# Status of LIGO

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LIGO Livingston Observatory

for the LIGO Scientific Collaboration

- **Overview of LIGO**
  - **Gravitational wave detection**
- **Report on fifth science run**
  - **Data taking started in November 2005**
  - **Sensitivity and duty factor**
- **Summary**

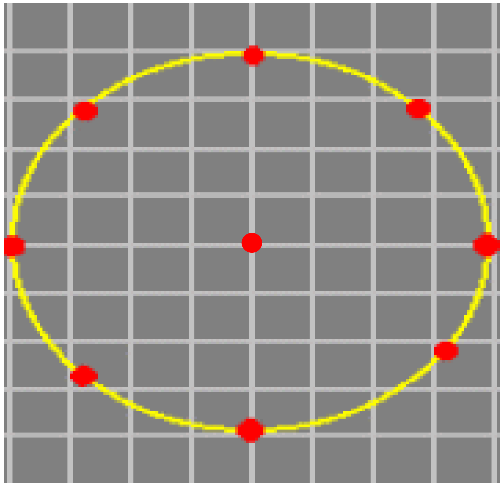
# Gravitational Waves

- **Predicted by General Relativity: Source = Stress-Energy Tensor**
- **Characterized by dimensionless strain *$h_{ij}$***

$$ds^2 = c^2 dt^2 - [1 + h_{ij}(t)] dx^i dx^j$$

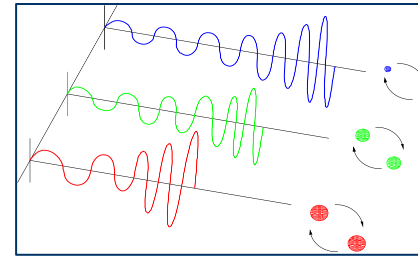
$$\boxed{h \approx \frac{\Delta L}{L}}$$

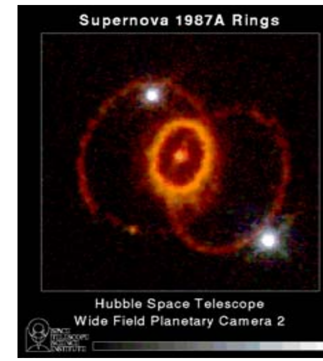
- **Quadrupolar radiation, two polarizations + and x**
- **Effect from gravity is tidal**
- **For astrophysical sources *h* ~ $10^{-22}$ - $10^{-21}$**
- **Generated by the bulk motion of matter**



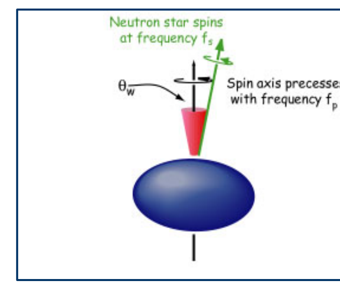
# GW Sources in LIGO Band 50-1000 Hz

- **Compact binary inspirals:** ***"chirp"***
  - NS-NS waveforms are well described.
    **1.4 $M_{solar}$ NS/NS inspiral is a standard candle.**
  - BH-BH waveforms are rapidly improving

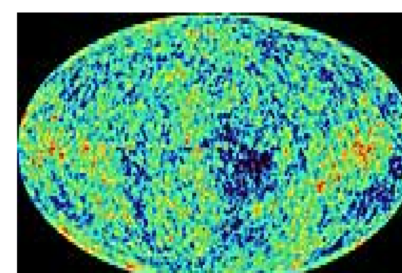





- **Supernovae / Mergers:** ***"burst"***
  - Short signals. Waveforms not well known.
  - Search in coincidence between two or more interferometers and possibly with electromagnetic and/or neutrinos signals



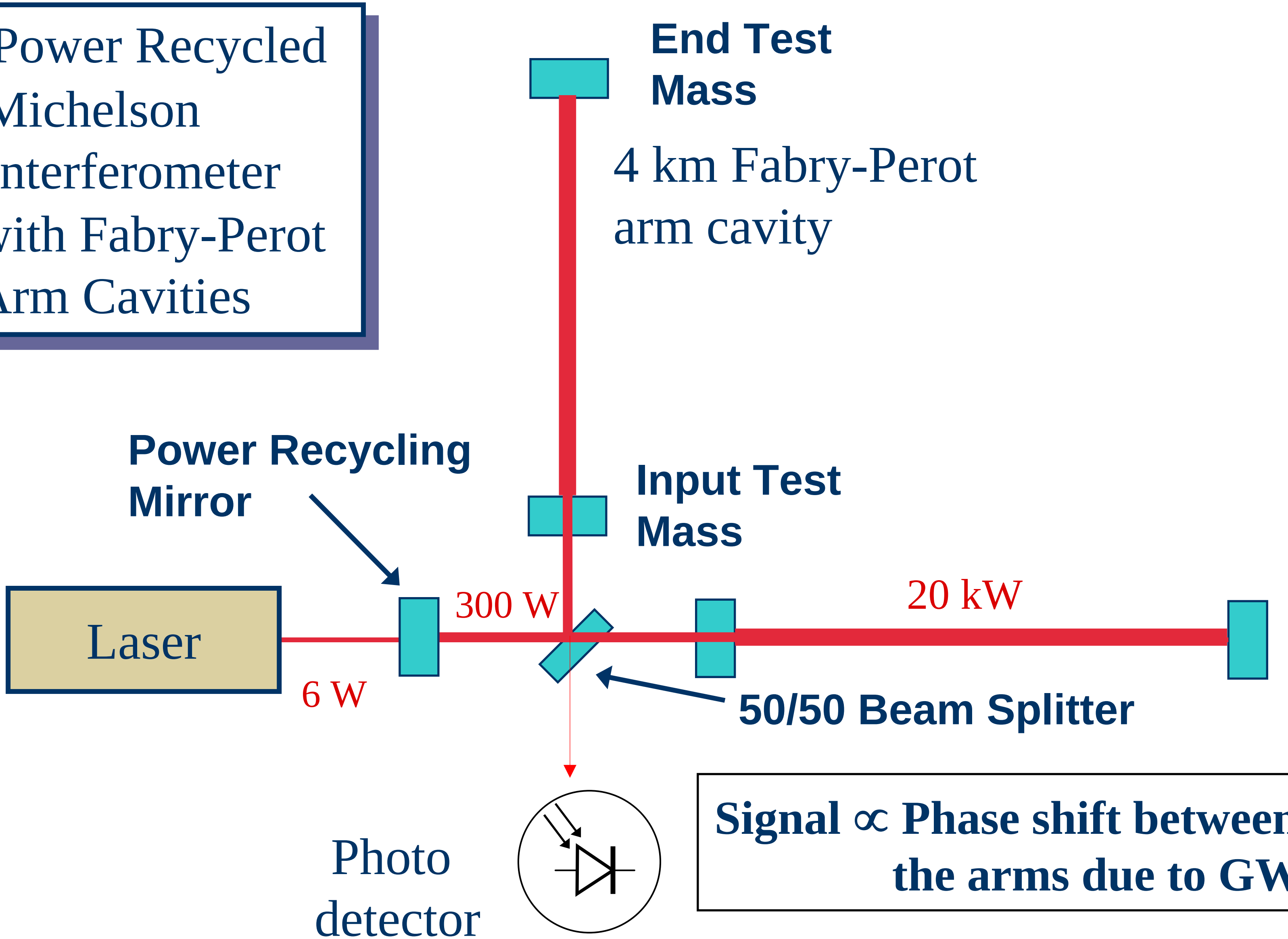

- **Spinning NS:** ***"continuous"***
  - search for signals from observed pulsars
  - all-sky search computing challenging



- **Cosmic Background:** ***"stochastic"***
  - Metric fluctuations amplified by inflation, phase transitions in early universe, topological defects
  - Unresolved foreground sources

# Interferometer Optical Layout

Power Recycled Michelson Interferometer with Fabry-Perot Arm Cavities




**Signal ∝ Phase shift between the arms due to GW**

# Initial LIGO Interferometer Sensitivity

## Seismic:
Attenuated seismic noise

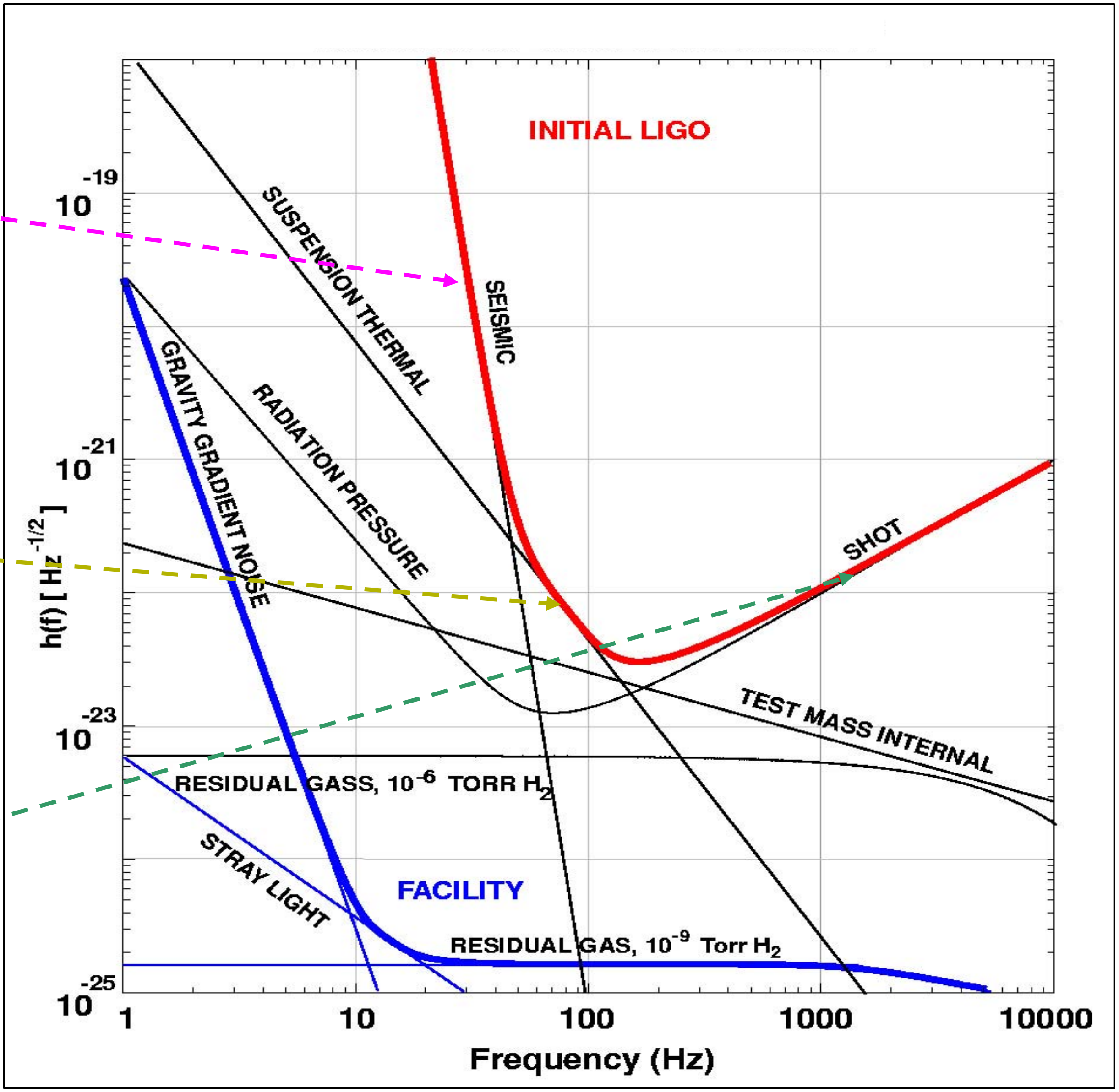
$h(f) \propto 1/f^{12}$

## Suspension thermal:
Viscously damped pendulum

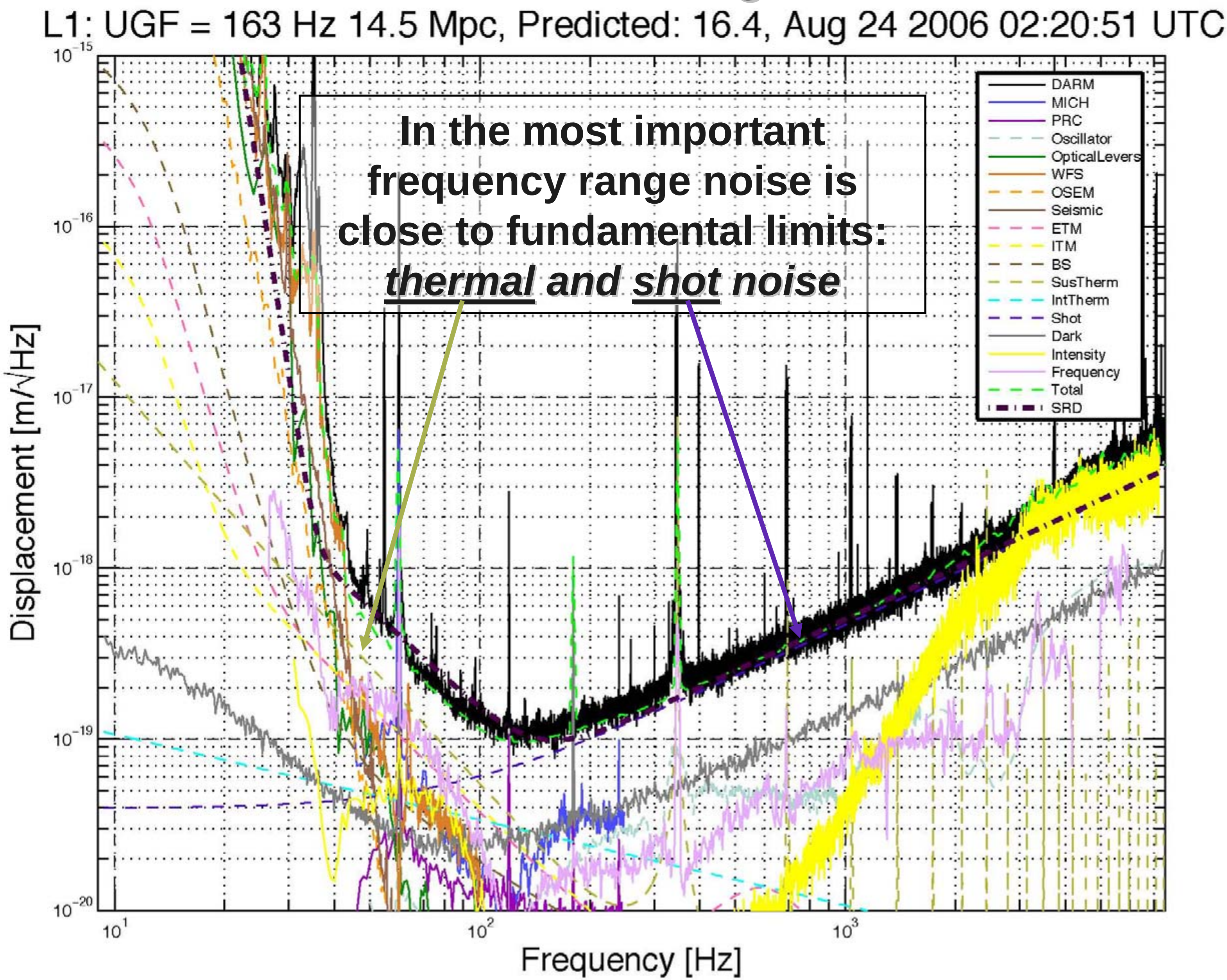
$h(f) \propto 1/f^{2}$

## Shot Noise:
Photon Counting Statistics

$h(f) \propto f$

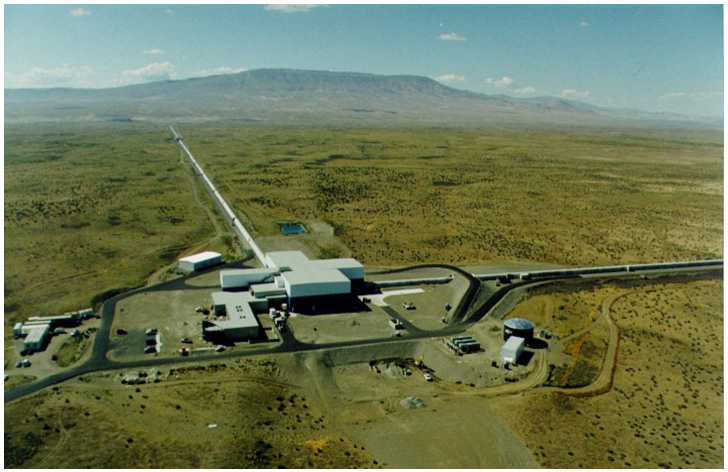


# Noise Budget

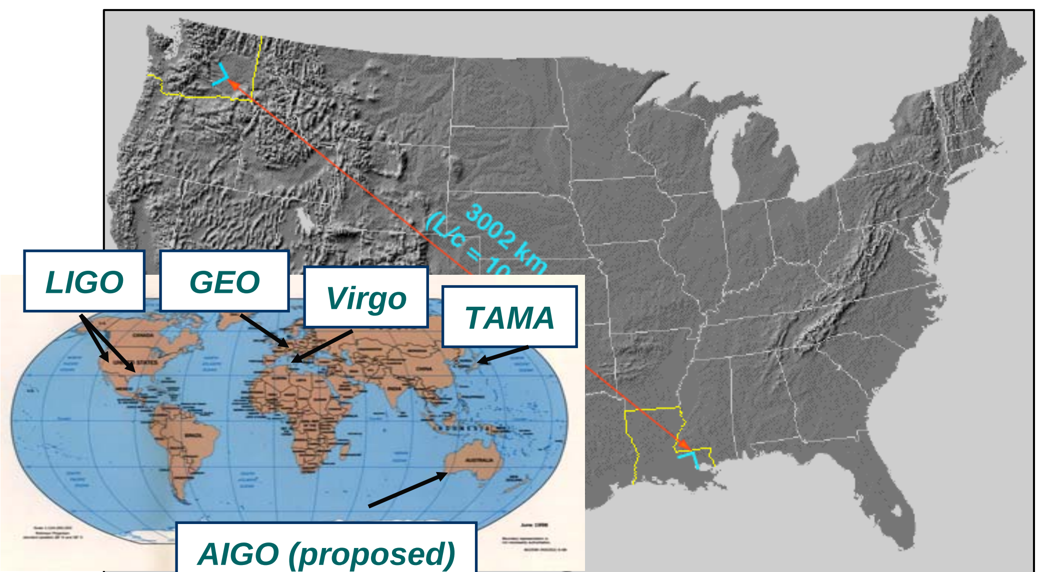


# LIGO Observatories

## Hanford, WA (H1 4km, H2 2km)



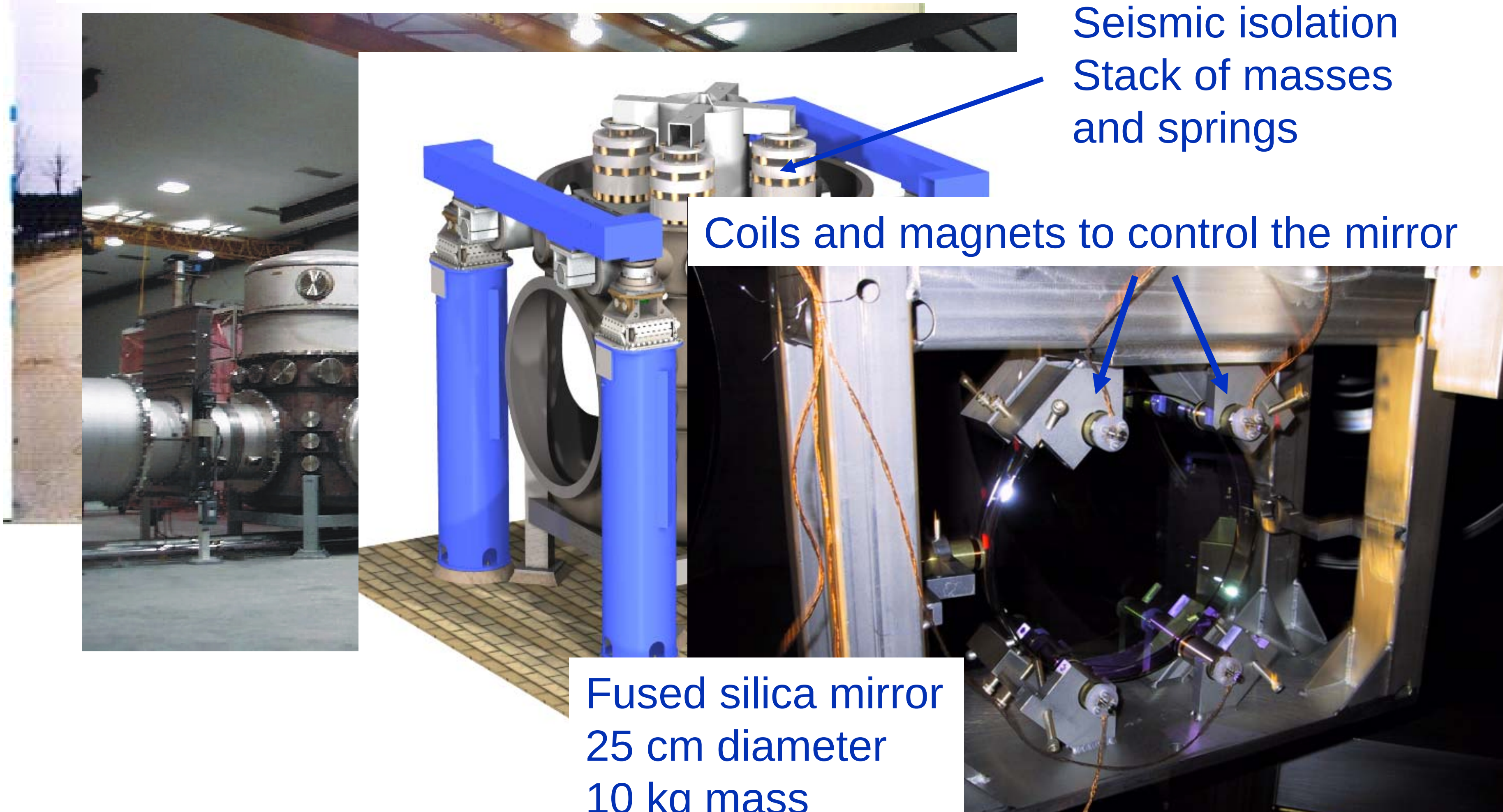
- *Interferometers are aligned to be as close to parallel to each other as possible*
- *Observing signals in coincidence increases the detection confidence*
- *Determine source location on the sky, propagation speed and polarization of the gravity wave*




## Livingston, LA (L1 4km)

# What Is Inside

1.2 m diameter - 3mm stainless 50 km of weld
$10^{-9}$ torr vacuum and no leaks!



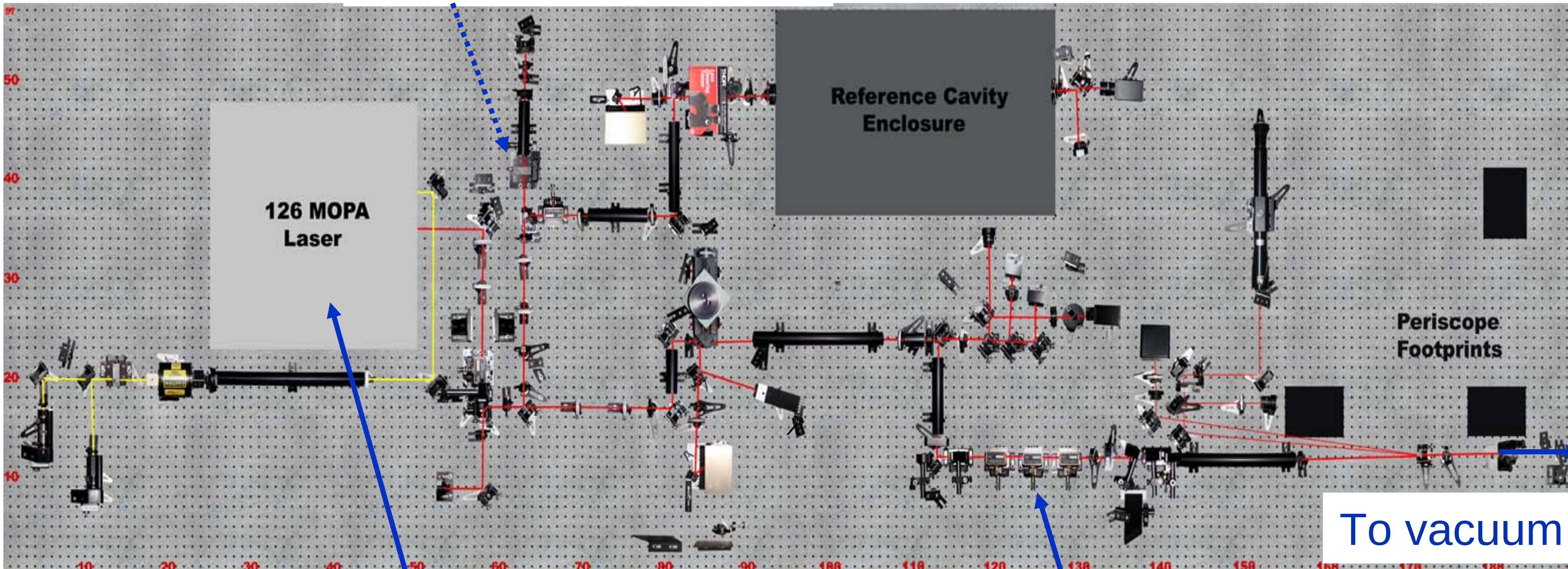
Seismic isolation
Stack of masses
and springs

Coils and magnets to control the mirror

Fused silica mirror
25 cm diameter
10 kg mass

# Laser Optical Table

Common arm signal

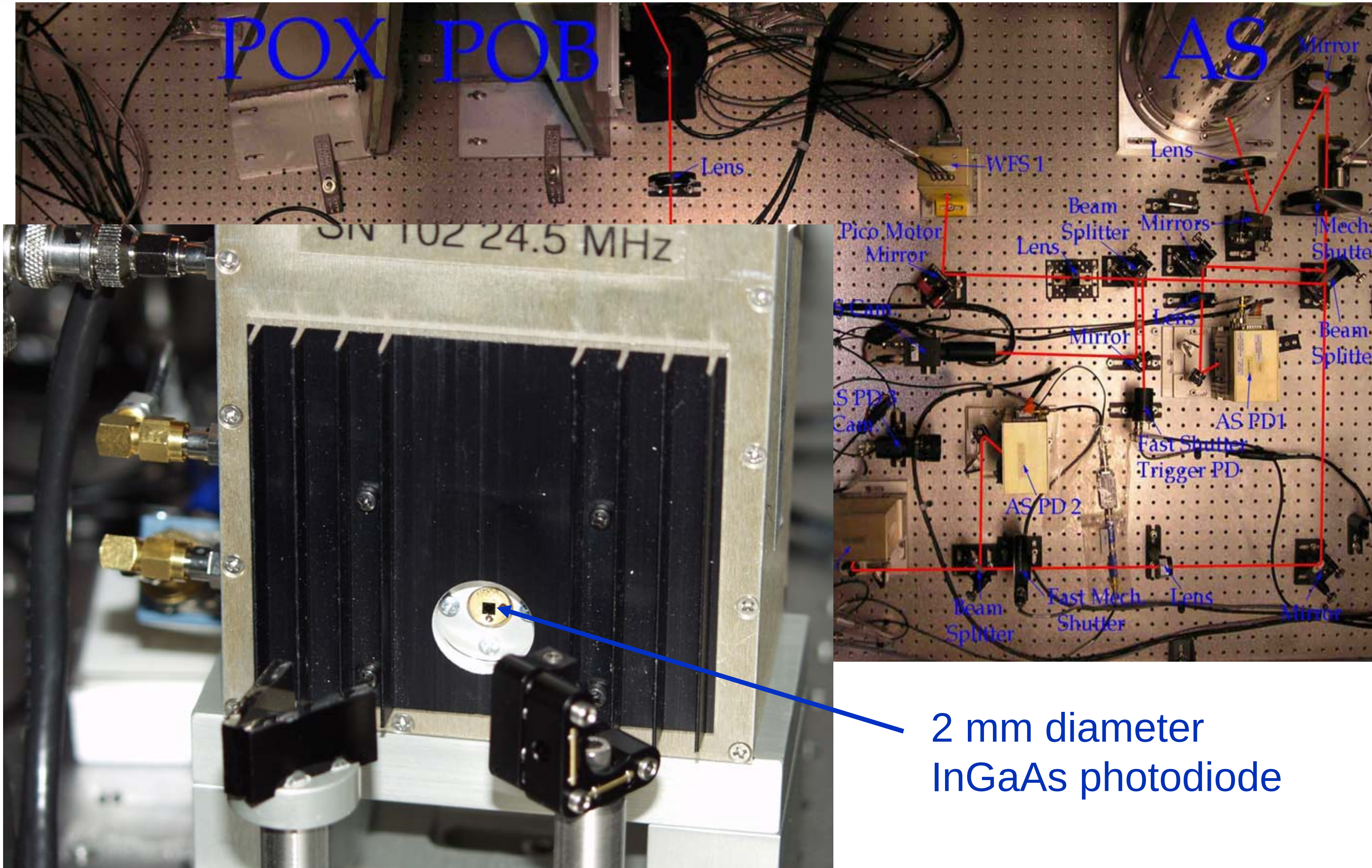



To vacuum

10 W NdYAG laser
$\lambda$=1.064 um
Stabilized in frequency
and intensity

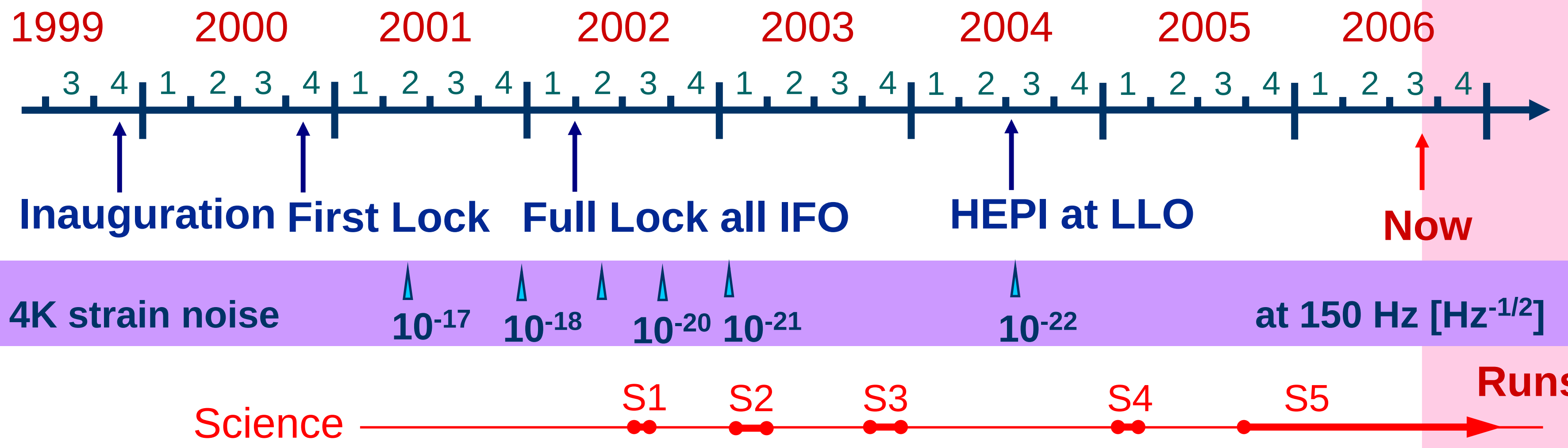
Electro-optic
modulators

# Dark Port Optical Table

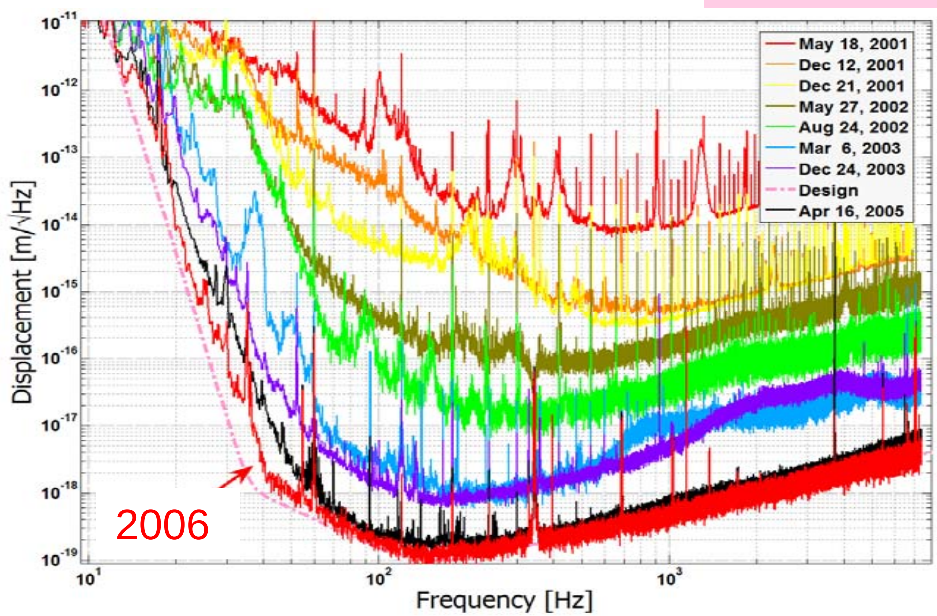



2 mm diameter InGaAs photodiode

# 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
HEPI at LLO
Now
4K strain noise
10-17
10-18
10-20
10-21
10-22
at 150 Hz [Hz-1/2]
Runs
Science
S1
S2
S3
S4
S5
First Science Data

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

# LIGO Scientific Collaboration

## ~40 institutions, ~550 scientists

| | | |
|---|---|---|
| **Caltech** | **LIGO Laboratory** | **MIT** |
| **LIGO Hanford Observatory** | | **LIGO Livingston Observatory** |

University of Adelaide ACIGA
Australian National University ACIGA
Balearic Islands University
Caltech LIGO
Caltech Experimental Gravitation  CEGG
Caltech Theory  CART
University of Cardiff  GEO
Carleton College
Cornell University
Embry-Riddle Aeronautical University
University of Florida-Gainesville
Glasgow University  GEO
NASA-Goddard Spaceflight Center
Hobart – Williams University
India-IUCAA
IAP Nizhny Novgorod
IUCCA India
Iowa State University

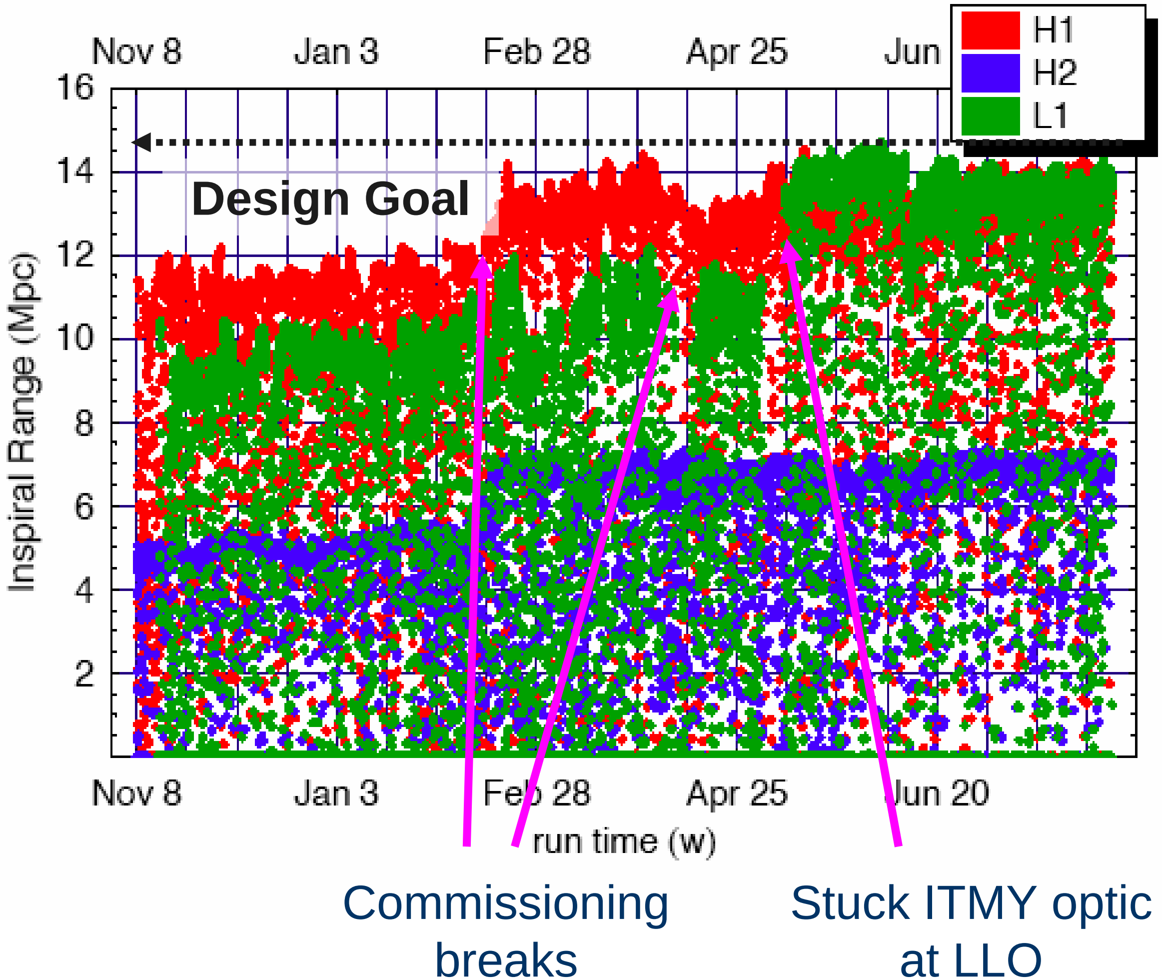
Loyola New Orleans
Louisiana State University
Louisiana Tech University
MIT  LIGO
Max Planck (Honnover) GEO
Max Planck (Potsdam) GEO
University of Michigan
Moscow State University
NAOJ  - TAMA
Northwestern University
University of Oregon
Pennsylvania State University
Southeastern Louisiana University
Southern University
Stanford University
Syracuse University
University of Texas-Brownsville
Washington State University-Pullman
University of Western Australia  ACIGA
University of Wisconsin-Milwaukee

# LIGO Science Run

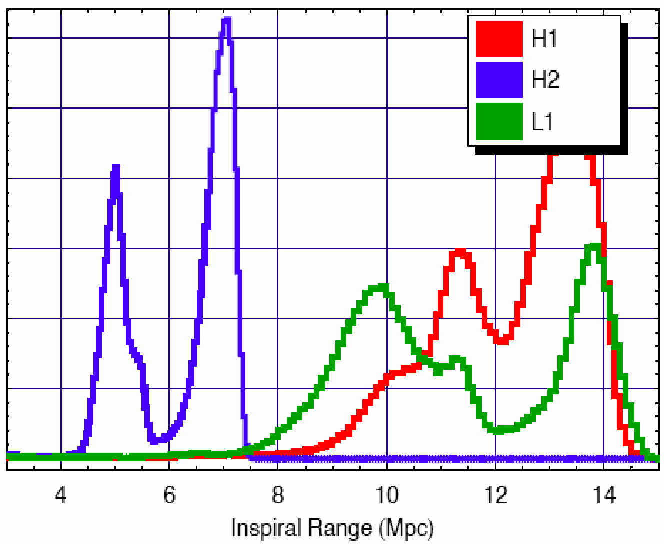
- **The fifth science run started in November 2005**
- **S5 goal is to collect one year of triple coincidence data at the design sensitivity**
- **Optimistic event rates: NS/NS ~3/year, BH/NS ~30/year**
  Nakar, Gal-Yam, Fox, astro-ph/0511254
- **Plan to reach the Crab pulsar spin down limit**
- **Expect to beat the Big-Bang Nucleosynthesis limit on gravitational wave density in the LIGO band**
- **GEO interferometer joined the S5 run in January 2006.**
- **Virgo interferometer plans to join S5 later this year.**

# NS-NS Inspiral Range Improvement

Time progression since the start of S5

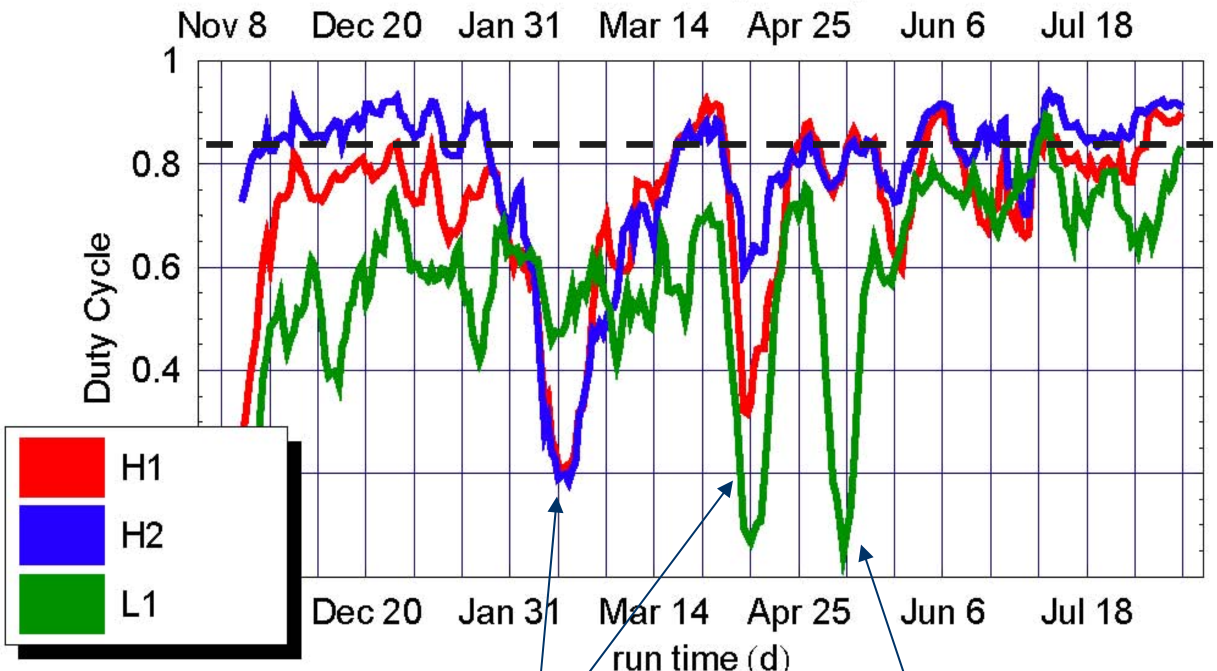



Histogram



# S5 Duty Factor

One week running average




Commissioning breaks

Stuck ITMY optic at LLO

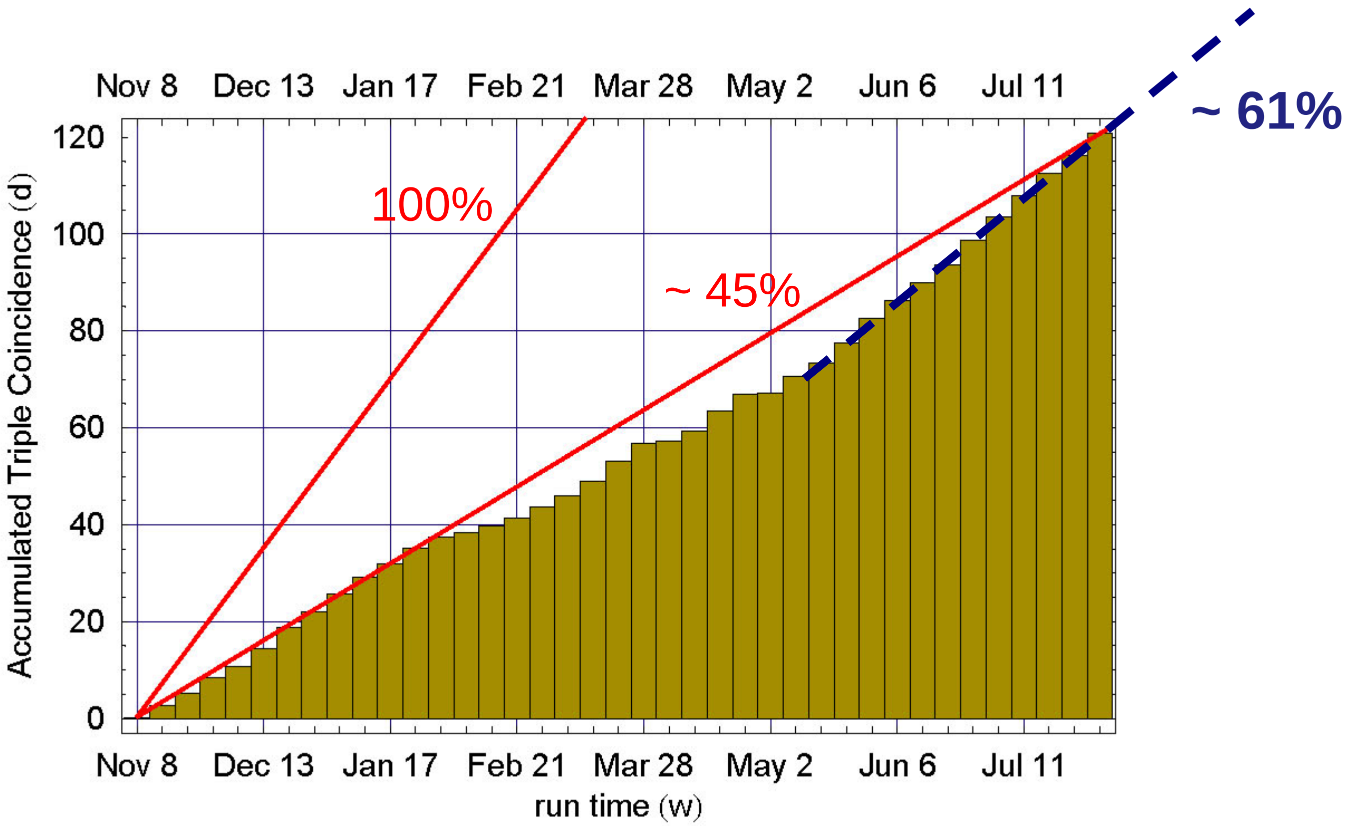
**S5 Goal is 85% for single interferometer and 70% for triple coincidence**

# S5 Duty Factor

| | H1 | H2 | L1 |
|---|---|---|---|
| ***Uptime*** | **72%** | **79%** | **60%** |
| *Wind, Storms, Earthquakes* | 4.5% | | 9% |
| *Nearby Logging, Construction, Trains* | - | - | 10% |
| *Maintenance, Commissioning, Calibration* | 10% | | 9% |
| *Hardware and Software Failures* | 3.5% | | 7% |
| *Lock Acquisition, Other* | 10% | | 5% |

**H1&H2&L1 = 45%** **H1||H2||L1||G1 close to 100%**

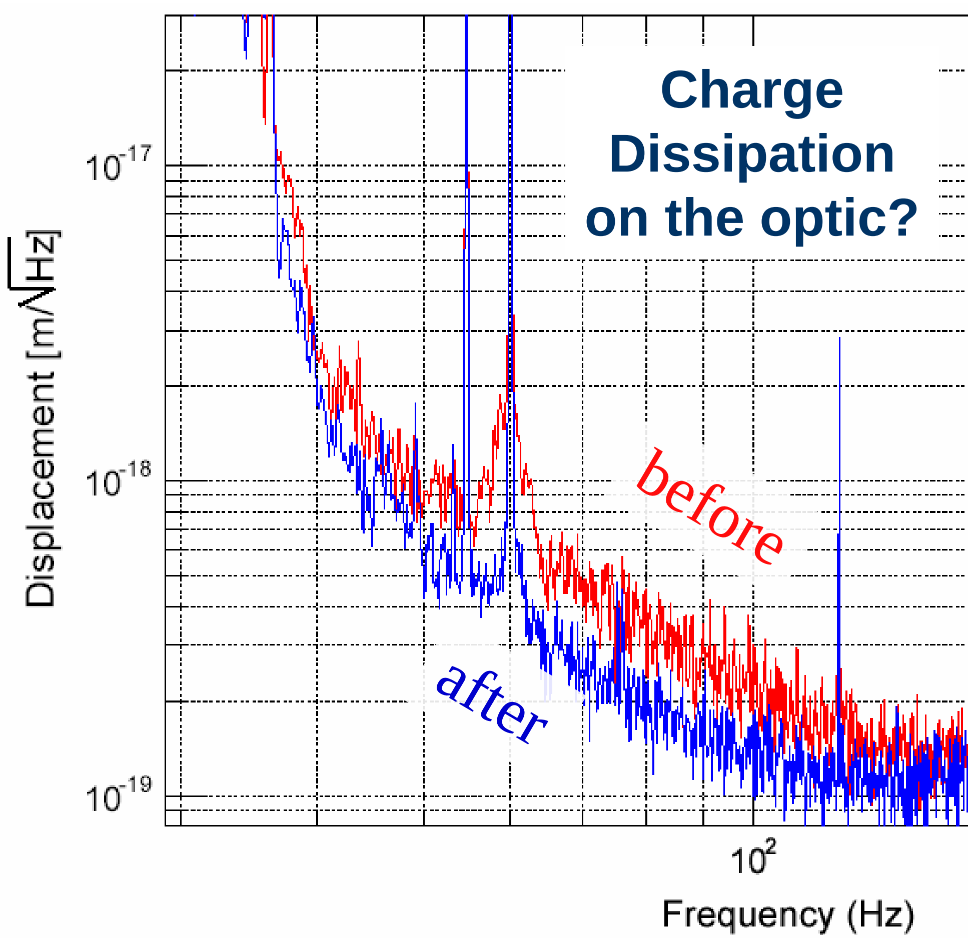
# Triple Coincidence Accumulation

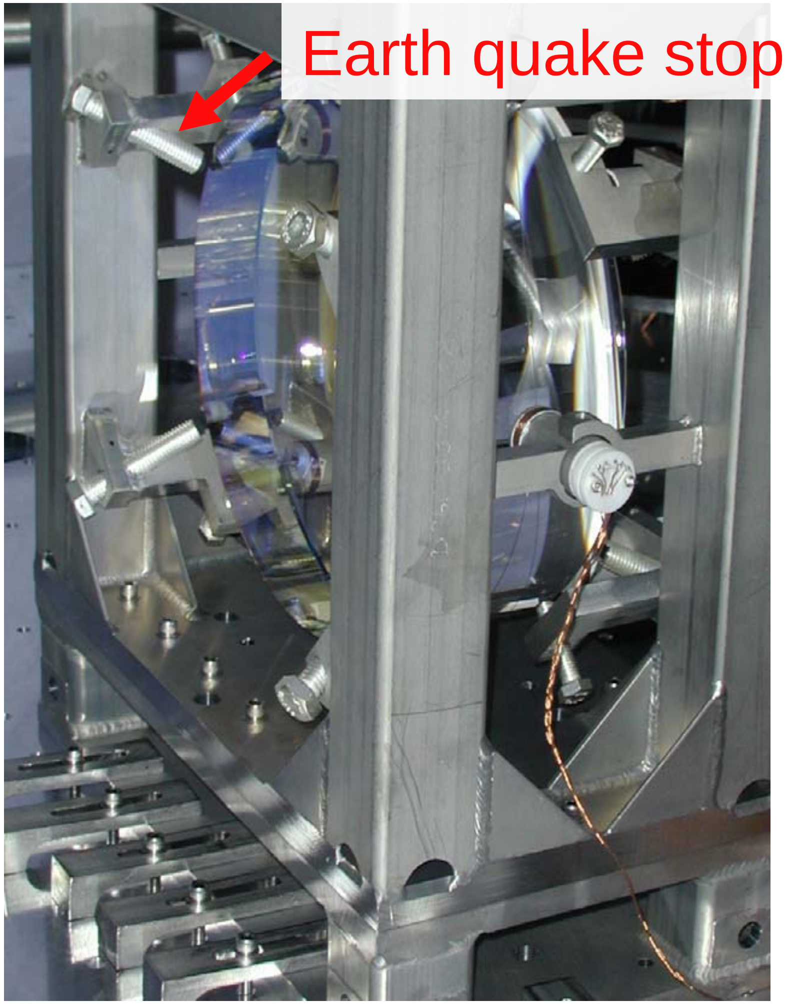



**Expect to collect one year of triple coincidence data by summer-fall 2007**

# Sometimes You Get Lucky

- **Large mirror (ITMY) was wedged into the earth quake stops**
- **Vented the vacuum and released it. Adjusted EQ stop.**
- **Noise improved!? 12->14 Mpc**



# Summary

- **The fifth science run started in November 2005**
- **LIGO instruments are performing at the design sensitivity level. Duty factor is improving.**
- **Expect one year of triple coincidence data by summer-fall 2007**