LIGO

LIGO
Overview

Barry Barish

NSF Annual Review

23-Oct-02

LIGO

schedule and plan

Primary Activities

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 $h \sim 10^{-21}$)
2006+	Begin 'Advanced LIGO' installation

LIGO

Oct 02

LIGO Scientific Collaboration

LSC Institutional Membership

44 collaborating groups > 400 collaborators

University of Adelaide ACIGA
Australian National University ACIGA
Balearic Islands University - Spain
California State Dominquez Hills
Caltech CACR
Caltech LIGO
Caltech Experimental Gravitation CEGG
Caltech Theory CART
University of Cardiff UK GEO
Carleton College
Cornell University
Fermi National Laboratory
University of Florida @ Gainesville
Glasgow University GEO
NASA-Goddard Spaceflight Center
University of Hannover GEO
Hobart – Williams University
India-IUCAA
IAP Nizhny Novgorod
Iowa State University
Joint Institute of Laboratory Astrophysics
Salish Kootenai College

LIGO Livingston LIGOLA
LIGO Hanford LIGOWA
Loyola New Orleans
Louisiana State University
Louisiana Tech University
MIT LIGO
Max Planck (Garching) 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

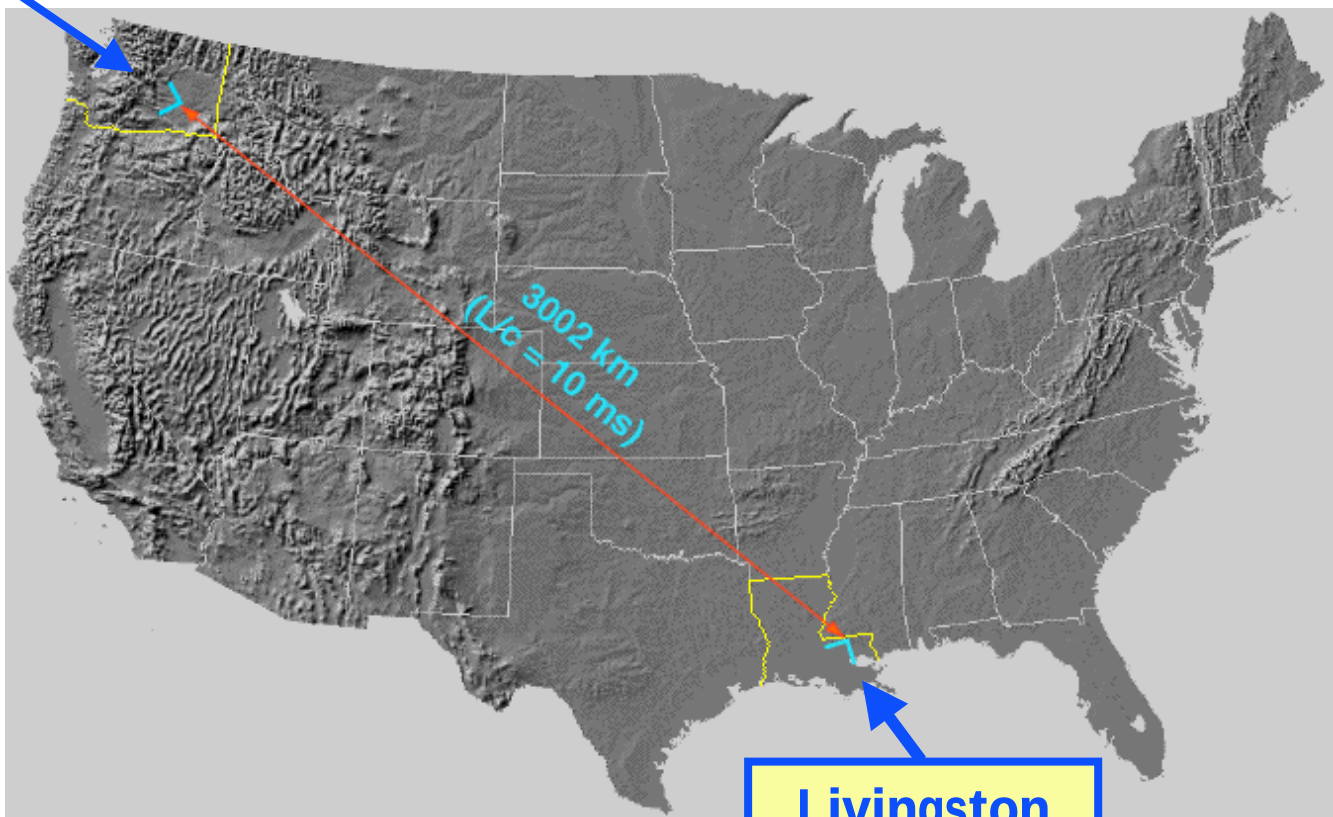
International

India, Russia, Germany, U.K, Japan, Spain and Australia.

The international partners are involved in all aspects of the LIGO research program.

LIGO

LIGO Observatories



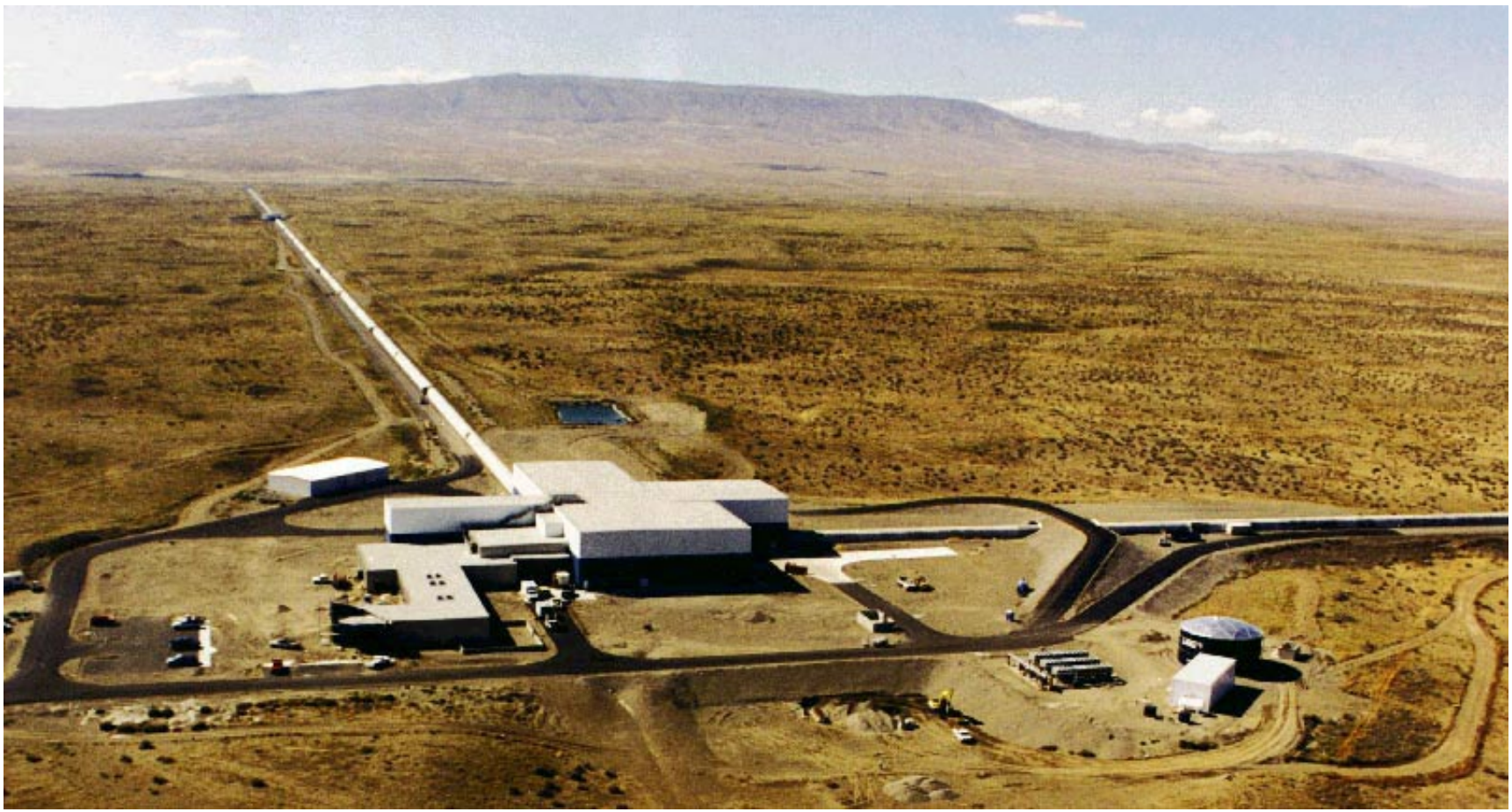
LIGO

Coincidences between Sites

- **Time Window**
  - » Separation ~ 3020 km ($\Delta\tau \approx \pm 10$ msec)
- **Two Sites – Three interferometers**
  - » Single interferometer non-gaussian level ~50/hour
  - » Local coincidence - Hanford 2K and 4K (÷~1000) ~1/day
  - » Hanford/Livingston coincidence (uncorrelated) <0.1/yr
  - » GEO / TAMA coincidences further reduces the false signal rate
- **Data (continuous time-frequency record)**
  - » Gravitational wave signal 0.2MB/sec
  - » Total data recorded 9 MB/sec
- **Gravitational Wave Signal Extraction**
  - » Signal from noise (noise analysis, vetoes, coincidences, etc)

LIGO Livingston Observatory

LIGO Hanford Observatory



Beam Pipe and Enclosure

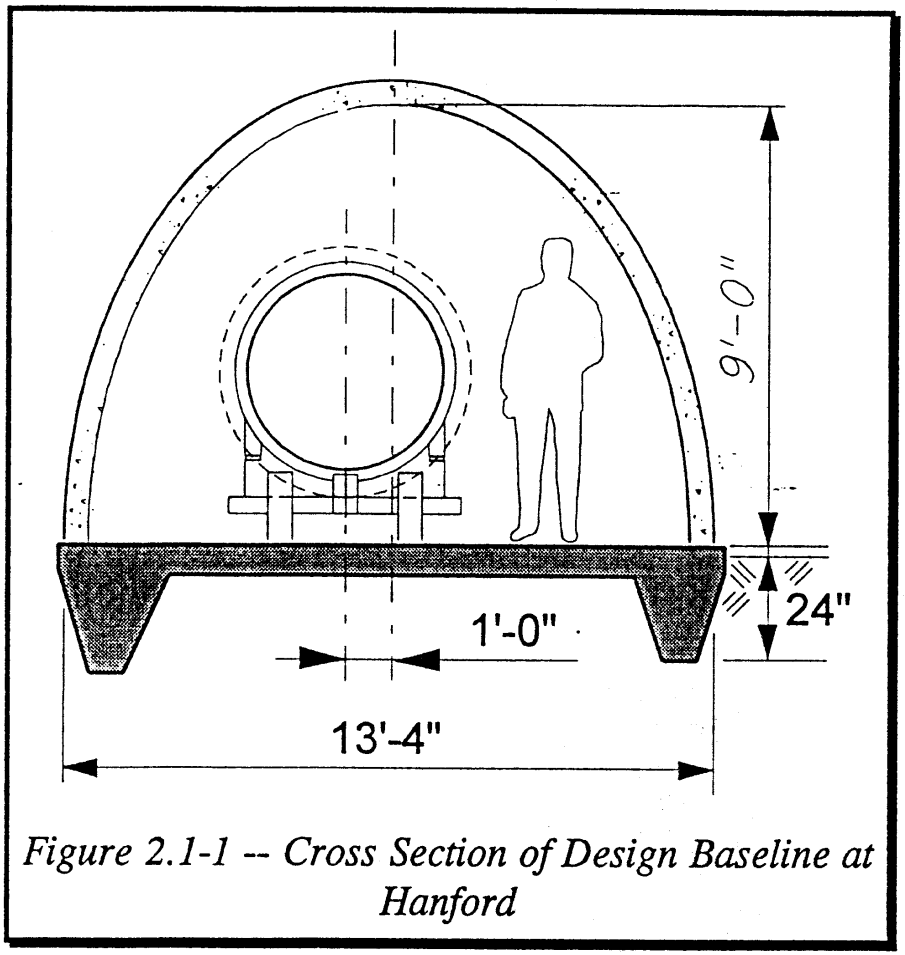
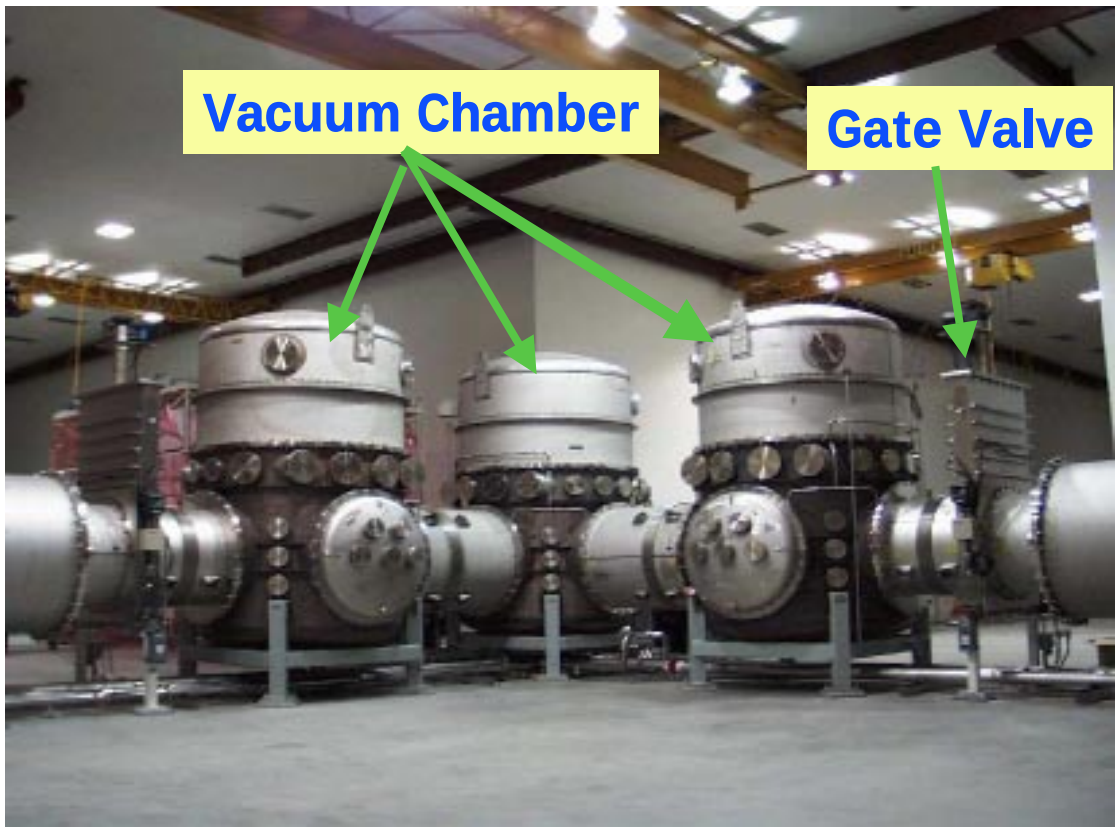


Figure 2.1-1 -- Cross Section of Design Baseline at Hanford

- **Minimal Enclosure (no services)**
- **Beam Pipe**
  - » **1.2m diam; 3 mm stainless**
  - » **65 ft spiral weld sections**
  - » **50 km of weld (NO LEAKS!)**

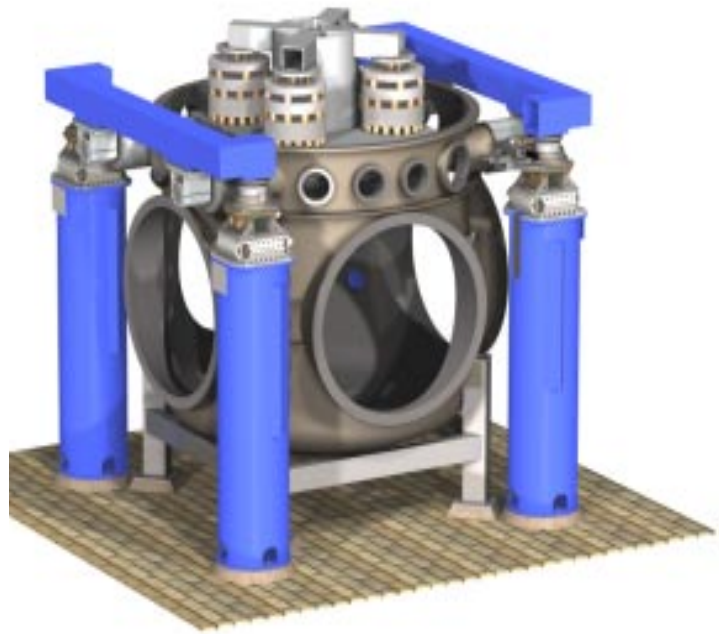
Vacuum Chambers and Seismic Isolation

Vacuum Chambers



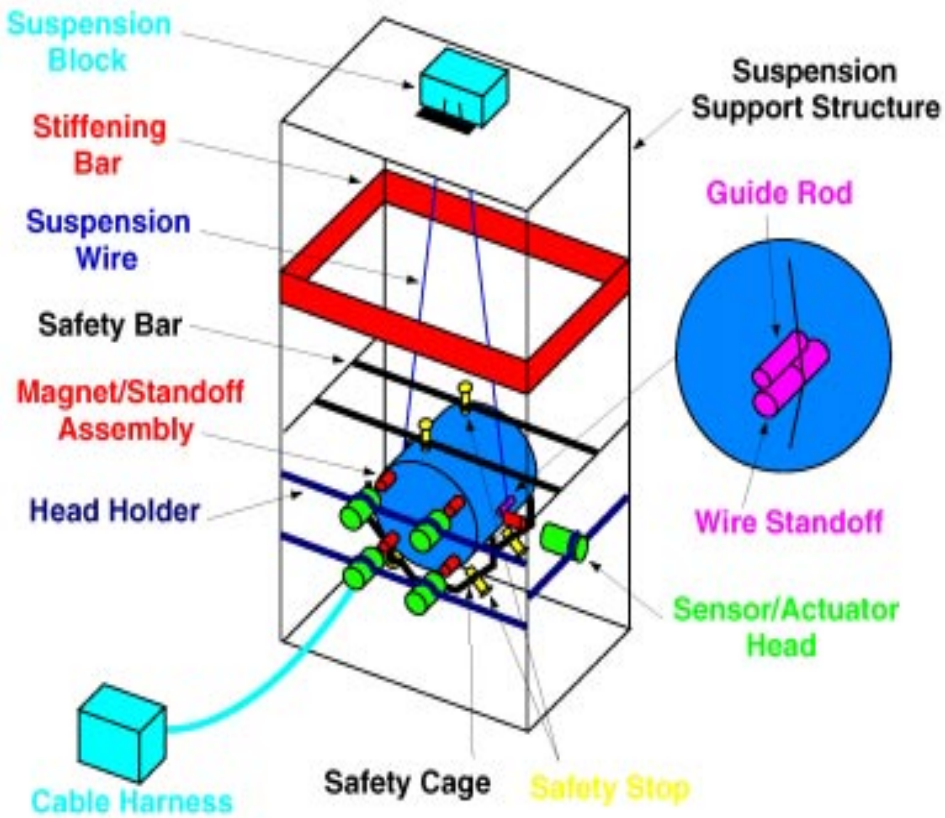
Constrained Layer Damped Springs

Passive Isolation

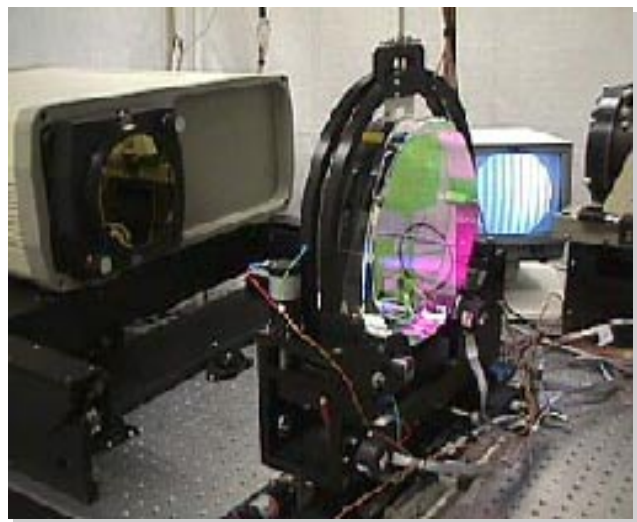


LIGO I Suspension and Optics

Single suspension 0.31mm music wire



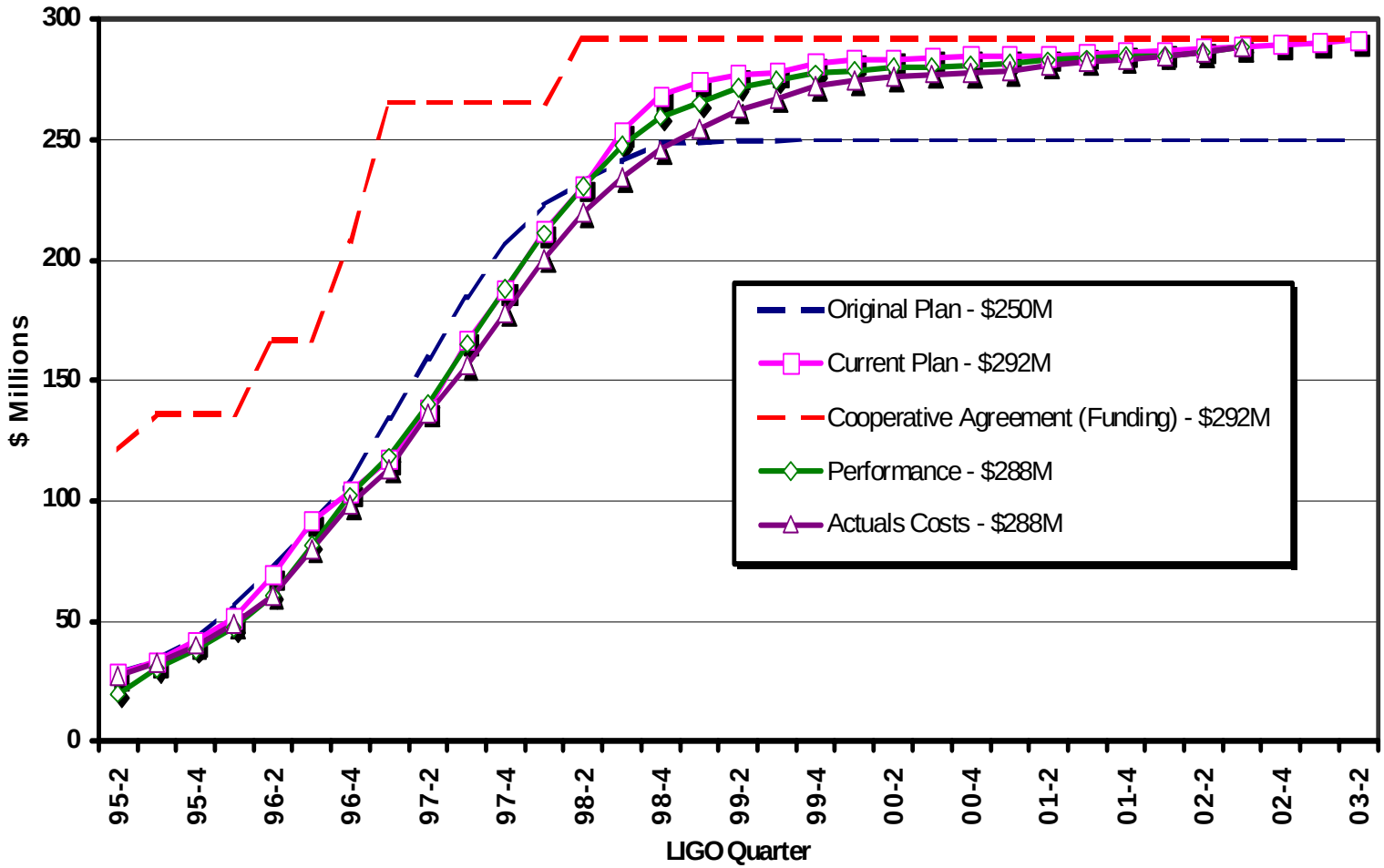
fused silica



Surface figure = λ/6000

- **surface uniformity < 1nm rms**
- **scatter < 50 ppm**
- **absorption < 2 ppm**
- **internal Q's > 2 10^6**

Construction Performance Chart



Construction Project Status

Sept 02

- **Total Funding: $292.1 million**
- **Actual Costs and Encumbrances: $288.9 million**
- **Percent Complete: 98.6%**
- **Estimate-to-Complete: $3.2 million**
  - » **LDAS Hardware: $2.5 million**
  - » **Detector: $0.5 million**
  - » **Livingston Building: $0.2 million**

LIGO

Operations
goals and priorities

- **Interferometer performance**
  - » Integrate commissioning and data taking consistent with obtaining one year of integrated data at $h = 10^{-21}$ by end of 2006
- **Physics results from LIGO I**
  - » Initial upper limit results by early 2003
  - » First search results in 2004
  - » Reach LIGO I goals by 2007
- **Advanced LIGO**
  - » Prepare advanced LIGO proposal this fall
  - » International collaboration and broad LSC participation
  - » Advanced LIGO installation beginning by 2007

Proposed 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" Proposed 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
- Our working assumption is that $33M will be awarded in 2003
  - » Priority for commissioning and toward LIGO I 24x7 Operations,

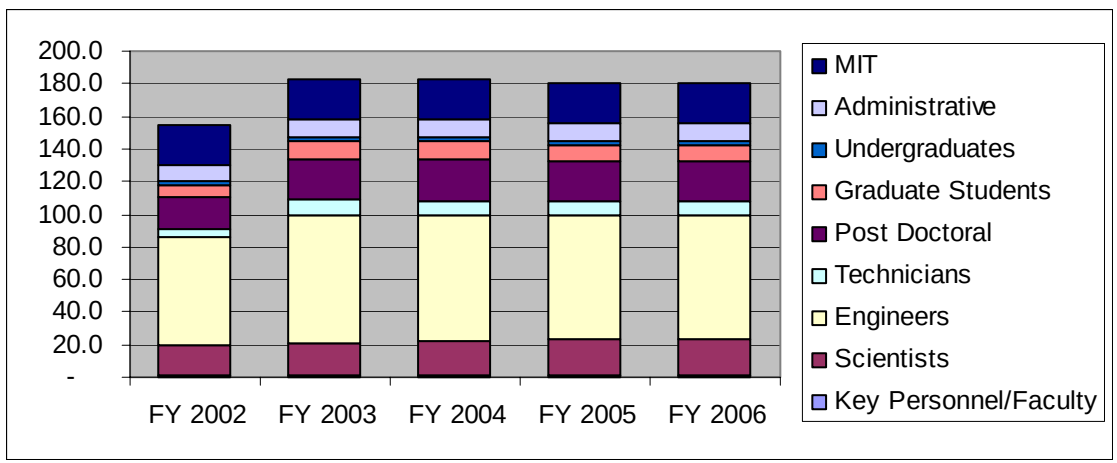
	FY 2002 ($M)	FY 2003 ($M)	FY 2004 ($M)	FY 2005 ($M)	FY 2006 ($M)
Operations	$24	$29	$30	$30	$30
Advanced R&D	$4	$4	$3	$3	$3

+ $5M

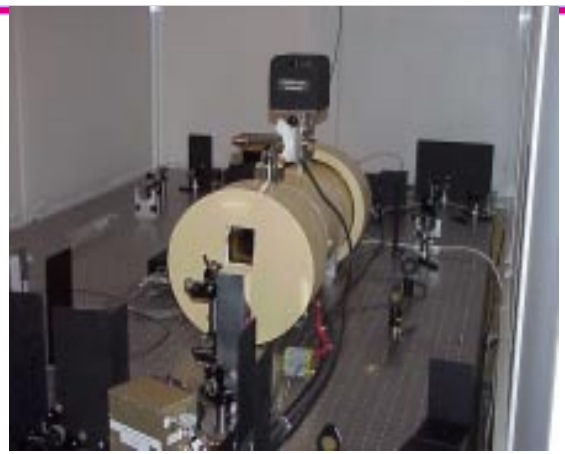
Staff

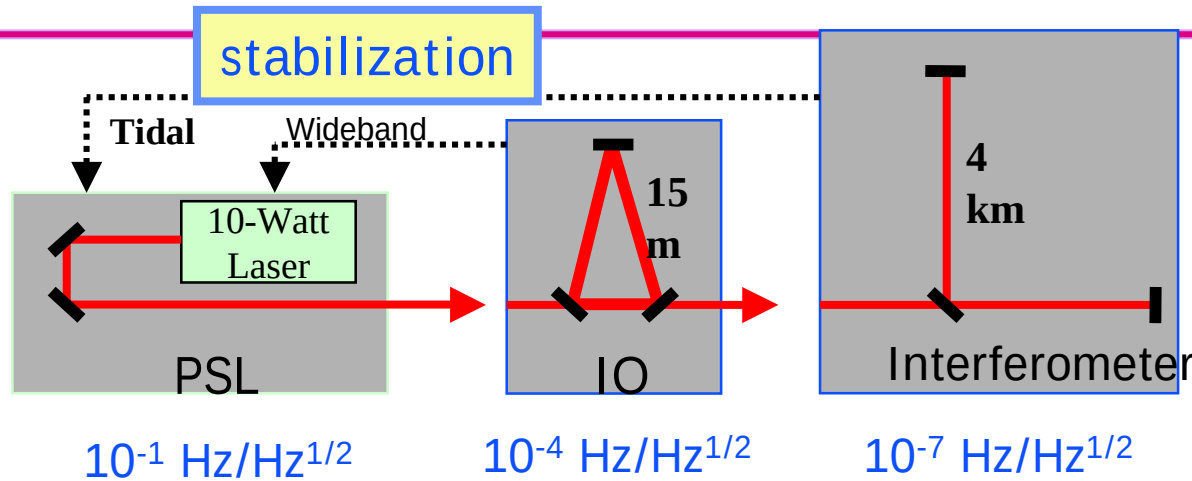
budgeted

	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006
Key Personnel/Faculty	1.3	1.3	1.3	1.3	1.3
Scientists	17.8	19.8	20.8	21.8	21.8
Engineers	66.3	78.8	77.3	75.8	75.8
Technicians	6.0	9.0	8.5	9.0	9.0
Post Doctoral	18.8	25.3	25.8	24.3	24.3
Graduate Students	7.0	11.0	11.0	10.0	10.0
Undergraduates	2.5	2.5	2.5	2.5	2.5
Administrative	10.4	10.7	10.7	10.7	10.7
MIT	25.0	25.0	25.0	25.0	25.0
Total	155.1	183.3	182.8	180.3	180.3



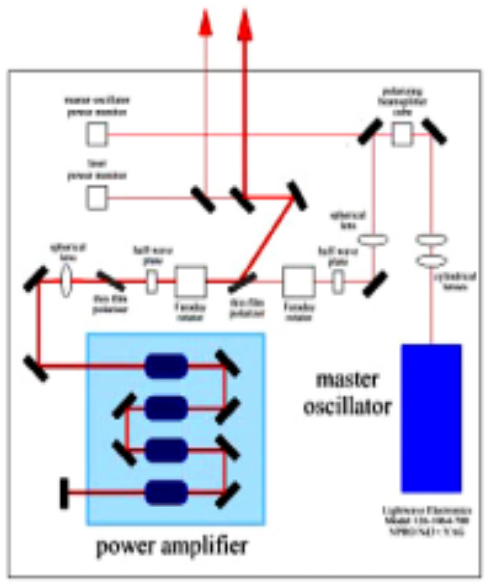
LIGO Commissioning LIGO Subsystems

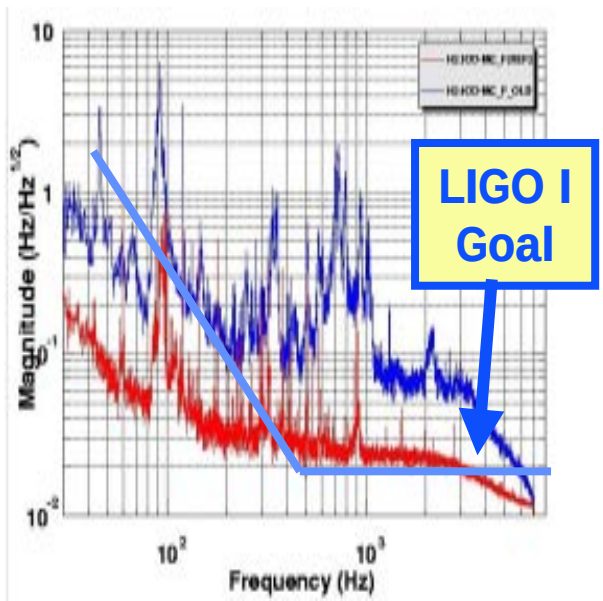




10^{-1} Hz/Hz$^{1/2}$ 10^{-4} Hz/Hz$^{1/2}$ 10^{-7} Hz/Hz$^{1/2}$

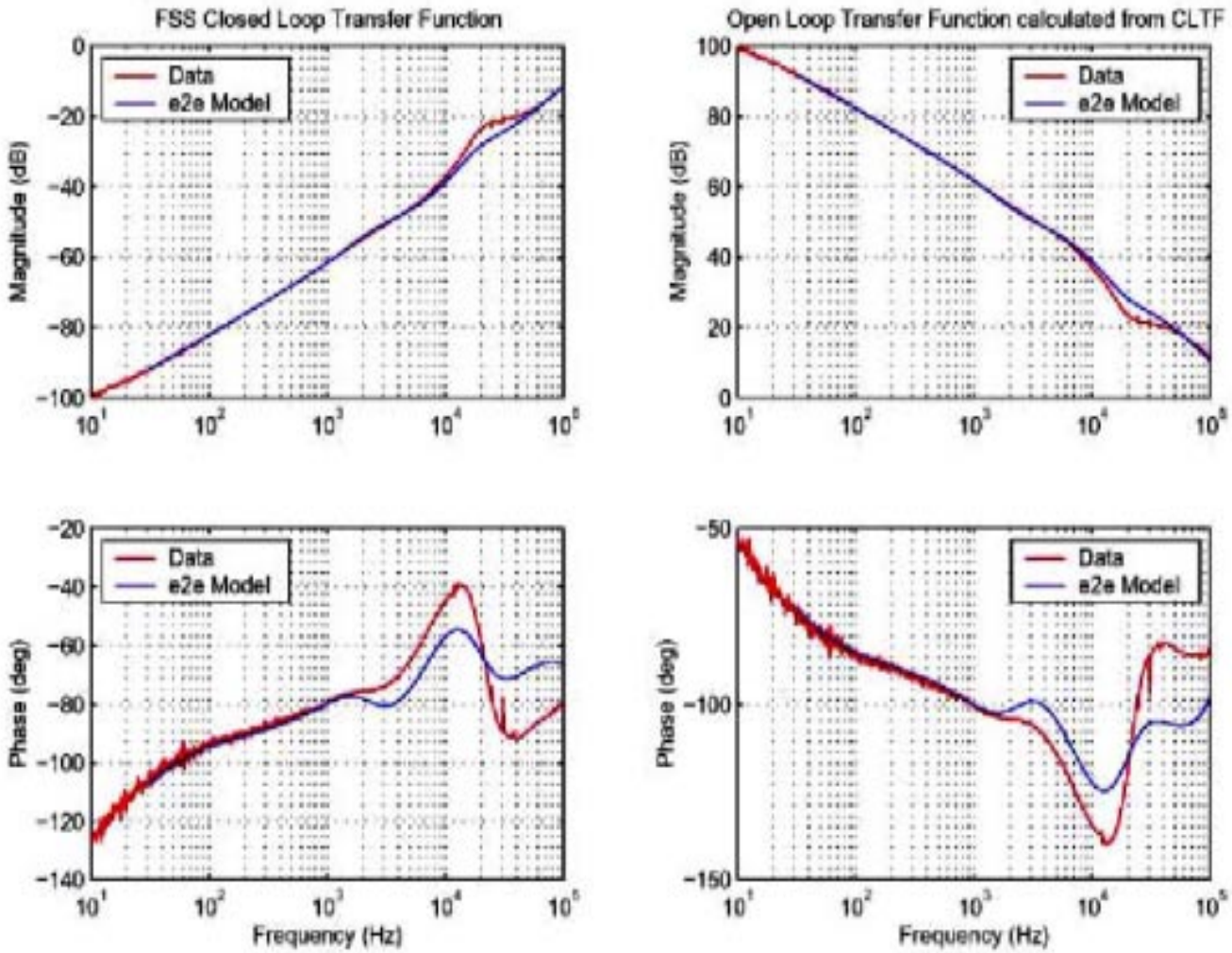
Nd:Yag 1.064 mm
Output power >8 Watt
TEM00 mode





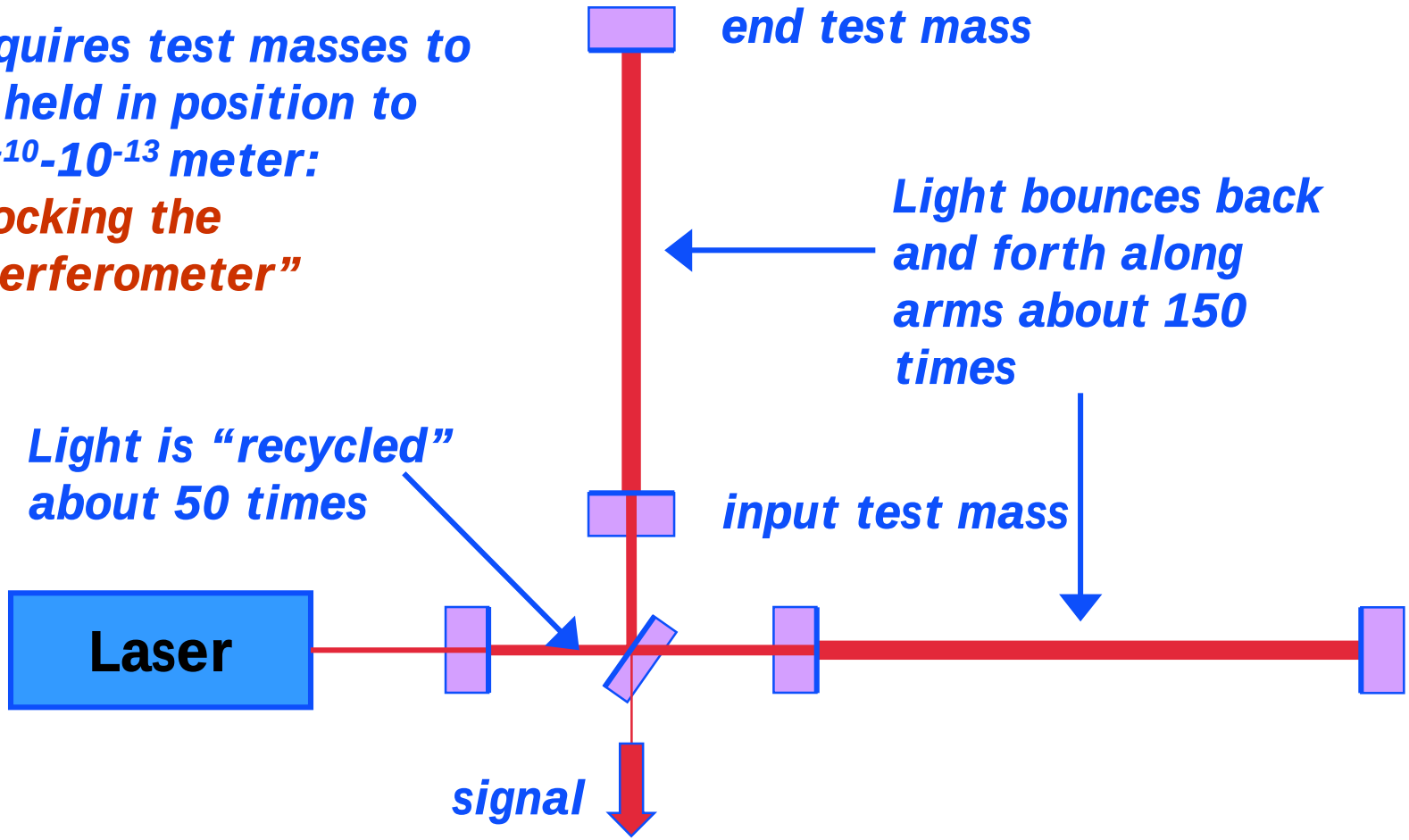
LIGO Prestabilized Laser

data vs simulation

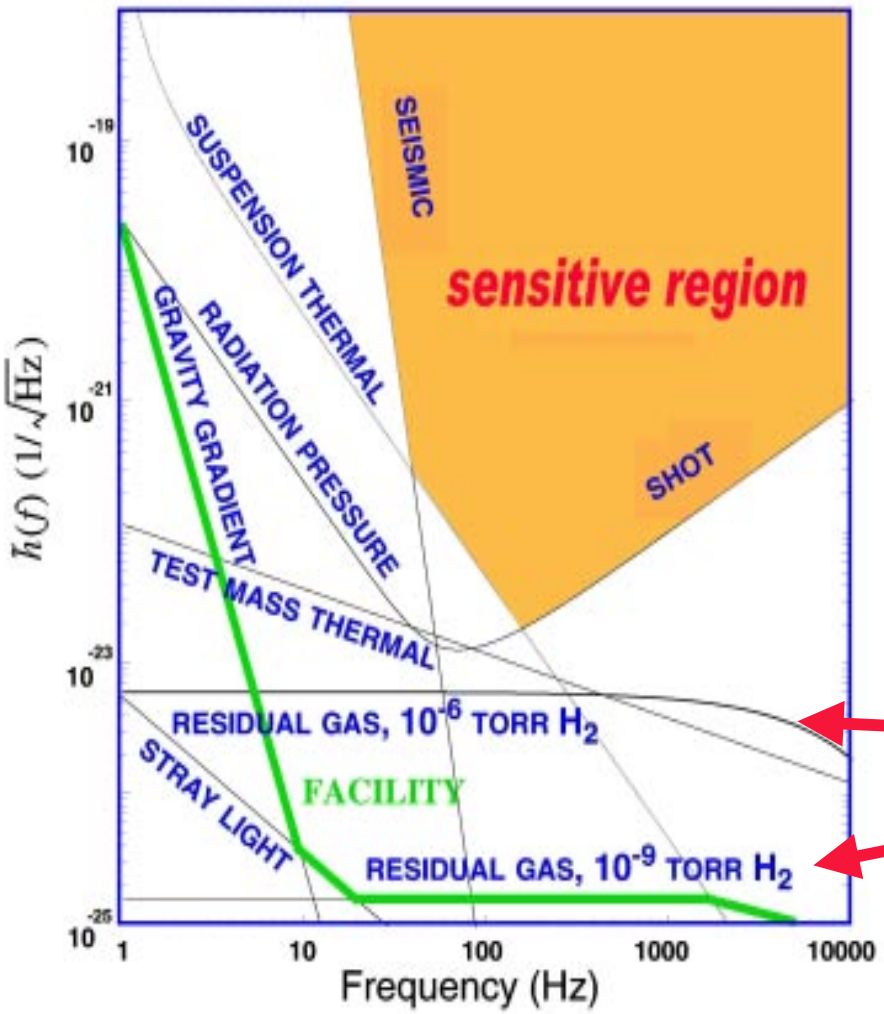


Interferometer Configuration

Requires test masses to be held in position to 10^{-10}-10^{-13} meter: "Locking the interferometer"



LIGO Facility Noise Levels

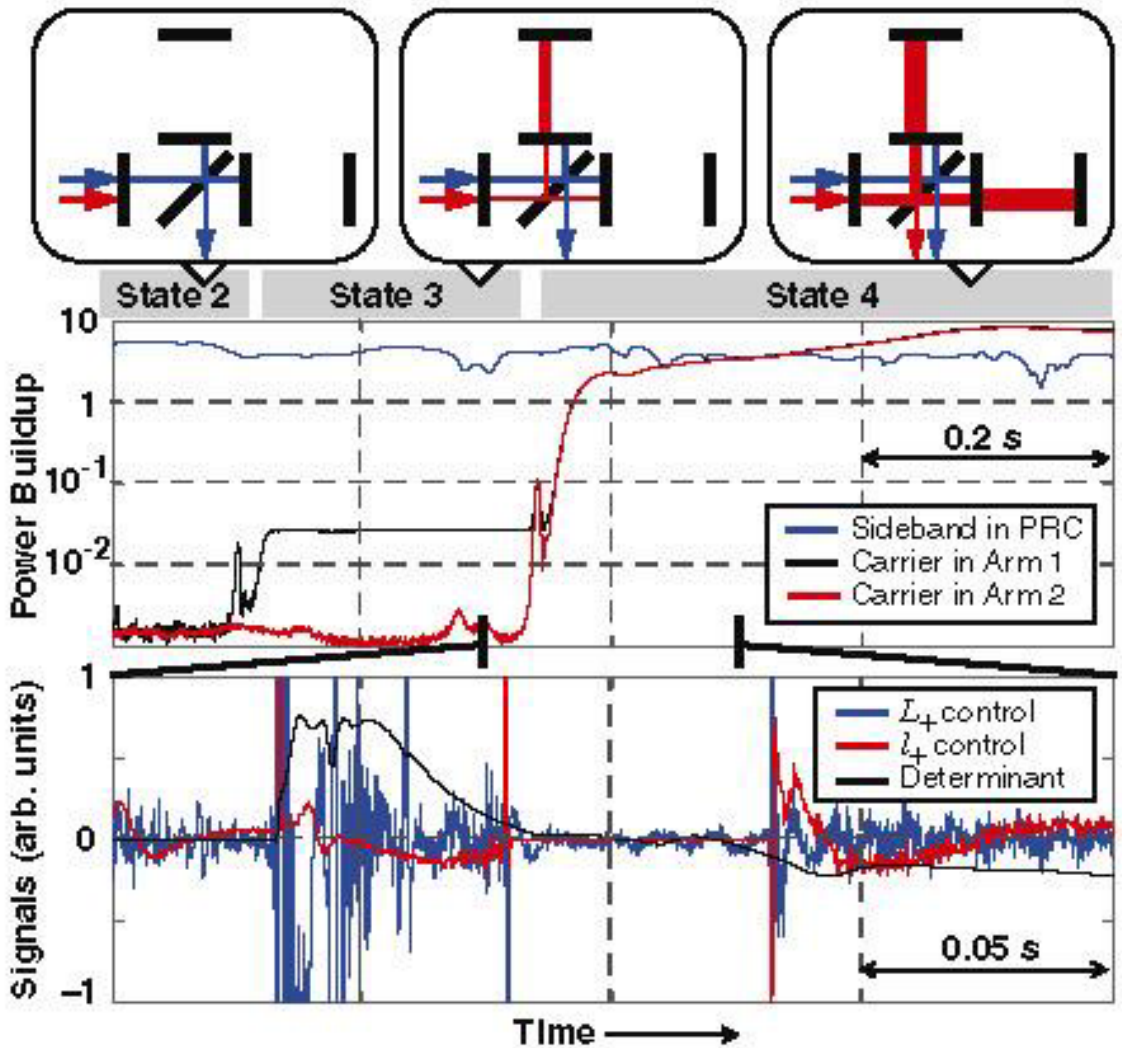


- **Fundamental Noise Sources**
  - » Seismic at low frequencies
  - » Thermal at mid frequencies
  - » Shot at high frequencies
- **Facility Noise Sources (example)**
  - » Residual Gas
    - ▪ 10^{-6} torr H_2 unbaked
    - ▪ 10^{-9} torr H_2 baked

Lock Acquisition

Developed by Matt Evans Caltech

PhD Thesis



LIGO Lab Planning Memo

August 2001

"…The LIGO Laboratory will carry out the E7 run before the end of the year. We anticipate that the run will take place during December and will be scheduled for two full weeks. The run is an engineering run and will be the responsibility of the LIGO Laboratory…"

Last LIGO Construction Project Milestone

- **PRIMARY GOAL:**
  - » **Establish coincidence running between the sites**
  - » **Obtain first data sample for shaking down data analysis**

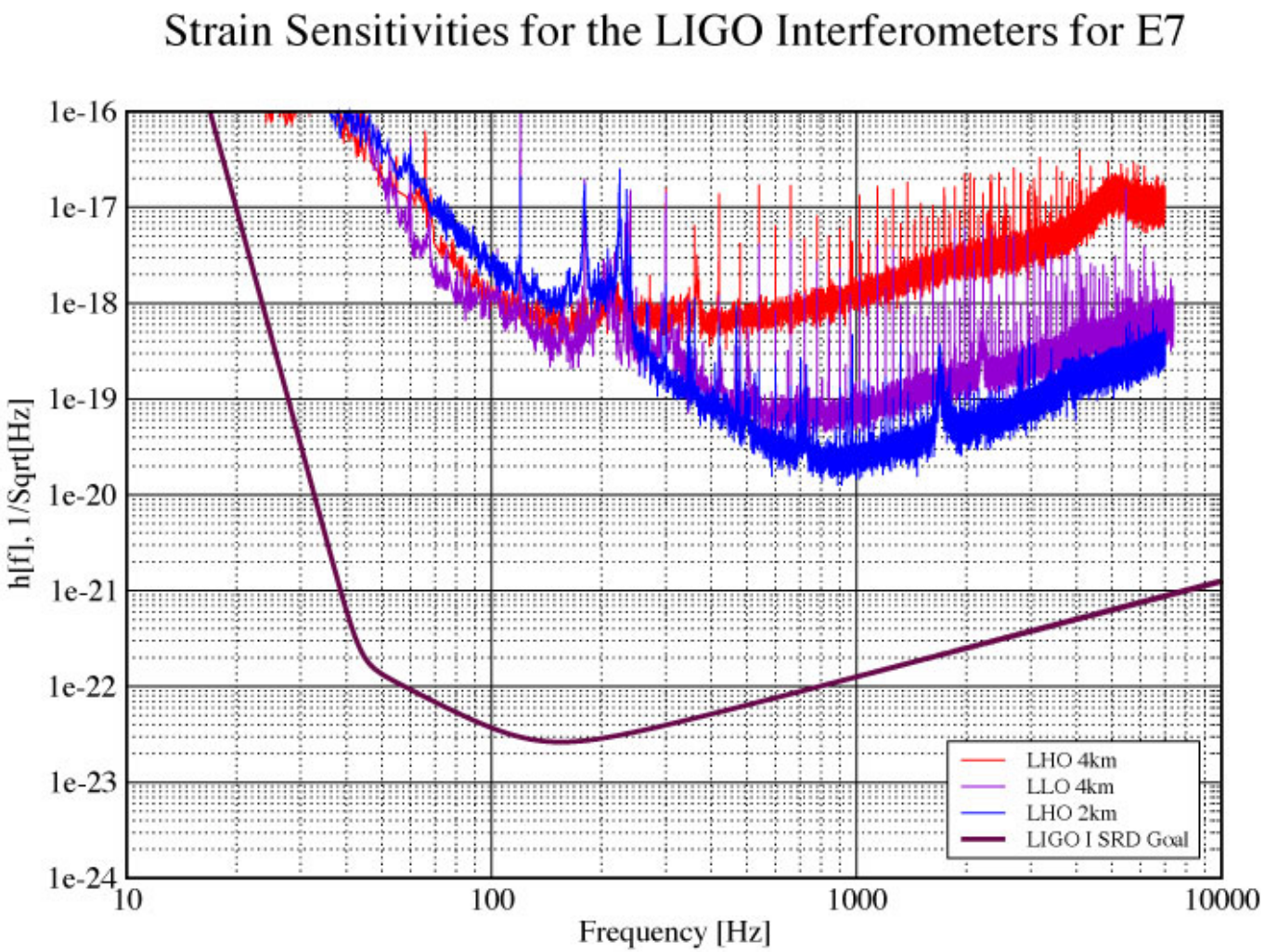
LIGO Engineering Run (E7)

Sensitivities

Final LIGO Milestone

"Coincidences Between the Sites in 2001"

Engineering Run 28 Dec 01 to 14 Jan 02



LIGO + GEO Interferometers

E7 Engineering Run

28 Dec 2001 - 14 Jan 2002 (402 hr)

Singles data

	All segments	Segments >15min
L1 locked	284hrs (71%)	249hrs (62%)
L1 clean	265hrs (61%)	231hrs (53%)
L1 longest clean segment: 3:58		
H1 locked	294hrs (72%)	231hrs (57%)
H1 clean	267hrs (62%)	206hrs (48%)
H1 longest clean segment: 4:04		
H2 locked	214hrs (53%)	157hrs (39%)
H2 clean	162hrs (38%)	125hrs (28%)
H2 longest clean segment: 7:24		

Coincidence Data

	All segments	Segments >15min
2X: H2, L1		
locked	160hrs (39%)	99hrs (24%)
clean	113hrs (26%)	70hrs (16%)
H2,L1 longest clean segment: 1:50		
3X : L1+H1+ H2		
locked	140hrs (35%)	72hrs (18%)
clean	93hrs (21%)	46hrs (11%)
L1+H1+ H2 : longest clean segment: 1:18		
4X: L1+H1+ H2 +GEO:		
	77 hrs (23 %)	26.1 hrs (7.81 %)
5X: ALLEGRO + …		

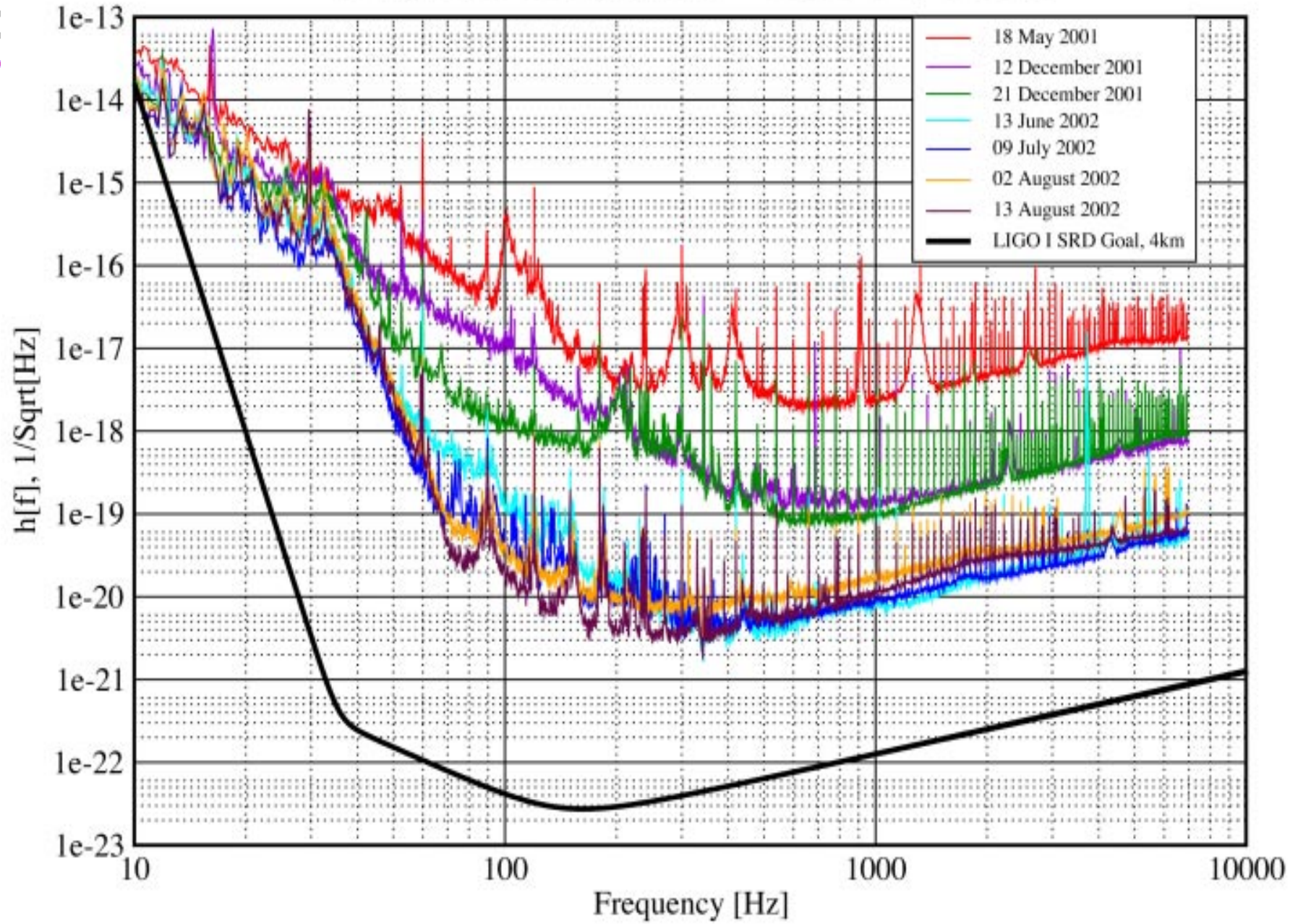
Conclusion: Large Duty Cycle is Attainable

Science Running
plan

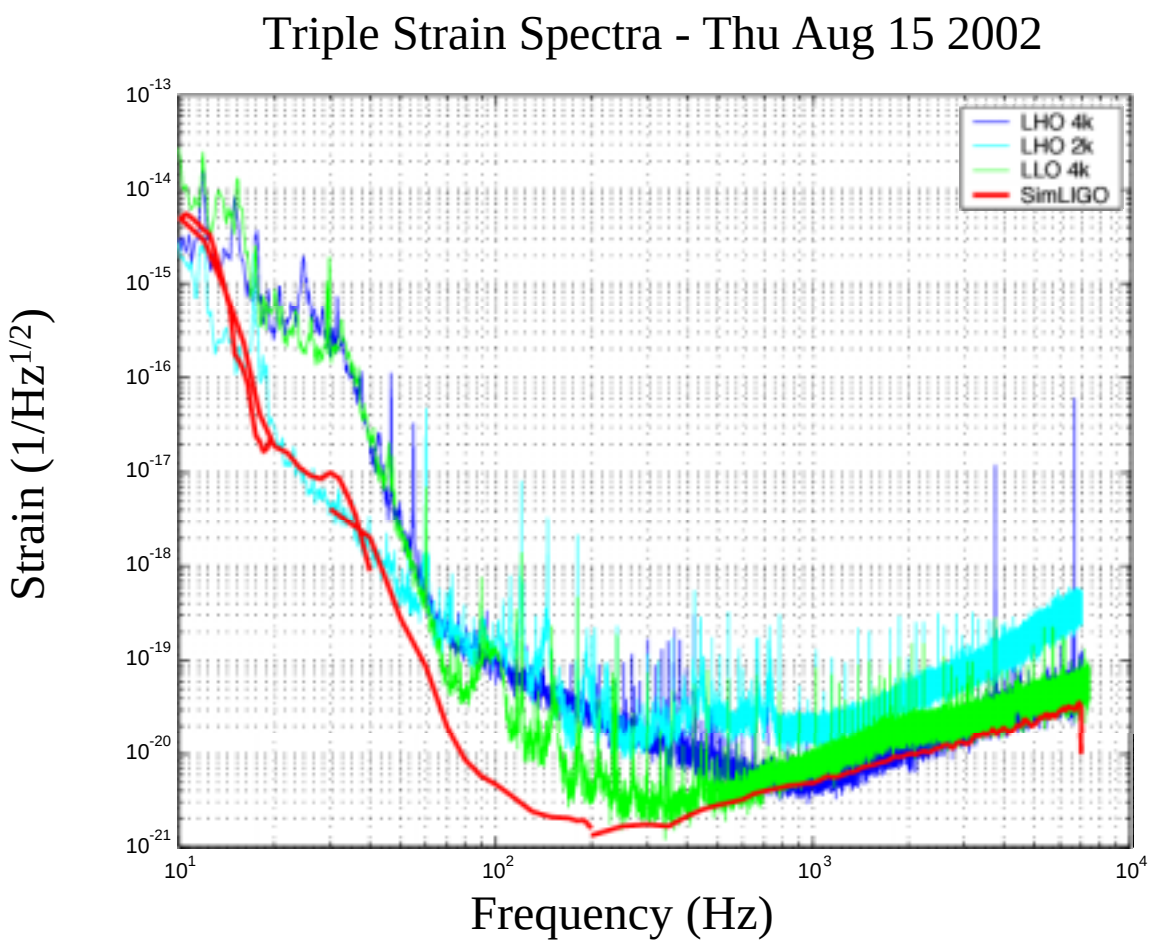
- **Two "upper limit" runs S1 and S2, interleaved with commissioning at publishable early sensitivity**
  - **S1 Sept 02 duration 2 weeks** 
  - **S2 March 03 duration 8 weeks**
- **First "search" run S3 will be performed in late 2003 (~ 6 months)**

Strain Sensitivities for the LIGO Livingston 4km Interferometer, E7 to S1

18 May 2001 - 13 August 2002 LIGO-G020451-00-E



LIGO data vs. SimLIGO



LIGO

S1 Run

"First Upper Limit Run"

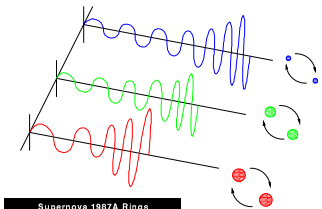
Aug – Sept 02

"Upper Limits"

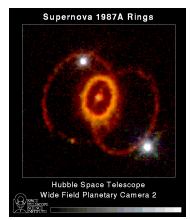
S1,S2 Data Analysis Groups

- **LSC Upper Limit Analysis Groups**
  - » **Typically ~25 physicists**
  - » **One experimentalist / One theorist co-lead each group**

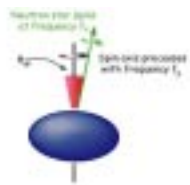
- **Compact binary inspiral:** ***"chirps"***



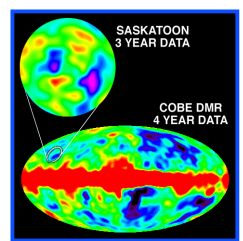
- **Supernovae / GRBs:** ***"bursts"***



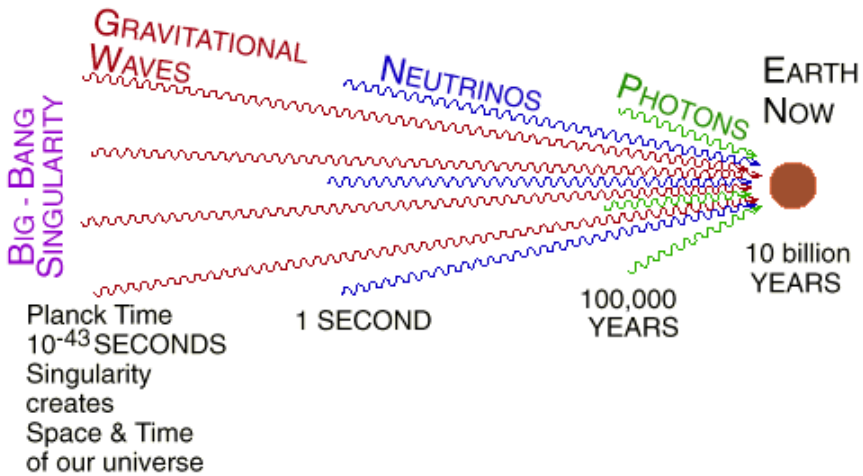
- **Pulsars in our galaxy:** ***"periodic"***

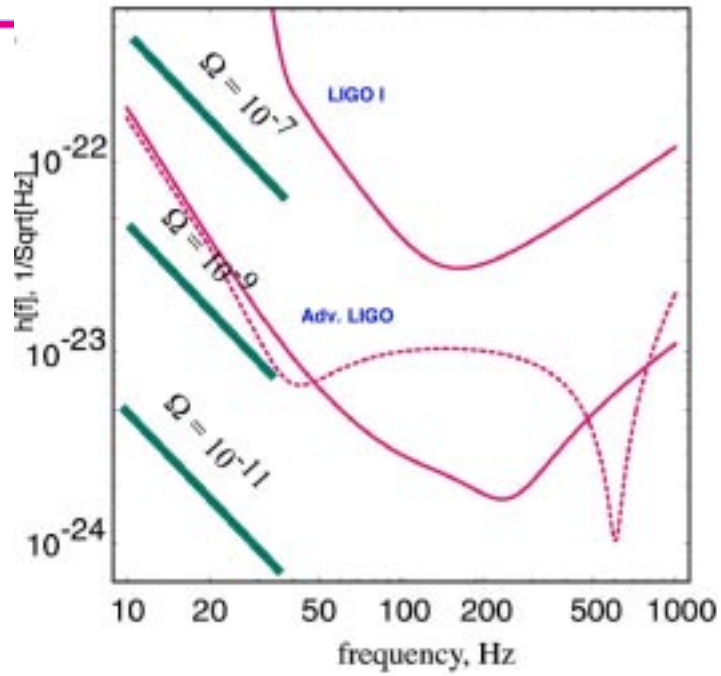


- **Cosmological Signal** ***"stochastic background"***



Stochastic Background Sensitivity

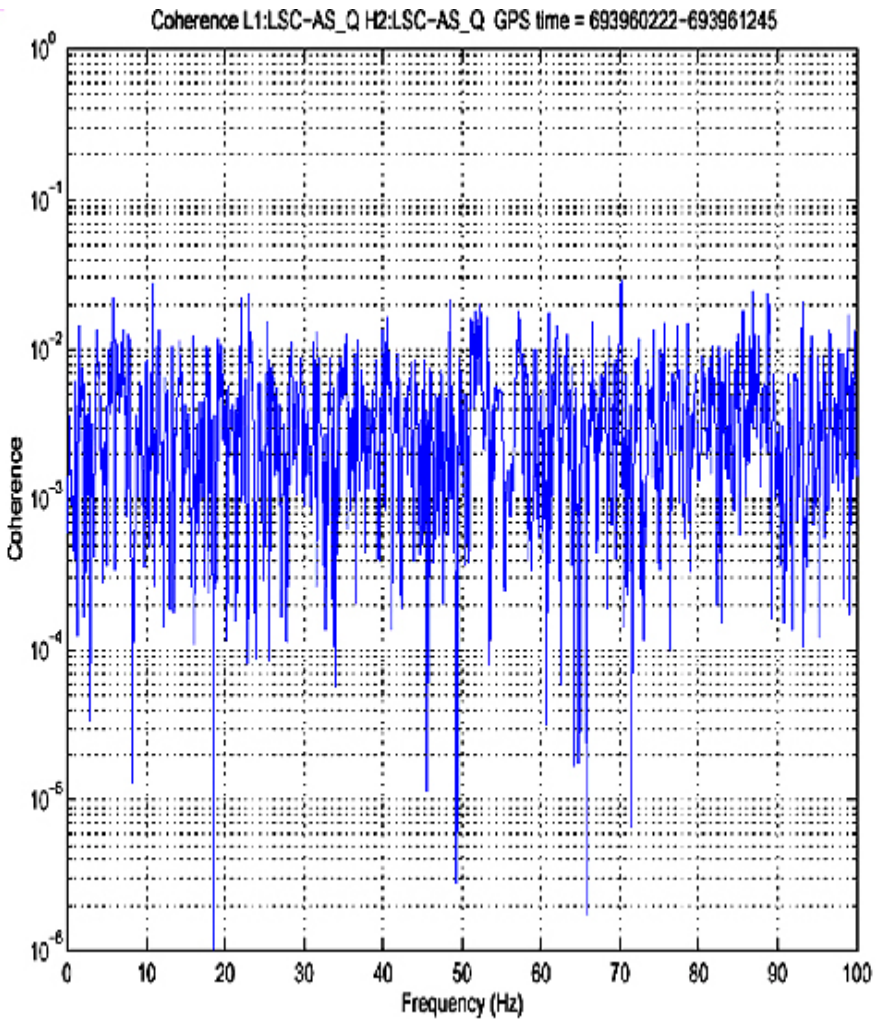


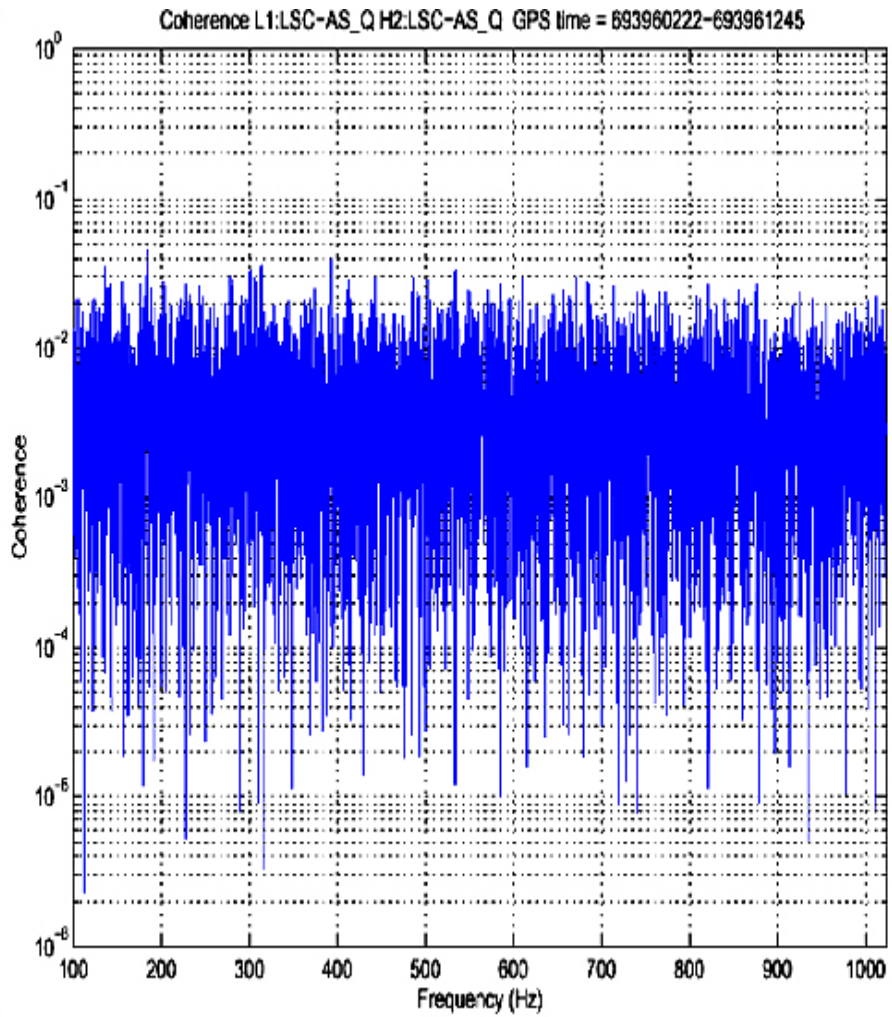


- **Detection**
  - » Cross correlate Hanford and Livingston Interferometers
- **Good Sensitivity**
  - » GW wavelength ≥ 2x detector baseline⇒ $f \leq 40$ Hz
- **Initial LIGO Sensitivity** $\Omega \geq 10^{-5}$
- **Advanced LIGO Sensitivity** $\Omega \geq 5\ 10^{-9}$

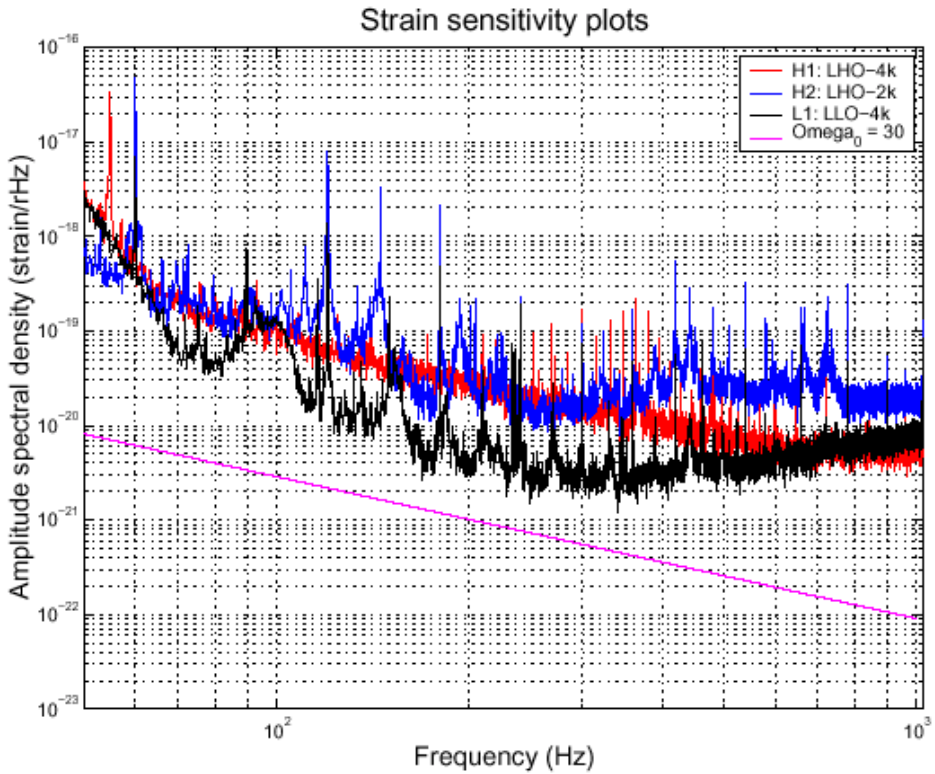
Stochastic Background

LHO/LLO coherence plots from E7





S1 – Expected Sensitivities



Upper limit: (90% CL, 70 hrs H2-L1 data)

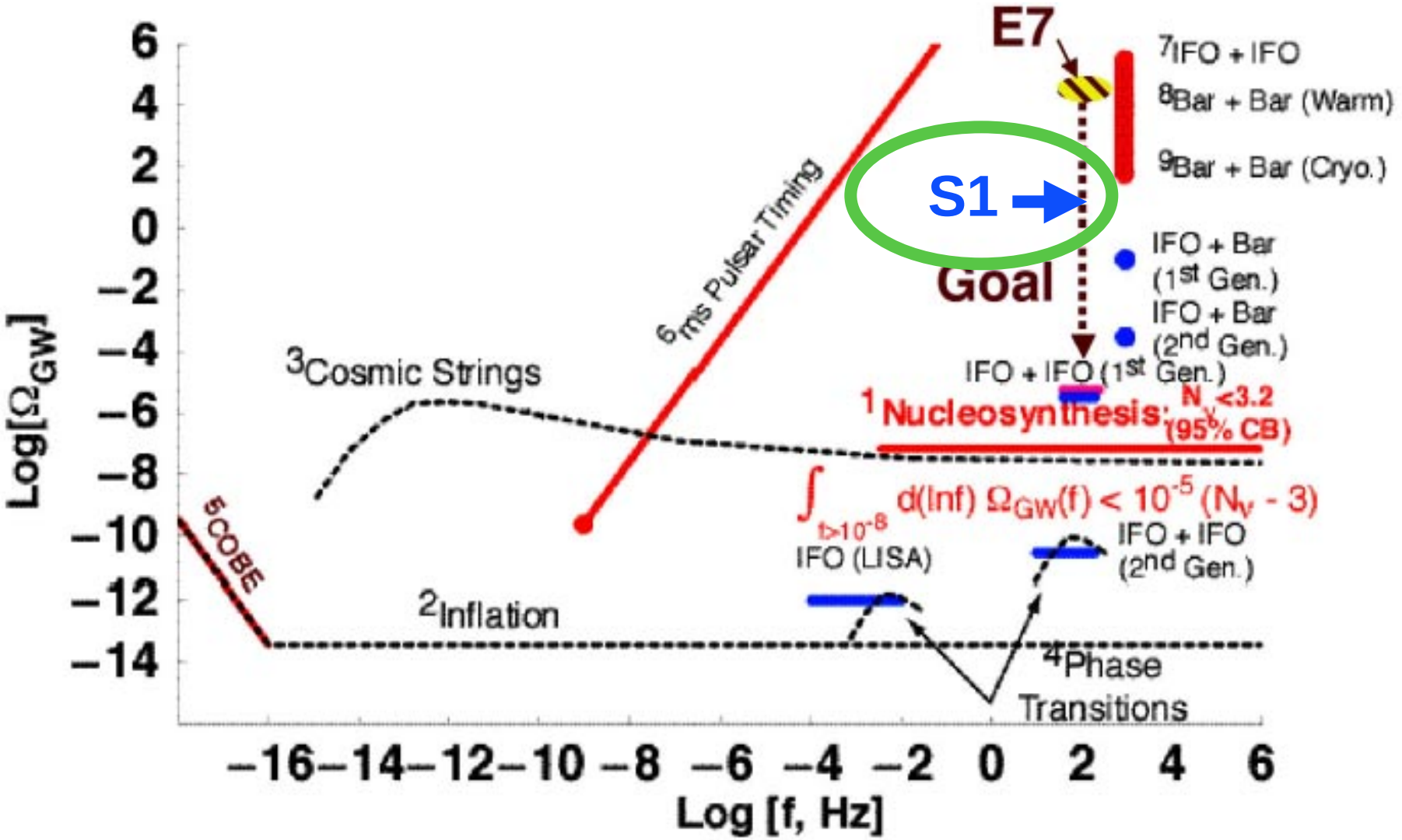
$\Omega_0 < 30$ *40 Hz < f < 215 Hz*

NOTE: Factor of 2 x 10^3 improvement over E7.

LIGO

Stochastic Background

sensitivities



Summary and Plans for S1
upper limits

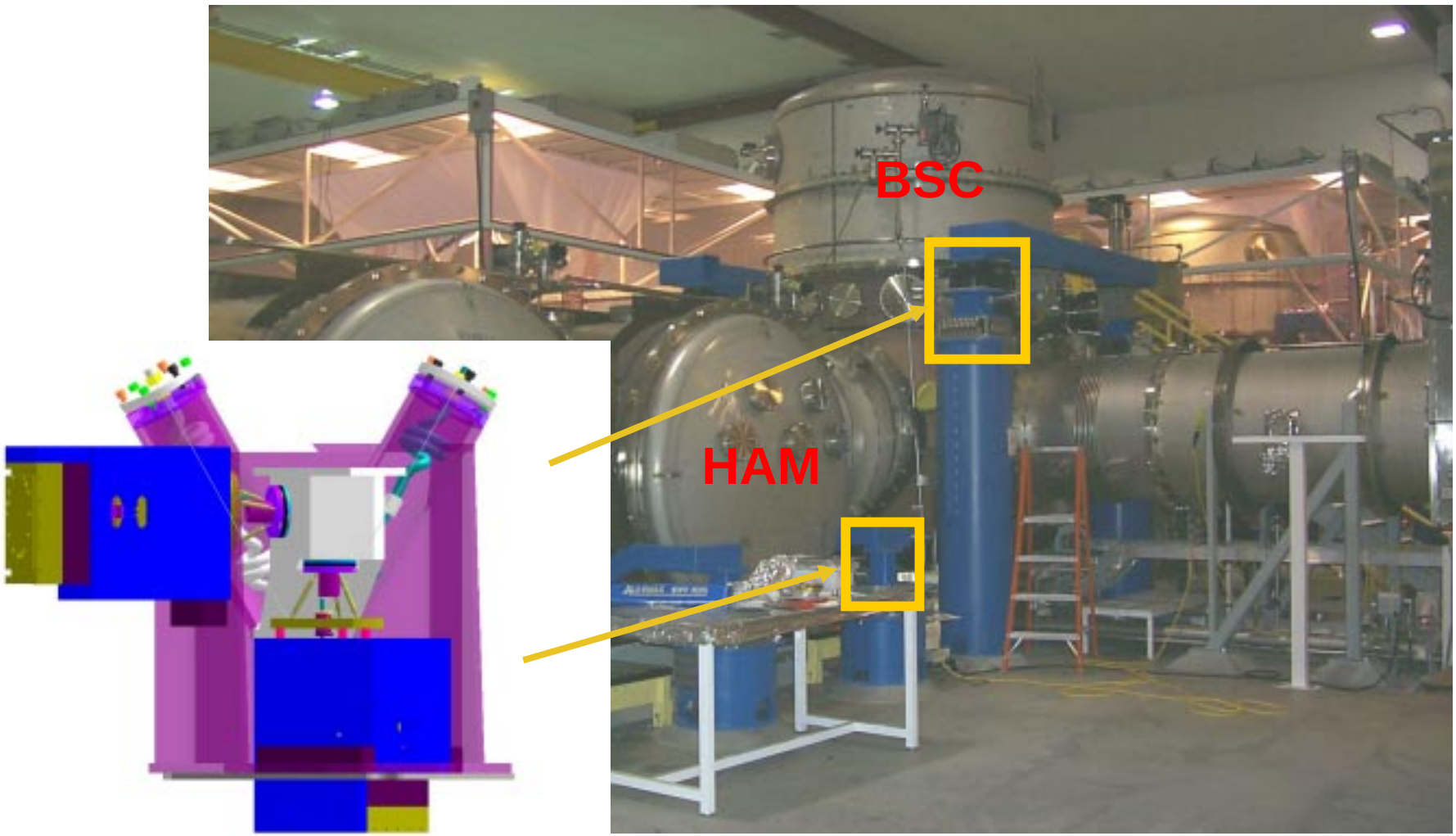
- **Stable data taking for 17 days**
- **Example expected "upper limit" sensitivities**
  - » **Stochastic backgrounds**
    - – **upper limit $\Omega_0 < 30$**
  - » **Neutron binary inspiral**
    - – **upper limit distance < 200 kpc**
  - » **Periodic sources PSR J1939+2134 at 1283 Hz**
    - – **Upper limit $h < 5\ 10^{-22}$ 90% CL**
- **Results for presentation in early 2003**
- **S2 should be at least 10x more sensitive than S1**

LIGO

Advanced Detector R&D and Advanced LIGO

Planned Detector Modifications

active external seismic



LIGO

Advanced LIGO R&D Status

- Working toward construction proposal in late 2002
- Advanced R&D program and baseline design is proceeding well
- Strong international partnership -- GEO and ACIGA
- Plan assumes construction funding available 2005
  - » some long lead funds in 2004
- Supports an installation start of 2007
- “Bottoms-up” costing nearly complete

Advanced LIGO R&D Status

interferometer sensing & control (ISC)

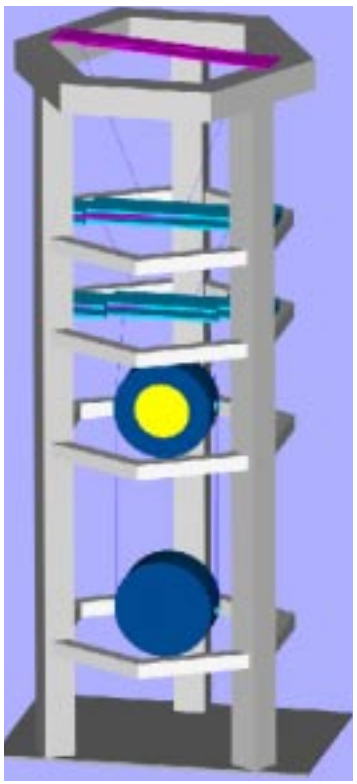
- **GEO 10m "proof of concept" experiment:**
  - **Results available for 40m Program in early 2003 (lock acquisition experience, sensing matrix selection, etc.)**
- **40m Lab for Precision Controls Testing:**
  - **Infrastructure has been completed (i.e. PSL, vacuum controls & envelope, Data Acquisition system, etc.)**
- **Gingin facility for High Power Testing:**
  - **Within the next year the LIGO Lab will deliver two characterized sapphire test masses and a prototype thermal compensation system (beam scan and/or ring heater)**

Advanced LIGO R&D Status

- **Seismic Isolation system (SEI):**
  - » **Development of pre-isolation system accelerated for use in retrofit on initial LIGO**
  - » **“Technology Demonstrator” system has been fabricated**
- **LASTI infrastructure has been completed (including BSC stack to support pre-isolation full scale testing for initial LIGO)**

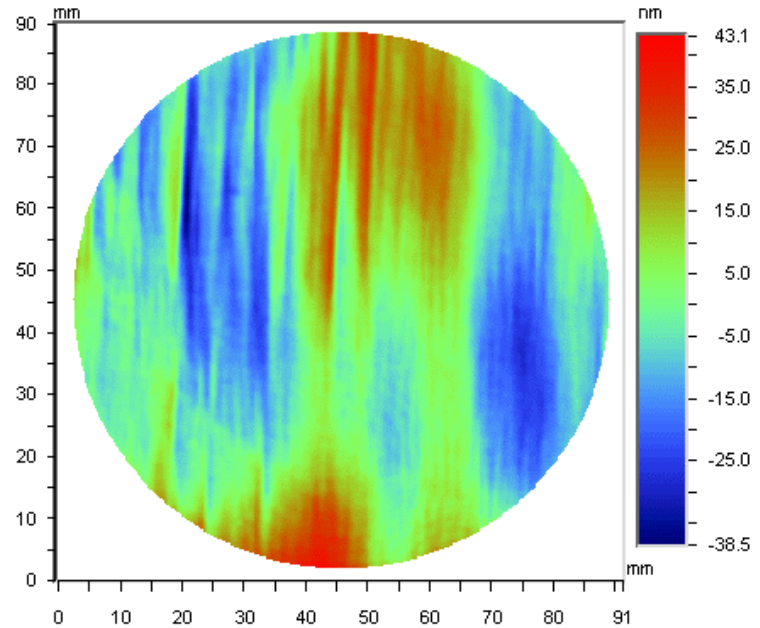
Advanced LIGO R&D Status

- **Multiple Suspensions (GEO)**
  - » Complete fused-quartz fiber suspensions in the GEO-600 interferometer
  - » Progress on both circular fibers (tapered) and ribbons
  - » Silica-sapphire hydroxy-catalysis bonding looks feasible
  - » TNI nearing final results for fused silica; sapphire is the next phase



Advanced LIGO R&D Status

- **Core Optics Components (Sapphire):**
  - » Optical homogeneity ‘a’ crystal axis close to acceptable (13nm RMS over 80mm path length)
  - » Sapphire annealing efforts are encouraging (20 ppm/cm vs 10 ppm/cm requirement)
  - » Coatings on large optics show sub-ppm losses (SMA/Mackowski)
  - » Coating mechanical loss -- materials rather than interfaces seem to be the culprit



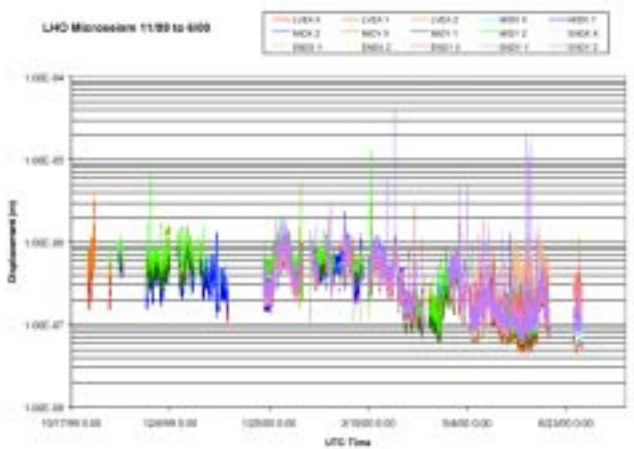
Date: 10/25/2001
Time: 13:59:18
Wavelength: 1.064 um
Pupil: 100.0 %
PV: 81.6271 nm
RMS: 13.2016 nm

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

Outreach Activities

- Outreach is a high priority in LIGO and we have pursued it vigorously
- We deferred proposed new initiatives in FY02 due to our budget shortfall
- We have recently taken steps to expand our outreach efforts In FY03.

Microseism And Ocean Waves LHO outreach



LLO Telescope for outreach activities

LIGO

Conclusions

- Reduced budgets and limited manpower are resulting in deferring some work and making difficult priority choices
- Progress is steady on three fronts: commissioning; data runs and analysis; preparations for advanced LIGO
- The coming year should be very exciting !