SHOLO: SIMULATED HOLOMETER DATA

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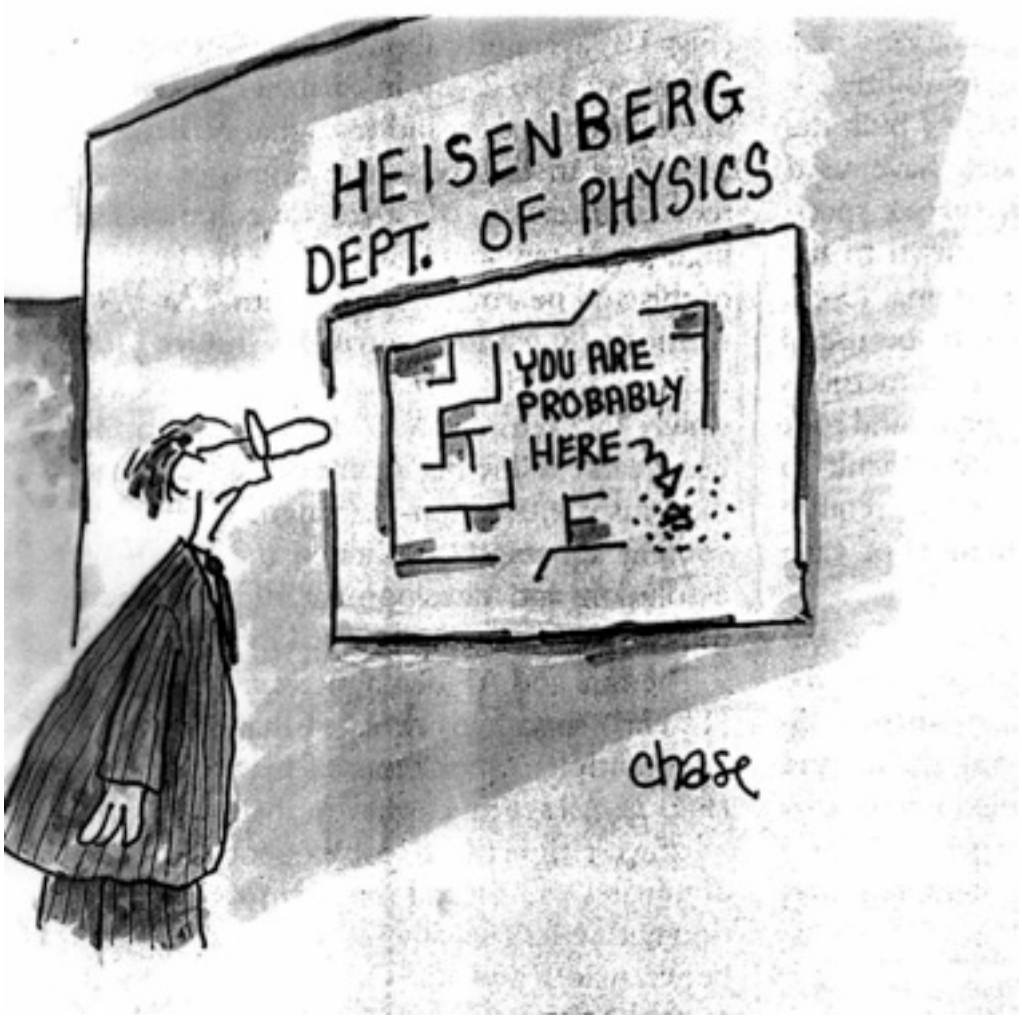
Our purpose

- To use simulations to analyze and understand data from the Fermilab Holometer



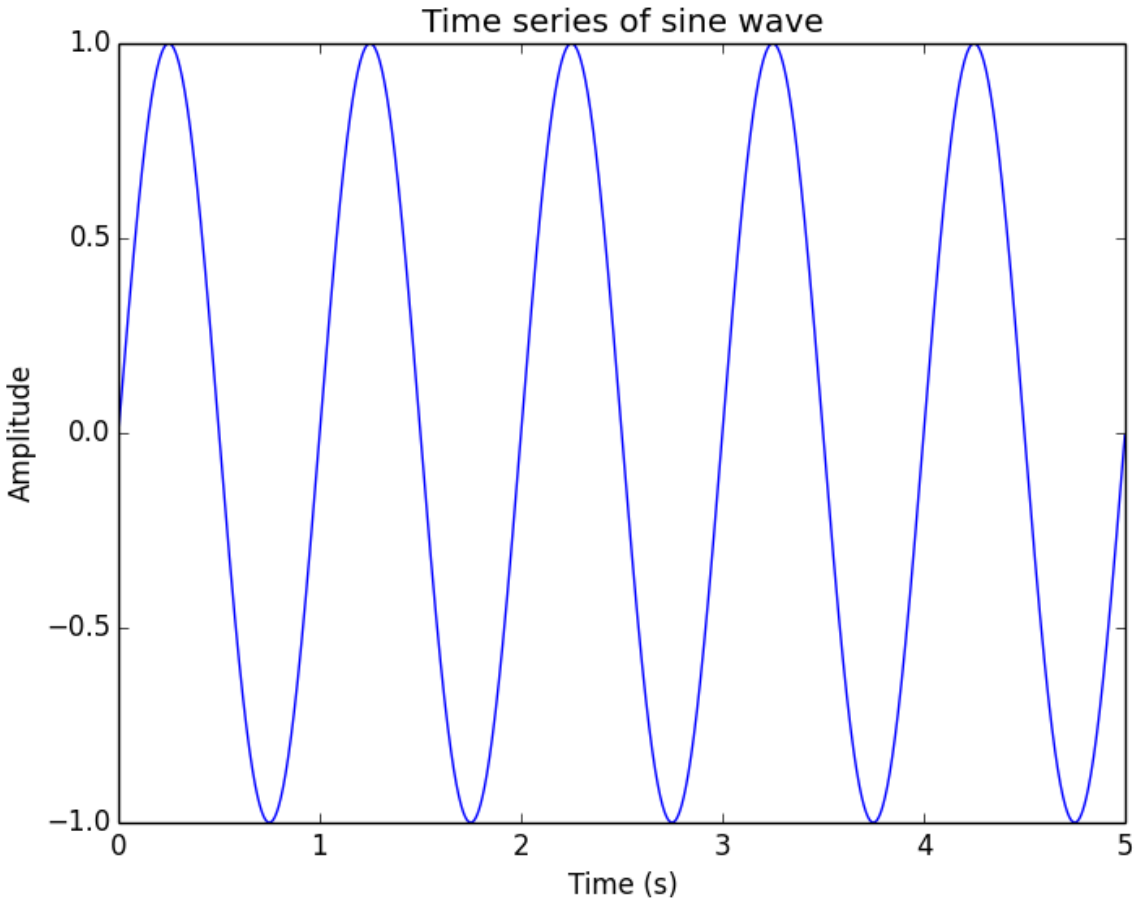
Heisenberg's Uncertainty Principle

Holographic noise

- Space and time may be quantized
- Heisenberg's Uncertainty Principle
- Random wavering of transverse position

Time series

- Commonly seen representation of wave
- Difficult to see important patterns in signal

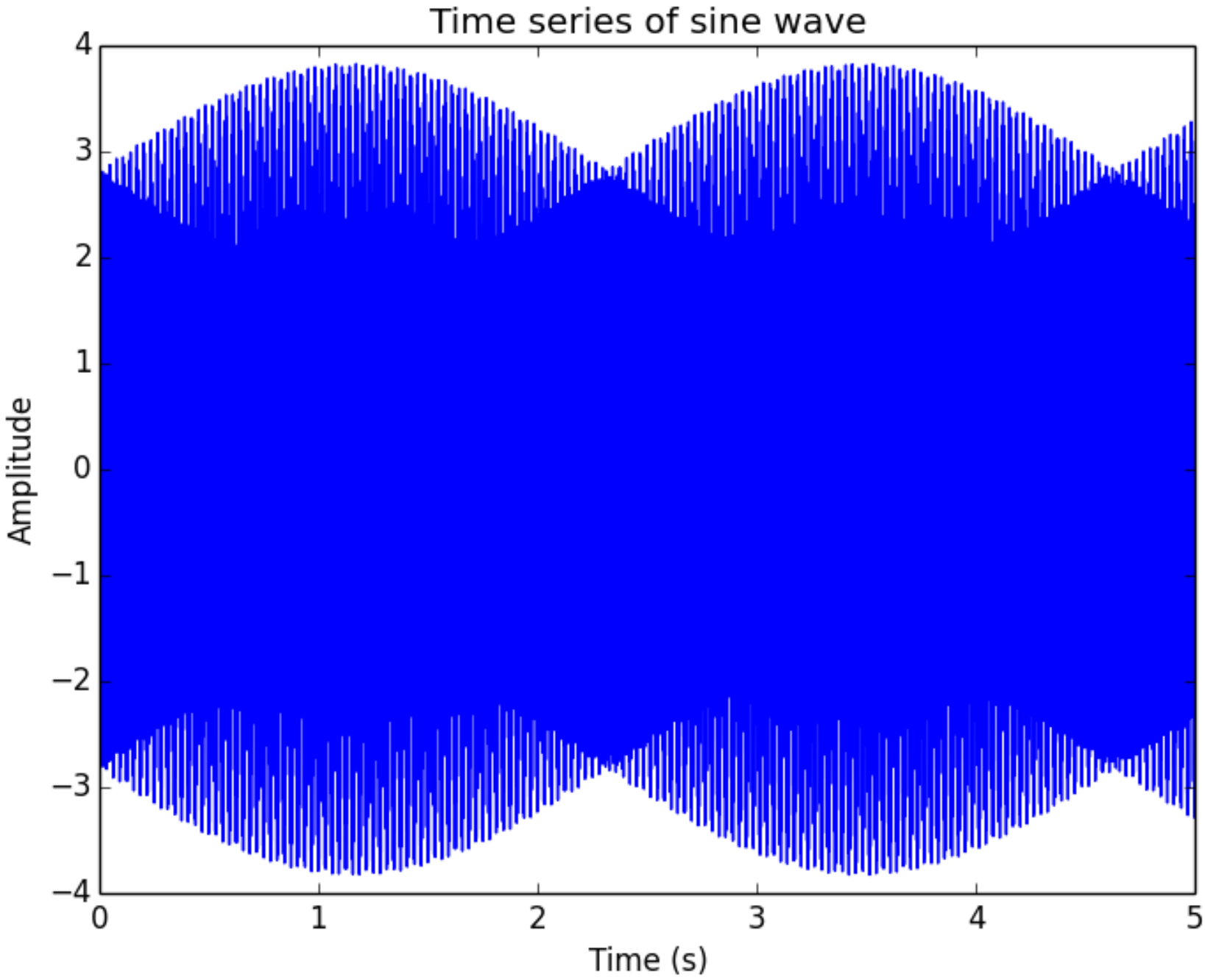


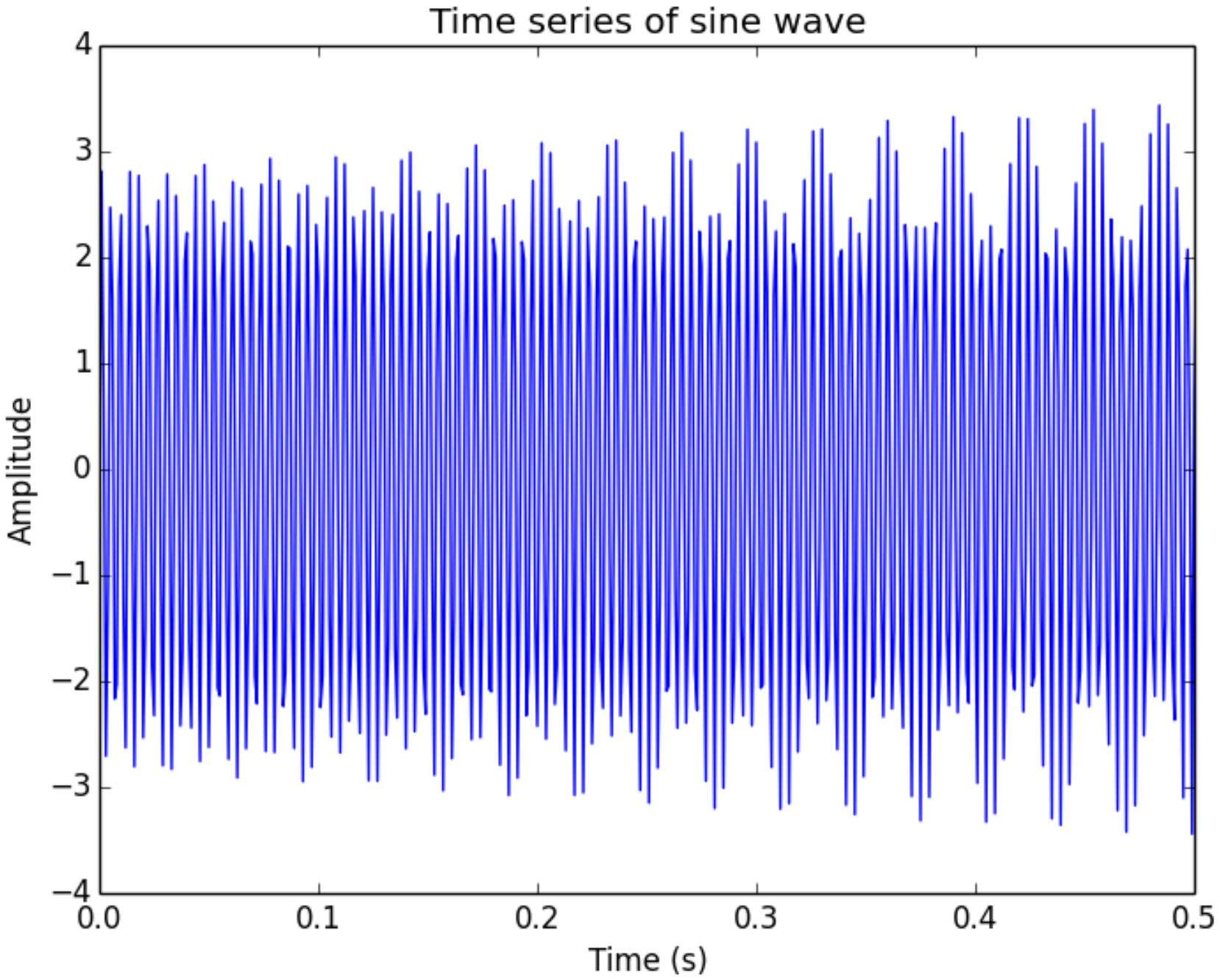
Fourier transformations

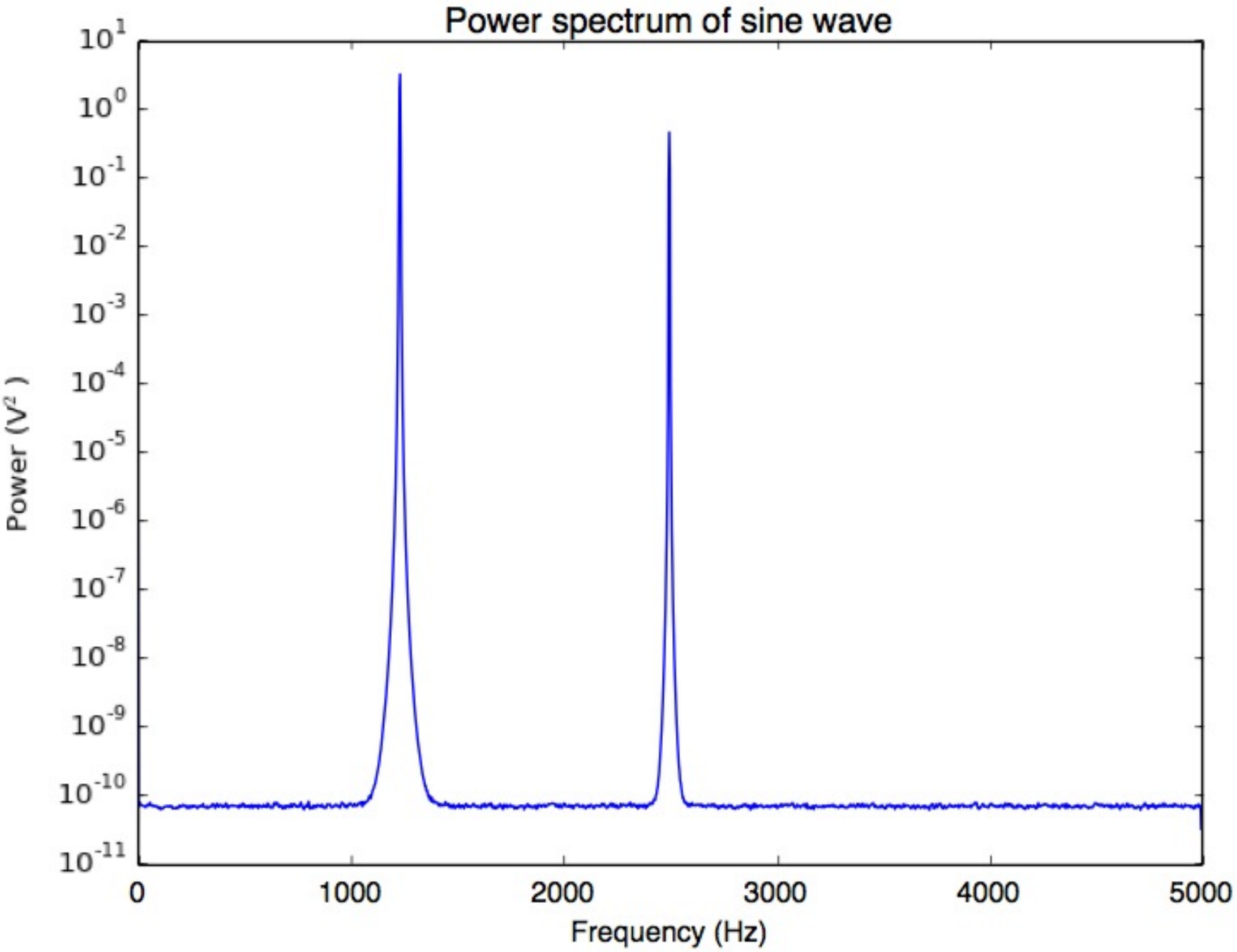
- Periodic functions are the sum of many simple sine and cosine waves

Power spectrum

- Portion of signal power in distinct frequency bins
- Much more readable and useful in signal processing
- Can be expressed in terms of power density


Time series of sine wave
Amplitude
Time (s)
4
3
2
1
0
−1
−2
−3
−4
0
1
2
3
4
5


Time series of sine wave
Amplitude
Time (s)
4
3
2
1
0
−1
−2
−3
−4
0.0
0.1
0.2
0.3
0.4
0.5

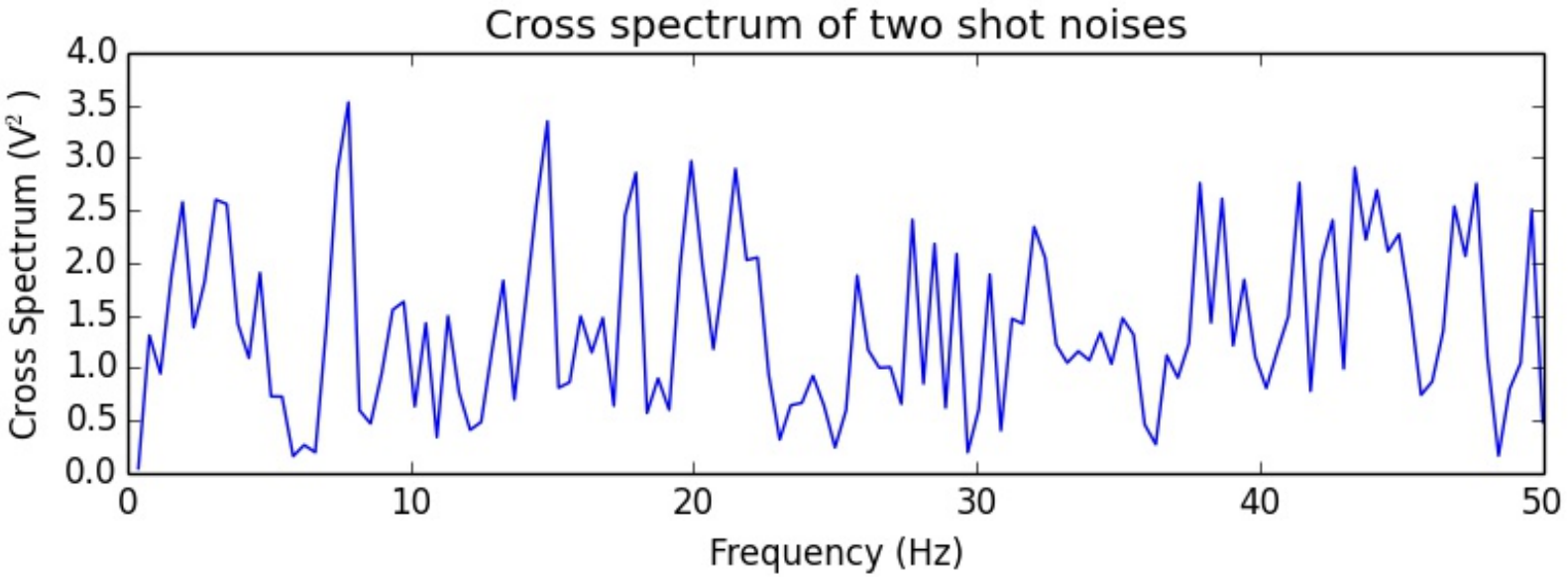

Power spectrum of sine wave
Power (V²)
Frequency (Hz)
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
0
1000
2000
3000
4000
5000

Cross spectrum

- Shows common activity between two time series
- Identifies similar spectral properties
  - High power in same spectral frequency bands
- Product of the Fourier transforms of two time series

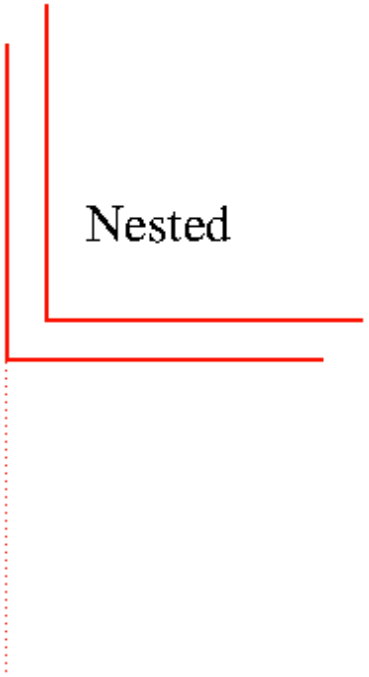
Cross-correlation: So what?

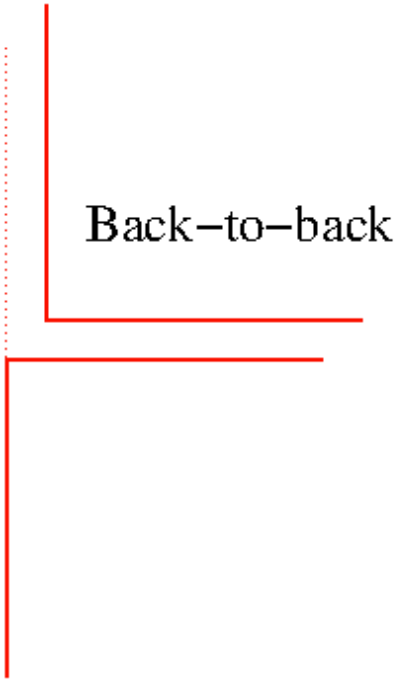
- Current ratio of holographic signal to noise:
  1/160
- Calculating cross spectrum minimizes uncorrelated noises between signals
- Increases signal to noise ratio



Level of power drops significantly in the cross spectrum of two uncorrelated signals.

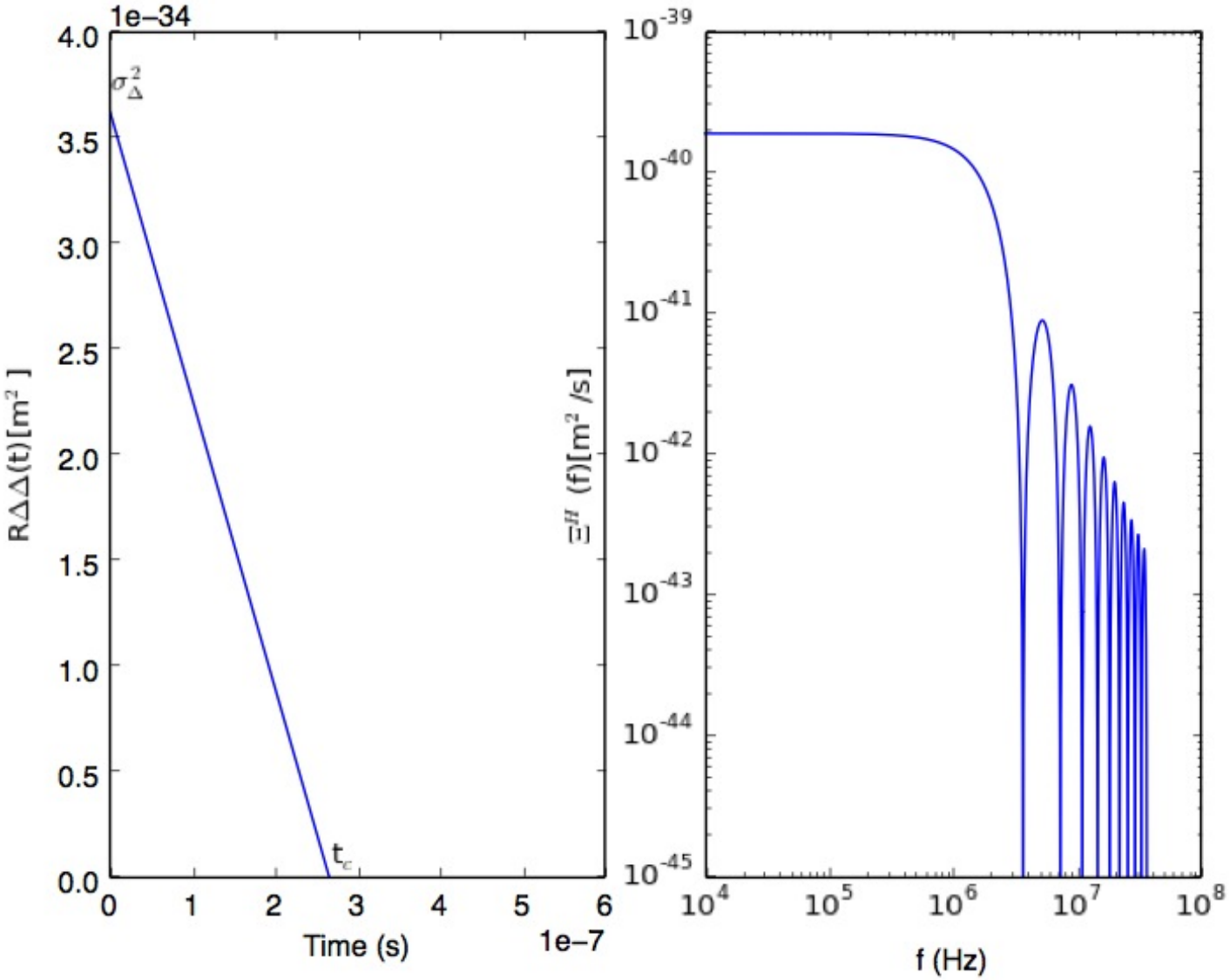
Michelson interferometers





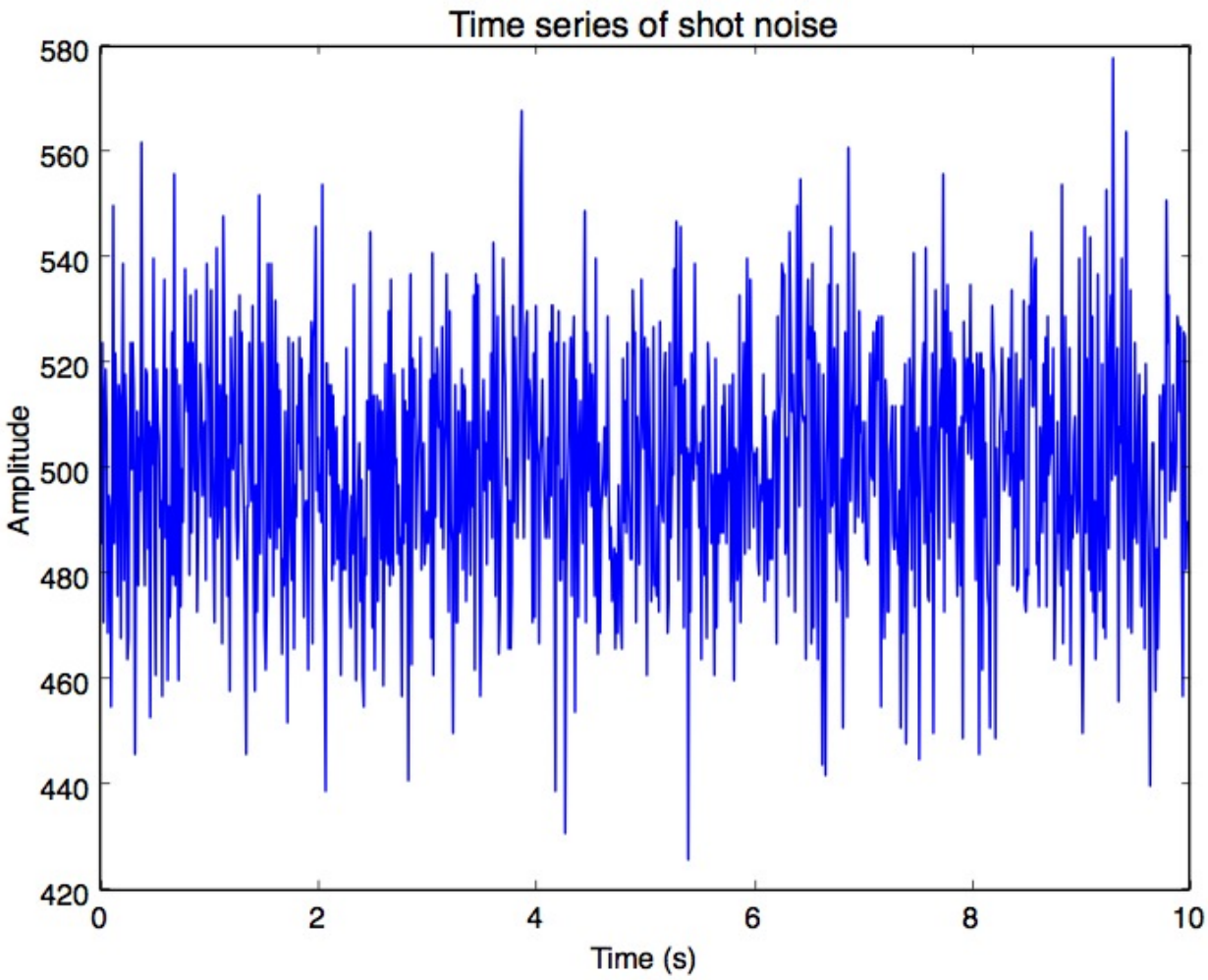
- Correlated Holographic noise
- Uncorrelated Poisson noise

Holographic noise: the new prediction

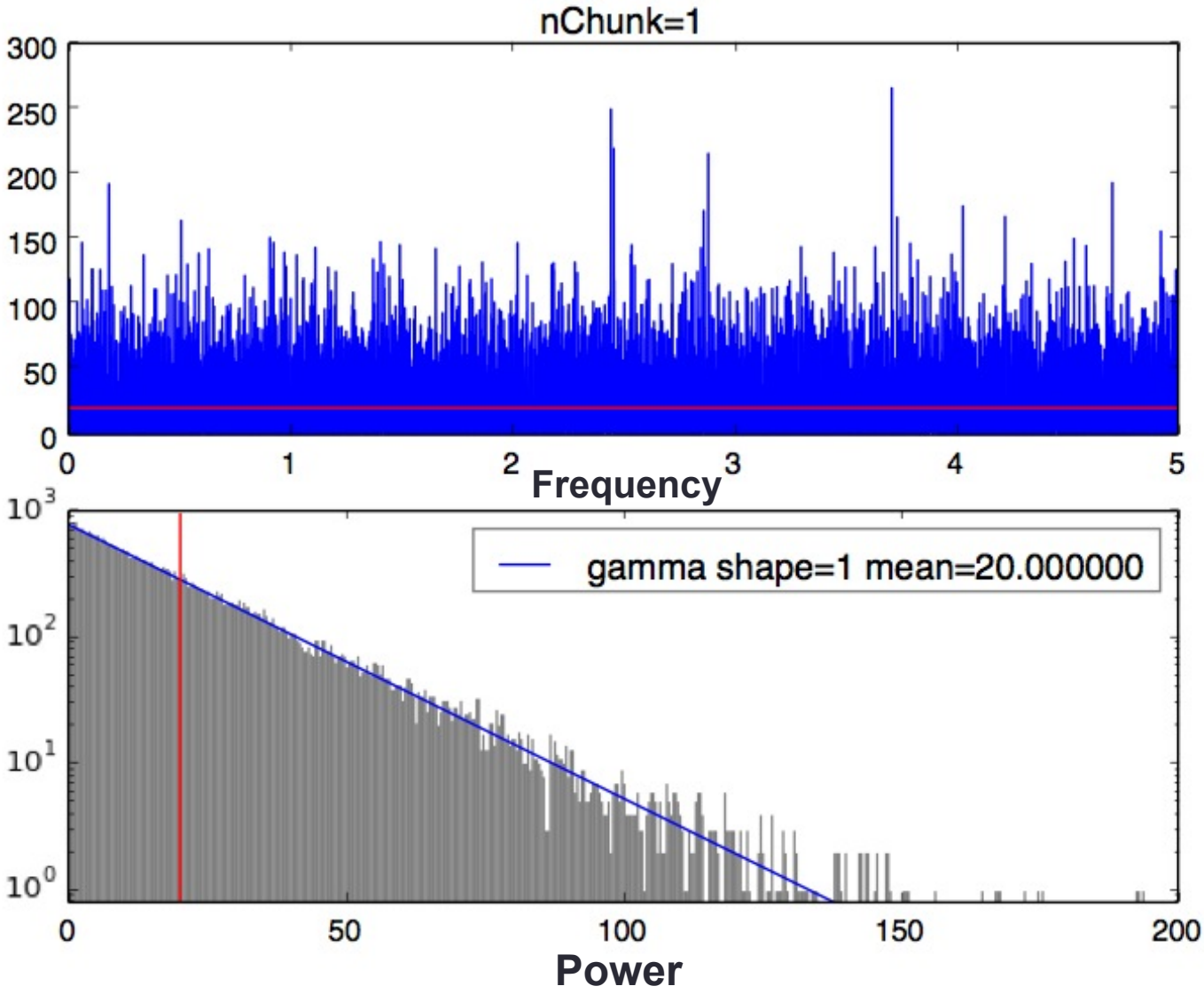


Generating shot noise

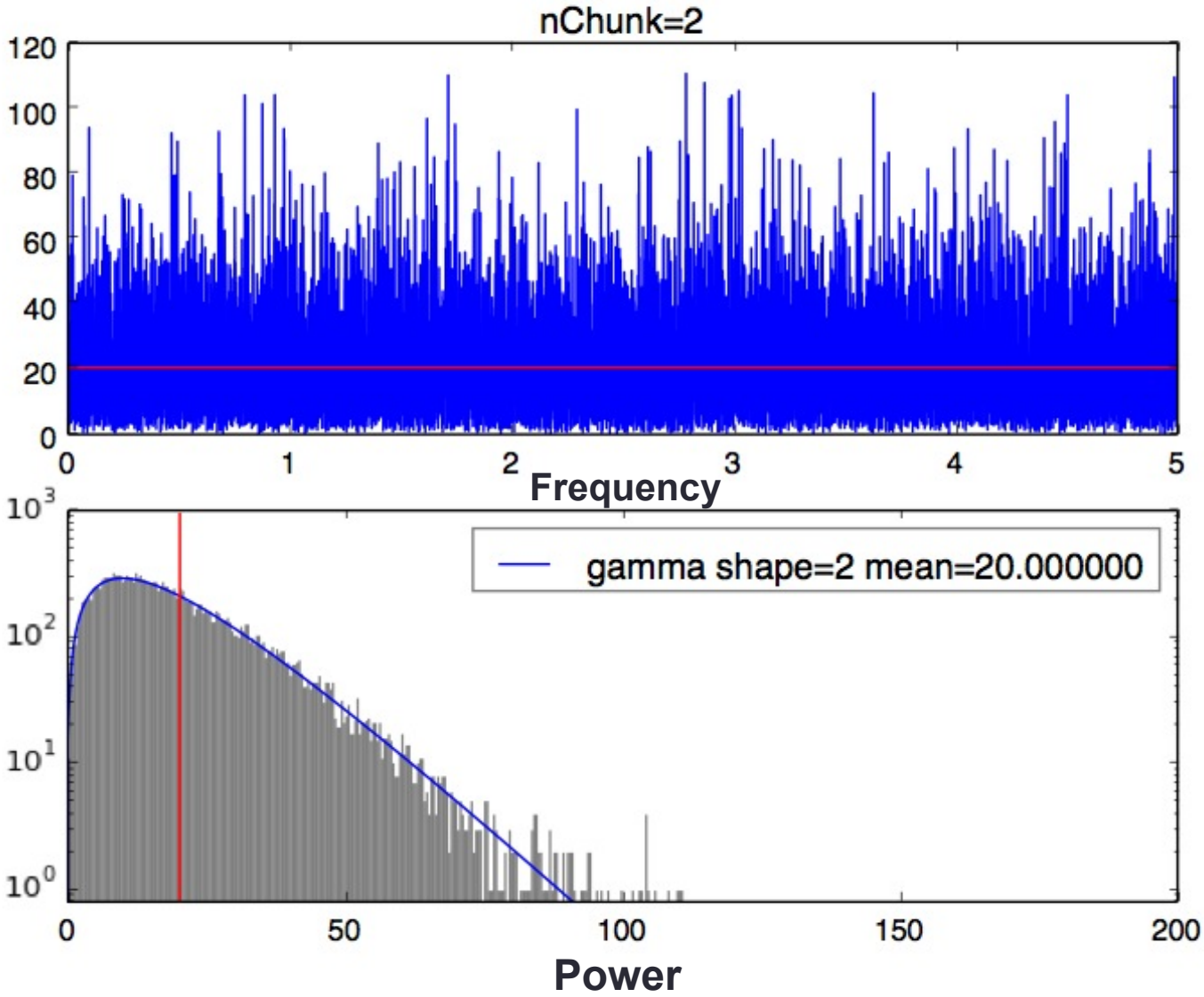
- Poisson noise: random statistics
- Uncertainty in measurement of light



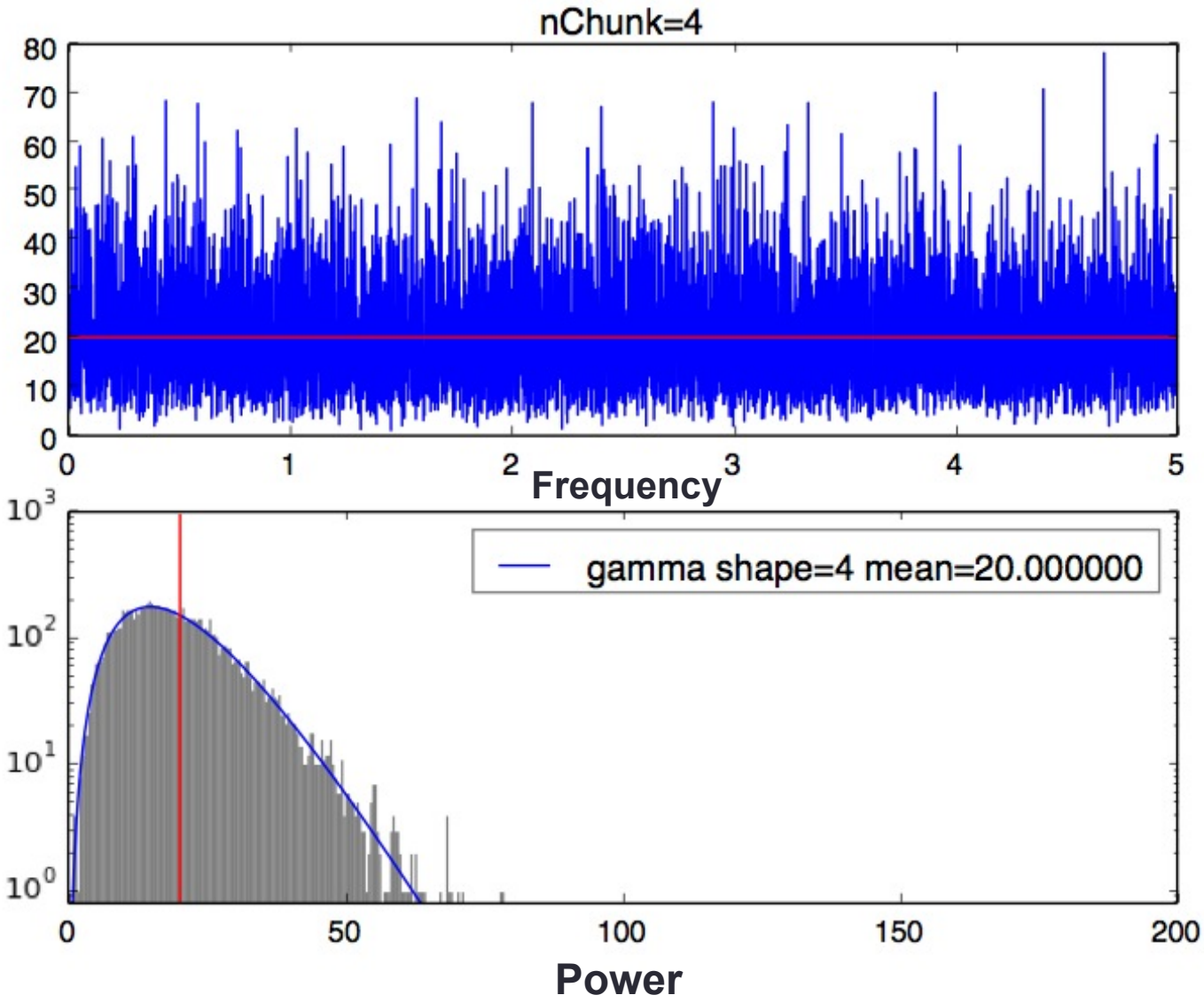
Generating power spectra



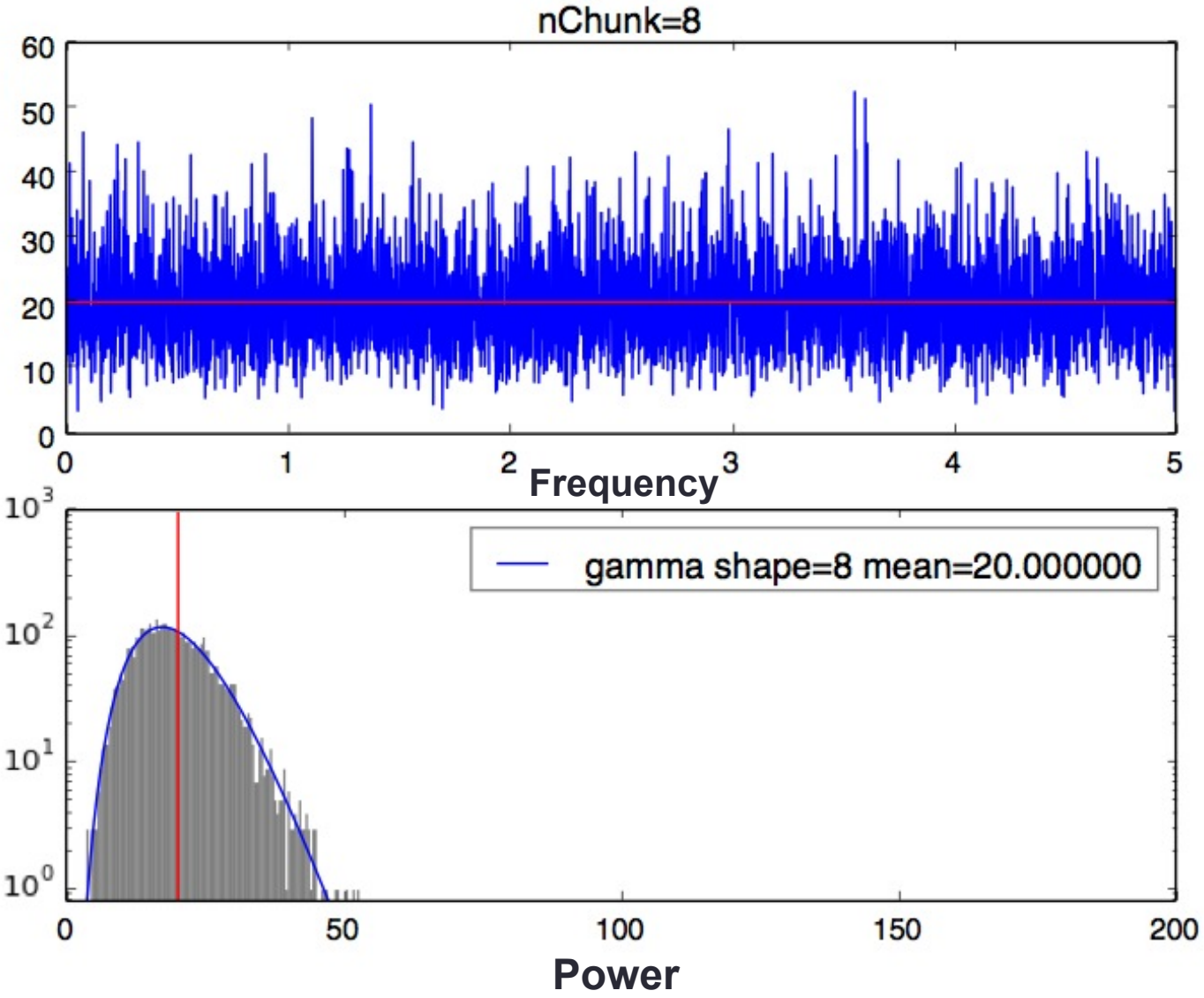
Generating power spectra



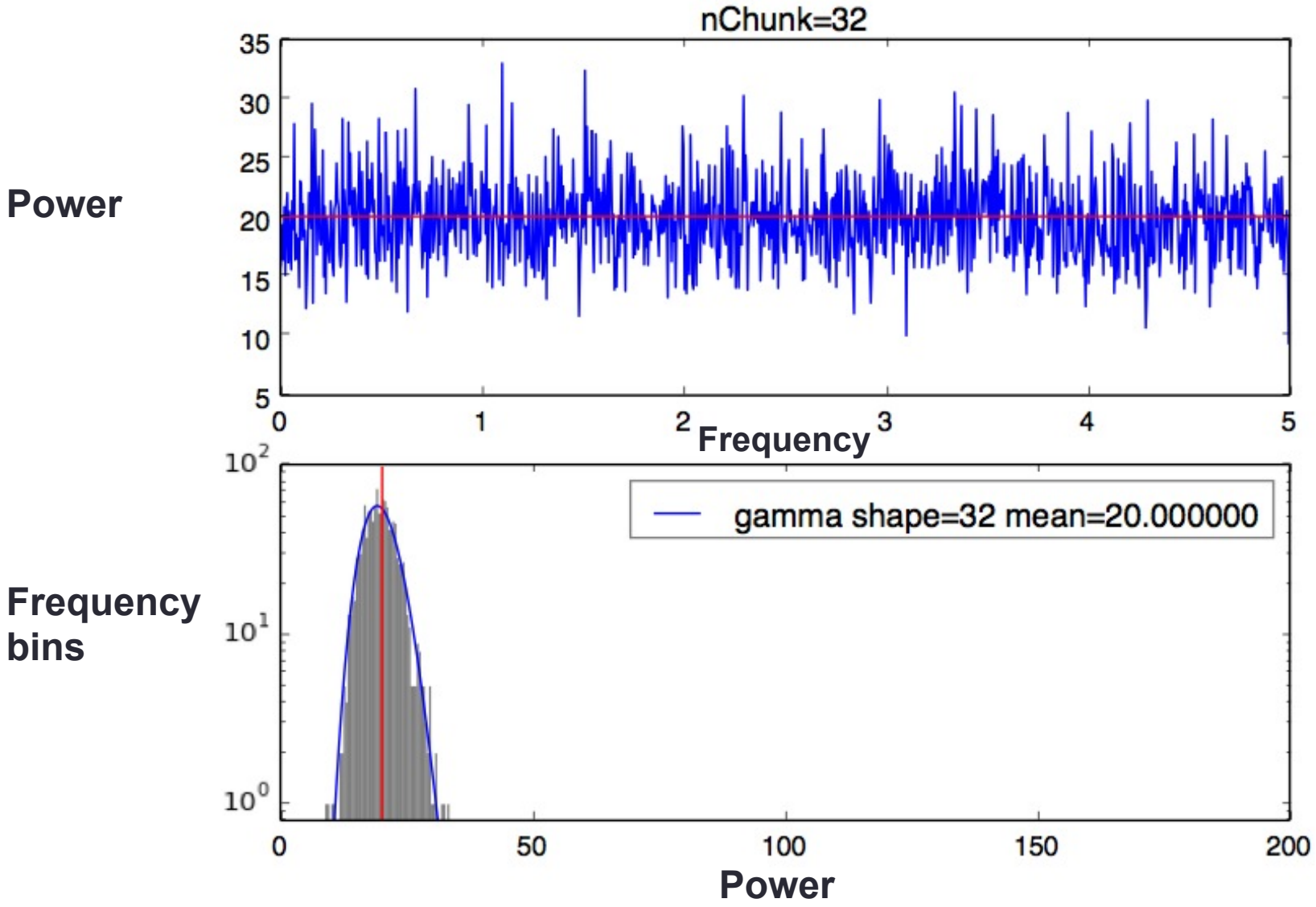
Generating power spectra



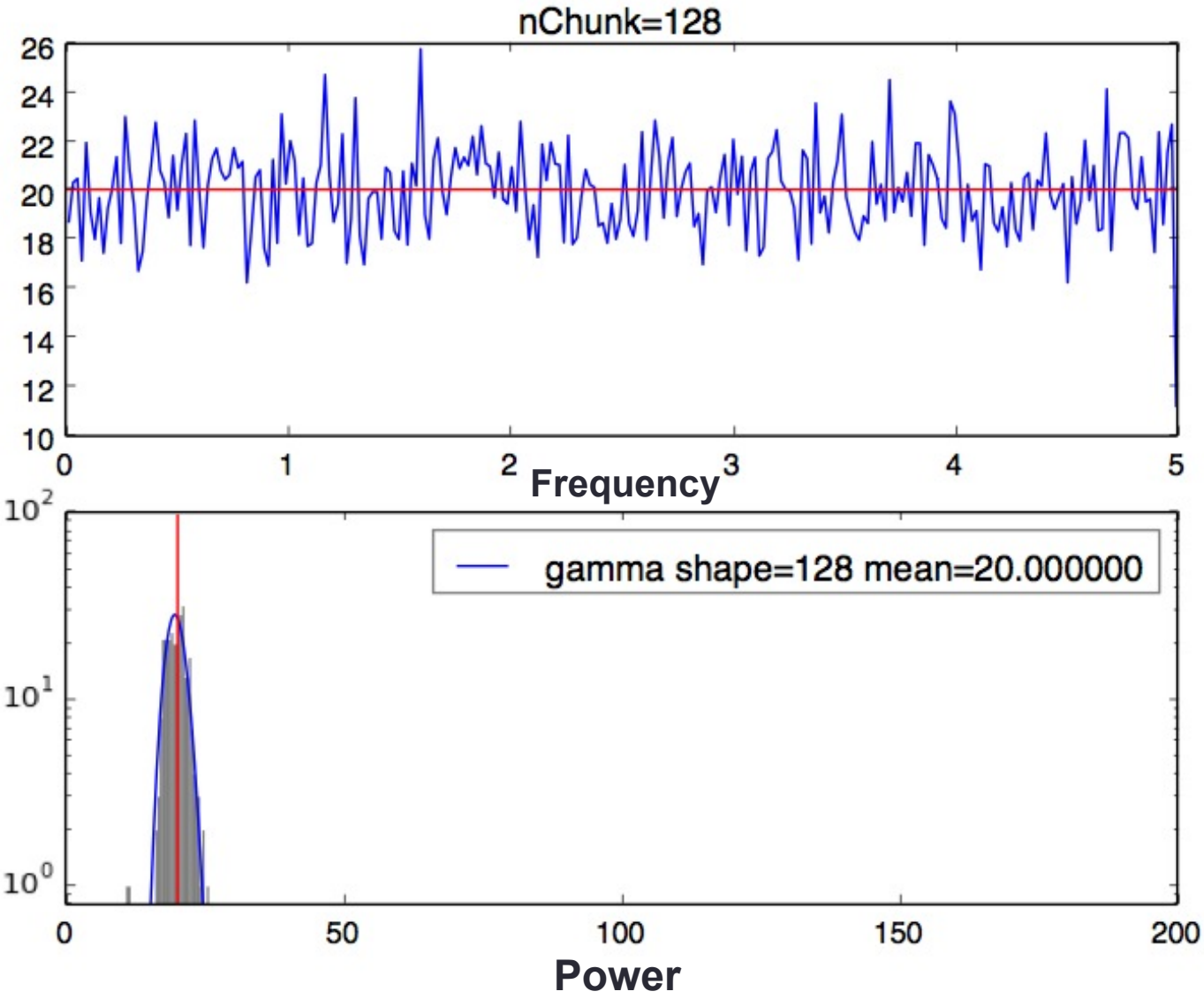
Generating power spectra



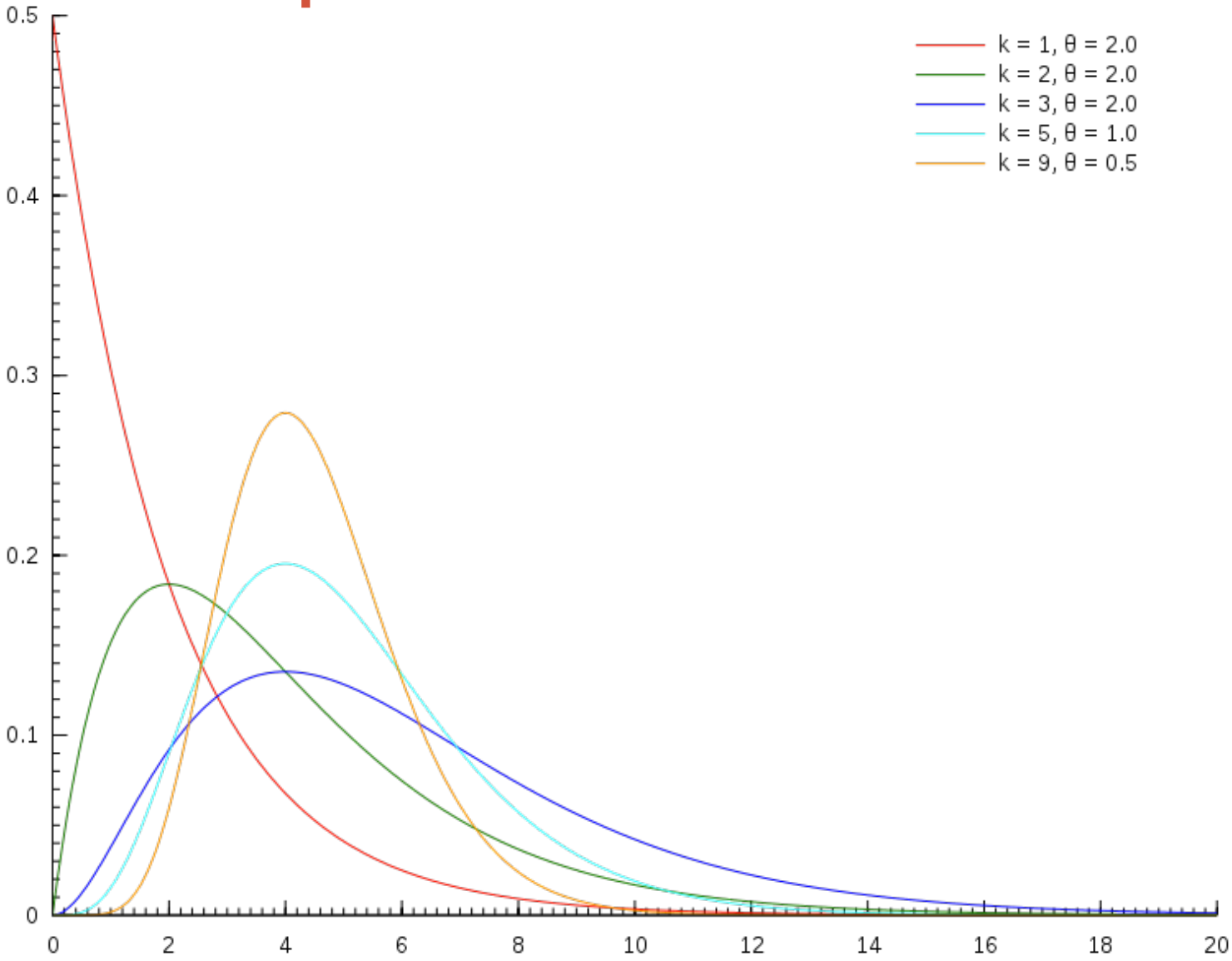
Generating power spectra



Generating power spectra

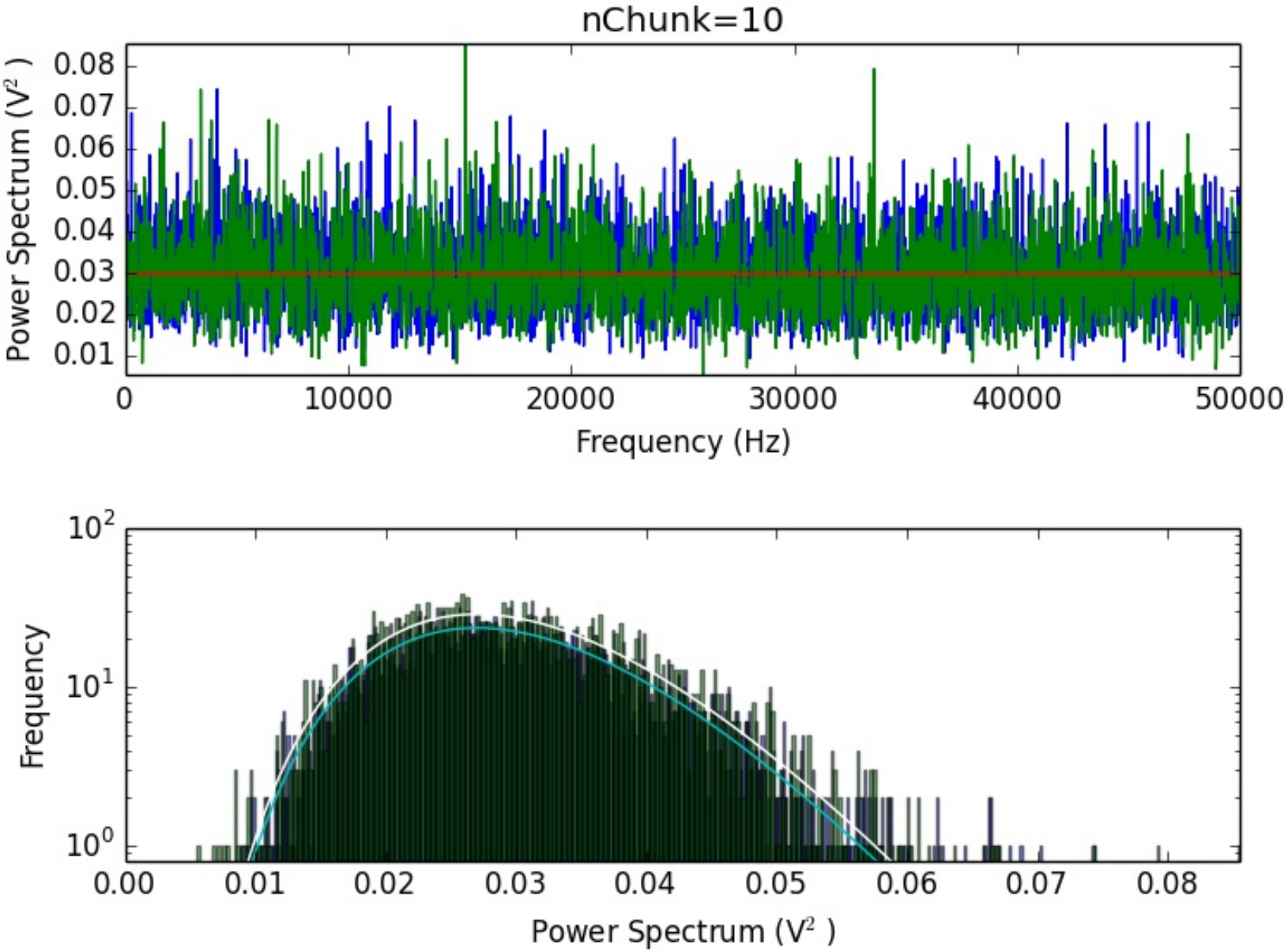


Is there a pattern?



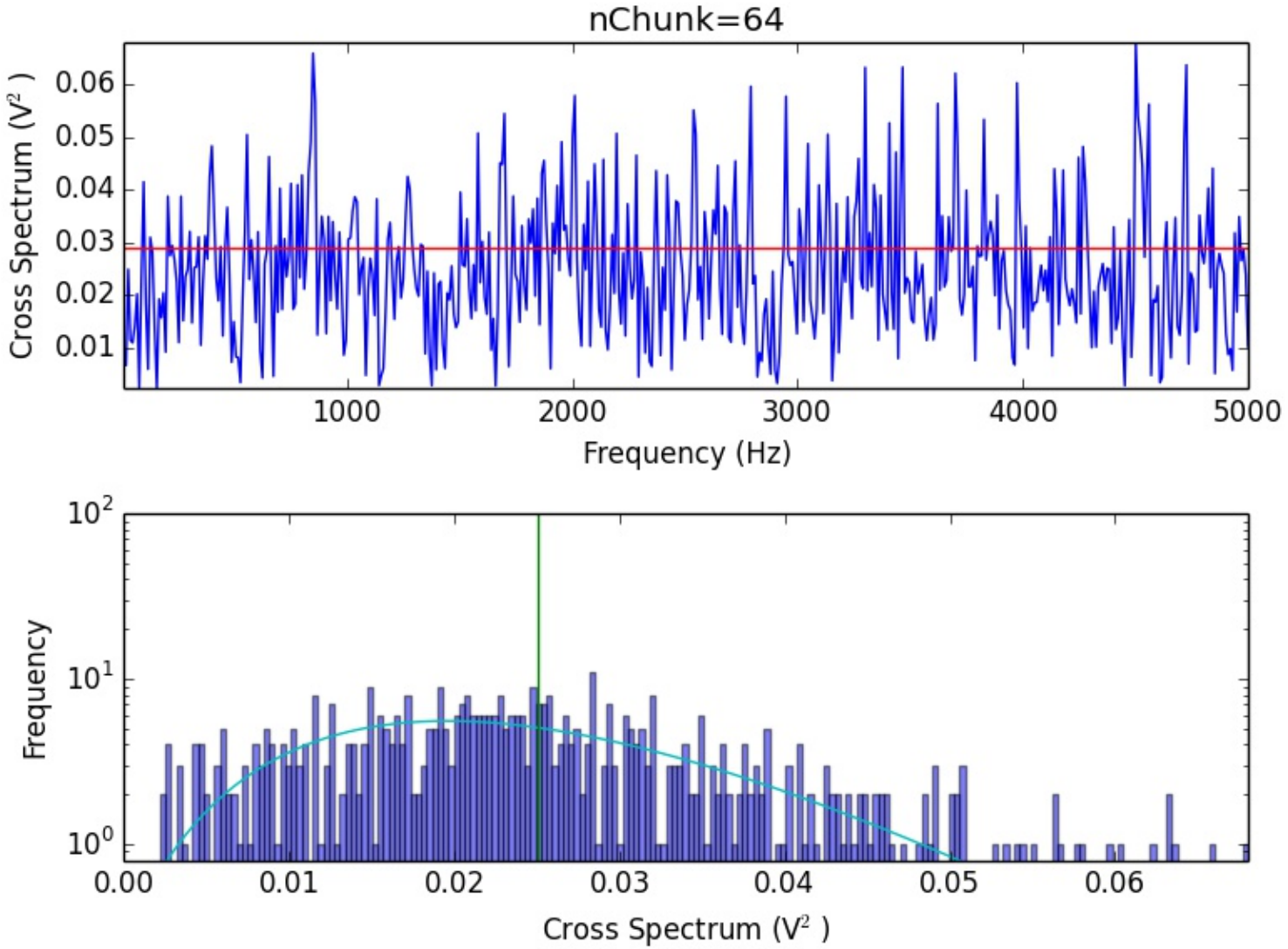
Gamma distribution

- Calculate mean value of power spectrum from given number of photons per second
- Randomly choose values along gamma distribution
- Shape and scale parameters



Comparison of power spectra generated from time series and generated directly.

Generating cross spectra

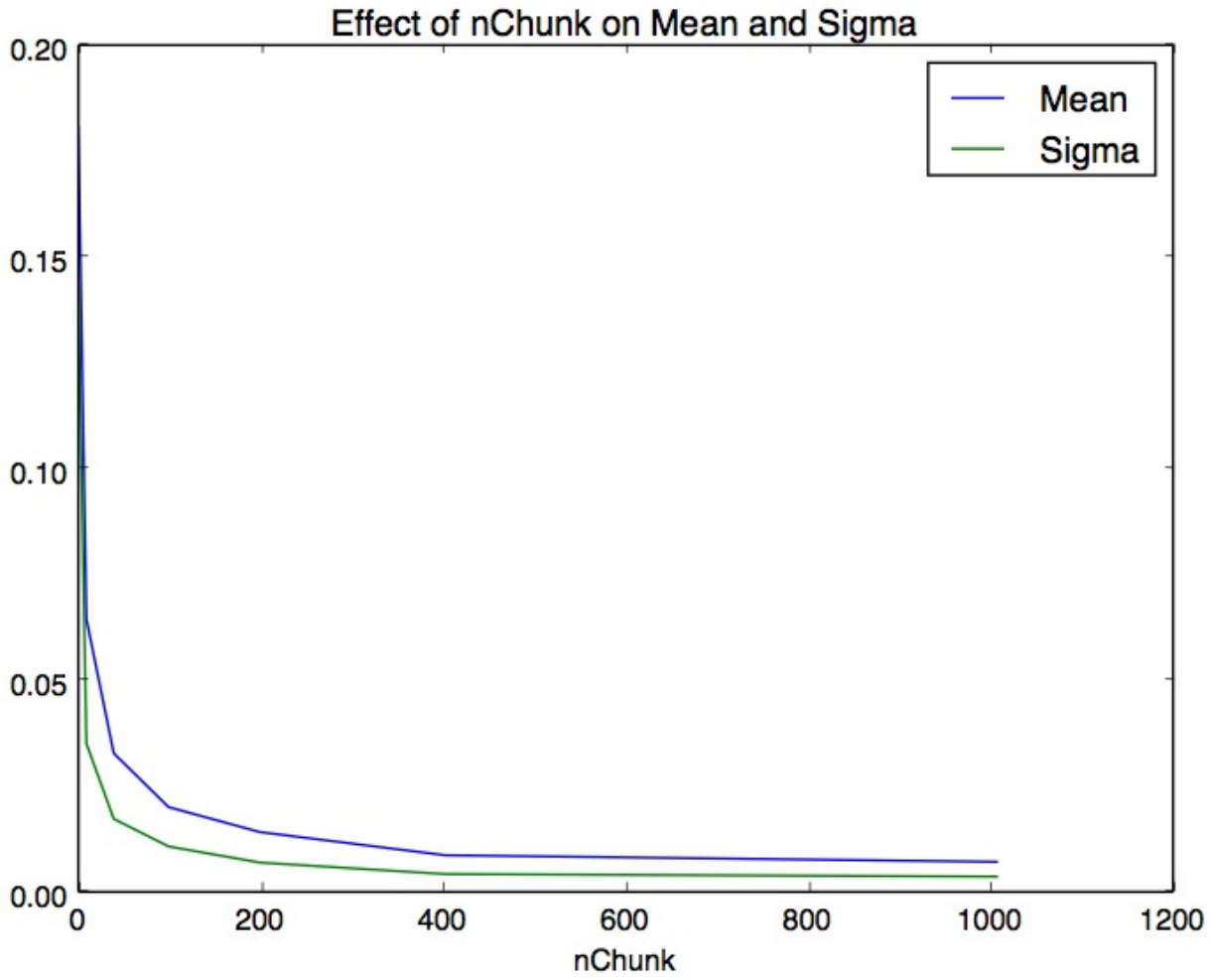


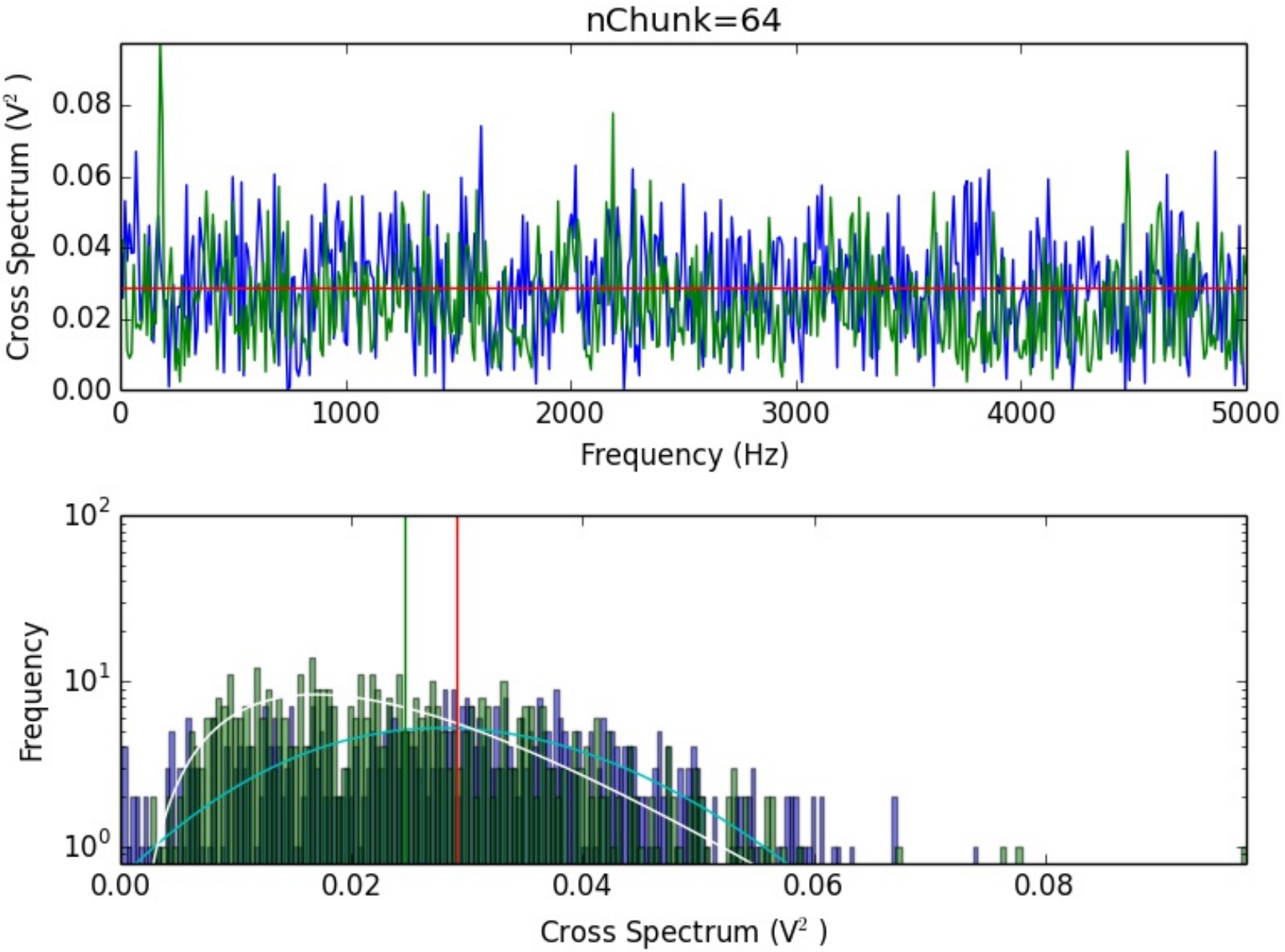
Is there a pattern?

- Central Limit Theorem
- Distribution resembles Gaussian with large number of samples
- Randomly choose values along normal distribution
- Mean and sigma parameters

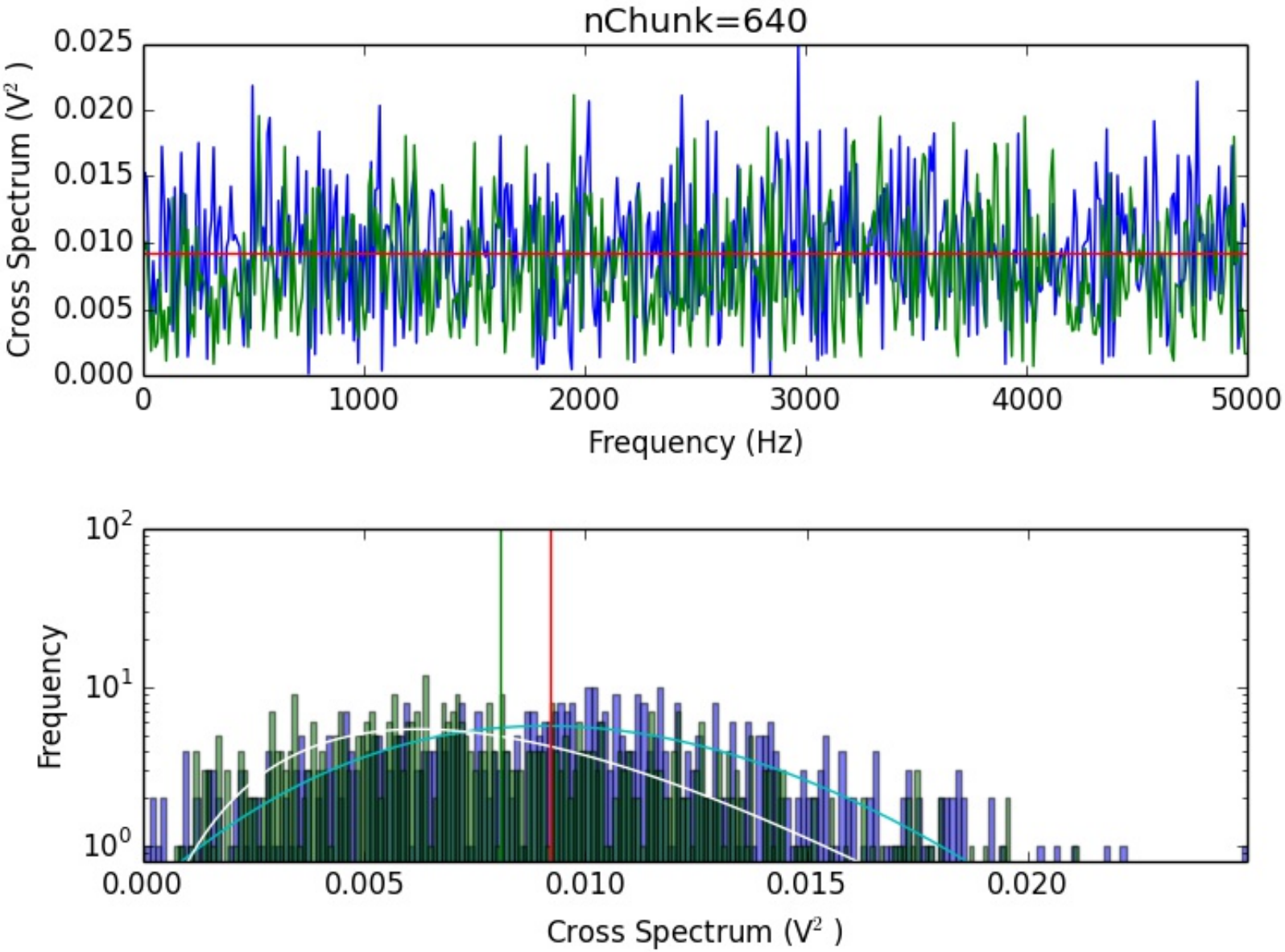
Is there a pattern?

- Mean decreases by square root of nChunk
- Sigma = ½ nChunk

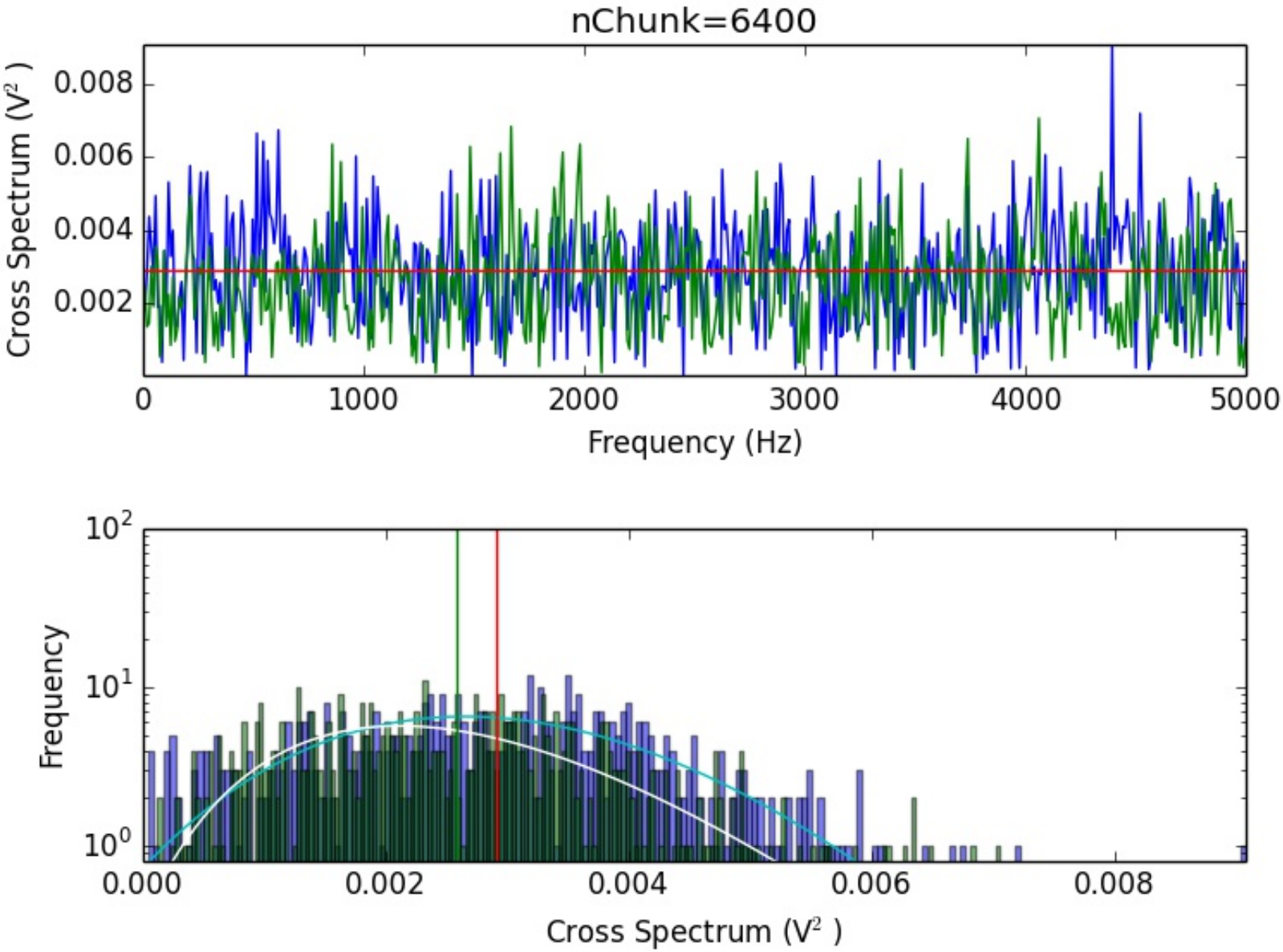




Comparison of cross spectra generated from time series and generated directly.



Comparison of cross spectra generated from time series and generated directly.

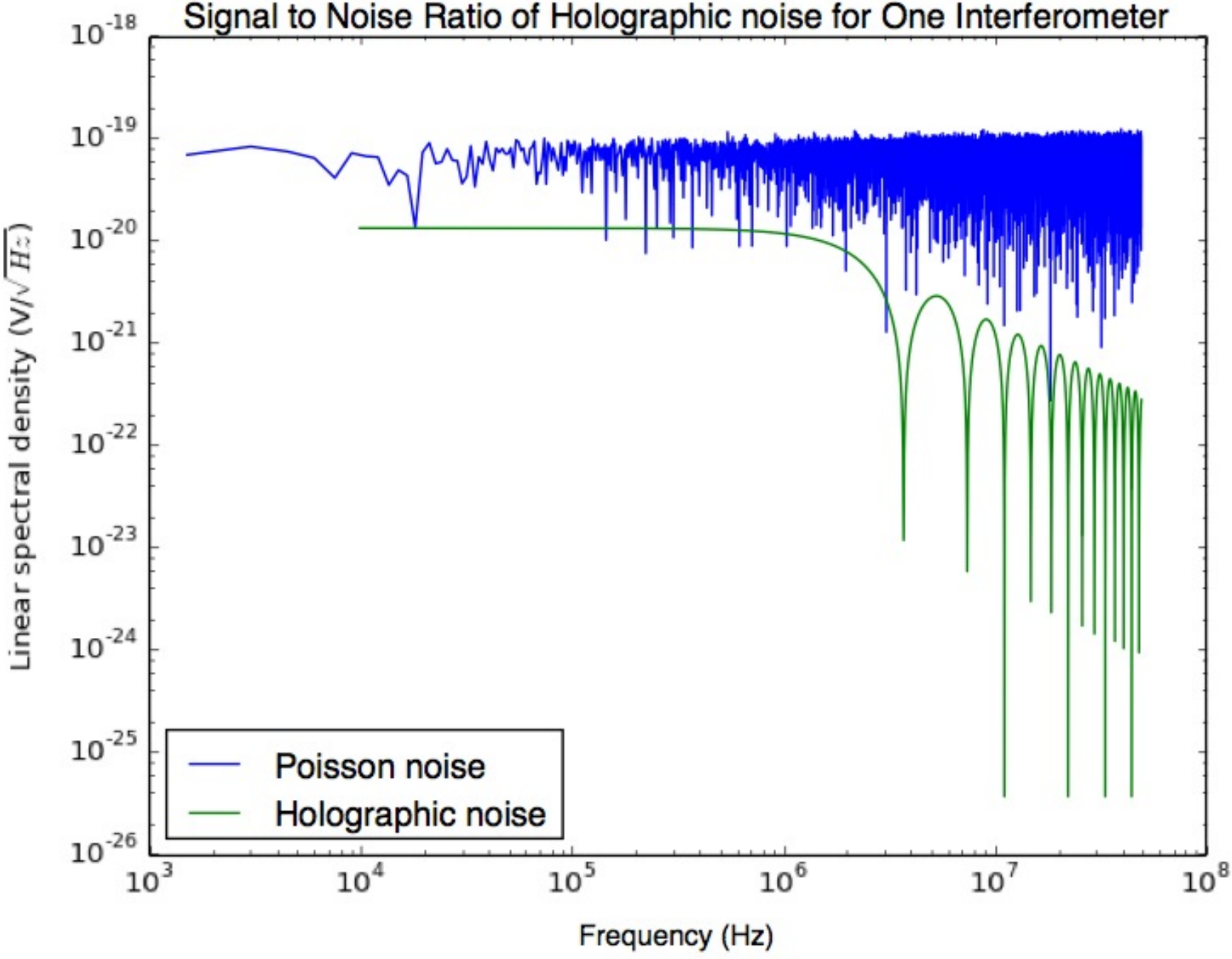


Comparison of cross spectra generated from time series and generated directly.

Poisson noise: One Interferometer

- Calculate mean linear spectral density

$$\sqrt{\Xi^P(f)} = \sqrt{\frac{hc\lambda_\gamma}{4\pi^2 P_{BS}}}$$


Signal to Noise Ratio of Holographic noise for One Interferometer
Linear spectral density (V/√Hz)
Frequency (Hz)
Poisson noise
Holographic noise
10^-18
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
10^-25
10^-26
10^3
10^4
10^5
10^6
10^7
10^8

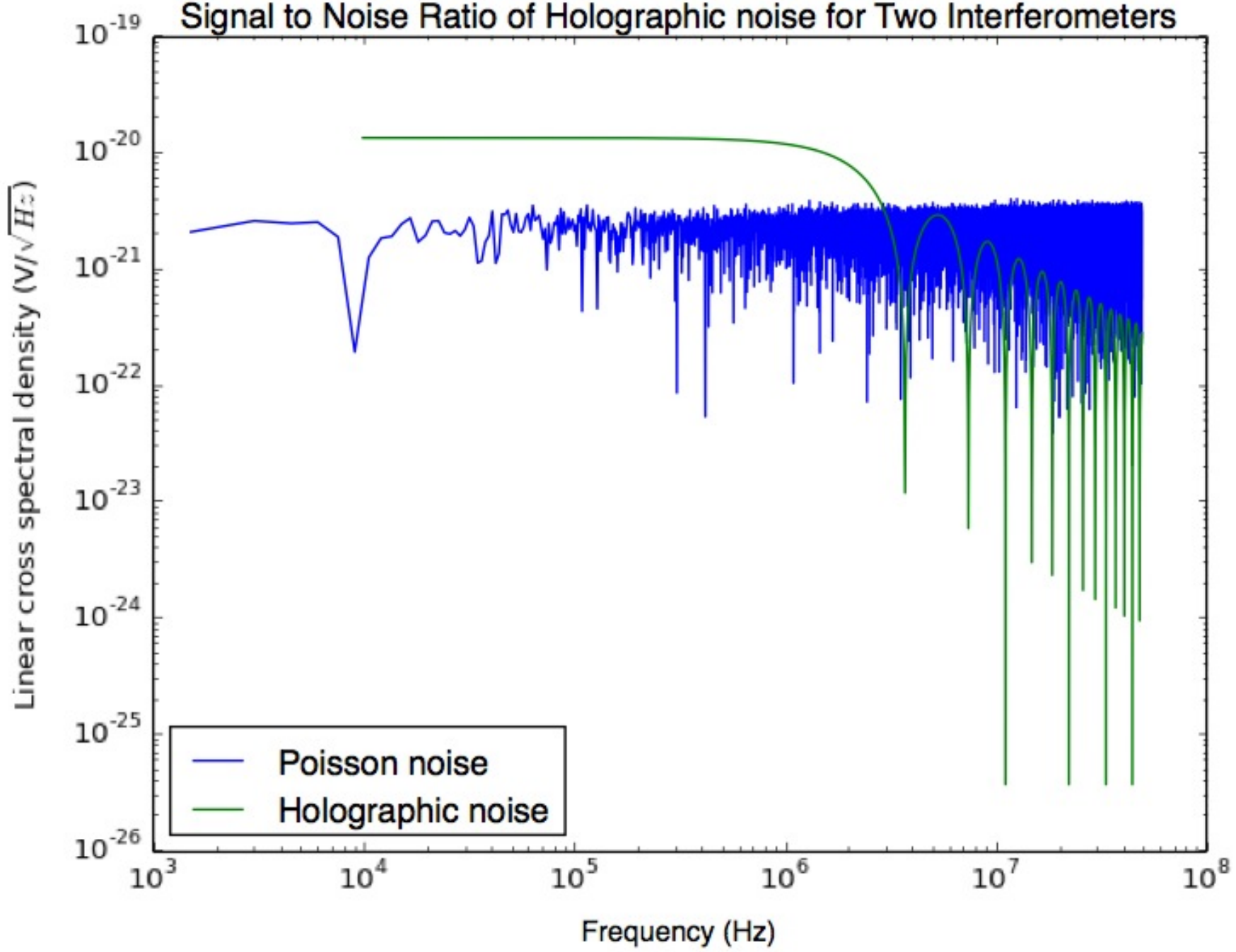
Poisson noise: Two Interferometers

- Calculate mean linear spectral density

$$\sqrt{\Xi^P(f)} = \sqrt{\frac{hc\lambda_\gamma}{4\pi^2 P_{BS}}}$$

- Divide by number of samples over which cross correlation is averaged

$$\Xi^P_{0,1}(f) = \frac{\Xi^P(f)}{\sqrt{N_s}}$$


Signal to Noise Ratio of Holographic noise for Two Interferometers
Linear cross spectral density (V/√Hz)
Frequency (Hz)
Poisson noise
Holographic noise
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
10^-25
10^-26
10^3
10^4
10^5
10^6
10^7
10^8

Future

- The Holometer team will use the produced simulation to test their observations.

My experience at Fermilab

- An incredible opportunity to work amazing scientists
  - (who really, *really* know their stuff)
- Real data, live experiments

Acknowledgements

- Chris Stoughton
- George Dzuricsko, Ian McNair
- Holometer team
  - Brittany Kamai
  - Jonathan Richardson
  - Stephan Meyer
- The Quarknet interns!