LIGO

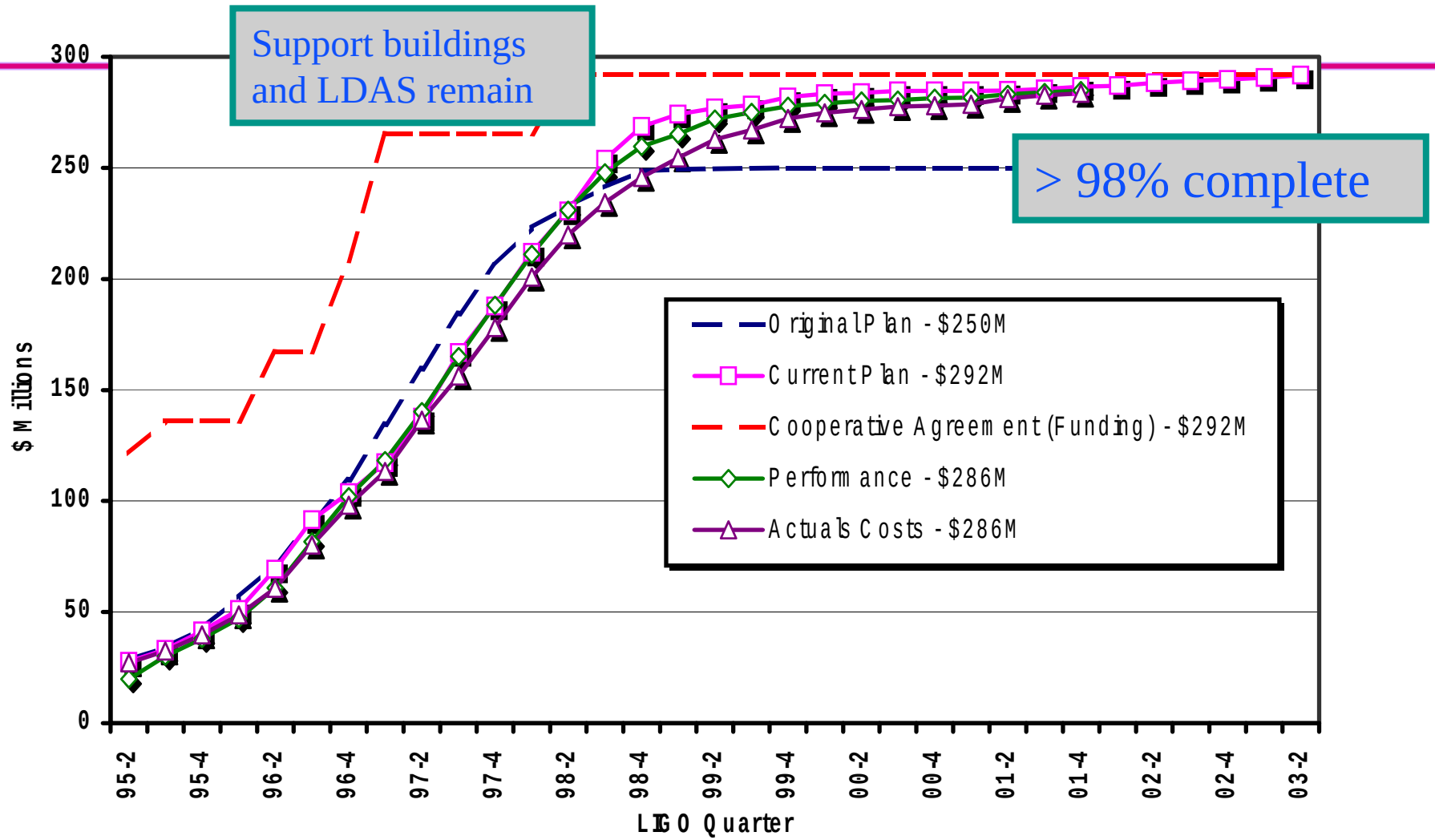
Status of LIGO

Gary Sanders
LIGO Laboratory
PAC-12 Meeting, June 2002
Cambridge

LIGO

Top Level LIGO Plan and Status

Construction Cost/Schedule Performance – May 2002



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 $h \sim 10^{-21}$)
2006+	Begin 'advanced' LIGO installation
2007	

August 2001 LIGO Lab Planning Memo (M010216-A-M)

- "…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…"
- "…The S1 run will be held in May 2002. The prime purpose for this run is to carry out the first scientific searches. This run will be the joint responsibility of the Laboratory and the LSC. The sensitivity goal is a two site coincidence with 3 interferometers running and the achieved scientific reach (volume searched x observation time in coincidence) should be an order of magnitude better than achieved in the E7 run. At least one interferometer at each site should be operated in the full recycled configuration…"

March 2002 LIGO Lab Planning Memo (M020136-A-M)

- The Upper Limits Runs S1 and S2 –

3. "… schedule the S1 run to begin at 8:00 am Pacific time on Saturday, June 29 and to be completed at 8:00 Pacific on Monday, July 15...The sensitivity goal is a two site coincidence with 3 interferometers running and the achieved scientific reach (volume searched x observation time in coincidence) should be an order of magnitude better than achieved in the E7 run. At least one interferometer at each site should be operated in the full recycled configuration."
4. "The S2 run will have a goal of at least an order of magnitude improvement in scientific reach … beyond S1 and should follow successful completion of analysis of the S1 data…we will schedule the next science run to begin at 8:00 am Pacific Friday November 22, 2002 with completion at 8:00 on Monday, January 6, 2003."

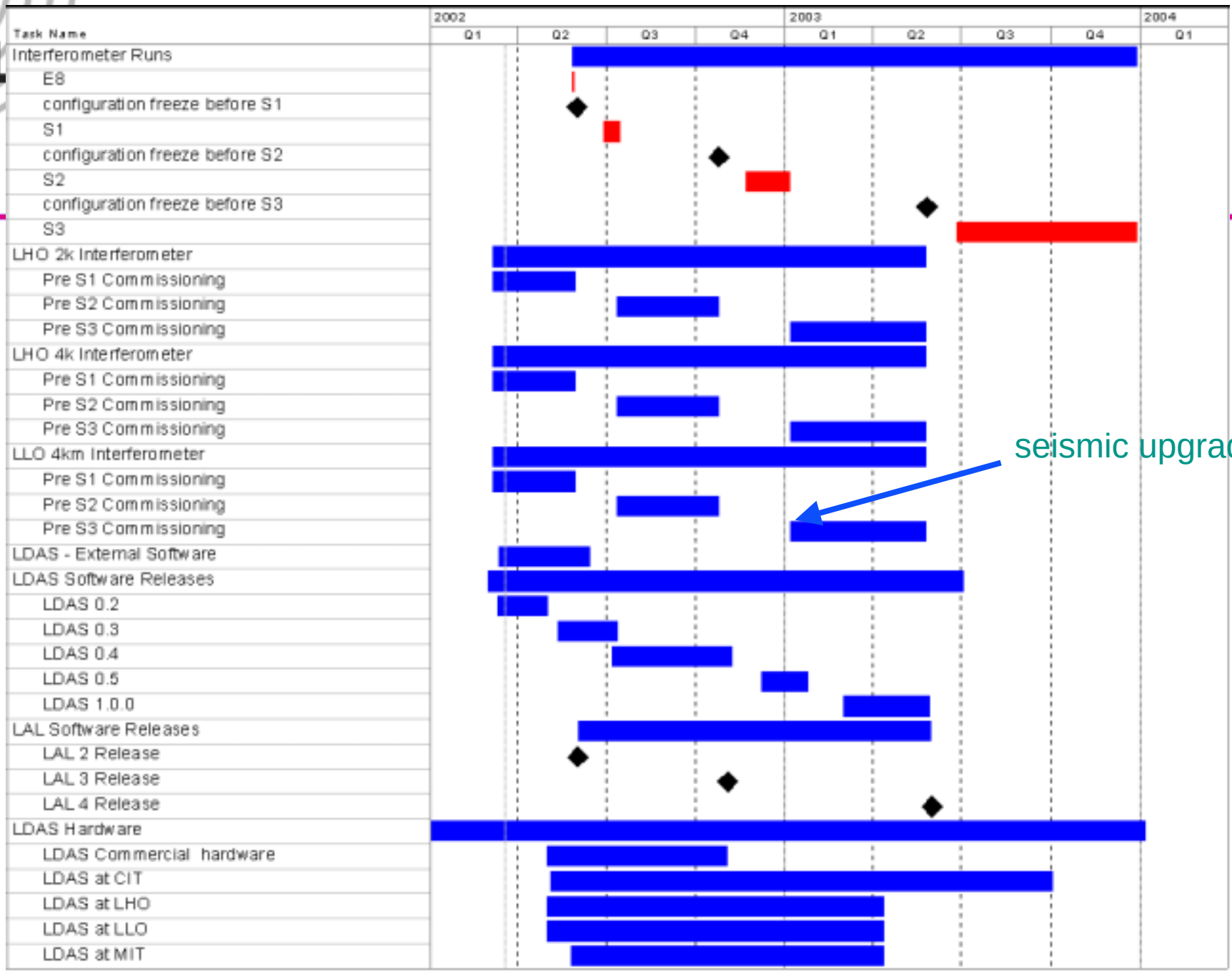
"These two runs will complete the upper limit running and the orientation for the LIGO running experience. We believe that this should lead to a broad set of new publishable limits, well beyond what has been previously published."

March 2002 LIGO Lab Planning Memo (M020136-A-M)

- Extended Search Runs

6. “The S3 run will mark the beginning of true search running, representing a step beyond setting upper limits on selected gravitational wave searches. S3 will be intended to accomplish a real search for gravitational waves with … astrophysical *significance*. We expect to schedule S3 to commence about June 27, 2003 and this run will be planned for several months duration.“

7. “During 2003 and 2004, we will plan to run in this search mode for at least 50% of the calendar time, followed by the planned one year integrated LIGO science run at design sensitivity. This science run will be completed prior to proposed major interferometer replacements.”


Task Name
2002
2003
2004
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Interferometer Runs
E8
configuration freeze before S1
S1
configuration freeze before S2
S2
configuration freeze before S3
S3
LHO 2k Interferometer
Pre S1 Commissioning
Pre S2 Commissioning
Pre S3 Commissioning
LHO 4k Interferometer
Pre S1 Commissioning
Pre S2 Commissioning
Pre S3 Commissioning
LLO 4km Interferometer
Pre S1 Commissioning
Pre S2 Commissioning
Pre S3 Commissioning
LDAS - External Software
LDAS Software Releases
LDAS 0.2
LDAS 0.3
LDAS 0.4
LDAS 0.5
LDAS 1.0.0
LAL Software Releases
LAL 2 Release
LAL 3 Release
LAL 4 Release
LDAS Hardware
LDAS Commercial hardware
LDAS at CIT
LDAS at LHO
LDAS at LLO
LDAS at MIT
seismic upgrade

Proposal Budget for Continuing 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.

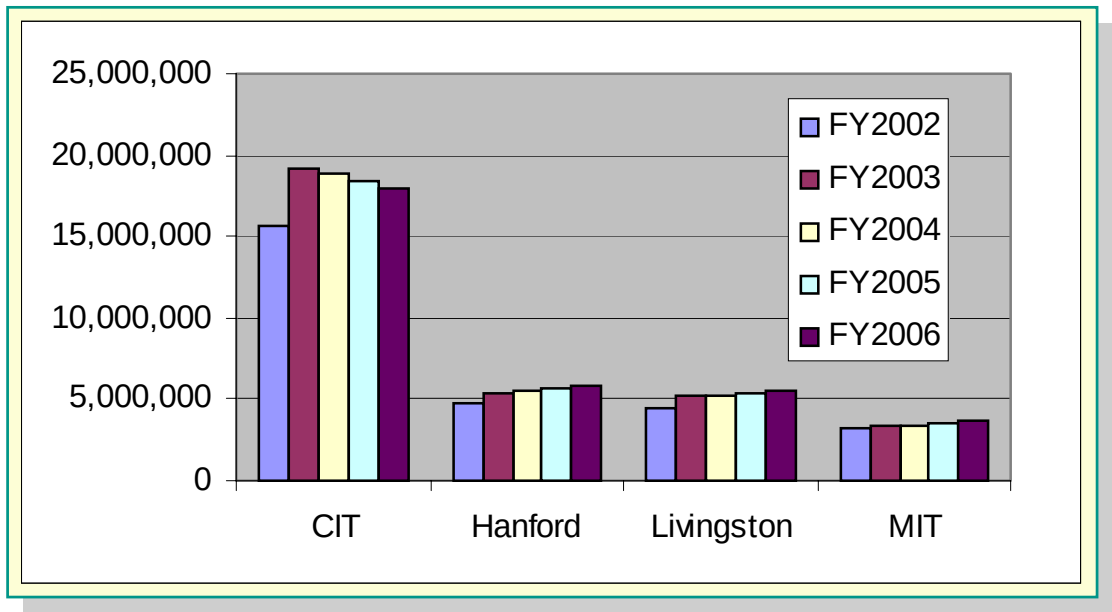
“Revised” Proposal Budget (2002-2006)

- $28 million provided for FY 2002 Operations in February and May 2002 (NSF PHY-0107417)
- Reduced or deferred hiring, R&D, equipment
- Assuming $33M will be awarded in 2003

	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

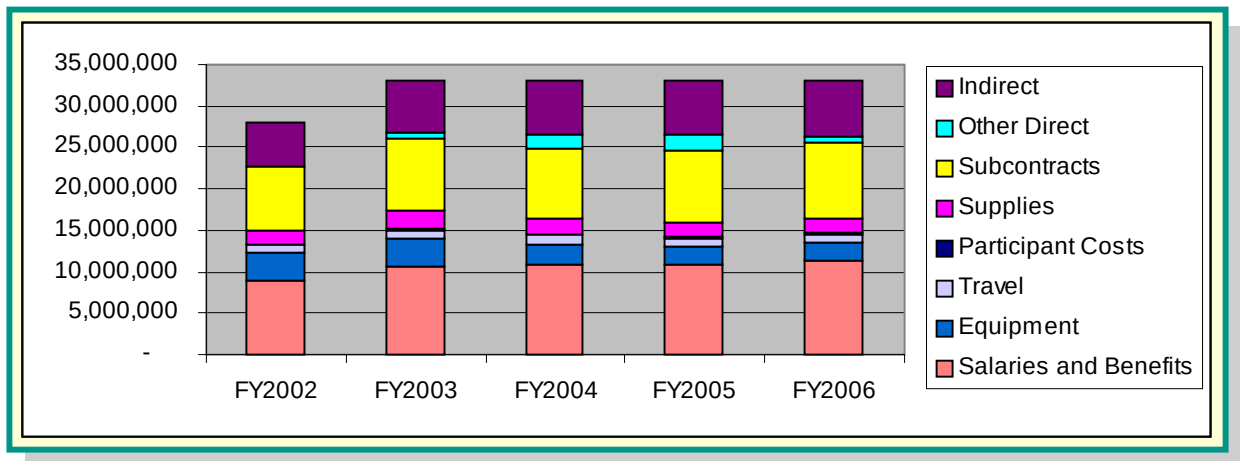
Proposal Budget by Location

Location	FY2002	FY2003	FY2004	FY2005	FY2006
CIT	15,574,955	19,129,542	18,822,123	18,415,444	17,991,714
Hanford	4,762,652	5,405,780	5,551,840	5,706,276	5,868,325
Livingston	4,459,705	5,165,062	5,226,551	5,375,890	5,531,542
MIT	3,202,687	3,299,615	3,399,486	3,502,390	3,608,419
Grand Total	**28,000,000**	**33,000,000**	**33,000,000**	**33,000,000**	**33,000,000**



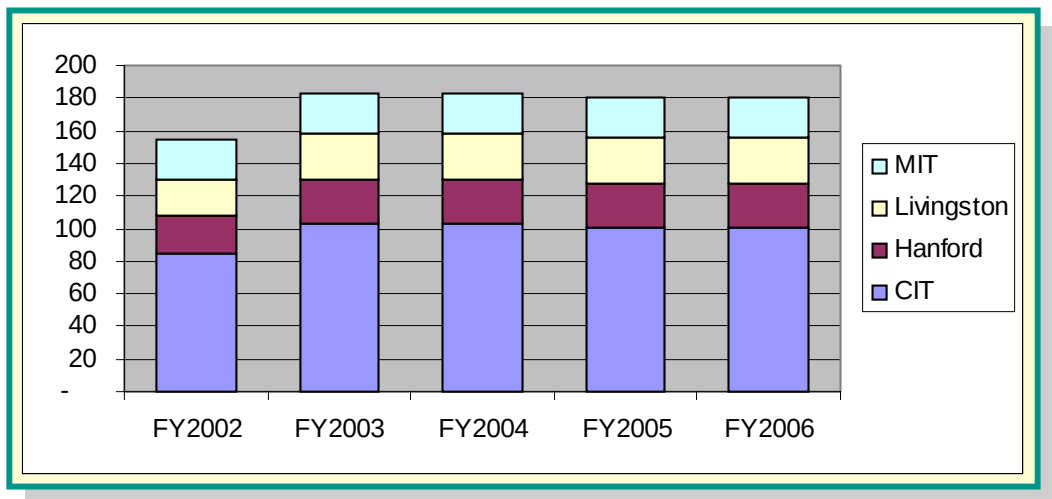
Proposal Budget by Cost Category

Cost Category	FY2002	FY2003	FY2004	FY2005	FY2006
Salaries and Benefits	8,877,356	10,524,544	10,793,996	10,935,752	11,343,325
Equipment	3,410,593	3,464,014	2,601,855	2,158,366	2,169,625
Travel	1,029,000	1,055,080	1,043,569	1,018,197	1,052,494
Participant Costs	20,000	60,000	70,000	70,000	70,000
Supplies	1,618,257	2,254,879	1,958,895	1,803,753	1,848,101
Subcontracts	7,631,822	8,795,461	8,507,815	8,711,357	8,985,966
Other Direct	123,998	572,363	1,592,807	1,754,181	749,368
Indirect	5,288,973	6,273,658	6,431,062	6,548,393	6,781,120
Total	28,000,000	33,000,000	33,000,000	33,000,000	33,000,000



Staff (Budgeted) by Location

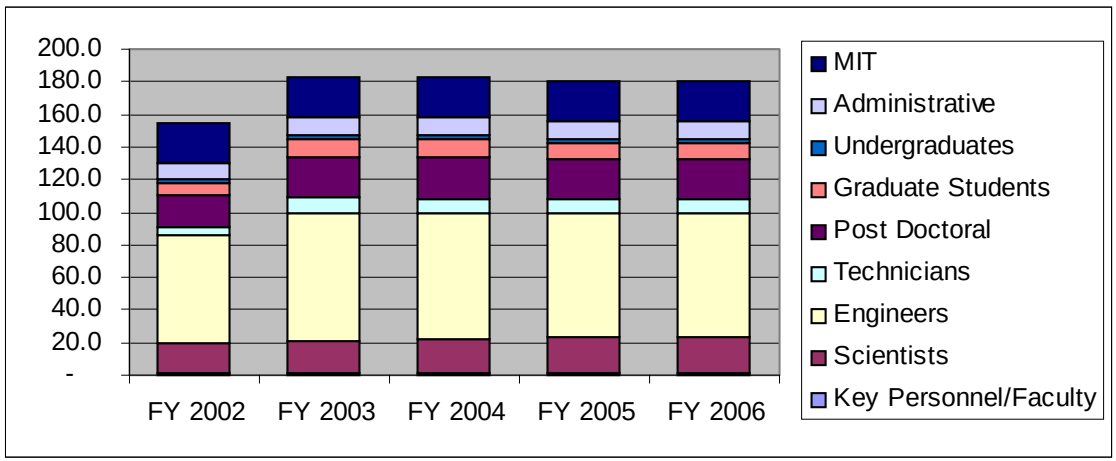
Location	FY2002	FY2003	FY2004	FY2005	FY2006
CIT	85	103	103	100	100
Hanford	23	27	27	27	27
Livingston	22	28	28	28	28
MIT	25	25	25	25	25
Total	155	183	183	180	180



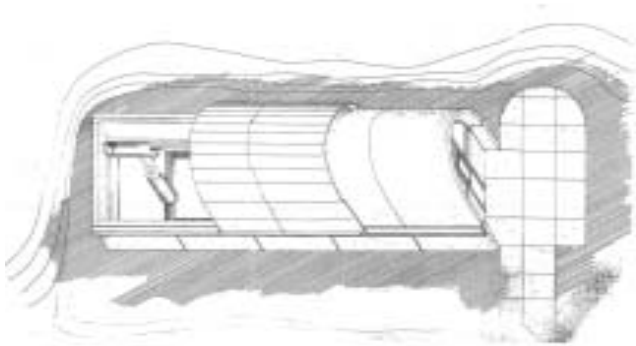
Plans to add 10 scientific staff – 4 at LHO, 2 at LLO, 3 at CIT, 1 at MIT

Staff (Budgeted) by Category

	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



LLO Telescope



Draft building concept utilizes surplus beam tube enclosures on raised footings with roll-off roof

Proposed telescope location on fire access road gives clear view to south

Telescope facts:

16 inch Richey Chretien telescope built by Optical Guidance Systems

Telescope provided by state funds via LSU. LIGO provides site and internet connection and incorporates telescope use into outreach program.

Internet accessible to facilitate classroom use

Delivery of telescope expected this week

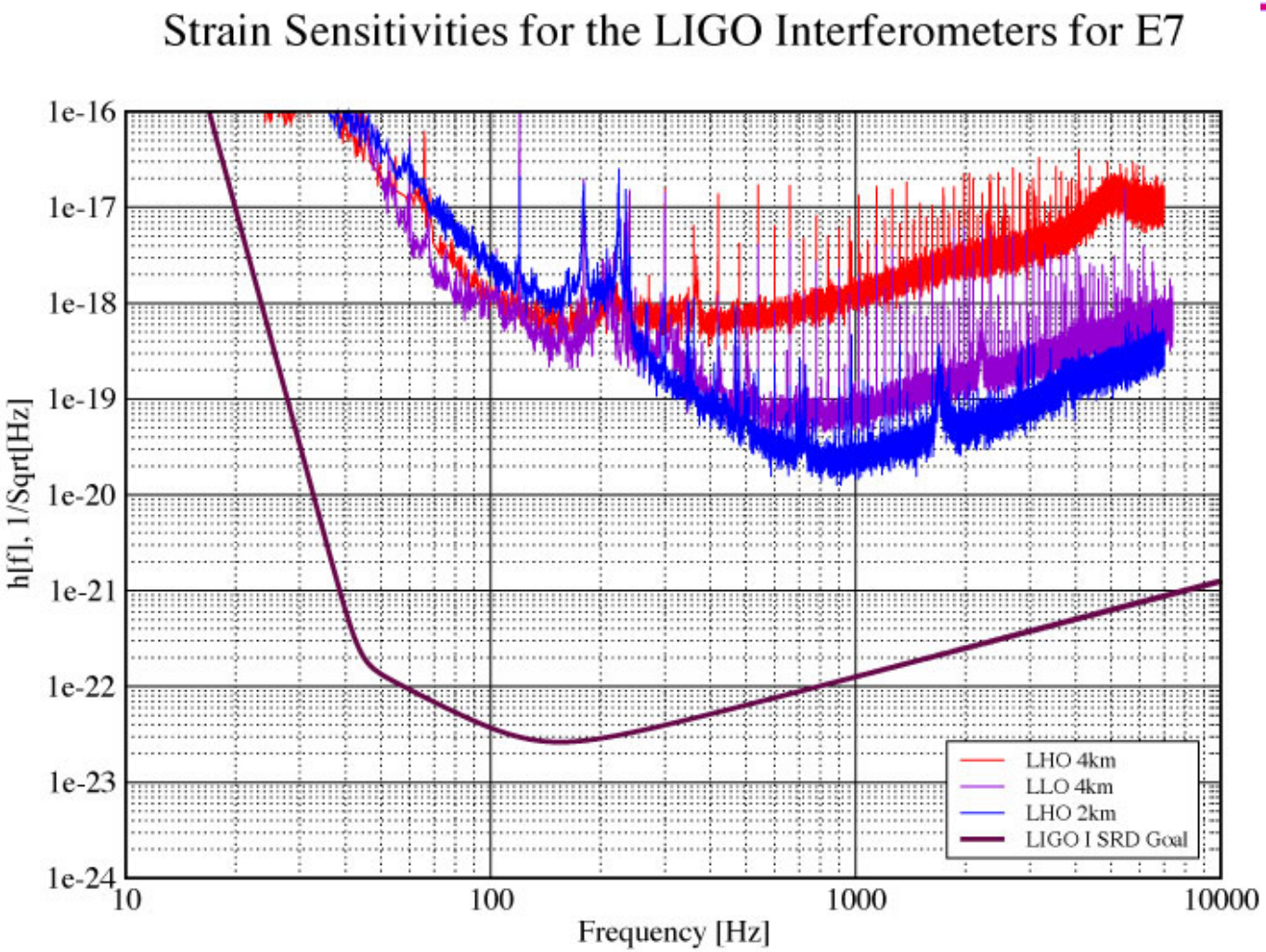
LIGO

E7 Engineering Run

E7 sensitivities for LIGO Interferometers

28 December 2001 - 14 January 2002

LHO2k: power recycled configuration;
LHO4k & LLO4k : recombined configuration, no power recycling



E7 Run Summary

LIGO + GEO Interferometers

Courtesy G. Gonzalez & M. Hewiston

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 + …		

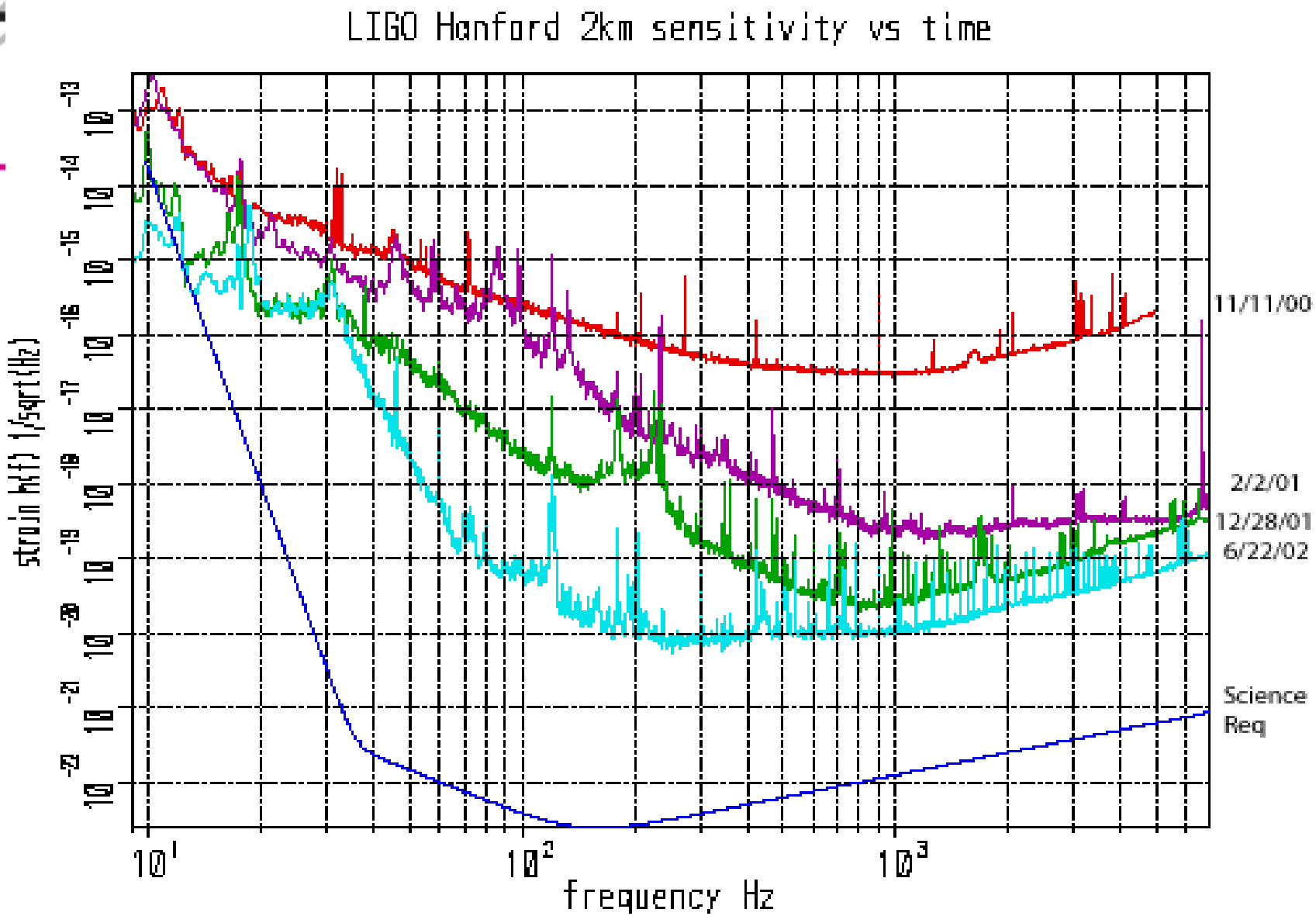
LIGO

Commissioning Status Up to the S1 Science Run

LHO 2 km Interferometer Status

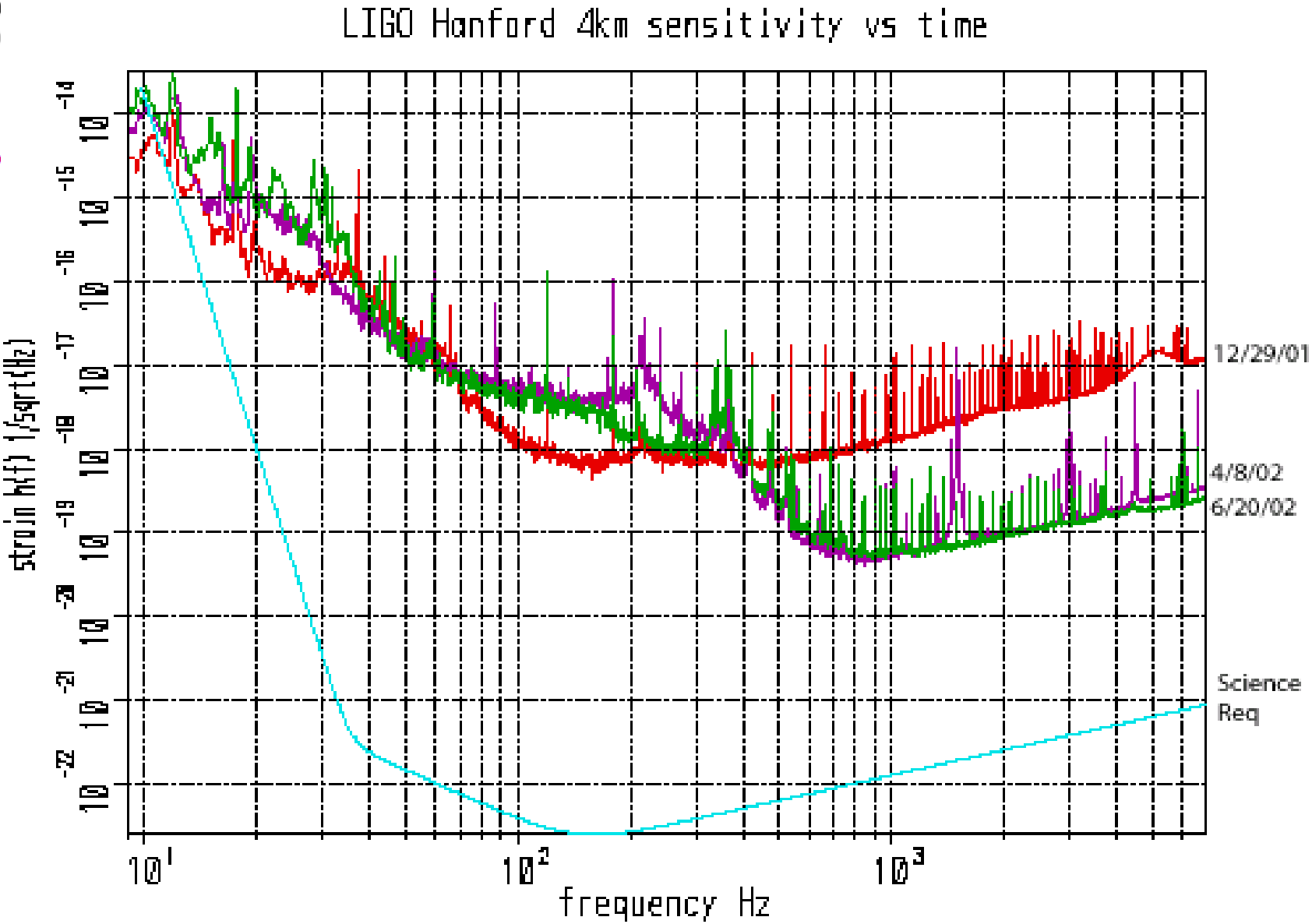
- Locked in power recycled configuration
  - » recycling factor up to 25, but typically ~15
- Common mode servo implemented
  - » Frequency stabilization from average arm length
  - » Establishes control system “gain hierarchy”
- 5 W power into mode cleaner
  - » Attenuators at photodiodes give effective input power 20 - 40 mW
- Tidal feedback operational
  - » Lock duration up to 15 hours
- DISPLACEMENT Sensitivity

Summer 2001	~ 3 x 10^{-16} m/$Hz^{1/2}$
December 2001 (E7)	~ 5 x 10^{-17} m /$Hz^{1/2}$ (~600 Hz)
Spring 2002	~ 2 x 10^{-17} m /$Hz^{1/2}$ (~350 Hz)


LIGO Hanford 2km sensitivity vs time
strain h(f) 1/sqrt(Hz)
frequency Hz
11/11/00
2/2/01
12/28/01
6/22/02
Science
Req

LHO 4 km Interferometer Status

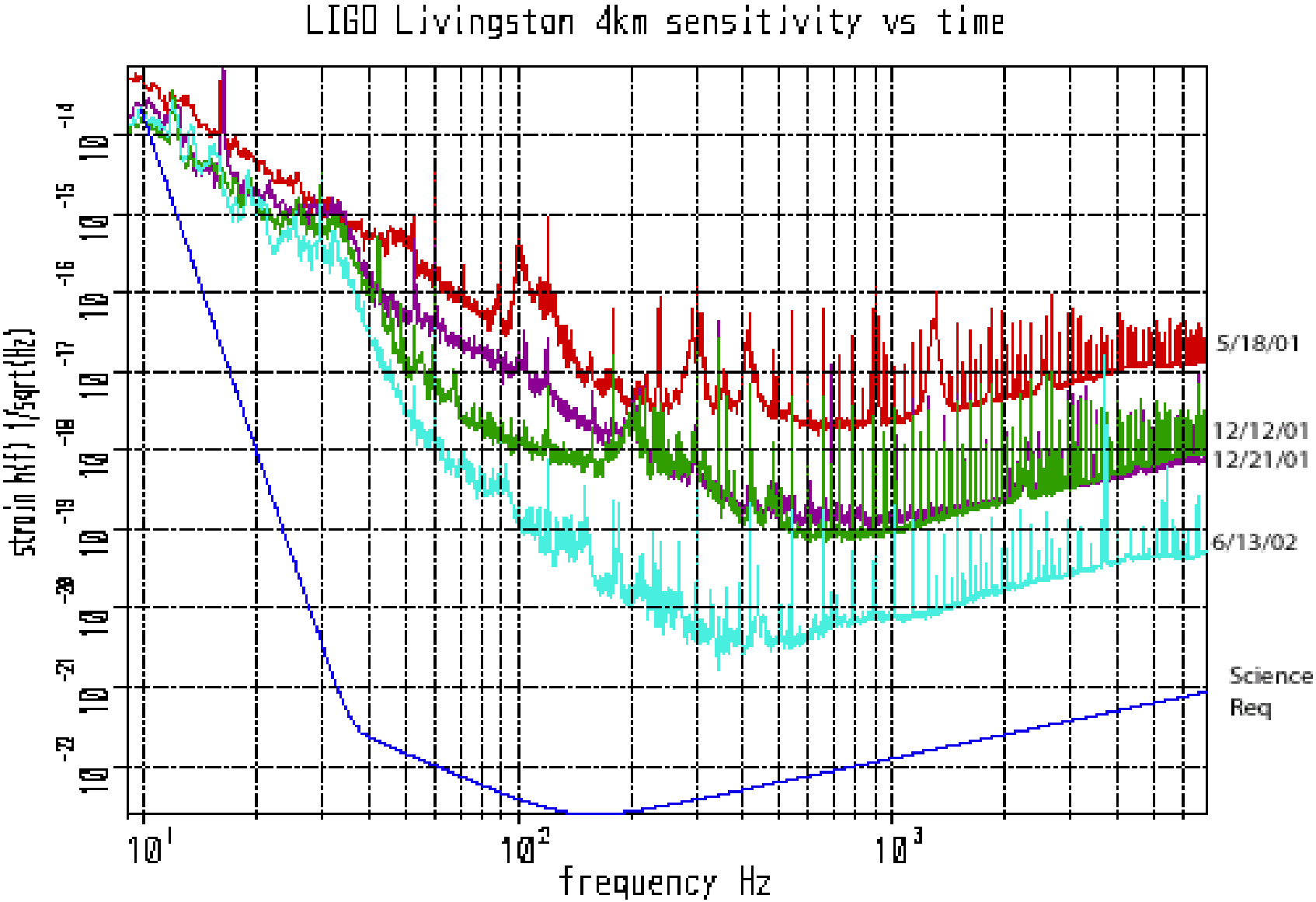
- In-vacuum installation completed last summer
- Digital suspension controllers
  - » Greater flexibility for tuning servos to improve reliability/noise
  - » Permits frequency dependent orthogonalization of the displacement and angular control of the suspensions
  - » Will be implemented on other interferometers after tests done
- 1 W power into mode cleaner
  - » Attenuators at photodiodes give effective input power 20 mW)
- Locked in power recycled configuration
  - » Recycling factor typically 40-50
- Tidal feedback operational
  - » Locks up to 4 hours
- DISPLACEMENT Sensitivity ~2 x 10^{-16} m/$Hz^{1/2}$


LIGO Hanford 4km sensitivity vs time
strain h(f) 1/sqrt(Hz)
frequency Hz
12/29/01
4/8/02
6/20/02
Science Req

LLO 4 km Interferometer Status

- Power recycled configuration
- 1.9 W power input laser power into mode cleaner
  - » Power recycling gain ~ 50
  - » 25-30 dB attenuation at dark port
- Reasonably robust lock during night
  - » Up to 4 hours
  - » 15 s – 3 min lock acquisition time
  - » Tidal feedback operational
  - » Wavefront alignment control operating on end mirrors
  - » Microseismic feedforward reduces the dynamic range required from the controller (unique to LLO at present time)
  - » PEPI reduces the seismic noise injected between 0.3 to 5 Hz at the end masses

DISPLACEMENT Sensitivity ~1.5 x 10^{-17} m/$Hz^{1/2}$ @ 400 - 600 Hz


LIGO Livingston 4km sensitivity vs time
strain h(f) 1/sqrt(Hz)
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
10^-22
10^1
10^2
10^3
frequency Hz
5/18/01
12/12/01
12/21/01
6/13/02
Science
Req

LIGO

LHO Observatory Status since E7

- Last of construction passes ground-shaking stage ➔ daytime locking
- Attempted 24-hr commissioning in late Jan & Feb
- Have cut back to 19-hr schedule to better concentrate resources

OSB East: LDAS, Science office/lab space; auditorium; on-site traffic stop

LIGO

LHO Emphasis Looking Toward S1

- Commission two interferometers with 7x24 coverage to meet goals
- Develop technical skills of operations staff
- Institute 24-hr shift rotations
- Complete building construction (scheduled for Aug 02)
- Seek to improve strength by encouraging visiting scientists and development of local university resources

LIGO

…and at LLO…

- control room staffed noon - 7 am every day
- 7 day per week night time commissioning schedule
- LSU group making a major contribution to commissioning
- All LLO technical staff participate in commissioning shifts to develop broadly experienced staff capable of operating apparatus.

LIGO

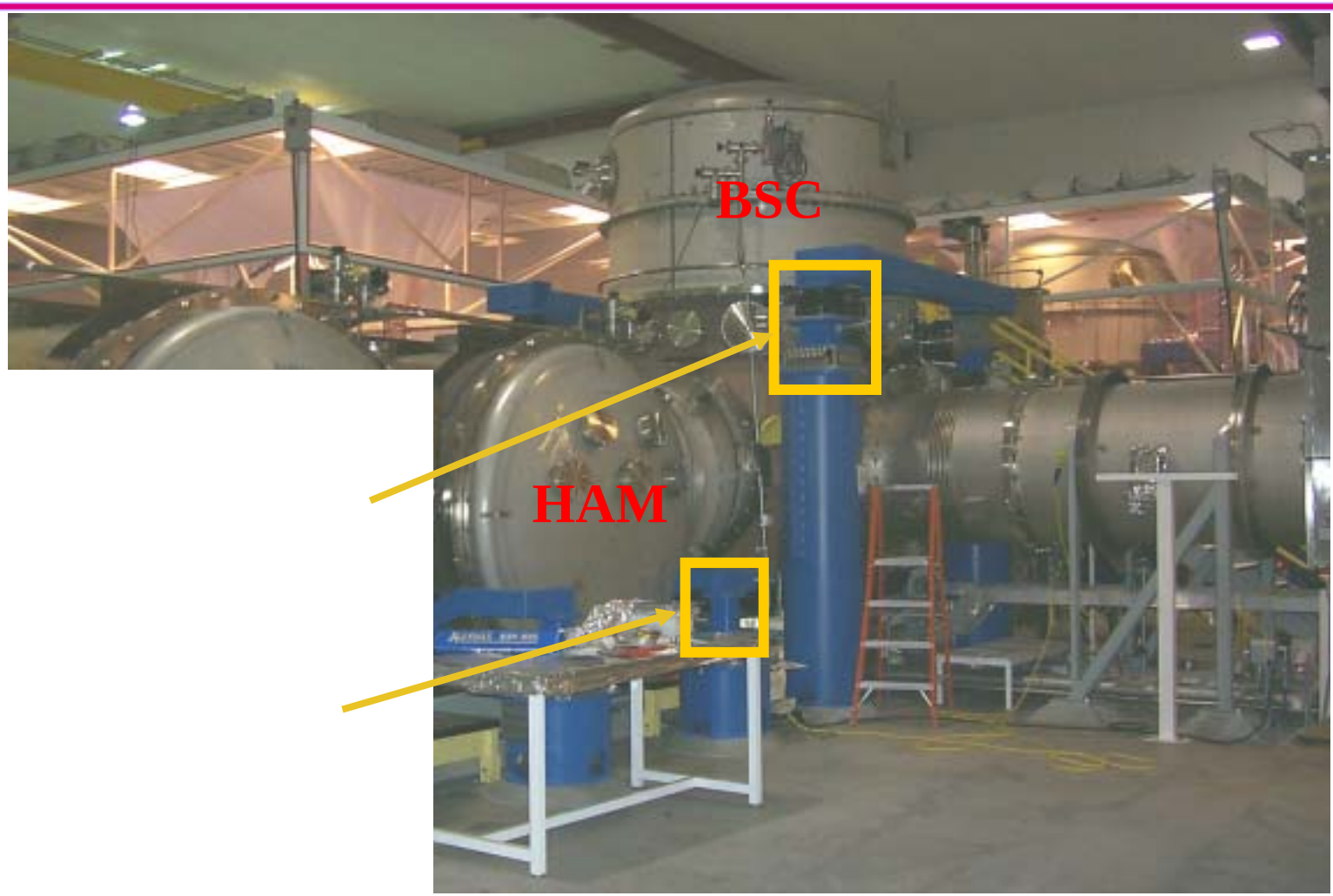
Commissioning After S1

Improved LLO seismic isolation after S1 and S2

- Fine actuation system stack mode suppression
  - » End test mass chambers for S1
  - » Input test mass chambers also for S2
  - » Possibly added to the Hanford observatory for S3
- Seismic retrofit with an active pre-isolation system
  - » Planned at the Livingston observatory right after S2
  - » The active pre-isolation system is placed under the existing passive stack, external to the chamber
    - – actuation is either hydraulic or electro-magnetic (both concepts are being developed & tested at LASTI)

LIGO

Planned Initial Detector Modifications



LIGO

Planned Initial Detector Modifications

Category	Task	Science Run		
		S1	S2	S3
Added Capability	Wavefront Sensor (WFS) and Optical Levers for LLO 4k (before DSC)	x		
	LSC & ASC code with new digital filter modules	x		
	Fine actuator tidal control for LLO 4k	x		
	Microseismic peak reduction for LHO 2k & 4k		x	
	Implement fine actuator 1-3 Hz isolation on ETMs for LLO 4k	x		
	Implement fine actuators & 1-3 Hz isolation on ITM chambers for LLO 4k		x	
	Automate FP arm cavity angular alignment		x	
	Digital Suspension Controls (DSC) for LHO 2k, LLO 4k		x	
	PSL Intensity Stabilization Servo (ISS) outer loop		x	
	Auto-centering for beams to ISC tables and transmission quad PDs		x	
	Coordinated software/hardware switch ramping for de-whitening filters		x	
Direct Noise Reduction	Suspension Coil Driver electronic noise reduction		x	
	RFI & 60 Hz clean up	x	x	
	Timing modules with variable delay		x	
	Optical Lever laser noise reduction		x	
	DSC: DAC Diff. driver/receiver, stack mode resonant gain stages, etc.		x	
	Seismic retrofit at LLO			x
	Lower noise Digital to Analog Converter (DAC)			x
	Further Noise Reduction TBD		x	x
Detector Data	CDS object code & filter parameter tagging	x	x	
	All slow channels in frames	x		
	EPICS LSC name cleanup	x	x	
	FrameBuilder reads arbitrary trend data	x		
	Frame version 5 implementation		x	

LIGO

Advanced Detector R&D and Advanced LIGO

LIGO

Advanced LIGO R&D Status

- Decision made to delay construction proposal to **Fall 2002**
- “bottoms-up” costing has nearly been completed
- Plan assumes construction funding available 1Q2005
  - » With some long lead funds in 1Q2004
- Supports an installation start of 4Q2006
- Soon ready to confront scope decisions (number of interferometers, trimming features to control costs, etc.)
- Advanced R&D program is proceeding well
- GEO team forming strong international partnership

LIGO

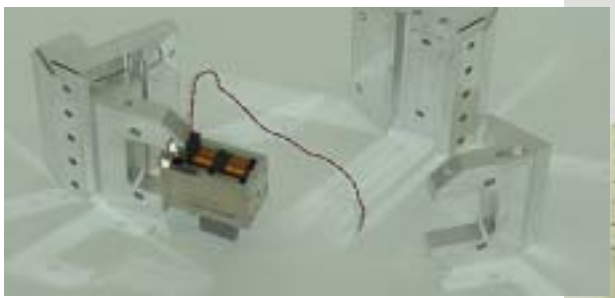
Advanced LIGO R&D Status

- Interferometer Sensing & Control (ISC):
  - » GEO 10m “proof of concept” experiment:
    - – Preparation proceeding well
    - – 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.)
    - – Working on the installation of the 12m input MC optics and suspensions, and suspension controllers by 3Q02
  - » 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)
    - – The facility development is advancing nicely
    - – Activities closely linked with subsystem, LASTI R&D plan

LIGO

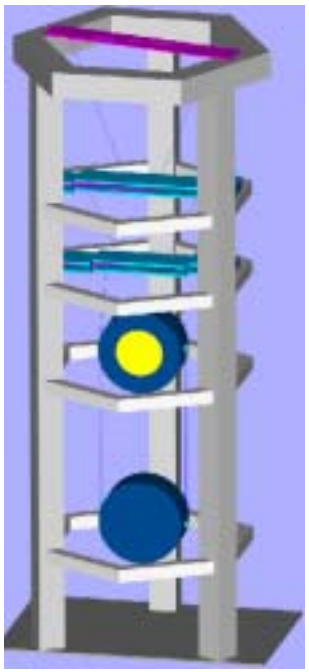
Advanced LIGO R&D Status

- Seismic Isolation system (SEI):
  - » Development of pre-isolation system accelerated for use in retrofit on initial LIGO
    - – hydraulic & electro-magnet actuation variants
    - – To be tested at the LASTI facility
  - » “Technology Demonstrator” system has been fabricated
    - – a two stage, 12 degree of freedom active, stiff, isolation system
    - – being installed into the Stanford Engineering Test Facility (ETF)
- LASTI infrastructure has been completed (including BSC stack to support pre-isolation full scale testing for initial LIGO)



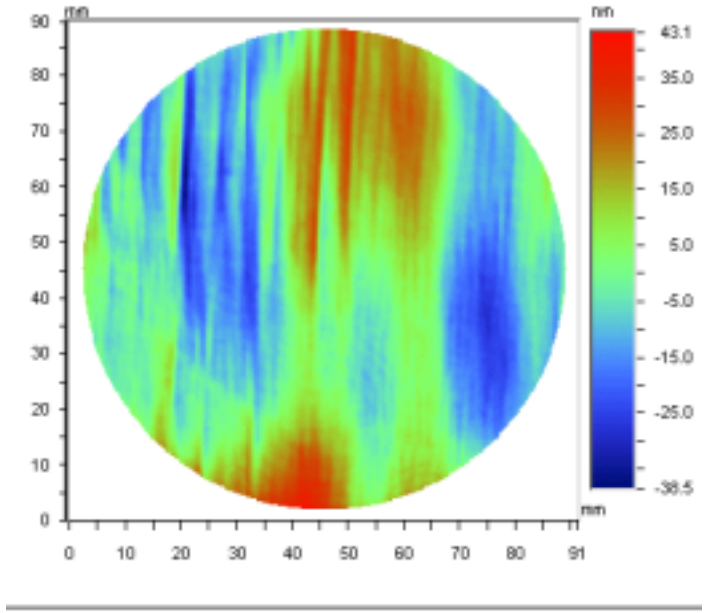
Advanced LIGO R&D Status

- Suspension System (SUS):
  - » Complete fused-quartz fiber suspensions functioning in the GEO-600 interferometer
  - » Progress, in theory and in experiment, on both circular fibers (tapered) and ribbons
  - » Dynamics testing is underway on a quadruple pendulum prototype
  - » Silica-sapphire hydroxy-catalysis bonding looks feasible; silica-leadglass to be explored
  - » Significant design work underway for ‘triple’ suspensions
  - » TNI nearing final results for fused silica; sapphire mirrors ready in Fall 2002 for next phase



Advanced LIGO R&D Status

- Core Optics Components (COC):
  - » New optical homogeneity measurements along the ‘a’ crystal axis are close to acceptable (13nm RMS over 80mm path length)
  - » Tests to compensate for optical inhomogeneity if required, look promising (computer controlled ‘spot’ polishing and ion beam etching)
  - » Recent sapphire annealing efforts are encouraging (reductions to 20 ppm/cm vs a requirement of 10 ppm/cm)
  - » Coatings on large optics show sub-ppm losses (SMA/Mackowski)
  - » Coating mechanical loss program in full swing; materials rather than interfaces seem to be the culprit



Schedule Options for Earlier Advanced LIGO Science

	Options	proposal submission	MRE $ available	start install	1st Obs on-line	2nd Obs on-line
-1	Aug/2001 LSC	4Q2001	4Q2003	Jan-06	Dec-08	Dec-08 (Jun-10)
0	Mar/2002 LSC	4Q2002	1Q2005	Jun-07	Apr-09	Feb-11
1	both oservatories in parallel			Jun-07	Apr-09	Apr-09
2	+ purchase core optics early			Mar-07	Jan-09	Jan-09
3	+ parallel (or no) first article test at LASTI			Nov-06	Sep-08	Sep-08
4	+ production SEI < (MRE, LASTI cavity test)			Dec-05	Nov-07	Nov-07

LIGO

Simulation and Analysis

LIGO

Simulation & Modeling

- Basic LIGO simulation package available
  - » Used to design the lock acquisition code for length control servo
  - » Limiting h[f] noise curve can be simulated in time domain
    - – Includes seismic, thermal and shot noise.
- Enhanced simulation package under development
  - » To study lock acquisition strategy with thermal effect
  - » To simulate the noise curve more accurately
    - – Realistic length control servo
    - – 3D mirror with 4 actuators,
    - – digital suspension controller,
- E2E school held on 2002.03.18
  - » Presentation materials: http:// www.ligo.caltech.edu/~e2e
- Monthly detector and modeling meeting held by D.Coyne and David Shoemaker

LIGO

LIGO Data Analysis System (LDAS)

- E7 performance:
  - » LDAS ran for full E7 Run: Dec. 28th, 2001 - Jan. 14th, 2002
  - » Approximately one job every 10 seconds and five rows every second (averaged).
  - » Greater than 90% of jobs completed successfully
  - » Pre-Release testing revealed 0.3% failure rate!
    - – Pre-release dominated by dataConditionAPI thread problems mpiAPI/wrapperAPI communications issues.
- Plans for rest of 2002, 2003:
  - » Successive LDAS releases coordinated with LAL releases
    - – S1 -- Last release planned for late April
    - – S2 -- Last release planned for September
    - – S3 -- Last release planned for April (2003)
  - » Incremental hardware build-up for S1, S2
  - » Final build-up1Q2003 will take advantage of 64 bit Intel architecture

E7 Data Analysis from an **Engineering** Run

- Different LIGO, LSC resources allocated to UL analyses
  - » MIT LDAS for burst group, simulation
  - » LHO LDAS for creating Short Fourier Transforms (SFTs) for all CW searches
    - – Directed source search to be done at LHO
  - » UWM LDAS/Condor cluster for inspiral searches, stochastic background search, Hough CW search, simulation
- Analyses at different stages of development:
  - » Inspiral: flat search implemented for templates; fast chirp transform being developed at Caltech
  - » Burst: calibrating trigger methods, use of vetoes
  - » Stochastic: first look reveals relatively “clean” cross spectrum for LLO-LHO
    - – ALLEGRO ran in coincidence -- 3 different orientations
  - » CW: producing short Fourier transforms at LHO for use by all subgroups
    - – Large area search code being developed at AEI by GEO
    - – Directed search version implemented as shared object for integration into LDAS
- Reduced data sets produced by Oregon (I. Leonor)
  - » Frames with greatly reduced channel count, for upper limits analysis

LIGO

Grid Computing

- GriPhyN research continues
  - » Development of a grid interface for LDAS
    - – Allows federation of different LDAS sites -- enhancement beyond original design, scope
    - – Publish available data onto grid resources to permit users to access data more easily
    - – Security will be based on grid tools for secure data transfer
  - » Porting of LAL (“stand alone wrapper” code version) search code to grid resources
    - – e.g., Teragrid project (CACR/SDSC/NCSA/ANL)
      - 500+ GFLOPS for, e.g., CW large area search
  - » Working on data replication, redundant backup of deep archive using grid resources at CACR, SDSC, NCSA, ANL
- International Virtual Data Grid Laboratory (iVDGL)
  - » LIGO, LSC represented on several key working groups:
    - – Facilities (B. Allen, co chair)
    - – Applications (S. Finn, co chair)
    - – Integration (S. Koranda)
  - » Tier 2 center at PSU to be built with iVDGL funds
  - » Maintenance, upgrade of UWM center
- LIGO working to implement higher bandwidth access to observatories
  - » Holding discussion with commercial and government (state, federal) groups

LIGO

LIGO-GEO Data Exchange

- Agreement is now in place
- Data is exchanged through the GEO and LIGO directorates only
  - » Exchange through the directors brings with it the implication that
    - – the data is of sufficient quality for the exchange
    - – the exchange is sanctioned
  - » Uncontrolled data exchange between upper limits working groups is not sanctioned
  - » Exchanged data is archived at a LIGO Laboratory archive and a site designated by GEO
- And agreement with TAMA on coincidence running and analysis just agreed to

LIGO

Summary

- E7 run accomplished a great deal
- GEO and Allegro coincidence running also a landmark
- LSC analyzing E7 data
- On to S1, S2 and S3 with interleaved analysis, detector development and engineering runs
- LDAS and simulations toolkits advancing
- Advanced R&D program making significant progress
- Advanced LIGO proposal planned late this year