LIGO

Status of LIGO

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LISA Symposium

13 July 2004

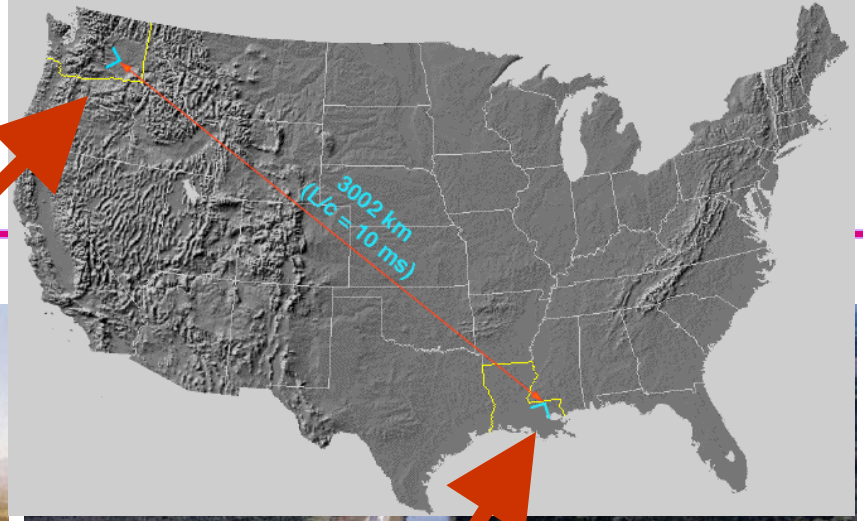
Ground-based interferometric gravitational-wave detectors

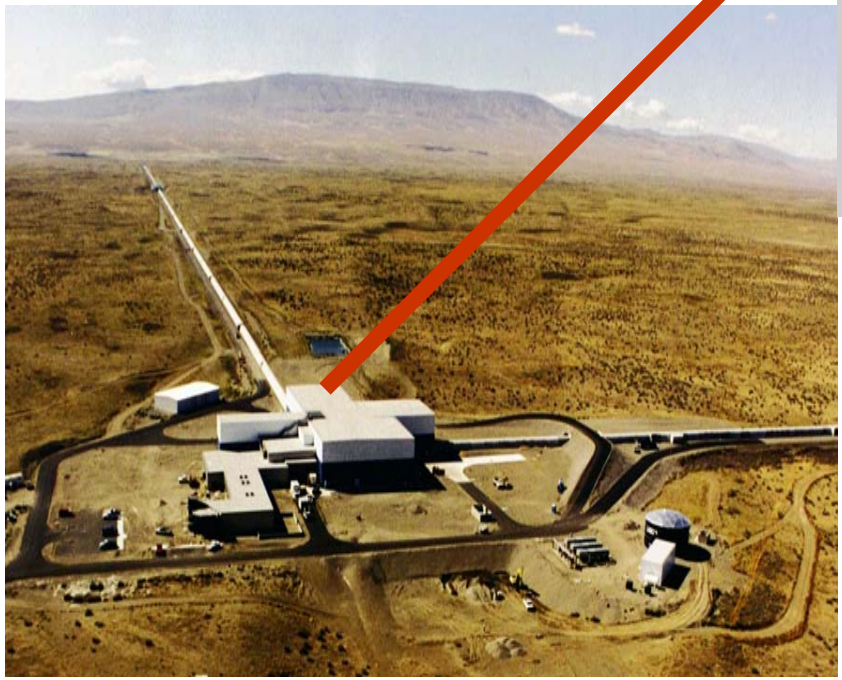
- Search for GWs above lower frequency limit imposed by gravity gradients
  - » Might go as low as 1 Hz ultimately; ~10…100 Hz present limit
  - » Direct seismic noise a practical limit now, should not be later
- Antennas short compared to GW wavelengths
  - » For f_{GW} = 100 Hz, $\lambda_{GW} = 3 \times 10^6$ m
  - » The longer the instrument, the larger the signal w.r.t. gravity gradients, thermal excitation of mirror surfaces, photon sensing noise
  - » Light must be in a good vacuum to avoid path length fluctuations

    → Length 0.3 < *L* < 4 km (order of 1-10 μLISA)
- Some nice advantages of being earthbound –
  - » Weight, size, power, bandwidth not limited!
  - » High power lasers, large mirrors and suspensions, complicated optical systems, high data rates all possible and employed to advantage
  - » Incremental improvements an integral part of the plan

  …also nice to be able to fix broken (or ill-conceived) parts…

LIGO Observatory Facilities





LIGO Hanford Observatory [LHO]

26 km north of Richland, WA

2 km + 4 km interferometers in same vacuum envelope

LIGO Livingston Observatory [LLO]

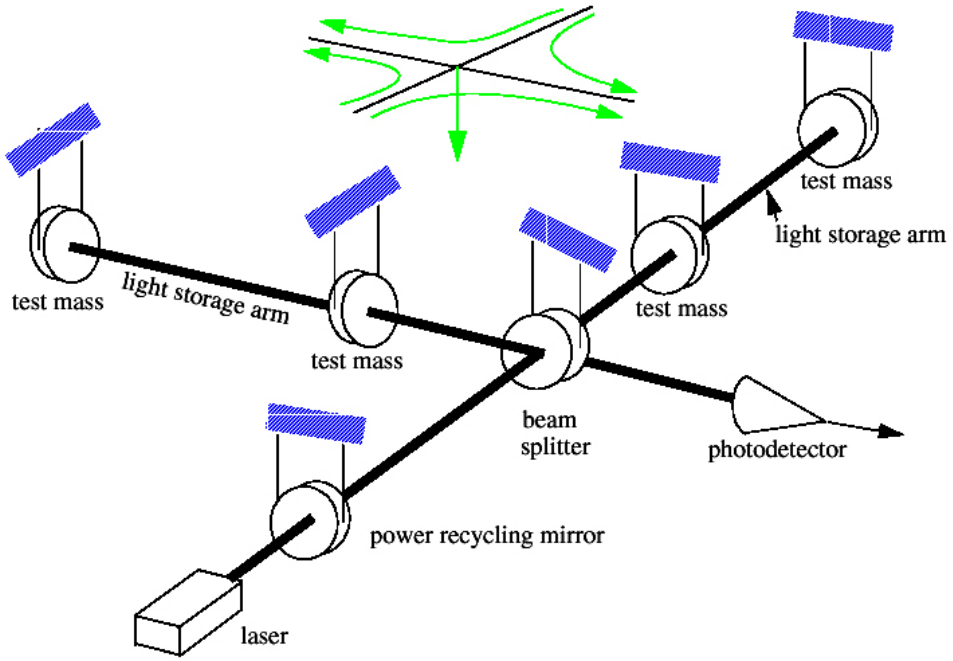
42 km east of Baton Rouge, LA

Single 4 km interferometer

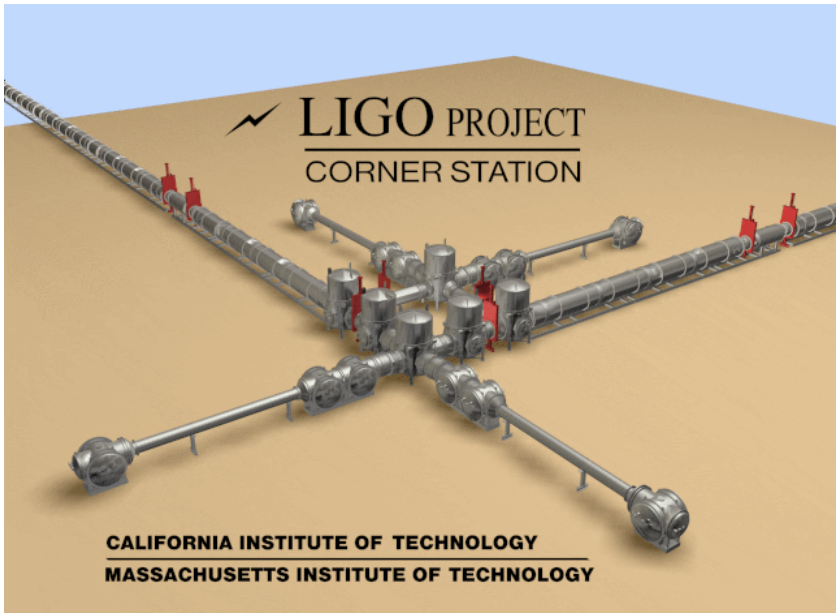
Two separated observatories for detection confidence, directional information

LIGO Interferometer

- Michelson with light stored in 4km arm Fabry-Perot cavities
- 10W laser, power recycling mirror reduces statistical uncertainty of fringe readout (10^{-10})
- Mirrors suspended freely, isolated from ground noise $f > 40$ Hz
- System under servo-control – in length, angle, frequency, intensity, radii of curvature, orthogonal RF phase…
- Sensitivity of h = dL/L ~ 10^{-21}, 1 kHz BW



- Interferometer enclosed in vacuum envelope
  - » Infrastructure foreseen to accommodate future instruments; ~20 year lifetime



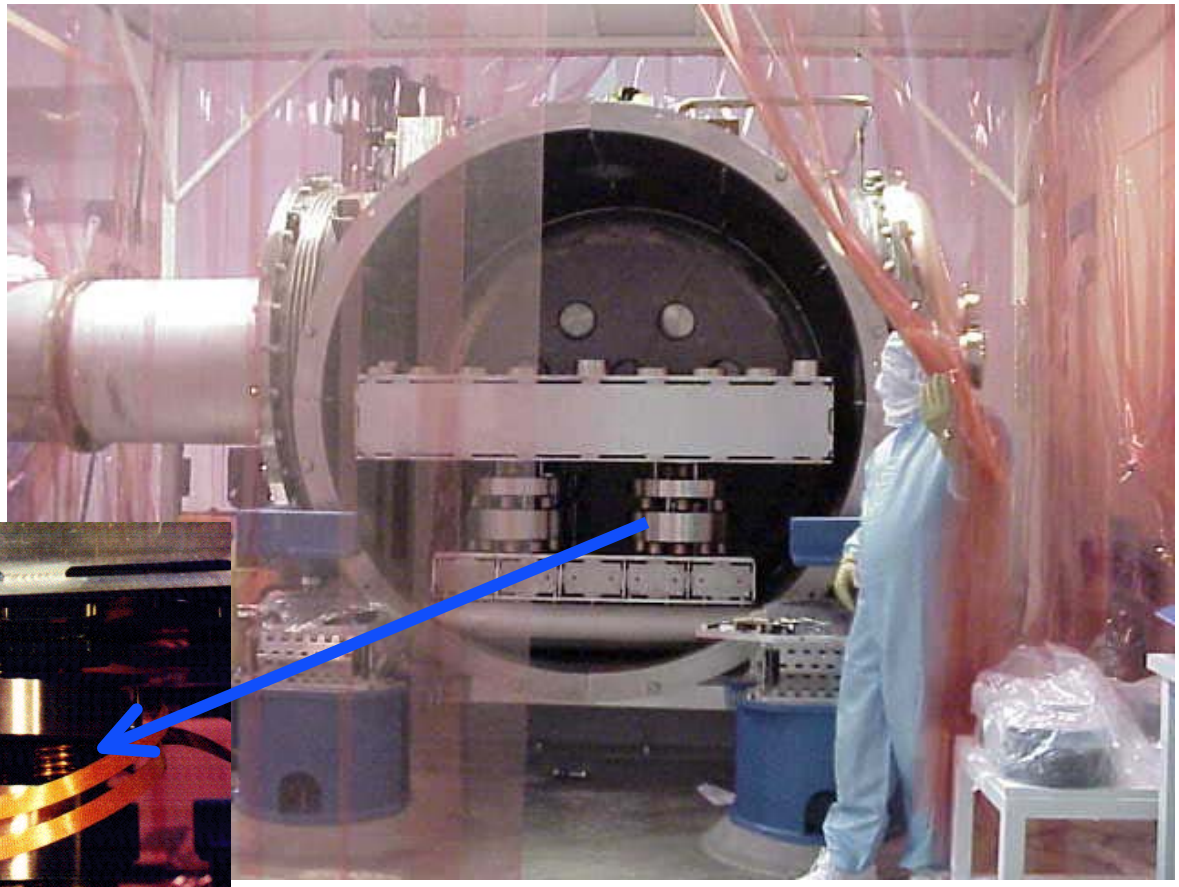
LIGO Beam Tube

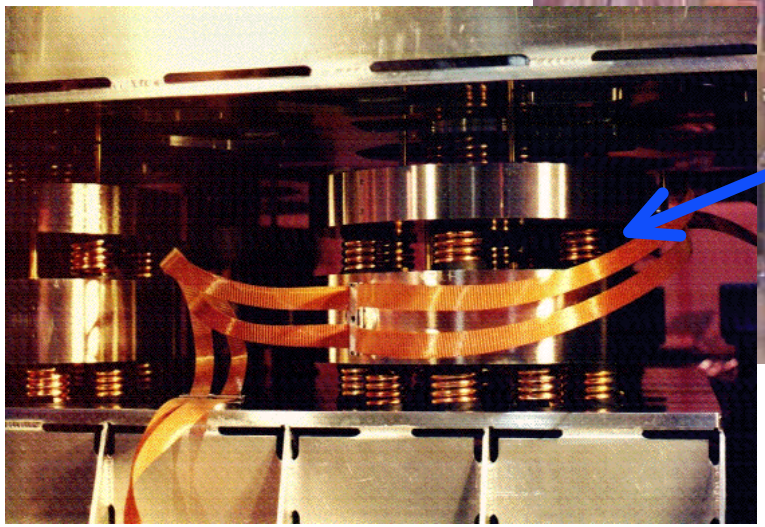
1.2 m diameter - 3mm stainless
50 km of tubing – no leaks!

Vacuum Equipment

Seismic Isolation System

Tubular coil springs with internal constrained-layer damping, layered with reaction masses

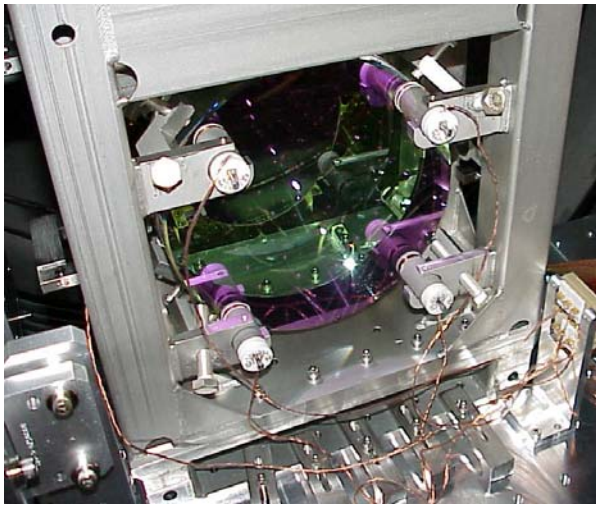




Isolation stack in chamber

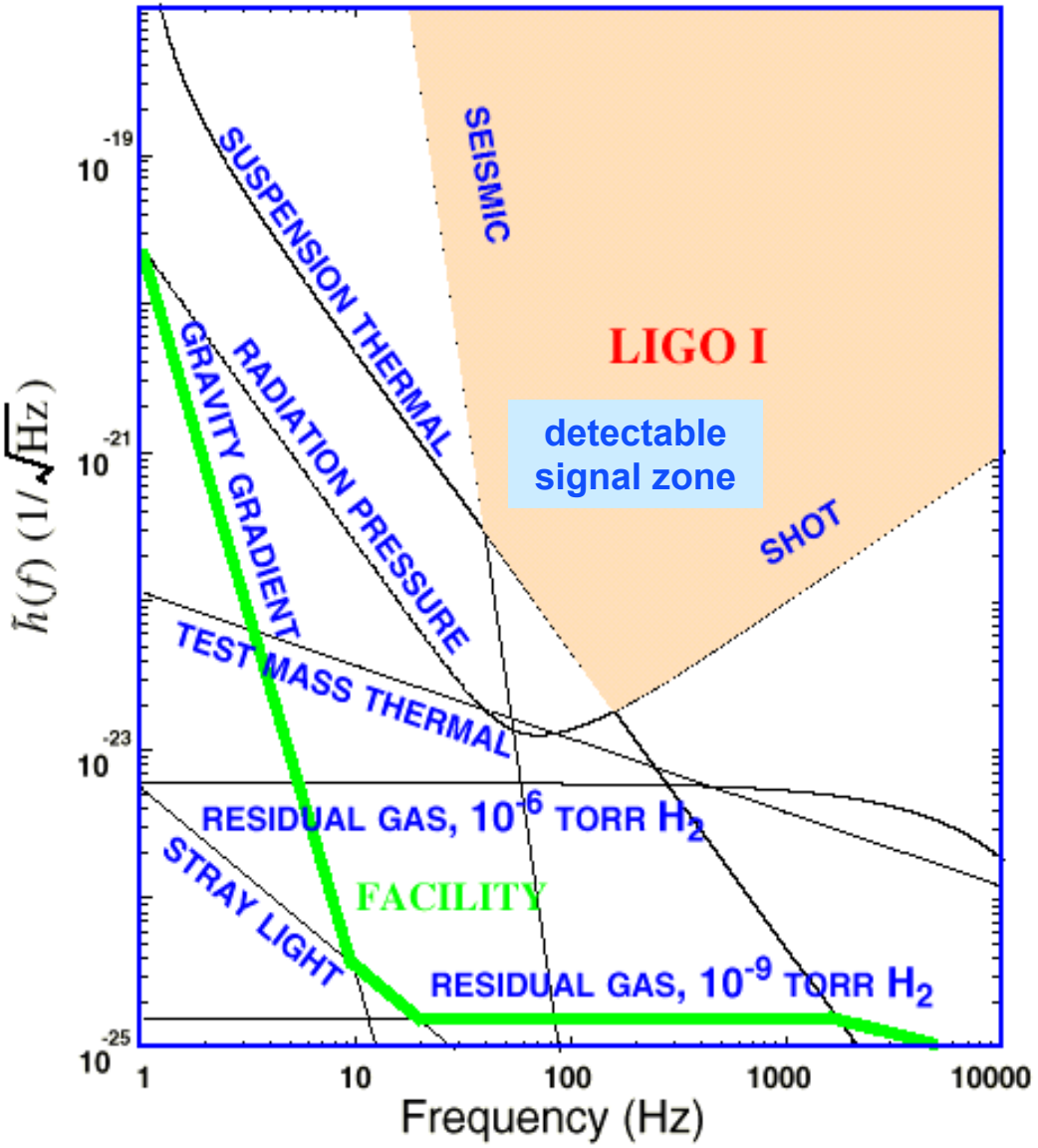
LIGO

Core Optics Suspensions
installation and alignment

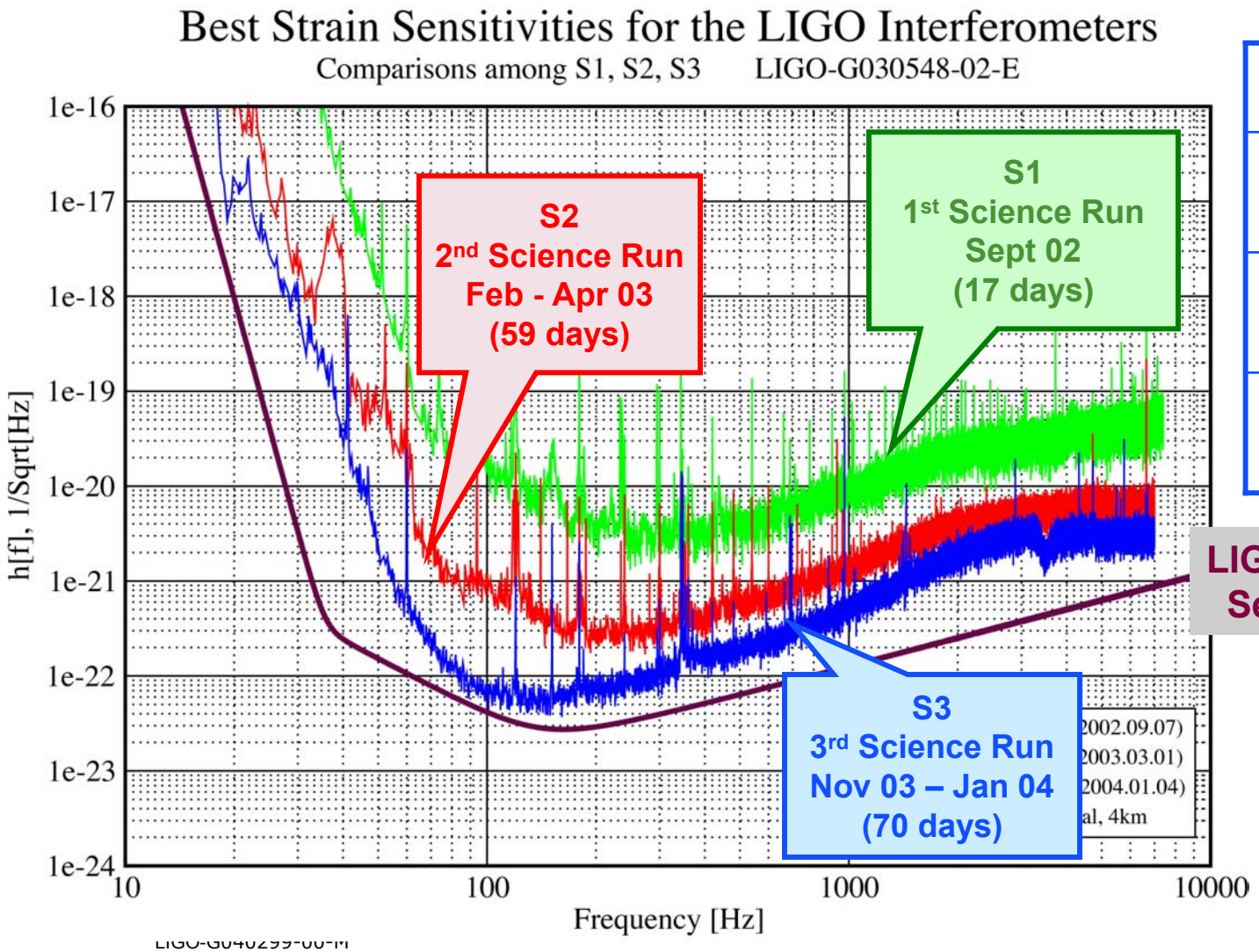


Interferometers: design noise budget

- Calculated practical and fundamental limits determined design goal:
  - **seismic** at low frequencies
  - **thermal** at mid frequencies
  - **shot noise** at high frequencies
- Other "technical" noise not allowed above 1/10 of these
- Facility limits much lower to allow improvement as technology matures



LIGO sensitivity evolution

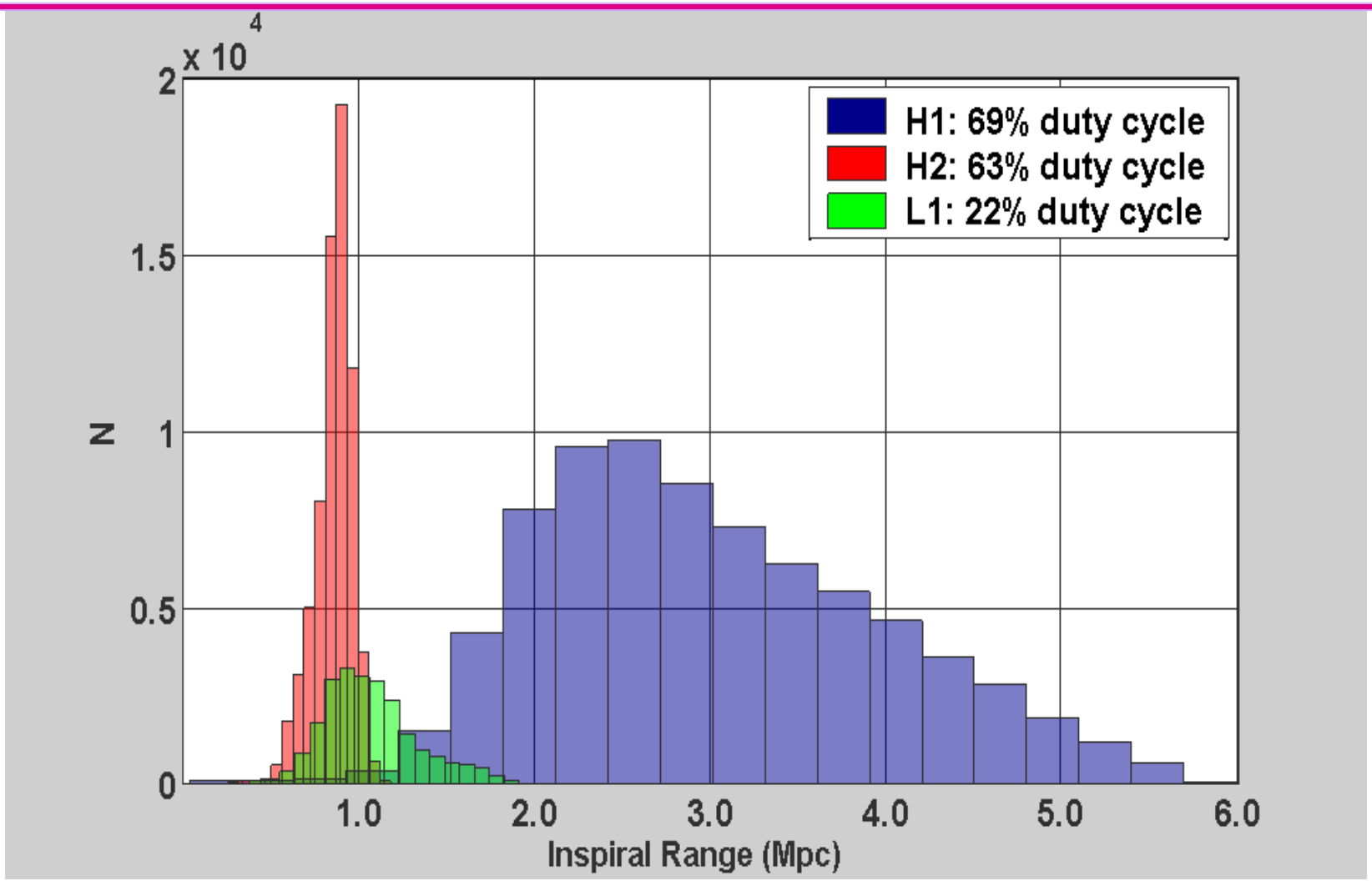


S3 Duty Cycle	
Hanford 4km	69%
Hanford 2km	63%
Livingston 4 km	22%*

*Limited by high ground noise—upgrade currently underway

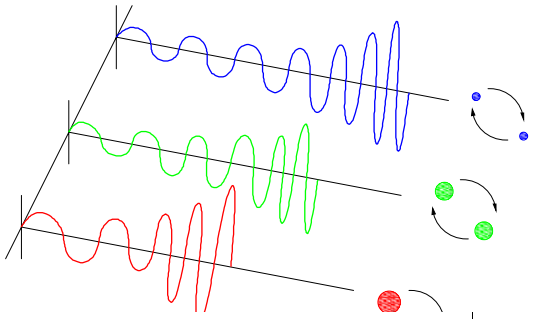
S3 range and stability

NS-NS binary inspiral range



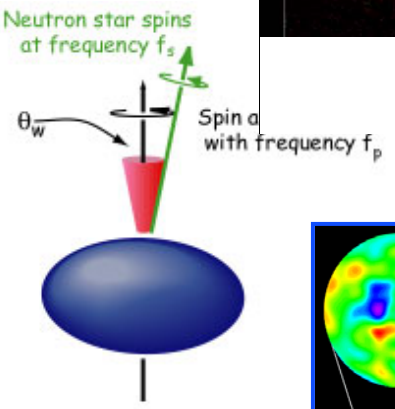
Astrophysical Searches with LIGO Data

- Compact binary inspiral: *"chirps"*
  - » NS-NS waveforms -- good predictions
  - » BH-BH (<10 M_s) – would like better models
  - » search technique: matched templates

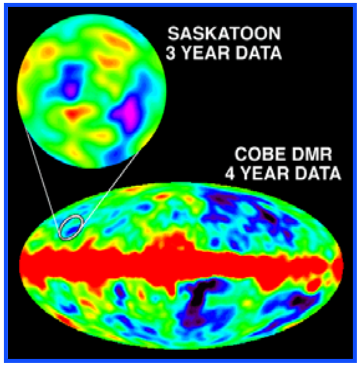


- Supernovae / GRBs/Strings: *"bursts"*
  - » burst signals in coincidence, maybe with signals in electromagnetic radiation, neutrinos
  - » prompt alarm (~ one hour) with neutrino detectors

- Pulsars in our galaxy: *"periodic"*
  - » search for observed neutron stars (frequency, doppler shift)
  - » all sky search (computing challenge)
  - » r-modes



- Cosmological Signals *"stochastic background"*



Astrophysics results

LIGO Science Collaboration (~370 authors, 40 institutions):

Papers based on S1 data, Phys Rev D:

- "*Setting upper limits on the strength of periodic gravitational waves using the first science data from the GEO600 and LIGO detectors*"
- "*Analysis of LIGO data for gravitational waves from binary neutron stars*"
- "*First upper limits from LIGO on gravitational wave bursts*"
- "*Analysis of First LIGO Science Data for Stochastic Gravitational Waves*"

Papers based on S2 data nearing maturity:

- GRB030329 – **No signals seen in coincidence with HETE, few x 10^{-21} / rHz**
- "All" known pulsars > ~50Hz - **Best 95% CL preliminary upper limit on h0:**
  - » **few x 10^{-24} (B0021-72L)**
- Binary neutron star inpirals - **R90% < 50 inspirals per year per "milky-way-equivalent-galaxy"**
- **Stochastic background upper limit of $\Omega < 10^{-2}$**

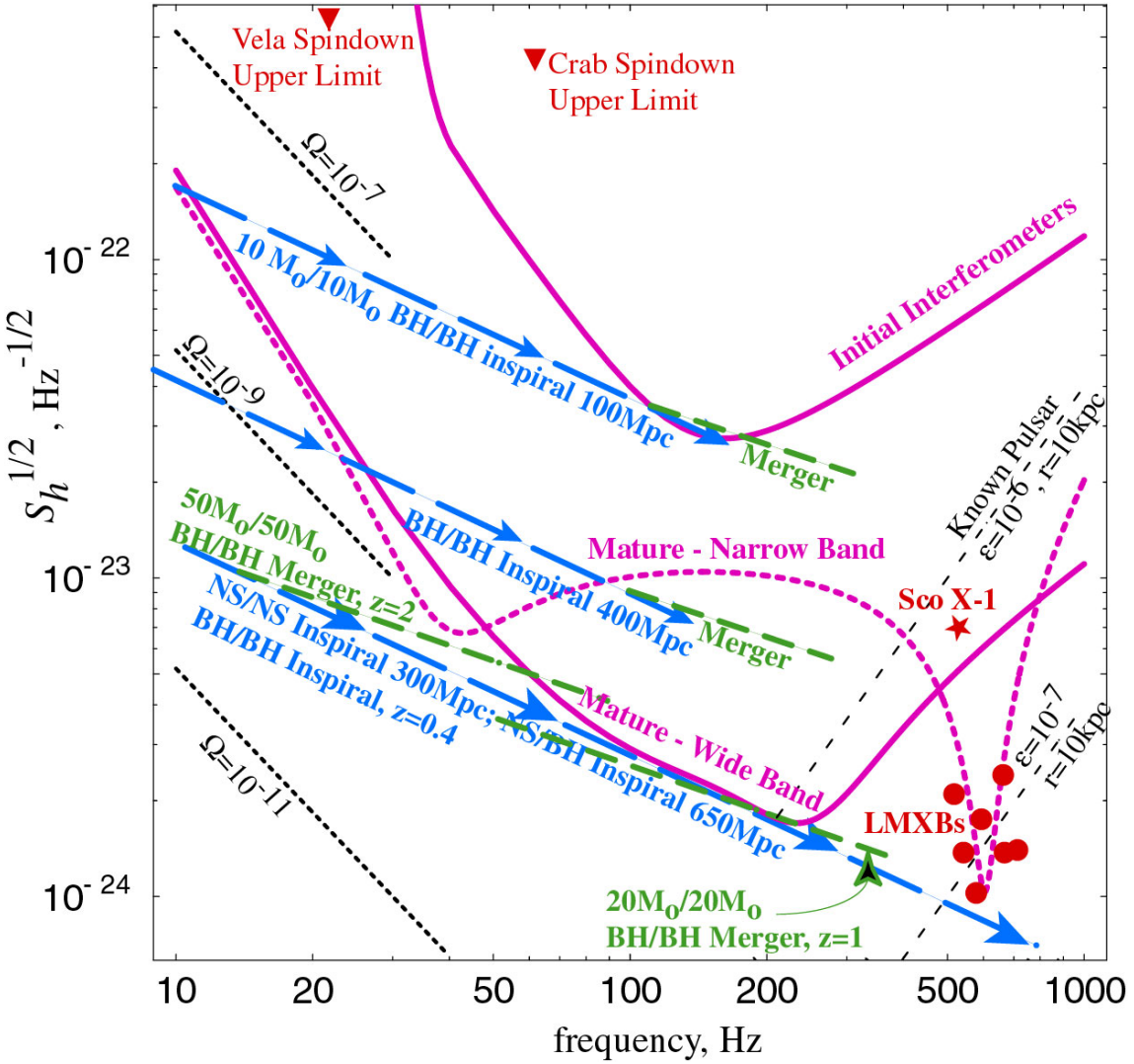
S3 data better yet – Binary inspirals distance as great as 6.8 Mpc (H1)

Observation Plan:

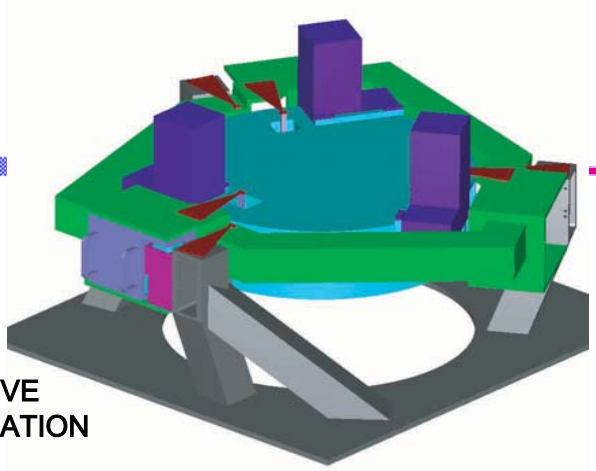
- Complete commissioning, then Initial LIGO science from 2005-2007
  - » At least one year integrated observation, also networking with other detectors
- Then…

Advanced LIGO

- Factor 10 better amplitude sensitivity
  - » (Reach)^3 = rate
  - » Several hours of search equivalent to initial LIGO
- Factor 4 lower frequency
- NS Binaries: for three interferometers,
  - » Initial LIGO: ~20 Mpc
  - » Adv LIGO: ~350 Mpc
- BH Binaries:
  - » Initial LIGO: 10 M_o, 100 Mpc
  - » Adv LIGO : 50 M_o, z=2
- Stochastic background:
  - » Initial LIGO: ~3e-6
  - » Adv LIGO ~3e-9



Advanced LIGO



40 KG SAPPHIRE
TEST MASSES

INPUT MODE
CLEANER

QUAD SILICA
SUSPENSION

ACTIVE
THERMAL
CORRECTION

T=0.5%

180 W LASER,
MODULATION SYSTEM

LASER

MOD.

125W

830KW

BS

PRM
T~6%

ITM

ETM

SRM

T=5%

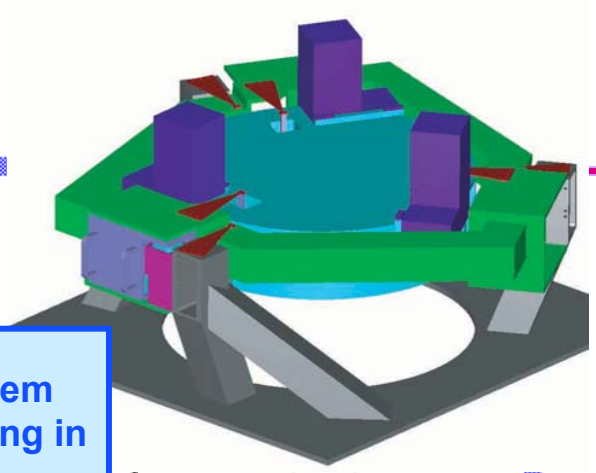
OUTPUT MODE
CLEANER

PD

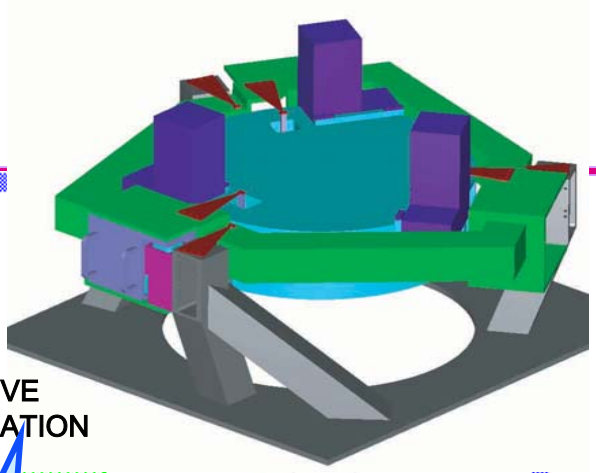
GW READOUT

PRM Power Recycling Mirror
BS Beam Splitter
ITM Input Test Mass
ETM End Test Mass
SRM Signal Recycling Mirror
PD Photodiode

Advanced LIGO



Advanced LIGO



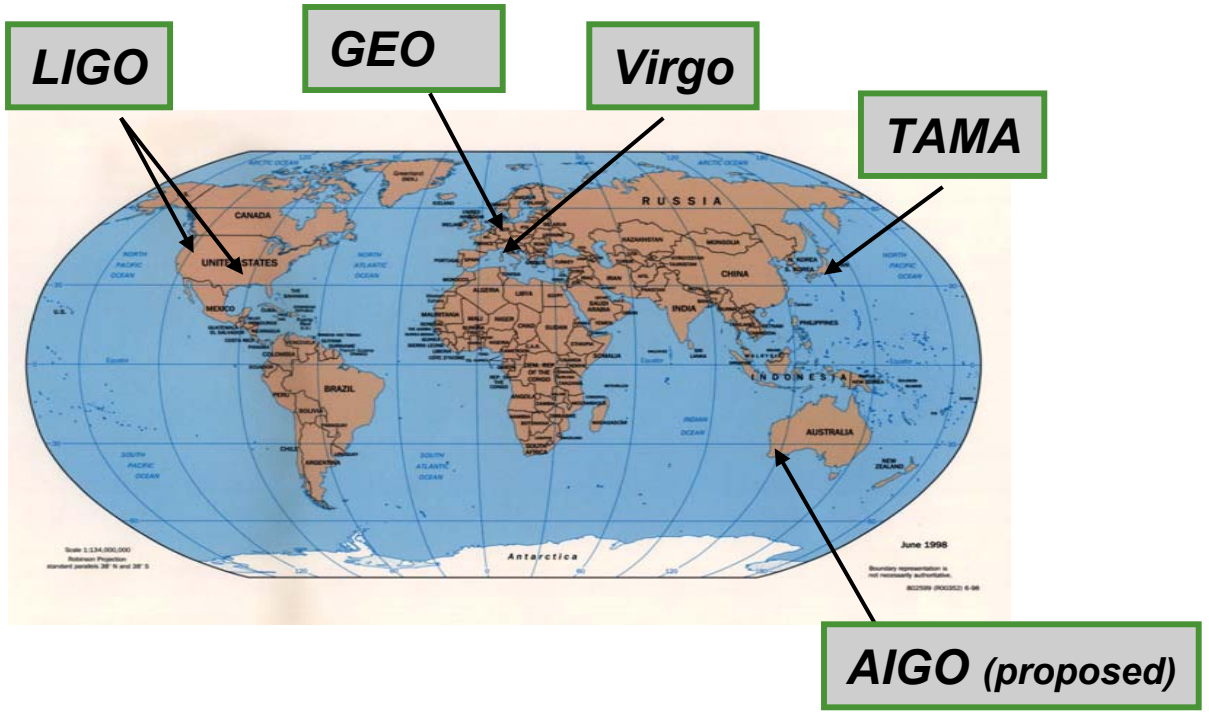
LIGO Scientific Collaboration

- Approximately 400 persons, 40 institutions
- LIGO, GEO, ALLEGRO instruments
- Commissioning
- Data analysis
- R&D toward future instruments
- Growing relationships with Virgo, TAMA, ACIGA, resonant bar community

Network of ground-based interferometers

The three LIGO and the GEO interferometers are part of a forming Global Network.

Multiple signal detections will increase detection confidence and provide better precision on source locations and wave polarizations



The End

- LIGO construction complete and expect instruments to be near design sensitivity by year's end
- First results are published, second results in preparation, third run ready for analysis
- 2005 will bring first long duration (~6 month) Science Run
- Advanced LIGO should be a major step toward gravitational astronomy, presently under consideration by NSF for funding in 2007
- Plan to be well into observation in 2012 – a good complement to LISA.

….and the Beginning