LIGO Picket Fence update and requests at NEIC

Simple Earthquake Early Warning for surface waves from teleseismic events

Edgard Bonilla, Isaac Aguilar, Brian Lantz
LIGO-G2301534, Aug 24, 2023
see also technical note T2300281

Following up on meeting in Jan. 2020
w/ Paul Earle, Grace Johns, Anne Baer
(also help from Scott Reid & Ryan Fisher)

TL; DR

- We have built a EEW "picket fence" for LIGO using existing sensors around each LIGO detector to measure the amplitude of incoming surface waves from teleseismic earthquakes.
- LIGO is doing new astronomy - looking for mergers of compact objects like black holes and neutron stars.
- The ~50 mHz motion is the largest source of known downtime for the detectors, we have developed the "EQ mode", a special control mode to help maintain operation as surface waves pass detectors.
- We'd like to turn on the EQ mode before the wave arrives, so we need less than ~50 seconds of latency from the sensors.
- Current latency of the public IRIS seedlink server is more than this, and our alerts are late.
- PNSN has given us access to a special server with latency of about 10 seconds.
- Can you help us get that for US, IU and CN network sensors?
- Also, I have some basic questions about earthquakes and sensor networks.

map of the fence

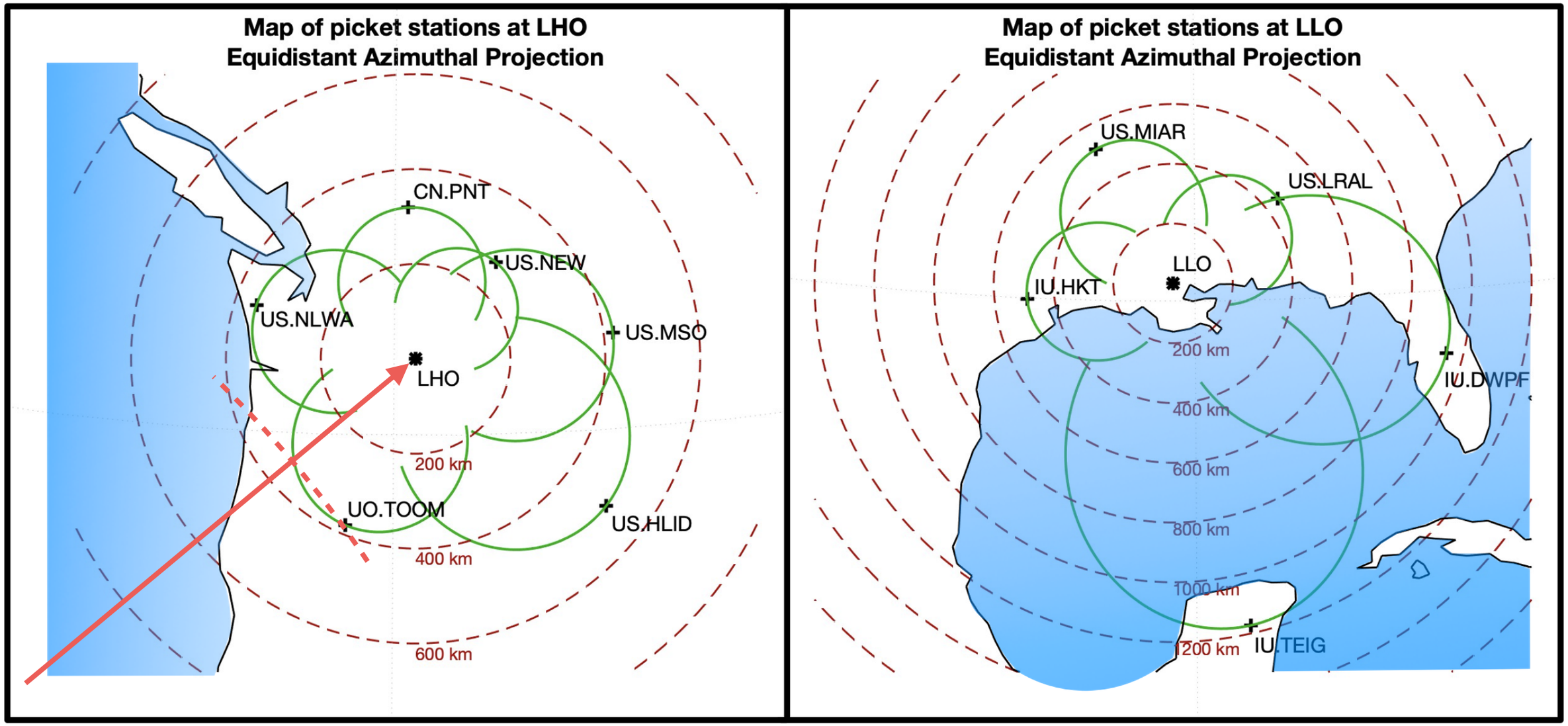
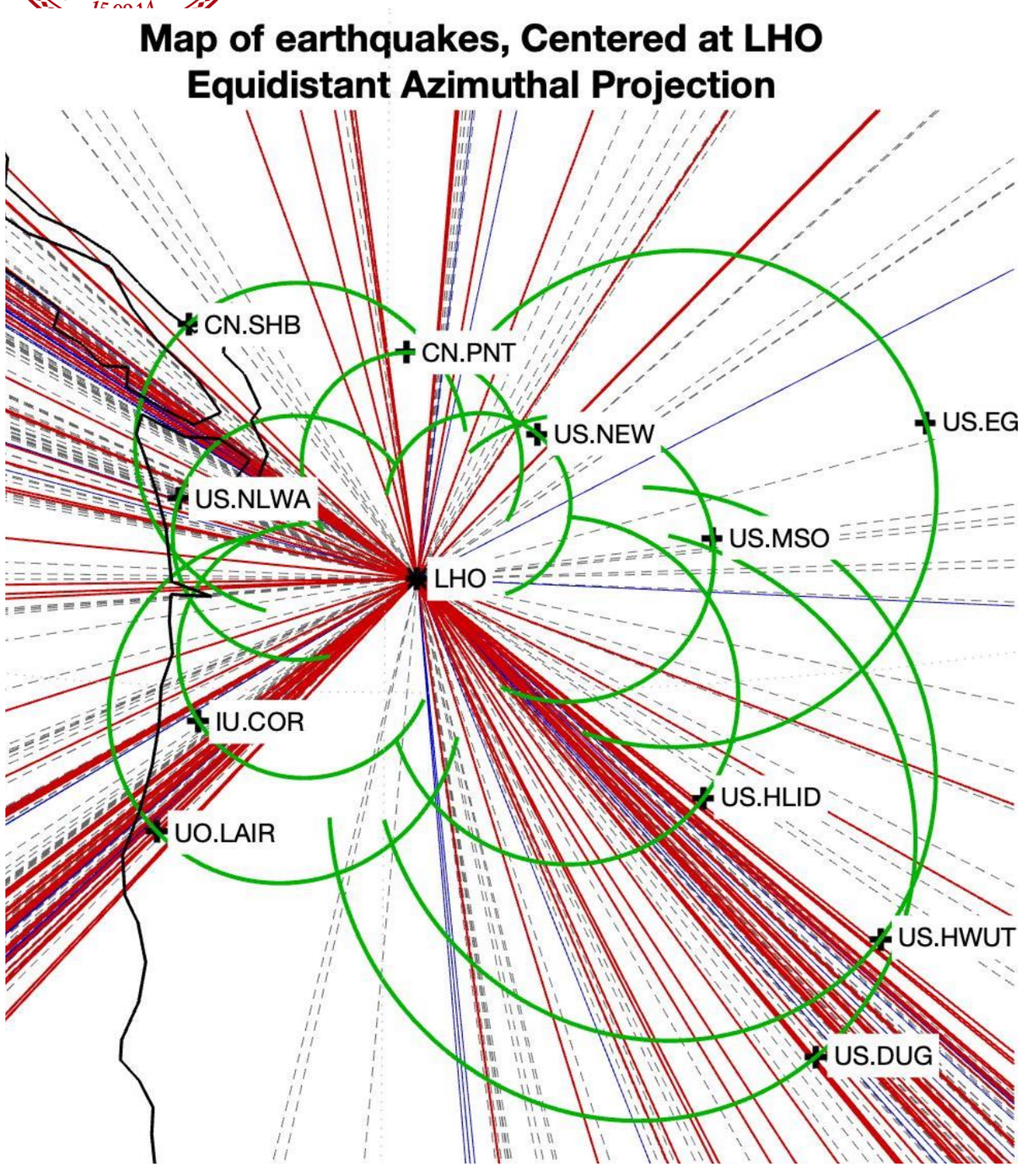
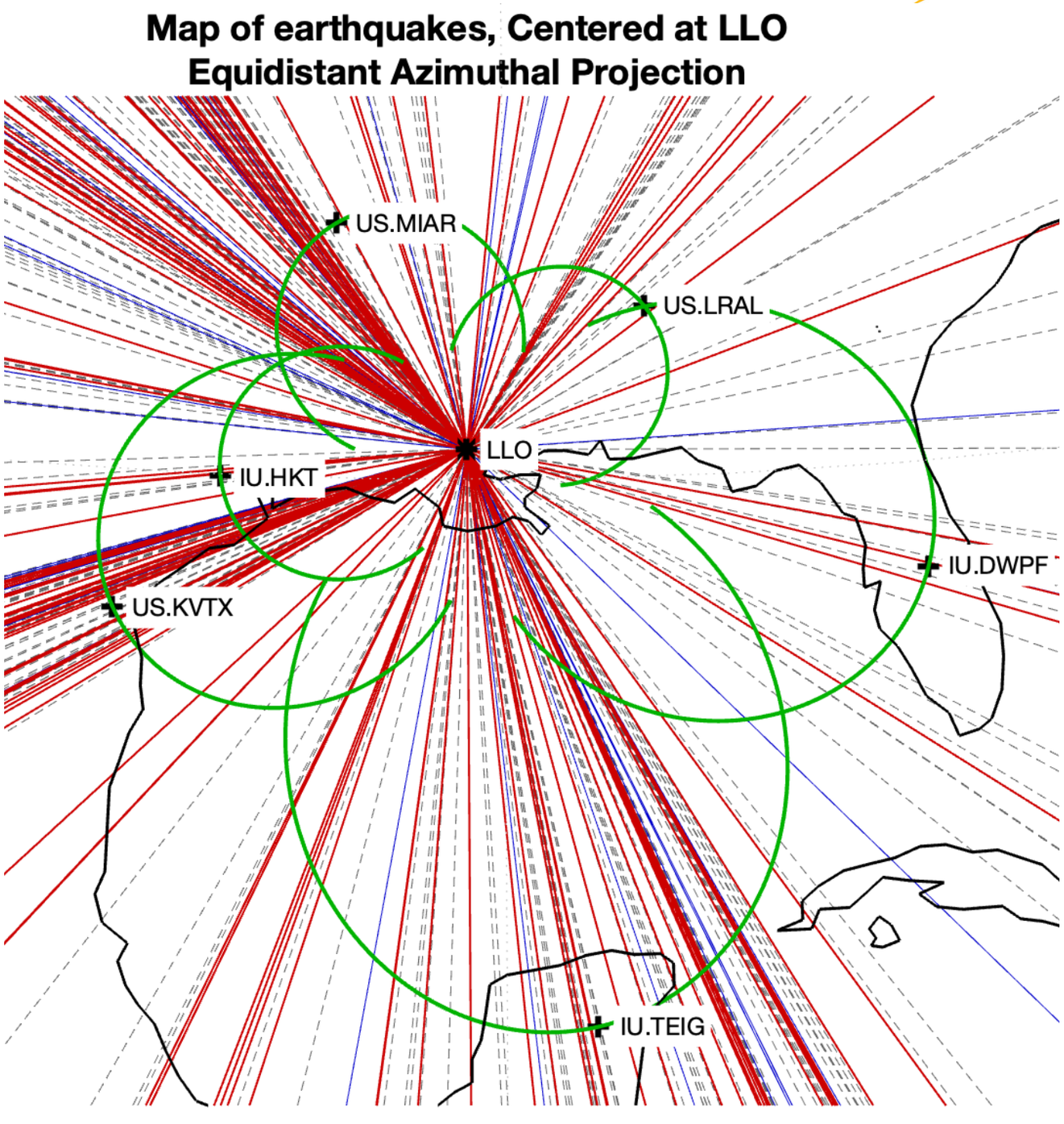


Figure 1: Picket stations around the Hanford, WA (LHO) and Livingston, LA (LLO) observatories. The solid green lines represent the zero-latency warning lines of the stations for incoming waves on a specific direction from the center of the map.

Possible sensors & events





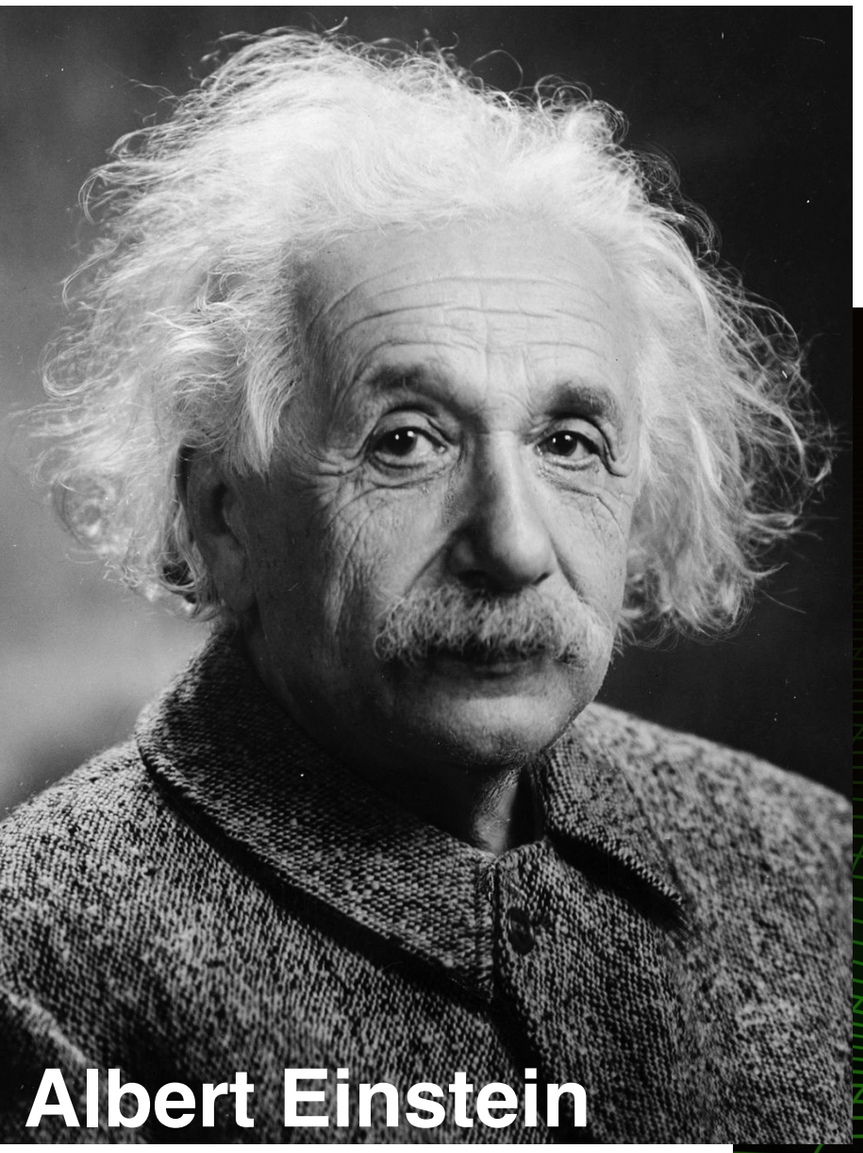
Red lines are in the direction "interesting" events - i.e. the local amplitude is in the range where we would make decisions based on the data from the fence.

What is a Gravitational Wave?

Predicted by Einstein in 1916 as part of GR.

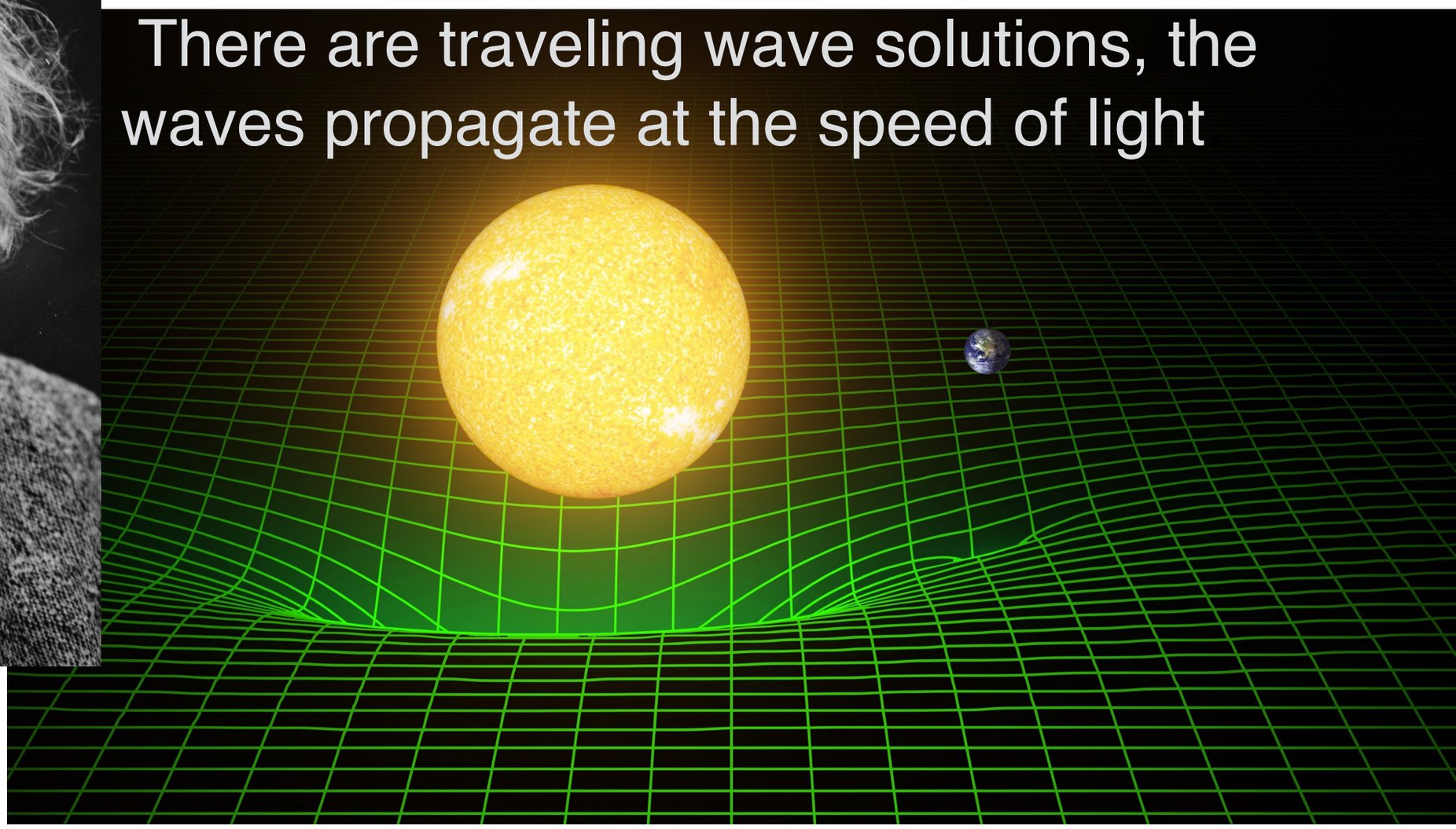
"Spacetime tells matter how to move,
matter tells spacetime how to curve"

- J. A. Wheeler



Albert Einstein

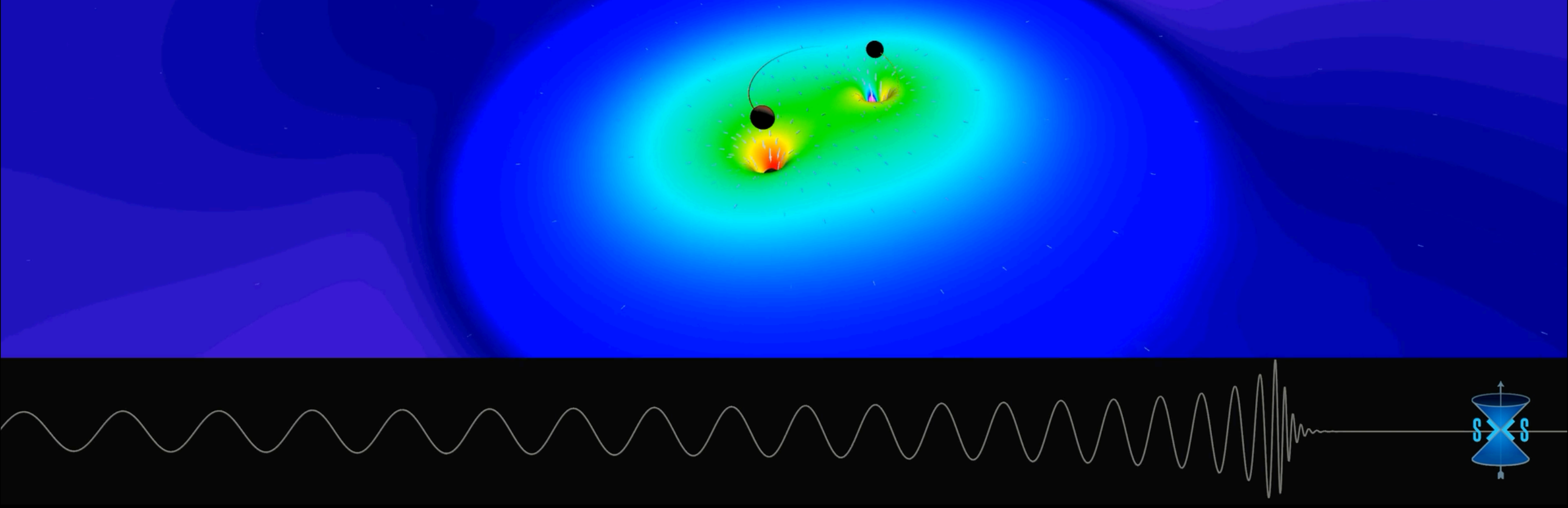
There are traveling wave solutions, the waves propagate at the speed of light



Photograph by Orren Jack Turner,
Library of Congress digital ID cph.3b46036.

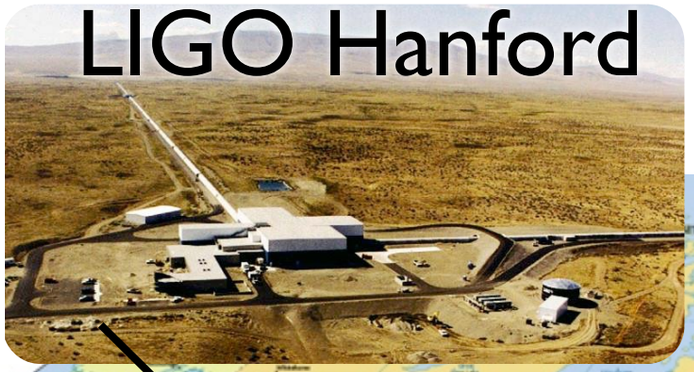
Simulation of the event

-0.62s



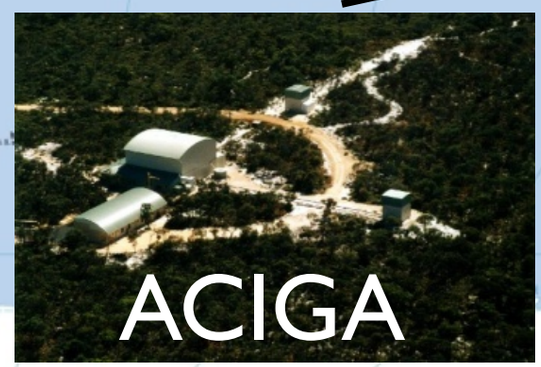
http://mediaassets.caltech.edu/gwave

LIGO overview



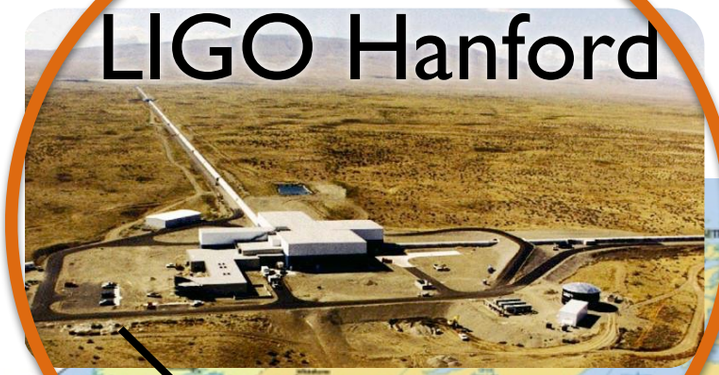
LIGO India

project approved

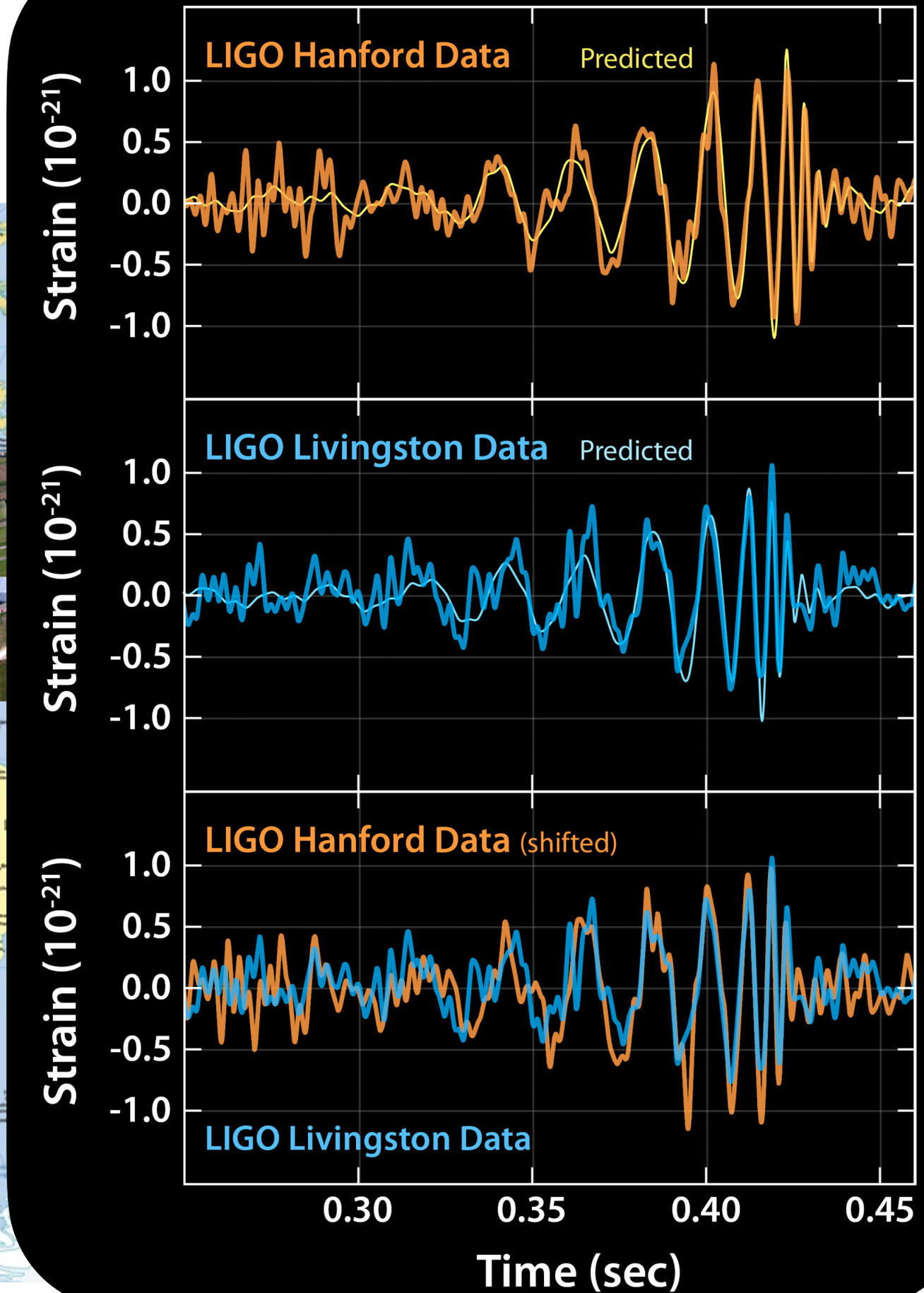


map from http://www.nationsonline.org/maps/political_world_map3000.jpg

LIGO Hanford



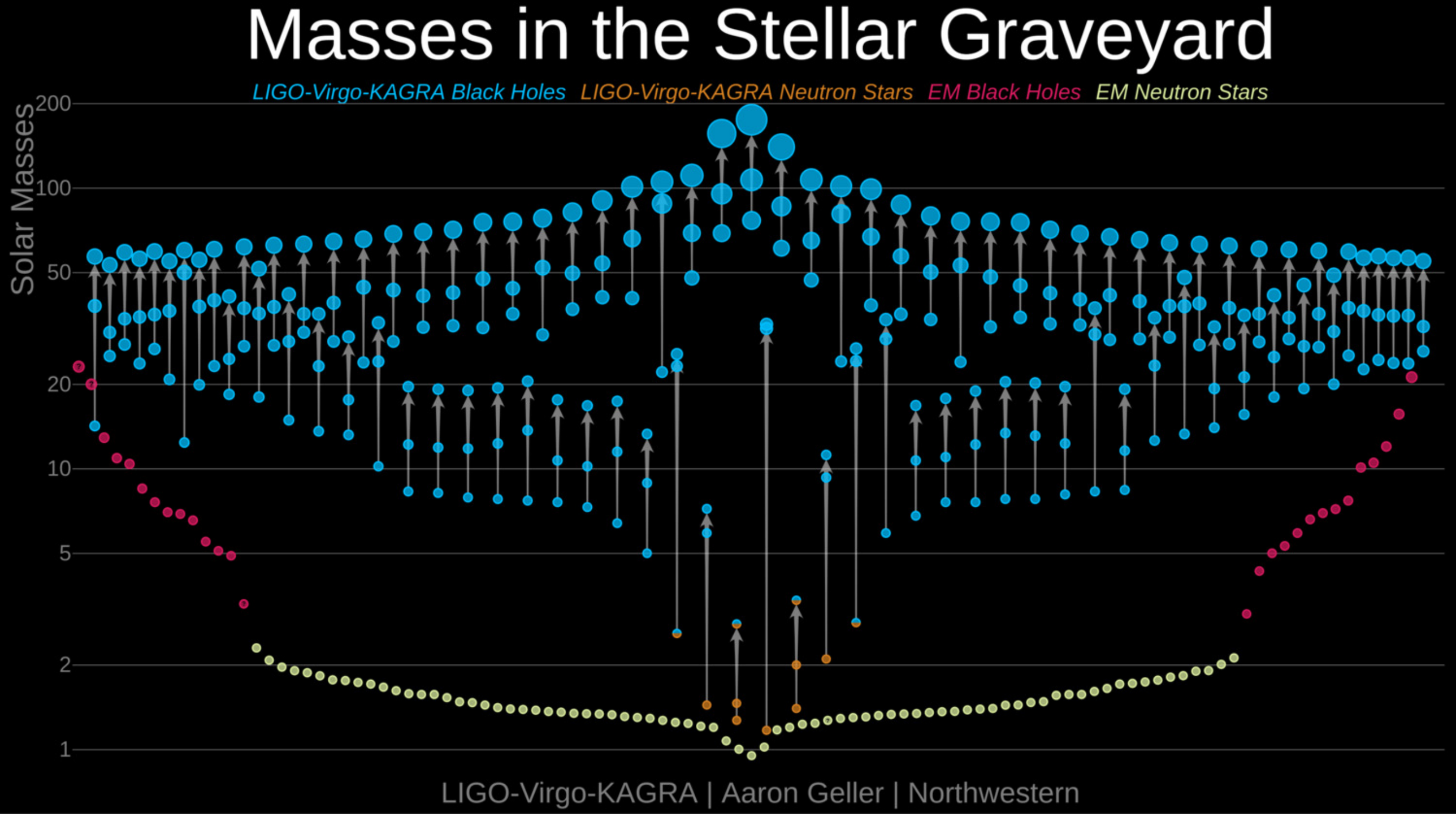
LIGO Livingston



AGRA

GO India

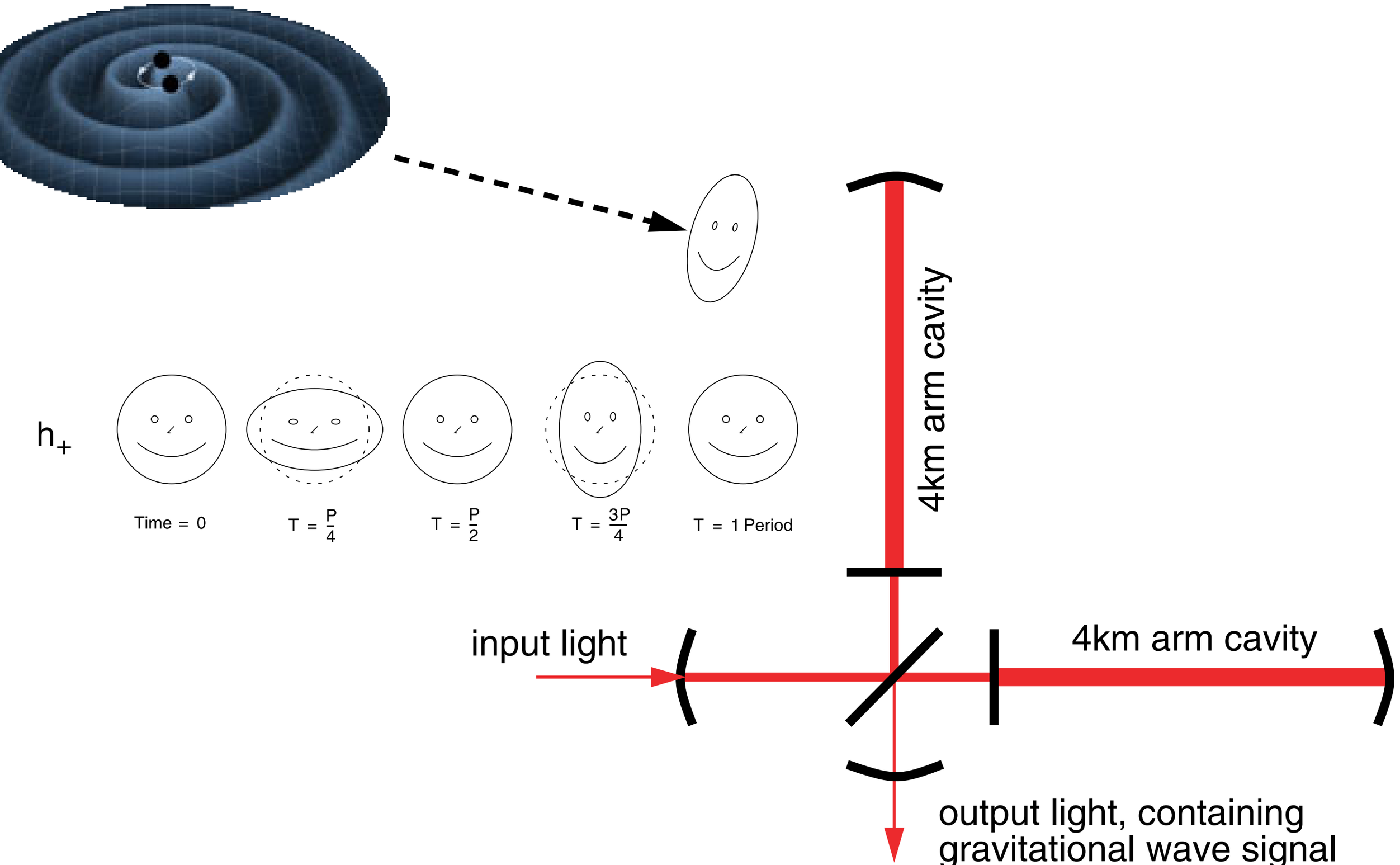
oject approved



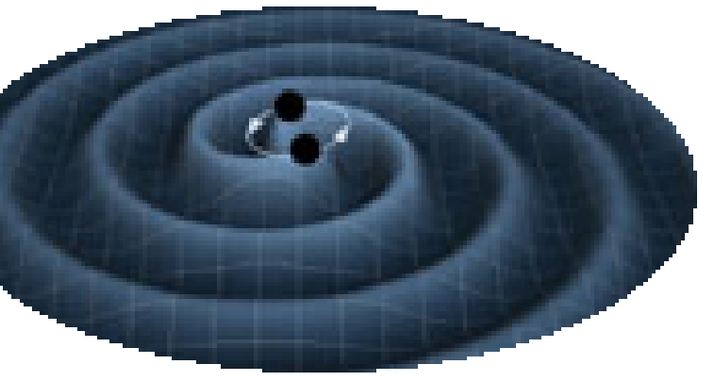
Since the first detection

- Nearly 100 confident detections in the first 3 observing runs
- 32 more "significant candidates" so far in O4 (started in May)
- Significantly expanding our understanding of black holes and neutron stars

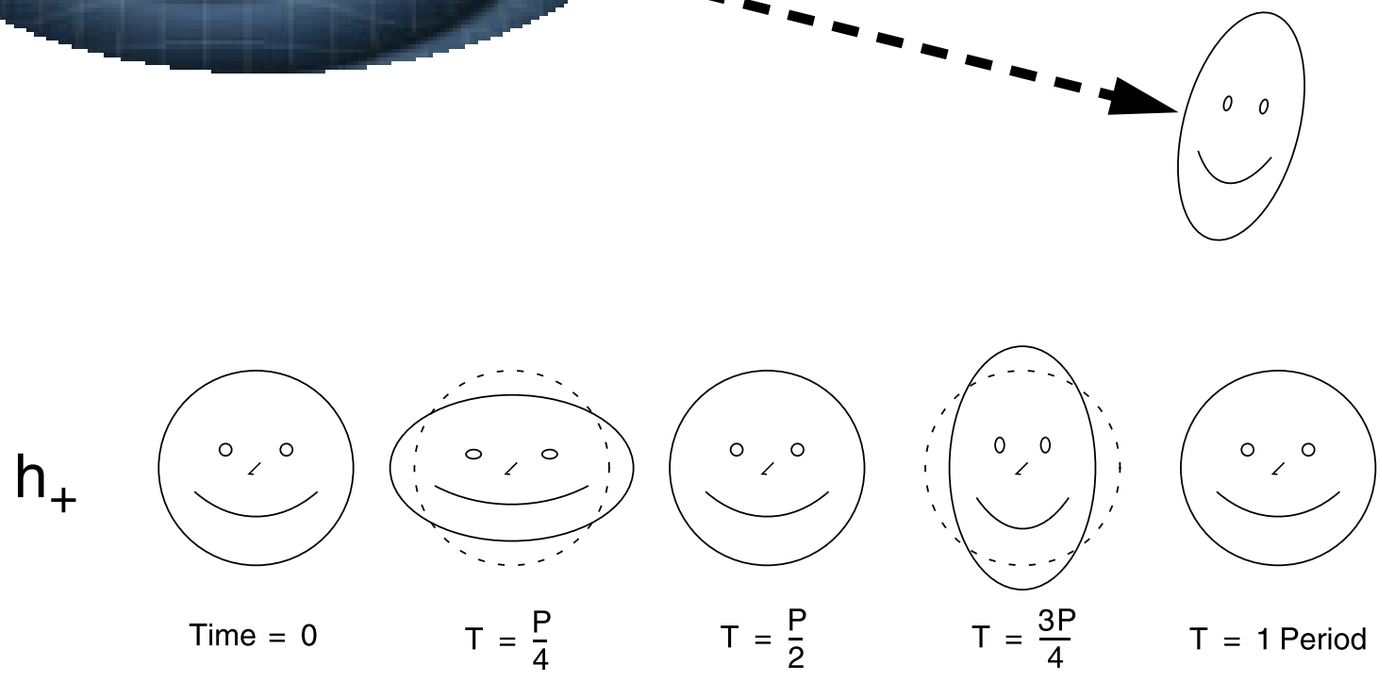
The LIGO concept

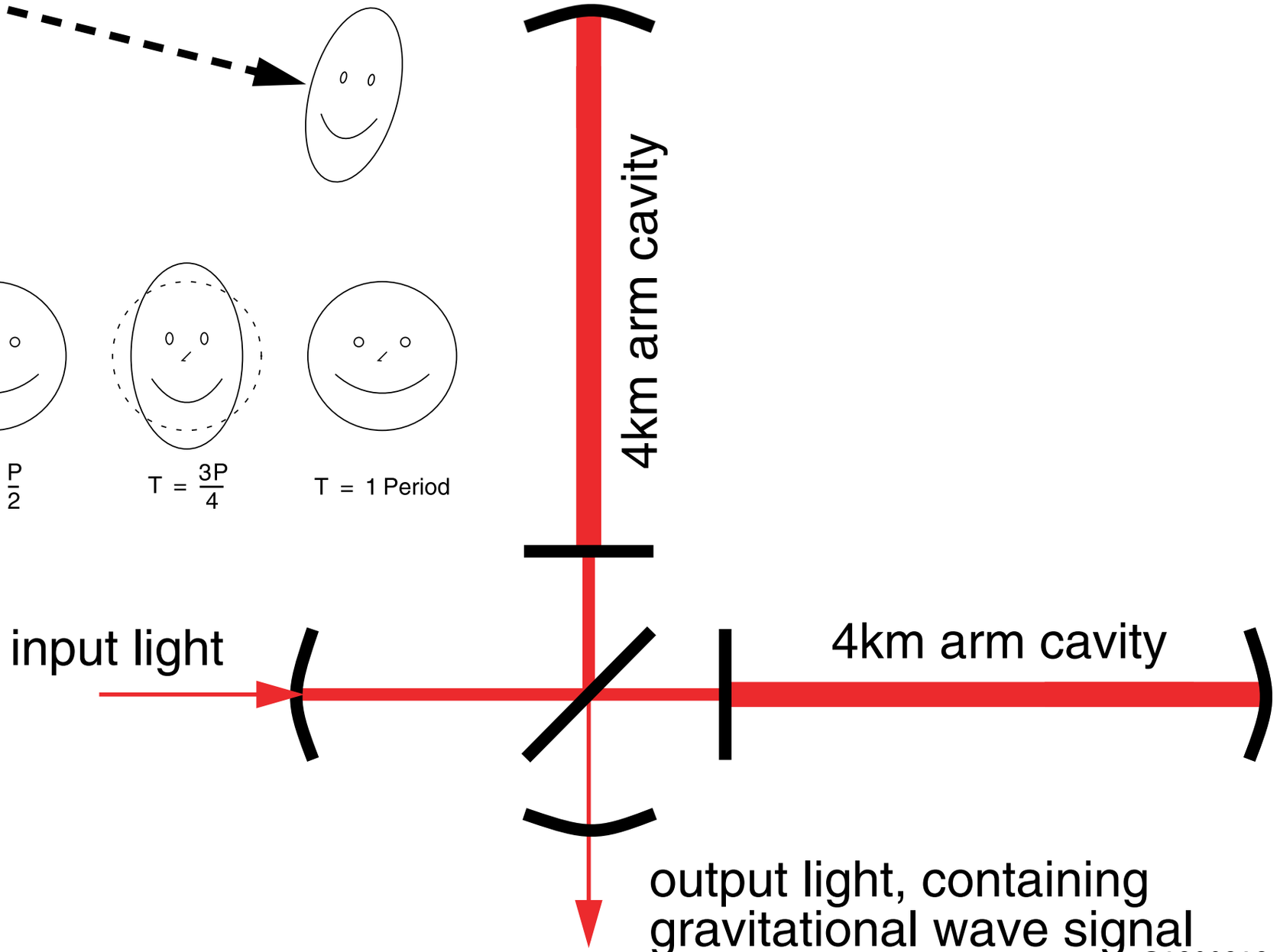


The LIGO concept



It's sort of like this,
except spacetime is stretching,
and the mirrors don't move.



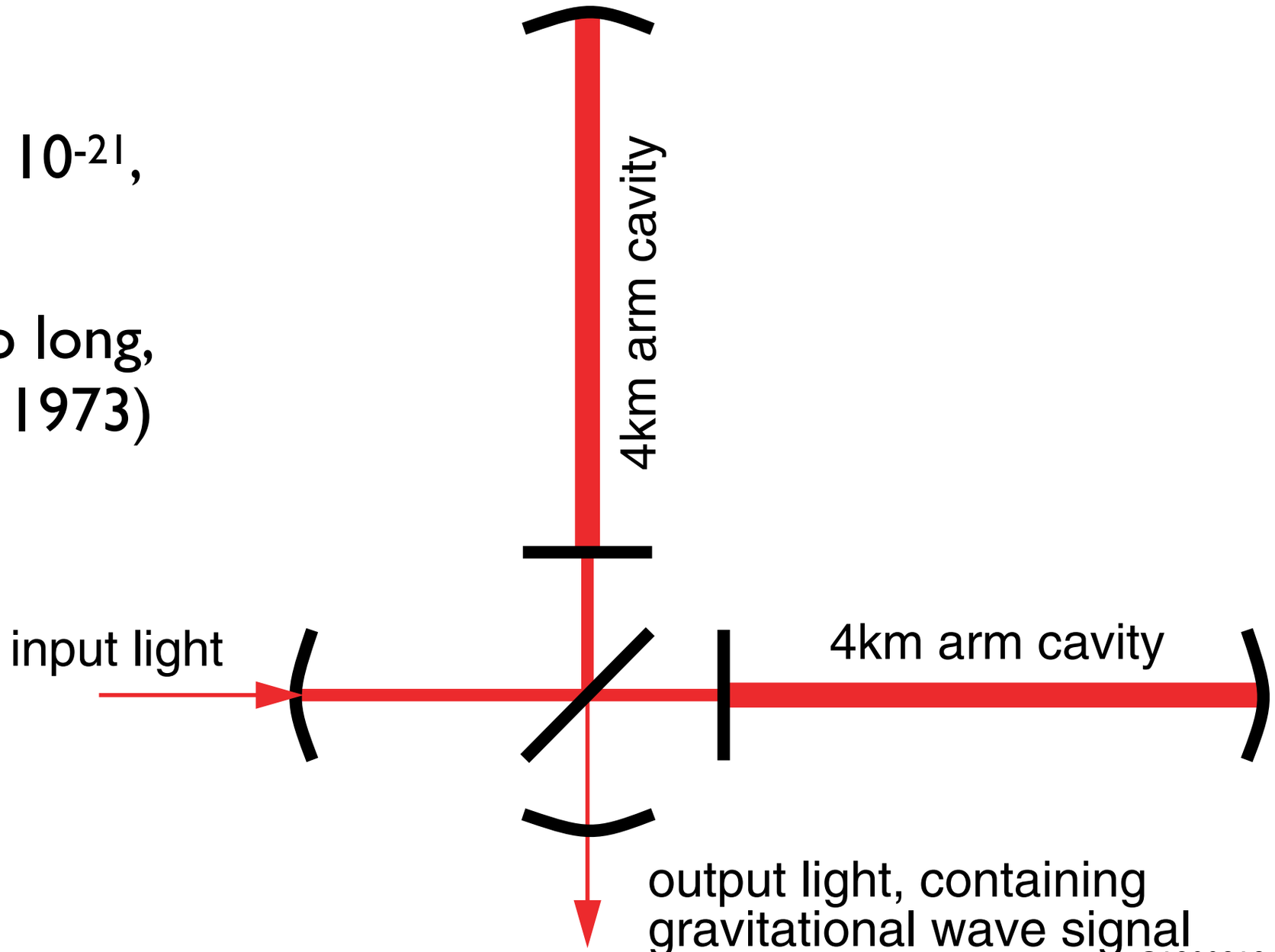


The LIGO concept

Gravitational waves are hard to measure because space doesn't like to stretch.

Our signal strain (h) = 10^{-21},
dL = $4*10^{-18}$ meters

(that's why it's taken so long,
Einstein 1916, Weiss 1973)

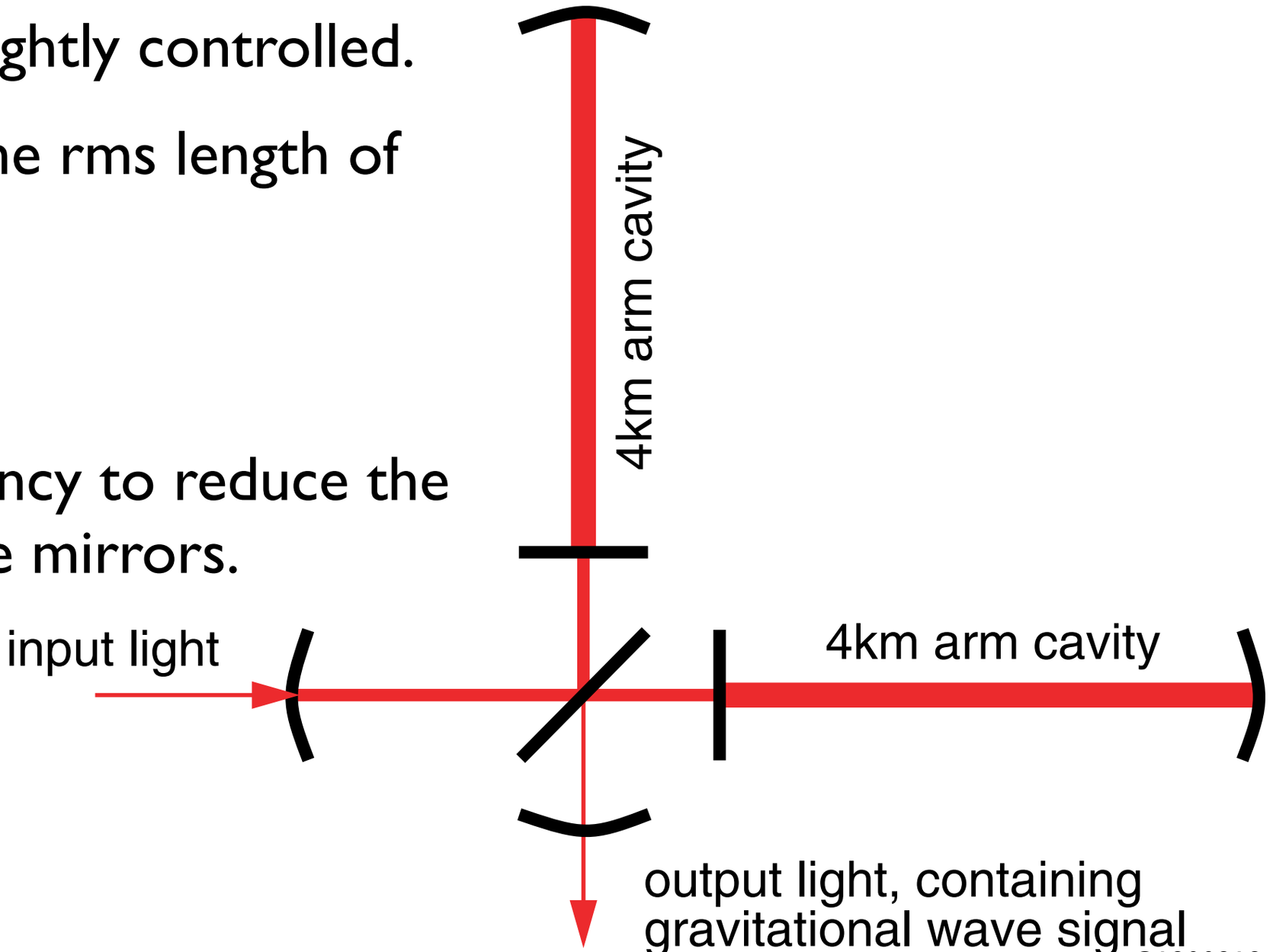


The LIGO concept

Arms are resonant "optical cavities" to enhance the optical performance
- which means -
Length and angle are tightly controlled.

Active controls hold the rms length of the arms stable to
~ 1e-13 meters, and
~ 1e-9 radians.

Isolation at low frequency to reduce the actuation forces on the mirrors.



Tables use active control to isolate from 0.1 to ~10 Hz. Usually isolating against secondary microseism without getting corrupted by tilt. (rotation sensor not shown)

optics table - stage 2

stage 1

support - stage 0

Why do we care about earthquakes?

- During the previous observing run (O3), earthquakes were the "known" largest source of lockloss (24%).
- Uptime ~ 78% for each site, 6? double
- Surface waves are lower frequency than our typical isolation band, but active control means that we can retune system during earthquakes.

Lockloss classification

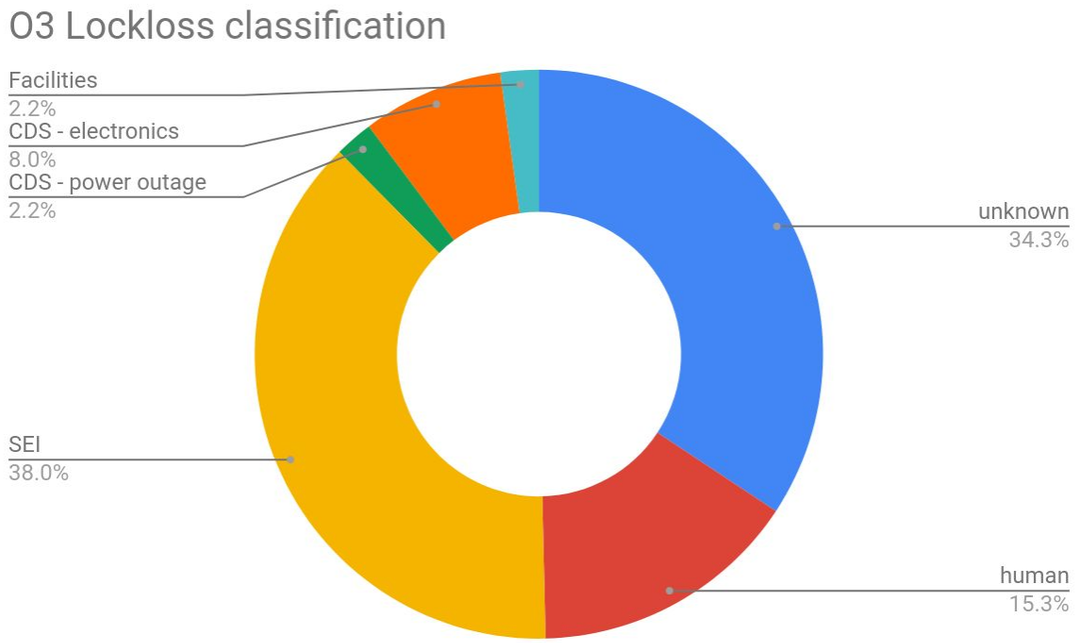
-SEI 38% [earthquakes (24.1%), wind (2.2%), trains/ anthropogenic noise (8%), useism (3.6%)]

-Unknown 34.3%

-Human 15.3% (tuesday maintenance, error, commissioning)

-CDS 10.2% (power outage 2.2%, electronics failure/computer lock-up 8%]

-Facilities 2.2% [temperature issue]



Picket Fence Info

- We use an "earthquake mode" to get better 50 mHz performance, and we turn it on based on Seismon (thanks Paul!) and local measurements.
- EQ mode works better if turned on
  ~30 seconds *before* the surface waves arrive.
- But only if the local amplitude is > 500 nm/sec

- General Specs:
  - Amplitude accuracy within 2x
  - 30 seconds to engage the EQ mode once we have a good warning
  - Very reliable, so we can engage automatic response

- Trying a "Picket Fence" EEW system to measure incoming signals
  - close enough to have accurate amplitudes
  - Is 20 seconds enough to confirm it's a surface wave?

Surface waves & LIGO

3 days in early O4 at Livingston Detector (June 24-26, 2023)

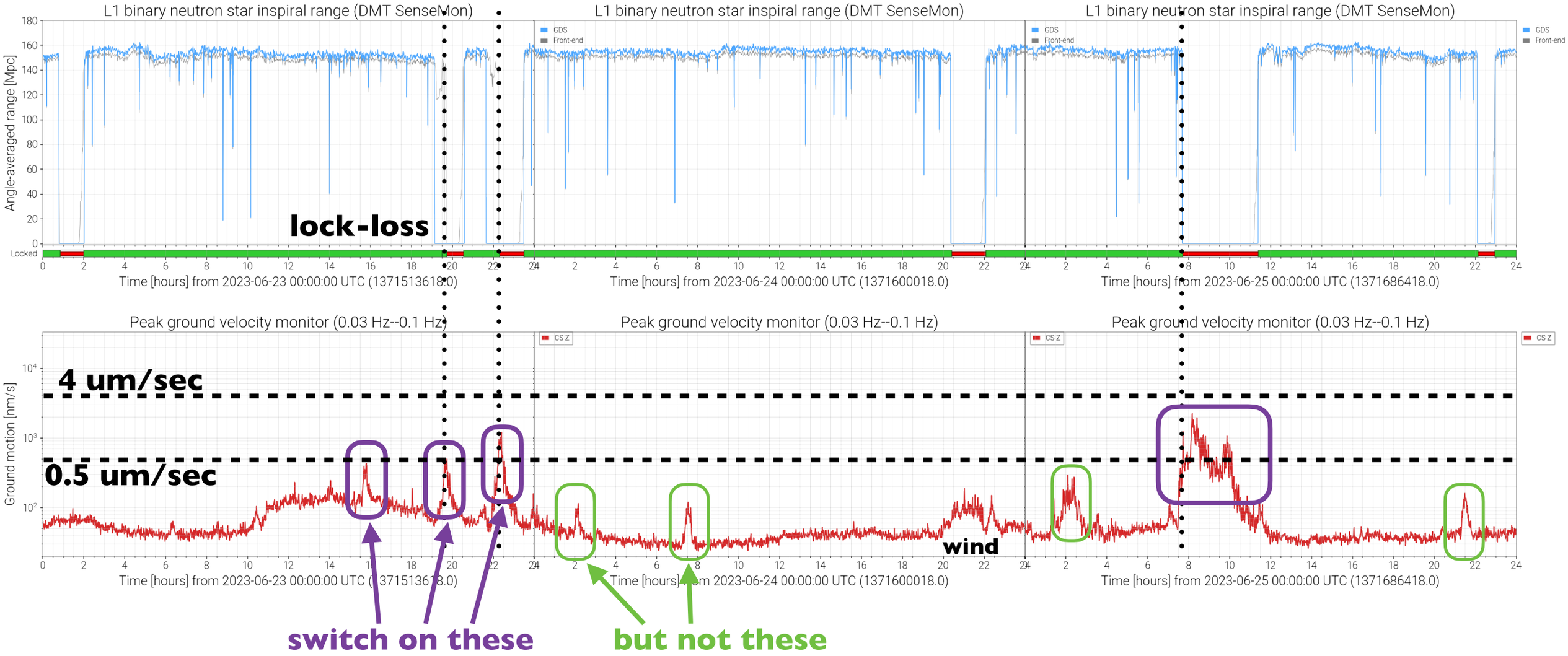
LLO Detector performance

Peak vertical velocity in EQ band (30-100 mHz)

Surface waves & LIGO

3 days in early O4 at Livingston Detector (June 24-26, 2023)

LLO Detector performance



back to the fence

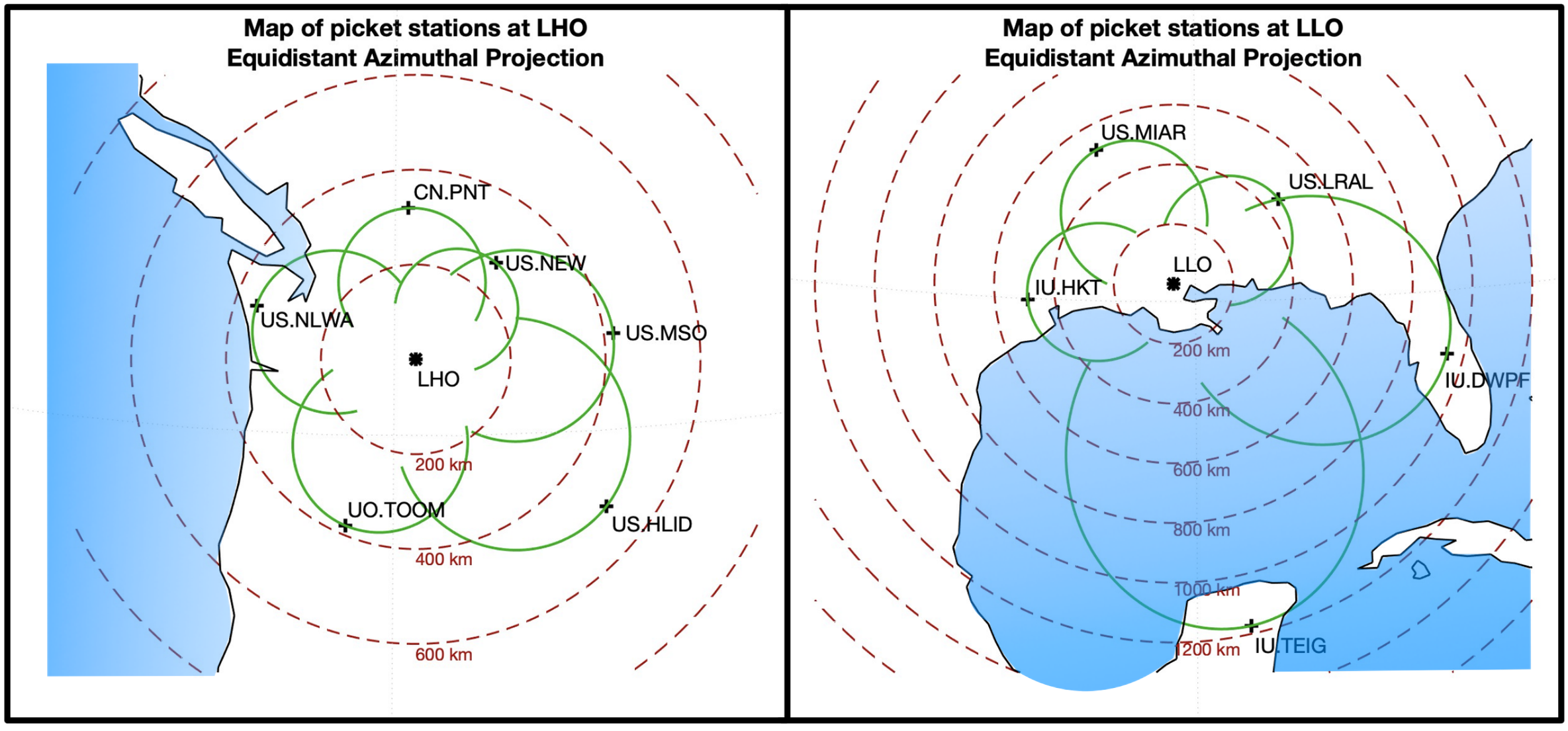
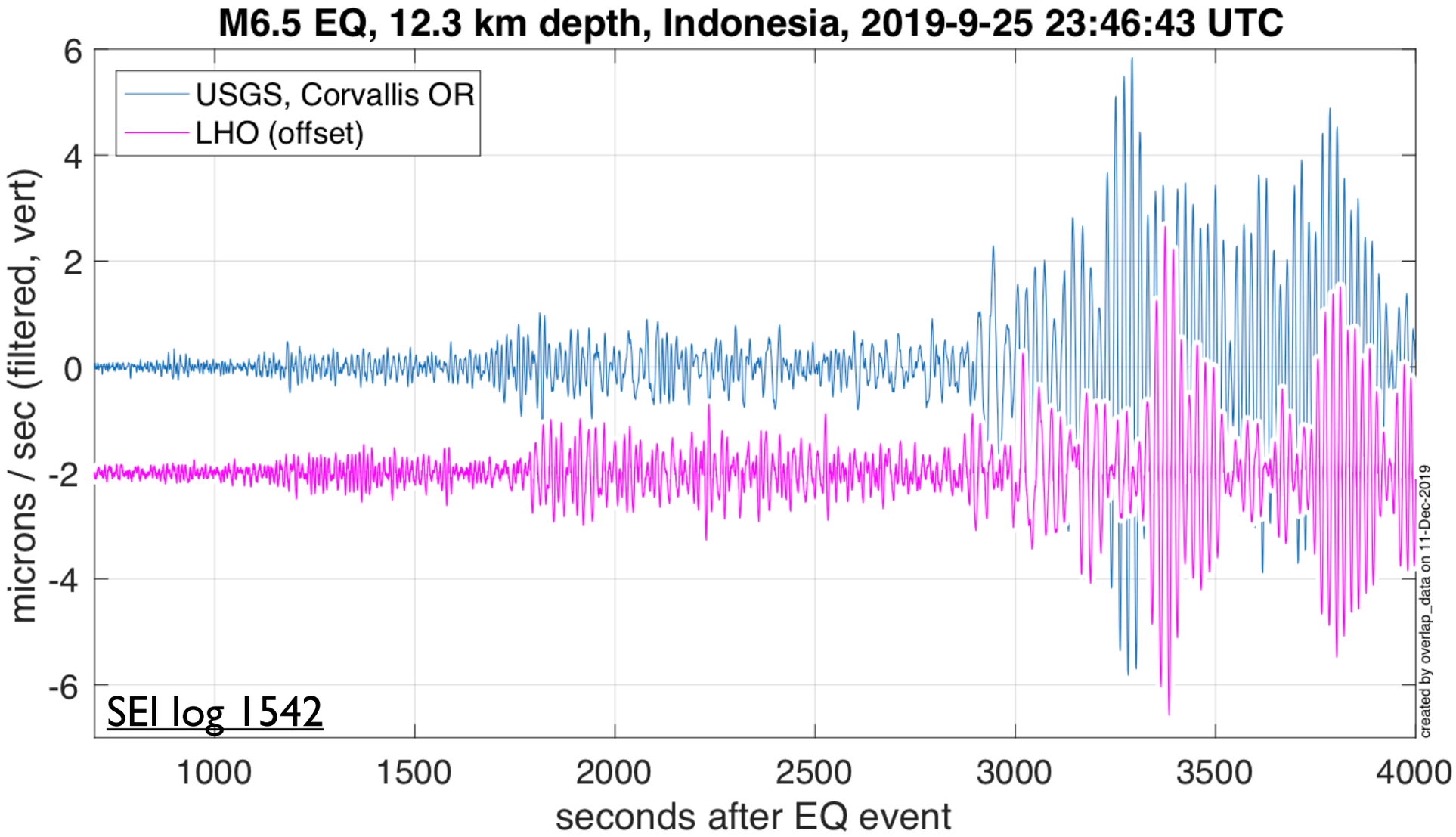


Figure 1: Picket stations around the Hanford, WA (LHO) and Livingston, LA (LLO) observatories. The solid green lines represent the zero-latency warning lines of the stations for incoming waves on a specific direction from the center of the map.

Earthquakes

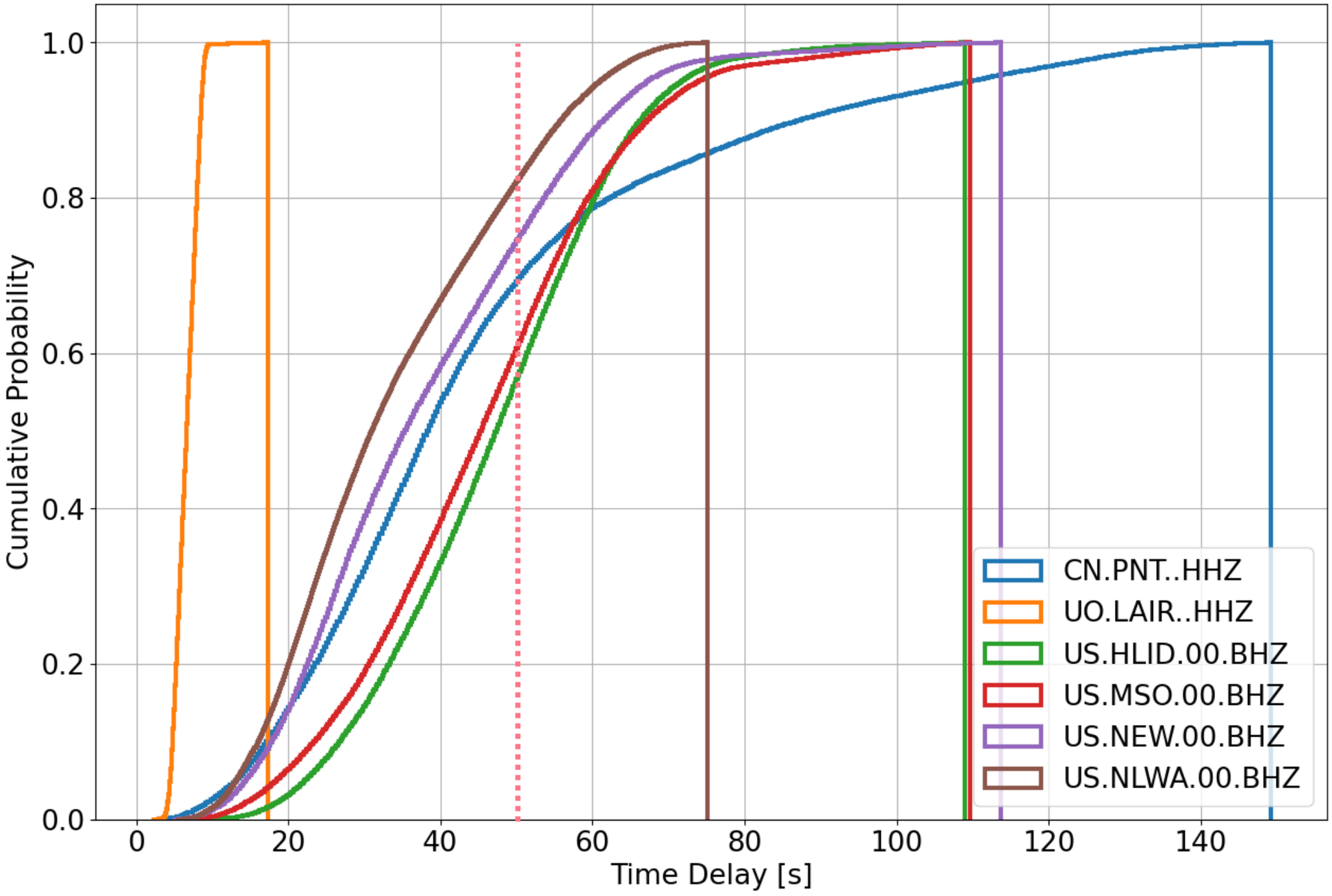
Blue trace is from a USGS station about 300 km closer to the EQ event than LHO is. This could be a good monitoring point and gives up to 75 seconds of warning. Potentially useful if you know an event is coming, but you're not sure how big it is.



Latency of PNSN vs IRIS

special thanks to Dr. Renate Hartog, UW

Cumulative Latency for Various Stations/ Networks



Timing: 100 sec (400km) - 30 sec (turn on) - 20 sec (ID) = 50 sec.

Edgard Bonilla https://alog.ligo-la.caltech.edu/SEI/index.php?callRep=2266

Technical notes

- Using ObsPy for all the data collection & processing
- Using seedlink client
- Building our stream with traces from 2 servers
- Using a modified version of seedlink plotter, likely to change this so we can have 1 machine connecting to the servers, and several plotters runnings

Questions

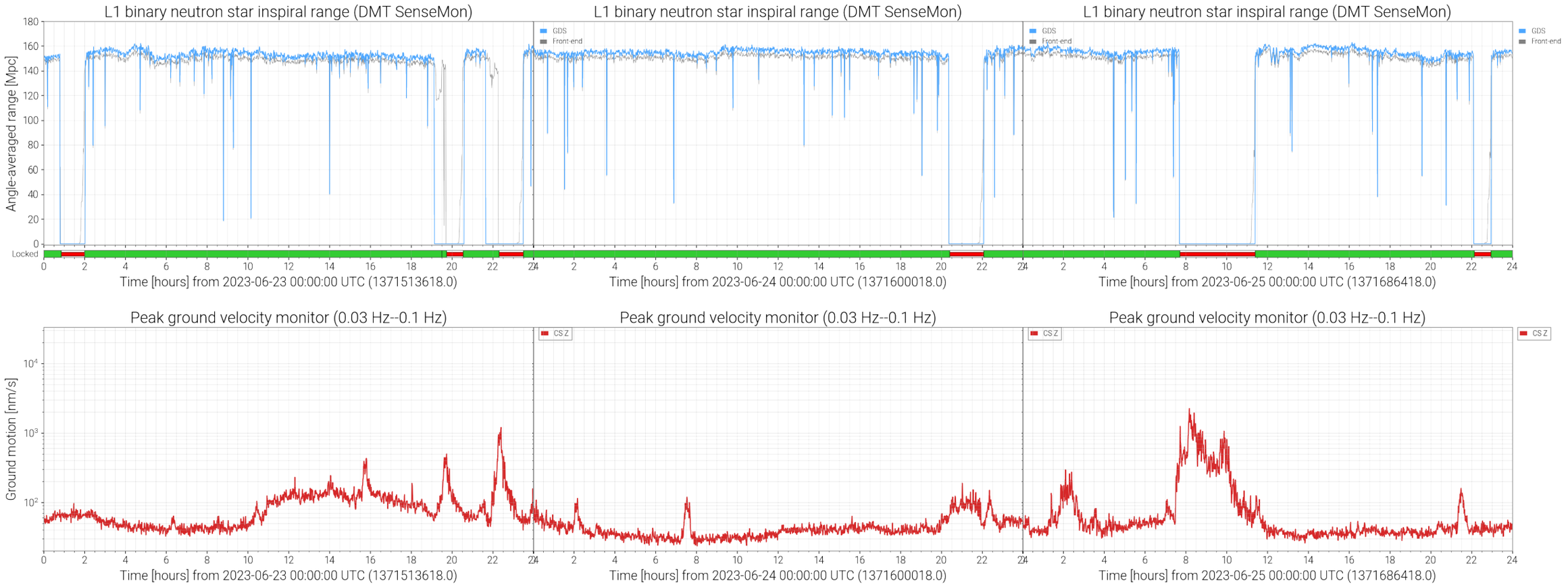
- Can we get < 50 sec latency for US, IU, and CN (Canadian) networks?
- How do we pick "quiet" stations?
  (low microseism, low anthropogenic noise)
  Trying to not do fancy analysis
- What about weird glitches?
  (CN station had a fast glitch 1/day)

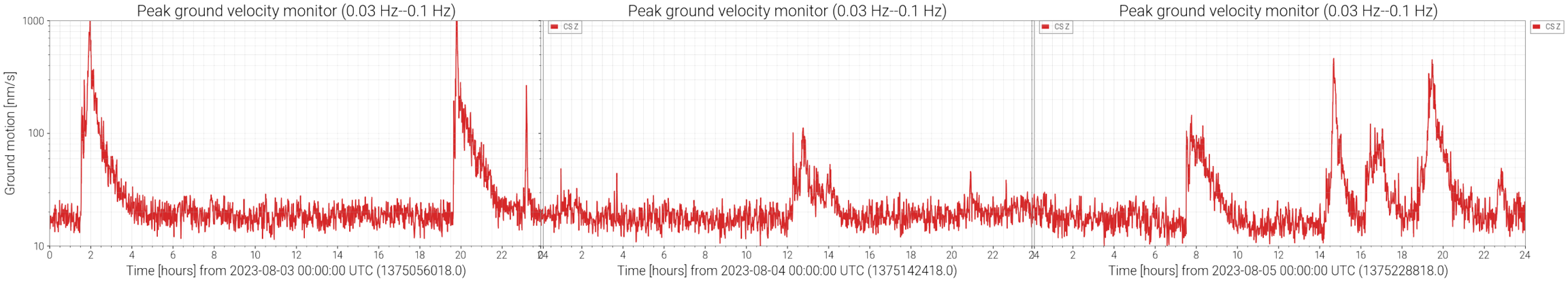
More questions

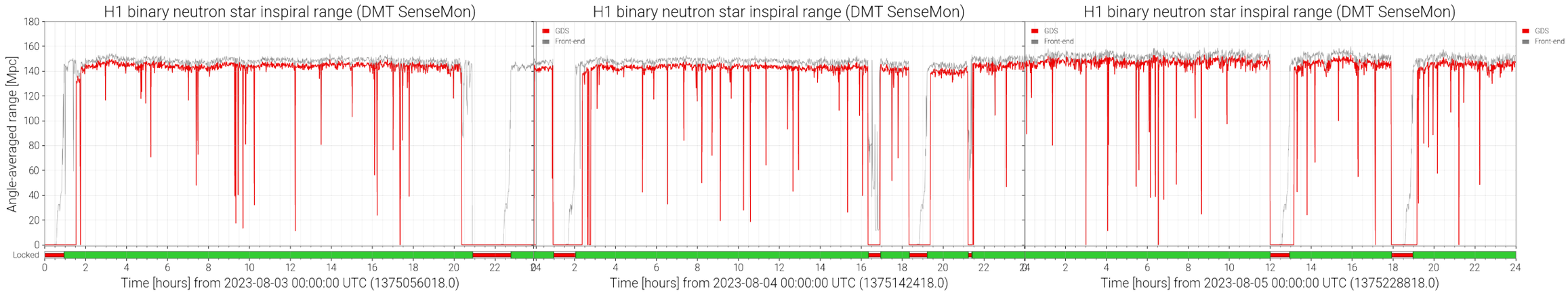
- Why do the surface waves look so different as time progresses (multi-path scattering & interference?)
- Are there sensors in the Gulf of Mexico?
- Sometimes we see events on the fence before we get an alert - is NEIC working to change this? I don't want LIGO to try and make an EEW system (but, physicists…)
- How different are the Vertical vs. Horizontal motion in the surface waves?
- There is 1 LIGO sensor in the UW network, who to talk to about getting LLO sensors added? and rotation sensors?

More questions

- For close events (particularly Mexico) the fence is not good. How likely are other predictors able to deal with this?
- How different are the Vertical vs. Horizontal motion in the surface waves?
- Who is the person who does the Earthscope page?
- How do you ID P, S, and surface waves?
- Who is the person who does the Earthscope page?
- How do you ID P, S, and surface waves?


L1 binary neutron star inspiral range (DMT SenseMon)
L1 binary neutron star inspiral range (DMT SenseMon)
L1 binary neutron star inspiral range (DMT SenseMon)
Angle-averaged range [Mpc]
GDS
Front-end
Locked
Time [hours] from 2023-06-23 00:00:00 UTC (1371513618.0)
Time [hours] from 2023-06-24 00:00:00 UTC (1371600018.0)
Time [hours] from 2023-06-25 00:00:00 UTC (1371686418.0)
Peak ground velocity monitor (0.03 Hz--0.1 Hz)
Ground motion [nm/s]
CSZ


Peak ground velocity monitor (0.03 Hz--0.1 Hz)
Ground motion [nm/s]
1000
100
10
CS Z
0 2 4 6 8 10 12 14 16 18 20 22 24
Time [hours] from 2023-08-03 00:00:00 UTC (1375056018.0)
Time [hours] from 2023-08-04 00:00:00 UTC (1375142418.0)
Time [hours] from 2023-08-05 00:00:00 UTC (1375228818.0)


H1 binary neutron star inspiral range (DMT SenseMon)
Angle-averaged range [Mpc]
180
160
140
120
100
80
60
40
20
0
Locked
GDS
Front-end
0 2 4 6 8 10 12 14 16 18 20 22 24
Time [hours] from 2023-08-03 00:00:00 UTC (1375056018.0)
Time [hours] from 2023-08-04 00:00:00 UTC (1375142418.0)
Time [hours] from 2023-08-05 00:00:00 UTC (1375228818.0)

Earthquakes are #1 source of known lockloss

Lockloss classification

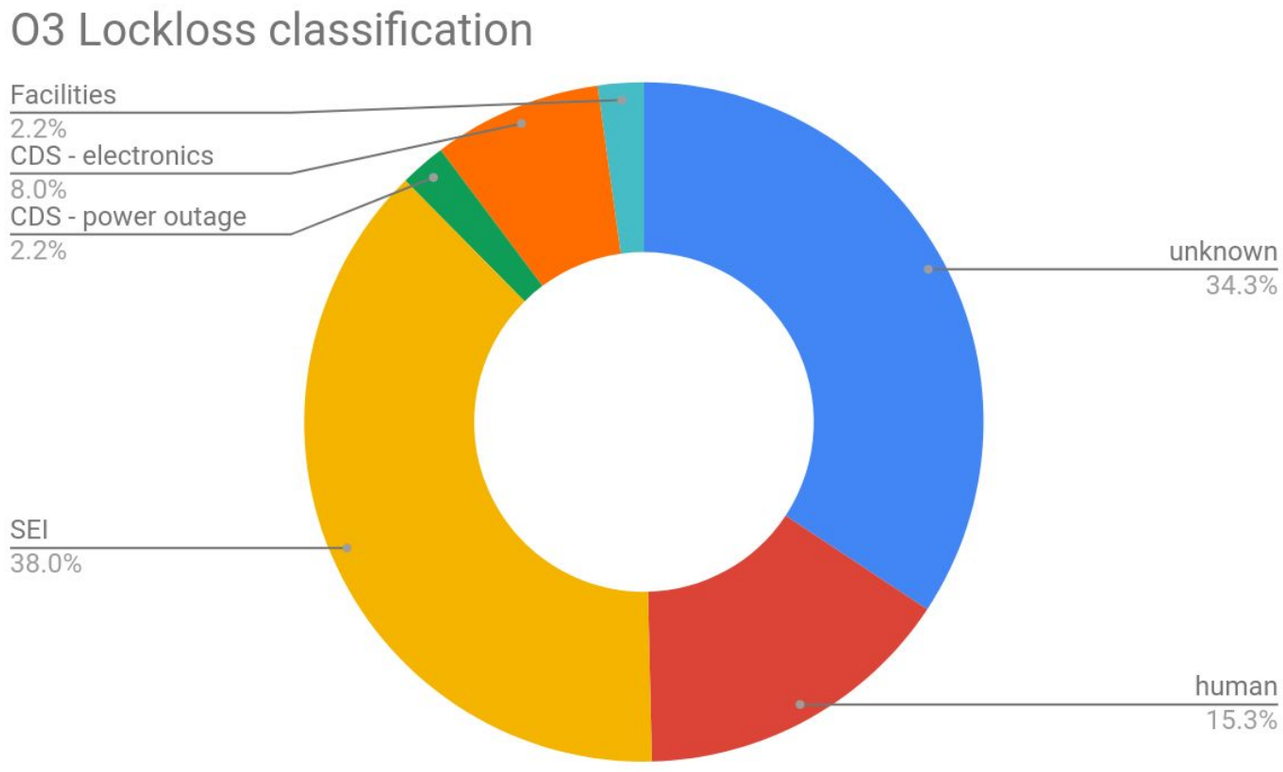
-SEI 38% [earthquakes (24.1%), wind (2.2%), trains/ anthropogenic noise (8%), useism (3.6%)]

-Unknown 34.3%

-Human 15.3% (tuesday maintenance, error, commissioning)

-CDS 10.2% (power outage 2.2%, electronics failure/computer lock-up 8%]

-Facilities 2.2% [temperature issue]



data from [LLO lockloss spreadsheet]