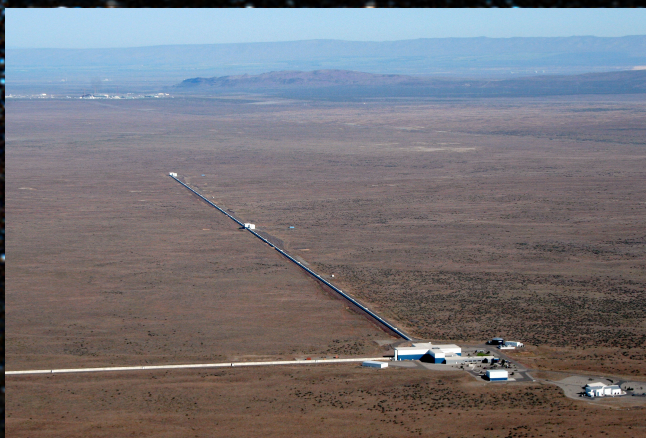
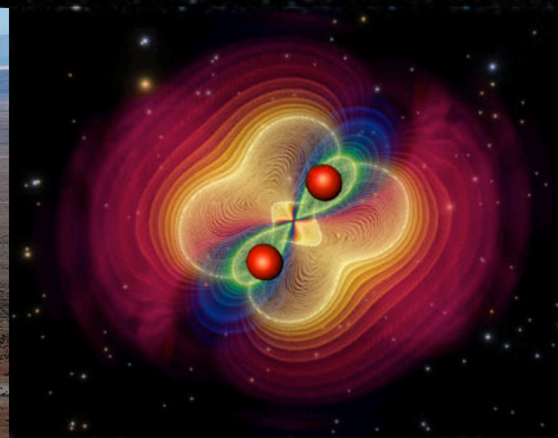
Laying a foundation for confident transient gravitational wave observations



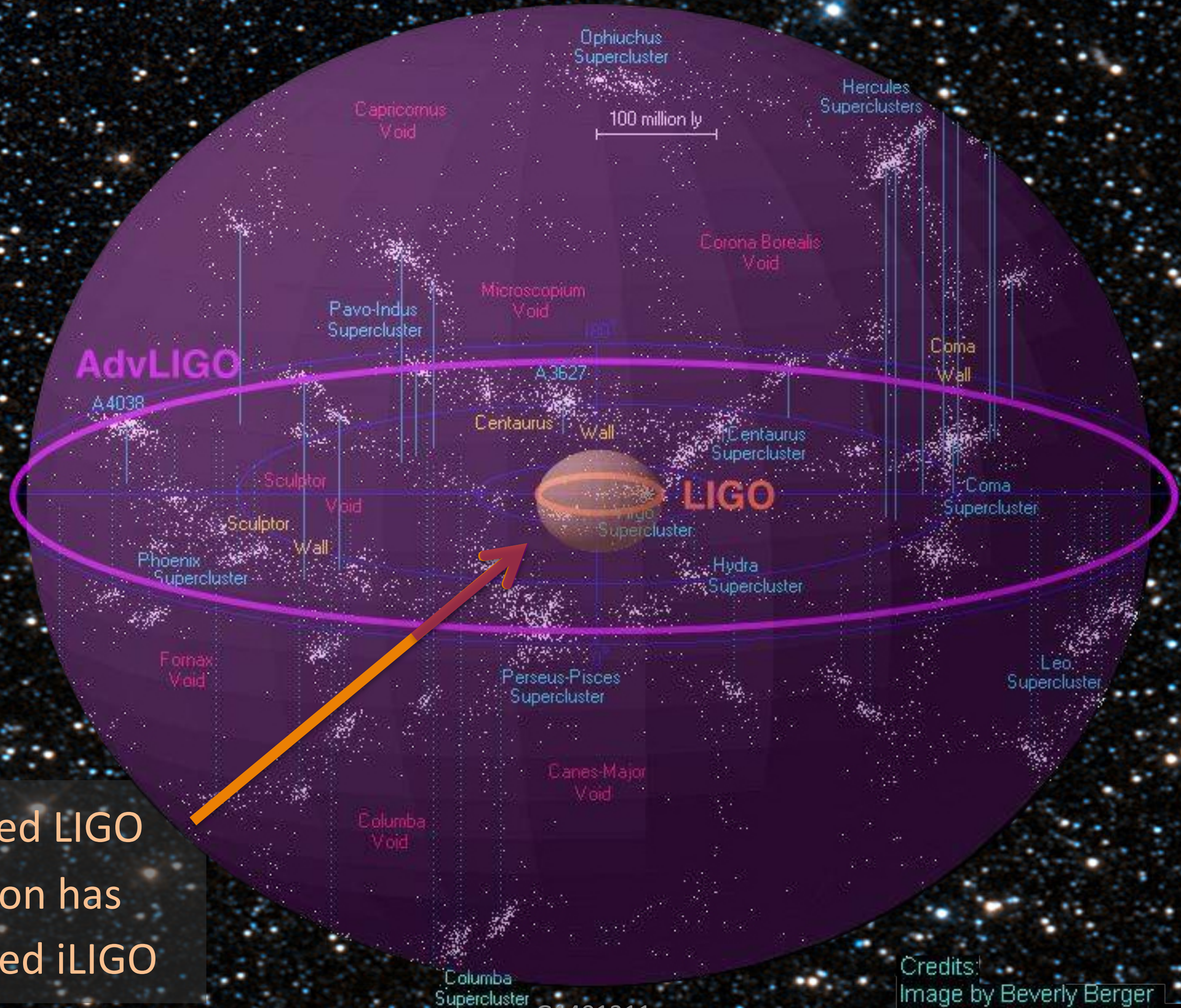


Characterizing the Advanced LIGO instruments

Jess McIver for the
LIGO Detector Characterization Group

January 20, 2015

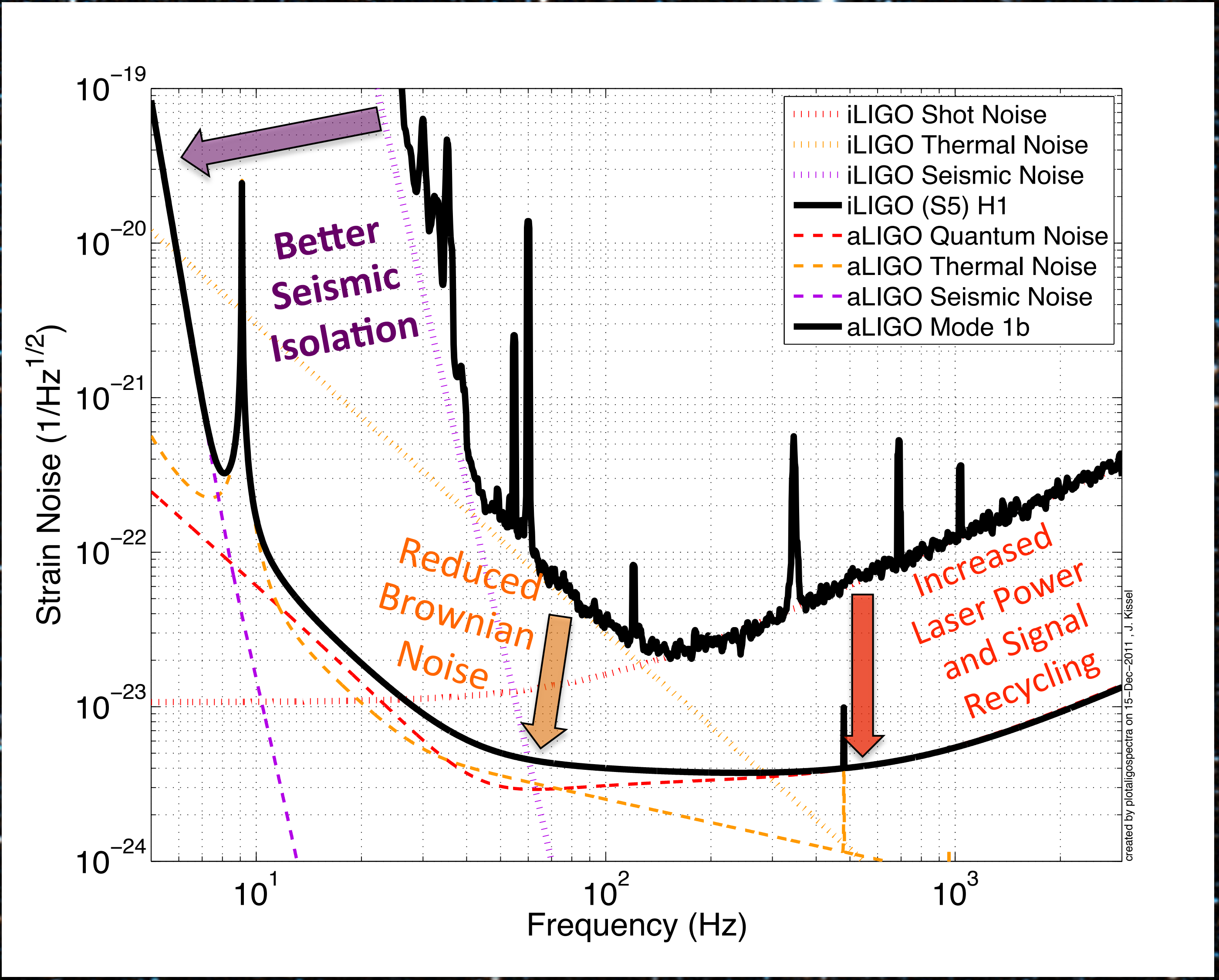
Advanced LIGO



Advanced LIGO Livingston has surpassed iLIGO

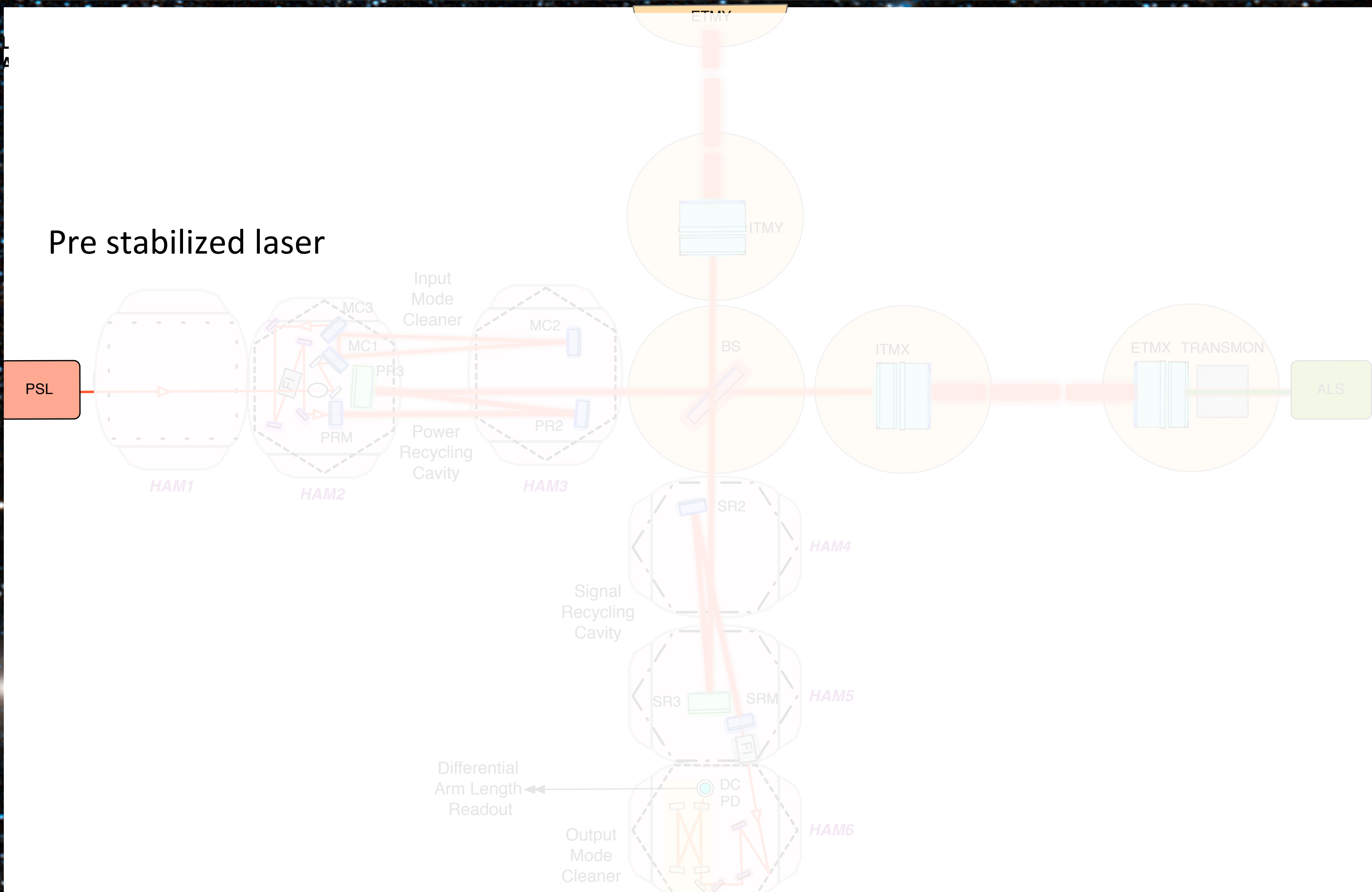
Credits:
Image by Beverly Berger
Cluster Map by Richard Powell

aLIGO instrumental improvements



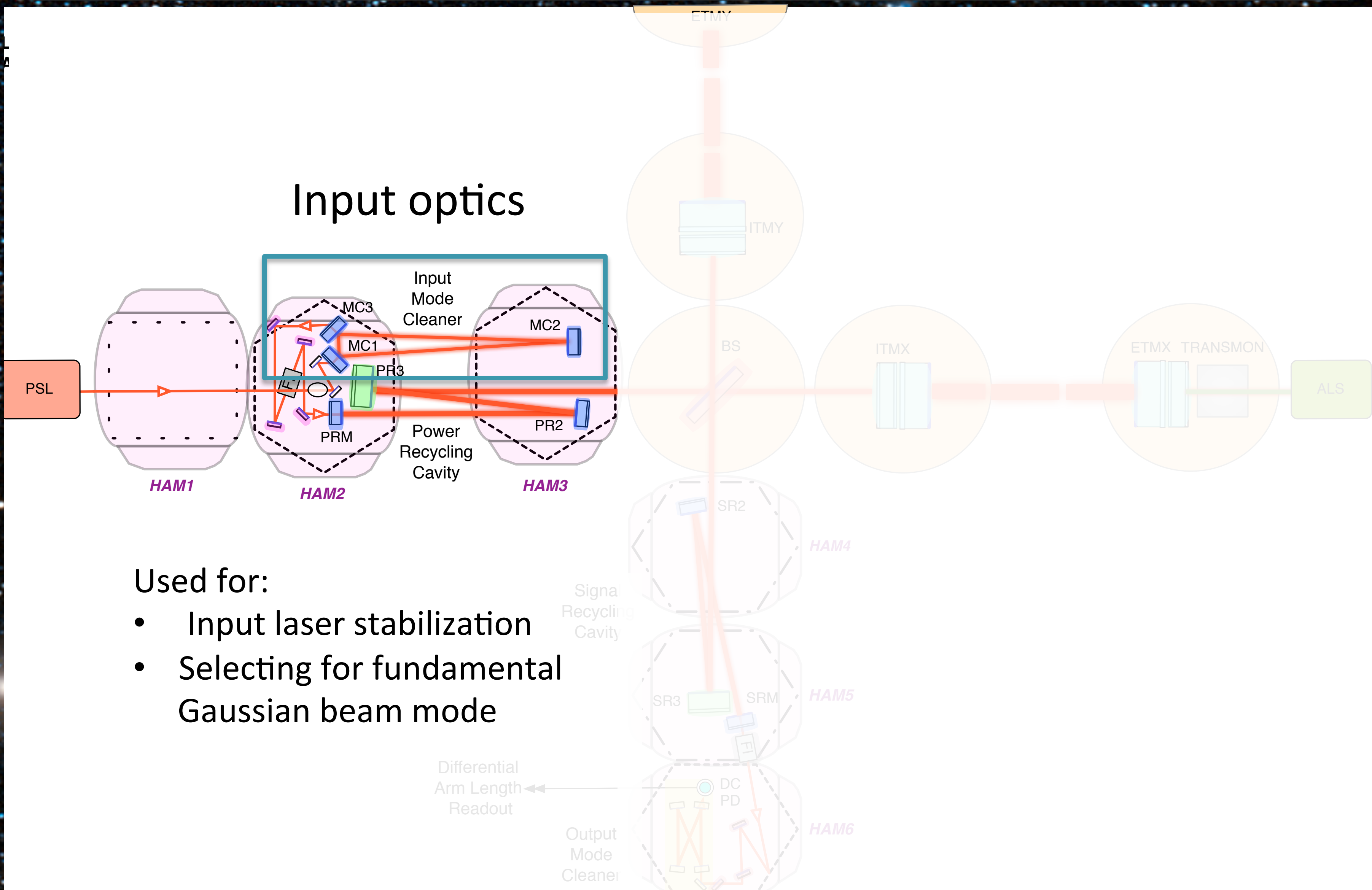
aLIGO installation and testing

Pre stabilized laser



aLIGO installation and testing

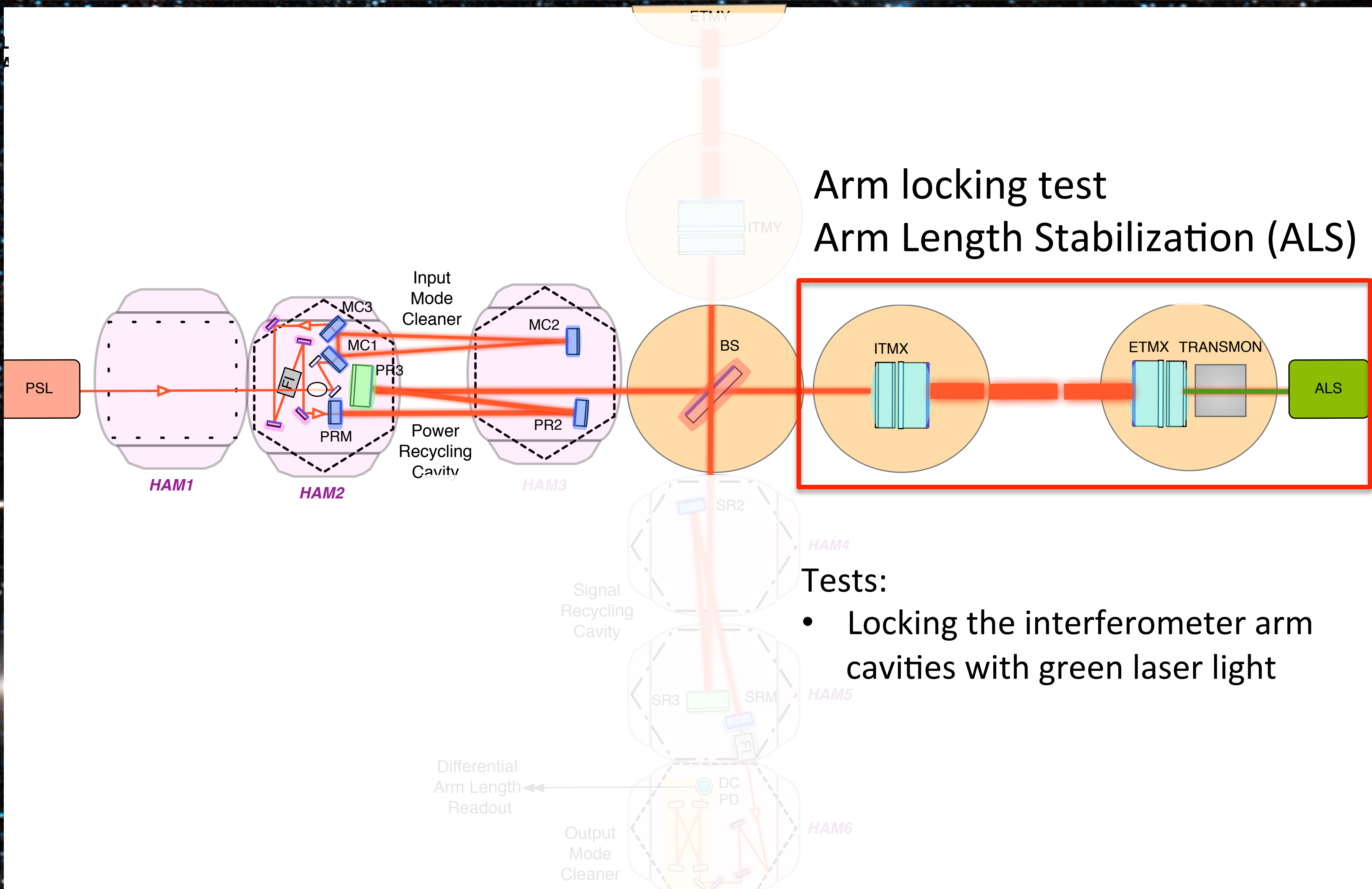
Input optics



Used for:

- Input laser stabilization
- Selecting for fundamental Gaussian beam mode

aLIGO installation and testing



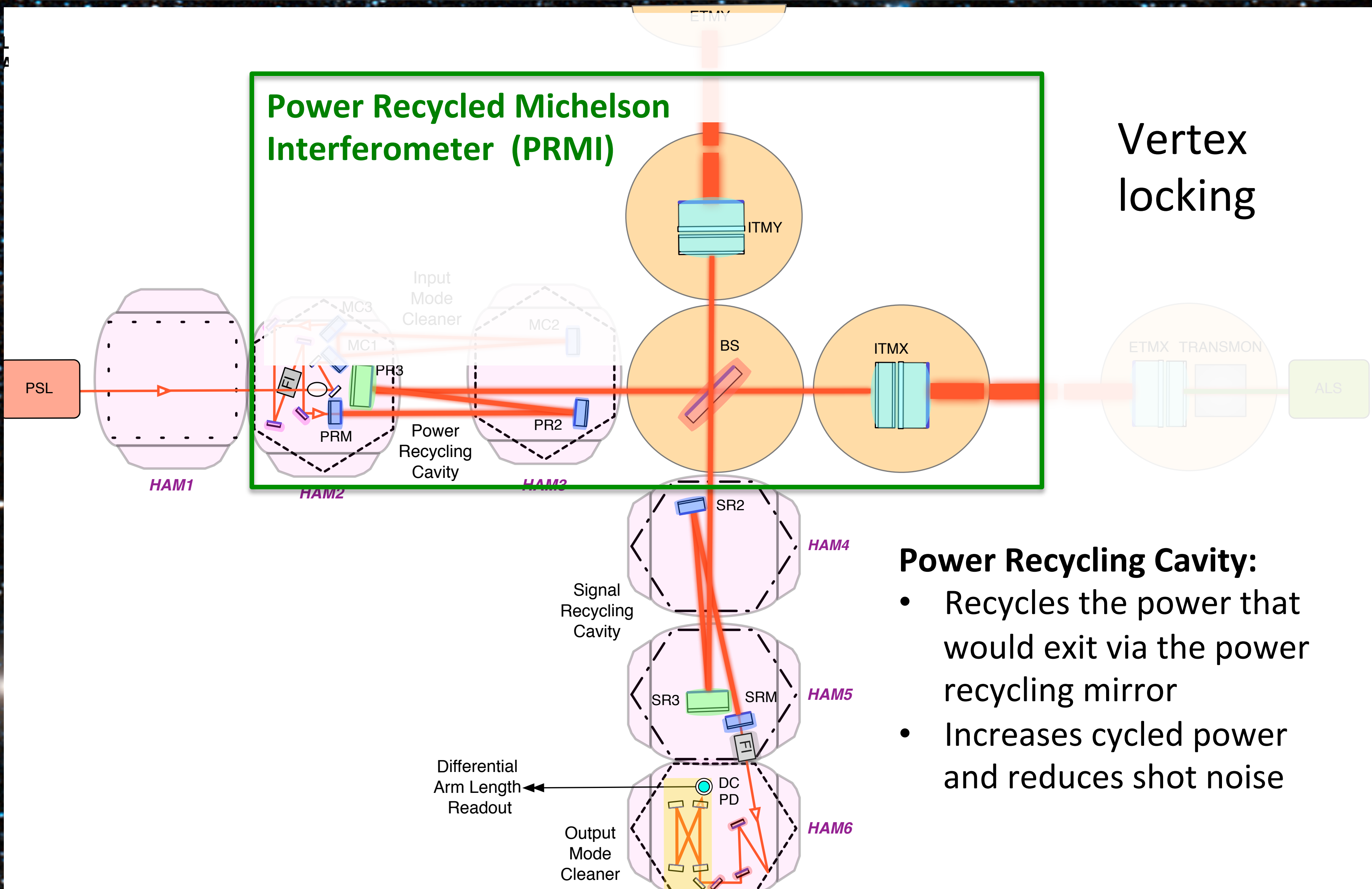
Arm locking test

Arm Length Stabilization (ALS)

Tests:

- Locking the interferometer arm cavities with green laser light

aLIGO installation and testing

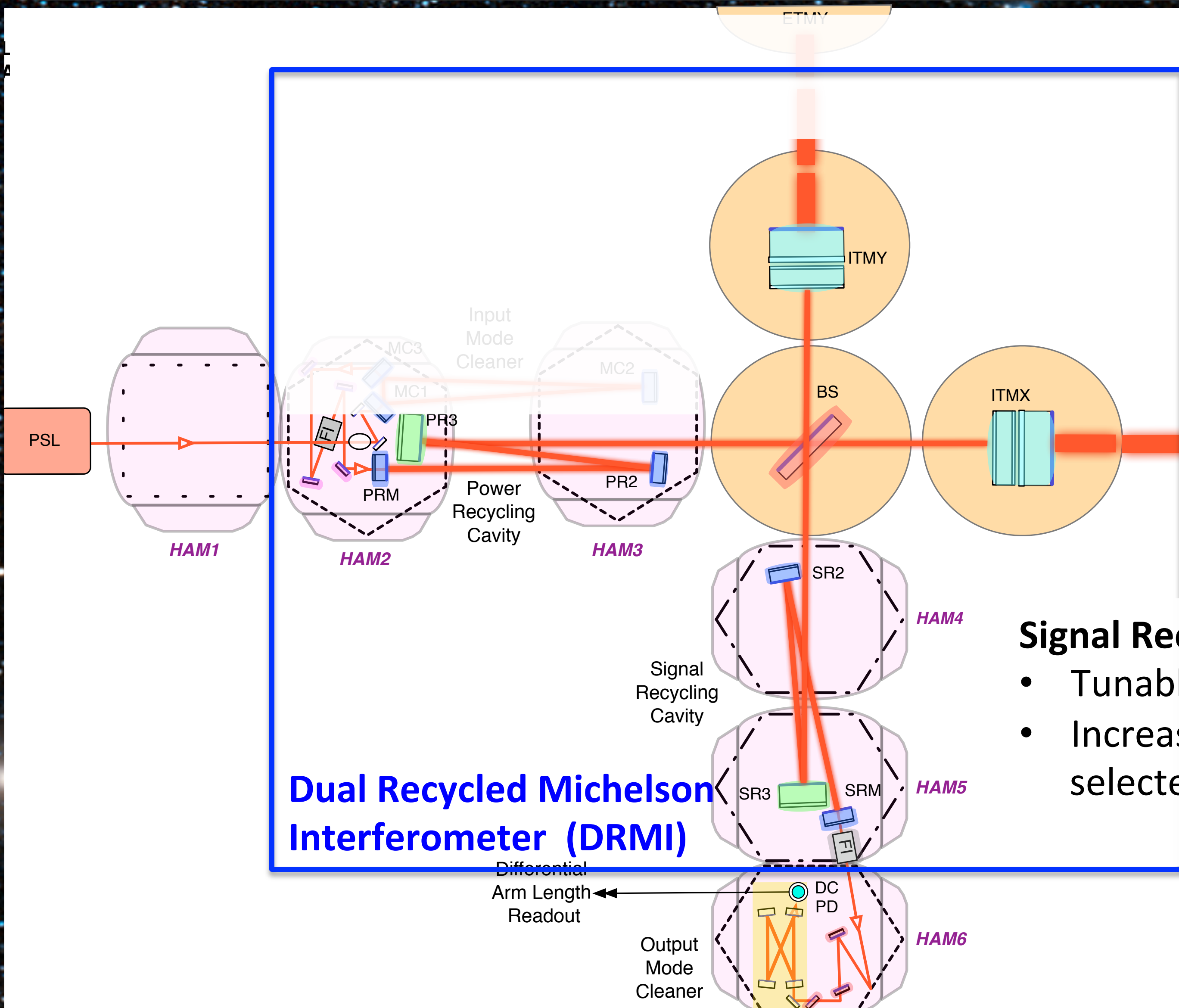


Vertex locking

Power Recycling Cavity:

- Recycles the power that would exit via the power recycling mirror
- Increases cycled power and reduces shot noise

aLIGO installation and testing



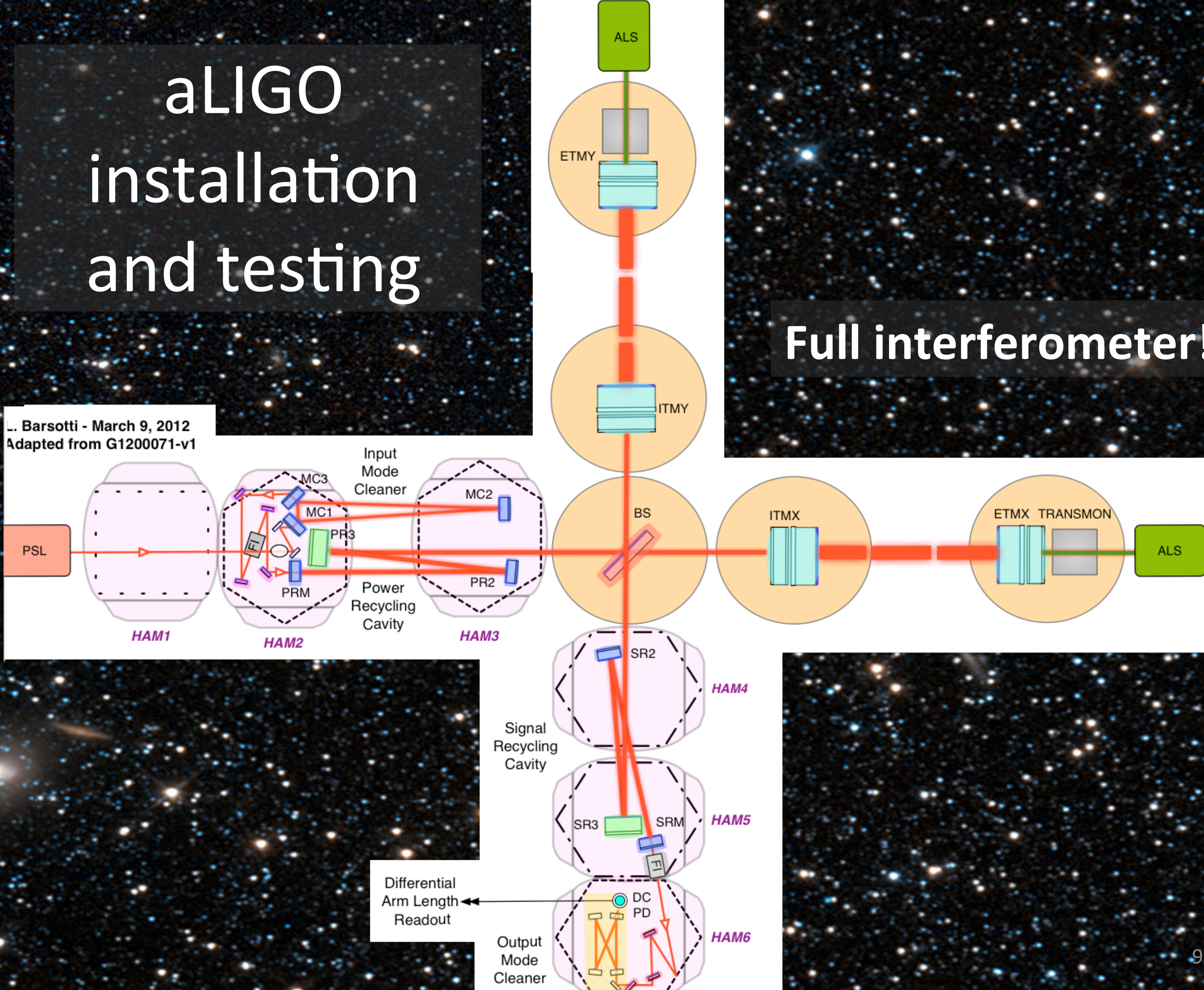
Vertex locking

Signal Recycling Cavity:

- Tunable
- Increases sensitivity in selected frequency band

aLIGO installation and testing

Full interferometer!



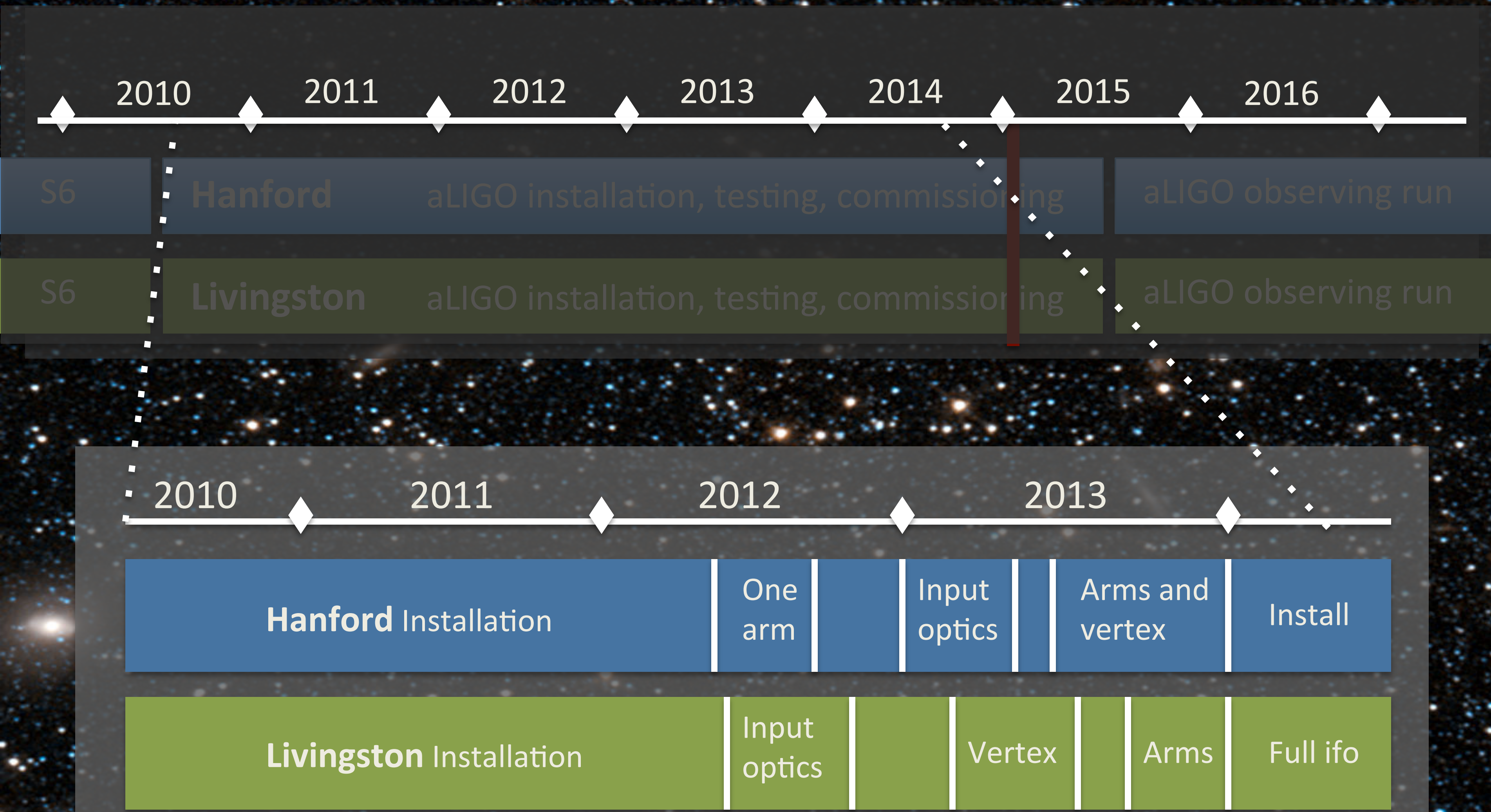
Timeline: from eLIGO to aLIGO

2010	2011	2012	2013	2014	2015	2016

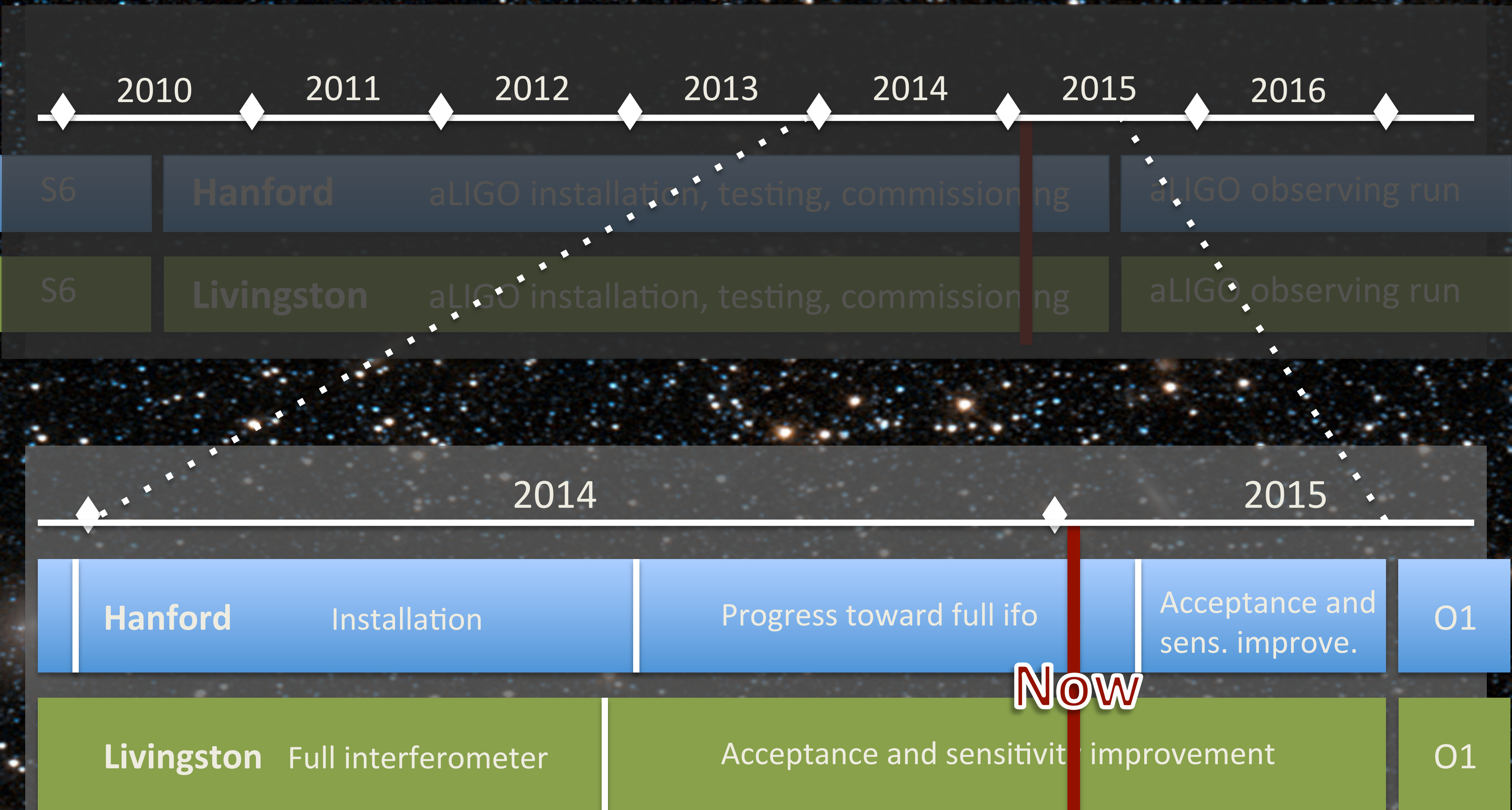
S6	**Hanford**	aLIGO installation, testing, commissioning	aLIGO observing run
S6	**Livingston**	aLIGO installation, testing, commissioning	aLIGO observing run

Timeline: from eLIGO to aLIGO

Timeline: installation and testing

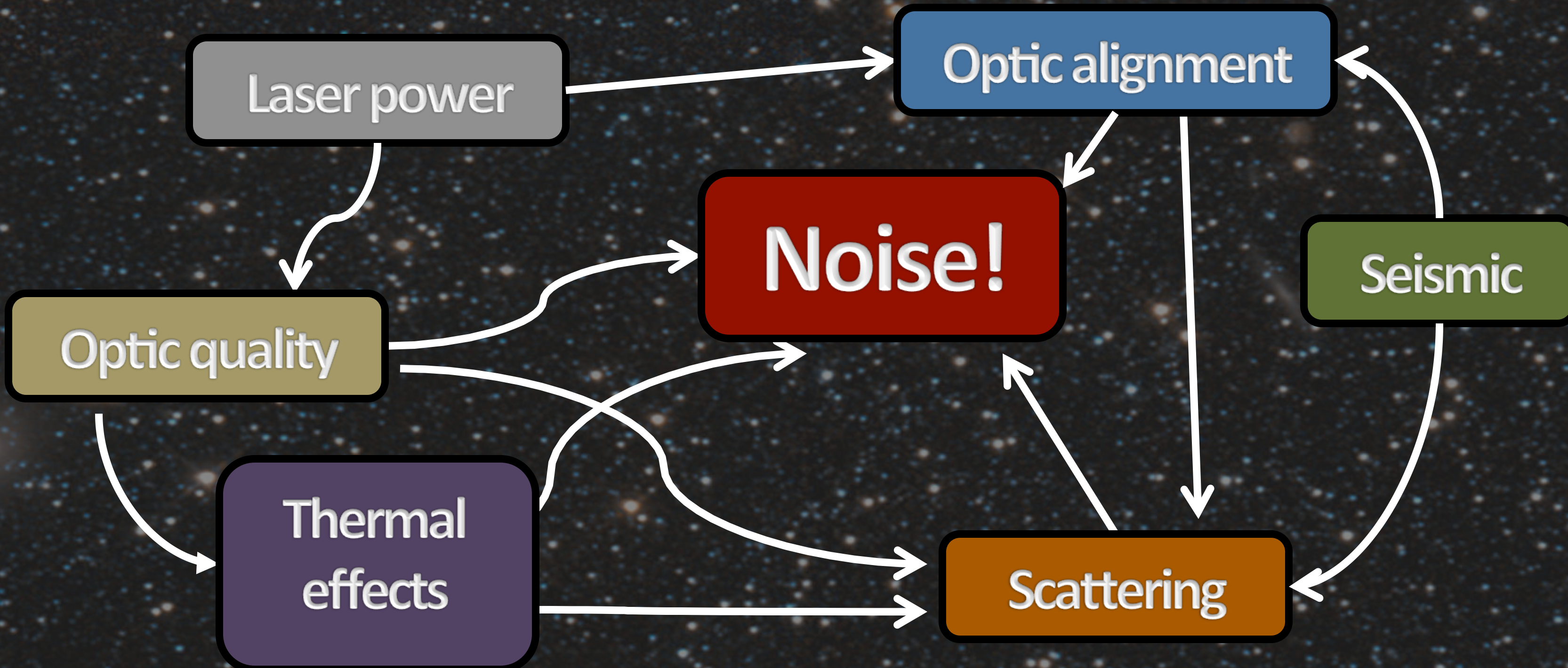


Timeline: the lead up to the first observing run



The challenges of commissioning

- Many effects cannot be tested prior to large scale implementation
- Often noise sources stem from the interaction of different subsystems and cavities

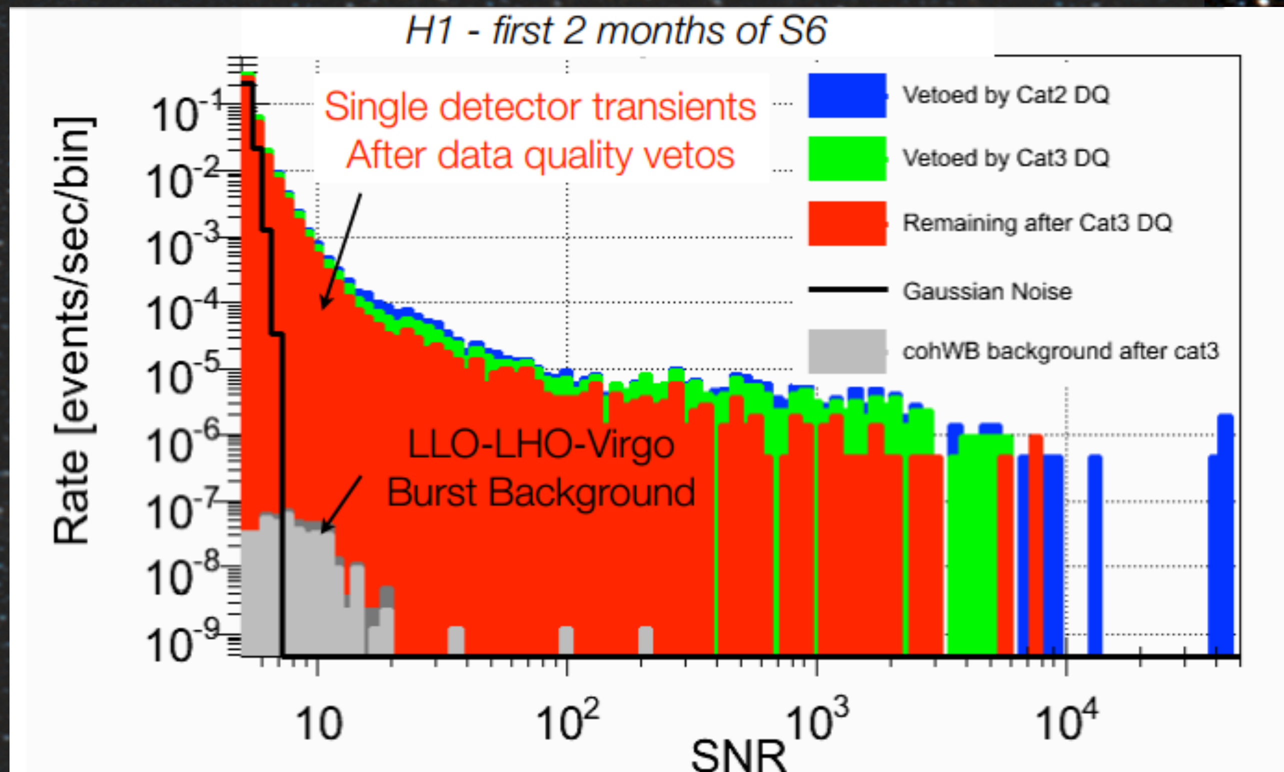


Adapted from L. Barsotti

Lessons from the past

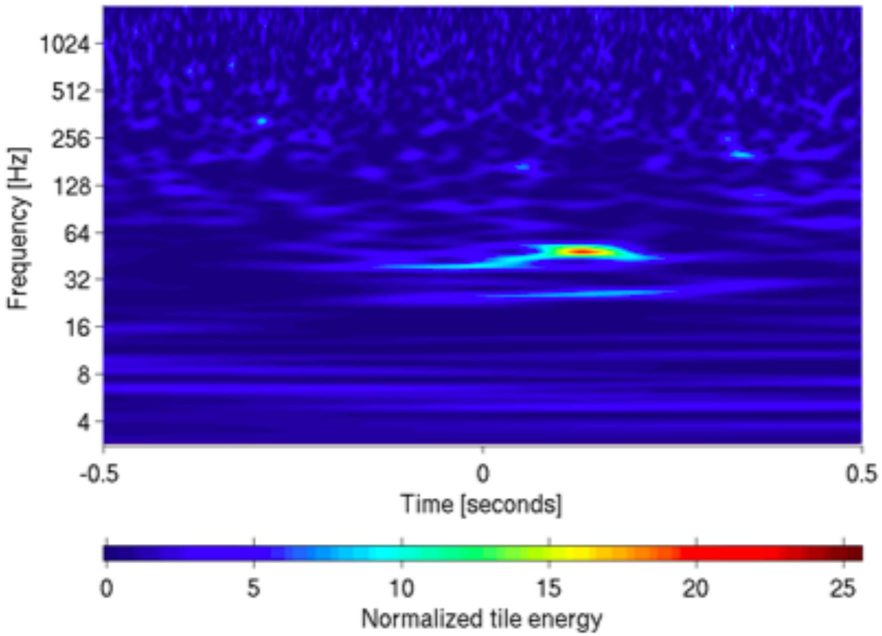
GW search pipelines are adversely affected by non-Gaussian data!

- Long tails (outliers) in all-sky GW burst search background triggers **greatly restrict achievable false alarm rate.**
- Non-Gaussian noise confuses parameter estimation for all transient searches.



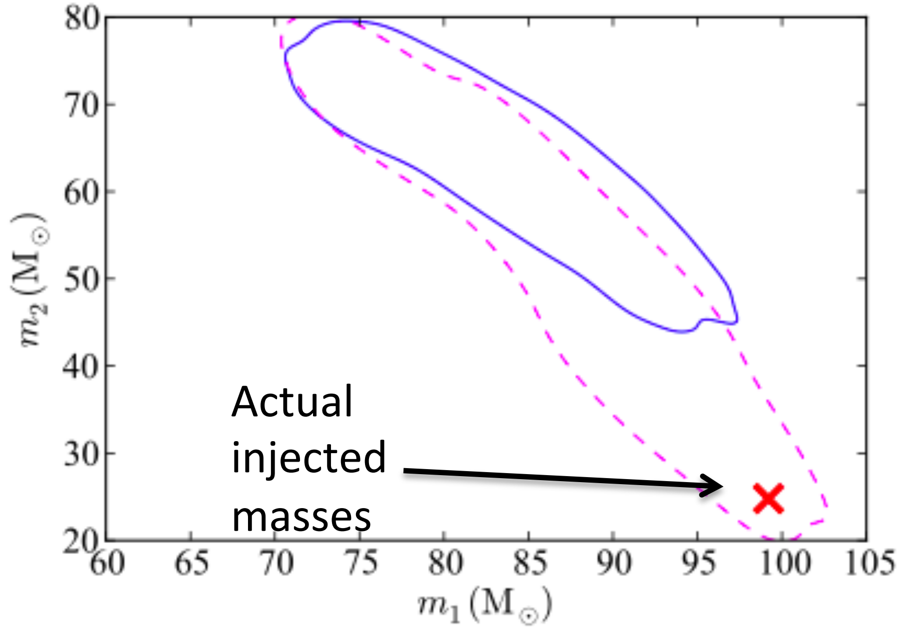
Slide: Josh Smith, 2014

Example: NINJA2 search results



arvix 1401.0939

(a)

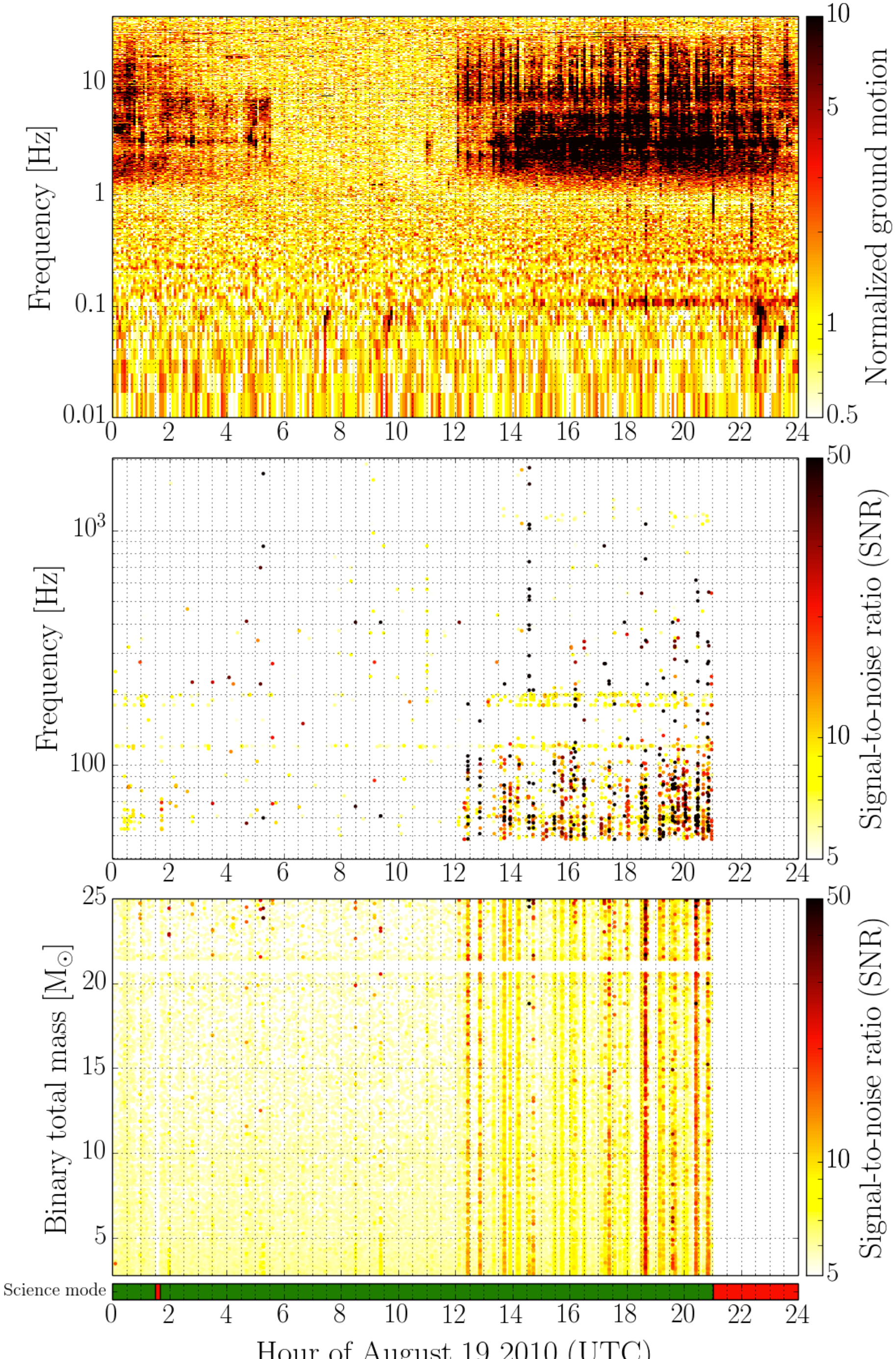


(b)

A normalized spectrogram of **Hanford recolored noise only** showing a transient event, or *glitch*, that happens to occur at the time of the injection.

Solid blue – the 95% credible region for mass estimation based on EOBNRv2 analysis using realistic recolored noise.

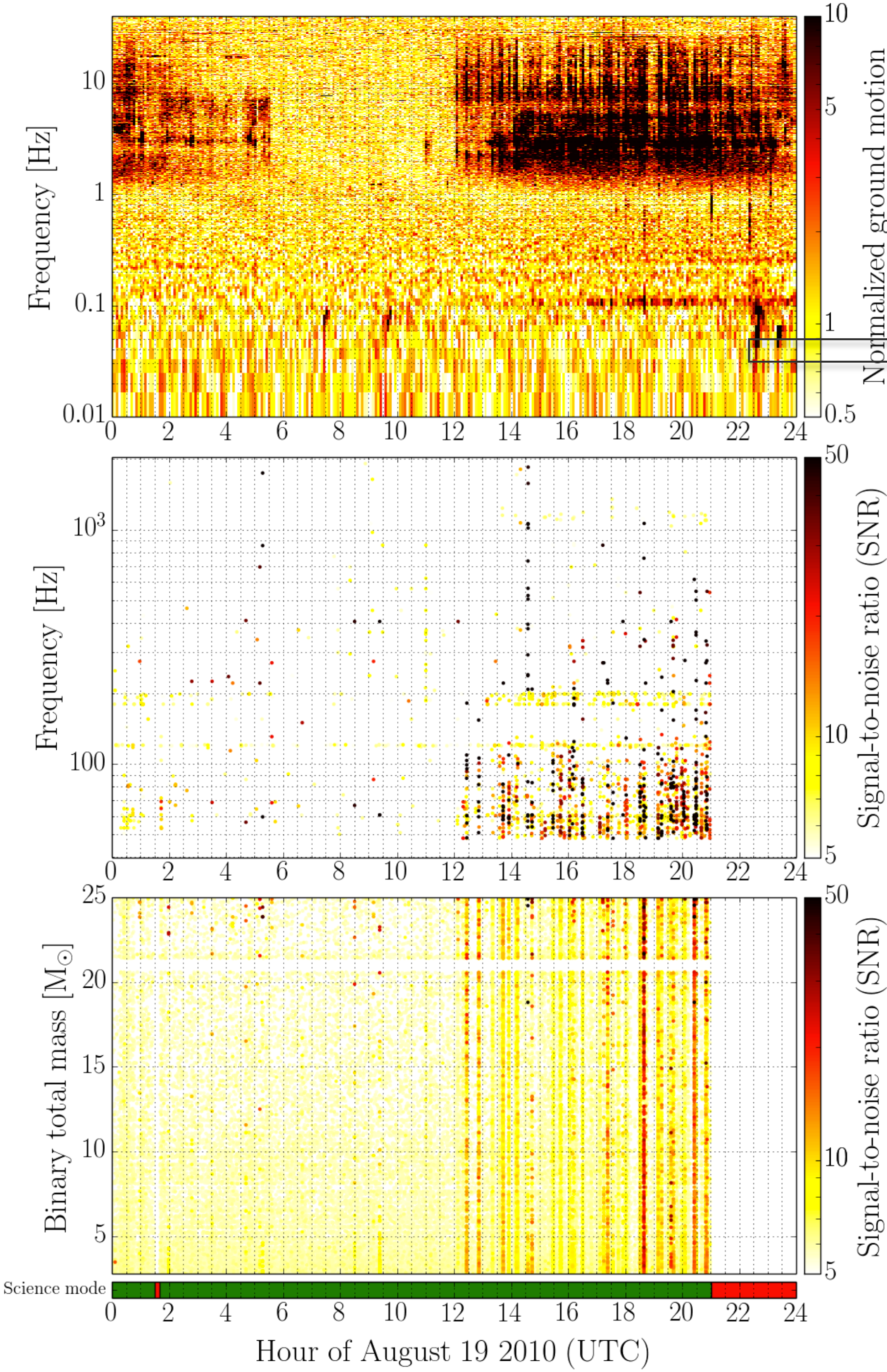
Dashed pink – in Gaussian noise.

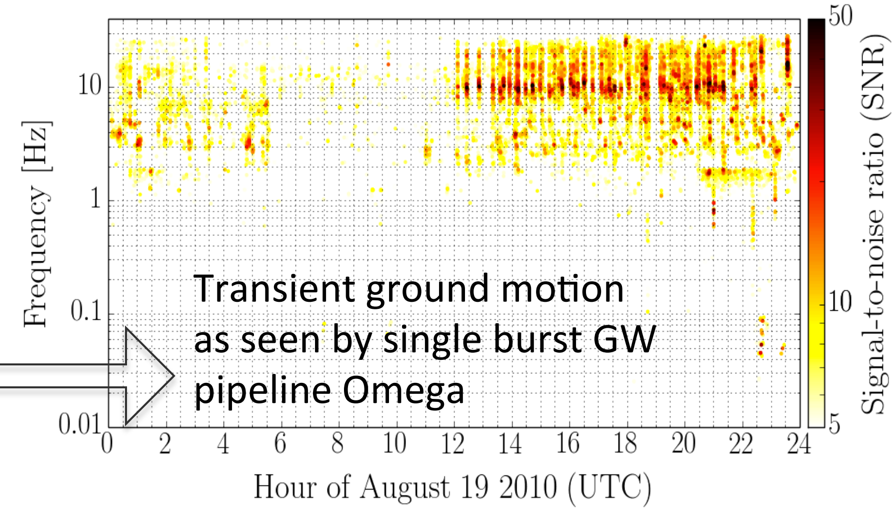


Example:

Transient seismic motion – a known and troublesome problem during S6.

arXiv preprint 1410.7764





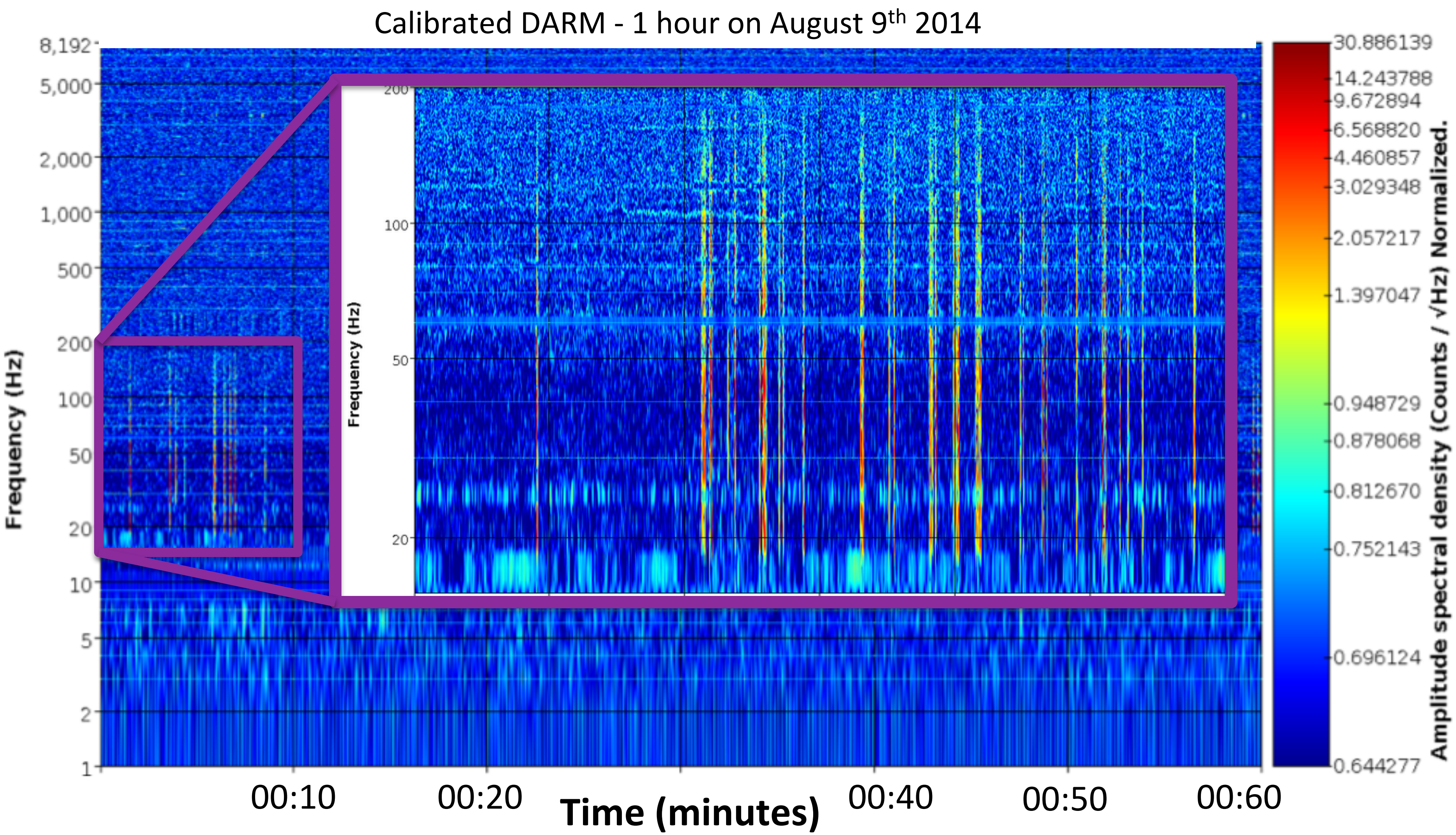
Transient seismic motion – a known and troublesome problem during S6.

arXiv preprint 1410.7764

Recent data from Advanced LIGO

Highlights of DQ features most troublesome for the transient searches

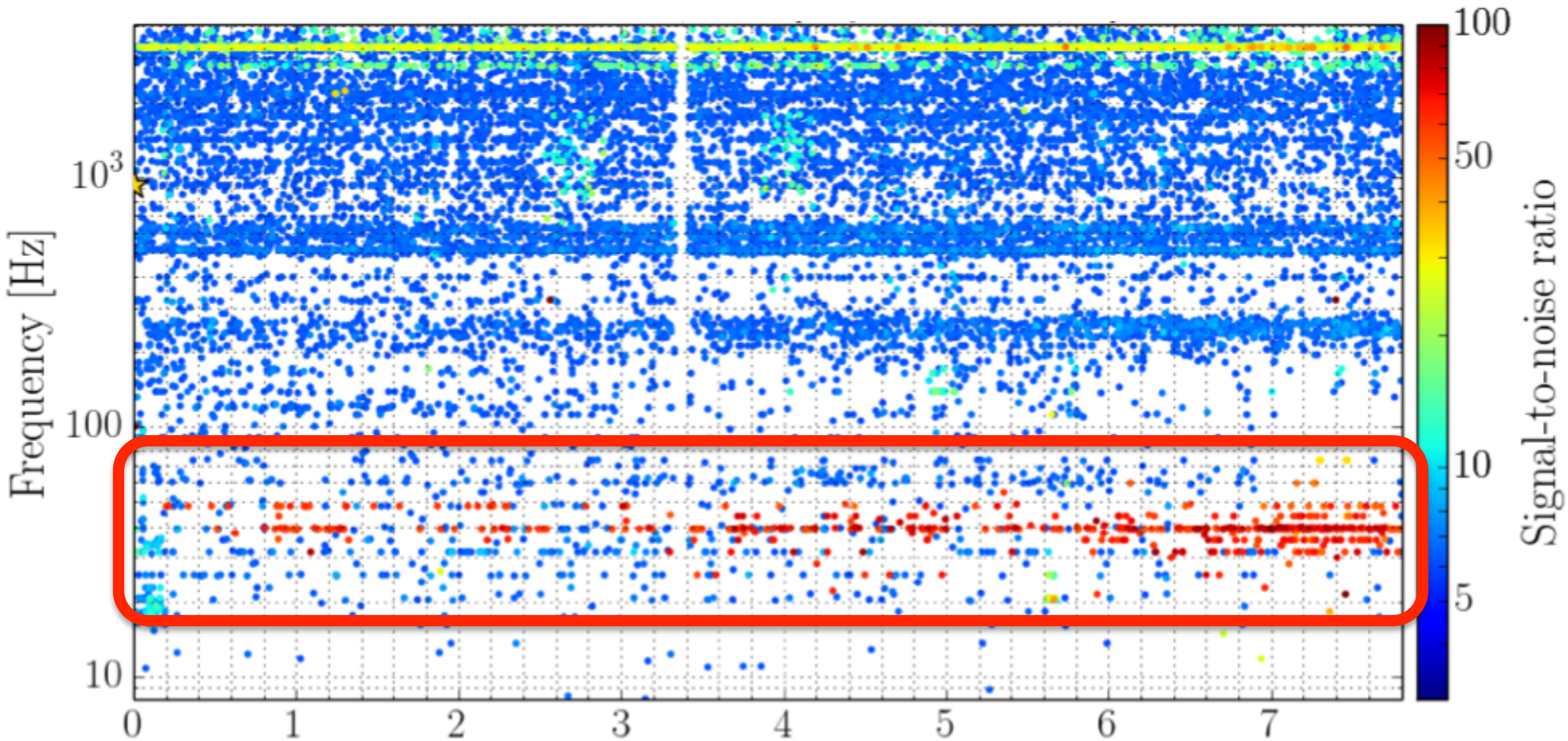
An early DQ issue diagnosis



Slide: Josh Smith, 2014

Through the lens of a single ifo burst GW pipeline

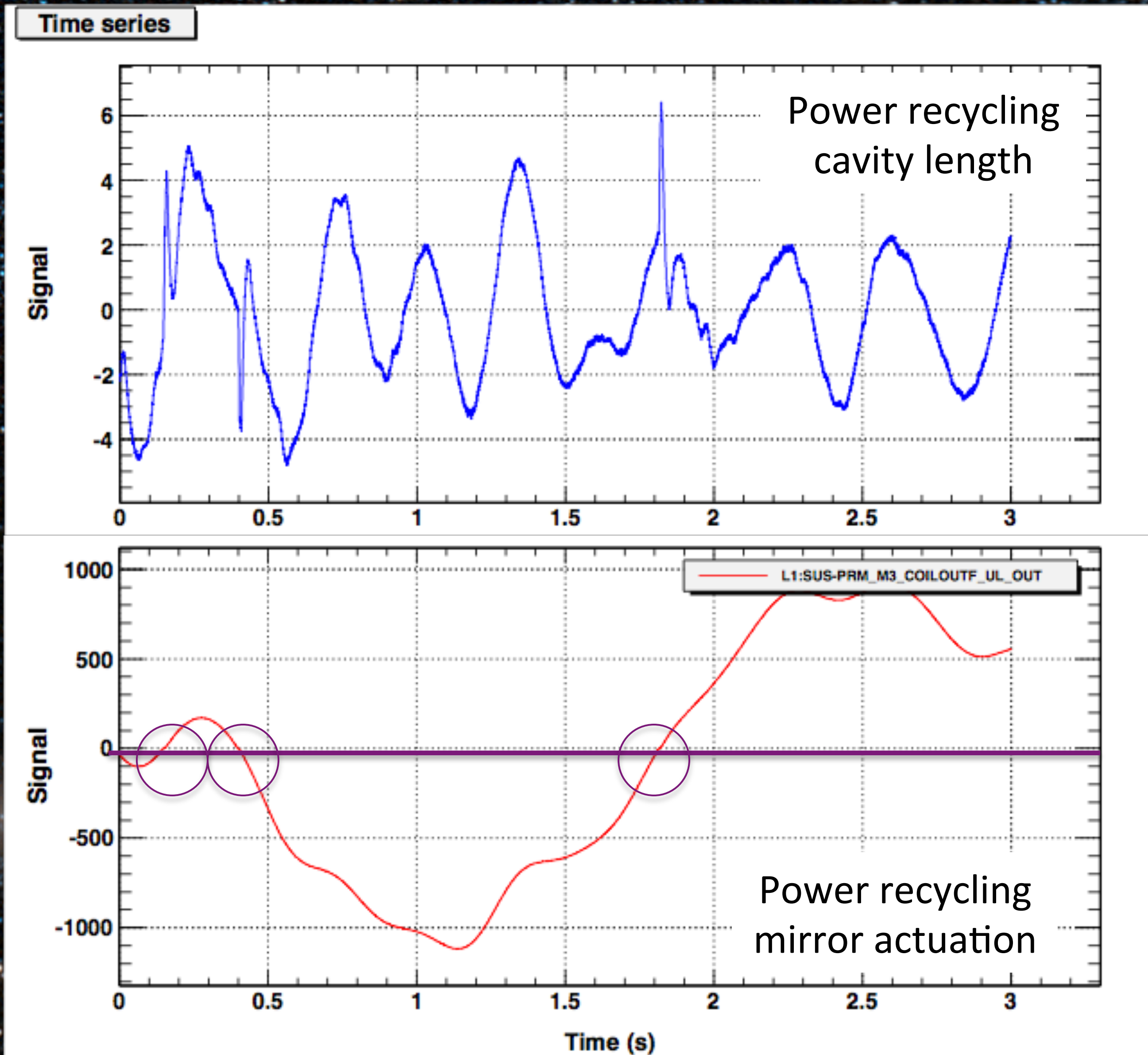
Calibrated DARM (differential arm length)



8 hours on August 9th 2014

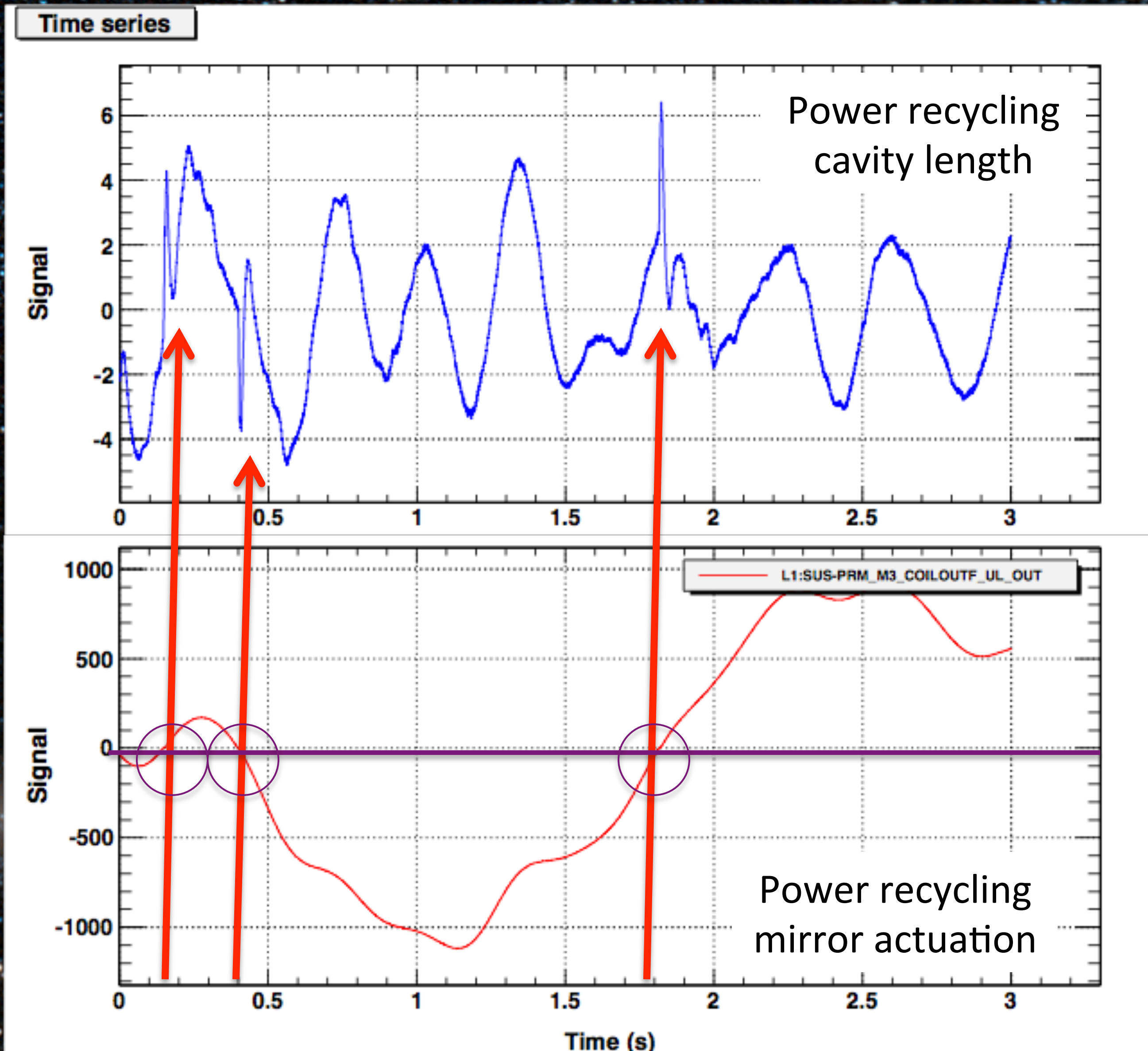
Slide: Josh Smith, 2014

The mechanism : major carry transition DAC glitching



Slide: Josh Smith, 2014

The mechanism : major carry transition DAC glitching

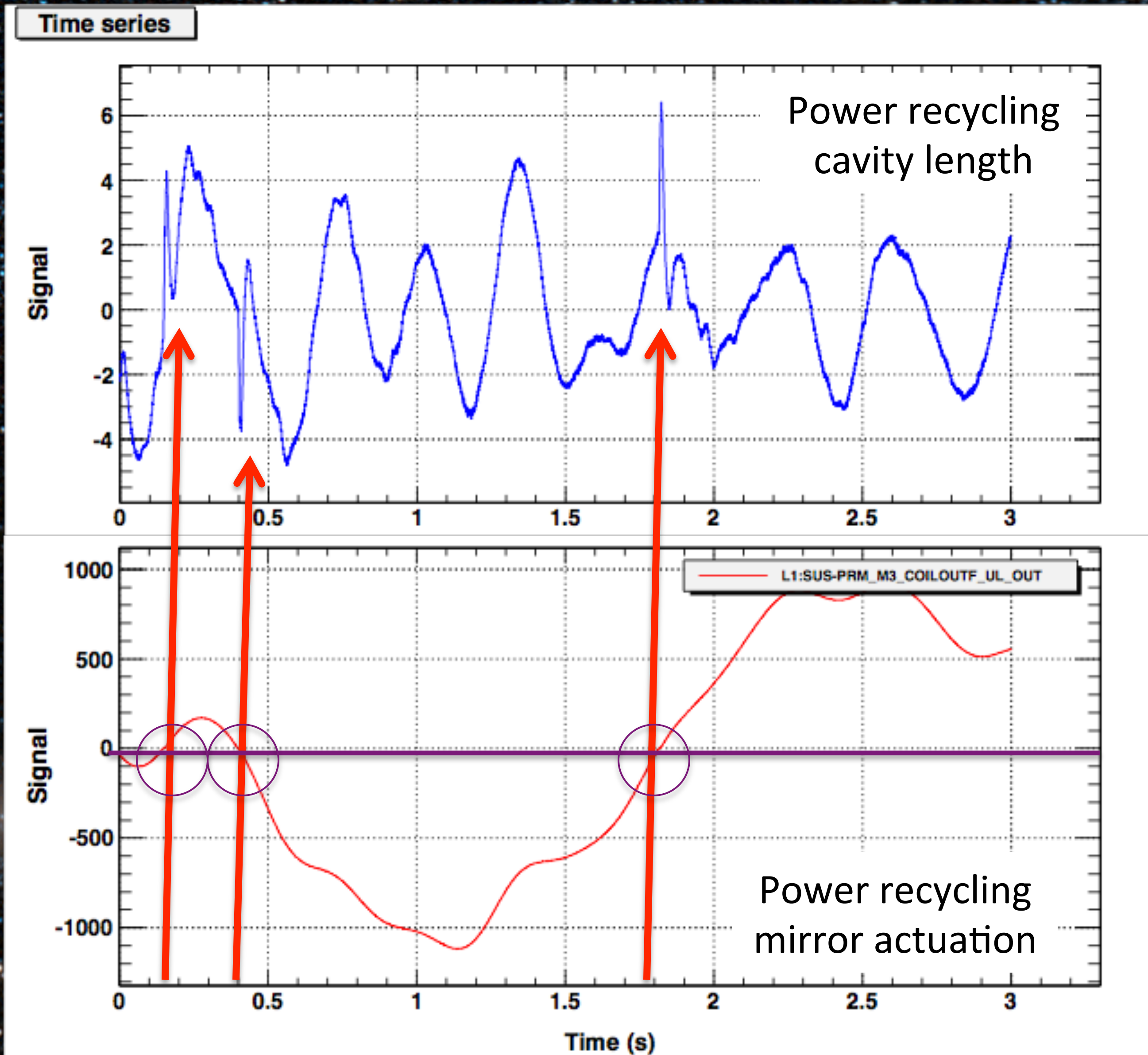


First dubbed "zero crossing" glitches – identified when vertex cavity actuation signals crossed zero.

Actually a subset of a broader known issue with these DACs.

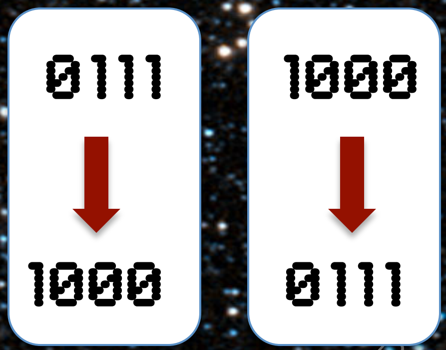
Slide: Josh Smith, 2014

The mechanism : major carry transition DAC glitching



Major-carry transitions (MCTs): value transitions that cause a most significant bit(s) to change

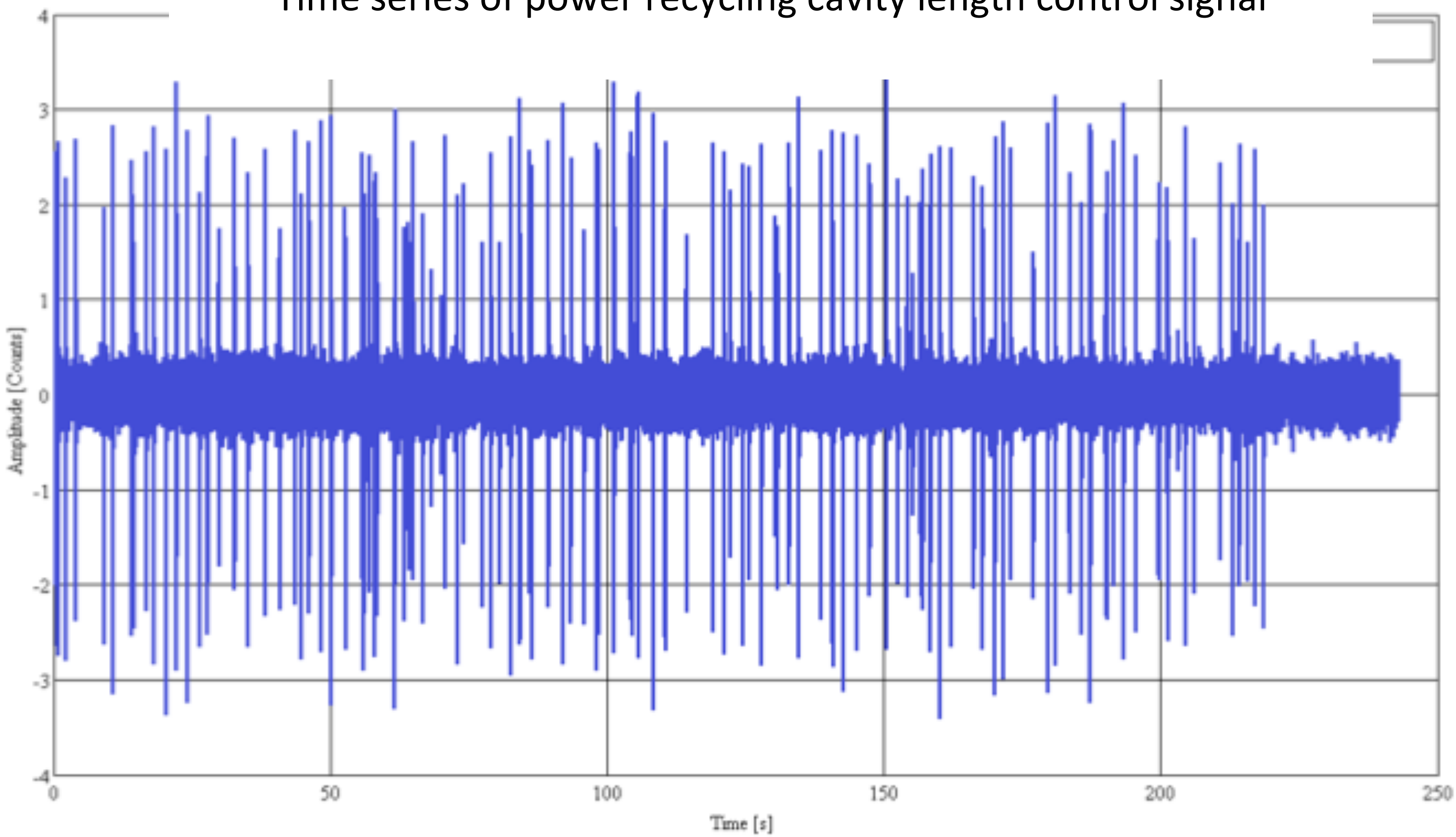
Examples:



Slide: Josh Smith, 2014

Offset applied to vertex cavity actuation

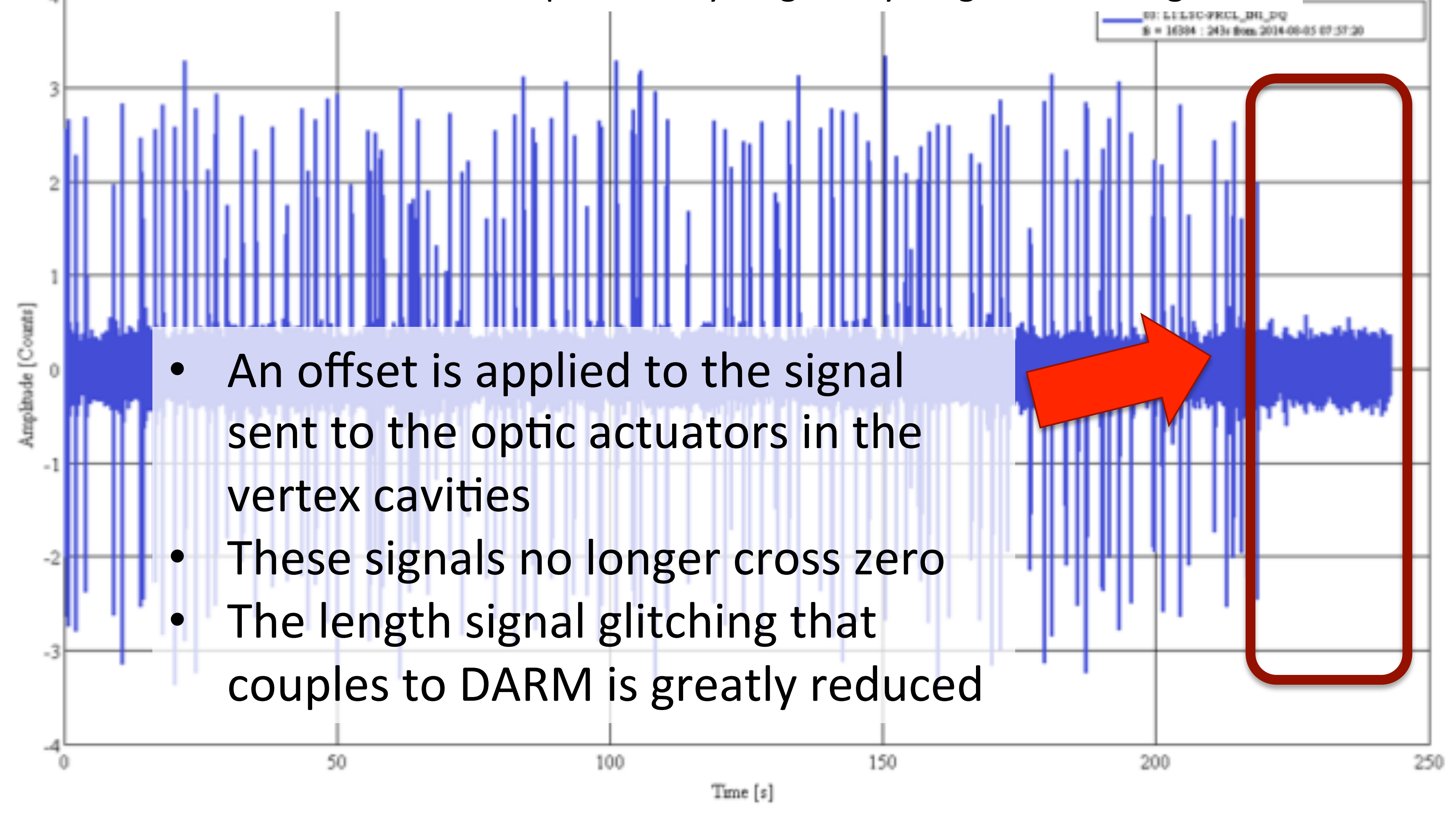
Time series of power recycling cavity length control signal



Slide: Josh Smith, 2014

Offset applied to vertex cavity actuation

Time series of power recycling cavity length control signal

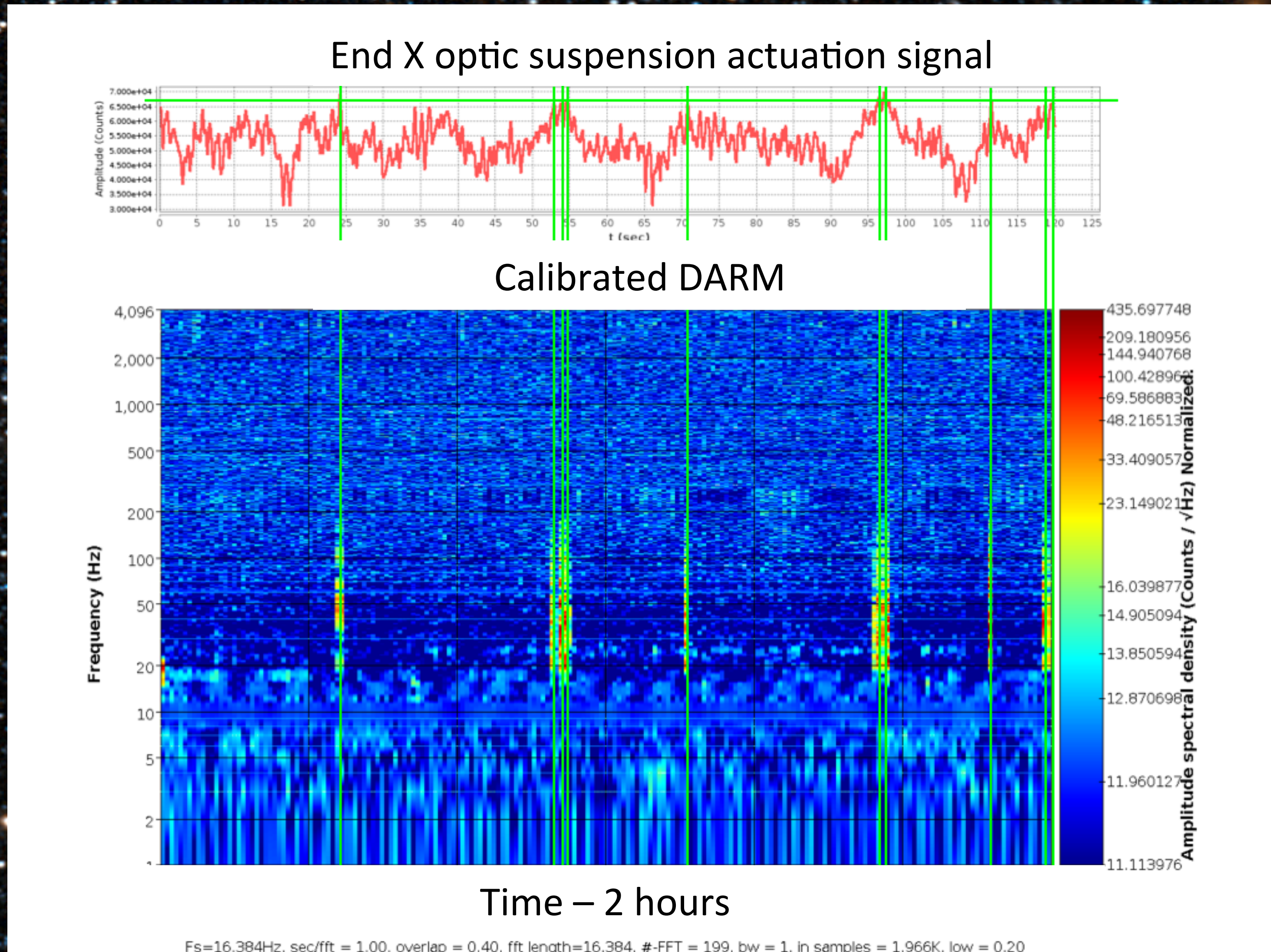


- An offset is applied to the signal sent to the optic actuators in the vertex cavities
- These signals no longer cross zero
- The length signal glitching that couples to DARM is greatly reduced

End station actuator glitches identified

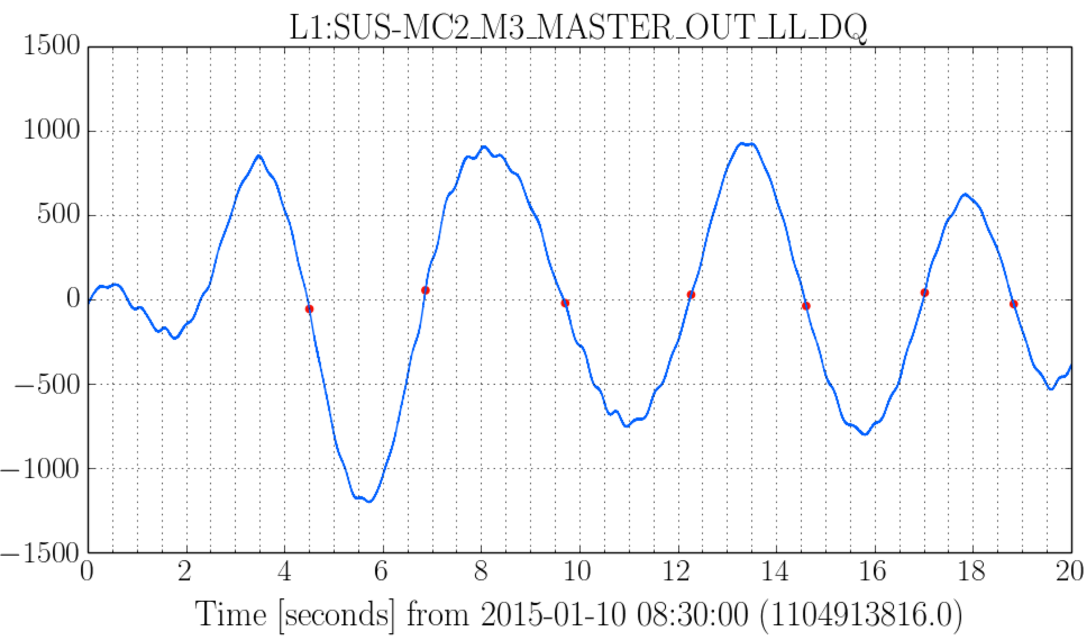
The Detector Characterization group also identified this behavior in one of the end stations at the 2^16 MCT

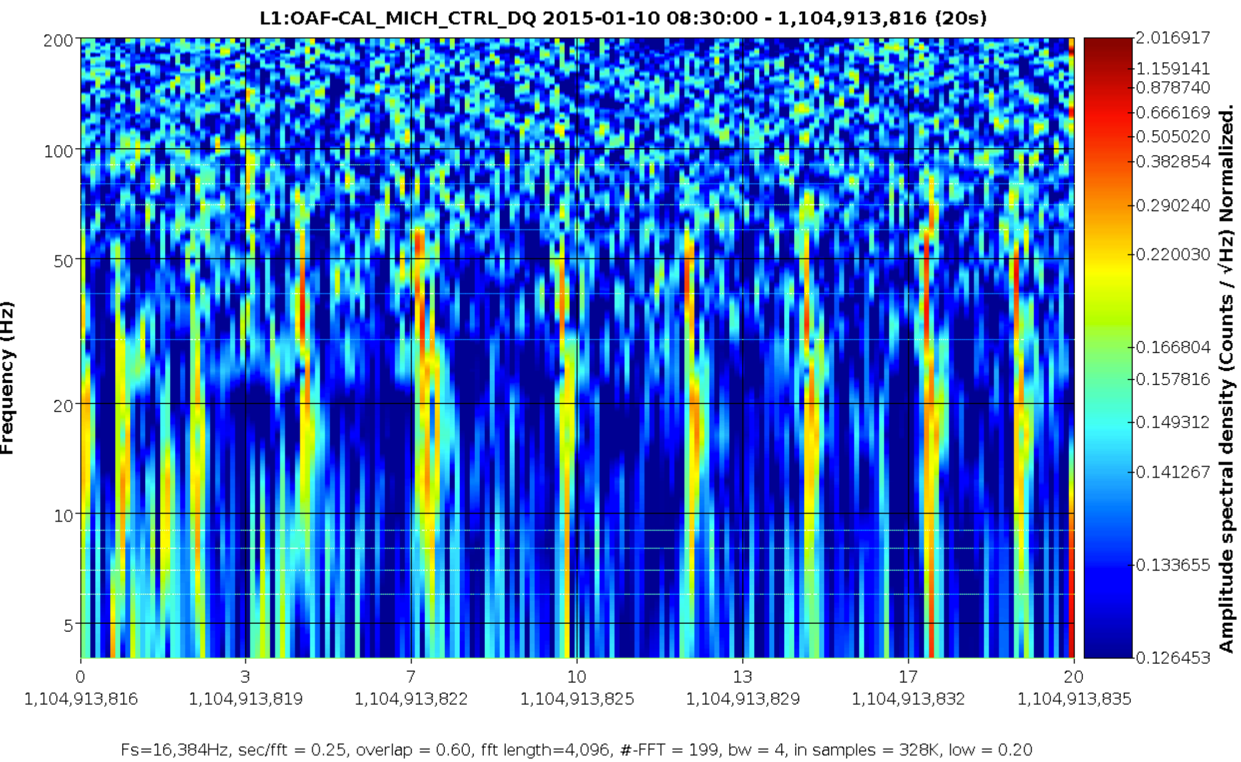
MCT glitching was later addressed with calibration of DACs – the offsets were removed in mid December



Slide: Josh Smith, 2014

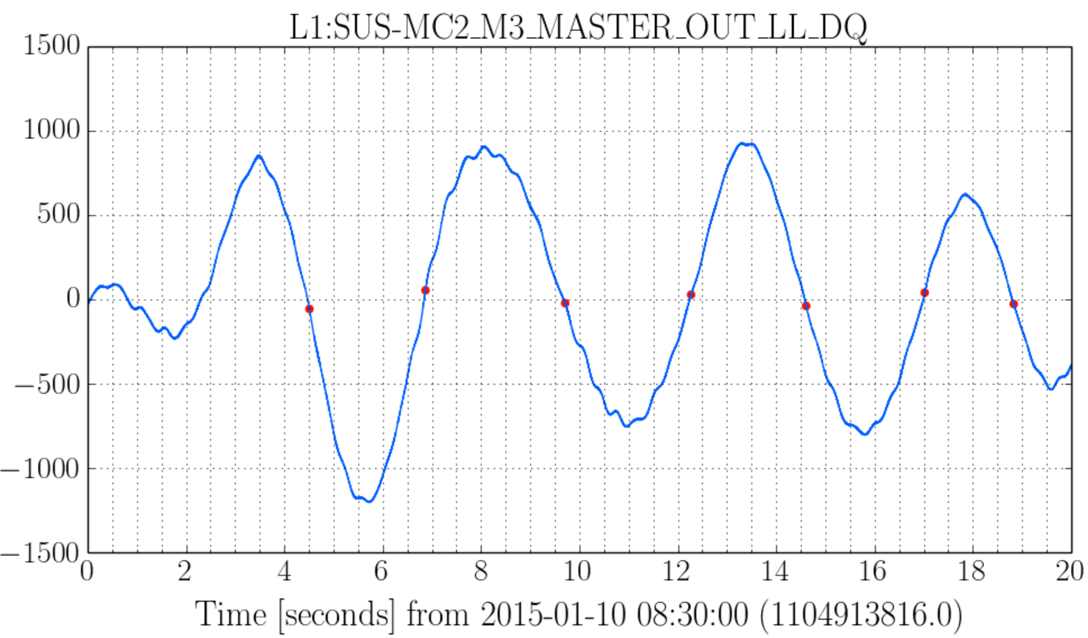
Return of DAC glitches

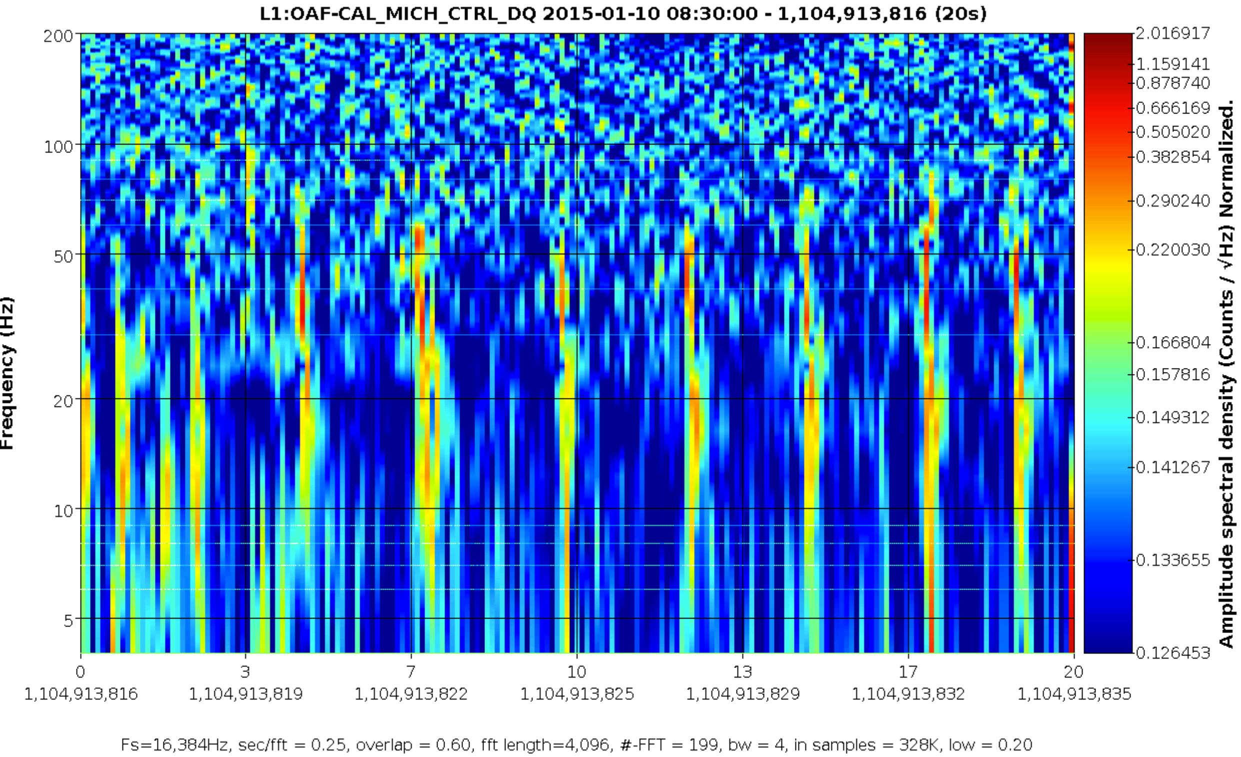




After ER6, loud glitches were observed in DARM that coupled with the vertex cavities (SRCL, PRCL, MICH)

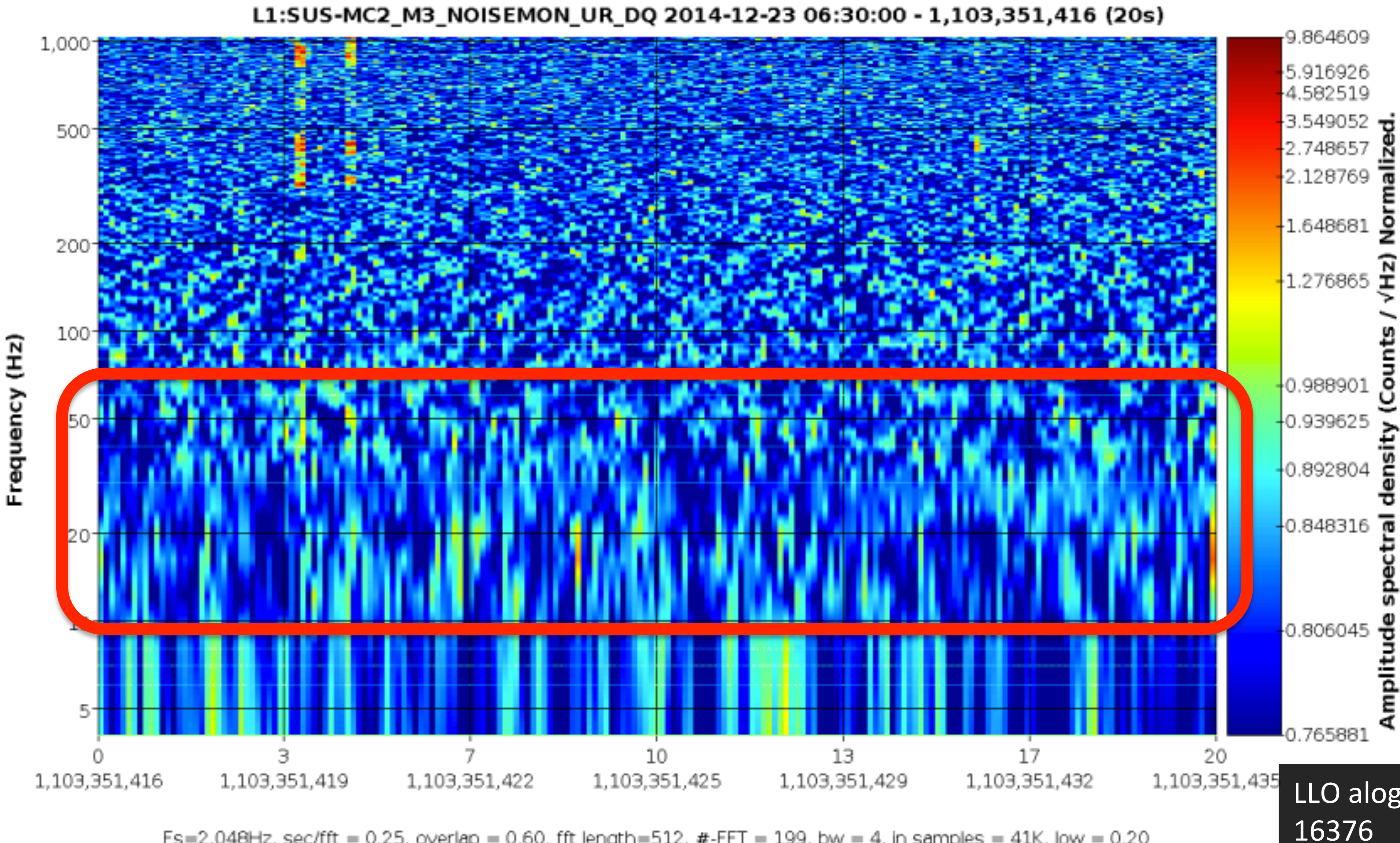
LLO alog 16354





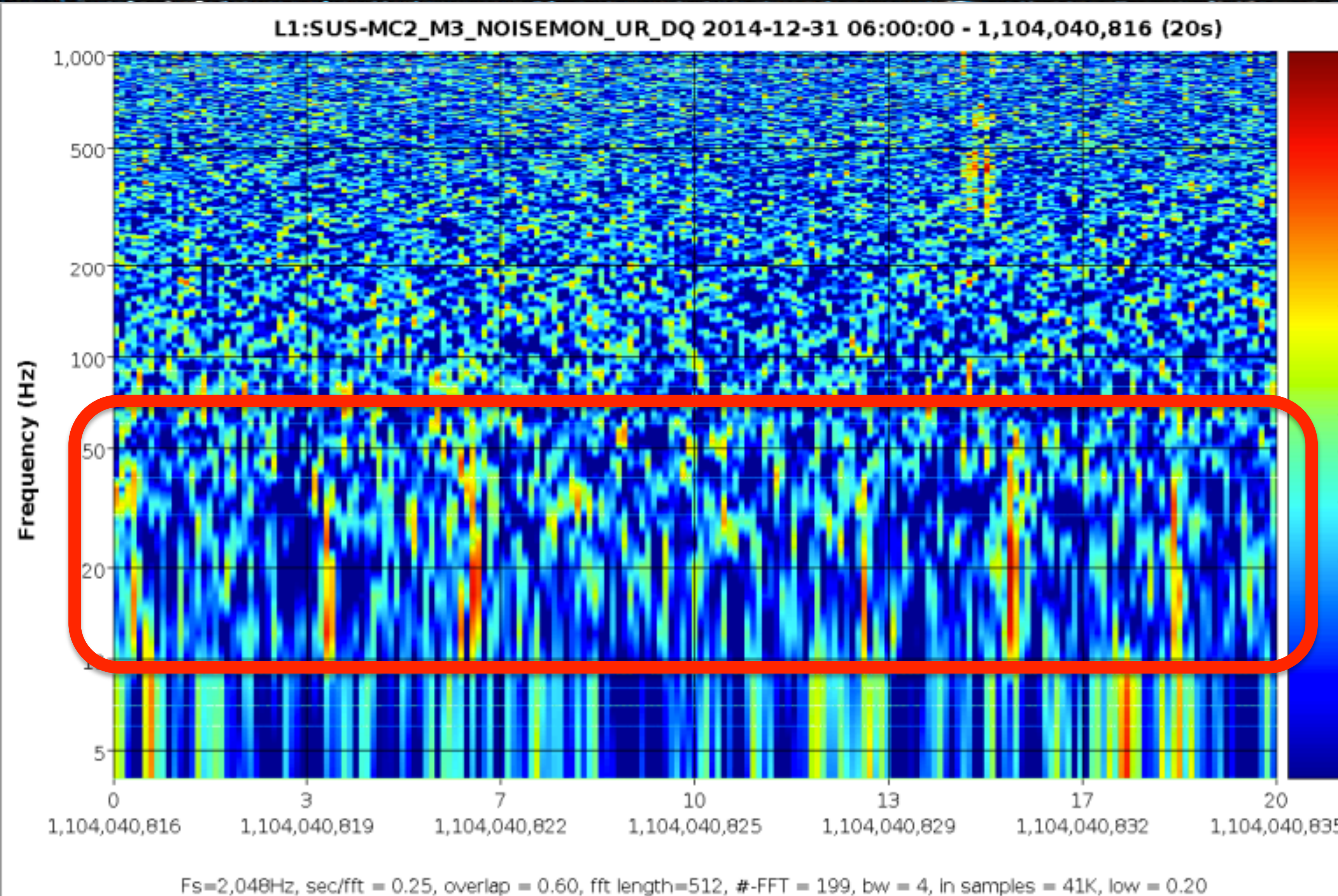
Wasn't DAC glitching fixed?

ER6 DAC calibration drift – week 1



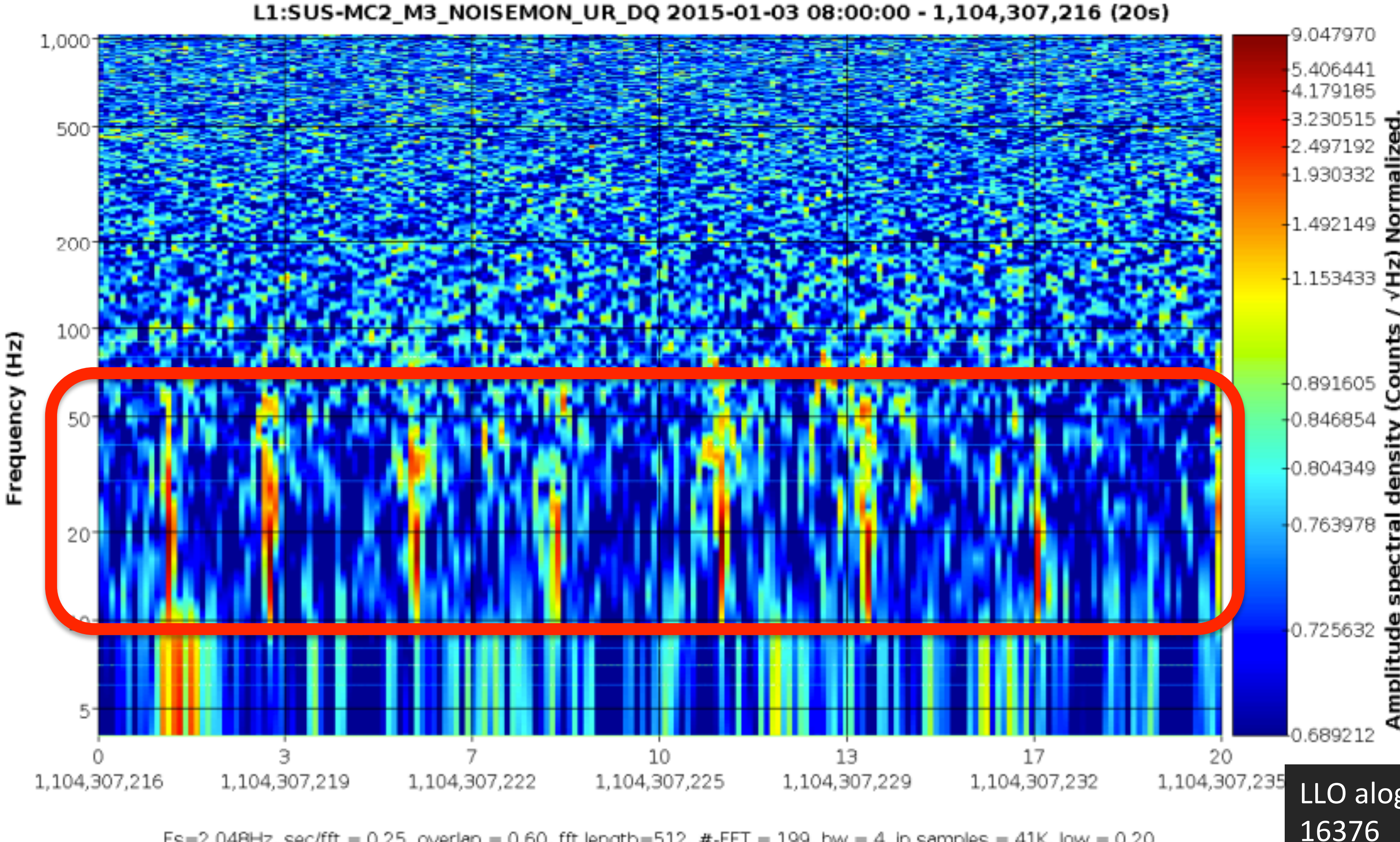
LLO alog 16376

ER6 DAC calibration drift – week 2



LLO alog 16376

ER6 DAC calibration drift – week 3

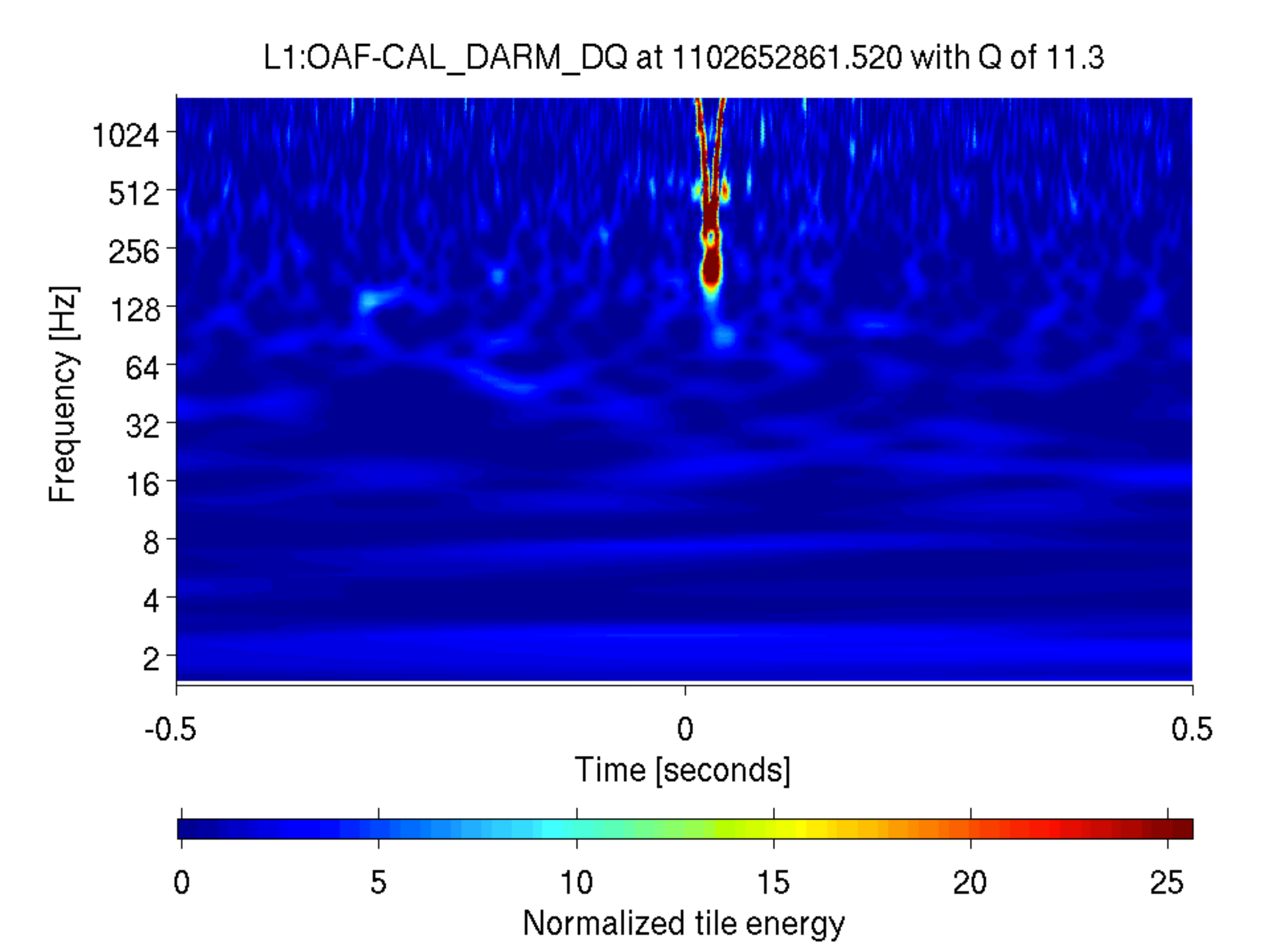


LLO alog 16376

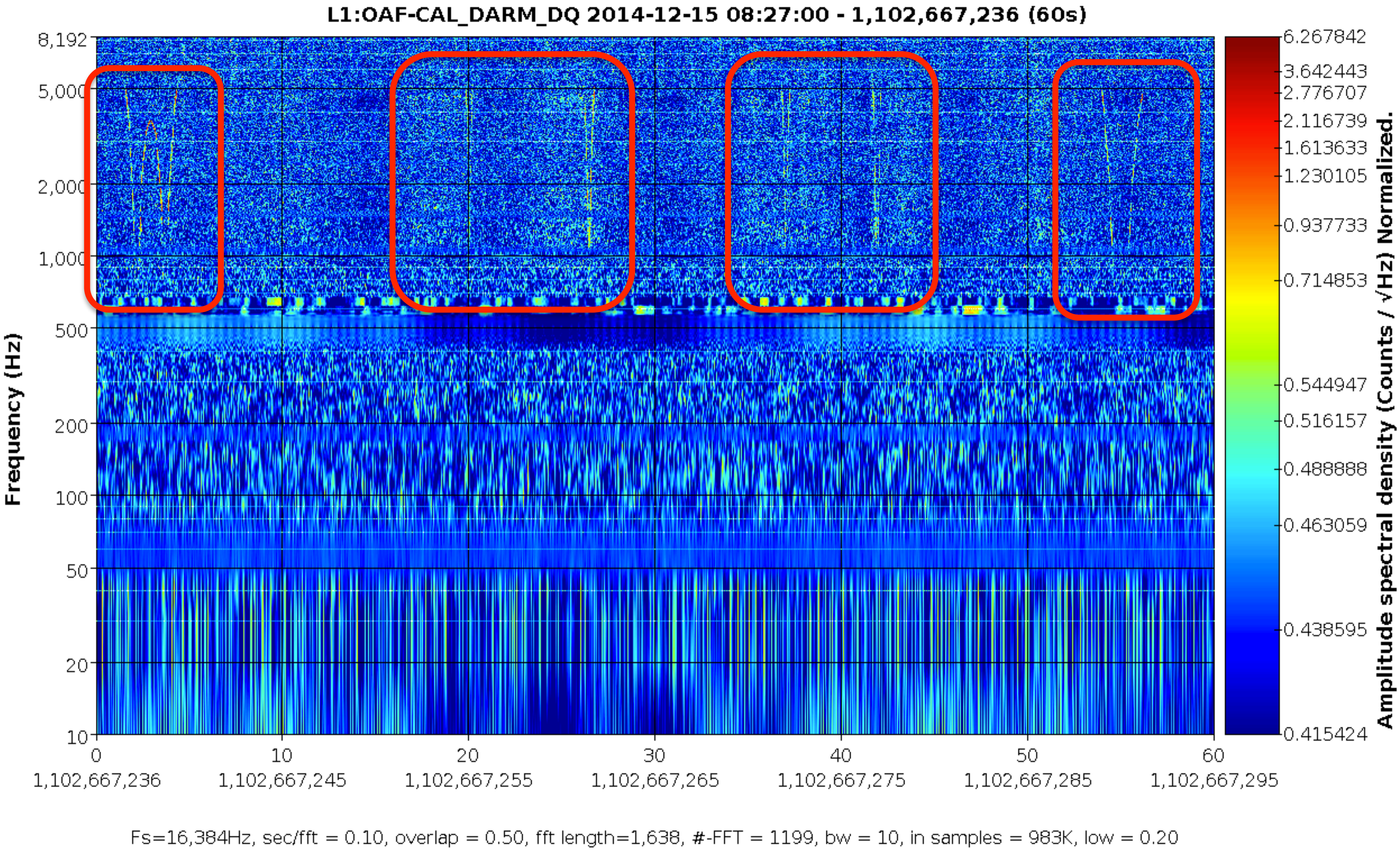
IMC beat frequency

Distinct "whistling" feature stemming from a beat frequency (WRT -817kHz) in the IMC that adversely affected the BBH search in ER6

Summary: LLO alog 16298

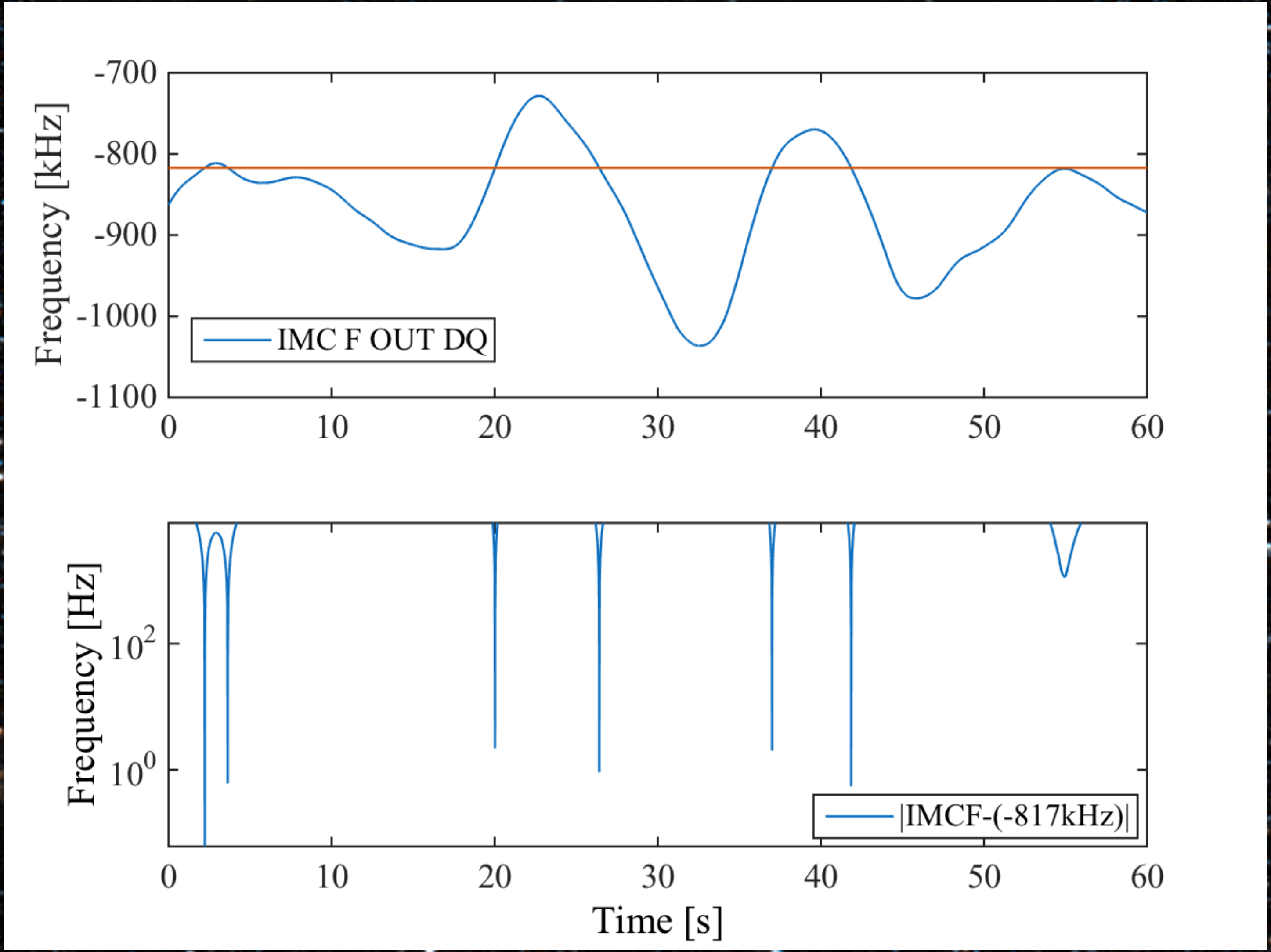


IMC beat frequency

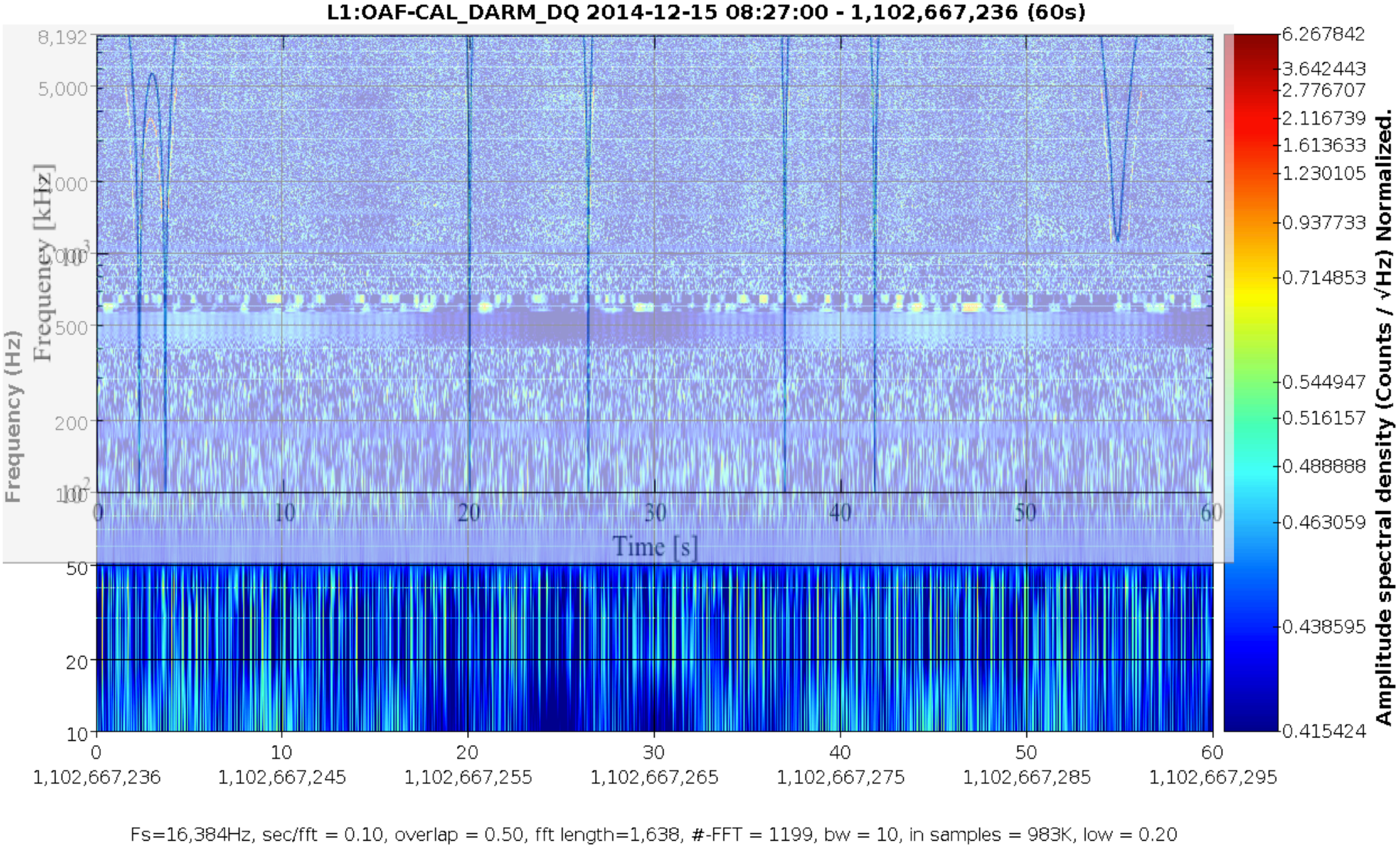


IMC beat frequency

Summary:
LLO alog
16298

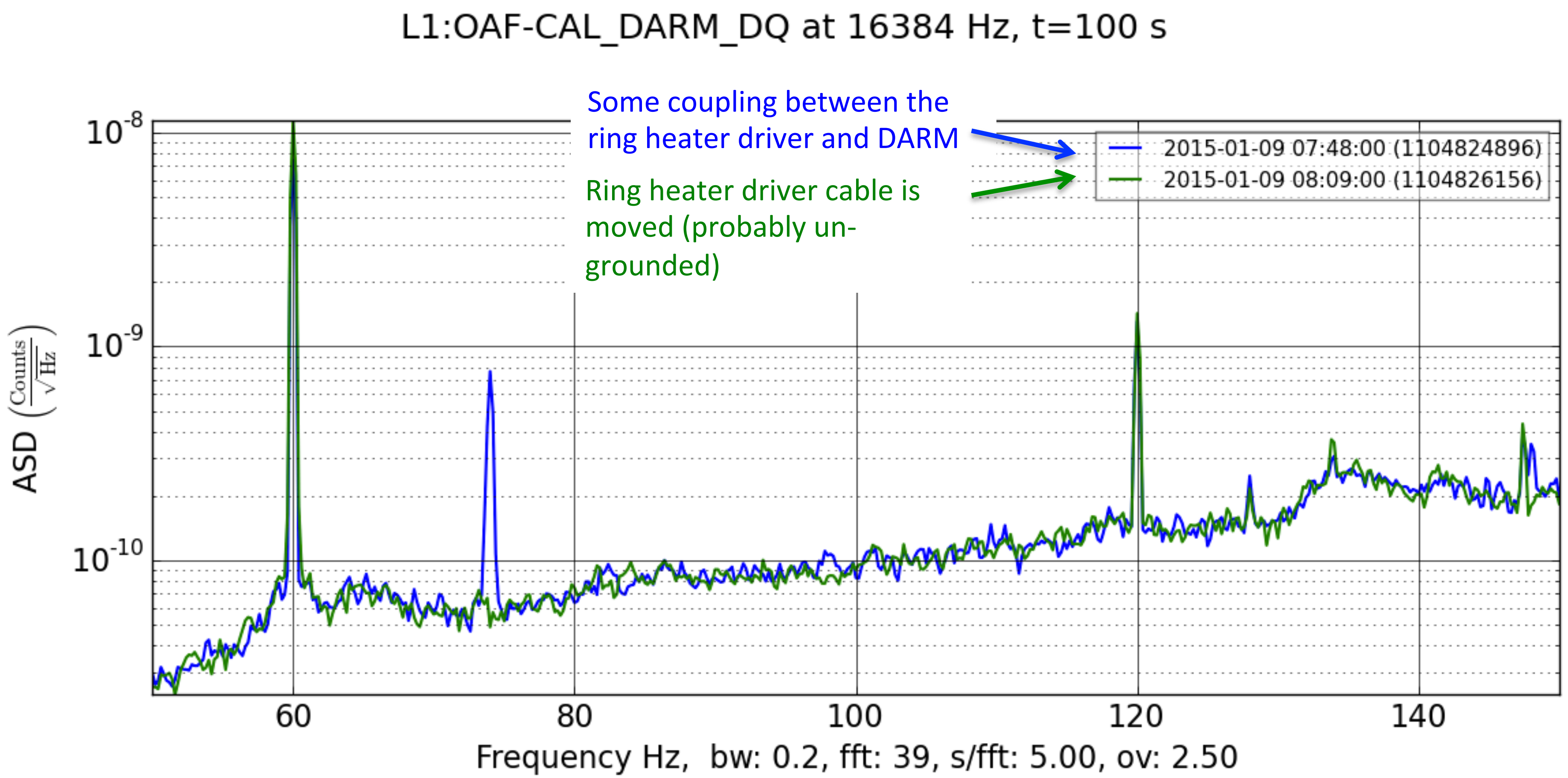


IMC beat frequency



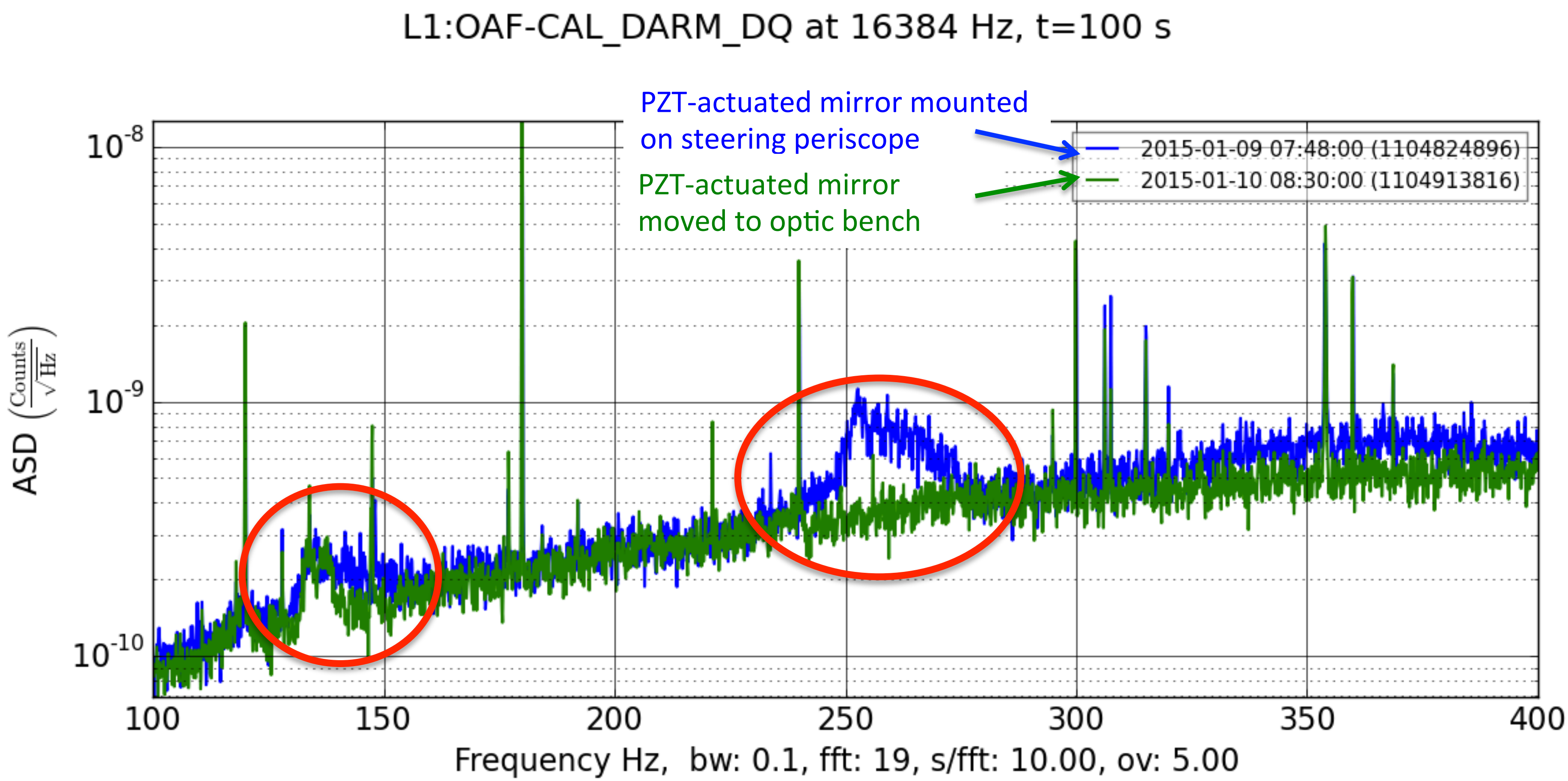
74 (72) Hz line – related to EY ring heater driver

LLO alogs 16316, 16291

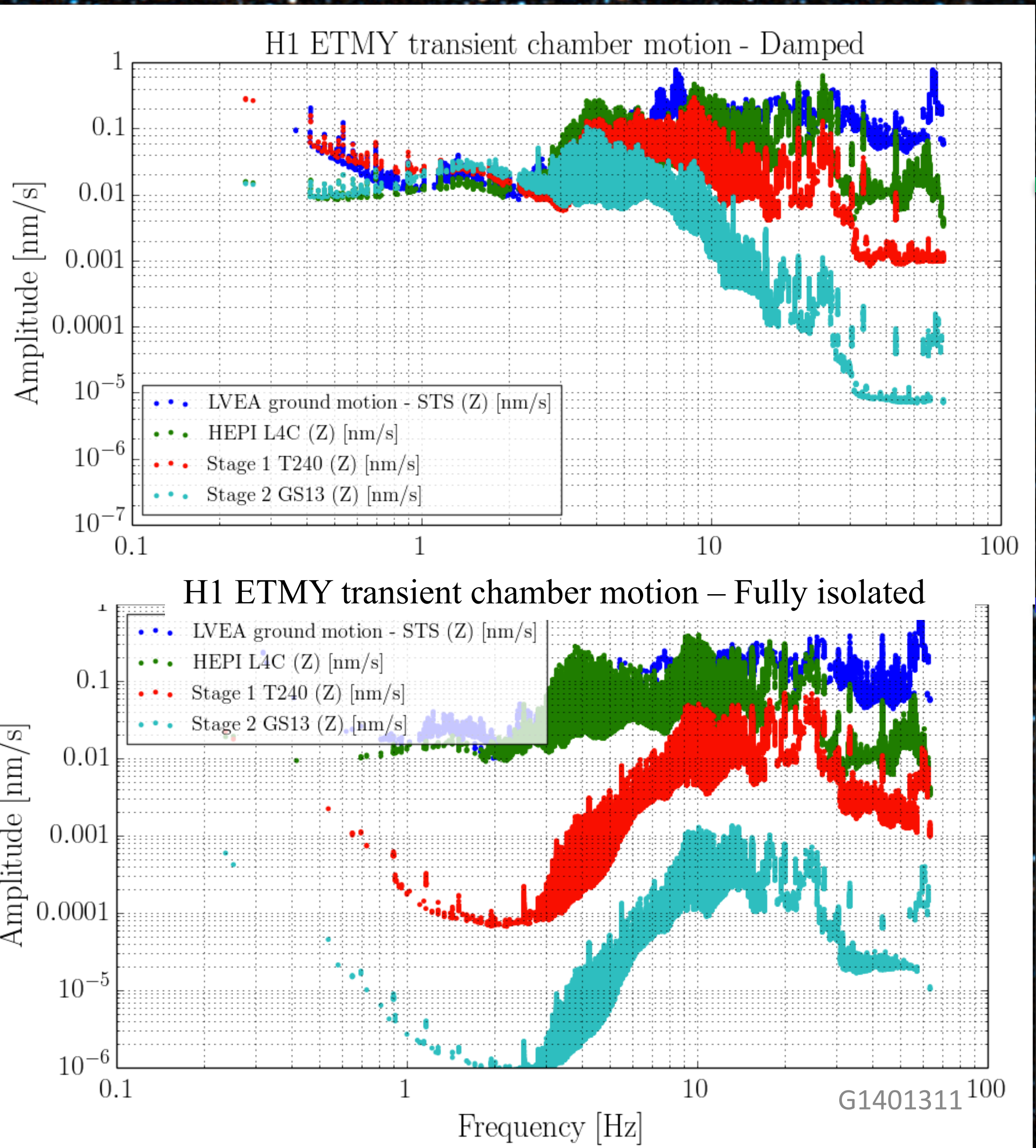


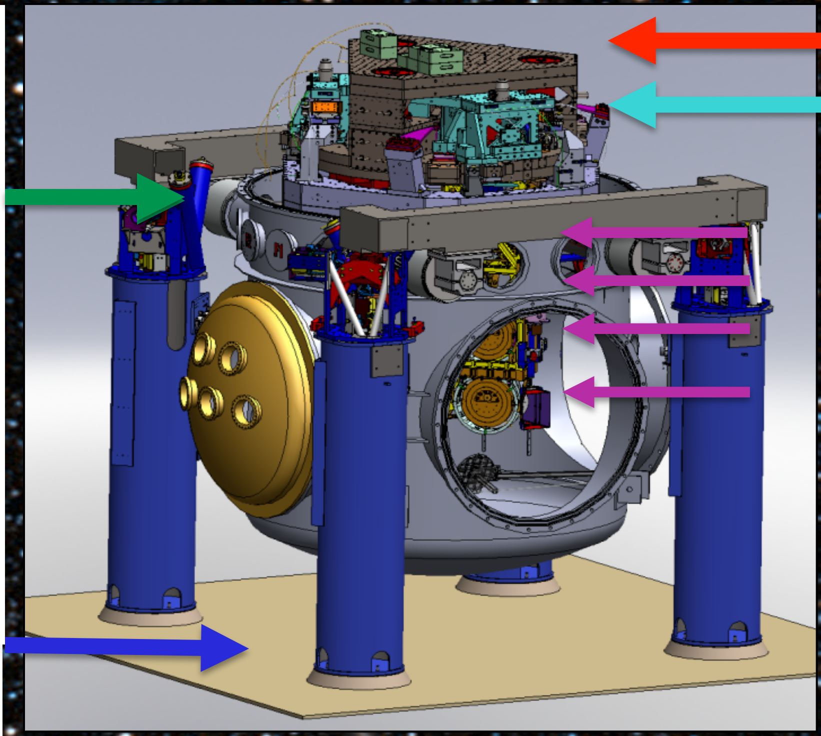
PZT-actuated mirror placement - 250Hz

LLO alog 16331



SEI transient propagation



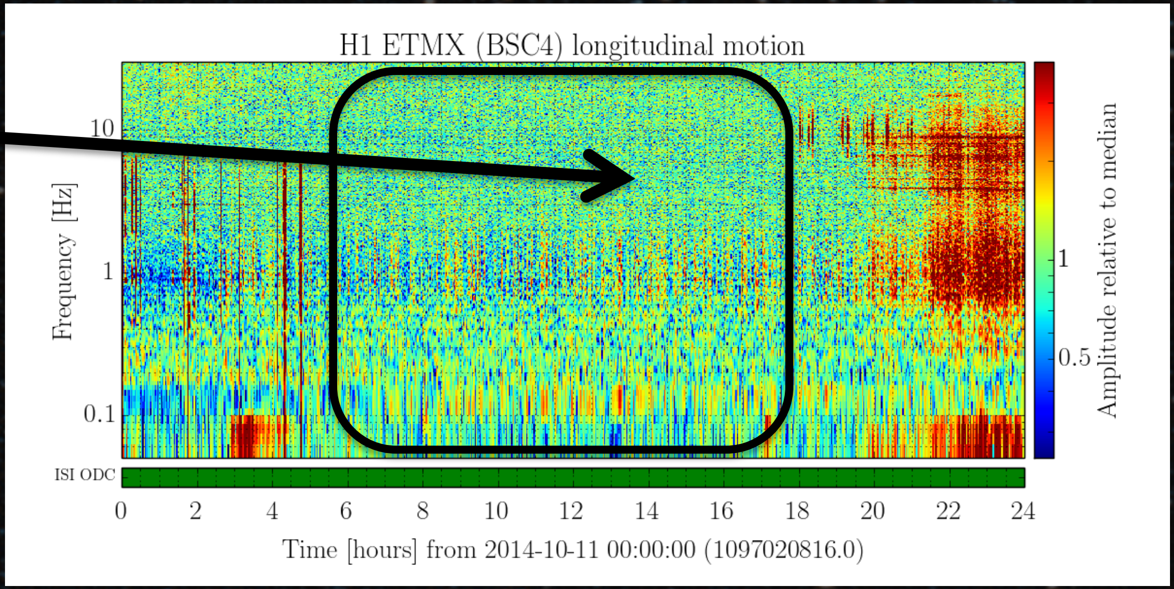


Tracing the transient motion from the ground to the optic table in various states of isolation loop aggression.

More aggressive isolation mitigates transients well < ~15Hz

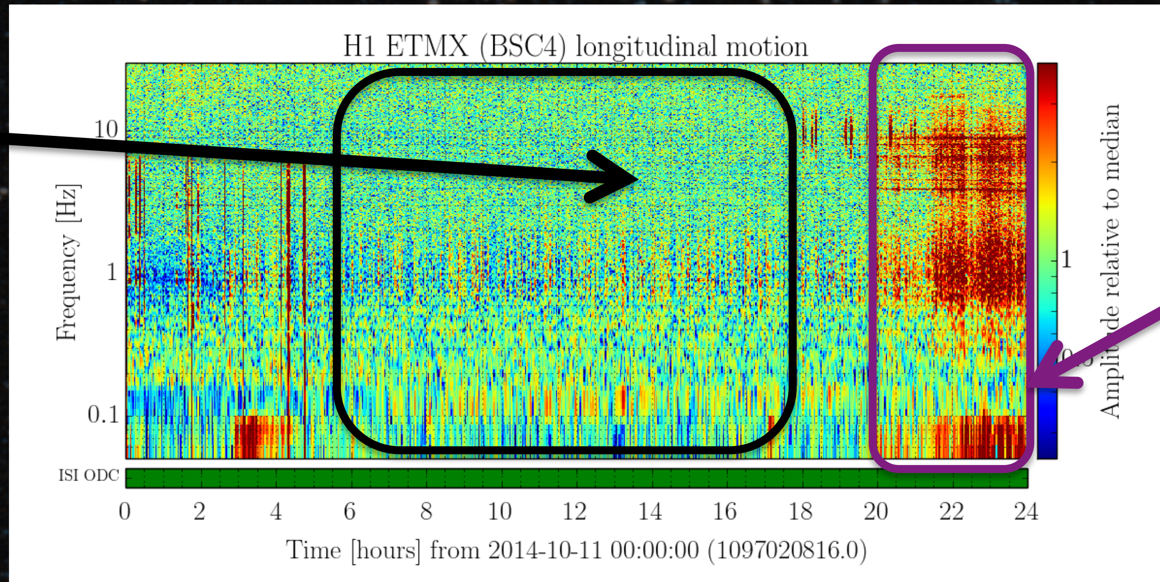
Windy vs. Quiet time transient SEI study at LHO

Most of the day, Oct 11, high microseism, low wind (~5MPH)



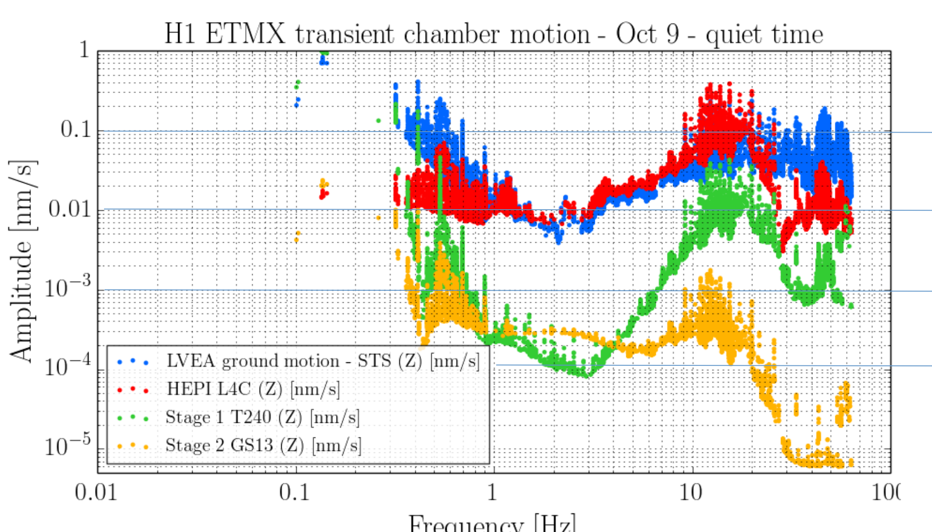
Windy vs. Quiet time transient SEI study at LHO

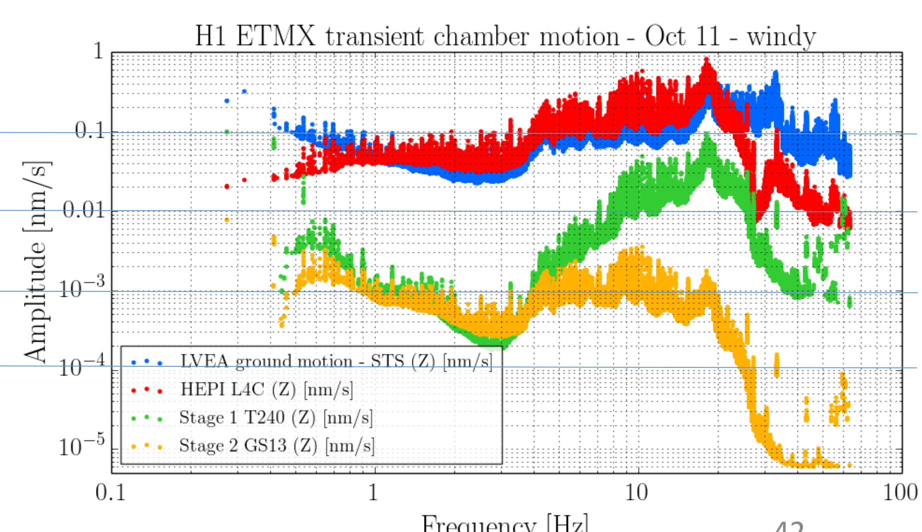
Most of the day, Oct 11, high microseism, low wind (~5MPH)



After~20:00 UTC, **high wind** (~30MPH)

Below are Omicron triggers of two hours of "quiet" time (left) and "windy" time (right). Each dot is a transient event. Transient motion amplitude is very elevated during high wind for events of freq < ~30Hz.



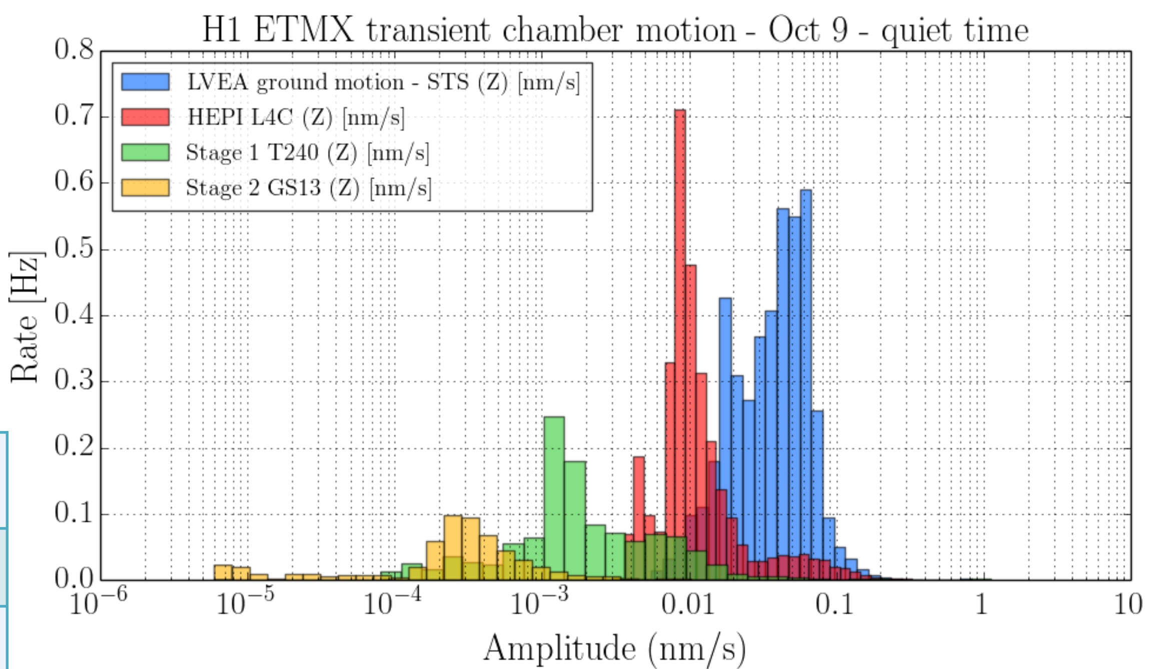


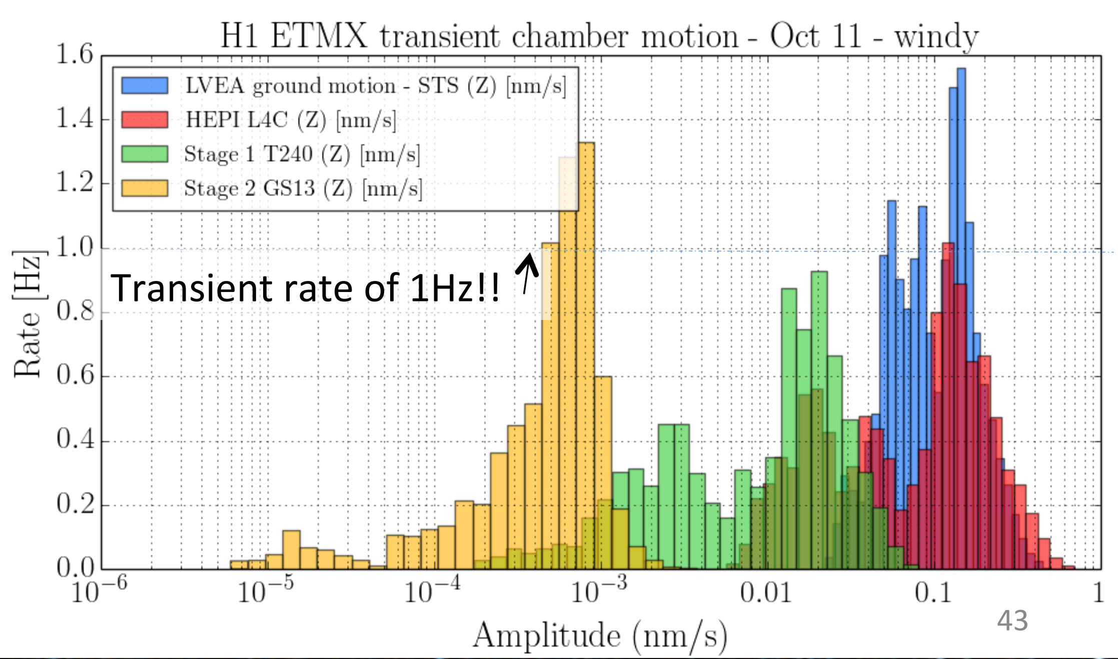
Note: these plots show ETMX local ground motion, not LVEA

The rate of transient motion events also increases dramatically during windy time – by over a factor of 10 in optic table motion at end X.

Stage	Quiet* (# trigs)	Windy* (# trigs)	Factor increase
Ground motion	30,755	116,601	3.8
HEPI (L4C)	21,317	74,624	3.5
ISI ST1 (T240)	7,791	57,948	7.4
ISI ST2 (GS13)	3,924	49,562	12.6

* For a two hour period of relatively quiet or windy time



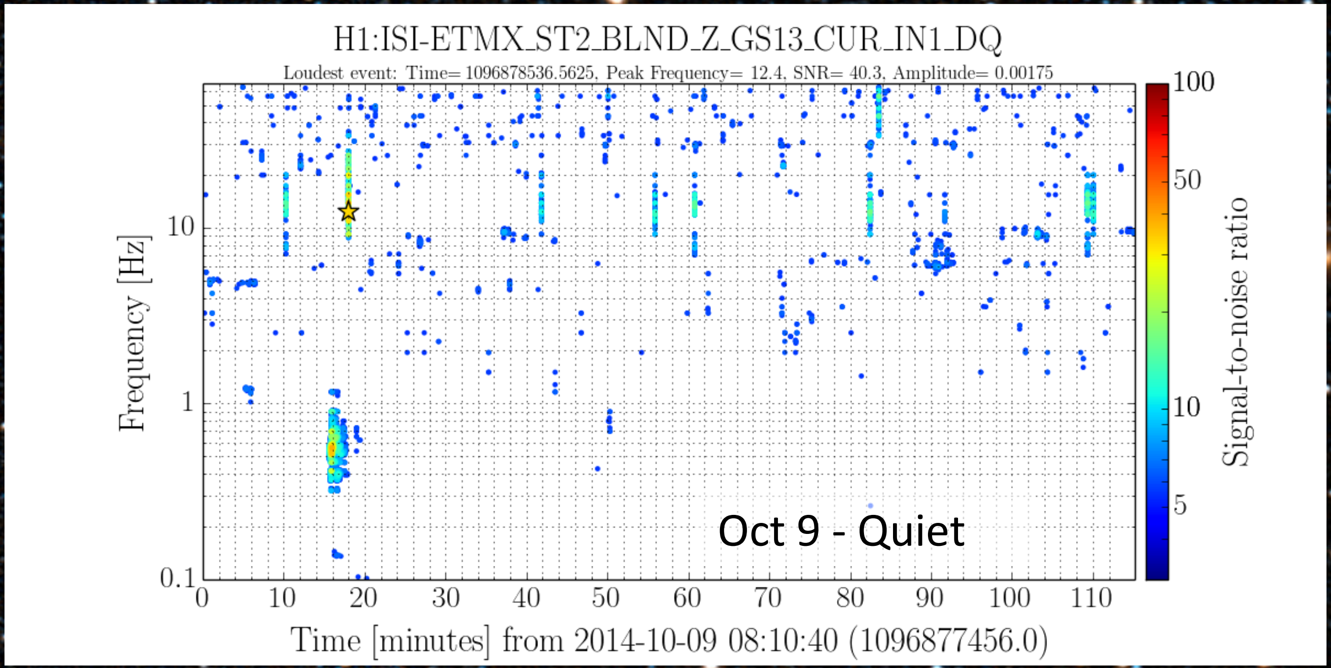


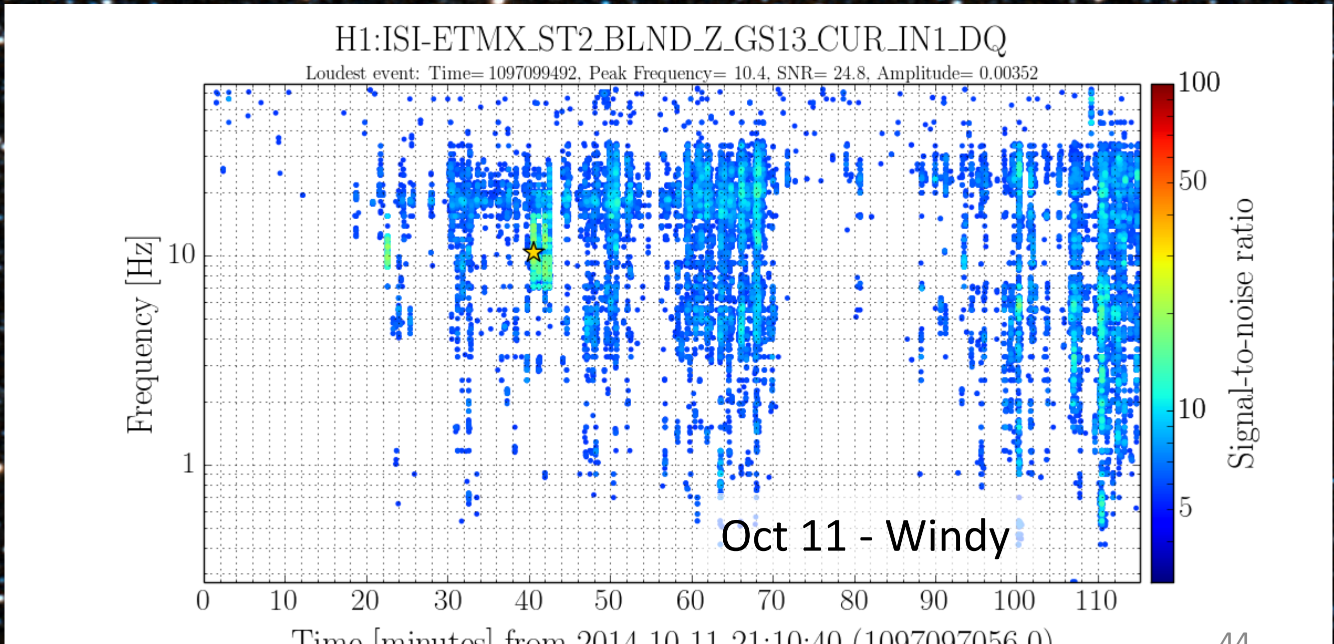
Isolated stages see a much greater increase in the rate of transients than ground motion during windy time.

Note: these plots show ETMX local ground motion, not LVEA

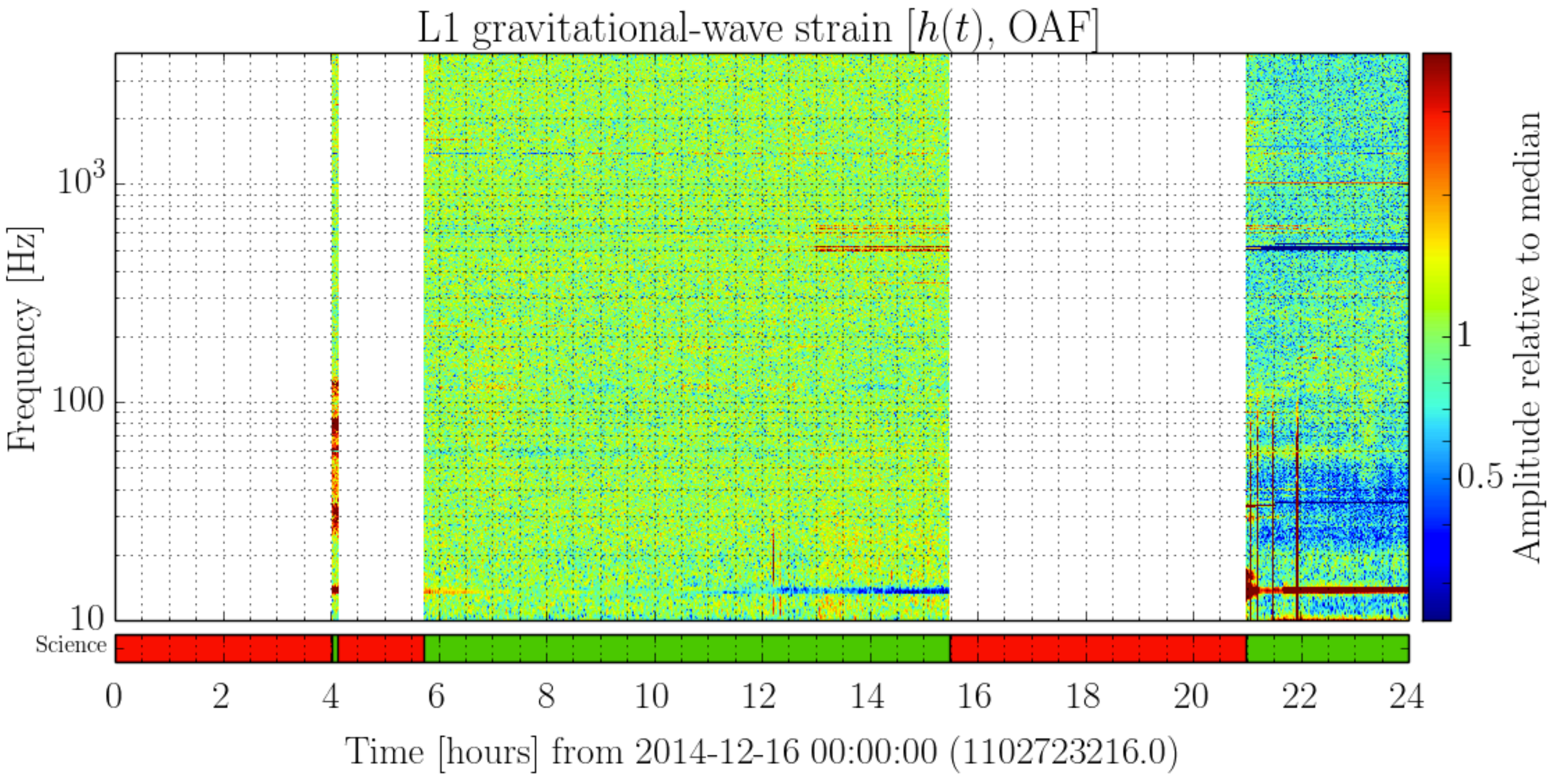
Conclusions for windy vs. quiet SEI transient study:

Ultimately, at the optic table the transient motion amplitude per event isn't significantly increased above 10-15Hz, but the **rate** of transients is greatly increased

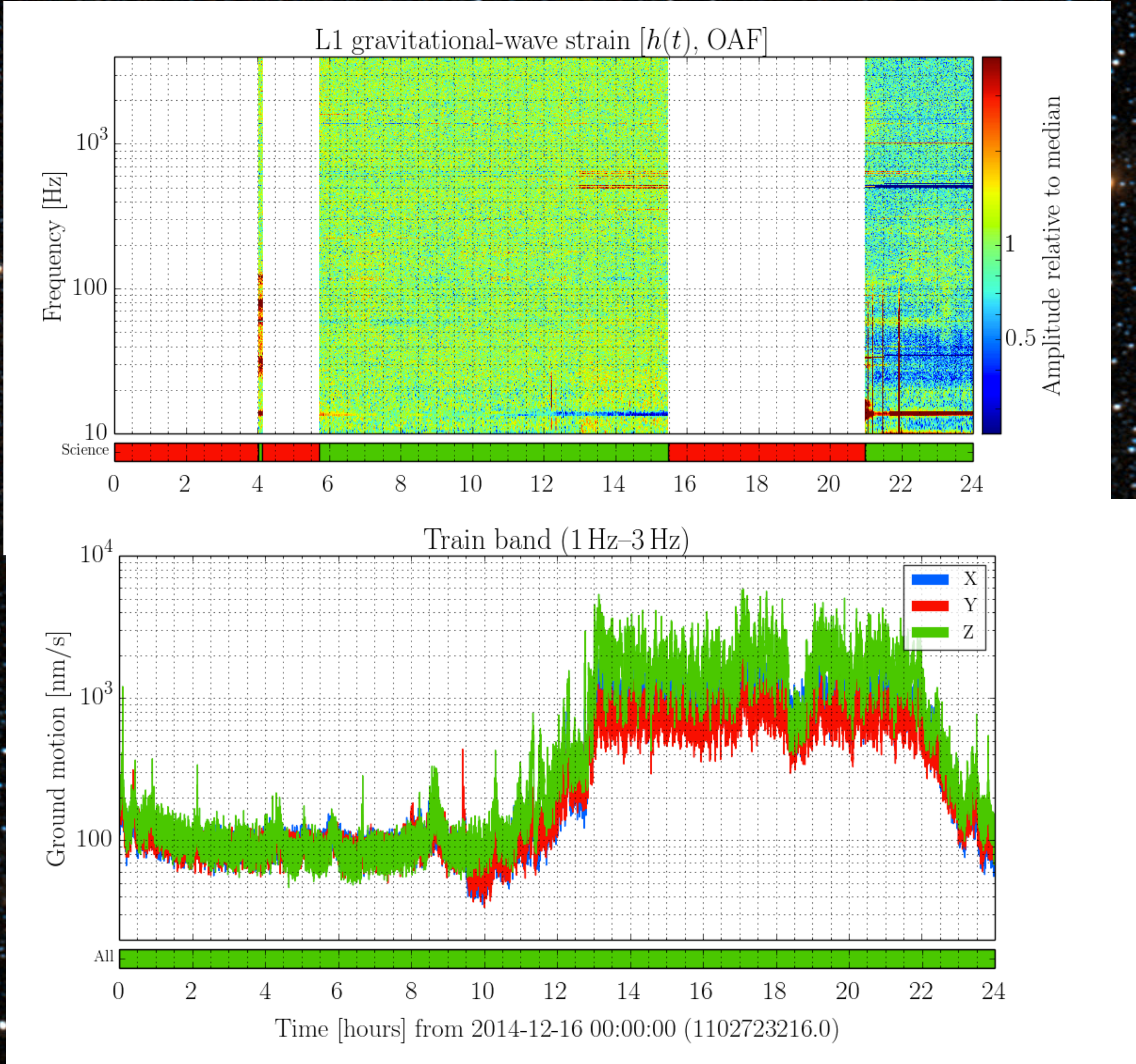




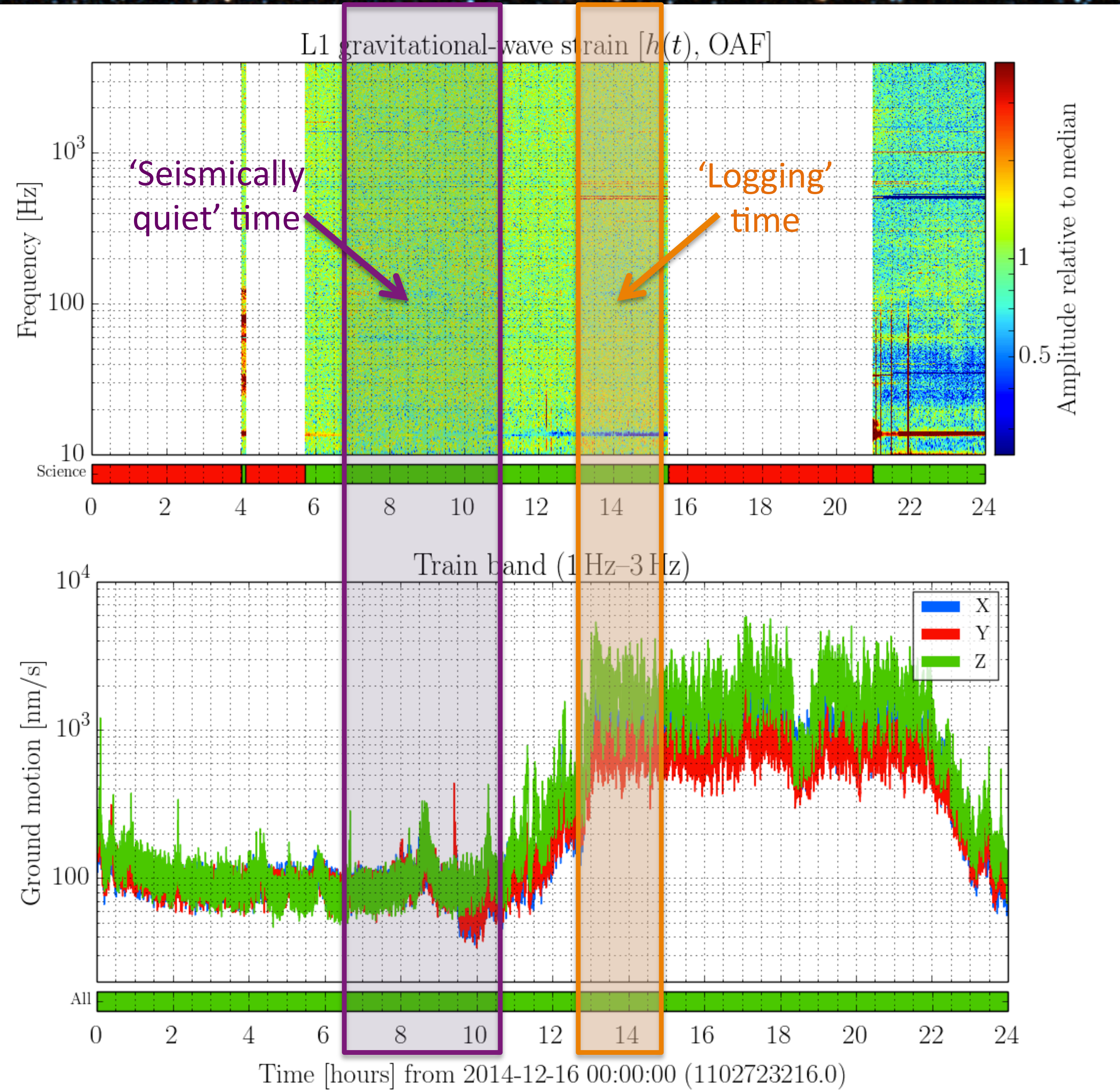
Livingston ER6 -Dec 16 lock



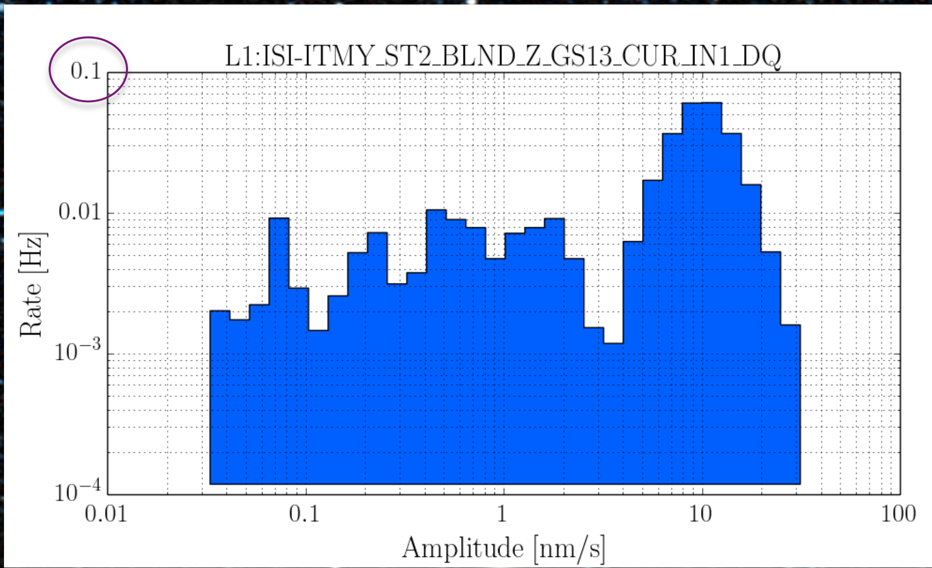
LLO alog 16101: "violin modes appear to be causing high trigger rate in CBC search" (also reported by cWB)

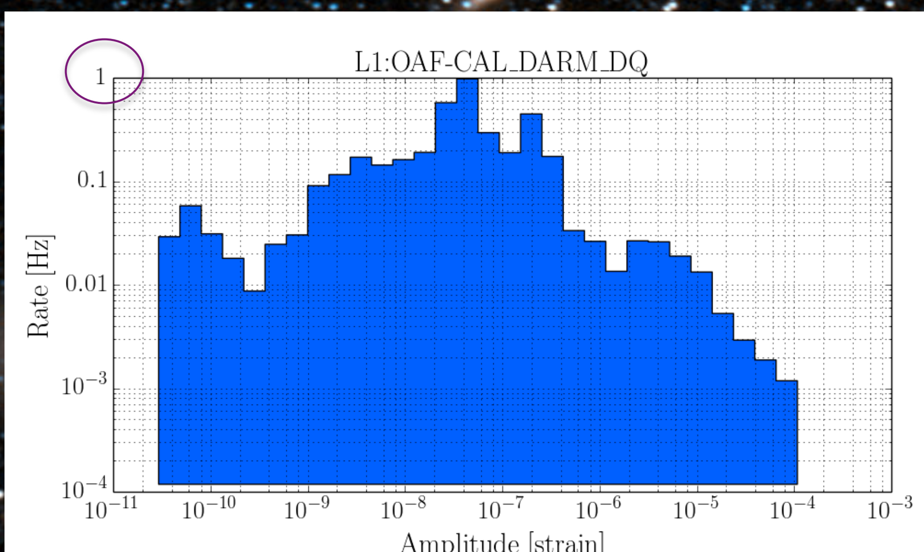


LLO alog 16101: “violin modes appear to be causing high trigger rate in CBC search” (also reported by cWB)

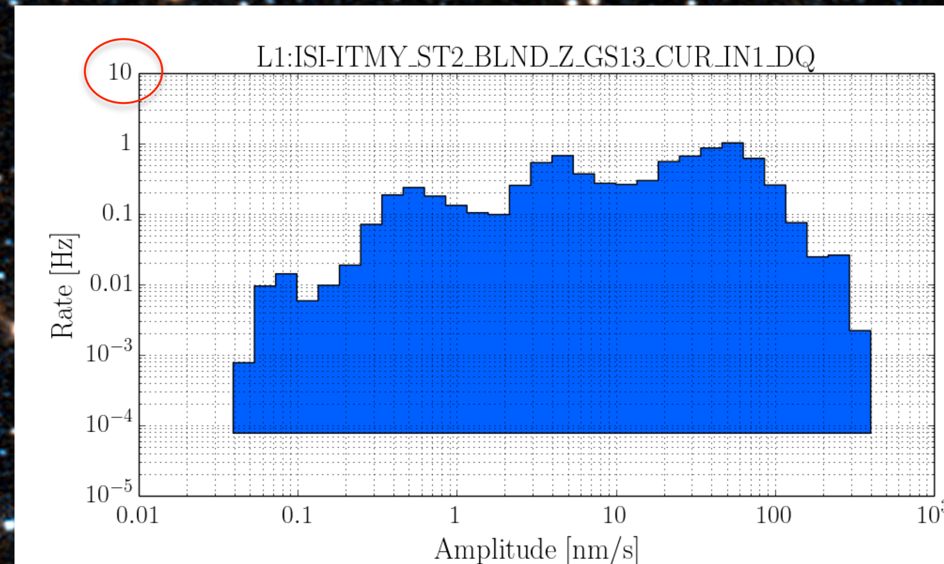


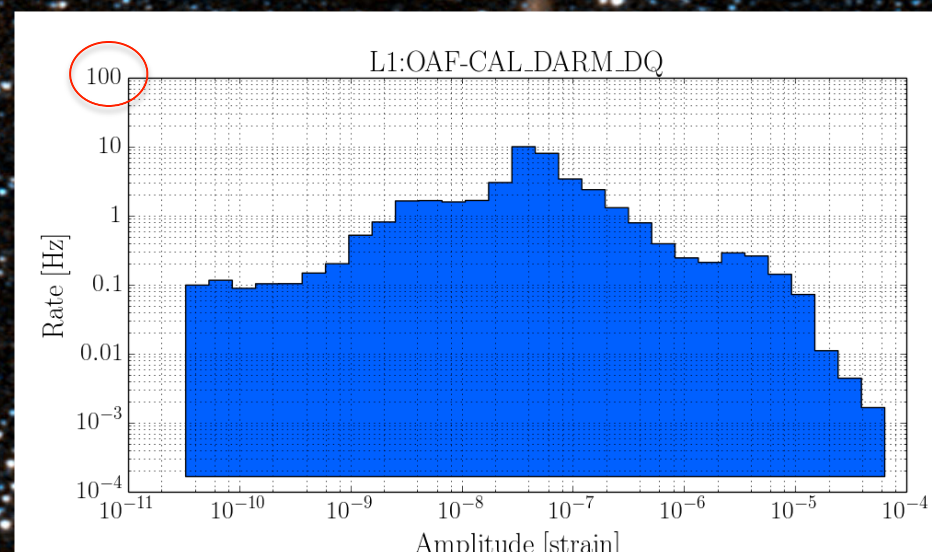
Seismically quiet part of lock





Logging stretch of lock

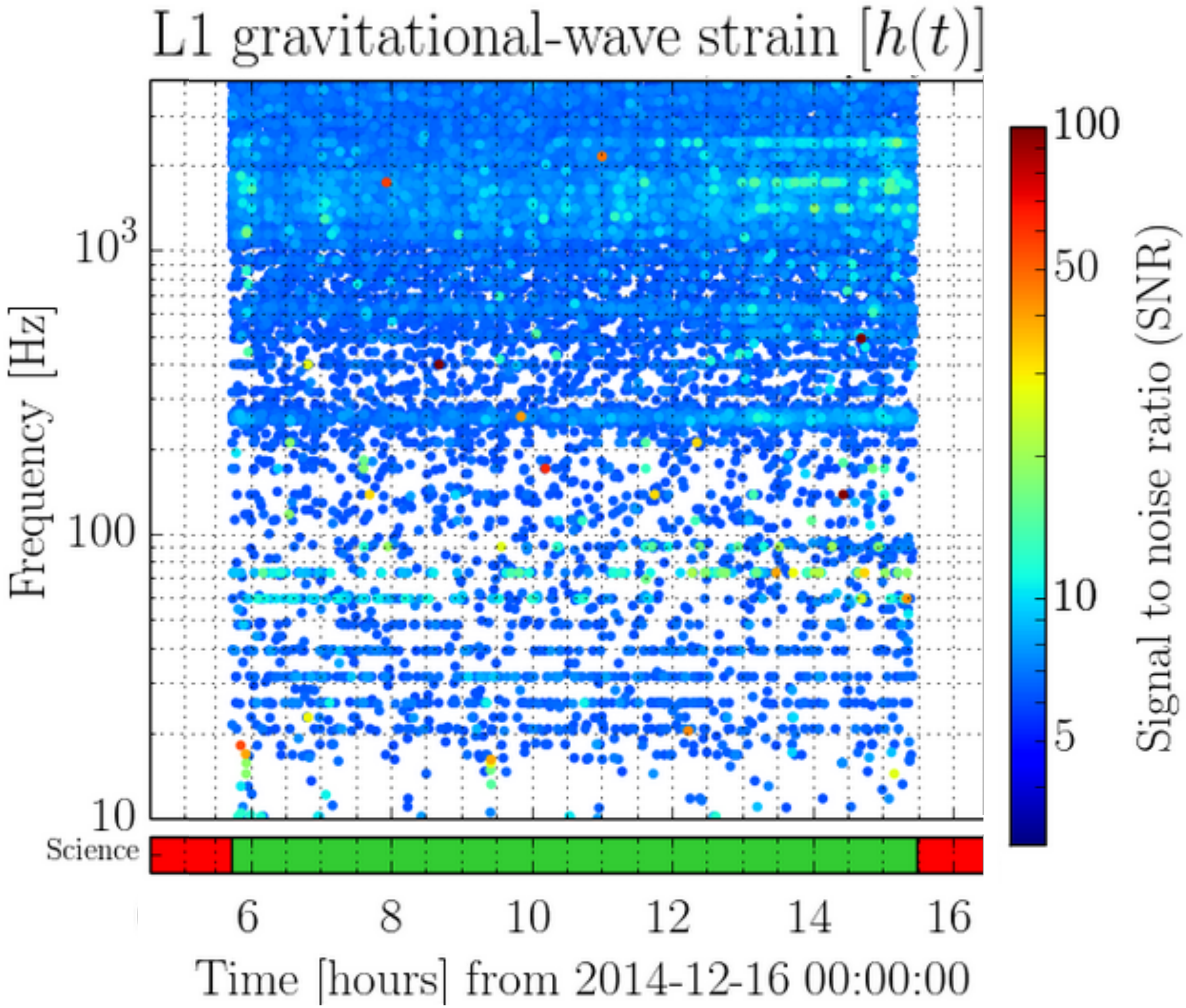




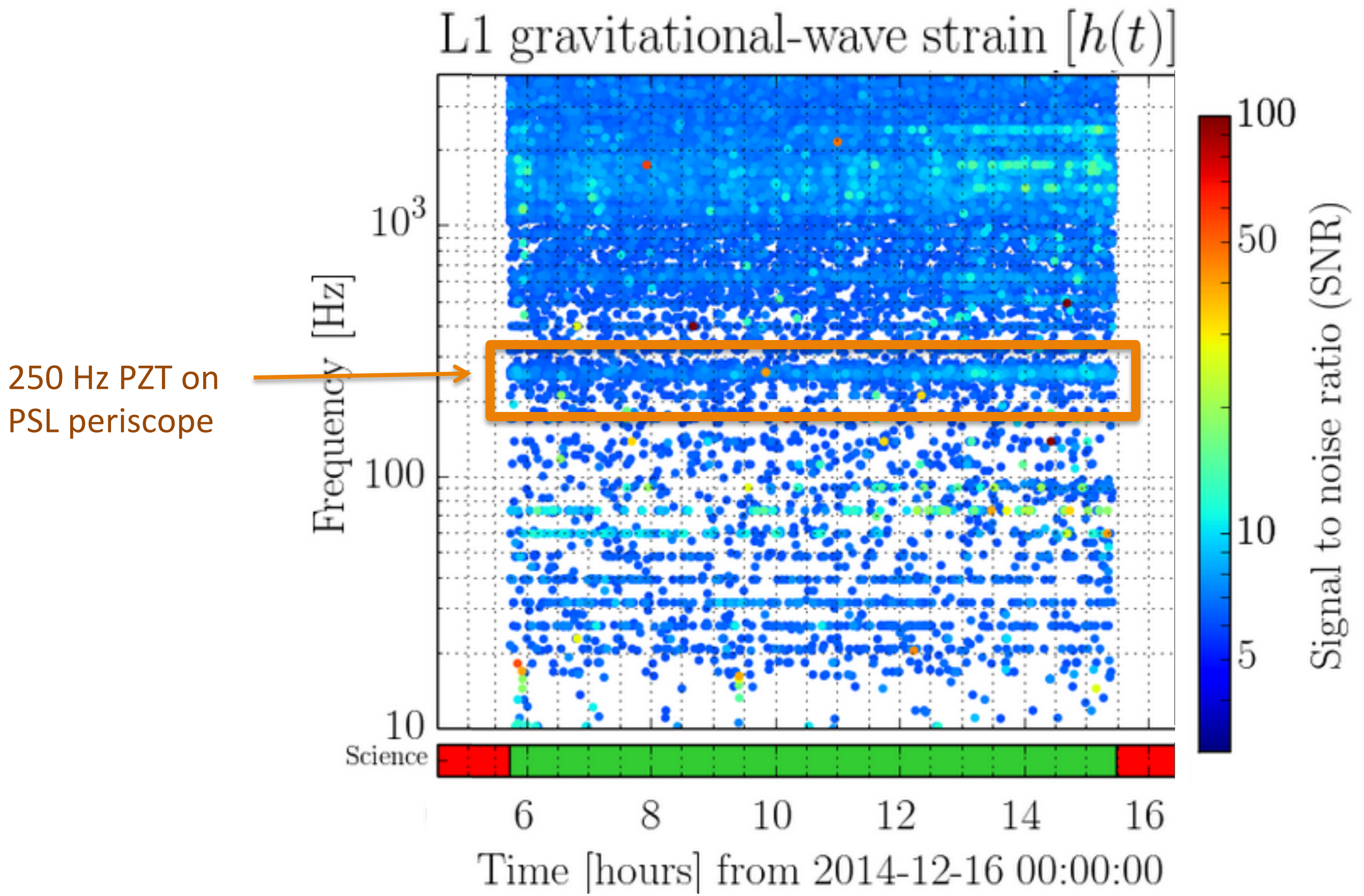
Summary - Dec 16 lock

ER6 glitch rate looked very clean on the whole!

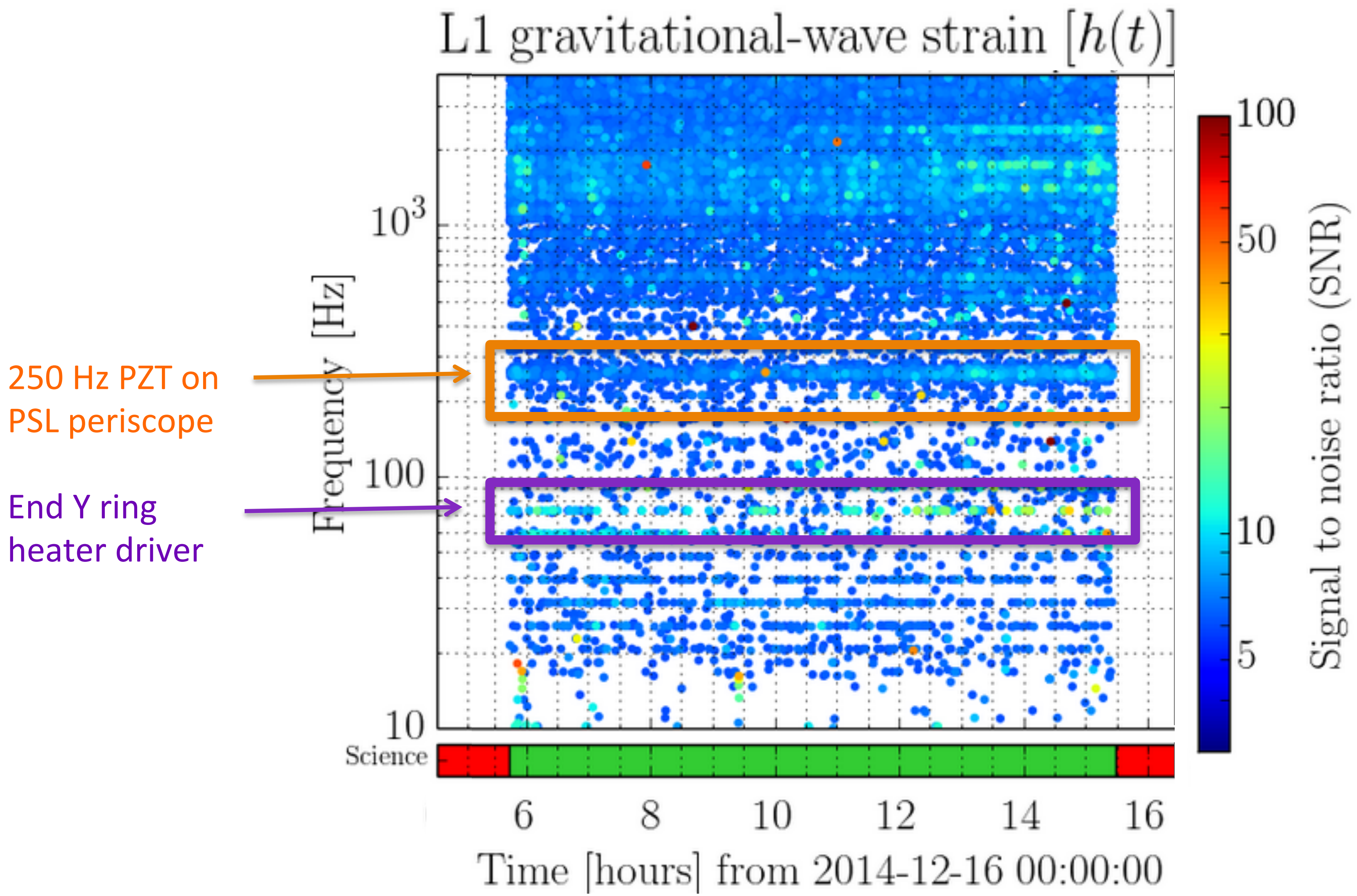
Most features that would affect the transient searches are now understood/resolved



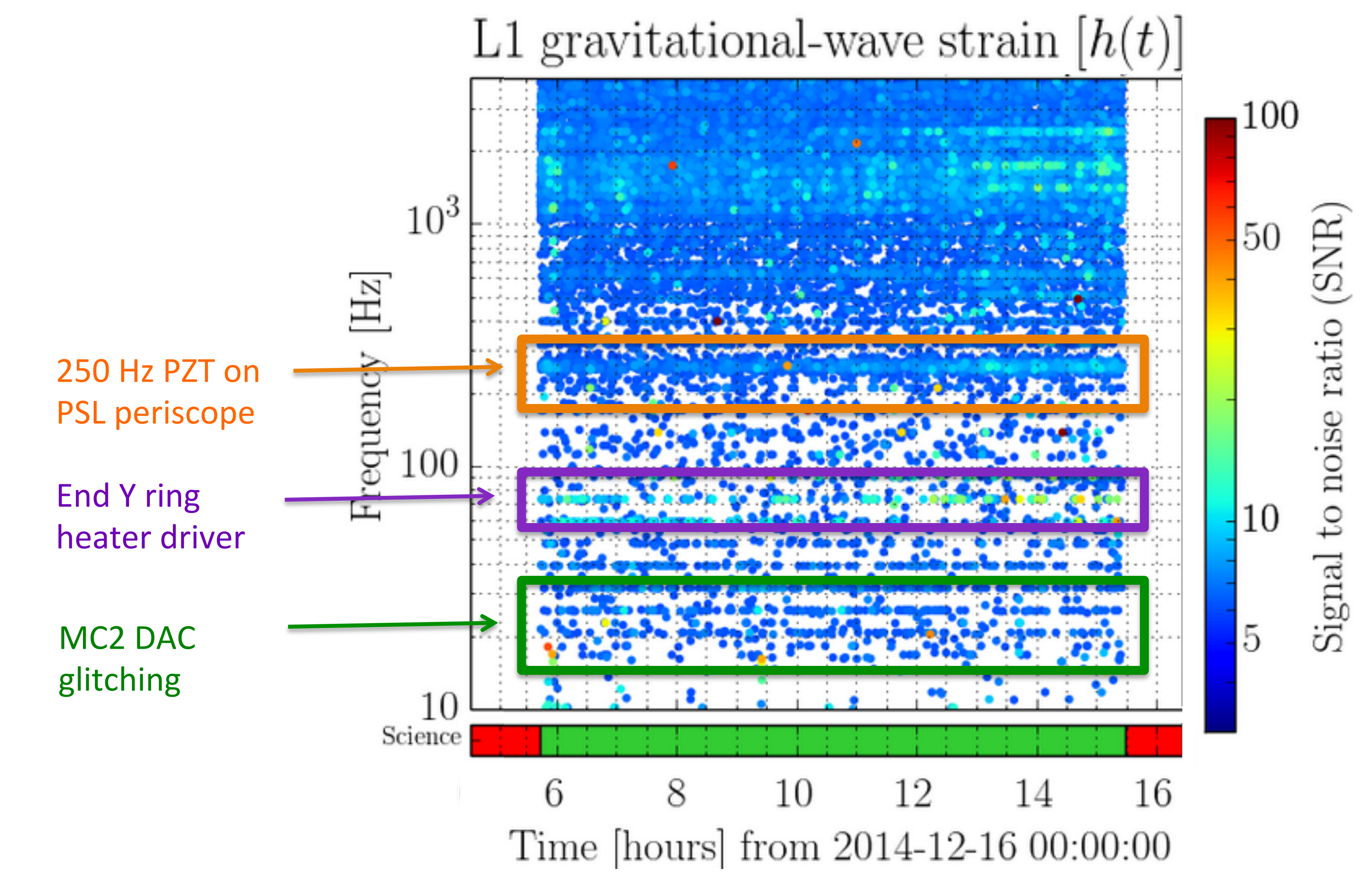
Summary - Dec 16 lock



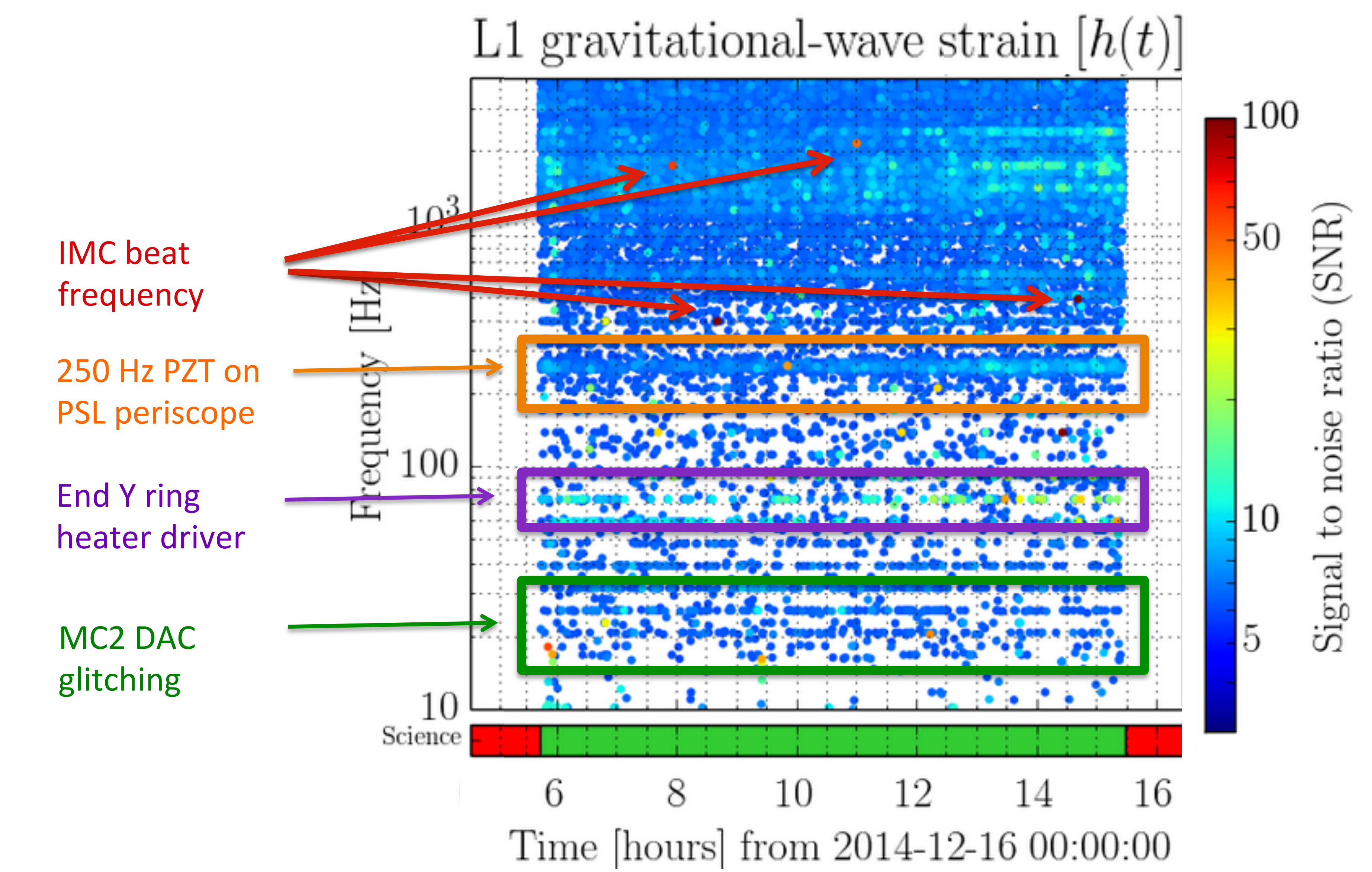
Summary - Dec 16 lock



Summary - Dec 16 lock

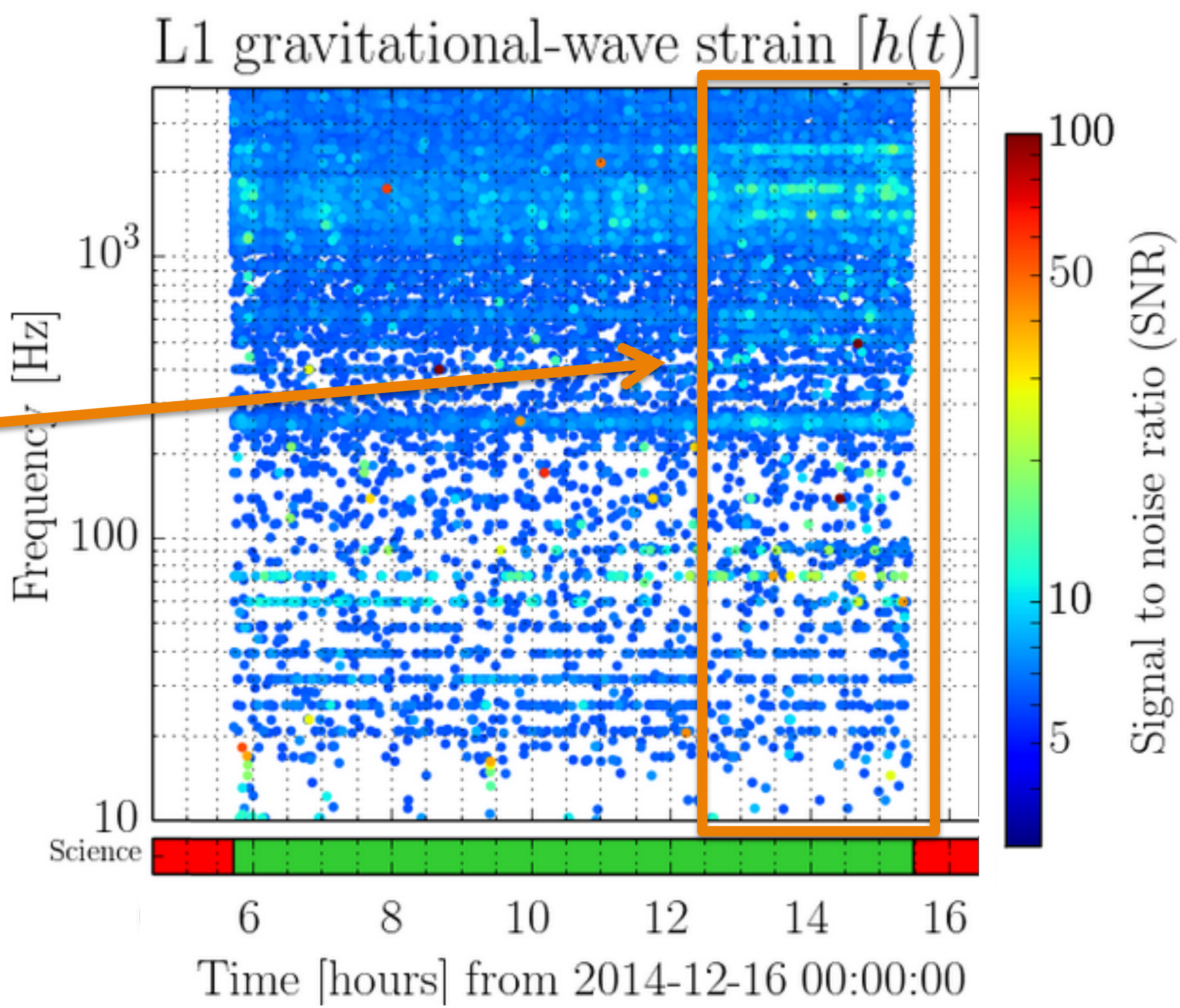


Summary - Dec 16 lock



Summary - Dec 16 lock

Seismic-related glitch rate increase



Conclusions

- Thanks largely to commissioning efforts, LLO data looks GREAT! Greatly improved glitch rate compared to August.
- Already characterizing Hanford at a subsystem level.
- Other noise features that are troublesome to the transient searches will undoubtedly surface as the ifos evolve and commissioners dig into the noise floor.
- Detchar has very good handle on potential DQ features that would most affect the search backgrounds.