# LIGO SURF 2023 Abstracts

### Quality Testing Optically Contacted Bonds

Optical contacting is a type of bonding that can be achieved when flat, polished surfaces are brought into close contact. When used as a replacement for fused silica, optically contacted silicon has the potential to increase the sensitivity of LIGO Voyager to gravitational waves. This project is aimed at determining the quality factor of optically contacted silicon bonds in order to quantify their potential to reduce the noise in LIGO Voyager. By maximizing the energy contribution from the bond and oscillating a silicon cantilever, the quality factor of the bond can be estimated. The eventual goal is to create an ideal optically contacted bond which minimizes damping and energy loss.

### Modeling Binary Neutron Star Collisions With SpECTRE

Neutron stars are some of the most extreme and relativistic objects in the known universe, with densities well beyond those of typical atomic nuclei. The multi-messenger detection of GW170817, the first measured binary Neutron Star merger gravitational wave event has given new opportunities to investigate these stars and the physics that govern them. However, at the moment, the post-merger signal carrying the greatest impact of the star's nuclear matter hasn't been detected with current gravitational wave detector sensitivities leaving numerical relativity simulations as the only form of investigation. Consequently, we aim to improve this avenue with SpECTRE, the simulation software developed by the collaborative Simulating eXtreme Spacetimes group (SXS), working toward more physical simulations to better understand Neutron Star's, their gravitational wave emission events, and extreme density nuclear physics.

### Incorporating Relative Time Delay and Magnification Distributions Predicted by Lens Models Into Ranking Possible Subthreshold, Strongly Lensed Candidates

We consider the possibility of gravitationally lensed pairs of gravitational waves, a phenomenon that has predominantly been studied in regard to electromagnetic waves. Under the strong lensing hypothesis, lensed gravitational waves from the same source are identical in waveform apart from a relative arrival time delay and an overall scaling factor in amplitude. It is possible that strong lensing produces magnified, super-threshold events that are registered as a trigger and demagnified, subthreshold events that get buried in the noise background. To remedy this, we search for subthreshold triggers using the gstLAL-based TargetEd Subthreshold Lensing SeArch (TESLA) pipeline, which considers the catalog of registered gravitational waves as potential lensed, super-threshold events. In this research, we modify the search pipeline's ranking statistic calculation to include the time delay and magnification probability distributions for a given lens model. This allows us to rank the trigger as a potential subthreshold counterpart to a specified super-threshold event. We determine the overall performance of this change in a final simulation campaign, gauging its effectiveness by its ability to uprank a lensed signal injected into the data.

### Sensor Fusion for Improved Length Sensing and Control of the LIGO 40m Prototype

The length sensing and control (LSC) system of a gravitational wave interferometer is key to maintaining control of the detector and generating a linear response to the gravitational wave signal. In the LIGO 40m prototype and at the Advanced LIGO detectors, the controlled length degrees of freedom are outnumbered by the RF photodiode sensors sensitive to their motion. This generates an overdetermined system where virtual sensors, calculated from combinations of sensors, can be designed to reduce the noises contributed by the LSC system. This project studied sensor fusion techniques for the power recycling Michelson interferometer (PRMI) configuration of the LIGO 40m prototype interferometer. Measurements were made of transfer functions and closed loop noises of the 40m LSC system during a PRMI lock. These were used to evaluate several methods for sensor fusion with the eventual goal of implementing one of them at the 40m interferometer.

### Using Multimessenger Synthesis to Constrain Core-collapse Supernova Distance and Orientation

Gravitational wave (GW) emission from the next nearby core-collapse supernova (CCSN) will be an important multimessenger, containing intrinsic properties of the CCSN and its progenitor star. Prior work has related expressions for the earlier GW "core-bounce" signal and later dominant frequency mode from the protoneutron star (PNS) to CCSN parameters like the rotation and density profile. Other work has shown similar relationships, including CCSN neutrino luminosities and mean energies. We run a set of 2D neutrino radiation-hydrodynamic CCSN simulations, via FLASH, to more precisely quantify relationships between neutrinos, GW observables, and CCSN properties: angular momentum and compactness. Likewise, we propose a new multimessenger-based method to break the existing degeneracy between CCSN distance and orientation, providing a constraint on both parameters in the event of a CCSN GW detection.

**Inferring the Population of Merging Binary Black Holes with Astrophysically Motivated Models**

Gravitational waves contain information about the properties of the binary black holes (BBHs) that produce them, such as their masses and spins. With 69 BBHs in the third Gravitational Wave Transient Catalogue (GWTC-3), it becomes possible to deduce bulk population properties of merging BBHs and hence probe their formation origins. Recent theoretical work has suggested that in certain field formation scenarios, it is possible for one of the black holes to attain spin via tidal spin-up, and that this spin should be correlated with its mass. Motivated by this finding, we fit a correlated model of masses and spins to GWTC-3 data using hierarchical inference. We find that the width of the distribution of the spin magnitude of the higher spinning black hole increases with its mass. We confirm the validity of our results with a simplified injection study.

**Implementing Nonlinear Control in a Classical Experiment to Reduce Measurement Noise**

A central problem in control theory is that most of the field focuses on linear controllers, even though most of the systems we are aiming to control are nonlinear in nature. To circumvent this issue, control theory aims to approximate the behavior of the nonlinear system around the desired mode of operation by a linear function. This unfortunately creates a theoretical limit on the performance specification of the linear as it tries to control a nonlinear system with a linear control law. We aim to show that this limitation can be overcome with a nonlinear controller based on Reinforcement Learning (RL) methods. As a proof of our concept, we aim to implement the RL-based controller in a purely classical experiment: temperature stabilization of a test mass. Moreover, we explore the possible implications of such a nonlinear controller in the field of quantum mechanics and non-classical experiments, where nonlinearities can be encountered even in the vicinity of the desired setpoint/mode of action of the system, exacerbating the need for a controller that can manage such nonlinearities.

**Measuring Birefringence and its Fluctuations in Crystalline Silicon**

Gravitational wave detectors, like LIGO, require high-quality test mass mirrors to accurately measure the minute changes caused by gravitational waves. While fused silica has been the preferred material for test masses, the upcoming cryogenic upgrades of gravitational wave detectors require materials with exceptional properties at low temperatures and compatibility with 1550-nm laser. Crystalline silicon has emerged as a potential alternative to fused silica due to its mechanical, optical, and thermal characteristics. However, birefringence in silicon can negatively impact detector performance by reducing the signal-to-noise ratio. This project aims to investigate birefringence in crystalline silicon through laser depolarization techniques.

The experimental setup involves a 1550 nm laser, polarizers, a half-wave plate, and photodiodes. Lock-in amplifiers and low-pass filters are employed to enhance sensitivity and reduce noise in the measurement system. The project aims to achieve measurements of birefringence fluctuations at the order of $10^{-15}$/rtHz at 100 Hz. The results will provide valuable insights into the suitability of crystalline silicon for future gravitational wave detectors and contribute to our understanding of material properties at extreme conditions.

**Identifying Correlations in Precessing Gravitational-Wave Signals With Machine Learning**

Binary binary hole (BBH) spins provide unique and important insights into the formation environments, evolutionary history, and dynamics of these objects. We would like to gain a better understanding of merger-dominated signals for highly massive highly spinning BBH systems, which are prone to spurious measurements due to their very short duration and low bandwidth. Astrophysical parameters from gravitational wave (GW) sources are extracted by match-filtering signals with numerical relativity (NR) waveforms templates. The degeneracies in waveforms, where dissimilar parameters yield similar waveforms, further complicates source identification. Using machine learning, we can visualize these degeneracies in the 14-dimensional BBH parameter space and develop models to quantify parameter correlations. We also propose enhancing existing mismatch-prediction neural networks with higher order modes and precession effects, thereby refining our ability to model these degeneracies. The results produced by this network will inform us about the measurability of spin parameters from inferred waveform signals of highly massive, precessing BBHs.

**Glitch Reweighting by Glitch Parameter Simulation**

Gravitational waves are ripples in space-time caused by the acceleration of high mass objects. They were first observed by LIGO (Laser Interferometer Gravitational-wave Observatory) in 2015. LIGO utilizes highly precise instrumentation to detect the differences in length of its perpendicular, 4 kilometer "arms" when a gravitational wave passes through. LIGO is able to detect the inspiral and merger of orbiting black holes and neutron stars. The resulting waveform is dependent on the parameters of the system. After accounting for the noise in the detectors, the waveform can be matched to a model and the parameters can be estimated.

Transient noise artifacts in LIGO data are called glitches. These glitches differ from typical detector noise in that they are non-Gaussian. Glitches vary in sources, frequency, time, duration and strength. They can interfere with how we account for noise before parameter estimation and lead to biased parameters. BayesWave is a Bayesian algorithm that can produce a posterior distribution accounting for various glitch models, but it cannot construct a CBC (compact binary coalescence) waveform model that includes precession. Our objective is to reweight a set of posterior samples from a BayesWave CBC+Glitch run and obtain a posterior distribution with both the glitch model and a fully precessing waveform.

**Frequency Stabilization of 2 Micron Lasers Using Optical Delay Self-Heterodyne Interferometry**

In the current LIGO design, 1064 nm light propagates through a Michelson interferometer and reflects off test masses. In order to accurately measure minuscule changes in the lengths of LIGO's arms, it is crucial to reduce various types of noise in the system, such as frequency noise. The next generation of LIGO detectors will likely switch from fused silica mirrors to crystalline silicon and will use a wavelength of about 2 microns in the interferometer; mirrors made of crystalline silicon have demonstrated lower levels of mechanical loss than fused silica mirrors and have low absorption of 2-micron light. Access to low-cost sources of stable 2-micron light is crucial for researchers to develop the next generation of LIGO detectors. This work will address the stabilization of a 2050 nm laser, and will focus on reducing the frequency noise of the laser with a self-delayed heterodyne interferometry technique. This low-cost method has the potential to facilitate further testing and development of 2-micron light for gravitational-wave detection.

**Linking the Population of Binary Black Holes with the Stochastic Gravitational-Wave Background**

The astrophysical stochastic gravitational-wave background (SGWB) is the product of overlapping waveforms that create a single unresolvable background. While current LIGO sensitivity is insufficient to uncover the SGWB, future space-based detectors and Third Generation (3G) experiments are expected to probe deep enough for detection. In addition, predictions of the SGWB can still constrain future searches as well as provide insight into star formation, merger history, and mass distribution. Here, two different methods are used to calculate a theoretical SGWB. The first method employs Monte Carlo integration with simulated data, while the second method predefines a grid of mass distributions. After standardizing a prior dictionary across both methods, the output energy density spectra is analyzed with regard to parameters such as binary black hole mass and merger rate. Increasing the maximum merger mass shifts the gravitational-wave (GW) energy density peak to lower frequencies, while increasing the local merger rate proportionally affects the GW energy density.

**Inferring Gravitational Wave Source Properties from Intermediate Pipeline Output with Machine Learning**

The LIGO-Virgo-KAGRA collaboration provides low-latency (near-real time) localization using the signal-to-noise ratio measured for a single point in the search parameter space. Parameter estimation pipelines subsequently samples the full parameter space to obtain more accurate estimates of the localization. However, this process is computationally expensive. The multi-messenger detection of the binary neutron star merger GW170817 confirmed the need for accurate and fast data products. Some detection pipelines utilize singular value decomposition to reduce the filtering cost. This project uses machine learning to input signal-to-noise ratios from singular value decomposition time-series into simulation-based inference (SBI), a likelihood-free inference algorithm, which outputs a posterior with an accurate parameter estimation, such as a sky map, to localize compact binary coalescences and infer other source properties.

**Leveraging the Stability of the Photon Calibrator X/Y comparison to Reduce System Uncertainty**

All second-generation gravitational wave detectors use laser radiation pressure to calibrate the detector output signals. A significant source of uncertainty for these Photon Calibrator (Pcal) systems, one usually installed at each interferometer end station, is unintended rotation of the suspended mirrors. Comparing the two Pcal system calibrations enables reducing calibration uncertainty. At the LIGO Hanford Observatory (LHO), this X/Y comparison has been calculated continuously since May 2023 and has been stable within 0.05 %. This stability can be leveraged to quantify interferometer and Pcal beam position offsets. Reducing Pcal beam position errors minimizes unintended rotation. Moving the position of one Pcal beam by 2.5 mm at the LHO X-end station is expected to the change the X/Y comparison by as much as 0.0054, more than ten times the observed X/Y comparison variations. A second measurement with the Pcal beam displaced orthogonally can be used to quantify both the magnitude and direction of the interferometer beam position offset. Making similar measurements after known displacements of the interferometer beam can be used to quantify center of force offsets for the Pcal beams. This method would provide a means for minimizing one of the largest sources of uncertainty for the Photon Calibrator systems.

**Taking It to the Next Level: Searching for Gravitational Waves With Eccentricity From Compact Binary Coalescences**

Gravitational waves (GWs)[1, 2] are fundamental predictions of the General Theory of Relativity (GR). GWs detections have introduced a novel window into the universe and are revolutionizing our understanding of as-trophysics. The motion of two massive objects in an eccentric orbit emits GWs which carry information about the eccentricity of the binary black hole (BBH) source. These waveforms are characterized by their eccentricity, which measures the deviation of the orbit from a quasi-circular orbit. Studying eccentric binary orbits provides evidence for the dynamic formation of the binary system. In this project, we study a new family of GWs waveforms from eccentric binaries and their implications for detecting and analyzing eccentric compact binary systems near mergers. I will develop eccentric waveform models and parameter estimation frameworksfor eccentric BBH and use these tools to analyze the data from current and upcoming GWs observations. Sinceeccentric waveforms are predicted to have similar waveforms with GWs from BBH systems with precessing,I will try to distinguish eccentric waveforms and precessing waveforms by investigating their differences. We will determine the minimum eccentricity that could be detectable with GWs as a function of SNR and other parameters.

**Understanding Combined Results From Multiple GW Searches Using Information Theory**

Determining whether a gravitational wave (GW) signal is of astrophysical origin or is caused by terrestrial noise still presents a challenge to the GW community. Current searches estimate the significance of events by calculating the false alarm rate (FAR) and p_astro, but these results are limited to a single search pipeline. In this work, we suggest a method of combining GW information by calculating harmonic mean FARs for different groups of searches and using them as the basis for calculating a joint p_astro. Using this approach, we compare the effectiveness of different combinations of GW searches, revisit the significance of previously detected events, and investigate the correlations between pipelines using the language of information theory.

**Testing Specific Theories Beyond General Relativity With LIGO**

Gravitational waves observed by LIGO have allowed us to test general relativity in the strong-field regime with populations of binary merger events. Observations thus far are consistent with general relativity at both the individual and population level. Current tests of general relativity utilize a single deviation parameter rather than generic deviation parameters, which makes it difficult to map this information to specific theories and robustly test them over ensembles of events. We apply Bayesian inference to the inspiral phase of gravitational-wave signals in binary black hole merger events, to obtain posterior distributions for the 15 source parameters and 10 post-Newtonian deviation parameters. This parameter estimation involves the hybrid sampling method which uses nested sampling to seed parallel-tempered Markov Chain Monte Carlo (MCMC) ensembles and allows us to explore degenerate parameter spaces. We apply a Principal Component Analysis (PCA) to reduce the dimensionality of the parameter space, to understand the underlying correlations between the deviation parameters. Hierarchical inference could then be applied to ensembles of events to test specific theories beyond general relativity, such as the dynamical Chern Simons (dCS) and Einstein-dilaton Gauss-Bonnet (EdGB) theories. This would result in constraining the bounds on the coupling coefficients that characterize these specific theories.

**Improving Frequency Stabilization for the Auxiliary Laser at the LIGO 40m Prototype**

The LIGO interferometers need to robustly lock its various degrees of freedom to be sensitive to Gravitational Waves. The LIGO 40m prototype uses an auxiliary (AUX) laser as a reference to lock the main laser to the arm cavity and stabilize it. The AUX laser is stabilized by locking it to the arm cavity using the Pound-Drever-Hall (PDH) technique. The stability of the AUX laser is crucial for the stability of the main laser. Mechanical resonances of the AUX laser's piezoelectric (PZT) actuator and the rigid nature of the currently implemented analogue PDH controller limits the performance of the system, hindering noise suppression especially at low frequencies. This project aims to develop a digital controller to replace the currently implemented AUX laser locking system. A digital controller will be more robust and easily customizable. Specifically, the features to be implemented include better controller performance in the 10Hz-20kHz range, where the AUX laser noise has greater contribution, supplying an increase in bandwidth over the current analogue system, enable fast lock reacquisition when lock is broken and adding resonant gain filters at specific resonant bands to facilitate calibration of the interferometer.

**Bayesian Inference for Fast Scattering Glitches**

Data collected by gravitational wave (GW) interferometers such as the Laser Interferometer Gravitational-wave Observatory (LIGO) is permeated by noise as a result of various sources of environmental interference. Parameter estimation pipelines such as Bilby used to analyse LIGO data assume that the noise in GW data is Gaussian and stationary: an assumption contradicted by the nature of non-Gaussian transient noise "glitches" prevalent within the data. We have constructed a mathematical model that emulates the waveform of fast scattering glitches, which we implemented into Bilby to perform tests of the model's robustness in glitch mitigation efforts. The incorporation of this model will facilitate the efficient subtraction of real fast scattering glitch instances from GW strain data, allowing for improved analysis for future observing runs.

**Analyzing LIGO Ring Heaters: Investigating Electrical Shorting, Troubleshooting Mechanical Failures, and Modeling Future Designs**

LIGO interferometers use frequency and amplitude-stabilized lasers that are reflected using test masses (large, cylindrical mirrors) to detect gravitational waves. Because the laser light is stored in optical cavities within the interferometer, the test masses heat up. This physically deforms the surface of the mirror. Physical deformation causes the test masses to not reflect the laser optimally and the interferometer will not function at its highest sensitivity. Ring heaters are coils that heat the outside of a test mass through resistance to counteract this effect and allow us to control the deformation of the test mass surface. Our objective is to modify the current ring heater design and develop improvements to be implemented in future ring heaters. We accomplish this by troubleshooting issues in the current design, comparing designs between versions, and modeling different designs in COMSOL. We have built spare ring heaters, identified causes of grounding issues and weaknesses in the current design, successfully modeled how differently-sized heating elements heat the test mass, and compared their effectiveness to the current design. With these results, we are now able to avoid grounding problems observed at other LIGO locations, as well as improve the ring heater design for future use.

**Upgrades to the Sensitivity and Energy Resolution of MKID-based WIMP Detectors**

Precise temperature control in the presence of noisy environments and heat loss through complex channels, involving conduction, convection, and radiation, presents a significant challenge. Traditional control methods, such as PID control, struggle to maintain a desired set-point due to system non-linearity and large disturbances caused by day-to-day ambient temperature fluctuations. The optimal tuning parameters also vary with external factors, further affecting performance.

In this project, we propose an adaptive control approach for nonlinear systems using neural networks trained via reinforcement learning. By introducing nonlinearity into the controller, we aim to address the limitations of traditional methods. The neural network-based controller leverages the entire state space, overcoming the challenge of non-separable and non-linear actuation functions where system parameters lack linear relationships.

Our approach offers several advantages for precise temperature regulation. Through reinforcement learning, the neural network controller learns to effectively respond to varying ambient conditions, adapt control signals, and dynamically adjust to disturbances. This adaptability eliminates the need for fixed tuning parameters, ensuring robust performance across different operating scenarios.

Extensive simulations are conducted to evaluate the proposed approach in realistic scenarios with diverse environmental conditions. The results demonstrate superior performance compared to traditional PID control methods. The neural network-based adaptive control exhibits enhanced set-point tracking accuracy and reduced sensitivity to low frequency (~1/day) fluctuations.

The significance of this work lies in its potential to advance temperature control in various nonlinear systems. By combining neural networks and reinforcement learning, our approach offers a practical solution for achieving precise control in the presence of disturbances. This work opens doors for the application of adaptive control in a wide range of fields where accurate control is essential in the face of complex dynamics and external fluctuations.

**Enabling the Discovery of Kilonovae Associated with Neutron Star Mergers with Electromagnetic Follow-up**

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is designed to detect gravitational waves (GWs) produced by events such as merging neutron stars or black holes. The first detection of GWs and electromagnetic radiation (EMR) from a binary neutron star (BNS) merger occurred on August 17, 2017, with the discovery of GW170817. The merger was followed by a kilonova (KN), responsible for the synthesis of heavy elements, beyond iron, in the universe. During LIGO's fourth observing run, O4, ZTF produces candidates for which photometric and spectroscopic data analysis are performed. This candidate vetting aims to uncover the KN counterpart associated with a particular GW event. The DRAGONS pipeline will be used to re-analyze the spectrum of GW170817 that was taken with Gemini Multi-Object Spectrograph (GMOS). We adapt the DRAGONS pipeline to include black-body curve fitting and spectroscopic line identification for potential candidates detected in O4 and future observing runs. This automated pipeline will help reduce the data and determine the composition and temperature of KNe. By updating this pipeline, the candidate KNe sample will be analyzed more quickly and efficiently during transient searches for EM counterparts by eliminating any contaminants, such as Supernovae (SNe), active galactic nuclei (AGNs), or cataclysmic variables. This method will enable the detection of early KN emission, which is crucial for studying the synthesis of heavy elements and understanding the physics of BNS mergers. This data reduction pipeline for photometry and spectroscopy of KNe during O4 will be used to aid in the real-time study of heavy element nucleosynthesis.

**Feedforward Frequency Stabilization of 2-Micron Lasers Using Optical Delay Homodyne Interferometry**

The proposed post-O5 LIGO Voyager upgrade as well as some proposed third-generation gravitational wave observatories center on a cryogenic silicon optics system for reduced thermal noise. This requires a shift of the laser wavelength further to the infrared using the comparatively noisy 2-micron technology to compensate for the high absorption of the current 1064nm laser in crystalline silicon. To meet the tight frequency noise requirements for desired sensitivities of these interferometers, we demonstrate a feed-forward frequency noise reduction system at 2050nm in fiber. Additionally, we characterize the sources of noise limiting the degree of noise reduction and the sensitivity of the interferometric measurement of the reduced frequency noise, allowing for the targeting of future improvements to the system.

**Estimation of the Stochastic Gravitational Wave Background from Binary Mergers**

The ground-based International Gravitational-Wave Observatory Network (IGWN), including the Laser Interferometer Gravitational-Wave Observatory (LIGO) stations at Hanford and Livingston, Virgo and KAGRA, has detected gravitational waves (GWs) from Compact Binary Coalescence (CBC) sources in distant galaxies as far away as 8 Gigaparsecs, which corresponds to a redshift of slightly greater than 1. More distant sources are too faint to be confidently detected as individual events. However, they are expected to be so numerous that they can be detectable as a Stochastic Gravitational Wave Background (SGWB). While stringent upper limits on the strength of the SGWB as a function of frequency in units of the cosmological closure density of the universe, $\Omega_{GW}(f)$, have been made through the IGWN, there has been no observed detection of the SGWB as such. However, while this was overturned as per the June 28, 2023, announcement on the preliminary — not completely confirmed — detection of an SGWB from supermassive black hole mergers, the overall astrophysical background from all CBC sources is still to be detected. Early implications for the SGWB from the first observation of Binary Black Hole (BBH) mergers and more recent models from advanced LIGO and VIRGO data have all provided estimates of the CBC merger rate that suggest that we are close to detection of the SGWB. The estimates from the 'Regimbau method' come from simple simulations of many individual events, while the 'Callister method' is based on numerical evaluation on an analytical expression for the SGWB. We reproduce these estimates through a thorough analysis of the methods used by Regimbau and Callister and study the degree to which they agree with each other, as well as look at the extent to which the results depend on uncertainties in the merger rate as a function of mass and redshift distributions of the sources. Overall, we investigate the predictions on SGWB parameters and constrain its limits, thereby decoding how the background changes due to uncertainties in several important variables. This incorporation of the latest theoretical models, with a key understanding of the limits and constraints in these frameworks, will aid in the long-term goal of refining estimates on the SGWB, thereby detailing future goals in the study of astrophysical GW backgrounds, challenges, and expected outcomes.

**Demonstration of Bayesian Transfer Function Fitting Method - A Potential Tool for Estimating Interferometer Uncertainty**

The Response Function of the LIGO Interferometer is central to reconstructing the strain produced by incoming gravitational waves. A function of the interferometer's response to external stimuli, the Response Function is both analytically modeled and experimentally measured using excitations from the photon calibrator system at discrete frequencies. The uncertainty in each data point is propagated to the residual of the model and measurements, with both the uncertainty and residual being interpolated over a broadband frequency range. While valid, interpolation methods lack the accuracy to estimate measurement uncertainty at non-measured frequencies that fitting an analytical transfer function could provide. This project analyzes the results of fitting a series of transfer functions to the Response Function using Bayesian statistics as opposed to traditional transfer-function-fitting methods. We use data gathered from the OMC DCPD S2300004 whitening chassis at discrete frequency points, varying the signal-to-noise ratio as a proxy for varying the uncertainty in the measurements, and compare the results of each method.

**Developing Methods to Characterize Frequency-Varying Combs in LIGO Strain Data**

Narrow spectral artifacts in strain spectra pose a unique challenge to searches for continuous waves. They appear as small vertical lines, obscuring potential detections. Combs are patterns of equally-spaced narrow lines representing the harmonics of a fundamental frequency. Characterizing combs and identifying their individual causes is challenging and is made more difficult by the fact that some of them change in fundamental frequency over time. We call these roaming combs, as their narrow spectral artifacts appear to roam around spectra. The Fscan spectral monitor used for continuous-wave detector characterization can automatically identify combs present on a particular day, but lacks a method to analyze how combs have changed in frequency over time. Our objective for this project was to develop a method to analyze frequency-roaming combs. We produced a script which automatically detects when combs have changed in frequency since their last appearance and can also be used to examine known combs which are not detected by Fscans. We also present results on known, high-priority combs contaminating Hanford data.