Noise hunting in Advanced LIGO

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LIGO - T1600159-v1

Improving LIGO’s sensitivity

- Characterizing sources of noise allows for improvements in:
  - » SENSITIVITY
  - » STABILITY
  - » DETECTION RATE

Examples of noise sources

- Fundamental
  - » Shot noise (dominates high frequencies)
  - » Suspension thermal noise
  - » Test mass thermal noise
  - » Seismic Noise (dominates lower frequencies)
- Environmental
  - » Wind
  - » Ground Motion
  - » Magnetic field variations
  - » Acoustic disturbances

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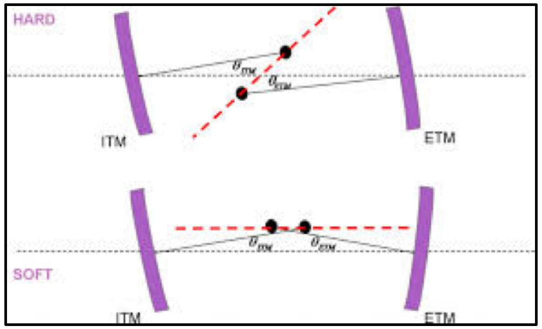
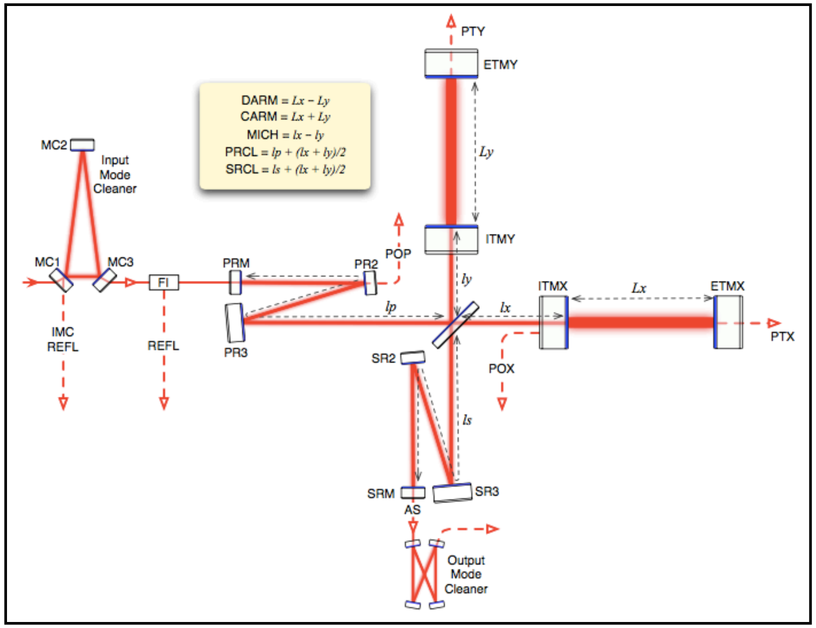
Wind as a source of noise

- Hanford: high winds are frequent
- Can cause optics to drift and result in ‘lock loss’
  » Instrument is locked when light is resonating in all cavities
- Can cause light to scatter
- If scattered light were to recombine with main beam, its phase will be shifted

Alignment sensing and control (ASC) channels

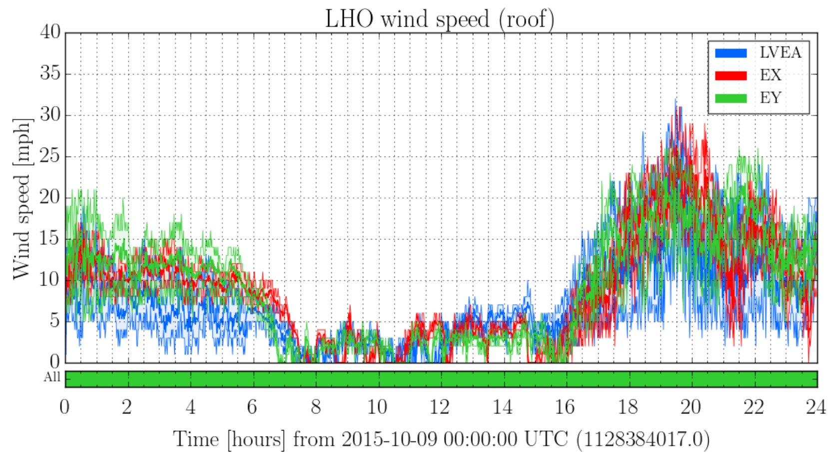
- Look at CARM and DARM for both SOFT and HARD modes and both pitch and yaw angular motion
- Look at transmitted power at photodiodes at end stations for both X and Y arms
- Any angular displacement will be problematic at higher laser power – photon pressure vs actuators' restoring force

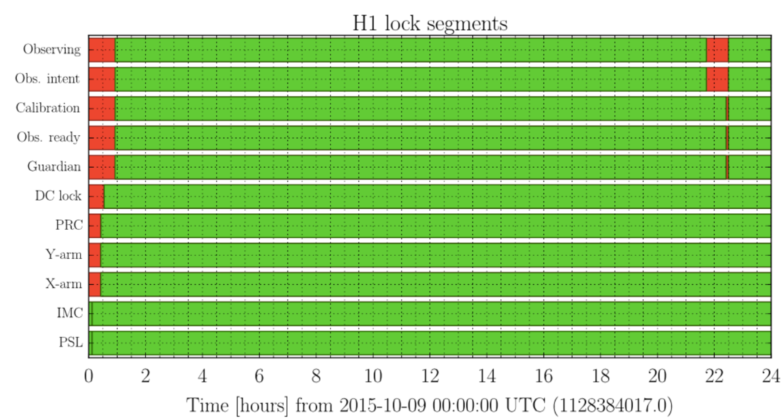




Identifying useful lock stretches

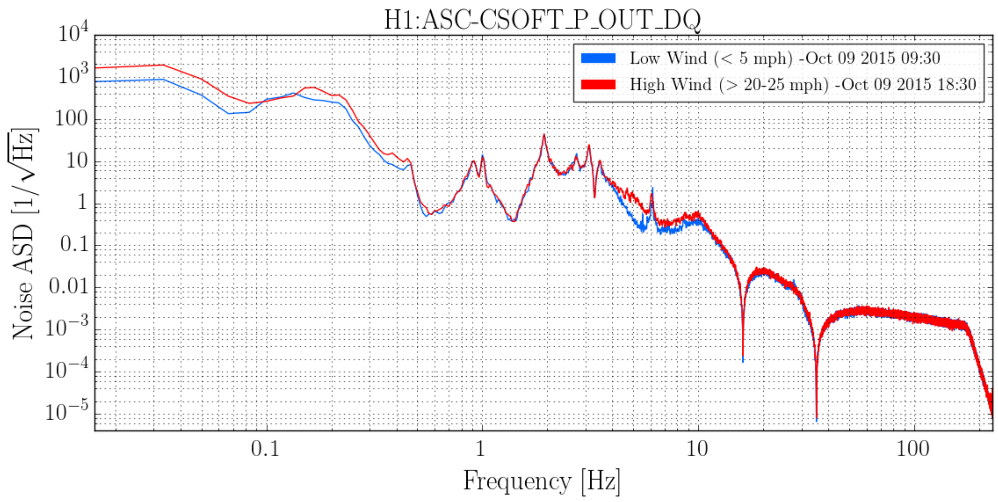
- Summary pages were used to identify lock stretches that coincided with periods of both high and low wind
- High wind > 20 mph
- Low wind < 5 mph
- All the cavities need to be resonant





ASD for ASC channels

- Time series is converted to frequency domain
- Useful to look at how power is distributed in different frequency bins
- Excursions are indicative of excess control applied to optics



- Three frequency bands stood out: 0-1 Hz, 4-20 Hz, 20-40 Hz (last one only for transmitted power at end stations)

ASD for ASC control loops 0-1 Hz

- https://dcc.ligo.org/DocDB/0126/T1600159/001/0_1_Hz_ASD.gif

ASD for ASC control loops 4-20 Hz

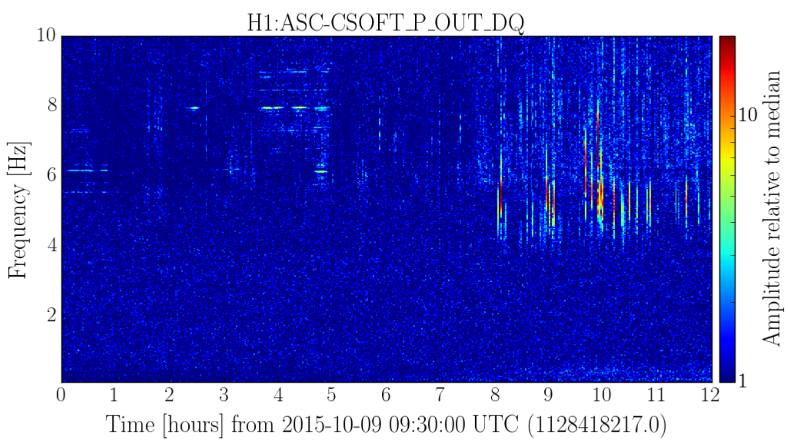
- https://dcc.ligo.org/DocDB/0126/T1600159/001/4_20_Hz_ASD.gif

ASD for ASC control loops 20-40 Hz

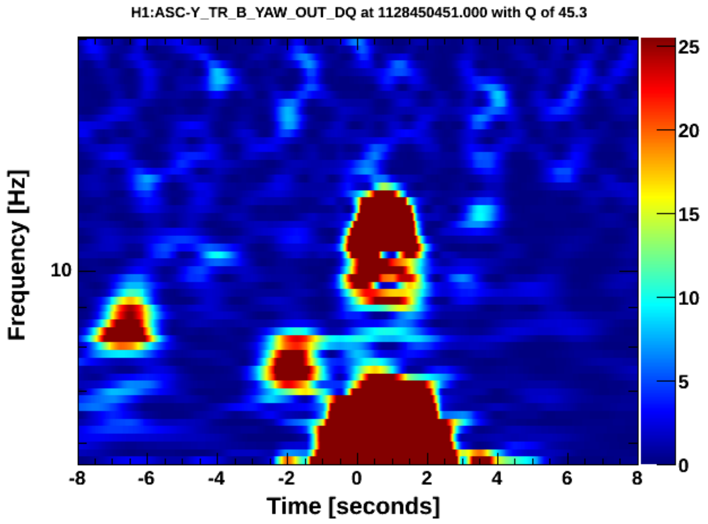
- https://dcc.ligo.org/DocDB/0126/T1600159/001/20_40_Hz_ASD.gif

Glitches in ASC control loops

- Spectrogram using Gwpy
- Glitch for CSOFT_P

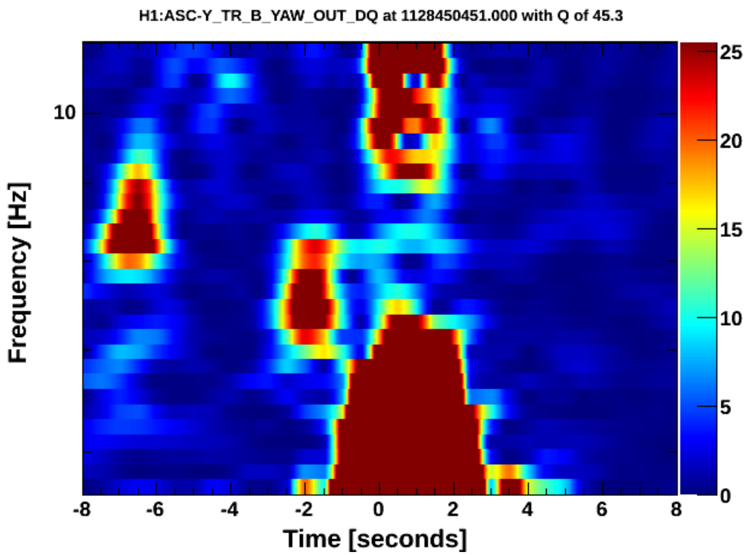


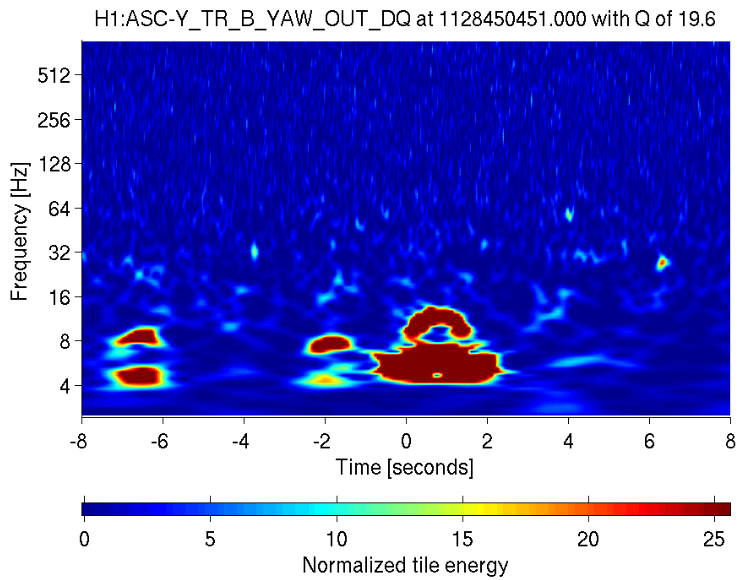
- Spectrograms using OmegaScan
- Glitch for Y_TR_B_YAW



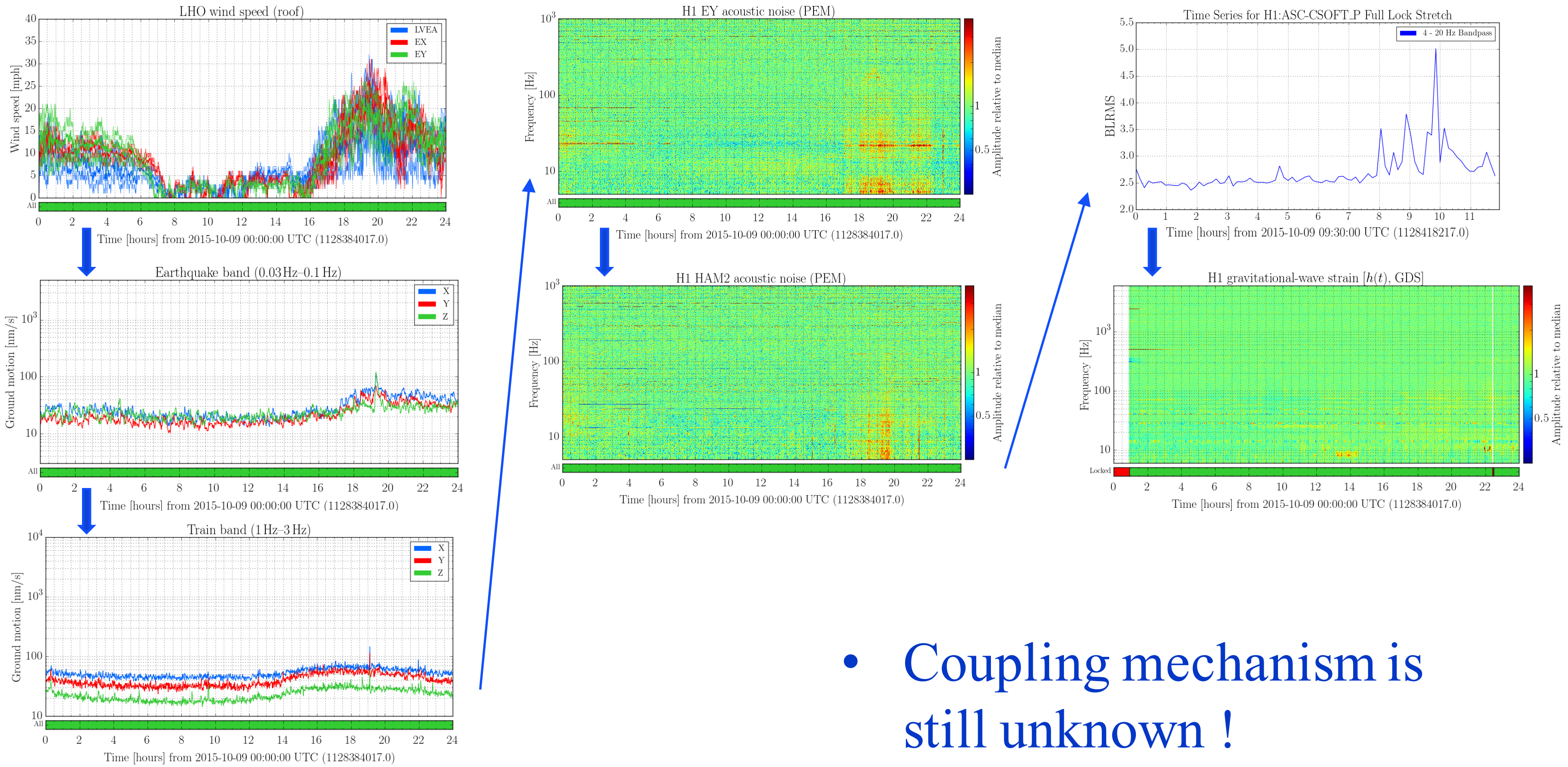
Glitch due to scattered light

- 5 Hz for Y_TR_B_YAW with a Q of 45.3
- 5 Hz for Y_TR_B_YAW with a Q of 19.6





Coupling through acoustic noise vs ground motion



- Coupling mechanism is still unknown !

Are glitches prevalent during extended periods of low wind?

- 12 lock stretches were observed
- Those that showed glitches coincided with periods of elevated ground motion:
  - 0.03 – 0.1 Hz (Earthquake Band)
  - 1 – 3 Hz (Train Band)
  - 3 – 10 Hz

- No elevated noise was observed in acoustic PEM channels

Effect of seismic motion on PRCL, SRCL and SRC2

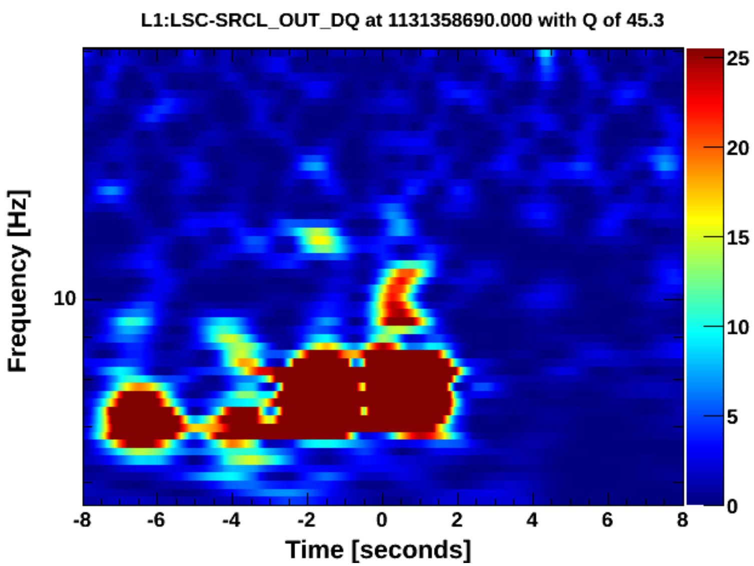
- Lock stretches in O1 with elevated ground motion were identified
- ASD indicate elevated noise levels for lower frequencies
- Glitches occur with a central frequency around 10 Hz
- Pitch vs yaw for alignment degree of freedom (SRC2) that controls SR2 show an increase in drift of optic

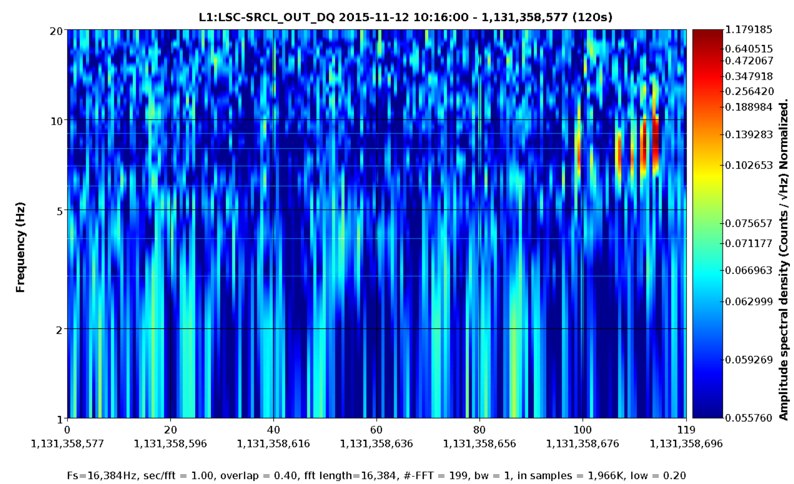
Effect of Seismic Motion on PRCL, SRCL and SRC2

- https://dcc.ligo.org/DocDB/0126/T1600159/001/pitch_yaw_11_06_2015_v2.mp4

- Excess control applied to SR2 occurs at 01:50 (UTC)
- Glitch is seen at around 10 Hz
- ASD are averaged over 15 minute periods

10 Hz Glitch


L1:LSC-SRCL_OUT_DQ at 1131358690.000 with Q of 45.3
Frequency [Hz]
10
Time [seconds]
-8 -6 -4 -2 0 2 4 6 8
25 20 15 10 5 0


L1:LSC-SRCL_OUT_DQ 2015-11-12 10:16:00 - 1,131,358,577 (120s)
Frequency (Hz)
20 10 5 2 1
0 20 40 60 80 100 119
1,131,358,577 1,131,358,596 1,131,358,616 1,131,358,636 1,131,358,656 1,131,358,676 1,131,358,696
1.179185 0.640515 0.472067 0.347918 0.256420 0.188984 0.139283 0.102653 0.075657 0.071177 0.066963 0.062999 0.059269 0.055760
Amplitude spectral density (Counts / √Hz) Normalized.
Fs=16,384Hz, sec/fft = 1.00, overlap = 0.40, fft length=16,384, #-FFT = 199, bw = 1, in samples = 1,966K, low = 0.20

Summary and conclusion

- Wind and ground motion cause elevated noise levels and glitching with a central frequency of 5 Hz and 10 Hz
- This will be more problematic at a higher laser power
- Understanding increase in noise levels is important in order to find ways to mitigate them
- Help focus on tuning ASC control loops in order to better mitigate noise during high wind periods

Future Work

- Further look into 10 Hz glitches and if they occur for other stretches with elevated ground motion
- Conduct full OmegaScans for a time when the 10 Hz glitch is present
- Use OmegaScan to look for time differences in glitches in order to resolve how a disturbance caused by wind is propagating through the interferometer
- Look at acoustic spectrograms and look at acoustic injection studies to see if 5 Hz glitching appears

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References

[1] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration). Characterization of transient noise in Advanced LIGO relevant to gravitational wave signal GW150914. *arXiv:1602.03844* (2016)

[2] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration). Observation of Gravitational Waves from a Binary Black Hole Merger. *Phys. Rev. Lett. 116. 061102* (2016)

[3] LIGO Scientific Collaboration. Advanced Ligo. *arXiv:1411.4547* (2014)

[4] D.M. Macleod et al. Reducing the effect of seismic noise in LIGO searches by targeted veto generation. *arXiv: 1108.0312v3* (2013)

[5] J. McIver. *The impact of terrestrial noise on the detectability and reconstruction of gravitational wave signals from core-collapse supernovae* (Doctoral dissertation). Retrieved from Scholar Works @ UMass Amherst. Paper 539. (2015)

[6] R. Abbott et al. Seismic Isolation for Advanced LIGO. *Class. Quant. Grav.,* Vol 19, No 7, 1591 (2002)

References

[7] Summary pages: https://ldas-jobs.ligo-wa.caltech.edu/~detchar/summary/
https://ldas-jobs.ligo-la.caltech.edu/~detchar/summary/

[8] Images for slide 6 obatined from: B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration). Observation of Gravitational Waves from a Binary Black Hole Merger. *Phys. Rev. Lett. 116. 061102* (2016)

[9] GWpy codes and documentation created by Duncan Macleod

APPENDIX: ASC CHANELS

H1:ASC-CHARD_P_OUT_DQ
H1:ASC-CHARD_Y_OUT_DQ
H1:ASC-DHARD_P_OUT_DQ
H1:ASC-DHARD_Y_OUT_DQ
H1:ASC-CSOFT_P_OUT_DQ
H1:ASC-CSOFT_Y_OUT_DQ
H1:ASC-DSOFT_P_OUT_DQ
H1:ASC-DSOFT_Y_OUT_DQ
H1:ASC-X_TR_A_PIT_OUT_DQ
H1:ASC-X_TR_A_YAW_OUT_DQ
H1:ASC-X_TR_B_PIT_OUT_DQ
H1:ASC-X_TR_B_YAW_OUT_DQ
H1:ASC-Y_TR_A_PIT_OUT_DQ
H1:ASC-Y_TR_A_YAW_OUT_DQ
H1:ASC-Y_TR_B_PIT_OUT_DQ
H1:ASC-Y_TR_B_YAW_OUT_DQ