Picket Fence:

an Earthquake Alert system for the LIGO detectors

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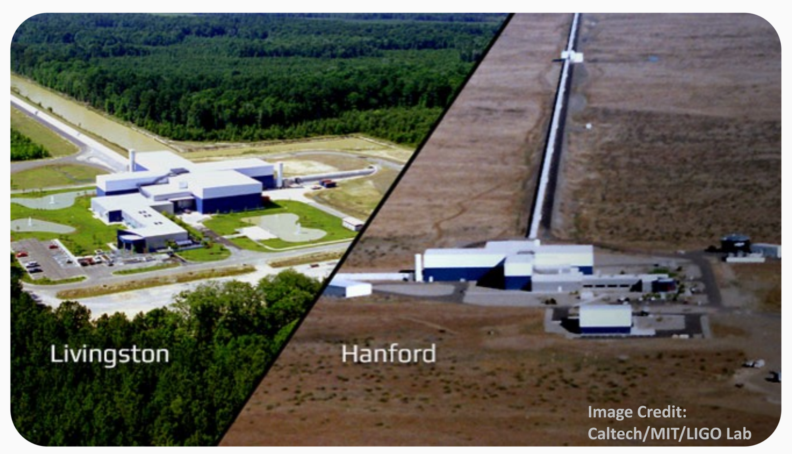
What is LIGO?

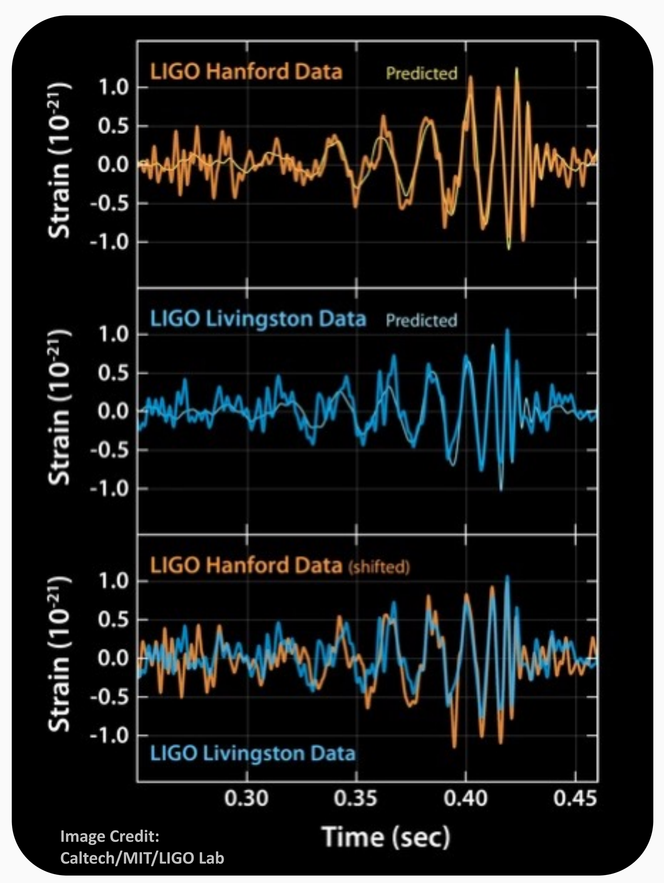
LIGO stands for Laser Interferometer Gravitational-wave Observatory. There are two separated interferometers with 4-km arms and attometer length change sensitivity [1]



Two LIGO detectors:

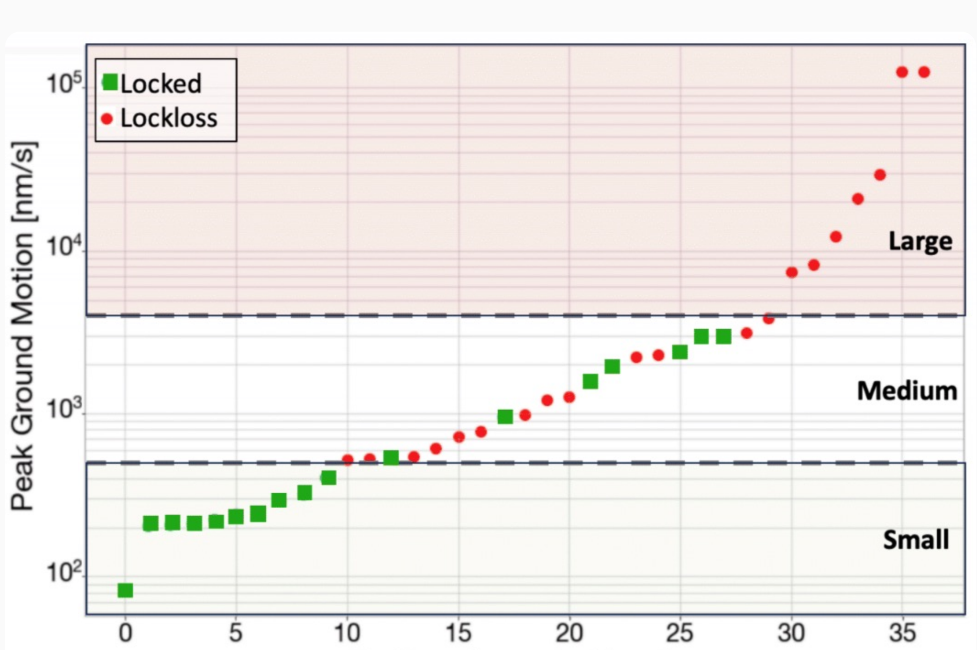
- Livingston, Louisiana
- Hanford, Washington

LIGO detects gravitational waves produced by cataclysmic events, like black hole or neutron star mergers [2].



LIGO and Earthquakes

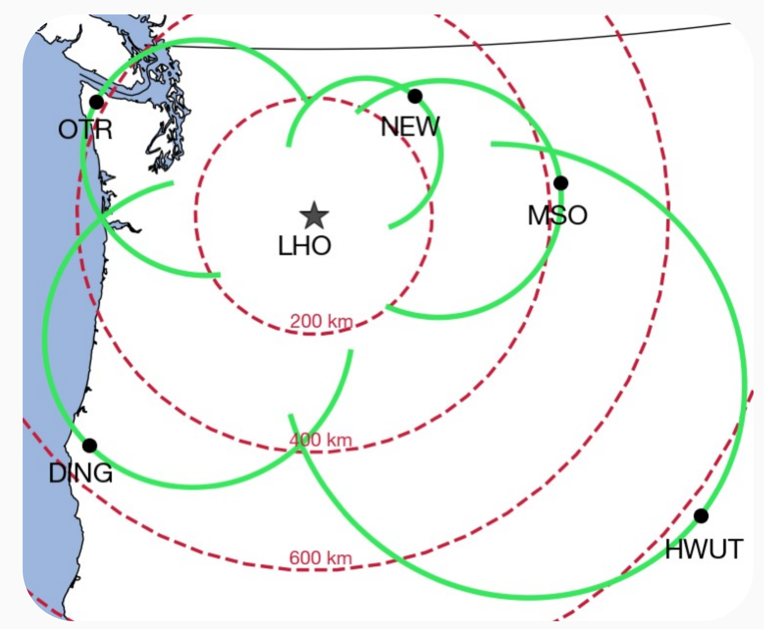
Earthquakes take LIGO out of 'Lock' or the resonance condition that grants it the sensitivity needed for gravitational-wave detection. Earthquakes caused 24% of locklosses during LIGO's third observing run [3].



An early warning strategy, together with control changes can be used to mitigate the impact of earthquakes with a peak local ground velocity of 500-2000 nm/s in the sub 0.1 Hz band.

What is the picket fence?

It is a stream of real-time data from broadband seismometers around the LIGO observatories to warn of incoming earthquakes. The data is streamed using ObsPy [4] and a seedlink connection.

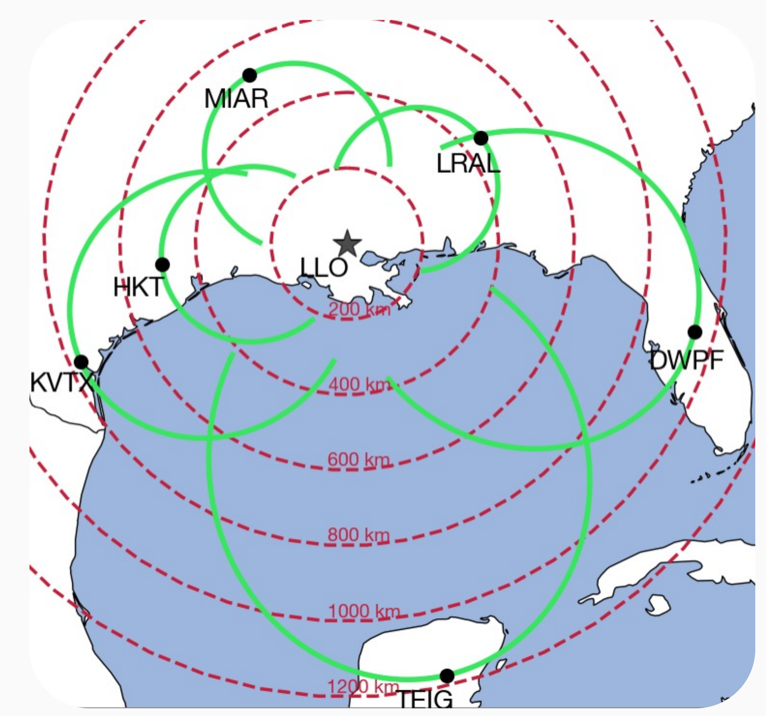


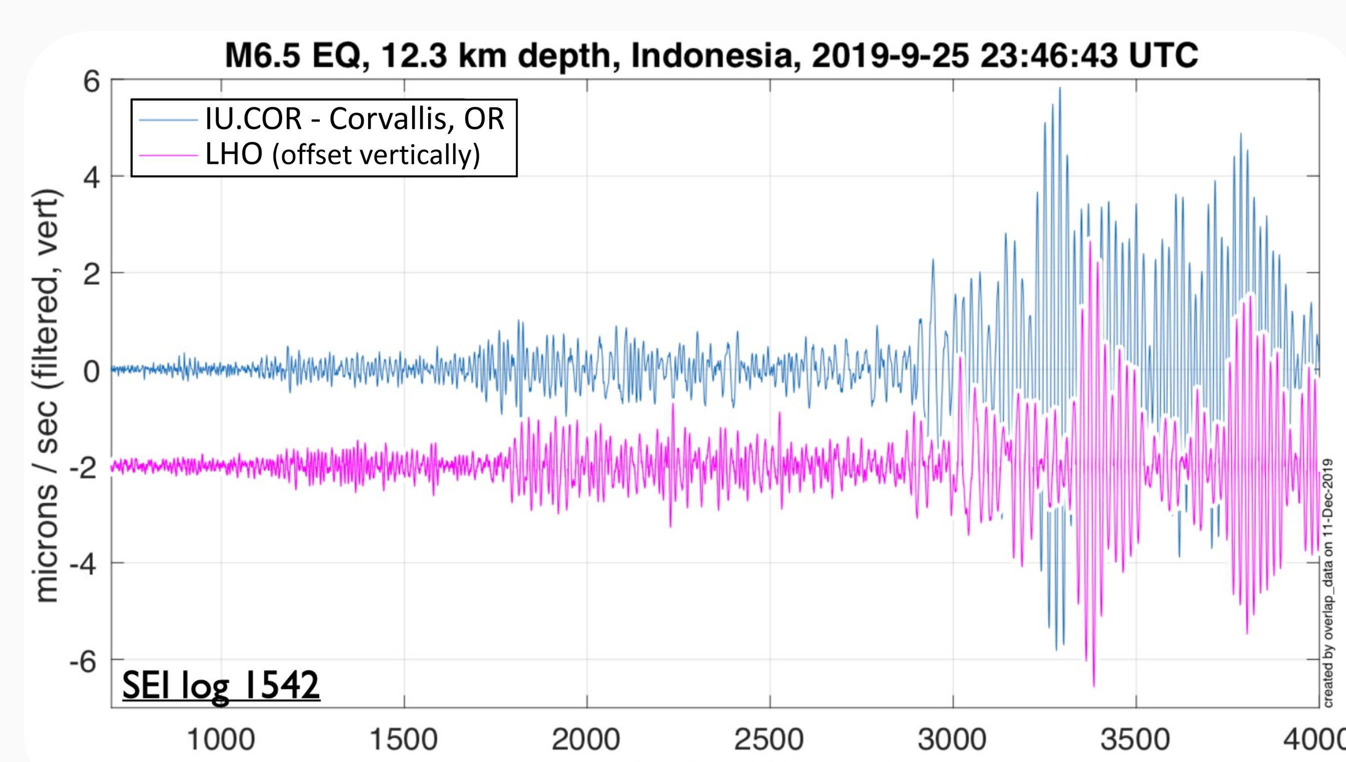
Equidistant azimuthal projection maps of the Picket Fence.

Top: LIGO Hanford Observatory (LHO).

Bottom: LIGO Livingston Observatory (LLO).

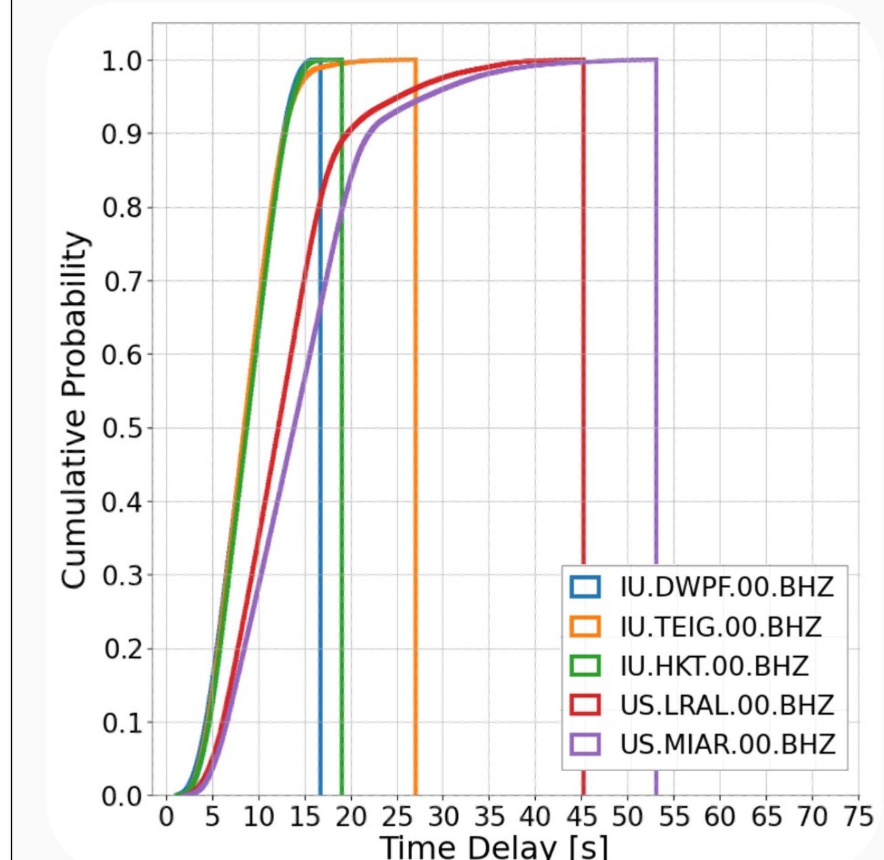
The solid lines represent virtual locations of the stations for events incoming from different azimuths. They form a protective 'fence' around the detectors.





By looking at the waveforms before they arrive, we can make semi-automated control decisions (Earthquake Mode [5]) to increase the robustness of the observatories.

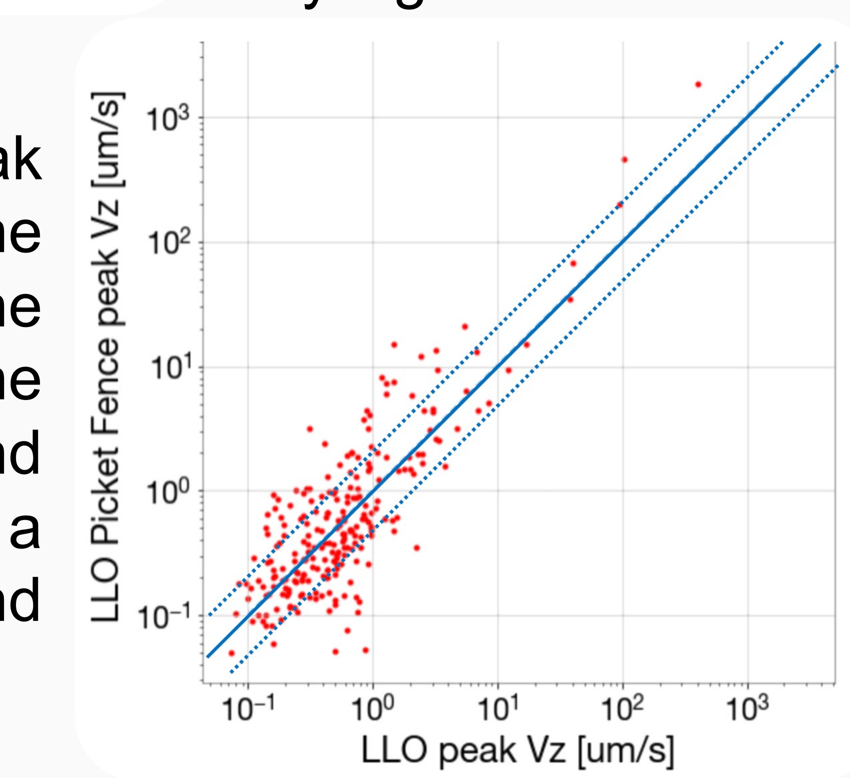
Picket Fence Performance



Thanks to the low-latency streams from NEIC and PNSN we gather data with less than 35 s delay from a remote station 95% of the time [6].

This translates into at least 30 seconds of warning for remote Rayleigh waves.

The predicted peak vertical amplitude of the Rayleigh waves at the LIGO sites and the actual measured ground motion agree to within a factor of two around 63% of the time [6].



Future Prospects

- Add redundancies for improved robustness.
- Use the picket fence to automate controls decisions
- Find low-latency Canadian stations.
- Use synthetic seismograms to assist the picket fence predictions.

Acknowledgements

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References and Links

[1] "What is LIGO?." Caltech, www.ligo.caltech.edu/page/what-is-ligo. Accessed 01 May. 2024.

[2] "GW150914 - the First Direct Detection of Gravitational Waves." GW150914 - The First Direct Detection of Gravitational Waves, www.ligo.org/detections/GW150914.php. Accessed 30 Apr 2024.

[3] A. Pele, "Lockloss status at the beginning of O3 (LLO)". https://dcc.ligo.org/LIGO-G1901122/public. Accessed 30 Apr 2024.

[4] M. Beyreuther, M., Barsch, R., Krischer, *et al.* "ObsPy: A Python Toolbox for Seismology". *Seismological Research Letters*, 81 (3), 530-533.

[5] E. Schwartz, *et al.* "Improving the Robustness of the Advanced LIGO detectors to Earthquakes". *Classical and Quantum Gravity* 37.23 (2020): 235007.

[6] E. Bonilla "Picket fence white paper". https://dcc.ligo.org/LIGO-T2300281/public. Accessed 01 May. 2024.