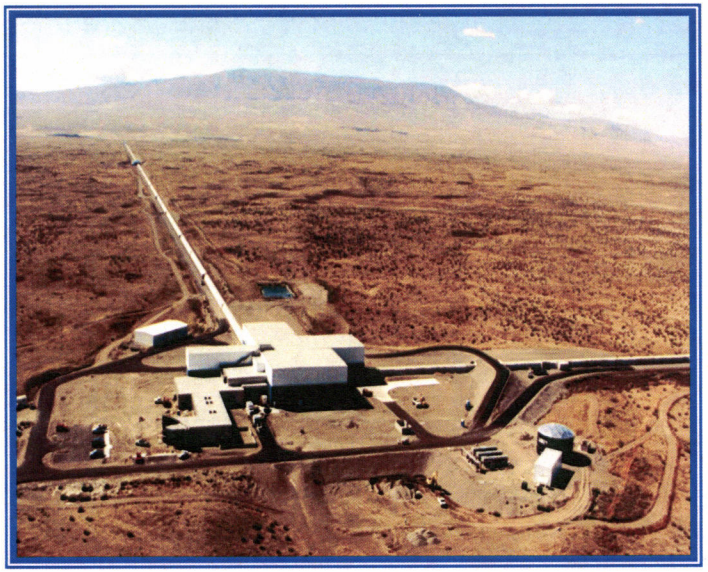
LIGO

Overview and Background



Jay Marx, LIGO Executive Director

Advanced LIGO Baseline review

May 31, 2006

LIGO-G050395-00-M

LIGO-G060334-00-M

Overview & Background Topics

LIGO- science mission; how it works

LIGO organization

Status of Initial LIGO and the S5 Science Run

Modest Enhancements to Initial LIGO

Overview of Advanced LIGO

LIGO's Science Mission

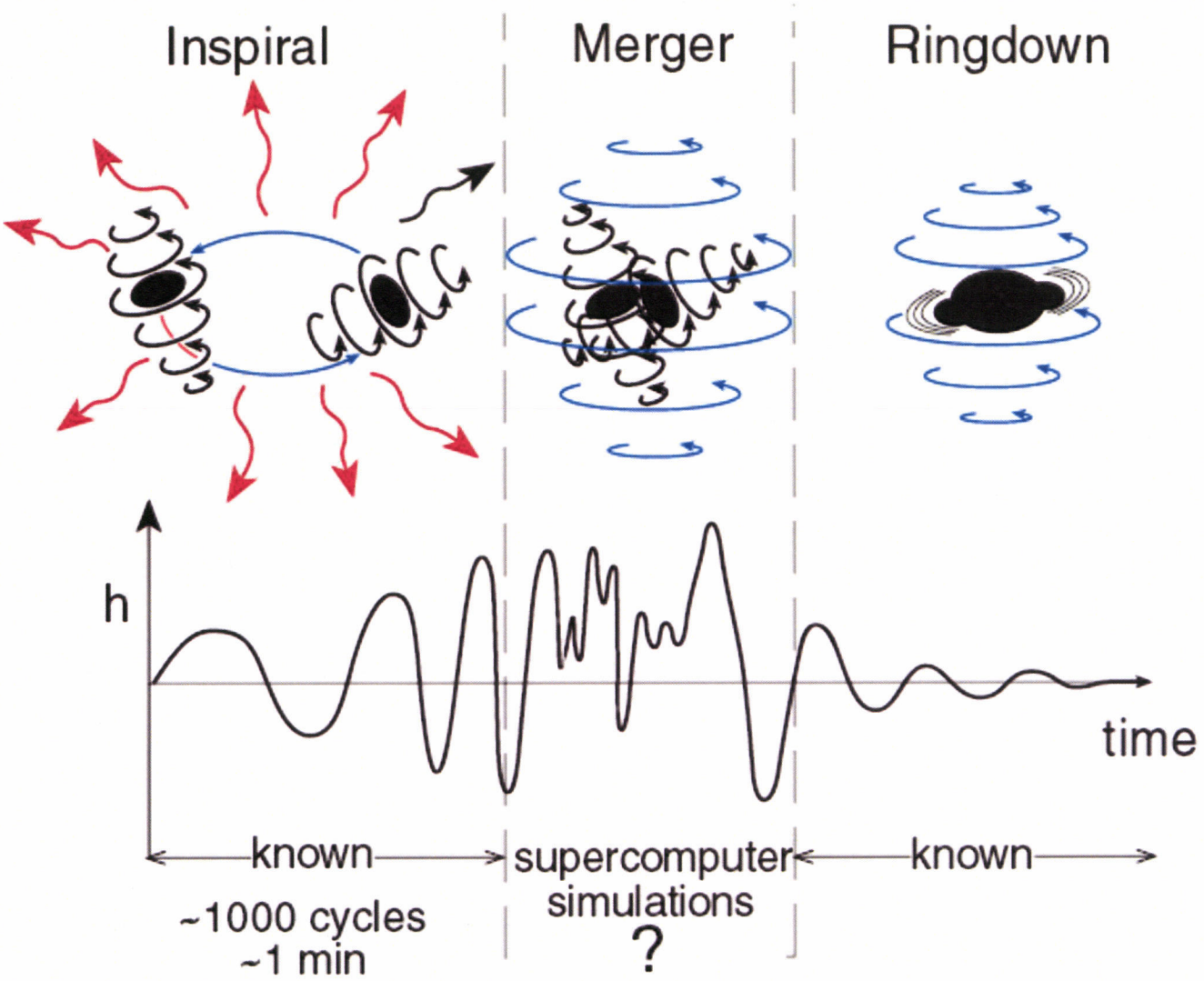
Physics--

- » Discover gravity 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

A "Baseline" Source: Waves From Orbiting Black Holes and Neutron Stars



Sketches courtesy of Kip Thorne

Exercises most of the frequency range of the detector

How LIGO Works

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

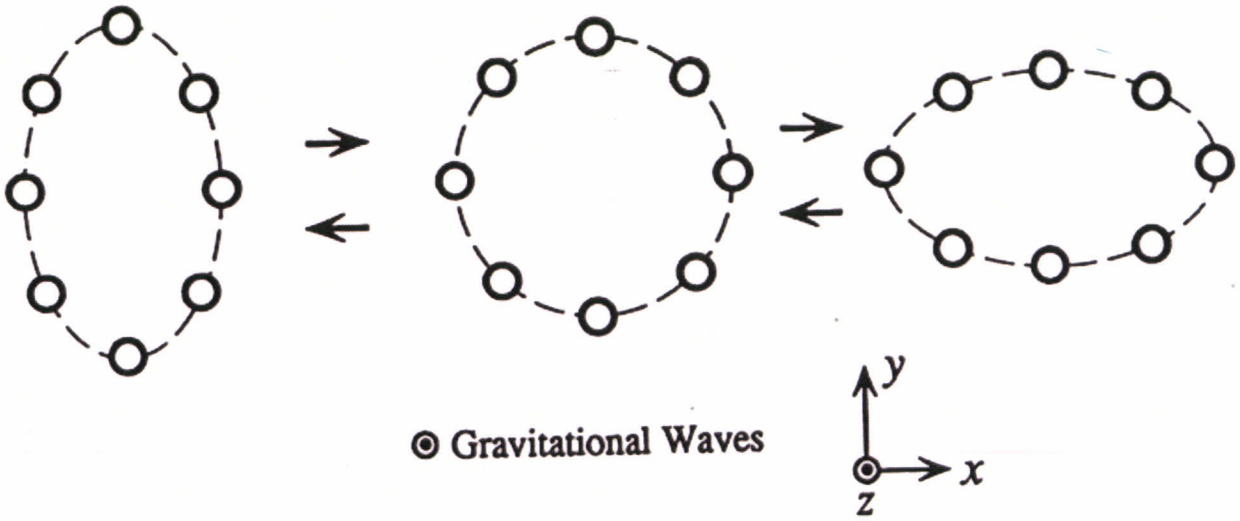
Use Interferometry to sense a time varying change in relative distance between free test masses in the two perpendicular arms

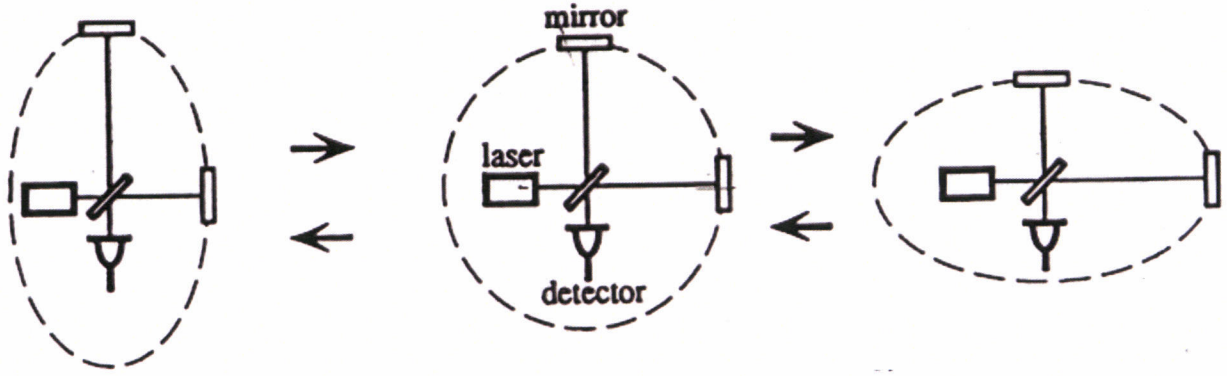
Sensitive to 10^{-21} in relative distance between test masses

Audio frequency domain (~40Hz to few KHz)

See Rai Weiss' talk (next)

Basic Signature of Gravitational Waves for





Organization of LIGO

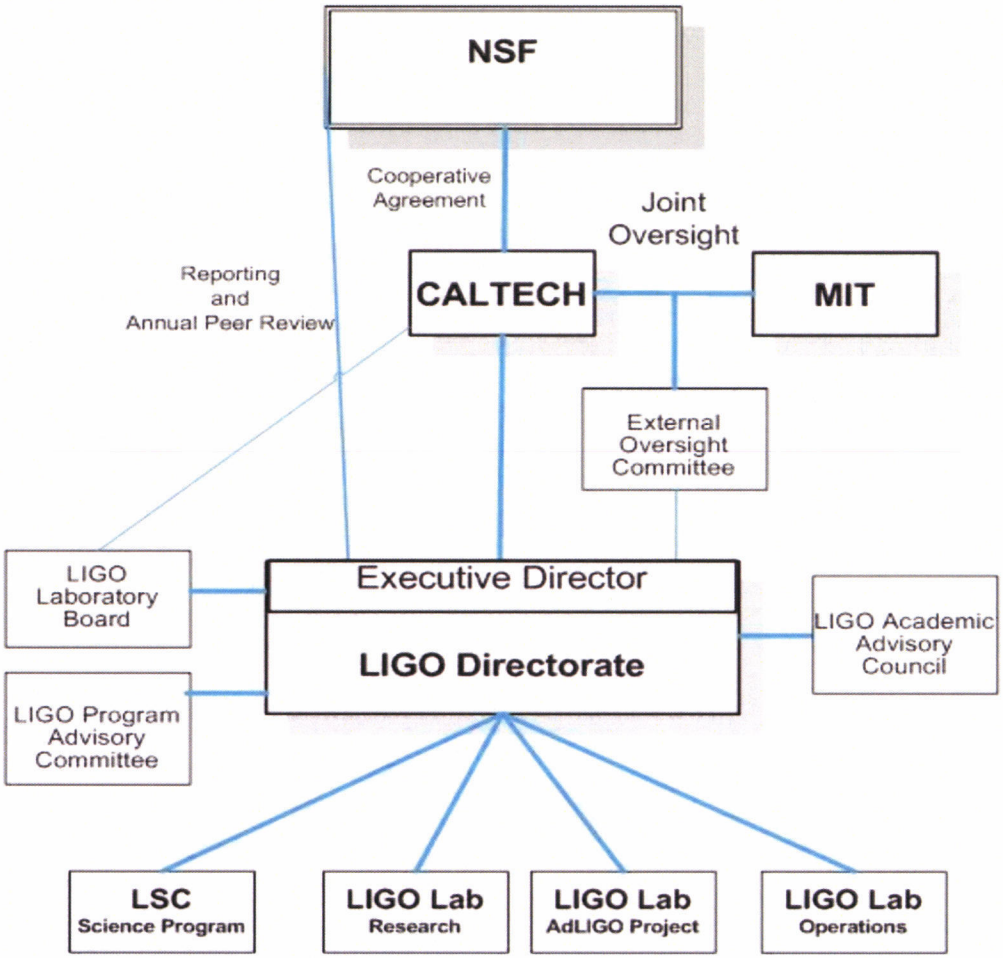
LIGO is an amalgamation of the LIGO Laboratory

- Operated by Caltech and MIT under Cooperative Agreement between NSF and Caltech
- NSB recently approved 2 year extension of Cooperative Agreement

and the LIGO Scientific Collaboration (LSC)

- ~400 scientists from 40 institutions and 8 countries

LIGO Organization



The Directorate & Advanced LIGO

Directorate--

- Executive Director (Jay); Deputy Director (Stan Whitcomb); LSC Spokesperson (Peter Saulson)

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

- Hands-on involvement in project
- Has had lots of big project experience
- This experience an important component of why he was recruited to LIGO

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--

- » Must share staff to carry out concurrent activities
- » When conflicting staff assignment requests, Directorate decides--- method to assure LIGO priorities govern staffing
- » Use subcontractors and temps as needed

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

- » 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)

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

LIGO Lab & LSC- a marriage that works

In past year, LSC has been integrated with LIGO Laboratory into a single entity--LIGO

- » LSC Spokesperson is part of LIGO Directorate
- » Effectively brings the LSC under the umbrella of the LIGO Lab.
- » Strengthens LIGO's functional organization and effectiveness without changing the internal structure of the LSC

LIGO Directorate an effective team; we work well together

- » e.g Peter on a tough assignment--Elba

Integration has gone well-- science program, operations, etc. are running smoothly

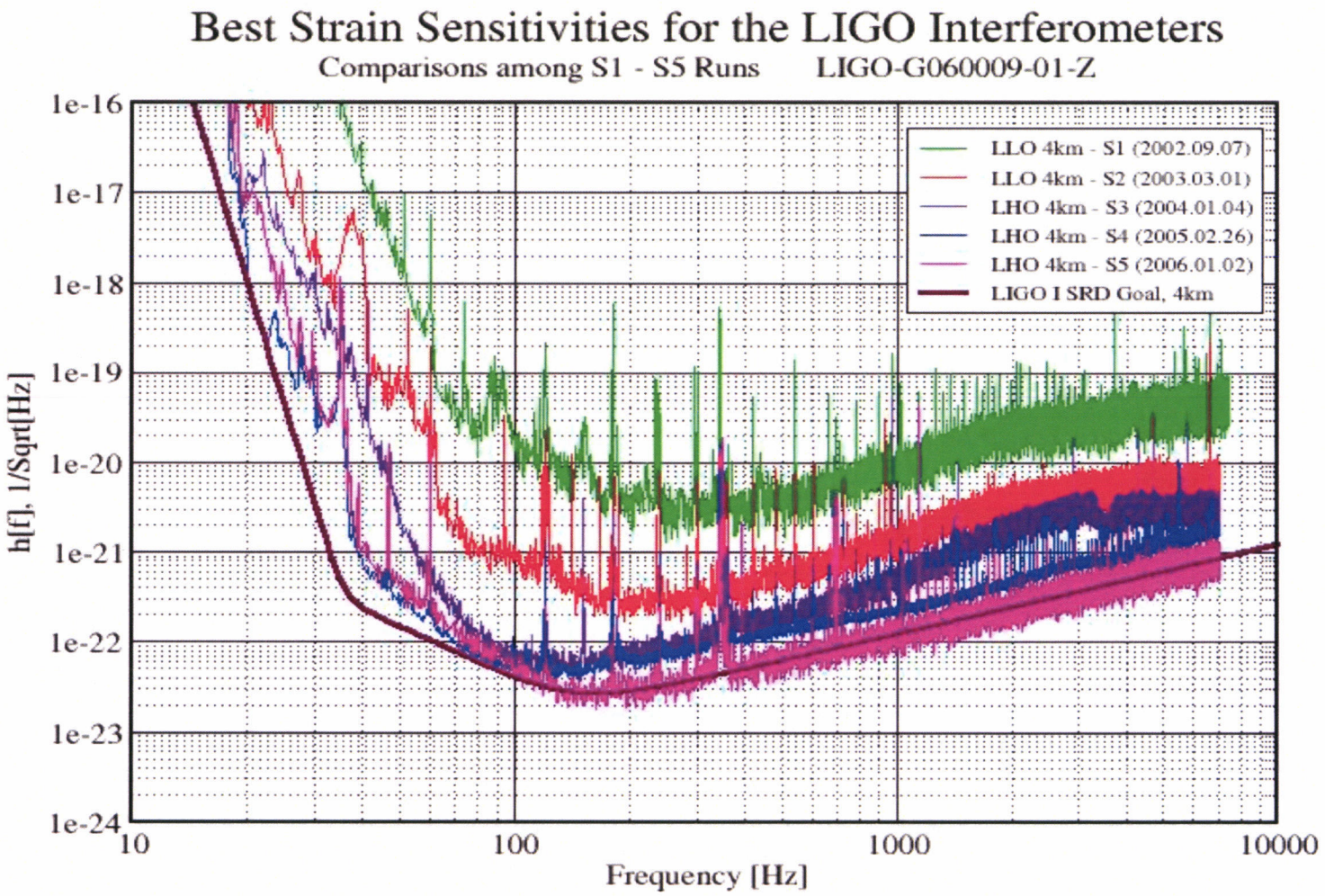
Current Status

LIGO has reached (and exceeded) strain sensitivity (10^{-21}) required by the Science Requirement Document (SRD) from 1995---a very big achievement!!

S5 Science run began Nov. 2005

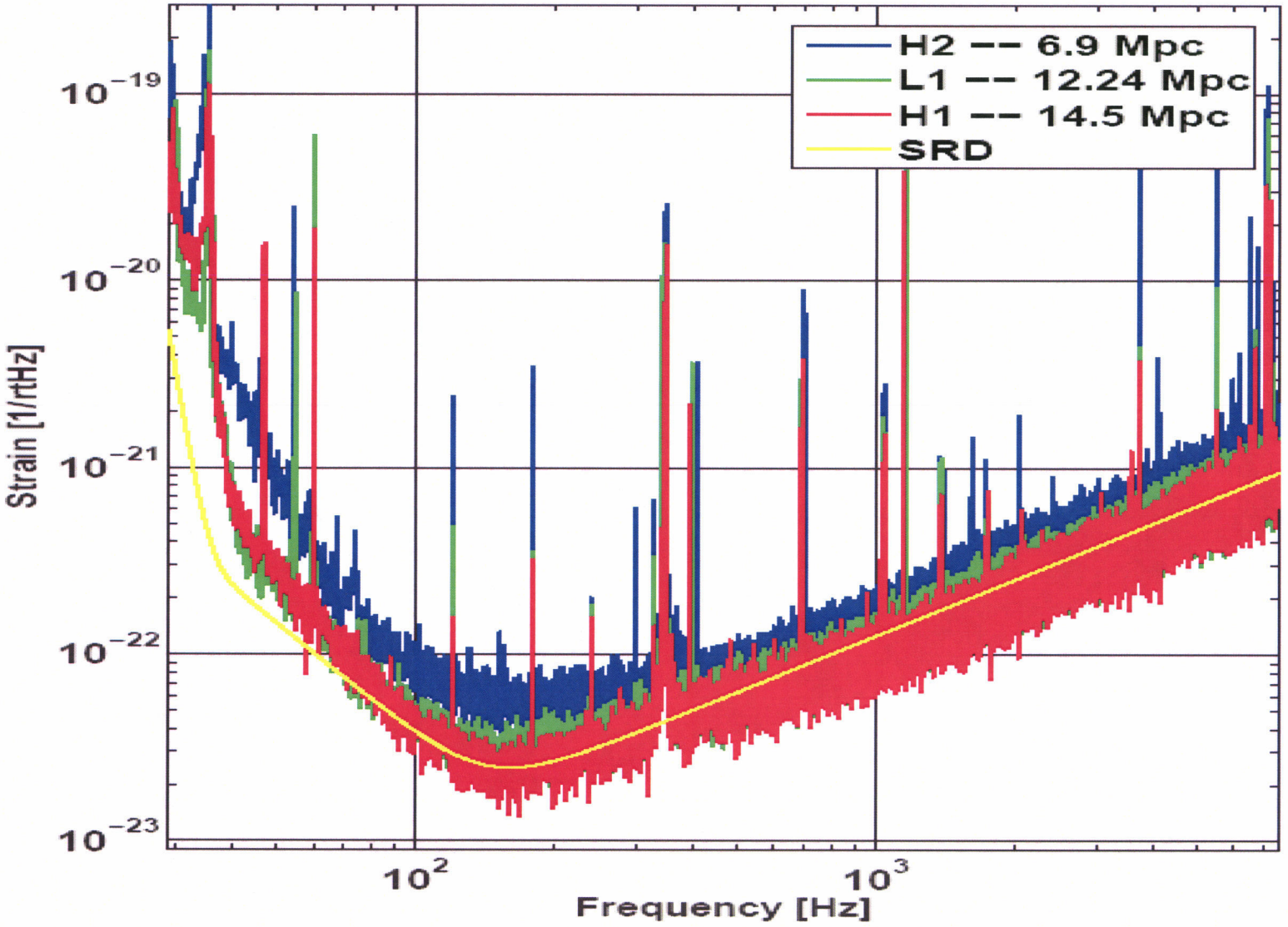
» goal --coincident operation at the SRD sensitivity accumulating 1 year equivalent amount of data

Huge improvement between S1 and S5
~3.5 years



Reached SRD sensitivity requirement

data- March 2006 before L1 sensitivity improvement



Internal performance metric for S5 run

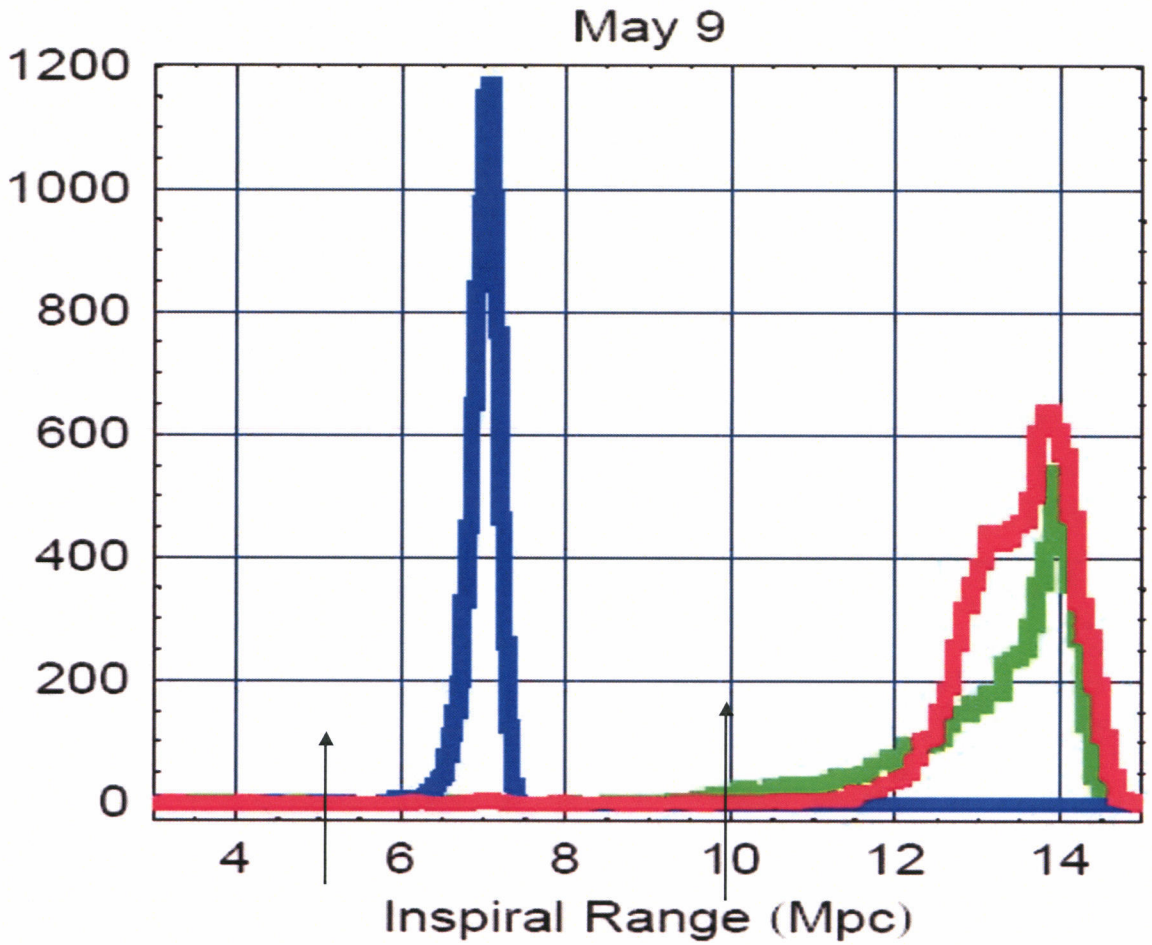
Range for 1.4 M_o NS-NS inspiral range with 8/1 S/N

- » 4 km interferometers (H1& L1)-- >10 Mpc
- » 2 km interferometer (H2)-- > 5 Mpc

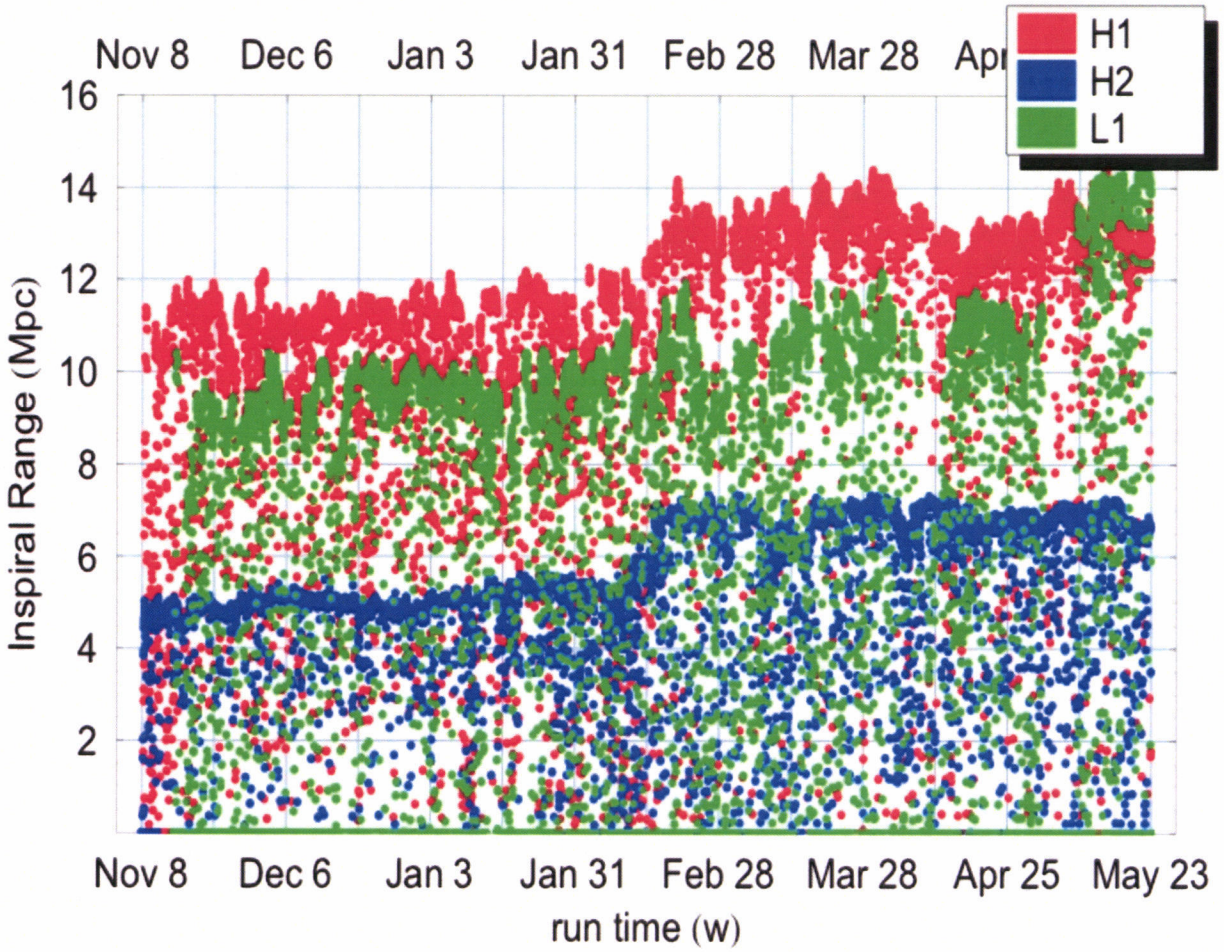
Have exceeded performance goals by 40%

- » 4 km interferometers (H1& L1)-- ~14 Mpc
- » 2 km interferometer (H2)-- ~7 Mpc

Range- typical of recent weeks



Range since S5 start



Duty cycle

- S5 Goal-- 85 % each interferometer; 70% Hanford-Livingston coincidence
  - » Since start of S5: H1~70%, H2~75%, L1~55%; LLO-LHO ~50%
- So far falling short; identifiable reasons and hopeful signs--
  - » Numbers include two 2 week commissioning breaks and 1 week downtime of L1 to fix hung mirror (~20% of run)
  - » Heavy construction of SEC at Livingston site
  - » Unusually heavy logging at Livingston & windy weather at Hanford
  - » Have been periods of robust operation--
    - – e.g. recently (5/20-21) 28 hours of continuous lock of L1; a record.
  - » Last week coincident duty cycle between Hanford and Livingston sites was 63.7%
- Focus of commissioning team is on more robust operation--
- Highest priority for operations crew--they take it very seriously

Science with LIGO is ongoing

11 papers on observational results submitted for publication in the past year (9 from S2, 2 from S3)

Analysis well along for S4 data

» Results from many groups reported at March LSC meeting and some papers in draft

Analysis for S5 data-- going well

Results from S4 & S5 presented at APS meeting in April 2006

Publications based on early S5 data being prepared

Modest Enhancements to 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--

e.g., for NS-NS inspirals- # galaxies~ (sensitivity)**3; factor of 2 reduction in strain noise ⇨~8x increase in number of galaxies LIGO can "see"

Approach- natural step towards Adv. LIGO

Use implementations of Advanced LIGO technologies & technique

Gain experience and reduce 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

Constraints- Hardware costs (≤$1.5M), time, manpower; being realistic in planning

LIGO Laboratory Operations

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

- » Includes adequate (not robust) support of full mission of LIGO Lab- capitalize on decades of effort/investment in LIGO
- » Operation of enhanced initial LIGO through 1st 2 years of project
- » R&D 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

See talk by Stan Whitcomb

Advanced LIGO-- NSF MREFC

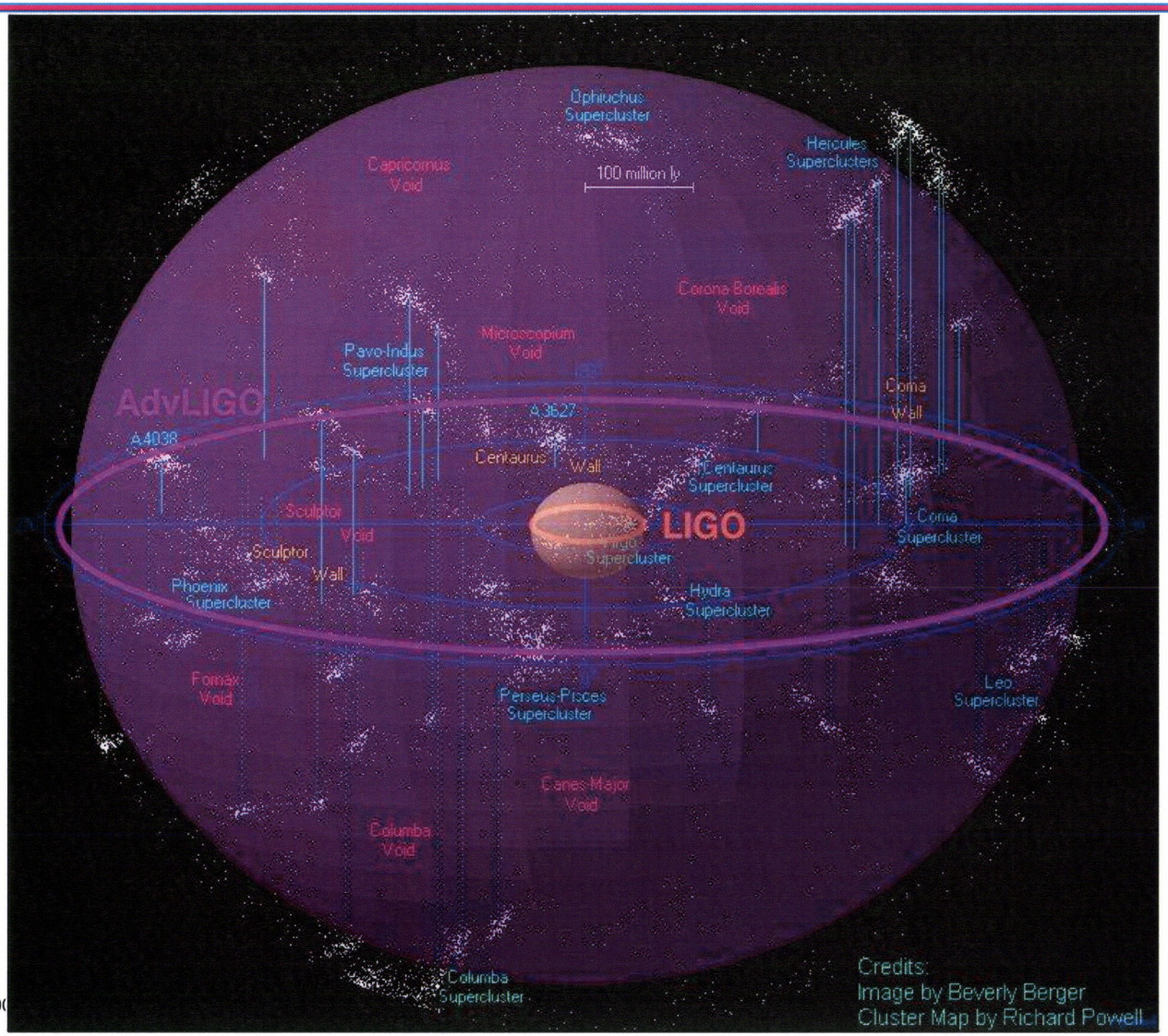
Goal-- increase sensitivity of LIGO by factor of ten

- Increases number of inspiral sources in range by factor of 1000!
- If source seen 1/10 years with initial LIGO, 1 every few days with Advanced LIGO
- Advanced LIGO will open the new field of GW astronomy and astrophysics

How does it happen?

- 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

Adv. LIGO Range for Binary Neutron Stars



Advanced LIGO-overview

Like optical observatory--

» Utilize infrastructure for decades, improve instrumentation as new technologies become available

Advanced LIGO--

» Reutilize buildings, vacuum system, beam tubes, environmental monitoring system and other expensive infrastructure from initial LIGO--

» Replace instrument components (laser, optics, seismic, etc.) to increase sensitivity and move seismic wall to lower frequencies

Management of Advanced LIGO

Under LIGO Laboratory umbrella; oversight and hands-on involvement by Directorate (major focus for Jay)

Strong experienced project team

- » Project leadership team experienced with projects, LIGO and relevant technology
  - – David Shoemaker- Project leader
  - – Carol Wilkinson-- Project manager
  - – Dennis Coyne-- System engineer
- » Experienced scientific/technical personnel from LIGO Lab (matrixed) and from LSC institutions

Project Advisory Panel (part of LIGO Lab. PAC)

- » chaired by M. Breidenbach (SLAC);
- » Jim Yeck has agreed to join

High level Scope/Cost/Schedule

Scope-- 3 improved interferometers, each 4 km long

Total cost (FY06$)-- $172M including 27% contingency

- » Compares well to estimate in 2003 proposal; 5.4 % above
- » With inflation total is ~$205M

Schedule- October 2007--August 2014 including 5 months schedule contingency

Ready for construction start in FY08 with strong technical basis for confidence

- » Experience with initial LIGO and high quality staff
- » Extensive R&D program

Solid cost estimate, schedule and risk analysis

Other things about project

Foreign contributions--- in-kind from experienced collaborators (capital partners; MOU)

- » Germany-- input laser (value ~$12M incl. development)
- » United Kingdom- Test mass suspensions and some tet mass optics (value ~$12M incl. development)
- » Funding for this is allocated; work in progress with prototypes tests underway
- » Well integrated into Adv. LIGO organization & project team

Plan "just in time" purchase of computing hardware for analysis of Advanced LIGO data

- » As late as possible-- after acceptance of interferometers
- » System testing during project to confirm requirements met.

About this review

Still ~1 1/2 years to construction start-- not all i's dotted and t's crossed. But solid cost, schedule, PEP, risk analysis, technical basis, staffing plan and management team (hope you agree).

In run-up to start, there may be some changes--

- » Opportunities for value engineering, cost savings, simplification and risk reduction (e.g. soft seismic isolation system for HAM chambers)

Expect this committee will validate our baseline scope/cost/schedule/funding profile and risk assessment

We will value any advice to improve the likelihood of success. Thanks