Making sense of narrow spectral artifacts

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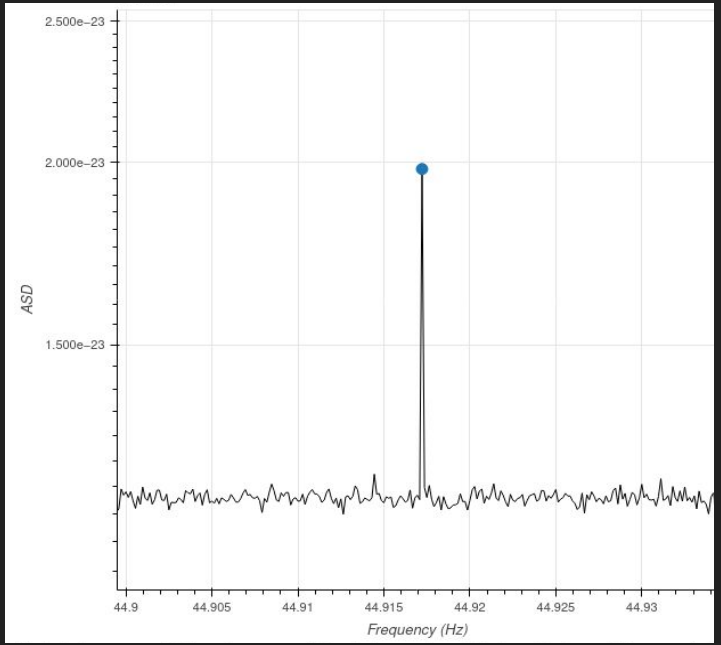
Multi-Messenger Continuous Gravitational-Wave Workshop, July 2023

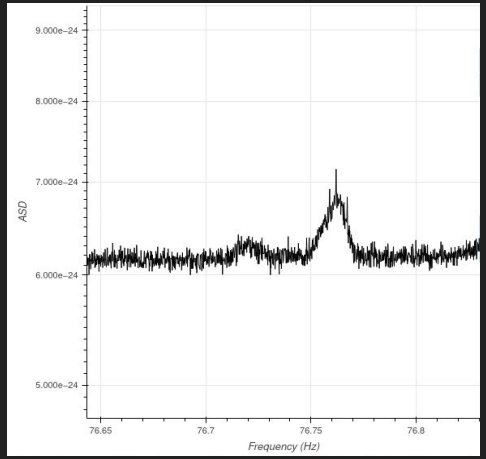
Outline for this session

- Overview of key terms and ideas
- Tutorial activity: determine which lines go on the vetted list given a small set of data
- Q&A / discussion

Key terms: “line”

A “line” is a narrow spectral artifact. This is the main type of noise which impacts CW searches.





Lines of interest for CW data quality are typically very narrow. Not all mentions of “lines” by detchar experts / commissioners on site are as narrow as the ones we care about!

Left: a narrow, sharply peaked line, almost resolution limited with SFT length 7200s.

Right: a broader feature, about 0.026 Hz wide. This might be called a “line” in other contexts, but would not be tracked by *most* CW data quality monitors / lists.

(Examples from O3 H1 run averaged spectrum)

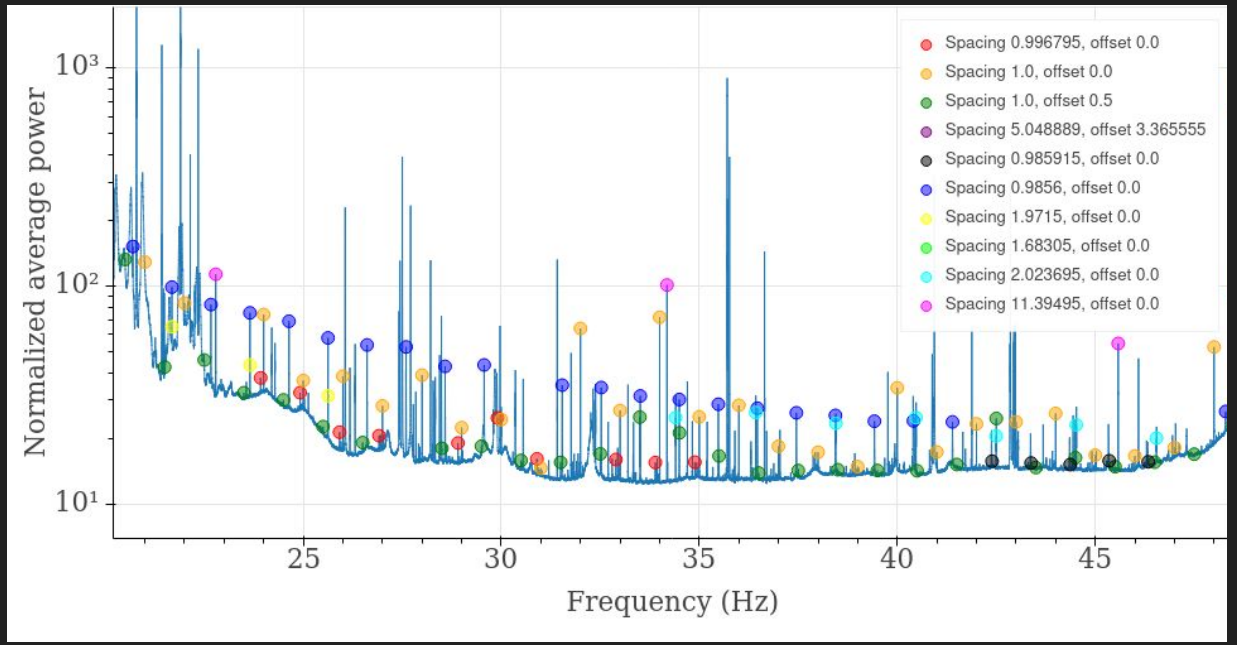
Key terms: “comb”

A “comb” is a series of lines seen at integer multiples (harmonics) of a fundamental frequency. We often refer to the lines in the comb as its “teeth”.

Caveat: comb teeth are not always at integer multiples of the spacing. We do see nonzero offsets. Sometimes these are easily explicable by Fourier analysis (e.g. only odd harmonics visible), and sometimes not.

In general, we describe combs using a frequency spacing and offset,

$$f_n = n*f_{space} + f_{off}$$



Examples from O3 H1 run averaged spectrum

Key terms: “safe”

We use “safety” here in the same sense as the broader detector characterization group: a channel is safe if it does not witness *h(t)*. Safe channels are understood to only witness noise and terrestrial artifacts, and can therefore be used to veto candidate signals.

Caveat: as with many detector characterization products, channel safety studies are usually done over shorter time scales than those relevant for CW searches.

Key terms: “vetted”

“Vetted” refers to a line for which clear evidence supports a non-astrophysical origin. Vetted lines can reasonably be used to veto candidates or exclude spectral bands from analysis.

How a line gets on the vetted list:

- It is part of a comb (does not match astrophysical signal models).
- It is clearly coherent with an otherwise safe channel.
- Enough is known about its source or coupling mechanism to establish that it is not astrophysical.

Key terms: “vetted”

Means of vetting	Relies on…
The line is part of a comb (does not match astrophysical signal models).	○ Strain spectrum for a single time period ○ A method to identify the comb: either automation or visual inspection
The line is clearly coherent with an otherwise safe channel.	○ Information about which channels are safe ○ Additional data products: coherences between h(t) and safe channels
Enough is known about the line’s source or coupling mechanism to establish that it is not astrophysical.	○ Detailed understanding of the detector hardware and environmental factors, which may require: ■ strain spectra across multiple time periods ■ coherence information, a described above ■ on-site tests and help from commissioners

Key terms: what is an “identified line”?

There is a lot of ambiguity in speech when it comes to lines that *are known* to exist in the data, but which may or may not be vetted / possible to vet, and for which the physical cause is *not known*.

In this presentation, I’ll try to keep my vocabulary clear – if I say something like “identified line” please stop me and ask for clarification!

State of comb identification	Terminology I will use in this presentation
Known to exist	“Observed”, “tracked”, “logged”, “noted”
Vetted	“Vetted”
Physical origin is understood	“Understood”, “fully identified”

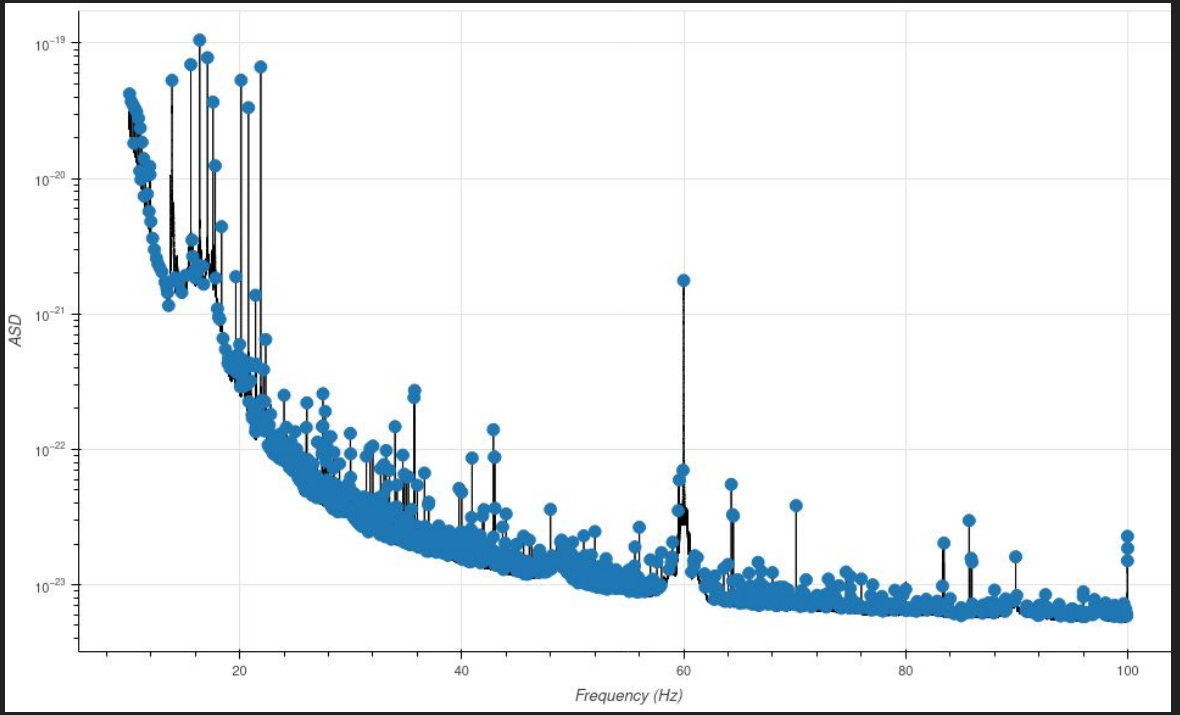
Key questions for CW detector characterization

- Which lines exist in some time period of interest?
- For which lines do we have evidence of terrestrial/instrumental origin? (“vetted lines”)
- When did the lines appear, and which channels witness them?
- What causes, or might cause, the lines to go away?

Challenge: listing lines

Getting a list of lines is hard. The line lists used by searches in O1-O3 have been generated once per observing run by a team of volunteers doing visual inspection of the run-averaged spectrum.

Example of complexity: zooming in on O3 run-averaged spectrum →



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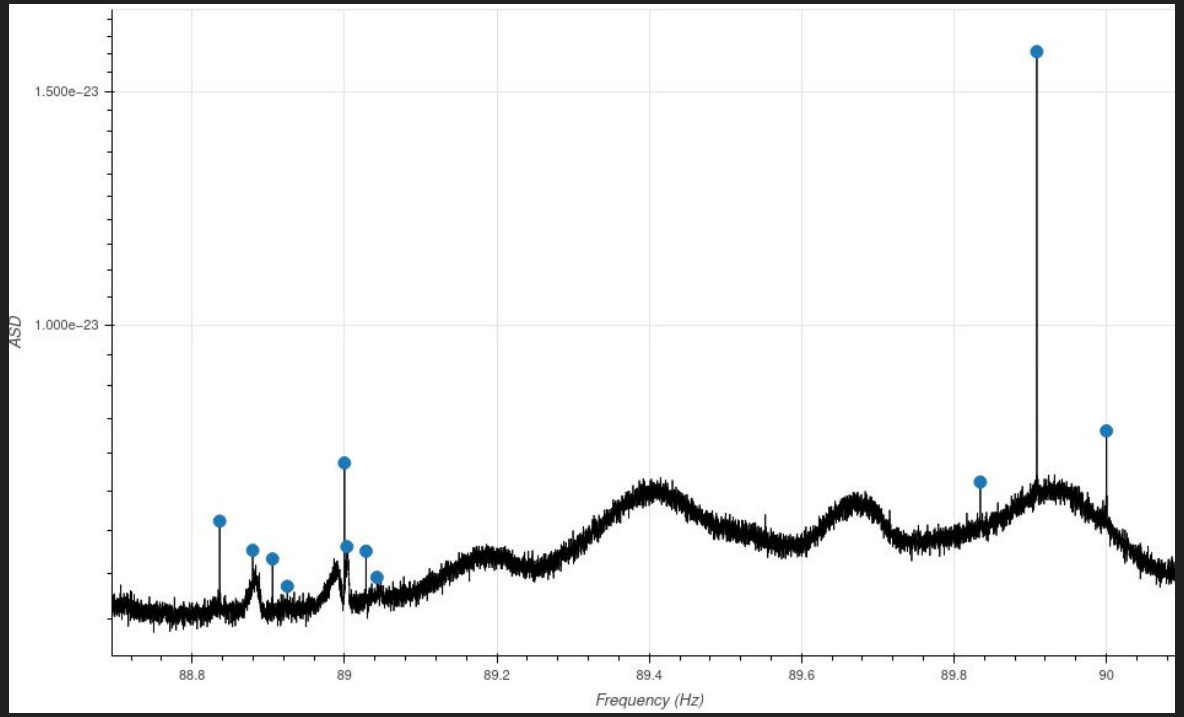

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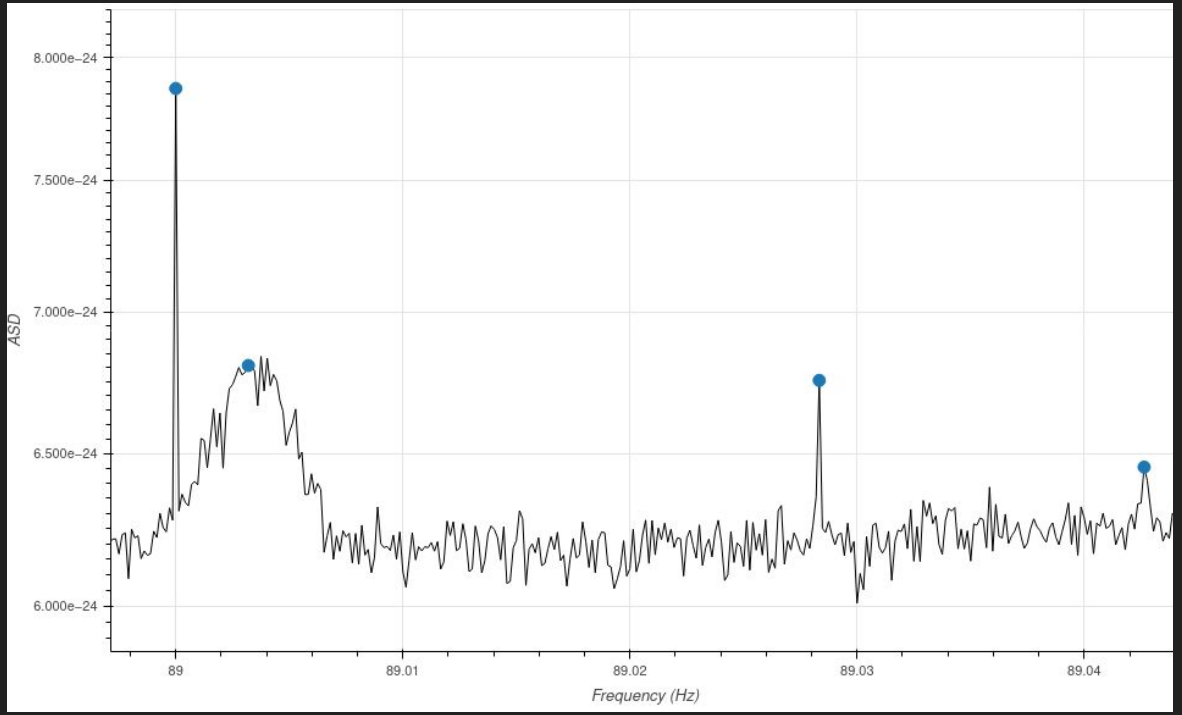
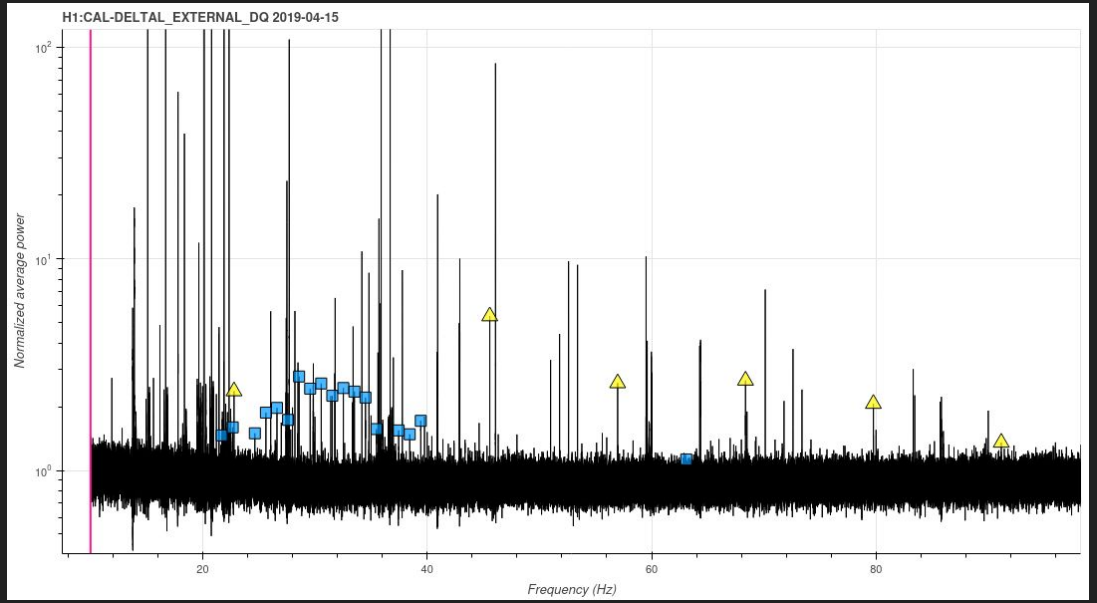


Challenge: listing lines, finding combs

- Can’t scale detailed visual inspection to daily, weekly, or even monthly spectra
- Automation has improved recently; generally not as good as visual inspection but much faster.
- In some cases, automation has an easier time picking out hard-to-see combs.

Example: automated detection of two combs amidst other lines (data from 2019, but using updated tools).

Note that automated comb detection requires automated *line* detection as a starting point. This code generates an attempted list of all lines, but only the combs are shown on the plot for visual clarity.



Challenge: the problem of time scales

Benefits of averaging spectra over a shorter duration	**Benefits of averaging spectra over a longer duration**
Intermittent / temporary noise can be observed	Weak lines can be observed
Noise evolution can provide clues about causes	Reflects most persistent noise (primary DQ issues for most searches)
Notice problems more promptly when they arise	Fewer plots produced, easier to work with

Challenge: multiple types of data

Strain data	• Most critical: identify artifacts that can affect searches
Auxiliary/PEM channel data	• Might witness noise seen in strain data • Provides clues about nature of noise • Can be used for vetting • Can be used to track artifact history when strain data not available / artifact not coupling to strain channel
Auxiliary/PEM channel coherence with strain data	• Provides a more strict measure of agreement with strain data • Typically results in cleaner spectra • Only available when strain data is available
Strain data coherence between interferometers	• Noise coherent between IFOs is less likely, but more serious in terms of search impacts

Tutorial activity

Data provided

- 3 days of H1 daily Fscan results 2019 (April 15-17), including:
  - Spectral plots
  - Coherence plots for 3 safe PEM channels
  - Persistence plots
  - Results from line and comb finder
  - Data used for the plots is also provided in npz format for completeness. (You should be able to get all the relevant info from the plots.)
- Note that this is O3 data, but generated using O4-era tools.
- Plots are normalized to make it easier to spot lines.
- Link to detector alogs, for context on the given time range: https://alog.ligo-wa.caltech.edu/aLOG/

Challenge: can you vet the line?

Imagine you have an outlier which overlaps with the spectral feature at ___ Hz. You go to investigate the feature. In which cases can you find evidence for adding the feature to the vetted lines list, based on available data?

- 28.58722
- 34.70000
- 70.12667
- 79.76778
- 107.11333

Line lists and links

- Public links for O3 line lists:
  - https://dcc.ligo.org/LIGO-T2100200/public
  - https://gwosc.org/O3/o3speclines/
    - In my opinion, the best way to cite the O3 lines lists when they have been used in a search is to point to the public DCC entry and indicate the version of the list used.

- For those in the LVK, pages to watch for O4:
  - https://git.ligo.org/CW/instrumental/aLIGO-lines-combs
  - https://git.ligo.org/detchar/noise-lines/-/issues ←consolidation of current issues / discussion

Acknowledgements

- *R. Abbott et al. (LIGO Scientific Collaboration, Virgo Collaboration and KAGRA Collaboration), "Open data from the third observing run of LIGO, Virgo, KAGRA and GEO", arXiv:2302.03676 (2023).*

- This research has made use of data or software obtained from the Gravitational Wave Open Science Center (gwosc.org), a service of the LIGO Scientific Collaboration, the Virgo Collaboration, and KAGRA. This material is based upon work supported by NSF's LIGO Laboratory which is a major facility fully funded by the National Science Foundation, as well as the Science and Technology Facilities Council (STFC) of the United Kingdom, the Max-Planck-Society (MPS), and the State of Niedersachsen/Germany for support of the construction of Advanced LIGO and construction and operation of the GEO600 detector. Additional support for Advanced LIGO was provided by the Australian Research Council. Virgo is funded, through the European Gravitational Observatory (EGO), by the French Centre National de Recherche Scientifique (CNRS), the Italian Istituto Nazionale di Fisica Nucleare (INFN) and the Dutch Nikhef, with contributions by institutions from Belgium, Germany, Greece, Hungary, Ireland, Japan, Monaco, Poland, Portugal, Spain. KAGRA is supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Society for the Promotion of Science (JSPS) in Japan; National Research Foundation (NRF) and Ministry of Science and ICT (MSIT) in Korea; Academia Sinica (AS) and National Science and Technology Council (NSTC) in Taiwan.