Status of LIGO

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LISA Symposium

13 July 2004

Ground-based interferometric gravitational-wave detectors

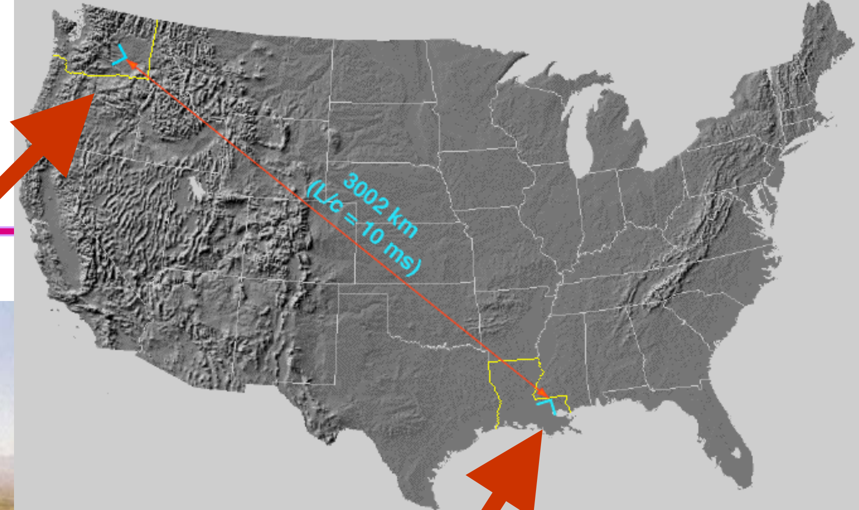
- Search for GWs above lower frequency limit imposed by gravity gradients
  - » Might go as low as 1 Hz ultimately; ~10…100 Hz present limit
  - » Direct seismic noise a practical limit now, should not be later
- Antennas short compared to GW wavelengths
  - » For f_{GW} = 100 Hz, $\lambda_{GW} = 3x10^6$ 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

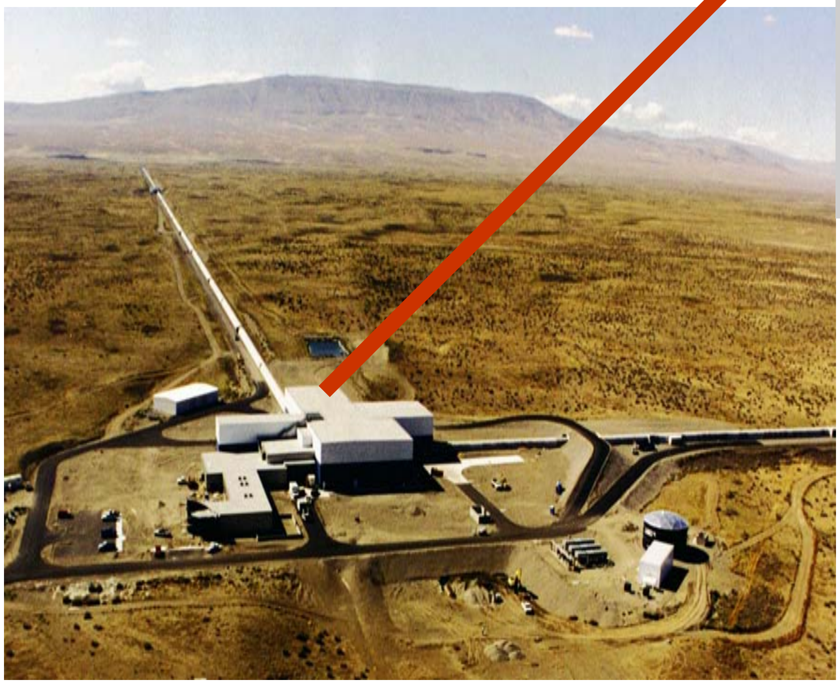
→ Length 0.3 < L < 4 km (order of 1-10 μLISA)

- 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]

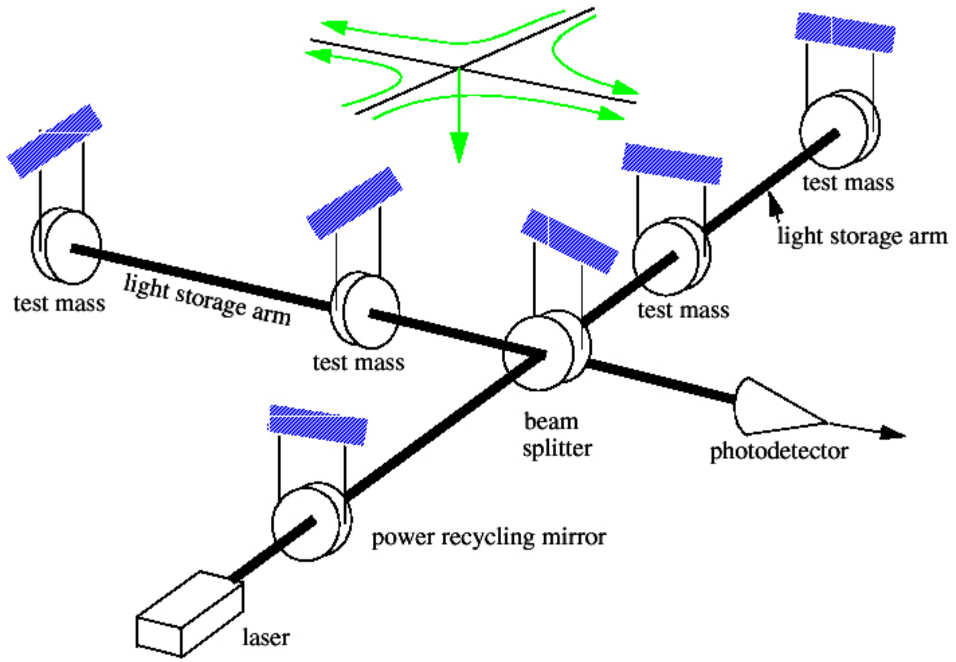
42 km east of Baton Rouge, LA

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



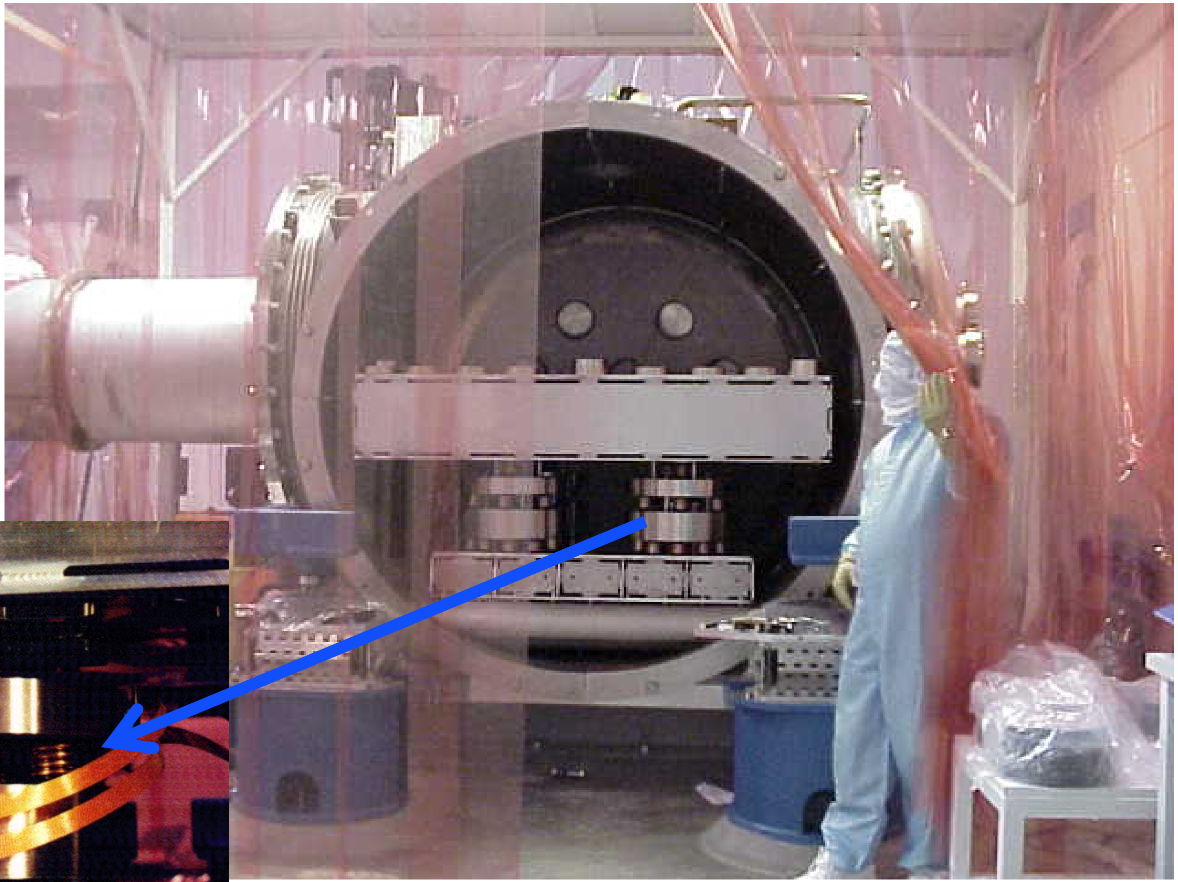
- Interferometer enclosed in vacuum envelope
  » Infrastructure foreseen to accommodate future instruments; ~20 year lifetime

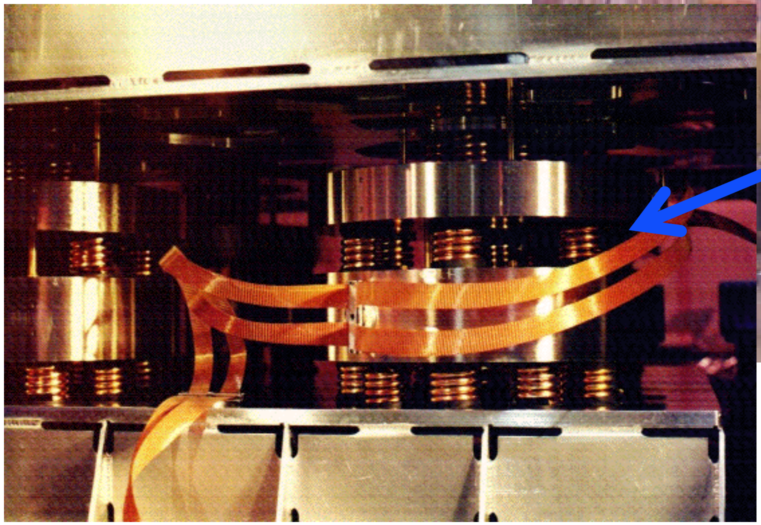
LIGO Beam Tube

Vacuum Equipment

Seismic Isolation System

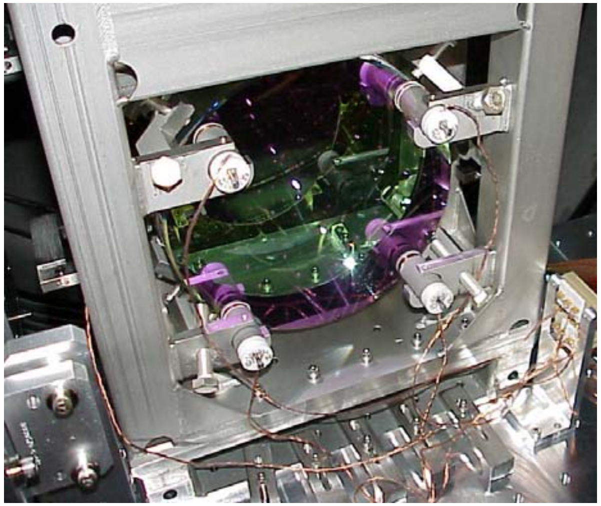
Tubular coil springs with internal constrained-layer damping, layered with reaction masses





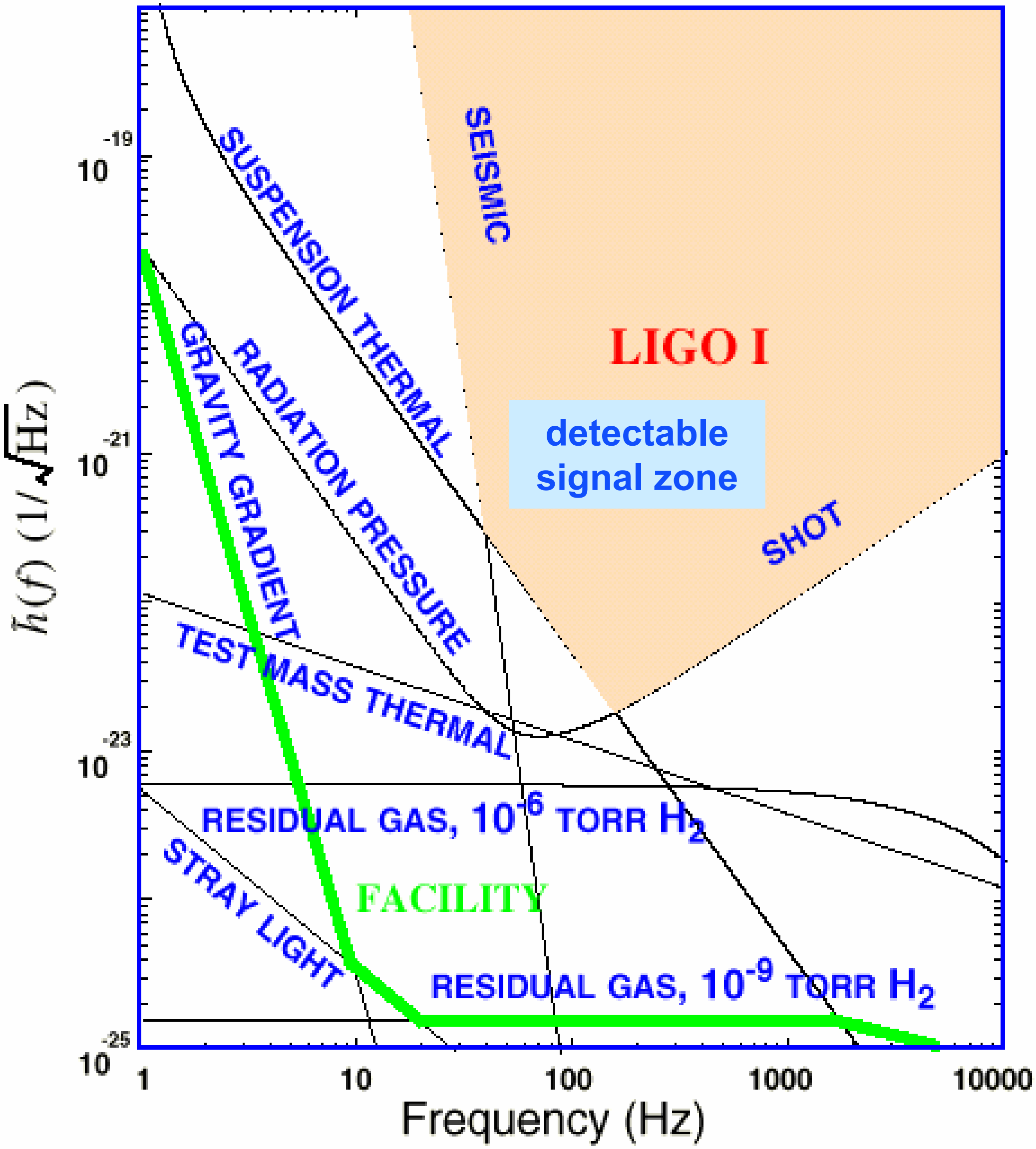
Isolation stack in chamber

Core Optics Suspensions
installation and alignment

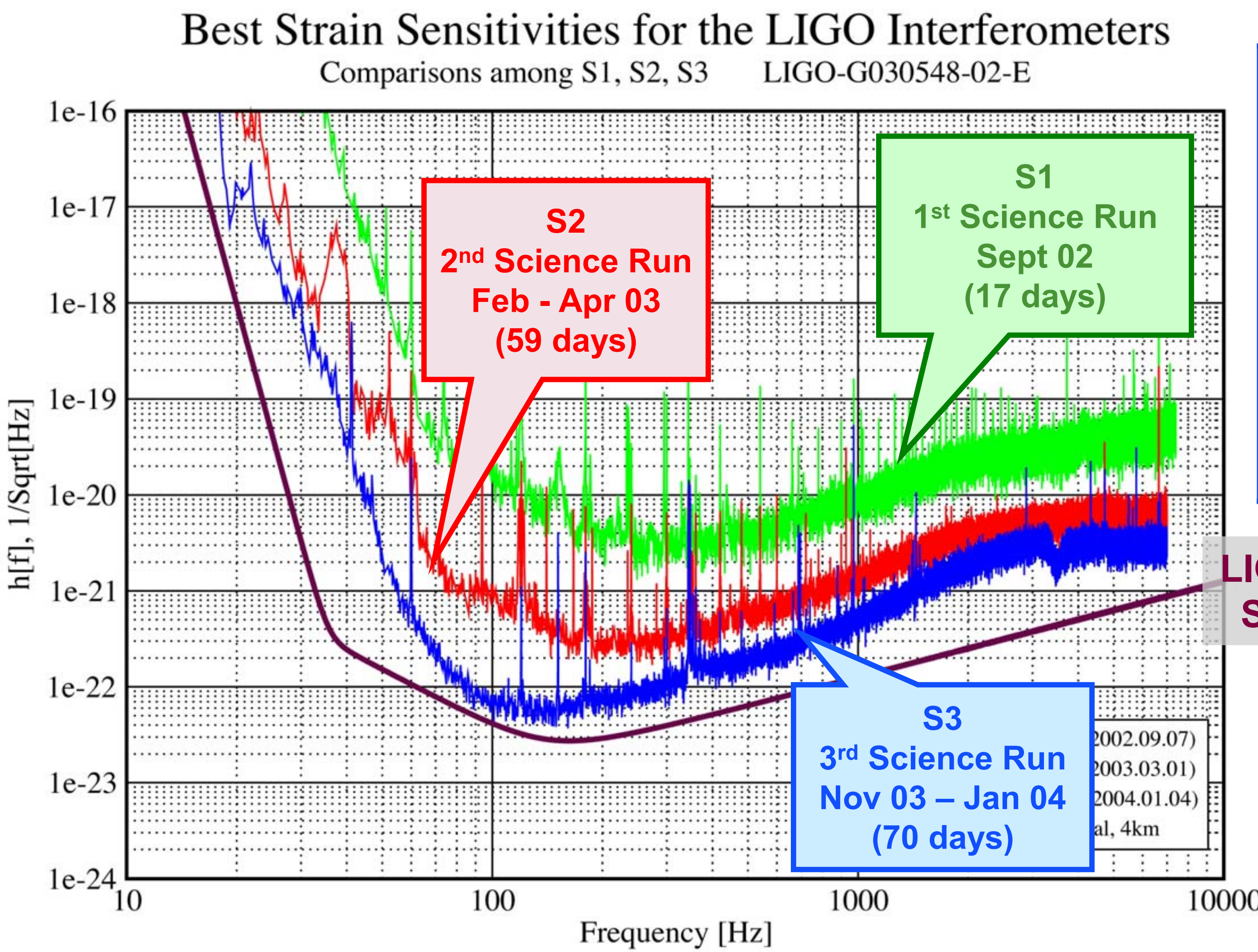


Interferometers: design noise budget

- 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

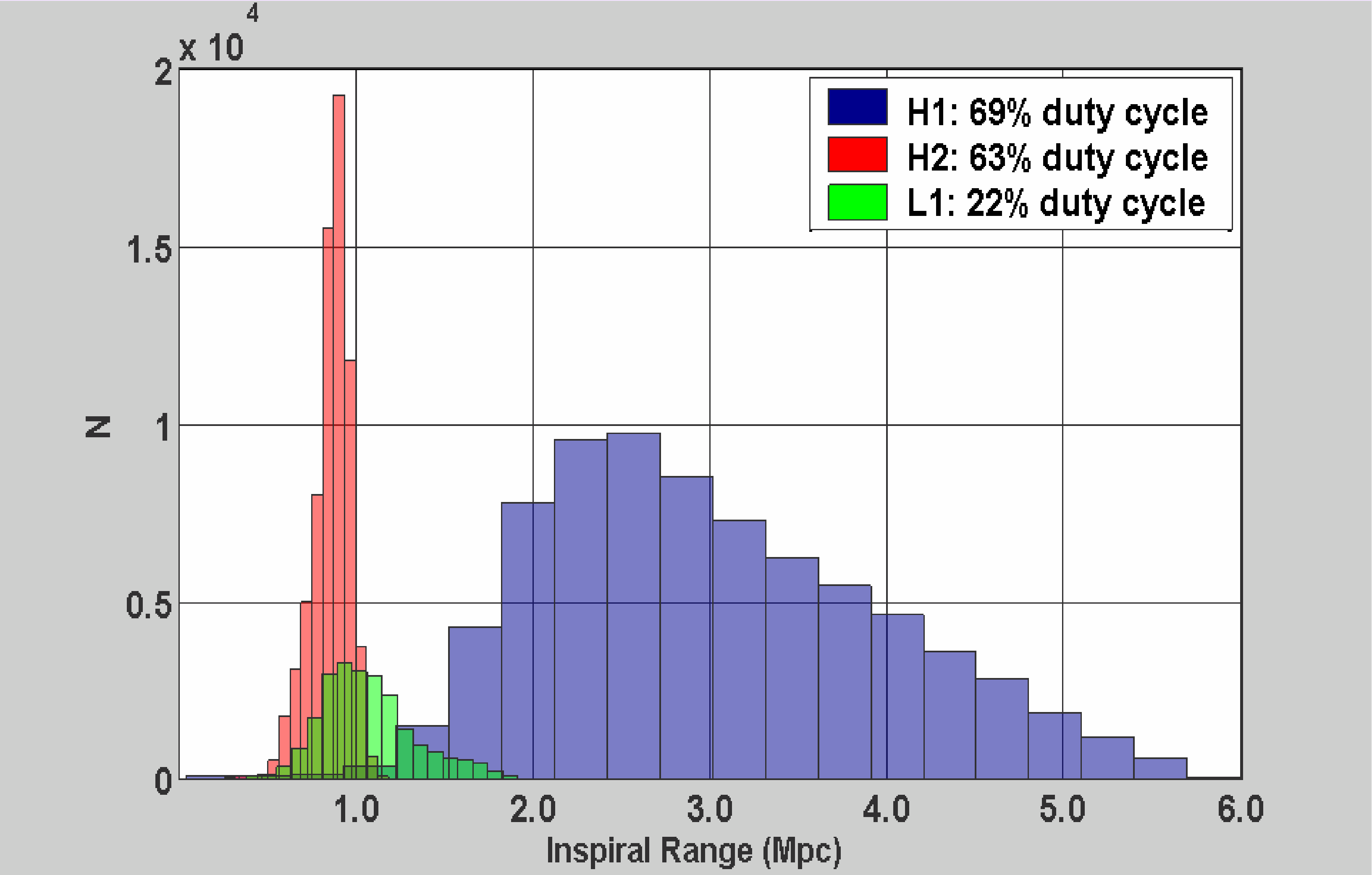


S3 Duty Cycle	
Hanford 4km	69%
Hanford 2km	63%
Livingston 4 km	22%*

*Limited by high ground noise—upgrade currently underway

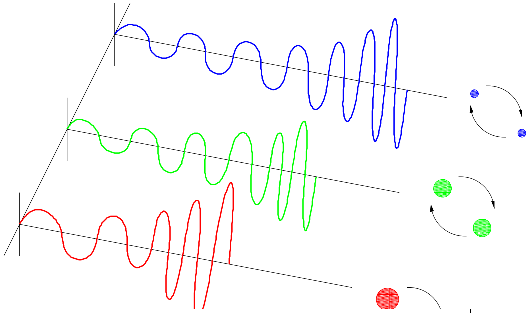
S3 range and stability

NS-NS binary inspiral range



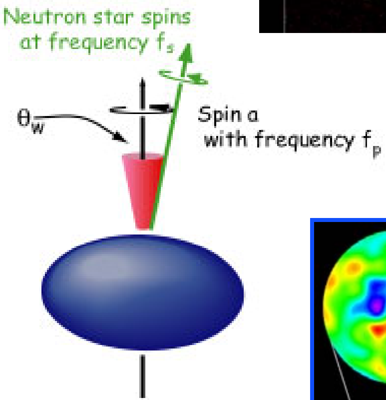
Astrophysical Searches with LIGO Data

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

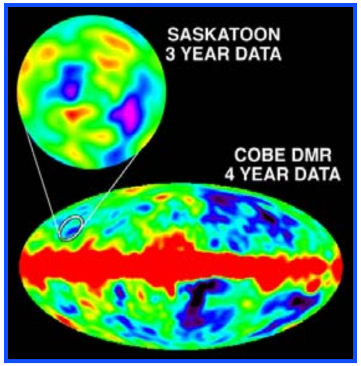


- Supernovae / GRBs/Strings: *"bursts"*
  - » burst signals in coincidence, maybe with signals in electromagnetic radiation, neutrinos
  - » prompt alarm (~ one hour) with neutrino detectors

- 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 $\Omega < 10^{-2}$**

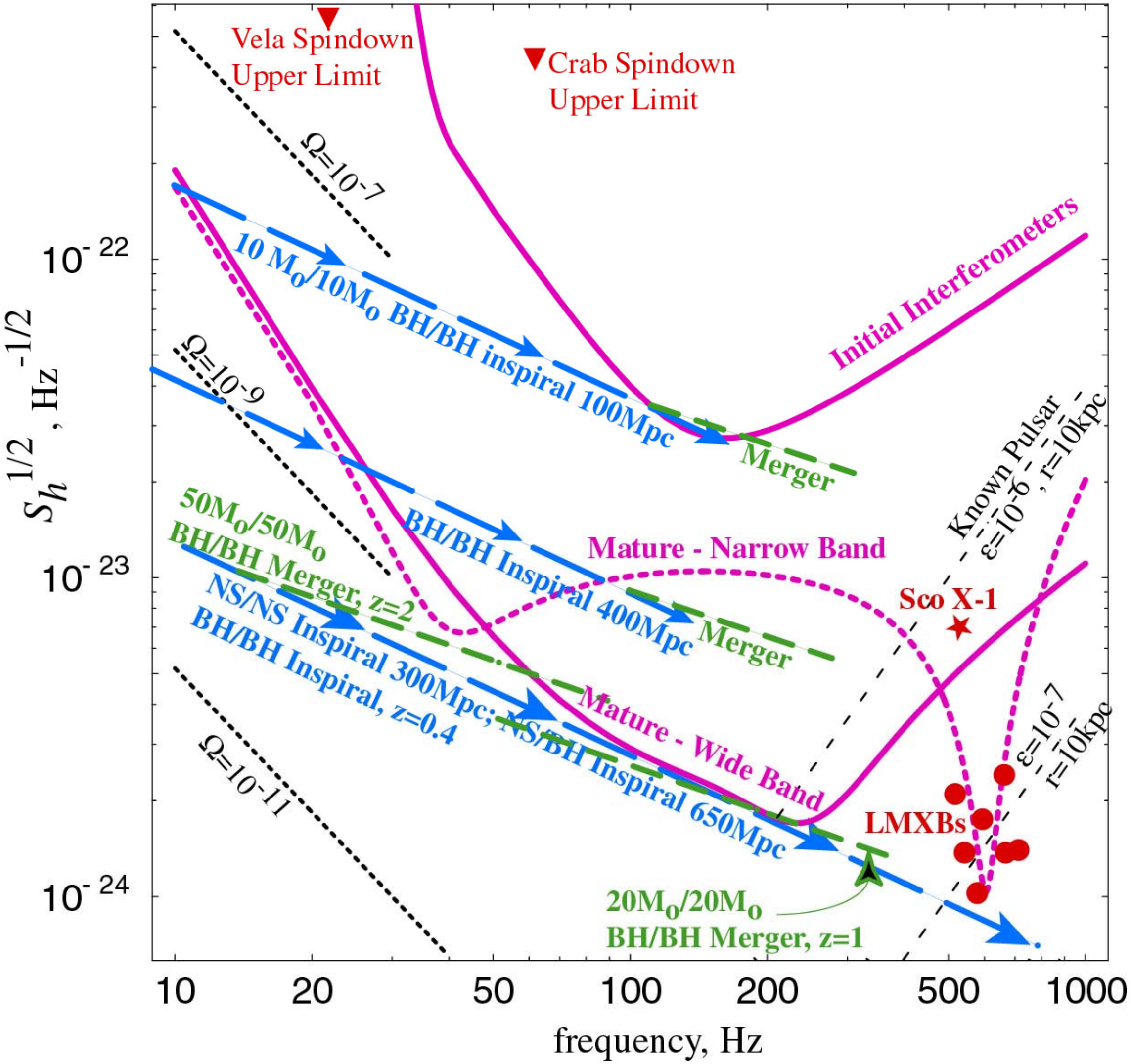
S3 data better yet – Binary inspirals distance as great as 6.8 Mpc (H1)

Observation Plan:

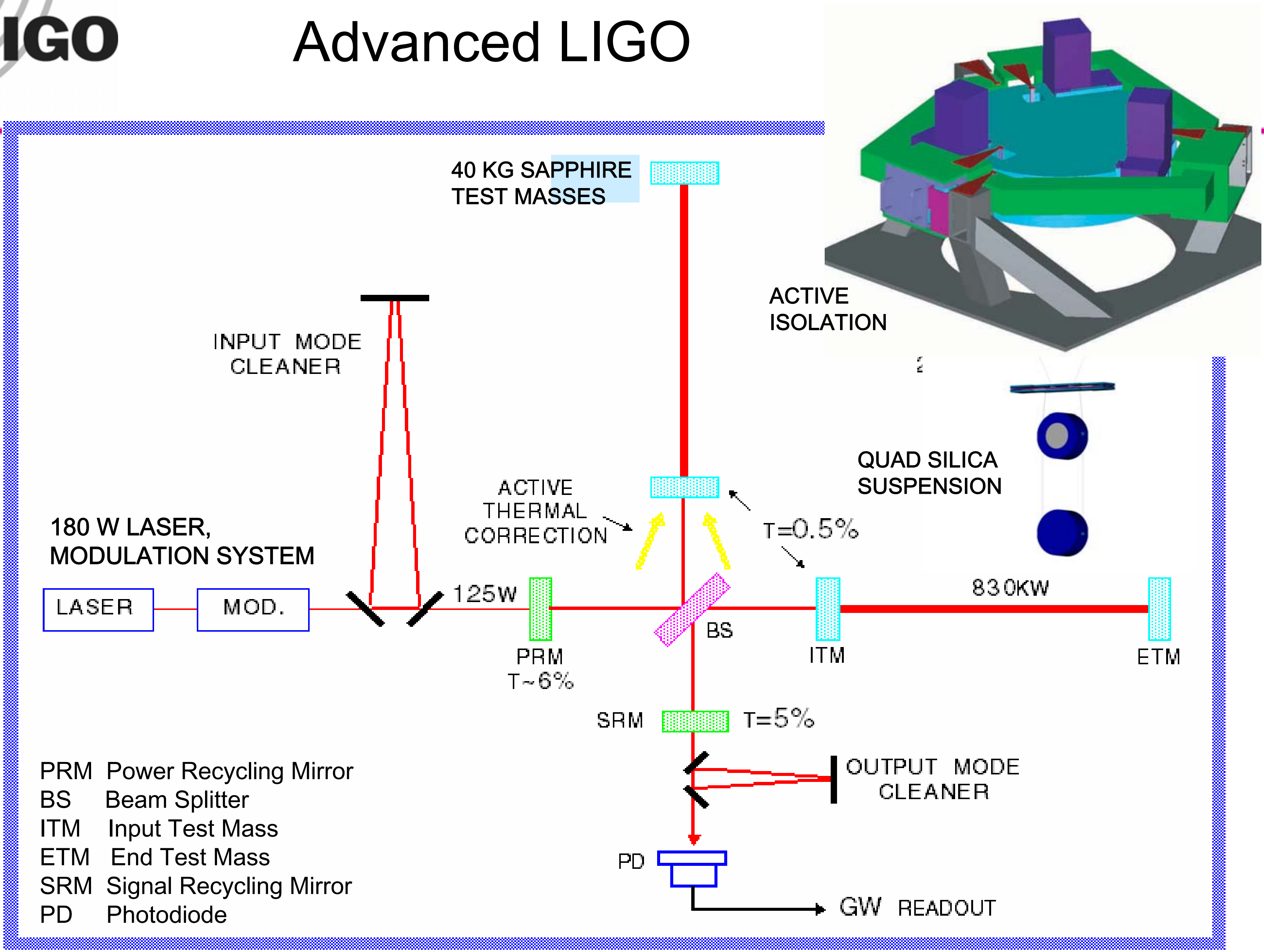
- Complete commissioning, then Initial LIGO science from 2005-2007
  - » At least one year integrated observation, also networking with other detectors
- Then…

Advanced LIGO

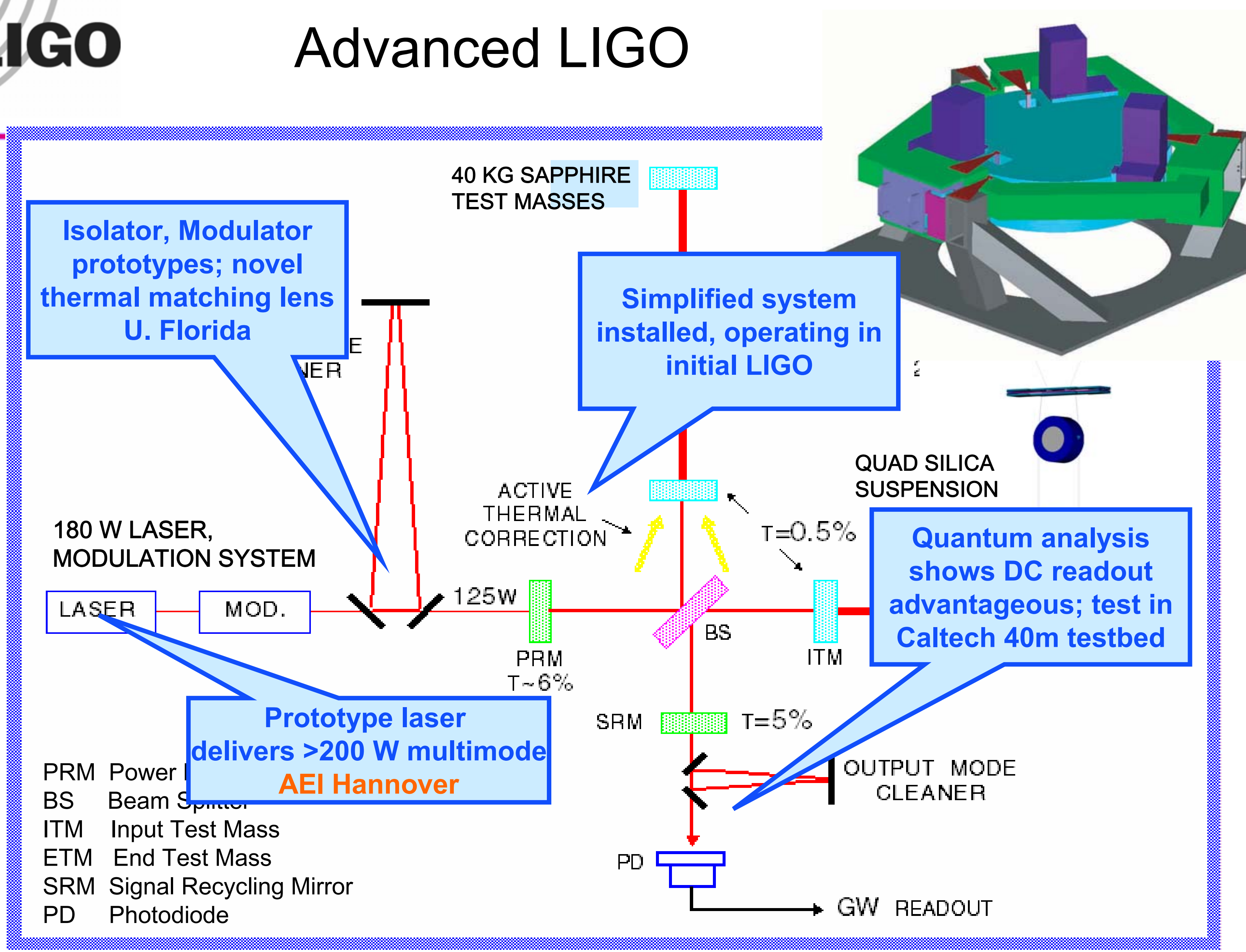
- Factor 10 better amplitude sensitivity
  - » $(\text{Reach})^3$ = rate
  - » Several hours of search equivalent to initial LIGO
- Factor 4 lower frequency
- NS Binaries: for three interferometers,
  - » Initial LIGO: ~20 Mpc
  - » Adv LIGO: ~350 Mpc
- BH Binaries:
  - » Initial LIGO: 10 M_o, 100 Mpc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



Advanced LIGO

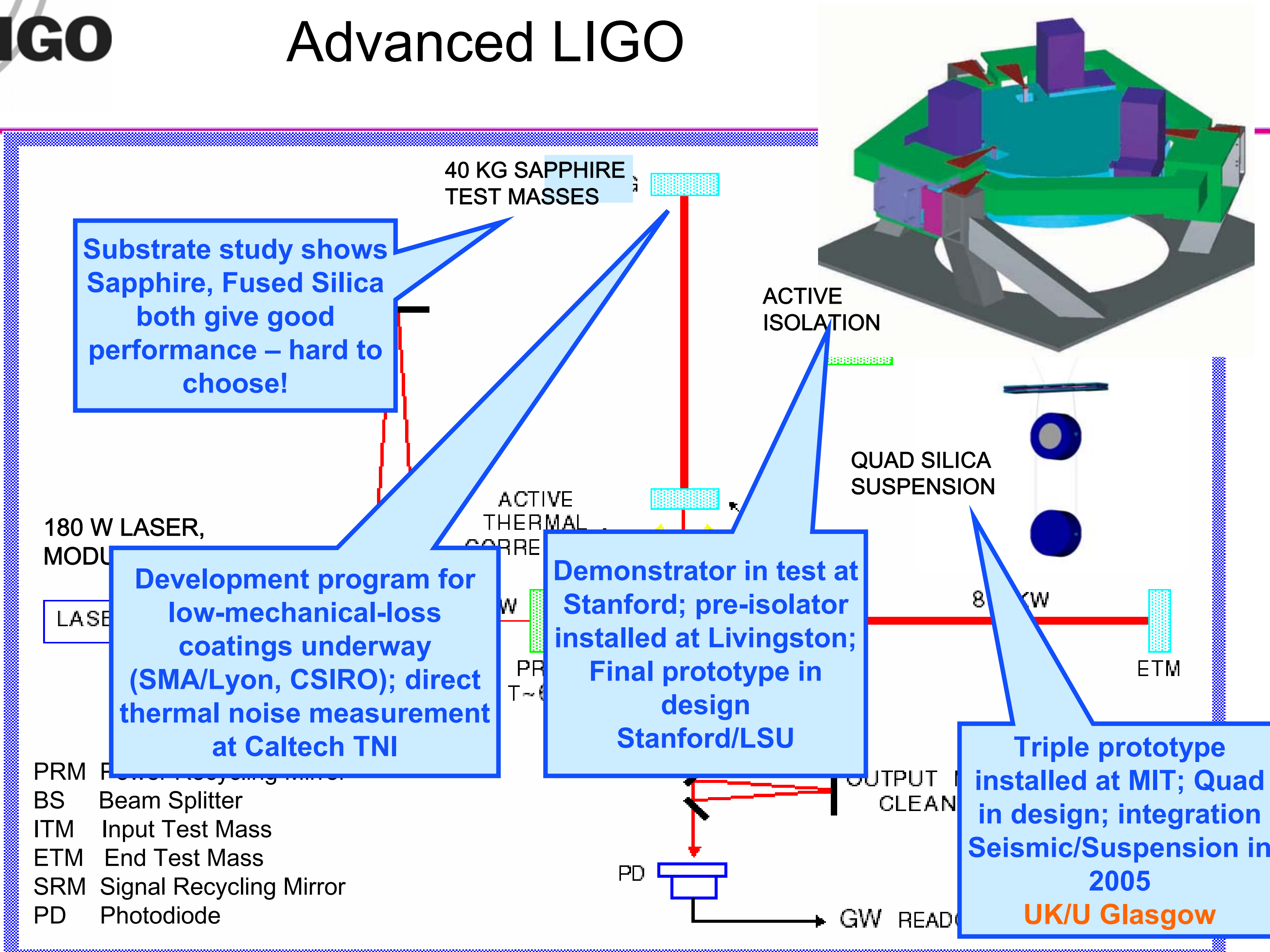


Advanced LIGO



LIGO

Advanced LIGO



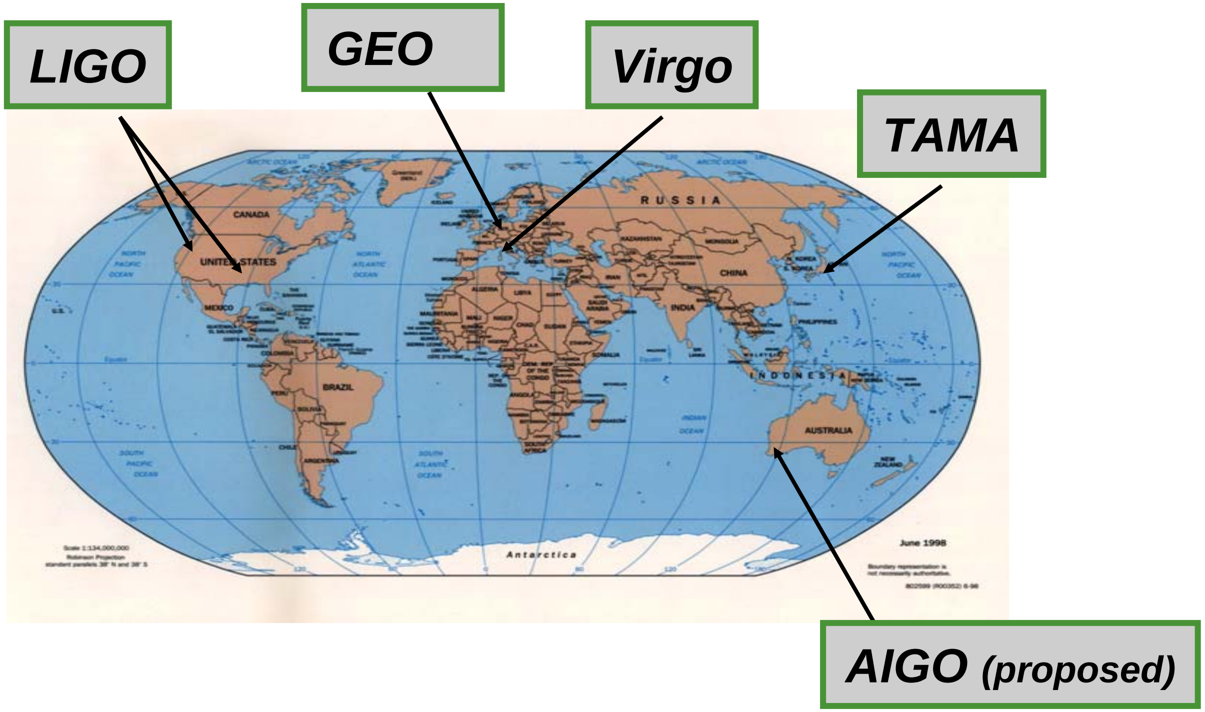
LIGO Scientific Collaboration

- 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