Advanced LIGO Systems & Interferometer Sensing & Control (ISC)

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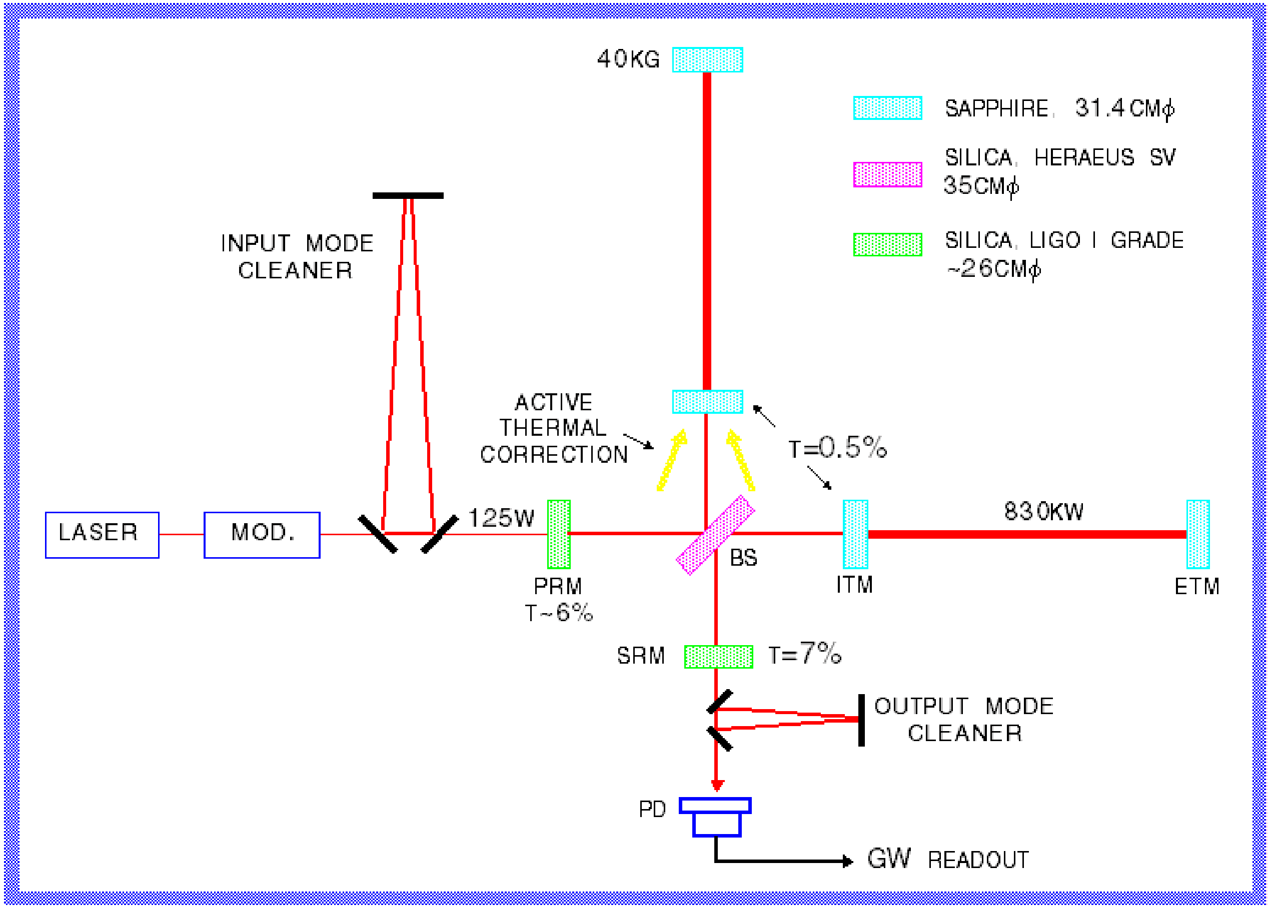
Upgrade approach & philosophy

- We don’t know what the initial LIGO detectors will see
  - » Design advanced interferometers for improved broadband performance
- Evaluate performance with specific source detection estimates
  - » Optimizing for neutron-star binary inspirals also gives good broadband performance
- Push the design to the technical break-points
  - » Improve sensitivity where feasible - design not driven solely by known sources
- Design approach based on a complete interferometer upgrade
  - » More modest improvements may be possible with upgrades of selected subsystem/s, but they would profit less from the large fixed costs of making any hardware improvement

Advanced Interferometer Concept



» Signal recycling

» 180-watt laser

» 40 kg Sapphire test masses

» Larger beam size

» Quadruple suspensions

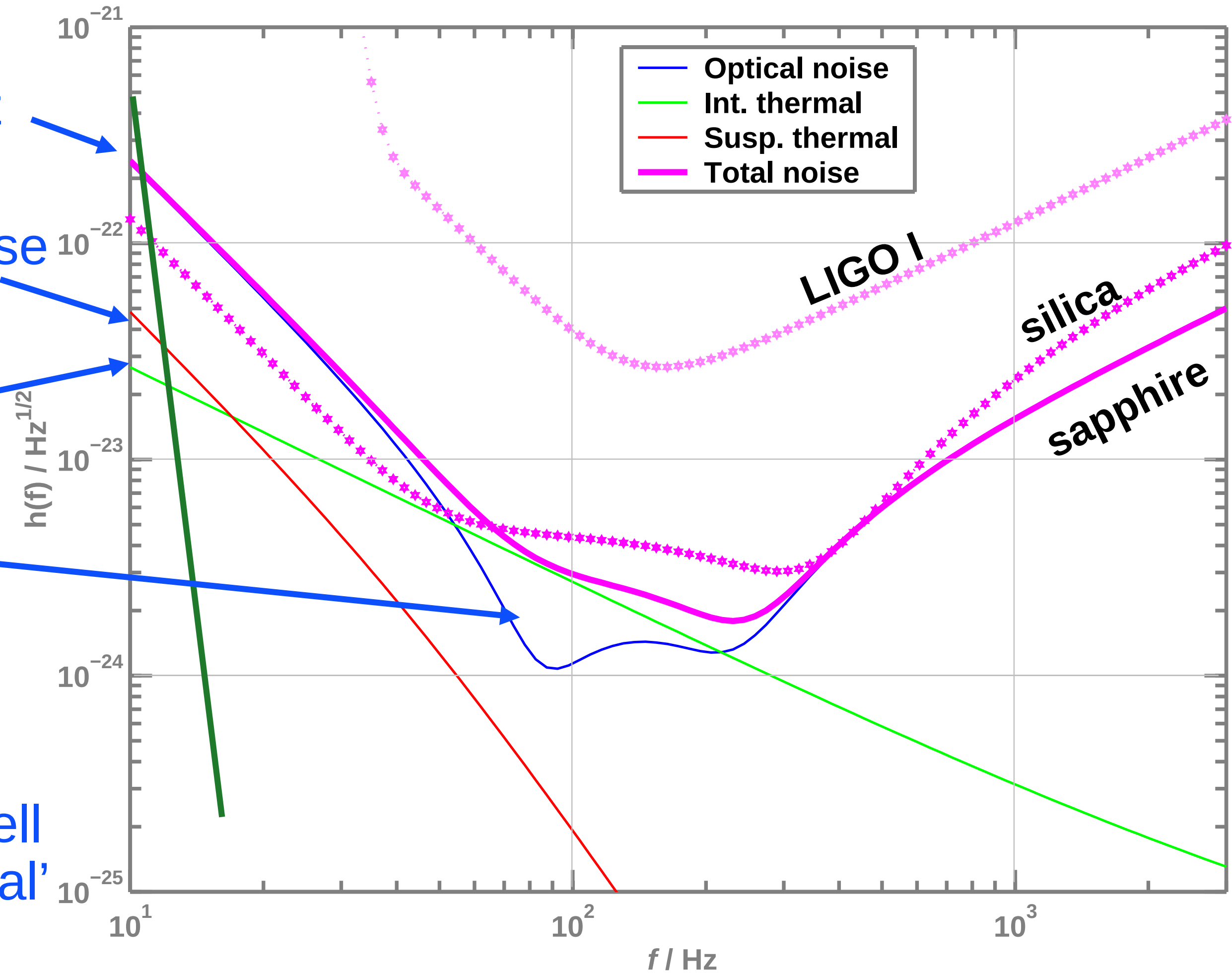
» Active seismic isolation

» Active thermal correction

» Output mode cleaner

Projected Performance

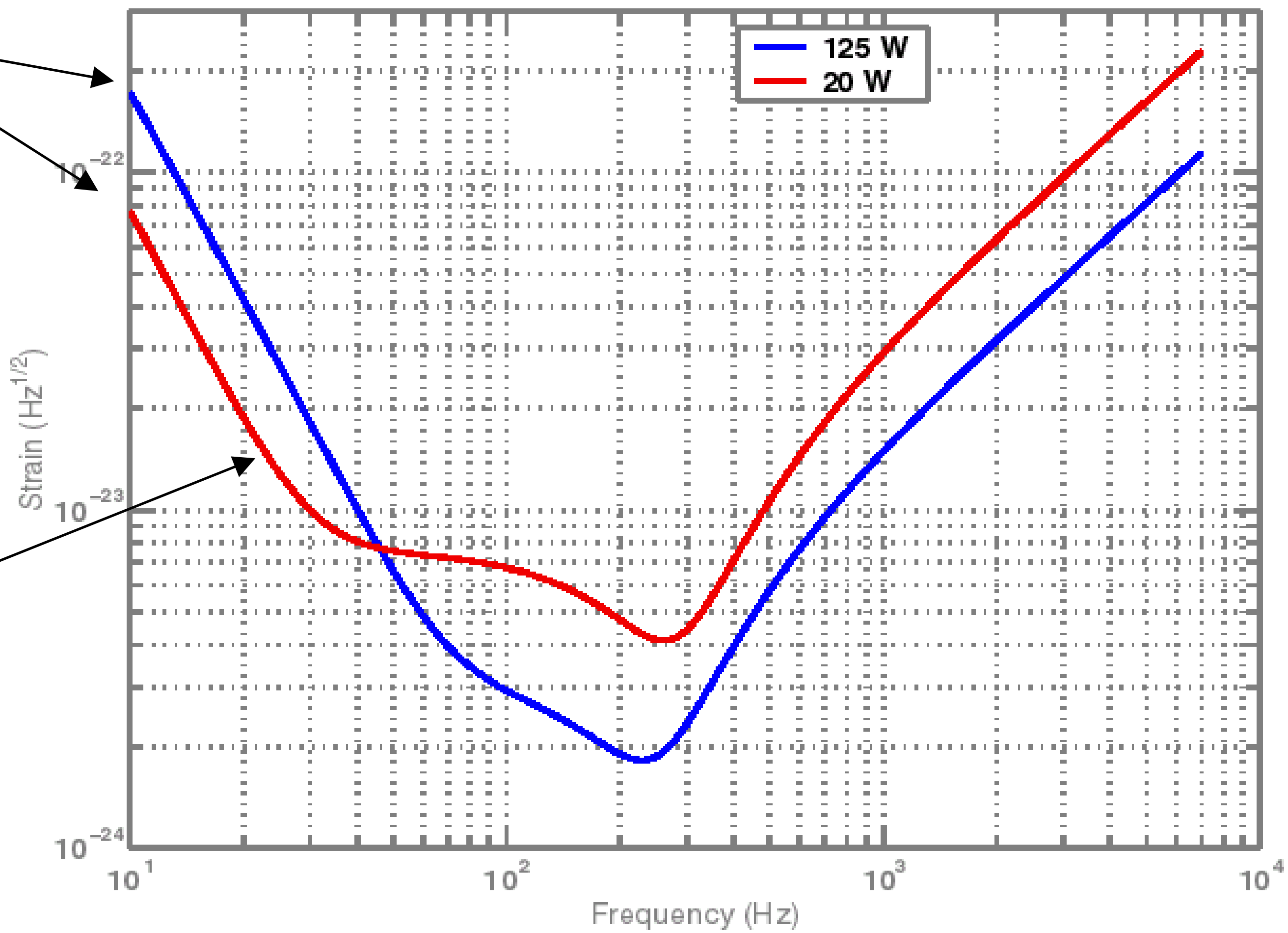
- Seismic ‘cutoff’ at 10 Hz
- Suspension thermal noise
- Internal thermal noise
- Unified quantum noise dominates at most frequencies
- ‘technical’ noise (e.g., laser frequency) levels held in general well below these ‘fundamental’ noises



Low & High power modes

Factor of 3 difference at low frequencies

Quantum radiation pressure roughly equal to suspension thermal noise

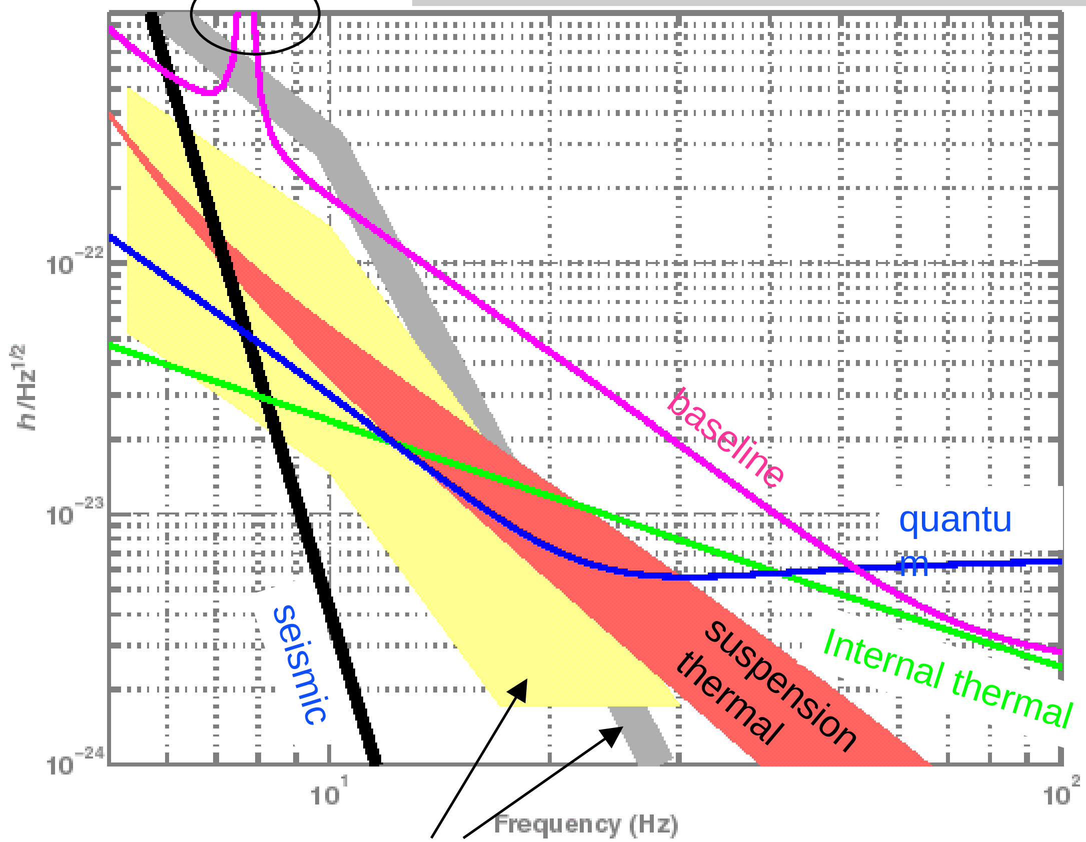


LIGO Top level performance & parameters

Parameter	LIGO I	Adv LIGO
Equivalent strain noise, minimum	3×10^{-23}/rtHz	2×10^{-24}/rtHz
Neutron star binary inspiral range	19 Mpc	300 Mpc
Stochastic backgnd sens.	3×10^{-6}	$1.5\text{-}5 \times 10^{-9}$
Interferometer configuration	Power-recycled MI w/ FP arm cavities	LIGO I, plus signal recycling
Laser power at interferometer input	6 W	125 W
Test masses	Fused silica, 11 kg	Sapphire, 40 kg
Seismic wall frequency	40 Hz	10 Hz
Beam size	3.6/4.4 cm	6.0 cm
Test mass Q	Few million	200 million
Suspension fiber Q	Few thousand	~30 million

Seismic wall frequency

Vertical mode of suspension is allowed to be as high as 12 Hz: doesn't necessarily impose a low frequency detection limit



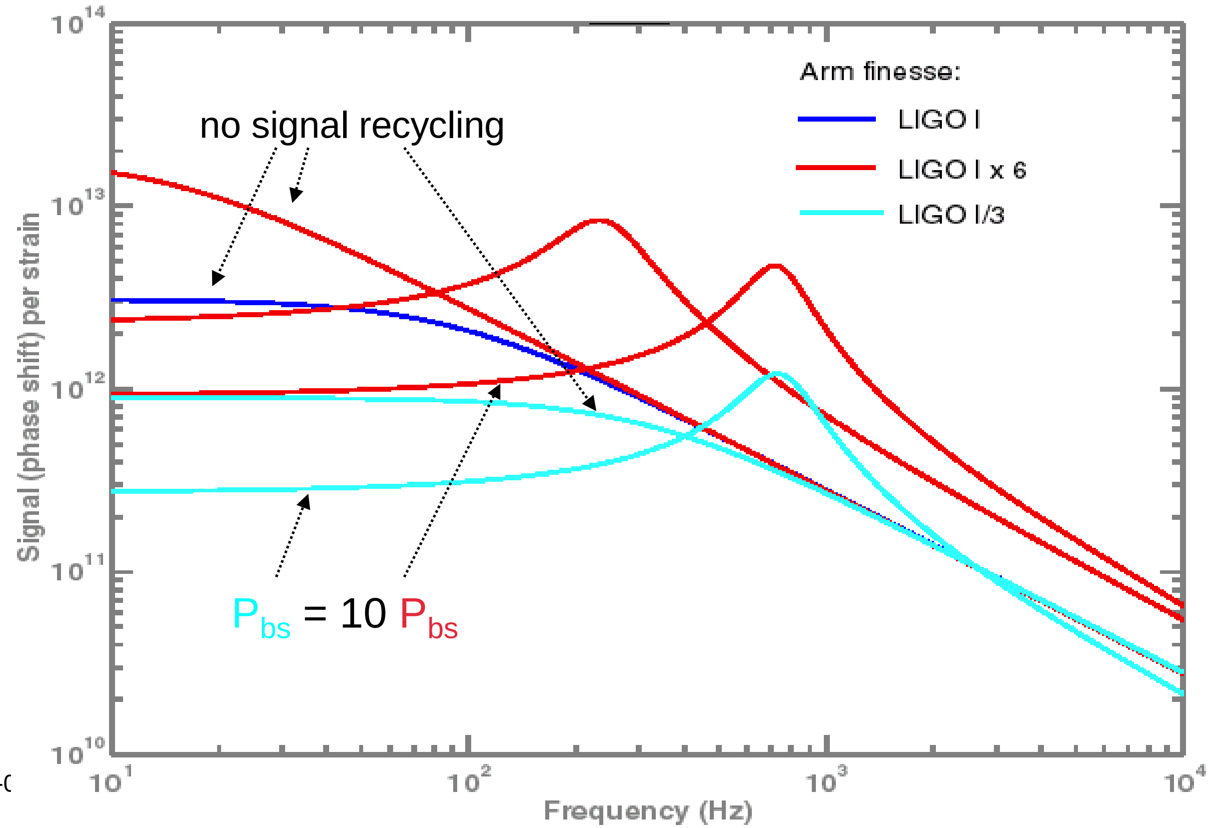
Gravity gradients

What we've left out

- Internal thermal noise
  - » Flat-topped beams to reduce thermo-elastic noise
  - » Cooling of the test masses
  - » Independent readout of test mass thermal motion
- Quantum noise
  - » Quantum non-demolition techniques
  - » Very high power levels, coupled with all-reflective configurations
- Seismic noise
  - » Significant filtering below the gravitational gradient noise limit
  - » Independent measurements of gravitational gradient noise

ISC: Advantage of signal recycling

- Provides ability to do some shaping of the response, but principal advantage is in power handling:
  - » Signal recycled: 200 Mpc NBI range, 2.1 kW beamsplitter power
  - » Non-signal recycled, same P_{in}: 180 Mpc range, 36 kW BS power



GW channel readout: 2 candidates

- RF readout, as in initial LIGO
  - » Phase modulate at interferometer input
  - » Arrange parameters for high transmission of RF sidebands (one anyway) to output port
- DC readout
  - » Small offset from carrier dark fringe
  - » GW signal produces linear baseband intensity changes
  - » Advantages compared to rf readout:
    - Output mode cleaner simpler
    - Photodetector easier, works at DC
    - Lower sensitivity to laser AM & FM
    - Laser/modulator noise at RF frequencies not critical
    - Appears to have better quantum-limited sensitivity, but comparison calculations still in progress
- Either would be used with an output mode cleaner to greatly reduce the detected power
- Chosen scheme will be tested on a suspended prototype
  - » Caltech 40m, possibly also Glasgow
  - » DC readout would be prototyped first at MIT

Summary & Plan

- Systems design: mostly in hand, a few open issues
  - » Sapphire vs fused silica
    - – Hinges mostly on success of sapphire development
    - – Selection scheduled for late-2002
  - » Readout scheme
    - – Sensitivity analysis in progress
    - – Testing to be planned
  - » Optics modeling
    - – Requirements for optics quality & active thermal compensation
- ISC system design
  - » Global sensing scheme exists; derived from table-top experiments over the last ~5 years
  - » Basic control system architecture of initial LIGO is applicable to Advanced LIGO
  - » New hardware envisioned: lower noise ADC/DAC; higher frequency wavefront sensors