# 2013 LIGO SURF Project Abstracts (draft of Feb 11, 2013)

**Projects at LIGO Laboratory at Caltech:**

- Dynamics and Gravitational Wave signatures of charged black hole binaries
  - Mentor: Huan Yang, Yanbei Chen
  - Abstract: Advanced LIGO will be in operation and is expected to make the first gravitational wave detection in the near future. Given the experimental waveforms, a natural question to ask is how to extract the gravitational wave source information including source types, mass, spin and etc. The student will look at charge effect on black hole binary dynamics and investigate the possibility of extracting charge information from the gravitational waveforms. The student should have taken courses on undergraduate-level general relativity. It is preferable that applicants have some experience on post-Newtonian theory and/or black perturbation theory.

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- Early Warning Detection of Gravitational Waves from Compact Binaries: Making it Happen
  - Mentor: Larry Price, Leo Singer, Nicolas Smith-Lefebvre
  - Abstract: As gravitational wave detectors gain low-frequency sensitivity, it becomes increasingly likely to detect binary inspiral signals before the end of the inspiral. This opens the door to issue astronomical alerts in time to see the merger as well as a number of ways of changing the state of the instrument in order to maximize its sensitivity to that particular signal. Using existing technology (see http://arxiv.org/pdf/1107.2665.pdf ) the student will determine how well the parameters of the binary system can be estimated before merger and therefore what the prospects and requirements are for making early warning detection a reality. The student should have expertise in C, Python and a Linux/Unix computing environment. Familiarity with GStreamer is extremely helpful but not required. The successful applicant will gain experience in high-performance computing and advanced techniques for detecting binary inspirals.

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- 3D Low-Latency Localization of Gravitational Wave Event Candidates
  - Mentor: Larry Price, Vivien Raymond, Leo Singer
  - Abstract: Advanced LIGO and Virgo brings with it the prospect of making joint electromagnetic and gravitational wave observations --- "seeing" and "hearing" neutron stars and black holes collide. In addition to having a probable sky location it is useful to know something about the corresponding possible distance to the source. This allows us to use what we already know about the likely origin of these events to help further constrain their location in the universe. The student will look at ways of combining our prior information (in the form of a galaxy catalog) with the 3D (sky location + distance) probabilistic information about the event to best determine the true source location. The student should have a strong command of the Python programming language and the Linux/Unix environment in addition to familiarity with C. The successful applicant will gain experience in high-performance computing and some experience with Bayesian inference and sources of joint electromagnetic and gravitational wave emission (especially short gamma ray bursts).

- Searching for Spinning Black Hole Binaries in Advanced LIGO and Virgo
  - Mentor: Stephen Privitera
  - Abstract: One of the primary targets for gravitational wave detection by LIGO and Virgo are mergers of binary black holes. Searches for such events benefit greatly from the accurate prediction of the signal waveform by General Relativity. However, while astrophysical black holes are expected to have significant spin, only recently have models of binary black holes with spin become available to the gravitational wave community. In this project, we aim to understand the role of black hole spin for the detectability of gravitational waves in advanced LIGO and Virgo instruments. The student will study predictions for the distribution of spins in binary black holes and fold this insight into an assessment of the importance of spin for binary black hole searches. This study will take place in the context of a realistic search of simulated advanced detector data. A good starting point for the uninitiated can be found in the living review http://arxiv.org/abs/1003.2480. The student should have a strong background in astrophysics, some programming experience (preferably with Python), and a basic of command of working in Unix/Linux computing environments.

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- Exploring the Gravitational-Wave Signature of Extreme Core-Collapse Supernovae
  - Mentor: Philipp Moesta and Christian Ott
  - Abstract: An extreme class of core-collapse supernovae, so-called "hypernovae", is hypothesized to be driven magnetorotationally by a combination of rapid rotation and ultra-strong magnetic fields and may explode extremely asymmetrically. The extreme conditions in the engine of such hypernovae are expected to lead to copious gravitational wave emission, which may perhaps be detectable out to megaparsec-distances with the upcoming generation of Advanced LIGO interferometers. The LIGO REU SURF participating in this project will work with Prof. Christian Ott and Dr. Philipp Moesta on simulations of stellar collapse in rapidly rotating, strongly magnetized progenitor stars. They will work out a new set of equations to extract the contribution of magnetic stress to the overall gravitational wave signal. They will then implement these equations in the Zelmani core-collapse simulation package, carry out, and analyze a set of 3D rotating stellar collapse simulations.

- Influence of the Precollapse Angular Momentum Distribution on Stellar Collapse and its Gravitational Wave Signature
  - Mentor: Ernazar Abdikamalov and Christian Ott
  - Abstract: The distribution of angular momentum in the cores of massive stars is one of the most pressing open issues in modern astrophysics. It plays an important role in stellar evolution and can have significant impact on the collapse, bounce, and postbounce stellar dynamics and the properties of explosion in core-collapse supernovae. It may also strongly influence the associated gravitational wave emission. The LIGO REU SURF participating in this project will work with Prof. Christian Ott and Dr. Ernazar Abdikamalov on axisymmetric simulations of stellar collapse of a large number of rapidly rotating progenitor stars with different angular momentum distributions. They will carefully analyze the impact of the differential rotation on the collapse, bounce, and postbounce dynamics. They will also explore if one can, in principle, infer any information about the precollapse angular momentum distribution from the emitted gravitational wave signal.

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- Higher-Order Gravitational Wave Emission in Core-Collapse Supernovae
  - Mentor: Steve Drasco, Christian Ott, Philipp Moesta
  - Abstract: Gravitational waves are important messengers that carry information on the multi-dimensional fluid dynamics in the central engines of core-collapse supernovae. So far, most simulations use the so-called quadrupole formalism to extract the waves from the matter dynamics, but recent results suggest that significant emission may also occur at higher than quadrupole order. The LIGO REU SURF participating in this project will work with Prof. Christian Ott, visiting Prof. Steve Drasco and Dr. Philipp Moesta on including the next order terms (the current quadrupole and the mass octupole) in simulations. This work will have two components. The first is a review of the theory of multipole expansions for gravitational waves, in order to determine the precise form of the correction terms in the context of various coordinate choices used in current supernovae simulation codes. The second is the implementation of these corrections in new simulations.

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- High-Fidelity Initial Models for Neutron Star Simulations
  - Mentor: Christian Ott, Mark Scheel
  - Abstract: Precision predictions of gravitational waves from pulsating and merging neutron stars rely on numerical relativity simulations, which, in turn, rely on physically and numerically accurate initial conditions. In this project, the LIGO REU SURF will work with Prof. Christian Ott and Dr. Mark Scheel on generating neutron star initial data with both cold and hot microphysical equations of state and evolve the generated neutron star models in the Simulating eXtreme Spacetimes numerical relativity code SpEC. In the first part of the project, the student will become familiar with the methods used to generate initial data for numerical relativity and will conduct a survey of available codes for neutron star initial data. In the second part, they will generate neutron star models using a set of different codes and evaluate their accuracy by evolving them in the SpEC code.

- Testing Fully Dynamical Adaptive Mesh Refinement in the Einstein Toolkit
  - Mentor: Roland Haas, Christian Ott
  - Abstract: The Einstein Toolkit (ET) is an open-source compilation of numerical relativity codes for simulating gravitational-wave emitting systems. ET includes an adaptive mesh refinement driver that -- in principle -- allows the arbitrary placement of resolution based on a user-defined criterion. In must current work, however, this is not used and regions of high-resolution are pre-defined and change rarely in the course of a simulation. In this LIGO REU SURF project, the participating SURF will work with Dr. Roland Haas and Prof. Christian Ott on developing criteria (and code) for fully dynamical placement of resolution without user intervention based on the dynamics/thermodynamics of the simulated system.

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- Sensing and control of six degrees of freedom magnetic suspension system
  - Mentor: Haixing Miao, Rana Adhikari
  - Abstract: Seismic noise is one of the important low frequency noise that limits sensitivity of advanced gravitational-wave detectors. For isolation, a usual approach that has been applied in advanced detectors is the multiple-stage pendulum type suspension. We consider a new type of seismic noise isolation scheme using magnetic levitation. Such a scheme utilizes the symmetry and local extremum of magnetic force between two disk magnets. By incorporating the sensing and feedback control system, the design configuration in principle allows stable low-frequency isolation of six degrees of freedom in a single setup. We are building a prototype to test this idea and trying to make a proof-of-principle demonstration. In the project, the students will characterize the sensing and control system, in particular, the coupling among different degrees of freedom, and acquire lock for the setup. It is preferable that the students have backgrounds in electronics and some knowledge in feedback control.

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- Modeling mirror shape to reduce Brownian Noise
  - Mentor: Matt Abernathy, Rana Adhikari
  - Abstract: Reducing Brownian thermal noise is of great interest in the design of advanced interferometric gravitational wave detectors. It has been postulated that the component of the thermal noise associated with the mirror may be reduced by altering their shape. This project would require the use of the COMSOL finite element modeling tool to model the effects of this shape on the Brownian thermal noise associated with the mirror substrates. The student should have a good understanding of mechanics and the theory of elasticity and be interested in learning and using basic finite element analysis techniques. A brief introduction can be found in: S. Rowan et al., "Thermal noise and material issues for gravitational wave detectors" Physics Letters A, vol. 347 pp.25-32 (2005).

- Searches for gravitational waves from inspiral binaries: the best visualization ever
  - Mentors: Michele Vallisneri, Roy Williams
  - Abstract: Inspiraling binaries of compact objects such as neutron stars and black holes are primary targets for ground-based gravitational-wave detectors, and the data from every LIGO science run has been searched for these signals. The searches consist of complex software "pipelines" that filter the data through many steps, creating many candidate "triggers", looking for coincidence among multiple detectors, selecting the most convincing triggers with several criteria, and finally evaluating the probability that the triggers are really gravitational-wave events (for instance, see http://arxiv.org/abs/1208.3491). Such a search produces a ton of plots (many types, and many of each), and gravitational-wave analysts are used to poring over them and understanding quickly how a search is performing. Nevertheless, a careful redesign could certainly improve the effectiveness (and the handsomeness!) of many of these plots. In this project we will design an end-to-end browser-based visualization of a binary-inspiral search, which will be useful both for the professionals running such searches, and for the astronomical community and the general public looking in from outside. Requirements: interest in gravitational-wave science and information design; familiarity with, or willingness to learn quickly, Python and Javascript (especially tools such as d3.js); a desire to make beautiful things.

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- Design of a coating-less reference cavity with total internal reflection
  - Mentor: Matt Abernathy, Koji Arai
  - Abstract: Thermal noise is considered one of the fundamental noise sources in optomechanics and laser frequency stabilization using an external reference cavity [1]. In particular, thermal noise associated with the reflective coatings can be a noise source that limits the stability of the reference cavity. It is also considered to be a sensitivity limit in second-generation interferometer gravitational wave detectors. One of the ideas to resolve the coating thermal-noise issue is to eliminate the coatings and instead utilizing total internal reflection (TIR) for the mirror surfaces [2]. A monolithic, polished substrate is used as a reference cavity while the input and output beams interact with the cavity via an evanescent coupling, in a process called Frustrated Total Internal Reflection (FTIR). Improvement in thermal noise may be achieved by this technique as the other thermal noises (Brownian, thermo-elastic, and thermo-refractive noises) of the cavity substrate can be reduced or canceled out by choosing the material, geometry, and operating temperature of the cavity body. In this project, we search for an optimal design of the TIR reference cavity for the thermal noise reduction. We plan to use COMSOL and MATLAB as the analysis environment. The student should have completed courses on mechanics and thermodynamics.
    [1] Physical Review Letters 93, 250602 (2004)
    [2] Optics Letters 17, 378 (1992)

- Design and commissioning of laser power stabilization
  - Mentors: Jenne Driggers, Nicolas Smith-Lefebvre, Rana Adhikari
  - Abstract: LIGO depends on having ultra stable lasers for the detection of gravitational waves. Similarly, the prototype labs at Caltech require frequency and power stabilized lasers to conduct experiments and develop technology that will be used for Advanced LIGO and future generations of gravitational wave detectors. This project entails a well-motivated student designing a servo to stabilize the power of a laser beam, using an acoustic-optic modulator as an actuator. Once design of the analog circuit is complete, the student will commission the system, including fabrication of electronics, installation of optical components, and integration with software for remote control. Experience with electronics design, controls theory and/or optical systems are preferred.

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- Nonlinear noise generation in mechanical systems
  - Mentors: Eric Quintero, Rana Adhikari
  - Abstract: Material defects can lead to nonlinear internal dynamics in any type of material – for example, metal blades that will be used as part of the seismic isolation system for the Advanced LIGO detectors. Blade motion at low frequencies can convert into high frequency motion, possibly making the system susceptible to random noise known as "crackle" noise. Since the conversion parameters will depend on material properties and details of the manufacturing process, a detailed investigation of crackle noise can provide information to further mitigate noise in seismic isolation systems, and more generally reduce unwanted nonlinear dynamics of metal blades. The student will work on a laser interferometer experiment to measure crackle noise in metal blades, and prototyping experiments to investigate other flexures where crackle noise may occur. The goal is to characterize various blade samples and relate measured crackle noise to material properties, and infer the impact that this noise source has on the Advanced LIGO suspension systems. The student will become familiar with feedback systems and the technique of locking an interferometer, which are fundamental concepts relevant for LIGO, and interferometry as a whole.

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- Angular position sensing and control for a 40m prototype interferometer
  - Mentors: Manasadevi P Thirugnanasambandam, Jenne Driggers, Rana Adhikari
  - Abstract: LIGO detectors are extremely sensitive to the angular orientation of the interferometer test masses. Fluctuations in the angular orientation of the test masses adversely affects laser power buildup in Fabry-Perot cavities and beam centering on mirrors. The goal of this project is to study the various angular degrees of freedom of the interferometer and commission an Angular Sensing and Control (ASC) system for the 40m prototype. This will include installation and alignment of piezoelectrically controlled mirrors, and integration of these actuators with software for remote monitoring and control, as well as design of a software servo to implement feedback to these mirrors. Experience with controls theory and/or optical systems are preferred.

- Modeling precise calibration of the Advanced LIGO detectors
  - Mentor: Alan Weinstein
  - Abstract: The Advanced LIGO detectors will begin taking data in the next 2 years. The response of the detector to a gravitational wave is encoded in digitized electro-optic signals from the detector; these must then be converted to gravitational wave strain through a calibration procedure. In Initial LIGO, the calibration procedure achieved an accuracy on the order of 10%. We aim for much better accuracy for Advanced LIGO. Also, the detector response is significantly more complex for Advanced LIGO because of the more complex optical configuration of the detectors. We will develop and work with computer models and simulations to quantify the accuracy of the calibration procedure.

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- Characterizing the data from the Advanced LIGO subsystems
  - Mentors: Vivien Raymond, Alan Weinstein
  - Abstract: The Advanced LIGO detectors will begin taking data in the next 2 years. Detector sub-systems (pre-stabilized laser, suspension systems, feedback loops and controls, etc) are being brought into operation right now, and data from these systems are already available. We aim to characterize the performace of these systems, identify problems and pathologies, and aid in fixing them before observational data taking begins.

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- Measuring the properties of gravitational waves using continuous waves from spinning neutron stars
  - Mentor: Alan Weinstein
  - Abstract: The direct detection of a gravitational wave with the Advanced LIGO detectors provides the opportunity to measure departures from General Relativity. These departures can arise in the speed of the gravitational wave, existence of alternate polarizations, and parity violation. To measure these, we can simulate a single detector measurement of a continuous gravitational wave from a well-defined pulsar source, for example the Crab pulsar, due to an asymmetry in the moment of inertia. The speed of a gravitational wave can be measured from the Doppler frequency modulation of the signal, with an accuracy that depends on the strength of the signal. This project aims to precisely quantify the achievable accuracy and compare it with other methods of measuring the "speed of gravity".

- Laser Frequency Stabilization to Ultra Stable Fabry-Perot Cavity
  - Mentor: Tara Chalermsongsak, Rana Adhikari
  - Abstract: Frequency noise of a laser can be suppressed by locking it to a Fabry-Perot cavity. Once the frequency noise is sufficiently low, the laser can be used for various sensitive interferometric measurements, i.e. thermal noise probe, crakling noise in blade spring measurements. We plan to lock laser frequency to a reference cavity and distribute the frequency stabilized via optical fiber system. This is a good opportunity for the student to have a hands on experience on optics and to characterize fundamental and technical noise of the cavity and the optical fiber.

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- Extracting Astrophysical Parameters from Gravitational-Wave Observations.
  - Mentor: Vivien Raymond, Alan Weinstein
  - Abstract: Gravitational-Wave Astrophysics involves, after a detection, the estimation of the signal parameters. Compact Binary Coalescences are prime scientific targets to extract astrophysical parameters because of the detailed families of model available, and the relatively high expected detection rates. Based on those models, a complete inference software has been developed within the LIGO-Virgo Collaboration, see http://arxiv.org/pdf/1201.1195.pdf and reference therein. The student will use this tool to evaluate its performances in terms of parameter estimation and model selection as a function of Compact Binary Coalescence source in the advanced detector era. And the student will be encouraged to try ways to improve the methods implemented… The student should have a strong command of the C programming language and the Linux/Unix environment. The successful applicant will gain experience in Bayesian inference, sampling techniques and high-performance computing (all ubiquitous in science).

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- Characterizing the stochastic gravitational-wave background with Advanced LIGO
  - Mentor: Eric Thrane
  - Abstract: A gravitational-wave background is expected to arise from the superposition of many gravitational-wave signals, which are too weak to detect individually, but which combine to create a "stochastic" gravitational-wave glow. By measuring the stochastic background, we can probe a wide range of interesting science, from neutron stars to the inflationary epoch shortly after the Big Bang. Studies are planned or underway in order to realize the full potential of Advanced LIGO stochastic analyses, and interested students can contribute to this effort in a number of ways. Some example investigations include: characterizing the Gaussianity of the stochastic background, optimizing data-processing parameters, determining the sensitivity of Advanced LIGO to different models. Students will gain expertise in programming, statistics, and signal processing while making an important contribution to Advanced LIGO science. Experience with matlab is a plus.

- A Fiber Optic Based System to Automatically Measure the Frequency Response of the Photodetectors in an Interferometric Gravitational Wave Detector
  - Mentors: Eric Gustafson, Prof. Rana Adhikari
  - Abstract: Before you can build an Interferometric Gravitational Wave Detector that works at the limits set by Quantum Mechanics it is necessary to first build a Detector that you can control and read out optically. There are several photodiodes in such a detector used to sense various degrees of freedom of the system to provide feedback signals for the control of the detector. In addition there is the main interferometric Gravitational Wave Signal that is read out with a photodiode. In this sort of precision physics experiment it is necessary to treat the photodiode and its readout electronics as systems whose performance including the frequency response can change over time and with changing operating conditions. This project will be to build an automatic Frequency Response measurement system for the Gravitational Wave Detector Photodiodes. This system will use a modulated diode laser coupled through a fiber optic distribution system to illuminate the Photodiodes and then to automatically and quickly measure the frequency response of each photodetector system. This experiment will involve hands-on experimenting with lasers, precision mechanical systems, optical equipment, fiber optic components and digital controls. Enthusiasm and energy are more important than any specific skills in quantum optics and controls.

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- Directly Comparing Ultra-Stable Lasers with Large Frequency Separations
  - Mentors: David Yeaton-Massey, Nicolas Smith-Lefebvre, Prof. Rana Adhikari
  - Abstract: Frequency stabilized lasers for use in a research lab environment exist at many different wavelengths. A comparison between the frequency stability of different light sources is often desired. Two sources we are interested in comparing are at 1064 nm and 1550 nm. As direct detection of optical beat signals is limited to the GHz scale, we need to use cleverer techniques such as doubling and/or fiber based frequency combs to compare the two. The project will focus on the analysis and comparison of the different techniques available, with a goal of choosing the optimal method to integrate with existing laboratory infrastructure, and creating an experimental layout.

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- Laser Frequency Stabilization to Cryogenic Crystalline Silicon Cavities
  - Mentors: David Yeaton-Massey, Nicolas Smith-Lefebvre, Prof. Rana Adhikari
  - Abstract: Fabry-Perot cavities with exceptional length stability are essential tools in the frequency stabilization of lasers for precision spectroscopy, optical atomic clocks, quantum optics experiments, and interferometric gravitational wave detectors. Several noise mechanisms can limit the performance, including thermal fluctuations, vibration-induced elastic deformation, laser power fluctuations, and coating thermal noise. This project will consist of noise hunting and optimizing an existing experimental setup using two ~1kg linear Fabry-Perot monocrystalline Silicon cavities operated at 120K, working towards a measurement of coating thermal noise at cryogenic temperatures.

- Quantum-noise reduction schemes for future advanced gravitational wave detectors
  - Mentors: Haixing Miao, Yanbei Chen
  - Abstract: Advanced gravitational-wave detectors will be limited by noise due to quantum fluctuations in the light, around the most sensitive detection band ~ 100Hz. There are different approaches for suppressing the quantum noise, e.g., by using squeezed light and by modifying the input and output optics of the detector. In this project, the student will investigate two feasible schemes: (i) the local readout scheme for coherently suppressing the quantum radiation pressure noise, in which an auxiliary light is used to sense the motion of input test masses; (ii) the band-limited optical spring for enhancing response of the test mass to gravitational-wave signals, in which we design a proper filter to limit the optical spring in a narrow band, and by piecing together several such optical springs, we are expecting to create a multiple resonances. Students with some elementary knowledge in quantum optics are preferred.

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- Setting upper limits on the strength or rate of gravitational waves in the presence of non-Gaussian noise
  - Mentors: Vladimir Dergachev, Alan Weinstein
  - Abstract: Searches for continuous gravitational waves are computationally limited and must cope with data containing large detector artifacts. Setting valid upper limits on the strength or rate of a signal is problematic if the distribution of background noise is not well modeled. A new method called the "universal statistic" has been developed to compute valid upper limits, independent of the background distribution. The aim of this project is to investigate and test improvements to universal statistic implemented in the latest generation of PowerFlux code used to search for weak continuous gravitational wave signals in LIGO data. Knowledge of statistics and of calculus is essential for this project. The student will have opportunity to apply tools from probability theory and optimization (in particular simplex method).

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- Predicting the future and making the Advanced LIGO Controls System work in the presence of Transient Thermal Effects.
  - Mentors: Aidan Brooks, Rijuparna Chakraborty, Alastair Heptonstall and Eric Gustafson
  - Abstract: The interferometer in the Advanced LIGO GW detector will use high optical powers to attain the sensitivity required to detect gravitational waves. The resulting transient thermal lenses in the interferometer optics will change its optical configuration and degrade the Interferometer Sensing and Control System (ISC). This project aims to develop a tool to predict the future thermal state of the interferometer based on its known thermal history and, crucially, predict necessary changes to the ISC over time to maintain a stable system. Such a tool will be very useful in increasing the performance of Advanced LIGO. It is preferable that the students have backgrounds in MATLAB and some knowledge of feedback control.

- Interferometer test mass acoustic mode damping
  - Mentor: Bill Kells
  - Abstract: Currently, the advanced LIGO interferometers (scheduled to commence operation in 2014) are expected to operate a extremely high DC laser beam powers. This power level is predicted to induce an opto-mechanical instability, the so called “parametric instability”(PI). This could seriously limit the ultimate sensitivity of the LIGO interferometers. Ongoing research (originally theoretical to better understand the circumstances of PI, but now extended to actual experimentation) has focused on observing and mitigating such instabilities. One such mitigation involves affixing dampers, so called “acoustic mode dampers” (AMD) to the interferometer test masses. These AMDs have at their heart a piezo-electric transducer which converts mechanical vibration (from the PI build up) to electrical current which is dissipated in an external resistance. A challenge has been to identify and select particular piezo materials that have intrinsically low mechanical loss. Relatively little is known about these materials’s loss, so that we need simple yet reliable testing to determine the loss of many prospective samples. An outline of how this testing could be advanced is described in a LIGO technical note (LIGO-T1200281-v2). As a SURF project for the Summer of 2013 it is proposed that this loss measurement concept be realized in the laboratory. Basic electronic assembly and measurement (with instrumentation existing here at Caltech) skills would be advantageous.
    References: C. Zhao, et. al., http://arxiv.org/abs/gr-qc/0502079; http://arxiv.org/abs/0801.1150; http://adsabs.harvard.edu/abs/2011PhRvA..84f3836Z.

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- Comparing coating Young's modulus measurement techniques
  - Mentor: Matt Abernathy
  - Abstract: The high-reflectivity optical coatings deposited on the LIGO test-masses are a serious contributor to the Brownian thermal noise in the detector. This is expected to be the limiting noise source at some of the most sensitivity frequencies in Advanced LIGO. It is therefore important to measure and understand the properties of these materials that contribute to the Brownian thermal noise. The Young's modulus of the coating serves to mediate how much the mechanical loss of the coating contributes to the overall mechanical loss of the mirror, with higher mechanical loss giving rise to higher Brownian noise. It is therefore necessary to measure directly the Young's modulus of the coating materials. Various groups within the LSC have been working to make these measurements, and two methods--nano-indentation and the acoustic reflection technique--have achieved promising results. This project will involve comparing the results of the two techniques used to measure the same samples in order to accurately extract a Young's modulus and Poisson's ratio of the coating materials. The applicant should have experience with Matlab, analysis in frequency space, and some knowledge of coating materials. Knowledge of the acoustic reflection technique is encouraged.

- Real-time Calibration of Gravitational-wave Strain
  - Mentors: Jameson Rollins, Rana Adhikari, Alan Weinstein
  - Abstract: Precise calibration of gravitational wave detectors is very important for extracting the most science from the data. To extract the maximum information from astrophysical explosions interferometer length and strain calibration will be done in real-time in the digital control system. This will be particularly important for the very low latency data analysis pipelines that will attempt to quickly identify gravitational wave candidate events, reconstruct their source positions on the sky, and notify follow-up telescopes. At the LIGO 40m prototype laboratory we will be prototyping real-time calibration methods on one of the 40m suspended arm cavities. The student will gain experience with interferometer control systems, calibration concepts, and working with real-time digital control and data acquisition.

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## Projects at LIGO Livingston Observatory:

- Simulating the advanced LIGO interferometer using the real control code
  - Mentor: Joseph Betzwieser (LIGO Livingston Observatory)
  - Abstract: The interferometers of advanced LIGO require complicated software controls to operate. To better understand both the hardware and software, we will use the same software used to control the interferometers in a simplified simulation of a running interferometer. By using the actual control code, we can better discover issues specific to that code and distinguish them more easily from issues that may arise in the hardware of the interferometer. This project requires some programming.

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- Online Adaptive Filtering for Advanced LIGO
  - Mentor: Valera Frolov, Denis Martynov (LIGO Livingston Observatory)
  - Abstract: The installation and commissioning of the Advanced LIGO interferometer is well underway at LLO. We expect to start commissioning the vertex section of the full interferometer in the spring of 2013. The vertex interferometer will operate in the dual recycled Michelson configuration. The student(s) will investigate the noise couplings of various environmental sources such as seismic, acoustic, and magnetic and develop the techniques to reduce the effect of these noise sources on the interferometer control signals. The student(s) will use various adaptive filtering methods including least mean square error minimization, optimal state estimation with Kalman filters, and linear quadratic regulator. The student(s) will setup and/or characterize the performance of the environmental sensors such as accelerometers, seismometers, magnetometers, and microphones. Experimental and analytical skills will be used. Knowledge of at least of one scripting language is required.

## Projects at LIGO Hanford Observatory:

- Spectral Line Monitoring Tool
  - Mentors: Greg Mendell, Rick Savage (LIGO Hanford Observatory)
  - Abstract: The goal of this project is to write a prototype of a monitor that tracks the amplitude and phase of lines in the data. The prototype will be written in Matlab or Python, and its purpose it to allow quick testing of new ideas to improve on existing line tracking tools, such as the computation of the additional factors needed to report the amplitudes in physical units. The primary use of the monitor will be to find the induced displacement of calibration lines, but monitoring of arbitrary channels will be possible. The project will also investigate improving an existing web interface for studying long term trends in the data such as that produced by the monitor. The monitor will be tested on existing data.

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- Setting up the Physical Environment Monitoring System for Advanced LIGO
  - Mentor: Robert Schofield and Daniel Sigg (LIGO Hanford Observatory)
  - Abstract: Environmental influences contribute noise to the gravitational wave data stream at LIGO. In order to reach advanced LIGO's design sensitivity, these environmental influences need to be identified and characterized. The physical environment monitoring (PEM) system was set up in initial LIGO, and consisted of a network of various sensors that detected seismic, magnetic, acoustic, and other disturbances in the detector environment. During the science runs at LIGO, lessons were learned about the performance of the initial PEM system and previously unexpected coupling mechanisms were found, so changes to the system are planned for advanced LIGO.

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- Tidal Prediction for Advanced LIGO
  - Mentor: Kiwamu Izumi (LIGO Hanford Observatory)
  - Abstract: The gravitational pull of the Sun and the Moon causes tidal strains on the LIGO interferometers which changes the distance between the mirrors. This is the largest longitudinal background effect removed by LIGO’s servo mechanisms. The goal of this project is to integrate a tidal predictor code into our slow controls system. This project requires some programming.

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- Characterization of Second Harmonics Generators for Advanced LIGO
  - Mentors: Sheila Dwyer and Daniel Sigg
  - Abstract: A squeezed light source is planned as a future upgrade to the Advanced LIGO detectors. The injection of squeezed vacuum will improve the sensitivity in regions where Advanced LIGO is quantum noise limited. Squeezed vacuum is generated in an optical parametric oscillator (OPO) which is pumped by a doubled Nd:YAG laser. The goal of this project is to build and characterize the second harmonics generator (SHG) which will be used as a doubler.