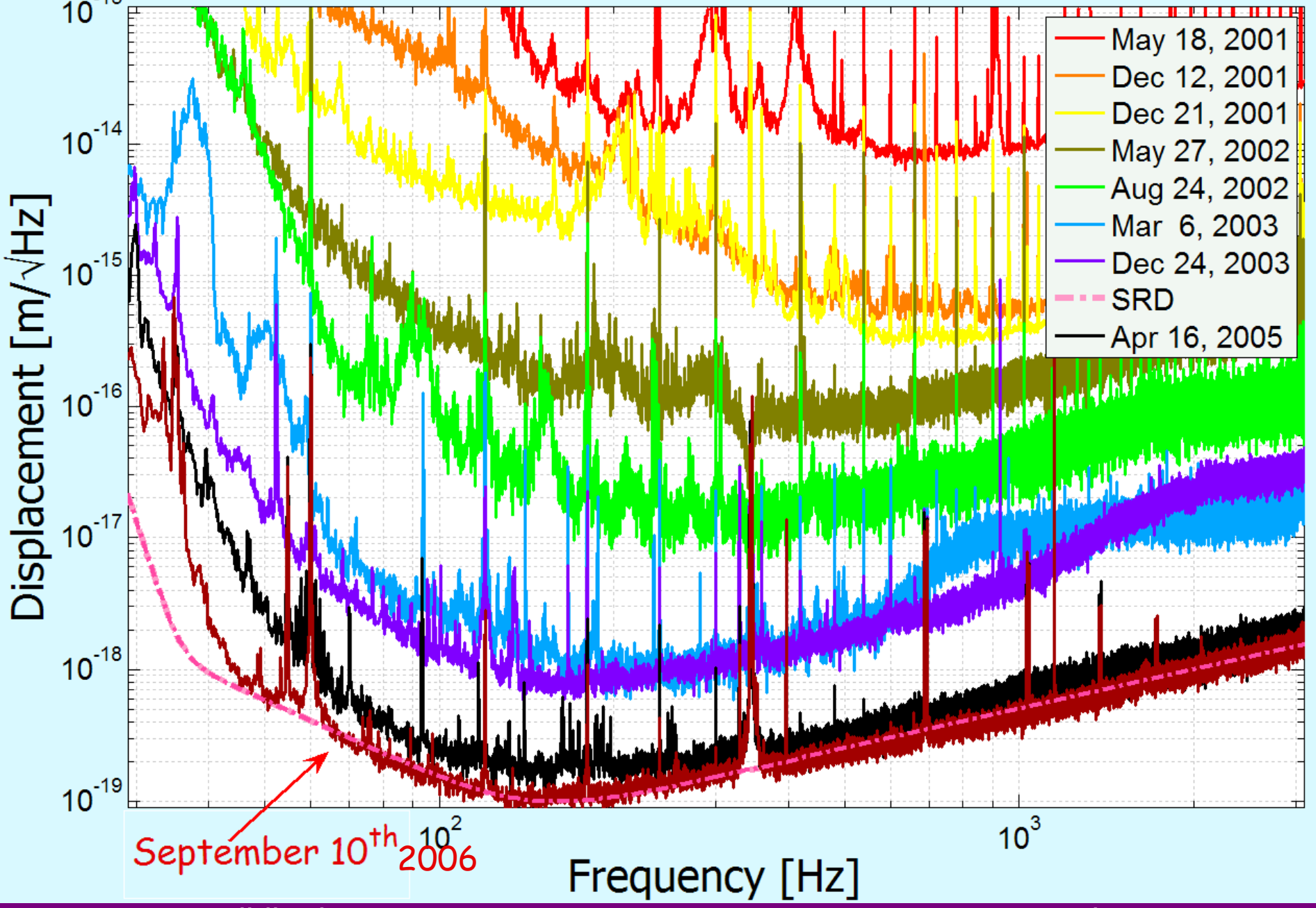
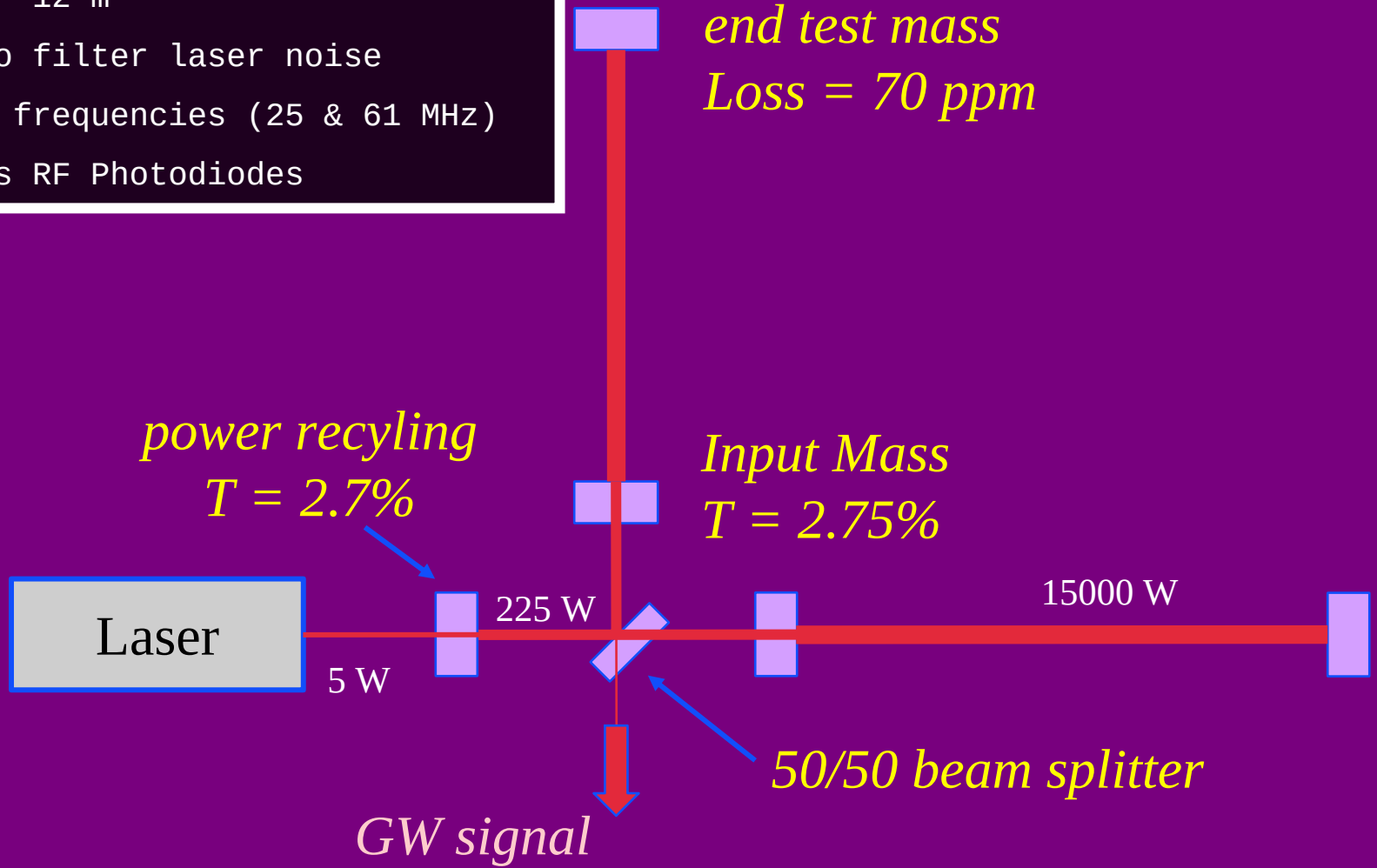

May 18, 2001
Dec 12, 2001
Dec 21, 2001
May 27, 2002
Aug 24, 2002
Mar 6, 2003
Dec 24, 2003
SRD
Apr 16, 2005
Displacement [m/√Hz]
Frequency [Hz]
September 10th 2006

Not Really *Mistakes*

- **iLIGO was a first**: 10^{-19} m/rHz and 10^{-10} rad/rHz @100 Hz
- **HUGE Vacuum System, HUGE Optics + Large power**
- **>100 servo loops: low-noise, real-time, high speed**
- First example of power recycled FPMI w/ frontal modulation
- First scaling from ‘table-top’ experiments to large scale observatories: large staff, big budget, high profile
- But still...design was very idealistic and inflexible. GW interferometery is a dynamic research effort: has to be made flexible because no one is smart enough.

LIGO

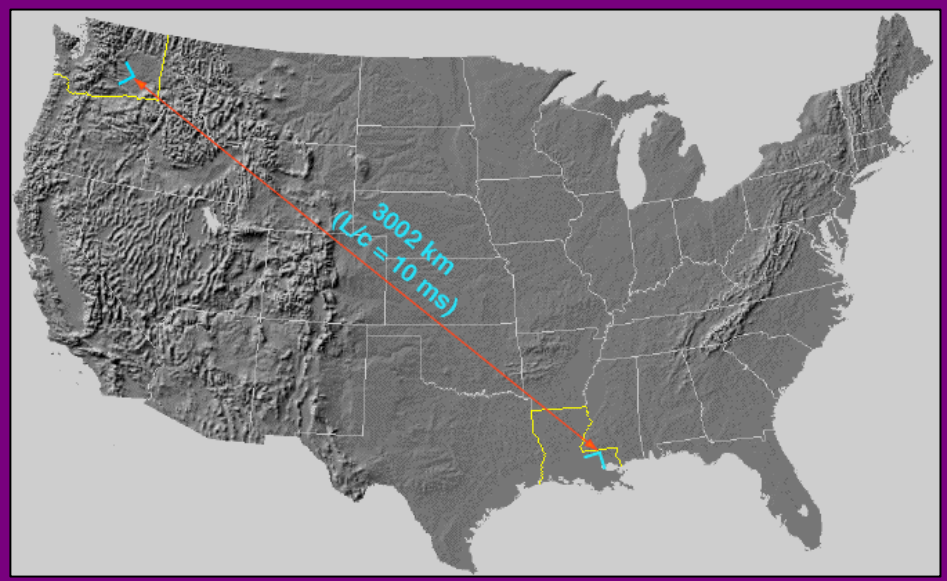
- Smaller mirrors
- Higher finesse arms
- 10 W laser --- 6-7 W into PR
- Critical Schnupp (~35 cm, Tsb = 3%)
- Short IMC – 12 m
- Pre – MC to filter laser noise
- Modulation frequencies (25 & 61 MHz)
- 2 mm InGaAs RF Photodiodes



LIGO Observatories

Hanford Nuclear Reservation, Eastern WA (H1 4km, H2 2km)

- *"Far away" from people*
- *Infrastructure compatible with LIGO 3*
- *20 year minimum lifetime*
- *Observatory, laboratory, office, school*



Livingston, LA (L1 4km)


mid station

Louisiana


water tank
fish pond
"borrow" ditch
Nitrogen
10 W laser
entrance

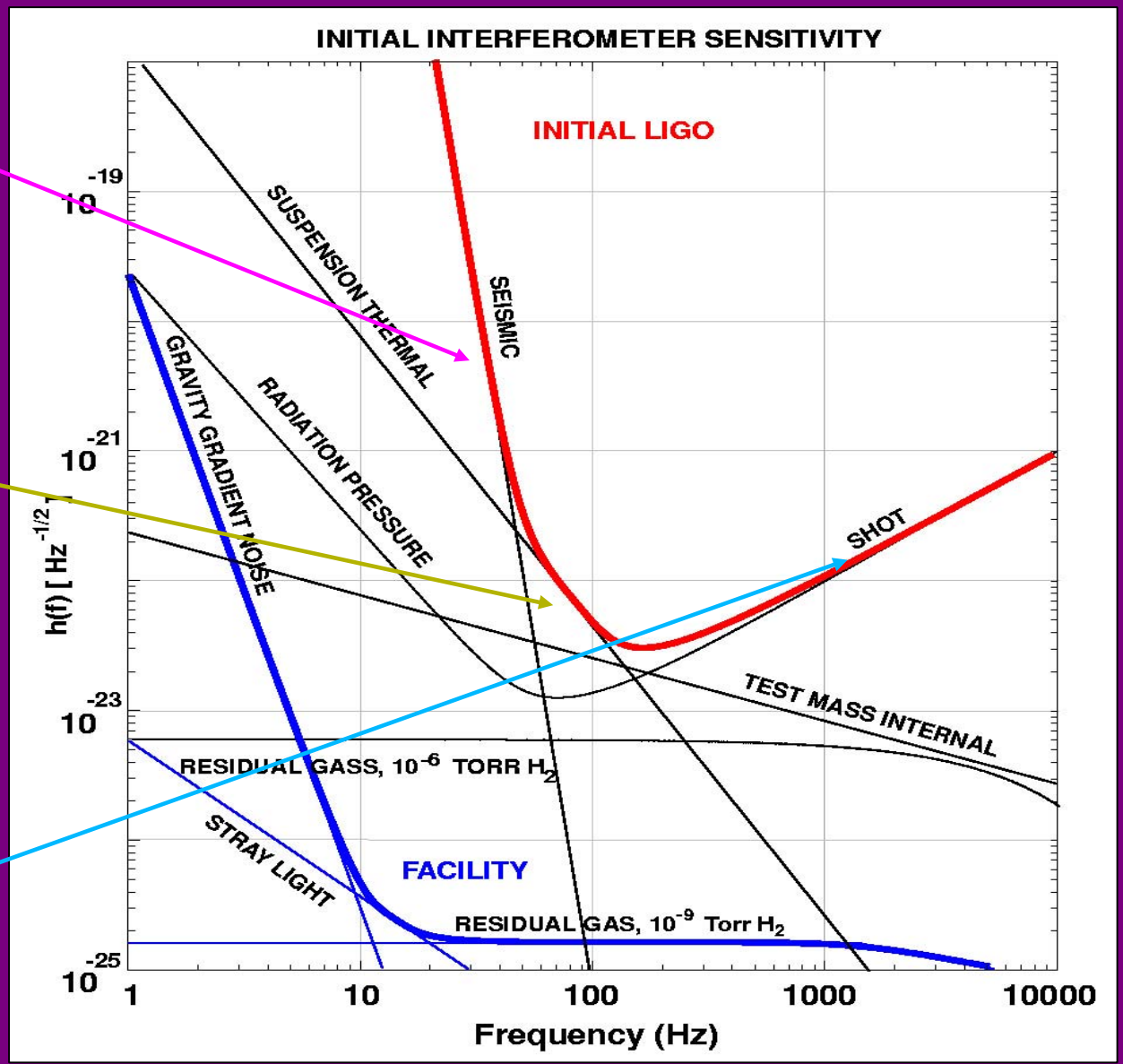
Science Requirements Doc: The LIGO-I Sensitivity Goal

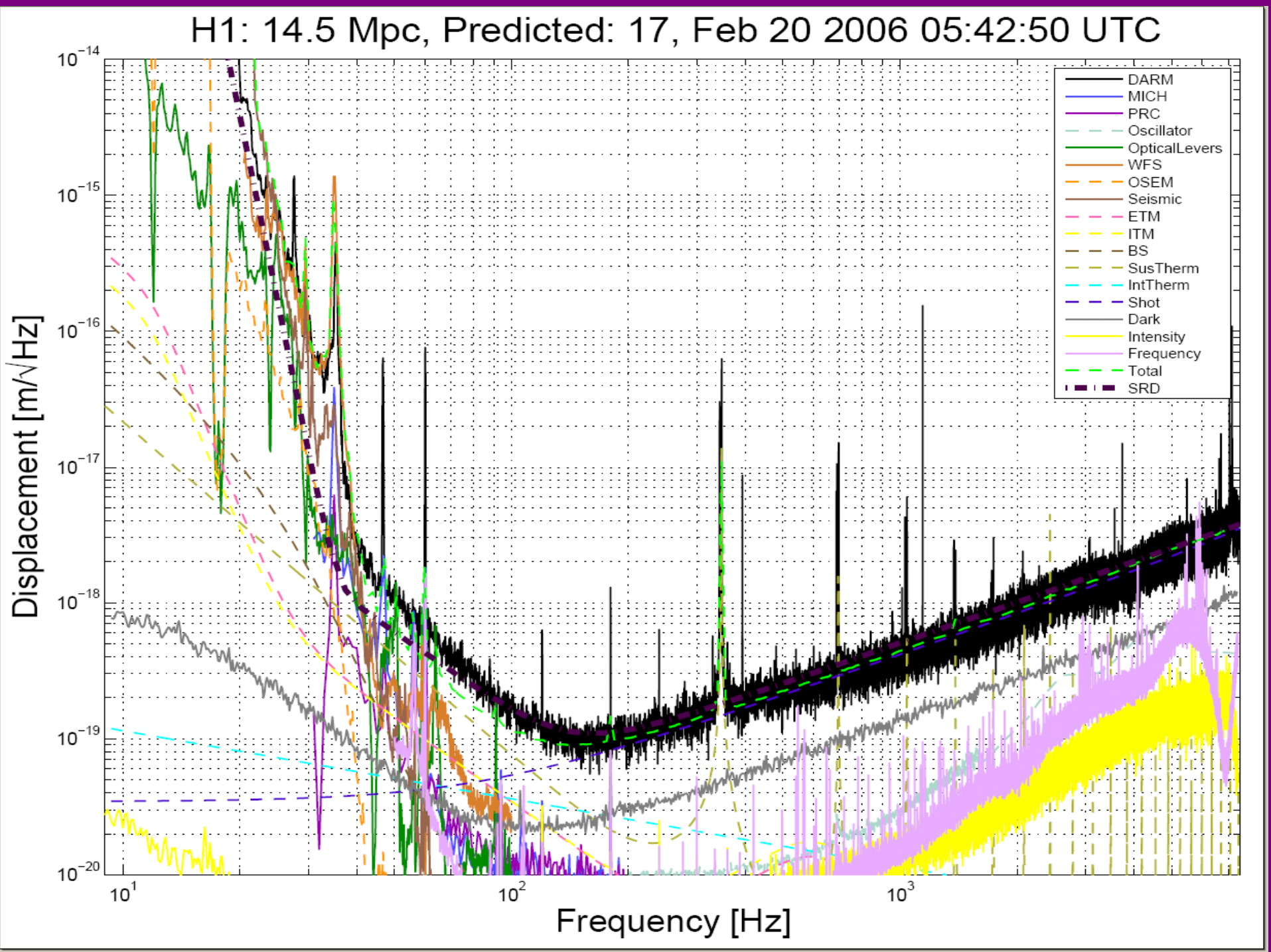
Seismic:
Ground noise filtered by seismic stack. Overkill above 20 Hz and makes noise below 2 Hz.

Thermal:
Brownian noise in the mirrors and in the mirrors' steel suspension wires.
Depends mostly on internal rubbing in the suspension wires.

Shot Noise:
Photon counting statistics --
> 10 kW in the cavities
~ 200 mW detected power

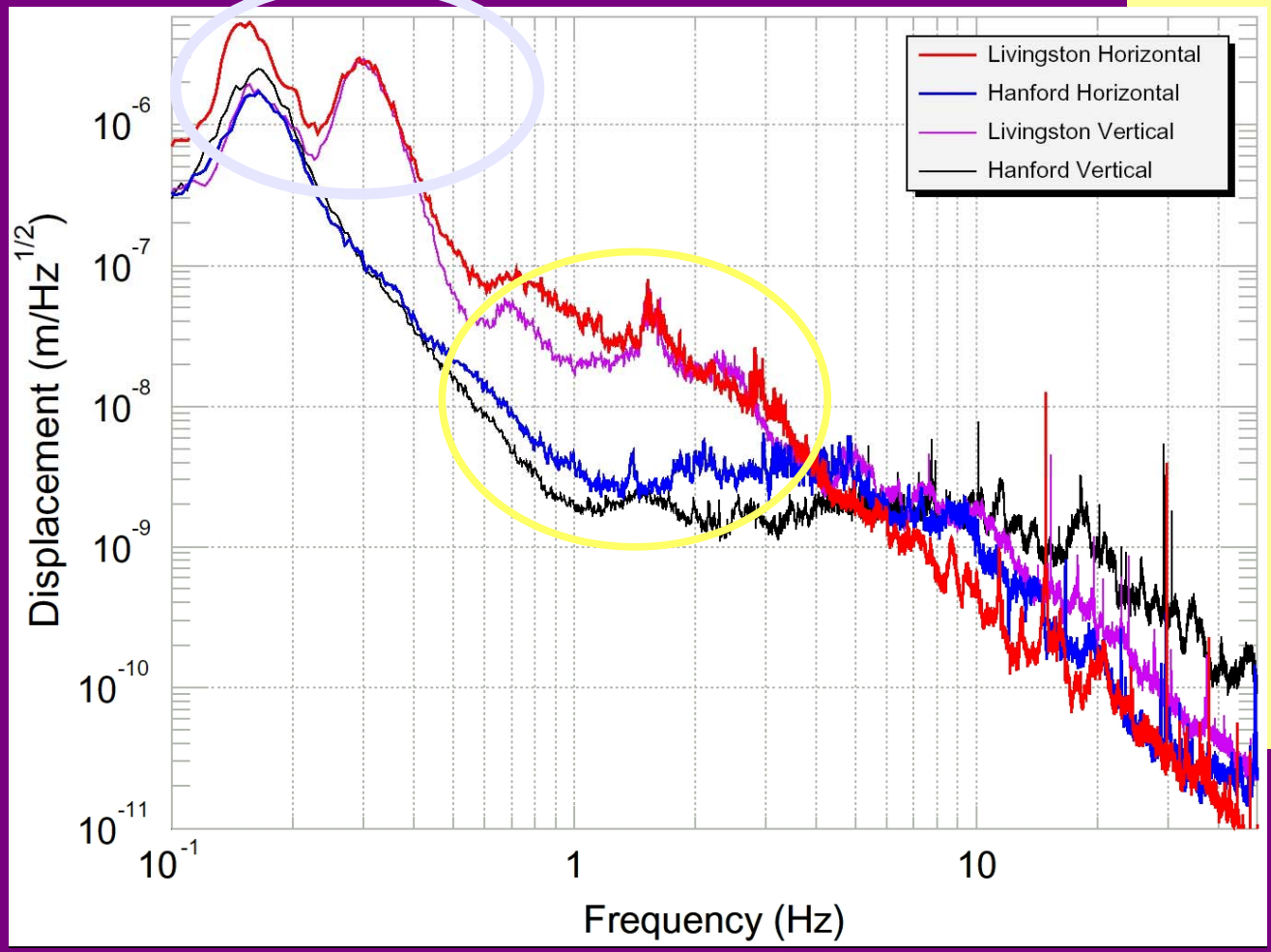
- Goes down with increased laser power and better fringe contrast




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

Seismic Noise

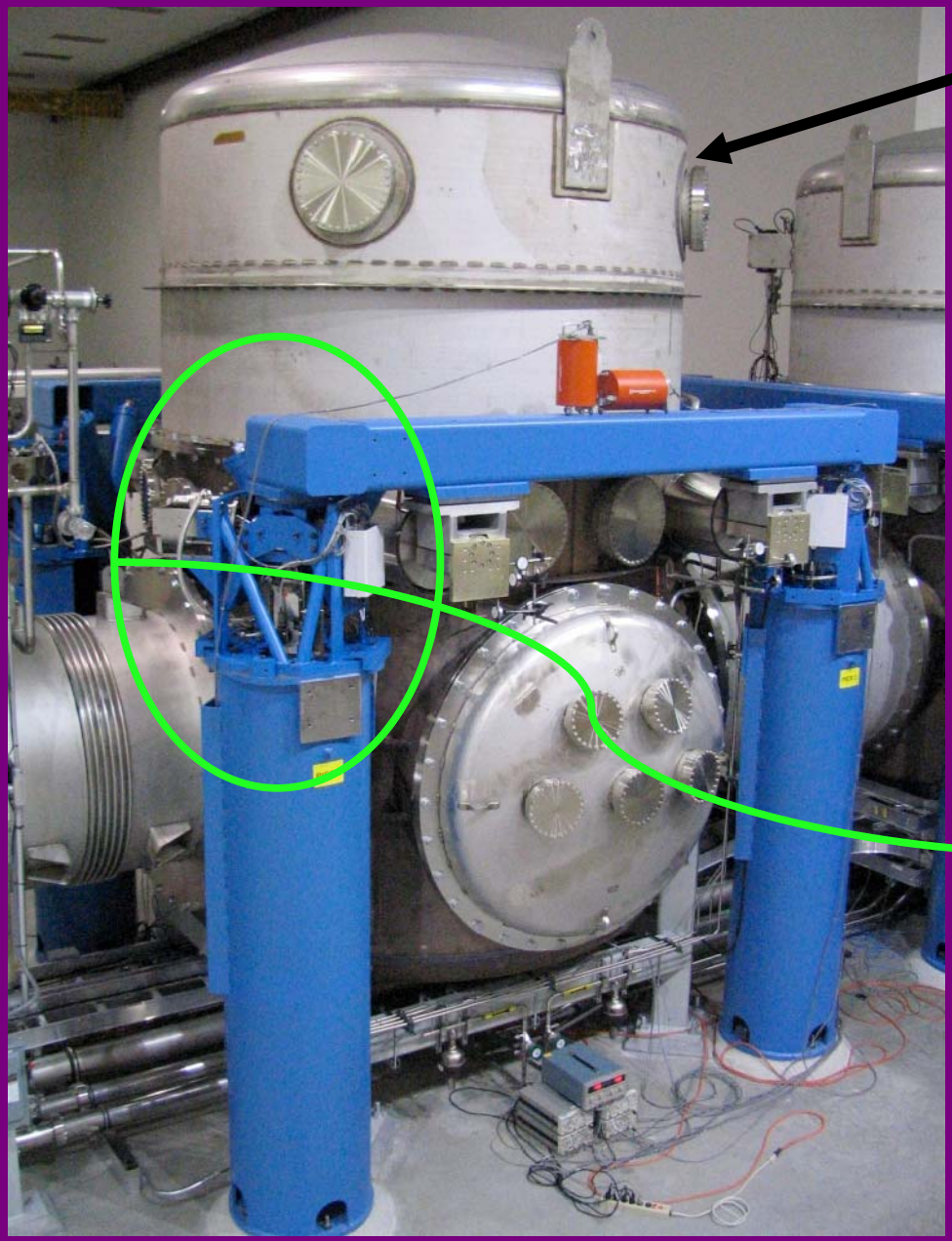
Ocean activity, hurricanes

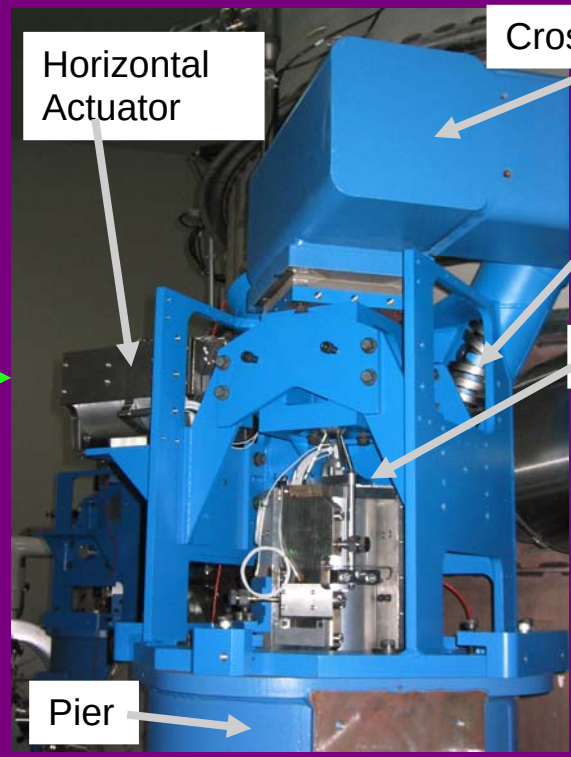


Caused by human activity:
Cars,
Trains,
Trucks,
Logging,
Well Drilling,
Oil Pipeline

Amplified by internal isolation stack resonances

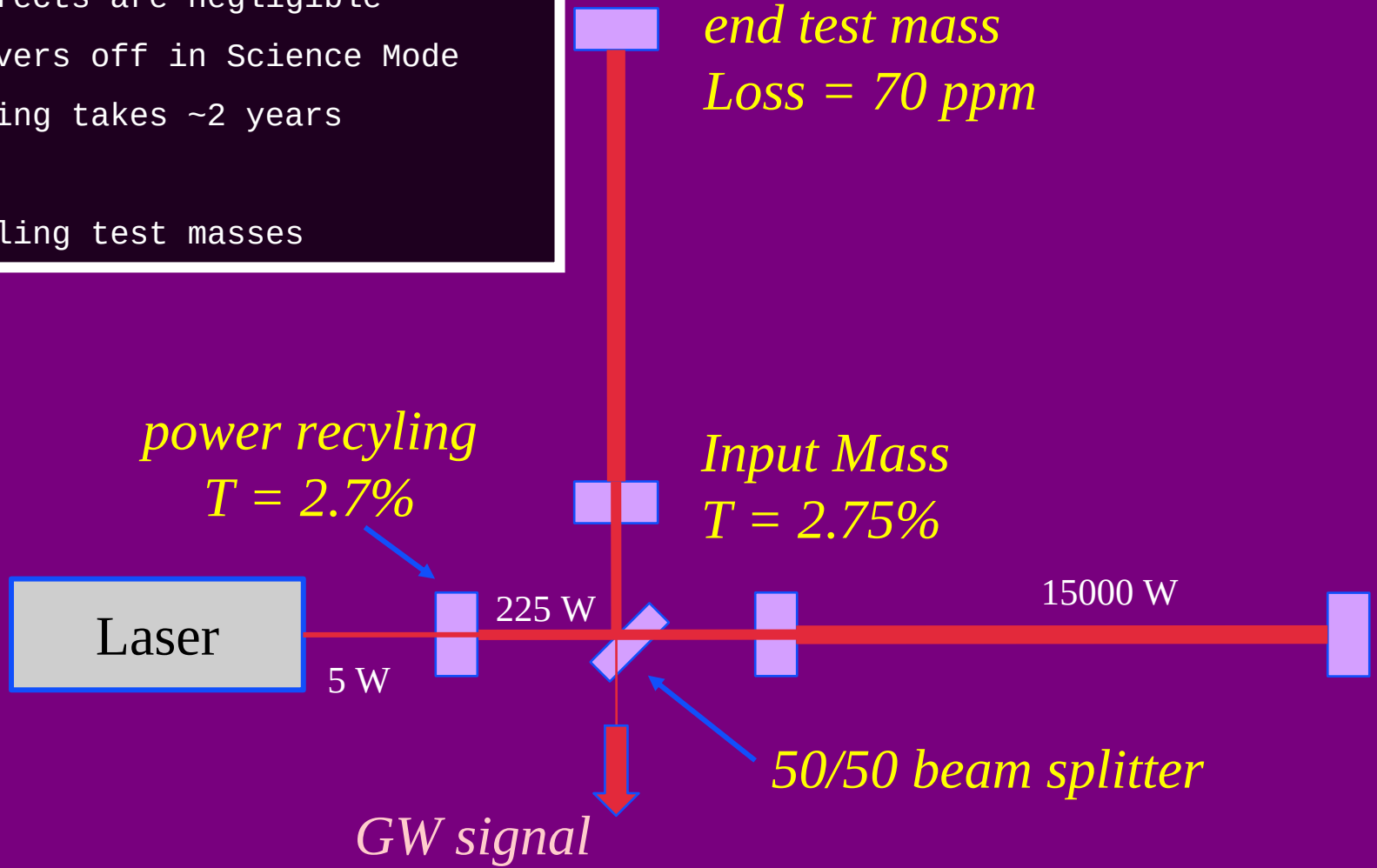
Input Test Mass Chamber



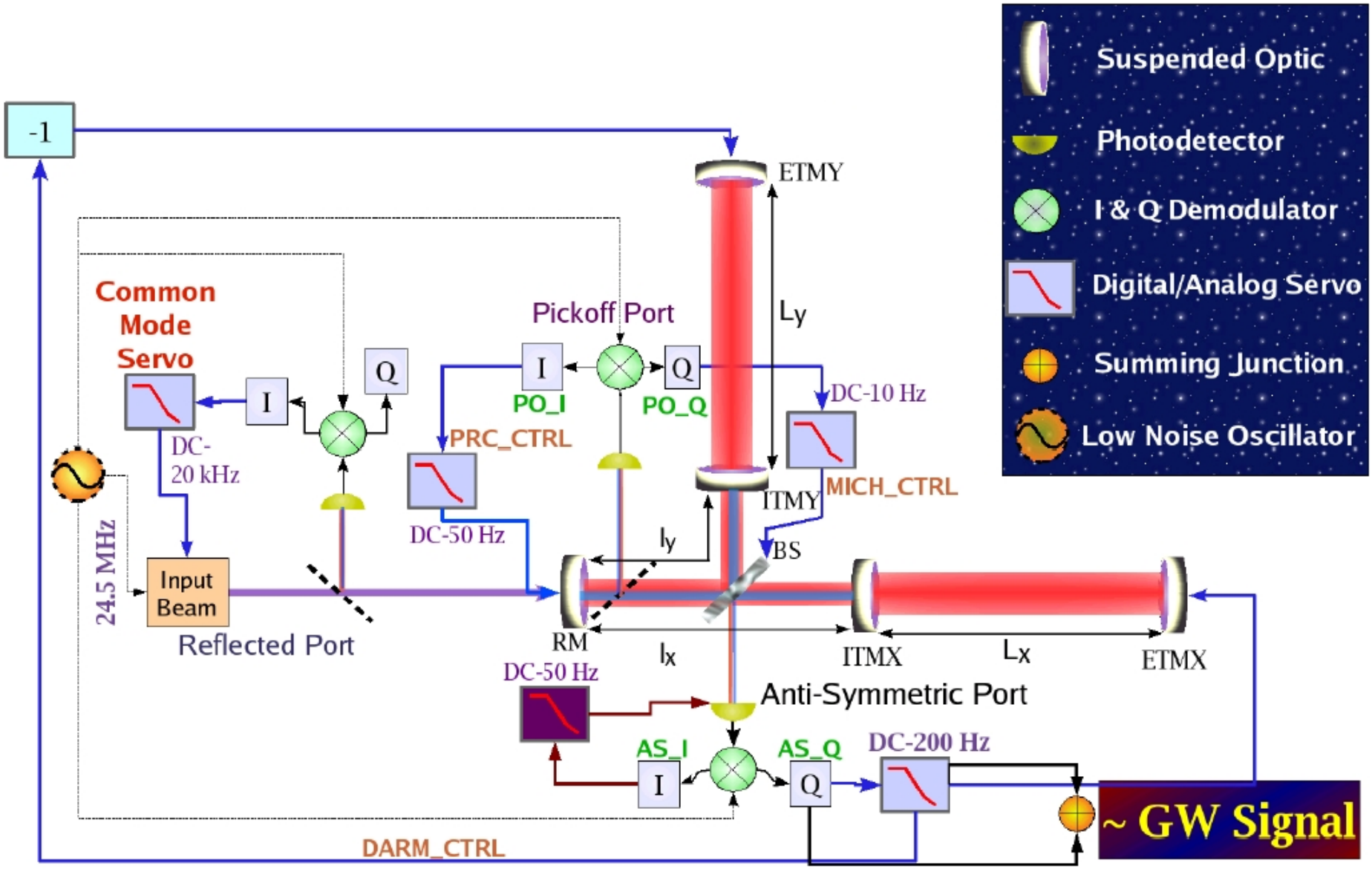


LIGO Myths

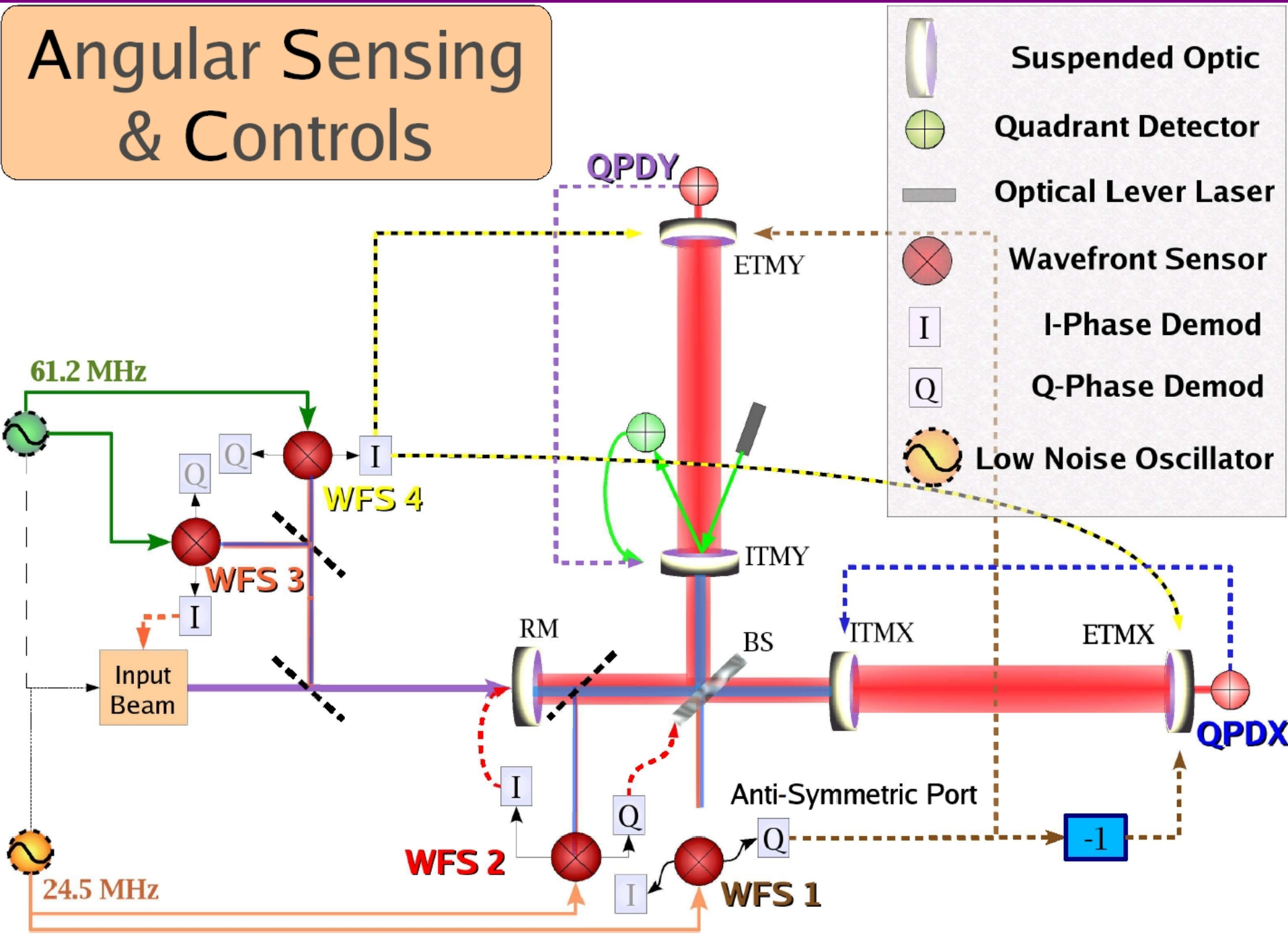
- xxx DOF does not couple to yyy
- Limited by fundamental noises
- Passive seismic attenuation
- Stays “locked” for 40 days and nights
- Thermal effects are negligible
- Optical Levers off in Science Mode
- Commissioning takes ~2 years
- 10 W laser
- Freely falling test masses

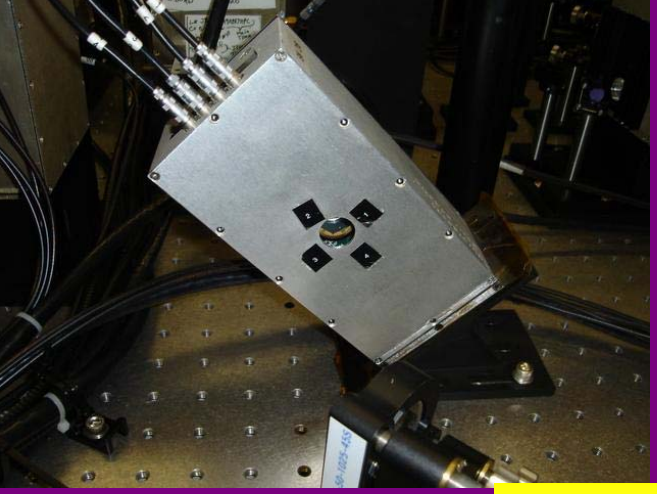


Global Length Controls



Angular Sensing & Controls

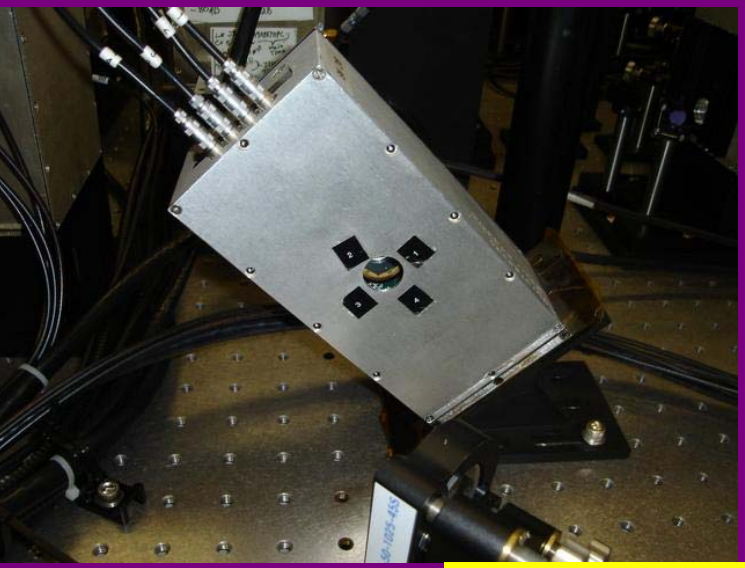




Alignment Control

(the hardest servo problem in LIGO)

- Controllability
  - 8(x2 DOF) sensors
  - Sensing matrix is not diagonal
  - Works along with non-diagonal optical levers
  - Sensing matrix is not constant (thermal stuff)
  - Radiation pressure instability (Sigg-Sidles Springs)
- Noise
  - Feedback w/ 5-10 Hz bandwidth
  - Make less than 10^{-19} m/rHz of noise at 40 Hz.
- Mirrors wiggle by a few nanoradians (RMS)



Alignment Control

(the hardest servo problem in LIGO)

Rai Weiss

- Sensing Noise = ~10^{-13} – 10^{-14} rad/rHz
  - Oscillating RF amps, noisy demod, Bouchon Compression, ADC

Hartmut Grote

- Gouy phase telescope for Dark Port was 88 deg. wrong
  - New 3 lens solution for hot ITFb

Matt Evans

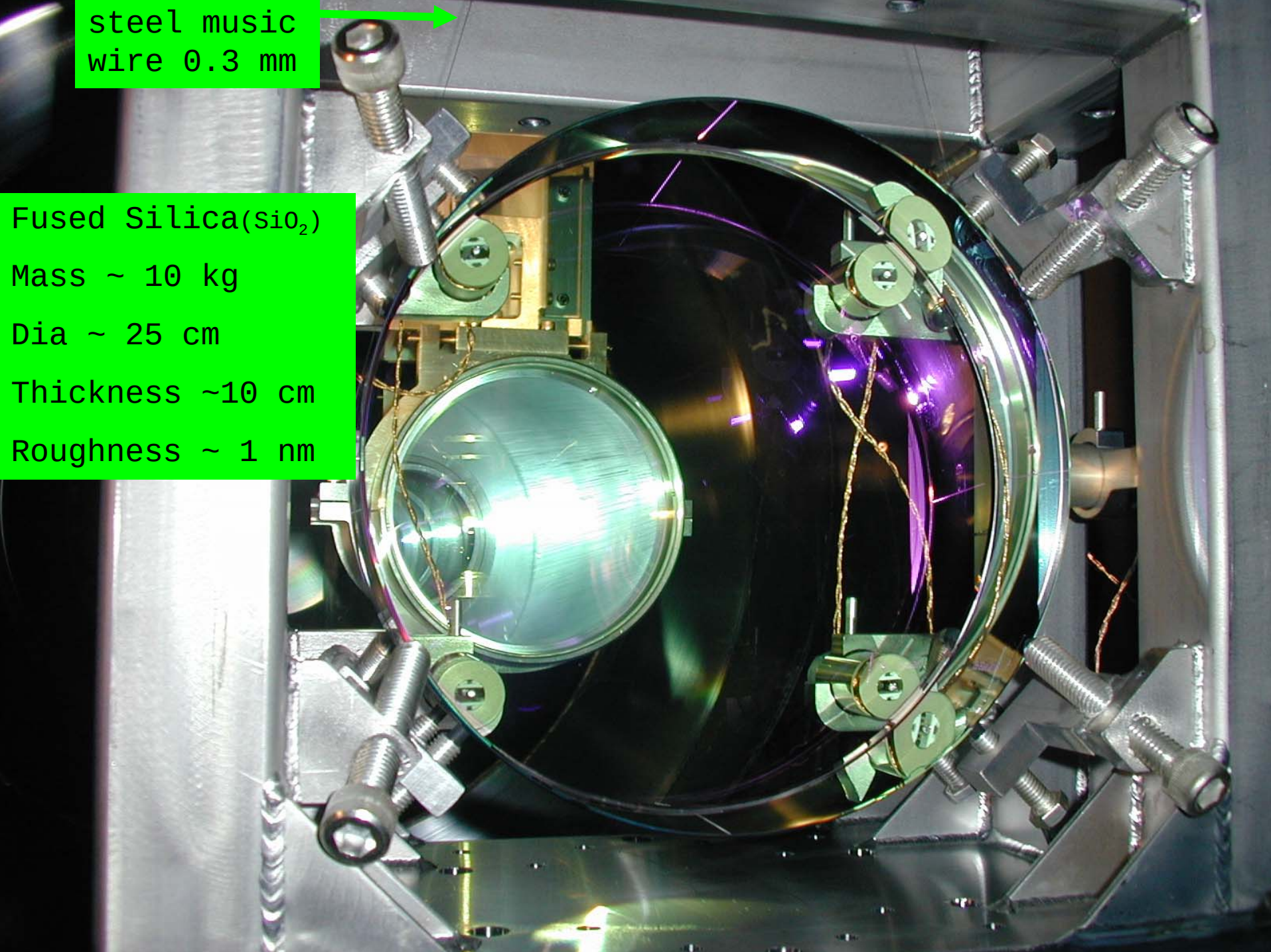
- Non-diagonal Sensing Matrix
  - Years and years of suffering => (Simple Matrix Adjustment Concept)

oops

- Sigg-Sidles Instability: Radiation Pressure induced torque
  - low frequency phase margin reduction

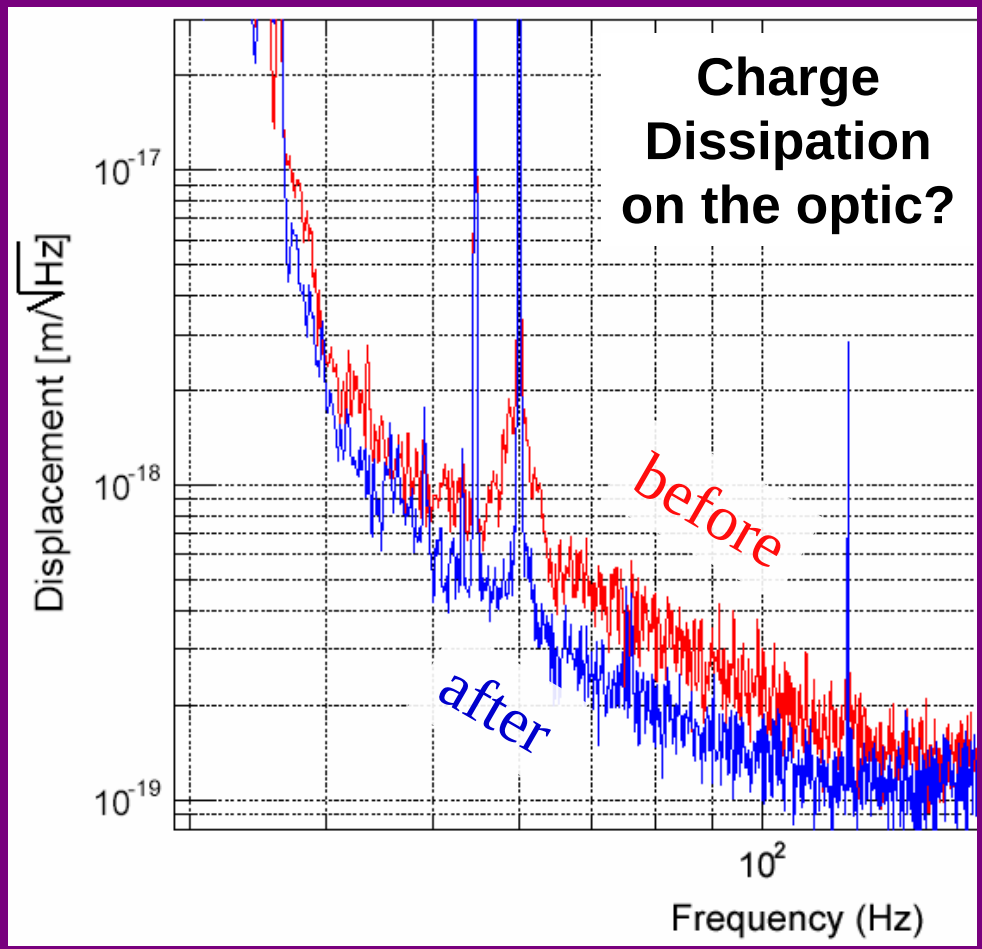
Scattering / Clipping

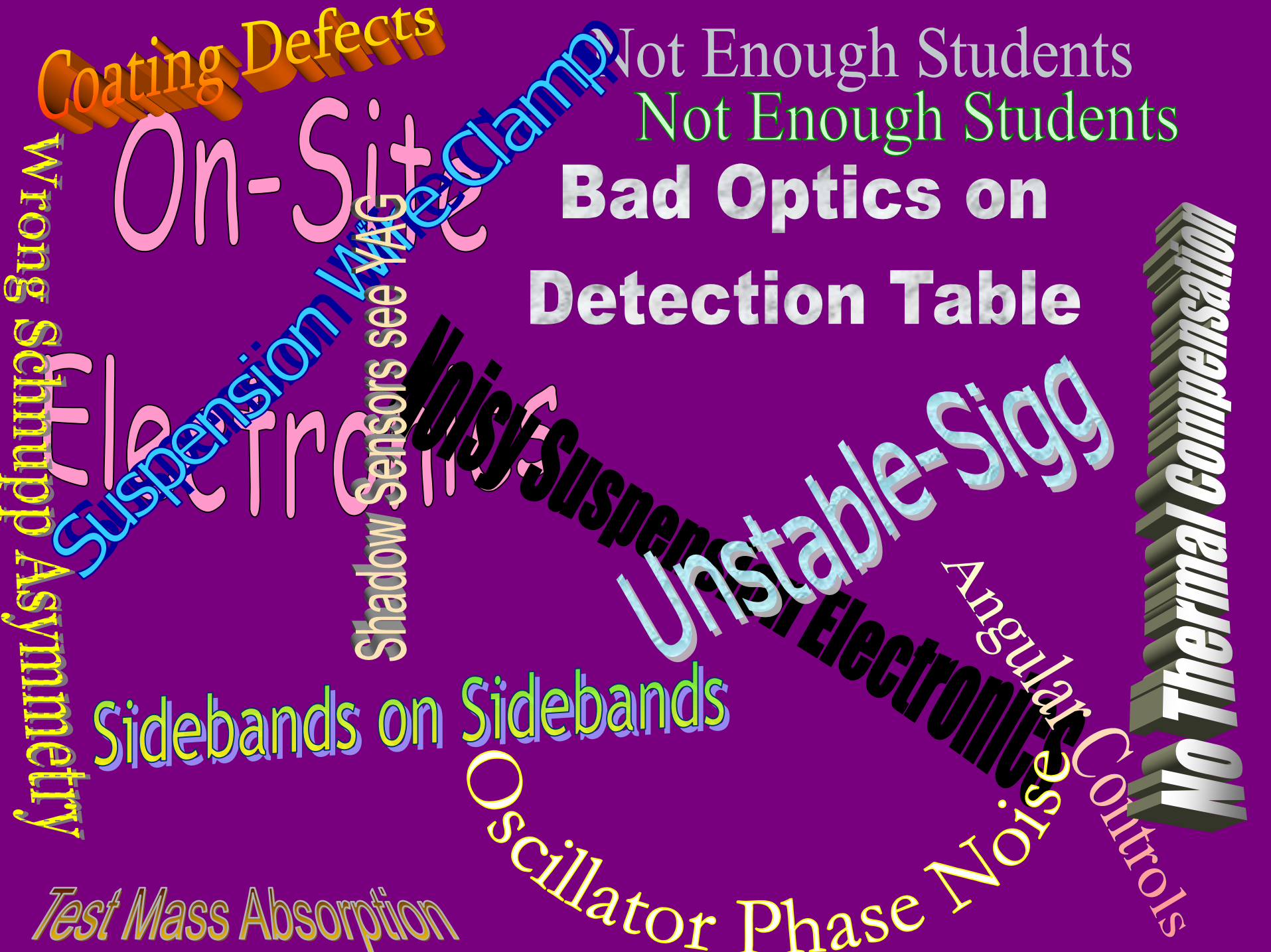
- Acoustic Enclosures on Detection Tables: -40 dB
- 2” Optics on main detections paths (every beam)
  - Super polished, super coated from REO (CVI AR = 0.5 %)
- Clean Detection Optics
  - Good optics practice (gloves, hats, coats, etc.)
  - ‘Mouse’ maze (plexi-glass box for the B1 beam)
  - HEPA filtered air for mouse. Very soft laminar flow.
- Stiff Mounts
  - Main resonance from ‘flagpole’ resonance
- Floating tables
  - Pressure regulated air legs

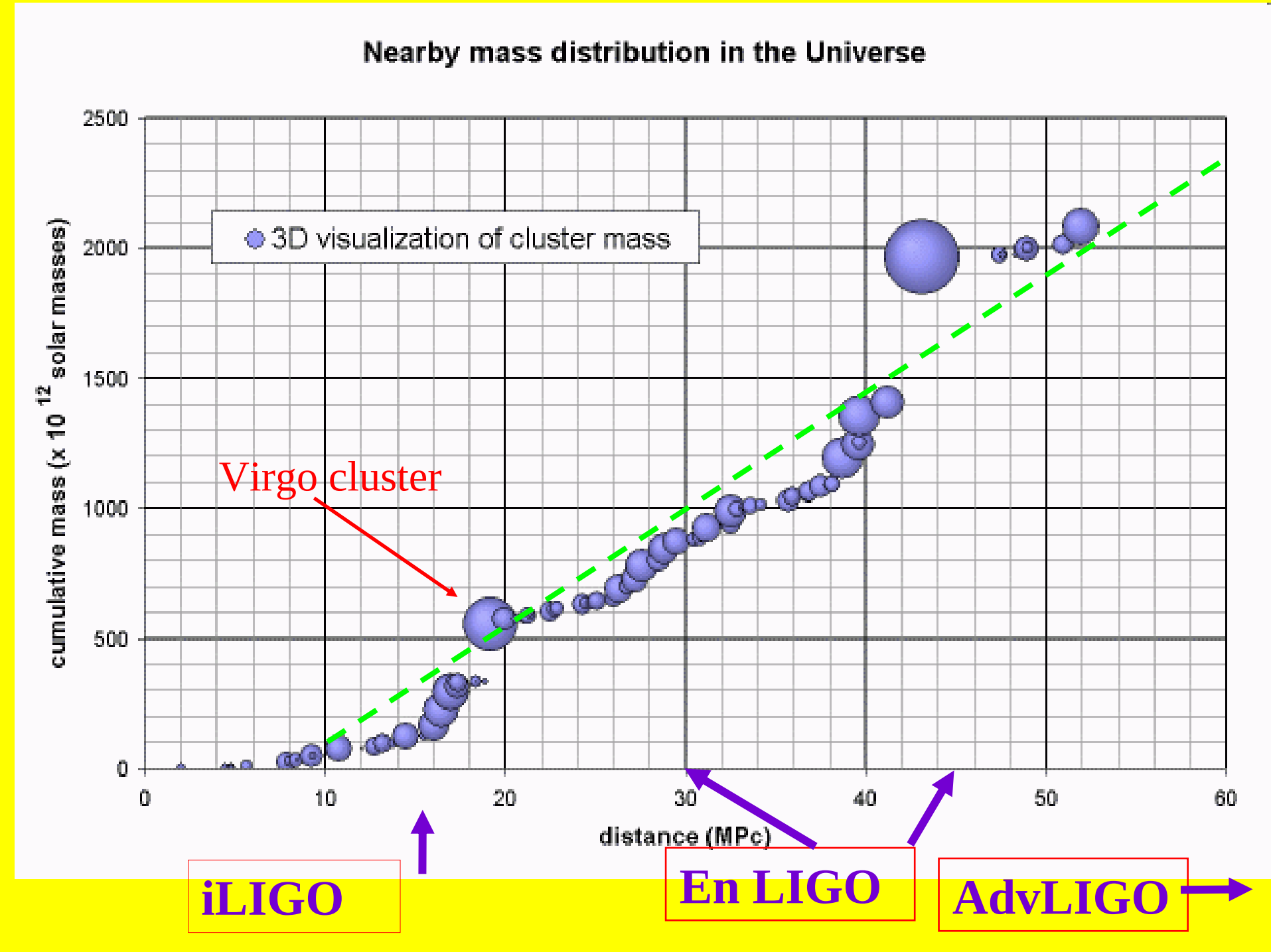

steel music wire 0.3 mm
Fused Silica(SiO_2)
Mass ~ 10 kg
Dia ~ 25 cm
Thickness ~10 cm
Roughness ~ 1 nm

Better to Be Lucky than Good

- Large mirror (ITMY) was wedged into the earth quake stops
- Vented the vacuum and released it. Adjusted EQ stop.




Coating Defects
On-Site
Not Enough Students
Not Enough Students
Bad Optics on
Detection Table
Suspension Wire Clamp
Shadow Sensors see WAG
Noisy Suspension Electronics
Unstable-Sigg
Wrong Scanning Asymmetry
Sidebands on Sidebands
Angular Controls
No Thermal Compensation
Oscillator Phase Noise
Test Mass Absorption

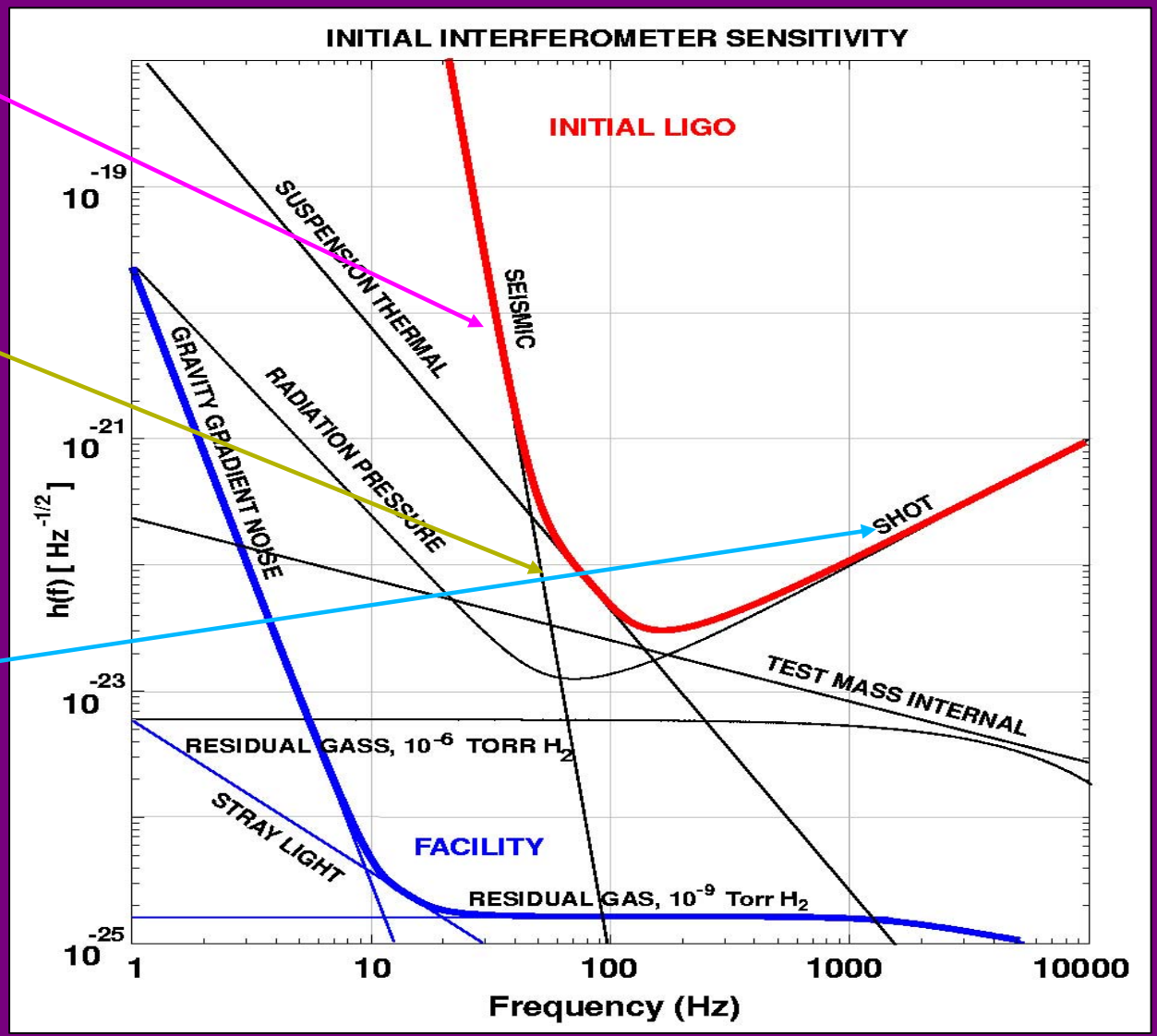

Nearby mass distribution in the Universe
3D visualization of cluster mass
cumulative mass (x 10 12 solar masses)
distance (MPc)
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
Virgo cluster
iLIGO
En LIGO
AdvLIGO

Science Requirements Doc: The LIGO-I Sensitivity Goal

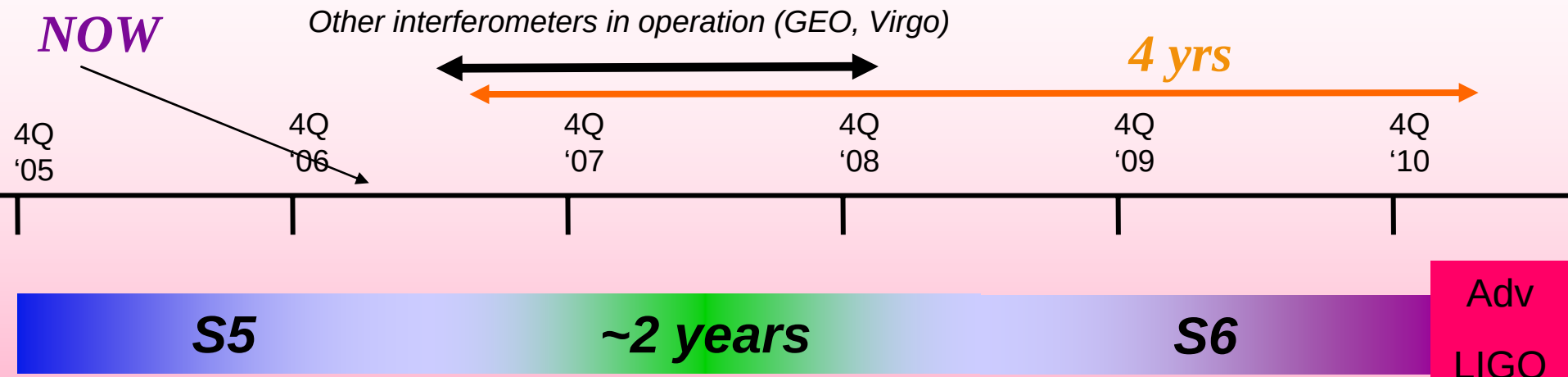
Seismic:
We are not fixing this anytime in the near future. Really.

Thermal:
Probably 2-3x less than this.

Shot Noise:
Better readout technique



The next several years

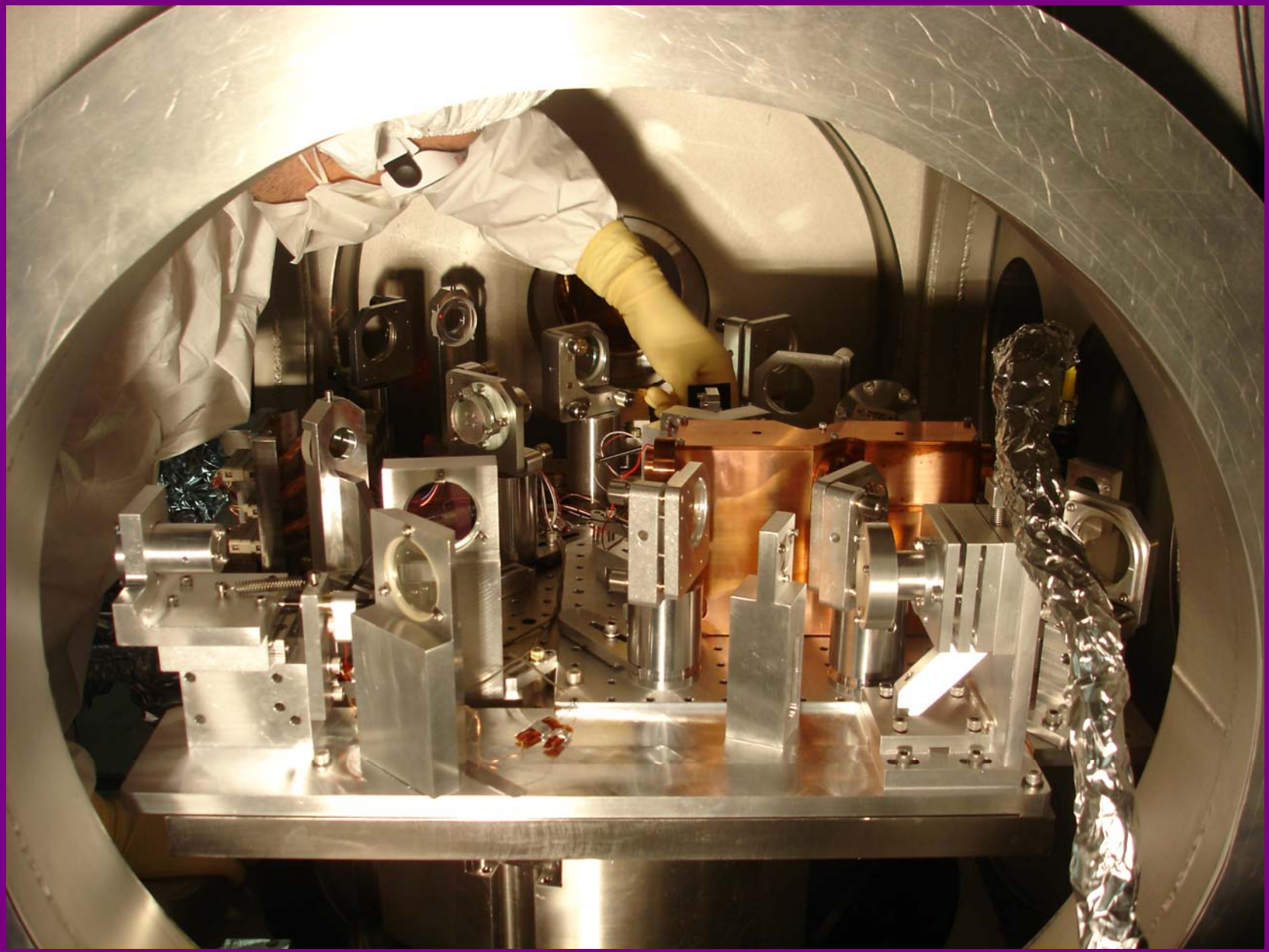


- Between now and AdvLIGO, there is some time to improve…
  1) ~Few years of hardware improvements + 1 ½ year of observations.
  1) Factor of ~2.5 in noise, factor of ~10 in event rate.
  2) *3-6 interferometers running in coincidence !*

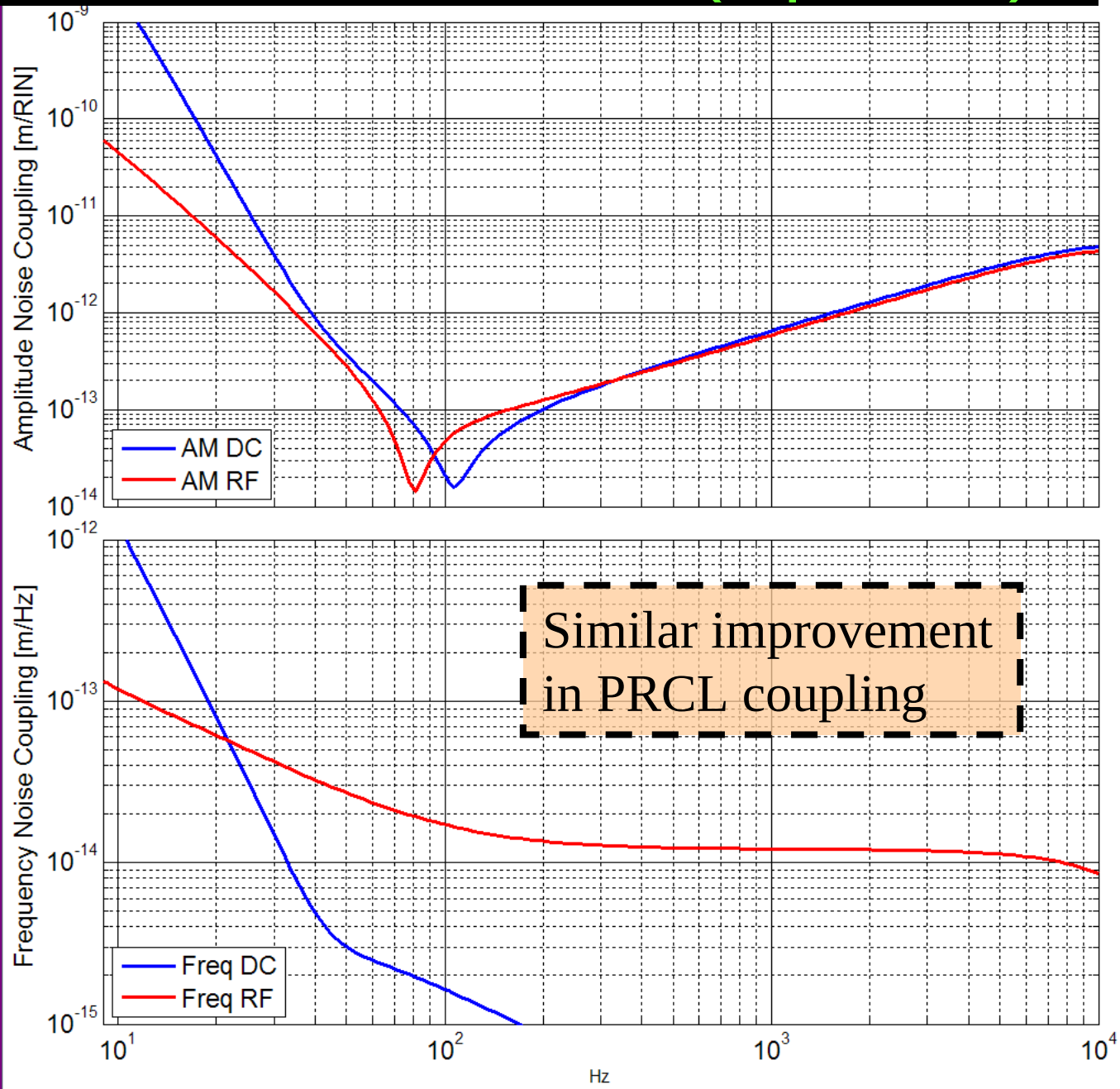
Enhanced LIGO Sketch

1. **DC Readout + OMC** (cavity/detectors in-vac)
   1. Reduce junk light, increase laser power
   2. Get back factor of 2 in optical gain (Watts/meter)
   3. Upgrade the detection system to the Advanced LIGO style.
2. Higher power laser (Hannover)
   1. 10 W lasers are dying. Laser company is gone.
   2. Collaborators at AEI/LZH are offering us 35 W lasers (for free!)
3. High Power Input Optics (Univ of Florida)
   1. Advanced LIGO Modulators
   2. Advanced LIGO Faraday Isolator
4. Miscellaneous …

DC Readout @ Caltech 40m lab

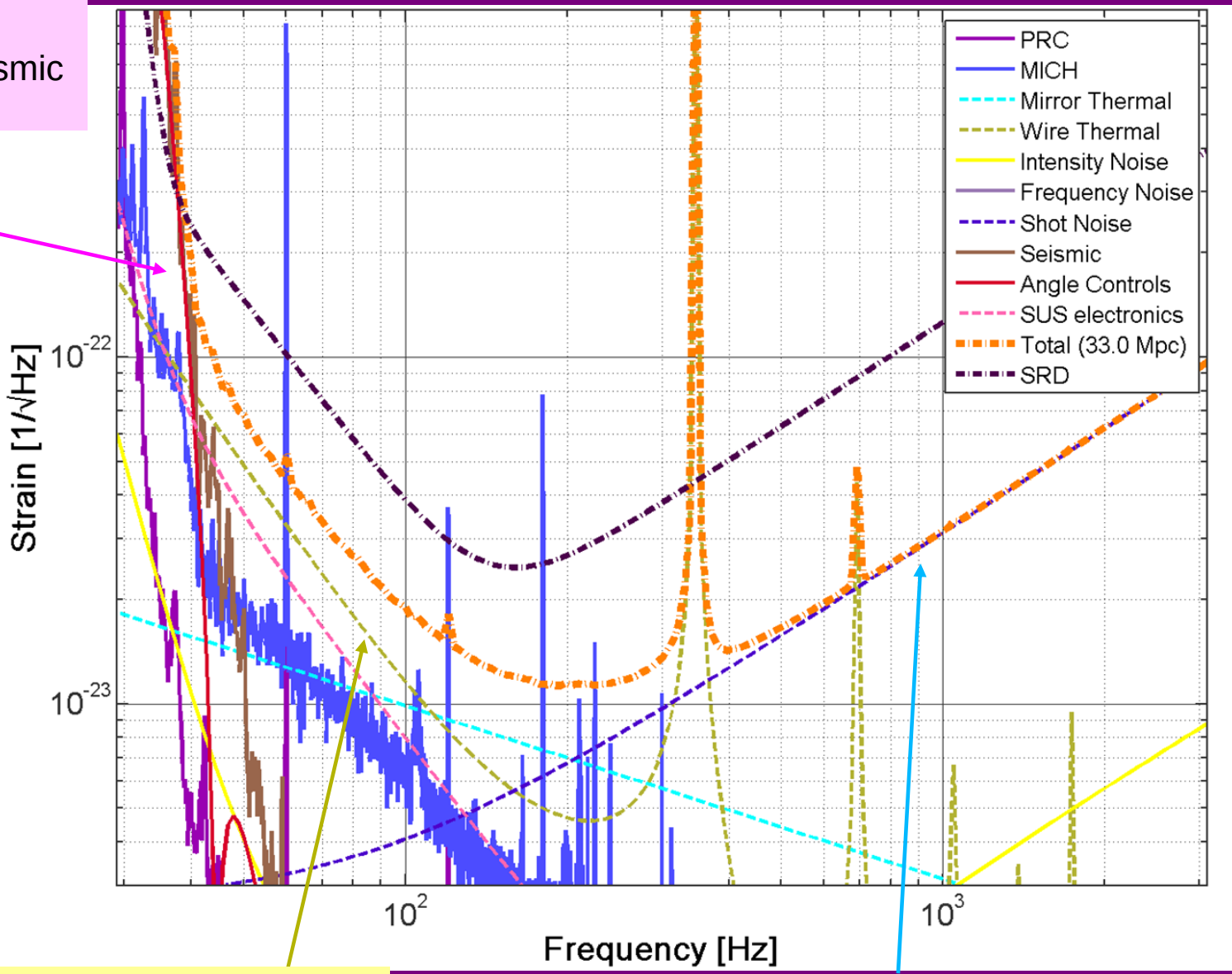


Using Evans' new software (Optickle)



Seismic:

No modification in seismic isolation systems

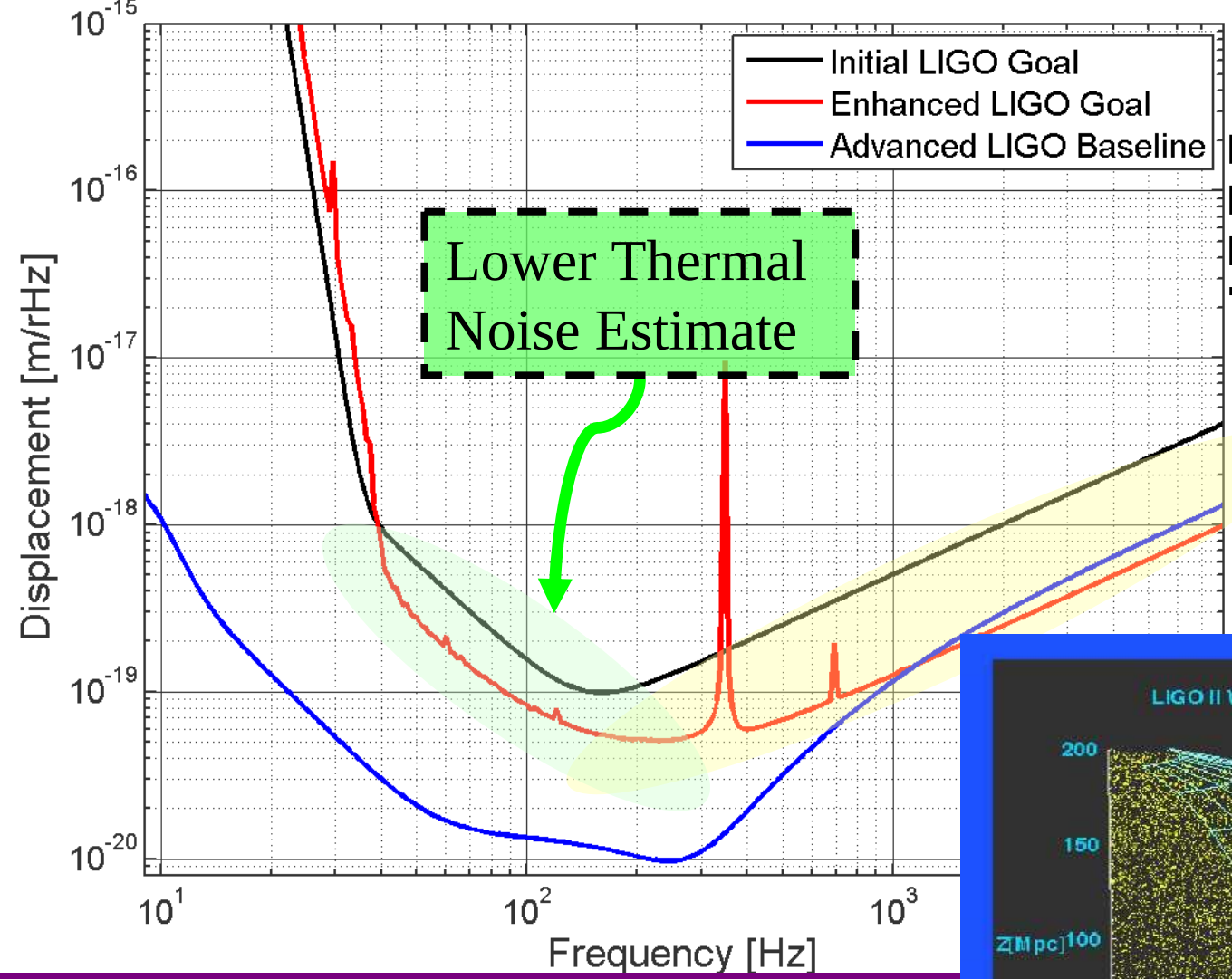


Thermal:

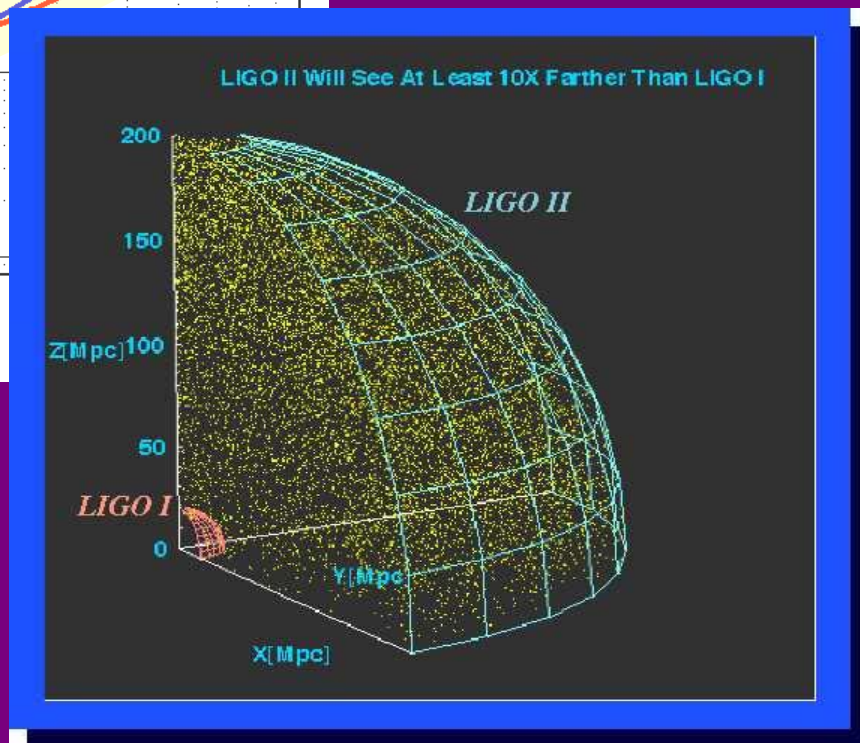
Good wires, good mirrors, and control of “technical” noises

Shot Noise:

- New in-vac filter cavity
- **4-5x more laser power**
- **Advanced readout**



Increased Power + Enhanced Readout



The Plan

- Improvements on the 4km IFOs starting in Sep. 07
- Do Louisiana first (pathfinder). Start Hanford after.
- Small fixes but no upgrades on the 2km IFO
- Then some more science running.

Not enough time/manpower to do all 3 IFOs.

A factor of 2.5 on H1/L1 is better than a factor of 2 on all three.

We don’t gain more AdvLIGO knowledge by doing 3 IFOs.