Detector Noise at LIGO

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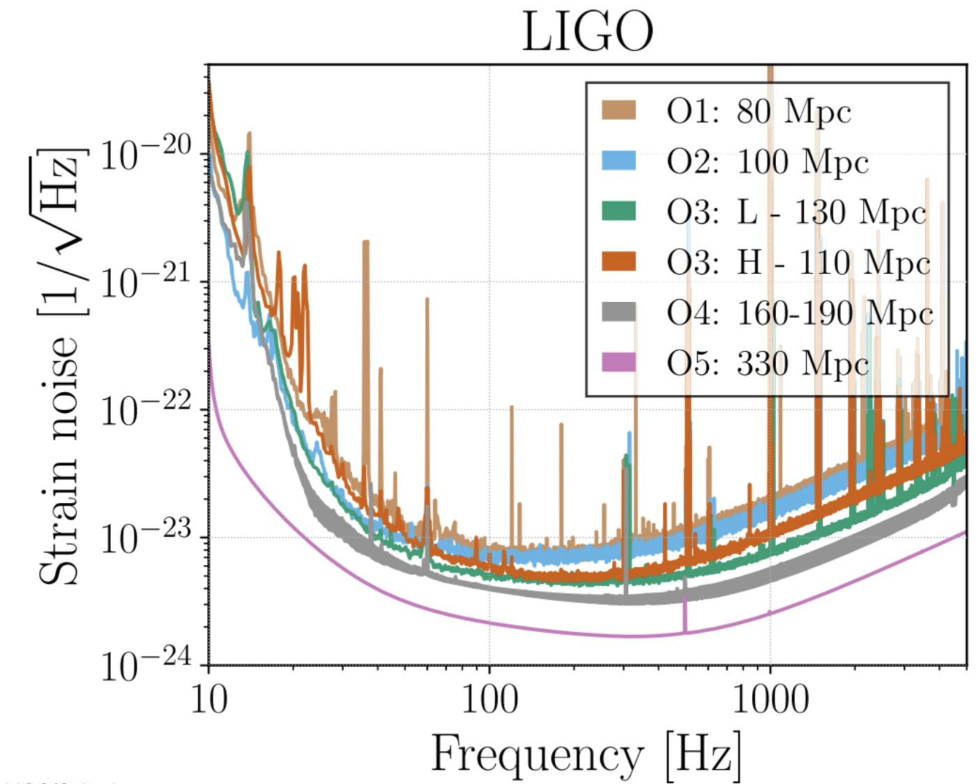
LIGO sensitivity

- To detect gravitational-waves (GWs), LIGO senses length changes on the order of 1/10,000th proton radius
- Analogous to measuring the distance to Proxima Centuri (4.3 light years) with an accuracy of less than a human hair.
- This makes LIGO sensitive to many forms of terrestrial noise
- For example:
  - Logging in nearby forests
  - Storms off the Washington and Alaska coasts
  - High winds

The noise floor

- Noise floor shows how strong a signal has to be in a certain frequency range in order to be detected
- LIGO is more sensitive in some frequency bands than others
- Black hole (within a certain mass range) and neutron star merger frequencies fall within most sensitive range



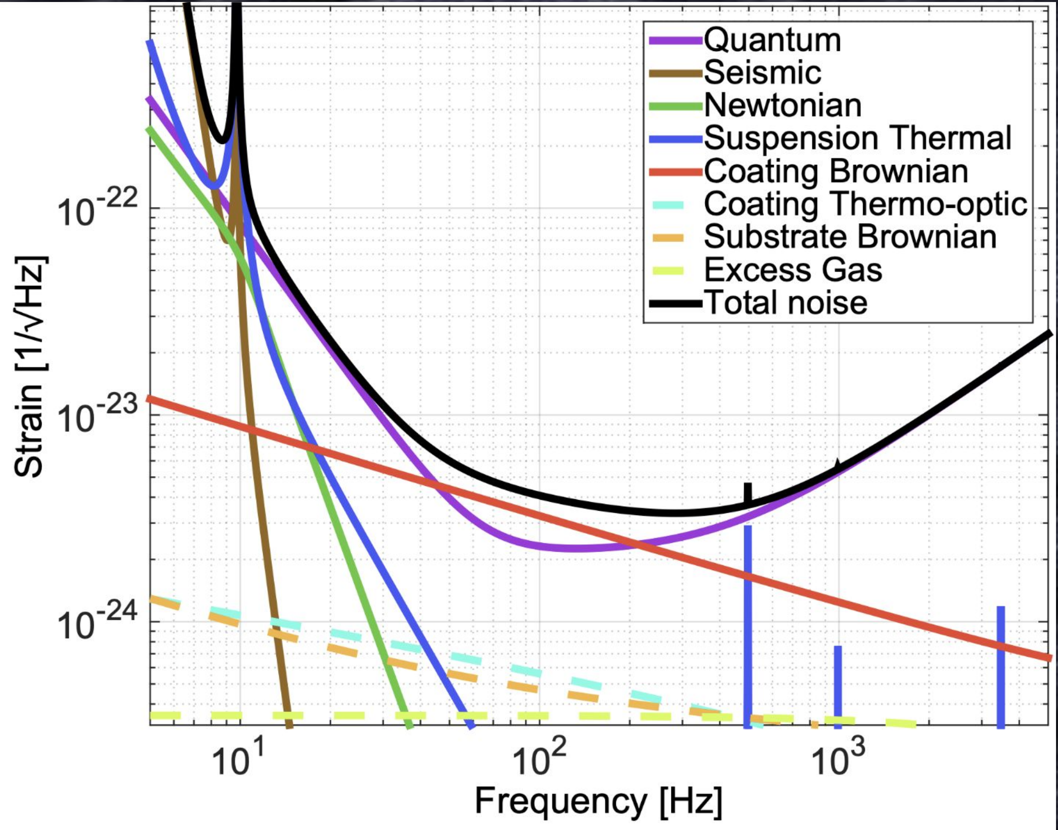
LIGO/Caltech

Noise in the detector

- Two categories of noise: background and transient
- Background:
  - Persistent, often fundamental in the noise spectrum
  - Vary over long timescales
- Transient:
  - Short-duration
  - Can have high signal to noise ratio

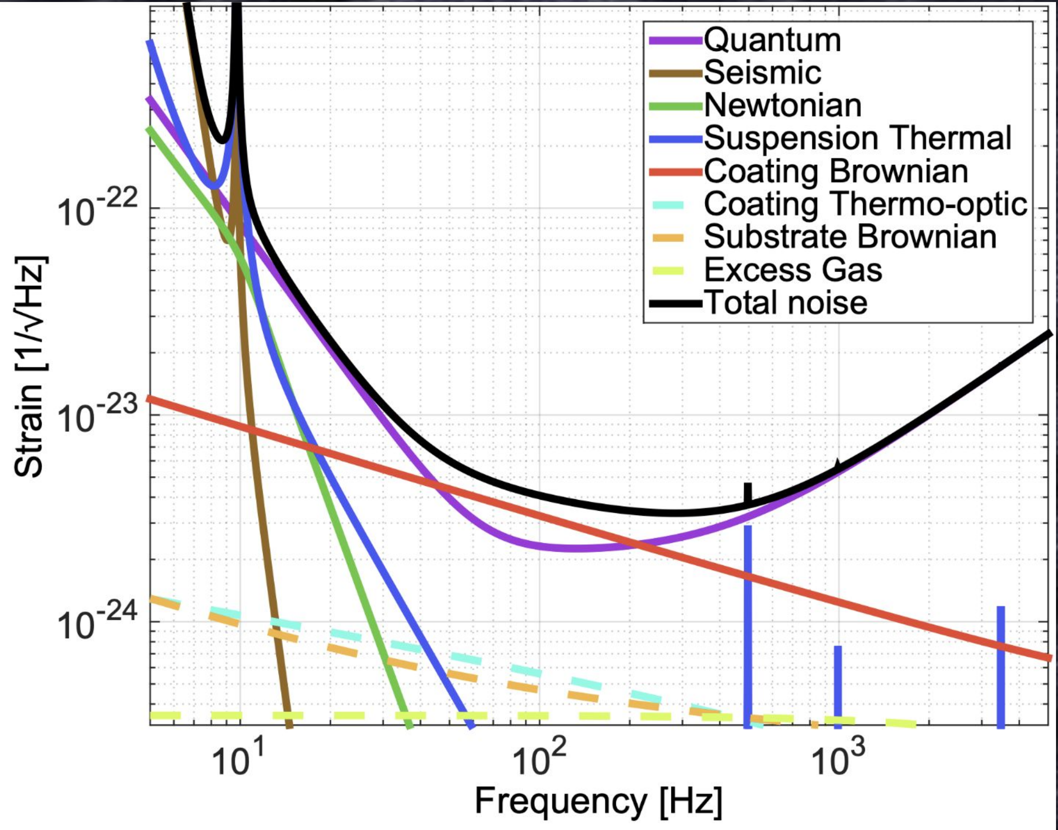
Background noise sources

- Noise budget: combination of known noise sources, each contributing at different levels and in different frequency bands
- Quantum: Quantum shot noise is statistical uncertainty in the number of photons counted by a photodiode. Dominates at high frequencies



Background noise sources

- Seismic: Seismic noise is caused motion of the mirrors due to ground vibrations.
- Newtonian: Caused by shifts in gravitational force from moving masses in the ground and air (ex: wind currents)



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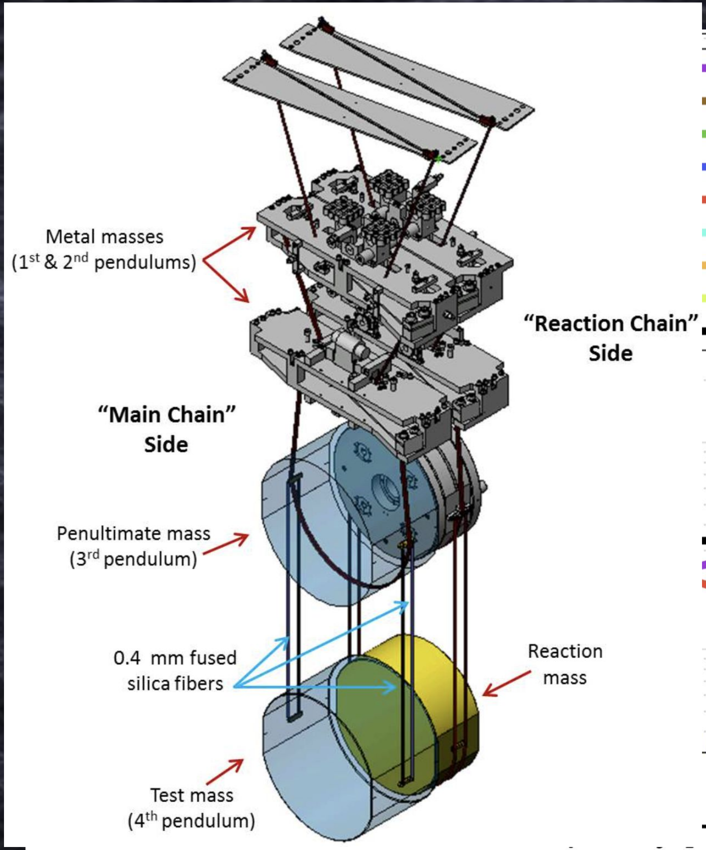

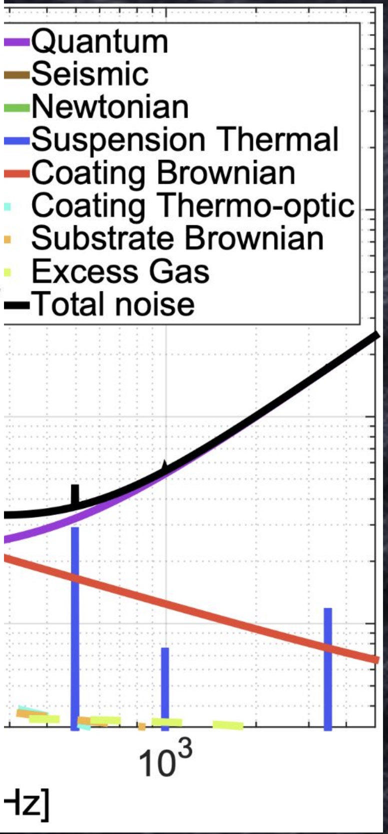

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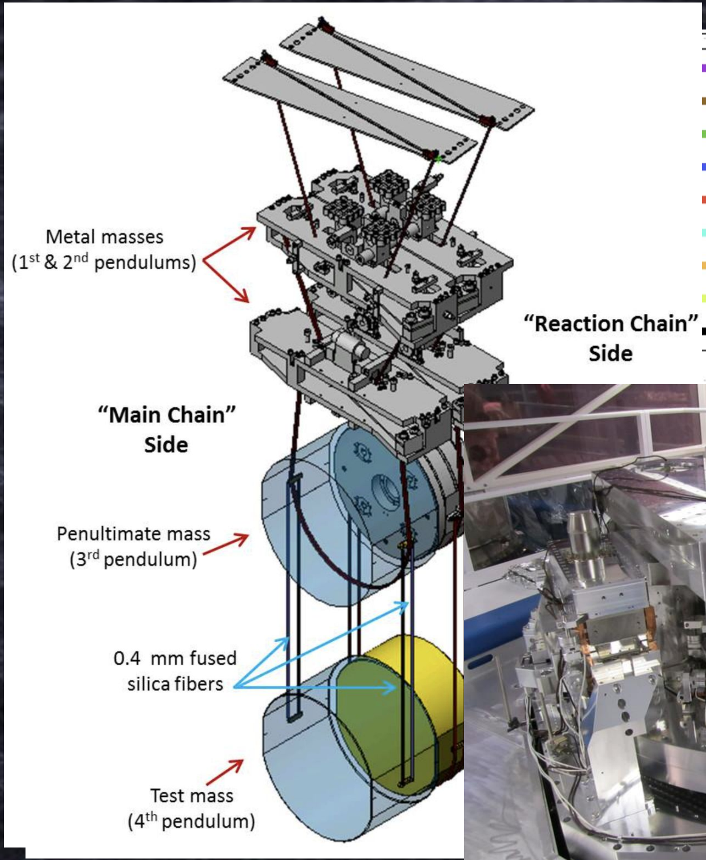
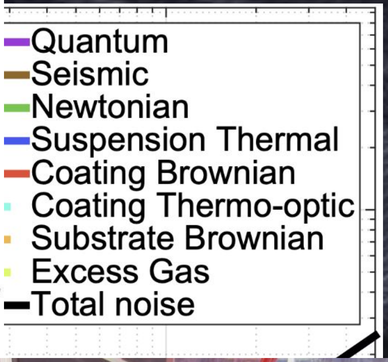
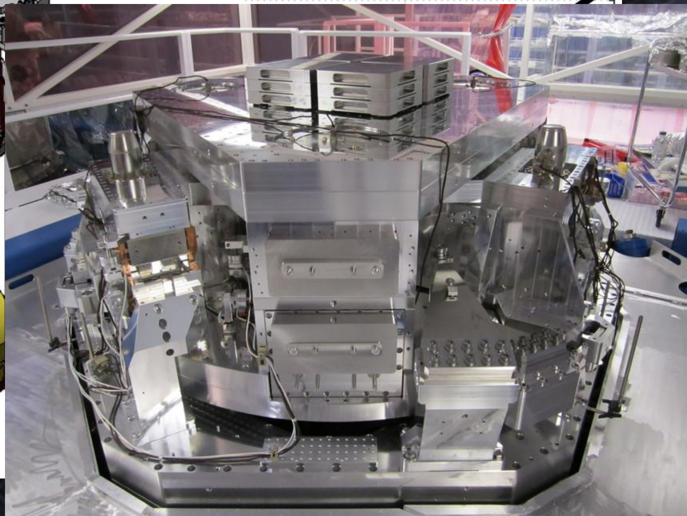
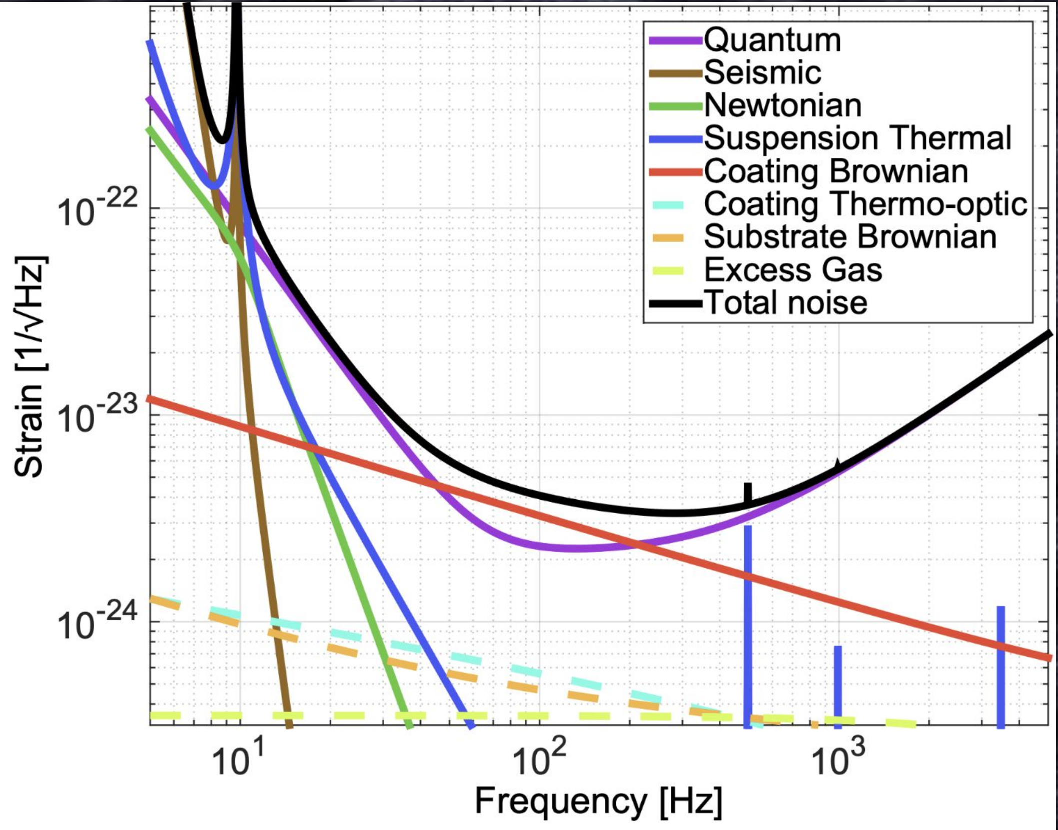






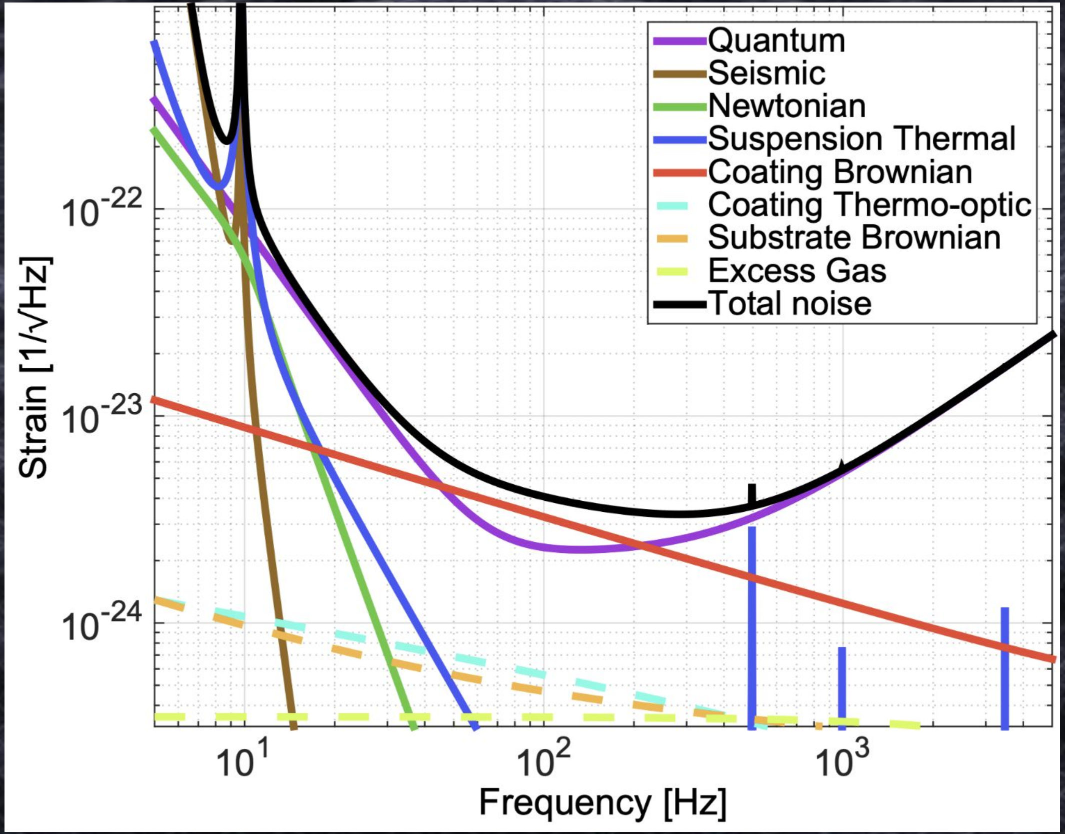
Background noise sources

- Suspension Thermal: Noise from thermodynamic fluctuations in the optical suspensions
- Coating Brownian: Brownian noise in the optical coatings that get heated by the absorbed laser (99.9999% reflectivity, 100 kW in the arms)



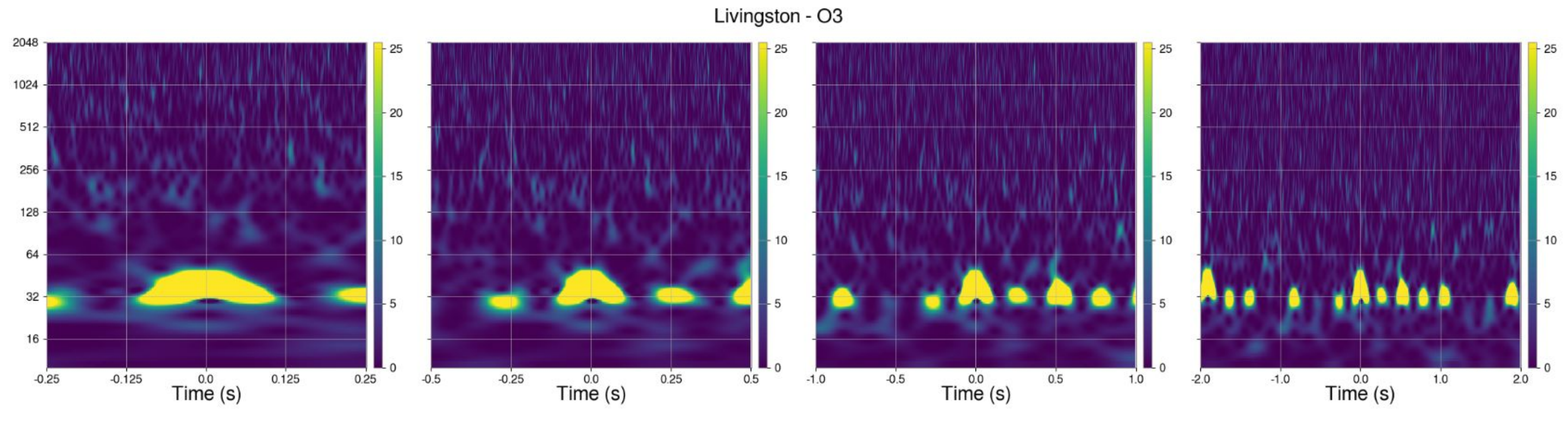
Background noise sources

- Coating Thermo-Optic: Noise due to thermal expansion of the coating, and change in the index of refraction
- Substrate Brownian: Brownian motion in the optics themselves
- Excess Gas: Noise from remaining gas particles in ultra-high vacuum bouncing around



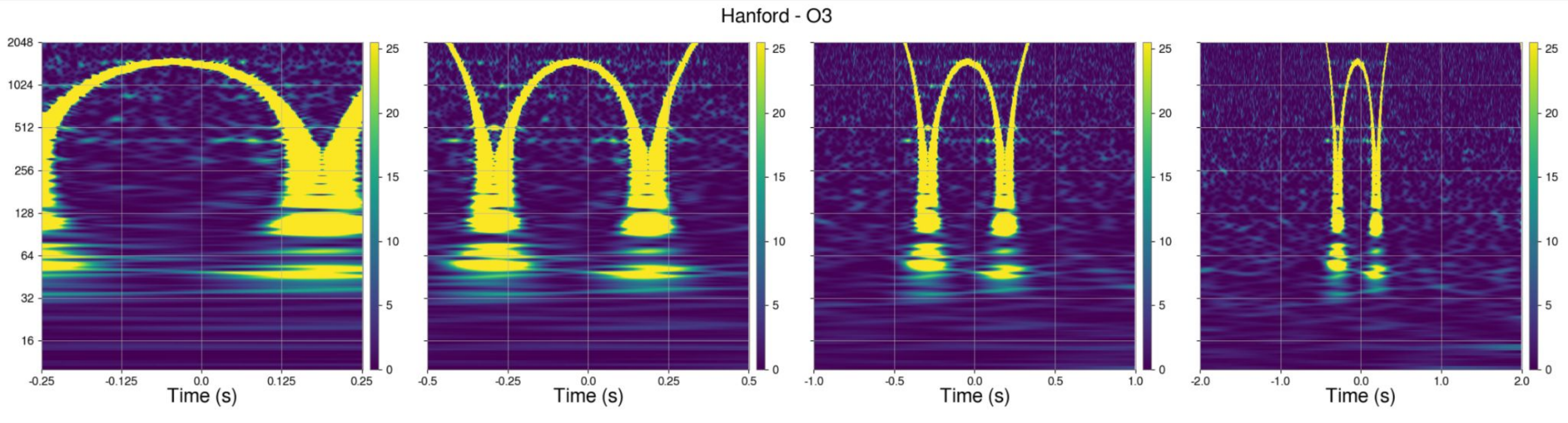
Transient noise sources

- Often referred to as "glitches", defined as transient non-Gaussian terrestrial noise observed by the detector
- Many types of glitches, not all of which are well-understood
- <u>Fast-scattering</u>: Correlated with ground motion in the anthropogenic band



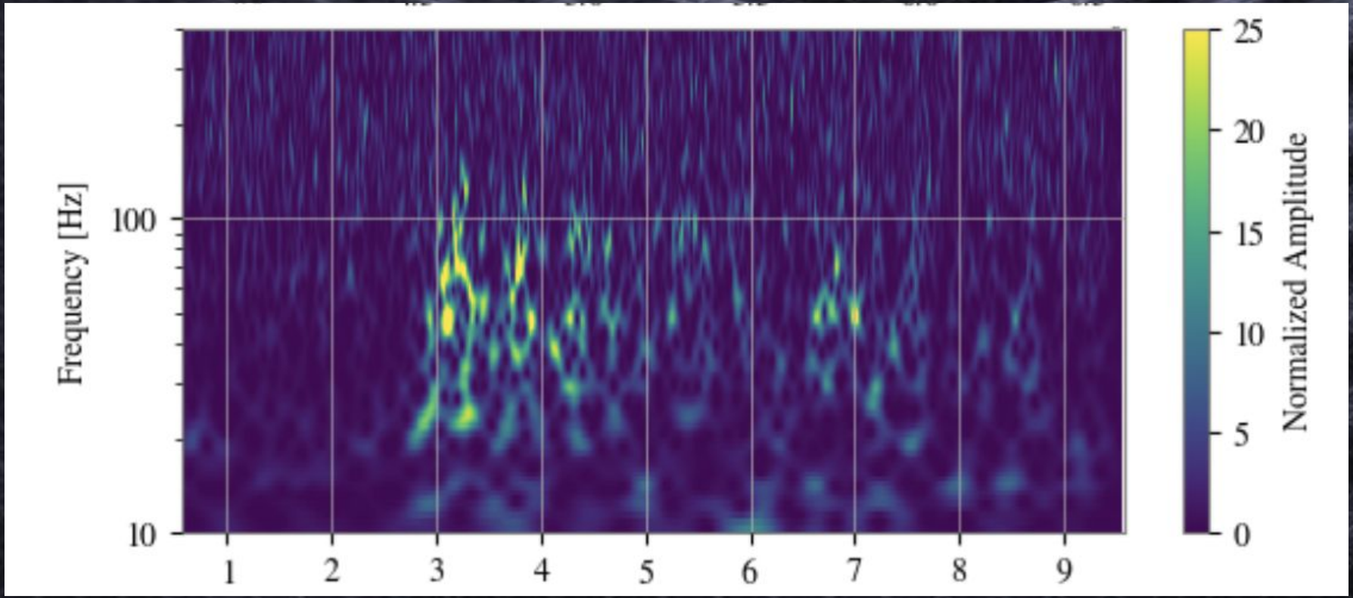
Transient noise sources

- Whistle: Caused by beat notes between RF modulation sidebands and voltage-controlled oscillators



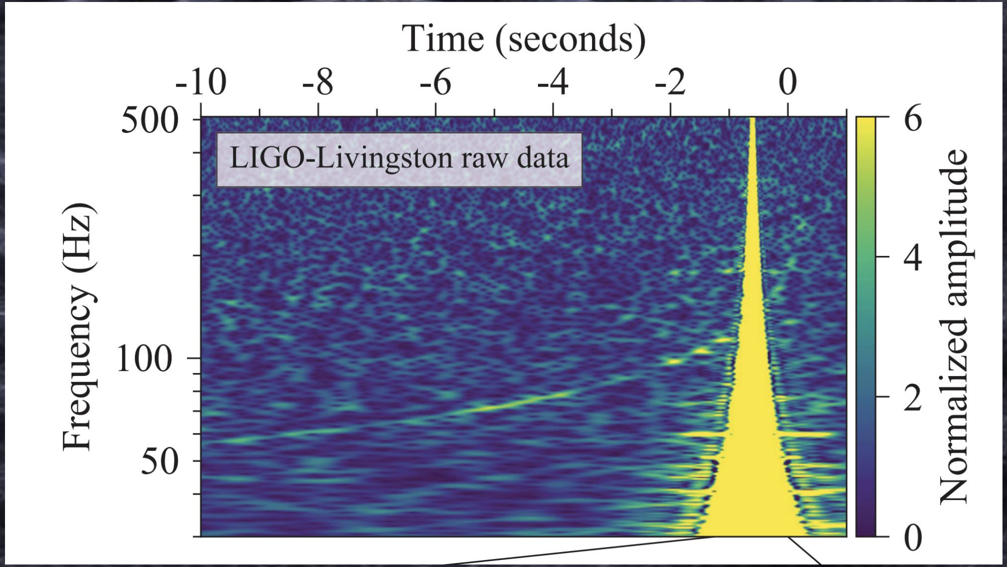
Transient noise sources

- Thunder: result of thunderstorms occurring near the detector acoustically coupling and causing light scattering noise



Glitch interference with GW signals

- Despite best efforts, there are many transient noise sources present in GW data
- These glitches can occur near GW signals, potentially interfering with the ability to estimate parameters
- A real example of a glitch overlapping a GW signal is GW170817



Question for small groups (5 min)

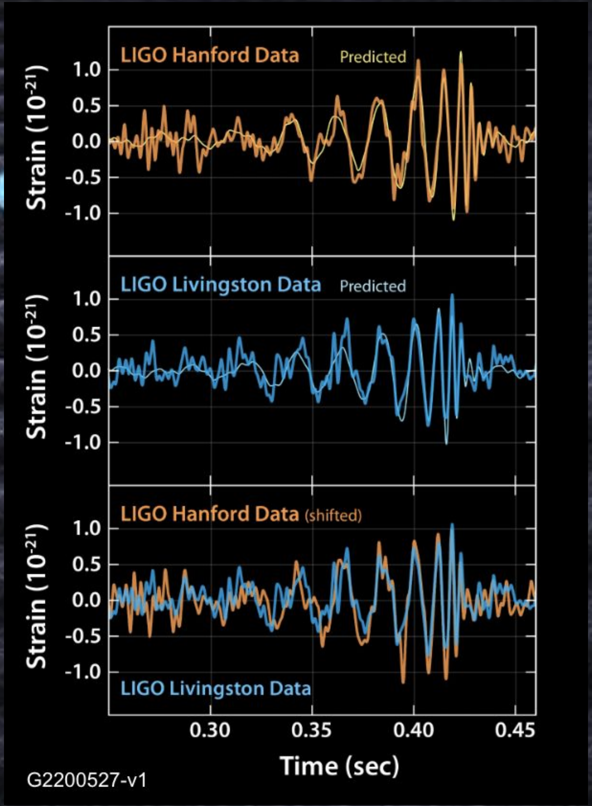
You are at LHO in the control room and you see transient noise in the strain channels:

- How do you determine that it’s not astrophysical?
- How do you find where the noise is coming from?
- How do you confirm your prediction of the source?

Methods for identifying glitches

<u>Check other interferometers for coincident signals</u>

- Signals have to occur within a certain amount of time (10 ms btw LHO/LLO)



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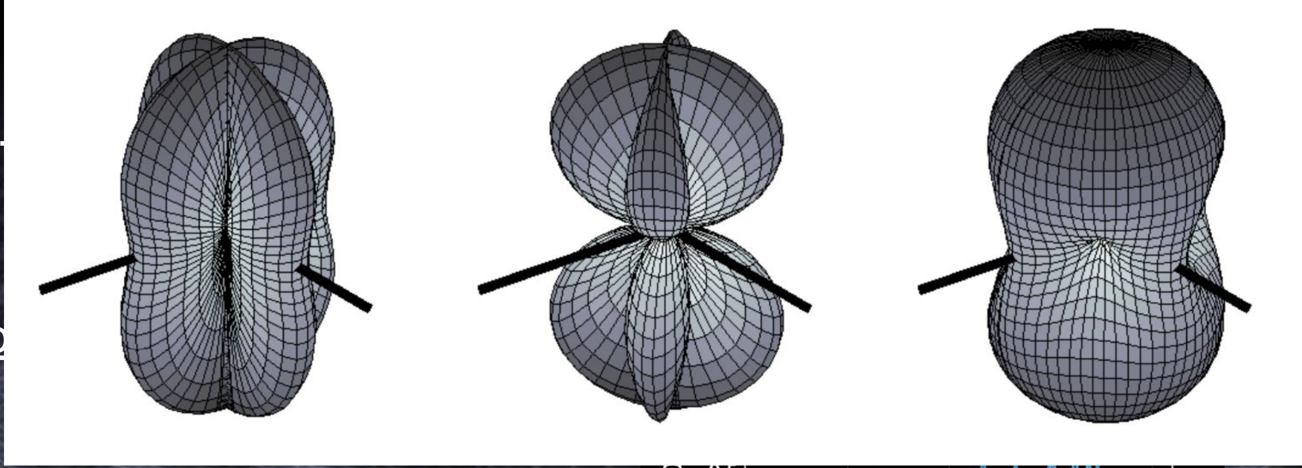
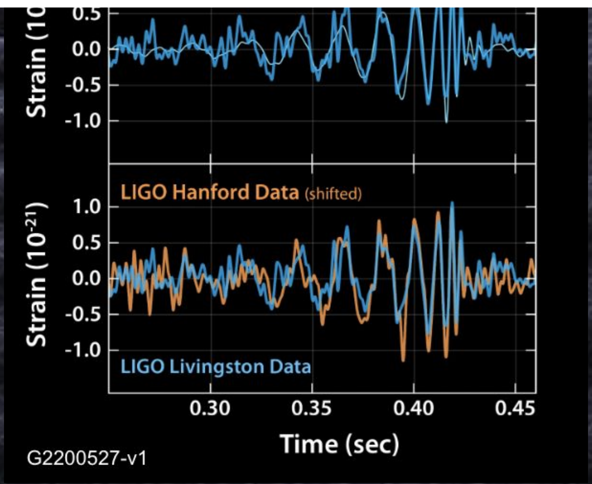


<u>Check other interfero</u>
<u>signals</u>

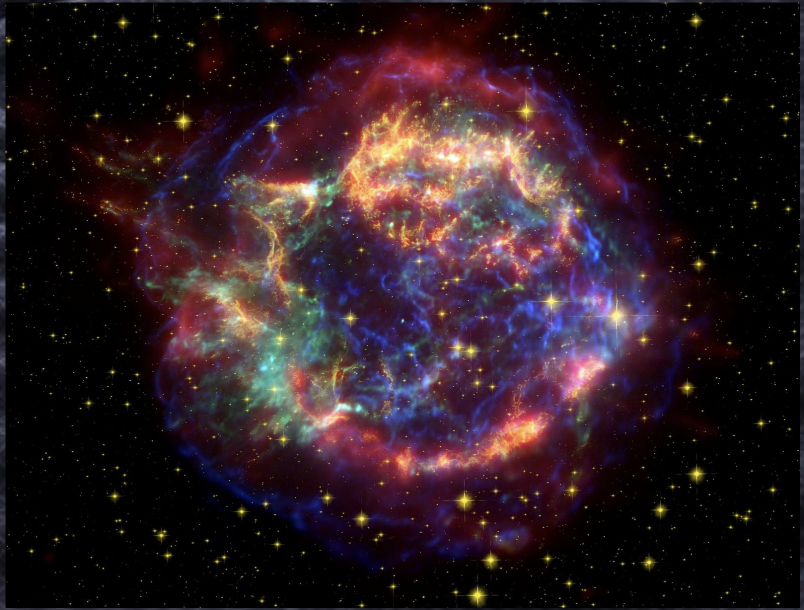
- Signals have to occur within a certain amount of time (10 ms btw LHO/LLO)
- IFO’s sensitivity to incoming GW waves depends on the direction they come from, so you may not see them in all detectors



Methods for identifying glitches

Check if noise matches signal template

- This is done automatically, but excess noise can confuse the matched filter search
- Some potential GW sources are not well known enough to confidently model their signals



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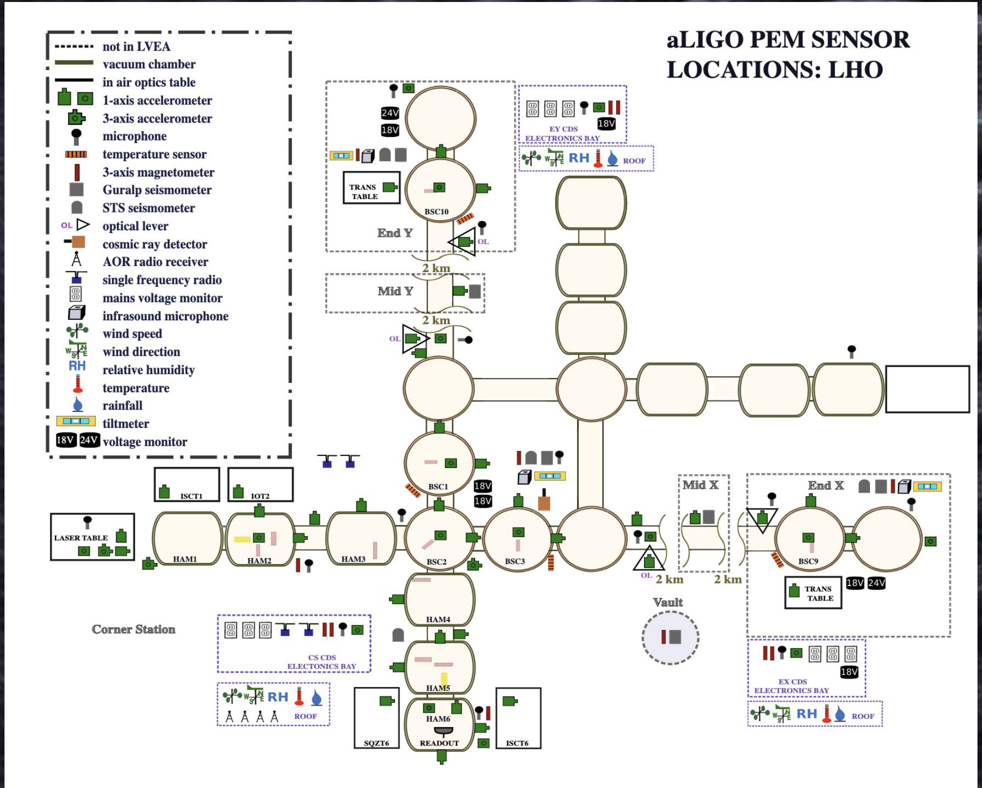
Check LIGO's auxiliary channels for coincident noise sources

PEM sensors



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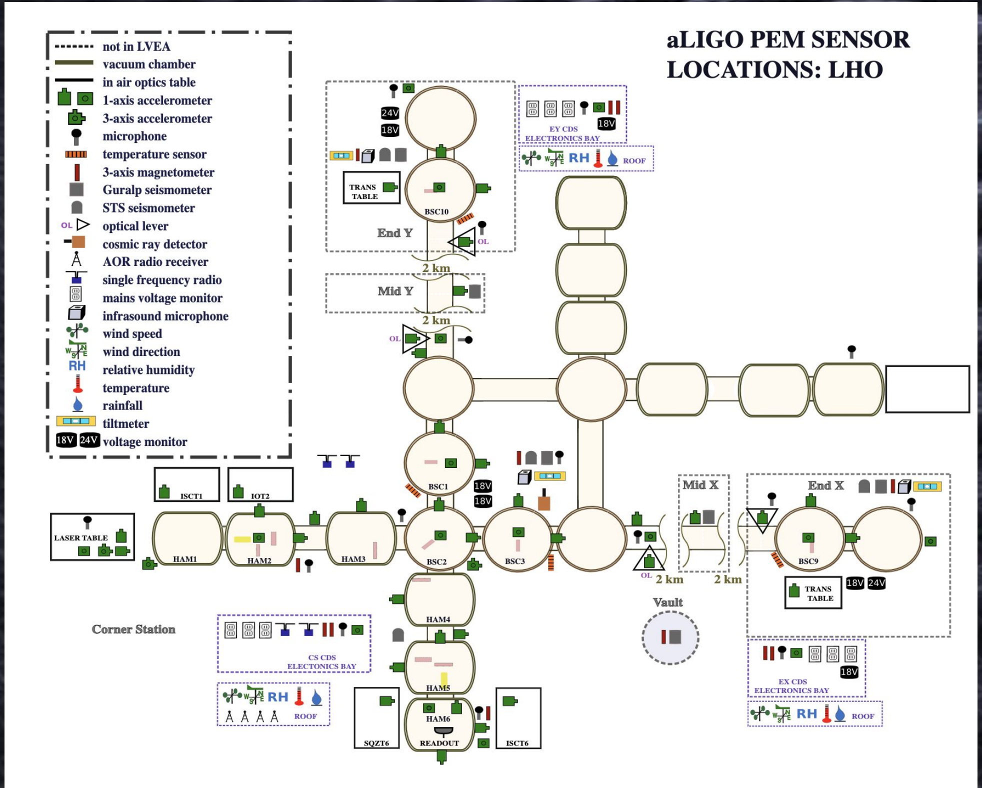
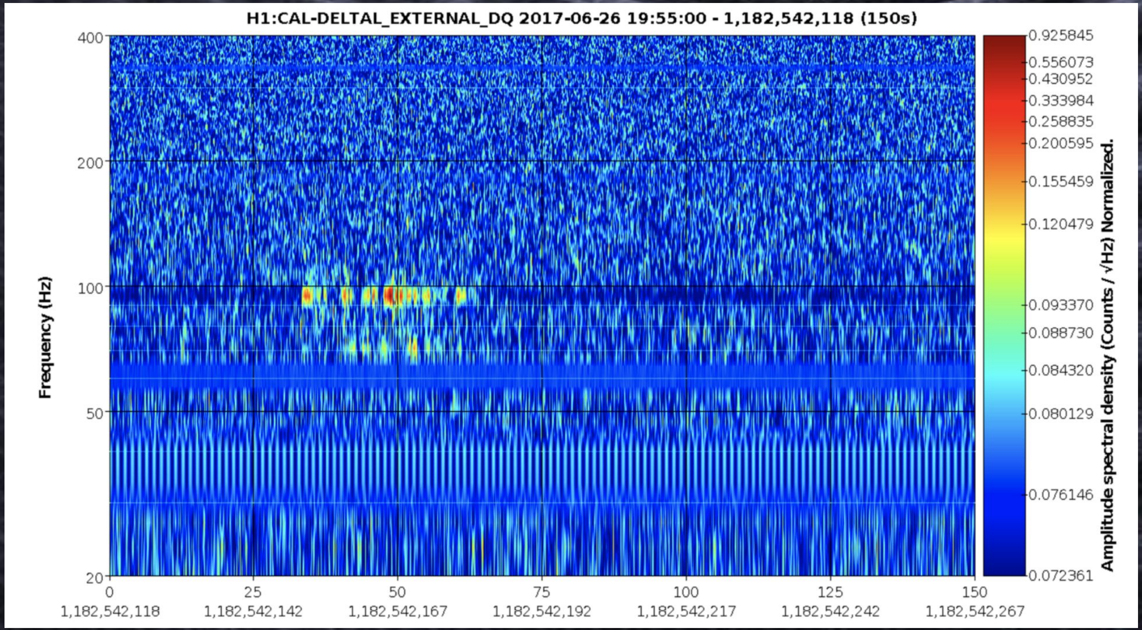


- May take multiple instances to be sure
- Also a good way to figure out the source of the noise!

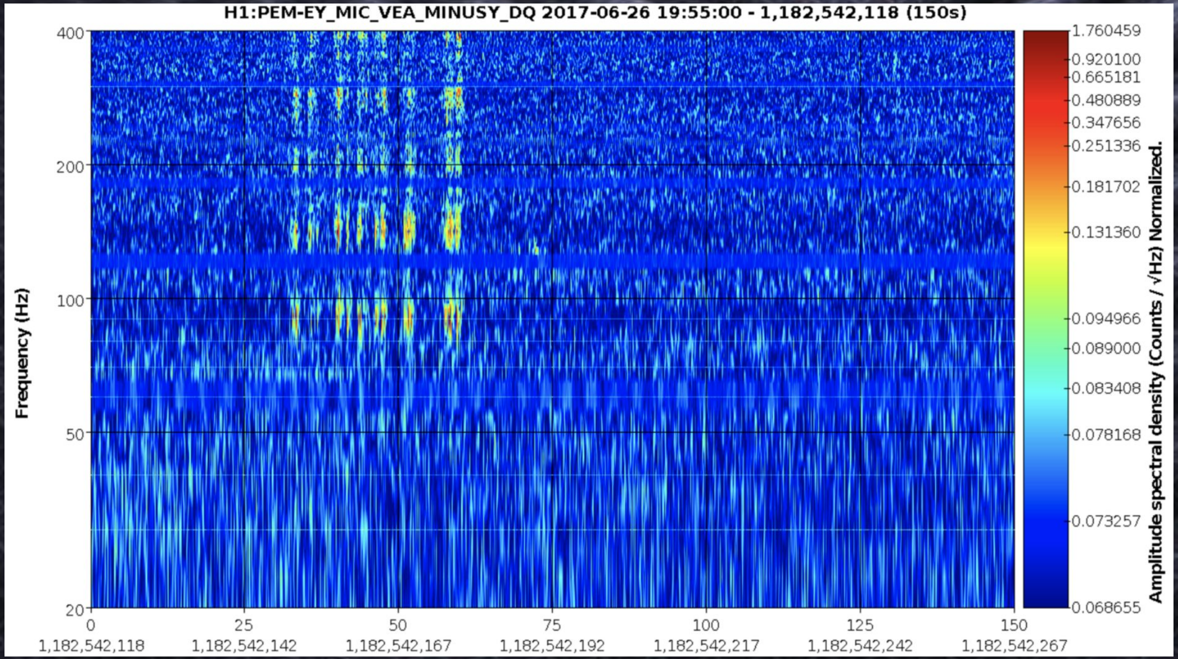
Noise can come from anywhere!

- Unknown transient noise appeared in July 2017



Coincident signal in auxiliary channel

- Glitches occurred at the same time as noise in an end station microphone



In-person investigation at EY

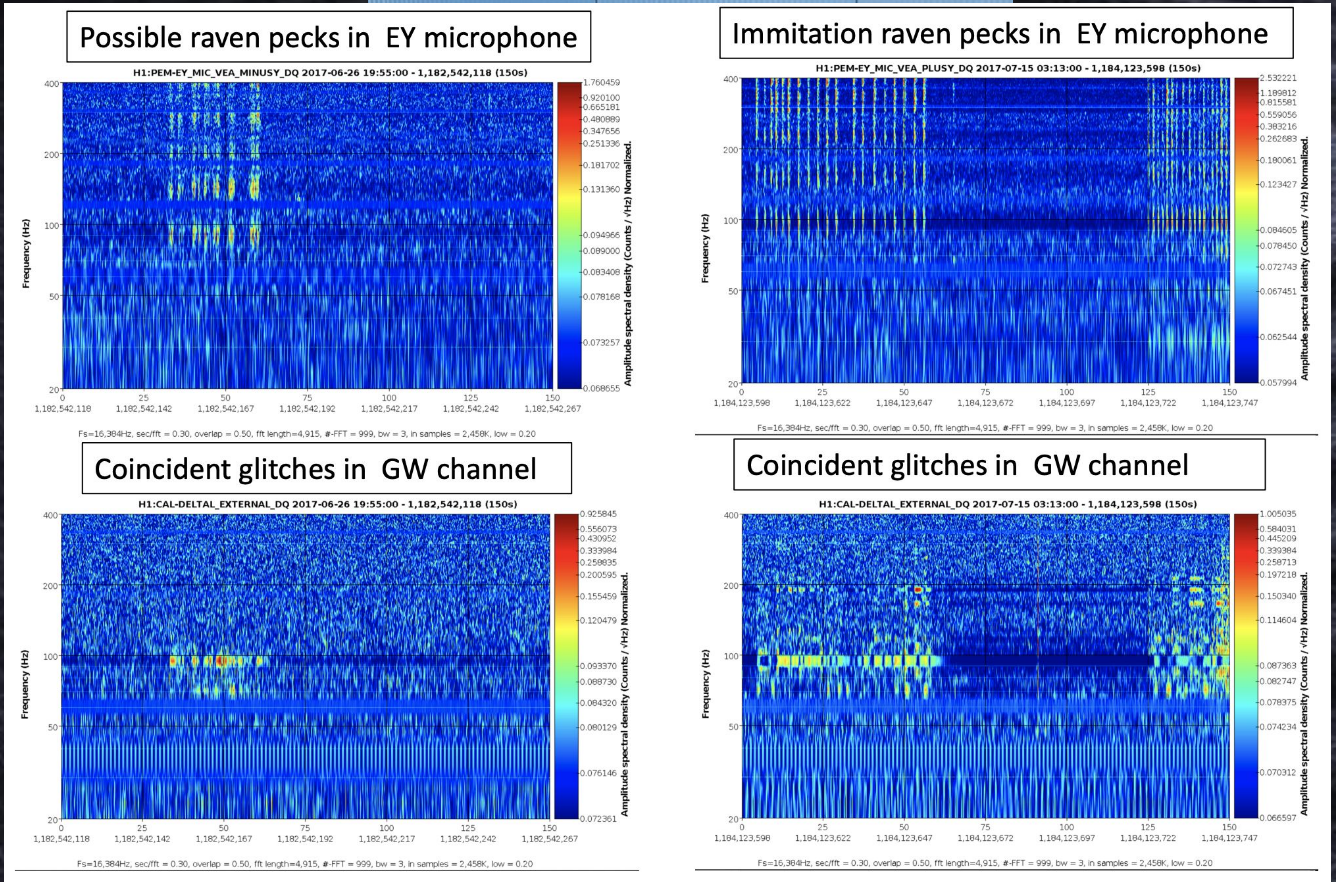
- Strange marks are found on pipes that run from the liquid nitrogen tanks to the cryopumps

The culprit!

- Ice forms on pipes, perfect for a thirsty raven on a hot summer day
- Pecking of ice on pipe creates vibrations that couple into the detector

Testing the theory

Testing the theory



Summary

- Noise mitigation at LIGO is extremely important
- Noise categories: background and transient
- Background: persistent/fundamental detector noise with long timescales for change
- Transient: shorter, stronger signals related to changes to the detector
- Noise in the strain channels can be tricky to track down