Searching for Transient Deformations:

What Can We See?

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Continuous recording of deformation aims to capture transient deformations.

These, we hope, will reveal new physics that is otherwise unobservable.

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- **Inside the Earth** (surface loads are easier to observe in other ways)
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- From **slip on faults**, or inelastic response – I will focus on slip.

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We combine source behavior and noise
to determine what sources we can detect.

Decay with Distance I

Displacement at a distance r from a moment-tensor source $\mathbf{M}(t)$ is

$$u = u_N + u_F = \frac{G_N(\theta,\phi)}{4\pi\rho c^2}\frac{1}{r^2}M(t - r/c) + \frac{G_F(\theta,\phi)}{4\pi\rho c^3}\frac{1}{r}\frac{dM(t-r/c)}{dt}$$

That is, u combines a **near-field** term decaying as r^{-2}, and a **far-field** (radiation) term decaying as r^{-1}.

Seismic waves are the far-field term – and they are, in this model, always present.

Decay with Distance II

If the time constant of the moment release is t_S, that the magnitude of $\frac{dM}{dt}$ is roughly M/t_S. The ratio of far-field to near-field displacement is, also roughly,

$$\frac{u_F}{u_N} = \frac{G_F \dot{M}}{G_N M} \frac{r}{c} \approx \frac{r}{t_S c} = \frac{T}{t_S}$$

where T is the travel time.

For a typical geodetic network, the spacing gives $T \approx 1$–10^2s, and the near-field term dominates for any source slower than that.

Detection in Noise

Given a signal, $u(t)$, with a Fourier amplitude spectrum $U(f)$, the signal-to-noise ratio is

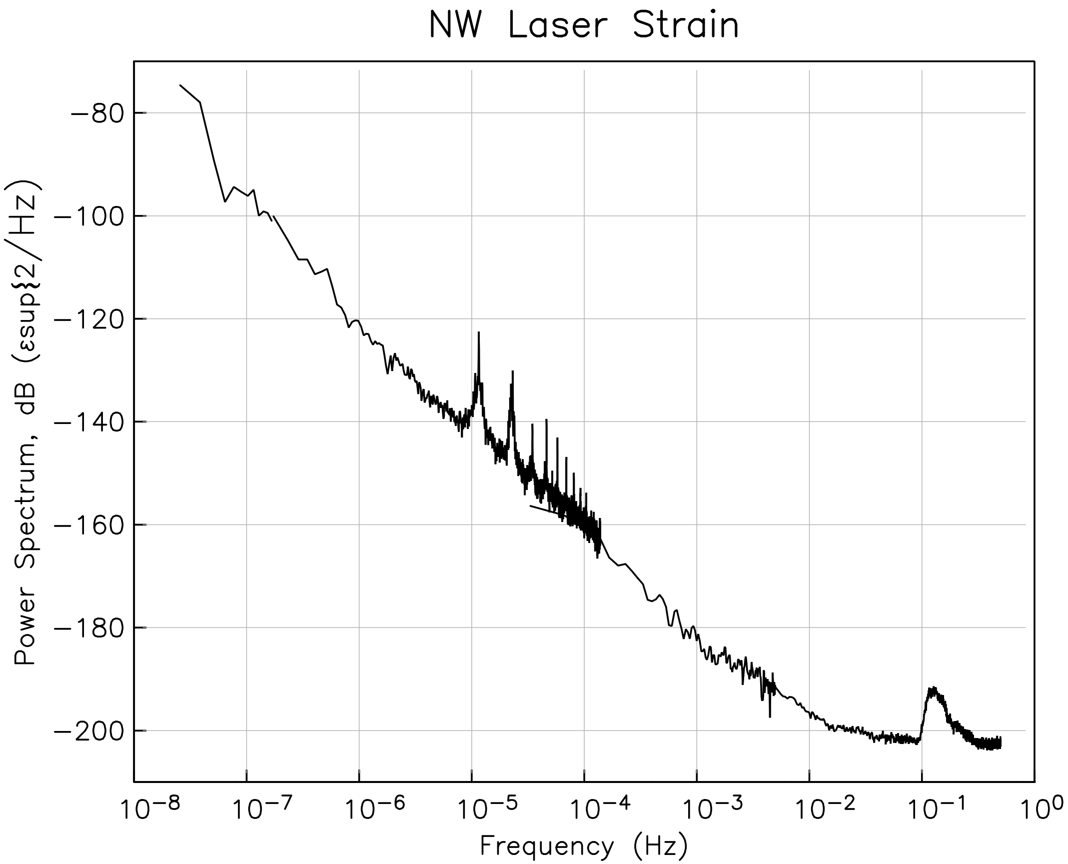
$$\mathrm{SNR} = \left[\int_0^\infty \frac{|U(f)|^2}{N(f)}\, df \right]^{\frac{1}{2}}$$

where $N(f)$ is the **power spectrum** of the noise (of whatever we are looking for).

If u has a time constant t_S, we can approximate the SNR by $\frac{u_{RMS}}{B(t_S)}$, where

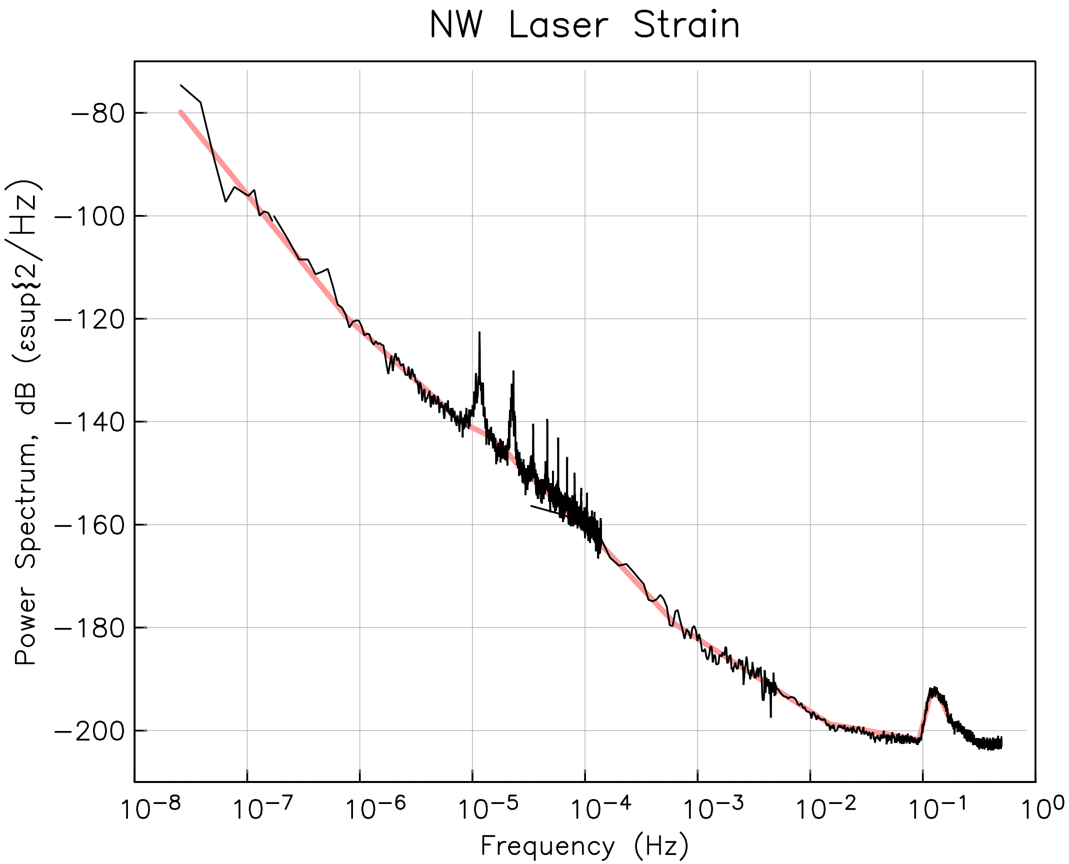
$B(t_S)$ is the RMS noise over a one-octave band: $B(t_S) = \left[\int_{\frac{1}{\sqrt{2}t_S}}^{\frac{\sqrt{2}}{t_S}} N(f)\, df \right]^{\frac{1}{2}}$

Strainmeter Spectrum I



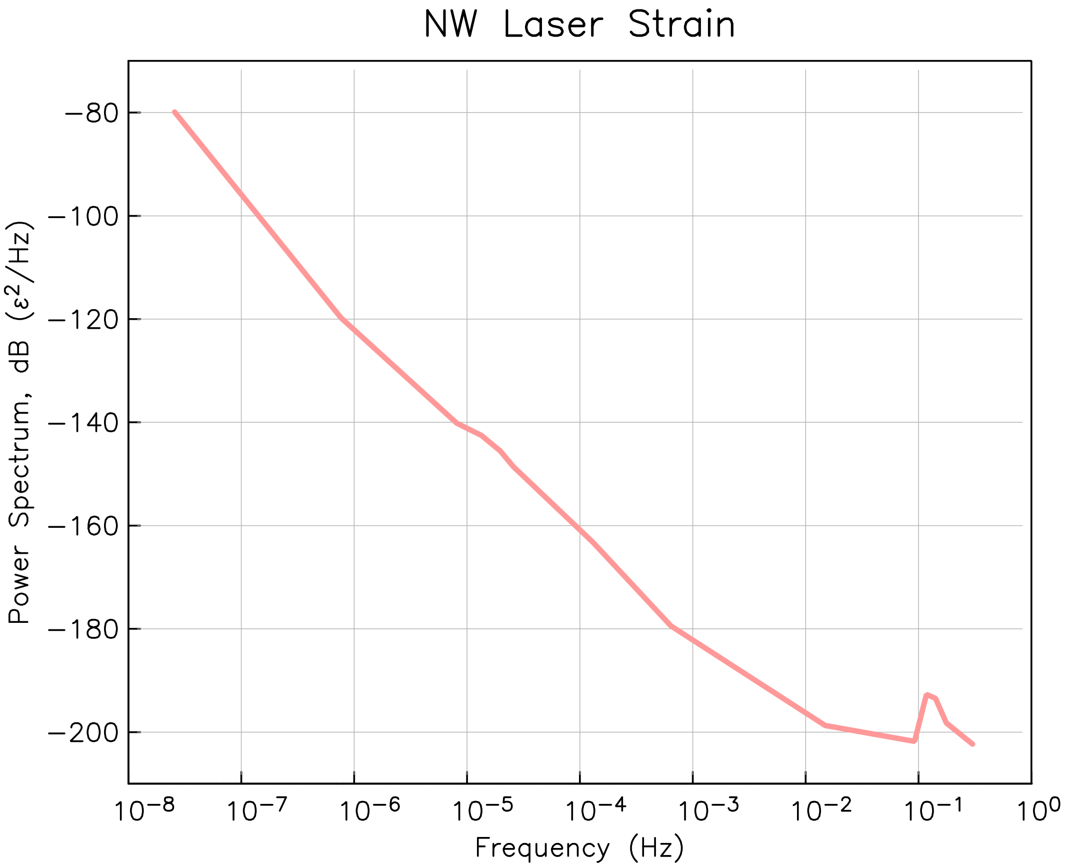
We use a high-quality strain record, from the NW-SE laser strainmeter at Piñon Flat Observatory:

Strainmeter Spectrum II



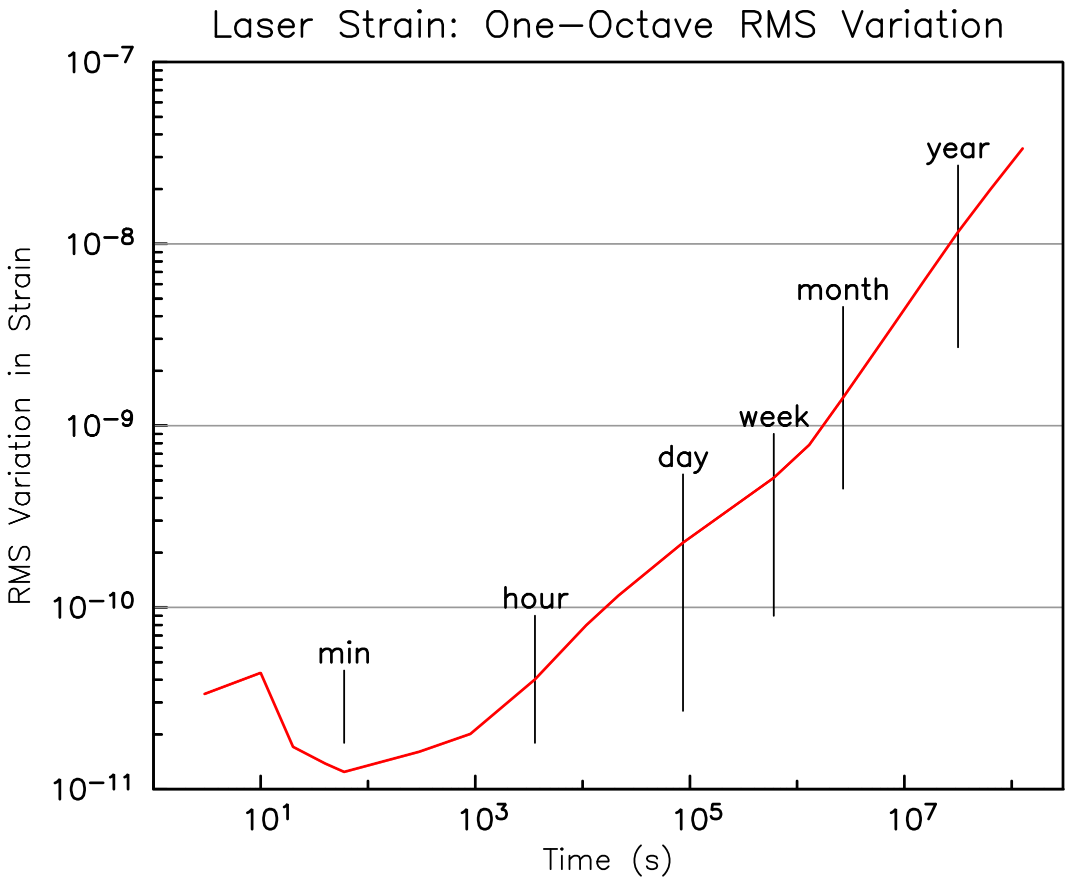
We fit a spectrum to this that consists of linear segments (in log-log space: a composite power-law spectrum.

Strainmeter Spectrum III



Here is the spectral model

Strainmeter Spectrum IV



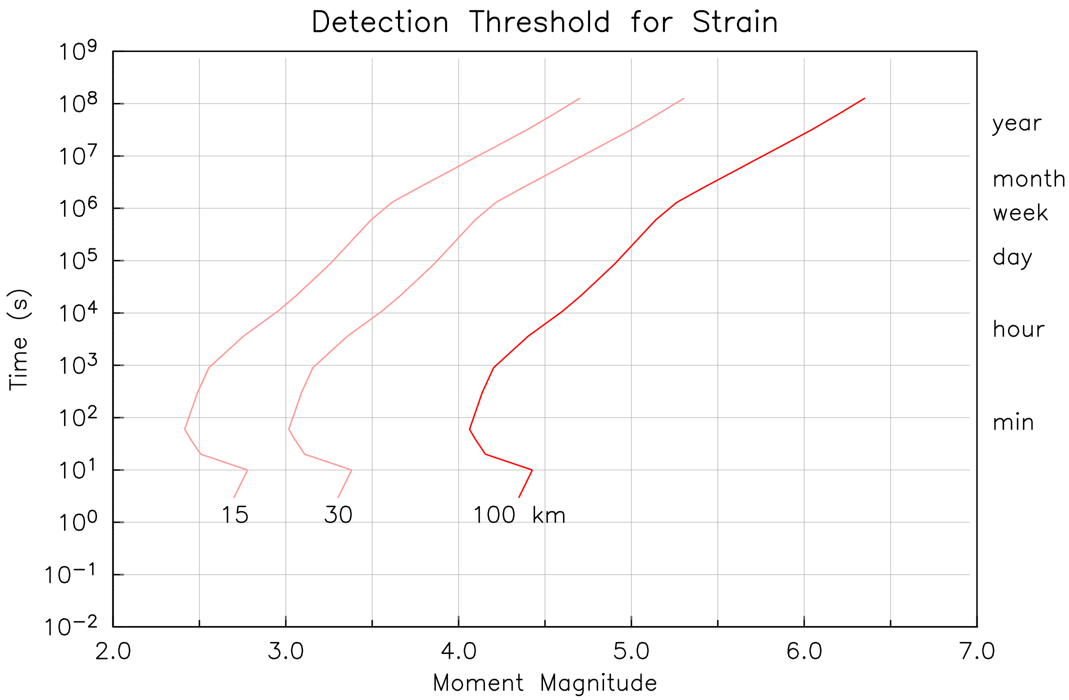
And from this we find $B(t_S)$.

Finding the Detection Level

To find out what moment we can detect, we equate the near-field strain $E = \frac{K_E M_0}{r^3}$ to $B(t_S)$. For a particular value of r, this gives a line in M_0 against t_S.

- On one side are events too small to detect.
- On the other, events we should be able to.

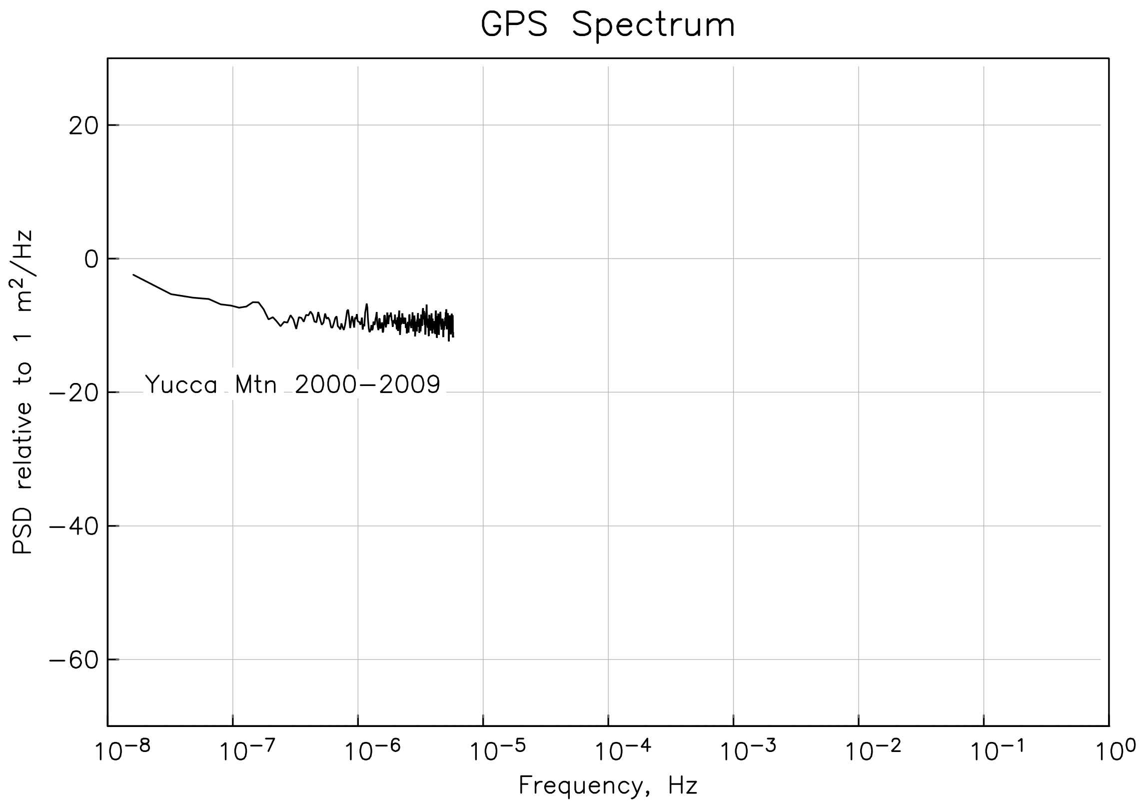
Detection Level for Laser Strainmeter



We choose distances 15 km (the minimum) to 100 km.

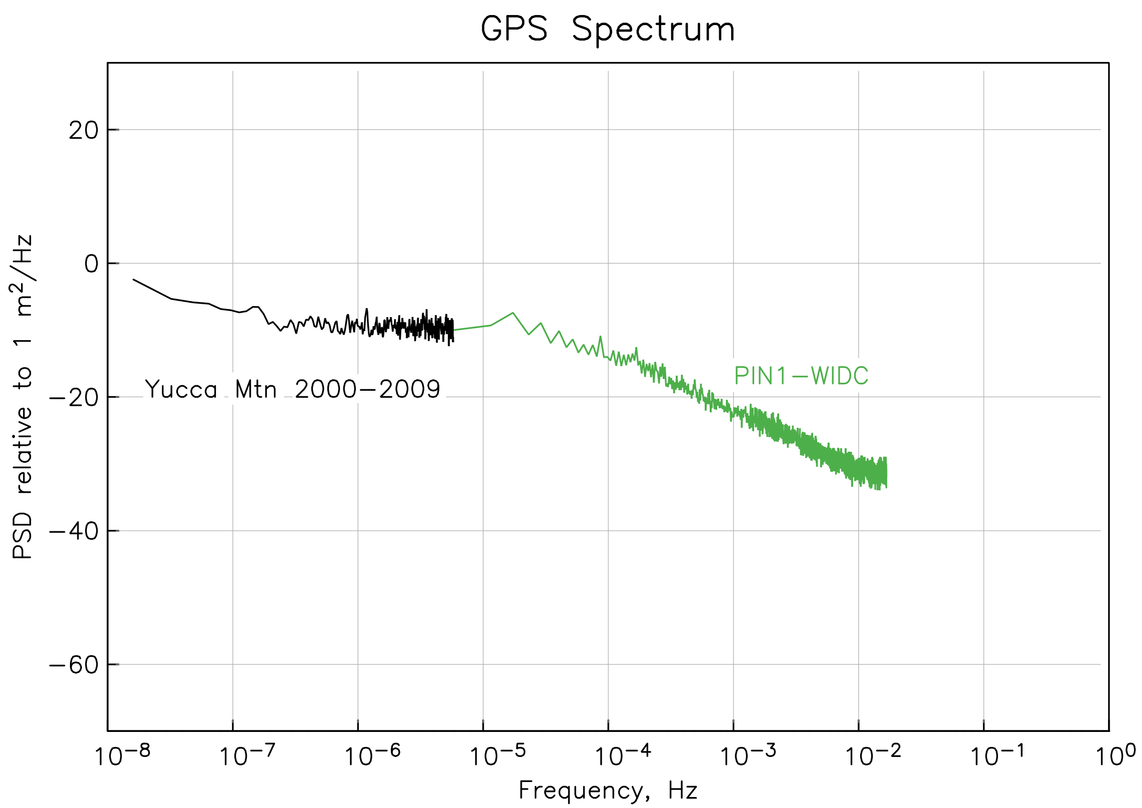
At short times and large distances the detection line would be farther left (more sensitive) because the far-field term becomes important.

GPS Spectrum 1



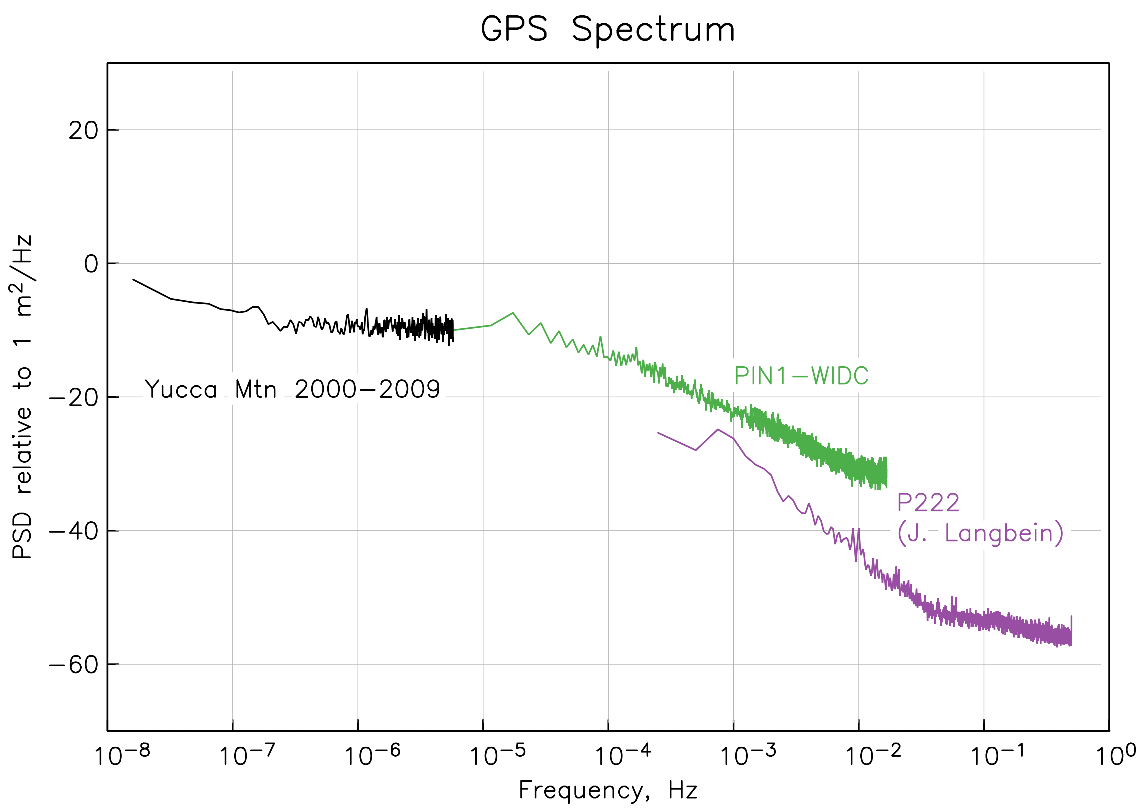
Probably a “best case”: the Yucca Mountain network, known for low noise.

GPS Spectrum 2



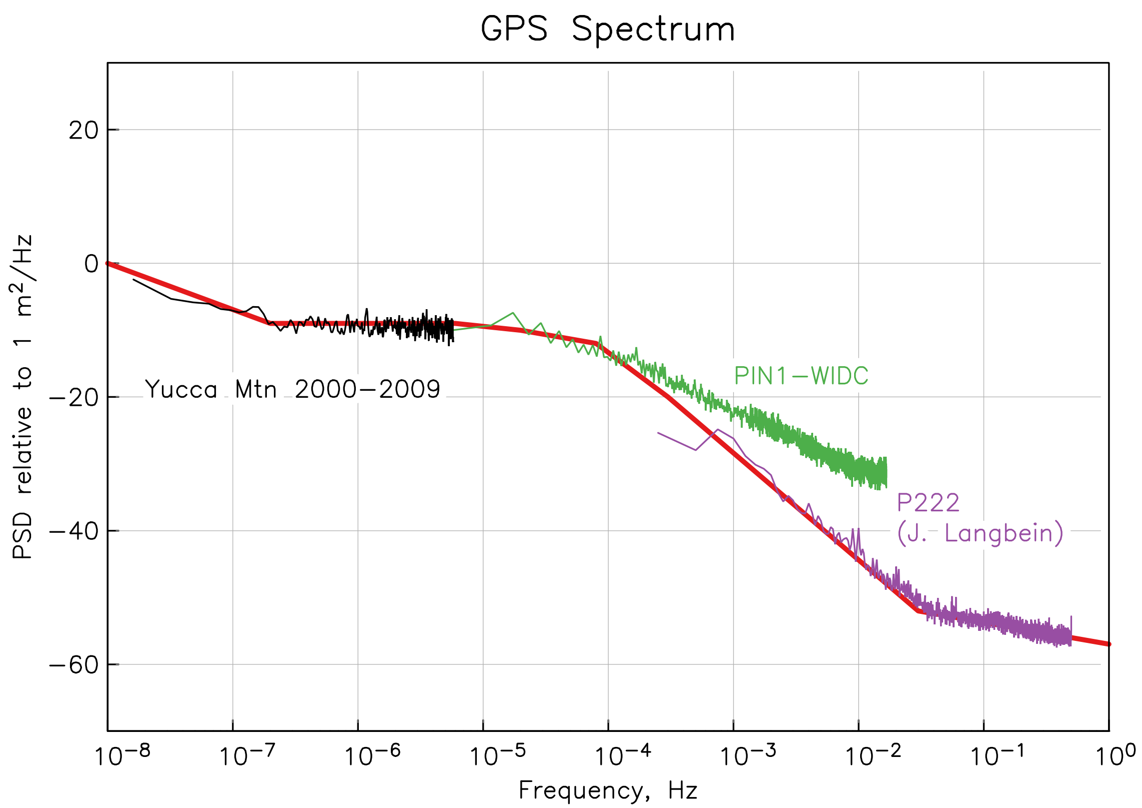
Repeat-time adjustment included, to reduce multipath.

GPS Spectrum 3



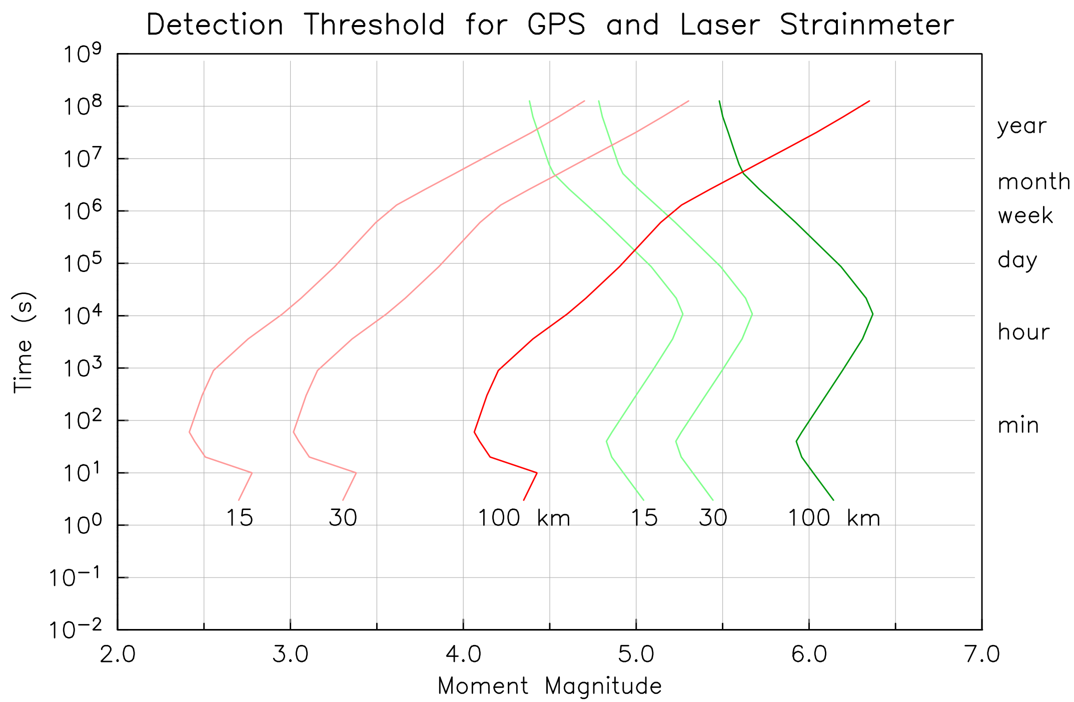
Data from P222, adjusted, courtesy of Dr. John Langbein

GPS Spectrum 4



Piecewise linear approximation to noise spectrum.

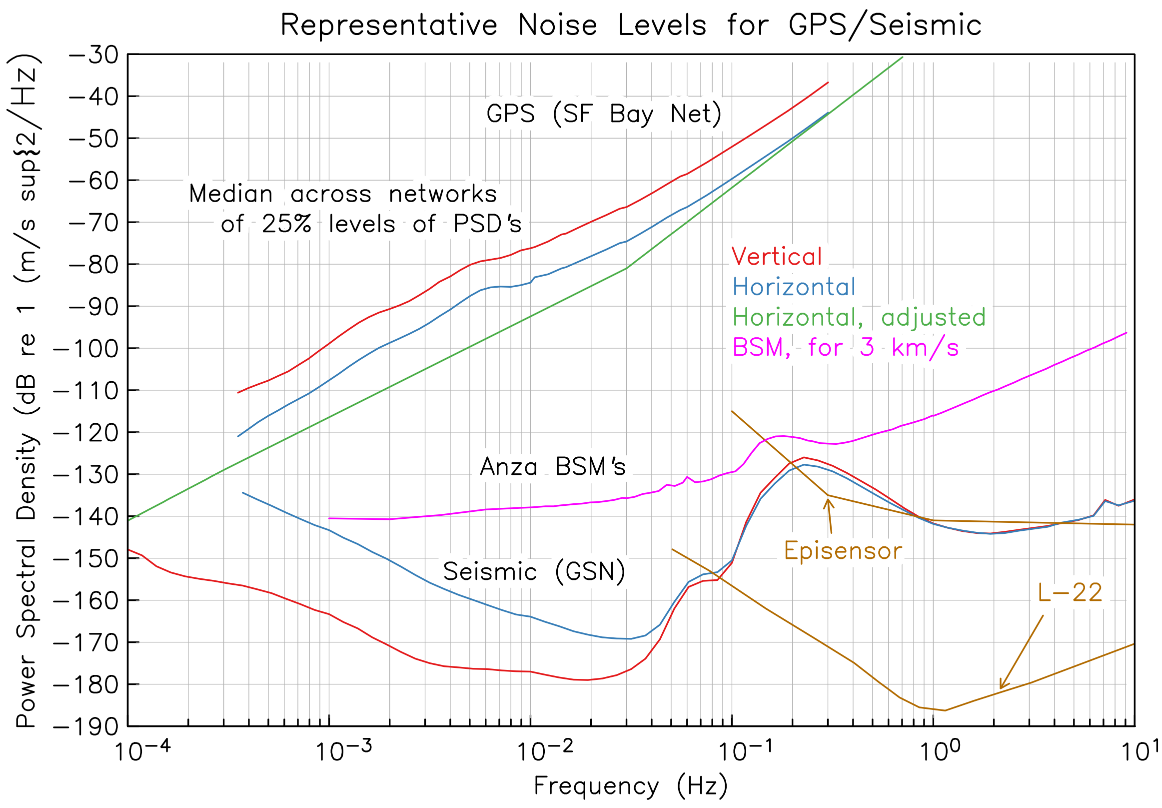
Detection Level for GPS and Laser Strainmeter



Close to the source, and at periods of less than years, the level can be **much** lower on the strainmeter.

There may be a large class of transient deformations detectable on strainmeters but not GPS.

Looking at Higher Frequencies



Broadband seismic best, especially vertical; GPS only useful for strong motion.