Estimation of seismic activity on Titan from tidal cracking

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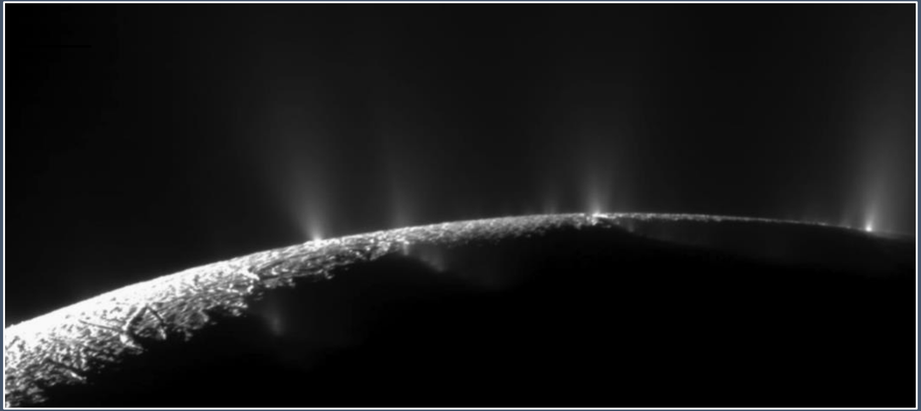
Seismology on Titan and ocean worlds

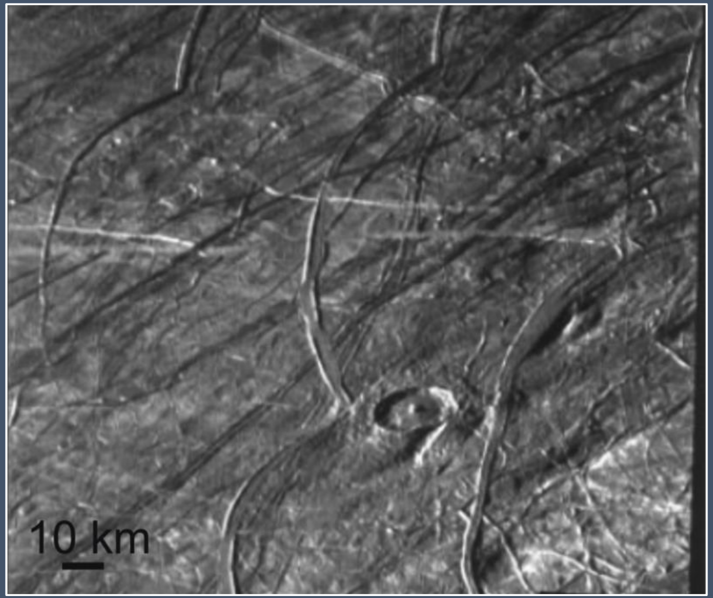
Sources

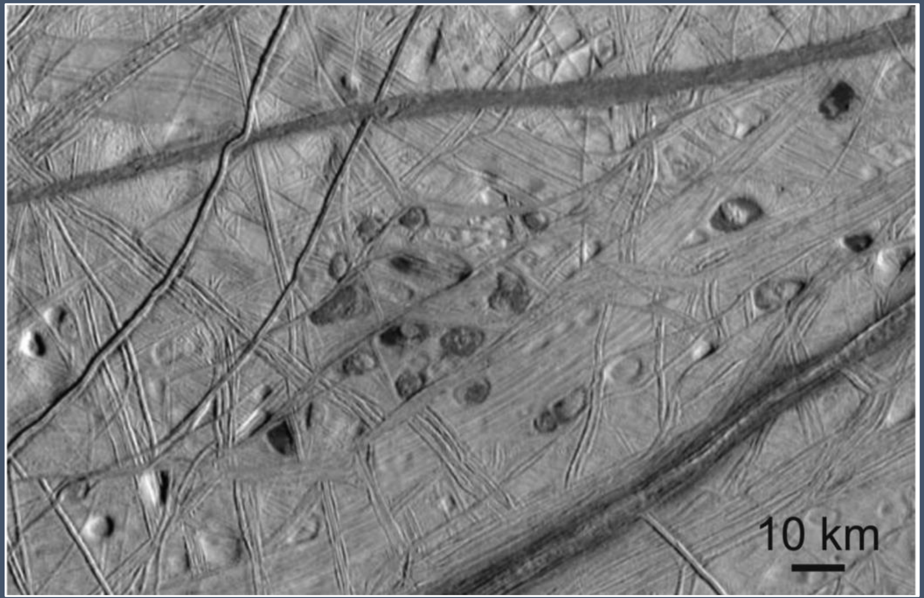
- Fracture
- Tides
- Fluid flow
- Cryovolcanoes
- (Impacts)

Structure

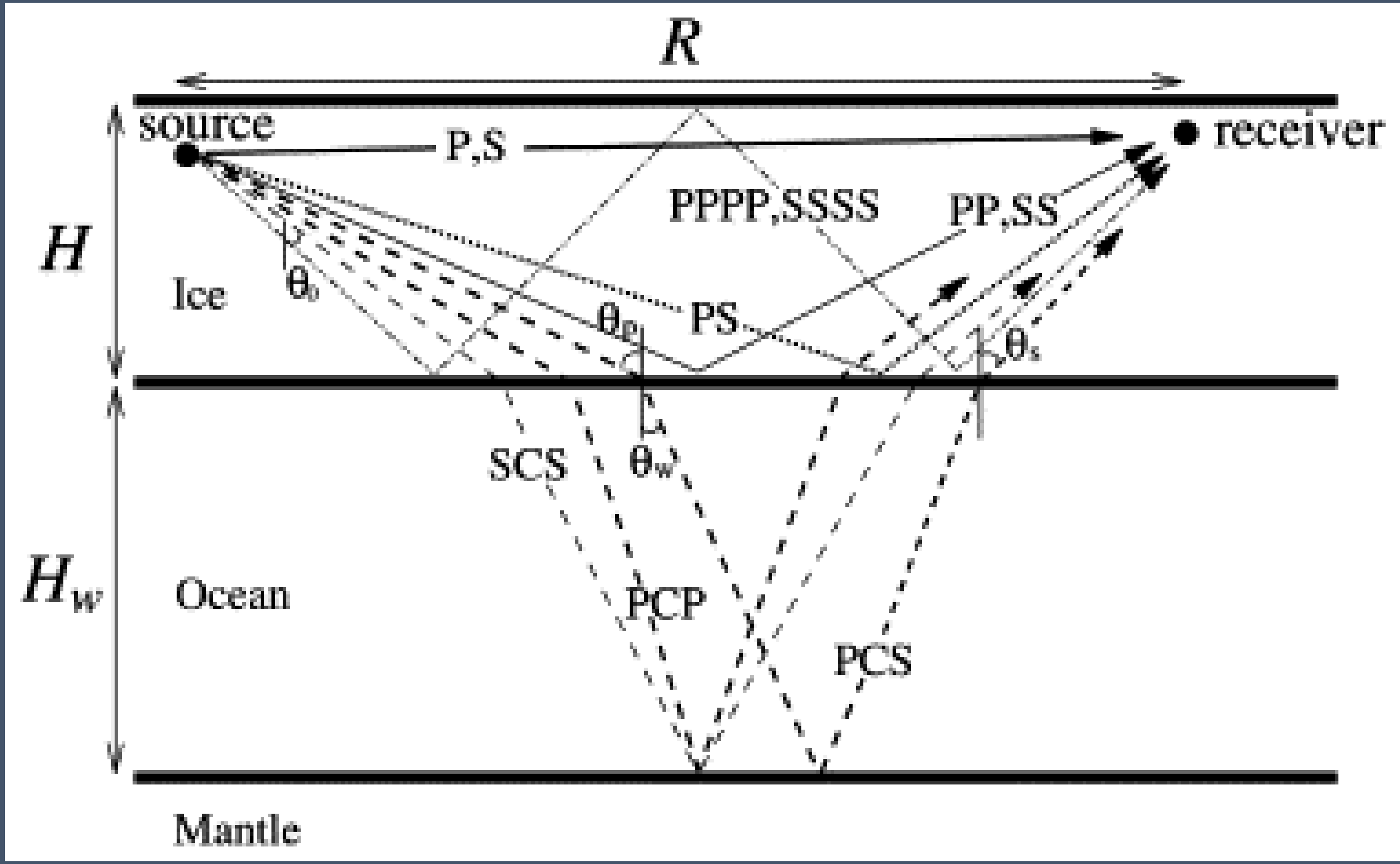
- Ice shell thickness
- Ocean depth
- High pressure ices
- Rocky interior
- Near-surface material







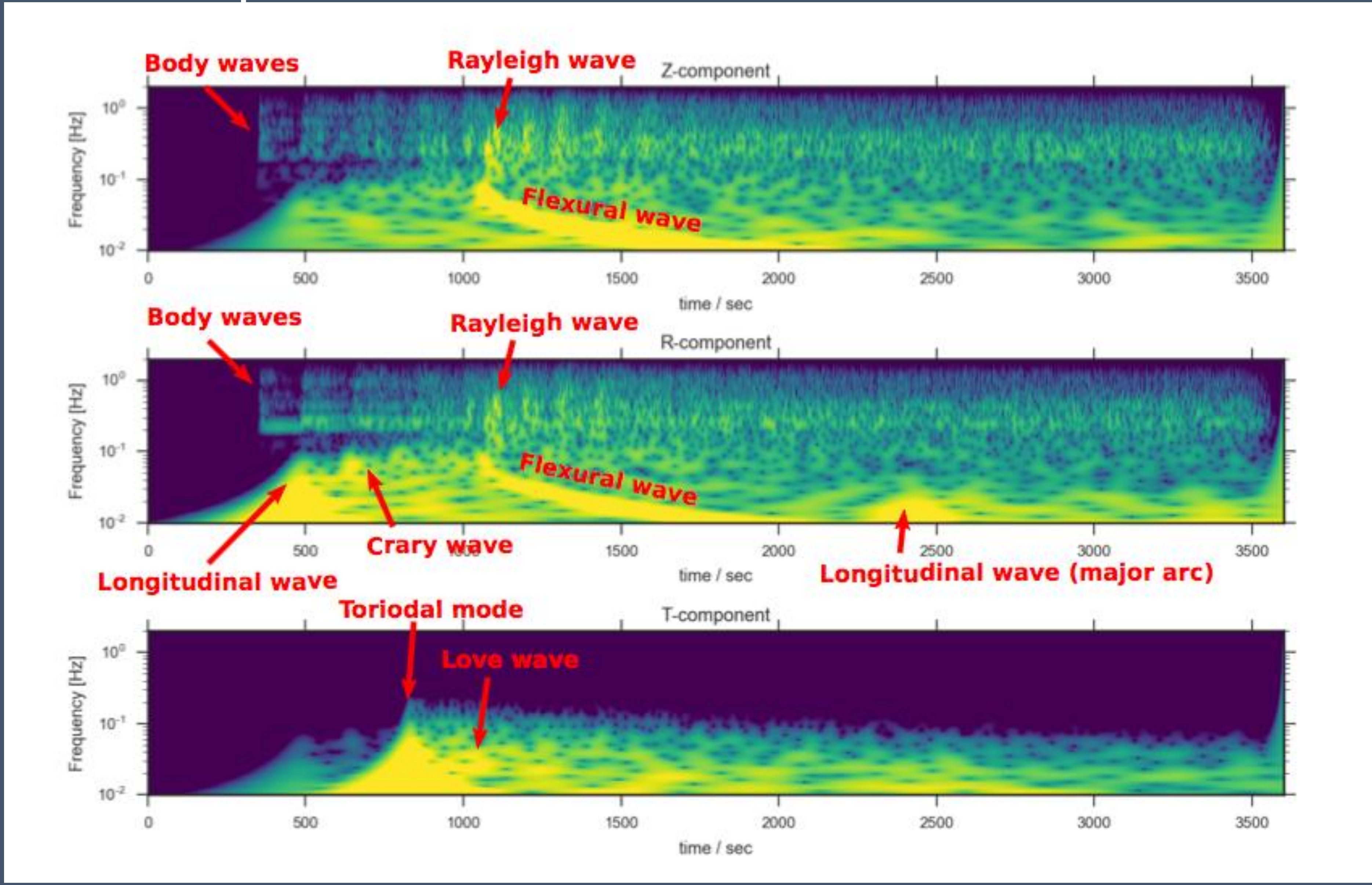
Icy ocean world seismology



From Lee et al., 2003

An obvious target for seismology is to determine ice shell thickness and ocean depth via timing of reflected waves

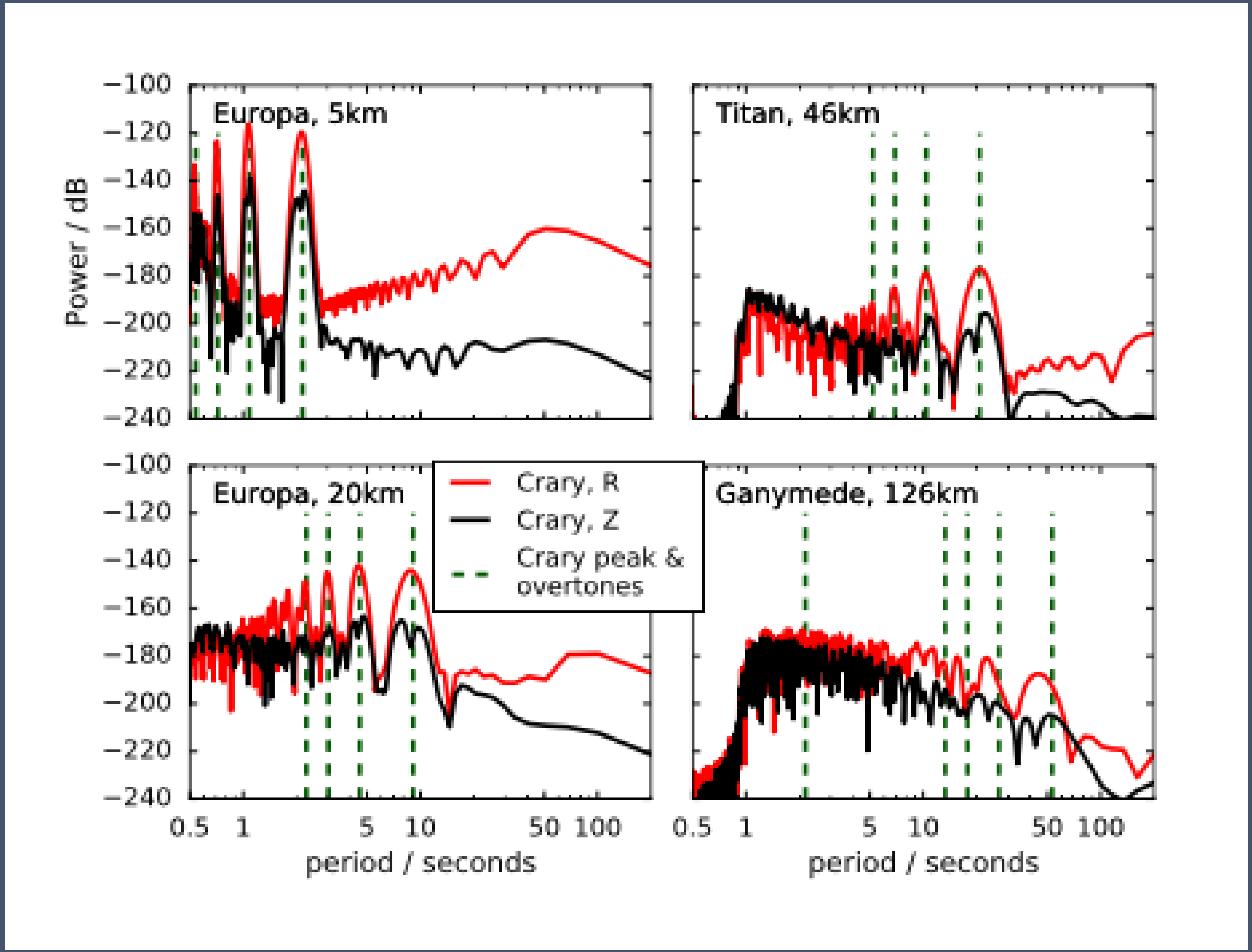
Ice phases



From Stähler et al., 2018

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.

Crary wave resonance



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, and assuming b < 1.5 (i.e. B < 1), we can relate this to cumulative seismic moment and maximum event size as $\Sigma M_0 = \frac{AB}{1-B}(M_0^{\star})^{1-B}$

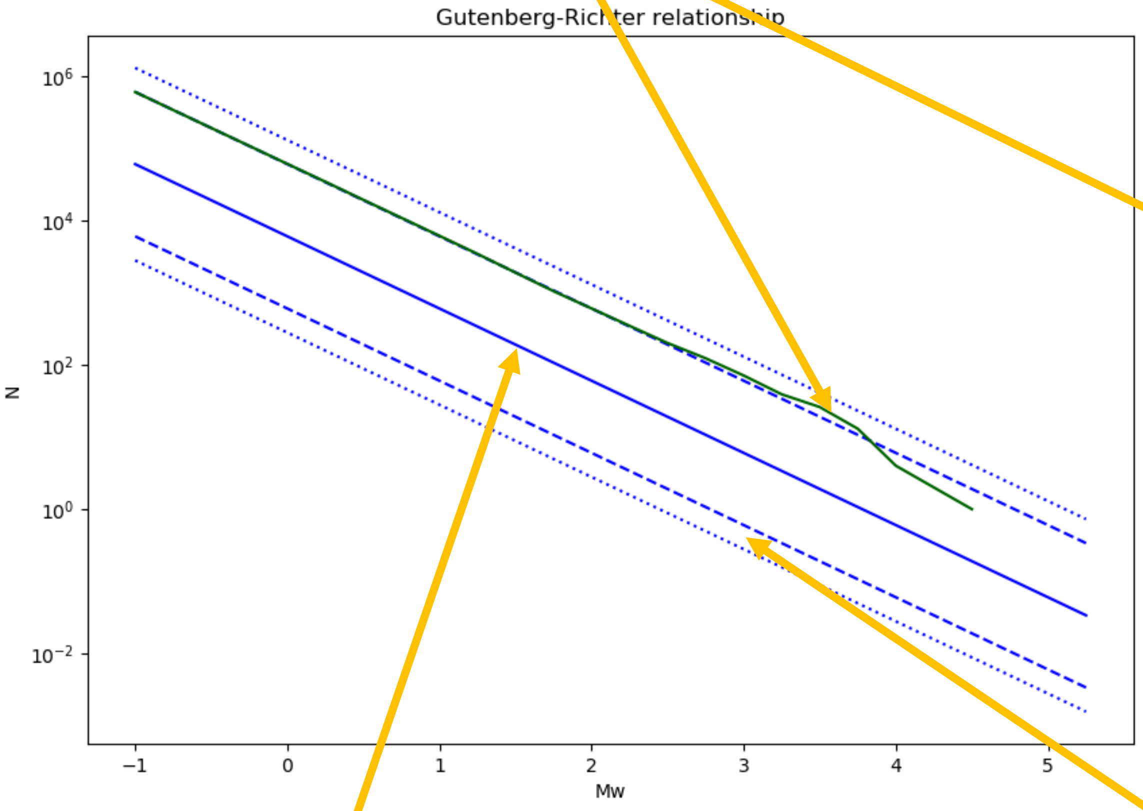
Cumulative seismic moment

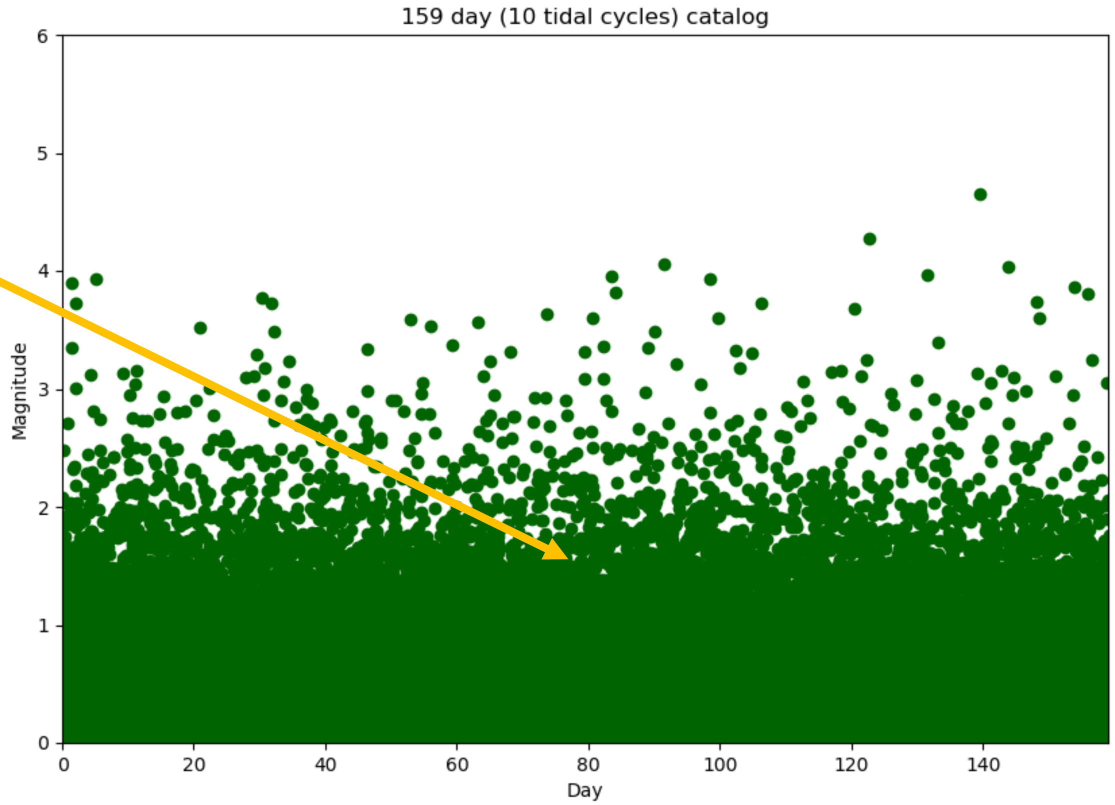
Maximum event size

Estimated catalog

- Estimate cumulative moment to be 5×10^{15} NM/tidal cycle scaled from lunar catalog
- Estimate max event size as M_W 5, which minimizes strain accumulation

Realization of 10 cycle catalog



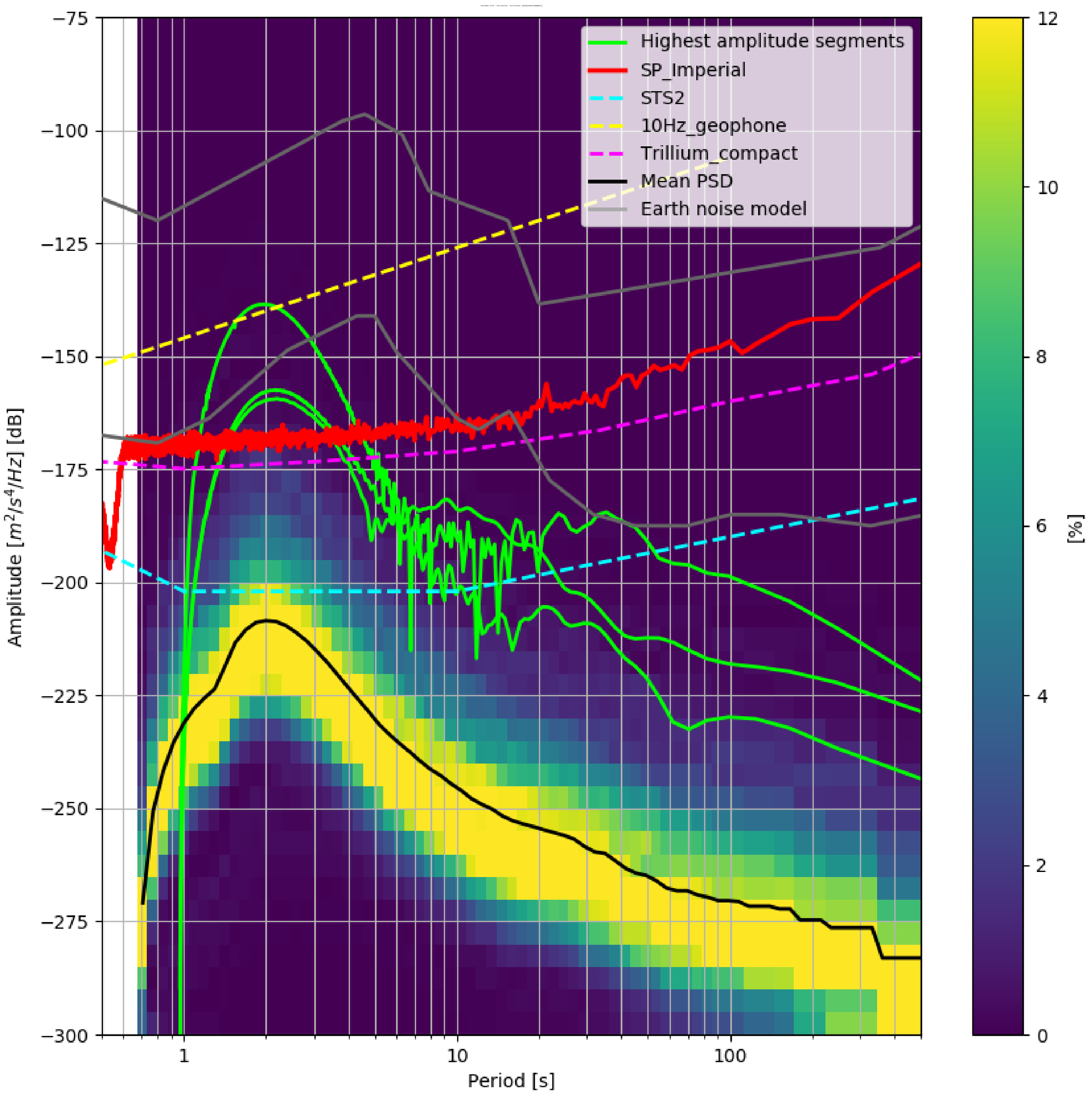


Expected value for 1 tidal cycle

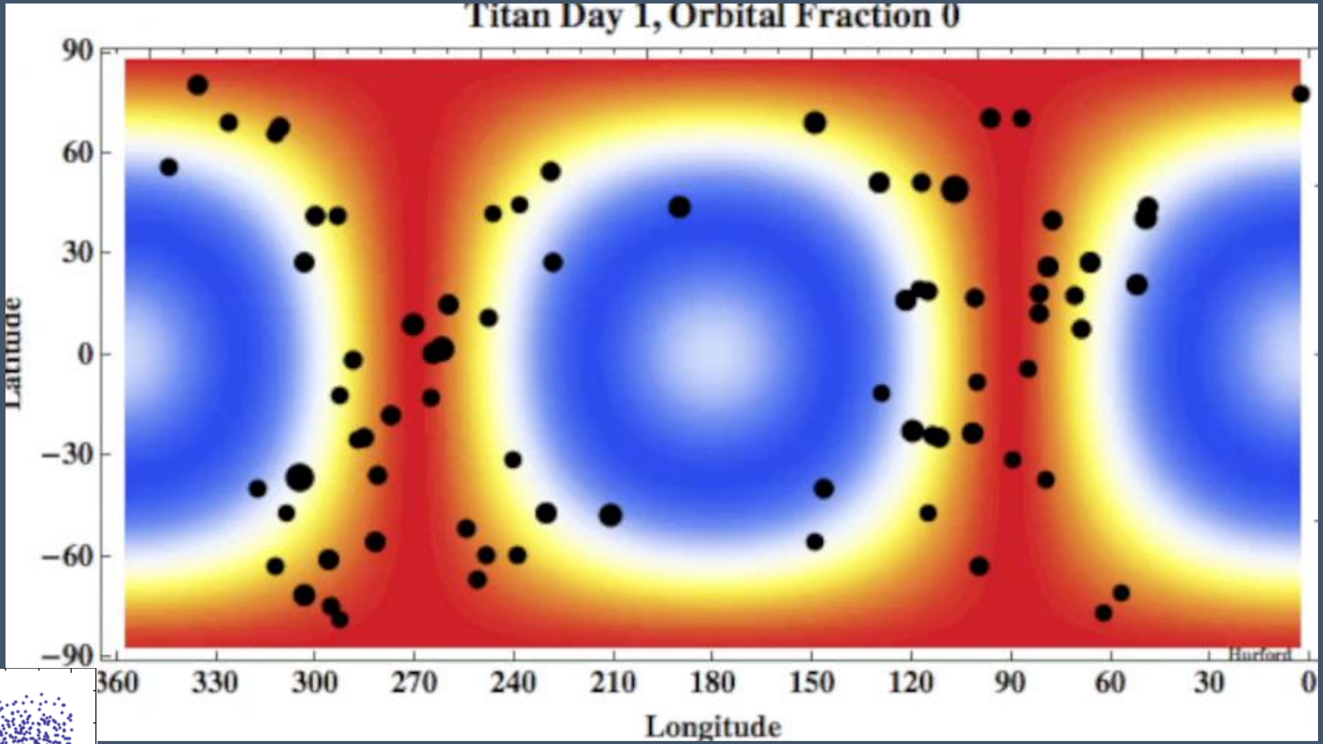
Order of magnitude uncertainties in cumulative moment and max size

Signal and noise power spectral density

- Use random catalogs uniformly distributed on the sphere and in the top 2 km in depth
- Calculate long simulated seismic records and look at the signal power at peak times (large events) and for the background of the almost continuous small events

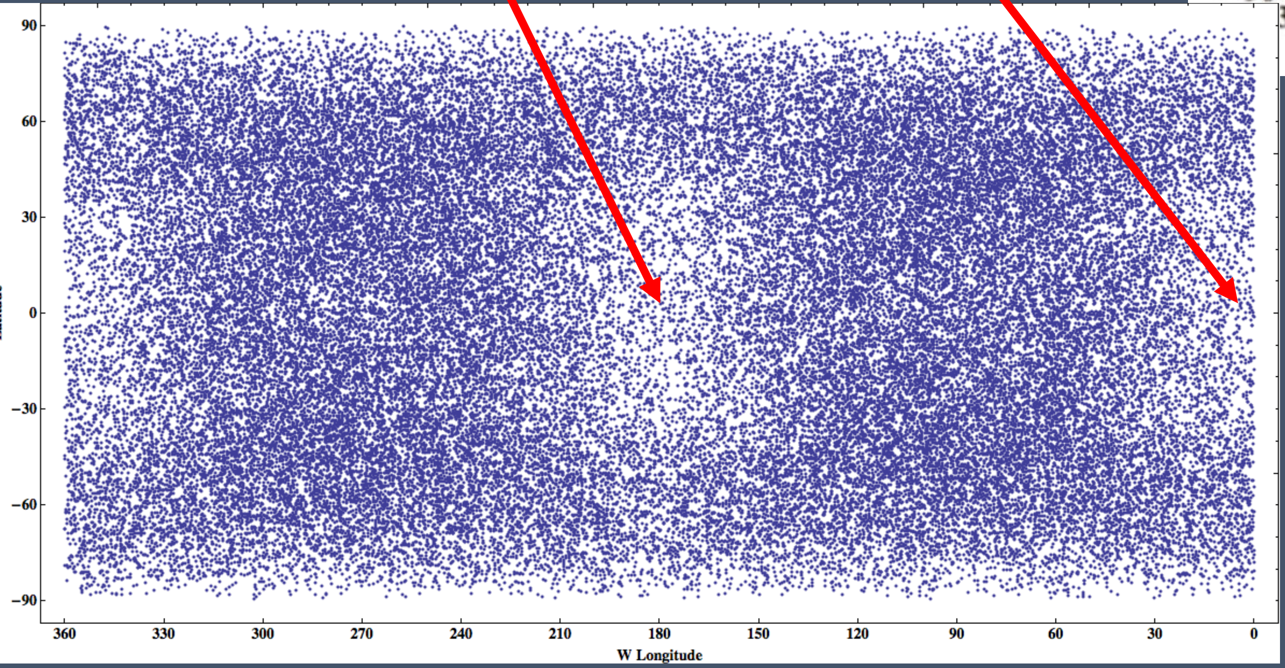


Spatial variability through tidal cycle



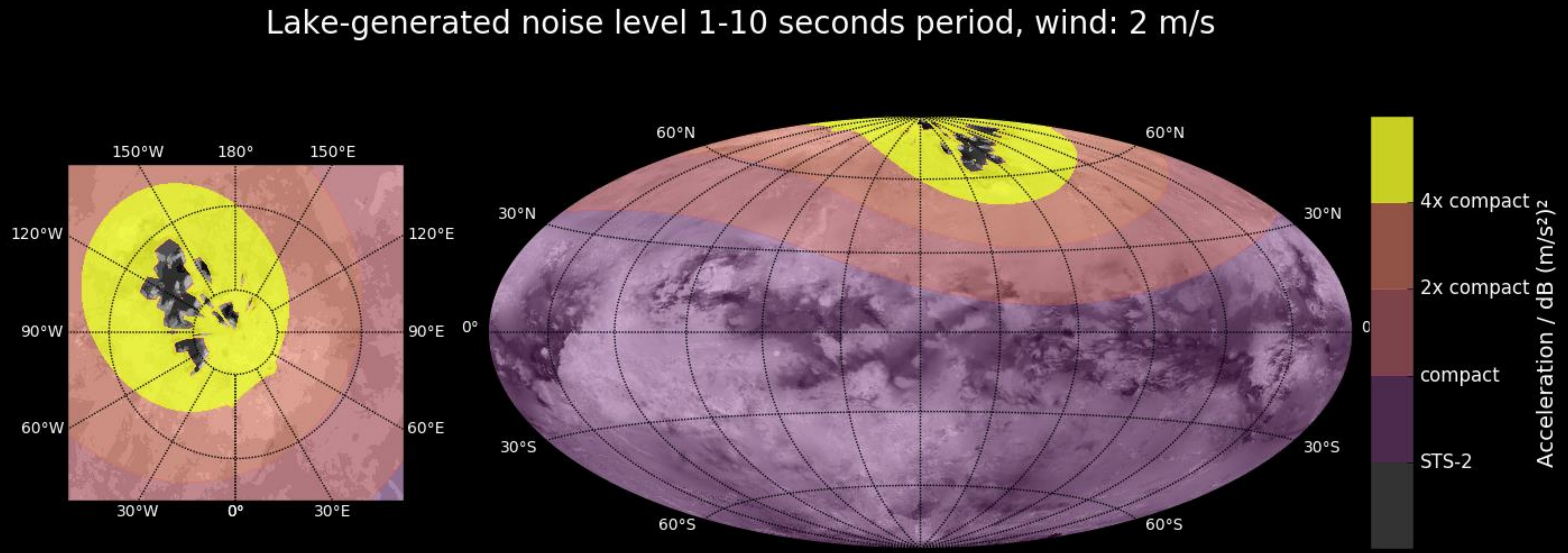
Anti-Saturn point

Sub-Saturn point



Modify event probability by spatial and temporal variability of tidal dissipation energy. See a more full description of the method at Hurford et al. poster “Tidally-Driven Seismicity: An Application to Europa” at poster location 656 on Thursday

Microseismic noise due to lake waves



Work by Simon Stähler for upcoming EGU presentation

Atmospheric noise

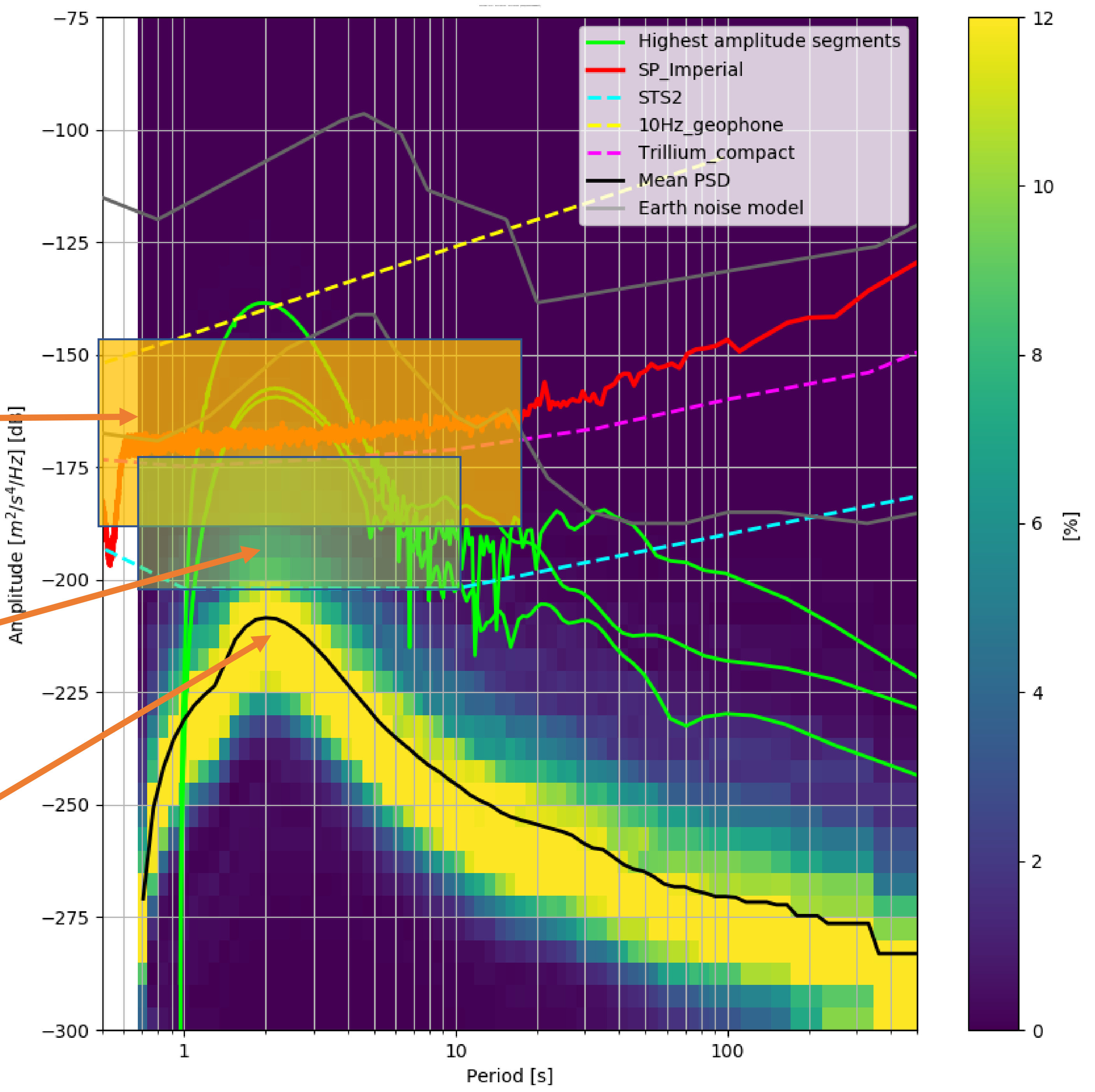
- For Mars, can be simulated with atmospheric circulation models coupled in elastically with the solid interior (e.g. Murdoch et al., 2017)
- For Venus, a very rough estimate of background noise (which should be dominated by atmospheric noise) is similar to a quiet Earth station based on very limited data from Venera geophones (Lorenz and Panning, 2018)
- We can scale between those estimates by the estimated acoustic impedance of the atmosphere at the surface, which is linearly related to the transmission to the interior (Venus/Titan ~ 25 and Titan/Mars ~ 220)

Signal and noise

Estimated atmospheric noise

Estimated lake wave noise at equator

Estimated tidal cracking noise



Conclusions

- The largest tidal ice-cracking events over a few tidal cycles will likely be observable by high-quality planetary seismic instruments.
- Landing sites away from sub-Saturn and anti-Saturn points maxmize chance of seeing events.
- Tidal cracking background noise is negligible, wave noise on lakes can be important in the northern hemisphere, and atmospheric noise is likely measurable everywhere.
- Atmospheric noise may be comparable with the amplitude of the largest events.