LIGO & Earthquakes

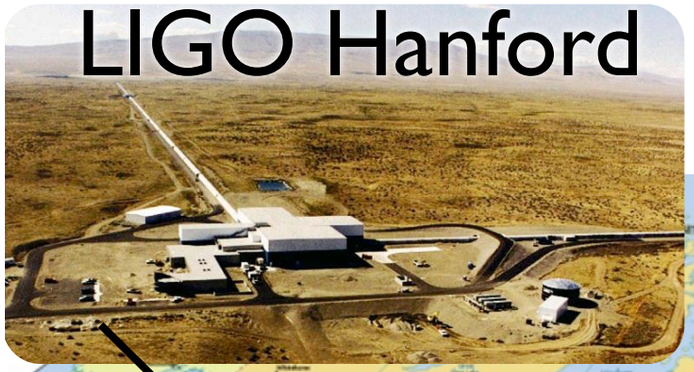
Brian Lantz, Anne Baer, Grace Johns

Jan 6, 2020, G2301536

LIGO Background

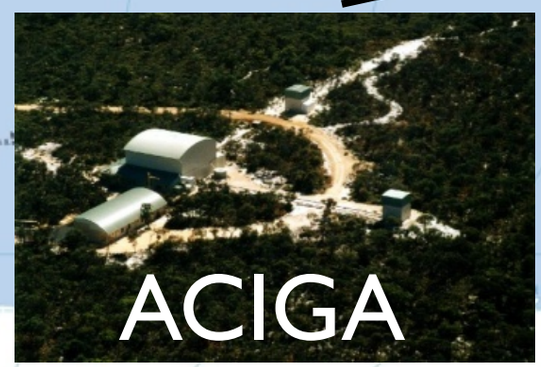
- 2 US detectors, also Virgo in Italy
- 4 km arms which are 'locked' on 'resonance'
- We use sophisticated seismic isolation.
  - Normally isolation works well, but
  - Not for surface waves from teleseismic events
- We can change the control schemes to adjust for different conditions
  - We have developed a special 'Earthquake mode'
  - It works pretty well, but would be better if:
    1) It were turned on BEFORE the earthquake arrived
    2) We knew how big the EQ would be, so we could pick the right parameters

International Network



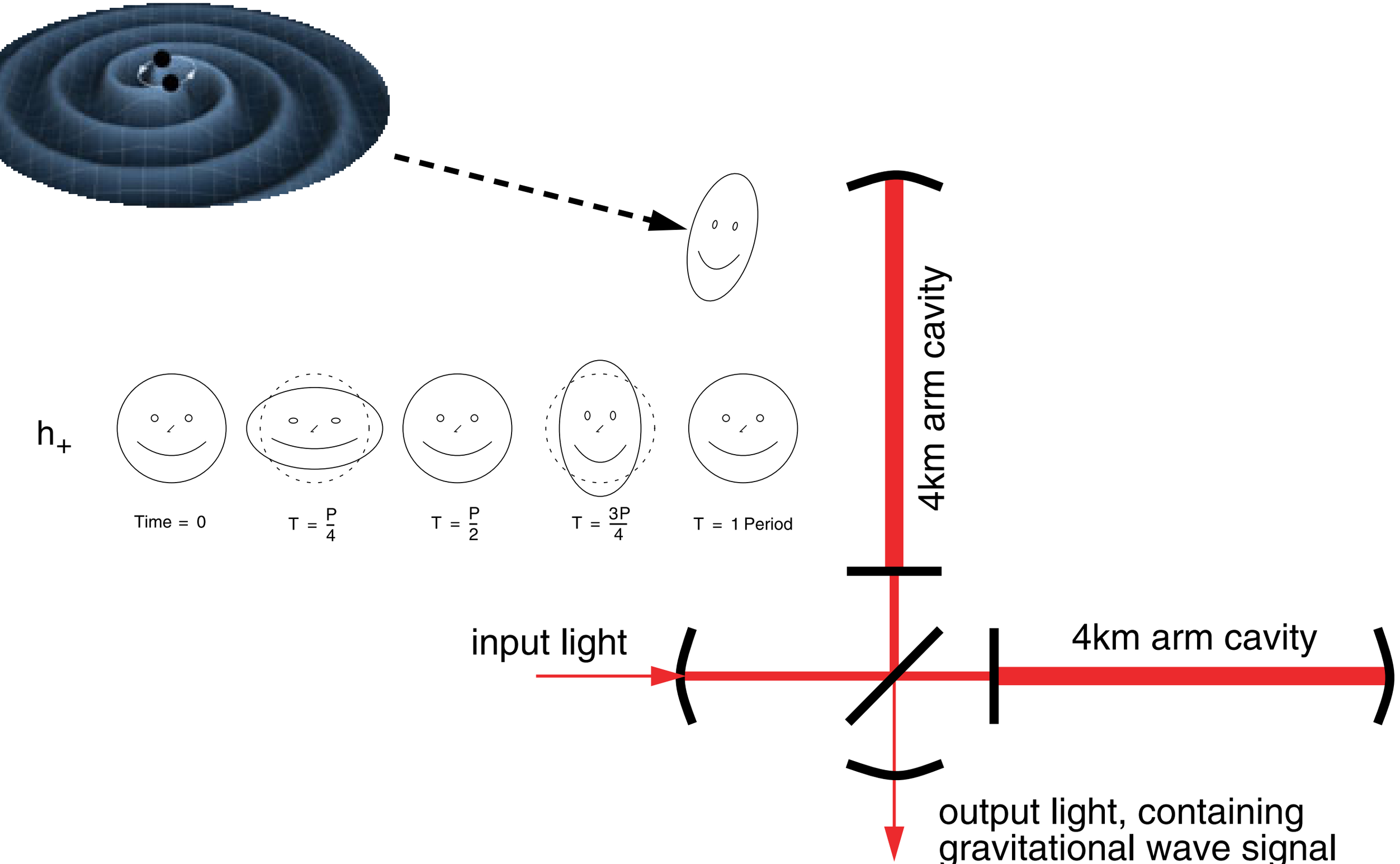
LIGO India

project approved

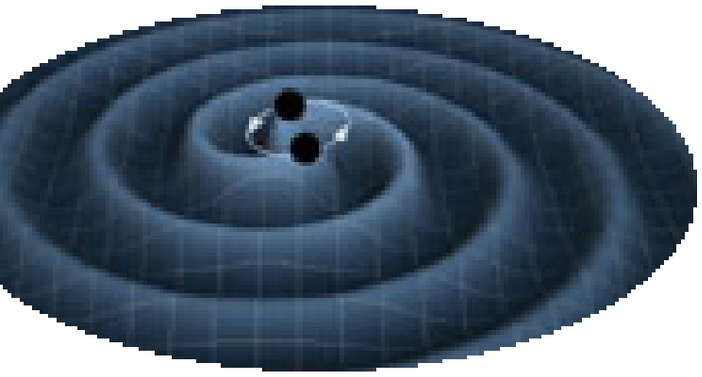


map from http://www.nationsonline.org/maps/political_world_map3000.jpg

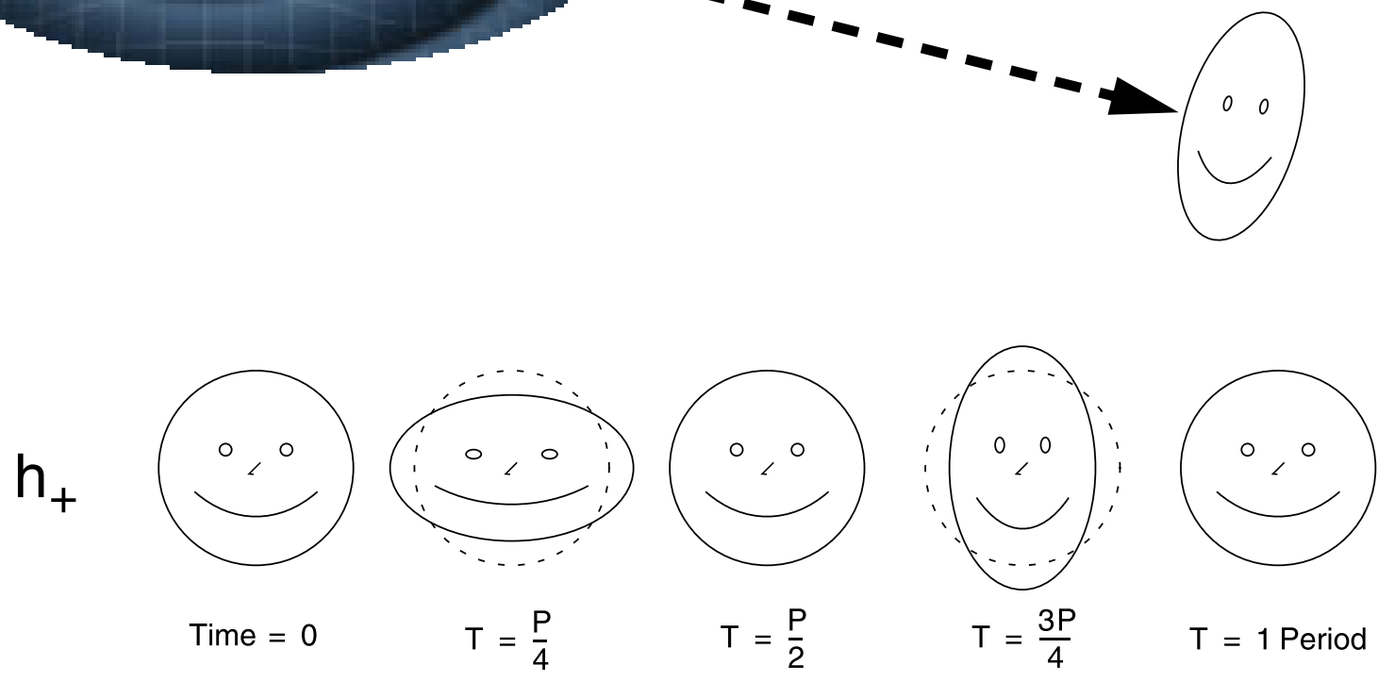
The LIGO concept

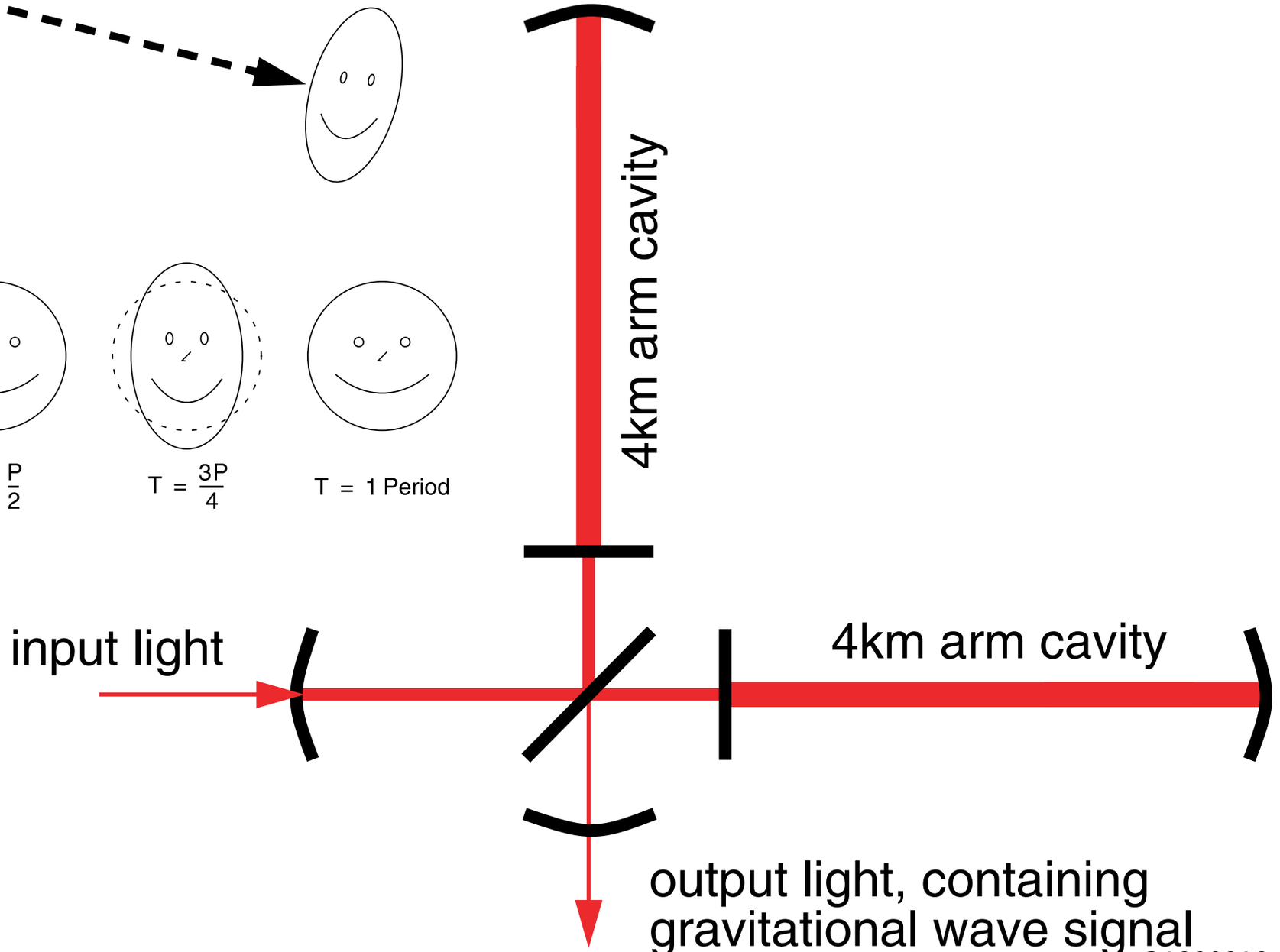


The LIGO concept



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



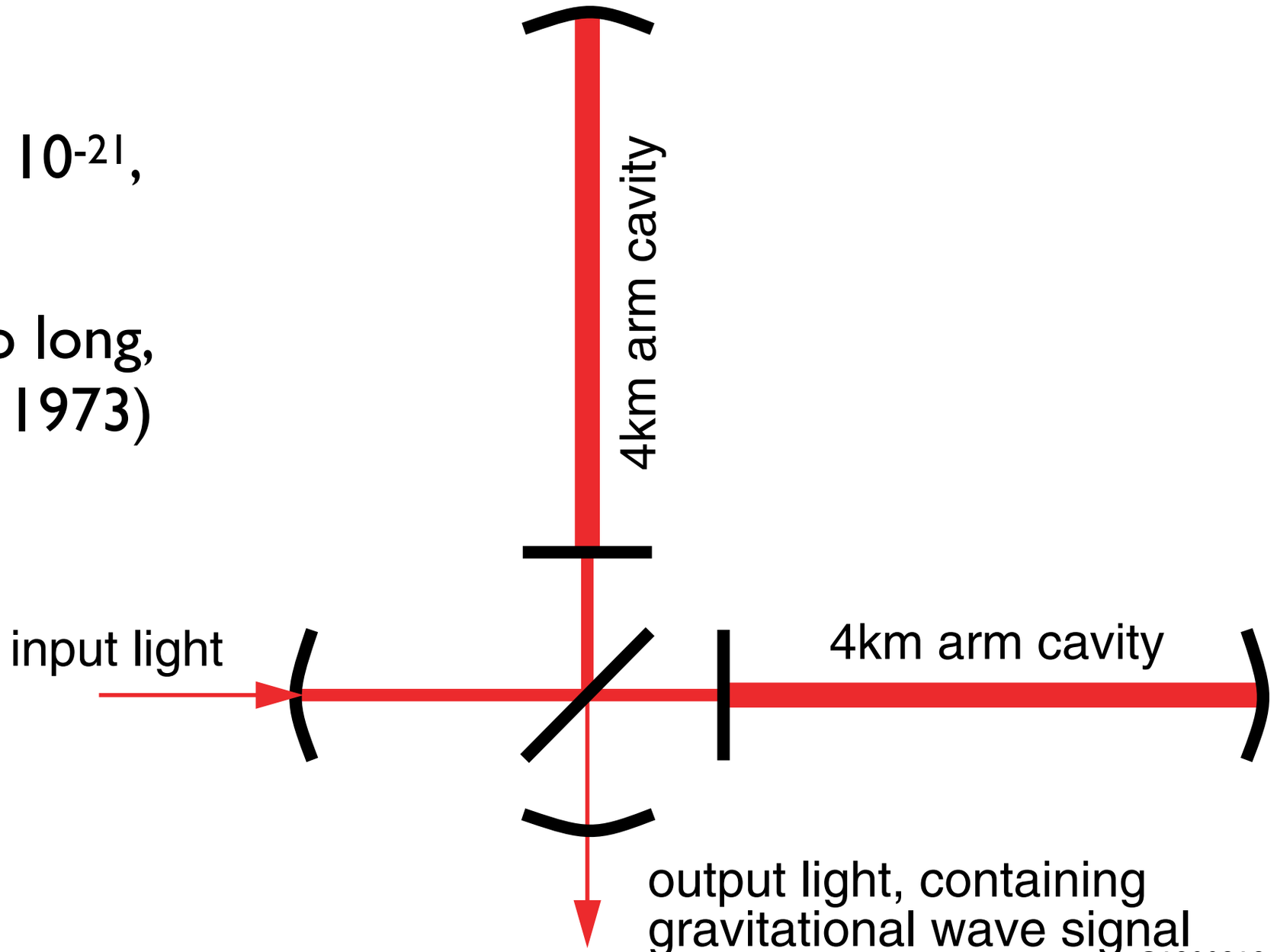


The LIGO concept

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

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

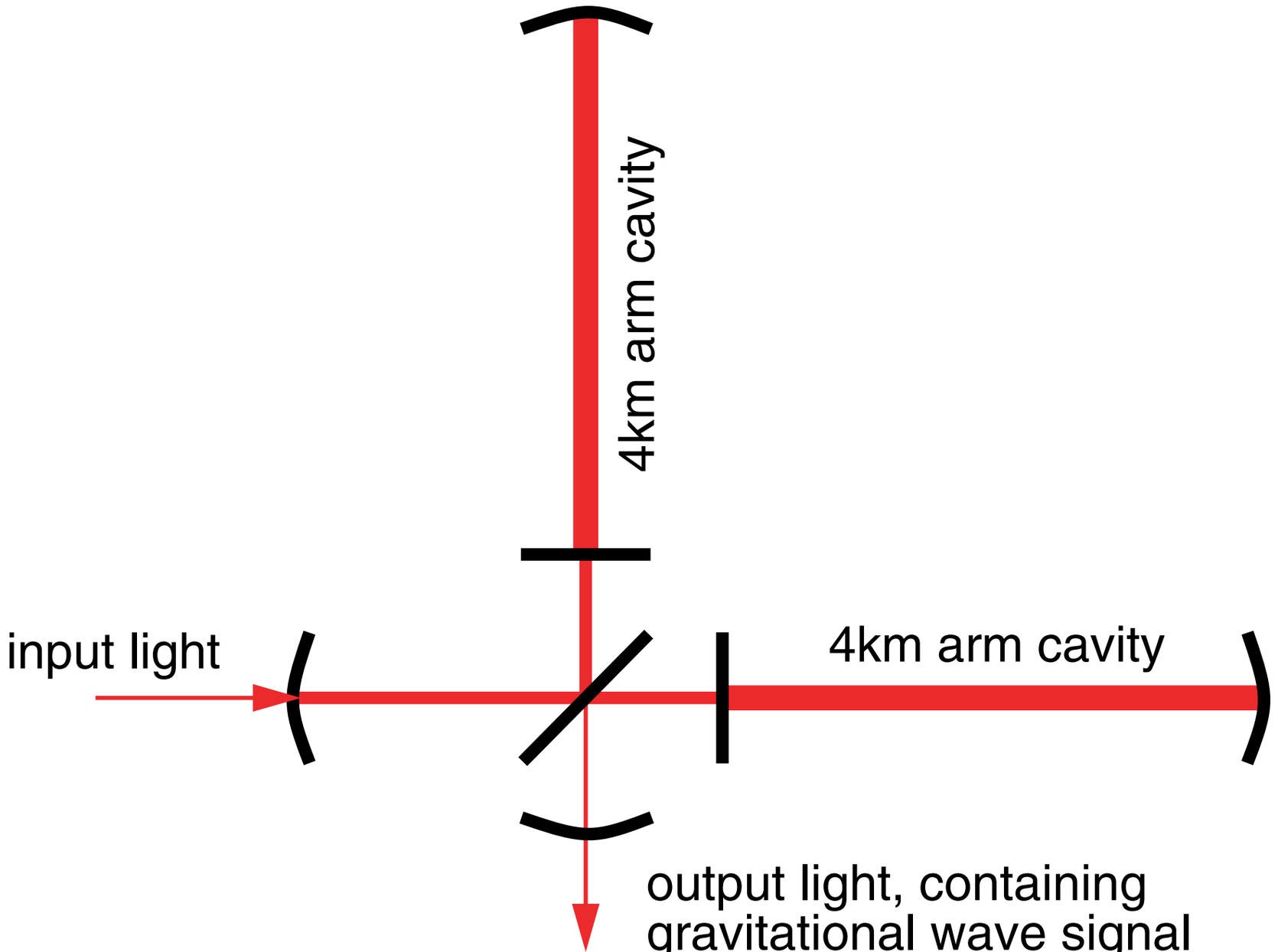
(that's why it's taken so long,
Einstein 1916, Weiss 1973)



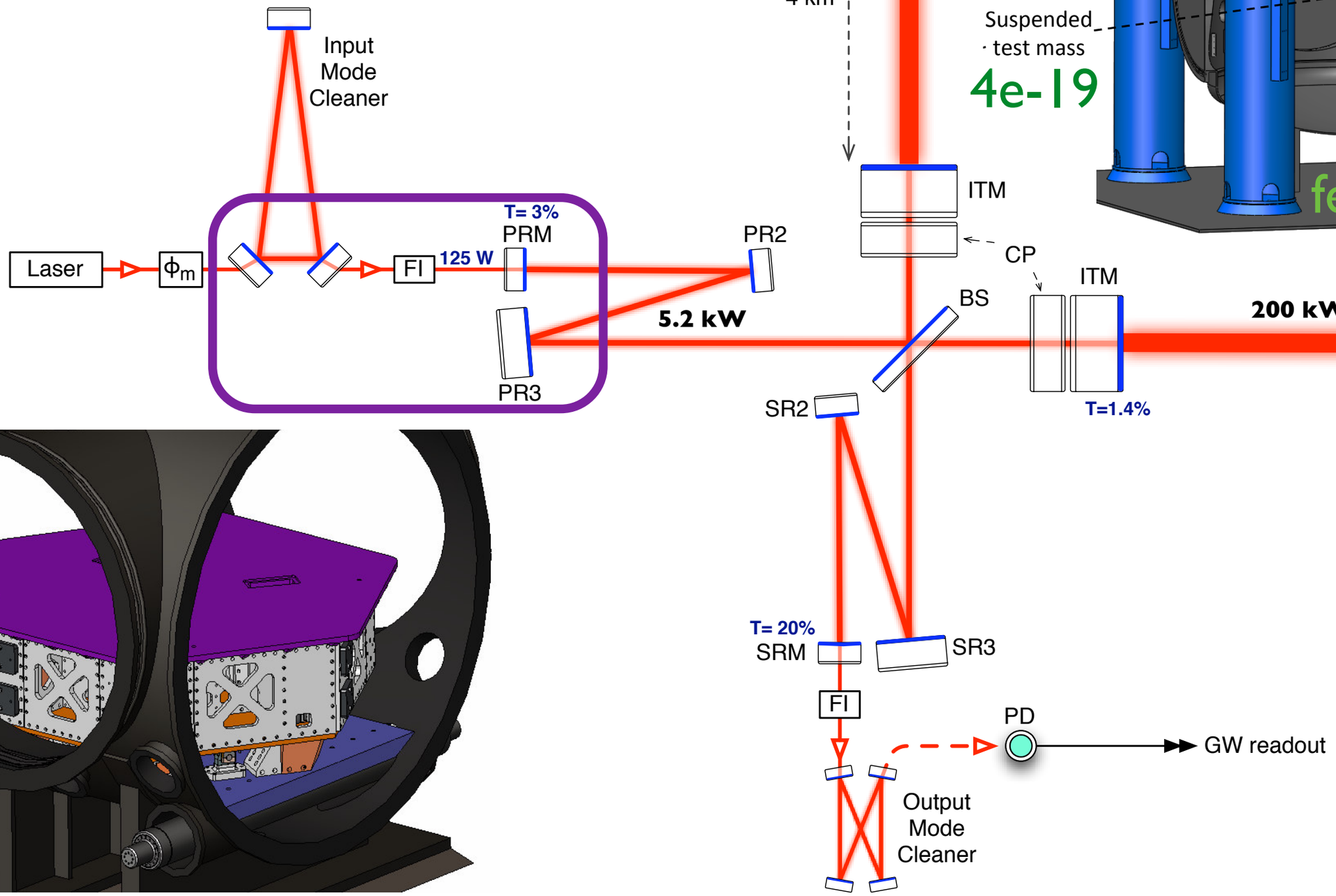
The LIGO concept

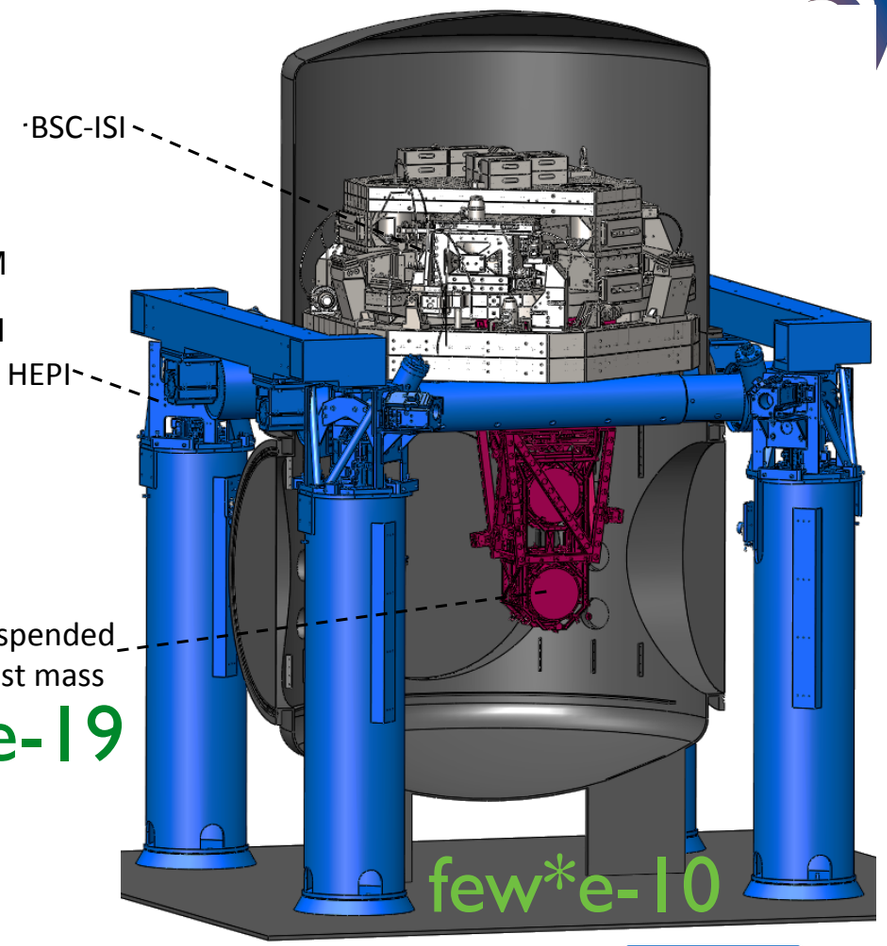
Active controls hold the rms length of the arms stable to
- ~ 1e-13 meters, and
- ~ 1e-9 radians.

Needed to keep large



Quiet mirrors

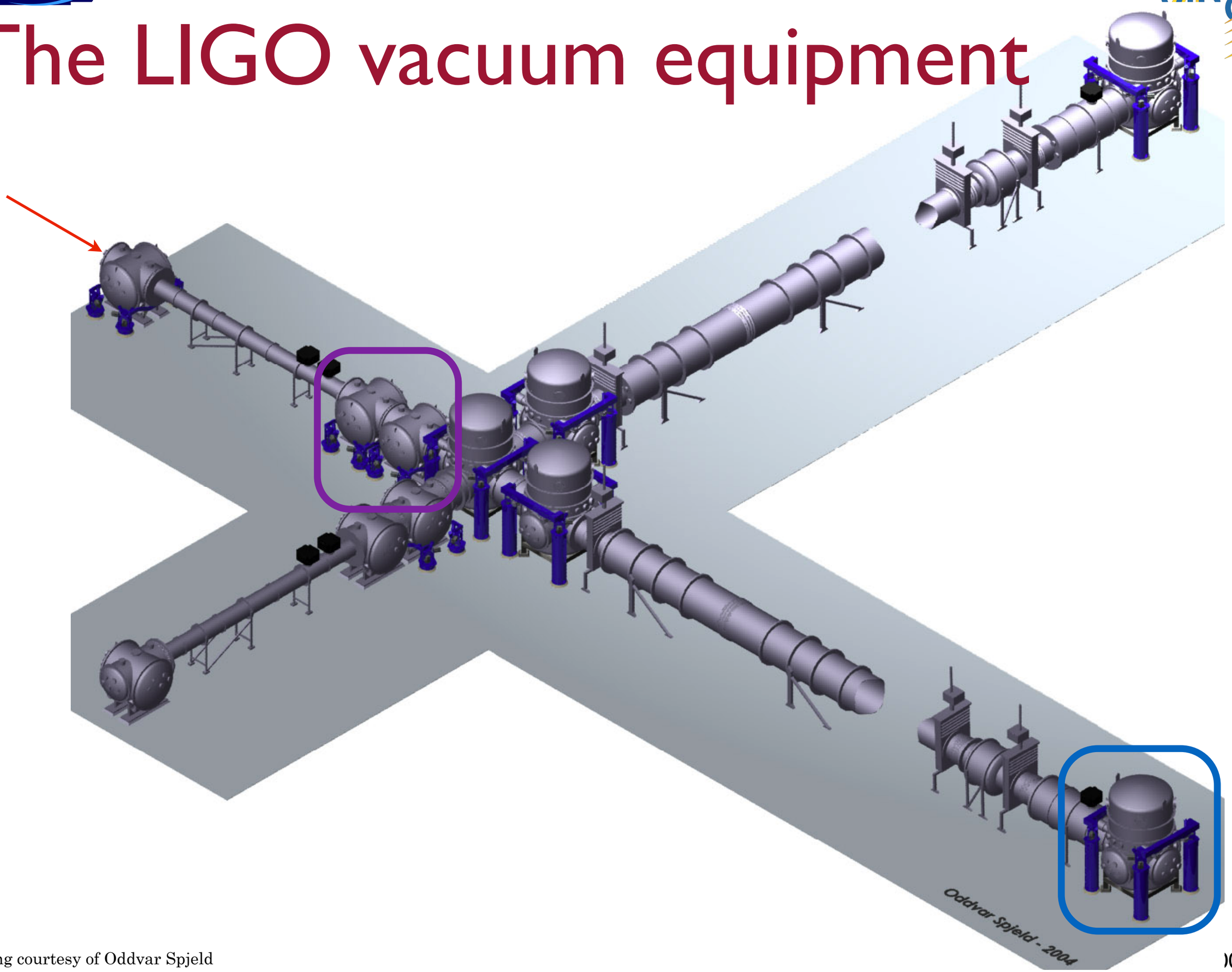




4e-19

few*e-10

The LIGO vacuum equipment



drawing courtesy of Oddvar Spjeld

optics table - stage 2

stage 1

support - stage 0

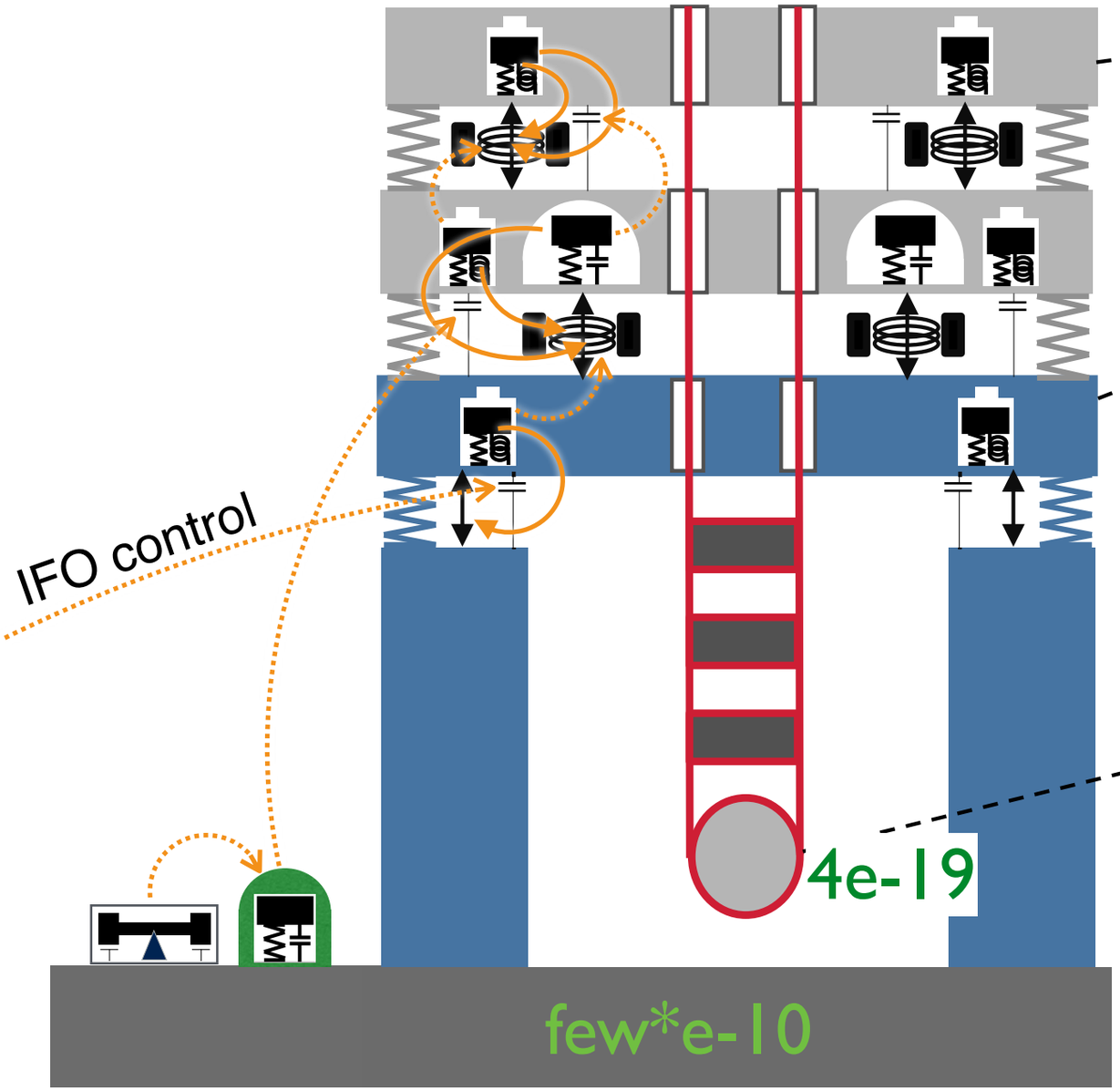
optics table - stage 2

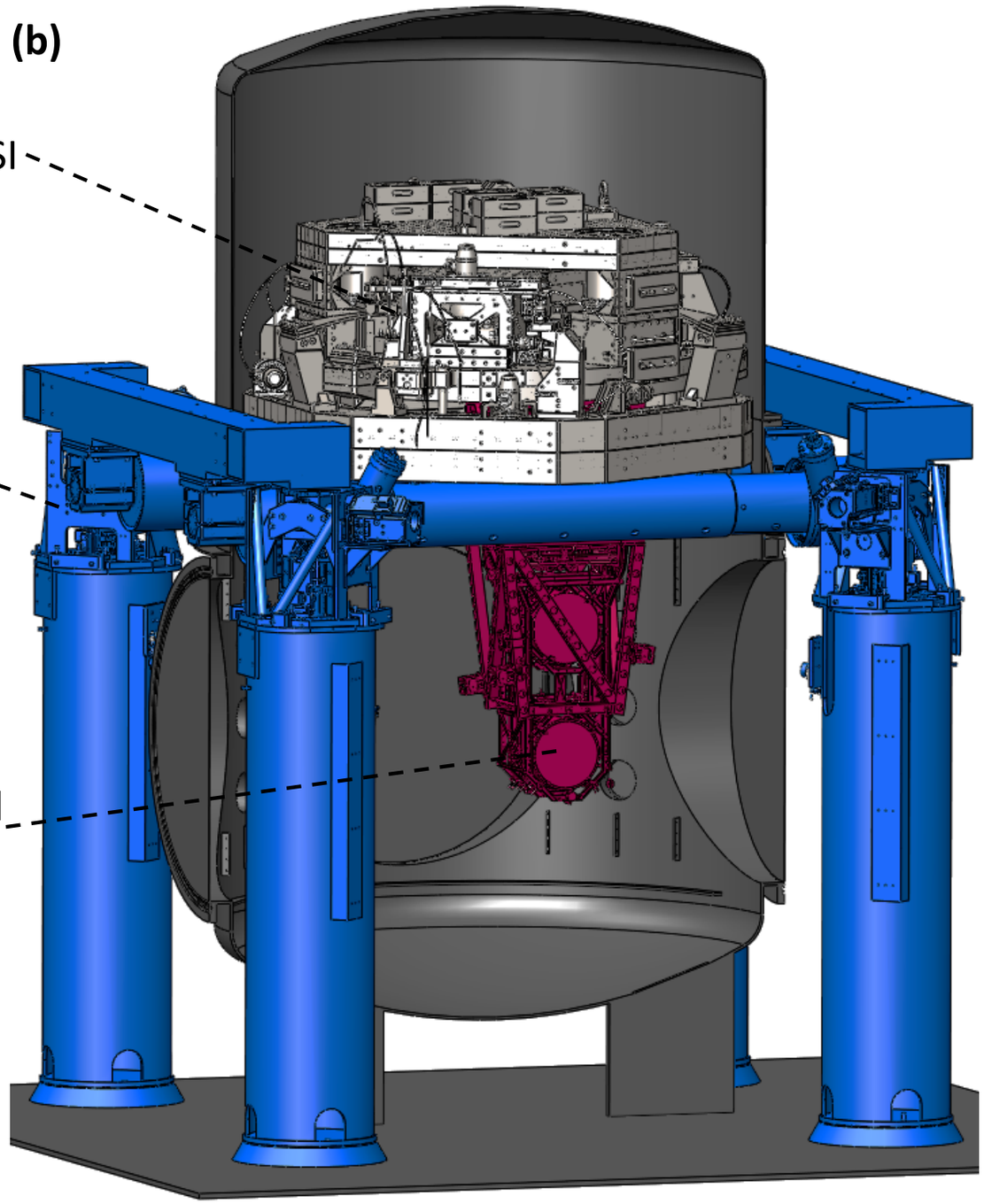
stage 1

support - stage 0

Isolation

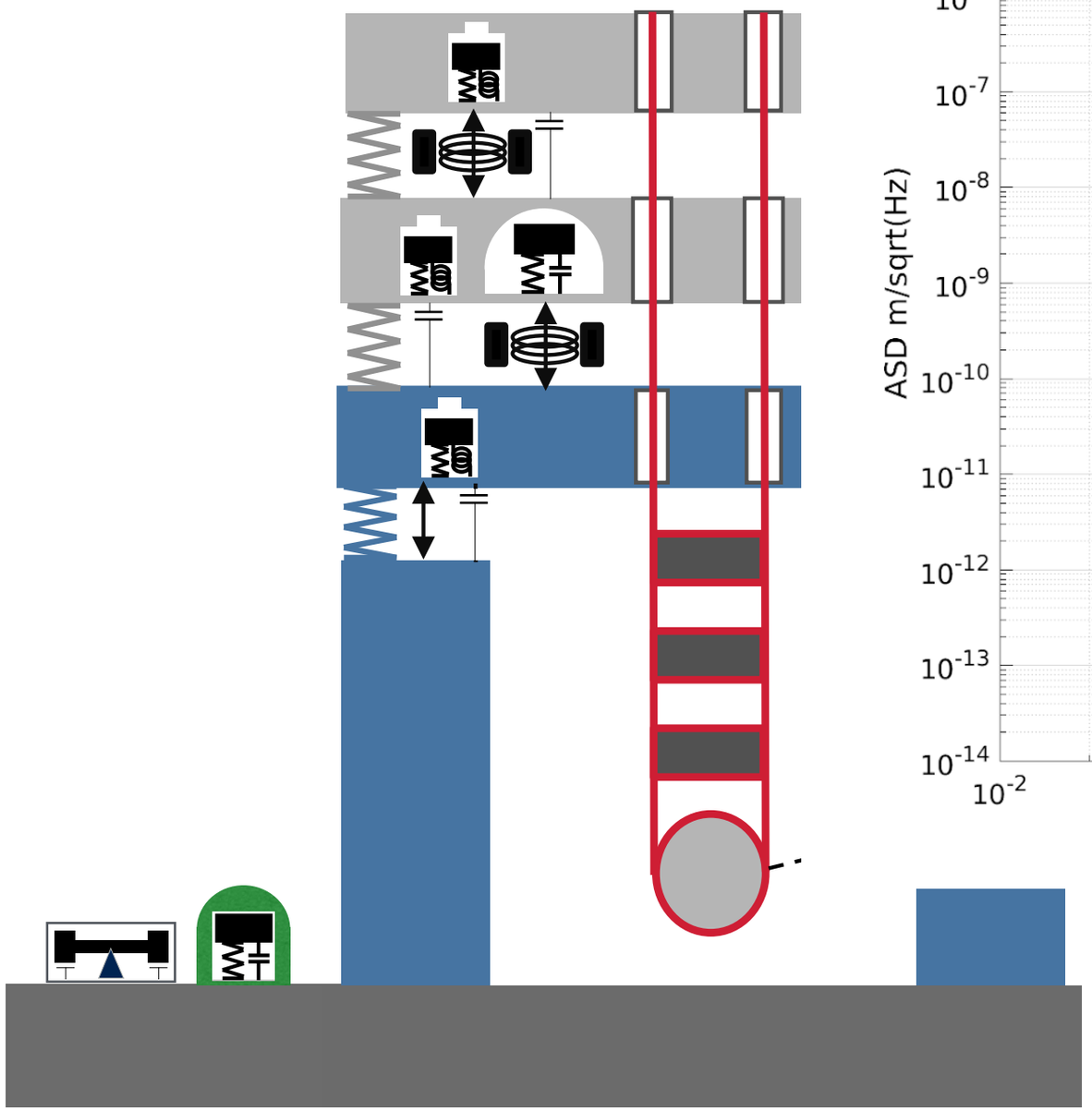
Feedback Damping
Blended Isolation
Sensor correction
Feedforward

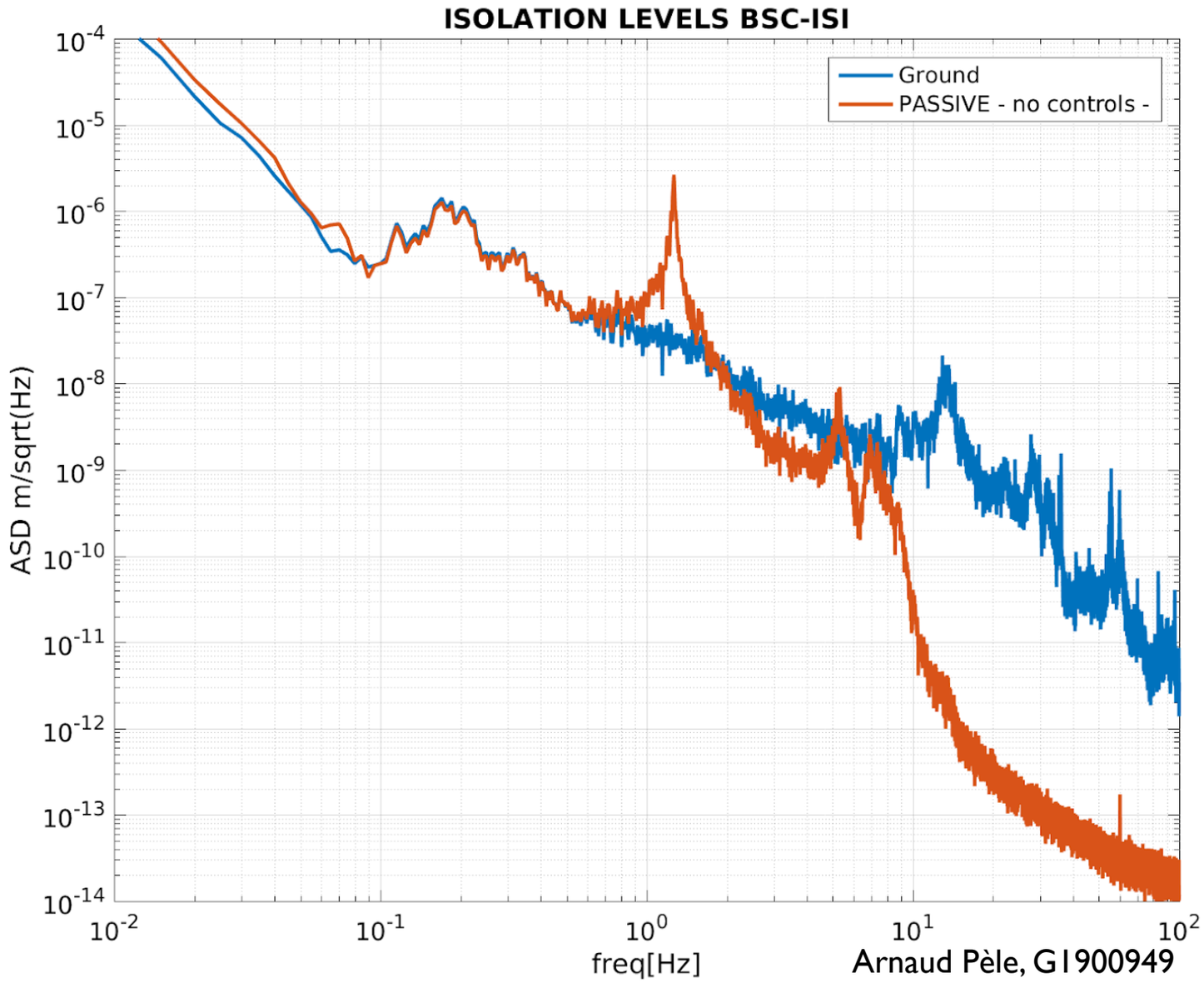


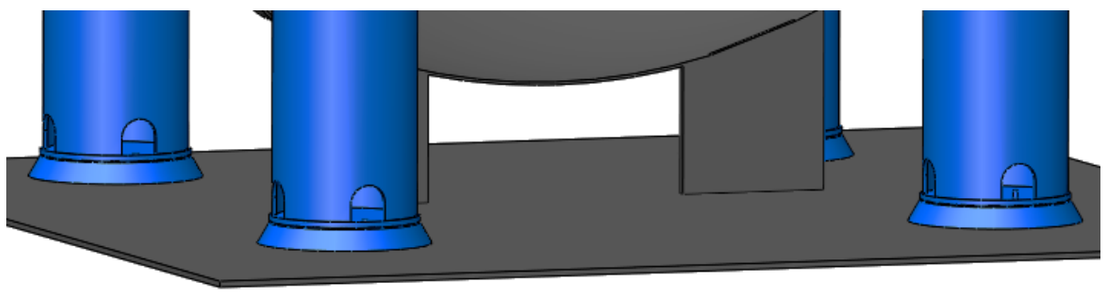


Isolation

(a)

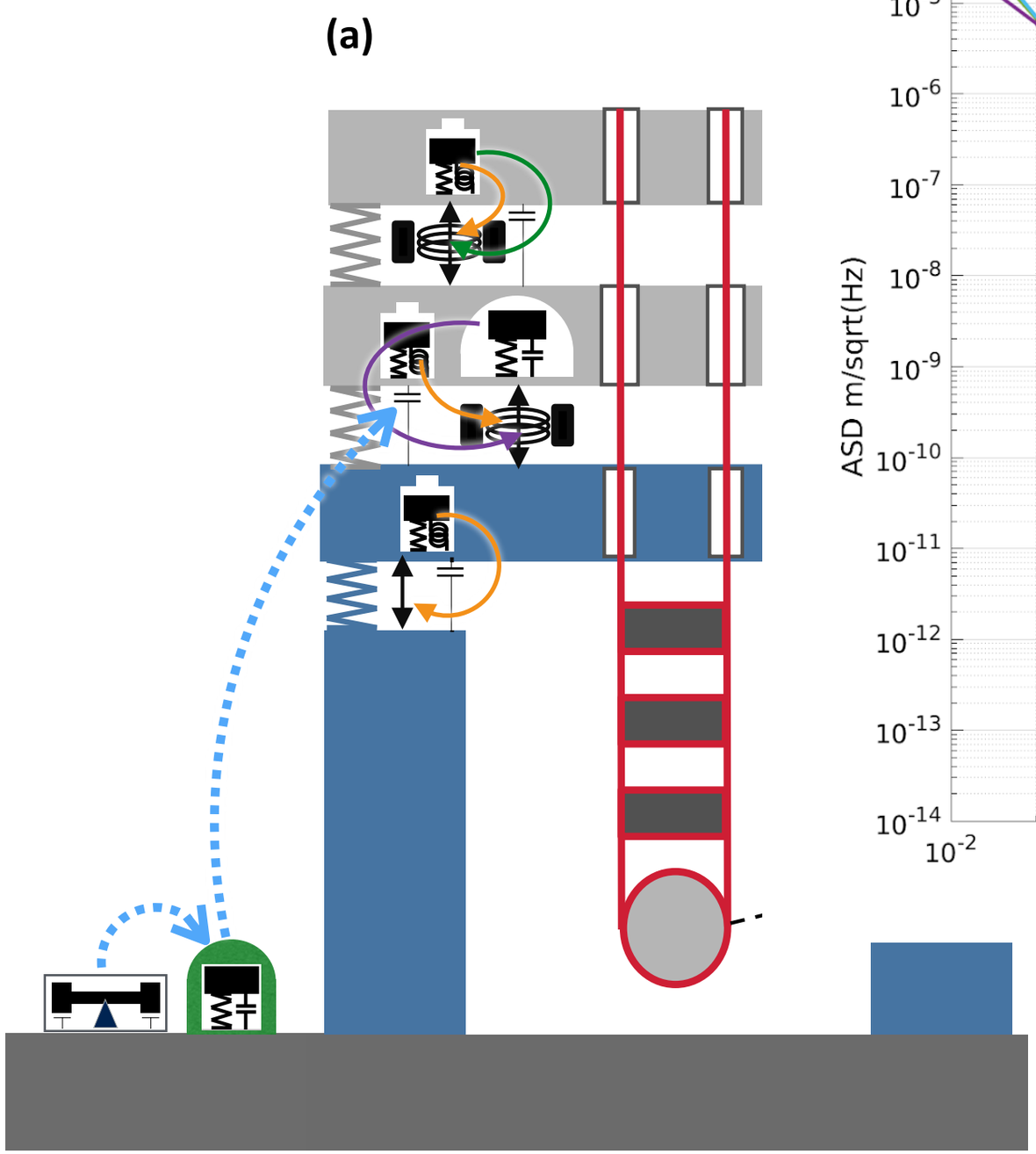


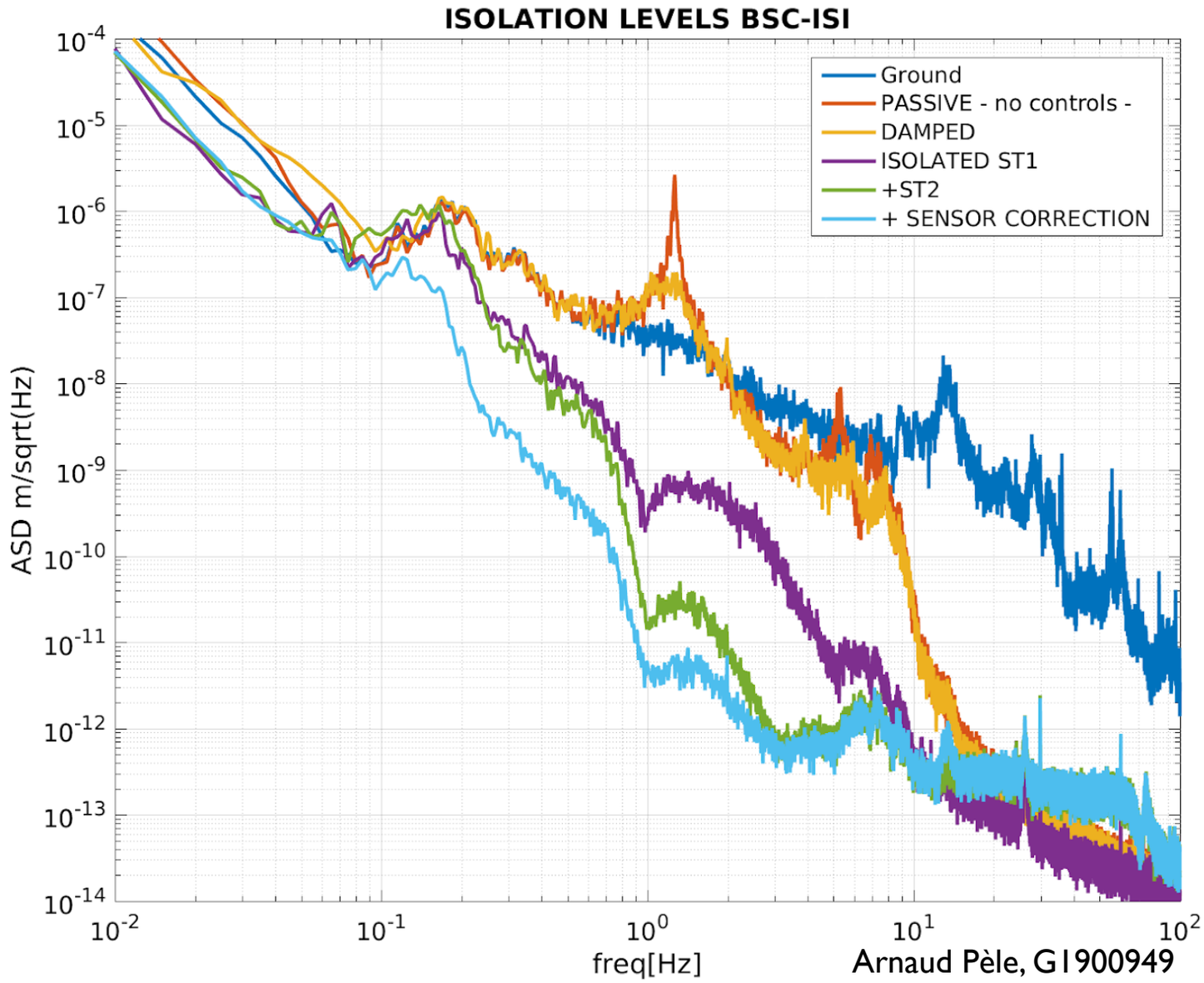

ISOLATION LEVELS BSC-ISI
Ground
PASSIVE - no controls -
ASD m/sqrt(Hz)
freq[Hz]
Arnaud Pèle, G1900949

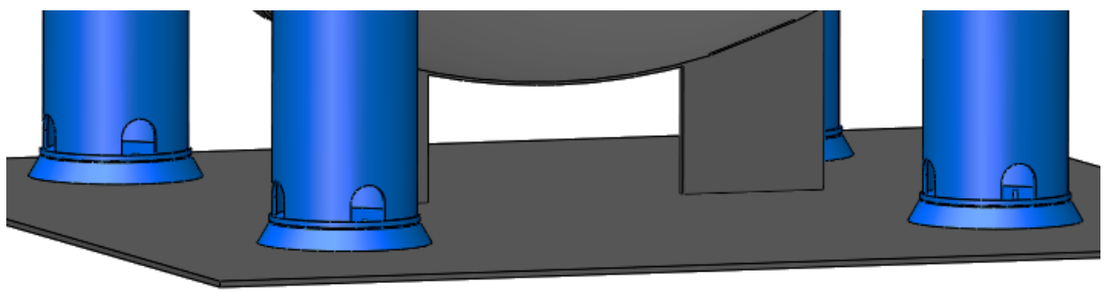


Isolation

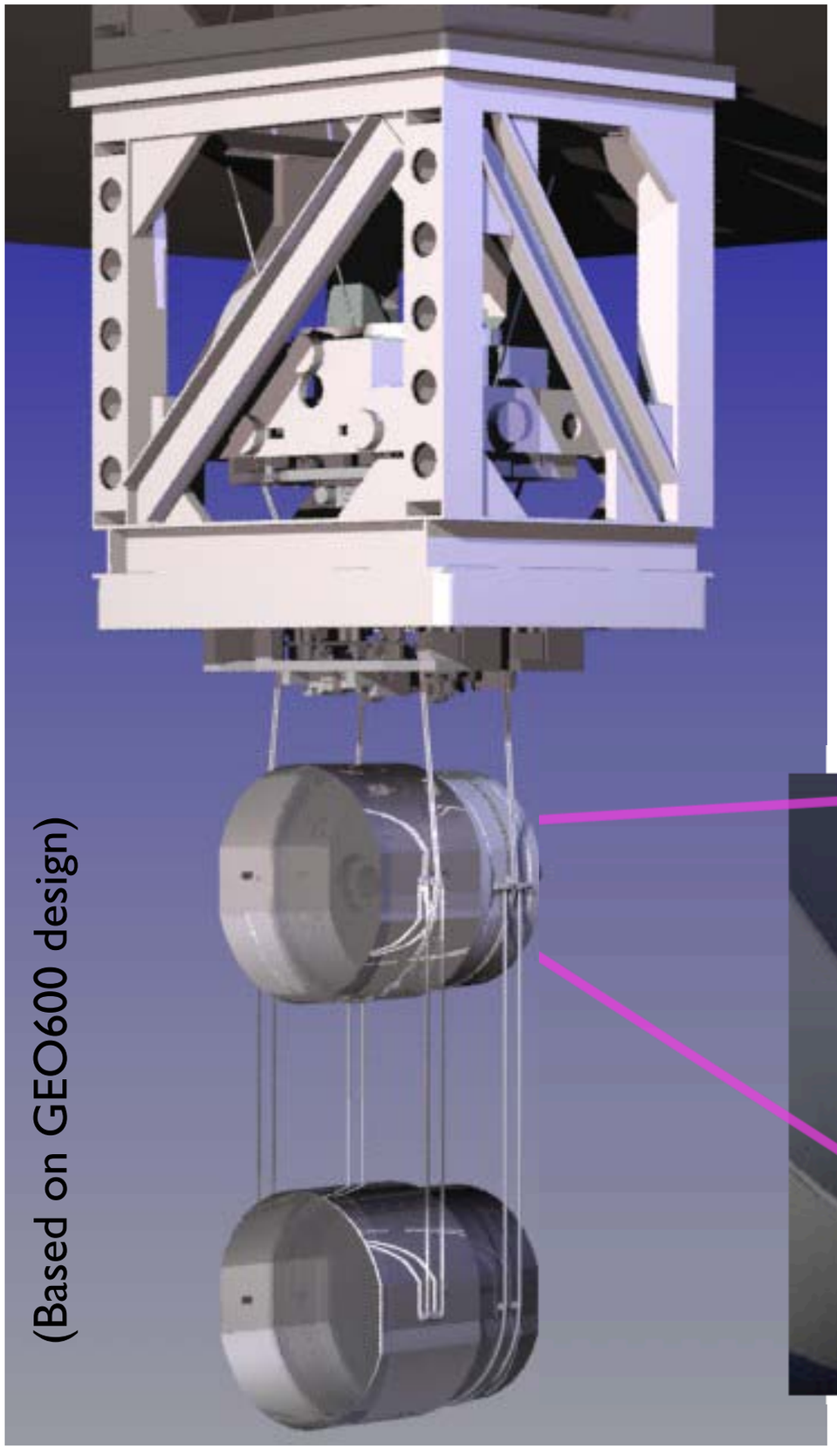
Feedback Damping
Blended Isolation
Sensor correction





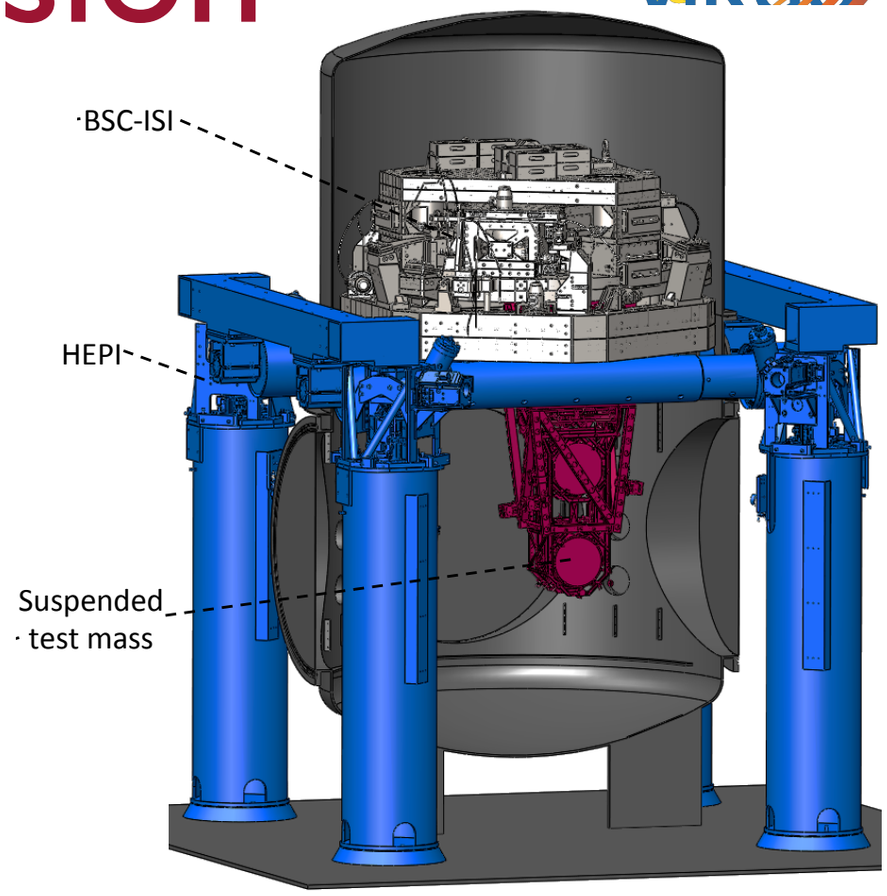


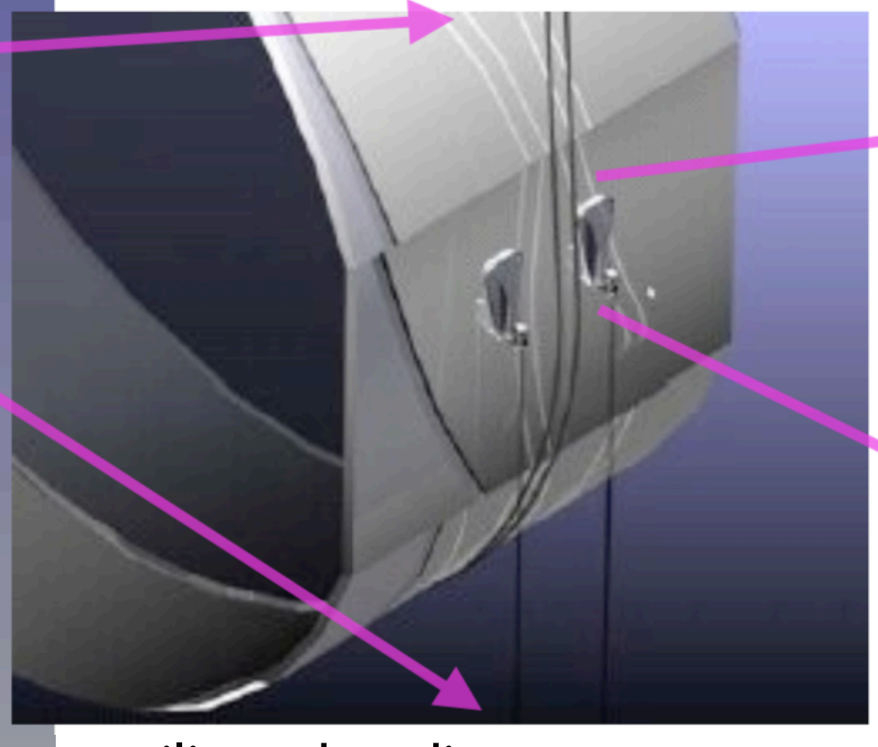
Pendulum Suspension



LIGO Mirrors:
Synthetic fused silica,
40 kg mass
34 cm diameter
20 cm thick

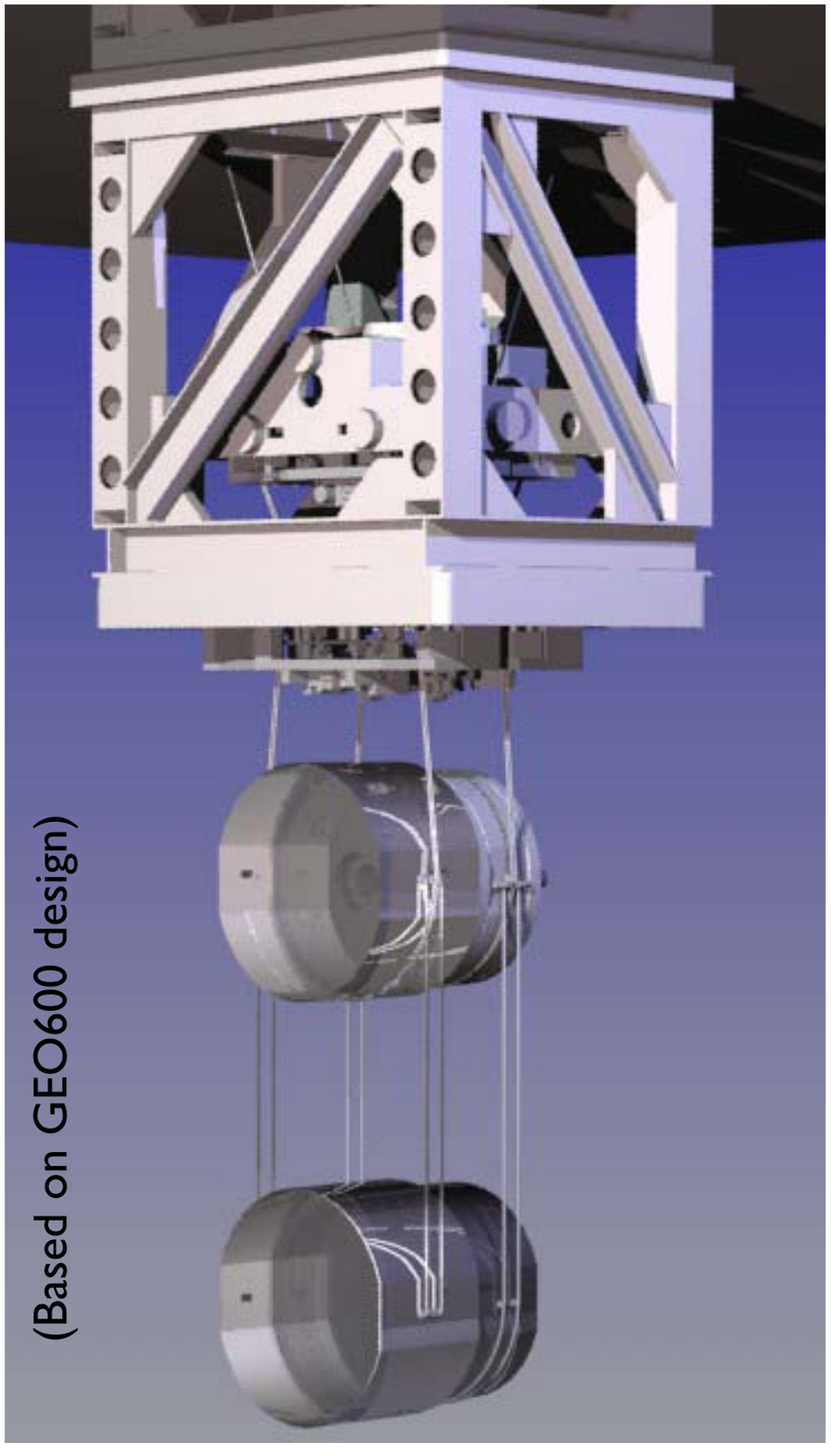
Suspended as a
4 stage pendulum





silicate bonding creates a monolithic final stage

Pendulum Suspension



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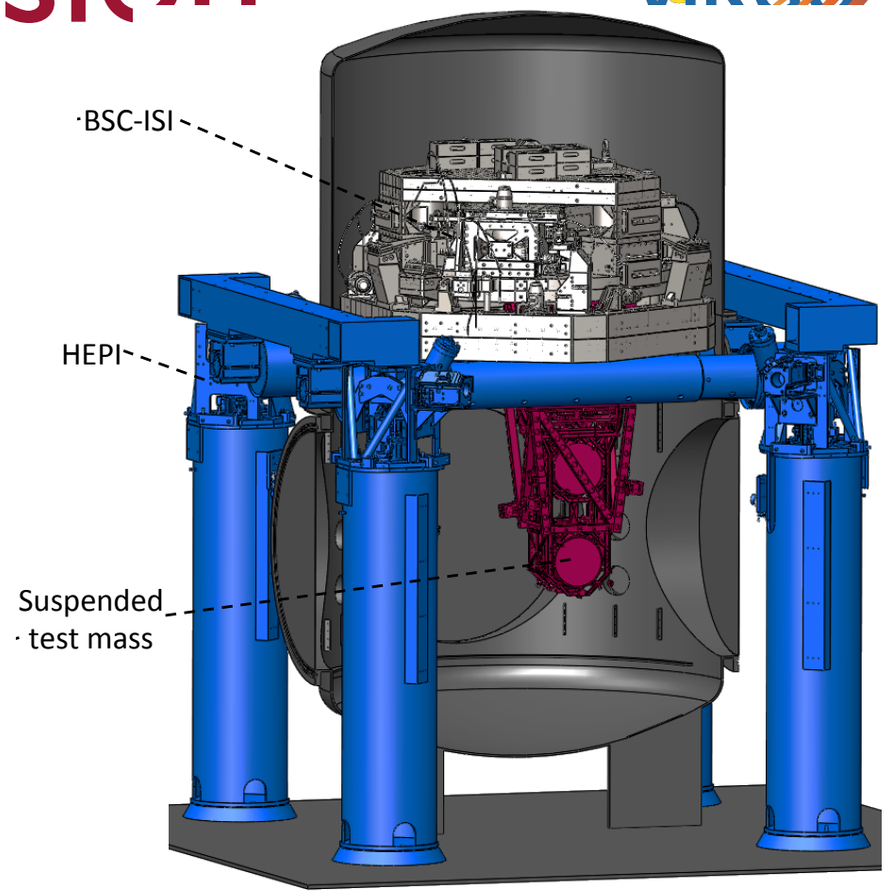
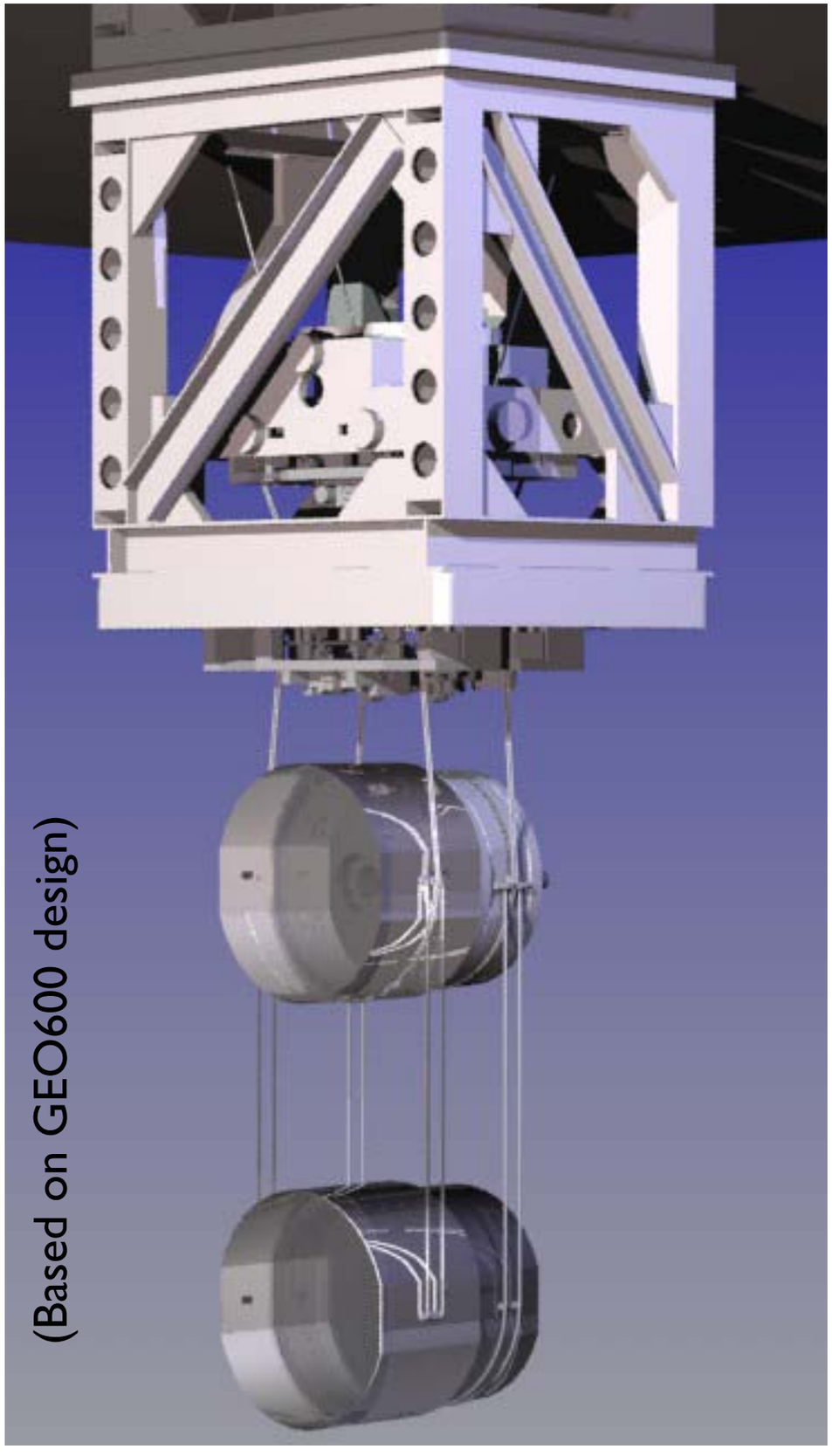


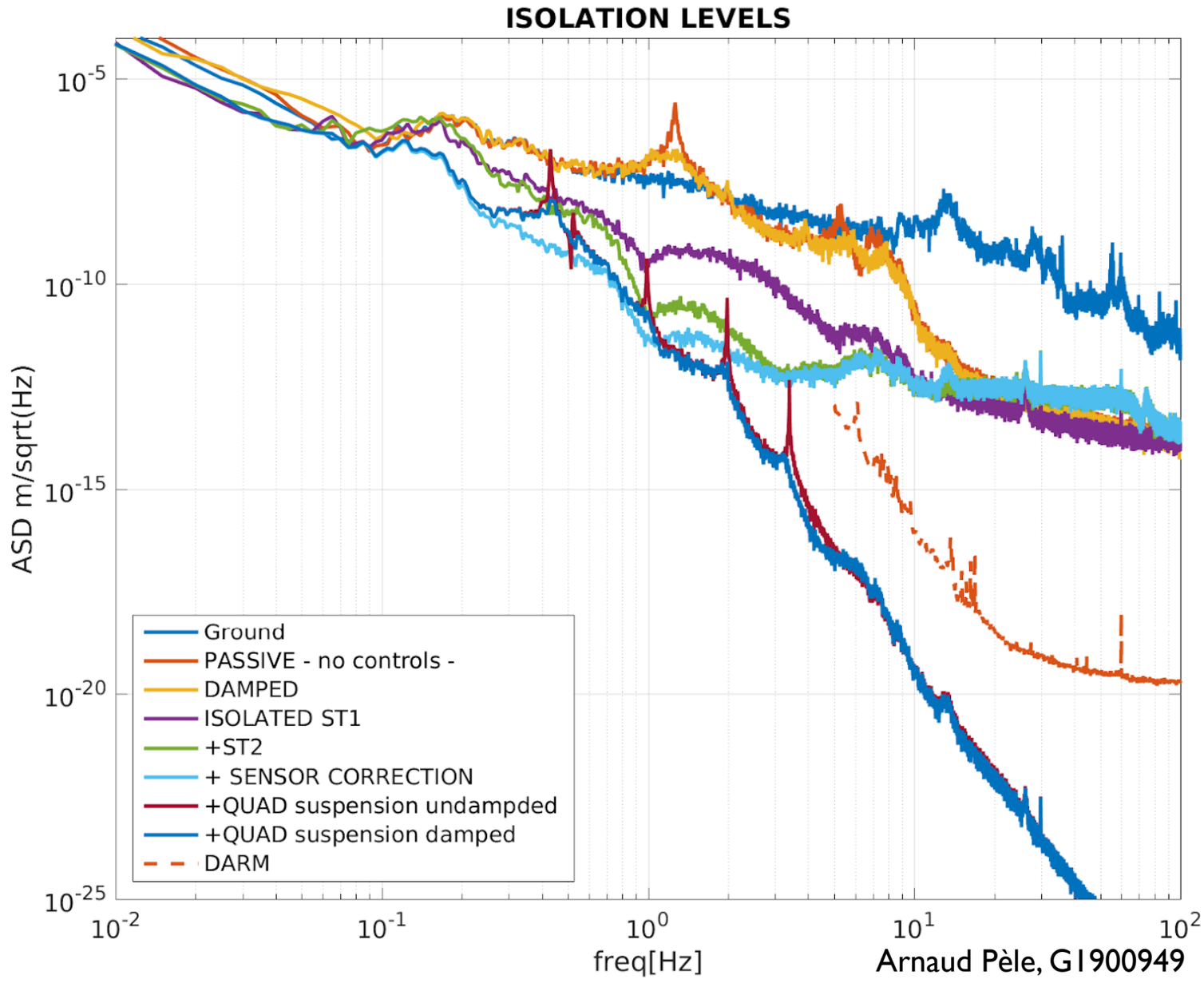
Best coatings available

Motion at 10 Hz set by
thermal driven vibration

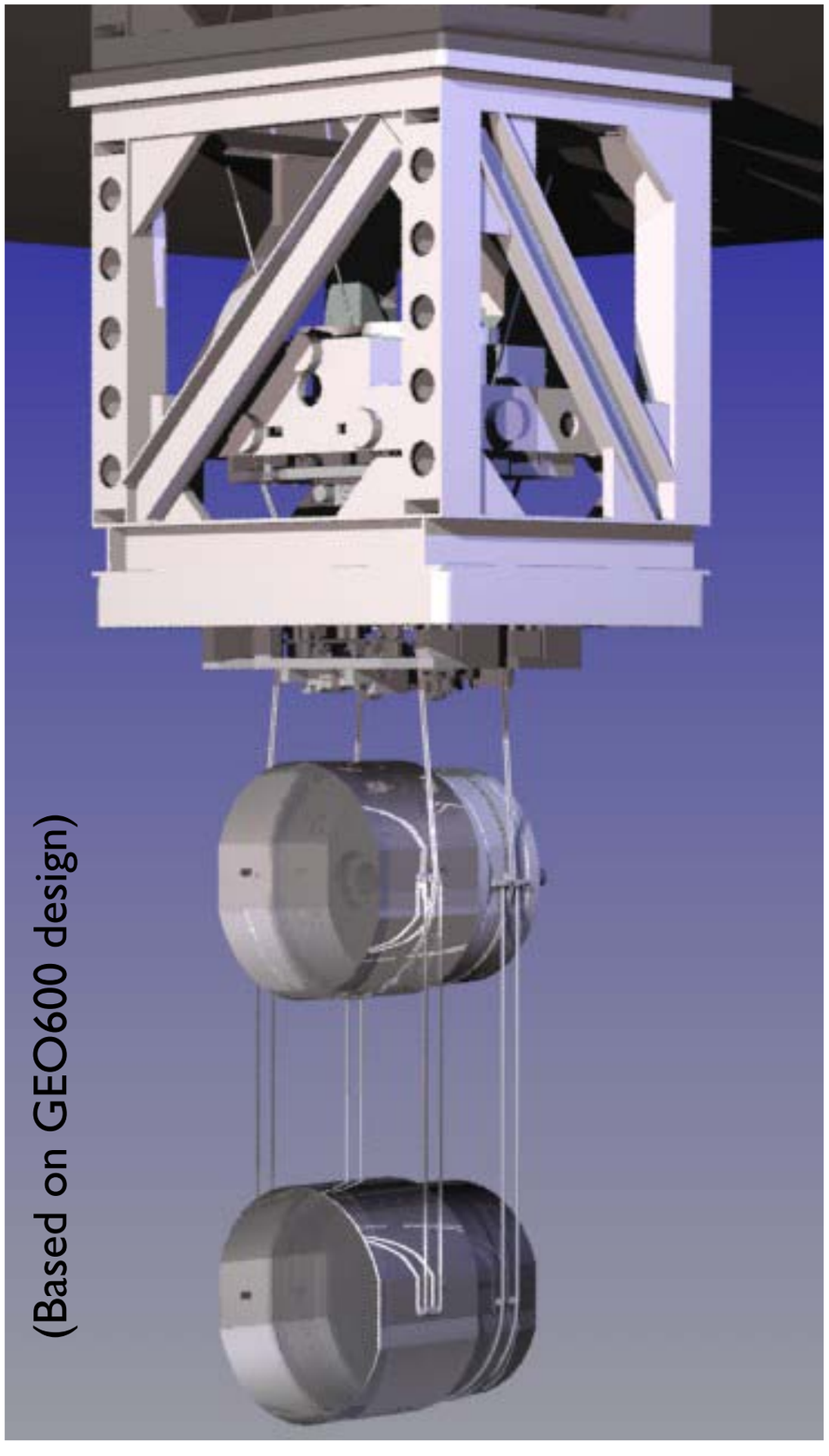
silicate bonding creates a monolithic final stage

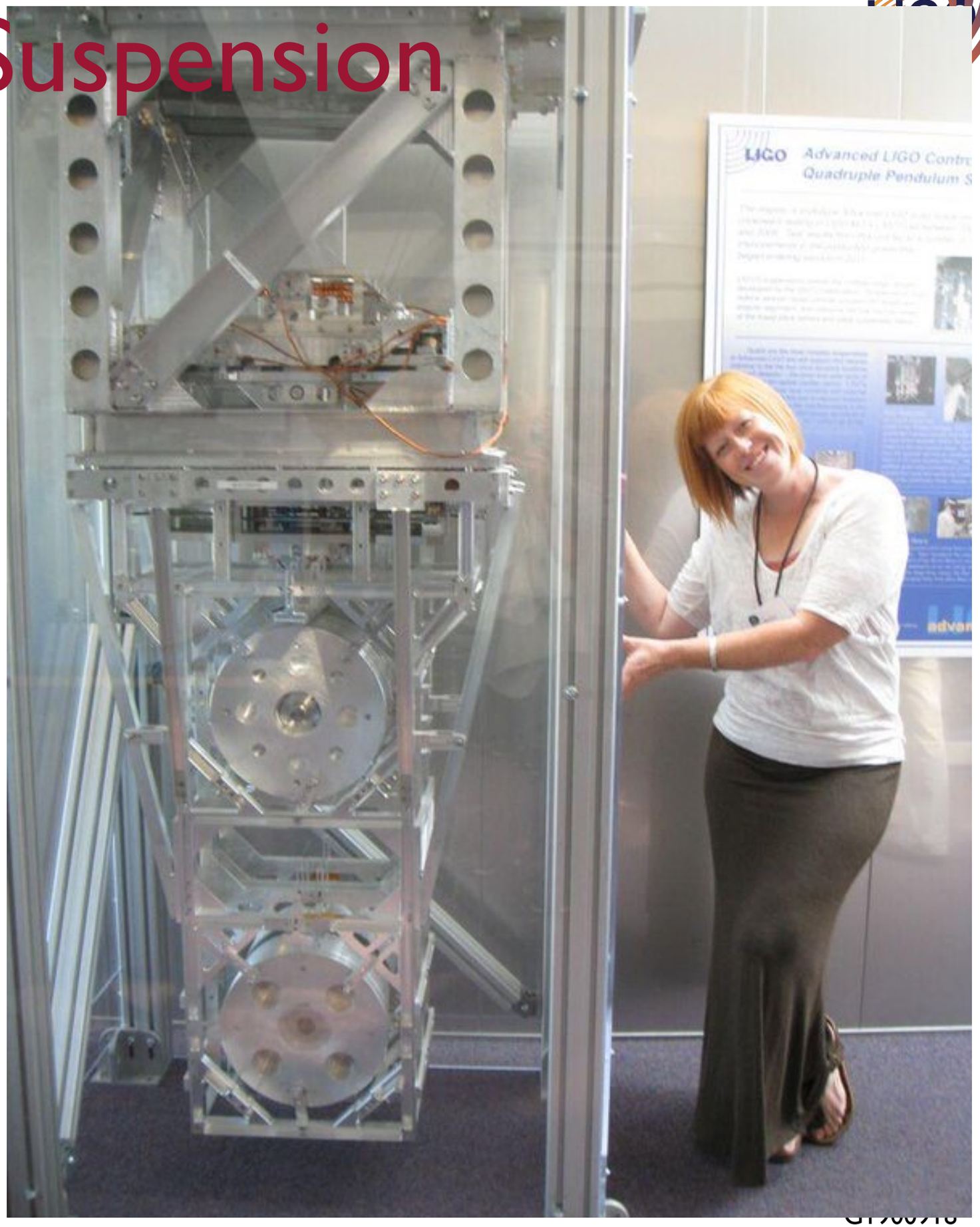
Pendulum Suspension



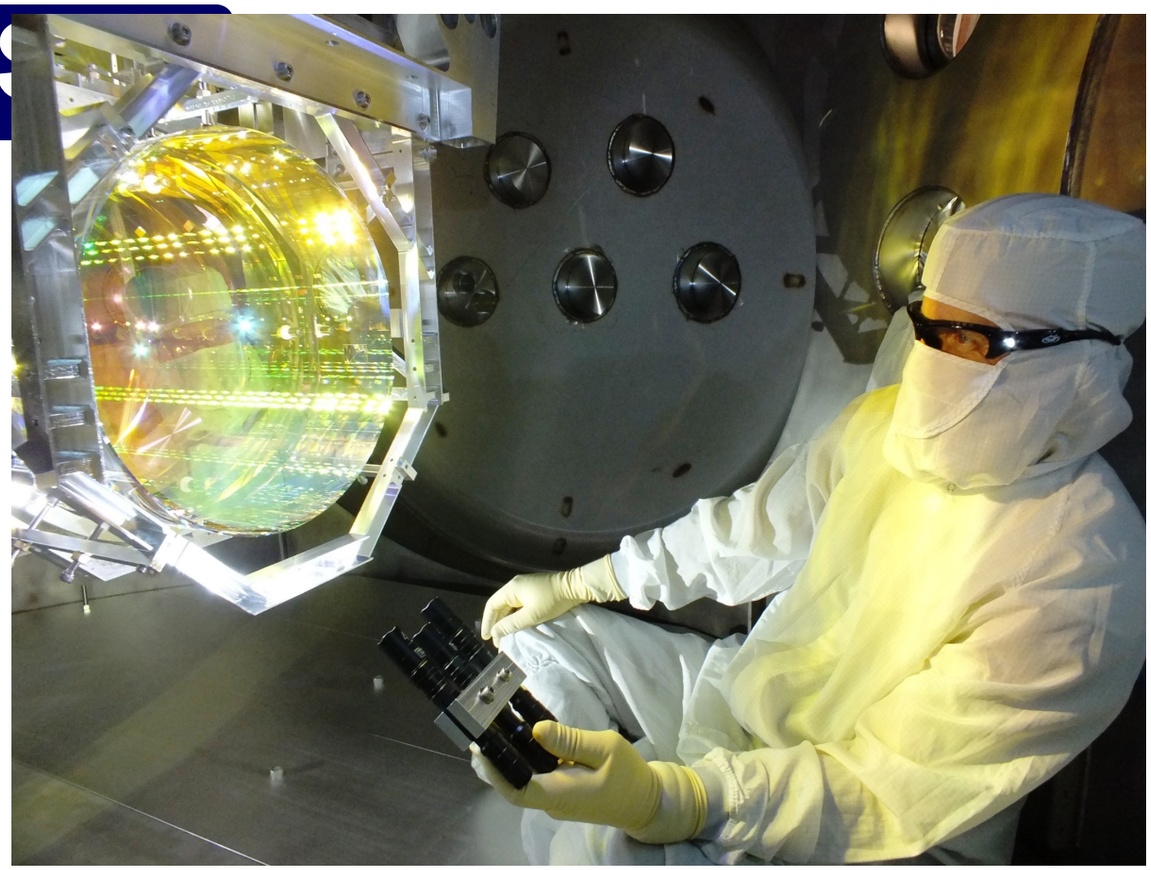


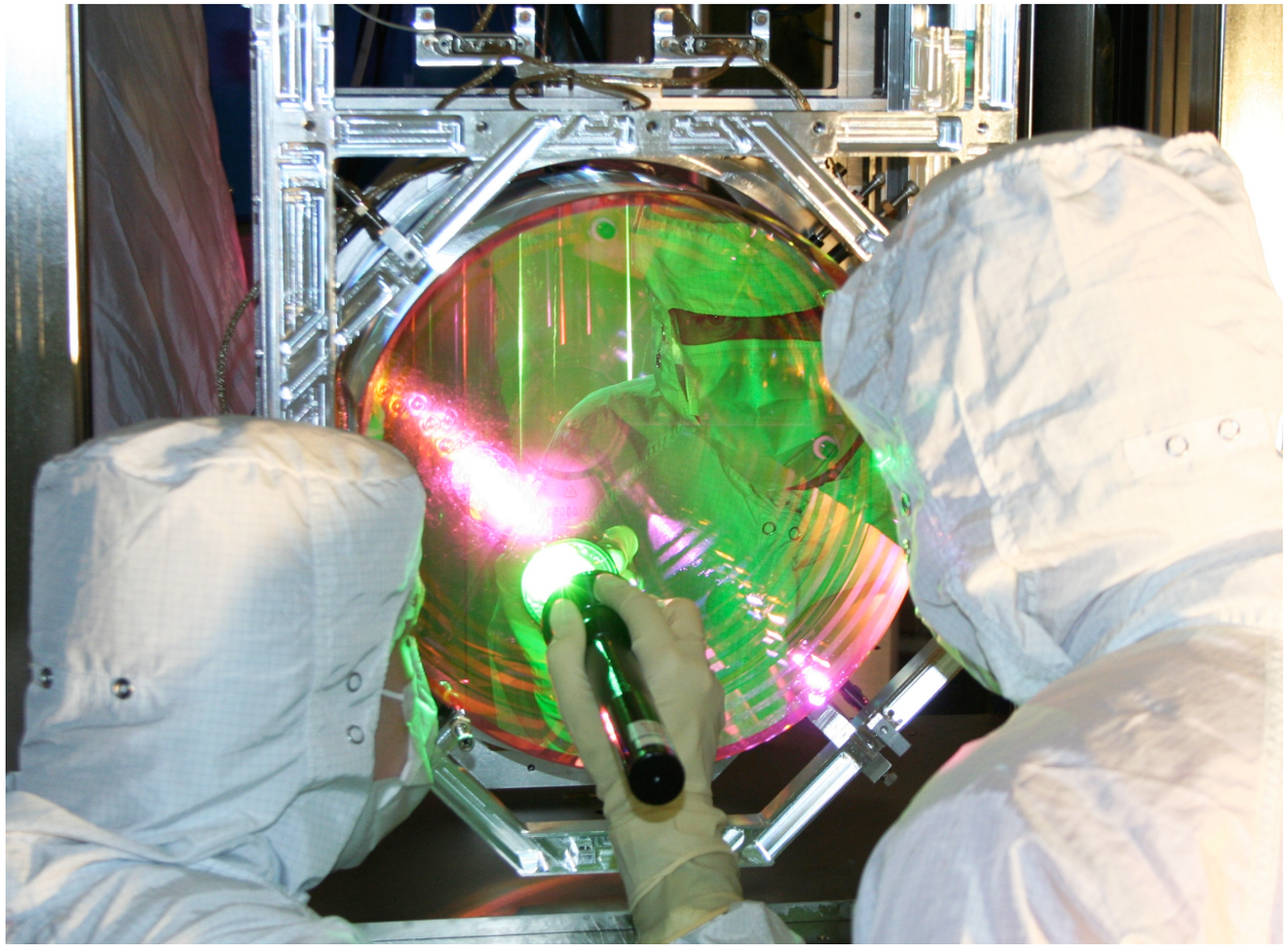
Pendulum Suspension





Mirror picts





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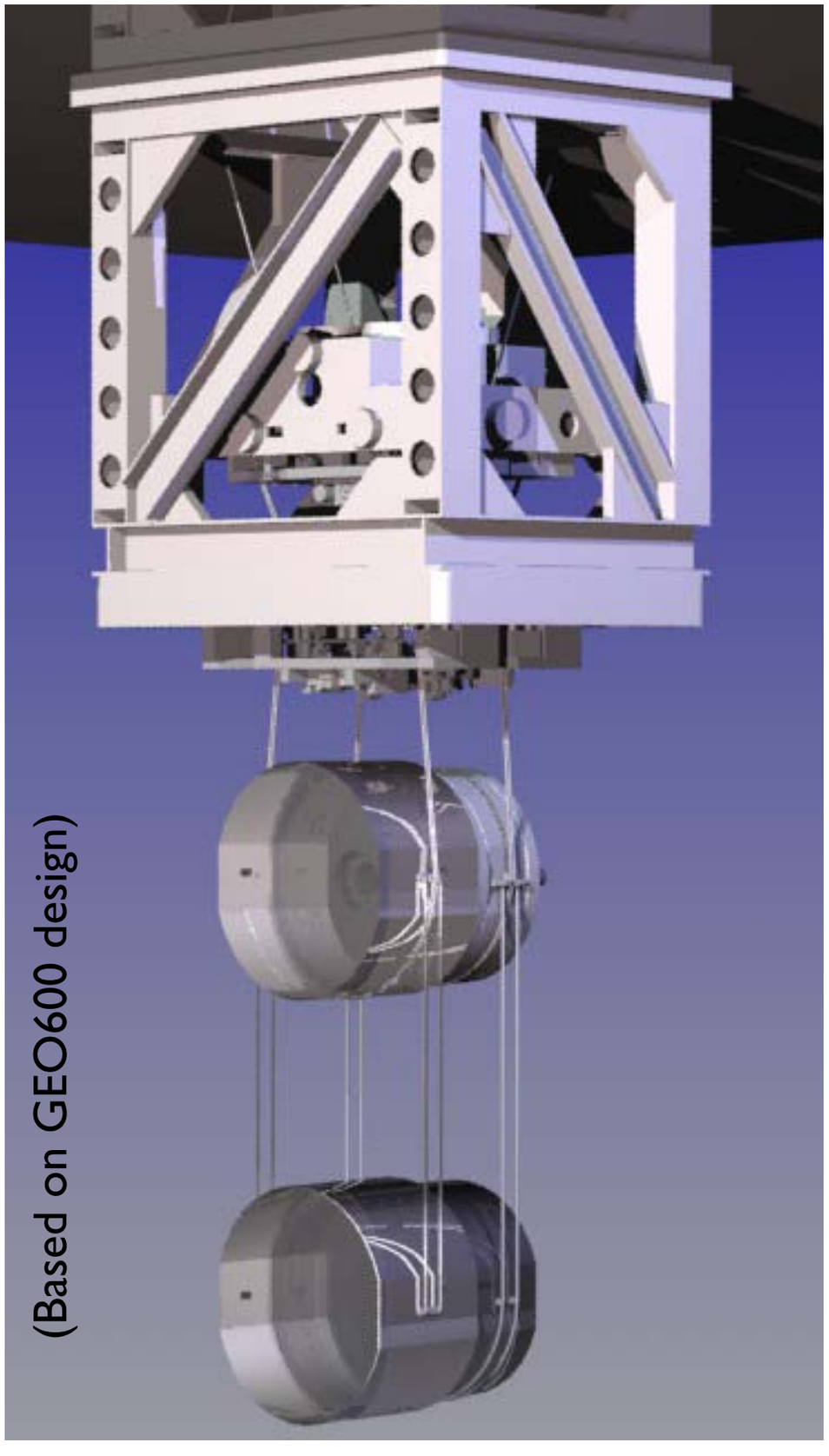
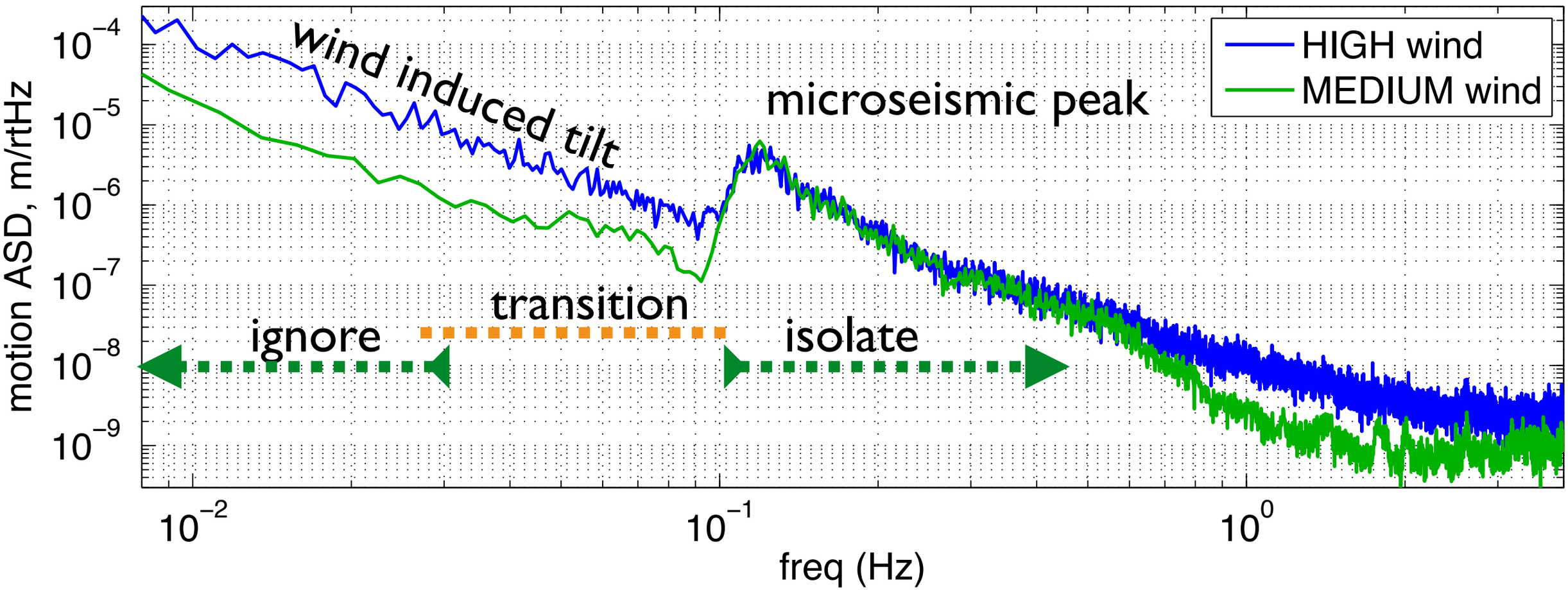


- Isolation at 10 Hz and above is great
- Isolation at 1 Hz and below is bad
- lots of cross coupling, ie
  length drive results in pitch and yaw motion
- control below 1 Hz, and large drives should
  be done with the platforms

Typical control condition

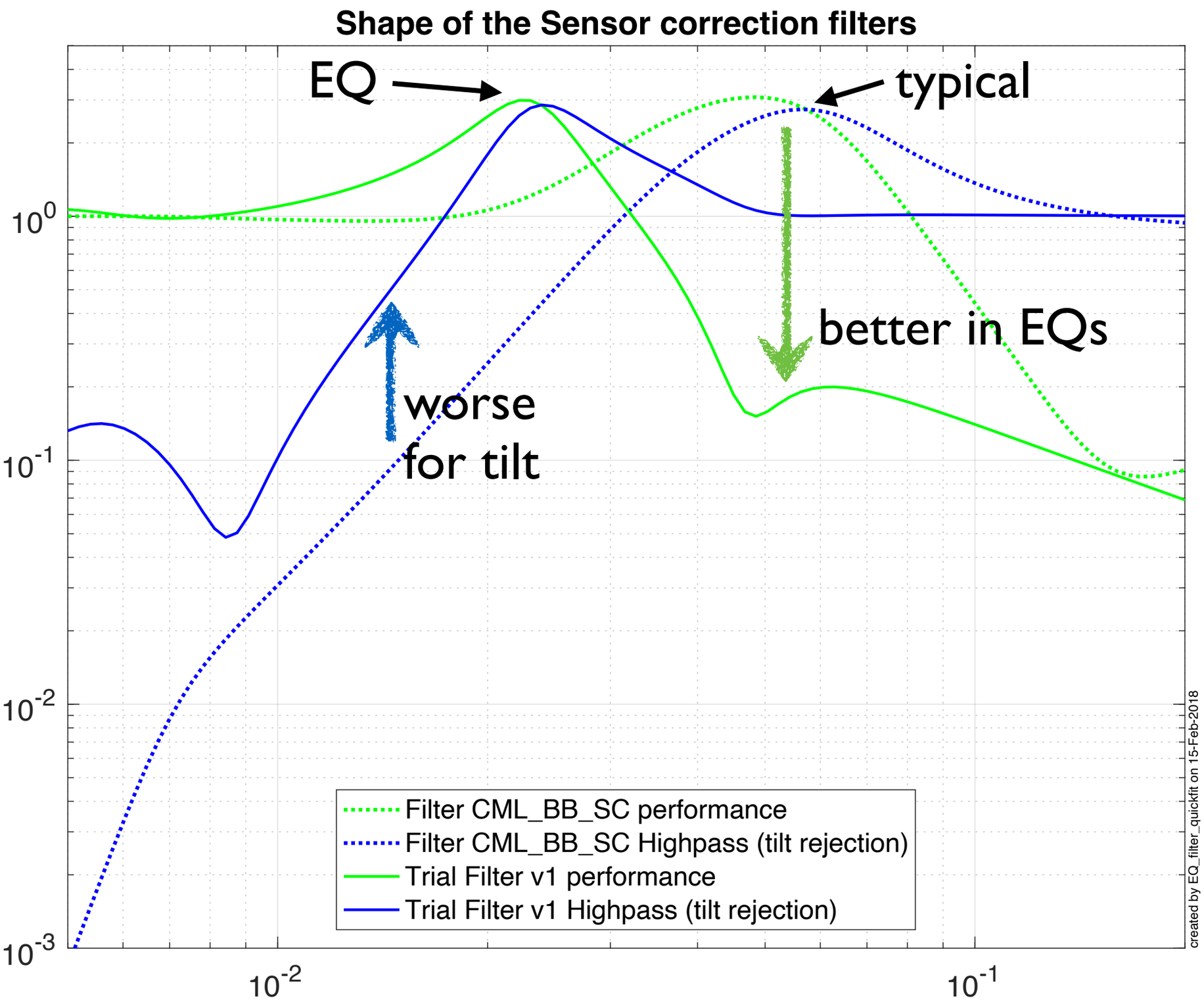


Use the ground motion signal for low freq. control (Sensor Correction)

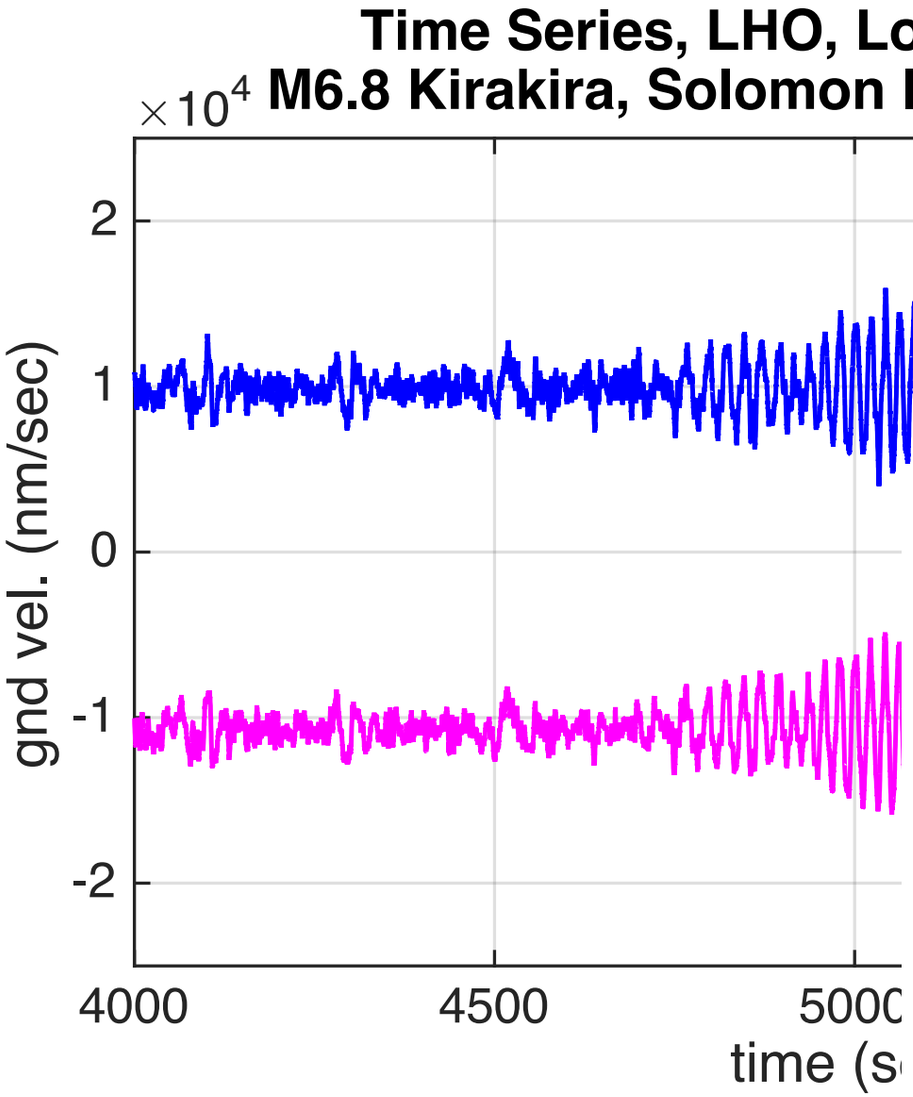
- Use the signals above ~100 mHz to isolate against the microseism
- Filter out signals below ~30 mHz to not couple *measured* ground tilt.
- Transition band has amplification (waterbed effect). *OK if band is quiet*.

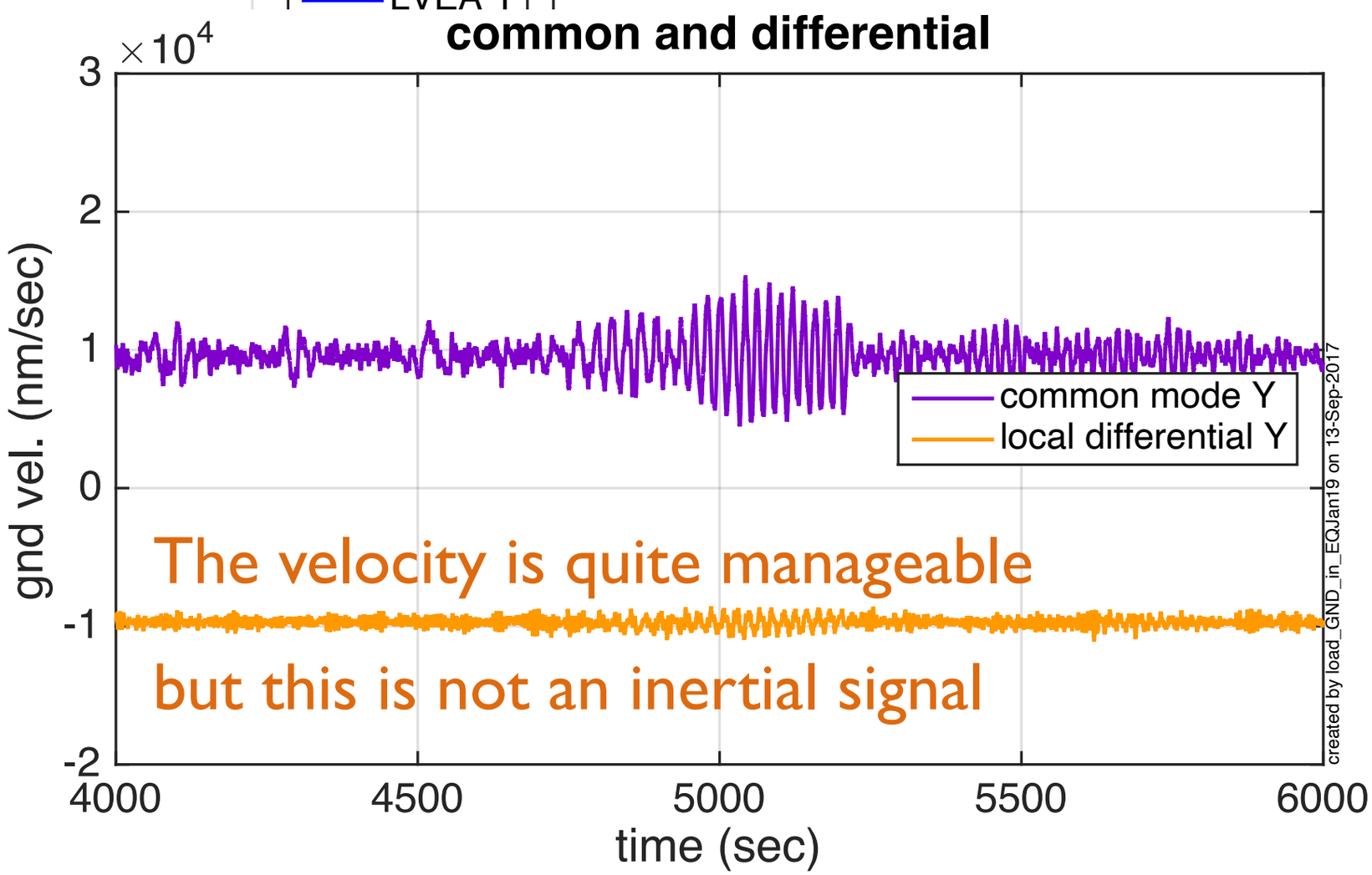
New Sensor Correction

Pick a shape that works better for the EQ motion



Most of the motion is Common-mode





Control schematic

seismon

USGS EQ monitor

arrival estimator (time and mag)

Operator (guardian) decides to switch

ITMX

ETMX

F-EQ

F-typ

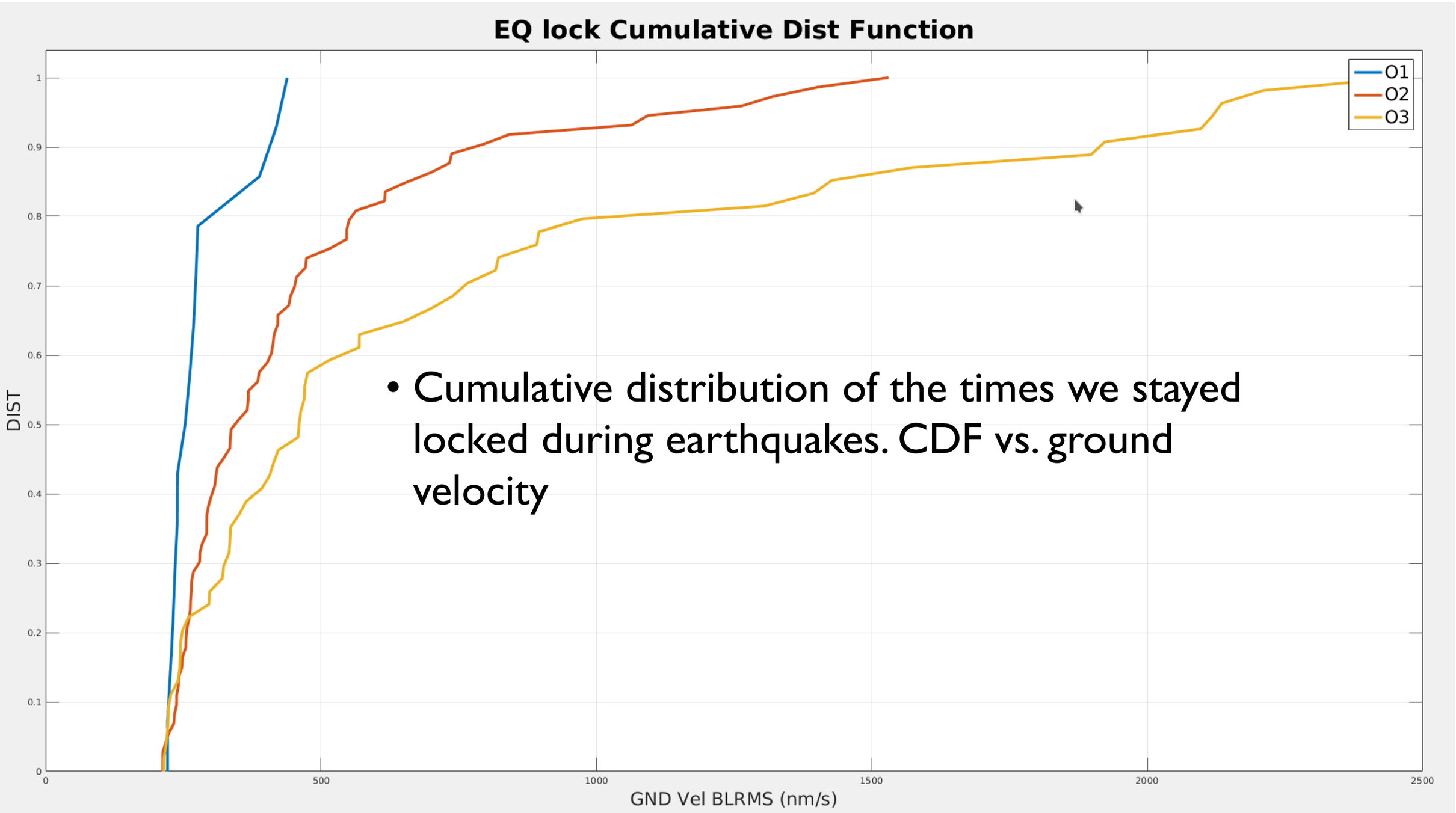
local differential

local abs.

avg.

common mode (average)

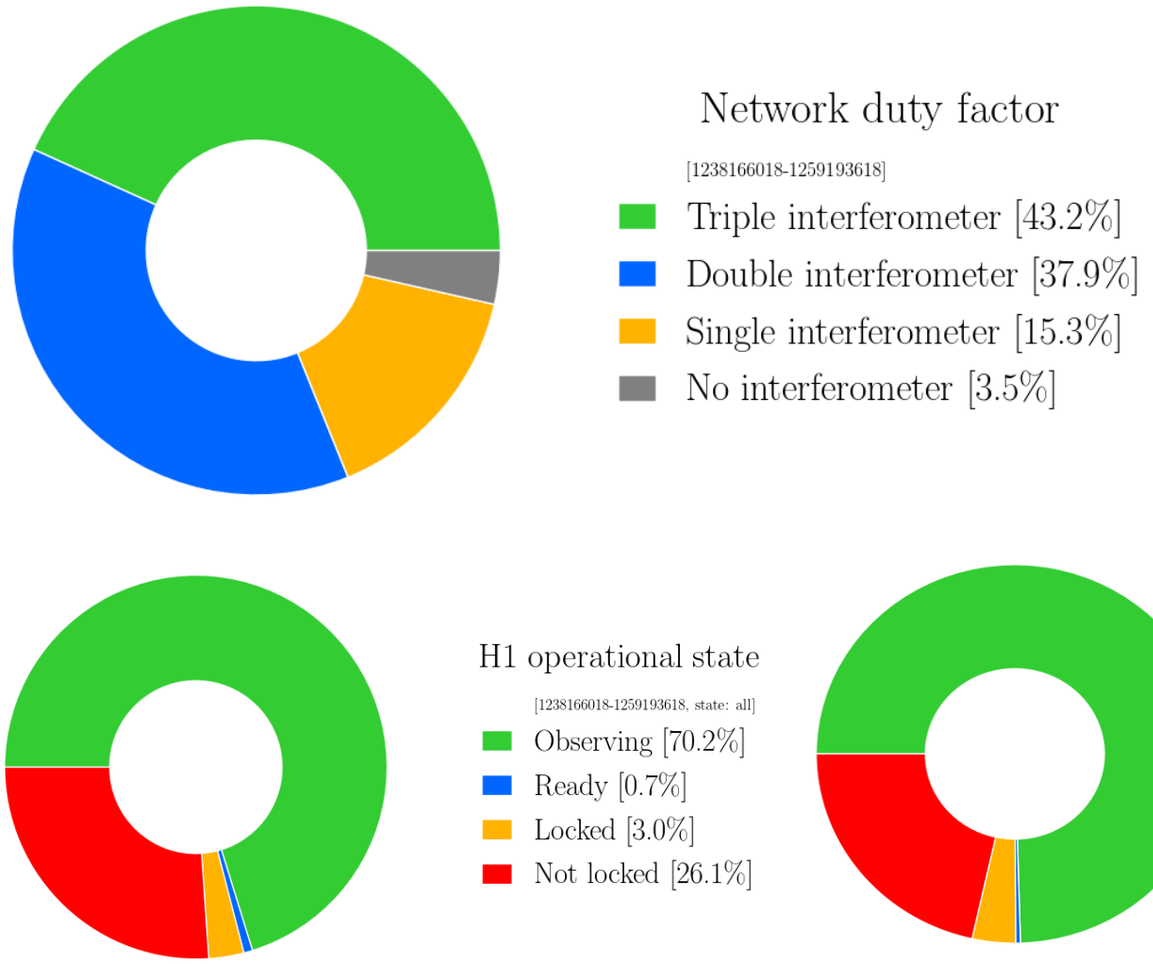
LHO stays locked with bigger ground motion



- Cumulative distribution of the times we stayed locked during earthquakes. CDF vs. ground velocity

- From J. Warner, LHO log 51388.
  When there is an Earthquake at LHO, does the detector stay locked?

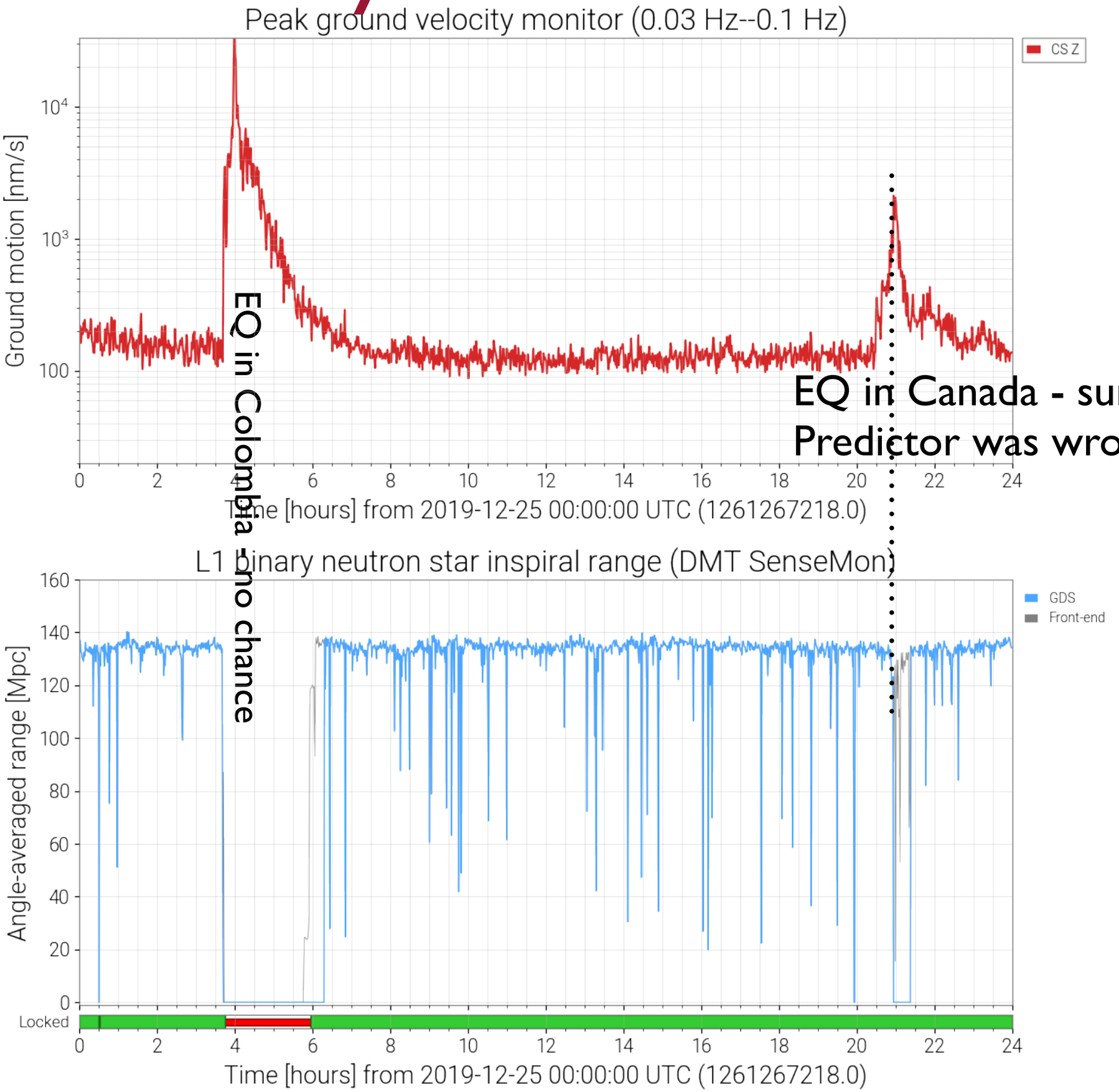
Detector Performance: O3 Cumulative Duty Factor



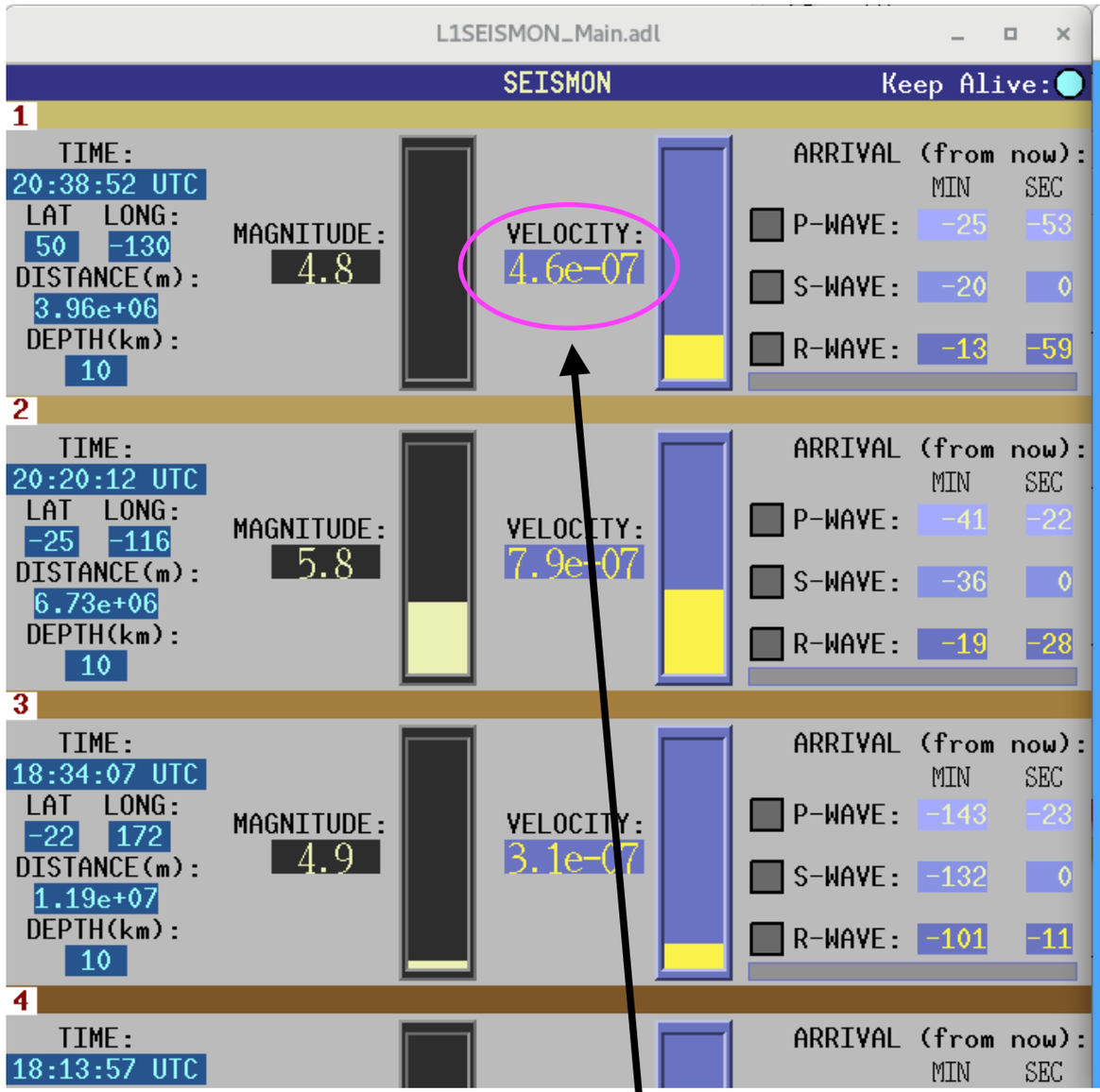
- 5 months with 43% triple interferometer duty factor
- >95% on sky coverage
- ~80% double IFO coverage
  - L1 & H1 coordinate non-observing time

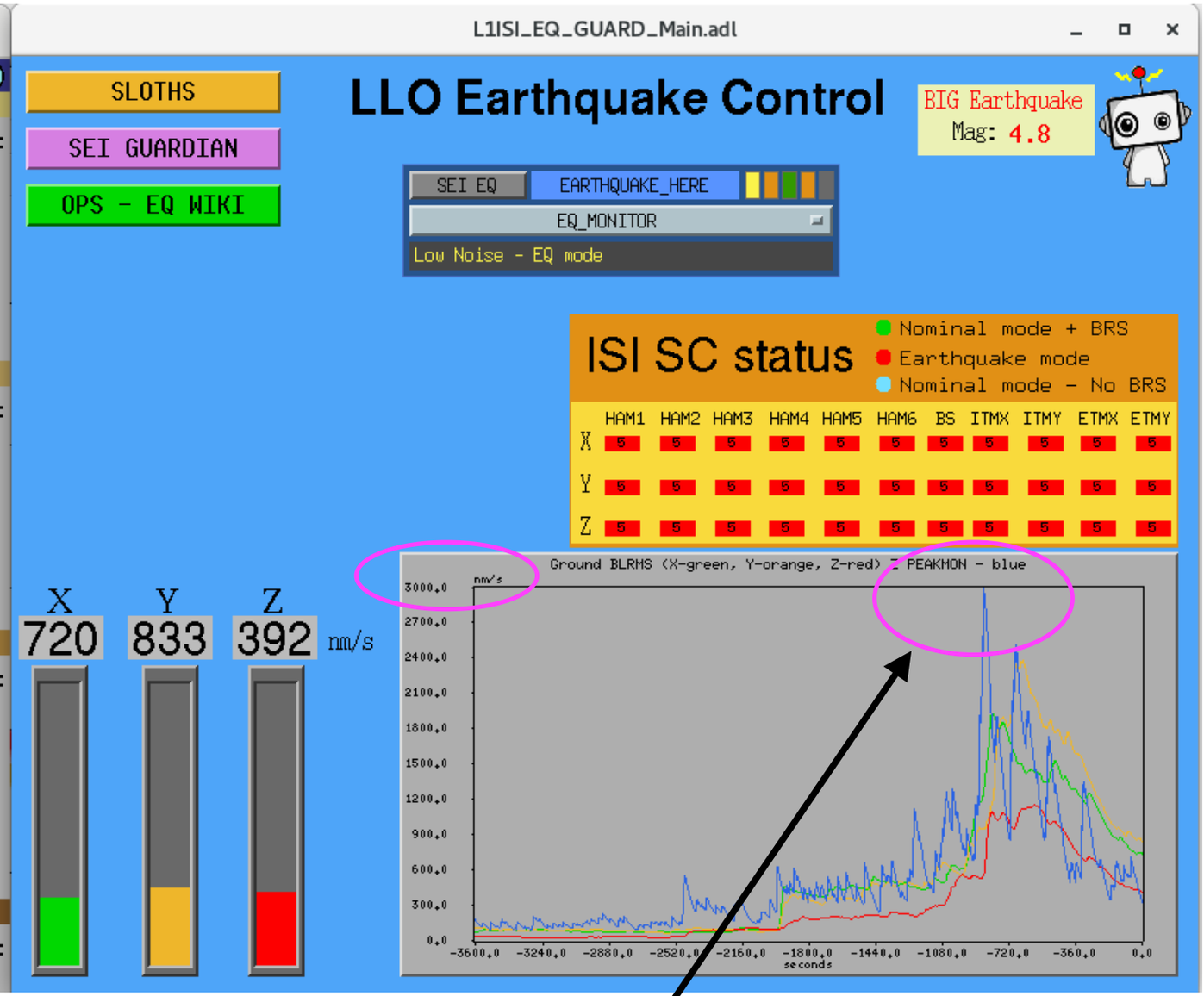
from G1901608

Merry Christmas!



- arrival time was pretty good (14 minutes ago)





predicted motion was 1/2 micron/sec
actual velocity was 3 microns/ sec

Log entry tells the story…

(From LHO log #50672 - Tom Evans, Eyal Schwartz)

- This was below our thresholds for EQ mode so the Quakebot did not trigger upon Seismon alert. However, when the R-wave hit us the ground motion was much higher than the predicted one by seismon
- hence the EQ mode was triggered automatically and we transitioned successfully just before the peak of the earthquake. There was an immediate reduction in the ETMX_L1_COILOFF_LL_OUTPUT that we have on the screen in the control room.

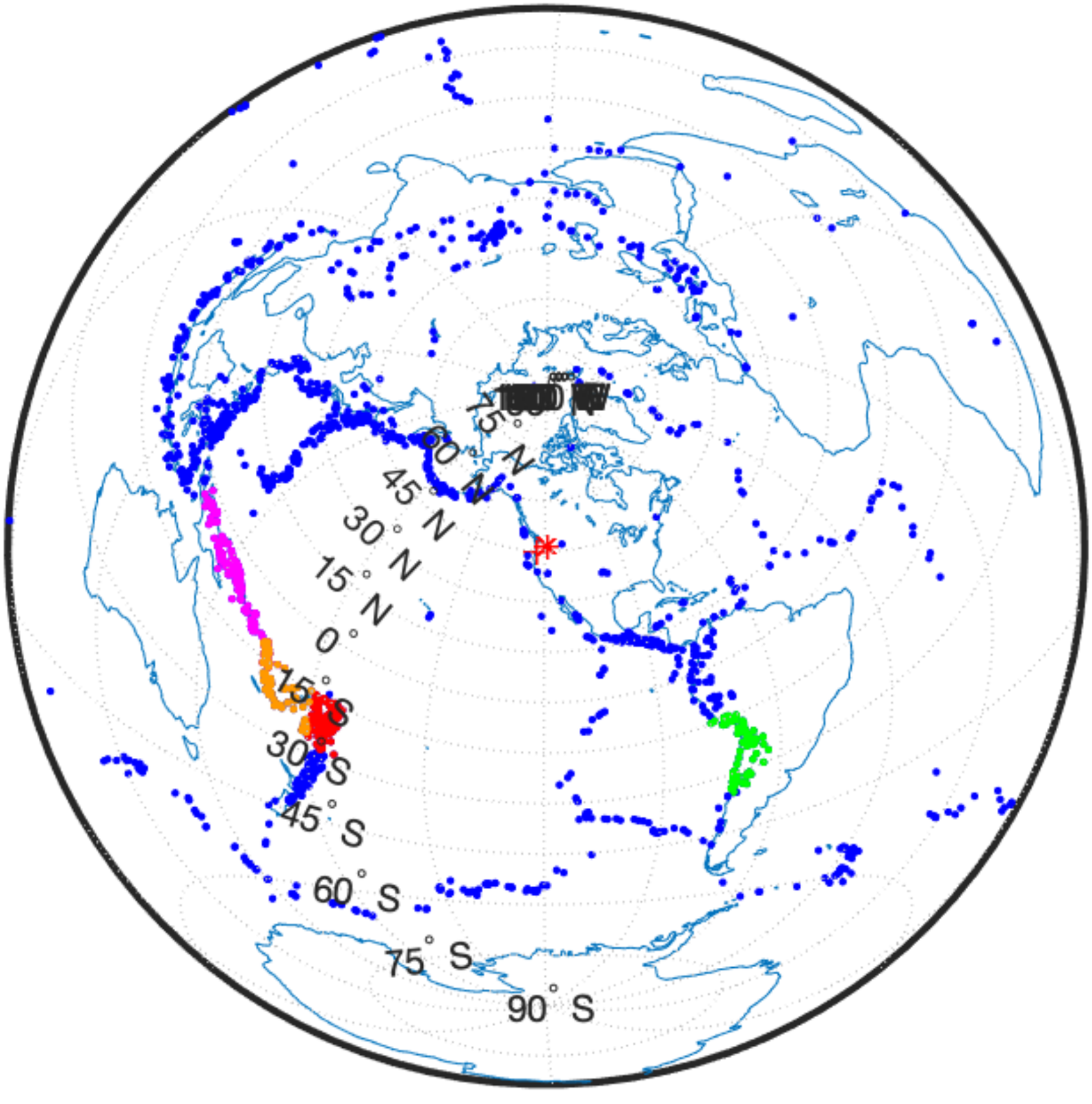
Earthquakes

- Eyal, Arnaud et. al. have gotten LLO nearly all the way to reliable operation of the earthquake mode. Is there any help needed to get across the finish line?
- Automation is very helpful. How to operate with a BRS offline has been an issue.
- Software cleanup will be necessary after O3 to deal w/ workarounds.

- Three new efforts to improve predictions of teleseismic events:
  - Nikhil is trying to rebuild the training database.
  - Picket Fence: Brian, Anne and Grace are working with Paul Earl, NEIC at USGS, to get low-latency monitor of the actual waves setup
  - Improve SeisMon prediction by combining new NEIC source information (moment-tensors and focal-mechanisms) and combine that with detailed global propagation models. Prof. Jascha Polet (Cal Poly, Pomona) offered to help.
- ShakeAlert is a rapid-alert system for local events, now live in CA. Brian and Jim are working with Margaret Vinci at USGS to get LHO set up as a beta-test site for the system in WA and OR. Hope is to get several seconds of alert and push detector into a 'safe' mode to help avoid troubles like we got from the Montana EQ in July 2017. (Montana is not in the WA, OR network, but that's the idea). We are looking for suggestions on responses.

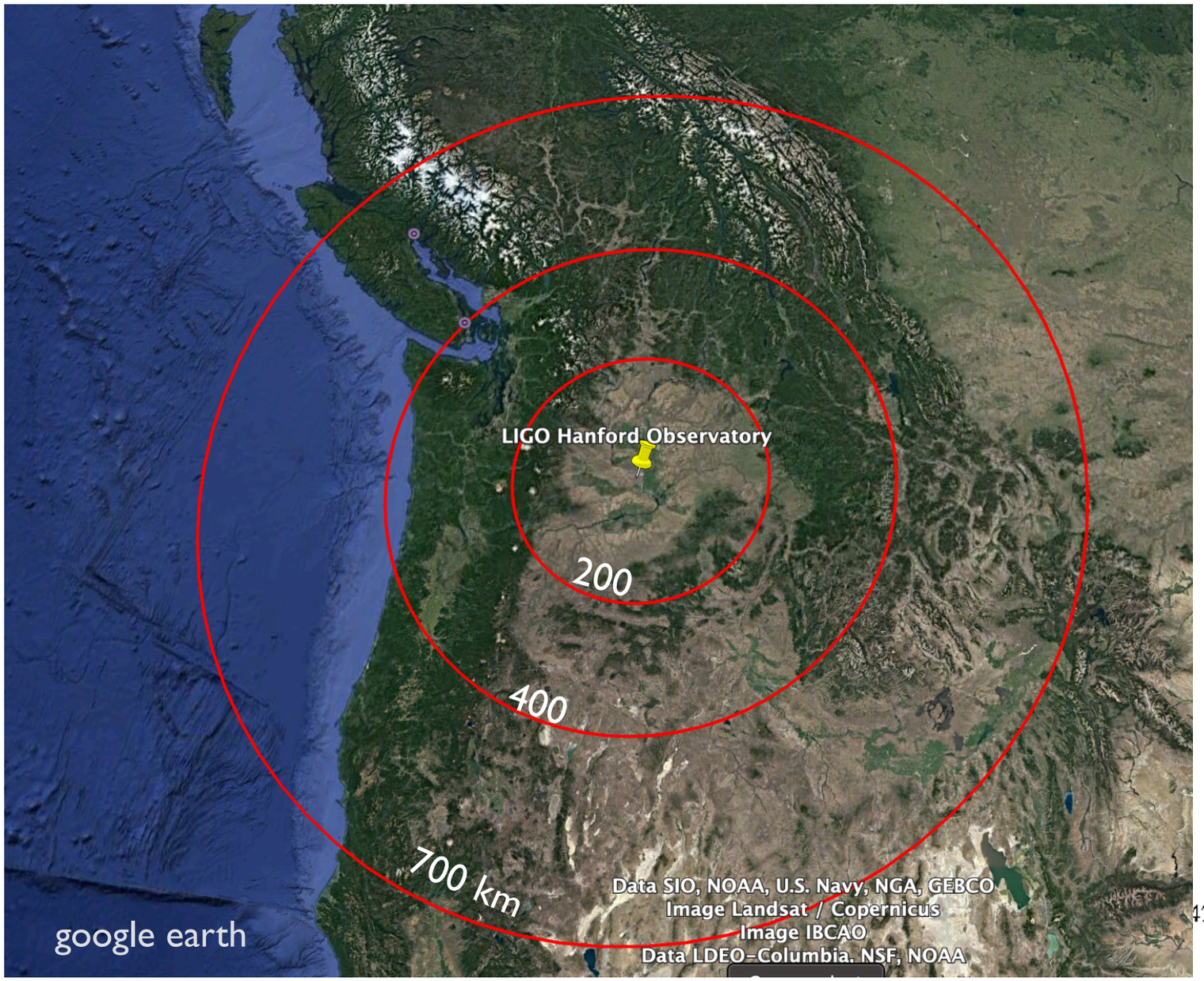
LHO's view of the world

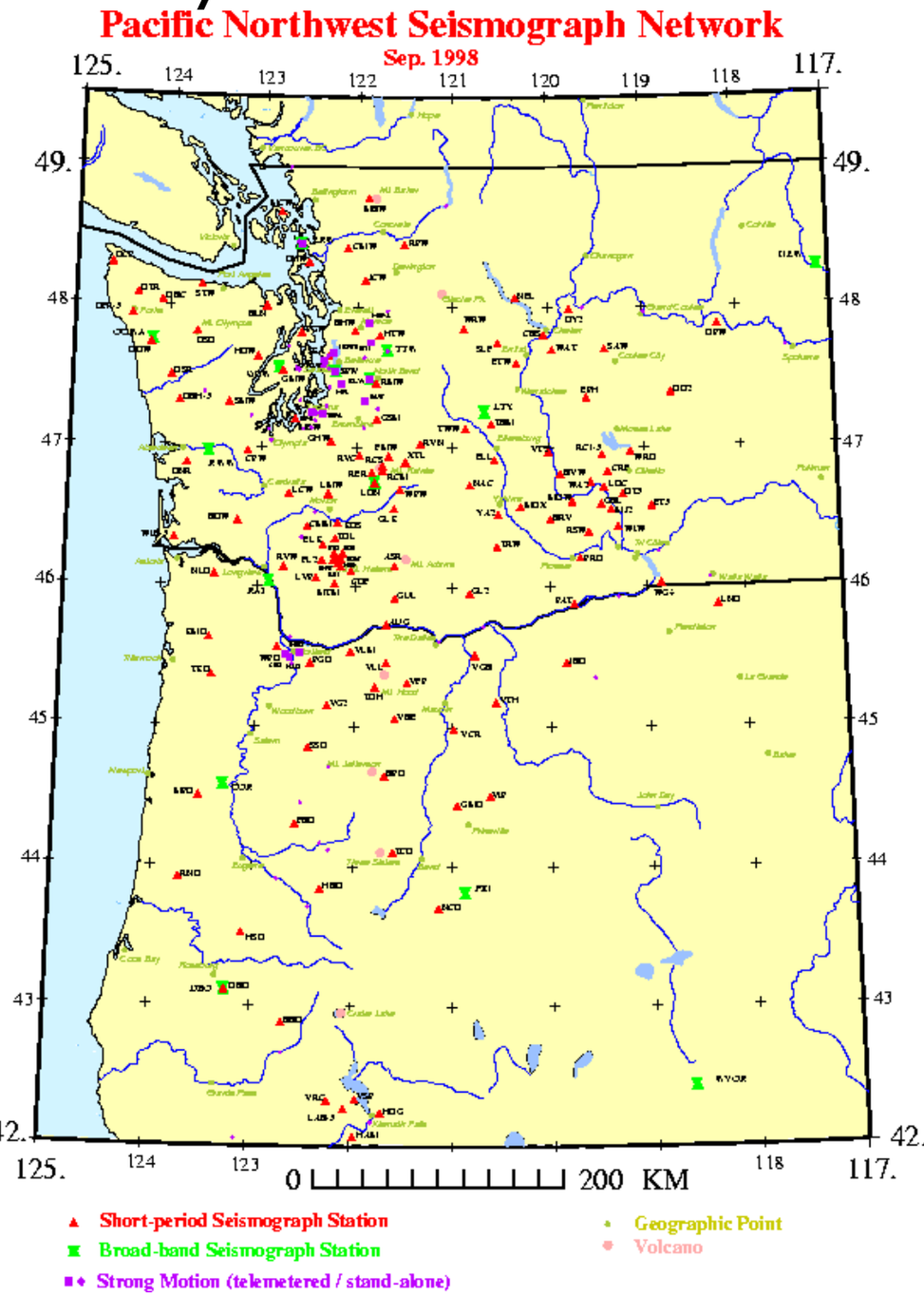
Can we watch the waves roll in?



Seem to be lots of stations

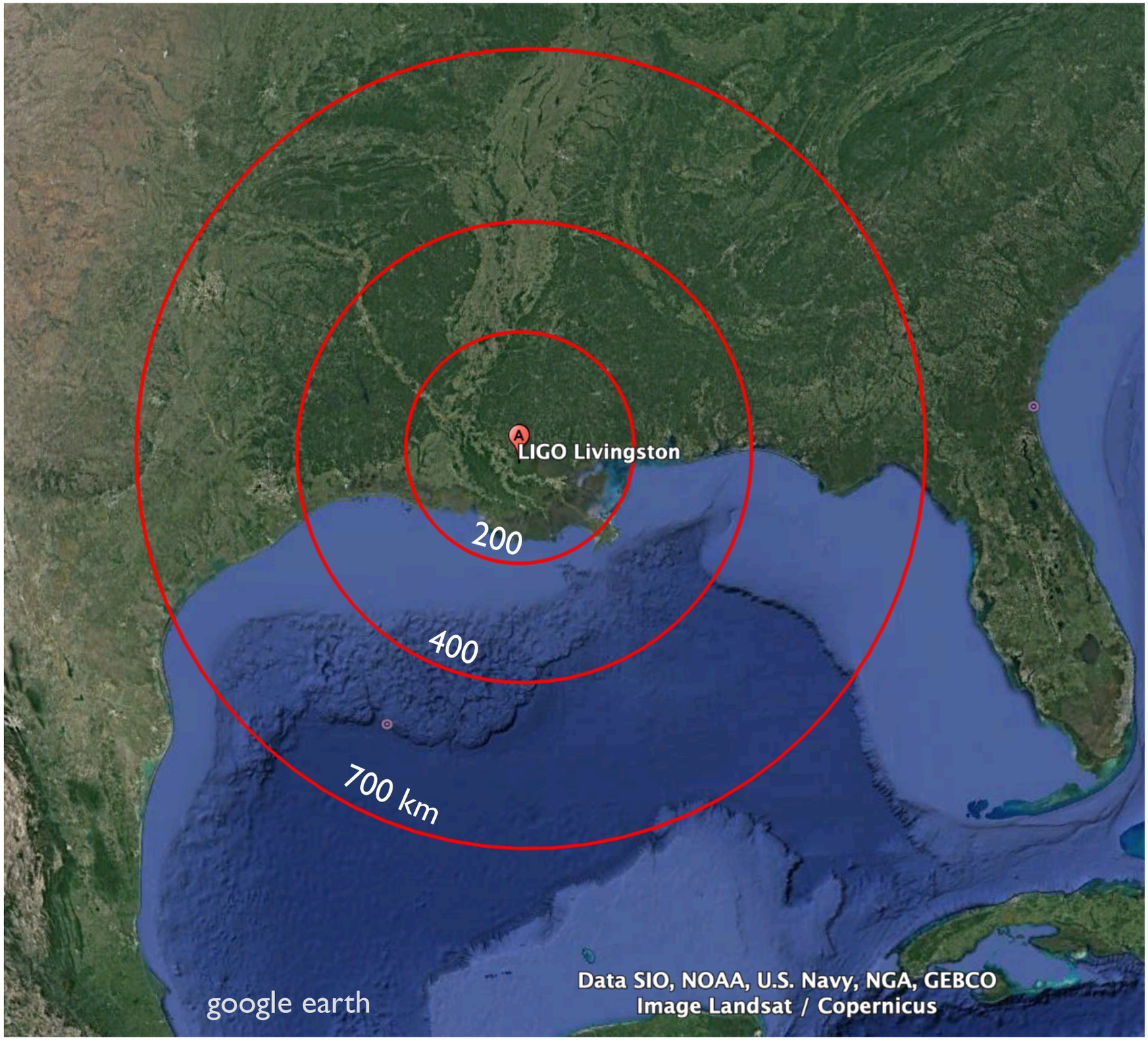
200 - 400 km gives 50 - 100 seconds of travel time delay





A. Baer

Not so clear for LLO…



A. Baer

Monitor the incoming waves?

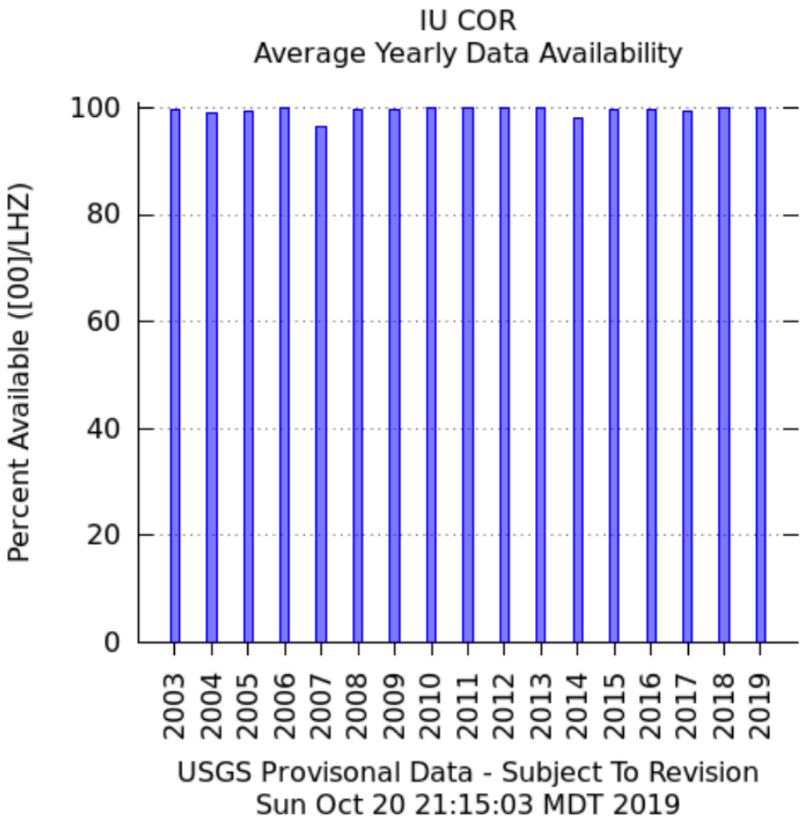
Station IU COR

Corvallis, Oregon, USA

IU COR commences operations on: 1989,299

https://earthquake.usgs.gov/monitoring/operations/stations/IU/COR/

Host	Oregon State University
Network	IU
Latitude	44.586
Longitude	-123.305
Elevation	110
Datalogger	Q330
Broadband	STS-1VBB_w/E300
Accelerometer	FBA_ES-T_EpiSensor_Accelerometer
Telemetry Status at the NEIC	▲ Last data in less than 10 minutes



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.