

Data Quality Challenges in LIGO and (a bit of) LISA

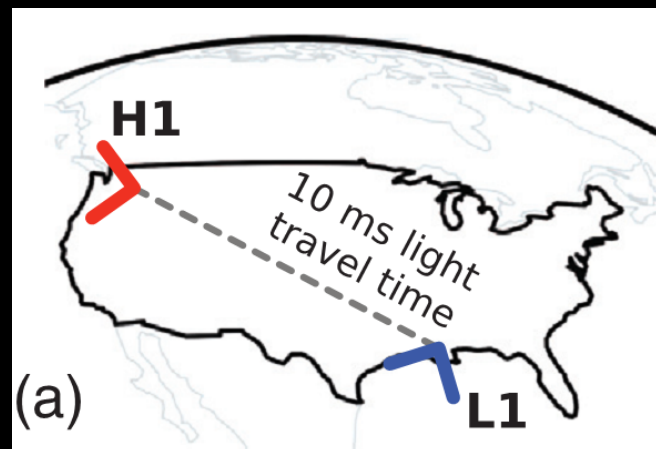
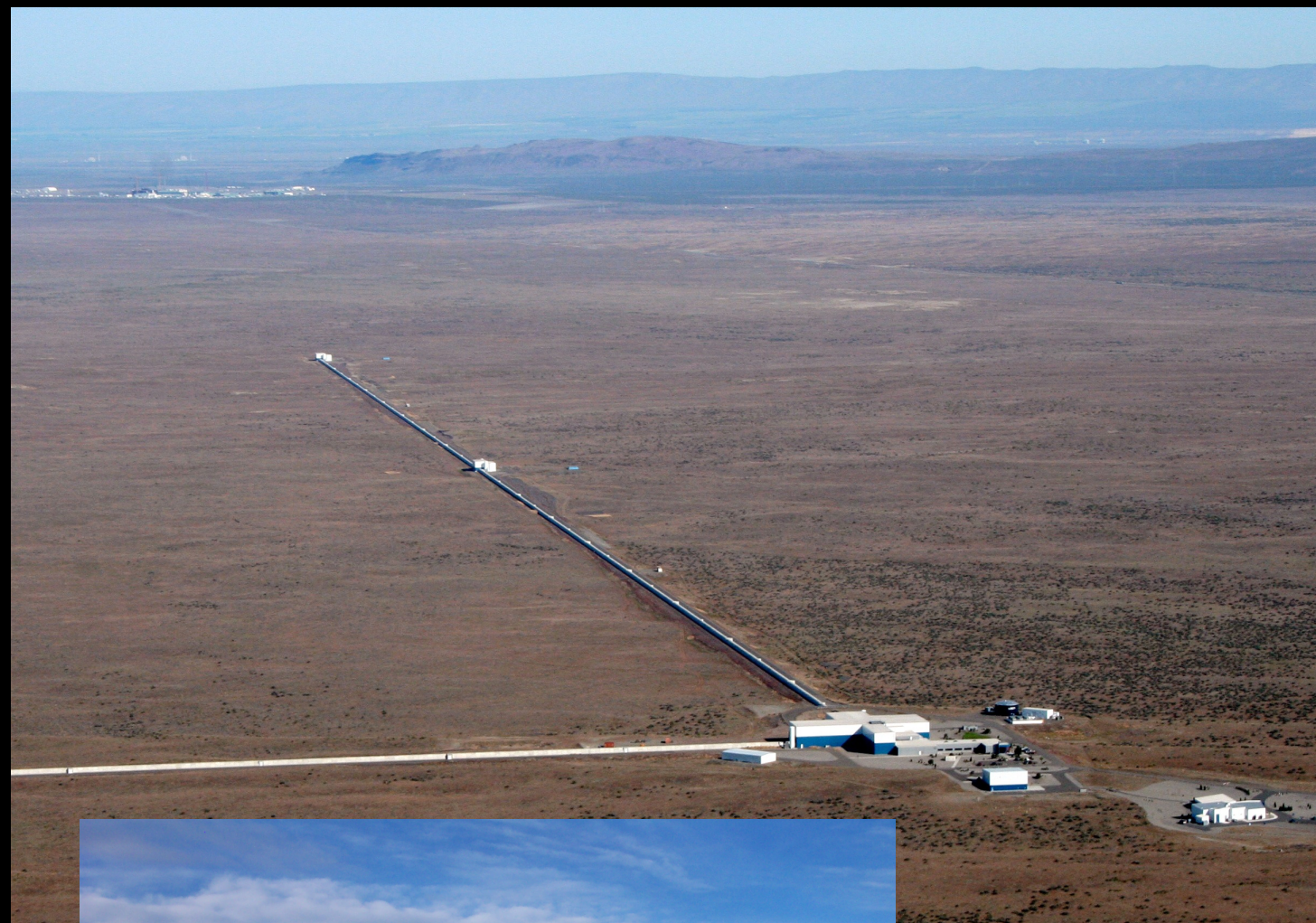
Laura K Nuttall
UKRI Future Leaders Fellow
University of Portsmouth

LIGO

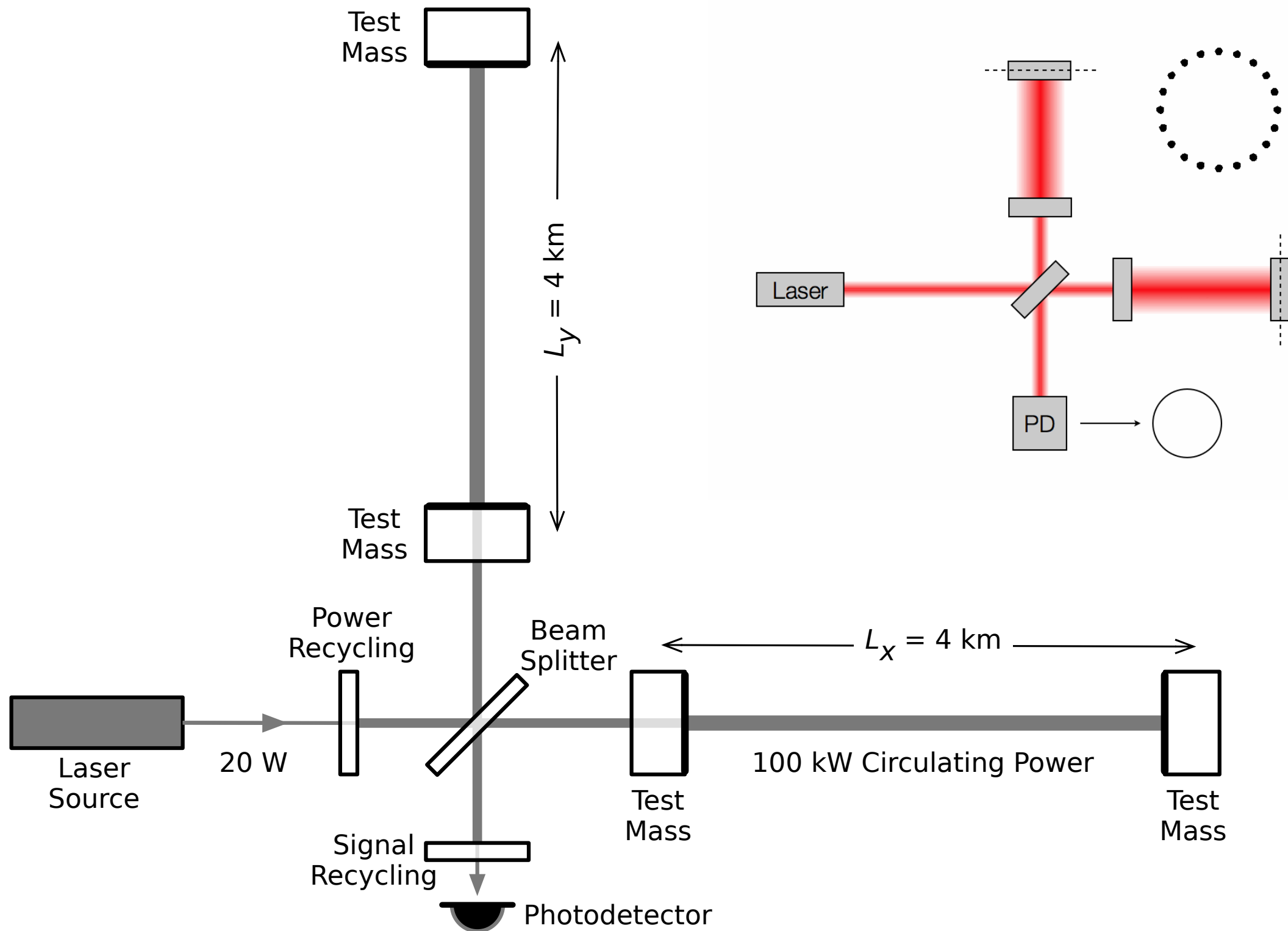
Laser Interferometer Gravitational-wave Observatory

LIGO-Hanford

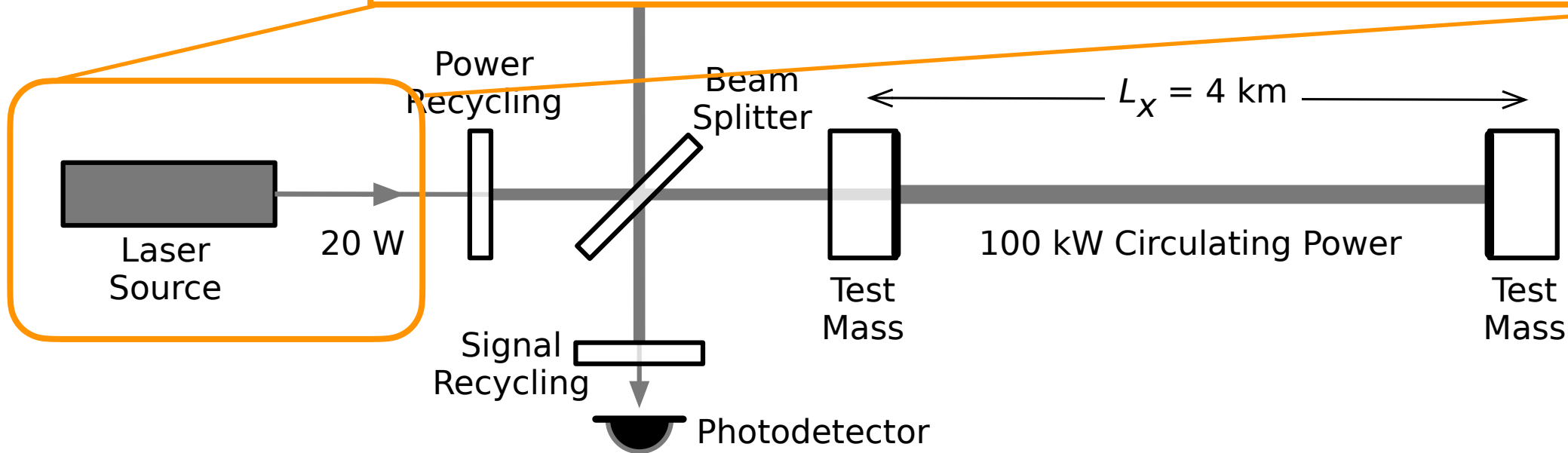
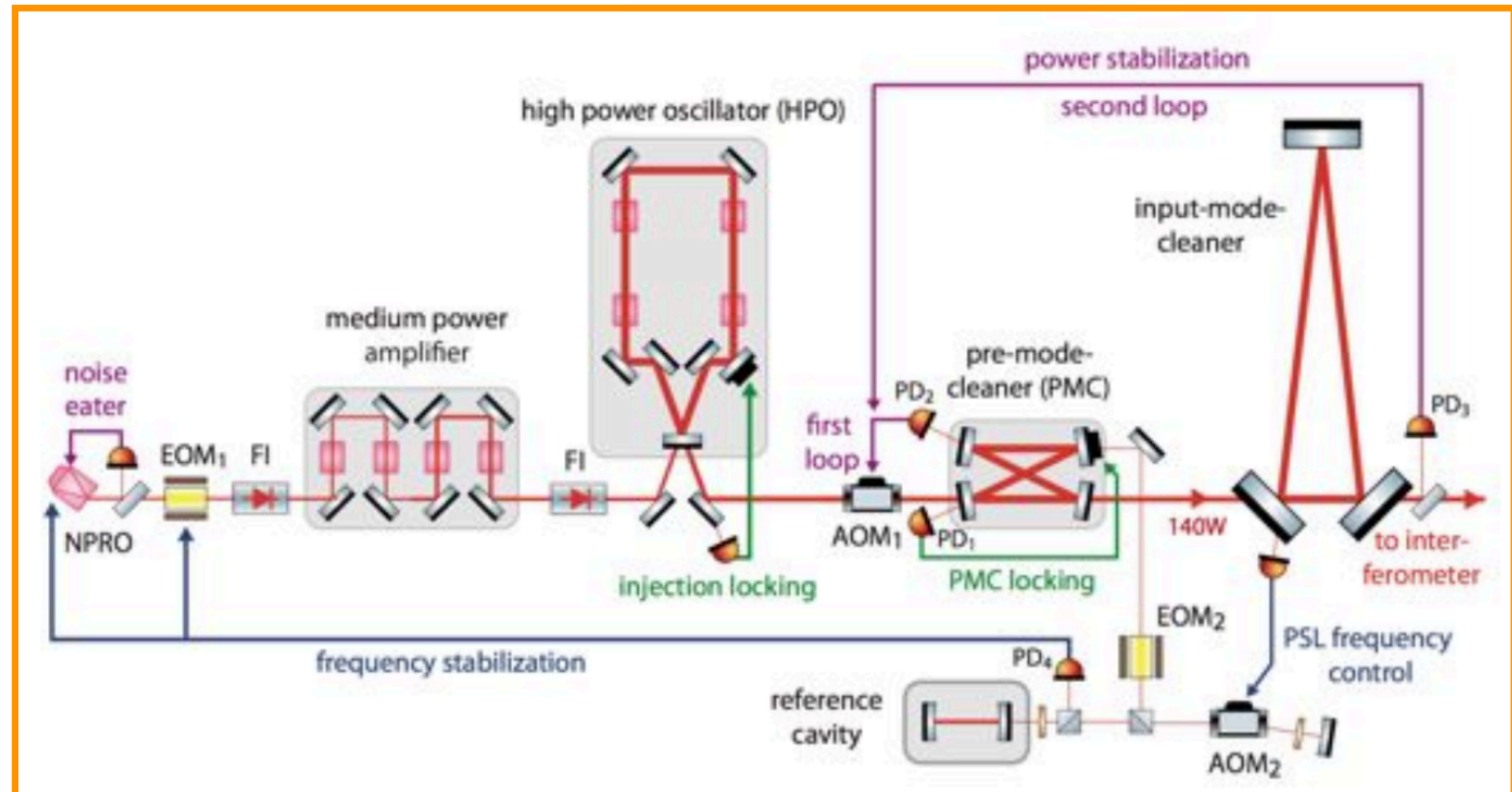
LIGO-Livingston



'Typical' way we think about the detector



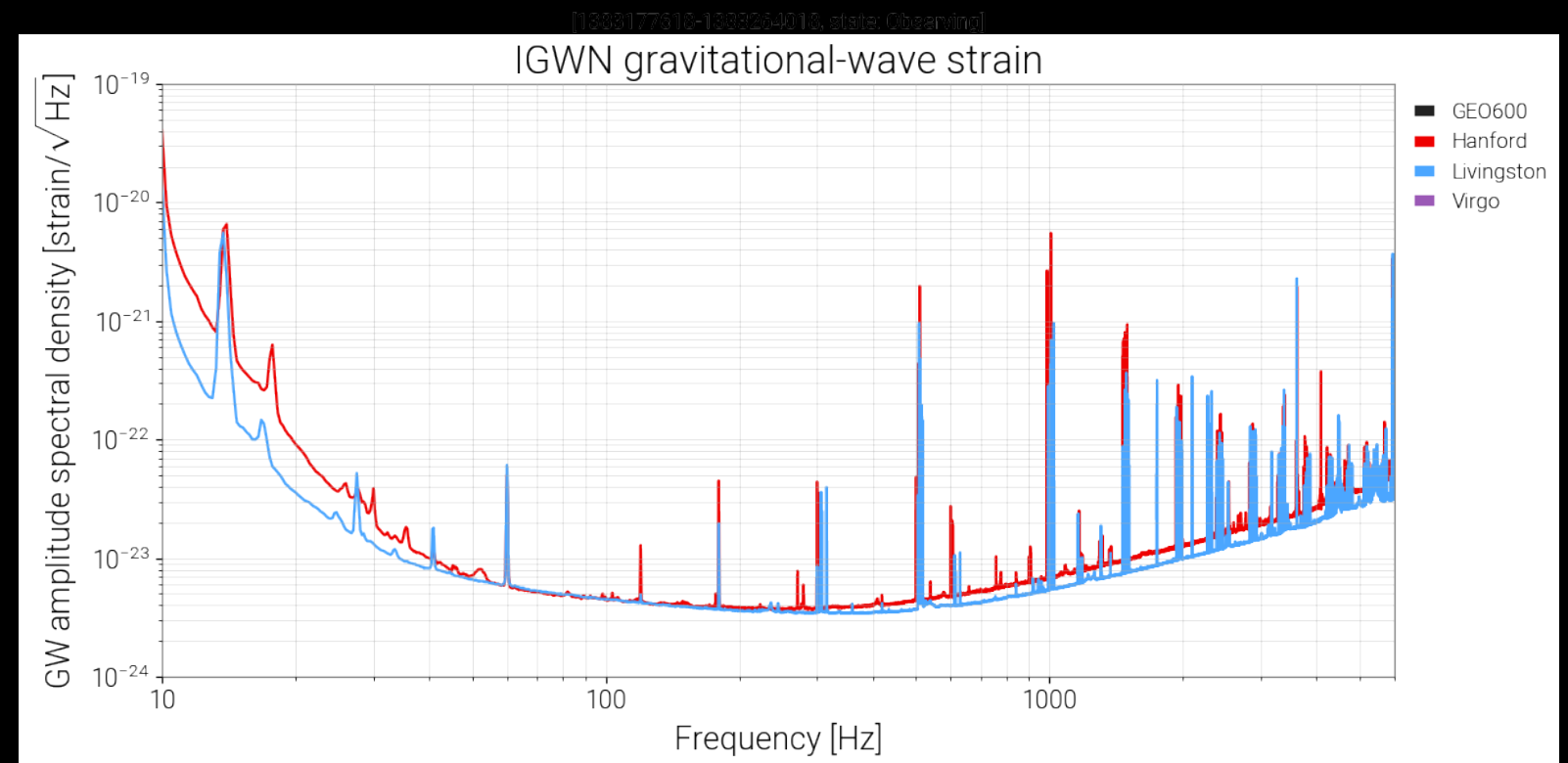
In reality though it's much more complicated...



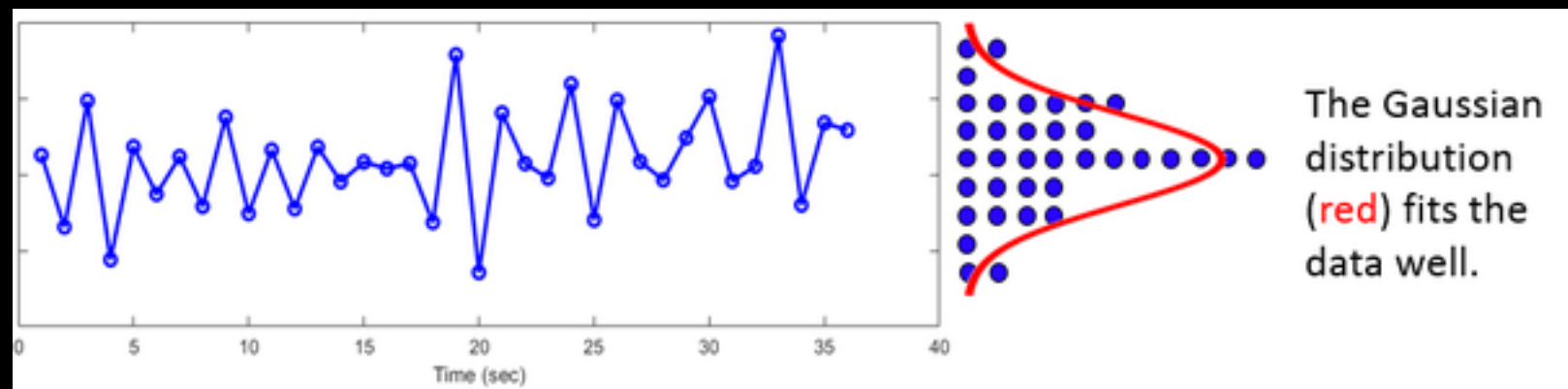
'Typical' way we think about the data

Often assume the LIGO data are stationary, coloured Gaussian noise

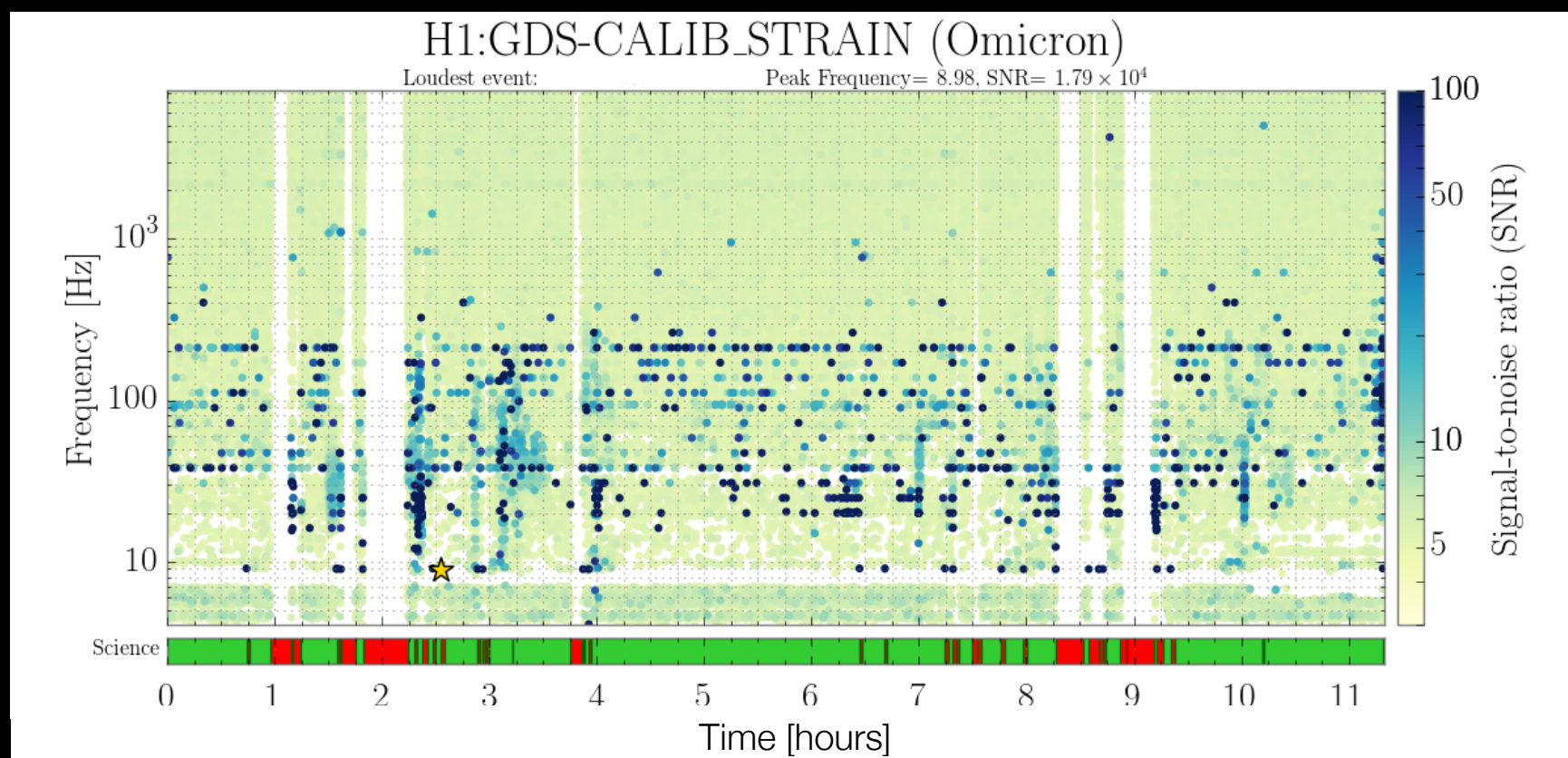
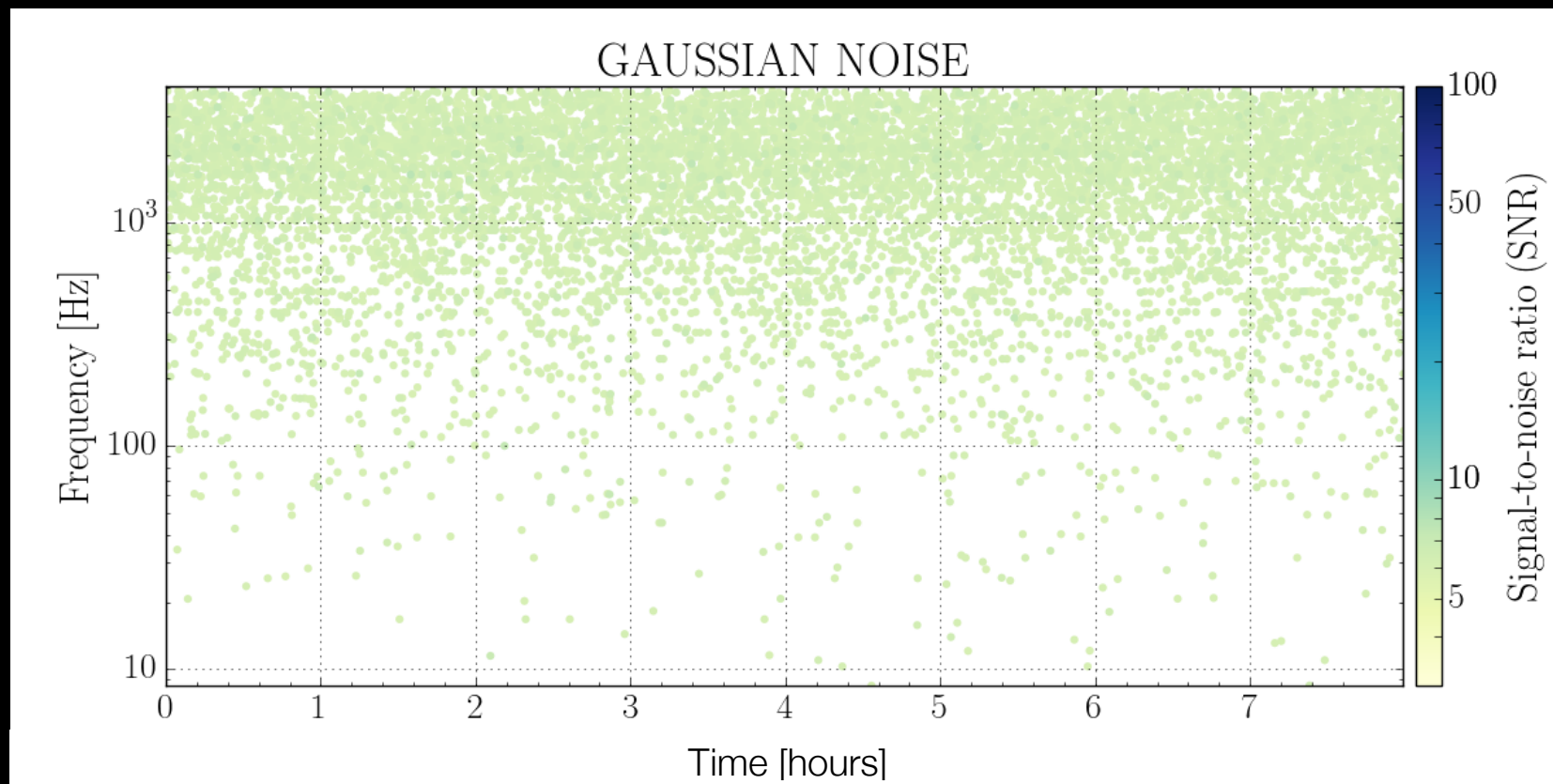
- Stationary - properties of the noise are constant with time
- Coloured - more noise at particular frequencies (as opposed to 'white' noise)
- Gaussian - value of the data follows a Gaussian distribution



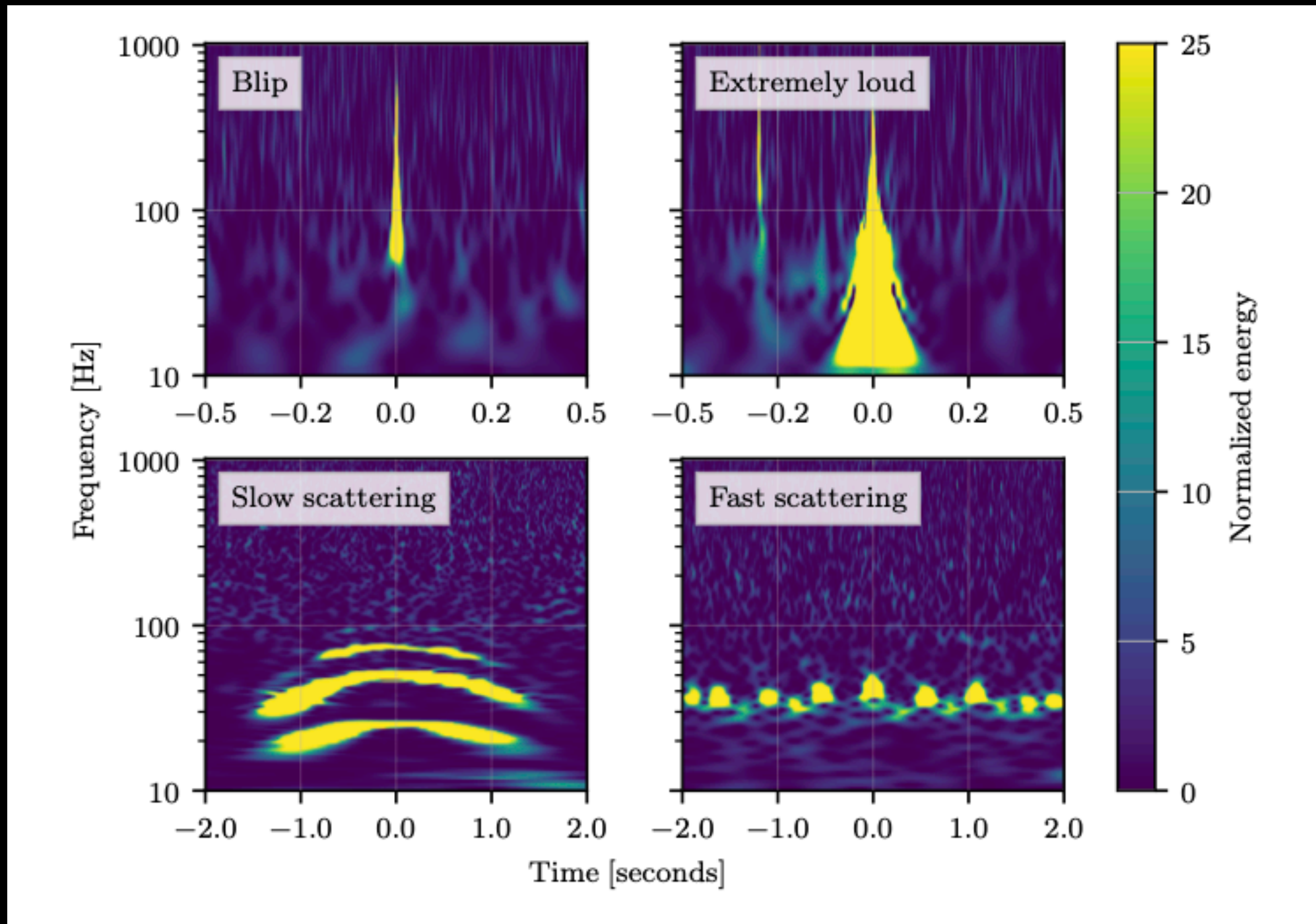
https://gwosc.org/detector_status/



In reality the data are not stationary or Gaussian

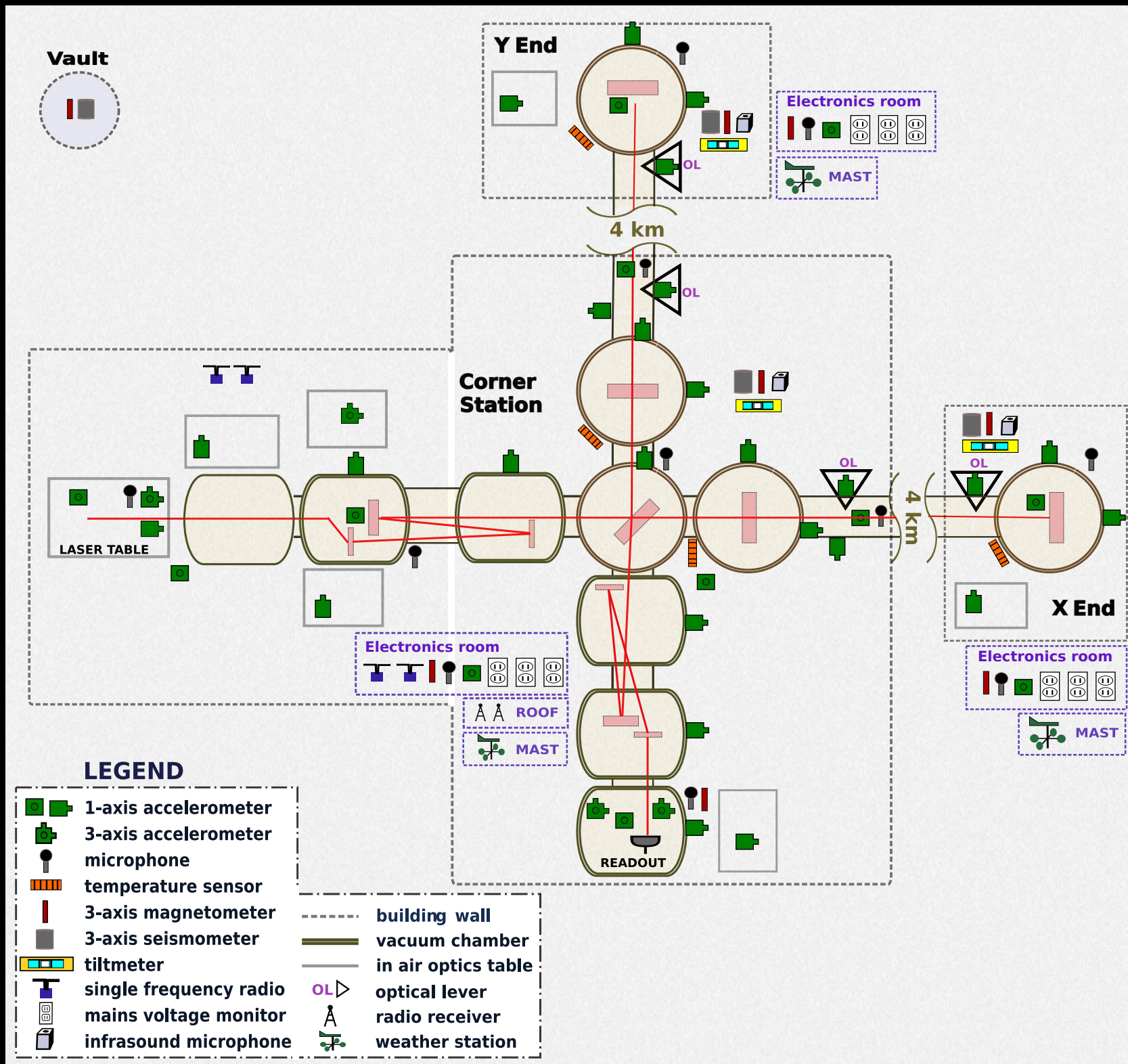


Lots of noise transients ('glitches')



You can help categorise glitches at:
<https://www.zooniverse.org/projects/zooniverse/gravity-spy>

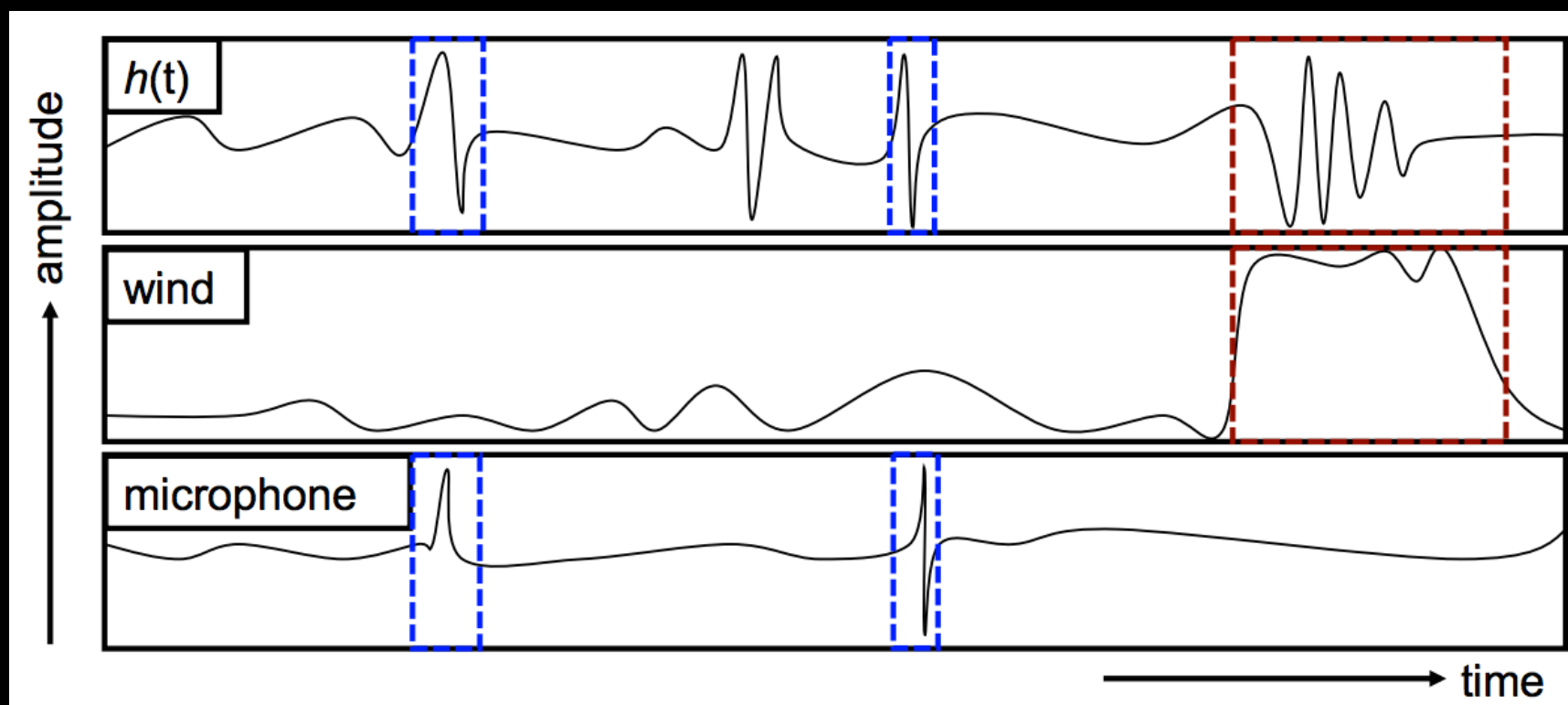
Detector Monitoring



- There are over 200,000 channels which monitor instrument behaviour and environmental conditions
- These channels witness a broad spectrum of potential coupling mechanisms
- We look for correlations between data in the gravitational wave channel and these auxiliary channels to identify times of bad data

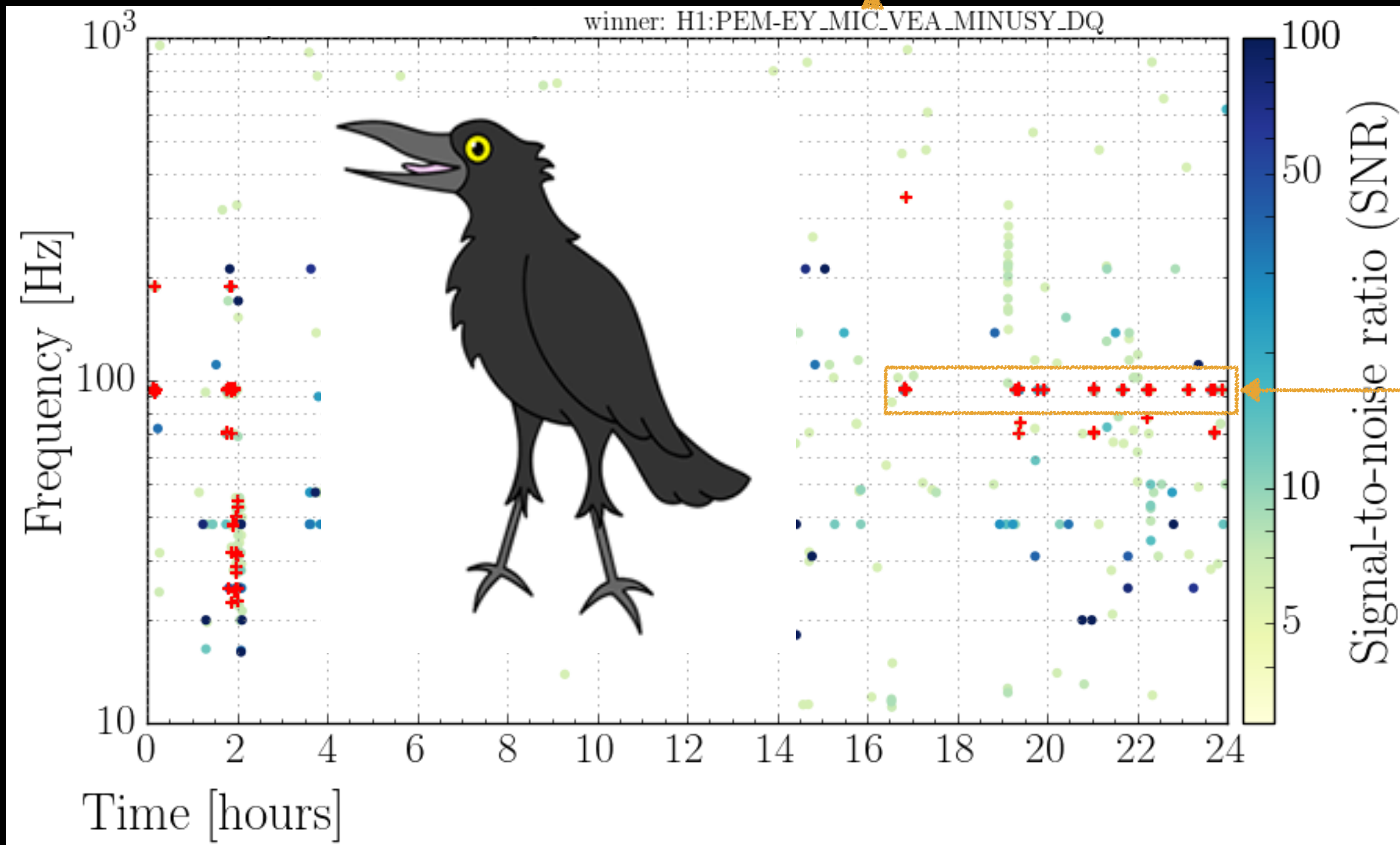
Mitigating noise sources

- We analyse all data which were collected when the detectors are in their observation state
- When a noise source is identified, the instrument hardware/software is modified to remove/reduce the effect of the noise
- We sometimes wish to remove egregious data from the search which was collected during a time of a known instrumental problems
- This is only done by systematically identifying and removing troublesome data



Mitigating glitches can sometimes be tricky though...

Correlation with a microphone channel at the Y-end

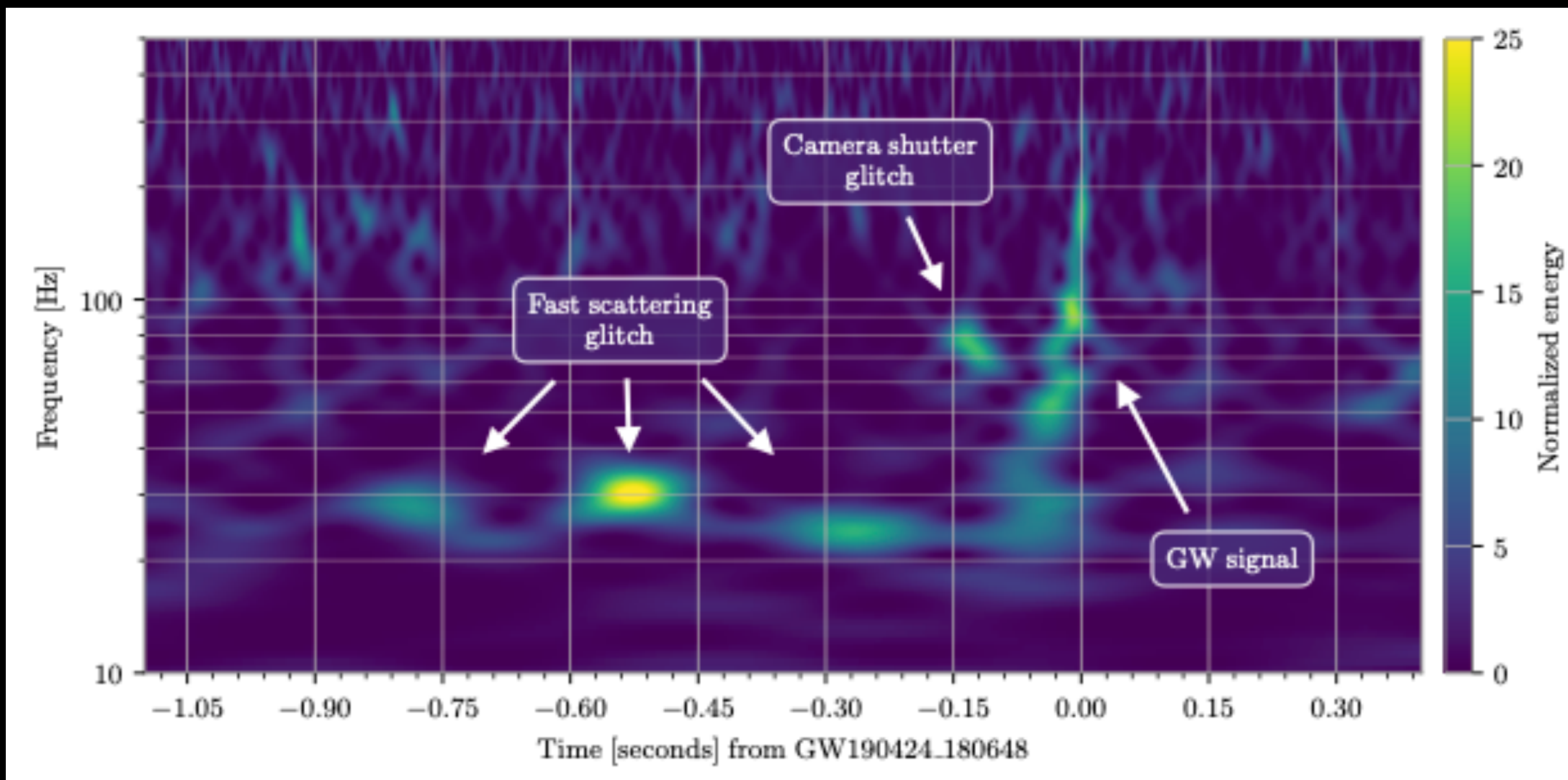


Lots of glitches around 94 Hz

Ravens peck at ice accumulating on nitrogen discharge line from cryopump

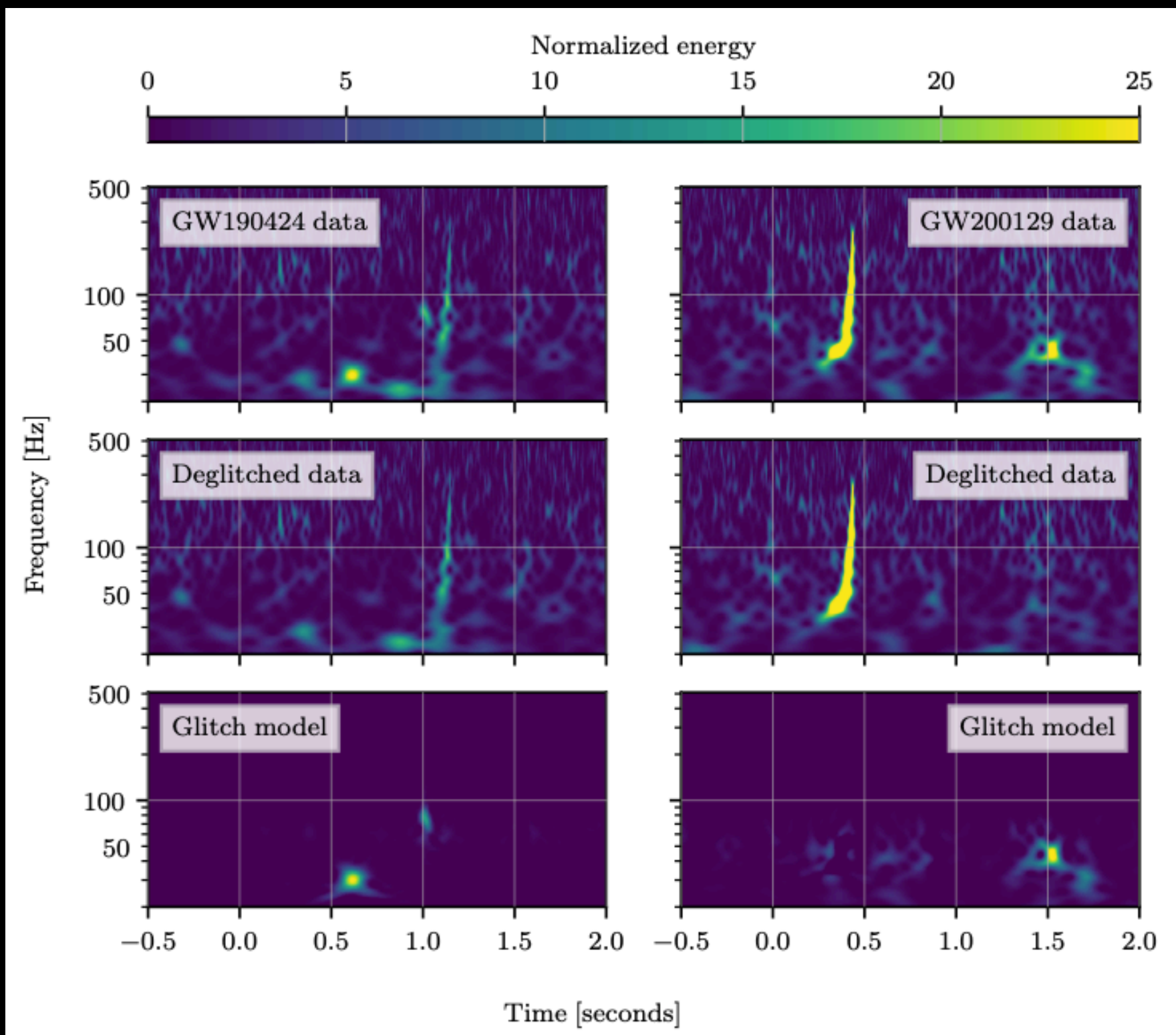


What can really happen around a GW event



Around **1/4** of events in O3 have data quality issues in the analysis window...
seeing the same in the current observing run

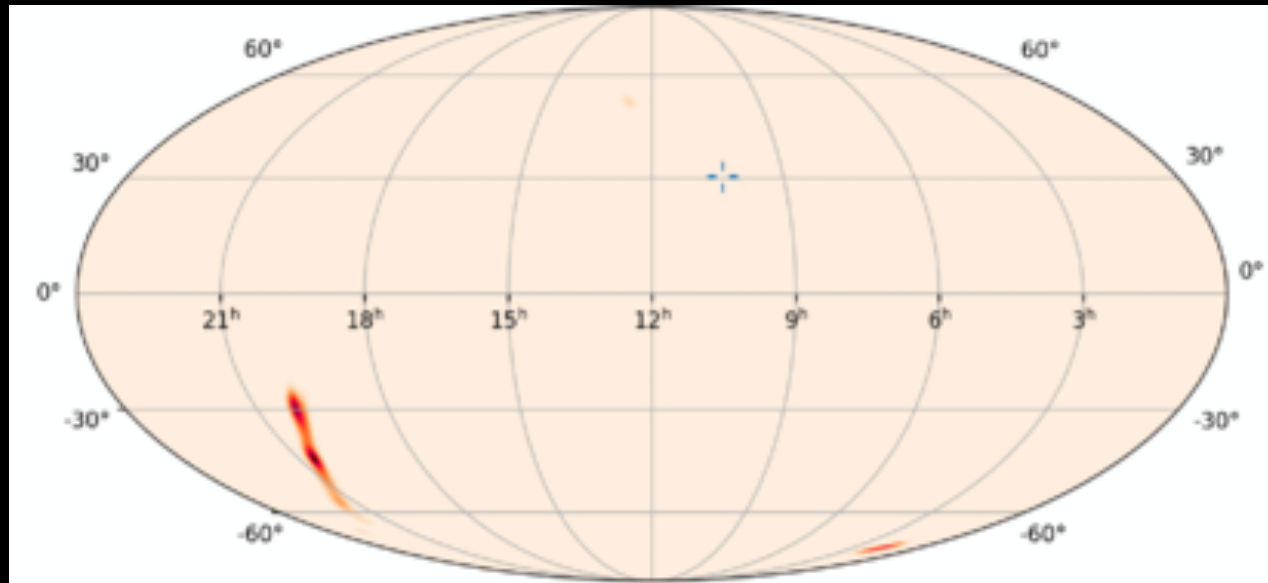
Subtracting glitches



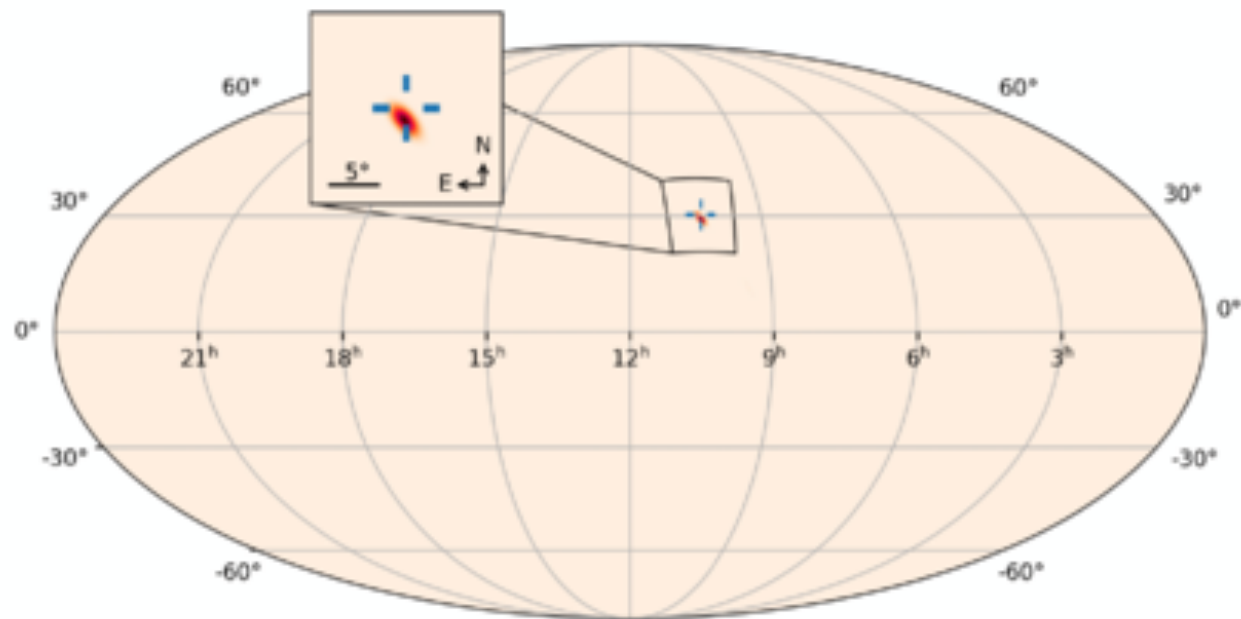
Bayeswave - models non-Gaussian features (both signal+glitch) as a sum of sine-Gaussian wavelets. Only uses strain data

gwsbtract - linear subtraction algorithm that uses auxiliary witness information

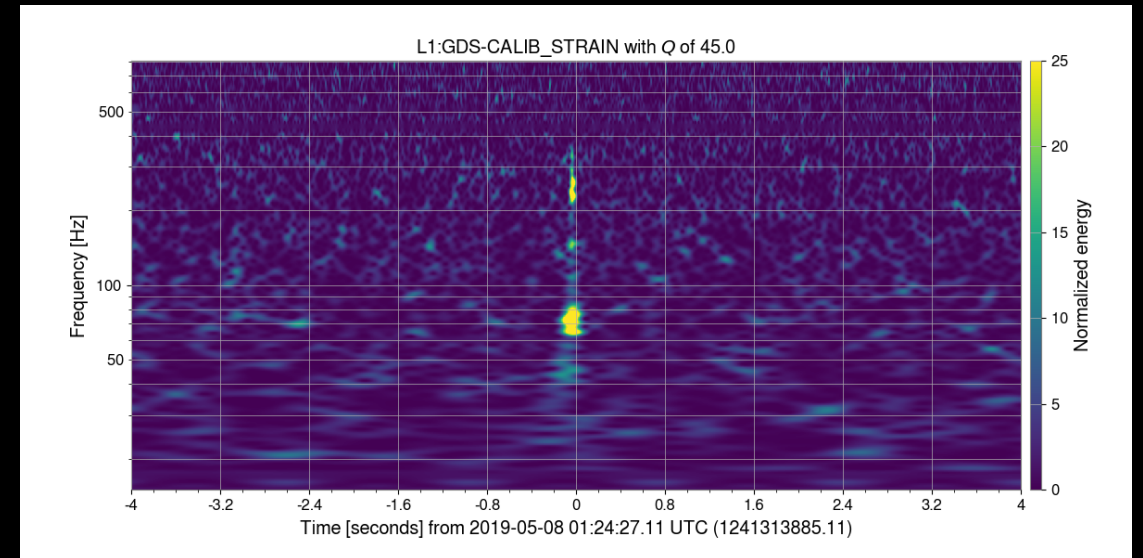
Noise can make it difficult to trust estimation of parameters



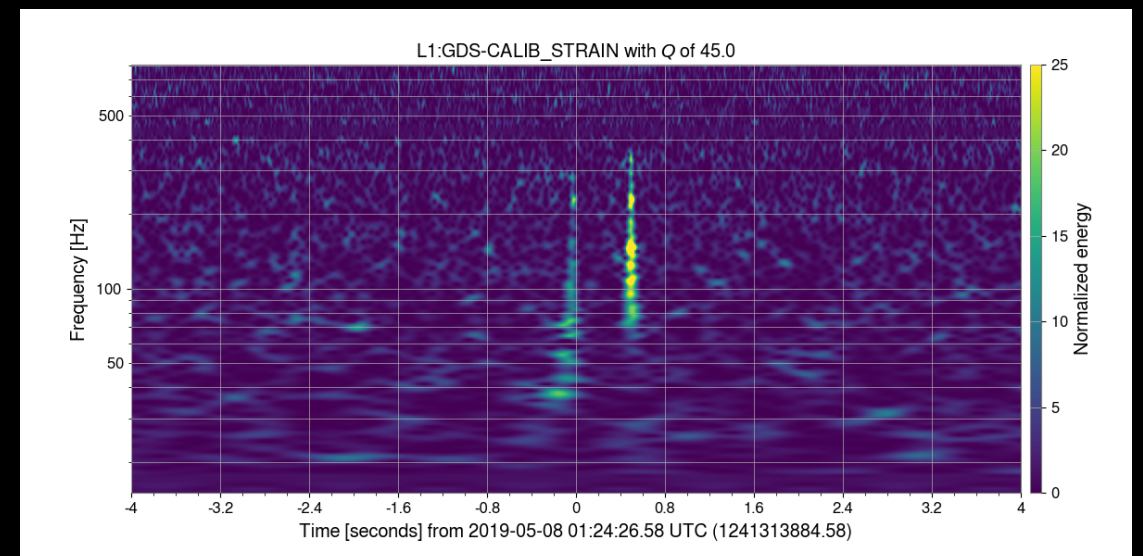
(a) Sky localisation of a GW150914-like event injected at $t_0 + 30$ ms relative to the blip glitch central time t_0 . The 90% credible area is 137 deg^2 .



(b) Identical skymap to Fig. 4a except that the injected GW signal was phase-shifted by $\pi/2$. The 90% credible area is 8 deg^2 .



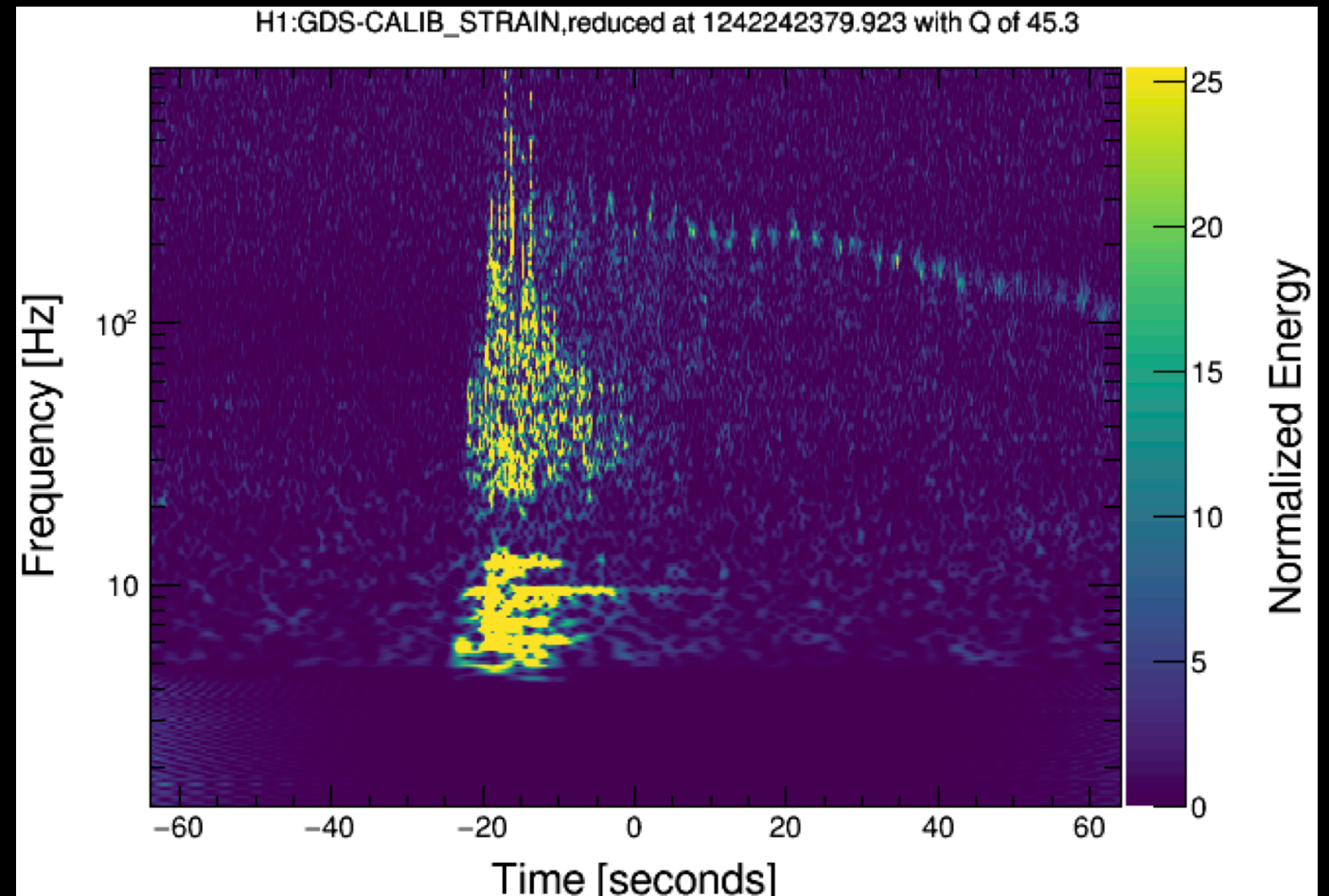
Find that if a $30M_{\odot}+30M_{\odot}$ BBH signal overlaps with a blip glitch a very specific point in the waveform, then the sky estimate can be really wrong.



Some forms of noise can confuse a search...

S190518bb - binary neutron star?

- Extreme DQ issues at the time of the event at LIGO Hanford
- Further investigation revealed that the noise was caused by a nearby earthquake
- This candidate event was retracted after 30 minutes



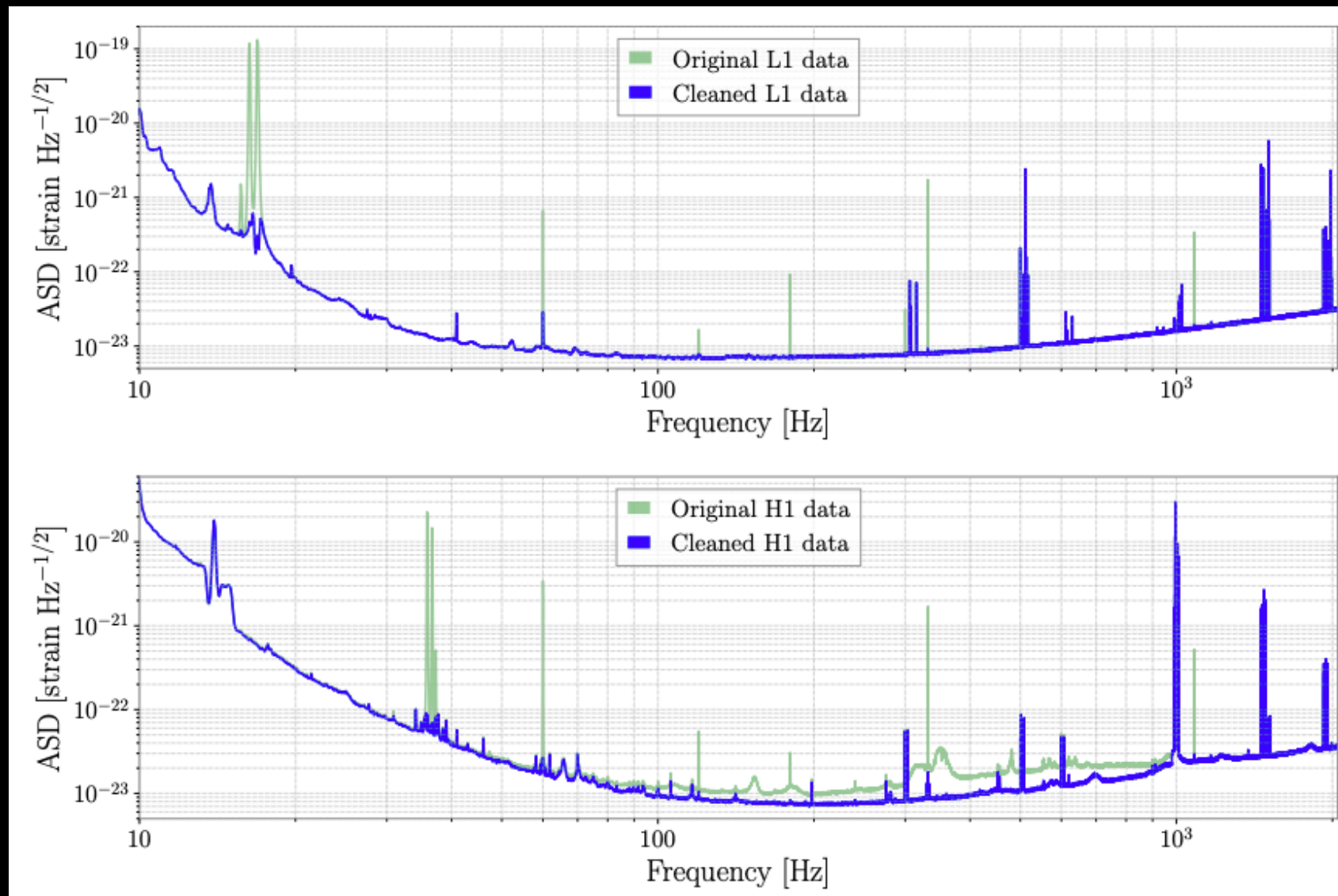
<https://gcn.gsfc.nasa.gov/other/S190518bb.gcn3>

Cleaning large amounts of data

Shaking of input laser table caused by turbulent water flows used to cool the laser resulted in extra noise at LIGO-Hanford

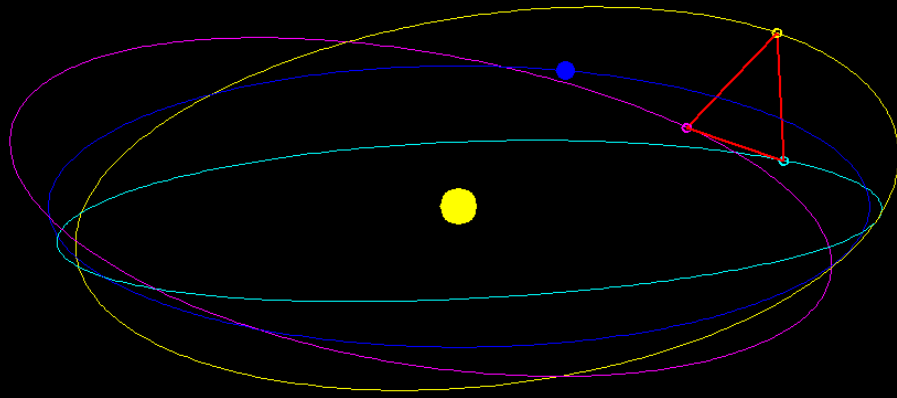
This noise was successfully measured using auxiliary witnesses and subtracted

Numerous line effects (due to calibration and correlations with the 60Hz mains) were also subtracted

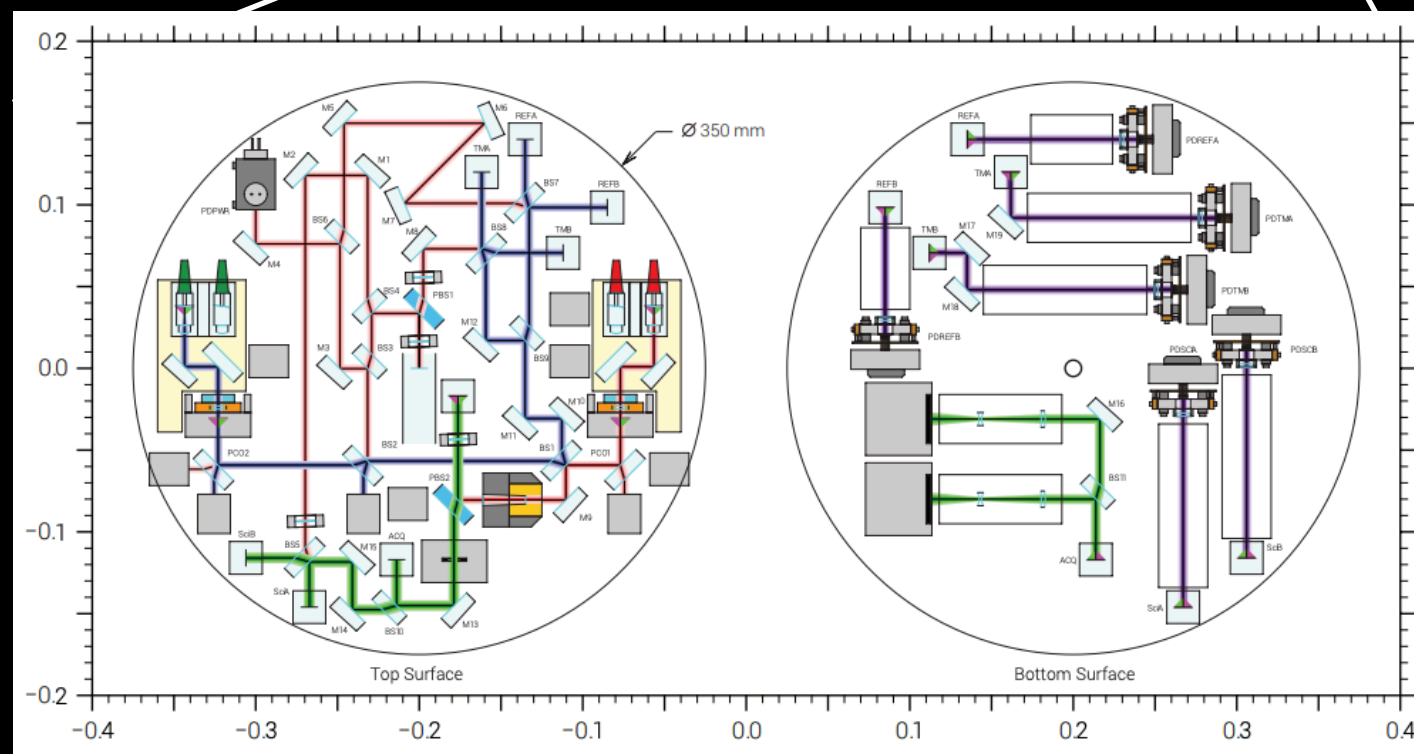
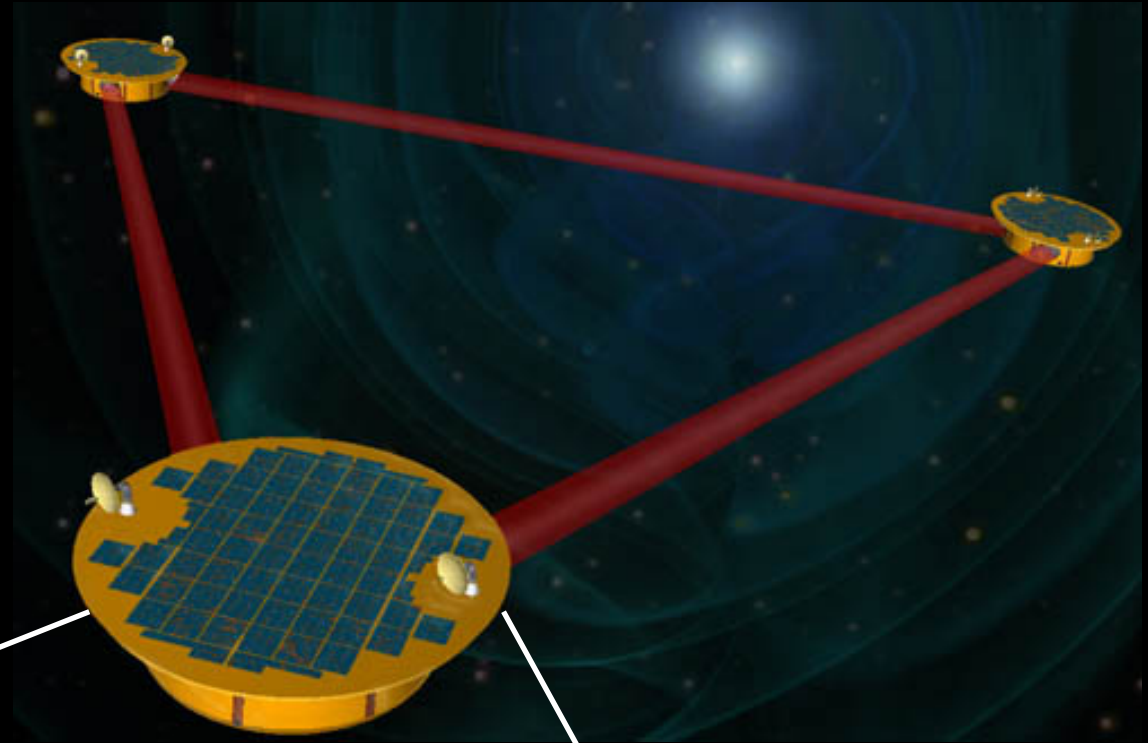


LISA

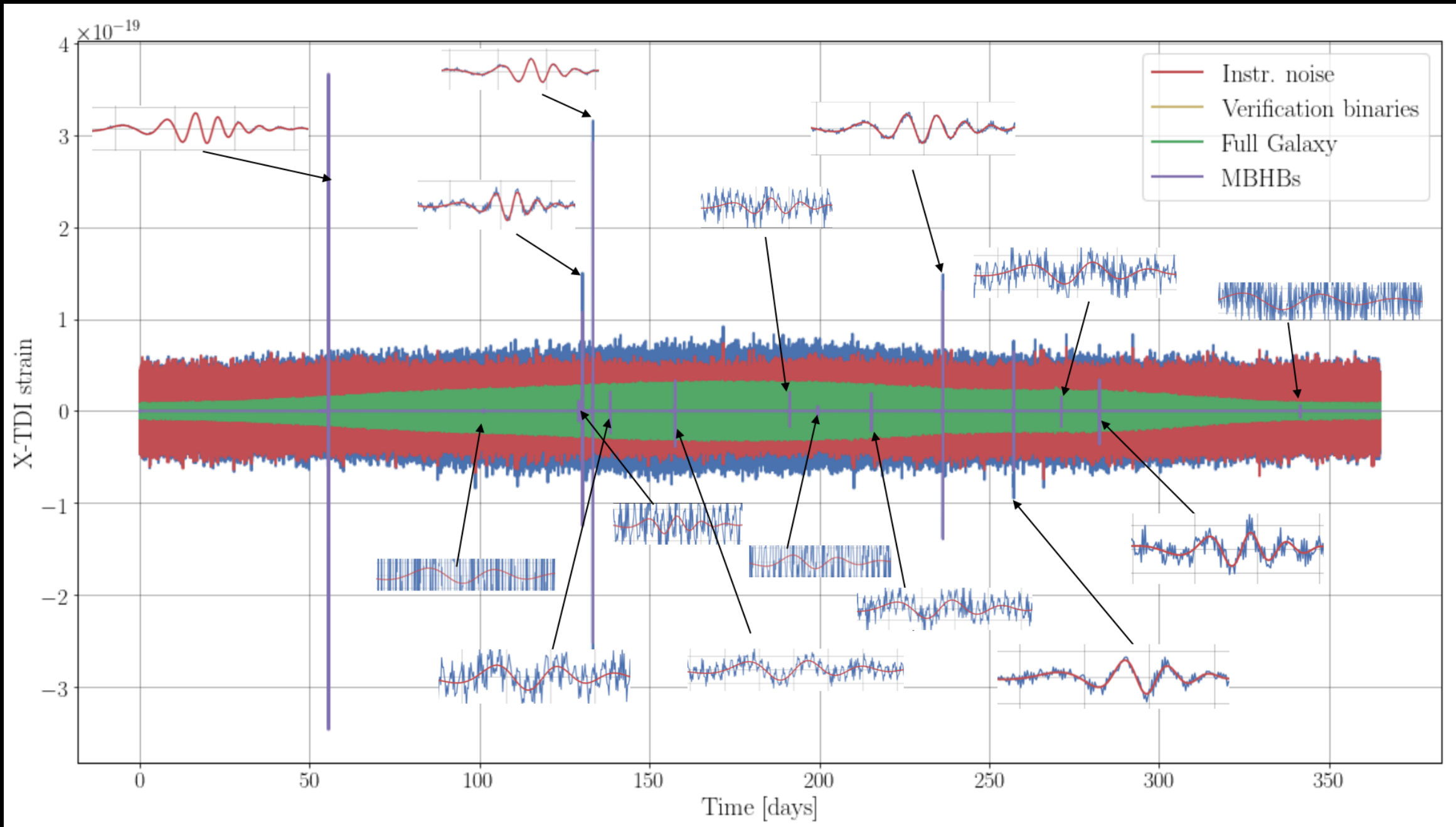
Laser Interferometer Space Antenna



Nicolas Douillet - ARTEMIS



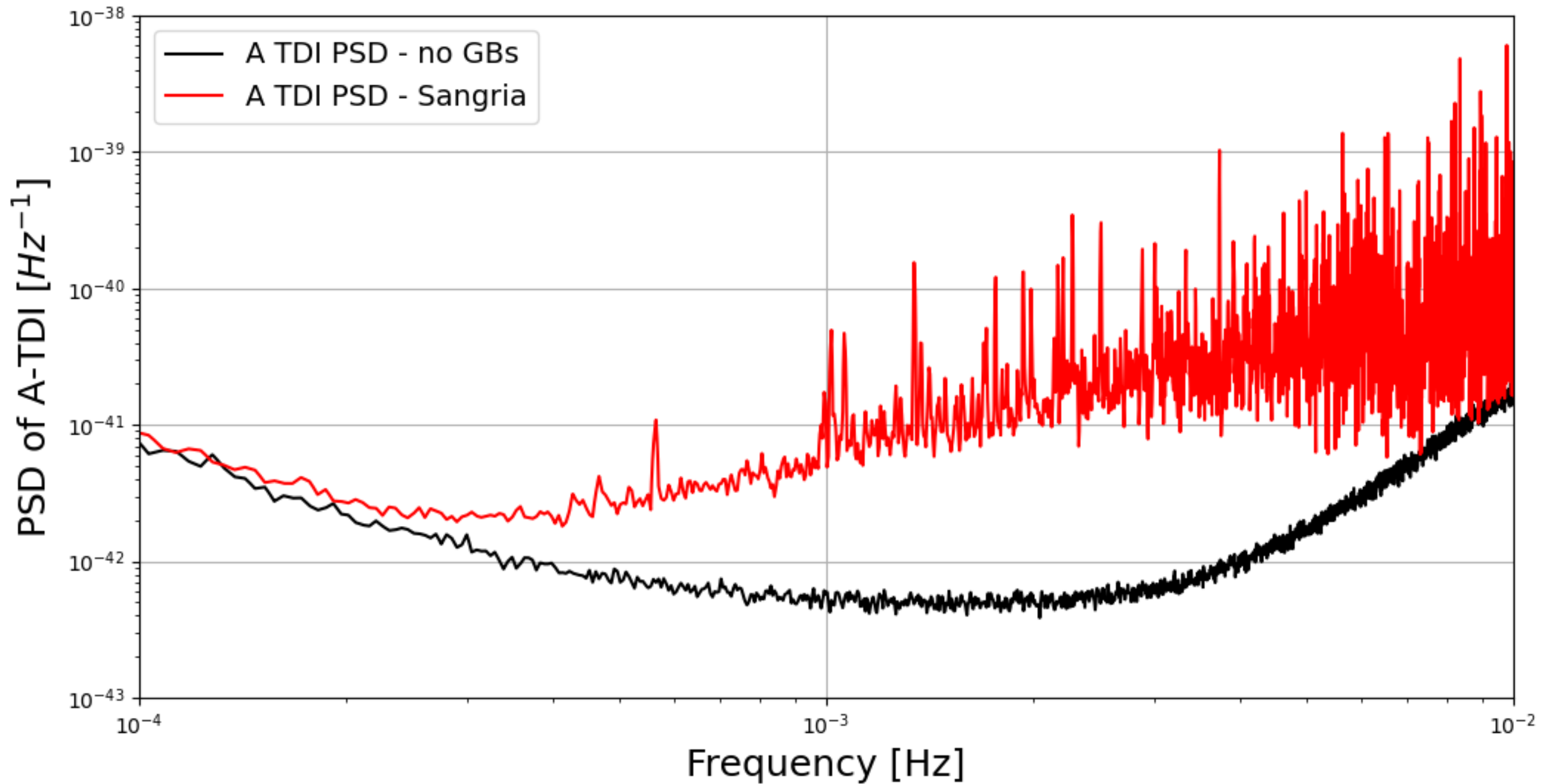
LISA Data Challenge



Sangria - Massive black hole binaries and galactic binaries injected in to Gaussian Noise

More information at: <https://lisa-ldc.lal.in2p3.fr/>

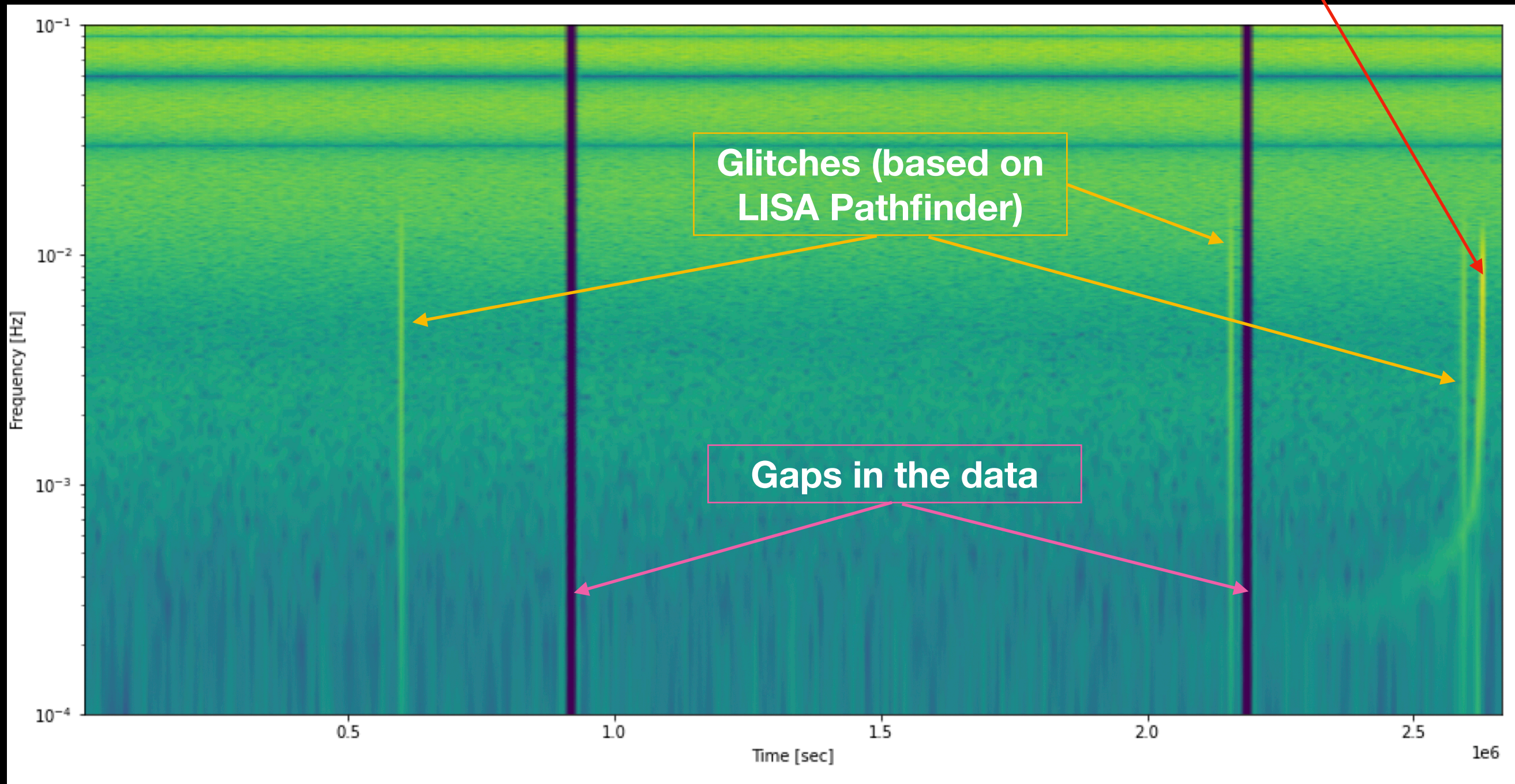
Estimating the noise - the annoyance of galactic binaries



Spritz

<https://lisa-ldc.lal.in2p3.fr/>

Massive black hole
binary



- K. Dey et al., 2021, PRD 104, 044035 - Effect of data gaps on the detectability and parameter estimation of MBHBs
- Q. Baghi et al., 2019, PRD 100, 022003 - GW parameter estimation with gaps in LISA - a data augmentation method

Challenges in GW DQ

- Non-Stationary noise
 - both instrument and source related
- Non gaussian noise transients (or glitches)
 - different timescales depending on the instrument, and these will affect source characterisation in different ways
- Noise lines
 - More likely to affect persistent sources of GWs
- Gaps in the data
- Unknown - you don't know for sure until you turn on the detector...

A 3D visualization of spacetime curvature. The background is a dark blue grid that warps into a deep well. Two Earth-like spheres are positioned in the center of the well. The word "Questions?" is written in white text across the middle of the image.

Questions?