Clustering Spectral Noise

to Improve Continuous Gravitational Wave Detector Characterization

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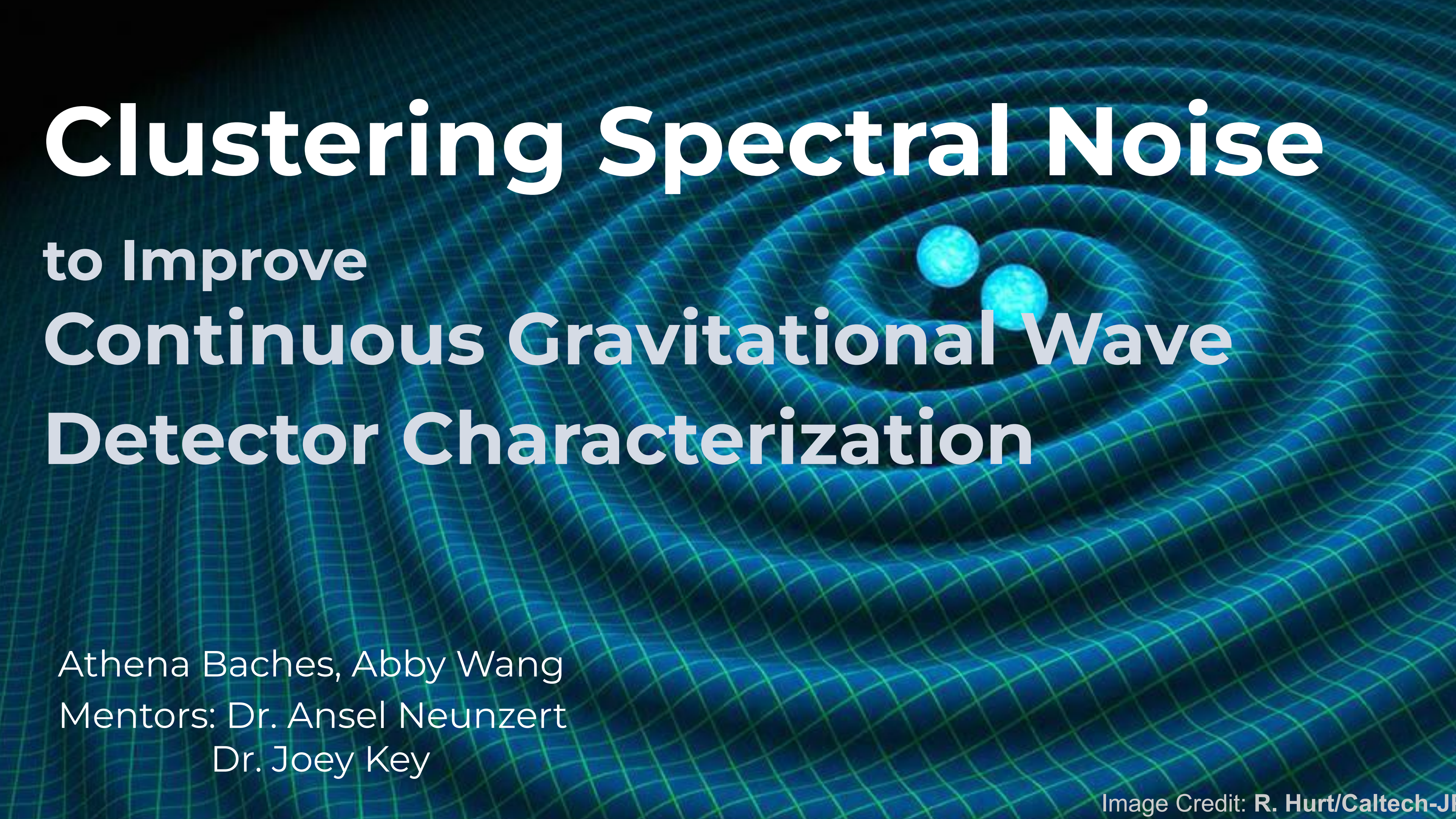

Image Credit: **R. Hurt/Caltech-JI**

CONTINUOUS GRAVITATIONAL WAVES

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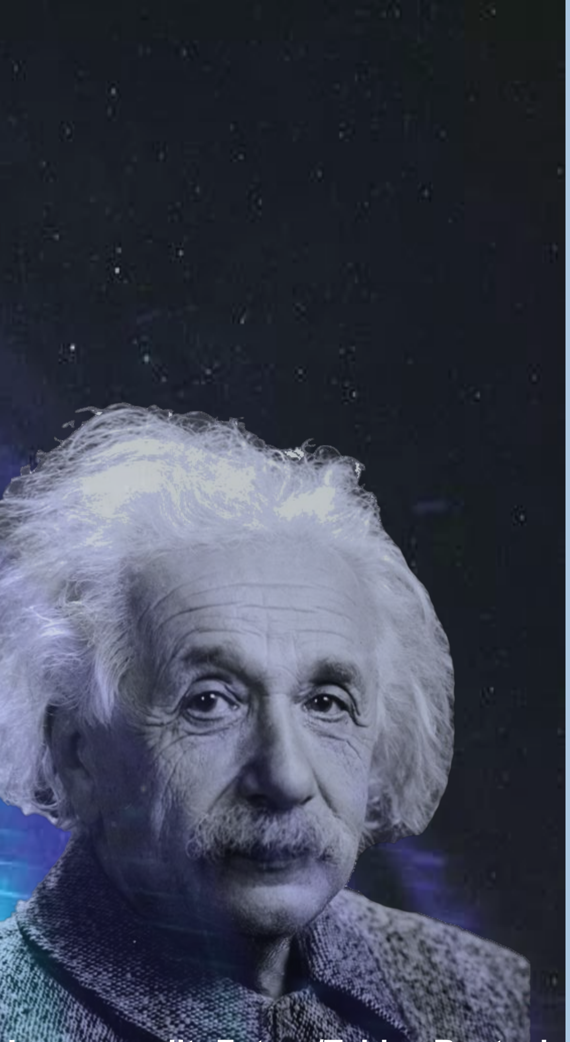
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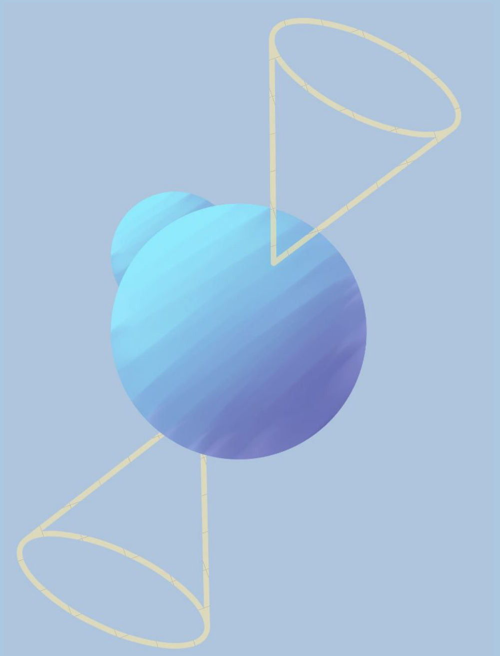
WHAT ARE CONTINUOUS GRAVITATIONAL WAVES?

Non-Axisymmetric Spinning Neutron Star



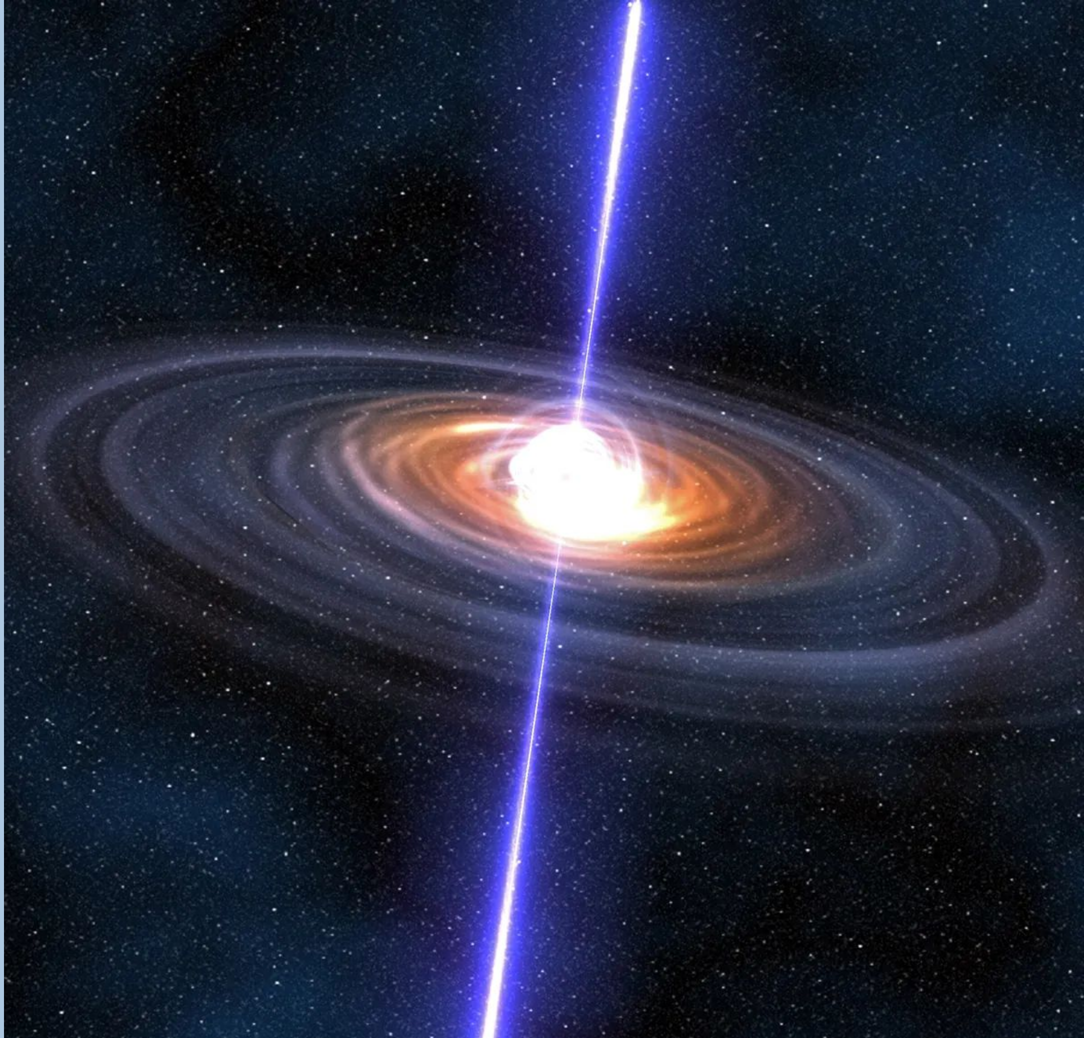


Image Credit: Michael Taylor

Continuous Gravitational Waves

Longer in duration, but weaker than CBC signals

Persistent and near single frequency

Have not yet been detected

Image Credit: **R. Hurt/Caltech-JPL**

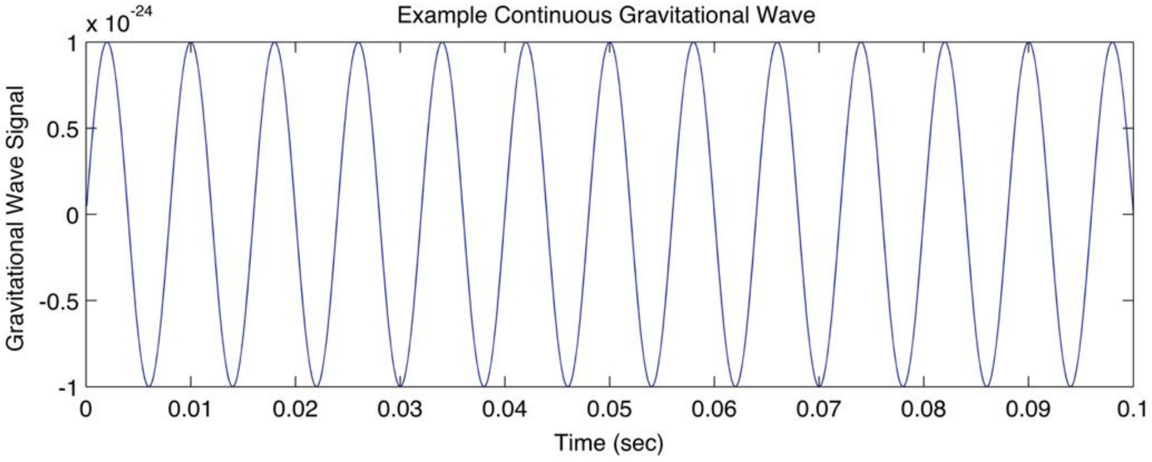


Image Credit: A. Stuver/LIGO

Continuous Waves - Variations

R Mode Oscillations

- A fluid oscillation mode, which contains a separate angular velocity from that of the stars rotation.
- Possible positive feedback loop of mode in case of negative angular momentum.
- Spin of the star is proportional to the frequency of the signal.

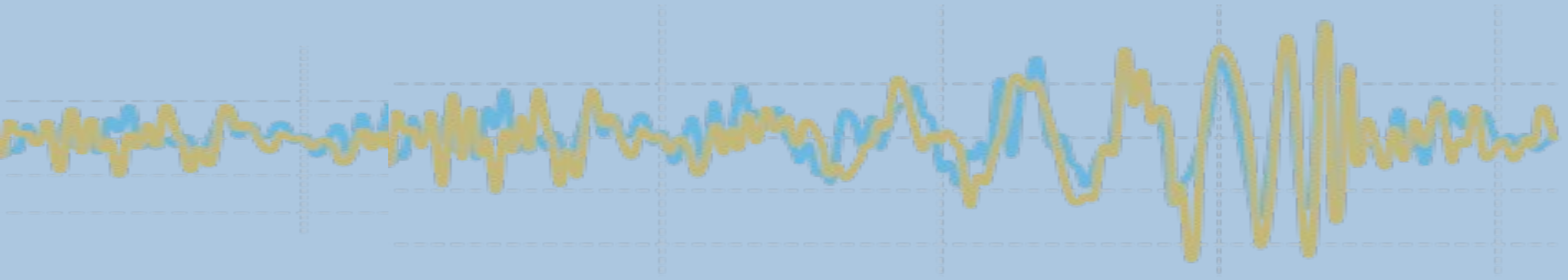
Binary Systems

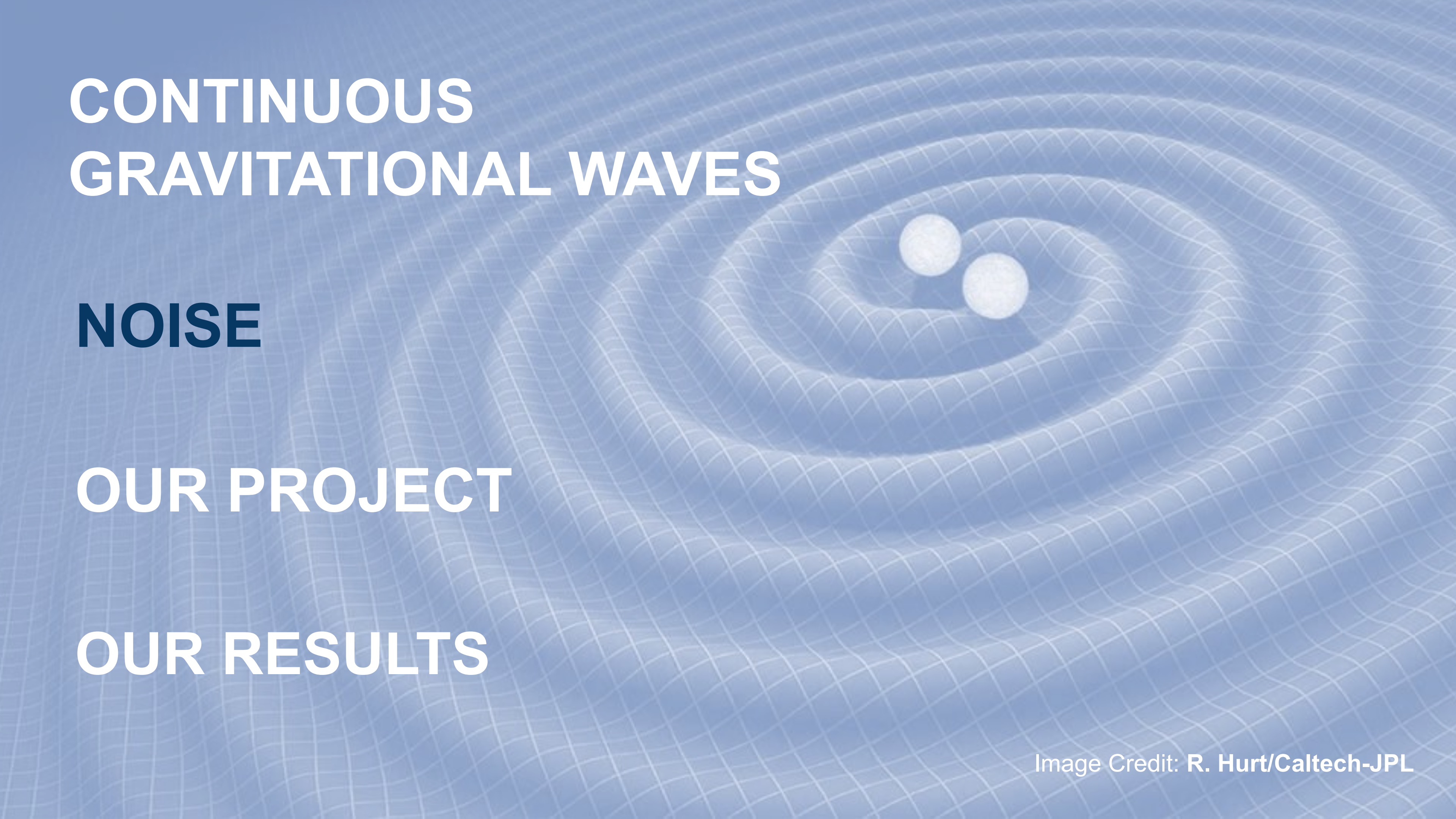
- Where the neutron star is in orbit with another celestial companion (ex. Low mass star, black hole, another neutron star).
- In case of mass accretion, the added mass could contribute to surface imperfection.
- Additional angular momentum from accretion from companion.
- Doppler shifts due to orbit on observed GW signal.

Reference [2], Wette

Continuous Waves - Analysis Challenges

- Weak signal
- Requires longer period of data
- High computational cost
- System variations creating variations in possible signals





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Spectral Noise Artifacts

Non-gravitational wave data inputs observed by these detectors are commonly referred to as *noise artifacts*

The sources are almost always from Earth, examples:

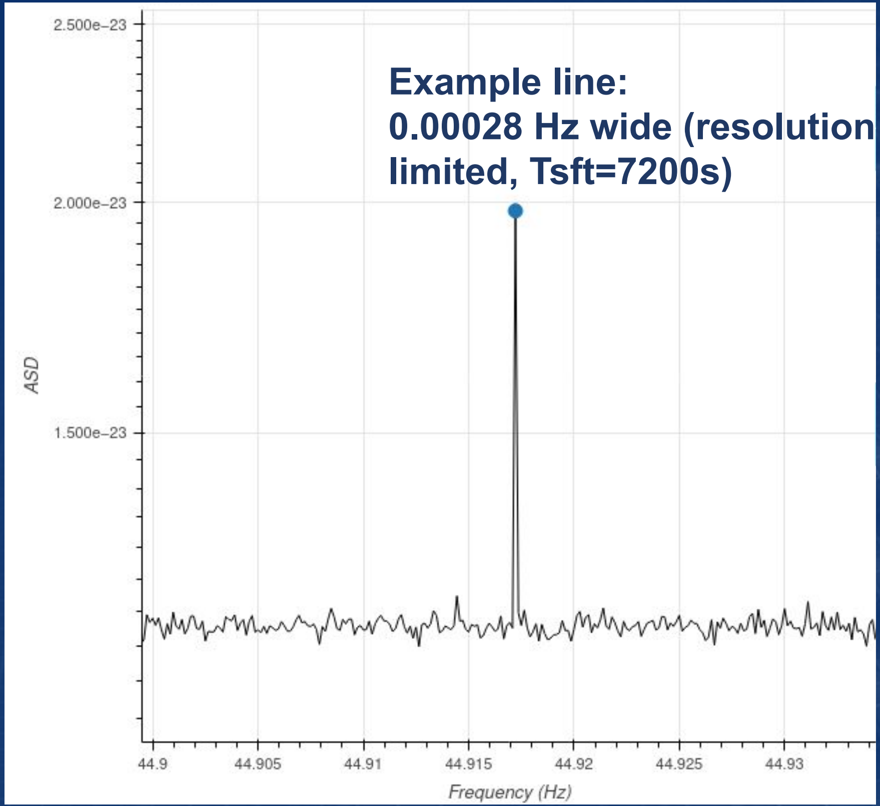
Environmental (wide frequency range)

- Seismic (ground disturbance)
- Thermal (atom fluctuations)

Instrumental (narrow frequency range)

- Electronic (from parts of the machine)

Narrow Spectral Artifacts ("Lines")



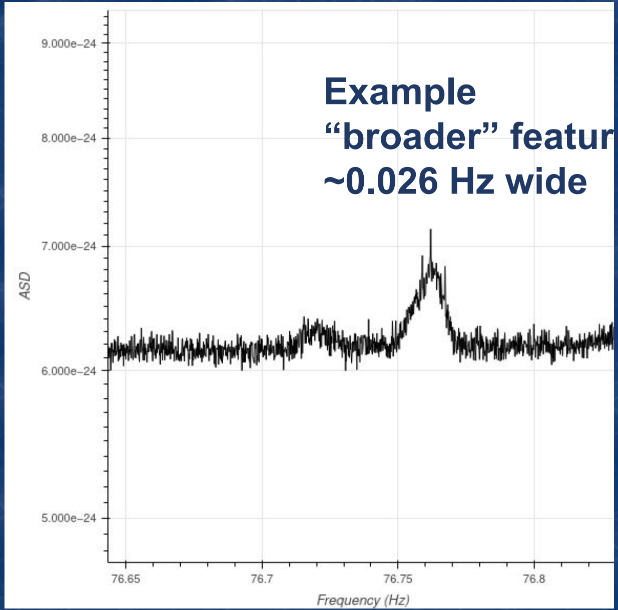
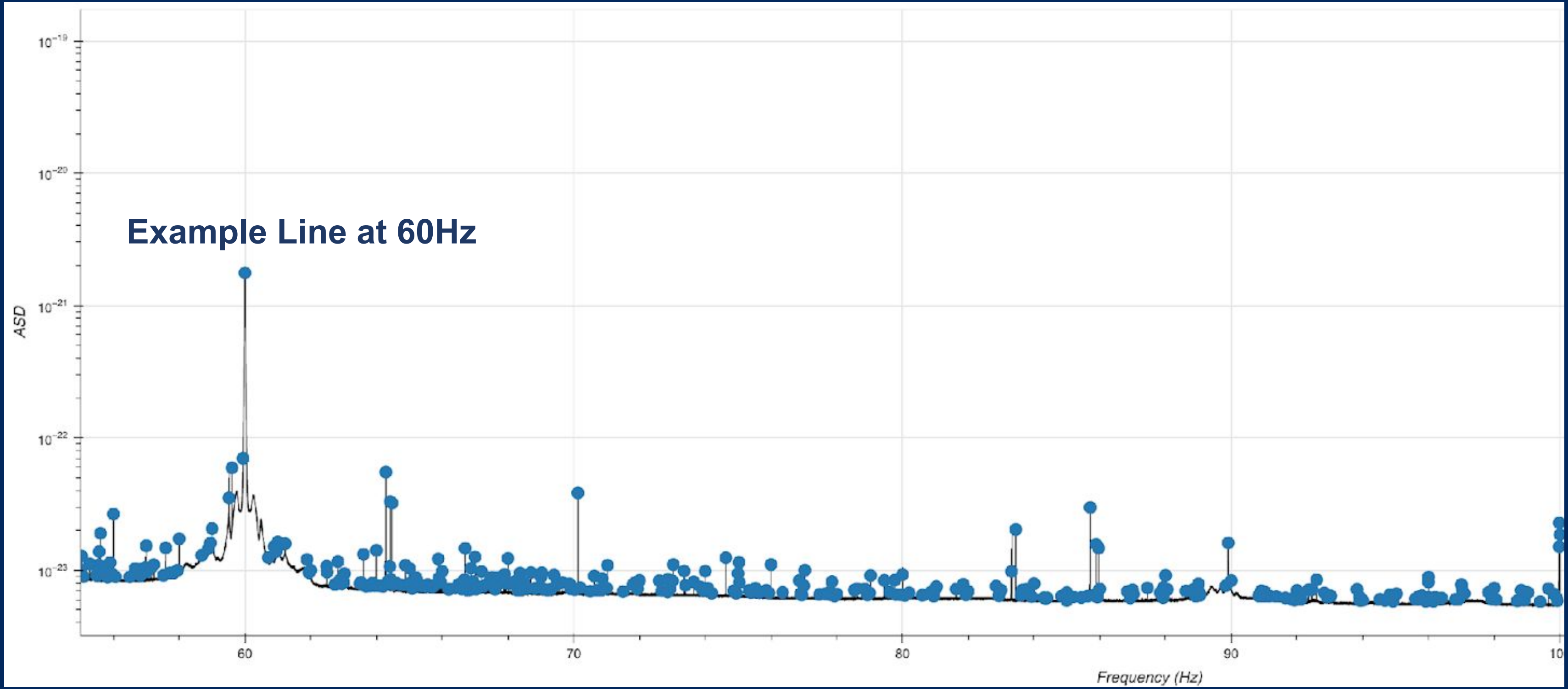


Image Credit: LIGO/Dr. Ansel Neunzert

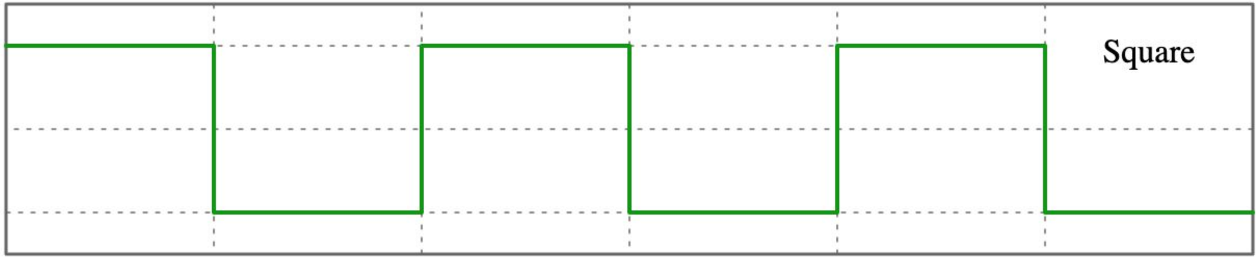
Narrow Spectral Artifacts (“Lines”)

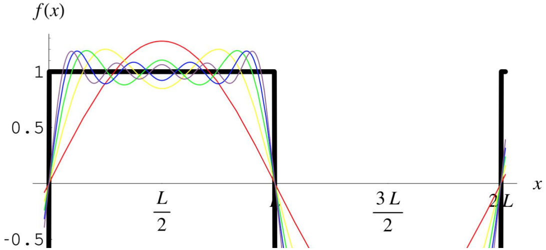


O3 Line list: https://gwosc.org/O3/o3speclines/

Combs

Time-domain





FFT

Frequency domain

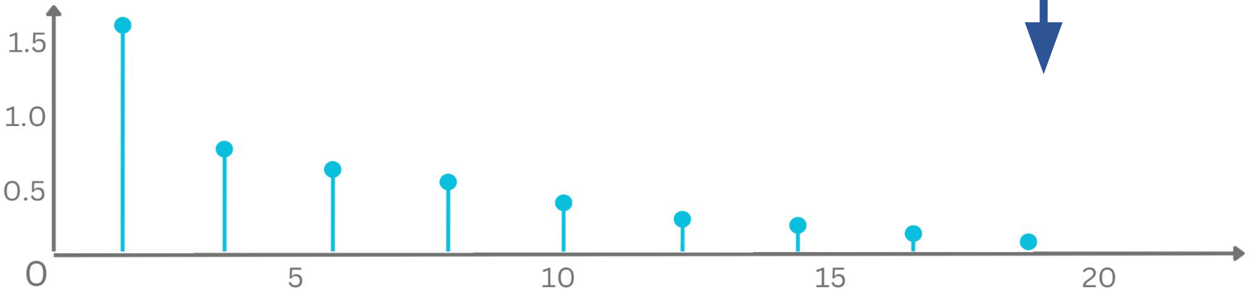
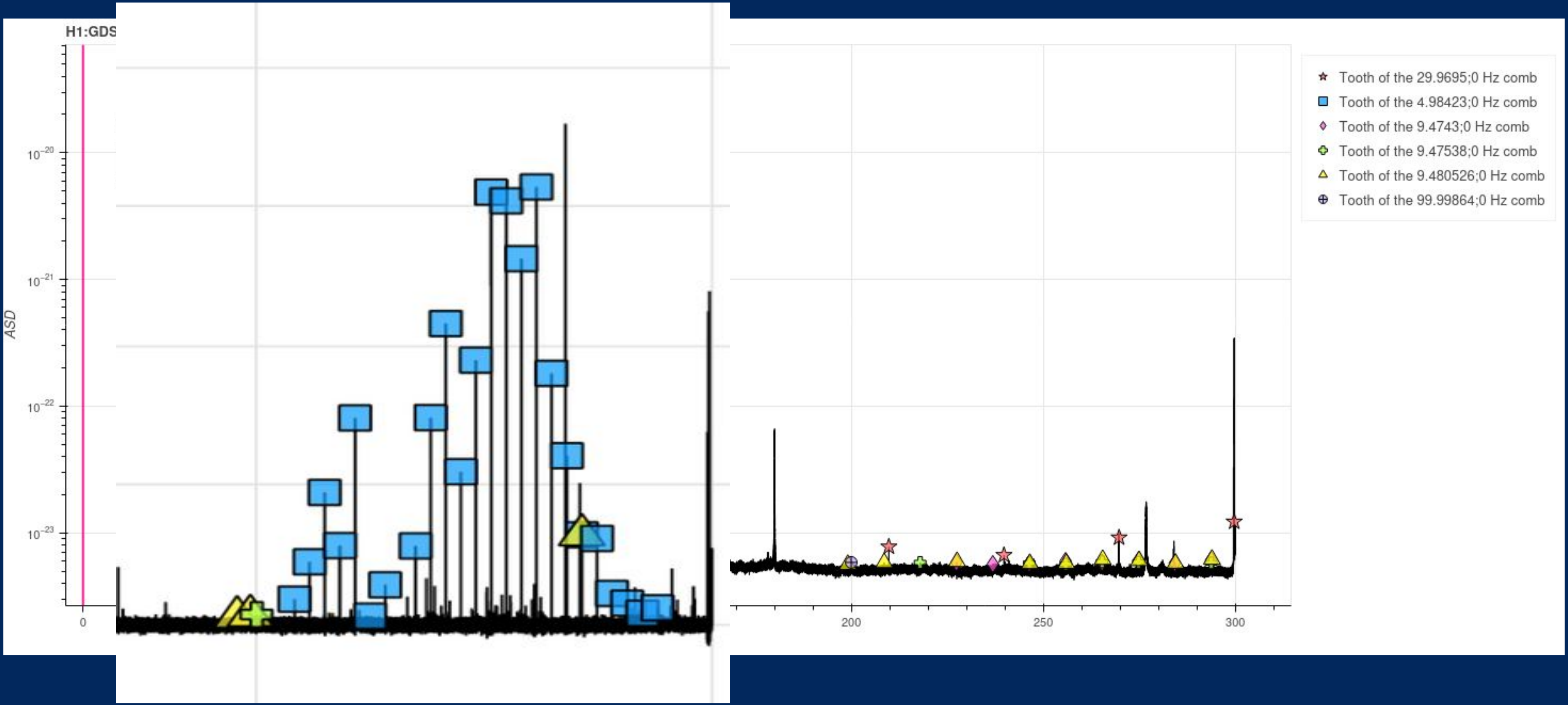


Image Credit: Wolfram Mathworld

Combs



H1:GDS
ASD
10^{-20}
10^{-21}
10^{-22}
10^{-23}
0
200
250
300
Tooth of the 29.9695;0 Hz comb
Tooth of the 4.98423;0 Hz comb
Tooth of the 9.4743;0 Hz comb
Tooth of the 9.47538;0 Hz comb
Tooth of the 9.480526;0 Hz comb
Tooth of the 99.99864;0 Hz comb

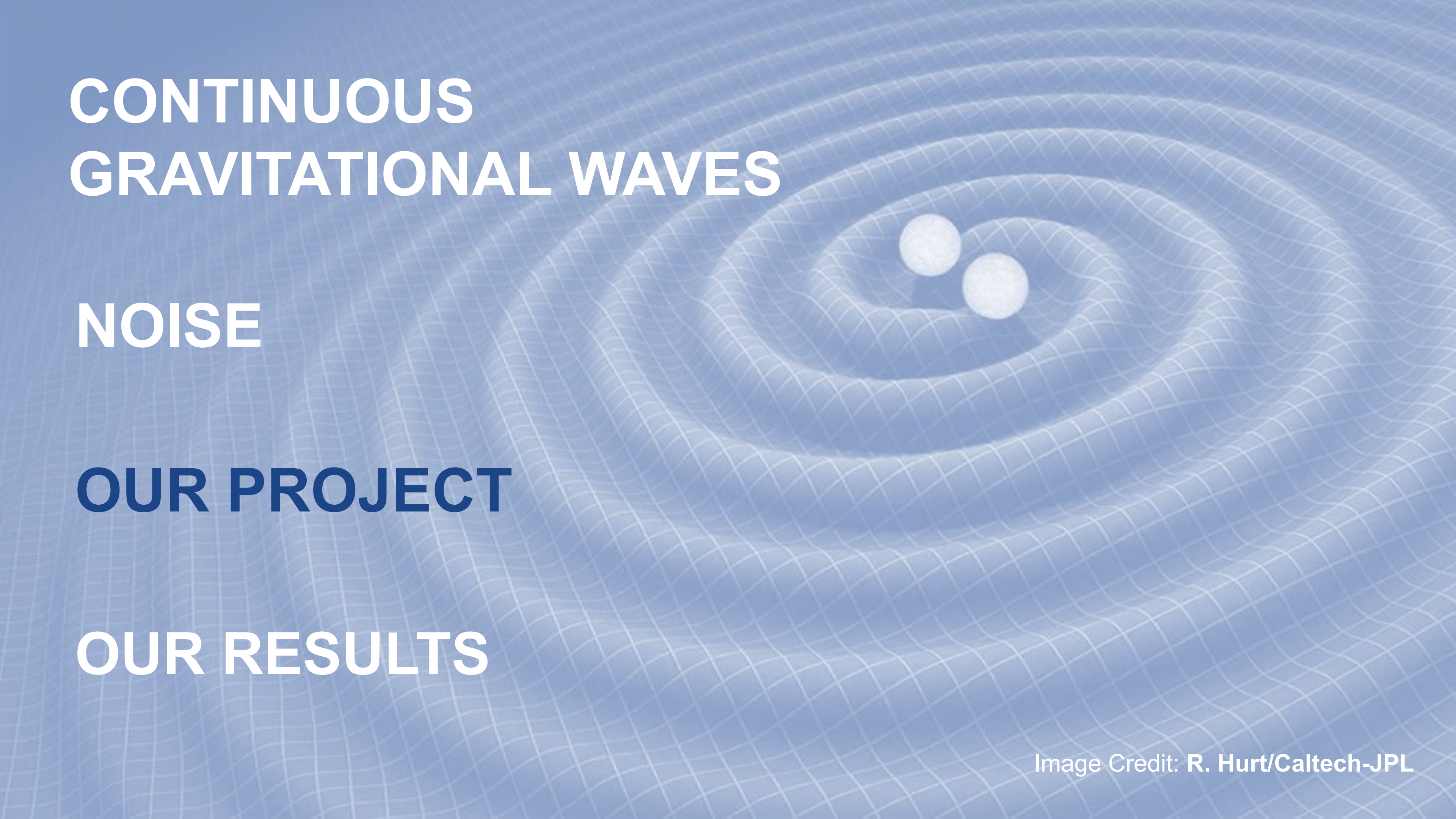

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Image Credit: R. Hurt/Caltech-JPL

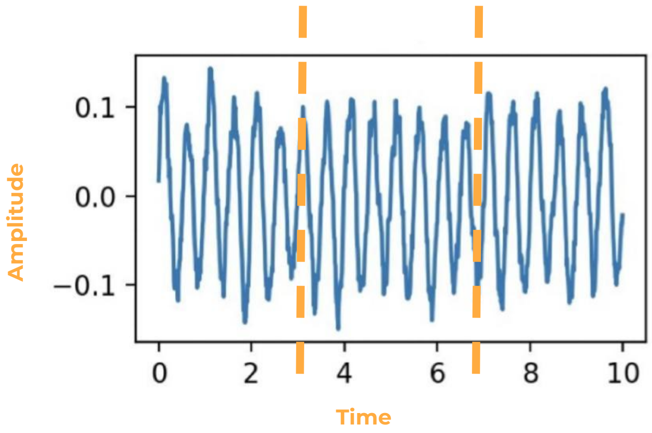
Importance

- Group noise lines by their time history;
- Identify potential combs and provide insights on noise sources;
- Studies relations/correlations between different noise lines;
- **Provide clues to help determine where and when noise lines are present that might mimic or obscure a CW signal.**

Image Credit: Fermilab

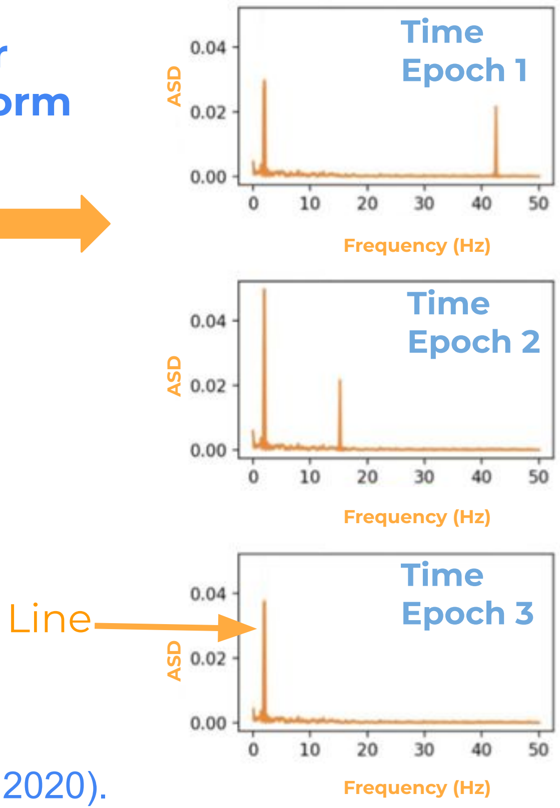
Clustering Process

Strain Data



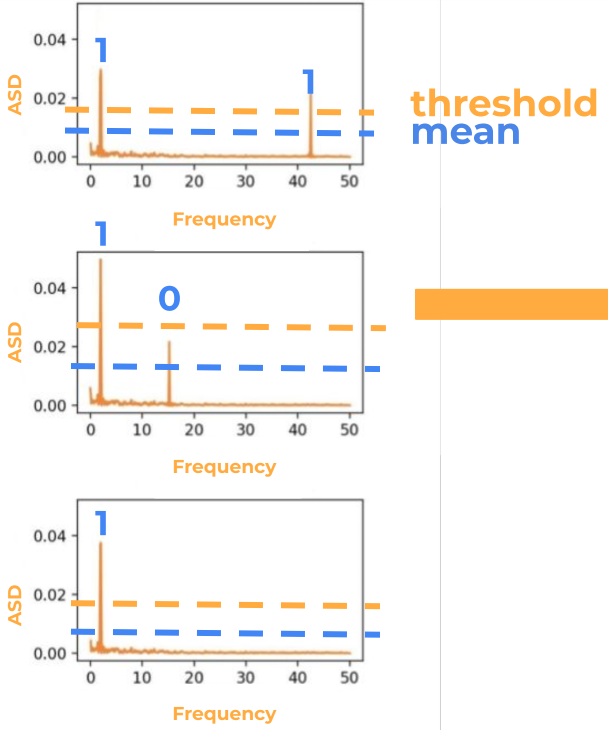
Short Fourier Transform (SFT)*

Spectrum



*This part of the project is carried out using the `lalpulsar_spec_avg_long` tool as part of the LALsuite (Wette, 2020).

Clustering Process



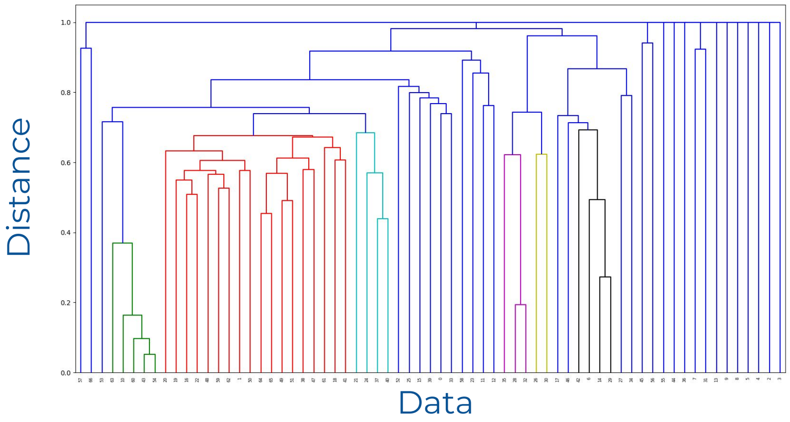
	Line 1	Line 2	Line 3
Time epoch 1	1	0	1
Time epoch 2	1	0	0
Time epoch 3	1	0	0

* Persistence = average of each column

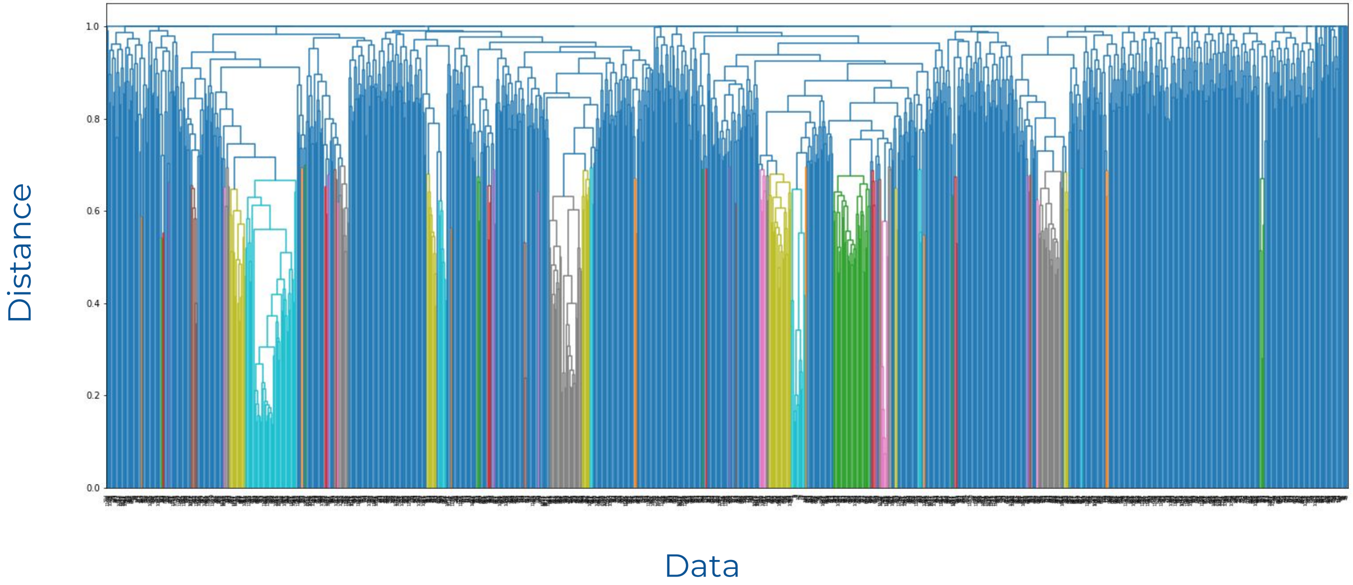
* This part is carried out using the persistence feature of the `lalpulsar_spec_avg_long` tool in LALsuite (Wette, 2020).

Clustering Process

- Group lines by **how similarly** their “0” and “1” sequences vary over time.
- **Hierarchical Clustering**: each line artifacts starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy.
- Hierarchy can be represented in a ***dendrogram***.



Actual Dendrogram



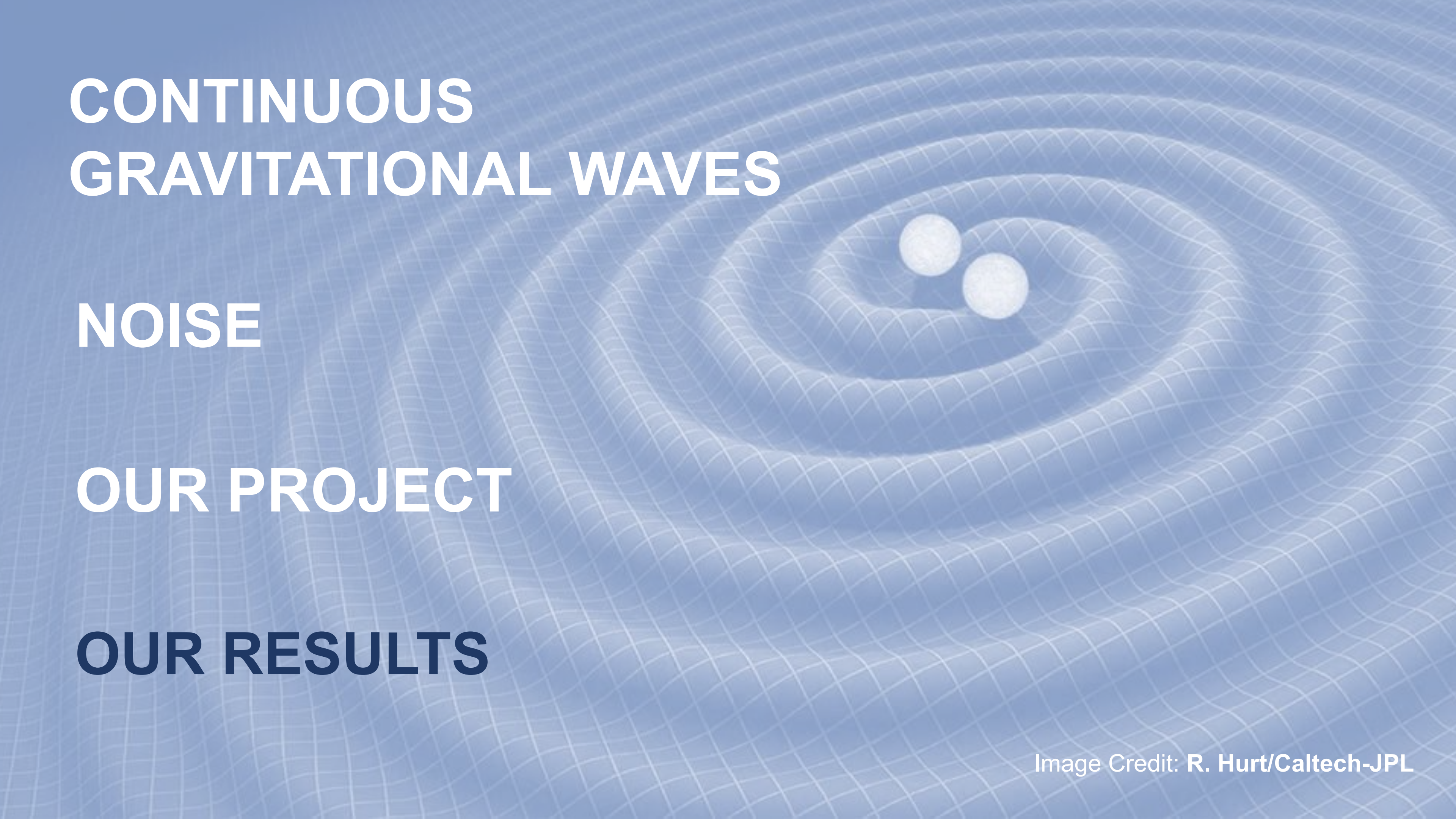

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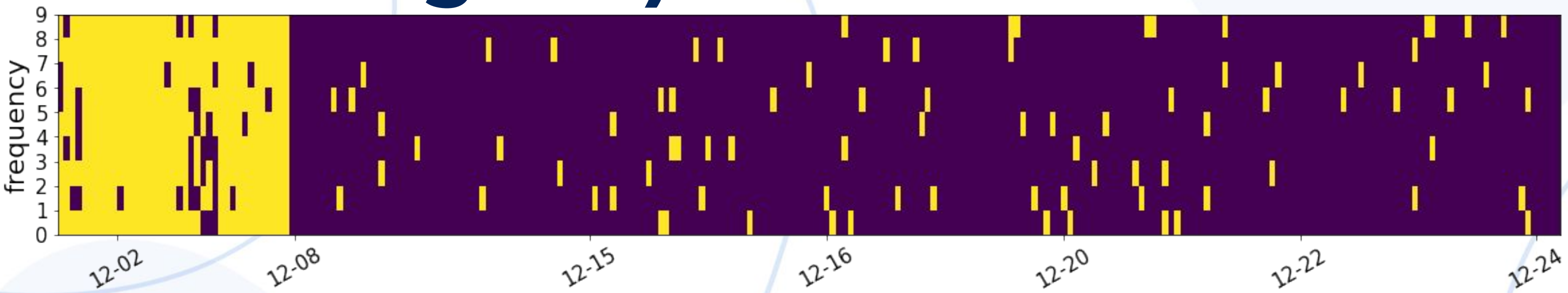
Image Credit: R. Hurt/Caltech-JPL

Sample Cluster from December 2022 LIGO Hanford Data (commissioning period, prior to observing run)

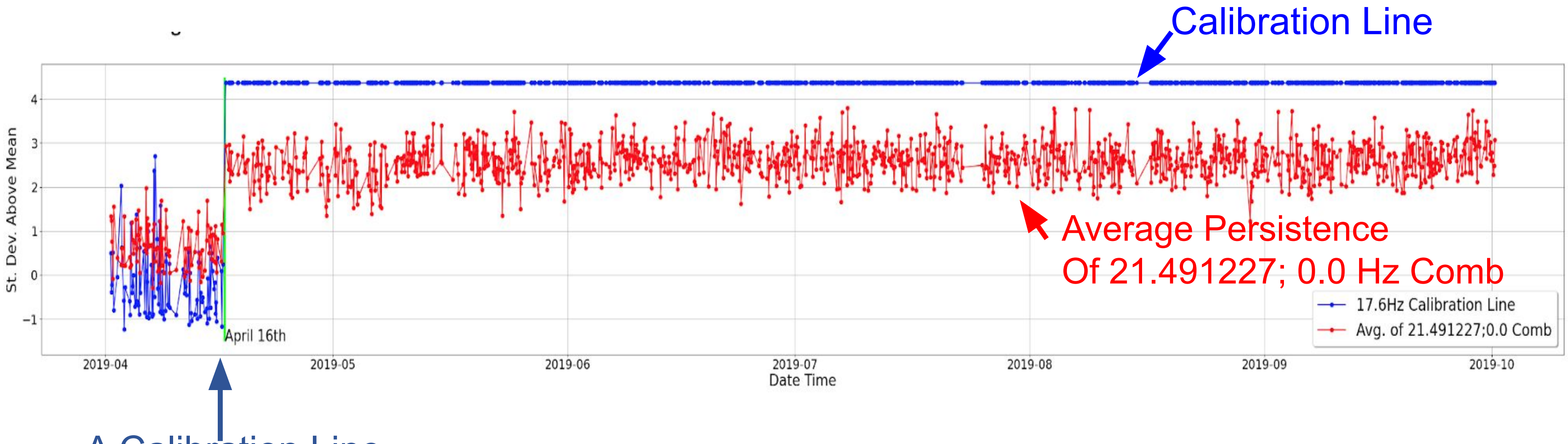
Cluster ID 891	
1	182.5 Hz
2	183.0 Hz
3	198.6 Hz
4	200.1 Hz
5	201.6 Hz
6	215.7 Hz
7	216.5 Hz
8	217.2 Hz
9	217.7 Hz



aLIGO Logbook Post: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=66925

Application: Comparison with Calibration Lines

Calibration lines are artificially injected into the data as tests.

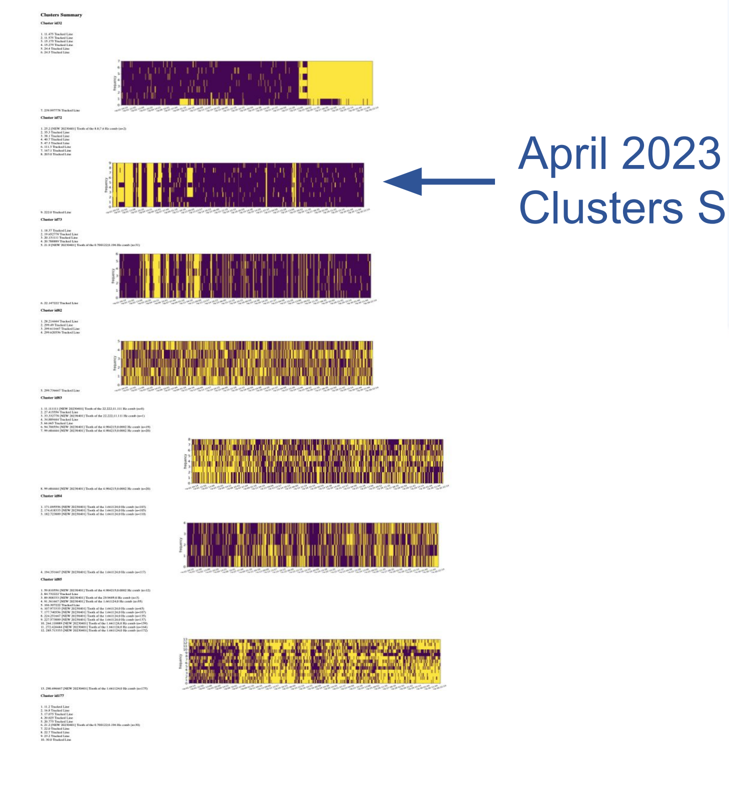


A Calibration Line Change Event took place on April 16th 2019.

aLIGO Logbook post:
https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=66697

Monthly Cluster Summary

- Currently being integrated into Fscan
- Run on monthly data from LIGO Hanford and LIGO Livingston
- Outputs a summary html page



April 2023 LIGO Hanford Clusters Summary Page

References

1. Covas et al., "Identification and mitigation of narrow spectral artifacts that degrade searches for persistent gravitational waves in the first two observing runs of Advanced LIGO", arXiv:1801.07204 (2018)
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4. Wette, K, “Searches for continuous gravitational waves from neutron stars: A twenty-year retrospective”, arXiv:2305.07106v1, (2023)
5. Riles, K. “Searches for continuous-wave gravitational radiation” (2023), *Living Reviews in Relativity*, 26, 3

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- The UWB REU Program and Students and Faculty
- LIGO and LSC and LVK
- National Science Foundation

QUESTIONS?

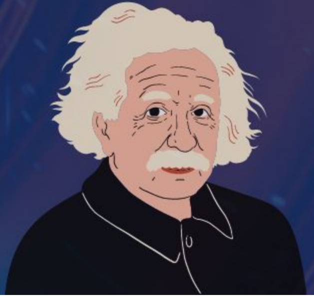

Image Credit: Carl Knox, OzGrav-Swinburne University.