LIGO Data

- https://www.gw-openscience.org/tutorials/
- Download: “file with data” will get you everything
- simple_read_ligo.py will read for you (once you have h5py installed and working)

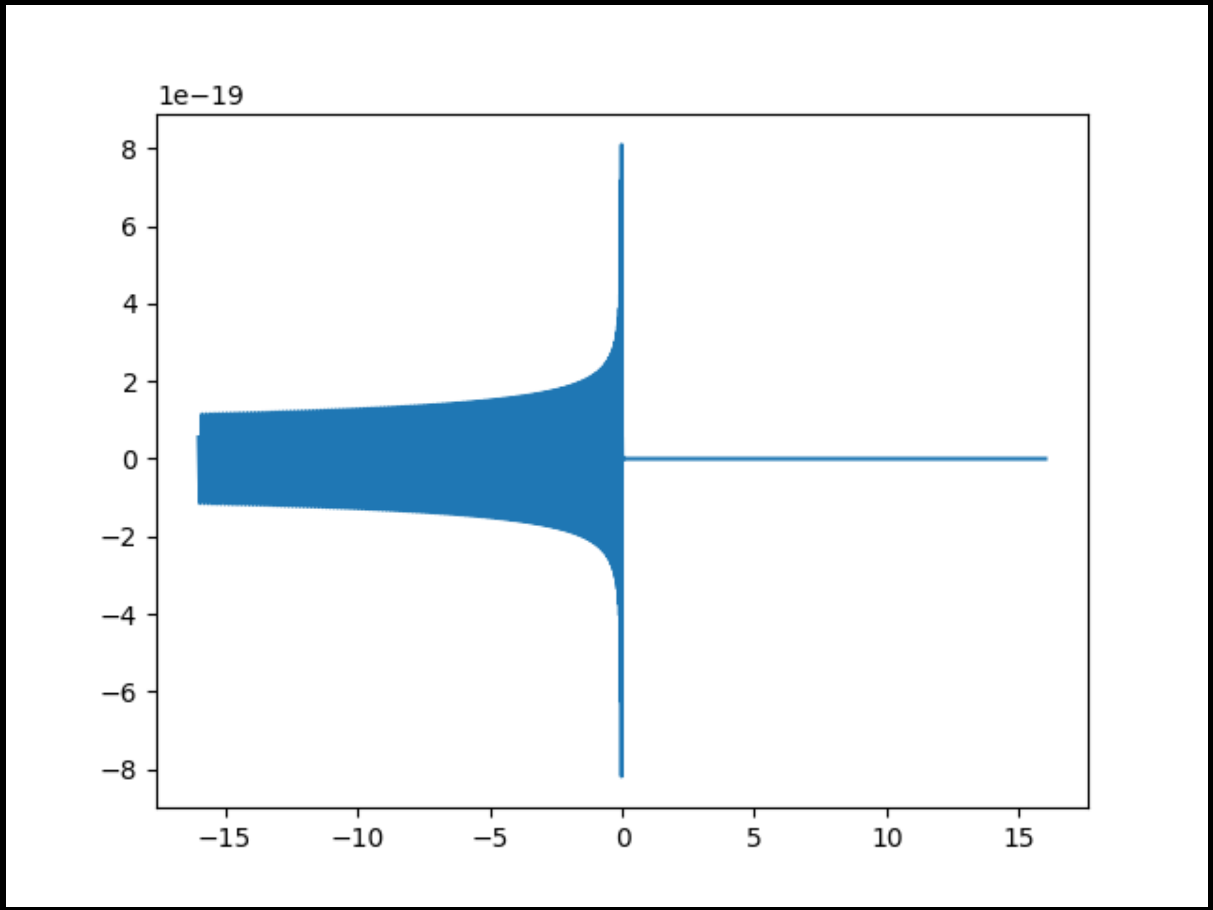
What Should Signal Be?

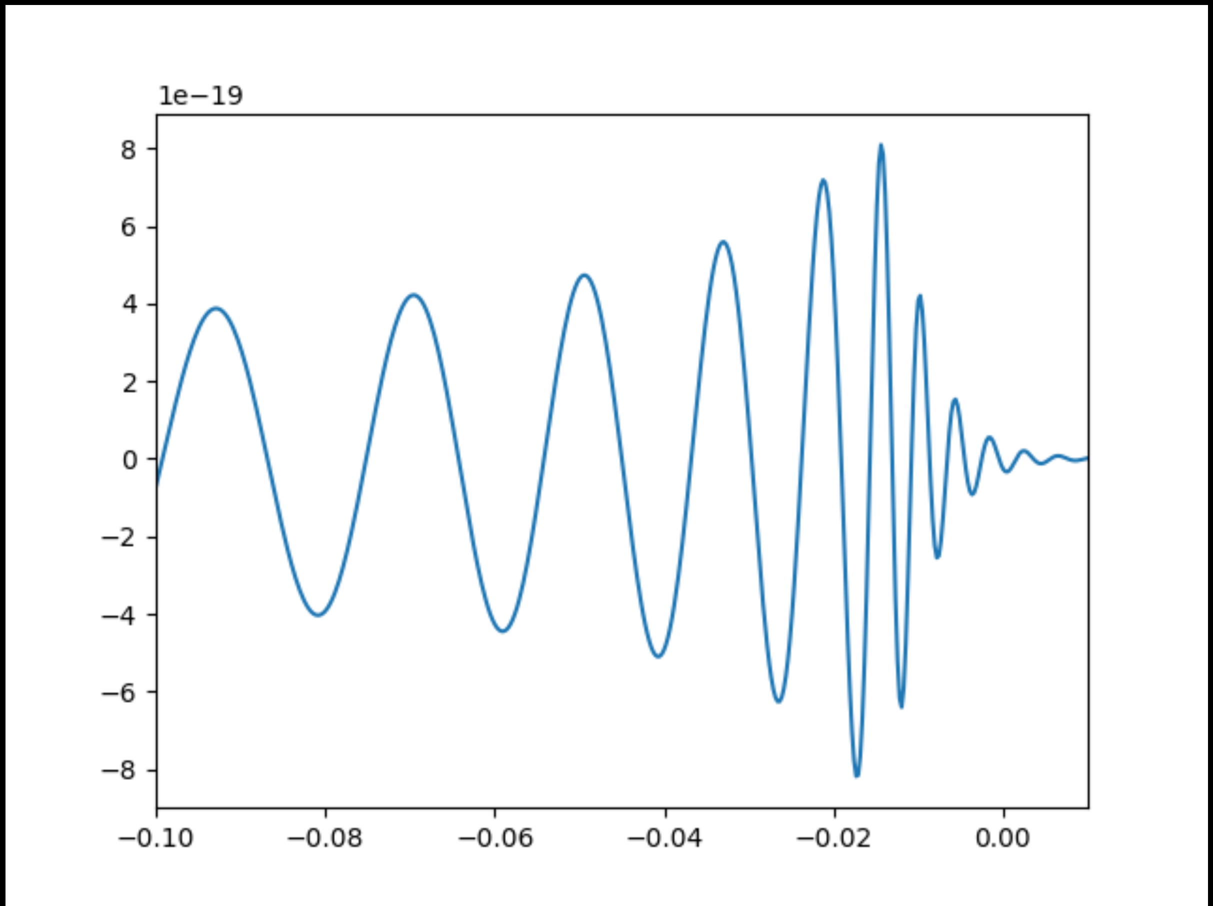
- Actual signal calculations extremely hard! But we can back-of-the-envelope
- Gravitational waves distort space - *strain* is fractional stretching of space.
- Strain order unity at Schwarzschild radius. Strain at Earth ~r_s/d.
- Frequency at merger ~$c/2\pi r_s$.
- As objects orbit, they get closer and speed up, emit larger strain. We'll see a *chirp* - sinewave with increasing frequency and amplitude up to merger.

Expected Signal ctd.

- Plug in numbers for 50 solar mass black hole merger.
- r_s=50*2.6=130 km. d~100 mpc, so strain (130e5/100*3.08e24)~1e-19.
- This is very small! 1e-19*4km ~1e-13, size of nucleus.
- Frequency: 3e10/130e5*2π ~100 hz

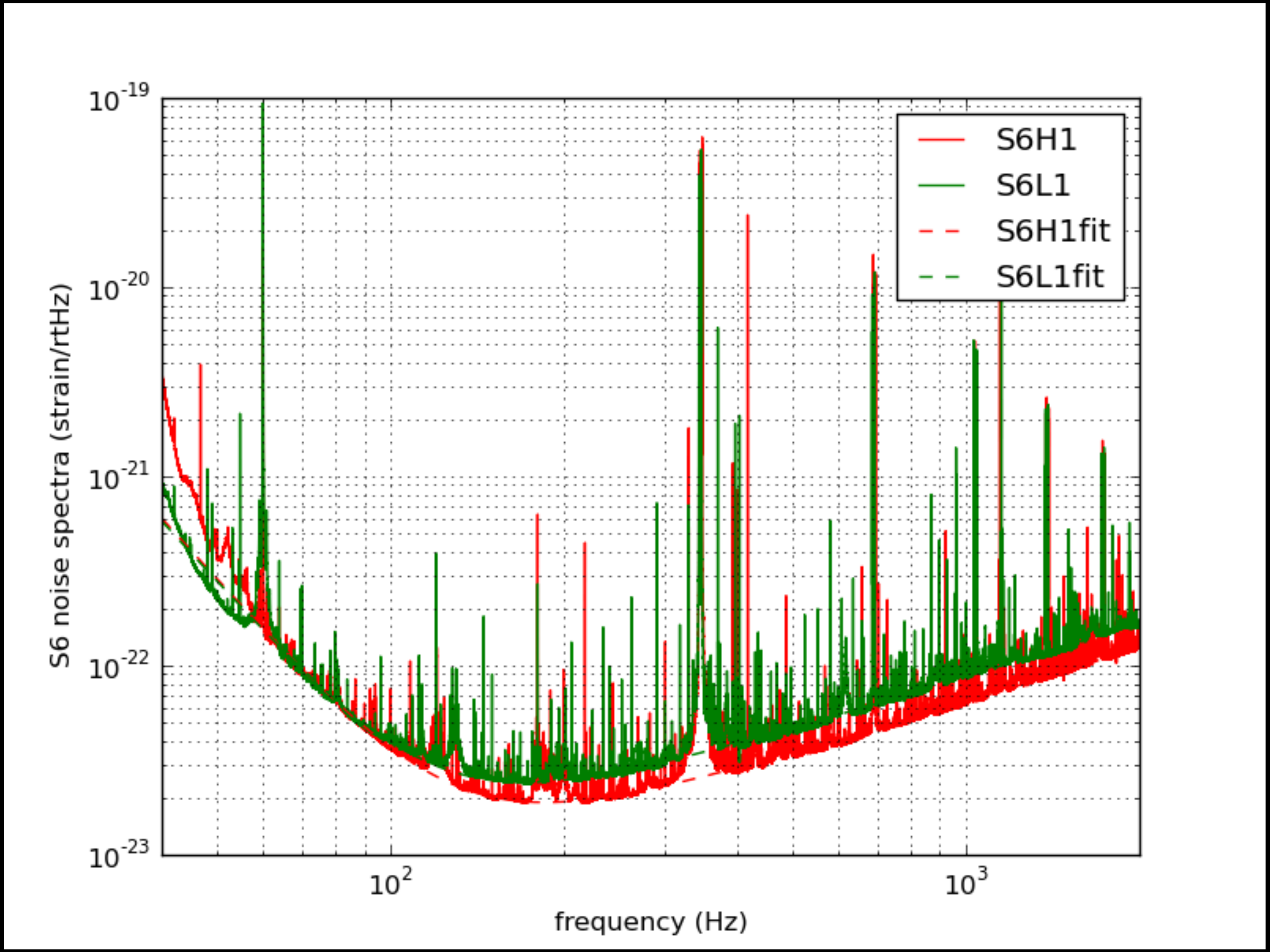
Actual Template





Not so far off! Strain indeed ~10^{-19}, frequency at merger ~100 Hz

First, what should we see for noise?



Matched Filter

- We want to search for a signal in data. We don't know where it will be. How do we find it?
- Best fit amplitude for 1-D template A is $A^T N^{-1} d / A^T N^{-1} A$
- We can search many possible locations of template with matched filter, replacing top by correlation of A with $N^{-1}d$ (or $N^{-1}A$ with d) if noise is stationary
- Alternatively, could take correlation of $N^{-1/2}A$ with $N^{-1/2}d$. What would the noise in $N^{-1/2}d$ look like?

Power Spectrum Description

- Modes are uncorrelated in Fourier space
- SNR^2/mode is set by (template FT)^2/noise PS
- Noise PS is just FT of correlation function

Fourier Interpretation

- Noise model has same total variance independent of correlation length.
- Looking at FT, long length packs noise power into many long wavelengths. Template has more power on high-frequency scales (good SNR)
- Short length spreads out power over many many modes, dropping average noise power. Template well above noise on large scales (good SNR).
- Intermediate packs all its noise into same scales as template. Never have good SNR.

When your noise looks like your signal,
you're going to have a bad day…

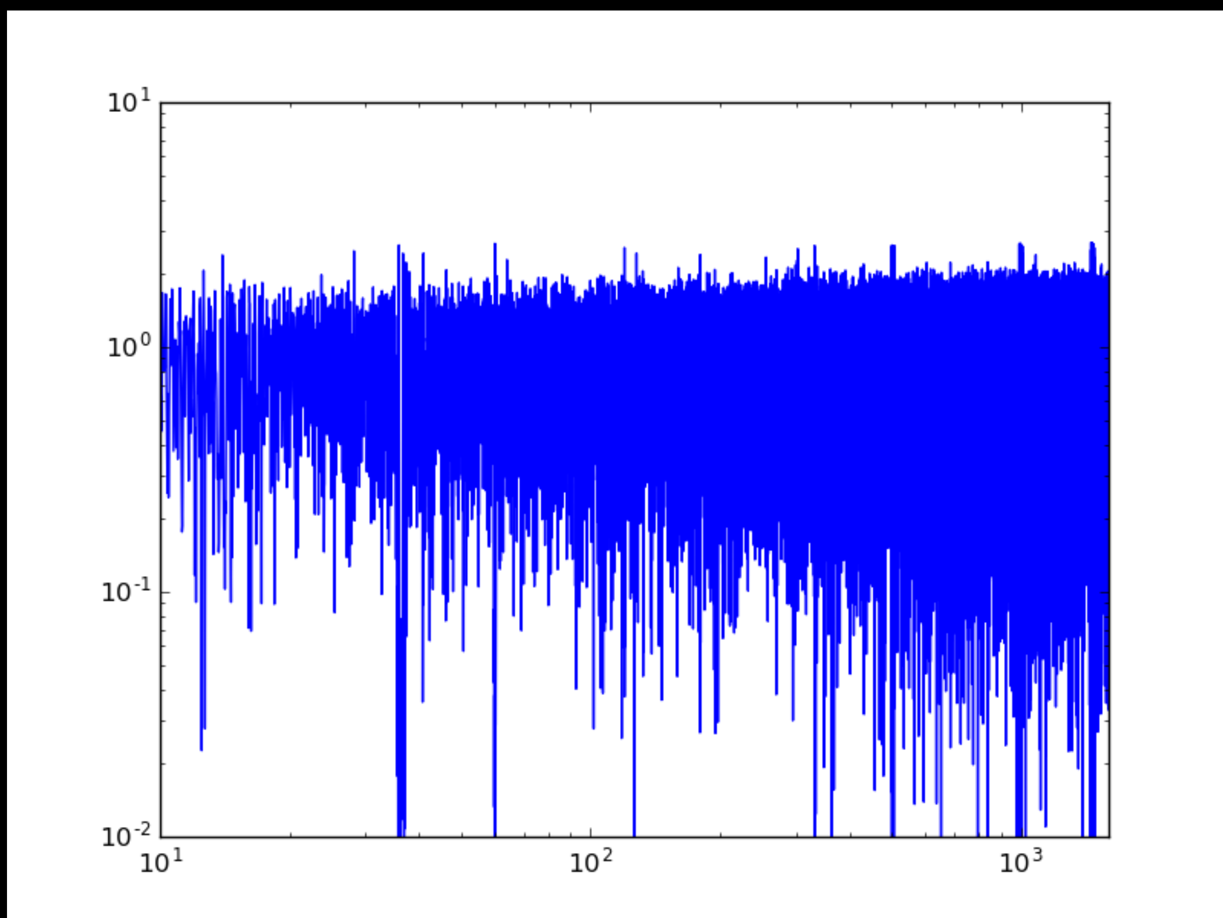
How Should We Estimate Noise?

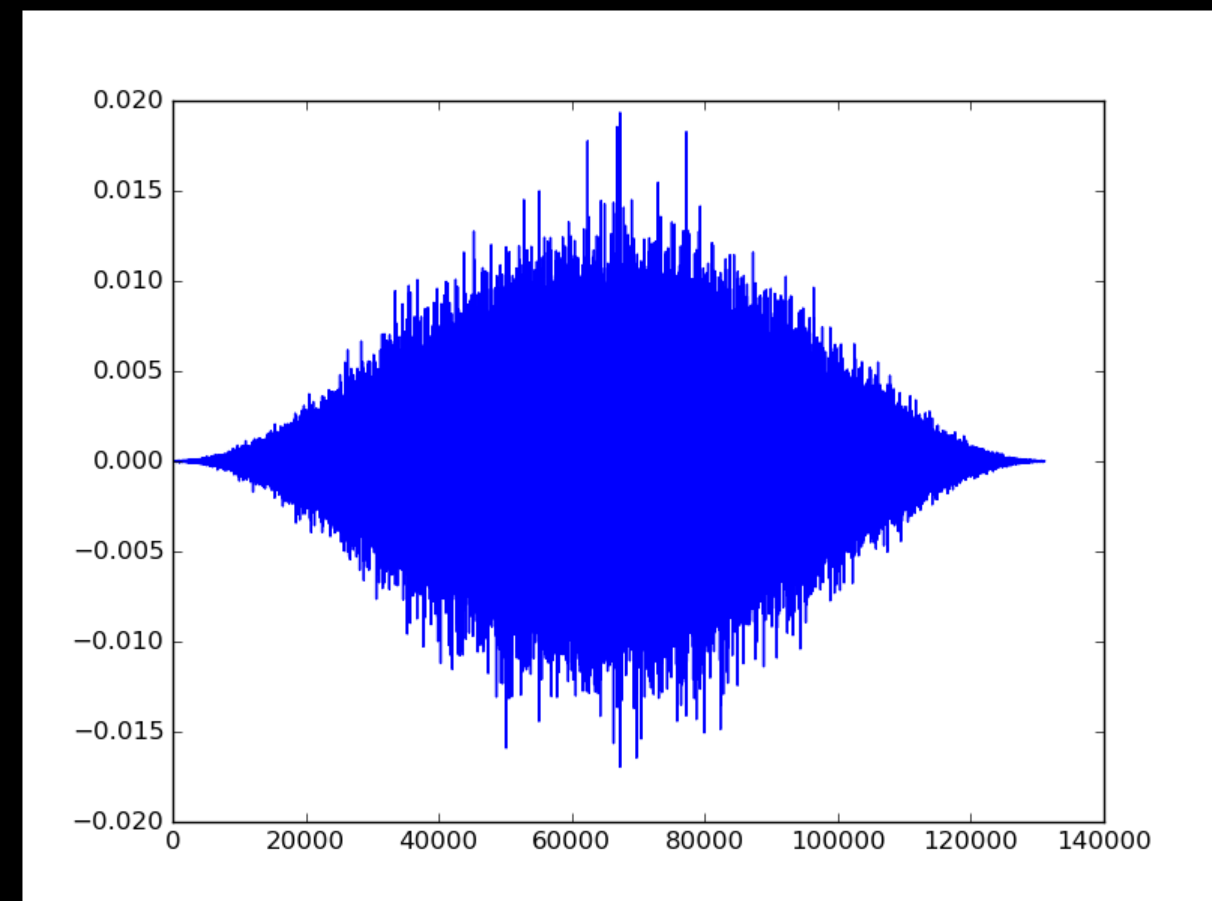
- Windowing key to avoiding FFT ringing
- smooths out spectral features
- Noise large per mode in FT, so we have to average
- What are your thoughts on averaging?

Smoothing PS

- Take $|FT|^2$, which is an estimate
- Smooth by convolving with an extended function.
- Thoughts on the function?

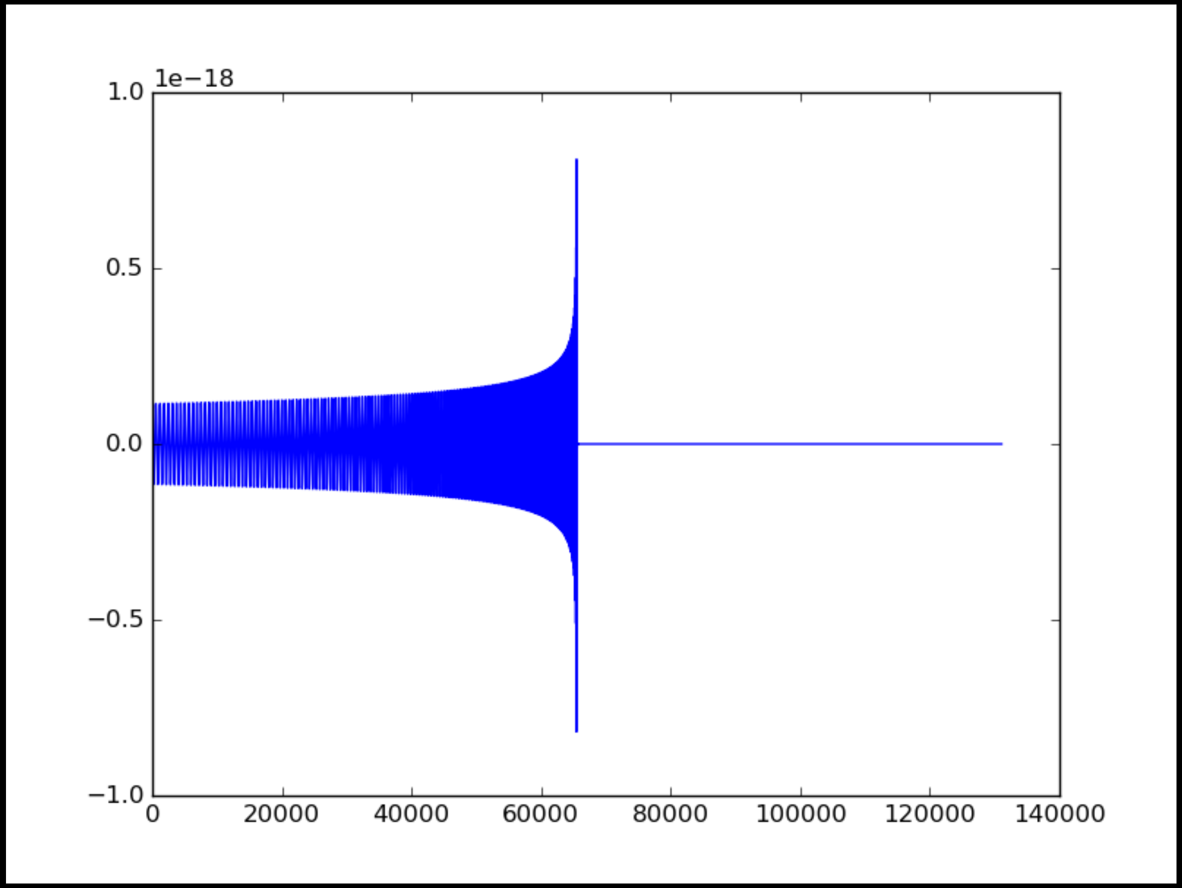
Pre-Whitened Data from Smoothed PS

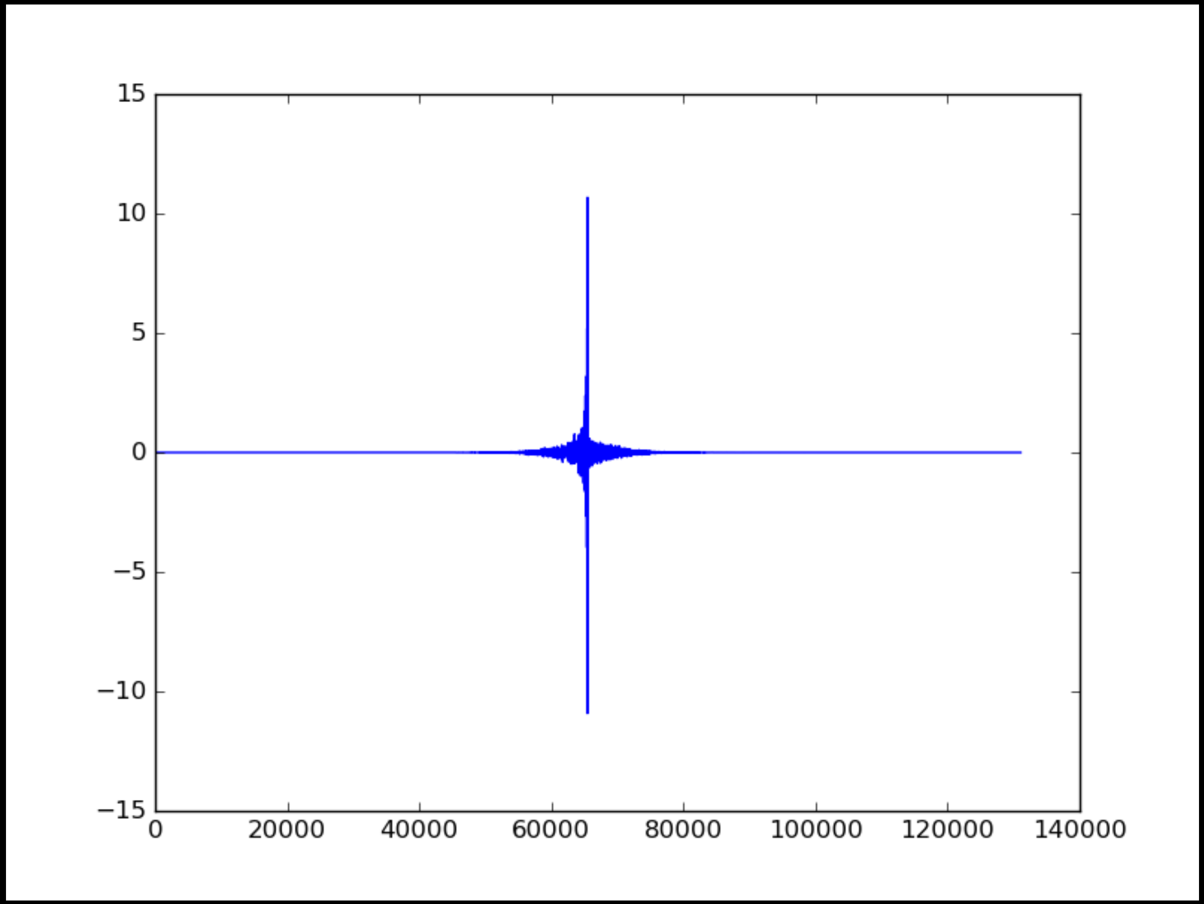




Left: Whitened FT of data. Looks not crazy. What are little nubbins sticking up?
Right: whitened data. Window shape is pretty obvious.

Pre-whitened template

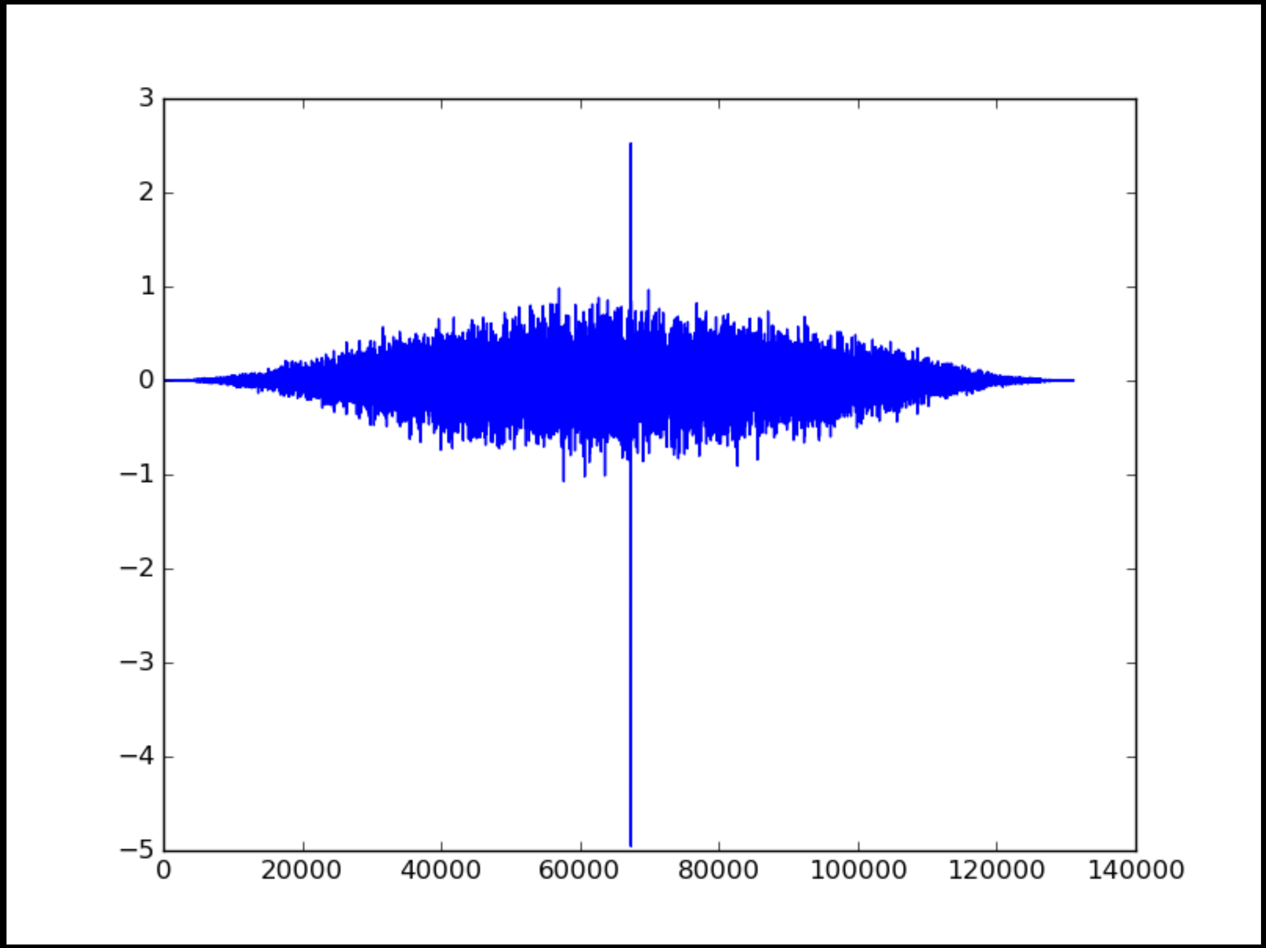




- For this event, template is not small at start of data. Will this be a problem?

- Can look at pre-whitened version of template to get an idea.

Can Use for MF now



FFT Shift of matched filter output. We found a GW!

Averaging PS

- Break PS up into small chunks so we have many
- Take the FT of each chunk
- Add the FT^2s together.
- How do we apply this (short) PS to original data?
- Qualitatively, how do we relate this PS estimate to smoothed one?

More Windowing

- Usual windows taper every sample.
- Reduces power in a way we probably aren’t happy with
- How could we modify window to make this less of an issue?
- Let’s try this on data…