Advanced LIGO status

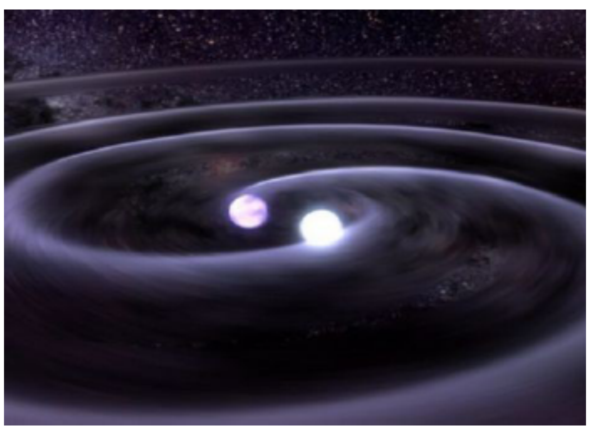
Hiro Yamamoto LIGO lab/Caltech

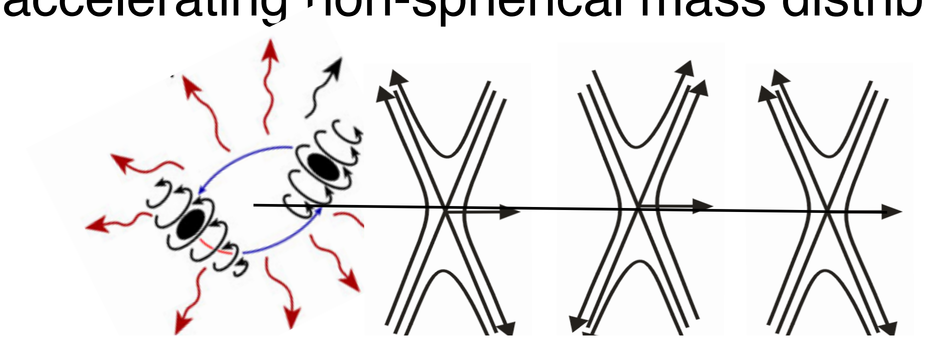
- Introduction
- Initial LIGO and advanced LIGO
- Sensitivities
- Commissioning status
- Targeting the first observations

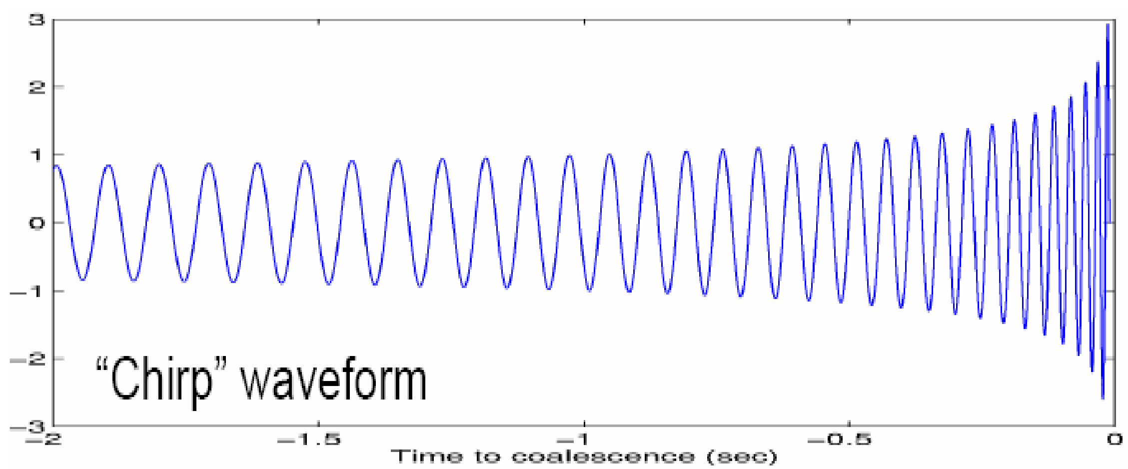
Some slides are from "ET-aLIGO and beyond", LIGO-G14001331, by David Shoemaker

Gravitational waves

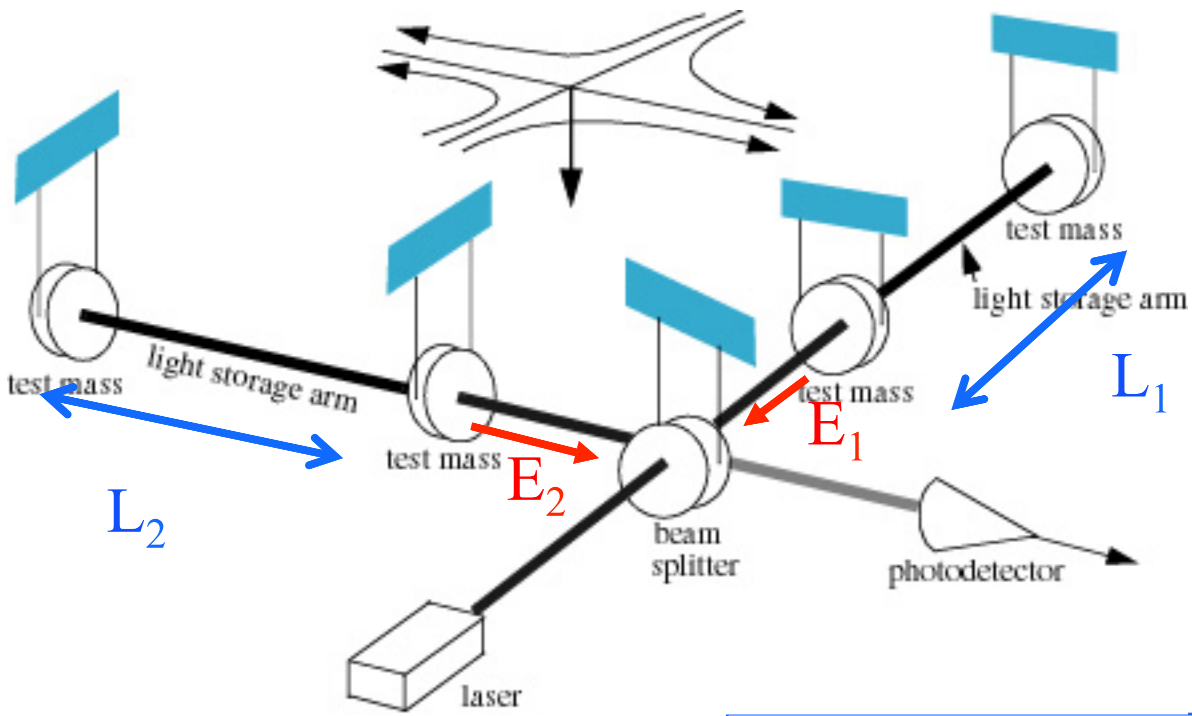
- Gravitational waves are propagating dynamic fluctuations in the curvature of space-time ('ripples' in space-time)
- Emissions from rapidly accelerating non-spherical mass distributions
  - » Quadrupolar radiation







Interferometer for Gravitational Wave detection



$E_1 - E_2 \propto L_1 - L_2$

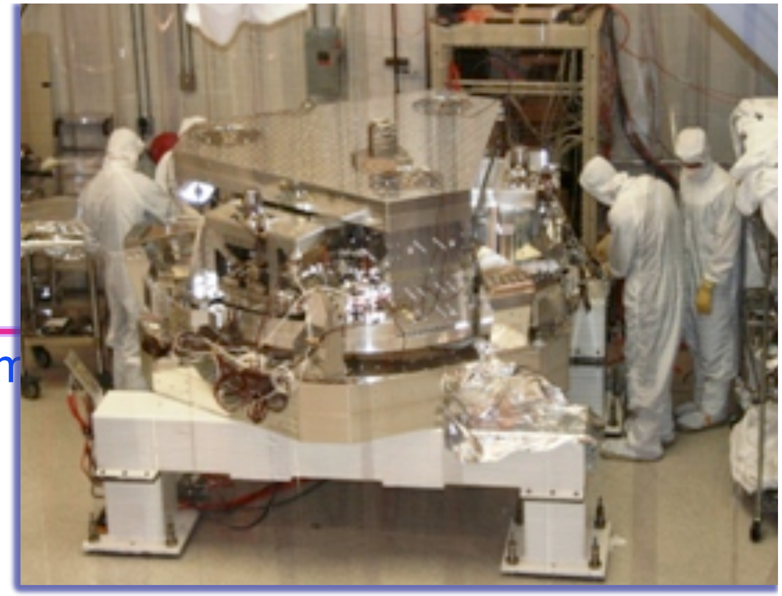
$$h = \frac{L_1 - L_2}{L_1 + L_2}$$

$h \sim 10^{-23}$

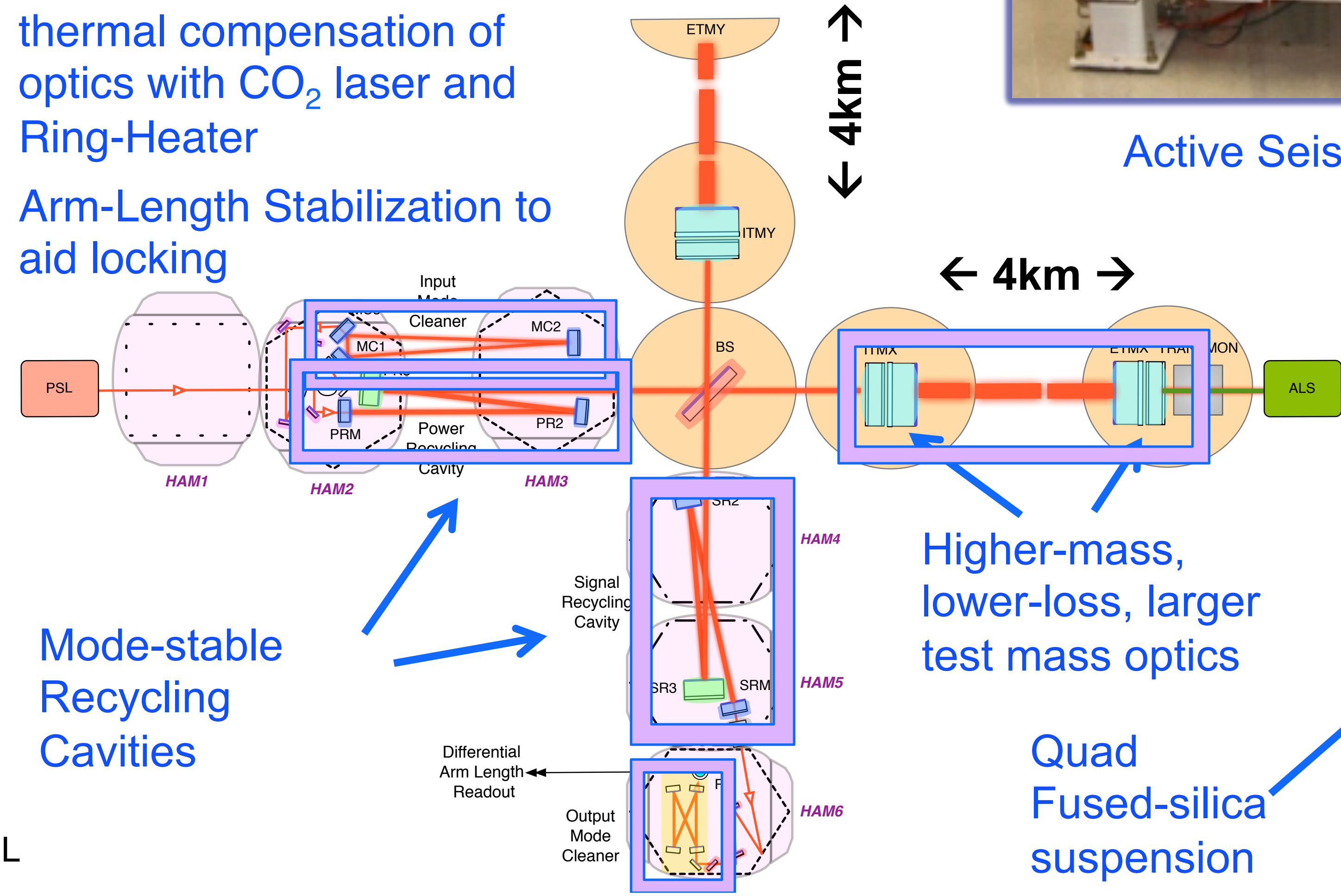
$L_1 - L_2 \sim 10^{-19}$m

Design Overview

- Signal- and Power-recycled Fabry-Perot interferom
- 180 W 1064 nm laser
- thermal compensation of optics with CO_2 laser and Ring-Heater
- Arm-Length Stabilization to aid locking

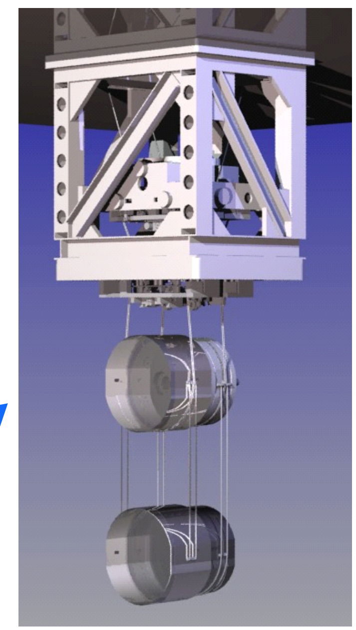


Active Seismic Isolation



Mode-stable Recycling Cavities

Higher-mass, lower-loss, larger test mass optics

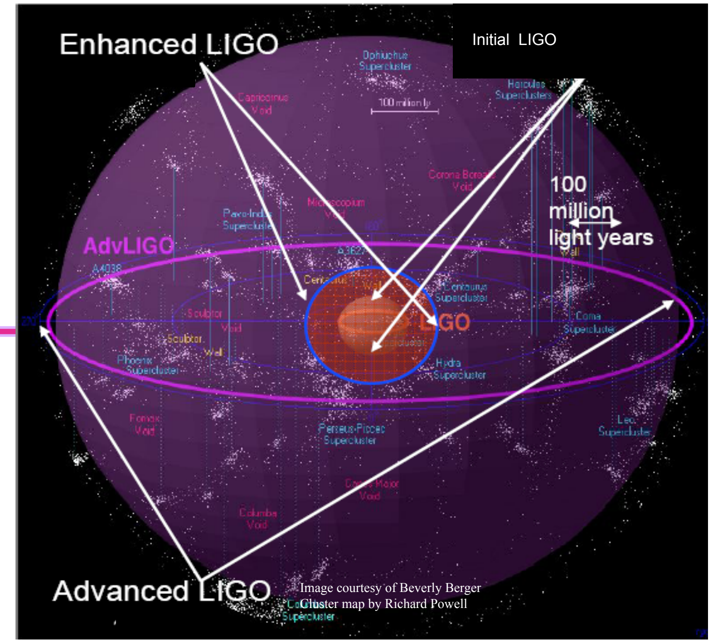


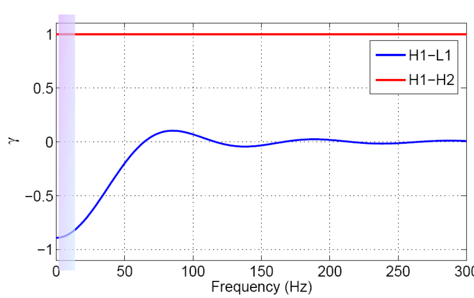
Quad Fused-silica suspension

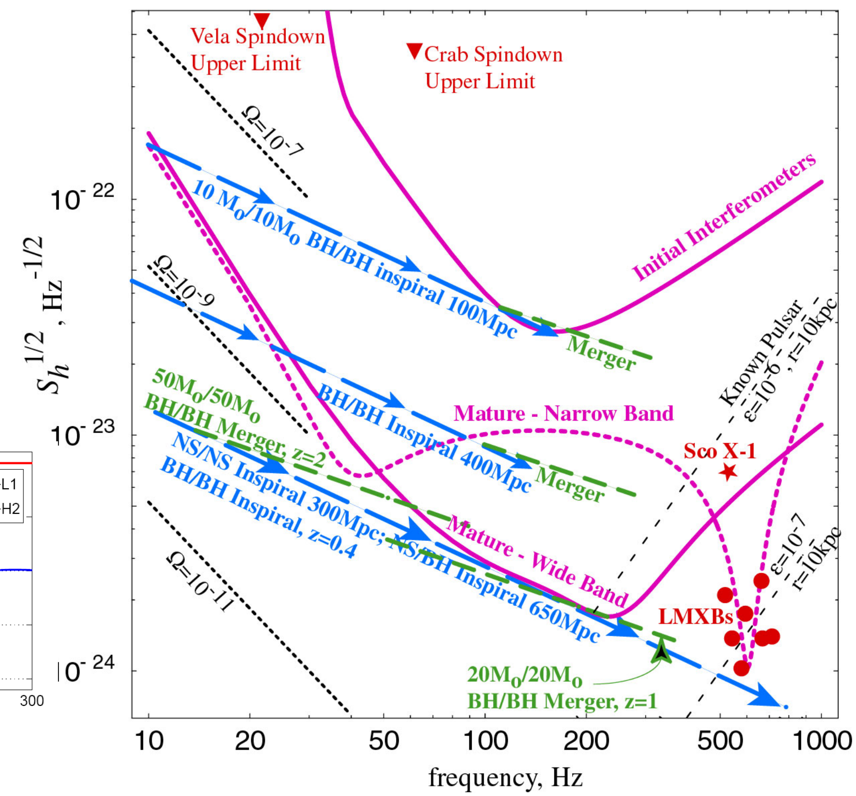
L

Advanced LIGO Scope and Deliverables

- Factor 10 better amplitude sensitivity
  - » $(\text{Reach})^3$ = rate
- Factor 4 lower frequency bound
- Tunable for various sources
- NS Binaries: for three interferometers,
  - » Initial LIGO: ~20 Mpc
  - » Adv LIGO: ~300 Mpc, expect one event/week or so
- BH Binaries:
  - » Initial LIGO: 10 M_o, 100 Mpc
  - » Adv LIGO : 50 M_o, z=2
- Stochastic background:
  - » Initial LIGO: Ω~3e-6
  - » Adv LIGO ~3e-9

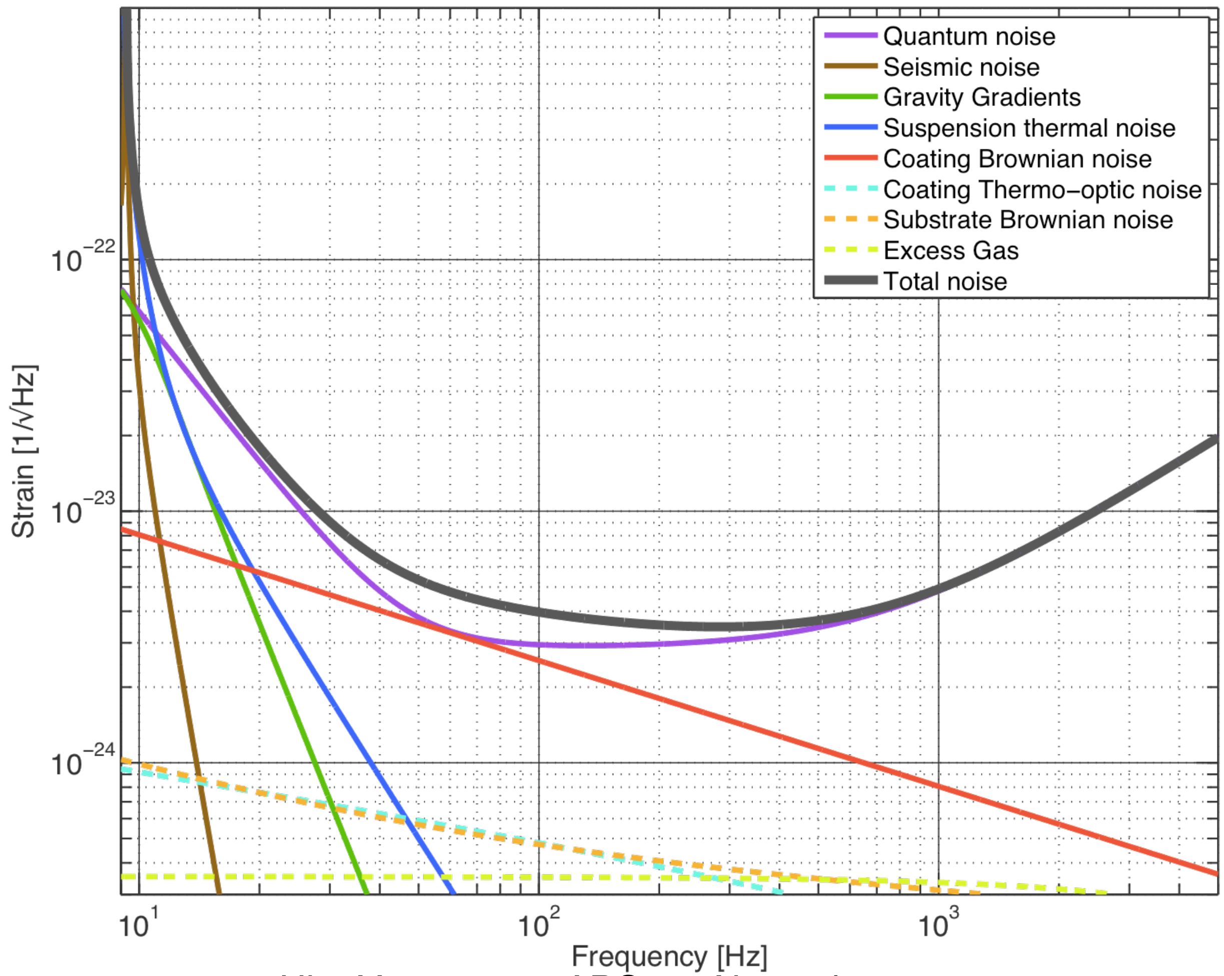




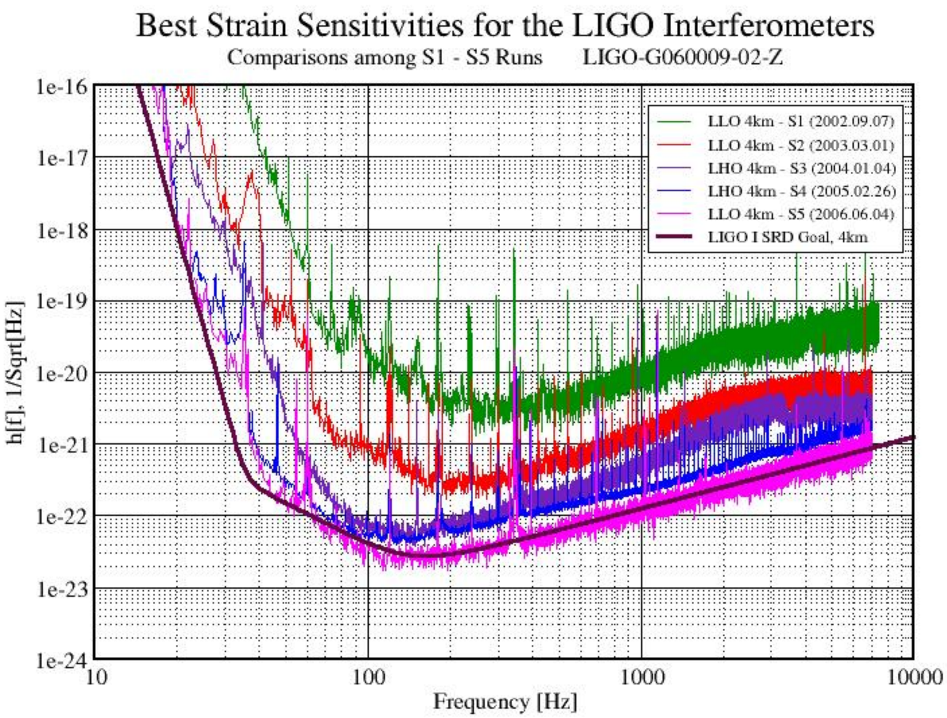


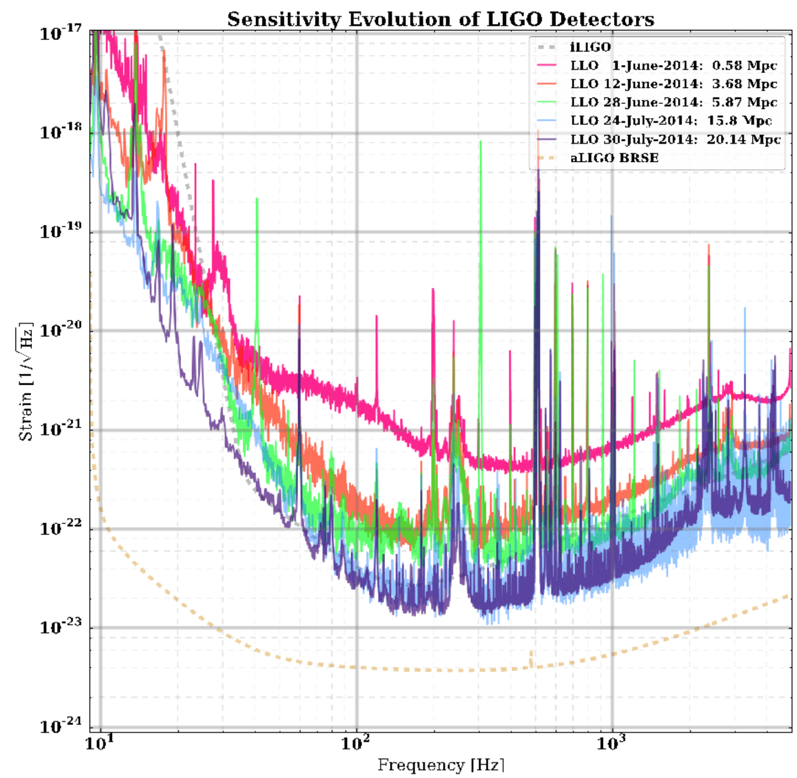
Noise components

iLOGO = seismic + thermal + shot
aLIGO = quantum noise + thermal



Improving sensitivities





LIGO sites

Hanford Observatory (H2K and H4K)

4 km
+ 2 km

Hanford, WA (LHO)

- located on DOE reservation
- treeless, semi-arid high desert
- 25 km from Richland, WA
- Two IFOs: H2K and H4K -> 4k LHO + 4k India

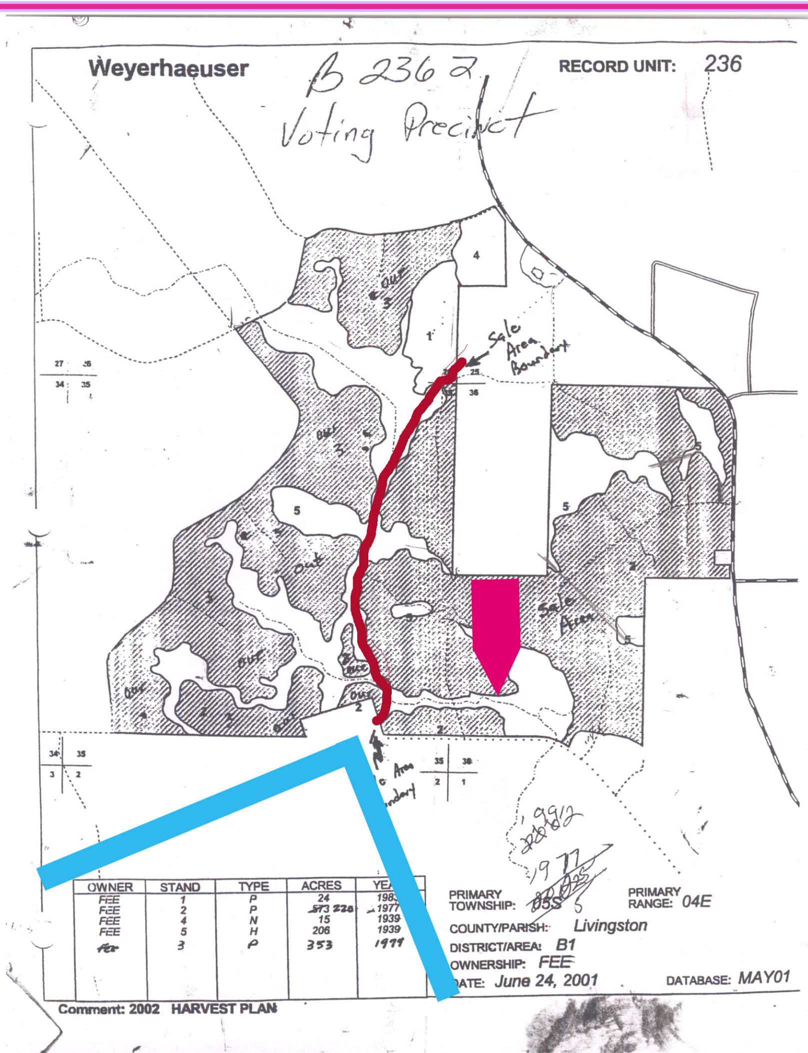
Livingston, LA (LLO)

- located in forested, rural area
- commercial logging, wet climate
- 50km from Baton Rouge, LA
- One L4K IFO

Livingston Observatory (L4K)

Both sites are relatively seismically quiet, low human noise - NOT!!

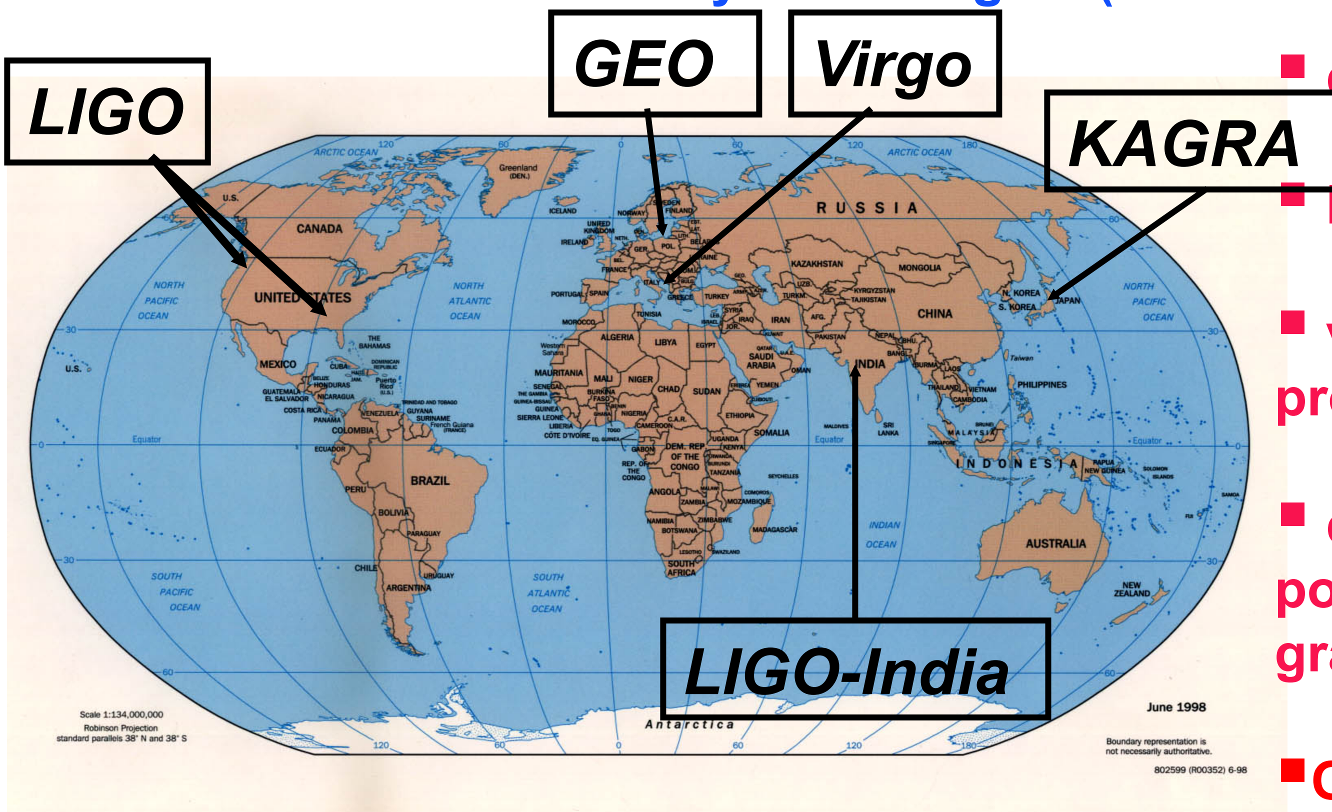
Logging at Livingston



Less than ~~3 km~~ a few 100 meters away…
Dragging big logs …
Remedial measures at LIGO are in progress; this will not be a problem in the future.

International network

Simultaneously detect signal (within msec)



- **detection confidence**
- **locate the sources**
- **verify light speed propagation**
- **decompose the polarization of gravitational waves**
- **Open up a new field of astrophysics!**

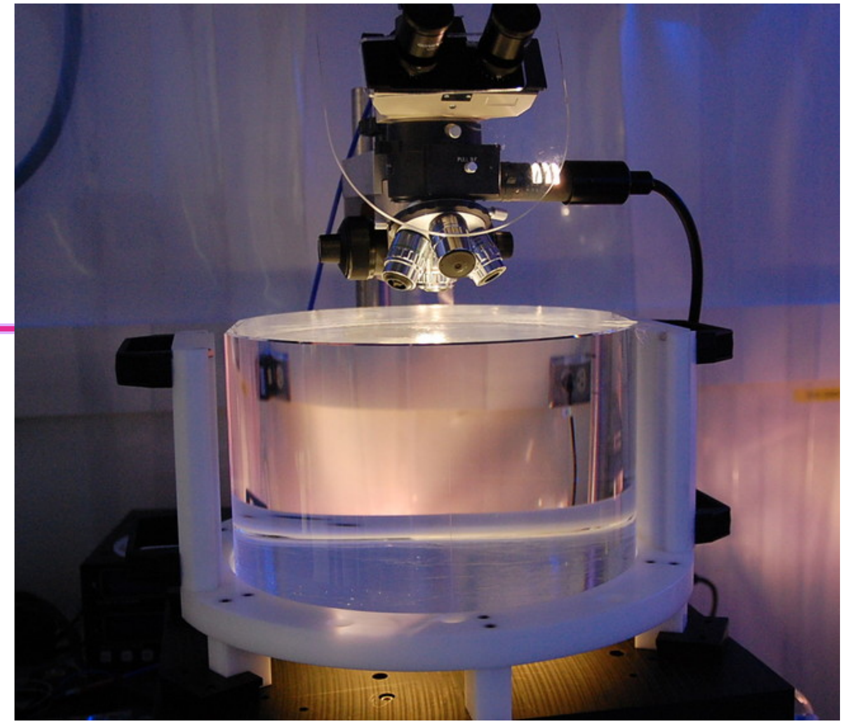
LIGO *vacuums*

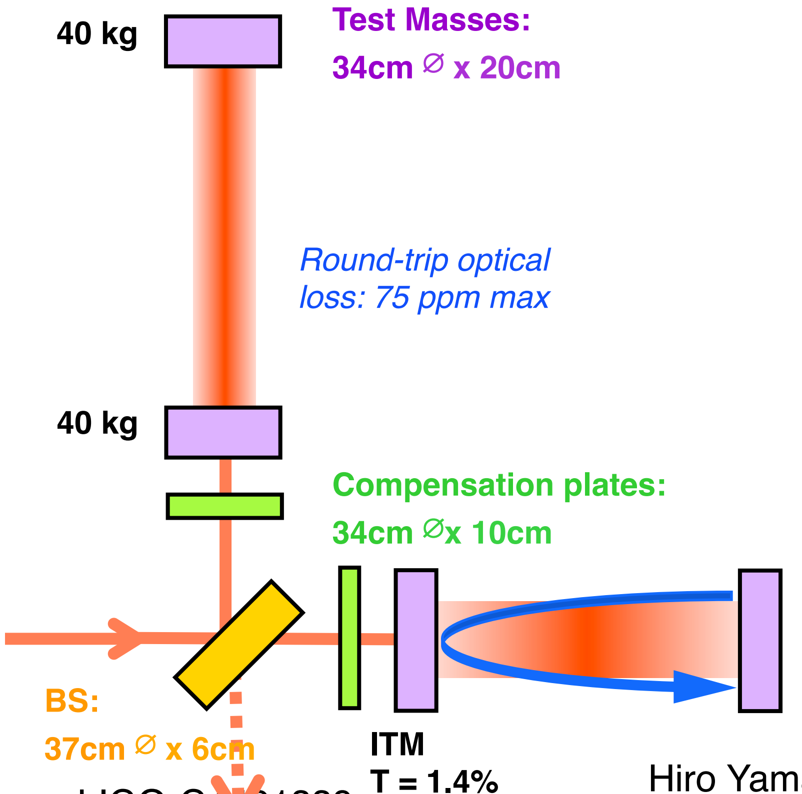
Beam light path must be high vacuum, to minimize "phase noise"

All optical components must be in high vacuum, so mirrors are not "knocked around" by gas pressure

aLIGO Test Masses

- Requires the state of the art in substrates, polishing, coating
- Both the physical test mass – a free point in space-time – and a crucial optical element

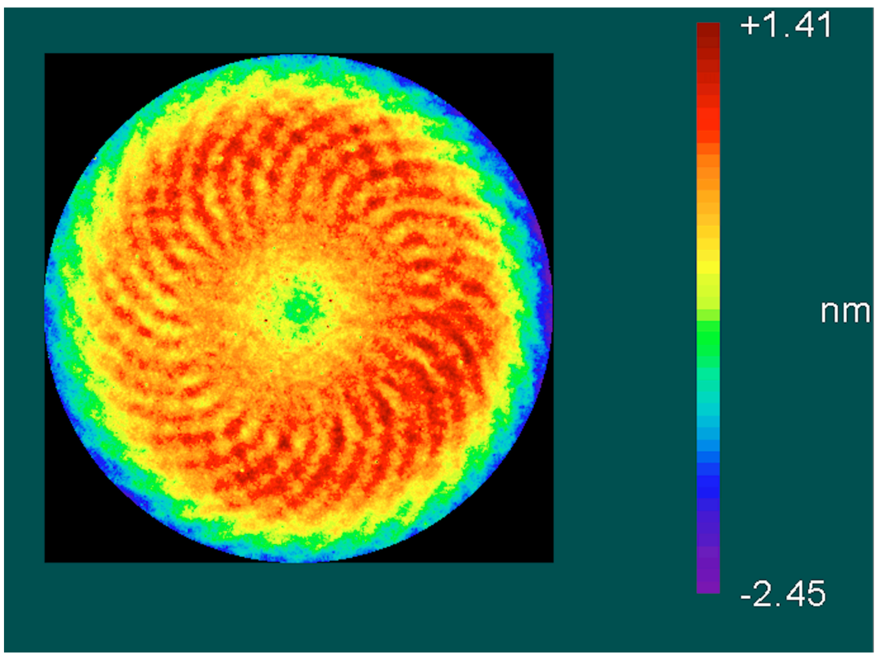


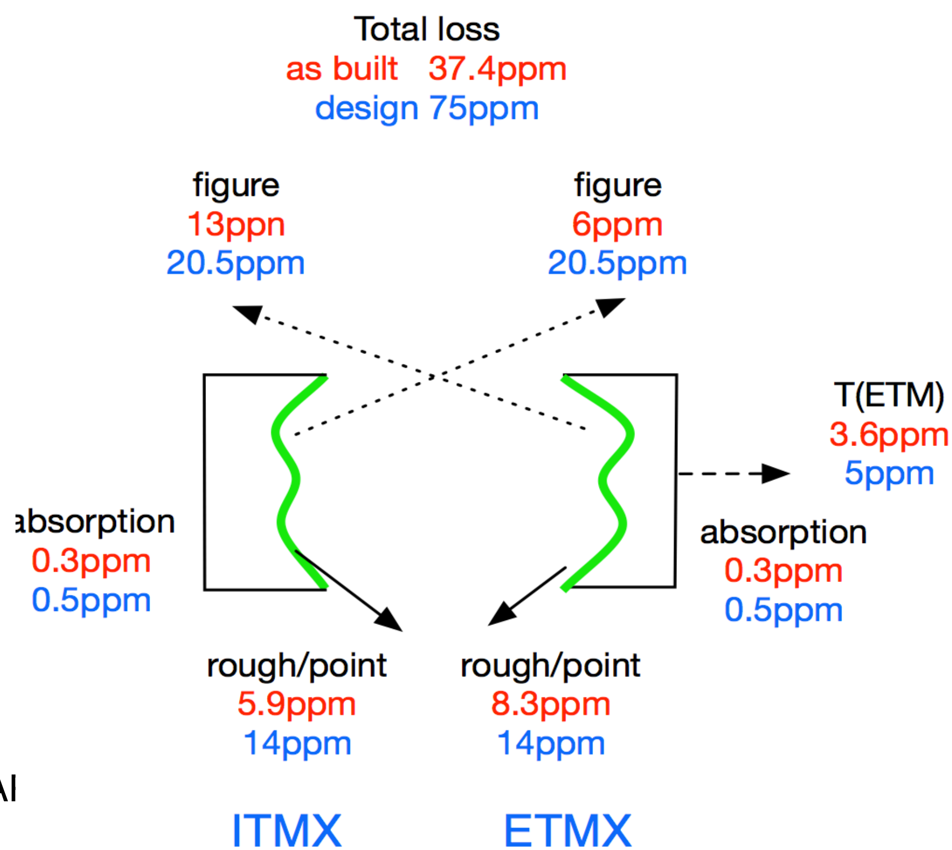


- Half-nm flatness over 300mm diameter
- 0.2 ppm absorption at 1064nm
- Coating specs for 1064 and 532 nm
- Mechanical requirements: bulk and coating thermal noise, high resonant frequency

Test mass Optics figure

- In-house metrology on 300 mm diameter shows 0.66 nm RMS
  - » Note spiral from planetary system; about 0.2 nm pk-pk
- In-situ measurements of as-built 4km cavity show results are better than requirements!

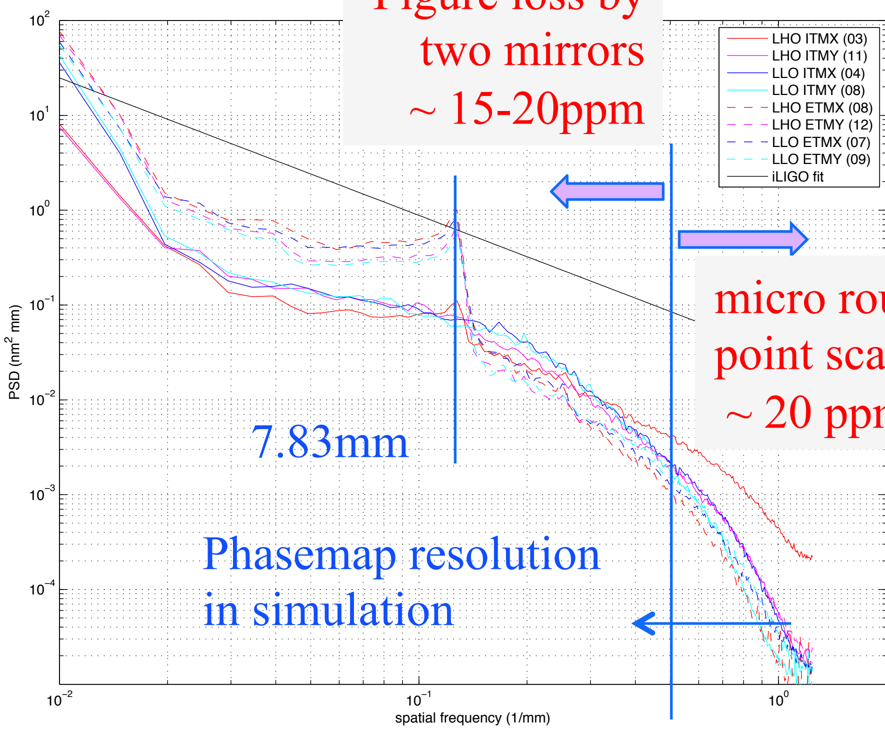




Hiro Yamamoto AI

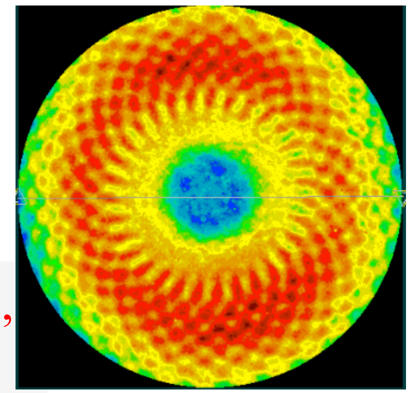
Noise injection by the spiral pattern on test mass coatings

Figure loss by two mirrors ~ 15-20ppm

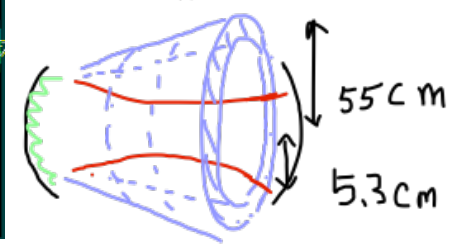


micro roughness, point scattering ~ 20 ppm

Phasemap resolution in simulation



ETM07 map



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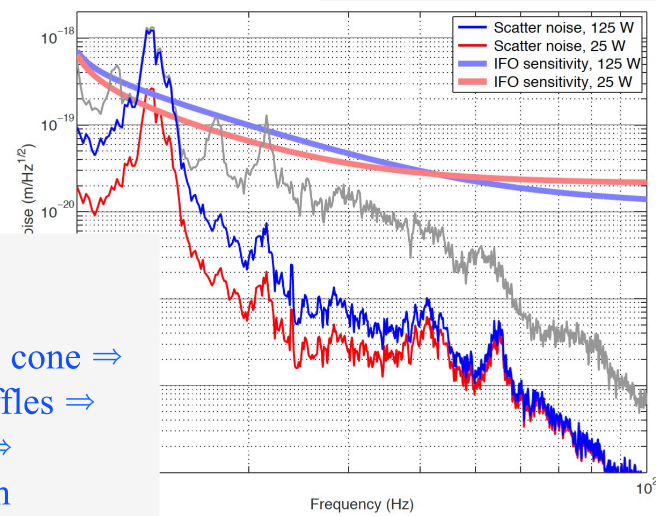
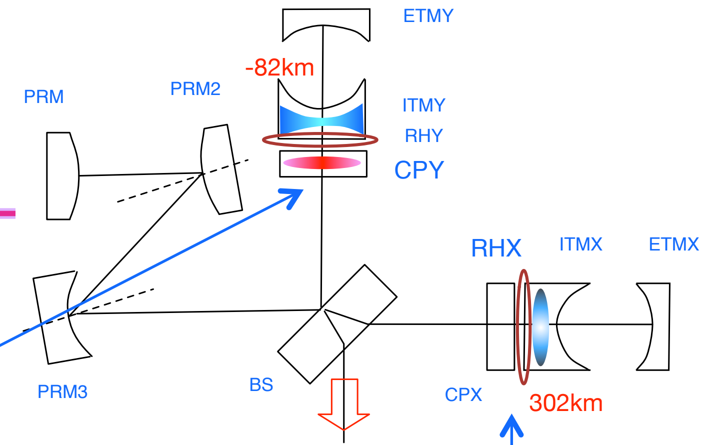


main beam ⇒
ETM reflection ⇒
larger angle scattering into cone ⇒
reflected by beam tube baffles ⇒
back scattered into ETM ⇒
merged into the main beam

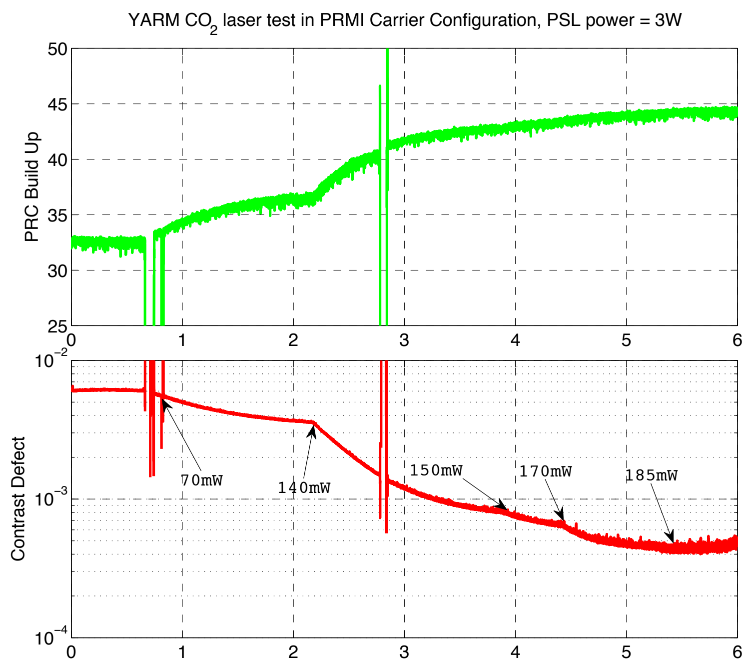
Hiro

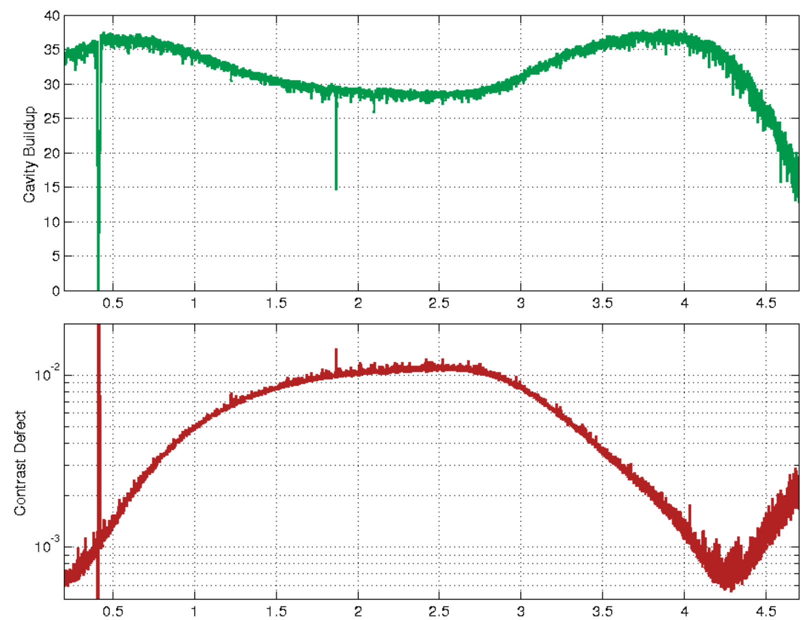
TCS corrections for LLO PRMI



RH optimal lens = n(SiO2) x 82km = 1/0.84 x10^{-5}

CP optimal lens = 82km = 1/1.22 x10^{-5}



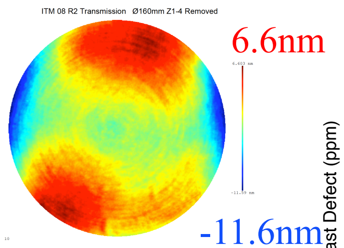


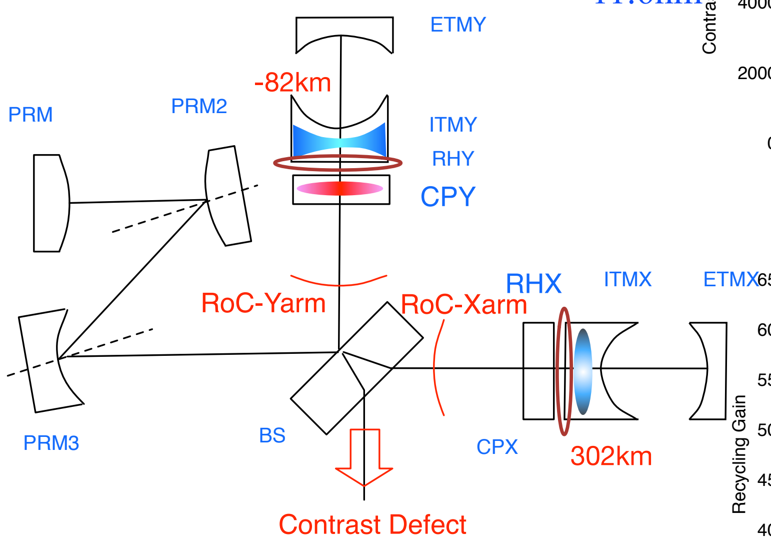
log11140 CD~400ppm, PRG~45

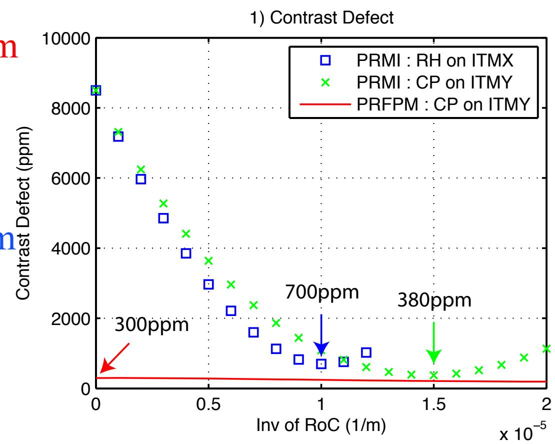
log#9733 CD~600ppm, PRG~35

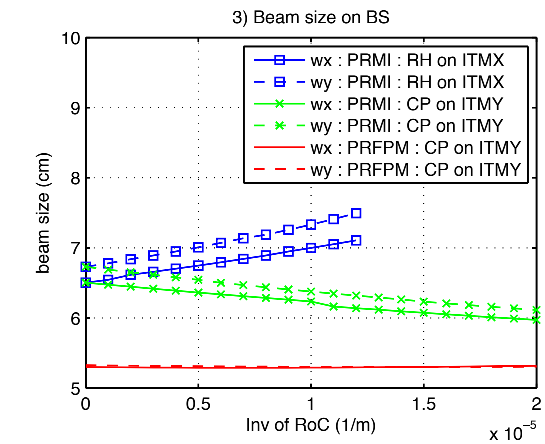
(In)Sensitivity on ITM SPTWE + CP lens

ITM08 / ITMY transmission map in 160mm w/o power

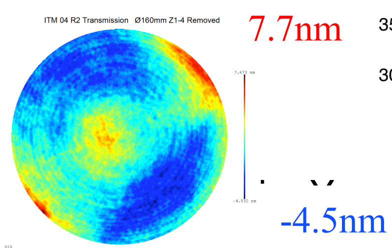


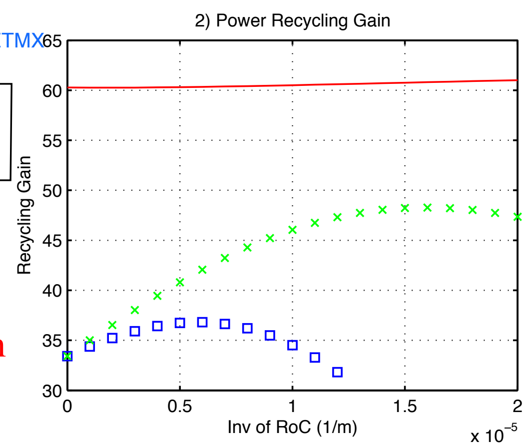


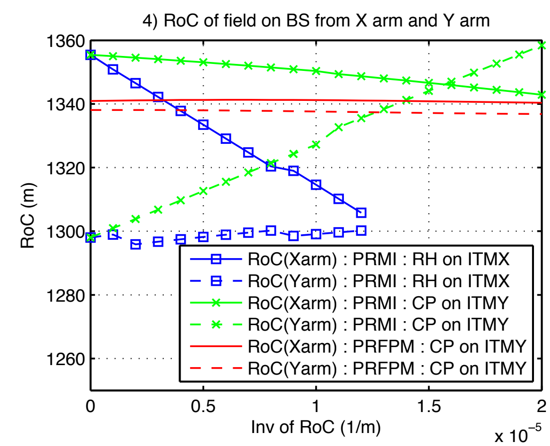




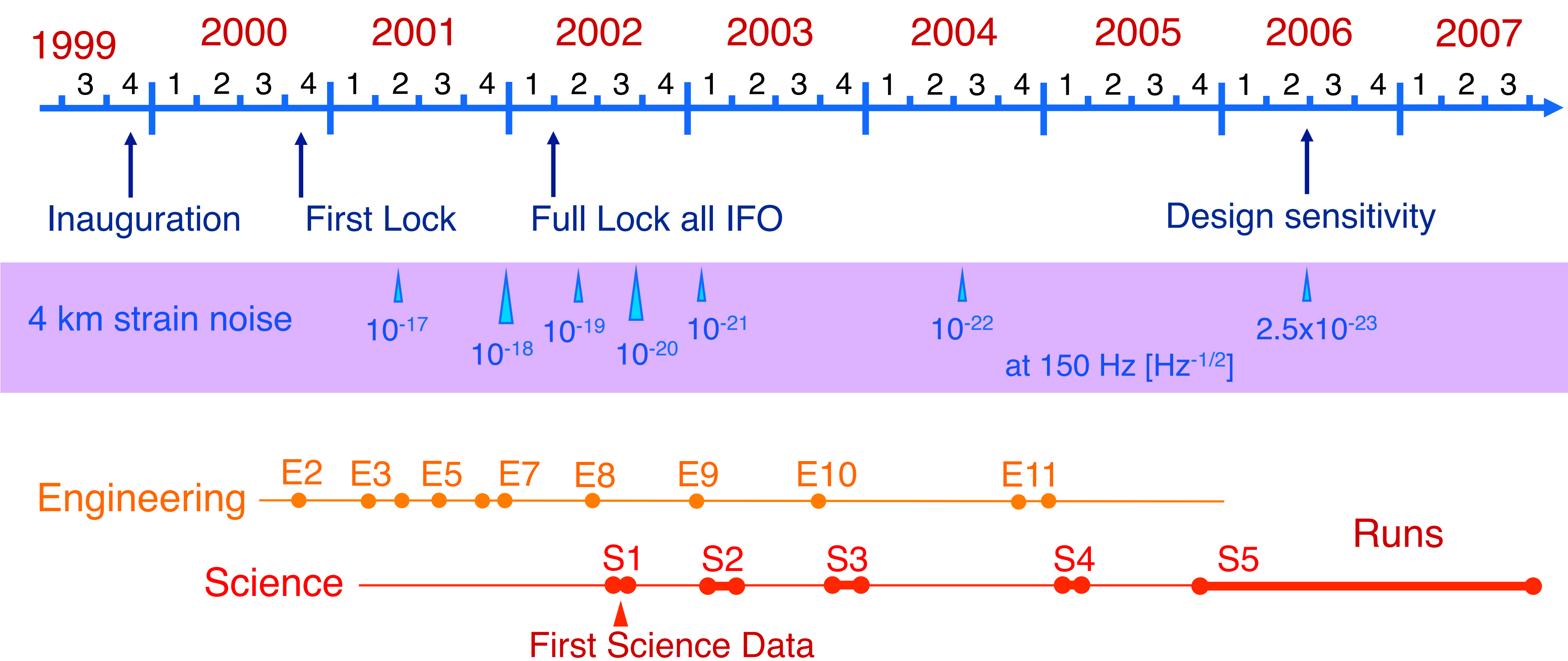
ITM04 / ITMX







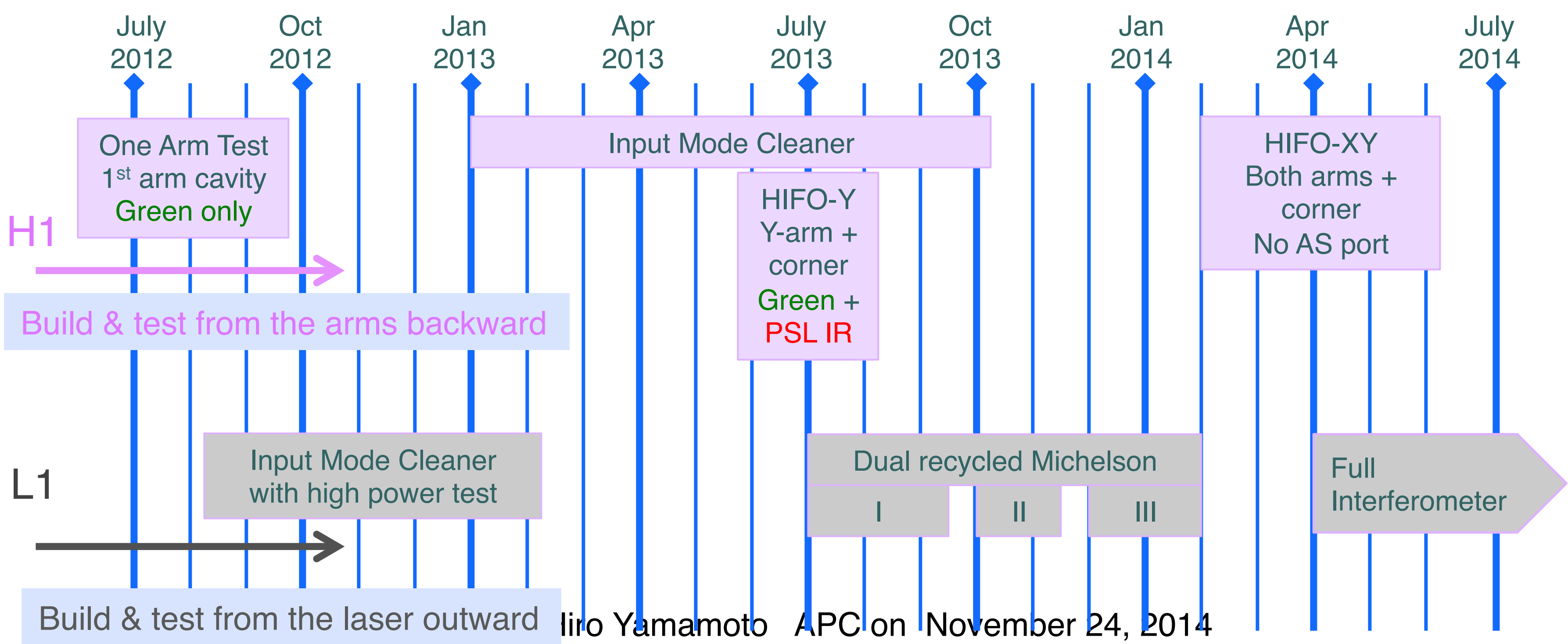
Historical perspective: Initial LIGO commissioning



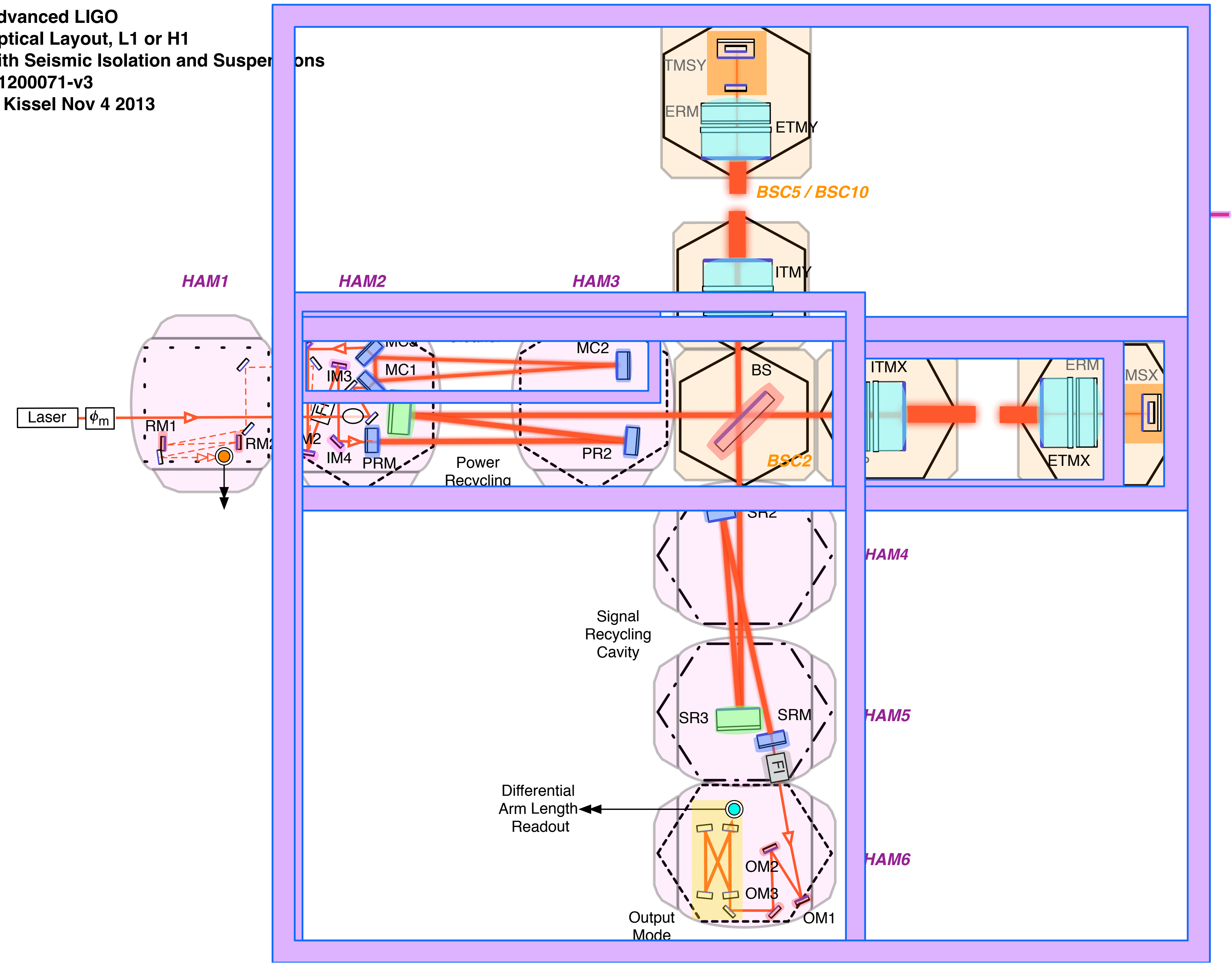
Overall, 4-5 years from locking to design sensitivity

Project Integrated Testing Plan

- Integrated testing phases interleaved with installation
- Complementary division between LHO and LLO
  - » Designed to address biggest areas of risk as soon as possible
  - » H1 focused on long arm cavities; L1 worked outward from the vertex



Advanced LIGO
Optical Layout, L1 or H1
with Seismic Isolation and Suspensions
G1200071-v3
J. Kissel Nov 4 2013



LLO Project scope finished

- **The full interferometer lock was achieved on May 26, 2014**
- **L1 formally met the aLIGO goal of a 2h stable lock**
- The IFO has been locked for as long as 7.5h
- Initial alignment and the lock acquisition are mostly automated
- Currently recovering from some in-vacuum work
- (Need to complete System Acceptance/ documentation)

LHO installation complete

- Now under vacuum at all stations. Dual-recycled Michelson test underway; arms lockable with green Arm Length Stabilization, working toward full lock
- Accomplished with huge help from LLO, CIT and MIT
- Next: installation acceptance, and get to two-hour-lock milestone
- Also, responsibility for 3rd ifo (India) is at Hanford – non-trivial task.

Targeting the first observations

- ER6 slated for start December 8th, 2014
  - L1 expected to be locked for multiple-hour intervals, although not at peak sensitivity; H1 not locking yet
  - Significant discussion in Joint Run Planning Committee on ER6 readiness (throughout the LSC), start date, calibration/freeze/run durations, and impact on commissioning
- O1 observation run slated for as early as mid-July 2015; an evolving discussion as commissioning progress is understood
- Important point: we want **Both** LIGO instruments working at **comparable sensitivity** for the first observing run
  - Catch-up needed at LHO – integrated testing starting ~6 months later than LLO, and e.g., operator/detector support training just getting going; lessons learned will help, but only so much
  - Still ‘all hands on deck’ from LLO, MIT, CIT and of course LHO to reach that goal, but with competing needs to complete aLIGO hardware and documentation, work on BeamTube leak repair

Advanced LIGO: anticipated science runs