Construction of a Seismic Array at the Former Homestake Mine

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LIGO-G0900736.

Abstract: *This summer, five additional seismometer stations were deployed at the Sanford Underground Laboratory in order to determine the magnitude of the seismic noise at various depths. Construction of the stations required insulation of the seismometers from air currents and temperature fluctuations. Sensor boards were installed at the sites to monitor environmental conditions. The data produced by this array of stations might aid in determining the feasibility of modeling seismic activity so that the associated Newtonian noise could be subtracted from gravitational-wave detector data. Correlation measurements between the signals from neighboring stations would provide the most relevant results for this noise-subtraction technique.*

Why a seismic array underground ?

Future generation ground based interferometric detectors for gravitational waves will operate below 10Hz.

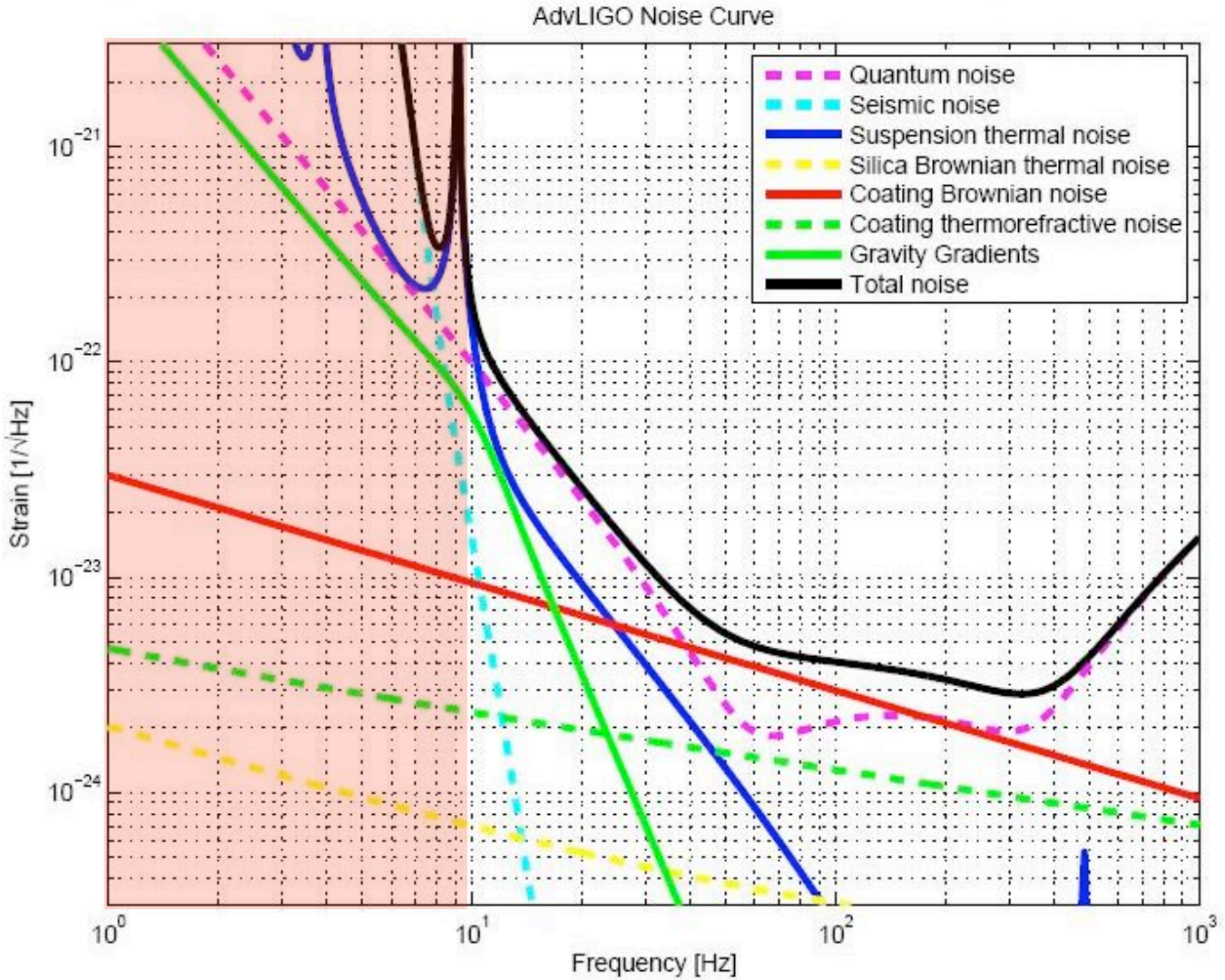
Significant noise sources in 1-10Hz frequency range :

- Newtonian Noise (i.e. gravity gradient noise) limit

- Earth's crust motion (tidal stresses and seismic activity)

- Cultural noise: human activity

Why a seismic array underground ?



Why a seismic array underground ?

Newtonian Noise is due to seismic and atmospheric density fluctuations
Fluctuating gravity fields couple to the test masses themselves:
no filter can act against it !

Underground in a seismic quiet site:

- lower density fluctuations
- higher correlation
- lower seismic noise
- no surface modes

Why a seismic array underground ?

Lower seismic noise… but how much?

Reduction expected:

$$e^{-\frac{d}{\lambda}}$$

To measure it and the wave propagation an underground array of seismometers is needed.

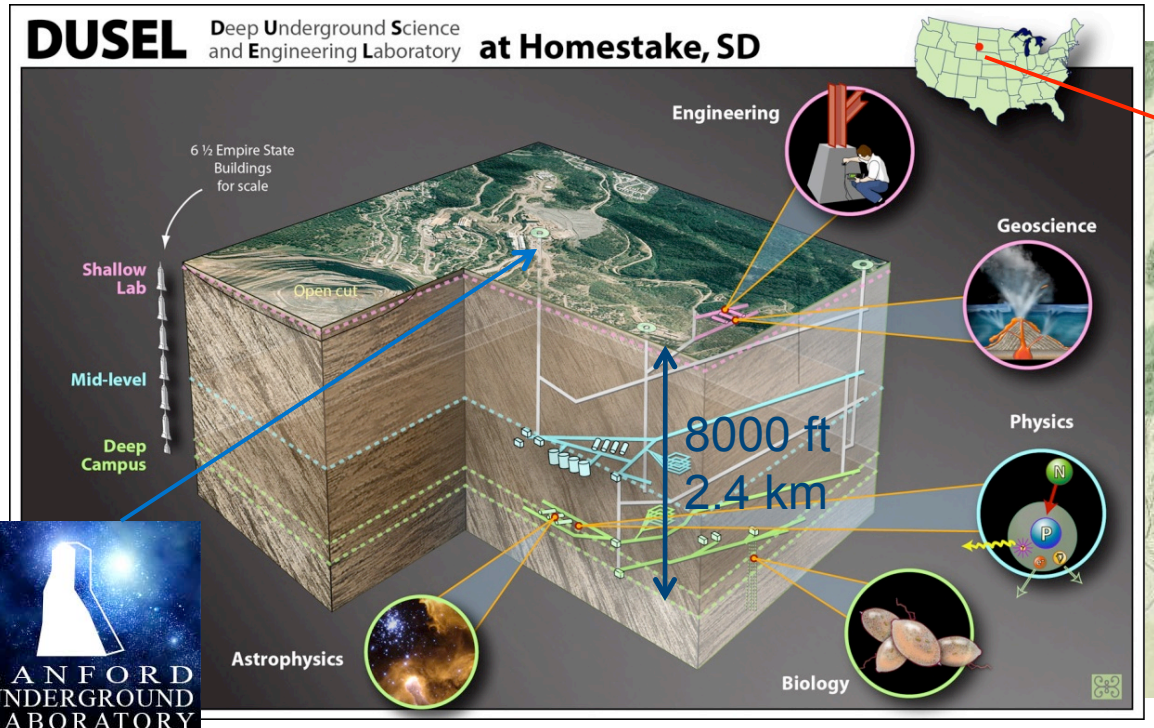
the seismic data produced by a 3D network of seismometers will help us to calculate and subtract it from the data of a future generation GWID.

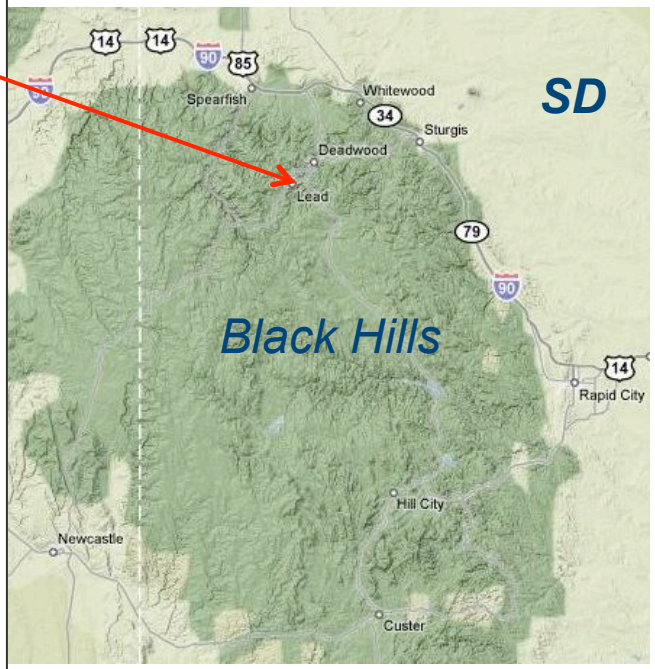
Why the Homestake former mine ?

Former Homestake gold mine in Lead is being transformed into an underground scientific laboratory by the SDSTA (*South Dakota Science and Technology Authority*)

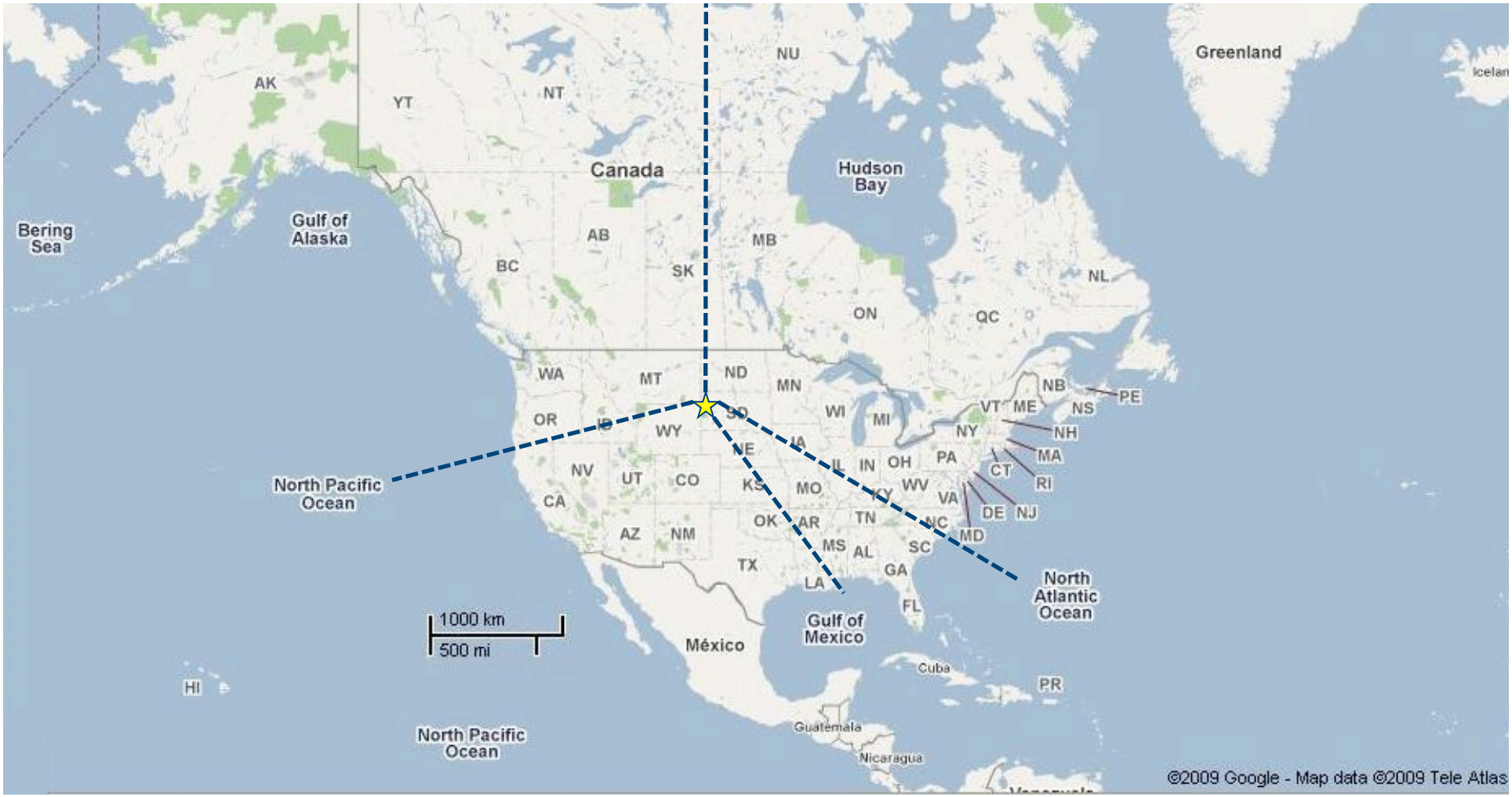
Now it is known as the **Sanford Underground Laboratory**

chosen also to host the future NSF DUSEL (*Deep Underground Science and Engineering Lab*)

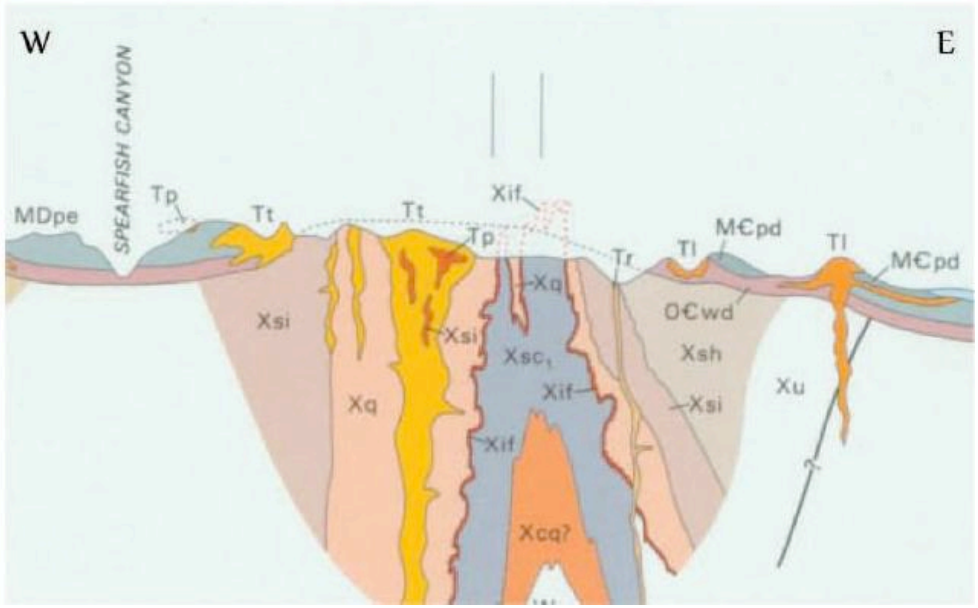


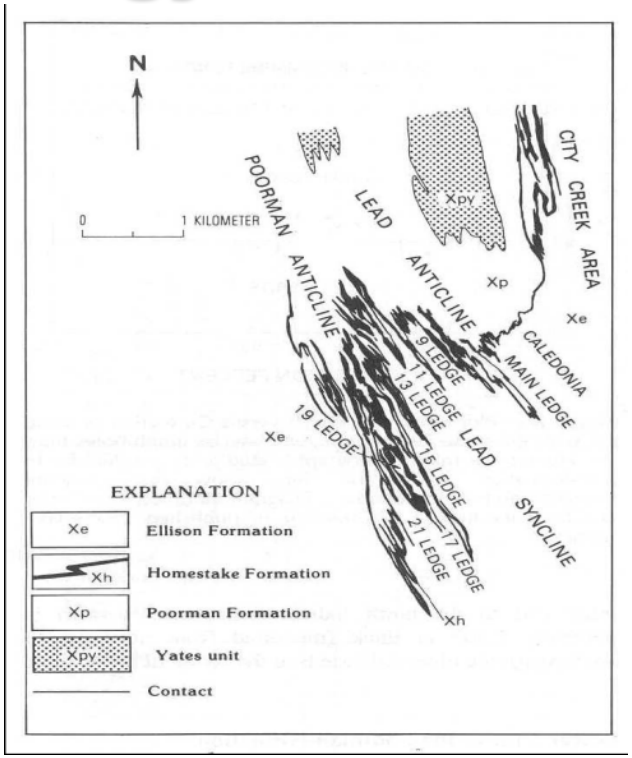


Why the Homestake former mine ?



Homestake site geology





The geological history of the Homestake site is quite complicated

- oldest rock strata 2 billion years old
- stratification, folding and metamorphism
- **discontinuity: original and intrusive rock strata**
- **network of fractures: meteoric water intrusion**

underground levels are accessible only with a constant water drain

A database of rock samples is owned by Sanford Lab

Homestake infrastructure

On July 2009 the deepest accesible level was 4100ft (although the 4850 ft level was recently made accesible).

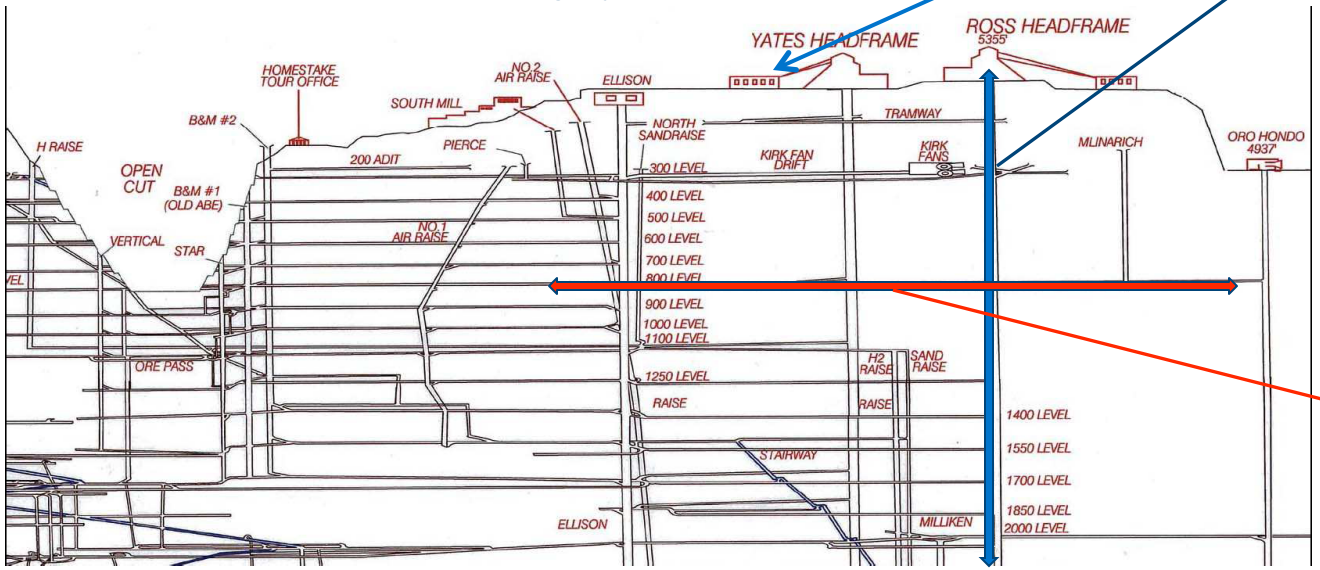
Actually the only Shaft accesible is the “Ross” Shaft. The main office building is situated in the “Yates” area

A power and internet connection between underground levels and surface is still developing by SDSTA.

Shaft +Office building

“Cage”

Shafts



Drifts and cross-cuts

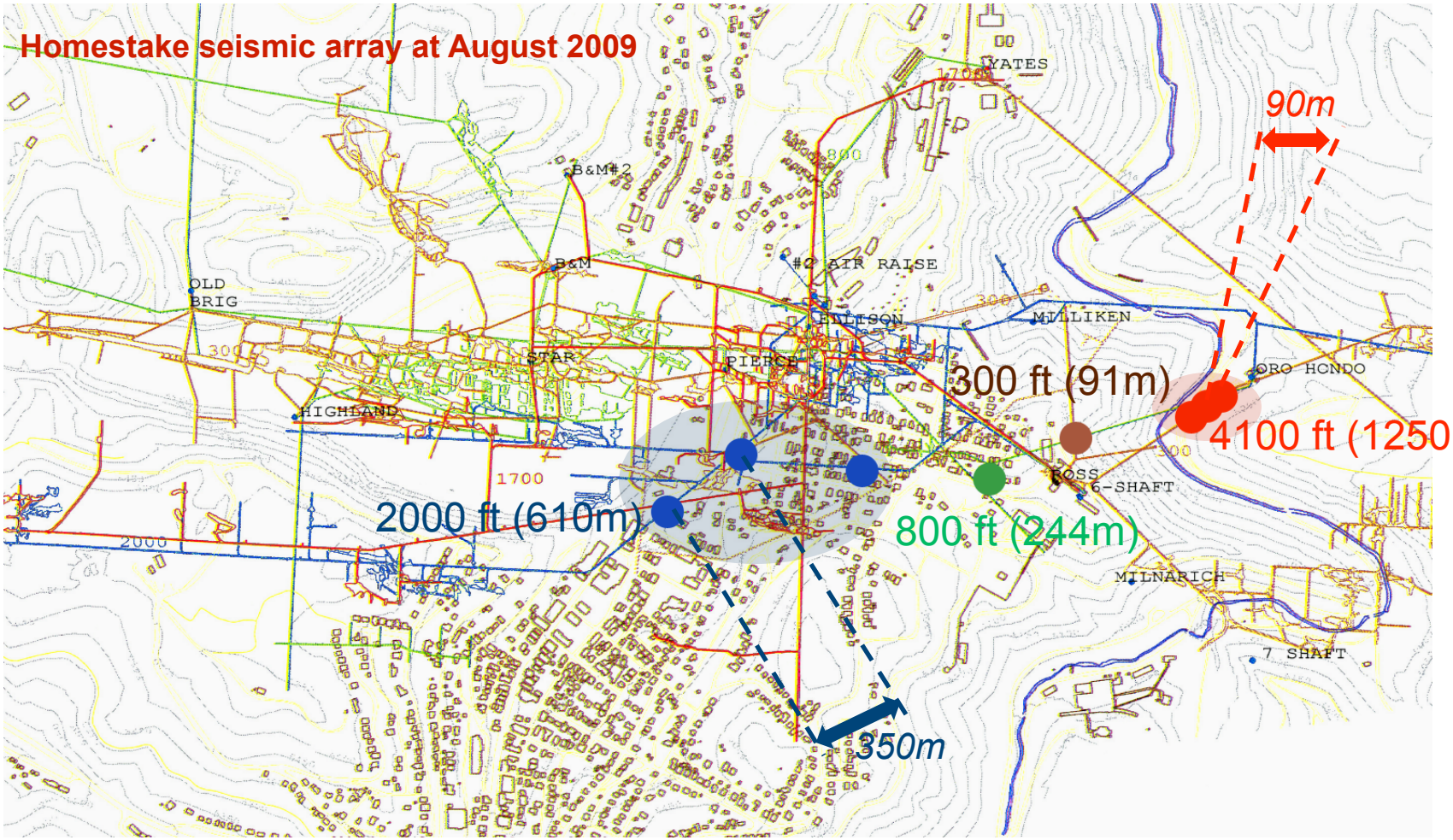
Construction of the new stations of the Homestake seismic array

Initial situation: three stations completed and at three different levels (300ft, 800ft, 2000ft)[1].
Our goal: fix the old stations configuration and extend the seismometers network with five new stations
Work duration: 9th June - July 31st
New stations: two at 2000ft level, three at 4100ft level

Collaboration with ET (group of Jo van den Brand from Netherlands) and Guido Mueller (from the University of Florida).

[1]: J. Harms et al. ; seismic studies at the Homestake mine in Lead, South Dakota

Construction of the new stations of the Homestake seismic array



LIGO

Preparing the sites… digging and concrete laying




- Locate a site
- dig and shovel rocks and debris
- sound the rocks to avoid rock fractures
- build a stable concrete base well connected to the bedrock

LIGO

Preparing the sites… the seismometer base

A levelled square granite tile for each seismic instrument is implemented with a concrete slab to the bottom rock. The seismometer itself can be levelled once it is placed on the tile.

Preparing the sites… insulation

Building a hut to insulate computers, DAQ and UPS

Polyisocyanurate panel

Instruments box

The “great stuff” (Polyurethane foam glue)

Double layer panel

Additional internal box

-Variable environmental conditions depending on ventilation
- Very high humidity (over 90% to 100%)
- Acoustic noise from ventilation or people working around
- Computers noise
- Insulation ensured by polyisocyanurate boxes

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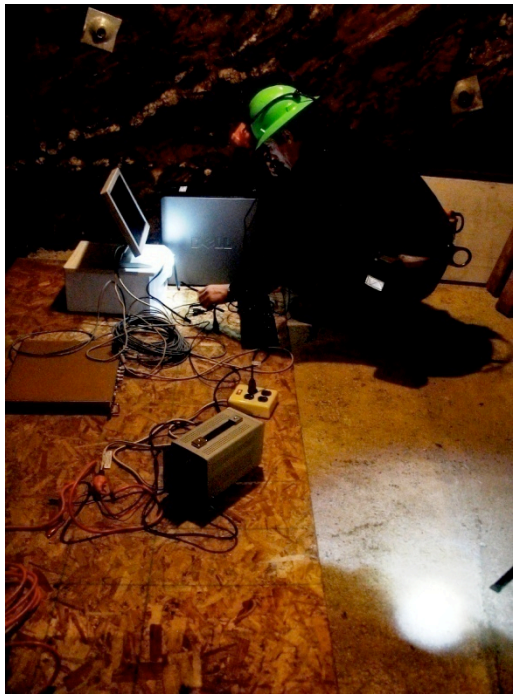
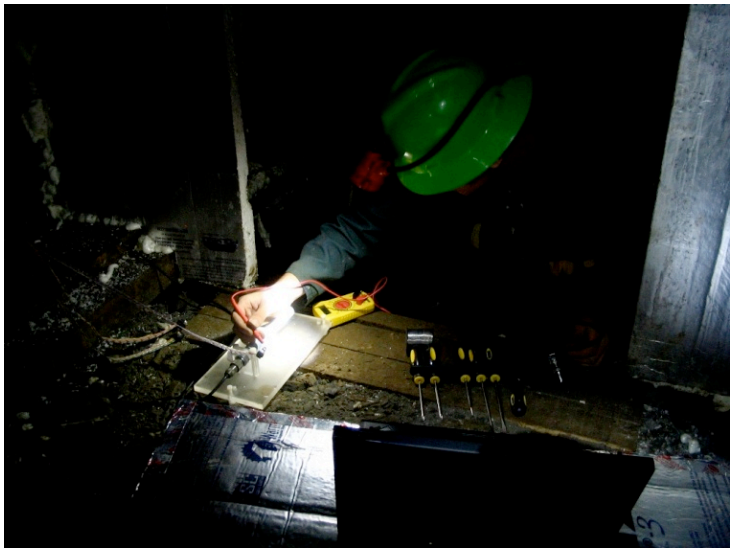
Preparing the sites… power and network



- Power and fiber-optic-cable network provided to an electric box by Sanford Lab
- Prepare connections and cable links
- UPS units ensures a continuous power supply, preventing black-outs and voltage surges

LIGO

Preparing the sites... constructing what is needed

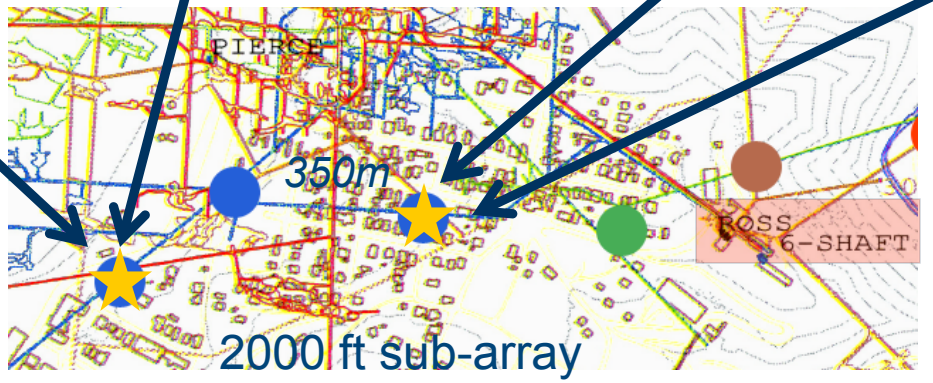


- Reparations
- Solder wires
- Fix eletronics
- carpentry work

Two new stations at 2000 ft




110V AC power supply:
available
Internet connection:
available

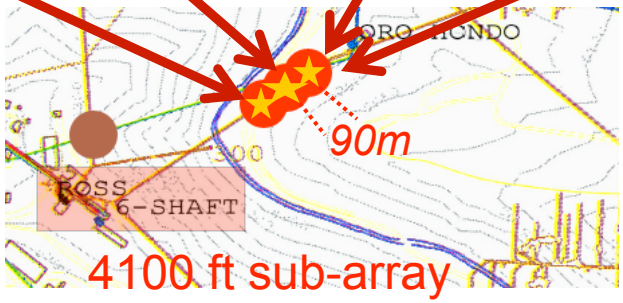


110V AC power supply:
available
Internet connection:
available

Three new stations at 4100 ft

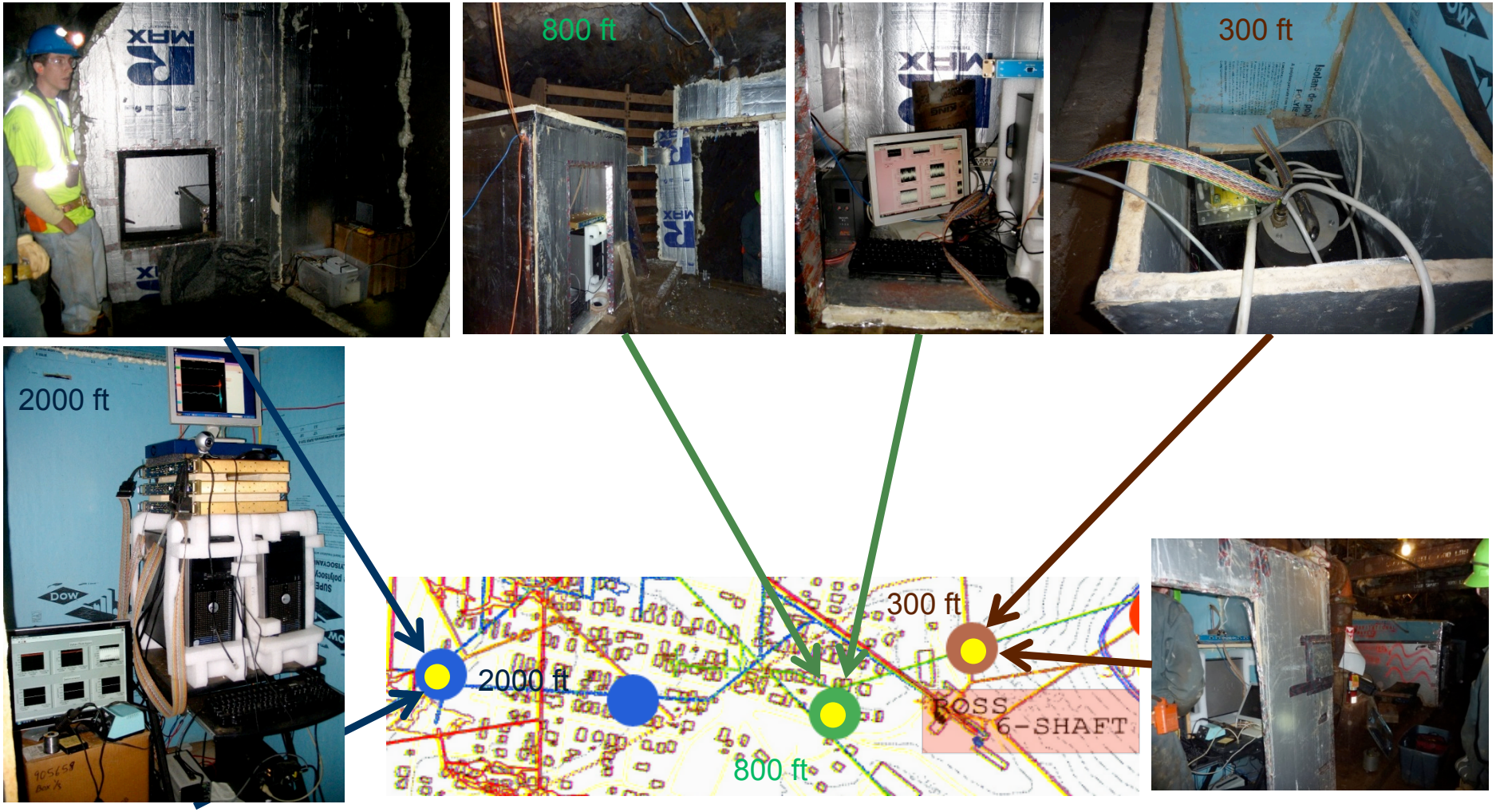



110V AC power supply:
available
Internet connection:
still not available

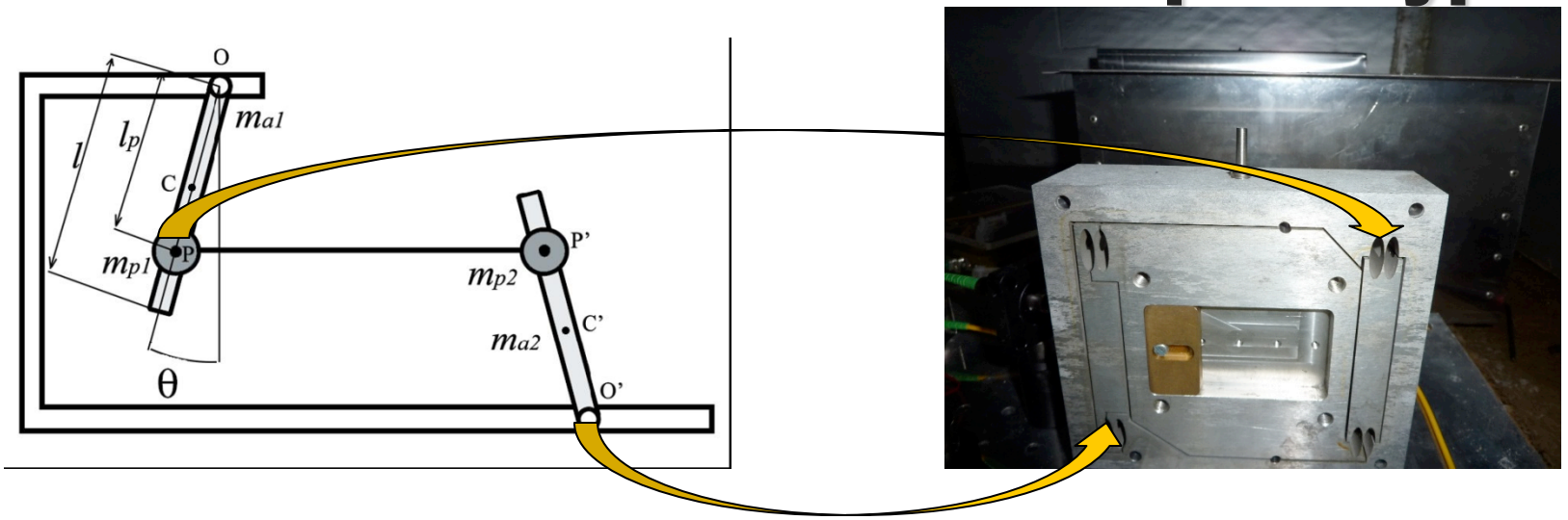


110V AC power supply:
available
Internet connection:
available

The old three stations



The horizontal seismometers prototypes



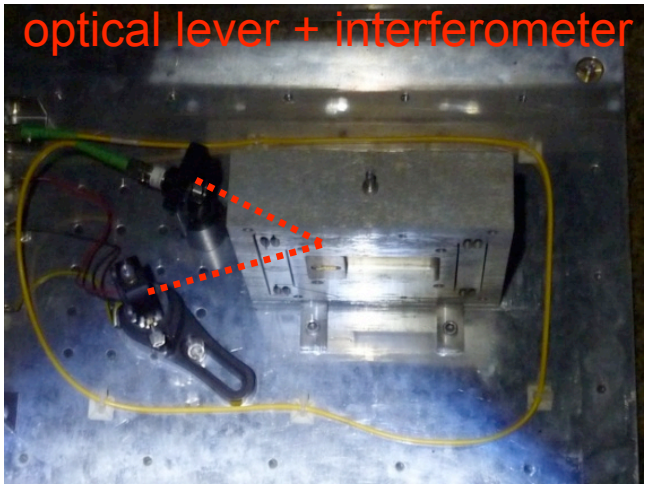
The 2000 ft station hosts two Italian horizontal seismometers prototypes (group of Fabrizio Barone -University of Salerno - INFN)

- monolithic tunable folded pendulum[2]
- shaped from one original body of Al-CuBe alloy
- central mass linked by 4 flex joints (100μm minimum thickness)
- very sensitive in the low frequency seismic noise band
- tunable resonance frequency and laser optical readout

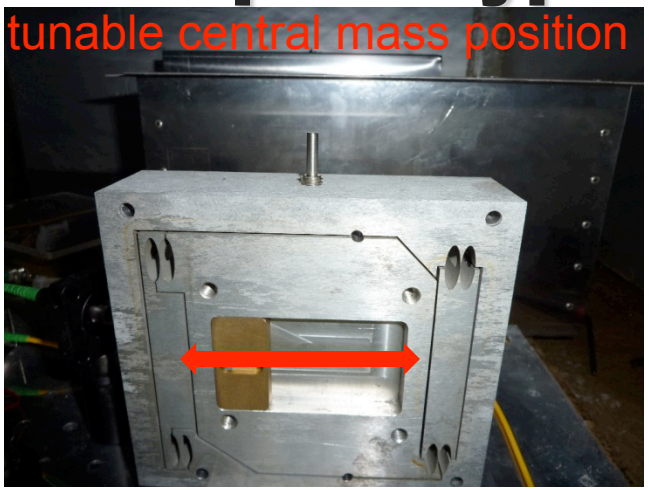
[2]: F. Acernese et al. ; tunable mechanical monolithic horizontal accelerometer for low frequency seismic noisemeasurement

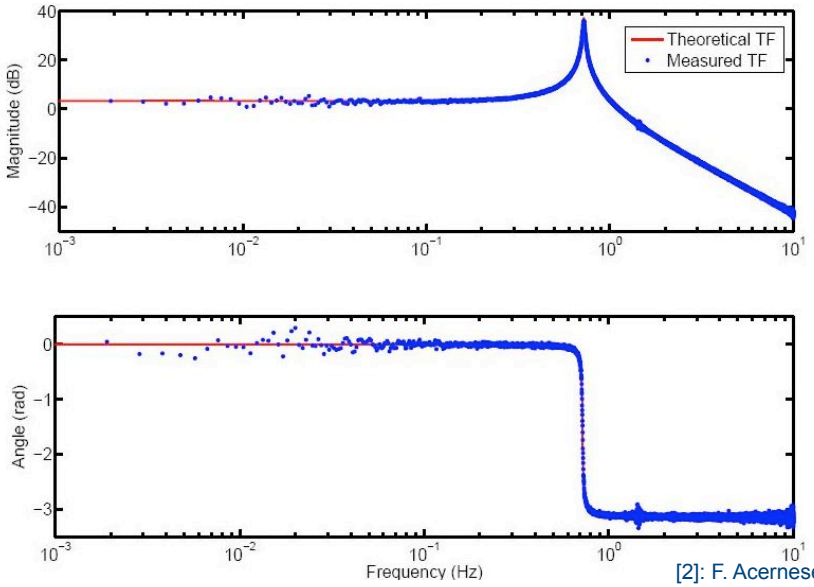
The horizontal seismometers prototypes

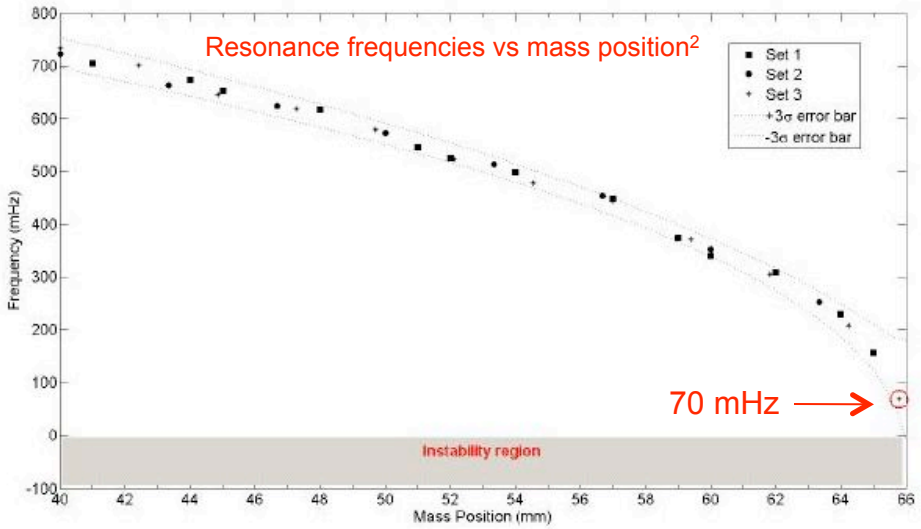
optical lever + interferometer



tunable central mass position

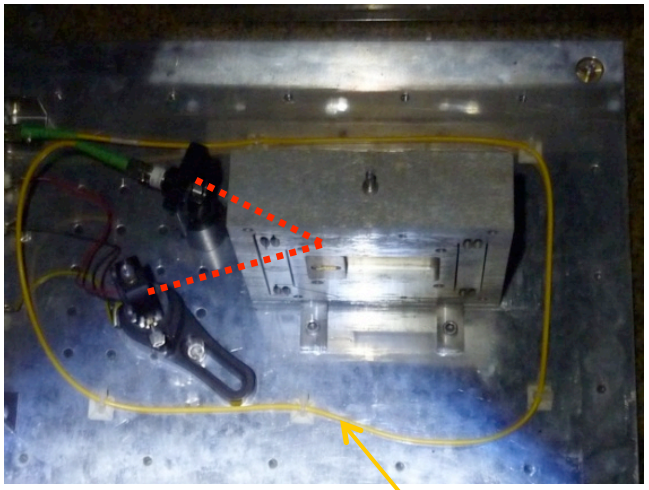


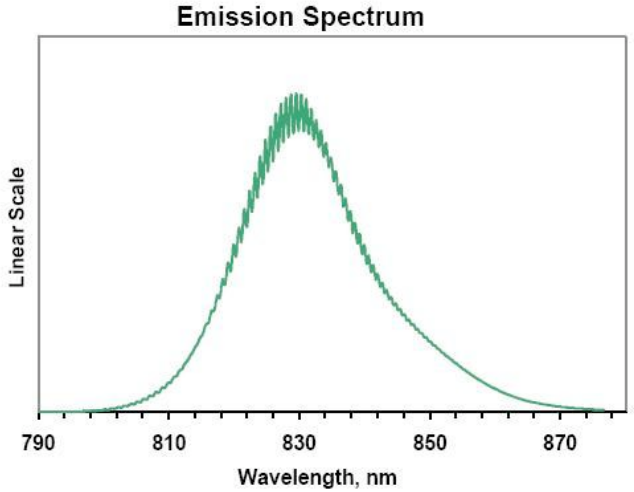




[2]: F. Acernese et al. ; tunable mechanical monolithic horizontal accelerometer for low frequency seismic noisemeasurement

The horizontal seismometers prototypes

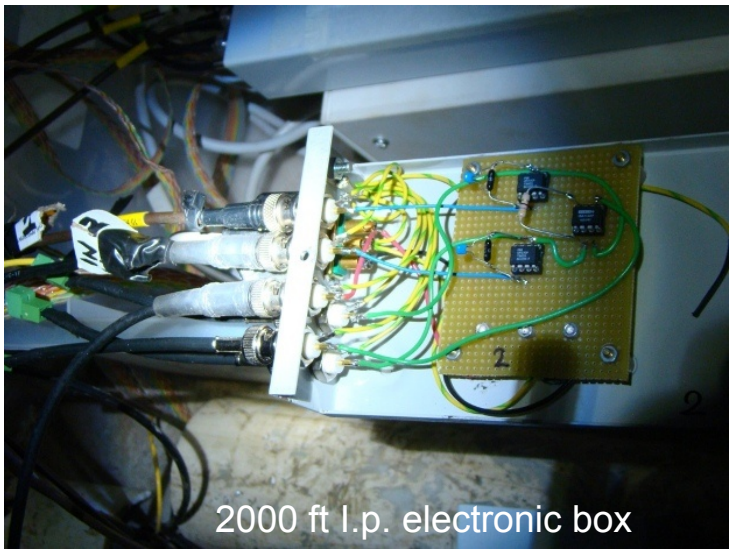




LIGO

The horizontal seismometers prototypes

2000 ft seismometers box

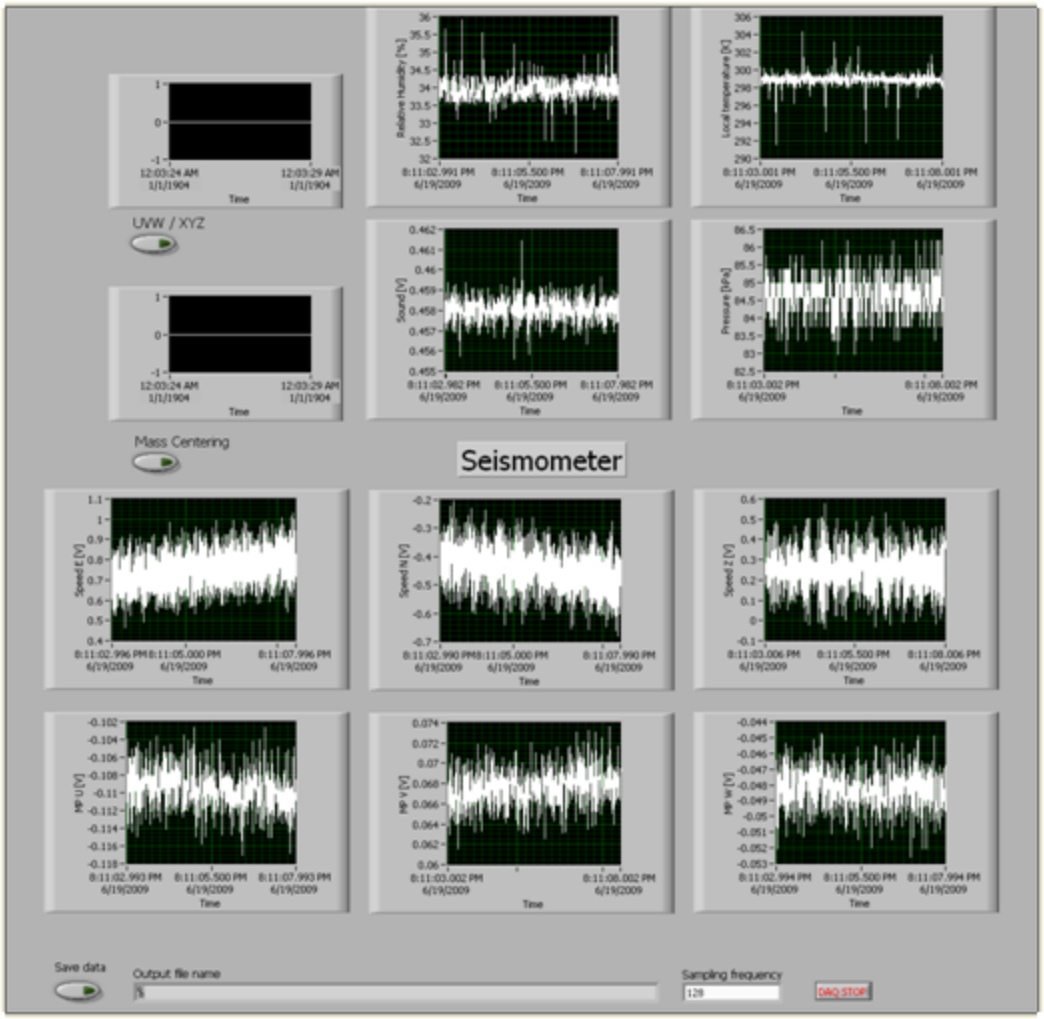


2000 ft l.p. electronic box

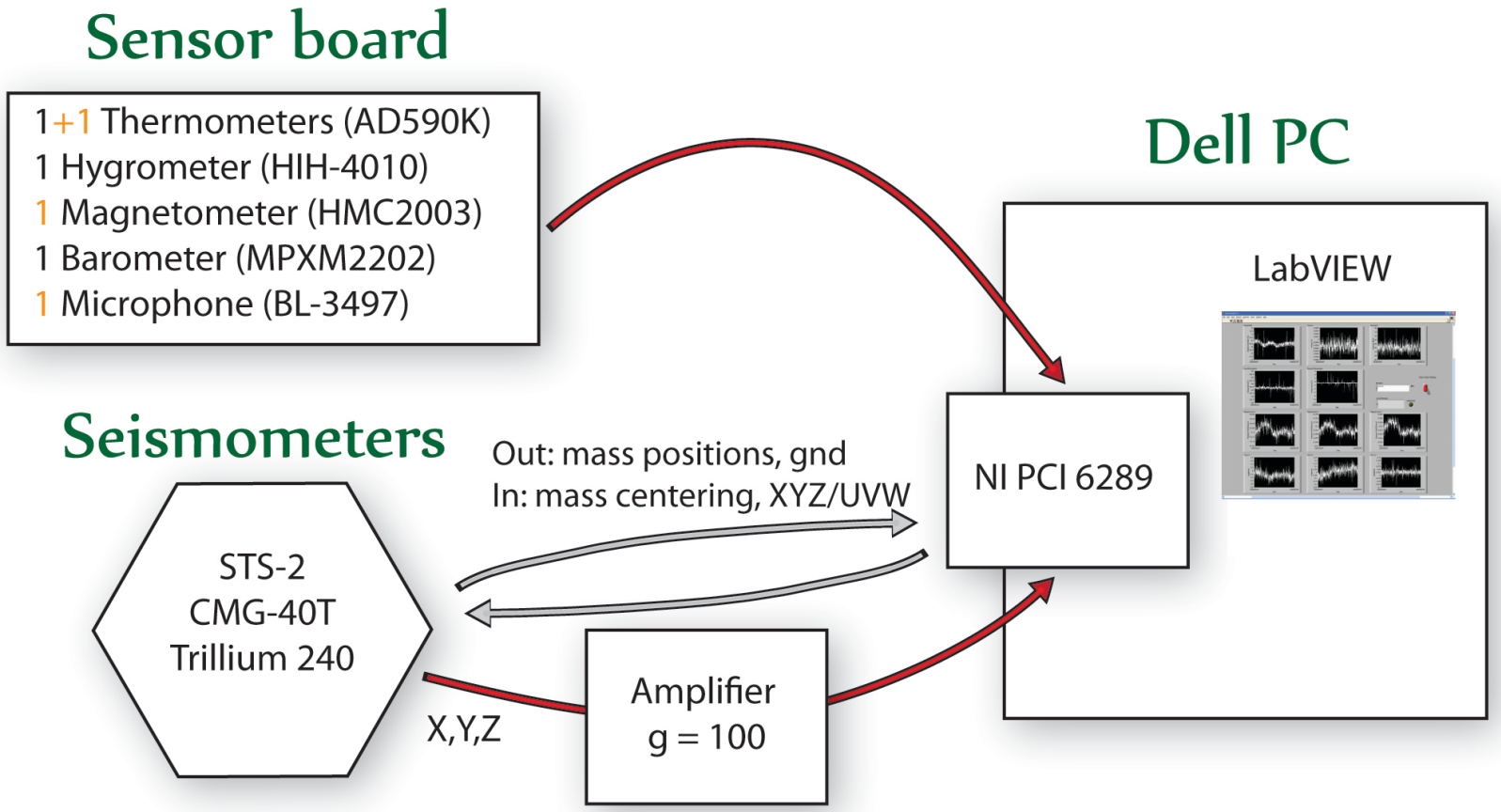
- failure in the DC power supply caused electronics damages
- new electronic box have been installed
- the DC power supply must be repaired or replaced
- a new instrument calibration may be needed
- new prototypes could be added to the seismometers array in the next future

Data Collection

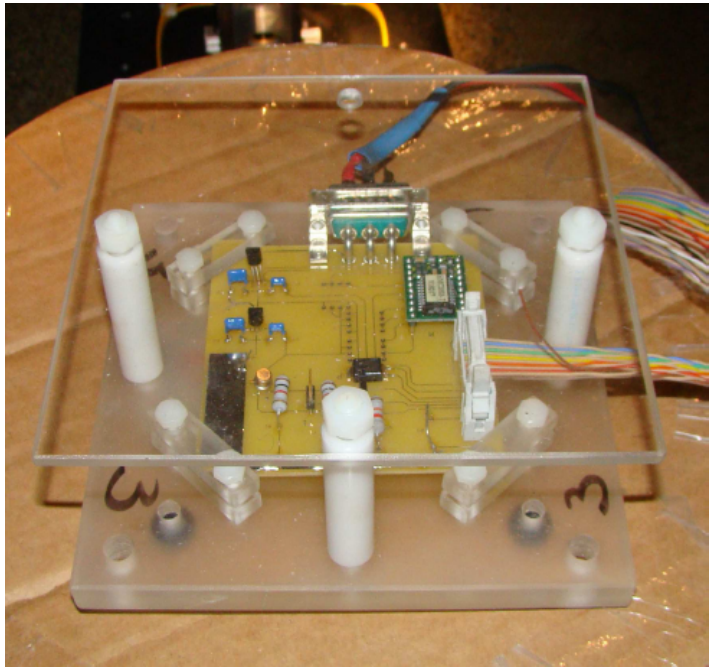
- LabVIEW
- Mass Centering
- LIGO frame conversion
- Amplifiers (bit conversion)
- Noise sources from mine

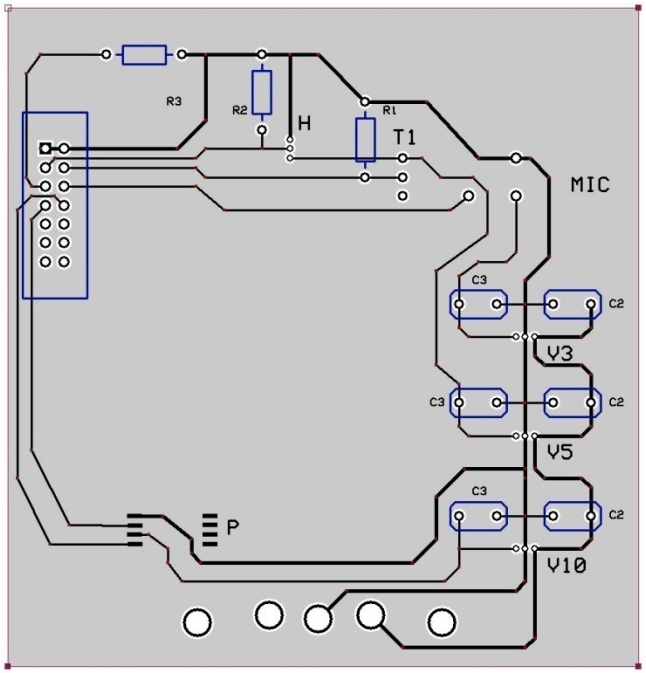


DAQ System—Local



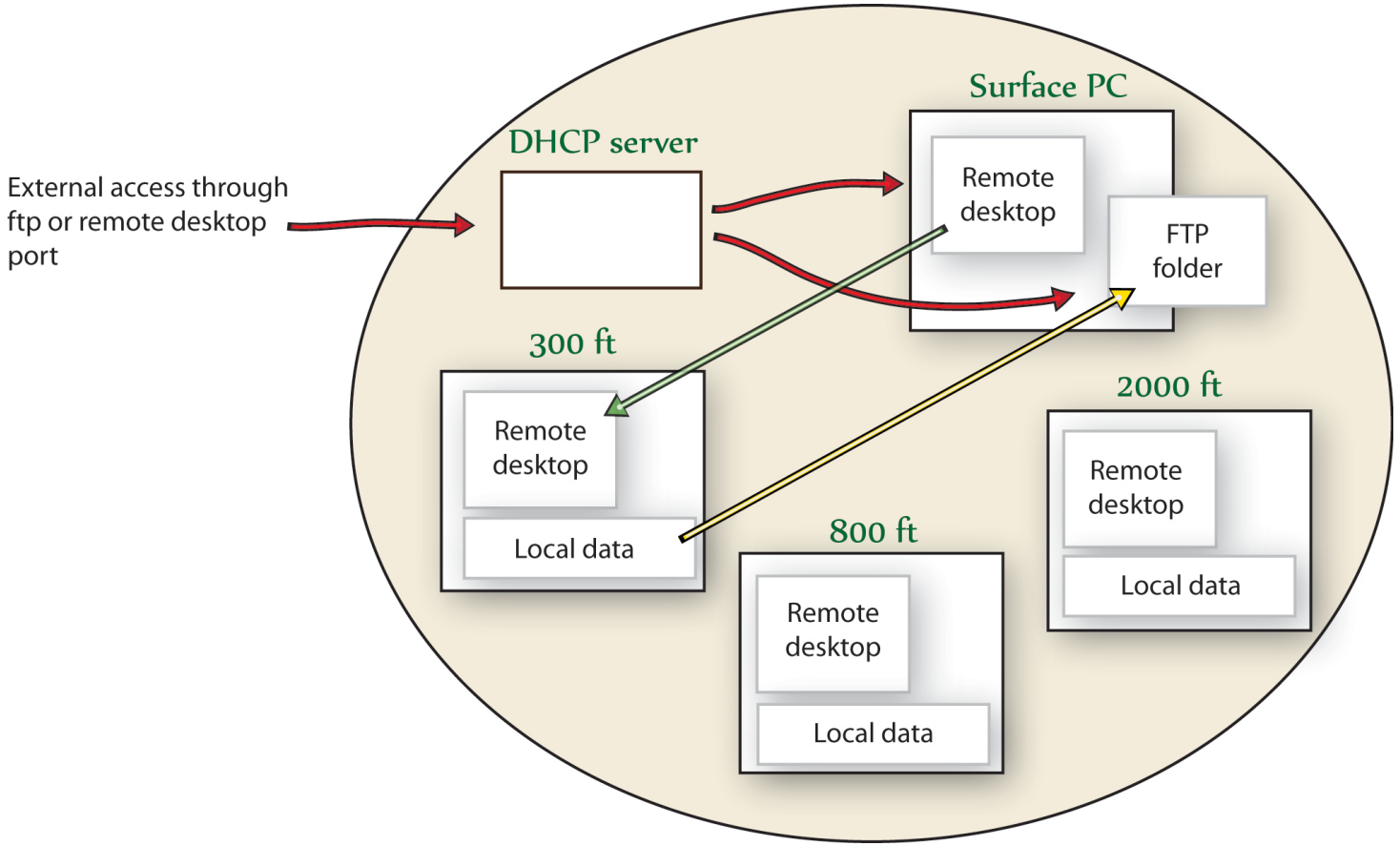
Sensor Boards





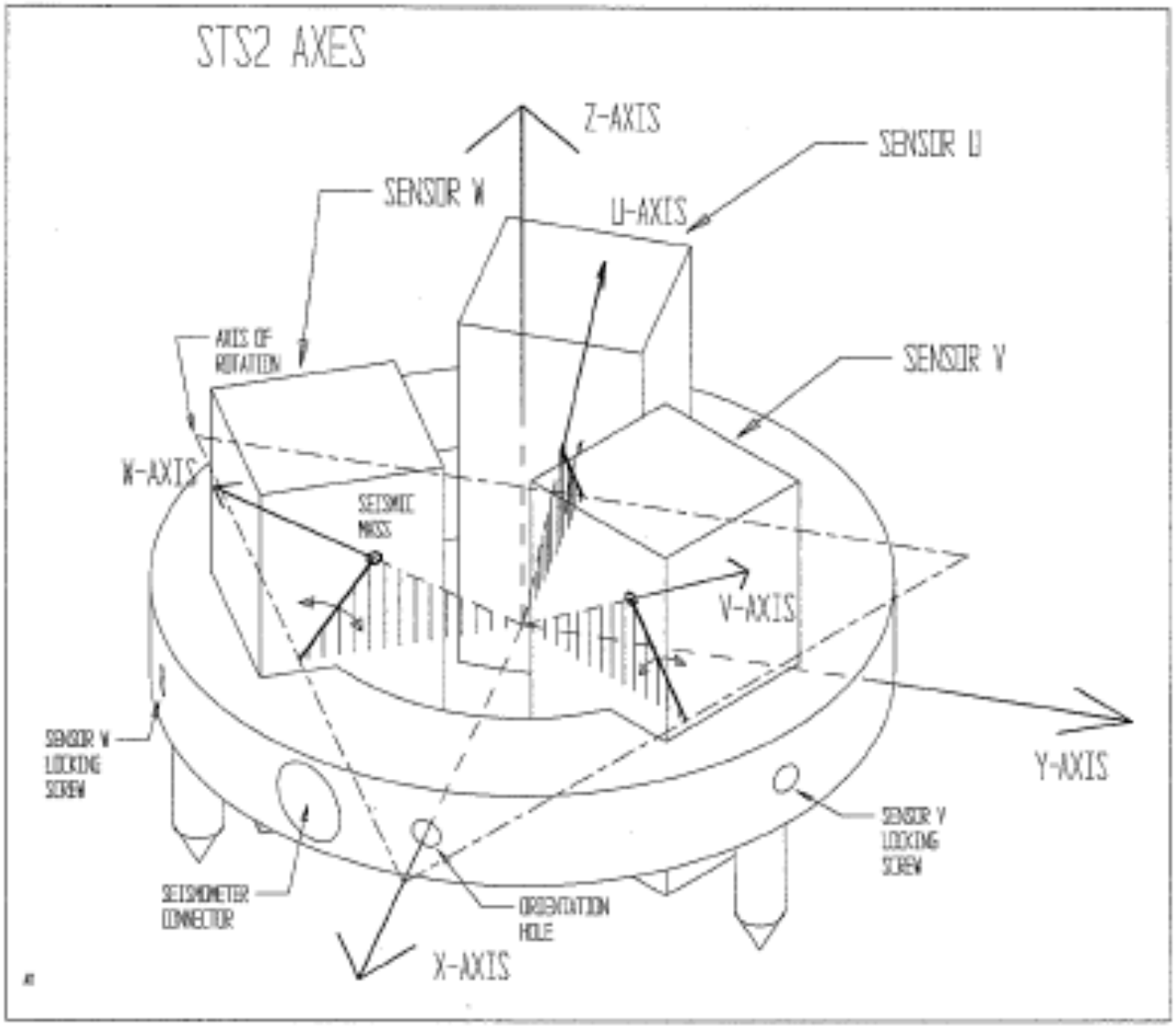
- Components used
- Components removed from old design for current design

DAQ System—General

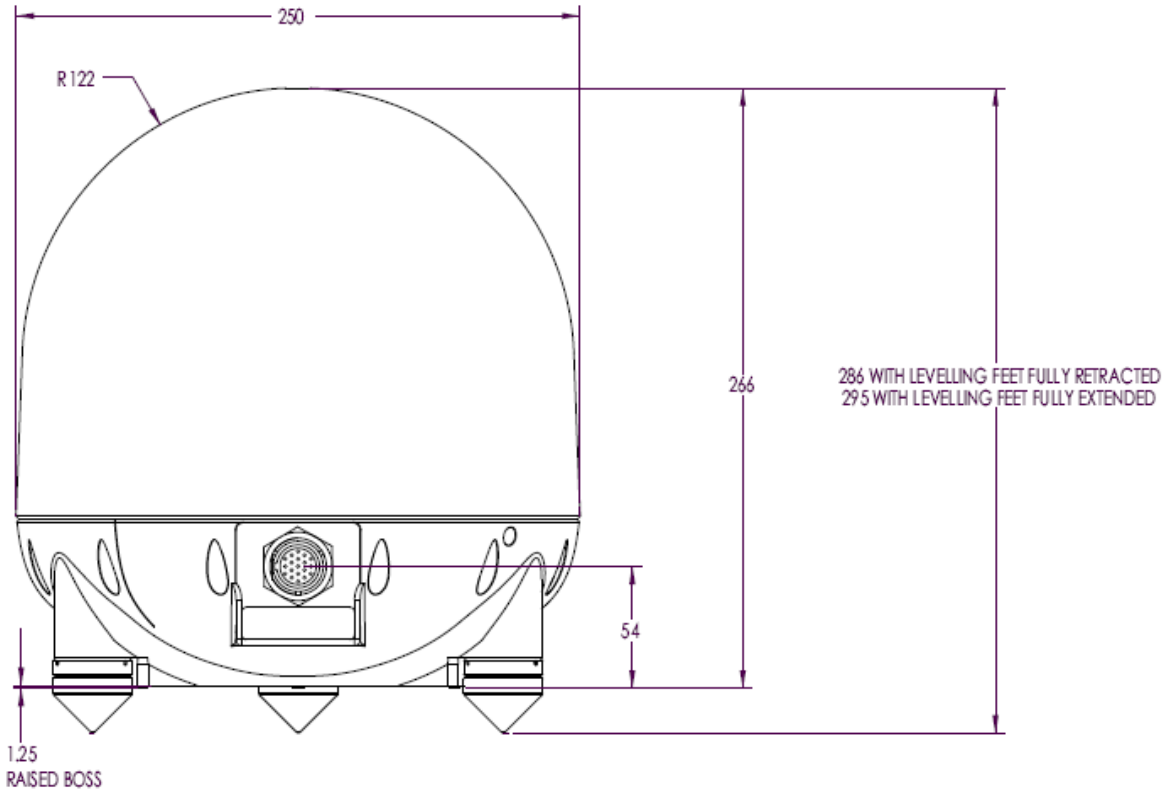


STS-2 Seismometers

- Two at 4100 ft level
- Coordinate systems
- Locking ability
- Frequency range without transfer function:
  10 mHz to 10 Hz
- Mass centering: as many times as necessary to within ±2V (±10°C)



Trillium 240 Seismometers



- One 800 ft
- Three 2000 ft
- One 4100 ft
- Center after installing and 12 hrs after
- Protective cover

Data Transformations

- Raw seismometer data: velocity in u-v-w coordinates
- Linear transformations
- Only Trillium 240 and STS-2

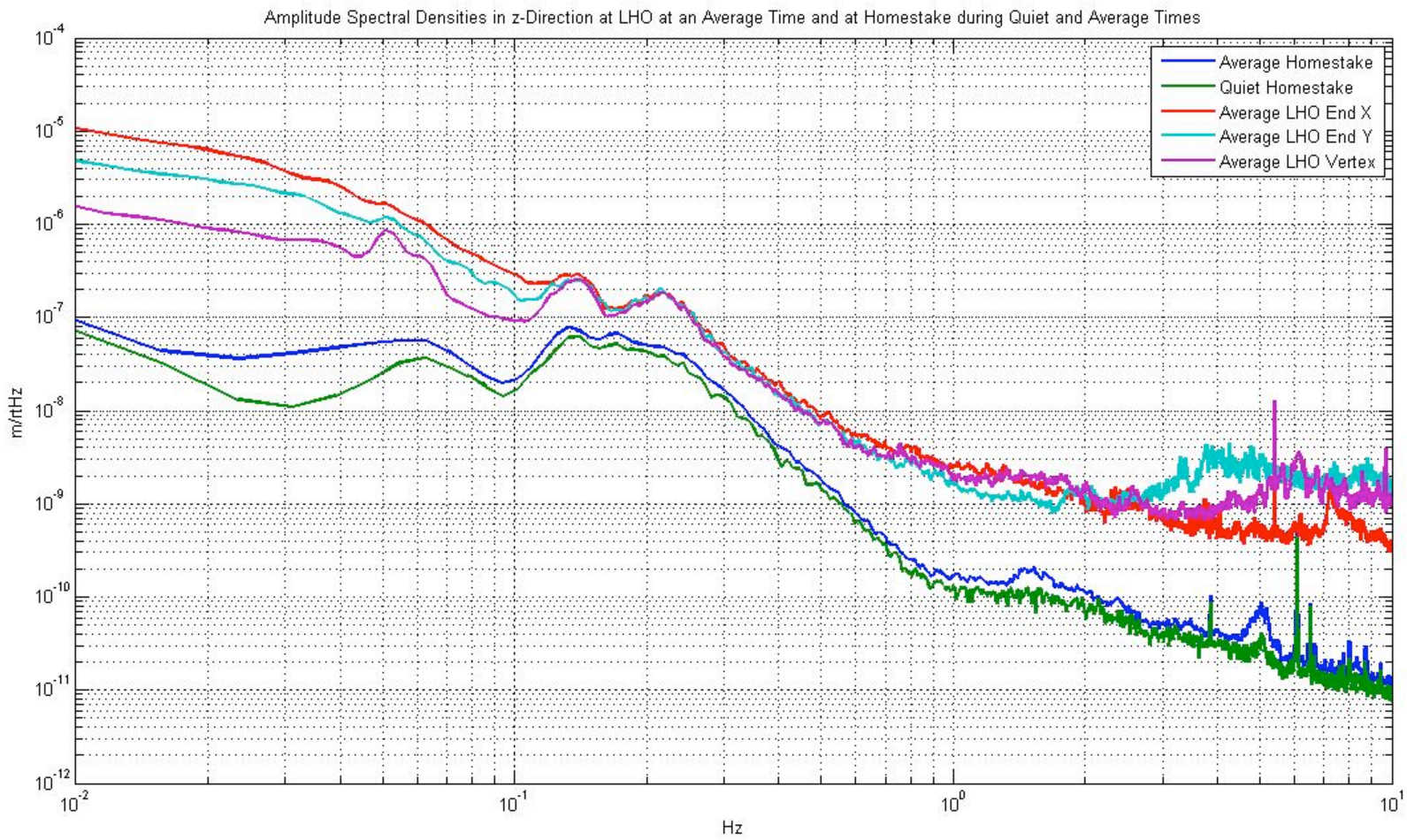
$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \frac{1}{\sqrt{6}} \cdot \begin{bmatrix} 2 & 0 & \sqrt{2} \\ -1 & \sqrt{3} & \sqrt{2} \\ -1 & -\sqrt{3} & \sqrt{2} \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{\sqrt{6}} \cdot \begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \\ \sqrt{2} & \sqrt{2} & \sqrt{2} \end{bmatrix} \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

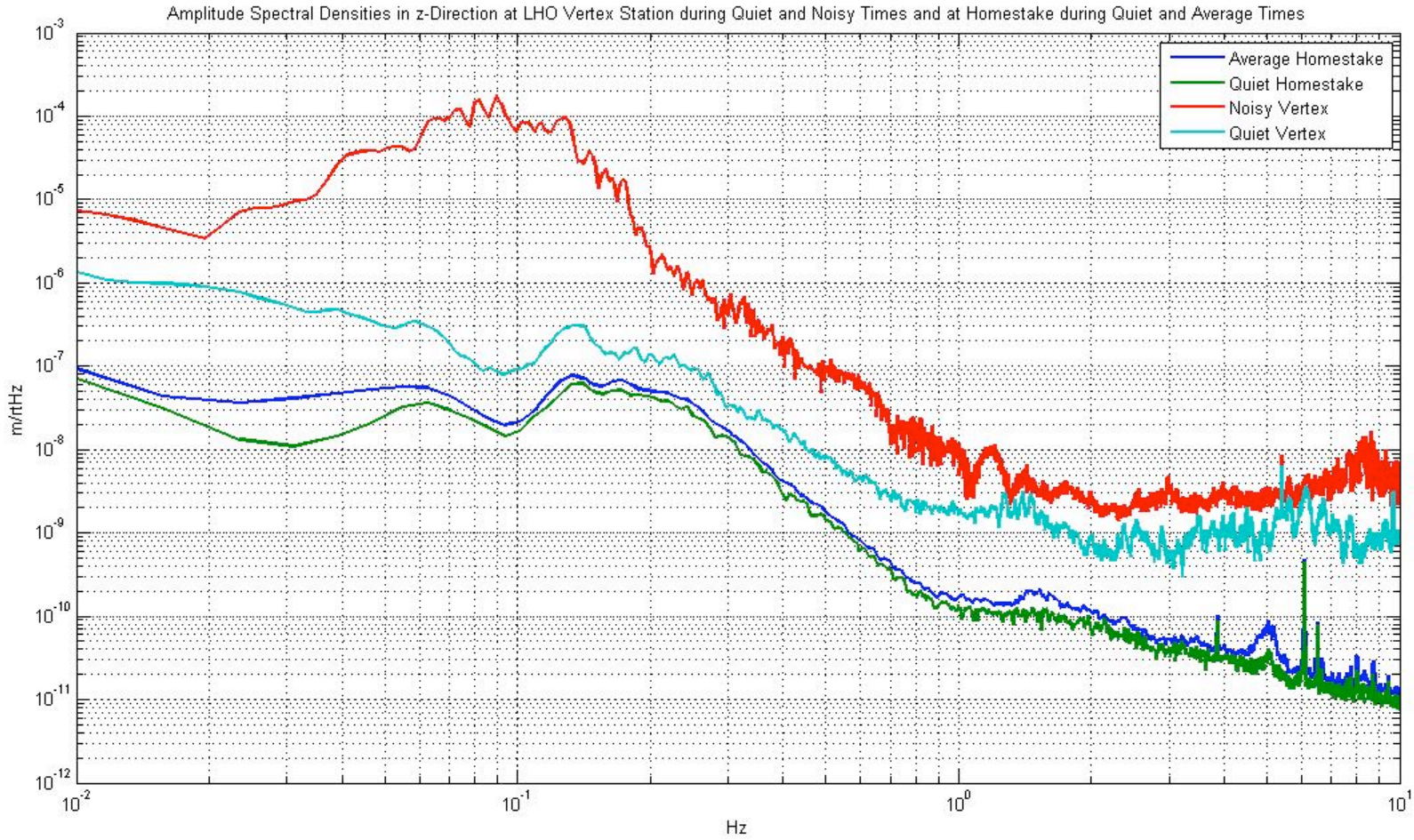
Güralp Seismometer

- Decoupled sensors
- Less sensitive but also less expensive
- One 300 ft

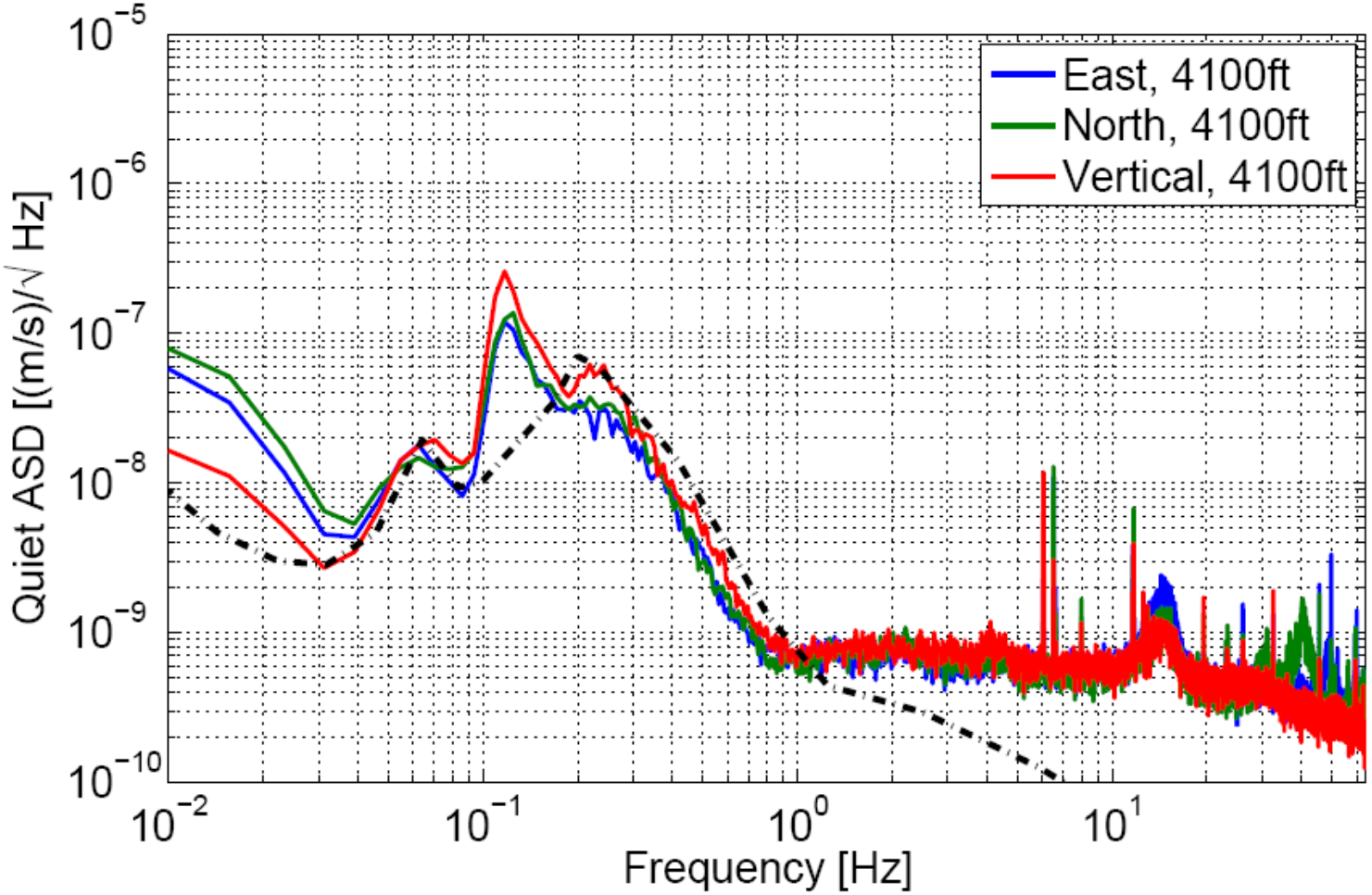
Homestake LHO ASD Comparison



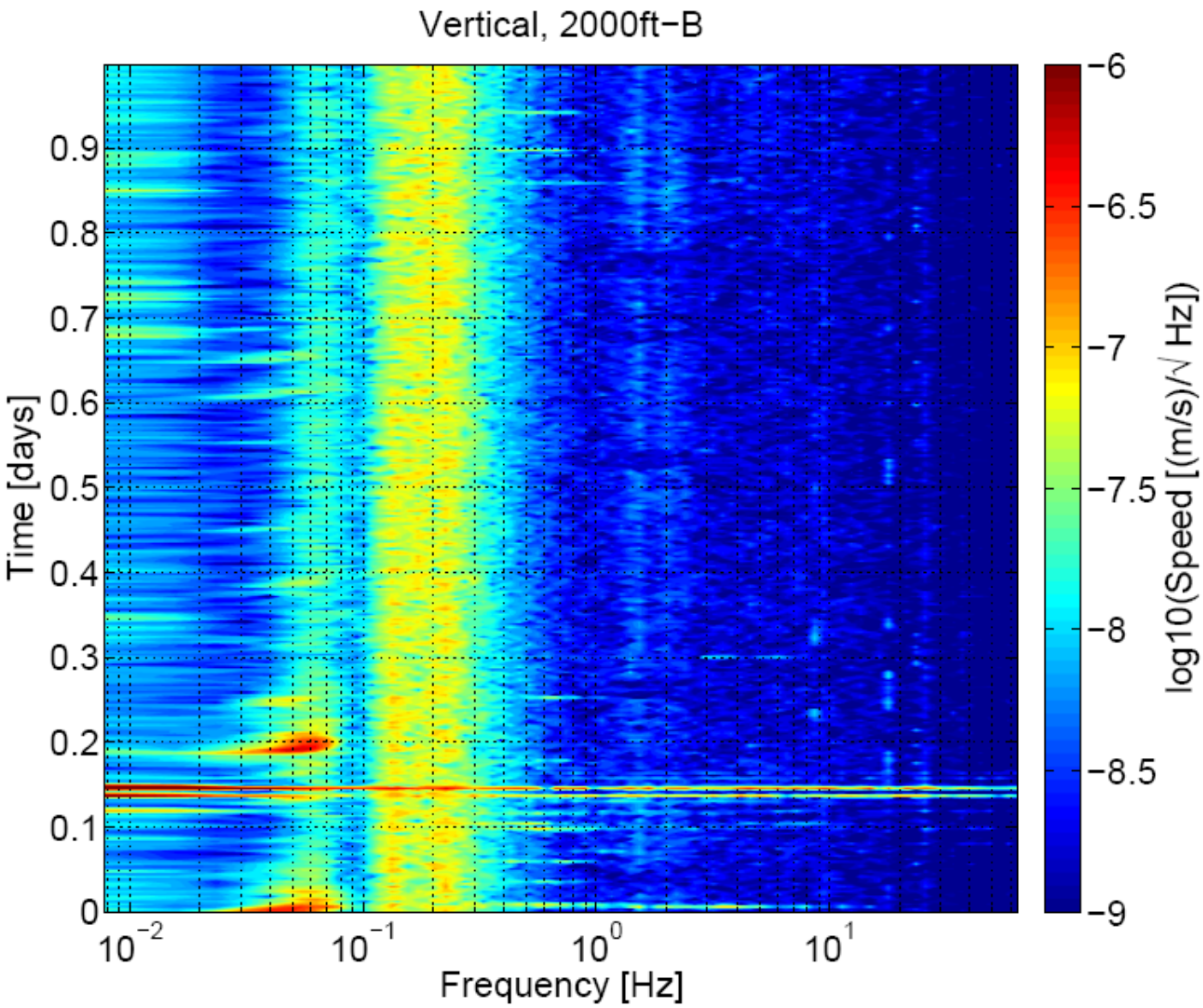
Homestake LHO ASD Comparison



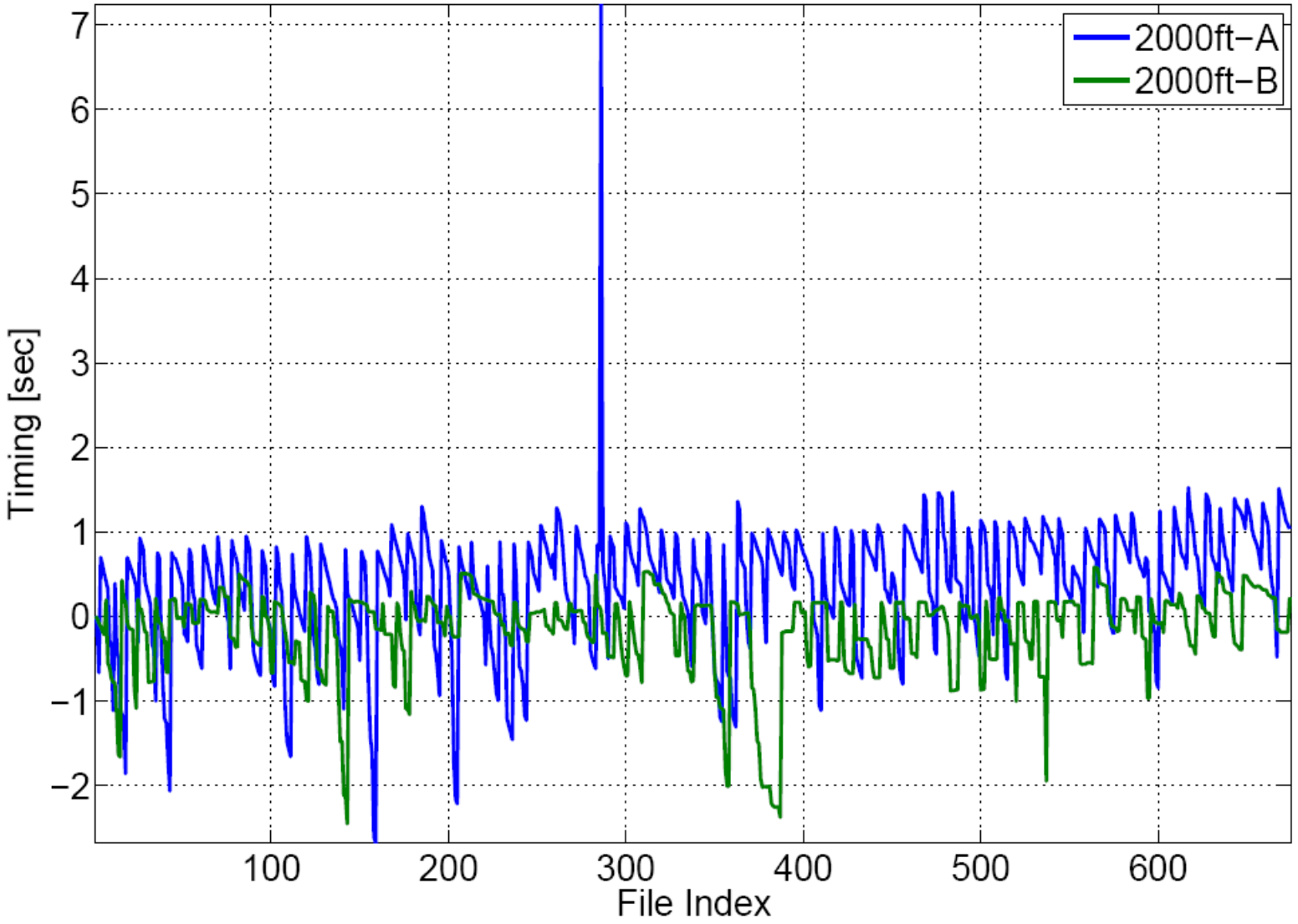
Comparison with Peterson Noise



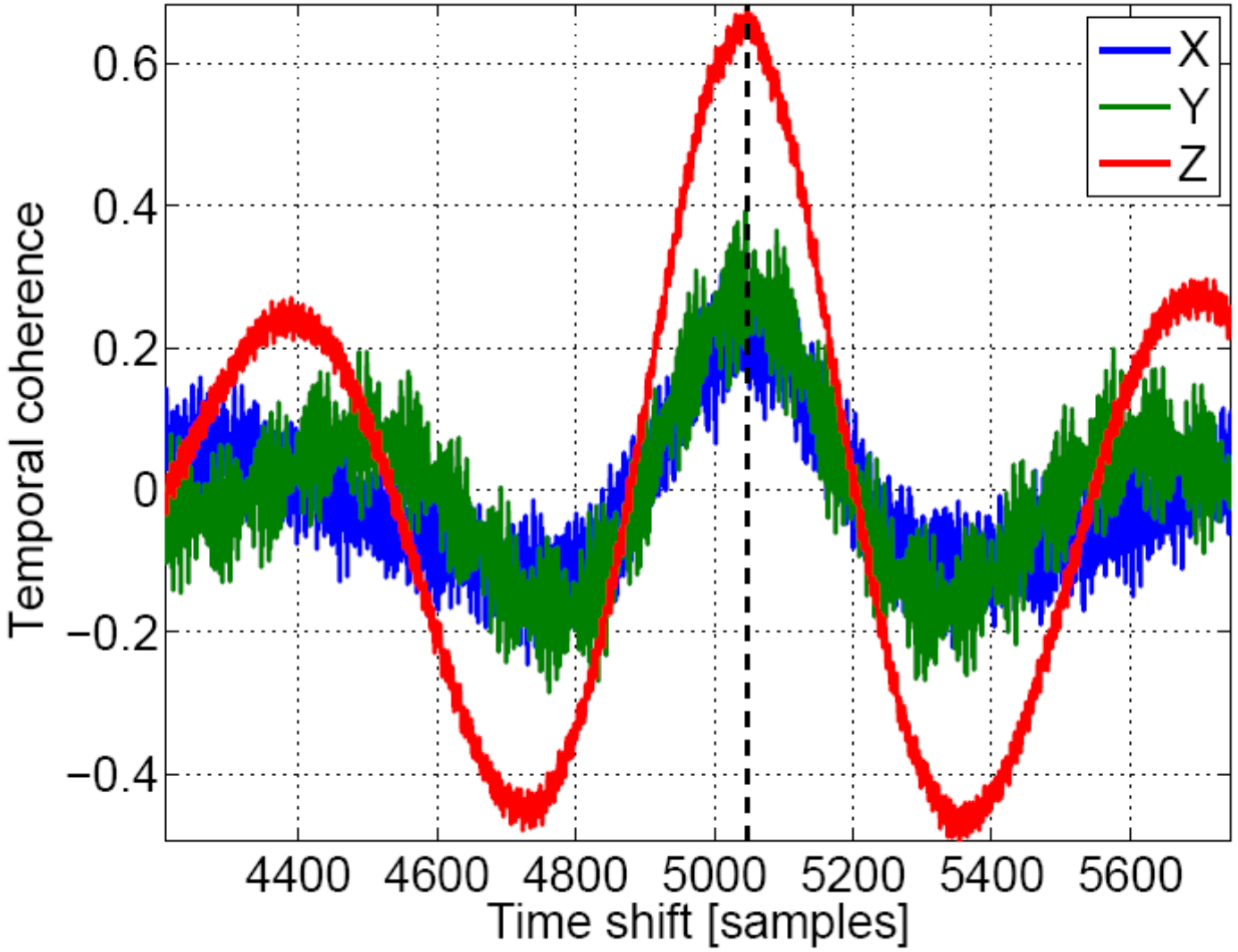
Homestake ASDs Over One Day



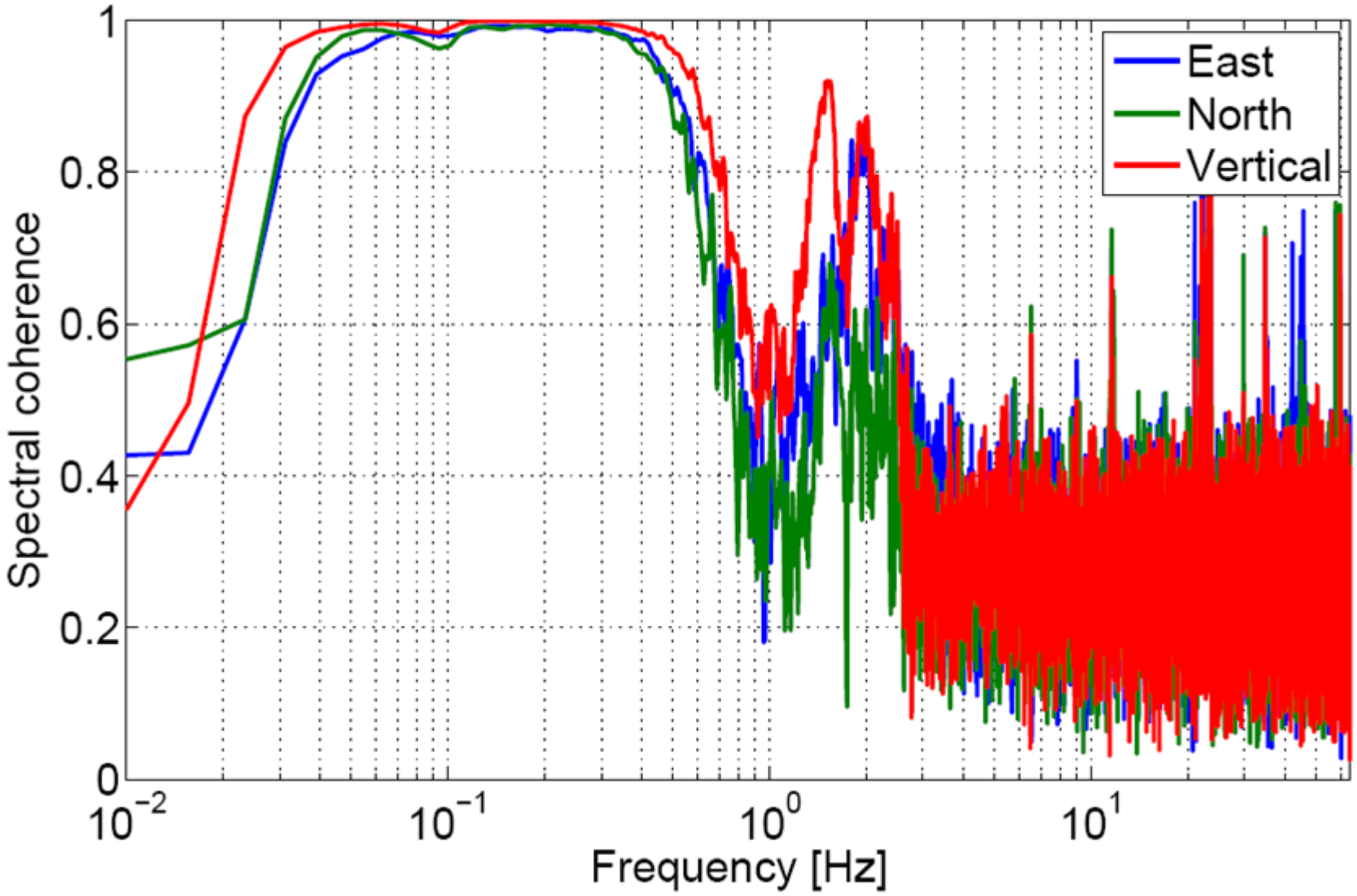
Timing Issues and Replacement



Finding the Necessary Time Shift



Spectral Coherence of 2000 ft Stations A and B



Concluding Remarks

• The LIGO timing system will take care of our timing problems and allow for more accurate correlation measurements between the 2000 ft stations.

• Knowing the calibrated time for the data will allow for a determination of the feasibility of modeling seismic activity.

• The seismic signals at LHO during noisy and quiet times can differ at some frequencies by as much as three orders of magnitude. Such extreme differences do not exist at the Homestake site.

Comments or Questions

Working conditions and safety procedures

-Safety training

-Site must be secured before scientific activities

-Experienced miner accompaining

-Daily work: 7am to 12.30pm or 4.30pm

-Daily action plan

- Tag-in system

- Be on time at the cage