

# Instrumental Validation of GW150914

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# Sources

- Characterization of transient noise in Advanced LIGO relevant to gravitational wave signal GW150914 (arXiv:1602.03844)
- LIGO detector logs (public):
  - [alog.ligo-wa.caltech.edu](http://alog.ligo-wa.caltech.edu)
  - [alog.ligo-la.caltech.edu](http://alog.ligo-la.caltech.edu)

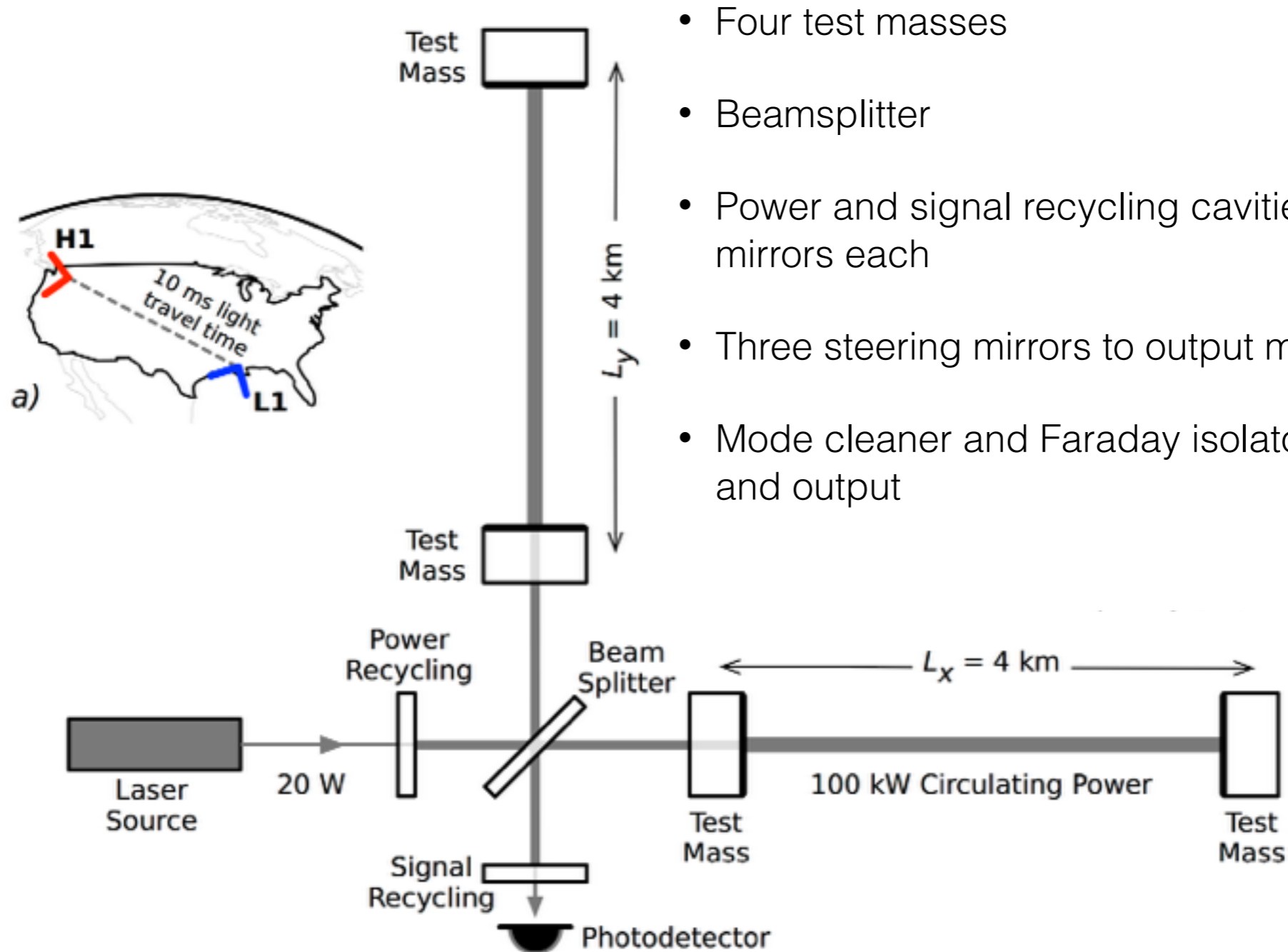
# Outline

- The Instrument
- Background Estimation: Measure not Model
- The Noise
- Background sources overview
  - Long Range Environmental
  - Local Environmental
  - Instrumental
  - The Unknowns

# The Instrument

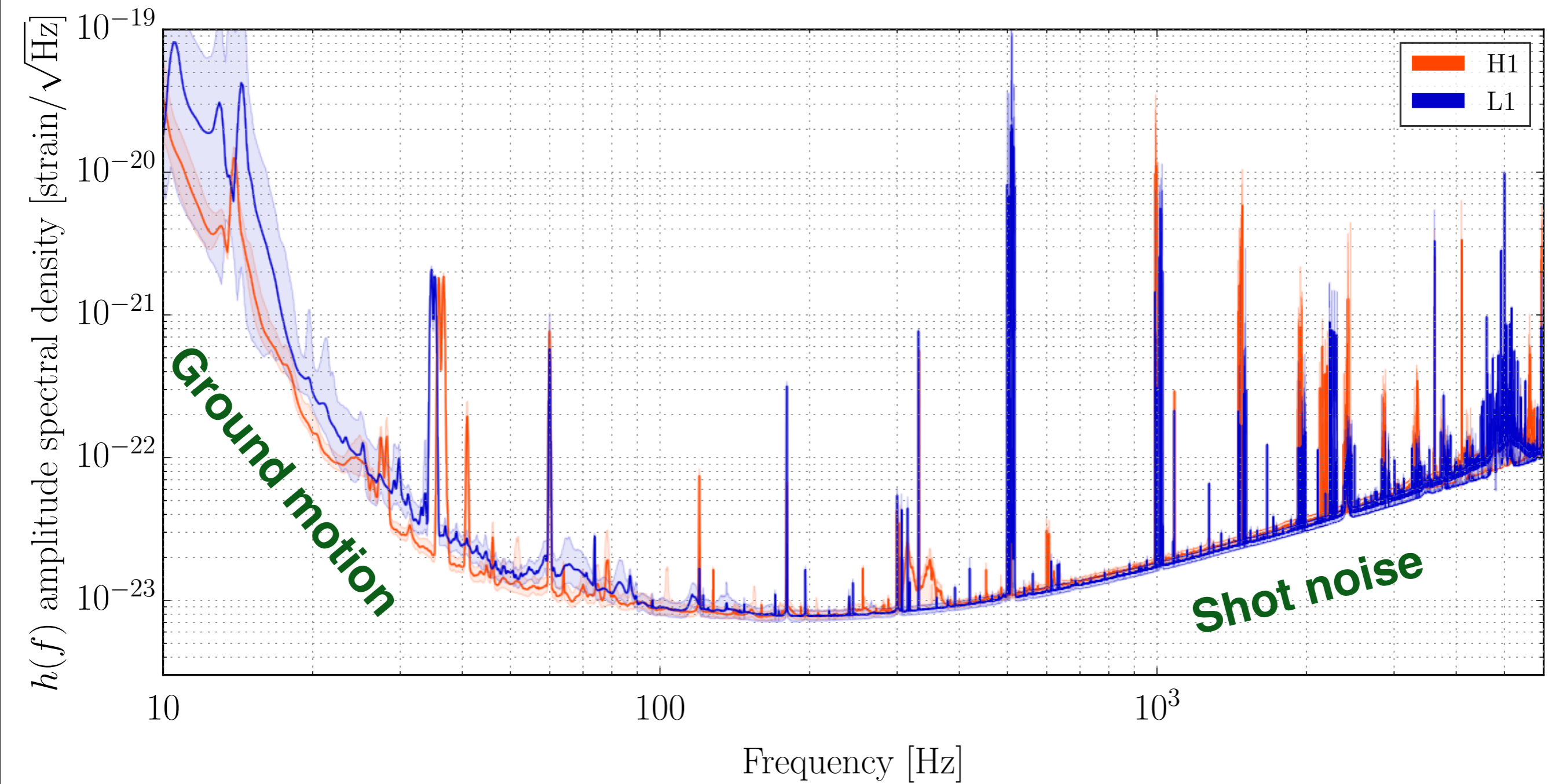


# The Instrument

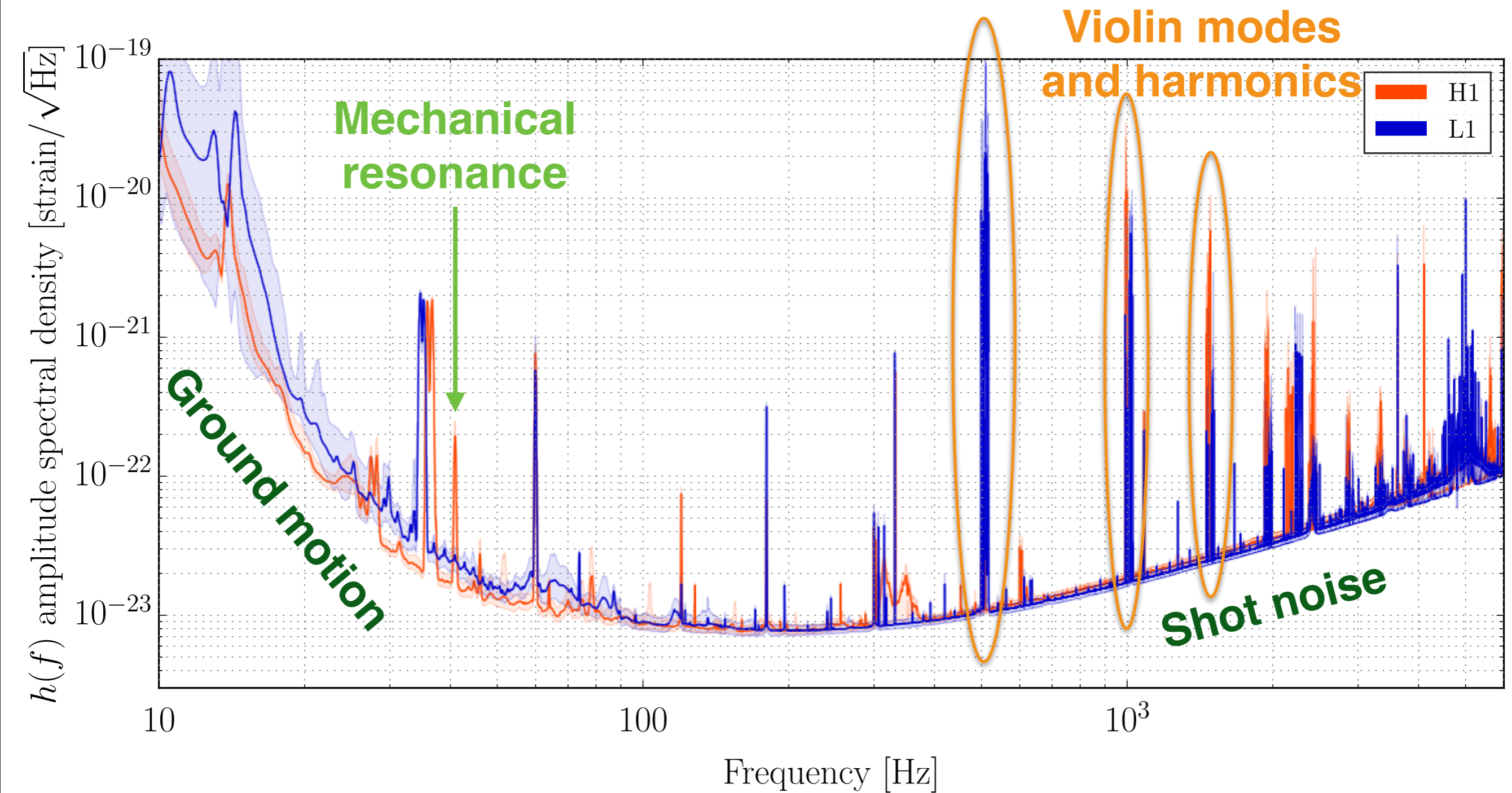


- Four test masses
- Beamsplitter
- Power and signal recycling cavities, three mirrors each
- Three steering mirrors to output mode cleaner
- Mode cleaner and Faraday isolator at input and output

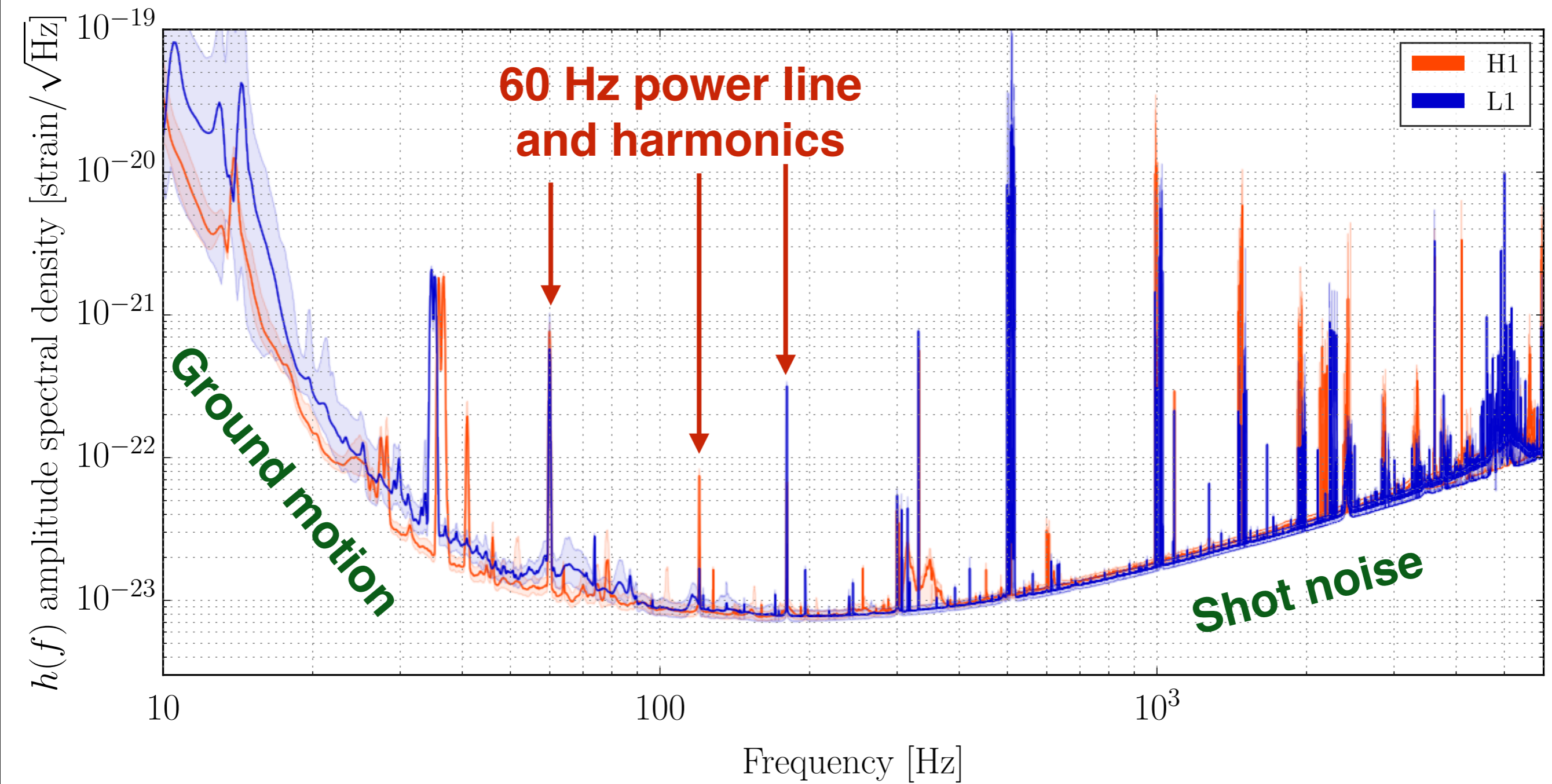
# The Noise



# The Noise

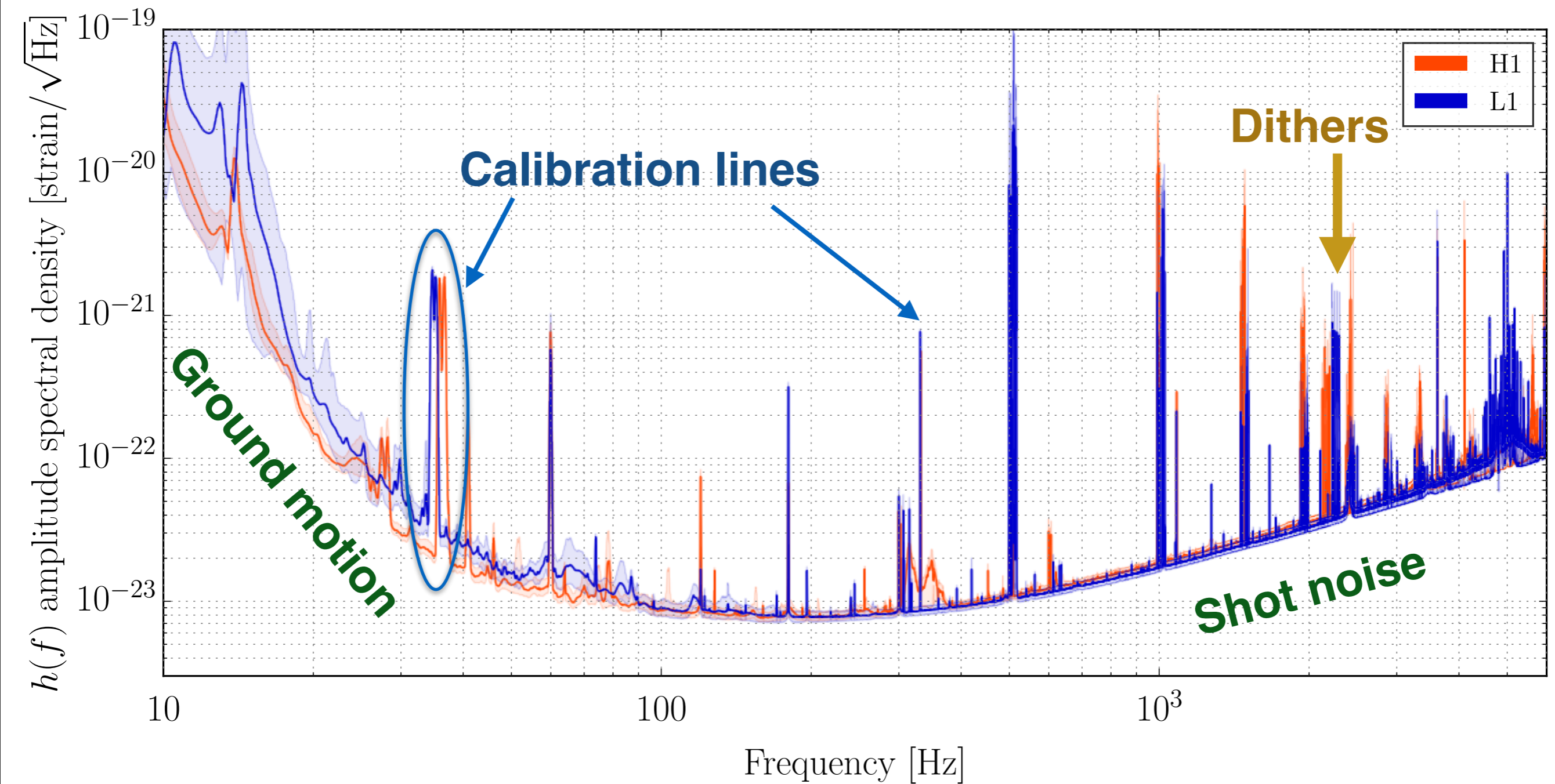


# The Noise





# The Noise



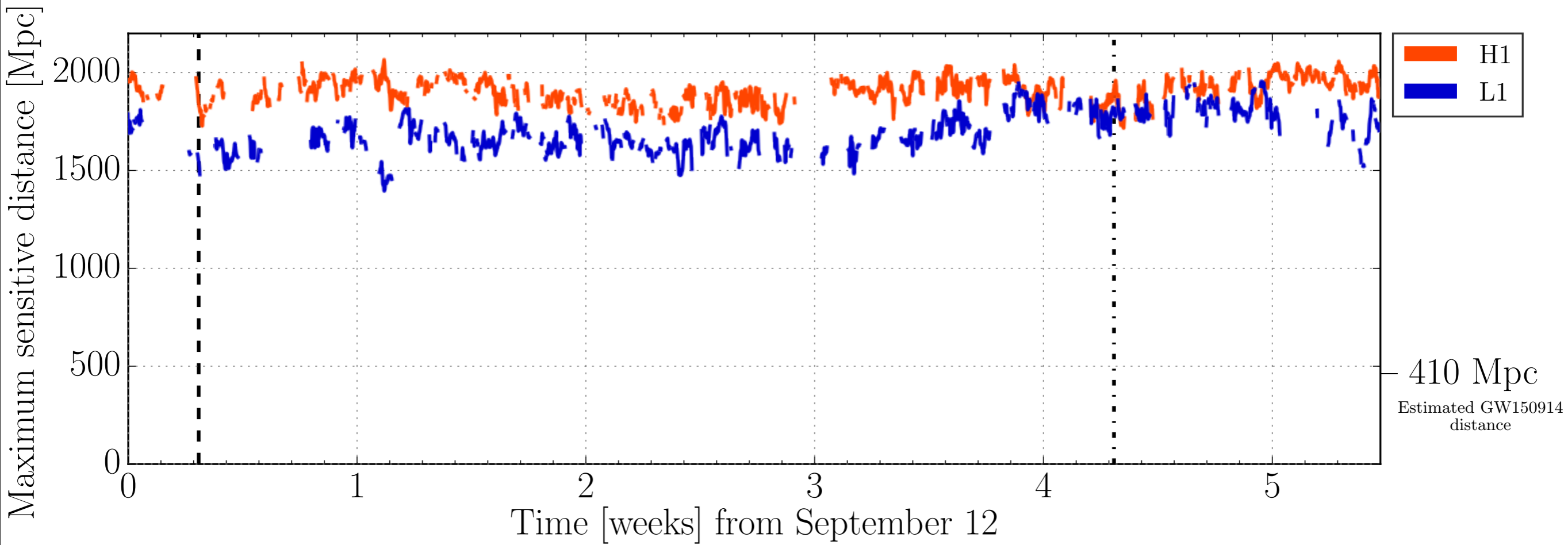
# Why Non-Stationary Noise

- Mirrors move due to residual seismic motion
  - Couplings change with angles
- Servo loops pushed to edge of their abilities
- Imperfect optics mean light is not just a resonant Gaussian beam
- Scattered light
- Electronics glitches
- Other

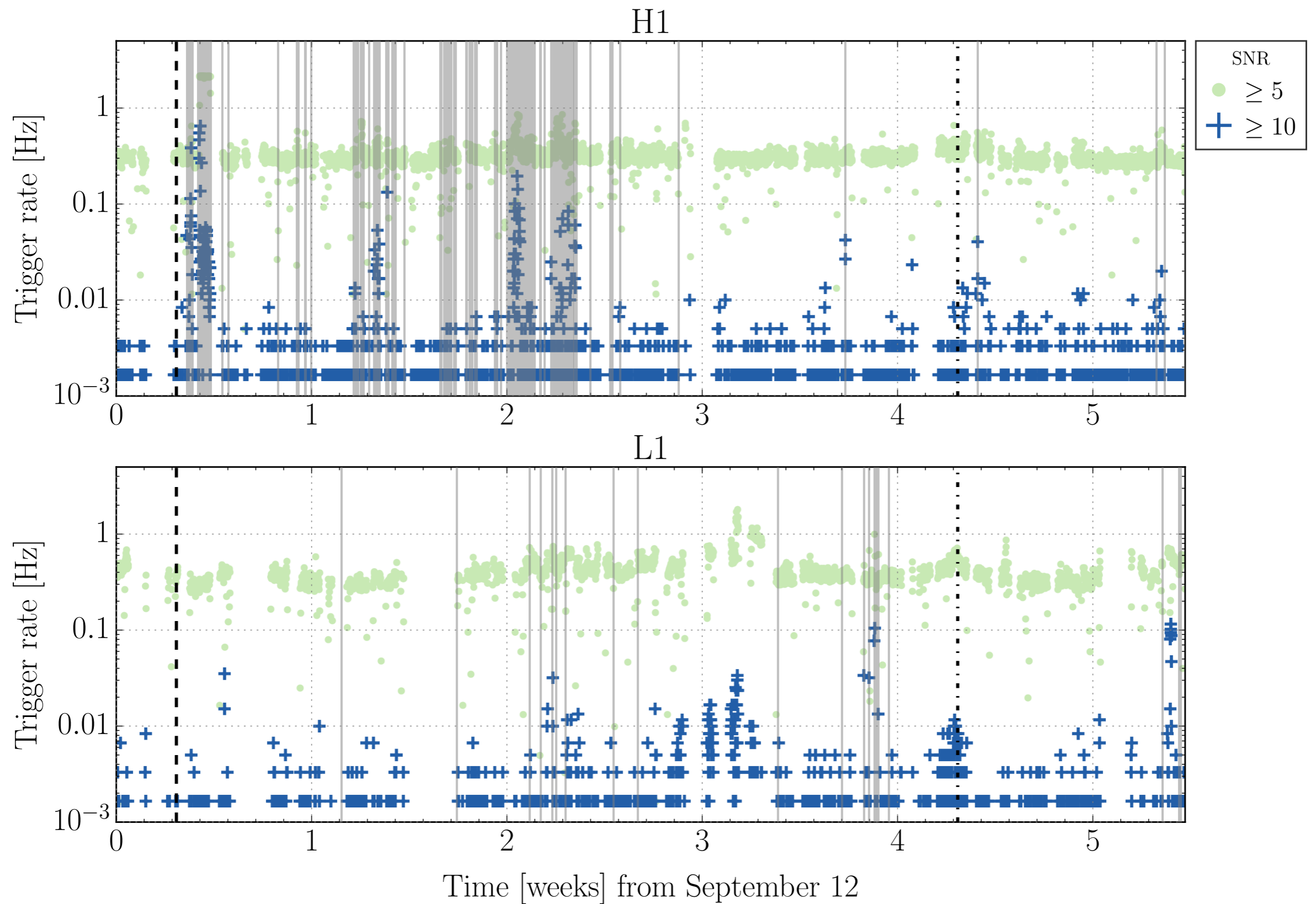
# Estimating the Background

- Cannot shield GWs (or turn them off)
- Cannot model instrument
  - Too complicated and heterogeneous
- Build two instruments and do time slides
- Separately, rule out common sources of noise
  - Sensors for any long-range effects

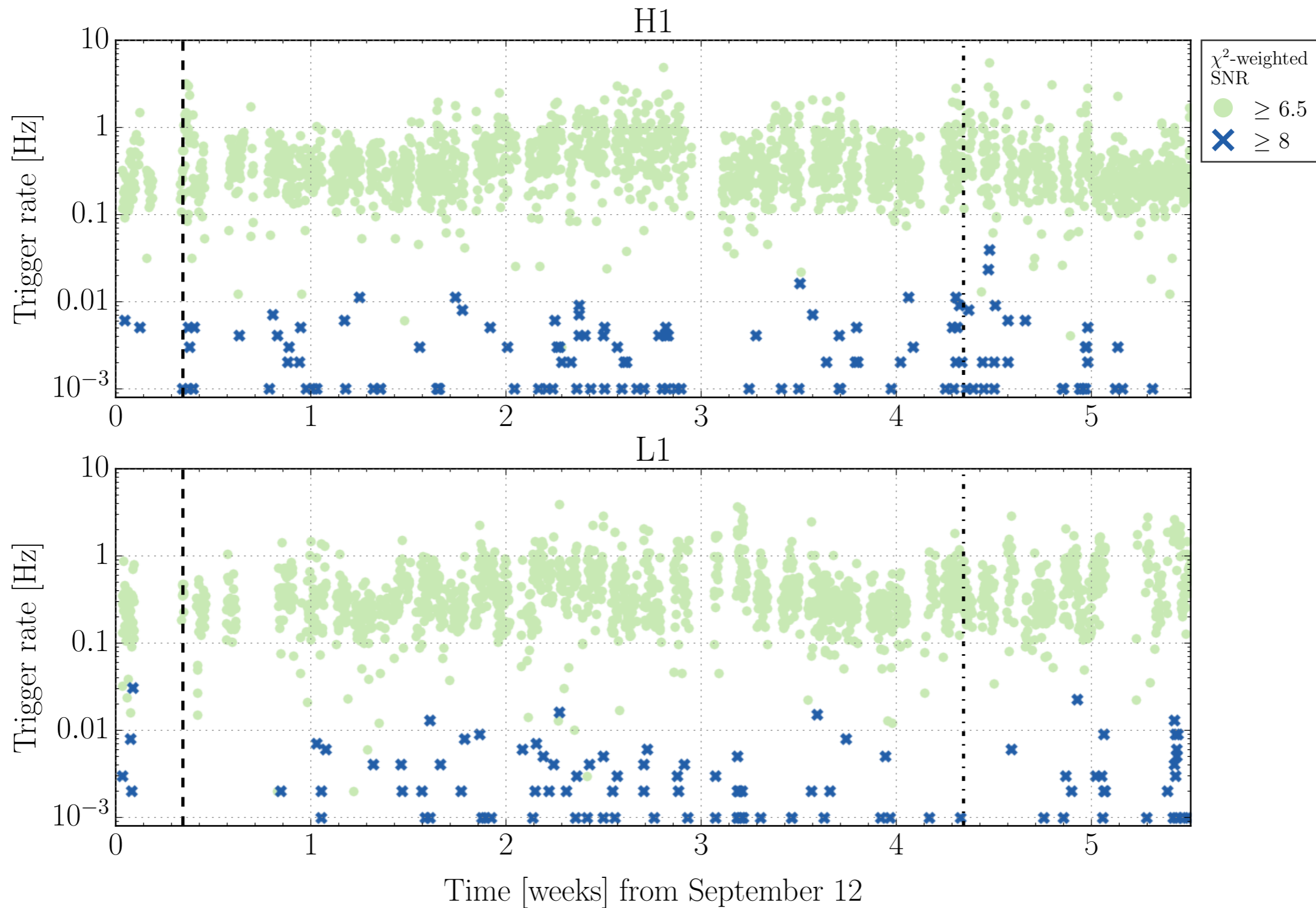
# Range



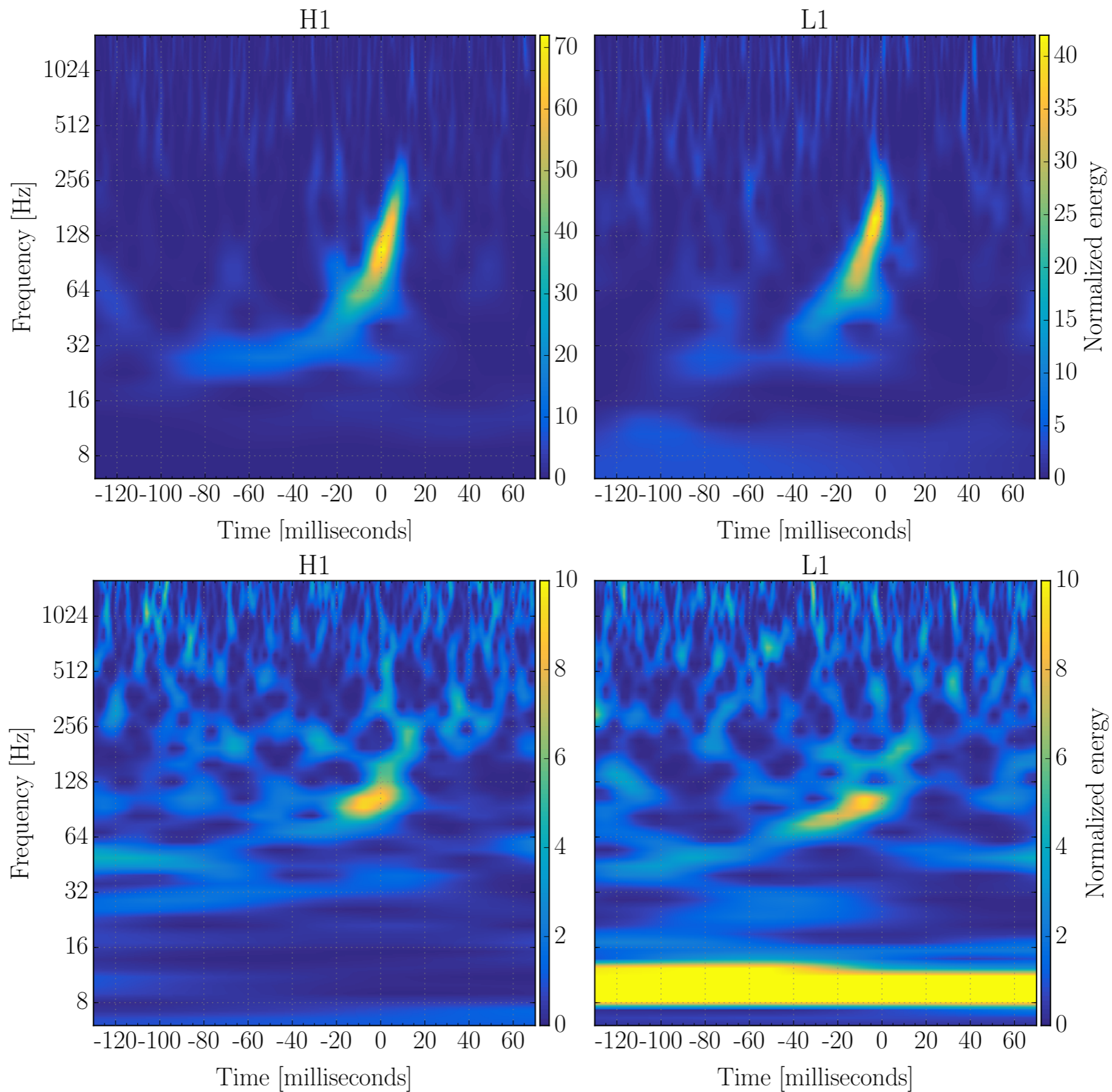
# Glitch rates



# CBC trigger rates



# The Candidates

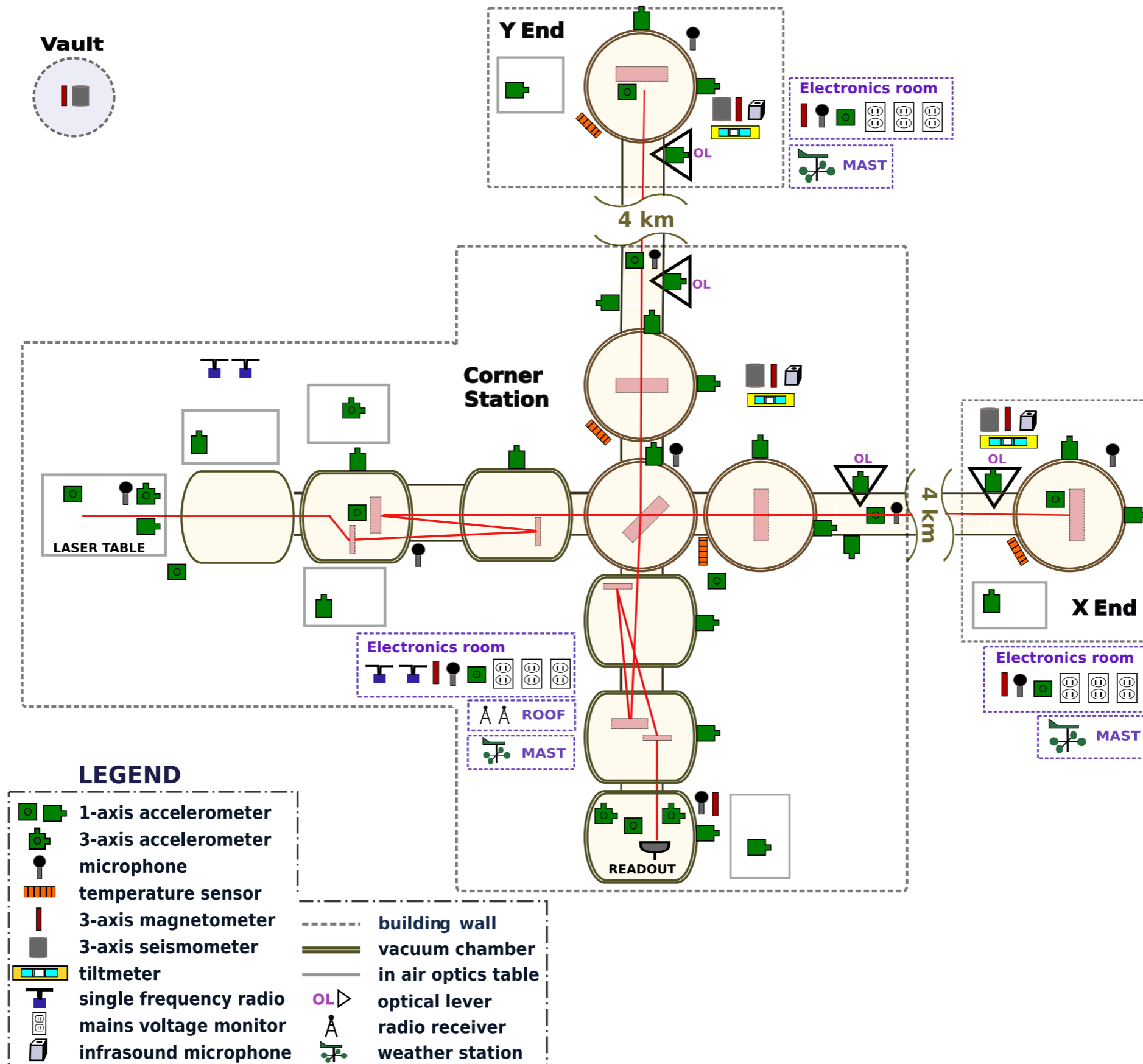


# Kinds of Coupling

- Seismic
- Acoustic
- Electromagnetic
- Optical (in the instrument)
- Other
- Long-range (inter-site)
- Local external (environmental)
- Local internal (instrumental)



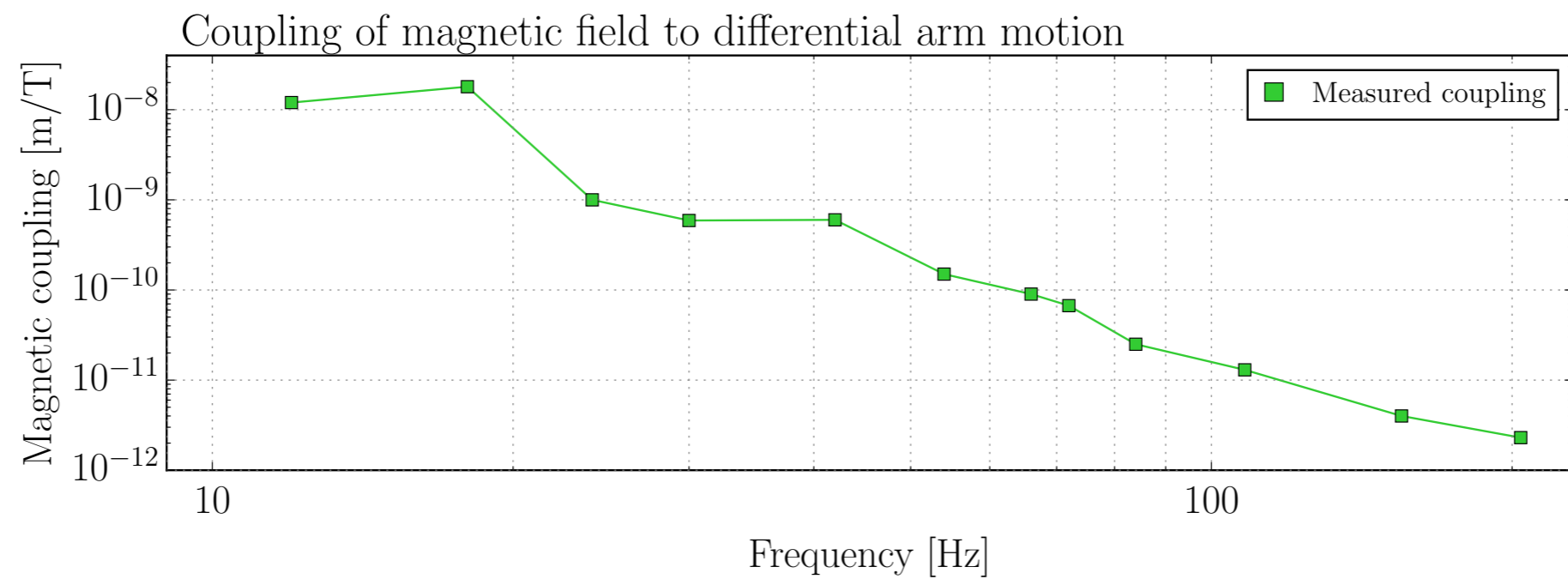
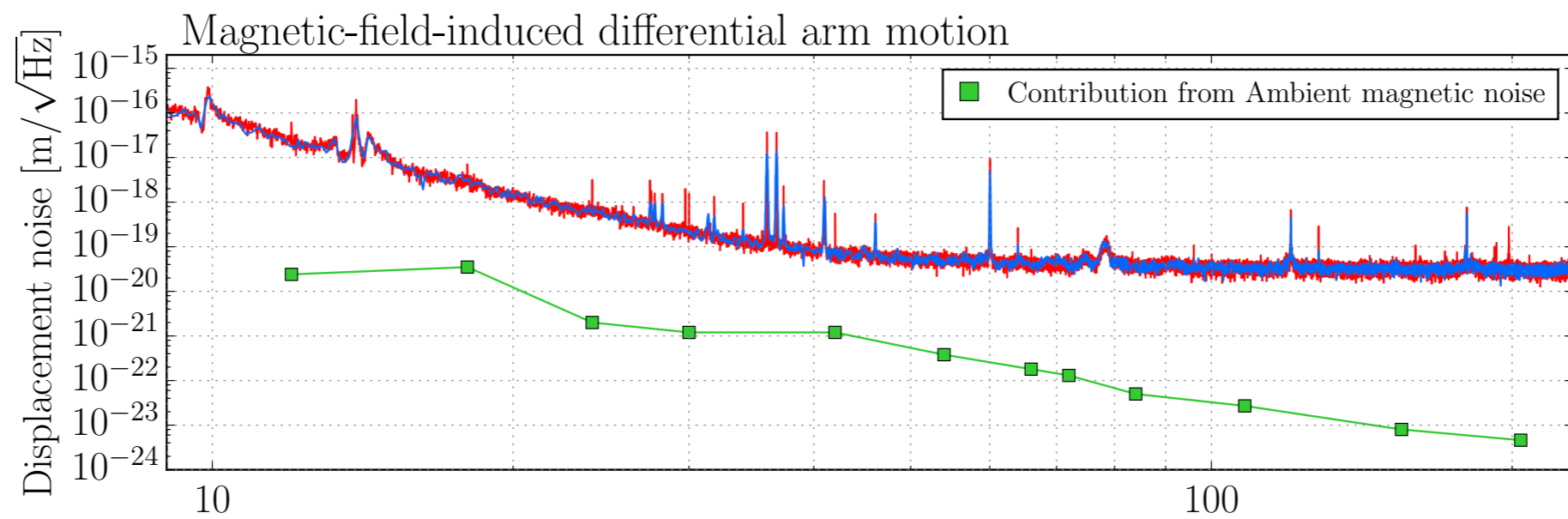
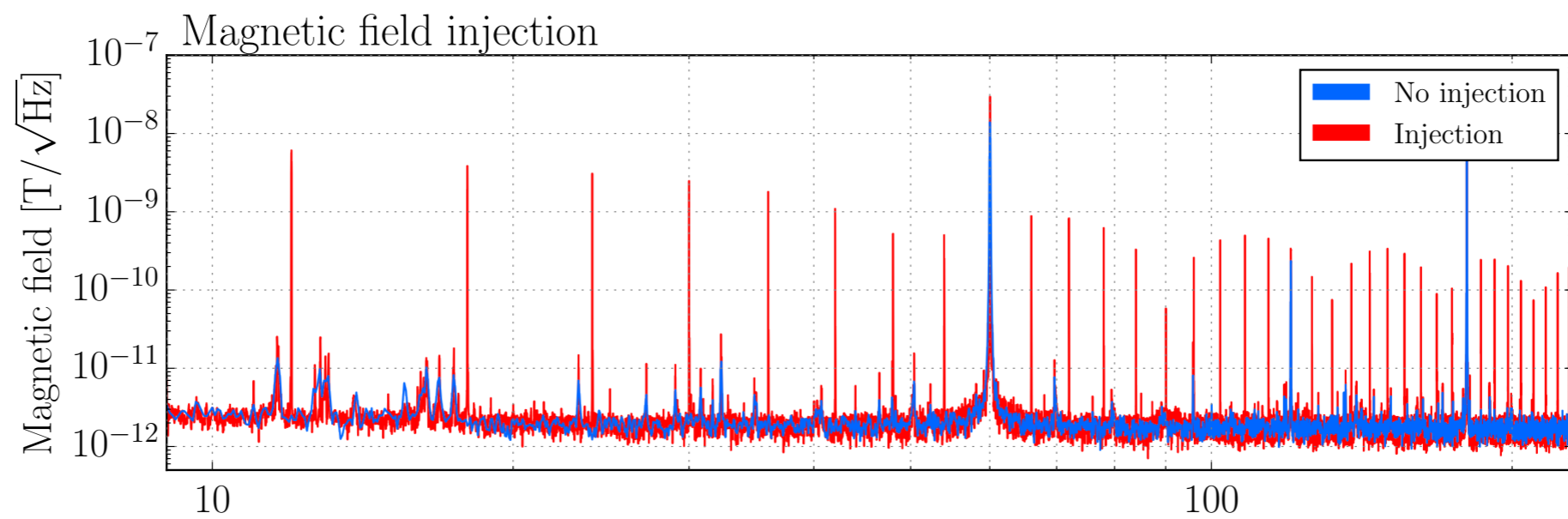
# Physical and Environmental Monitor Layout



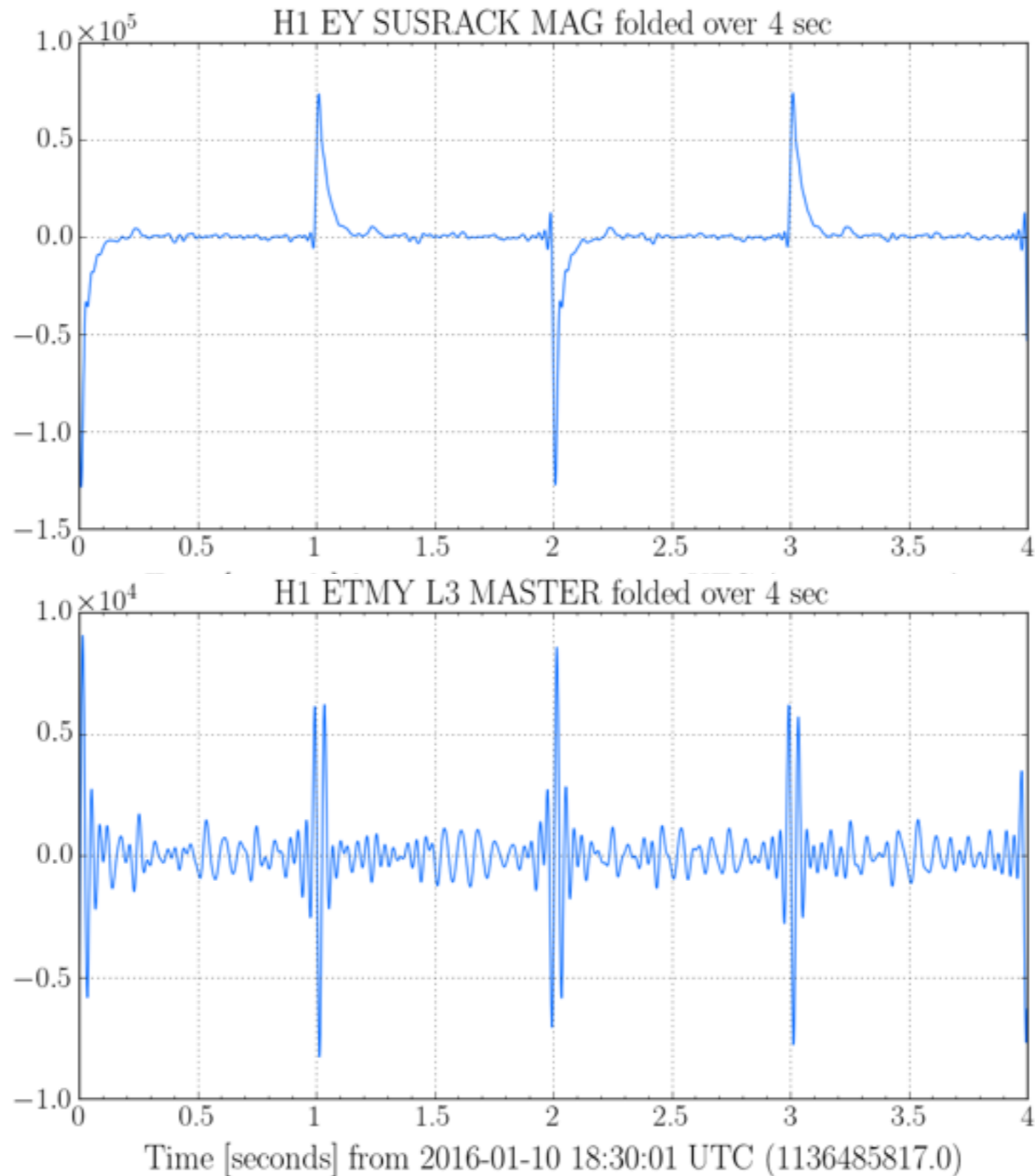
Long-range

# Rule out long-range effects

- Only earthquakes were magnitude 2.1
- Only two magnetometers at L1 saw anything at all
  - Factor of 40 too low
- Interesting lightning strike in Burkina Faso
  - Not able to affect either site
- Cosmic ray rates low
- External observatories reported no particular EM interference



# GPS-synchronized noise

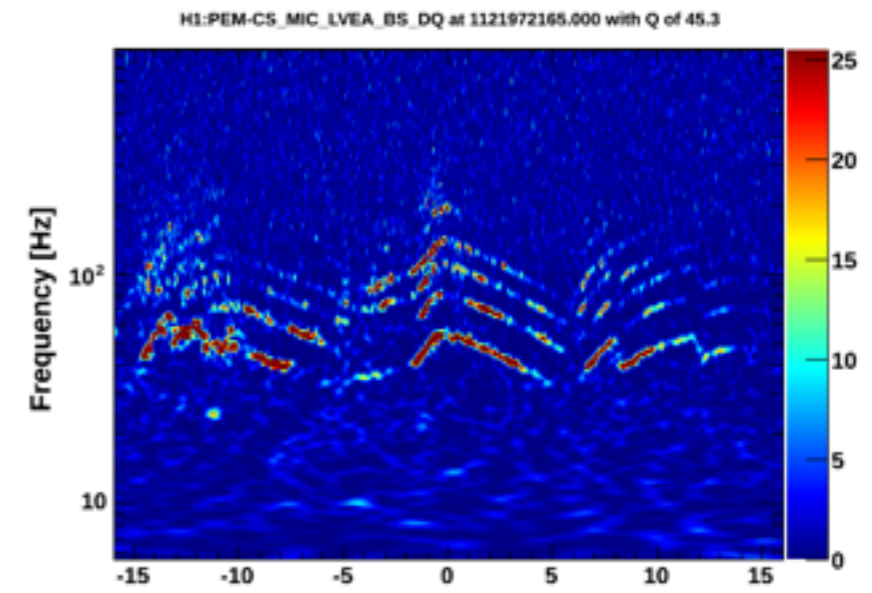
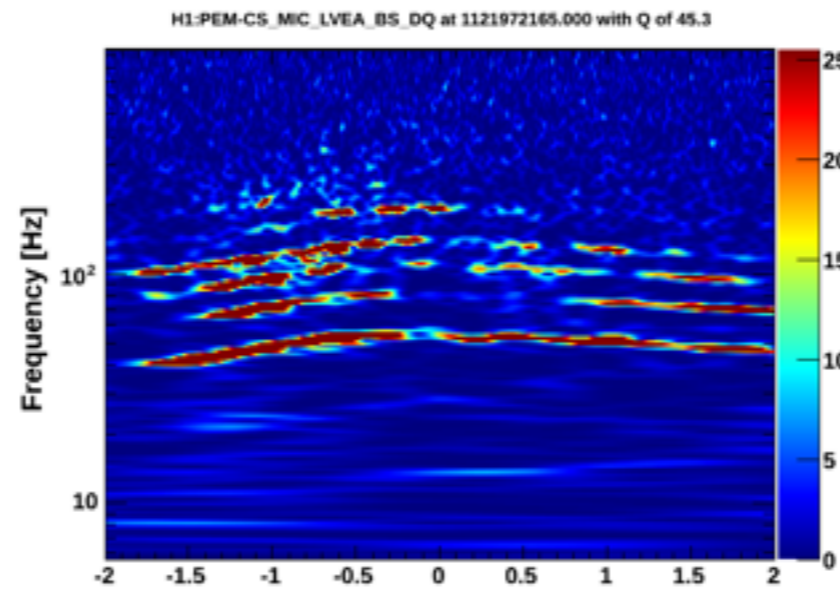


Local Environmental

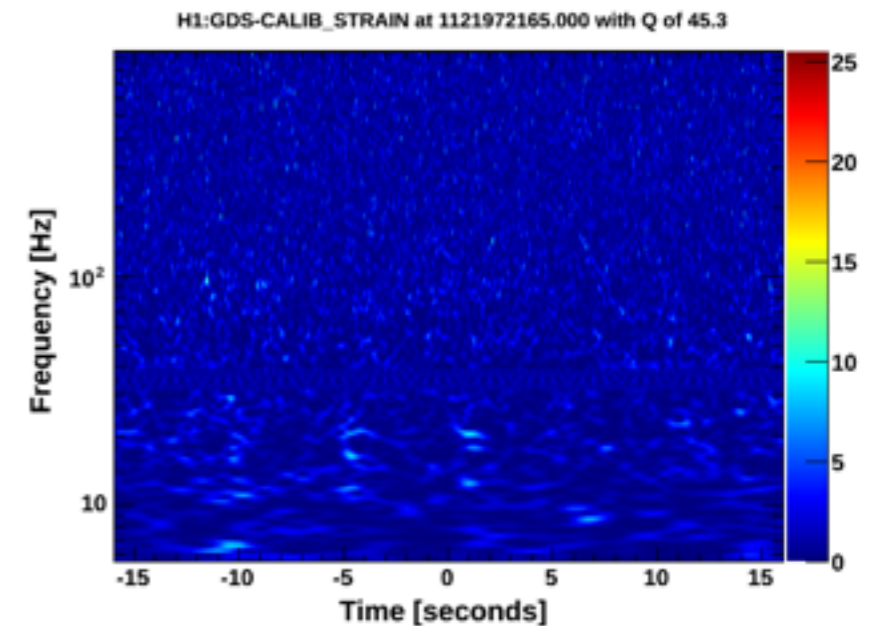
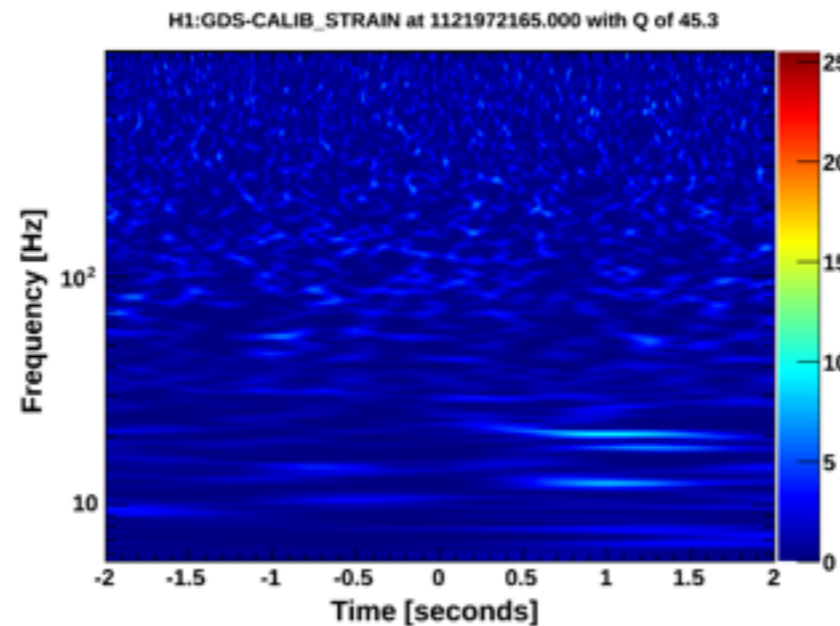
# Microphones

Local acoustic noise can couple (usually at the laser)

Microphones



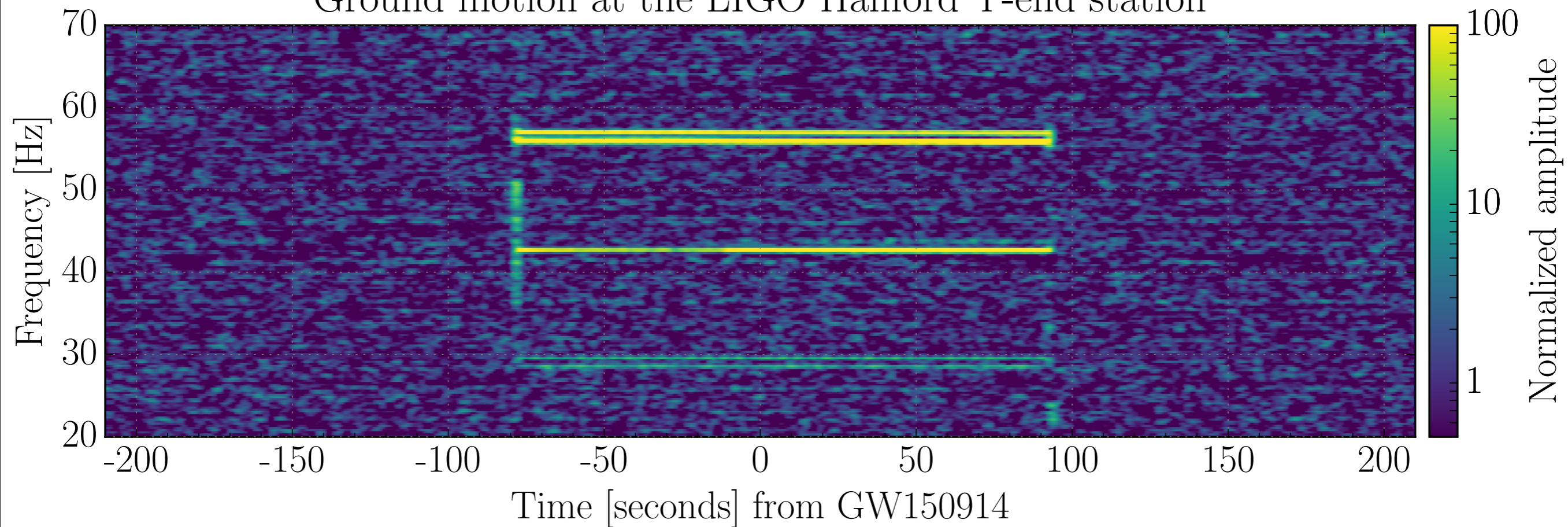
GW strain channel



Motorcycle driver: Bubba Gateley

# Air compressor

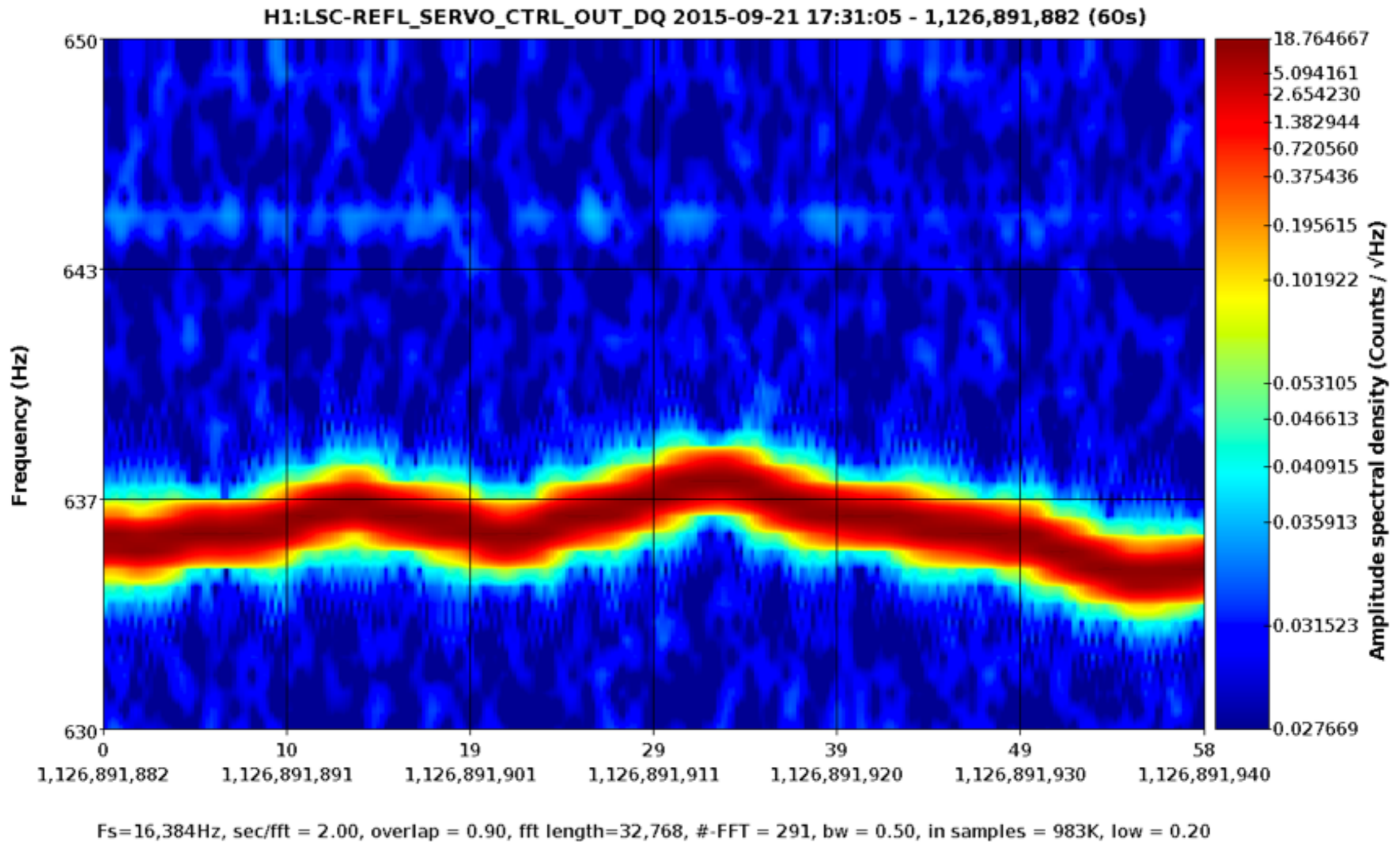
Ground motion at the LIGO Hanford Y-end station





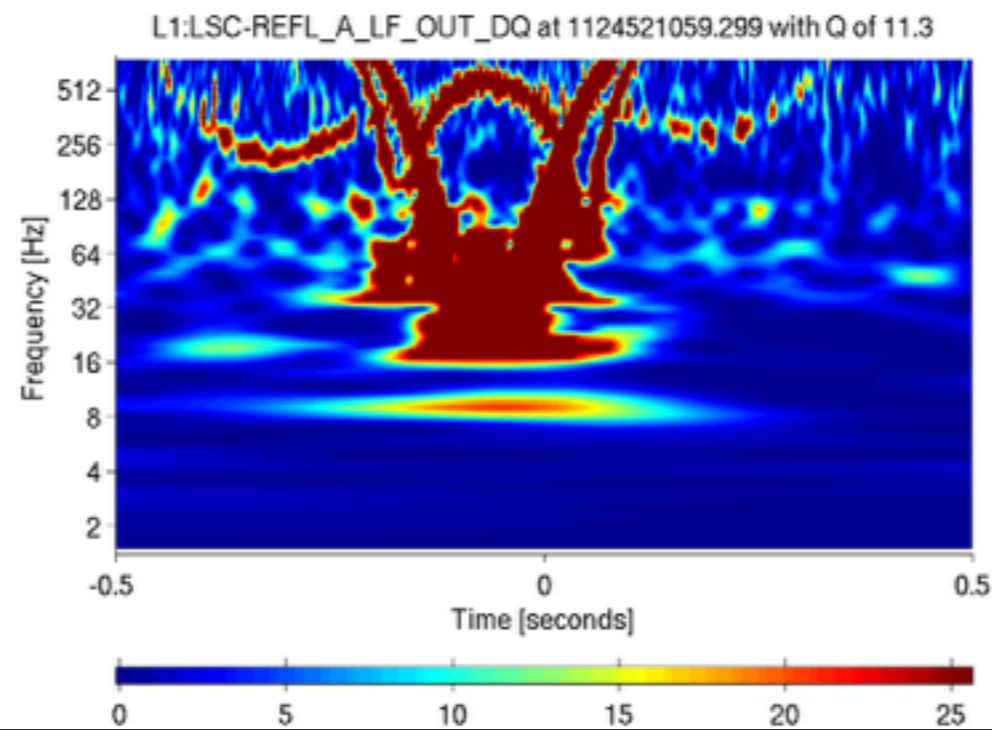
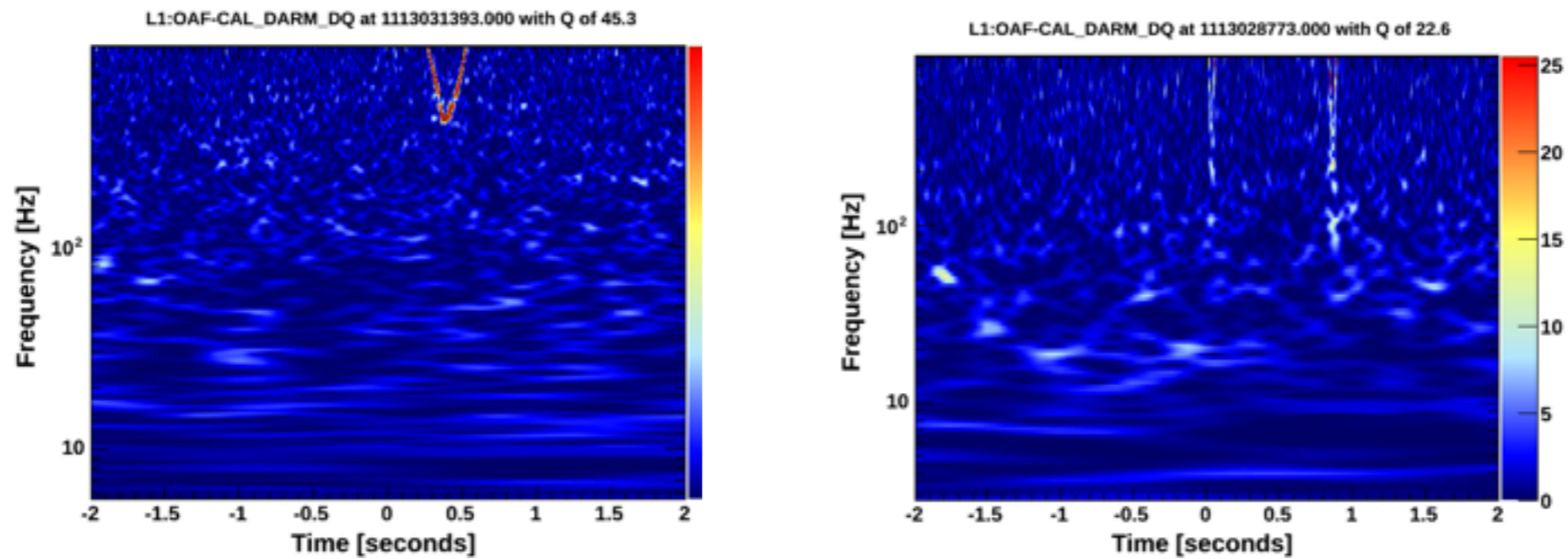
Instrumental

# RF Noise

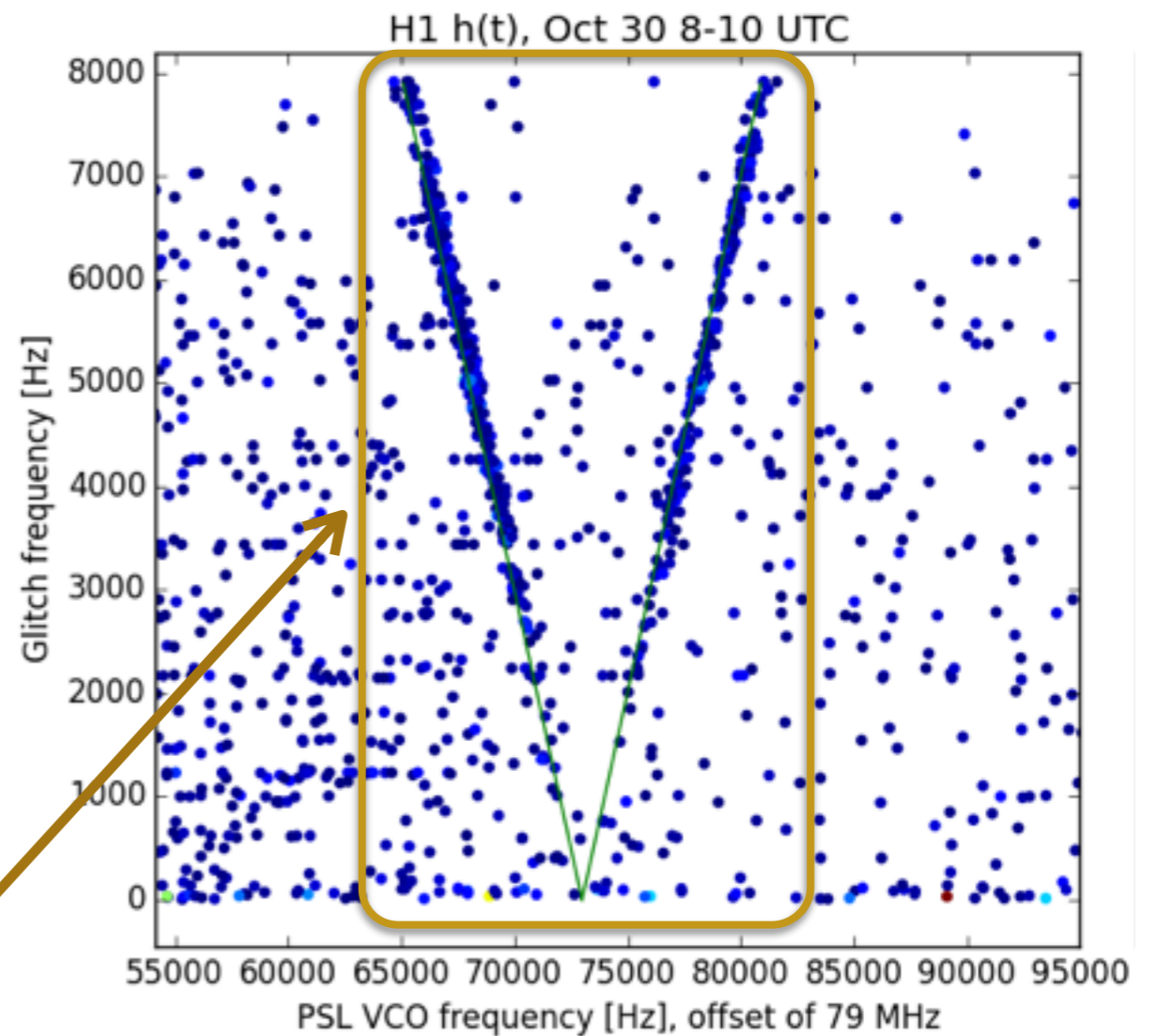
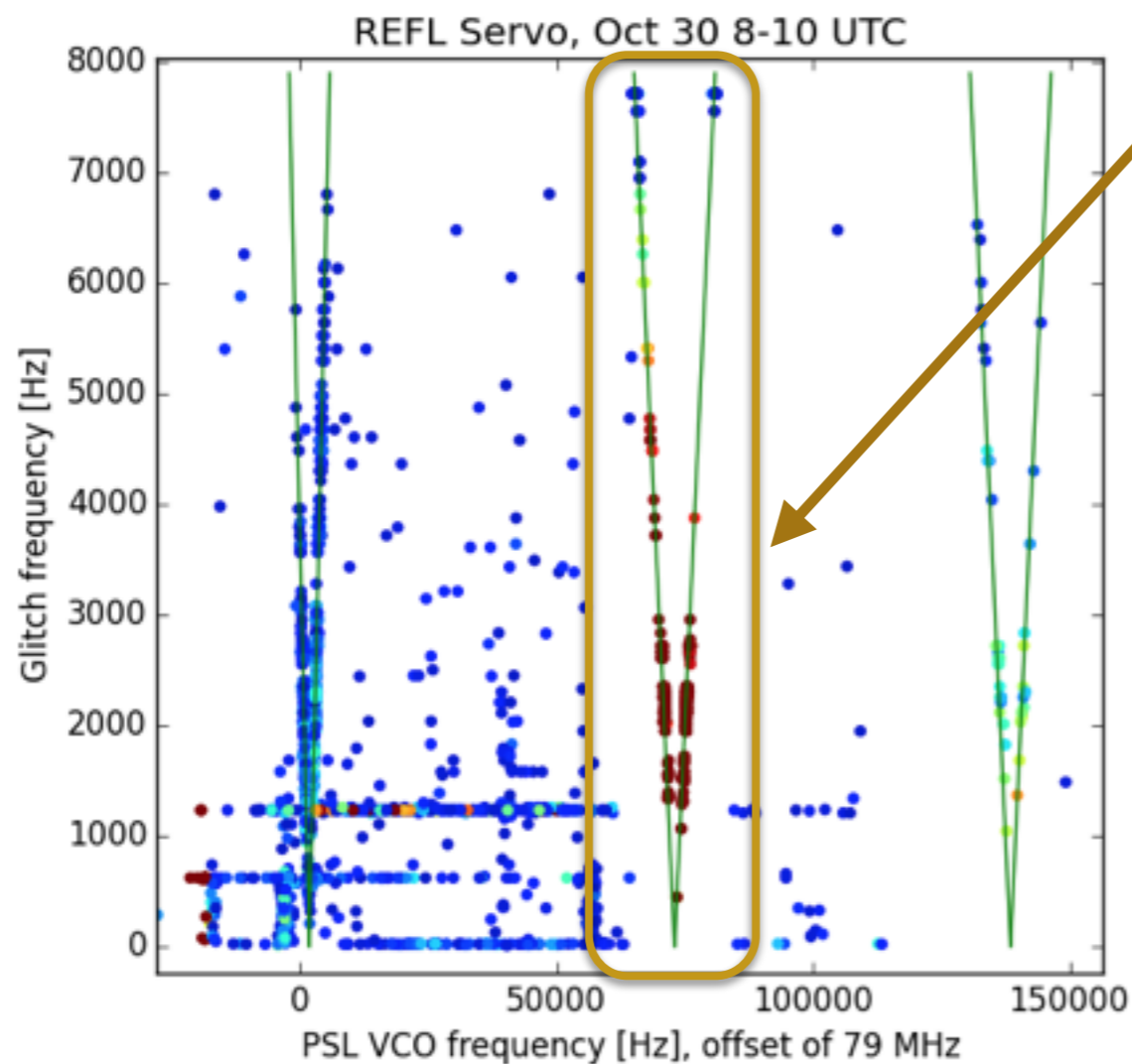


# RF Whistles

Beat note of two RF lines

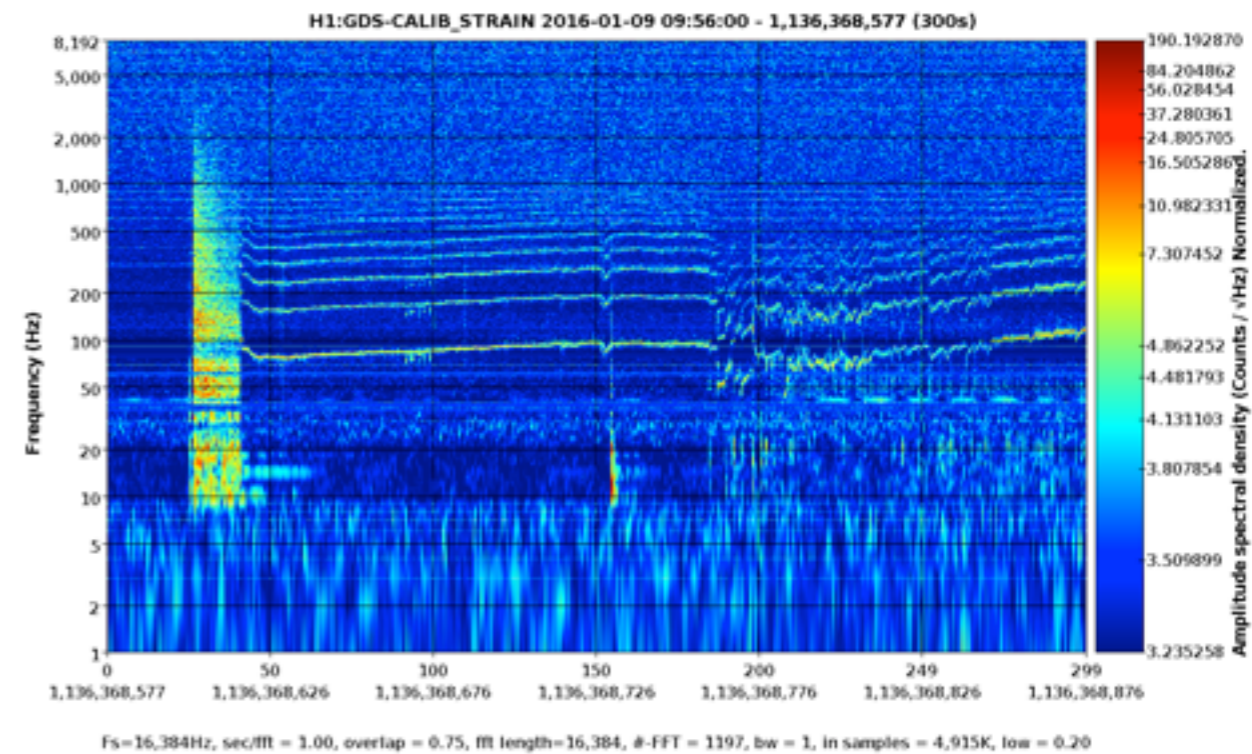
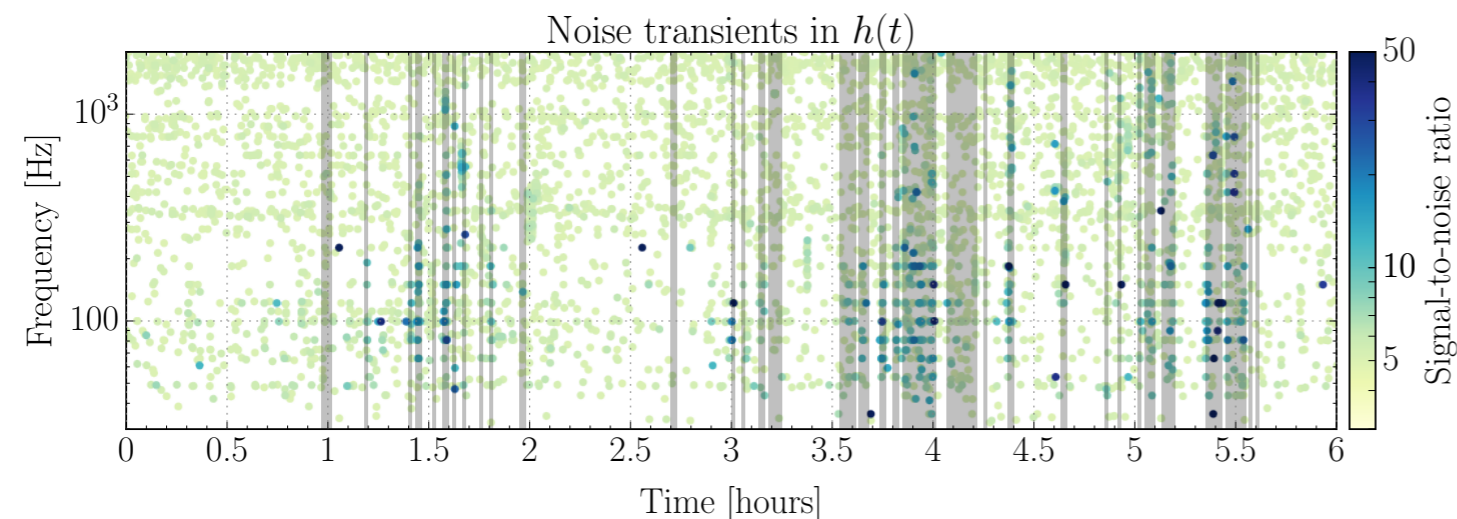
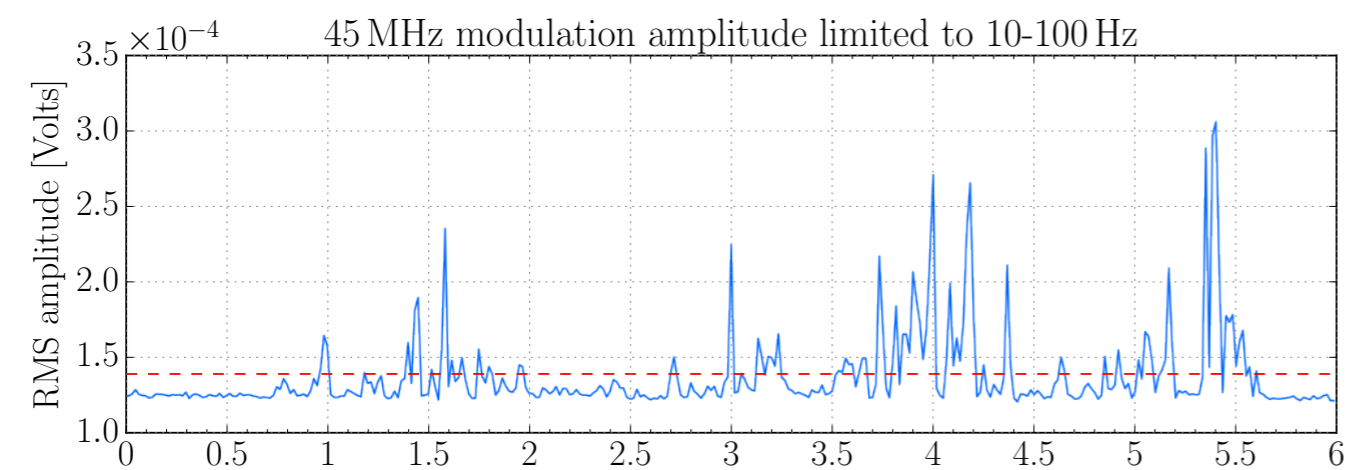
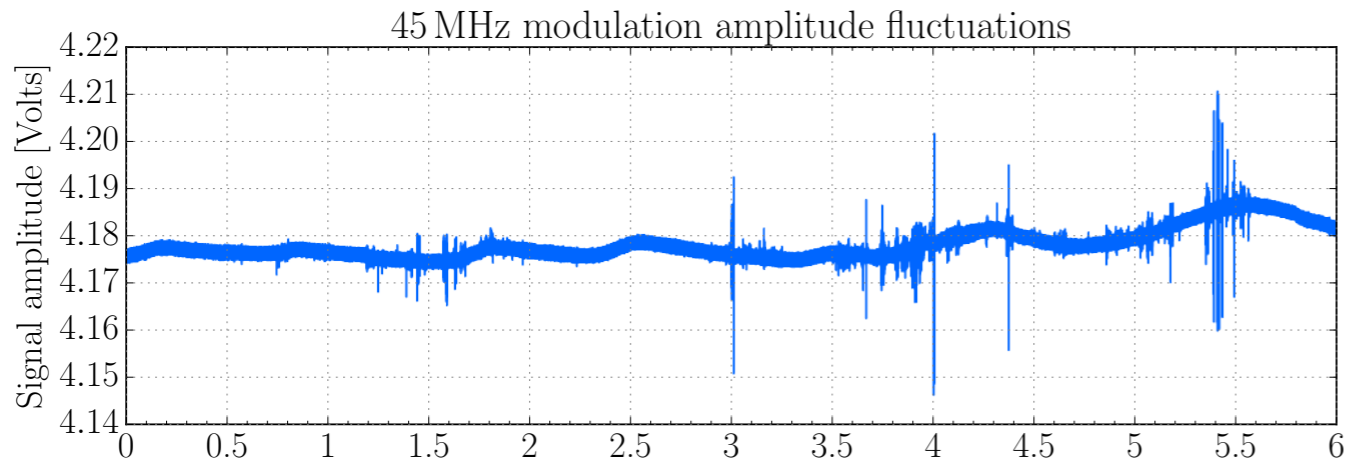


# RF Whistles



- Only happen when RF modulator crosses a known line
- Always worse in auxiliary channels than in GW strain channel

# 45 MHz Modulation

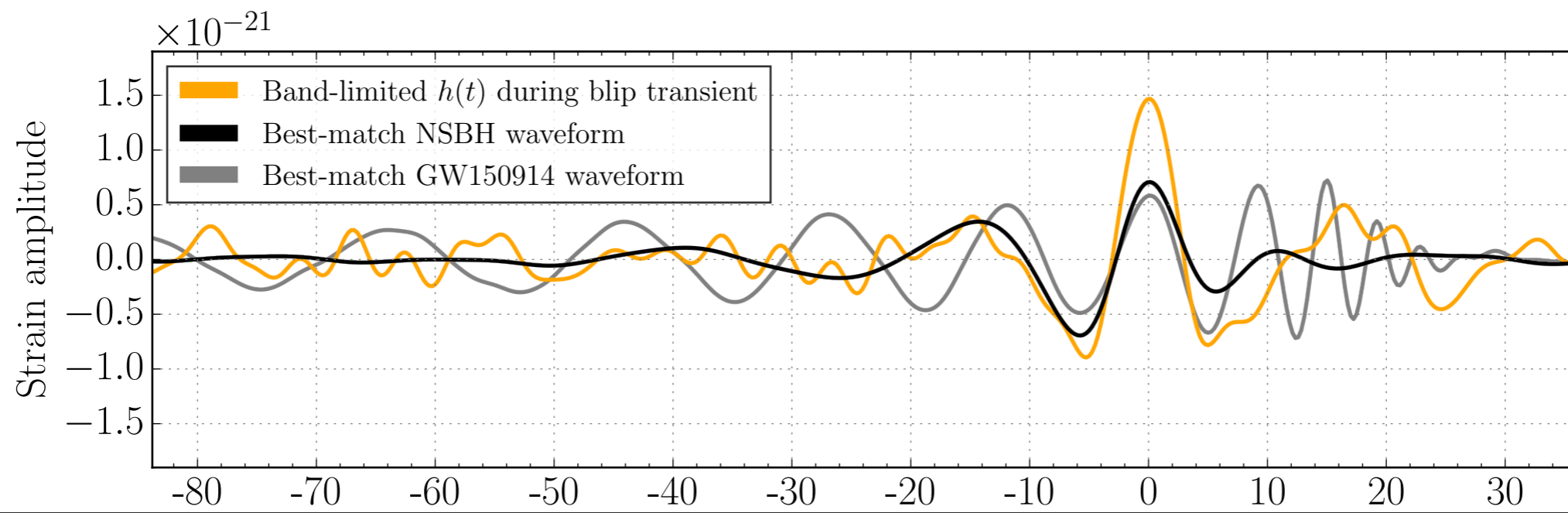
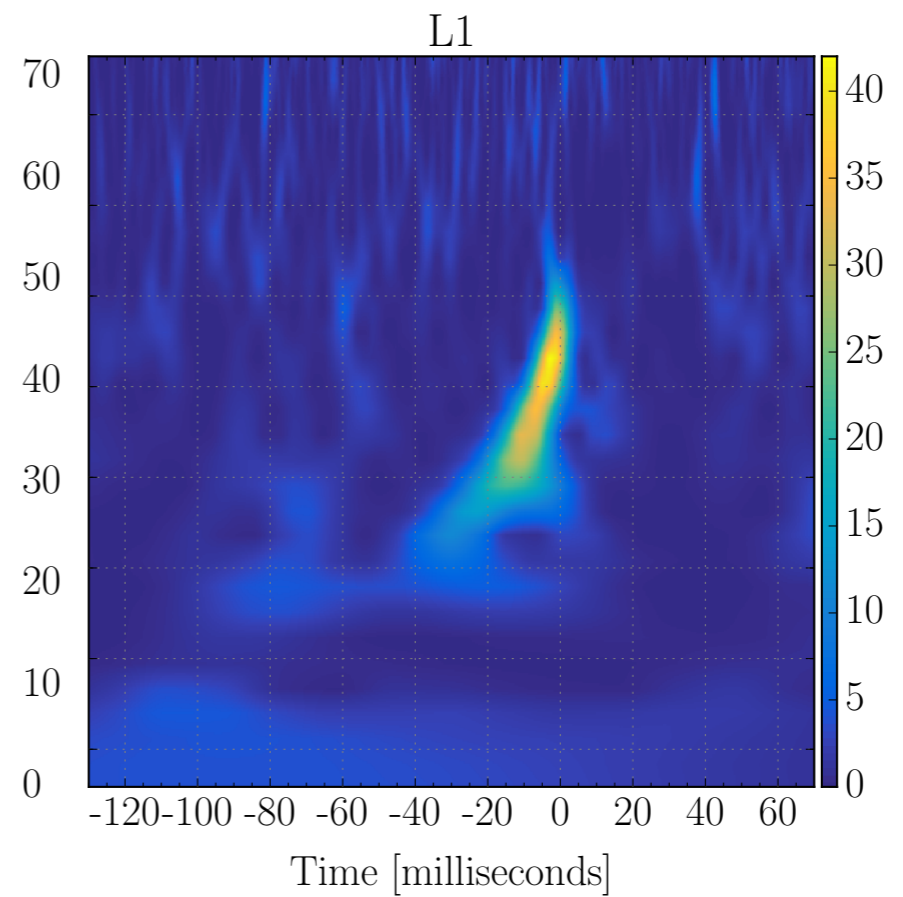
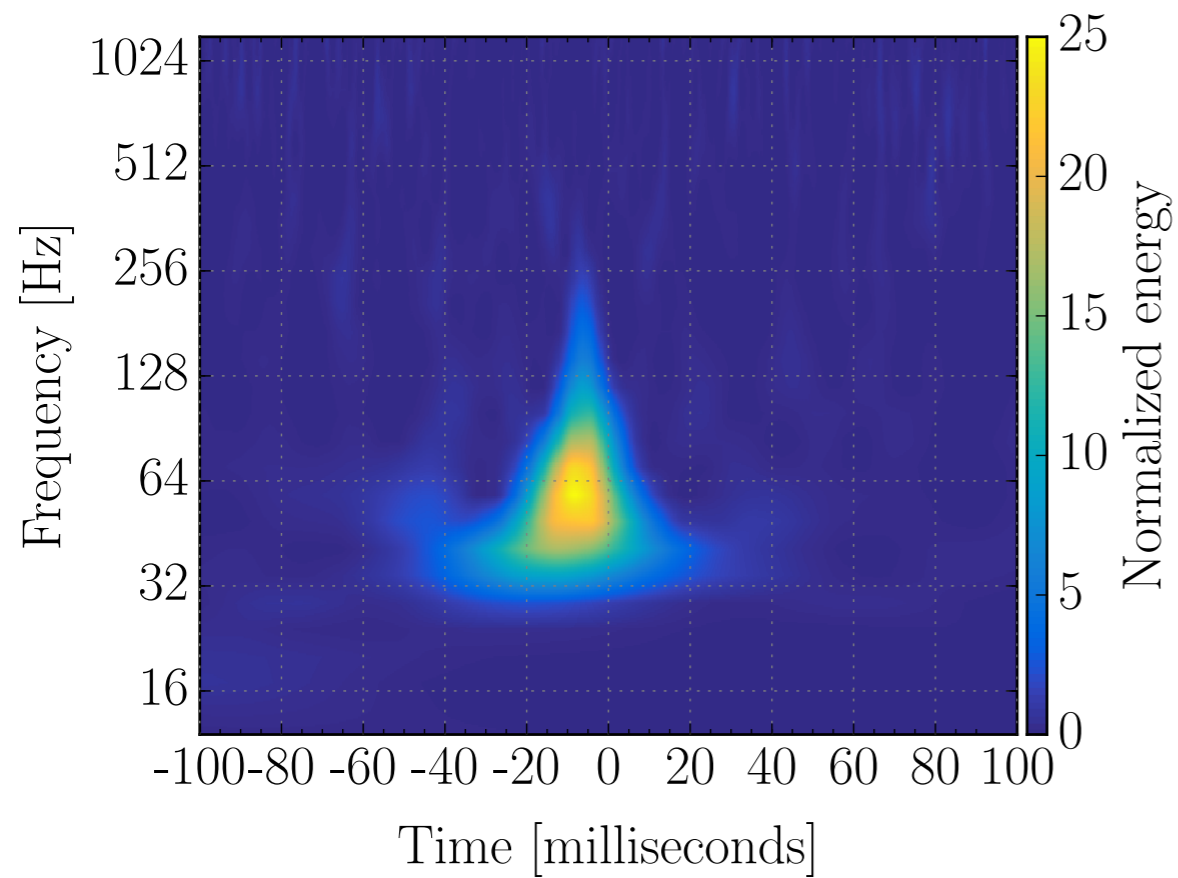


More RF troubles

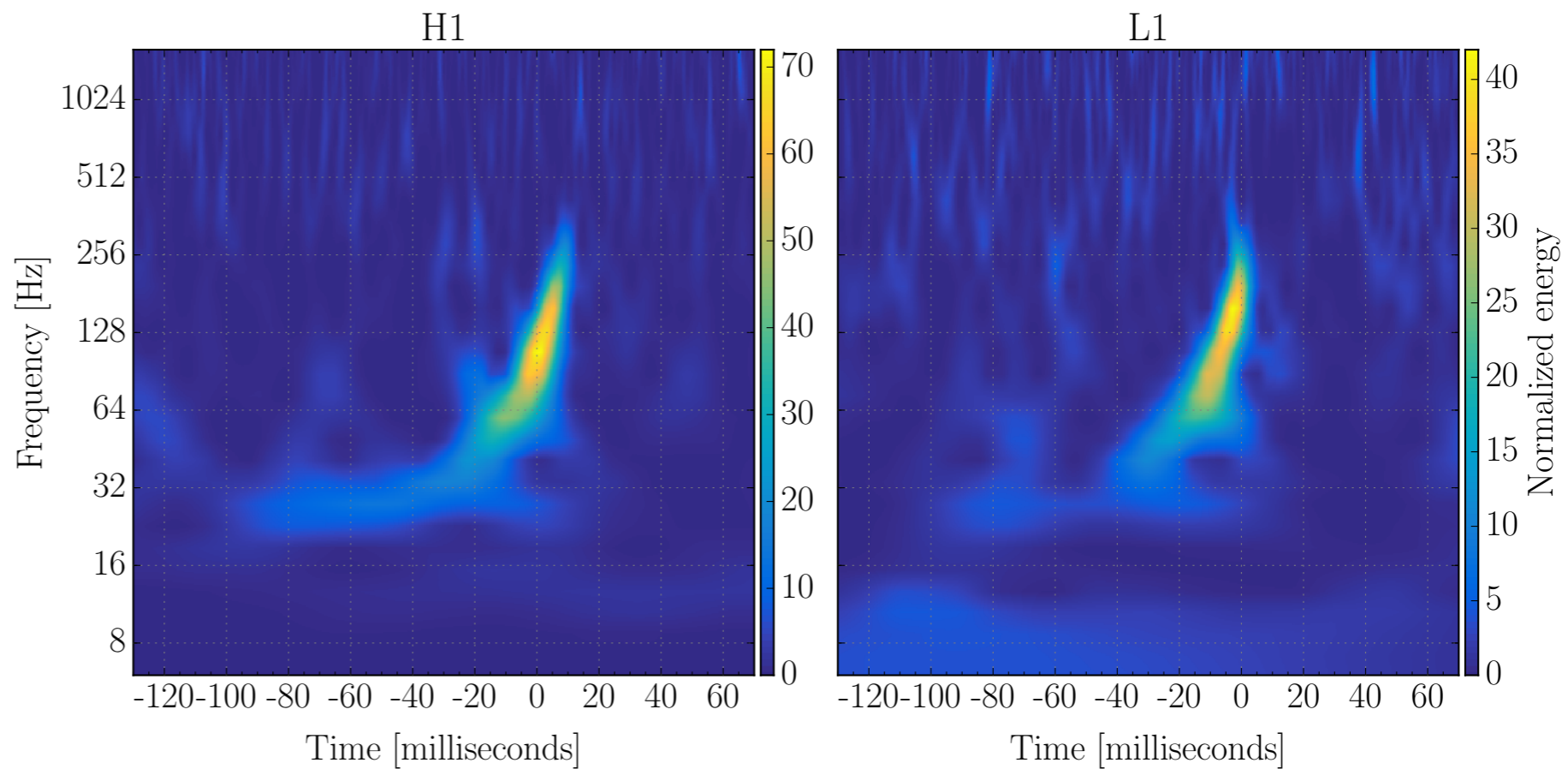
45 MHz phase modulation used for control

Once again, it's stronger in auxiliary channels and we track it

# The Blips



**GW150914**



**LVT151012**

