Correlated Noise Created by Schumann Resonance

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Overview

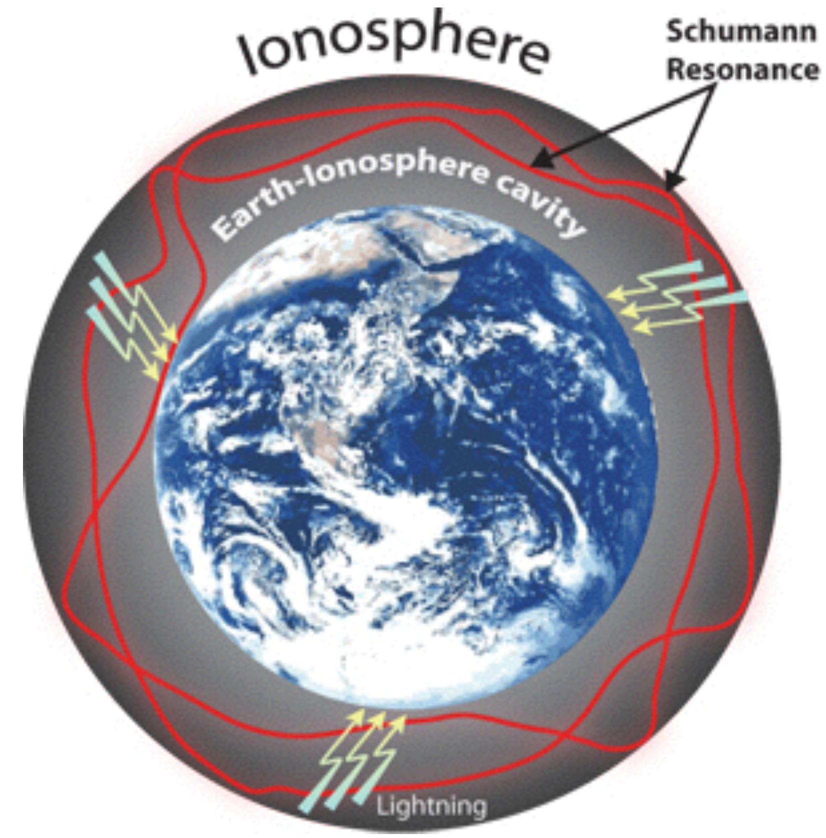
- What are Schumann resonances?
- Why are the important to aLIGO?
- New Magnetometers and Initial Data
- Cleaning Techniques
- Comparing LEMIs to Bartington magnetometers
- Predicted Gains from Low Noise Magnetometers

Stochastic Gravitational Wave Background

- Gravitational waves coming from all directions all the time
- Signals are too weak to detect individually, but the sum of all the signals might be able to be seen…
- … by cross correlating data from two detectors
- Coherent noise at multiple detectors would look like a gravitational wave!

Schumann Resonance

- Caused by lightning
- Ground/Ionosphere create a spherical shell
- Most lightning strikes are in the Amazon or the Congo
- Primary frequency at 7.48 Hz



$$f = \frac{c}{2 \cdot \pi \cdot r_e}$$

Implications for aLIGO

- Coherent fields at both detectors
- Test masses are affected by magnetic fields
- Variations in coherent magnetic fields create coherent noise the detector
- Subtract correlated noise with magnetometers

Coherence

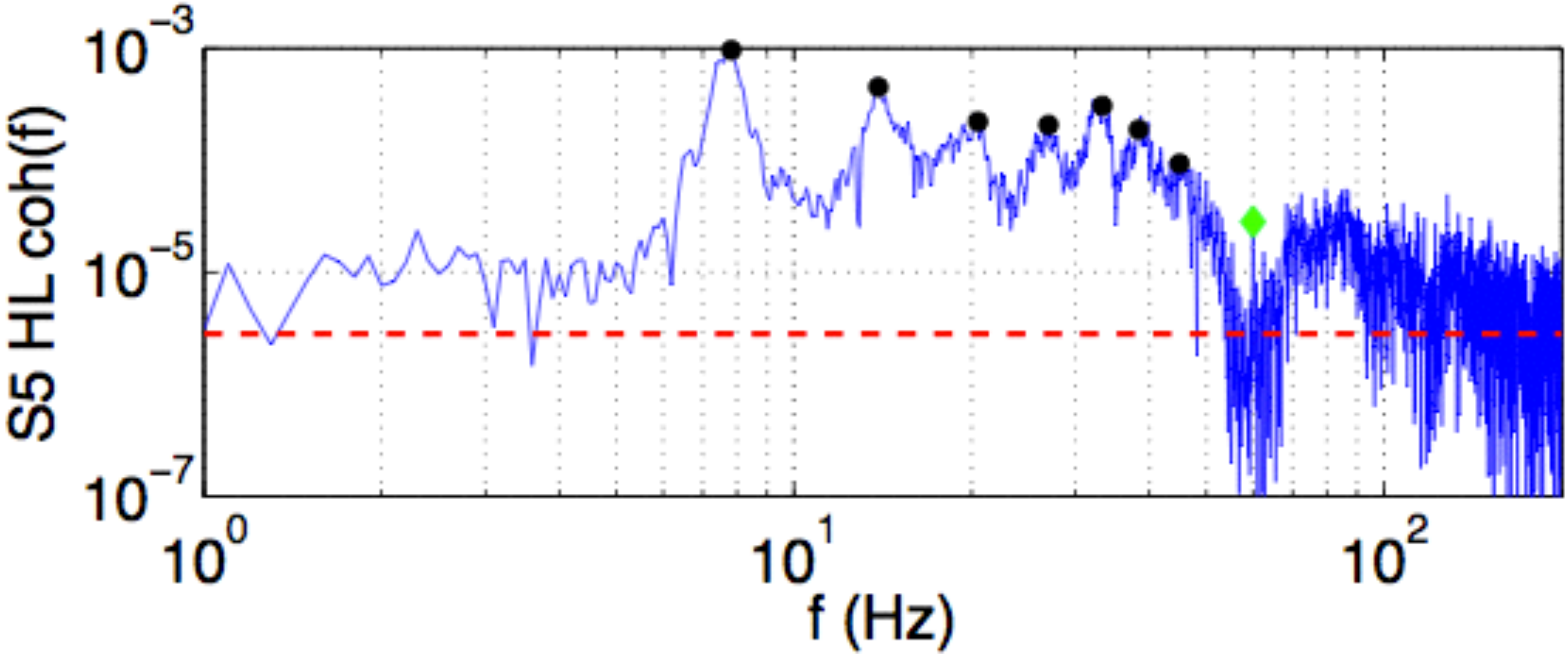
$$C_{xy} = \frac{|G_{xy}|^2}{G_{xx}G_{yy}}$$

Cross Spectral Density

Power Spectral Density

- If the signals are the same the coherence is 1
- If the signals are not related this goes to zero as the time goes to infinity

Magnetic Field Coherence Between LLO and LHO (t = 330 days)



E. Thrane, N. Christensen, R. M. S. Schofield, March 2013

LEMI Magnetometer

Frequency (Hz)	*0.01*	*0.10*	*1.00*	*10.00*
Noise Floor (pT/Hz^1/2)	*20.00*	*2.00*	*0.20*	*0.04*

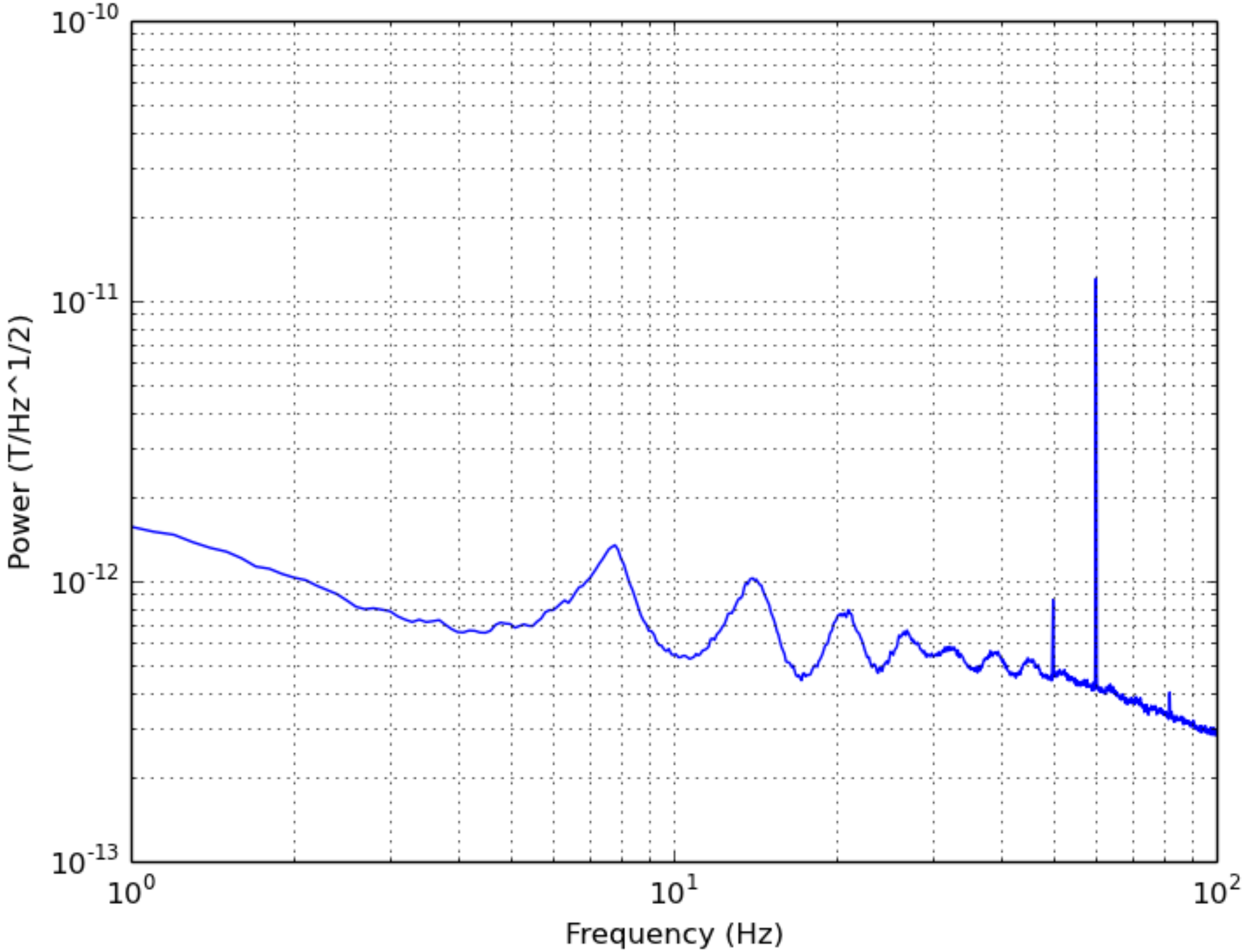
LHO Sites


Drumheller
LHO
Rattlesnake
Table Mountain
Everett
Seattle
Bellevue
Renton
Kent
Tacoma
Olympia
Puyallup
Aberdeen
Centralia
Astoria
St Helens
Vancouver
Portland
Forest Grove
Tigard
McMinnville
Olympic National Park
Olympic National Forest
Mt Rainier National Park
Columbia River Gorge National Scenic Area
Mt Hood National Forest
Wenatchee
Washington
Ellensburg
Yakima
Kennewick
Walla Walla
Pendleton
La Grande
Spokane
Coeur d'Alene
Coeur D'Alene National Forest
Moscow
Lewiston
Wallowa-Whitman National Forest
National Forest

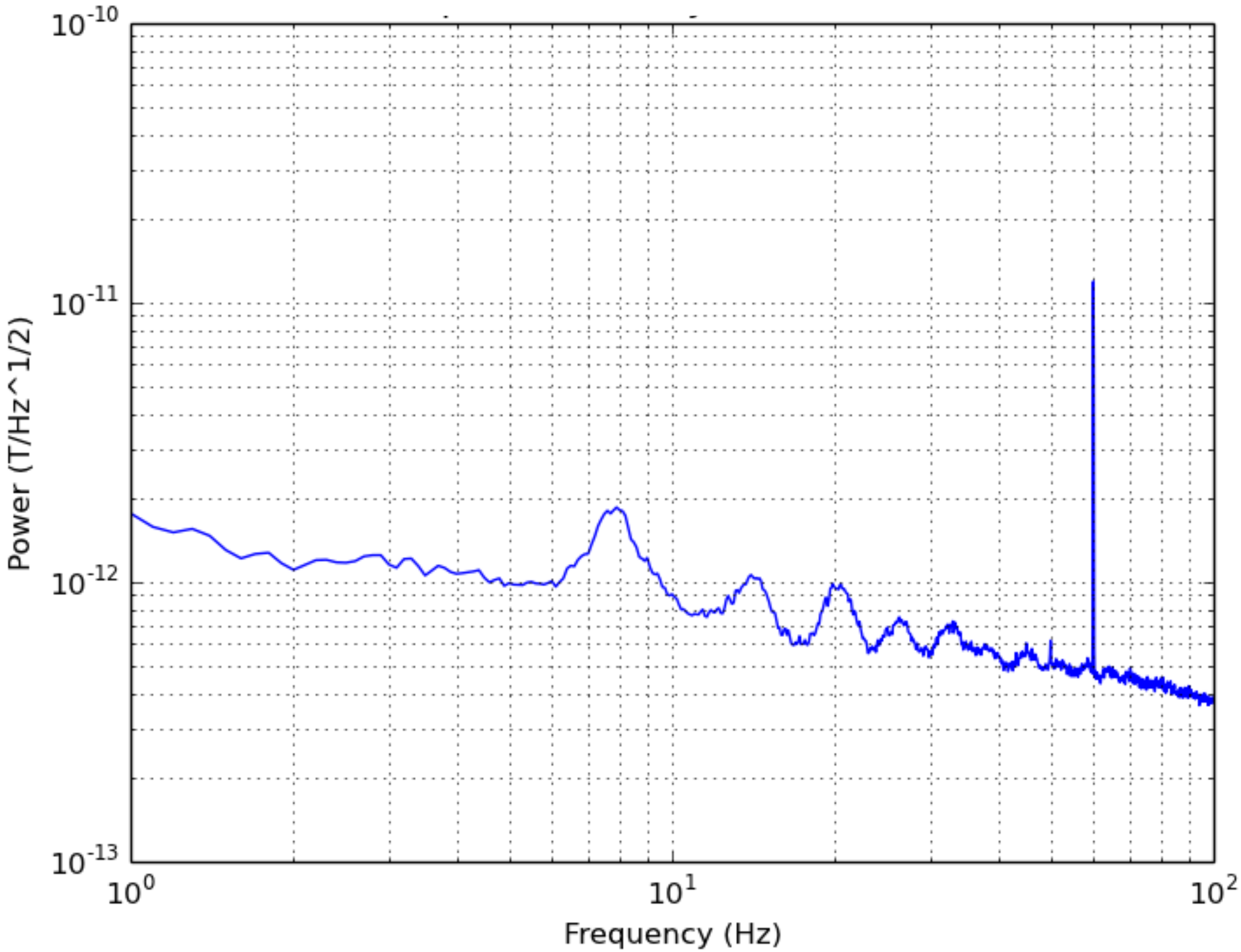
LLO Sites


Tickfaw Park
LLO
Amite City
Loranger
Zachary
Baker
Central
Denham Springs
Walker
Hammond
Robert
Baton Rouge
Port Allen
Ponchatoula
Highlands/ Perkins
Inniswold
Shenandoah
South Baton Rouge
Prairieville
Plaquemine
St Gabriel
Lake Maurepas

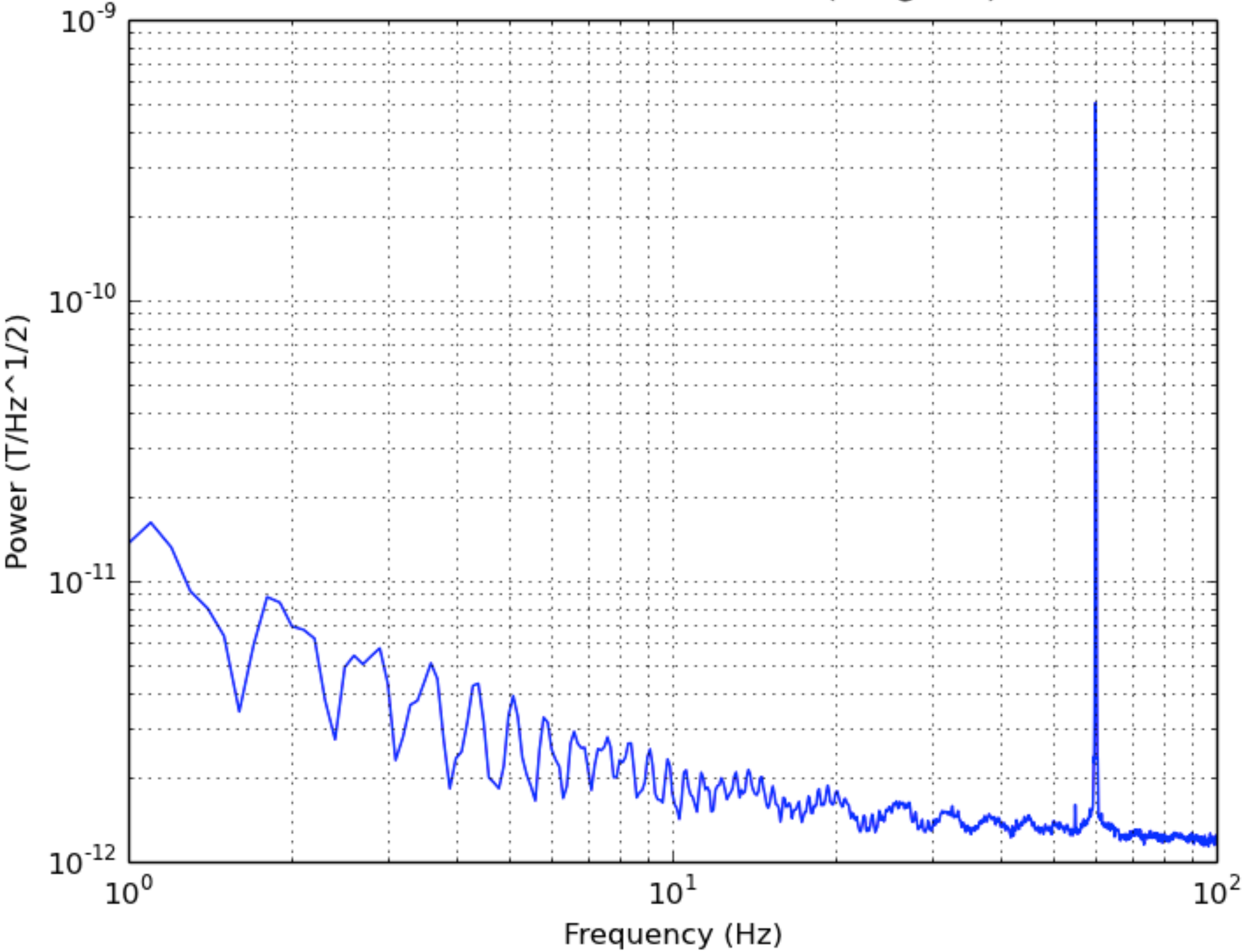
PSD Table Mountain EW

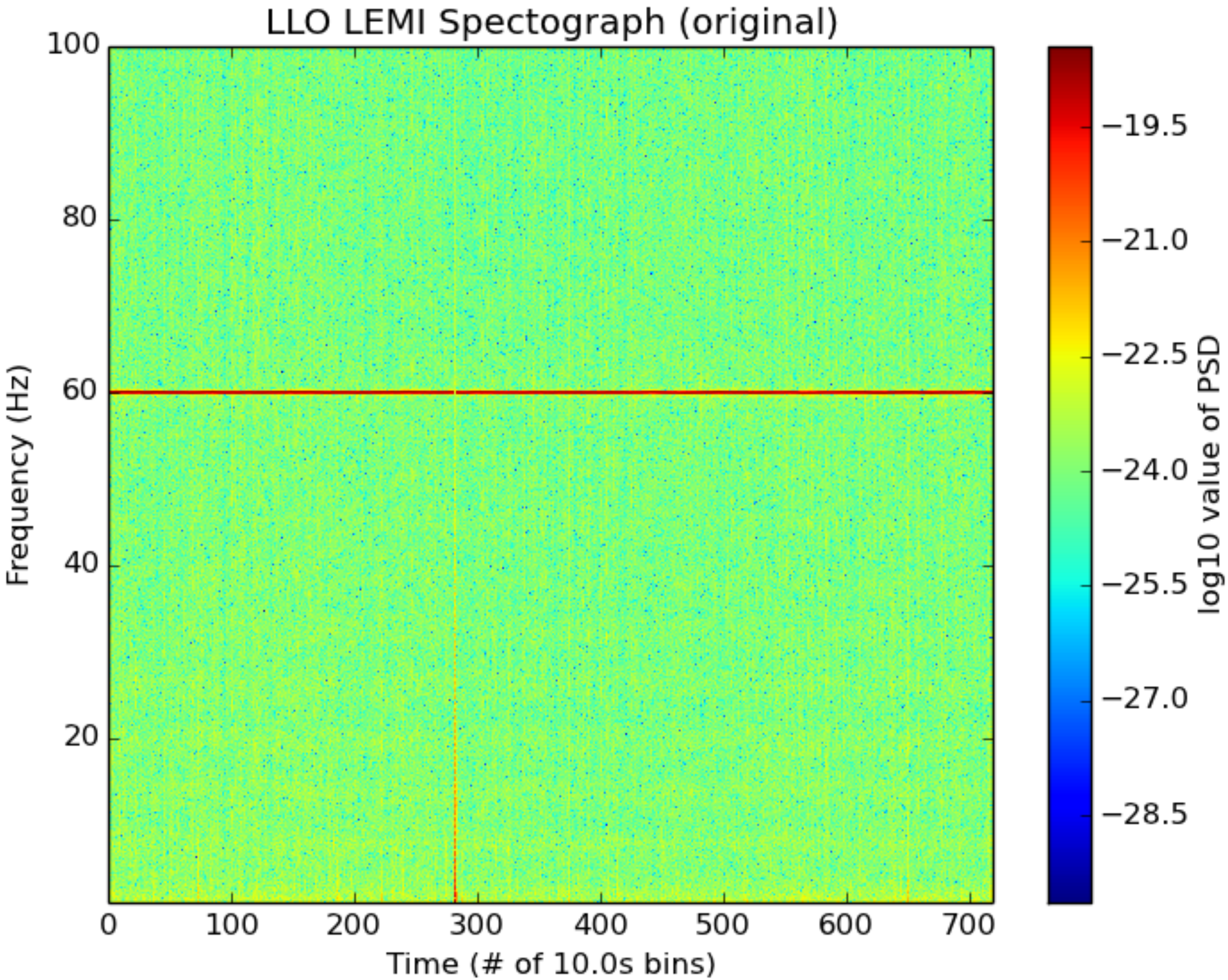


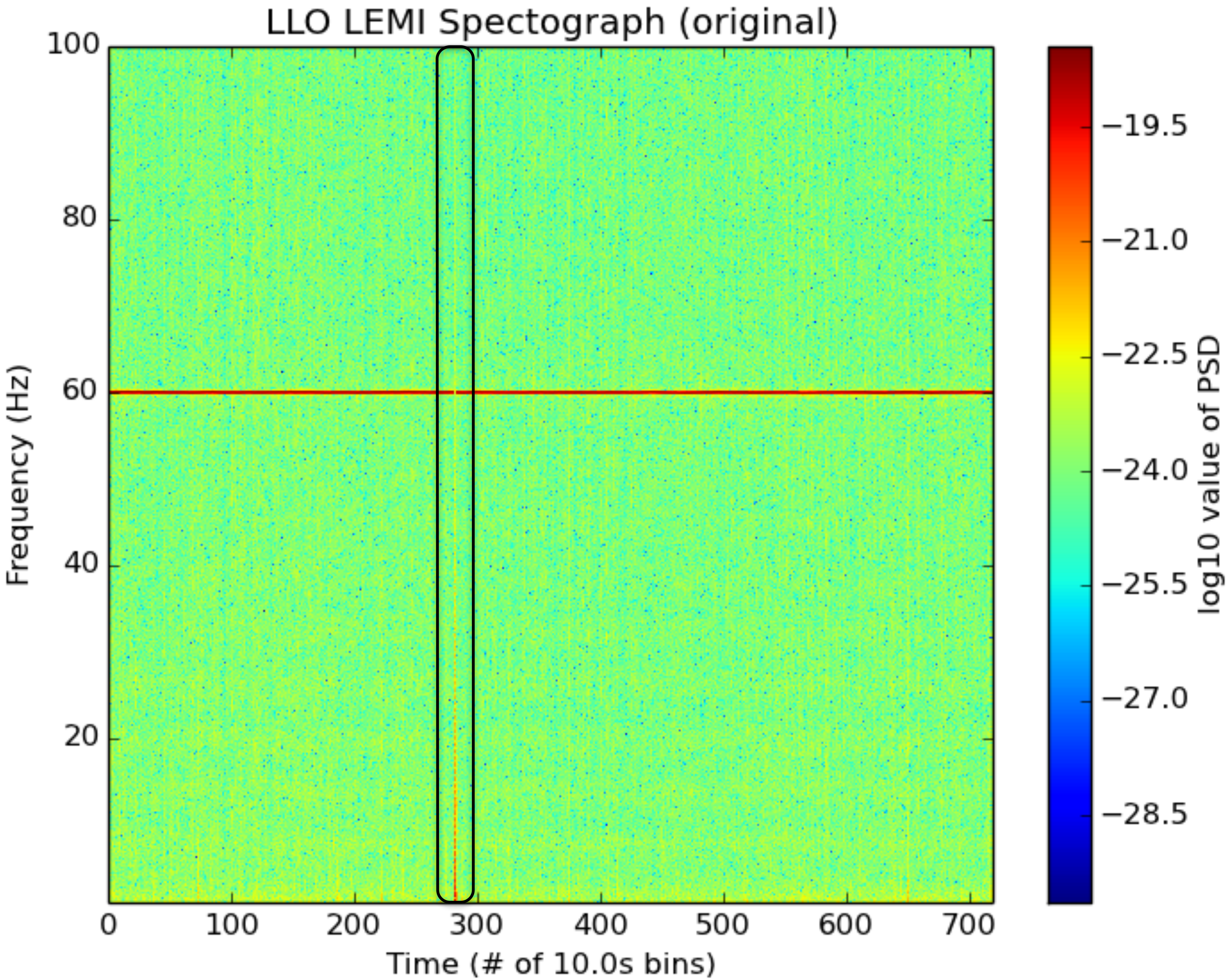
PSD Table Mountain NS

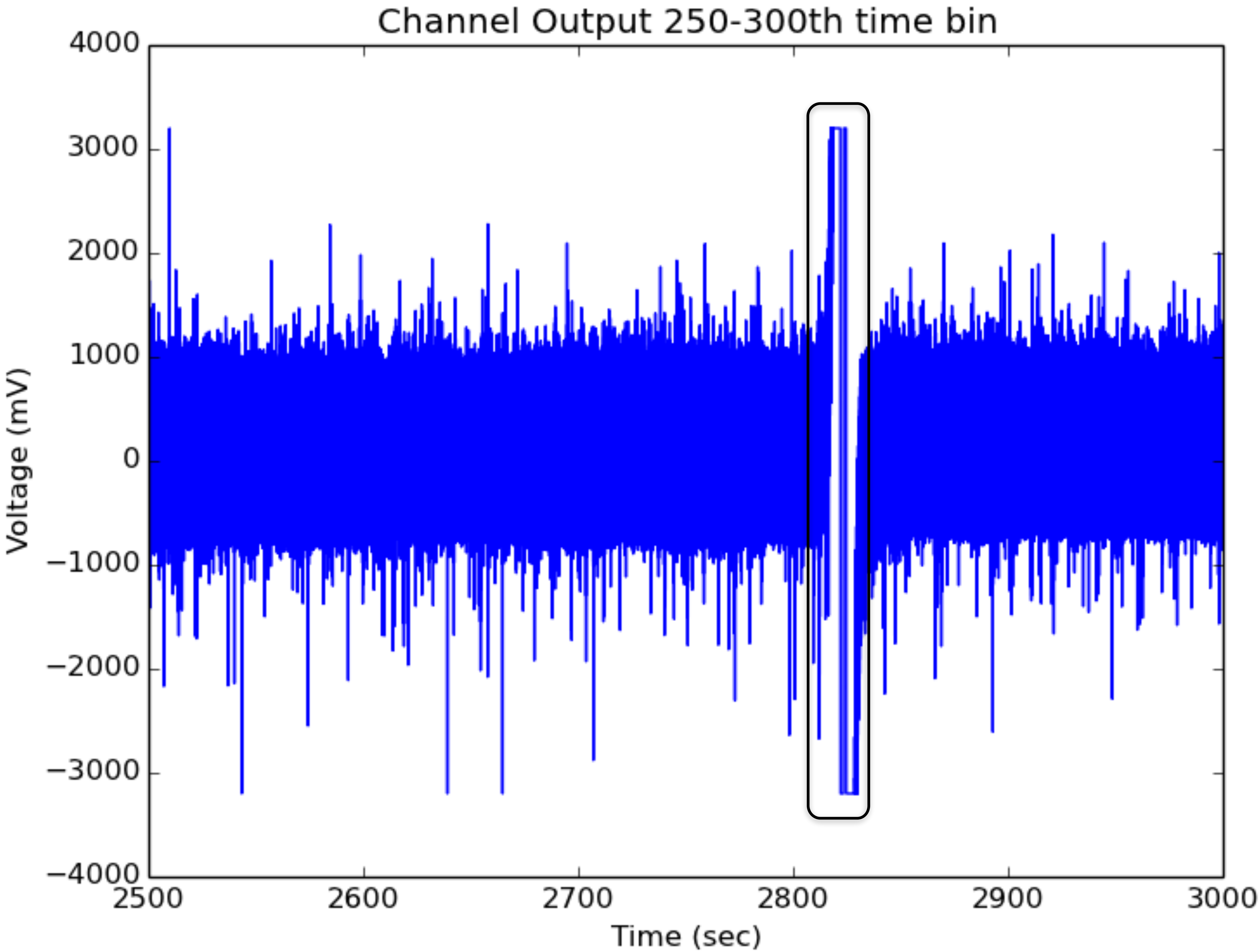


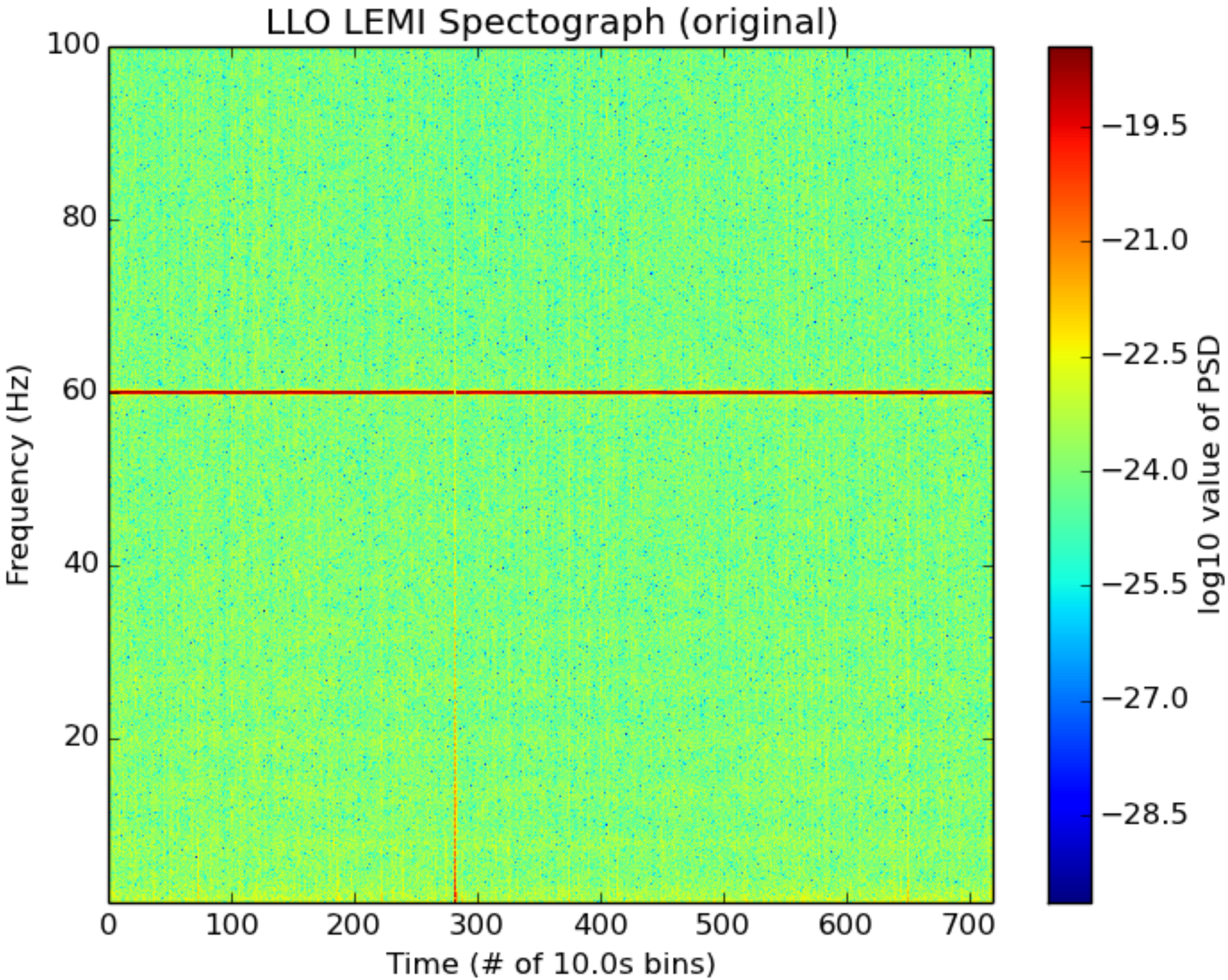
LEMI LLO Woods PSD (Original)

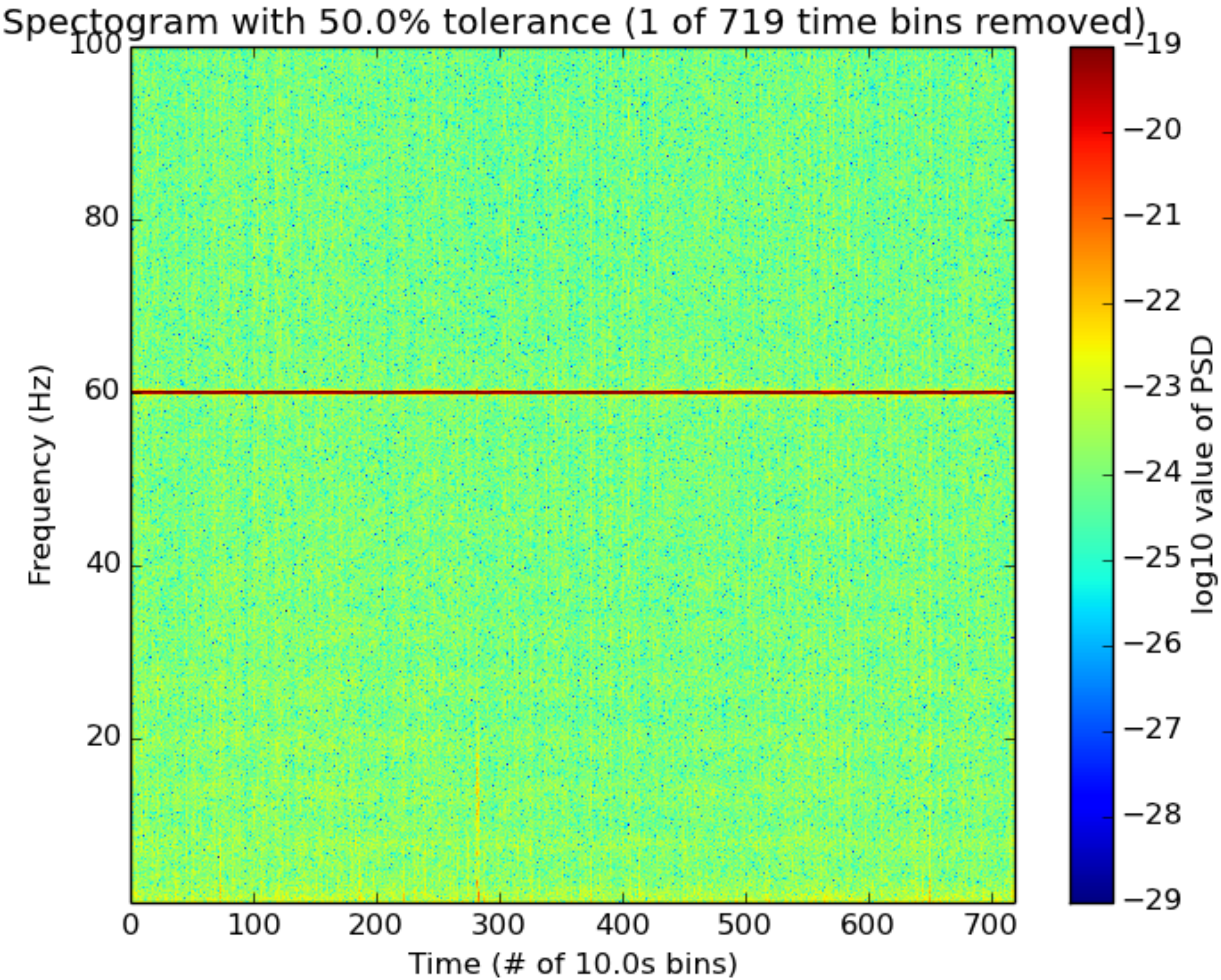



LLO LEMI Spectograph (original)
Frequency (Hz)
100
80
60
40
20
0
100
200
300
400
500
600
700
Time (# of 10.0s bins)
−19.5
−21.0
−22.5
−24.0
−25.5
−27.0
−28.5
log10 value of PSD


LLO LEMI Spectograph (original)
Frequency (Hz)
Time (# of 10.0s bins)
log10 value of PSD
100
80
60
40
20
0
100
200
300
400
500
600
700
−19.5
−21.0
−22.5
−24.0
−25.5
−27.0
−28.5

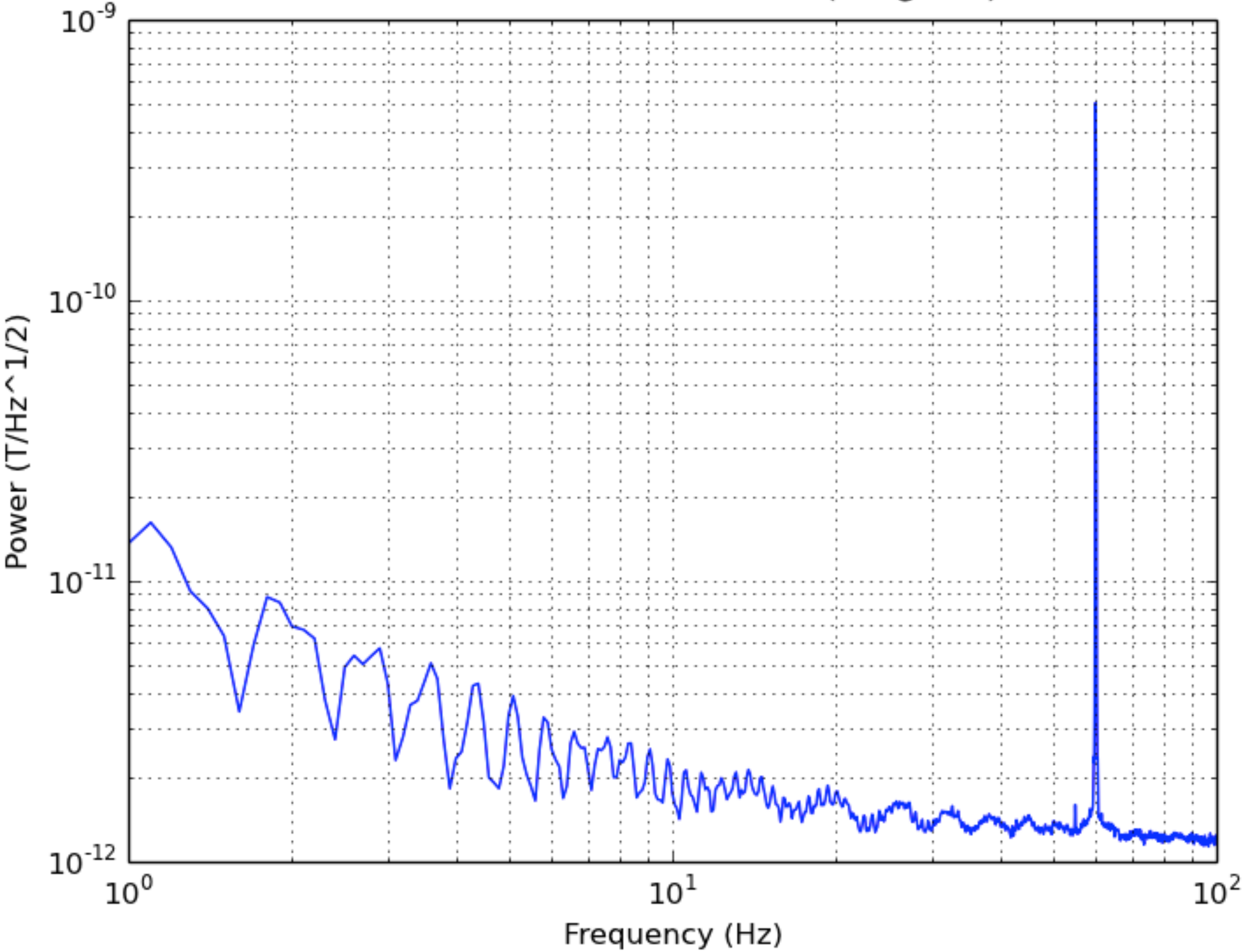

Channel Output 250-300th time bin
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
Voltage (mV)
2500
2600
2700
2800
2900
3000
Time (sec)

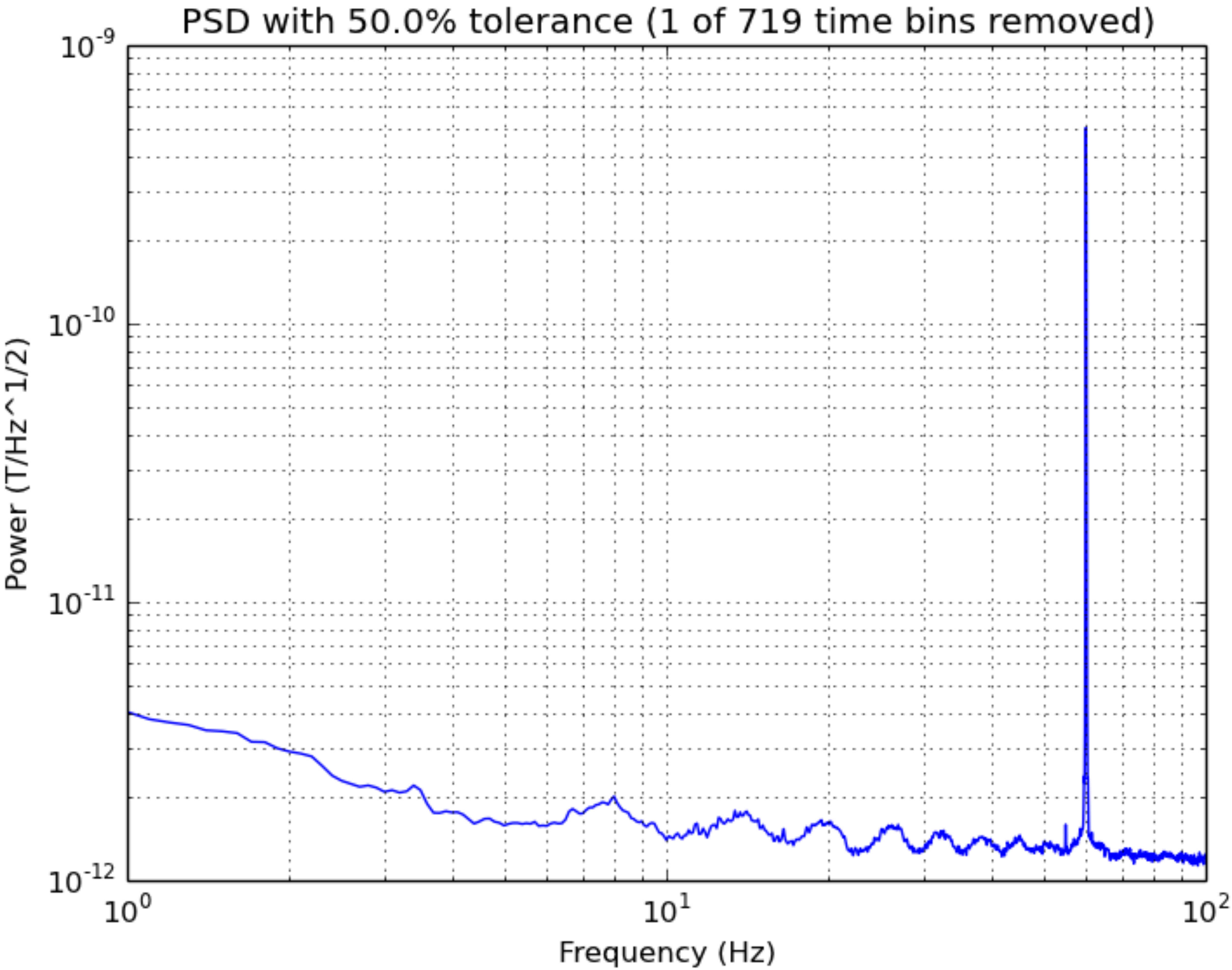

LLO LEMI Spectograph (original)
Frequency (Hz)
100
80
60
40
20
0
100
200
300
400
500
600
700
Time (# of 10.0s bins)
−19.5
−21.0
−22.5
−24.0
−25.5
−27.0
−28.5
log10 value of PSD

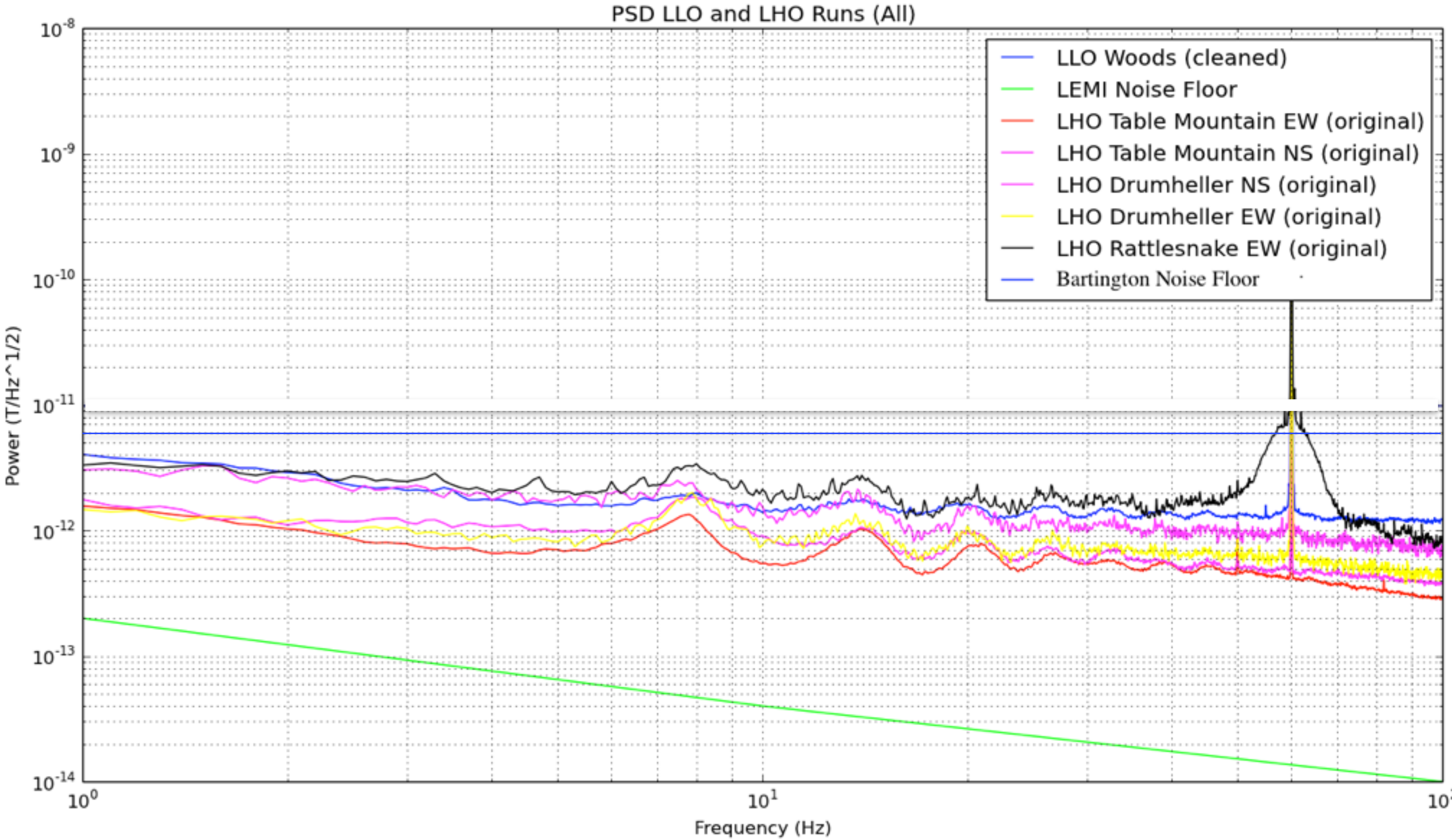


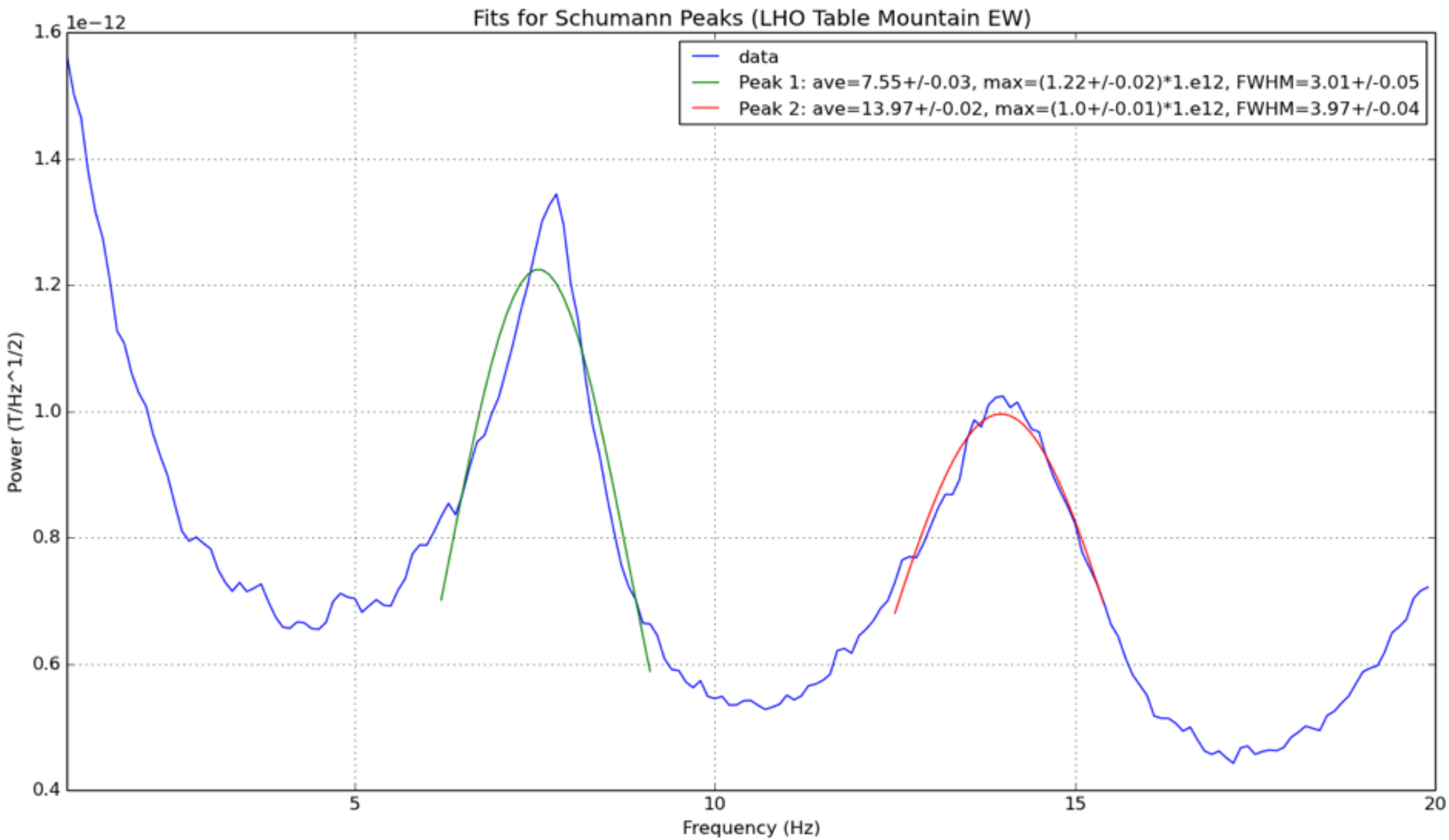
Spectogram with 50.0% tolerance (1 of 719 time bins removed)
100
80
60
40
20
Frequency (Hz)
0
100
200
300
400
500
600
700
Time (# of 10.0s bins)
−19
−20
−21
−22
−23
−24
−25
−26
−27
−28
−29
log10 value of PSD

LEMI LLO Woods PSD (Original)




PSD with 50.0% tolerance (1 of 719 time bins removed)
Power (T/Hz^1/2)
10-9
10-10
10-11
10-12
10^0
10^1
10^2
Frequency (Hz)


PSD LLO and LHO Runs (All)
LLO Woods (cleaned)
LEMI Noise Floor
LHO Table Mountain EW (original)
LHO Table Mountain NS (original)
LHO Drumheller NS (original)
LHO Drumheller EW (original)
LHO Rattlesnake EW (original)
Bartington Noise Floor
Power (T/Hz^1/2)
Frequency (Hz)
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^0
10^1
10^2



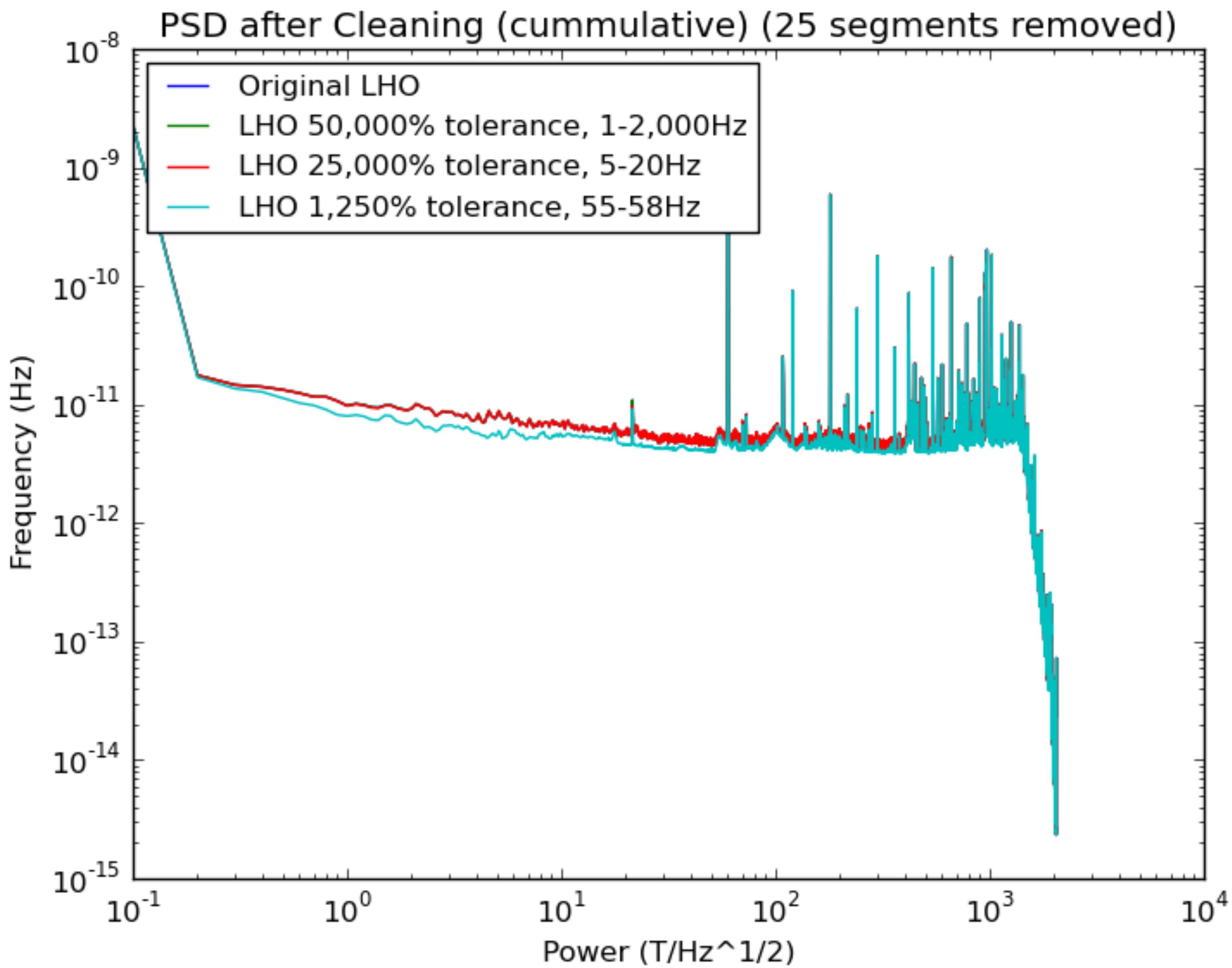
Fits for Schumann Peaks (LHO Table Mountain EW)
1e−12
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Power (T/Hz^1/2)
5
10
15
20
Frequency (Hz)
data
Peak 1: ave=7.55+/-0.03, max=(1.22+/-0.02)*1.e12, FWHM=3.01+/-0.05
Peak 2: ave=13.97+/-0.02, max=(1.0+/-0.01)*1.e12, FWHM=3.97+/-0.04

Schumann Peak Properties

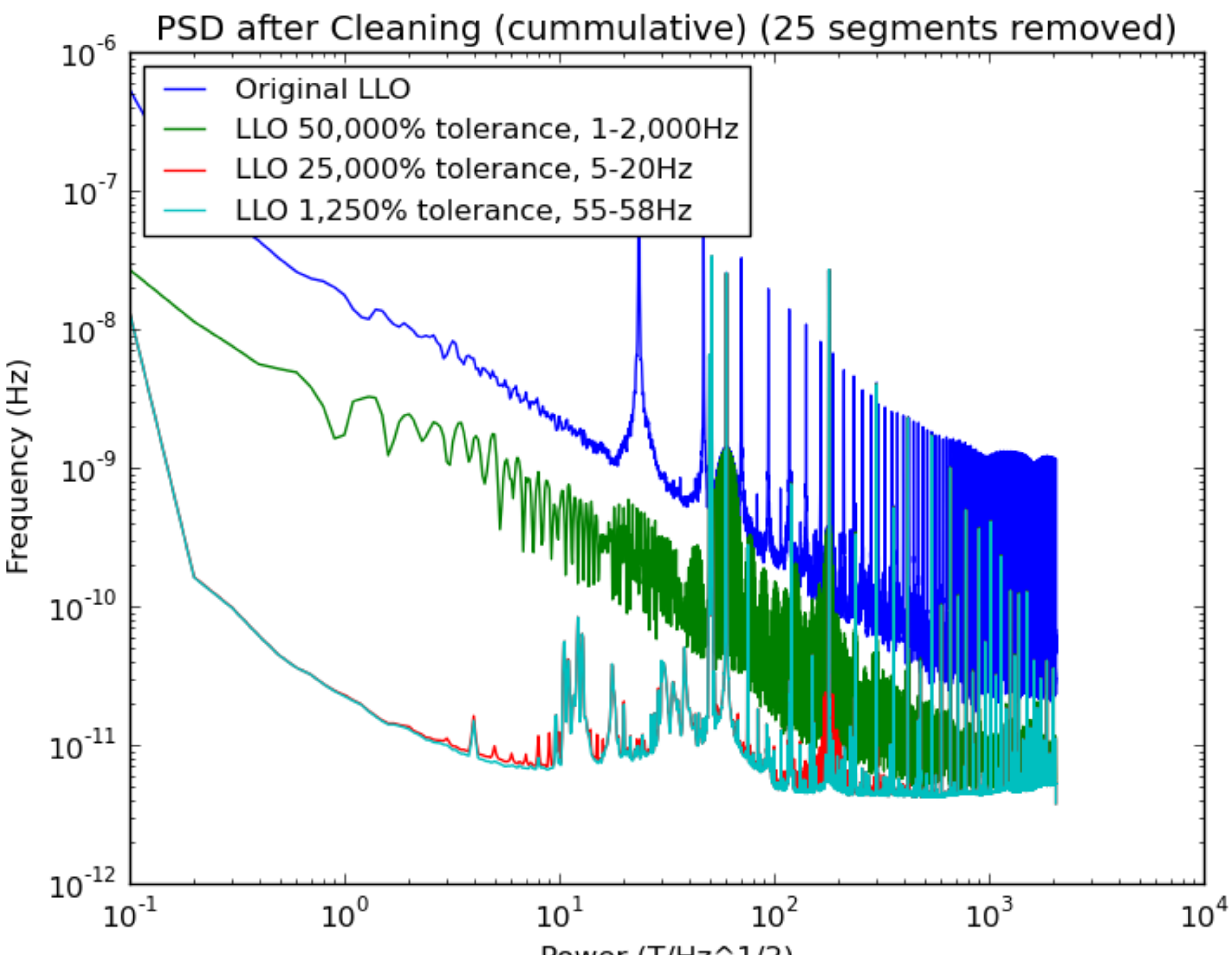
	1st Peak Frequency	Error (Hz)	1st Peak Amplitude (pT/Hz^1/2)	Error (pT/Hz^1/2)
Averages	7.82	0.18	1.88	0.57

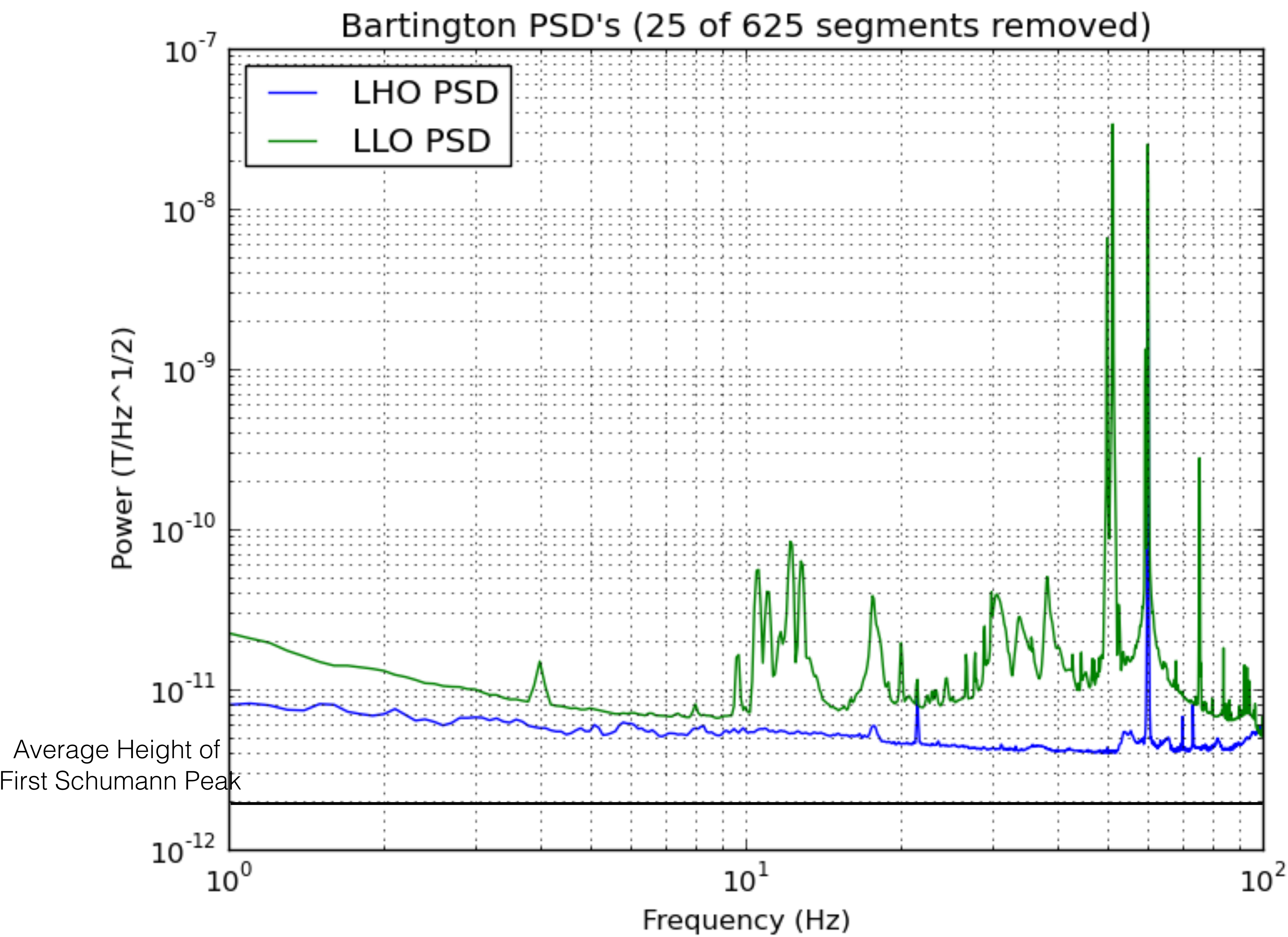
	2nd Peak Frequency	Error (Hz)	2nd Peak Amplitude (pT/Hz^1/2)	Error (pT/Hz^1/2)
Averages	13.96	0.15	1.50	0.56

LHO Data (07/21/14-08/2/14)



LLO Data
(July 21st-August 2nd)




Bartington PSD's (25 of 625 segments removed)
LHO PSD
LLO PSD
Power (T/Hz^1/2)
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^0
10^1
10^2
Frequency (Hz)
Average Height of
First Schumann Peak

Conclusions

- Bartington magnetometers can't see that Schumann peaks directly
- It takes multiple months of data to see the peaks in the coherence spectrum
- Efficient subtraction would require multiple LEMI-like detectors (at least one at each site)

Proposed Future Tests

- Record coincident LEMI data at LLO and LHO.
- Also record quadruple coincidence data with standard (Bartington) magnetometers at LHO/LLO.
- Calculate coherence spectra.
- Try cleaning LEMI a with LEMI b.
- Estimate residual power: a combination of local noise and non-common Schumann noise.

Proposed Future Tests

- Try to reduce coherence between LHO-LLO from 10^{-3} to $<10^{-5}$.
- This would require ~12 days of data (assuming 10s segments).
- A reduction of 100 in coherence corresponds to a factor of 10 reduction in SNR.
- This demonstration would be an important first step.

Acknowledgements

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