LIGO near-term and second-generation sensitivities

David Shoemaker
MIT

R-mode Mini Workshop

2 August 00

Outline

- LIGO I: brief status and planned performance
- LIGO II: Key technical elements
- LIGO II: notions of performance
- LIGO II: notions of the timeline

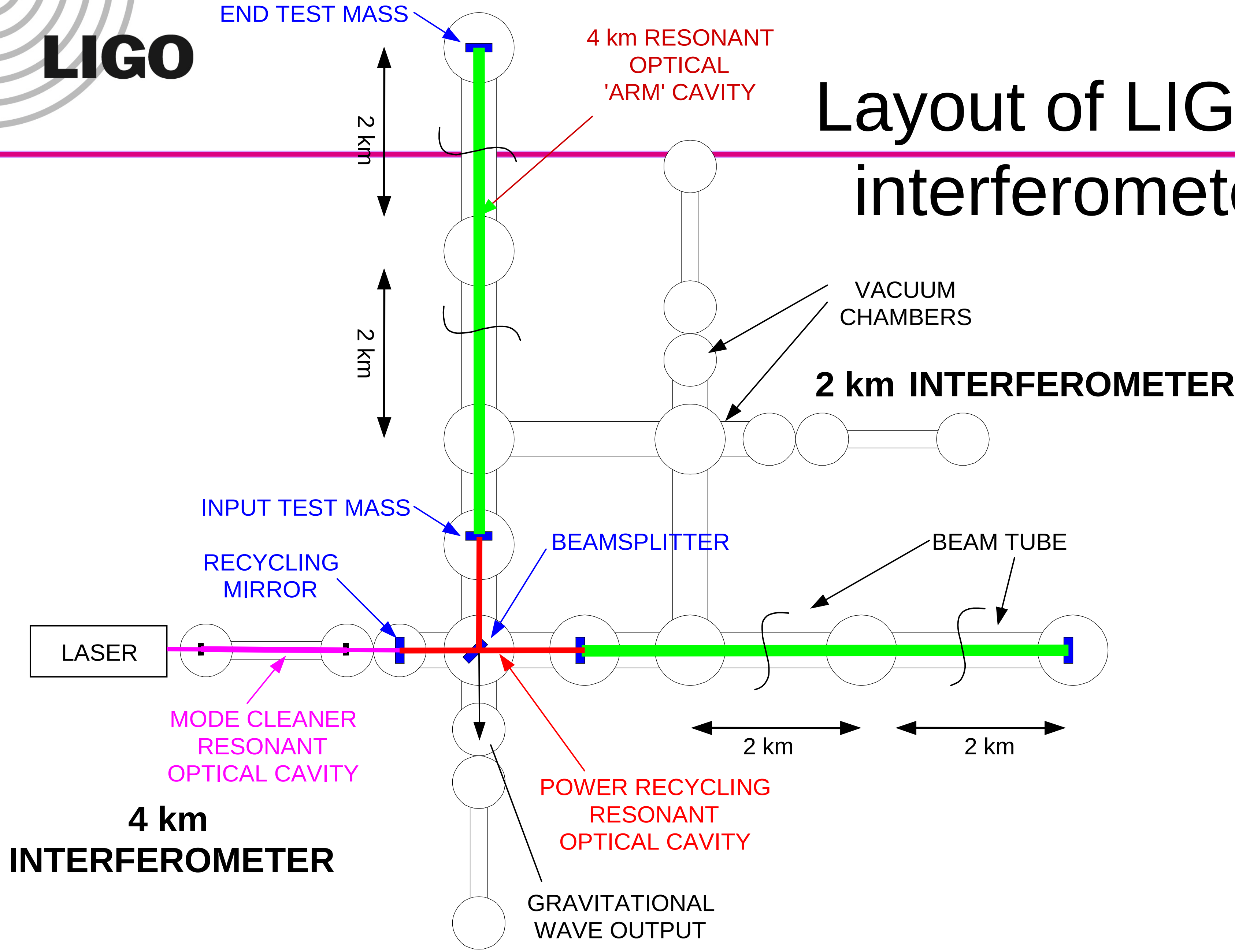
Status of LIGO I

- facility infrastructure complete
- 1+0.9+0.5 interferometers complete
- all subsystems tested: no catastrophes

LIGO Livingston Observatory

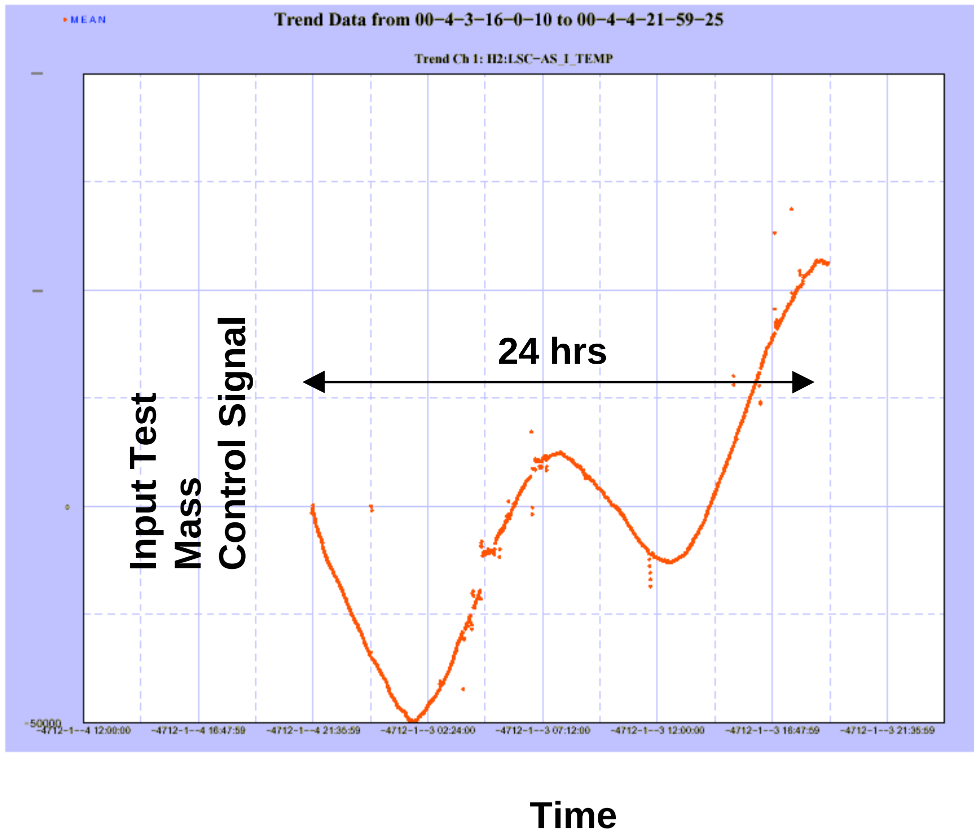
LIGO Hanford Observatory

Layout of LIGO I interferometer



Commissioning: subsystems tests

- mirror suspensions, controllers
- models of environment
  - » tidal strains changing baselines
  - » seismometer/tilt correlations with microseismic peak
- laser noise, intensity fluctuations
- mirror characterization
  - » losses: 1-2% dip in reflected signal intensity
  - » scatter: appears to be better than requirements
- length and angular sensing and controls systems
- data acquisition, software tools

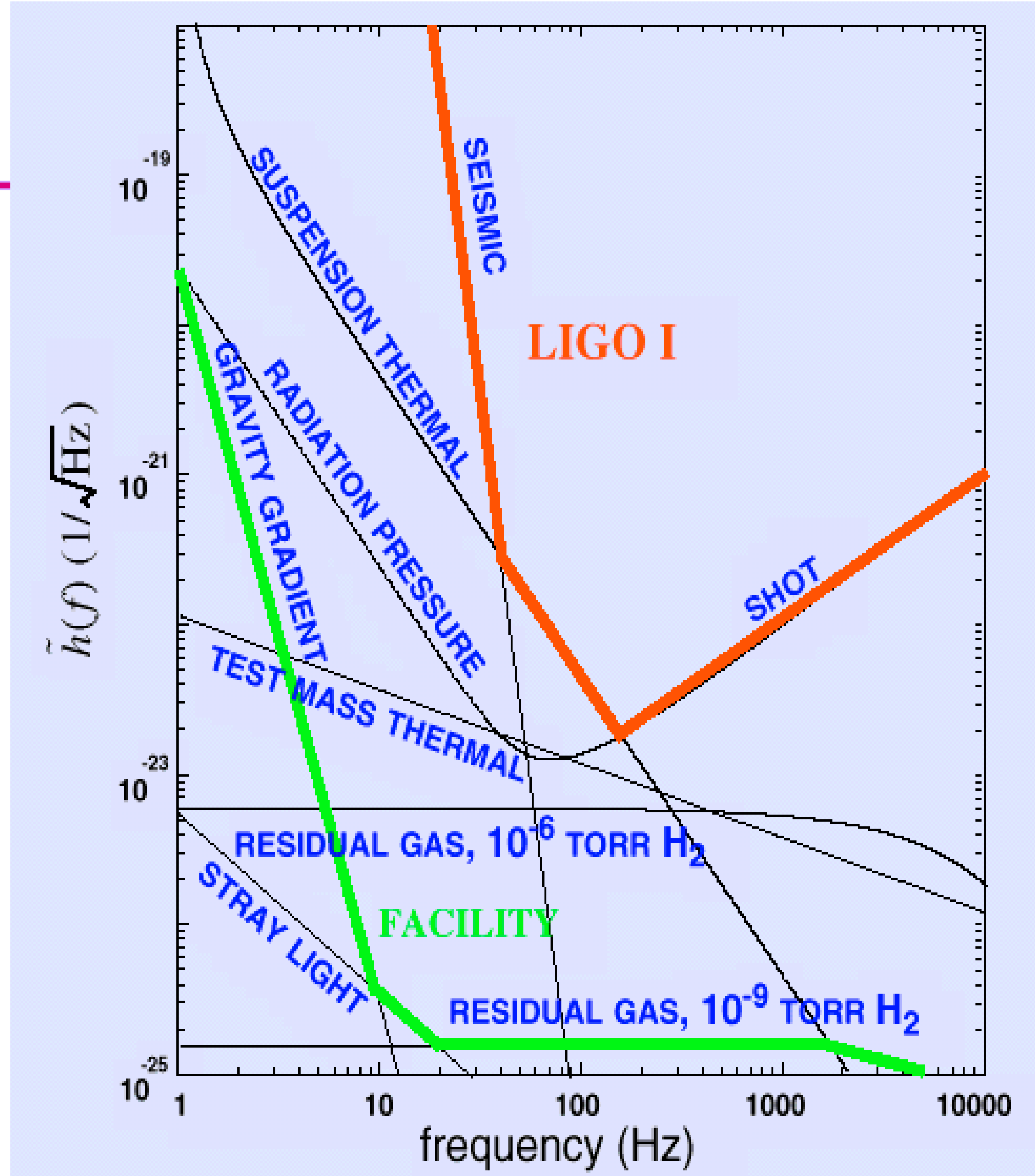


24 hr Engineering Run

- A 24-hour engineering data run was conducted 4/3-4 using the 2 km x-arm
- Quite useful for detector characterization studies
  - » understanding the single arm's behavior
  - » exercising algorithms
  - » excellent opportunity for LSC members to learn more about the interferometer
- Invited any interested LSC physicist
  - » 8 non-detector scientists participated
- Data is archived on hpss at CACR
- to be followed with a series of engineering and then science runs

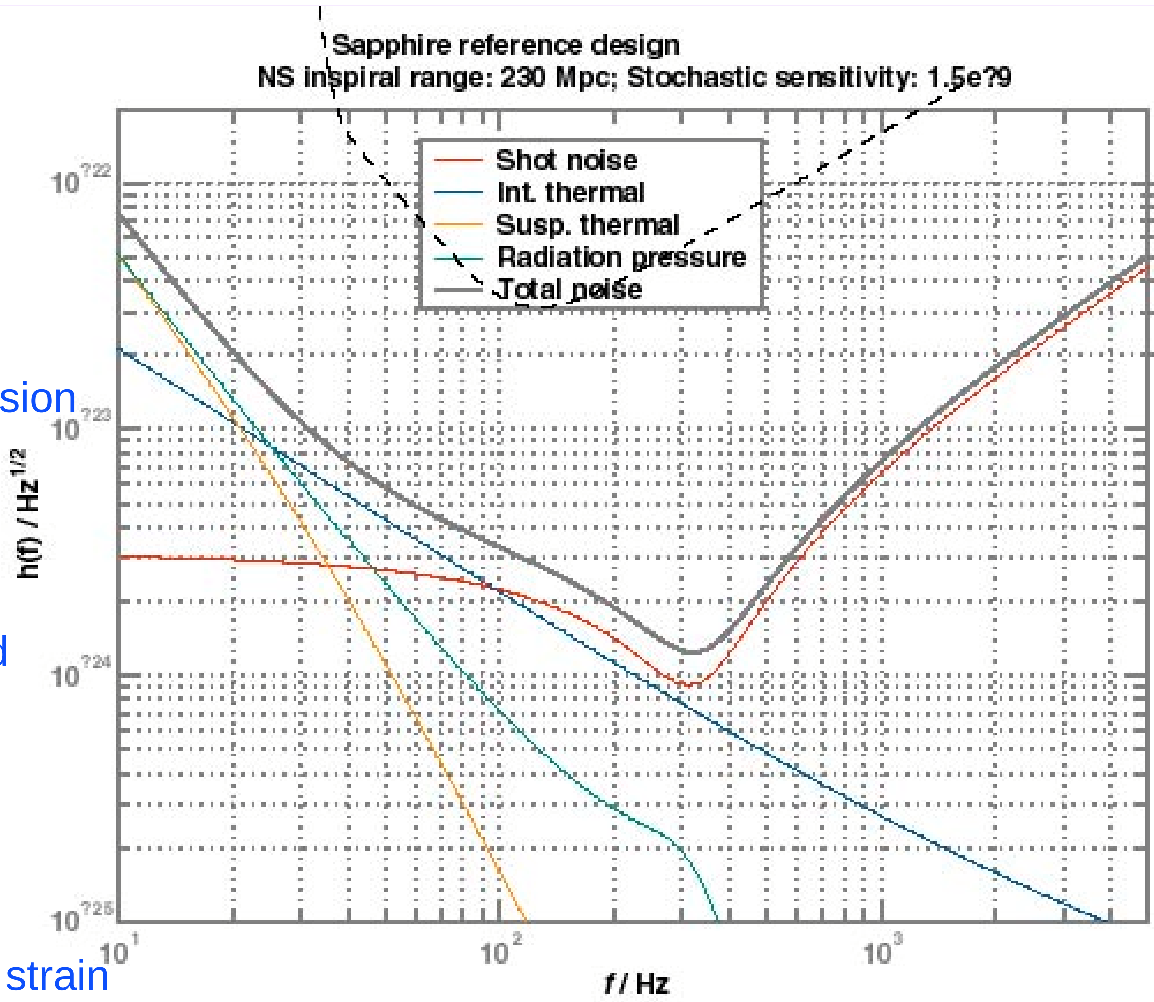
Goals for LIGO I

Performance and Facility Limits



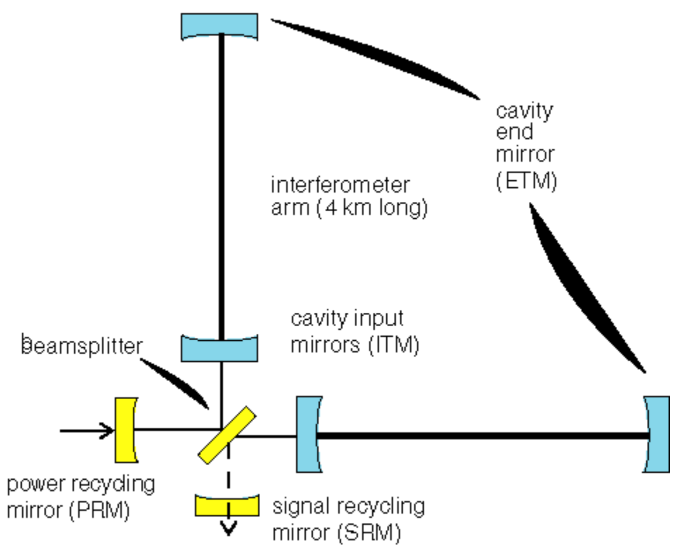
Sensitivity of LIGO II

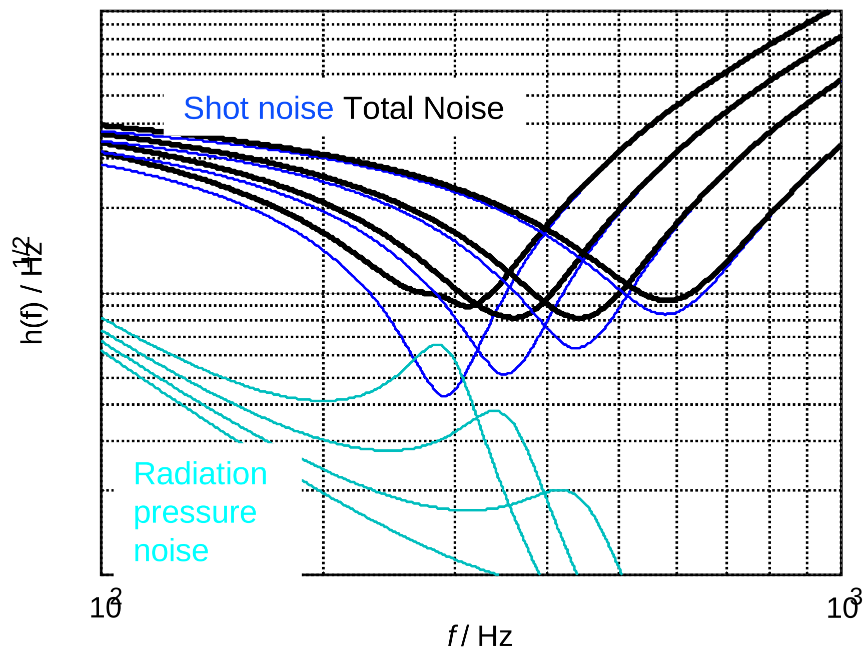
- Sensing noise
  - » greater laser power
  - » signal recycling
  - » (radiation pressure)
- Thermal noise
  - » silica ribbon suspension
  - » sapphire test mass
- Seismic noise
  - » 10 Hz ‘brick wall’
  - » VLF motion reduced
- Net improvement:
  - » ~50 in rms
  - » ~5 in bandwidth
  - » ~25 in narrow-band strain



Configuration: signal recycling

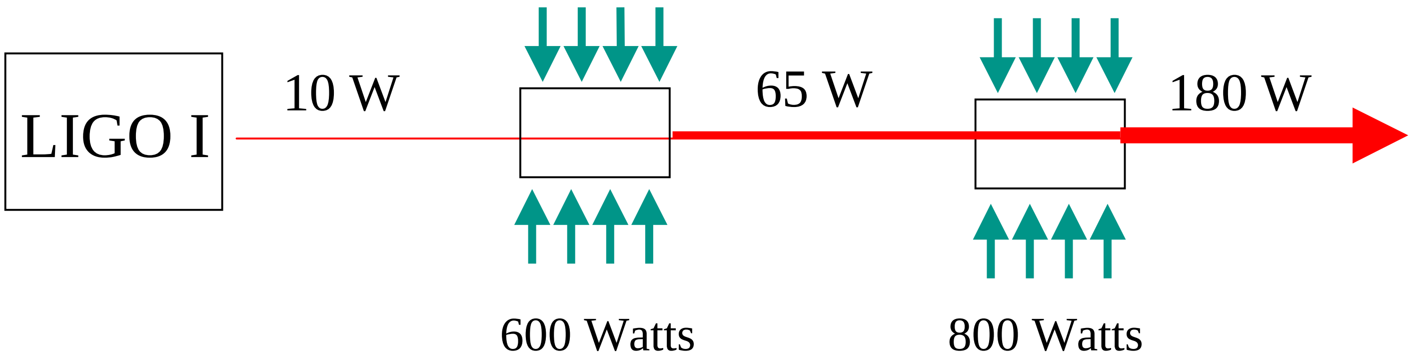
- LIGO I: Power-recycled Fabry-Perot Michelson
- addition of Signal Recycling: allows adaptation of sensitivity to interesting frequency band
- make resonant, or anti-resonant, cavity for GW signal ‘sidebands’
- significant development needed, underway





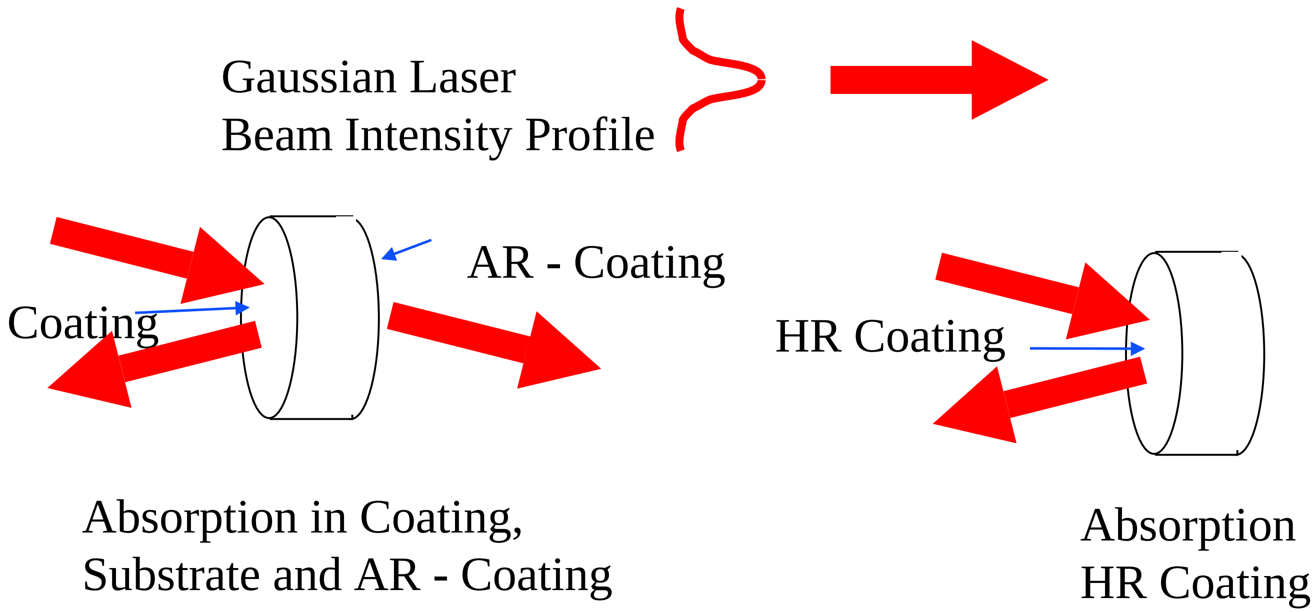
Laser power: to quantum limit

- optimize power given overall design
  - » shot noise decreasing as sqrt(Power)
  - » radiation pressure increasing as sqrt(Power)
- 180 W, nominally with system similar to LIGO I



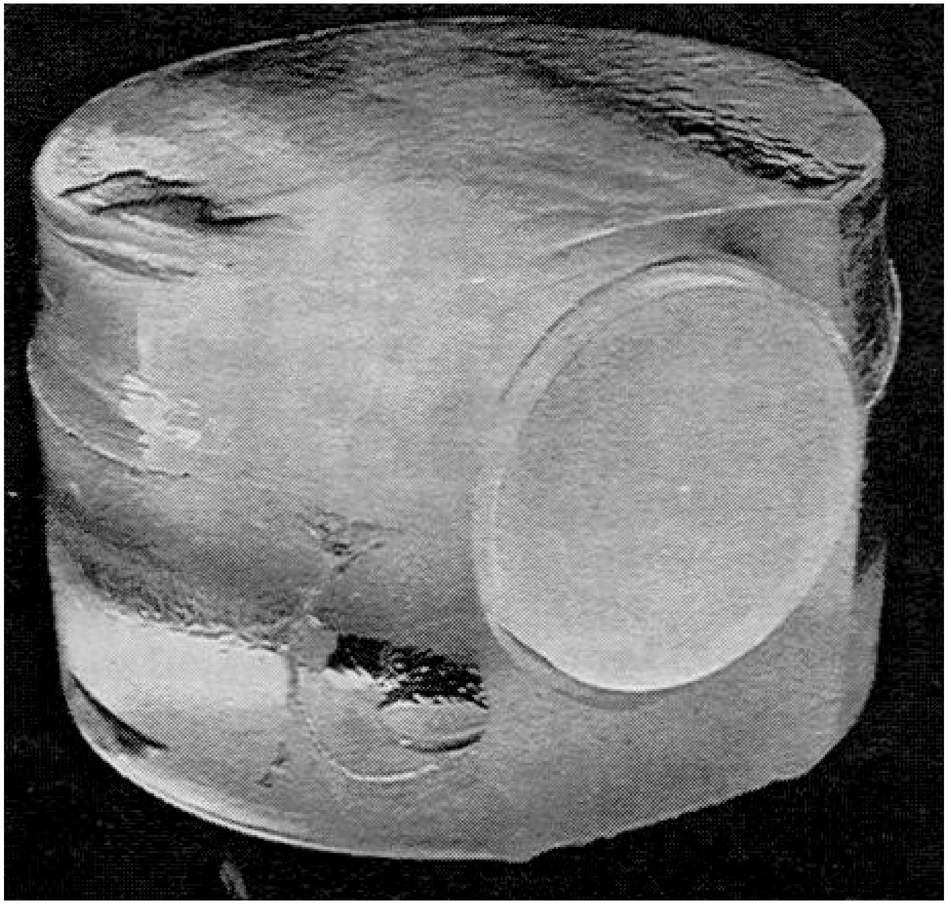
Thermal Management

- 0.7 MW in arm cavities, 5 kW in central interferometer
- auxiliary optics: small beams, high intensities
- thermal focussing in Test Mass optics
  - » additional heat as corrective measure

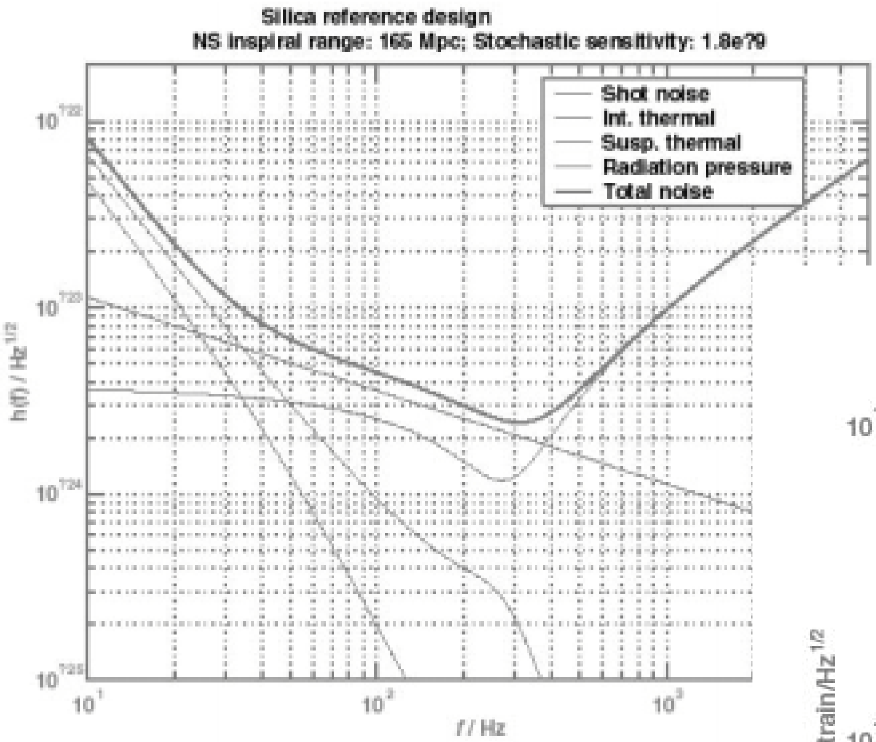


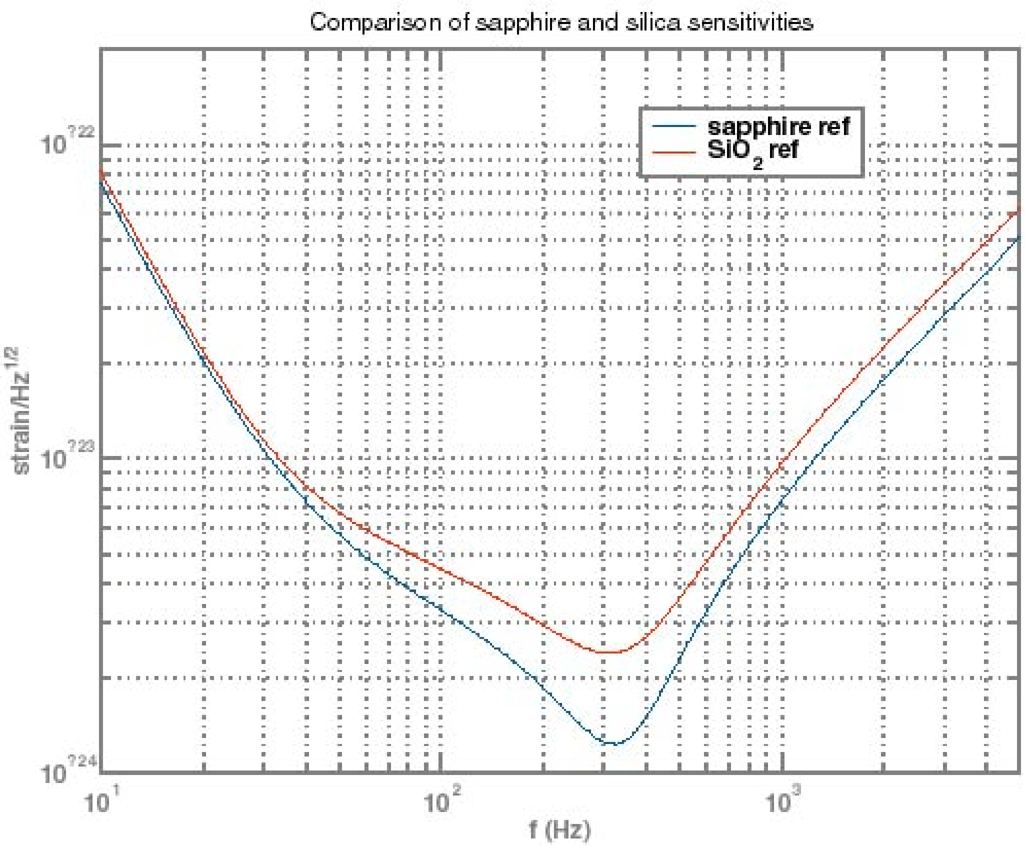
Test Mass optics: sapphire

- LIGO I: fused silica, 10 kg
- LIGO II: sapphire, 30 kg
- thermal noise from internal modes of test mass: improved sensitivity floor
- radiation pressure: desire for greater mass
- sapphire better, but…
- requires trades with optics
- significant development
- fallback/interim (if needed): fused silica



Test Mass optics: sapphire or silica?

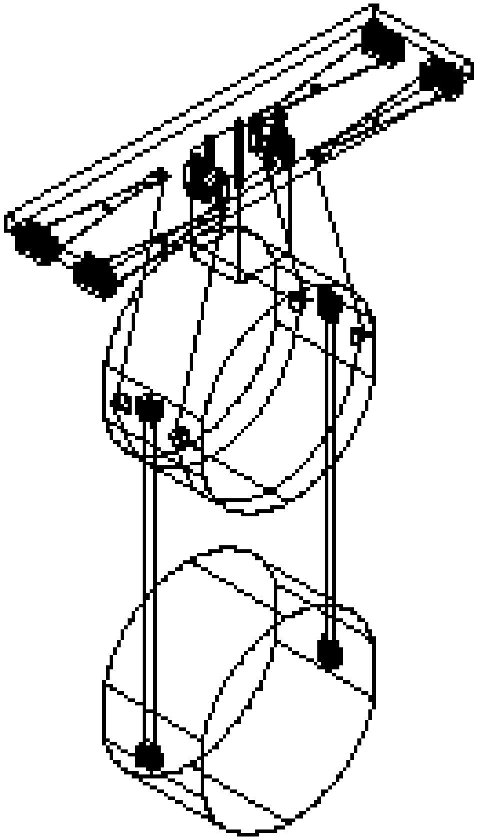




G000180-00-M

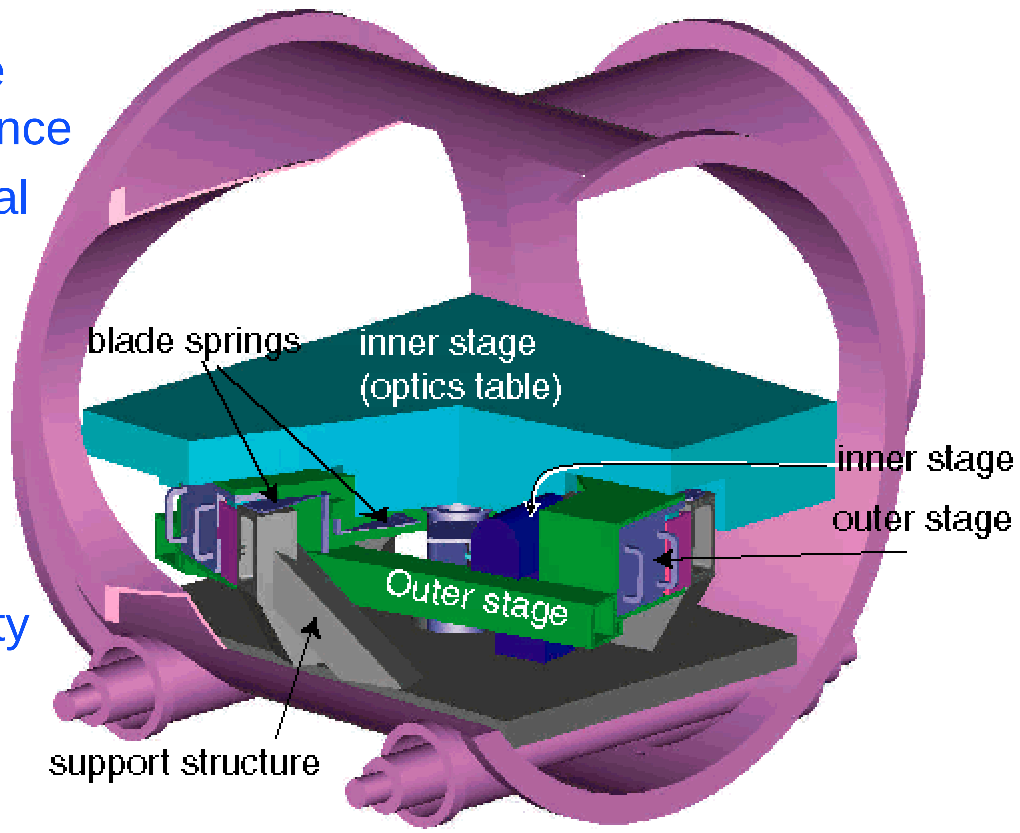
Suspensions: multiple pendulums

- LIGO I: simple wire loop suspension
- multiple pendulum suspensions evident path
  - » improved seismic isolation
  - » better control distribution
- fused silica suspension fibers
  - » lower loss material, MUCH less thermal noise
  - » ribbon cross-section reduces further energy stored along optic axis
- GEO to supply design, help with engineering



Isolation systems: 10 Hz cutoff

- LIGO I: lossy springs under compression, large masses: Simple Harmonic Oscillators above resonance
- want to benefit from reduced thermal noise, better sensing
- choose 10 Hz as cutoff: good compromise given other noise sources, most anticipated signals
- control band (0 Hz to 10 Hz) very important: reduced velocity for acquisition, reduced control authority at test masses
- use high-gain servo systems, low noise sensors



LIGO II Reference Design Parameters / LIGO I Comparison

Subsystem and Parameters	LIGO II Reference Design	LIGO I Implementation
Comparison With LIGO I Top Level Parameters		
Strain Sensitivity [rms, 100 Hz band]	2×10^{-23}	*10^{-21}*
Displacement Sensitivity [rms, 100 Hz band]	8×10^{-20} m	*4×10^{-18} m*
Fabry-Perot Arm Length	4000 m	*4000 m*
Vacuum Level in Beam Tube, (Vacuum Chambers)	$< 10^{-6}$, ($< 10^{-7}$) torr	*$< 10^{-6}$ torr*
Laser Wavelength	1064 nm	*1064 nm*
Optical Power at Laser Output	180 W	*10 W*
Optical Power at Interferometer Input	125 W	*5 W*
Power Recycling Factor	80 x	*30 x*
Input Mirror Transmission	3%	*3%*
End Mirror Transmission	15 ppm	*15 ppm*
Arm Cavity Power Loss on Reflection	1%	*3 %*
Light Storage Time in Arms	0.84 ms	*0.84 ms*
Test Masses	Sapphire, 30 kg	*Fused Silica, 11 kg*
Mirror Diameter	28 cm	*25 cm*
Test Mass Pendulum Period	1 sec	*1 sec*
Seismic Isolation System	Active/Passive, 6 stage	*Passive, 4 stage*
Seismic Isolation System Horizontal Attenuation	10^{-8} (10 Hz)	*$\geq 10^{-5}$ (100 Hz)*
Maximum Background Pulse Rate	1 per 10 years, triple interferometer coincidence	*1 per 10 years, triple interferometer coincidence*

Timeline

Most optimistic schedule - LIGO II funding TBD

YEAR	LIGO I	LIGO II
2000	Installation and commissioning	R&D
2001	Installation and commissioning	R&D
2002	Science run	R&D, design, long lead items
2003	Science run	R&D, design, fabrication
2004	Additional science run	Fabrication, on-site assembly
2005	LIGO I interferometers removed	Fabrication, on-site assembly, installation into vacuum system
2006		Installation and commissioning

LIGO, Built to Last