SEISMOMETER TO INVESTIGATE ICE AND OCEAN STRUCTURE (SIIOS)

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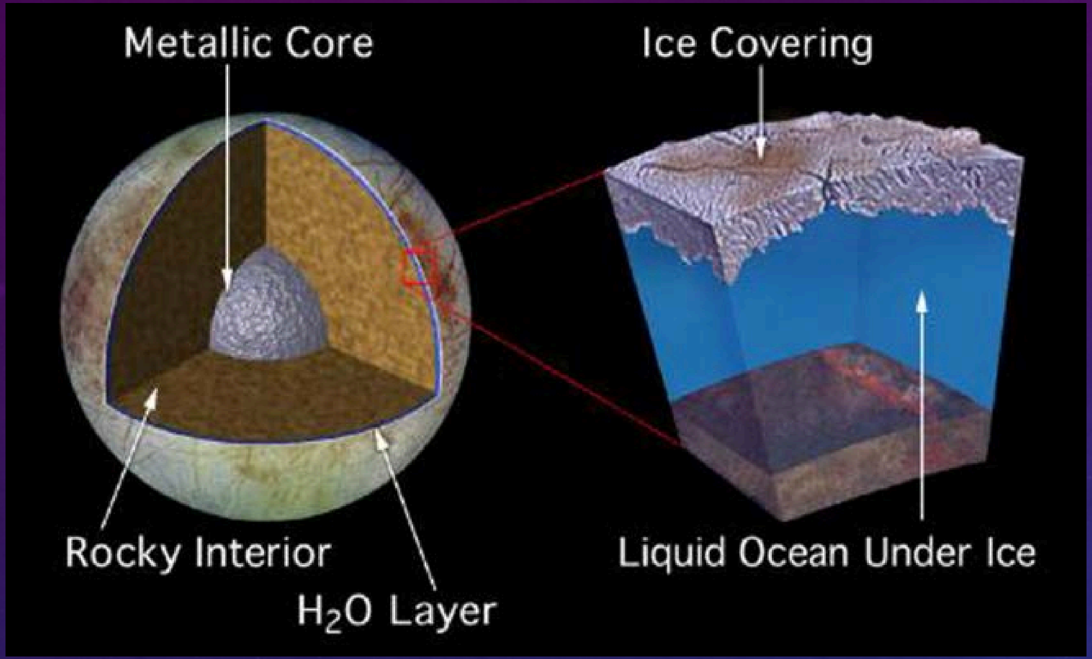
WHAT IS SIIOS?

- The Seismometer to Investigate Ice and Ocean Structure (SIIOS) is a NASA-funded instrument maturation effort to develop a seismometer for inclusion on a landed mission to Europa
- The Europa Lander Mission includes a seismic instrument in the baseline in both the 2012 and 2016 JPL Lander Studies
- Objectives for this instrument usually include:
    - Measuring the depth of the ice and water layers (and hence the internal structure of Europa)
    - Determining the proximity to any intermediate water layers
    - Determining the local properties of the ice shell proximal to the landing site
- ~30 day surface mission

QUAKES ON EUROPA?



- Naturally-generated low-frequency seismic waves resulting from fracture propagation, fault movements, and tidal effects propagate over great distances in ice.
- This enables detection of the ice-water boundary and the sounding of liquid water pockets within the ice layer, at distances on the scale of Europa.

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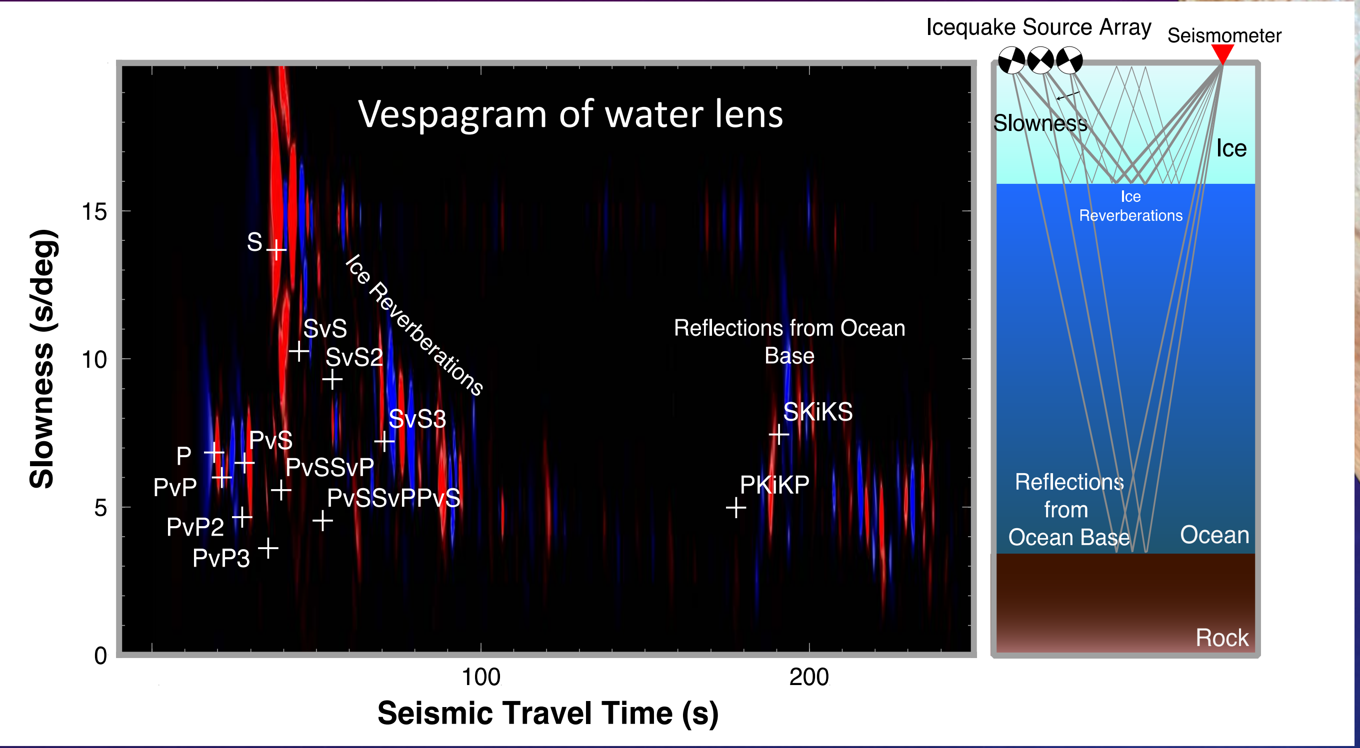

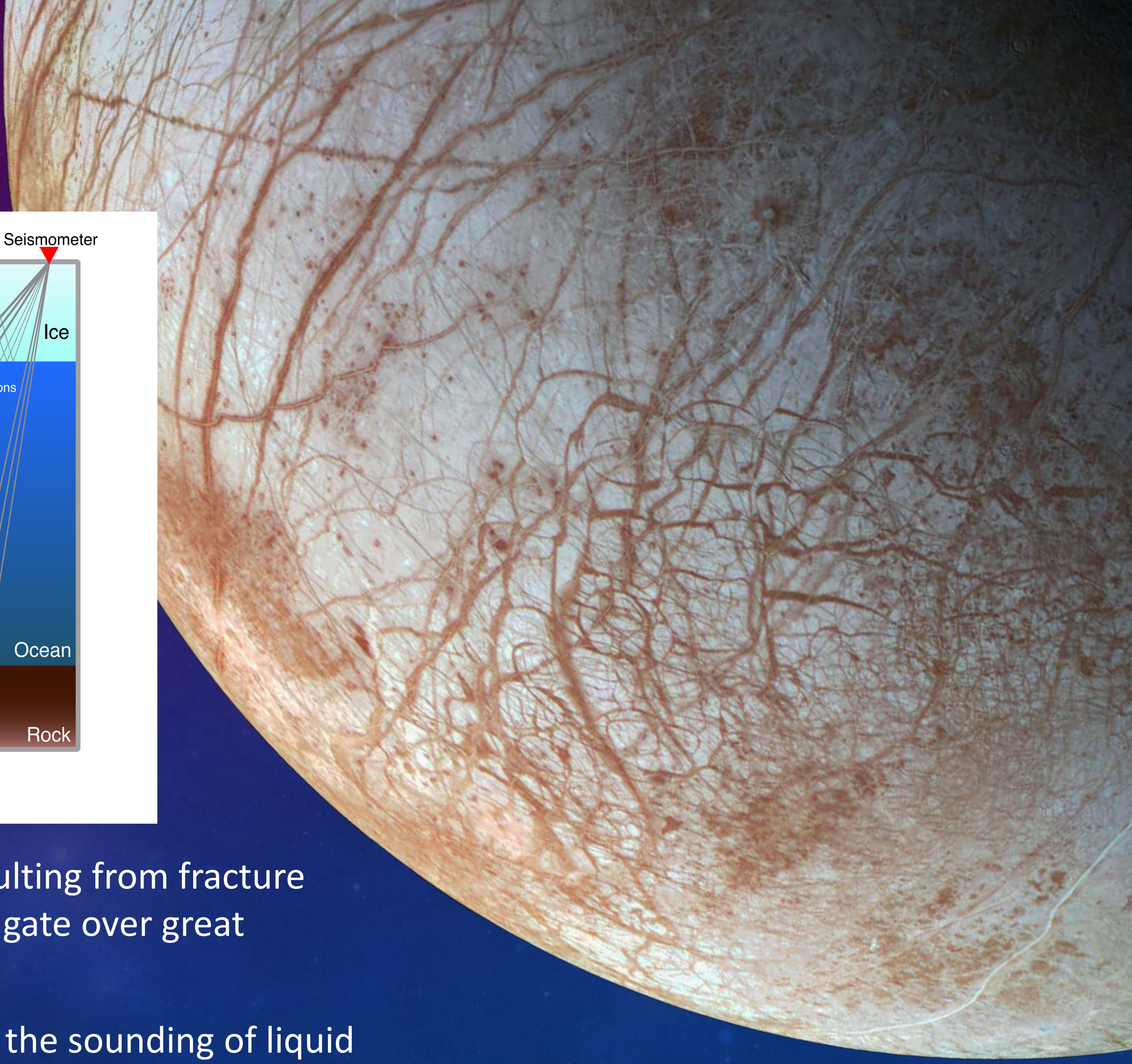

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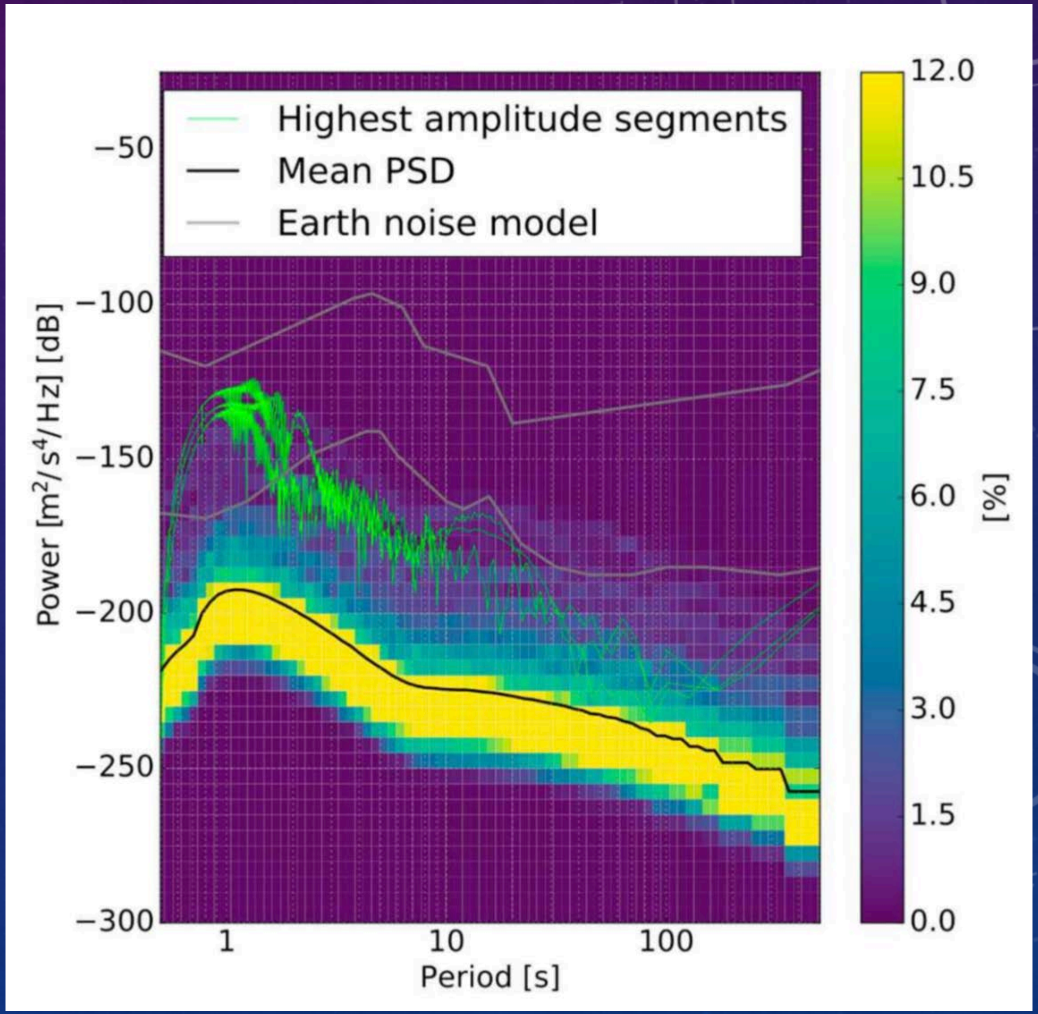
EXPECTATIONS FOR SEISMICITY ON EUROPA

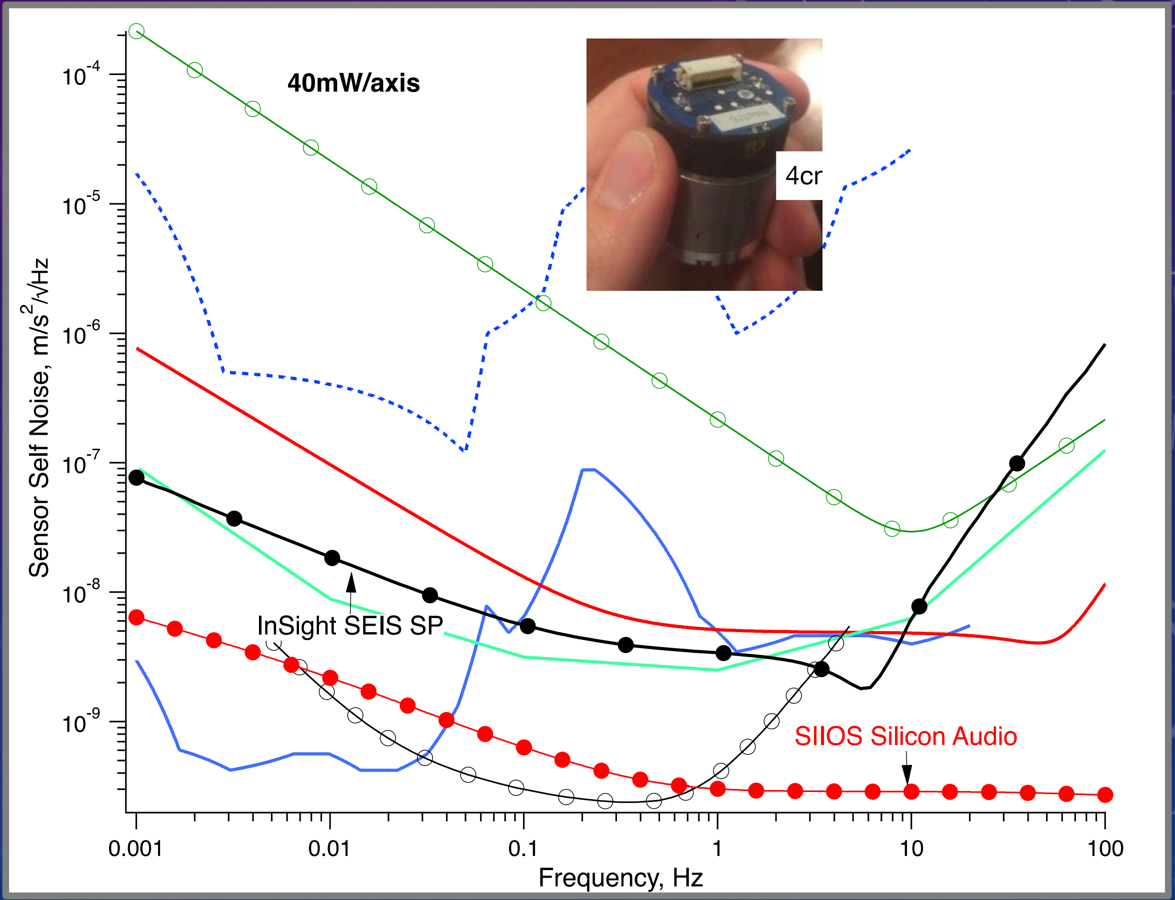
- Estimates from tensile cracks, normal and strike slip faults suggest potential Mw 5.2 events
- Deep "moonquakes" related to tidal stresses (Mw~3) were revealed in the Apollo seismic data
- Tidal stresses on Europa are estimated to be 8-20x larger than on the Moon
- Detectable impacts are estimated at 0-20 per year are not likely to be observed be a seismic instrument deployed for less than one year
- Quakes generated in the rocky part?
- Seismic noise models of Europa are an area of on-going research (e.g. we really don't know!)



Panning et al., 2018 Europa Noise Model

THE SILICON AUDIO OPTICAL SEISMOMETER

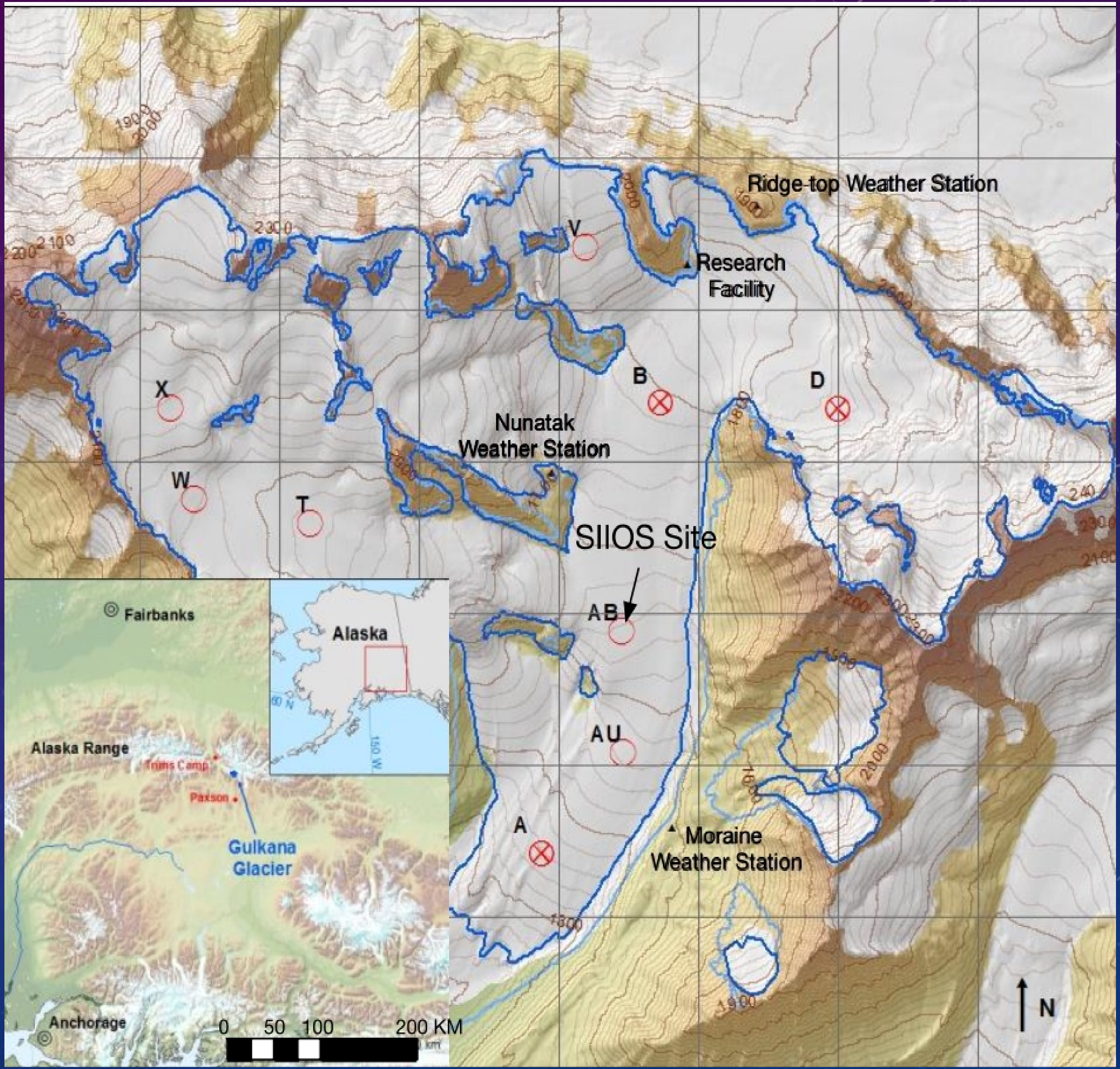
- The Silicon Audio instrument integrates the mechanics of a conventional geophone with a miniaturized laser interferometer system
- Captures signals across a wide bandwidth of frequencies (0.005–600 Hz)
- Large dynamic range —183 dB compared to Apollo’s 60 dB.
- Ultralow distortion (≤ 0.03%)
- 40-degree tilt-insensitive in Europa’s low-gravity field and calibrated to work in any orientation (omni-tilt).
- Low self-noise
- Low mass



ANALOG FIELD EXPERIMENTS

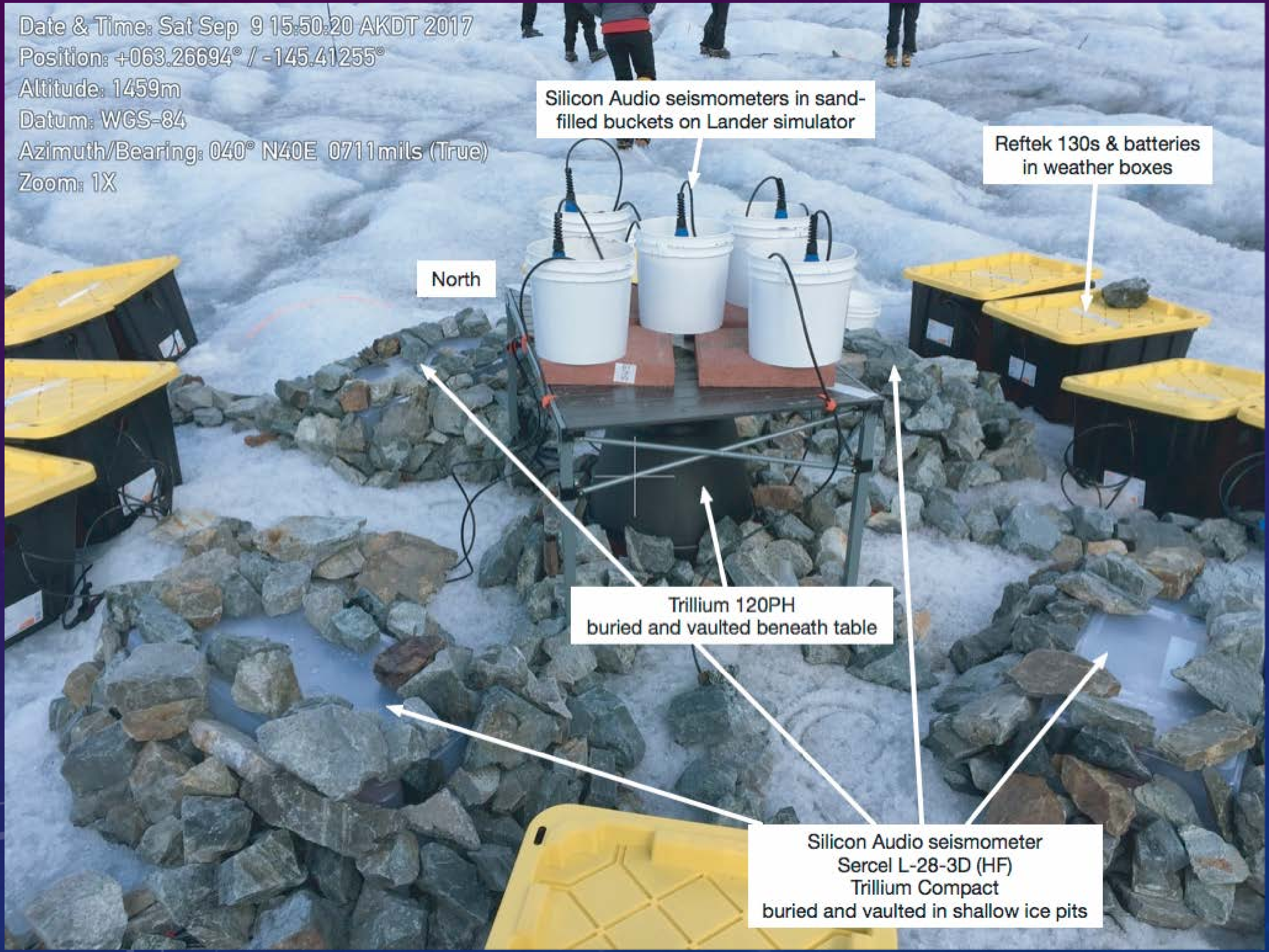
- Our team has conducted field analog measurements of terrestrial seismic events in ice, with the following goals:
  - Assess performance of an ‘in-vault’ seismometer
  - Demonstrate the ability of a small aperture (< 4 m) seismic array in a “lander-like” configuration
  - Develop protocols and requirements for spacecraft onboard-generation of data products
  - Assess the effectiveness of passive seismicity for constraining crustal thickness on Europa
  - Deploy flight candidate Silicon Audio broadband seismometers
- We deployed our candidate seismometer on a purpose-built lander simulator on a glacier in Gulkana, Alaska and on a subglacial lake in northwest Greenland.
- In each experiment, we compared on-lander (as an analog to the Europa lander’s vault) to in-ice measurements.
- Both deployments demonstrated the ability of our instrument to detect seismic phases unique to ice-water interfaces in an analog environment, and also constrain the thickness of an ice column.

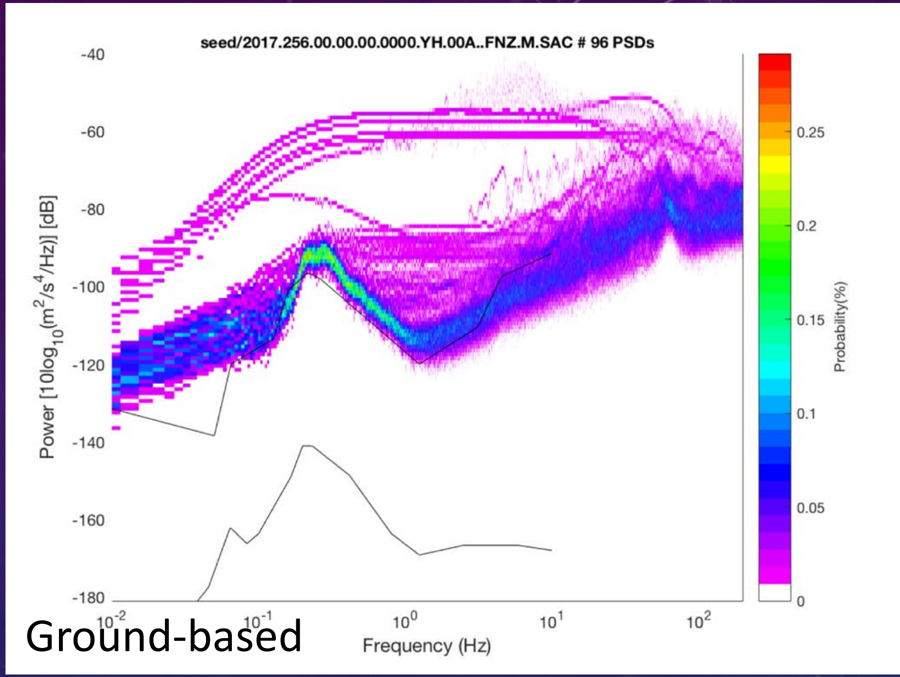
GULKANA GLACIER, ALASKA

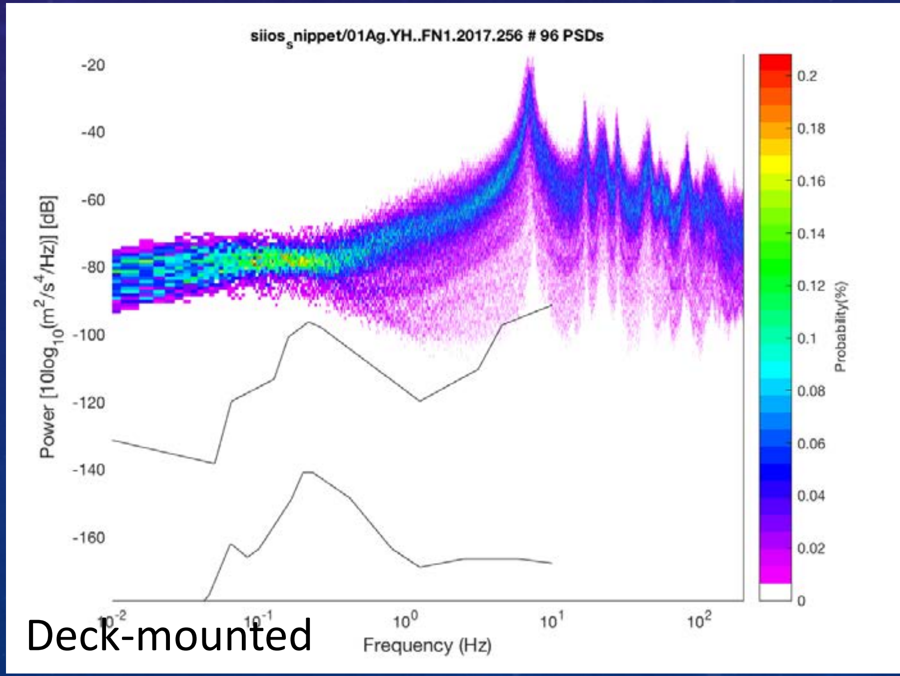


GULKANA GLACIER, ALASKA

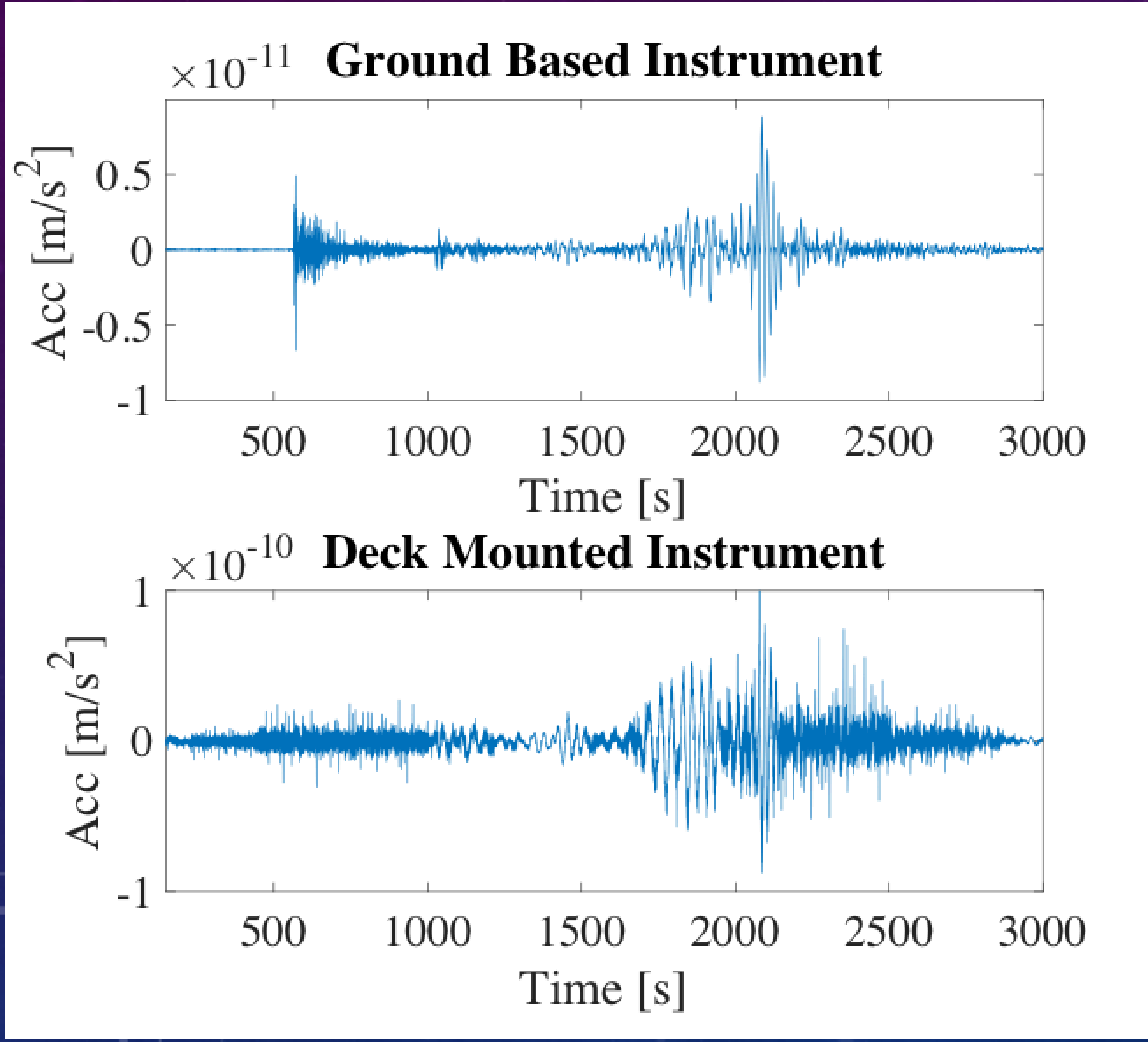
GULKANA, ALASKA EXPERIMENT





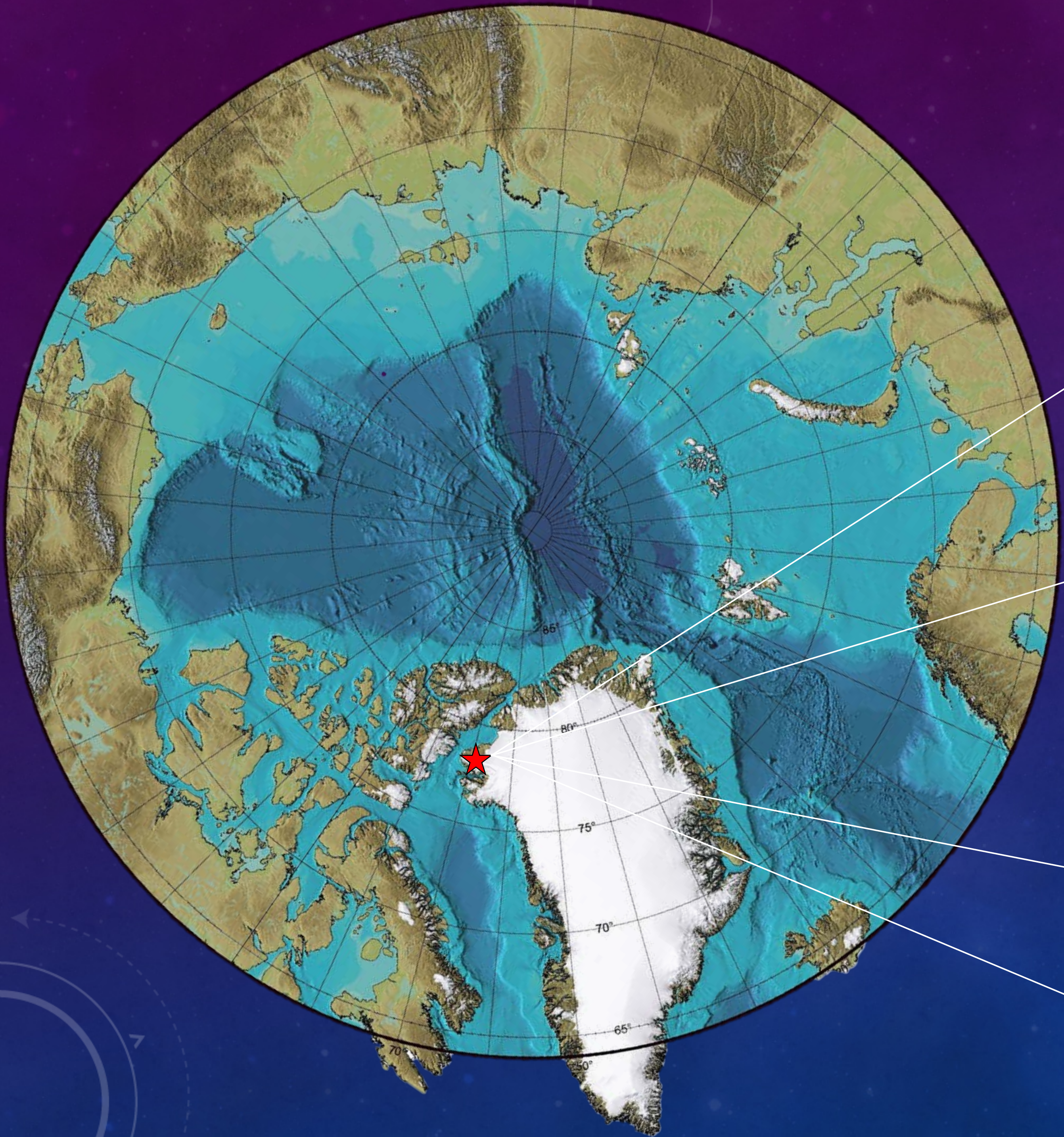


PASSIVE SEISMICITY COMPARISON: GULKANA

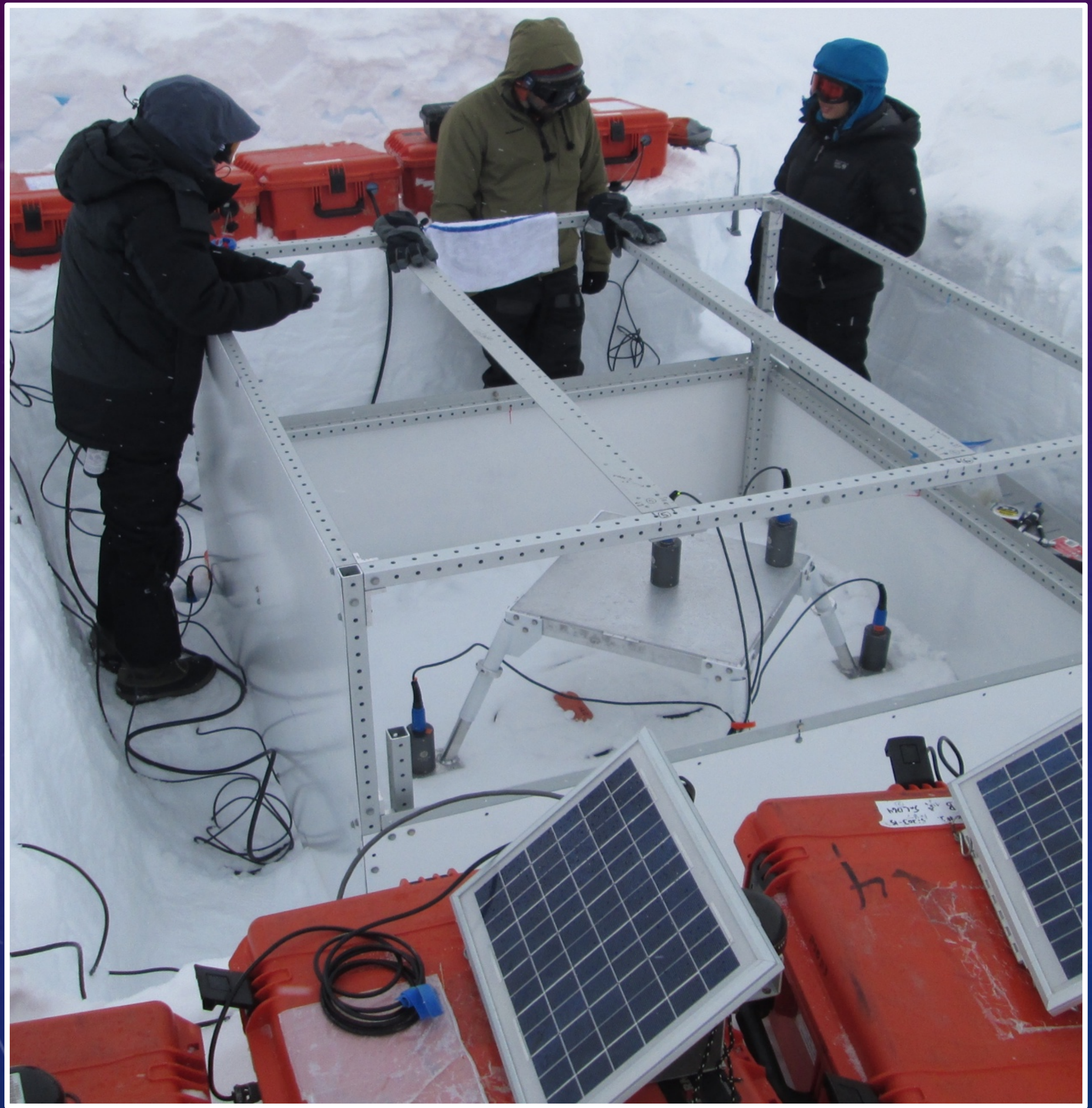


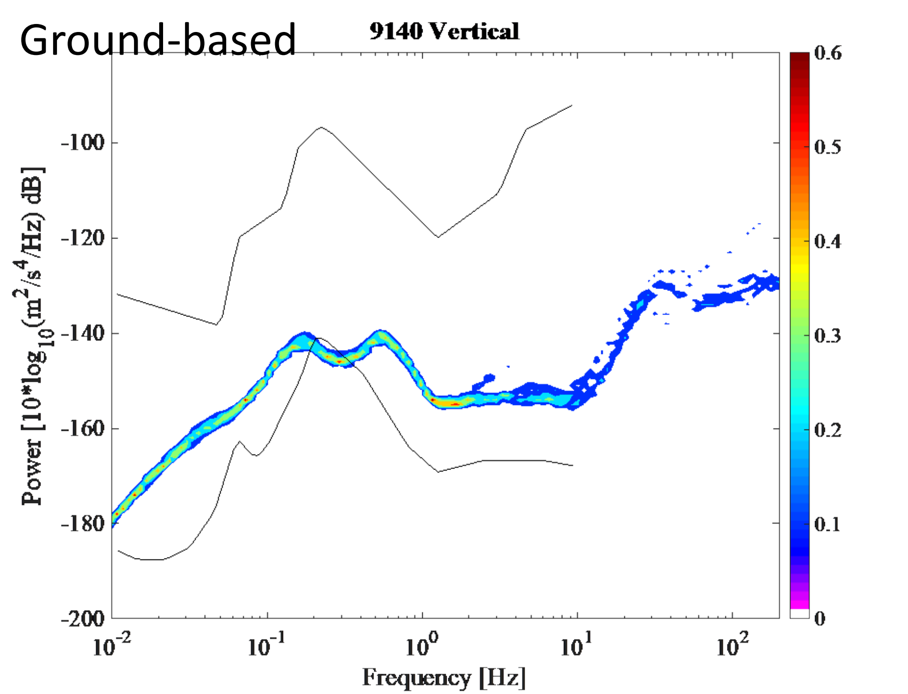
- Sept 19th 2017 M_W 7.1
- Bandpass filter 1-50s, instrument response removed, vertical component
- Deck-mounted instrument exhibits more background noise and obscured arrivals

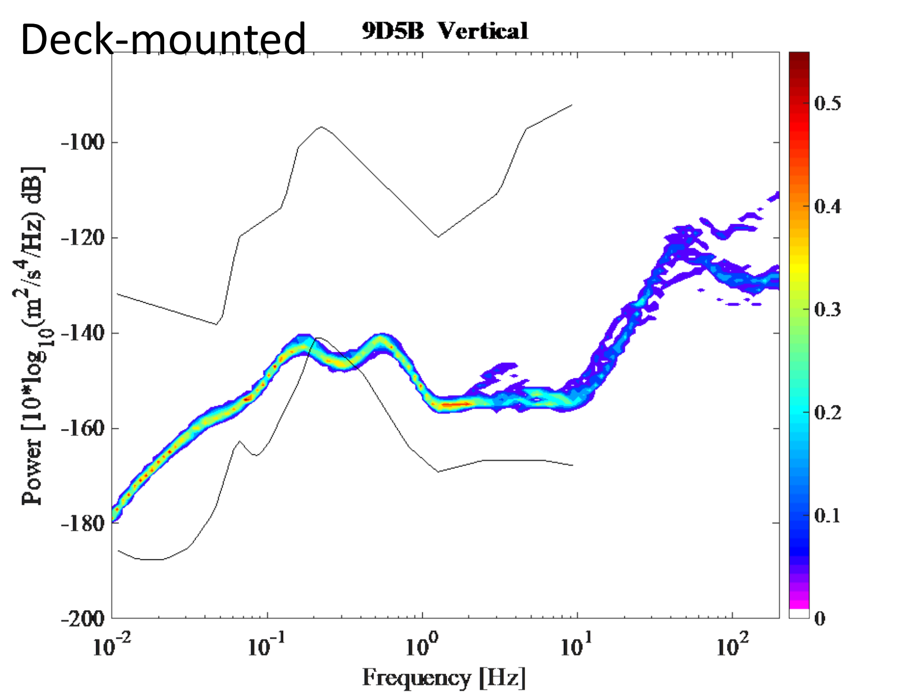
“CAMP EUROPA” GREENLAND

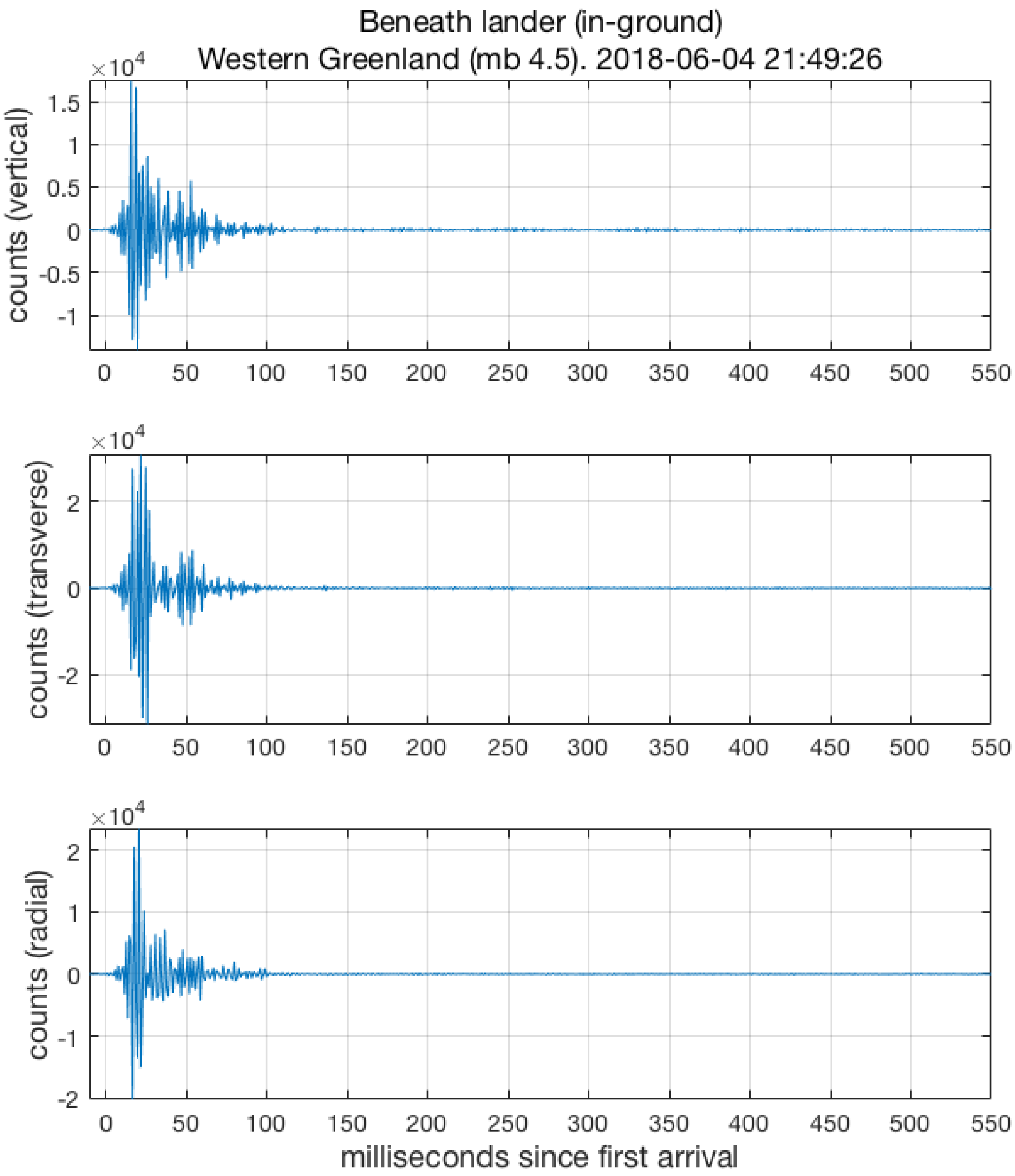


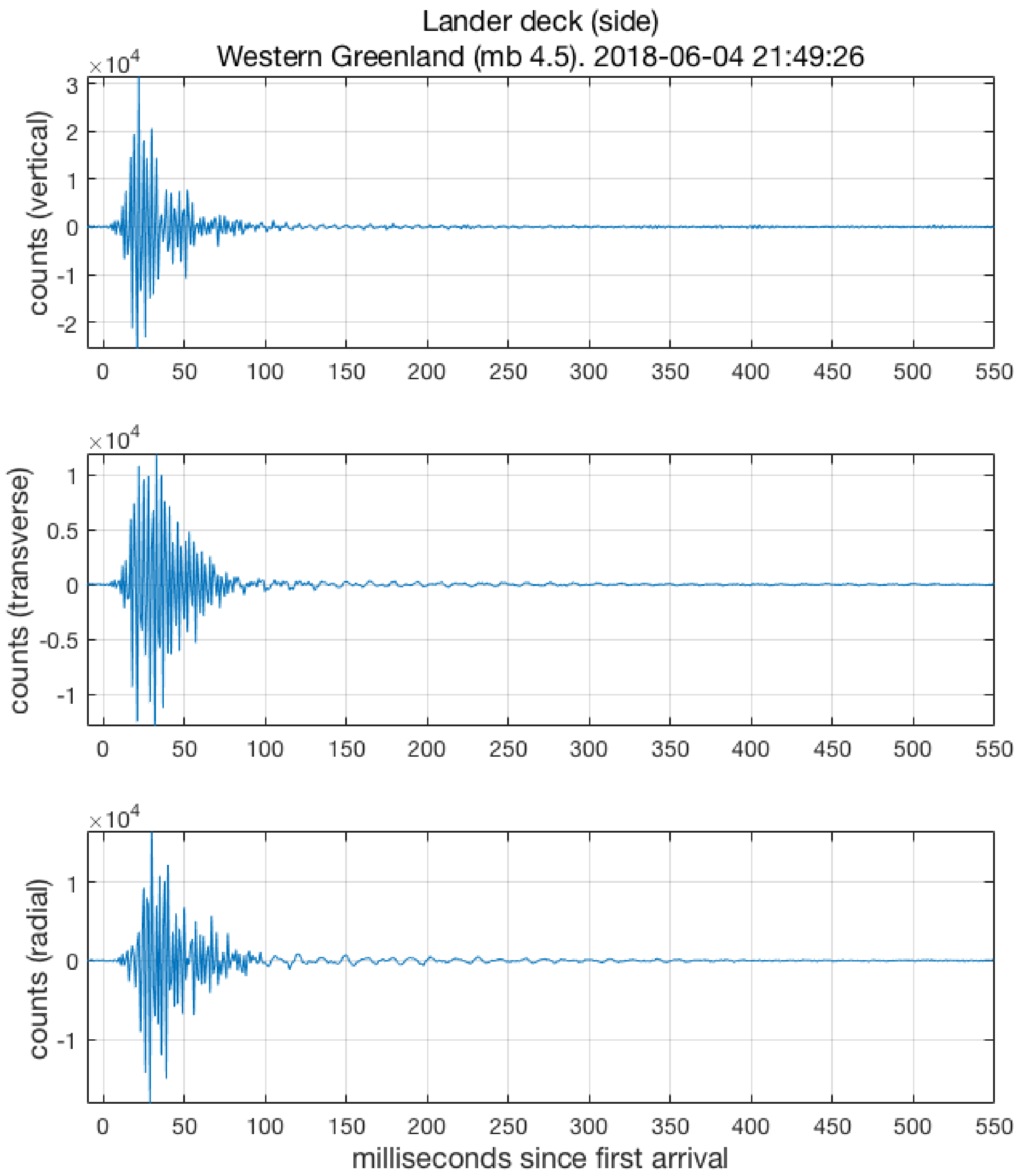
GREENLAND EXPERIMENT



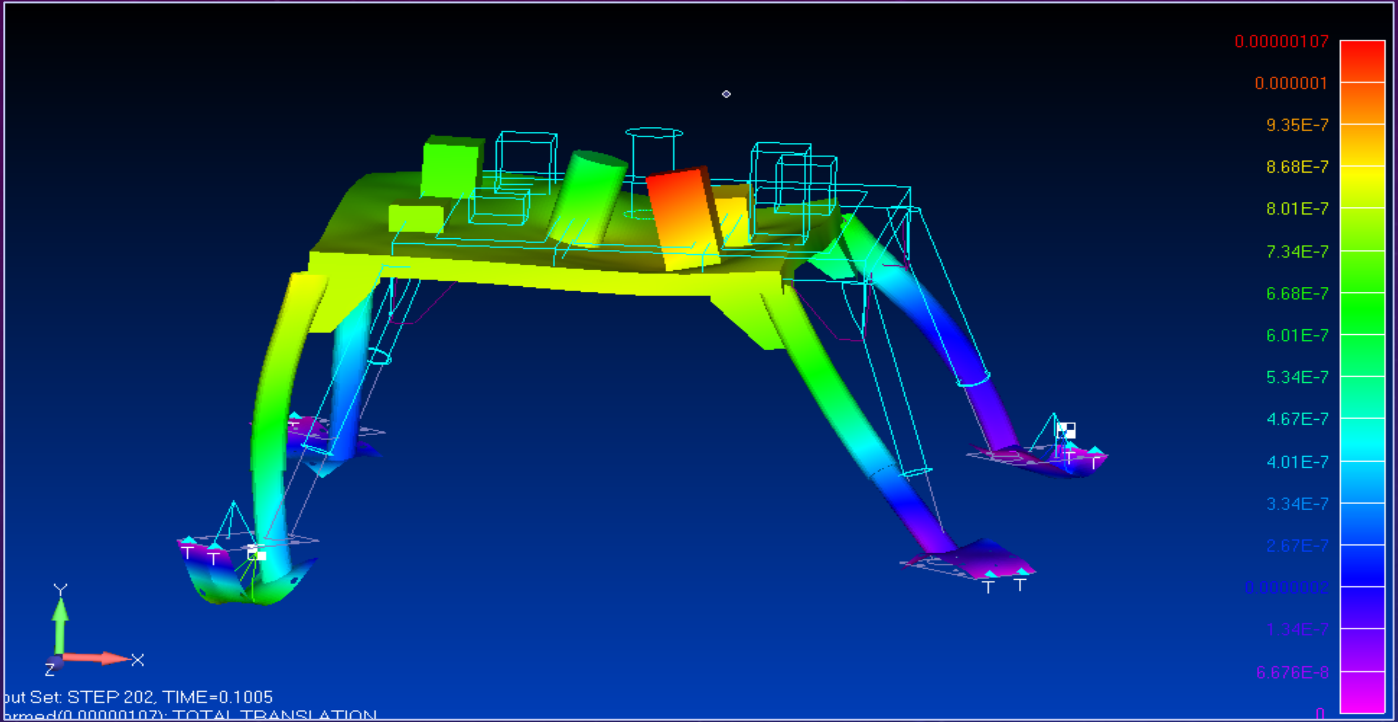


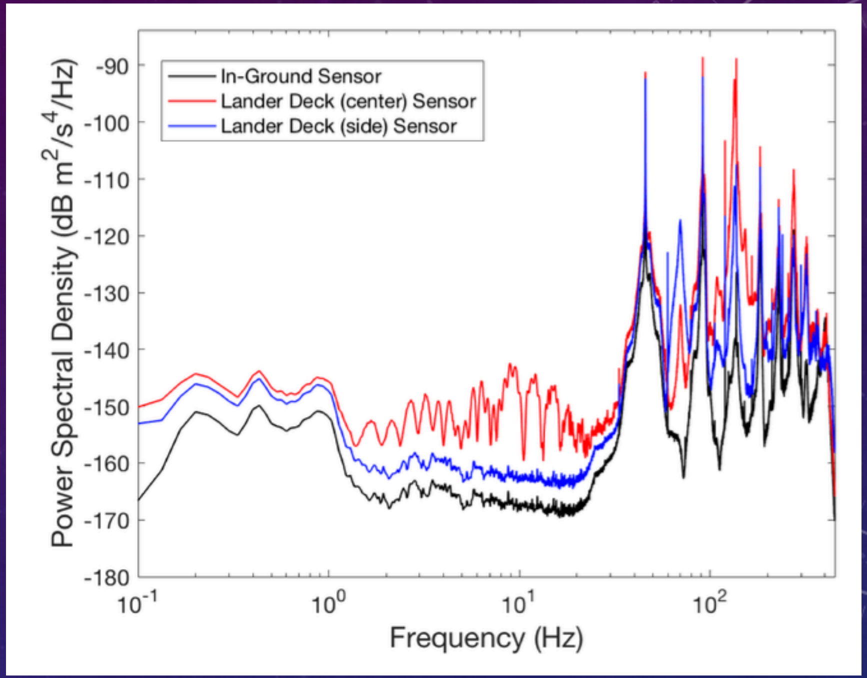


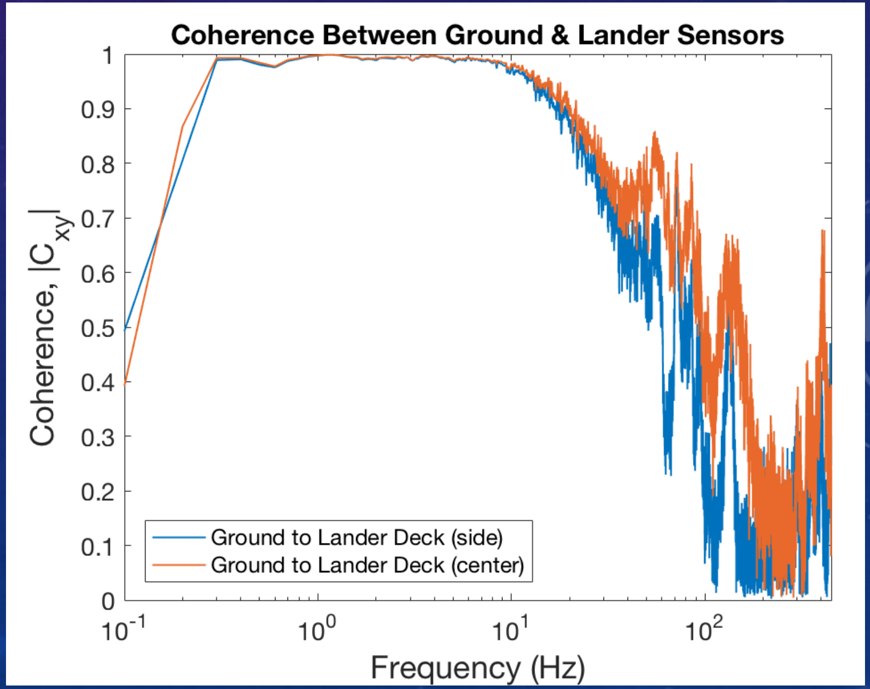

Beneath lander (in-ground)
Western Greenland (mb 4.5). 2018-06-04 21:49:26
counts (vertical)
counts (transverse)
counts (radial)
milliseconds since first arrival


Lander deck (side)
Western Greenland (mb 4.5). 2018-06-04 21:49:26
counts (vertical)
counts (transverse)
counts (radial)
milliseconds since first arrival

LANDER RESPONSE







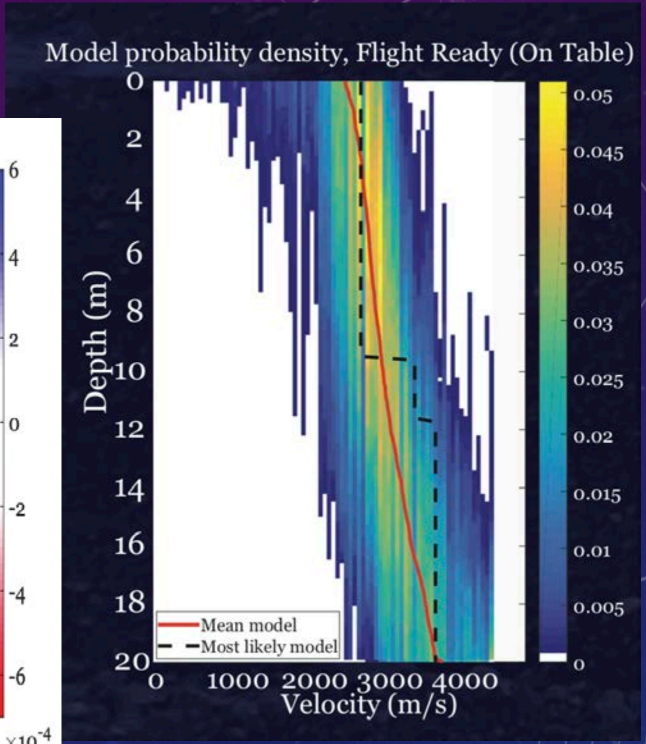
finite element modeling of our lander simulator showing the response to a simulated seismic signal

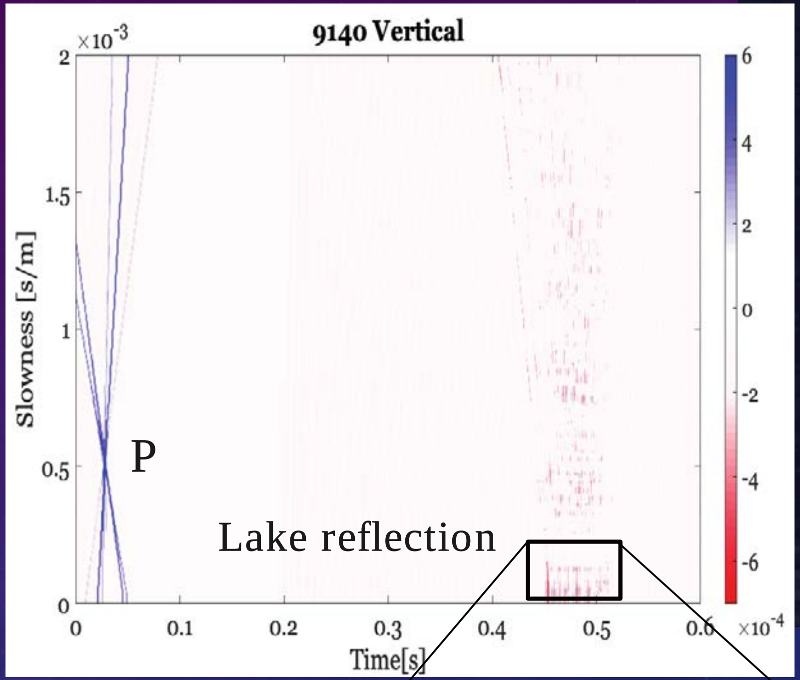
Response is sensitive to mounting location

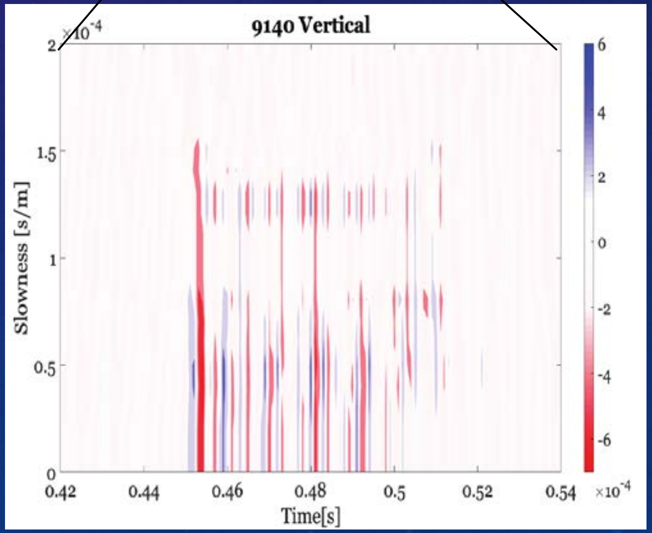
SUMMARY/DISCUSSION

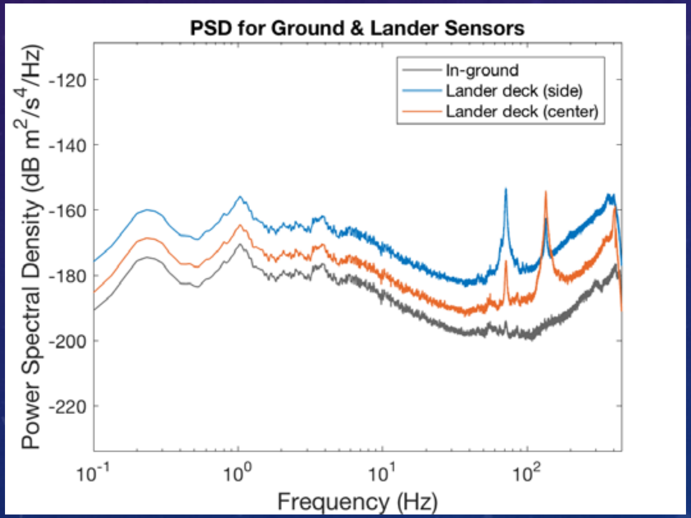
- Single-station or small arrays can be powerful tools
  - Can detect both large global events, and small local events
  - Located events can be used to invert for structure
  - Special techniques for recovering distance and azimuth of events now being employed on Mars with InSight

- Deck mounted deployment can be as powerful as grounded (with precautions)
  - Necessary to quantify the response and self-noise of the lander & sensor as a combined system









LUNAR CASE

- SIIOS team is also developing the Silicon Audio seismometer for use on the Moon

- Includes subsurface gas-jet deployment system for sub-surface burial

- Provides thermal isolation and mitigates the effects of scattering in the lunar regolith

- Candidate instrument for future lunar geophysical network