Searching for Transient Deformations:

What Can We See?

Duncan Carr Agnew

IGPP/SIO/UCSD

What Are We Doing?

Continuous recording of deformation aims to capture transient deformations.

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

These sources will be:

- Slow enough that the deformations are a quasi-static elastic response.

What Are We Doing?

Continuous recording of deformation aims to capture transient deformations.

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

These sources will be:

- Slow enough that the deformations are a quasi-static elastic response.
- Inside the Earth (surface loads are easier to observe in other ways)

What Are We Doing?

Continuous recording of deformation aims to capture transient deformations.

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

These sources will be:

- Slow enough that the deformations are a quasi-static elastic response.

- Inside the Earth (surface loads are easier to observe in other ways)
- At seismogenic depths.

What Are We Doing?

Continuous recording of deformation aims to capture transient deformations.

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

These sources will be:

- Slow enough that the deformations are a quasi-static elastic response.
- Inside the Earth (surface loads are easier to observe in other ways)
- At seismogenic depths.
- From slip on faults, or inelastic response – I will focus on slip.

What Can We See?

This depends on

- How signals decay with distance.

What Can We See?

This depends on

- How signals decay with distance.
- Instrument noise levels: if we can’t detect a signal, we cannot succeed.

What Can We See?

This depends on

- How signals decay with distance.
- Instrument noise levels: if we can’t detect a signal, we cannot succeed.

So, we need to combine these to determine what sources we can see.

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}.

The far-field term is what we usually call “seismic waves”.

Decay with Distance II

If the time constant of the moment release is t_S, we can say that the magnitude of $\frac{dM}{dt}$ is M/t_S. Then the ratio of far-field to near-field displacement is $\frac{u_F}{u_N} = \frac{G_F \dot{M}}{G_N M}\frac{r}{c} \approx \frac{r}{t_S c} = \frac{T}{t_S}$ where we ignore the different geometric factors G; T is the traveltime.

Over the typical spacing of a geodetic network, $T \approx 1$–10^2s, and the near-field term will dominate for any source with a longer time constant.

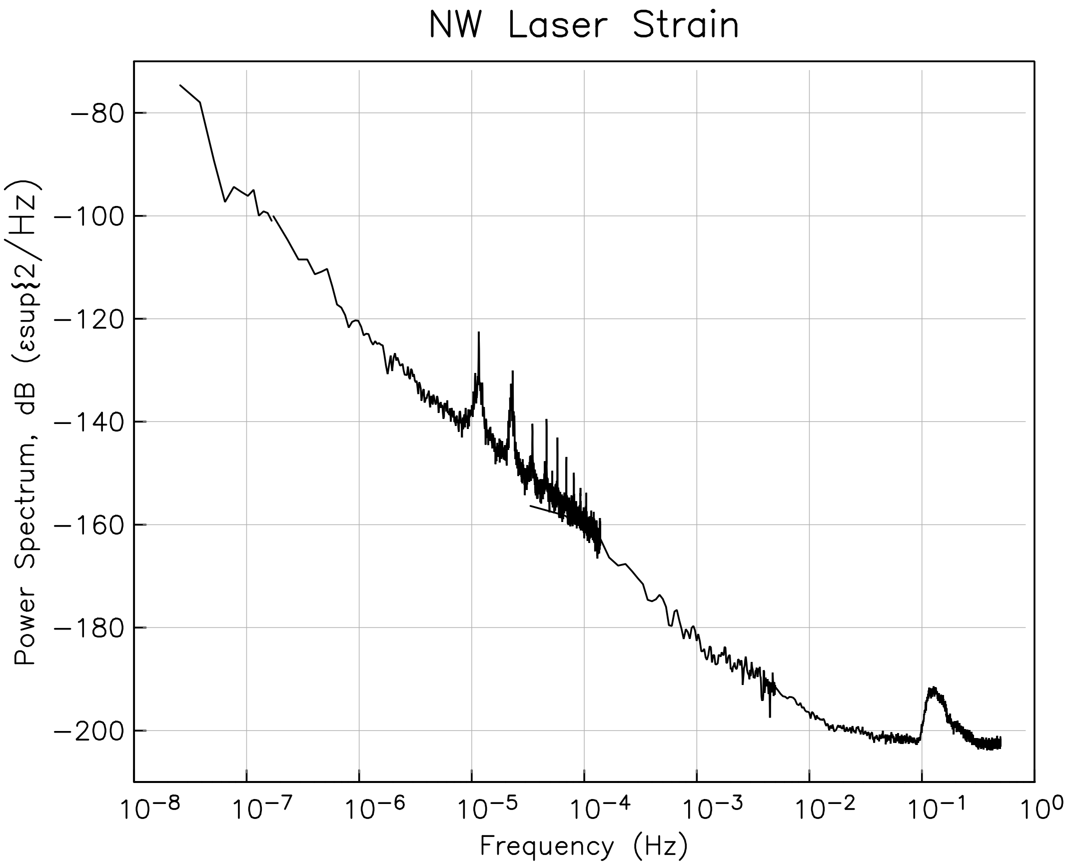
Instrument Noise

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

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

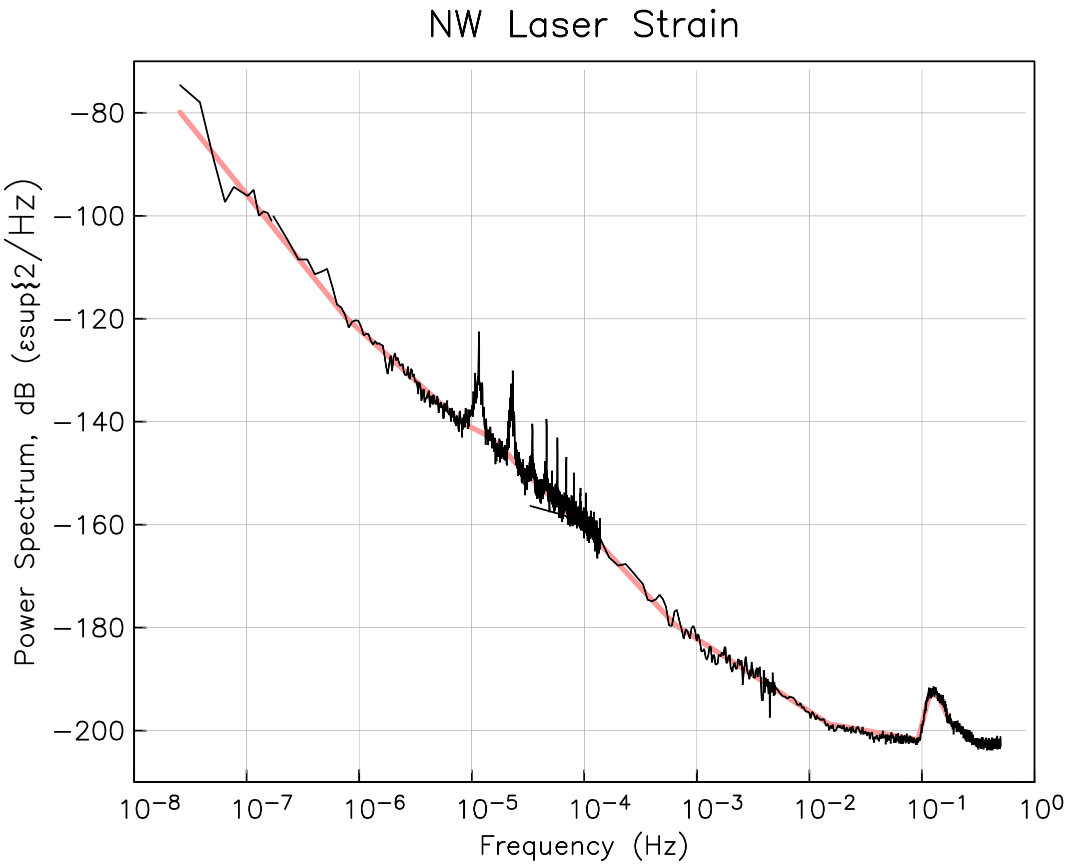
where $N(f)$ is the power spectrum of the noise. If u has a time constant t_S, we can approximate this by $\frac{u_{RMS}}{B(t_S)}$, where $B(t_S)$ is the RMS noise over a one-octave band: $B(t_S) = \left[\int_{\frac{1}{\sqrt{2}t_S}}^{\frac{\sqrt{2}}{t_S}} N(f)\, df \right]^{\frac{1}{2}}$

Strainmeter Spectrum I



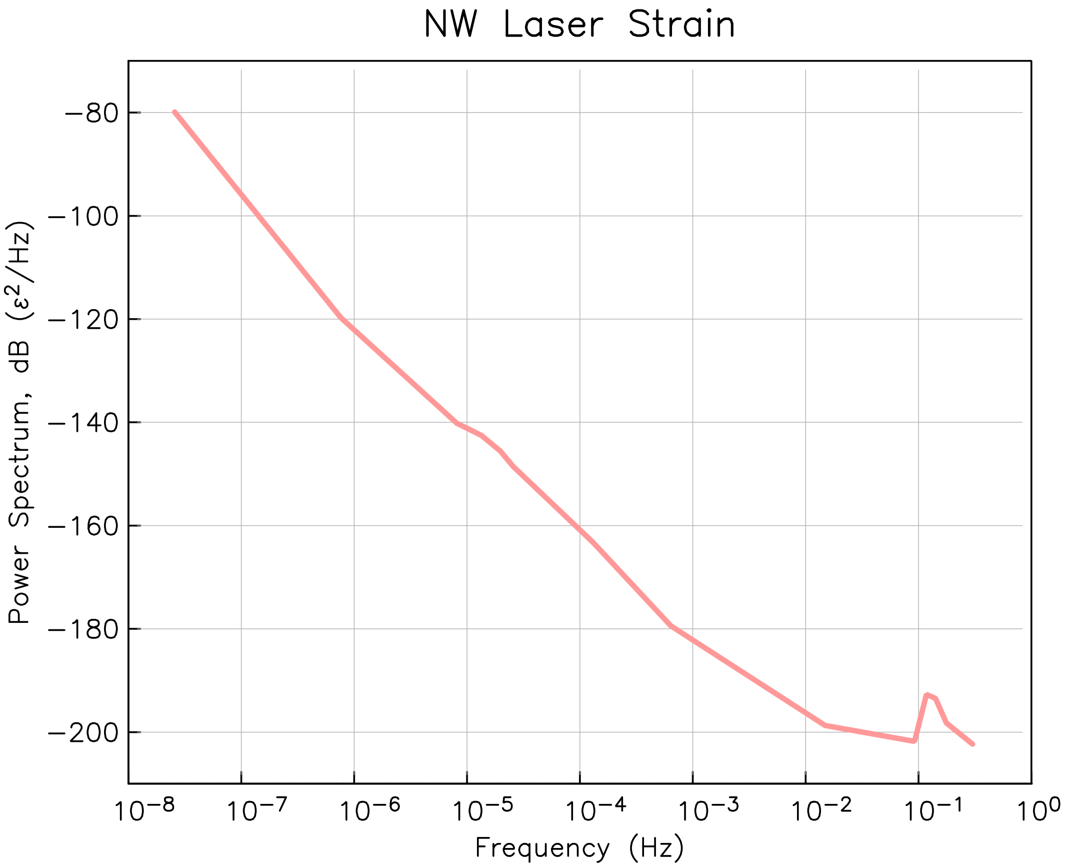
We use a high-quality strain record, from the NW-SE laser strainmeter at Piñon Flat Observatory:

Strainmeter Spectrum II



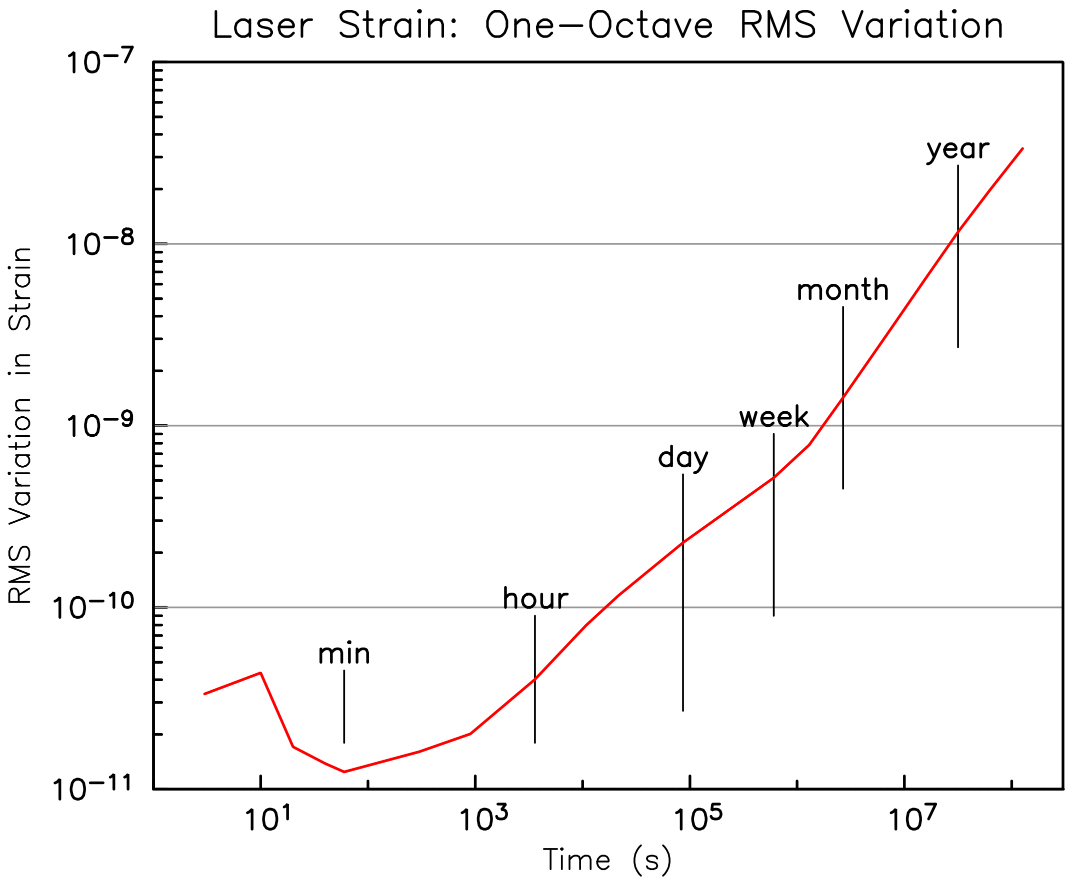
We fit a spectrum to this that consists of linear segments (in log-log space: a composite power-law spectrum.

Strainmeter Spectrum III



Here is the spectral model

Strainmeter Spectrum IV



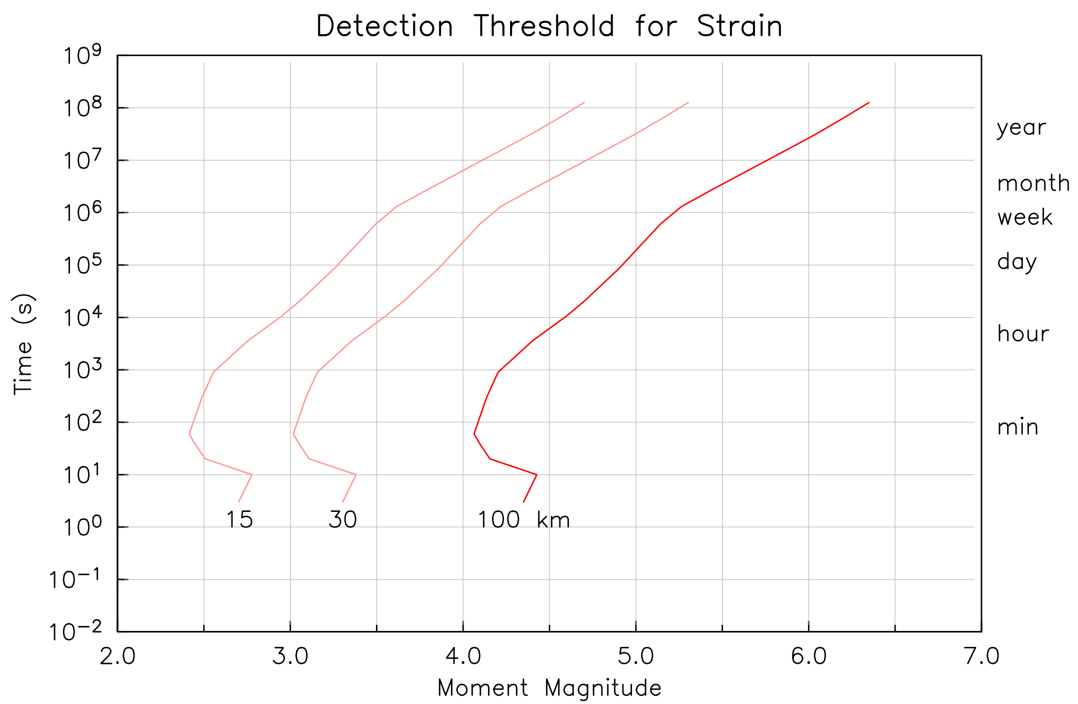
And from this we find $B(t_S)$.

Finding the Detection Level

To find out what moment can be detected, 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 we have events too small to detect.
- On the other, we have events that we should be able to.

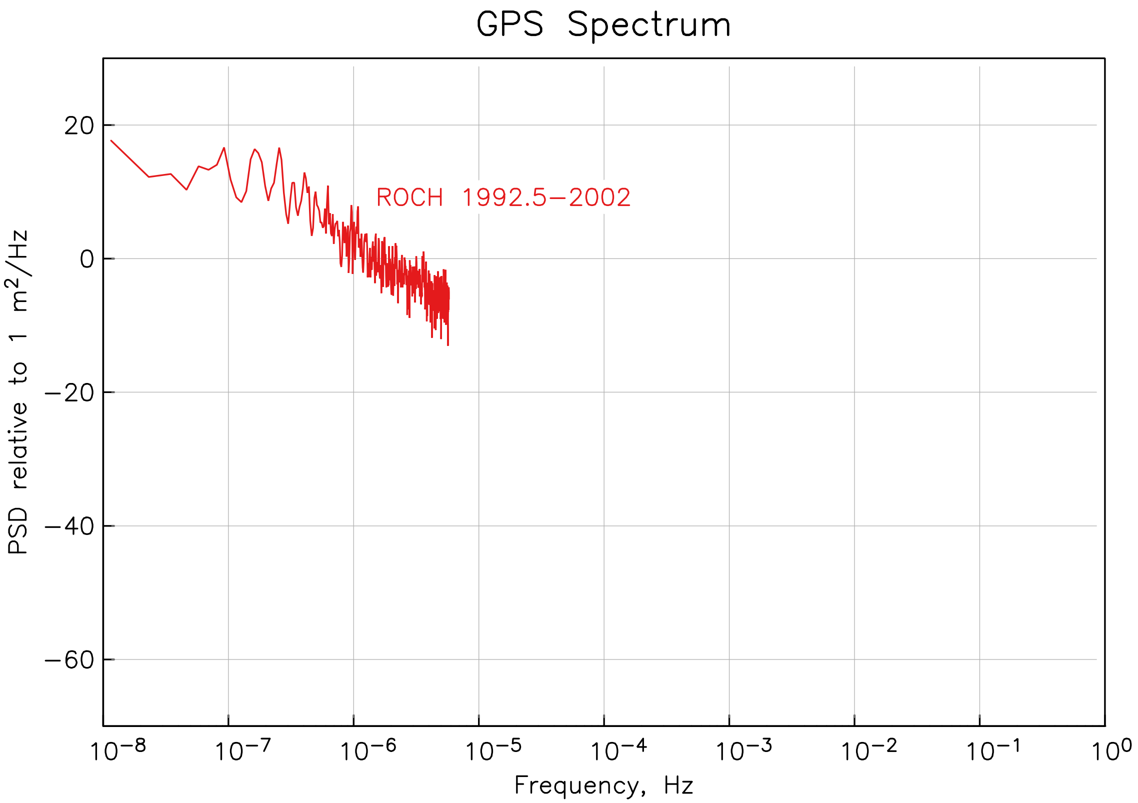
Detection Level for Laser Strainmeter



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

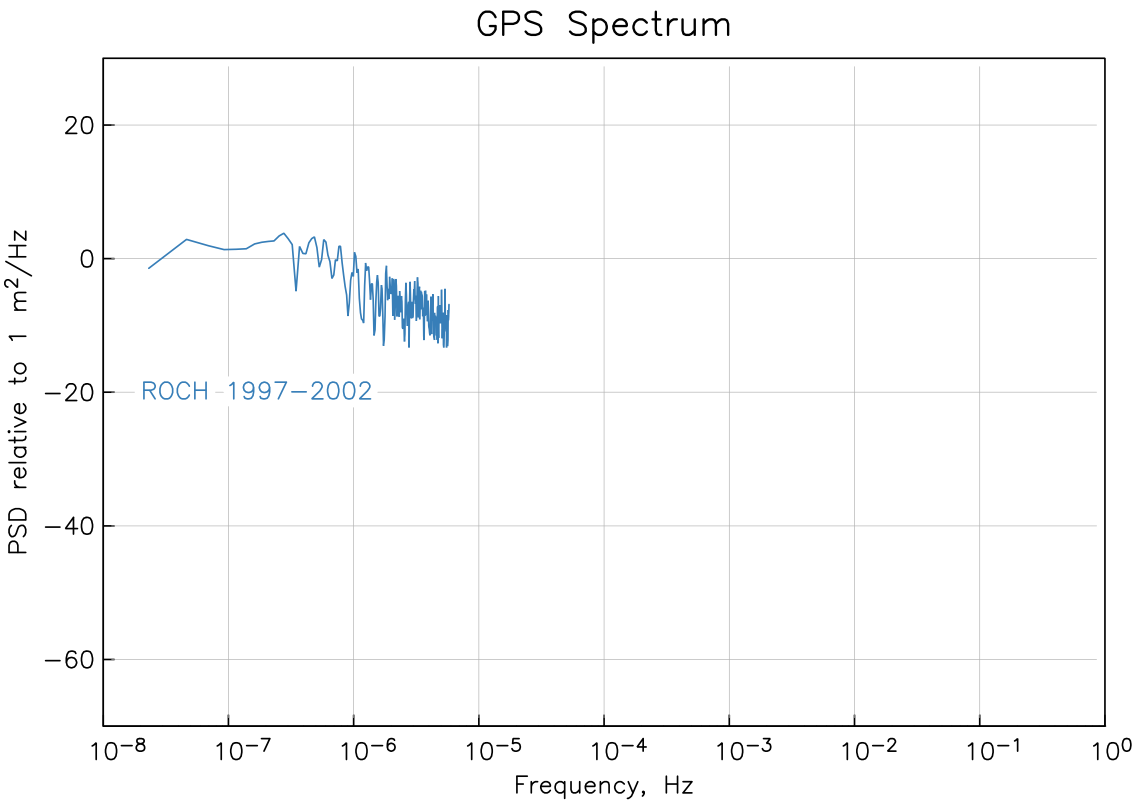
At short times and large distances the detection line would be farther left (more sensitive) because the far-field term becomes important.

GPS Spectrum 1



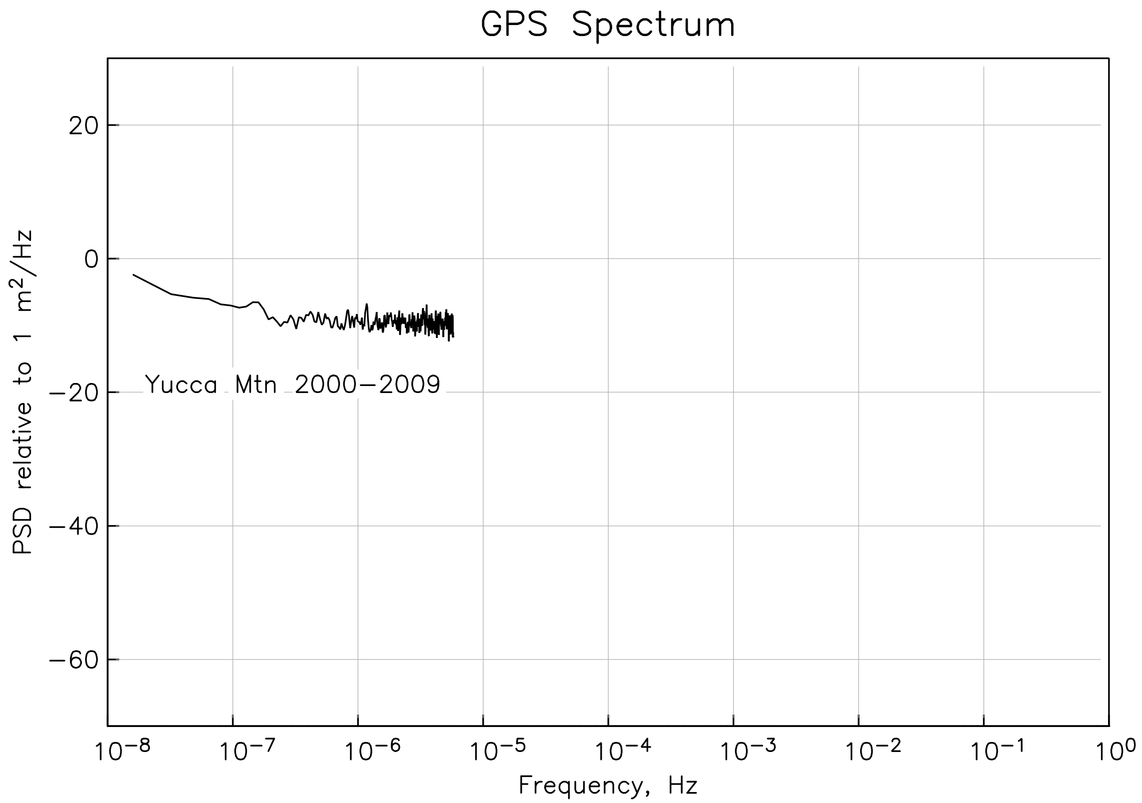
At long periods GPS spectra show lower noise with date; this is early data.

GPS Spectrum 2



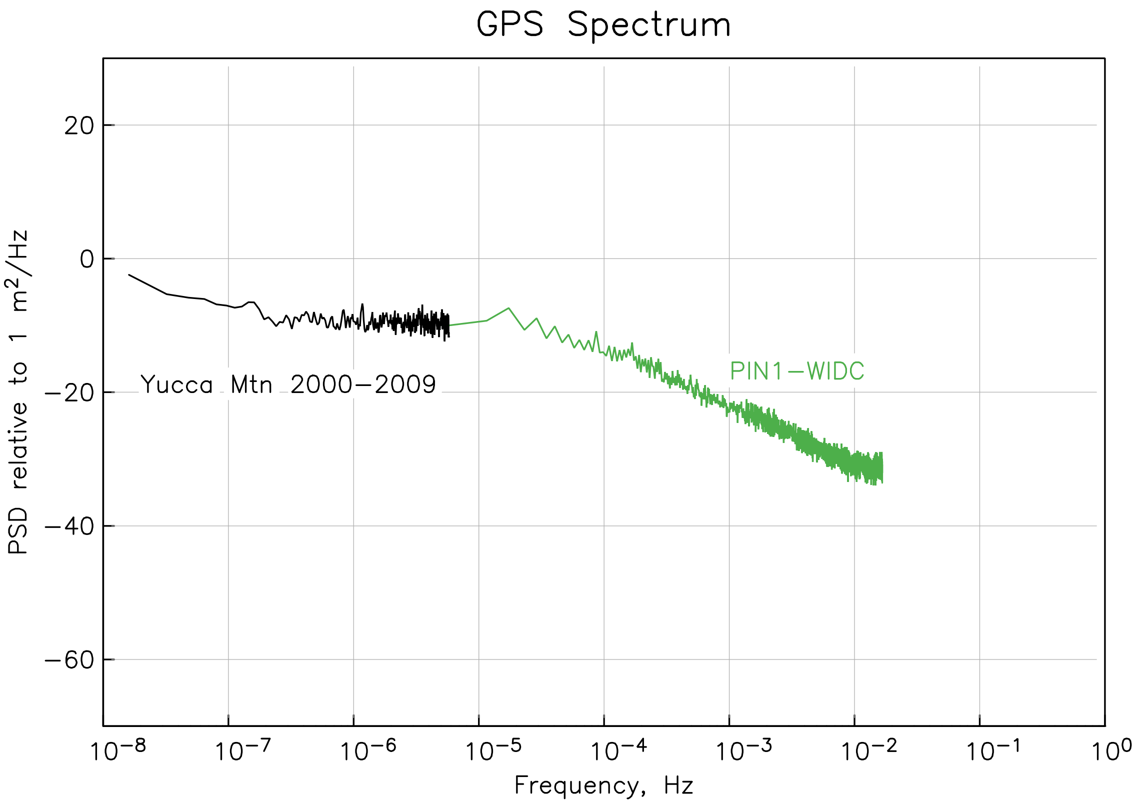
And this is later, on the same baseline.

GPS Spectrum 3



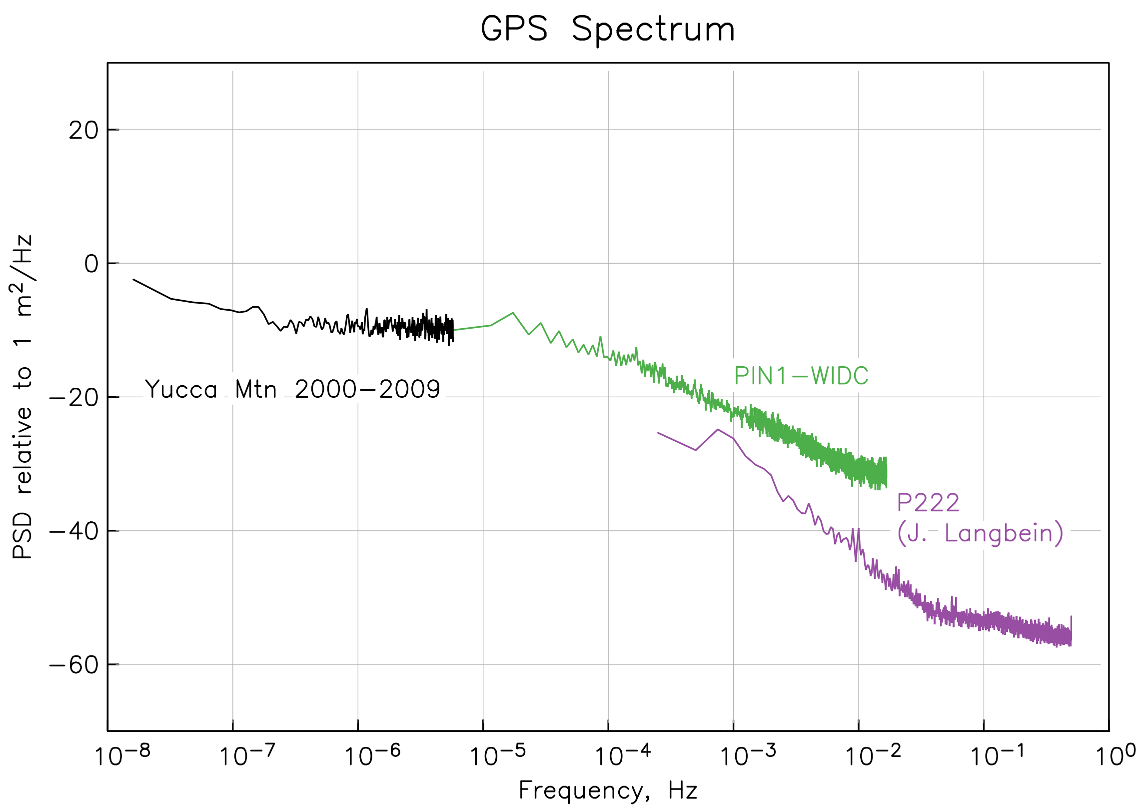
This is probably a “best case”: the Yucca Mountain network, known for low noise.

GPS Spectrum 4



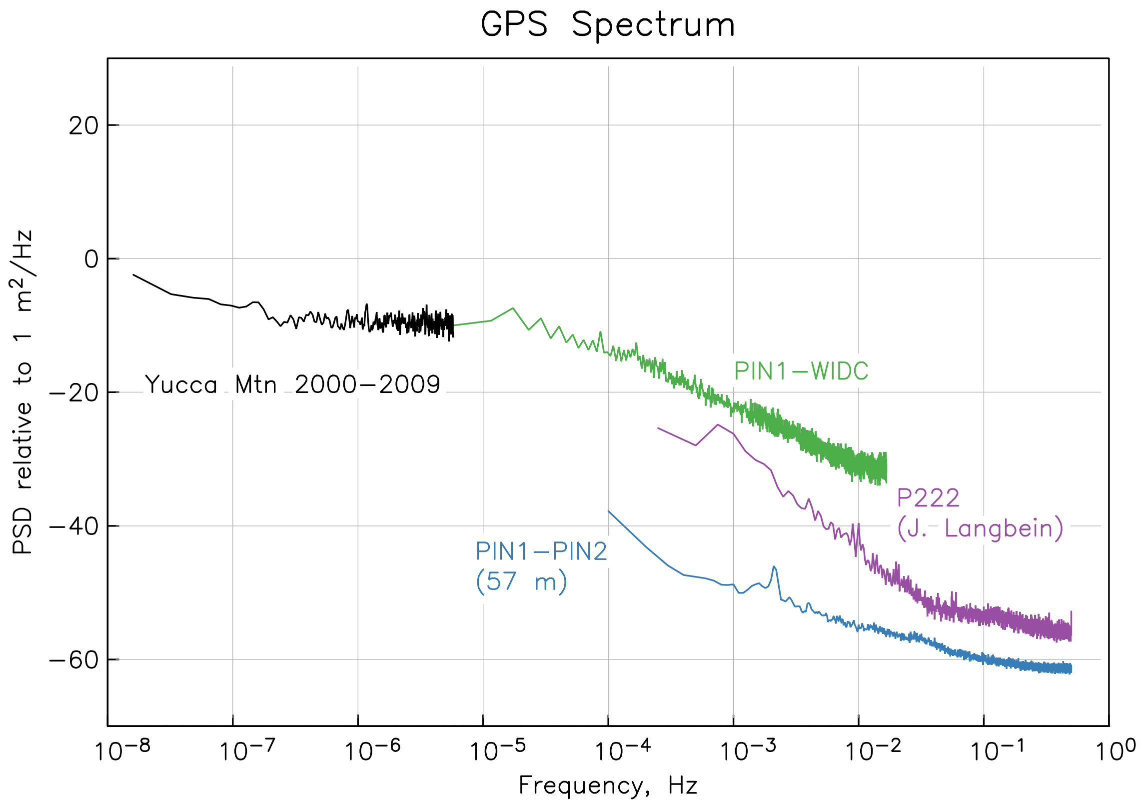
Sidereal adjustment (using lowpass of previous 5 days) made to reduce multipath.

GPS Spectrum 5



Data from P222, with common-mode and sidereal adjustments, data courtesy of Dr. John Langbein

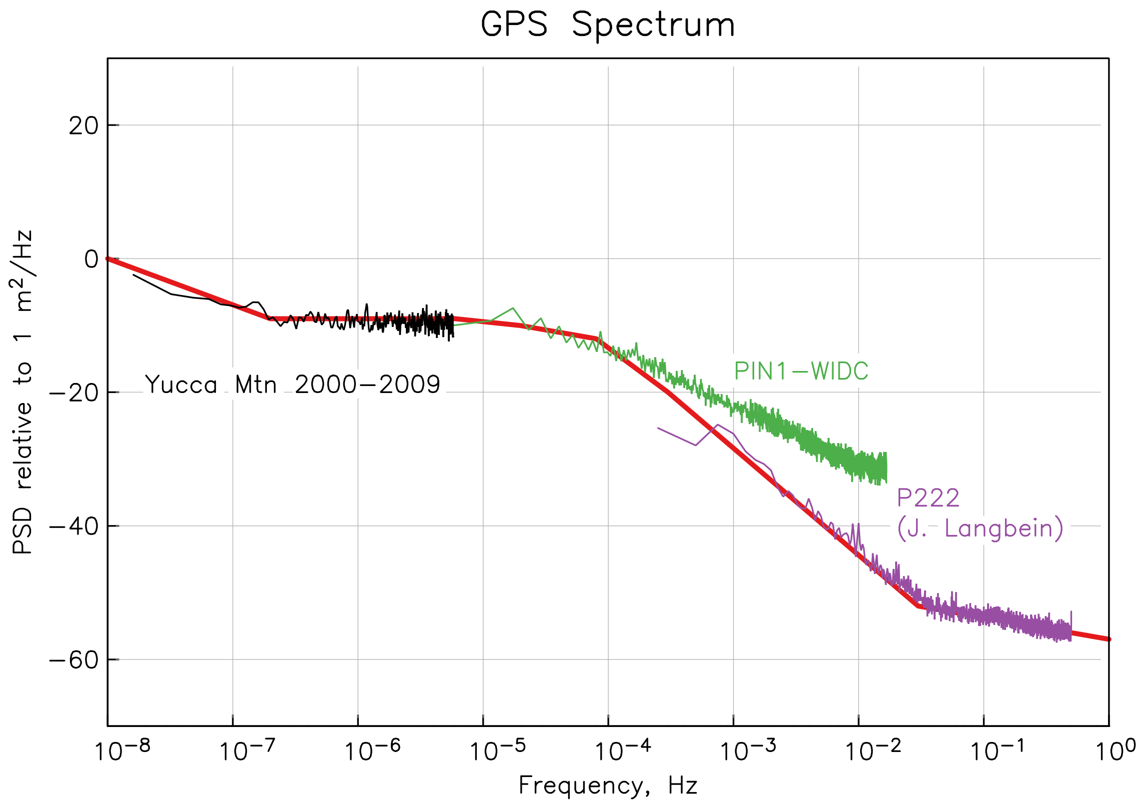
GPS Spectrum 6



PIN1-PIN2 is a very short baseline – note that noise floor close to -60 db (1 mm rms white noise).

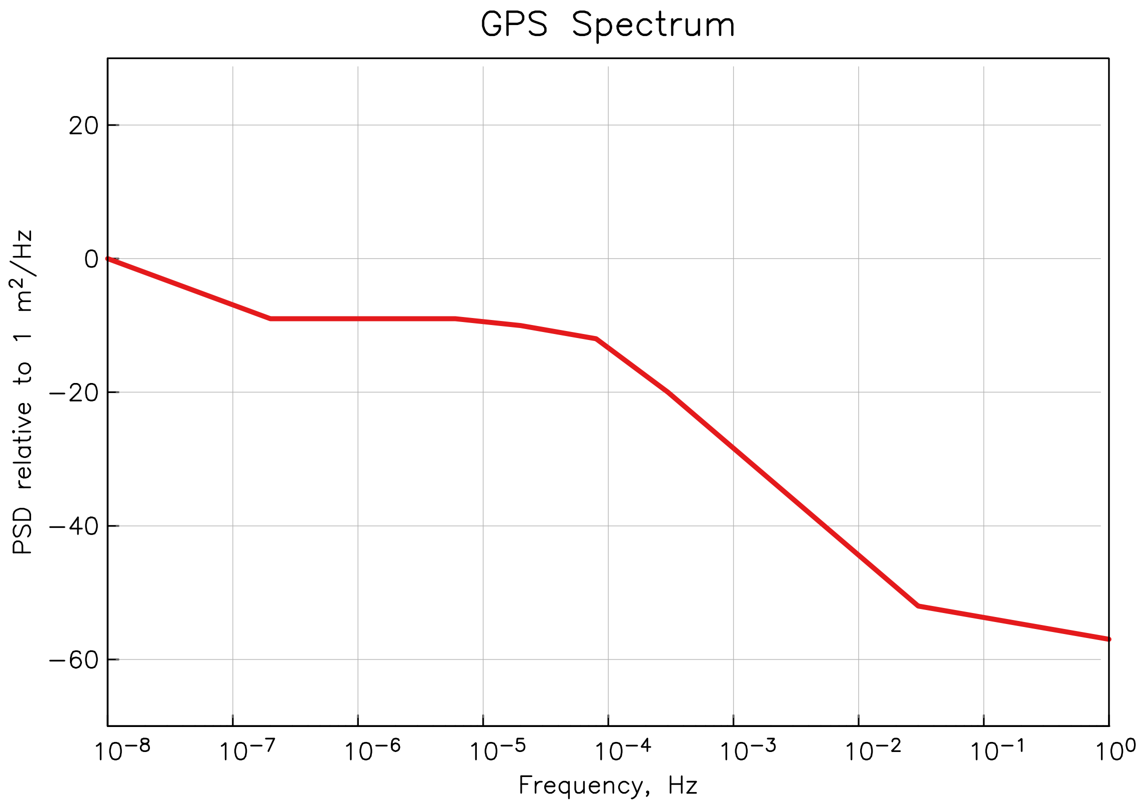
< >

GPS Spectrum 7



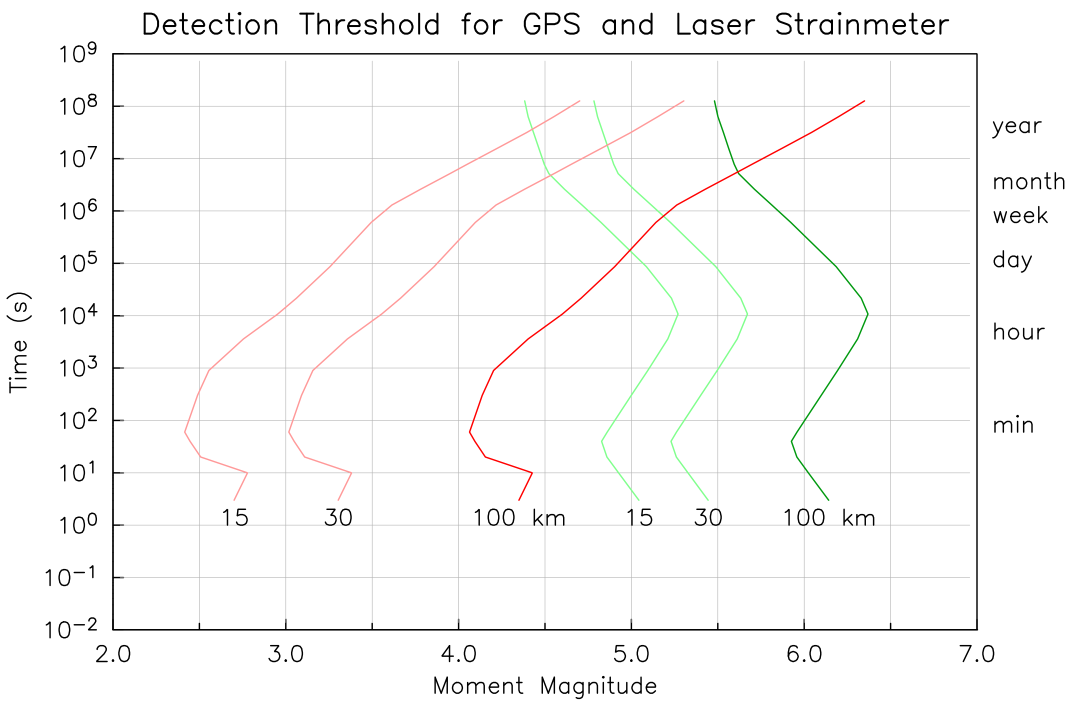
Piecewise linear approximation to noise spectrum.

GPS Spectrum 8



Piecewise linear approximation, without the data.

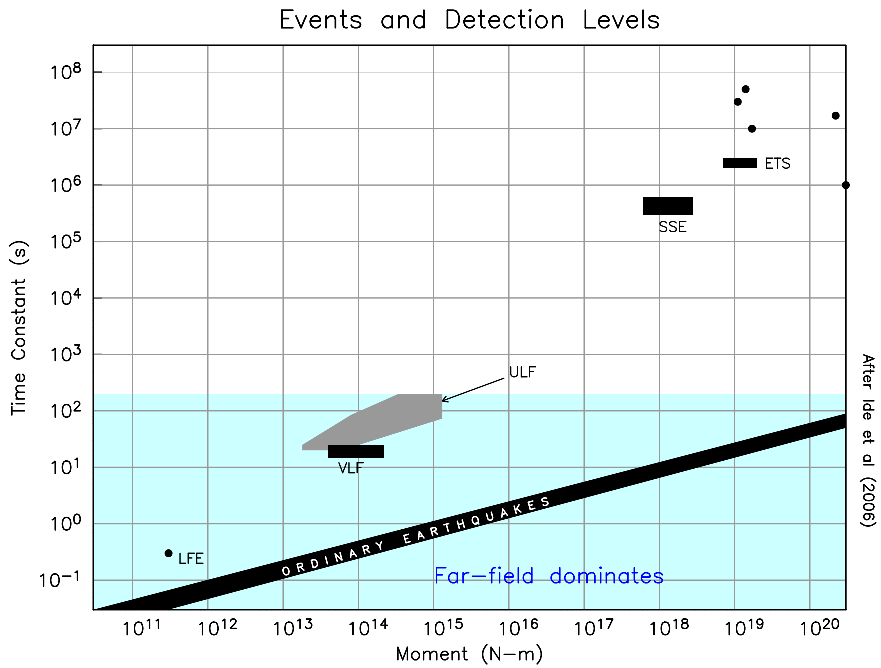
Detection Level for GPS (and Laser Strainmeter)



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.

How Does this Match Observations?



Lack of events on the upper left is not a scaling law, but the limits of observation.