# INVESTIGATION OF THE IMPACT OF SEISMIC NOISE ON LIGO INTERFEROMETER PERFORMANCE

RACHEL BRODSKY

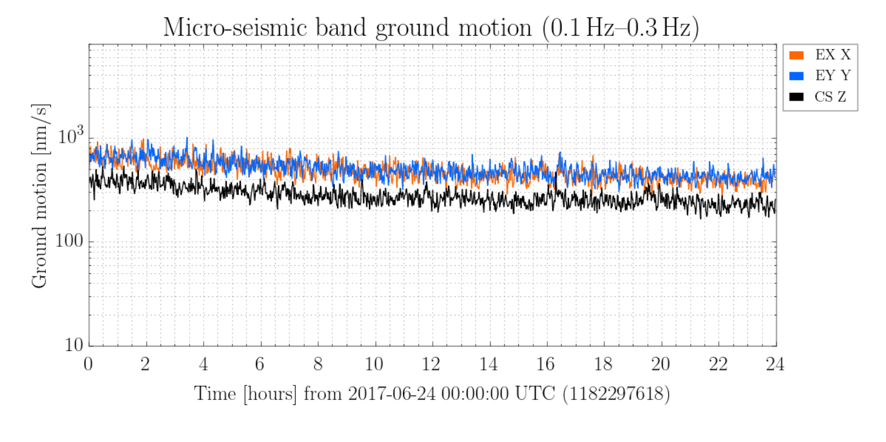
MENTORS: THOMAS MASSINGER AND JESSICA MCIVER

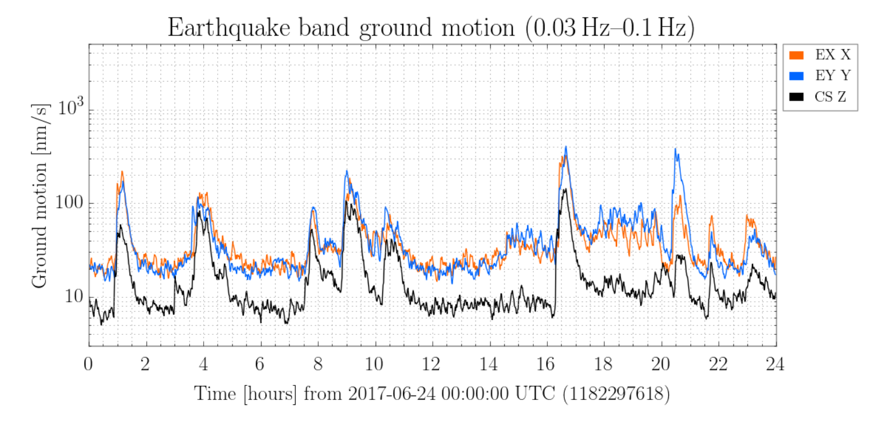
# THIS PRESENTATION

- Why is it important to monitor and understand the effects of seismic noise?
- How have we tried to do this in the past?
- What can we do to improve this method?
- How did we achieve this improvement?
- Difficulties we faced
- Future endeavors

# WHAT IS SEISMIC NOISE AND WHY DO WE CARE?

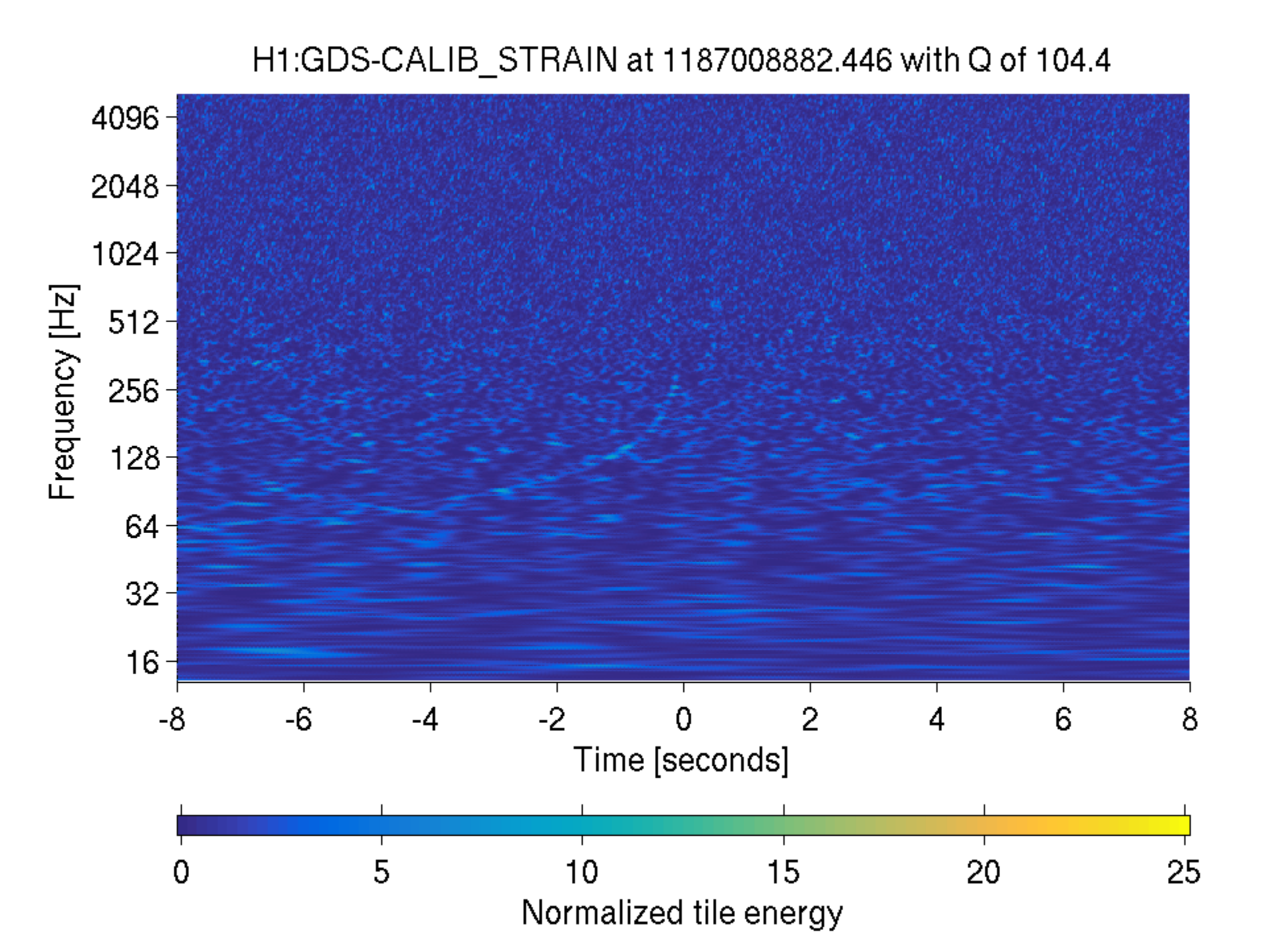
- Detector Characterization (DetChar): Understand noise sources and how they affect the search for gravitational waves
- Seismic noise: Ground motion greatly affects the sensitivity of the detectors to gravitational waves
  - Excess motion of the optics
    - Light scattering
    - Glitches
- **Glitches can overlap with gravitational wave signals** (especially long duration BNS waveforms), inhibiting the ability to recover the signals *(sound familiar?)*
  - BNS waveforms: ~30-60 seconds (from 20Hz onward)
  - BBH waveforms: ~0.1- 4 seconds (from 20Hz onward)
- We need to understand our noise sources better in order to improve our sensitivity

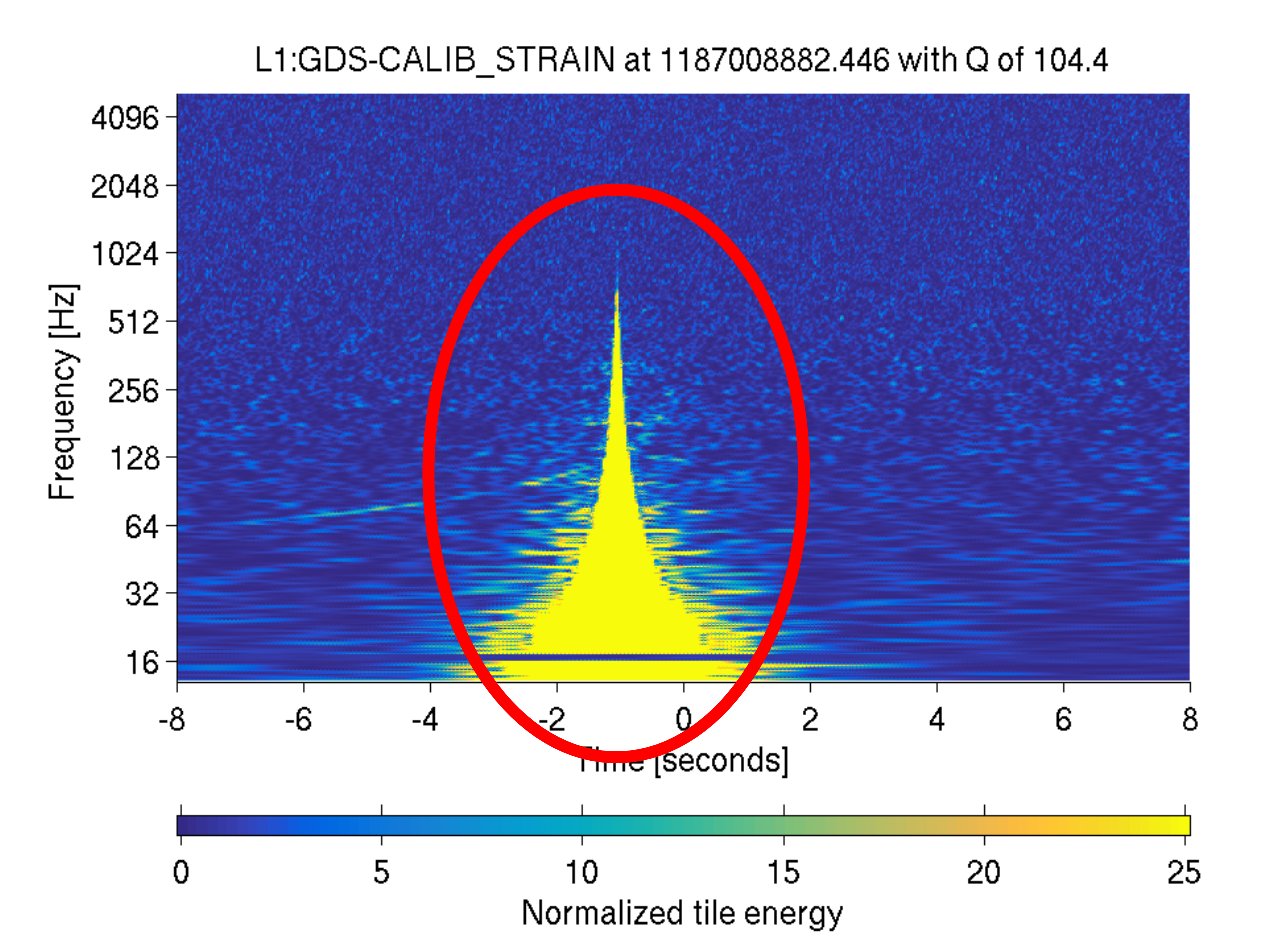


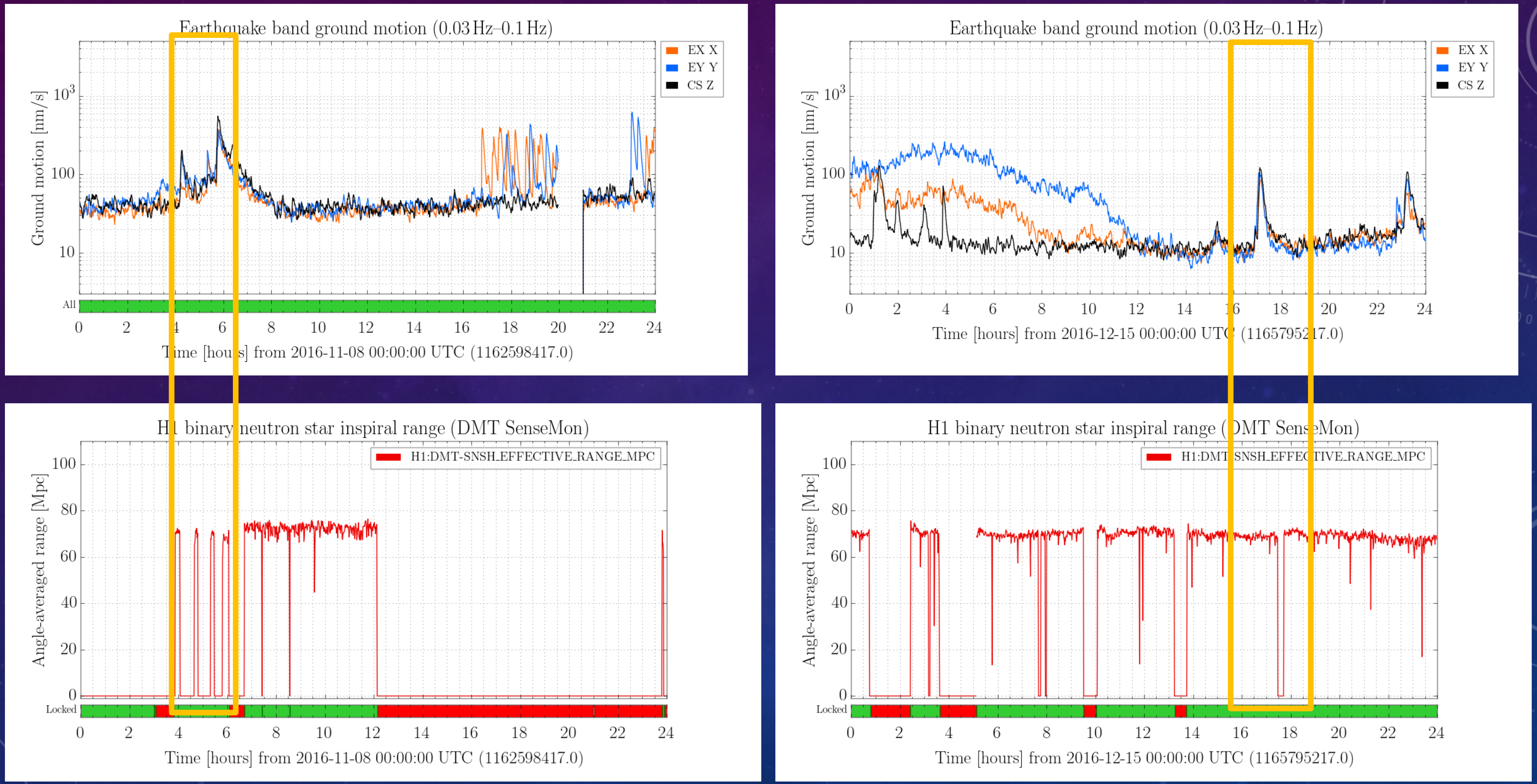

June 24th, 2017

# THIS IS WHY WE CARE!



# Transient noise affects our sensitive distance!

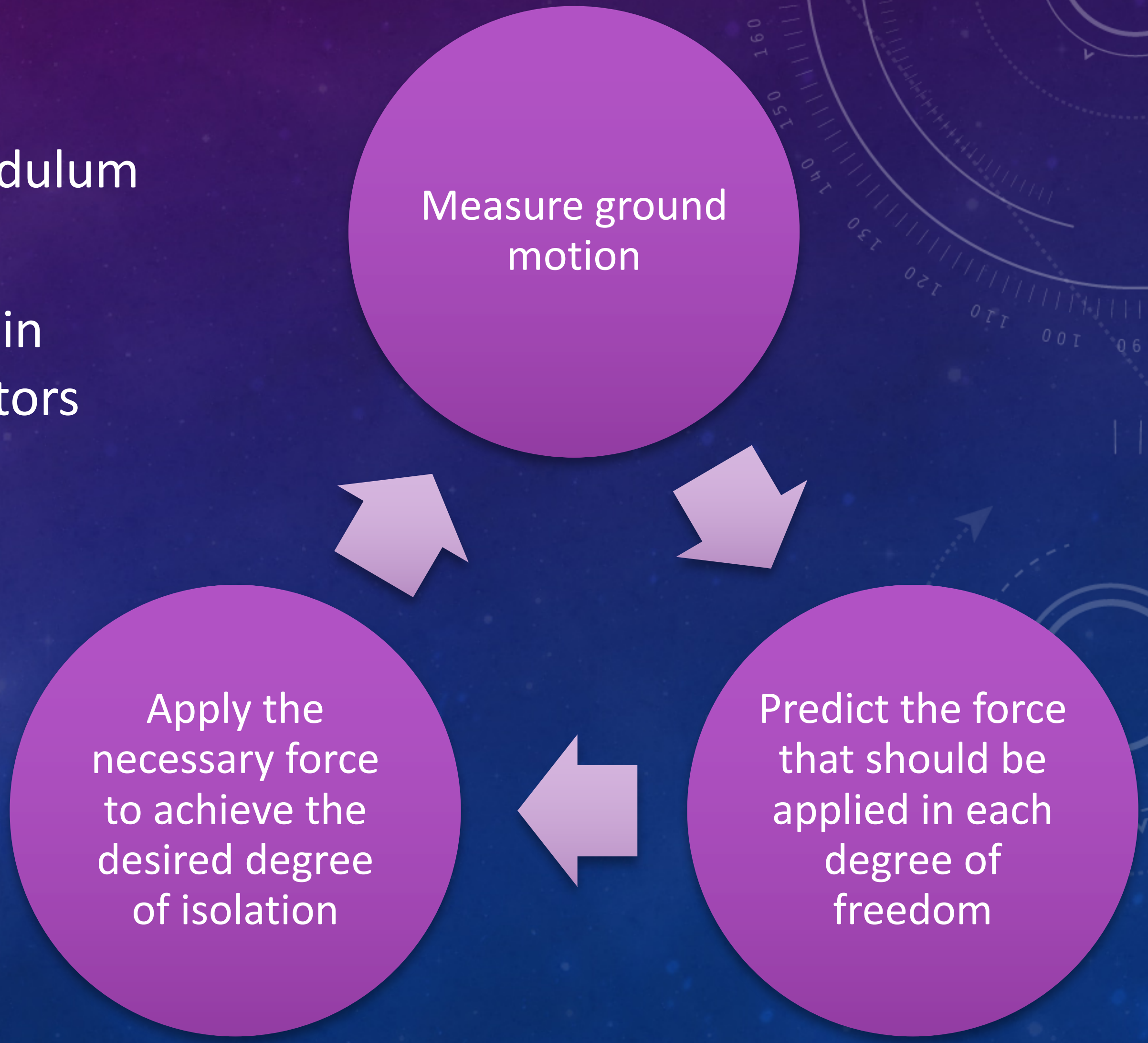



BLRMS vs inspiral range for November 8th, 2016 and December 15th, 2016

# WHAT CAN WE DO ABOUT SEISMIC NOISE?

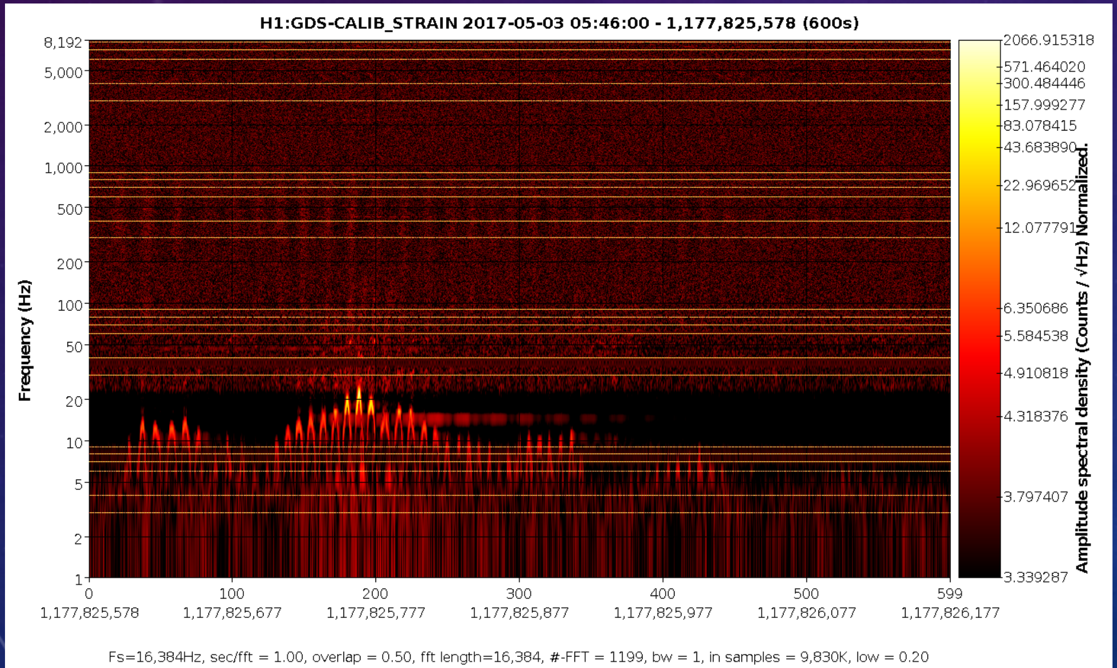
- Isolation
  - **Passive:** Vacuum chambers, quadruple pendulum suspension
  - **Active:** Position sensors and seismometers in conjunction with feedback loops and actuators

But not all motion is attenuated!  Some reaches the optics!

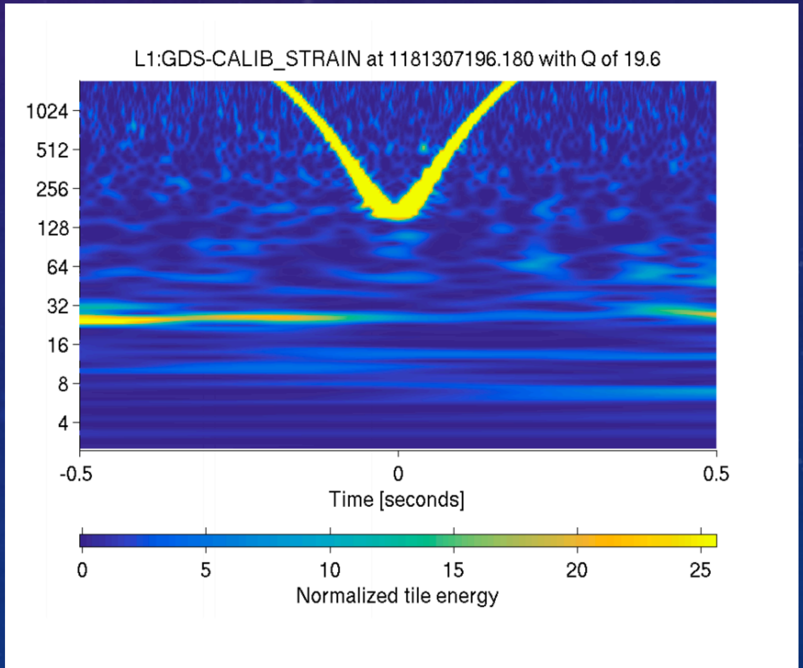


# MONITOR DETECTOR MOTION AND ITS EFFECTS

- Find correlations between elevated motion and investigate their sources
  - Scattering arches
    - Due to light scattering in the detectors (increases with elevated motion)
  - Whistles
    - Caused by radio signals at megahertz frequencies that beat with the LIGO voltage controlled oscillators

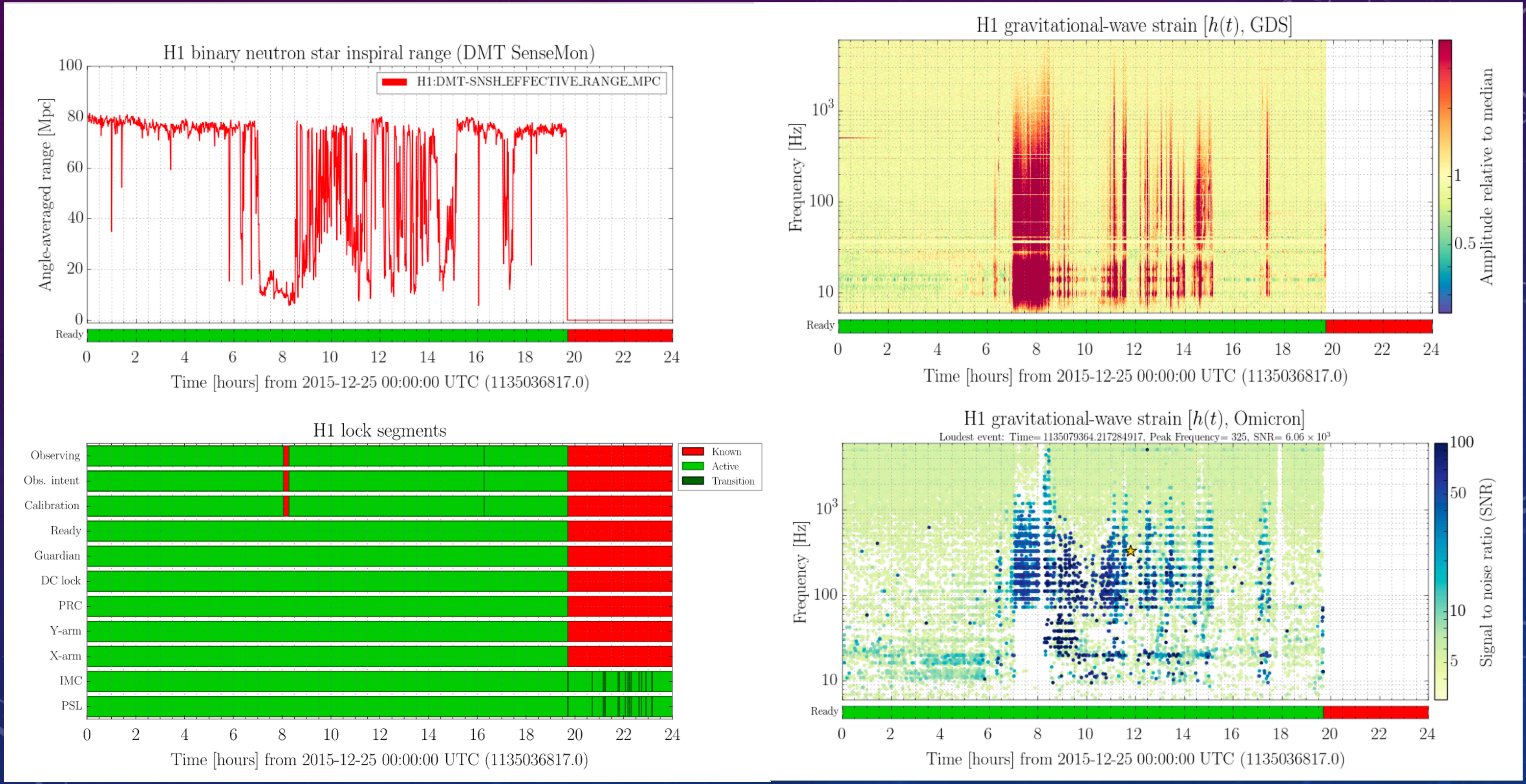



Scattering arches

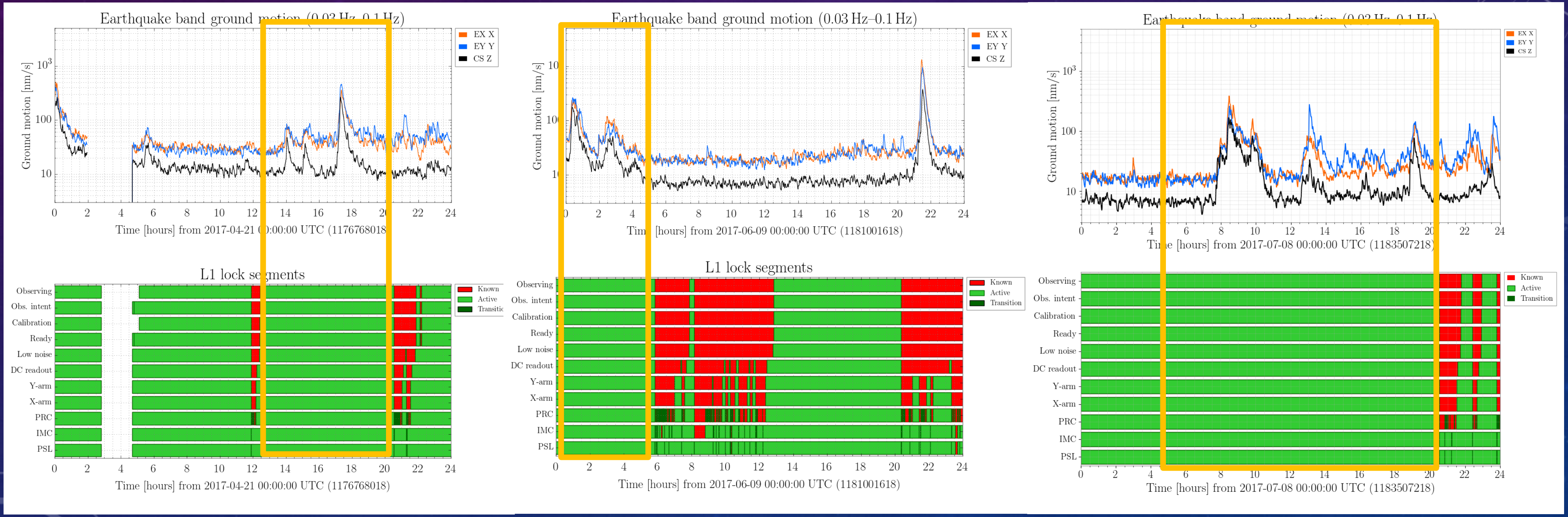


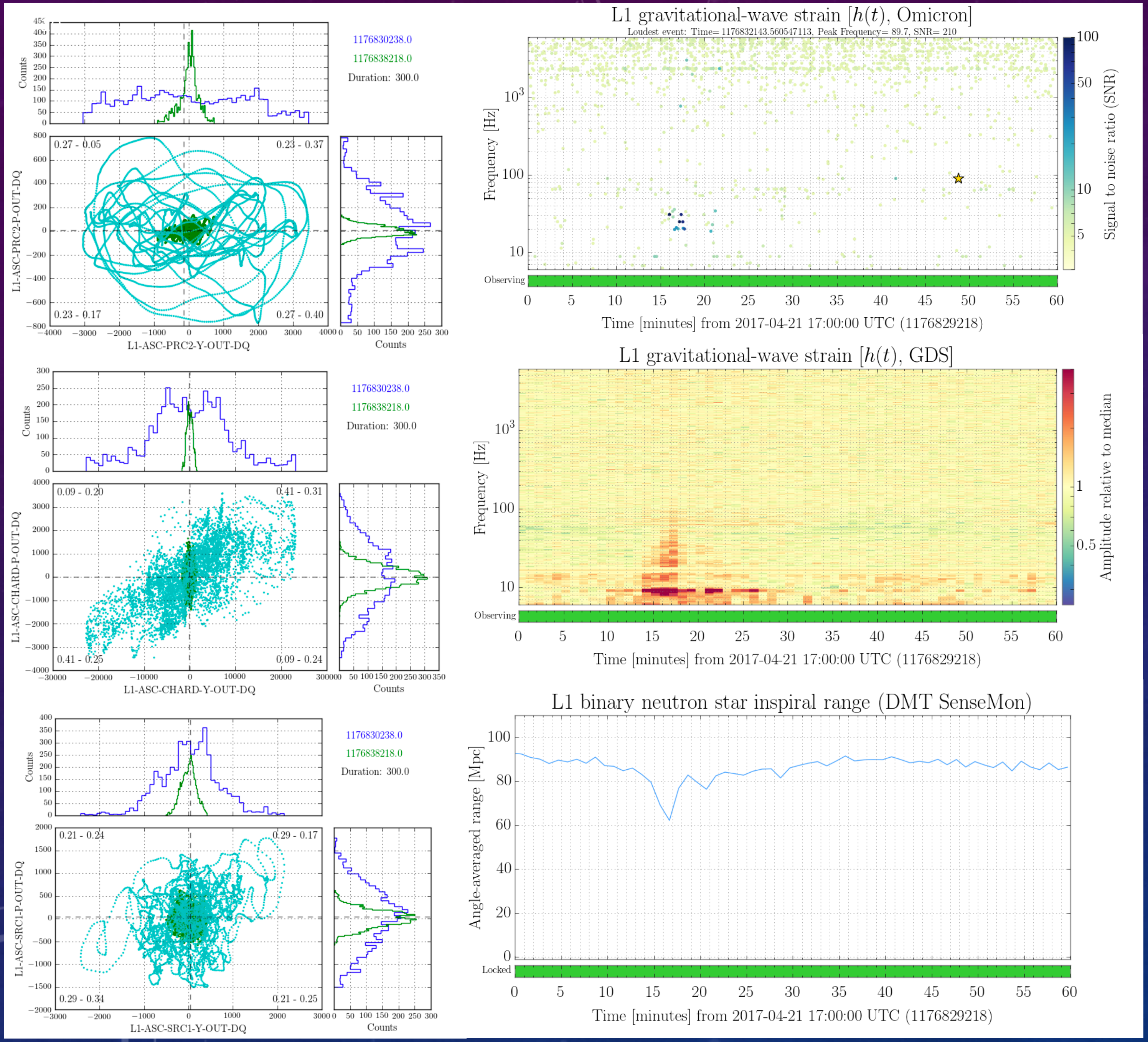

Whistle

# REMOVE DATA WITH A LOT OF NOISE



# WHAT IF THE DETECTORS ARE STILL LOCKED DURING ELEVATED SEISMIC NOISE?






# WHAT IS HAPPENING DURING AN EARTHQUAKE?

- Increased motion of the optics
- Elevated level of glitches
- Measure strain increases
- BNS inspiral range dips
- All of this affects our ability to detect signals!
- How do we quantify the effect this has on the detectors?

# INSPIRAL RANGE AS A MEASURE OF SENSITIVITY

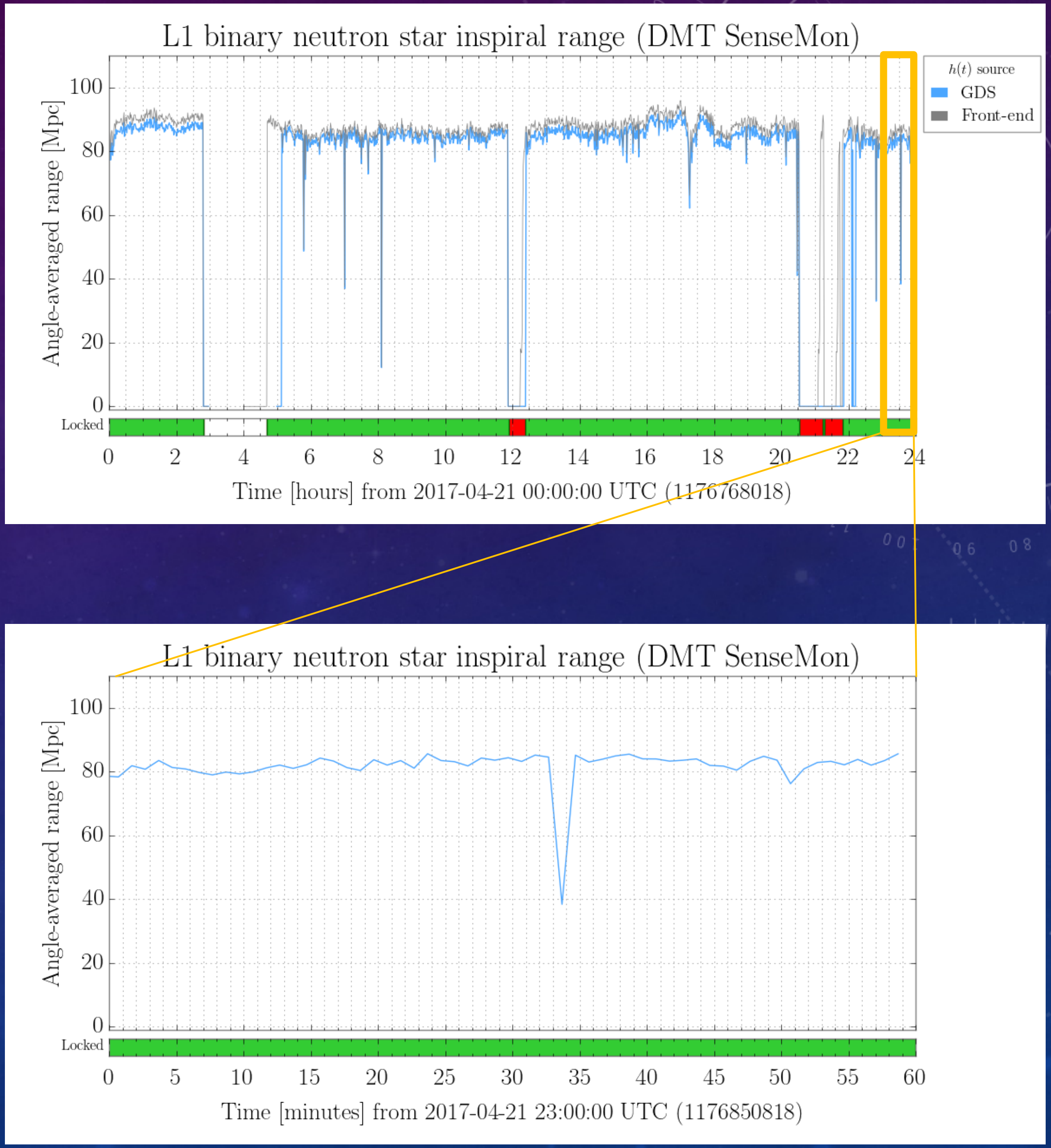
BNS range:

- Given:
  - 1.4-1.4 solar mass BNS system
  - SNR 8

- On average, how close does the signal have to be for us to recover it given the **average noise**?

- Doesn't consider individual glitches which might interrupt a long duration BNS signal

- How can we improve this?
  - Uses MANY injections with different orientations, masses, and distances



# DETECTOR SENSITIVITY

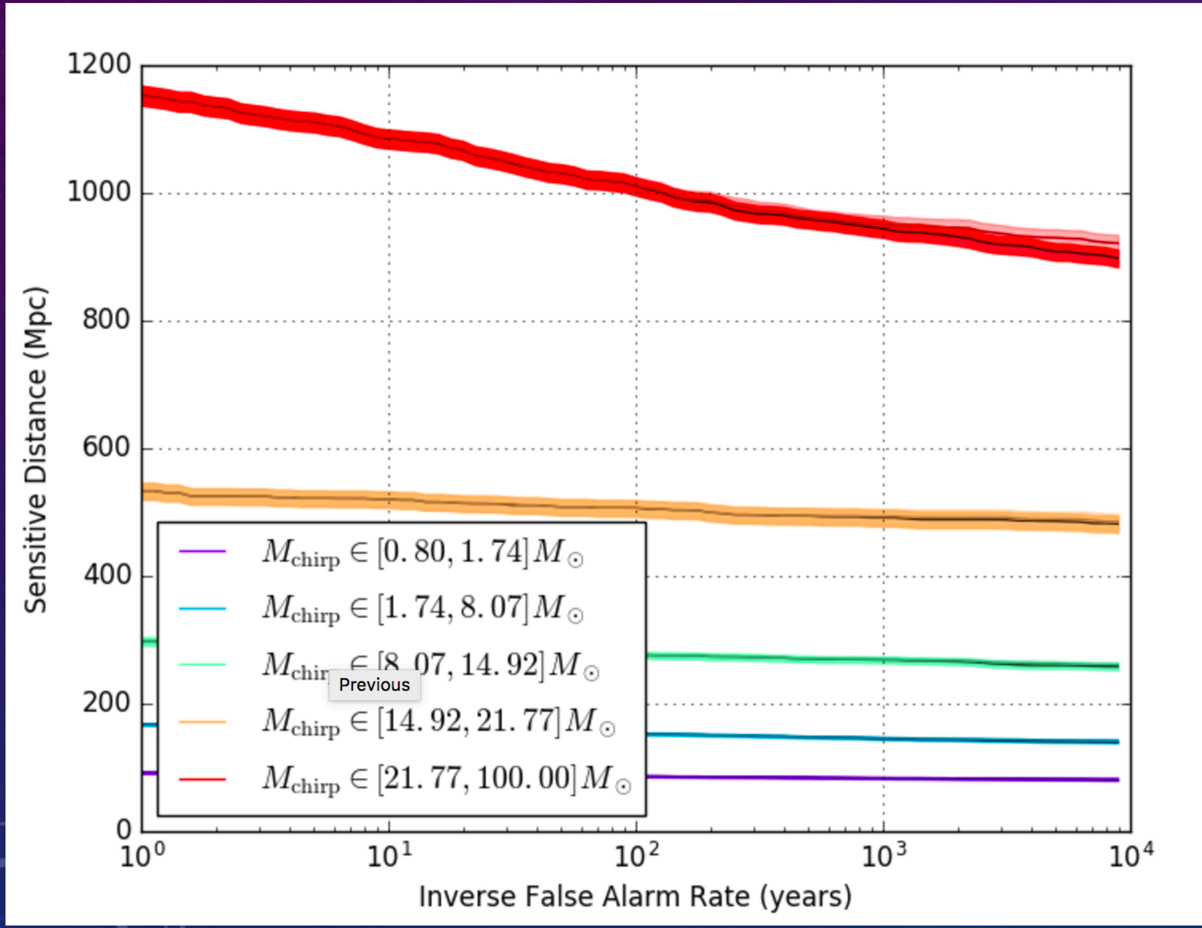
- Sensitive volume (cubic Mpc) and sensitive distance (Mpc)
- Injections
  - pyCBC software generates waveforms to inject into data
  - Varying parameters: chirp mass, orientation, distance, spin, etc.
  - Sensitive volume is determined by the recovery of these injections

- $V(F) = \int \epsilon(F; x; \Lambda)\, \phi(x; \Lambda)\, dx d\Lambda$
  - V(F) = $4\pi(Sensitive\ Distance)^3$

- $\epsilon$: efficiency of detecting a signal with
  - Physical parameters $\Lambda$, in volume x, with false-alarm rate F
- $\phi(x; \Lambda)$: represents the distribution of signals in the universe

# PREVIOUS METHOD OF EVALUATING SENSITIVITY

Sensitive Distance vs IFAR: binned by mchirp using pylal method

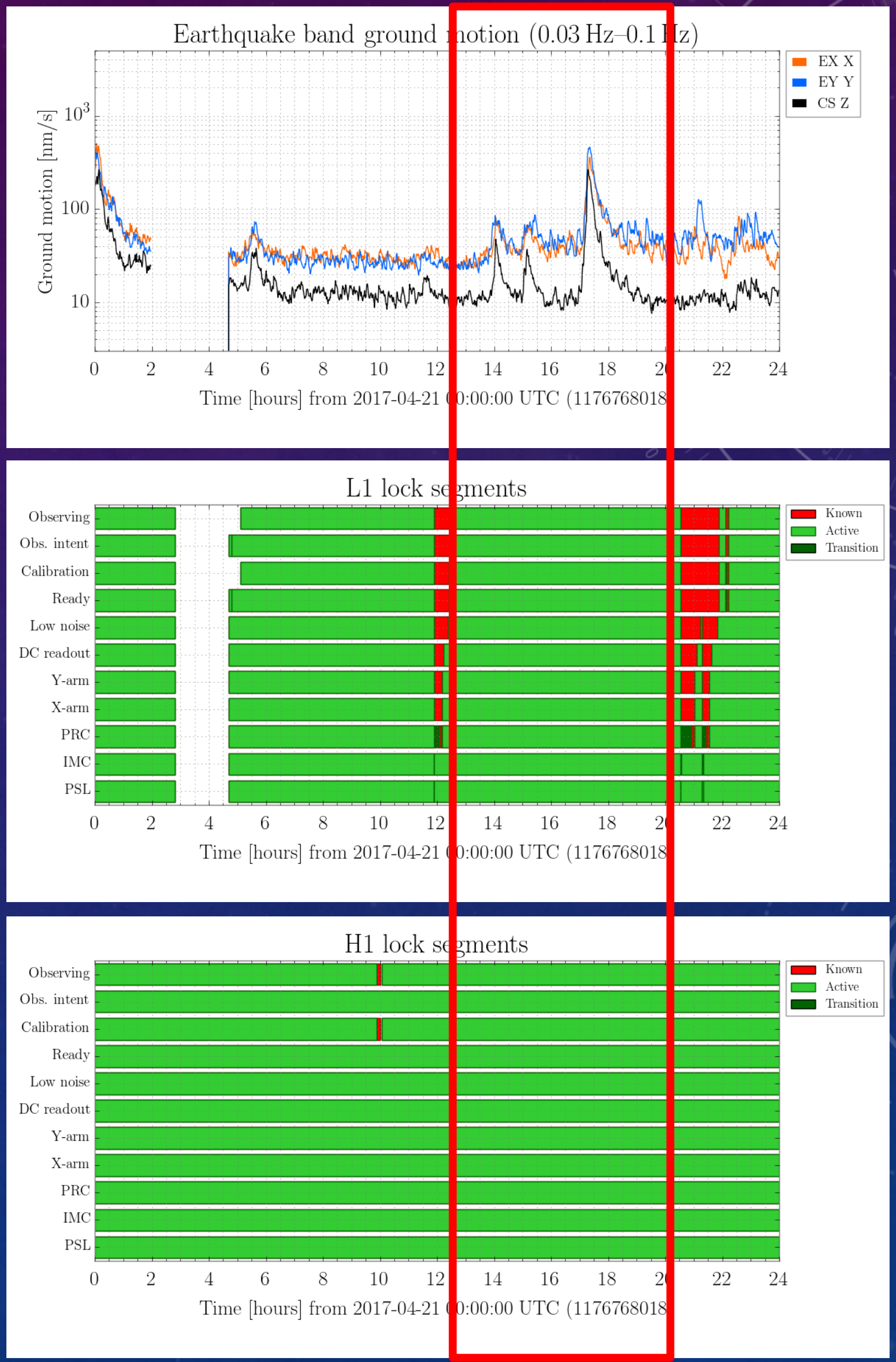



- Interval 09/11/15 – 10/20/15
- Total duration: 38.563 days
- Sensitivity averaged over 5 days
  - Makes understanding effects of transient noise difficult
- **How can we better evaluate sensitivity?**
  - **Our method:**
    - Smaller time scales
    - Enable us to see transient dips in sensitivity!

# HOW DO WE DO THIS?

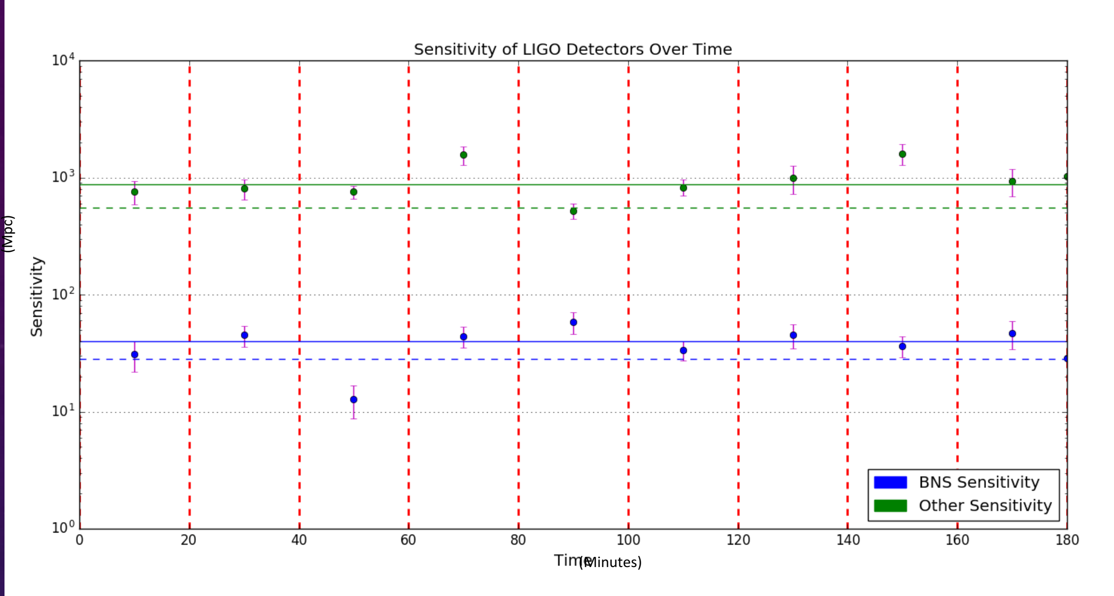
Identify instances of significant transient noise where it would be useful to evaluate sensitive volume.

- Earthquake band ground motion between ~200nm/s and ~700nm/s
  - There has to be enough noise to affect sensitivity
  - Cannot be too much noise, because the detector has to remain locked
- Both detectors need to be in observing mode at the same time in order to recover injections

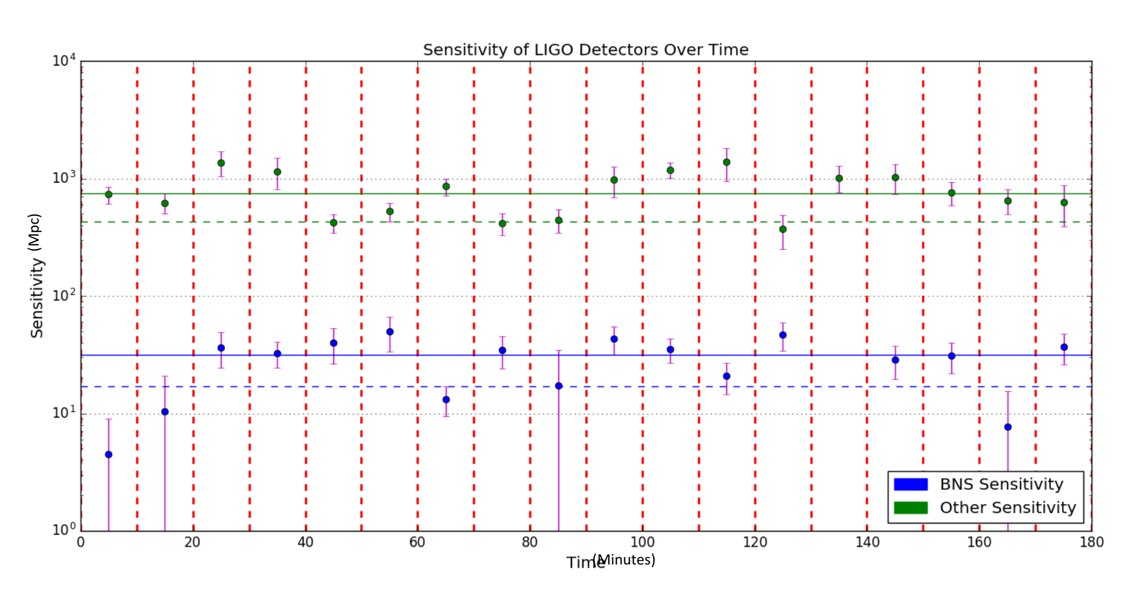


# CHOICE OF TIME SCALE

20 minute bins




10 minute bins




- Why not 20 minute bins?
  - Earthquake noise to normal noise ratio is not high enough to see a big difference in sensitivity
  - Less accurate median sensitivity because there are fewer total bins

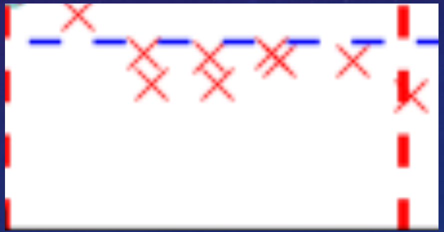
- Why not 5 minute bins?
  - Binary error: $\hat{p} \pm \sqrt{\frac{1}{n}\hat{p}(1-\hat{p})}$
    - $\hat{p}$ = probability of finding an injection
    - n = number of injections
  - Fewer trials -> larger error -> overlapping error bars, which makes it difficult to distinguish changes in sensitivity
  - **Small number statistics**

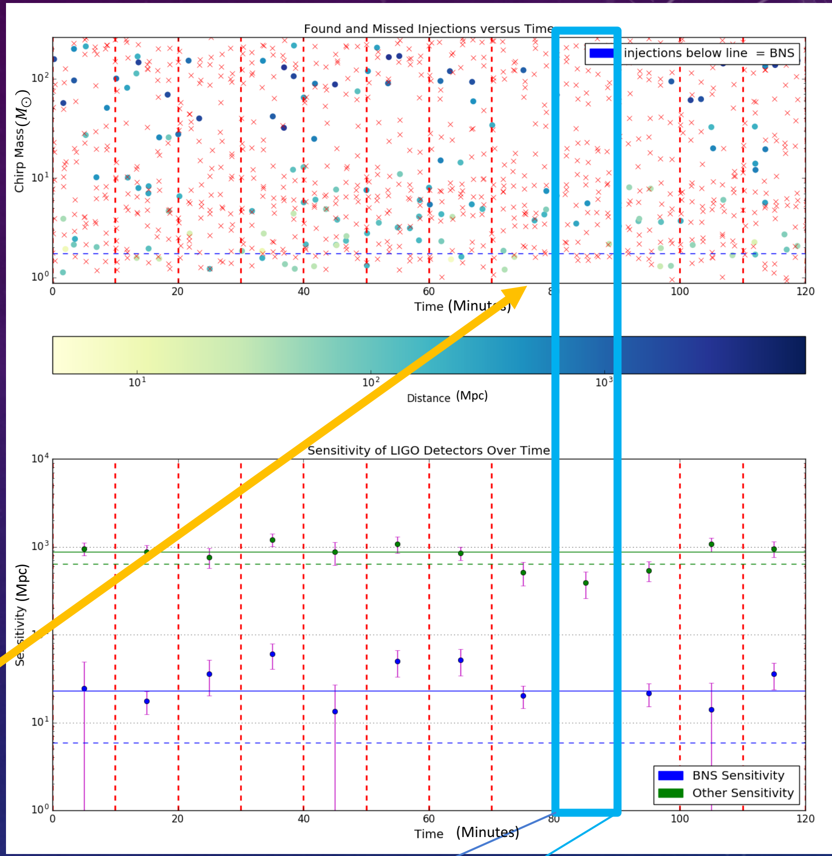
# STILL, THERE ARE PROBLEMS WITH USING 10 MINUTE BINS

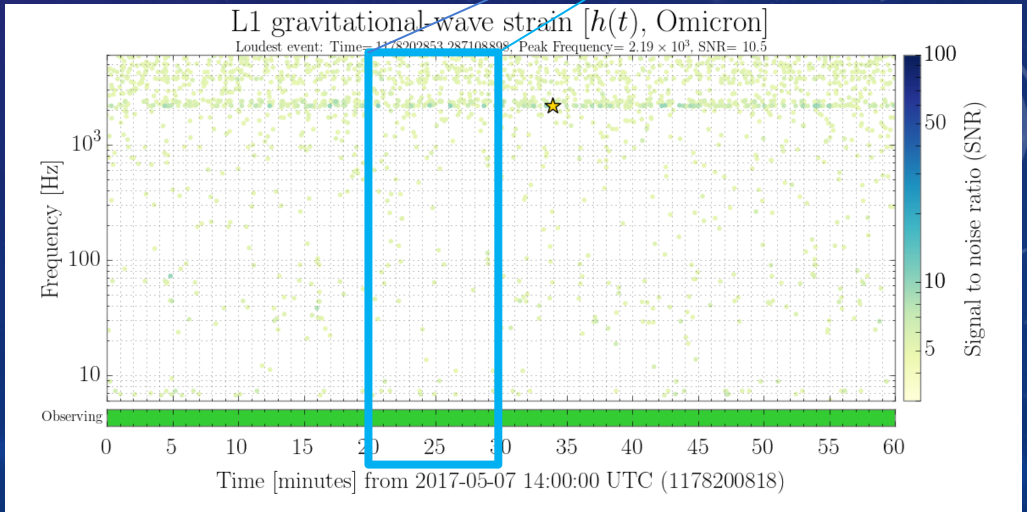
- We were finding bins with BNS sensitivity of 0Mpc, but no corresponding elevated noise, glitches, strain, etc.

- What could be causing this dip?

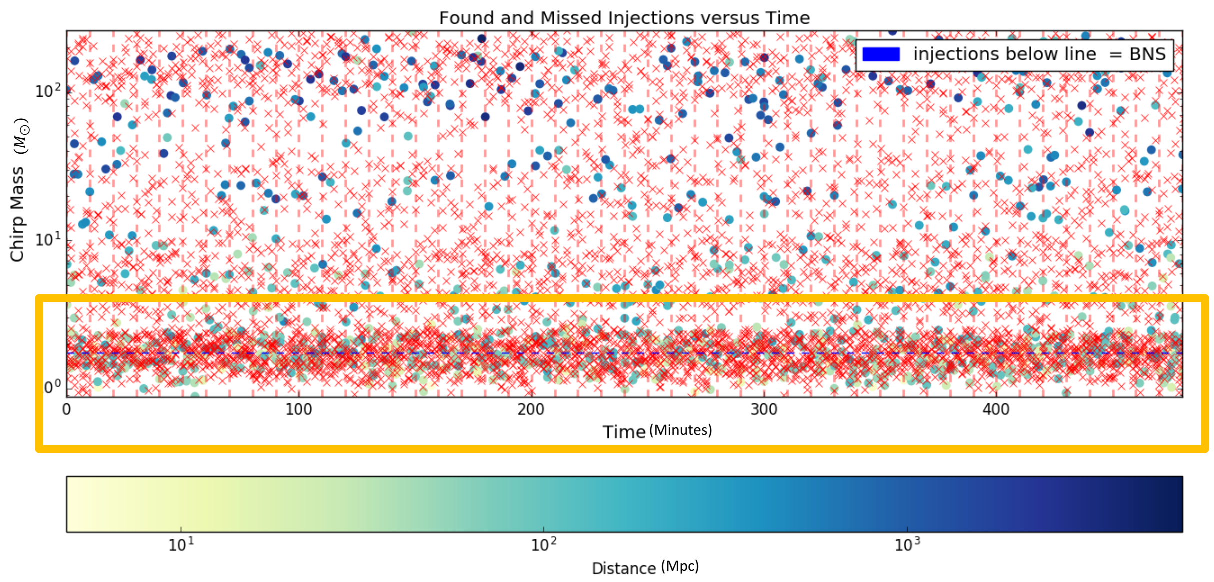
- Small number statistics (BNS waveform)
  - Total BNS injections is ~12 per bin
  - Found BNS injections ~4 per bin
  - If 0 BNS injections were found (which was not unlikely due to the small number of total injections) sensitivity would drop to 0Mpc.

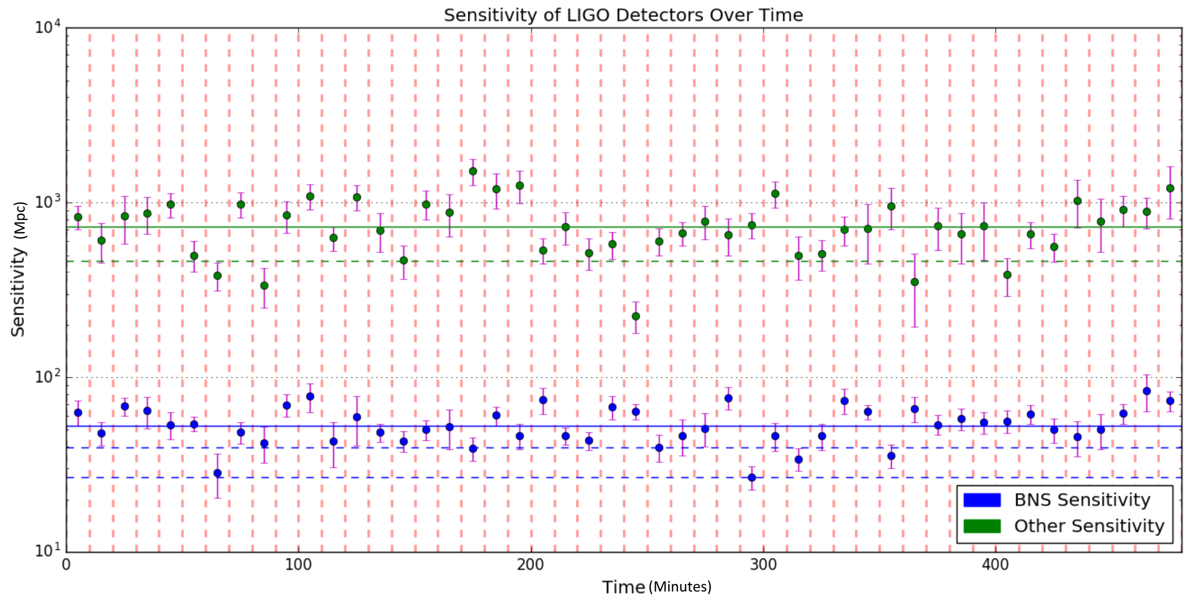




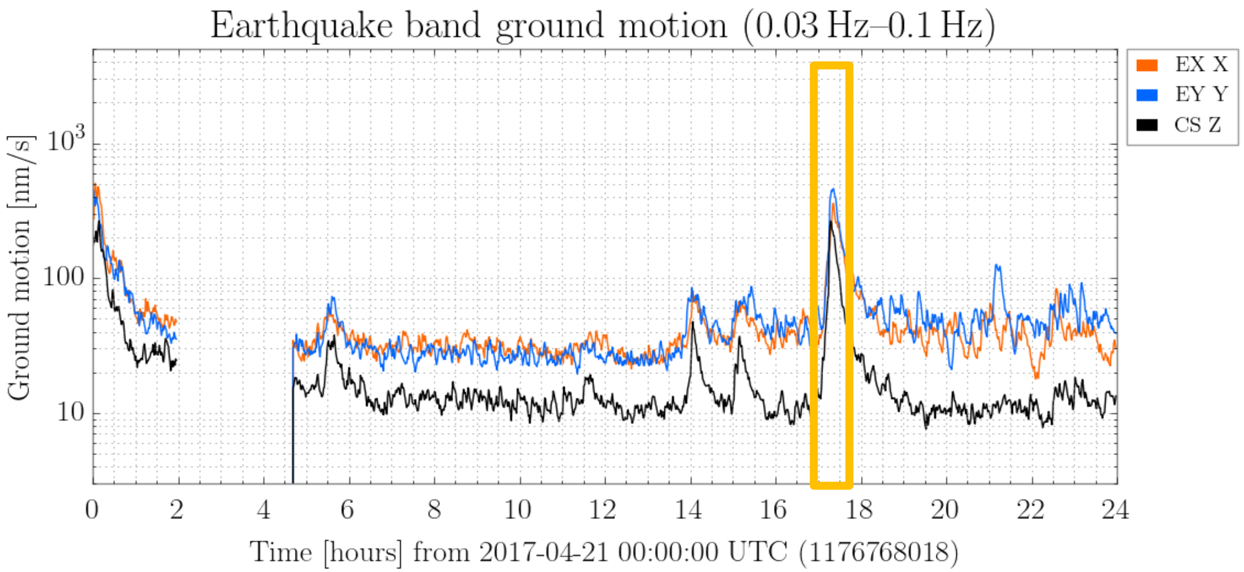

**How statistically significant are these bins of zero sensitivity?**

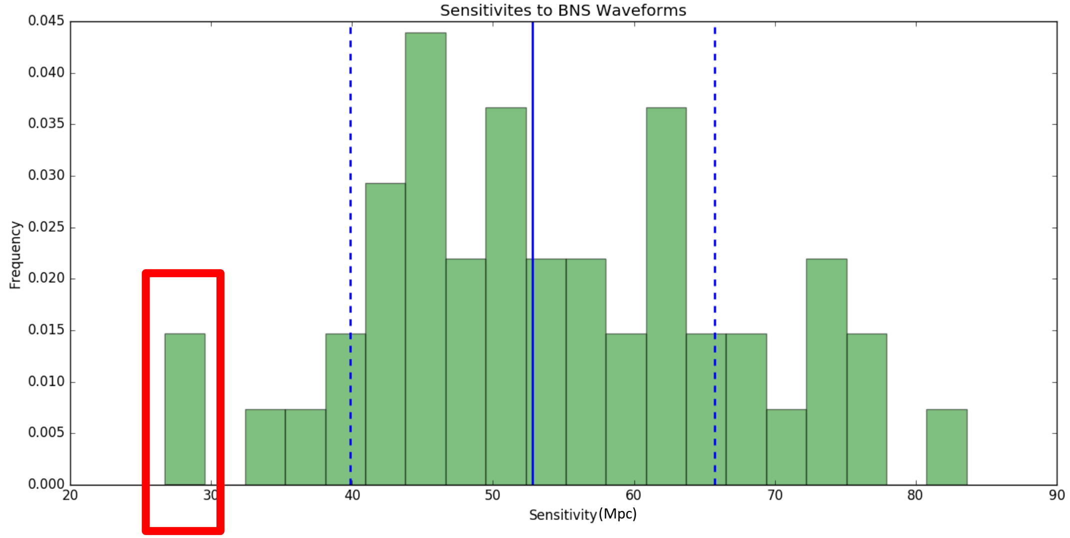


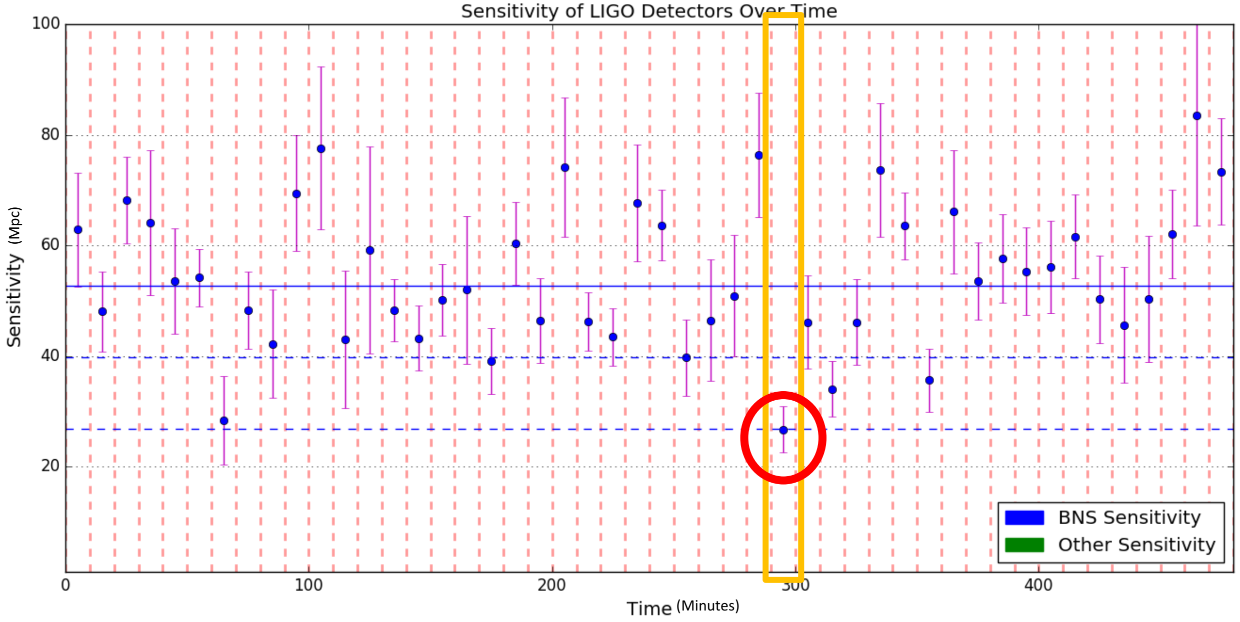



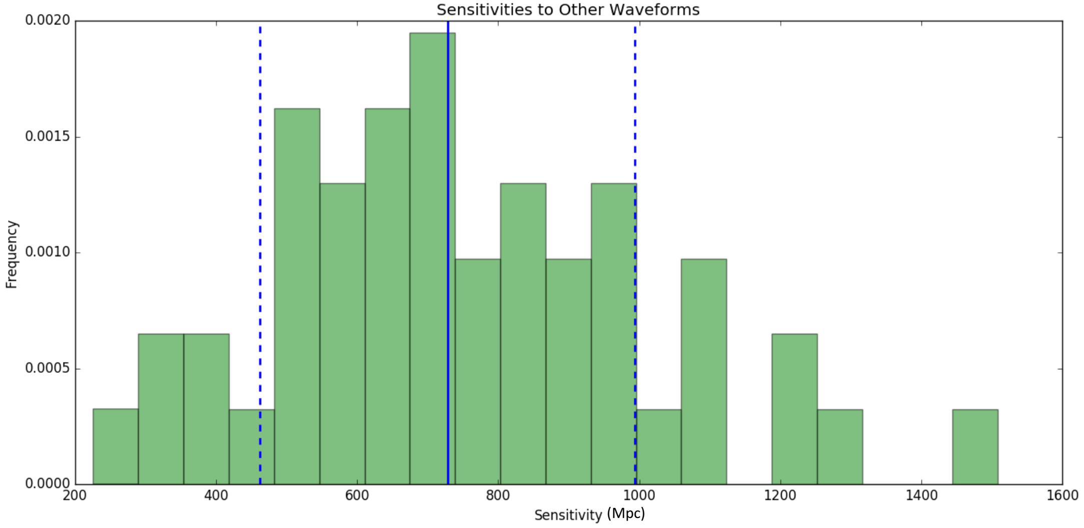

- Many more BNS injections
  - No bins with 0Mpc sensitivity

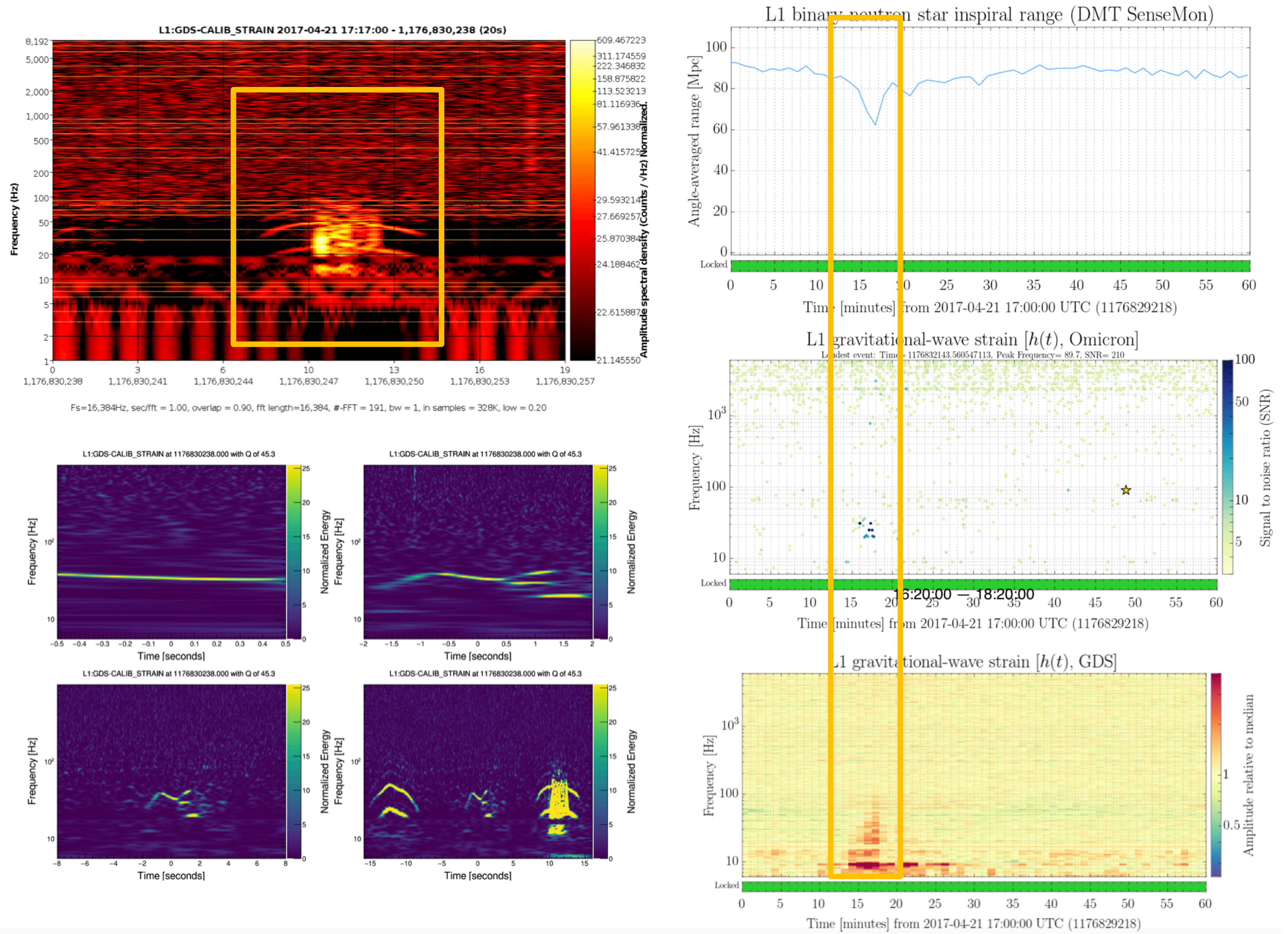
# April 21st, 017 12:30:00 UTC – 20:30:00 UTC2

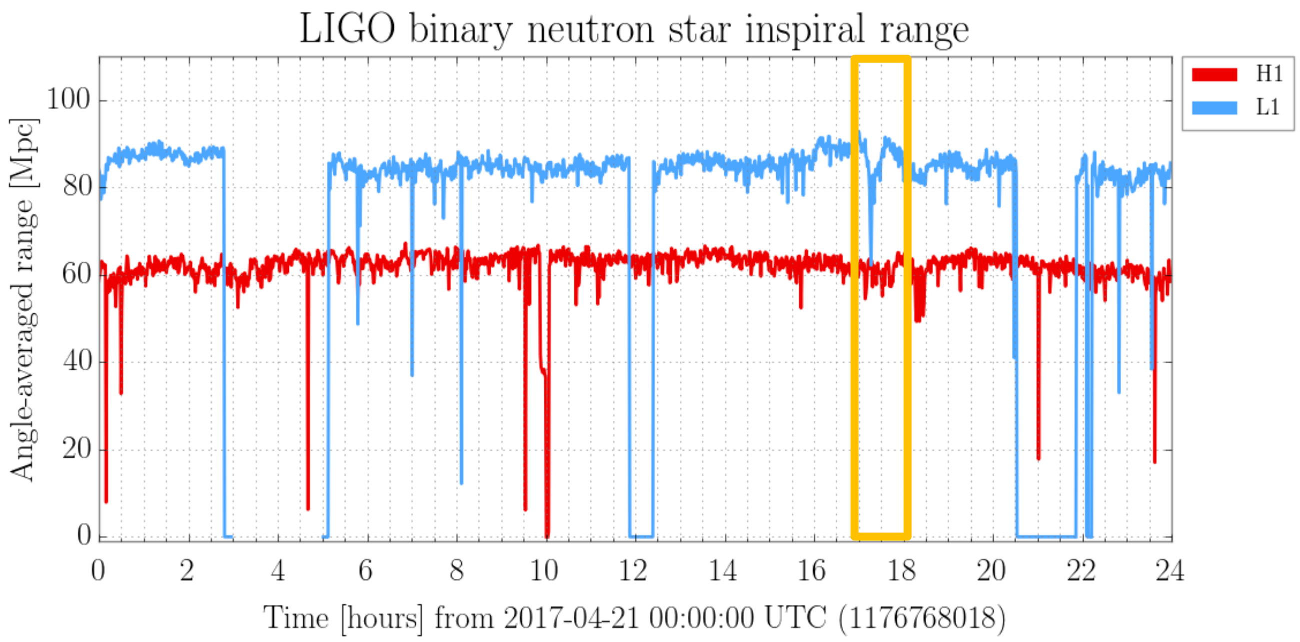


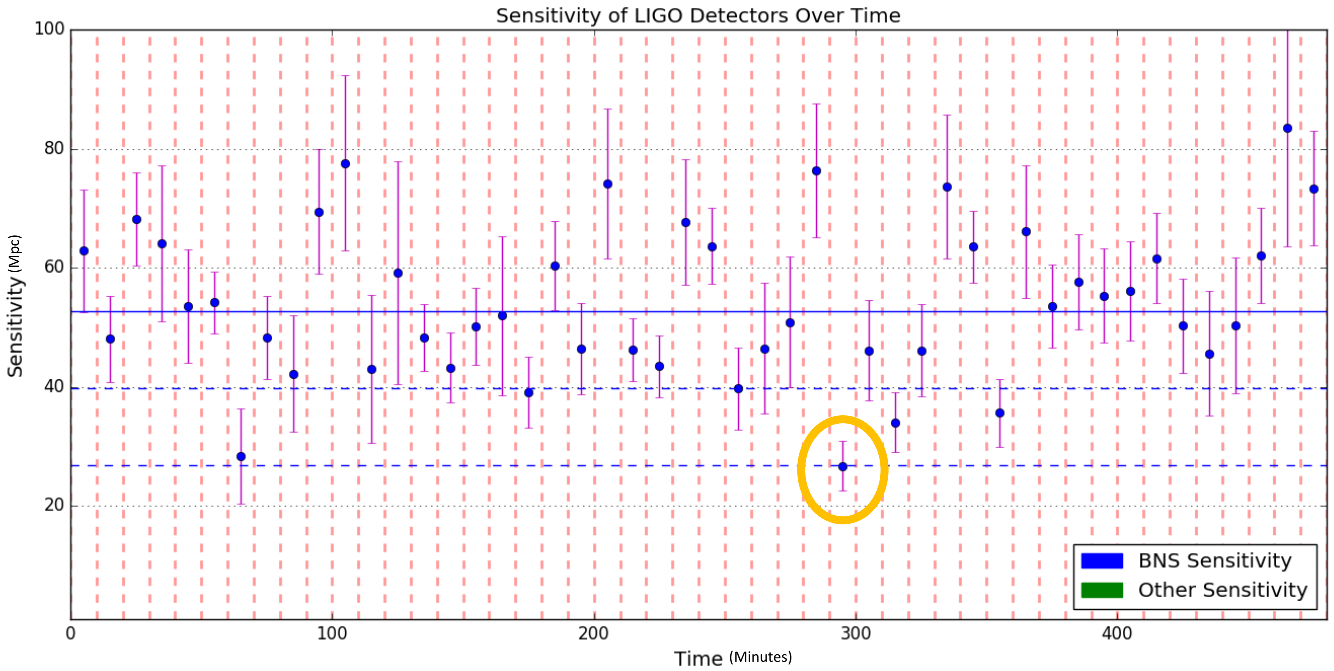




L1:GDS-CALIB_STRAIN 2017-04-21 17:17:00 - 1,176,830,238 (20s)
Frequency (Hz)
Amplitude spectral density (Counts / √Hz) Normalized.
Fs=16,384Hz, sec/fft = 1.00, overlap = 0.90, fft length=16,384, #-FFT = 191, bw = 1, in samples = 328K, low = 0.20
L1:GDS-CALIB_STRAIN at 1176830238.000 with Q of 45.3
Frequency [Hz]
Normalized Energy
Time [seconds]
L1 binary neutron star inspiral range (DMT SenseMon)
Angle-averaged range [Mpc]
Locked
Time [minutes] from 2017-04-21 17:00:00 UTC (1176829218)
L1 gravitational-wave strain [h(t), Omicron]
Loudest event: Time= 1176832143.560547113, Peak Frequency= 89.7, SNR= 210
Signal to noise ratio (SNR)
16:20:00 — 18:20:00
L1 gravitational-wave strain [h(t), GDS]
Amplitude relative to median



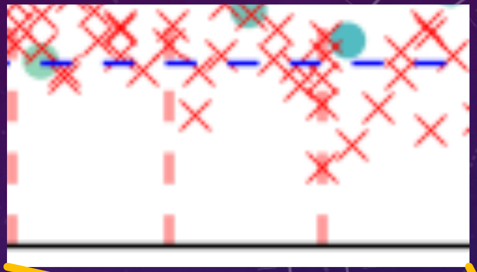



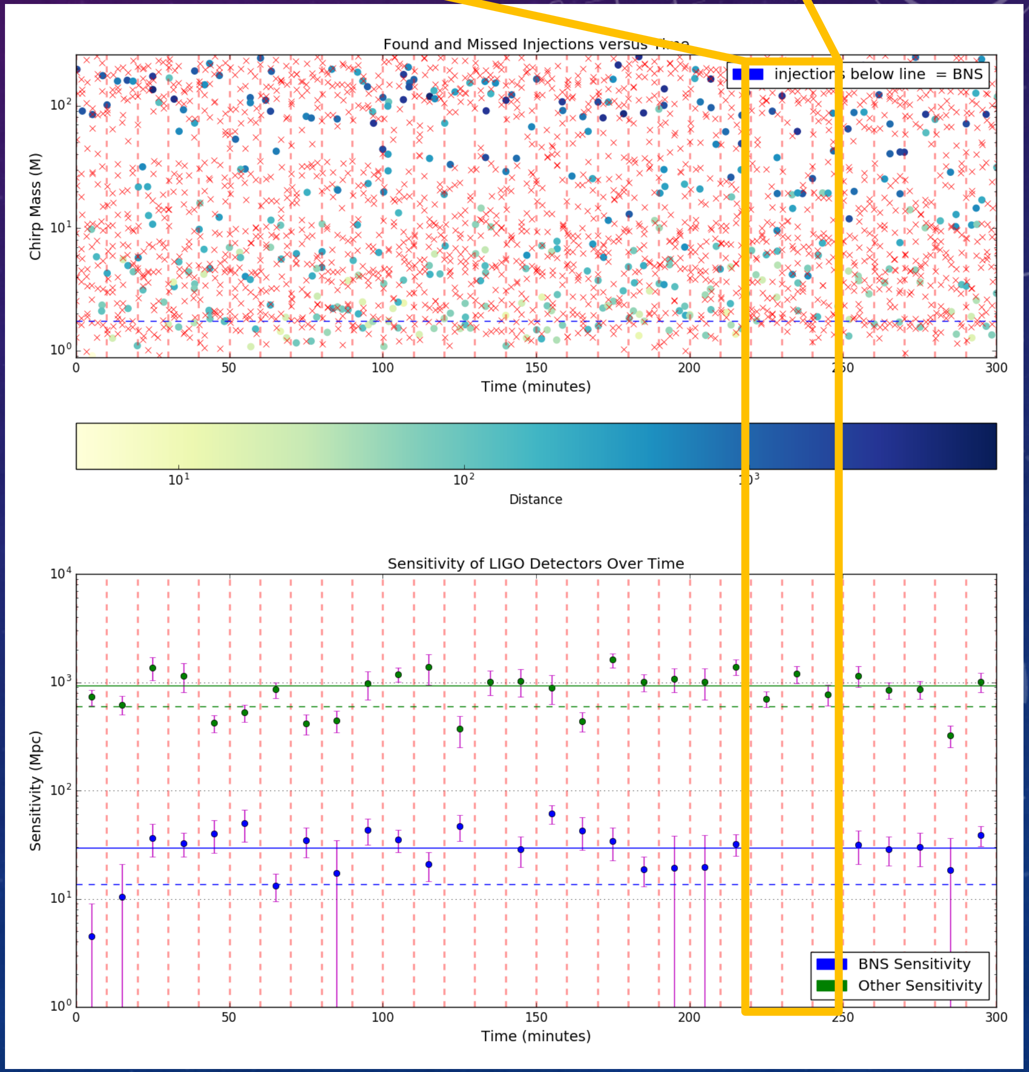

We get a different measure of sensitivity for BNS inspiral range and our method of calculating sensitive distance!

BNS inspiral range: average ~60Mpc
Our method: ~26.7 Mpc

# FUTURE WORK

- Increase accuracy of sensitivity calculation
  - Separate sensitivity into more chirp mass categories
  - Increase number of injections across all chirp masses
- More fully investigate times with 0Mpc sensitivity
  - Create a program to evaluate the significance
    - Depending on how many injections in that chirp mass category
  - Determine the cause if not seismic noise
- Apply this method to other forms of noise





# THANK YOU

I’d like to thank Thomas Massinger and Jessica McIver for their guidance and support during my research this summer.  I’d also like to thank everyone at the LIGO Scientific Collaboration for this incredible opportunity.