The Status of Enhanced LIGO.

Aidan Brooks. December 2008

AIP Congress 2008, Adelaide, Australia

LIGO-G080621-00-I

Outline

- Gravitational Waves
  - » Potential sources
  - » Initial LIGO interferometer
- Enhanced LIGO upgrades
  - » Increased laser power
  - » Output mode cleaner
  - » DC readout
  - » Auxiliary upgrades
- Astrophysical estimates

Gravitational Wave Sources

What sources are we trying to detect?

- CW (pulsars) [1]
- CBC – (Compact Binary Coalescences)
- Stochastic background (Big Bang remnant)
- Bursts (GRBs, supernovae)

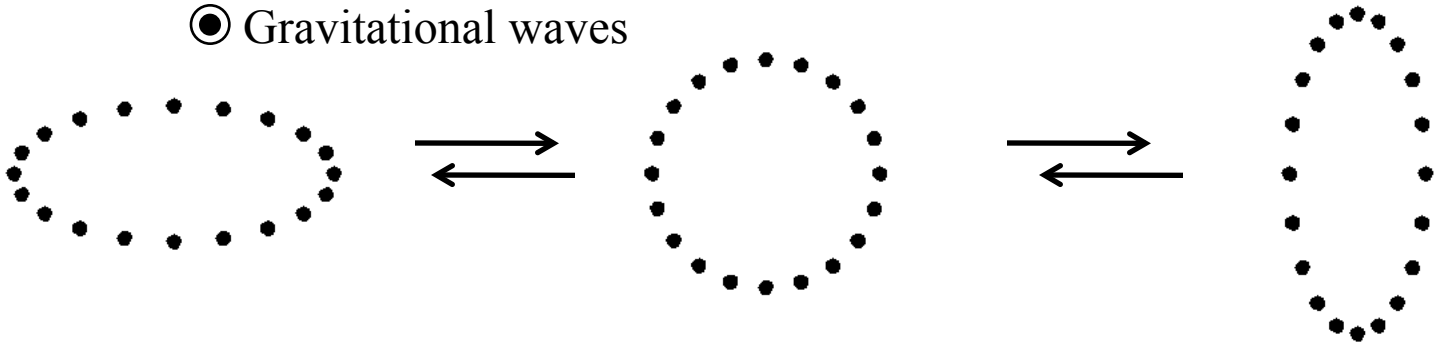
Observable by the strain, h(t), produced.

[1] Ap. J Lett, **683**, 1, ppL45–L49 (2008)

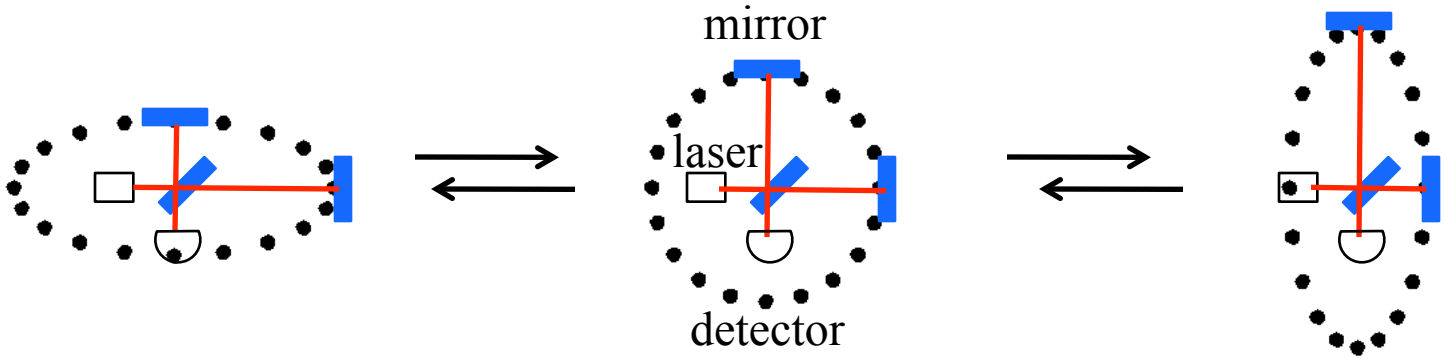
Ripples in Space-time

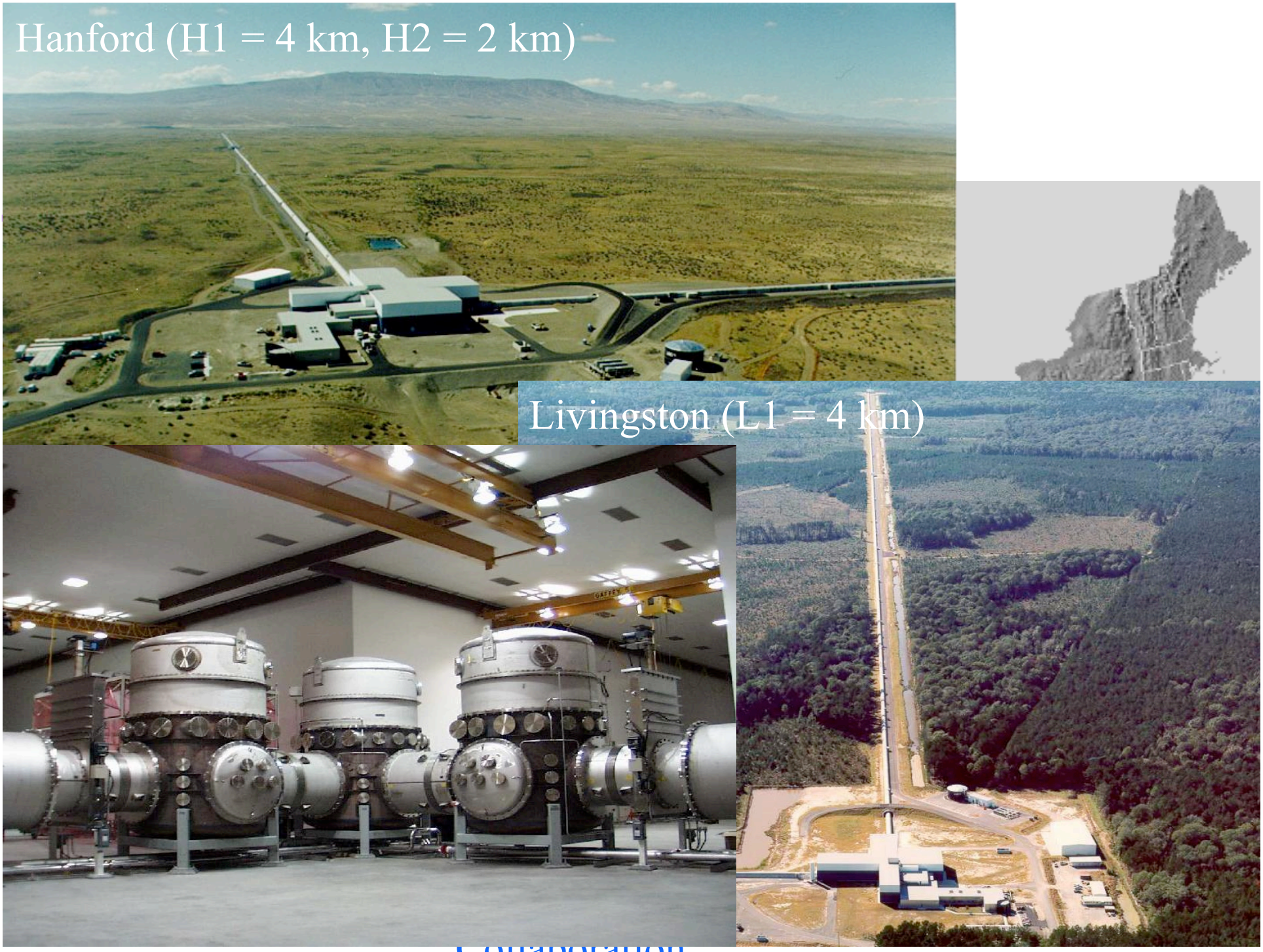
Physically, *h* is a *strain*: $\delta L/L$

LIGO measures $h < 10^{-22}$
➔ $\delta L = 10^{-18}$ m !



A Michelson type interferometer is the ideal tool to measure GWs.

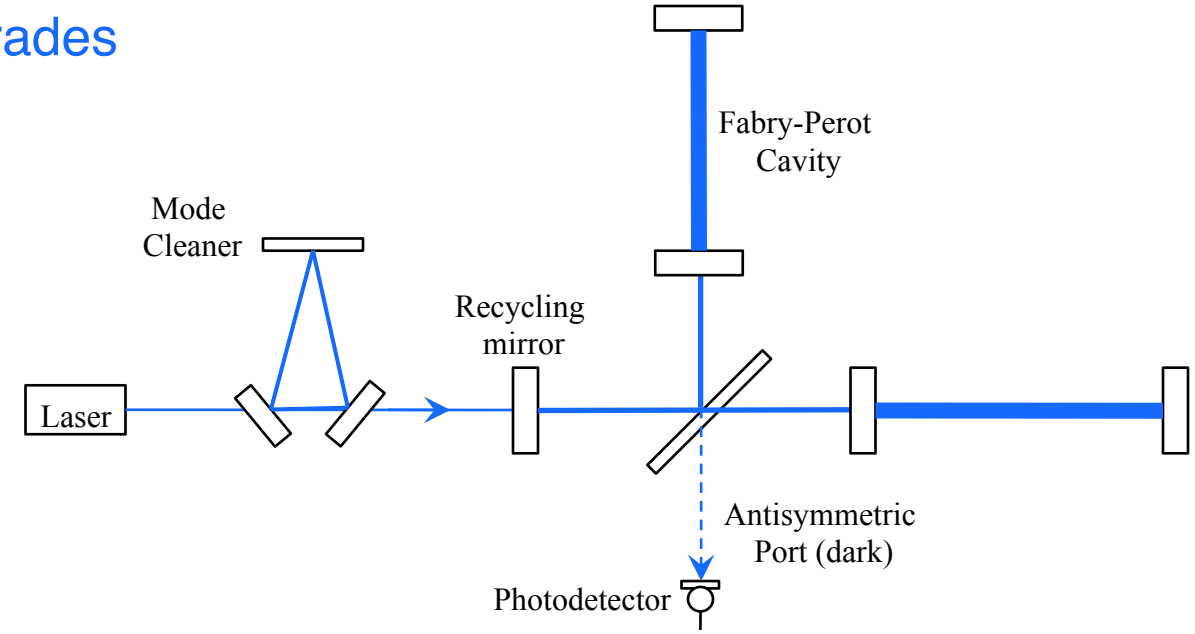




Collaboration

LIGO Interferometry

- Initial LIGO: late 90's to 2007
- RF readout - heterodyne
- Advanced LIGO
  - » Major upgrades
  - » 2011-



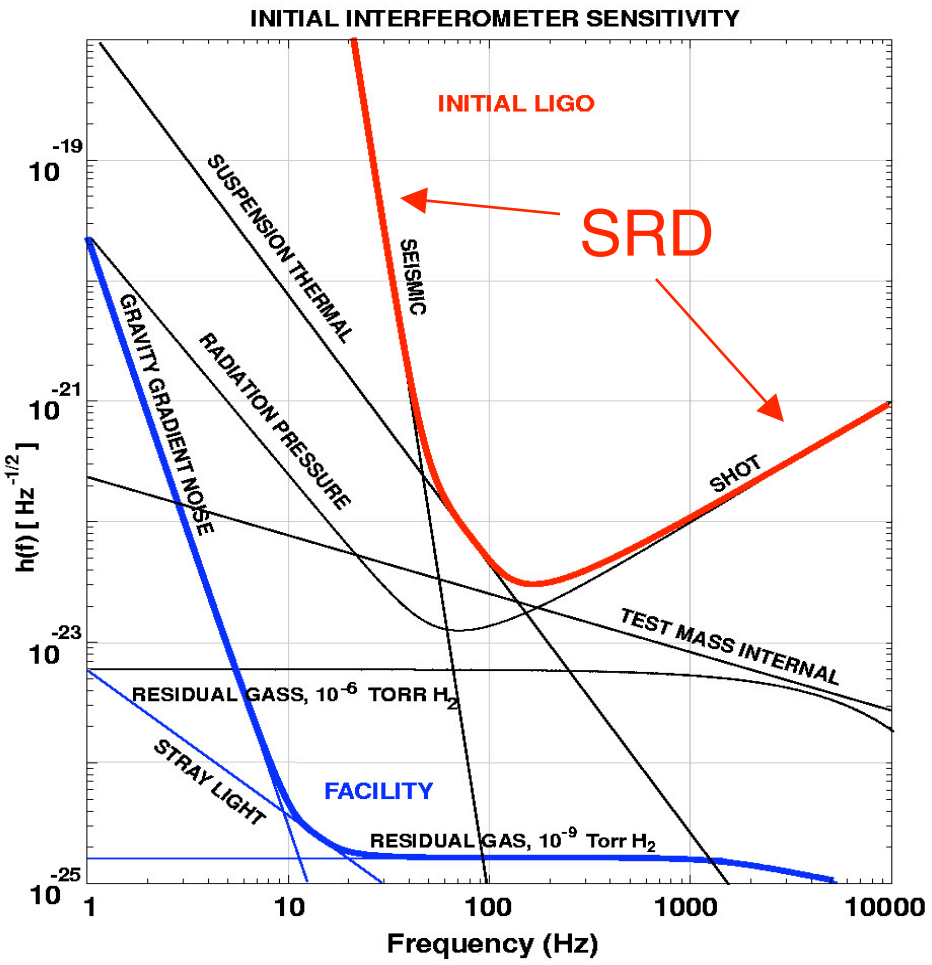
Strain Sensitivity Curve

Scientific Requirement

Features

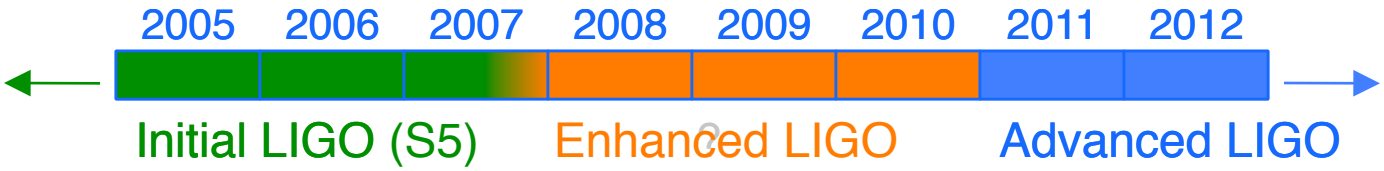
- High frequency
  - » Shot-noise limited
- Low frequency
  - » Limited by seismic noise
- Intermediate
  - » Mostly suspension thermal
  - » Actually more complicated than shown here

The Initial LIGO goal ✓



Why Enhanced LIGO?

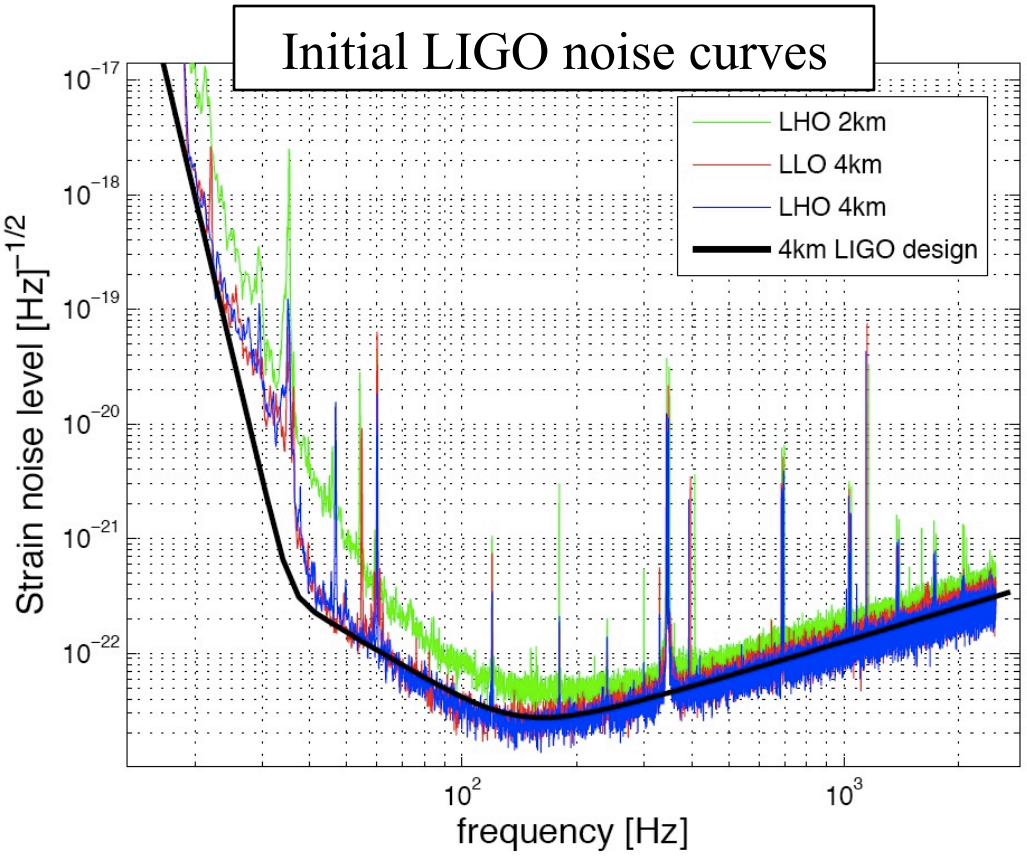
- Timeframe



- Philosophy
  - » Last chance to do GWI until ~2015
  - » Modest improvement to sensitivity
  - » Risk mitigation for AdvLIGO

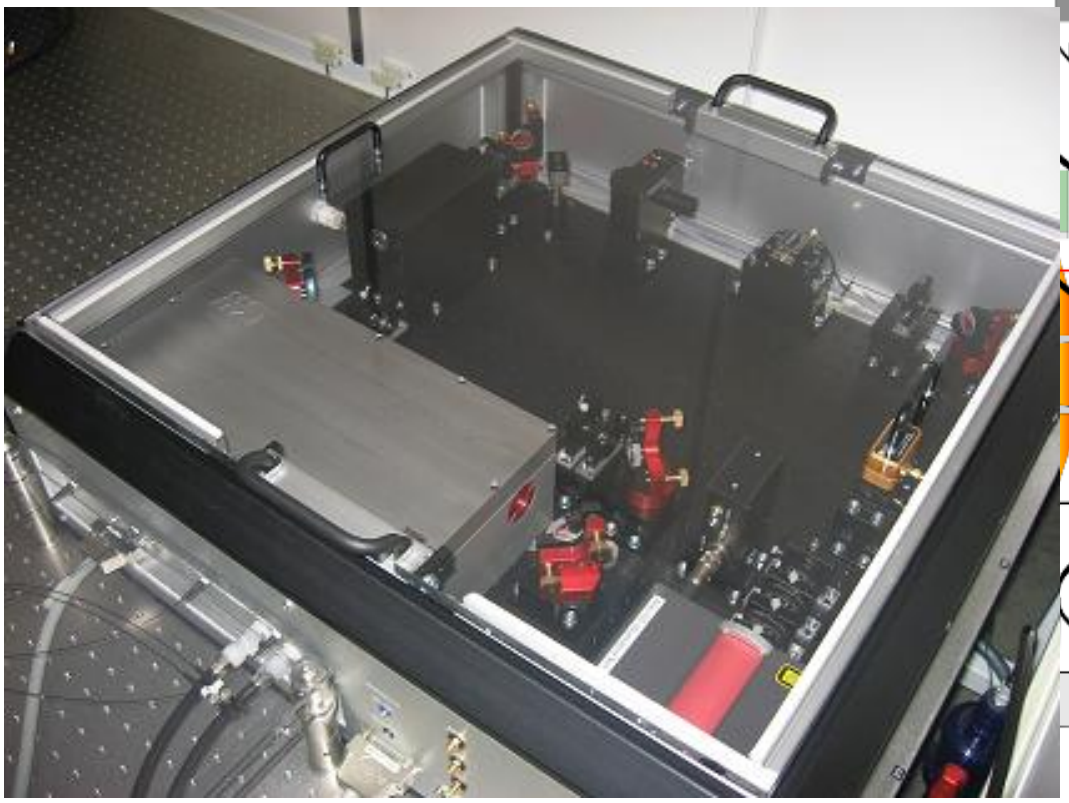
35W Laser
Why?

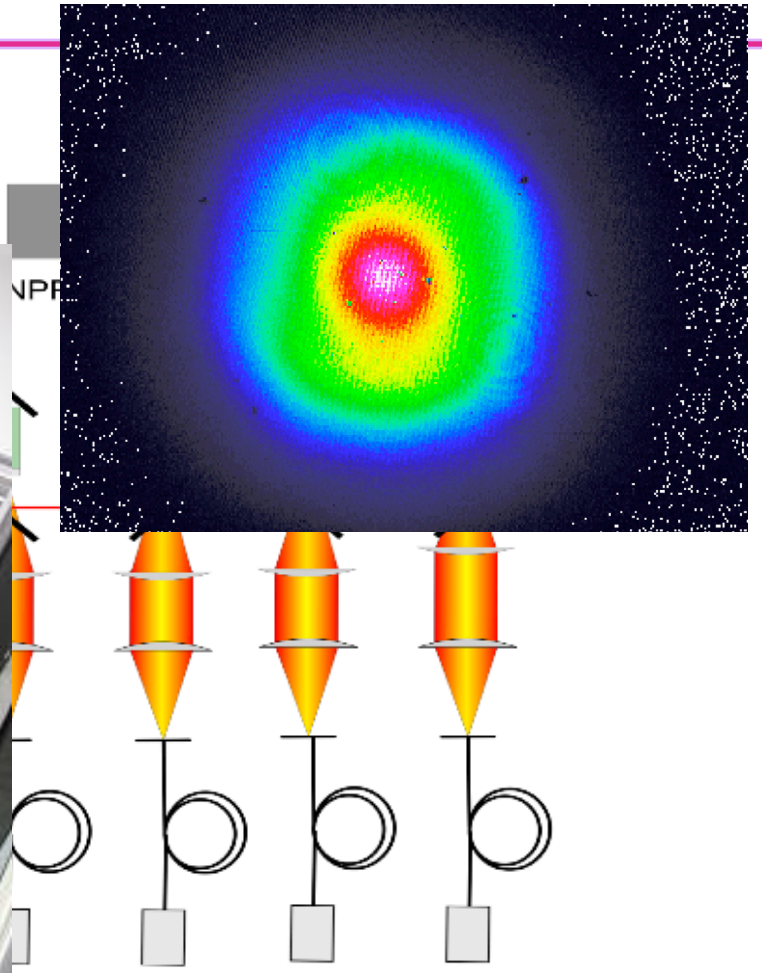
- Decreases the shot noise limit above 100Hz



35W Laser
Specifications

- Courtesy of AEI/LZH

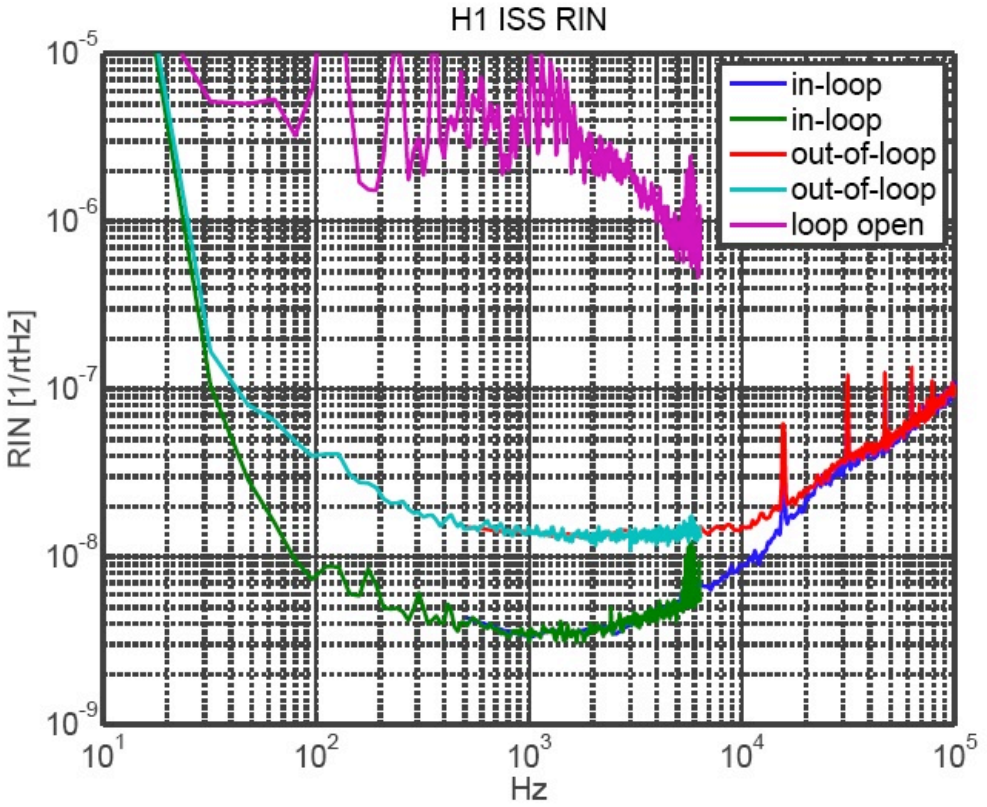




35W Laser

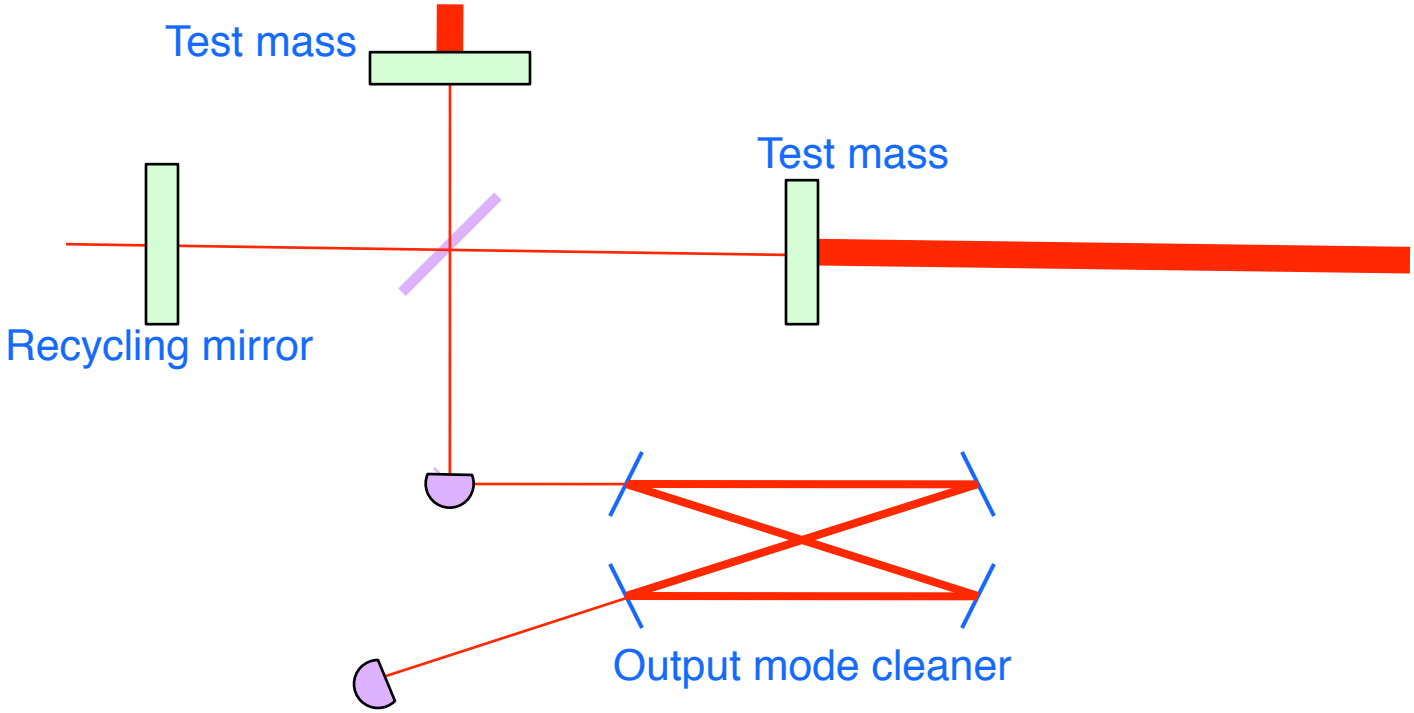
Installation experience and performance

- Hanford: Late-March 2008
- Livingston: Late-July 2008
- Intensity stabilization
  - » 2.5E-8 $Hz^{-1/2}$ @ 200Hz
  - » very good



Output mode cleaner
What is it?

- Resonant optical cavity at output of interferometer

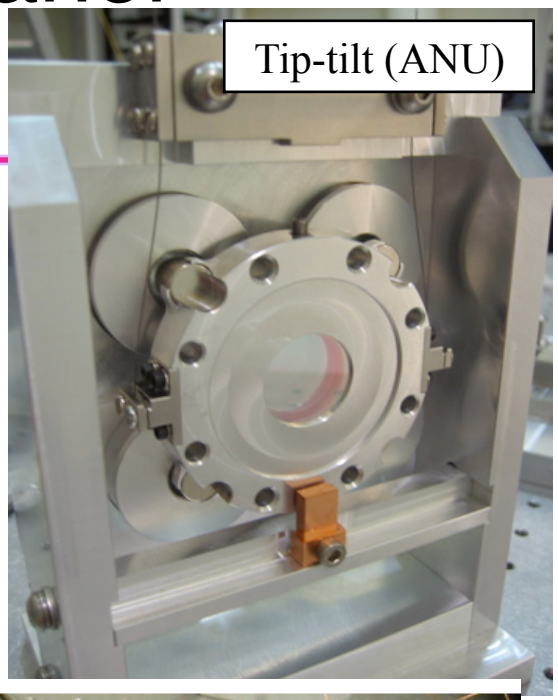


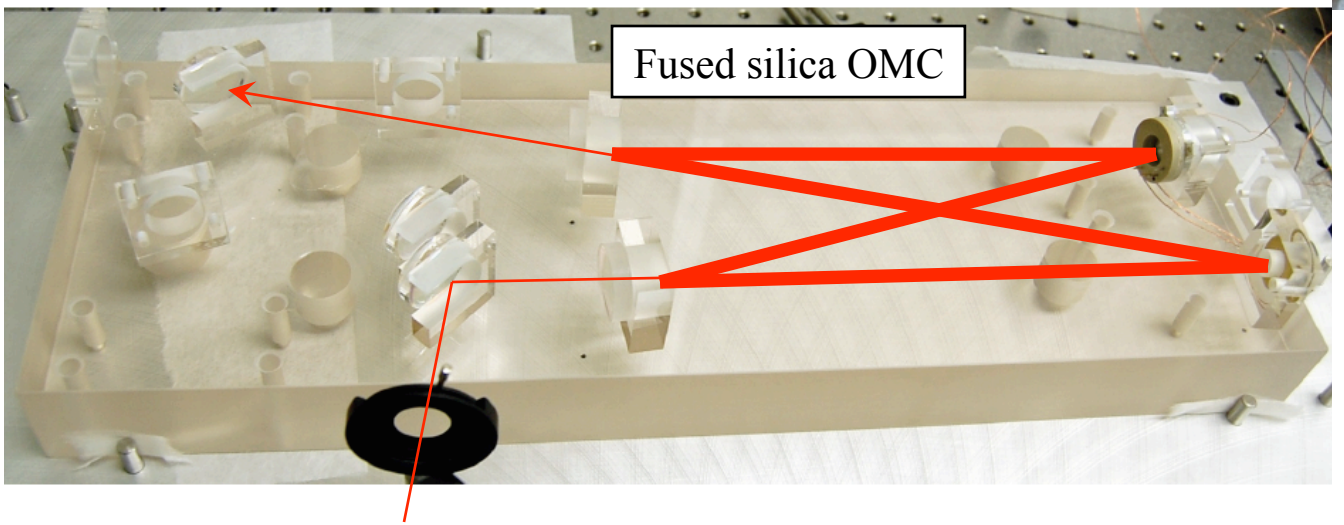
Output mode cleaner
Why?

- Filters transmission at the dark port
- Reduces shot noise
  - » Only transmits TEM00
  - » Same mode that is resonant in the cavity
  - » ***Reduces contrast defect observed by detector***
- Strips off RF sidebands
  - » Reduces intensity noise coupling

Output mode cleaner
Specifications

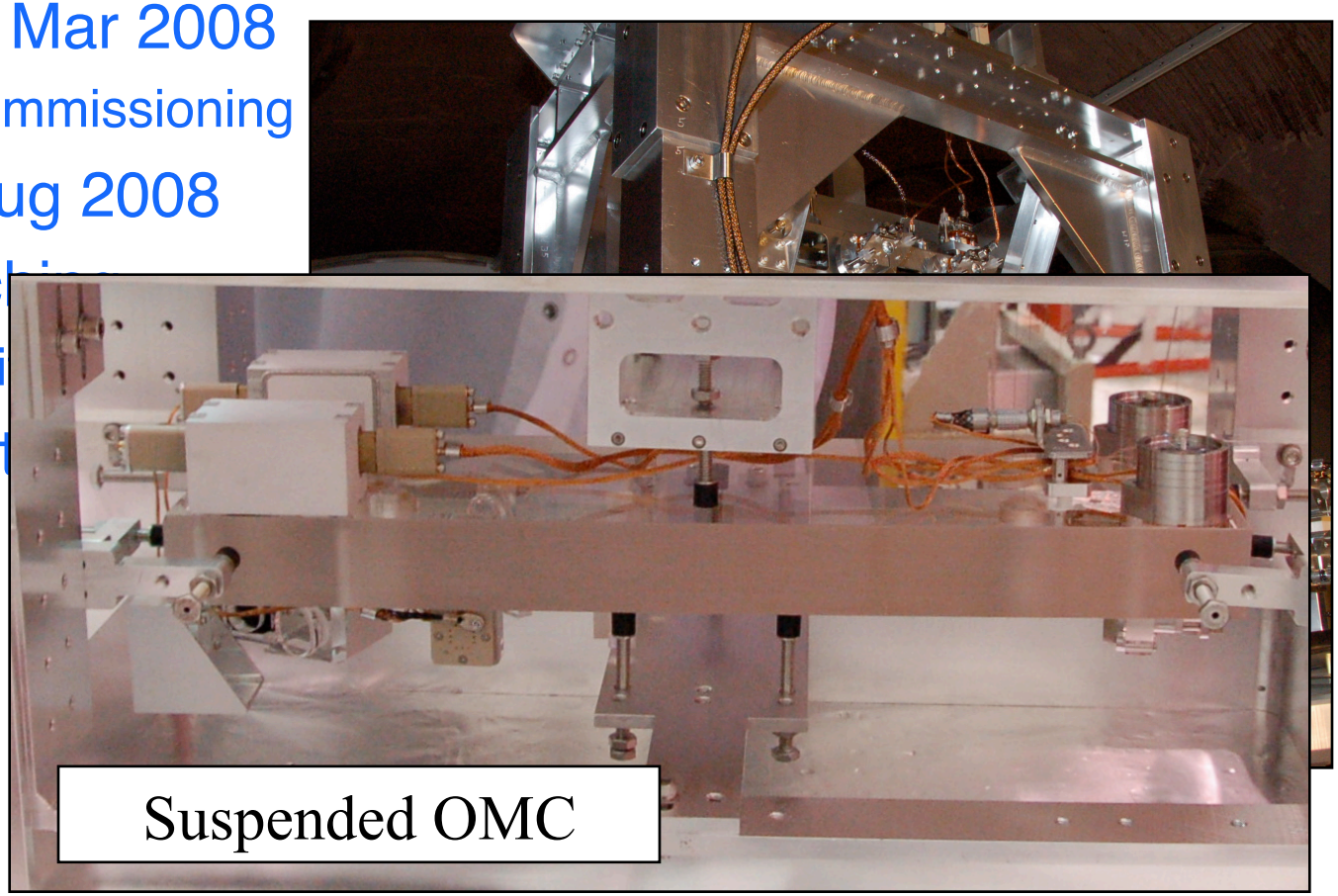
- Bow-tie 4 mirror resonant cavity
- Tip-tilts (ANU): mode-matching
- All fused silica design
- Fast and slow acutators
- Suspended





Output mode cleaner
Installation experience

- Livingston: Mar 2008
  - » Lots of commissioning
- Hanford: Aug 2008
- Mode matc
  - » tip tilt posi
- Tip-tilt shutt

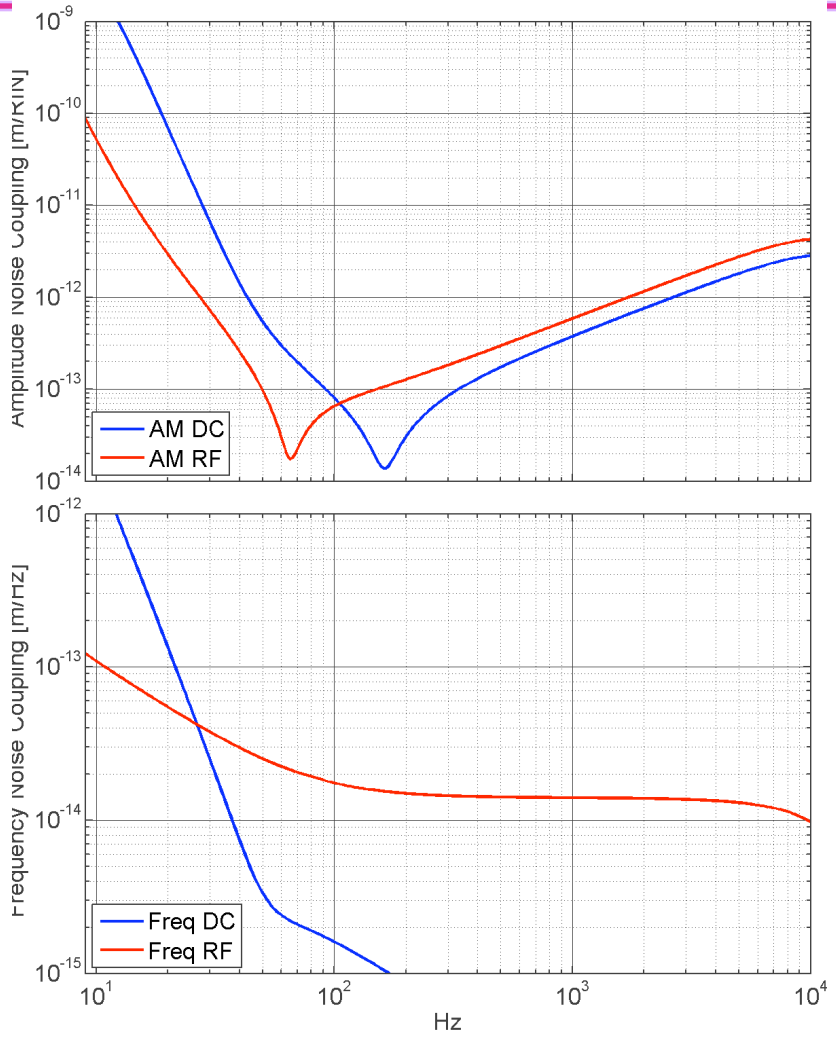


DC Readout
Why?

- Baseline design for AdvLIGO
- Output power: linear readout of differential arm length
- Noise coupling reduced
  - » laser frequency noise
  - » power recycling cavity length noise
  - » RF oscillator noise
- ***DC readout has never been demonstrated on a complex, suspended interferometer.***

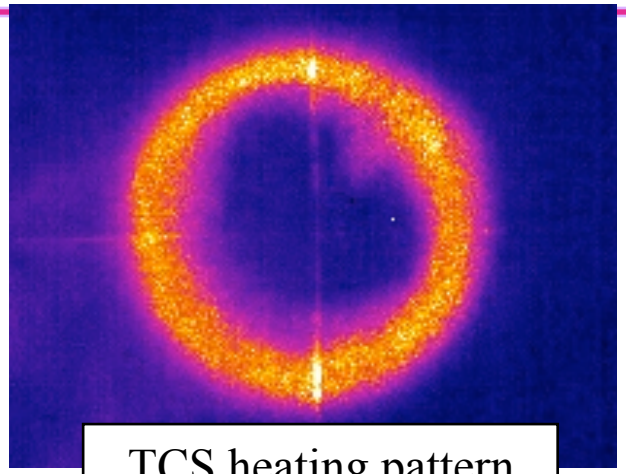
DC readout

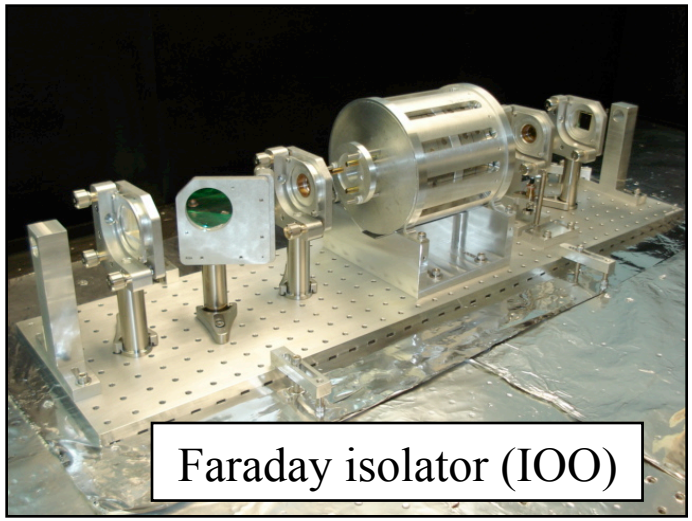
Reduced noise coupling …

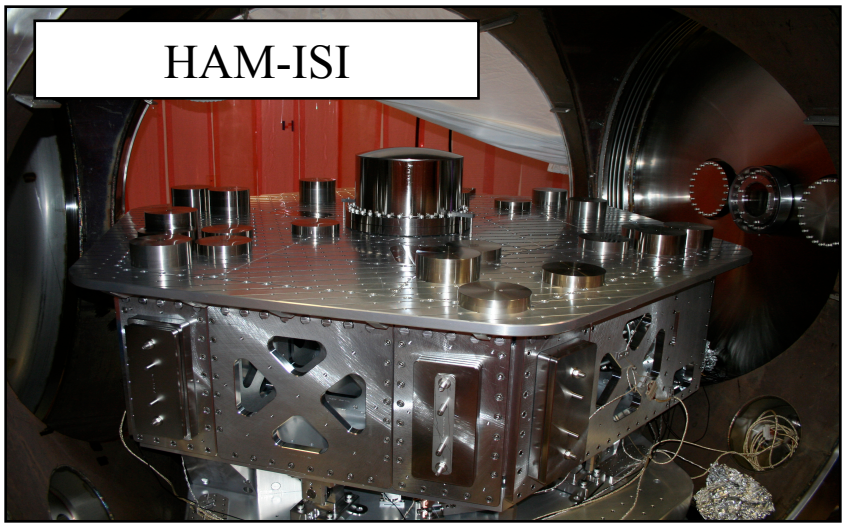


Auxiliary upgrades

- Thermal Compensation System (TCS)
- Input optics (IOO)
- AdvLIGO seismic isolation (HAM-ISI)
- etc

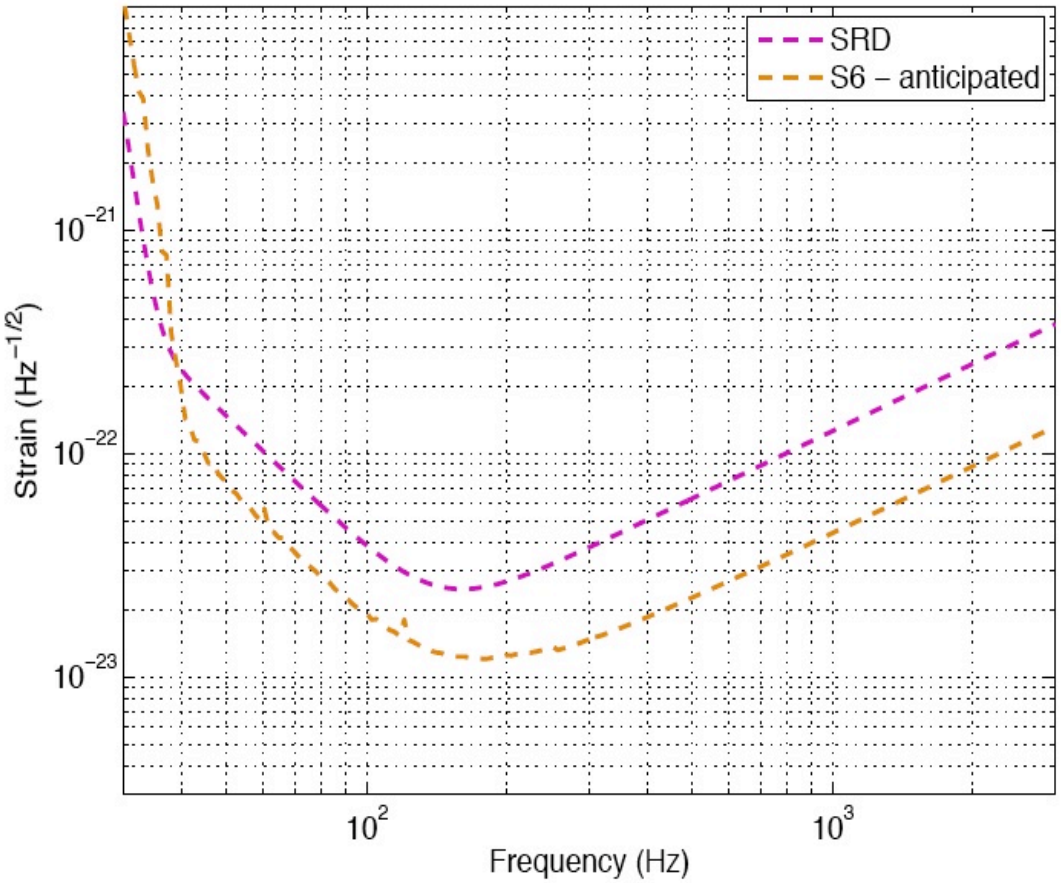

TCS heating pattern


Faraday isolator (IOO)


HAM-ISI

Astrophysical implications

Noise curves



Astrophysical estimates*
eLIGO vs SRD

- Generalization: ~2x increase in inspiral range.
  - » Hence ~8x increase in volume of space
- Sensitivity to NS/NS ($1.4M_{solar}$) increases by ~2.1x
- Sensitivity to BH/BH ($30M_{solar}$) increases by ~1.7x
- Stochastic: Ω_0 decreases by ~1/3

* Estimated using Gravitational Wave Interferometer Noise Calculator (GWINC) with S6 and SRD simulated noise curves: [5, 5000]Hz

The Status of Enhanced LIGO

Summary

- Physical installation of hardware: complete ✓
- Initial commissioning work: ongoing
  - » Locking ✓
  - » Higher power
    - – Livingston ~15W input
    - – Hanford ~ 12W input

    1st
  - » Noise hunting … (like death and taxes)
- Science Run (recording real data) – early-mid 2009

Acknowledgements

- Everyone at the LSC
- National Science Foundation
- Special thanks to Kate Dooley for assorted slides

LIGO Scientific Collaboration

Abstract

The Status of Enhanced LIGO

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At the end of September 2007, the Laser Interferometer Gravitational-Wave Observatory (LIGO) achieved its goal of one cumulative year of triple-interferometer-coincidence runtime, known as science run S5. The interferometers operated at their design sensitivity of 2.5 x 10^{-23} $Hz^{-1/2}$ equivalent strain noise at 150 Hz. Installation of a major upgrade of the interferometer (Advanced LIGO), designed to reduce the strain noise by an order of magnitude, is scheduled to begin at the start of 2011 and continue through to the end of 2014. The three-year period between the end of S5 and the start of Advanced LIGO affords an opportunity to make some intermediate upgrades to the interferometer and execute another year long science run (S6) with double the sensitivity of S5 – the last sensitive observations by LIGO until 2015. This intermediate phase is known as Enhanced LIGO.

The main upgrades to the interferometer are a) a new 35W laser power to reduce the shot noise at higher frequencies, b) an output mode cleaner (OMC) to remove higher order modes that contribute to shot noise and c) a move from RF readout to DC readout. Assorted changes are also being made to auxiliary systems to facilitate these upgrades. Installation across the two LIGO sites is nearing completion and will be followed by approximately six months of commissioning and noise hunting.

I will describe in detail these upgrades and their current commissioning status in Enhanced LIGO. Additionally, I will briefly address the predicted consequences for astrophysical gravitational-wave observations.