Earth's Response to Gravitational Waves

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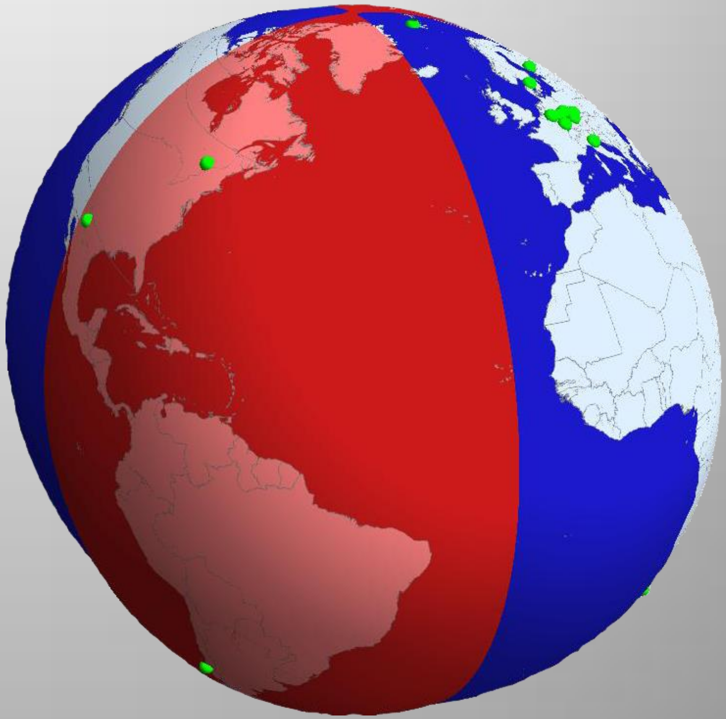
In collaboration with Michael Coughlin

Earth Response: Two Models

f >> 10mHz

F. Dyson, ApJ 156 (1969)

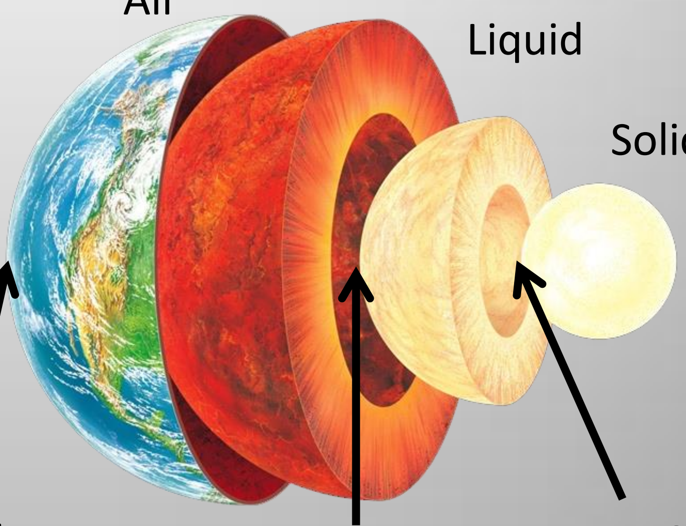
f << 10mHz



A. Ben-Menahem, N. Cim. C 6 (1983)

Elastic Body GW Response

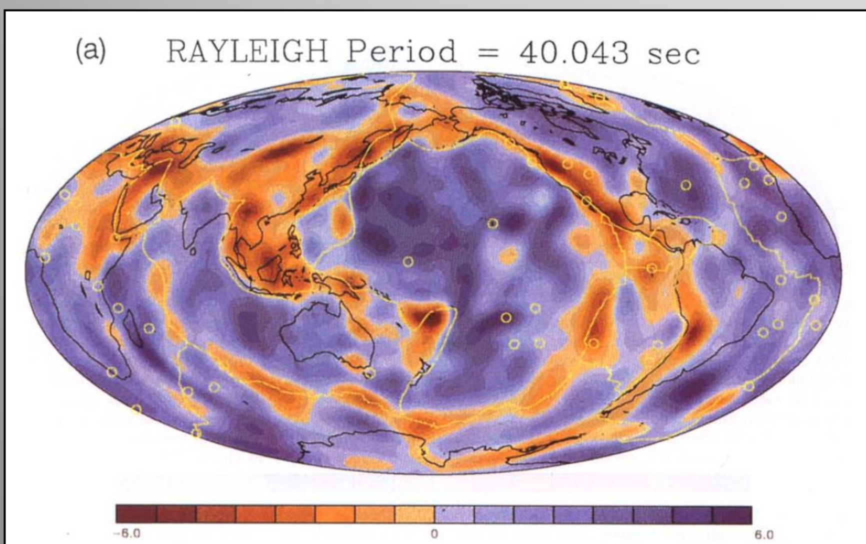
Requires change in shear modulus.



Flat Surface: Calibration

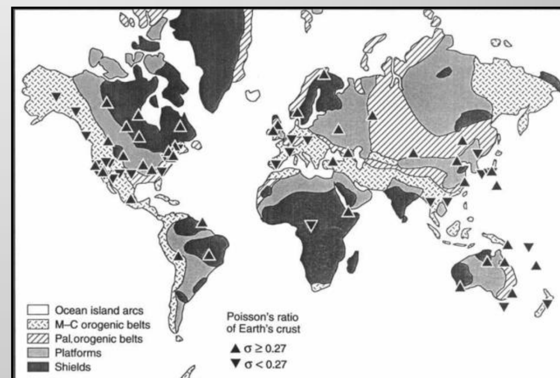
$$\dot{\xi}_z(\vec{r},t) \approx -\frac{\beta^2}{\alpha}\vec{e}_z^{\top} \cdot h(\vec{r},t) \cdot \vec{e}_z$$

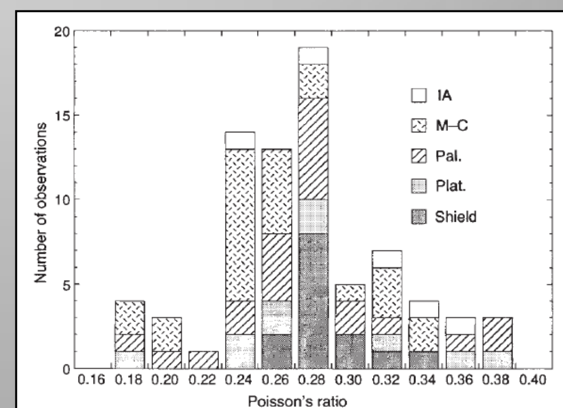
Rayleigh-wave speed



Trampert, Woodhouse (1995)

Poisson's ratio

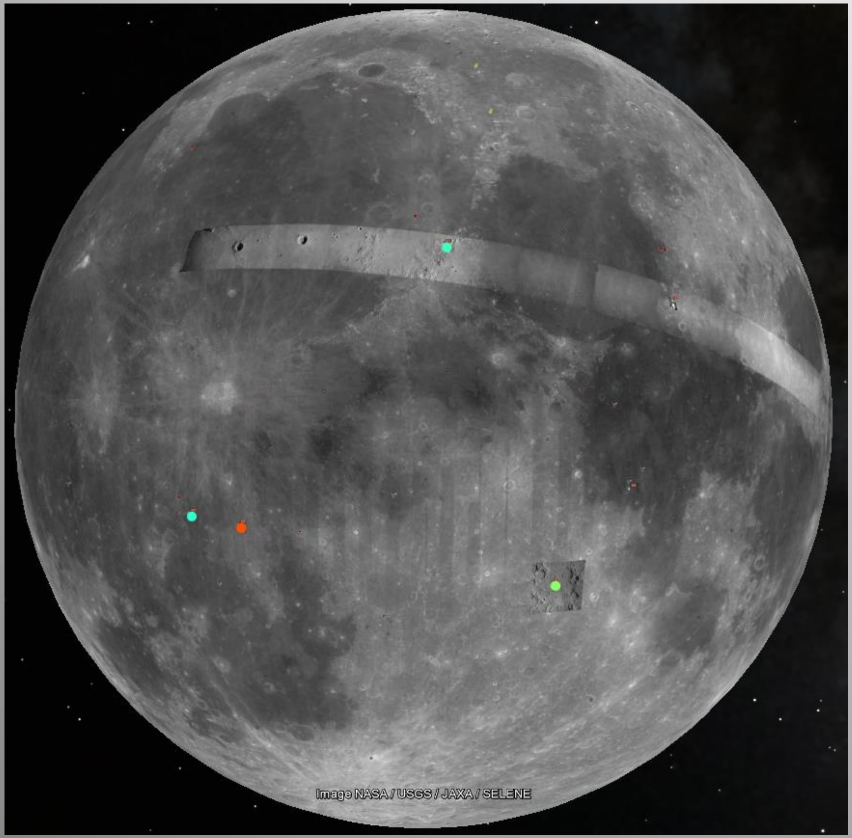


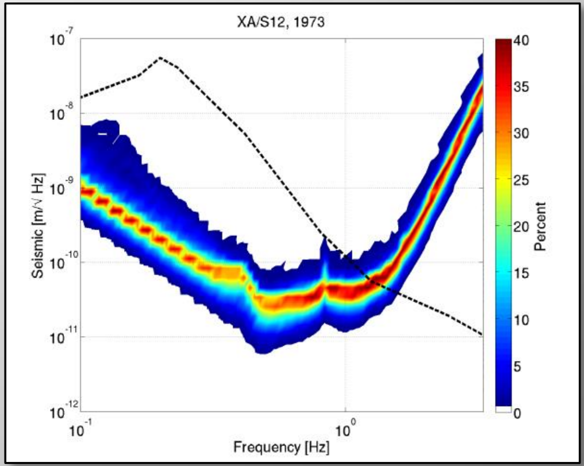


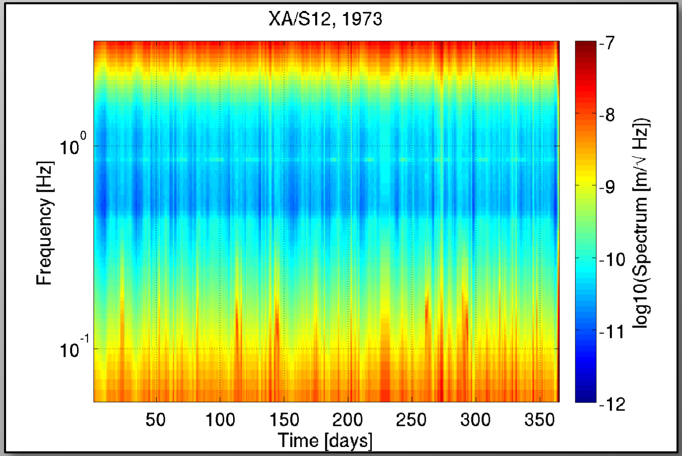
Zandt, Ammon (1995)

Moon Seismometers

4 seismometers on the Moon. Ambient noise well under terrestrial low-noise model.



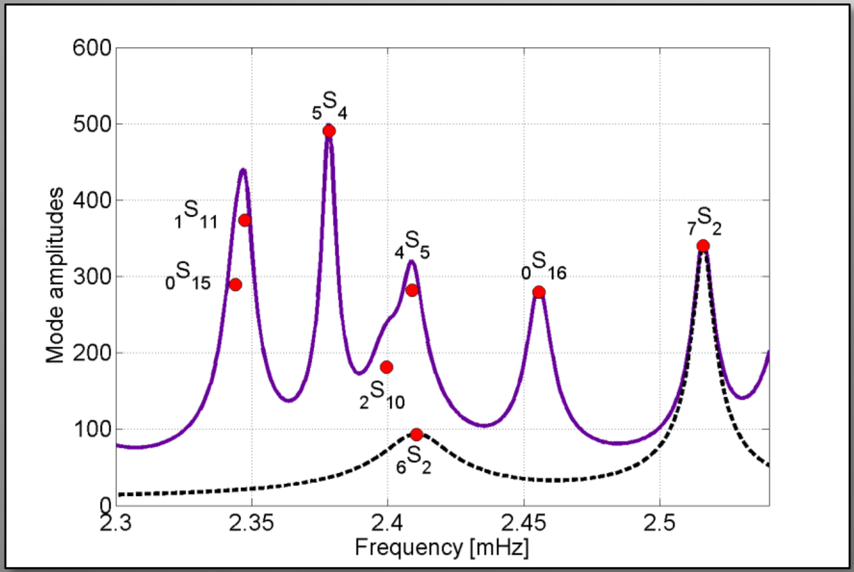


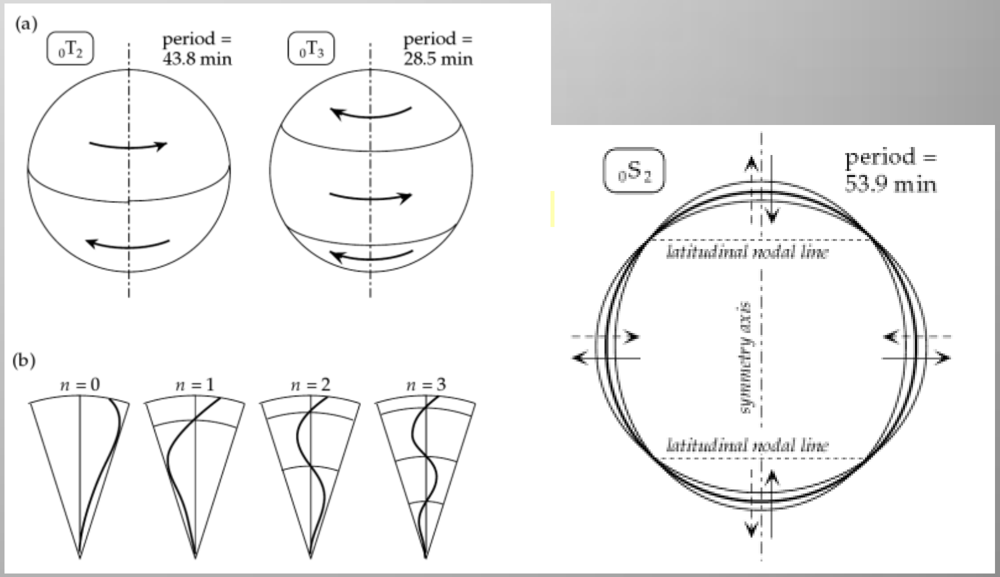


Earth Normal Modes

Only spheroidal modes produce radial displacement and gravity perturbations.

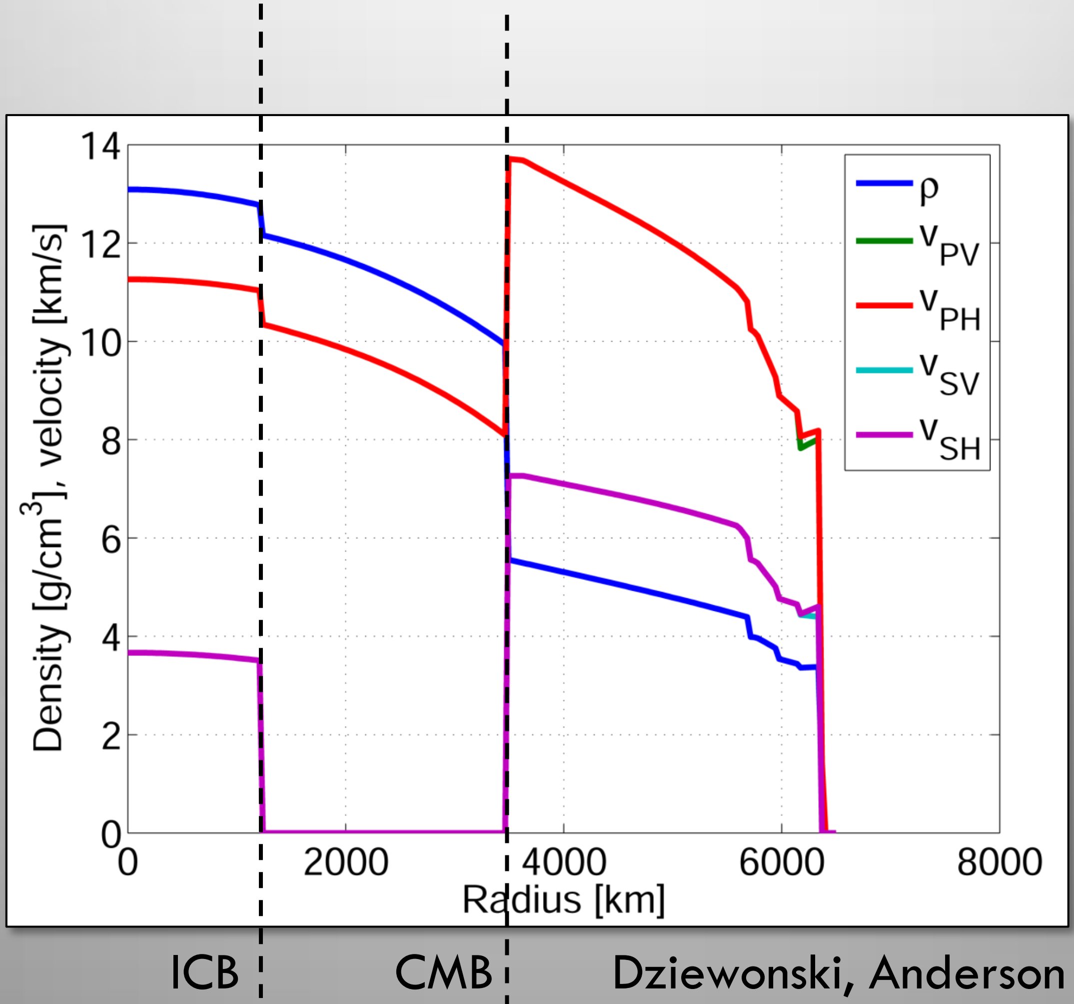
Earth free oscillations divide into spheroidal and toroidal modes.





W. Lowrie (2007)

PREM



Dziewonski, Anderson (1981)

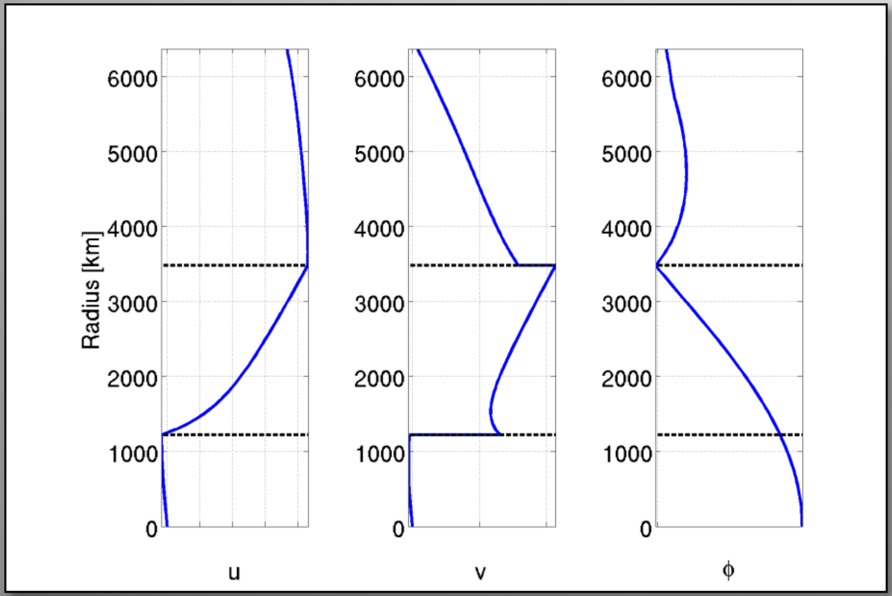
Quadrupole Modes

Quadrupole mode $_0S_2$

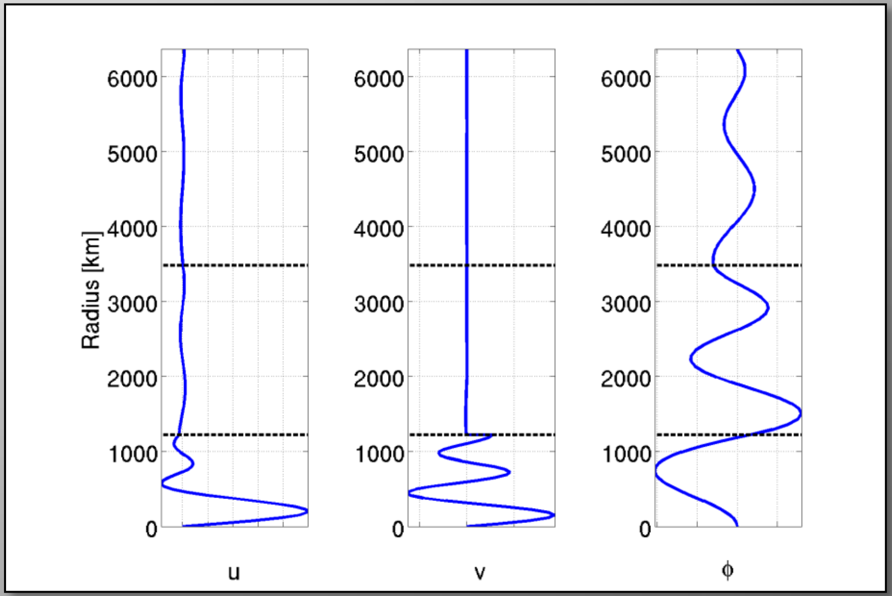
f = 0.31mHz, Q = 510

Quadrupole mode $_{20}S_2$

f = 7.35mHz, Q = 509



Radial Lateral Gravity

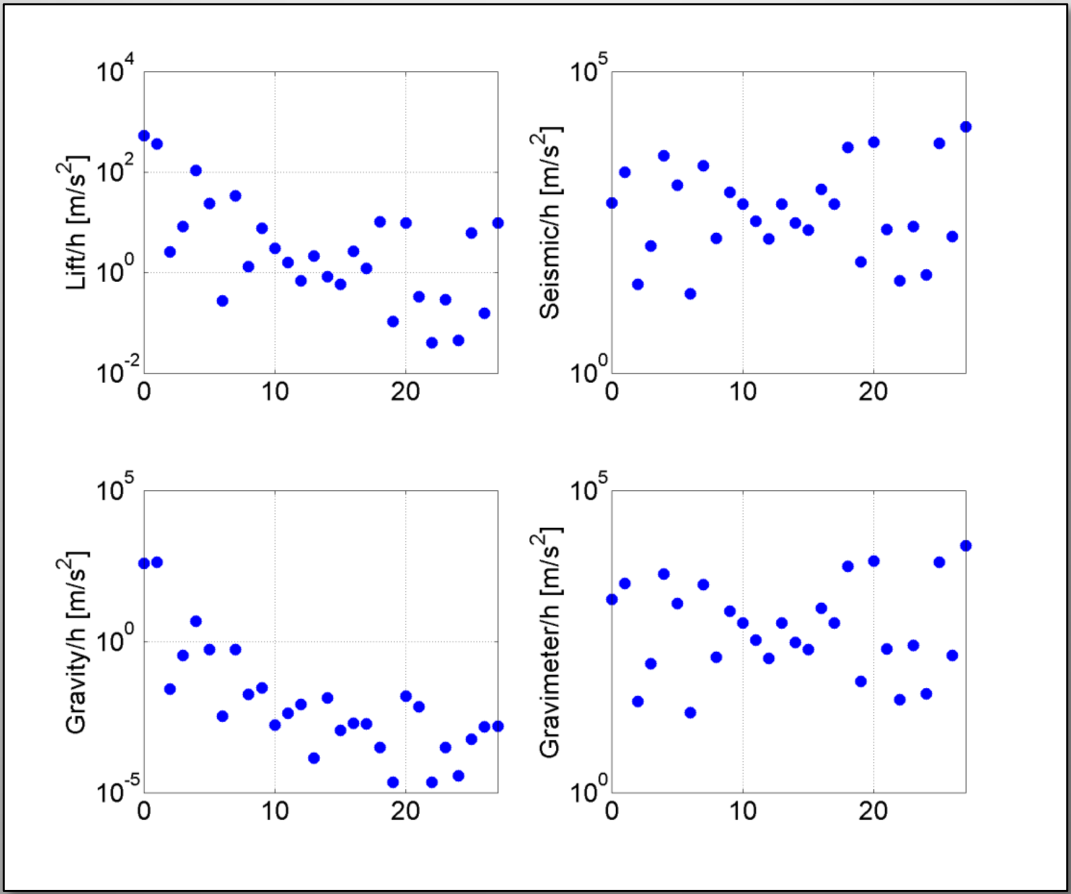


Minos simulation

GW Response

Lift against static gravity gradient

Perturbation of gravity potential

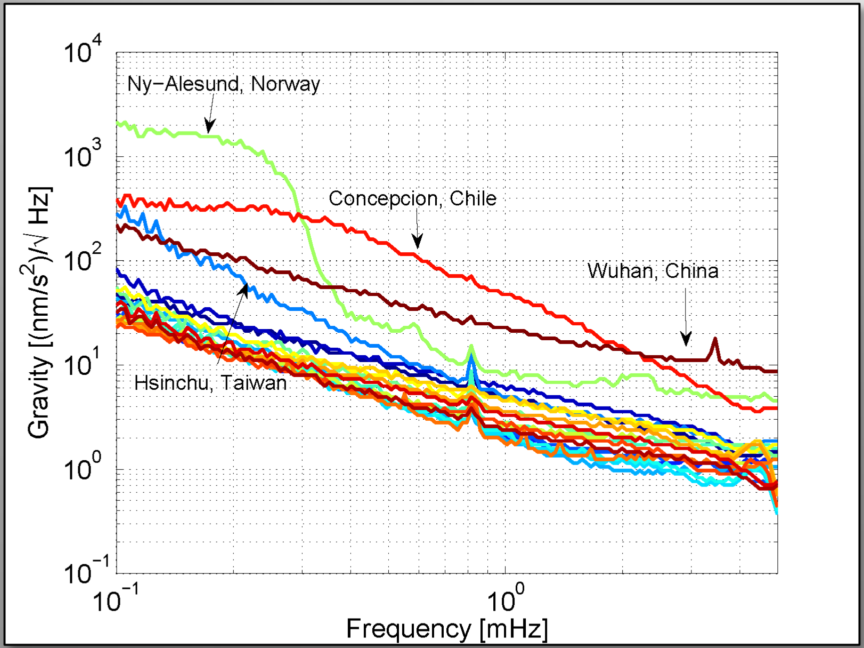


Seismic acceleration

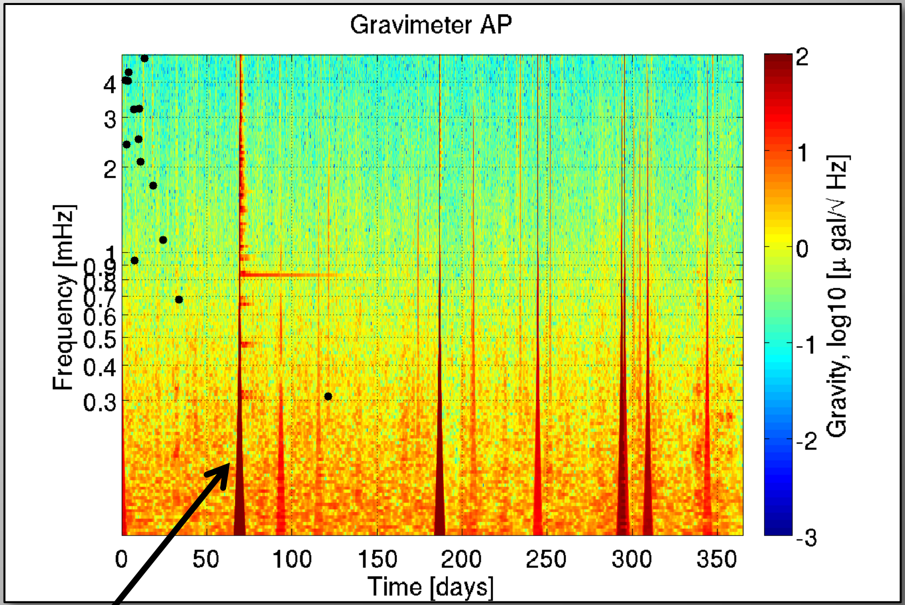
Total

Gravimeter Data

Similar stationary noise background

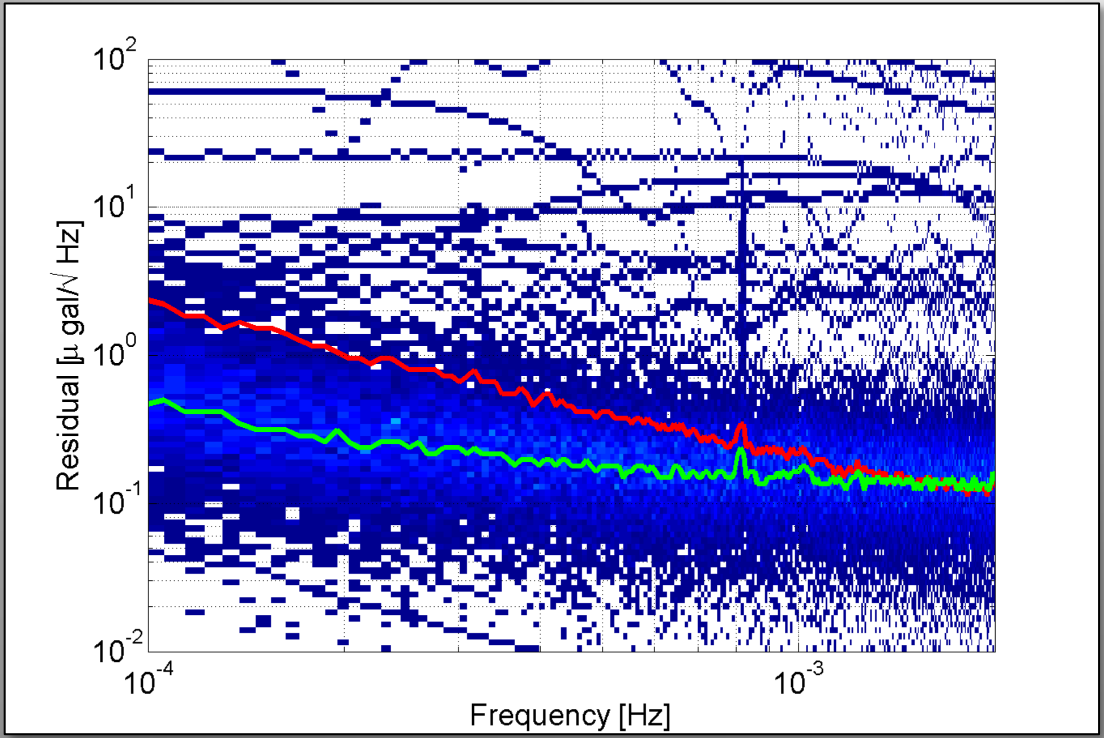


M>6.5 earthquakes



Tohoku, 2011 (M9.0)

Newtonian Noise Subtraction



Practicable method:

(1) Take collocated pressure sensor

(2) Subtract with constant coefficient: -0.39 μgal/hPa

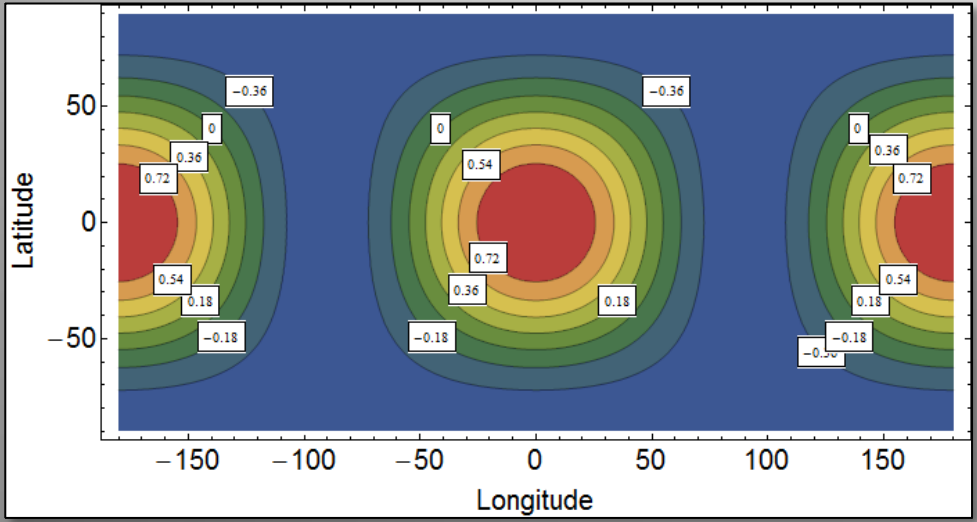
Wiener filters:

(1) Require high data quality (which not all gravimeters have)

(2) Requires a lot of tweaking of the algorithm to calculate the coefficients

Overlap-Reduction Function

Where do you have to place two sensors to maximize GW correlation?



Option 1:

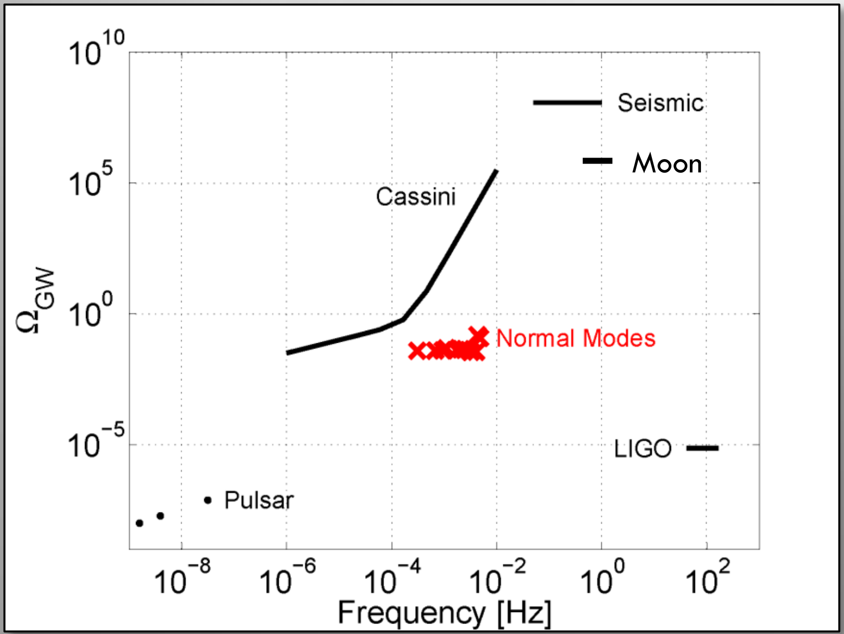
Place them next to each other.

Problem: terrestrial sources can potentially produce correlations.

Option 2:

Make it an antipodal pair.

Constraints on GW Energy Density



GW models at 1mHz

Cosmological binaries: 1e-12

Inflation: 1e-15

Cosmic strings: 1e-7

Conclusion: 3 orders of magnitude GW strain sensitivity missing to constrain exotic models of GW backgrounds, or to detect galactic WD/WD.