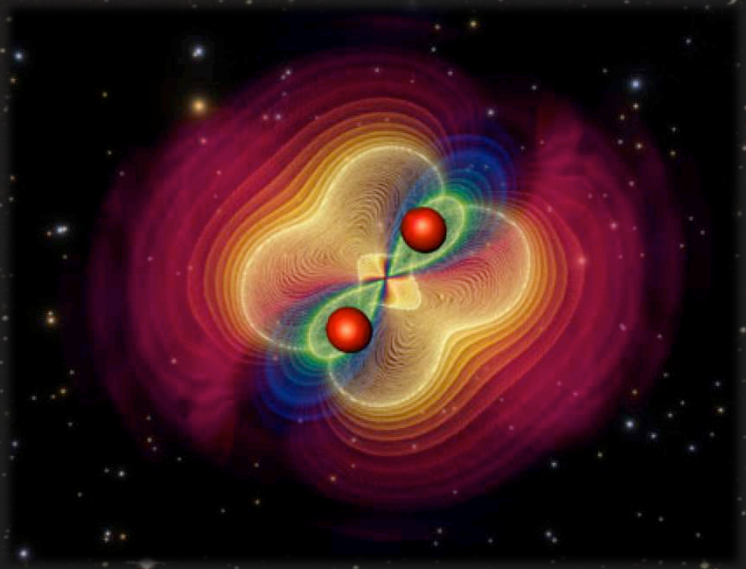
The road to Advanced LIGO's first observations


Photo: Michael Eyle



Jess McIver for the
LIGO Scientific Collaboration

Outline

- **Observing transient GW signals with Advanced LIGO**
  - The Advanced LIGO interferometers
  - Projected commissioning timeline
  - Likely observing scenarios
- **Detector characterization efforts**
  - Past strategies, challenges, and successes
  - First glimpse of Livingston data quality

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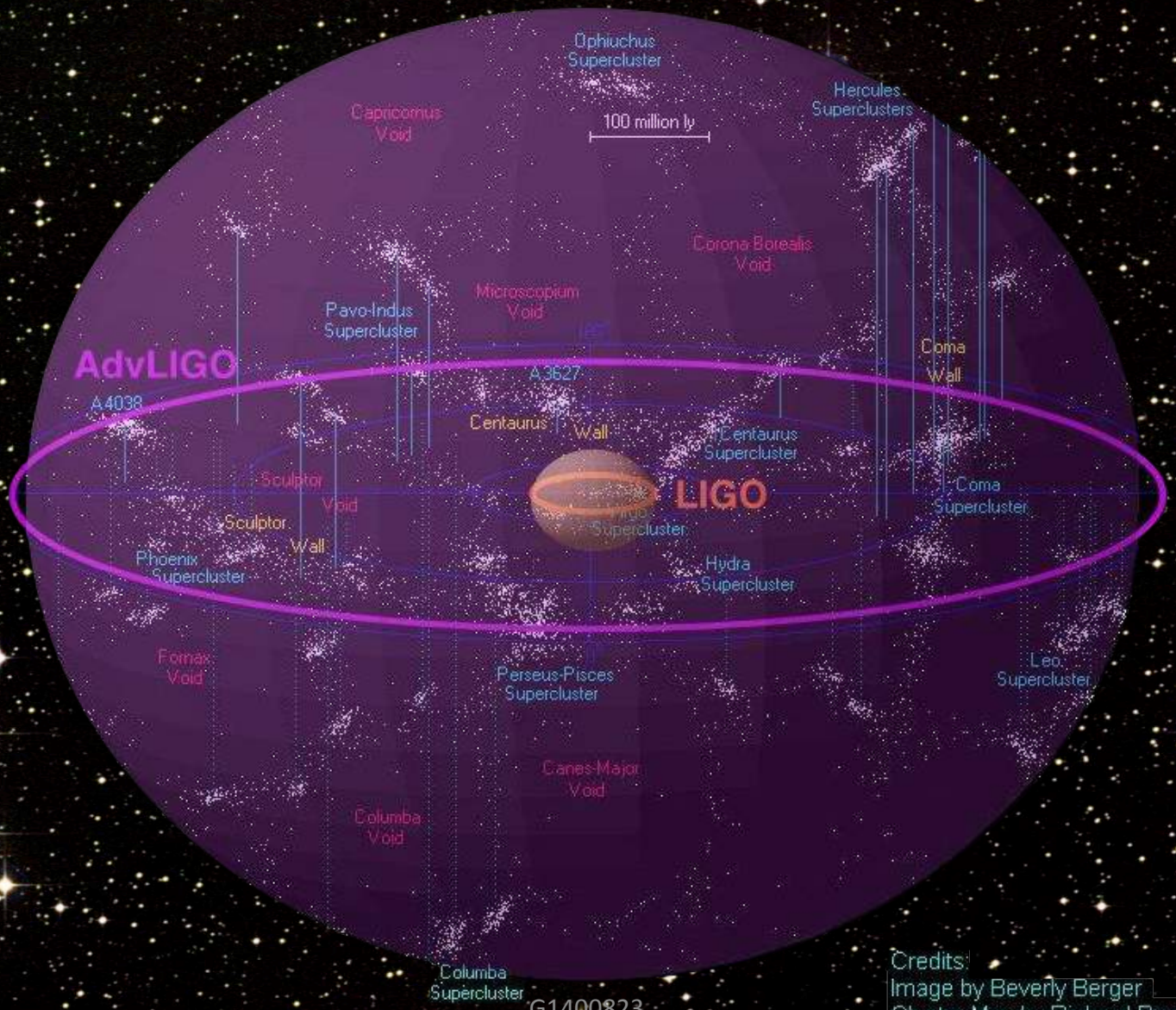
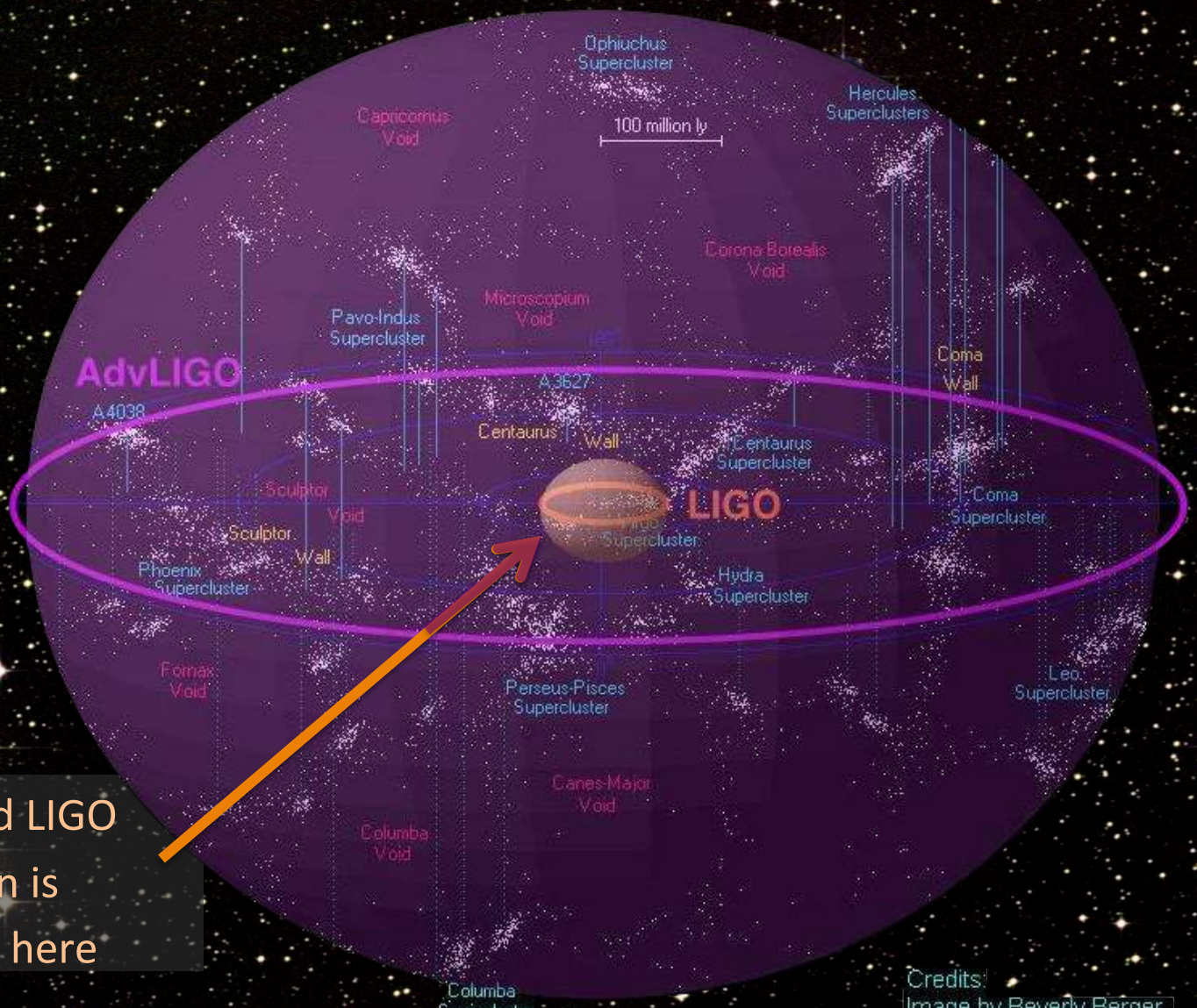
Advanced LIGO



Credits:
Image by Beverly Berger
Cluster Map by Richard Powell

Advanced LIGO



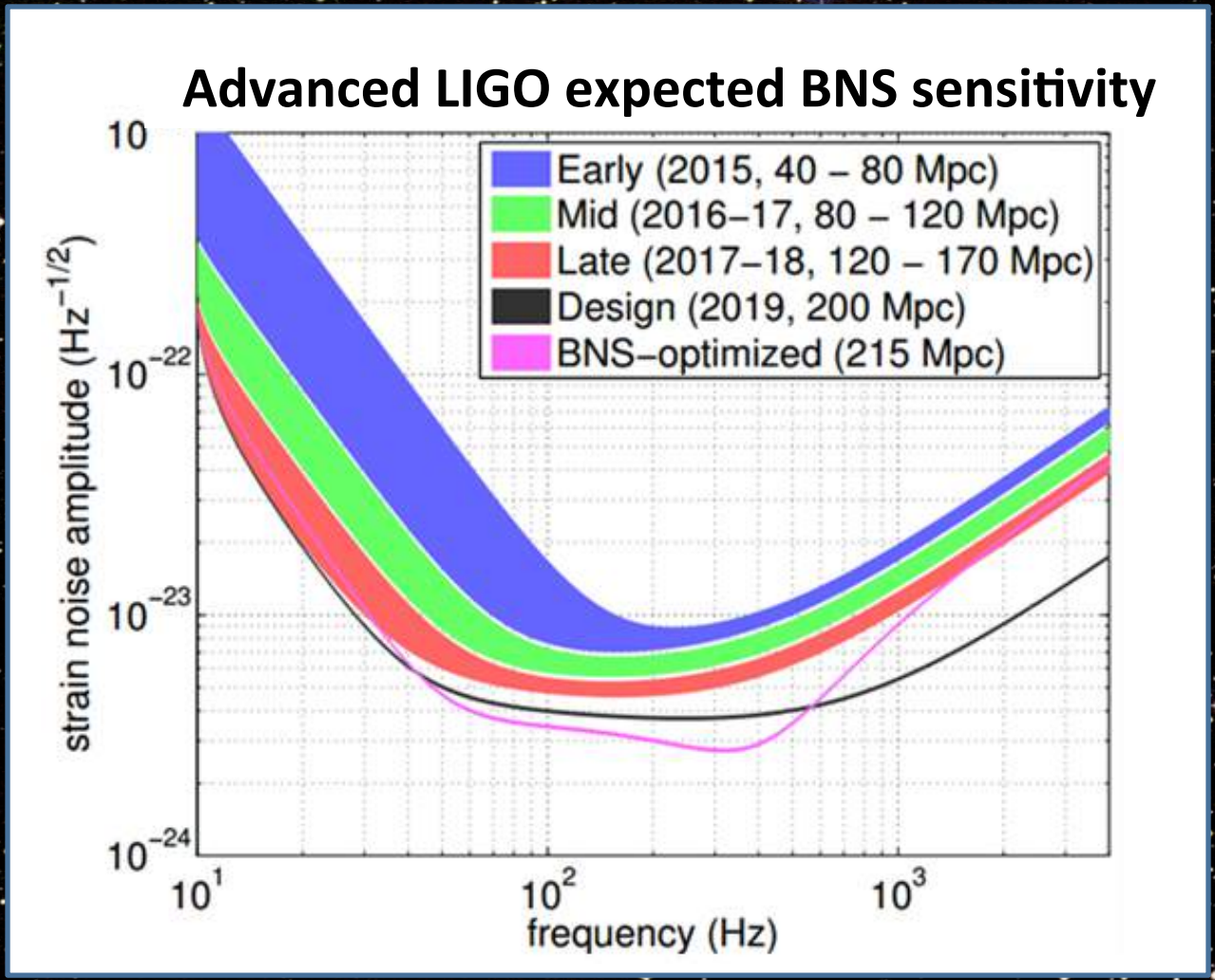
Advanced LIGO Livingston is currently here

Credits:
Image by Beverly Berger
Cluster Map by Richard Powell

Likely aLIGO observing scenarios

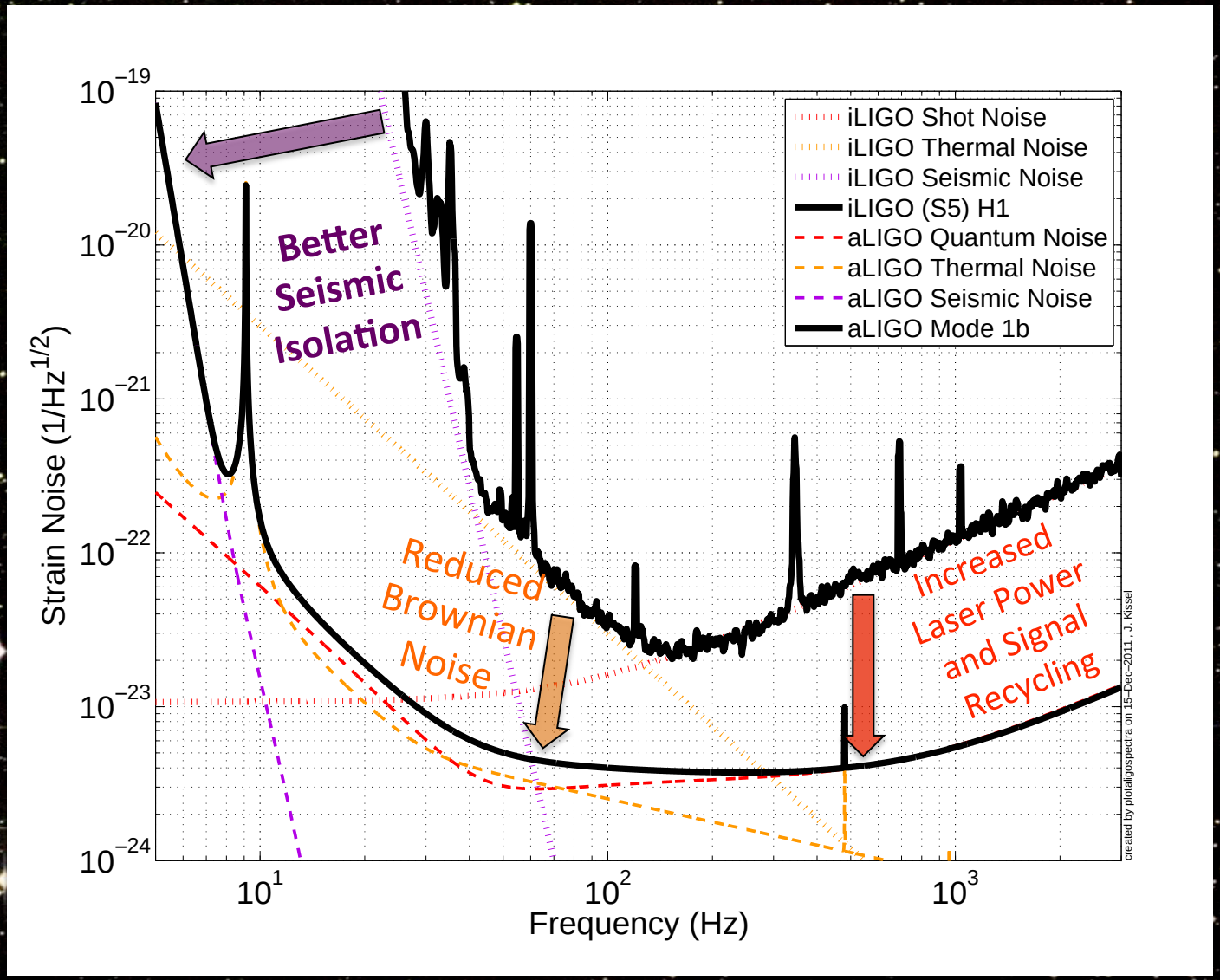
Aasi, et al. 2013

arxiv 1304.0670

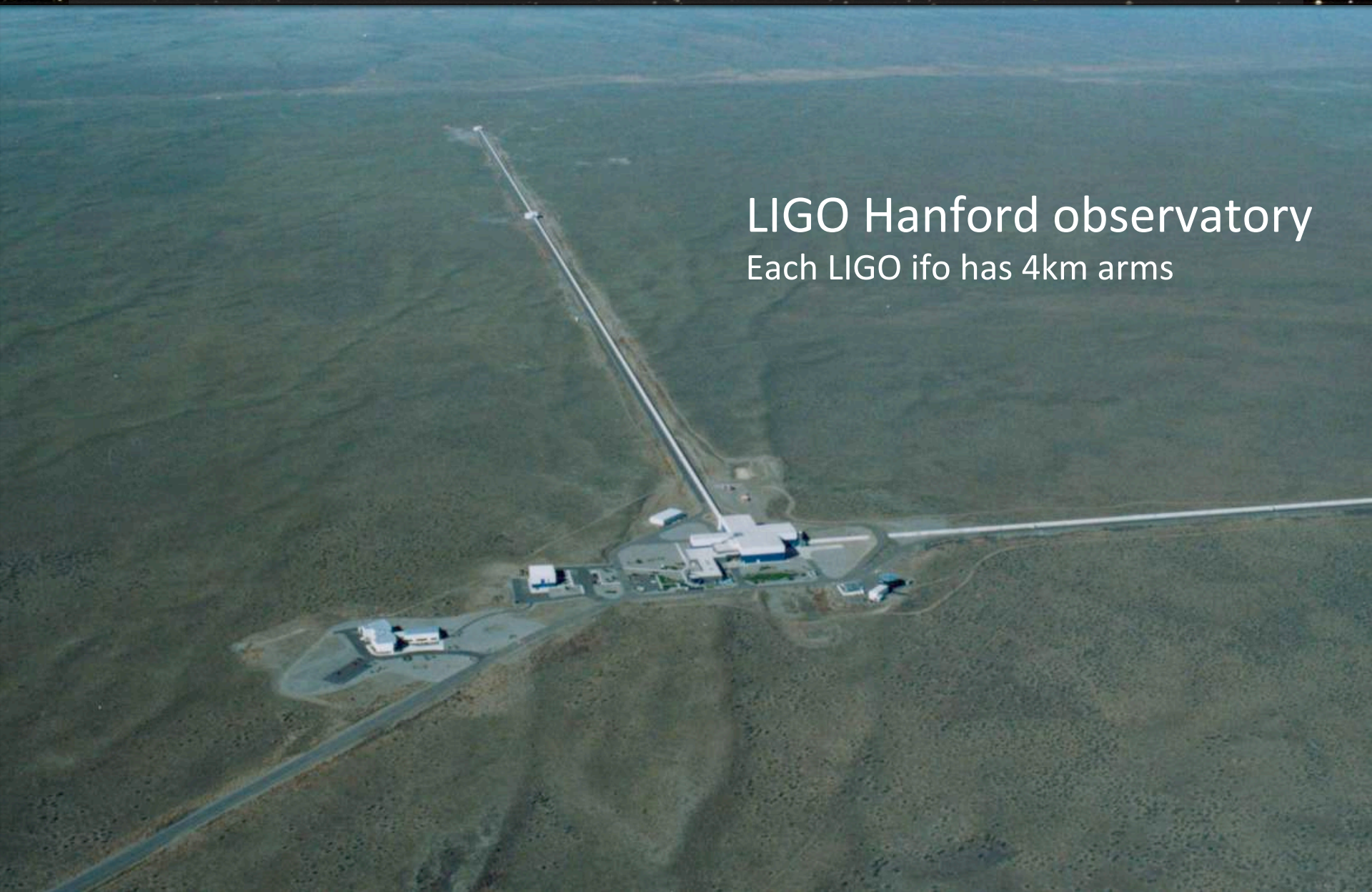


How will we get there?

aLIGO instrumental improvements

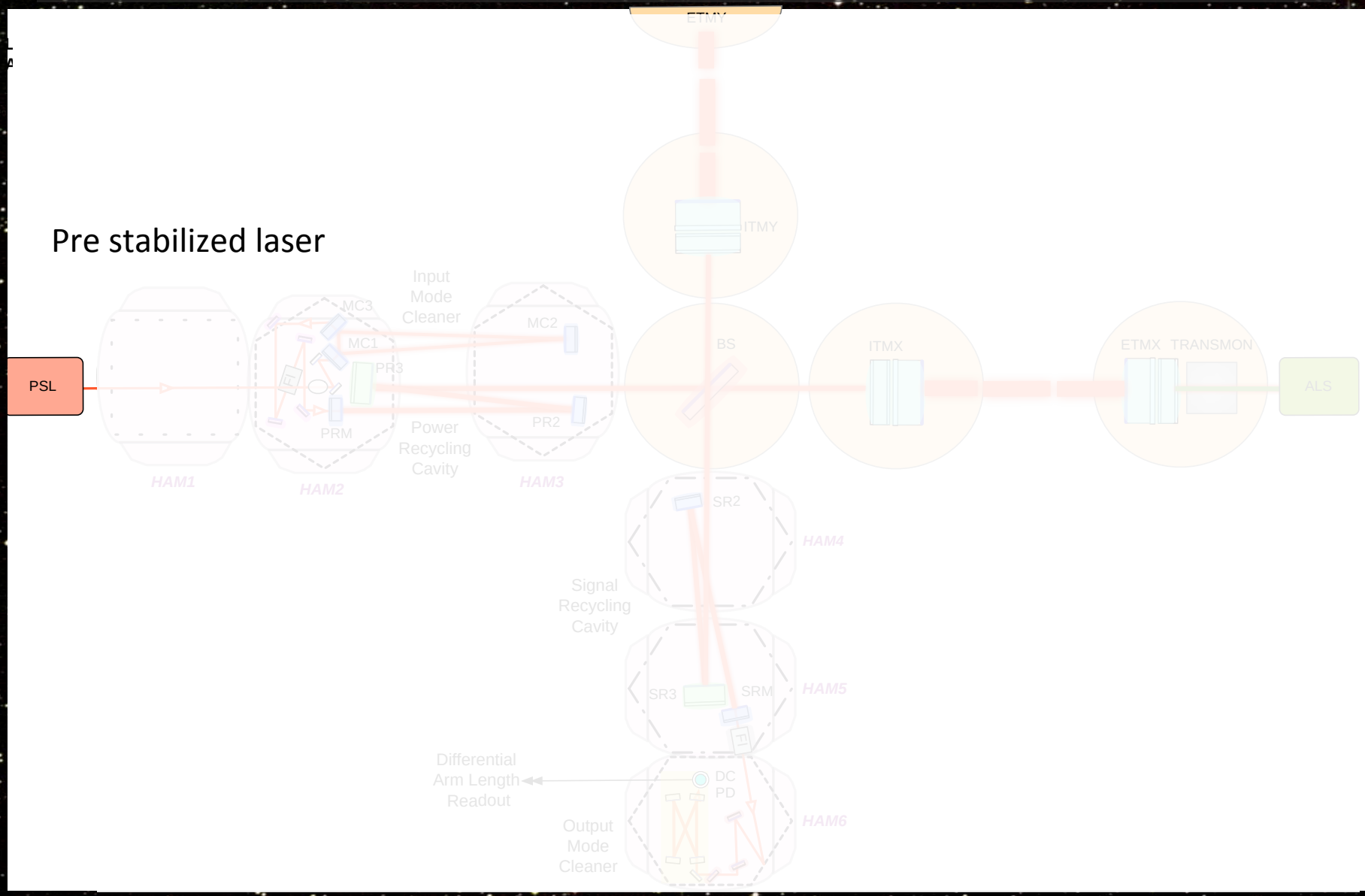


aLIGO installation and testing



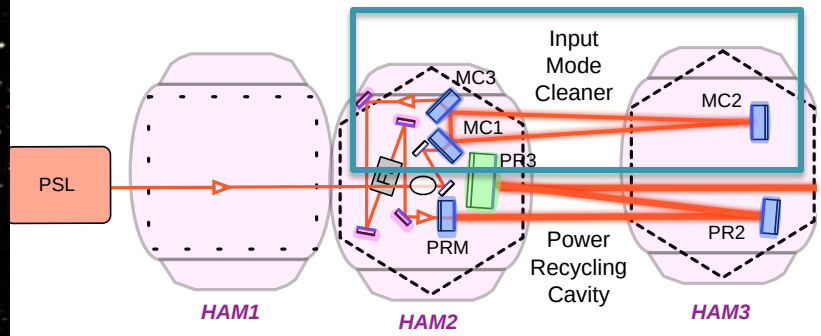
aLIGO installation and testing

Pre stabilized laser



aLIGO installation and testing

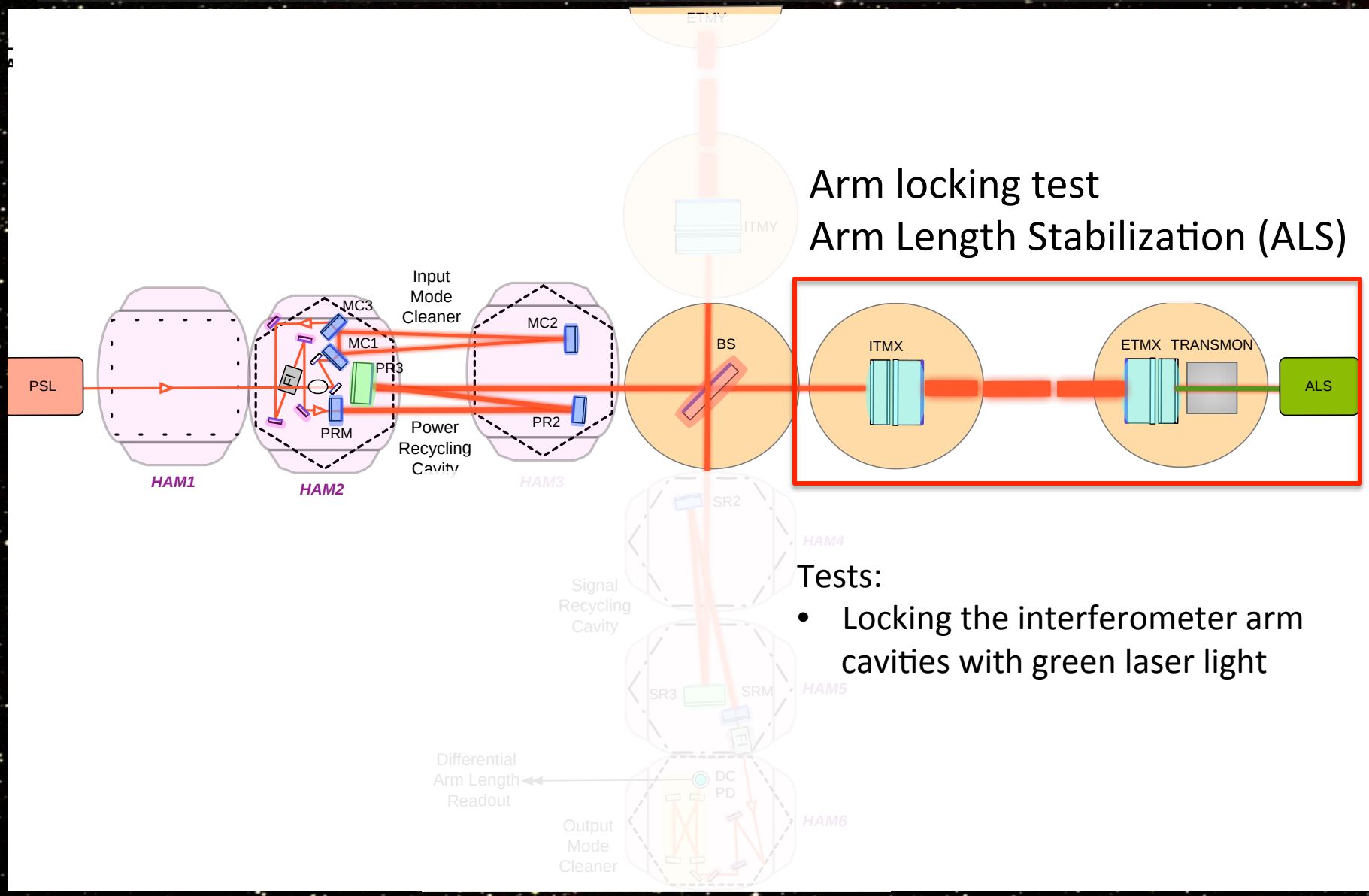
Input optics



Used for:

- Input laser stabilization
- Selecting for fundamental Gaussian beam mode

aLIGO installation and testing

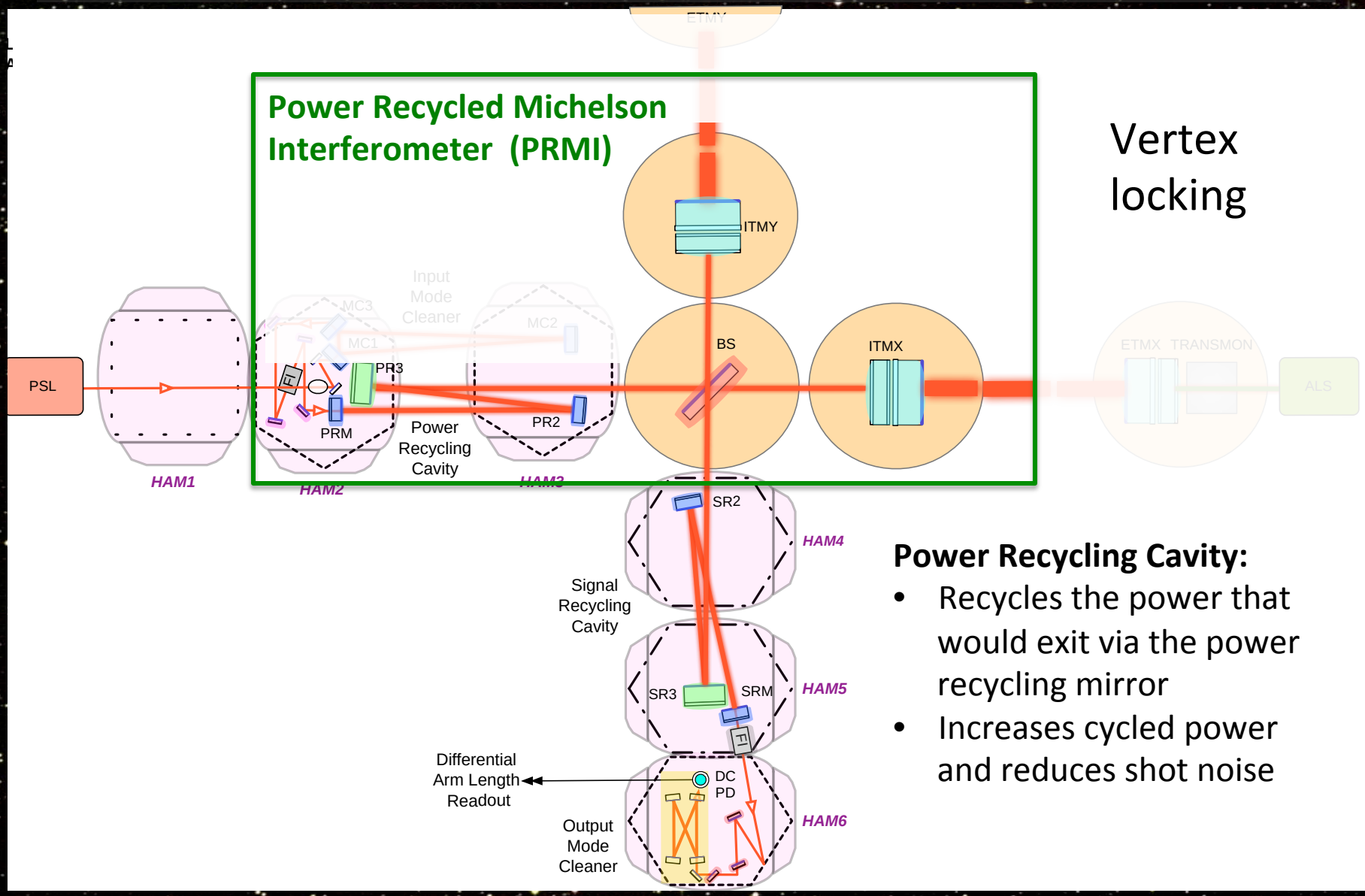


Arm locking test
Arm Length Stabilization (ALS)

Tests:

- Locking the interferometer arm cavities with green laser light

aLIGO installation and testing

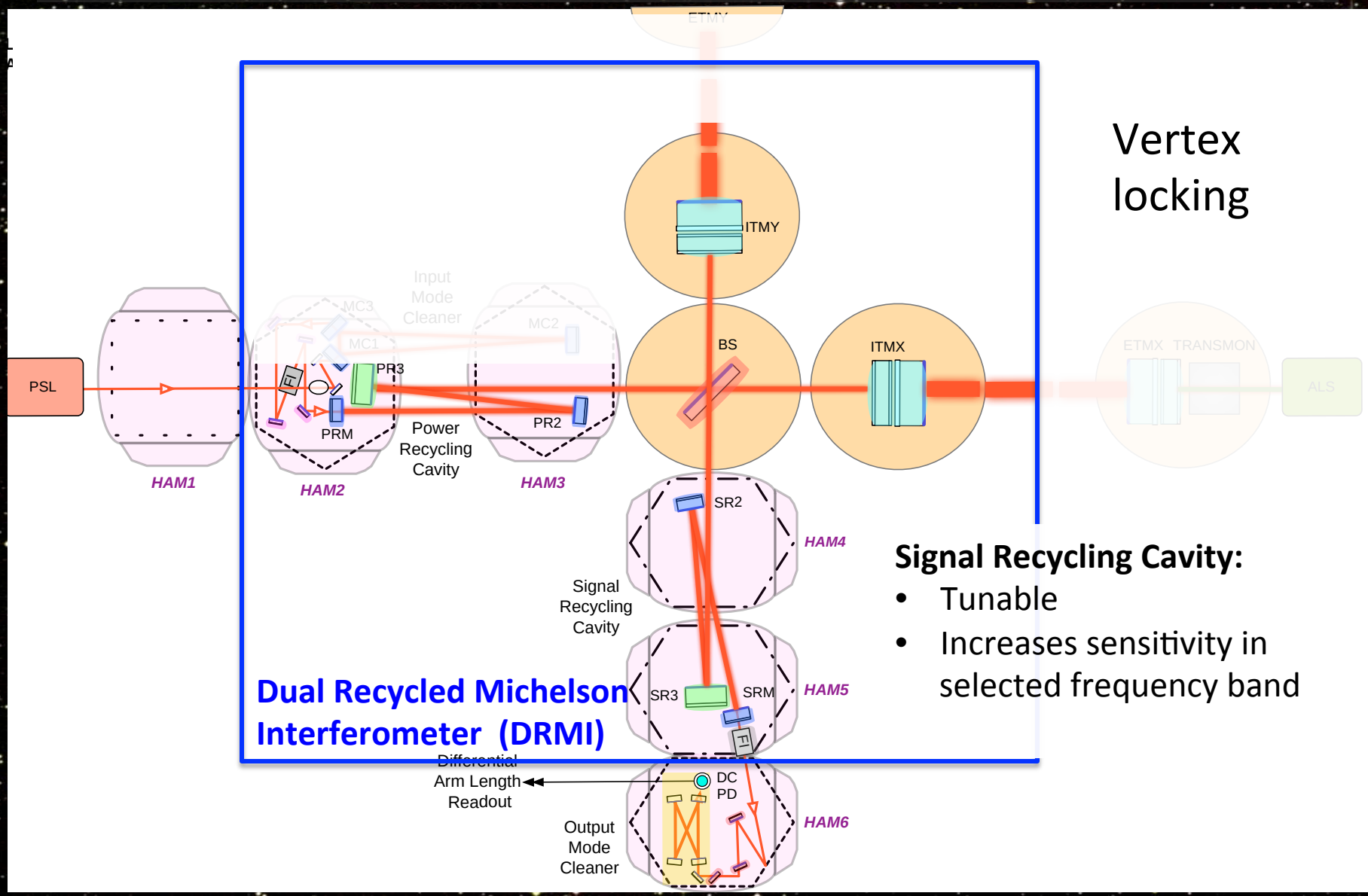


Vertex locking

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



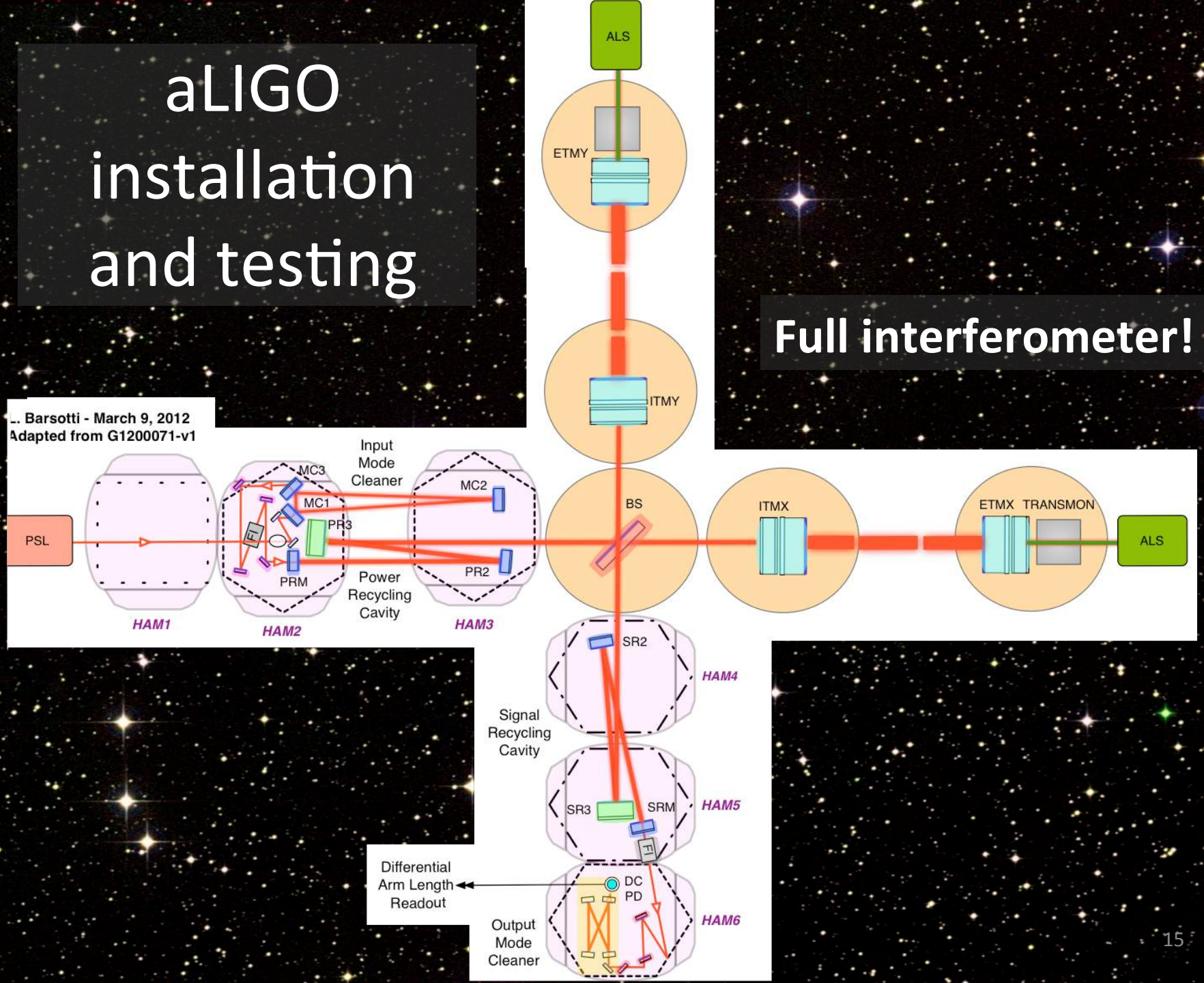
Vertex locking

Signal Recycling Cavity:

- Tunable
- Increases sensitivity in selected frequency band

aLIGO installation and testing

Full interferometer!

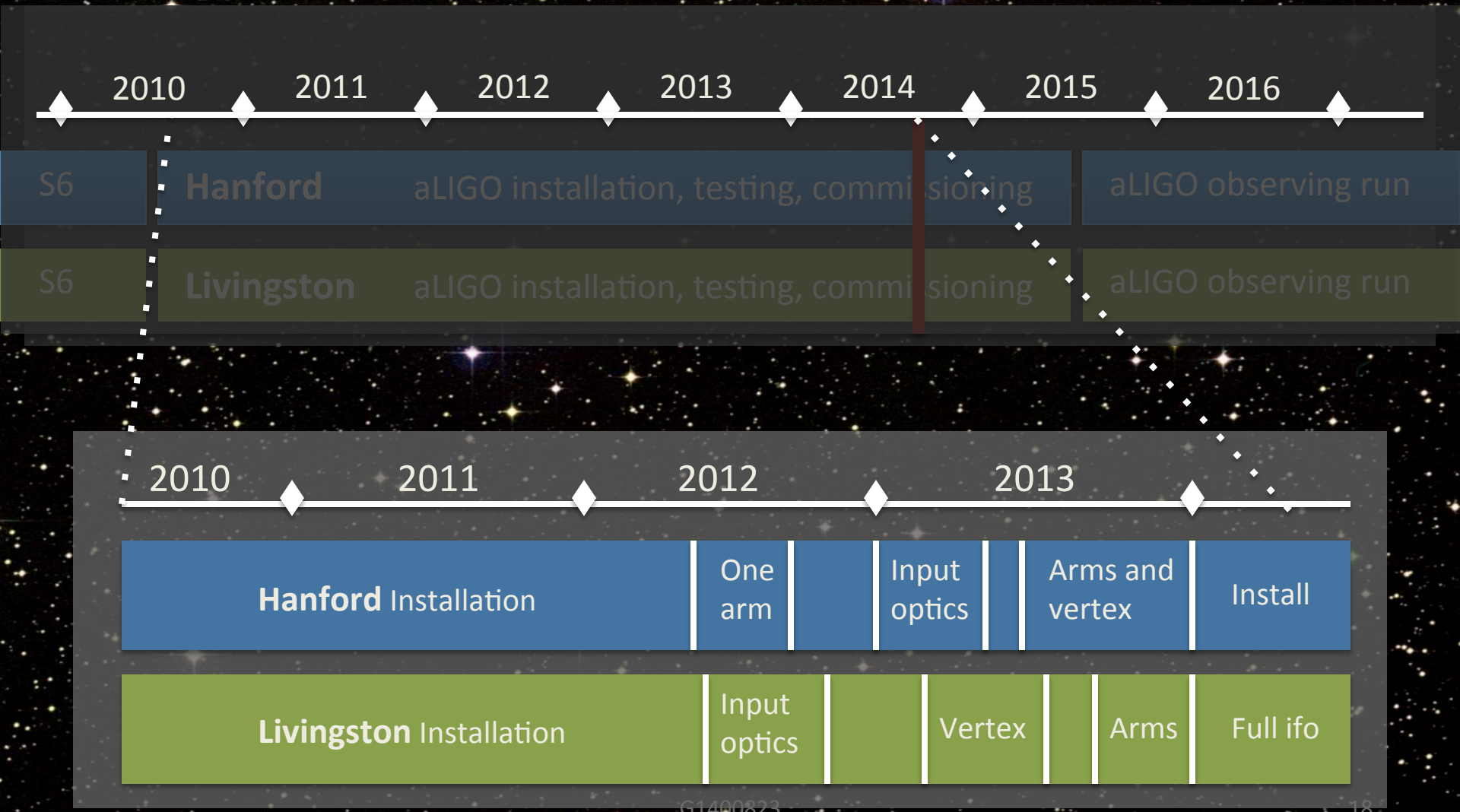


Timeline: from eLIGO to aLIGO

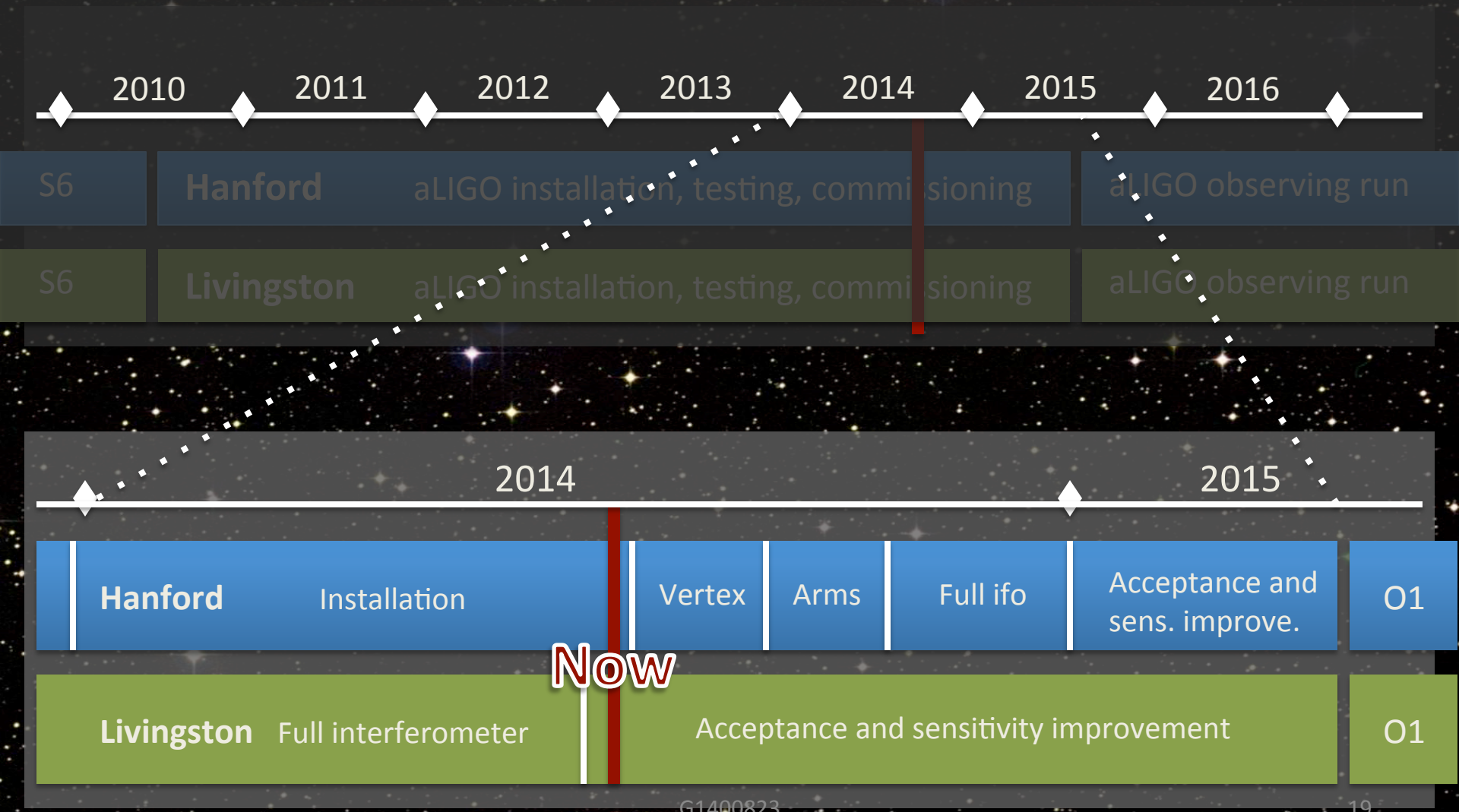
	2010	2011	2012	2013	2014	2015	2016
S6	**Hanford**	aLIGO installation, testing, commissioning					aLIGO observing run
S6	**Livingston**	aLIGO installation, testing, commissioning					aLIGO observing run

Timeline: from eLIGO to aLIGO

Timeline: installation and testing



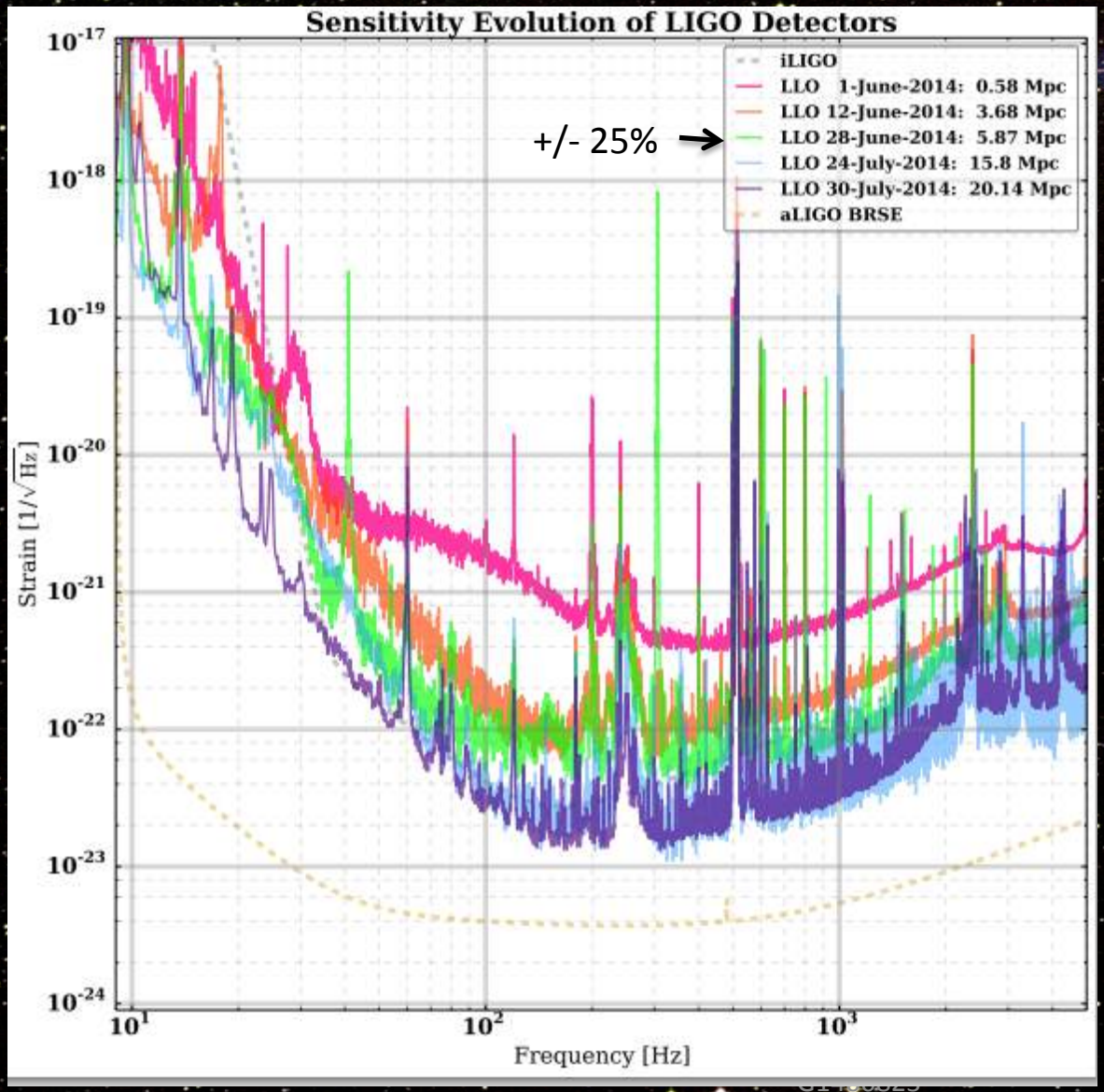
Timeline: the lead up to the first observing run



aLIGO project acceptance requires:

- Subsystems meet their acceptance criteria
  - Design and use documentation produced
  - Meet individual performance requirements
- Each interferometer locks for an extended time (2 hours) ← Livingston has achieved this!
  - Locking: acquire and maintain interferometer resonance under automated control

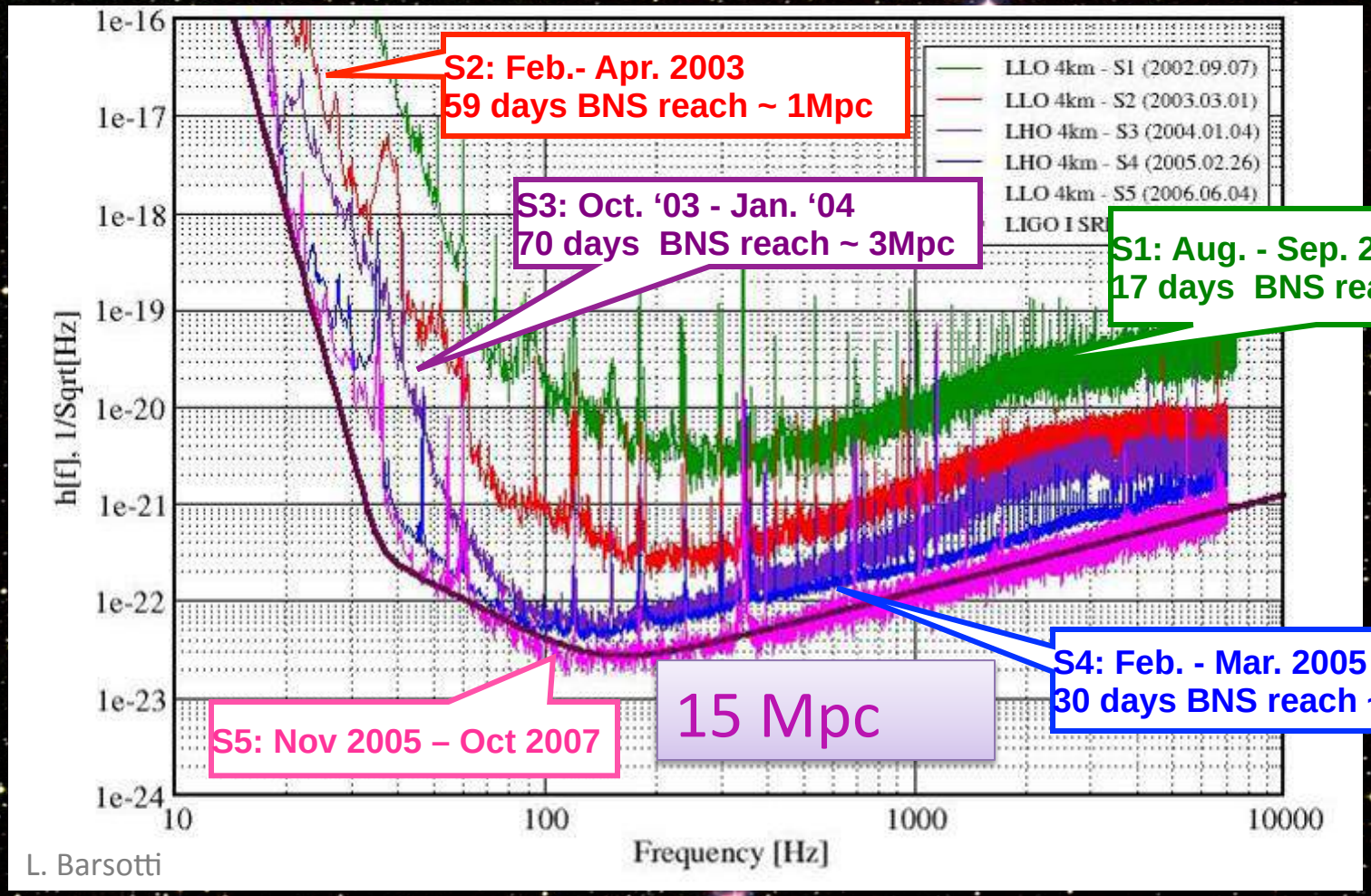
Commissioning at Livingston



Improving sensitivity

- Increased laser power
- Noise hunting
- Transition to DC readout
- Improved optic alignment and angular stability

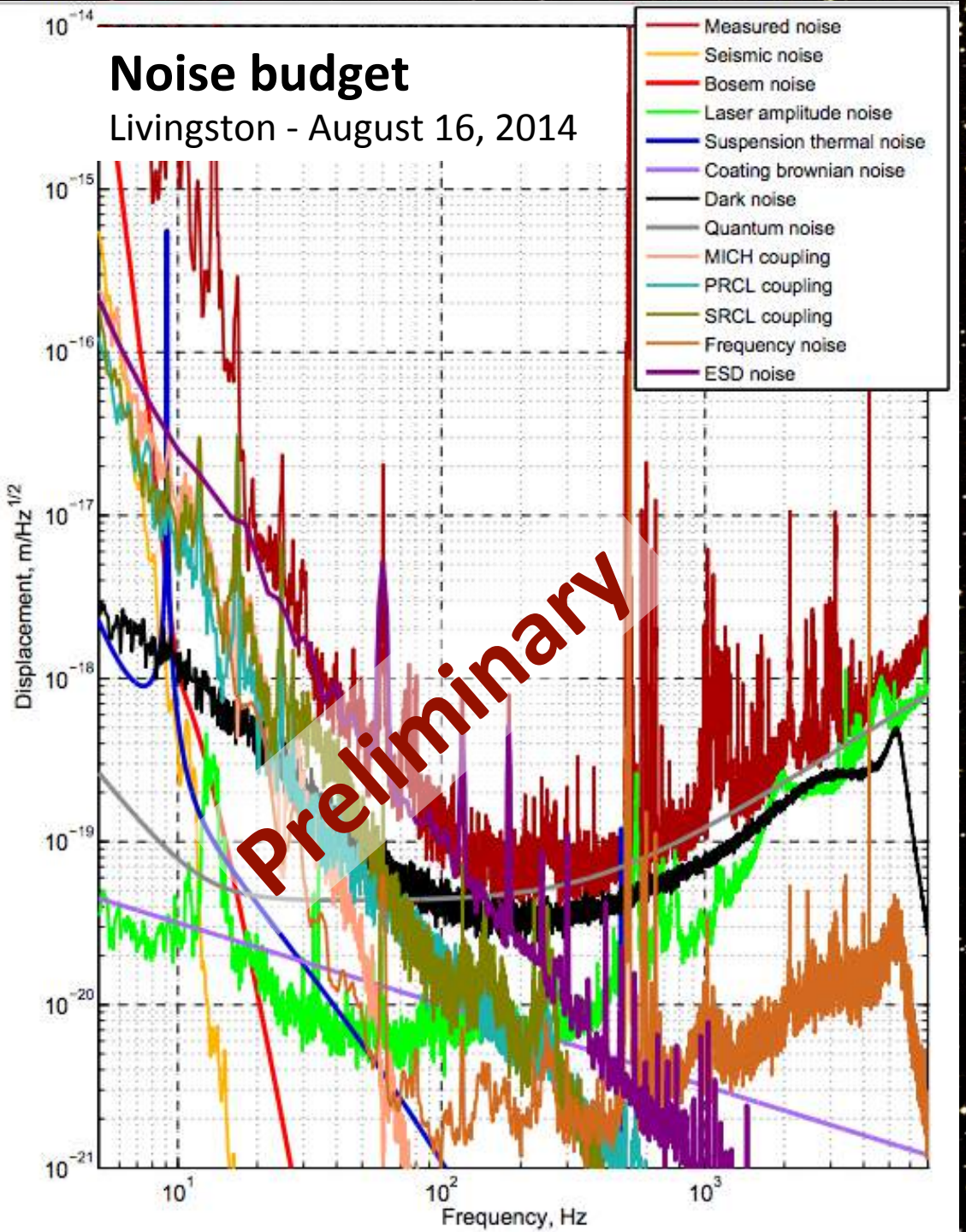
Prior commissioning progression



L. Barsotti

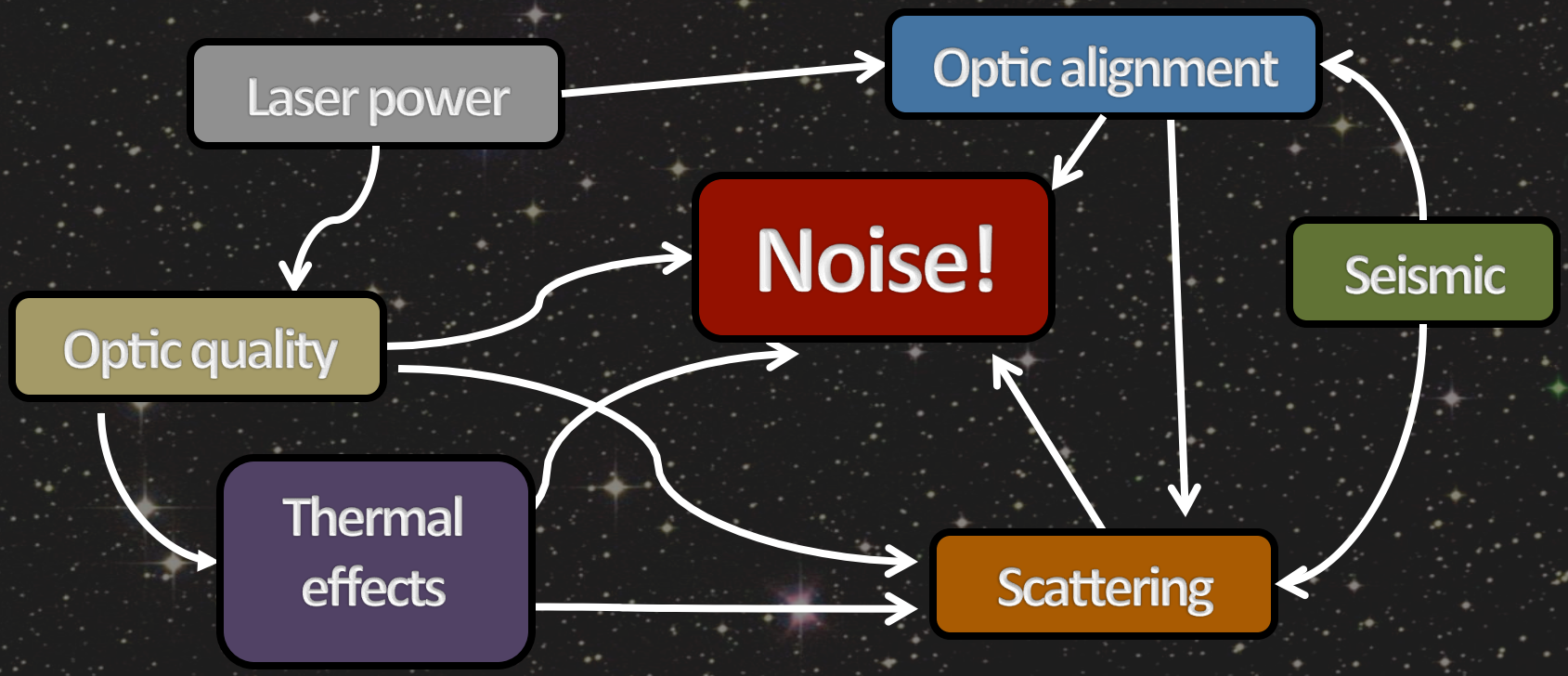
Noise budget

Livingston - August 16, 2014



The challenges of commissioning

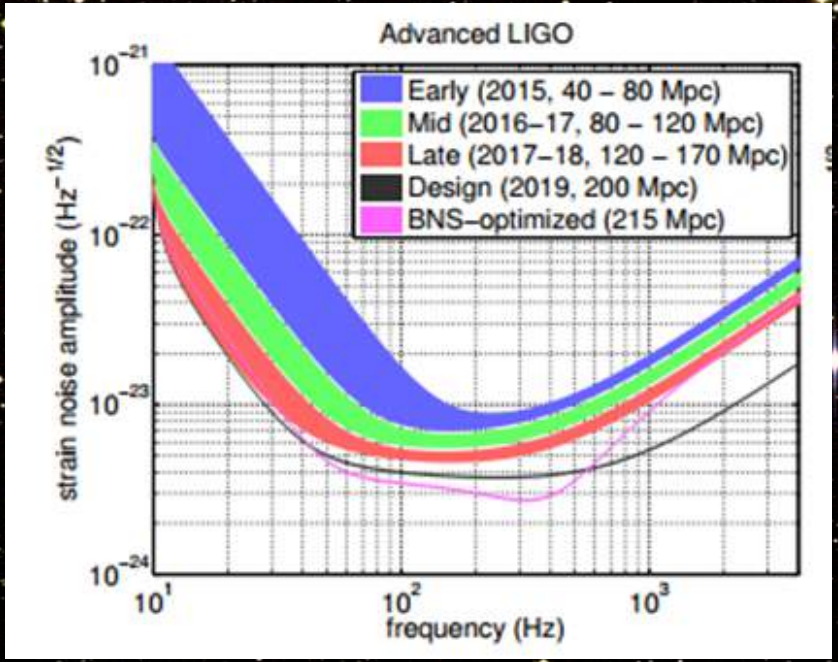
- Many effects cannot be tested prior to large scale implementation
- Often noise sources stem from the interaction of different subsystems and cavities



Planning observing runs

Number of detections =

Rate x Volume x Time



Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc)		BNS Range (Mpc)		Number of BNS Detections	% BNS Localized within	
		LIGO	Virgo	LIGO	Virgo		5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

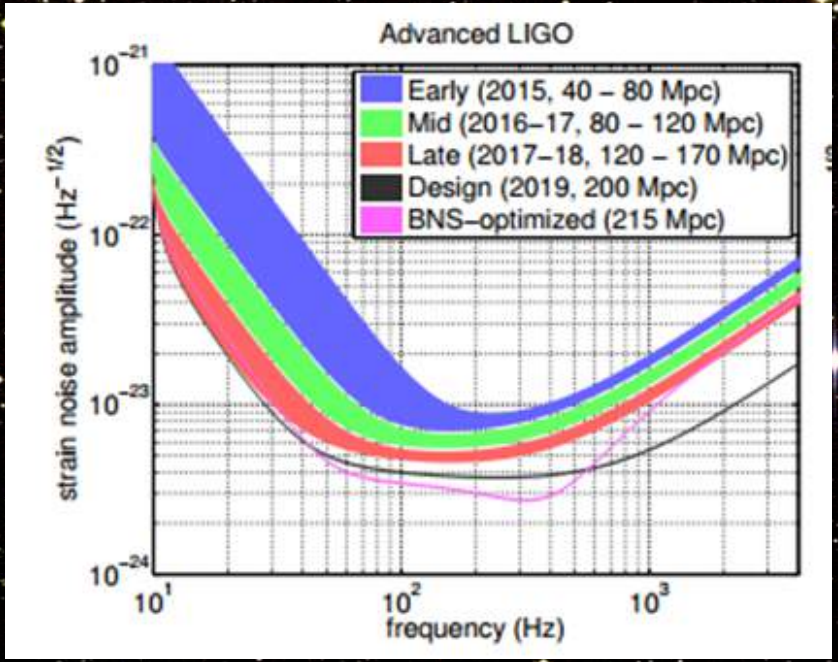
Planning observing runs

For Binary Neutron Stars:

Number of detections =

Rate x Volume x Time

arxiv 1003.2480



Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
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2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

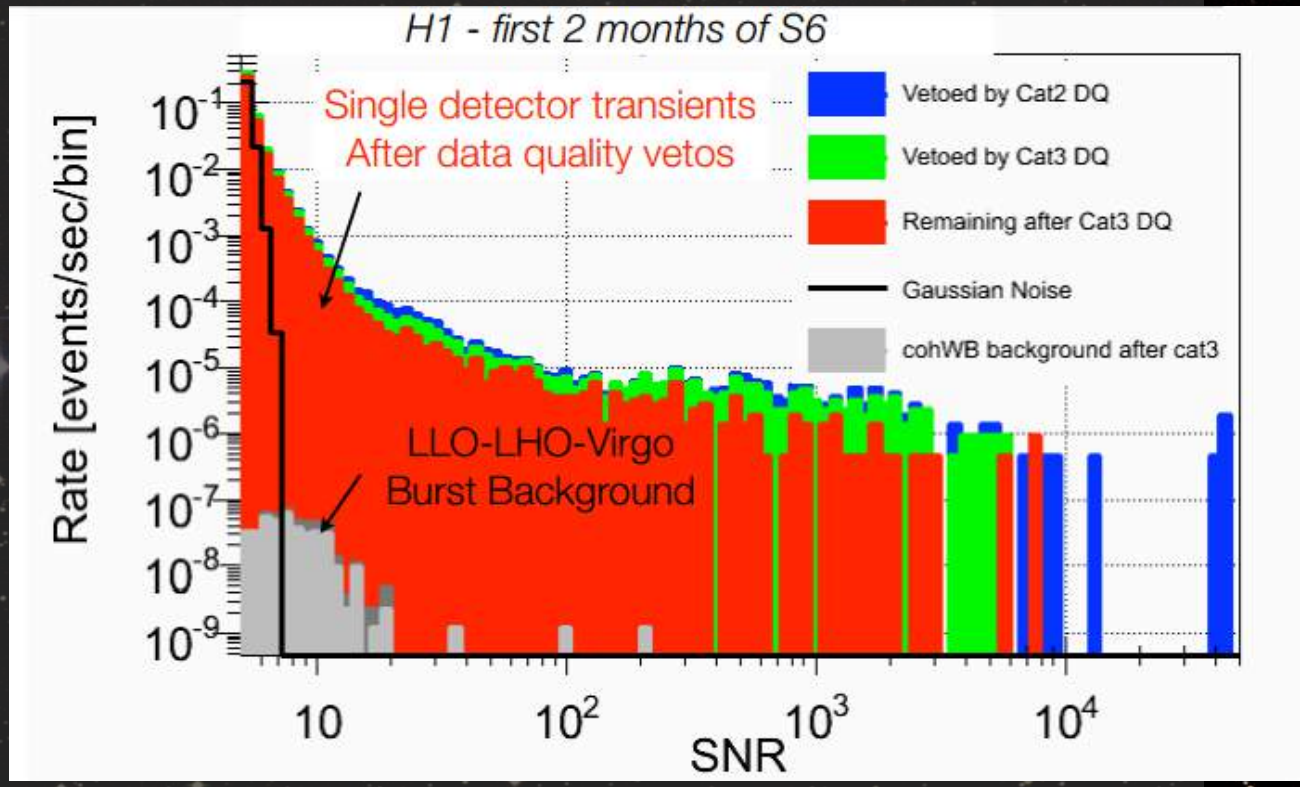
Outline

- **Observing transient GW signals with Advanced LIGO**
  - The advanced detector network
  - Projected commissioning timeline
  - Likely observational scenarios

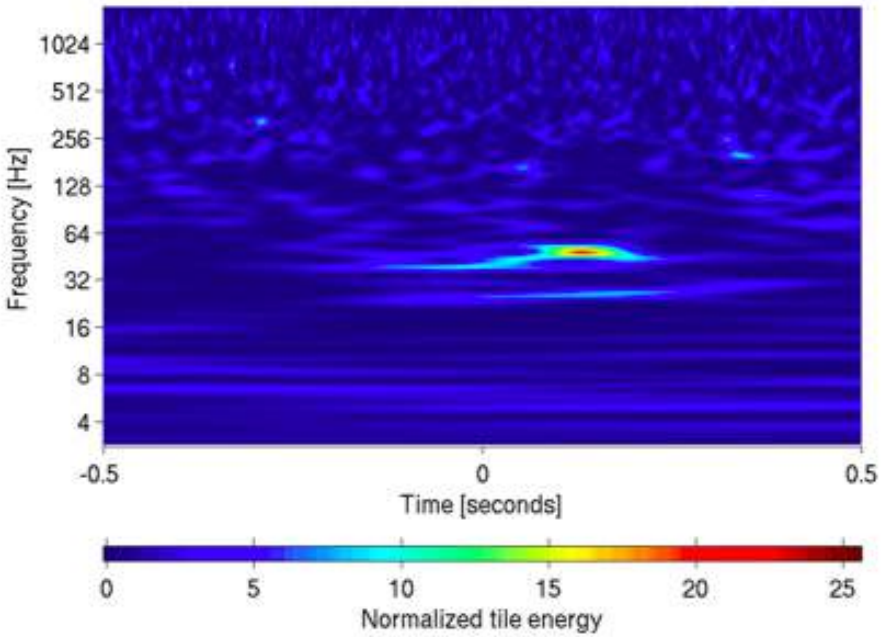
- **Detector characterization efforts**
  - Past strategies, challenges, and successes
  - New approach to characterizing complex instrumentation
  - First glimpse of Livingston data quality

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

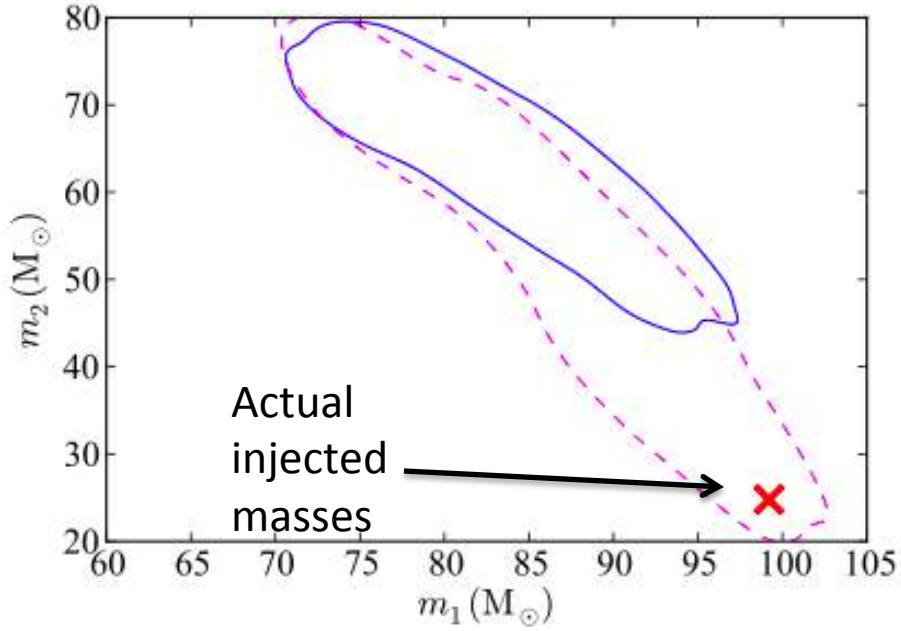
- Long tails (outliers) in all-sky GW burst search background triggers **greatly restrict achievable false alarm rate.**
- Non-Gaussian noise confuses parameter estimation for all transient searches.



Example: NINJA2 search results



(a)



(b)

arvix 1401.0939

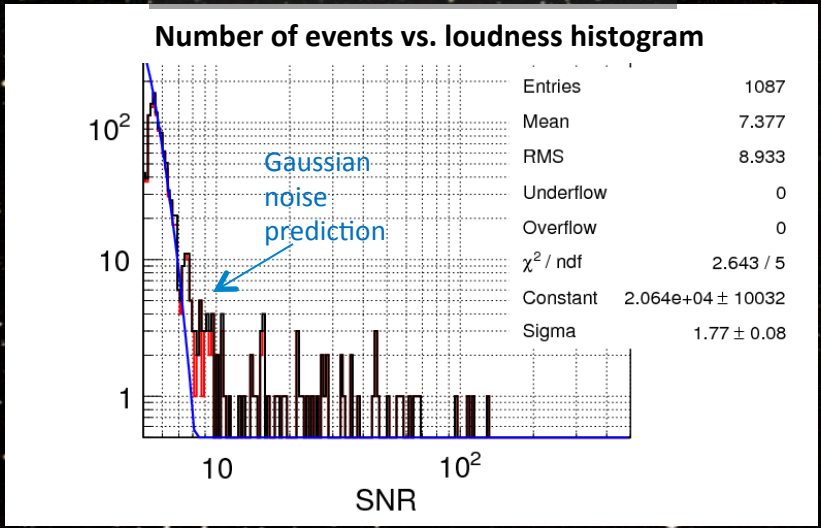
A normalized spectrogram of **Hanford recolored noise only** showing a transient event, or *glitch*, that happens to occur at the time of the injection.

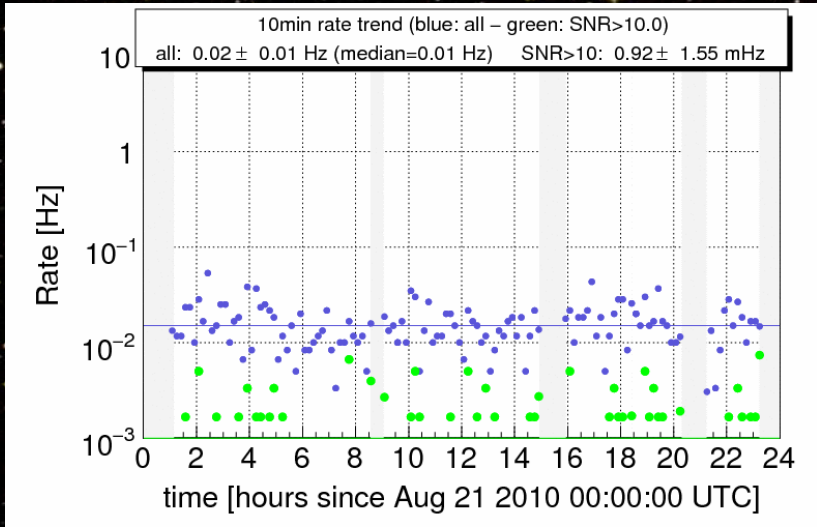
Solid blue – the 95% credible region for mass estimation based on EOBNRv2 analysis using recolored noise.

Dashed pink – in Gaussian noise.

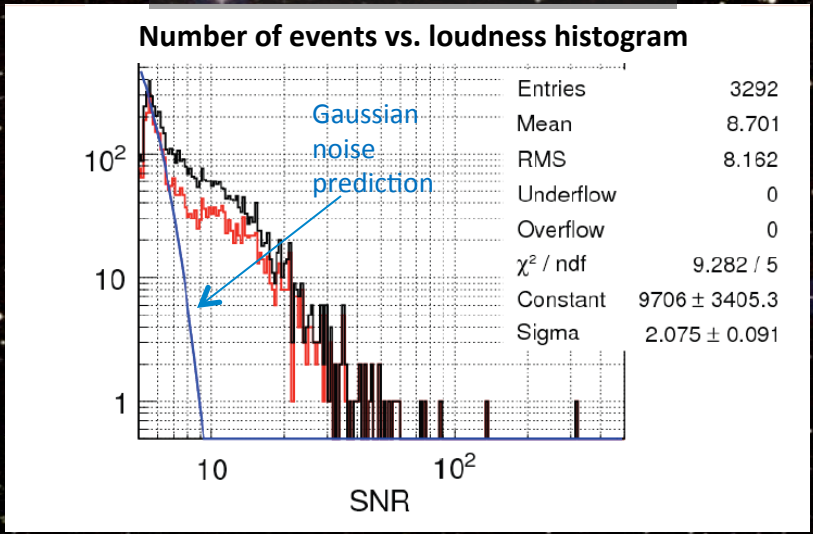
How glitchy were data in past runs?

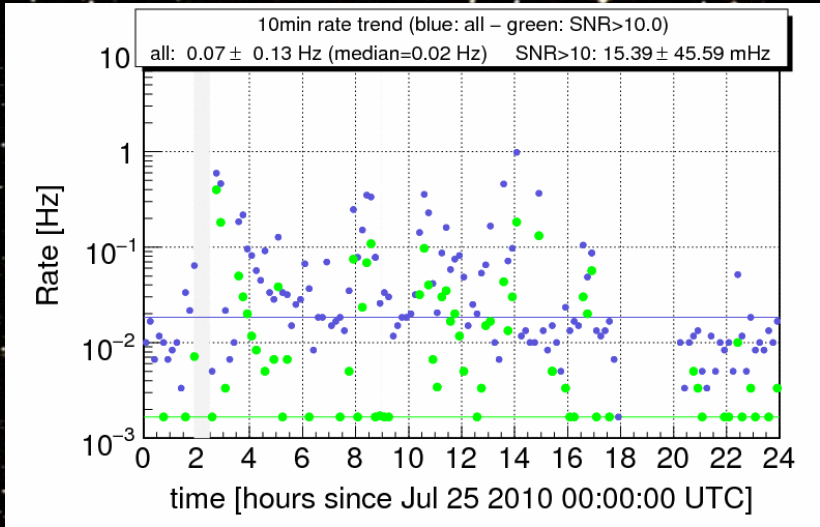
A 'good' day in S6





A 'bad' day in S6

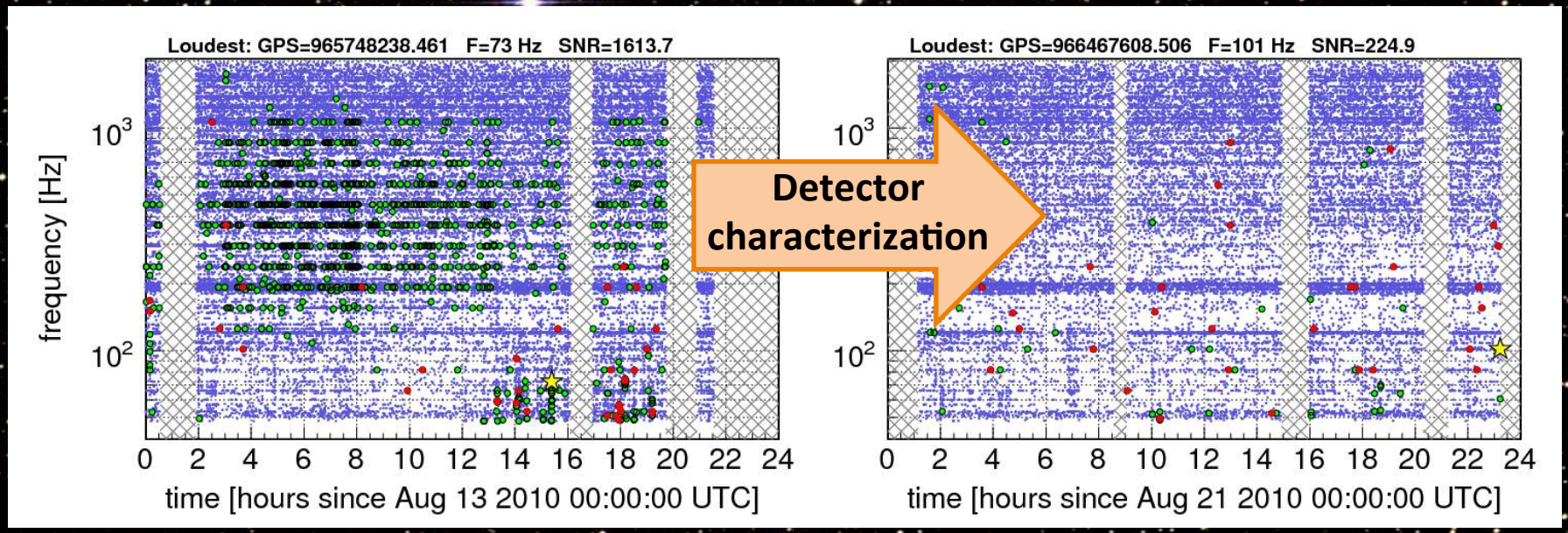




What kinds of glitches affect the transient GW searches?

The **burst** search, requiring coherence and time coincidence between ifos, is more affected by very frequent glitches

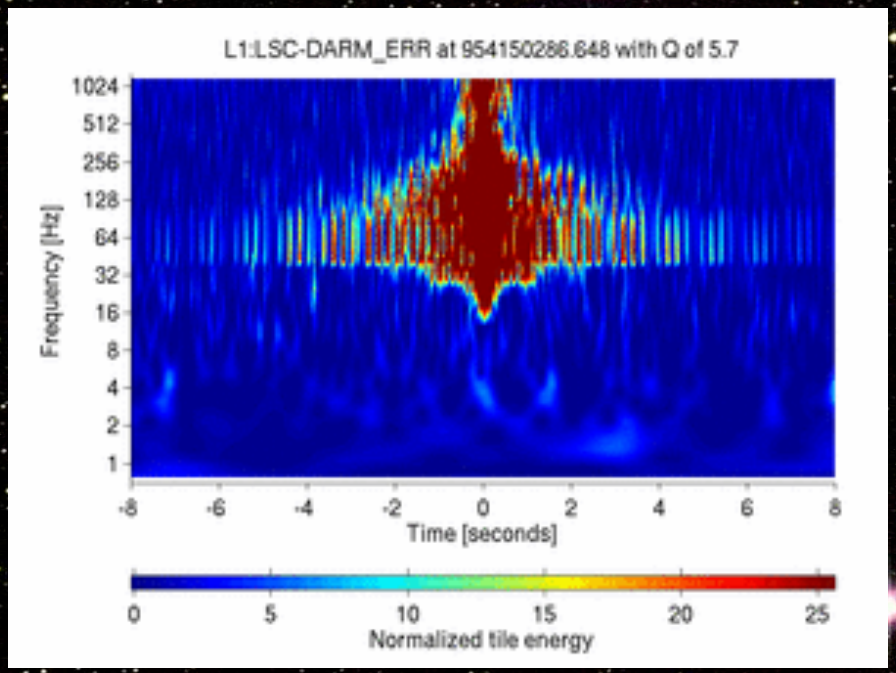
Example: 'Grid' Glitches

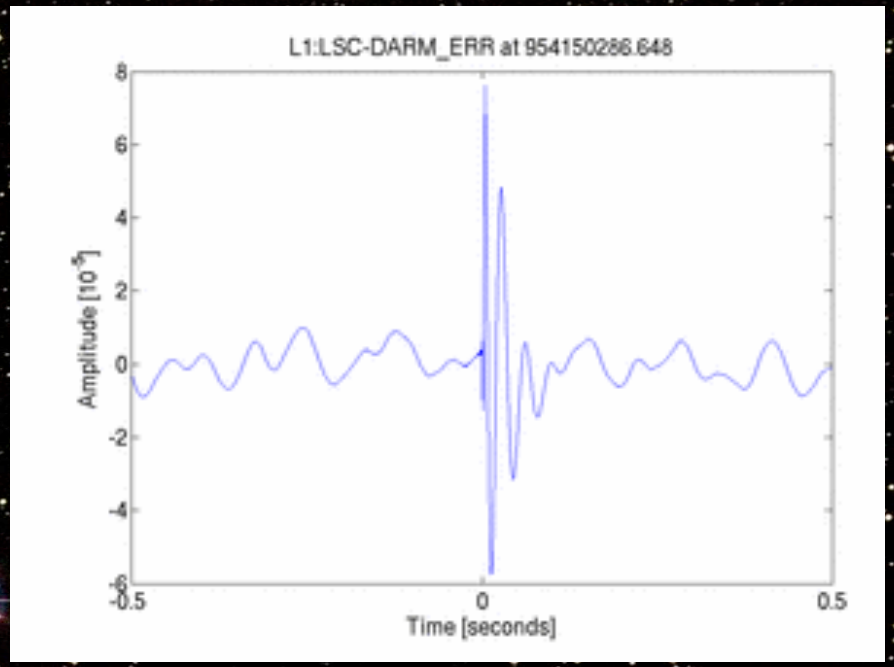


What kinds of glitches affect the transient GW searches?

The **CBC** search is more affected by very loud glitches, which will convolve with many waveform templates in the template bank and pollute large chunks of data

Example: 'Spike' Glitches





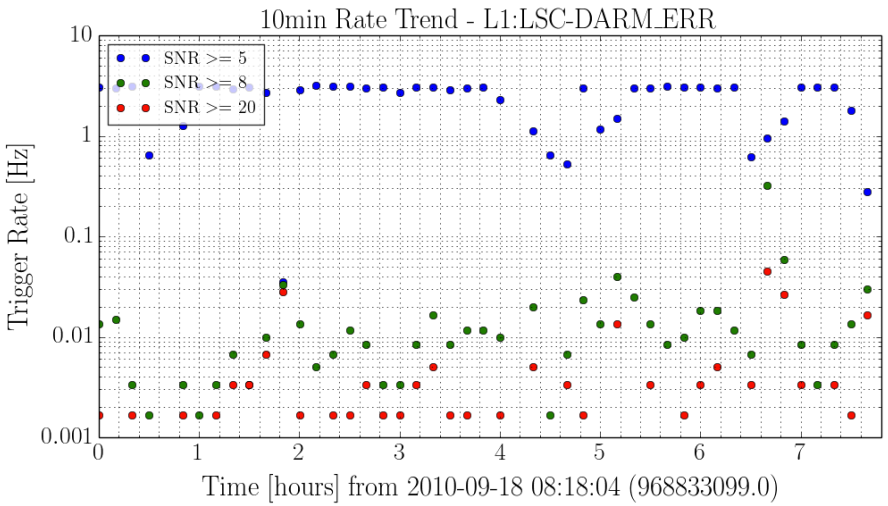
First Glimpse

Advanced LIGO Livingston DQ

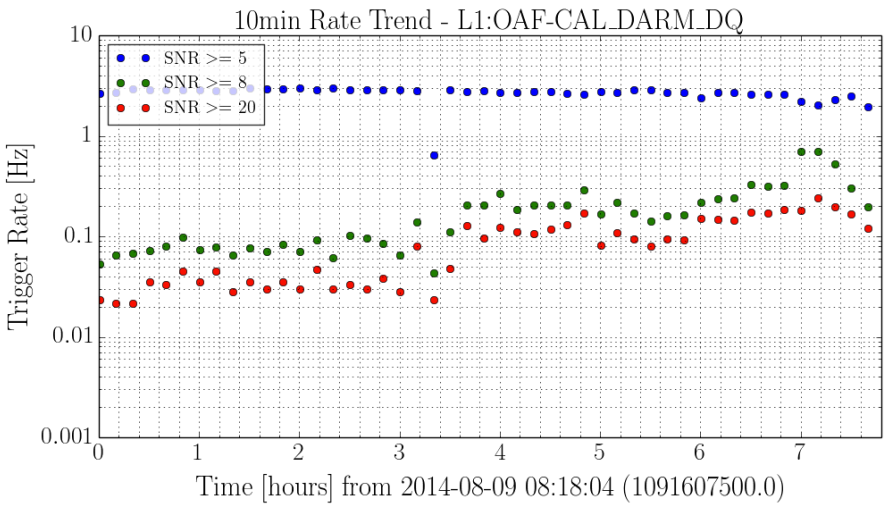
Livingston full interferometer glitching

Calibrated DARM (differential arm length) glitch rate comparison

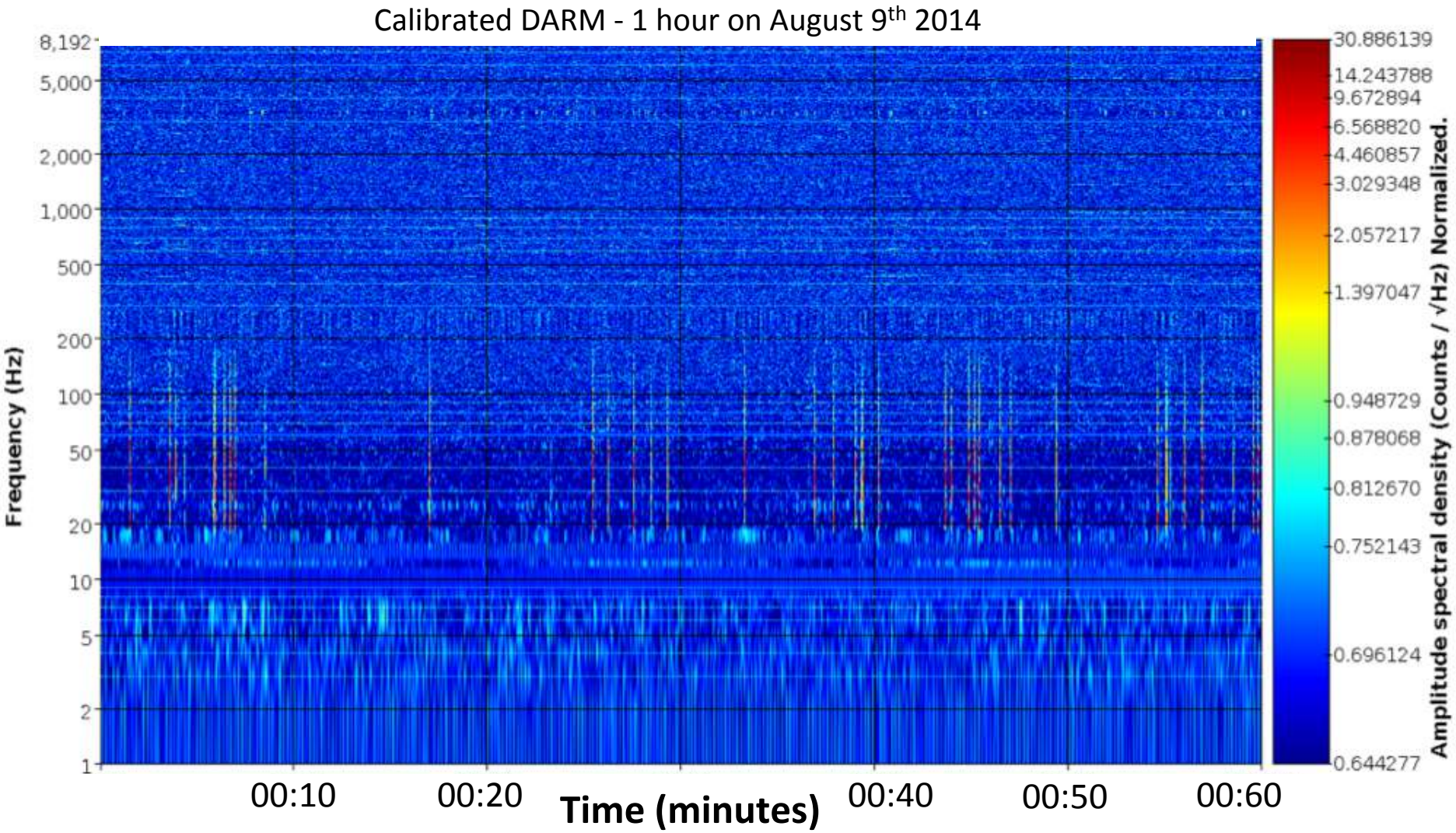
September 2010 (S6)



August 2014

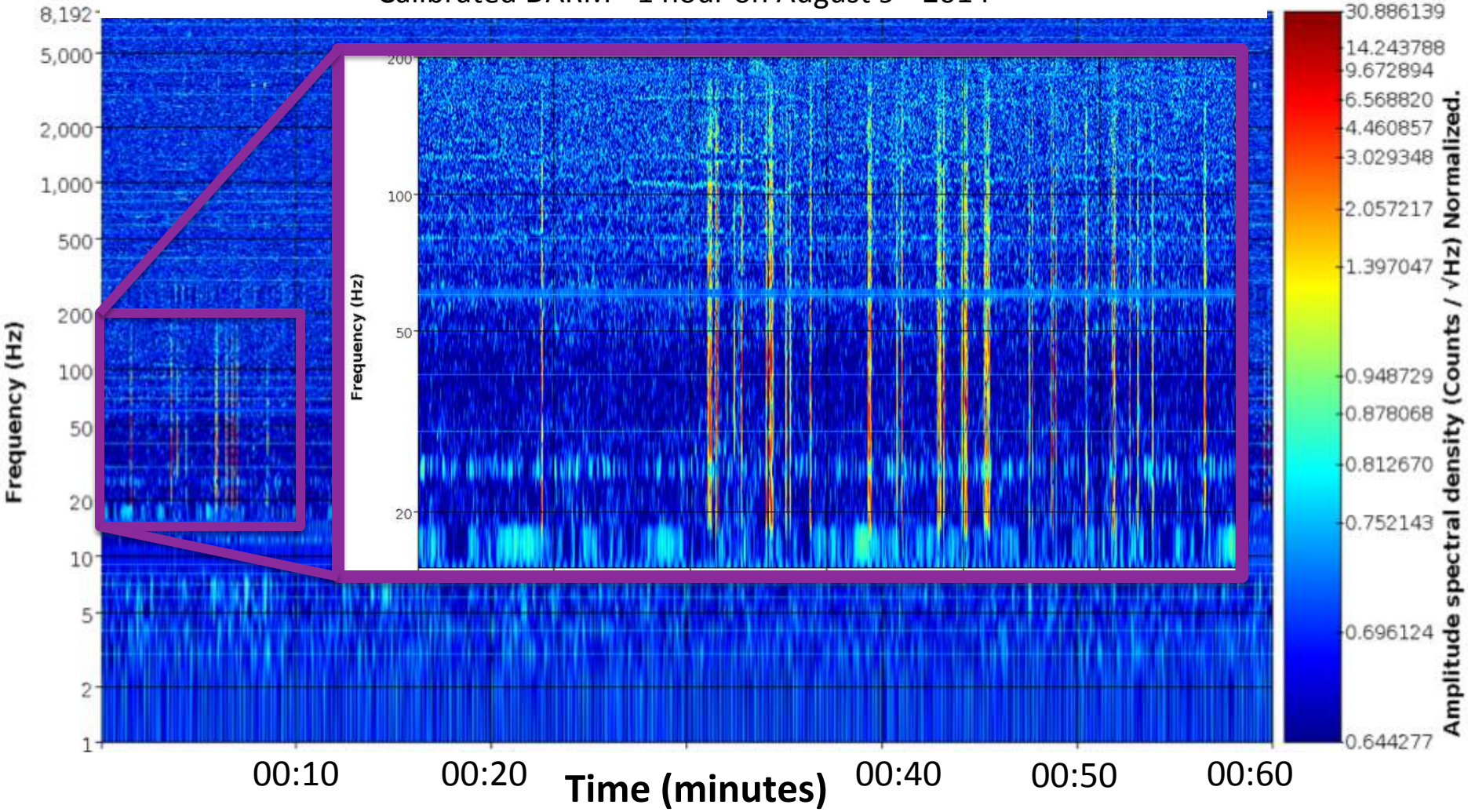


An early DQ issue diagnosis



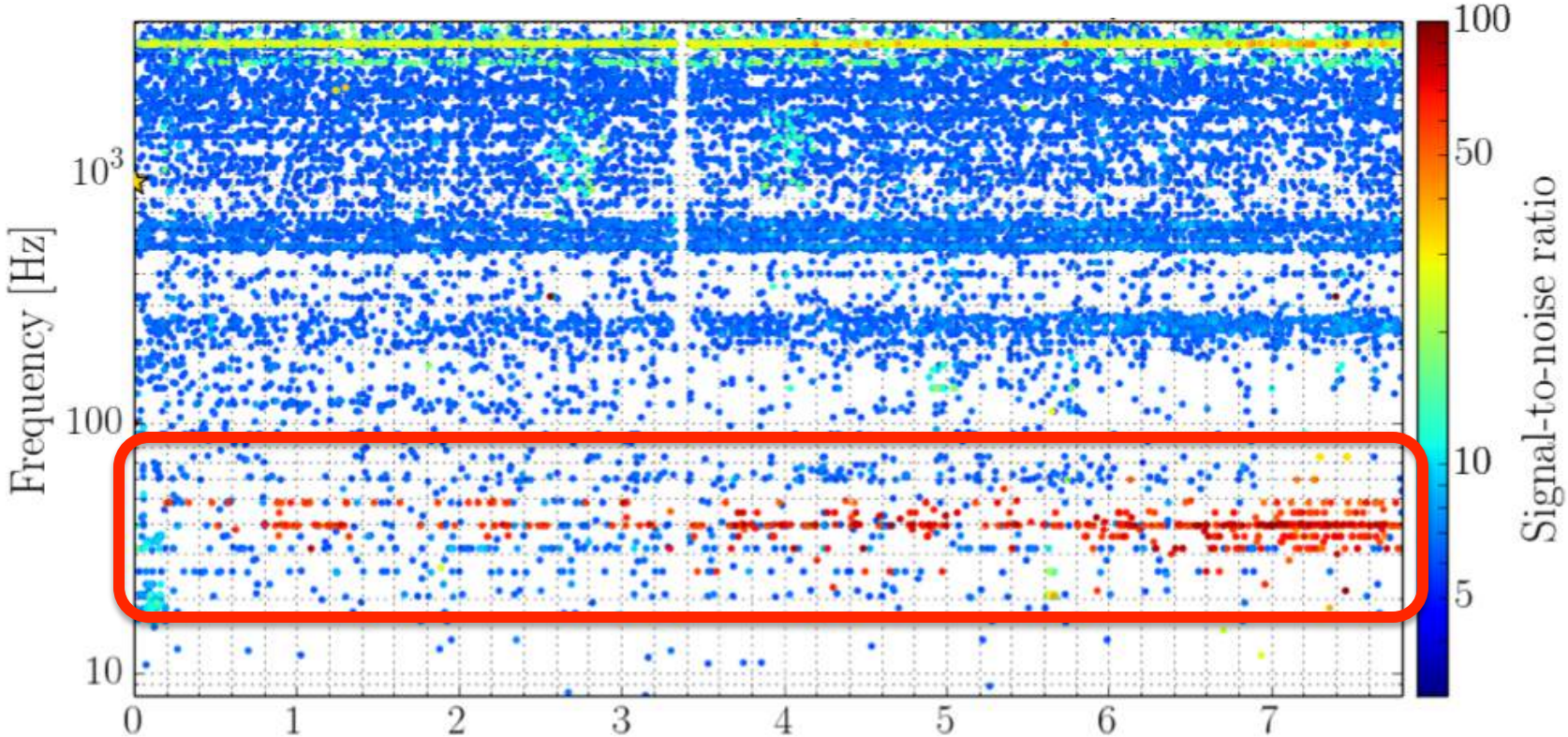
An early DQ issue diagnosis

Calibrated DARM - 1 hour on August 9th 2014



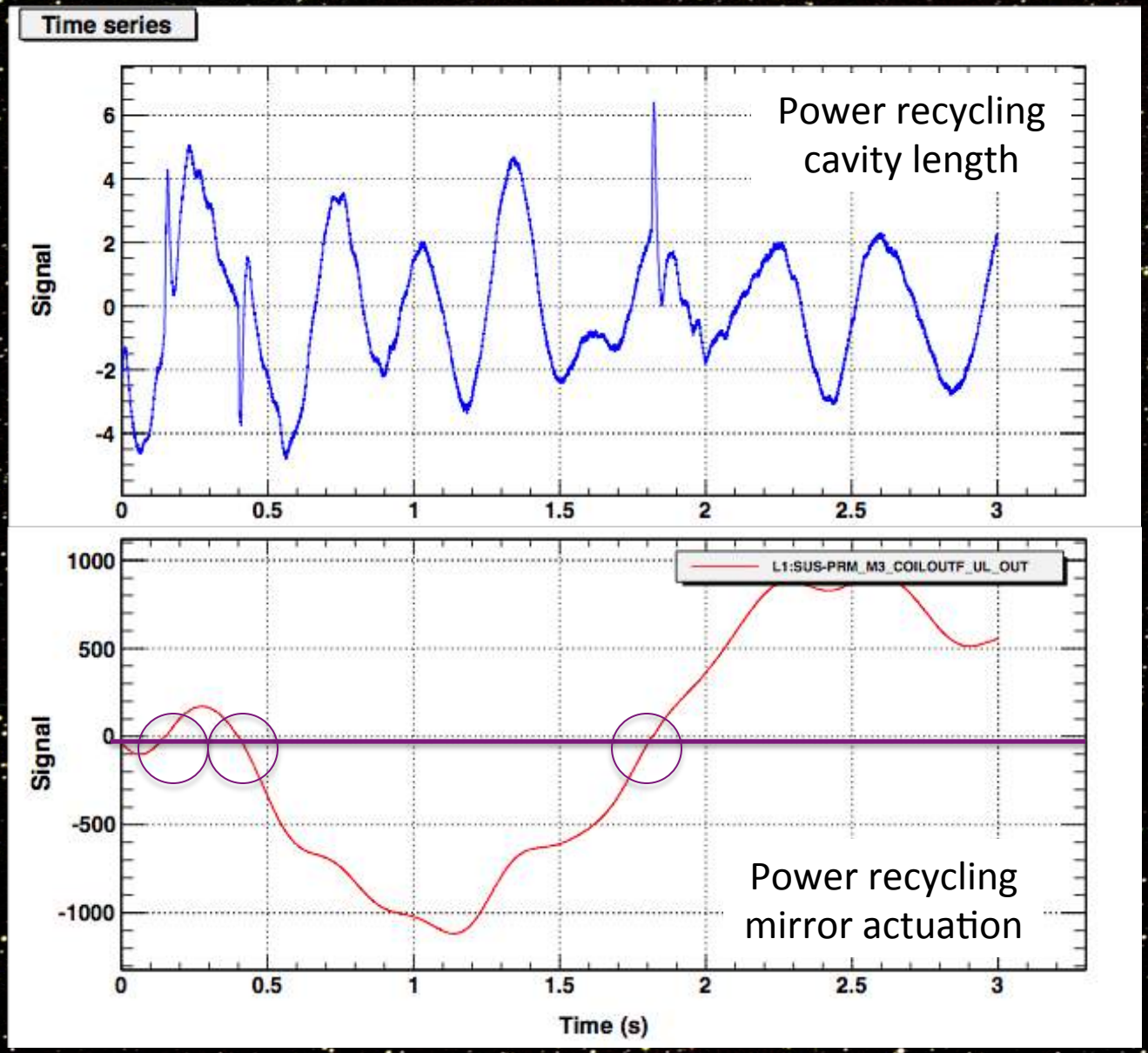
Through the lens of a single ifo burst GW pipeline

Calibrated DARM (differential arm length)



8 hours on August 9th 2014

The mechanism : major carry transition DAC glitching



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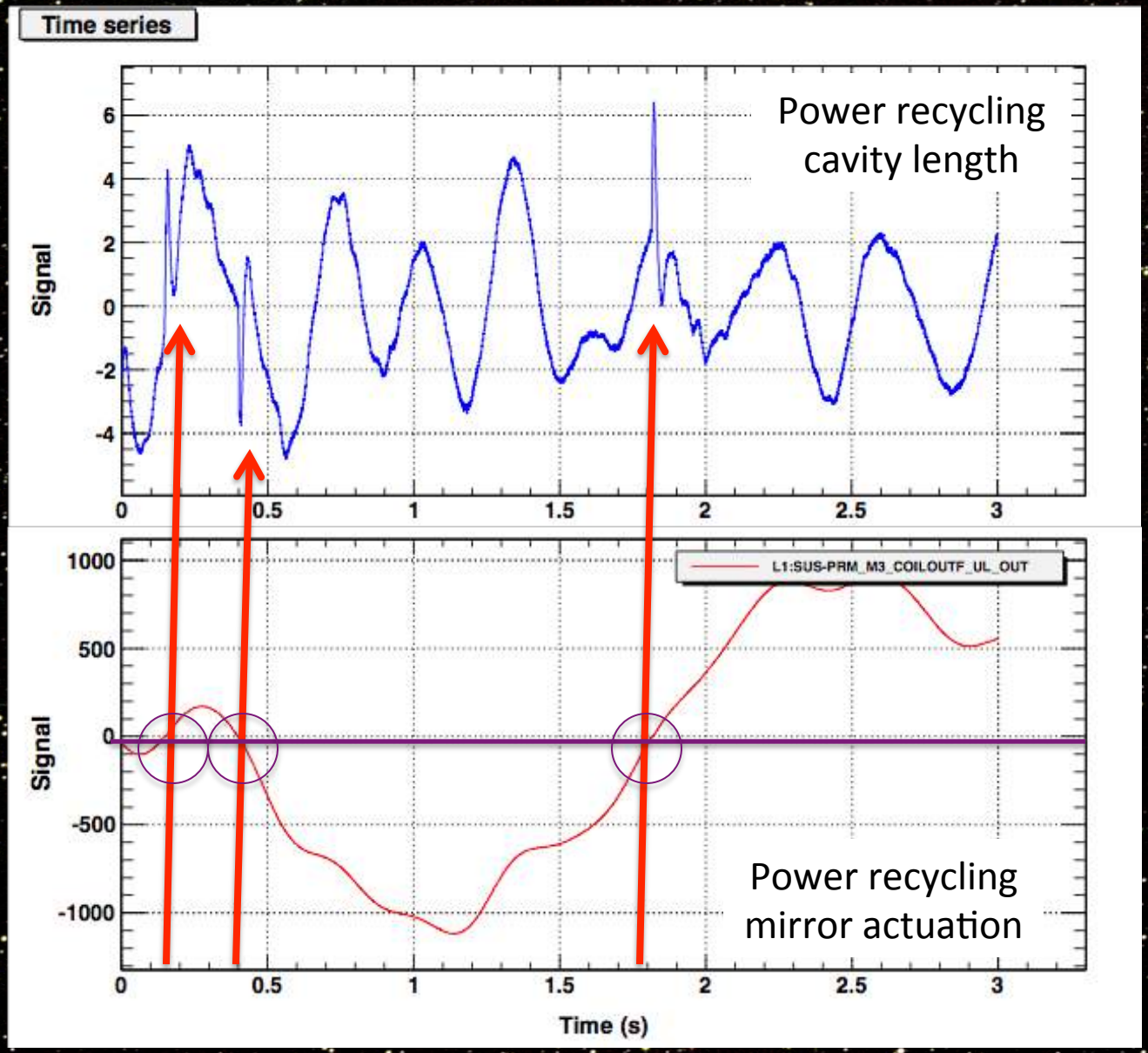
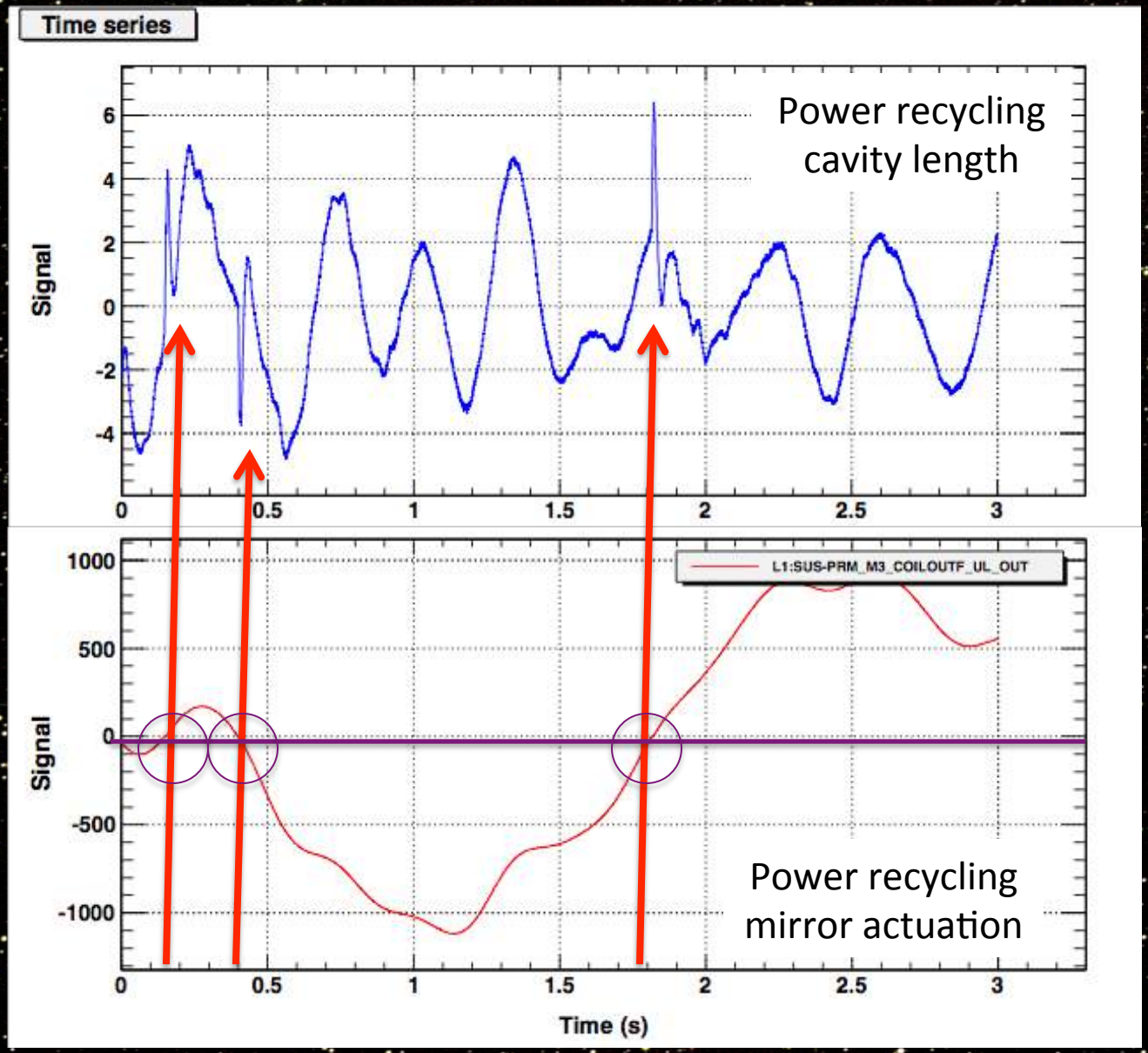


First dubbed "zero crossing" glitches – identified when vertex cavity actuation signals crossed zero.

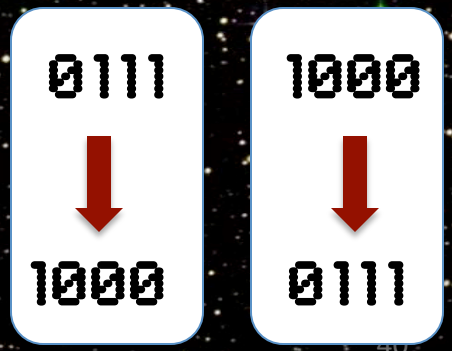
Actually a subset of a broader known issue with these DACs.

The mechanism : major carry transition DAC glitching

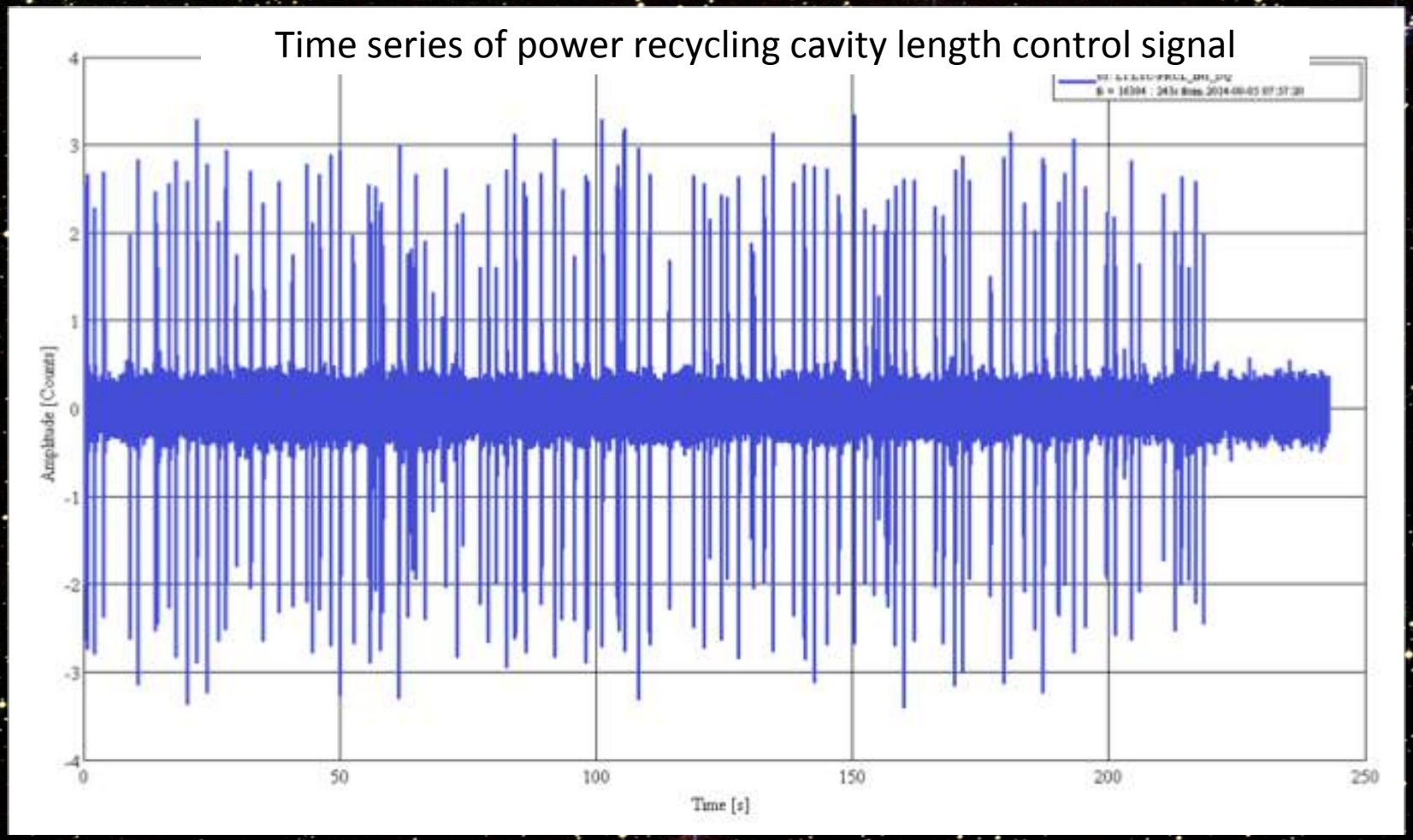


Major-carry transitions: single-code transitions that cause a most significant bit (to change because of the lower bits transitioning.

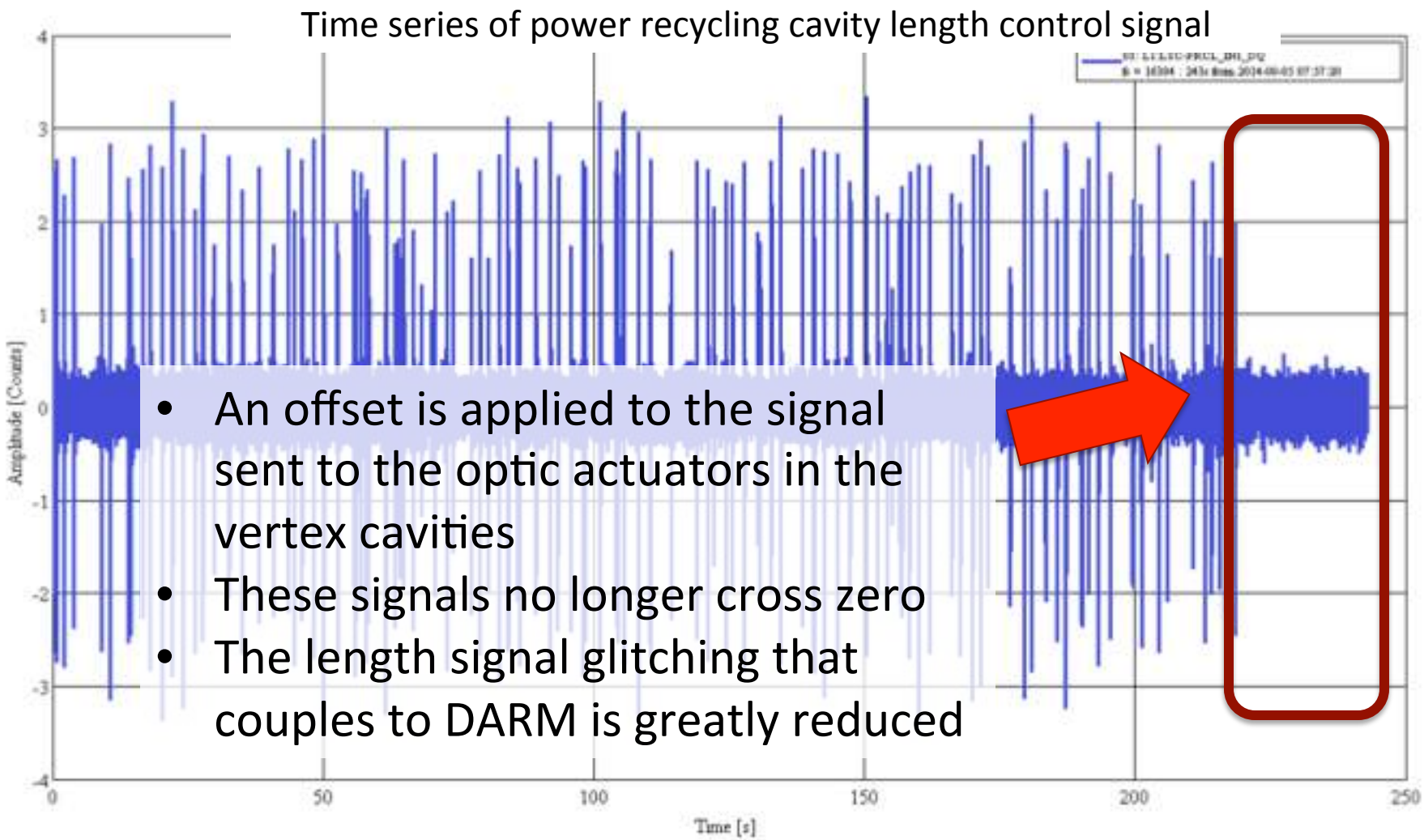
Examples:



Offset applied to vertex cavity actuation



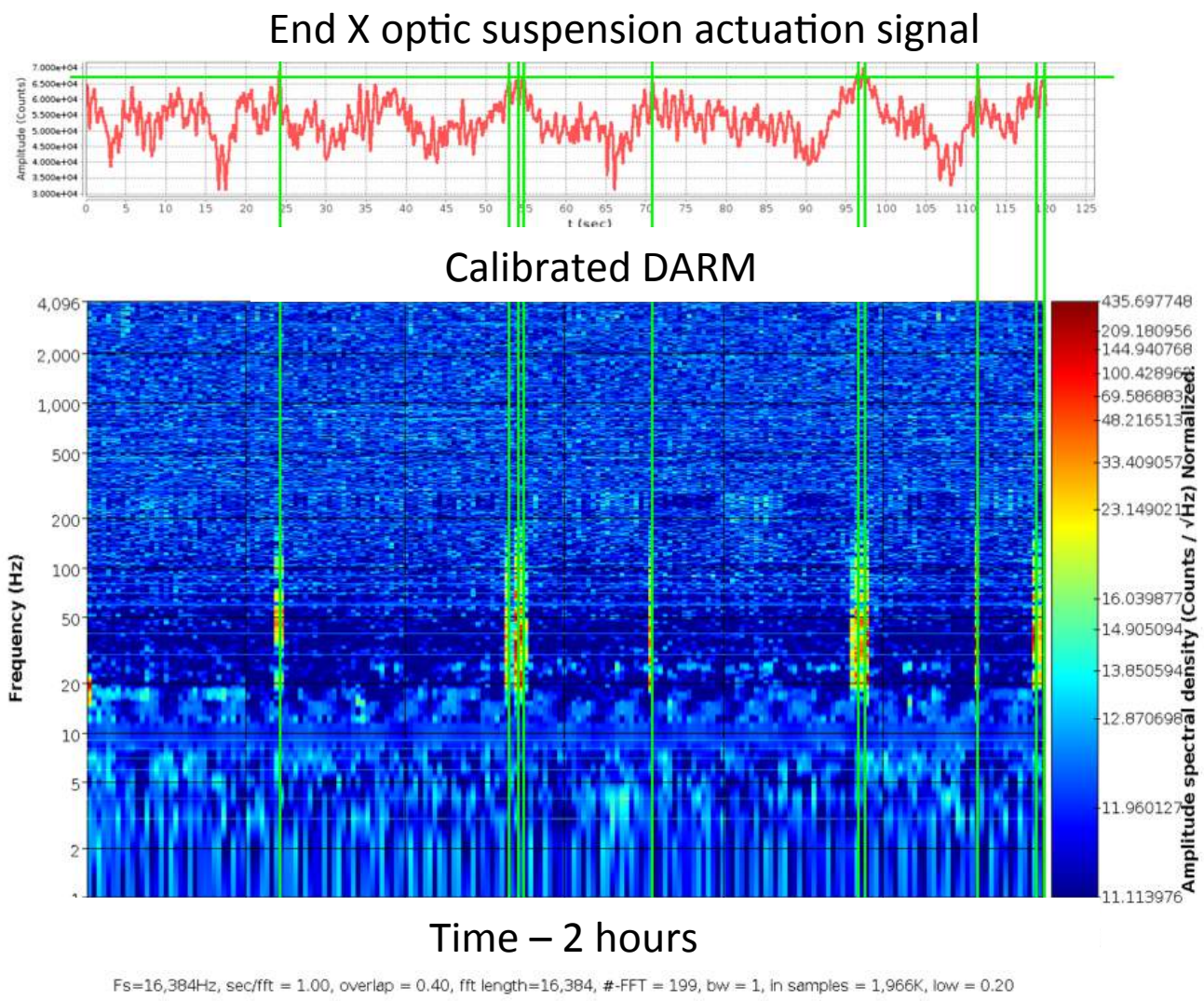
Offset applied to vertex cavity actuation



- 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 **accounting for ~80% of loud glitches** remaining after offset applied to vertex cavity actuators



Conclusions

- With less than a year to go, making good progress toward commissioning and data analysis goals
  - Commissioning following a rapid timeline, advances in sensitivity expected and well understood
  - Detector characterization investment in instrumental expertise already fruitful in preparing to improve data quality for GW searches in O1
- All indications are that we will be ready!