A LIGO II Project Concept

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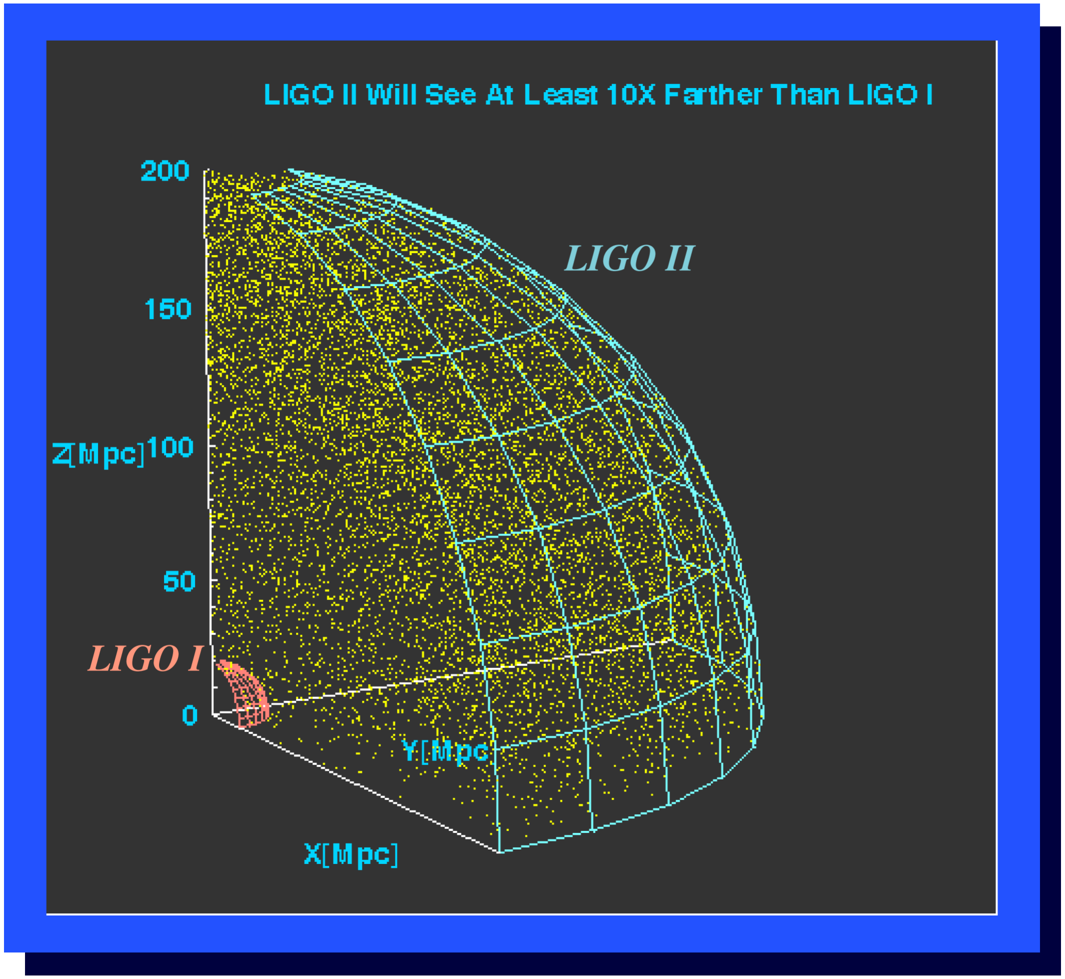
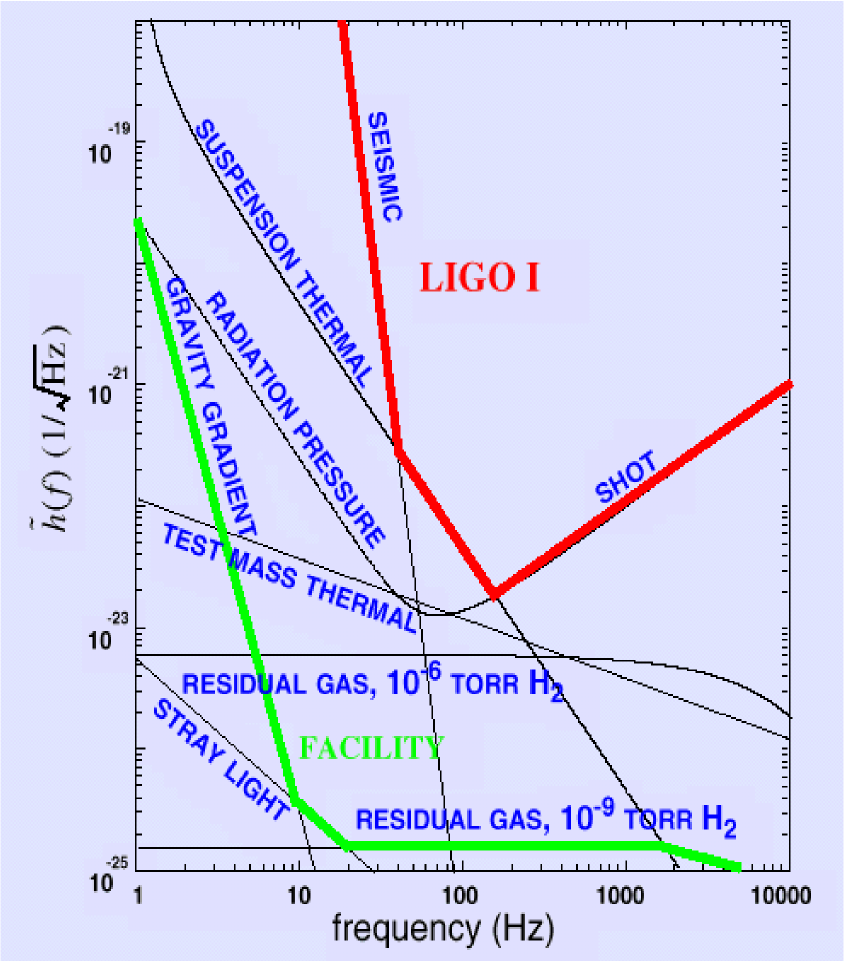
LIGO II Special Emphasis Panel Review
October 25, 1999

LIGO II Reach



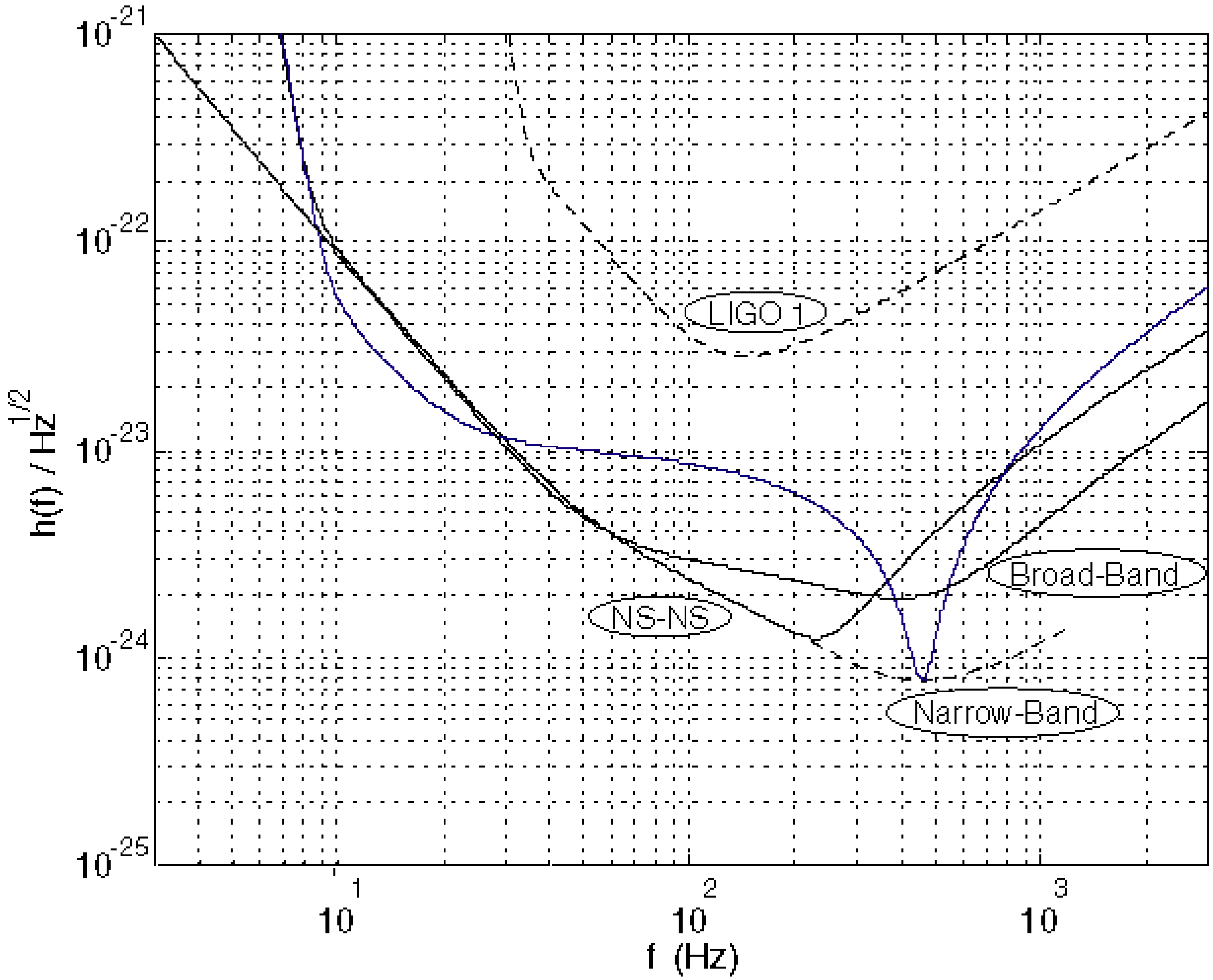
“Original” Goals for LIGO I Performance and Facility Limits



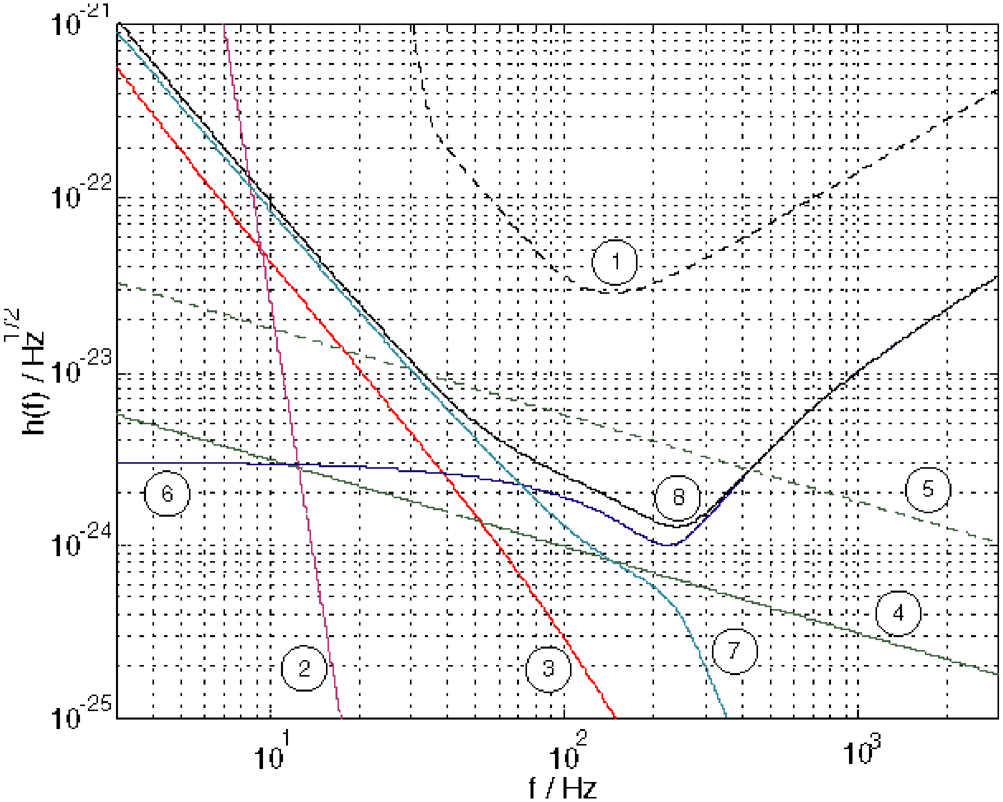
LIGO II Reference Design Parameters / LIGO I Comparison

Subsystem and Parameters	**LIGO II Reference Design**	**LIGO I Implementation**
Comparison With LIGO I Top Level Parameters		
Strain Sensitivity [rms, 100 Hz band]	2×10^{-23}	*10^{-21}*
Displacement Sensitivity [rms, 100 Hz band]	8×10^{-20} m	*4×10^{-18} m*
Fabry-Perot Arm Length	4000 m	*4000 m*
Vacuum Level in Beam Tube, (Vacuum Chambers)	$< 10^{-6}$, ($< 10^{-7}$) torr	*$< 10^{-6}$ torr*
Laser Wavelength	1064 nm	*1064 nm*
Optical Power at Laser Output	180 W	*10 W*
Optical Power at Interferometer Input	125 W	*5 W*
Power Recycling Factor	80 x	*30 x*
Input Mirror Transmission	3%	*3%*
End Mirror Transmission	15 ppm	*15 ppm*
Arm Cavity Power Loss on Reflection	1%	*3 %*
Light Storage Time in Arms	0.84 ms	*0.84 ms*
Test Masses	Sapphire, 30 kg	*Fused Silica, 11 kg*
Mirror Diameter	28 cm	*25 cm*
Test Mass Pendulum Period	1 sec	*1 sec*
Seismic Isolation System	Active/Passive, 6 stage	*Passive, 4 stage*
Seismic Isolation System Horizontal Attenuation	10^{-8} (10 Hz)	*$\geq 10^{-5}$ (100 Hz)*
Maximum Background Pulse Rate	1 per 10 years, triple interferometer coincidence	*1 per 10 years, triple interferometer coincidence*

LIGO II and LIGO I Sensitivity



Noise Anatomy of LIGO II



1 LIGO I total
2 Filtered seismic noise
3 Suspension thermal noise
4 Internal thermal noise - sapphire
5 Internal thermal noise - fused silica (fallback)
6 Shot noise
7 Radiation pressure noise
8 LIGO II total

This Reference Design and Project Scenario

- It is a very consistent improvement in all of the performance areas
- It includes improvements that improve sensitivity to broad classes of sources
- It avoids the inefficiency of “reopening the patient” and replacing serially upgraded systems

Implications of the LIGO II Reference Design

- Advanced Detector R&D program is driven to accomplish more
- Upgrade of all subsystems and of interferometer configuration in one phase increases scope and pace of upgrade project
  - » Reducing interruption of LIGO data collection offers possible increased productivity of program
  - » LSC must take a greater role in development and in the construction
- Large sensitivity step makes initiating the upgrade attractive as soon as it is feasible
  - » if ~ one day of LIGO II running provides sensitivity of entire LIGO I run ... !

LIGO Laboratory Planning Assumptions - The Start

- LIGO I data run planned for 2 years commencing in 2002
- Advanced R&D program does not support LIGO II installation into the LIGO vacuum system early in 2004
  - » This is a planning constraint on the LIGO I program
  - » In the absence of an observation of gravitational waves in the 2 year run, the third year can be used for operational development and running, or for a possible networked data run with other large interferometers
- MRE start in 2002 does not support 2004 installation
- Earliest feasible installation into vacuum system taken as early 2005

The Scenario

YEAR	LIGO I	LIGO II
2000	Installation and commissioning	R&D
2001	Installation and commissioning	R&D
2002	Science run	MRE funds start, R&D, design, long lead items
2003	Science run	R&D, design, fabrication
2004	Additional science run	Fabrication, on-site assembly
2005	LIGO I interferometers removed	Fabrication, on-site assembly, installation into vacuum system
2006		Installation and commissioning

LIGO Laboratory Planning Assumptions - The Scope

- For this conceptual study, our goal has been to identify a maximum scope for the LIGO II project
- Major program options are set to maximum scope in order to "bracket" the project scope
  - » Mature construction proposal will describe an optimized scope
- Resource estimates are made conservatively
- Final scope will require an MRE request less than or equal to the request described in this conceptual study

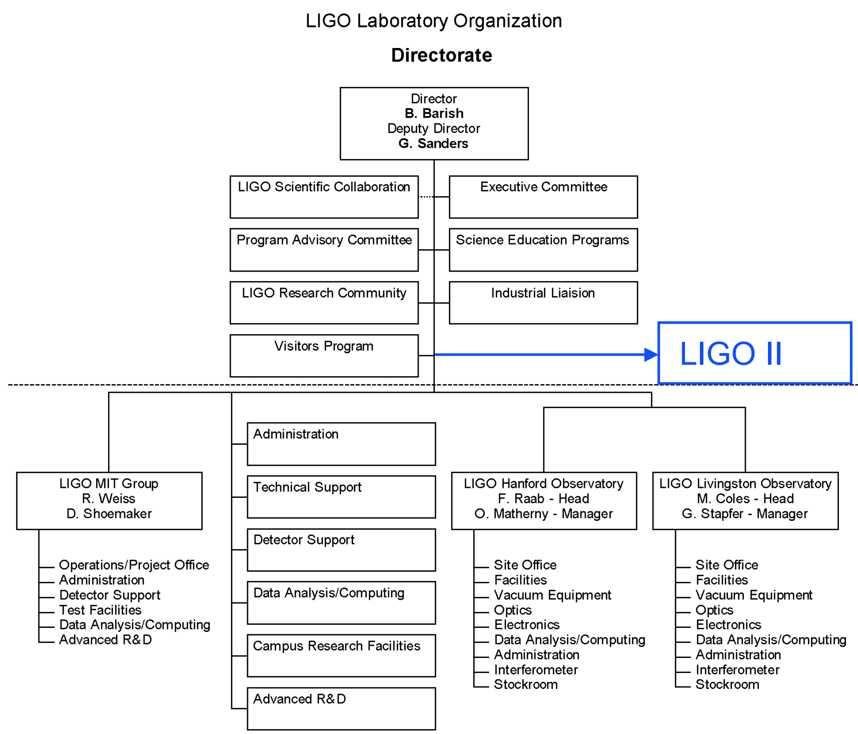
Major Project Options

- How many interferometers to upgrade?
  - » Assume all 3 interferometers upgraded
- Convert the Hanford 2 kilometer to a 4 kilometer?
  - » Assume length is increased
- Upgrade done in one phase?
  - » Assume all 3 interferometers upgraded in one parallel installation
  - » Decision on this may interact with other gravitational wave detectors to insure that observational coverage is considered
- Test mass substrate to be made of sapphire or silica?
  - » Assume sapphire

LIGO Laboratory Organization for LIGO II Construction

- LIGO Laboratory has now evolved from a deliverable-oriented construction project to an operating organization
- The LIGO II construction project will be organized in the same manner as the LIGO I project, but reporting into the LIGO Laboratory organization
- LIGO II Project management will be described in a Project Management Plan that will be very close to that used in LIGO I
  - » LIGO I PMP available on the LIGO web pages

LIGO II Project Relation to Laboratory Organization



LIGO Laboratory and LSC Role

- LIGO Laboratory is the party in the Cooperative Agreement with the NSF and we will organize and manage the LIGO II project
- LSC participation in the construction of LIGO II will be governed by Memoranda of Understanding (MOU) and specific, periodic Attachments describing tasks, funding, milestones and personnel, with subcontracts
  - » this model used successfully with Univ. of Florida during LIGO I
  - » this model used with LSC for R&D activities, without subcontracts
- GEO is proposing a collaborating role and a capital contribution role
  - » GEO will discuss proposed role at this review

LIGO II Work Breakdown Structure (WBS)

- 4.0 LIGO II
  - 4.1 Facility Modifications
  - 4.2 Seismic Isolation
  - 4.3 Suspension
  - 4.4 Prestabilized Laser
  - 4.5 Input Optics
  - 4.6 Core Optics Components
  - 4.7 Support Optics
  - 4.8 Interferometer Sensing and Control
  - 4.9 Data Acquisition and Diagnostics
  - 4.10 Support Equipment
  - 4.11 R&D
  - 4.12 Computing and Data Analysis
  - 4.13 Installation
  - 4.14 Project Management

Cost Estimate for This Conceptual Study

- This estimate is strongly based upon the actual cost experience of the LIGO I project
  - » design, fabrication, installation labor basis used directly from actual LIGO I experience
  - » actual LIGO I fabrication and procurement costs used to establish unit costs
  - » estimates performed by the experienced leaders of the comparable LIGO I systems

Cost Estimate for This Conceptual Study

- Estimated in FY2000 $
  - » Escalation applied to mid-point of cost profile (FY2004)
- Options almost always chosen to be maximum options
- Subsystems staffed without overlaps or sharing of efforts
- Though costs based closely on actuals, contingency has been applied at the subsystem level for most subsystems
  - » but considerable scope contingency exists

Cost Estimate for This Conceptual Study

- Effort was estimated fully without regard to existing staff
- LIGO Laboratory Operations permanent staff has then been assigned head-by-head to estimate and MRE estimate includes only the incremental staff
  - » permanent staff assignment to LIGO II work is made with priority given to LIGO I operations and data analysis

Cost Estimate for This Conceptual Study

- LIGO II Cost Estimating Plan already written for the future mature estimate and is available on the LIGO II web pages
- We will perform a “bottom-up” estimate from the lowest feasible WBS level

4.1 Facility Modifications

- 4.1.1.1 - Conversion of 2 kilometer IFO to 4 kilometer assumes moving mid-station vacuum chambers to end station
  - » costs based upon vendor quote from actual LIGO I vendor
- 4.1.1.2 - Parallel installation requires additional portable cleanrooms
  - » costs based upon actual costs for identical units
- 4.1.1.3 - Vacuum equipment bakeout included for 3 major volume rebakes plus contingency for 2 additional volumes, based upon actual costs

4.1 Facility Modifications

- Keep LIGO I running as long as possible
  - » Assembly of seismic and suspension subsystems concurrent with running in 2004
  - » Installation in 2005 when LIGO I shutdown
  - » Requires staging space for onsite assembly of complete isolation systems
- 4.1.3 - Livingston Staging Building and 2 5-ton hall cranes included if we cannot provide these in LIGO I construction
- Costs based upon actual costs from LIGO I for building at Hanford of same design and same cranes

4.1 Facility Modifications Costs

4.1	**Facility Modifications**	
4.1.1	Vacuum Equipment	
4.1.1.1	2K to 4K Conversion	
4.1.1.2	Clean Room Systems	
4.1.1.3	Rebakeout	
4.1.3	Conventional Facilities	
4.1.3.1	Staging Building	
4.1.3.2	Staging Cranes	
	(includes 25% contingency)	(FY 2000 $)

4.2 Seismic Isolation

- Two options with comparable performance under study
  - » Downselect April, 2000
- Unlike LIGO I, this system includes active loops
- Test of full scale prototypes in LASTI facility
  - » essential to reduce risk in aggressive program
- Assembly of full seismic assemblies planned during 2004 in on-site staging buildings
- Rapid installation of fully ready systems into vacuum tanks in 2005

4.2 Seismic Isolation Costs

- Drawings of “soft” version sent to the same vendor who fabricated, cleaned, vacuum prep. LIGO I seismic system for budgetary quote
  - “stiff” version later shown to have similar costs
- Senior LIGO engineering staff (Asiri, Coyne) added in design, assembly, tooling and cable costs based upon LIGO I actual costs
- Controls costs estimated by LIGO controls group (Bork) based upon actual costs for LIGO I comparable systems

4.2 Seismic Isolation Costs

4.2	**Seismic Isolation System**	
4.2.1	Final Design	
4.2.2	Mechanical Fabrication	
4.2.3	Controls	
	(includes 20% contingency)	(FY 2000 $)

4.3 Suspension Subsystem

- Based upon the GEO design
- Full scale prototypes to be tested in GEO facilities and in LASTI
- Assembly of full subsystems, up to suspension of optics, to be carried out during 2004 at LIGO observatory sites
- Installation of ready systems into vacuum system, with last-minute suspension of optics, planned for 2005

4.3 Suspension Subsystem Costs

- GEO sketches used by LIGO suspension engineers (Romie, Coyne) to prepare estimate based upon LIGO I costs
  - » fiber production based upon current Caltech Willems facility
  - » intermediate masses estimated by LIGO optics group
  - » no credit taken for reuse of LIGO I suspensions
- Controls estimated by controls group (Bork) based upon known LIGO I suspension controls costs

4.3 Suspension Subsystem Costs

4.3	**Suspension Subsystem**	
4.3.1	Suspension Design	
4.3.2	Suspension Fabrication	
4.3.3	Suspension Controls	
	(includes 20% contingency)	(FY 2000 $)

4.4 Prestabilized Laser Subsystem

- Consists of 180 W 1064 nm laser and stabilization system in which it is embedded
- Responsibility and estimate come from Stanford group and the LIGO Laboratory team that produced the LIGO I system (Camp)
  - » LIGO II laser is 2x actual cost of LIGO I laser
  - » Use actual costs for stabilization system
  - » Controls cost are very conservatively scaled from LIGO I
  - » Labor is same team as in LIGO

4.4 Prestabilized Laser Costs

4.4	**Prestabilized Laser System**	
4.4.2	PSL Fabrication	
4.4.3	PSL Controls	
	(includes 20% contingency)	(FY 2000 $)

4.5 Input Optics

- Very much like the LIGO I system
  - » except must handle higher power with lower noise level
    - – these issues to be solved during R&D phase
- Estimate performed by LIGO I group (Camp, Bork)
  - » Optomechanical components estimated to cost the same as LIGO I actual costs with the additional suspensions, optics and Mach-Zehnder modulator added
    - – suspension costs moved to suspension estimate
  - » Controls costs based upon actual costs of LIGO I core optics controllers and mode cleaner controls
  - » Labor costs assume Univ. of Florida contract costs and known CDS group costs
    - – not a cost driver of the estimate

4.5 Input Optics Costs

4.5	**Input Optics**	
4.5.1	IO Design and Fabrication	
4.5.3	IO Controls	
	(includes 20% contingency)	(FY 2000 $)

4.6 Core Optics Components

- Work scope is similar to LIGO I COC scope except that the “Pathfinder” process is part of the R&D program
- Estimate from LIGO group (Camp)
  - » sapphire blanks informal quote from vendor
  - » scaled polishing and coating costs
  - » LIGO I metrology, other costs
  - » some design effort carried out under R&D program

4.6 Core Optics Costs

4.6	**Core Optics Components**	
4.6.1	COC Design	
4.6.3	COC Fabrication	
	(includes 20% contingency)	(FY 2000 $)

4.7 Support Optics Subsystem

- Includes
  - » stray light control (beam dumping, baffling) (as in LIGO I)
  - » output beam delivery optics (as in LIGO I)
  - » active thermal compensation of optics (NEW)
    - – have selected most ambitious option, active sensing and laser scanning
    - – this option is being developed under R&D program
- Estimate performed by LIGO group (Camp, Zucker)
  - » stray light and output optics taken to equal LIGO actual costs
    - – then mode cleaner is added
  - » bottom up estimate performed on active compensation using actual LIGO I component costs

4.7 Support Optics Costs

4.7	**Support Optics**	
4.7.1, 4.7.2	Output Optics, Stray Light Control	
4.7.3	Active Optics Compensation	
	(includes 20% contingency)	(FY 2000 $)

4.8 Interferometer Sensing and Controls

- System includes interferometer length sensing, alignment sensing and global controls
  - » Similar to LIGO I topology but the signal recycling loop is added
  - » Many more degrees of freedom to control and sense in subsystems
  - » requirements are more stringent
  - » higher resolution ADC is needed
- Estimate prepared by CDS group (Bork)
  - » **Unit** costs taken from LIGO I
  - » ASC/LSC labor has been doubled to reflect complexity of design
  - » ADC development costs based upon Virgo project costs

4.8 Interferometer Sensing and Controls Costs

4.8 ISC	
ISC material costs	
ISC labor costs	
Contingency %	
Contingency $	

4.9 Data Acquisition and Diagnostics

- LIGO I and LIGO II DAQ requirements differ due to improved sensitivity and performance. Three principal DAQ modifications are:
  - » increased ADC dynamic range to accommodate a greater disparity between narrowband features (i.e. violin resonances) and lower broadband noise
  - » greater number of channels to monitor a greater number of active control systems
    - – 101 vs. 16 loops!
  - » possible higher data acquisition rate to exploit the increased instrumental sensitivity for extraction of astrophysical parameters (as opposed to event detection)
- A major lesson and a cost driver

LIGO

4.9 Data Acquisition and Diagnostics Costs

4.9 Data Acquisition	
DAQ material costs	
DAQ labor costs	
Contingency %	
Contingency $	

4.10 Support Equipment

- Equipment used to supply the observatories with tools, materials handling, test instruments, etc.
- Observatories are fully equipped in LIGO I
  - » Restocking is included in LIGO Laboratory operations budget
- We include only those incremental items needed by LIGO II assembly and installation given the compressed schedule and parallel approach
  - » subsystem specific tooling is included in subsystems
- Estimate is 50% of LIGO I costs
  - » LIGO II estimate is $782 K

4.11 Research and Development

- LIGO I project had a funding category for project related R&D
  - » we created a place for this in the LIGO II WBS
- LIGO II R&D is provided by the current advanced detector R&D program funded separately
- Some R&D is included in the LIGO operations budget
- We have not identified any tasks to include in this LIGO II WBS element
  - » if future funding of the advanced detector R&D program is not adequate this conclusion may not be valid
    - – additional R&D funds addressed by LSC speakers

4.12 Data Analysis and Computing

- Driven by detector sensitivity improvement
  - » lower noise floor
  - » wider sensitive band
- Estimate prepared by Lazzarini using calculated processing power, programmer cost experience from LIGO I, today's unit costs for hardware
  - » only partial price/performance credit taken
  - » programming done by staff not assigned to LIGO I tasks

4.12 Data Analysis and Computing Costs

4.12 Data Analysis (COMP)	
COMP material costs	
COMP labor costs	
Contingency %	
Contingency $	

4.13 Installation and Commissioning

- Installation commences at beginning of 2005 with full parallel installation of pre-staged seismic and suspension assemblies
  - » requires prepared space
  - » expert team leaders and effective crews
  - » minimum interference with LIGO I operations through 2004
- Schedule and cost prepared by LIGO I Installation Director (Coyne) based upon detailed durations and team sizes understood in LIGO I
- Vacuum equipment rebake is included in schedule
- Observatory staff assigned to installation in 2005, 2006 and funded by operations budget

4.13 Installation and Commissioning

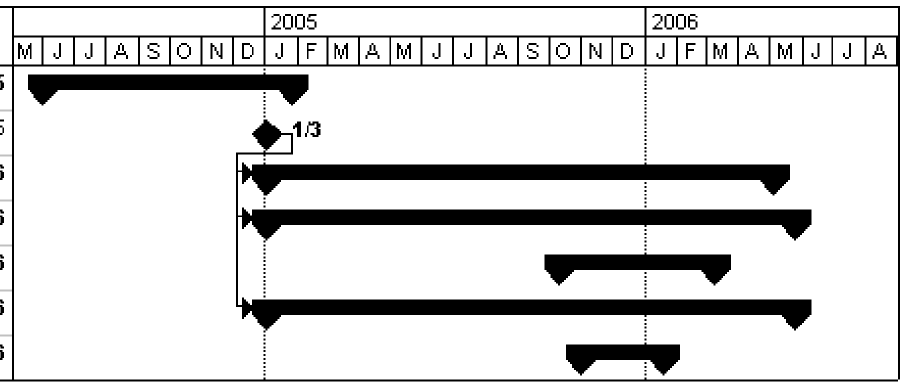
- Goal was 1 year for all physical installation and subsystem commissioning
- Result of study was minimum 16 months
  - » we have probably explored a limit of the problem
- Pressure is to get the observatory back online
  - » Mature plan will have to optimize use of operating staff, availability of detectors relative to other detectors
- A slower, or phased, installation will make possible greater use of LIGO Laboratory staff, reduced incremental staff
- No LSC labor assumed, though it is expected

4.13 Installation and Commissioning Costs

- Total installation costs are $00 million
  - » MRE LIGO II cost $0,000 K
  - » LIGO operating budget cost $0,000 K
- This high MRE cost offsets costs that would be borne by the operating budget for a lengthier installation with less parallelism
  - » but it offsets the missed opportunity costs of not running the observatory for science
  - » this is a matter for review and study

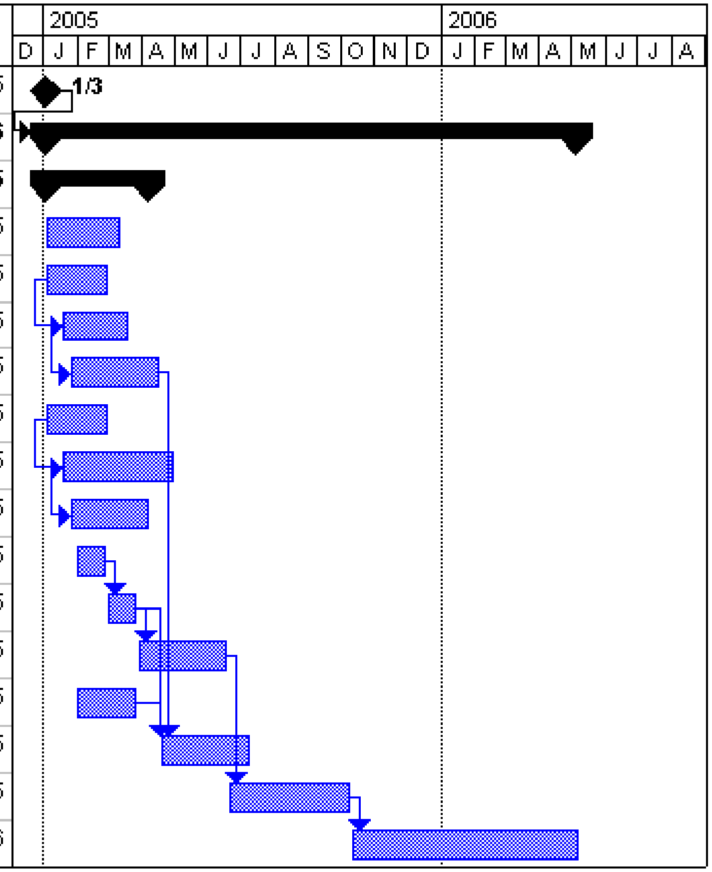
4.13 Installation Summary Schedule

ID	Task Name	Start	Finish
1	**Staging of Subsystem Assemblies**	**6/1/04**	**1/28/05**
4	Shutdown LIGO-1	1/3/05	1/3/05
5	**Hanford Interferometer 1**	**1/3/05**	**5/5/06**
24	**Hanford Interferometer 2**	**1/3/05**	**5/26/06**
42	**Hanford Vacuum Bake**	**10/10/05**	**3/10/06**
49	**Livingston Interferometer**	**1/3/05**	**5/26/06**
67	**Livingston Vacuum Bake**	**10/31/05**	**1/20/06**



4.13 Single Interferometer Summary Schedule

ID	Task Name	Start	Finish
4	Shutdown LIGO-1	1/3/05	1/3/05
5	**Hanford Interferometer 1**	**1/3/05**	**5/5/06**
6	**Installation Infrastructure/general**	**1/3/05**	**4/8/05**
10	PSL changeout	1/3/05	3/11/05
11	SEI/HAM Removal	1/3/05	2/28/05
12	SEI/HAM Installation	1/17/05	3/18/05
13	IO/SUS HAM Installation	1/24/05	4/15/05
14	SEI/BSC Removal	1/3/05	2/28/05
15	SEI/BSC Installation	1/17/05	4/29/05
16	SUS/BSC Installation	1/24/05	4/5/05
17	SUS electronics installation	1/31/05	2/25/05
18	IO controls installation	2/28/05	3/25/05
19	ISC installation	3/28/05	6/17/05
20	DAQ Installation	1/31/05	3/25/05
21	PSL/IO Commissioning	4/18/05	7/8/05
22	ISC Commissioning	6/20/05	10/7/05
23	Noise performance improvement	10/10/05	5/5/06



4.14 Project Management

- Most management done by staff supported by the LIGO Laboratory operating budget
  - » LIGO II project to support only the incremental effort
- Assume 2002-2005
  - » one each admin. assistant, procurement clerk, subcontract manager, cost/schedule analyst, QA/ESH manager, system engineer
  - » modest M&S budget
- Cost estimate is $0,000 K

Summary Cost Estimate

- "Base Year" FY 2000 MRE Cost Estimate is $00,000 K
- GEO proposed contribution is $00,000 K, half from each country
- Reduced MRE request is FY 2000 $00,000 K
- Escalate this sum to approximate mid-point of cost profile (FY 2004) at US DOL inflator of 2.4%. This yields an "as spent" MRE request of $00,000 K

Cost Estimate

- This estimate reliably “brackets” the costs required for the scope described
- Reliability derives from
  - » firm basis in LIGO I actual labor and hardware costs
  - » direct experience of LIGO estimators
  - » inclusion of contingency funds on top of estimate heavily based upon actual costs
  - » scope contingency
  - » program assumptions that entail maximum costs

Some Options

Option	Project Descope?	IFO Performance Descope?	Cost Reduction	Comment
Retain 2 km IFO	Yes	Possible less robust detector		Decision by proposal submission
Phase upgrade (do one at a time and use regular staff)	No	No		Possible reduced observatory availability, reduced technical risk, missed observing opportunity funds installation
Test mass substrate to fused silica	Yes	Yes		Could replace test masses later
No major seismic upgrade (add some active isolation to current stacks)	Yes	Yes		Difficult to retrofit, compromises advantage of suspensions, changes suspension design, major fallback, implies phasing of upgrades in major way
Drop RSE/SR	Yes	Yes		Lose narrow band tunes, power handling control
Round suspension fibers	No	Yes		Increase in suspension thermal noise, can be refit
Upgrade only major suspensions	No	Yes		Mode cleaner thermal noise worse, can be retrofit

More Options

Option	Project Descope?	IFO Performance Descope?	Cost Reduction	Comment
No upgrade of 3rd IFO	Yes	Possible less robust detector		Decision by proposal submission
Drop photon drive of end masses, use conventional solution	No	Possible		Possible increase in actuation noise, possible risk reduction, could be retrofit
Lower laser power (but retain thermal compensation)	No	Yes		Increased shot noise
Reuse LIGO I optics for LIGO II large IO optics	No	No		Possible schedule stretchout
Eliminate output mode cleaner	Yes	Yes		Noisier output signal
Use simpler active thermal compensation	No	Possible		Reduce complexity, can be retrofit
Retain 16 bit ADC	No	Possible		Lose dynamic range for noise features
Defer computational power for analysis?	Yes	Yes		Loss of mass range on binary inspirals, lose long FFT for long inspirals, can refit later

Schedule Overview

- R&D schedule was first developed by the LSC working groups with quarter-year resolution
  - » LIGO Laboratory participated closely in this
- LIGO Laboratory added construction project milestones for critical path elements
  - » the R&D and construction programs overlap as development of design requirements, preliminary designs, first article prototypes, optics “Pathfinder” process, occur during R&D phase
  - » LIGO Laboratory integrated both milestone schedules
  - » Integrated review led to some adjustments
- Integrated milestones now entered into Microsoft Project to support future schedule development

Milestones

Milestone	Date at End of Quarter Per Calendar Year
NSF Major Research Equipment Funds Available	1Q02
Vacuum Equipment Contract Placed	2Q02
Vacuum Equipment Ready to Install	4Q04
Clean Rooms Contract Placed	2Q02
Clean Rooms Available for Staging Areas	4Q03
Clean Rooms Available for Vacuum Equipment Areas	4Q04
Livingston Staging Building Contract Placed	2Q02
Staging Buildings/Cranes Ready For Assembly and Staging	4Q03
Seismic Isolation Option Selected	2Q00
Seismic Isolation Design Requirements Review	3Q00
Seismic Isolation Preliminary Design Review	1Q01
Seismic Isolation Final Design Review	3Q03
Seismic Isolation Assembly Started	2Q04
Seismic Isolation Installation Started	1Q05
Suspension Subsystem Design Requirements Review	2Q00
Suspension Subsystem Preliminary Design Review	4Q01
Suspension Subsystem Final Design Review	3Q03
Suspension Subsystem Assembly Started	2Q04
Suspension Subsystem Installation Started	1Q05
Prestabilized Laser Design Requirements Review	4Q00
Prestabilized Laser Preliminary Design Review	1Q02
180 W Laser Contract Placed	1Q02
Prestabilized Laser Final Design Review	2Q03
Prestabilized Laser Installation Started	4Q04
Core Optics Components Design Requirements Review	4Q99
Core Optics Components Preliminary Design Review	3Q01
Core Optics Components Substrate Selection	1Q02
Core Optics Components Final Design Review	2Q02
Core Optics Components First Articles Available for Suspension	2Q04
Interferometer Sensing and Control Design Requirements Review	2Q01
Interferometer Sensing and Control Preliminary Design Review	3Q02
Interferometer Sensing and Control Final Design Review	4Q03
Installation Begins	1Q05
Installation Complete	2Q06

Single Upgrade Approach

- Large effort required to add or retrofit subsystems
- Incremental upgrades are not generally additive
  - seismic system performance intimately balanced with suspension requirements
  - laser power impacts all elements of optics and control
  - controls problem strongly influenced by system aspects of design
- System coherence
- Optimize detector scientific use

LIGO Laboratory Funding Plan To Date

MRE

Fiscal Year	Construction	R&D	Operations	Advanced R&D	Total
Through 1994	35.9	11.2			47.1
1995	85	4			89
1996	70	2.4			72.4
1997	55	1.6	0.3	0.8	57.7
1998	26	0.9	7.3	1.6	35.8
1999	0.2		20.9	2.5	22.5
2000			21.1	2.6	23.7
2001			19.1 (10 months)	2.7	22.9
Total	272.1	20	68.7	10.2	371.1

Staffing LIGO II Related R&D

- LIGO Laboratory Advanced Detector R&D is funded separately from LIGO Laboratory Operations budget
  - » staff for R&D was planned "on top" of Operations staff
  - » R&D is supported by Operations funded engineers, administrative support, and infrastructure
    - – campus interferometers (40 Meter, LASTI)
    - – engineering mostly supplied from Lab staff engineers
  - » R&D supported staff composed mainly of postdocs and graduate students
    - – intent was to have a cost structure similar to non-LIGO Lab university groups
  - » intent was to protect operations from effort drain to R&D

Staffing LIGO II Construction

- LIGO II construction has been planned by LIGO Lab using:
  - » existing Operations and Advanced R&D staff where available with minimum impact on Operations program
    - – data analysis staff also isolated
  - » contractor staff “on top” of existing staff to be funded from LIGO II MRE request
- Integrated head-by-head staff model has been developed
  - » model is available for examination at this review

Staffing LIGO II Construction

- LSC effort not used in the staffing model
  - » except Univ. of Florida assumed to contract for Input Optics as in LIGO I
- LSC participation is invited and expected
  - » Participation to be organized and managed by LIGO Laboratory using existing MOU and Attachment mechanism employed in LIGO I and in LSC

LIGO Laboratory Conclusions

- LIGO II proposed physics reach is impressive
- LIGO II reference design goal is impressive
  - » a quantum noise limited detector
- LIGO II reference design requires considerable R&D
  - » isolation subsystems and sapphire core optics require complete, full-cycle development
- LIGO II reference design can be built, given successful R&D

LIGO Laboratory Conclusions

- Schedule studied is the most aggressive schedule
  - » Schedule design must include scientific input
- Effort required to install LIGO interferometers argues for efficient upgrades
  - » significant improvements executed rapidly
- Major program options exist
  - » Decisions should be made for the mature MRE proposal
- LIGO I experience in FY 2000 and 2001 will influence LIGO II program design
  - » interferometer noise, correlations, availability, robustness, diagnostics, data characteristics, archiving, analysis

LIGO Laboratory Conclusions

- LIGO Laboratory will take the central responsibility to implement this program of the LIGO Scientific Collaboration
- LIGO Laboratory is confident that a LIGO II upgrade can be constructed within the estimate presented
- LIGO II is clearly the right thing to do given the large investment in LIGO and the new “bang for the buck”