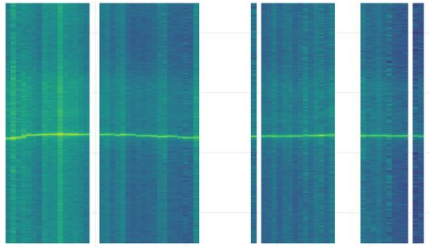
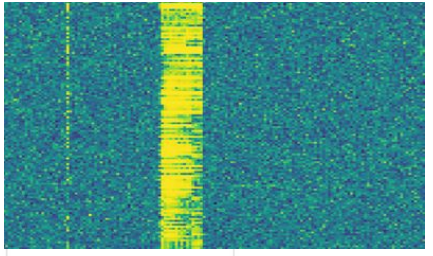
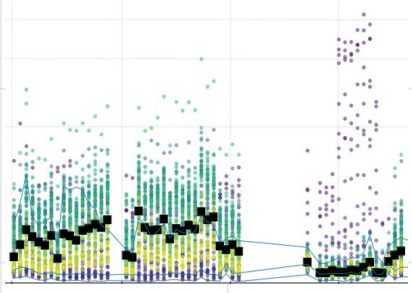
Data visualization for narrow spectral artifact studies in LIGO data

Ansel Neunzert | GWANW 2025







Roadmap

- Background: continuous gravitational waves & narrow artifacts
- Time scales 101: slicing up the data
- Spectra and spectrograms
- Time scales 102: beware the average!
- Annotating spectra
- Tracking combs
- Tracking groups of lines
- Monitoring lines in general

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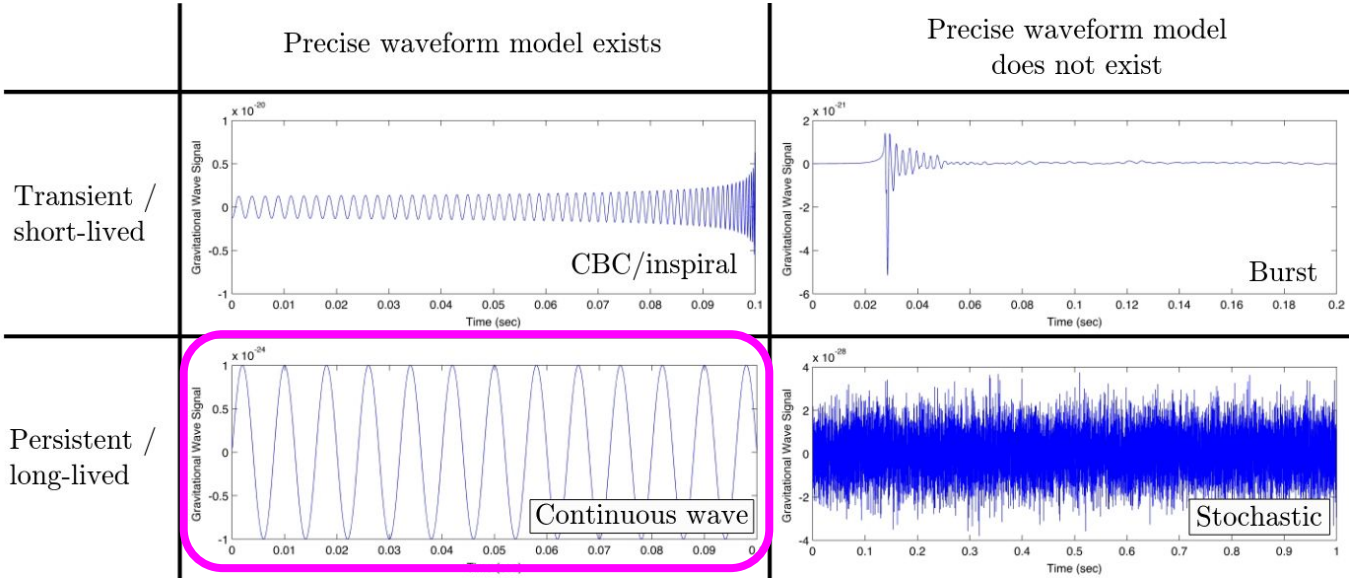
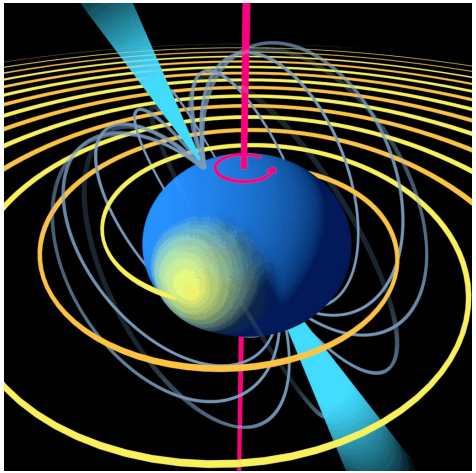
Background - continuous waves



Credit: A. Stuver / LIGO Scientific Collaboration

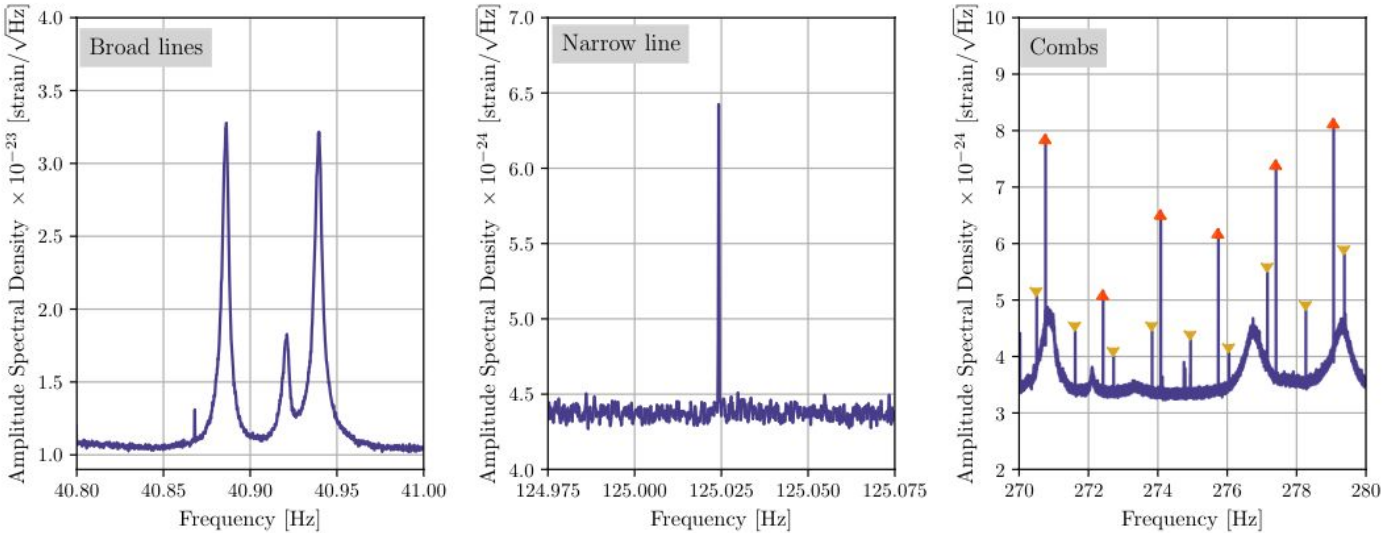


Credit: Sonya Neunzert

Optical: NASA/HST/ASU/J. Hester et al. X-Ray: NASA/CXC/ASU/J. Hester et al.

Background - narrow spectral artifacts

Searching for signals that are narrow in frequency → we care about noise that is narrow in frequency!



LIGO Detector Characterization in the first half of the fourth Observing run, Soni et al, 2024

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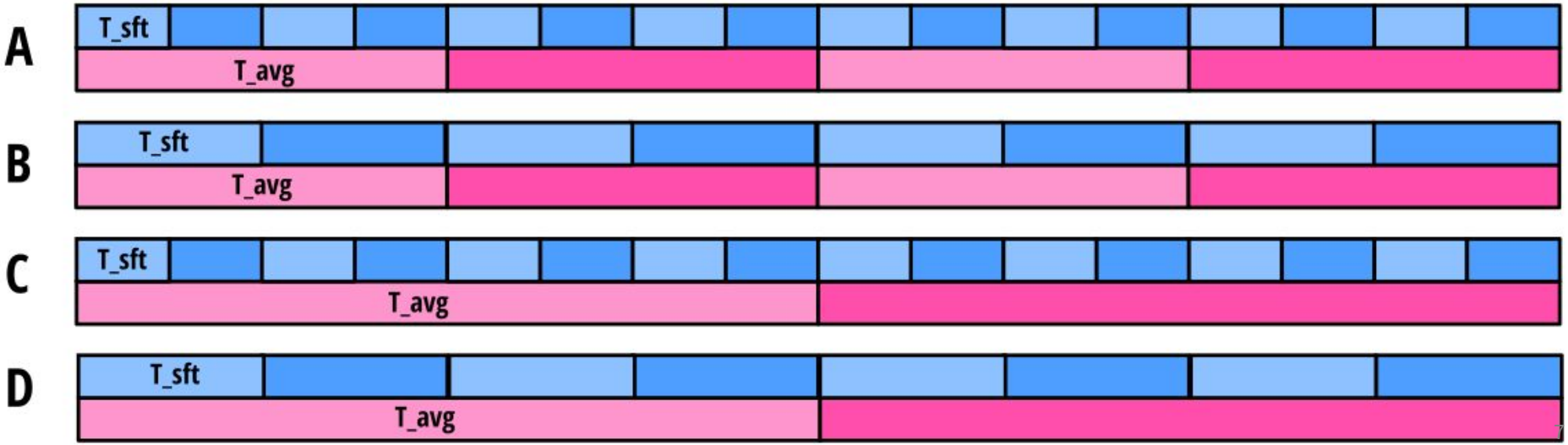
Time scales 101: slicing up the data

SFT = “short” Fourier transform (e.g. 30 minutes of data)

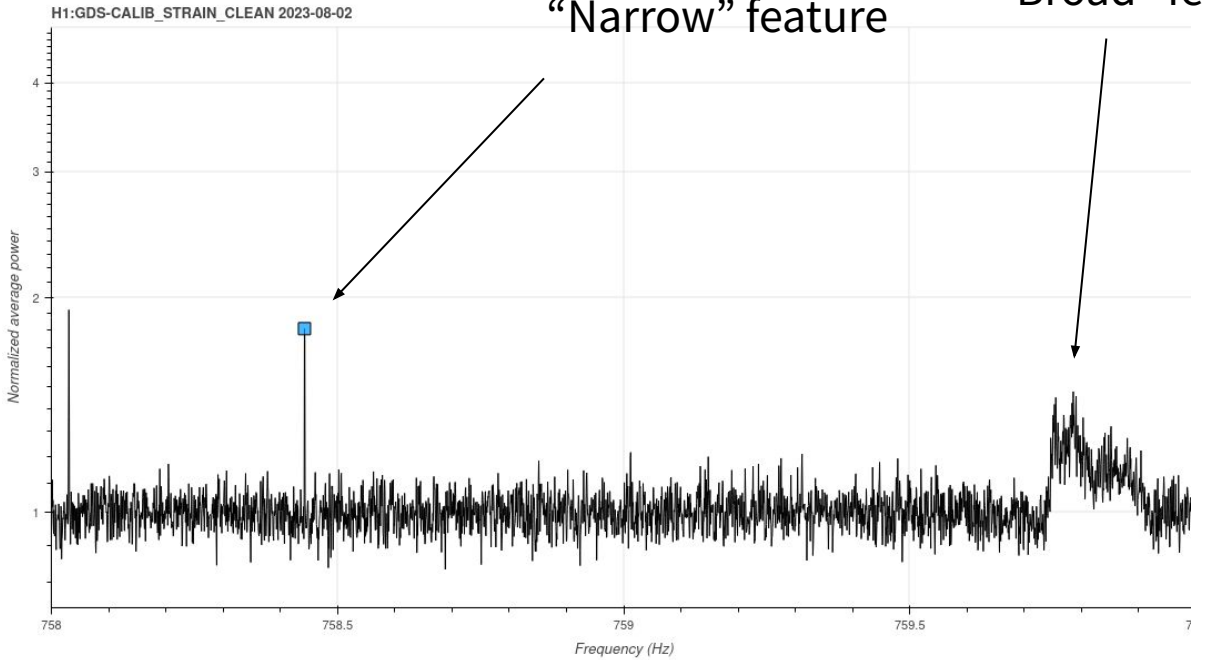
Greater SFT length → better spectral resolution

Greater number of SFTs per averaged spectrum → better statistics

Shorter total time per averaged spectrum → better time resolution



Spectra and spectrograms



One averaged spectrum (in this case 1 week) includes many SFTs.

Both narrow and broad features can be seen.

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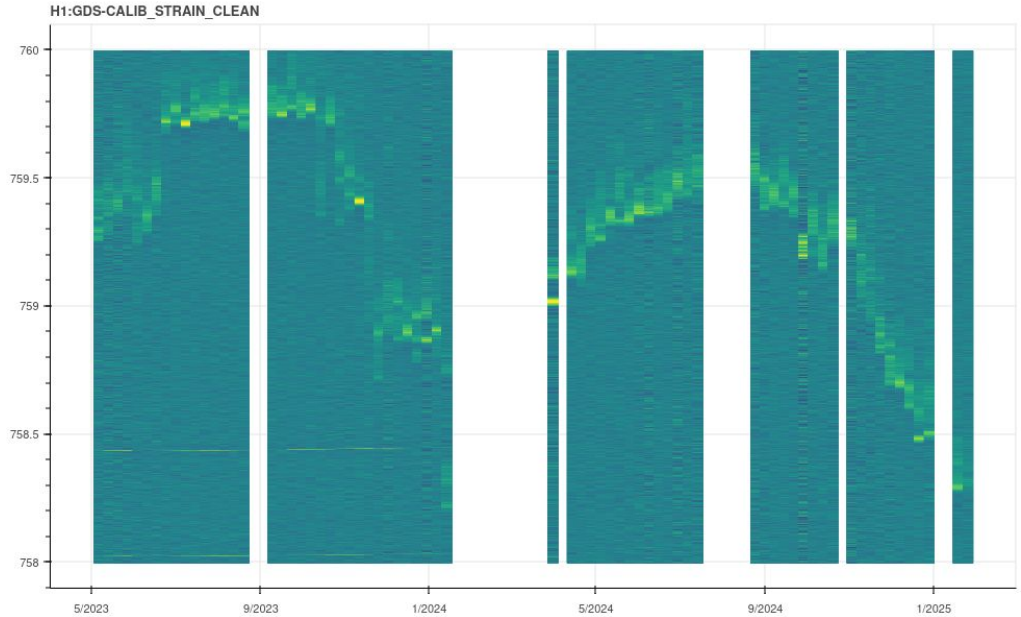
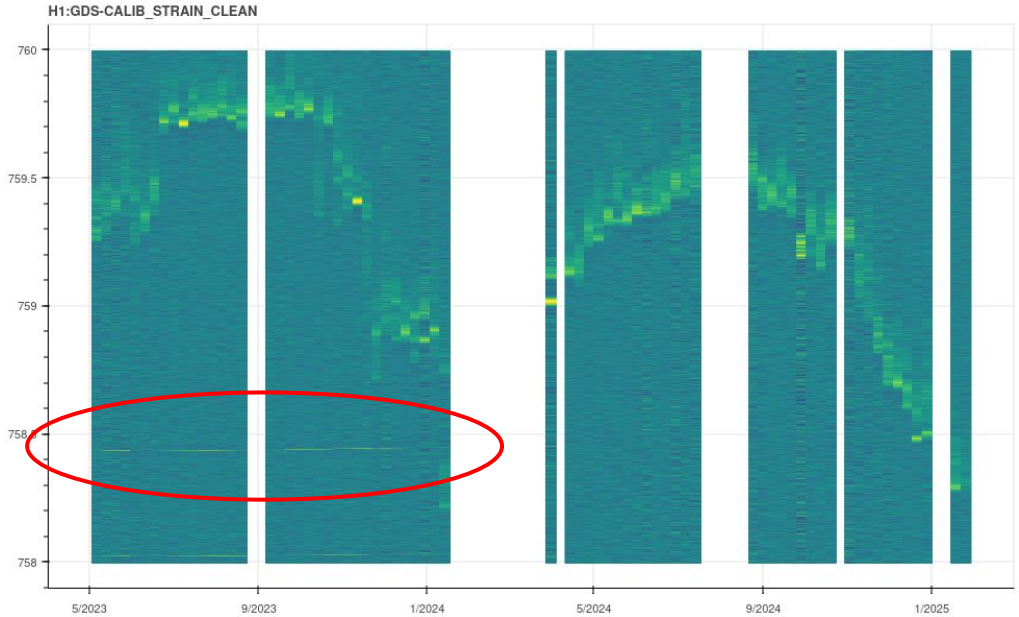


By looking at many averaged spectra at once, we can see that the “broad” feature from the previous plot is wandering over time.

https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=82632

Spectra and spectrograms



The “narrow” feature moved less, and eventually disappeared.

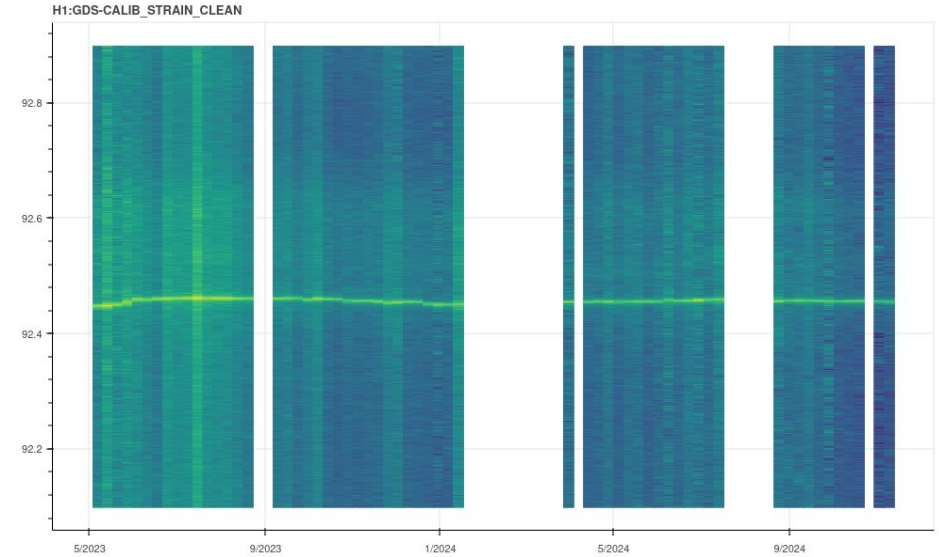
(Much tougher to spot on this plot!)

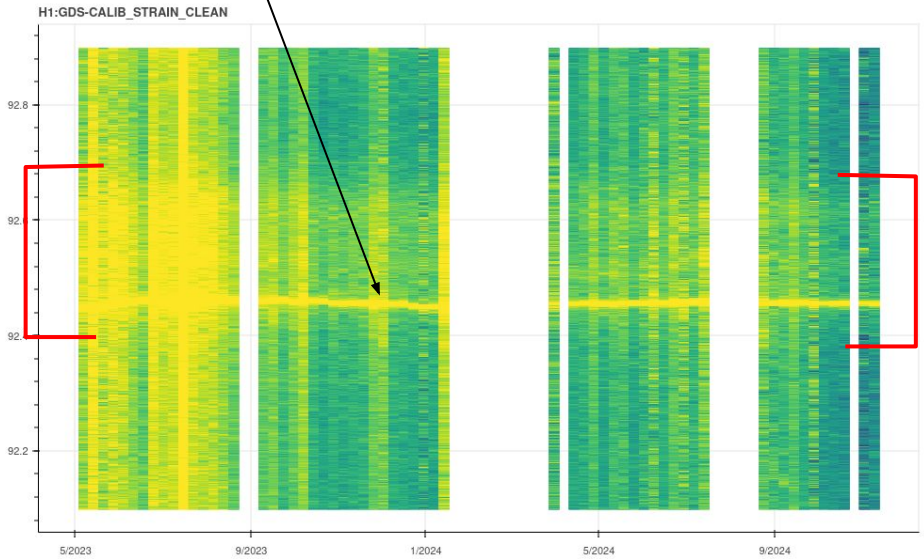
https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=82632

Spectra and spectrograms

Sharp strong line

Weaker broad noise, extent in [ ]





Color bar adjustments may be needed to see strong & weak features simultaneously

Spectra and spectrograms

Spectrum	Spectrogram
✅ **Better for making peak height comparisons**	Color bar not ideal for peak height comparisons
✅ **Better for seeing fine details alongside large artifacts**	Color bar not ideal for covering many orders of magnitude in peak height
✅ **Can make a full-run spectrum**	Requires multiple T_avg time periods to be meaningful
✅ **Can make interactive plots over a larger frequency span**	Interactive plots over a large frequency span are slow
Can’t see time evolution	✅ **Can see time evolution**

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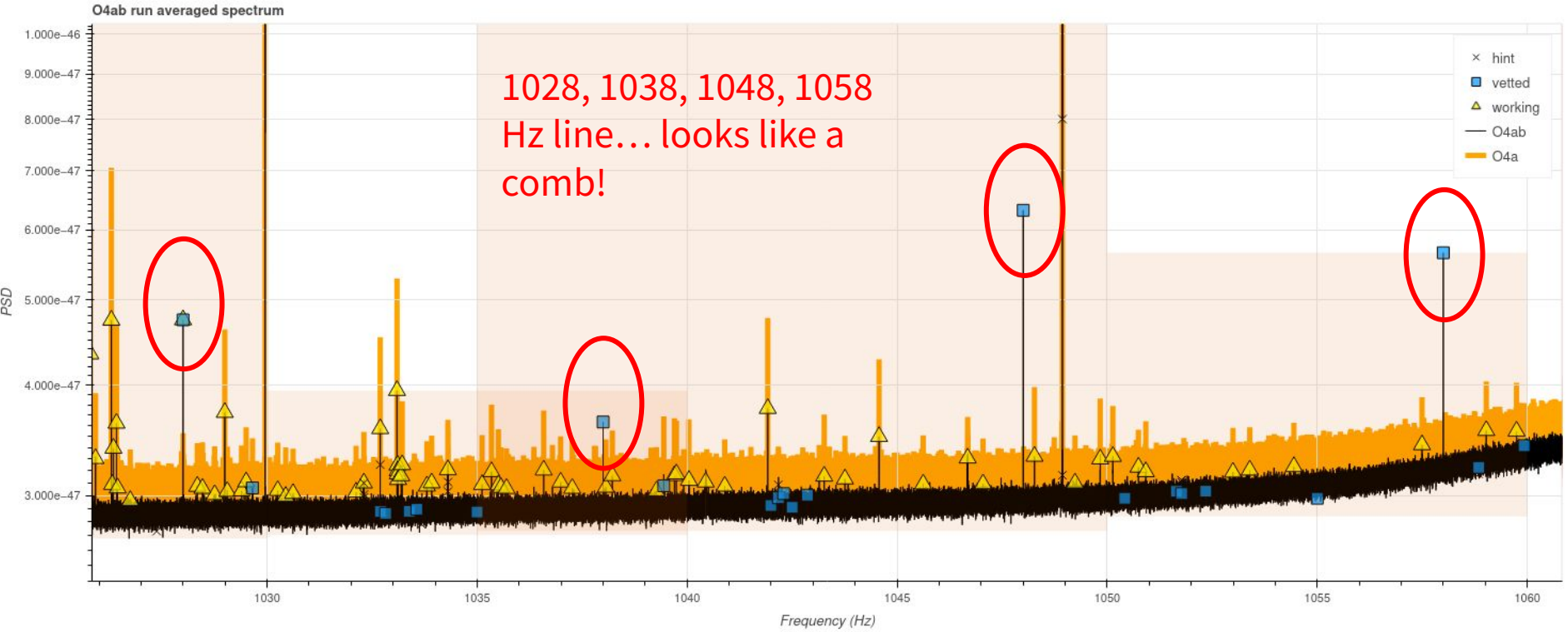
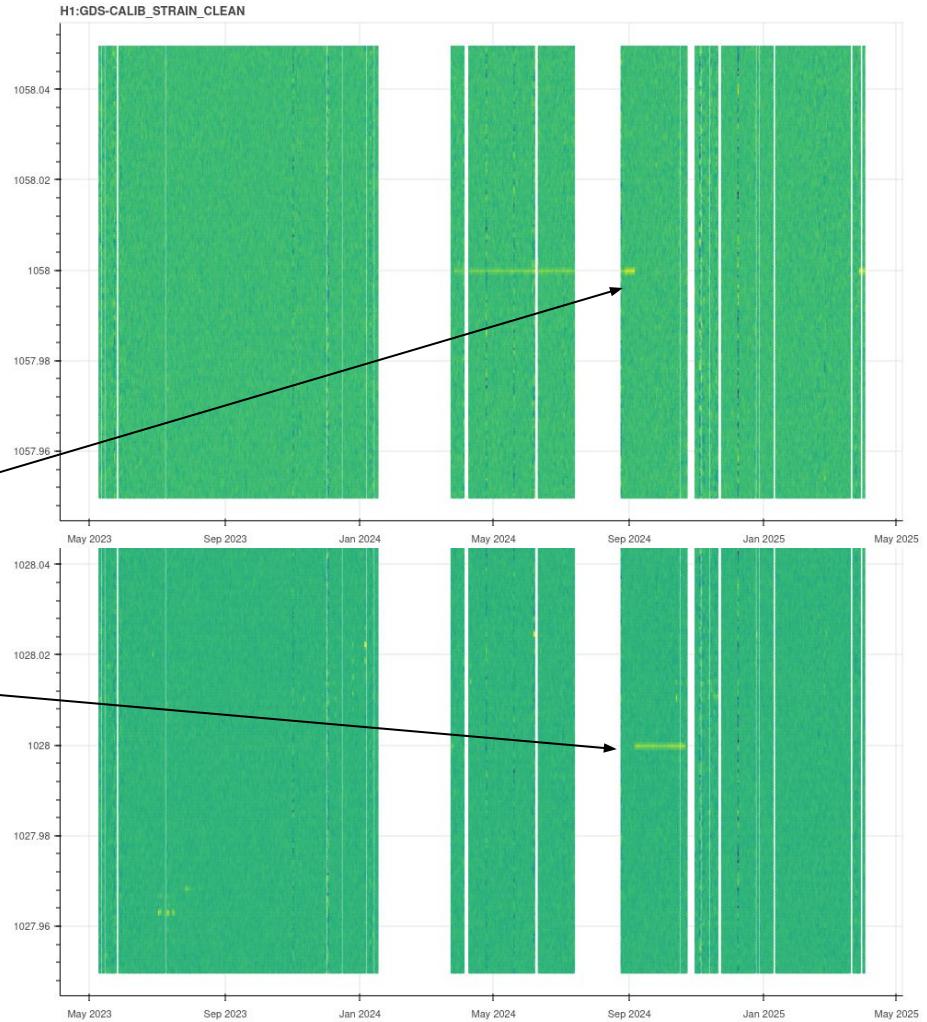
Time scales 102: beware the average!



Time scales 102: beware the average!

Disappears from 1058 Hz…

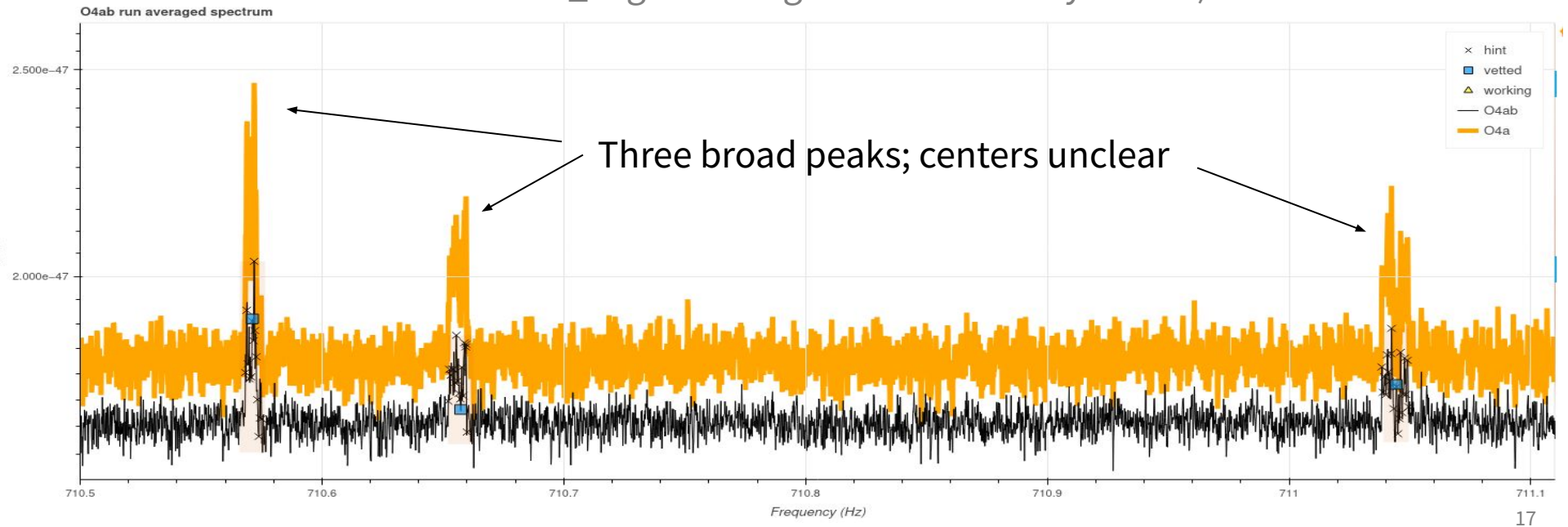
… and appears at 1028 Hz on the same day

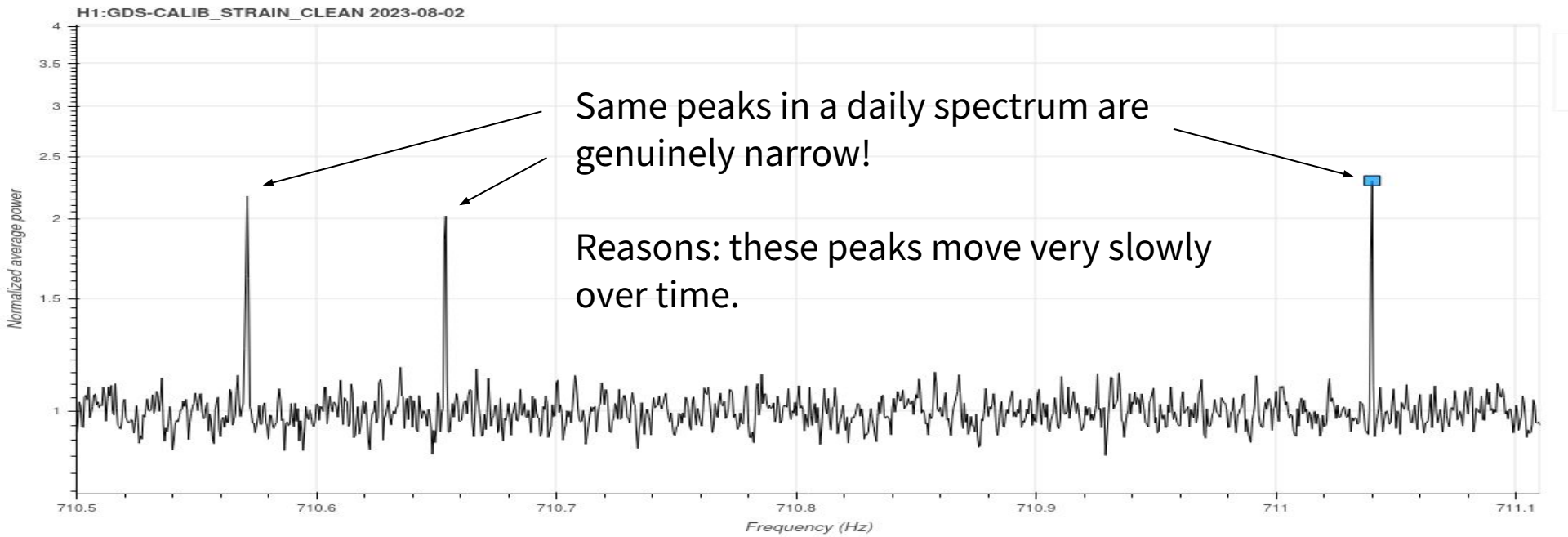


https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=84546

Time scales 102: beware the average!

Run-averaged spectrum
(T_avg for black curve = entirety of O4a & b,
T_avg for orange curve = entirety of O4a)





Same peaks in a daily spectrum are genuinely narrow!

Reasons: these peaks move very slowly over time.

Very long average “smears out” the peak shape.

(Note: we are also using a higher spectral resolution here, but this does not account for the difference.)

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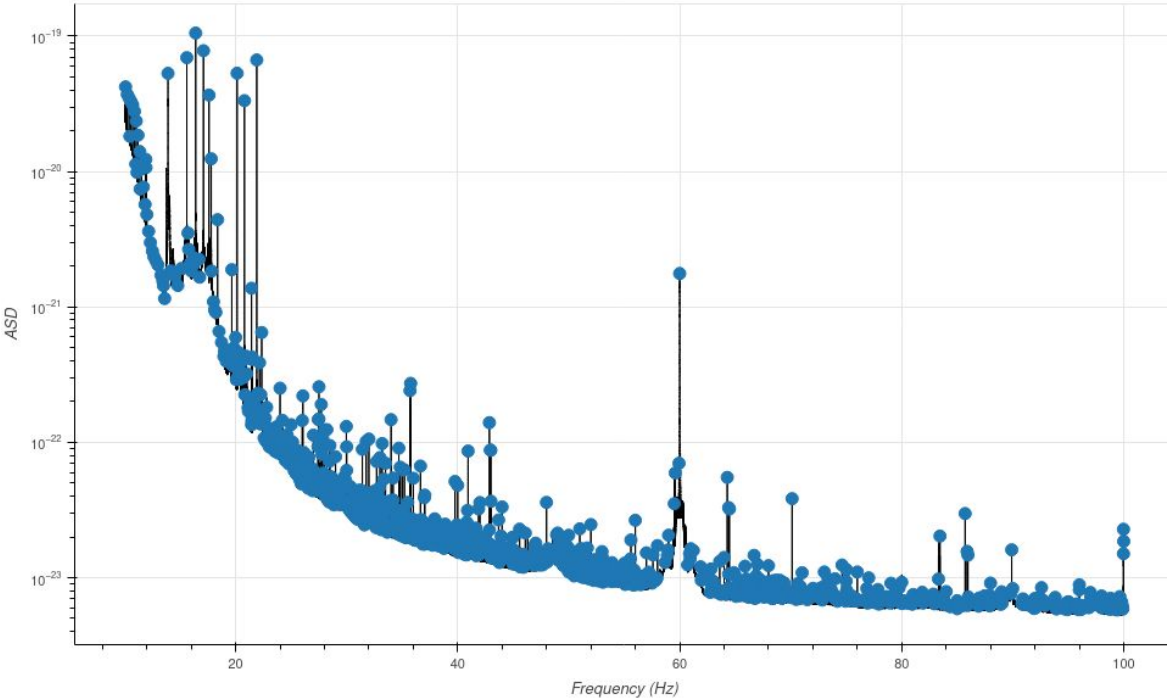
Annotating spectra

Spectra are complicated!

Here's a plot of the O3 run-averaged spectrum between 10 and 100 Hz (about 1/20th of the spectral range over which we attempt to characterize narrow artifacts).

Every dot is an labeled line.



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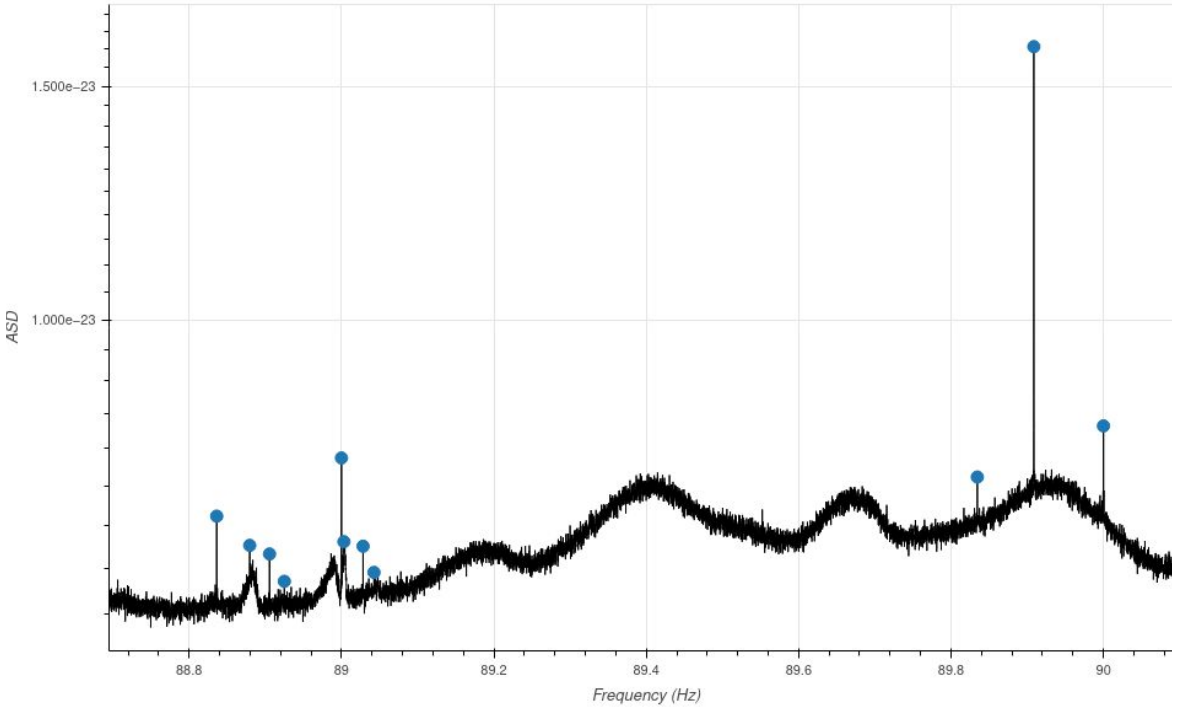

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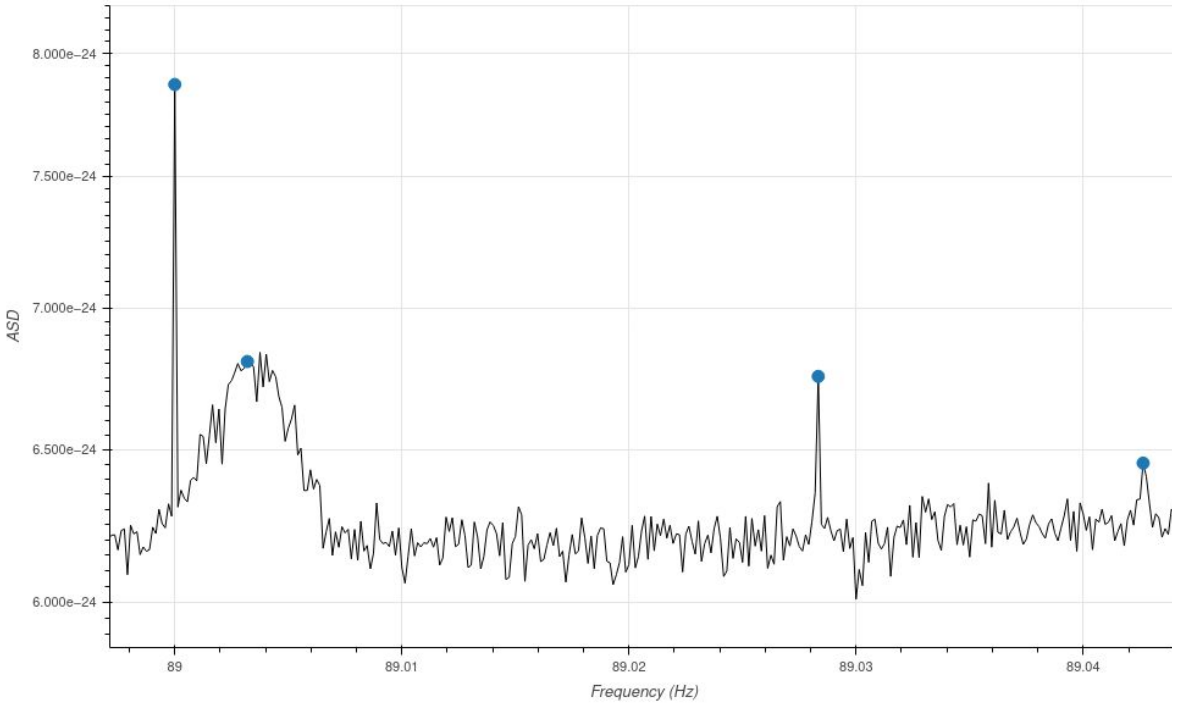
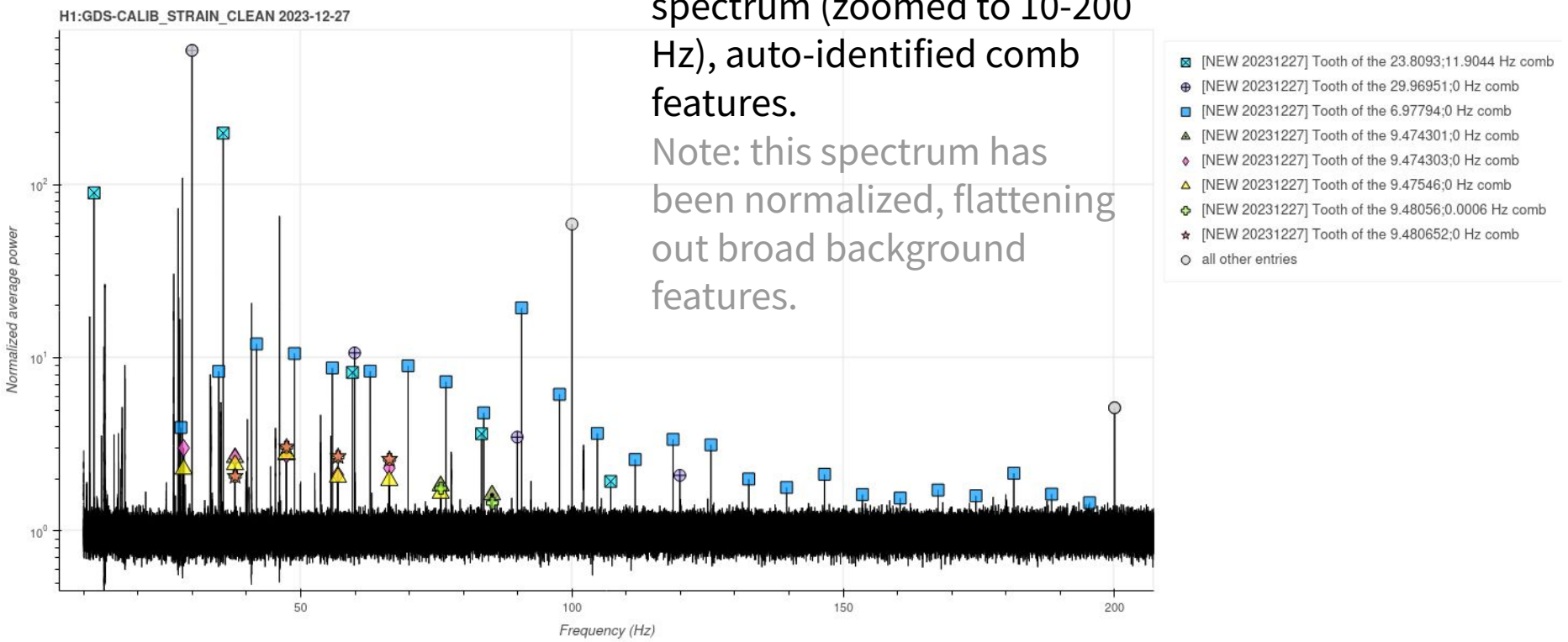


Annotating spectra

Here is a daily-averaged spectrum (zoomed to 10-200 Hz), auto-identified comb features.

Note: this spectrum has been normalized, flattening out broad background features.

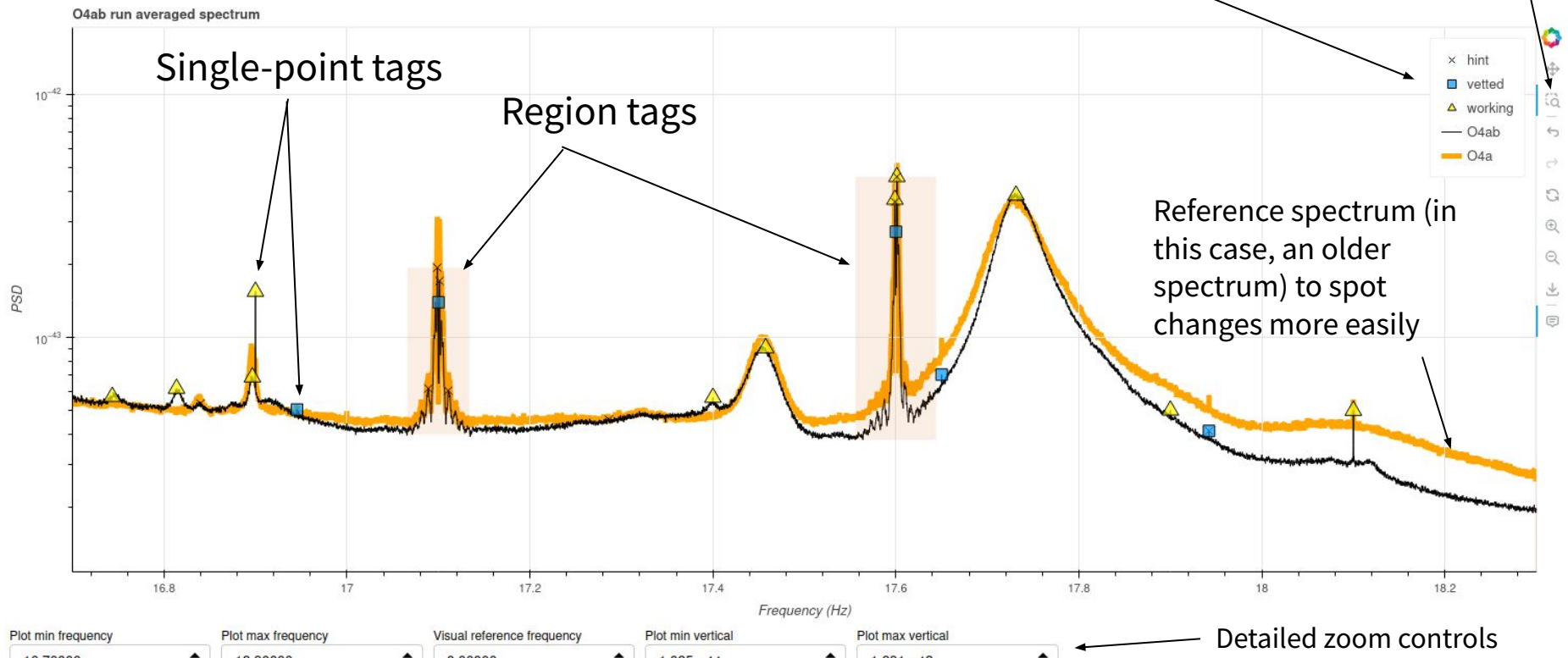


Annotating spectra

- What we needed:
  - Quickly zoom to any level of detail
  - Display details in hover text
  - Label points & regions
  - Flexible color-coding options

- Solution:
  - Custom plotting tool built into Fscan (written in Python)
    - https://pypi.org/project/fscan/
    - https://git.ligo.org/CW/instrumental/fscan/
  - Based on bokeh interactive plotting library, http://bokeh.org/

Annotating spectra



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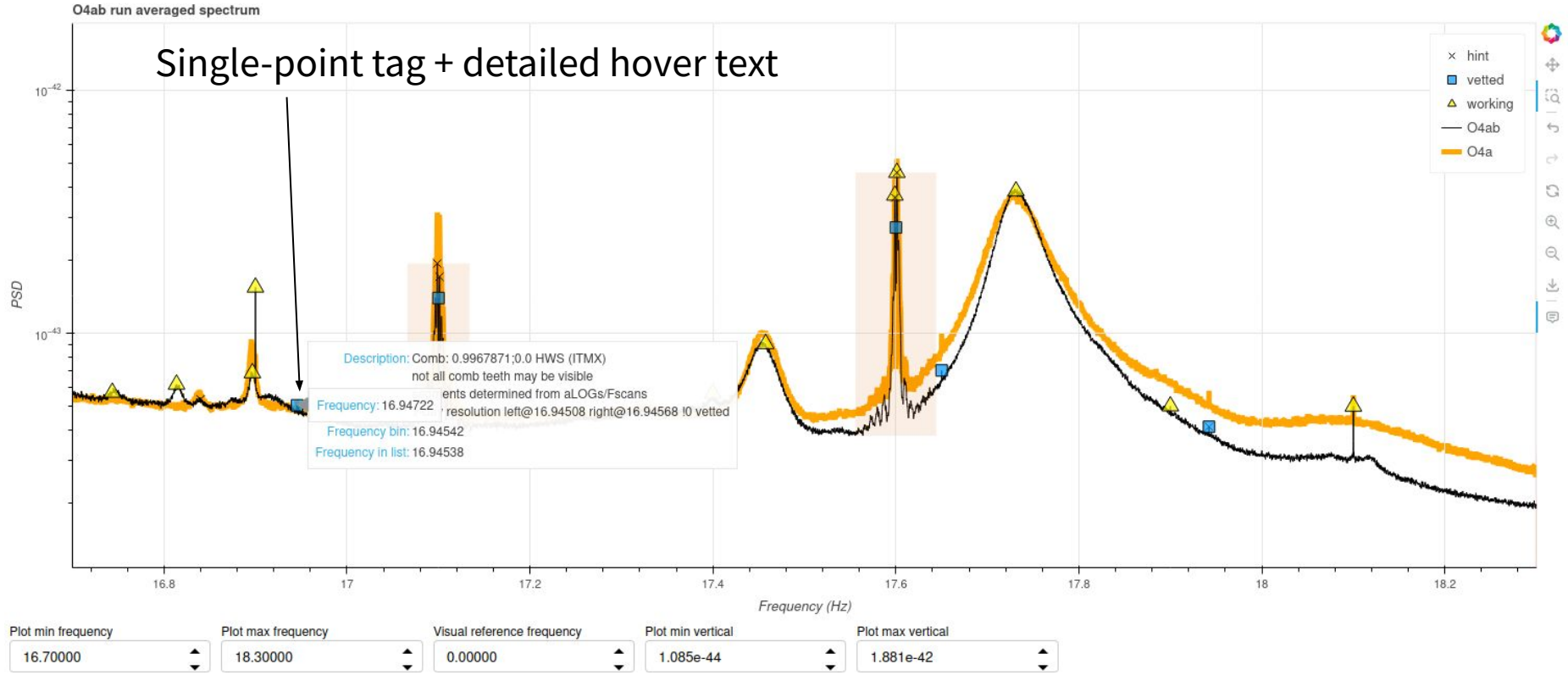

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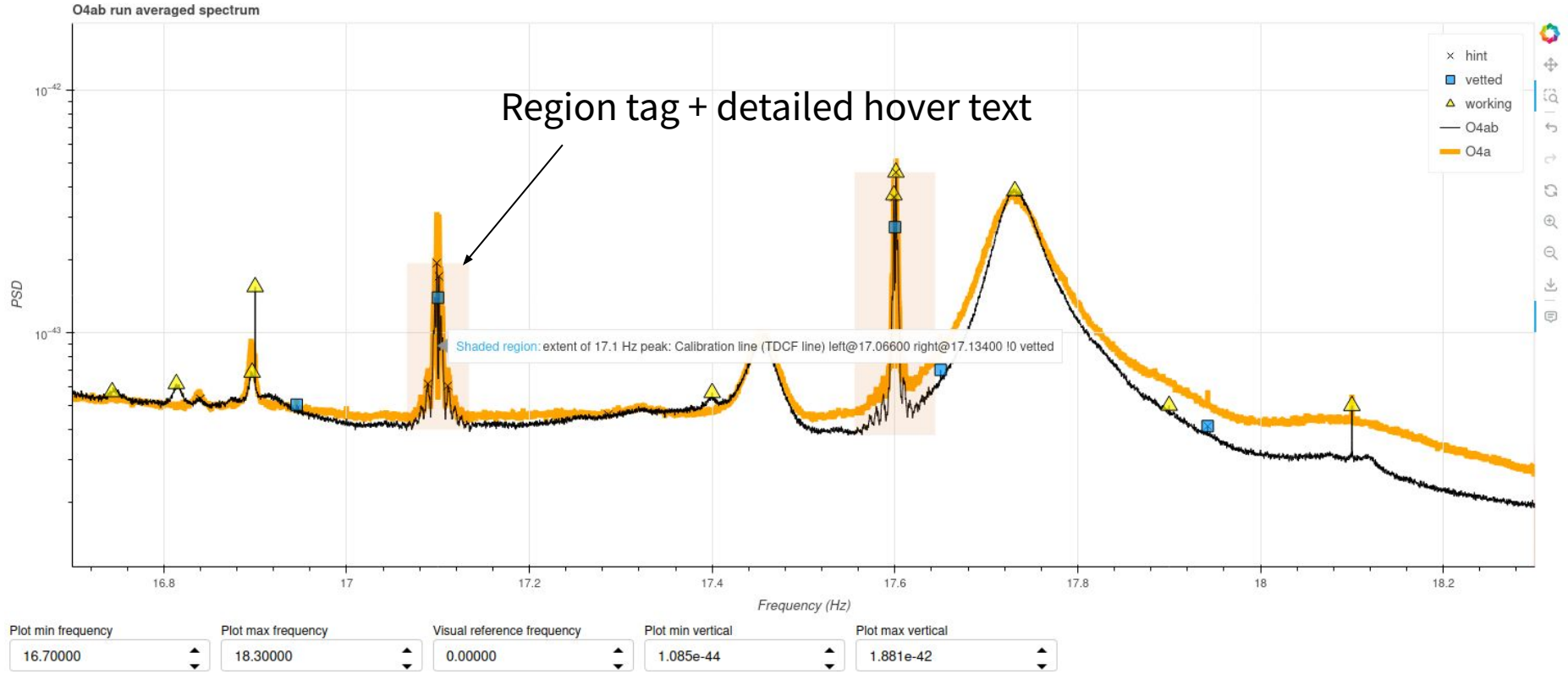

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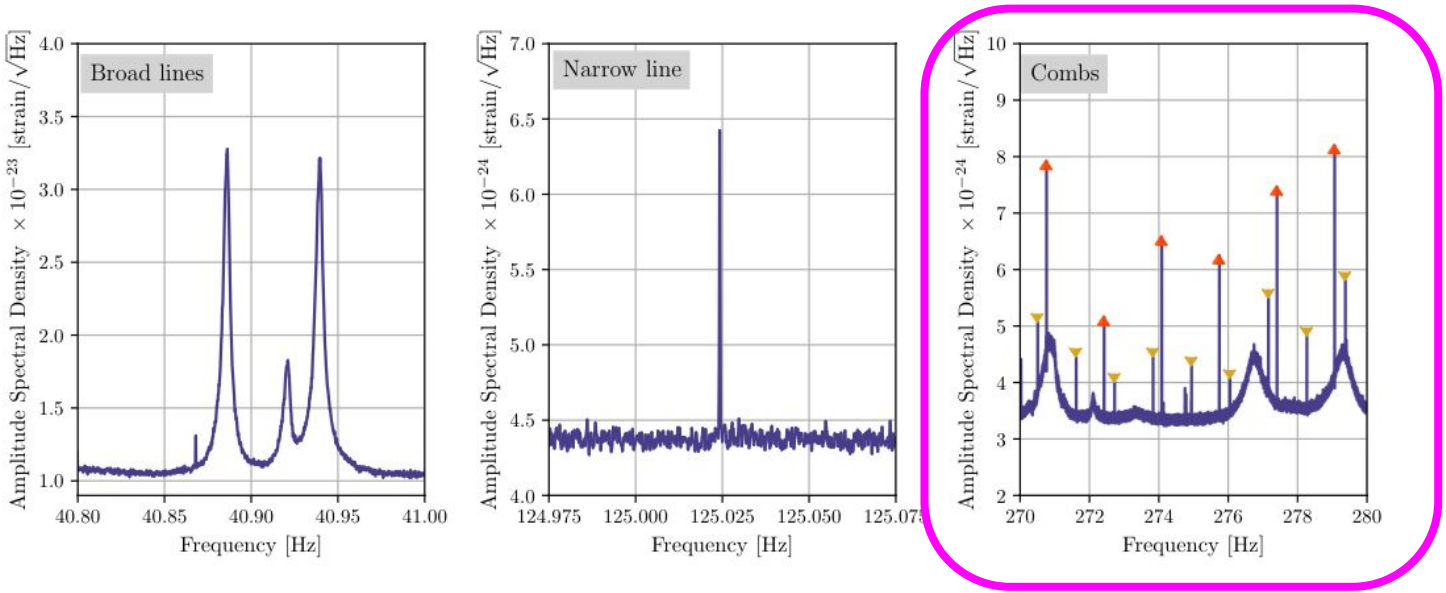


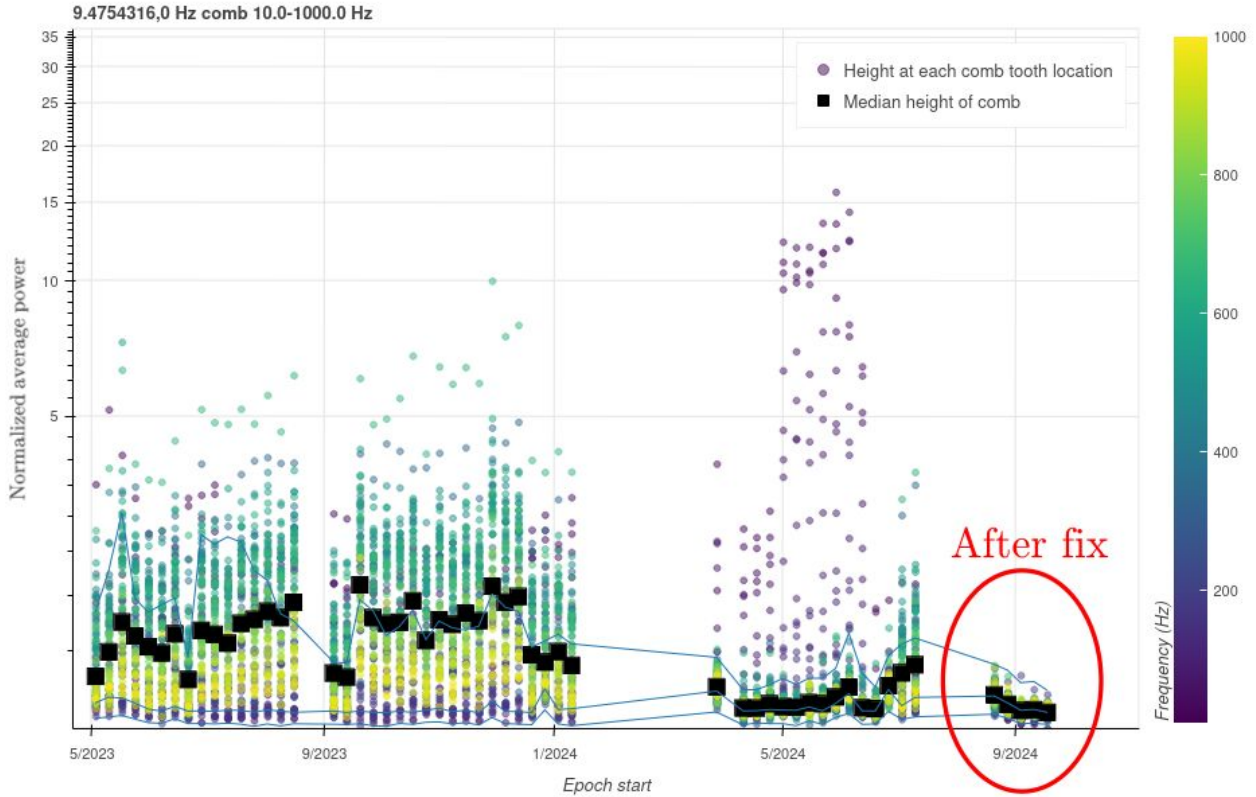
LIGO Detector Characterization in the first half of the fourth Observing run, Soni et al, 2024

Tracking combs

- What we needed:
  - Track the general behavior of the comb at a glance
  - See the individual peak behavior as needed
  - Don’t get confused by changes in the spectral background
  - Handle combs that move/shift around

- Solution:
  - More bokeh plots :)
  - Tool dependent on Fscan, but not (yet?) built into it
  - https://git.ligo.org/CW/instrumental/line-investigations/-/blob/main/ansel-scripts/whenwhere.py

Tracking combs



https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=79822

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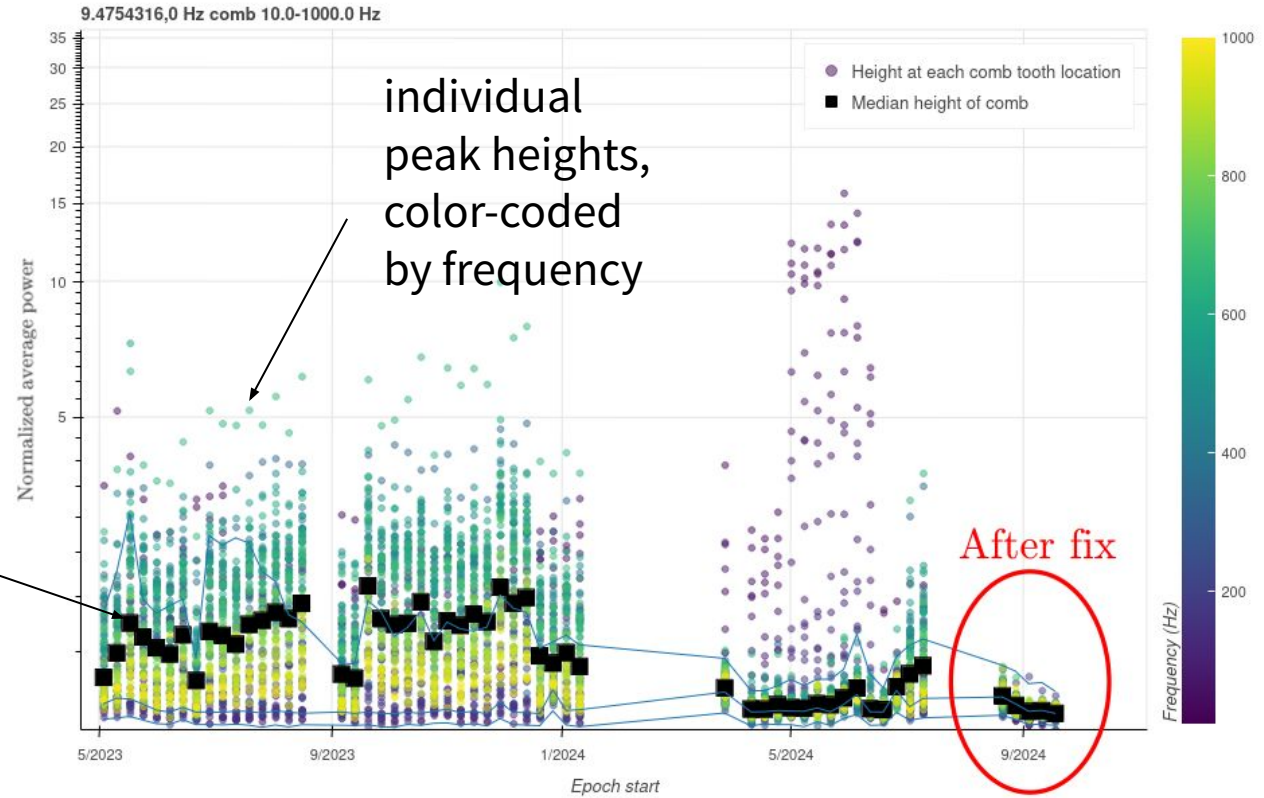

individual peak heights, color-coded by frequency

Median height of all comb peaks

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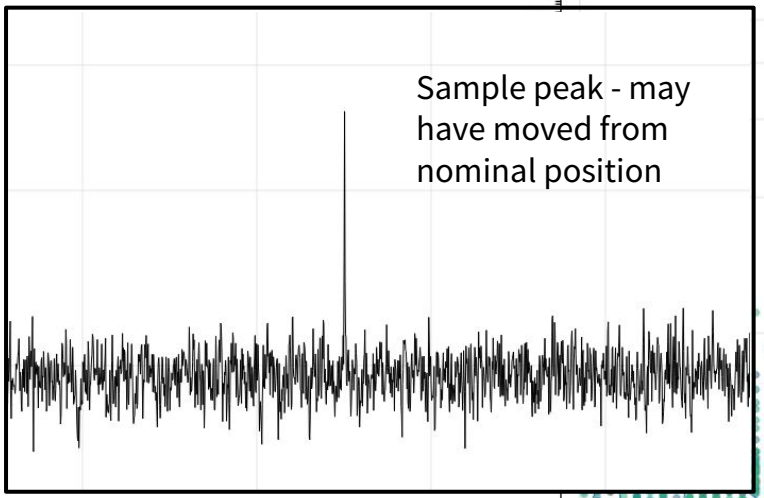

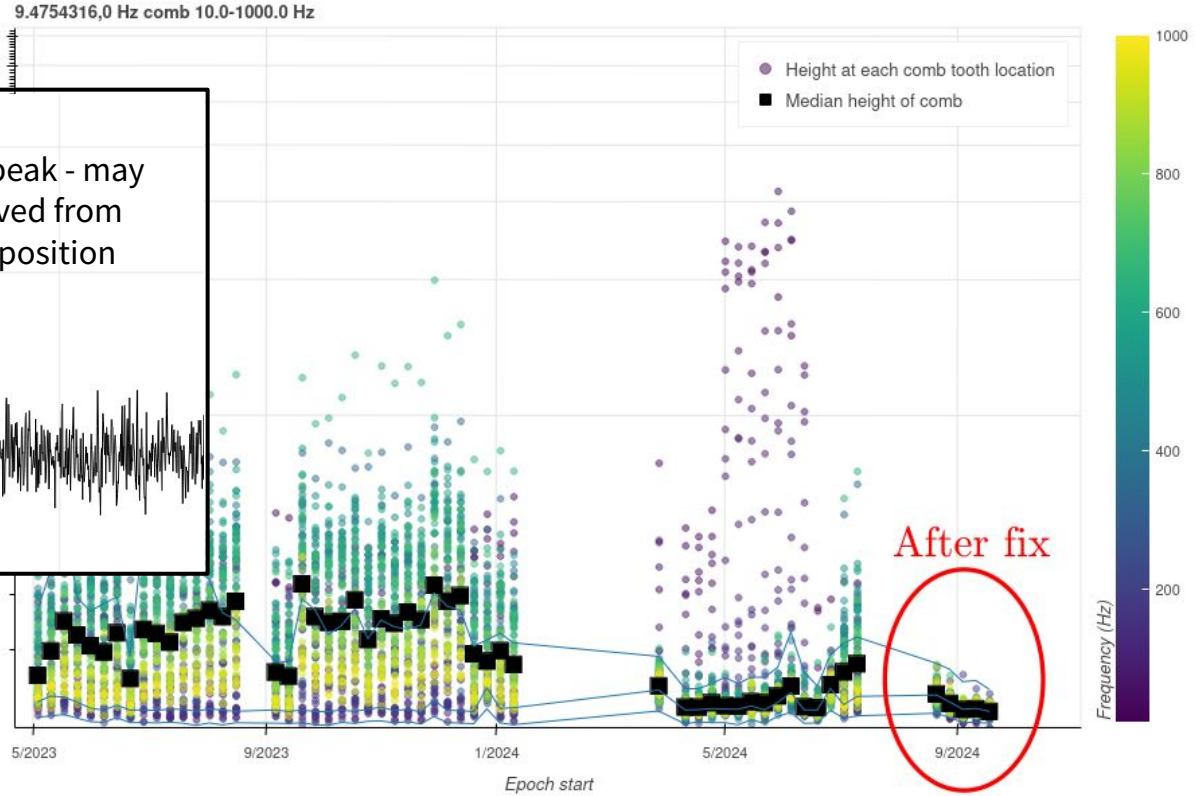

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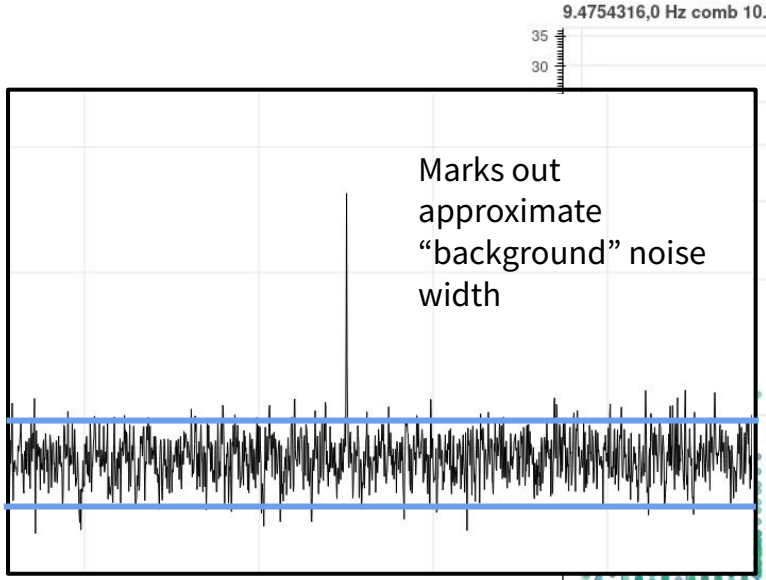

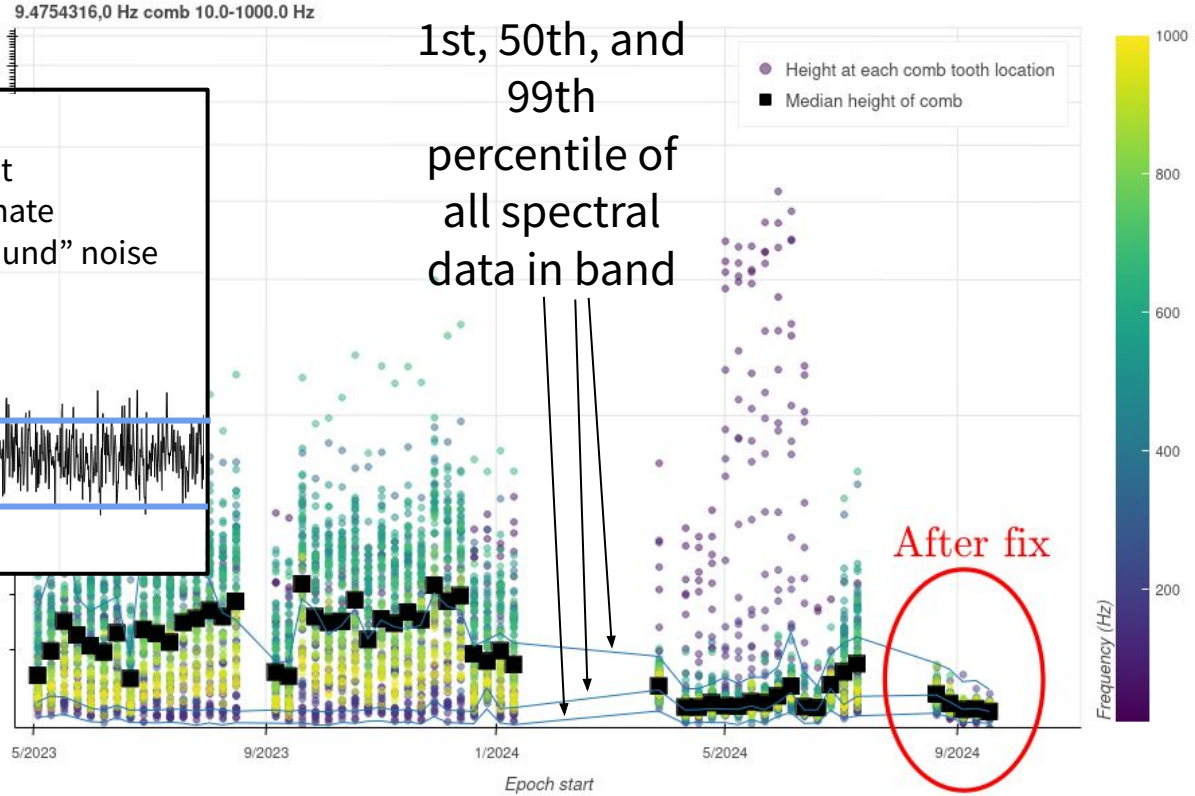

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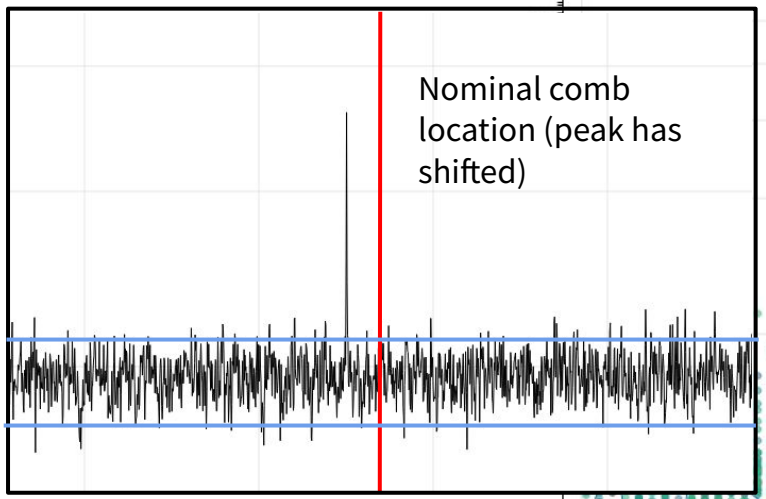

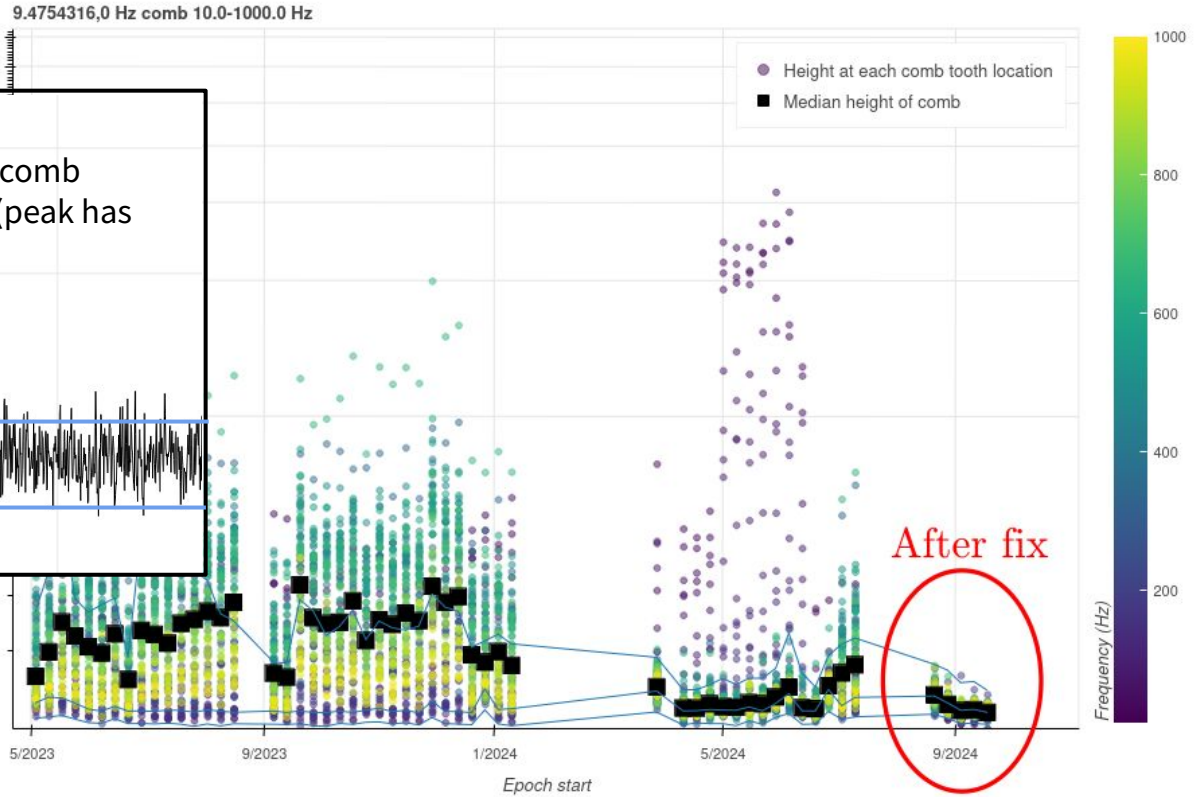

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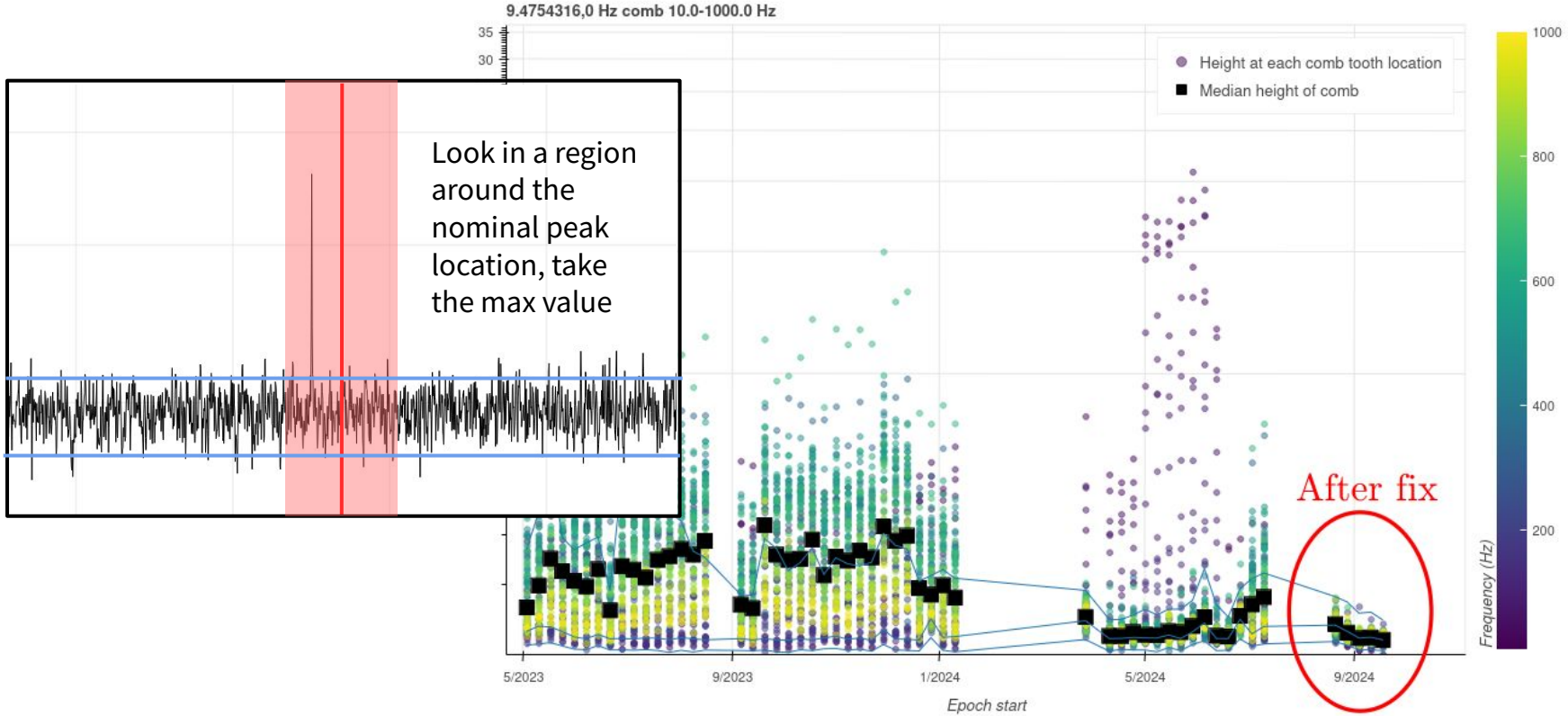

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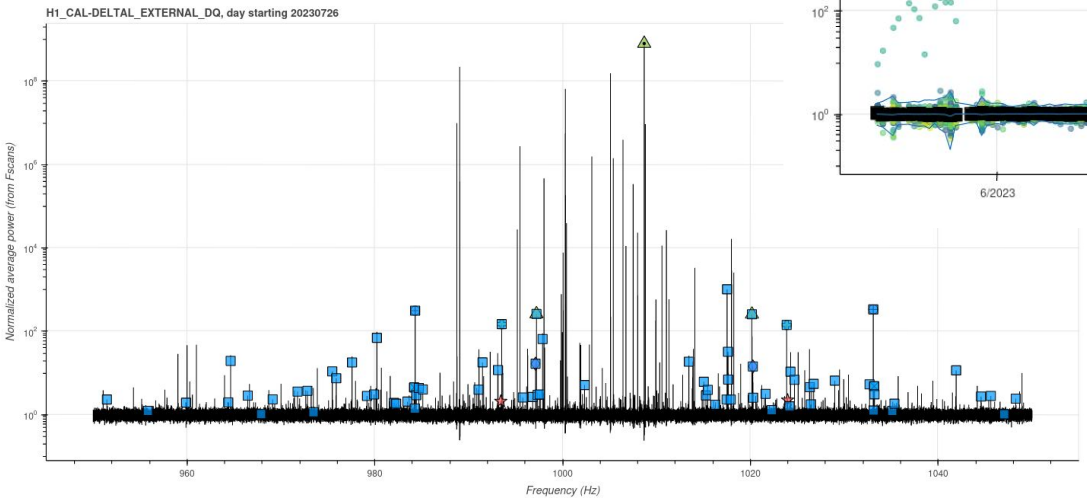

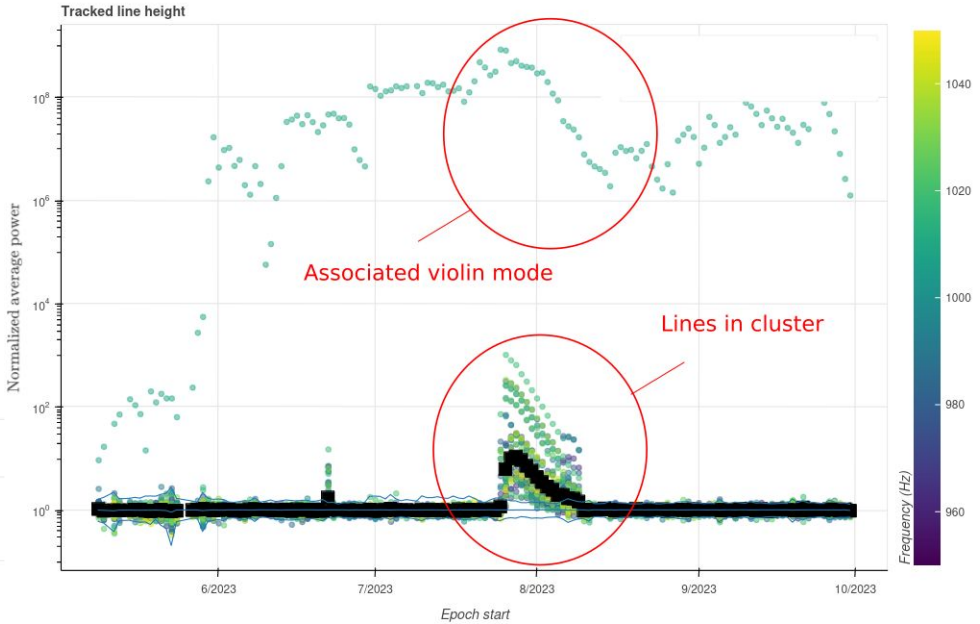

https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=79825

Tracking groups of lines

Not actually a spectrogram– frequency axis is not continuous (or even necessarily monotonic).

Result of **clustering lines by the similarity of their time evolution histories**.

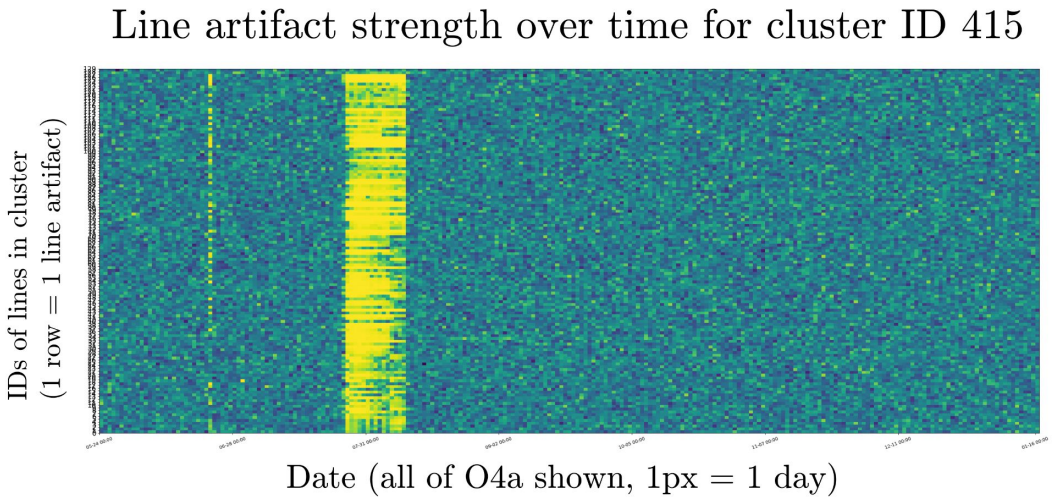

Image credit: Tyra Collier, Autumn Marceau (UW Bothell)
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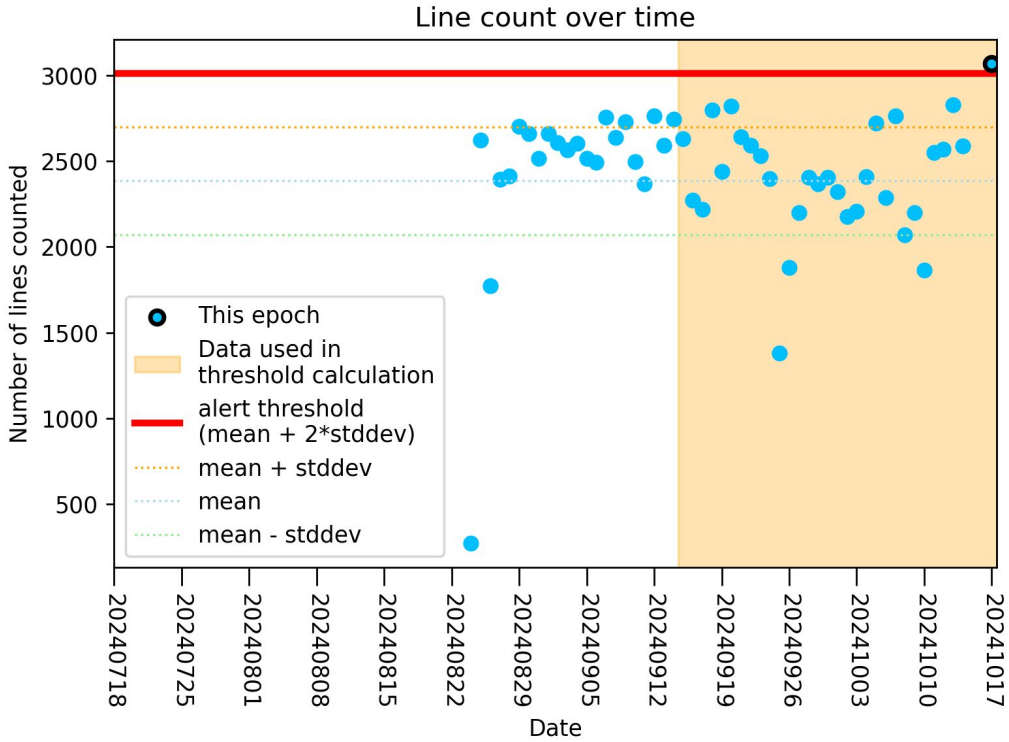
Monitoring line behavior in general



Sample Fscan plots; co-credit to Evan Goetz and Taylor Starkman

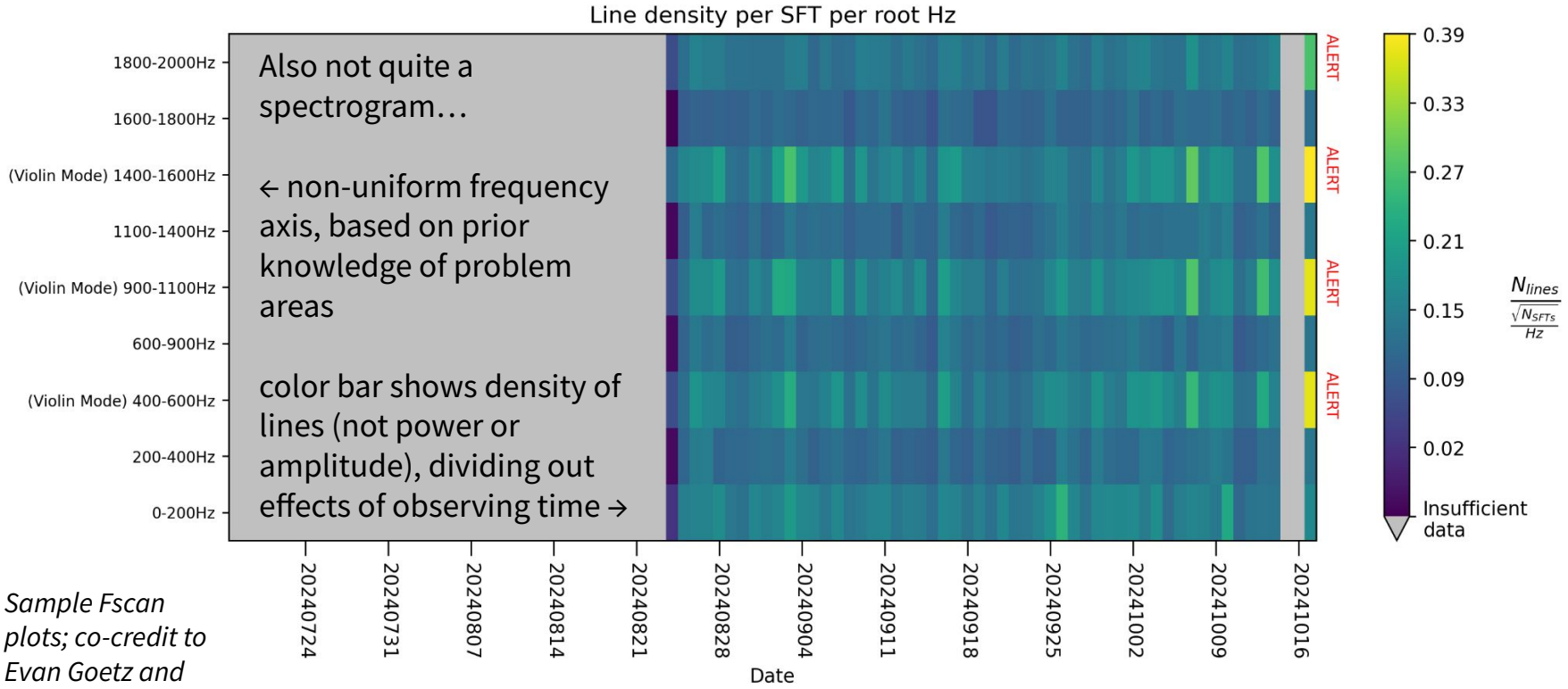
What we need:

- Catch unexpected changes in the noise
- Alert viewers when noise increases

Solution:

- Under the hood: line counter (also used for automated comb identification)
- Static plots on Fscan daily pages, for use by data quality shifts

Monitoring line behavior in general



Sample Fscan plots; co-credit to Evan Goetz and ***Taylor Starkman***

Questions? Comments?