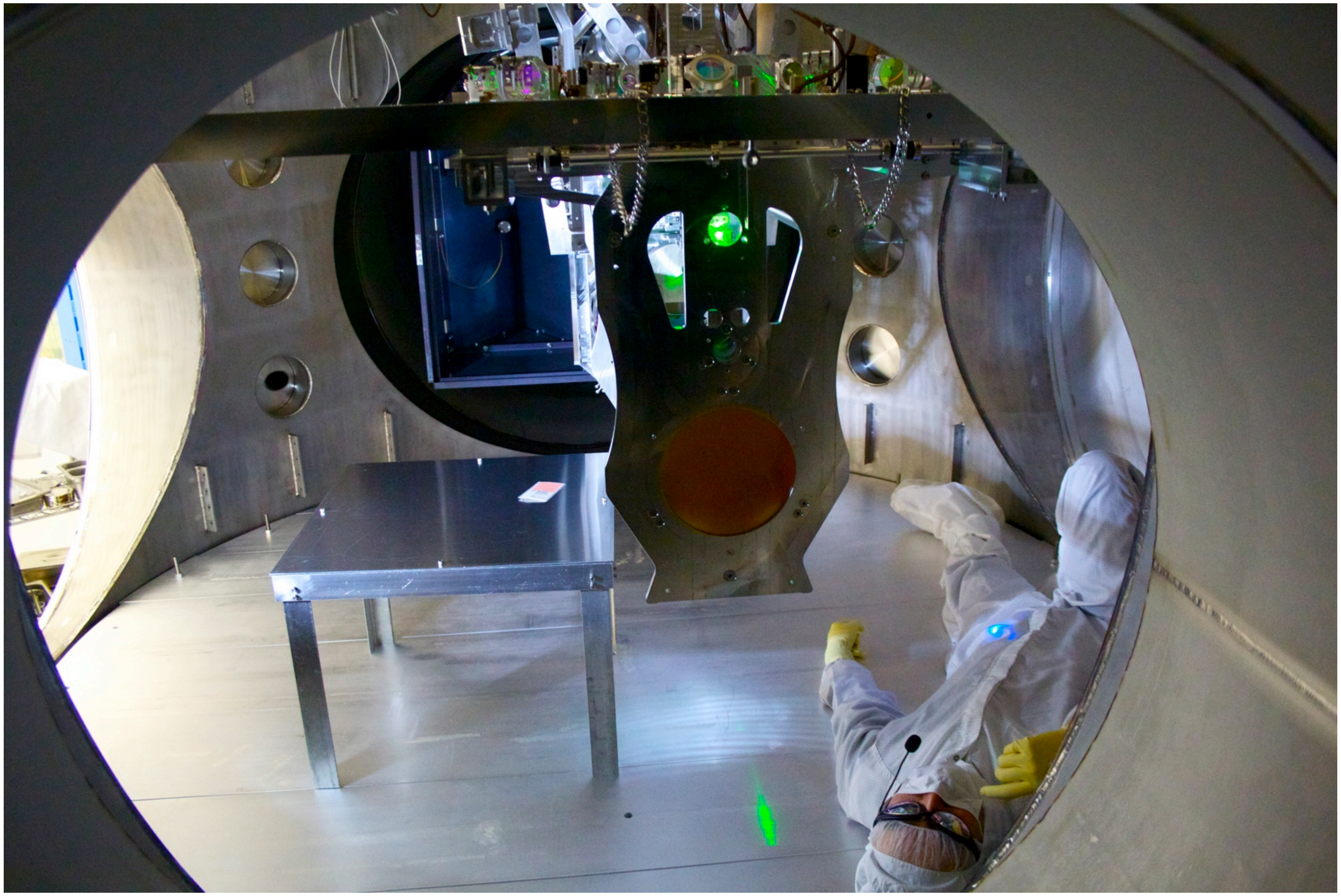
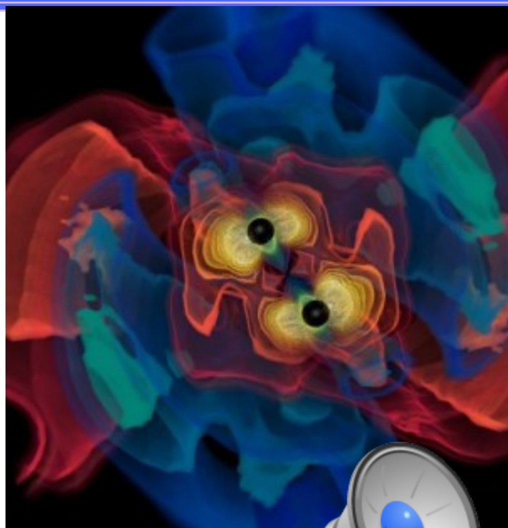
Advanced LIGO Status



M. Landry
for the LIGO Scientific Collaboration
LIGO Hanford Observatory/Caltech
BNS INT – University of Washington
30 June 2014
LIGO-G1400727-v1

LIGO Astrophysical Sources of Gravitational Waves

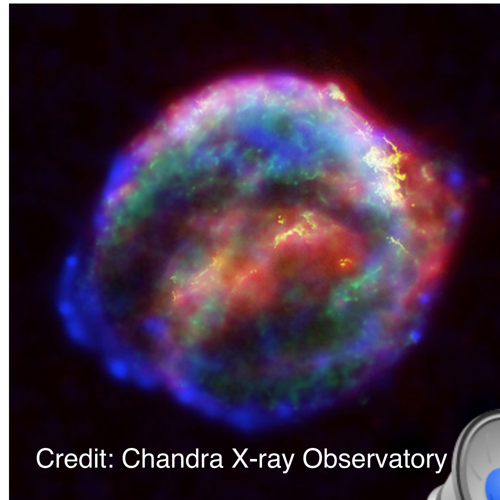


Credit: AEI, CCT, LSU

Coalescing Compact Binary Systems: *Neutron Star-NS, Black Hole-NS, BH-BH*

- Strong emitters, well-modeled,

- (effectively) transient

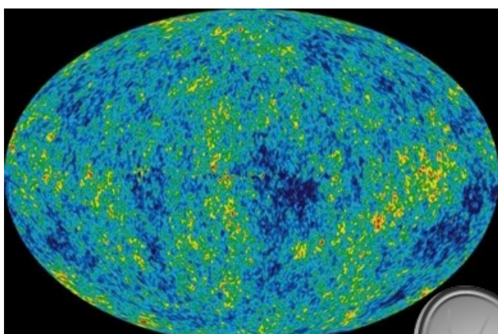


Credit: Chandra X-ray Observatory

Asymmetric Core Collapse Supernovae

- Weak emitters, not well-modeled ('bursts'), transient

- Also: cosmic strings, SGRs, pulsar glitches

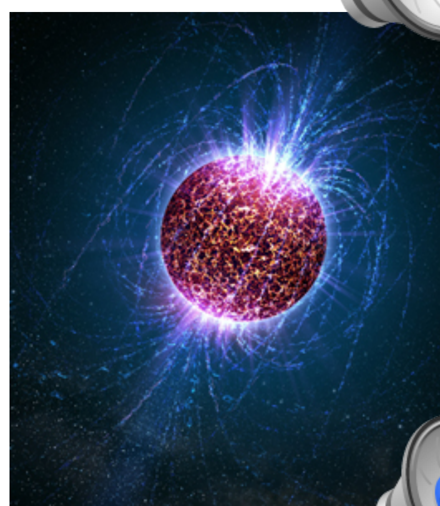


NASA/WMAP Science Team

Cosmic Gravitational-wave Background

- Residue of the Big Bang

- Long duration, stochastic background



Casey Reed, Penn State

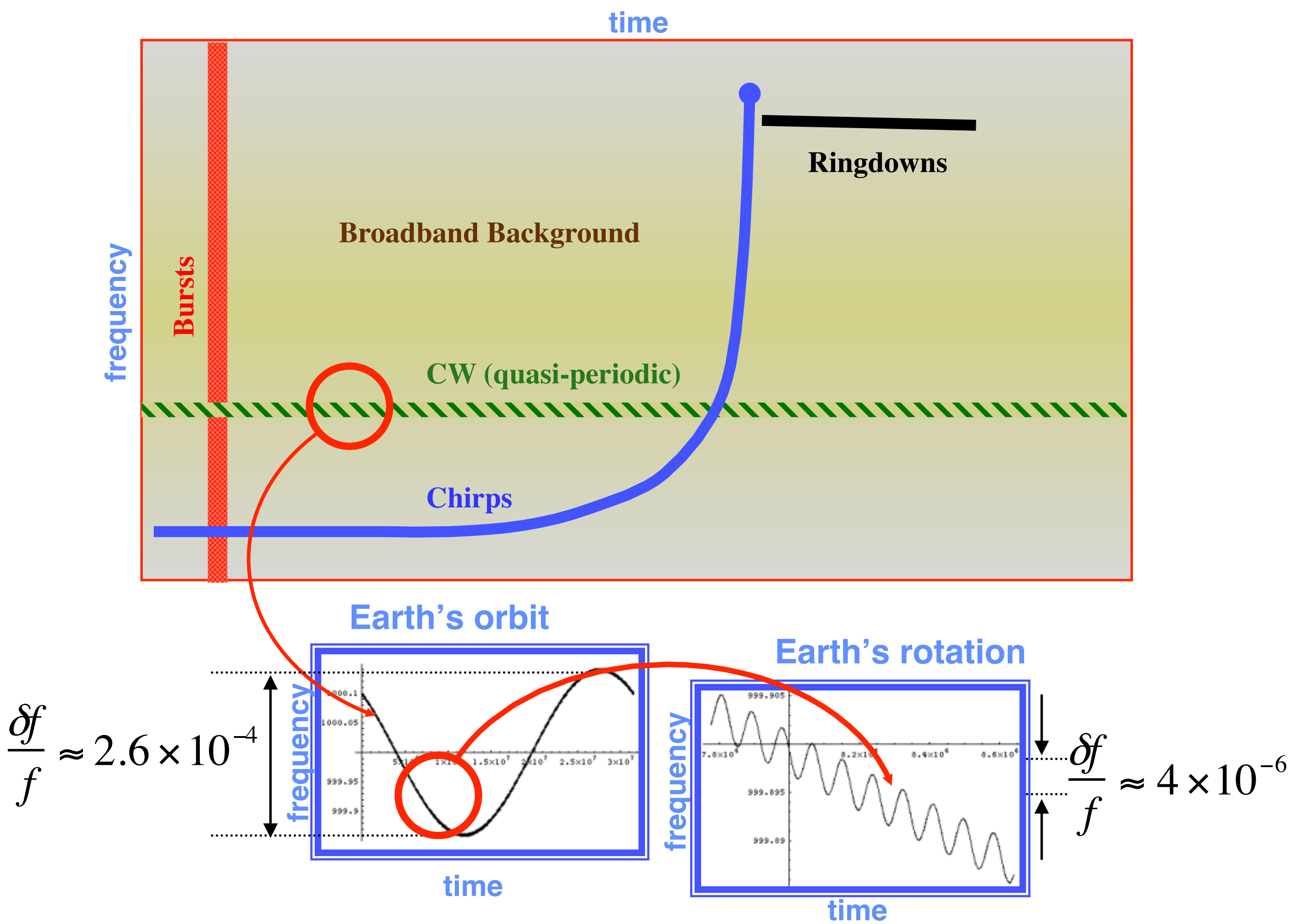
Spinning neutron stars

- (nearly) monotonic waveform

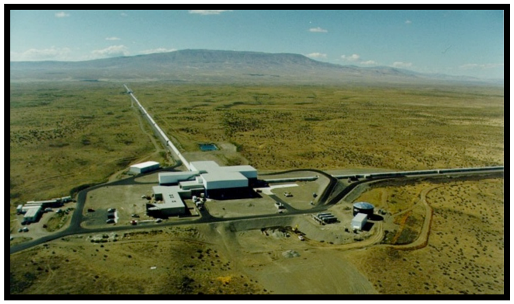
- Long duration

Audio credit: E. Thrane, CIT

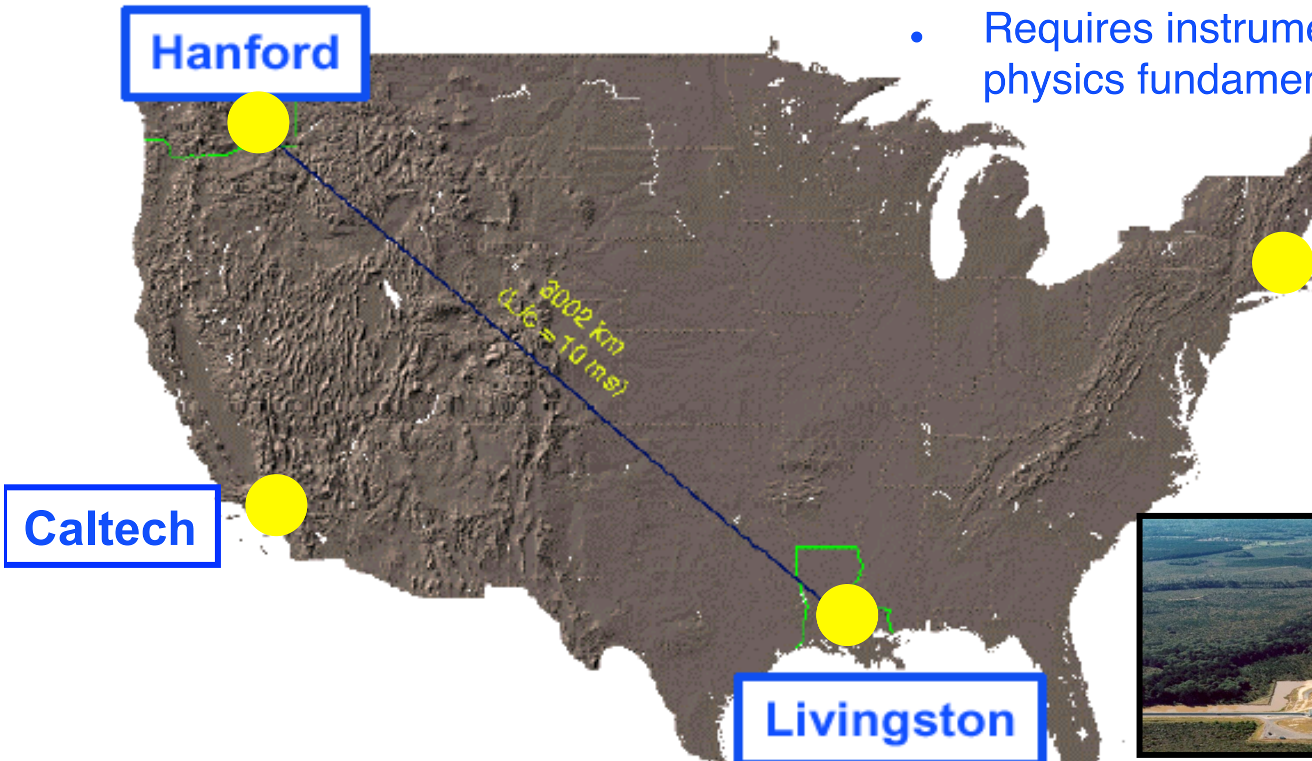
Frequency-Time Characteristics of GW Sources



LIGO Laboratory: two Observatories, Caltech and MIT campuses



- Mission: to develop gravitational-wave detectors, and to operate them as astrophysical observatories
- Jointly managed by Caltech and MIT; responsible for operating LIGO Hanford and Livingston Observatories
- Requires instrument science at the frontiers of physics fundamental limits



LIGO Scientific Collaboration

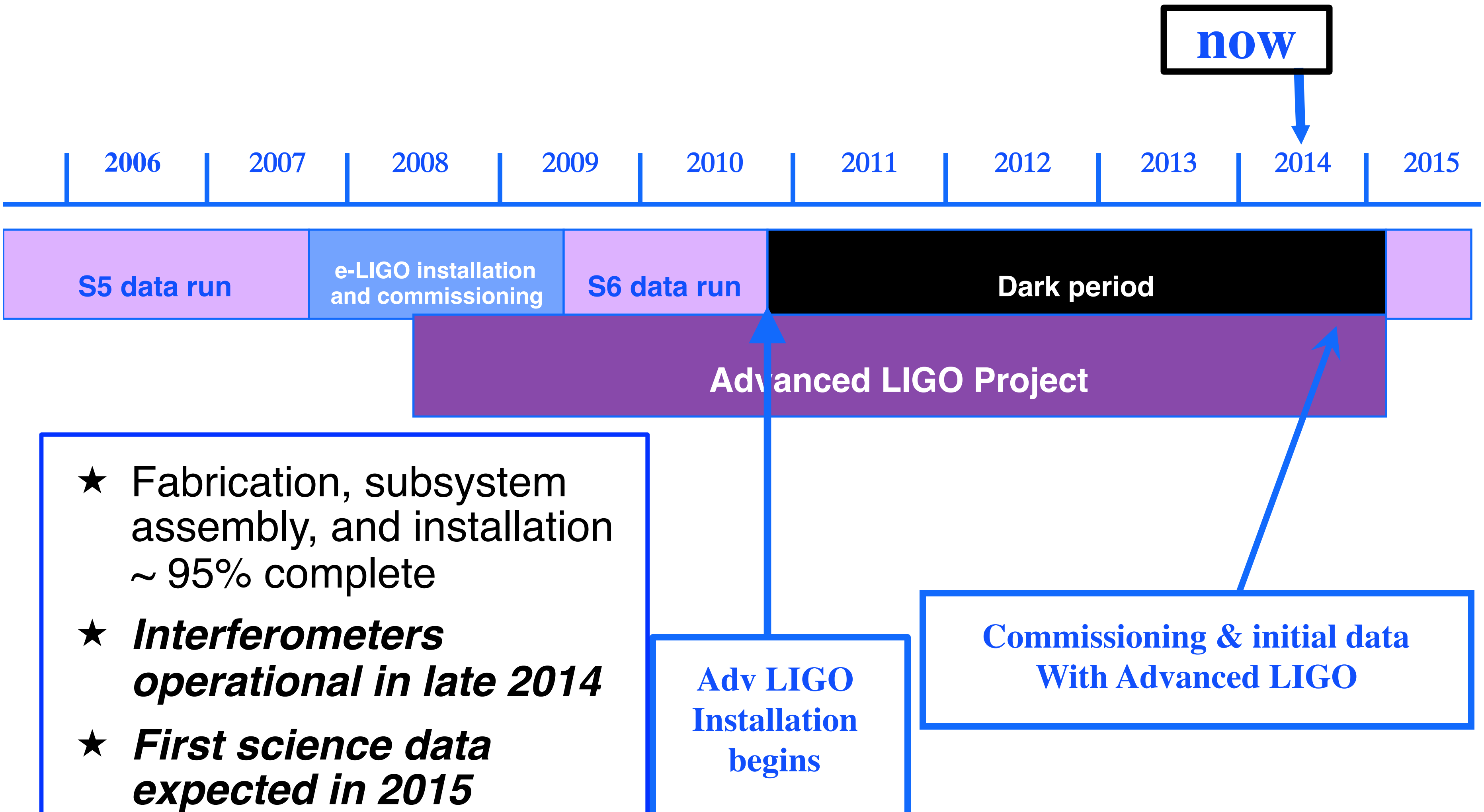
- 900+ members, 80+ institutions, 17 countries

LIGO Scientific Collaboration

- Australian Consortium for Interferometric Gravitational Astronomy
- The Univ. of Adelaide
- Andrews University
- The Australian National Univ.
- The University of Birmingham
- California Inst. of Technology
- Univ. of Cambridge
- Canadian Institute for Theoretical Astrophysics and Perimeter Institute for Theoretical Physics
- Cardiff University
- Carleton College
- Charles Sturt Univ.
- Columbia University
- CSU Fullerton
- Embry Riddle Aeronautical Univ.
- Eötvös Loránd Univ.
- University of Florida
- German/British Collaboration for the Detection of Gravitational Waves
- University of Glasgow
- Goddard Space Flight Center
- Hanyang University
- Korea Institute of Science and Tech Information
- Leibniz Universität Hannover
- Lund University
- Hobart & William Smith Colleges
- Inst. of Applied Physics of the Russian Academy of Sciences
- Polish Academy of Sciences
- India Inter-University Centre for Astronomy and Astrophysics
- Louisiana State University
- Louisiana Tech University
- Loyola Univ. of New Orleans
- University of Maryland
- Max Planck Institute for Gravitational Physics
- McNeese State University
- Univ. of Melbourne
- University of Michigan
- University of Minnesota
- The University of Mississippi
- Massachusetts Inst. of Technology
- Monash University
- Montana State University
- Montclair State University
- Moscow State University
- National Astronomical Observatory of Japan
- National Inst. of Mathematical Sciences
- University of New Hamshire
- Northwestern University
- University of Oregon
- Pennsylvania State University
- Pusan National University
- Rochester Inst. of Technology
- Rutherford Appleton Lab
- University of Rochester
- San Jose State University
- Univ. of Sannio at Benevento, and Univ. of Salerno
- Seoul National University
- University of Sheffield
- University of Southampton
- Southeastern Louisiana Univ.
- USC - Information Sciences Institute
- Southern Univ. and A&M College
- Stanford University
- University of Strathclyde
- Syracuse University
- Univ. of Texas at Austin
- Univ. of Texas at Brownsville
- Trinity University
- Tsinghua University
- Universitat de les Illes Balears
- Univ. of Massachusetts Amherst
- University of Western Australia
- Univ. of Wisconsin-Milwaukee
- Washington State University
- University of Washington

LIGO

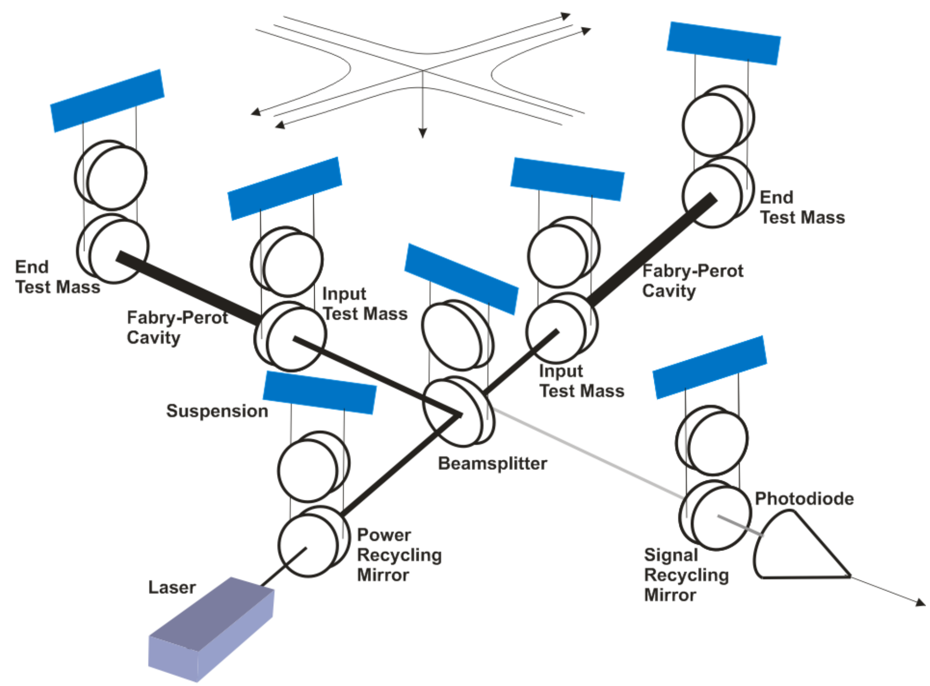
LIGO time line

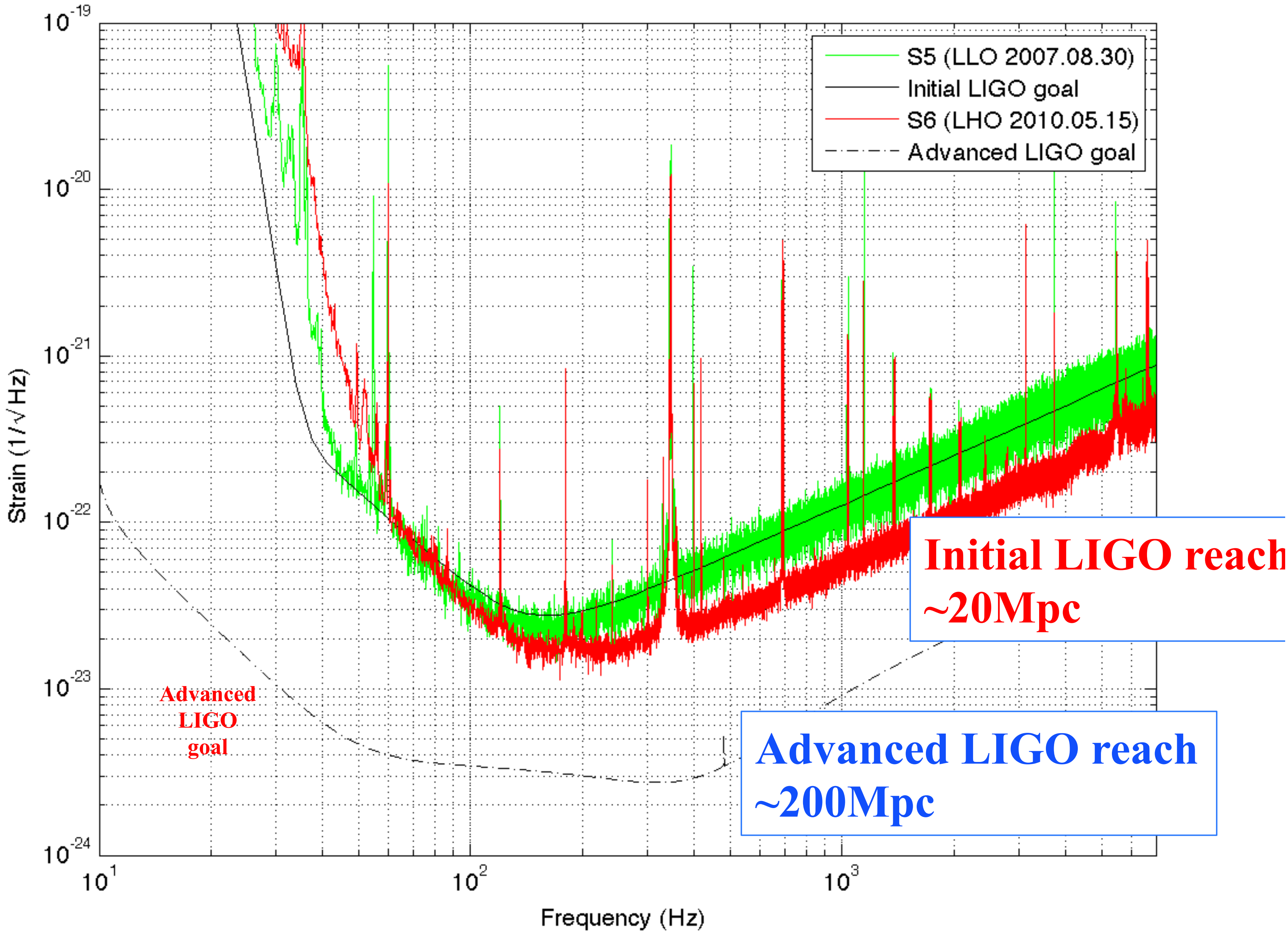


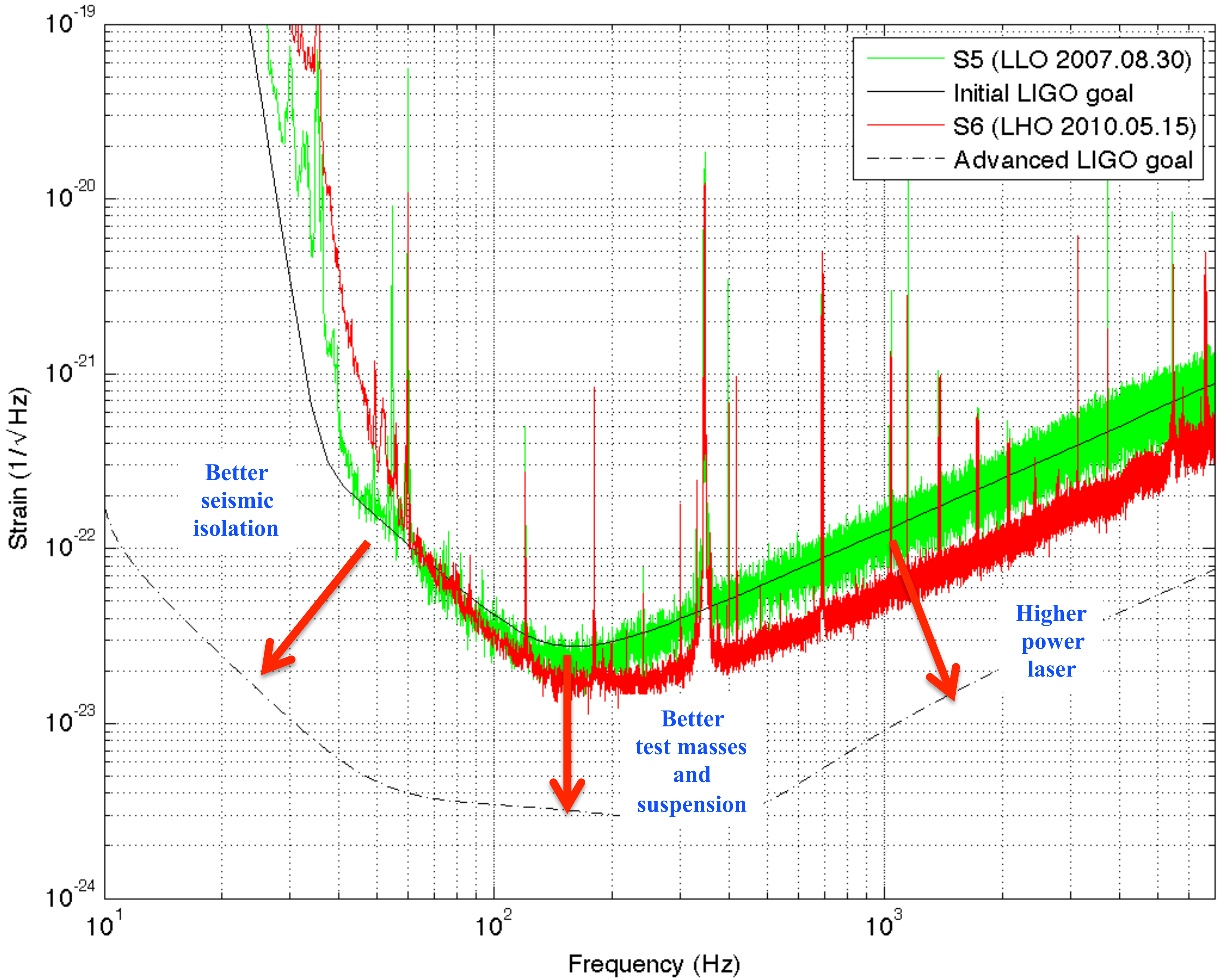
- ★ Fabrication, subsystem assembly, and installation ~ 95% complete
- ★ ***Interferometers operational in late 2014***
- ★ ***First science data expected in 2015***

Advanced LIGO

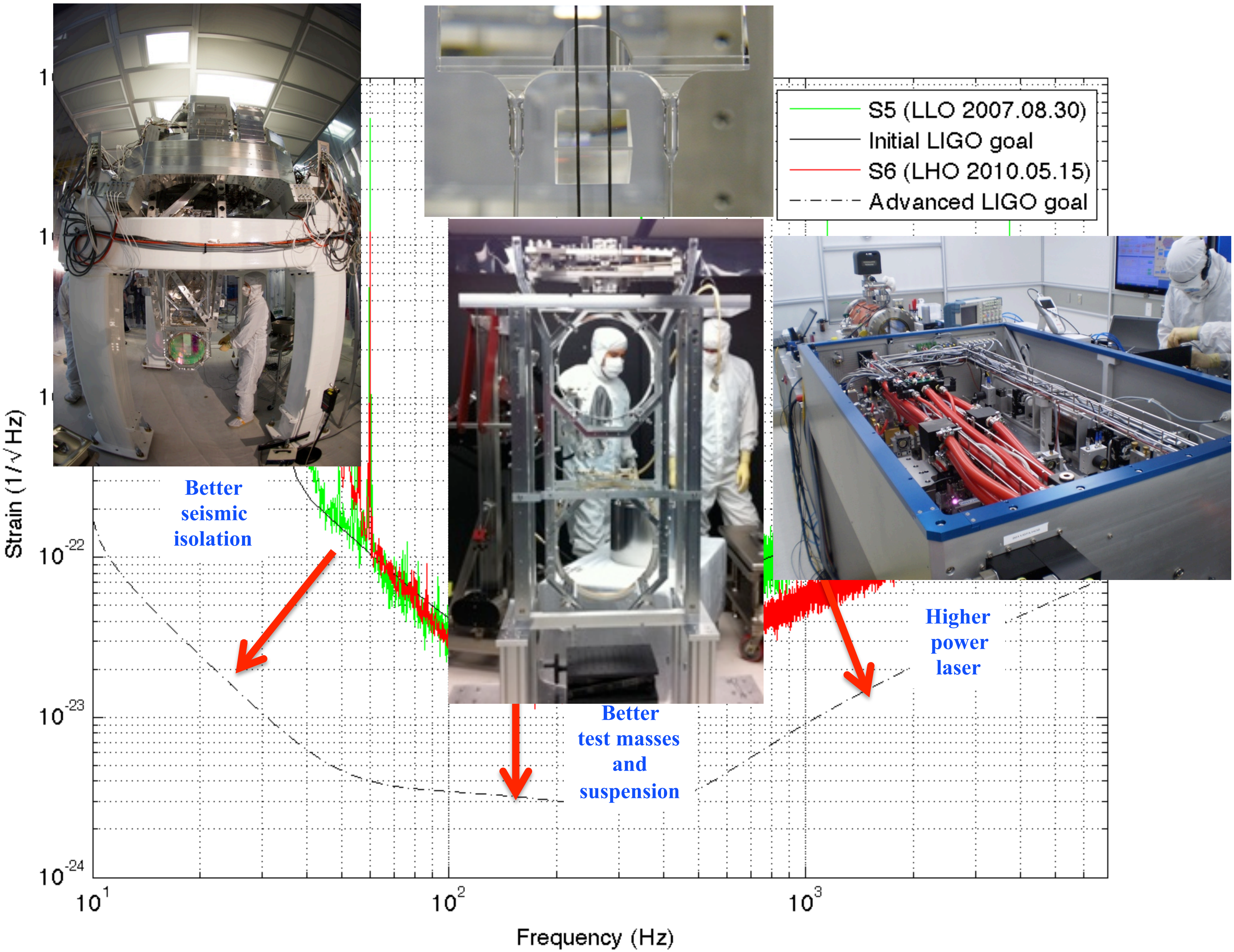
- Power recycled Fabry-Perot Michelson with Signal recycling (increase sensitivity, add tunability)
- Active seismic isolation, quadruple pendulum suspensions (seismic noise wall moves from 40Hz to 10Hz)
- DC readout, Output Mode Cleaner (better use of photons)
- ~20x higher input power (lower shot noise)
- 40 kg test masses (smaller motion due to photon pressure fluctuations)
- Larger test mass surfaces, low-mechanical -loss optical coatings (decreased mid-band thermal noise)
- Fused Silica Suspension (decreased low-frequency thermal noise)



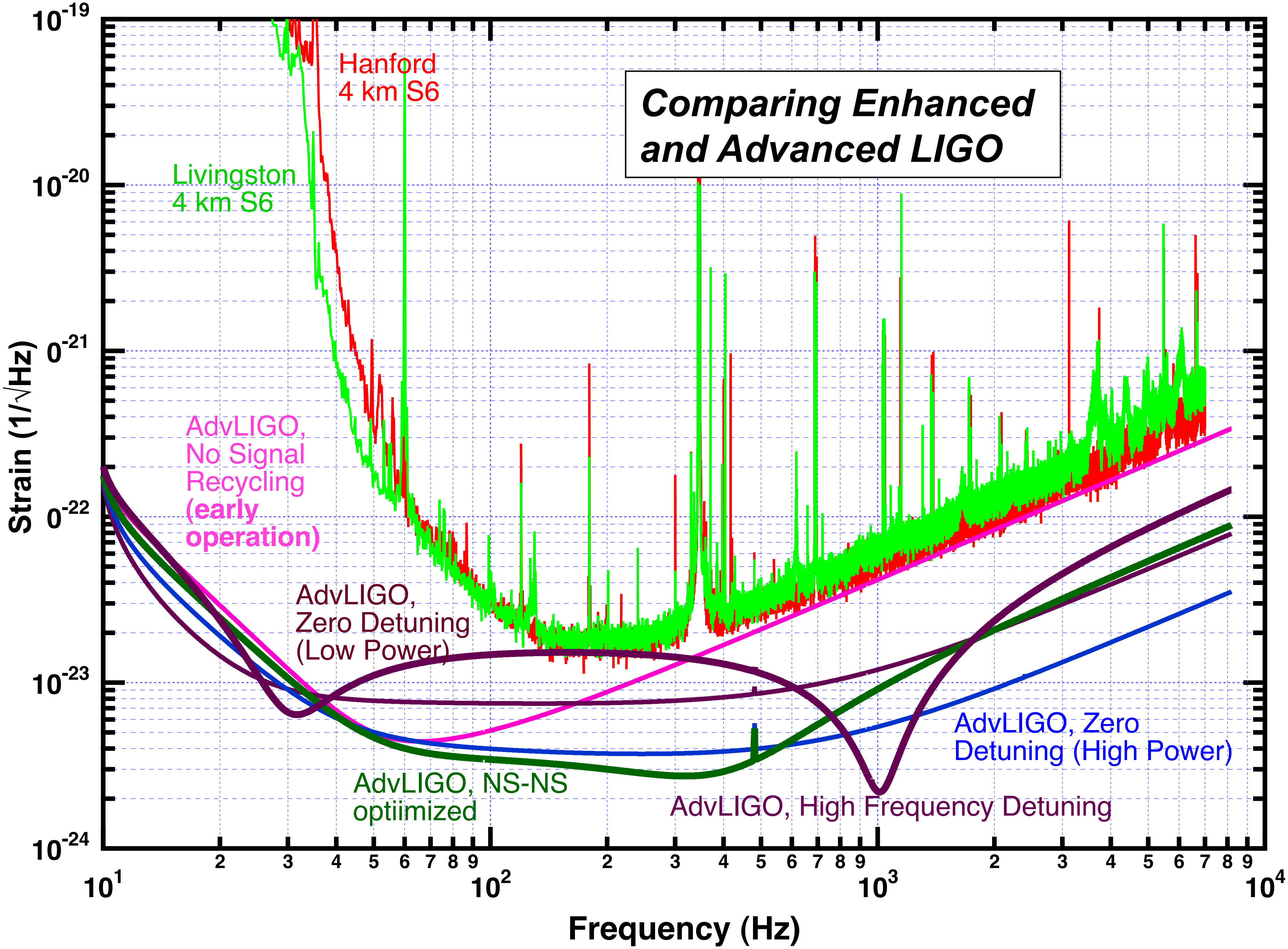

S5 (LLO 2007.08.30)
Initial LIGO goal
S6 (LHO 2010.05.15)
Advanced LIGO goal
Strain (1/√Hz)
Frequency (Hz)
Advanced LIGO goal
Initial LIGO reach ~20Mpc
Advanced LIGO reach ~200Mpc



S5 (LLO 2007.08.30)
Initial LIGO goal
S6 (LHO 2010.05.15)
Advanced LIGO goal
Better seismic isolation
Better test masses and suspension
Higher power laser
Strain (1/√Hz)
Frequency (Hz)
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
10^1
10^2
10^3



S5 (LLO 2007.08.30)
Initial LIGO goal
S6 (LHO 2010.05.15)
Advanced LIGO goal
Better seismic isolation
Better test masses and suspension
Higher power laser
Strain (1/√Hz)
Frequency (Hz)
10^-22
10^-23
10^-24
10^1
10^2
10^3

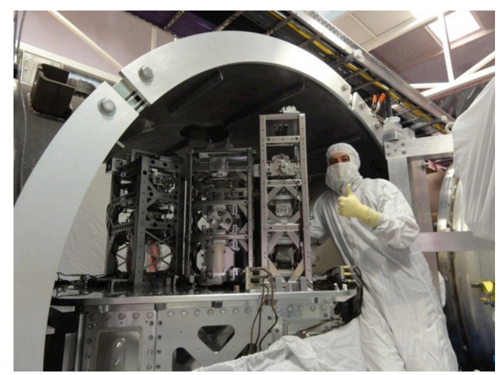

Comparing Enhanced and Advanced LIGO
Hanford 4 km S6
Livingston 4 km S6
AdvLIGO, No Signal Recycling (early operation)
AdvLIGO, Zero Detuning (Low Power)
AdvLIGO, Zero Detuning (High Power)
AdvLIGO, NS-NS optiimized
AdvLIGO, High Frequency Detuning
Strain (1/√Hz)
Frequency (Hz)
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
10^{4}

Phases in installation

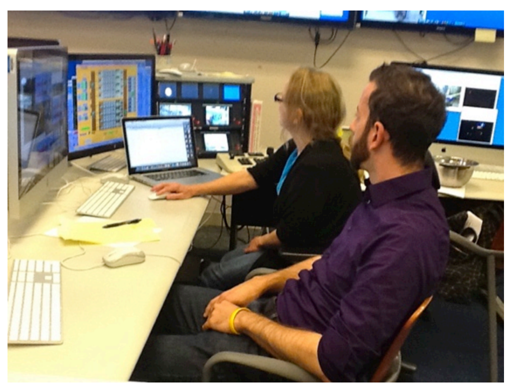
deinstall

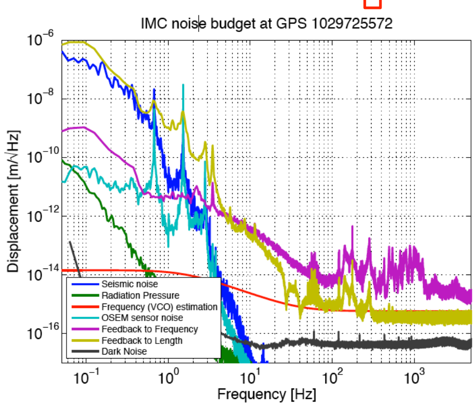
modify vacuum

in-chamber clean



install



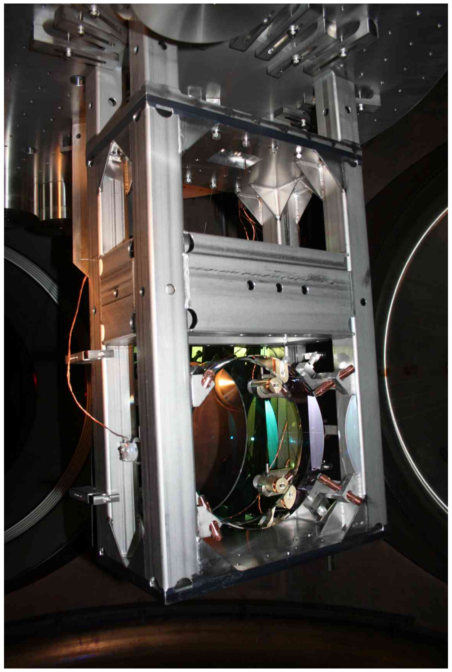


commission

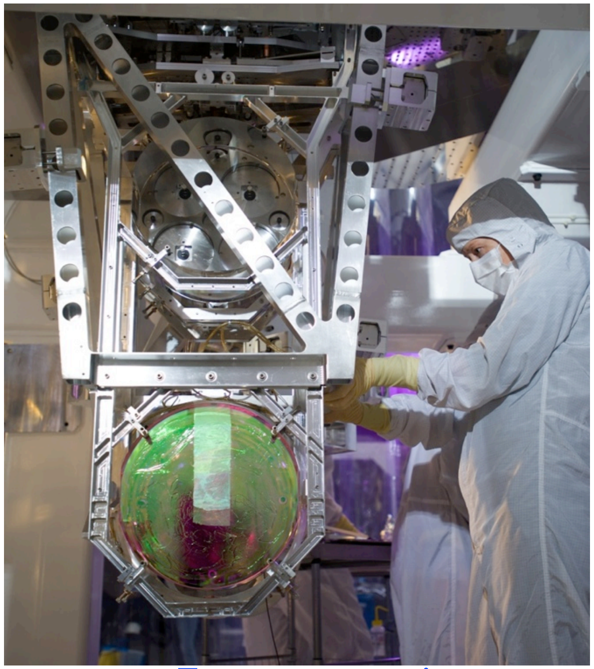
10X more sensitive, >10X harder…

- 14 unique fabricated parts
- 68 fabricated parts total
- 165 total including machined parts and hardware

- 188 unique fabricated parts
- 1569 fabricated parts total
- 3575 total including machined parts and hardware



Test mass suspension
From Initial LIGO

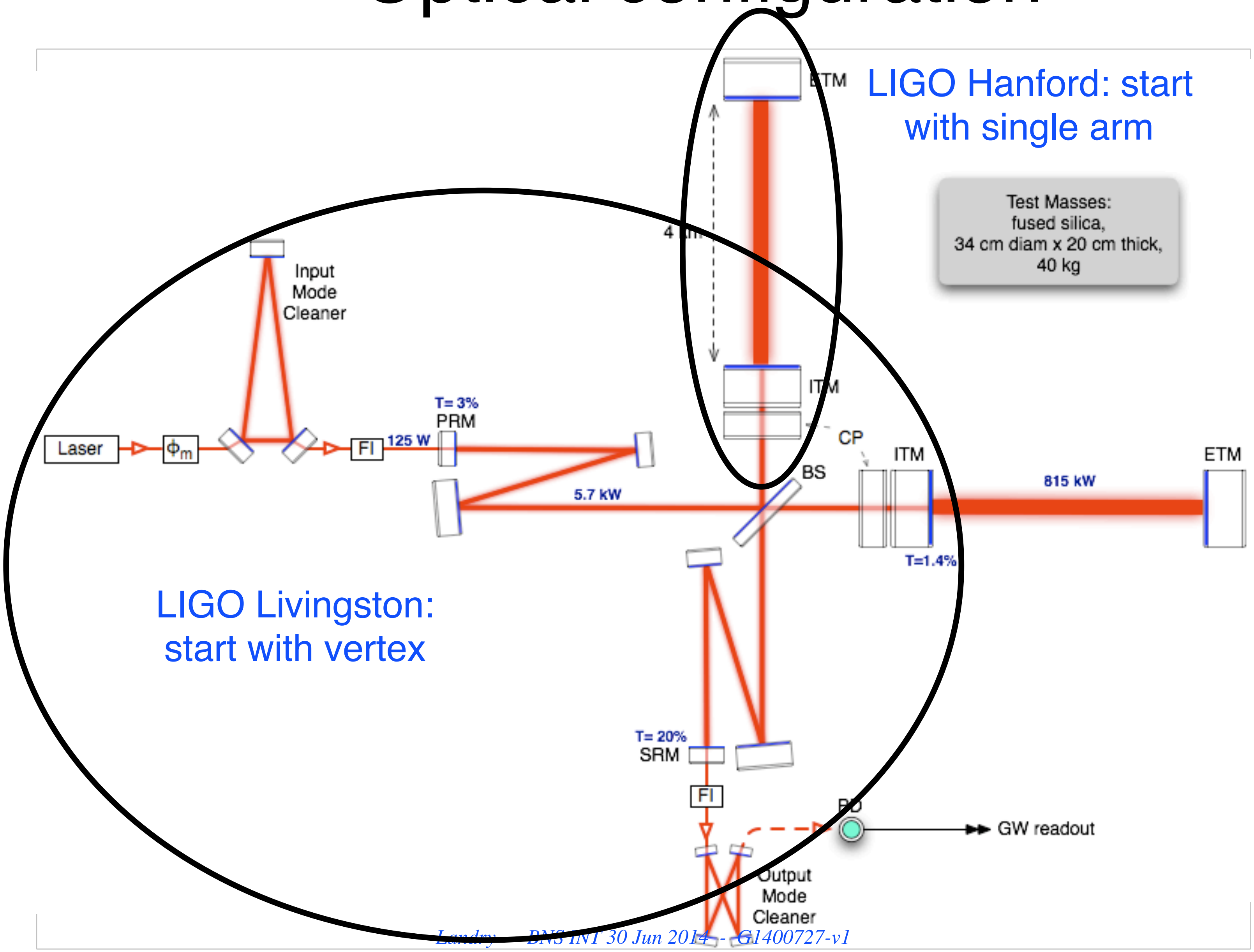


Test mass suspension
From Advanced LIGO

Installation progression

- Advanced LIGO installation start : Oct 20, 2010
- Livingston Observatory was the pathfinder
  - » Natural progression from laser, to input optics, to corner test masses, output and finally, arms
- Hanford Observatory had more complicated path
  - » 4km instrument was frozen for ~6mo, then a squeezed light experiment run for ~1 year
  - » 2km instrument deinstalled
  - » LIGO India evolved
  - » Deinstalled the 4km machine and commenced installation
- Philosophy : get to testing as quickly as possible

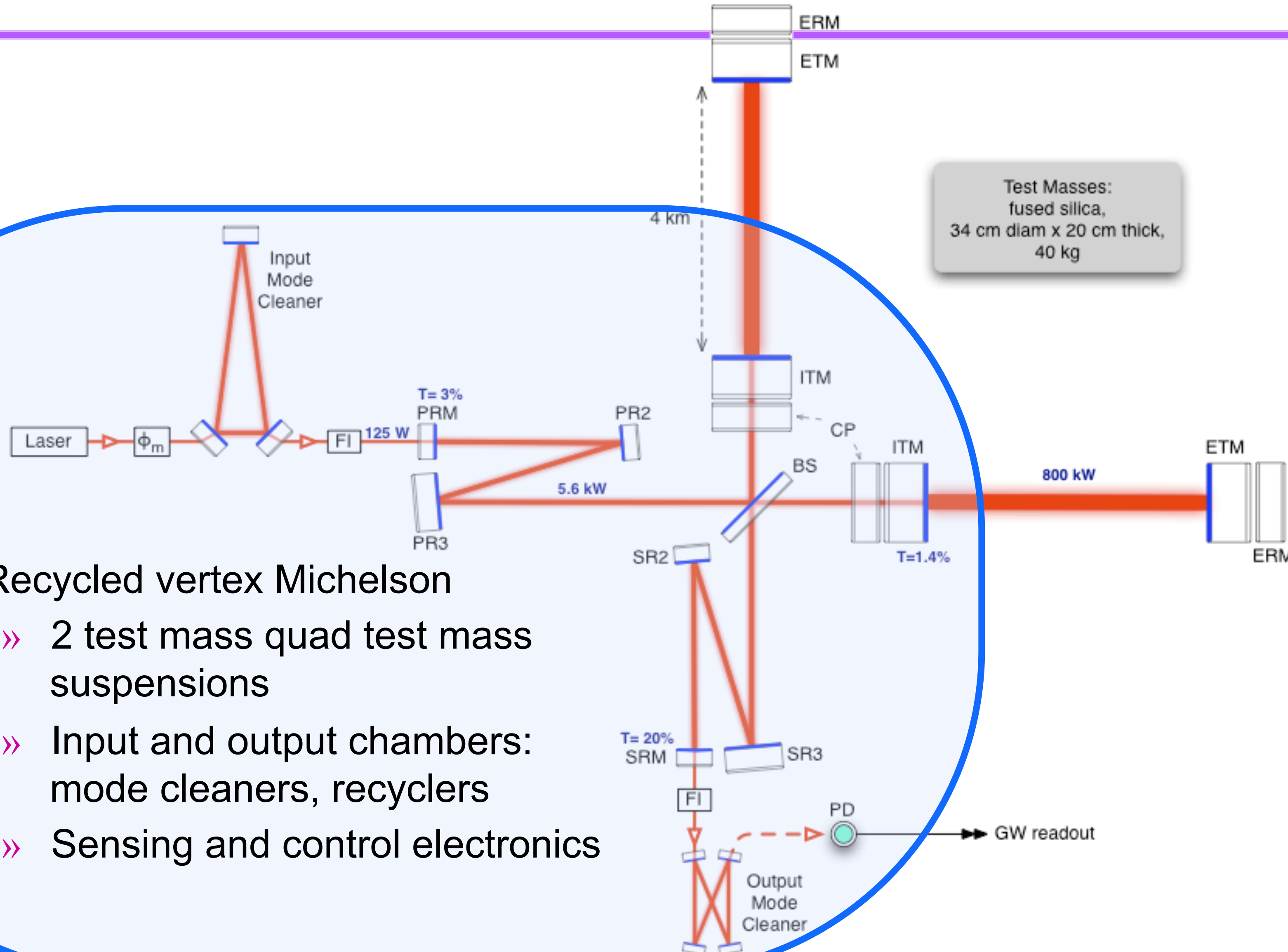
Optical configuration



LIGO Hanford: start with single arm

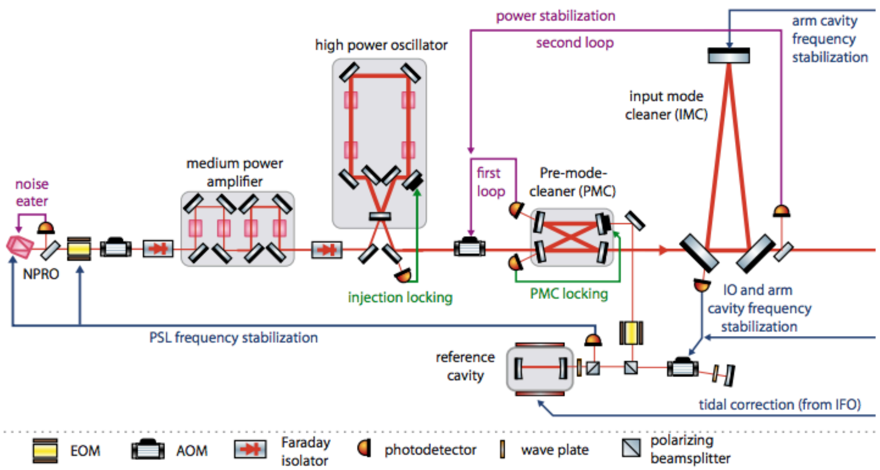
LIGO Livingston: start with vertex

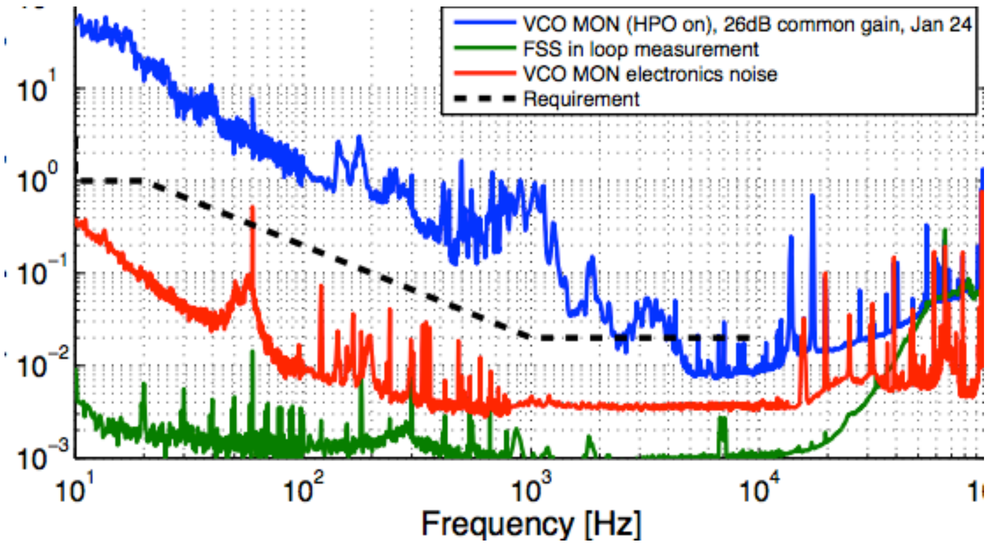
LIGO Livingston Install



- Recycled vertex Michelson
  - 2 test mass quad test mass suspensions
  - Input and output chambers: mode cleaners, recyclers
  - Sensing and control electronics

Pre-stabilized laser

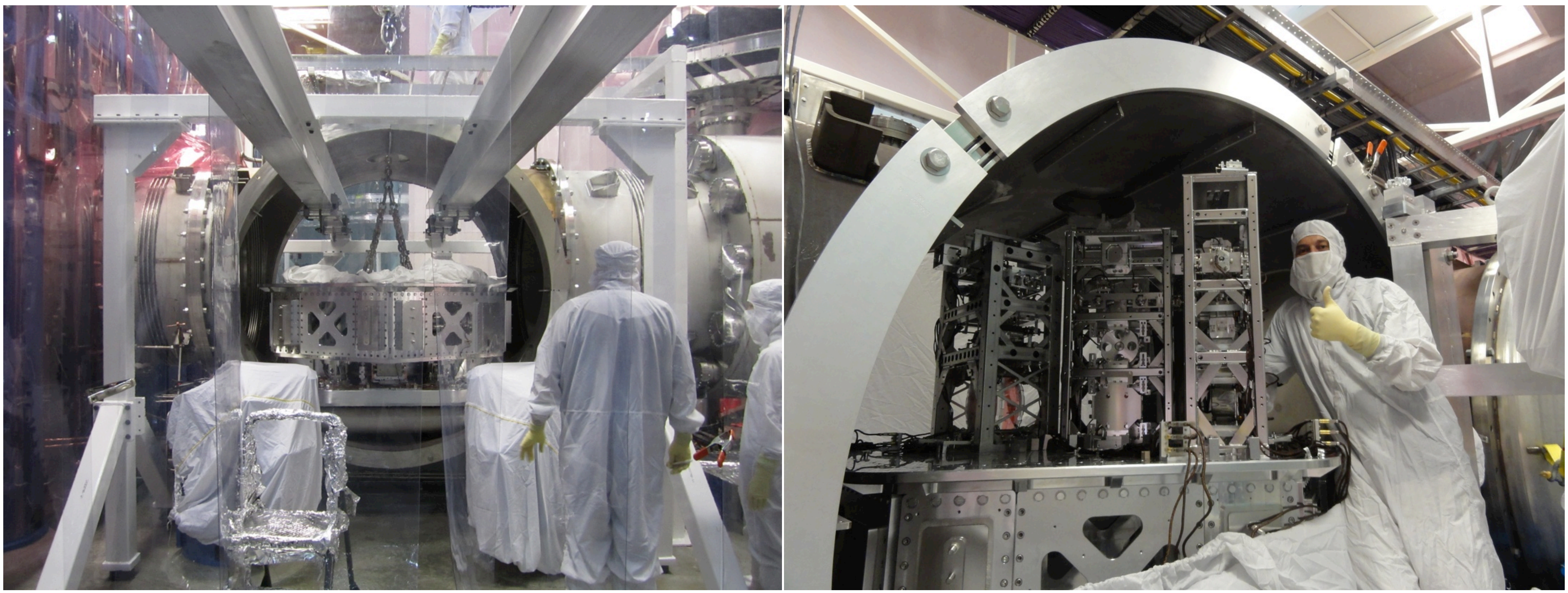




- Frequency noise measured at Livingston
- 3 W input to IMC
- noise between 10 and 100 Hz is already better; expect to meet spec without difficulty

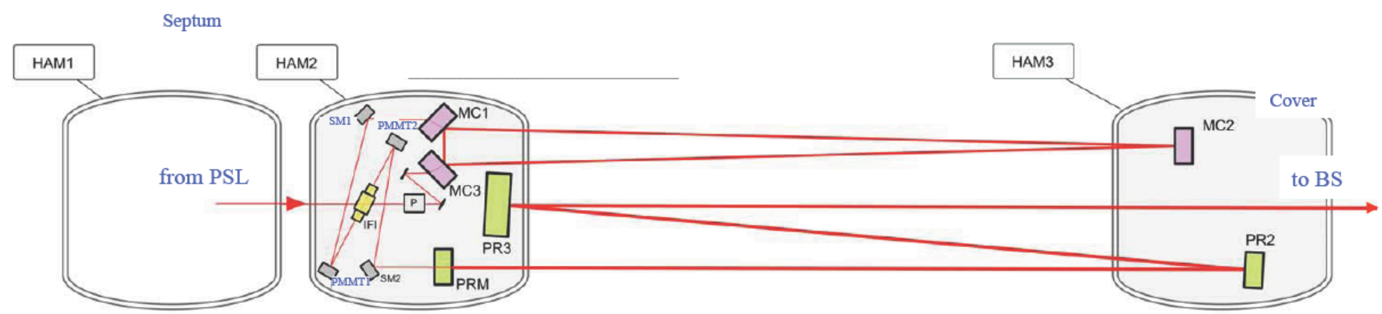
HAM installations

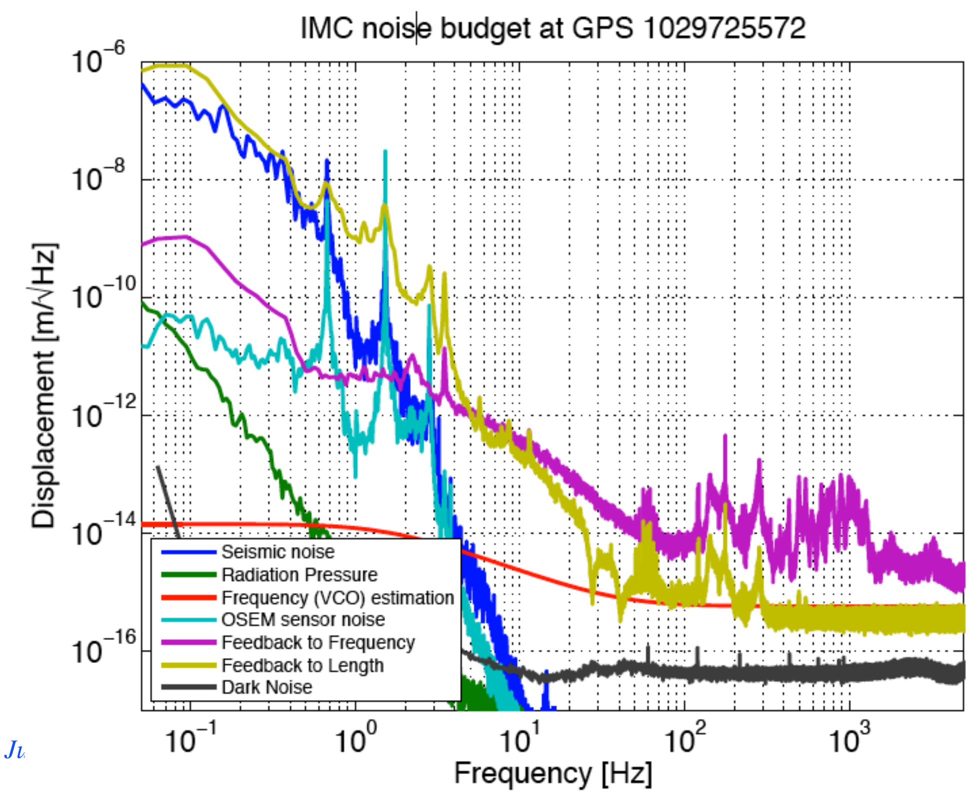
- For LIGO smaller chambers (“HAMs”), we install the seismic isolation platform into the chamber, and then populate it in situ



LLO HAM installation

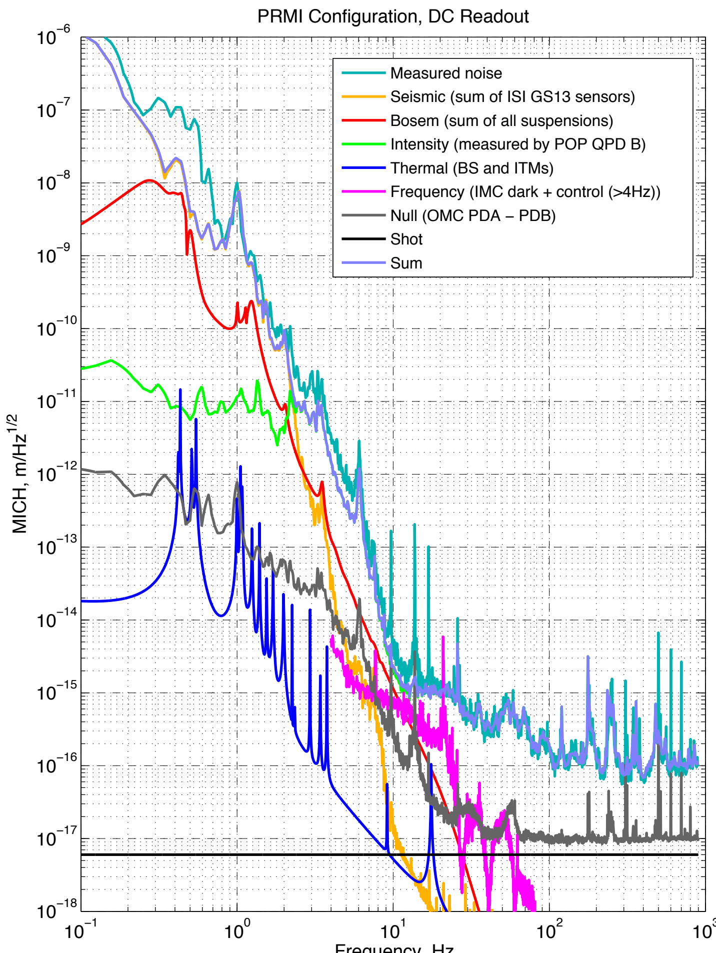
LIGO Livingston input mode cleaner

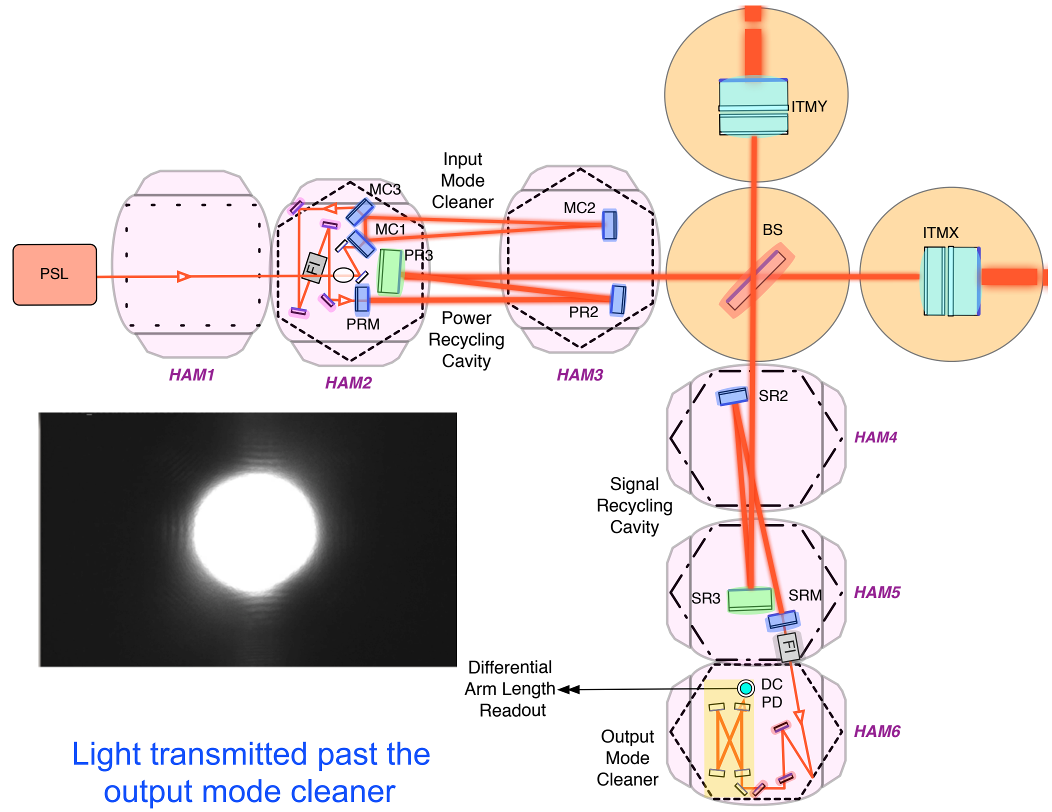




Livingston DRMI

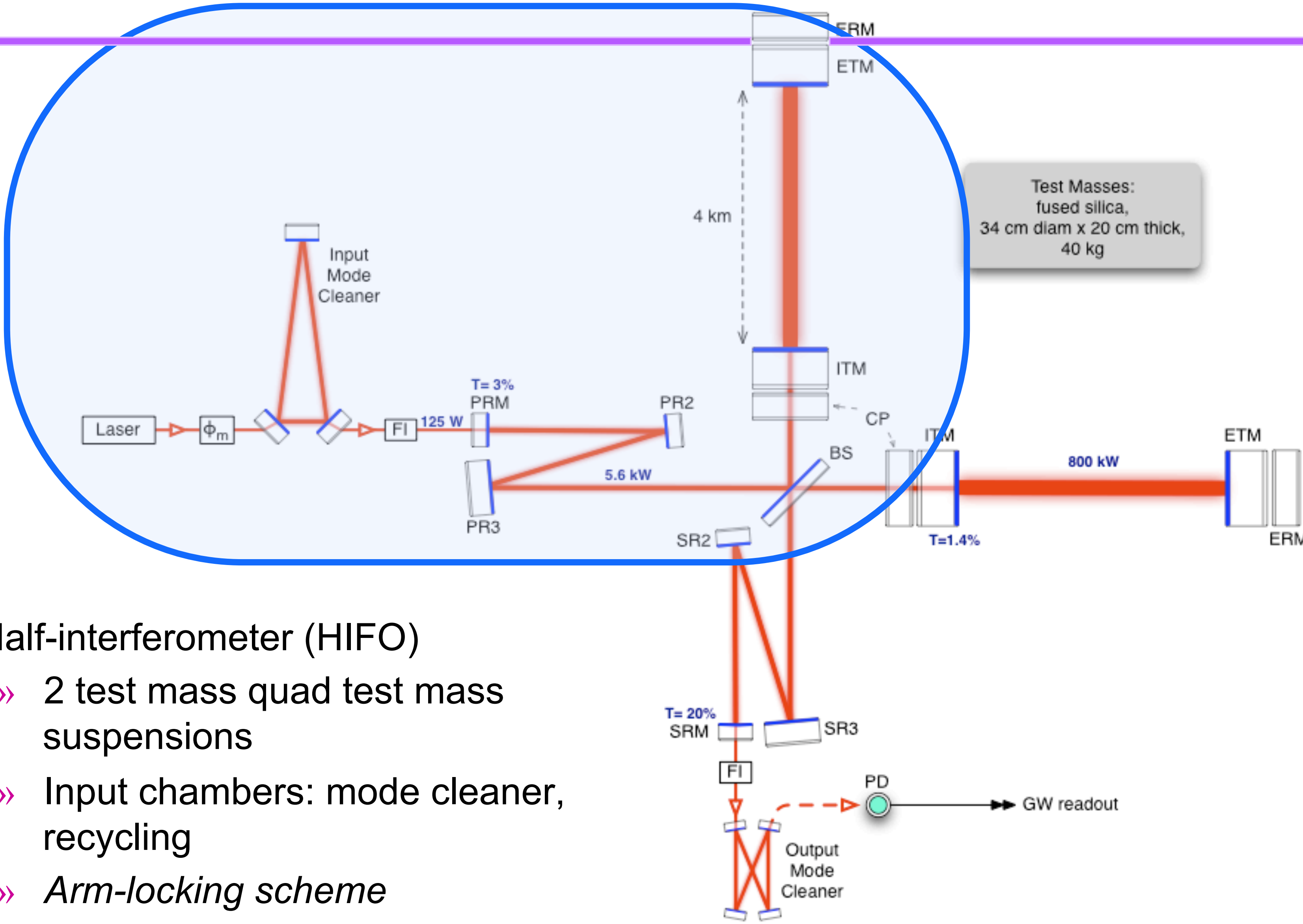
- Dual-recycled Michelson Interferometer (‘***DRMI***’)
  - » Power recycled Michelson locked on DC readout, calibrated





Light transmitted past the output mode cleaner

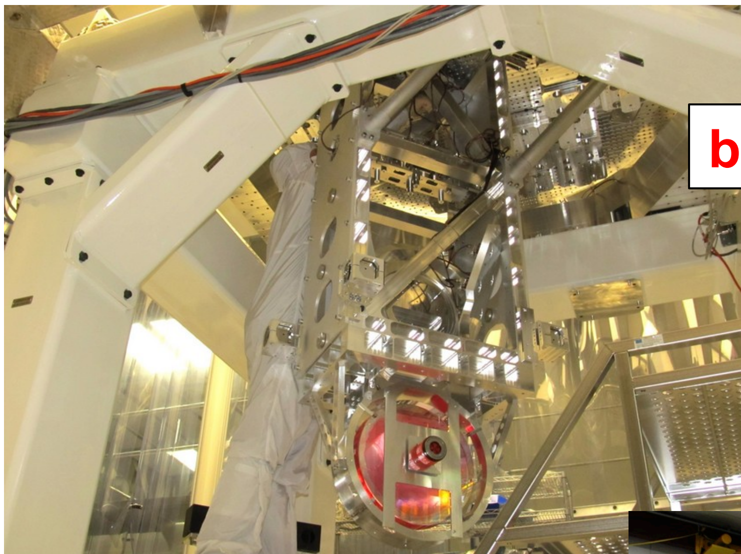
LIGO Hanford Install



- Half-interferometer (HIFO)
  - 2 test mass quad test mass suspensions
  - Input chambers: mode cleaner, recycling
  - *Arm-locking scheme*

BSC installations

- For LIGO large chambers (“BSCs”), we assemble a cartridge in a given hall, and then crane it into the vacuum envelope



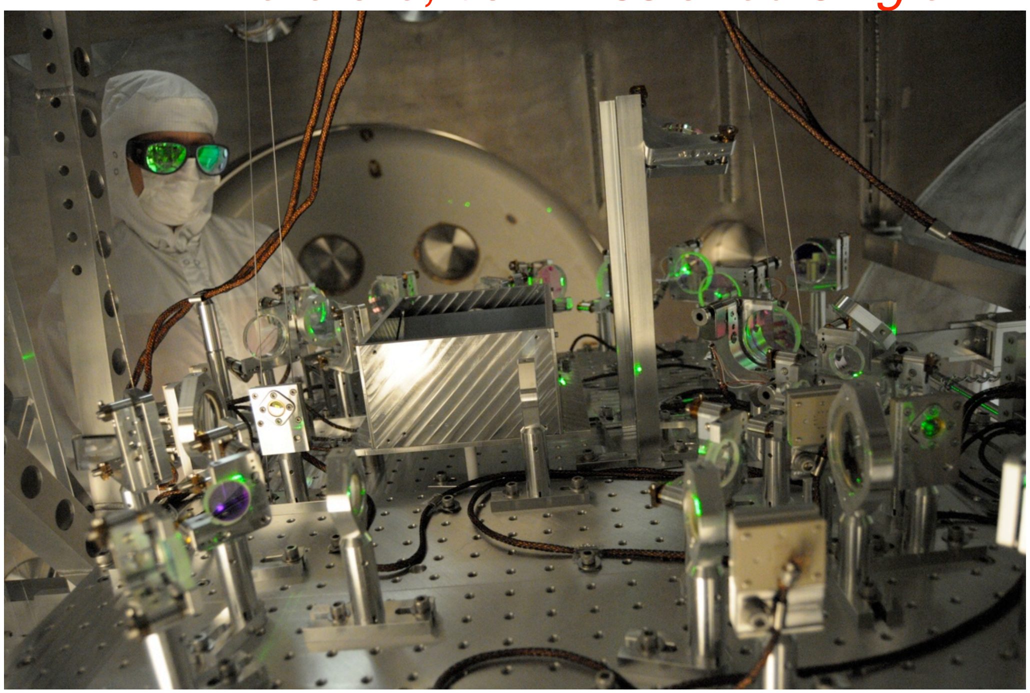
beamsplitter

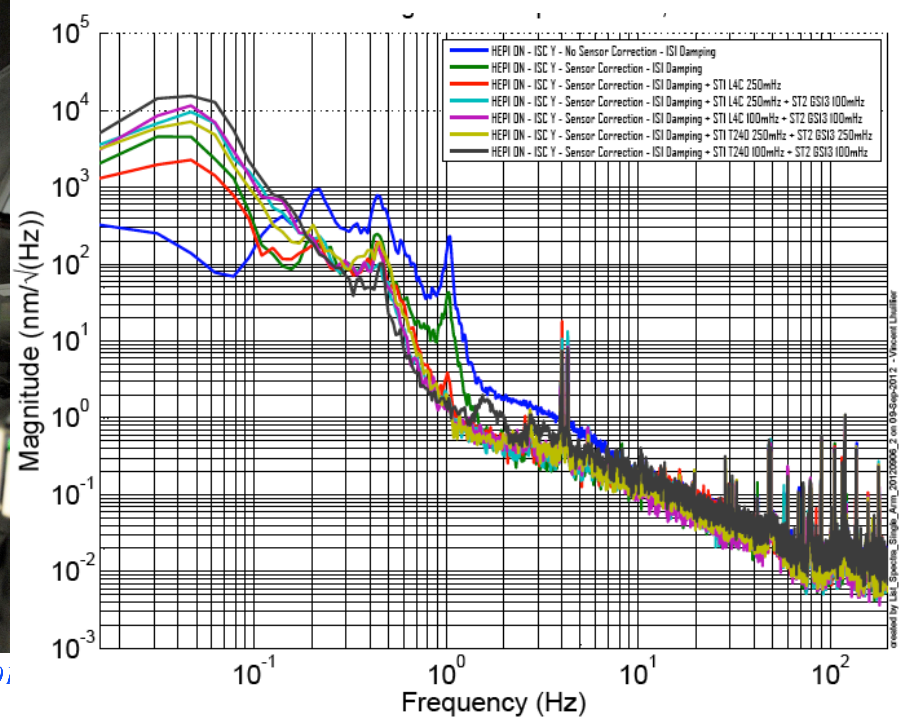
cornerstation Y mirror

End Y mirror

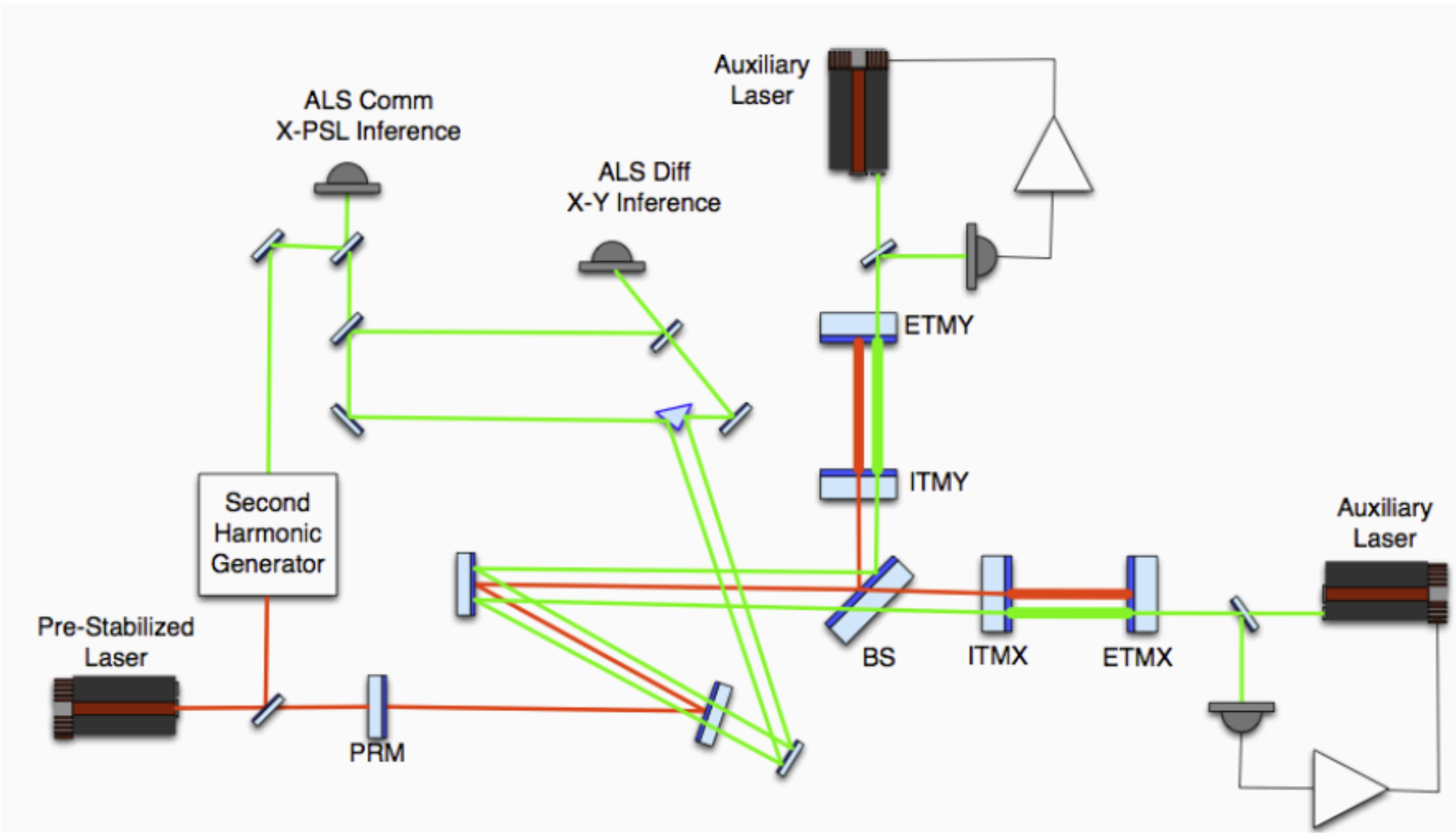
Hanford single-arm integration

- New lock acquisition strategy developed for Advanced LIGO
  - Arm Length Stabilization system controls each arm cavity, putting them off-resonance
  - The 3 vertex lengths are controlled using robust RF signals
  - Arm cavities are brought into resonance in a controlled fashion
- *Therefore, commissioned single 4km arm*



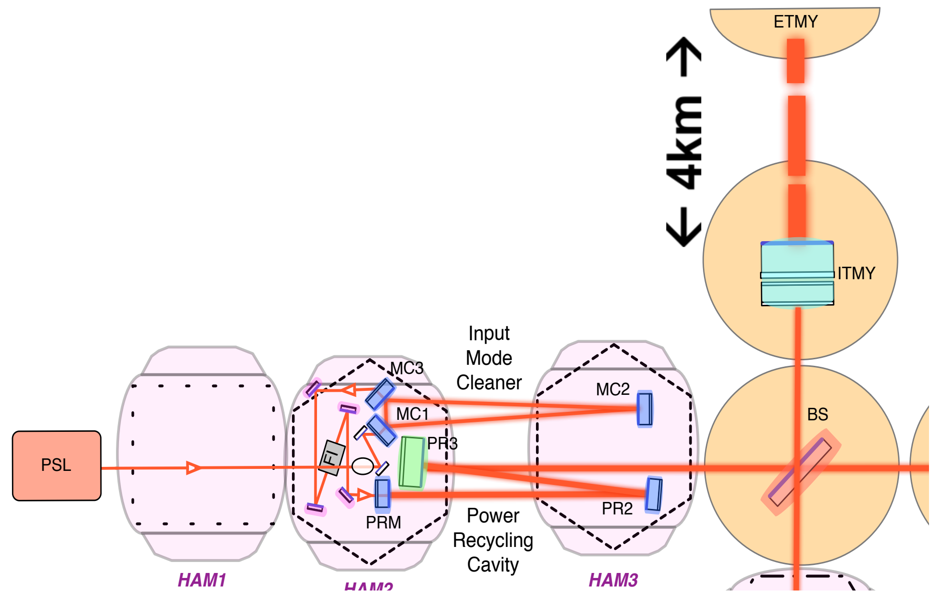


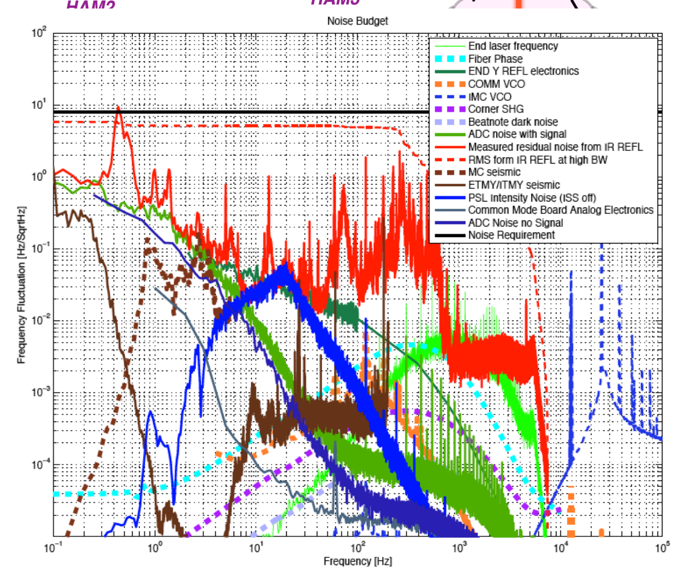
Arm length stabilization



Hanford HIFO-Y

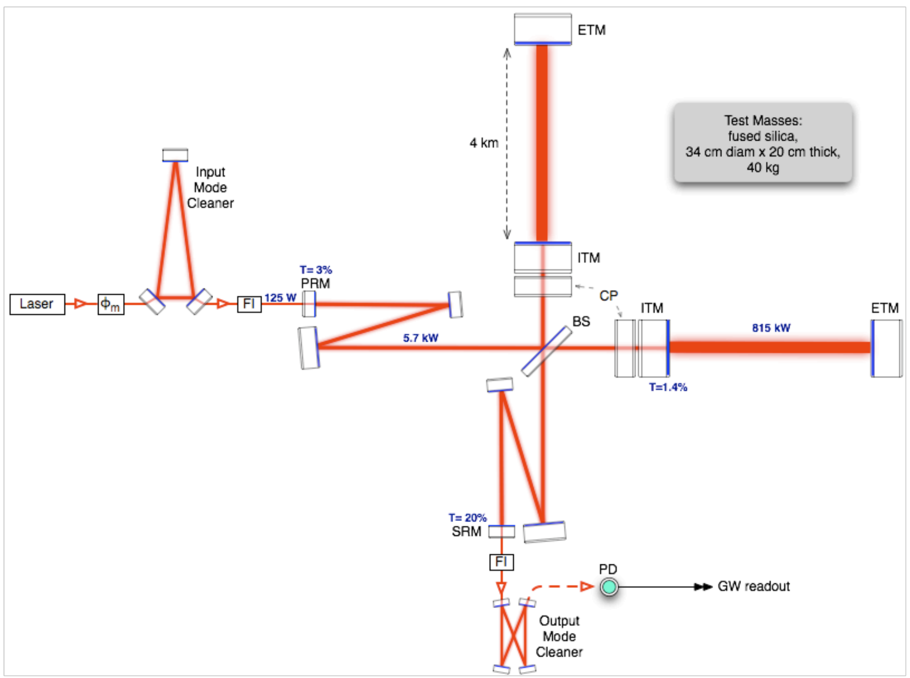
- Half-Interferometer (***'HIFO'***)–Y arm
  - » Green light demonstrated to allow a continuous controlled positioning of cavity
  - » Fluctuations of the HIFO-Y length ~5 Hz RMS (meets noise requirement of 8Hz)
  - » May require acoustic mitigation (in-air periscopes in corner and table motion) and modified suspension control filters for known mechanical modes



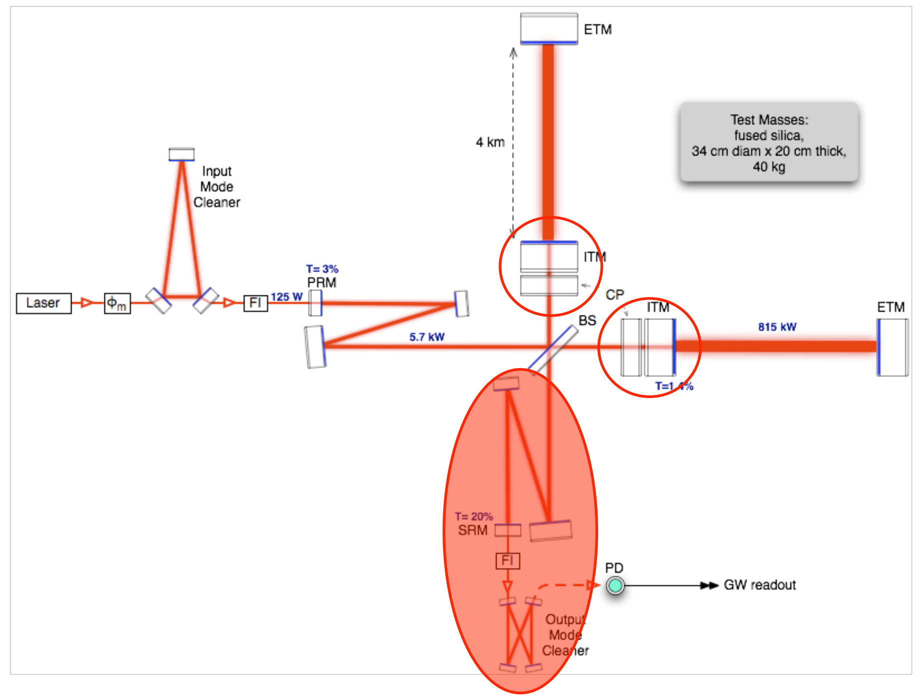


What's left to align? Everything is in the vacuum envelope*

LIGO Livingston

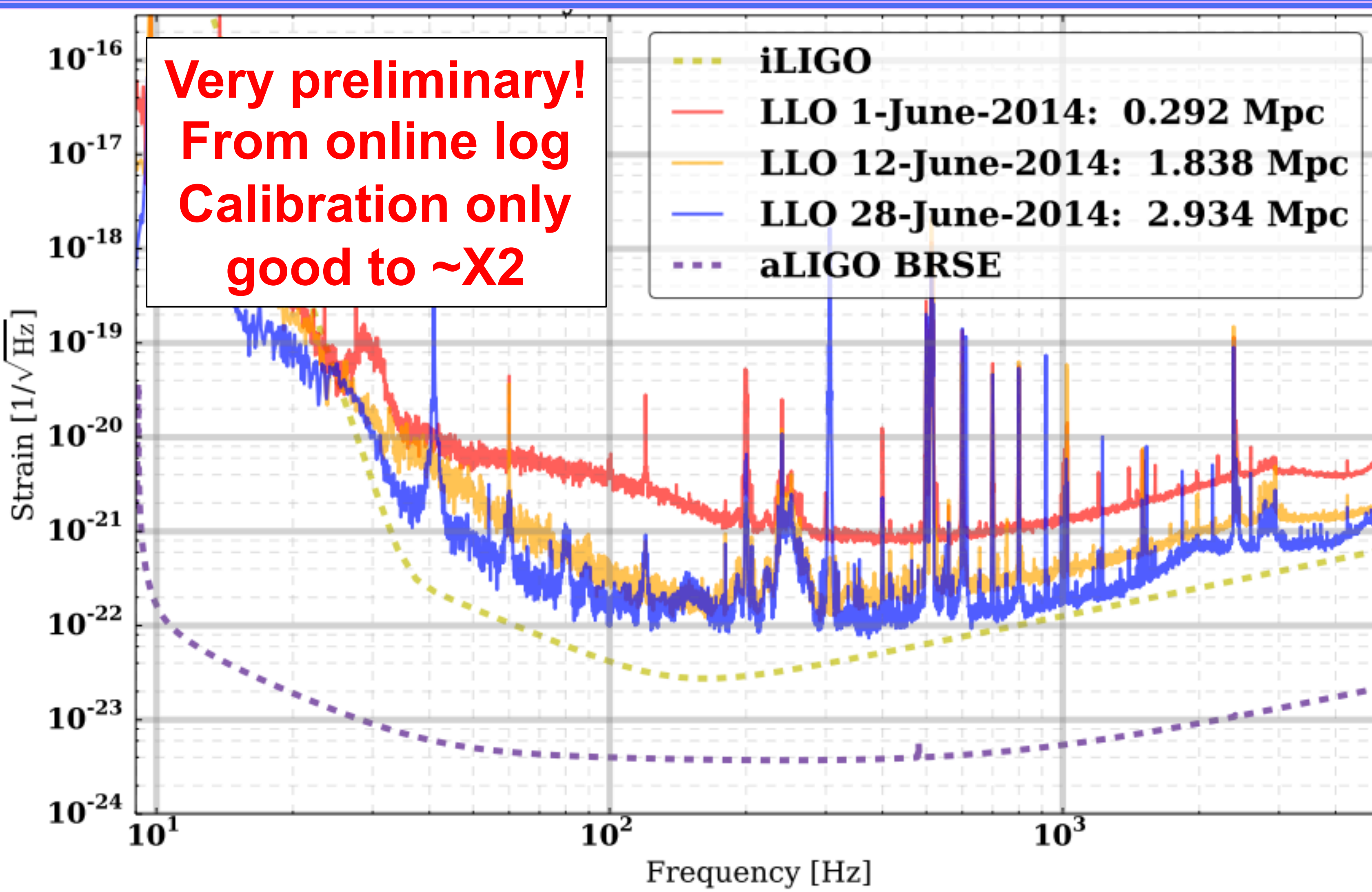


LIGO Hanford

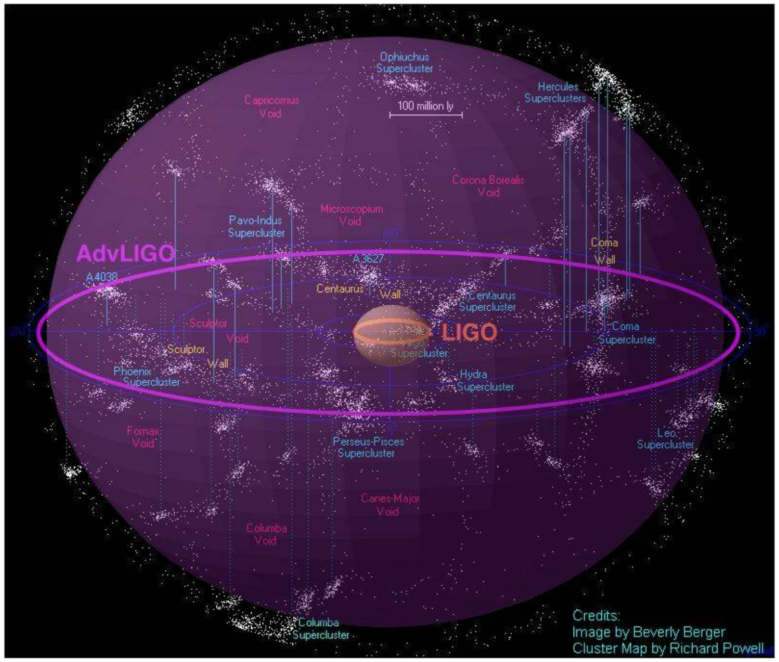


* Almost.

Full locking at Livingston



Science



Binary neutron stars

- Initial LIGO reach: 15Mpc; rate ~ 1/50yrs
- Advanced LIGO ~ 200Mpc
- 'Realistic' rate ~ 40 events/yr

Table 5. Detection rates for compact binary coalescence sources.

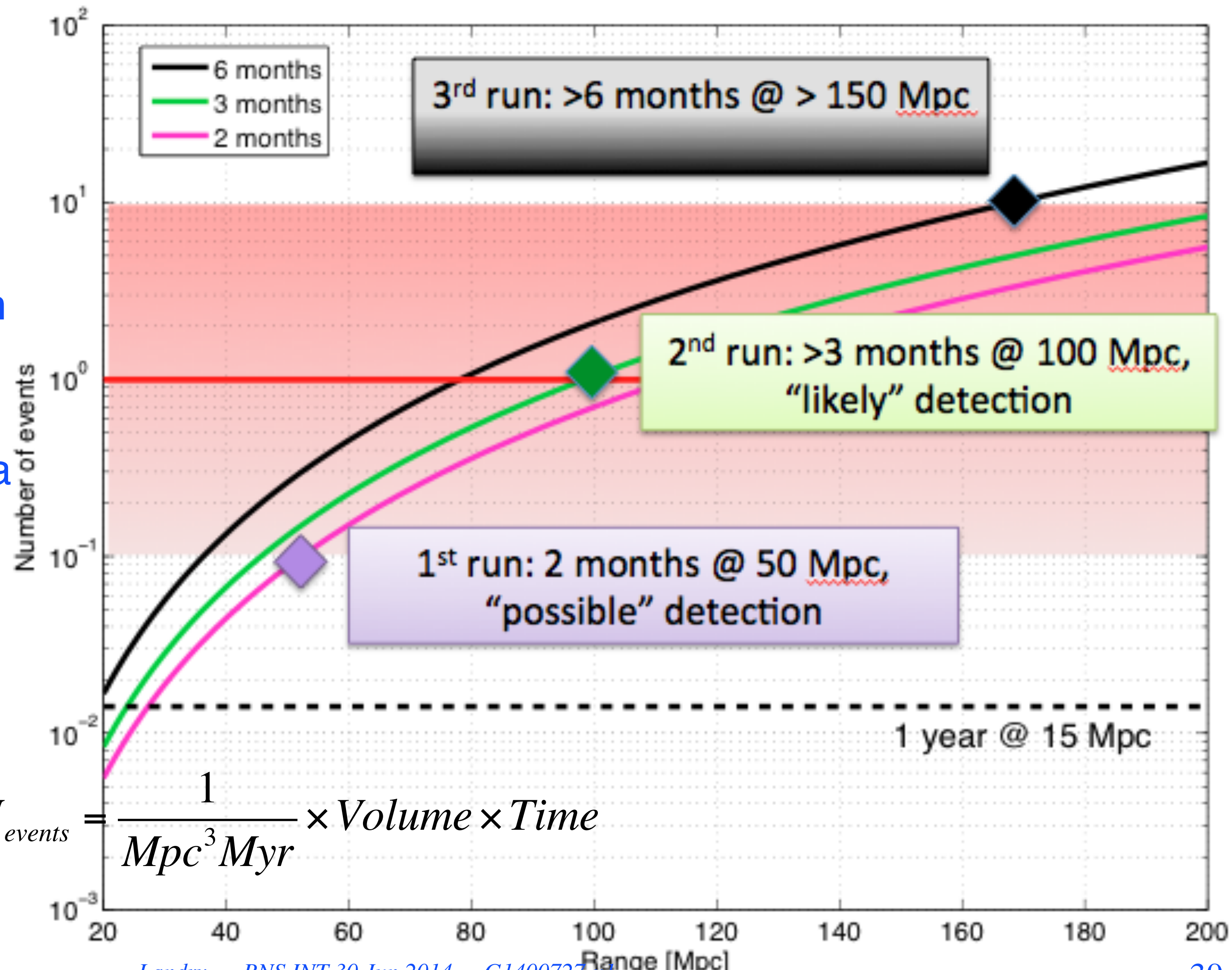
IFO	Source[a]	$\dot{N}_{\rm low}$ yr^{-1}	$\dot{N}_{\rm re}$ yr^{-1}	$\dot{N}_{\rm high}$ yr^{-1}	$\dot{N}_{\rm max}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
Initial	BH–BH	2×10^{-4}	0.007	0.5	
	IMRI into IMBH			<0.001[b]	0.01[c]
	IMBH-IMBH			10^{-4}[d]	10^{-3}[e]
	NS–NS	0.4	40	400	1000
	NS–BH	0.2	10	300	
Advanced	BH–BH	0.4	20	1000	
	IMRI into IMBH			10[b]	300[c]
	IMBH-IMBH			0.1[d]	1[e]

Rates paper: Class. Quant. Grav, 27 (2010) 173001

Current guess for sensitivity evolution, observation

- Vertical scale is the number of binary inspirals detected
- Rates based on population synthesis, realistic but uncertain
- LIGO Scientific Collaboration (LSC) preparing for the data analysis challenge
- Close collaboration with Virgo
- Early detection looks feasible

- arXiv:1304.0670, arXiv:1003.2480



$$N_{events} = \frac{1}{Mpc^3 Myr} \times Volume \times Time$$

Summary

- Advanced LIGO installation is drawing to a close, and rapid progress is being made towards 2hr lock
- We expect to make first science run with the second generation detectors in 2015 and 2016, runs which may produce detections
- We will press onward with sensitivity improvements to design sensitivity
- We expect gravitational waves will be detected in the coming few years

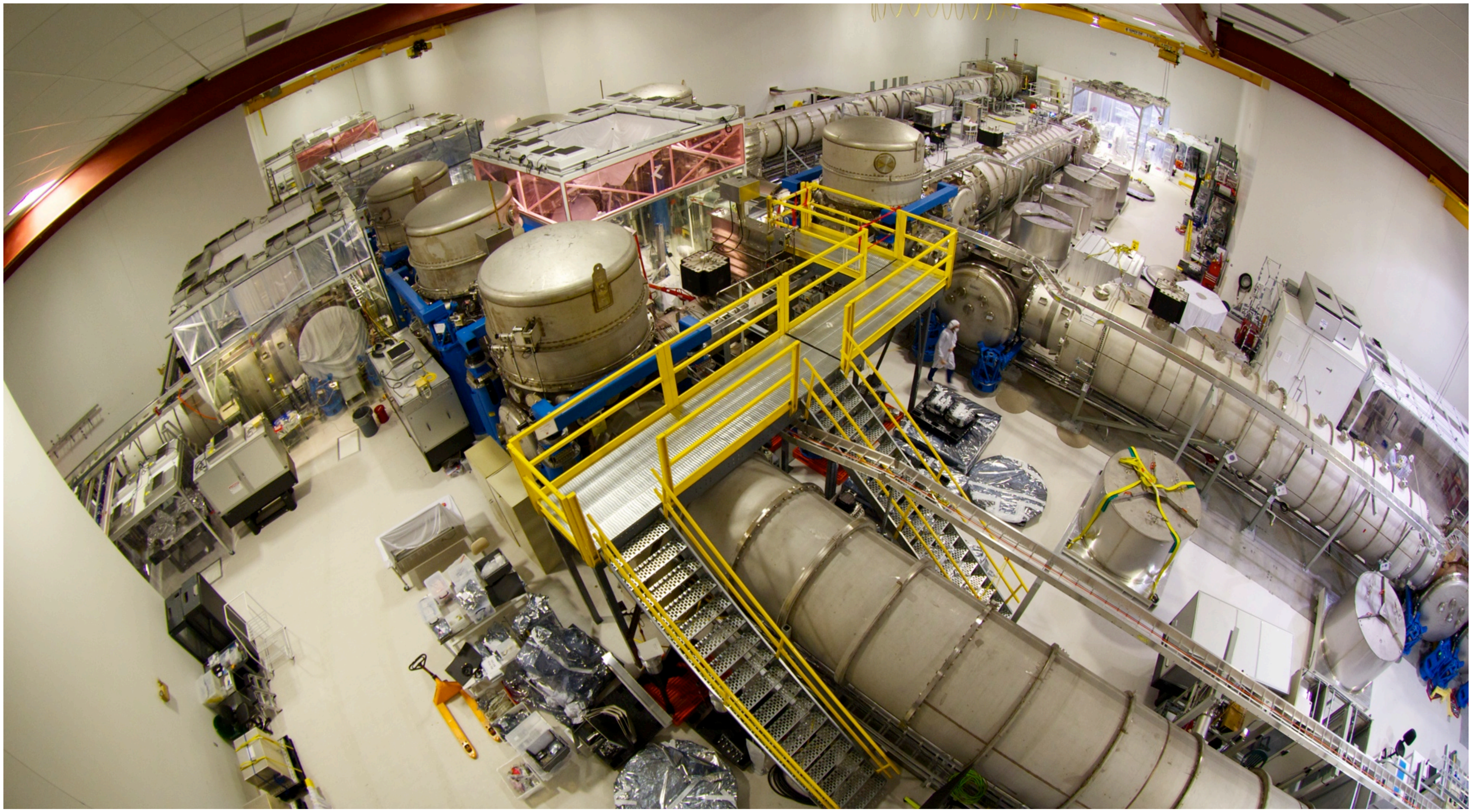
Light at the end of a tunnel

Tours of LIGO Hanford Observatory

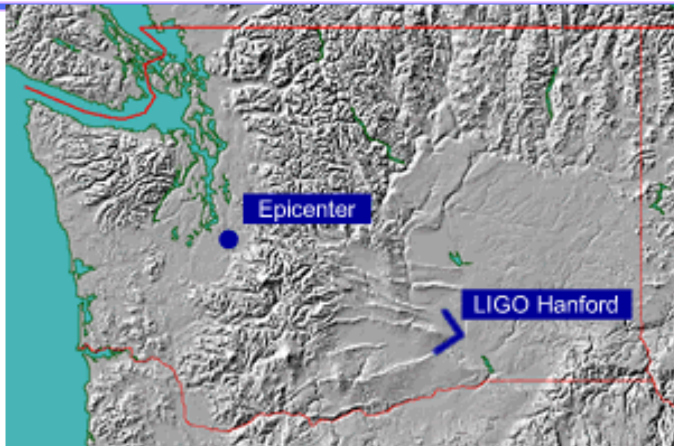
Saturday July 12^{th}
Saturday July 26^{th}

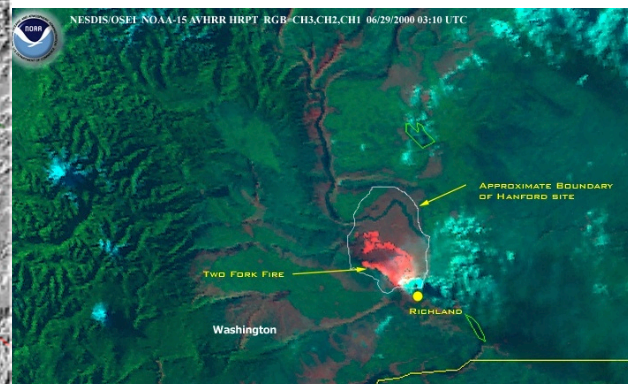
michael.landry@ligo.org

Some things you'll see



Some things I hope you won't see…





How many more miles?

About 320km east of Seattle, or about a 3 hour drive