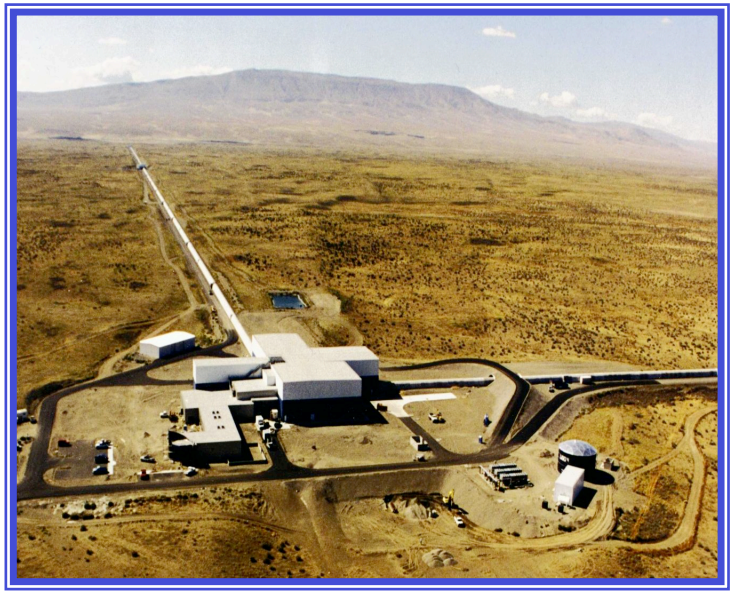
Overview of LIGO and Background



Jay Marx, LIGO Executive Director

Advanced LIGO Baseline review

June 5, 2007

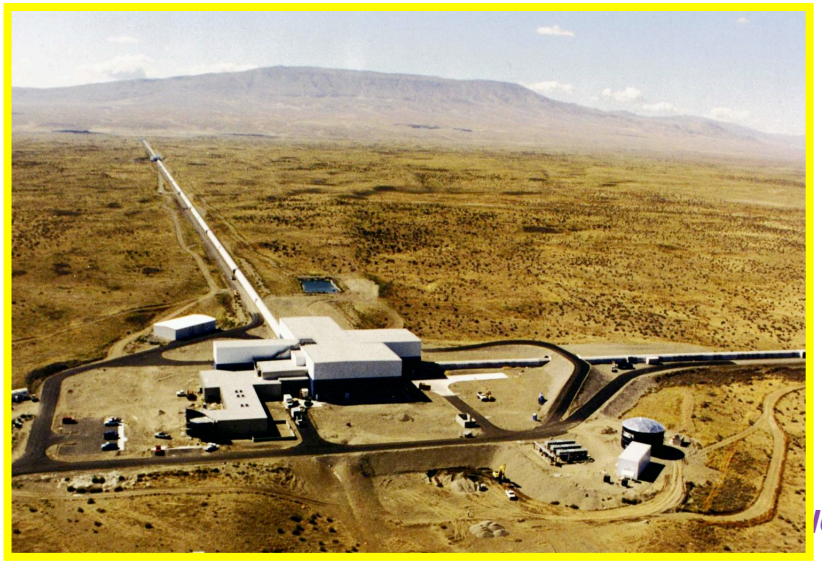
G070368-00-M

Topics to discuss

- LIGO-- science mission; how LIGO works
- LIGO organization- LIGO Laboratory and the LSC
- Status of LIGO
  - » The S5 Science Run
  - » Modest Enhancements to Initial LIGO- the next step
- Overview of Advanced LIGO from 40,000 feet
  - » Scope, cost, schedule, funding, technical, management, inflation and overhead
- Bottom-line

What is LIGO?

- Effort to directly observe gravitational waves predicted by General Relativity and pioneer the new field of gravitational wave astronomy
- Uses extremely high precision kilometer-scale laser interferometry
- 2 observatory sites- Hanford Washington and Livingston Louisiana



LIGO's Science Mission

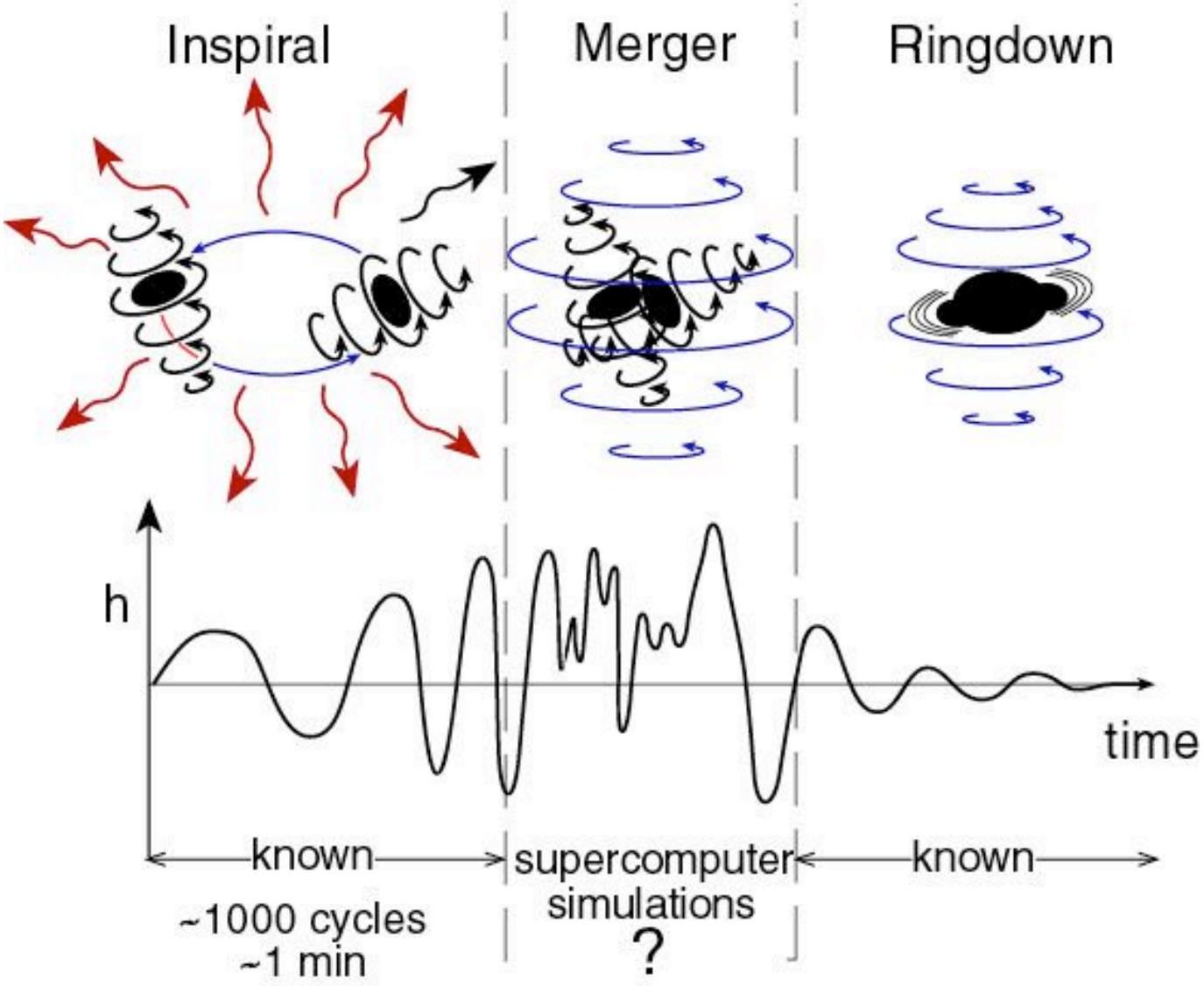
Physics--

- » Discover gravitational waves from cosmic sources
- » Explore General Relativity in the high field region where cosmic sources emit gravitational radiation

Astronomy and Astrophysics

- » Pioneer the new field of GW astronomy;
  - – Information about the most cataclysmic events in the cosmos are encoded in gravity waves

Astrophysical information encoded in GWs: e.g. black hole and neutron star pairs



Exercises most of the frequency range of the detector

Sketches courtesy of Kip Thorne

How LIGO Works

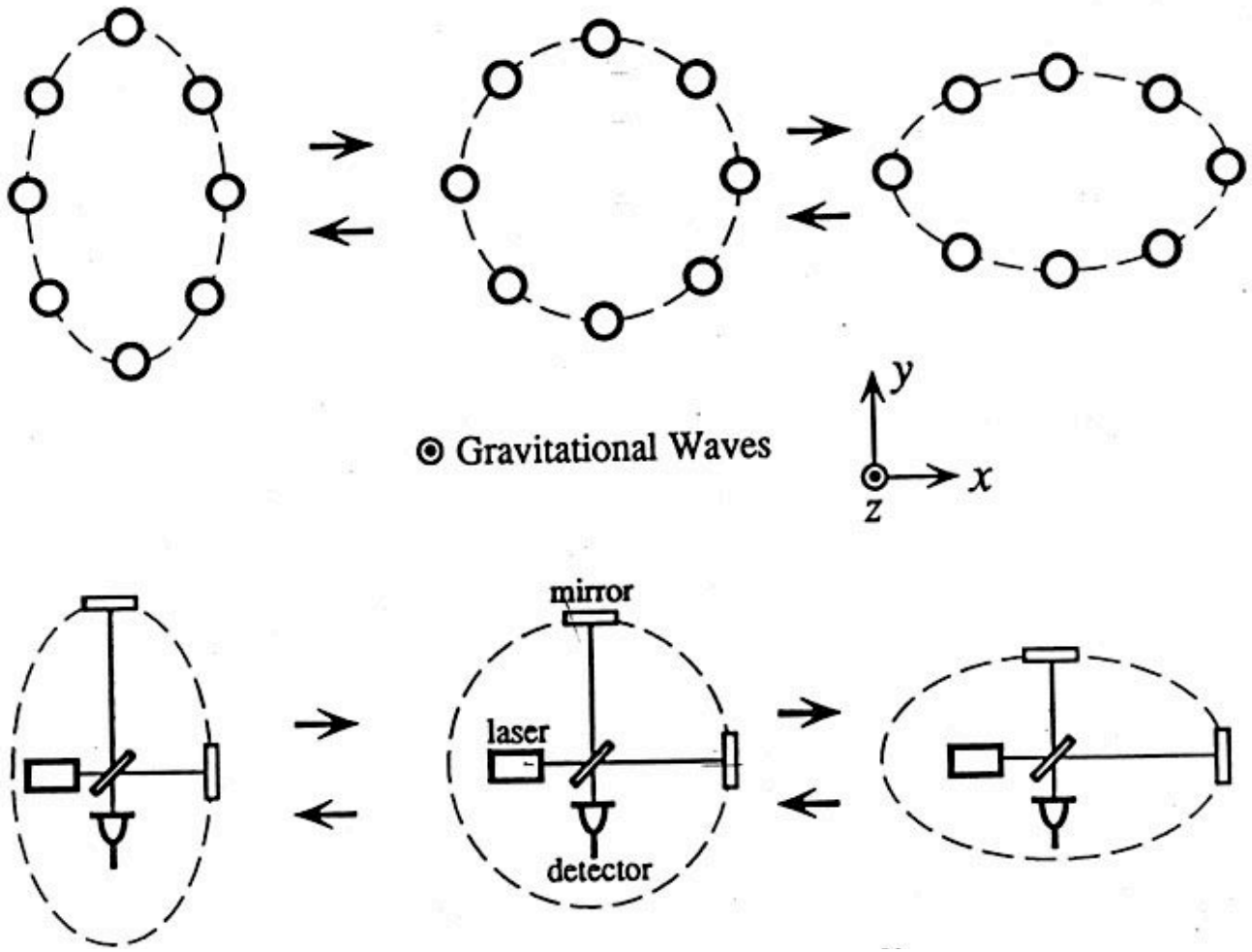
Gravitational wave causes a time varying stretch-compression of the fabric of space/time

Use Interferometry to sense a time varying change in relative distance between free test masses in the two perpendicular arms

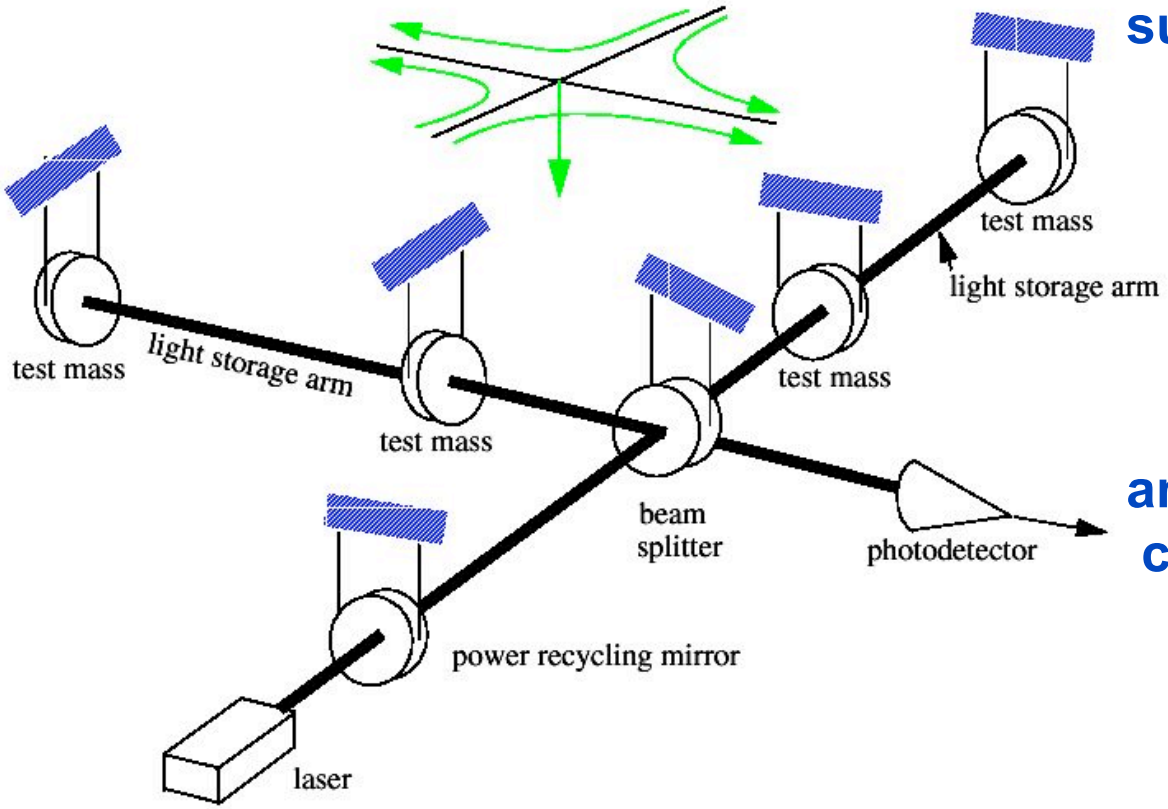
Initial LIGO sensitive to 10^{-21} in relative distance between test masses; needed to observe standard source (NS-NS) in Virgo cluster

Initial LIGO sensitive in audio frequency domain (~40Hz to several KHz)

Basic Signature of Gravitational Waves



Laser-Interferometer or "Free-Mass" Detectors (initial LIGO)



suspended mirrors mark inertial frames

antisymmetric port carries GW signal

Organization of LIGO

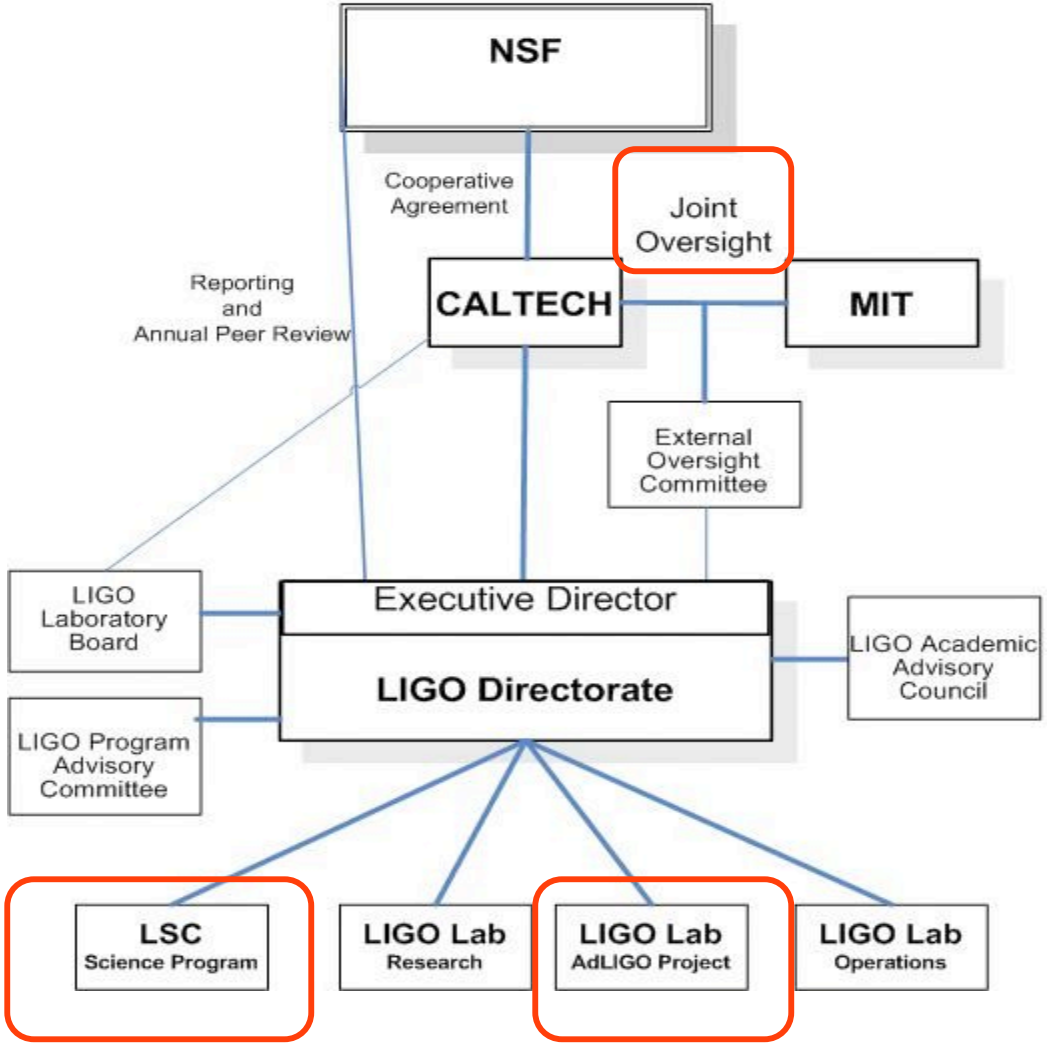
LIGO is an amalgamation of the LIGO Laboratory

- » Operated by Caltech and MIT under Cooperative Agreement between NSF and Caltech
  - – NSB approved 2 year extension of Cooperative Agreement through FY2008
  - – Proposal for new 5 year operations grant (FY2009-FY2013) will be submitted September 2007

and the LIGO Scientific Collaboration (LSC)

- » ~550 scientists from 45 institutions and 11 countries (including LIGO Lab)

LIGO Organization



The Directorate & Advanced LIGO

Directorate--

- » Executive Director (Jay Marx-- Caltech); Deputy Director (Albert Lazzarini-- Caltech); LSC Spokesperson (Dave Reitze-- Univ. of Florida)

In the Directorate, Jay is the person who has the responsibility to assure that Advanced LIGO is a success.

- » Hands-on involvement in project
- » Has had lots of big project experience

Mission of LIGO Laboratory-

- Observe gravitational wave sources and open new field of GW Astronomy;
- Operate the LIGO facilities to support the national and international scientific community;
- Develop advanced detectors and techniques that push the limits of interferometer performance for GW science;
- Support scientific education and public outreach related to gravitational wave astronomy;
- Successfully carry out Advanced LIGO.

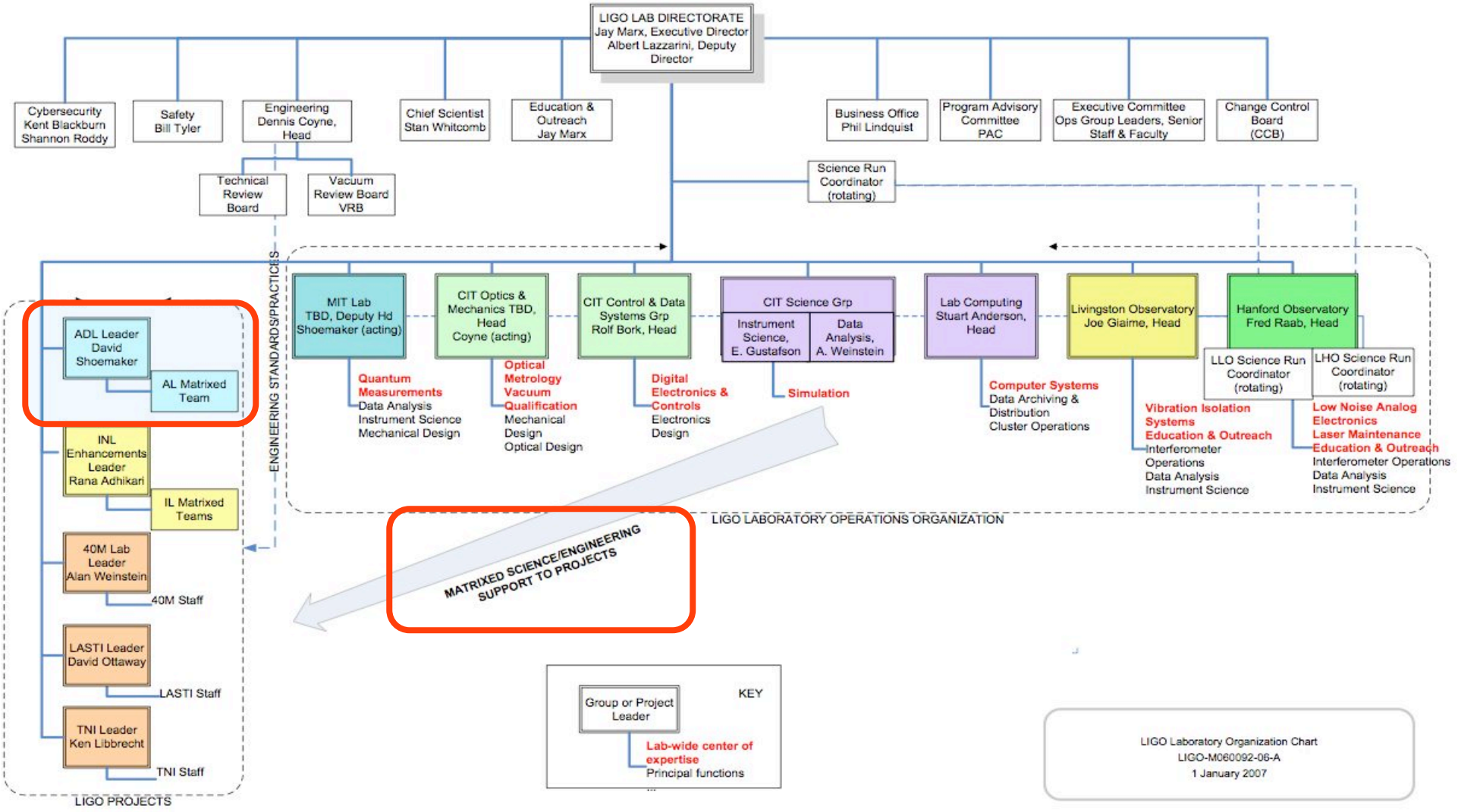
LIGO Laboratory

Use matrix organization to support Advanced LIGO, operations, R&D, and other activities

LIGO Laboratory operates major facilities where development hardware/software/systems, techniques for Advanced LIGO are exercised and verified, staff trained, etc.

- » LASTI at MIT-- test full scale prototypes
- » 40 M interferometer at Caltech-- refine techniques (e.g. control loops)
- » The two observatories (training during operations and commissioning)
- » Data storage and processing center at Caltech

LIGO Laboratory Organization Chart



LIGO Laboratory Operations during Adv. LIGO

We have planned staffing and an operations budget through and beyond Advanced LIGO project;

- Includes support of mission of LIGO Laboratory except Advanced LIGO construction
  - » Operation of enhanced initial LIGO in FY2009-FY2010
  - » R&D to reduce risk for project, to enhance performance post-construction and to enable future advancements
  - » Data analysis & other science activities by LIGO Lab staff
  - » Education and Outreach
  - » Ramp-up of Advanced LIGO commissioning activities
  - » Post-project operations of Advanced LIGO

LIGO Scientific Collaboration (LSC)

Mission of LSC

- » Analyze and publish data from LIGO
- » Carry out the LIGO research and development program,
- » Enable participation by collaborating groups in all aspects of LIGO including Advanced LIGO

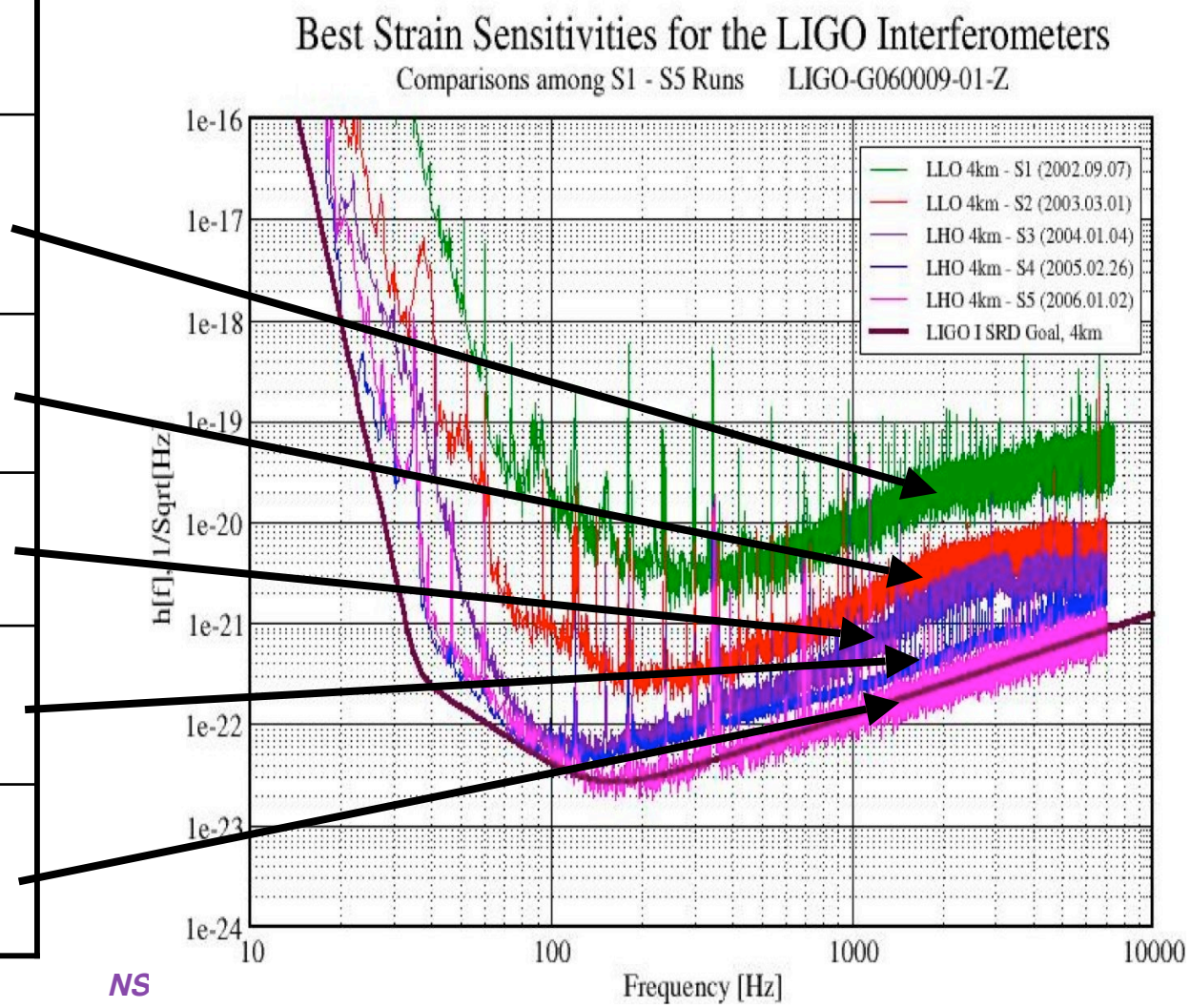
Note---LIGO Lab staff (scientists, engineers, students…) are members of LSC; they are involved in data analysis, publications and R&D

Current Status of initial LIGO

- In 2005 LIGO reached (and exceeded) design strain sensitivity
  - » 10^{-21} in 100 Hz bandwidth required by the 1995 Science Requirement Document
  - » measure to 1/1000 of proton size; or size of hair to distance to nearest stars
- First long science run began November 2005
  - » goal --coincident operation at the SRD sensitivity accumulating 1 year equivalent amount of data at or better than design sensitivity
- Run is going extremely well-- will end ~ September 2007
  - » During run have improved sensitivity by ~50%
  - » 4 km inteferometer range now > 15 Mpc (~50 million light years) for 1.4 M_o neutron star binary mergers
  - » Run is ~90% complete
- Initial LIGO experience and success is a foundation for Advanced LIGO

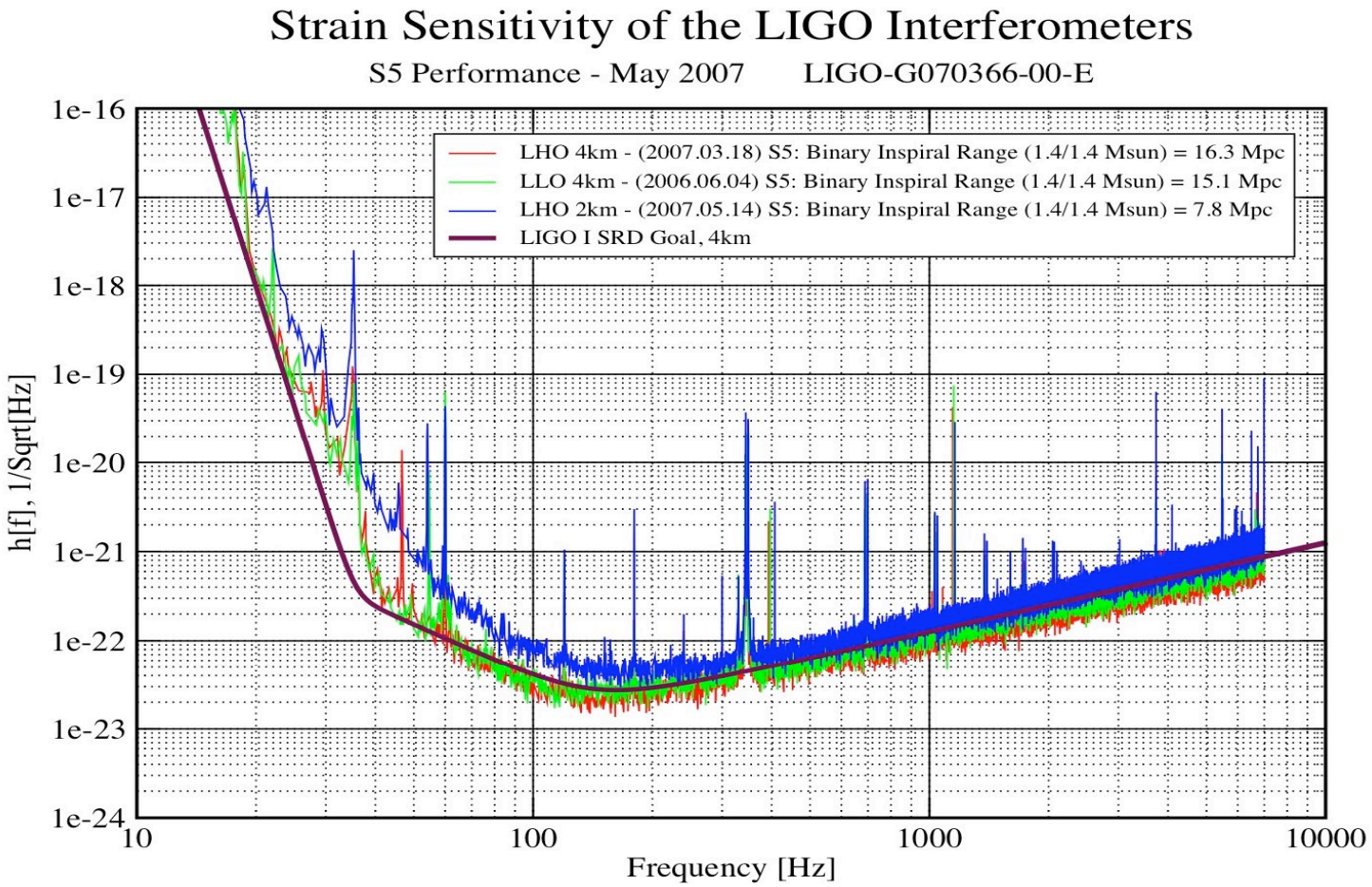
5 years of effort to reduced noise by ~ 3 orders of magnitude to design sensitivity of 10^{-21} strain in a 100 Hz range

Run	# calendar days
S1 Sept '02	17
S2 Feb 02-Apr 03	59
S3 Nov 03-Jan 04	70
S4 Feb- March 05	30
S5 Nov 05------	Over 600 so far

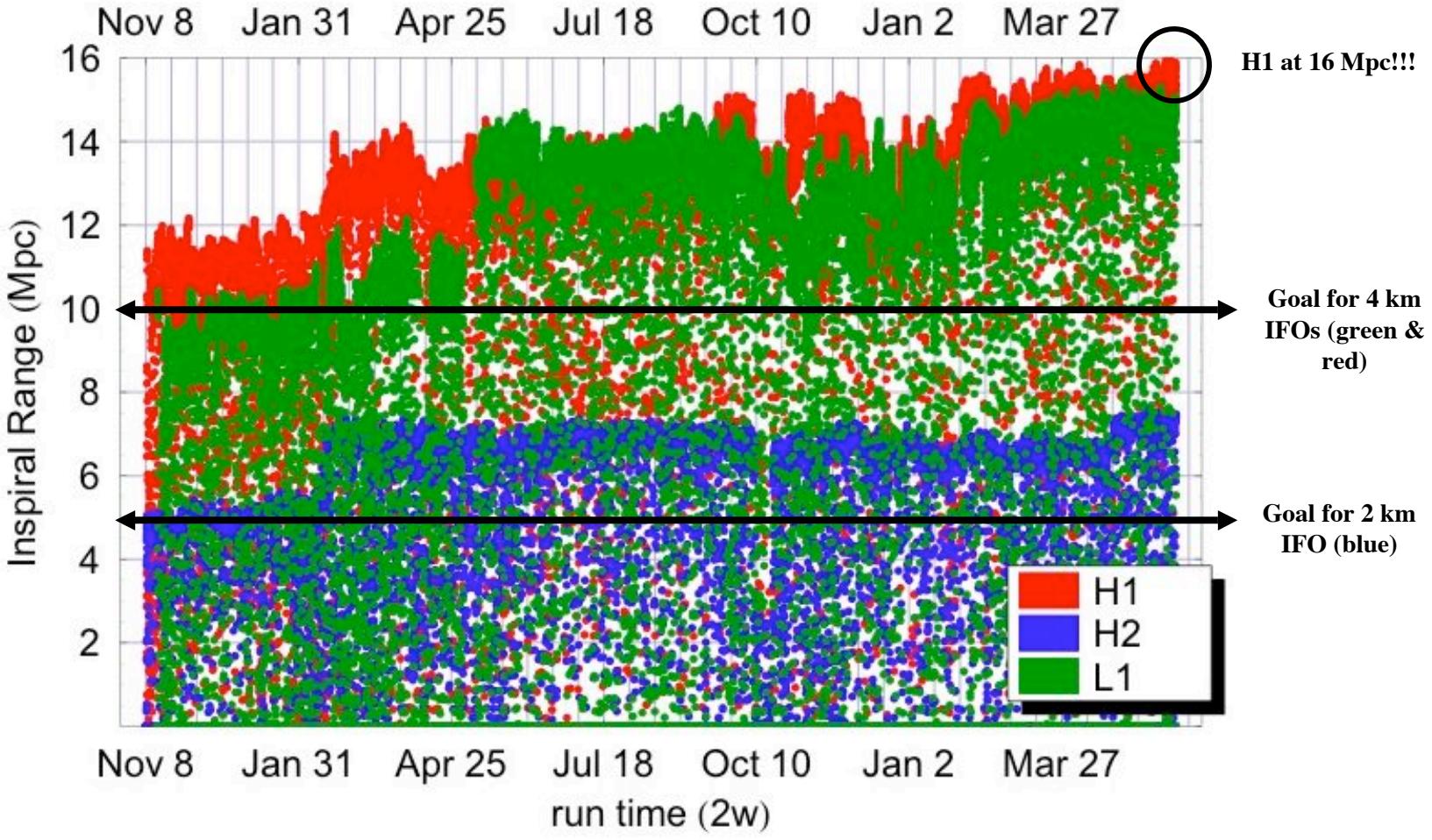


NS

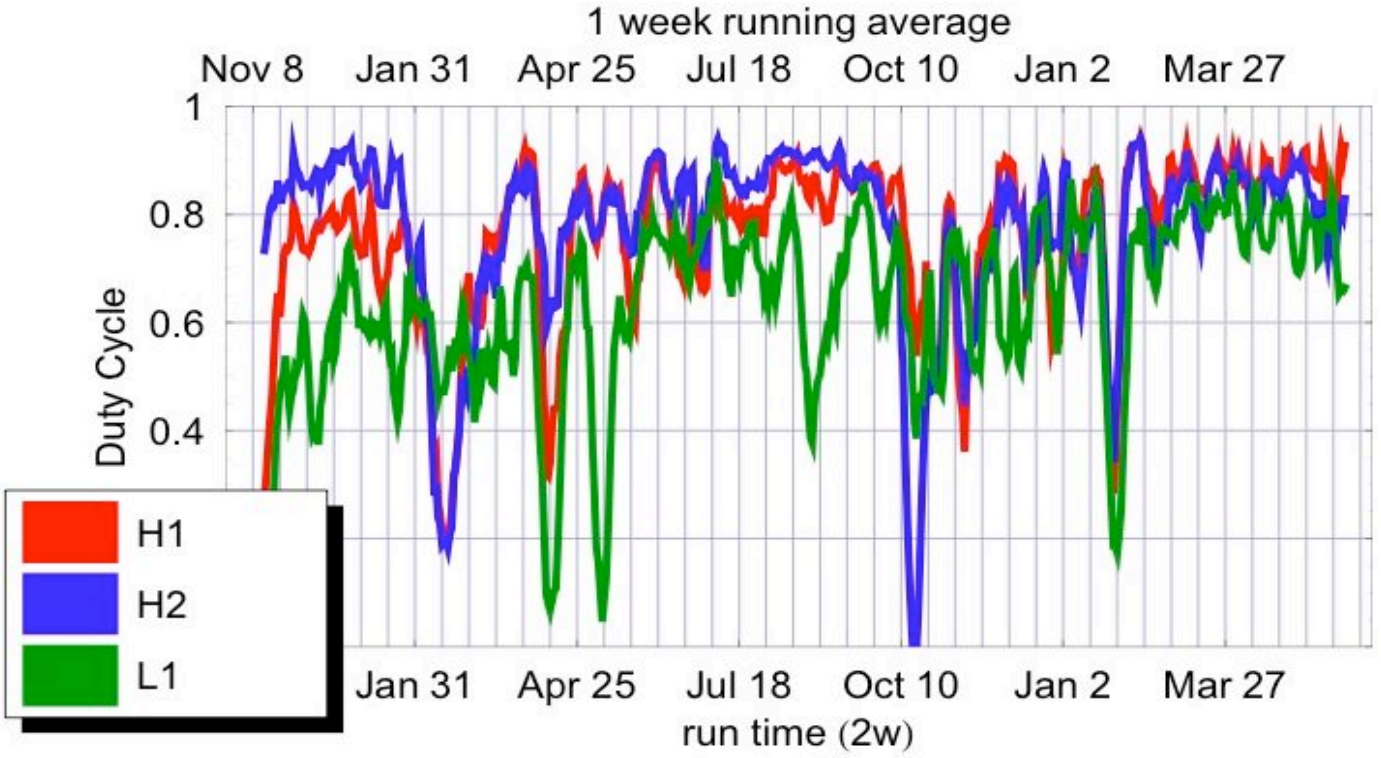
Design sensitivity indicated in the 1995 LIGO Science Requirements Document has now been exceeded



Range since S5 start



Duty cycle during S5



Astrophysics with Initial LIGO

- 9 papers on observational results submitted for publication since January 2006 (2 from S2, 2 from S3/S4, 4 from S4, 1 from Astrowatch)
- 12 talks on observational results from S3, S4 and S5 presented at APS meeting in April 2006
- 15 talks on observational results from S4 and S5 presented at APS meeting in April 2007
- 1 paper (GRB070201 upper limit) in draft form; S5 analyses in all search groups underway
- Joint data analysis with Virgo began May 18, 2007

Next step-modest enhancement of Initial LIGO

Between end of S5 and decommissioning of initial LIGO in 2010

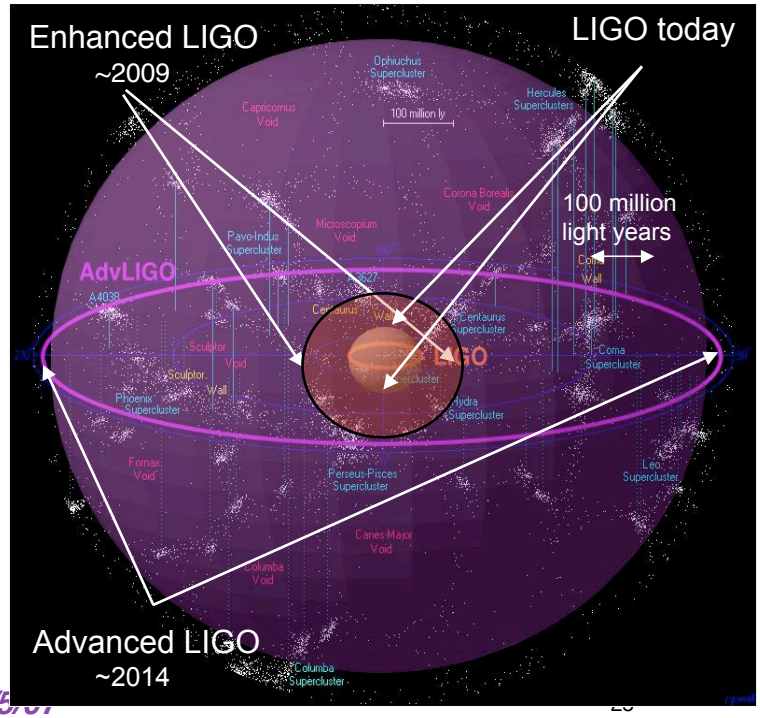
- Opportunity to enhance sensitivity by ~2 and significantly increase the chances of observing GW sources--
  - # observable galaxies~ (sensitivity)**3
  - Factor of 2 reduction in strain noisegivens ~8x increase in number of galaxies LIGO can "see"
- Enhancements are a natural step towards Advanced LIGO
  - Use implementations of Advanced LIGO technologies & techniques
  - Gain experience, find problems early and reduce eventual Advanced LIGO commissioning time
- Scope of enhancements
  - Increase laser power by ~2; allow system to handle additional power
  - Reduce noise at dark port sensing-- move into vacuum, seismically isolate, add mode filter cavity

Advanced LIGO-- NSF MREFC

- Increase the sensitivity of LIGO by factor of ten
  - » Increases number of inspiral sources in range by factor of 1000!
  - » For extra-galactic sources, 1 day's data of Advanced LIGO like few years of initial LIGO data
- And move seismic wall down from ~40 Hz to ~10Hz
  - » See higher mass BH-BH inspirals and follow more of inspiral chirp
- Advanced LIGO will open the new field of GW astronomy and astrophysics

The scientific evolution of LIGO

- 1st full science run of LIGO at design sensitivity in progress
  - » Began November 2005; ~90% complete
  - » Hundreds of galaxies now in range for 1.4 M_o NS-NS binaries
  - » Discovery possible but not likely (guess ~5%)
- Enhancement program
  - » In 2009 ~8 times more galaxies (thousands) in range
  - » Moderate discovery possibility (guess ~40%)
- Advanced LIGO
  - » 1000 times more galaxies in range (millions)
  - » Expect ~1 signal/day -- 1/week in ~2014
  - » Will usher in era of gravitational wave Astrophysics



Advanced LIGO from 40,000 feet

Advanced LIGO technical scope

- Reutilize buildings, vacuum system, beam tubes, environmental monitoring system and other expensive infrastructure from initial LIGO--
- Upgrade instrument components (laser, optics, seismic, etc.) to increase sensitivity and move seismic wall to lower frequencies
  - » Increase laser power by factor ~20 to increase sensitivity
  - » New optics and other components to handle higher power
  - » Recycle signal to increase sensitivity over limited bandwidth
  - » Improved seismic isolation and suspension to move seismic wall to lower frequencies

Management of Advanced LIGO

- Under LIGO Laboratory - experienced host lab important factor
  - » Oversight and hands-on involvement by Executive Director
- Project leadership team experienced with projects, LIGO and relevant technologies
  - – David Shoemaker- Project leader
  - – Carol Wilkinson-- Project manager
  - – Dennis Coyne-- System engineer
  - – Peter Fritschel-- System scientist
- Experienced scientific/technical/project personnel from LIGO Lab and from LSC institutions
- Project Advisory Panel
  - » Chaired by M. Breidenbach (SLAC);
  - » Jim Yeck is a member- brings his management experience
  - » Other members are technical experts

Baseline review of Advanced LIGO

- Successful NSF Baseline Review of Advanced LIGO-
  - » May 31-June 2, 2006;
  - » ~20 outside experts; chair- Don Hartill

"The Panel looked carefully at the Advanced LIGO project and was impressed."

*"The Panel recommends that the Advanced LIGO project go forward and agrees that the project can be constructed for (*the estimated cost*) a total cost of 172.2 M$ (FY 2006 $) on the proposed schedule and is ready for a construction start in FY 08."*

Current project status compared to baseline

- Scope-- 3 improved interferometers, each 4 km long-
  - » same as baseline
- Total NSF* cost (FY06$)-- $172M including 28% contingency
  - » same cost as baseline with more contingency
  - » (* note- Foreign in-kind contributions worth ~$12M to constructions; ~$12M to development)
- Small change (~2%) in total then-year cost
  - » Since 2006, OMB/NSF escalation factors have changed
  - » On this basis, additional escalation is $4.32M
  - » With new escalation factors total is $209.44M- up 2.1% compared to baseline, all due to escalation change
- Schedule- October 2007--August* (December**) 2014 including 11 months schedule contingency- same as baseline
  - » * Acceptance of 3rd interferometer
  - » ** Computer installation complete- formal end to project

Indirect costs and Advanced LIGO

- We've successfully negotiated with Caltech to have Advanced LIGO be designated an "equipment fabrication" with no overhead.
- The project will directly support the people at Caltech and LIGO Lab that provide overhead services to the project.
  - » This is more cost effective than paying overhead to Caltech with a fixed rate within its overhead structure.
  - » Separation of Advanced LIGO funds is more transparent and auditable
- Bottom-line result- increase contingency by $3.2M to $46.5M (then-year $); from 26.3% to 28.0%

Since June 2006 baseline review

- FY08 start approved by National Science Board (August 2006)
- We responded to recommendations and suggestions from June 2006 Baseline Review
- Project Advisory Panel scrutinized the project
- We continued key development activities aimed at FY08 start
- Celebrated project start in President's budget
- Scrubbed cost/schedule, including some updated bids
- Made significant technical decisions
  - e.g developed alternative for seismic isolation and decided to retain baseline approach
- Had in-depth internal review
- Staffed up in anticipation of FY08 start
- Continued development of project planning and implementation of project controls
- Committed to enhanced LIGO which will retire project risk

LIGO is in President's budget for FY08 start

AdvLIGO Funding Profile

(Obligated Dollars and Estimates in Millions)

	Concept/ Development		Implementation		Operations & Maintenance		Totals		Grand Total
	R&RA	MREFC	R&RA	MREFC	R&RA	MREFC	R&RA	MREFC	
FY 2004 & Earlier	15.60						$15.60		$15.60
FY 2005	9.20						$9.20		$9.20
FY 2006 Actual	9.70						$9.70		$9.70
FY 2007 Request	6.24						$6.24	-	$6.24
FY 2008 Request				32.75	28.20		$28.20	$32.75	$60.95
FY 2009 Estimate				51.43	27.60		$27.60	$51.43	$79.03
FY 2010 Estimate				46.30	27.80		$27.80	$46.30	$74.10
FY 2011 Estimate				15.21	29.20		$29.20	$15.21	$44.41
FY 2012 Estimate				23.73	32.20		$32.20	$23.73	$55.93
FY 2013 Estimate				15.50	36.00		$36.00	$15.50	$51.50
FY 2014 Estimate				19.78	42.90		$42.90	$19.78	$62.68
FY 2015 Estimate				0.42	47.90		$47.90	$0.42	$48.32
Subtotal, R&RA	$40.74		-		$271.80		$312.54		
Subtotal, MREFC		-		$205.12		-		$205.12	
Total, Each Stage		$40.74		$205.12		$271.80			$517.66

Advanced LIGO is a solid, robust project

- We know what we want to do and how to do it
  - » The project is based on extensive experience with initial LIGO
  - » The scope has been stable for years
  - » Extensive development program has proven out key technologies
  - » The project team is very experienced
- We know what it will cost and how long it will take
  - » The base cost has been very stable
  - » Rigorous standards for cost and schedule development matched to scope
- The management team is solid and experienced
  - » project controls in place and ready to go
- We are fully ready to start construction in FY08