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# Scattering Noise Studies at LLO via Injection Techniques

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# Overview

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- Scattering noise
- Injection techniques
- Specific injections
  - » Clean room fans
  - » Acoustic injections
  - » HAM6 ISI table
- Proposed noise creation mechanism
  - » Supporting evidence
- Noise Budget Plots
- What next?

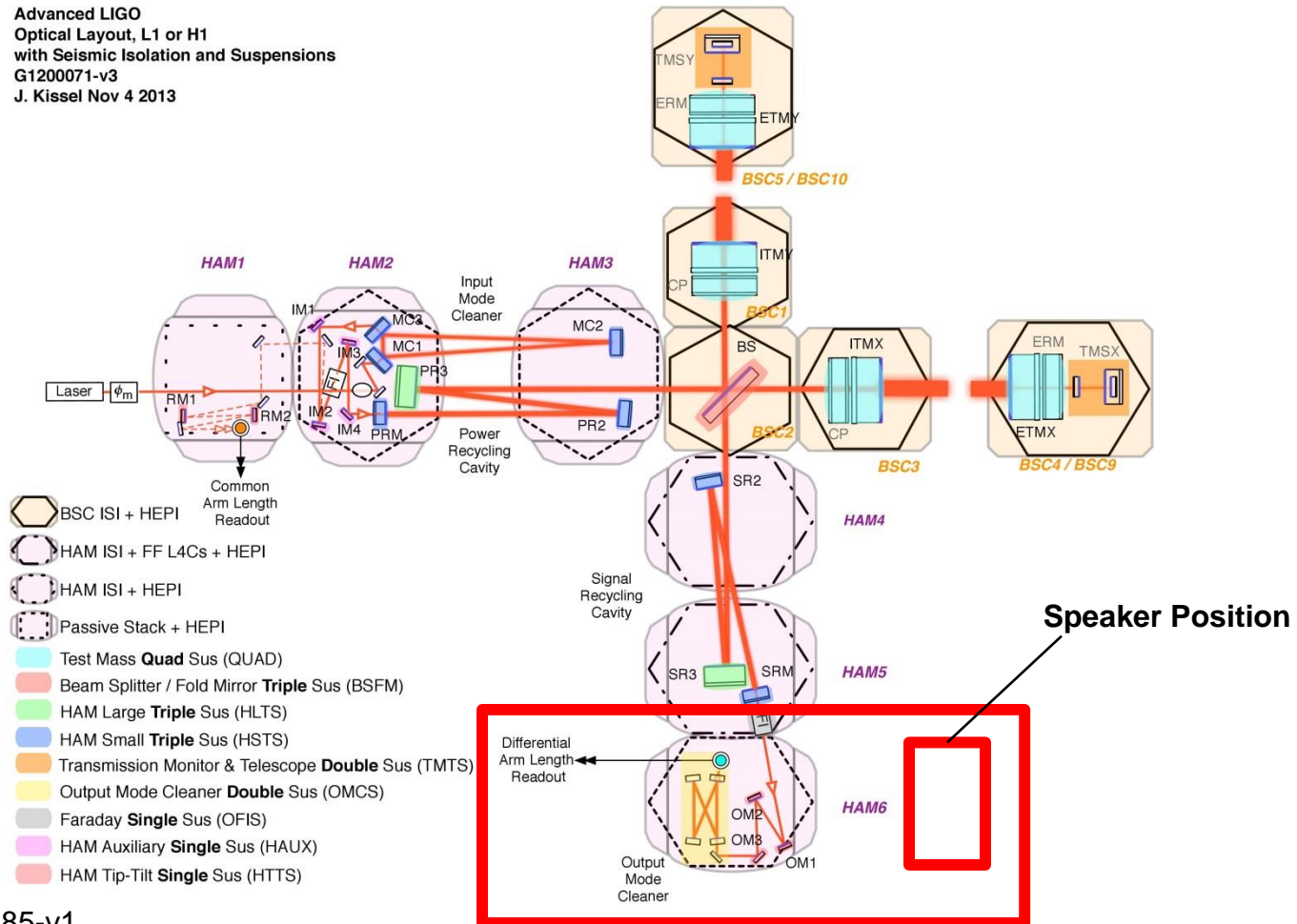
# What are “injections”?

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- Introduce known disturbance/noise
- Examples:
  - » Acoustic
  - » Mechanical
  - » Electrical/Magnetic
- How is this useful?
  - » Quantify noise coupling and ambient contribution
    - Linear/non-linear
  - » Show mechanism path

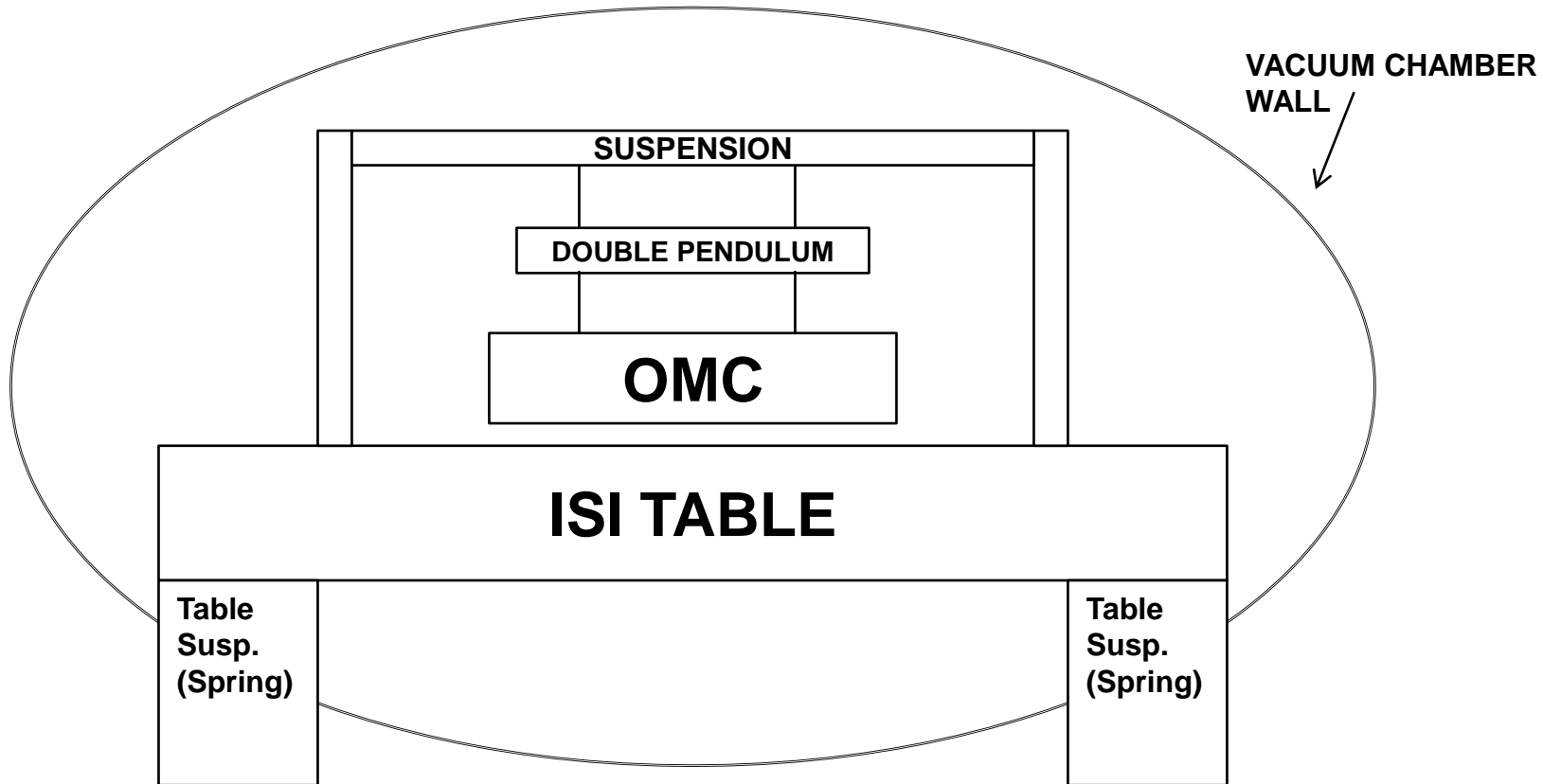
## HAM6 Chamber

Advanced LIGO  
 Optical Layout, L1 or H1  
 with Seismic Isolation and Suspensions  
 G1200071-v3  
 J. Kissel Nov 4 2013



LIGO-T1500285-v1

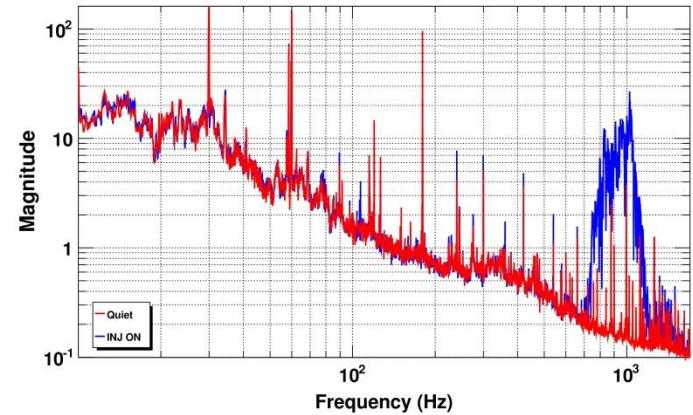
# HAM6 Suspensions



## HF Acoustic Injections

- Done using a large speaker pointing at the +X wall of HAM6

MIC between HAM5 and HAM6

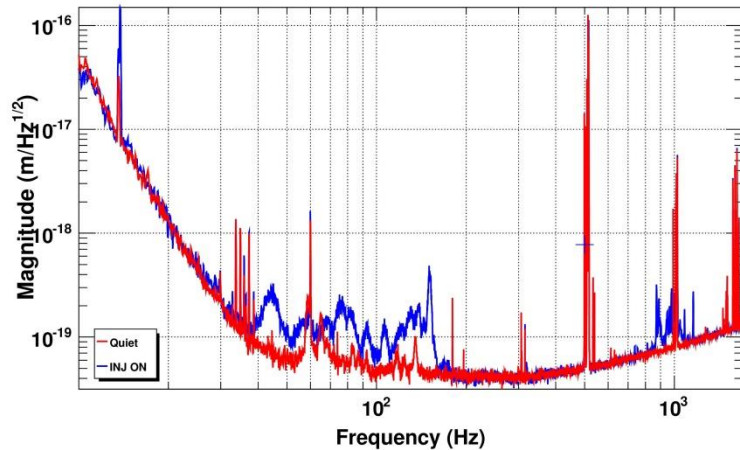


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\*Avg=1/Bin=3L

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DARM

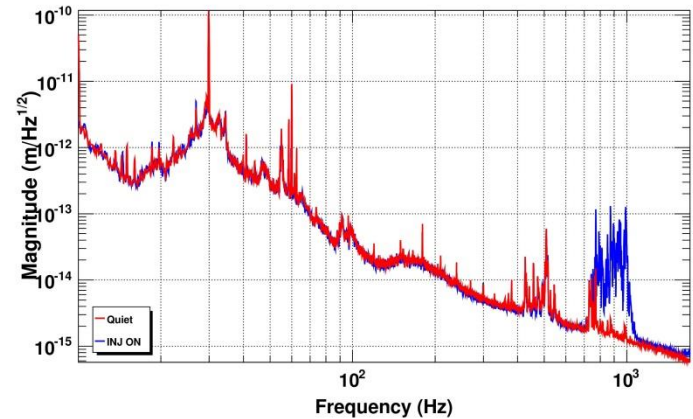


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HAM6 ISI X



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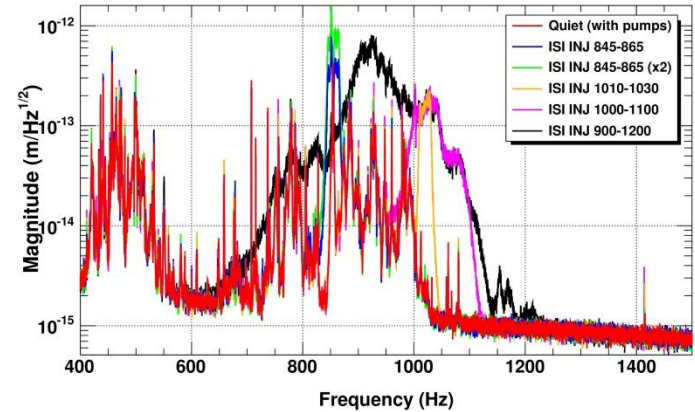
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## Direct ISI Table Injections

- Direct injections to the ISI table in HAM6
- Many injections over various bands to try to identify the noise causing mechanism

ISI (GS13) Y

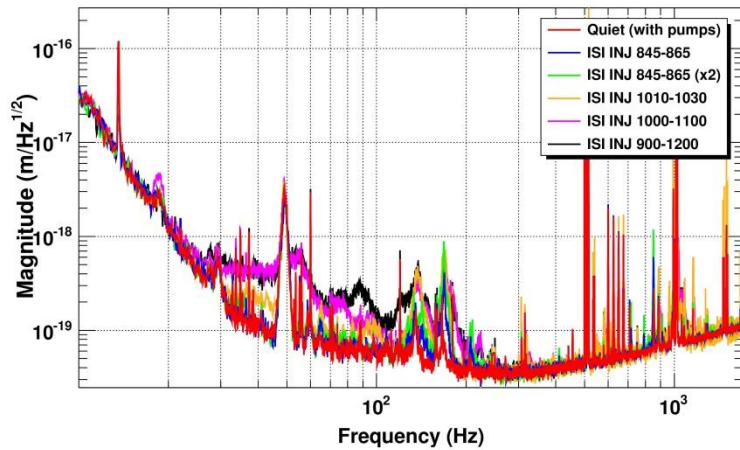


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DARM

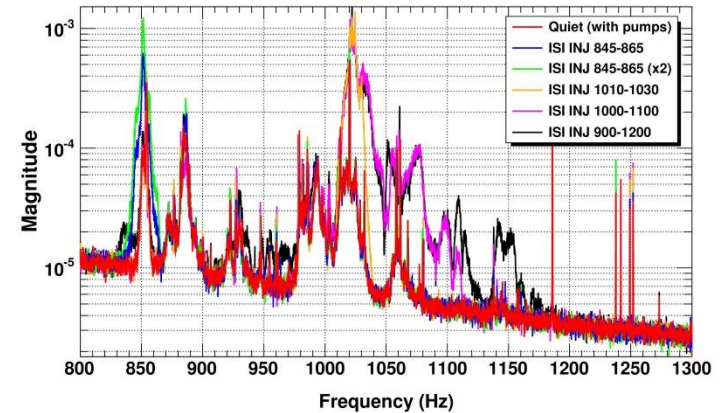


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OMC LSC SERVO OUT

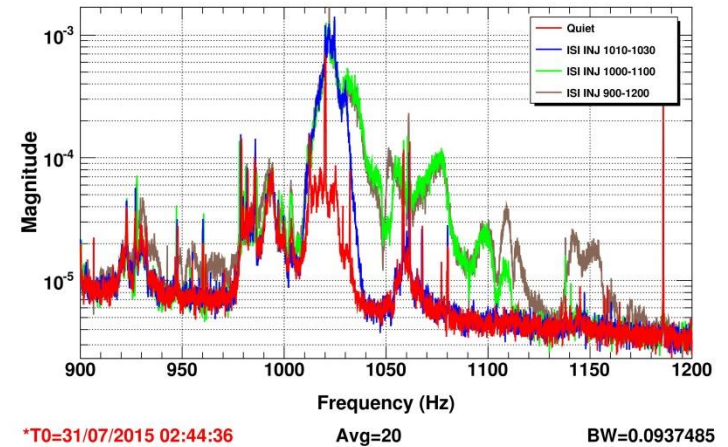


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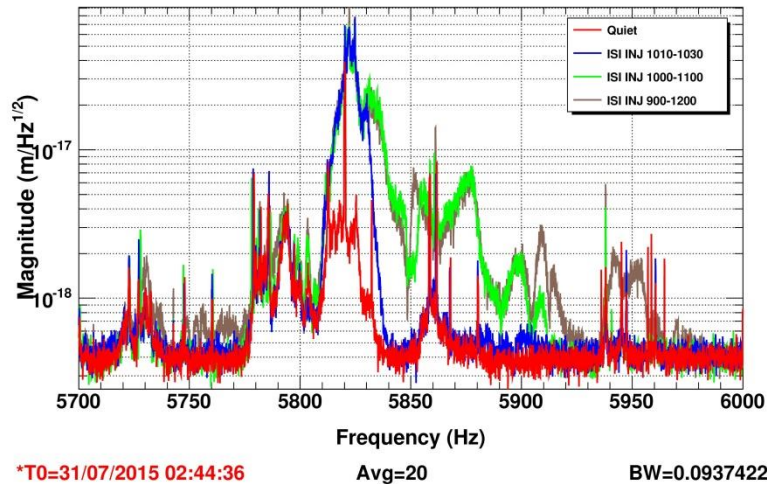
## More supporting evidence

- Evidence of down/up conversion due to beating with an expected peak in DARM
- 4800Hz is the modulation/demodulation frequency used in controlling the OMC cavity

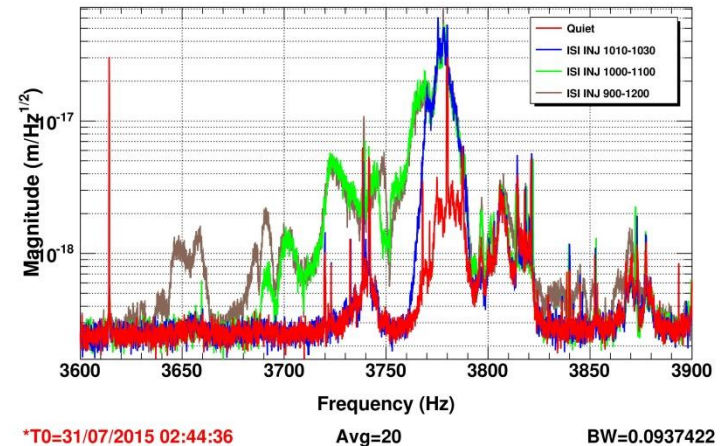
OMC LSC OUT



DARM below 4800Hz



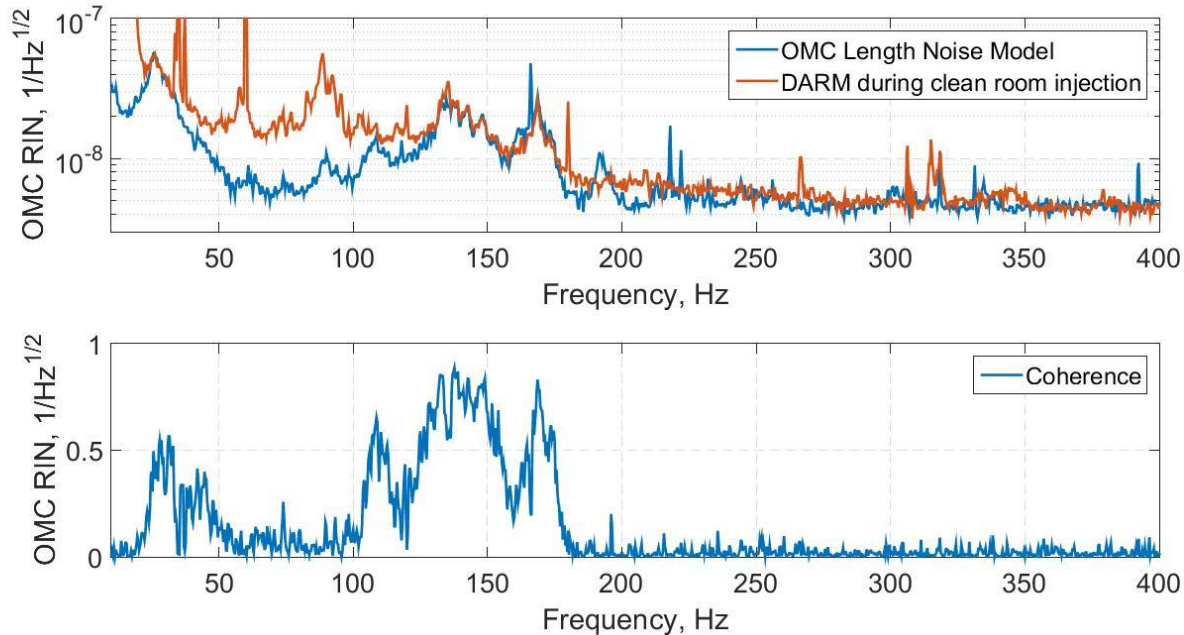
DARM above 4800Hz



LIGO-T1500285-v1

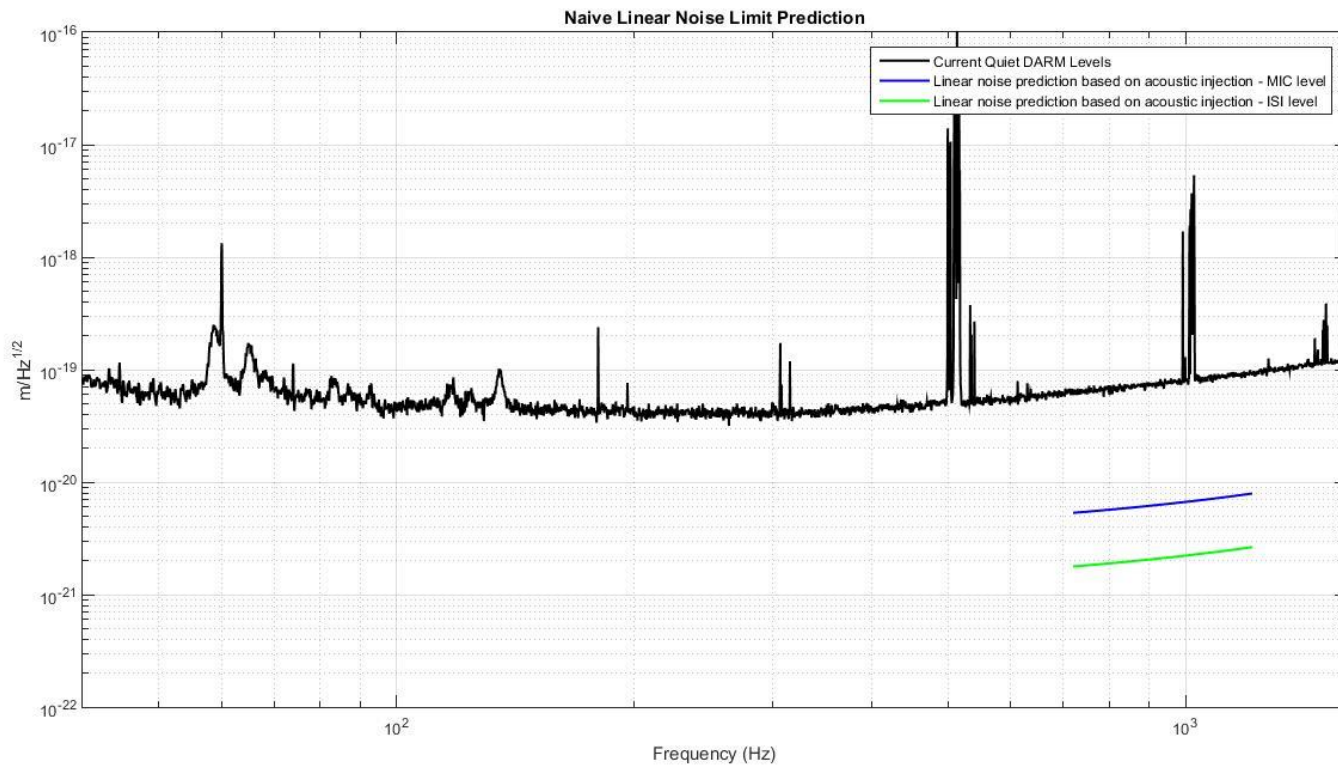


# More Supporting Evidence



$$\begin{aligned}
 P_{det} &= |E_t|^2 \propto L^2 = A^2 \cos^2(\omega_1 t) + B^2 \cos^2(\omega_2 t) + 2AB \cos(\omega_1 t) \cos(\omega_2 t) \\
 &= \frac{1}{2} (A^2 + B^2 + A^2 \cos(2\omega_1 t) + B^2 \cos(2\omega_2 t) + 2AB \cos((\omega_1 - \omega_2)t) + 2AB \cos((\omega_1 + \omega_2)t))
 \end{aligned}$$

# Linear Noise Budget Plot



# What next?

- How does ISI table noise get to the OMC?
  - » Double pendulum isolation =  $f^{-4}$  HF isolation!
  - » Scattering?
- Investigate other peaks shown in ISI during clean room injections
- Investigate other LF noise excited by injections not adequately explained by the aforementioned mechanism

# References

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- Effler, Anamaria. 'HAM6 Scatter/Shaker Tests Continued'. *aLIGO LLO Logbook* 2015. Web. 19 June 2015.
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- Schofield, Robert. 'High Acoustic Coupling Likely Due To HAM6 ISI Blade Spring And Suspension Wire Resonances; Wire Damping Demonstrated'. *aLIGO LHO Logbook* 2015. Web. 2 July 2015.
- Schofield, Robert. 'Shaking Study Suggests Beam-Tube Baffle Scattering Noise Will Be Borderline Near 14 Hz, Below Noise Floor Elsewhere'. *aLIGO LLO Logbook* 2015. Web. 7 July 2015.
- Smith, Joshua. 'Tracking Down 1020Hz Line'. *aLIGO LLO Logbook* 2015. Web. 1 Aug. 2015.

# Further Works

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- Further scattering/noise studies conducted during this project can be found in the aLIGO LLO Logbook ([alog.ligo-la.caltech.edu](http://alog.ligo-la.caltech.edu)) under the following log numbers:
  - » 19450
  - » 19419
  - » 19315
  - » 19077
  - » 18825

# Acknowledgements

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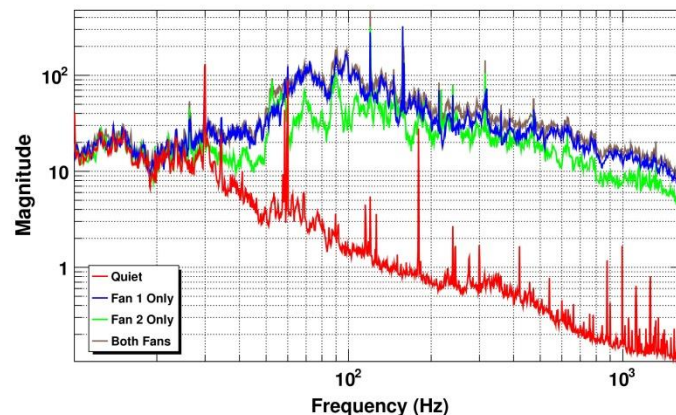
I'd like to thank:

- My mentors, Anamaria and Valera
- LLO staff
- My fellow SURF, John
- The National Science Foundation

## Clean Room Fan Injections

- Both acoustic and mechanical injections to the entire chamber

MIC between HAM5 and HAM6

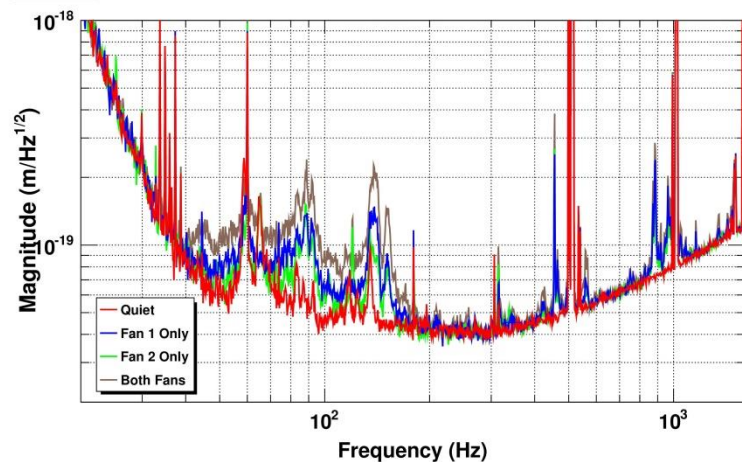


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DARM

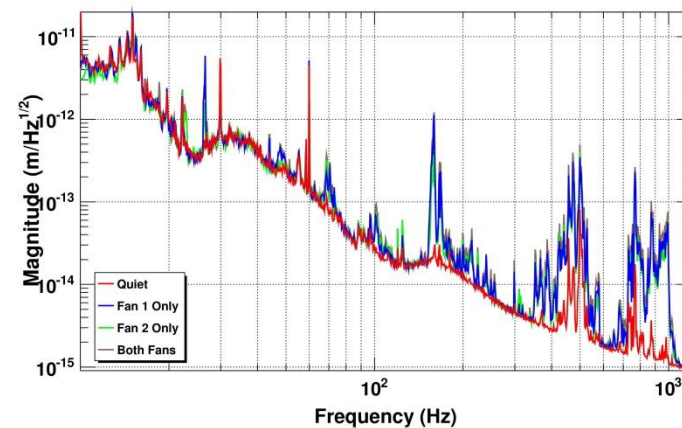


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HAM6 ISI Y



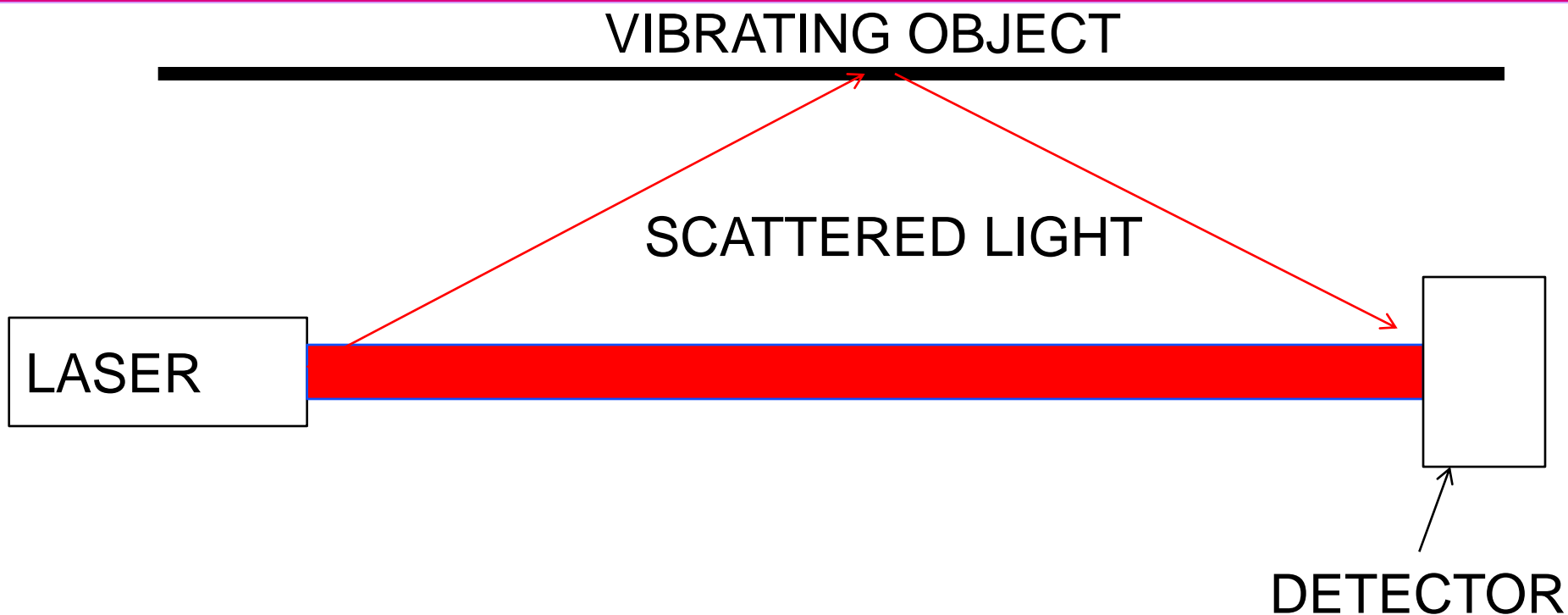
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LIGO-T1500285-v1

# What is scattering noise?



$$E = Ae^{i\omega_1 t} + B\cos(\omega_2 t)$$

Same as GW modulation!