Advanced LIGO Project
Scope, Deliverables, Structure

NSF Review of Advanced LIGO Project

31 May 2006

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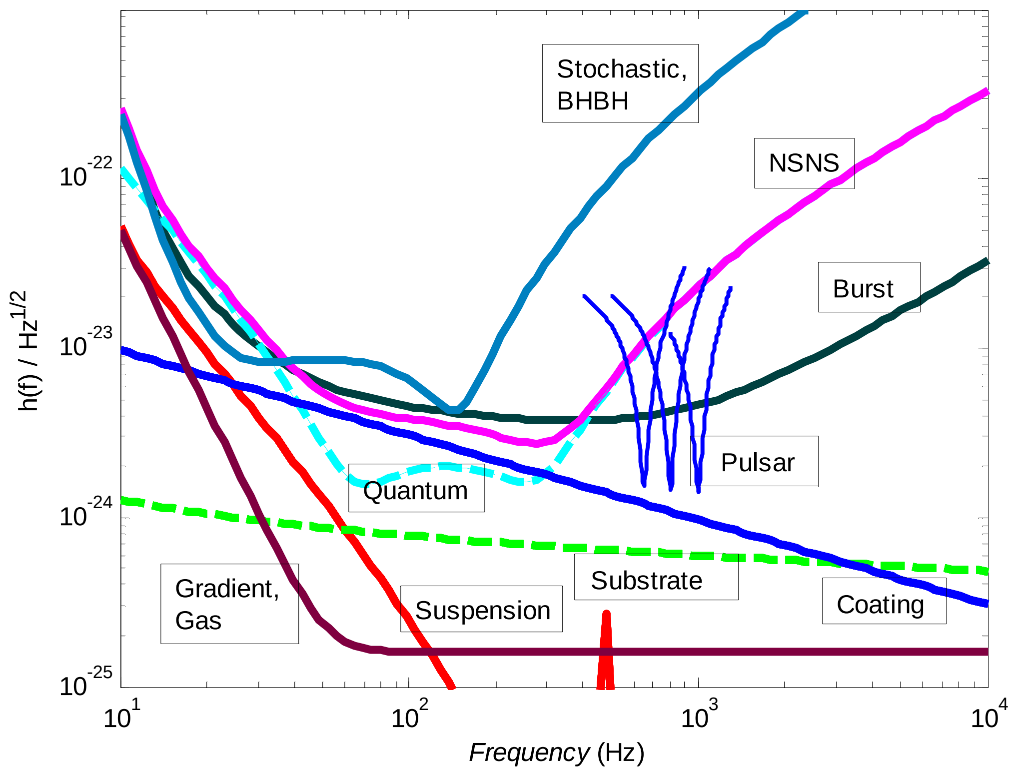
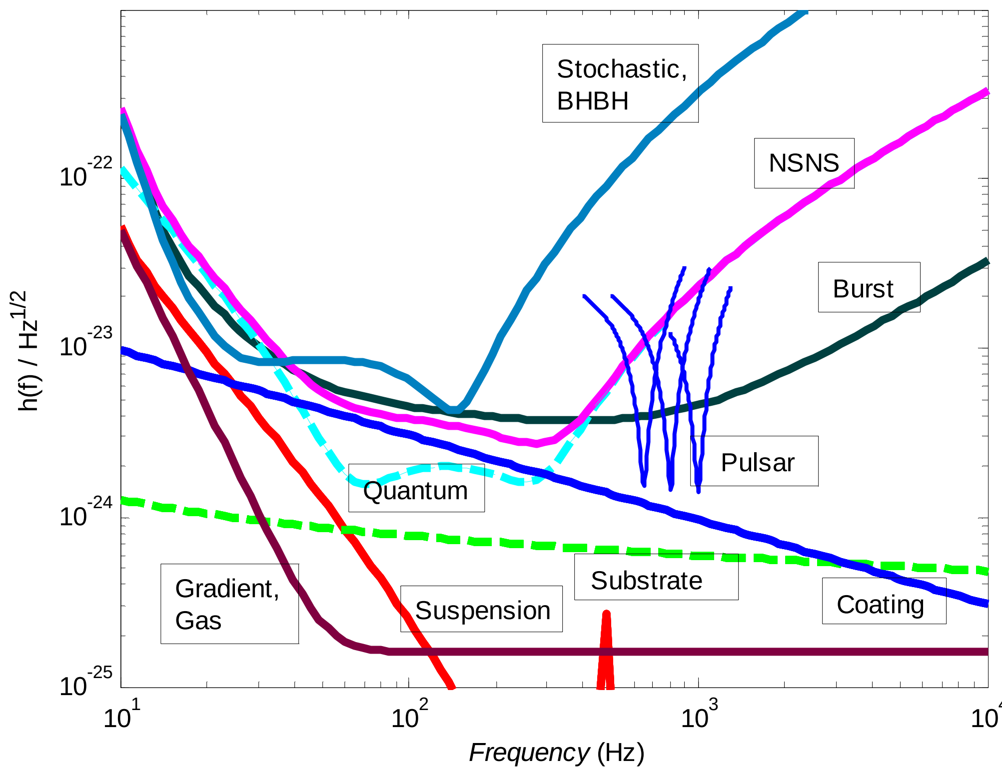
Advanced LIGO: Sensitivity

- As for Initial LIGO, we specify the sensitivity of Advanced LIGO by an RMS sensitivity:
  10^{-22} h_{RMS} in a 100 Hz band
  - » A factor of 10 improvement over Initial LIGO
- Flexibility of tuning will allow a range of responses, and the configuration of the three-interferometer system should be determined by the astrophysics we are chasing
  - » Not easy, or very useful, to give a list of sensitivities, or a curve
- Anticipated performance is better than above (as seen for Initial LIGO) – roughly 3x10^{-23} h_{RMS} in a 100 Hz band, around 250 Hz, tuned for NSNS inspirals



More on sensitivity

- Mid-band performance limited by Coatin
thermal noise – a clear opportunity for
further development, but present coatin
satisfactory
- Low-frequency performance limited by suspension thermal noise, gravity gradients
- Performance at other frequencies limite
by quantum noise (shot, or photon
pressure); have chosen maximum pract
laser power
- Most curves available through a combination of signal recycling mirror tuning (sub-wavelength motions) and changes in laser power
- ‘Pulsar’ tuning requires a change in sign
recycling mirror transmission – several
weeks to several days (practice) of
reconfiguration



Advanced LIGO Configuration

- Three interferometers, as for Initial LIGO
- Advanced LIGO's flexibility and sensitivity leads to many proposals for configuration; some examples:
  - » Three identical instruments for best SNR, astrophysical interpretation for un-modeled burst sources
  - » A narrow-band instrument for continuous-wave sources, complementing a low-frequency pair
  - » One instrument tuned to somewhat higher frequencies to capture inspiral 'plunge' after tracking with low-frequency pair
  - » Coordination with other observatories also an ingredient
- Decision best delayed until schedule requires action (early '09)
  - » Coating transmission of one optic; can coat spare with other transmission, could afford additional optics
  - » Discoveries in astrophysics, and of gravitational wave sources, likely to influence the decision

Advanced LIGO Configuration

- All three interferometers 4km in length
  - » For initial LIGO, one of the two instruments at Hanford is 2km
- Further analysis, and experience with data, indicates advantage for astrophysics for all instruments to be 4km
  - » Advantage of signature of
    '½ signal strength in ½ length interferometer'
    is outweighed by greater sensitivity of a 4km instrument for three identical instruments
  - » For differently tuned instruments, longer is always better
- Advantages for Project as well
  - » All principal optics identical, in particular common spares
  - » Although it requires moving a chamber from 2km to 4km at Hanford, net cost savings

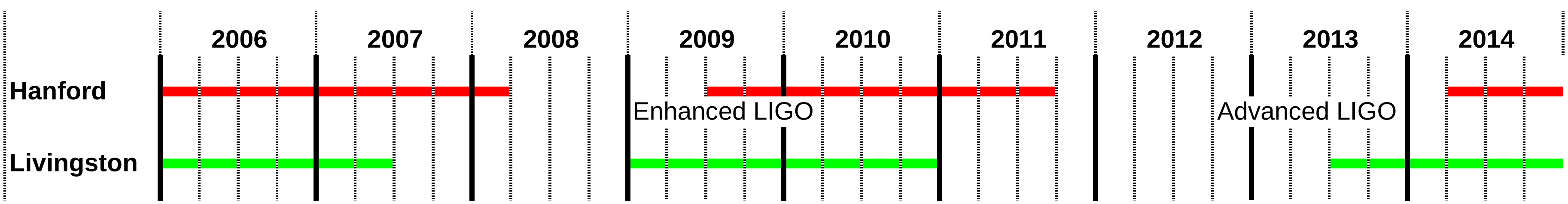
Advanced LIGO in context

Black: Operations (R&RA); Blue Project (MREFC)

- Initial LIGO S5 run to reach goal of one year of integrated data in mid-2007
- Advanced LIGO funding at start of FY2008; fabrication, assembly, and stand-alone testing of detector components
- Enhancements to be installed, commissioned progressively at Hanford, Livingston; first running in early 2009
- Science runs with enhancements starting in early 2009, running to beginning-mid 2011
- Advanced LIGO starts decommissioning initial LIGO instruments in early 2011, installing new detector components from stockpile
- First Advanced LIGO interferometer accepted in early 2013, second and third in mid-2014. Project completes!
- Commissioning of instruments, engineering runs starting in 2014

Overall schedule

- Choose a construction schedule which minimizes the time between shutdown of initial/enhanced LIGO and start of Advanced LIGO
  - » …consistent with our manpower and other resource constraints
- Appears at this time to give the best astrophysics –
  - » Running with a single LIGO detector is not very attractive; misalignment w.r.t. Virgo does not allow many searches to be done for just-detectable signals
  - » Just hours/days of observation is equivalent to a year of observation with initial/enhanced LIGO in terms of volume and thus rates of sources
- Keeps pace with other efforts (Virgo, LCGT (Japan), GEO)
- Efficient use of Project funds (efficiency of scale, skilled staff)



Advanced LIGO Detector Acceptance, Commissioning

- A detector is accepted when
  - » All subsystems are installed, integrated, and have passed stand-alone *in-situ* testing, and
  - » The detector can acquire the 'locked' state (all optical cavities under length servocontrol and with a functioning strain readout) for several hours
- This is a 'breakthrough' point, after which the systems are operating in a linear state, and many tools become available to improve the robustness and the noise performance of the system
- It allows a crisp definition and one that can be planned well, avoiding uncertainty in planning Project 'marching army' costs
- Commissioning is better undertaken in a non-Project organization
  - » Heavy in graduate students and postdocs working at midnight
  - » Choosing the best path when it appears, taking advantage of new ideas, dropping plans when irrelevant
- Commissioning takes place after acceptance, and is beyond the Advanced LIGO Project scope (supported by LIGO Laboratory Operations R&RA).

Sketch of Advanced LIGO Commissioning

- Commissioning, *under Operations*, is planned to be approached in steps sketched here
- First commissioning phase:
  - » low laser power operation, ~30 W from laser,
  - » goal 60 MPc NSNS inspiral per interferometer, ~2x more sensitive than enhanced initial LIGO, ~8x volume and rate
  - » Requires ~one year of commissioning after acceptance of a given interferometer;
  - » observation run of duration ~6 months after 2 sites (not necessarily 3 ifos) operable, so first observation run starting early 2015; goal duty cycle 30% for coincidence
- Second commissioning phase,
  - » concentration on low frequencies (and servo stability, locking, etc.); 30 W laser power
  - » goal 120 MPc for NSNS inspirals, 2x more than first phase, 8x volume and rate
  - » Requires ~one year of commissioning, all three IFOs brought to good operation
  - » Observation run of duration ~6 months starting late 2016; duty cycle 60% coincidence, so net volume*time increase over first run is 2*2^3 = 16x
- Third commissioning phase,
  - » full Advanced LIGO sensitivity
  - » goal ~180 MPc for NSNS inspiral
  - » plan to start long run in late 2017/early2018
- This sketch will almost **certainly** be modified by the discoveries made either before Advanced LIGO Commissioning starts, or those made with early steps of the instruments
  - » Discussion with the LIGO Laboratory Program Advisory Committee, the NSF, and the worldwide GW network will be used by the LIGO/LSC to determine the actual plan in a dynamic but considered fashion

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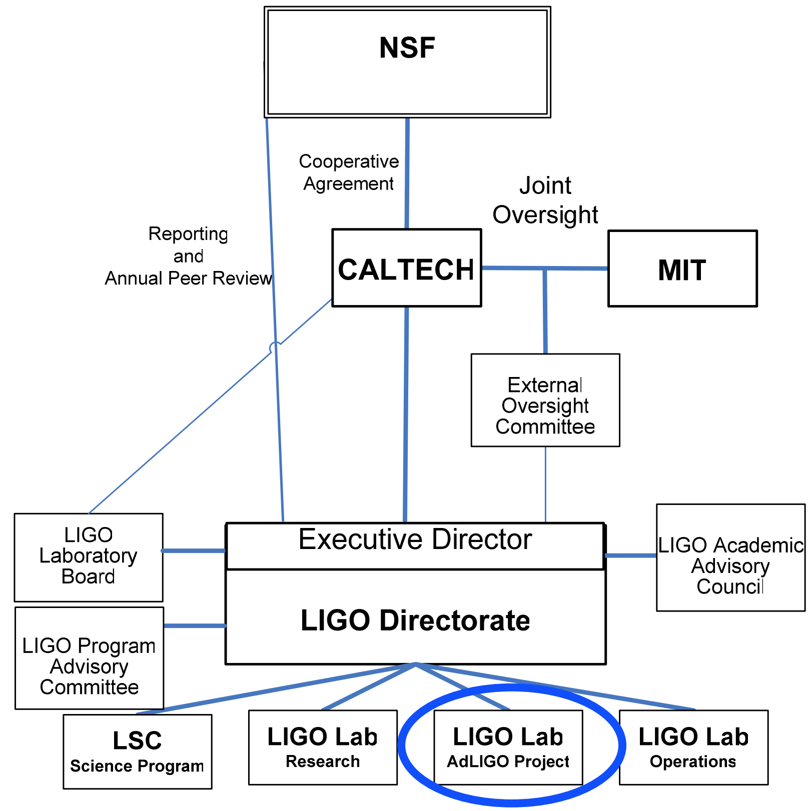
Transition from Development to Project

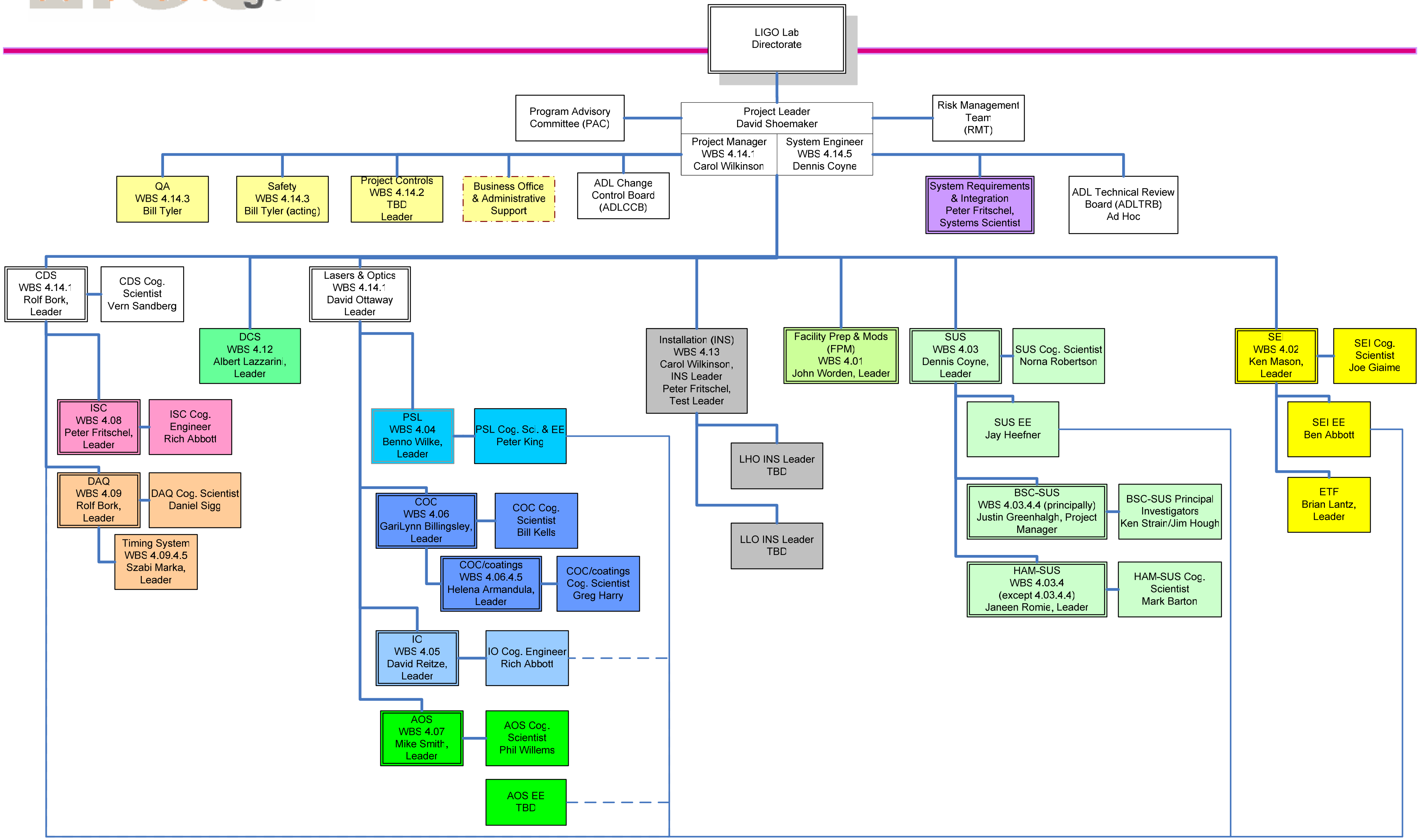
- Advanced LIGO Project limited to fabrication, installation, integration, and test
- Development effort (funded under Operations/R&RA) to deliver Final Designs to the Project (funded under MREFC)
  - » Completed Final Design Review
  - » Prototype construction completed, sufficient test to give confidence in design, often integrated with other subsystems, trial installation when appropriate
  - » Modeling, analytical backup, documentation of requirements, specifications, processes
- Some overlap of two – a number of development activities planned for FY2008 to run in parallel with Project activities
  - » Will be detailed in individual subsystem descriptions
- Some Campus integrated testbed prototyping continues well into Project, to allow software refinement, training of staff in preparation for installation, integration, and test, and also tests of First Articles from Project

Organization: LIGO Lab context

- Advanced LIGO is a Project undertaken in the structure of the LIGO Laboratory
- Staff are assigned via matrix organization across sites to Advanced LIGO
- LSC members participate in several modes, and have roles and responsibilities like Lab staff



Advanced LIGO Organization



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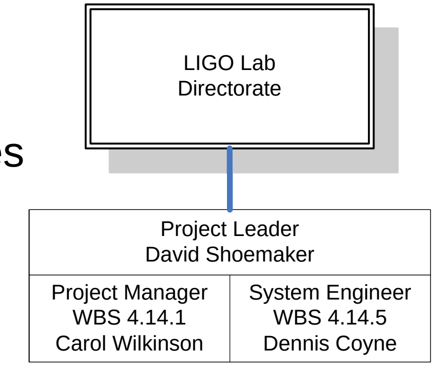
Advanced LIGO Leadership

- Three people, one box, distinct roles
- Advanced LIGO Leader reports to LIGO Lab Executive Director
  - » Accountable for the Advanced LIGO Project and its deliverables
  - » Define and modifies overall strategy for completing project
  - » Manages project contingency
  - » Acts on advice from the Advanced LIGO CCB, TRB, RMT (Risk Management Team)

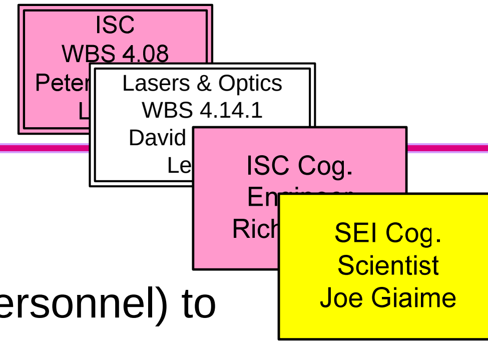


- Project Manager reports to Leader
  - » Develops & Maintains WBS, schedule, cost estimate, and resource plan
  - » Implementation of Advanced LIGO safety policies, direction of personnel engaged in safety concerns
  - » Directs the efforts of the subsystem leaders to manage project scope, cost, and schedule goals
- Systems Engineer reports to Leader
  - » Oversees all engineering for Advanced LIGO, including systems engineering
  - » Manages interface definition and control, and configuration control
  - » Direction of all system engineering staff and resources

A few important Project elements

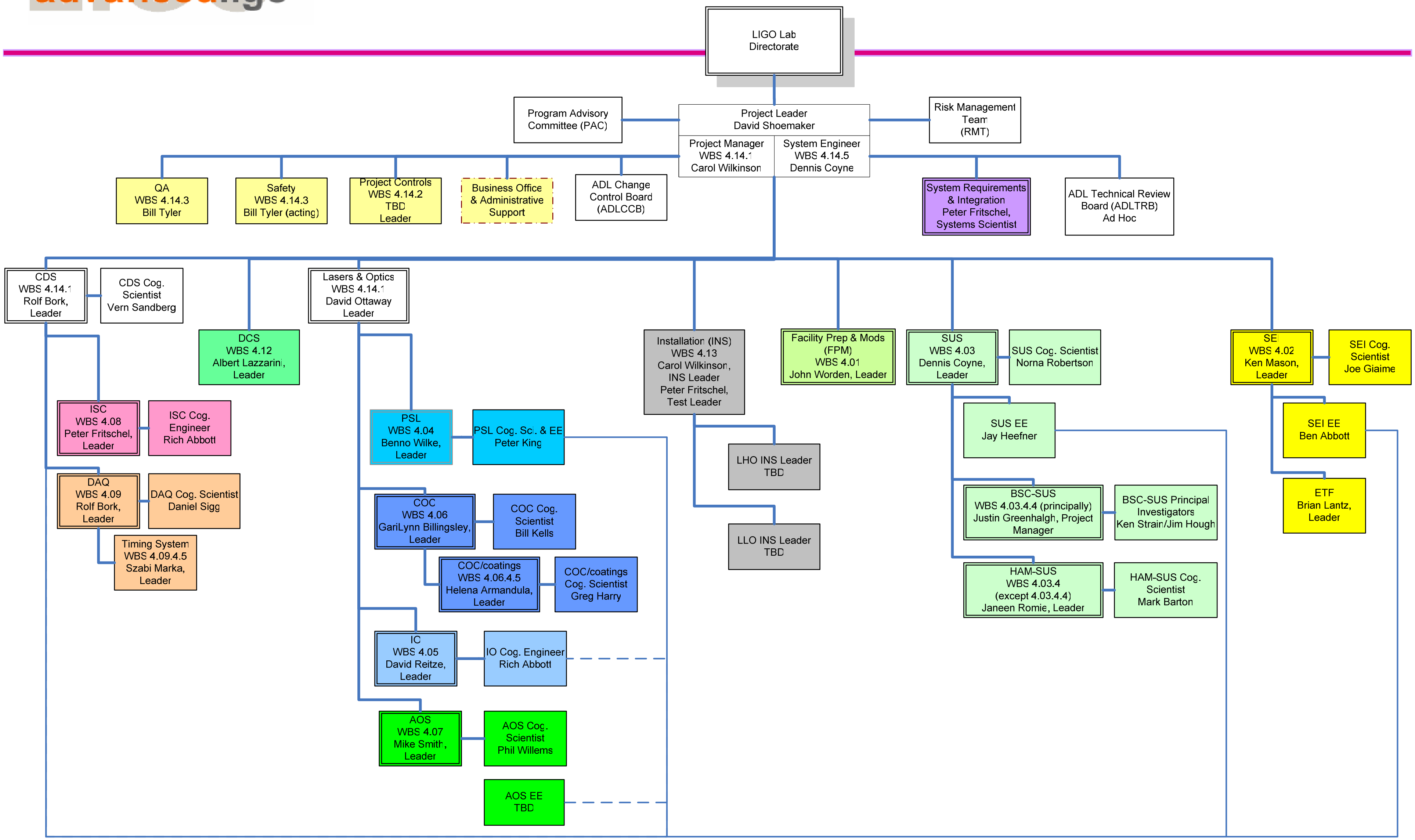
- Program Advisory Committee: augmented subset of the LIGO Lab PAC, with chair (M. Breidenbach) and members with expertise in management of large projects and specific technical expertise
  - Plan once a year meetings, strategic issues, advice sought – first meeting Fall 2006
  - Can also call meetings if need arises
  - Charged by, and reporting to, the LIGO Lab Executive Director (with consultation with Advanced LIGO Leader)
- Quality Assurance
  - Intended to be a strong and pro-active office – not a clipboard and checklist
  - A full-time person, with expertise in core Advanced LIGO technologies
- Safety
  - Advanced LIGO operates under the Safety Organization and rules of the LIGO Laboratory, responsibility of Lab Deputy Director, with Advanced LIGO Leader responsible for Advanced LIGO safety
  - Successful pro-active program currently in place for Observatories and Campuses
  - Increment from 10W to 180W laser is the one significant change from Initial LIGO

Roles in WBS management



- Subsystem Leader
  - » Manages/directs the assigned resources (hardware and personnel) to perform the tasks
  - » Makes decisions (programmatic and technical) at the subsystem level based on advice from staff (in particular the cognizant ‘significant other’)
  - » Manages major subcontracts (as a Technical Monitor), or delegates this responsibility
- Integrated Subsystems Leader
  - » Manages/directs the overall assigned resources (hardware and personnel) to perform the tasks for the designated set of subsystems
  - » Acts as point-of-contact for the leaders of the designated set of subsystems and the Advanced LIGO Management for reporting against the plan. Optimizes across the designated set of subsystems
- Cognizant Engineer
  - » Oversees all technical aspects of the subsystem implementation
  - » Oversees all form, fit, function assessment (CAD, simulation and test)
- Cognizant Scientist
  - » Establishes the subsystem requirements in collaboration with the System Scientist
  - » Oversees all performance related assessment (via analysis and test)

Advanced LIGO Organization



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Advanced LIGO Organization

- For fun: a total of four centuries of experience in gravitational wave interferometry on the Organization Chart!

	Date Joined Field	Years	Advanced LIGO Role	Recent Relevant Experience
Abbott, Ben	2000	7	SEI Electrical Engineer	40m Caltech testbed electrical engineer; photodiode amplifier design, Initial LIGO
Abbott, Rich	1995	12	ISC, IO Cognizant Engineer	PSL Cognizant Engineer for Initial LIGO; Commissioning Deputy for Initial LIGO
Armandula, Helena	1998	9	Coatings Leader	Coating Leader, initial LIGO; Initial LIGO Suspension assemblier
Barton, Mark	2001	6	SUS HAM Cognizant Scientist	Suspensions design, implementation, modeling for Initial LIGO
Billingsley, Garilynn	1995	12	COC Leader	Leader for COC, initial LIGO
Bork, Rolf	1994	13	CDS Integrated Leader	Co-leader CDS and Leader, real-time programming and architecture, for initial LIGO
Coyne, Dennis	1995	12	Systems Engineer, SUS Leader	Chief Engineer for the LIGO Laboratory and Initial LIGO; Installation Leader for Initial LIGO; adaptive and active optics, structural dynamics analysis
Fritschel, Peter	1994	13	Systems Scientist, ISC Cognizant Scientist	Co-leader of Interferometer Sensing and Control for Initial LIGO; Commissioning Leader for Initial LIGO
Giaime, Joe	1995	12	SEI Cognizant Scientist	SEI Cognizant Scientist, Initial LIGO; controls
Greenhalgh, Justin	2002	5	SUS UK Project Manager	Seismic isolation designs for GEO-600
Harry, Gregg	2001	6	Coatings Cognizant Scientist	Resonant bar transducers; Thermal Noise coordinator, LIGO Lab
Heefner, Jay	1994	13	SUS Cognizant Engineer	Electronics design, Initial LIGO
Hough, Jim	1970	37	SUS UK Principal Investigator	University of Glasgow Group Leader
Kells, Bill	1995	12	COC Cognizant Scientist	Cognizant Scientist, COC, initial LIGO
King, Peter	1997	10	PSL Cognizant Scientist, Engineer	Leader of PSL, initial LIGO; Initial LIGO Commissioner
Lantz, Brian	1994	13	SEI ETF Leader	Development of active seismic platforms; controls; precision interferometry
Marka, Szabi	1999	8	Timing System Leader	Commissioning of Initial LIGO; atomic clock independent timing reference for Initial LIGO
Mason, Ken	1997	10	SEI Leader	ISC Cognizant Engineer, Initial LIGO; alignment systems design for Initial LIGO
Ottaway, David	2000	7	Lasers&Optics Integrated Leader	High-power laser designs; Commissioning at Hanford for Initial LIGO; responsible for MIT LASTI development
Reitze, Dave	1996	11	Input Optics Leader	Input Optics Leader, Initial LIGO
Robertson, Norna	1977	30	SUS Cognizant Scientist	GEO-600 Suspension Leader
Romie, Janeen	1995	12	SUS HAM Leader	Cognizant Engineer for Suspensions, Initial LIGO
Sandberg, Vern	2003	4	CDS Cognizant Scientist	System and electronics design in nuclear, particle, and space physics; relativity theory
Shoemaker, David	1980	27	Leader	Deputy Detector Leader, Systems Engineer for Initial LIGO
Sigg, Daniel	1995	12	DAQ Cognizant Scientist	Alignment system design, Initial LIGO
Smith, Mike	1996	11	AOS Leader	AOS Leader, Initial LIGO
Strain, Ken	1984	23	SUS UK Principal Investigator	Centrally involved in developing the design, construction, commissioning and organising initial observing for GEO-600
Tyler, Bill	1995	12	Safety Officer	Safety Officer for Initial LIGO
Wilkinson, Carol	2003	4	Project Manager	Project Manager for DAHRT (Dual Axis Radiographic Hydrodynamic Testing) Project, DOE electron linear induction accelerator
Willems, Phil	1998	9	AOS Cognizant Scientist	Interferometer Configurations, thermal noise, suspensions and fibers
Willke, Benno	1993	14	PSL Leader	Organized and led the commissioning of GEO-600
Worden, John	1996	11	Facilities Leader	Vacuum Equipment Leader, Initial LIGO
	Total Years	**397**		

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LSC Participation in Advanced LIGO

- Origin of Advanced LIGO in the (then nascent) LSC – '99 White Paper
- Strong and (voluntarily) coordinated R&D program led to current design
- Many groups/individuals are part of the Project plan:

- Glasgow, Rutherford, Birmingham UK: Capital Contribution!
  - » Lead responsibility, delivery of Test Mass Suspensions, some Optics Substrates
- Albert Einstein Institute/Max Planck Germany: Capital Contribution!
  - » Lead responsibility, delivery of Pre-stabilized Lasers
- University of Florida:
  - » Lead responsibility, delivery of Input Optics (on subcontract)
- Columbia University:
  - » Lead responsibility, delivery of Timing System (on subcontract)
- Louisiana State University:
  - » Lead scientific responsibility for Seismic Isolation
- Stanford University:
  - » Lead scientific responsibility for Suspensions, core scientific expertise in Seismic Isolation
- Australian National University:
  - » Lead responsibility, delivery of Output Mode Cleaner (on subcontract; proposal for Capital Contribution to Australian funding agency)

LSC Participation in Advanced LIGO

- MOUs to be written with each partner
  - » Negotiated and signed with UK, Columbia University
  - » Previous arrangement with UFla, being updated
  - » In discussion with Max Planck, ANU; others to follow
- Individual cases best discussed in breakout sessions
  - » Representatives from most groups here
- Vitally important that the greater LSC (instrument scientists, and analysts) remain deeply engaged in Advanced LIGO throughout the Project – and beyond
  - » Contributions to end of Development
  - » Active participation in the astrophysics/instrument science during fabrication, installation, integration, and test – while supported by own NSF (or other) support
  - » Commissioning, characterization, and analysis post-Project

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Advanced LIGO

- Based on a great deal of initial LIGO experience
  - » Technical: no longer the first time to design, fabricate, and bring to operation a 4km-baseline gravitational-wave detector
  - » Organizational: Now in context of Laboratory/LSC; plans take advantage of these resources
- Cost, Schedule, Risk tools in place and well exercised
  - » Stability in Project cost per scope reassuring
- Establishing transitions, sharing of staff with Operations is a challenge
  - » Two-year continuation of cooperative agreement very useful
  - » Will continue to work the details of Advanced LIGO staffing needs in expertise and epoch, synchronize with Operations
- Distributed organization – time zones, institutions, funding
  - » Significant experience during ~7-year coordinated development effort: Groups, individuals, plans, promises
  - » Project will be managed by those who led R&D phase
- The design is flexible, development nearing completion, significant prototyping underway, the teams are working well –

The astrophysics will be great.