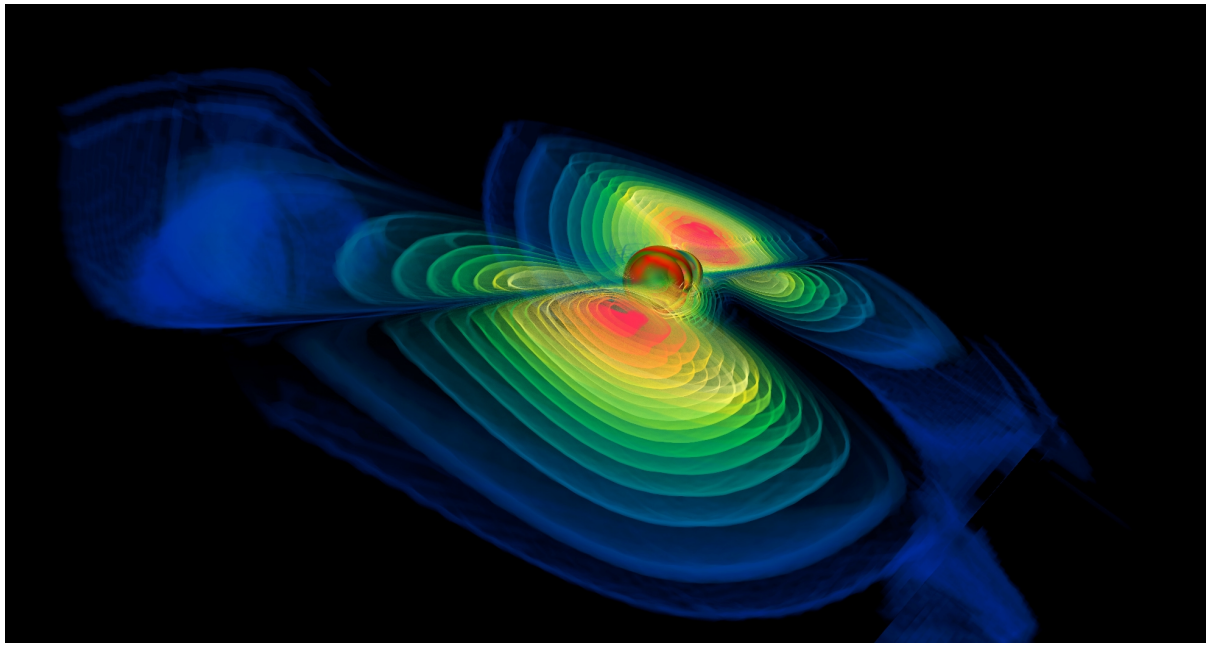
Scientific Operation of LIGO

Gary H Sanders
LIGO Laboratory
California Institute of Technology

APS Meeting APR03, Philadelphia
Gravitational-Wave Detection with LIGO

LIGO-G030160-03-M

Scientific Operation of LIGO



"Colliding Black Holes"

Credit:
National Center for Supercomputing Applications (NCSA)

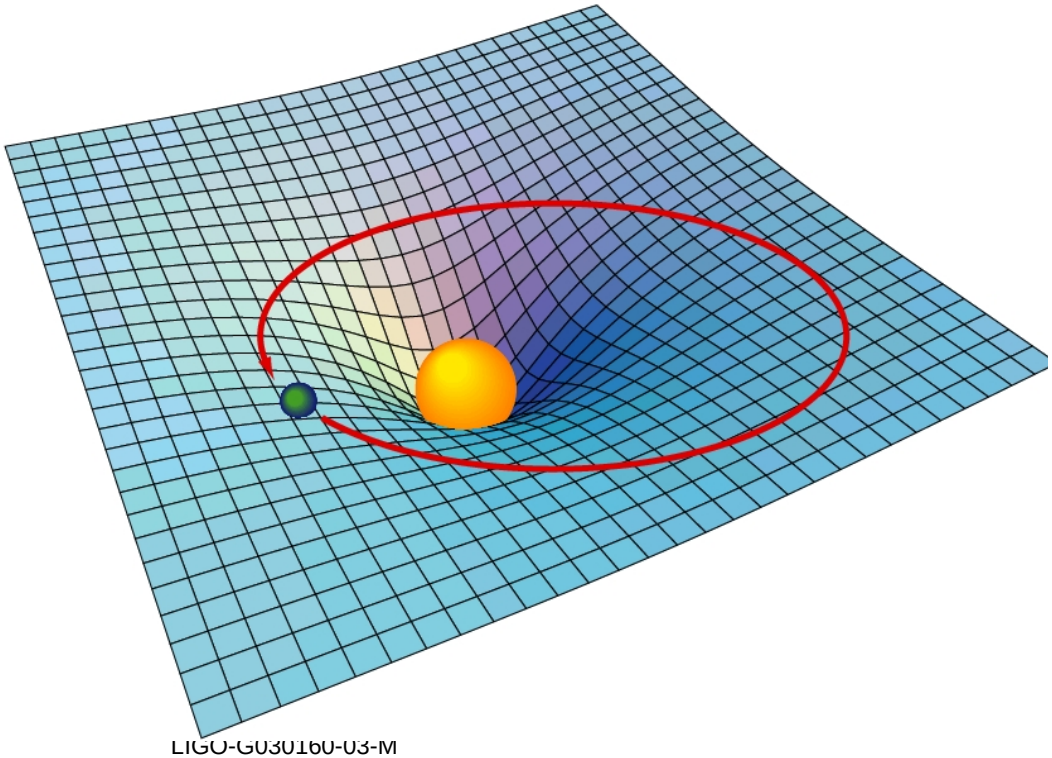
Gary H Sanders
Caltech
(on behalf of a large team)

APS April Meeting
Philadelphia
6-April-03

LIGO-G030160-03-M

General Relativity

Einstein theorized that smaller masses travel toward larger masses, not because they are "attracted" by a mysterious force, but because the smaller objects travel through space that is warped by the larger object

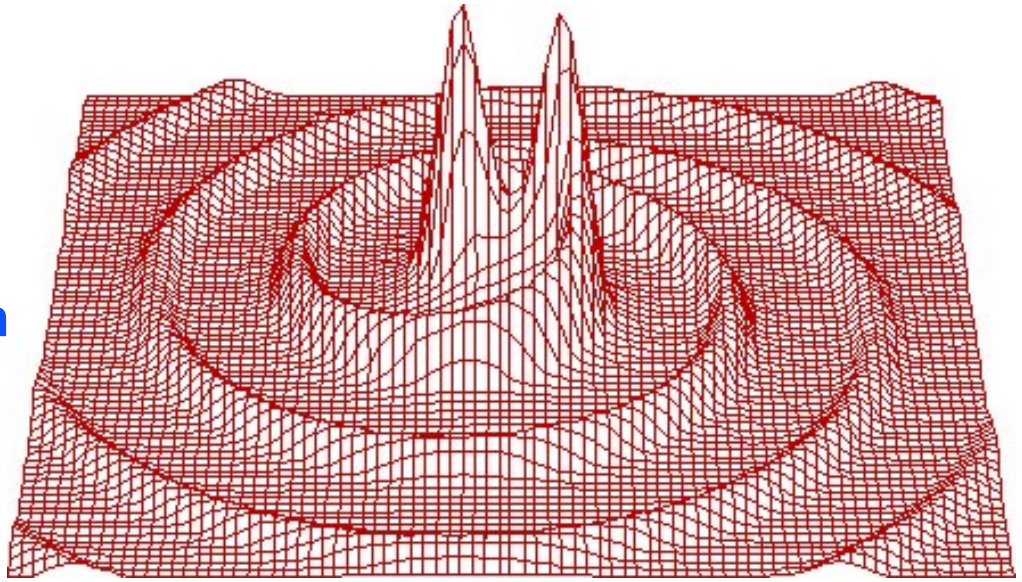


- **Imagine space as a stretched rubber sheet.**
- **A mass on the surface will cause a deformation.**
- **Another mass dropped onto the sheet will roll toward that mass.**

Gravitational Waves

- a necessary consequence of Special Relativity with its finite speed for information transfer

- time dependent gravitational fields come from the acceleration of masses and propagate away from their sources as a space-time warpage at the speed of light

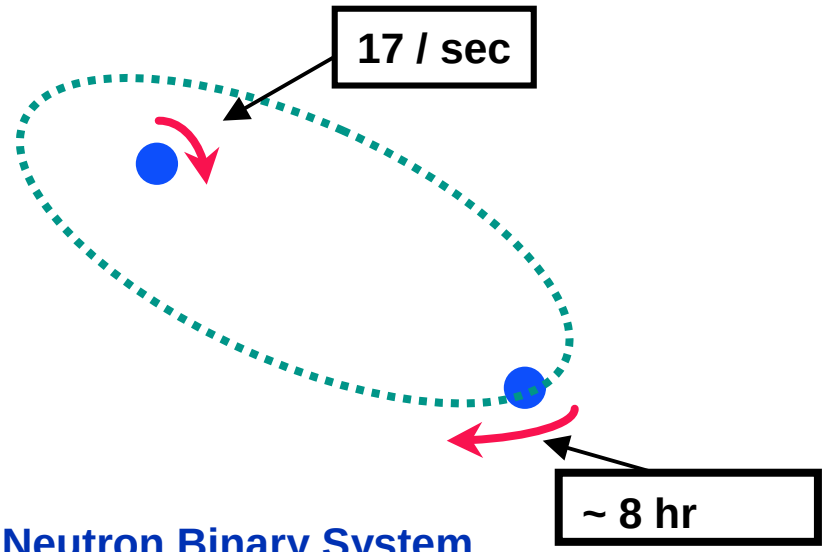


gravitational radiation from binary inspiral of compact objects

Evidence for Gravitational Waves

Neutron Binary System – Hulse & Taylor

PSR 1913 + 16 -- Timing of pulsars



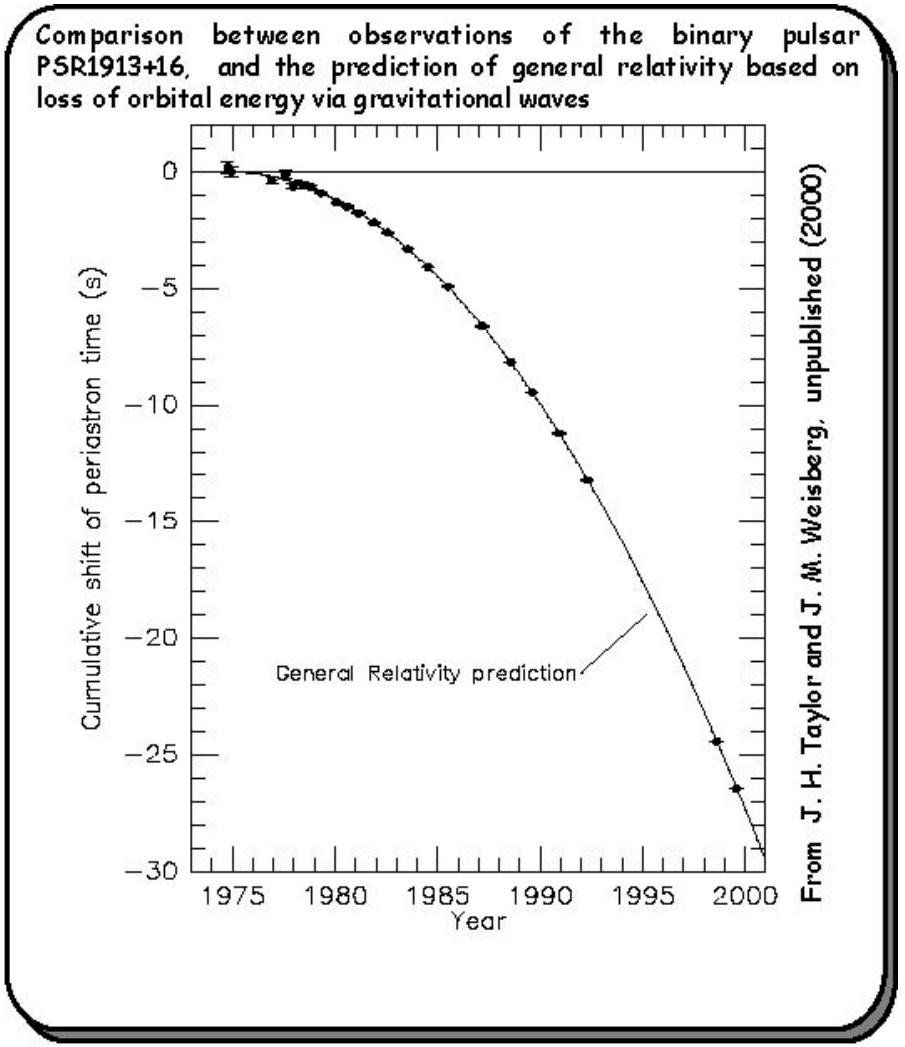
Neutron Binary System

- **separated by 10^6 miles**
- **$m_1 = 1.4m_\odot$; $m_2 = 1.36m_\odot$; $\varepsilon = 0.617$**

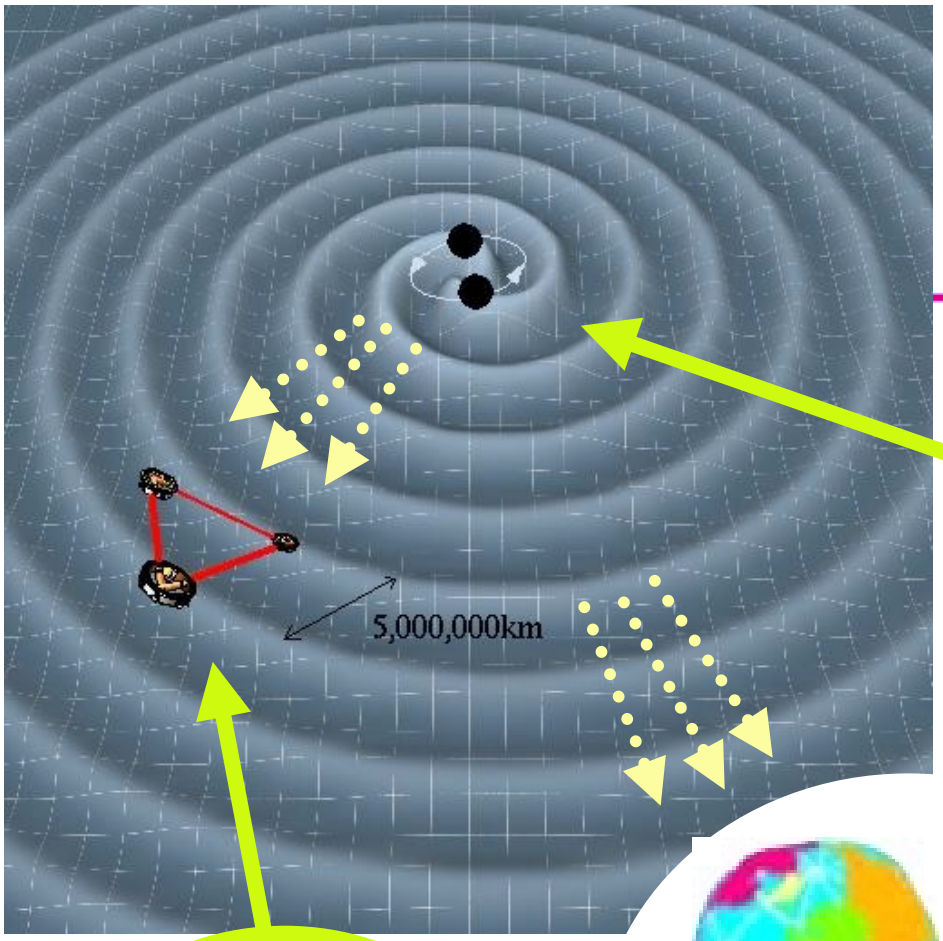
Prediction from general relativity

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

Emission of gravitational waves



Direct Detection



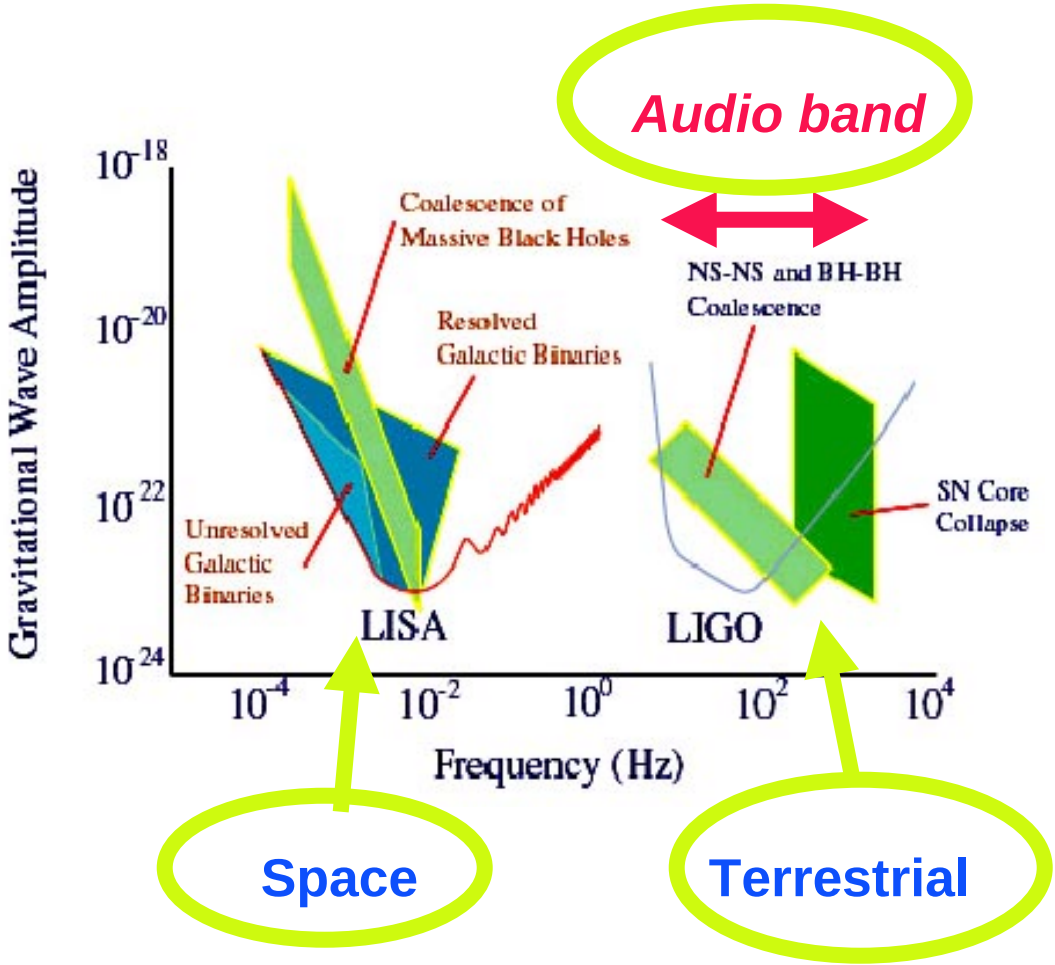
Gravitational Wave Astrophysical Source

Detectors in space
LISA

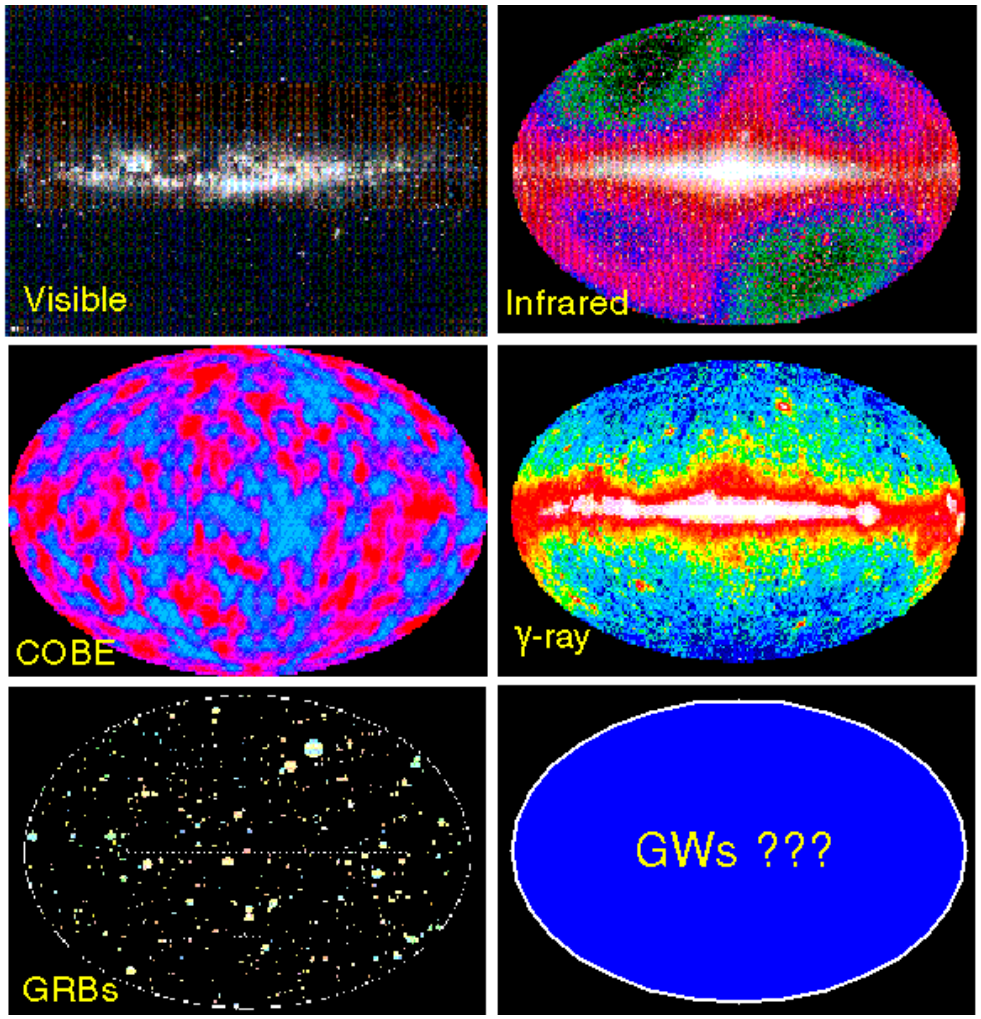
Terrestrial detectors
LIGO, GEO, TAMA, Virgo

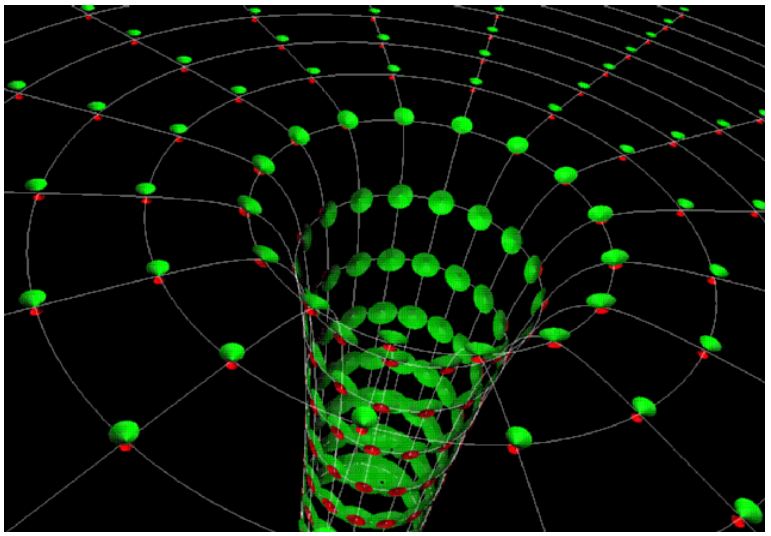
Astrophysics Sources by Frequency

- EM waves are studied over ~20 orders of magnitude
  - » (ULF radio –> HE γ-rays)
- Gravitational Waves over ~10 orders of magnitude
  - » (terrestrial + space)



A New Window on the Universe

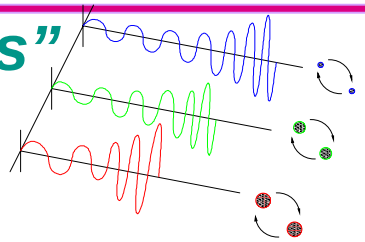




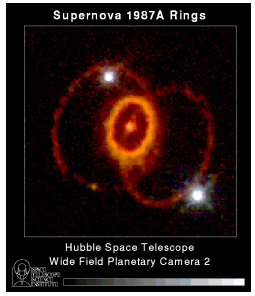
Gravitational Waves will provide a new way to view the dynamics of the Universe

Astrophysical Sources of Gravitational Waves

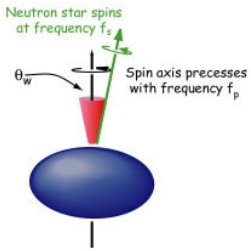
- Compact binary inspiral: ***"chirps"***
  - » NS-NS waveforms are well described
  - » BH-BH need better waveforms
  - » search technique: matched templates



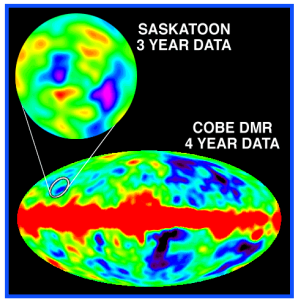
- Supernovae / GRBs: ***"bursts"***
  - » burst signals in coincidence with signals in electromagnetic radiation
  - » Challenge to search for untriggered bursts



- Pulsars in our galaxy: ***"periodic signals"***
  - » search for observed neutron stars (frequency, doppler shift)
  - » all sky search (computing challenge)
  - » r-modes

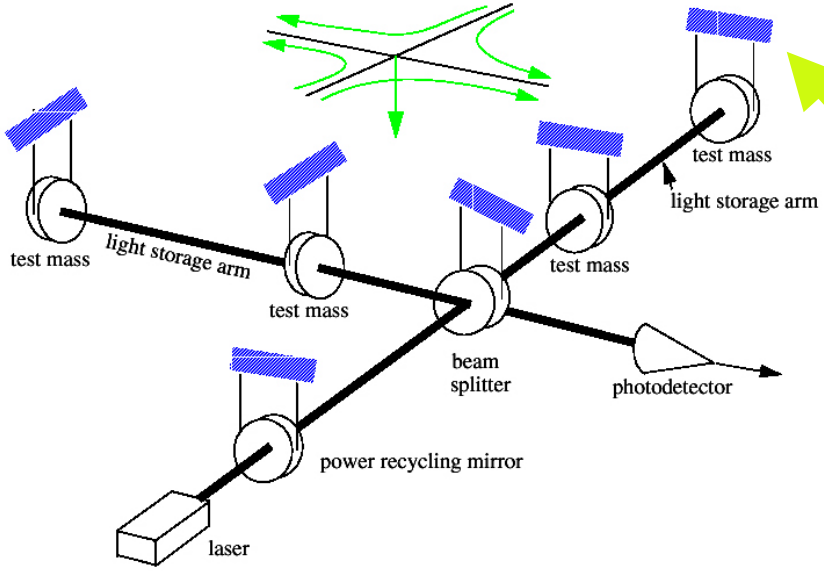


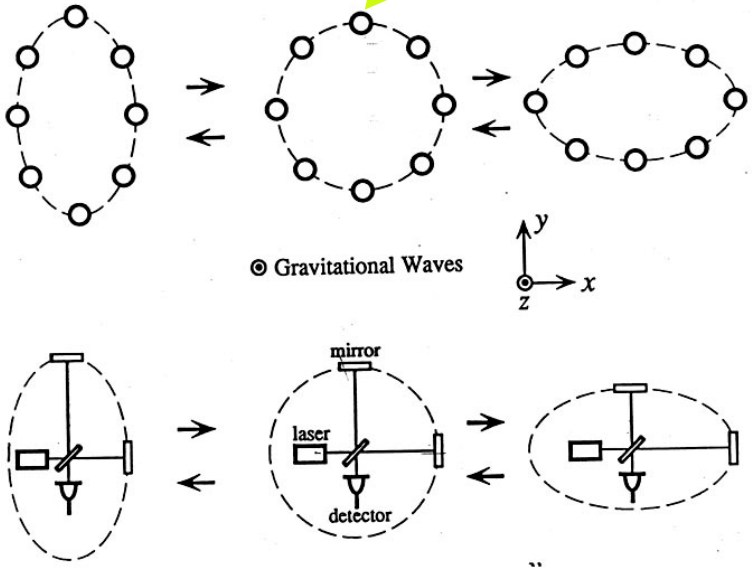
- Cosmological Signals ***"stochastic background"***



Terrestrial Interferometers

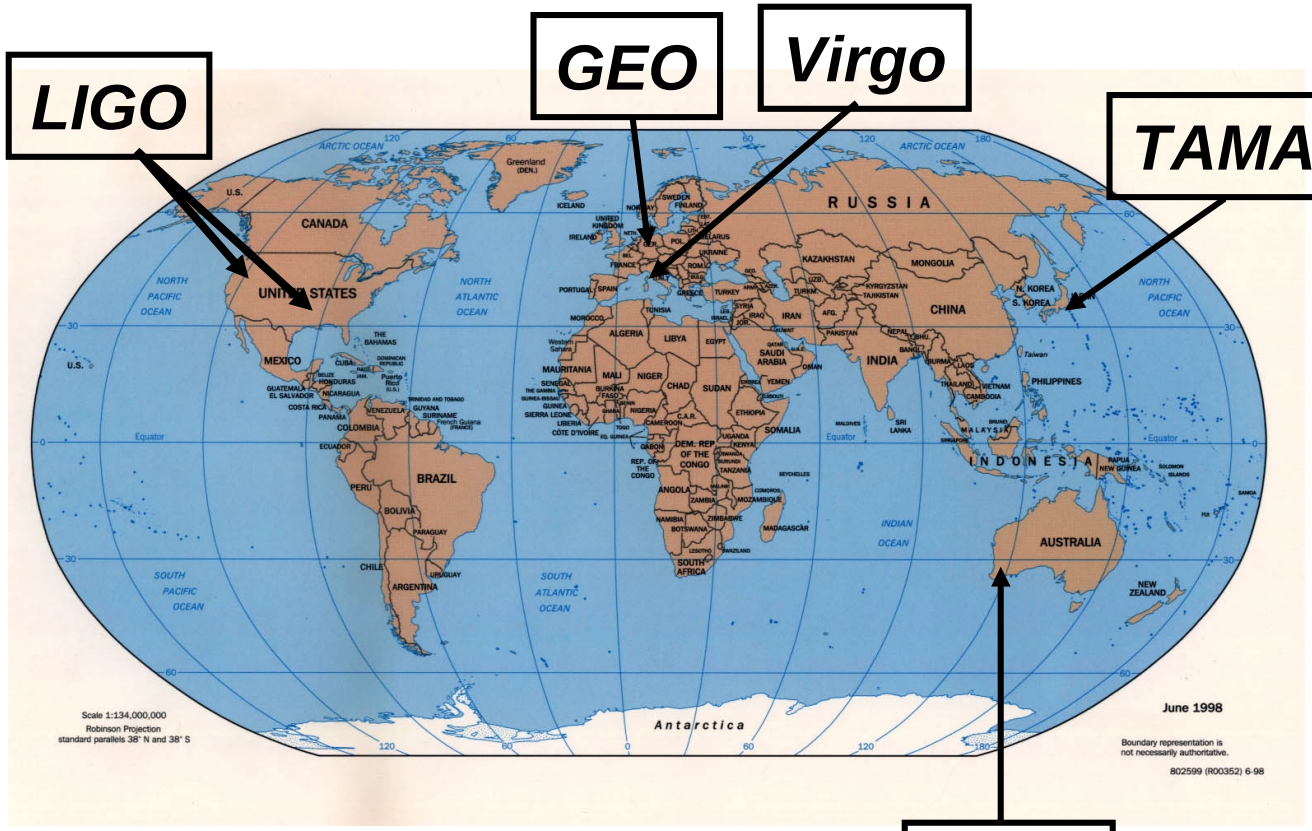
International network (LIGO, Virgo, GEO, TAMA) of suspended mass Michelson-type interferometers on earth's surface detect distant astrophysical sources





An International Network of Interferometers

Simultaneously detect signal (within msec)

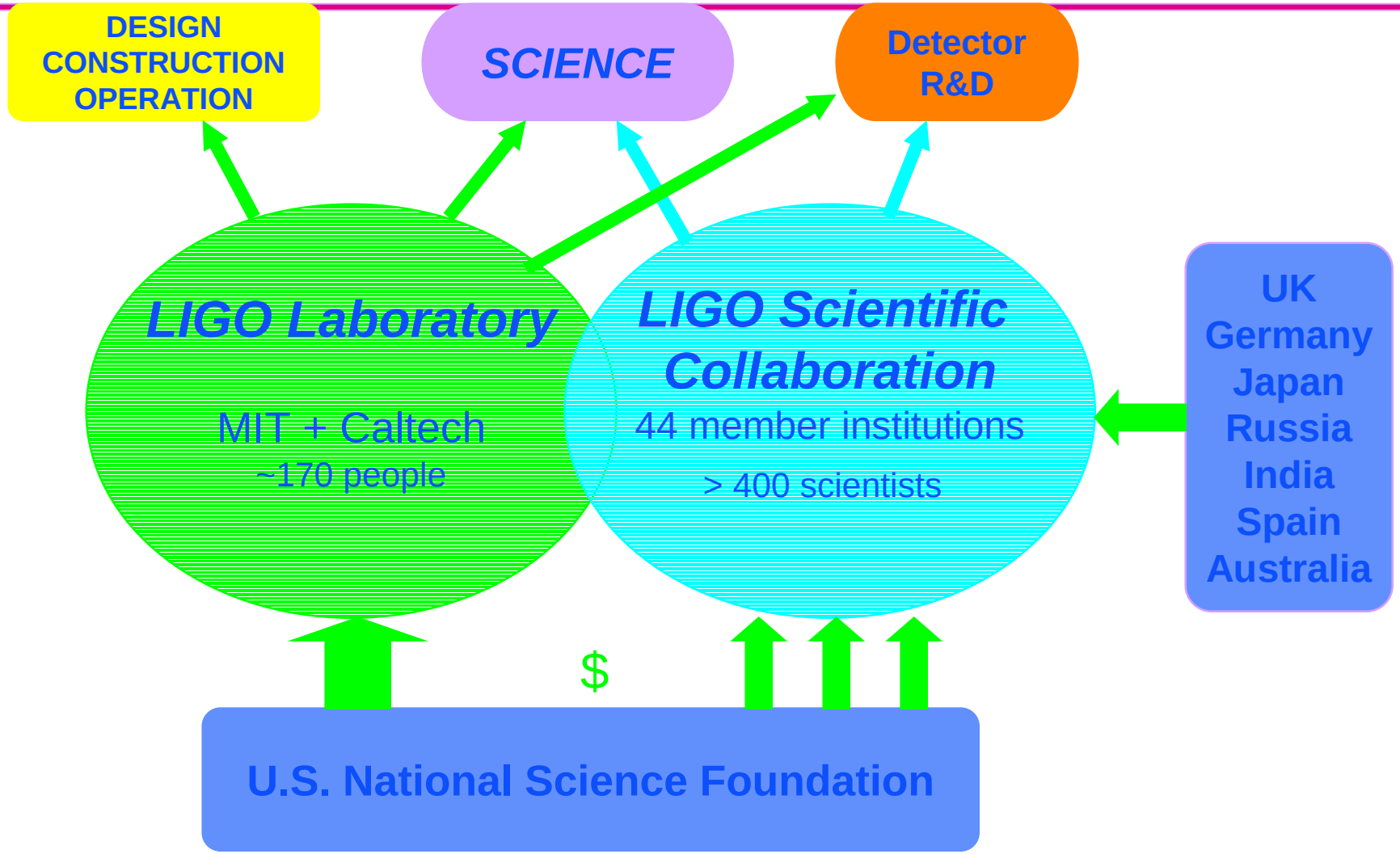


detection confidence

locate the sources

decompose the polarization of gravitational waves

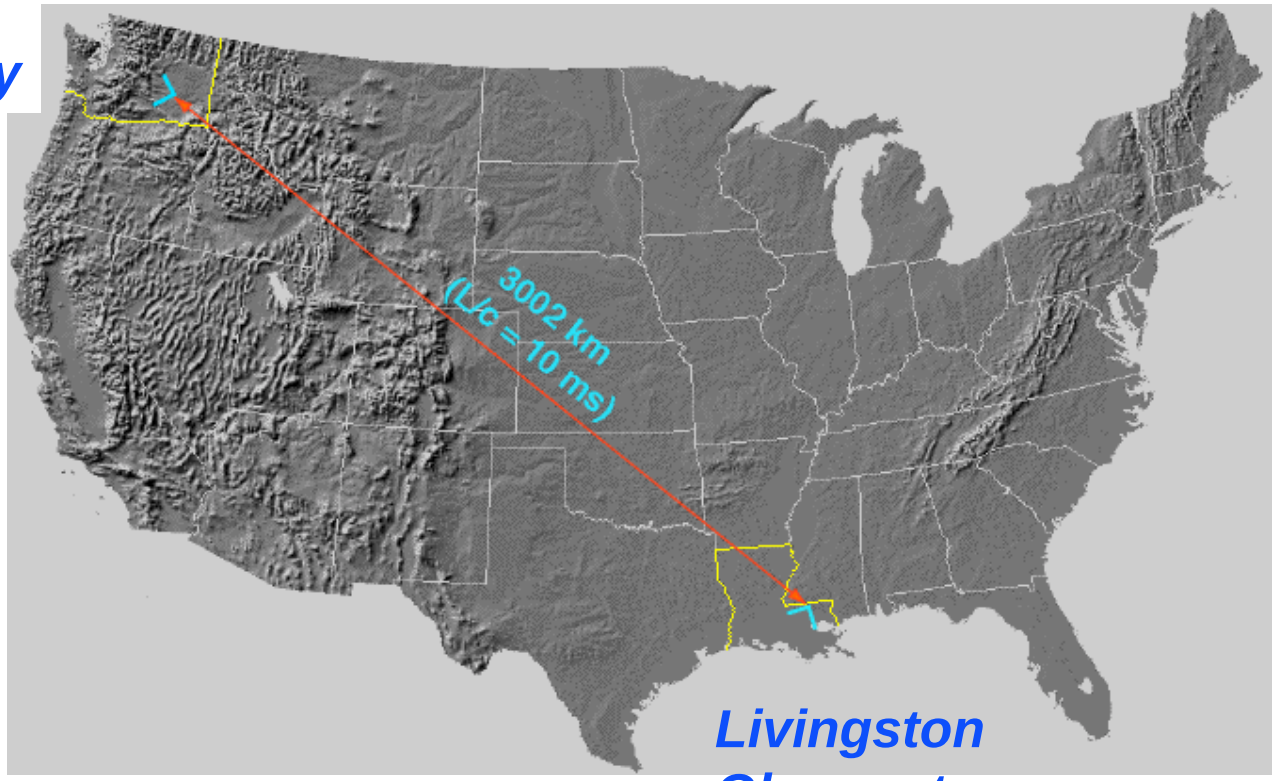
LIGO Organization & Support



The Laboratory Sites

Laser Interferometer Gravitational-wave Observatory (LIGO)

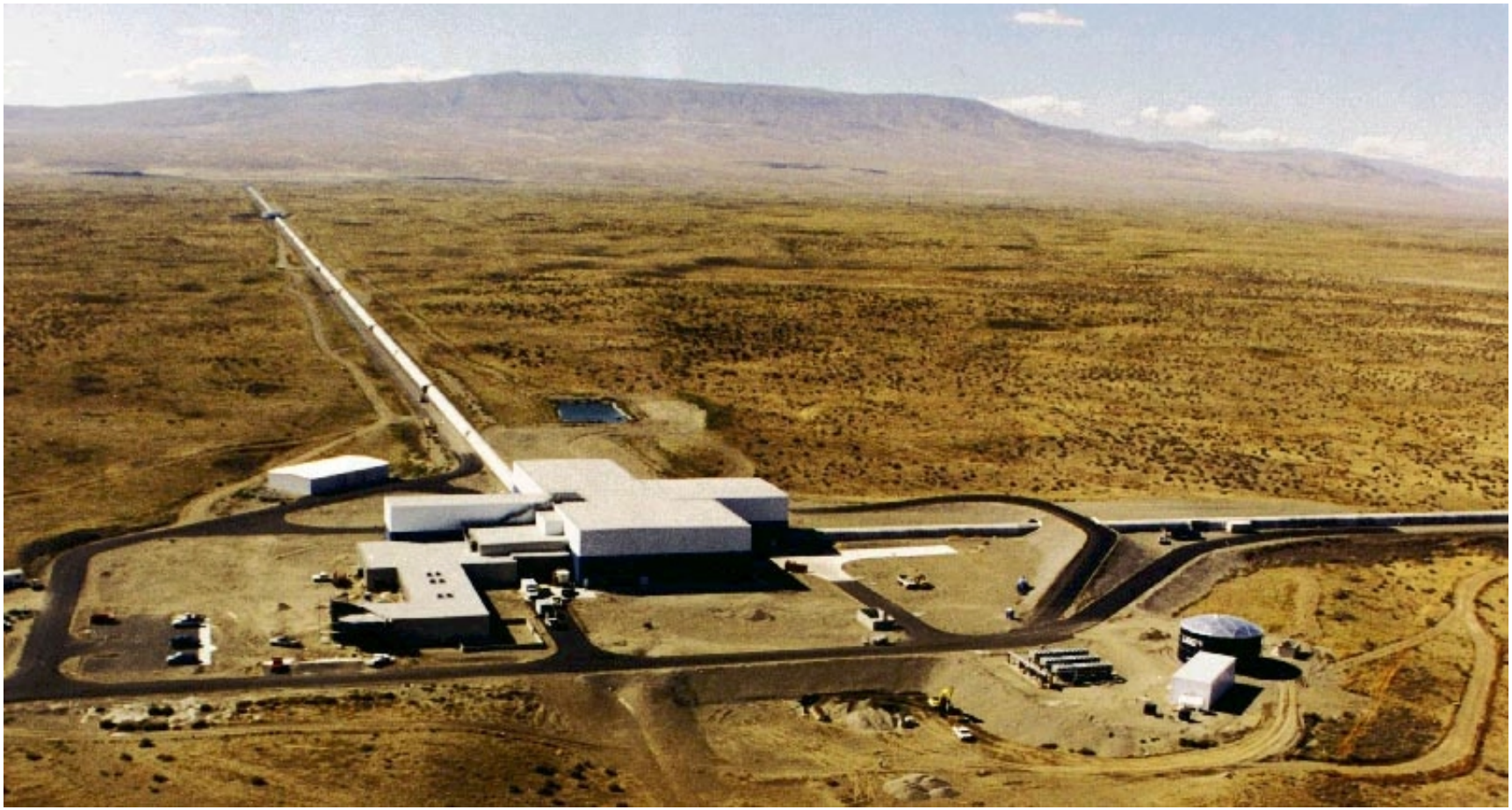
Hanford Observatory



Livingston Observatory

LIGO Livingston Observatory

LIGO Hanford Observatory



GEO 600

LIGO Beam Tube

- LIGO beam tube under construction in January 1998
- 65 ft spiral welded sections
- girth welded in portable clean room in the field

1.2 m diameter - 3mm stainless
50 km of weld

NO LEAKS !!

LIGO Vacuum Equipment

A LIGO Mirror

Substrates: SiO_2

25 cm Diameter, 10 cm thick

Homogeneity < 5×10^{-7}

Internal mode Q's > 2×10^{6}

Polishing

Surface uniformity < 1 nm rms

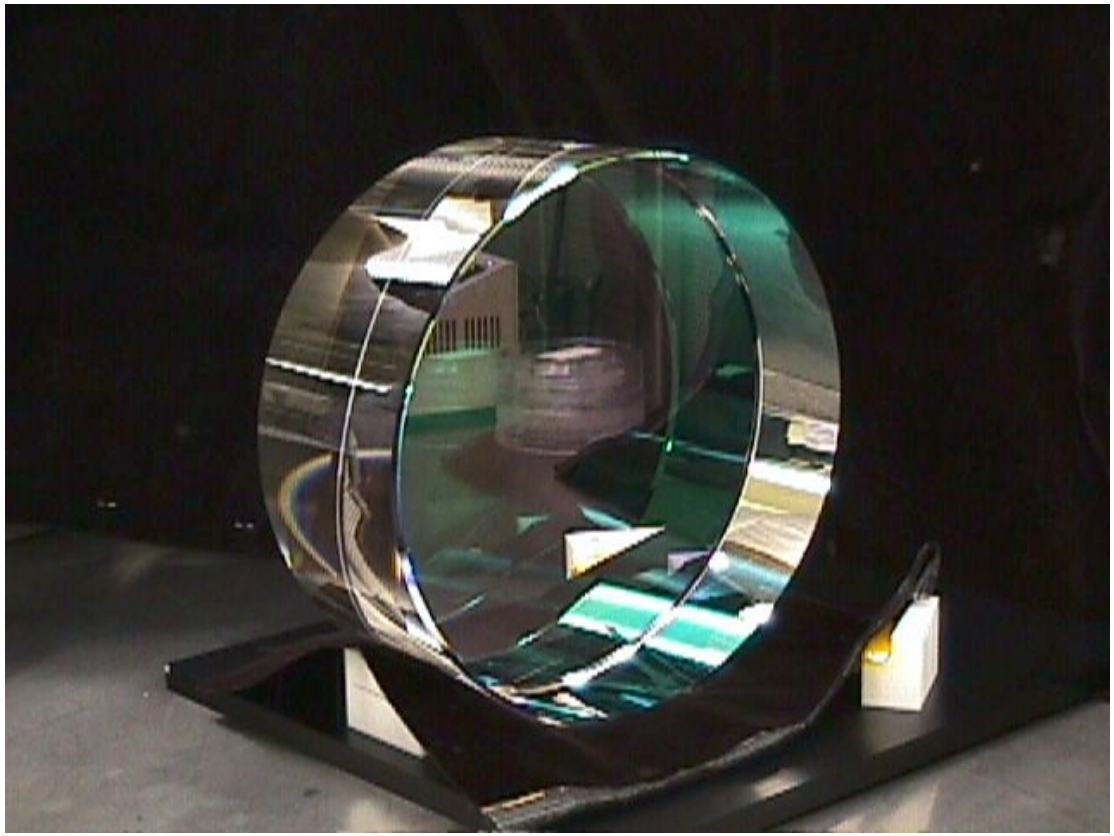
Radii of curvature matched < 3%

Coating

Scatter < 50 ppm

Absorption < 2 ppm

Uniformity <10^{-3}

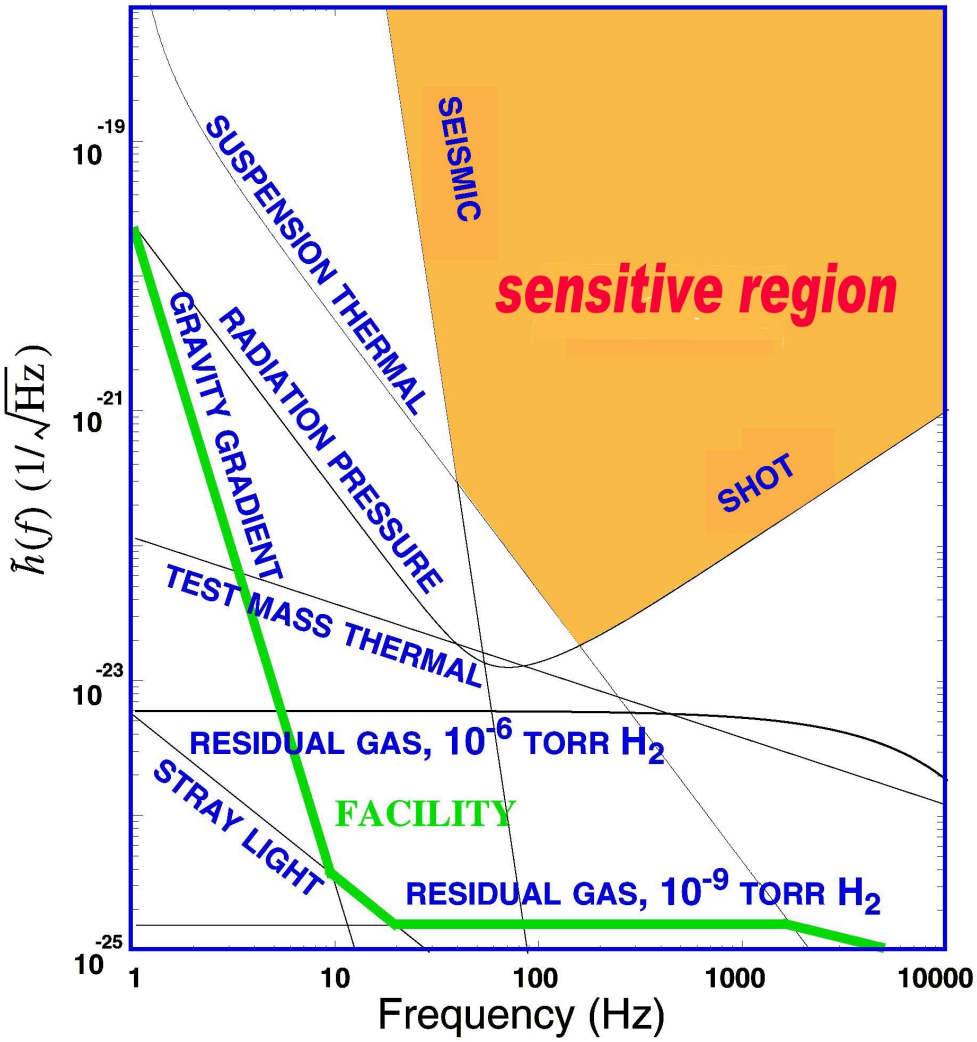


Core Optics

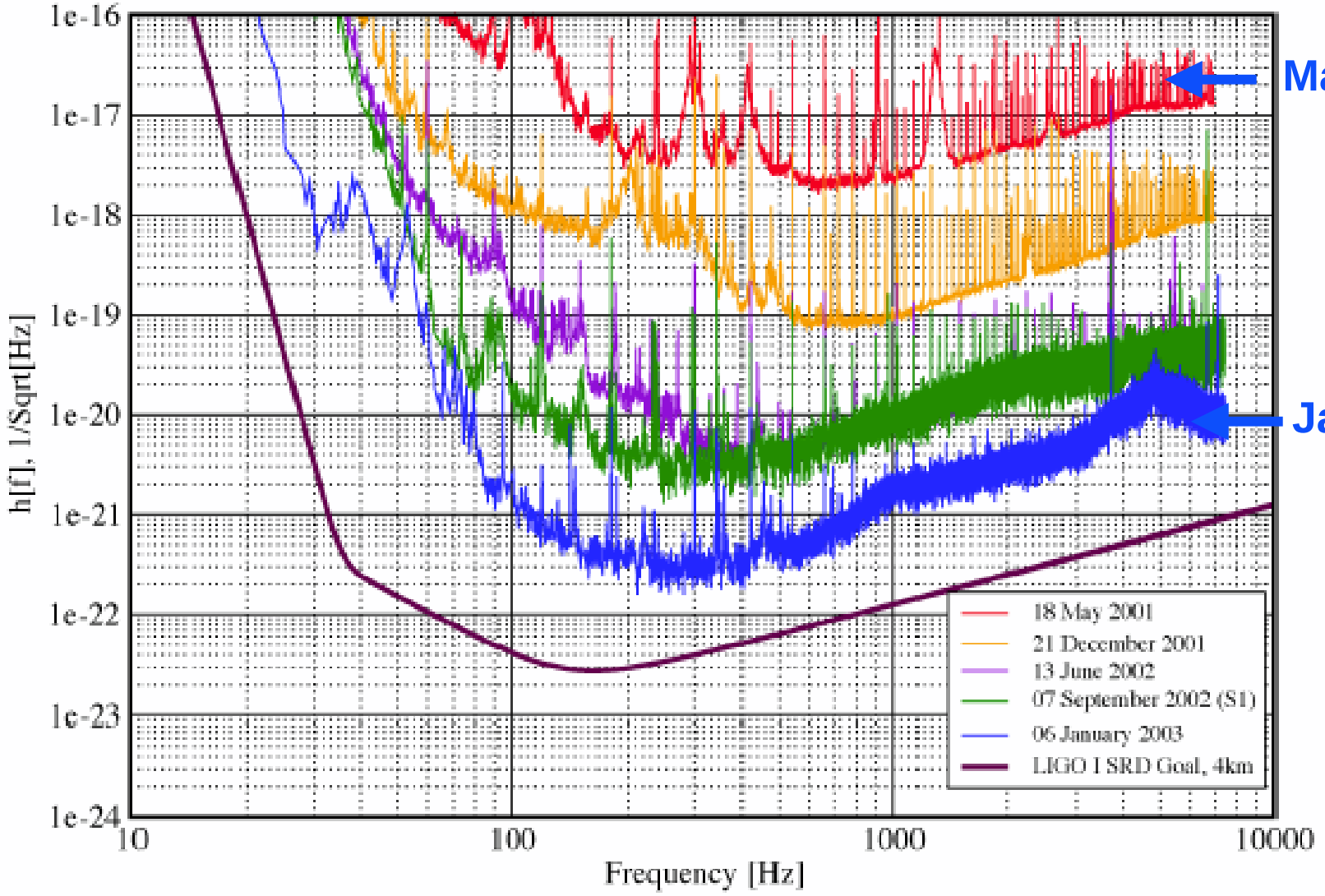
installation and alignment

What Limits Sensitivity of Interferometers?

- Seismic noise & vibration limit at low frequencies
- Atomic vibrations (Thermal Noise) inside components limit at mid frequencies
- Quantum nature of light (Shot Noise) limits at high frequencies
- Myriad details of the lasers, electronics, etc., can make problems above these levels



LIGO Sensitivity
Livingston 4km Interferometer



May 2001

Jan 2003

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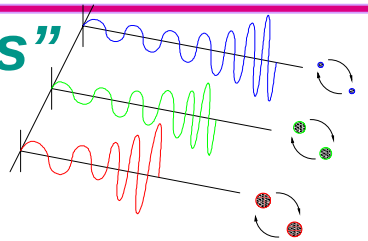
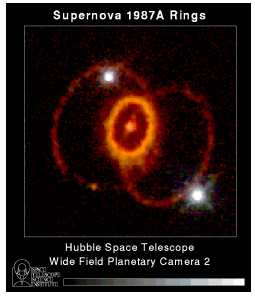
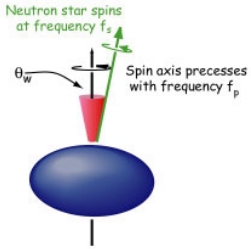
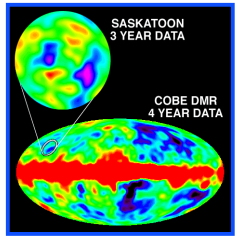
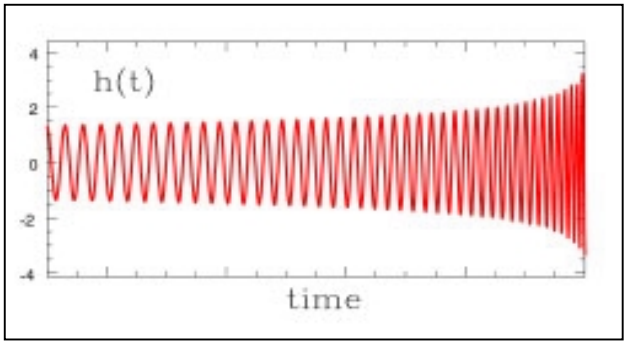








Inspiral Upper Limit

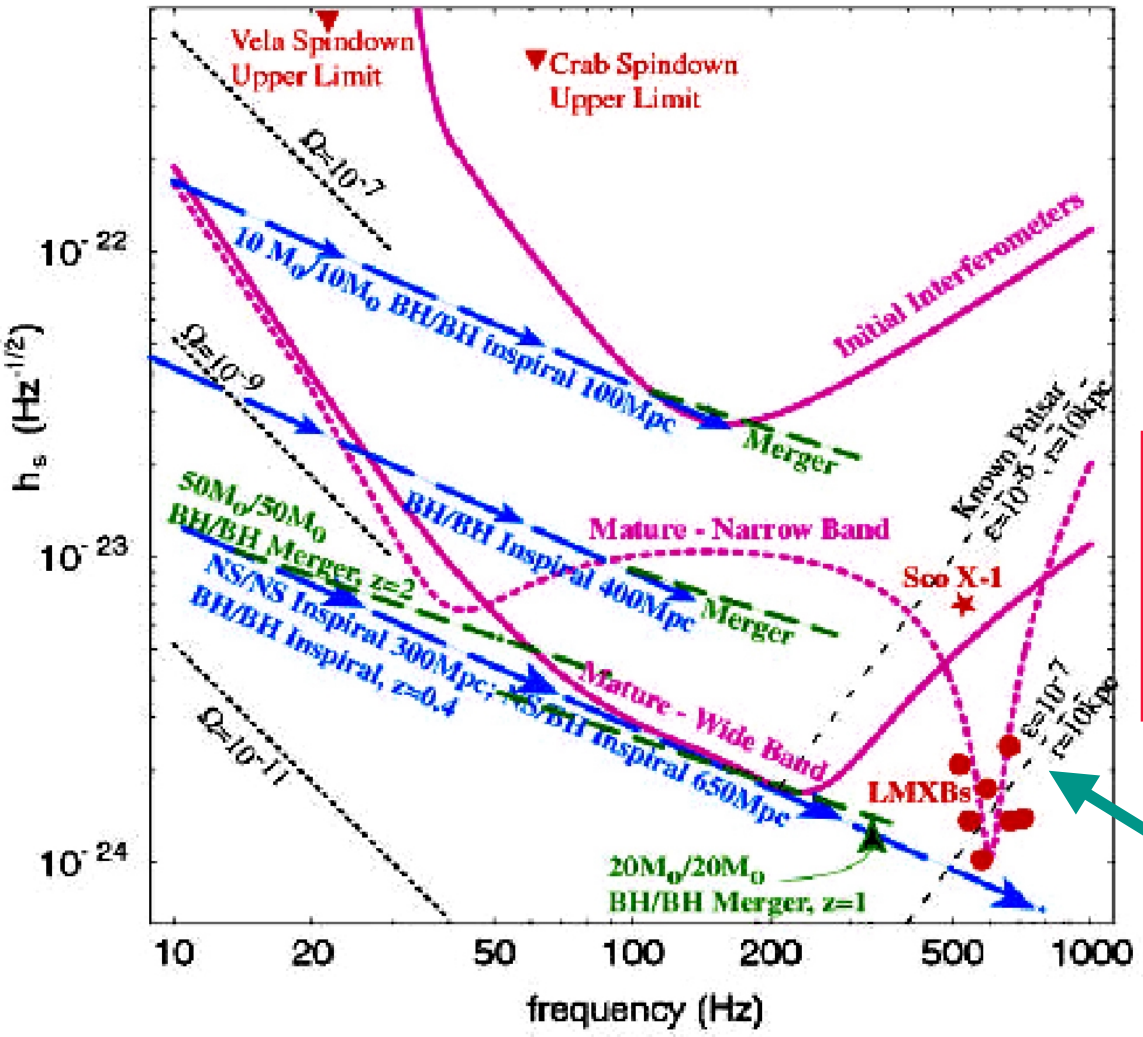


- Template based search
- 1 to 3 solar mass neutron stars
- Hanford 4 km + Livingston 4 km
- Sensitivity in Milky Way, LMC, SMC
- Result:

R < 164 / yr / **M**ilky**W**ay**E**quiv.**G**alaxy (90% confidence level)

Advanced LIGO

2007 +



Enhanced Systems

- laser
- suspension
- seismic isolation
- test mass

Improvement factor in rate

~ 10^4

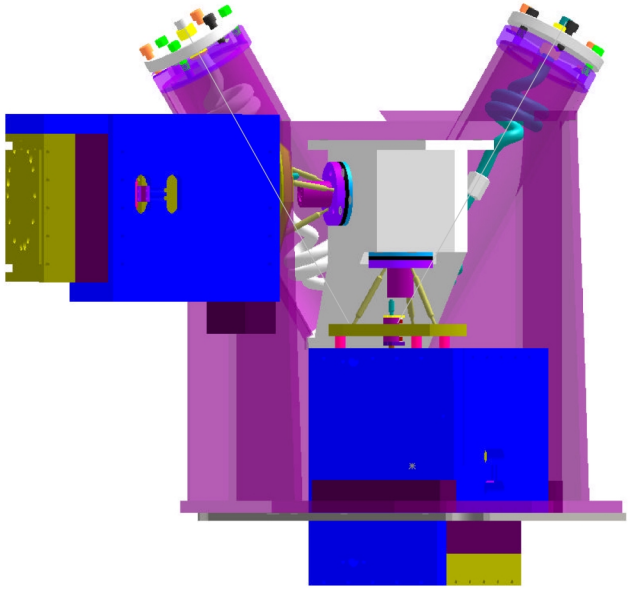
+

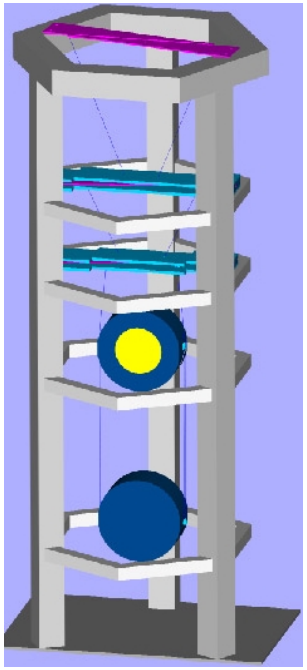
narrow band optical configuration

Advanced LIGO Development Underway

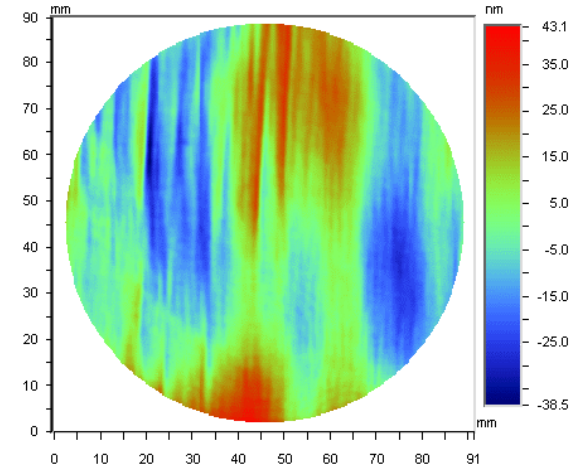
Multiple Suspensions

Active Seismic





Sapphire Optics



Date: 10/25/2001
Time: 13:59:18
Wavelength: 1.064 um
Pupil: 100.0 %
PV: 81.6271 nm
RMS: 13.2016 nm

X Center: 172.00
Y Center: 145.00
Radius: 163.00 pix
Terms: None
Filters: None
Masks:

Higher Power Laser

- LIGO commissioning is well underway
  - » Good progress toward design sensitivity (Raab)
- Science Running is beginning
  - » Initial results from our first LIGO data run (Katsavounidis)
  - » The sources (Creighton)
  - » Talks this afternoon (Brady, Daw, Papa and Romano)
- Our Plan
  - » Improved data run is underway
  - » Our goal is to obtain one year of integrated data at design sensitivity before the end of 2006
  - » Advanced interferometer with dramatically improved sensitivity – 2007+ (Rowan)
- LIGO should be detecting gravitational waves within the next decade !