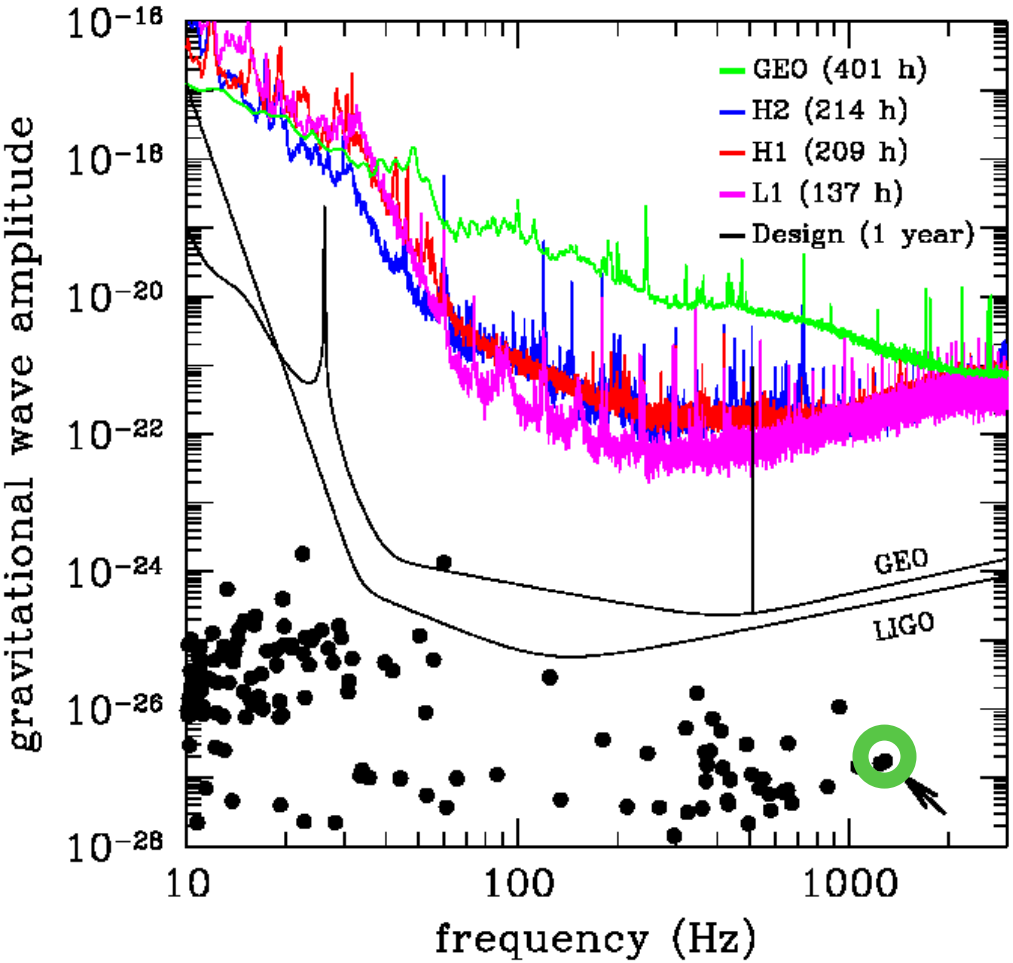
LIGO



State of LIGO

Barry Barish

LSC Meeting

Hannover, Germany

19-Aug-03

LIGO

Schedule and Plan

LSC -Aug 02

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

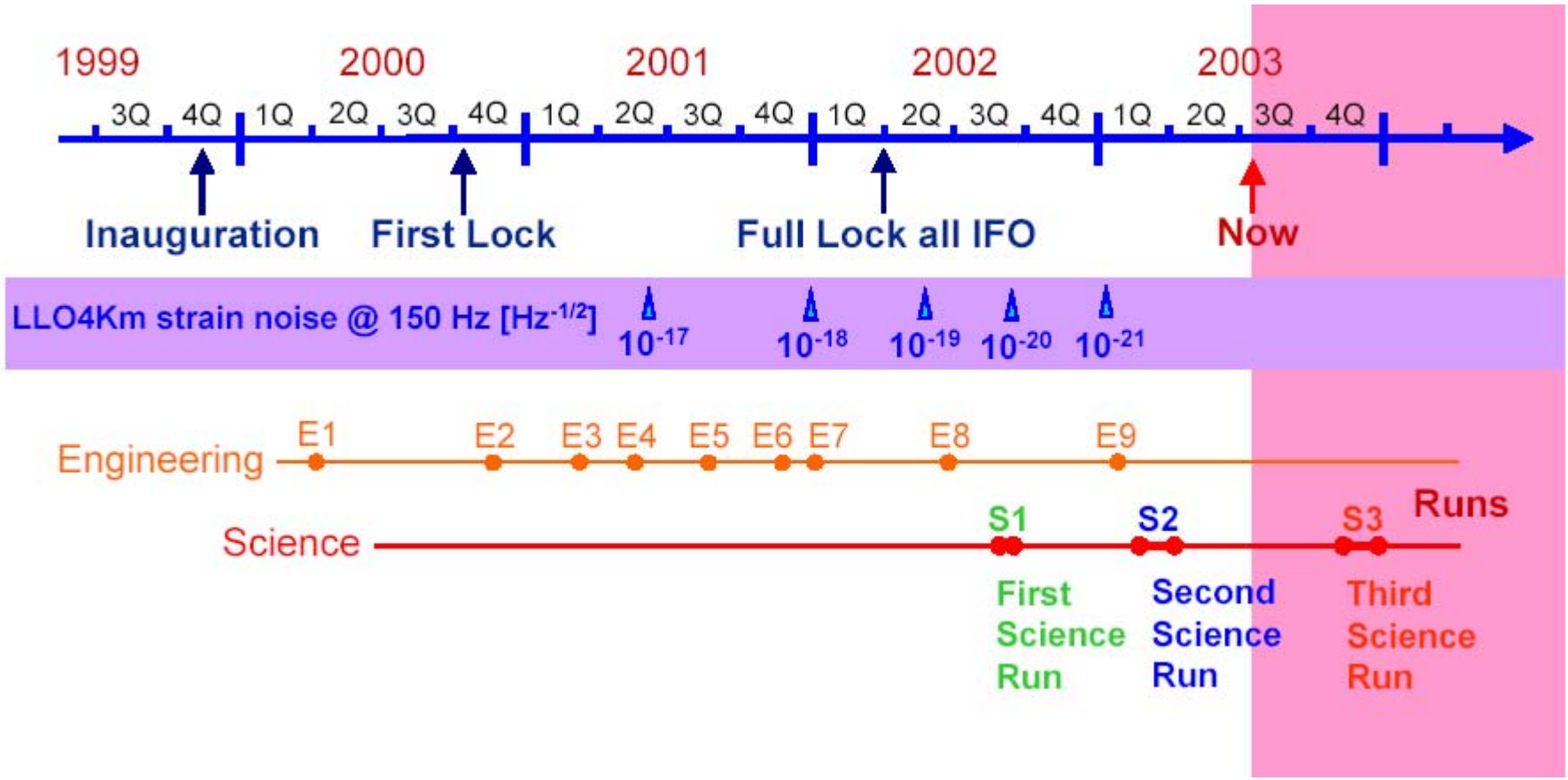
LIGO

Goals and Priorities

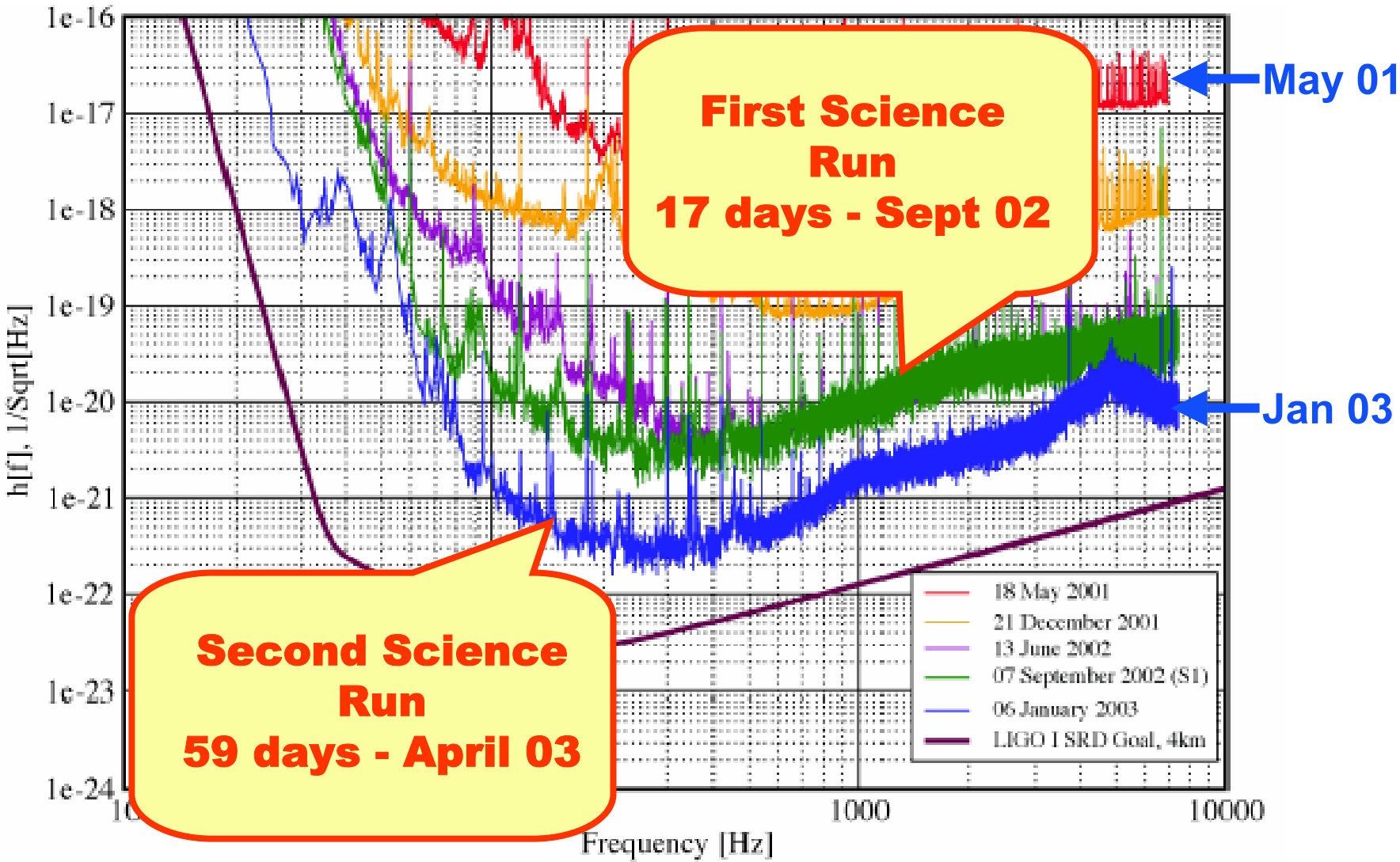
LSC -Aug 02

- **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

Commissioning / Science Timeline



LIGO Sensitivity -- L1



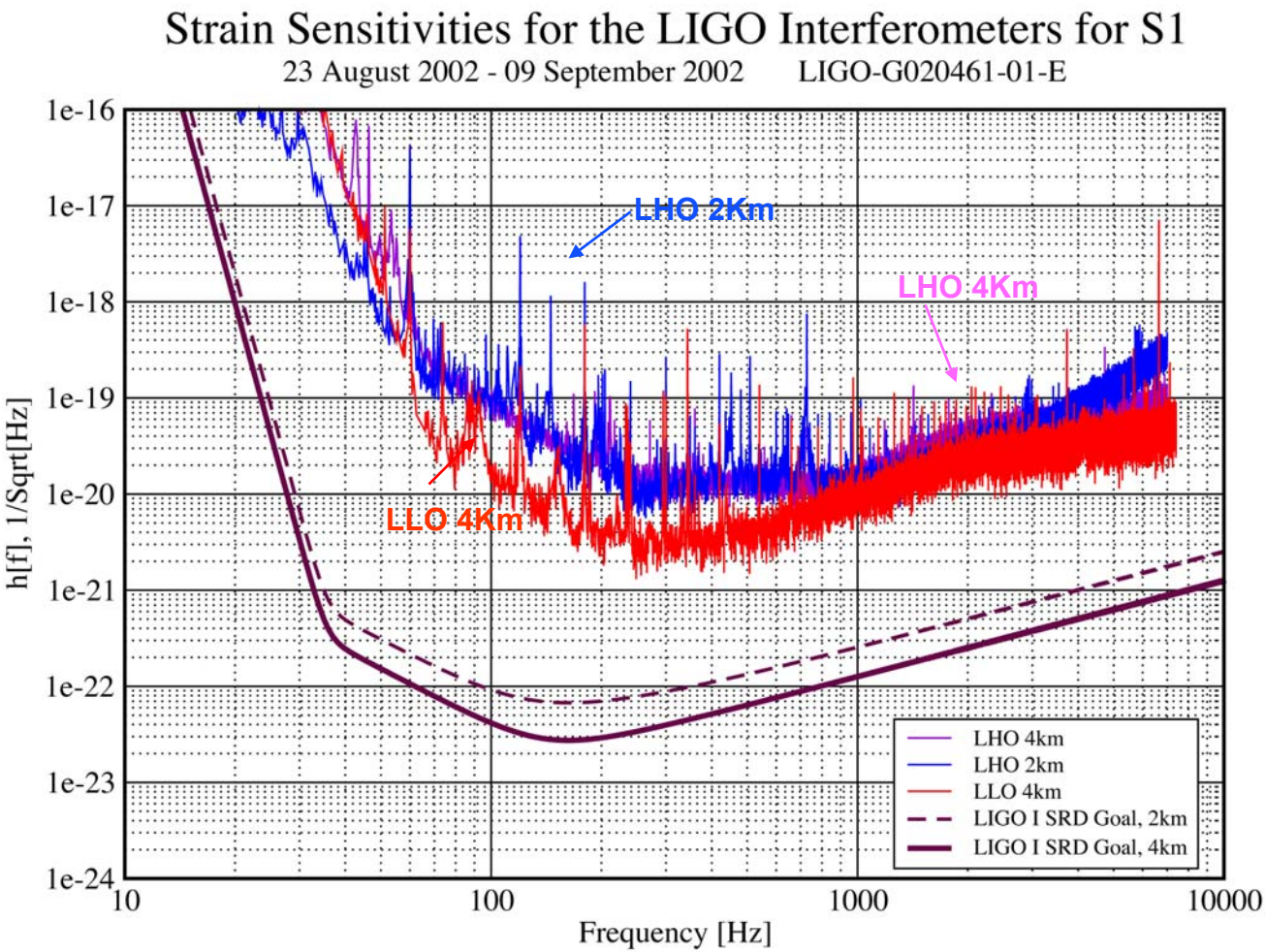
Sensitivity during S1

LIGO S1 Run

"First Upper Limit Run"

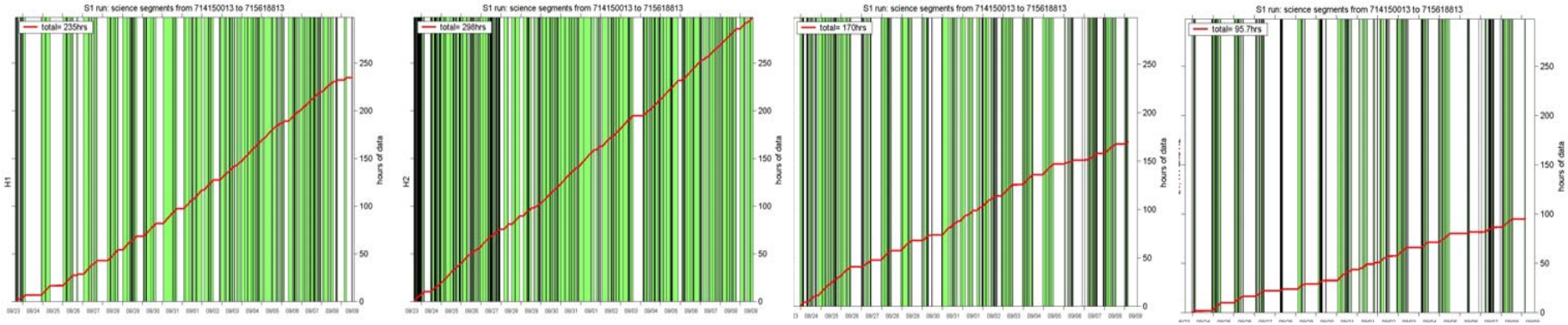
- 23 Aug–9 Sept 2002
- 17 days
- All interferometers in power recycling configuration

GEO data exchange for S1 RUN



In-Lock Data Summary from S1

H1: 235 hrs **H2: 298 hrs** **L1: 170 hrs** **3X: 95.7 hrs**



Red lines: integrated up time Green bands (w/ black borders): epochs of lock

- August 23 – September 9, 2002: 408 hrs (17 days).
  - H1 (4km): duty cycle 57.6% ; Total Locked time: 235 hrs
  - H2 (2km): duty cycle 73.1% ; Total Locked time: 298 hrs
  - L1 (4km): duty cycle 41.7% ; Total Locked time: 170 hrs

- Double coincidences:
  - L1 && H1 : duty cycle 28.4%; Total coincident time: 116 hrs
  - L1 && H2 : duty cycle 32.1%; Total coincident time: 131 hrs
  - H1 && H2 : duty cycle 46.1%; Total coincident time: 188 hrs

Triple Coincidence: L1, H1, and H2 : duty cycle 23.4% ; total 95.7 hours

LIGO

S1 "Methodology" Papers

- **Instrumentation Paper** (gr-qc/0308043 v1 14 Aug 2003)

  "Detector Description and Performance for the First Coincidence Observations between LIGO and GEO"

- **Periodic Sources** (gr-qc/0308050 v1 14 Aug 2003)

  "Setting upper limits on the strength of periodic gravitational waves using the first science data from the GEO600 and LIGO detectors"

- **Inspiral Sources**

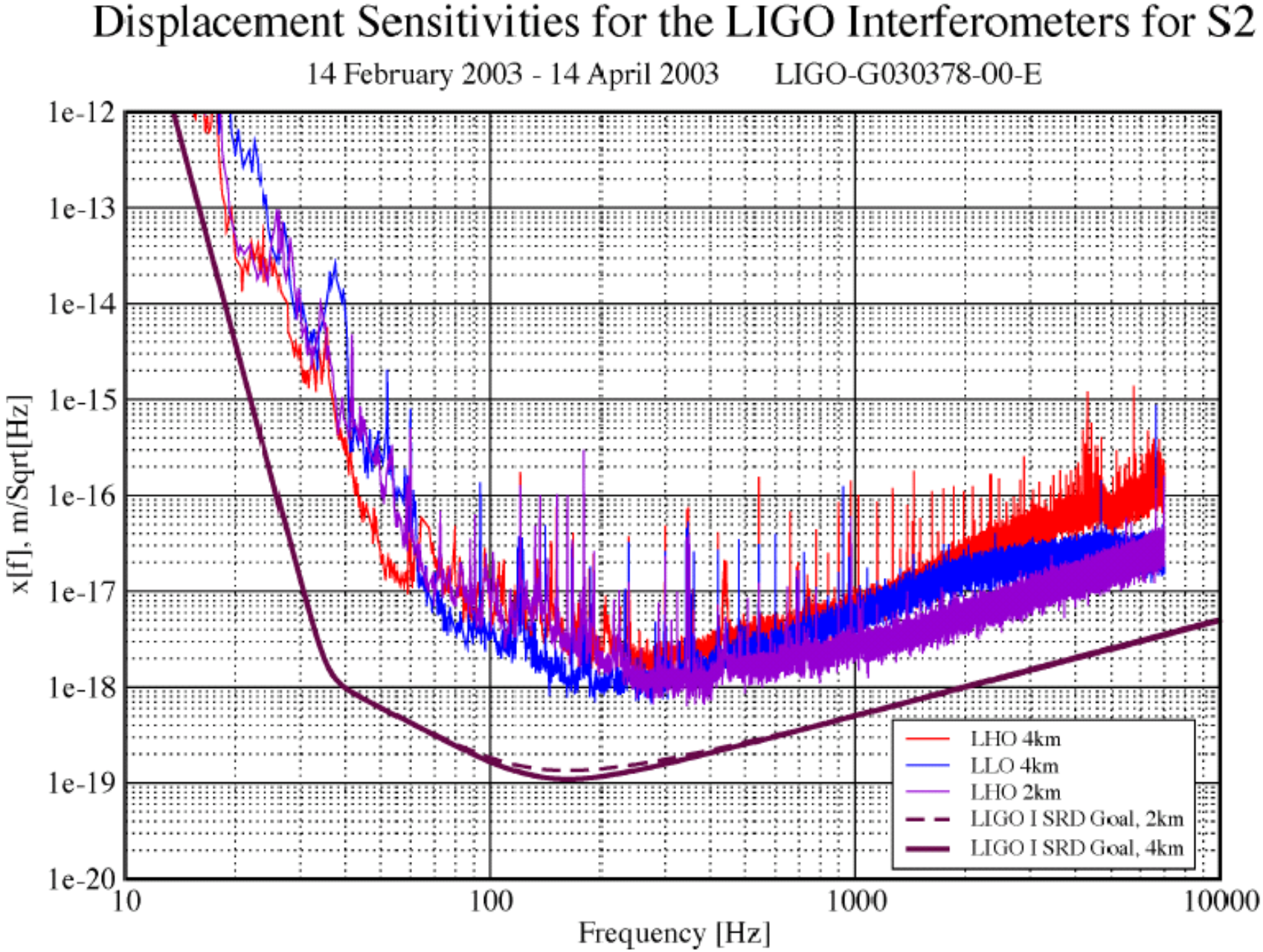
  "Analysis of LIGO data for gravitational waves from binary neutron stars"

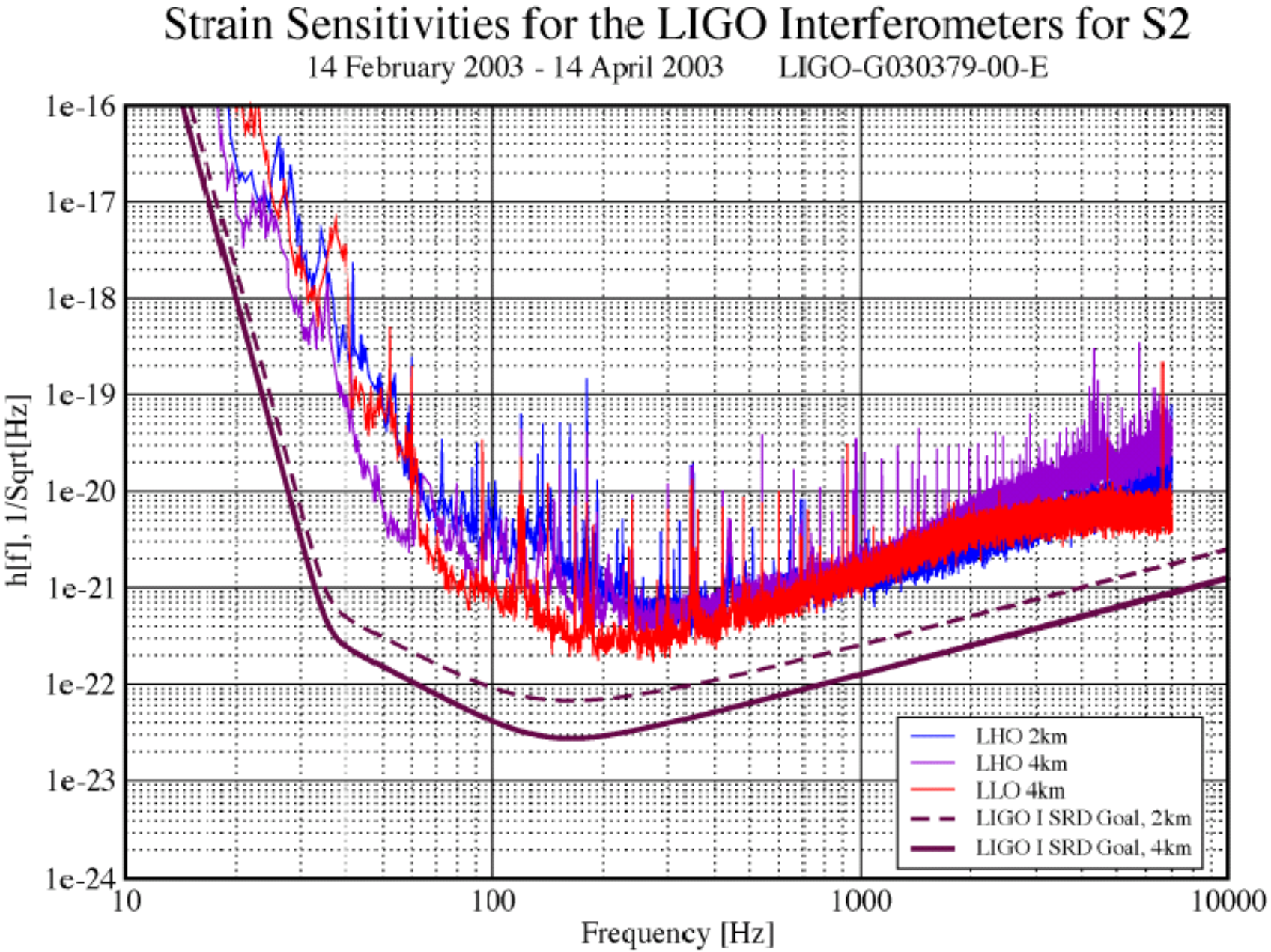
- **Stochastic Sources**

  "Analysis of First LIGO Science Data for Stochastic Gravitational Waves"

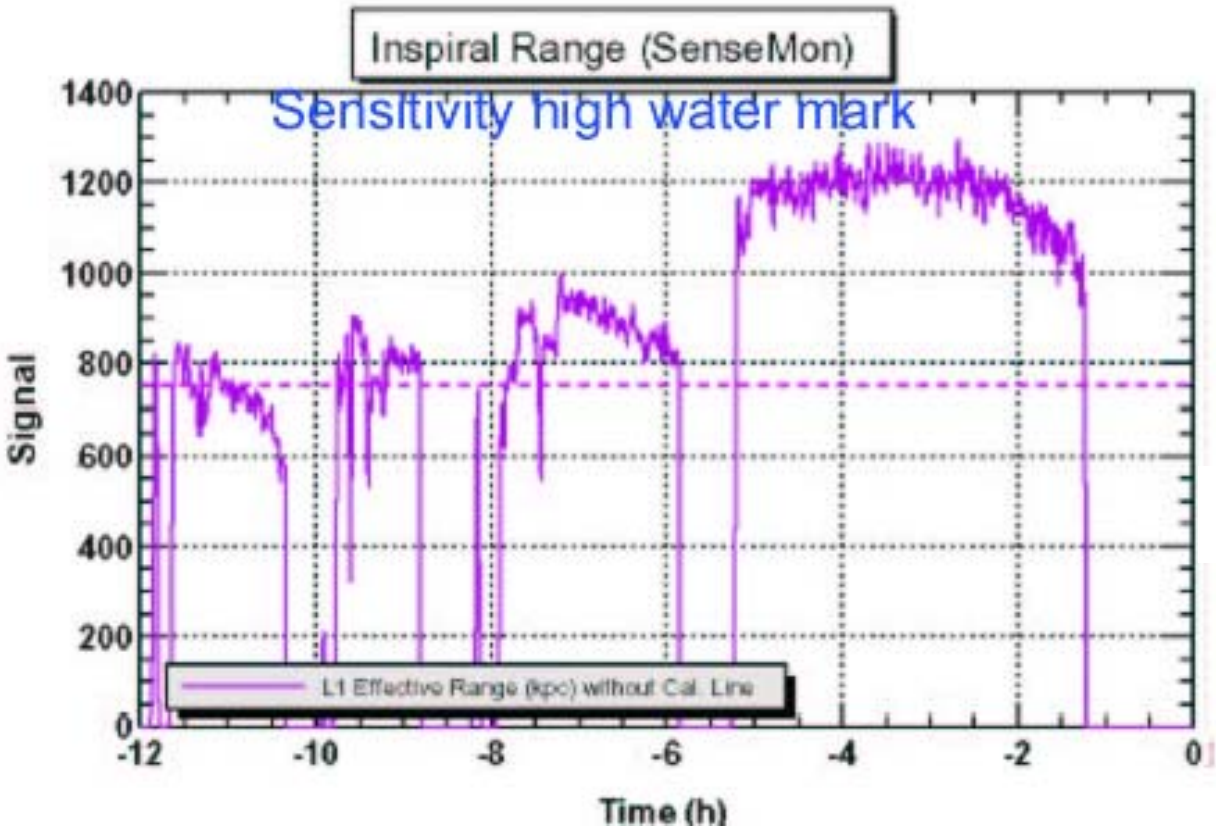
- **Burst Sources**

  "First upper limits on gravitational wave bursts from LIGO"

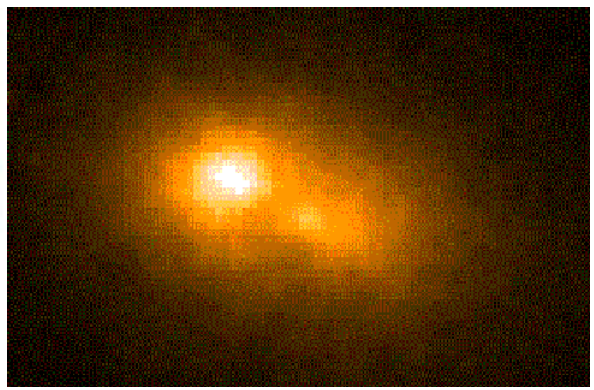

Displacement Sensitivities for the LIGO Interferometers for S2
14 February 2003 - 14 April 2003
LIGO-G030378-00-E
1e-12
1e-13
1e-14
1e-15
1e-16
1e-17
1e-18
1e-19
1e-20
x[f], m/Sqrt[Hz]
10
100
1000
10000
Frequency [Hz]
LHO 4km
LLO 4km
LHO 2km
LIGO I SRD Goal, 2km
LIGO I SRD Goal, 4km


Strain Sensitivities for the LIGO Interferometers for S2
14 February 2003 - 14 April 2003
LIGO-G030379-00-E
h[f], 1/Sqrt[Hz]
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
1e-24
10
100
1000
10000
Frequency [Hz]
LHO 2km
LHO 4km
LLO 4km
LIGO I SRD Goal, 2km
LIGO I SRD Goal, 4km

S2 -- L1 reaches Andromeda



M31 in Andromeda



Lock Summaries - S1and S2

	S1 (23/8-9/9/02, 408 hours)			S2 (14/2-14/4/03, 1415 hours)		
	Locked	%	Longest	Locked	%	Longest
H1 (2km)	235	58%	11	1040	74%	66
H2 (4km)	298	73%	8	818	[illegible]	[illegible]
L1 (4km)	170	42%	8	523	37%	7
H1 & H2	188	46%	5	699	42%	12
H1 & L1	116	28%	6	431	31%	7
H2 & L1	131	32%	4	351	25%	5
H1 & H2 & L1	96	23%	3	312	22%	5

S1 Sensitivities: H2 < H1 < L1 (~ 3×10^{-21} $1/Hz^{1/2}$ @300Hz)

S1 Data Analyses completed – Publications in final stage of preparations

LIGO

S2 Data Analysis

- LIGO I groups are completing the S1 papers. They are being posted on gr-qc and LIGO Website. After waiting a few weeks for community reaction, they will be submitted for publication.

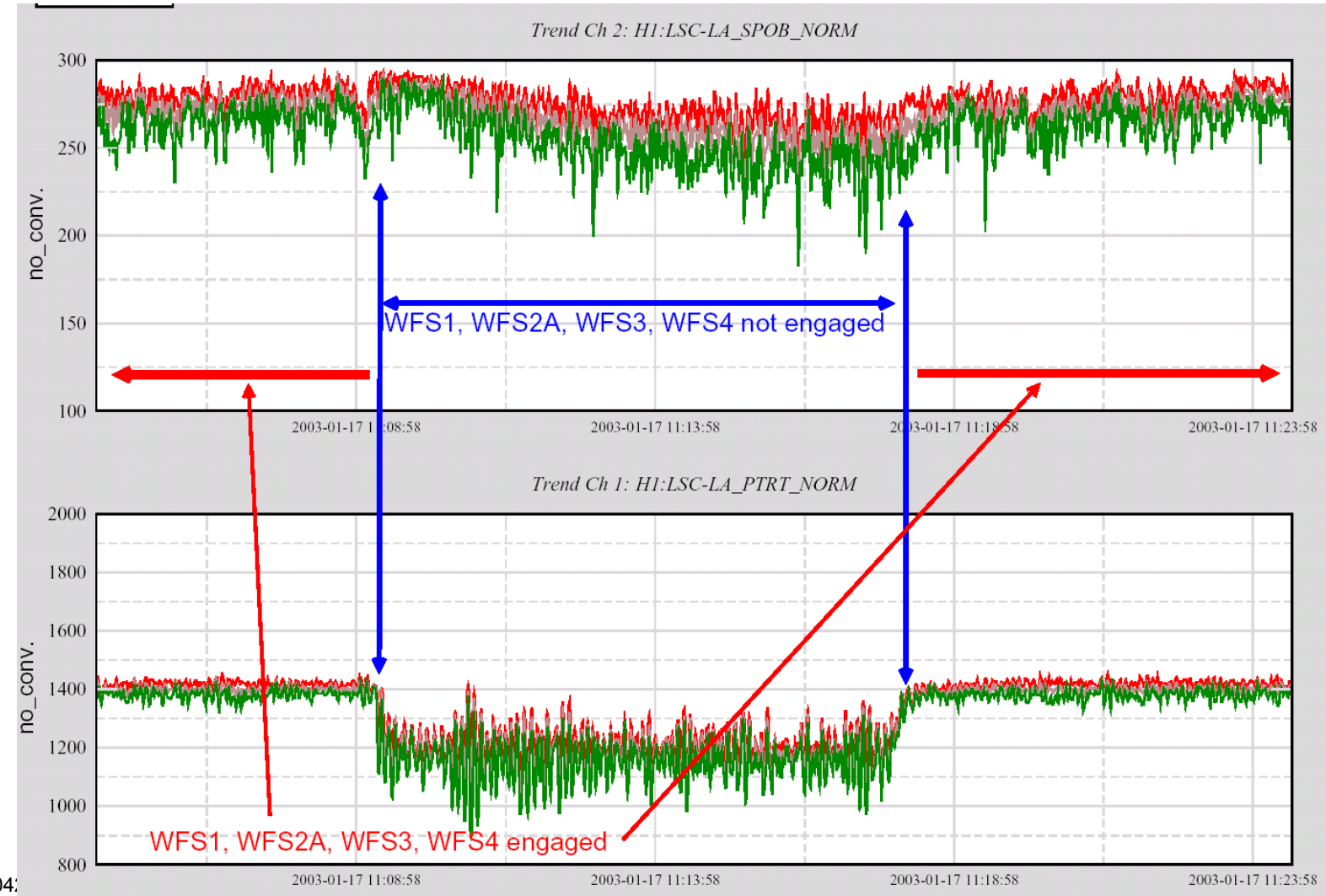
- S2 Data Analysis: Many lessons learned from S1 data analysis. One of the main tasks at this meeting is to transition fully to S2 data analysis.

LIGO

S3 Preparations

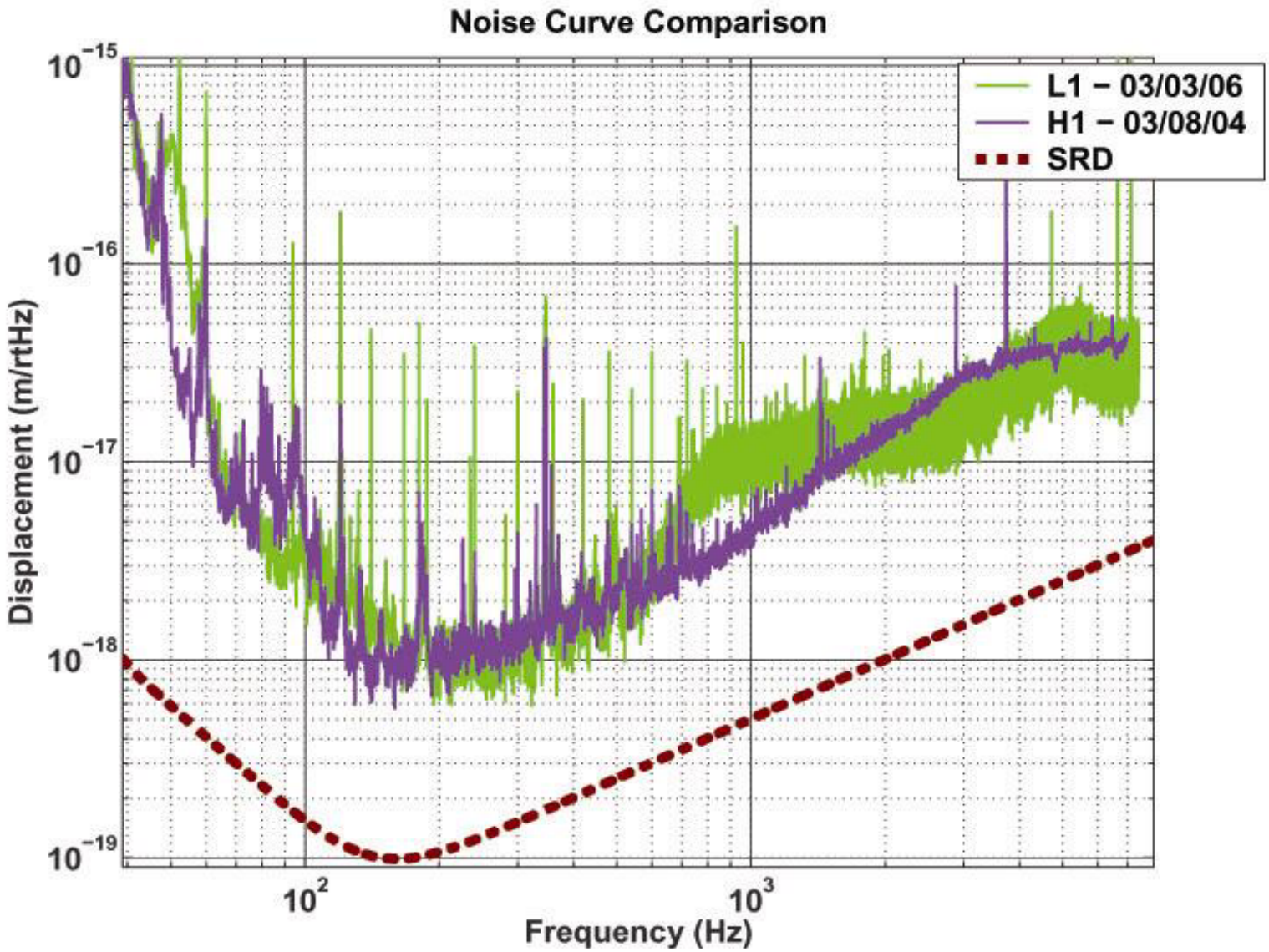
- **Commissioning : A primary goal is to equalize interferometers for coincidence work**
- **Improve sensitivity and robustness**
- **What can we learn from S2 data analysis that should be applied to the S3 run?**

Controlling angular degrees of freedom



LIGO

S3 - Improvement of H1



LIGO

Seismic retrofit at LLO

External Pre-Isolators

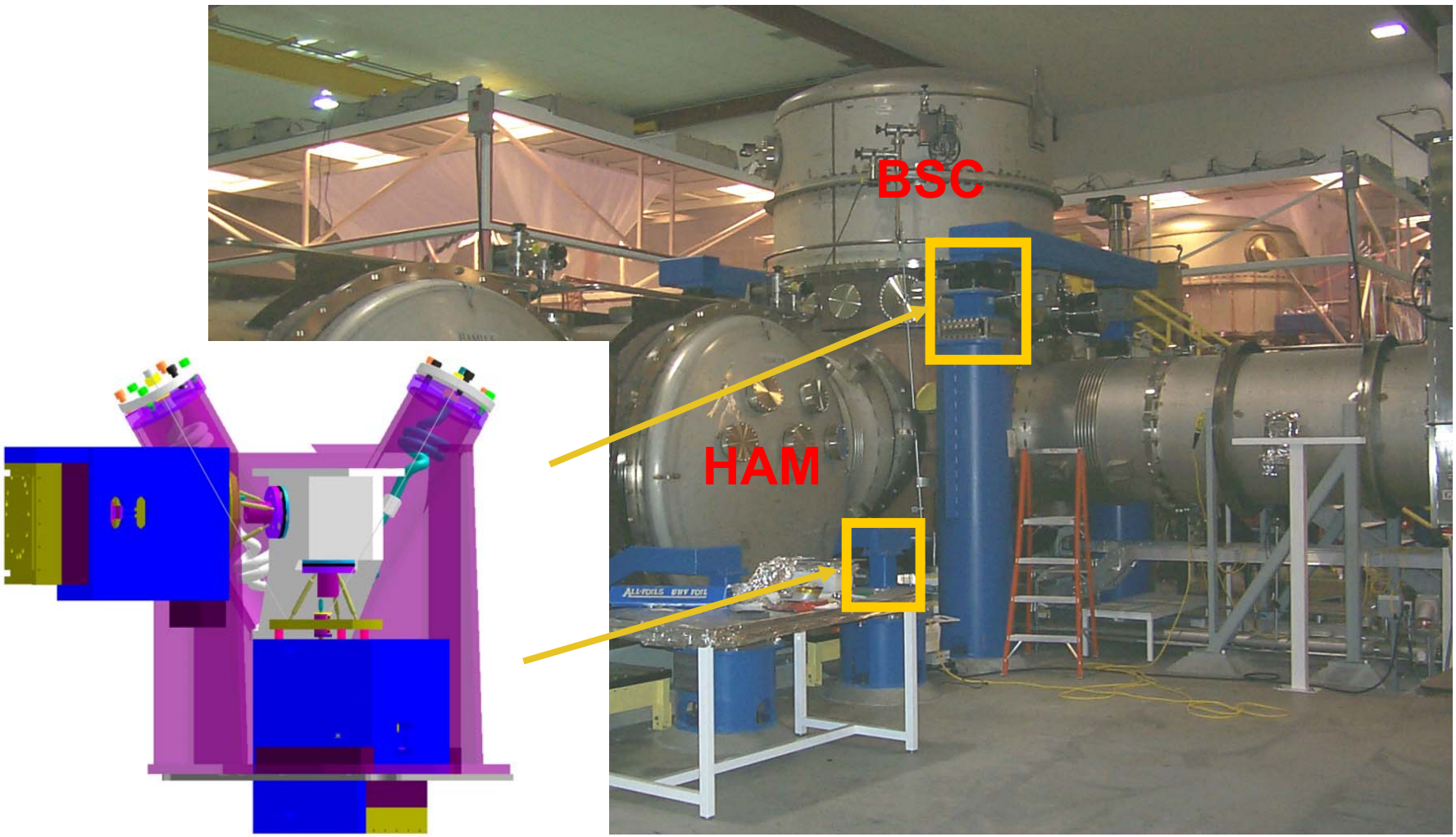
» Need to achieve 24/7 operation at Livingston

» Crash development program at MIT LASTI facility

» Scheduled installation at LLO in early 2004

Planned Detector Modifications

active external seismic



EPI Decision Memo (17 June 03)
Barish and Gary Sanders
(extracted from LIGO Lab memo).

Based upon an April 2003 comparative review of the HEPI and MEPI test programs, a May review report, responses to set of specific questions from us and several discussions with the involved scientists, we have decided to select the HEPI system for implementation in Livingston. Both actuators promise to meet the LIGO requirements and it is a tribute to the MEPI team that they were able to achieve such performance in a short time.

However, based upon the HEPI:

- **"Robustness" - the ability of its design to function reliably and safely, with good engineering margins and without excessive fine-tuning, and**

- **Superior suitability for application in Advanced LIGO**

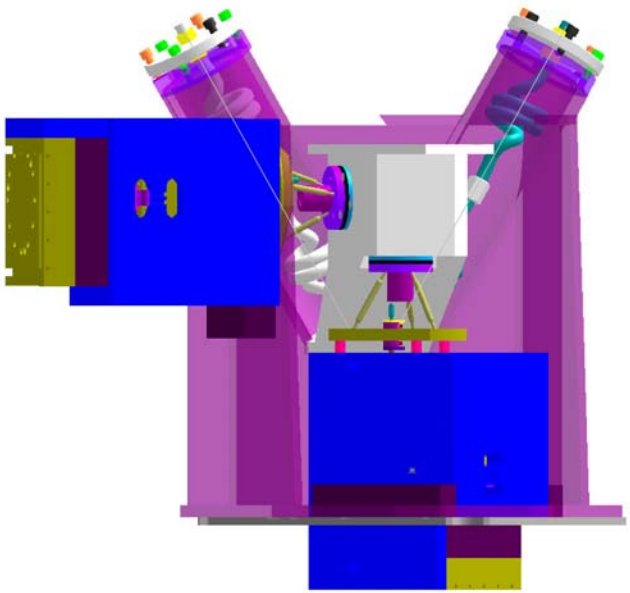
We have concluded that HEPI is the advantageous option. We have carefully considered many other factors, including other projected performance issues, cost, schedule, implementation, etc. in making this final decision.

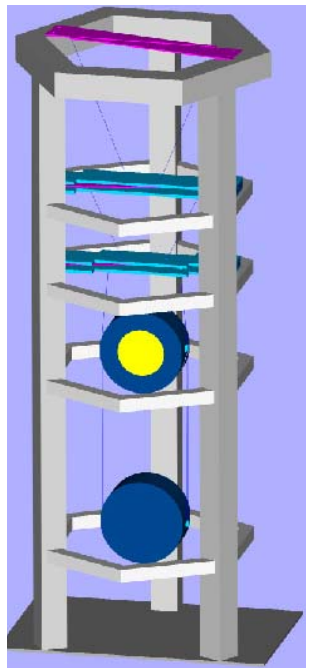
Advanced LIGO

proposed in early 2003

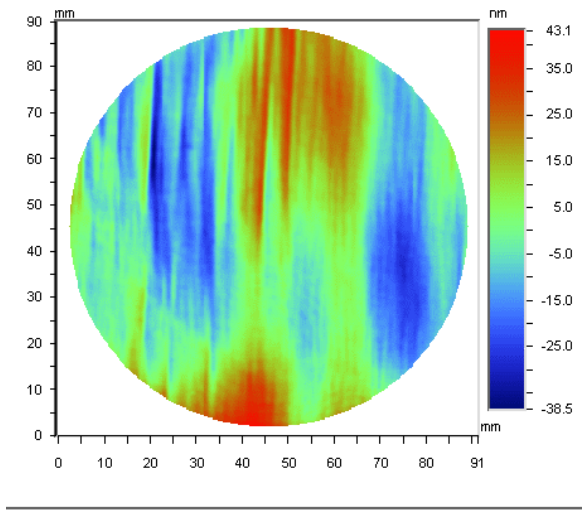
Multiple Suspensions

Active





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

NSF Adv LIGO Review -- June 04 Committee Closeout Statement

Advanced LIGO will provide the capability to observe a variety of astrophysical phenomena including inspiral events, continuous-wave sources, bursts, and stochastic backgrounds. Achievement of the design strain sensitivity (more than a factor of ten beyond Initial LIGO) is feasible and detection of events is plausible. Detection of any source would be a dramatic direct confirmation of the existence of gravitational waves and would have exciting and wide-ranging implications for gravitational physics, astrophysics, and our understanding of the universe.

The committee agrees that the current state of the proposed project is at a sufficiently mature level that the process leading to construction should proceed. Although technical challenges remain, the plan for solving the technical problems appears sound and no major obstacles have been identified that would justify delaying the construction of Advanced LIGO.

NSF Processes

- Large Projects at NSF are funded through MREF account (projects with total cost of more than ~10% of the annual division budget)

- Physics, Astronomy, etc each propose future projects to Math-Physical Sciences (MPS) Directorate

- A long list of possible MREF projects (23) are under discussion by all the directorates and the list changes with time.

- A shorter list of reviewed projects (11) are discussed annually with the NSB annually (a more stable list, but not prioritized) - *[comment]*

- The Assistant Directors advise the Directorate (who decides) what and when to bring projects forward to NSB for consideration and approval

MREFC Account in the FY 2004 Request

Dollars in Millions

	FY 2002 Actual	FY 2003 Request	FY 2004 Request	FY 2005 Request	FY 2006 Request	FY 2007 Request	FY 2008 Request
ONGOING PROJECTS							
ALMA Construction	12.50	30.00	50.84	49.67	48.84	47.89	46.49
EarthScope: USArray, SAFOD, PBO		35.00	45.00	54.26	40.00	23.00	
High-performance Instrumented Airborne Platform for Environmental Research	35.00		25.53				
IceCube Neutrino Observatory	10.12		60.00	33.40	34.30	35.30	36.30
Polar Aircraft Upgrades	0.89						
Large Hadron Collider	16.90	9.72					
Network for Earthquake Engineering Simulation	24.40	13.56	8.00				
National Ecological Observatories Network		12.00	12.00	16.00	20.00	20.00	20.00
South Pole Station	15.55	6.00	0.96				
Terascale Computing Systems		20.00					
NEW STARTS							
Scientific Ocean Drilling				76.85	23.00		
Rare Symmetry Violating Processes					30.00	42.66	44.00
Ocean Observatories					24.76	40.33	72.46
Totals	$115.35	$126.28	$202.33	$230.18	$220.90	$209.18	$219.25

MREFC Account Adjustments for FY 2003-4

Dollars in Millions

	FY 2003 Request	FY 2003 Approps	Adjusted FY 2003 Current Plan	**FY 2004 Request**	**Adjusted FY 2004 Request**
Highest Priority: Ongoing Projects					
ALMA Construction	30.00	29.81	29.81	**50.84**	**51.04**
EarthScope	35.00	29.81	[illegible]	[illegible]	**43.73**
HIAPER		25.36	25.53	**25.53**	
IceCube		24.54	24.54	**60.00**	**35.46**
LHC	9.72	9.66	[illegible]		
NEES	13.56	13.47	13.47	**8.0**	**8.09**
SPSM	6.00	5.96	5.73	**0.96**	**1.11**
Terascale	20.00	9.94	9.94		**10.06**
Subtotal	$114.28	$148.54	$148.54	**$190.33**	**$149.49**
Priority 2: NSB-Approved Projects					
NEON	12.00	0.00	0.00	**12.00**	**12.00**
Scientific Ocean Drilling (vessel)					**40.85**
RSVP (currently to begin in FY 2005)					
OOI (currently to begin in FY 2006)					
Subtotal	$126.28	$148.54	$148.54	**$202.33**	**$202.33**

NSB Proposes to raise MREFC to $300-350M

Prioritization of MREFC Projects

- HIGHEST PRIORITY: Ongoing Projects
  - Projects which have received funding and are not yet completed
- SECOND PRIORITY: NSB-Approved Projects
  - Projects that have received NSB approval, are included in a budget request, and have not yet received funding.
- THIRD PRIORITY: Potential New Projects
  - New projects that have not yet received NSB approval for inclusion in a budget request and which have not yet been included in a budget request or received funding.

LIGO

HIGHEST PRIORITY: Ongoing Projects

Projects which have received funding and are not yet completed

- ALMA Construction
- EarthScope: USArray, Plate Boundary Observatory (PBO) and San Andreas Fault Observatory at Depth (SAFOD)
- IceCube Neutrino Observatory

SECOND PRIORITY: NSB-Approved Projects

Projects that have received NSB approval, are included in a budget request, and have not yet received funding

- National Ecological Observatory Network (NEON)
- Scientific Ocean Drilling vessel (SOD)
- Rare Symmetry Violating Processes (RSVP)
- Ocean Observatories Initiative (OOI)

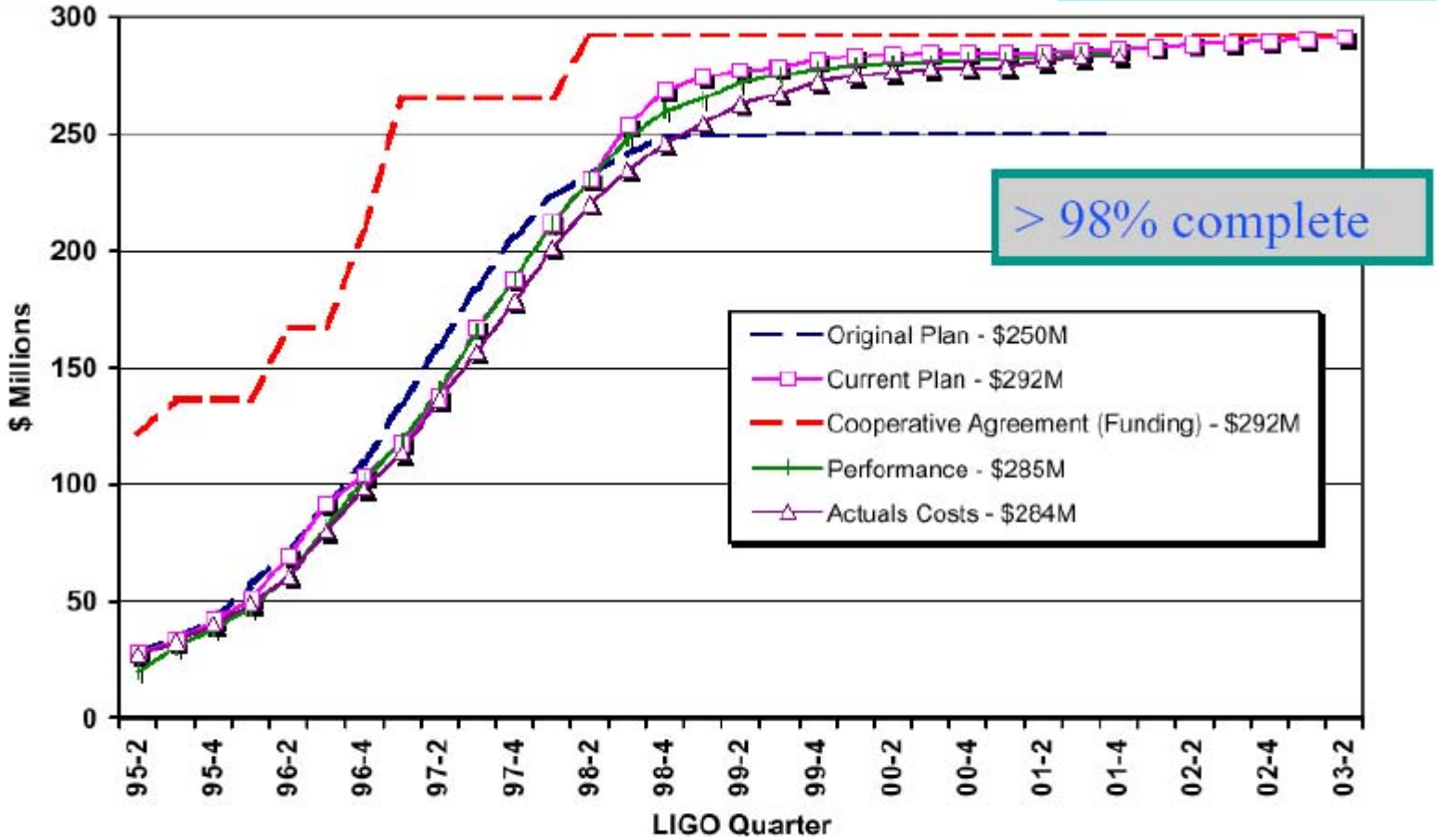
Current MREFC Panel Discussion List

- Advanced LIGO
- Advanced Technology Solar Telescope
- Alaska Region Research Vessel
- CLEANER
- Deep Underground Science and Engineering Laboratory
- Expanded Very Large Array (EVLA) Phase II
- Giant Segmented Mirror Telescope Technology Development
- GNSS Earth Observing System (GEOS)
- Large Aperture Synoptic Survey Telescope
- South Pole Future Communication Needs
- Square Kilometer Array

Construction Cost/Sch Performance

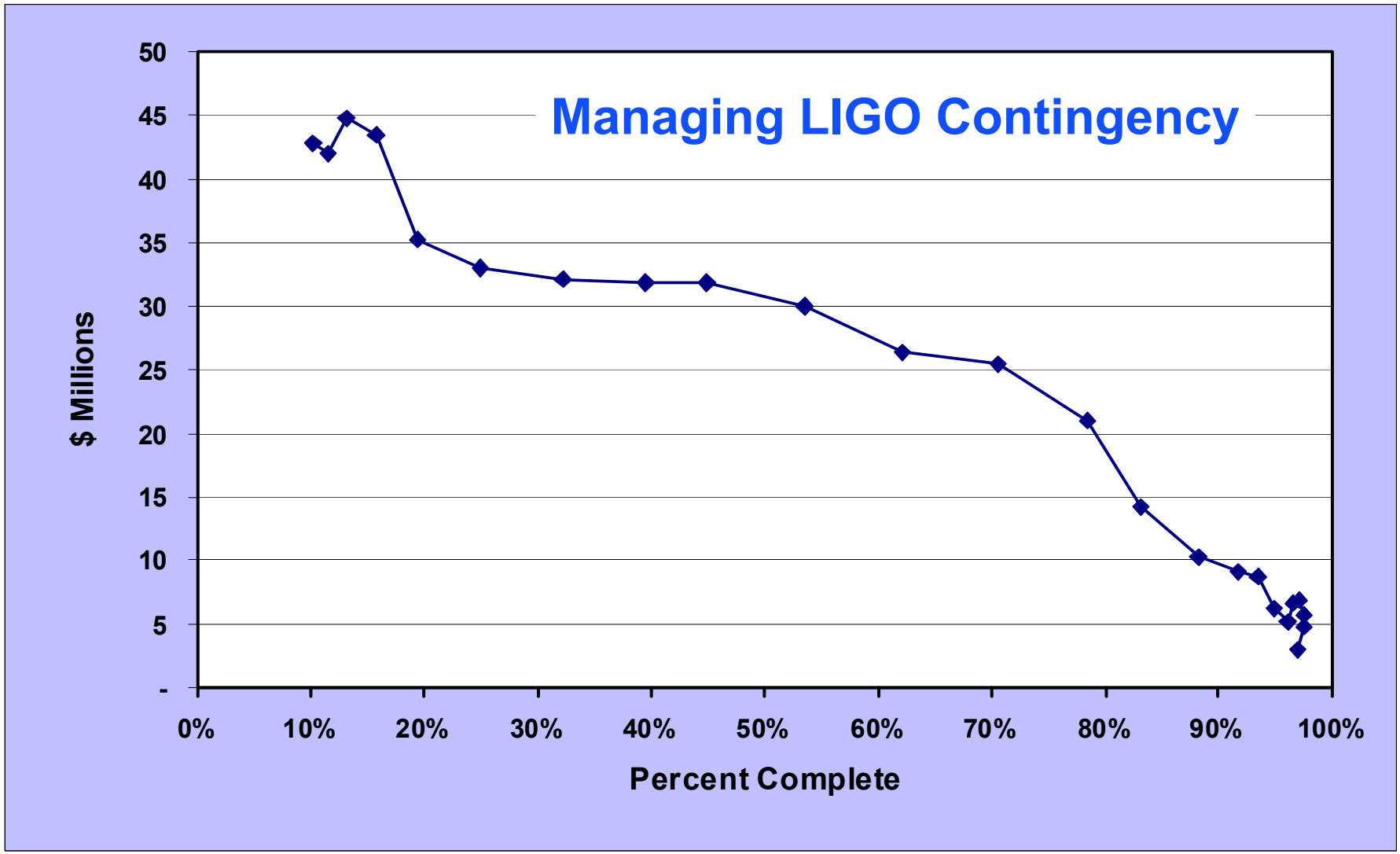
LSC -Aug 02

Support buildings and LDAS remain



> 98% complete

LIGO "Spend the Last $$ on the Last Day"



11 days to go and within .01%

Date: Thu, 19 Jun 2003 11:49:57 -0700
To: Albert Lazzarini <lazz@ligo.caltech.edu>,
Phil Lindquist <lindquist_p@ligo.caltech.edu>
From: Florence Kaufman <fkaufman@ligo.caltech.edu>
Subject: Re: Construction Closeout Status

After moving the computer maintenance contracts to Operations, the budget for the Data Group in the Construction Award is currently projected to be overspent by $22K.

Florence

Proposal Budget

LIGO Operations (2002 – 2006)

LSC -Aug 02

	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)

LSC -Aug 02

- **$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

Received April 03

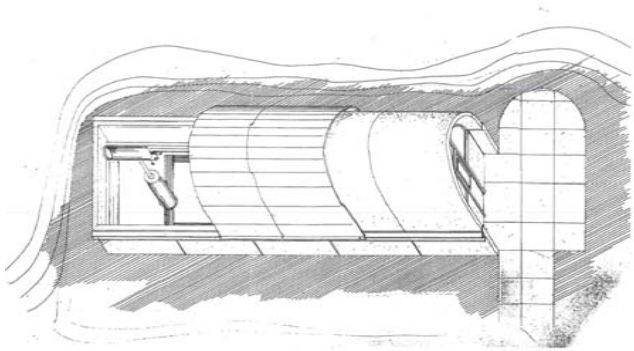
LIGO

LIGO Outreach

Proposal Submitted 01-03
Collaboration of LIGO
Southern University and the Exploratorium

Under revision for resubmission -- $5M for 5 years

LLO Telescope



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

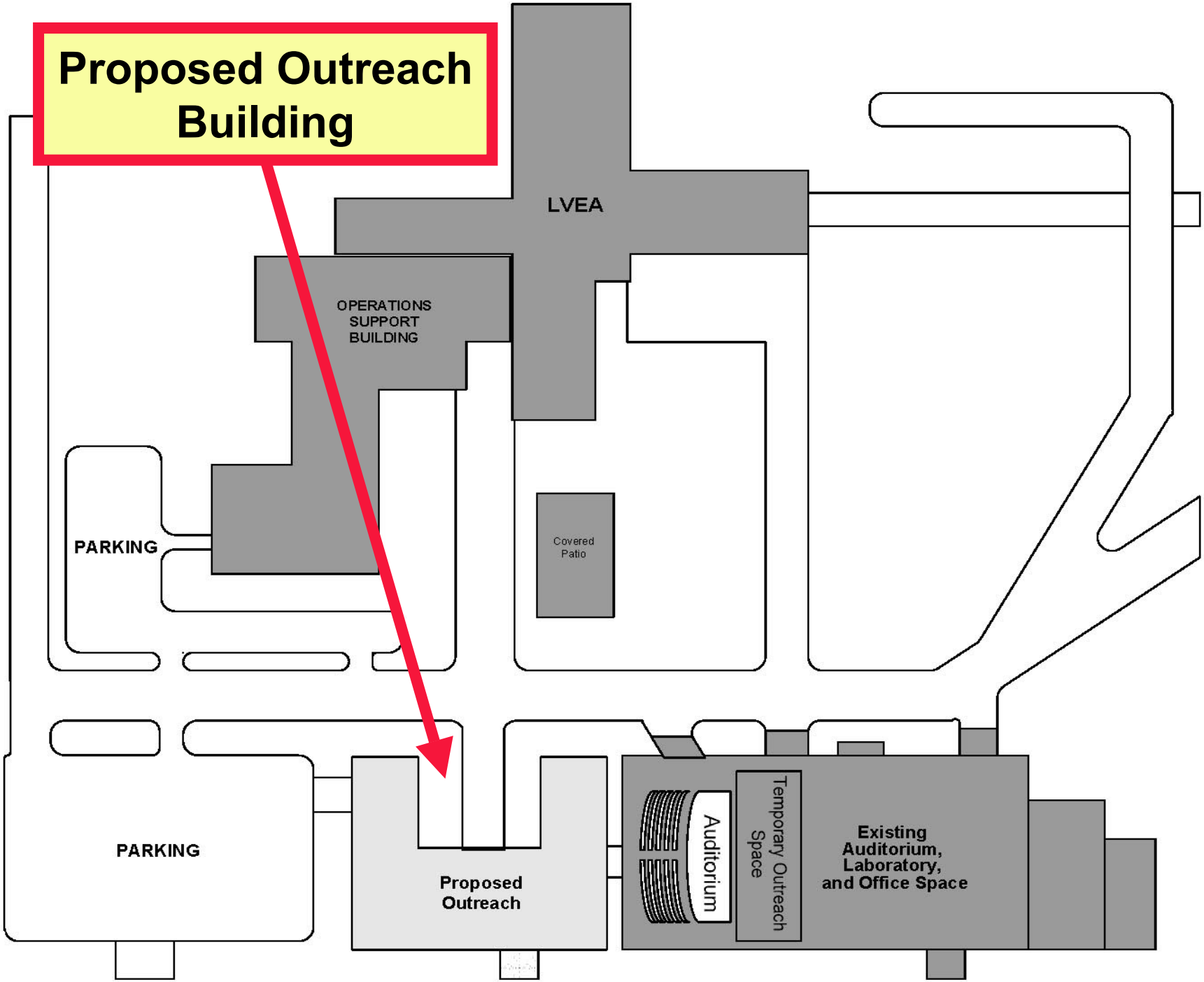
Proposed telescope location on fire access road gives clear view to south

Telescope facts:

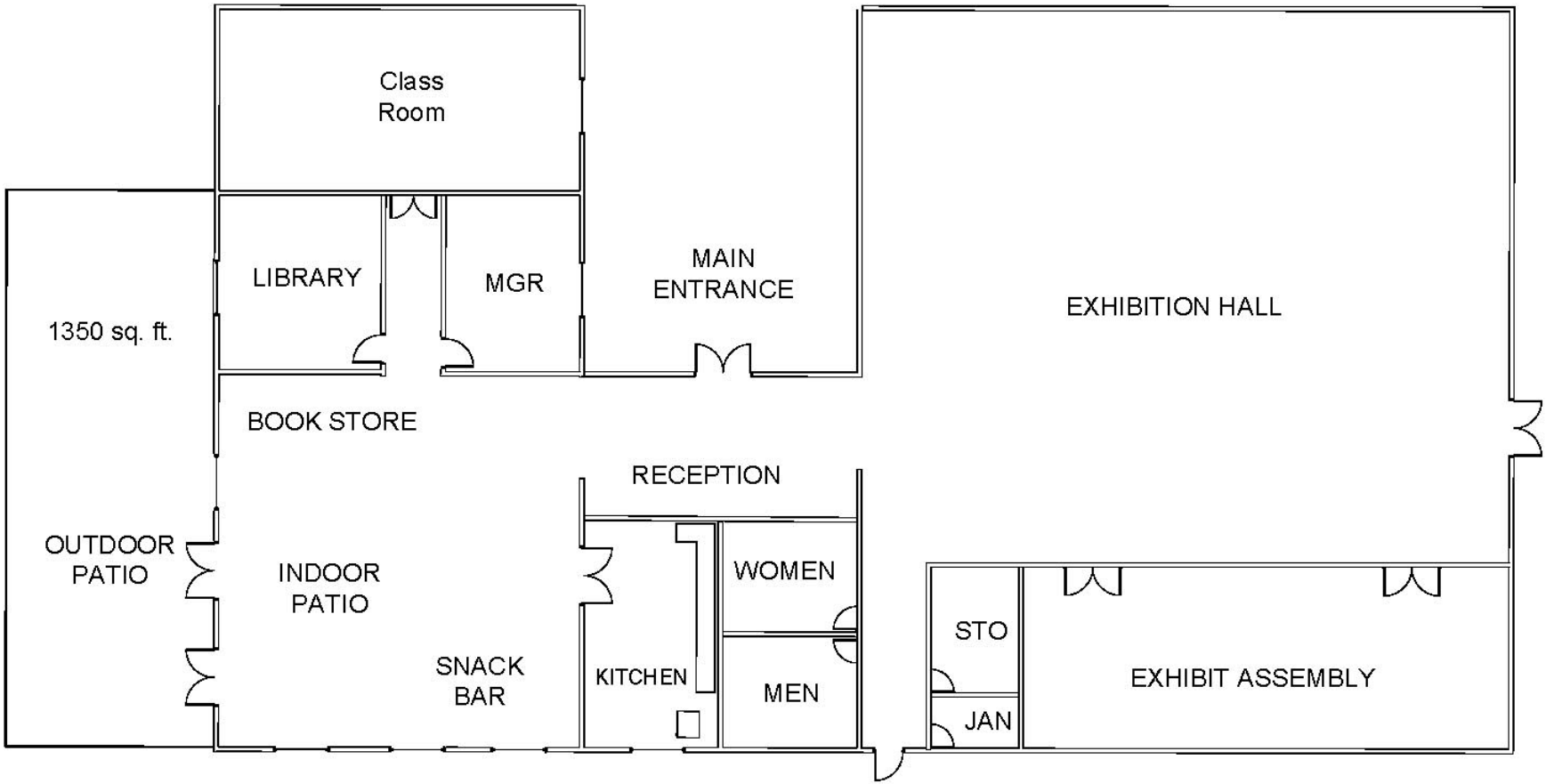
16 inch Richey Chretien telescope built by Optical Guidance Systems

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

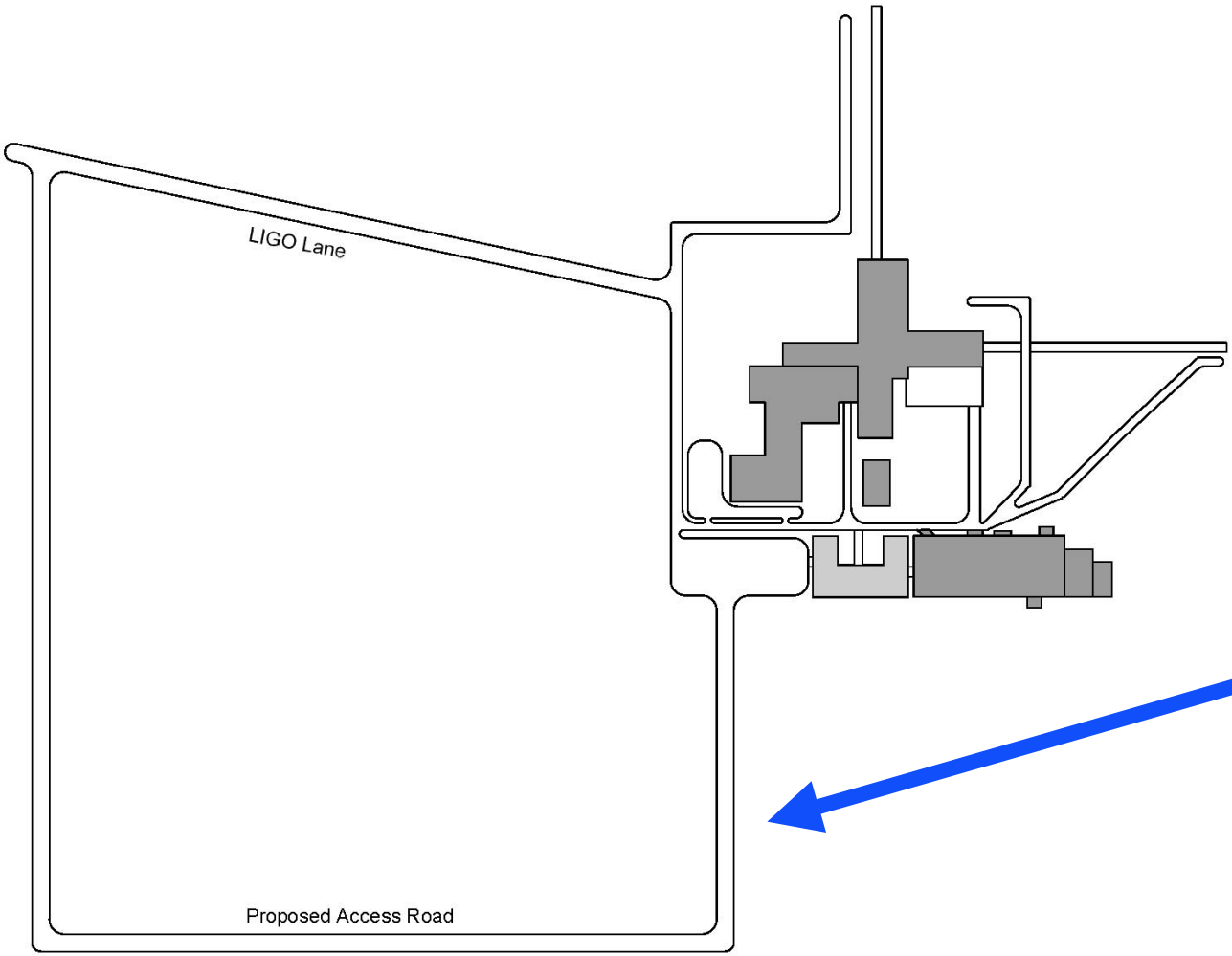

Proposed Outreach Building
LVEA
OPERATIONS SUPPORT BUILDING
PARKING
Covered Patio
PARKING
Proposed Outreach
Auditorium
Temporary Outreach Space
Existing Auditorium, Laboratory, and Office Space

Outreach Center -- Floor Plan



Reduce Space ???

The proposed access road providing visitor access to the outreach center is shown above. It takes a circuitous route to minimize vehicle induced ground vibration coupling into the interferometer. Traffic on LIGO Lane, the existing access road, could be problematic for interferometer operation.



Eliminate ??

LIGO

Conclusions

- S1 Science Run achieved its goals, results include an instrumentation and four science papers that are in the process of being distributed and then will be submitted for publication
- S2 Data Run was ~x10 better sensitivity and ~x4 more running time. Data analysis is getting underway and we can look forward to much more significant results.
- Good progress continues on commissioning and an improved S3 Data Run will be undertaken in late fall
- Then LIGO will shutdown to install L1 seismic mitigation - early 2004
- Advanced LIGO was proposed in Jan 03 and was well reviewed. It is now progressing through NSF/NSB toward funding.
- Hopefully, after shutdown next year we will improve sensitivity and reliability to the point that our extended LIGO I searches can begin.

LIGO

Some Final Questions …

- How close do we need to get to design sensitivity/duty cycle to start a long search run? Will we be ready for this after the S3 and the seismic retrofit. (e.g. S4)?

- LIGO/GEO Collaboration is strong, both for data analysis and preparations for Advanced LIGO. Is there more we need to do to get the most science from the exchange?

- Steps toward a world-wide network: TAMA/LIGO exhange data analysis needs priority. When do we begin data exchange with Virgo and what form should the LIGO/Virgo collaboration take?

- As our sensitivity improves and data sets become more significant, are we prepared to make the discoveries that are in the data?

To Do

- DCC #