A seismic signal and noise budget for Titan: Preparation for Dragonfly

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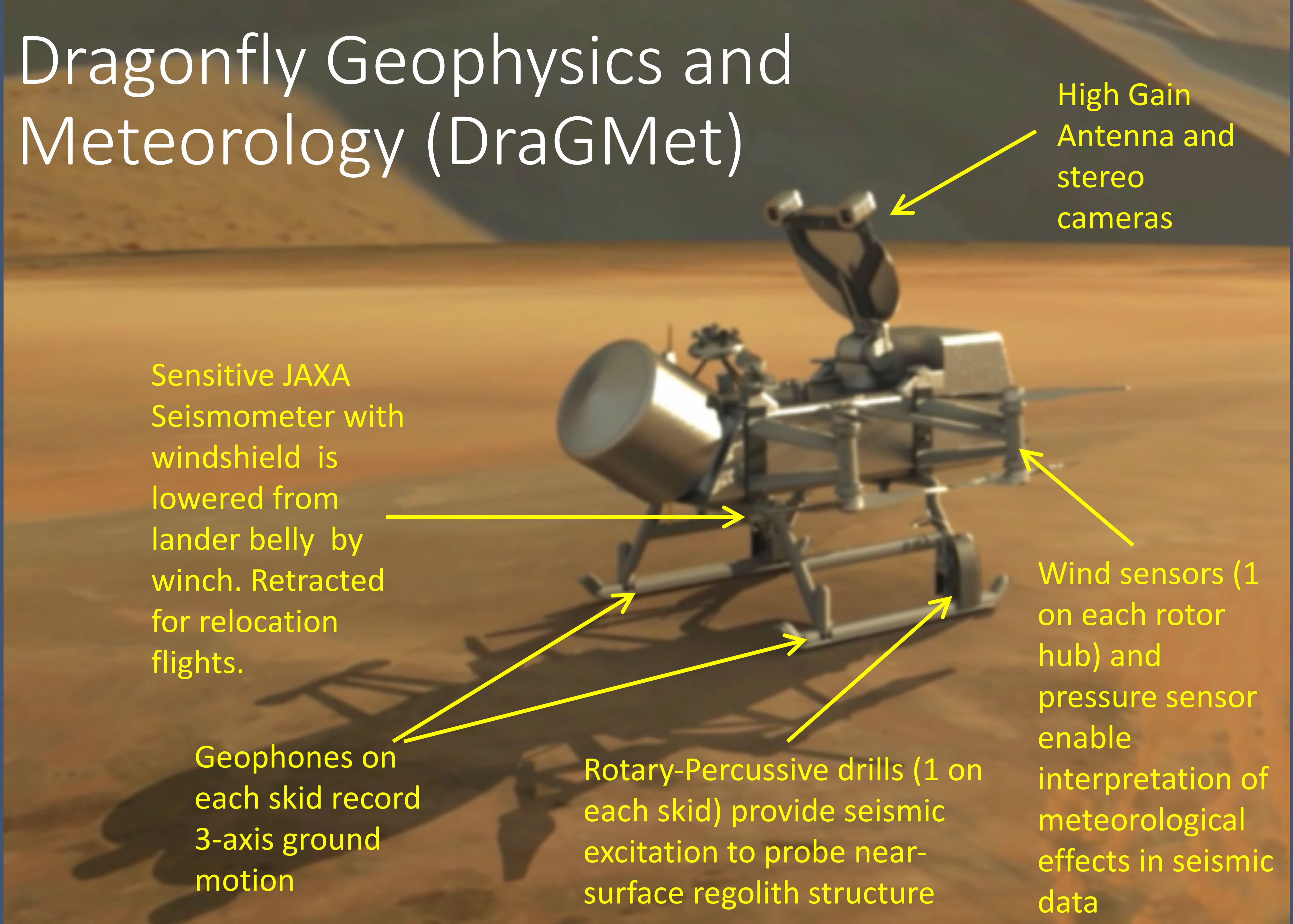
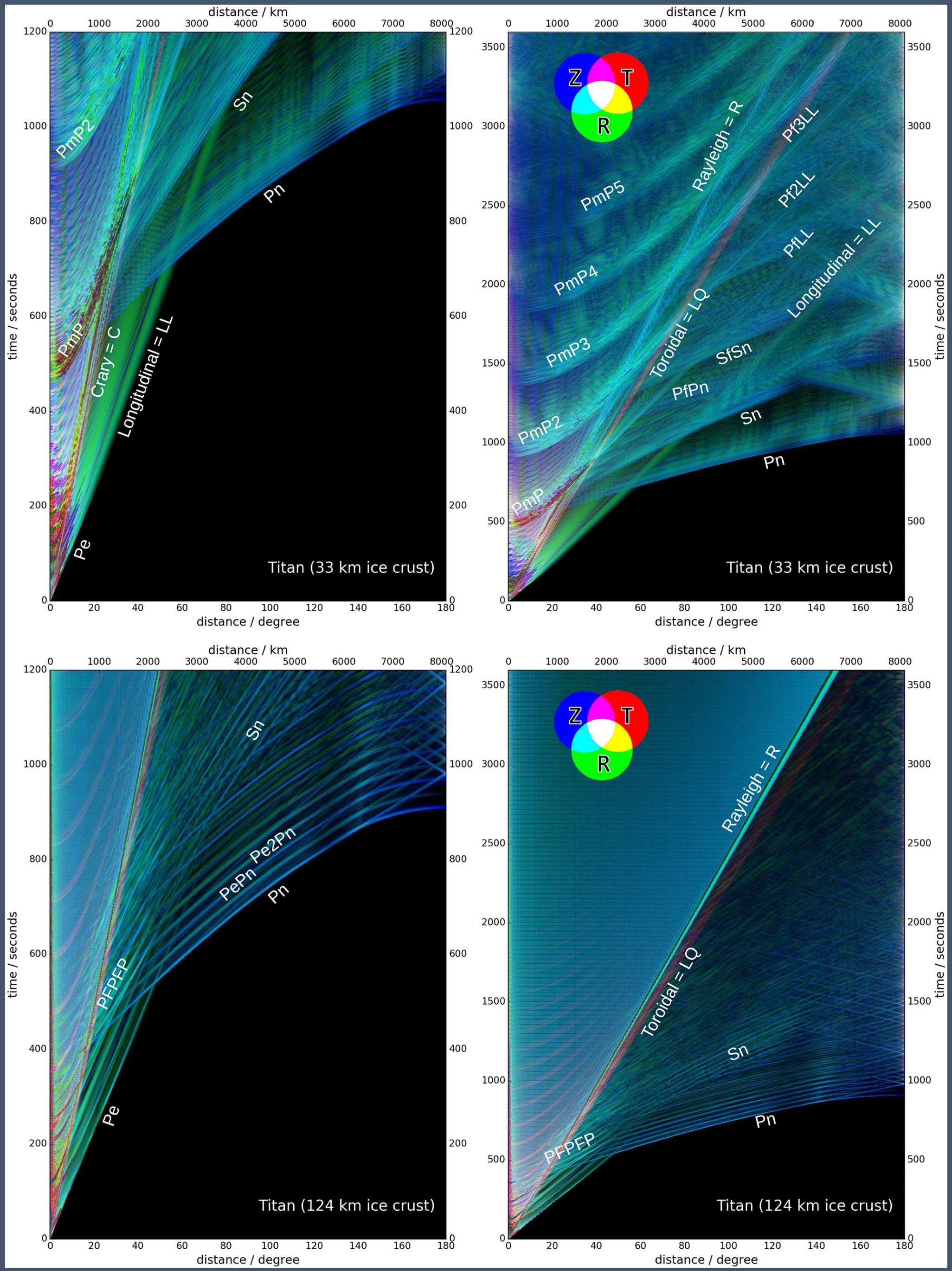
Dragonfly Geophysics and Meteorology (DraGMet)



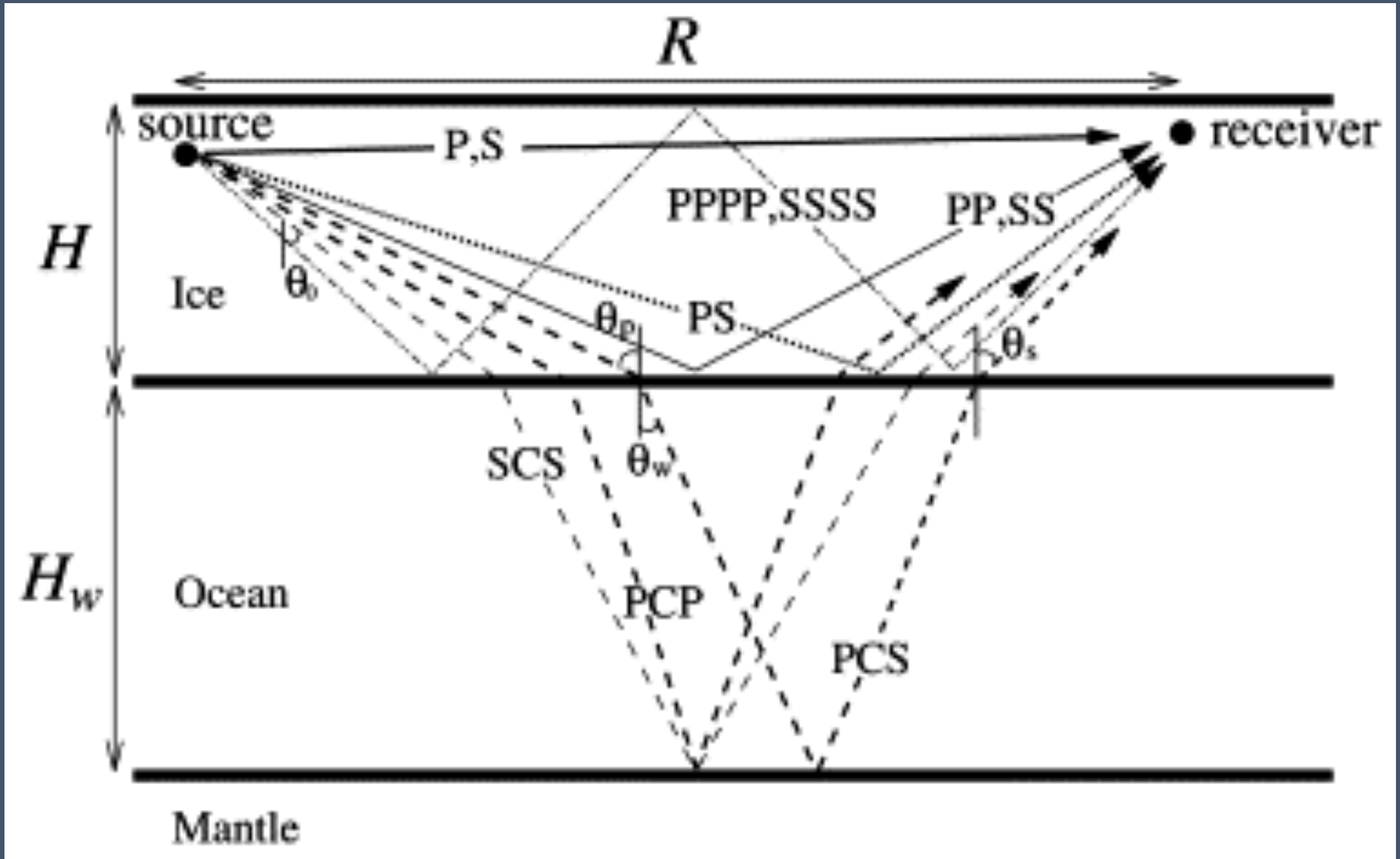
Titan seismology

- Why?
- Tidal cracking as signal and noise
- Titan's seas as noise
- Atmospheric and wind noise
- Other sources



Simulated seismic signals as a function of distance in Titan model (Stähler et al., 2018)

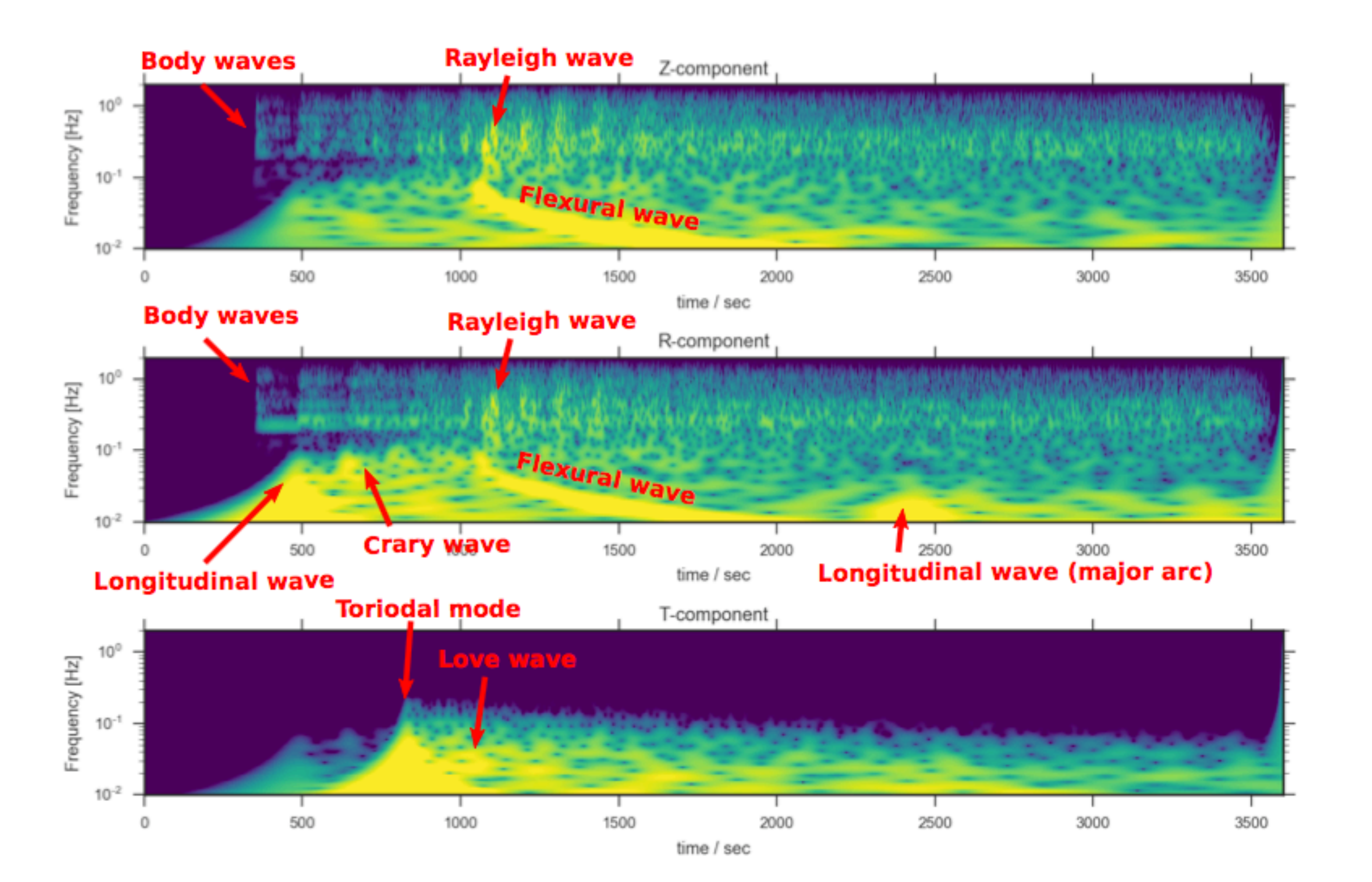
Icy ocean world seismology



From Lee et al., 2003

The most obvious target for seismology is to determine ice shell thickness and ocean depth via timing of reflected waves which can be recorded at relatively high frequencies (e.g. 1-10 Hz)

Ice phases



Many other signals are present in the broadband signal that can be used to determine ice shell thickness and other properties, such as flexural waves and resonant Crary waves.

From Stähler et al., 2018

Building an icequake seismicity model

- Assume icequakes follow a Gutenberg-Richter relationship, $\log_{10} N(M_W) = a - bM_W$, so we can define expected seismicity through a and b
- We can tie this to energy constraints, by rewriting in terms of seismic moment as $N(M_0) = AM_0^{-B}$
- With some manipulation, we can relate this to cumulative seismic moment and maximum event size as $\Sigma M_0 = \frac{AB}{1-B}(M_0^\star)^{1-B}$

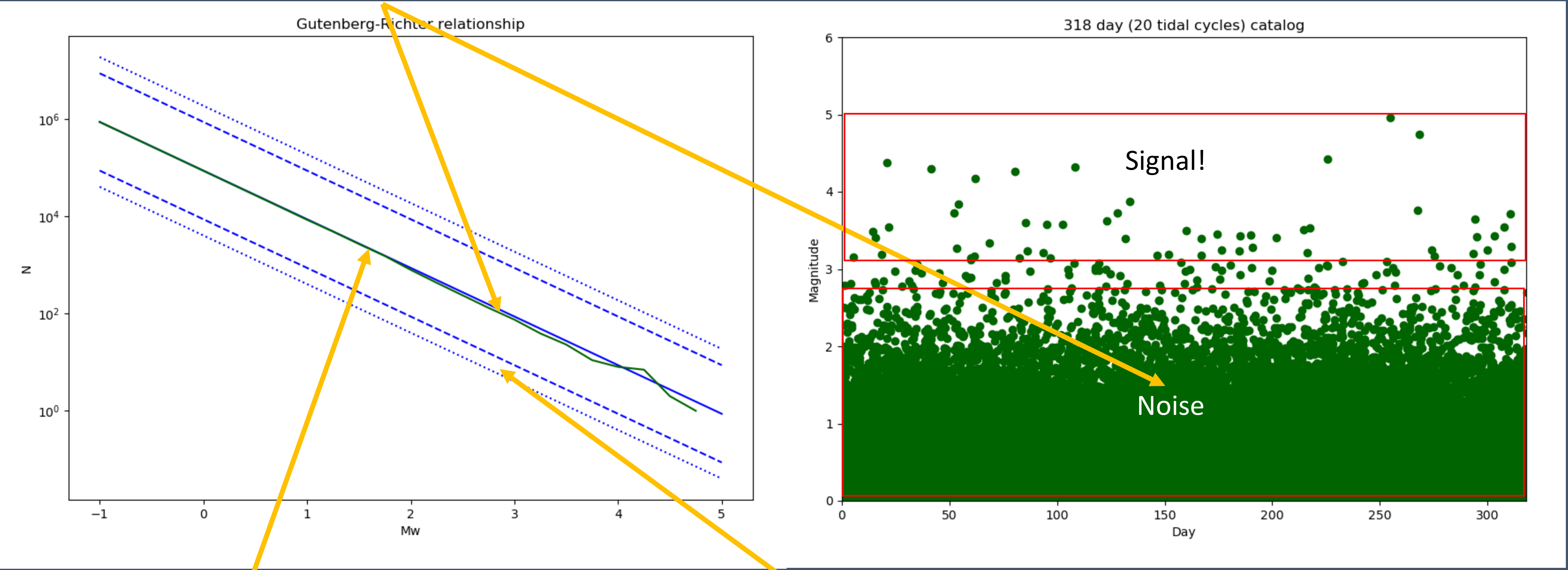
Cumulative seismic moment

Maximum event size

Estimated catalog

- Estimate cumulative moment to be 2.9×10^{15} Nm/tidal cycle scaled from lunar data (Hurford et al., 2020)
- Estimate max event size as M_W 4.8, which minimizes strain accumulation

Realization of 20 cycle catalog in green



Expected values in blue

Order of magnitude uncertainties in cumulative moment and max size

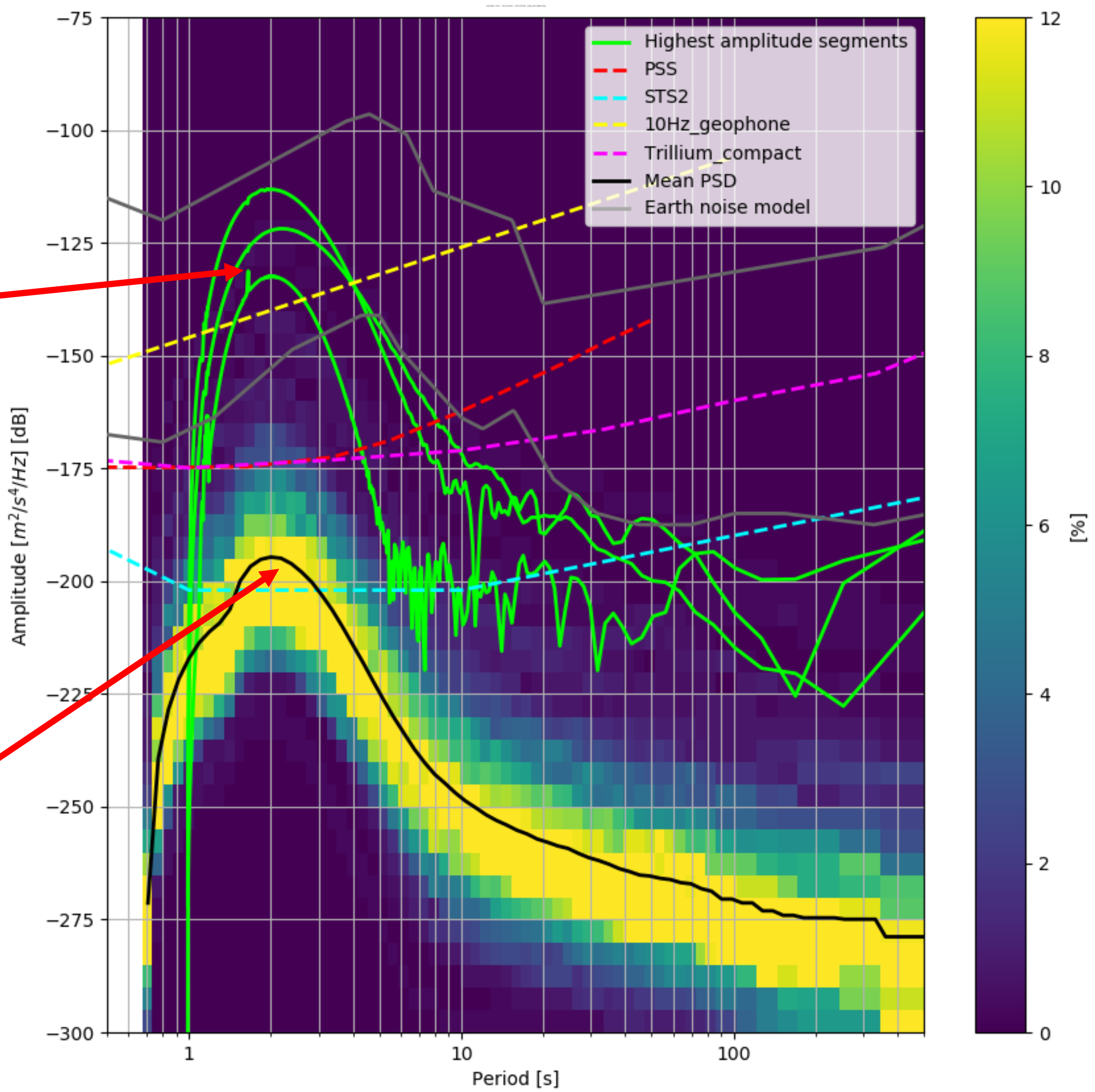
Signal and noise power spectral density

- Use random catalogs uniformly distributed on the sphere
- Calculate long simulated seismic records (2 tidal cycles here) and look at the background and peak signal power
- Signal 50 dB above moderate instrument sensitivity

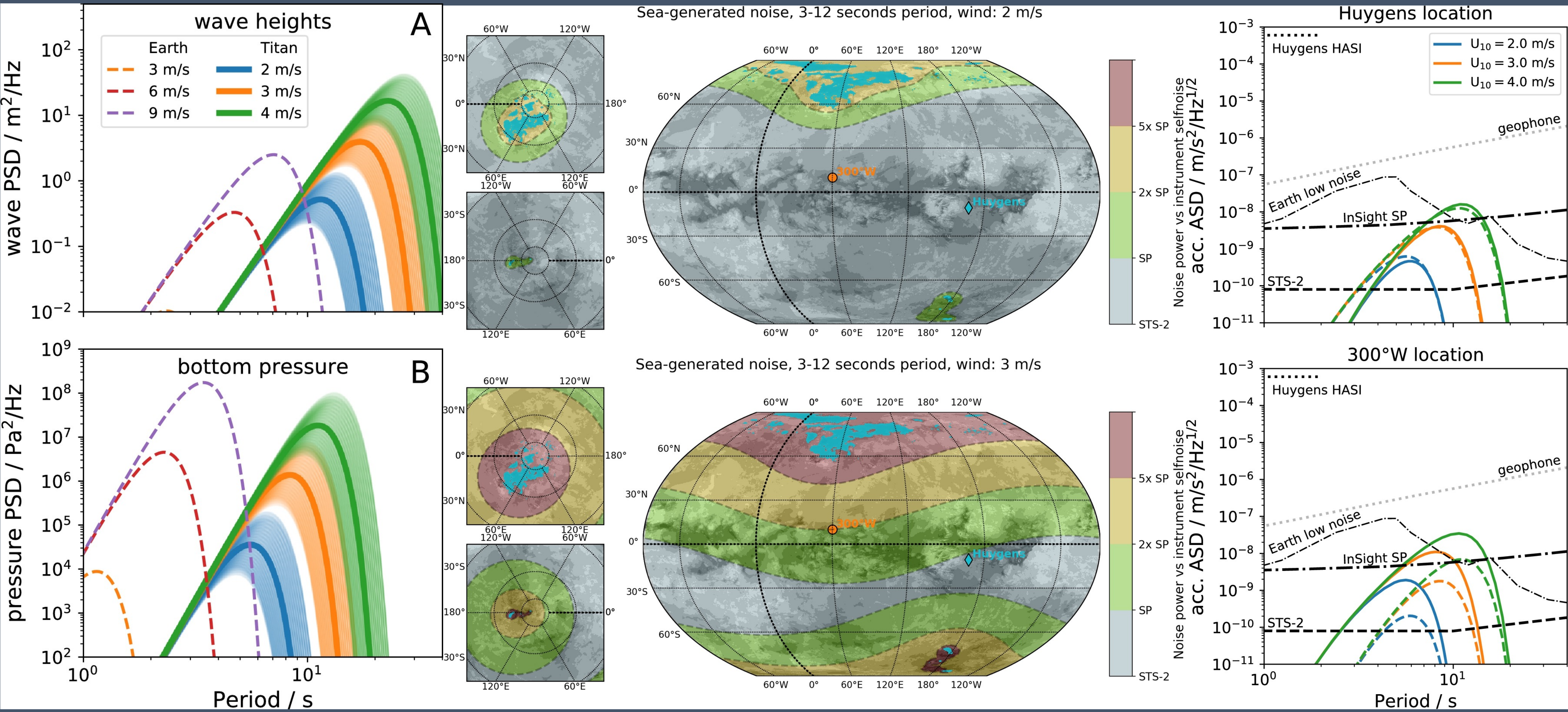
Largest events -125 dB

Seismometer sensitivities (dashed)

Tidal cracking noise



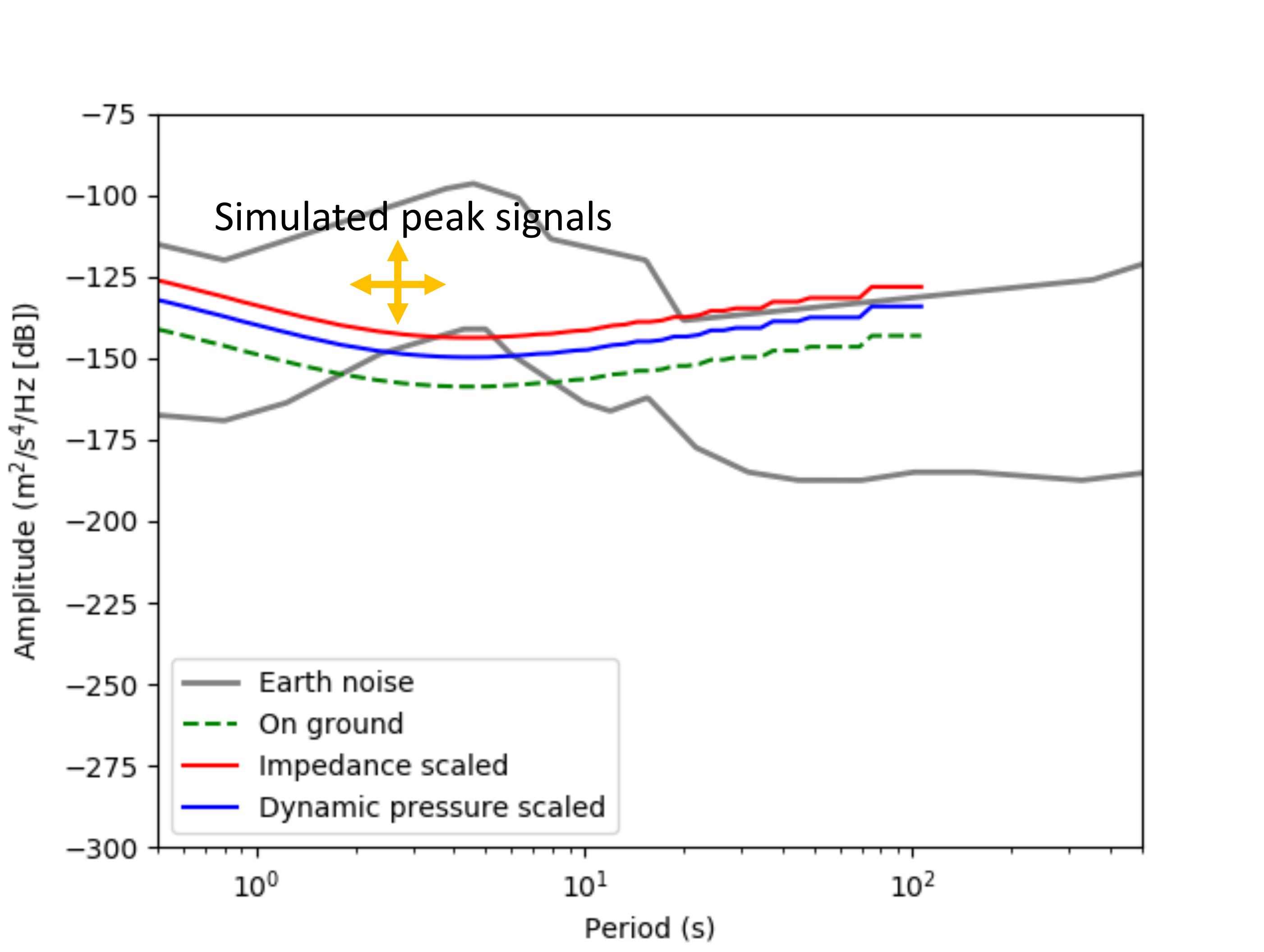
Microseismic noise due to waves on seas



from Stähler et al., 2019

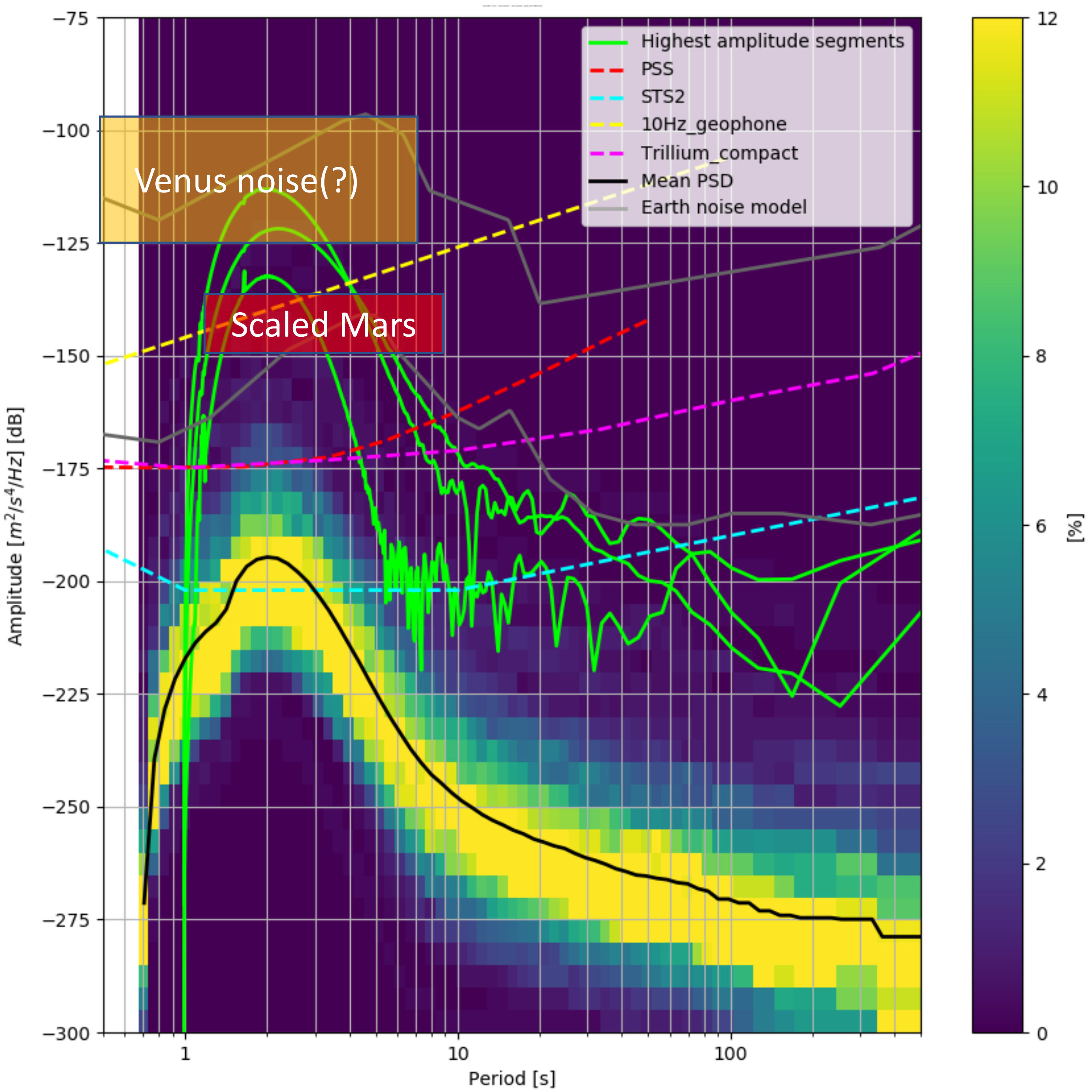
Scaling atmospheric noise from Mars

- We have observations of noise on Mars, which is dominated by atmospheric effects
- To scale this to Titan, there are a couple options:
  - Scale by atmospheric acoustic impedance (higher on Titan) and solar flux (lower on Titan)
  - Scale by dynamic pressure, which includes atmospheric density (higher on Titan) and wind speeds squared (lower on Titan)



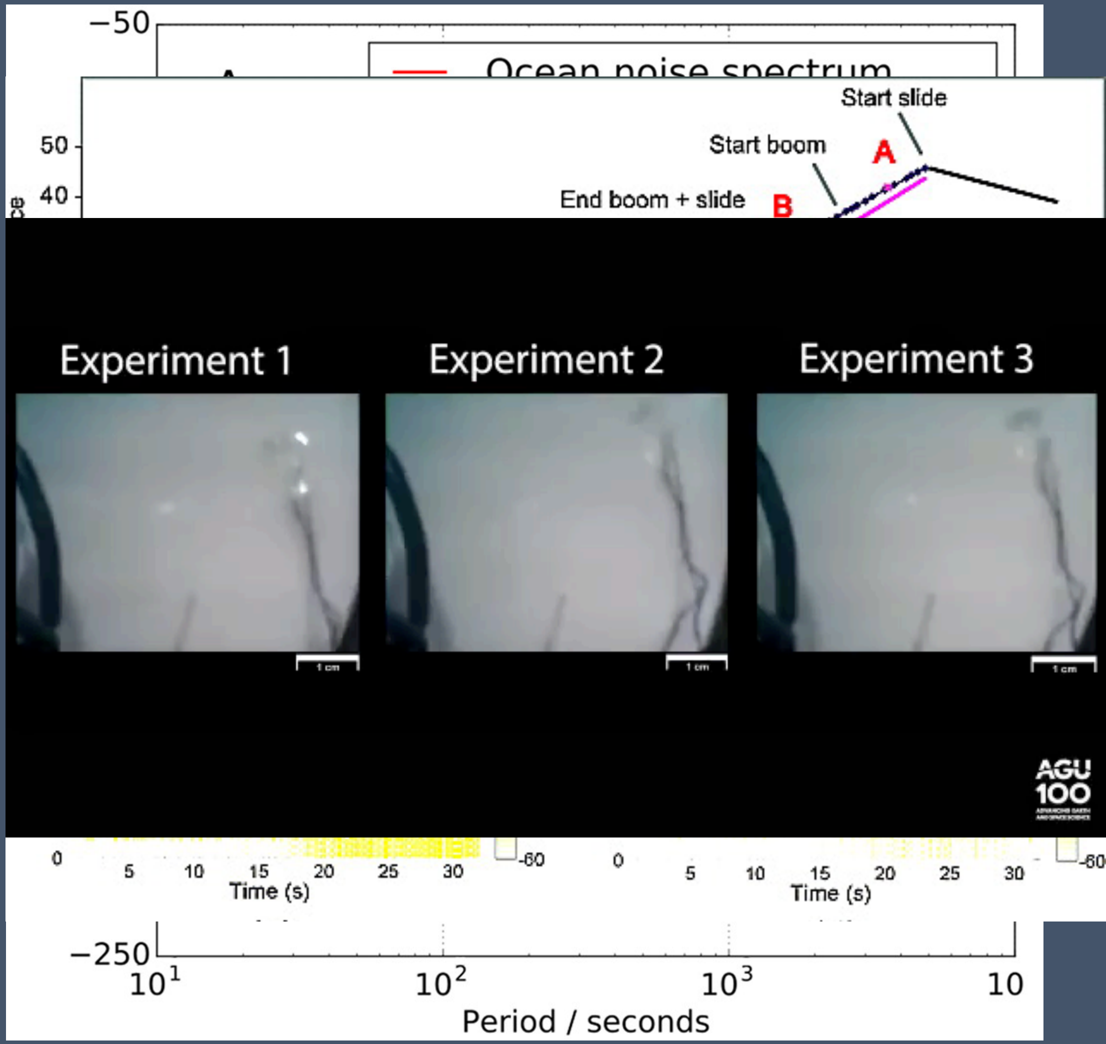
What about Venus?

- Lorenz and Panning (2018) very roughly estimated Venus noise comparable to Earth based on limited Venera data
- Scaling down using acoustic impedance and solar flux produces noise estimates below the scaled Mars estimates



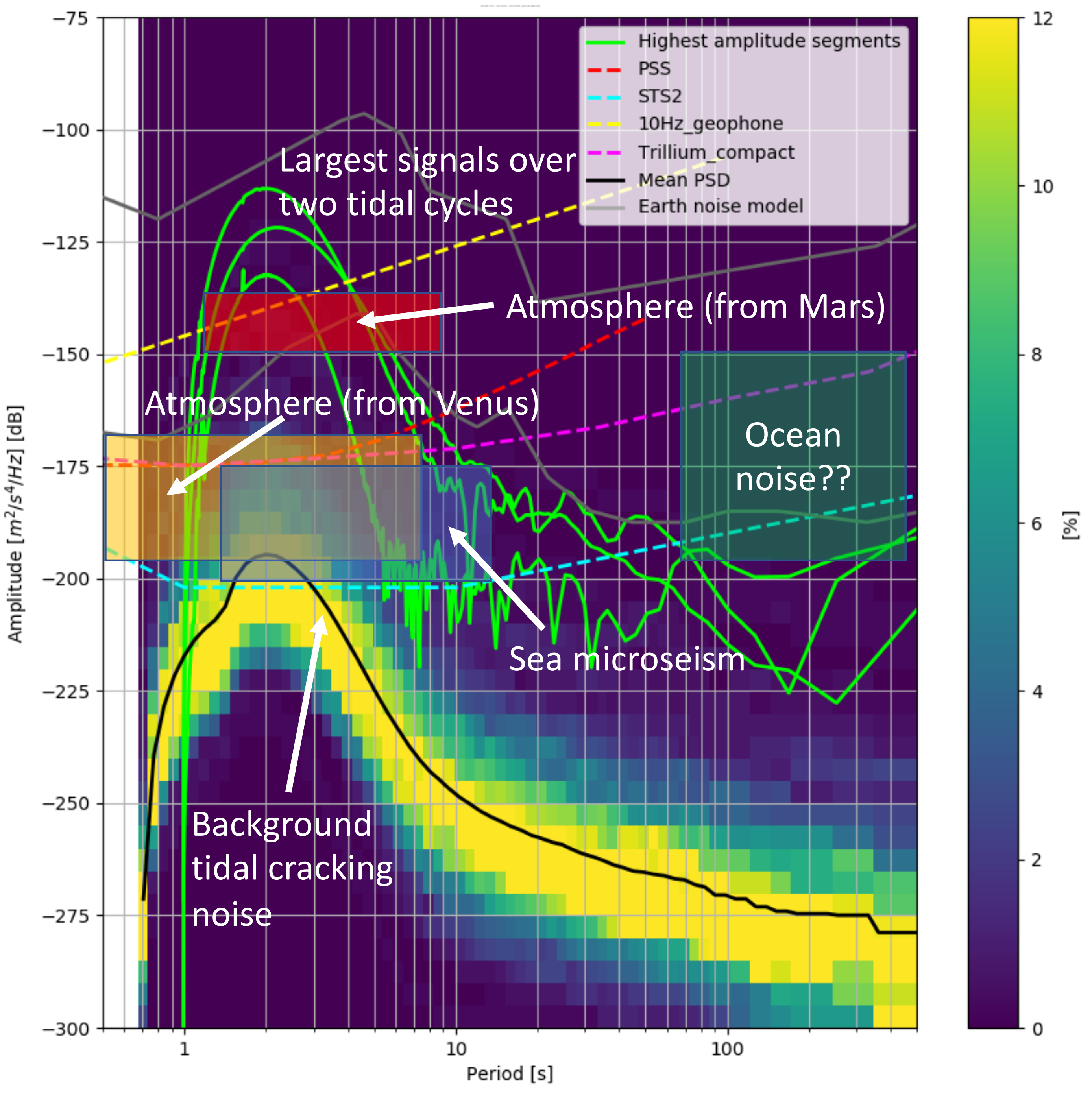
Other seismic sources to consider

- Ocean noise? Modeling for Europa (Panning et al., 2018) based on ocean simulations from Soderlund et al. (2014) suggest signals between -150 and -200 dB from 100-1000 second period (below instrument noise) – How to extrapolate to Titan?
- Booming dunes – Many sand dunes produce a booming or singing in audible frequencies (80-120 Hz) which appears to be related to sand avalanche processes. Could this happen on Titan?
- Deep Titanquakes – Earth's moon shows many deep quakes located at depths of hundreds of kilometers, but these are quite small and only detectable due to how quiet the Moon is
- Exploding bubbles? Farnsworth et al. (2019) simulate exsolution of N_2 bubbles in the seas.



Summary of signals and noise

- Broad estimates of amplitudes suggest the following relative ranking of signal and noise power
  1. Largest ice-cracking signals over one to a few tidal cycles
  2. Atmospheric noise
  3. Intrument self-noise
  4. Microseismic noise from seas
  5. Background tidal cracking noise



Conclusions

- The largest tidal cracking events occurring every few tidal cycles are well above likely instrument noise using tidal dissipation energy scaling from lunar seismicity
- Microseismic noise due to sea waves may be important at more polar sites, but is likely below or close to instrument noise at the equator
- Atmospheric noise will likely be the dominant noise source and can be scaled from Mars or Venus data. Based on scaling, we expect that the noise will be well above instrument noise, and predicted to be less than but close to signal power from the largest events, although Venus-scaled estimates are lower
- Many other seismic sources are possible, and Titan will certainly surprise us somehow