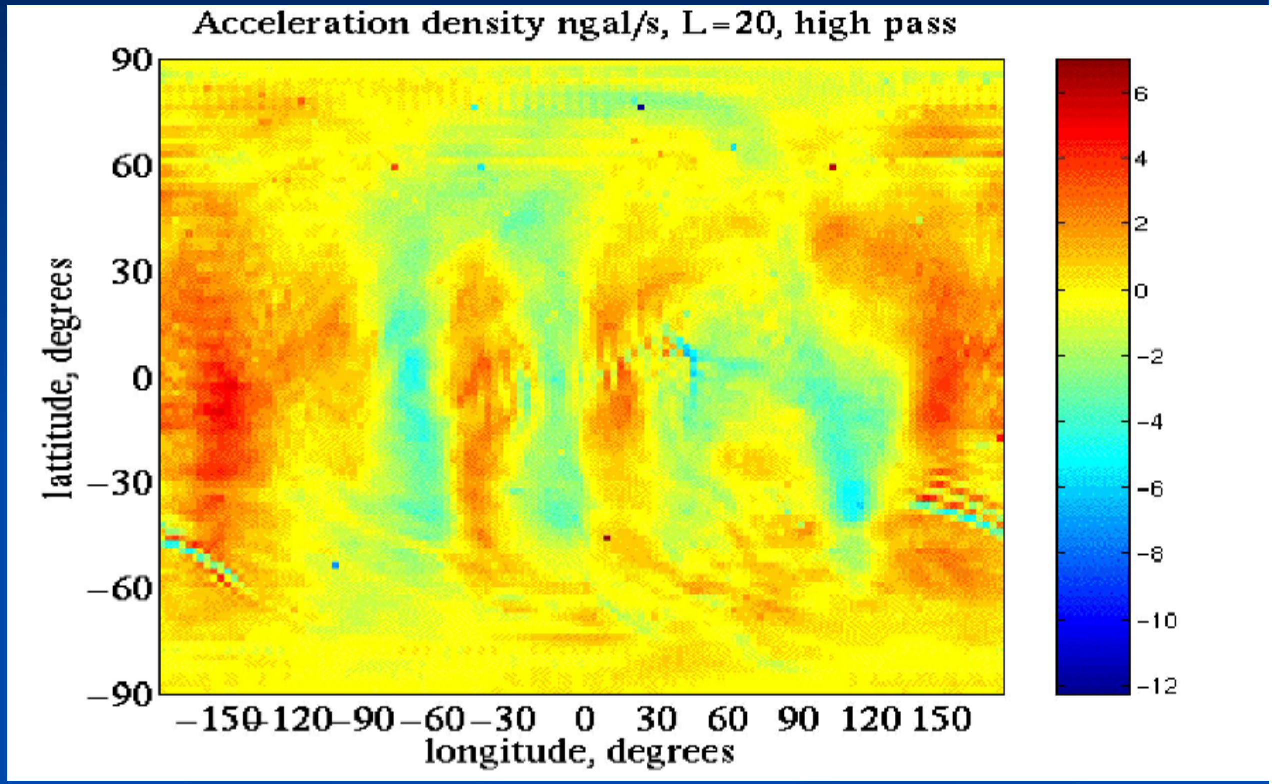


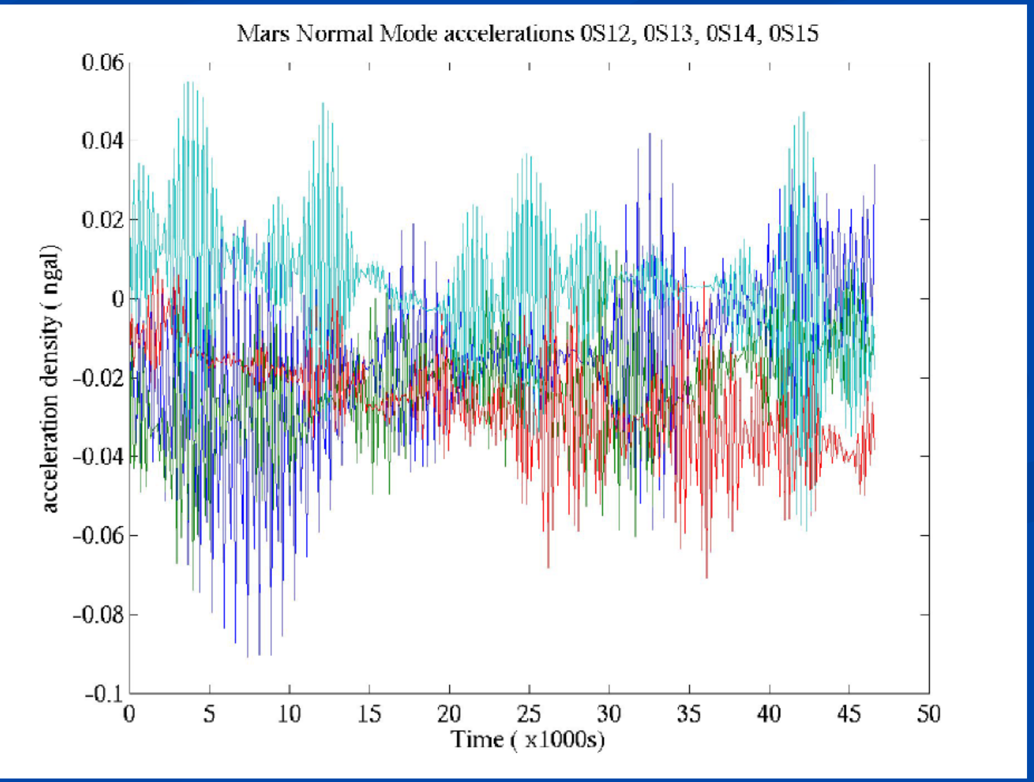


- This is used now on local, regional and global scales on the Earth
- This has been used on the Moon with the Apollo 17 geophones on a local scale

Seismology without quakes: 2 stations

- Seismic modeling
  - Model the excitation of ground vibrations associated to the global meteorology activity
  - Very small signals but simulations suggest a S/N ratio of 20 after 1 Martian year of stack with realistic noise
- Will provide without quakes seismic velocity in the lithosphere (z < 300 km) between the 2 stations





Summary for one/two stations

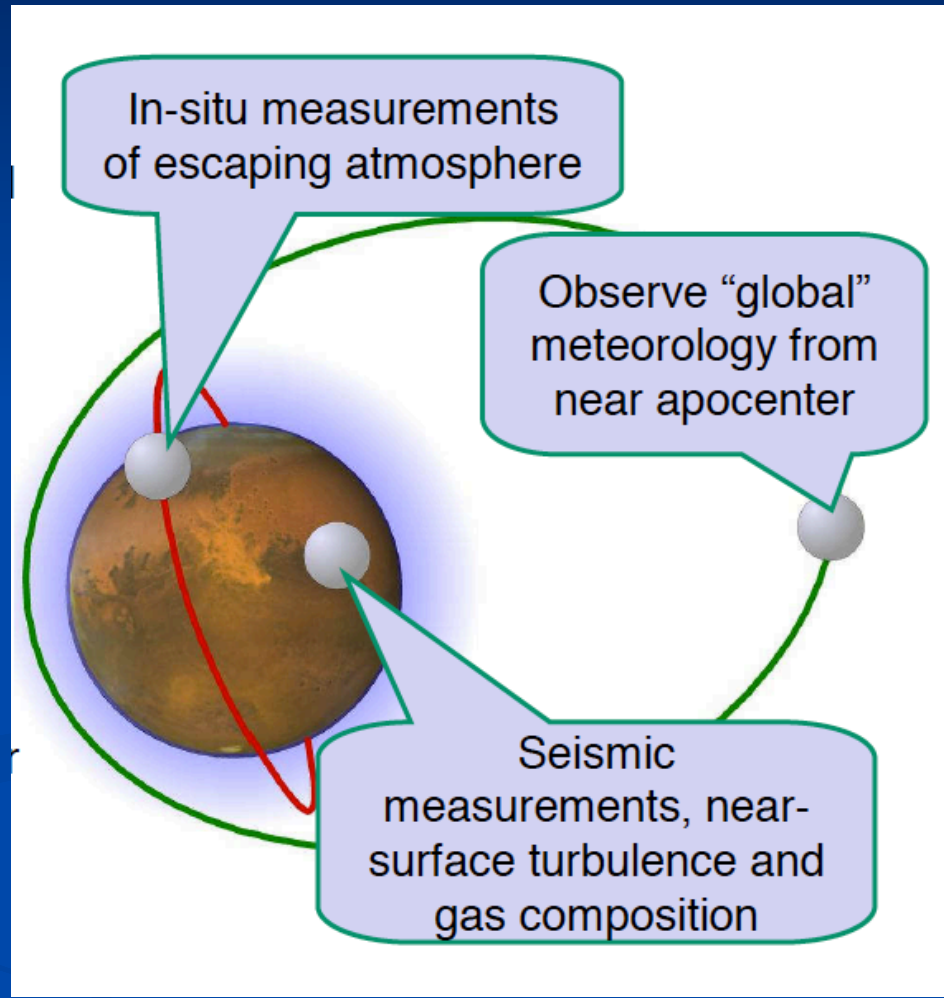
- With one station
  - Core with tide
  - Global upper mantle with seismic hum and orbiter located impacts
  - Crustal thickness with receiver function
  - Azimuth and approximate epicentral distance of quakes
- With two stations: same as above plus
  - Regional upper mantle with cross-correlation
  - Detailed regional crustal structure with located impacts
  - Approximate location of quakes

NASA-ESA Near Future opportunities

- ESA's 2016 technology lander
  - As big as Pathfinder but with only 4 kg of payload and one week of operation..
  - Very Low Power (total power ~60 mW) autonomous seismic survival module is however possible if the lander is able to sleep without dying… or to carry a seis survival module with its own TM/TC capability
- NASA-ESA's dual rovers 2018 project
  - 2 rovers network, 1050 kg landed mass
  - Can 5% of the landed mass be allocated to a pathfinder network station?
- ESA MarsNext project (2020-2022)
  - 3-4 landers depending on the payload focus and budget
- NASA competitive programs
  - Discovery program for a one lander Pathfinder mission
  - New Frontier program for a 2-3 landers mission

JAXA-RKA opportunities

- MELOS JAXA project
  - Expected launch in 2018
  - Joint Orbiter-lander science
- Possible RKA project
  - Mars96 remains as the BEST Network mission concept in the two last decade



The 2020-2022 launch windows might be an unique opportunity for and International Mars Network (IMN)

conclusion

- A Network mission with a 3+1 configuration is the ultimate goal of geophysics and is required for understanding the interior structure of the planet as well as the coupling between the interior and atmosphere
- New techniques in seismic data processing, as well as the improvement of instruments are providing very significant science return for missions with one or two seismic stations.
- A Pathfinder mission will GREATLY improve the science return of a Network mission…
- Instruments are ready and waiting…
- Let be 2020-2022 the launch windows of the International Mars Network….