Wavefront Sensing and Control
Nancy Aggarwal
Mentors: Rana Adhikari and Koji Arai

LIGO has an input mode cleaner, which is a 3 mirror resonant cavity. It is designed to let pass through only 1064 nm TEM00 light out of all the frequencies and modes emitted by the Pre-Stabilised Laser. This design involves the position as well as the alignment of the mirrors. Hence, a potential problem becomes to sustain a particular length and alignment of the cavity, given all the disturbances tend to mis-align the cabity. The scheme for the length alignment (PDH) is there, we aim at now improvising on the alignment part. The Wavefront Sensing Scheme has essentially been devised for the same. Here, a dynamic feedback control system is designed, to look at WFS/QPD signals coming from lights containing information of the MC, and send it as a feedback to the actuators to the mirrors. We particularly look at the light reected from the input mirror of the MC, and at light leaked out from the curved mirror. This gives us 6 signals for 6 rotational dof. The final goal will be to try and diagonalise this 6*6 alignment sensing matrix.

Implementing a Loosely Coherent Statistic Using Reduced Arithmetic Precision
Osbert Bastani
Mentor: Vladimir Dergachev

The sensitivity of algorithms for analyzing data for continuous gravitational wave signals is severely limited by available computational power. We have implemented a simulation to analyze the effect of reduced precision arithmetic on the sensitivity of fully-coherent, semi-coherent, and loosely-coherent algorithms. Such algorithms perform arithmetic in the lattice $Z[\omega_6]$ or its finite quotient rings. We also analyze how analogs of the fast Fourier transform algorithm behave in these objects. For appropriate encoding parameters arithmetic on $Z[\omega_6]$ results in no loss of signal to noise ratio but significantly compresses the data. Encoding into finite quotient rings of $Z[\omega_6]$ boosts the signal to noise ratio for a certain range of amplitude and suppresses it in other ranges. This increases both the time and the memory efficiency of the search.

Development of the Advanced LIGO Timing System IRIG-B Interface Module
Ilya Belopolski
Mentors: Daniel Sigg, Richard Gustafson, and Paul Schwinberg

The Advanced LIGO Timing System distributes a highly accurate timing signal to the three LIGO interferometers. By synchronizing data collection to better than 1μs precision, the timing system (1) reduces timing jitter, (2) improves direction reconstruction, and (3) improves background rejection, all of which serve to improve LIGO's overall sensitivity. The timing system consists of a set of electronics modules which collectively distribute a GPS timing signal to LIGO subsystems. The central node of the timing system is a master clock which receives a timing signal via a GPS antenna. Slave modules, synchronized to the master clock via fiber optic cable, interface between the timing system and any given LIGO subsystem. The IRIG-B chassis is one timing system slave module. It supplies the timing signal to frame-building servers in the LHO/LLO Mass Storage Room and the interferometer end stations. The IRIG-B chassis converts the internal timing system signal encoding to the IRIG-B signaling standard, which can be interfaced with commercial servers through use of commercially available PCI modules. By ensuring that timing information is accurately stamped on all LIGO data, the IRIG-B module maintains timing synchronization, improving the likelihood of a successful detection of gravitational waves.

Thermoelastic Noise of Thin-Films
Bryce Bjork
Mentors: Eric Black and Greg Ogin

A possible limiting factor for the sensitivity of future versions of LIGO is thermoelastic damping noise from the thin-film coating of the test masses. This noise is determined by the coefficient of thermal expansion (CTE) and the thermal conductivity (kappa) of the film, and these quantities are often significantly different for materials in thin-film form than for the same material in bulk. We have built an experiment to measure these parameters in coatings using a variant of photothermal displacement spectroscopy, a technique where the sample is heated periodically, and its resulting thermal expansion is measured, as a function of heating frequency, interferometrically. In our experiment, samples are placed in a Fabry-Perot resonator. Pump (heating) and probe (measurement) beams with orthogonal polarization both resonate in the cavity at the same time. In this talk I will describe how the instrument works and show the data we have obtained.

Electromagnetic Observations of Magnetar Bursts: Preparations for a Gravitational Wave Search and an Investigation of Burst Properties
Giles Colclough
Mentor: Peter Kalmus

Soft Gamma Repeaters (SGRs) and Anomolous X-Ray Pulsars (AXPs) are astrophysical objects which release bursts of soft gamma-rays. The magnetar model, first proposed by Thompson and Duncan, suggests both types of objects are manifestations of neutron stars with exceptionally strong magnetic fields (10^{14} – 10^{17} Gauss). Burst emission involves the release of energy stored in a star's twisted magnetic field. If the magnetic stresses are counterbalanced by shear stresses in the stellar crust, crustal fracture may actuate magnetic field reconfiguration. It is then possible that non-radial global oscillatory modes be excited, providing a mechanism for gravitational wave (GW) release.

In order to conduct a sensitive 'stacked' search for GWs, using the LIGO data for hundreds of different burst events, accurate start times for the magnetar bursts are required. This project initialises a database to collect observations of magnetar bursts, starting with the *SWIFT* satellite, and analyses the lightcurves to find the required trigger times. In addition, this collection of data will allow a broad investigation of the properties of bursts from many sources. It is hoped that this may help to identify trends in, and correlations between, burst properties; also to further analyse the relationship between AXPs and SGRs.

Noise Investigations of a Fabry-Perot Reference Cavity
Megan Daily
Mentors: Frank Seifert and Rana Adhikari

An understanding of noise sources is vital in understanding how to use a Fabry-Perot reference cavity to decrease the frequency noise of the laser used for LIGO's gravitational wave observatories and other experiments requiring low-noise laser sources. The reference cavity is used as a frequency reference for the laser. By understanding the noise sources, the noise can be reduced and the frequency stability of the laser can be increased. Noise sources include seismic noise, thermal fluctuations, Brownian noise, shot noise, pointing noise, power fluctuations, radio frequency amplitude modulation (RF-AM) noise, and phase noise. Seismic noise, thermal fluctuations, power fluctuations, and phase noise have all been measured to determine their contribution to overall noise. Brownian noise, shot noise, pointing noise, and RF-AM noise all have calculated levels of noise as well. By understanding the noise contribution of each source, the total noise of the system can be understood and new ways of reducing noise can be proposed.

The Construction, Alignment, and Focusing of the Viewfinder Telescopes for the Optical Lever System in Advanced LIGO
Michael Enciso
Mentor: Riccardo DeSalvo

The viewfinder telescopes mounted on top of the launcher telescopes are the alignment eyes of the optical lever system. Each viewfinder telescope has a CCD camera attached to the back that produces an image of the target on a computer screen. This image is used to locate the test mass and align the launcher telescope's beam to the desired spot. The secondary use of the telescopes is to monitor the main beam 1064 nm beam spot and its scattering; therefore it not only needs to be able to see in visible light for a clear image of the optical element, it also must be able to focus on the sources of scattered infrared light. A manual is being written giving precise directions for finding the maximal focus of each telescope so that they can be properly aligned on site at Advanced LIGO.

Correlation of Scattered Light Due to Surface Roughness With Fresnel Specular Reflectivity
Alyssa Frey
Mentor: William Kells

This study experimentally investigates how closely correlated the Fresnel specular reflectivity is with more realistic situations that include scatter. In reality, all surfaces are rough; however, when the surface has a roughness smaller than the wavelength of the incident light, the surface scatter is closely correlated to Fresnel reflectivity. The amount of scatter from a surface increases as the surface roughness increases and thus the reflectivity decreases as does the correlation. To inspect this correlation, the ratio of intensities of scatter when S and P polarized light are incident on an un-coated window at Brewster's Angle was observed. These optical configurations were selected because any correlation between the amounts of scatter would be more obvious with these configurations than most others. Measurements are taken on multiple spots on various samples to confirm results and determine reproducibility. These experimental results are then compared to theory which predicts that the ratio of the intensity of reflected S polarized light versus the intensity of reflected P polarized light from a dielectric interface.

Building a Magnetic Suspension System at the Caltech 40m Interferometer
Sharmila Dhevi Gunasekaran Gnanam
Mentors: Rana Adhikari and Koji Arai

LIGO (Laser Interferometer Gravitational Wave Observatory) is a quest for gravitational waves to experimentally verify The General Theory of Relativity. It also opens gateways to look farther into the past of the universe which cannot be revealed by electromagnetic waves. But, there are many practical limitations which make this mission difficult and efforts are being made to smoothen this journey. Among the many problems which LIGO faces is achieving desired sensitivity for a given frequency band of gravity wave signals. Sensitivity is very important for low-frequency gravity waves because many of the interesting astronomical happenings are hidden in these bands. This calls for a good seismic vibration isolation scheme for the detection of gravity waves at these frequencies. We propose suspension systems based magnetic levitation as a solution. This report describes the presently used techniques for vibration isolation outlining the features of magnetic suspensions. The current work is described in good detail. We have achieved magnetic levitation with active feedback control and characterized the system. In the end ideas have been given for possible future work.

A New Visualization Tool for Simulations of Black Holes and Neutron Stars
Yi Chen Hu
Mentors: Christian Ott, Mark Scheel, and Jeff Kaplan

The SpEC (Spectral Einstein Code) project has been simulating the coalescence of binary compact objects with the goal of providing LIGO with gravitational-wave waveforms of the highest accuracy. In our project, we have implemented a new visualization tool in the SpEC code for simulations of black holes and neutron stars. This tool will make it easy to output any two-dimensional slice of given three-dimensional simulation data. Users only need to specify a few parameters for input (including necessary information for the two- dimensional slice), then the code will generate a Delaunay triangulation which describes the connectivities between points on the sliced plane, and utilize interpolators coded in SpEC to parallelize the interpolating of tensor data for each point. With all of the data of the two-dimensional slice specified, our code will automatically output a VTK format file, which is viewable for ParaView, scientific visualization software intensively used in visualizing SpEC simulations. The code is applied to analyzing the oscillation eigenfrequencies of perturbed Tolman–Oppenheimer–Volkoff stars.

Development of a Low-Latency Inspiral Pipeline for LIGO Data Analysis
Erin Kara
Mentors: Antony Searle, Alan Weinstein, and Chad Hanna

The coalescence of compact objects in binary systems, such as neutron star and black holes, is one of the most promising sources for gravitational wave detection for ground-based gravitational-wave (GW) detectors such as the Laser Interferometer Gravitational-Wave Observatory (LIGO). The next generation GW detectors are expected to detect these events several times a year. With the inception of instrumental advancement, analysis techniques are also improving. The gstlal Inspiral pipeline is a prototype, low-latency pipeline for the analysis of compact binary coalescence events. It will have the ability to analyze a gravitational-wave signal and send confident trigger alerts to telescopes within minutes. I present my 2010 LIGO SURF project on the development and testing of the gstlal Inspiral pipeline. This includes writing an element to render Skymap plots, an element that sends trigger candidates to an external database, and a script that makes daily plots for the real-time analysis of S6 data.
I have also worked on testing the pipeline with unit tests to characterize the performance of stages of the pipeline using software and hardware injections.

Using Supernova Observations in the Electromagnetic Spectrum to Guide LIGO Searches for Gravitational Waves
Katherine E. Kaufman
Mentors: Christian Ott, Peter Kalmus, and Leo Singer

Core-collapse supernovae are predicted to be significant sources of gravitational waves; however, their signals are also predicted to lie close to the noise threshold of LIGO. In order to make a search for true signals from any of these events practical, the time of core-collapse should be constrained to a reasonable window within the data. In this project, we have compiled a catalogue of over 100 supernovae of types Ib, Ic, and II within 50 Megaparsecs that occurred after November 2005. The first light visible from a supernova, the shock breakout, is almost never observed directly, so methods must be developed to trace back to that time from observations made days or weeks afterward. We have been able to constrain the shock breakout times to within a few days or less for 7 supernovae based on non-detections made just before discovery. The Expanding Photosphere Method will be used to determine the shock breakout times for type II supernovae once photometry and spectra for each become available, but we continue to search for a similar method for the remaining types Ib/c.

Tiltmeter Data Acquisition System
Caroline Kim
Mentors: Riccardo DeSalvo and Vladimir Dergachev

The tiltmeter is a high sensitivity ground rotation sensor composed of a brass beam pivoting on a knife edge or a flexure hinge. This instrument is used in investigation of hysteresis and fractal noise in the hinges as well as in measurement of ground tilt. The data acquisition and control system is a mixed mode system comprising analog preamplifiers and drivers, data converter electronics, and a computer-based controls, and is designed to measure the tiltmeter position that varies over the sensitivity of six orders of magnitude. The initial implementation was sufficient to reach 3e-9 rad/sqrt(Hz), but further improvements required reduction of intrinsic noise sources. We investigated different subsystems, made improvements on power supplies for the FPGA board, and studied performances of different voltage references and the LVDT driver. Combined with other improvements, the tiltmeter can now reach the sensitivity of 2e-9 rad/sqrt(Hz).

Hartmann Sensor Diagnostics: An Investigation of Thermal and Temporal Stability
James Kunert
Mentors: Aidan Brooks and Phil Willems

Thermal lensing in the test masses of Advanced LIGO (aLIGO) would be a limiting source of error if not corrected for. In order to correct for wavefront distortion that such thermal lensing produces, it is necessary to know the spatial profile of the distortion which it creates. A Hartmann Wavefront sensor (HWS) will be used in aLIGO to measure this distortion directly. To measure the distortion caused by the test masses, it will be necessary to understand and minimize additional sources of wavefront distortion and noise which appears in the HWS measurement. The behavior of the HWS was analyzed over both thermally stable and thermally unstable conditions. Analysis under thermally stable conditions revealed an error within the digitization process of the camera, which was then investigated further. Analysis under thermally unstable conditions confirmed and quantified a predicted thermal defocus which appears in the HWS output as the sensor temperature changes. An experiment was then carried out to test a method of minimizing the effect of thermally and temporally dependent wavefront distortions.

Heterodyne Single Photon Detection
Kevin Kuns
Mentors: Herold Richard Gustafson, Vern Sandberg, and Guido Mueller

A heterodyne photon detector measures the number of photons in a signal beam through the beat signal with a reference beam shifted in frequency. A model detector was built to investigate how few photons it is possible to detect with a heterodyne detector while still detecting no photons when no signal beam is present. Detection schemes measuring the RF beat signal, a demodulated AC signal, and a demodulated DC signal are investigated. The theoretical noise limits of such a detector for each of these schemes are described and compared with the experimental results.

Building a Magnetic Suspension at the 40m Interferometer
Katharine Larson
Mentors: Rana Adhikari and Koji Arai

The success of a gravitational wave sensor depends crucially on its ability to minimize noise in its measurements, which may come from seismic (lowest frequency), thermal (intermediate frequency), or quantum noise (highest frequency). In this project, we aim to minimize seismic noise in future generation (post-aLIGO) gravitational wave detectors. Using feedback control and permanent magnets, we have built magnetic suspension for test masses (e.g., mirrors) at the prototype 40m laser interferometer that we hope to ultimately switch from analog to digital control system. We have achieved single-magnet levitation and are realizing levitation of a 2×2 array of magnets that will allow for stable low-frequency isolation in multiple degrees of freedom.

Towards a Better Analytical Understanding of the Parameter Estimation of Compact Binaries
Marc LeBourdais
Mentors: P. Ajith and Michele Vallisneri

Gravitational waves emitted from compact binary systems of stellar remnants are expected to be the first signals detected from ground-based interferometers. Numerical-relativity simulations have accurately constrained the waveform dependence on the physical parameters of the system. The expected parameter-estimation accuracies have been historically explored by the use of the Fisher-matrix formalism. But in some regimes, e.g. as in the low-SNR limit where current detectors such as LIGO reside, the Cramér-Rao Lower Bound (CRLB) cannot be trusted as a close approximation to the true errors. The final form of the second-order corrections to the Fisher matrix were derived from work by M. Vallisneri and are used to compute more accurate approximations to the true errors of parameter estimation (M. Vallisneri, 2008). Although more computationally expensive than using the CRLB, including the second-order corrections better describes the errors in regimes where current detectors reside and does not rely on the even more time-consuming approach of using Monte Carlo injection simulations.

Suspension Upgrade Research for Gravitational Wave Detectors
Kyung-ha Lee
Mentors: Alastair Heptonstall and Norna Robertson

In 2011 the LIGO detectors will be upgraded to create Advanced LIGO. The aim of this upgrade is to increase the sensitivity by a factor of 10 across the detection band. One of the limiting noise sources in gravitational detectors is Brownian noise in the mirrors and their suspensions. Advanced LIGO will use fused silica test masses and suspension fibers to reduce the effect of Brownian noise. One of the goals of our study is to investigate certain aspects of mechanical dissipation in fused silica fibers to understand better the suspensions in Advanced LIGO. We will also investigate potential future upgrades to the Advanced LIGO suspensions to further reduce suspension thermal noise. In addition to Advanced LIGO upgrade, GEO 600 and 40m interferometer are also undergoing the upgrade process. In our study, energy loss calculation for GEO 600 suspensions and tip tilt suspension building for 40m interferometer were also completed.

Evaluating the Efficiency of the Gstlal Inspiral Pipeline for Advanced LIGO
Laura Liao
Mentors: Chad Hanna and Stephen Privitera

The current inspiral data analysis pipeline will not be sufficient to handle the demands of Advanced LIGO. A new pipeline called gstlal inspiral is under development. gstlal is a GStreamer based wrapper for the LSC Algorithm Library (LAL) that will provide low latency, stream based analysis in the pipeline. The gstlal inspiral pipeline will be robust in handling gaps in data. In order to lighten computational burden, it will also incorporate new elements such as singular value decomposition. Since the gstlal inspiral pipeline is new technology, an end-to-end evaluation of its efficiency is required. Strain data from LIGO and Virgo detectors are analyzed with this new procedure. The pipeline is tested via software injections using simulated signals from populations of low-mass binary neutron stars. A receiver operating characteristic curve will be constructed to validate the pipeline, as well as, evaluate the detection efficiency. Once this is done, the pipeline's performance will be optimized upon this benchmark. Ultimately, the number of detections in the simulated search may make estimations for the rate of detection of binary neutron star sources.

AM-Stabilized RF Amplifier Driver
Jing Luo
Mentor: Daniel Sigg

The AOM/EOM driver is a high power RF amplifier used to drive an eletro-optic modulator [EOM] or an acousto-optic modulator [AOM] for Advanced LIGO. It provides up to 2W of RF power adjustable over a 24dB range, from 10 dBm to 34 dBm. It has an amplitude stabilization circuit to minimize the oscillator amplitude noise. The main structure of the present design consists of a radio frequency [RF] chain with a 10 dBm source input, an RF preamplifier, a voltage-controlled attenuator, a high power amplifier and two in series directional couplers. For RF AM stabilization, there is an in-loop and an out-of-loop circuit. The in-loop circuit includes an RF detector, which is fed by the first coupler and connects an RF servo to control the voltage-controlled attenuator. This detector can accurately measure the RF noise and remove unwanted noise. The out-of-loop circuit has an independent RF detector to verify the AM noise after the stabilization.

Finite Element Analysis of Seismic Isolation Stacks at the 40-Meter Interferometer
Gopal Nataraj
Mentors: Rana Adhikari and Koji Arai

The sensitivity required for gravitational wave detection demands effective isolation of astrophysical disturbances from surrounding seismic and mechanical disturbances. In an effort to reduce the effects of these unwanted forces, the LIGO facilities utilize passive isolation systems consisting of alternating layers of metal and viscoelastic dampers in order to attenuate ground motions. Mechanical analysis of these seismic isolation “stacks” amounts to understanding the eigenmodes of oscillation as well the transfer functions relating stack-base drives to stack-top responses. We use Finite Element Analysis software packages to perform such characterizations on the mode cleaner stacks at the 40-meter Prototype Interferometer at Caltech. Eventually, these efforts will be useful towards developing an adaptive active noise cancellation control system for Advanced LIGO.

Tiltmeter Studies and Characterization: Measuring Seismic Disturbances for Potential Use in LIGO/VIRGO Detectors
Amanda O’Toole
Mentor: Riccardo De Salvo

The detection of theoretical gravitational waves emitted from colliding pulsars has yet to be accomplished, but that is precisely the goal of the Laser Interferometer Gravitational Wave Observatory (LIGO). Because these waves are on the order of 10^-22 meters, the detectors must be extra sensitive and be able to overcome interference from the atmosphere, thermal changes, seismic motion, and more. A high-sensitivity, ultra-high vacuum compatible prototype balance tiltmeter was designed to test and measure the tilt component of seismic motion. In order to be used in the planned Advanced LIGO detectors, the sensitivity for a tiltmeter needs to be on the order of 1e-10 radians per sqrt(Hz). Previous studies of noise and hysteresis on maraging blades have shown that the main source of noise and dissipation in metals at low frequencies comes from self-organized criticality. In an attempt to minimize noise at these low frequencies, the tiltmeter is balanced on a knife-edge blade instead of a flexure hinge (used in other tiltmeter implementations). A new high-precision tungsten carbide pivot blade has been machined, polished, photographed, and coated, and frequency and hysteresis measurements performed on the system.

Development and Characterization of Phase Camera for LIGO

Razib Obaid
Mentor: Joseph Betzwieser

The Laser Interferometer Gravitational Wave Observatory (LIGO) is designed to detect and measure the characteristics of gravitational waves as predicted by general theory of relativity. To do this, LIGO uses a high power laser beam in a Michelson-type interferometer which has been augmented with additional optical cavities. Several radio-frequency sidebands are added to this beam to help provide control signals for Fabry-Perot cavities that have been established at different parts of the interferometer. Since these sidebands resonate in different parts of the interferometer, they can suffer distortion in their spatial and phase profiles as they propagate through the instrument. We want to measure this distortion and have feedback to help reduce the sources of the distortion. This is done by a 'Phase Camera' that we have built using both CCD and CMOS optical sensors. In this project, we focused on building the camera and characterizing the noise sources for both the optical sensor systems to determine the performance in measuring the distortion present in the sideband in comparison to the carrier.

Gravitational Waves From Turbulence in Newborn Neutron Stars
Kaushal Patel
Mentor: Christian D. Ott

Neutron stars are born at the very hearts of supernovae, and their birth is marked by violent turbulence. The hot and unstable newborn neutron star cools and contracts via neutrino emmission, and this cooling process is accompanied by turbulent Ledoux convection. Such turbulent motion of matter naturally emits powerful gravitational waves. In this project, we use a formalism previously applied to primordial turbulence to derive estimates for key properties of these gravitational waves. In the process, we study the statistical nature of protoneutron star turbulence, and the emission of gravitational waves. Our results bring insight into the complex processes occurring inside a protoneutron star and will be useful for LIGO's search of gravitational waves from them.

Using Multivariate Statistics to Calculate False Alarm Rates
Colorado J. Reed
Mentors: Alan Weinstein and Kari Hodge

The LIGO-Virgo collaboration uses a global network of kilometer-scale interferometers to search for gravitational waves (GWs) from astrophysical sources. Since no GWs have been found to date, we must create a method of ranking potential GW signals that are produced by a data analysis pipeline. For any ranking statistic, we can define the false alarm rate (FAR) as the number of false gravitational wave signals beyond a ranking threshold per time period. In the past few months, the ranking statistic has changed from the effective signal-to-noise ratio to a stronger classification criterion that is calculated using a multivariate statistical classification tool. Upon implementing this change, the distribution of the FARs for potential GW triggers appeared abnormal when compared to the distribution of the time-shifted triggers (which serve as an estimate of the background in GW searches). Our work has shown that this unexpected change in the FAR distribution was not caused by a failure in the multivariate statistical classification tool, but rather, a subtle difference between the time-shifted triggers and potential GW triggers.

Advanced LIGO Silicon Photodetectors
Raymond Simons
Mentors: Keita Kawabe and Vern Sandberg

A more complex optical configuration in Advanced LIGO calls for assisted green-light locking the Fabry-Perot arm cavities. The goal of this project is to design and test a prototype RF Amplitude Modulated (AM) green laser source. The laser source will be developed to characterize the response of silicon photodiodes used for the new green-lock method. The RF modulation techniques are primarily electronic.

Template Placement in the Search for Coalescing Black Holes
Dan Stratman
Mentors: Ajith Parameswaran and Chad Richard Hanna

The technique of matched filtering is an important method for finding a specific signal from within a set of noisy data. This technique is used to find the gravitational-wave signal from a coalescing compact binary. However, while it is effective for determining if a specific signal is present, it has a huge performance loss for finding signals that depend on a broad, continuous spectrum of parameters, since to test for every possible signal would be impossible to do. To make up for this shortcoming, only a specific set of signal waveforms will be tested--a set designed such that up to a specific tolerance level, regions of the parameter space can be tested with a single waveform. This set must be selected so that the entire parameter space is covered using as few waveforms as possible. This can be achieved by creating a metric of the parameter space to determine how 'far' apart any two waveforms are from each other. Using this metric, we can calculate approximate regions of allowable tolerance, and thus determine the right waveforms to test with matched filtering. In this work we compute the metric in the parameter space of waveforms coherently describing the inspiral, merger and ring down of binary black holes. The metric can be employed in the search for gravitational-wave signals from binary black holes.

Seismometer Modeling and Modifications
Gregory Vansuch
Mentors: Jan Harms and Riccardo DeSalvo

Future gravitational wave observations will be limited by Newtonian noise arising from gravitational disturbances from local sources. It is predicted seismically generated Newtonian noise (NN) will limit measurements at frequencies between 1-30Hz, making it desirable to formulate a method for subtracting it. To study NN, seismic stations have been set up at the former Homestake mine in Lead, South Dakota, where this noise is a factor of ten less than above ground. Contributing to this study, the prototype of an insulation box was constructed to prevent computers that are gathering data there from breaking down due to humidity. This box must be tested for efficiency on site. The seismometers at the mine require increased sensitivity to characterize NN. To fix this, the seismometer titled the SS-1 Ranger has been opened and modeled on AutoCAD to study. Modifications of the design allowing for increased sensitivity need be determined. Using ExpressPCB, a new capacitor bridge has been designed for the Ranger, though this design needs to be tested. Also, the Ranger and other seismometers will undergo noise measurements and the results analyzed to determine limitations of seismometers due to mechanical noise. Methods to fix these issues will be determined afterwards.

Development of Optical Gyroscopes for Advanced LIGO
Jenna Walrath
Mentors: Rana Adhikari and Alastair Heptonstall

The next generation in gravitational wave detectors, Advanced LIGO, will implement a seismic isolation system which employs seismometers to feed information forward to actuators to subtract out the ground motion. However, at low frequencies, ground tilt motion is interpreted by the seismometers as horizontal motion. The goal of this project is to develop an optical gyroscope, operating on the Sagnac Principle, to measure pure rotation so the rotational signal can be subtracted out of the seismometer signal. In our system, a phase-modulated laser beam is split in two and sent in opposite directions around a ring cavity, and the Pound-Drever-Hall method is implemented to lock the beams to the cavity. A rotation in the cavity will cause a frequency shift, according to the Sagnac Principle, so when the beams are recombined at the output using a Mach-Zehnder, the beat frequency will be proportional to the rotation rate. Work this summer has included analyzing individual noise sources, such as laser frequency noise, mechanical mirror noise of the cavity, and VCO noise. Future work will focus on improving sensitivity.

Identifying and Subtracting Noise Transients in Gravitational-Wave Detectors
Alex Wein
Mentors: Ajith Parameswaran, Rana Adhikari, and Alan Weinstein

The gravitational-wave (GW) detectors used by LIGO are such sensitive instruments that a variety of instrumental and environmental noise sources interfere with their ability to detect and measure GWs. In order to correct for these glitches, a number of known noise sources are being continuously recorded independently from the main detector's GW channel. Also, the couplings between many such noise channels and the GW channel have been studied and modeled. This allows for statistical analysis on the data to determine whether a transient in the GW channel was caused by a coincident transient measured by a noise channel. The goal is then to be able to veto or subtract glitches from the GW channel once they have been identified as noise rather than GWs. This project aims to develop a method for subtracting glitches in the GW channel of LIGO making use of the data recorded in auxiliary channels.

Multi-Messenger Astronomy With Gravitational-Wave Bursts
Nathan I. Youngblood
Mentor: Antony Searle

Gravitational-wave bursts are short-duration signals ($\lesssim$1s) that are thought to be generated from some of the most energetic cosmological events in the universe (merging compact binaries, core-collapse super-novae, starquakes, etc.). The Omega pipeline is a software package with the express purpose of detecting gravitational-wave burst events in real time and identifying the most probable source location of such an event. Because it is impossible to physically generate such events to test the effectiveness of the pipeline, simulated signals must be generated through the use of hardware and software injections. My research with LIGO (Laser Interferometer Gravitational-wave Observatory) and the topic of this paper involves creating skymap images (probability density functions of possible signal locations) of these injections in addition to generating tables and graphs gauging Omega's performance.