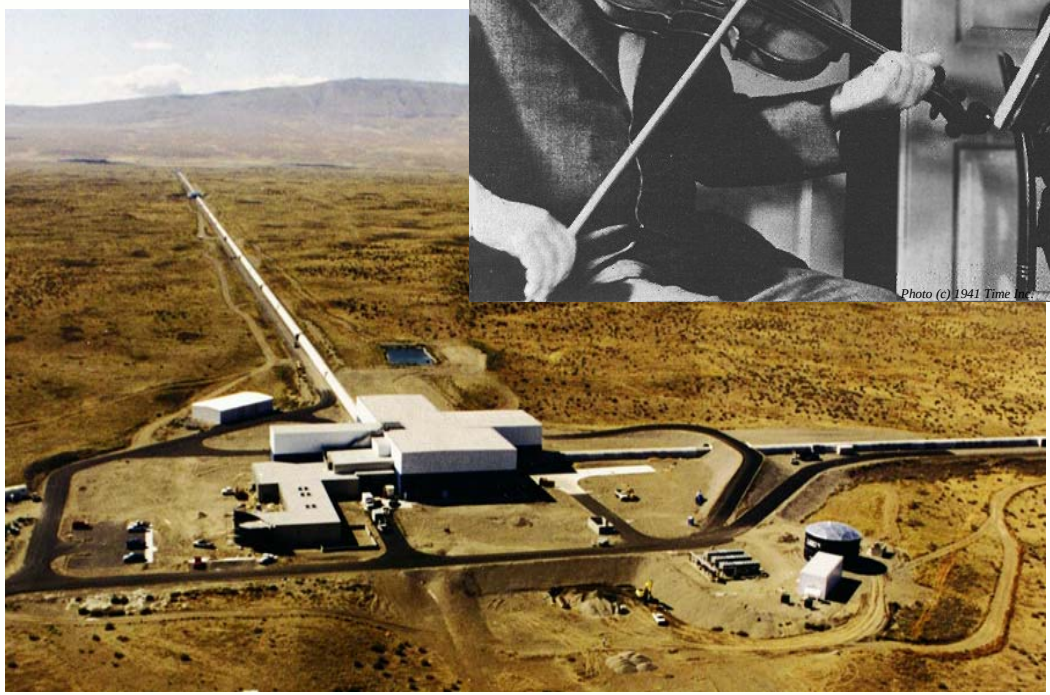
Observational search overviews:
**Brady** and **Sutton**, next
Plenary by **Gonzalez**: Tuesday morning
**Astro results**: session C7 next door
**Search Results**: session W11 on Tuesday
**+Posters**

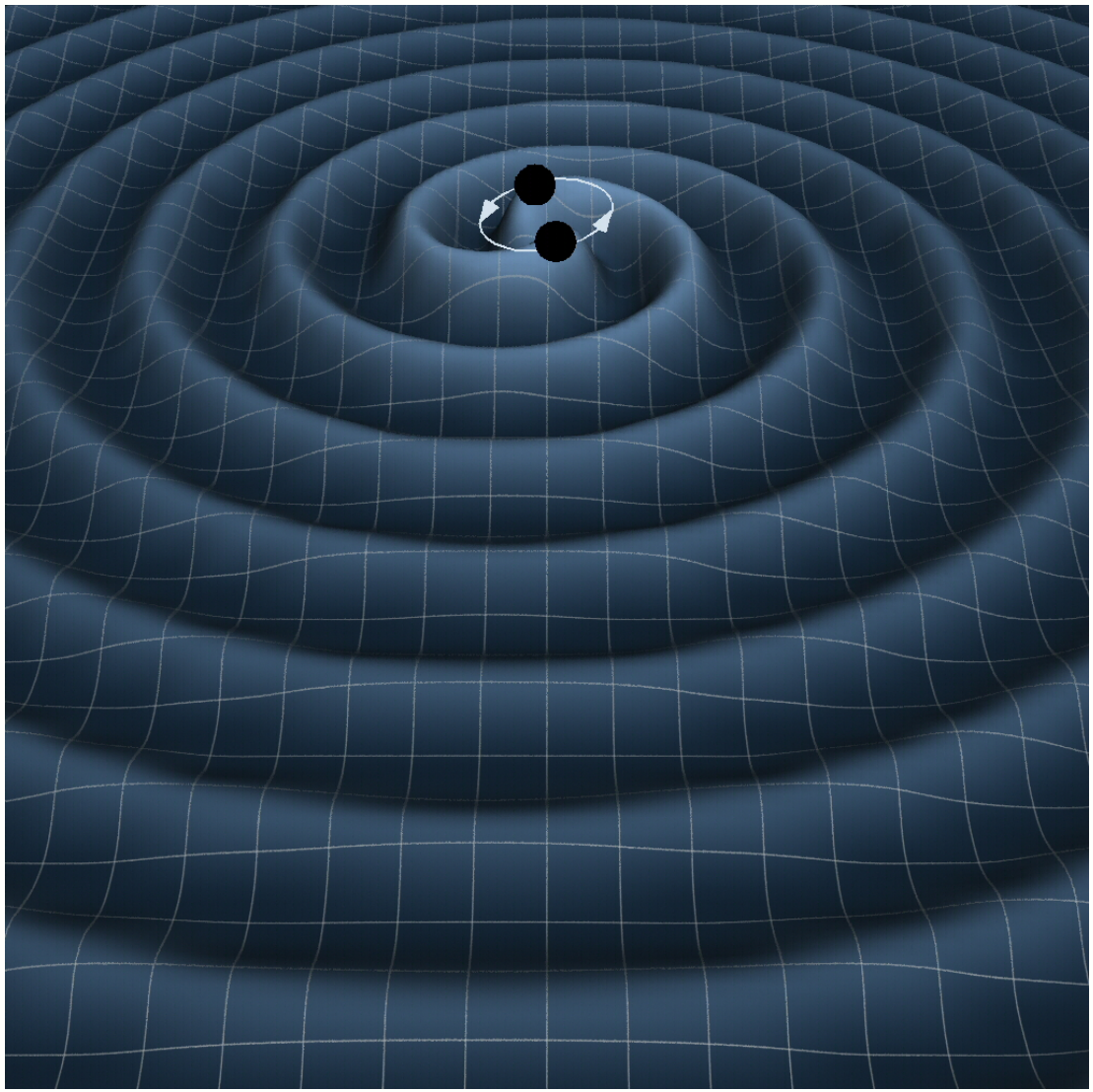
# *A status report on the LIGO interferometers*

*M. Zucker*
*LIGO Livingston Observatory*
*for the LIGO Science Collaboration*

*American Physical Society*
*Dallas, 22 April 2006*

LIGO-G060198-05-D

# Gravitational Waves SEE TUESDAY AM PLENARY BY G. GONZALEZ!!



Perturbations of geometry can be expressed as *fractional distortion* of proper distances:

$$\boldsymbol{h} = d\boldsymbol{x}/|\boldsymbol{x}|$$

For varying source quadrupole moment $\boldsymbol{Q}$

$$h \approx \frac{2G}{3c^4 r}\ddot{Q} \quad \textit{amplitude of wave}$$

$$|\dot{E}| \approx \frac{G}{45c^5}\dddot{Q} \quad \textit{radiated power}$$

# Do the math…

A wave's strength is characterized by its *strain*

$$h = \Delta L / L$$

We can calculate the expected strain at Earth for, say, an orbiting binary system;

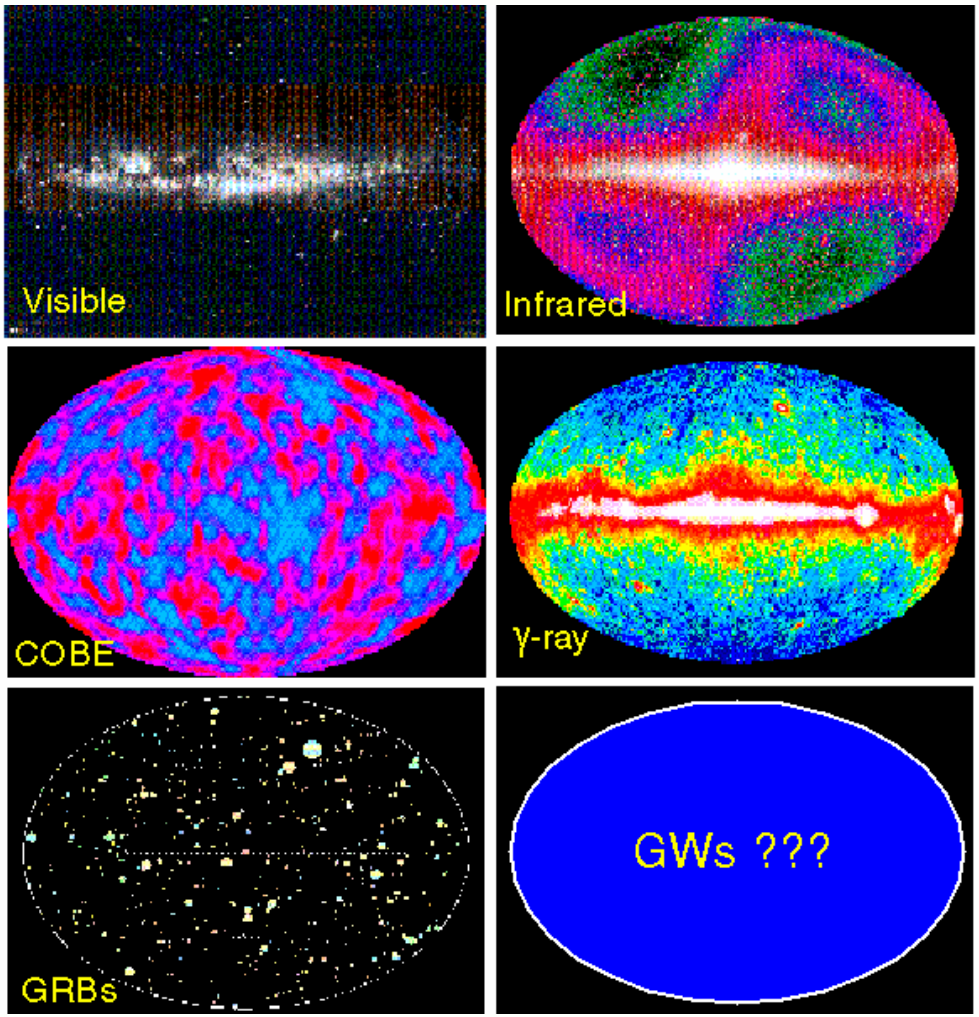
$$|h| \approx 4\pi^2 G M R^2 f_{orbit}^2 / c^4 r \approx 10^{-21} \left(\frac{R}{20\text{km}}\right)^2 \left(\frac{M}{M_\Theta}\right) \left(\frac{f_{orbit}}{400\,\text{Hz}}\right)^2 \left(\frac{10\text{Mpc}}{r}\right)$$

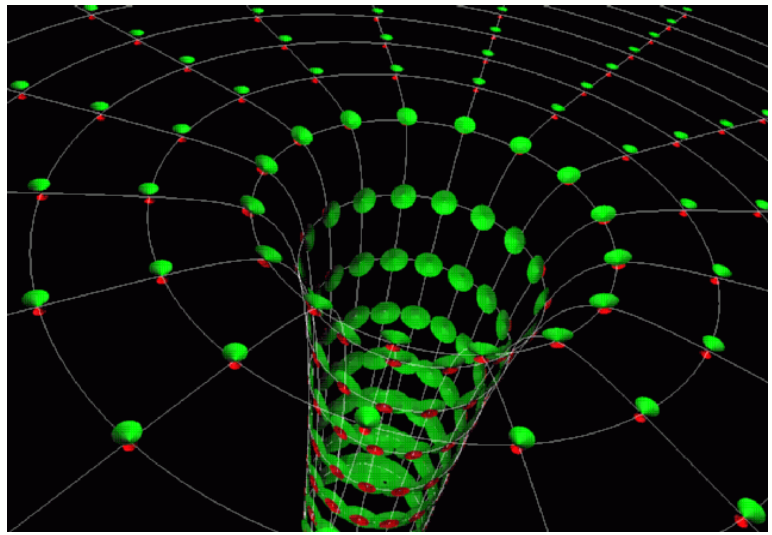
If we make our interferometer very big, say 4,000 meters long, then

$$\Delta L = h \times L \approx 10^{-21} \times 4{,}000\,m \approx 10^{-18}\,m$$

LIGO

# *A New 'Sense'- A New Universe*



**Gravitational Waves will provide complementary information, as different from what we know as sound is from sight.**


- Coincidence
  - local environments uncorrelated
- Amplitude discrimination
  - half- and full-length IFO's share Hanford site
  - 1:2 ratio required for true signals
- Source triangulation
  - ± 10 ms time of flight
  - ~ arcminute directionality
- Source polarization

LIGO

# GW I ete



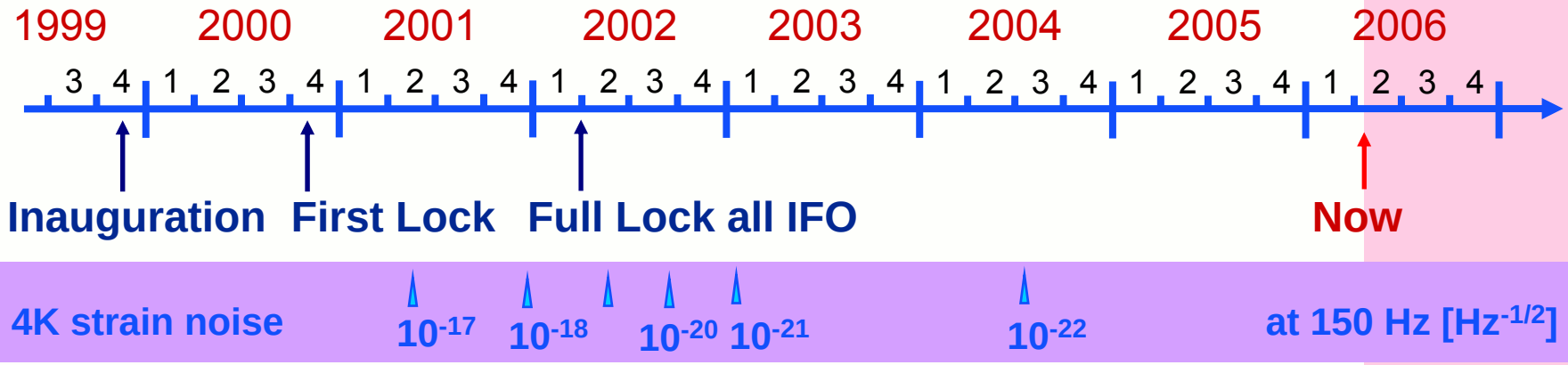




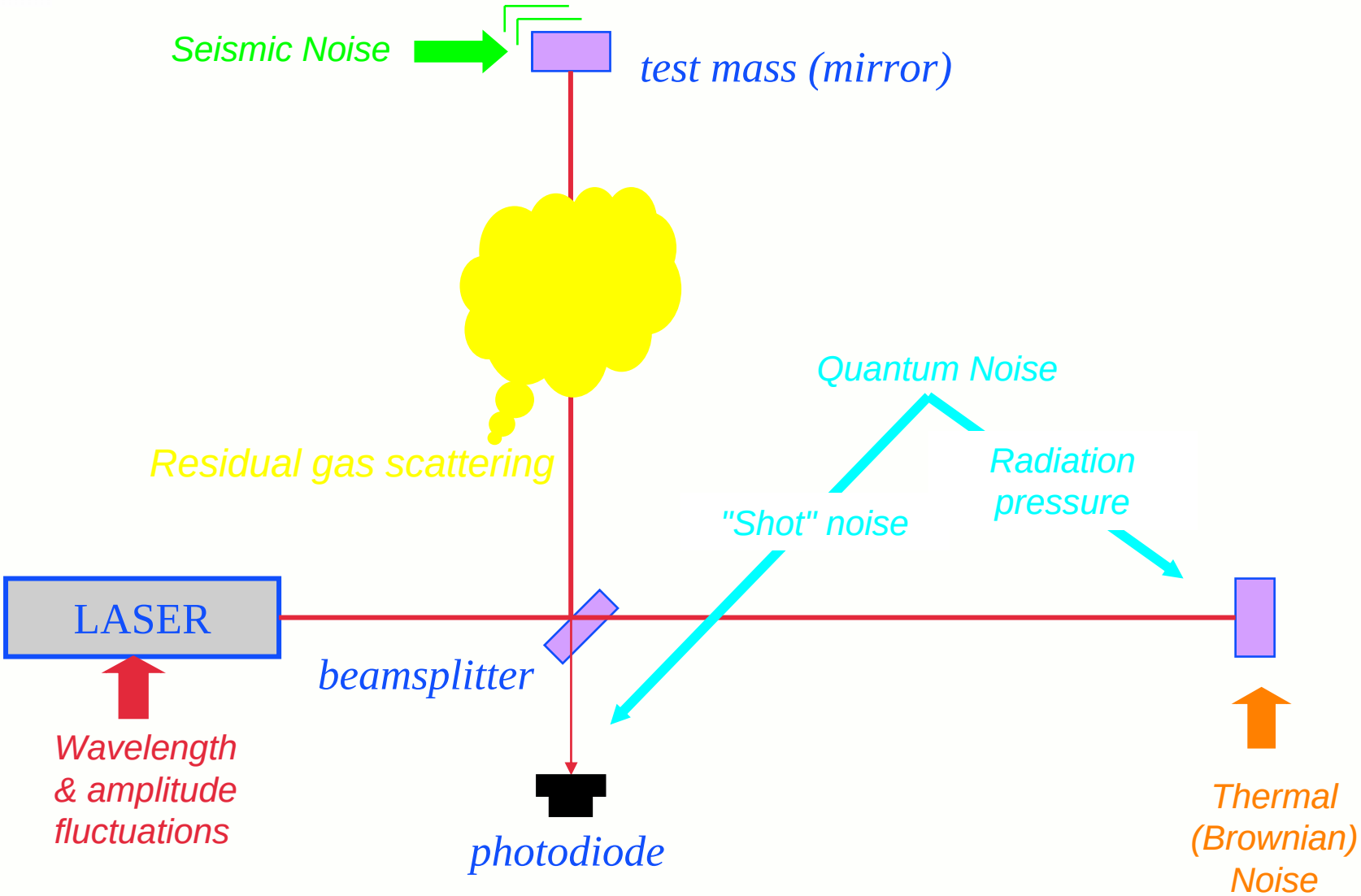
- Worldwide Network:
  - We coordinate observations and share data with TAMA and GEO
  - We are just finalizing similar agreements with VIRGO
  - AIGO is still in planning stage; AIGO personnel currently share in LIGO operation

# Collaborating Institutions

# Time Line

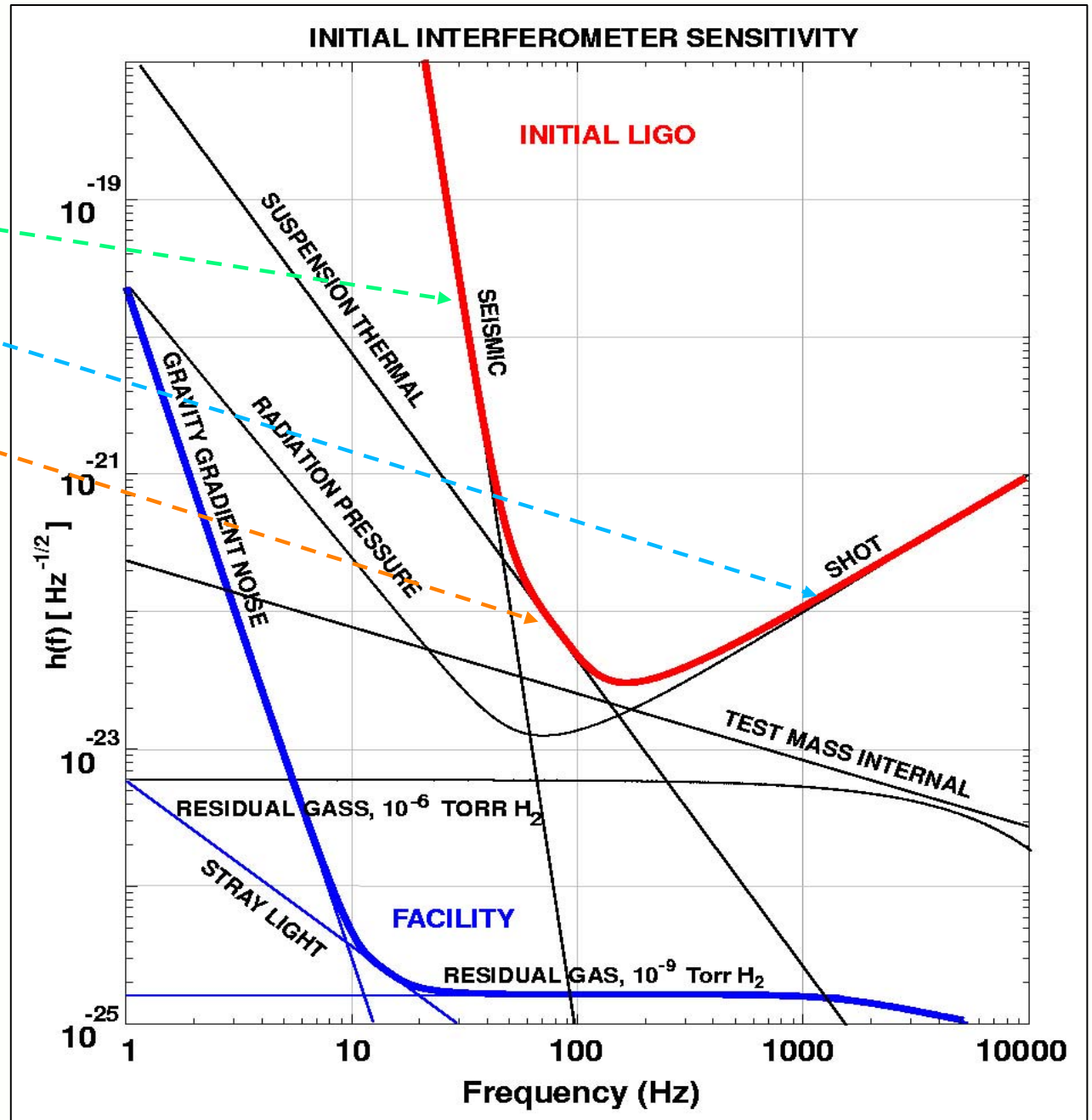

1999
2000
2001
2002
2003
2004
2005
2006
3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
Inauguration
First Lock
Full Lock all IFO
Now
4K strain noise
10-17
10-18
10-20
10-21
10-22
at 150 Hz [Hz-1/2]
Engineering
E2 E3 E5 E7 E8 E9 E10 E11
Science
S1 S2 S3 S4 S5
Runs
First
Science
Data

# Interferometer Noise



# Design Noise Limits

- Initial sensitivity limits
  - **seismic noise** at the lowest frequencies
  - **shot noise** at high frequencies
  - **thermal noise** at intermediate frequencies
- Based on conservative extrapolation of prototype technologies (circa ~'97)
- Facility limits designed much lower to allow improvement as detector technology advances



# Beam Tubes and Enclosures

Precast concrete enclosure: *bulletproof*

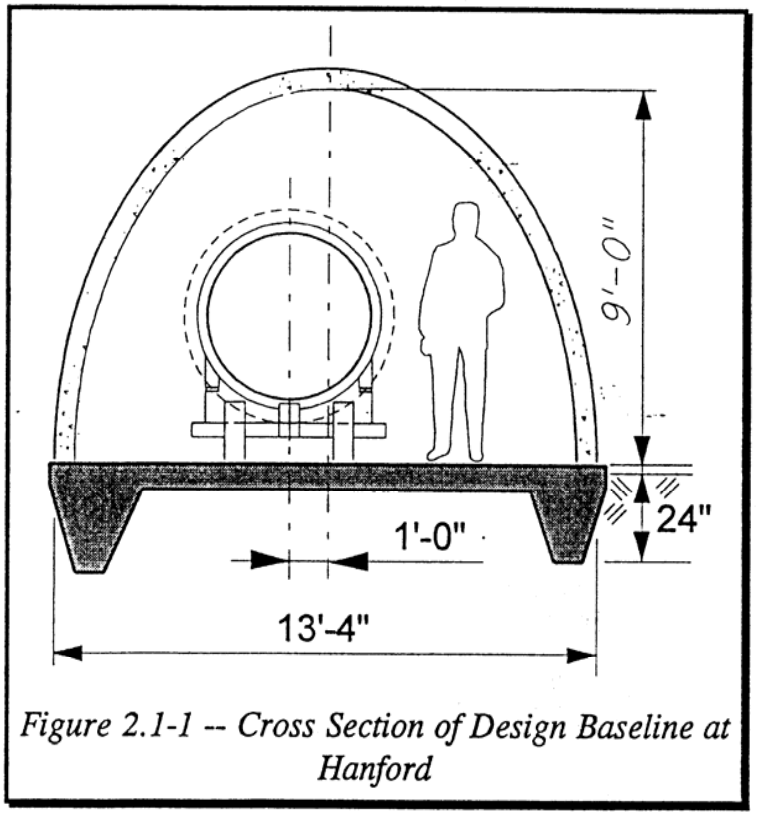



*Figure 2.1-1 -- Cross Section of Design Baseline at Hanford*

- **Beam Tube**
  - 1.2m diam; 3 mm stainless
  - special low-hydrogen steel process
  - 65 ft spiral weld sections
  - 50 km of weld (NO LEAKS!)
  - 20,000 $m^3$ @ $10^{-8}$ torr; earth's largest high vacuum system

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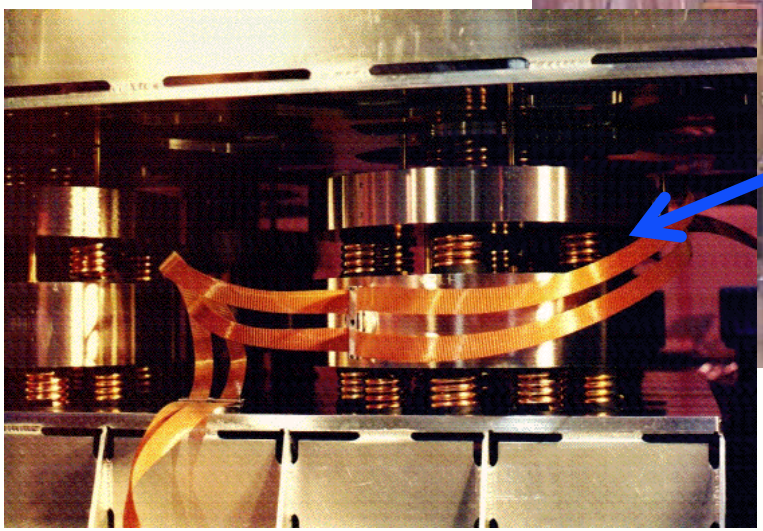
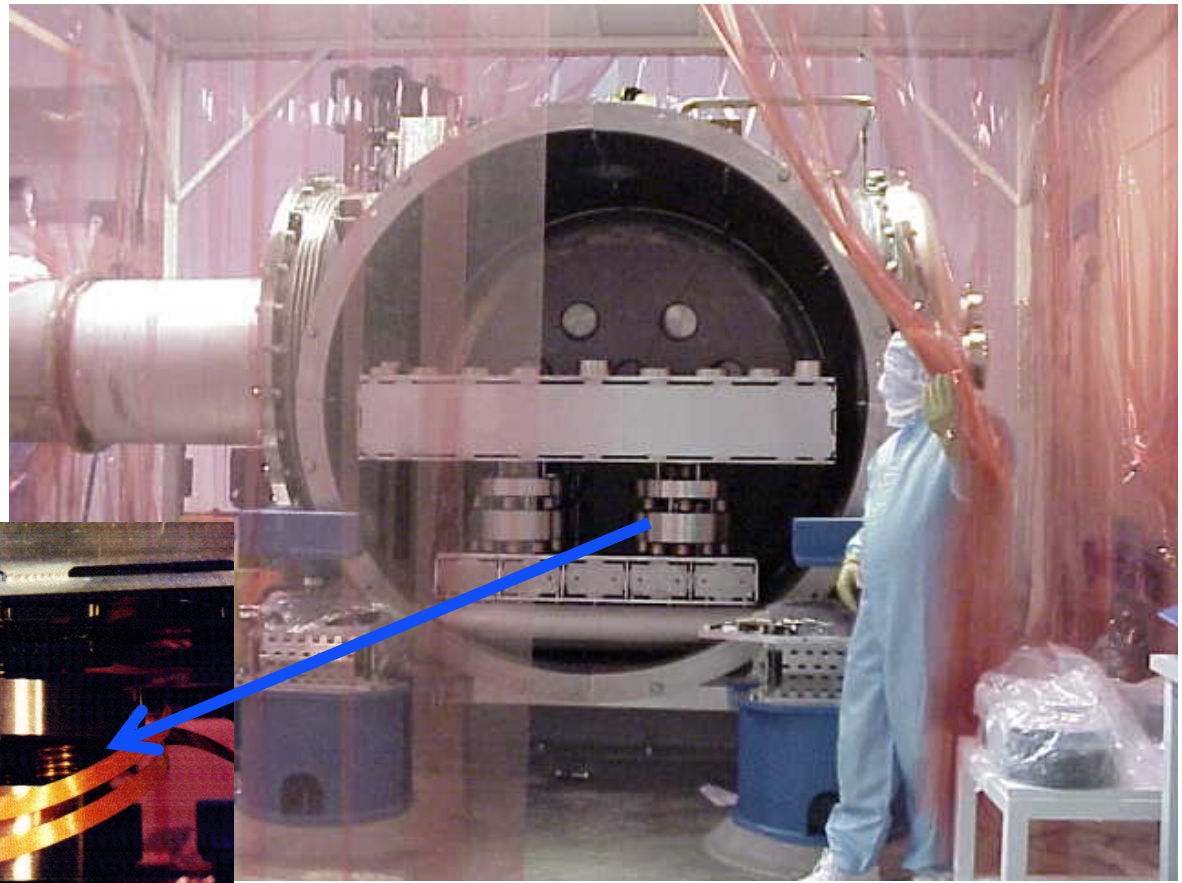
# Vacuum Equipment

# Seismic Isolation System

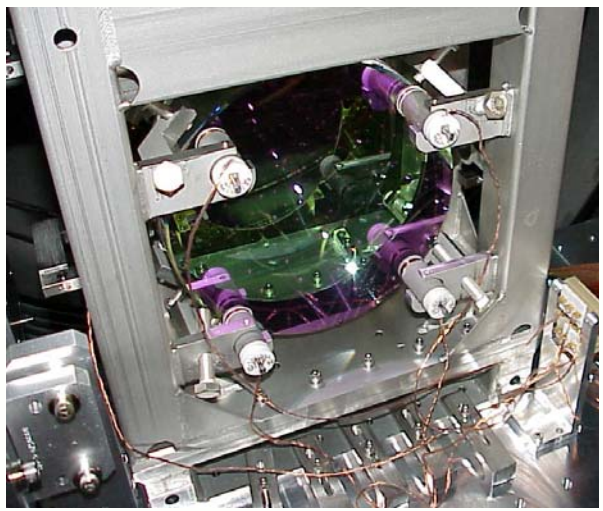
Tubular coil springs with internal constrained-layer damping, layered with reaction masses





Isolation stack in chamber

# Core Optic Suspensions

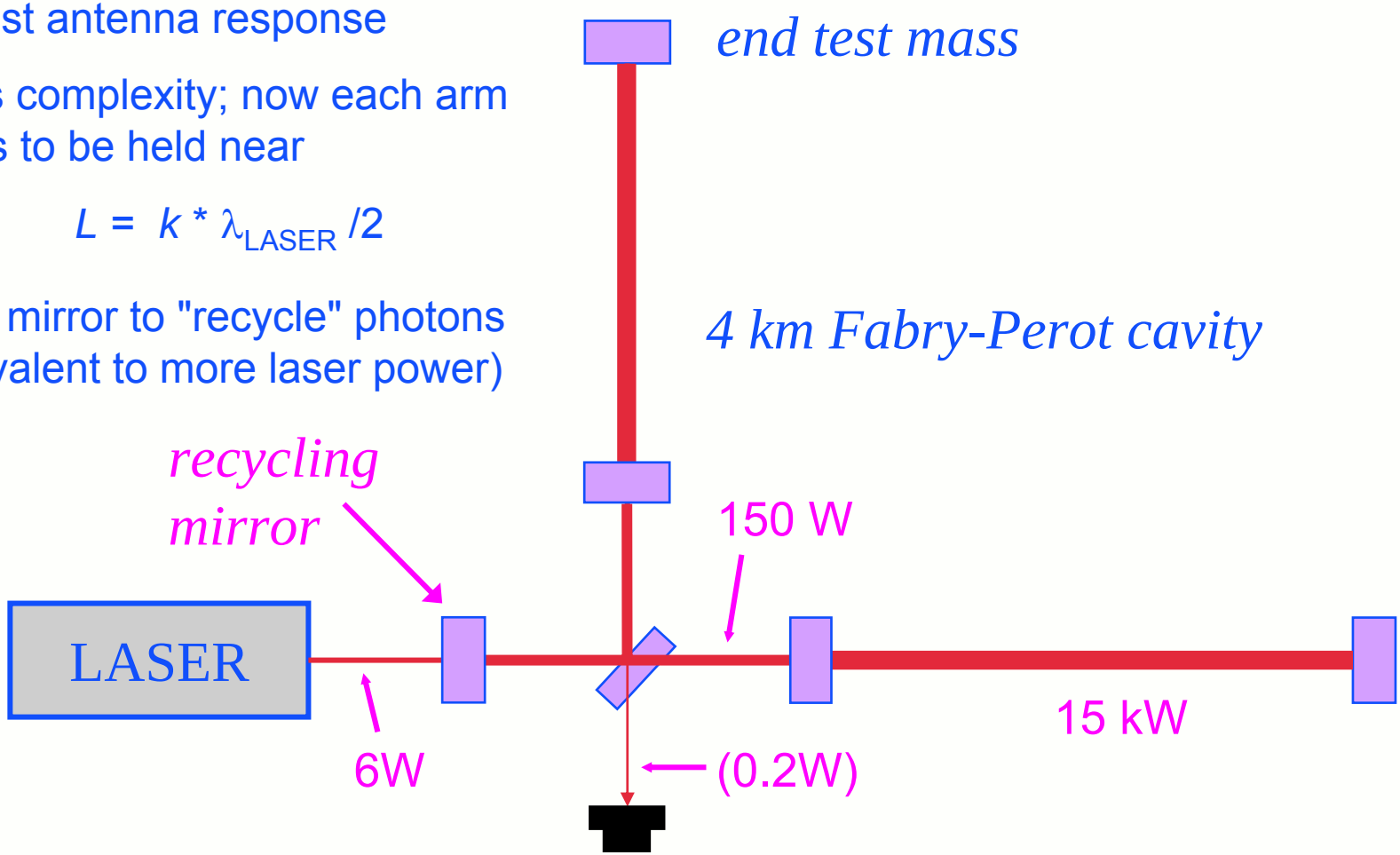


# Interferometry

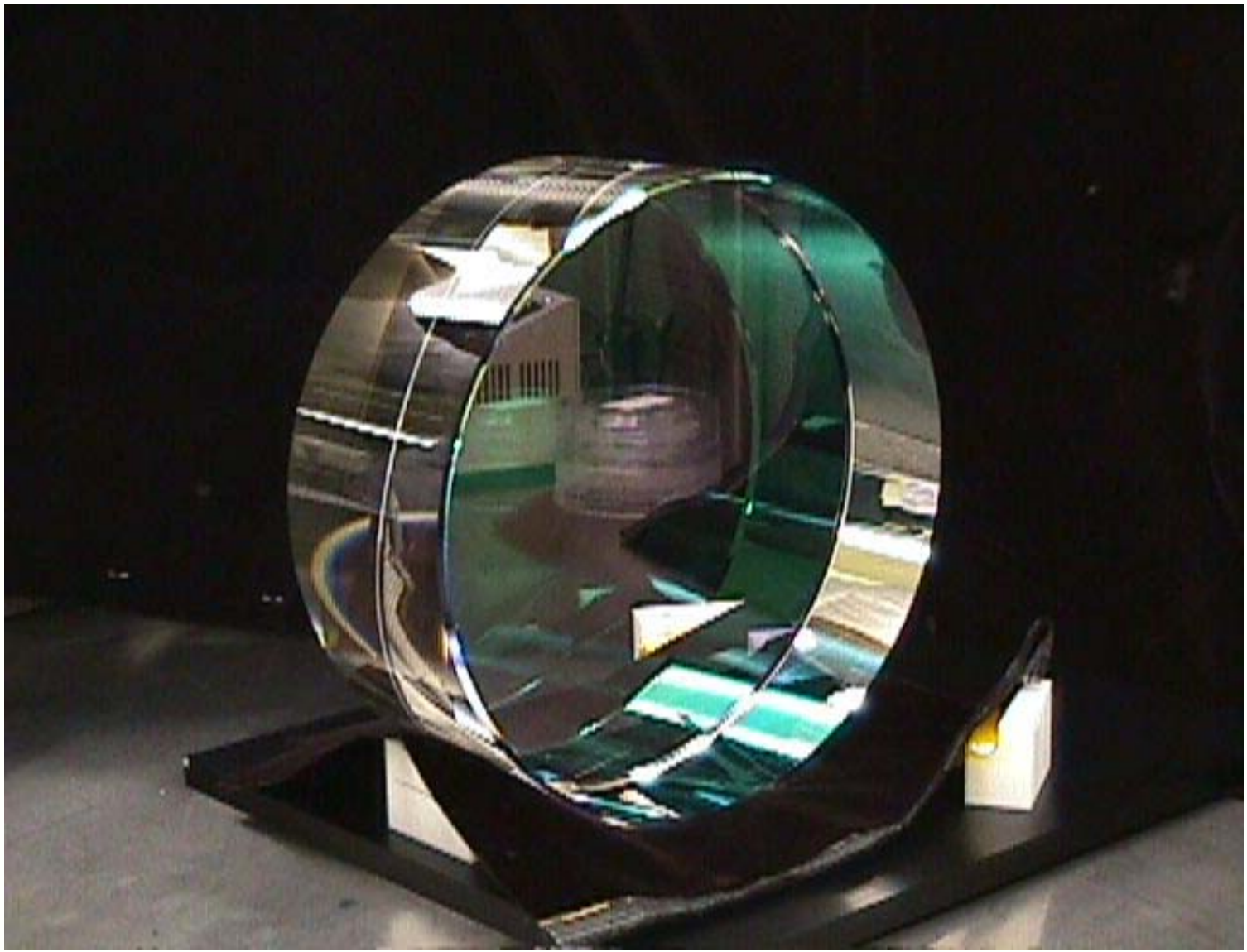
- Want "optical" arm length ~ $\lambda_{GW}$ /4 for best antenna response
- Adds complexity; now each arm needs to be held near

$$L = k * \lambda_{LASER} / 2$$

- Add mirror to "recycle" photons (equivalent to more laser power)

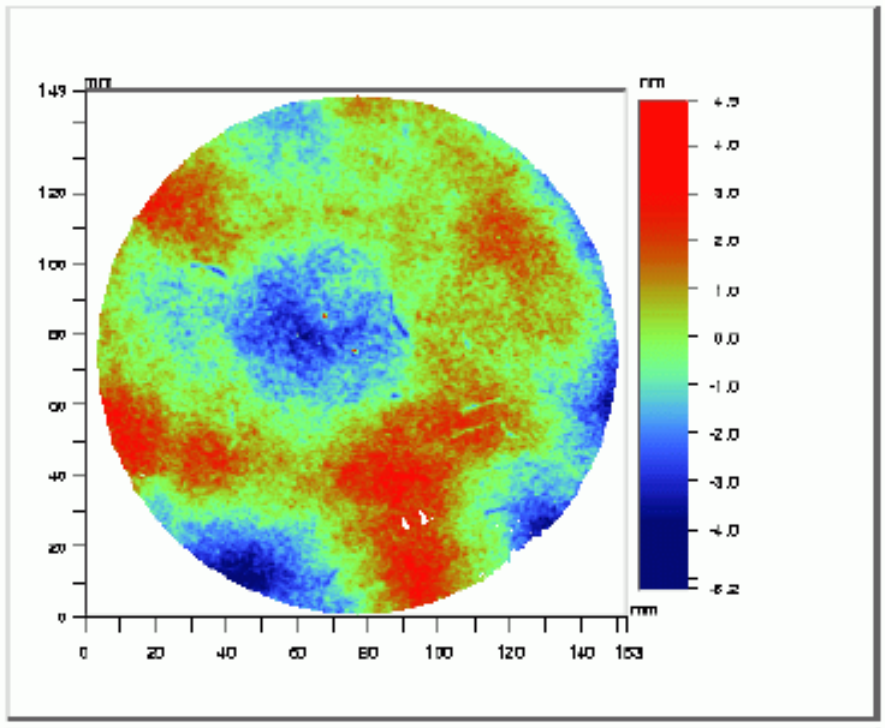


# Core Optics

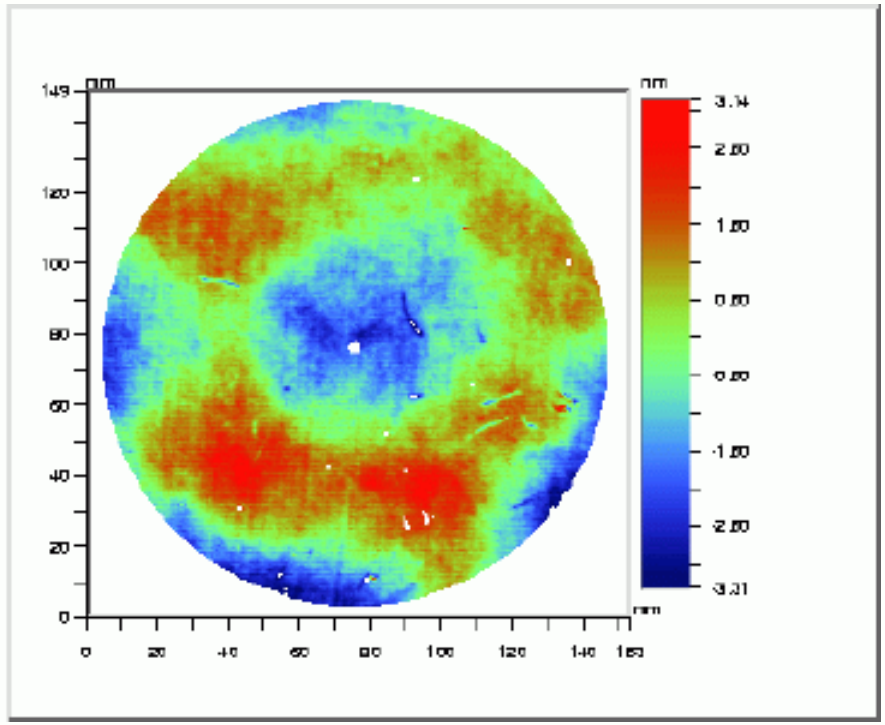


# *Core Optic Metrology*

- Current state of the art: 0.2 nm repeatability



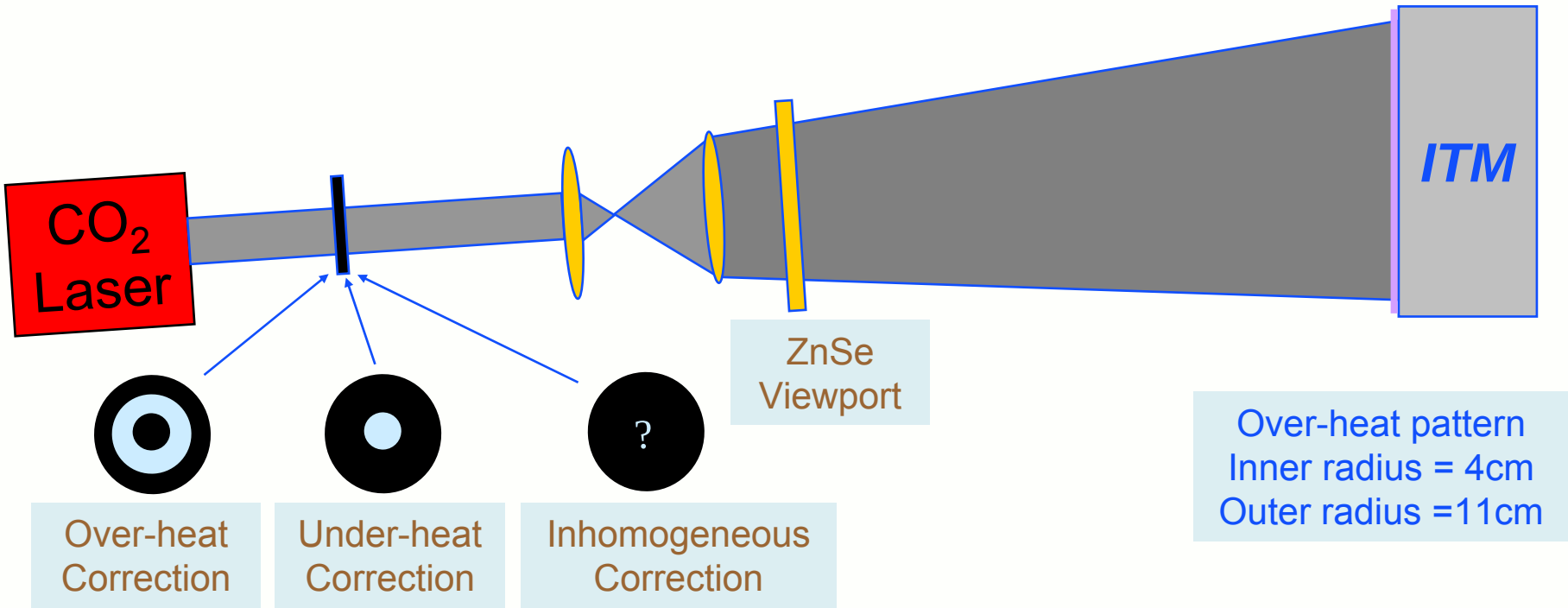
LIGO data (1.2 nm rms)



CSIRO data (1.1 nm rms)

➢ ***Best mirrors are λ/6000 over the central 8 cm diameter***

# Thermal Compensation System




- Cold power recycling cavity is unstable: poor buildup and mode shape for the RF sidebands
- Require 10's of mW absorbed by 1μm beam

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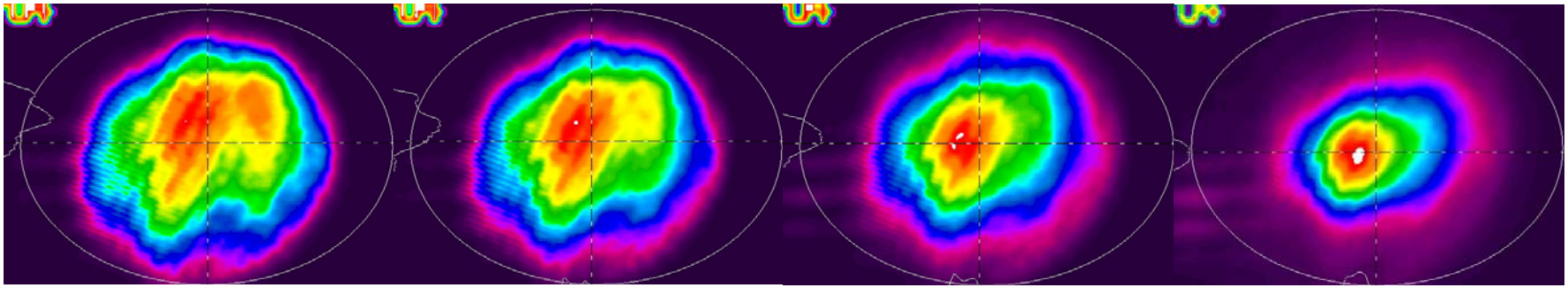
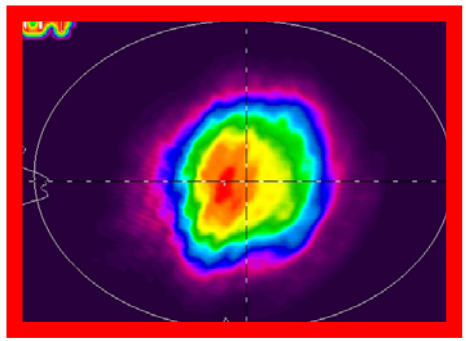
# *Circulating Sideband Mode Profiles vs. Thermal Compensation Power*

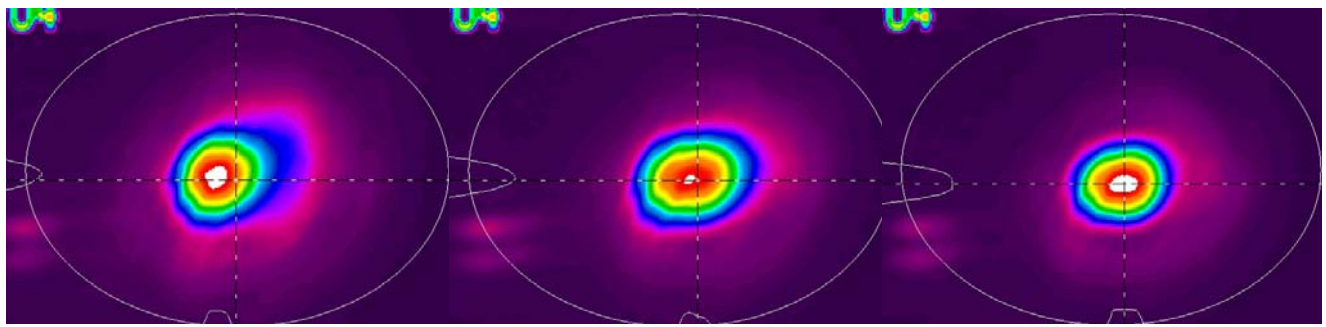
No Heat | 30 mW | 60 mW | 90 mW



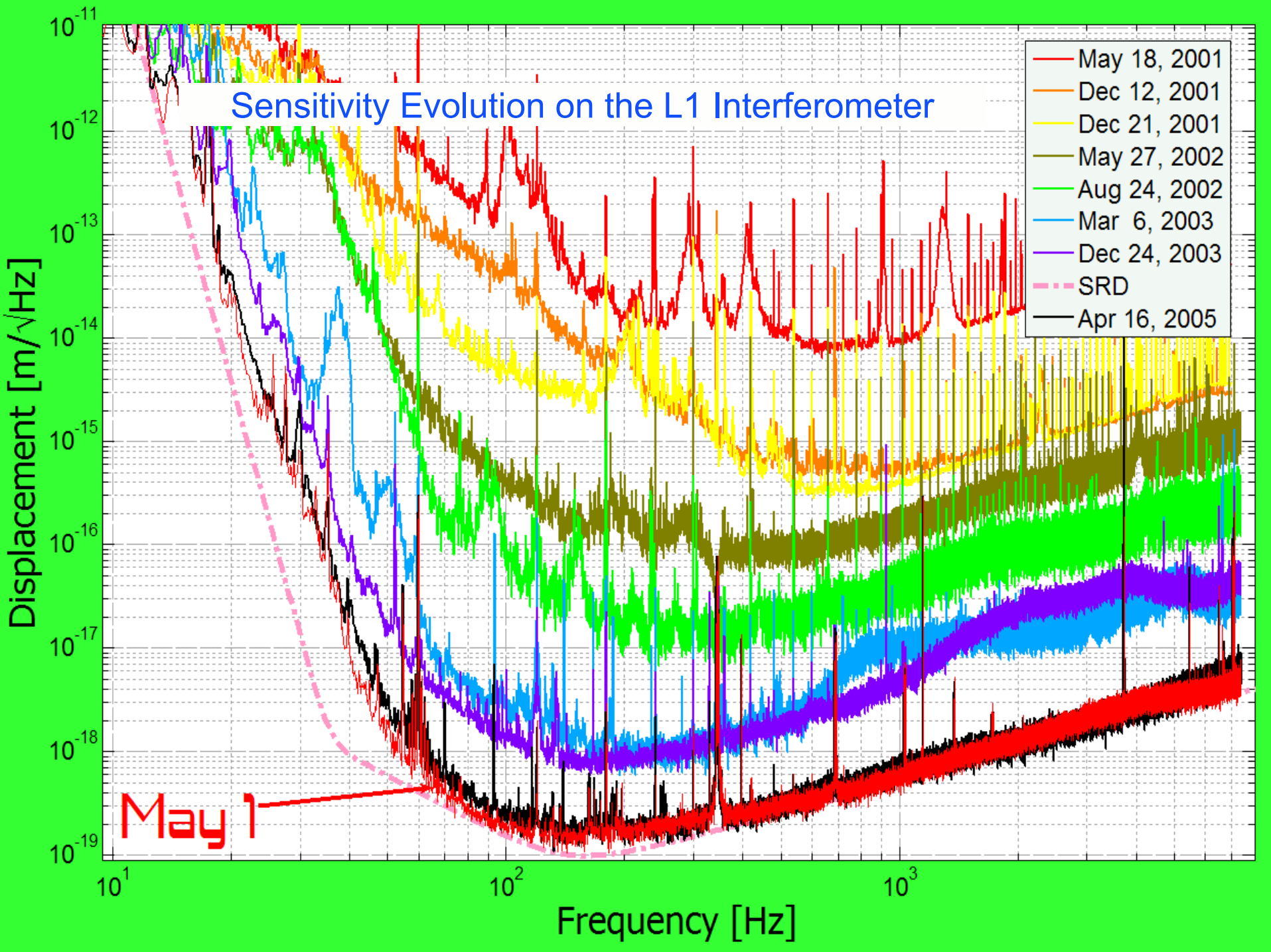
*Incident beam*

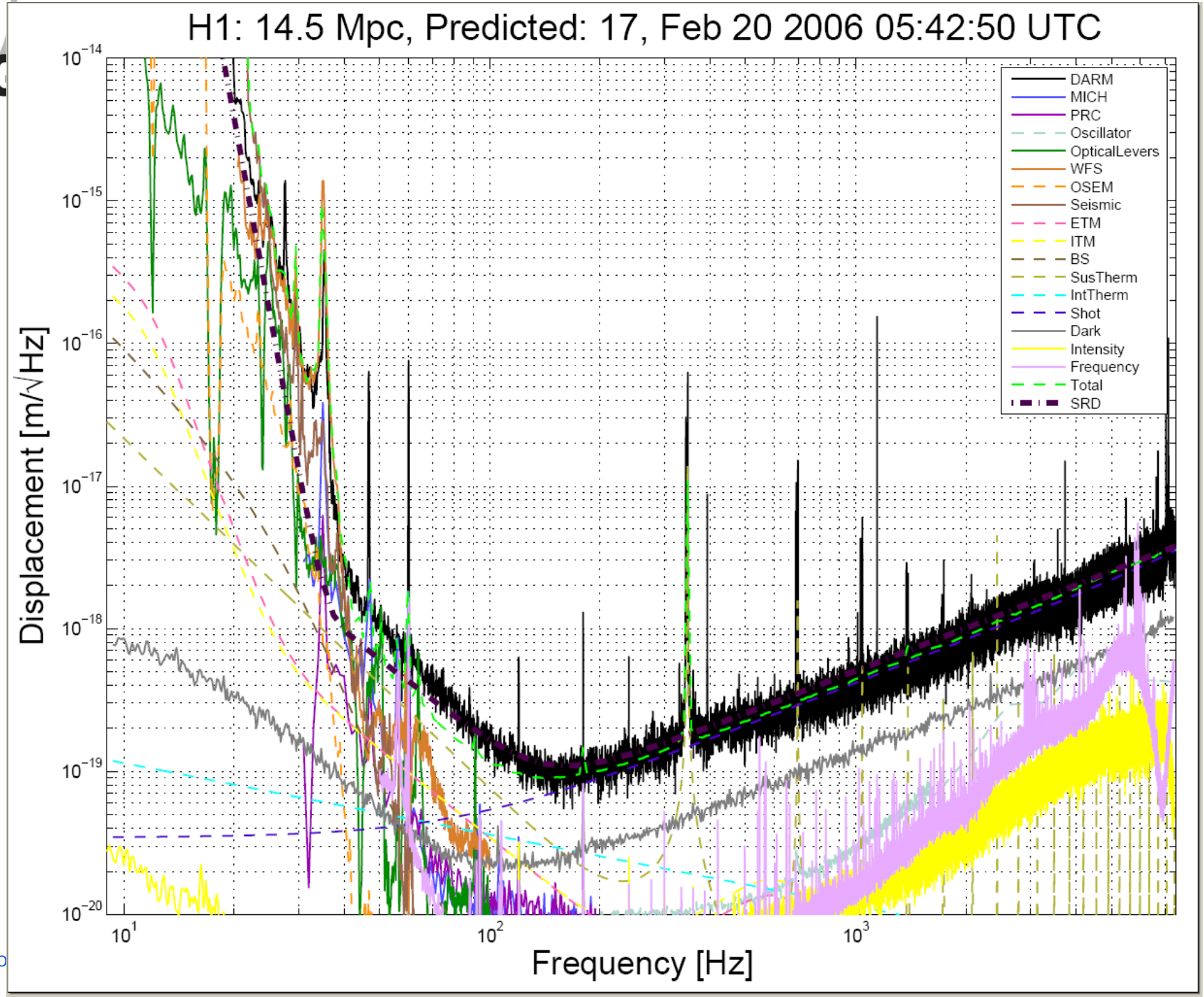


**Best match**



120 mW | 150 mW | 180 mW


Sensitivity Evolution on the L1 Interferometer
May 18, 2001
Dec 12, 2001
Dec 21, 2001
May 27, 2002
Aug 24, 2002
Mar 6, 2003
Dec 24, 2003
SRD
Apr 16, 2005
May 1
Displacement [m/√Hz]
Frequency [Hz]
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^1
10^2
10^3


H1: 14.5 Mpc, Predicted: 17, Feb 20 2006 05:42:50 UTC
Displacement [m/√Hz]
Frequency [Hz]
DARM
MICH
PRC
Oscillator
OpticalLevers
WFS
OSEM
Seismic
ETM
ITM
BS
SusTherm
IntTherm
Shot
Dark
Intensity
Frequency
Total
SRD

# S5 Performance So Far

## S5 NS-NS Binary Inspiral Range vs. Time

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

# S5 Performance So Far

## NS-NS Inspiral Range Histogram

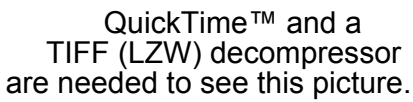
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

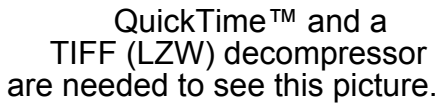
## Coincidence Factor by Week

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

↔ start delay

↔ commissioning ↔ breaks


QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.


QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

# *Public Education and Outreach*

## LIGO Science Education Center at Livingston Observatory

- 8000 ft$^2$ facility with ~50 hands-on exhibits illustrating LIGO science themes
- School group, family, club visits
- Science teacher professional development
- *Under construction!*

LIGO

# STATUS

- LIGO completed S1, S2, S3, S4 science data runs at successively higher sensitivities

*No confirmed detections yet*

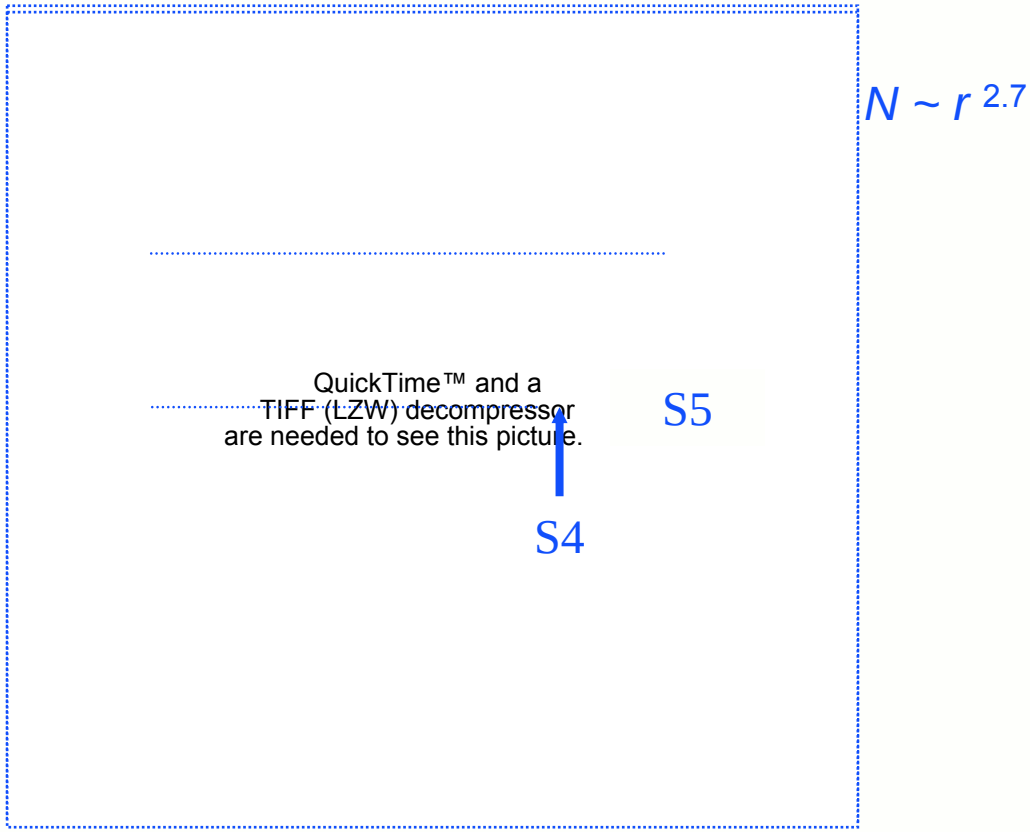
- ALL 3 LIGO INTERFEROMETERS NOW OPERATING AT DESIGN SENSITIVITY
- Sharing data, coordinated operation w/ GEO, TAMA (soon also VIRGO)
- Upper limits published on periodic, burst, stochastic and binary signals

*See analysis talks at this and other sessions!*

- S5 science run is in progress: "1 year at design sensitivity"
- Good chance we will soon confirm detections, but we want MORE…

# *Perspective: why not just sit tight ?*

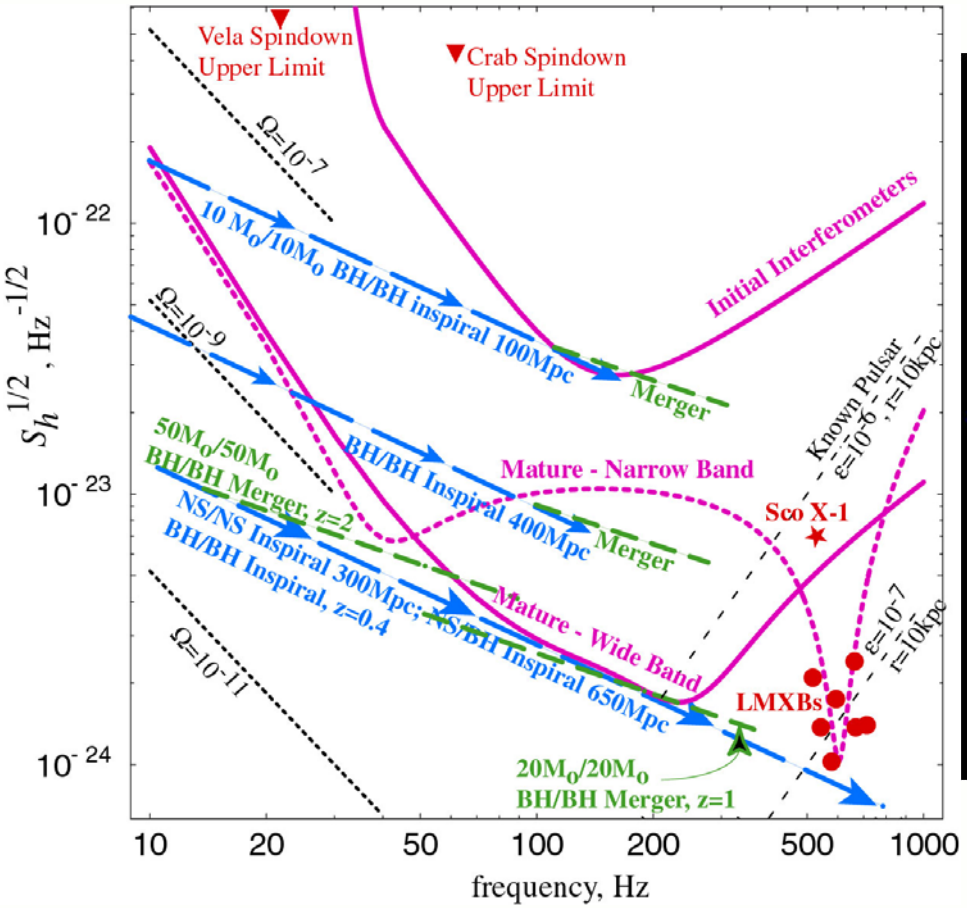
- BNS inspiral detection range is now well into VIRGO cluster

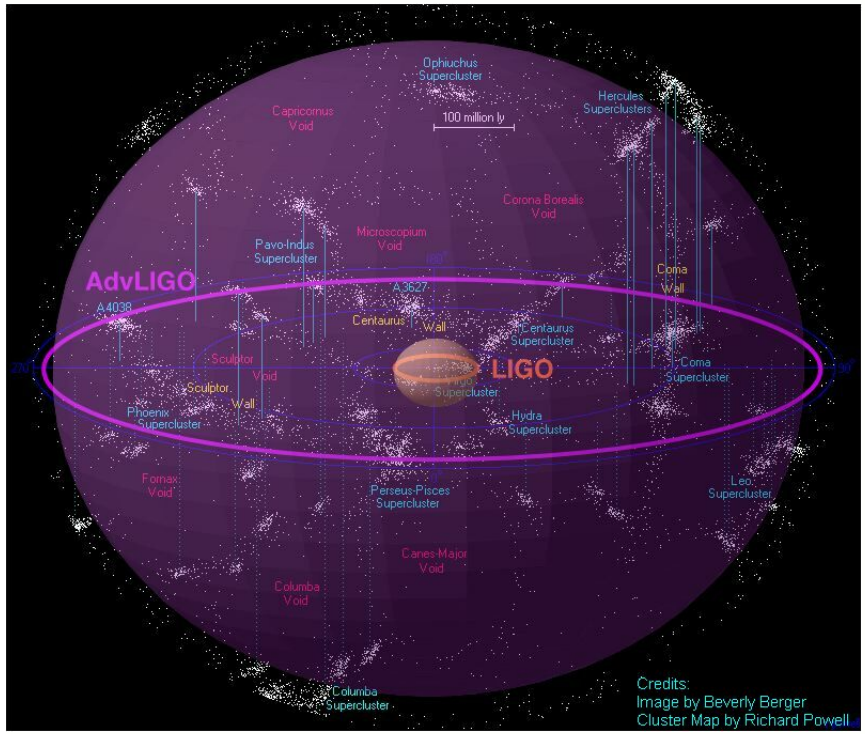



Nutzman et al., arXiv:astro-ph/0402091 v2, 28 Jun 2004

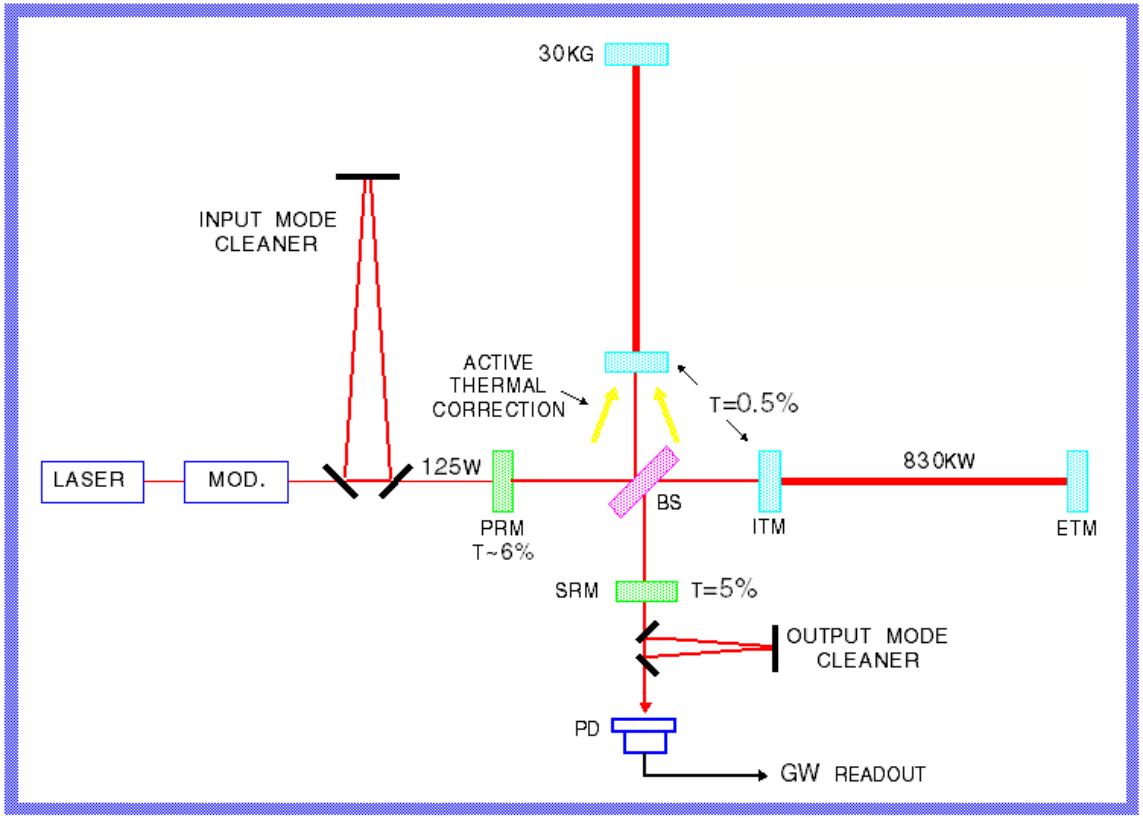
# *Advanced LIGO*

- NSB approved for FY2008 start
- Online in 2012 (if funded in '08)



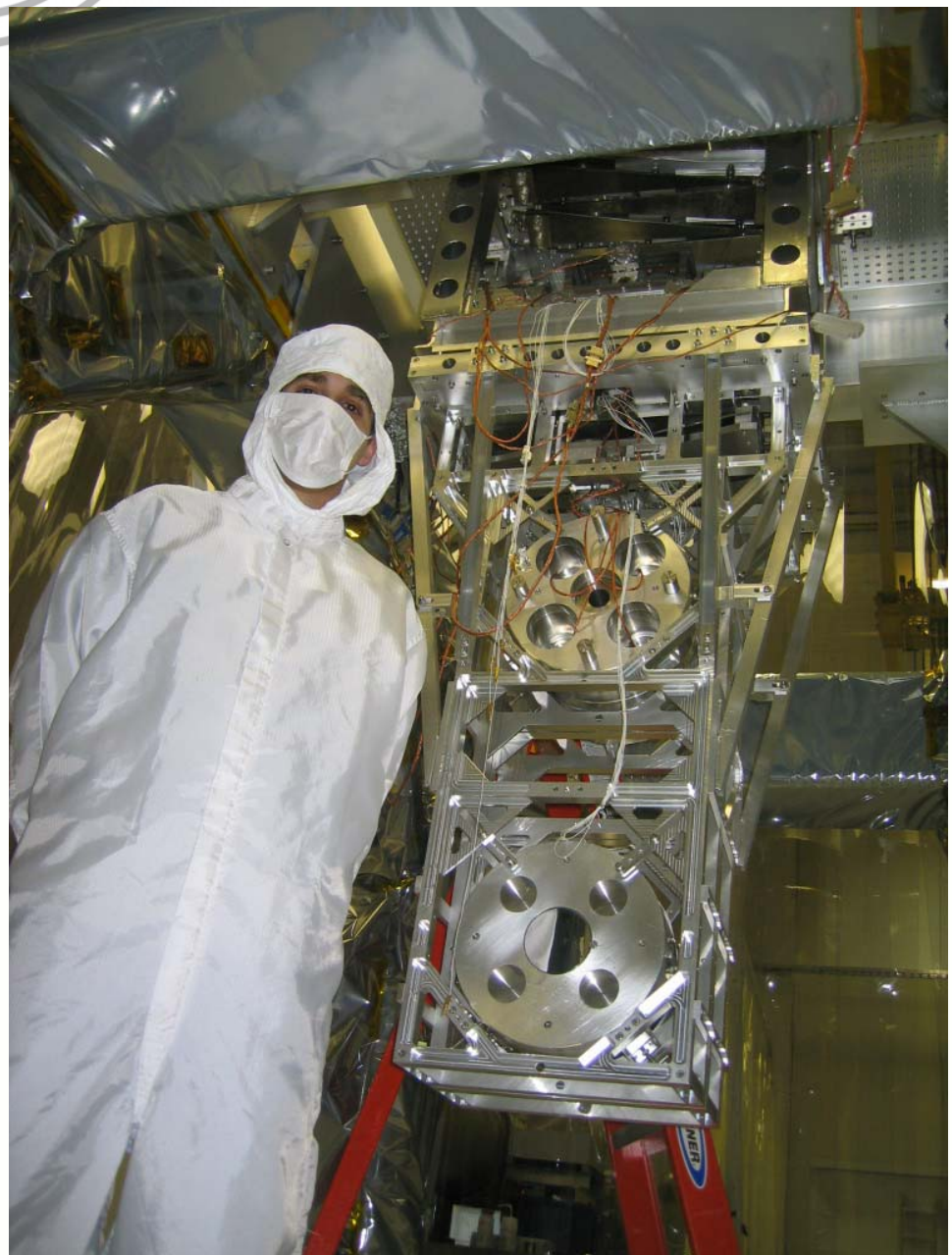
# Advanced Interferometer Concept




- » Signal recycling
- » Output mode cleaner
- » 180 W laser
  (800 kW in arms)
- » 30 kg test masses
- » Quadruple suspensions
- » Active seismic isolation
- » Active thermal correction

LIGO

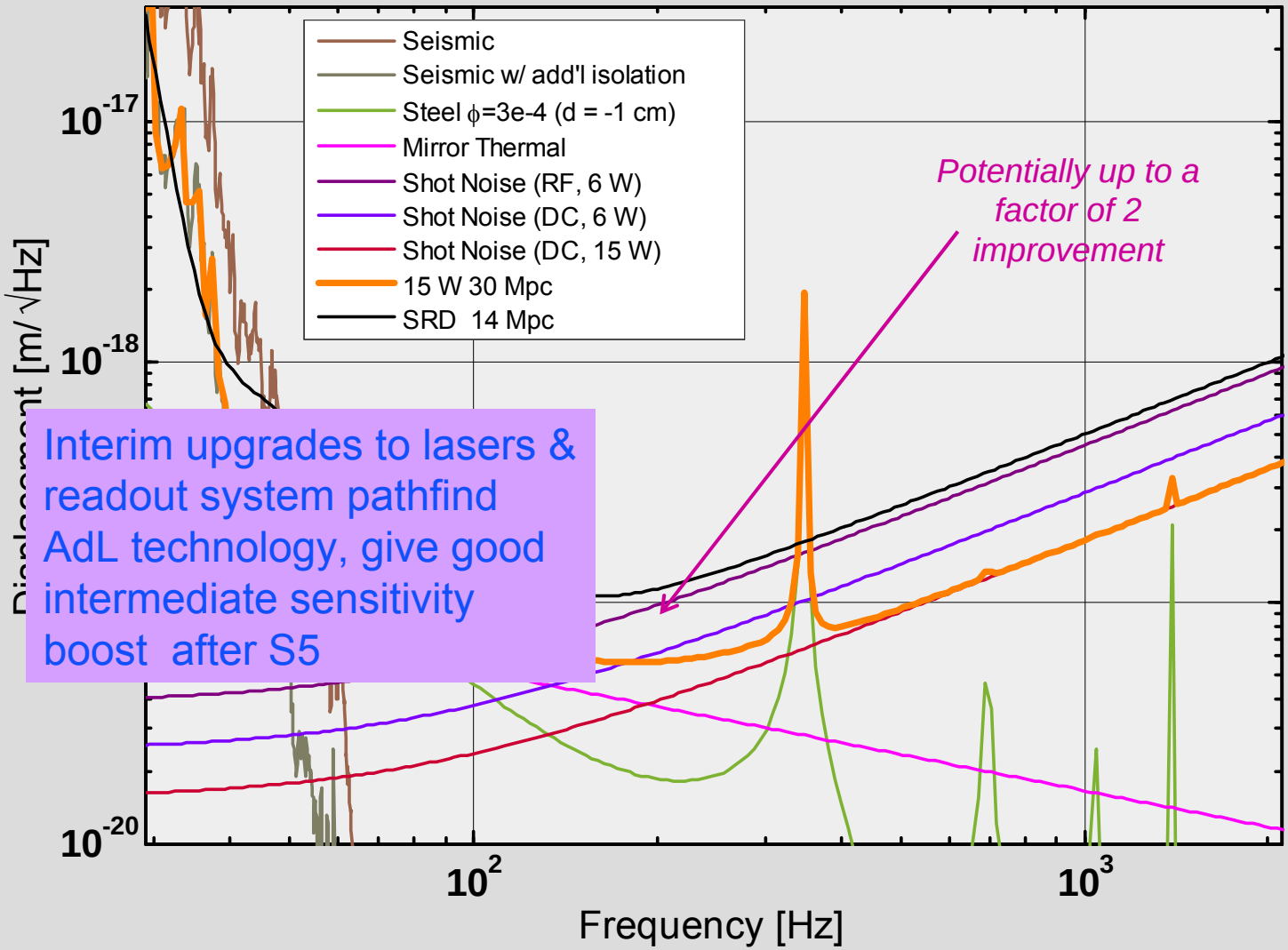
# *Advanced Suspensions*



- Based on successful GEO triple pendulum design
- Quad pendula for TM, BS; Triples for input optics
- Blade springs for vertical isolation
- Indirect damping through upper stage recoil
- Electrostatic or photon drive for fast control at final stage; reaction mass for ES recoil

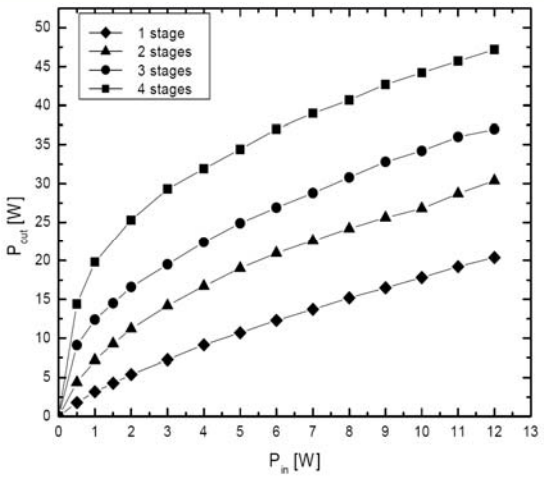
LIGO

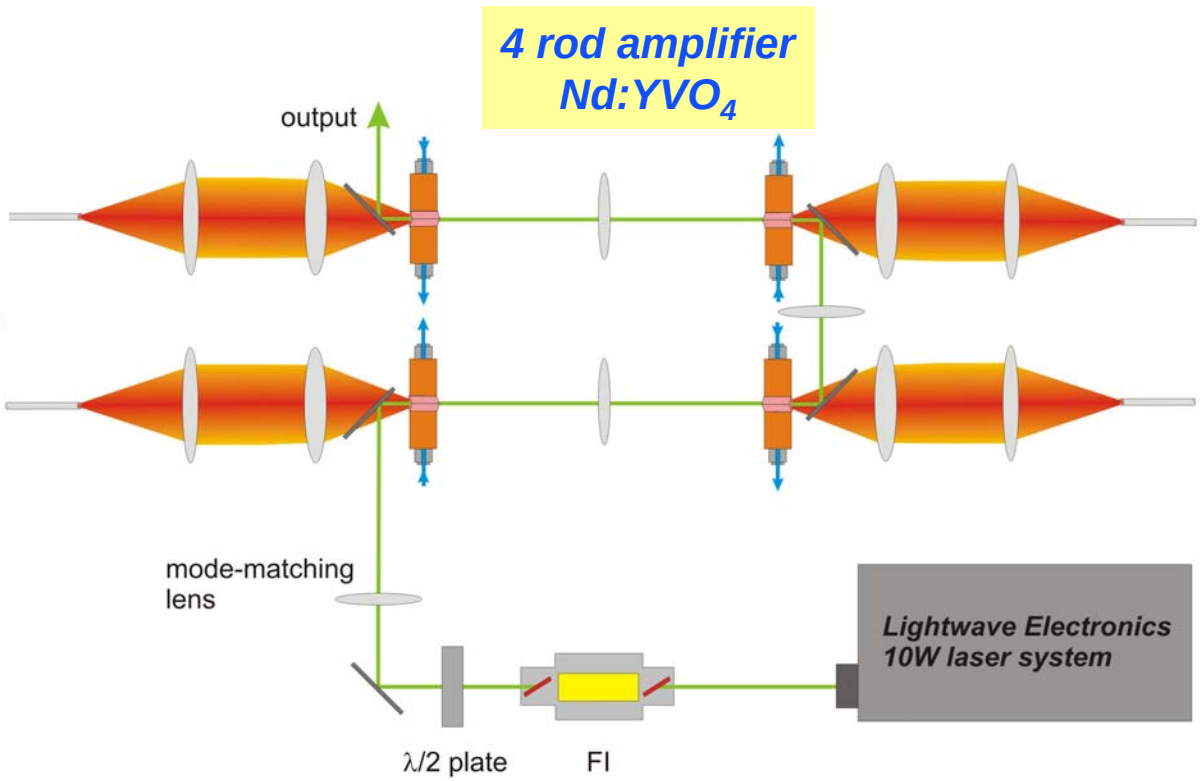
# *Baby steps: Certain AdL upgrades are ready early and can be "gently" integrated (tested) early*



# Higher Power Laser

- 4-rod amplifier from LZH (a component of AdL laser now under development) to run as a booster for current lasers



# *Concluding Remarks*

- LIGO is **on the air at design sensitivity**
- We're working to improve our duty factor
- We already have at least 20x more coverage than any previous GW search; confirmed detection(s) a *strong possibility*
- As we search, we're designing advanced instruments to install in 2012; recent technology can improve by a factor of 10 in *h* or 1000 in event rate
- Boosts in laser power and readout technology planned for 2008 can net an early factor of 2 (x8 in BNS event rate!); also help reduce AdL risk and startup time

*GOOD EXPERIMENTERS WANTED-- WE HAVE OPENINGS AT LLO!*