LIGO II Concept and Performance

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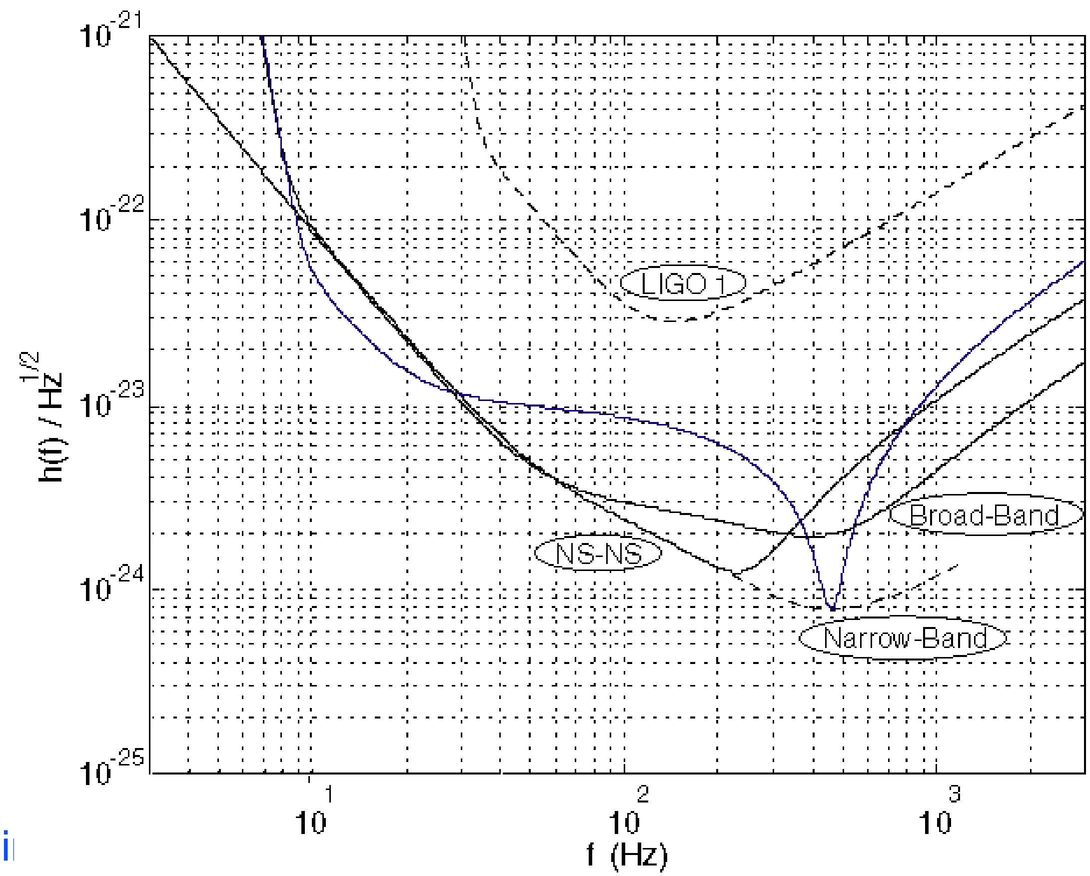
Outline

- Conceptual design
- Physics Reach
- Key technical elements
- Planning (Gary Sanders)

Sensitivity of LIGO I, 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
  - » ~30 in narrow-band strai



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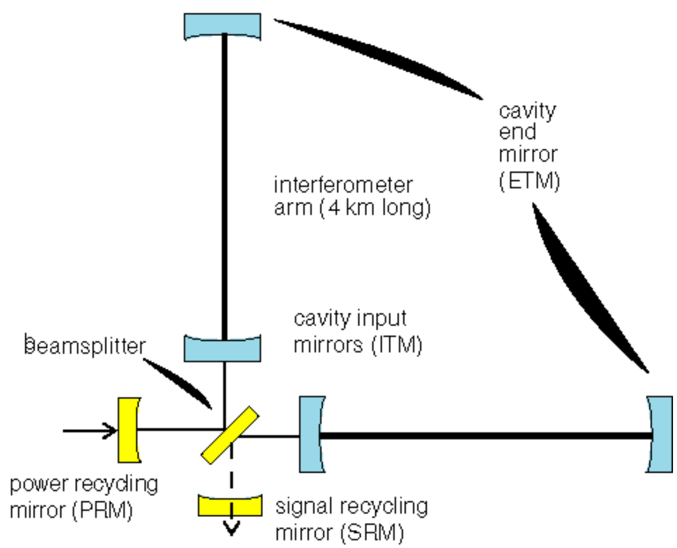
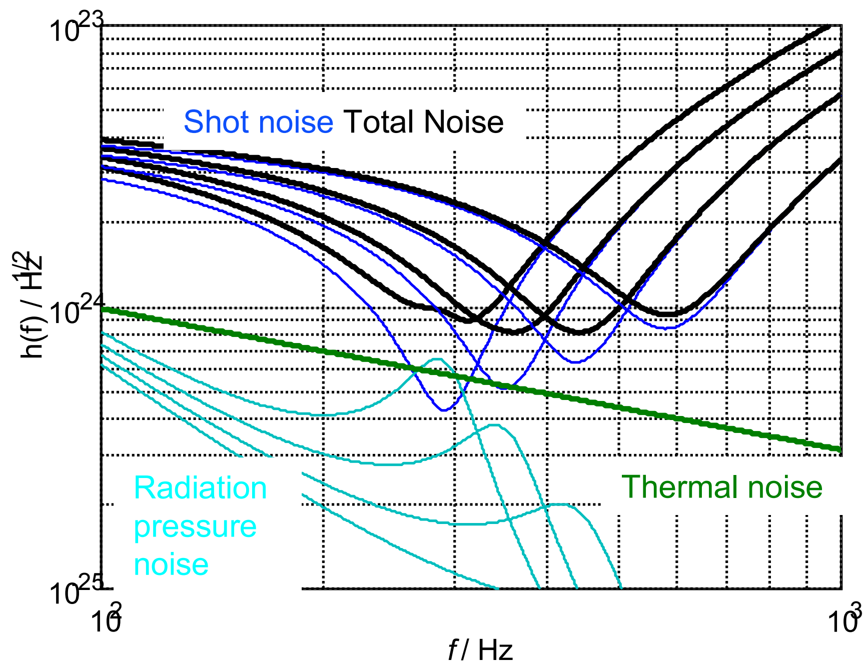
Physics Reach

- Compact Binaries: Inspiral & Merger
  - » Masses, Spins, Distance, Location on sky to ~1 degree
- Neutron-Star Births (supernovae)
  - » most certain source; can see to 450Mpc, 1/month
- Neutron-star Spins (pulsars)
  - » Very uncertain rates; guess 800Mpc, ~1/week
- BH-BH Inspiral and merger
  - » Rates Highly Uncertain. Best estimates:
  - » LIGO-I: 100 Mpc, 1/year. LIGO-II: z=0.5, 1/hour
  - » (one day of LIGO II data equivalent in reach to entire LIGO I run)
- Stochastic Background from Big Bang
  - » LIGO-I: $\Omega=10^{-5}$ LIGO-II: $\Omega=3\times10^{-9}$
- SURPRISES!

Configuration: signal recycling

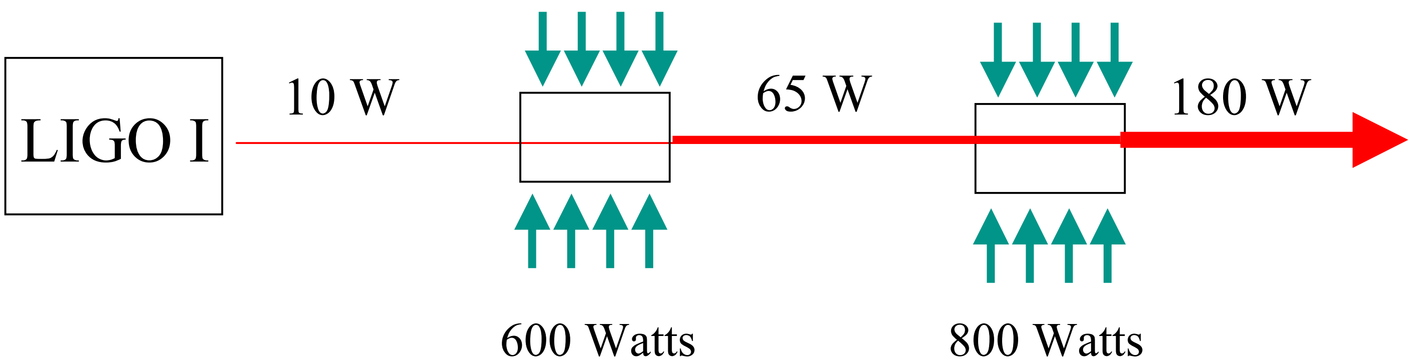
- LIGO I: Power-recycled Fabry-Perot Michelson
- addition of Signal Recycling: allows adaptation of sensitivity to interesting frequency band
- make resonant, or anti-resonant, cavity for GW signal ‘sidebands’
- significant development needed, underway





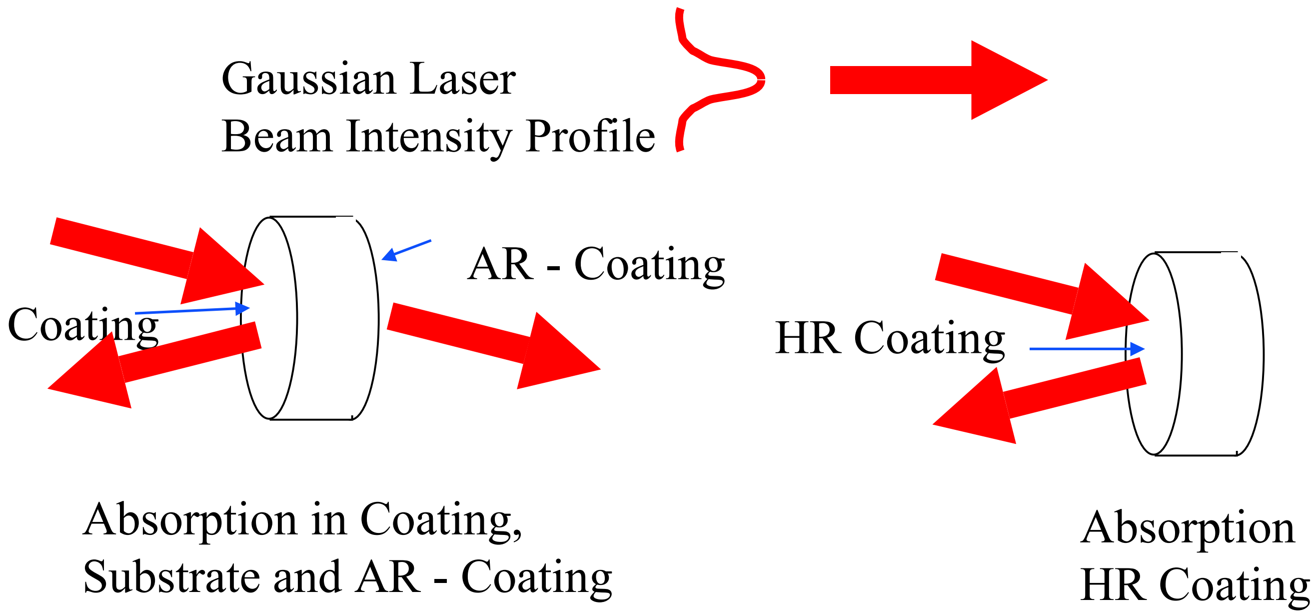
Laser power: to quantum limit

- 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



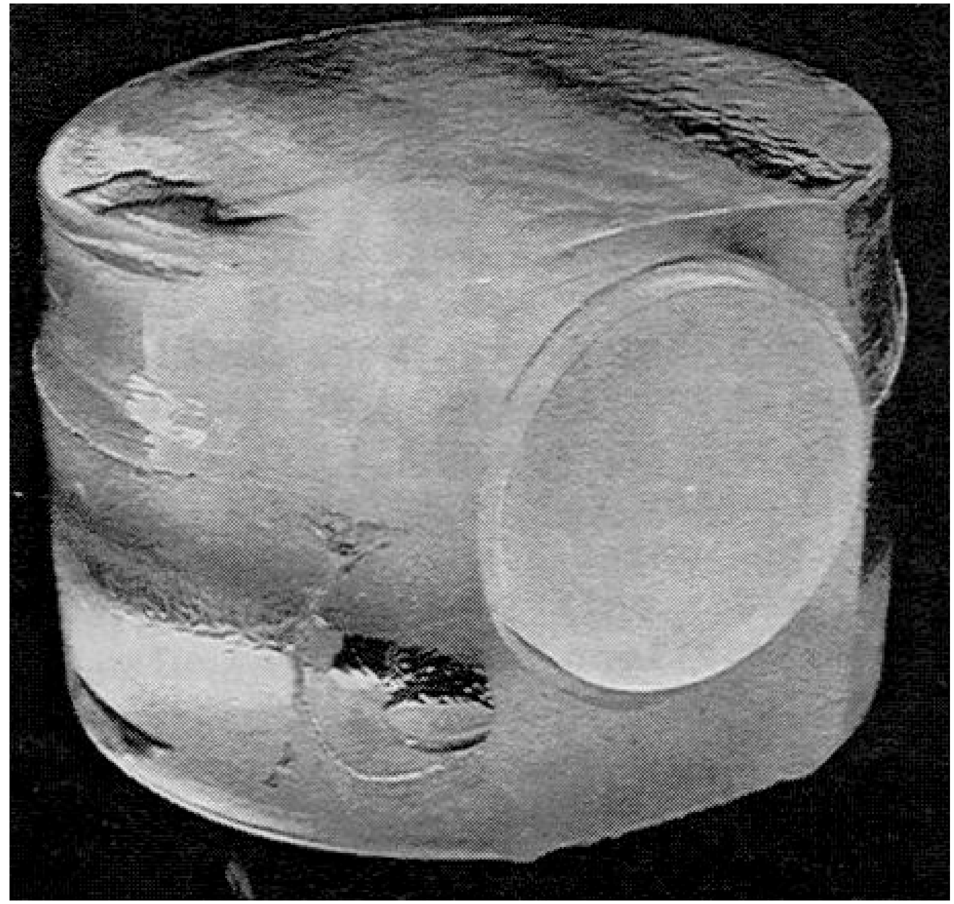
Thermal Management

- 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



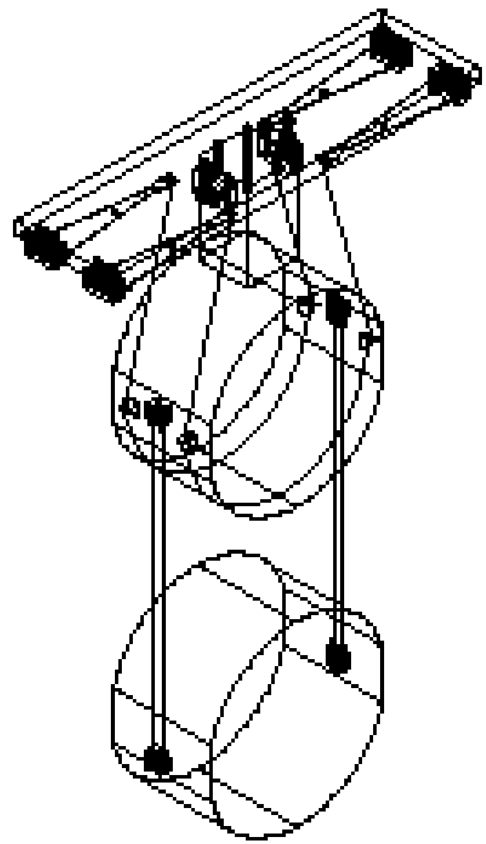
Test Mass optics: sapphire

- LIGO I: fused silica, 10 kg
- LIGO II: sapphire, 30 kg
- thermal noise from internal modes of test mass: sensitivity floor
- radiation pressure: desire for greater mass
- sapphire excellent (on most pieces of paper)
- significant development item; uncertainty of success
- fallback/interim (if needed): fused silica



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, 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
- two solutions under study
  - » ‘soft’: VIRGO-like (and inspired) multiple pendulum solution
  - » ‘stiff’: high-gain servos which ‘slave’ optics table to quiet seismometers
- development of ideas, prototypes, to determine best course
- evaluation in April ‘00

Seismic Isolation Concepts

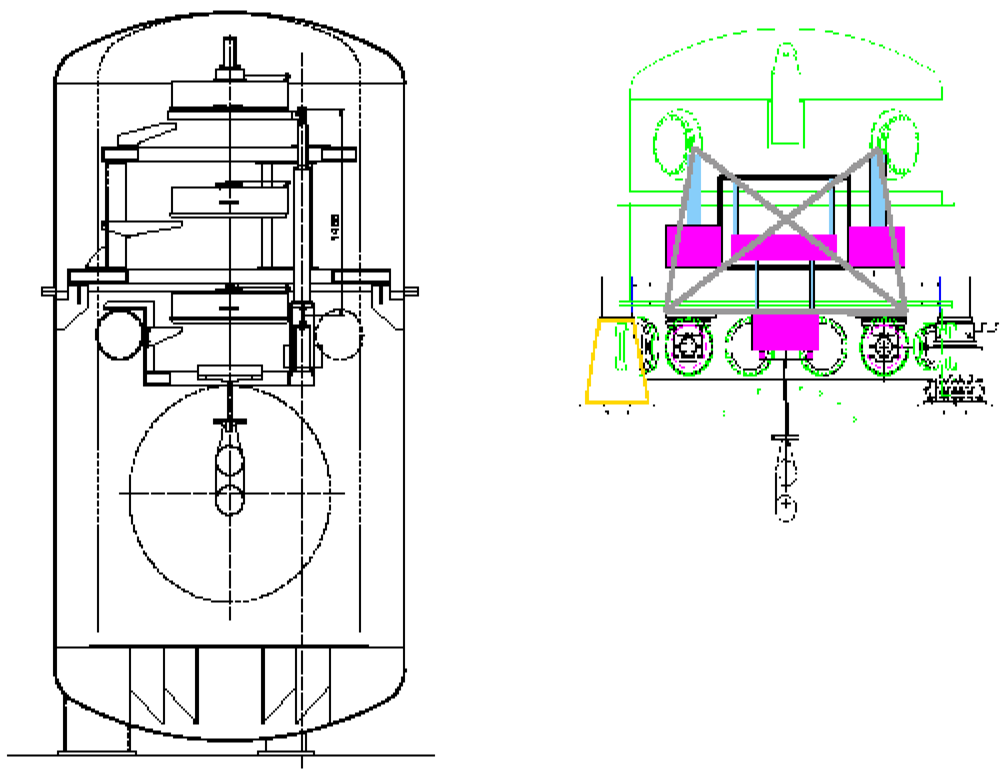
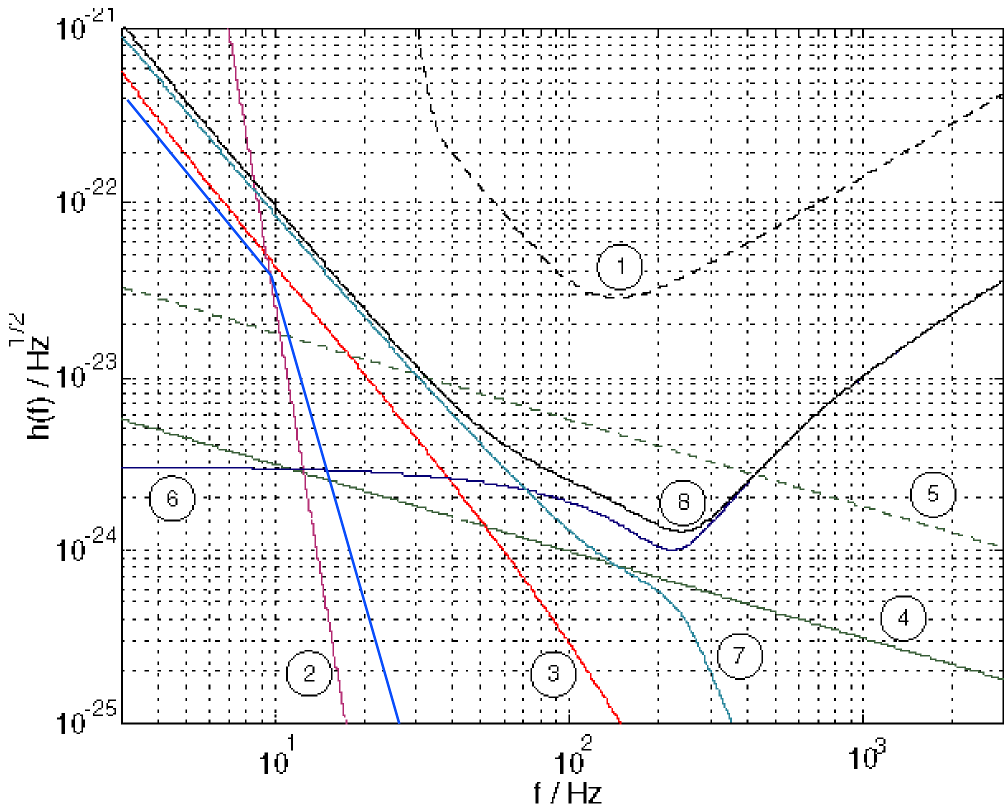


Figure A7. Two Seismic Isolation concepts for LIGO II.

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*

Noise Anatomy of LIGO II



1 LIGO I total
2 Filtered seismic noise
3 Suspension thermal noise
4 Internal thermal noise - sapphire
5 Internal thermal noise - fused silica (fallback)
6 Shot noise
7 Radiation pressure noise
8 LIGO II total

LSC Working Groups

- LSC central to development of LIGO II concept, continuing R&D
- Many institutions contributing; coordinators in R&D domains are:
- Configurations: Ken Strain (Glasgow) chair
  - » Sensing scheme: MIT; Science prototype: GEO; Control prototype: Caltech
- Lasers&Optics: Eric Gustafson (Stanford) chair
  - » Core optics: Caltech; Compensation, photodiodes: MIT; Thermal modeling: HP; Ancillary optics: U Florida; Laser: Stanford; PSL: Hanford
- Suspensions/Isolations: David Shoemaker (MIT) chair
  - » Testmass materials: Stanford; TM Integration, Fiber Development, Suspension development: GEO; Isolation systems: Many; Controls: Stanford; System tests: MIT

- Change in mode is needed --- many milestones approaching!

LSC/Lab in more detail

Institution	Heads	FTE	LIGO I - Heads	LIGO I - FTE
ACIGA -Australia	23	14.9	0	0
Caltech - CACR	3	0.7	3	0.7
Caltech - CaRT	8	3.4	8	3.4
Caltech - CEGG	2	1.6	1	0
Cornell	2	1.8	2	1.8
Univ of Florida	12	9.2	12	9.2
GEO	34	19.2	2	0.3
NAOJ - TAMA	3	1.1	0	0
JILA	6	3.1	0	0
LSU	5	3.4	0	0
Lousiana Tech	6	1.2	6	1.2
Univ of Michigan	2	1.5	2	1.5
Moscow State University	11	10	0	0
Oregon University	7	4.4	7	4.4
Institute of Applied Physics - Russia	12	9.5	0	0
Stanford University	21	14.3	0	0
Syracuse	5	5	1	1
Univ of Texas - Brownsville	2	0.5	2	0.5
Univ of Wisconsin - Milwaukee	7	4.5	7	4.5
Total : non LIGO Laboratory	171	109.3	53	28.5
LIGO Hanford	12	12	12	12
LIGO Livingston	7	7	7	7
LIGO MIT	17	17	17	17
LIGO Caltech	52	51	52	51
Total : LIGO Laboratory	88	87	88	87
Total LSC	259	196.3	133	115.5