

The LIGO logo is positioned in the top left corner, featuring the word "LIGO" in a bold, black, sans-serif font. To the left of the text are several white, curved lines that resemble the top of a gravitational well or the curvature of spacetime.

**LIGO**

# Advanced LIGO, Advanced VIRGO and KAGRA: Precision Measurement for Astronomy



Stefan Ballmer

For the LVC

Miami 2012

Dec 18, 2012

LIGO-G1201293



- **Introduction:**
  - What are Gravitational Waves?
  - The brief history of LIGO
  - The Advanced LIGO project
- Where are we now?
- Where are we going?

# The weakness of Gravity

- Gravitational waves produced by orbiting masses:

$$h_{\mu\nu} = \frac{2G}{c^4 d} \ddot{I}_{\mu\nu}$$

- For 2  $1.4M_{\text{Sun}}$  Neutron stars, at 1 Mpc (3 million light years):

$$h = \frac{dL}{L} \approx 3 \times 10^{-21} \left( \frac{f}{100\text{Hz}} \right)^{2/3}$$

$$\text{Flux}_{\text{GW}} \sim 1 \text{ mWatt} / \text{m}^2$$

## The wave's field

- “Ripples in Space-Time”

Amplitude:

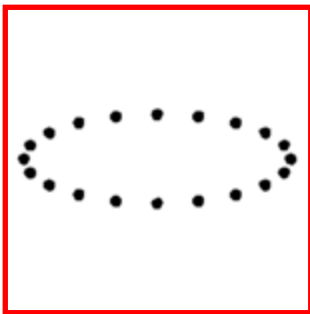
$$dL/L = h$$

- Measureable effect:

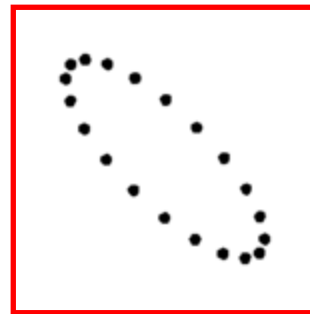
- Stretches/contracts distance between test masses perpendicular to propagation



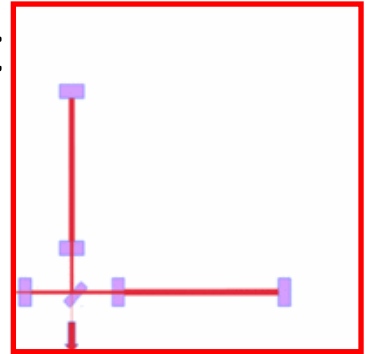
Image credit: Google

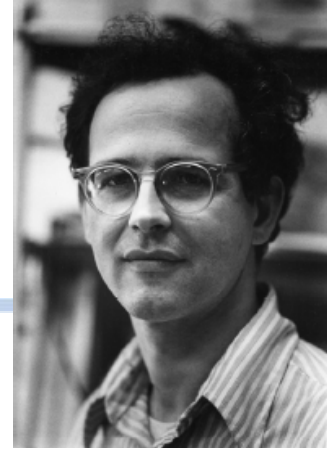


+ polarization

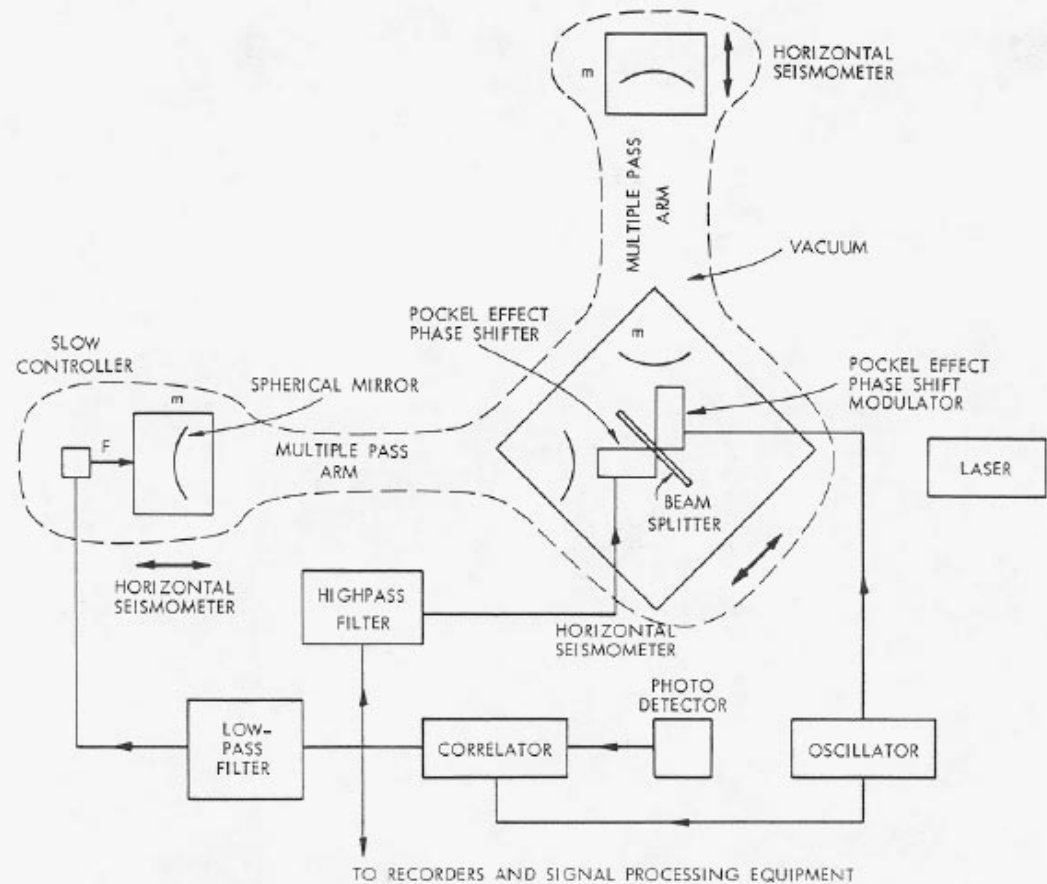


x polarization

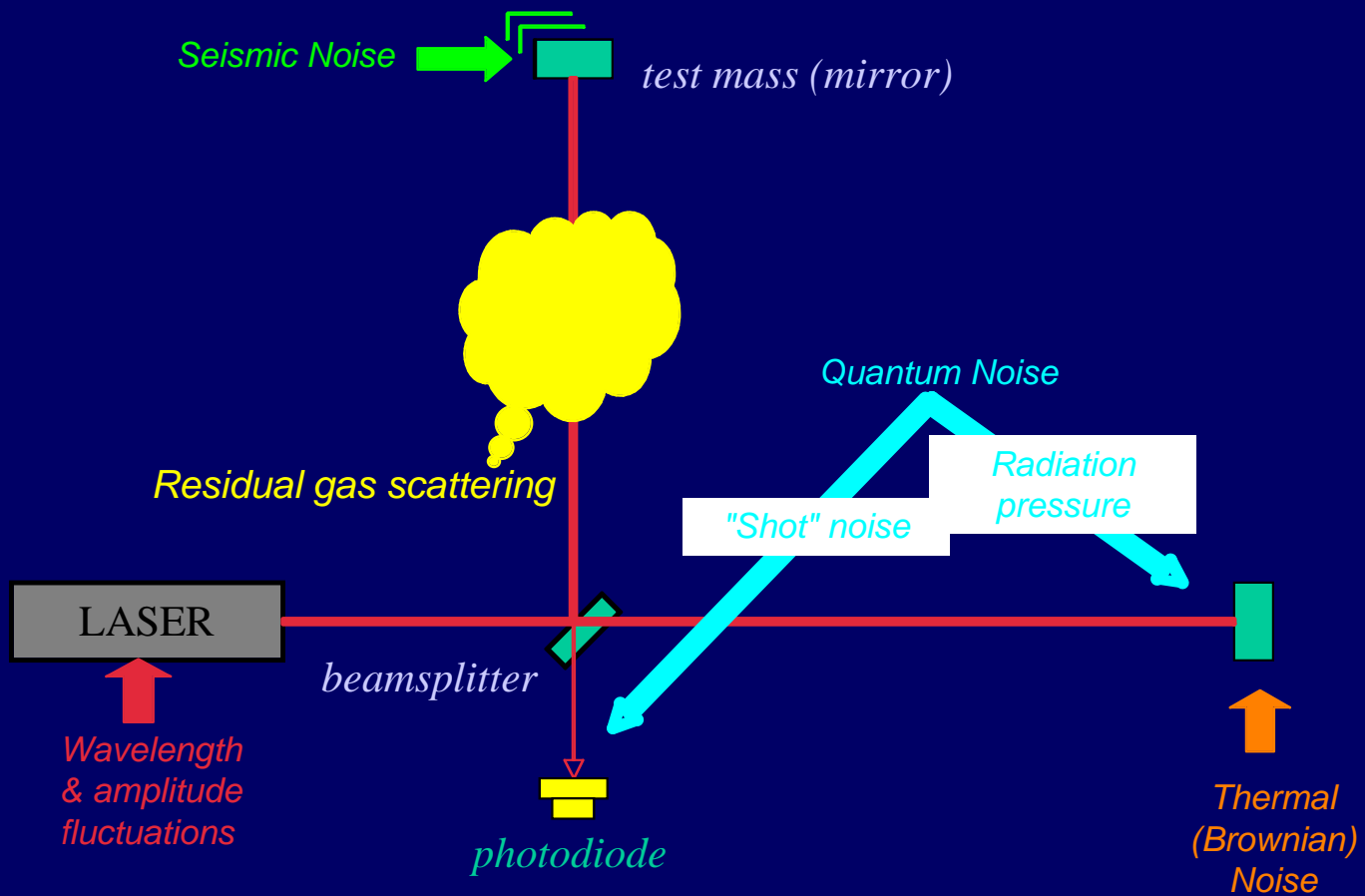




- Electromagnetically coupled broad-band gravitational wave antenna, R.Weiss, MIT RLE QPR 1972
- NSF funding and construction in the 1990's
- Design sensitivity and observation in 2005



# Noise Cartoon

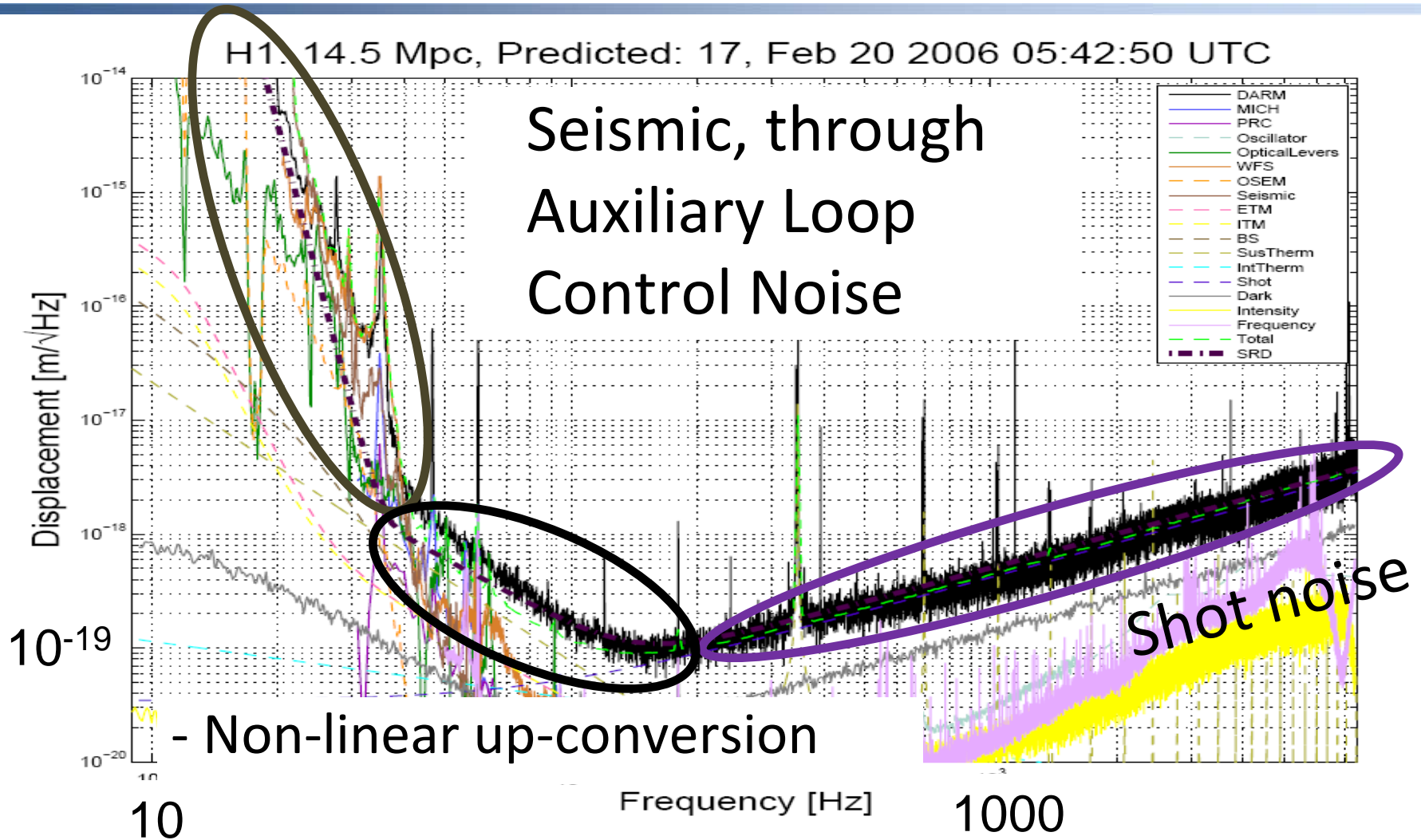




LIGO Livingston  
Observatory

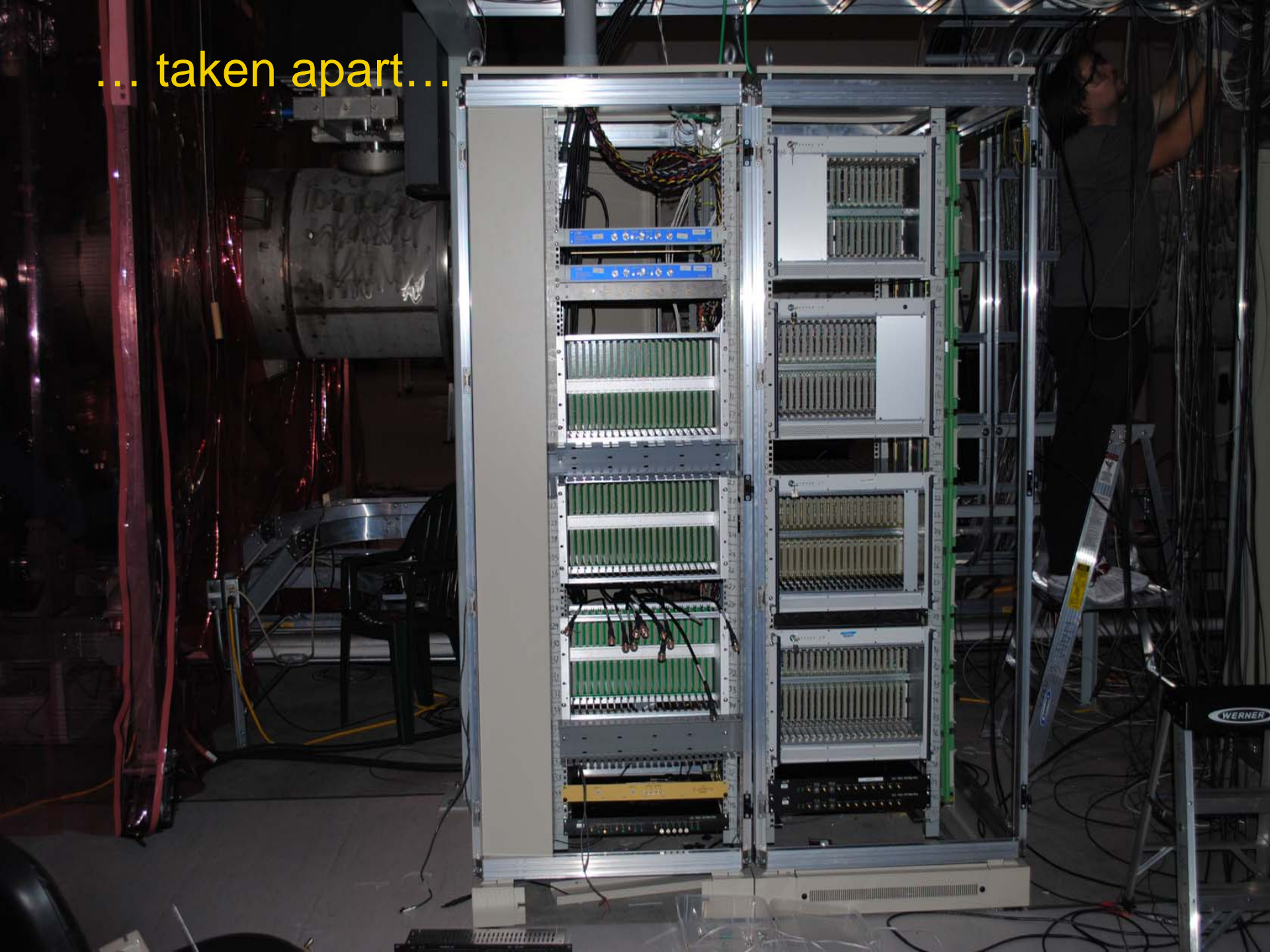


LIGO Hanford  
Observatory

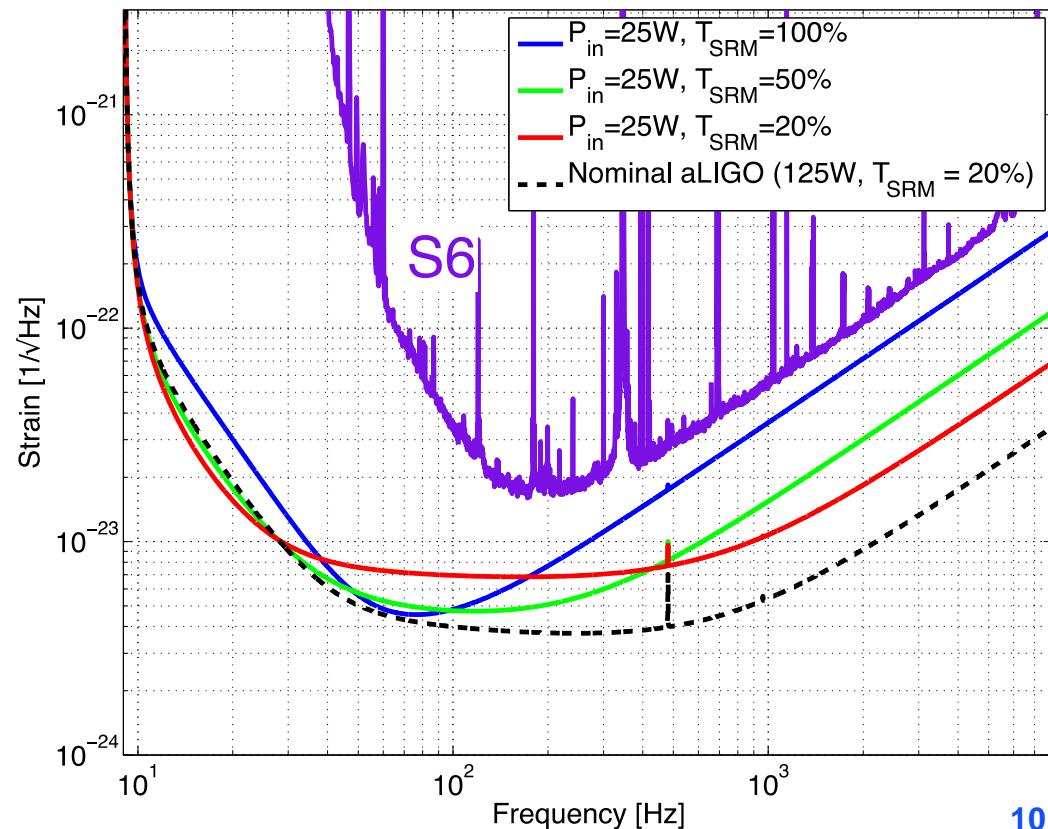




... taken apart...



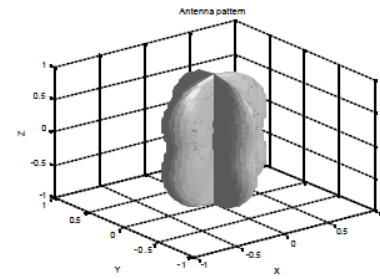
- Two completely new interferometers in the US LIGO vacuum enclosures and infrastructure in Louisiana and Washington
- 3<sup>rd</sup> interferometer, to be installed in India in a new LIGO-India Observatory
- Compared to initial LIGO, a factor of 10 better sensitivity, down to 10Hz



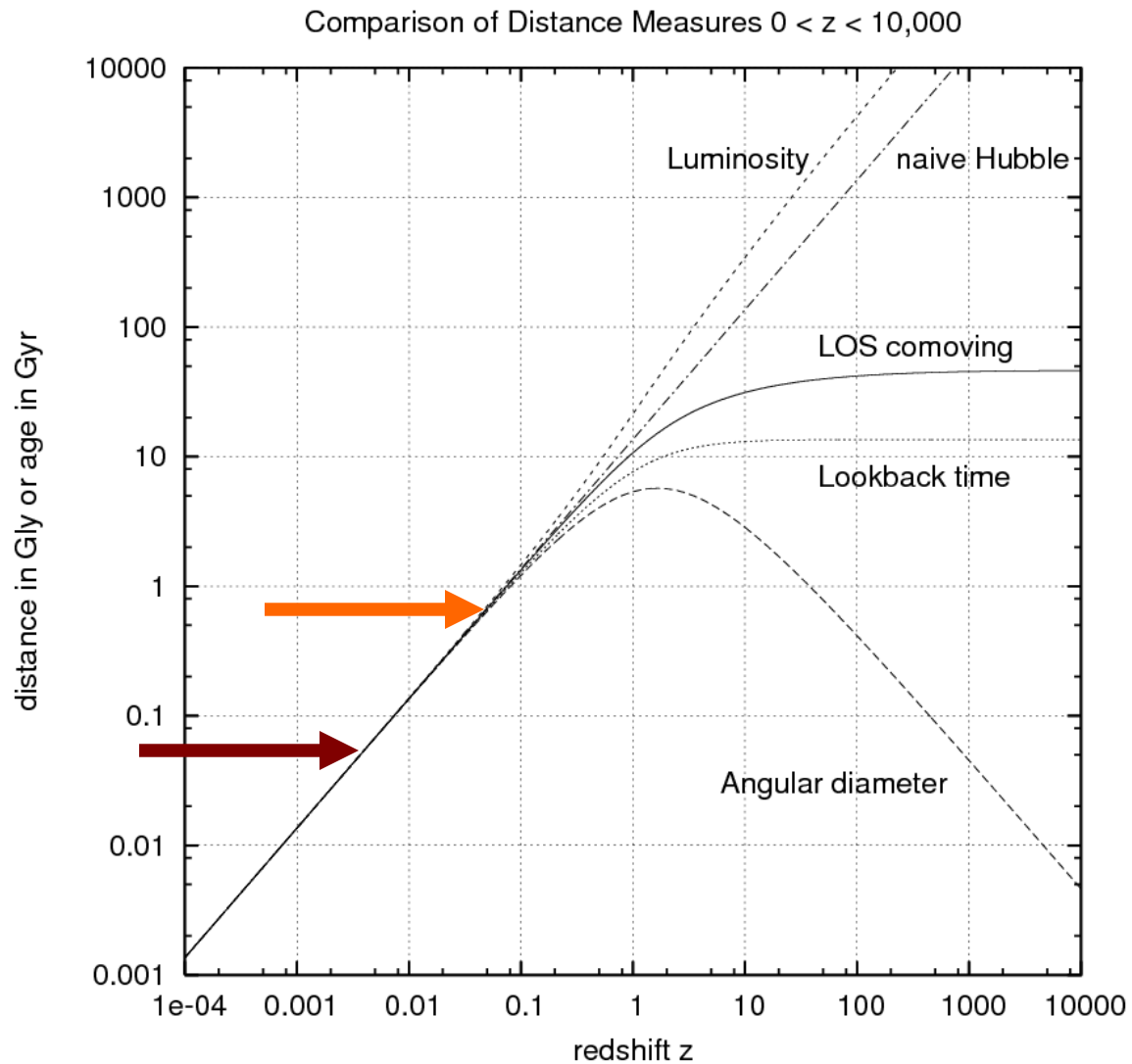


**LIGO**

# NS-NS standard candle (sky-averaged distances)



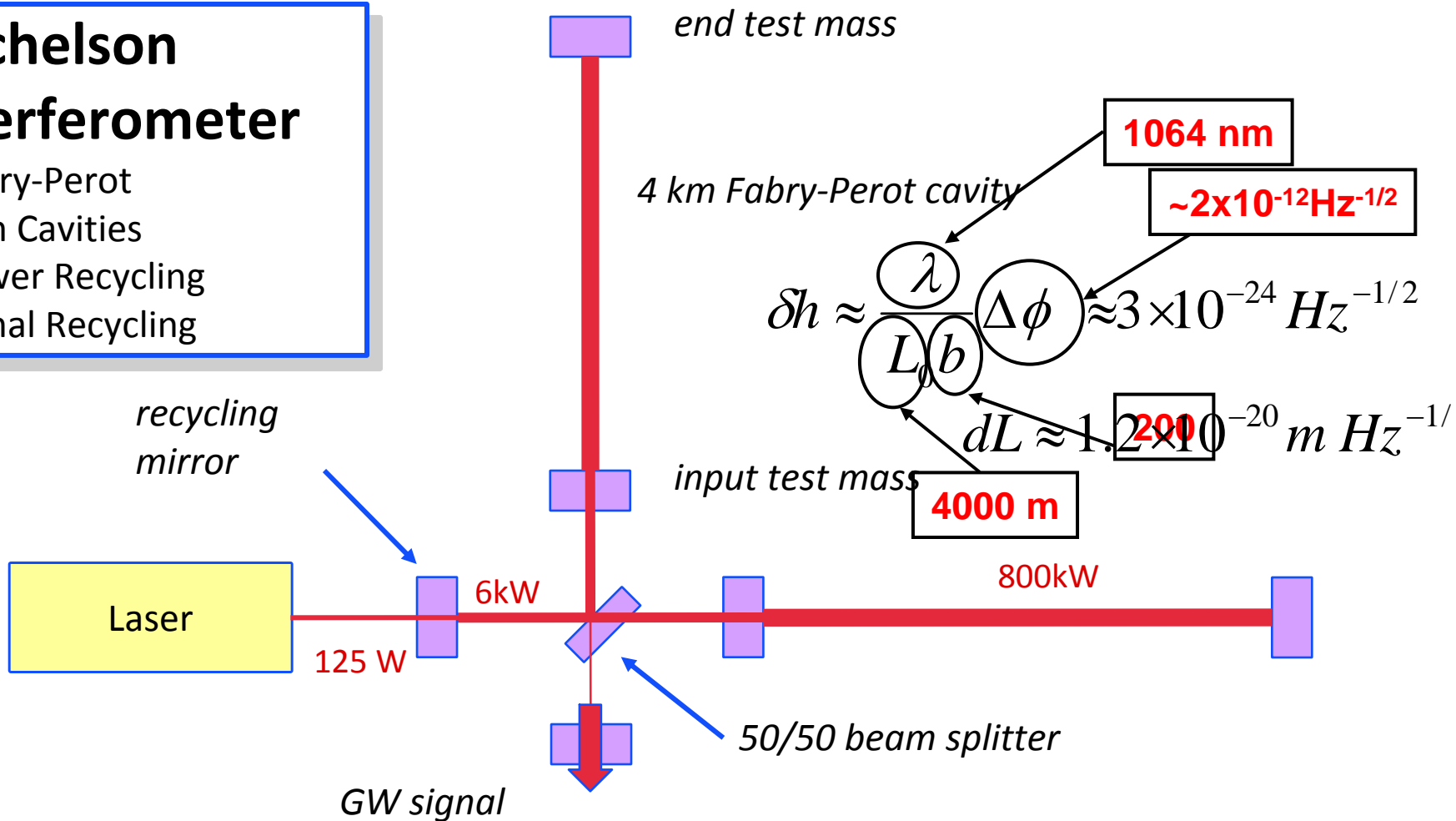
- Initial LIGO  
(1<sup>st</sup> gen.)  
20 Mpc
- Adv LIGO  
(2<sup>nd</sup> gen)  
~200Mpc



## Interferometer Sensitivity

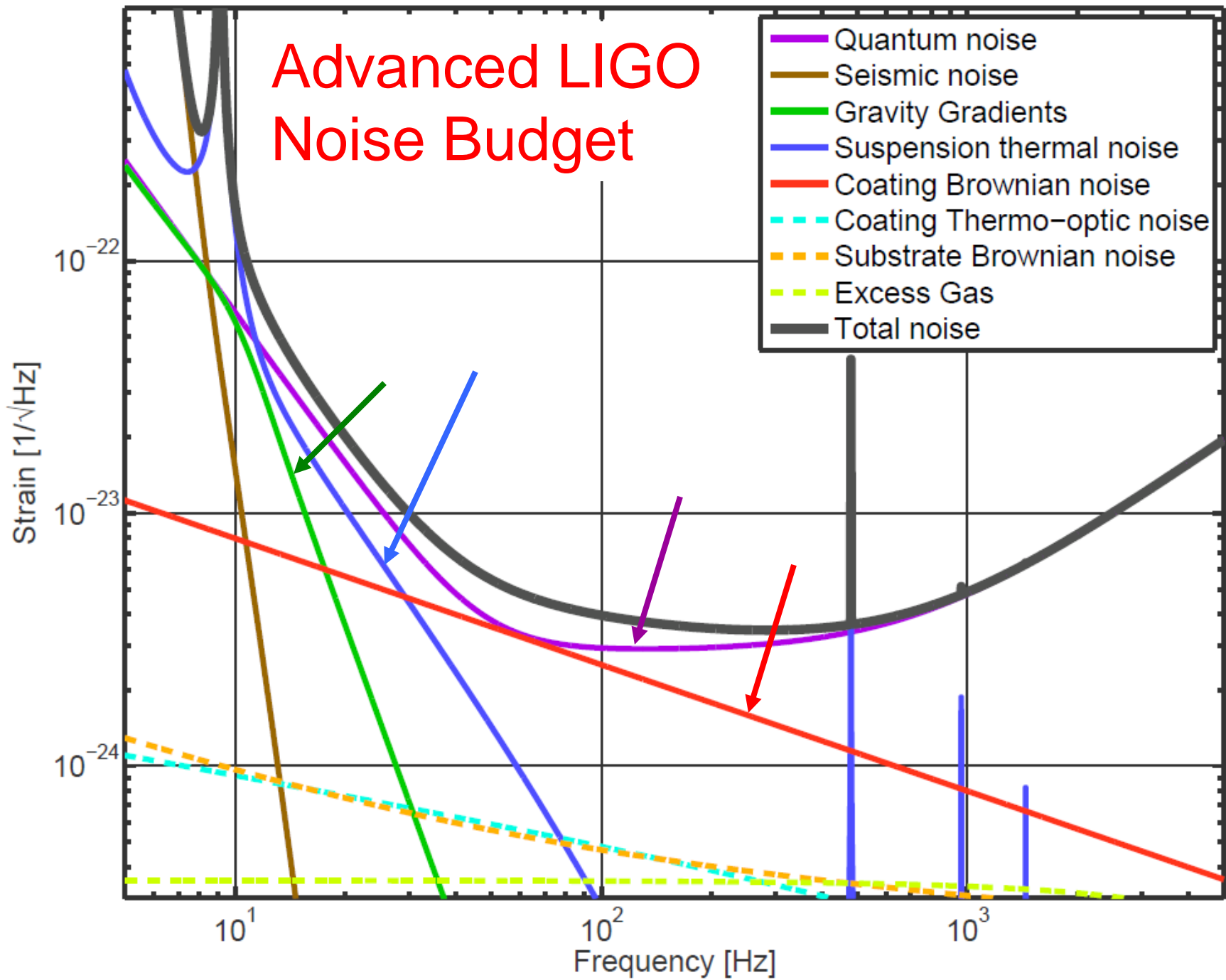
### Michelson Interferometer

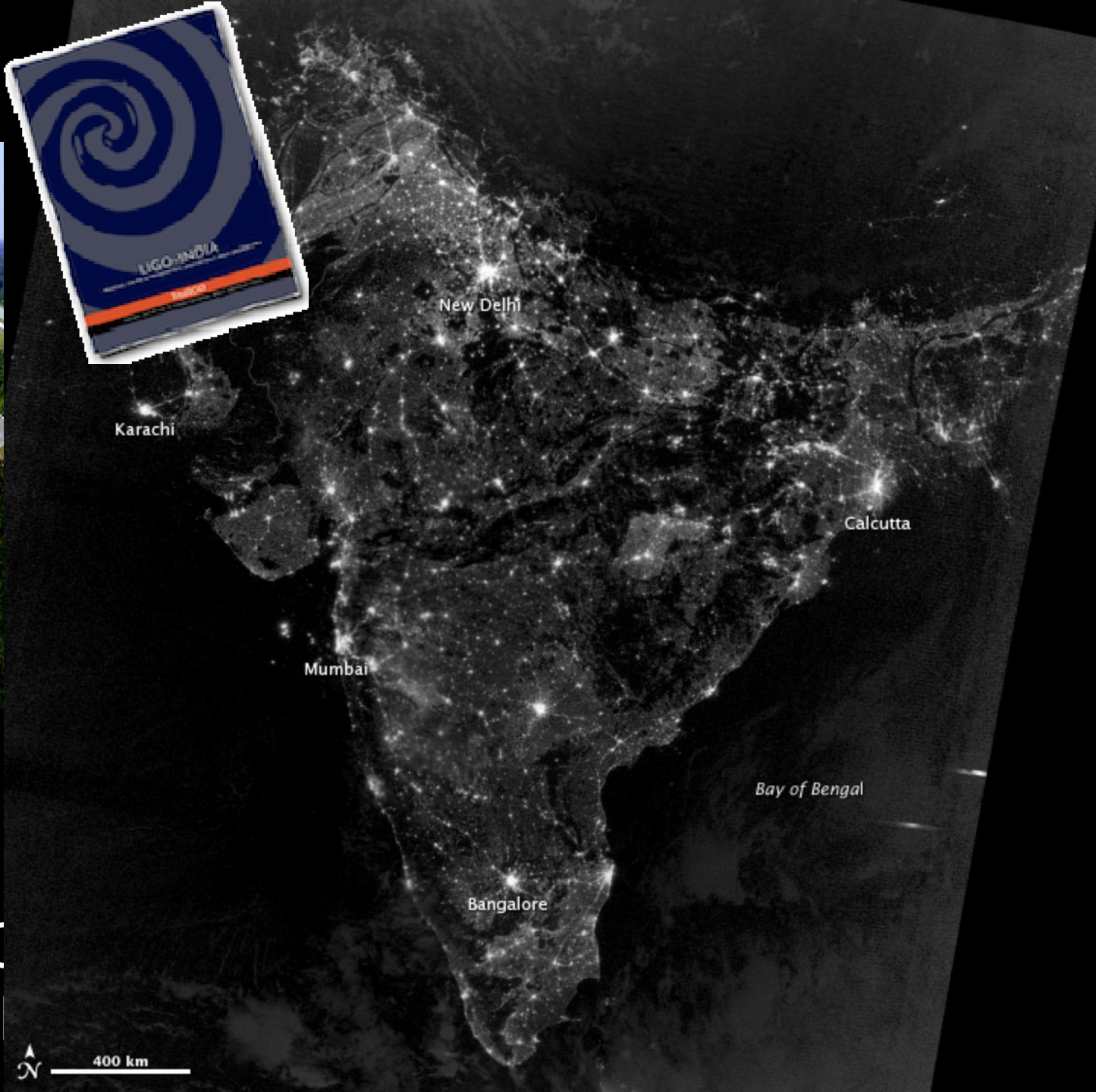
- + Fabry-Perot Arm Cavities
- + Power Recycling
- + Signal Recycling



(Numbers for aLIGO design)

# Advanced LIGO Noise Budget





009)

LIC  
O



400 km

# VIRGO

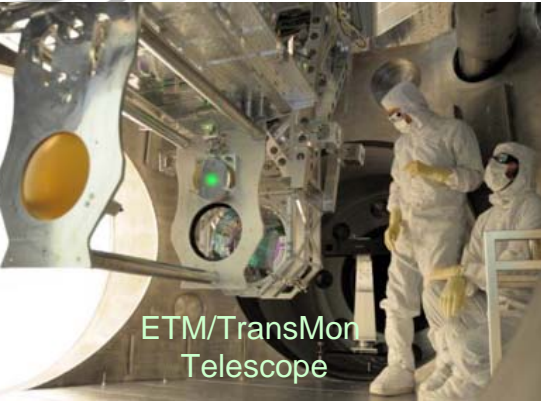






- Introduction:
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- **Where are we now?**
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## 1) Installation

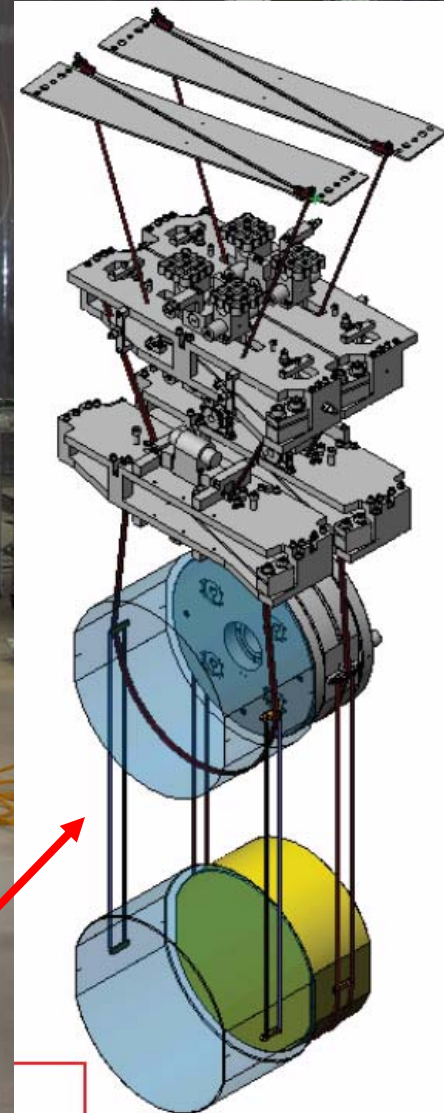


# Mating of suspension and seismic isolation

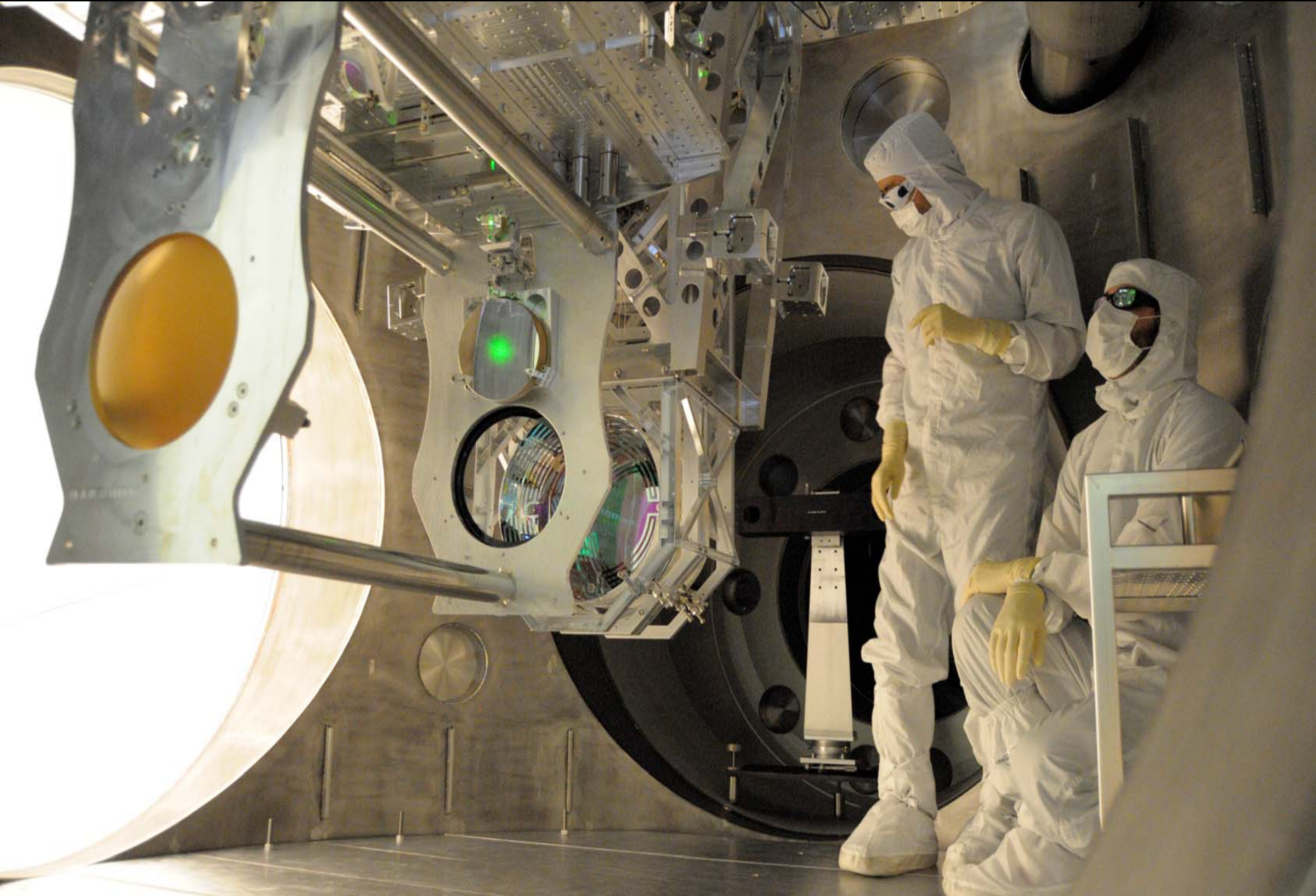


Internal Seismic Isolation Platform

Quadruple Pendulum Optics Suspension



# Transmission telescope installation

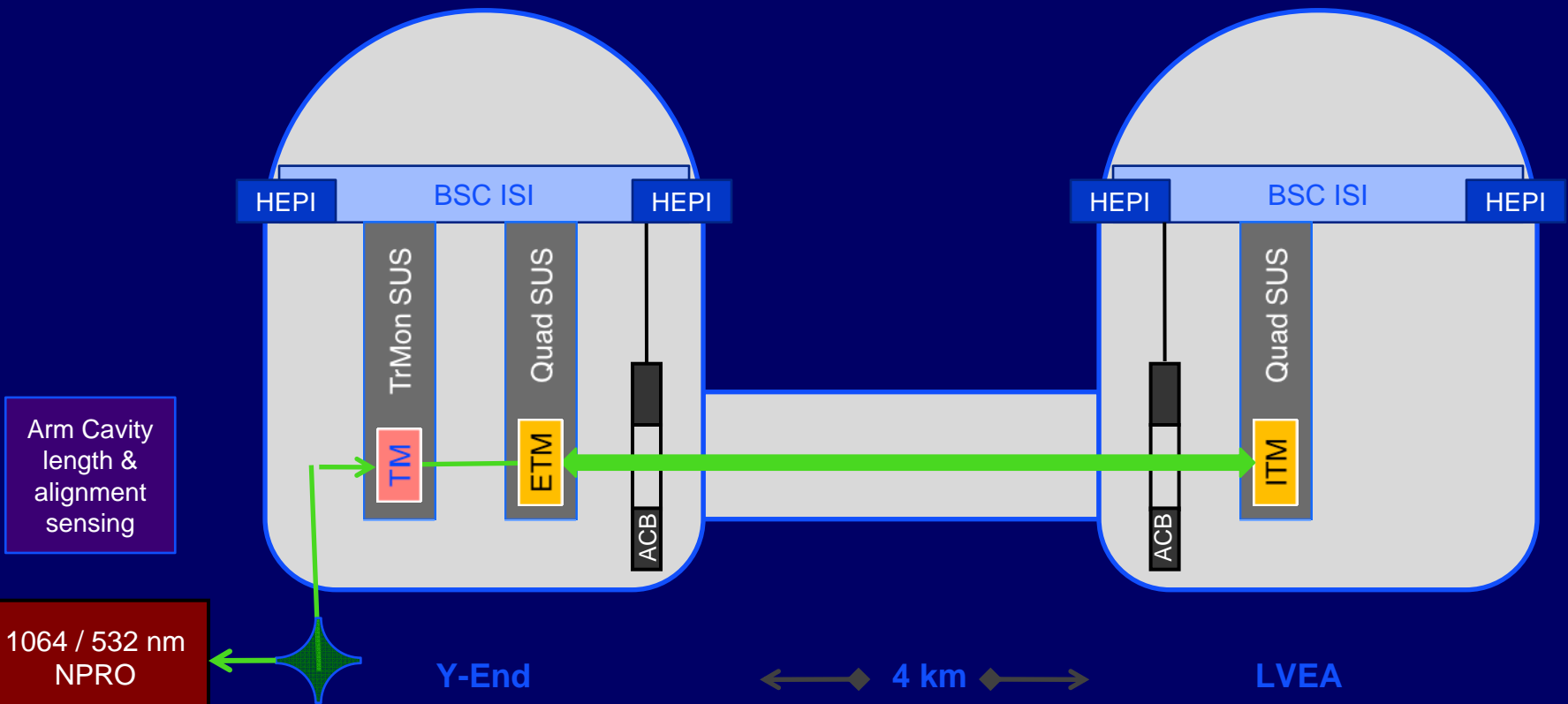


## 2) Integrated Testing

- ◉ Hierarchical testing process is key to rapid success
- ◉ Currently testing two significant items:
  - » A 4km long arm ('One Arm Test' or OAT)
  - » An input mode cleaner and pre-stabilized laser (MC-PSL)

## One-Arm Test (OAT)

- A single, complete **4km arm** at Hanford Observatory
- **Two complete chambers**: Optics, suspensions, seismic isolation
- **Arm-length stabilization** system using **second color** of light
  - » New for aLIGO; addresses biggest initial challenge – **locking**



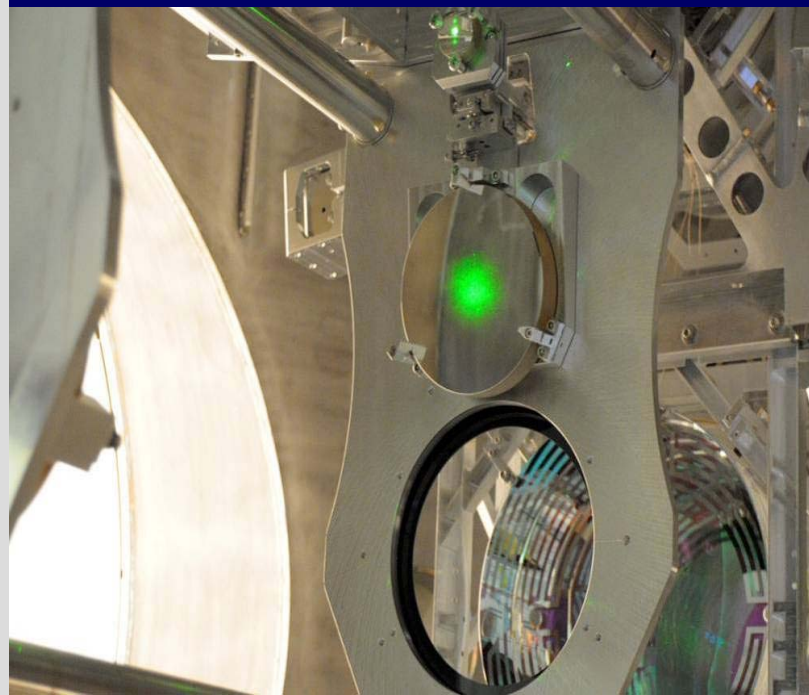
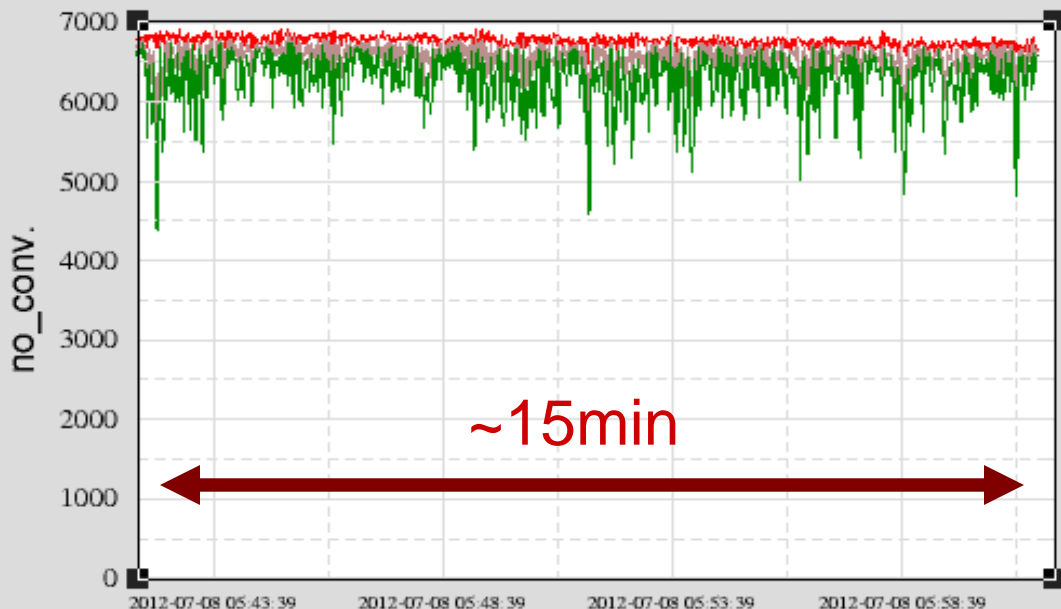
# One-Arm Test

Successful by every measure

- » Locking came **very quickly**
- » Very **stable** locks

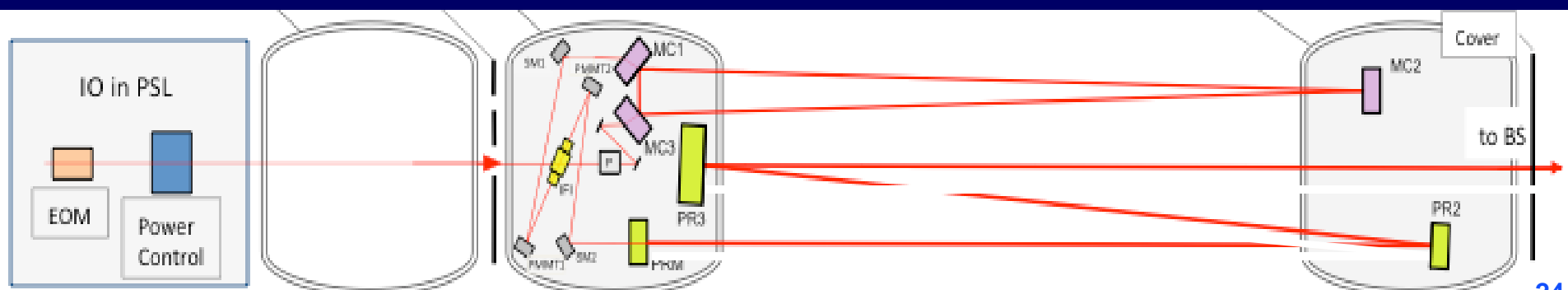
Allows whole-interferometer integration with  $\frac{1}{2}$  interferometer

Ch 6: H2:ISC-ALS\_EY\_PDH\_DC\_OUT16



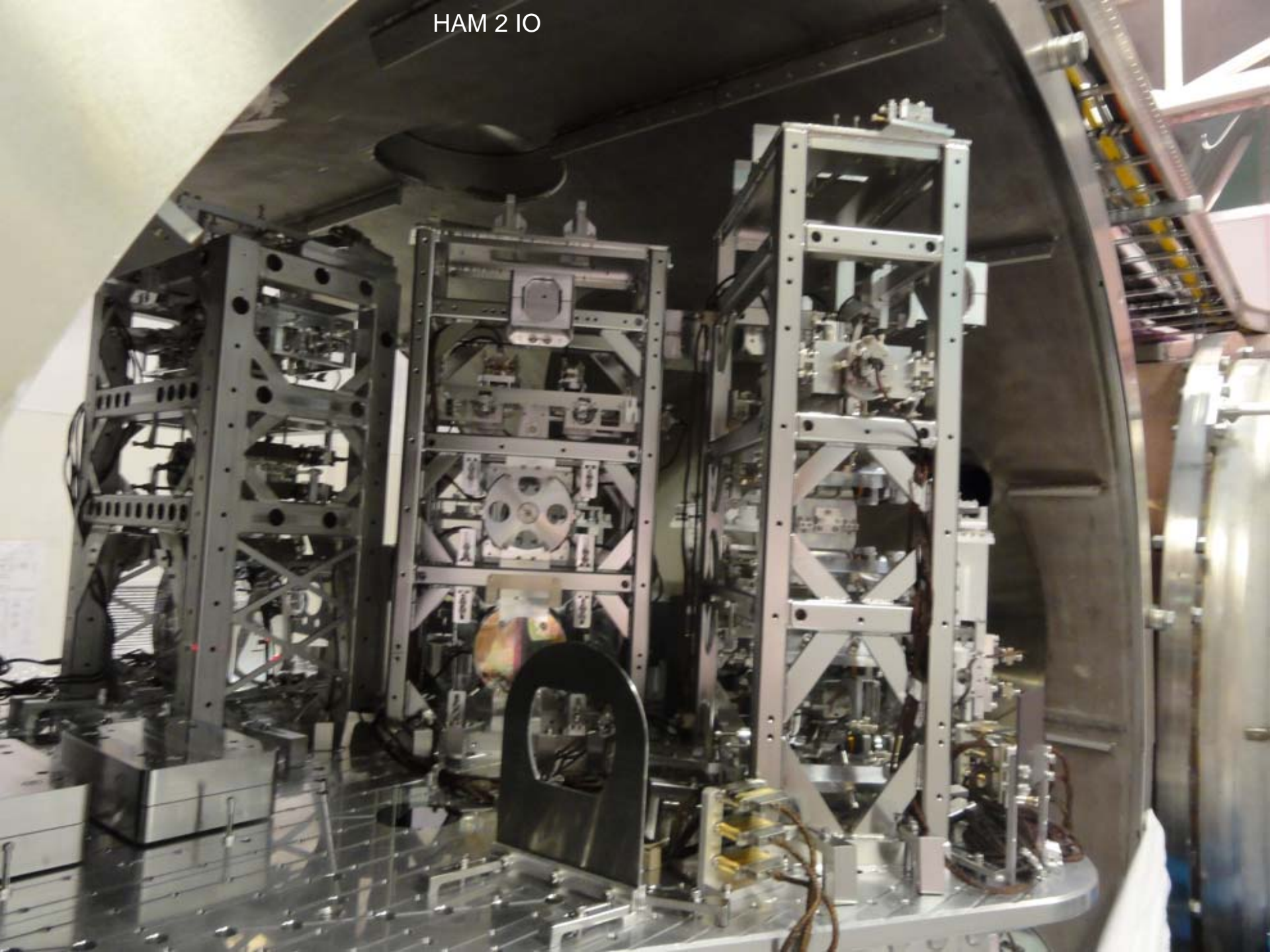
## Mode Cleaner – Pre-Stabilized Laser

- A **200W Nd:YAG laser**, from AEI Hannover, Germany
- A **suspended-mirror ring cavity**, ~15m length, in transmission
- The two **most complex vacuum chambers** in aLIGO





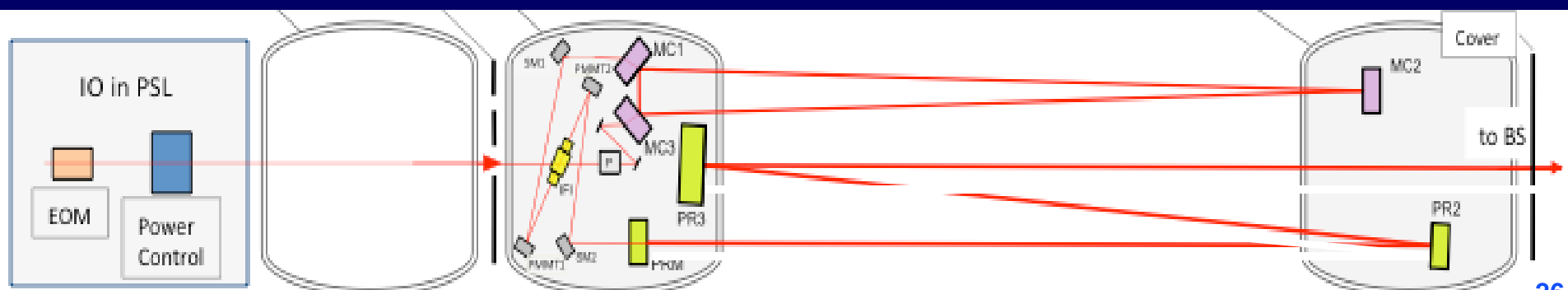
HAM 2 IO



## Mode Cleaner – Pre-Stabilized Laser

### Goals:

- » Achieve **robust operation** of the Input Mode Cleaner
- » Evaluate the **thermal effects** in IMC and FI: transmission, isolation ratio, absorption, mode distortion, drift
- » Optimize **low frequency** performance of seismic isolation



Livingston mode cleaner first lock, 7/28/2012



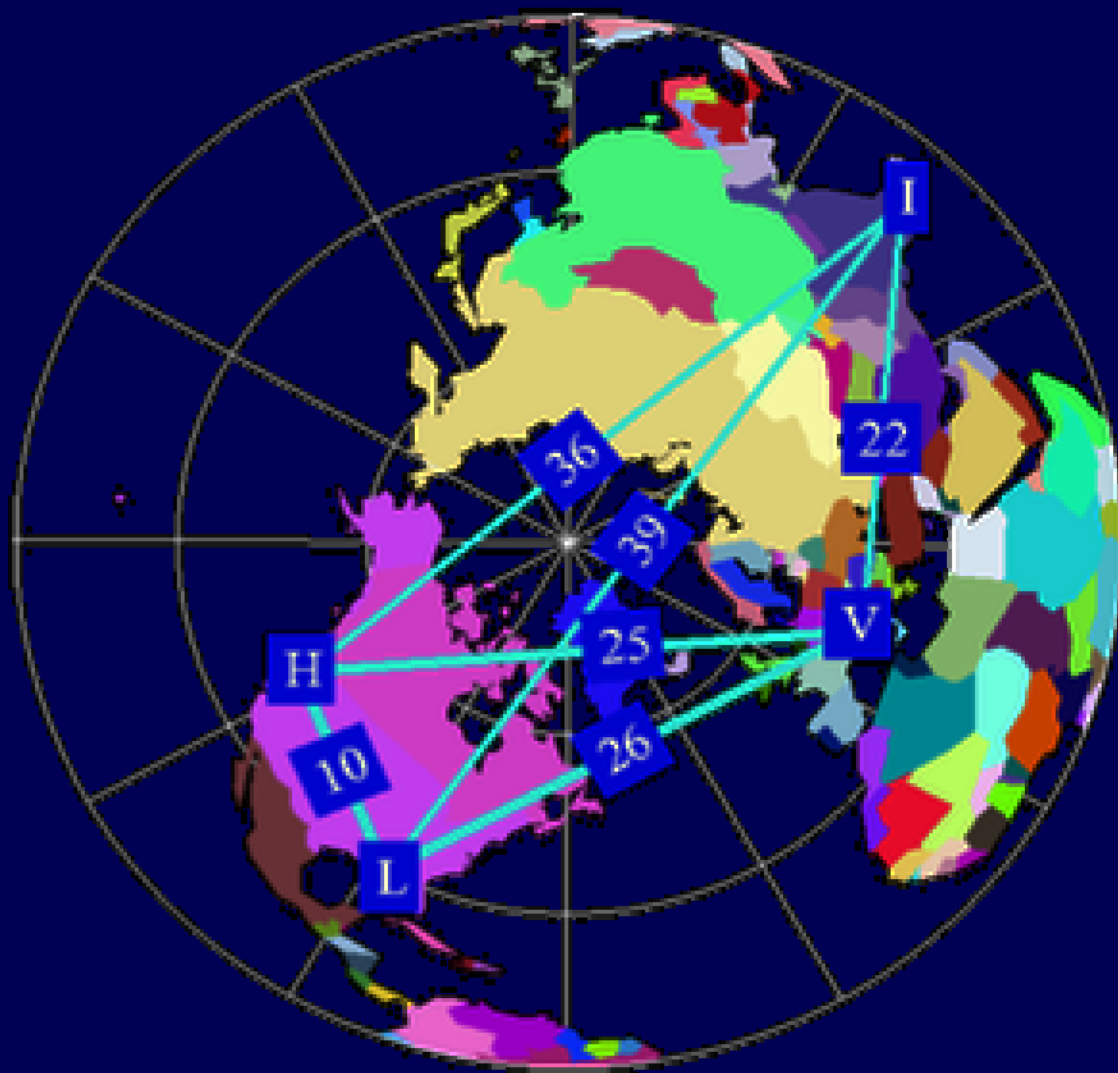
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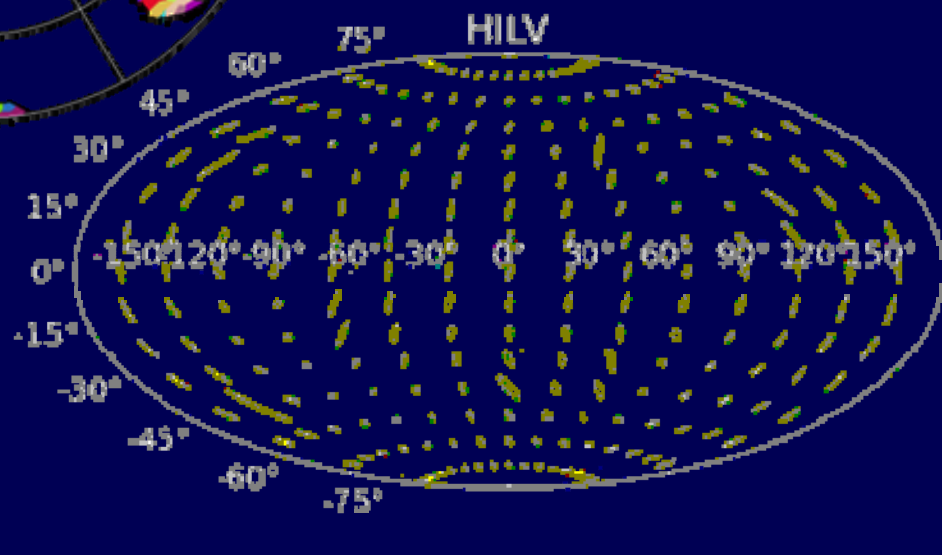
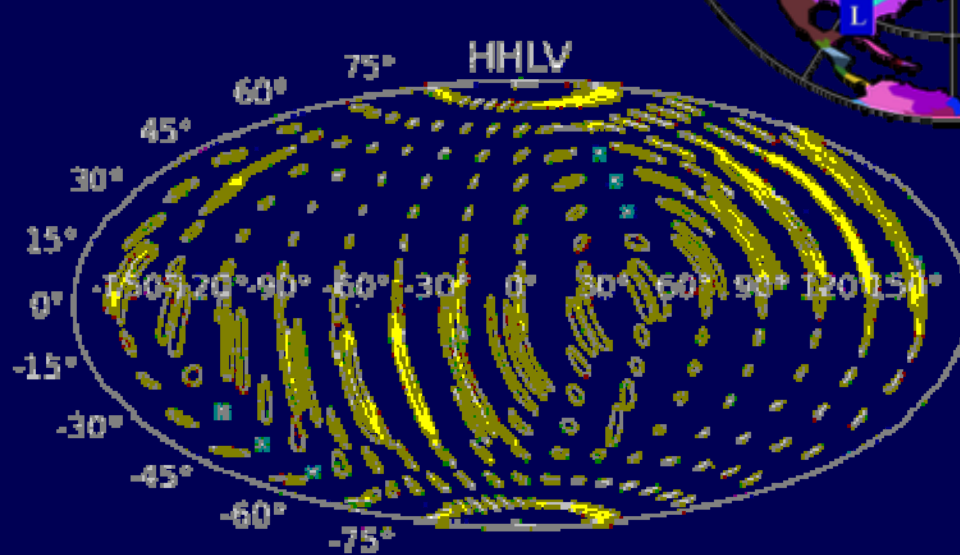
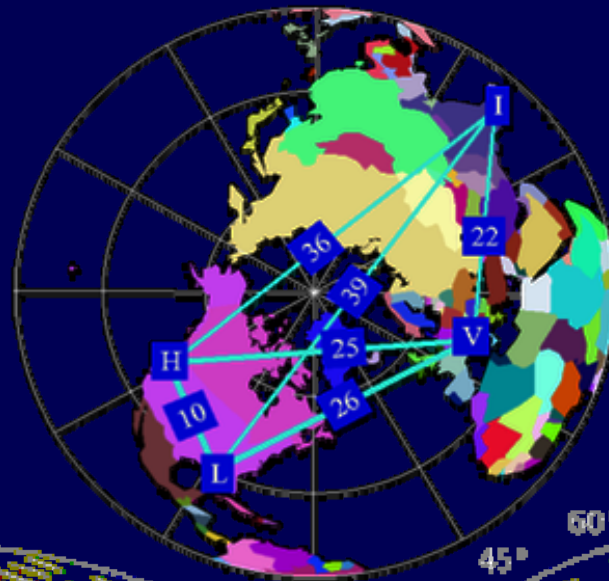
## *LIGO-India*

- aLIGO currently has 2 sites, 3 interferometers
- 3 sites with long baselines scientifically more valuable
  - » Better source localization
- Goal: build the 3<sup>rd</sup> LIGO interferometer on Indian soil
- LIGO Lab provides components for one Advanced LIGO interferometer
- India provides the infrastructure, “shipping & handling,” staff for installation & commissioning, operating costs for 10 years beyond construction

# LIGO-India network



# LIGO-India network



*The localization accuracy for binary neutron stars located at 160 Mpc*



# LIGO-India news

- In August the **National Science Board** approved a **change in scope**, enabling plans for the relocation of one detector to India.
- The NSB resolution empowers the **NSF** to make the decision to proceed with LIGO-India.
- Discussions now: **How will LIGO India be implemented** and managed.



# What's next?

## Installation complete:

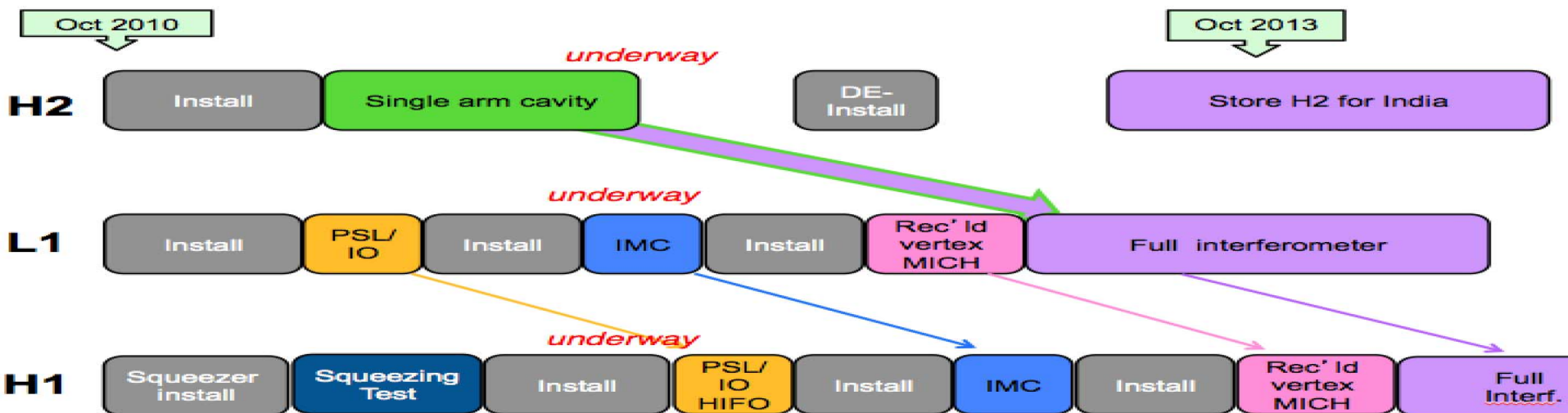
» Livingston May 2013, Hanford Sept 2013

## 'Acceptance' (definition: 2-hour lock):

» Livingston April 2014, Hanford May 2014

Full-Interferometer locking **may come quite quickly...**

...but lots of **follow-up work** only possible with whole interferometer required



# Timeline

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- ◌ US interferometer acceptance:
  - » Summer 2014
  
- ◌ First science run near design sensitivity:
  - » maybe 2016
  
- ◌ LIGO-India:
  - » Facility construction begins: Aug 2014
  - » First science run (all interferometers): 2020

# Conclusion

- Advanced LIGO hardware installation progressing at good pace
- Integrated tests successful (one-arm & mode cleaner)
- LIGO-India has passed major thresholds in the US – it's moving forward



Thank you!

