Characterization of rock vibrations at the Homestake mine

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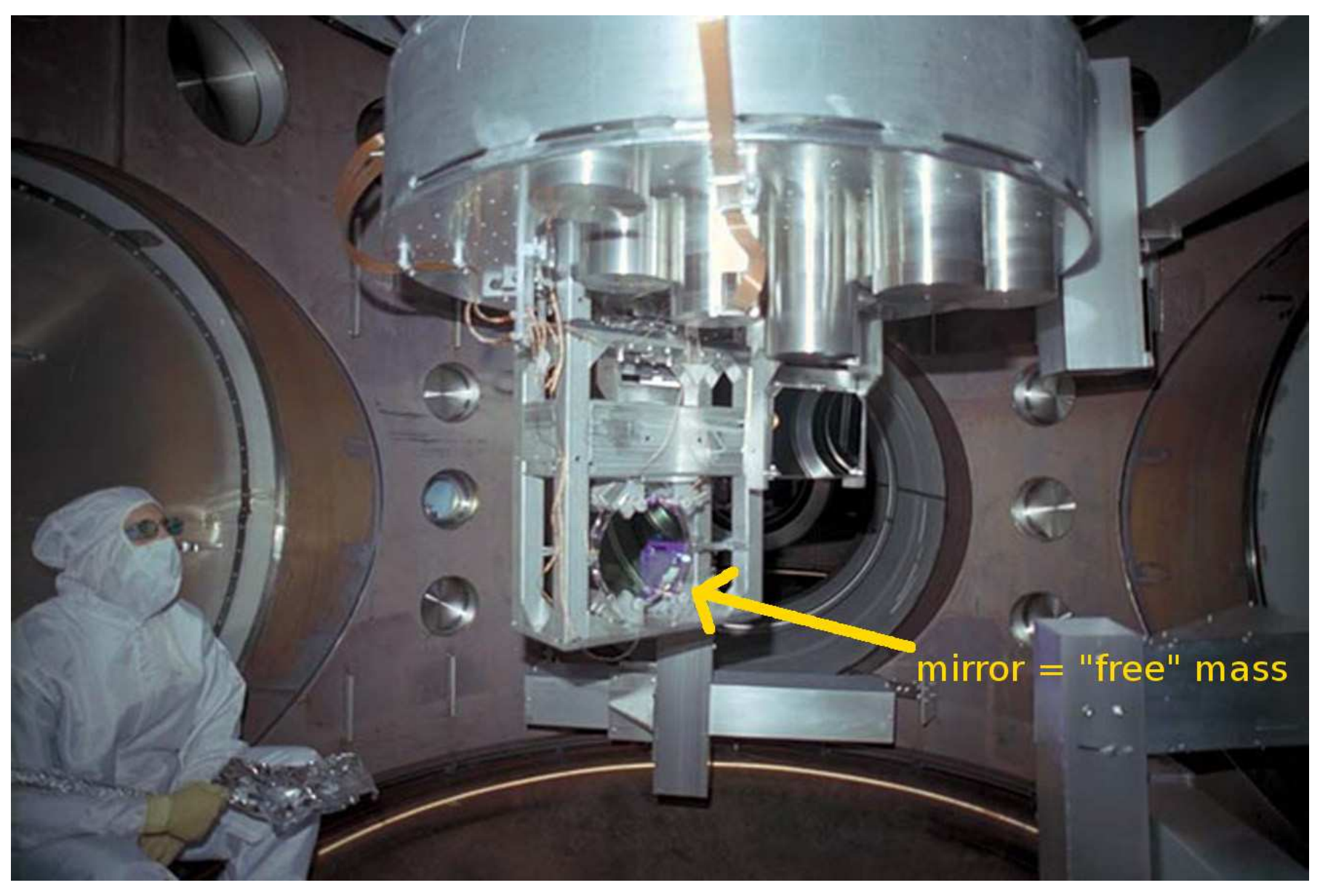
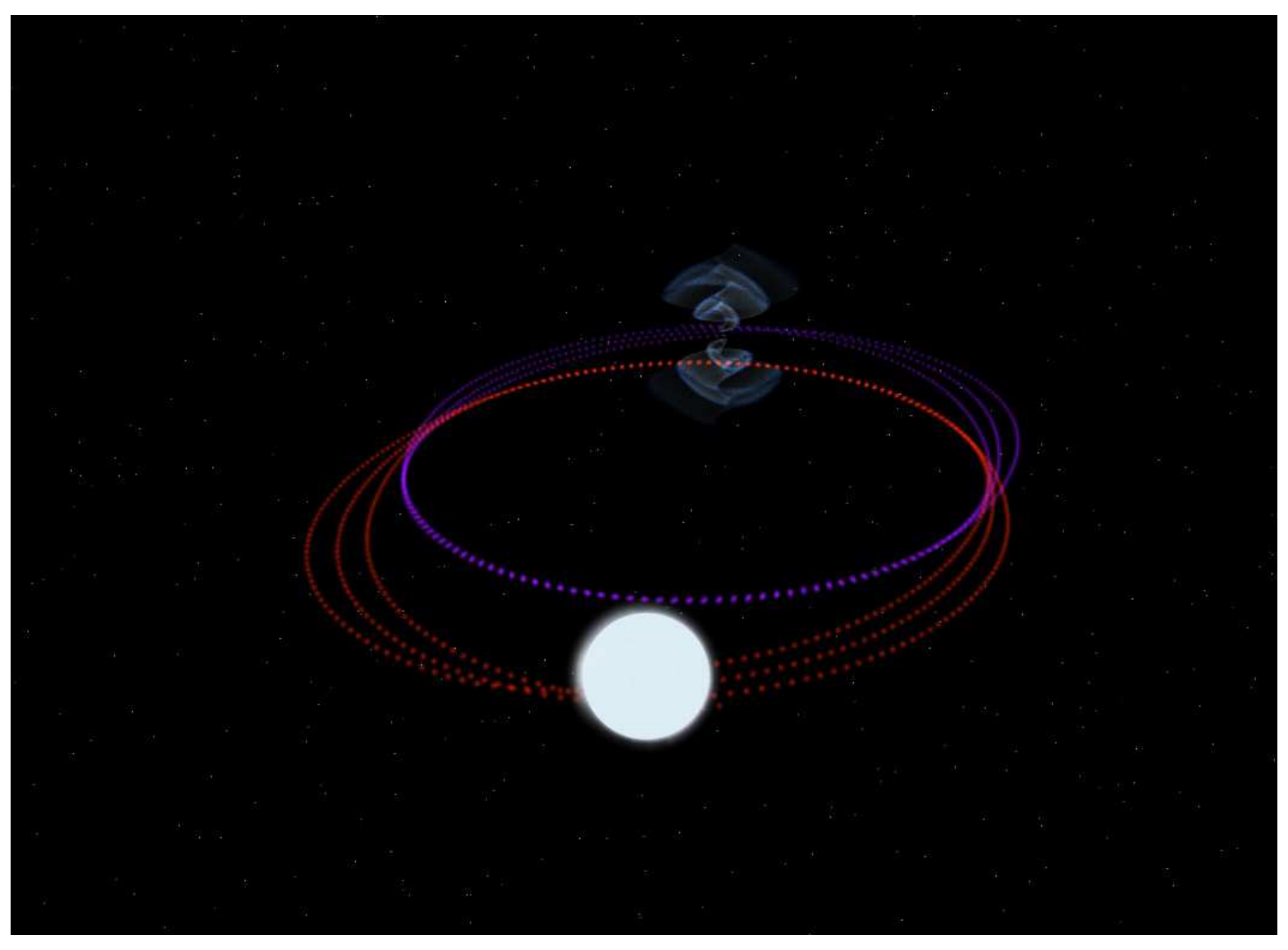
Gravitational-wave detection

Physicists describe a gravitational wave as an **oscillatory disturbance of spacetime**. For most purposes, it can be understood as a force field travelling at the speed of light which **changes distances between free masses**. A gravitational-wave detector has to monitor these changes. The **LIGO scientific collaboration** has built kilometer scale antennas (picture left) which use **laser light** to measure the distance between suspended mirrors.



Many additional forces acting on the mirrors may mimic the influence of a gravitational wave: vibrations of the ground, thermally excited vibrations of the mirror's surface, fluctuations inherent to the laser light and **fluctuations of the gravitational field due to density fluctuations of the environment** (i.e. **Newtonian noise**). Of all mentioned forces, it is the latter one which is considered to be the most problematic in the long run. Our goal at Homestake is to better understand the Newtonian noise and to develop methods which attenuate its detrimental effects on the gravitational-wave detector.



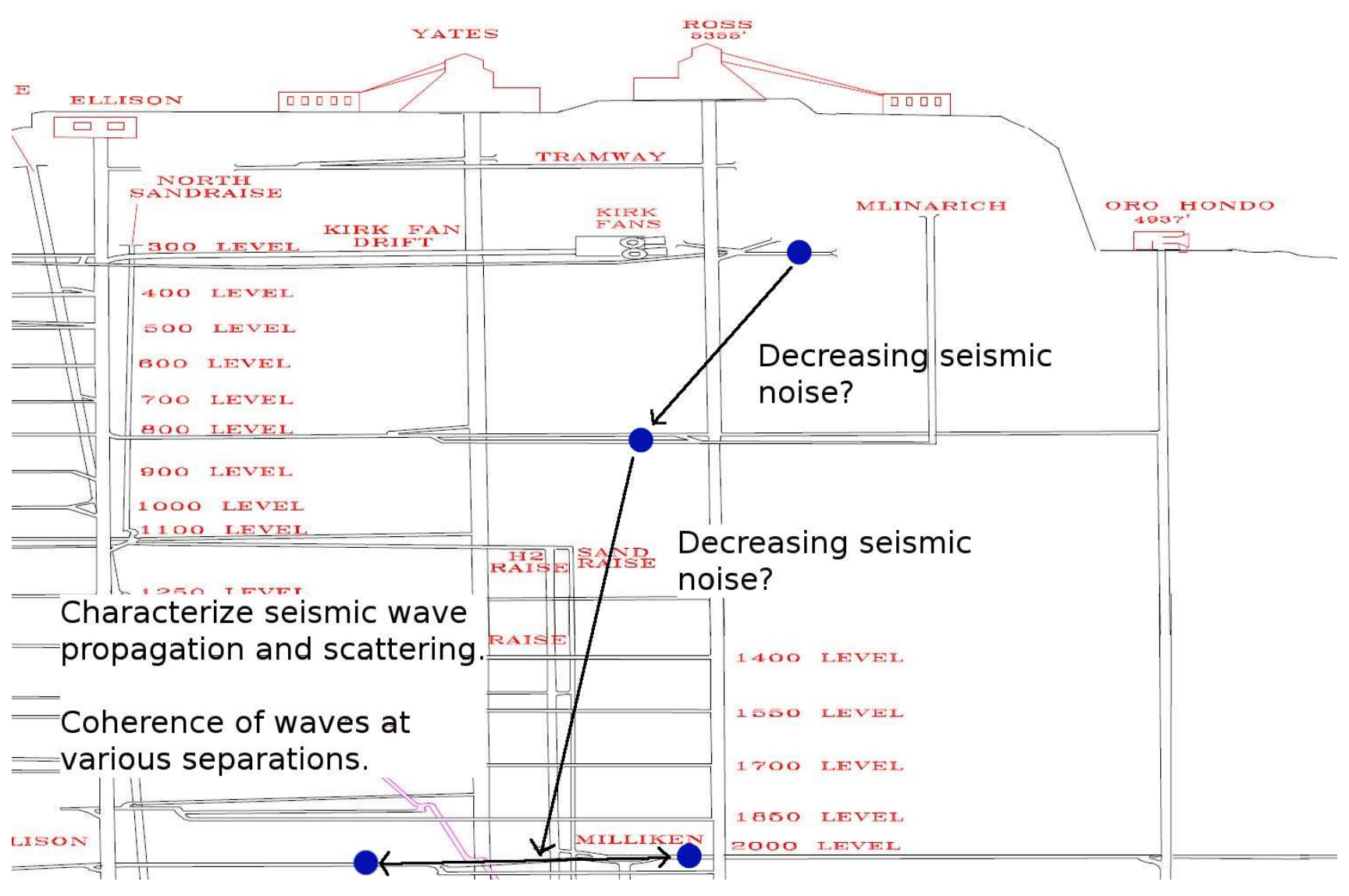
Gravitational waves are very difficult to measure. That is why we have to aim for the most energetic processes in the universe, like **inspirals of binary black holes or neutron stars**, the explosion of stars (**supernovae**) or the **Big Bang** itself which marks the birth of everything we observe today. Even then, distances between two mirrors inside a gravitational-wave antenna would not change more than a **tiny fraction of the radius of atomic nuclei** due to one of these cosmic events. Once we measure these waves, antennas around this world will open a completely new window to our universe. This time we would not look out of the window, but hold our ears to the glass pane and **listen to the death of stars and the birth of our observable universe**.

Our first steps at Homestake

Our experiments at Homestake are determined by two main goals:

1. We want to characterize seismic noise and rock density fluctuations in an underground environment.

2. We want to assess the quality of the Homestake mine as a candidate for a third-generation underground gravitational-wave detector.



Decreasing seismic noise?

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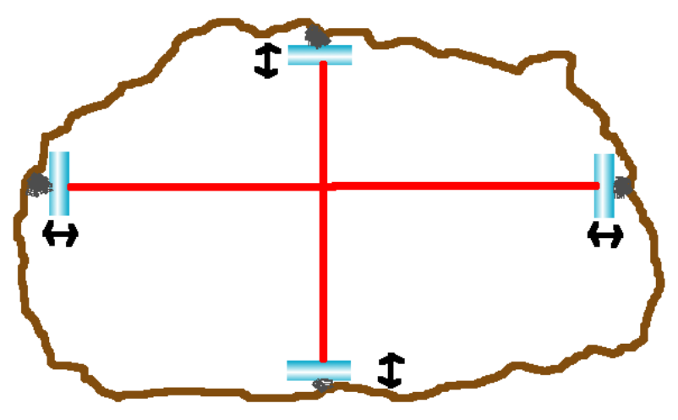
Characterize seismic wave propagation and scattering.

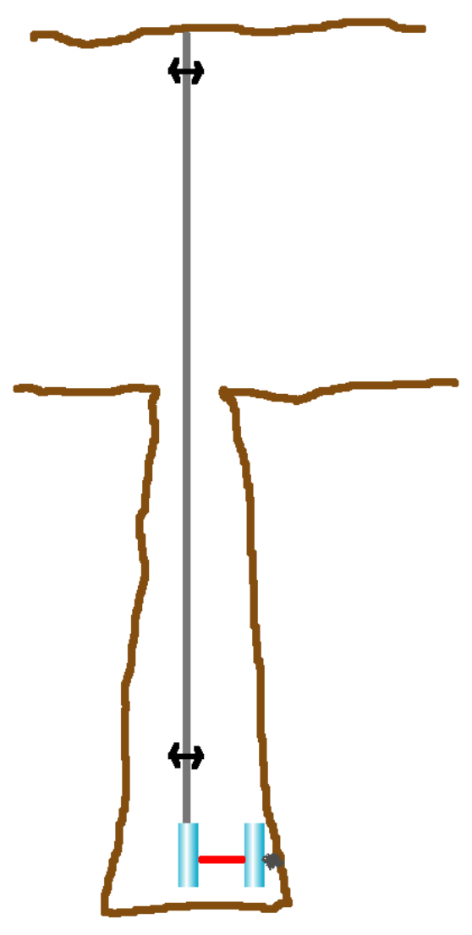
Coherence of waves at various separations.

As shown in the schematic section of the Homestake mine, we set up stations at various levels (blue dots do not indicate the actual locations) and investigate how much **seismic noise decreases with increasing depth** and measure variations of rock vibrations at different locations (i.e. **coherence between different stations**). In principle, these two kinds of measurement are sufficient to qualify the mine as a good or bad candidate for an underground antenna.

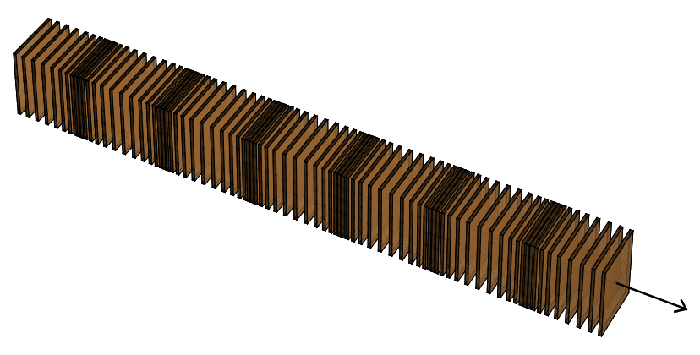
In the future, we want to add **optical instruments** to the array of mechanical seismometers. These instruments are needed to distinguish between the two fundamental types of seismic waves, **shear waves** and **pressure waves**, since standard seismometers are always sensitive to both types of waves. One of these instruments will be the **optical bar** which measures the pressure waves. Another one, the **shear pendulum** will also be sensitive to shear waves. Presumably, optical instruments will allow to make more sensitive measurements of seismic noise.



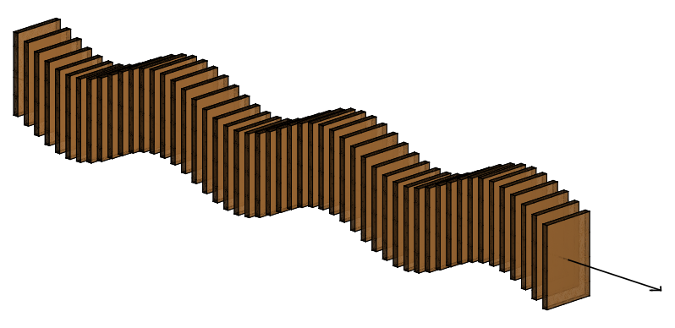
Optical bars



Shear pendulum



Pressure wave



Shear wave

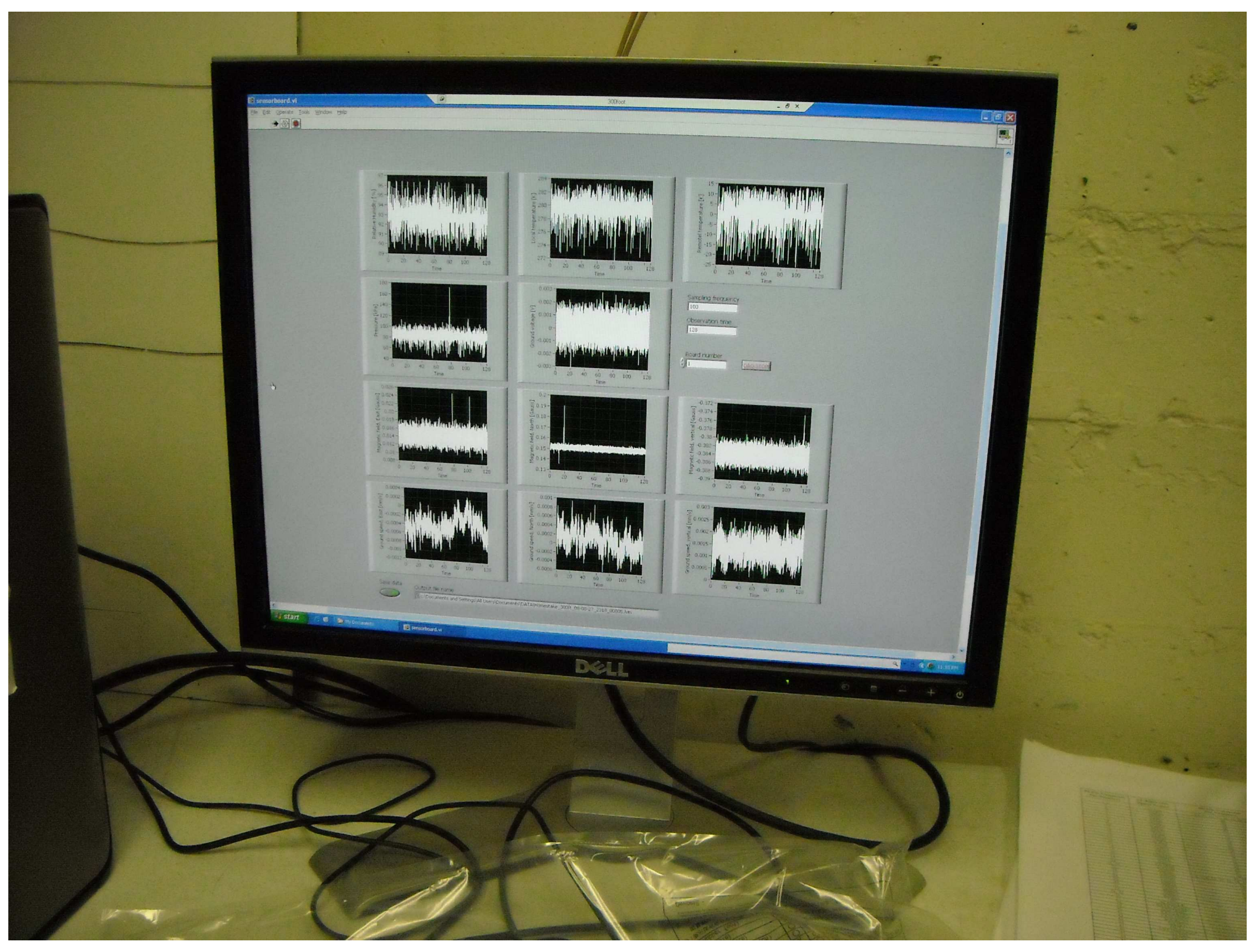
Another question which needs to be answered is whether the seismic waves come from all directions with equal strength (i.e. if the wave field is **isotropic**). If waves coming from certain directions contribute more energy to the seismic noise than other directions, the wave field is called **anisotropic**. To measure this, one would have to increase the number of seismic stations, align them into a 3D grid and measure coherence between their data.

The authors gladly acknowledge the support of the National Science Foundation for their effort, and SUSEL and the SDSTA for hosting them.

The seismic stations

At each station, one rigid-foam panel hut houses the sensors, whereas a second hut houses a computer and a power supply. The sensor hut serves as **shield against acoustic noise and water**. Inside the sensor hut is another container which serves as additional shield. The green instrument on the picture is our **high-sensitivity seismometer**. It has to be shielded against **air currents and noise**. Next to it, a sensor board with **microphone**, **thermometer**, **barometer**, **hygrometer** (humidity) and **magnetometer** is monitoring the environment of the seismometer.

The laboratory



The instruments and the data acquisition are **controlled remotely** from our lab which is inside the Ross dry. Also, the data is regularly **transmitted to our lab** where we can start to analyze it. In the near future, we will have access to this system from **any place in the world**, so that we and our colleagues can work with the data, whereever we are and whenever needed. In the end, all data – each station produces about **2 GByte each day** – will be copied to storage and analysis facilities at the California Institute of Technology. The clocks of all stations inside the Homestake mine will be synchronized to the microsecond level building a sort of **synthetic antenna** for rock vibrations.

G080562-00-R