LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Current Work on the LIGO 40m Noise Budget

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1 Overview of Project

The Laser Interferometer Gravitational Wave Observatory (LIGO) is one of the most ambitious projects in modern physics. A joint effort between researchers at Caltech and MIT, LIGO hopes to simultaneously realize two goals

1. Verify by direct observation the existence of gravitational waves as predicted by general relativity.
2. Use the world's first gravitational observatory to make unique observations of the universe's most dense and least understood phenomena.

To achieve these goals LIGO employs three heavily modified Michelson Interferometers as gravitational wave observatories. The first observatory has an arm-length of 4 km and is located in Hanford, Washington along with the second observatory with a 2 km arm-length. The third observatory is located in Livingston, Louisiana and has an arm-length of 4 km. Multiple observatories located far from each other allows LIGO analysts to mitigate local effects by demanding coincident detection of a gravitational wave. Furthermore, with separated observatories, analysts may triangulate the source of an incoming signal. General relativity predicts that sources such as inspiraling neutron stars and certain types of stellar collapse will emit strong, polorized gravitational waves that will radiate outward through space at the speed of light. When such a gravitational wave passes through the dectector, one arm of the interferometer will lengthen while the other will contract. The 4 km interferometers can detect a change in arm-length on the order of 10^{-18}. Because the volume of space probed is proportional to the cube of the strain sensitivity [7], minimization of environmental and instrumental noise sources becomes paramount.

The level of precision required for the observatories, roughly a thousandth the diameter of a proton, demands careful catalogue and control of noise sources. These sources include environmental and instrumental noise sources:

1. Environmental
   - Seismic - This is noise associated with minor and major seismic disturbances near the observatory. These can include minor earthquakes, nearby constructions, or even a well used highway located near by. LIGO attempts to seismically isolate the mirrored test masses by placing the entire system on a series of stacks.
2. Instrumental
   - Thermal noise This is noise associated with heating of various elements of the interferometer. As an example, the laser light incident on the mirrored test masses raises the temperature of the test masses. The thermally excited test masses then begin to vibrate at detectable amplitudes [7].
   - Shot noise This is noise associated with statistical fluctuations in the number of photons in the beam. To reduce thermal noise LIGO employs a lower power beam. With a beam of this type, the statistical nature of photon collision becomes noticeable.

- OSEM noise - This is noise associated with the optical shadow sensor and electro-magnetic actuator. The OSEM system uses a series of small electro-magnets mechanically coupled to the mirrored test-masses to sense their location, pitch, and yaw. The OSEM system is able to sense perturbations and correct for them in order to keep the test-masses in alignment.

The above are the principle noise sources that I hope to evaluate and add to the 40 m noise budget. An accurate catalogue of noise sources and their effect on the interferometer is necessary to determine what is limiting the accuracy of the observatory [1]. This catalogue is a noise budget.

The creation of a noise budget begins with identifying a potential noise source. As an example, let us take seismic activity as a potential noise source. After a potential noise source has been identified, sensors which can measure that source's influence on the detector must be procured and installed. For the seismic noise source, LIGO employs 6 accelerometers positioned in the mode-cleaner unit of the interferometer. After installing sensors, the interferometer must be put into detecting configuration. This is referred to as "locking the detector". After achieving lock, noise is injected at a particular frequency, in this case by shaking the mode-cleaner at a given frequency with given amplitude. This results in a change in the the signal from the differential arm-length sensor. This is the channel that will be used to determine the presence on an incoming gravity wave. The ratio of the change in output to the change in input is a transfer function.

2 Previous Work on 40m Noise Budget

Previous work to construct a noise budget for the 40m facility has centered around modifying existing methods for creating an automated noise budget. The sites at Livingston, Louisiana and at Hanford, Washington both use a set of MATLAB scripts to regularly create noise budgets. The goal is to modify that code to work at the 40 m site. These modifications are non-trivial since new transfer functions must be measured for each noise source and new sources specific to the 40 m site must also be added to the scripts while preserving cross-site functionality. Previous SURF students Ryan Kinney and David Malling both worked on the 40 m noise budget. Kinney measured the transfer for the seismic noise source and added it to the working noise budget. I intend to build on their work by adjusting the seismic noise budget to work with the current 40 m configuration and adding PRC, SRC, and OSEM noise sources.

2.1 Noise Budget Script

A block diagram of the current noise budget script is shown at the end of the paper. The procedure begins with the activation of getNoiseBudget.m which together with runmeas.m sets file paths specific to each site and calls the script NoiseBudget.m. NoiseBudget.m updates the pre-loaded parameter files with updatepardata.m. Then NoiseBudget.m calculates the unitary gain frequency with getUGF.m and takes data from each of the source channels with files such as getSeismic.m. The get files take data and with a known transfer function calculates the noise contribution. NoiseBudget.m then plots and saves the noise budget.

3 Current State of Noise Budget

The current noise budget is shown at the end of the paper. The noise budget includes DARM and seismic sources. The seismic transfer function is the same as that measured by Ryan Kinney and will need to be changed to reflect changes at the 40m lab. Note that the SRD (scientific requirements curve) is for one of the main sites and does not reflect the expectations of the 40 m group. It is a current goal to acquire a 40 m specific SRD curve.

4 Future Goals

I am currently working on measuring noise associated with the OSEM system. This involves the calibration of a Bartington magnetometer. With a calibrated magnetometer, I can measure a transfer function for the OSEM system. Simultaneously, I am assisting with the creation of a new noise budget for the seismic accelerometers.

References

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[4] Unknown: *Shot Noise*, http://en.wikipedia.org/wiki/Shot_noise.

[5] Unknown: *LIGO*, http://en.wikipedia.org/wiki/LIGO.

[6] Unknown: *LIGO Fact Sheet*, http://www.ligo.caltech.edu/LIGO_web/about/factsheet.html.

[7] LIGO Science Collaboration: *LIGO: The Laser-Interferometer Gravitational-Wave Observatory*, http://www.arXiv.org, 2007.

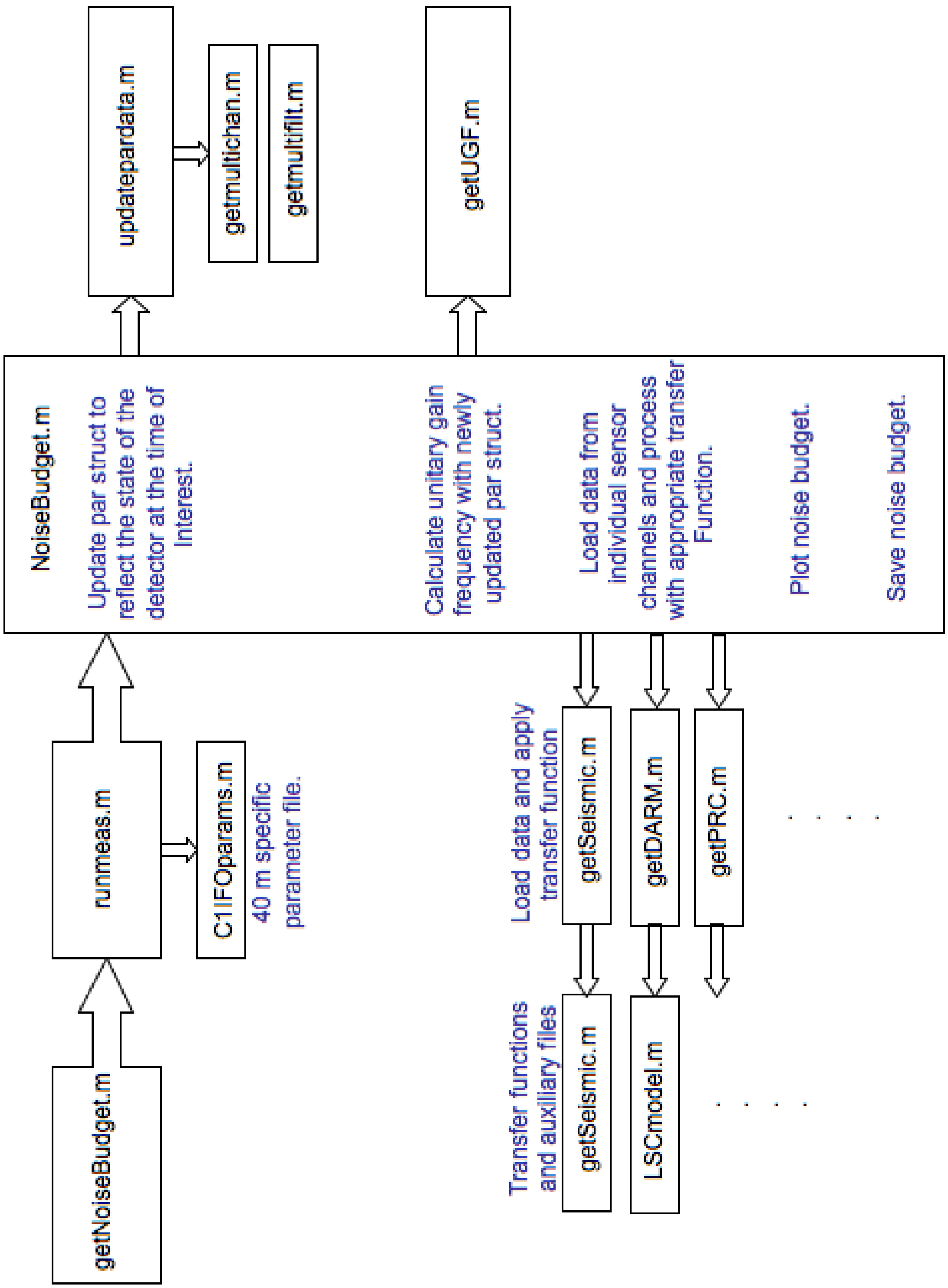

Figure 1: Noise Budget Script Block Diagram

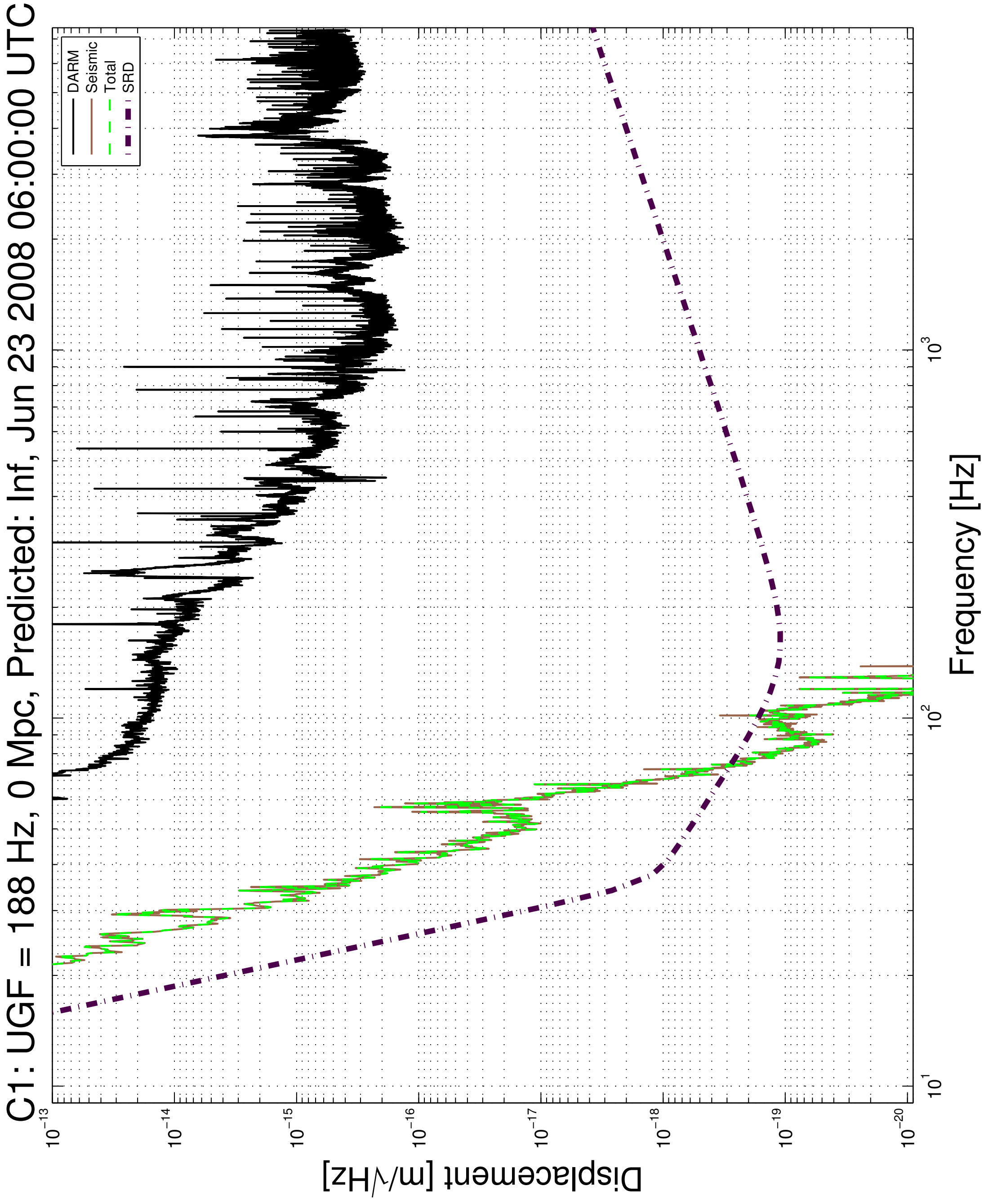

Figure 2: 40 m Noise Budget