# LIGO Overview
# PAC 14 DRAFT VERSION

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NSF Review of Advanced LIGO

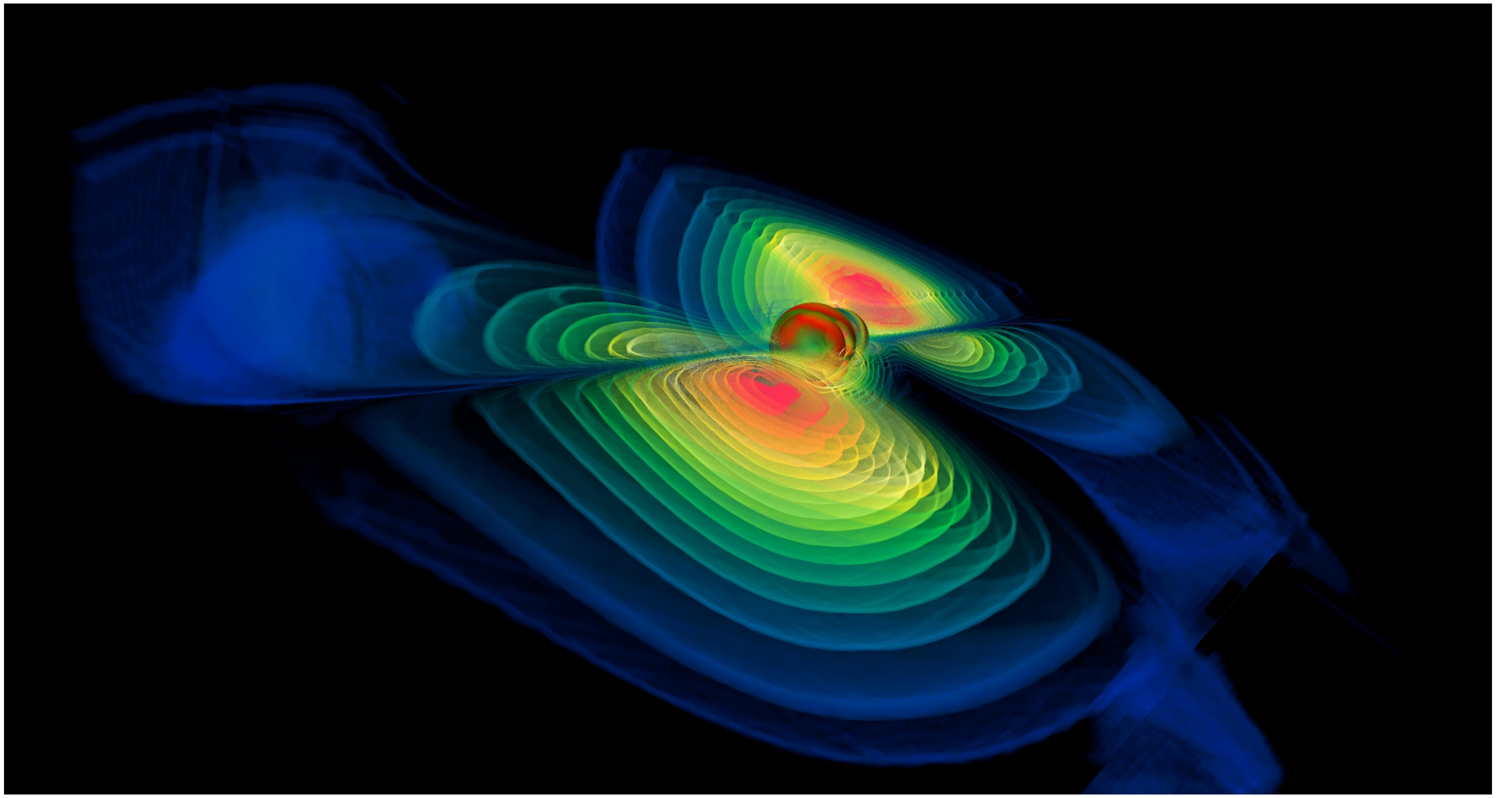
Caltech, June 11, 2003

LIGO-G030250-00-M

# This talk

- Introduction to LIGO and terrestrial gravitational wave detectors
- Current sensitivity **and some results**
- The LIGO mission and the upgrade strategy
- The scientific reach and impact of Advanced LIGO
- How we are organized for Advanced LIGO
- Broader impacts

# LIGO Overview

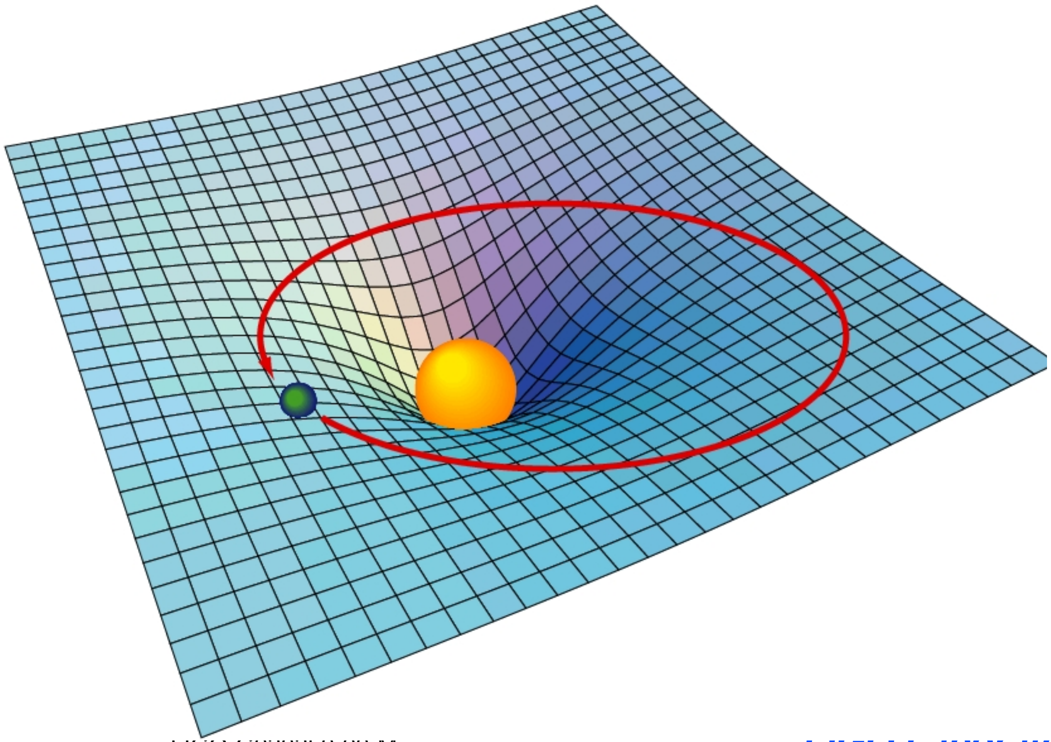


*"Colliding Black Holes"*

Credit:
National Center for Supercomputing Applications (NCSA)

# 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***

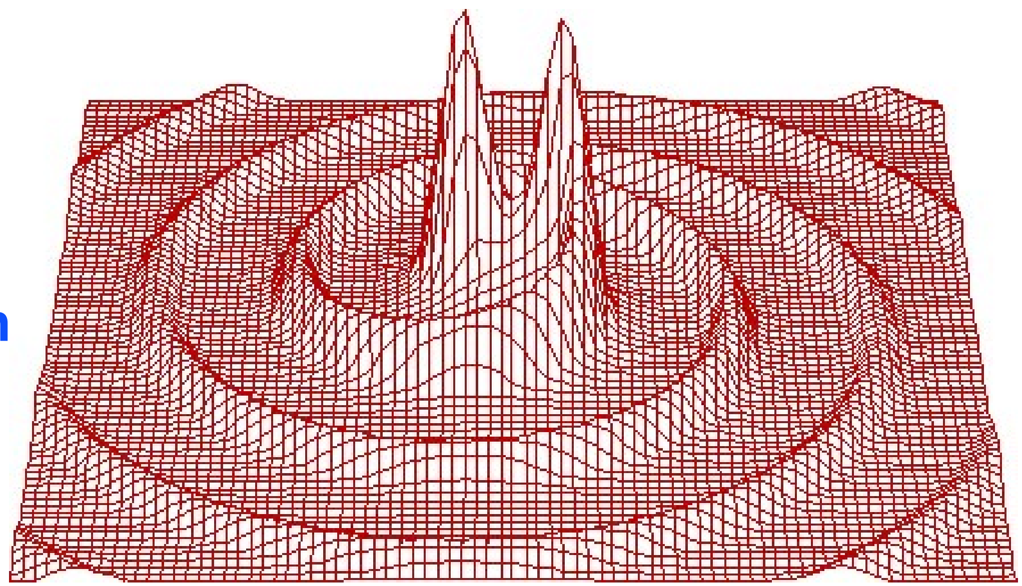


- **Imagine space as a stretched rubber sheet.**
- **A mass on the surface will cause a deformation.**
- **Another mass dropped onto the sheet will roll toward that mass.**

# 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

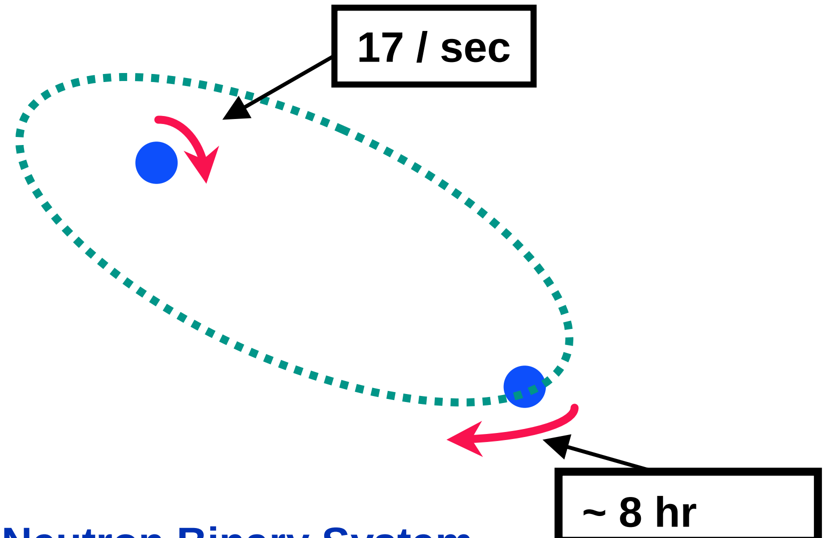


***gravitational radiation from binary inspiral of compact objects***

# Evidence for Gravitational Waves

Neutron Binary System – Hulse & Taylor

PSR 1913 + 16 -- Timing of pulsars




**Neutron Binary System**

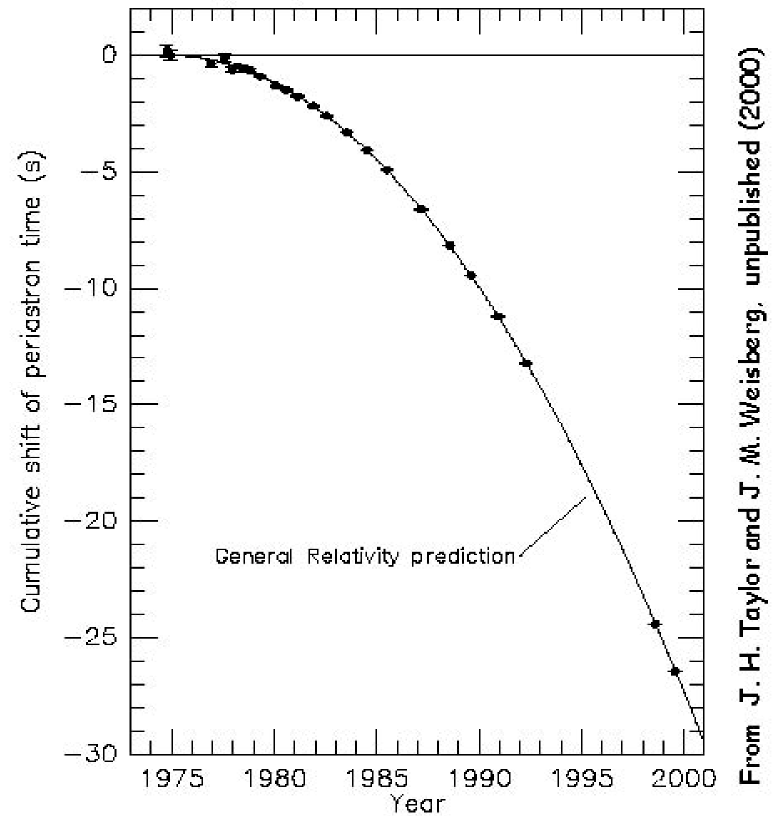
- **separated by $10^6$ miles**
- **$m_1 = 1.4m_\odot$; $m_2 = 1.36m_\odot$; $\varepsilon = 0.617$**

**Prediction from general relativity**

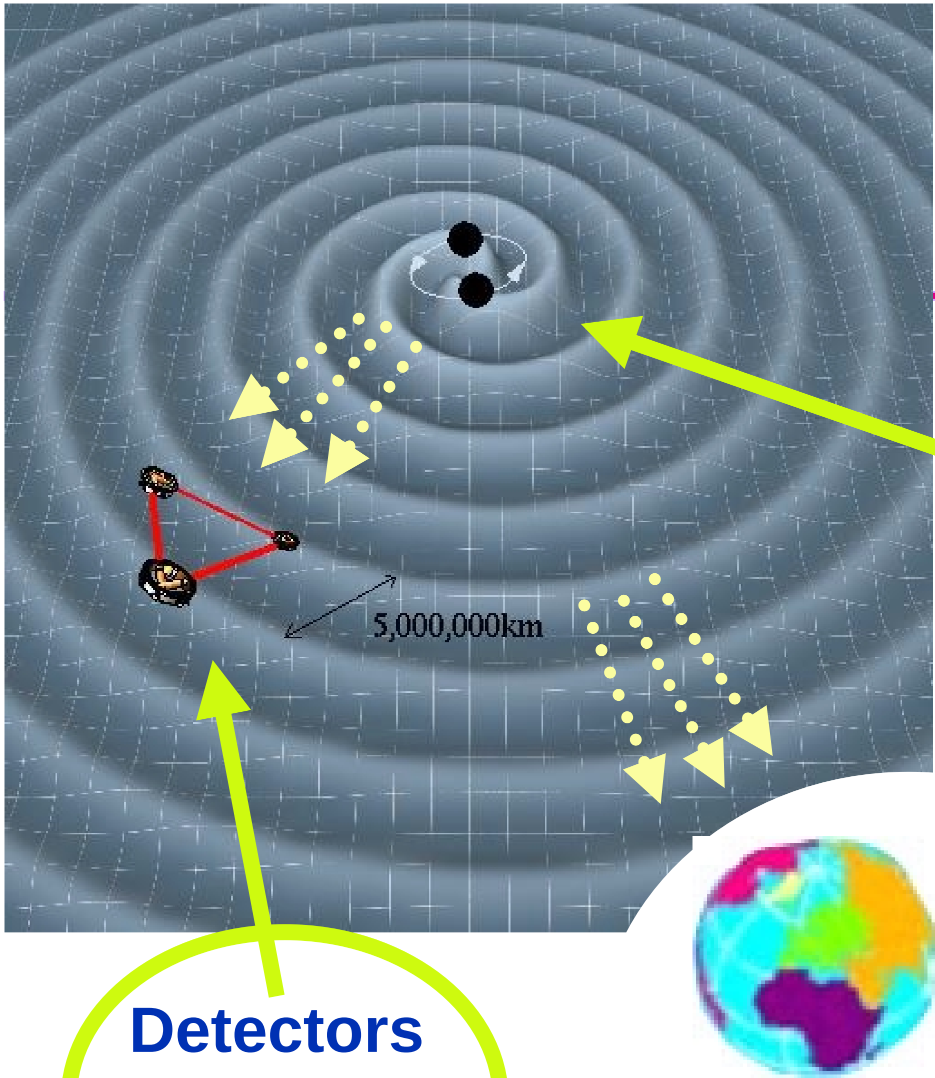
- **spiral in by 3 mm/orbit**
- **rate of change orbital period**

**Emission of gravitational waves**

Comparison between observations of the binary pulsar PSR1913+16, and the prediction of general relativity based on loss of orbital energy via gravitational waves



# Direct Detection



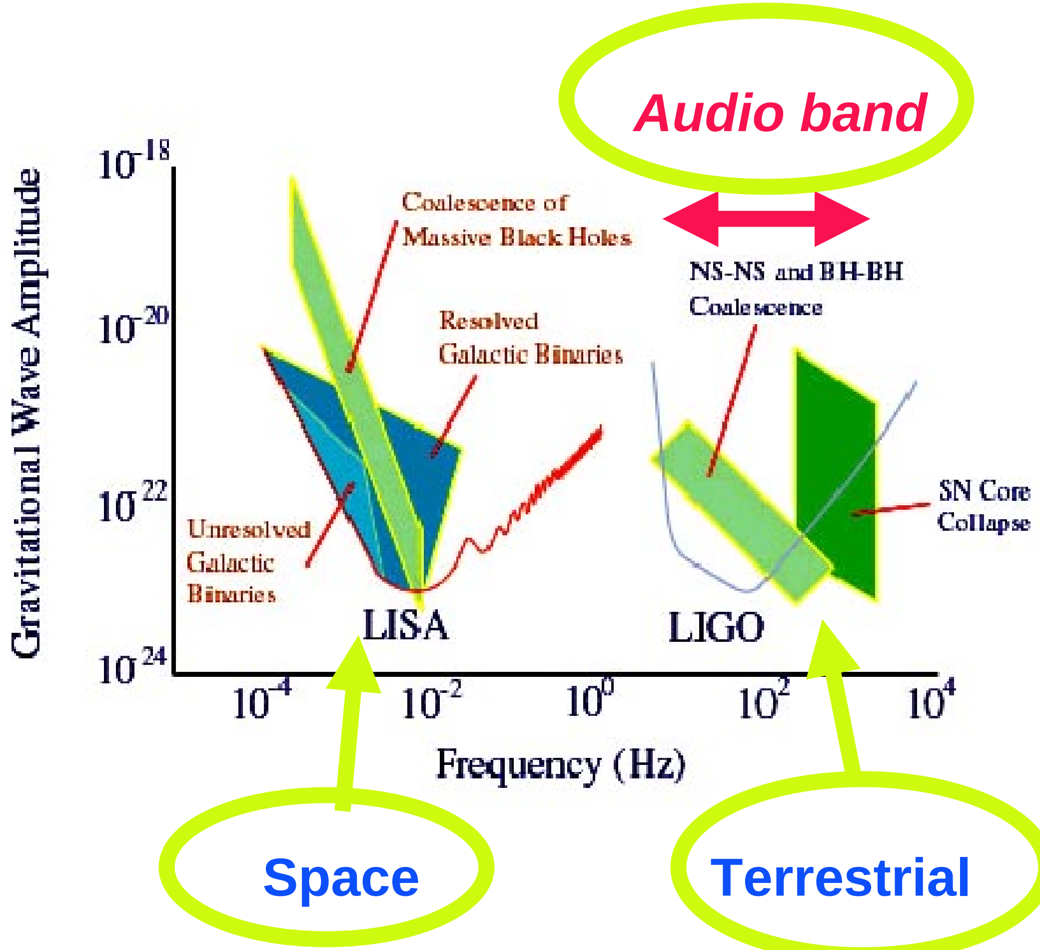

**Gravitational Wave Astrophysical Source**

**Detectors in space**
**LISA**

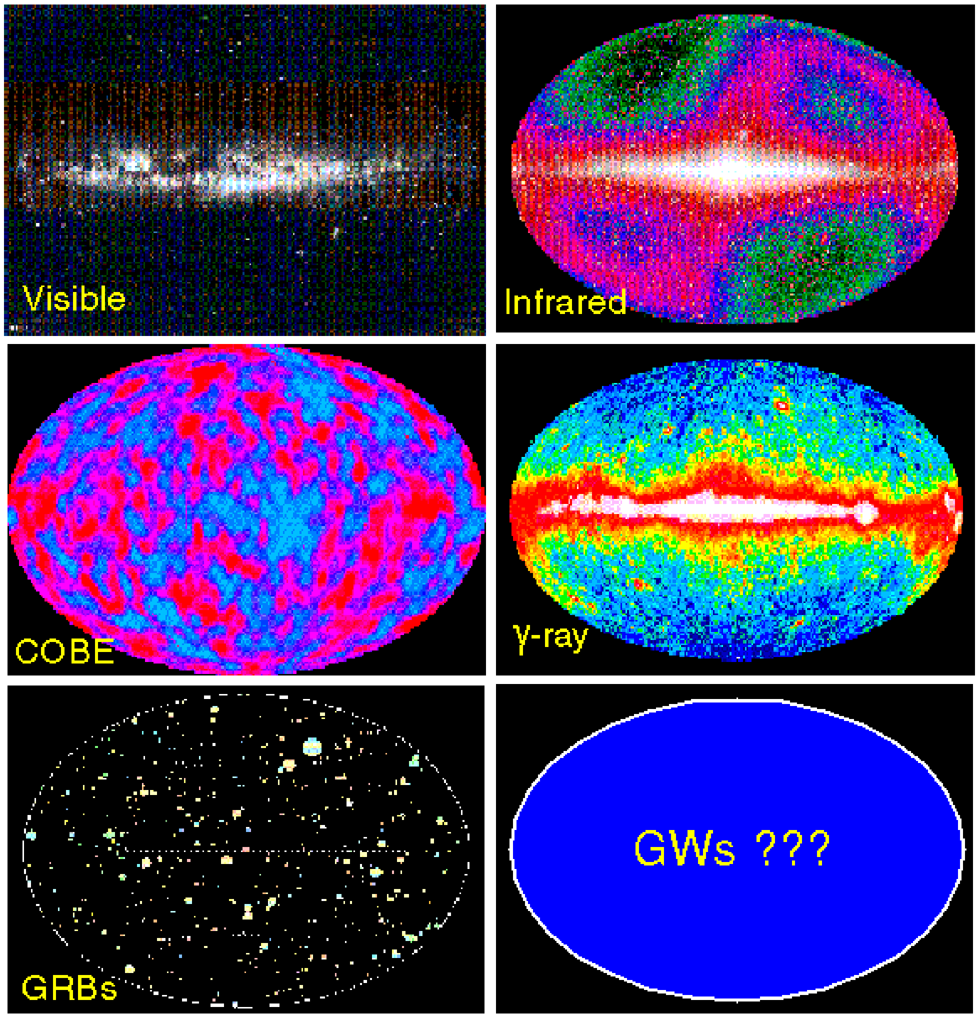
**Terrestrial detectors**
**LIGO, GEO, TAMA, Virgo**

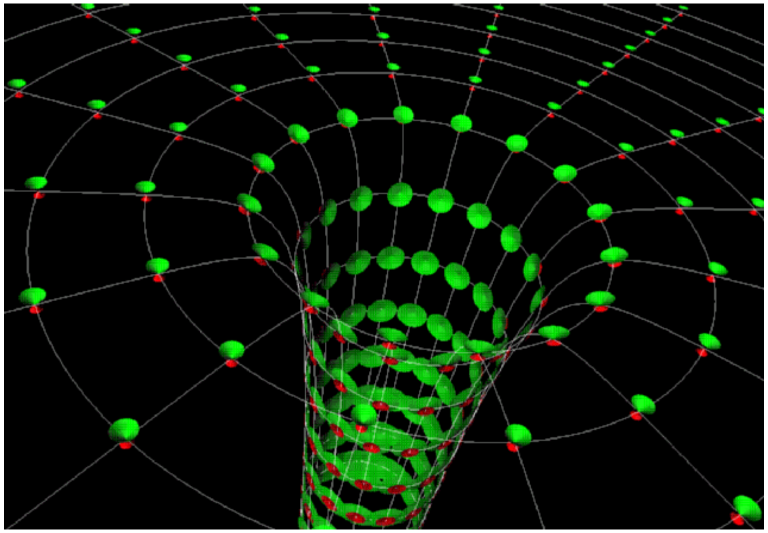
# Astrophysics Sources by Frequency

- 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

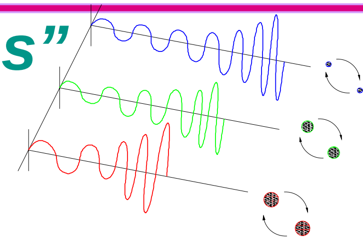


**Gravitational Waves will provide a new way to view the dynamics of the Universe**

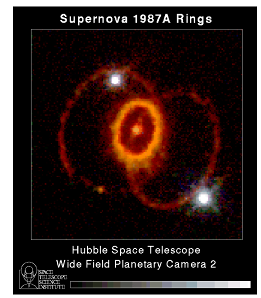
# Astrophysical Sources of Gravitational Waves

- Compact binary inspiral: *"chirps"*

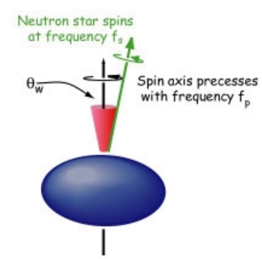


Thorne

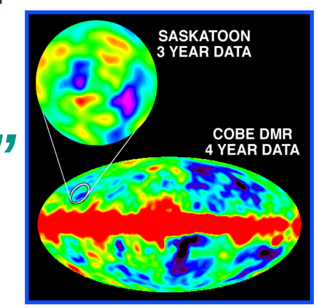
  - » NS-NS waveforms are well described
  - » BH-BH need better waveforms
  - » search technique: matched templates




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



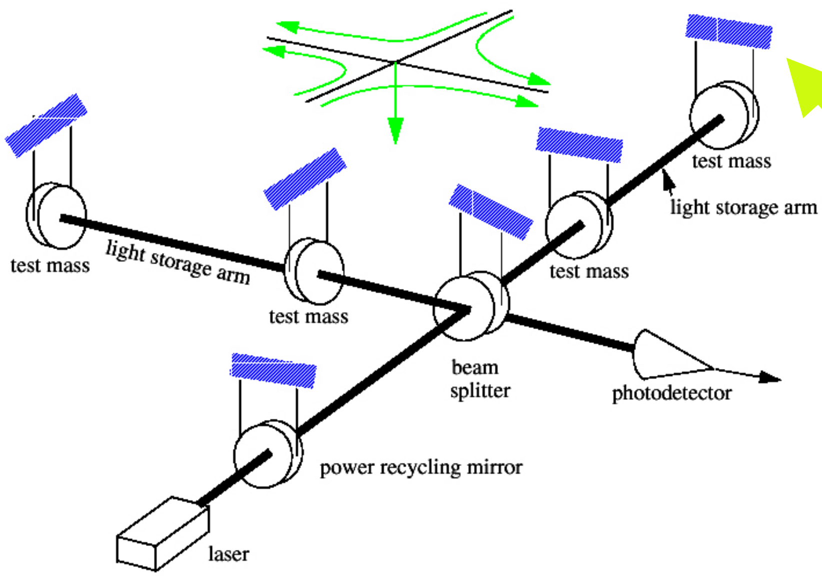

- Pulsars in our galaxy: *"periodic signals"*
  - » search for observed neutron stars (frequency, doppler shift)
  - » all sky search (computing challenge)
  - » r-modes



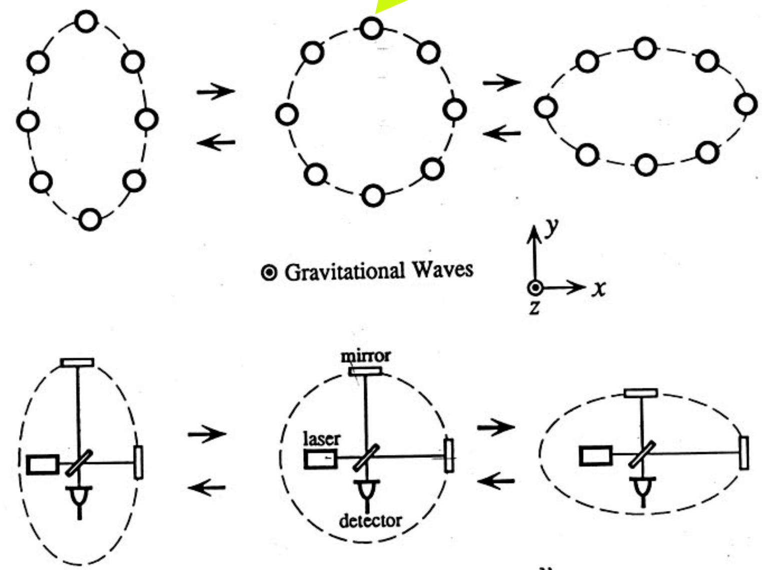

- Cosmological Signals *"stochastic background"*

# Terrestrial Interferometers

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



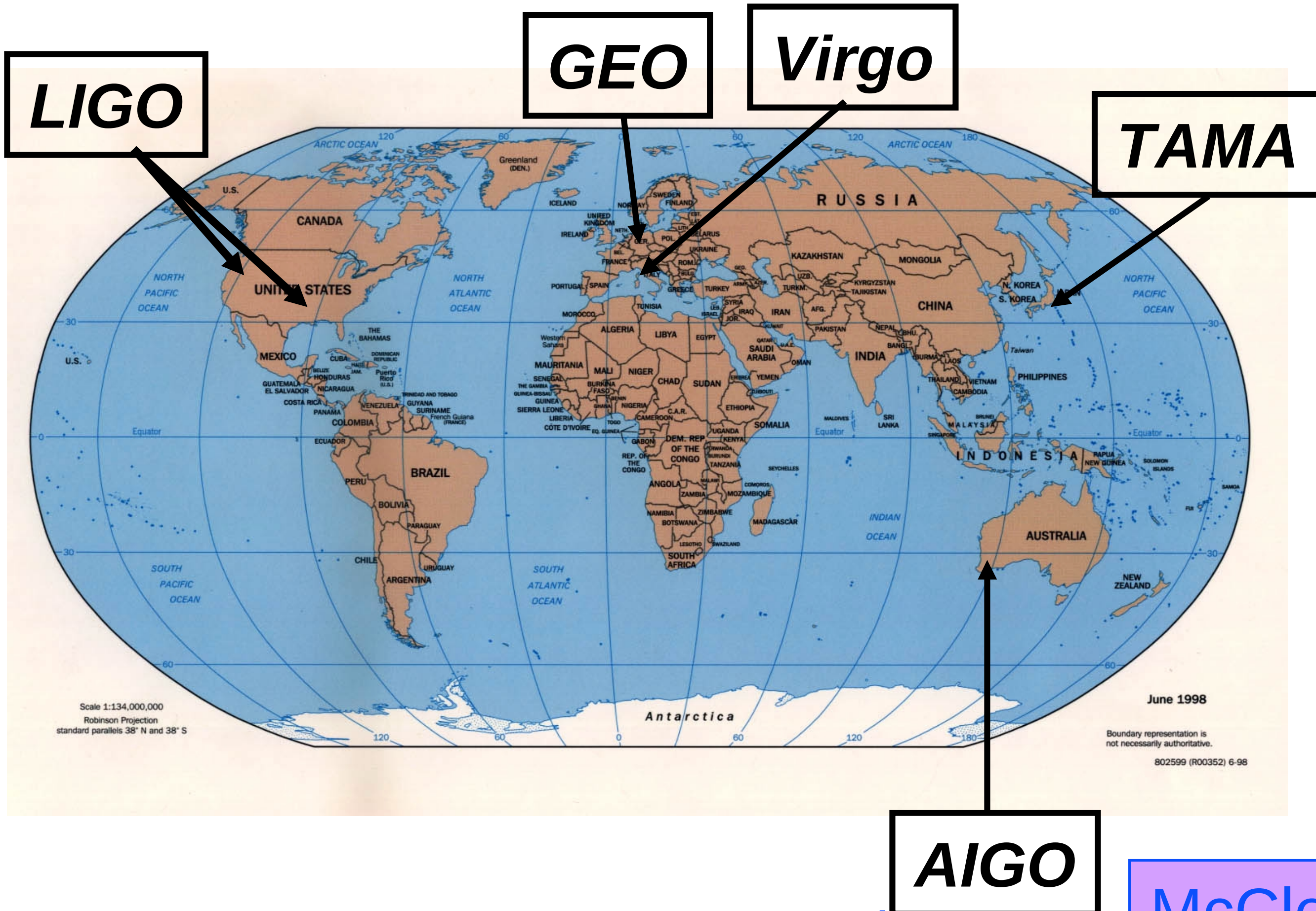

free masses




suspended test masses

# An International Network of Interferometers

Simultaneously detect signal (within msec)




Saulson

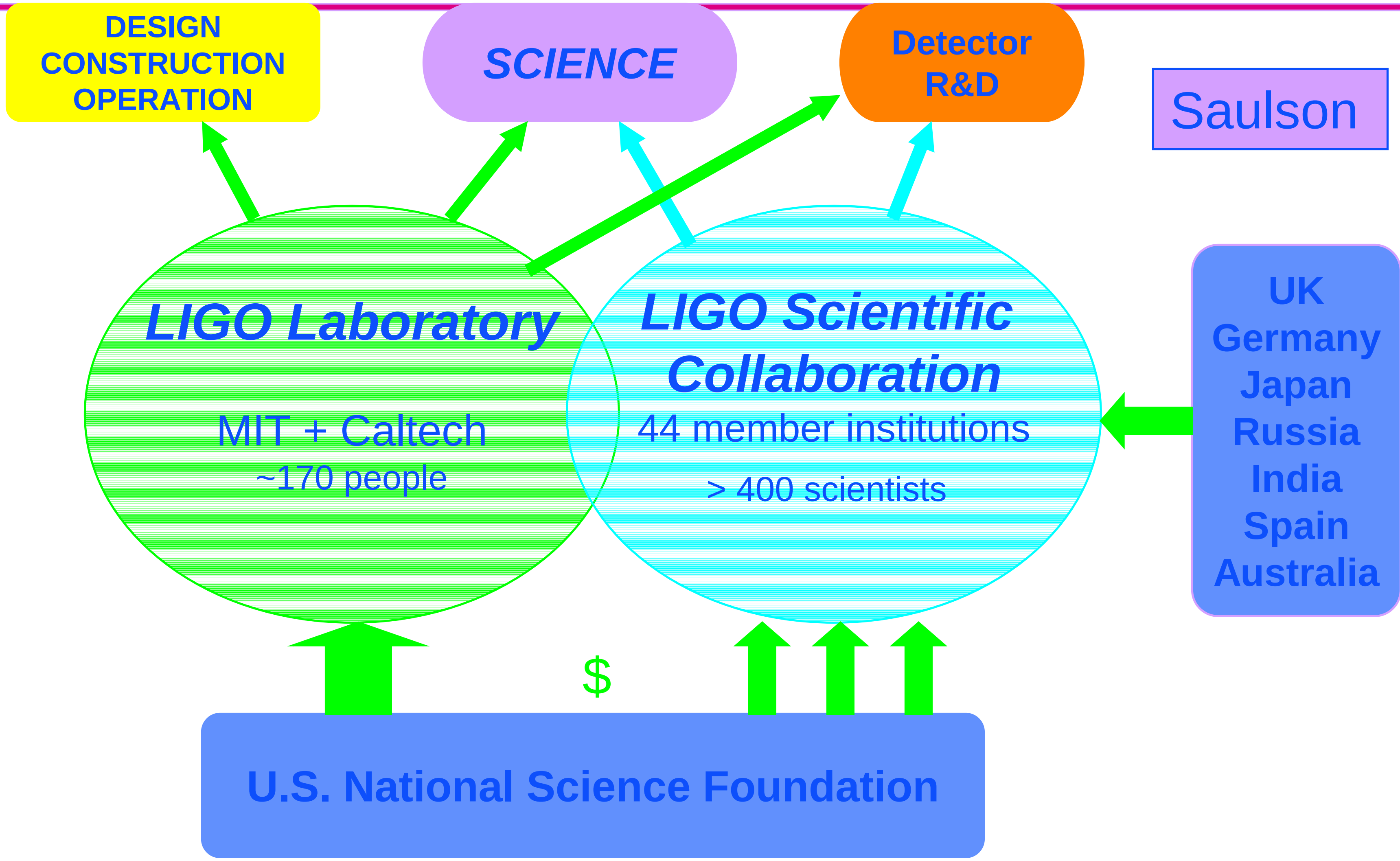
detection confidence

locate the sources

decompose the polarization of gravitational waves

McClelland

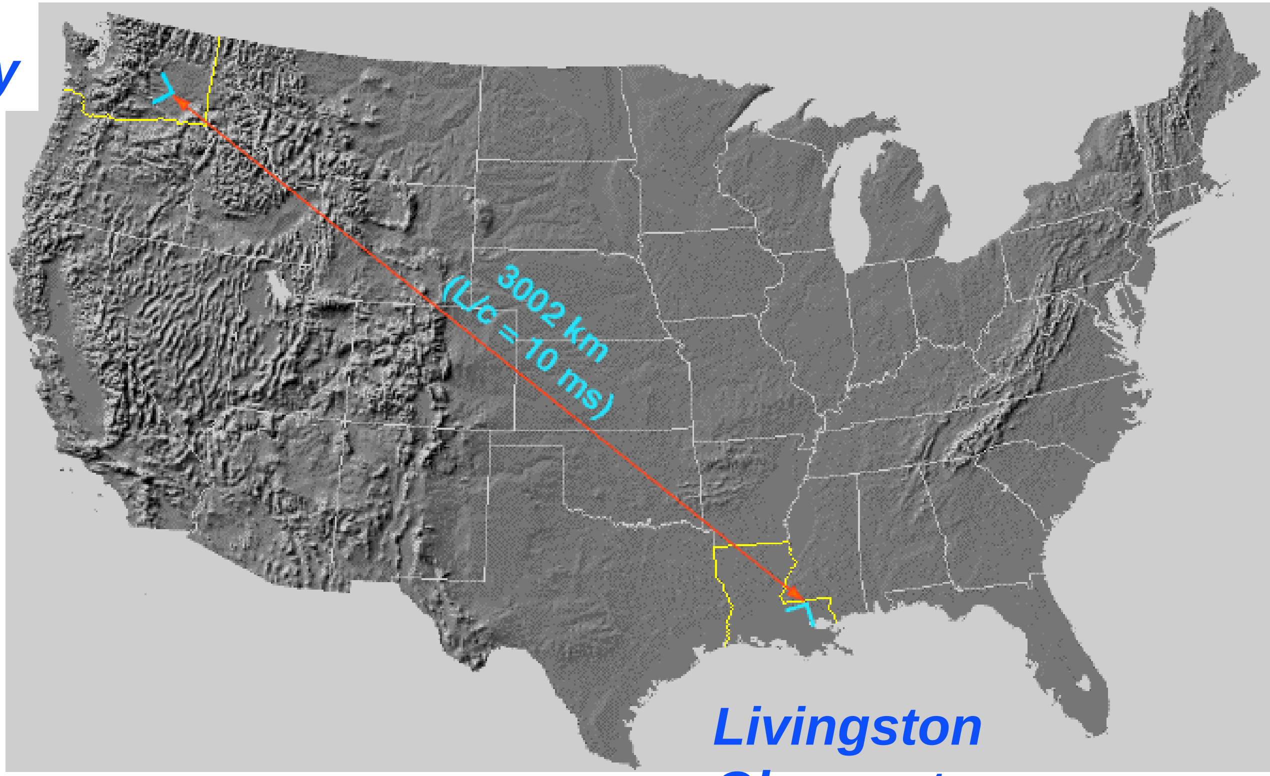
# LIGO Organization & Support



# The Laboratory Sites

**Laser Interferometer Gravitational-wave Observatory (LIGO)**

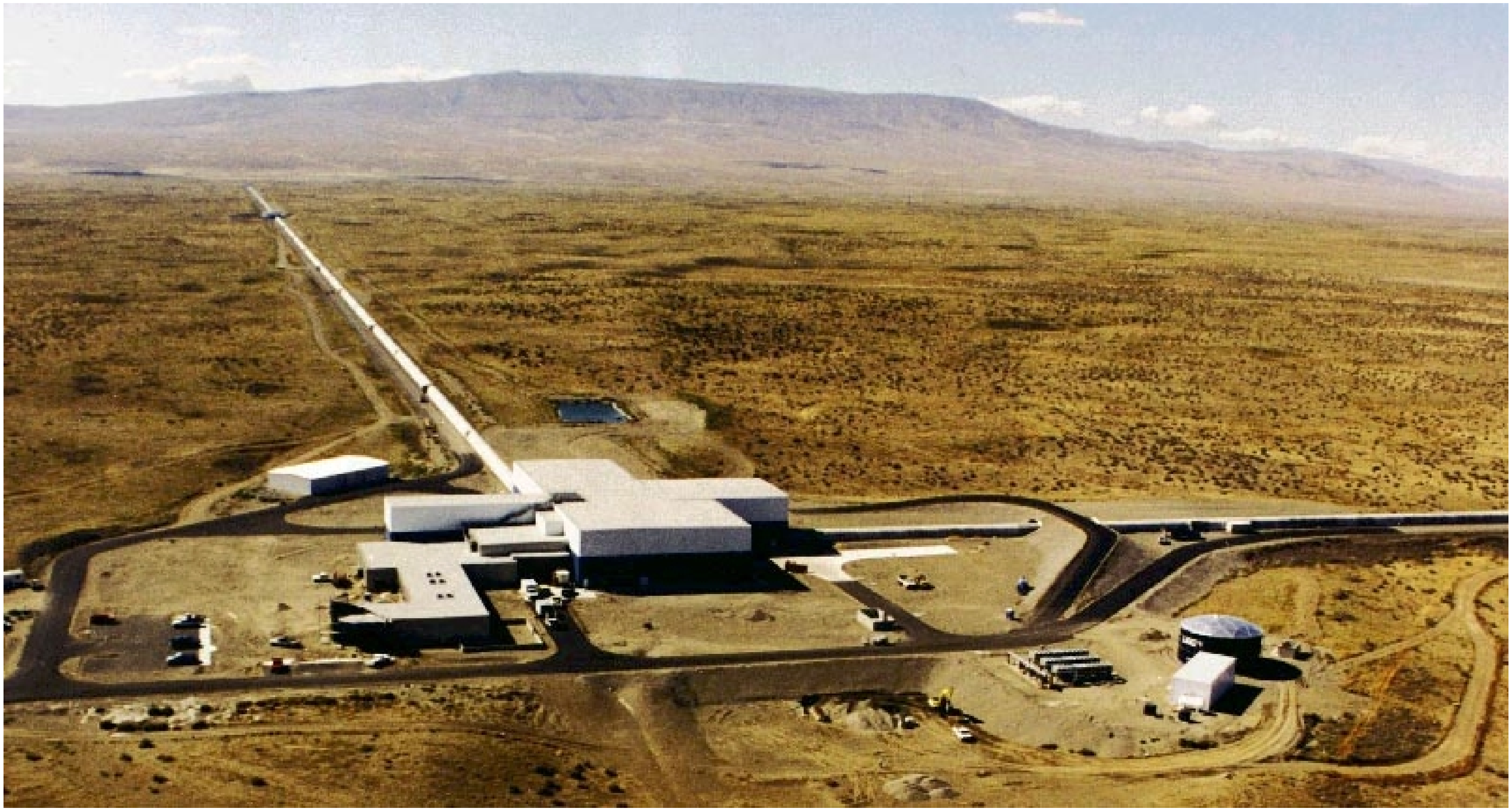
***Hanford Observatory***




***Livingston Observatory***

# LIGO Livingston Observatory

# LIGO Hanford Observatory



# GEO 600

Hough, Willke

LIGO

# 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 x $10^{-7}$

Internal mode Q's > 2 x $10^{6}$

Polishing

Surface uniformity < 1 nm rms

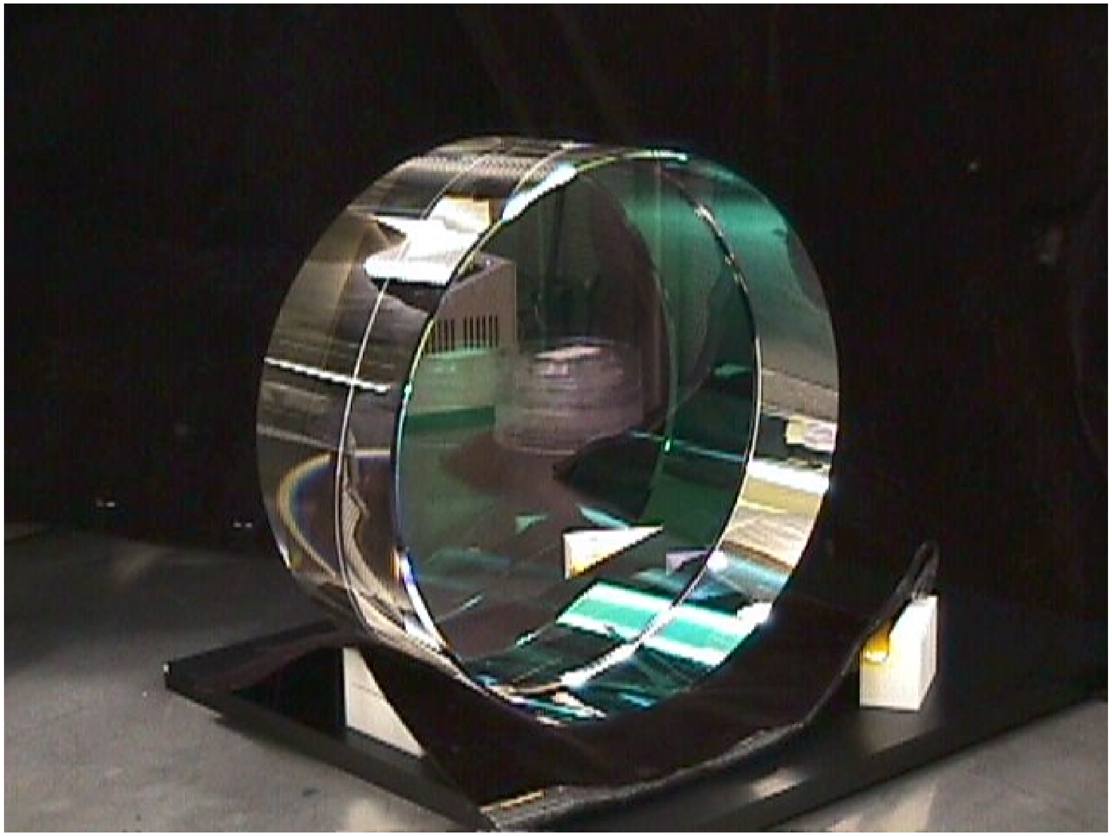
Radii of curvature matched < 3%

Coating

Scatter < 50 ppm

Absorption < 2 ppm

Uniformity <$10^{-3}$

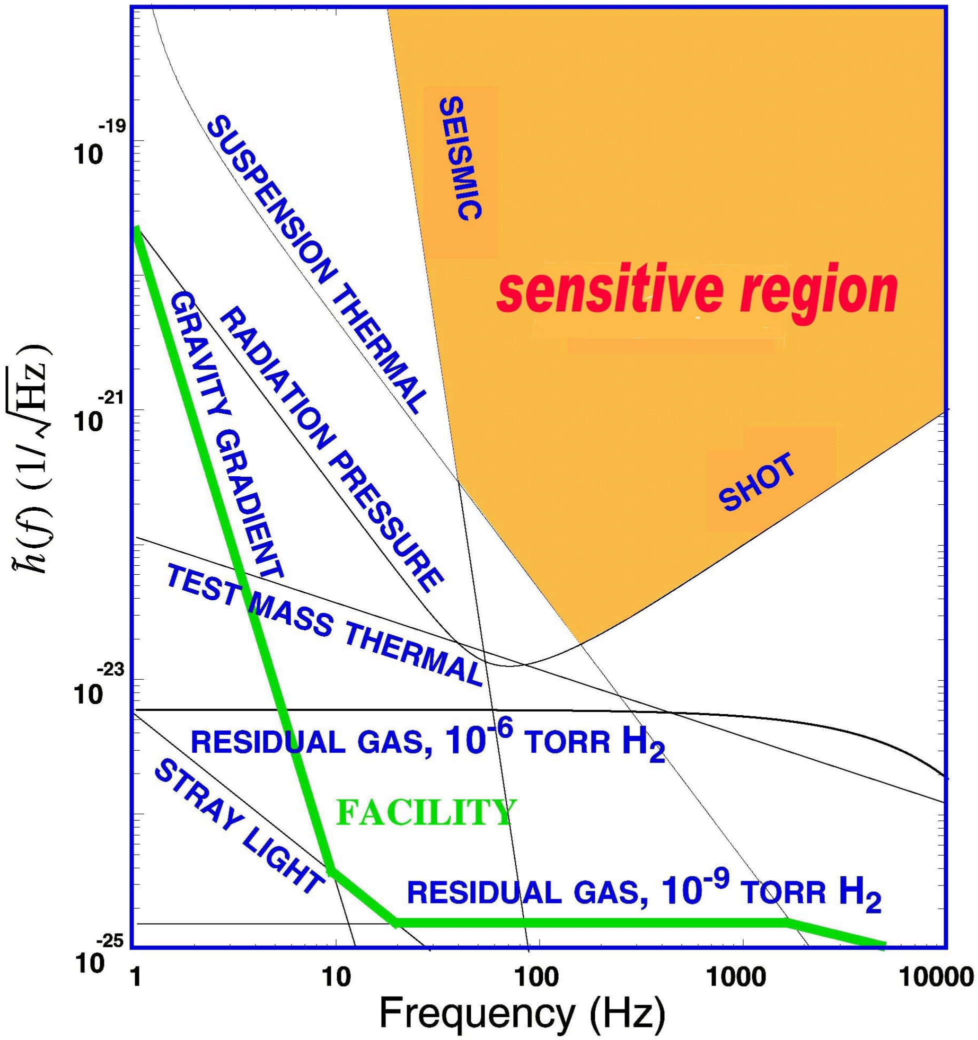


# Core Optics

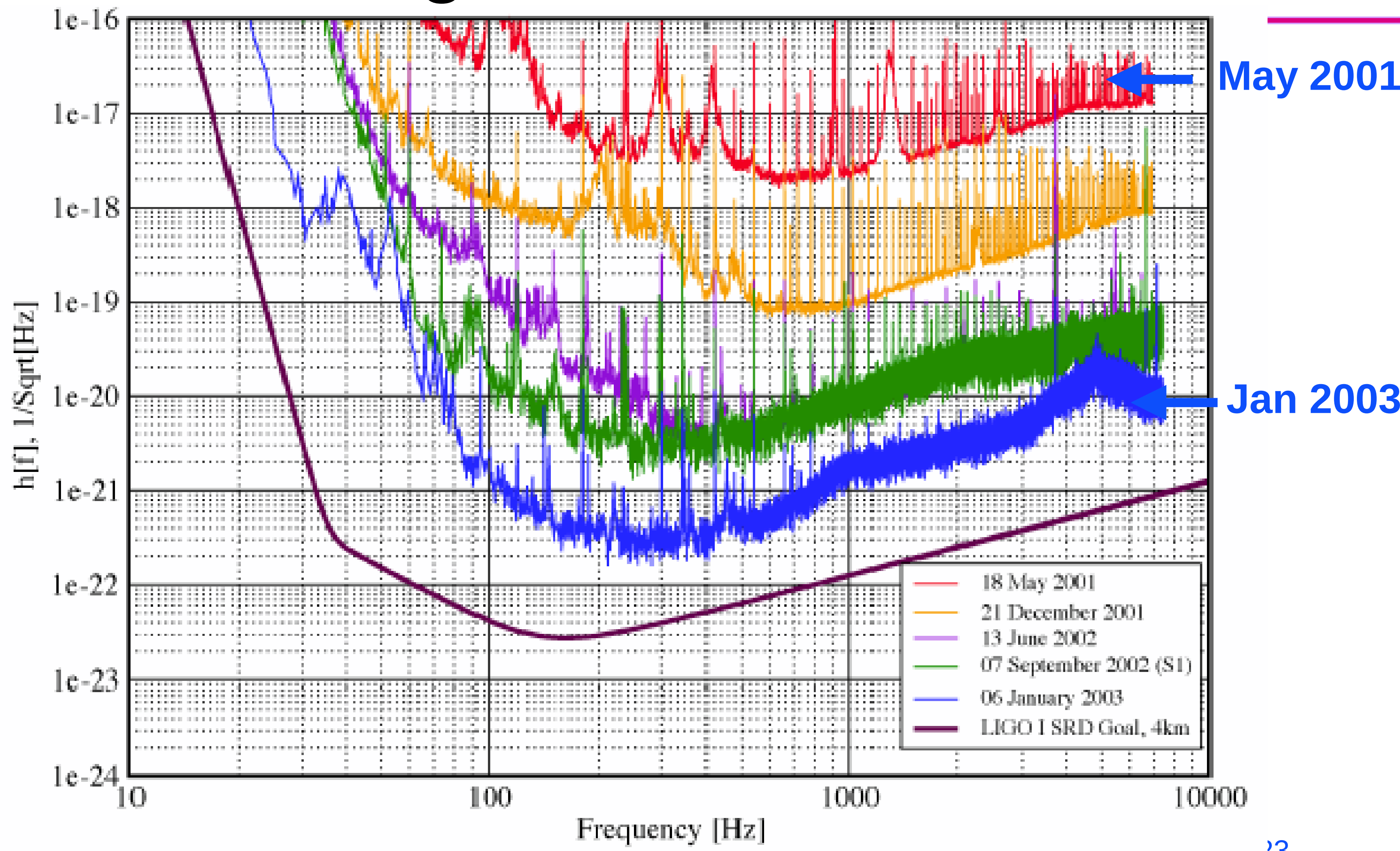
## *installation and alignment*

# 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

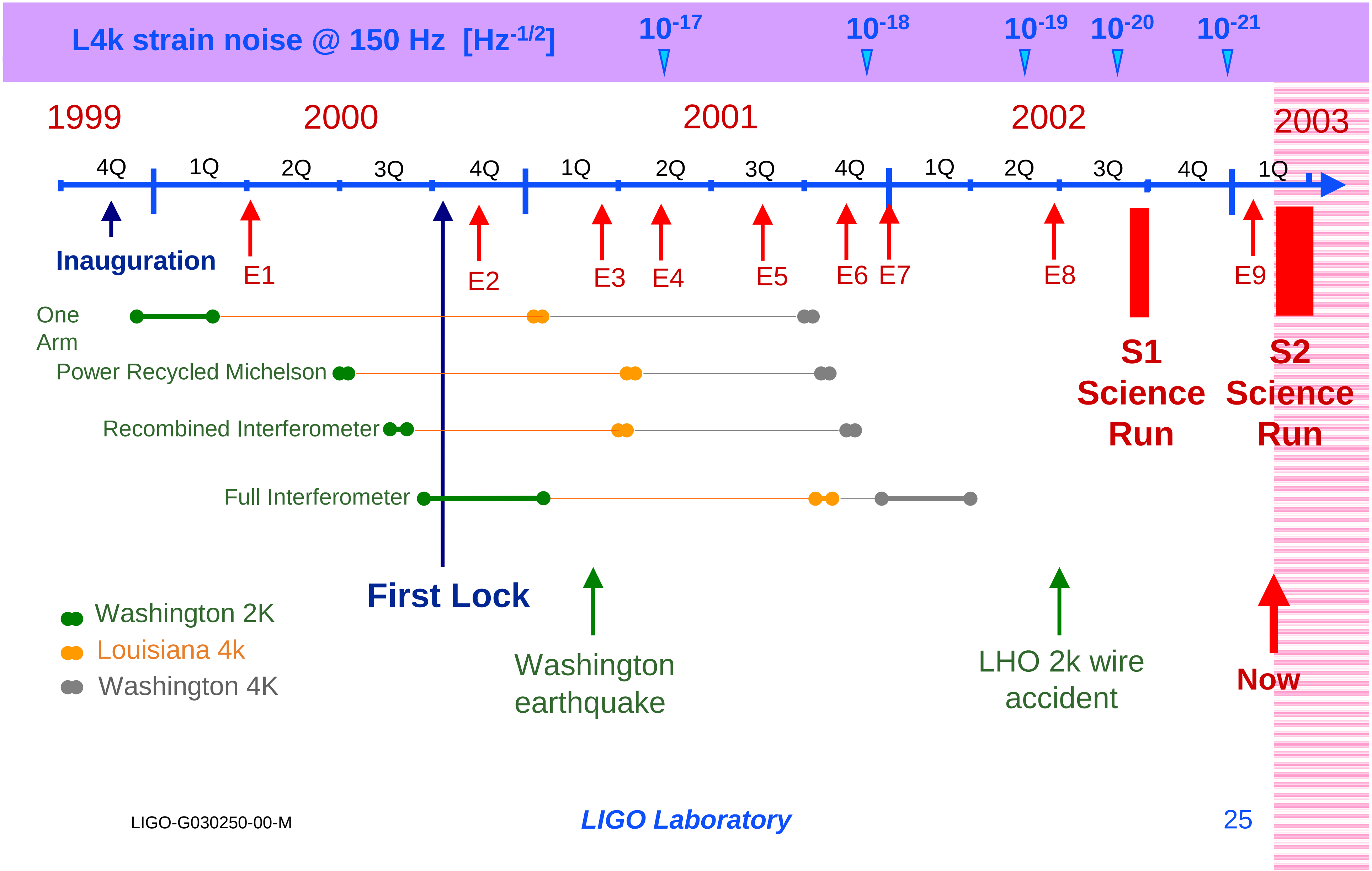


# LIGO Plans

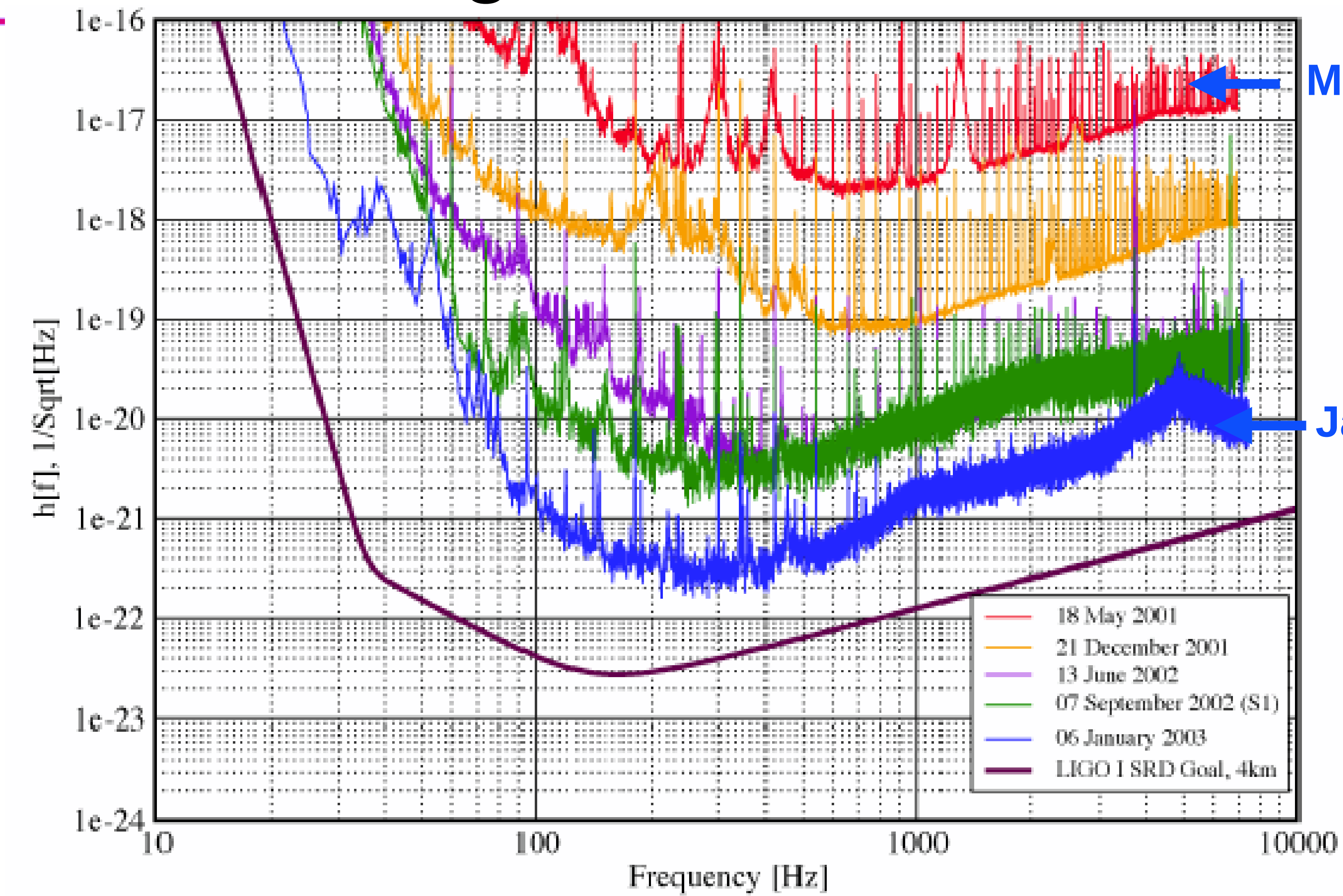
## *schedule*

| | |
|---|---|
| 1996 | Construction Underway (mostly civil) |
| 1997 | Facility Construction (vacuum system) |
| 1998 | Interferometer Construction (complete facilities) |
| 1999 | Construction Complete (interferometers in vacuum) |
| 2000 | Detector Installation (commissioning subsystems) |
| 2001 | Commission Interferometers (first coincidences) |
| 2002 | Sensitivity studies (initiate LIGO I Science Run) |
| 2003+ | LIGO I data run (one year integrated data at $h \sim 10^{-21}$) |
| 2007 | Begin 'advanced' LIGO installation |

# Commissioning History



# LIGO Sensitivity
# Livingston 4km Interferometer



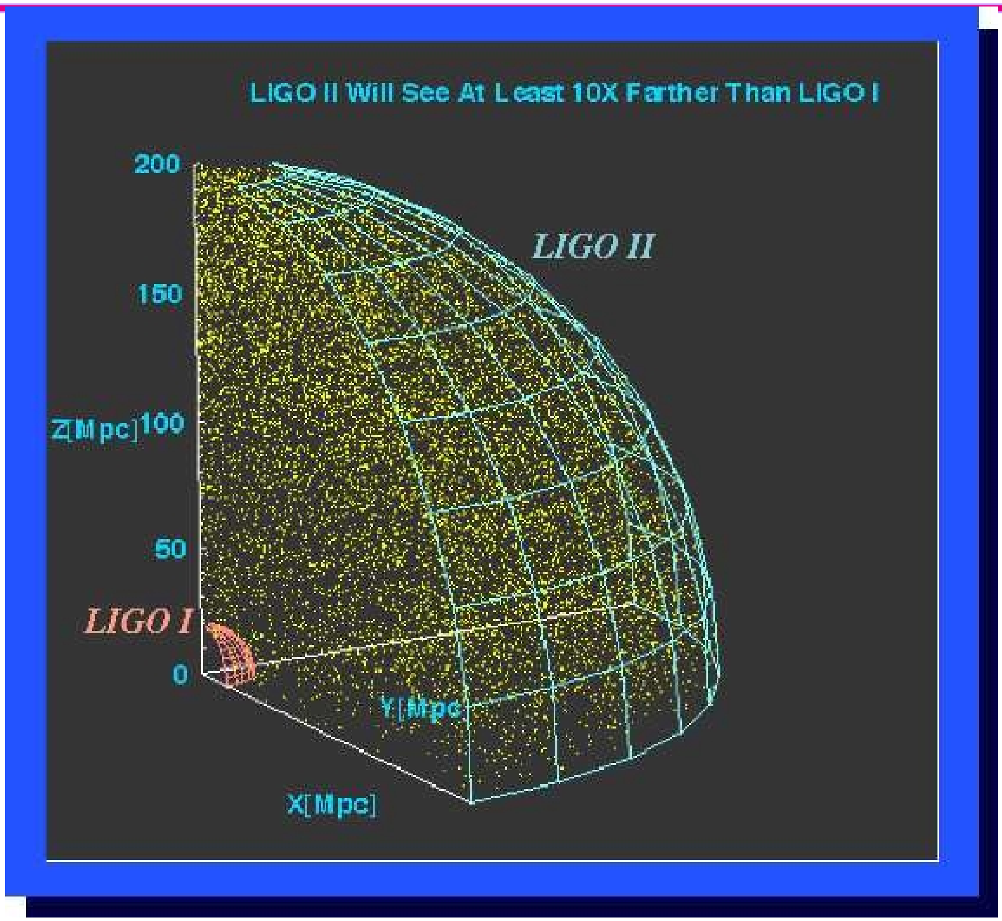

May 2001

Jan 2003

# Results From S1 Run

- See Barry's Colloquium this afternoon

# Advanced LIGO Reach




***Science from the first few hours of Advanced LIGO observing should be comparable to 1 year of initial LIGO!***

# Historical Background

- LIGO was approved for construction of
  - » a platform suitable for successive and additional interferometers
  - » an initial set of interferometers
- 1996 McDaniel report endorsed plans for:
  - » NSF support of an Advanced R&D program to lead to the detectors beyond initial LIGO
  - » formation of a scientific collaboration
    - – LIGO Scientific Collaboration (LSC)
- R&D proposals from LIGO Lab and LSC received late 1996
  - » NSF defined a budget and program in 1998
  - » R&D was organized and initiated in 1997 – 2001 period

# Establishing a Supported Development Program

- LSC authored a White Paper on an advanced LIGO detector in 1998 and described a reference concept and R&D program
  - » This was an international R&D program from the start
- LIGO Lab and LSC jointly submitted a revised White Paper and a project conceptual document to NSF in late 1999
  - » Proposed upgrade of 3 interferometers, all 4 km arms, simultaneous installation
  - » Peoples panel endorsed concept and urged support of the development program
  - » NSF decided to support further R&D for Advanced LIGO development

# The Current LIGO Laboratory Development Program

- In 2000, LIGO Lab proposed to NSF continuation of LIGO operations and R&D for the period FY2002 – FY2006
  - » Program and budget included support of
    - – Operating initial LIGO
    - – Analyzing data and producing science
    - – Developing Advanced LIGO through Final Design
  - » Permanent LIGO staff scientists and engineers engaged in Advanced LIGO development were to be supported from the basic operating budget
  - » Equipment, fabrications, incremental labor were to be supported from an Advanced R&D budget line

# Proposal Budget
# LIGO Operations (2002 – 2006)

| | FY 2001 ($M) | FY 2002 ($M) | FY 2003 ($M) | FY 2004 ($M) | FY 2005 ($M) | FY 2006 ($M) | Total 2002-6 ($M) |
|---|---|---|---|---|---|---|---|
| Currently funded Operations | 22.92 | 23.63 | 24.32 | 25.05 | 25.87 | 26.65 | 125.52 |
| Increase for Full Operations | | 5.21 | 5.20 | 4.79 | 4.86 | 4.95 | 25.01 |
| Advanced R&D | 2.70 | 2.77 | 2.86 | 2.95 | 3.04 | 3.13 | 14.76 |
| R&D Equipment for LSC Research | | 3.30 | 3.84 | 3.14 | | | 10.28 |
| Total Budgets | 25.62 | 34.91 | 36.21 | 35.93 | 33.77 | 34.74 | 175.57 |

FY 2001 currently funded Operations ($19.1M for ten months) is normalized to 12 months and provided for comparison only and is not included in totals.

# "Revised" Proposal Budget LIGO Operations (2002-2006)

- $28 million provided for FY 2002 Operations in February and May 2002
  - » Reduced or deferred hiring, Adv R&D, equipment, outreach, etc
- Priority for commissioning and toward LIGO I 24x7 Operations
- Full $33 million awarded for FY2003 (6 months late)

| | FY 2002 ($M) | FY 2003 ($M) | FY 2004 ($M) | FY 2005 ($M) | FY 2006 ($M) |
|---|---|---|---|---|---|
| **Operations** | **$24** | **$29** | **$30** | **$30** | **$30** |
| **Advanced R&D** | **$4** | **$4** | **$3** | **$3** | **$3** |

# Funding for LIGO Laboratory Program

- NSF award for continuing LIGO operations is at a level less than requested
- FY2003 appropriations delayed 6 months
- Initial LIGO operations and data analysis/science is highest priority
- Nevertheless, the Advanced LIGO development program has accomplished much of what was proposed
  - » The LSC has been a full partner in all of these activities
  - » Advanced LIGO R&D not run as a firm project though we are ready

# A Development Project Across the LSC

- Since late 1999, we have planned the Advanced LIGO development program as if it was part of a construction project
  - » Work Breakdown Structure
  - » Cost estimate
  - » Schedule
  - » Management structure
  - » Requirements documented and systems engineering and modeling
  - » Design process established
- This “projectized” development program has been operating in a serious collaborative manner across the LSC
  - » LSC Working Groups
    - – Advanced detector configurations working group
    - – Core optics working group
    - – Suspensions working group

# Advanced LIGO Proposal

- R&D through final design and first articles now underway
  - » supported by LIGO and partner funds already awarded
  - » a true LSC-wide activity
- Proposal requests funding for the construction
  - » $122 million beginning in 2005
  - » Some early purchases in 2004
- International partners propose support of additional $25.5 million
  - » GEO (UK) - $11.5 million **(approved)**
  - » GEO (Germany) - $11.5 million
  - » ACIGA - $2.5 million

Hough, Willke

McClelland

# What are we proposing?

- Replace all three interferometers
- Convert current 2 km interferometer in Hanford to a 4 km interferometer
- Phase replacement schedule to:
  - » minimize duration of LIGO down time
    - – Supports replacing all 3 simultaneously
  - » Minimize costly duplication of skilled teams and tooling and keep at least one interferometer operating as much as possible
    - – Supports serial replacement of interferometers
  - » but apply skilled teams in rapid succession without costly duplication of teams and tooling
    - – rapid and overlapping phasing of replacement/upgrade

Shoemaker

# Buildup of Education and Outreach

- LIGO Lab outreach has been primarily observatory centered
- LIGO Lab renewal called for increased activity
- Supported new effort and formed a strategy and Local Educator's Networks at each observatory
- This process led to a new proposal with partners for a greatly expanded program
  - » Next slide has some details
- NSF is beginning an effort to produce a "half-hour" video on LIGO
- **Advanced LIGO proposal calls for an LSC-wide education and outreach program**

# February 2003 Proposed Education & Outreach Program

- Proposal submitted to NSF Feb. 10 for major enhancement to outreach activity:
  - » Collaboration of Caltech, SUBR, La Board of Regents, Exploratorium of San Francisco
- Construct an educational outreach center on-site at LLO.
- Place hands-on exhibits from Exploratorium in center (with subset at LHO).
- Implement teacher pre-service and in-service training initiative to teach inquiry based science techniques at SUBR – extend to LHO communities
- Use LIGO staff to provide science leadership in selection of exhibits, development of science content in teacher training programs
- La Board of Regents, through La Systemic Initiative with leveraged resources from US Dept of Education LA GEAR UP program, will facilitate teacher training and student visits to outreach center from underserved communities.

# Mission and Strategy

- Observe gravitational waves directly
- Initiate gravitational wave astronomy
- Bring initial LIGO to design sensitivity and observe for one integrated year at that sensitivity
  - » "plausible" chance to detect gravitational waves
- Upgrade detector with a very significant increment in sensitivity
  - » "likely" chance to detect gravitational waves

# Specific Charge

- Is the scientific case for the needed upgrade convincing? Are the scientific requirements achieved in a cost-effective manner?
- Is the specific proposed Advanced Detector upgrade appropriate to accomplish the scientific goals? In particular, is the decision to convert the 2-km Hanford interferometer to a second 4-km interferometer well founded, and will the specific subsystems each meet the required performance specifications?
- Are the requested budget (including contingency) and manpower levels appropriate to carry out the proposed upgrade?
- Are the schedule and milestones achievable with the proposed resources? Does the phasing of the downtime of detectors achieve a proper balance of cost, manpower, and observation time?
- Is the proposed management plan appropriate to oversee the R&D, construction, installation and commissioning of the upgrade?
- Has the issue of cost effectiveness in operating the more complex Advanced LIGO system been addressed?
- Is the proposed education and outreach plan well designed, and are the proposed manpower and funds appropriate to carry it out?