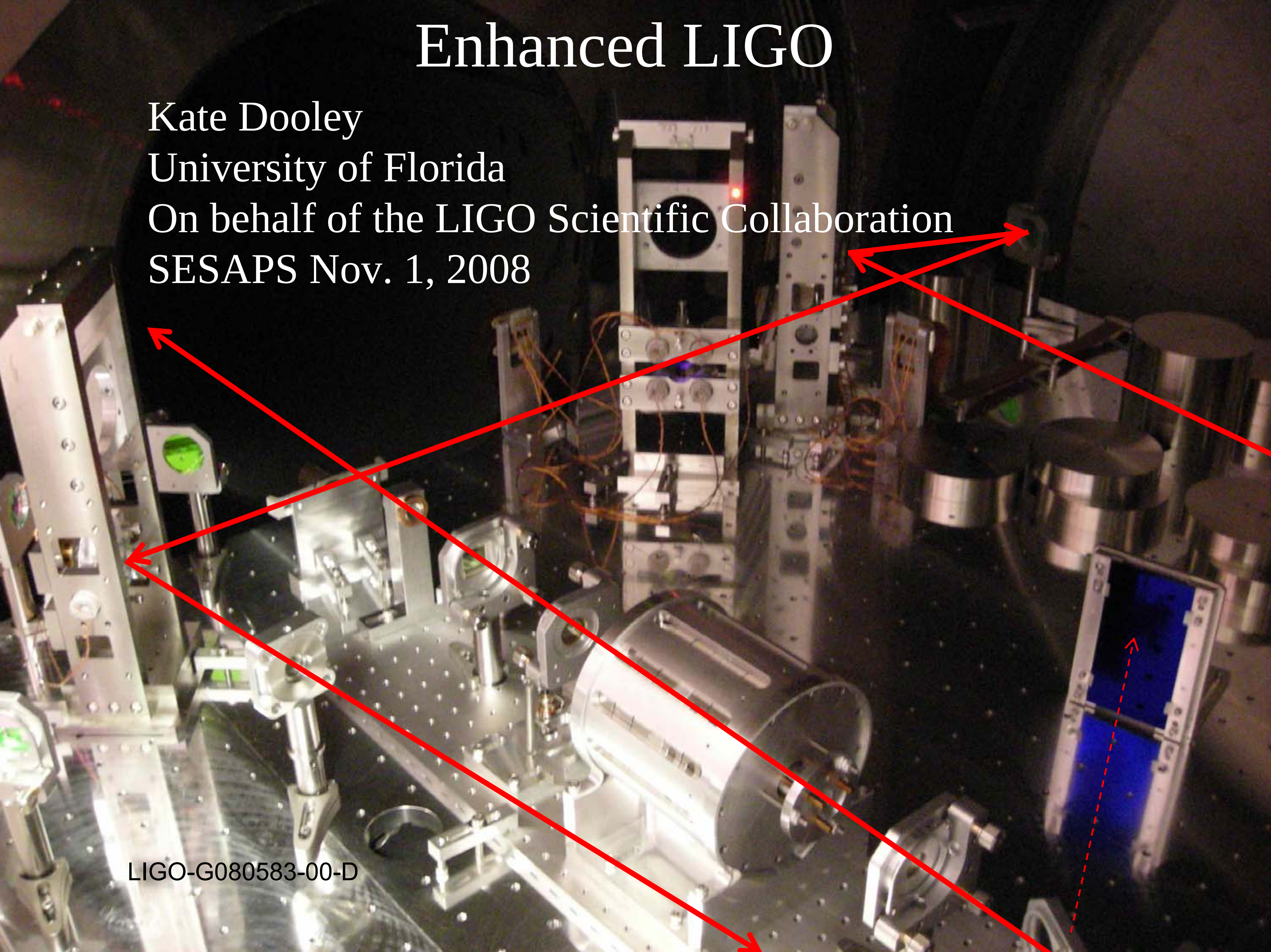
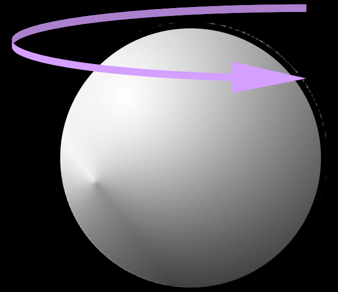
Enhanced LIGO

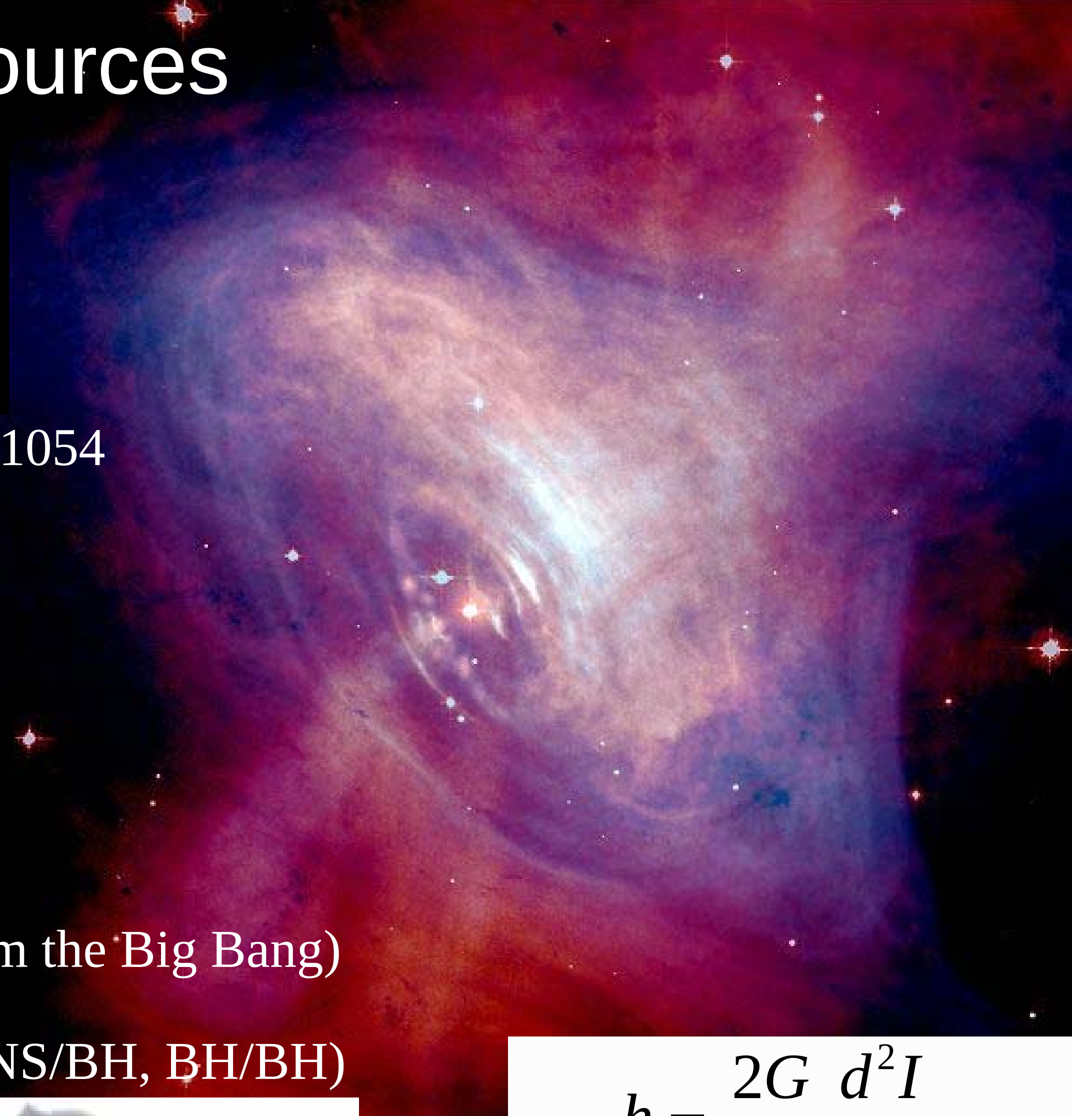
Kate Dooley
University of Florida
On behalf of the LIGO Scientific Collaboration
SESAPS Nov. 1, 2008



LIGO-G080583-00-D

Gravitational Wave Sources





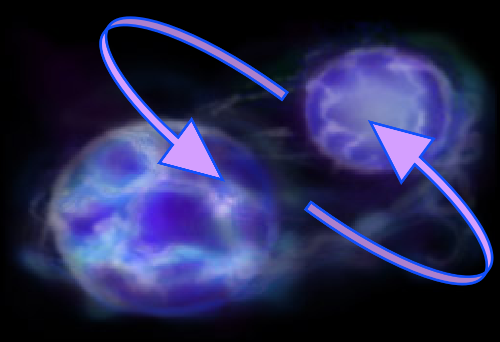
THE CRAB PULSAR

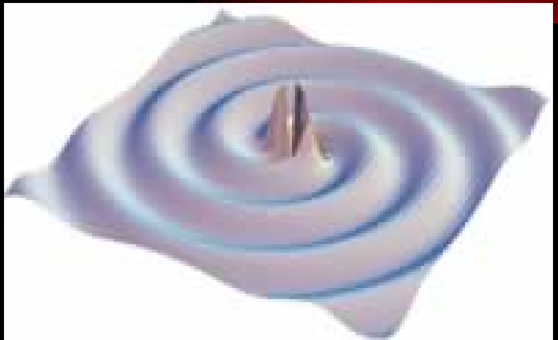
- spinning neutron star
  - remnant from supernova in year 1054
- gw frequency $\nu_{gw} = 59.8$ Hz
- spin down due to:
  - electromagnetic braking
  - *GW emission?*

BURSTS (GRBs, supernovae)

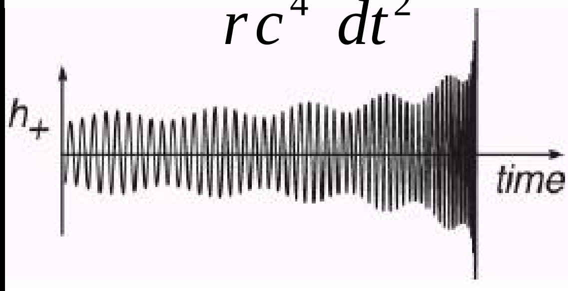
STOCHASTIC BACKGROUND (from the Big Bang)

COALESCING BINARIES (NS/NS, NS/BH, BH/BH)





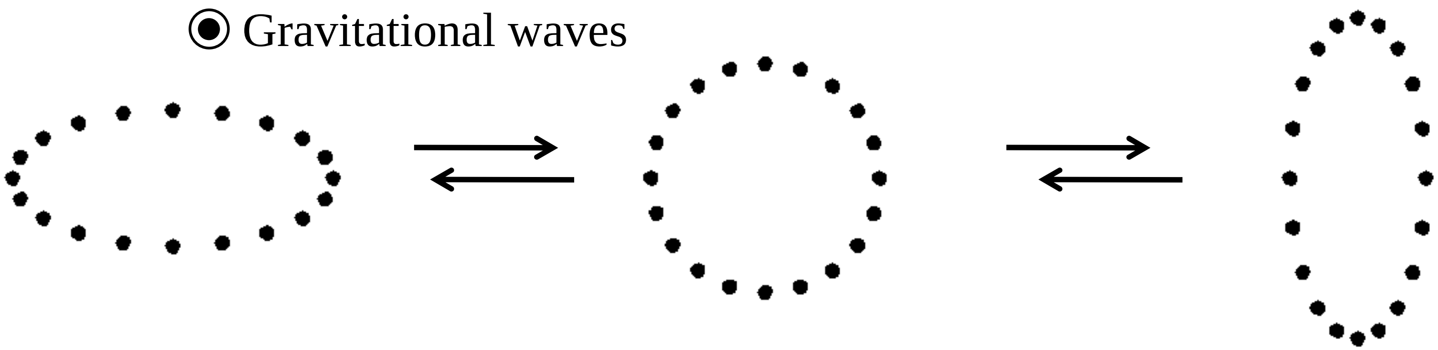
$$h = \frac{2G}{rc^4}\frac{d^2I}{dt^2}$$



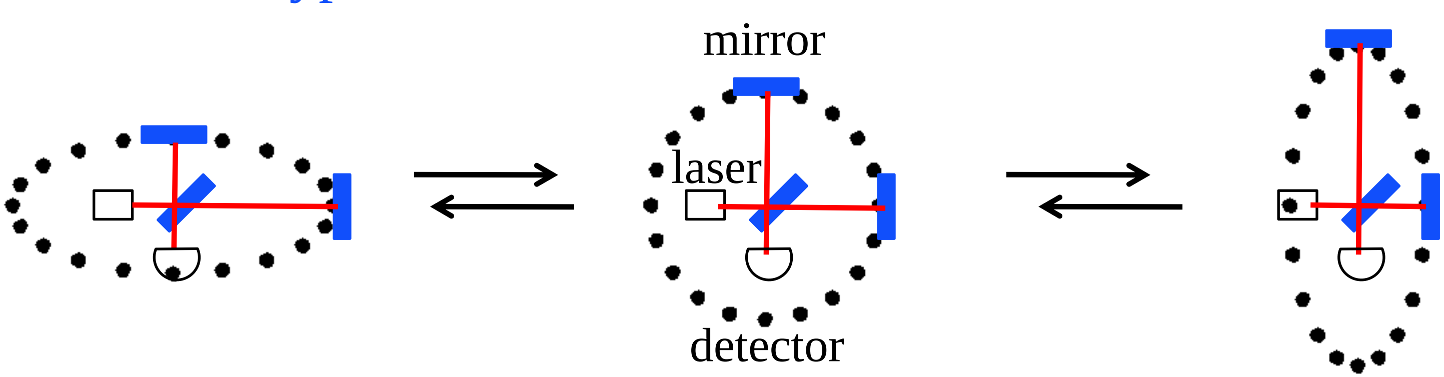
Ripples in Space-time

Physically, *h* is a *strain*: $\delta L/L$

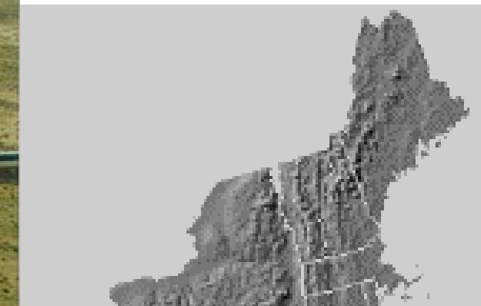
LIGO measures h < 10^{-22}
➔ $\delta L = 10^{-18}$ m !

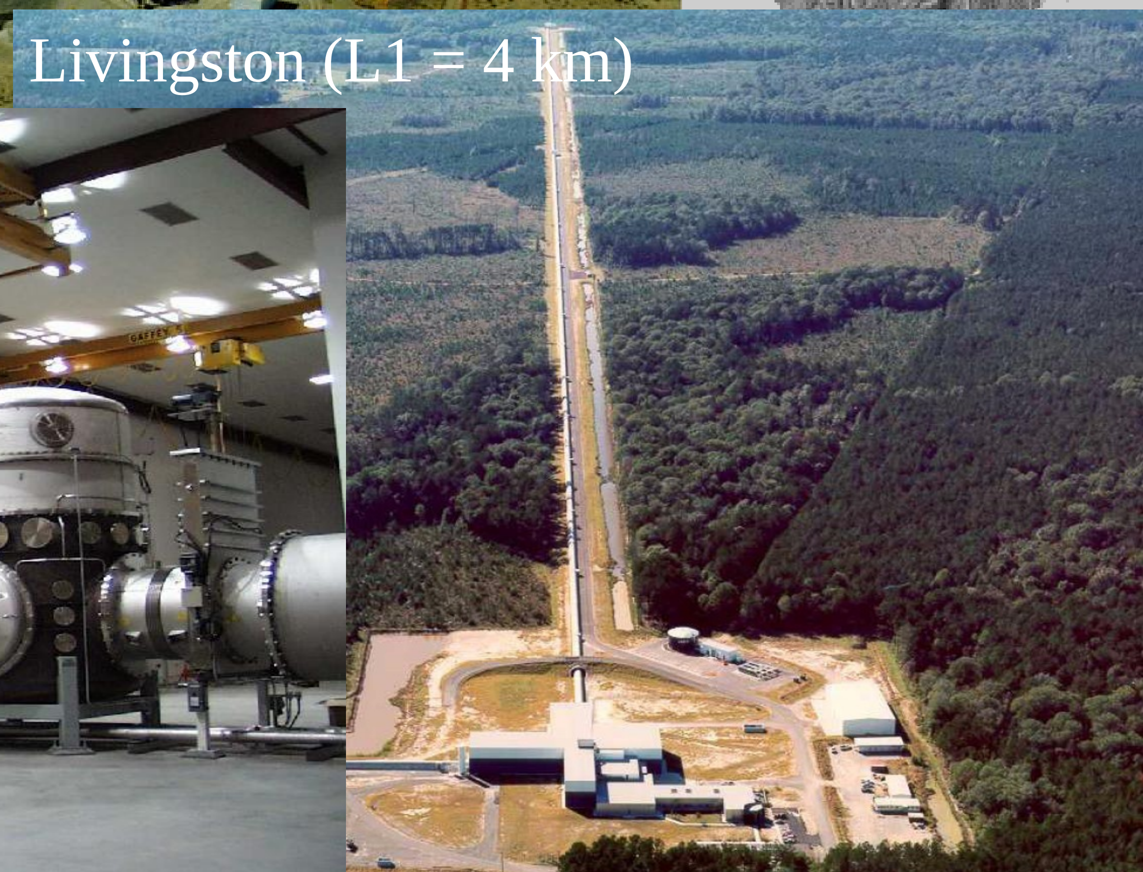


A Michelson type interferometer is the ideal tool to measure GWs.



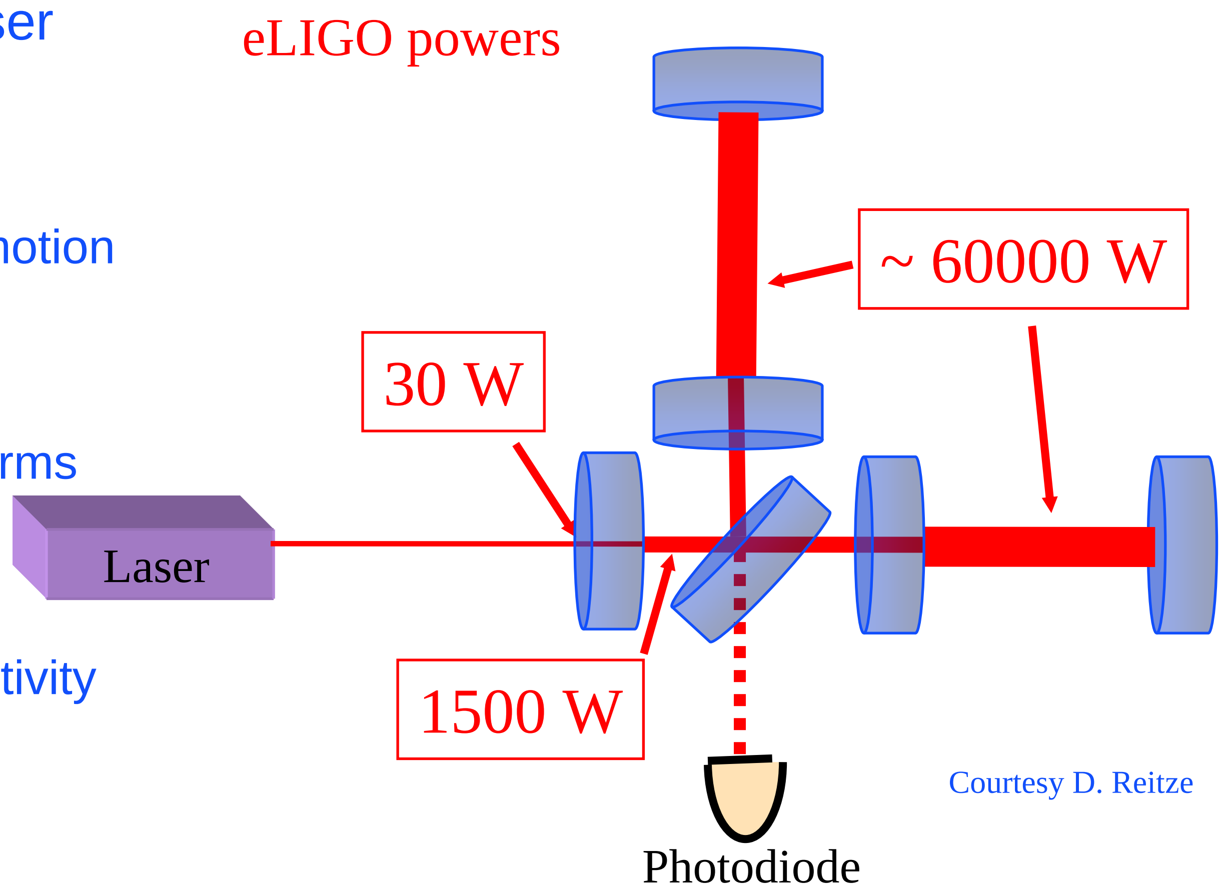

Hanford (H1 = 4 km, H2 = 2 km)




Livingston (L1 = 4 km)

Gravitational Wave Detectors

- Frequency stabilized laser
- Suspended masses
  - » Isolated from ground motion
- Fabry-Perot cavities
  - » Effectively lengthens arms
- Recycled reflected light
  - » Enhances phase sensitivity



LIGO Sensitivity

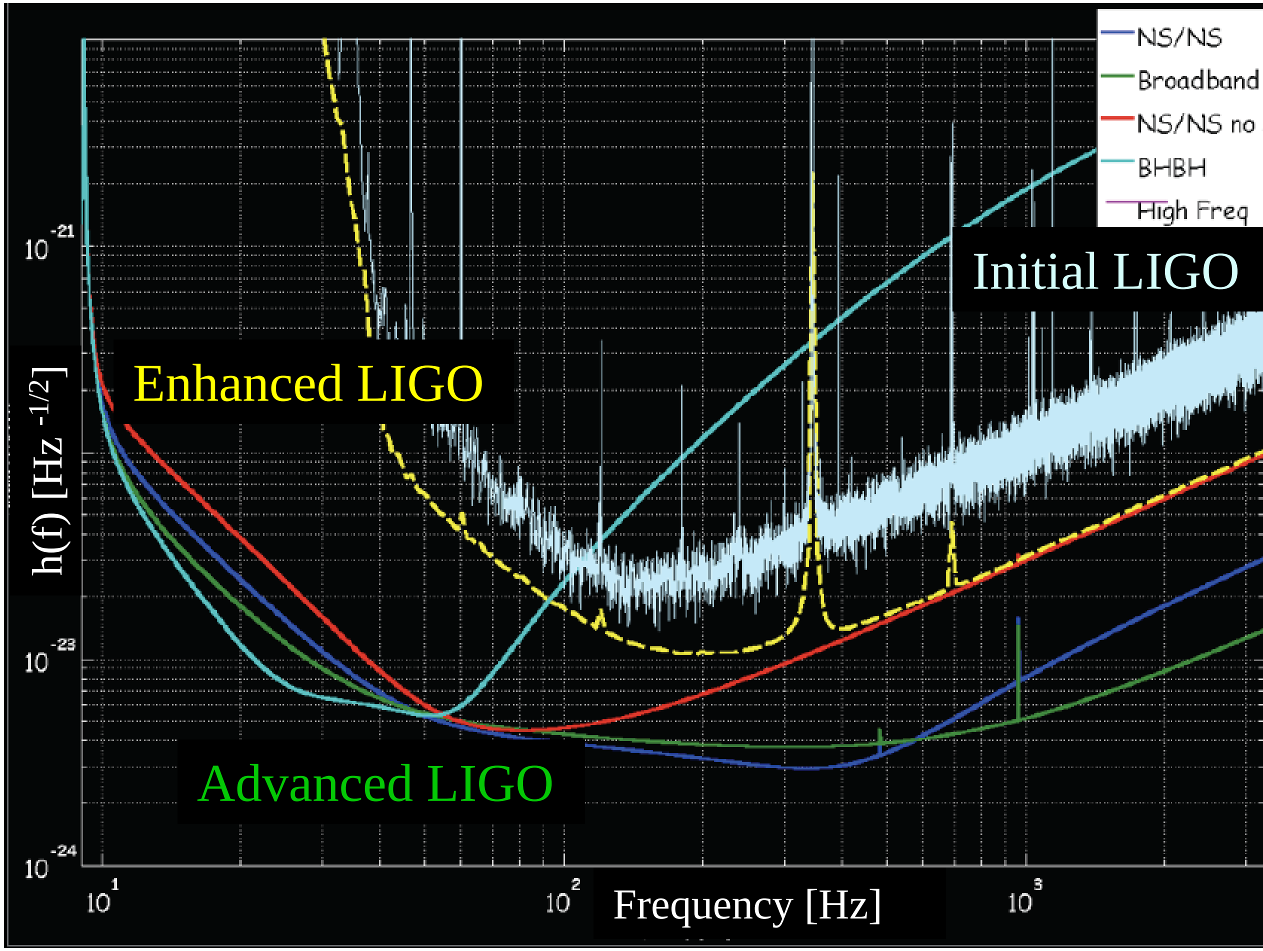
Motivation for eLIGO:

2x increase in sensitivity

→ ~ 8x inc. in detection rate

Changes:

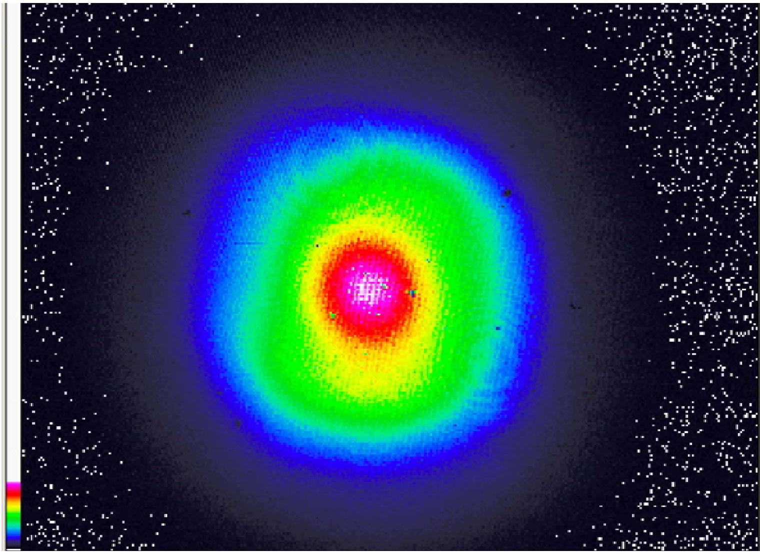
- 4x more laser power
- New GW readout scheme
- Upgraded Input Optics
- Prototype of advanced seismic isolation
- Upgraded Thermal Compensation System



35 Watt Laser

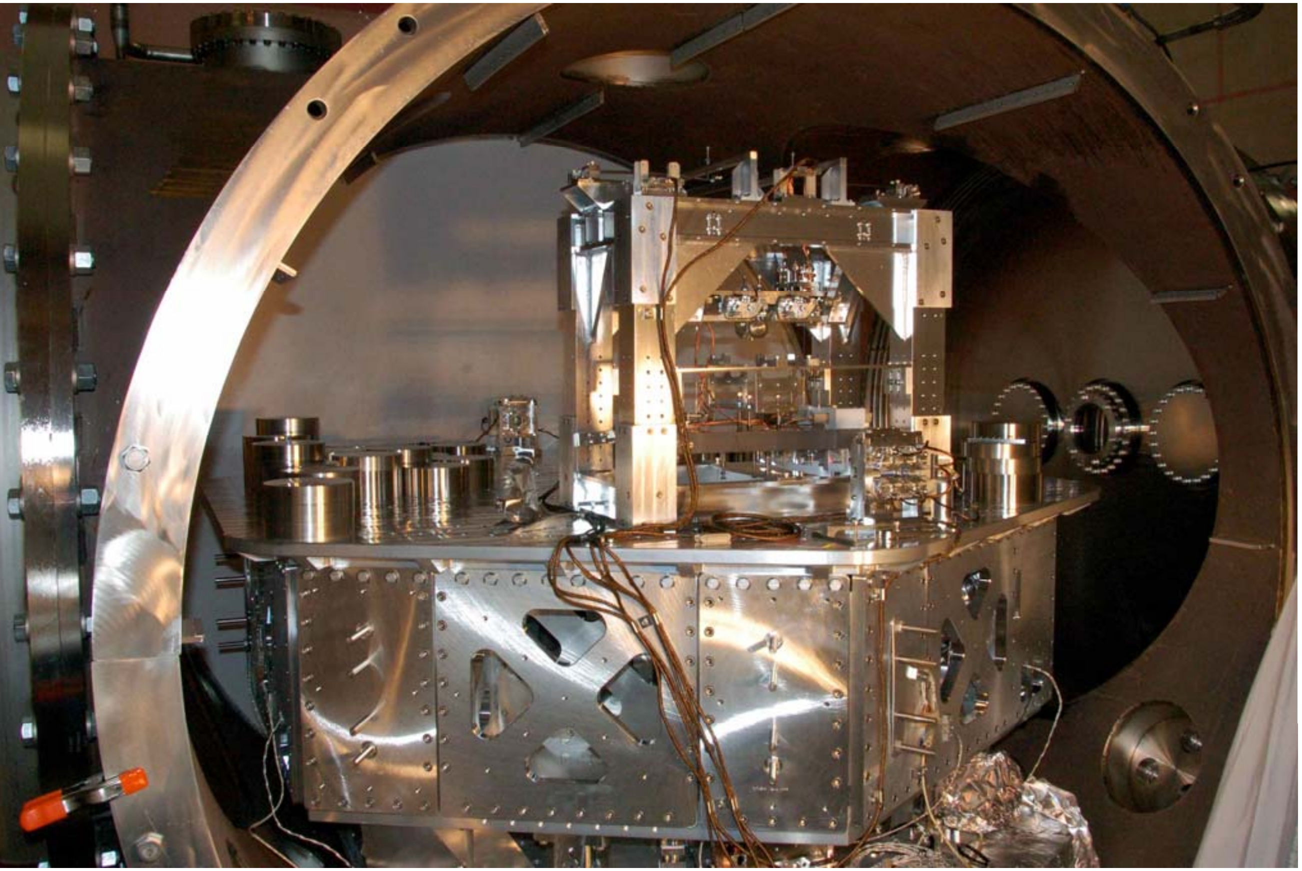
LZH (Germany) built us a custom 35W laser

- 2W NPRO amplified by a 4 rod Nd:YVO4
- lambda = 1064 nm
- frequency stabilized by reference cavity



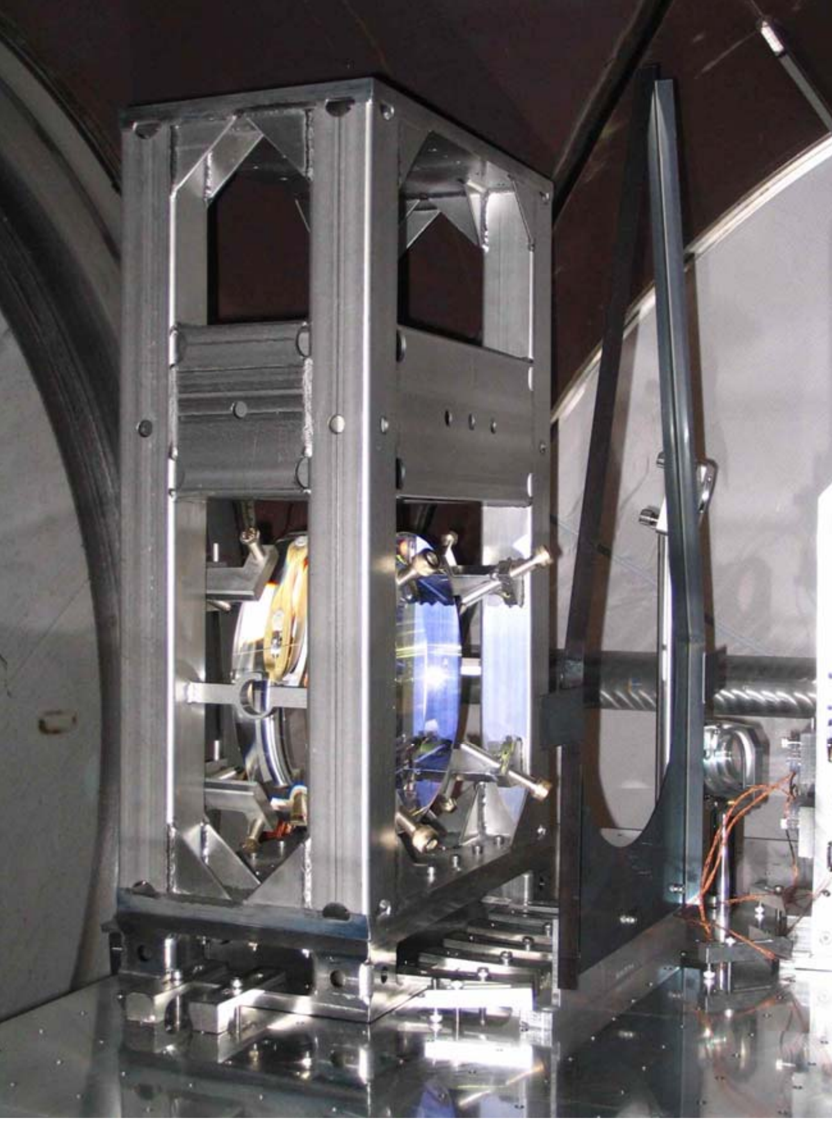
Laser produces beautiful TEM00 Mode

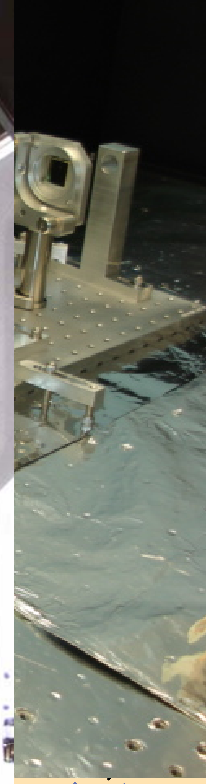
Gravitational Wave Readout



Hardware:
- Output Mode Cleaner
- advanced seismic isolation

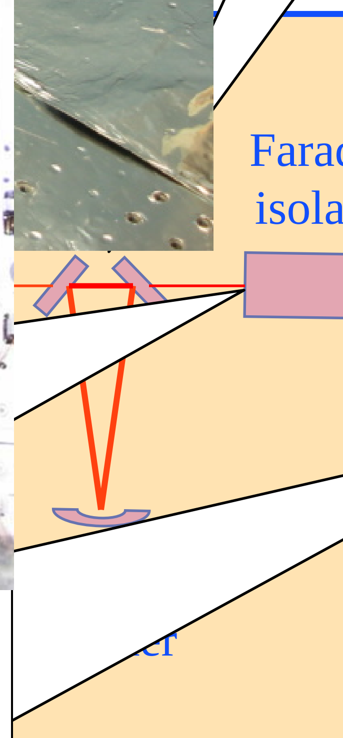
Improves:
- shot noise
- laser intensity noise

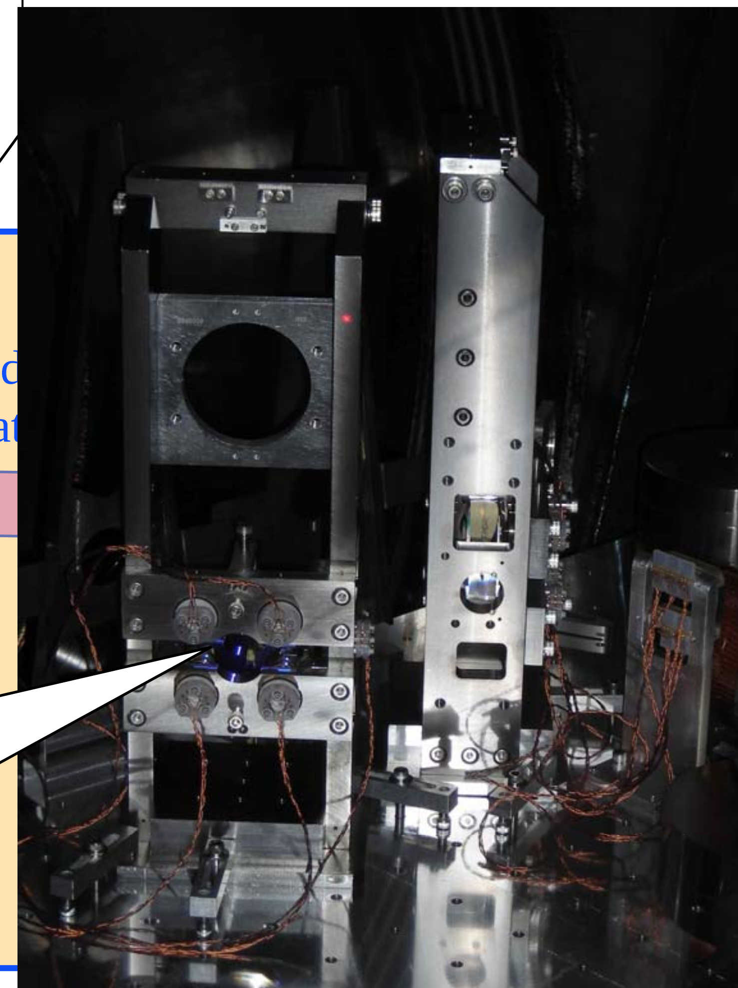




oti

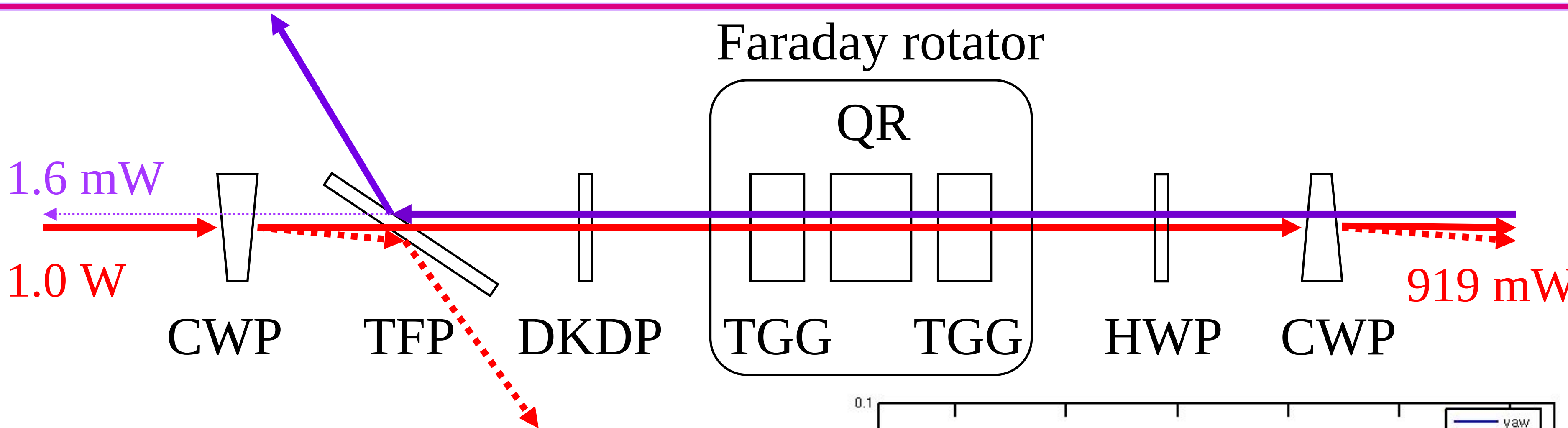
Mode Cleaner – 3 mirror cavity filters out higher order modes delivered from laser

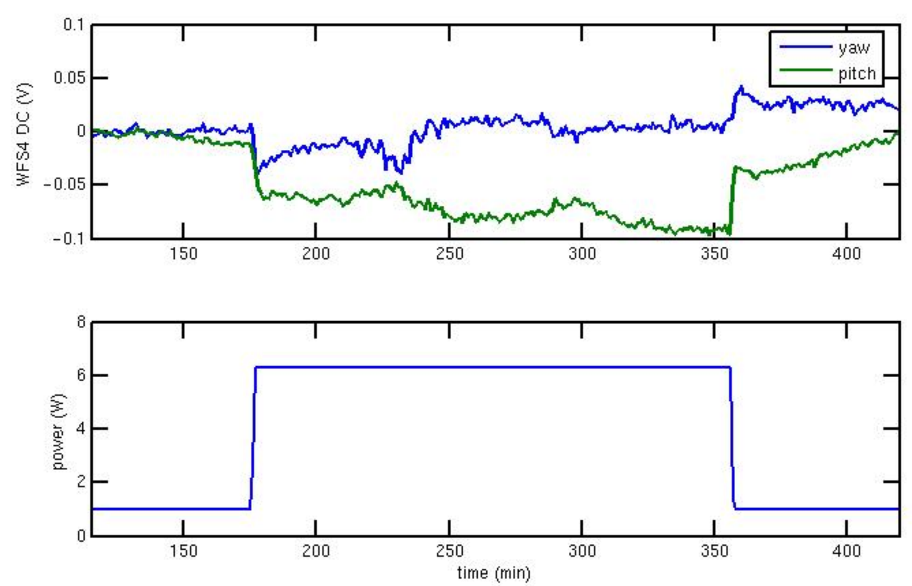




Mode Matching Telescope – 3 spherical mirrors deliver correct beam size and shape to interferometer

Faraday Isolator



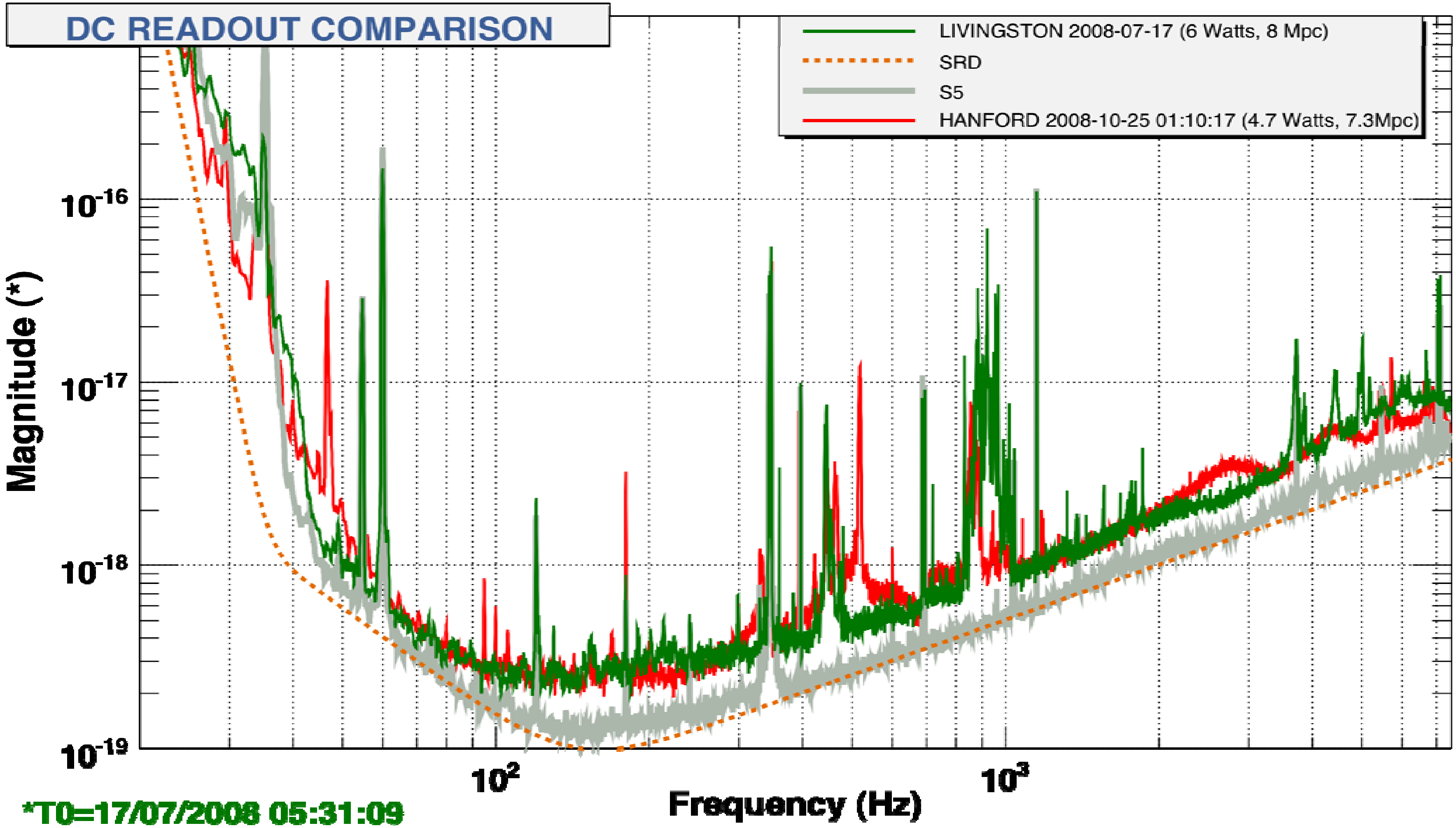


For higher power need:

Isolation ratio: 14 dB → 28 dB
Transmission: 89% → 92%
Thermal Drift: 100 urad/W → 10 urad/W

minimal thermal lensing
minimal thermal drift
high transmission
high isolation ratio

Status Today



Summary

- Enhanced LIGO hardware upgrade nearly complete
- Challenges we still face:
  - » Angular instabilities from higher radiation pressure
  - » Alignment control of Output Mode Cleaner
  - » Blasting for oil in Louisiana requires night-time work
- Much noise hunting to do!
- Expect the detection rate for BH/BH to increase from 1/100 years to 1/9 years (uncertain by 2 orders of magnitude in either direction)
- Enhanced LIGO science run to begin Spring 2009

LIGO Scientific Collaboration

LIGO

LSC

University of Maryland 1856

Michigan

University of Strathclyde

ACIGA

Montana State University

PAH

Loyola University New Orleans

University of Washington

Syracuse University Founded AD 1870

University of Glasgow

Università degli Studi del Sannio

Trinity University

ANU The Australian National University

San José State University

University of Wisconsin UW Milwaukee

UTB TSC

The University of Western Australia

1754

NASA Goddard Space Flight Center

LSU

California Institute of Technology 1891

Northwestern University

Rochester Institute of Technology R·I·T 1829

Andrews University

Massachusetts Institute of Technology 1861

Southeastern Louisiana University

The University of Texas at Austin

Moscow State University

The University of Adelaide Australia

PAN

GEO 600

Sigill. Coll. Carleton Northfield, Minn. AD 1866

University of Massachusetts Amherst 1863

Embry-Riddle Aeronautical University

University of Southampton

PennState 1855

Cardiff University

UIB Universitat de les Illes Balears

Washington State University

UF University of Florida

1848 The University of Mississippi

Charles Sturt University

University of Rochester

NAOJ

University of Minnesota

Southern University Agricultural & Mechanical College

Hobart and William Smith Colleges

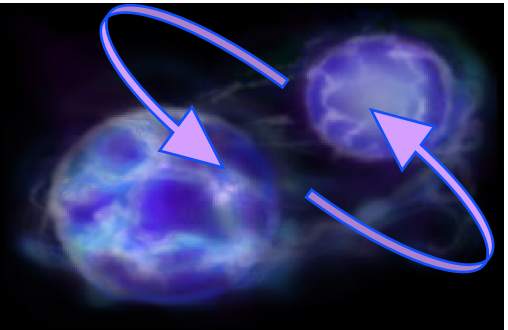
Science & Technology Facilities Council Rutherford Appleton Laboratory

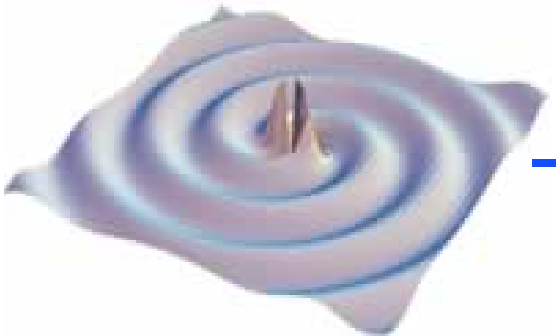
Universität Hannover

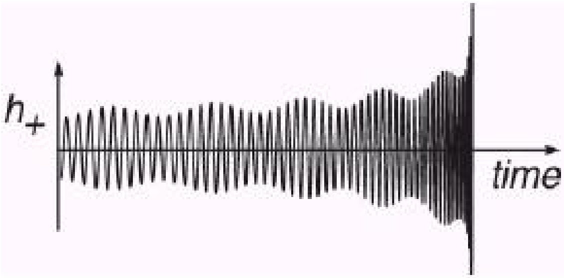
LIGO

Gravitational Waves

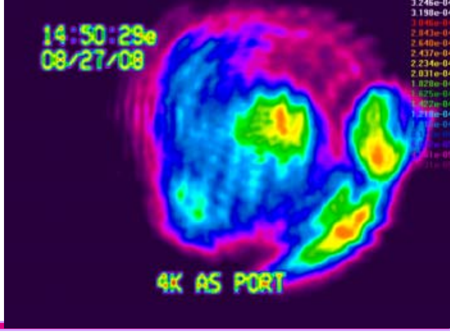
	Electromagnetic waves	Gravitational waves
Source:	moving charge	moving mass
Speed:	c	c
Wavelength:	c/f	c/f
Solution:	$\vec{E}(\vec{r},t) \sim \frac{\mu_0}{4\pi r}\left[\hat{r} \times \left(\hat{r} \times \ddot{\vec{p}}\right)\right]$	$h_{\mu\nu}(\omega,t) = \frac{2G}{r\,c^4}\ddot{I}_{\mu\nu}(\omega,t)$
Polarizations:	σ^+, σ^-	h^+, h^x
Particle:	photon	graviton
Spin:	1	2



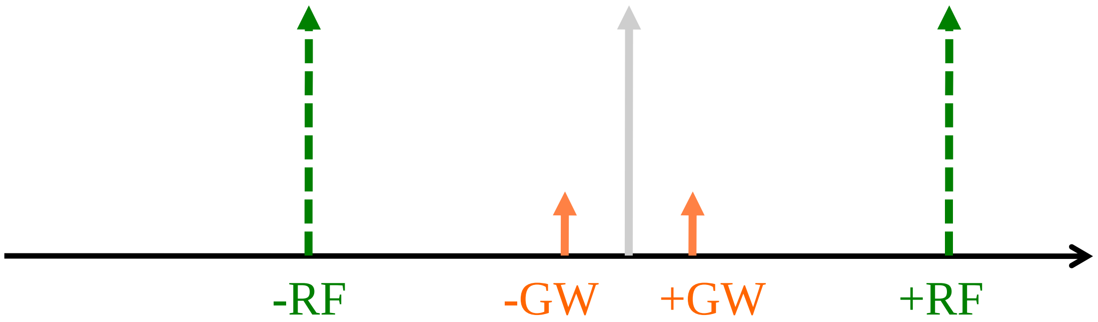




RF vs. DC Readout

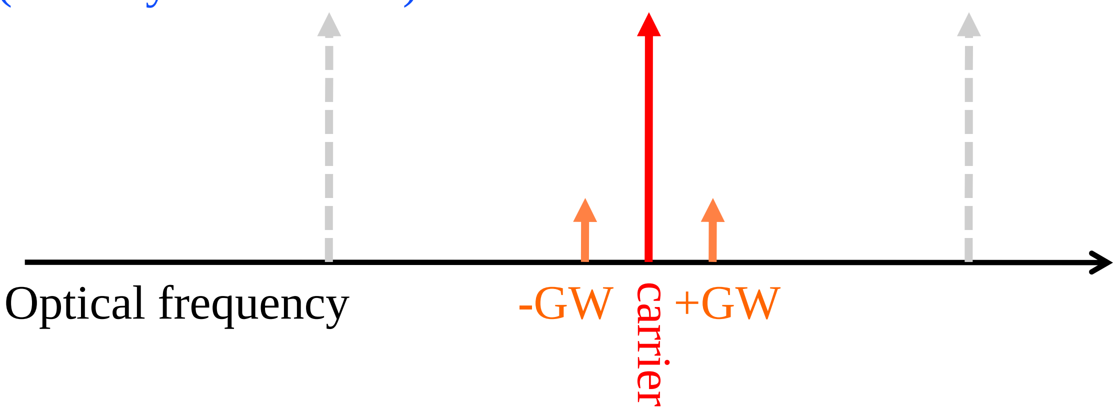


RF Readout
(heterodyne detection)



- Operate at dark fringe
- GWs beat against sidebands

DC Readout
(homodyne detection)



- Operate off dark fringe
- Sidebands removed by Output Mode Cleaner
- GWs beat against carrier

Noise Budget