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# Spectral Lines in S3 / S4

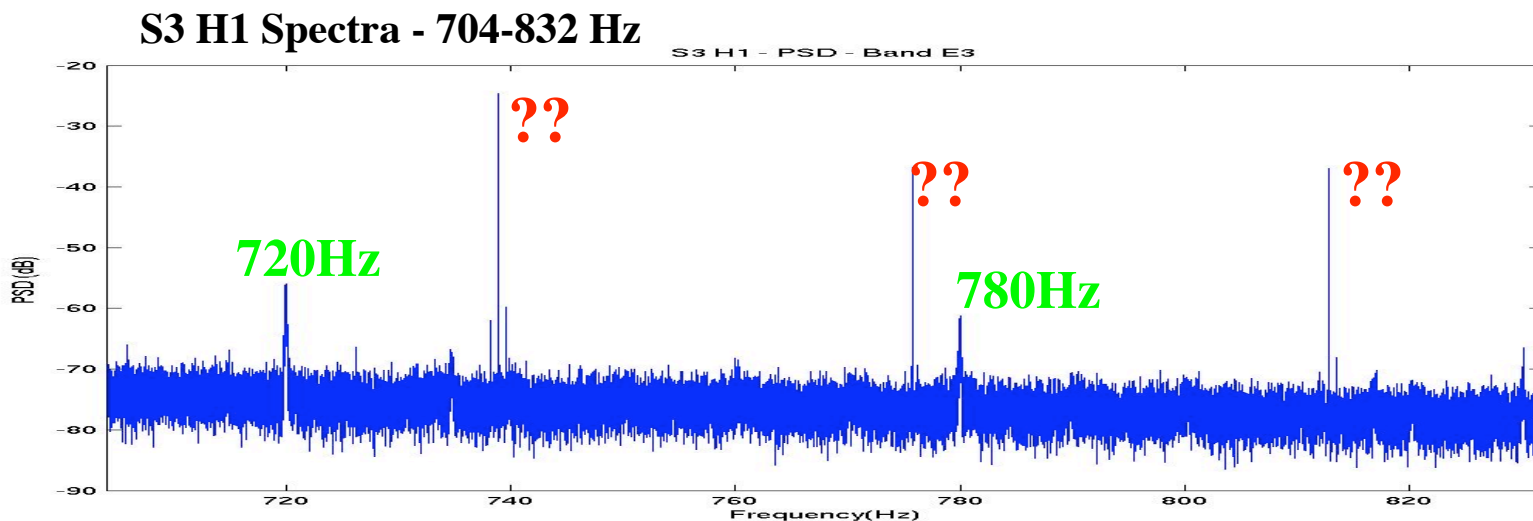
Keith Thorne  
Penn State University

<https://gravity.psu.edu/~s4/detchar>



# Spectral Lines in LIGO Data

- The presence of spectral lines (resonances) in AS\_Q data complicates data analysis
- Some resonances are known in LIGO I (Violin Modes, 60Hz)
- Other resonances (often narrow) have been left unexplained



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# Automated Narrow Line-Finding

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- Motivation: BlockNormal ETG has used Kalman filtering to remove narrow line features not due to 60Hz, calibration
- Developed simple automated method to search for persistent lines in PSDs, for which to later develop Kalman filters
  - » Concentrated on high-Q lines within BlockNormal frequency bands (avoided violin modes)
  - » High-resolution PSD ( $\sim 0.002$  Hz bins) over 2500-5000 seconds
  - » Skipped power line harmonics, calibration lines
  - » Simple repeated search
    - Find bin with highest value in PSD
    - Find bins to left, right at 1/2 height.
    - Go out 3 sigma and reset PSD to average of background PSD
    - Repeat
  - » Required  $Q > 500$ ,  $SNR > 3$



# Narrow Lines found in S3 Data

- Searched 35 2500-sec periods of S3 triple-coinc data
- Required lines match between >50% of samples
- Required  $Q > 500$ , skipped power, calibration lines  
<https://gravity.psu.edu/~s3/detchar/Kalman>
- Note large # of narrow lines at higher frequencies

Freq. Band	128-192	192-320	384-512	512-640	704-832	832-1024	1065-1365	1408-1708	1758-2048
H1	1	5	3	10	5	10	14	13	4
H2	3	5	10	9	4	7	8	6	0
L1	0	2	2	4	3	9	6	6	8

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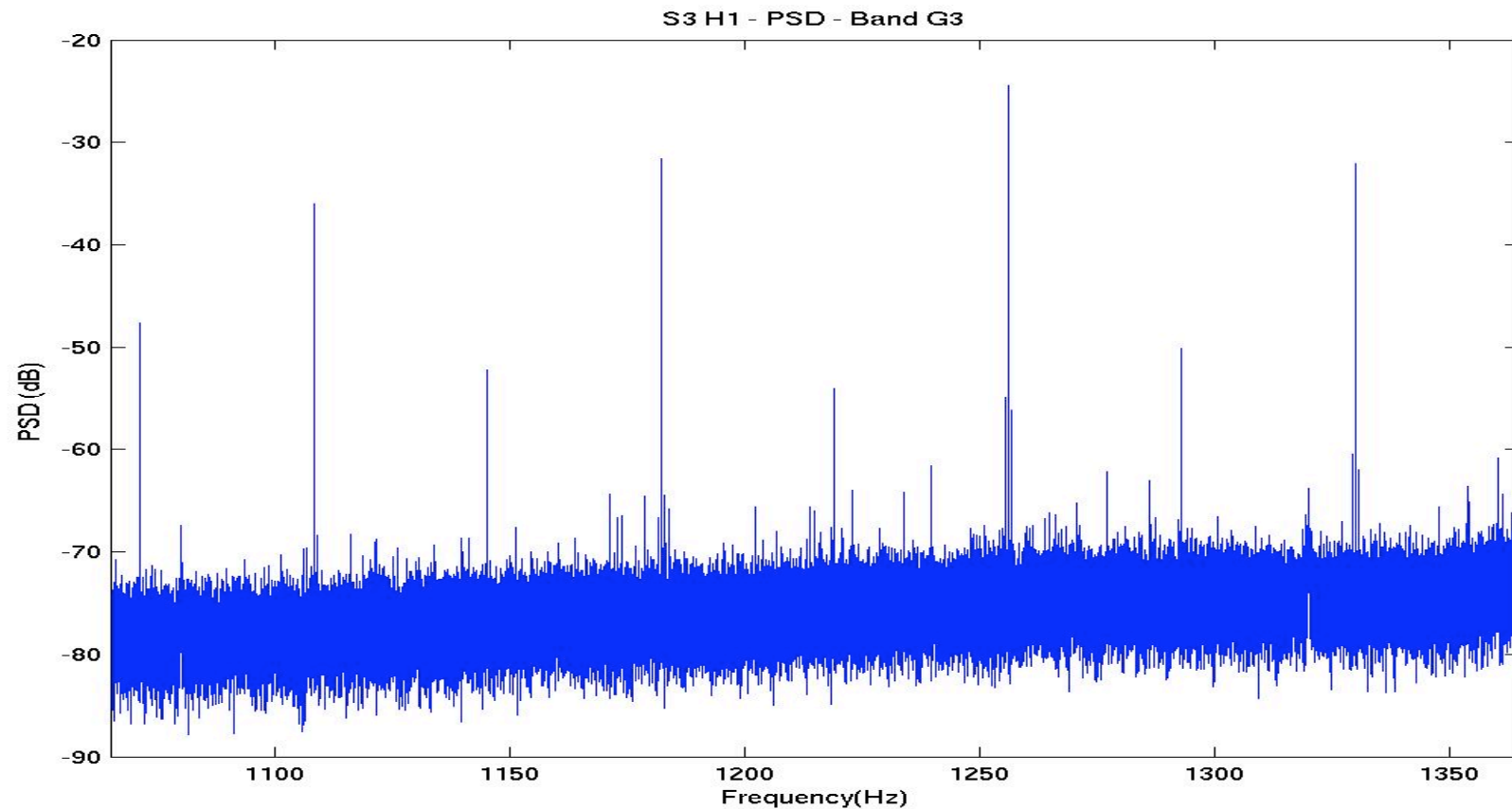
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# Forest of narrow lines in H1 for S3



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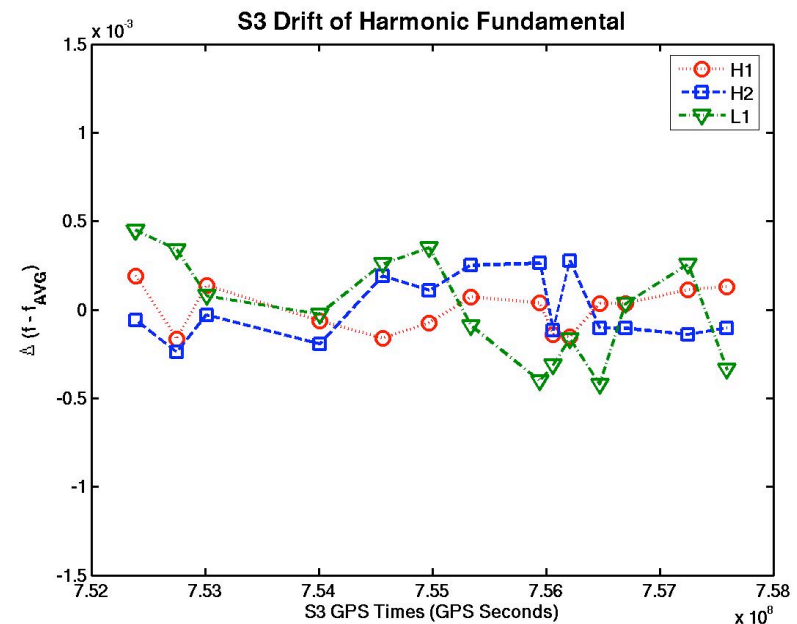
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# Major Culprit in Narrow S3 Lines

- Many narrow ( $\Delta f < 0.004$  Hz) lines are harmonics of  $\sim 37$  Hz
  - » H1: 45 out of 66
  - » H2: 22 out of 52
  - » L1: 32 out of 40
- H1 even showed sidebands around harmonics
- Slightly different frequencies at each IFO
- The frequencies drifted slightly during the run
  - » Invalidates fixed-frequency Kalman filters, especially at higher harmonics

IFO	Freq.(Hz)	Sideband
<b>H1</b>	<b>36.944</b>	<b>0.733</b>
<b>H2</b>	<b>36.974</b>	--
<b>L1</b>	<b>36.867</b>	--





# E11 - Improvement in H1

- Used same code as for S3
- Searched 7 2500-sec periods of E11 double-coinc data
- <https://gravity.psu.edu/~s4/detchar>
- H1 - much cleaner, no 37Hz comb!
  - So what was changed?
- H2 - still has harmonics of 36.972 Hz

Freq. Band	96-192	192-320	384-512	512-640	704-832	832-1024	1065-1365	1408-1708	1758-2048
<b>H1</b>	<b>3</b>	<b>5</b>	<b>0</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>3</b>	<b>0</b>	<b>0</b>
<b>H2</b>	<b>5</b>	<b>15</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>6</b>	<b>6</b>	<b>10</b>	<b>2</b>



# Daily Line-Finding in S4

- Implemented daily pipeline to report line-finding in S4
- Automatically posted web pages during the run  
[https://gravity.psu.edu/~s4/detchar/S4\\_Daily\\_LineFinding.html](https://gravity.psu.edu/~s4/detchar/S4_Daily_LineFinding.html)
- H1 is very clean, H2 not quite so
- L1 had 37Hz comb strongly at first, but totally disappeared after oscillator change on Mar 10th

Freq. Band	128-192	192-320	384-512	512-640	704-832	832-1024	1065-1365	1408-1708	1758-2048
H1	5	7	0	5	2	1	0	0	0
H2	4	6	2	2	3	3	2	5	0
L1-A	12	8	3	2	5	5	12	10	12
L1-B	11	3	1	0	1	1	0	2	0

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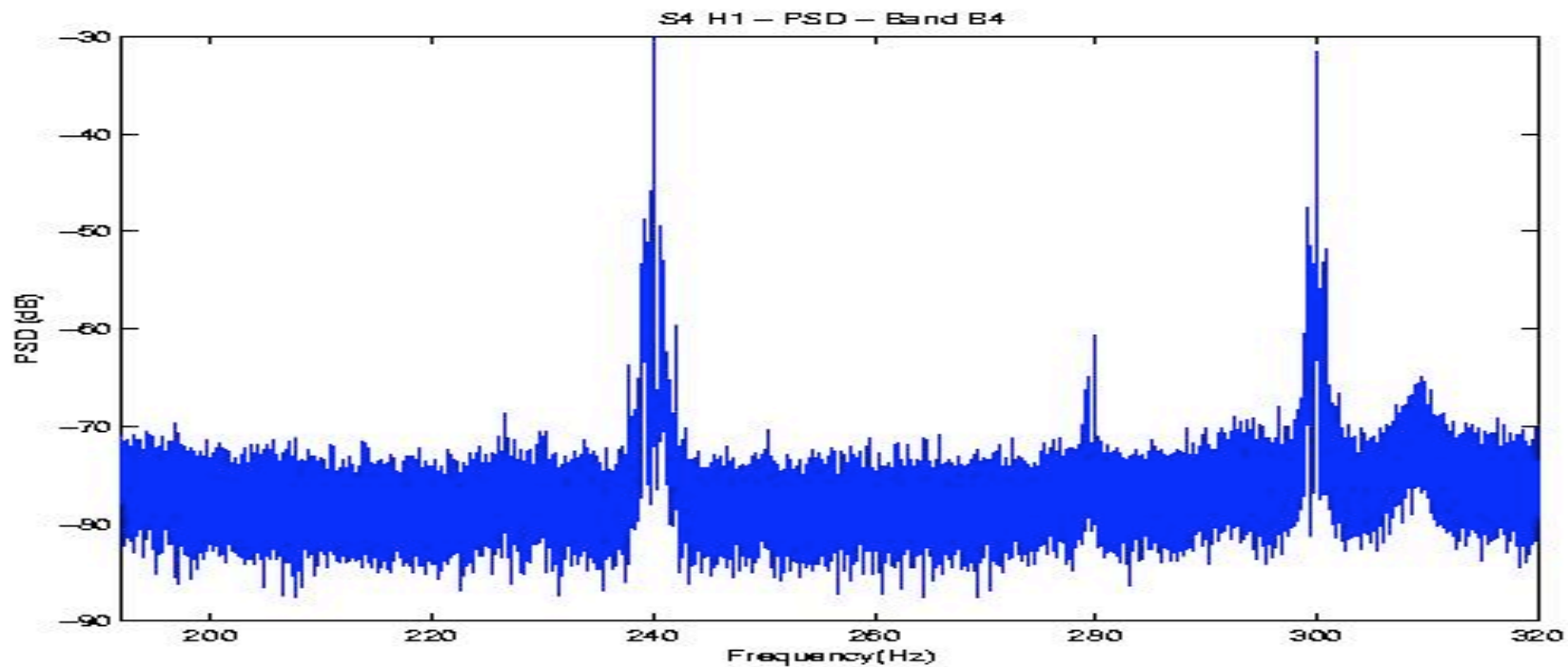
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# H1 Concern in S4

- 60Hz harmonics are very strong and broad, with many sidebands.
- May be major remaining clean-up issue > 100 Hz



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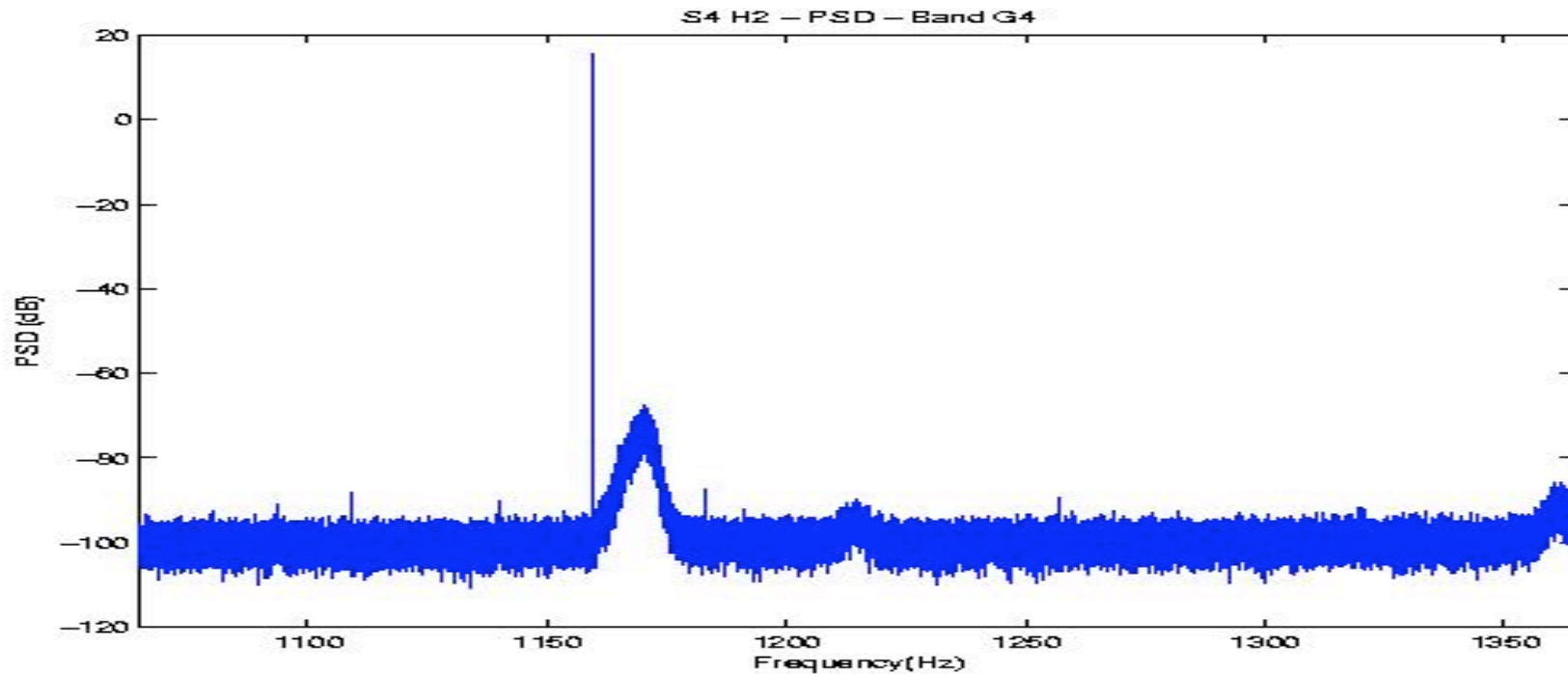
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## H2 Concern in S4

- Drifting broad peak (1170 - 1190 Hz) - Seen in online monitors
- These were not detected by LineFinder (Q only ~ 100)



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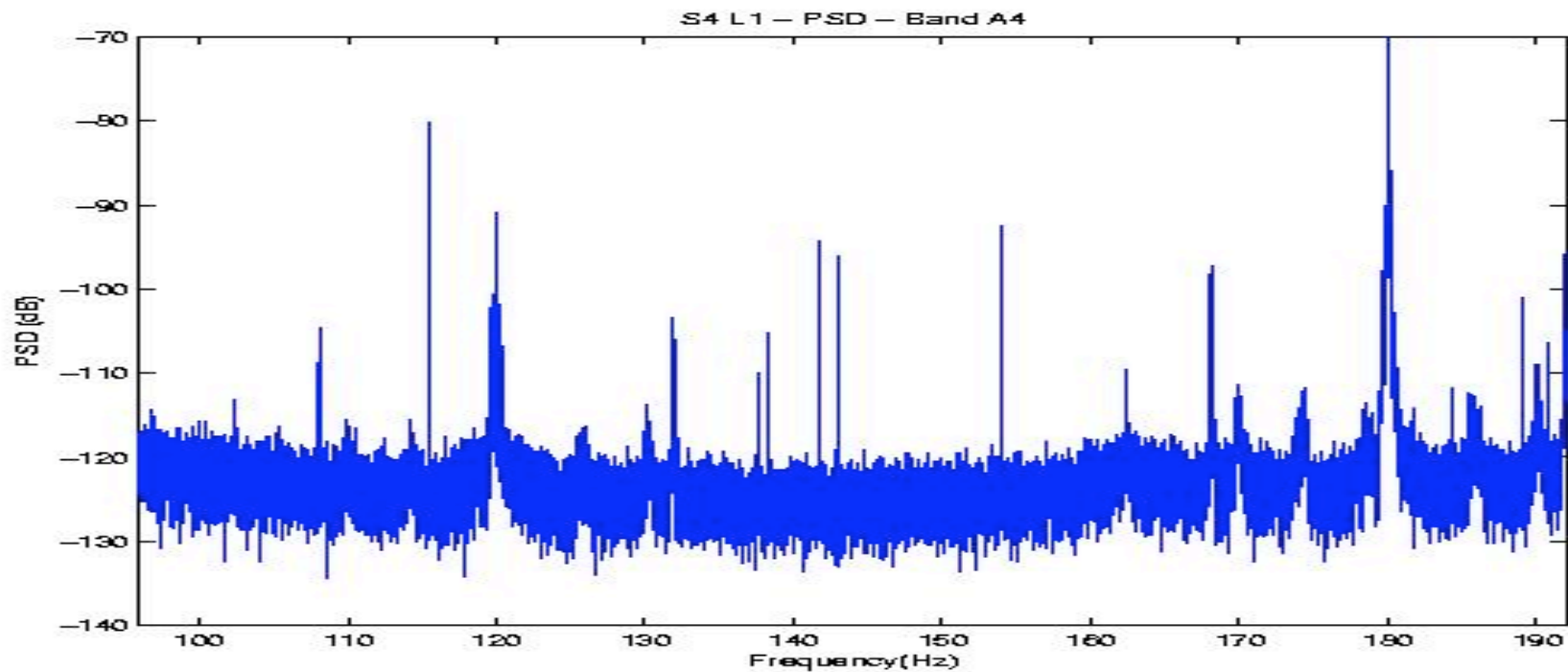
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# L1 Concern in S4

- Still far too many lines from 96 - 192 Hz
- Would like to know the sources of these



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# Next Steps

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- Complete report on persistent lines in S4
  - » NOTE: S4 tool required little work beyond existing software
  - » Implemented mostly due to urging by Keith Riles
- Evaluate what to do for S5
  - » Should it be improved to find wider lines? To provide trend analysis?
  - » Should reporting be more frequent?
  - » Should it be expanded to different frequency regions?
- NOTE: we already have LineMon - shouldn't we use it?