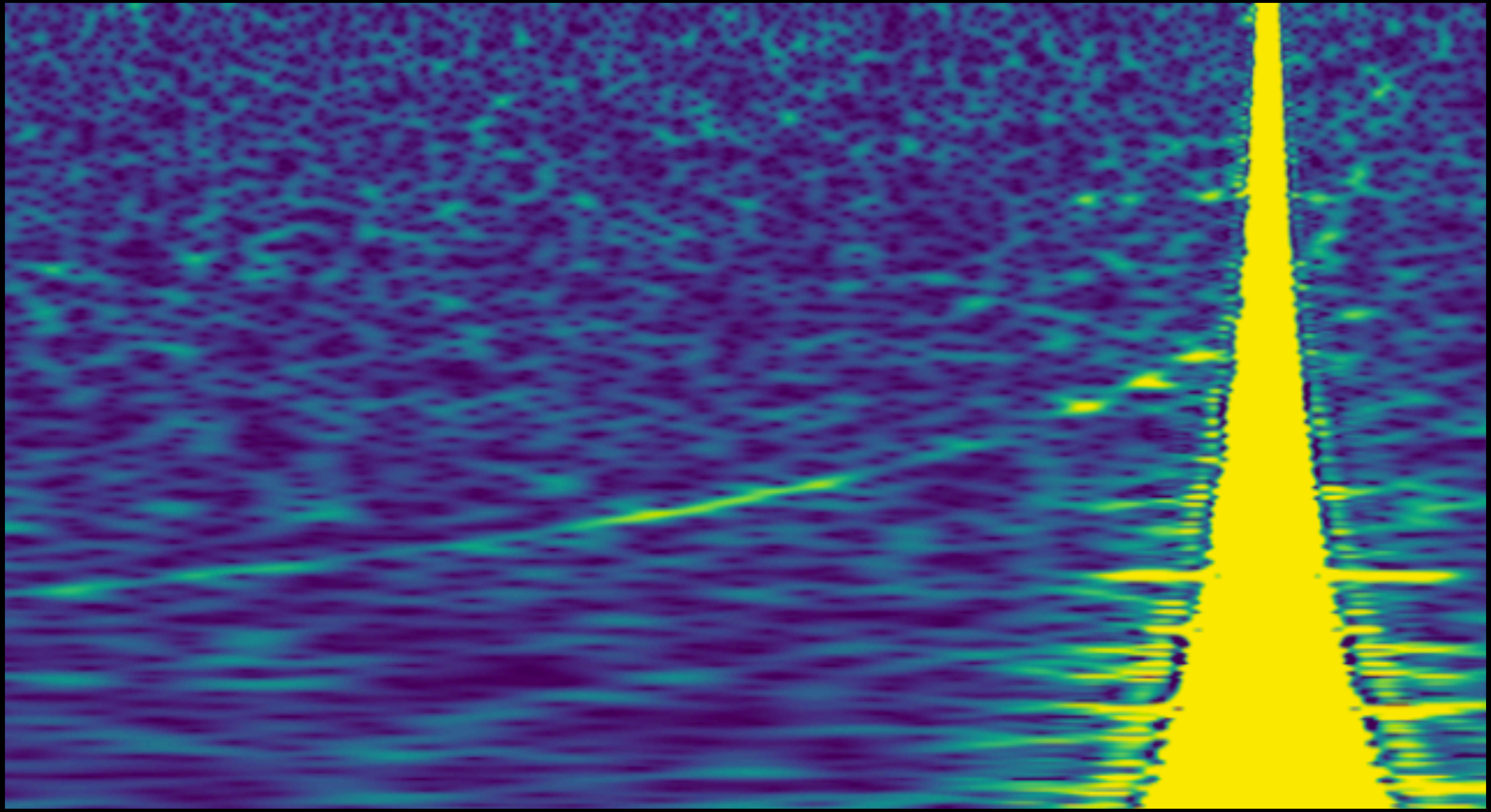
Mitigating noise artifacts in gravitational-wave detector data in the era of open public alerts



Dr. Jess McIver
on behalf of the LIGO-Virgo Collaboration

January 28, 2019

Outline

Advanced gravitational wave interferometers and noise

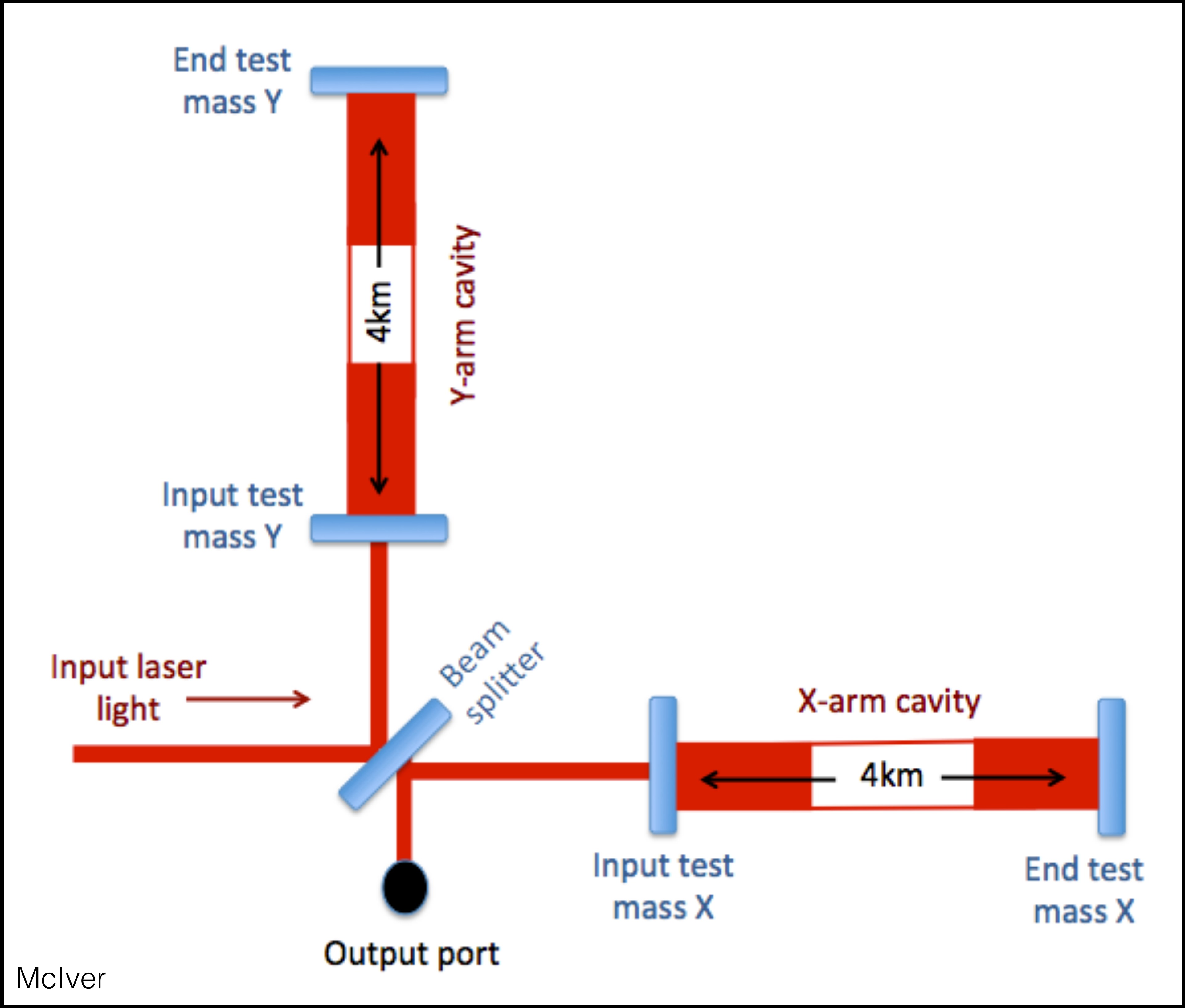
The challenges of transient detector noise:

- The impact of noise on identifying transient GW events
- Validating event candidates in noisy data

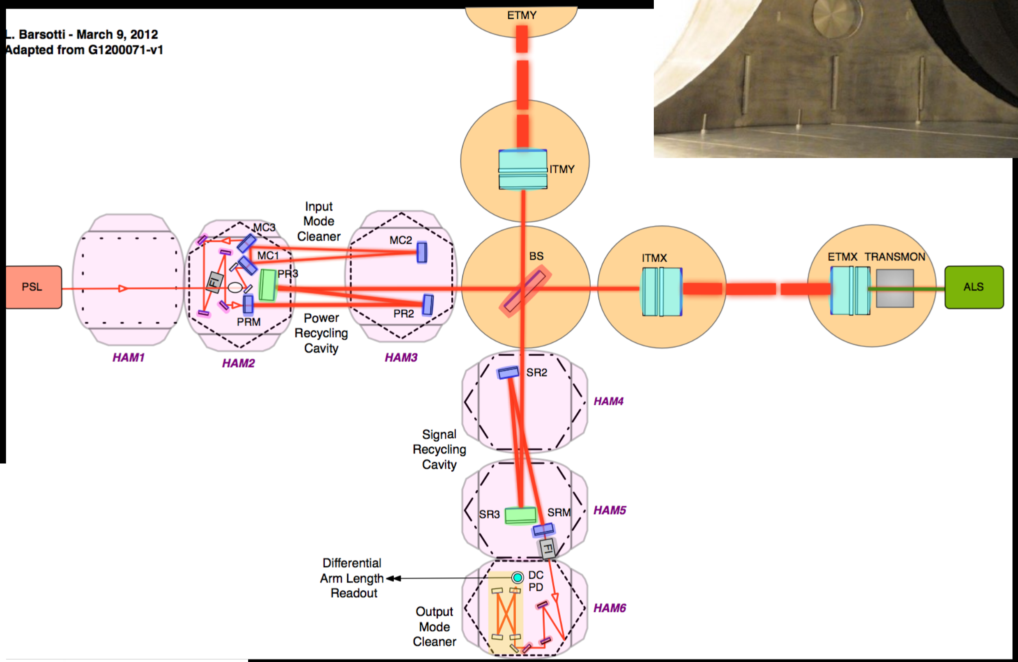
Past computational approaches

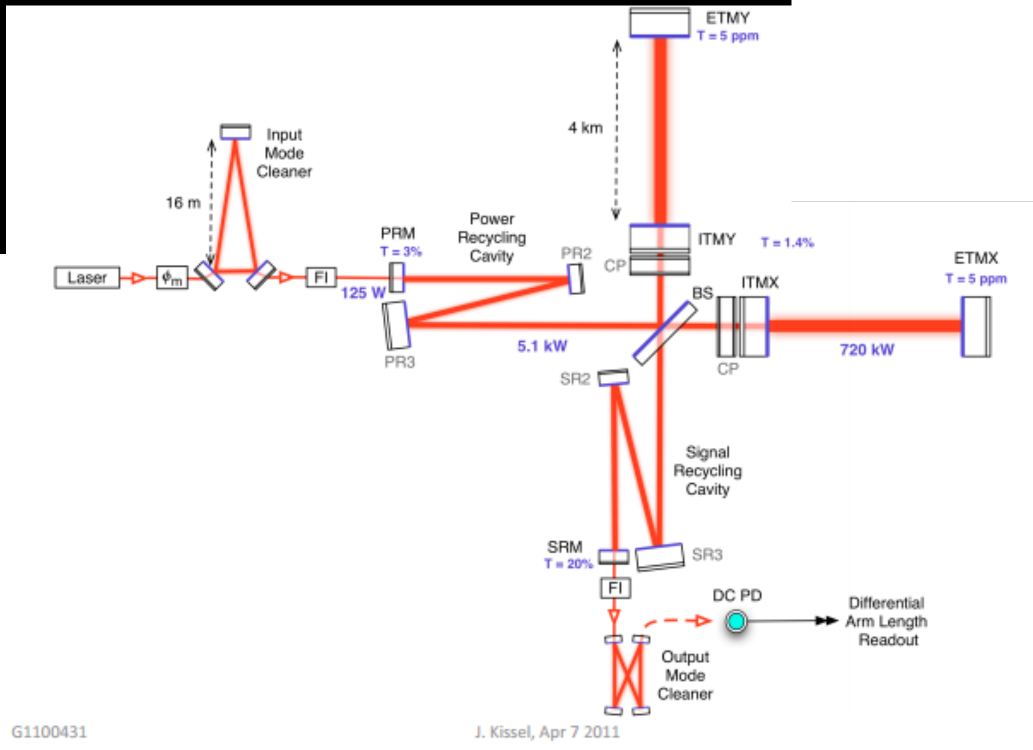
Future computational strategies

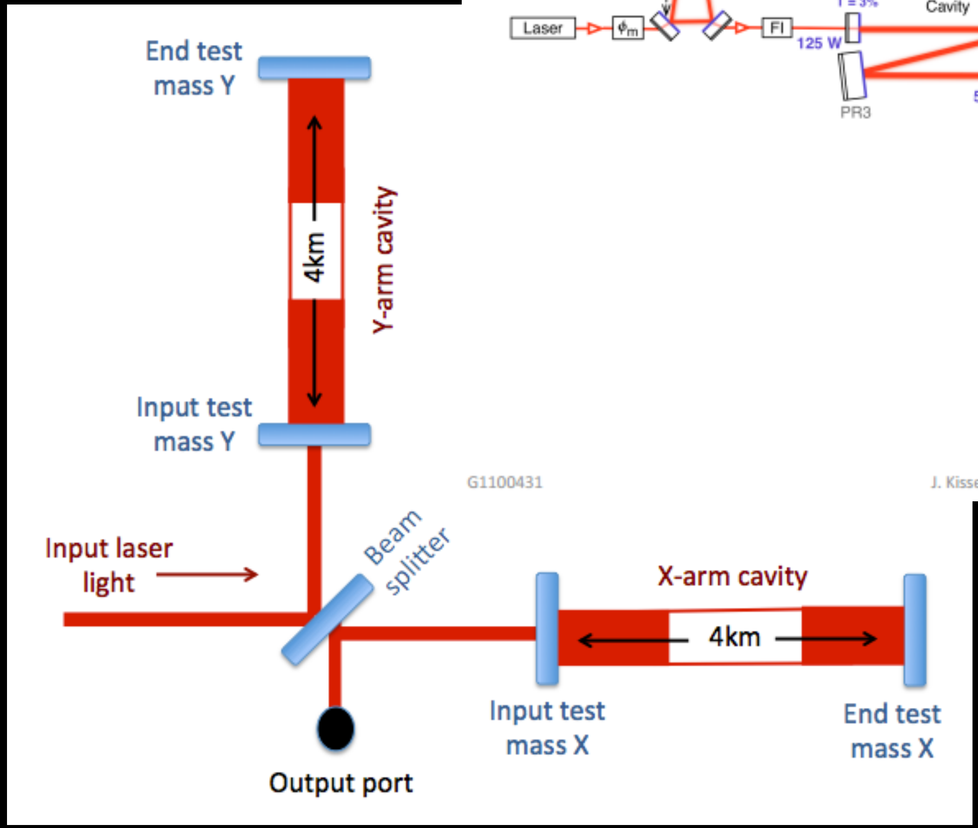
Observing GWs with interferometry



Advanced LIGO is extremely complex.



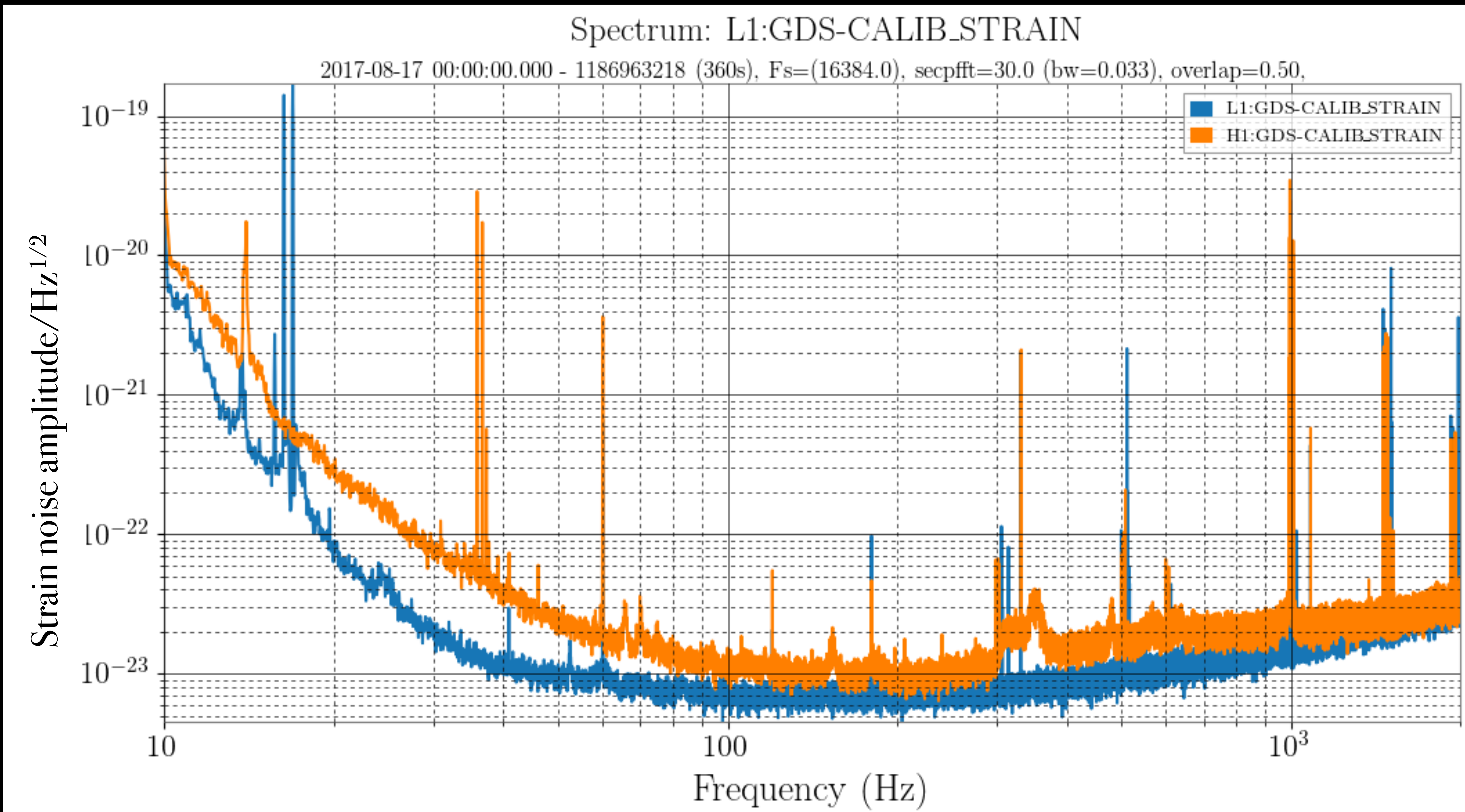




Reality

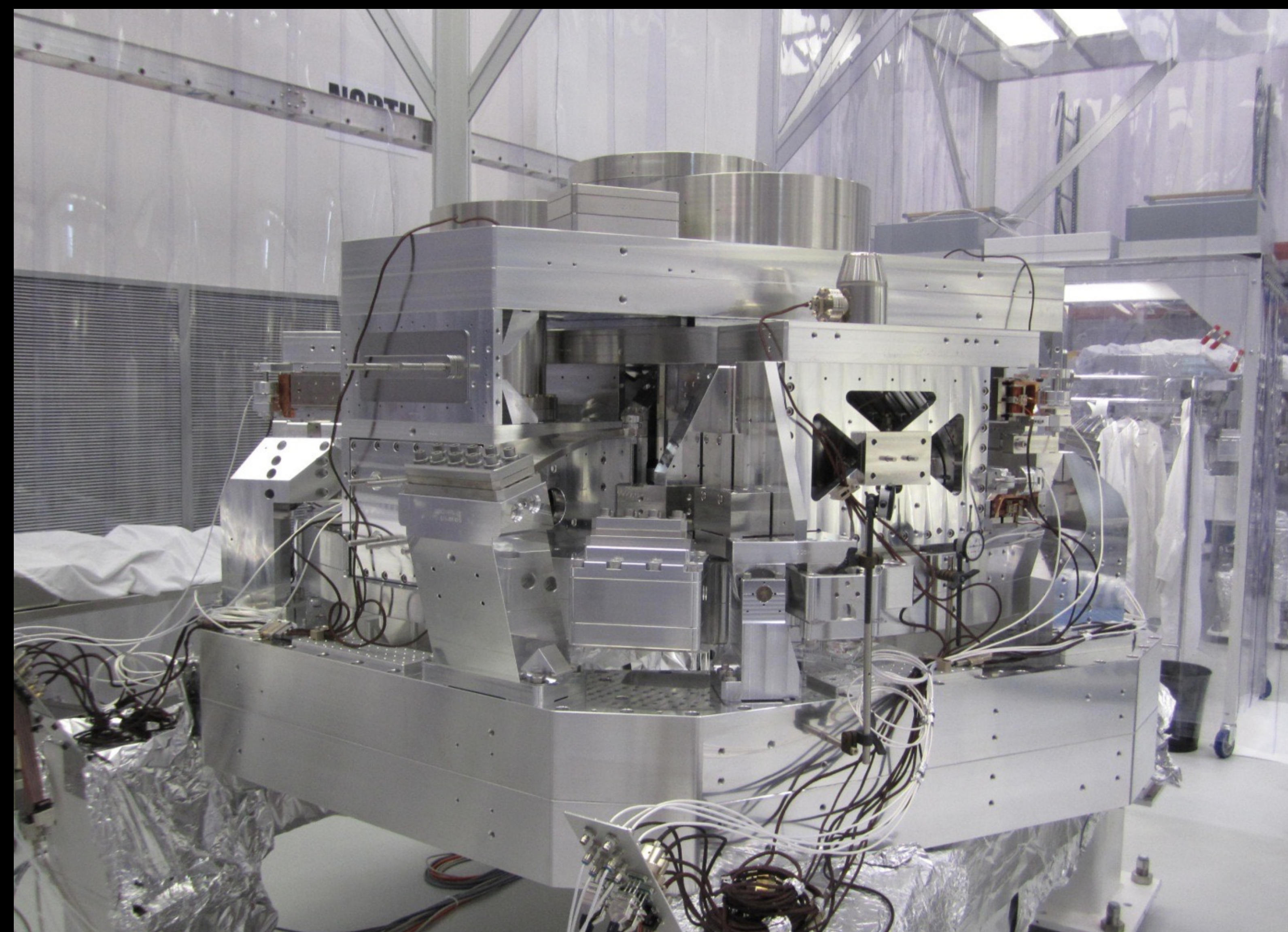
Adapted from D. Shoemaker

Advanced LIGO noise in O2



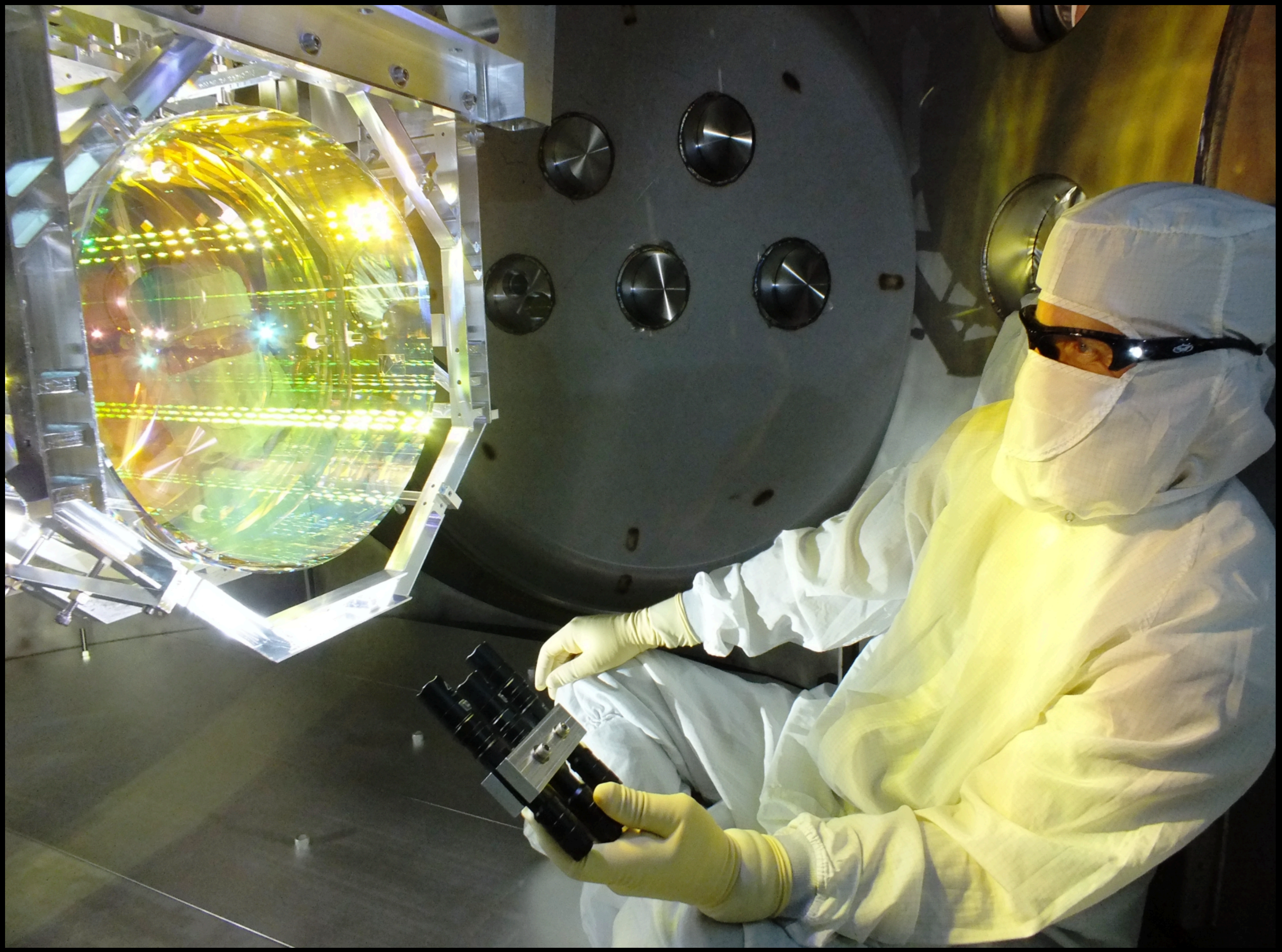
Made with ligoDV web: https://ldvw.ligo.caltech.edu/ldvw/view

Seismic isolation: active isolation

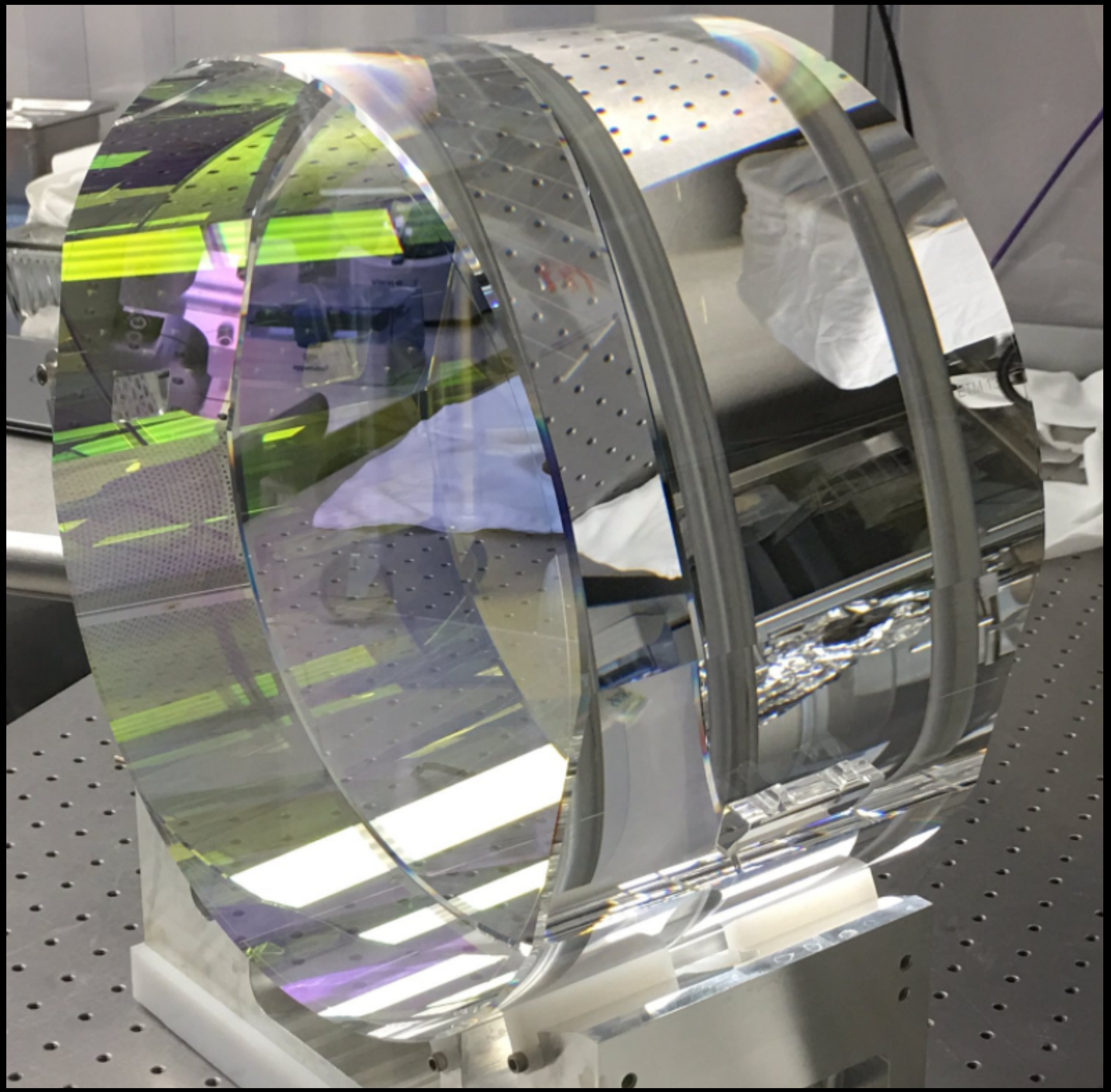


LIGO/Caltech

Advanced LIGO optics

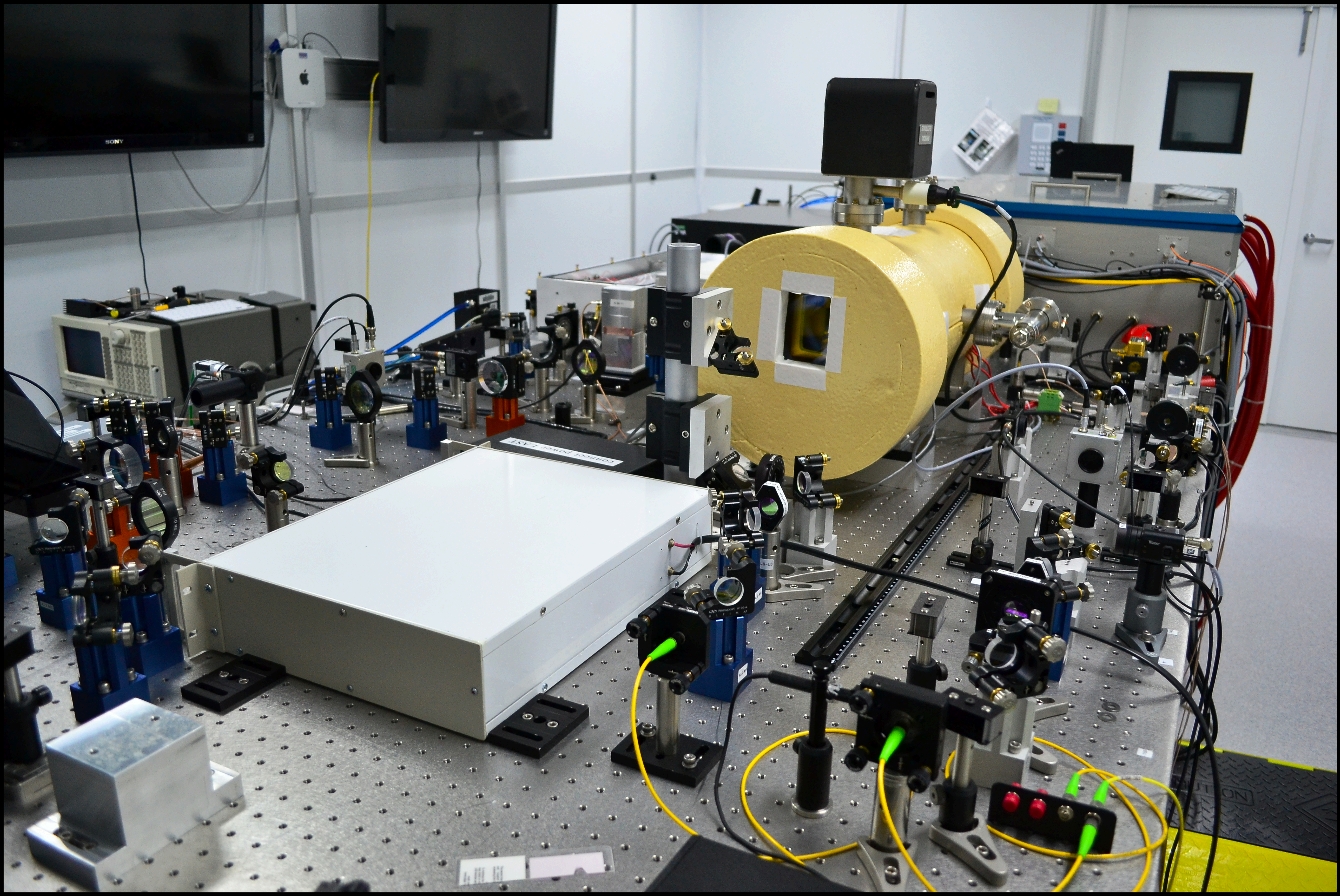


M. Heintze



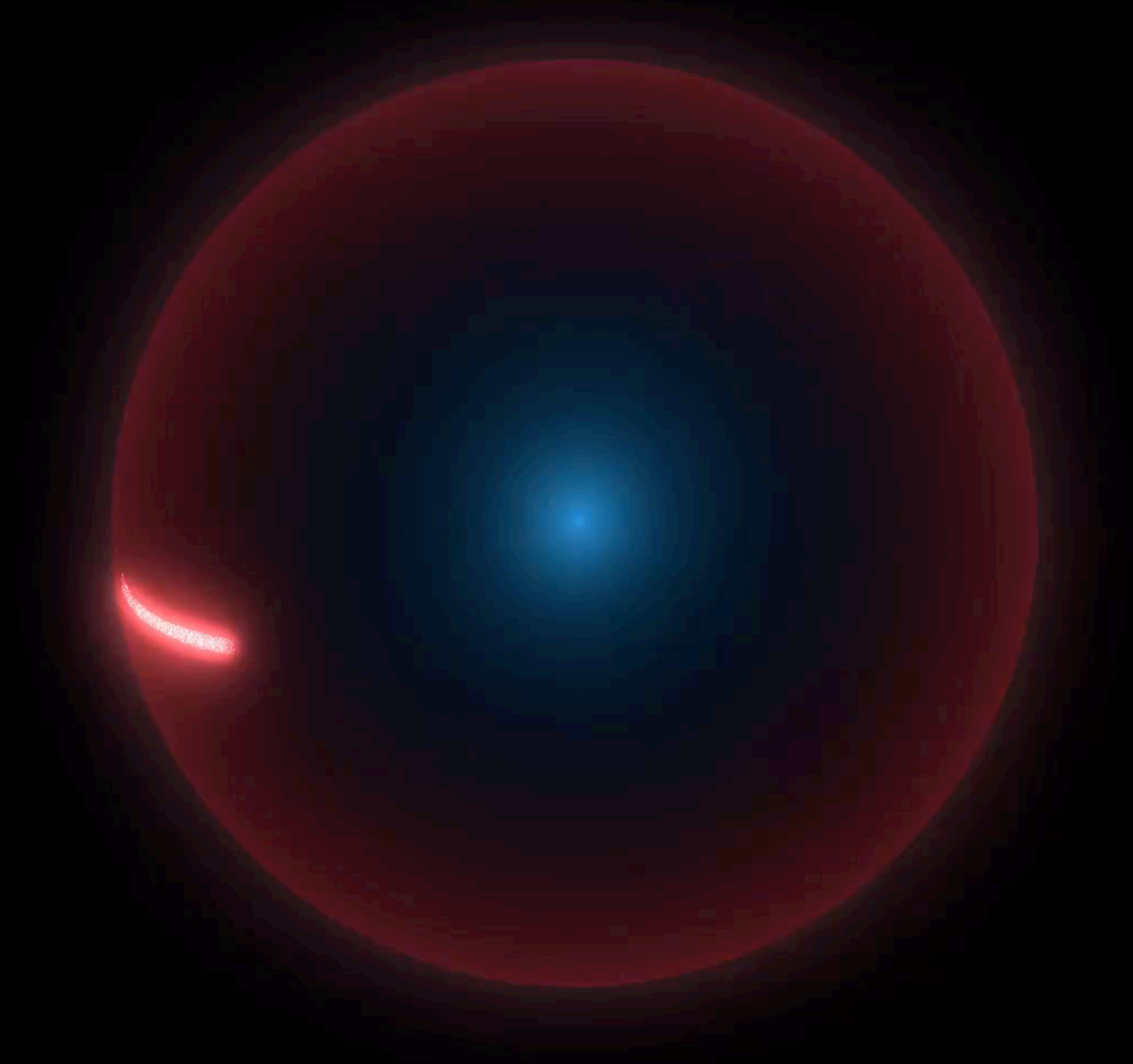
K. Toland

The Advanced LIGO input laser



AEI-Max Planck/LZH

LIGO detector sensitivity

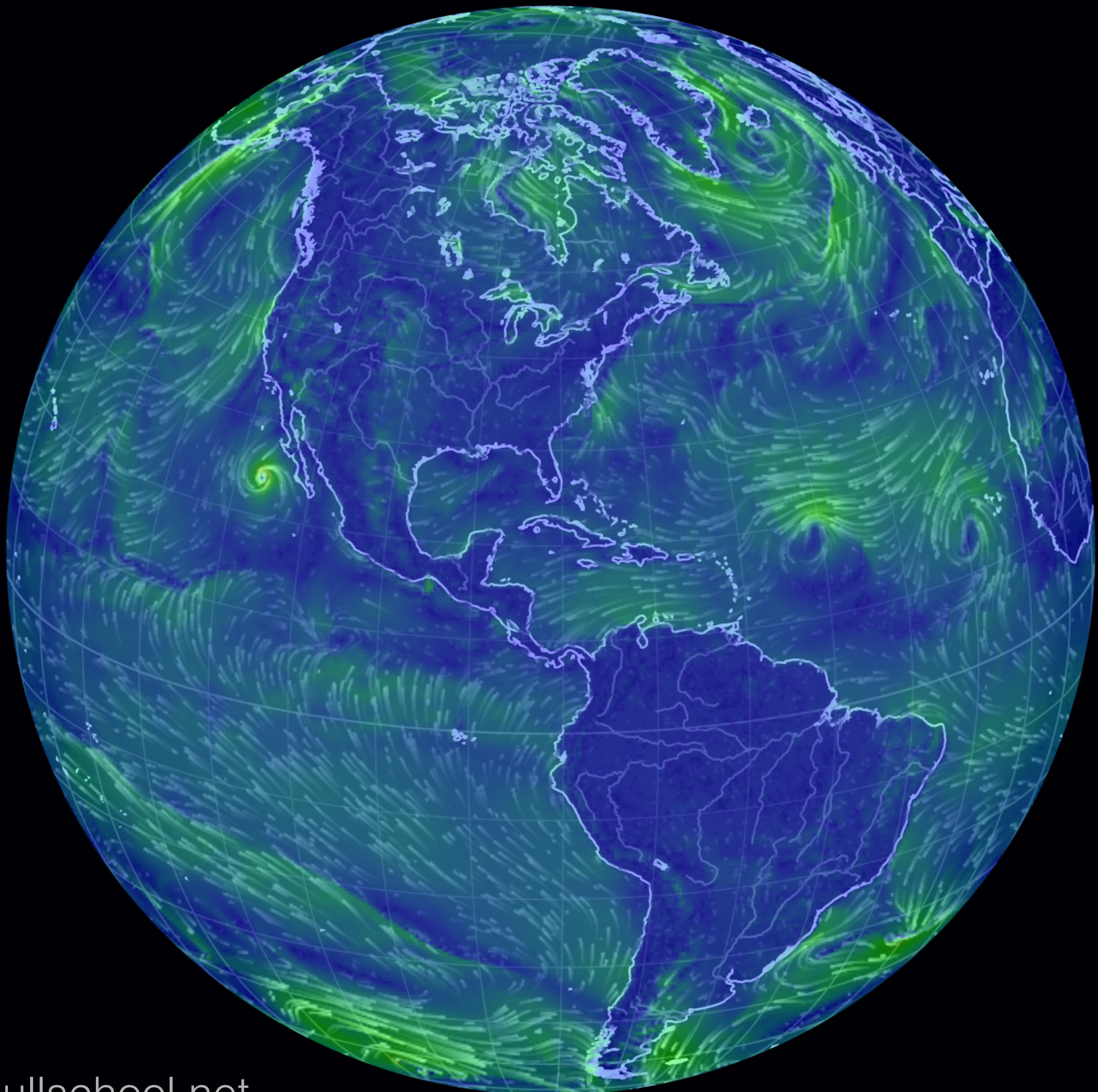


LIGO/Caltech

A three interferometer network
and EM observer partners

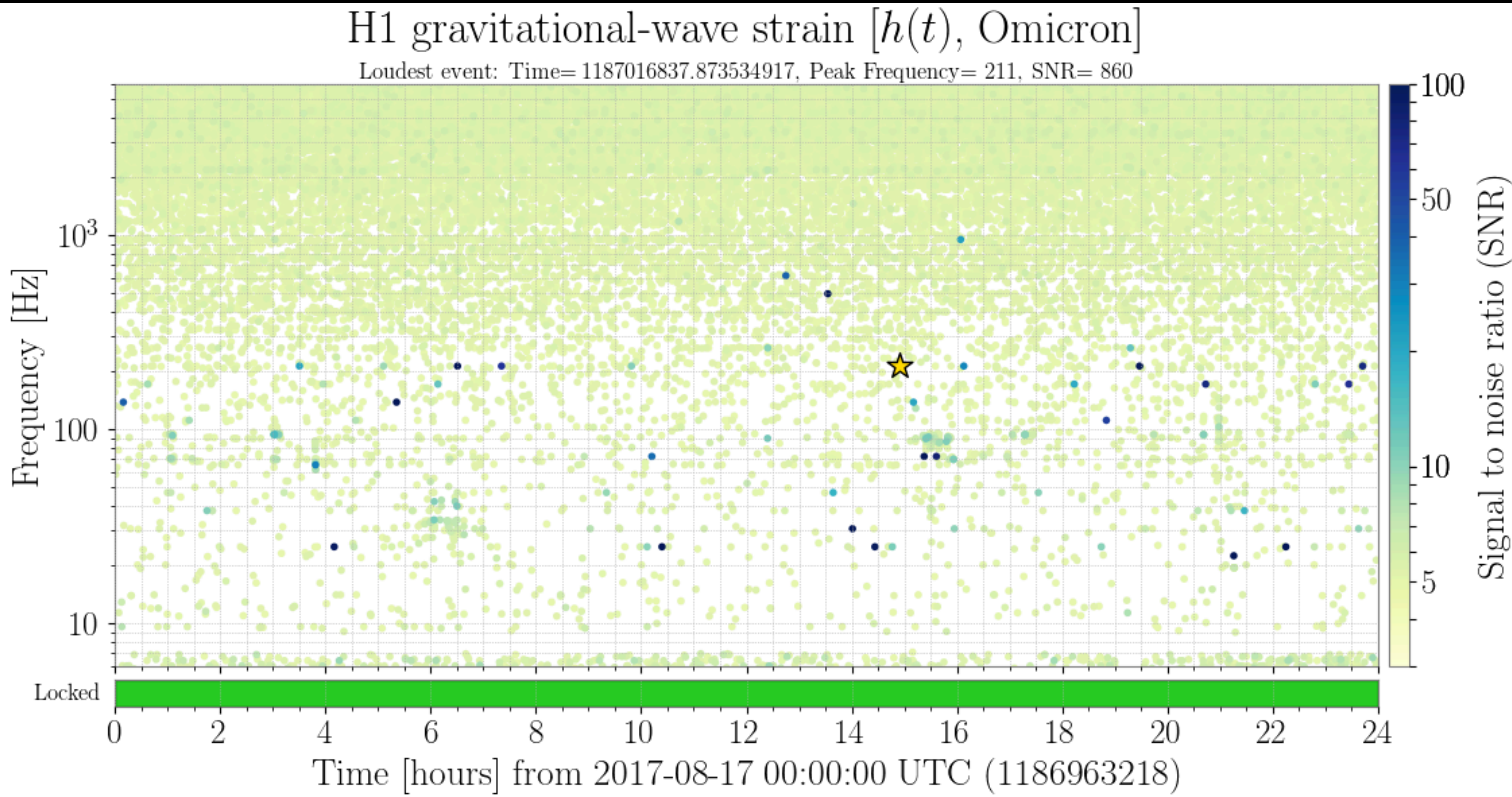
LIGO/Caltech

Interferometer stability



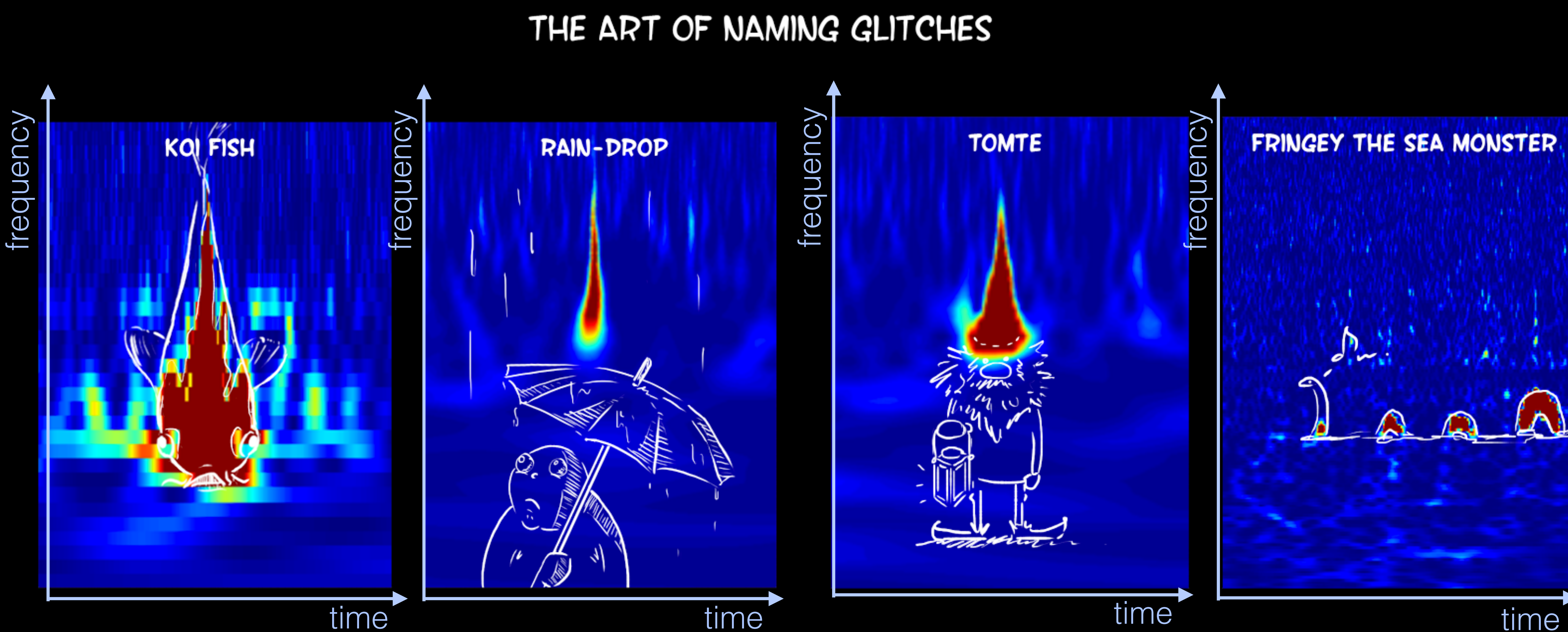
earth.nullschool.net

LIGO data is non-stationary!



https://ldas-jobs.ligo-wa.caltech.edu/~detchar/summary/

LIGO data is non-stationary!

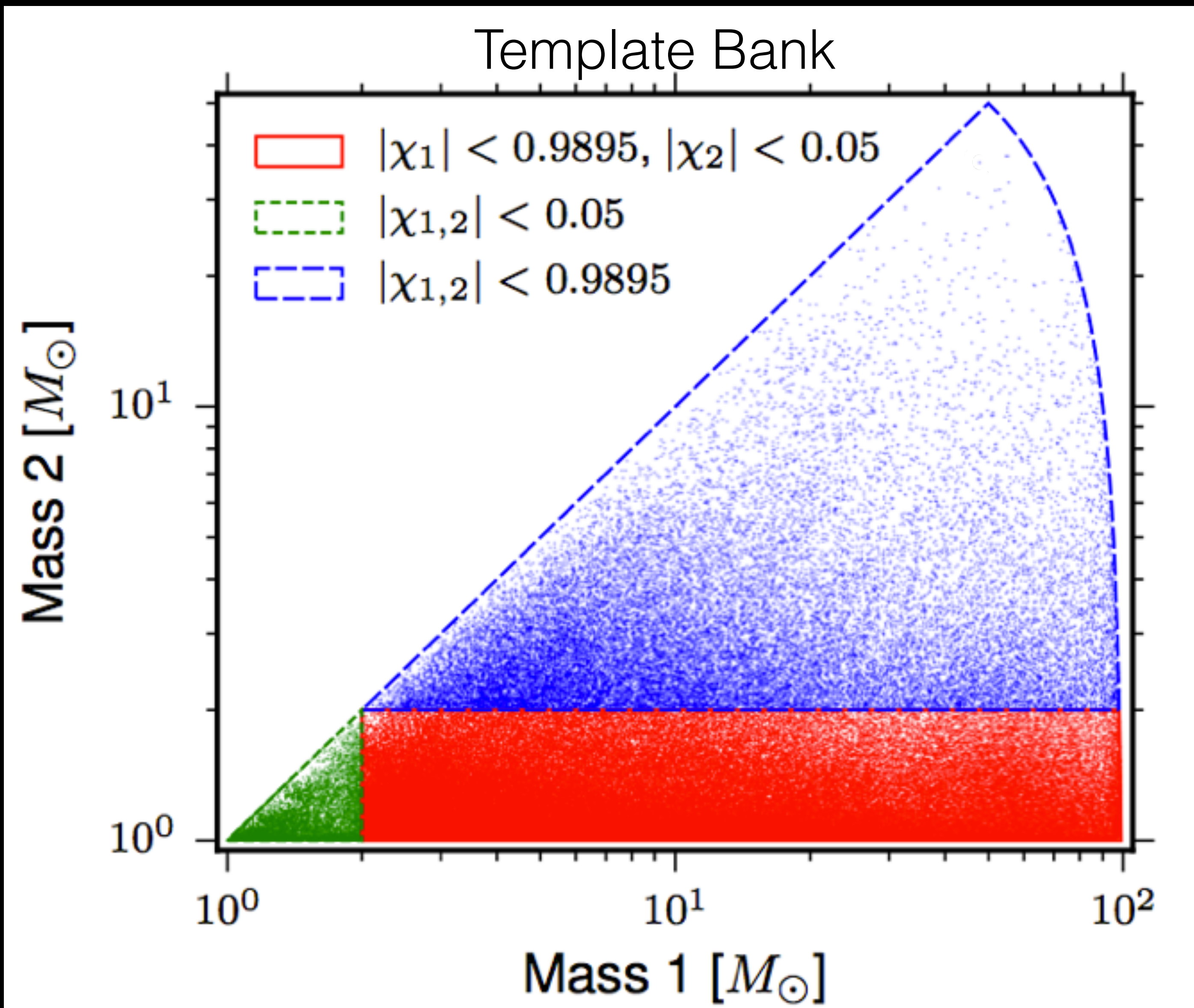


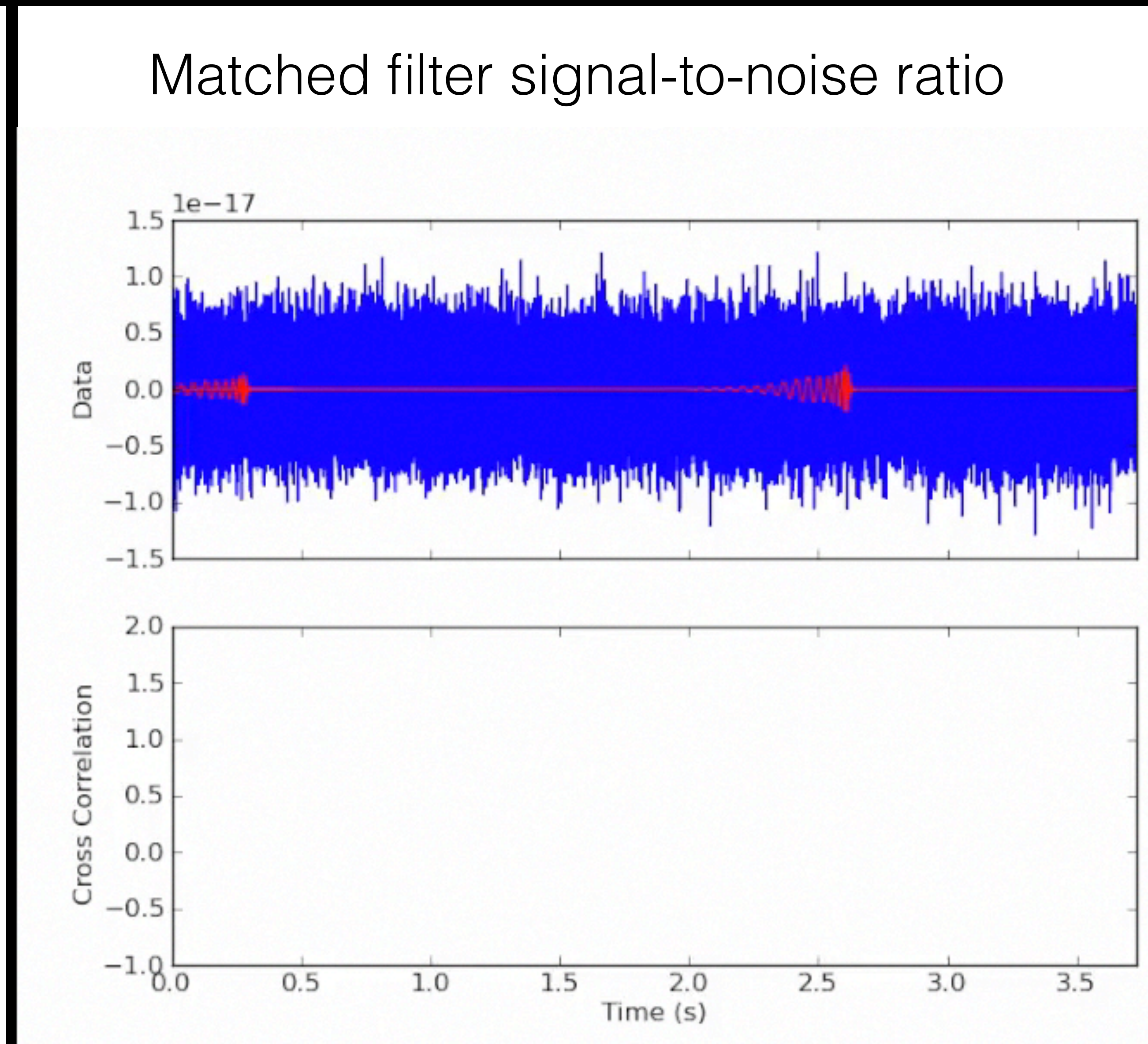
Nutsinee Kijbunchoo

ANTIMATTERWEBCOIMICS.COM

Searching for signals with matched filtering

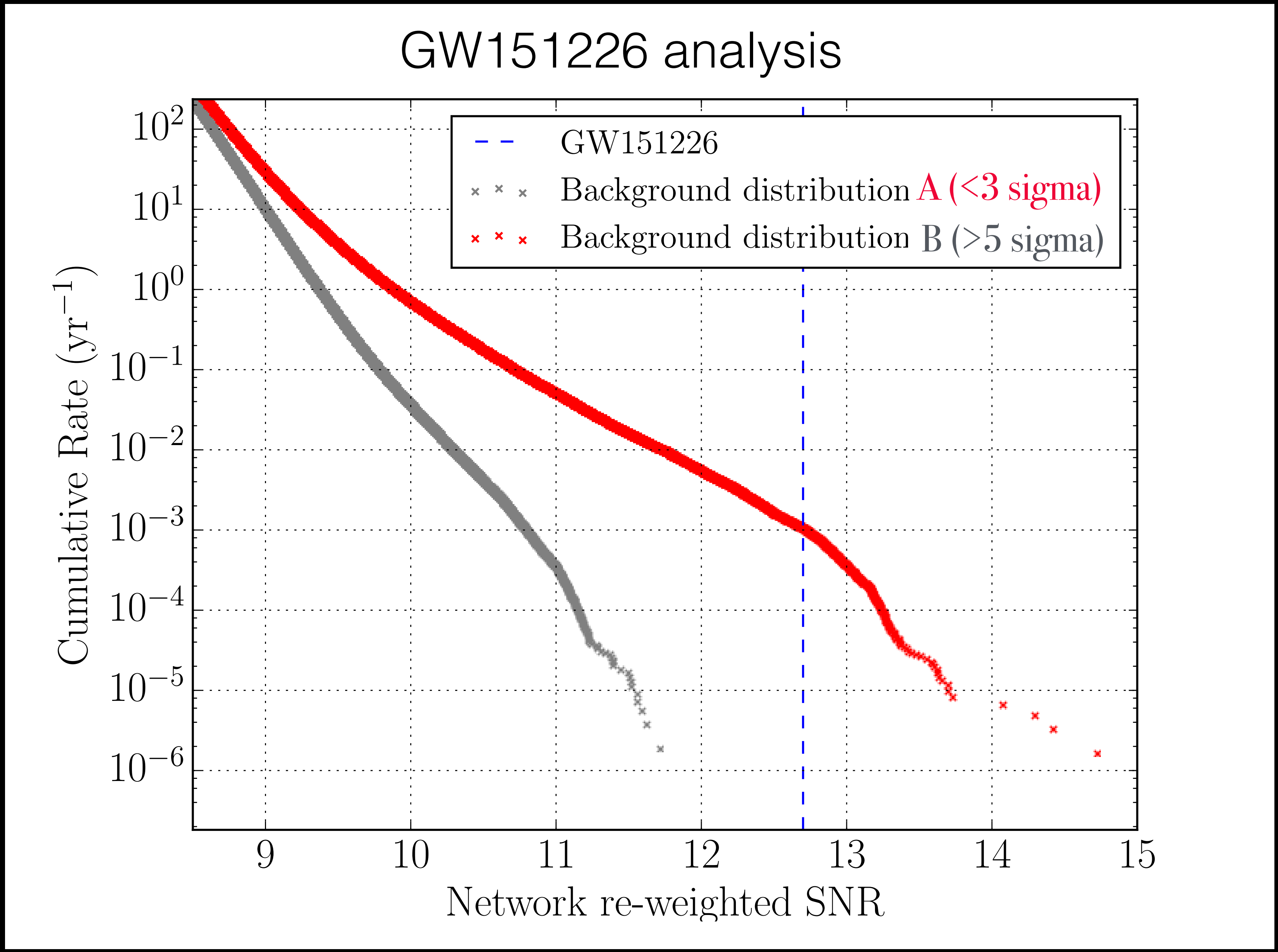
Slide adapted from S. Caudill





B. P. Abbott et al. Phys. Rev. X (2016)

The significance of a detected event



B.P Abbott et al. CQG (2018)

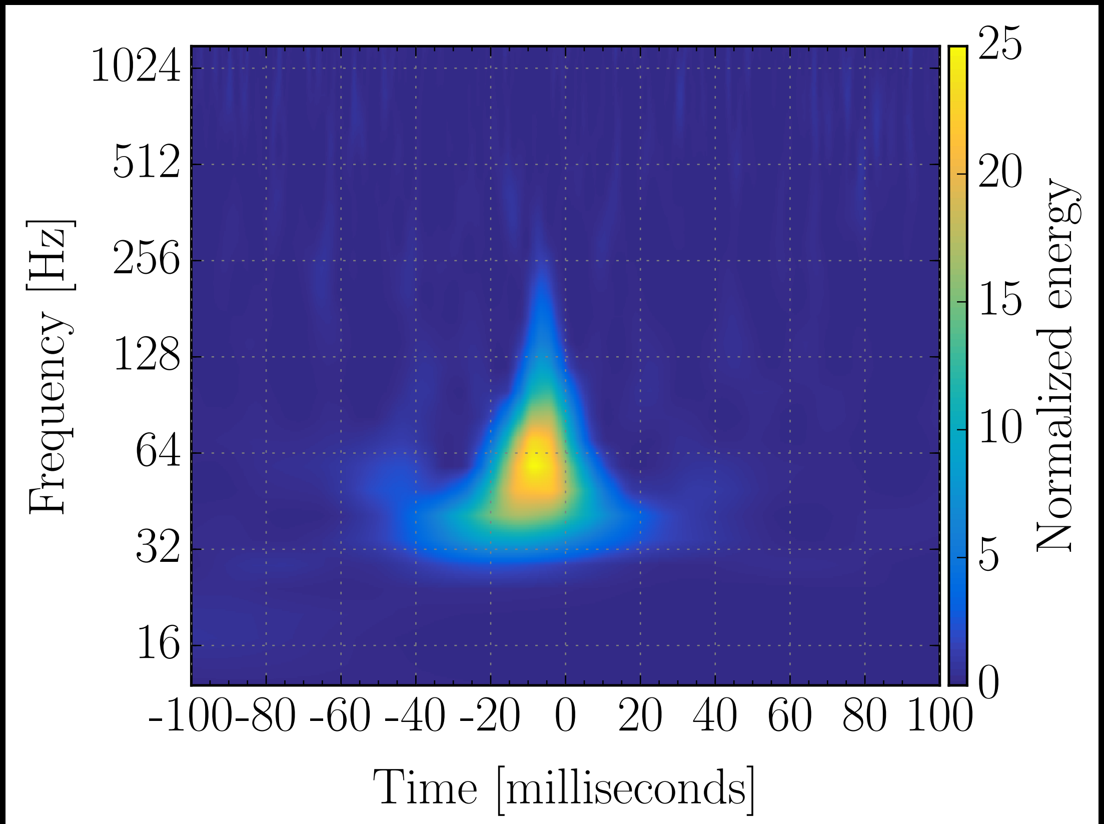
The most problematic glitches

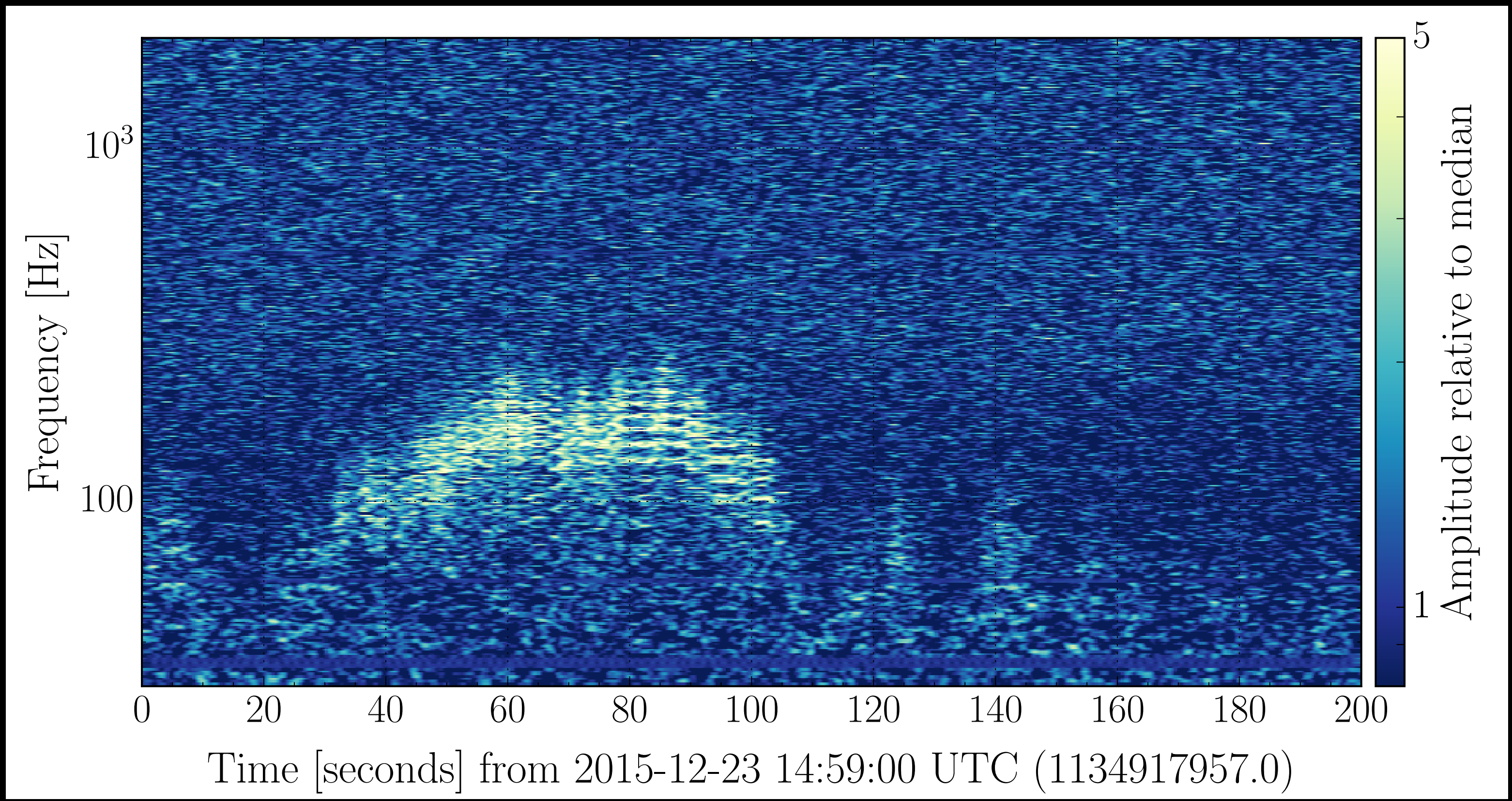
Blip glitches

- The biggest contributor to the transient GW search backgrounds
- Seen in both LIGO detectors (non-coincident)
- No known correlation with instrument behavior or environment.

60-200 Hz non-stationary noise

- Pollutes LIGO-Livingston data in a critical frequency range (~50-500Hz)
- Longer duration (10s or 100s of seconds)
- Major contributor to CBC and burst backgrounds

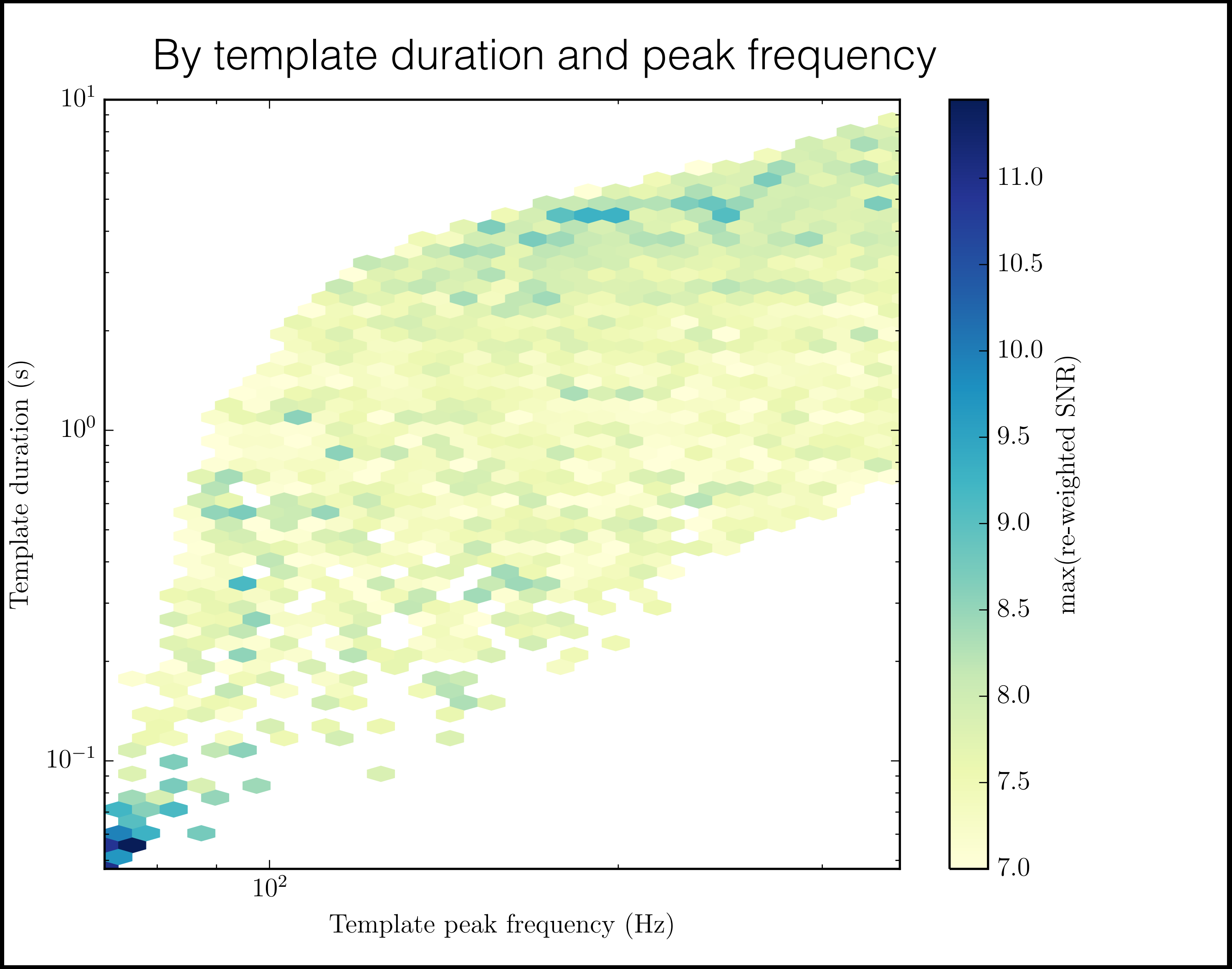




B.P Abbott et al. CQG (2018)

CBC templates most susceptible to background noise

Highest re-weighted SNR of LIGO-Livingston CBC triggers during O1

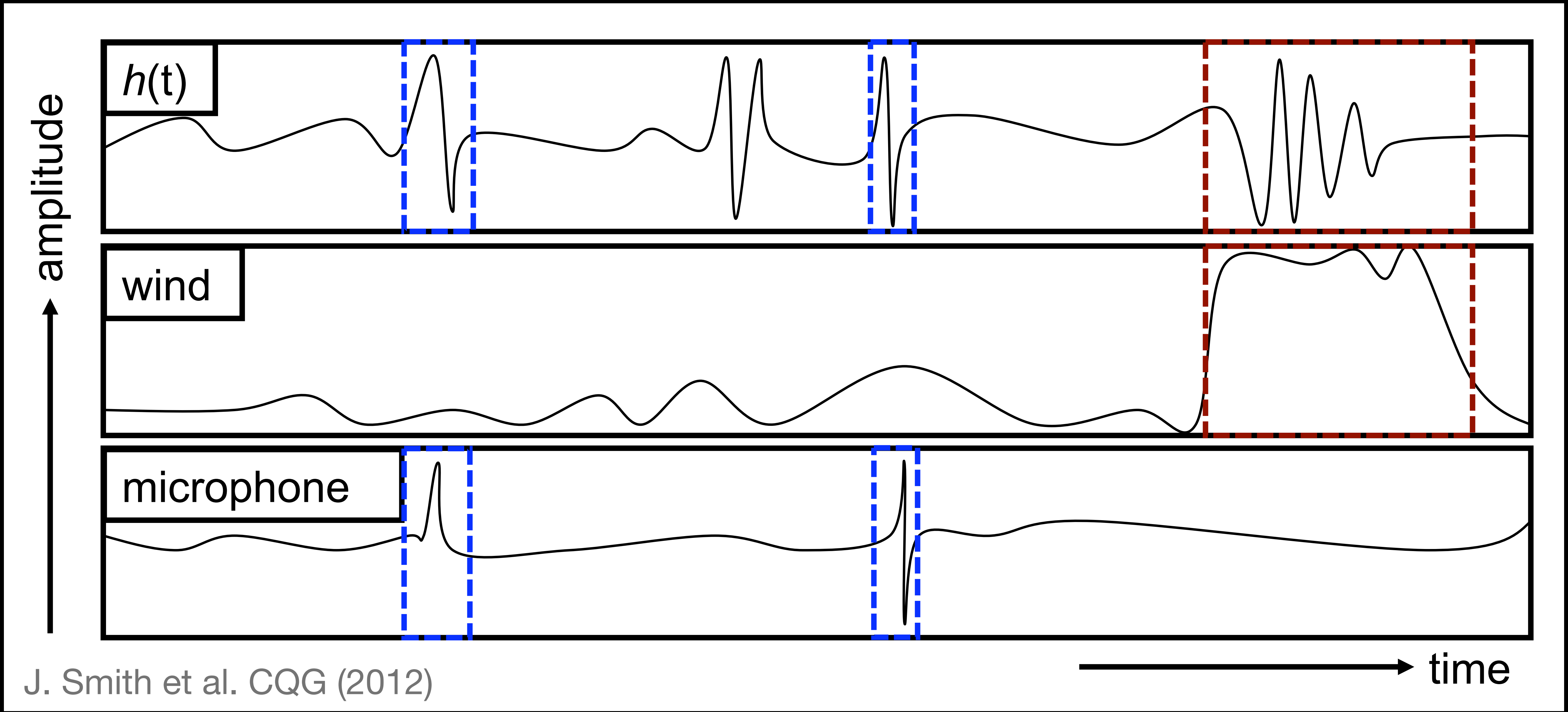


B. P. Abbott et al., CQG 2017

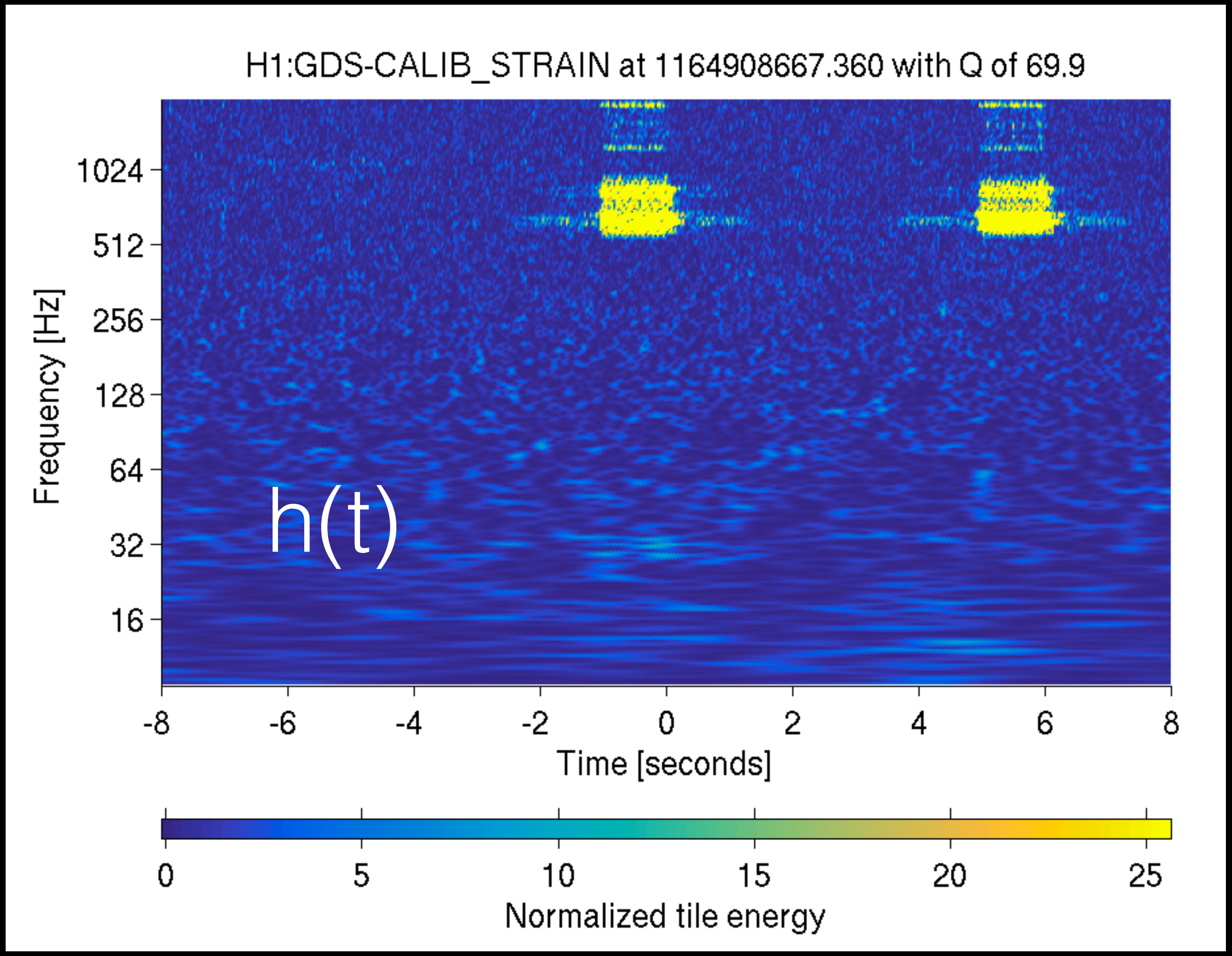
Big data challenge: 'auxiliary' correlations

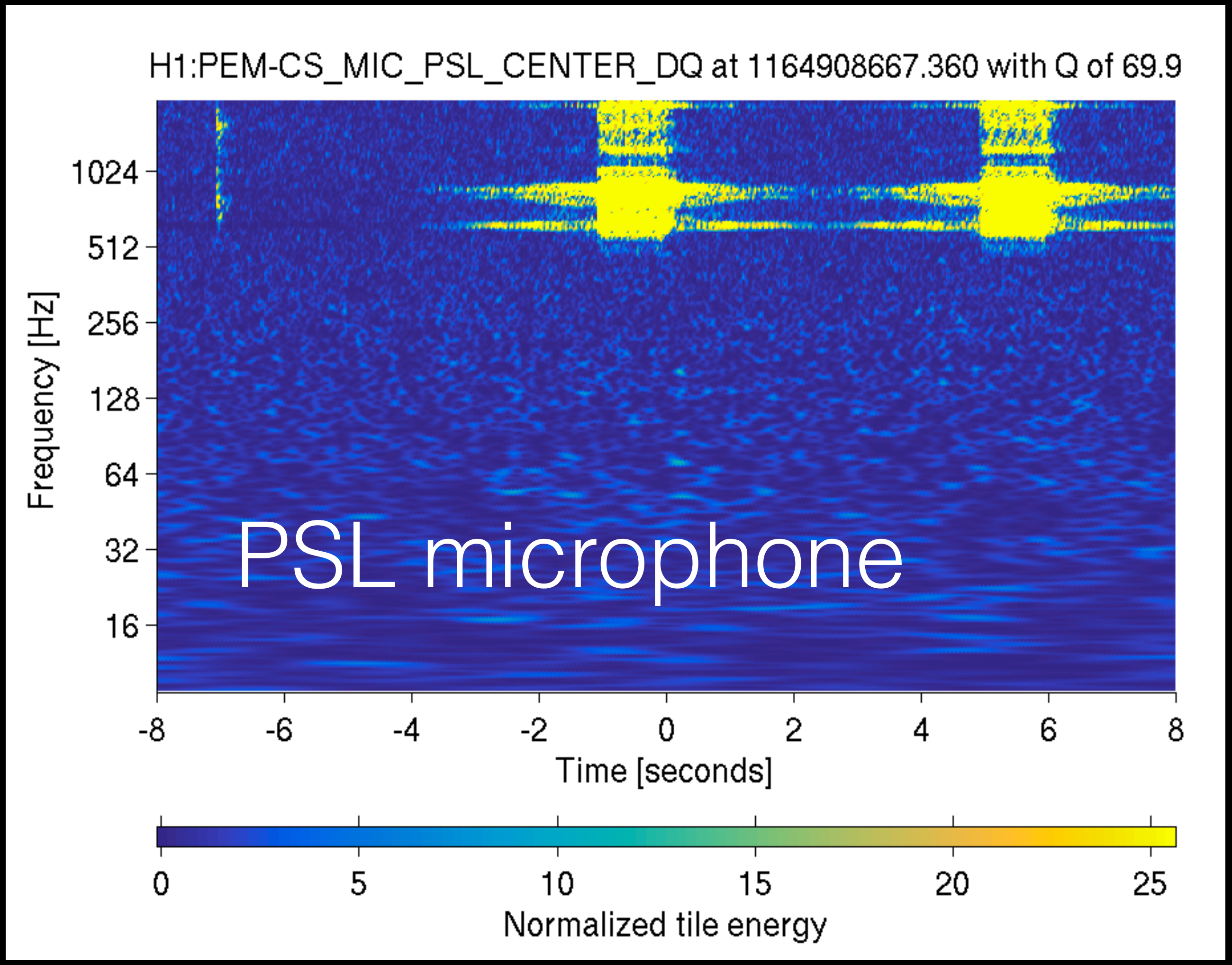
We record **over 200,000 channels per detector** that monitor the environment and detector behavior.

We can use these to **help trace the instrumental causes of glitches** that pollute the search backgrounds.



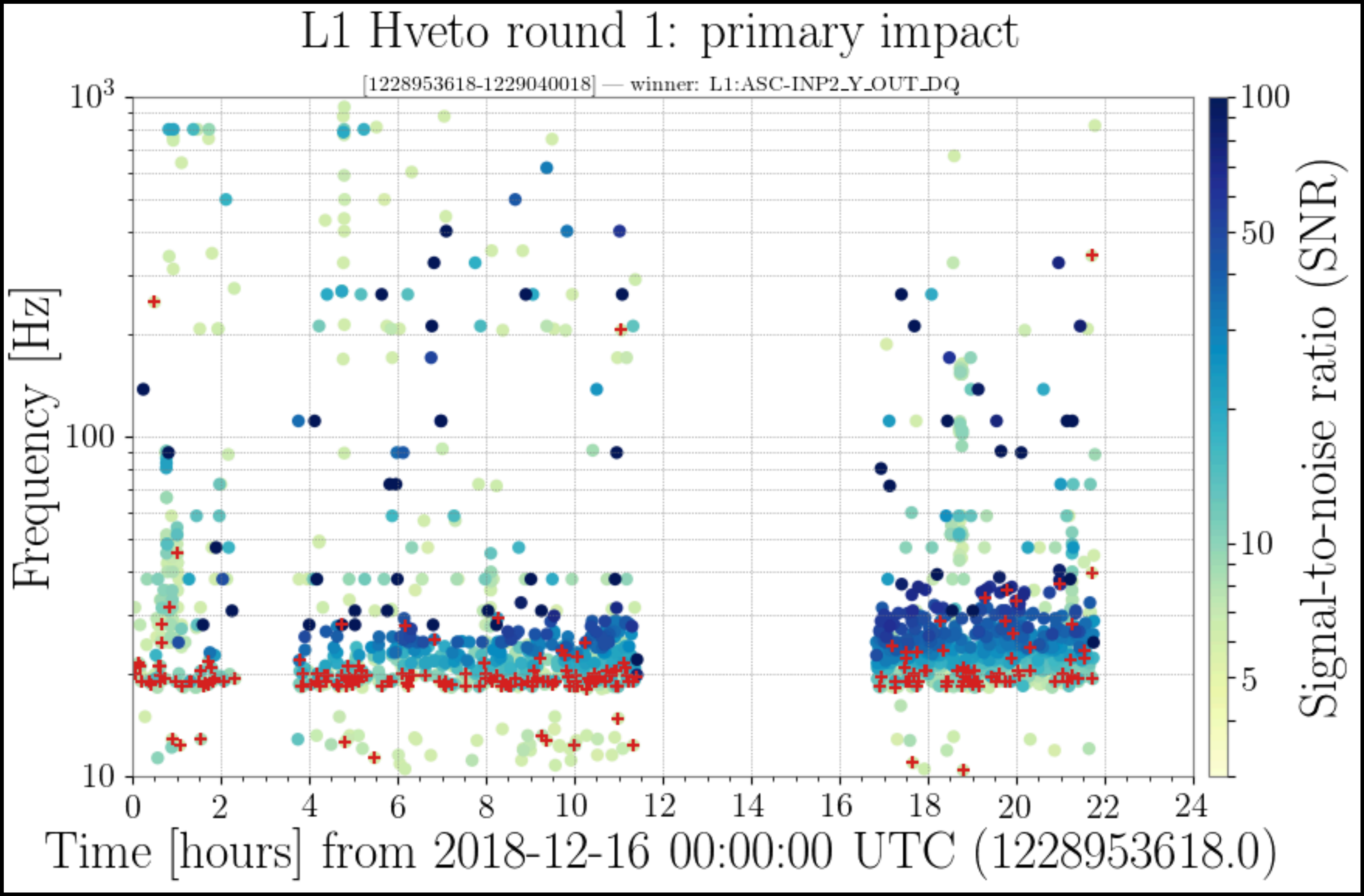
Laser glitches - h(t) vs. microphones





LHO alog #32503: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=32503

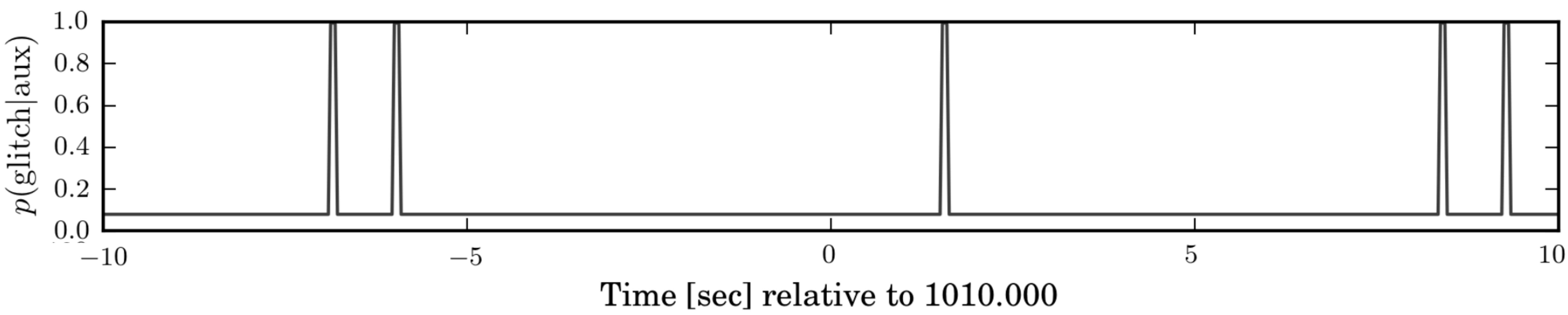
Statistical correlations



J. Smith et al. CQG (2012)

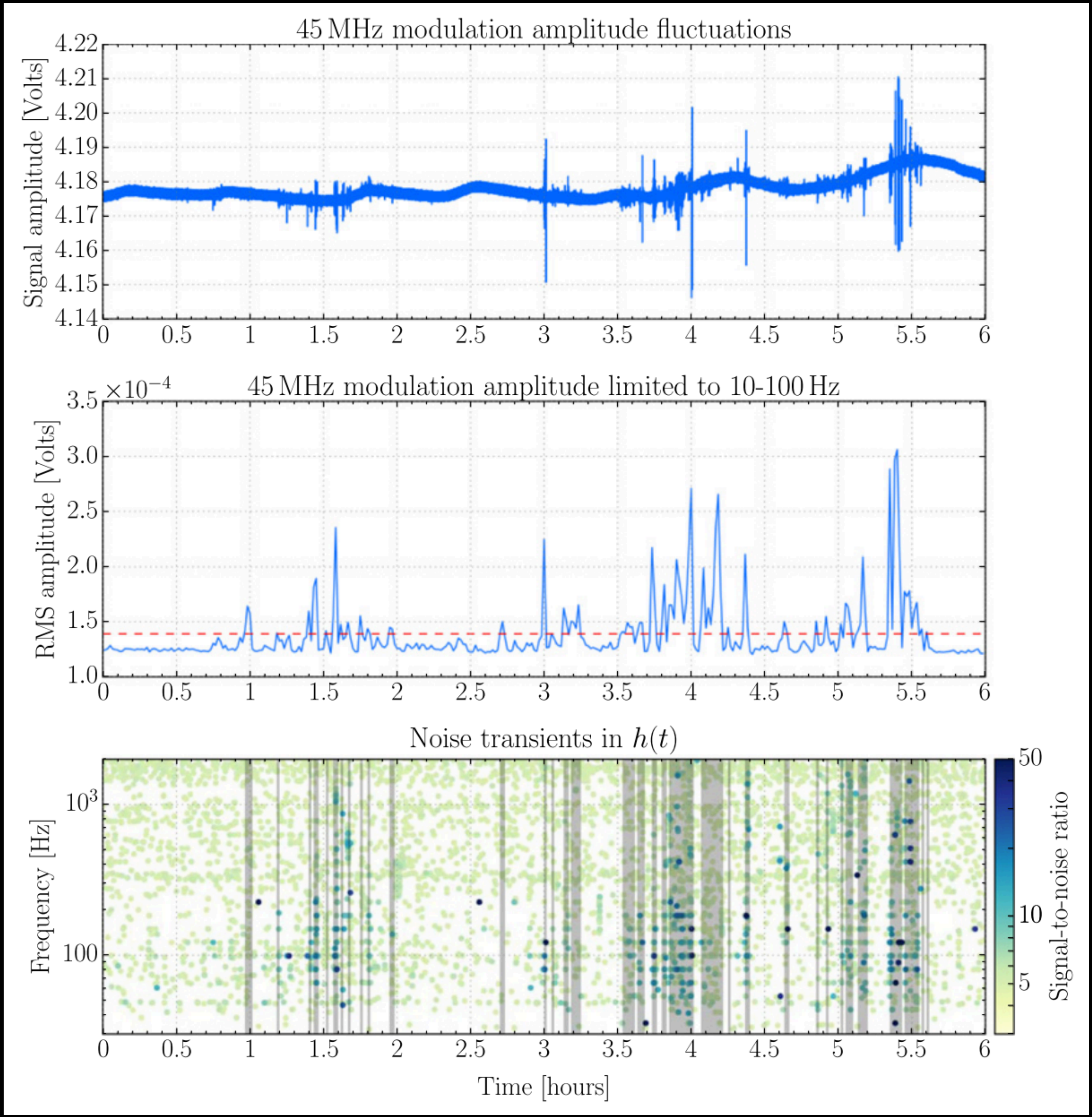
Low latency correlations: iDQ

- iDQ is an **engine for statistical inference**
- Will produce a time series of the probability of a glitch in h(t) in the LIGO detectors based on auxiliary channel information in O3 — a **key data quality product that will inform Open Public Alerts**
- iDQ supports a variety of supervised learning techniques
- Broadly useful architecture for streaming classification



R. Essick et al. CQG (2013)

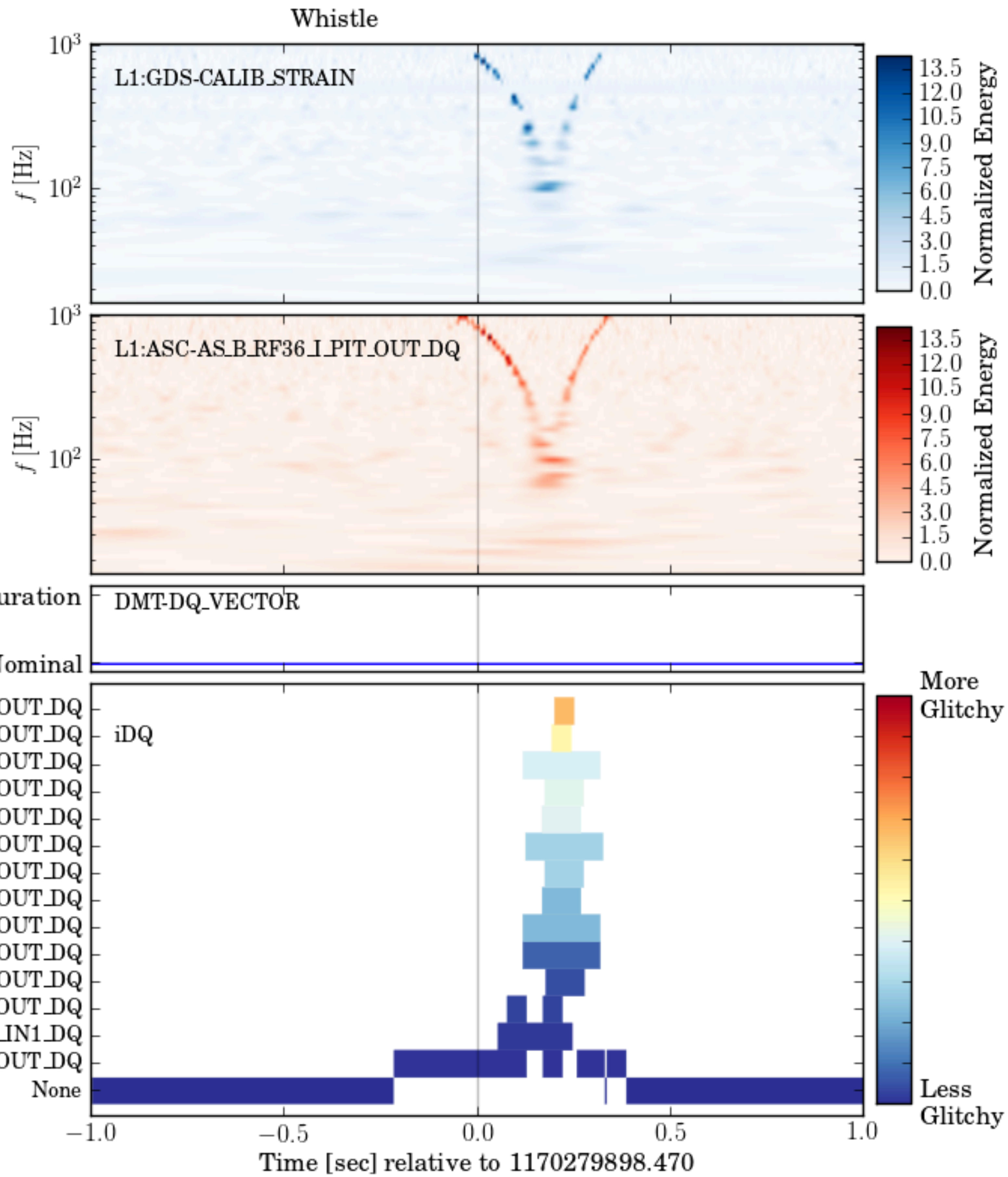
‘Veto’ DQ mitigation



B.P. Abbott et al. CQG (2016)

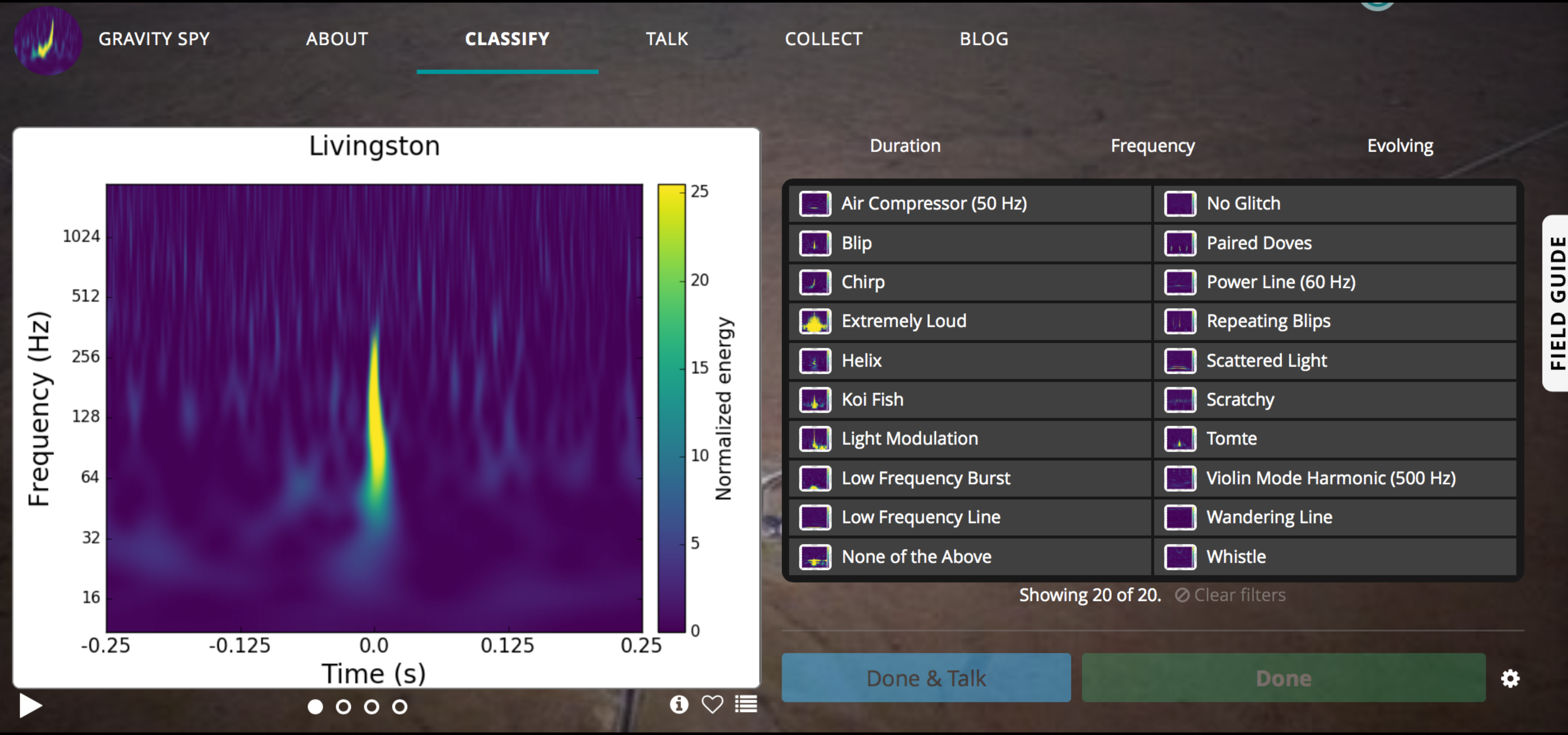
Low latency DQ mitigation

Figure by R. Essick from T.J. Massinger et al., in prep



Using citizen science and machine learning

gravityspy.org



Zevin et al, 2017, CQG

Identifying glitches by type

LigoDV-Web — *v0.1.07 Glitch DB*

Welcome Jessica McIver (admin)

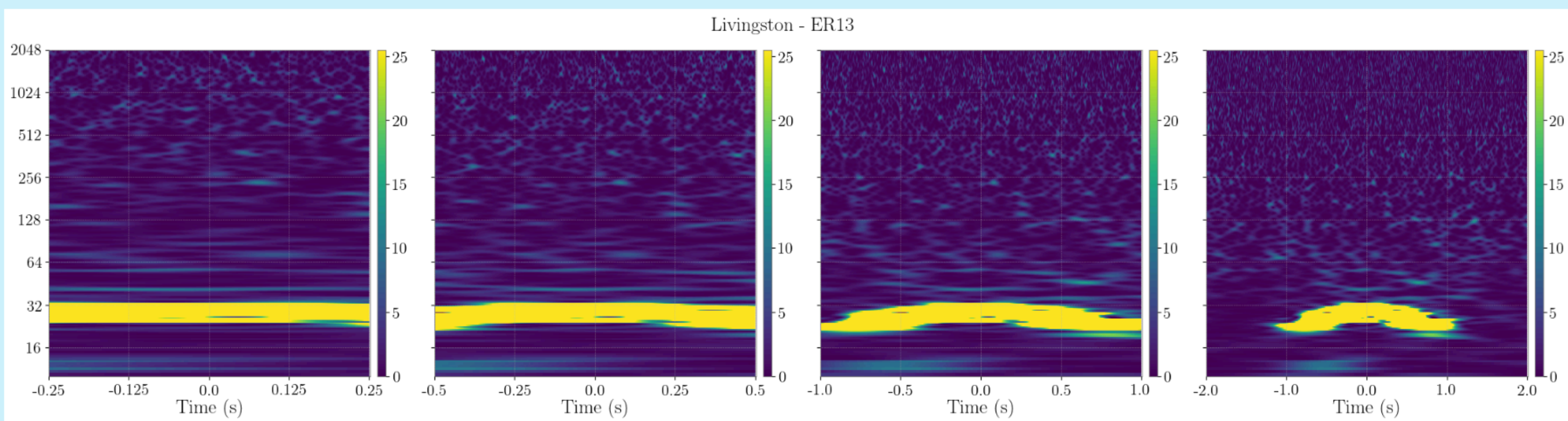
Home | History ▾ | Status ▾ | Glitch DB ▾ | Batch ▾ | Help ▾ | Admin ▾

Link to this search

< | Page: 1 of 3 | Go | > | Save comments

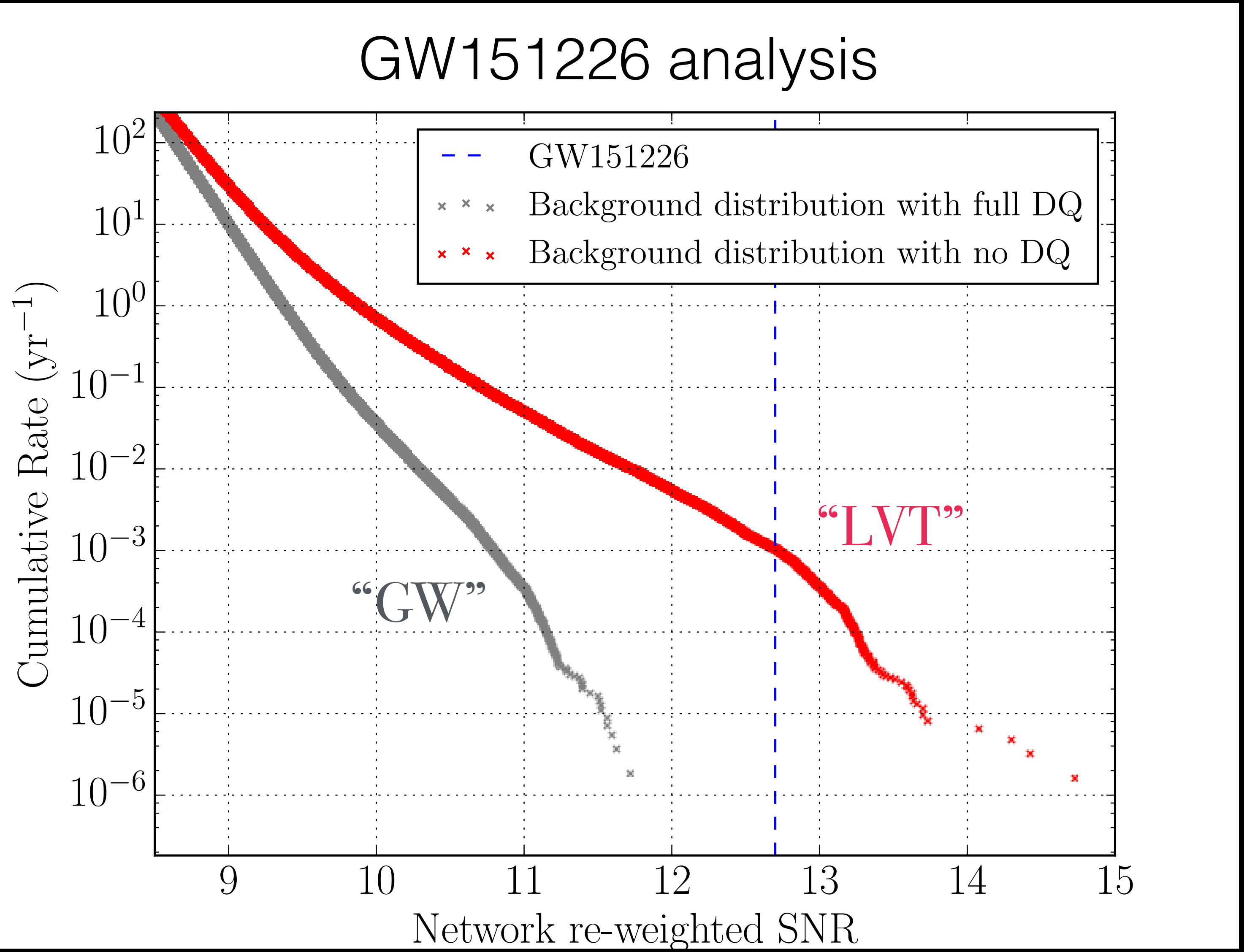
249 matches found.

Unique Id	tihveWX1dQ
GPS Time	1229057821.313
UTC Time	2018-12-17 04:56:43
Pipeline	GravitySpy
Class	Scattered_Light
Status	testing
Ifo	L1
SNR	80.946
Amplitude	1.89e-21
Peak freq	28.117
Central freq	3977.720



J. Areeda et al. Astronomy and Computing (2017), S. Coughlin et al *in prep*

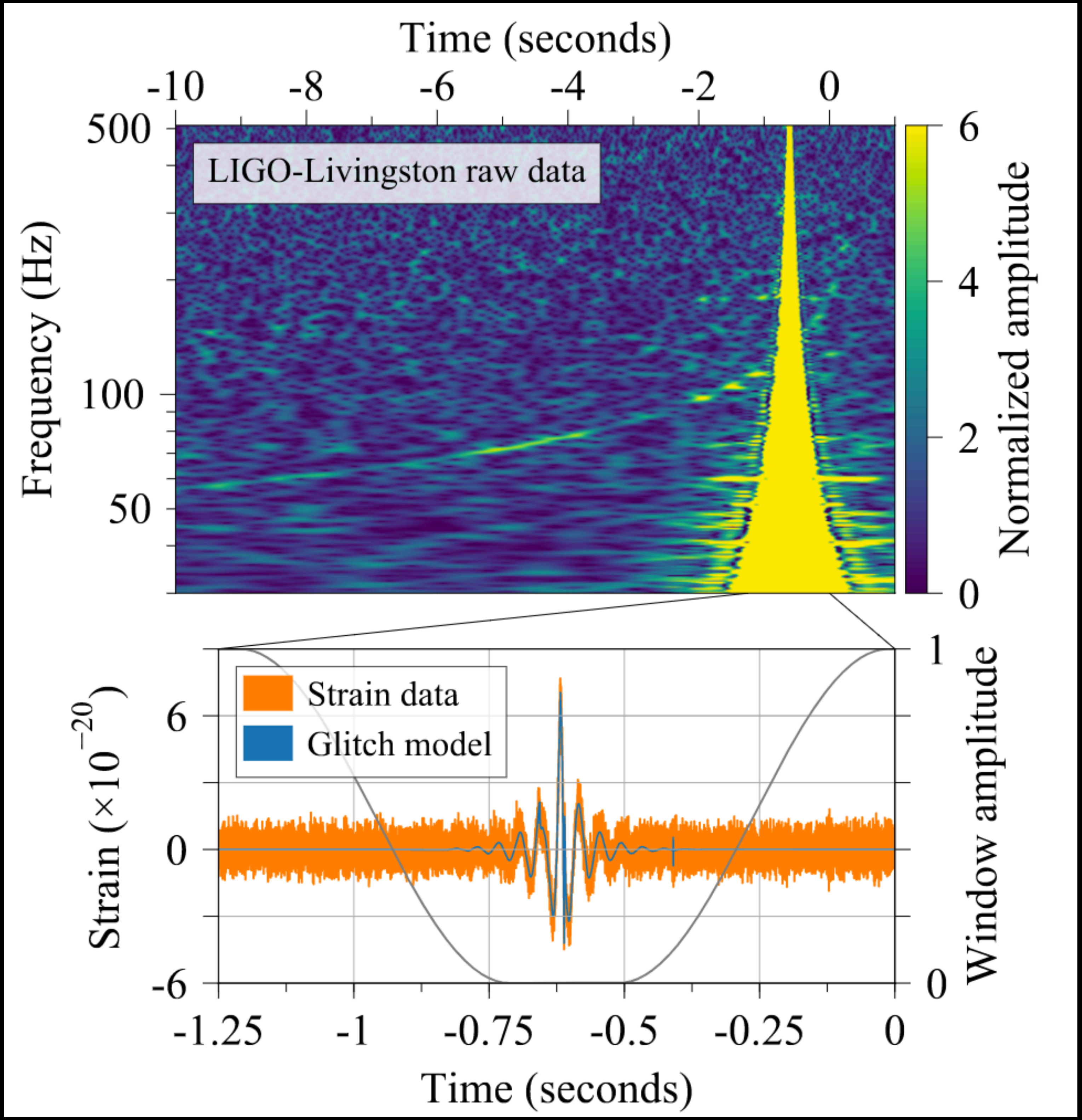
The impact of detector characterization



B.P Abbott et al. CQG (2018)

The false alarm rate of GW151226 **improves by a factor of >500**, from 1 in 320 years to 1 in 183,000 years, **with interferometer data quality information!**

The impact of noise on source property estimation: a glitch in LIGO-Livingston



B.P. Abbott et al PRL. (2017), Pankow et al. (2018)

GWTC-1: confident detections

All event candidates were validated for the potential impact of coincident or nearby transient noise

Event		UTC Time	FAR [y^{-1}]			Network SNR		
			PyCBC	GstLAL	cWB	PyCBC	GstLAL	cWB
GW150914		09:50:45.4	$< 1.53 \times 10^{-5}$	$< 1.00 \times 10^{-7}$	$< 1.63 \times 10^{-4}$	23.6	24.4	25.2
GW151012		09:54:43.4	0.17	7.92×10^{-3}	–	9.5	10.0	–
GW151226		03:38:53.6	$< 1.69 \times 10^{-5}$	$< 1.00 \times 10^{-7}$	0.02	13.1	13.1	11.9
GW170104		10:11:58.6	$< 1.37 \times 10^{-5}$	$< 1.00 \times 10^{-7}$	2.91×10^{-4}	13.0	13.0	13.0
GW170608		02:01:16.5	$< 3.09 \times 10^{-4}$	$< 1.00 \times 10^{-7}$	1.44×10^{-4}	15.4	14.9	14.1
GW170729	V	18:56:29.3	1.36	0.18	0.02	9.8	10.8	10.2
GW170809	V	08:28:21.8	1.45×10^{-4}	$< 1.00 \times 10^{-7}$	–	12.2	12.4	–
GW170814	V	10:30:43.5	$< 1.25 \times 10^{-5}$	$< 1.00 \times 10^{-7}$	$< 2.08 \times 10^{-4}$	16.3	15.9	17.2
GW170817	V(G)	12:41:04.4	$< 1.25 \times 10^{-5}$	$< 1.00 \times 10^{-7}$	–	30.9	33.0	–
GW170818	V	02:25:09.1	–	4.20×10^{-5}	–	–	11.3	–
GW170823		13:13:58.5	$< 3.29 \times 10^{-5}$	$< 1.00 \times 10^{-7}$	2.14×10^{-3}	11.1	11.5	10.8

B.P. Abbott et al. arXiv 1811.12907 (2018)

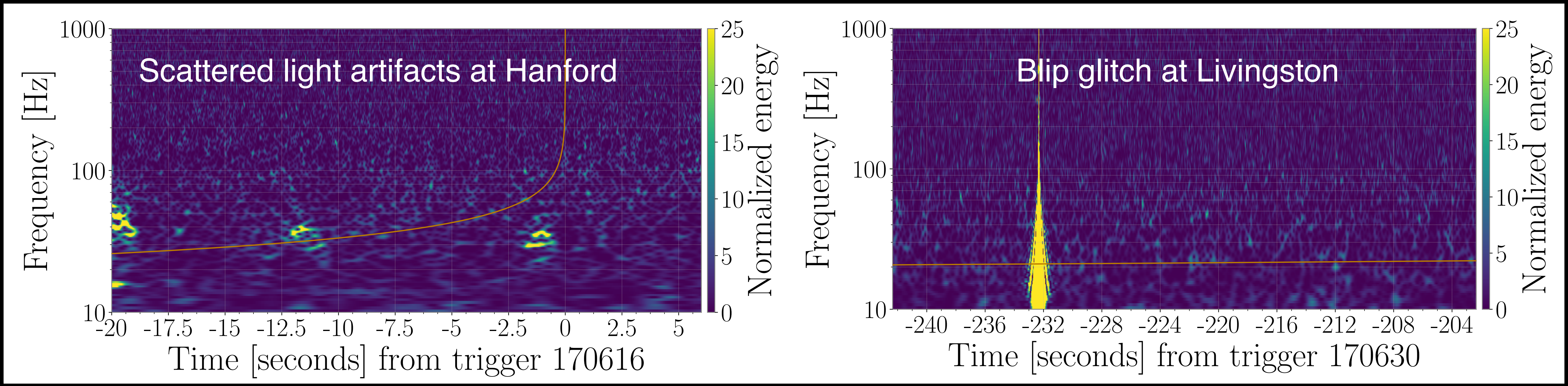
GWTC-1: marginal events

- Event candidates with an estimated FAR < 1 in 30 days
- Some may possibly be of astrophysical origin
- For four marginal events, a noise transient can account for (possibly caused) the SNR of the trigger

Date	UTC	Search	FAR [y^{-1}]	Network SNR	$\mathcal{M}^{det}$ [$M_\odot$]	Data Quality
151008	14:09:17.5	PyCBC	10.17	8.8	5.12	No artifacts
151012A	06:30:45.2	GstLAL	8.56	9.6	2.01	Artifacts present
151116	22:41:48.7	PyCBC	4.77	9.0	1.24	No artifacts
161202	03:53:44.9	GstLAL	6.00	10.5	1.54	Artifacts can account for
161217	07:16:24.4	GstLAL	10.12	10.7	7.86	Artifacts can account for
170208	10:39:25.8	GstLAL	11.18	10.0	7.39	Artifacts present
170219	14:04:09.0	GstLAL	6.26	9.6	1.53	No artifacts
170405	11:04:52.7	GstLAL	4.55	9.3	1.44	Artifacts present
170412	15:56:39.0	GstLAL	8.22	9.7	4.36	Artifacts can account for
170423	12:10:45.0	GstLAL	6.47	8.9	1.17	No artifacts
170616	19:47:20.8	PyCBC	1.94	9.1	2.75	Artifacts present
170630	16:17:07.8	GstLAL	10.46	9.7	0.90	Artifacts present
170705	08:45:16.3	GstLAL	10.97	9.3	3.40	No artifacts
170720	22:44:31.8	GstLAL	10.75	13.0	5.96	Artifacts can account for

B.P. Abbott et al. arXiv 1811.12907 (2018)

GWTC-1: marginal events



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161202	03:53:44.9	GstLAL	6.00	10.5	1.54	Artifacts can account for
161217	07:16:24.4	GstLAL	10.12	10.7	7.86	Artifacts can account for
170208	10:39:25.8	GstLAL	11.18	10.0	7.39	Artifacts present
170219	14:04:09.0	GstLAL	6.26	9.6	1.53	No artifacts
170405	11:04:52.7	GstLAL	4.55	9.3	1.44	Artifacts present
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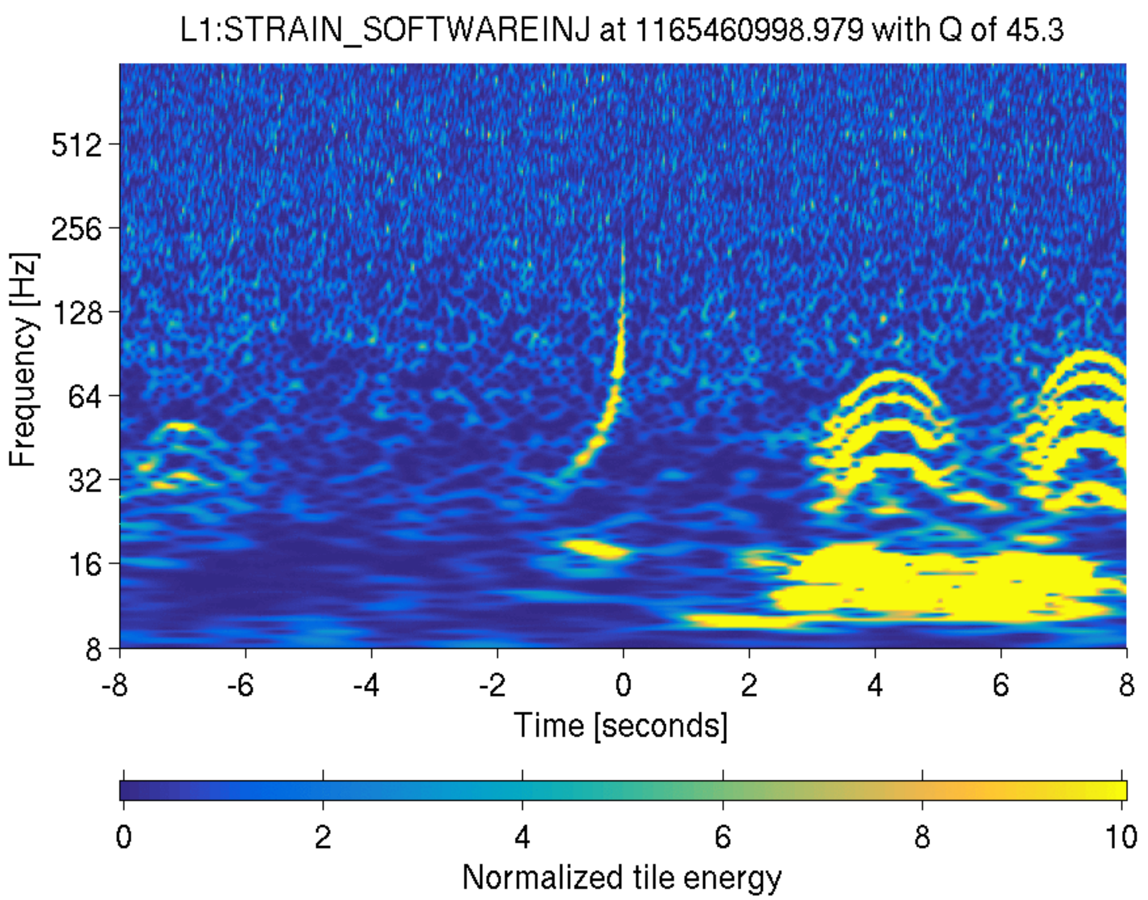
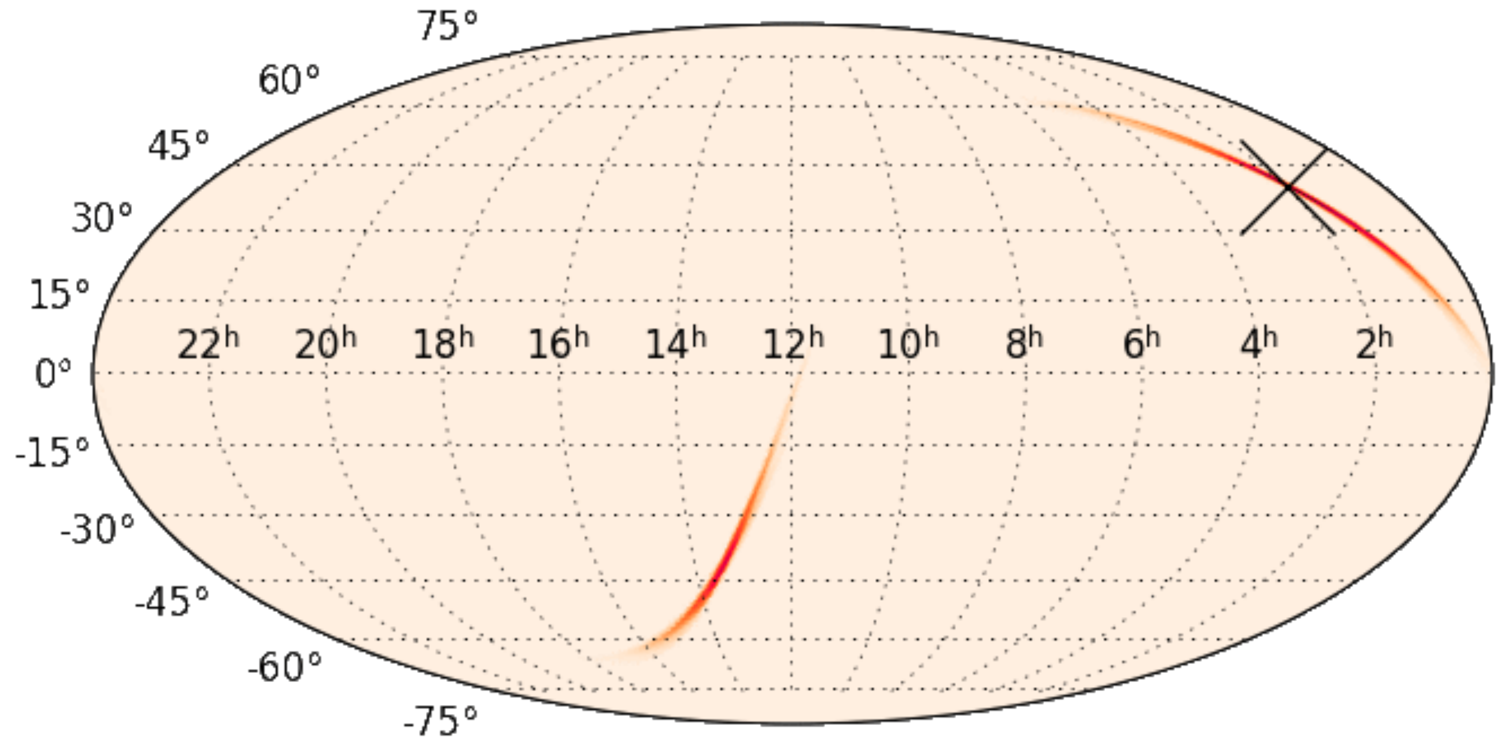
170720	22:44:31.8	GstLAL	10.75	13.0	5.96	Artifacts can account for

B.P. Abbott et al. arXiv 1811.12907 (2018)

Impact of light scattering on sky localization





McIver et al.

Parameter estimation produced with the lalinference pipeline: arXiv 1409.7215

See also Powell 2018.

Minimum 90% confidence sky area (2 seconds before the scattering noise feature): 300 sq. deg.
Maximum 90% confidence sky area: (During the first 0.5 seconds of the scattering noise): 540 sq. deg.

Infrastructure: GWpy

GWpy 0.12.0 Examples Contents « First steps Installation » Search

What is GWpy?

The basic idea

Source

Search

The basic idea

The basic idea of GWpy is to simplify all of the tedious bits of analysing data, allowing users to study and plot data quickly and effectively. For example, GWpy provides simple methods for input/output:

```
from gwpy.timeseries import TimeSeries
h1 = TimeSeries.fetch_open_data('H1', 1126259457, 1126259467)
l1 = TimeSeries.fetch_open_data('L1', 1126259457, 1126259467)
```

and signal processing:

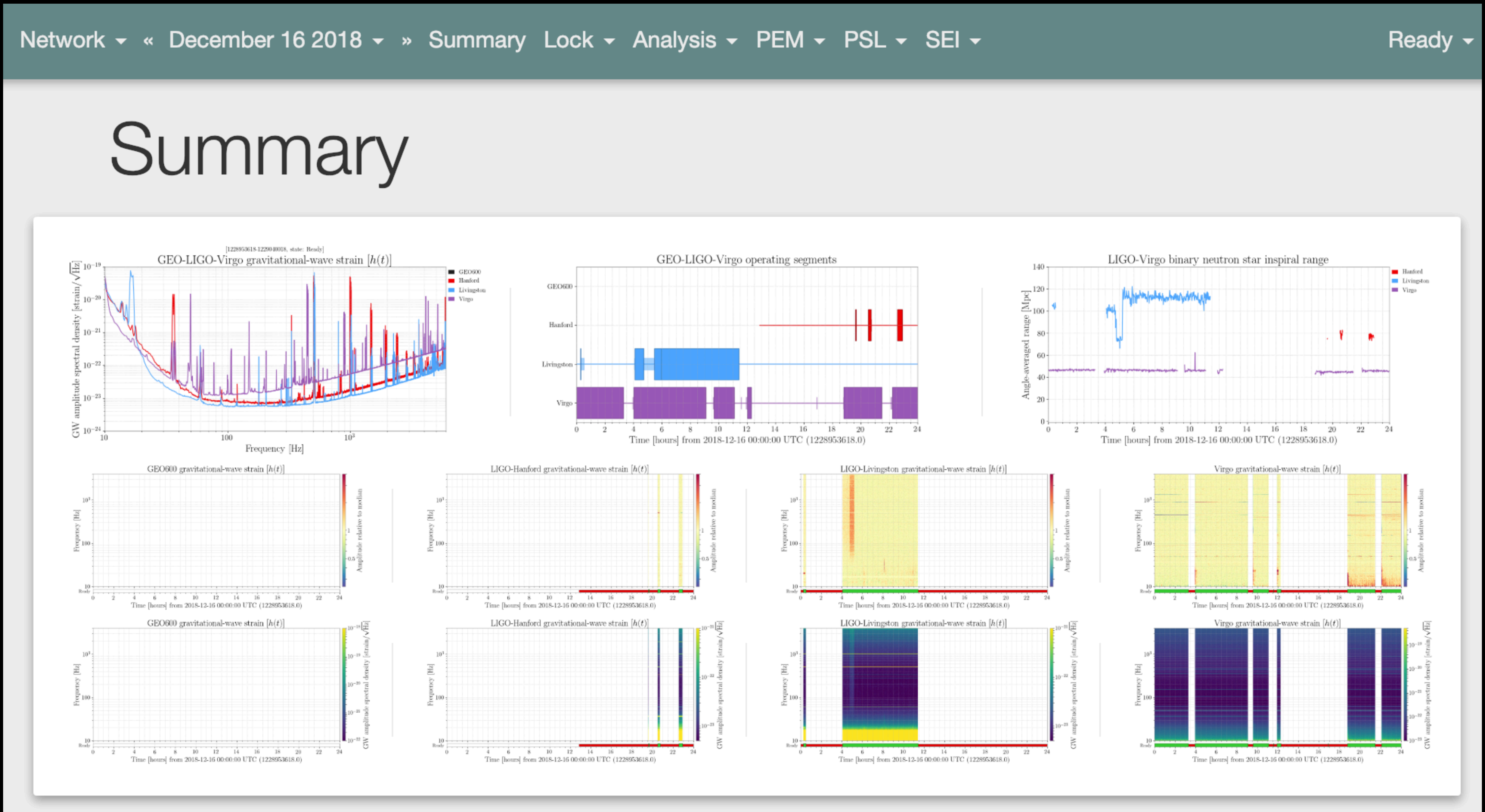
```
h1b = h1.bandpass(50, 250).notch(60).notch(120)
l1b = l1.bandpass(50, 250).notch(60).notch(120)
l1b.t0 += 0.0069 * l1b.xunit
l1b *= -1
```

and visualisation:

```
from gwpy.plotter import TimeSeriesPlot
plot = TimeSeriesPlot()
```

D. Macleod et al. https://gwpy.github.io

Monitoring: The LIGO summary pages



https://ldas-jobs.ligo.caltech.edu/~detchar/summary/

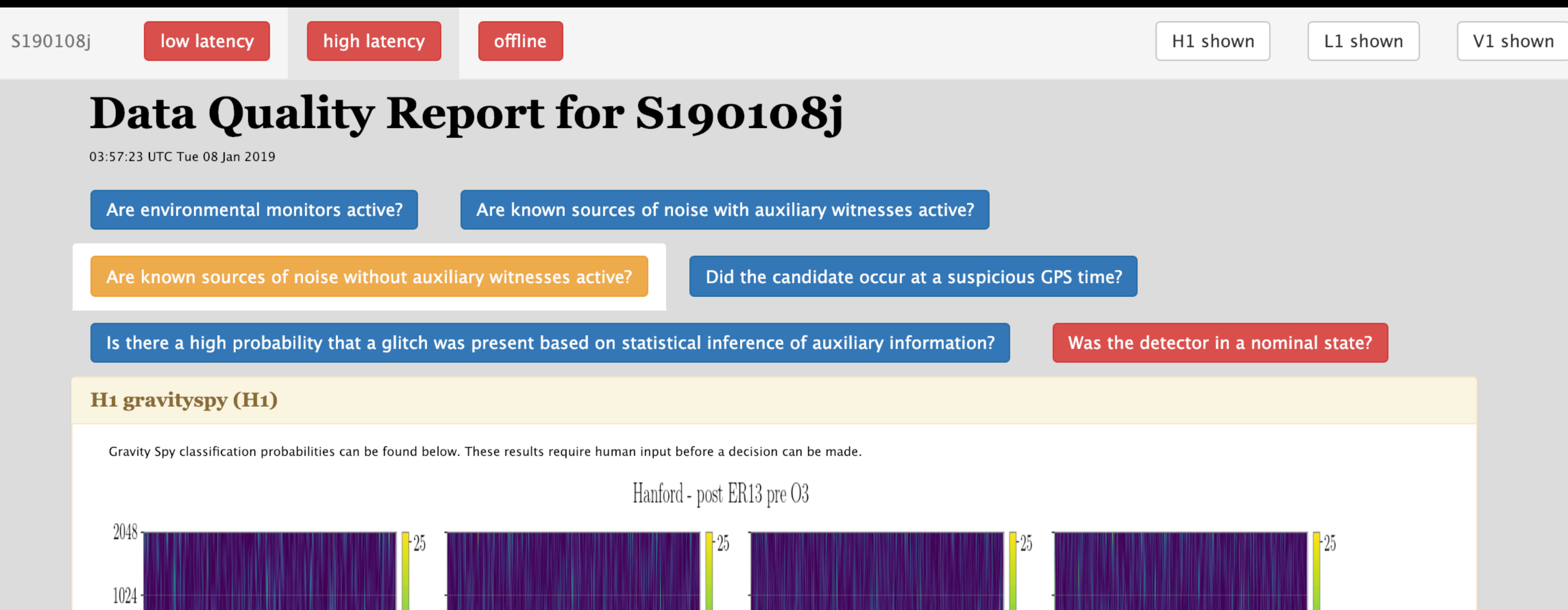
Public GWOSC version: https://www.gw-openscience.org/summary_pages/detector_status/

Automation for event validation

Based on DQ information:

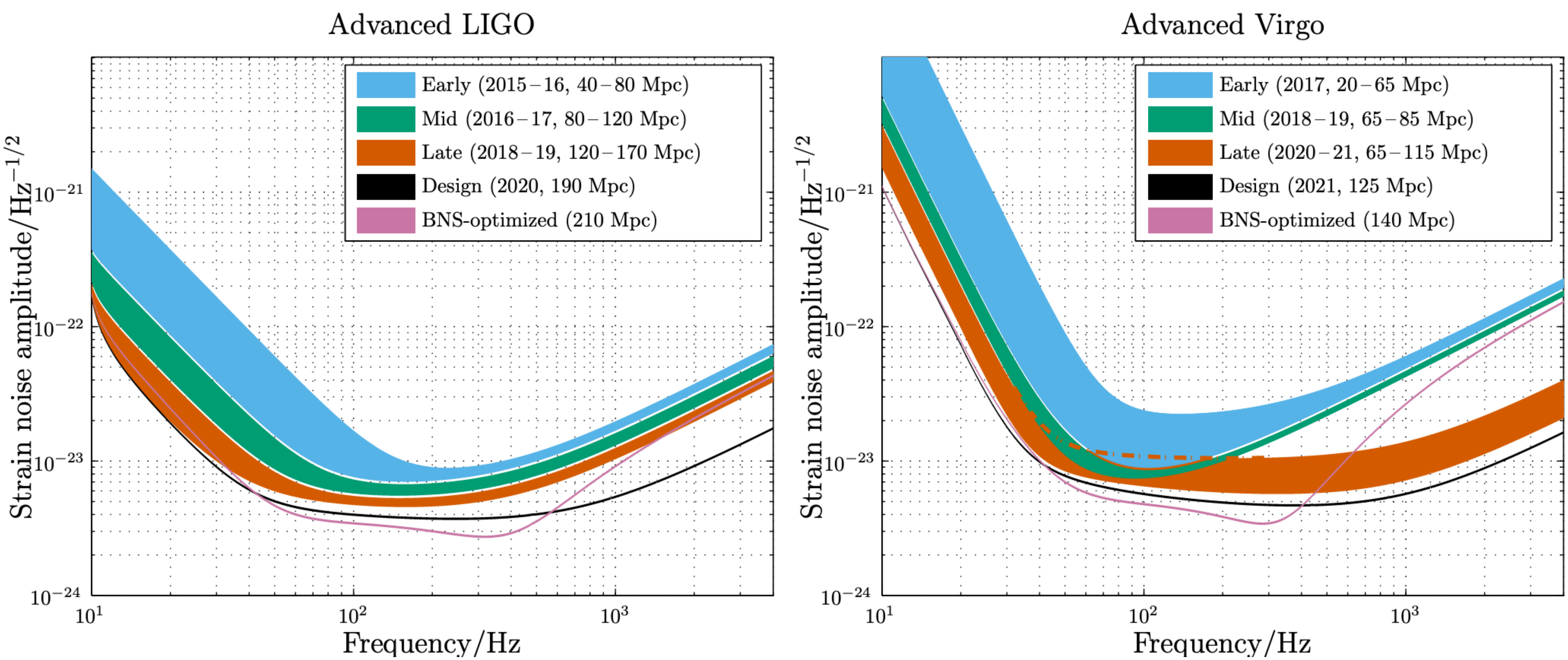
Is an event retraction merited?

Is noise artifact mitigation needed to produce the best possible skymaps and event information for EM followup?



R. Essick et al. https://docs.ligo.org/detchar/data-quality-report/

Roadmap to design sensitivity



Expectation for the third LIGO observing run (O3): up to **1 signal/week!**

Up to **1 signal/day** at design sensitivity!

B.P. Abbott et al. arXiv 1304.0670 (2018)

Conclusions

- Transient noise in gravitational wave detector data presents a major challenge for the astrophysical analyses
- Computational solutions have allowed us to successfully extract astrophysical signals with higher confidence and more accuracy.
- Investment in automation and infrastructure will allow us to more quickly diagnose noise and validate event candidates — **crucial for a higher expected event rate!**
- As the detectors progress toward design sensitivity, new and different noise sources will be unearthed!
- Noise studies will remain critical to enabling future GW discoveries.
- Stay tuned for the next observing run (O3)!