Lock-loss Due to Earthquakes at LIGO Hanford Observatory

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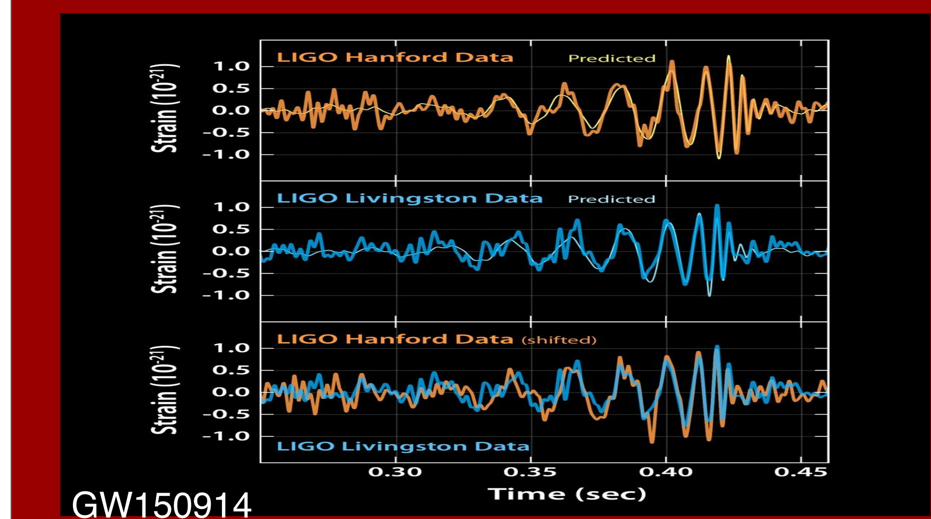
Introduction



GW150914

LIGO (**L**aser **I**nterferometer **G**ravitational-Wave **O**bservatory) directly detected gravitational waves on September 14, 2015. The signal came from an event that occurred 1.3 billion years ago where two black holes rapidly revolved around one another and merged, distorting the fabric of space-time, and creating ripples known as gravitational waves. The latest Observing period averaged a detection of such an event every 3 days.

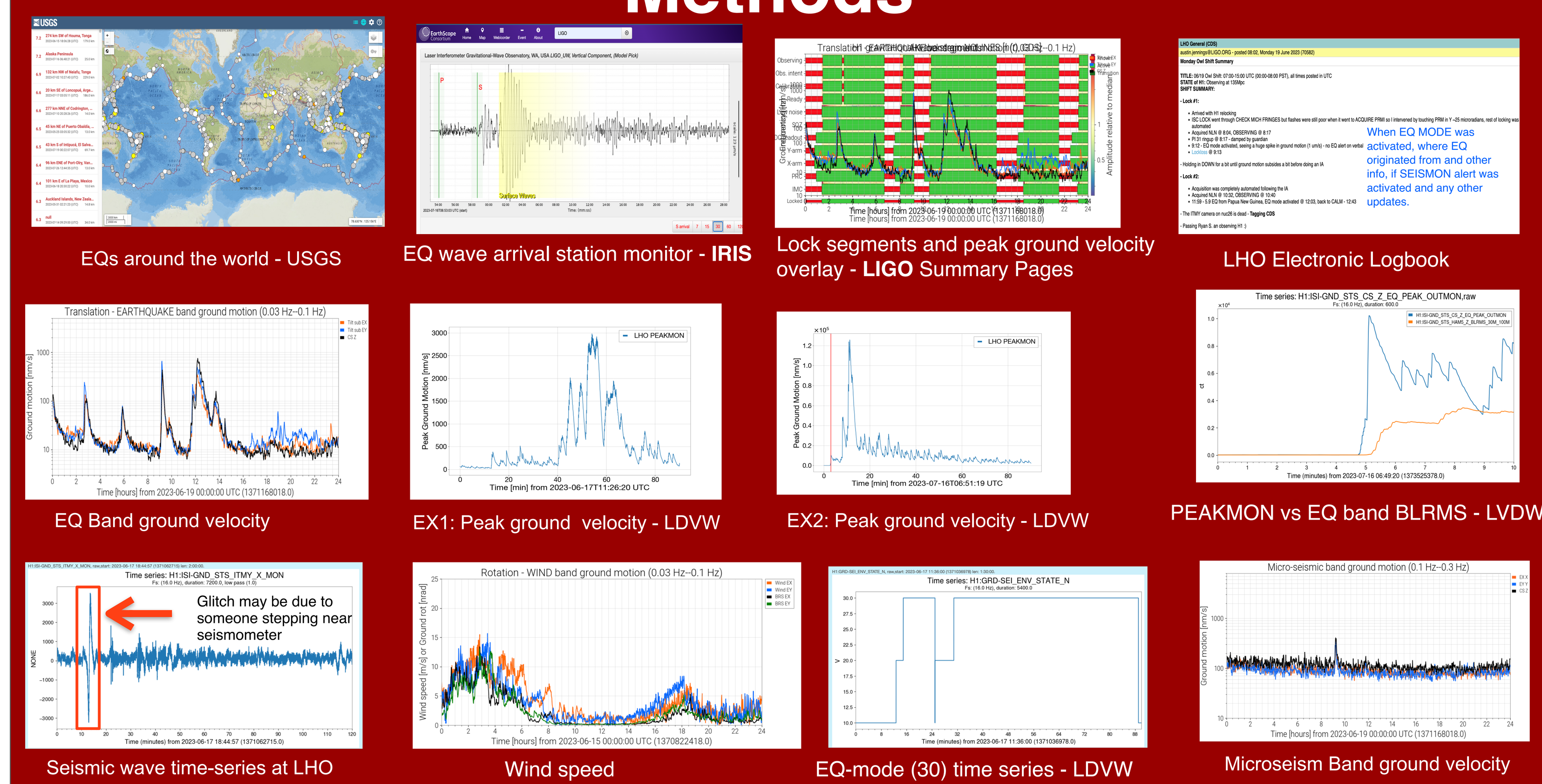

Hanford, Washington (LHO)


Livingston, Louisiana (LLO)

To make this detection, incredible precision is required. LIGO's interferometers are the largest ever built as the size is crucial to detecting gravitational waves. The longer the arms of an interferometer, the smaller the measurements able to be made. Its 4 km arms allow **LIGO** to detect a change in distance 10,000x smaller than a proton.

Everything in the outside world interferes with the ability to make these measurements. This research focuses on the effect of earthquakes (EQs) at **LIGO** Hanford Observatory (LHO).

Methods


EQs around the world - USGS
EQ wave arrival station monitor - IRIS
Lock segments and peak ground velocity overlay - LIGO Summary Pages
LHO Electronic Logbook
EQ Band ground velocity
EX1: Peak ground velocity - LDVW
EX2: Peak ground velocity - LDVW
PEAKMON vs EQ band BLRMS - LVDW
Seismic wave time-series at LHO
Wind speed
EQ-mode (30) time series - LDVW
Microseism Band ground velocity

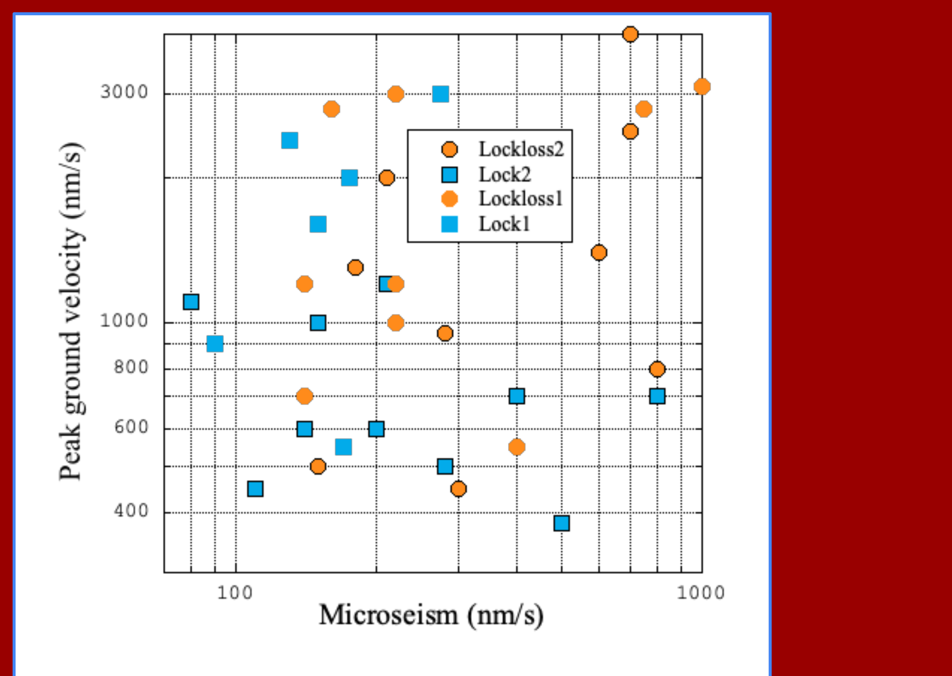
Objective: To find correlations between properties of EQ caused ground-motion and lock-loss.

Used data from more than fifty EQs from USGS (United States Geological Survey) and IRIS (Incorporated Research Institutions for Seismology) during the fourth observing run (04a) that began on May 24, 2023 and ended on January 16, 2024.

Analyzed the ground motions at LHO likely to have been produced by EQs using a variety of LIGO tools such as LIGO's daily summary pages, logbooks, LIGO data plotting software (LDVW).

Factors considered: EQ-Mode (on or off) - response to make the IFO less sensitive to ground motion in the EQ band after an alert that an EQ is coming is received (SEISMON); EQ location and time, amplitudes of peak ground motion in the EQ and Microseism frequency bands, wind speed, seismic-wave time series at LHO, laser power.

Validation - looking at more EQs

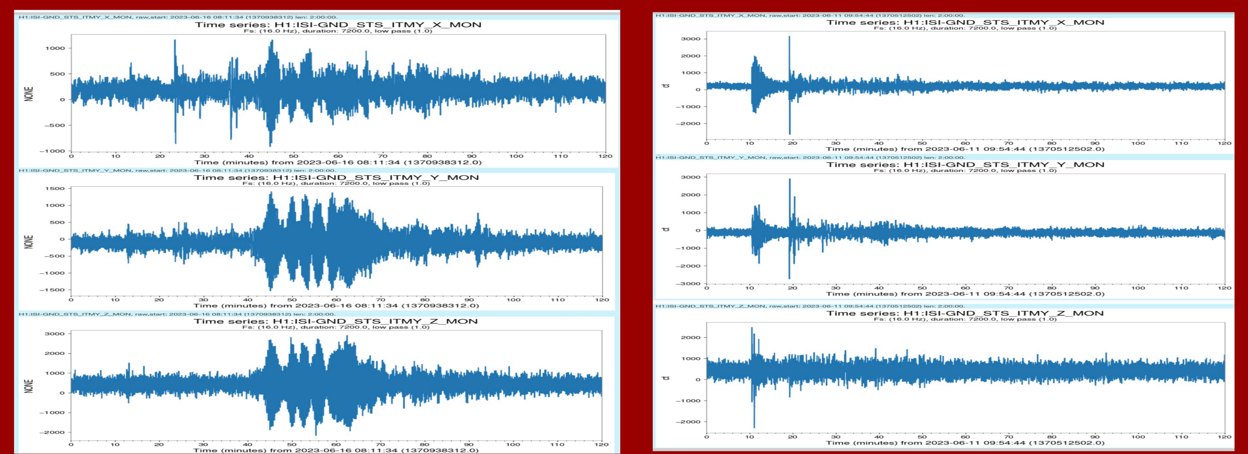


Adding EQs in the Medium category shows that lock may or may not be lost as with the first set (all Medium EQs are shown here). There are a small number of EQs where lock is maintained but the microseism is high although most retained locks have microseism below 300 nm/s. The symbols for the new EQs have a black border.

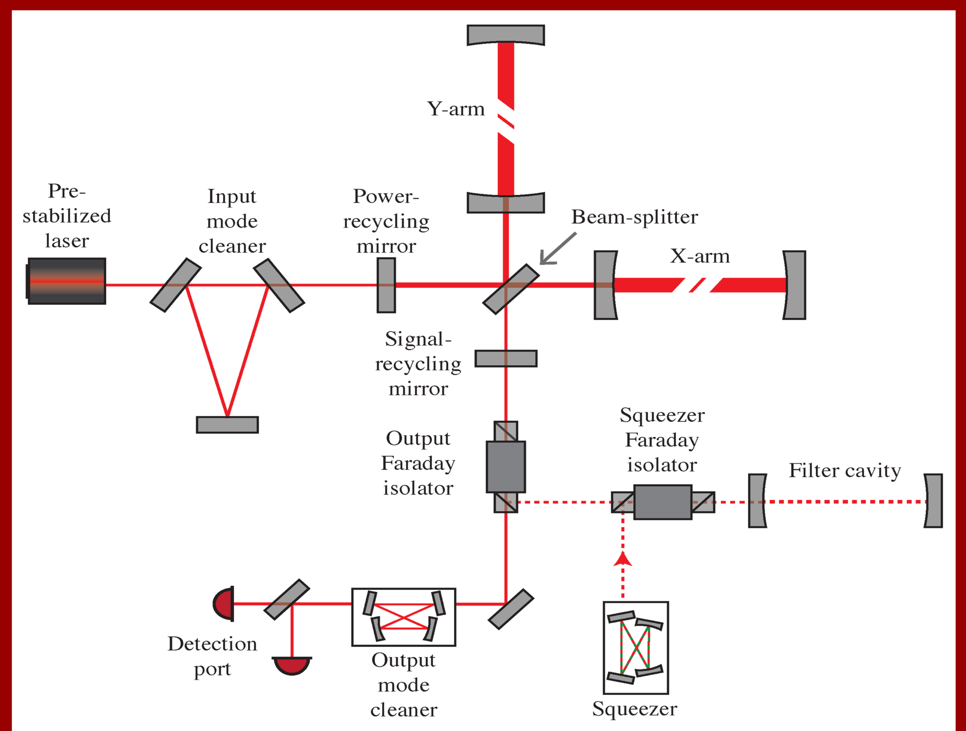
Properties that did not yield correlations

EQ location and time, wind speed, laser power, and seismic-wave time series.

We believe the last of these are a font of information but, without a deeper study, show too much variation to yield obvious correlations. Two examples are shown.



Lock-loss



From Cahillane and Mansell

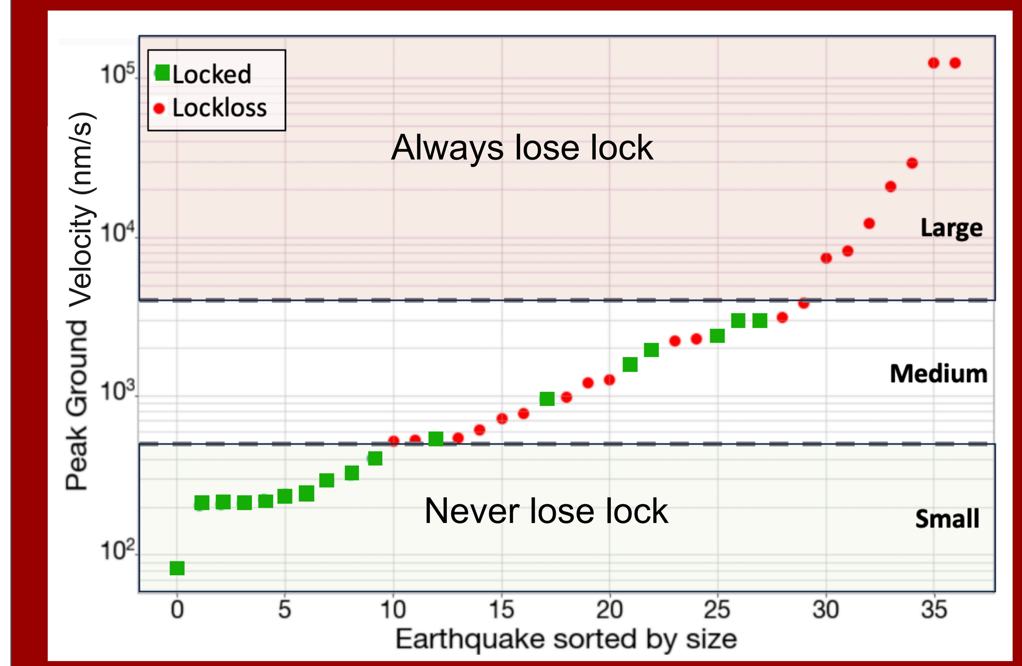
In order to operate, the LIGO Interferometers must have all the optical elements positioned and aligned so that the laser light is resonant in all the optical cavities (this is analogous to the resonance of sound waves in an organ pipe). When this condition is satisfied, we say that the interferometer is LOCKED.

Excess ground motion such as from EQs could mess up the careful alignment and thus cause lockloss.

An additional source of ground motion which plays a role in this study is microseism which is produced by ocean waves caused by storms.

Frequency of EQ band: 0.03 - 0.1 Hz
Frequency of microseism band: 0.1 -0.3 Hz

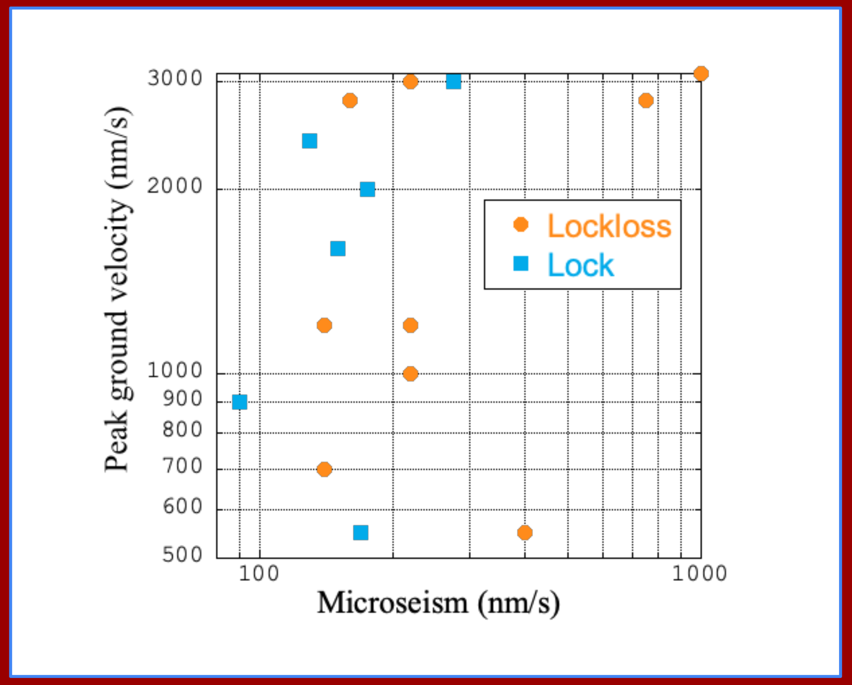
Findings



EQs sorted by peak ground velocity [nm/s] and whether it caused Hanford's interferometer to lose lock or stay locked. EQs can be divided into three different categories depending on size. Locklosses for EMS in the "Medium" category do not correlate with peak ground velocity (either remain locked or lose lock) and thus require further investigation.

When peak ground velocity is plotted against microseism ground motion, it appears that avoiding lock loss requires microseism below 300 nm/s for EQs in the Medium category. Note that EQ-mode has been imposed for all these EQs.

The high microseism can appear as a peak coincident with the EQ (from leakage into the microseism band from a broadband seismic wave) or as a high ambient value.



Acknowledgments

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C. Cahillane, G. Mansell, Review of the Advanced LIGO gravitational wave observatories leading to observing run four, Galaxies 2022, 10(1), 36; https://doi.org/10.3390/galaxies10010036.

https://en.wikipedia.org/wiki/Seismic_wave#/media/File:Overview_Seismic_Waves.jpg