Identifying and reducing noise due to scattered light in aLIGO detectors.

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1 Introduction

I am a graduate research assistant working in the field of experimental gravity under the supervision of my advisor, Dr. Gabriela Gonzalez. I have been a member of LIGO Detector Characterization group since 2018 and have spent time at the LIGO Livingston Observatory (LLO) during the third Observing run. My work with Anamaria Effler at LIGO Livingston (LLO) and Robert Schofield at LIGO Hanford (LHO) led to the recognition of the Slow Scattering noise couplings in the detector and the consequent massive reduction in the noise during the second part of O3. Following this, I focused on improving the identification of Fast Scattering noise in the detector. This involved retraining GravitySpy, a machine learning framework to classify transient noise in aLIGO. Next I discuss the details of these two projects which led to improved sensitivity of the detector and better noise characterization.

2 My work and results

Stray light has been a frequent source of transient noise in Advanced LIGO detectors since the first observing run in September, 2015. During high ground motion in the vicinity of the detectors, when a fraction of light gets scattered off of an optical component and strikes a moving surface, a part of it can reflect back and rejoin the main laser beam. The path length modulation caused by the relative movement between the mirror and the moving surface, introduces a phase and amplitude noise on top of the static field [1]. During the third observing run, two different populations of scattering noise, colloquially called Slow Scattering and Fast Scattering were observed.

While investigating slow scattering noise in the primary gravitational wave channel h(t), I found a strong correlation between h(t) scattering arches and the fringe frequency motion of the penultimate stage (PUM) of the quad suspension. I calculated the amplitude spectral density of the PUM motion and it matched the noise in differential arm cavity. This correlation pointed towards a scattering path between the end test mass (ETM) and the gold trace electro-static drive on the annular end reaction mass (AERM). Reaction chain (RC) tracking, implemented in January, 2020 at LLO and LHO, reduced this relative motion between the test mass chain and the reaction mass chain [2,3]. **This resulted in a huge drop in the rate of slow scattering noise for the same amount of ground motion.** The rate fell down by a factor of more than 100 for ground motion above 1000 nm/s at both the detectors as shown in Fig. 1 and we also observed a big reduction in

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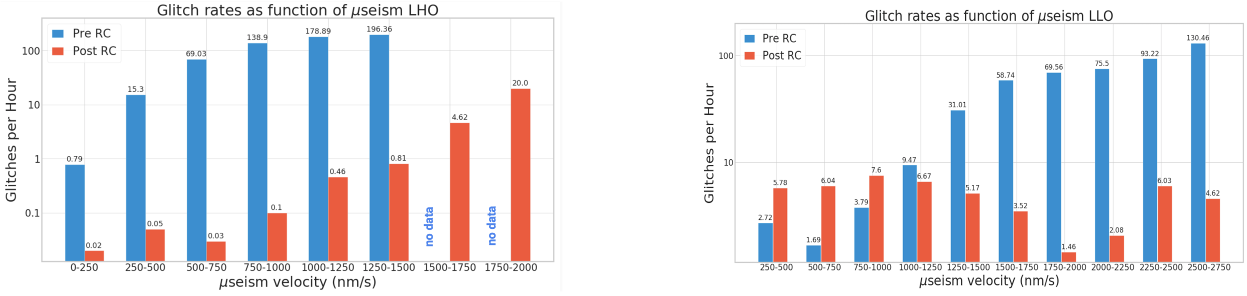
the signal-to-noise ratio (SNR) of the slow scattering triggers [4, 5]. Along with the ETM-AERM scattering, **I found the path length modulation between the ETM and the transmission motor system (TMS) behind the mirrors as the second source of slow scattering noise in the detector** [6]. To reduce the noise due to this relatively weaker coupling, TMS tracking has been tested at LLO and would be switched on before the next observing run [7]. I led a paper that provides more details on the reduction of scattering noise during O3 [8].



(a) Rate of Slow scattering LHO.

(b) Rate of Slow scattering LLO.

Figure 1: Glitch rate comparison of Slow scattering for Pre and Post Reaction chain tracking.

Fast scattering, the other population of the scattering noise, did not impact data quality during O2. During O3 however, fast scattering is the second most frequent disturbance at LLO [9].

To investigate noise and noise sources and to answer questions such as *When is a specific transient noise present in the detector?* and *How does the noise appear in time-frequency spectrograms?*, we use several different detector characterization tools such as **Hveto**, **gwdetchar-omega**, **GravitySpy** [10–12]. GravitySpy in particular is an algorithm based on machine learning to classify transient noise into several different categories. It trains on the time-frequency spectrograms of transient noise and then classifies a given image into one of the several different noise categories. Since Fast scattering was not prevalent in the previous observing run, GravitySpy did not classify it as a separate glitch class. **I retrained GravitySpy to recognize fast scattering and reclassified the whole O3 transient noise data [13, 14]**. This reclassification proved to be extremely useful as it provided me with an abundance of data which I could analyze and correlate with ground motion in different frequency bands. **This led to an improved characterization of the noise and within the newly classified data, I found two separate types of fast scatter (4 Hz and non 4 Hz), that coupled with different ground motion frequency bands [9, 15].**

3 Conclusion

LIGO data quality is adversely affected by the presence of non-astrophysical transient noise in the detector. These environmental or instrumental noise artifacts can reduce our confidence in the detection of gravitational waves and complicate the process of parameter estimation [16]. Decreasing the rate of transient noise is one of our biggest challenge given the high number of detections expected in the next Observing run. My work during O3 directly contributed to reduction and identification of two of the most common sources of transient noise in aLIGO detectors.

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