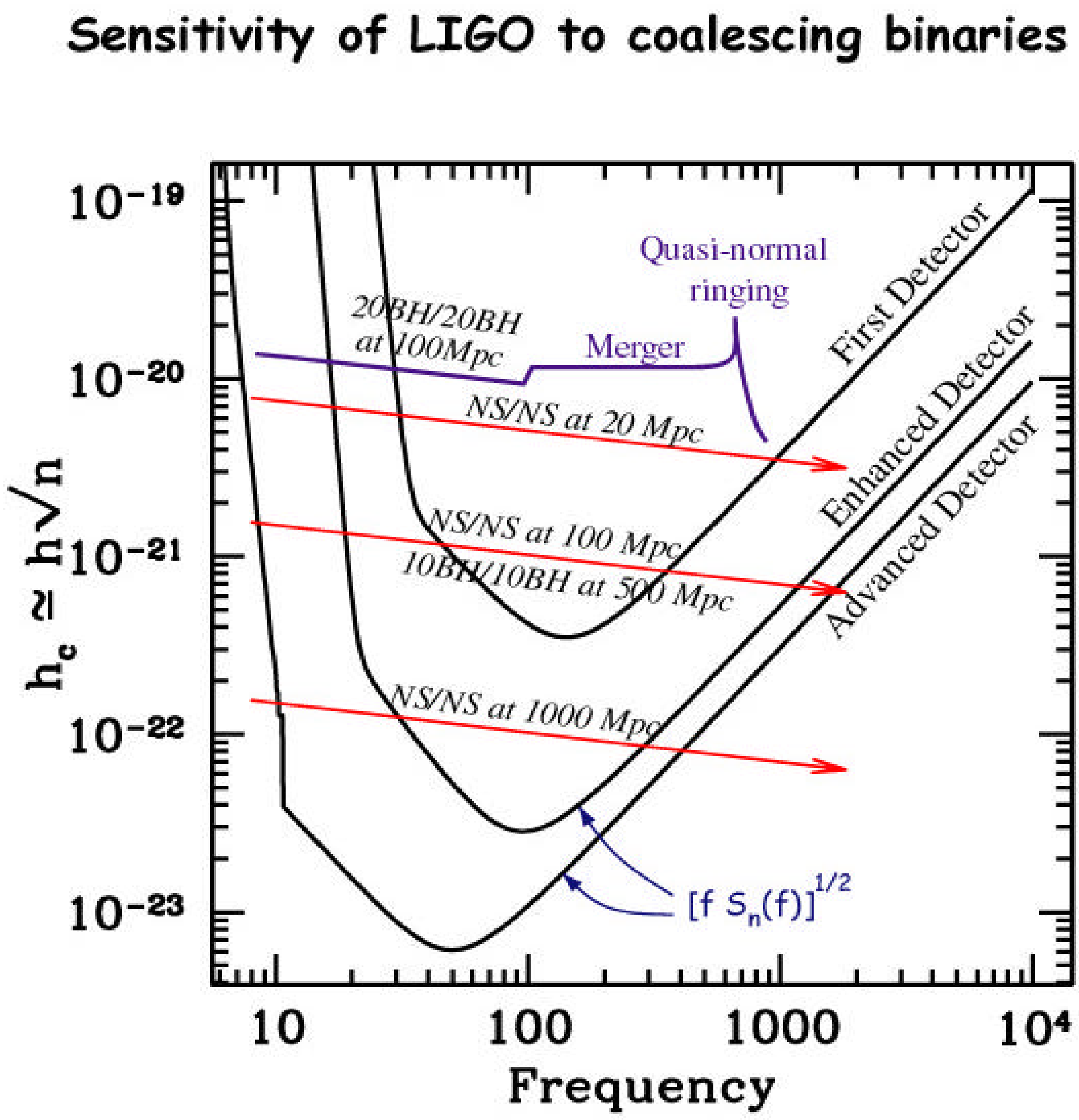
LIGO I
and the vision for
LIGO II

Barry Barish

NSF Panel

Oct 25, 1999

LIGO
astrophysical sources



LIGO
approach

- LIGO I
  - » detector parameters chosen as a balance between demonstrated technologies and sensitivity sufficient for plausible detection
  - » designed in the flexibility for upgrading subsystems for LIGO II
  - » advanced R & D program toward LIGO II begun in 1997

- Rate for the detection of gravitational waves from burst sources
  - » *Strain:* $h \alpha 1/d$ [*d* = source distance]
  - » *Rate:* $R \alpha d^3$
  - » $R_{LIGOII} / R_{LIGOI} > 1000$

- LIGO II
  - » the timing and the concept are driven by the large increased physics reach

LIGO
NSB Report

Barry Barish

November 17, 1994

NSB
11/17/94

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LIGO Sites

Gravitational Wave Detection Strategy

- Interferometer Sensitivity
  - ⇒ R&D Program
    - Technology Development
    - Demonstration Experiments
  - ⇒ Engineering Implementation
    - Precision Engineering Design
    - Quality Control
- Two Sites - Three Interferometers
  - ⇒ Single Interferometer ~50/hr
    - non-gaussian level
  - ⇒ Hanford (Doubles) ~1/day
    - correlated rate (x1000)
  - ⇒ Hanford + Livingston <0.1/yr
    - uncorrelated (x5000)

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Detection Strategy

Coincidences

- Two detectors separated by 3000 km
  - » coincident within difference in time of arrival for gravitational waves moving at speed of light
  - » coincident time window *D t ~ 30 msec* required

- Note that from the recently published 40m analysis:
  - » *"Observational Limit on Gravitational Waves from Binary Neutron Stars in the Galaxy"*
    - – Phys.Rev.Lett. 83 (1999) 1498
  - » candidate rate ~ 50 / hour
    - – (> 4 sigma bursts)
  - » limit after template analysis < 0.3 / hour

LIGO Plans
main activity

1996	**Construction Underway**
	-mostly civil
1997	**Facility Construction**
	-vacuum system
1998	**Interferometer Construction**
	-complete facilities
1999	**Construction Complete**
	-interferometers in vacuum
2000	**Commission Detectors**
	-first light; testing
2001	**Engineering Tests**
	-sensitivity; engineering run

LIGO
Facilities

- The Sites
- Civil Construction
- Beam Tubes
- Vacuum Systems

Civil Construction

- Characteristics
  - ⇒ Structures, Foundation, Roads, etc
    - Large and Clean Laboratory Bldgs
    - Beam Enclosures
    - Office/Lab Space
  - ⇒ Requirements
    - Seismic Stability, Noise Sources, etc
    - Cleanliness

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Civil Construction

- Characteristics
  - ⇒ Structures, Foundation, Roads, etc
    - Large and Clean Laboratory Bldgs
    - Beam Enclosures
    - Office/Lab Space
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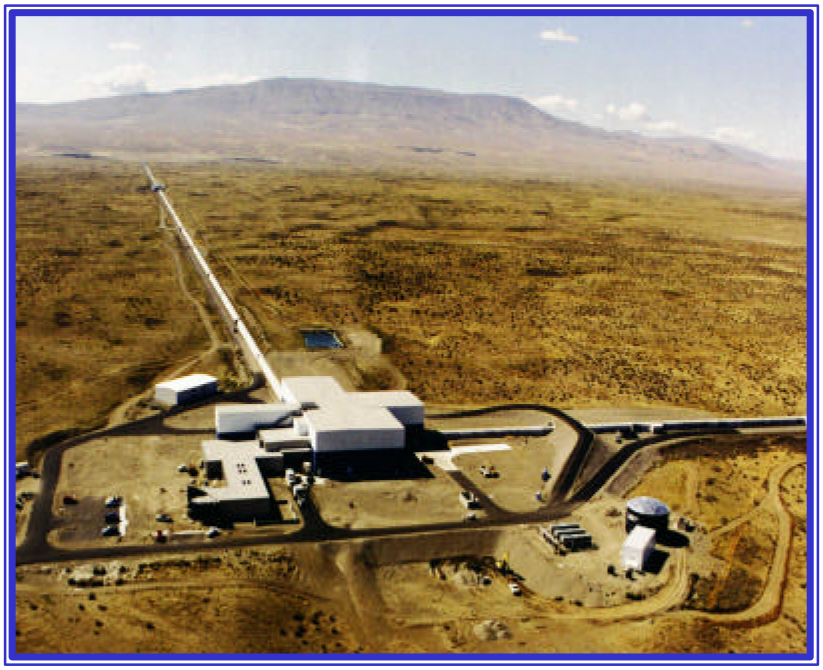
LIGO

sites



- Hanford Obseratory

- Livingston Observatory

Civil Construction
office & corner station

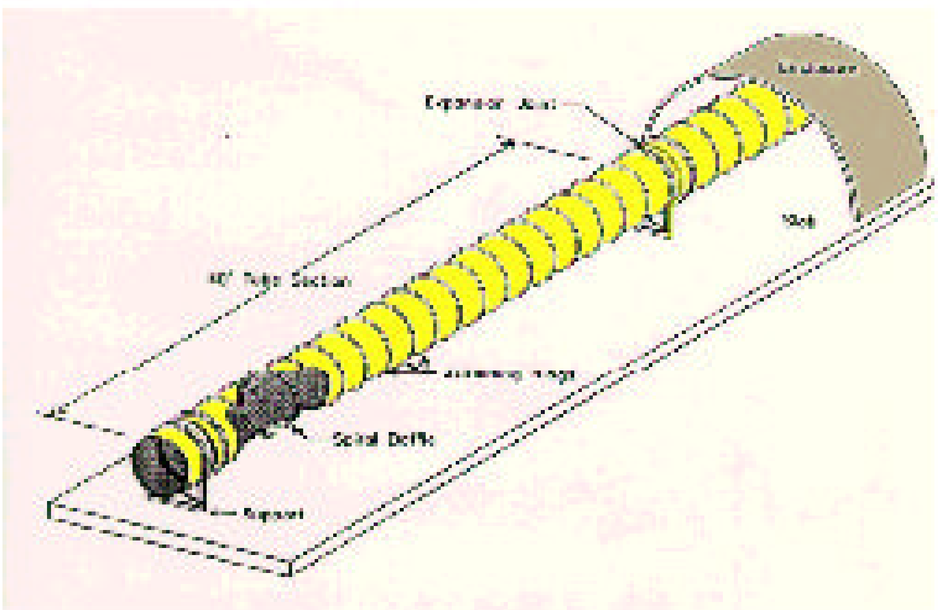
- Hanford

- Livingston

Beam Tube

- Characteristics
  - ⇒ Arm Lengths - 4km
  - ⇒ Tube Diameter - 4 ft
  - ⇒ Initial Detector
    - 10^{-6} torr Hydrogen; 10^{-7} torr Water
  - ⇒ Advanced Detectors
    - 10^{-9} torr Hydrogen; 10^{-10} torr Water
  - ⇒ Quality Control
    - (materials, welding, cleaning, etc)

Beam Tube



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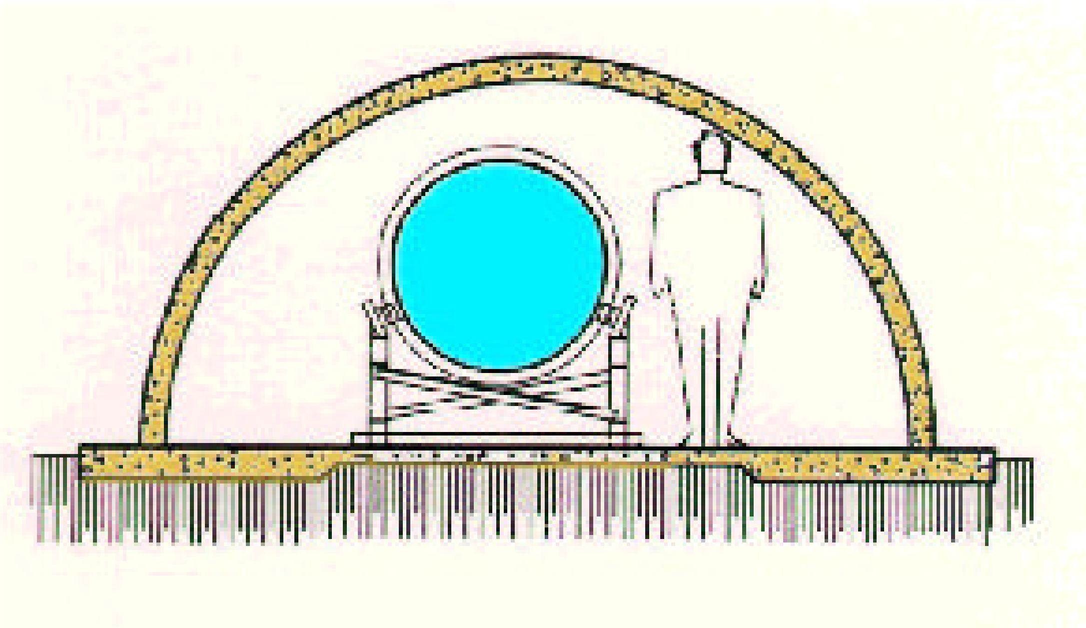
Beam Tube Enclosure



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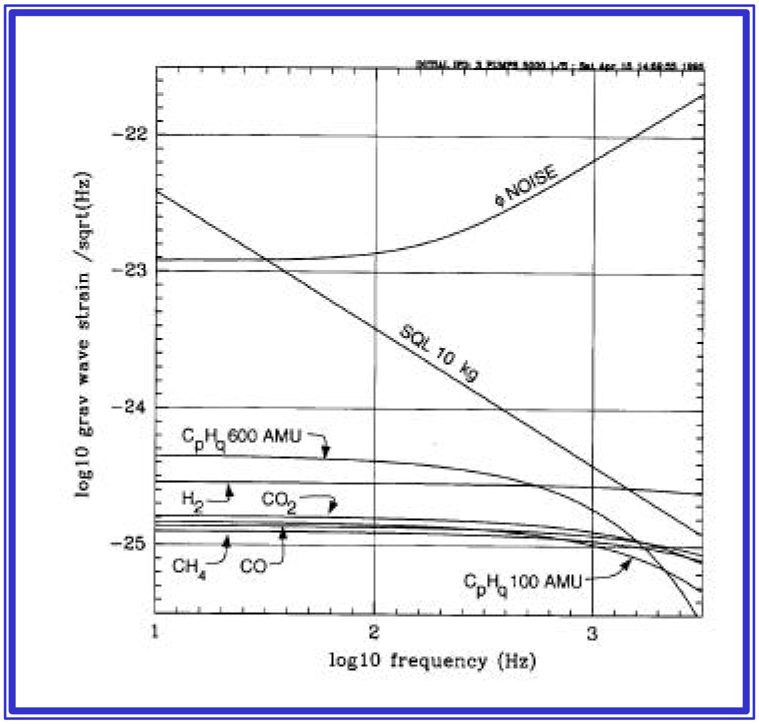
Beam Tube

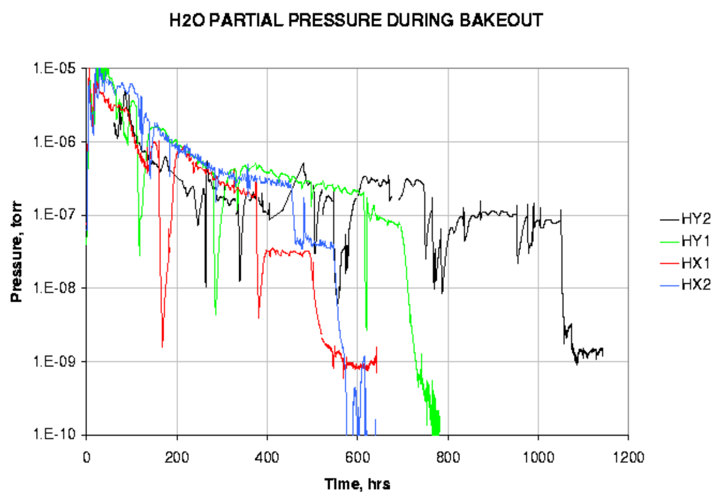
- Livingston beam tube under construction in January 1998
- 65 ft spiral welded sections
- girth welded in portable clean room in the field

Beam Tube Bakeout



Bakeout

results



Beam Tube Bakeout Results [a]

NOTE: All results except for H_2 are upper limits

		Hanford				Livingston	
Species	Goal [b]	HY2	HY1	HX1	HX2	LX2	
H_2	*4.7*	4.8	6.3	5.2	4.6	4.3	x 10^{-14} torr liters/sec/cm^2
CH_4	*48000*	< 900	< 220	< 8.8	< 95	< 40	x 10^{-20} torr liters/sec/cm^2
H_2O	*1500*	< 4	< 20	< 1.8	< 0.8	< 10	x 10^{-18} torr liters/sec/cm^2
CO	*650*	< 14	< 9	< 5.7	< 2	< 5	x 10^{-18} torr liters/sec/cm^2
CO_2	*2200*	< 40	< 18	< 2.9	< 8.5	< 8	x 10^{-19} torr liters/sec/cm^2
NO+C_2H_6	*7000*	< 2	< 14	< 6.6	< 1.0	< 1.1	x 10^{-19} torr liters/sec/cm^2
$H_nC_pO_q$	*50-2* [c]	< 15	< 8.5	< 5.3	< 0.4	< 4.3	x 10^{-19} torr liters/sec/cm^2
air leak	*1000*	< 20	< 10	< 3.5	< 16	< 7	x 10^{-11} torr liter/sec

[a] Outgassing results correct to 23 C

[b] Goal: maximum outgassing to achieve pressure equivalent to 10^{-9} torr H_2 using only pumps at stations

[c] Goal for hydrocarbons depends on weight of parent molecule; range given corresponds with 100-300 AMU

Vacuum Equipment

- Characteristics
  - ⇒ Enormous Volume (~20,000 m^3)
  - ⇒ Mostly Standard Vac. Equipment
    - 1st stage roughing - Atm -> 0.1 torr
    - 2nd stage roughing - 0.1 torr ->10^{-6} torr
    - Steady State - Ion/getter pumps.
  - ⇒ Large Gate Valves (4ft diam)
    - access and flexibility
  - ⇒ Controls and Monitoring

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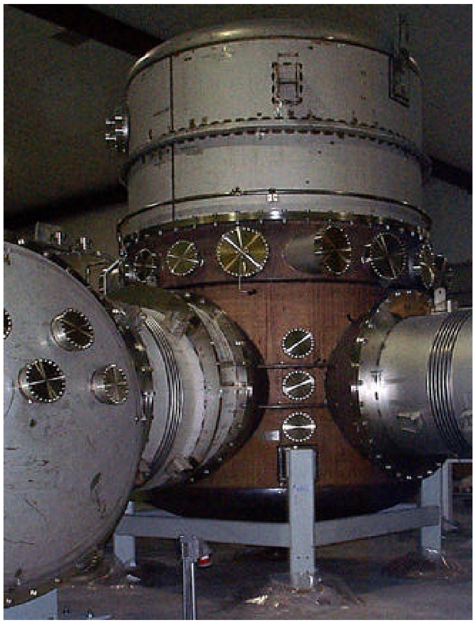
Vacuum Chambers

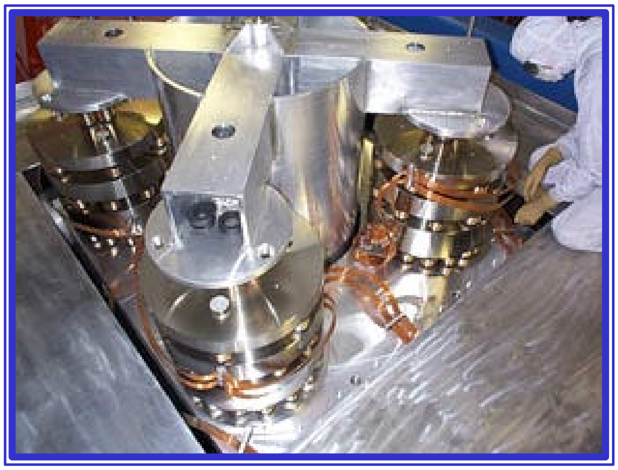


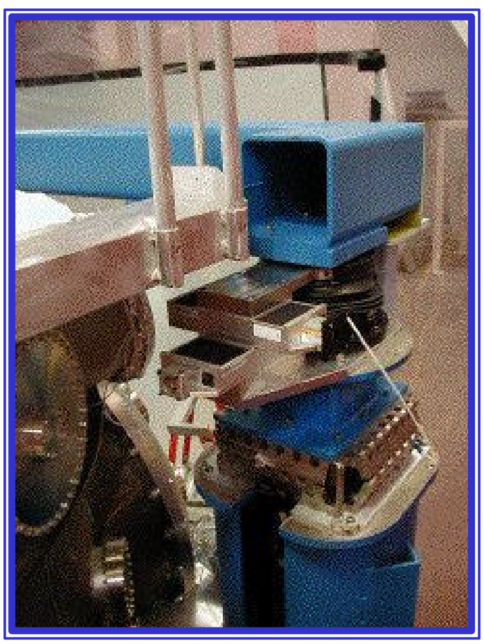
- Large Vacuum Chambers (BSC)

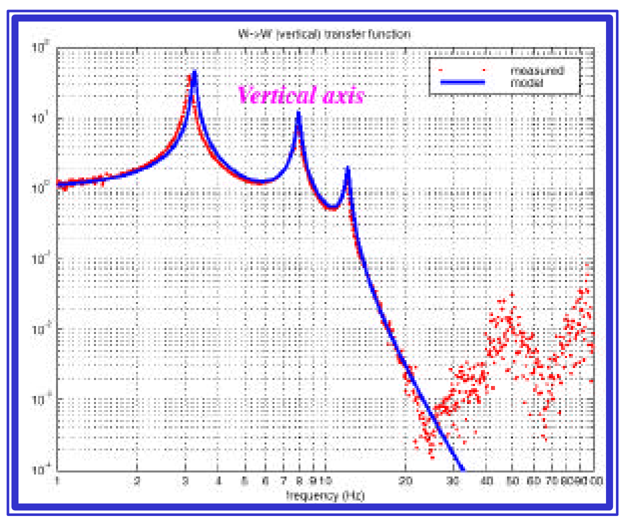
- Horizontal Access Chambers

Vacuum Equipment
Livingston Corner Station

Seismic Isolation

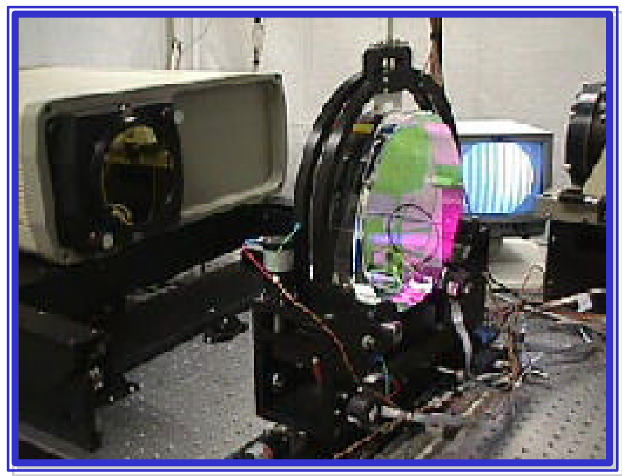




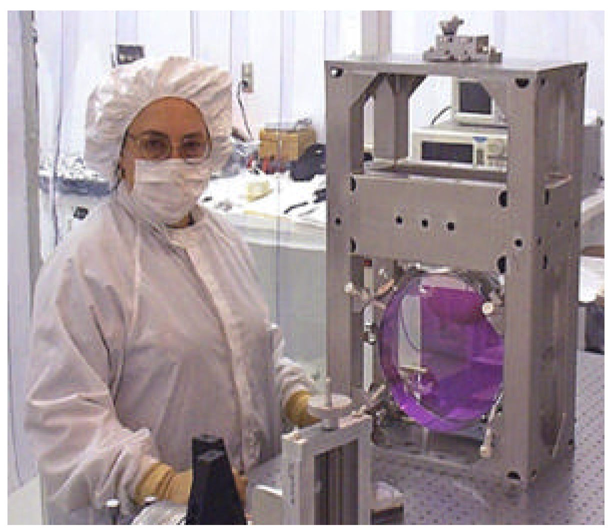


Optics

- All optics polished & coated
  - » Microroughness within spec. (<10 ppm scatter)
  - » ROC within spec. ($\delta R/R < 5\%$, except for BS)
  - » Coating defects within spec. (pt. defects < 2 ppm, 10 optics tested)
  - » Coating absorption within spec. (<1 ppm, 40 optics tested)



- LHO 2km interferometer:
  - » All optics at site, complete
- LLO:
  - » Characterization in progress at Caltech
  - » Recycling mirror delivered for installation



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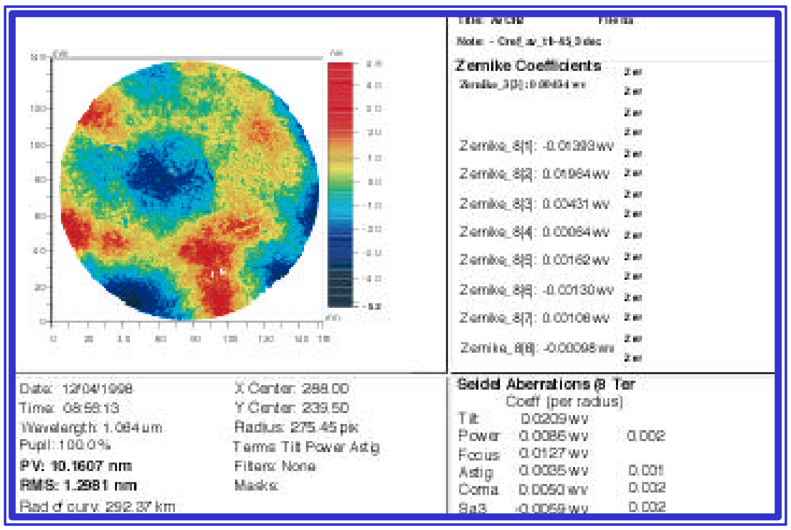
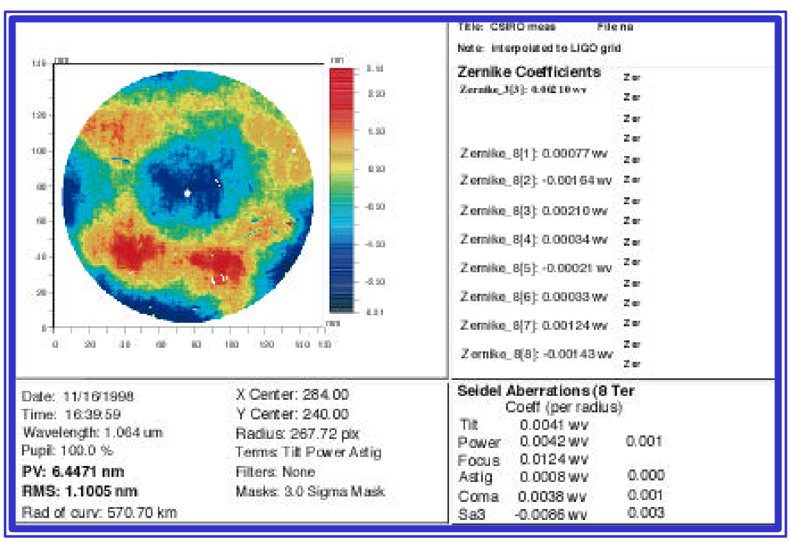
metrology



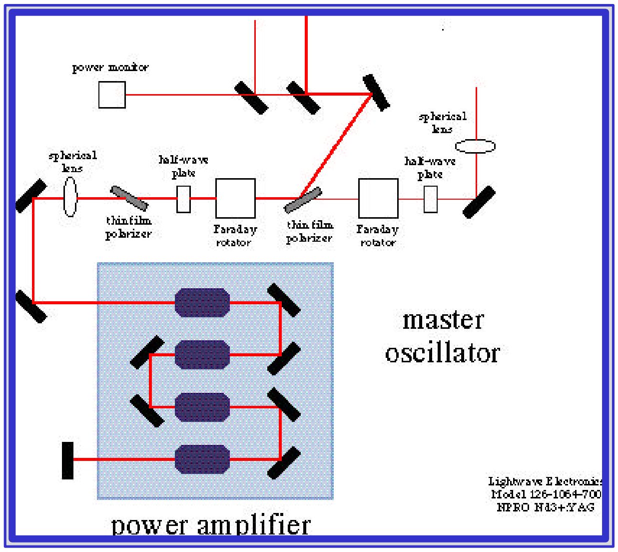
- Caltech



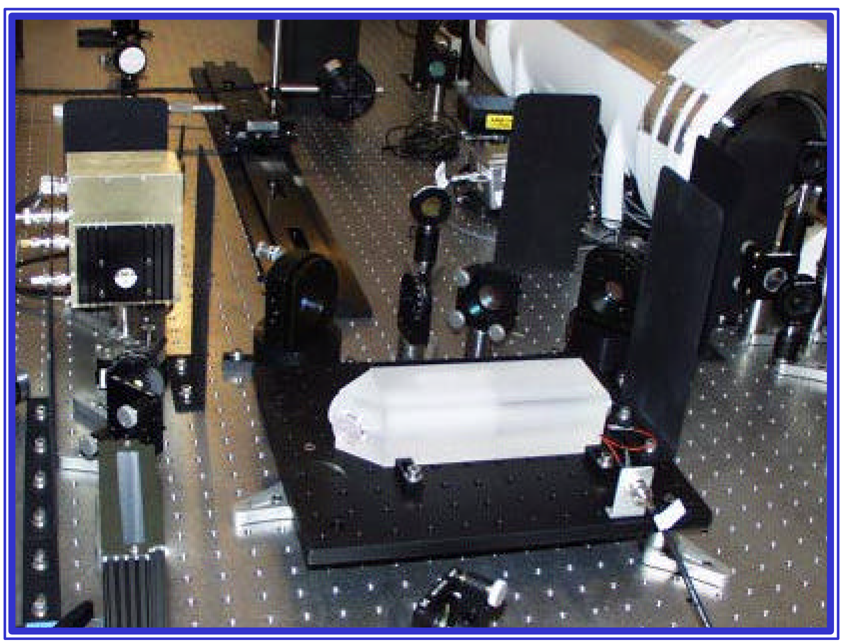
- CSIRO

LIGO

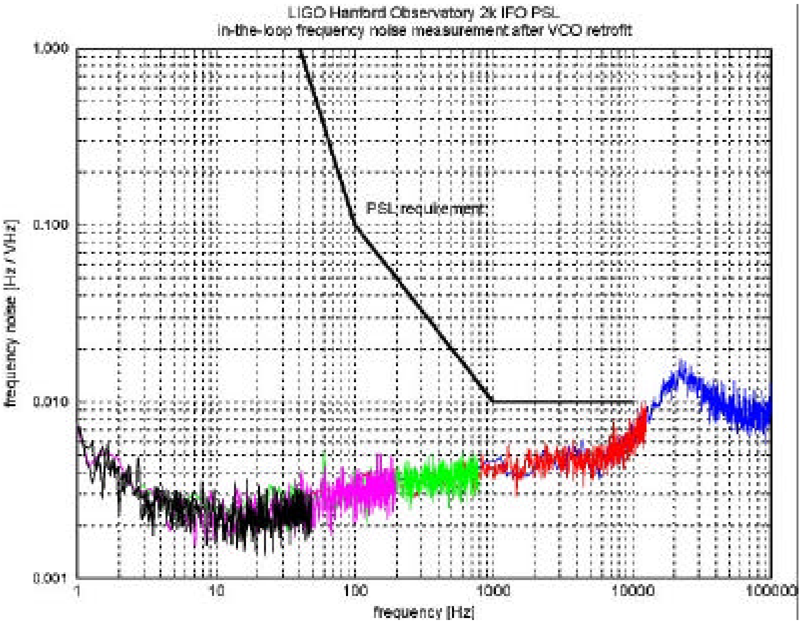
Laser



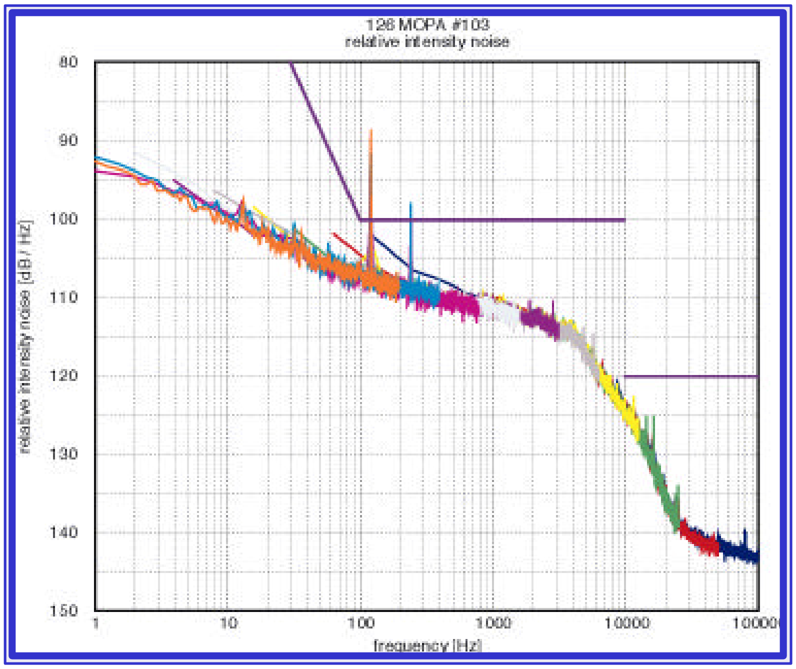
- Nd:YAG
- 1.064 µm
- Output power > 8W in TEM00 mode



Laser Prestabilization



- frequency noise: $\delta\nu(f) < 10^{-2} Hz/Hz^{1/2}$ $40Hz<f<10KHz$



- intensity noise: $\delta I(f)/I < 10^{-6}/Hz^{1/2}$, $40 Hz<f<10 KHz$

Status and Plans

- The LIGO facilities are essentially complete (fall 1999), as stated to the NSB in 1994. This has motivated us to host a dedication ceremony in Livingston (Nov 11-12).
- The 'performance' of the facilities meets the LIGO requirements and will support LIGO II and beyond.
- The detector subsystem construction is far along and meets our performance requirements.
- The detector commissioning is underway. The planning milestones will allow sufficient validation from LIGO I before the LIGO II project funds are awarded.

Project Structure

- Traditional Structure
  - ⇒ "Product" Oriented
  - ⇒ Parallels WBS System
- Project Management (top level)
  - ⇒ Overall Responsibility for LIGO
    - NSF;MIT; Caltech
  - ⇒ Integration of LIGO
    - Systems Eng; Integration; Modeling
  - ⇒ Project Controls
    - Cost/Schedule
    - Configuration Management
    - Contingency Management
- Group and Task Leaders
  - ⇒ Responsible for Deliverables

Project Management Personnel

- Reorganization/Strengthening
  - ⇒ New Structure and Top Management
  - ⇒ Augmented Staff
    - Total: (+22 all levels; 4+ yrs; +$16M)
- Key Management Personnel
  - ⇒ Principal Investigator
    - B. Barish (Caltech) March 94
  - ⇒ Project Manager
    - G. Sanders (LANL) Aug 94
  - ⇒ Project Controls
    - P. Lindquist (CEBAF) Oct 94
  - ⇒ Project Integration
    - A. Lazzarini (KAMAN Corp) Oct 94
- Other Important Additions

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Cost Estimate

- LIGO Costing Bases
  - ⇒ New WBS - Products, Manpower
  - ⇒ Contingency Methodology
  - ⇒ Estimate in $FY94, then escalated
- Cost Estimate Documentation
  - ⇒ Cost Book; Baseline 1; Summaries
- Cost Estimate (All Costs)
  - ⇒ Pre-Construct R&D (1991) $ 4.6M
  - ⇒ Construct (incl R&D) $292.1M
  - ⇒ Operations (thru 2001) $68.7M

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LIGO

facilities milestones

Milestone Description	PMP	Projection/ Actual	PMP	Projection/ Actual
	Hanford		Livingston	
Initiate Site Development	Mar-94	Mar-94	Aug-95	Jun-95
Beam Tube Final Design Review	Apr-94	Apr-94	Apr-94	Apr-94
Select A&E Contractor	Nov-94	Nov-94	Nov-94	Nov-94
Complete Beam Tube Qualification Test	Feb-95	Apr-95	Feb-95	Apr-95
Select Vacuum Equipment Contractor	Mar-95	Jul-95	Mar-95	Jul-95
Complete Performance Measurement Baseline	Apr-95	Apr-95	Apr-95	Apr-95
Initiate Beam Tube Fabrication	Oct-95	Dec-95	Oct-95	Dec-95
Initiate Slab Construction	Oct-95	Feb-96	Jan-97	Jan-97
Initiate Building Construction	Jun-96	Jul-96	Jan-97	Jan-97
Joint Occupancy	Sep-97	Oct-97	Mar-98	Feb-98
Accept Tubes and Covers	Mar-98	Mar-98	Mar-99	Oct-98
Beneficial Occupancy	Mar-98	Mar-98	Sep-98	Dec-98
Accept Vacuum Equipment	Mar-98	Nov-98	Sep-98	Jan-99
Initiate Facility Shakedown	Mar-98	Nov-98	Mar-99	Jan-99

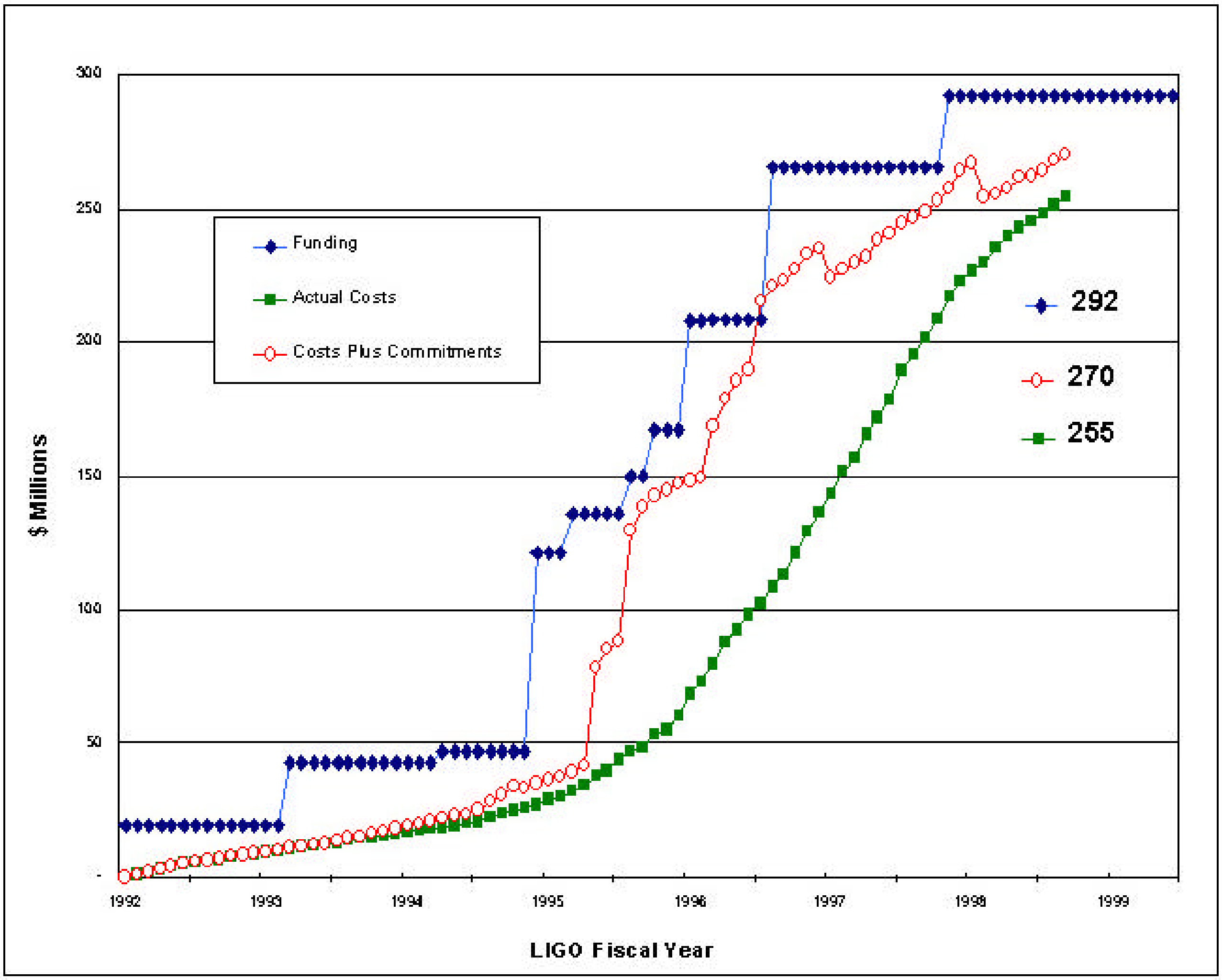
LIGO

detector milestones

Milestone Description	PMP	Projection/ Actual
Beam Splitter Chamber Stack Final Design Review	Apr-98	Aug-98
Core Optics Support Final Design Review	Feb-98	Nov-98
Horizontal Access Module Final Design Review	Apr-98	Jun-98
Core Optics Components Final Design Review	Dec-97	May-98
Input/Output Optics Final Design Review	Apr-98	Mar-98
Pre-Stabilized Laser Final Design Review	Aug-98	Mar-99
Alignment Sensing Final Design Review	Apr-98	Jul-98
Length Sensing Final Design Review	May-98	Jul-98
Washington Controls Area Net Ready to Install	Apr-98	Mar-98
Control and Data System (CDS) Data Acquisition Fi	Apr-98	May-98
Physics Environment Monitoring Final Design Reviev	Jun-98	Oct-97
Detector System Preliminary Design Review	Dec-97	Oct-98
Begin Washington Interferometer Installation	Jul-98	Jul-98
Begin Louisiana Interferometer Installation	Jan-99	Jan-99
Begin Coincidence Tests	Dec-00	Dec-00

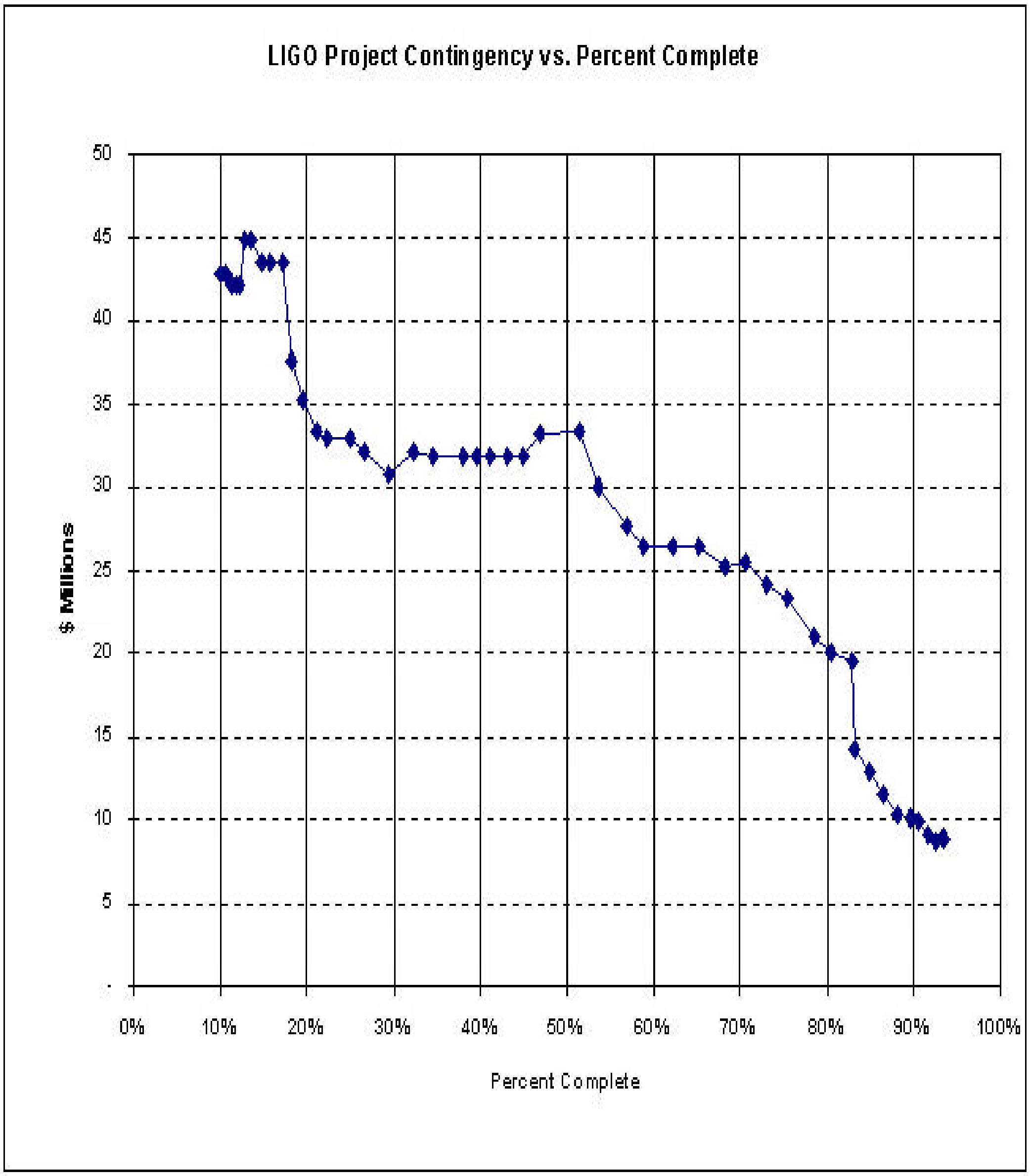
LIGO

costs & commitments



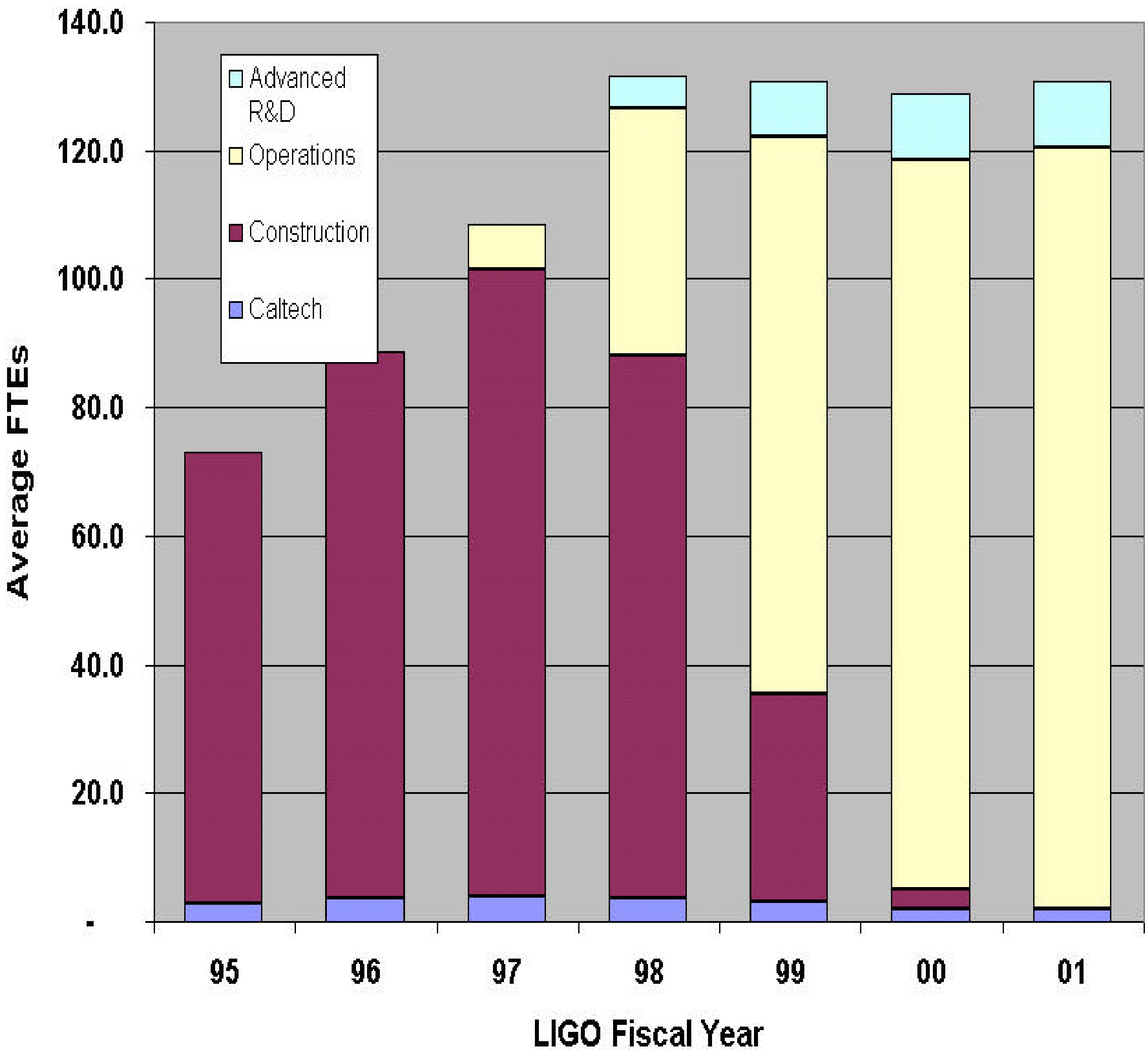
LIGO

contingency vs percent complete



Staffing

labor distribution projections



Project Status and Plans

- Ready for Construction Phase
  - ⇒ Acquisition Plans; Designs; etc
- Construction Project
  - ⇒ Complete in 1999
- Operations
  - ⇒ Begins as Construction is Completed
  - ⇒ Operational during 2000
  - ⇒ Design Goal by end of 2001

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The Path to LIGO II

LIGO II

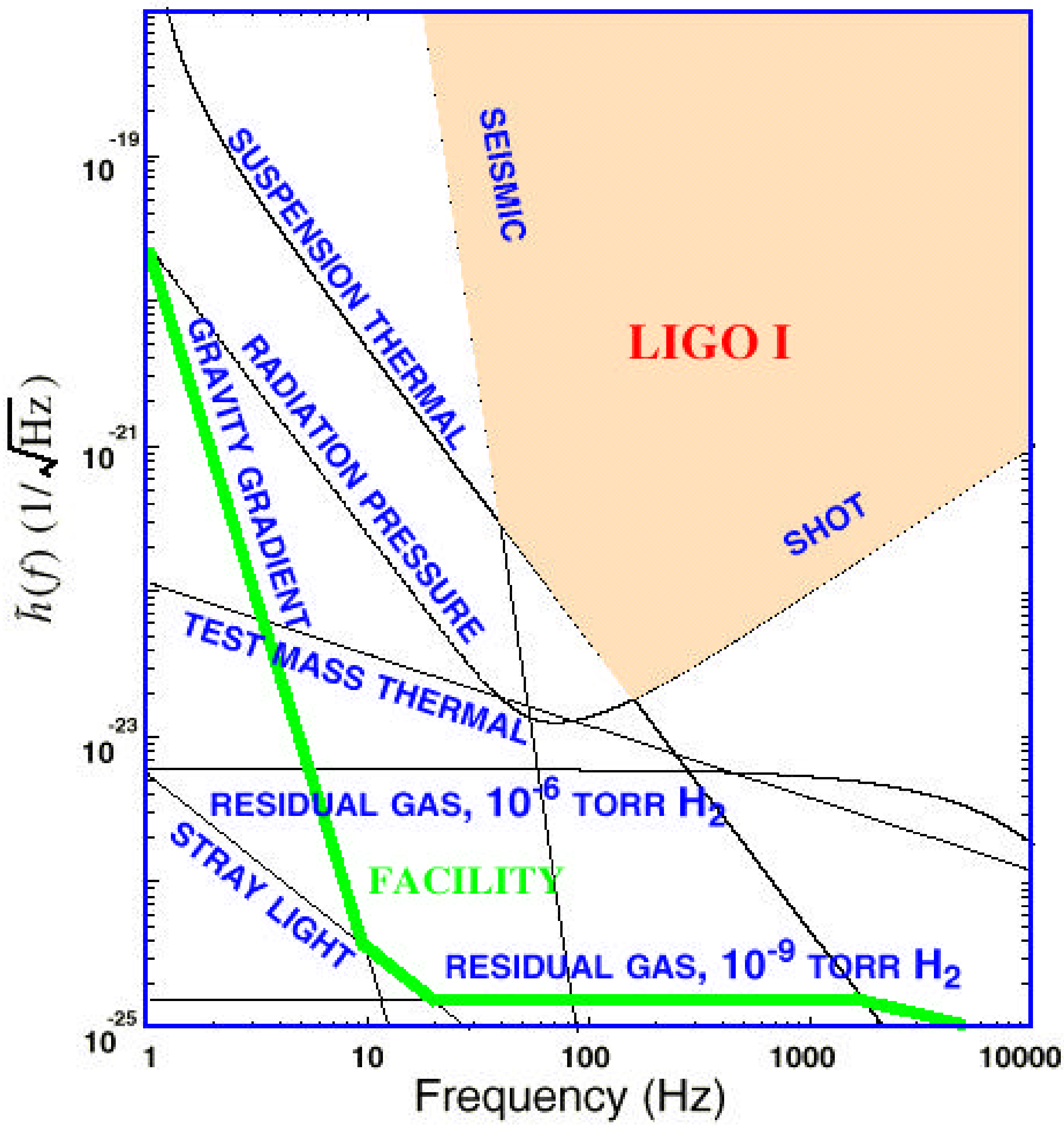
- LIGO Scientific Collaboration (LSC)
- Advanced R & D toward LIGO II
  - » funded in LIGO Lab and LSC groups since 1998 at level of ~$6M/yr
- LSC White Paper (concept for LIGO II)
  - » the physics reach (K. Thorne)
  - » the technical reach (R. Weiss)
  - » reference design (Strain, Gustafson and Shoemaker)
- Conceptual Project Book (Sanders)
  - – cost & management
  - – schedule, manpower and impact on LIGO I
  - – installation and commissioning
- Other aspects of LIGO II (closed session)
  - » international collaboration (GEO, ACIGA)
  - » electronics and computing (Lazzarini)

LIGO Scientific Collaboration

Institution	Heads	FTE	LIGO I - Heads	LIGO I - FTE
ACIGA -Australia	23	14.9	0	0
Caltech - CACR	3	0.7	3	0.7
Caltech - CaRT	8	3.4	8	3.4
Caltech - CEGG	2	1.6	1	0
Cornell	2	1.8	2	1.8
Univ of Florida	12	9.2	12	9.2
GEO	34	19.2	2	0.3
NAOJ - TAMA	3	1.1	0	0
JILA	6	3.1	0	0
LSU	5	3.4	0	0
Lousiana Tech	6	1.2	6	1.2
Univ of Michigan	2	1.5	2	1.5
Moscow State University	11	10	0	0
Oregon University	7	4.4	7	4.4
Institute of Applied Physics - Russia	12	9.5	0	0
Stanford University	21	14.3	0	0
Syracuse	5	5	1	1
Univ of Texas - Brownsville	2	0.5	2	0.5
Univ of Wisconsin - Milwaukee	7	4.5	7	4.5
Total : non LIGO Laboratory	171	109.3	53	28.5
LIGO Hanford	12	12	12	12
LIGO Livingston	7	7	7	7
LIGO MIT	17	17	17	17
LIGO Caltech	52	51	52	51
Total : LIGO Laboratory	88	87	88	87
Total LSC	259	196.3	133	115.5

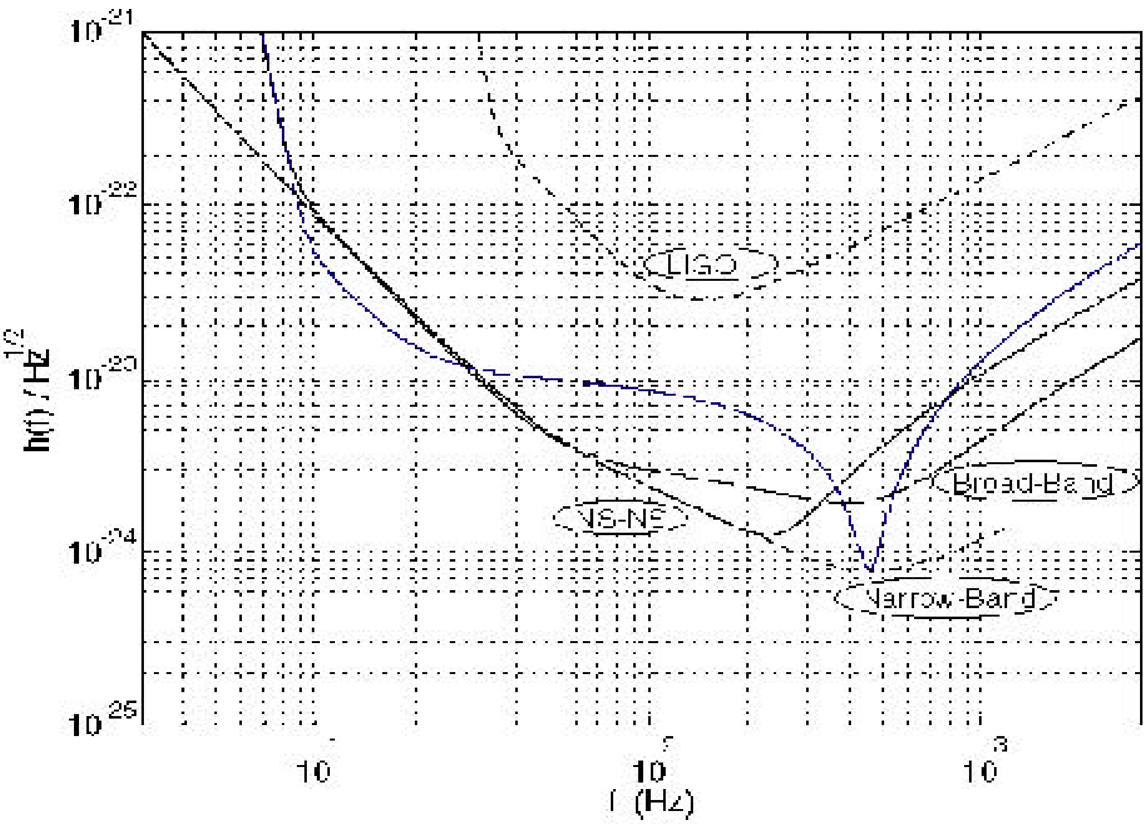
LIGO I to LIGO II

the noise floor



LIGO II

reference design



- **Features**
  - » increased laser power
  - » improved suspension
  - » improved seismic isolation
  - » new test mass material
  - » new optical configuration

LIGO Science

physics schedule

- Run I (LIGO I ~2002-2005)
  - » begins after $h \sim 10^{-21}$ attained
  - » two year run allows first neutron binary search (live time ~ *1 yr*)
  - » plus one extra year for special running or coincidences with Virgo etc.
  - » LIGO I Collaboration
- Run II (LIGO II ~2007-2009)
  - » design sensitivity $h \sim 10^{-22}$
  - » rate > 1000 x LIGO I $\Longrightarrow$ **1 day to exceed Run 1**
  - » broad LSC participation in implementation
- Advanced Detectors (> 2010)
  - » sensitivity $h \sim 10^{-23}$?
  - » not limited by noise floor from facilities
  - » new optical configurations, new vacuum chambers, floor space, etc