# Status of Advanced LIGO

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**MIT-LIGO Laboratory**

On behalf of the
**LIGO Scientific Collaboration**

LIGO-G1300708

Amaldi/GR20 Conference – July 8, 2013

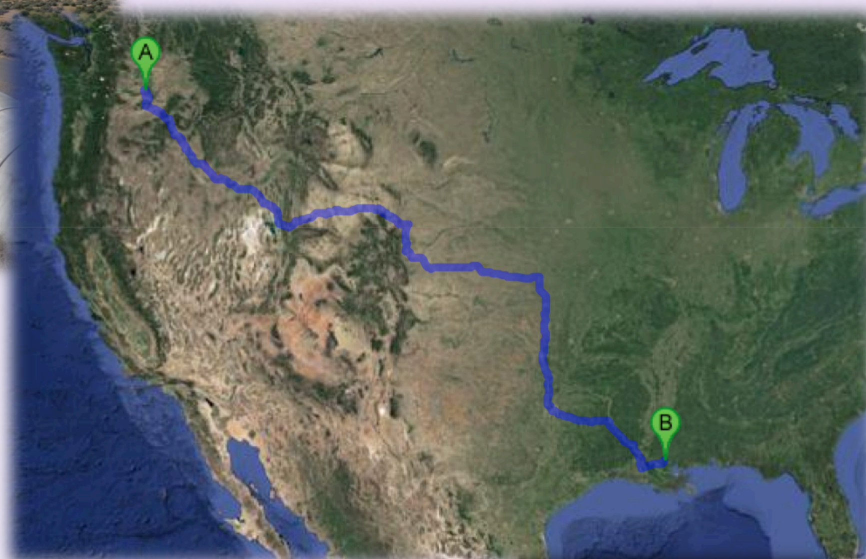
# Upcoming Advanced Detector Network


Plans for placing a third aLIGO instrument in India are well advanced, search for suitable sites underway

Credit: C. Mayhew & R. Simmon (NASA/GSFC), NOAA/ NGDC, DMSP Digital Archive

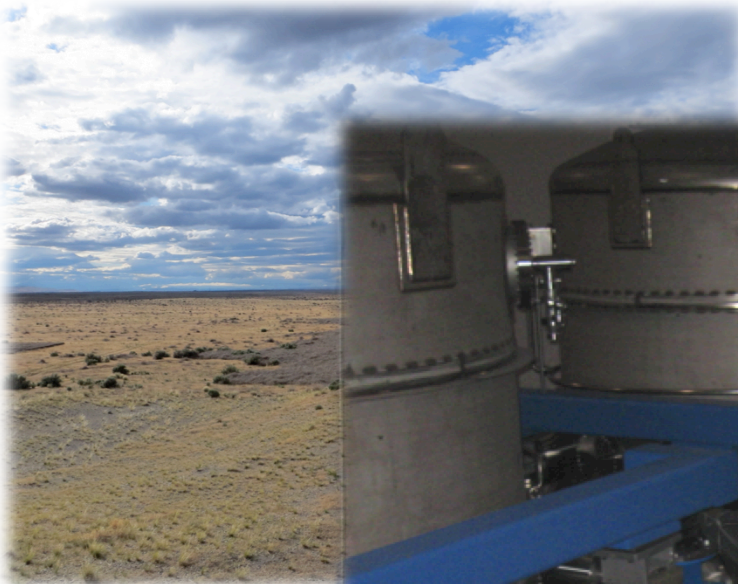
# Hanford (Washington State) & Livingston (Louisiana)

✓4 km arms
✓Ultra High Vacuum: $10^{-9}$ torr



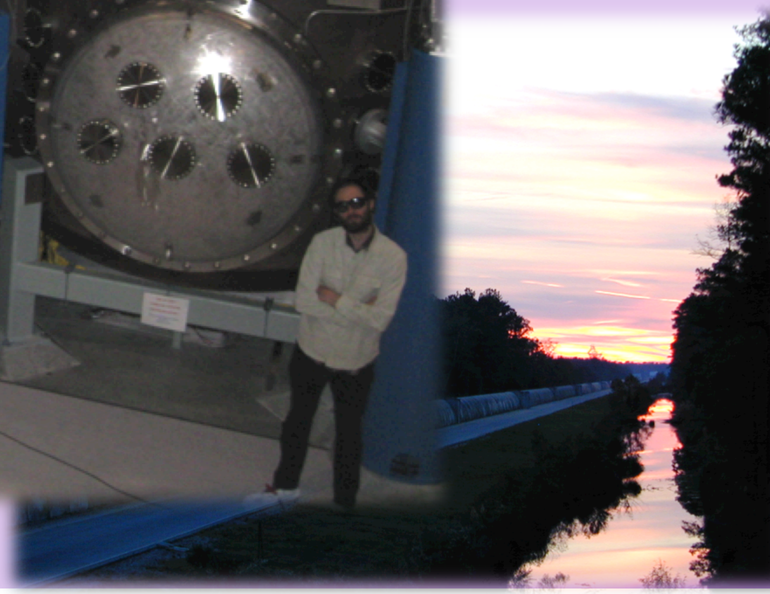

✓Hanford–Livingston: **36 hours** drive
✓**10 ms** if traveling at the speed of light

# Hanford (Washington State) & Livingston (Louisiana)



✓4 km arms

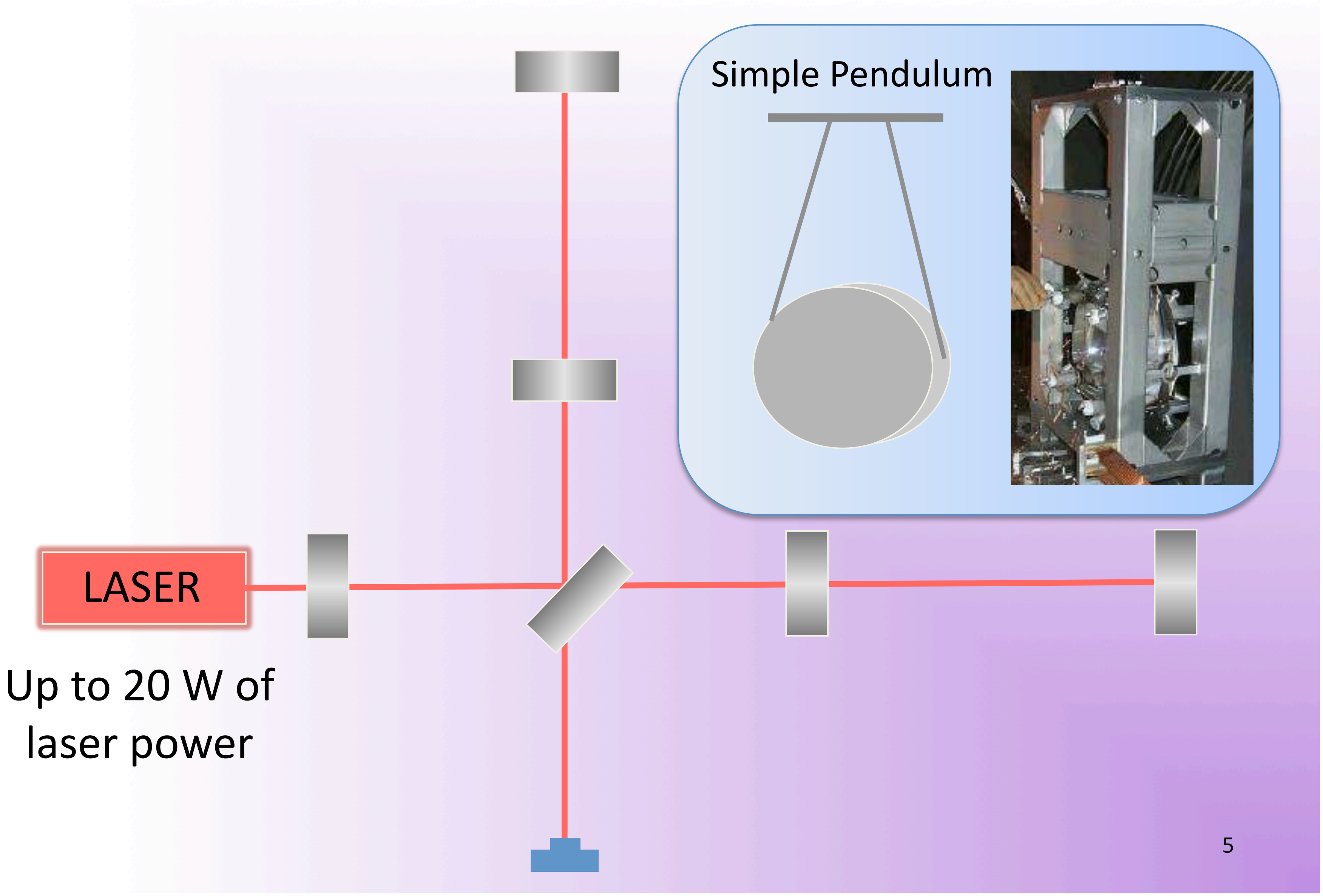
$0^{-9}$ torr



✓Hanford–

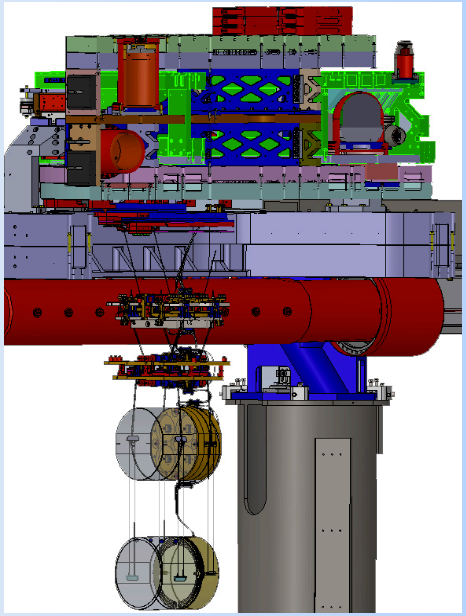
✓**10 ms** if traveling at the speed of light

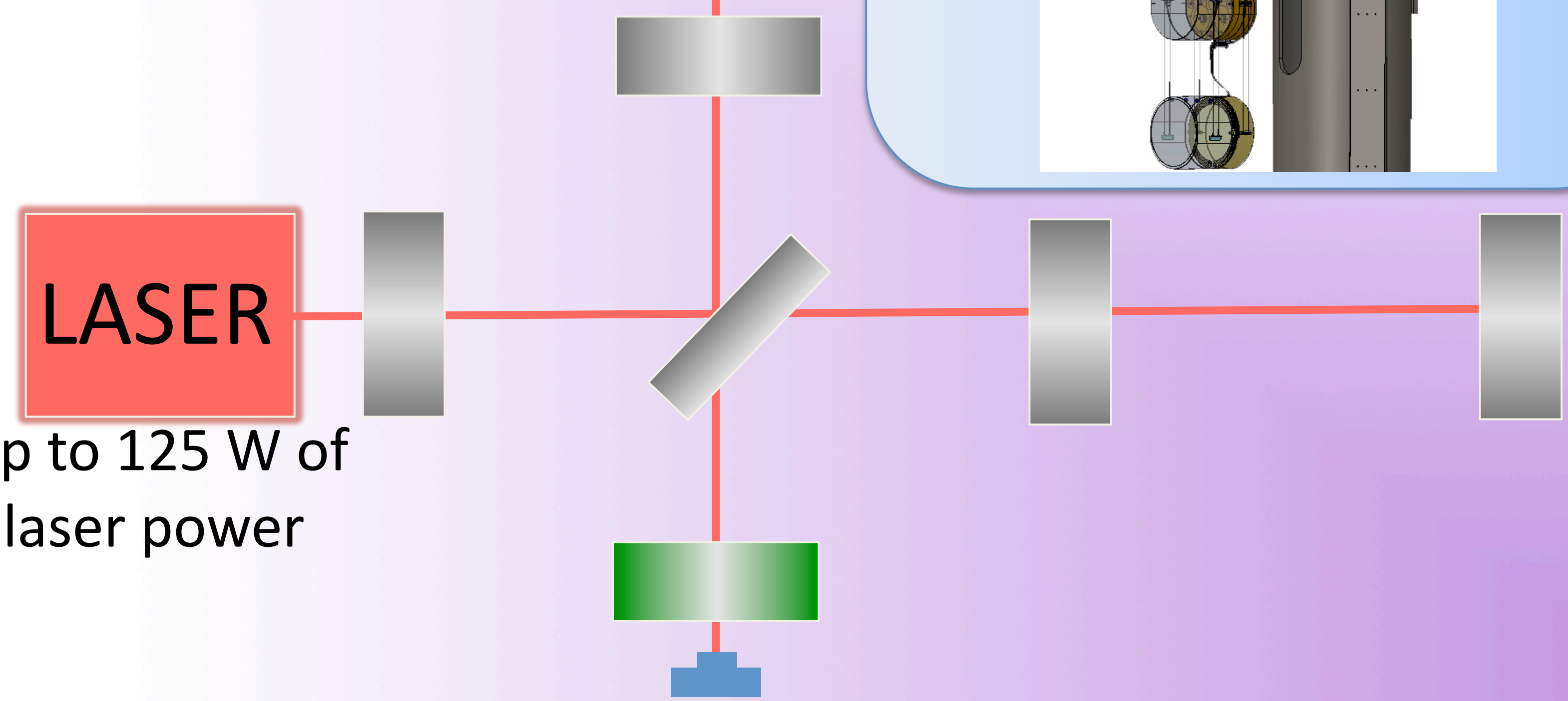
# How LIGO looked like (2001-2010)



# Advanced LIGO in a Nut Shell

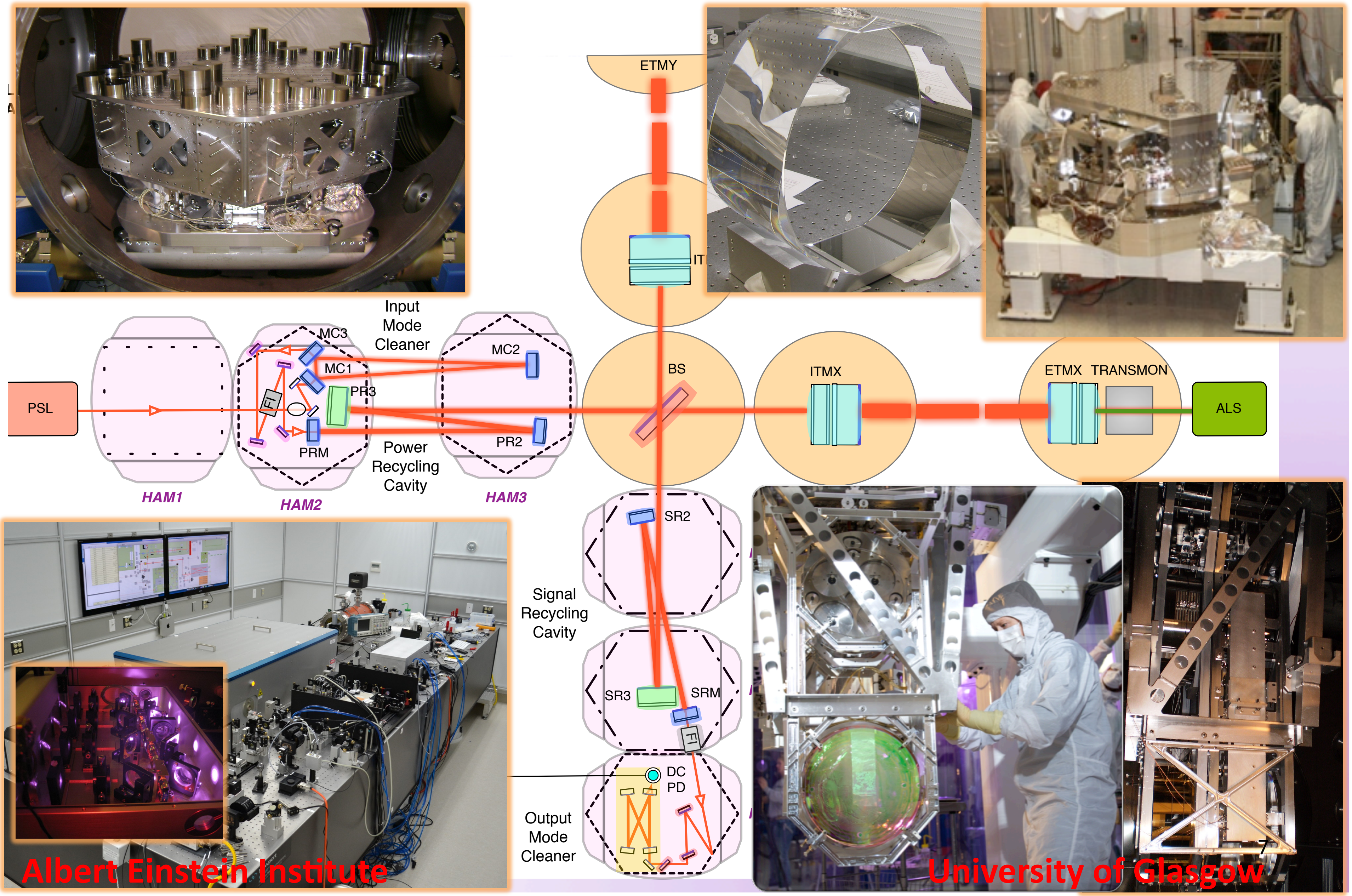
- ✧Larger mirrors
- ✧More laser power
- ✧Less seismic noise
- ✧Better optical layout



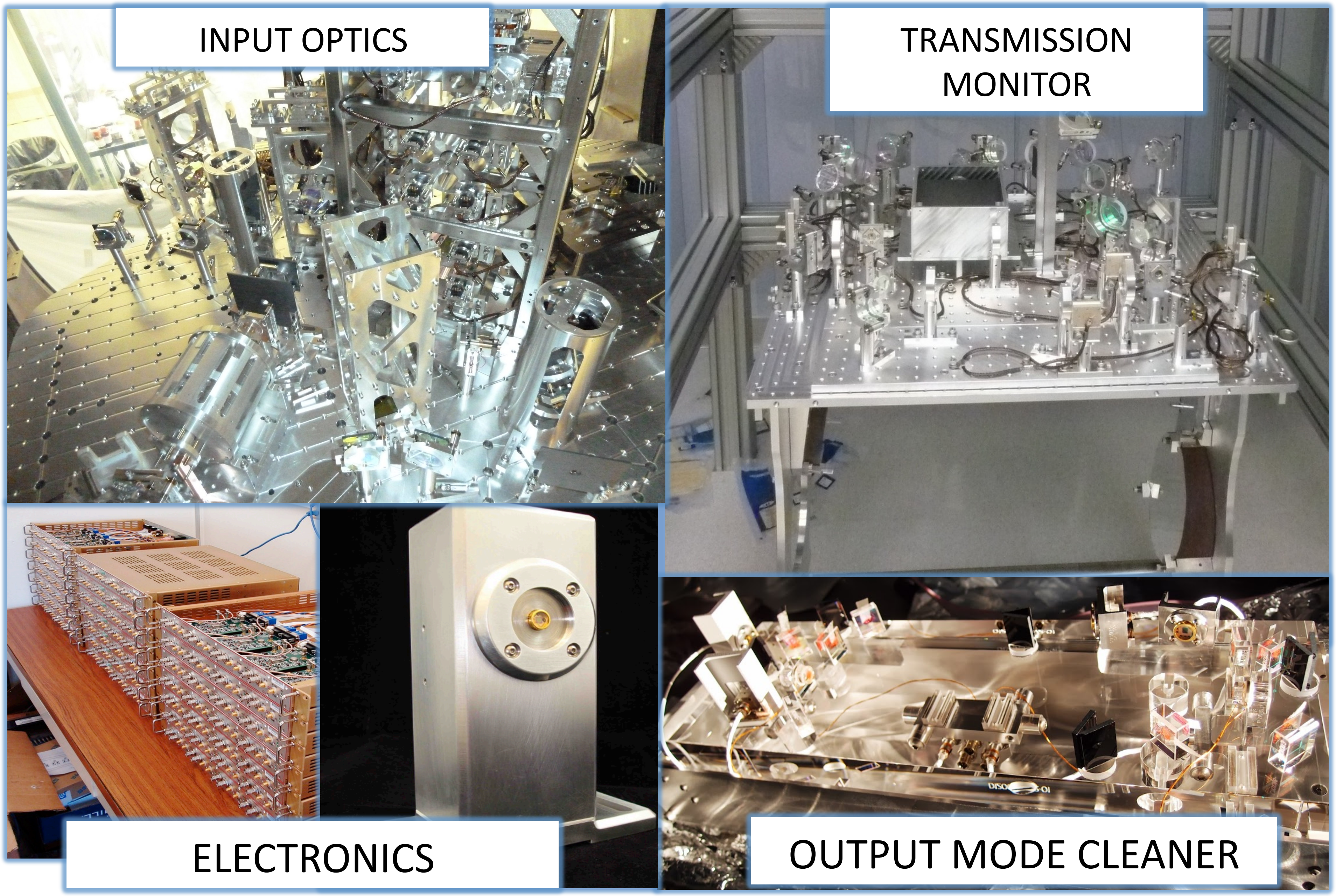



Up to 125 W of laser power

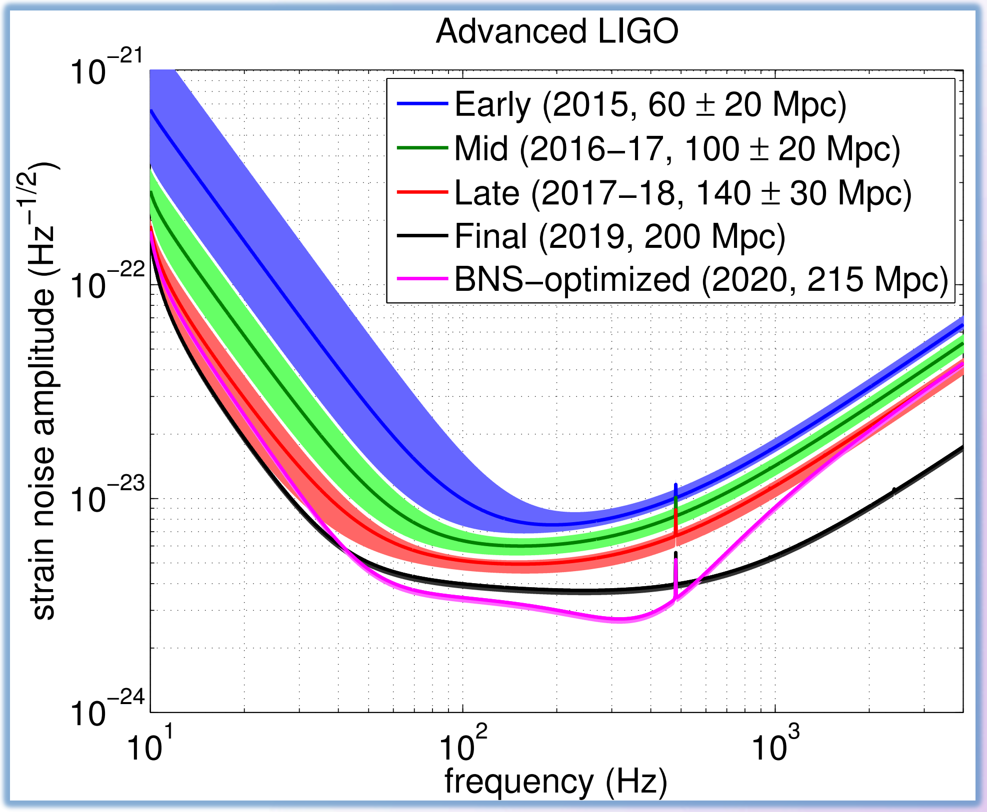
# Advanced LIGO



# “EVERYTHING is better in Advanced LIGO!”



# We want a scientifically interesting sensitivity as soon as possible




http://arxiv.org/abs/1304.0670

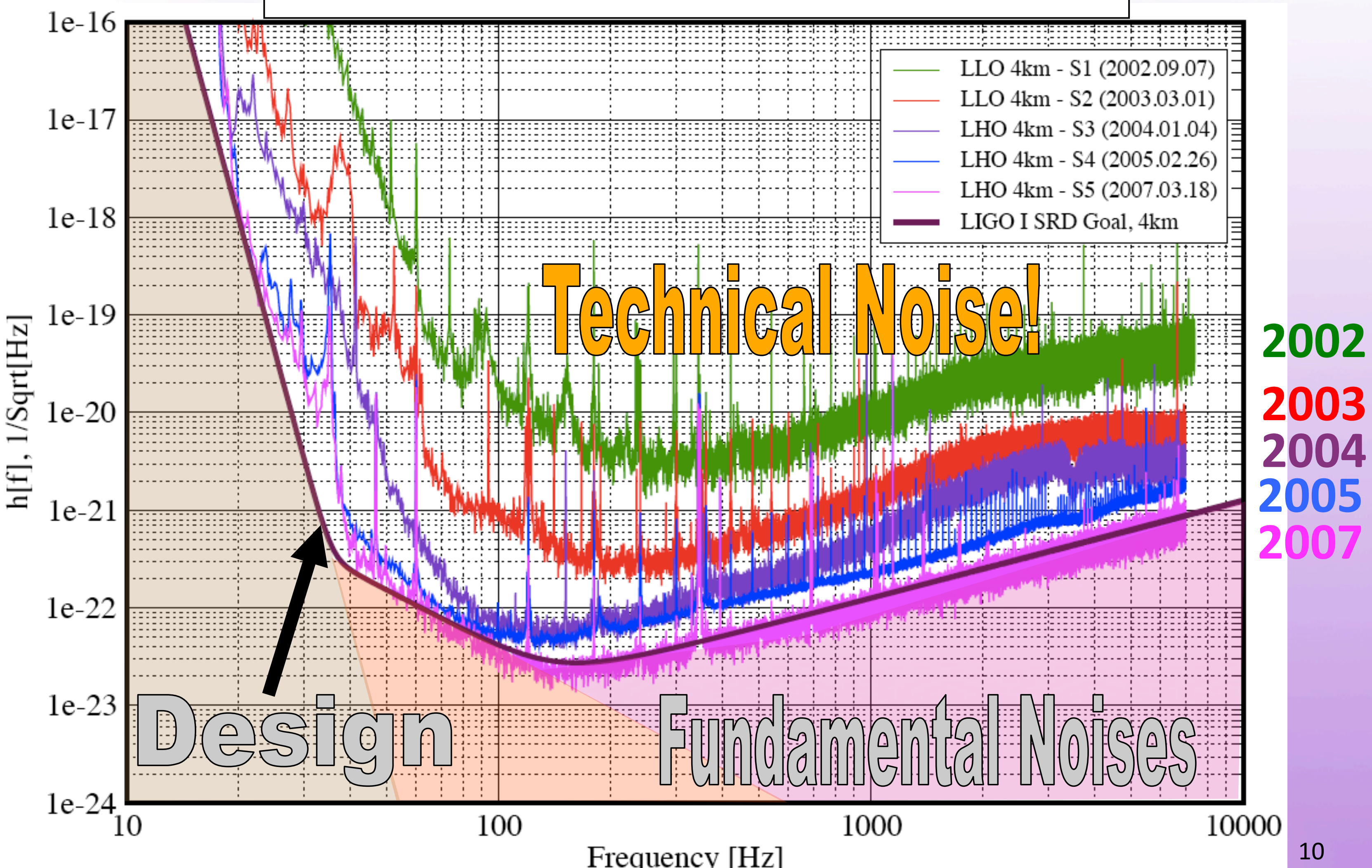
**TENTATIVE** TIMELINE:

- Complete integration by 2014 (interferometer "locked")
- "Early" Science Run in 2015 (~60 Mpc)
- Within a factor of 2 of design sensitivity by 2016 (~100 Mpc)

**Does it seem slow?**

# It actually took longer the first time..

LIGO: First lock at the end of **2000**…



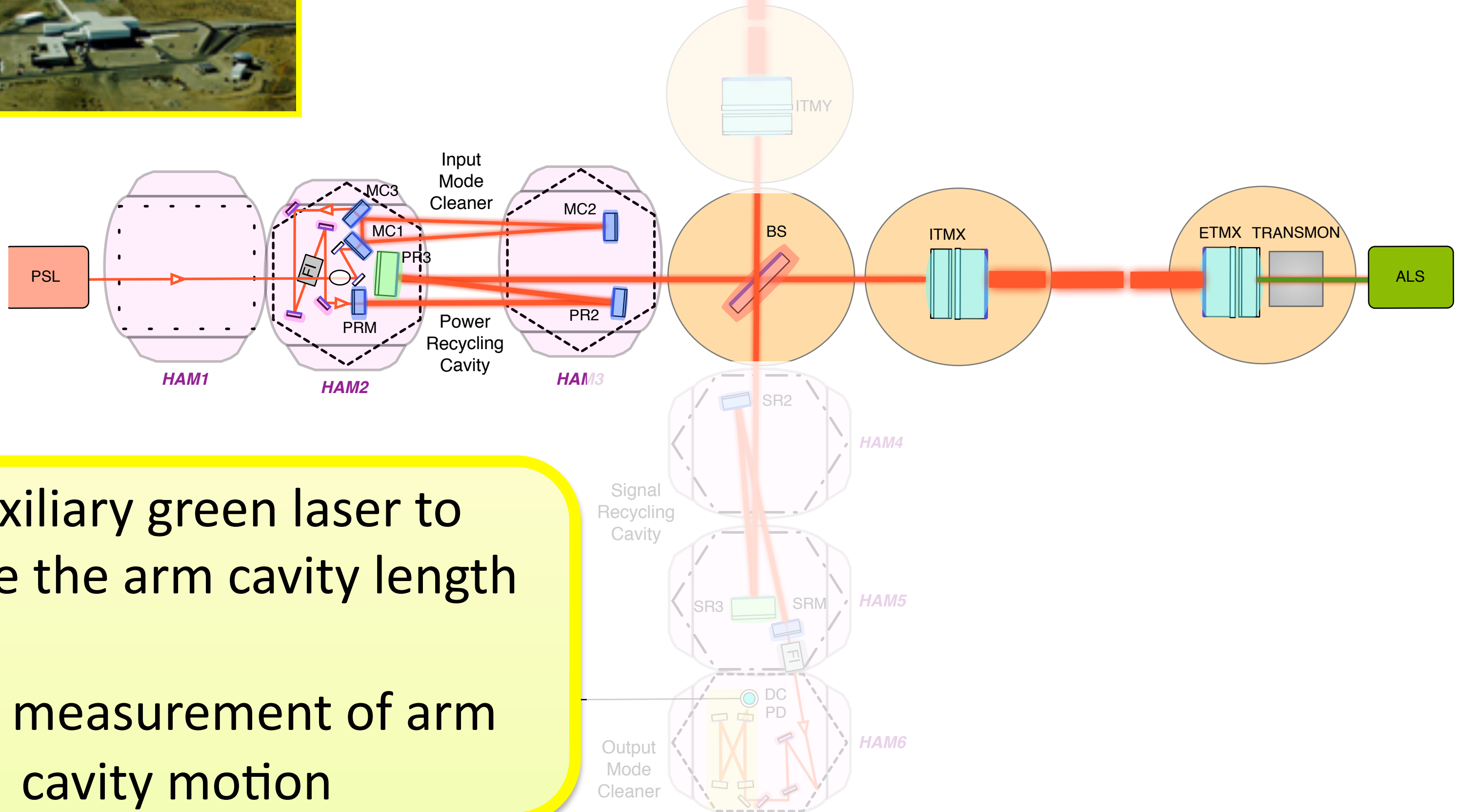
# …but this time will be different!

## Advanced LIGO Installation and Commissioning Strategy:

✧Extensive "standalone" testing before installation
✧Installation of "new" things as soon as possible
✧Configurations of increased complexity
✧Parallel effort between Hanford and Livingston
✧Better design and engineering informed by LIGO, more experienced staff

It took 4 months to lock the input mode cleaner cavity in LIGO, it took less than 1 week in Advanced LIGO (the first time at Livingston), more like 1 day the second time at Hanford

# "Half Interferometer" in progress @ Hanford (now one arm, in the fall the other)

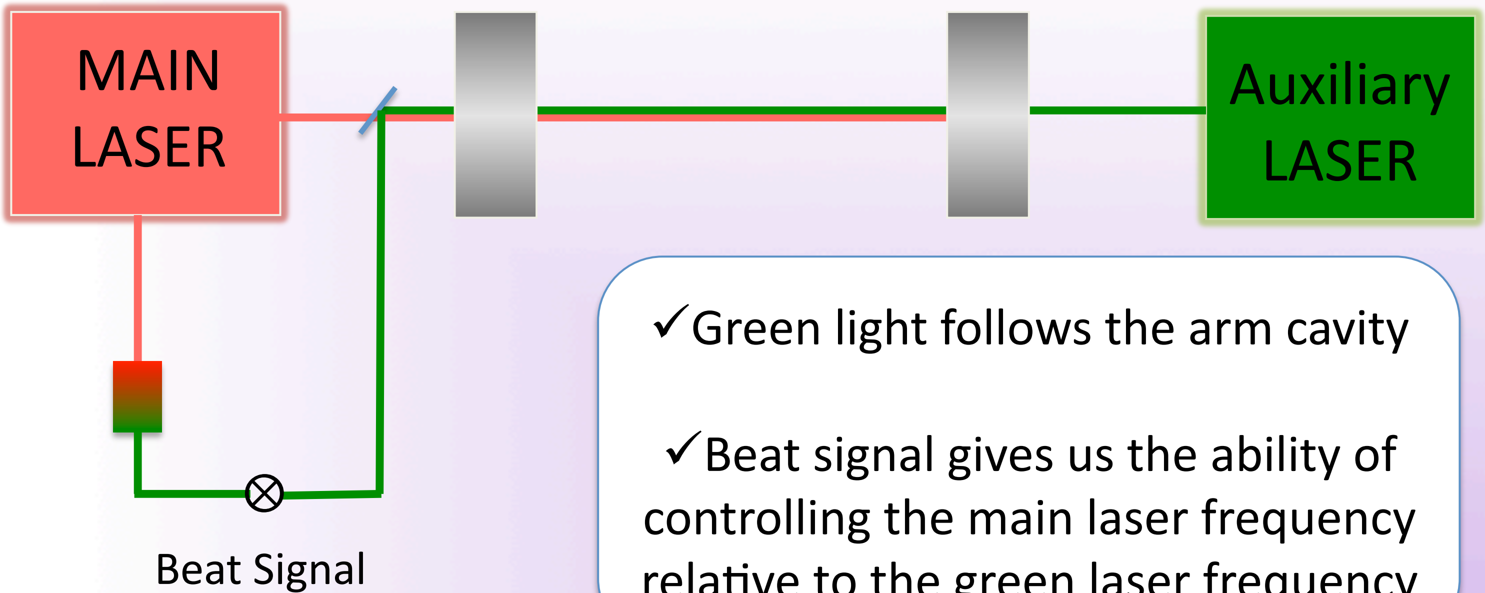




✓Auxiliary green laser to stabilize the arm cavity length

✓First measurement of arm cavity motion


# "Arm Length Stabilization" System

in collaboration with the Australian National University




✓Green light follows the arm cavity

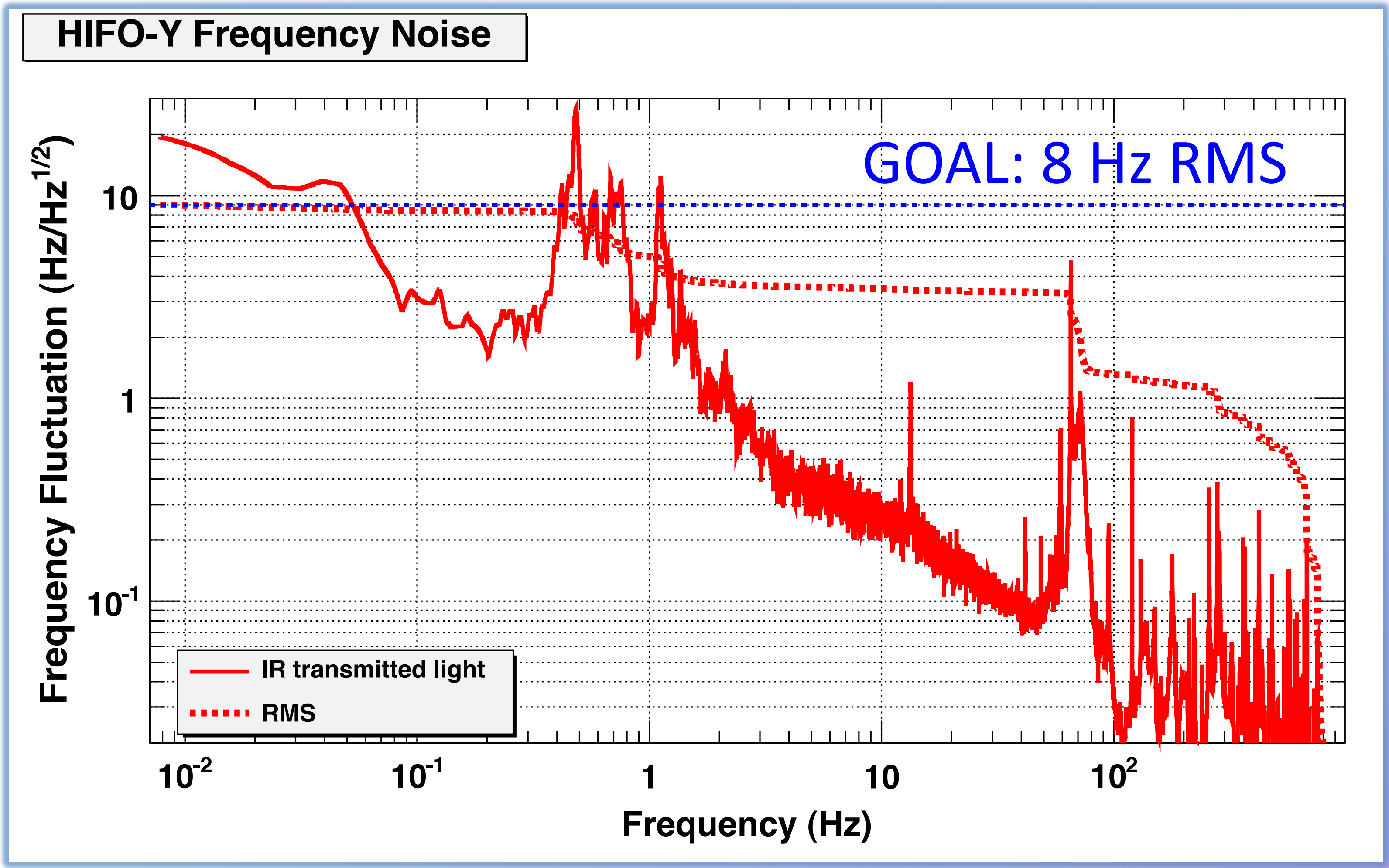
✓Beat signal gives us the ability of controlling the main laser frequency relative to the green laser frequency

Green light won't be used in "science mode" but it will help us to bring the interferometer on its working point reliably

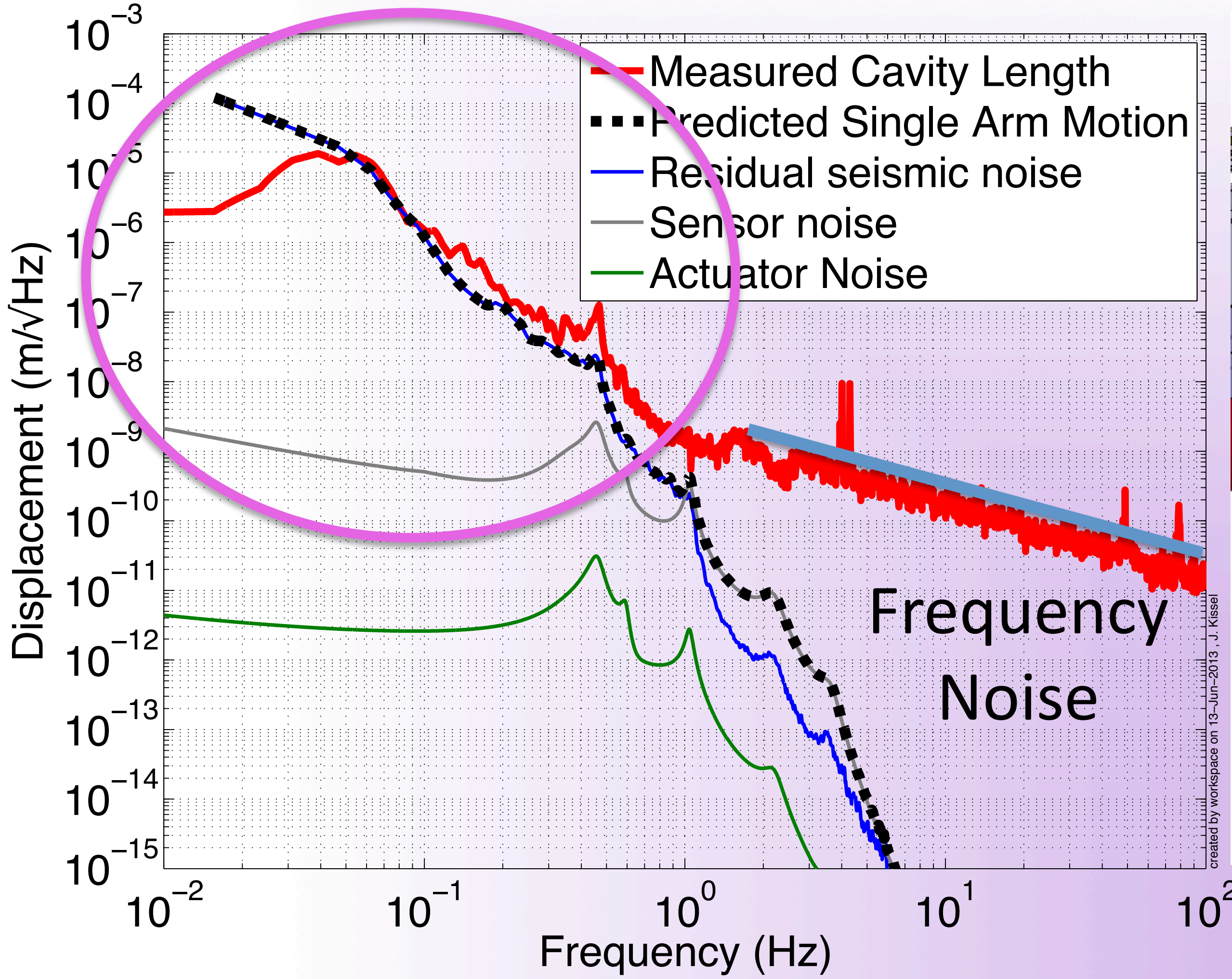
C3: Tuesday, 17:18 - 17:36 **Adam Mullavey (LIGO Livingston)**
The Arm Length Stabilization System for Advanced LIGO Lock Acquisition

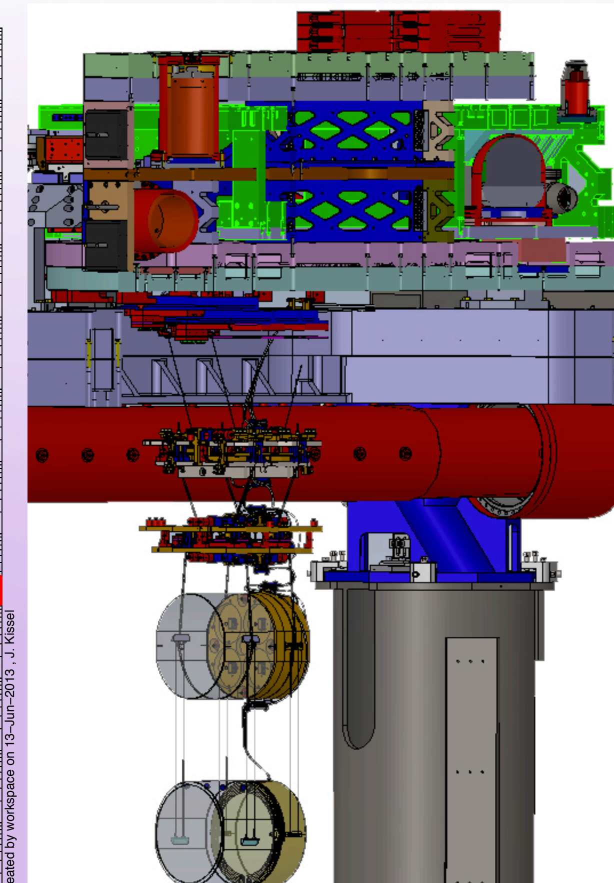
# "Arm Length Stabilization" System


Frequency fluctuations of main laser light is already "good enough" (1/10 of the cavity linewidth), "noise hunting" still in progress

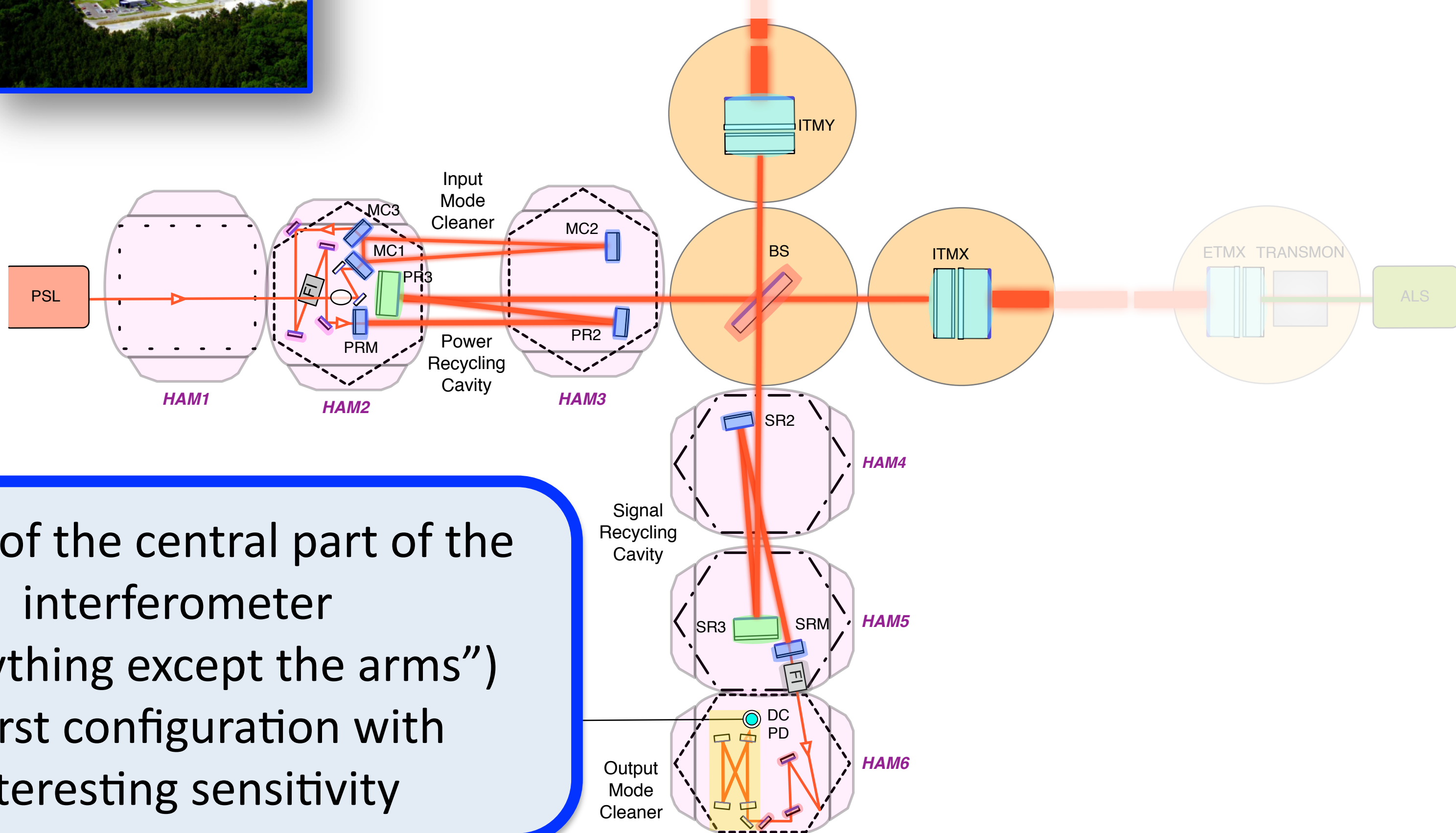


# Cavity motion in good agreement with model (Jeff Kissel, MIT)

# “Short” Interferometer in progress @ Livingston (Dual Recycled Michelson Interferometer)

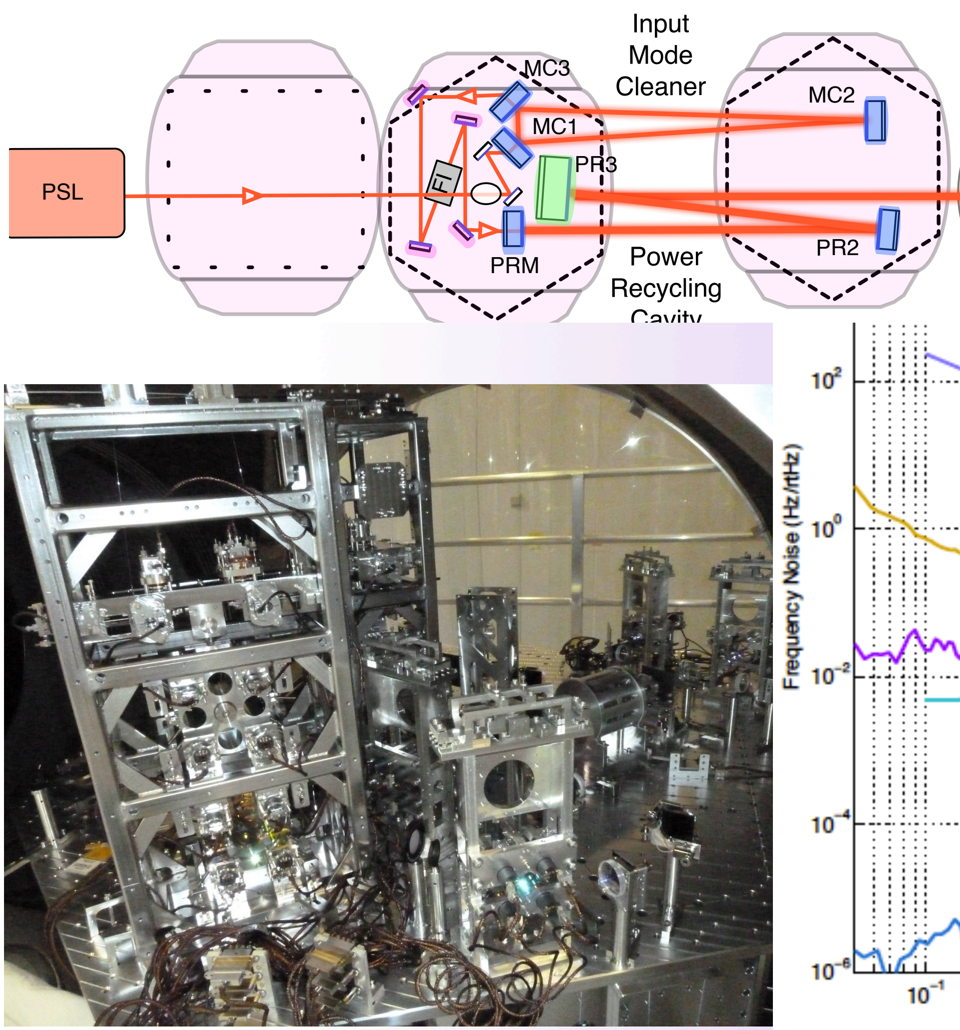

✓ Lock of the central part of the interferometer (“everything except the arms”)

✓ First configuration with interesting sensitivity

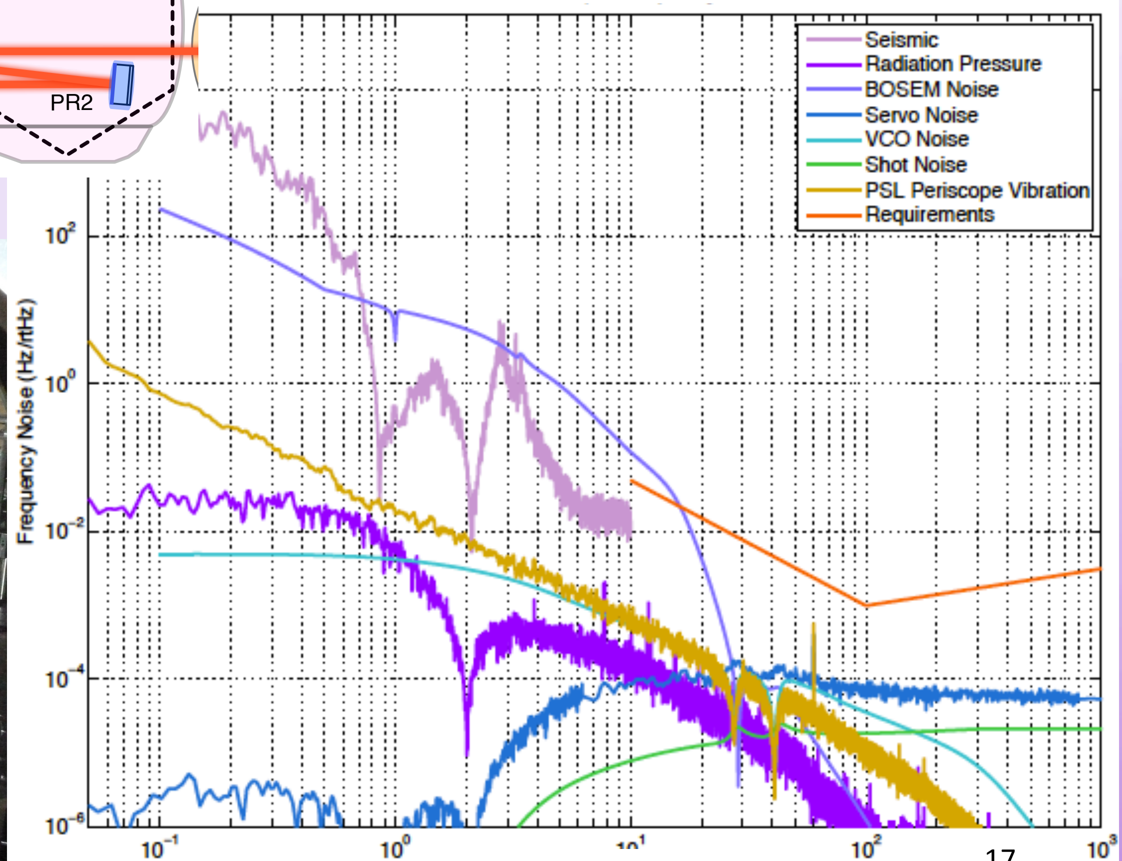

# The Input Mode Cleaner

C3: Tuesday, 17:00 - 17:18 **Chris Mueller (University of Florida)**

Characterization of the Input Optics for the Advanced LIGO Detectors



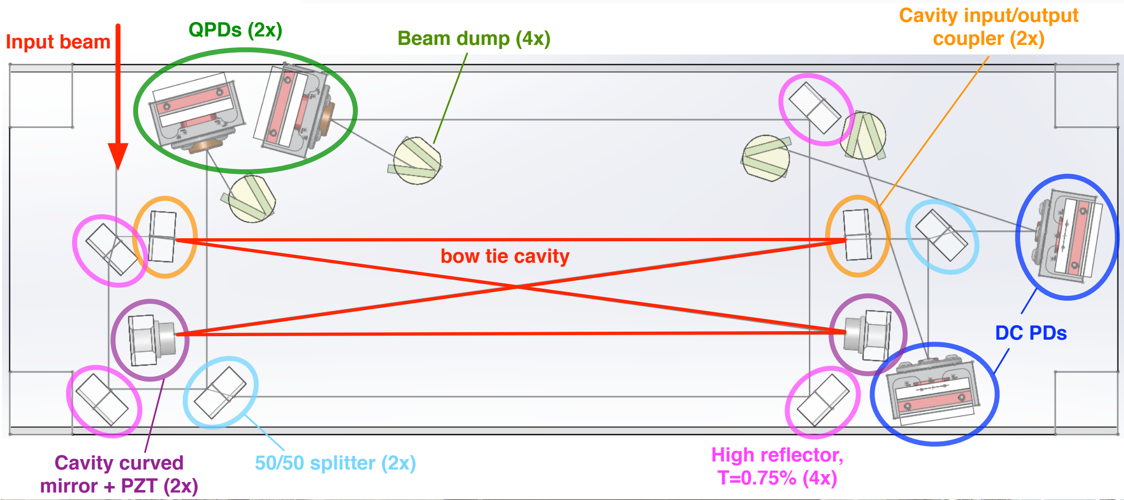

MODE CLEANER OUTPUT FREQUENCY NOISE (Hz)

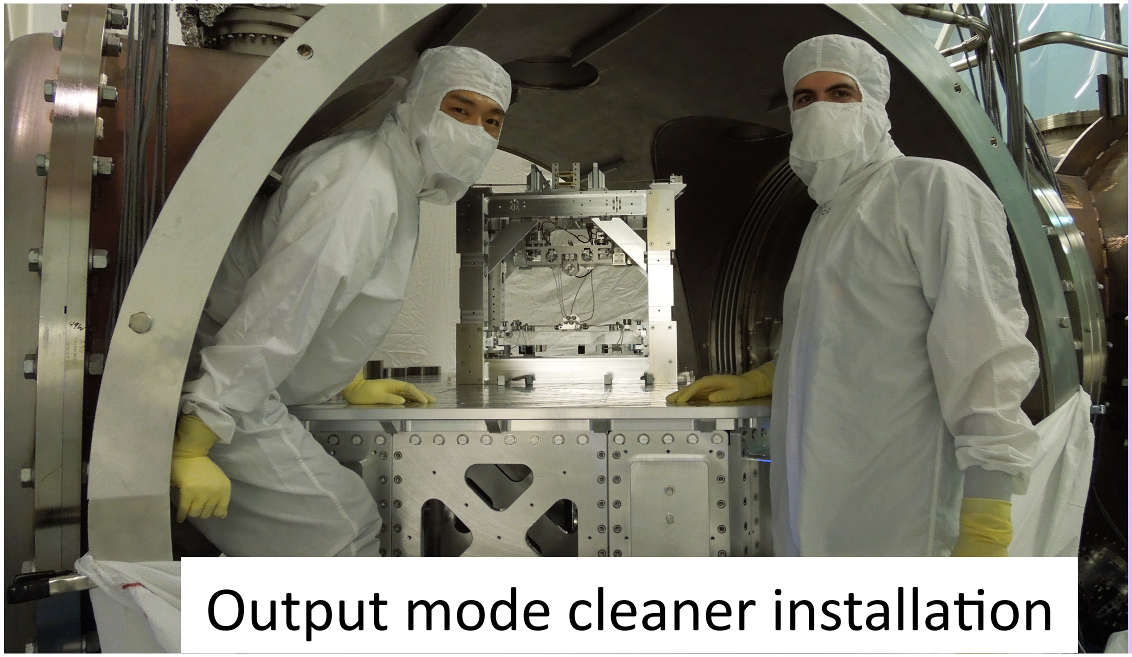



FREQUENCY (Hz)

# Dual Recycled Michelson Interferometer


The aLIGO Output Mode Cleaner

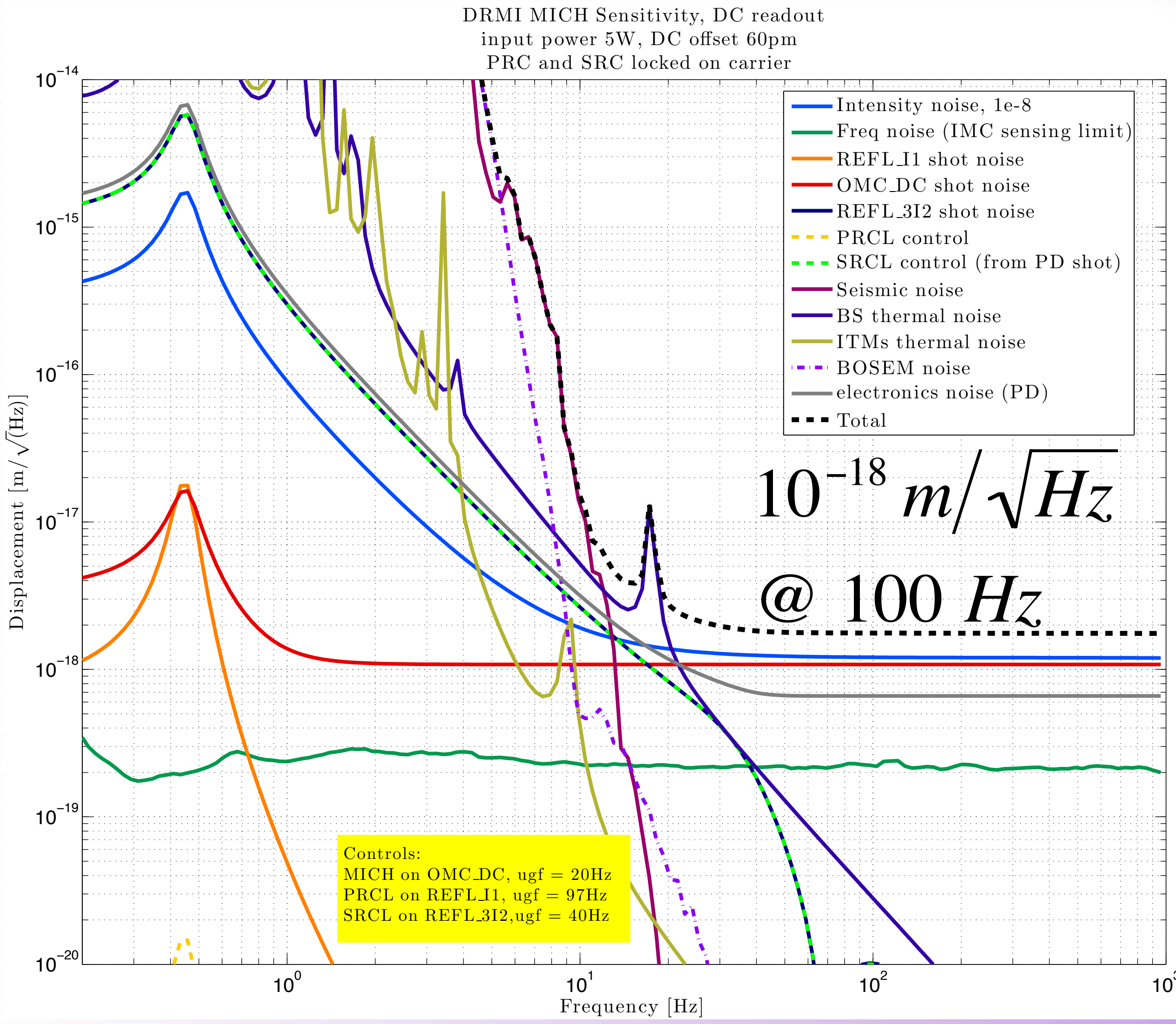


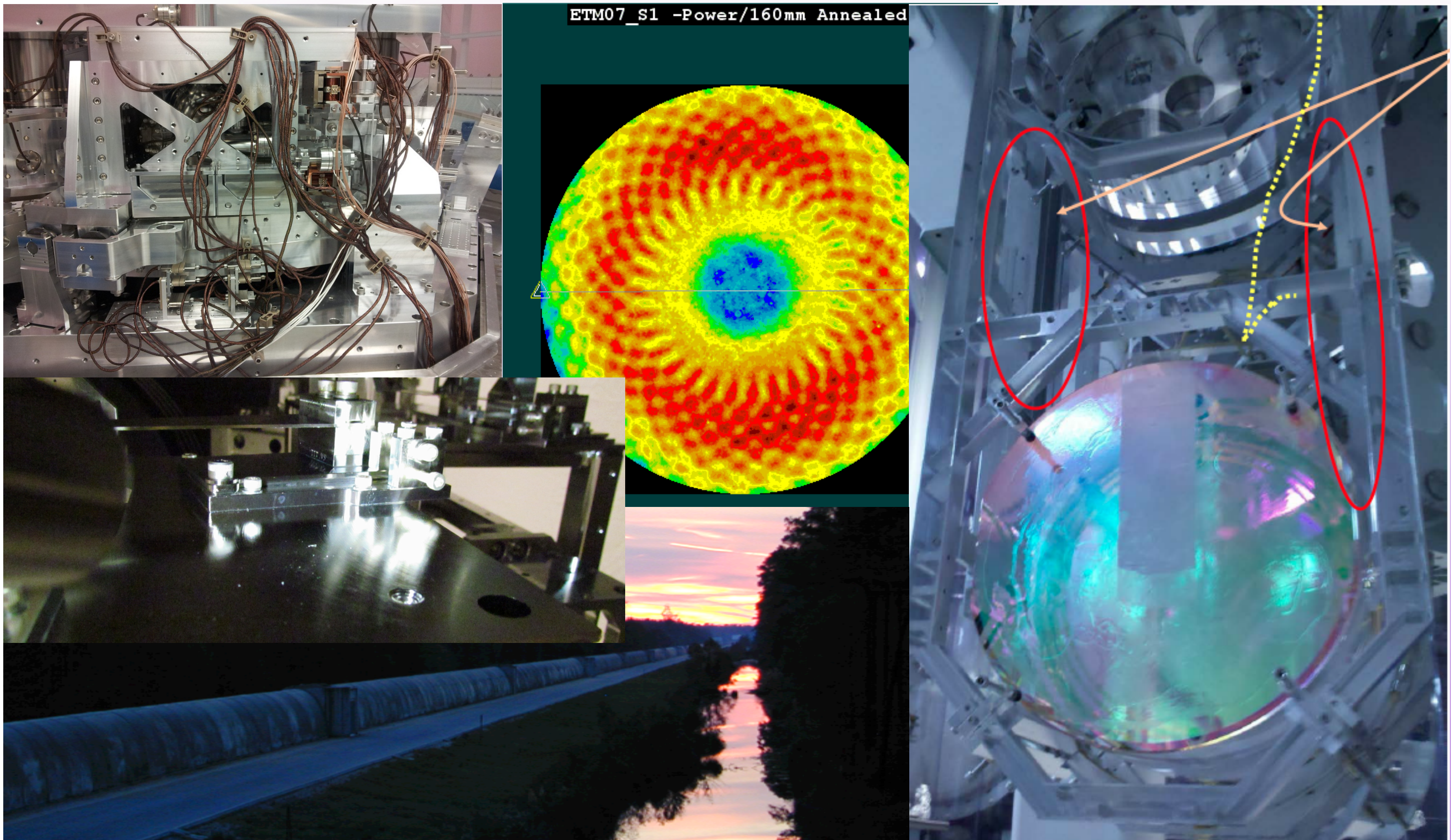
Output mode cleaner installation

- ✓ Installation almost completed
- ✓ Commissioning just started
- ✓ Short Michelson already locked

# DRMI Noise Budget Model (Anamaria Effler, LSU-LIGO Livingston)

# Bumps in the road, but no showstoppers



# Outlook

✧ Within a couple of months:

- ✓ each "type" of chamber will have been populated at least at one of the two sites
- ✓ main steps of lock acquisition sequence will have been tested, full locking in progress at the Caltech 40m prototype

✧ "Second-site" testing to follow

(DRMI @ LHO, Arms @ LLO)

✧ Full Interferometer Lock:

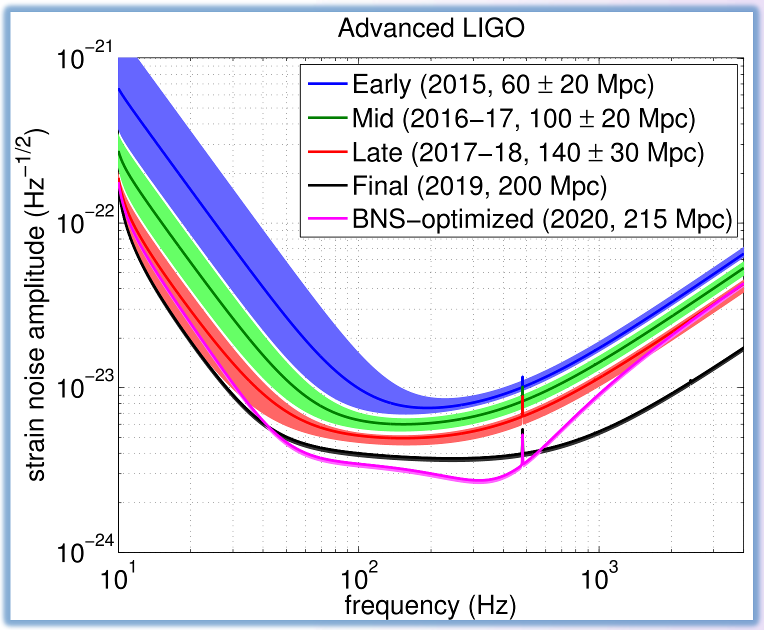
- ✓ Starting February 2014 @ LLO
- ✓ Starting May 2014 @ LHO

✧ On track for Advanced LIGO "acceptance" target

- ✓ "2 hours of lock", end of 2014

# Detection Rates

| 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 deg² | 20 deg² |
|---|---|---|---|---|---|---|---|---|
| 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 |




**Neutron Star Binaries:**

Advanced LIGO: ~ 200 Mpc

*"Realistic rate" ~ 40/year*

Class. Quant. Grav. **27**, 173001 (2010)

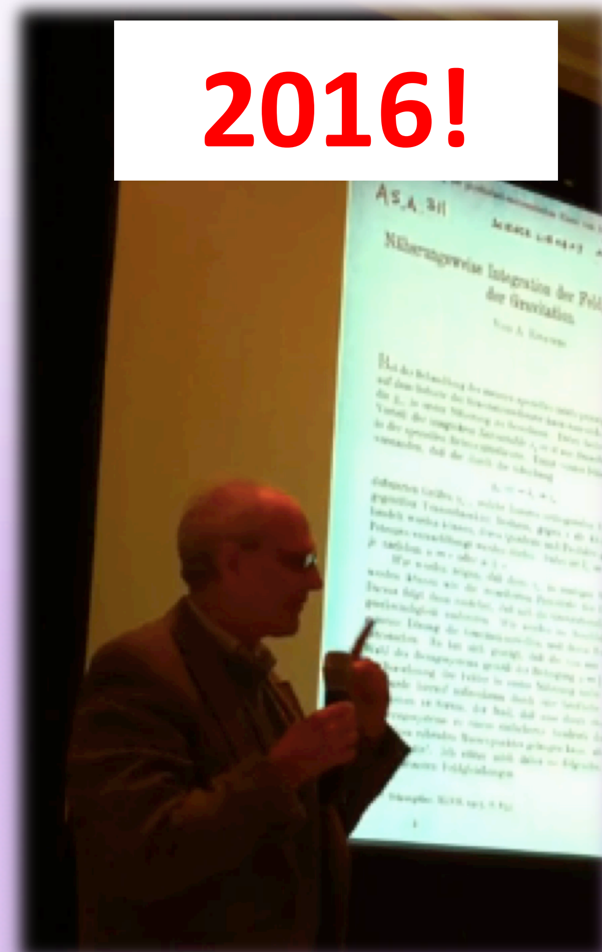
(Initial LIGO: ~15 Mpc, Rate ~1/50years)



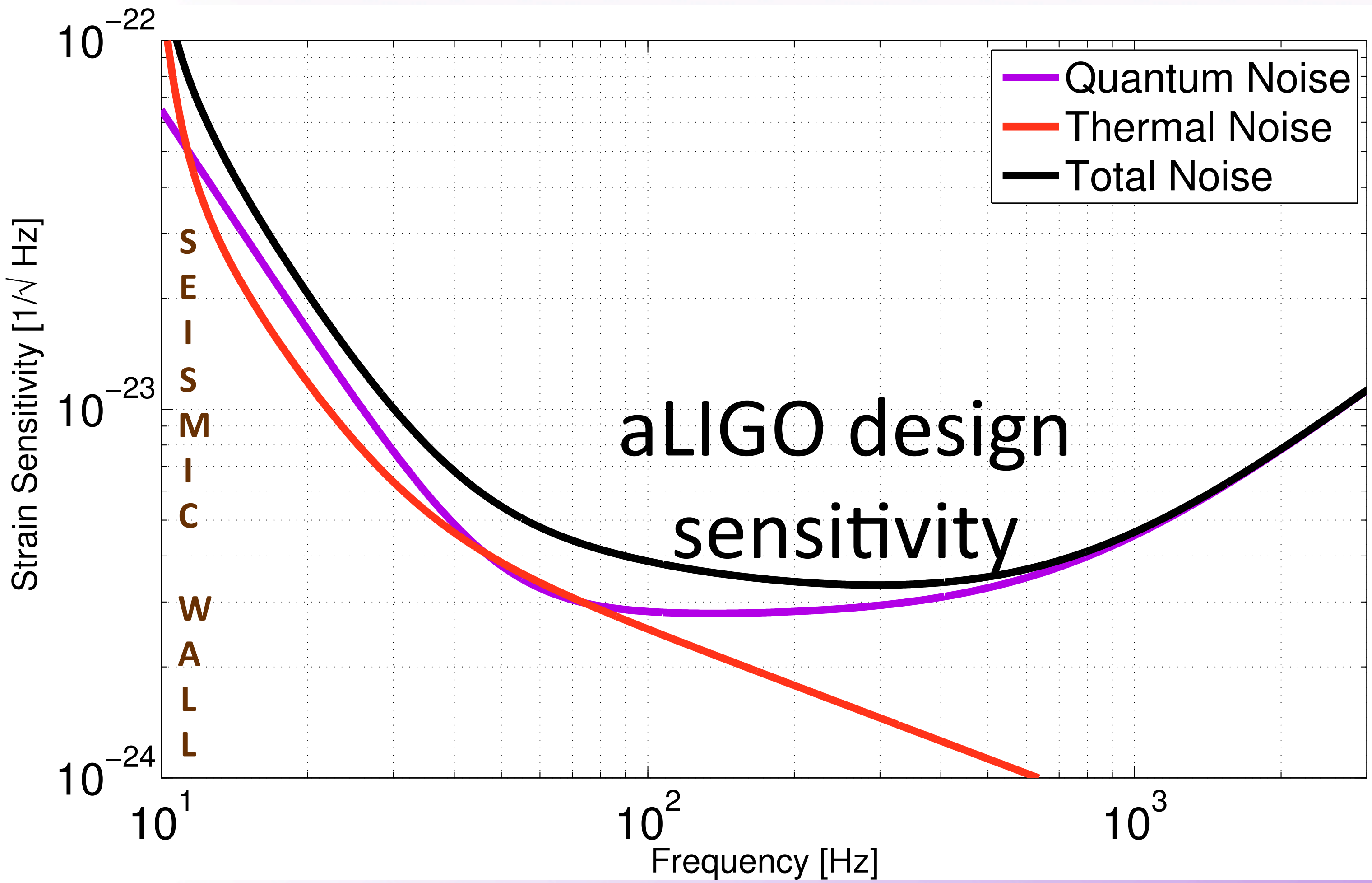
http://arxiv.org/abs/1304.0670

# The Message

- ✧The sooner we detect gravitational waves, the better!
- ✧Advanced LIGO aims to reach a scientifically interesting sensitivity as soon as possible (~60 Mpc @ 2015, ~100 Mpc @ 2016)
- ✧Several pieces of Advanced LIGO have been already installed and commissioned...
- ✧Still a lot of work to do, but so far so good!



# By the way, is Advanced LIGO the best that we can do?




C3: Tuesday, 17:54 - 18:12 Sheila Dwyer (LIGO Hanford Observatory)

[Quantum noise reduction using squeezed states in LIGO]

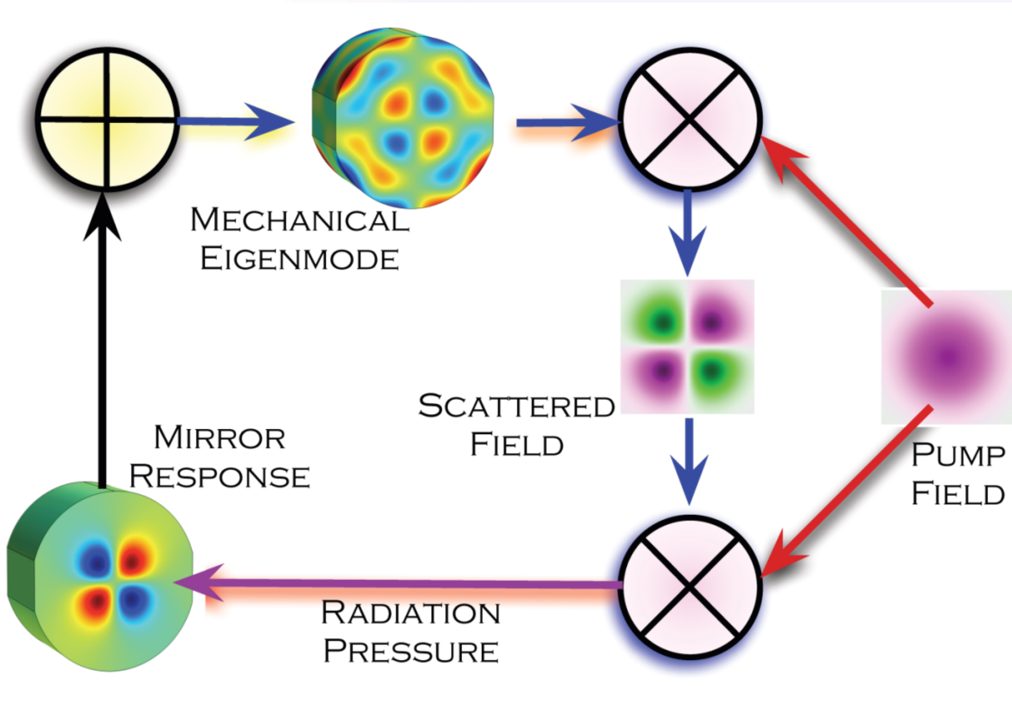
# Spare slides

# Principal Technical Risks

- **High power operations**
  - Absorption & thermal compensation; potential parametric instability
- **Required displacement noise levels not verified directly**
  - Essentially impossible to test in subscale setups
  - Thermal noises (suspension and mirror coating): rely on design calculations; material parameter measurements; scaled noise tests
  - Technical noises
- **Increased complexity**
  - Number of control loops x10 larger than in iLIGO
  - Mechanical systems have many more degrees-of-freedom: Test Mass Quad suspension has 48 DOF, vs. 6 in iLIGO

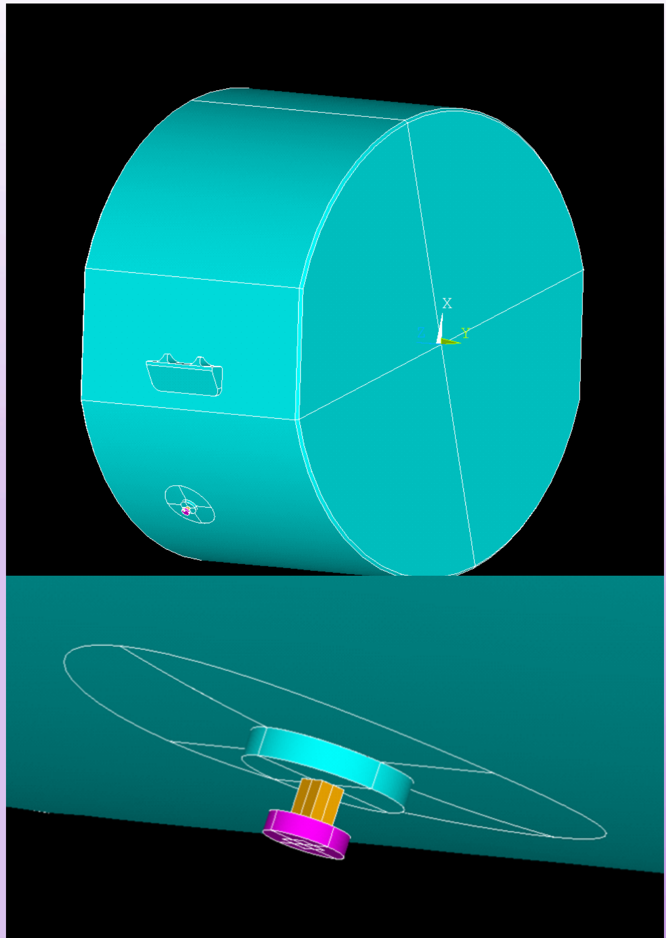
# Parametric Instabilities

Slawek Gras (LIGO-MIT)




**1.** Test mass mechanical mode scatters fundamental mode (pump) into the higher order mode

**2.** After round trip scattered mode returns to the test mass and couples via radiation pressure in the mechanical mode

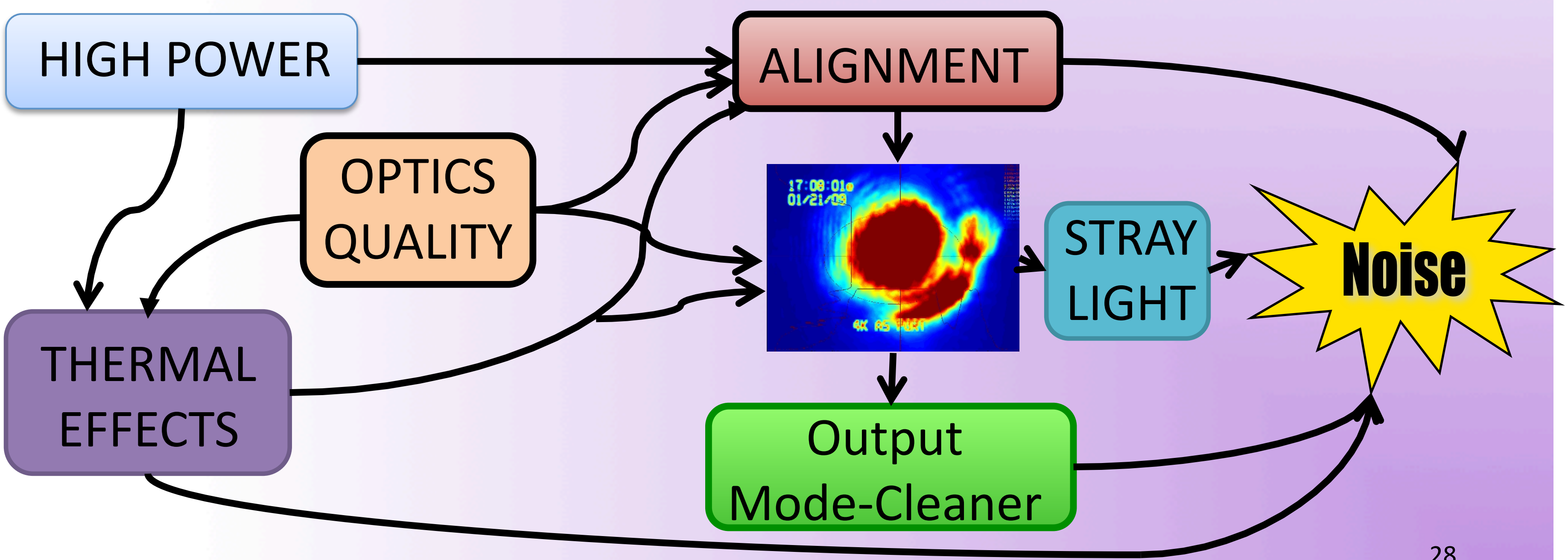


POSTER: Acoustic mode damper for parametric instabilities control C3.16

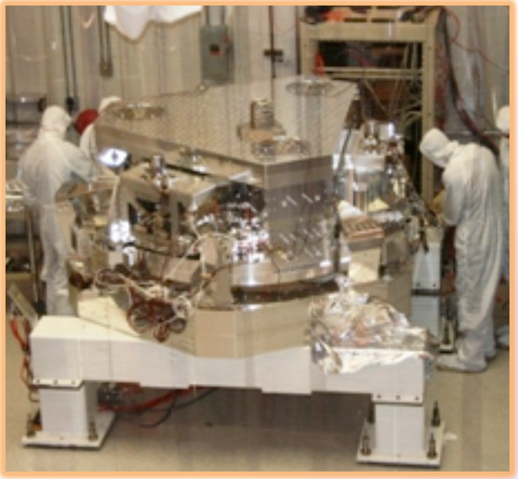
# What we call “commissioning”: from installation to **science** data

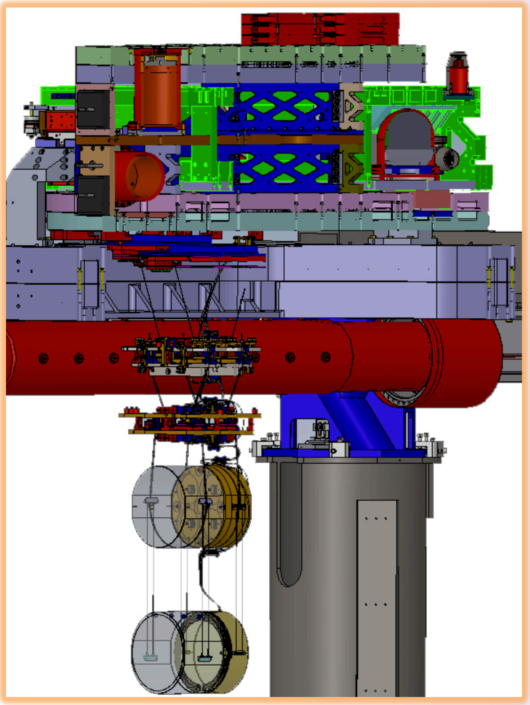
## Understand and fix an entanglement of noise coupling mechanisms

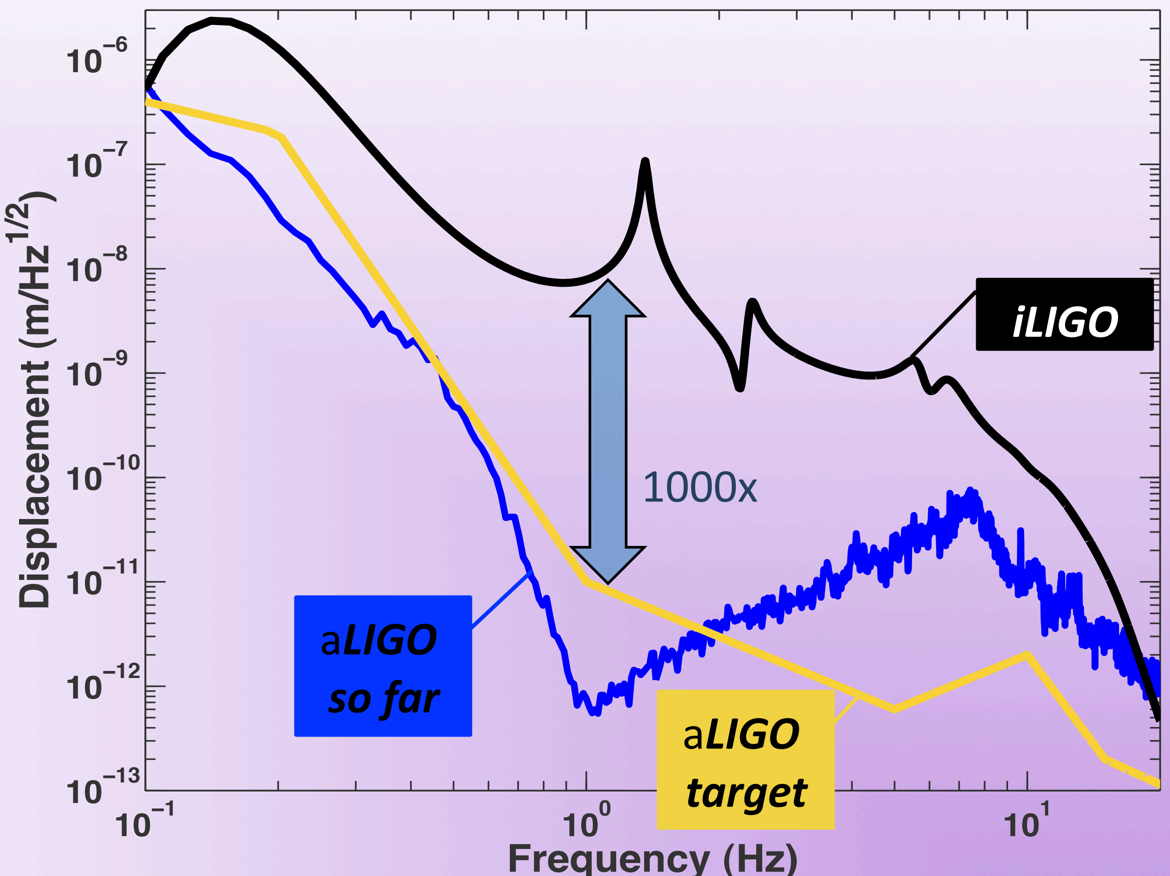
Example from Enhanced LIGO



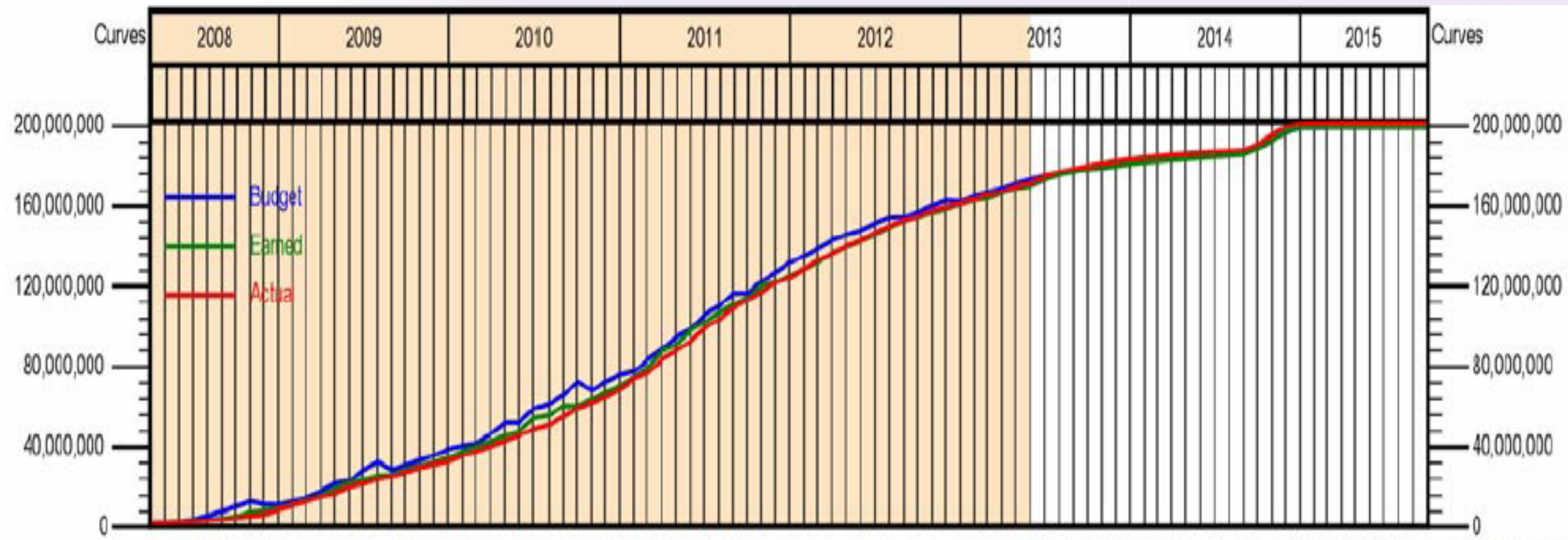
# Seismic isolation performance





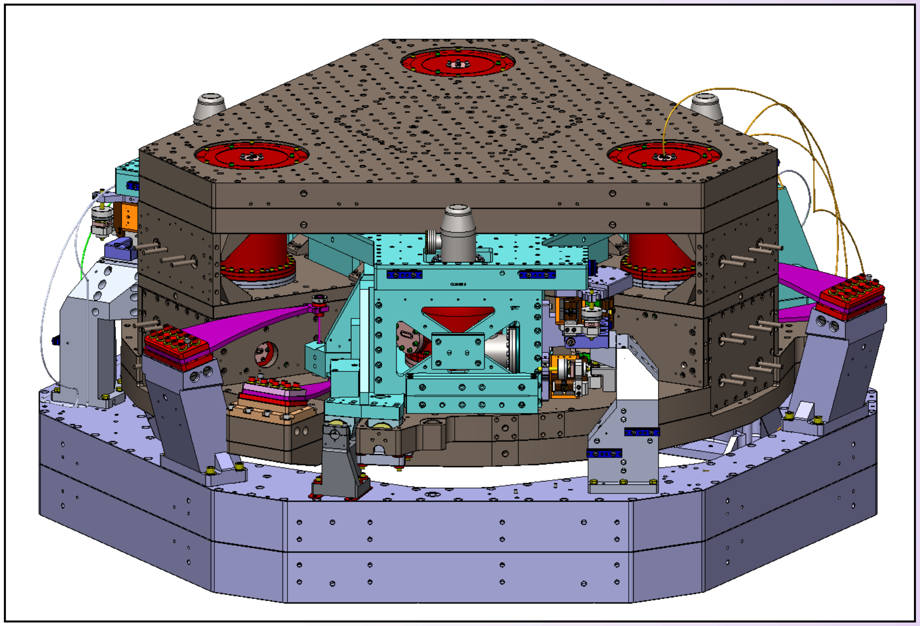
# Advanced LIGO is 85.4% complete



# The In-vacuum Seismic Isolators (ISI)

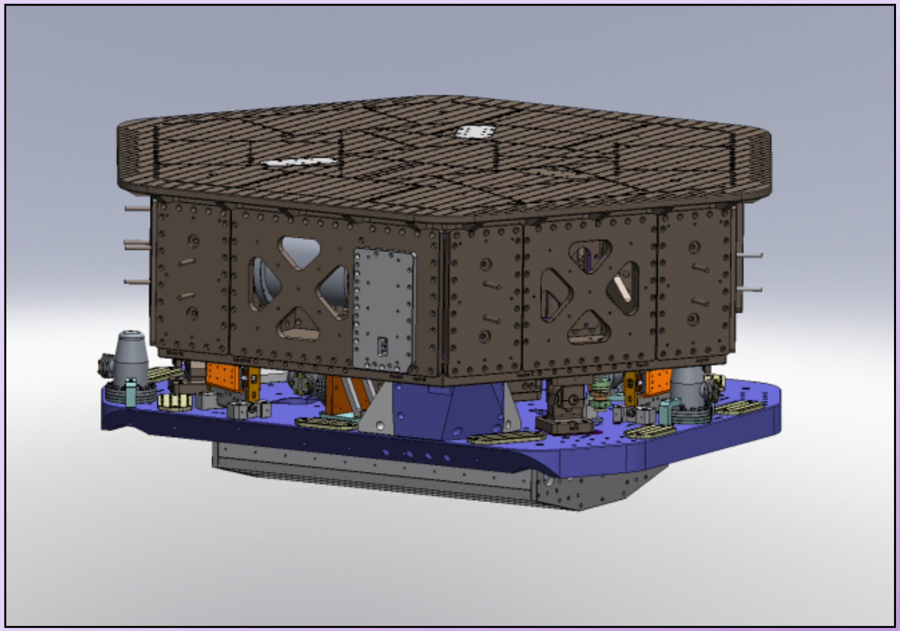
## BSC ISI (Core Optics)

- Two-stage system
- 6 DOF motion per stage
- **Passive isolation**
  2 x 3 Blade springs + wire flexure systems
  Fundamental modes ~ 1Hz
- **Active isolation**
  12 and 15 on-board Displacement and Inertial Sensors, with 12 EM Coil actuators

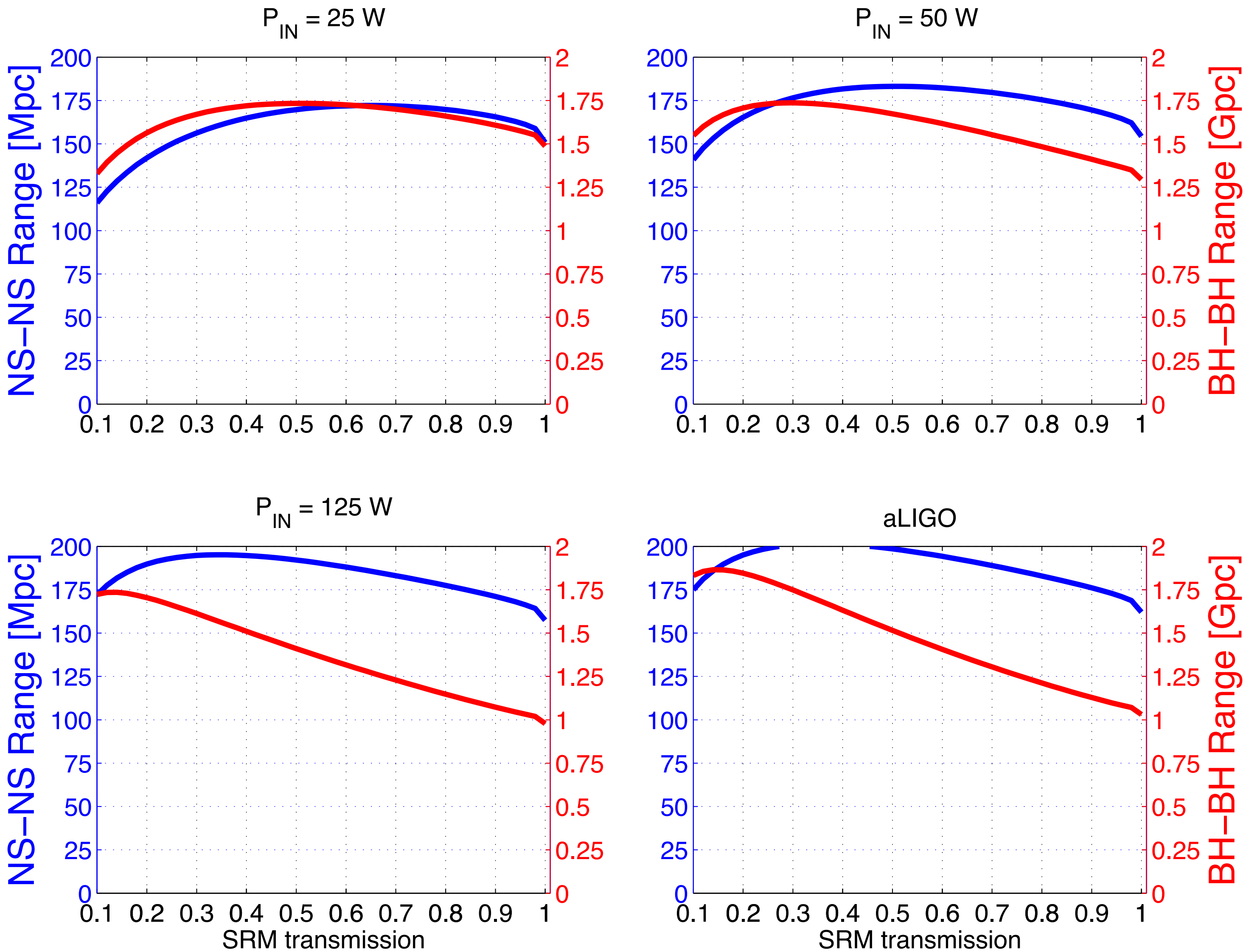


## HAM ISI (IOO Optics)

- Single-stage System
- 6 DOF motion single stage system
- **Passive isolation**
  3 Blade springs + wire flexure systems
  Fundamental modes ~ 1Hz
- **Active isolation**
  6 and 6 on-board Displacement and Inertial Sensors, with 6 EM Coil actuators



# Optimization of SRM transmission



# Optimization of SRM transmission