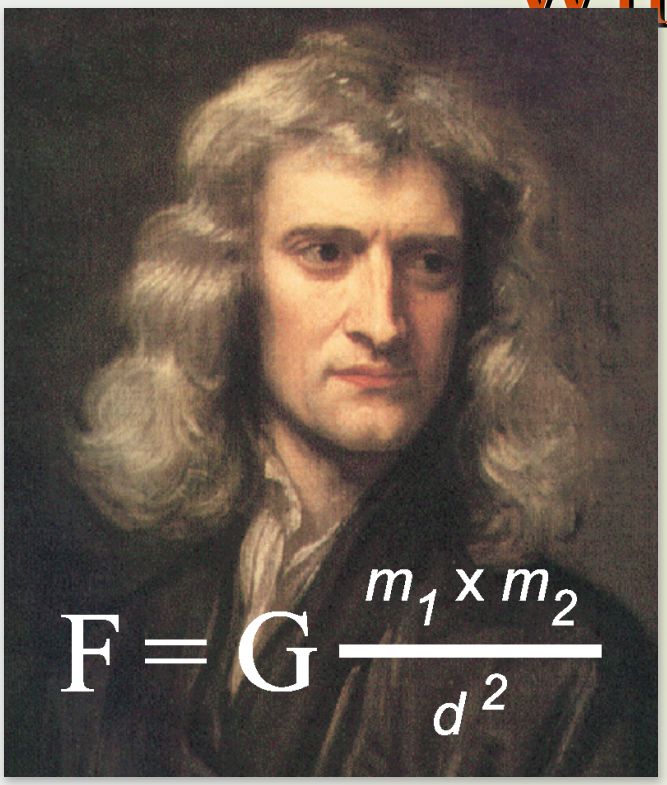
Status of LIGO

Brian O'Reilly (Caltech)

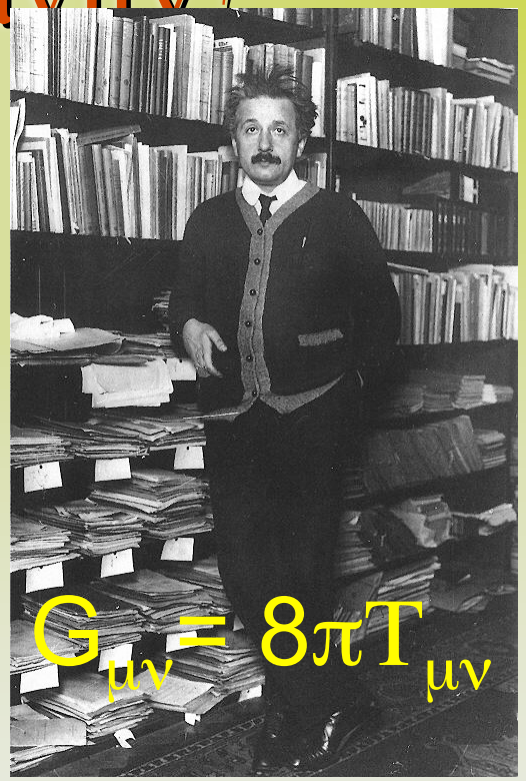
for the LIGO Science Collaboration

What is Gravity?



Newton

Action at a distance



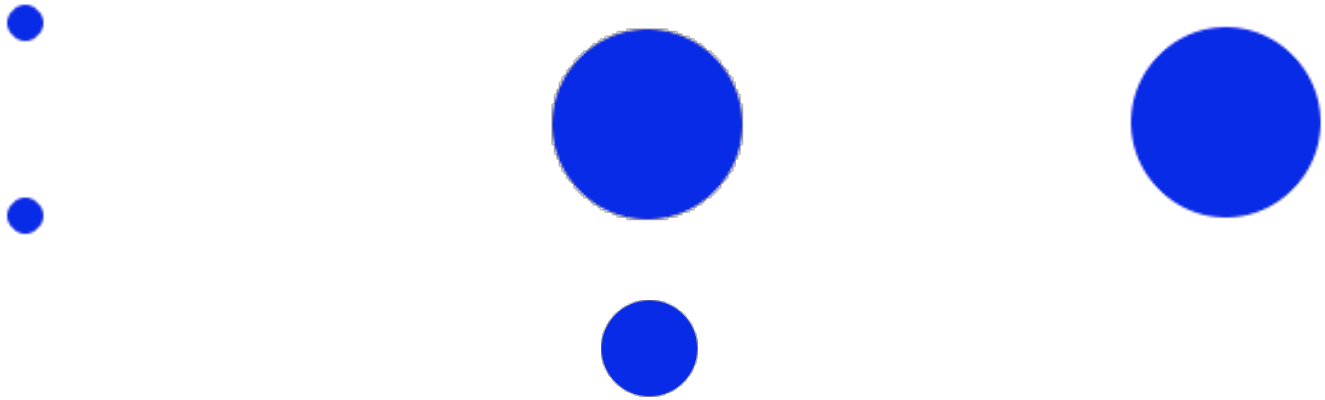
Einstein

Gravitational Radiation
traveling at the speed of light

Gravitational Waves in Action

Two massive, compact objects in orbit

deform space (and any object in it) with a frequency which is twice the orbital frequency



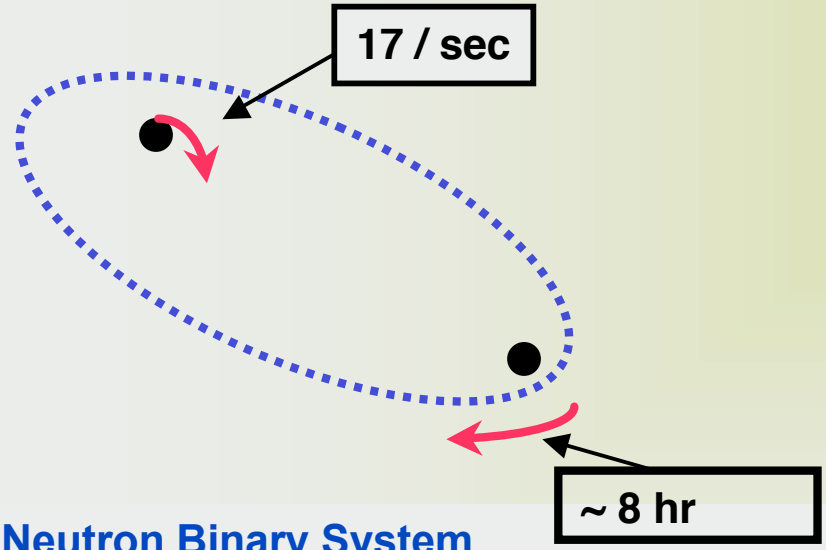
The stretching is described by a dimensionless strain, $h = \Delta L / L$

h is inversely proportional to the distance from the source

Strong Evidence:
Orbital Decay

Neutron Binary System – Hulse & Taylor

PSR 1913 + 16 -- Timing of pulsars



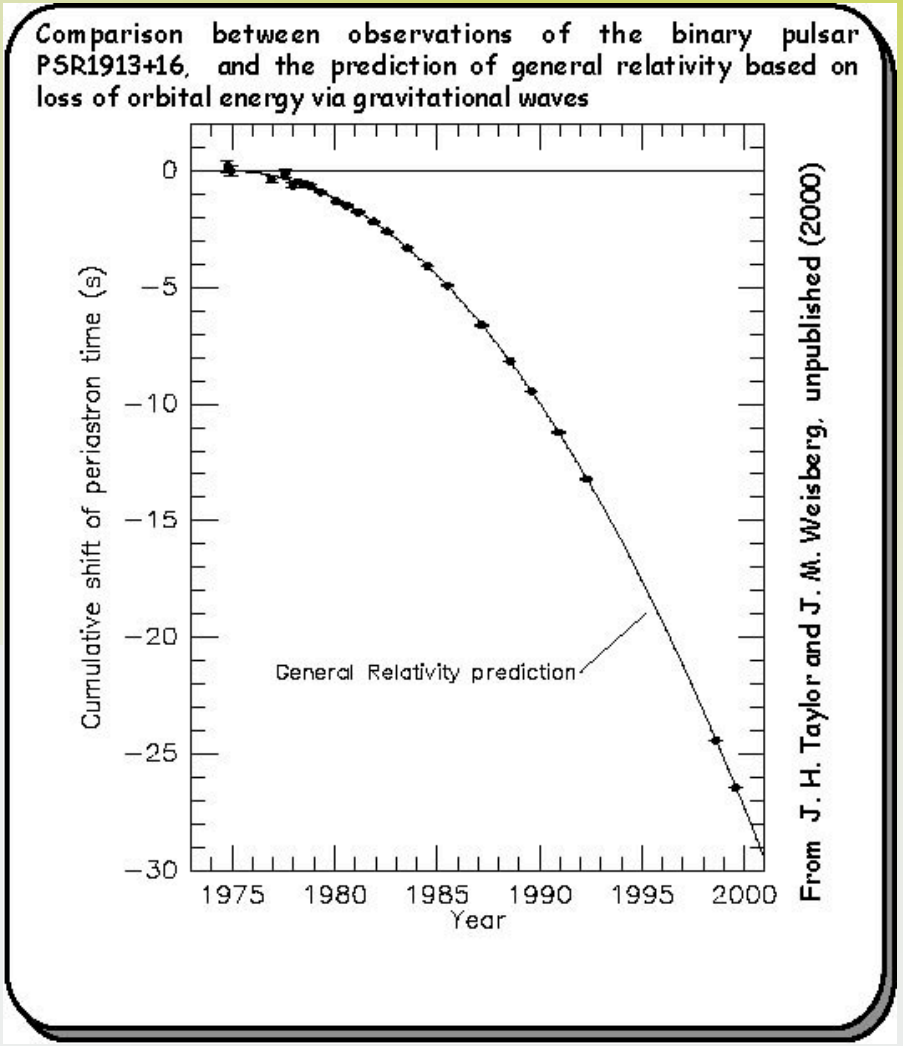
Neutron Binary System

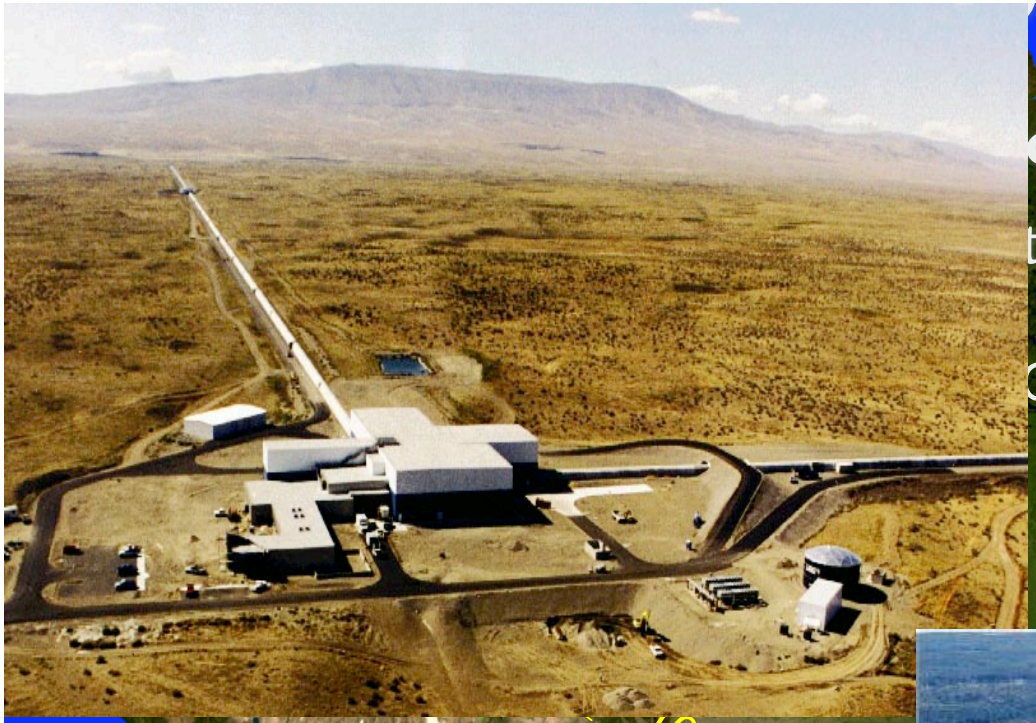
- **separated by 10^6 miles**
- **$m_1 = 1.44 m_\odot$; $m_2 = 1.39 m_\odot$; $\varepsilon = 0.617$**

Prediction from general relativity

- **spiral in by 3 mm/orbit**
- **rate of change orbital period**

Emission of gravitational waves

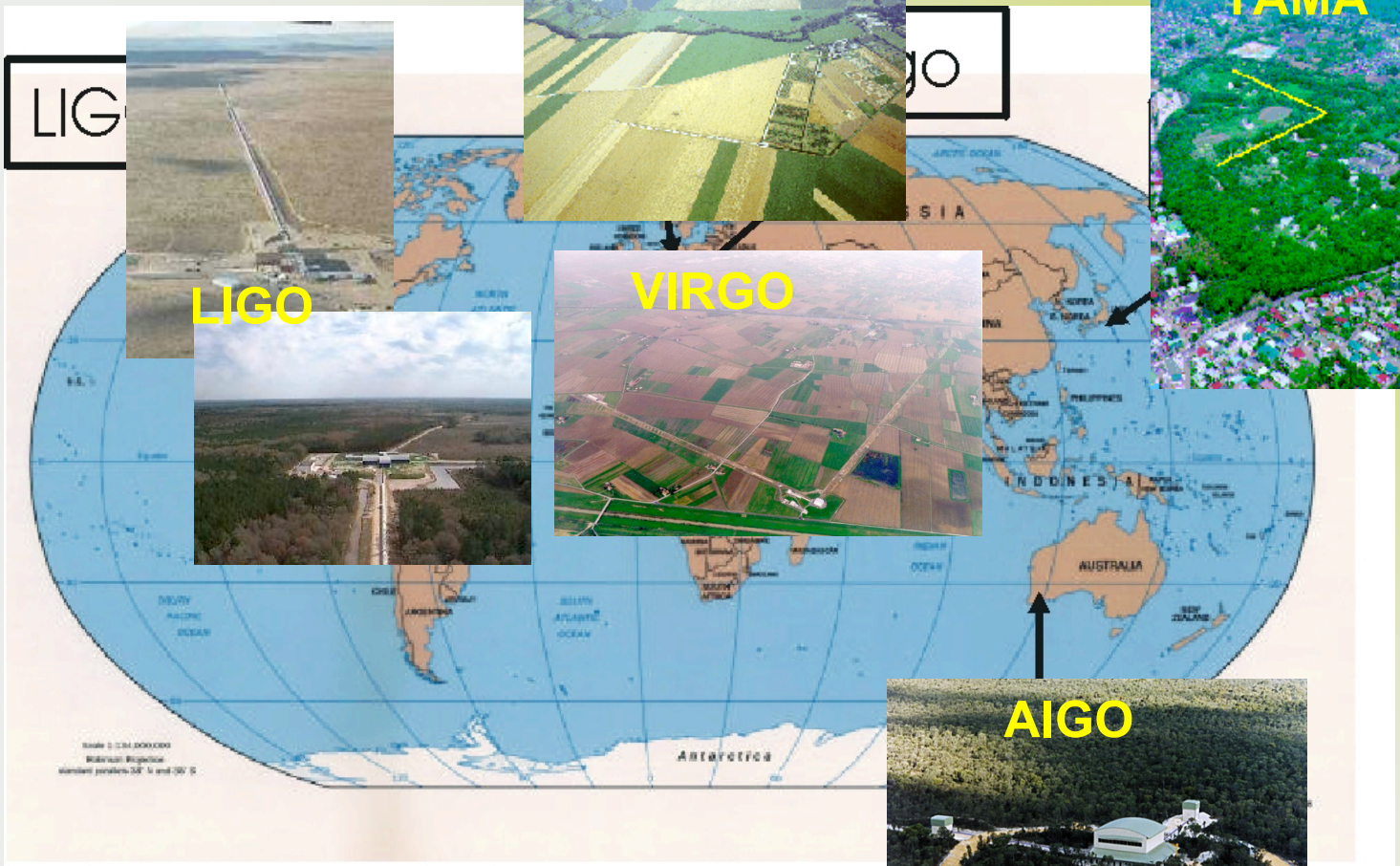





servatories
d along the great circle
the sites
O)
MIT


10 ms
Caltech
➢Adapted from "The Blue Marble: Land Surface, Ocean Color and
➢NASA Goddard Space Flight Center Image by Reto Stöckli (land
(ocean color, compositing, 3D globes, animation). Data and technic
MODIS Atmosphere Group; MODIS Ocean Group Additional data
Sensing Flagstaff Field Center (Antarctica); Defense Meteorologica

GW Interferometers



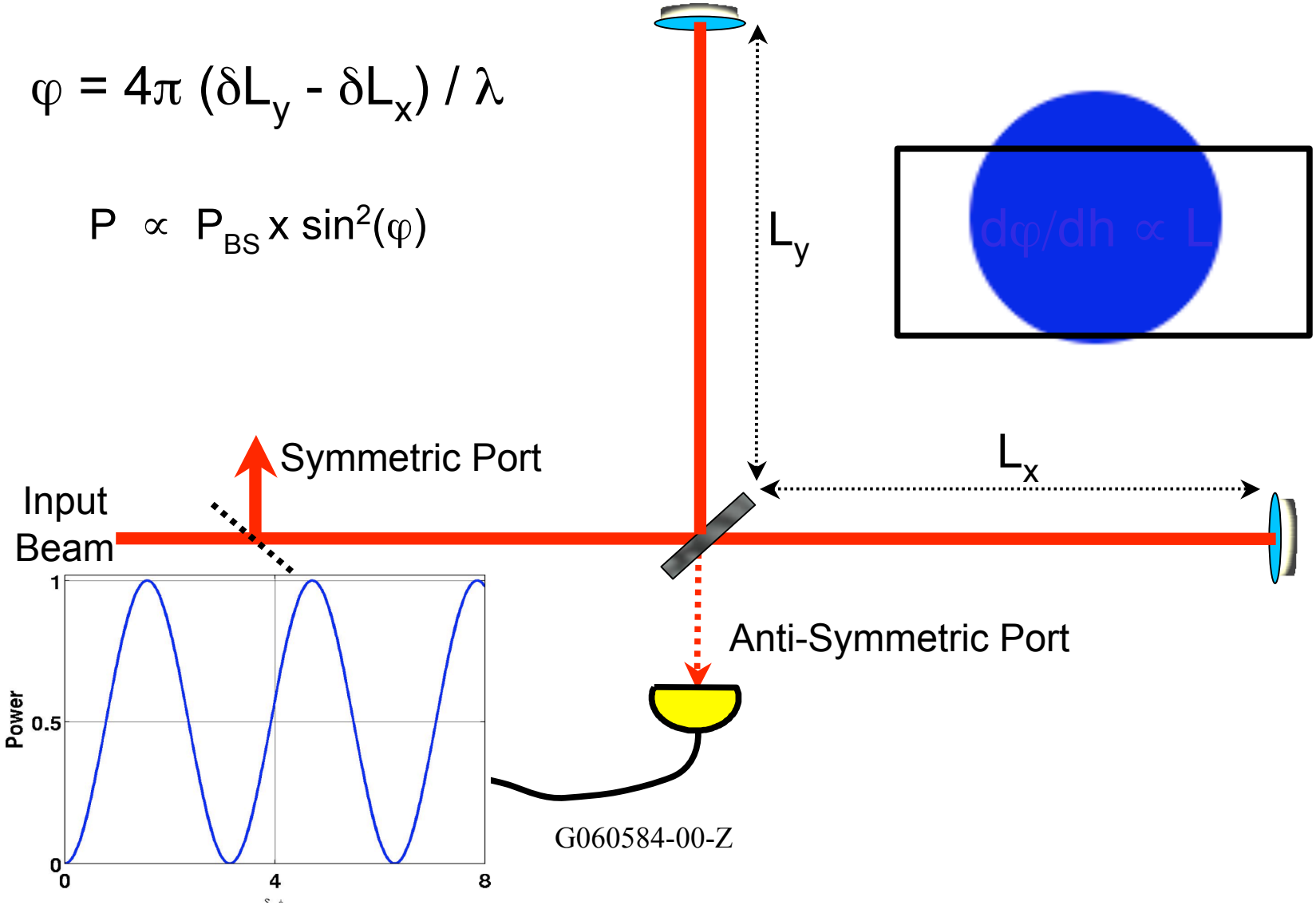
Small signals $\delta L \sim 10^{-18}$ m

Coincidence and triangulation

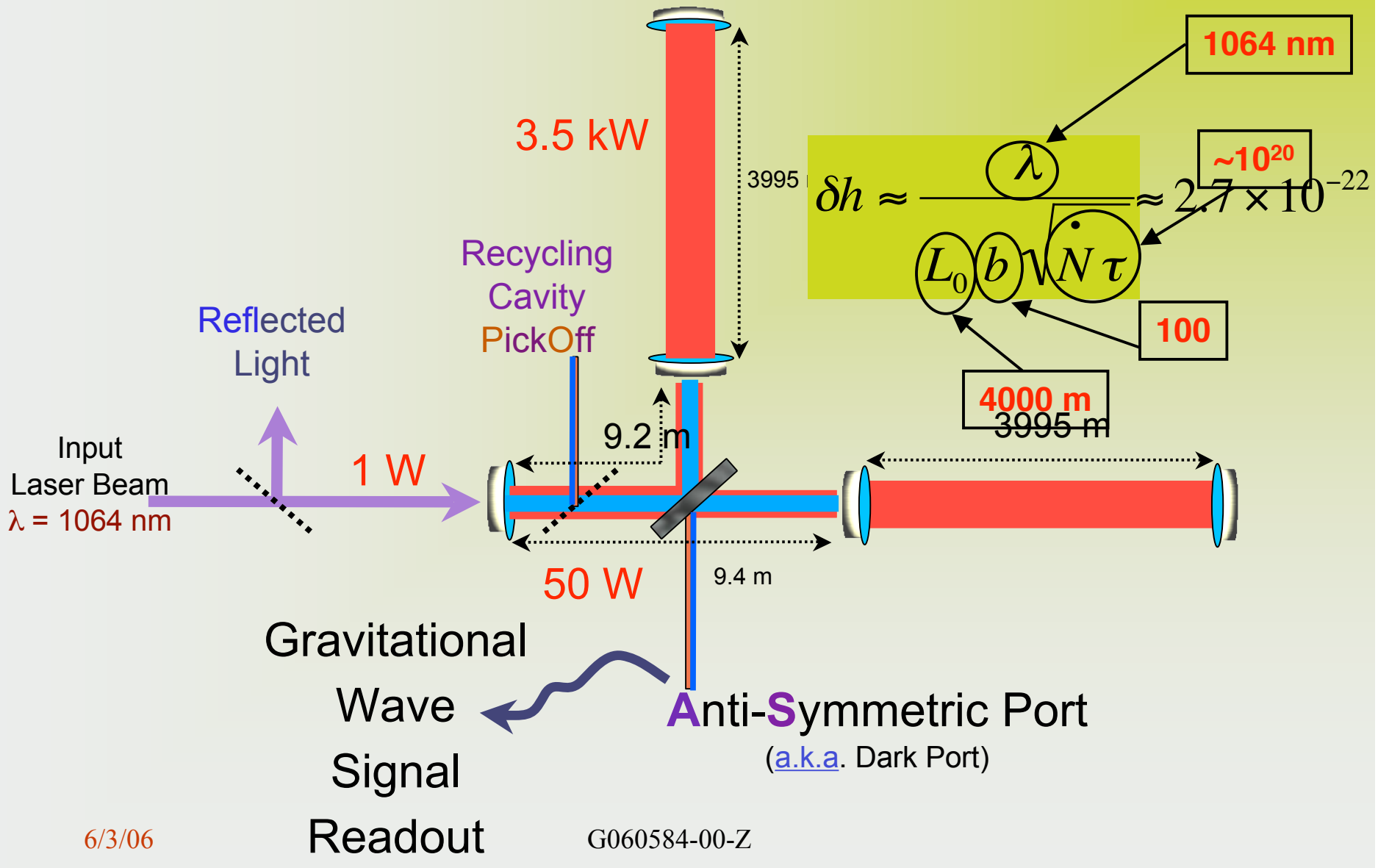
Michelson Interferometer

$$\varphi = 4\pi\,(\delta L_y - \delta L_x) / \lambda$$

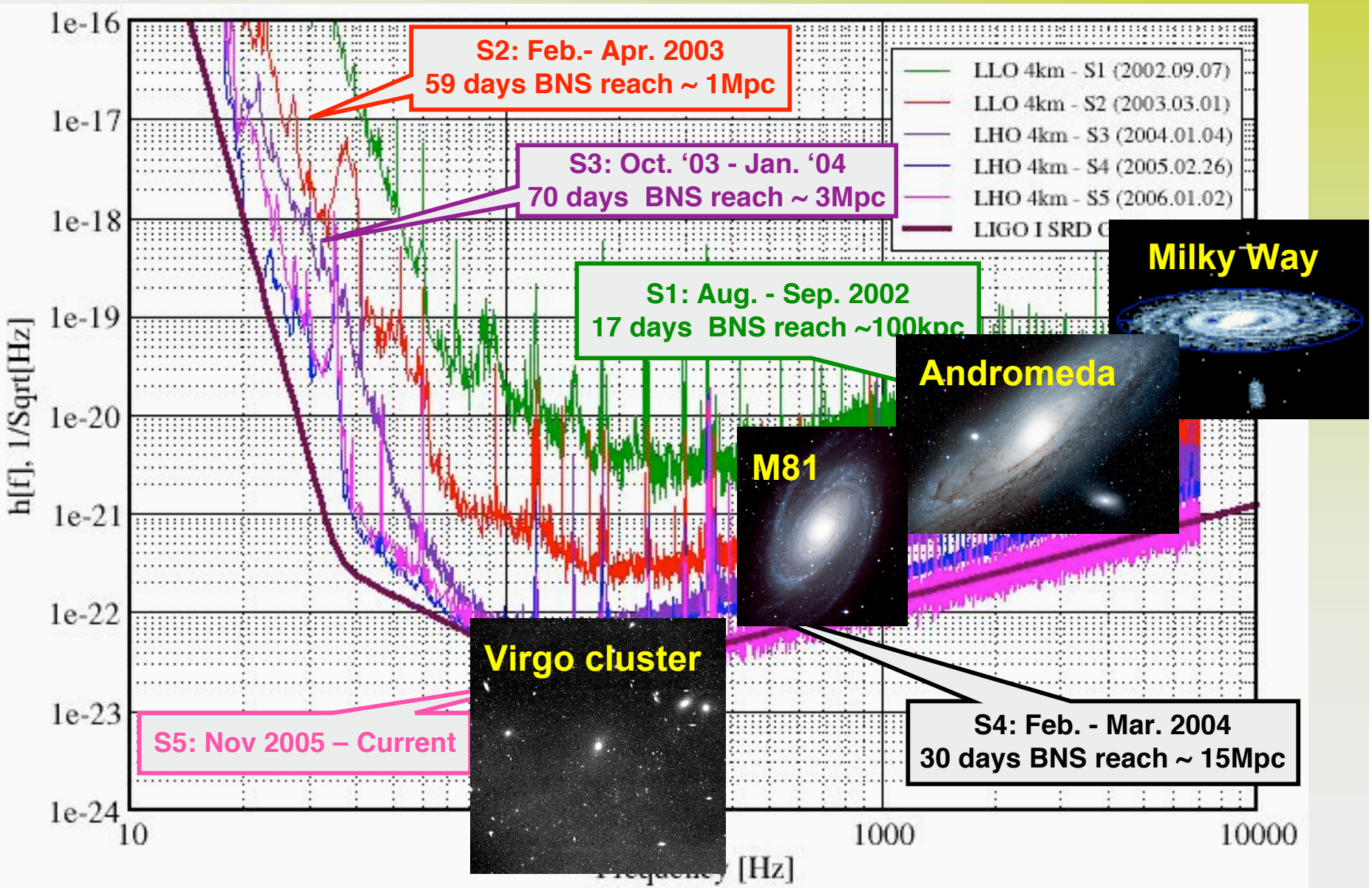
$$P \propto P_{BS}\, x\, \sin^2(\varphi)$$



LIGO INTERFEROMETER



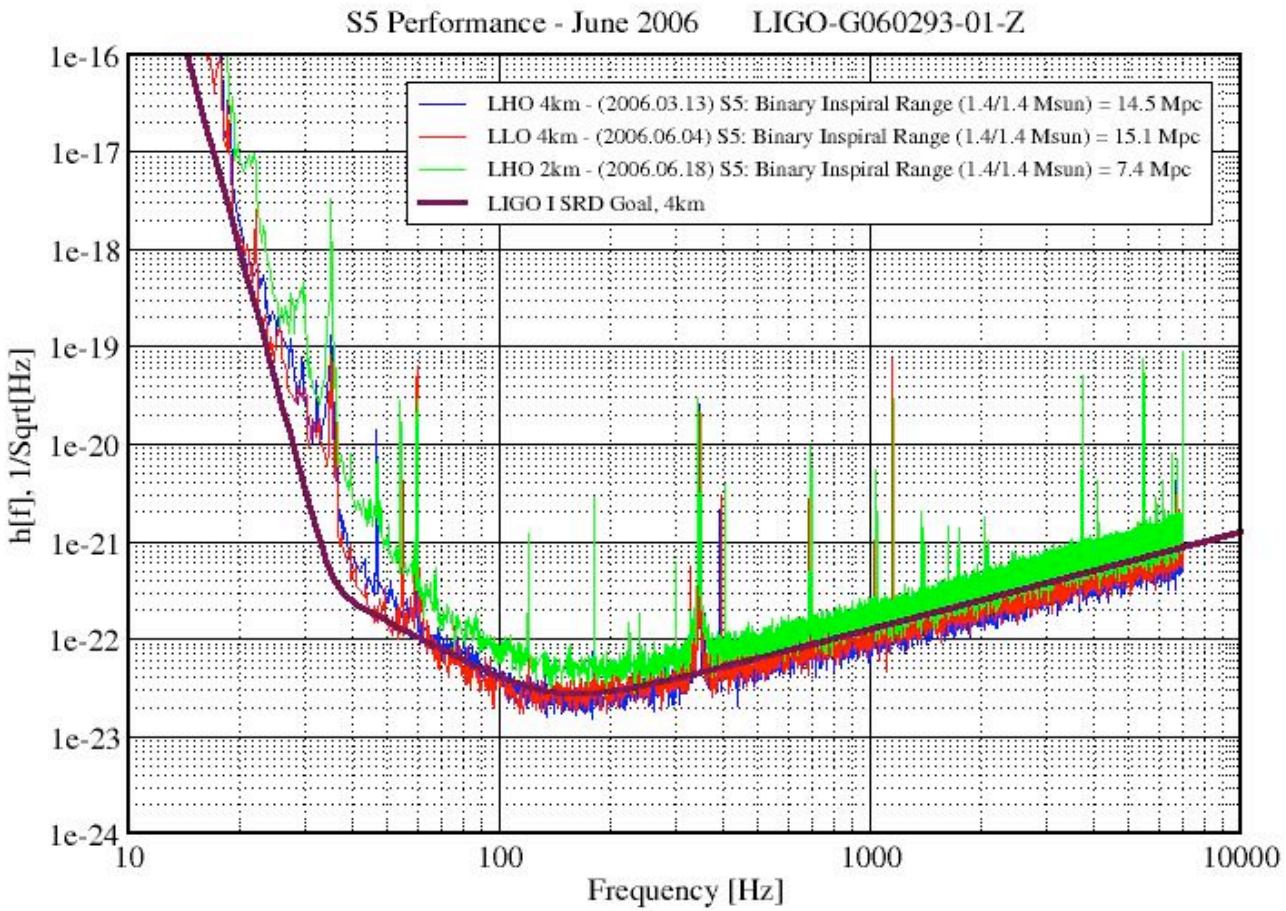
Measure of sensitivity: BNS reach



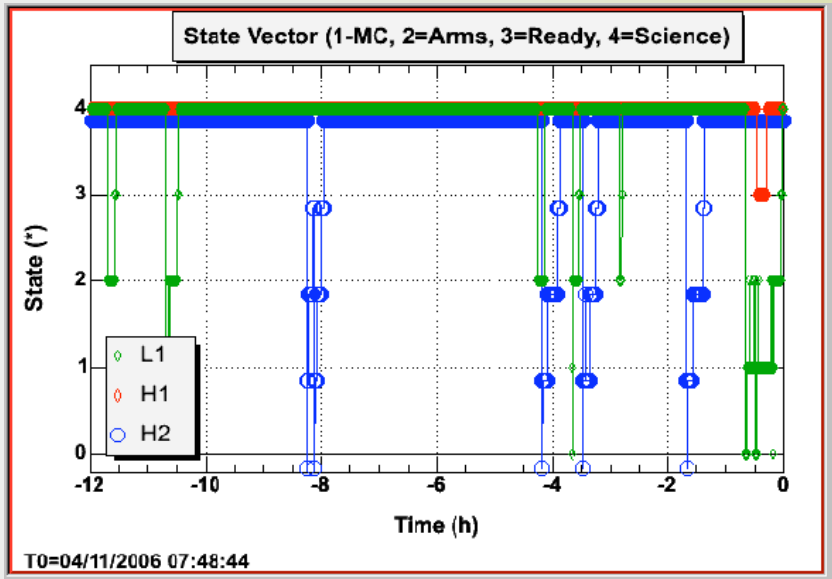
S5: The Fifth LIGO Science Run

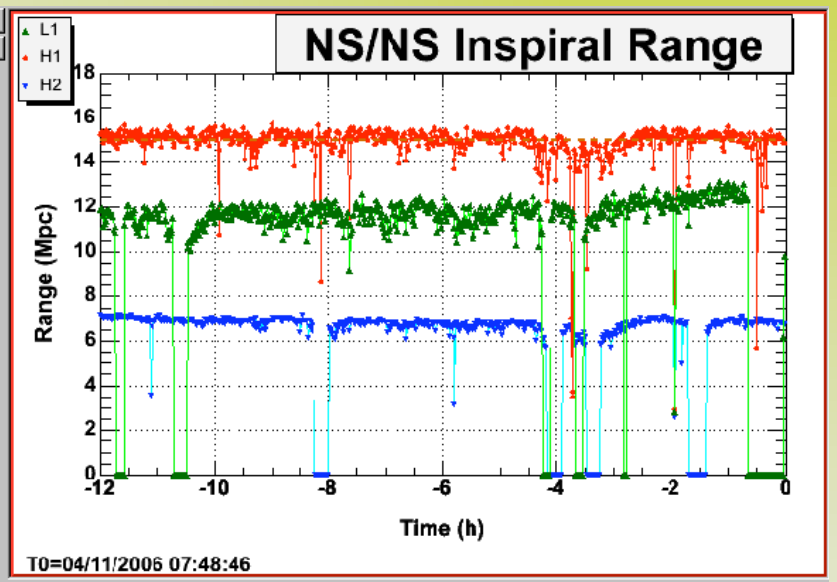
- Goal is to take one year of coincident data at design sensitivity.
- Run started in Nov. 2005.
- We are learning a lot about our capacity to run for an extended period of time.
- We are about half-way to our goal.

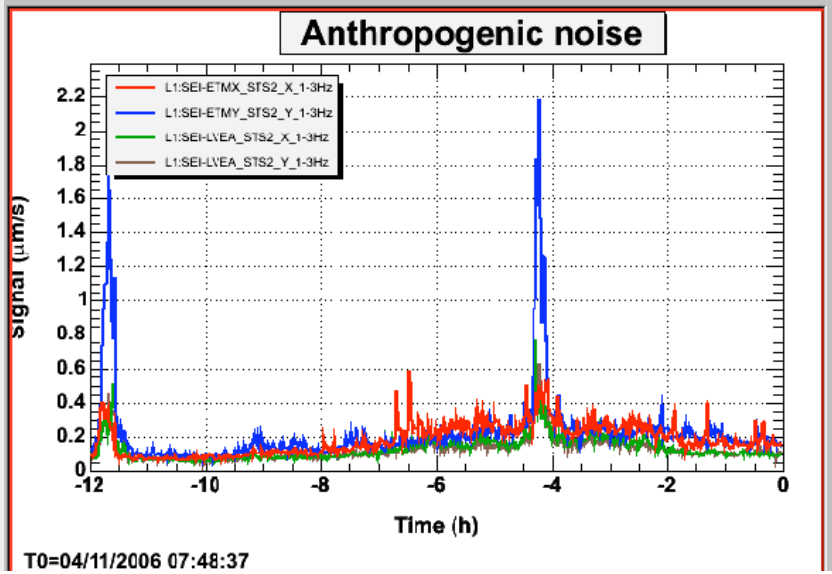
S5 Performance

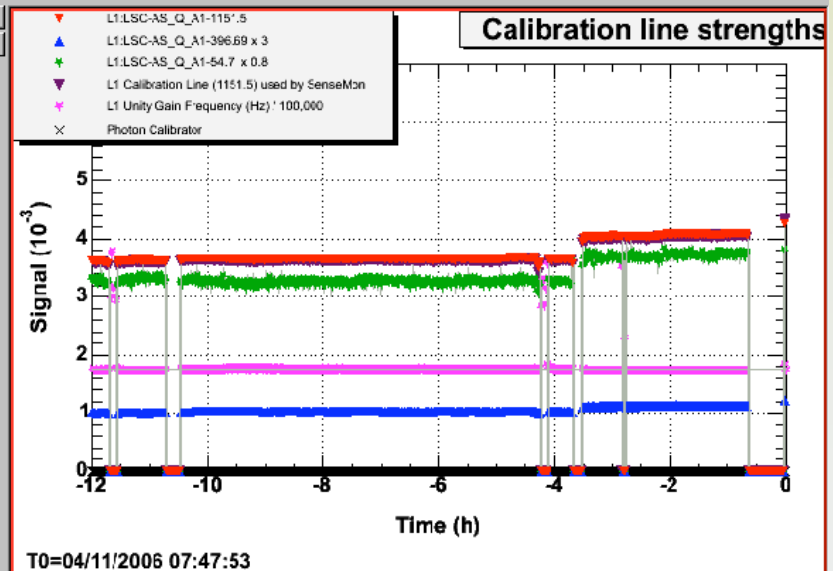


Figures Of Merit

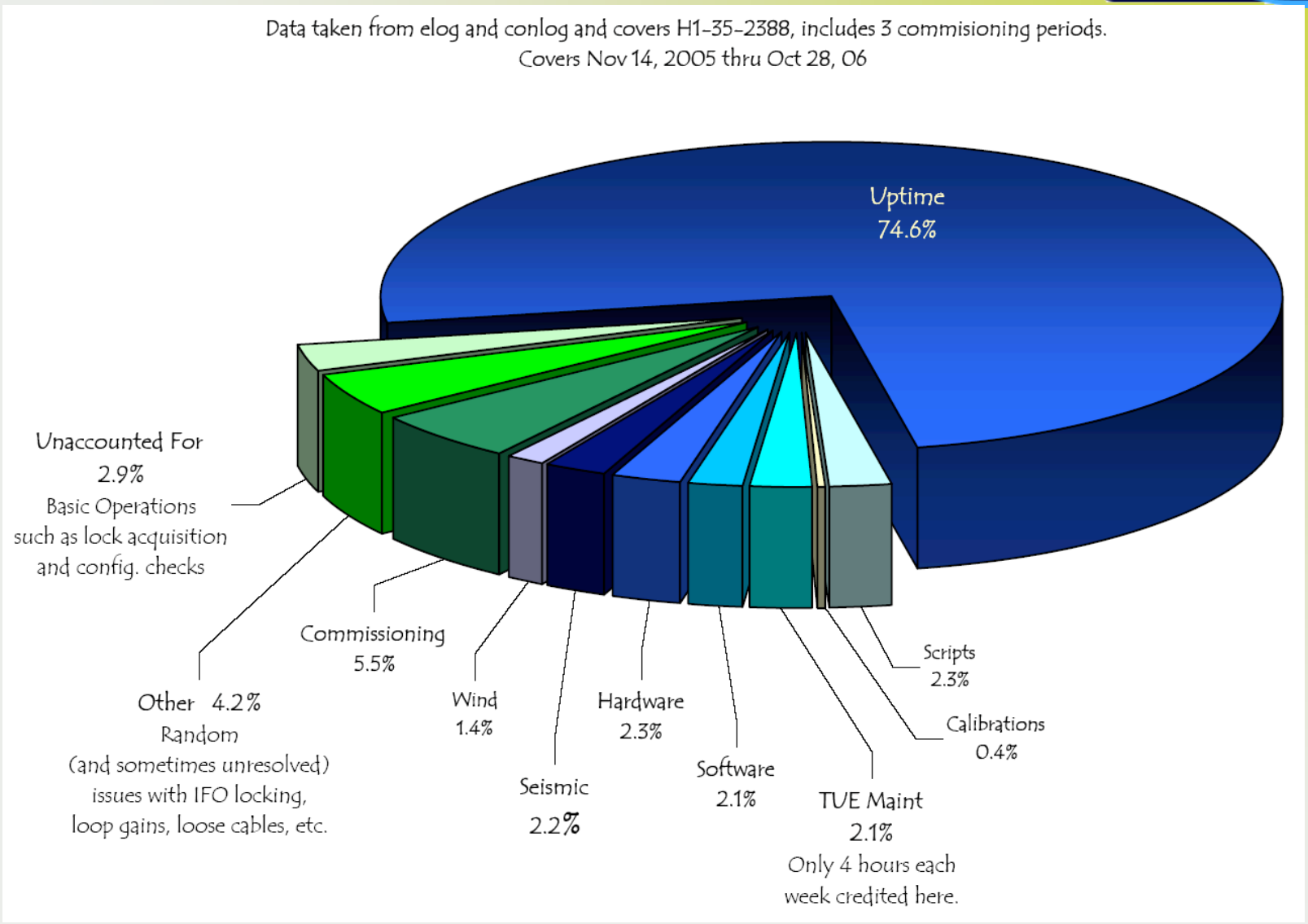






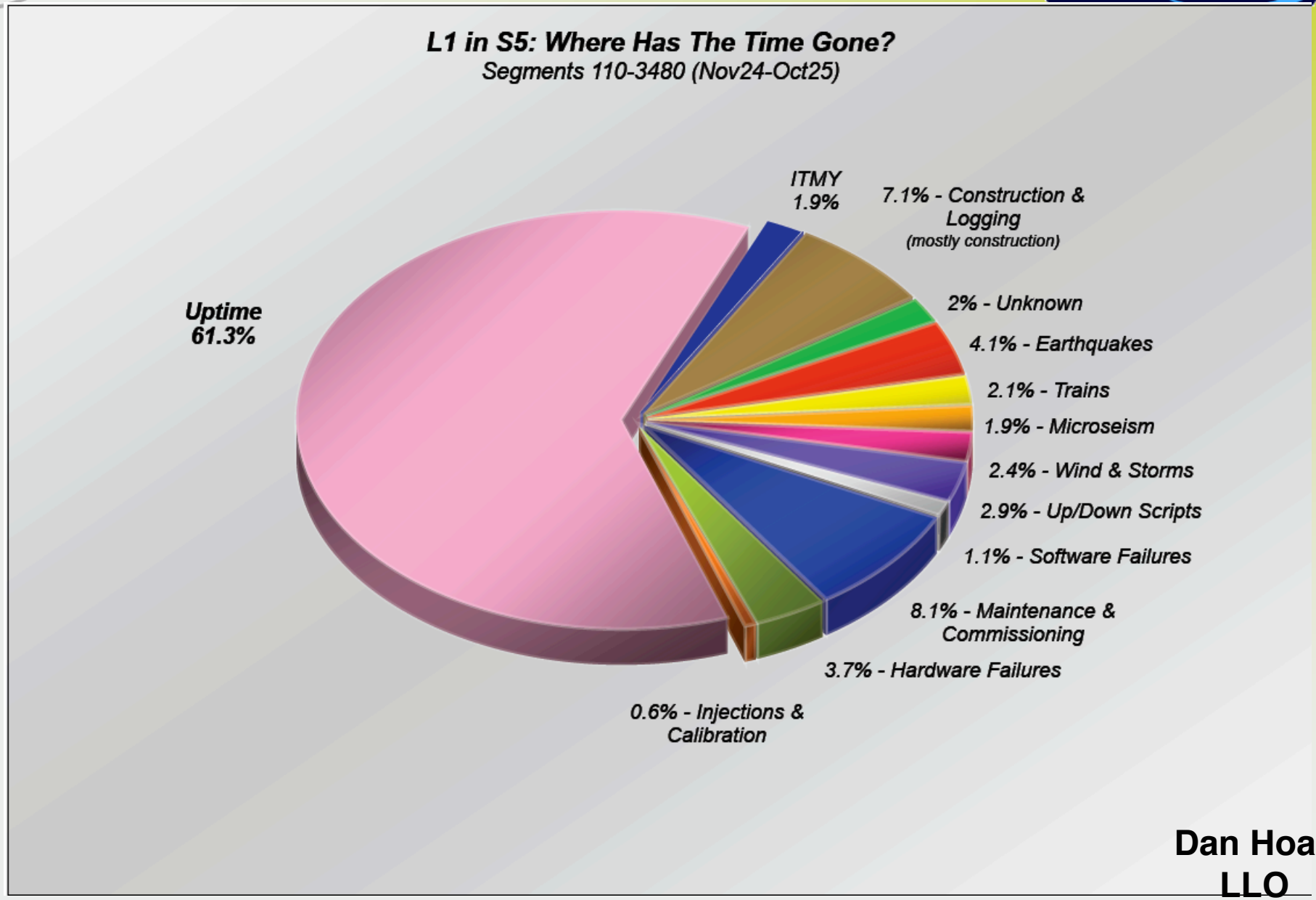


S5 H1 Uptime



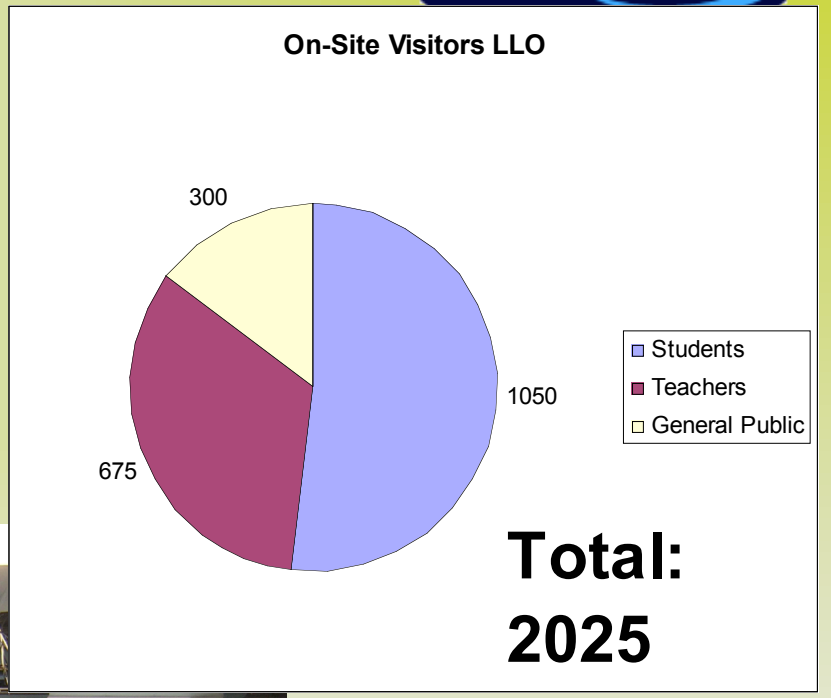
Betsy Bland
LHO

S5 L1 Uptime

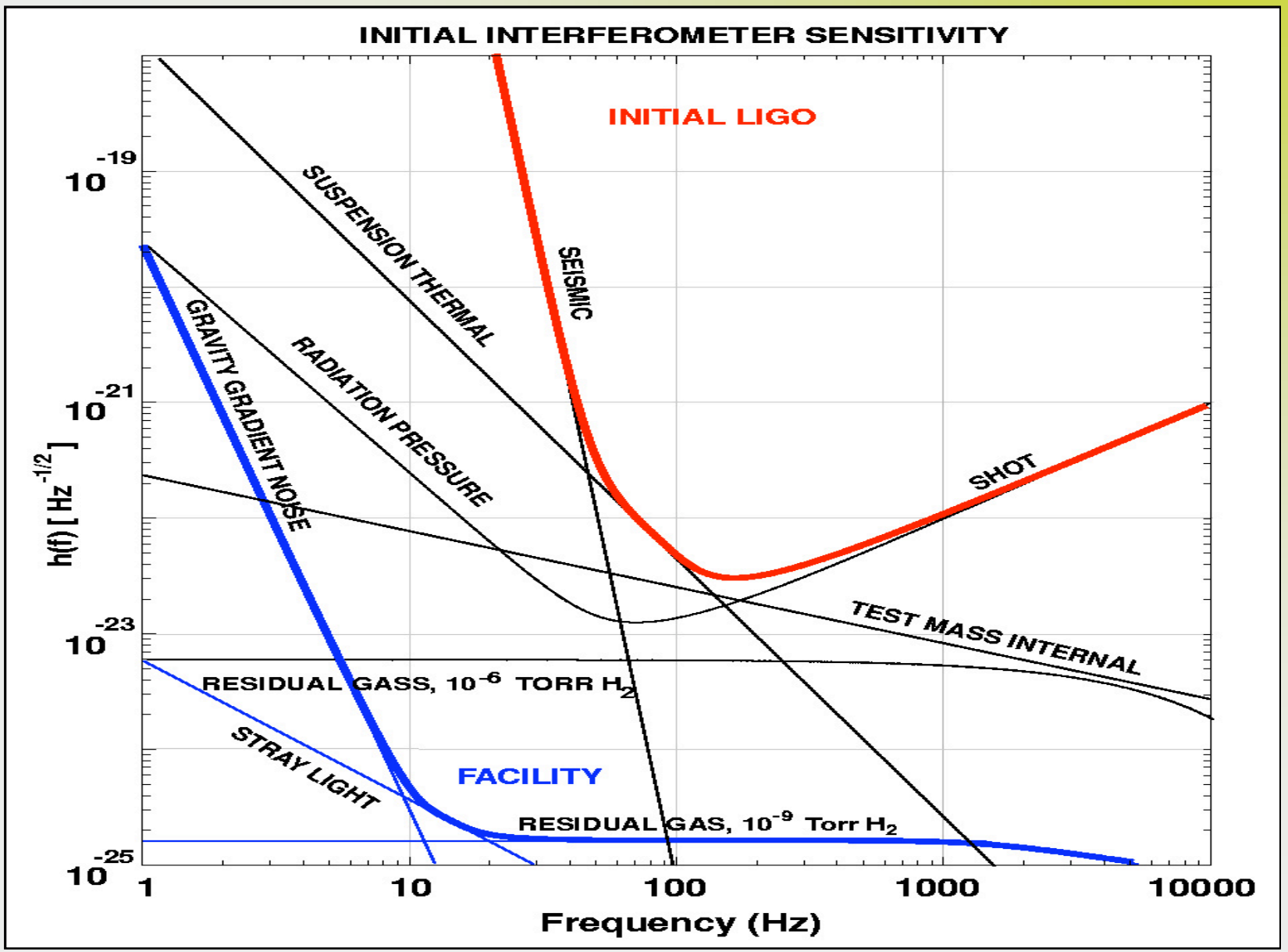


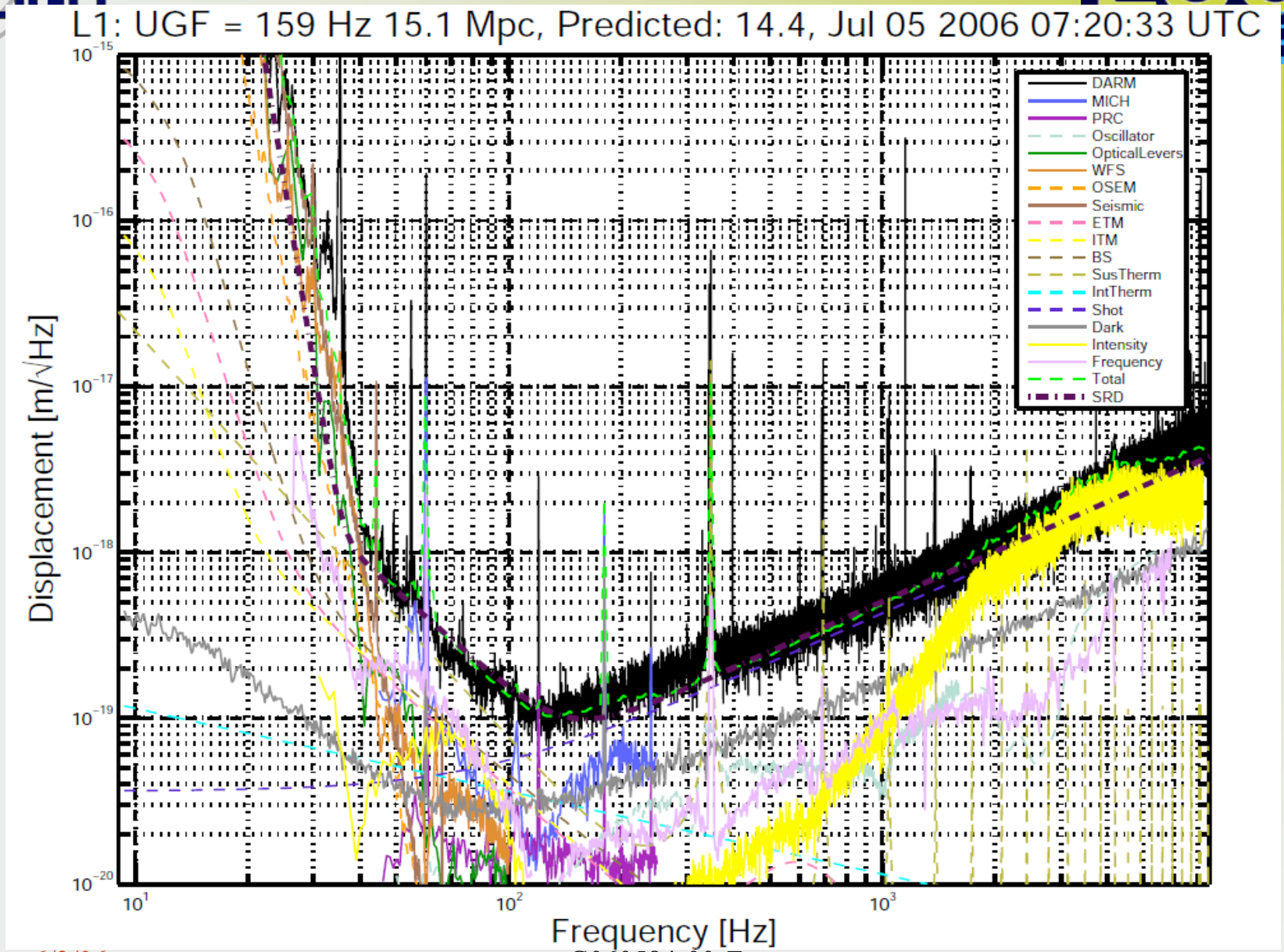
Dan Hoak
LLO

Outreach


On-Site Visitors LLO
300
1050
675
Students
Teachers
General Public
Total:
2025


LIGO Science
Education Center
Teacher
Training
Student
Field
Trips
Educational
Research
Opportunities
Grand Opening
November 13, 2006
(Opening Ceremony by Invitation Only)


INITIAL INTERFEROMETER SENSITIVITY
INITIAL LIGO
SUSPENSION THERMAL
SEISMIC
GRAVITY GRADIENT NOISE
RADIATION PRESSURE
SHOT
TEST MASS INTERNAL
RESIDUAL GASS, 10-6 TORR H2
STRAY LIGHT
FACILITY
RESIDUAL GAS, 10-9 Torr H2
h(f) [Hz-1/2]
10-19
10-21
10-23
10-25
1
10
100
1000
10000
Frequency (Hz)


L1: UGF = 159 Hz 15.1 Mpc, Predicted: 14.4, Jul 05 2006 07:20:33 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

Noise Budgeting

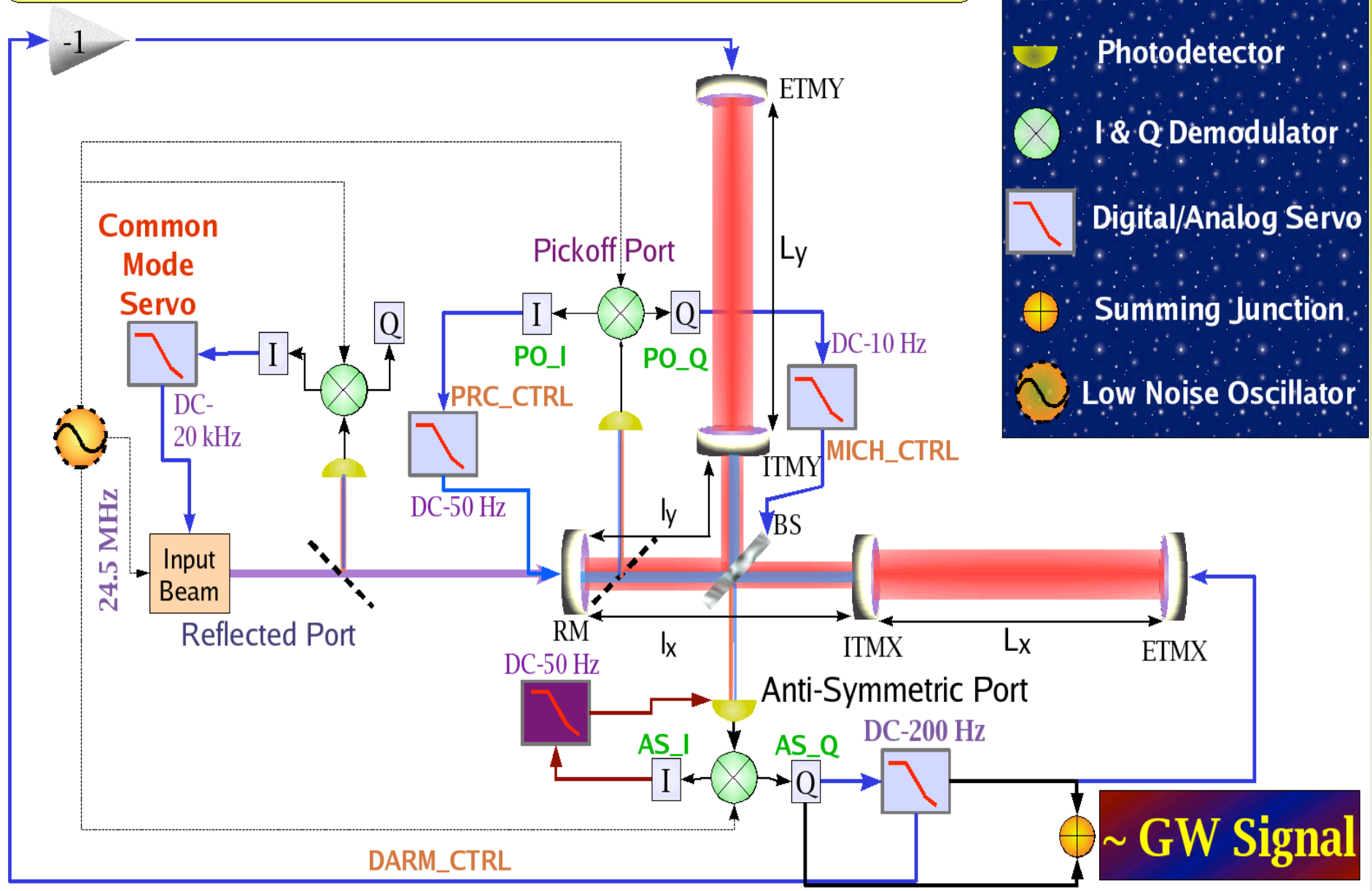
Method #1

- Measure the noise source term
- Measure the coupling transfer function
- Compare transfer function and source spectrum with detailed interferometer model (optical, mechanical)

- Electronics
- Laser Frequency
- Angular controls
- Local damping
- Auxilliary Length Controls
- Shot Noise

No mysteries, no problems. Lots of time and effort.

Length Readout & Controls



Noise Budgeting

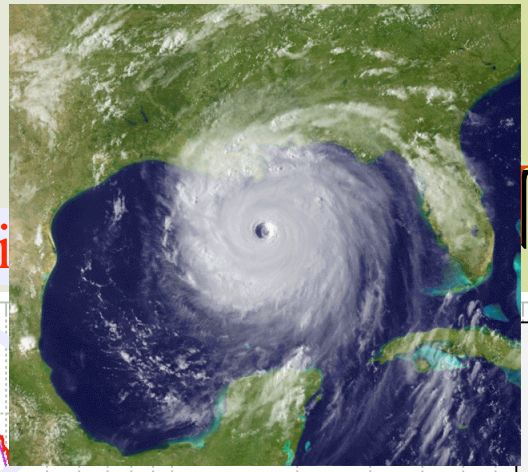
Method #2

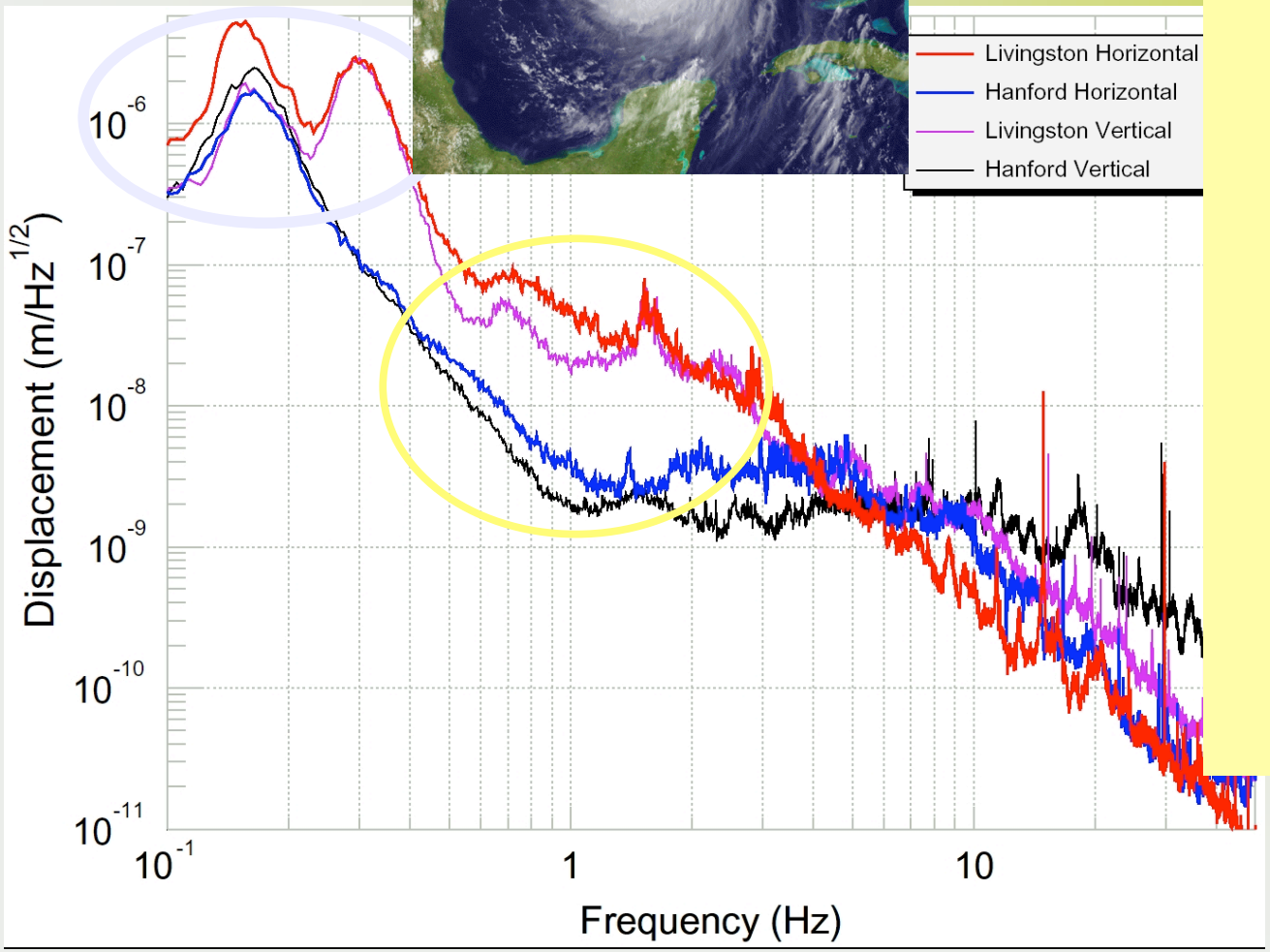
- Measure the noise source term
- Measure the coupling transfer function
- Model is totally wrong or there is no model
- Not understood, but can be fixed

- Oscillator Phase
- Laser amplitude
- Seismic

Noise

Ocean activity, hurri



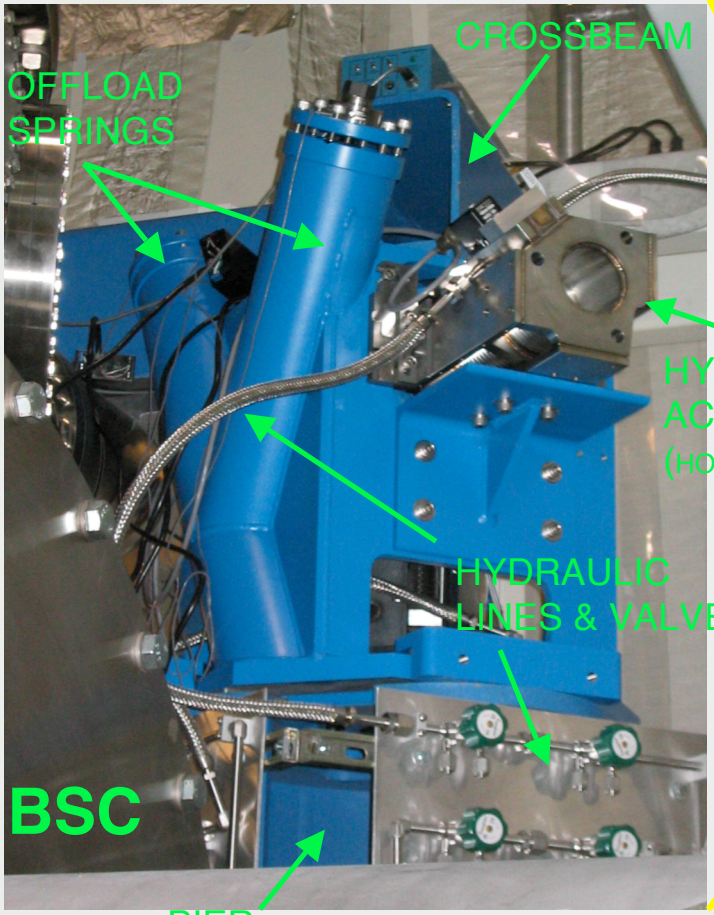


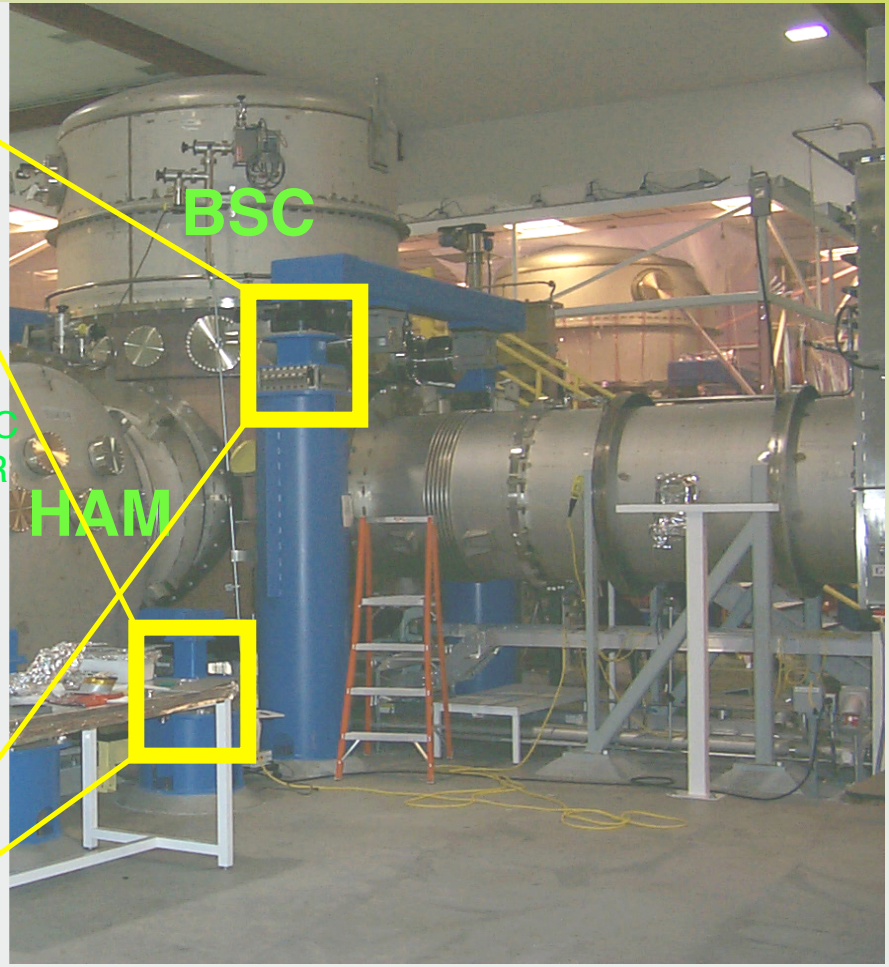
Human activity:
Cars,
Trains,
Trucks,
Logging,
Well Drilling,
Oil Pipeline

Amplified by internal isolation stack resonances

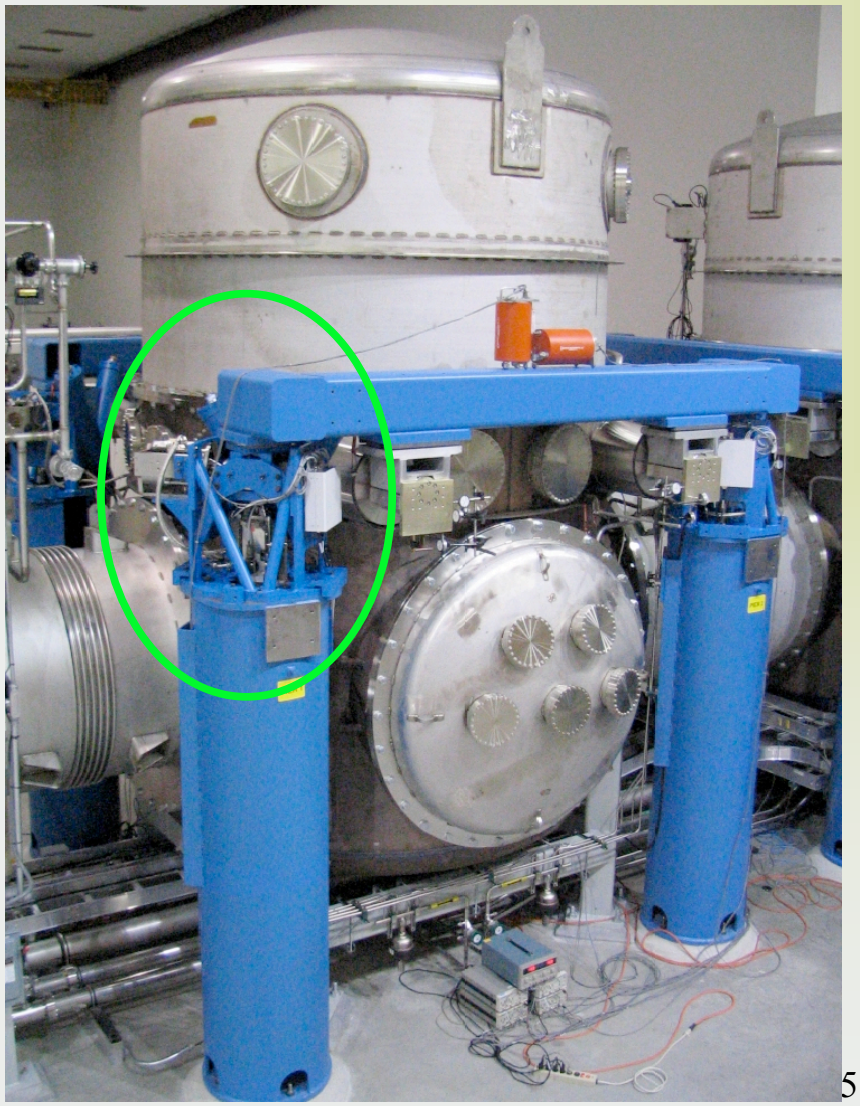
Active Seismic Isolation

Hydraulic External Pre-Isolator (HEPI)





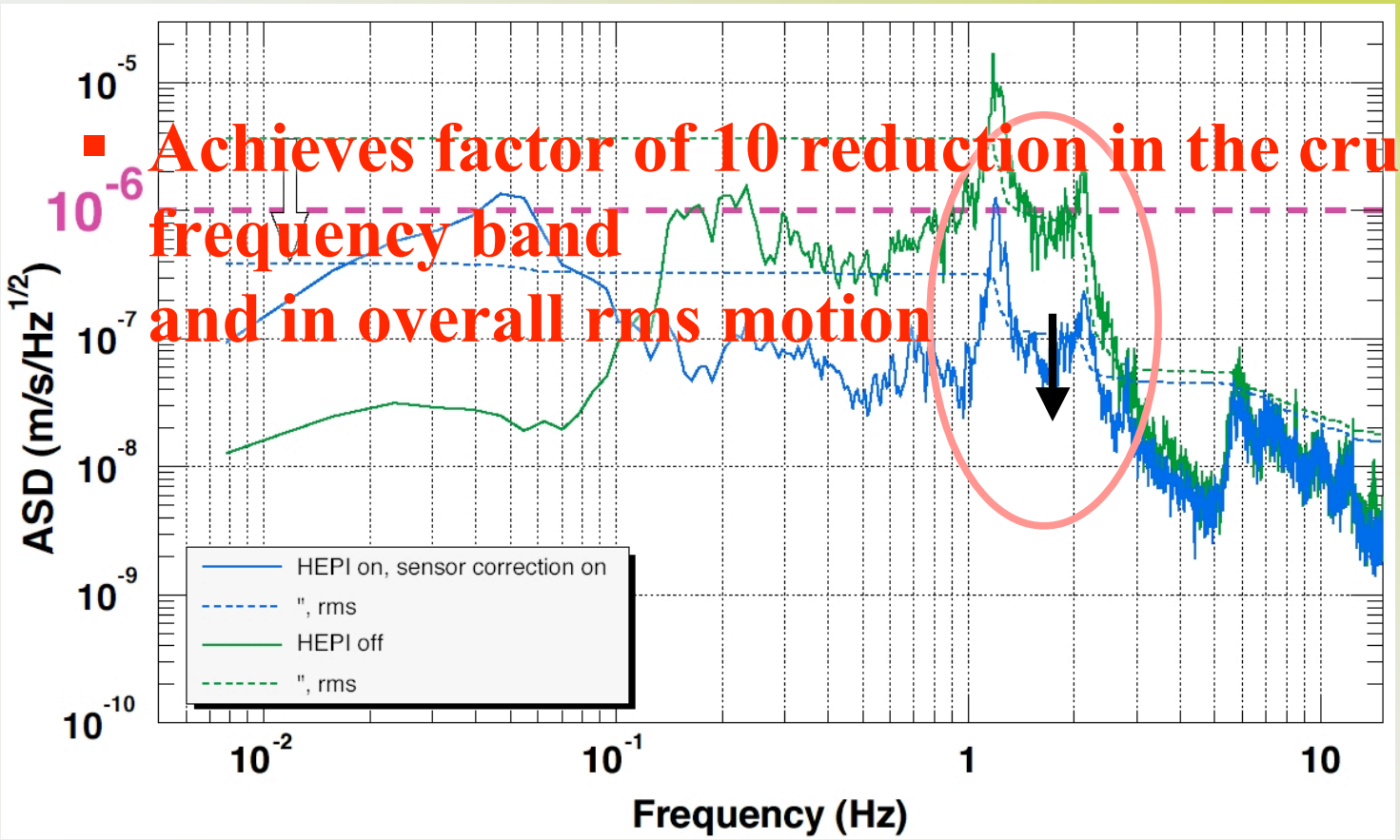
Active Seismic Isolation



- Hydraulic external pre-isolator (HEPI)
- Signals from sensors on ground and cross-beam are blended and fed into hydraulic actuators
- Status:
  - Installed on all 4 piers at each of 9 vacuum chambers
  - Fully operational

Active Seismic Isolation

- **Achieves factor of 10 reduction in the crucial frequency band and in overall rms motion**



Can lock (and do commissioning work!) during daytime

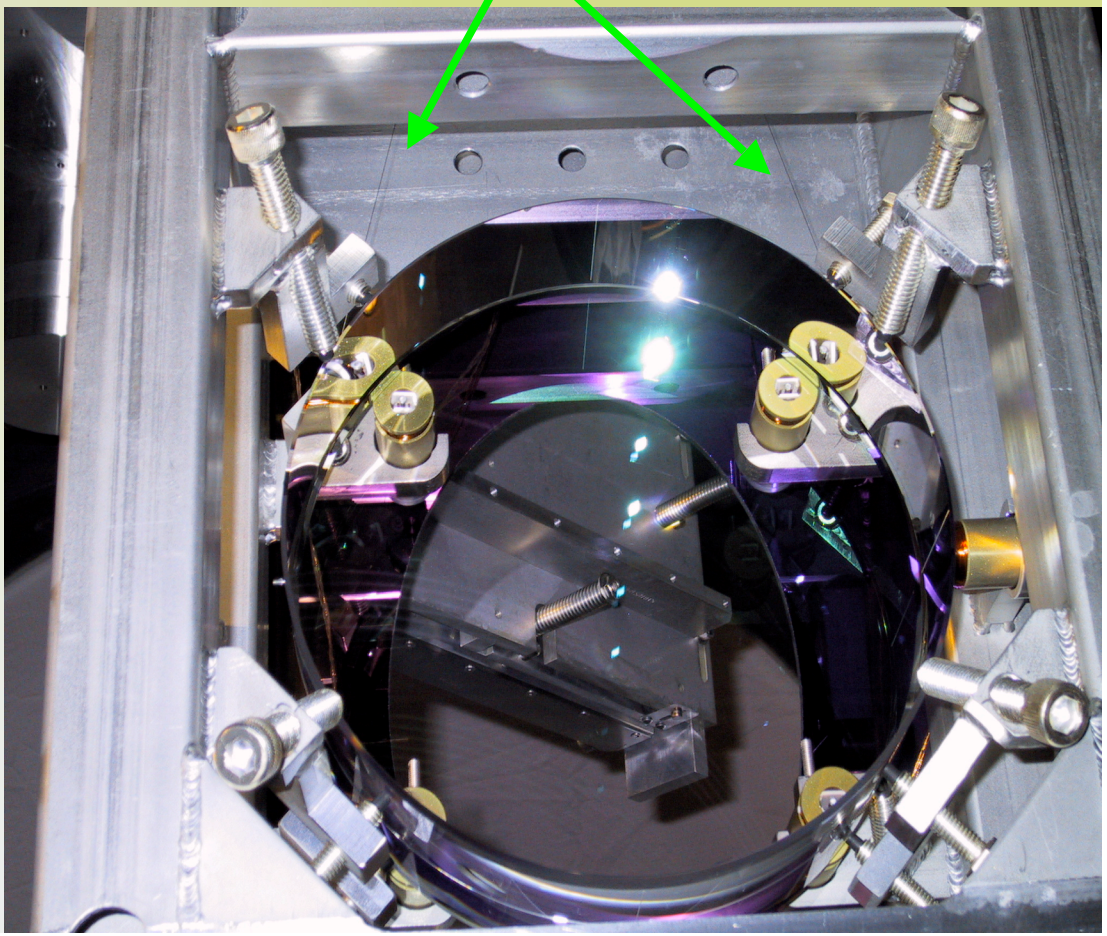
Able to stay locked even when train passes nearby

Noise Budgeting

Method #3

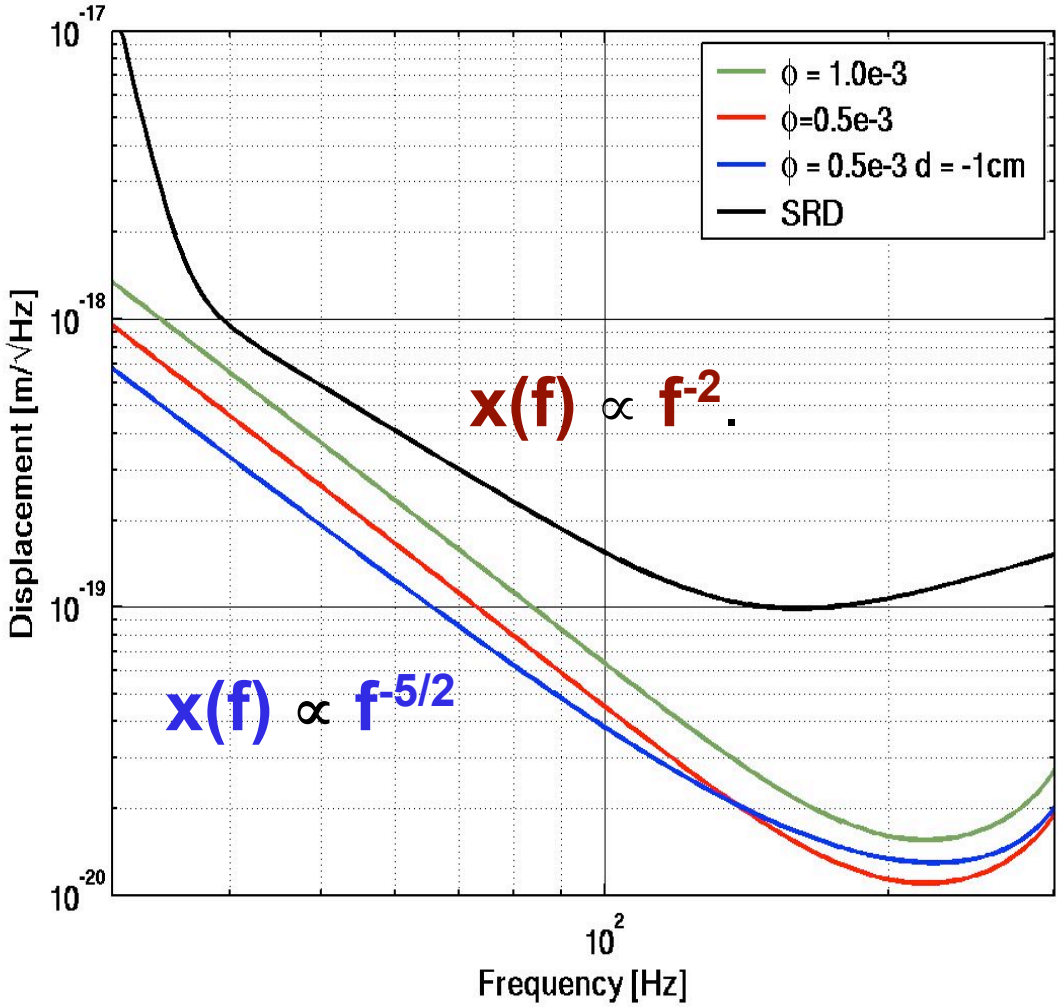
- Have model, but cannot verify yet
- Measure some model parameters
- No knobs to turn: cannot be easily fixed

- Thermal



Measurements:
Suspension Thermal Noise

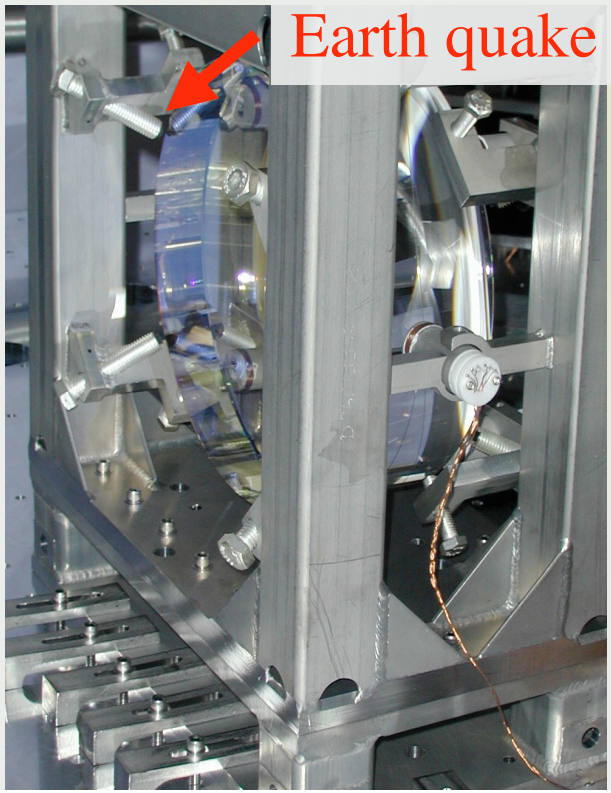
- Assumes NO loss except for the internal wire friction:
  Good clamps, no rubbing.
  Not yet verified.
- High upper limit of 1.3×10^{-3} set by measuring in lock linewidth of violin modes.
- Linewidths limited by temperature drift of ~1 deg.
- Violin mode ringdown measurements take minutes, not hours..
- **May turn out to be ~3-4x less than SRD.**

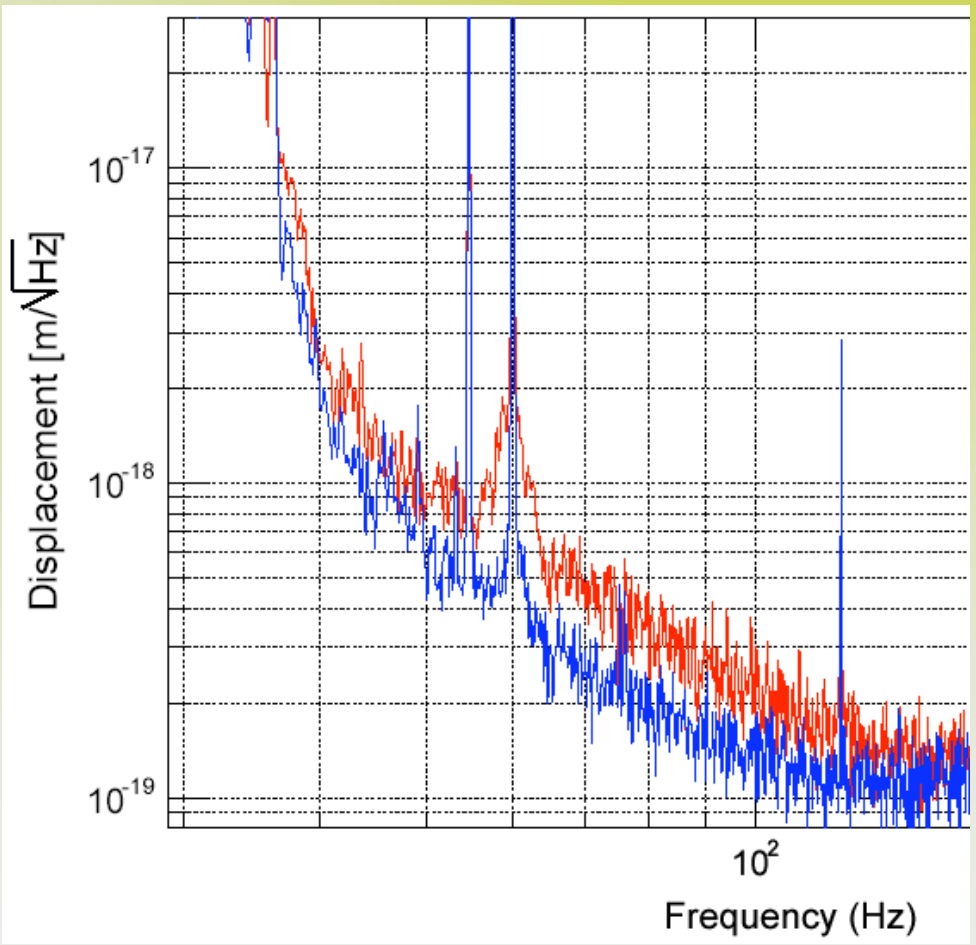


Noise Budgeting

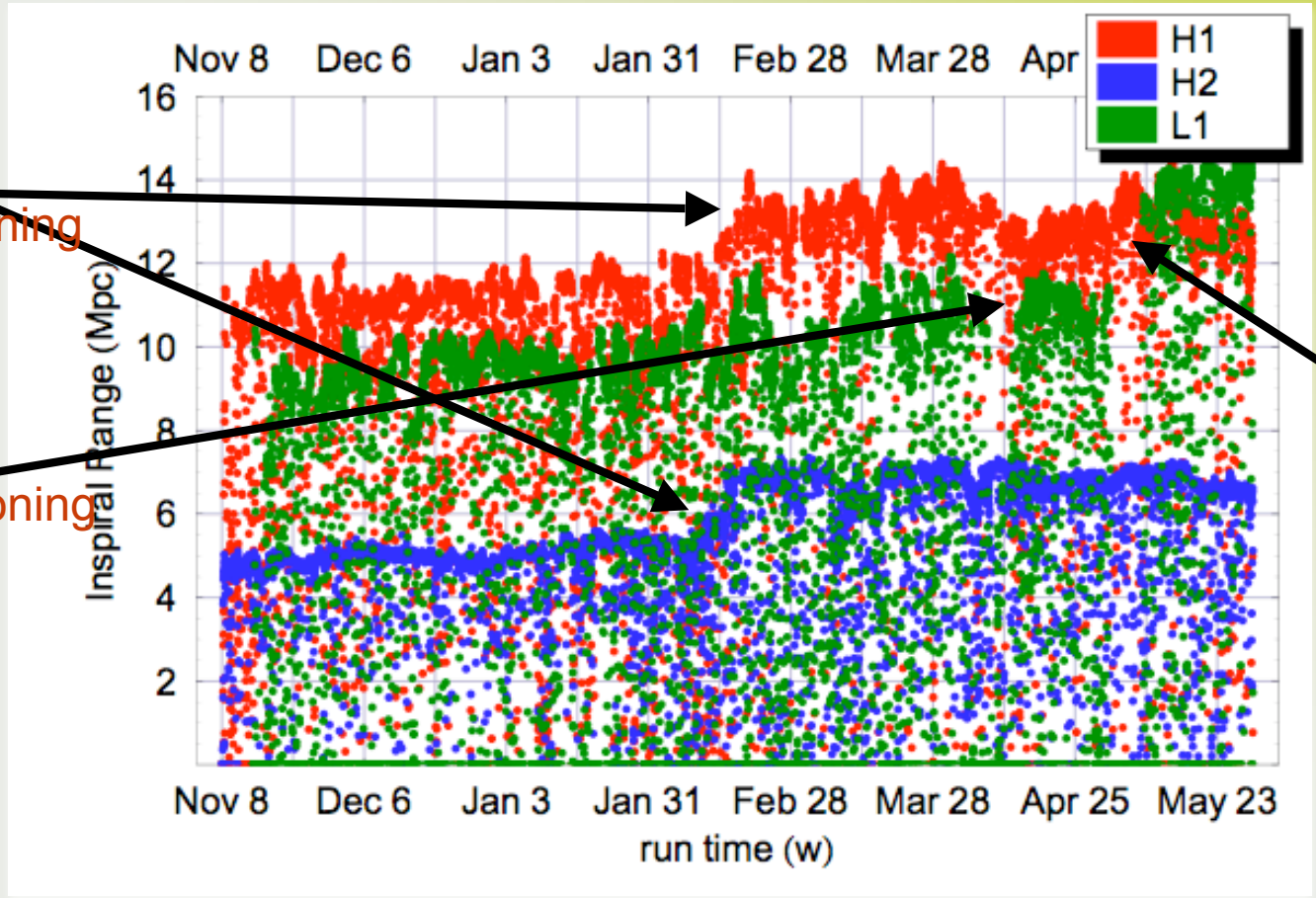
Method #4

- Unknown source
- Unknown coupling
- Cannot be fixed
  Yet!





Serendipity

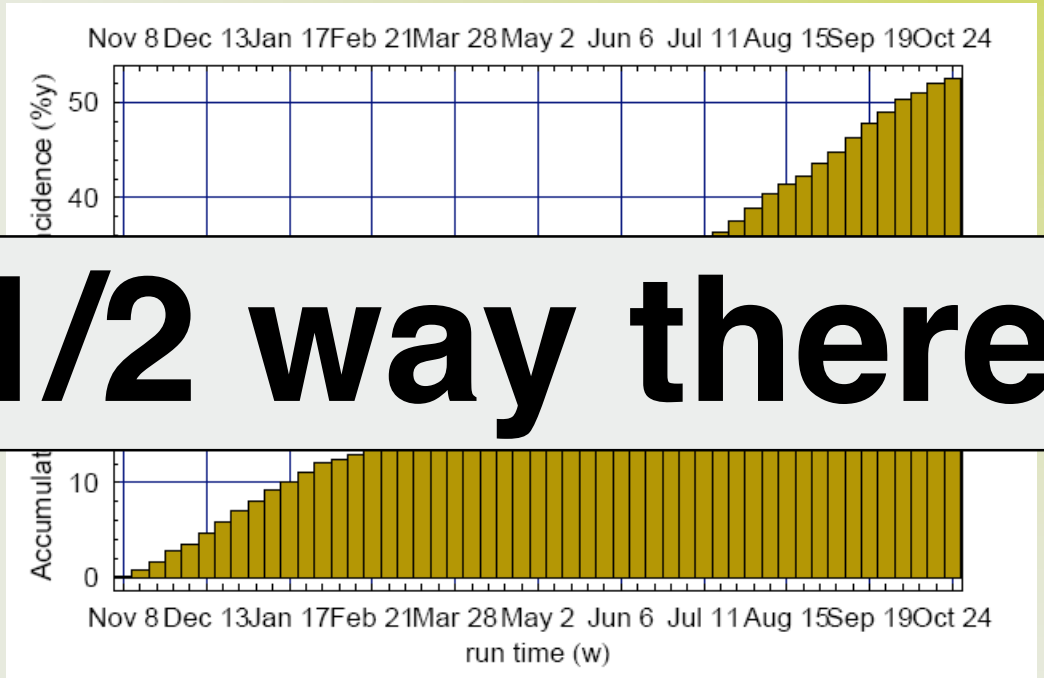


LHO Commissioning

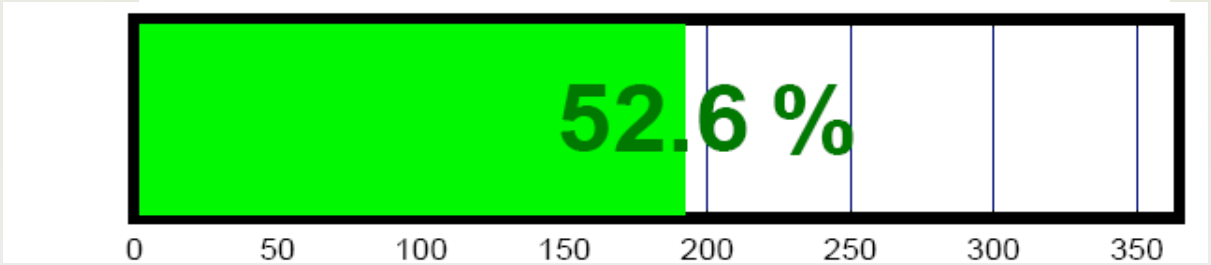
LLO Commissioning

LLO Vent

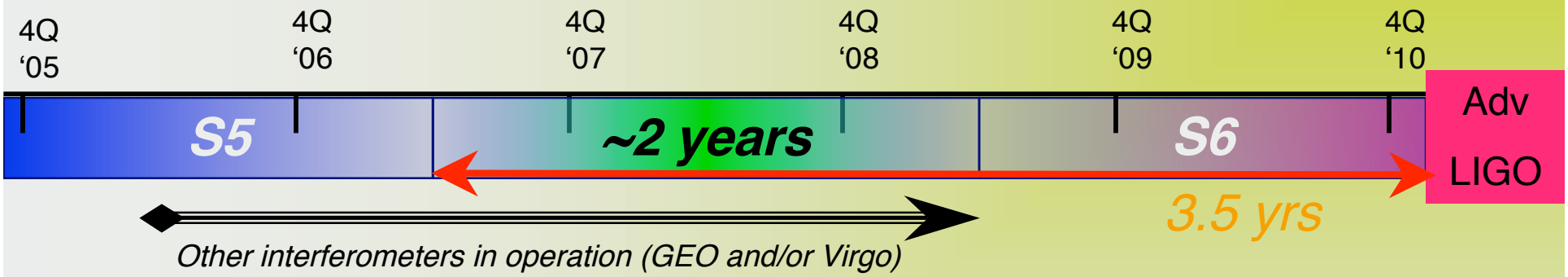
S5 Run



1/2 way there!



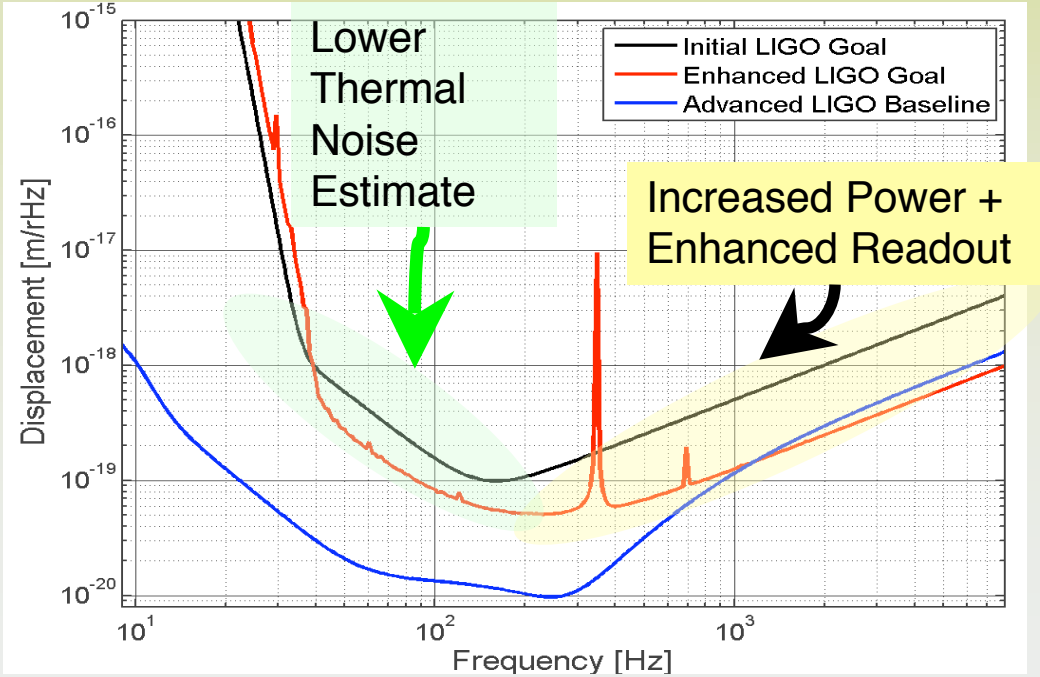
Enhanced LIGO for S6



Motivation:

Factor of ~2.5 in noise improvement above 100 Hz
Factor ~5-10 in inspiral binary neutron star event rate

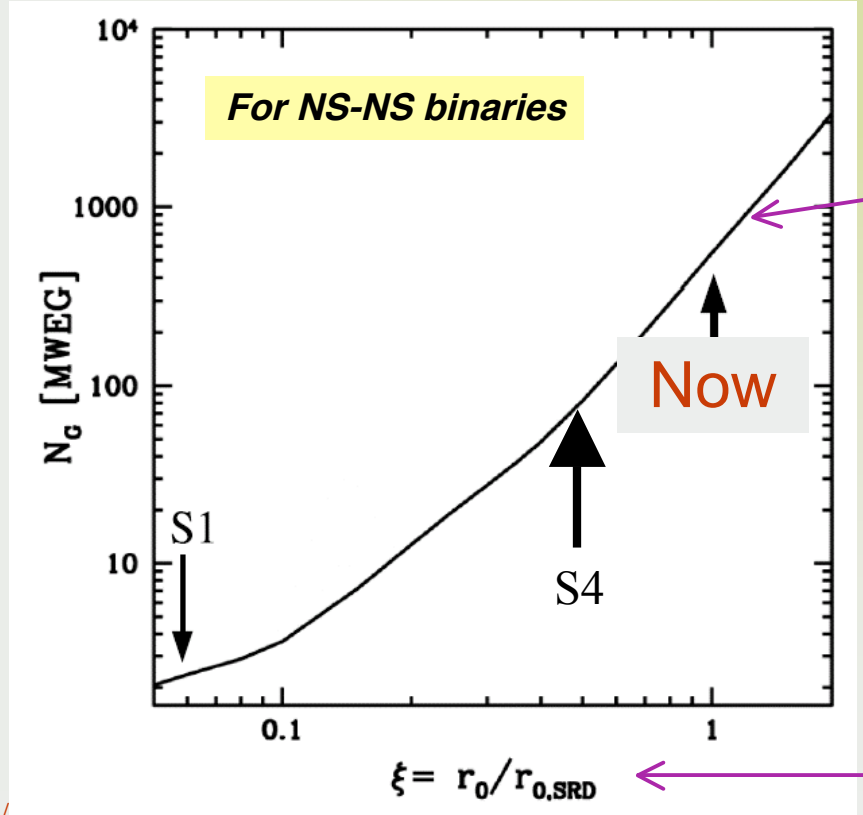
Debug new Advanced LIGO technology in actual low noise interferometers
Reduce the Advanced LIGO commissioning time



Astrophysics

How does the number of surveyed galaxies increase as the sensitivity is improved?

From astro-ph/0402091, Nutzman et al.



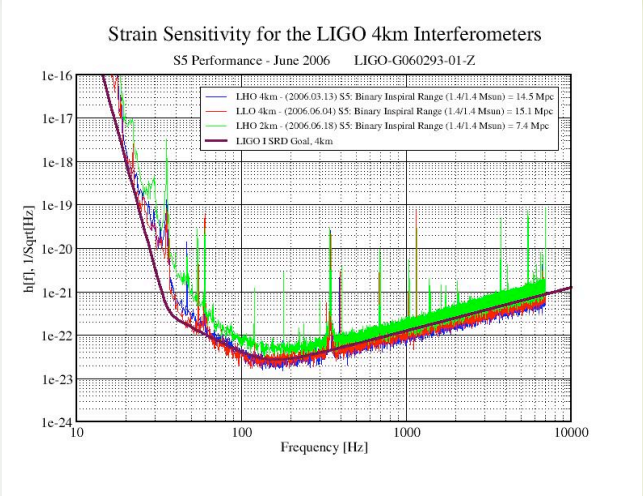
Power law: 2.7

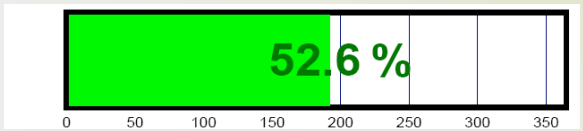
Factor of 2-2.5 reduction in strain noise,

⇨factor of 6.5-12 increase in MWEG

Prop. to inspiral range

LIGO at Design





- We are now at design sensitivity and actively looking for signals.
- See talk by L. Cadonati NEXT
- advLIGO, which would extend our reach by another factor of 10 is already the subject of much R&D work.
- See talk by B. Lantz later in this session.