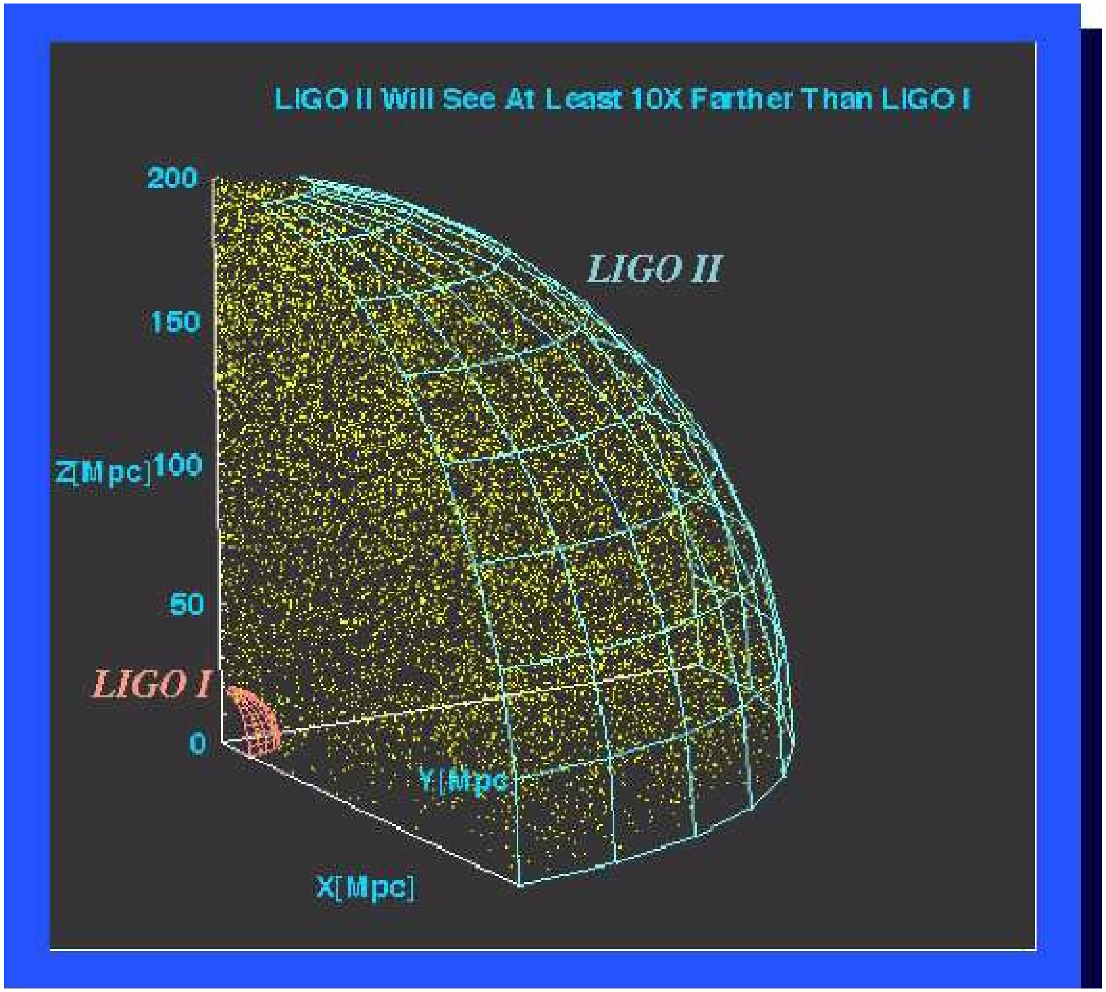
LIGO II: The Second Generation Interferometers



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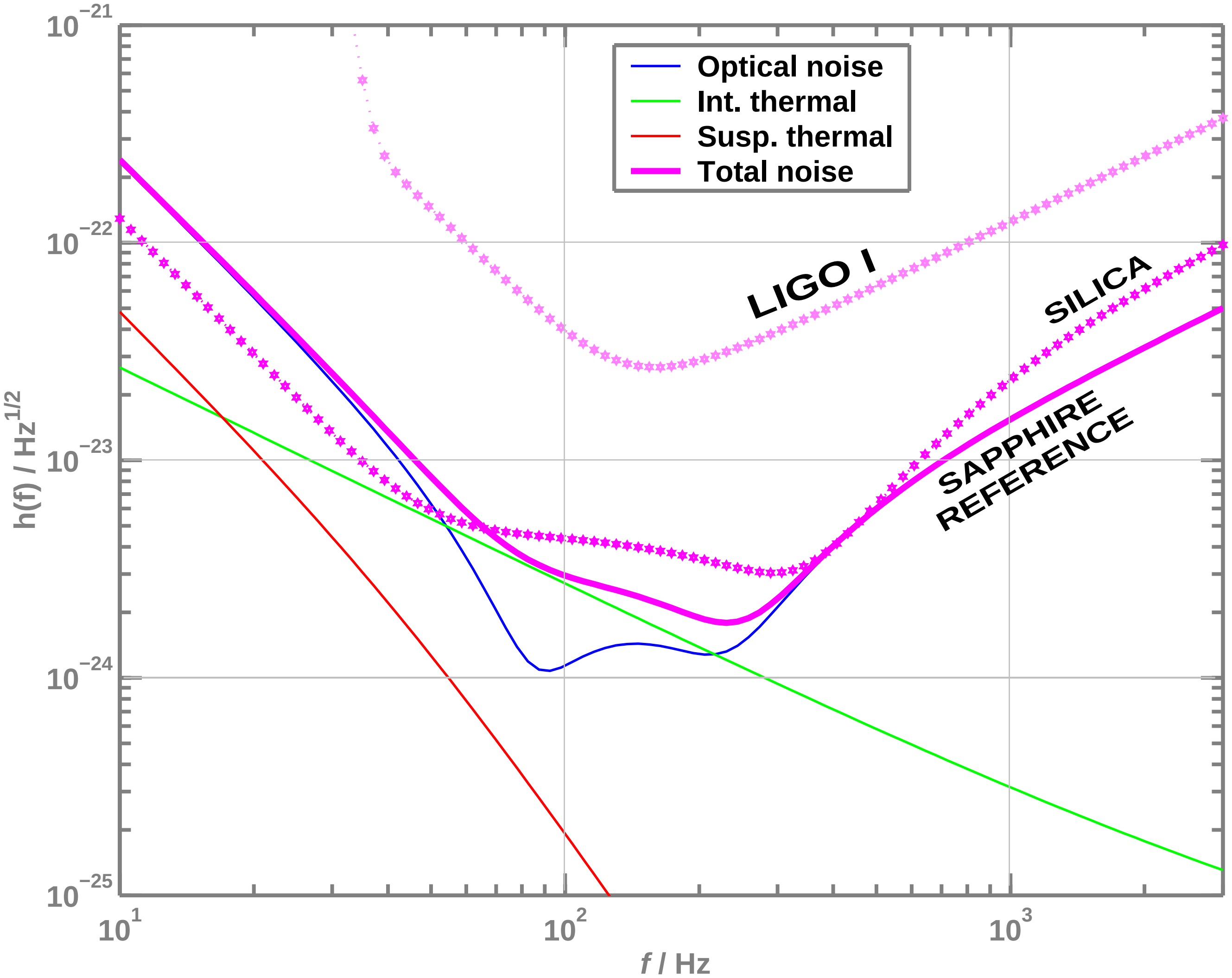
LIGO II: A QUANTUM LIMITED INTERFEROMETER



FROM LIGO I TO LIGO II

- Design comparison:

Parameter	LIGO I	LIGO II
Equivalent strain noise, minimum	$3\times10^{-23}/\sqrt{Hz}$	$2\times10^{-24}/\sqrt{Hz}$
Neutron star binary inspiral det. range[a]	19 Mpc	285 Mpc
Stochastic backgnd sens., $H_{100}^2 \cdot \Omega_{GW}$	3×10^{-6}	$1.5\text{-}8\times10^{-9}$
Interferometer configuration	Power-recycled Michelson w/ FP arm cavities	LIGO I, plus signal recycling
Laser power at interferometer input	6 W	120 W
Test masses	fused silica, 11 kg	sapphire, 30-40 kg
Suspension system	single pendulum, steel wires	quad pendulum, silica fibers/ribbon
Seismic isolation system, type	passive, 4-stage	active, 2-stage
Seismic wall frequency	40 Hz	10 Hz

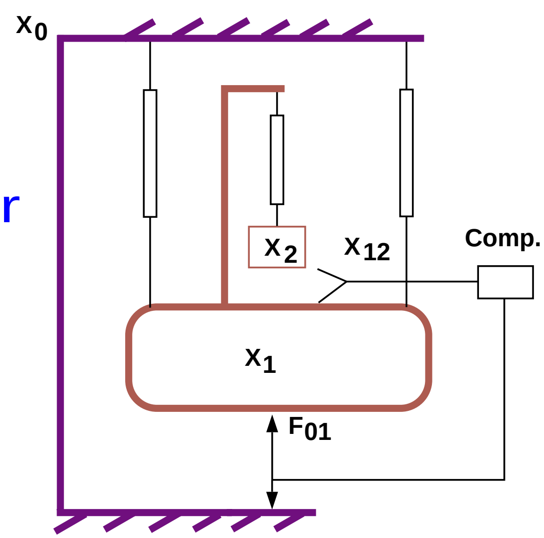
a. numbers are 1.5x the ‘BENCH’ output, to account for multiple interferometers

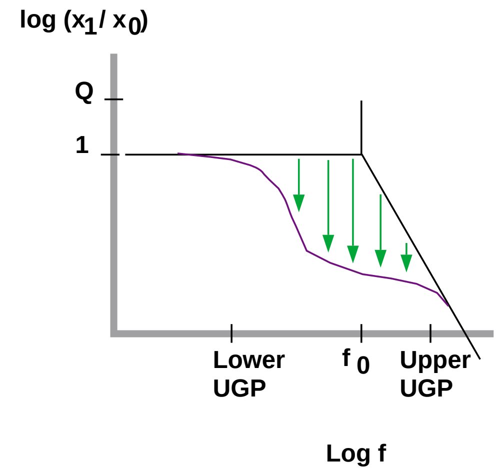
FROM LIGO I TO LIGO II

- Upgrade approach:
  - ➤ number of ifos? *assume all three ifos are upgraded*
  - ➤ increase 2-km ifo to 4-km? *current recommendation is yes*
  - ➤ response? *make 2 optimized for NS-NS inspiral detection, 3rd to be a tunable narrowband instrument*
  - ➤ phasing? *implement one new ifo first (18 mths?), then the second two in parallel*
  - ➤ when? *current thinking is start of 2006 for first ifo*
- Design approach
  - ➤ motivated by what is technically feasible, though still very challenging ➔ achieving a quantum limited ifo, e.g.
  - ➤ motivated by astrophysical benchmarks ➔ heavy use of ‘BENCH’ program to calculate detection sensitivities

ADVANCES IN SEISMIC NOISE

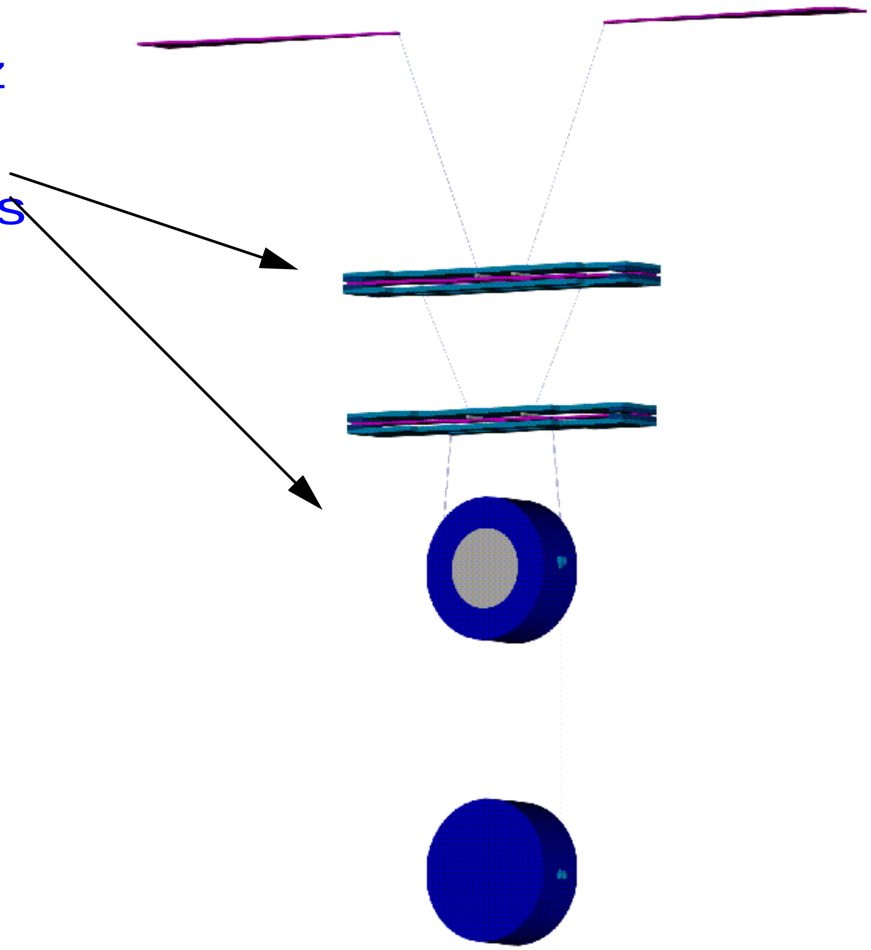
- Goal taken as 10^{-19} m/√Hz at 10 Hz
  - corresponds to level of suspension thermal noise
  - very close to gravity-gradient noise around 10 Hz
  - ground noise attenuation of 10^{10} required
- Active seismic isolation
  - provides ~1/3 of the required attenuation
  - provides ~10^3 reduction of rms at lower frequencies, crucial for controlling technical noise sources





Advances in Seismic Noise

- Quadruple suspension:
  - ➤ ~10^7 attenuation @ 10 Hz
  - ➤ controls applied to upper layers; noise filtered from TMs



- Seismic isolation and suspension systems together: 10^{-20} m/√Hz at 10 Hz
  - ➤ factor of 10 margin

ADVANCES IN THERMAL NOISE

- Suspension thermal noise
  - fused silica fibers, ~10^4x lower loss than steel wires
  - ribbon geometry - more compliant along relevant direction
- Internal thermal noise

Sapphire test masses:

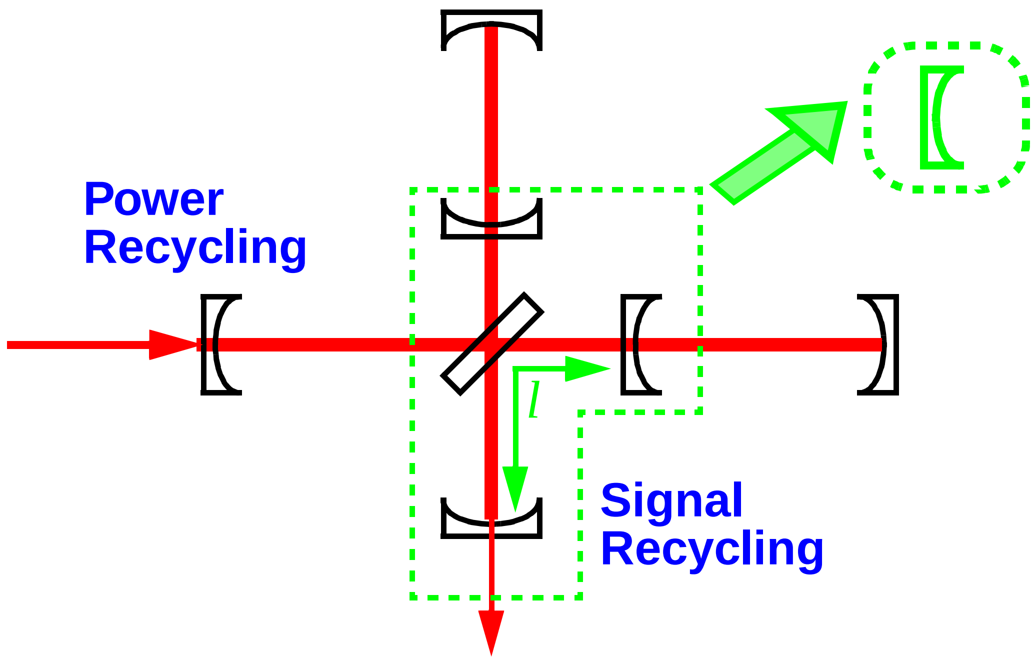
- much higher Q: $2x10^8$ vs $2\text{-}3x10^6$ for LIGO I silica
- BUT, higher *thermoelastic damping* (higher thermal conductivity and expansion coeffs); can counter by increasing beam size (more from Kip)

Fused silica test masses:

- intrinsic Q can be much higher: ~$5x10^7$? (avoid lossy attachments)
- increasing beam size also helps, though more slowly

ADVANCES IN SENSING

- ❑ Input laser power ➔ 120 W
  - ➤ incremental progress in laser technology
  - ➤ thermal management in the IFO becomes a big issue!
- ❑ Optimizing interferometer response

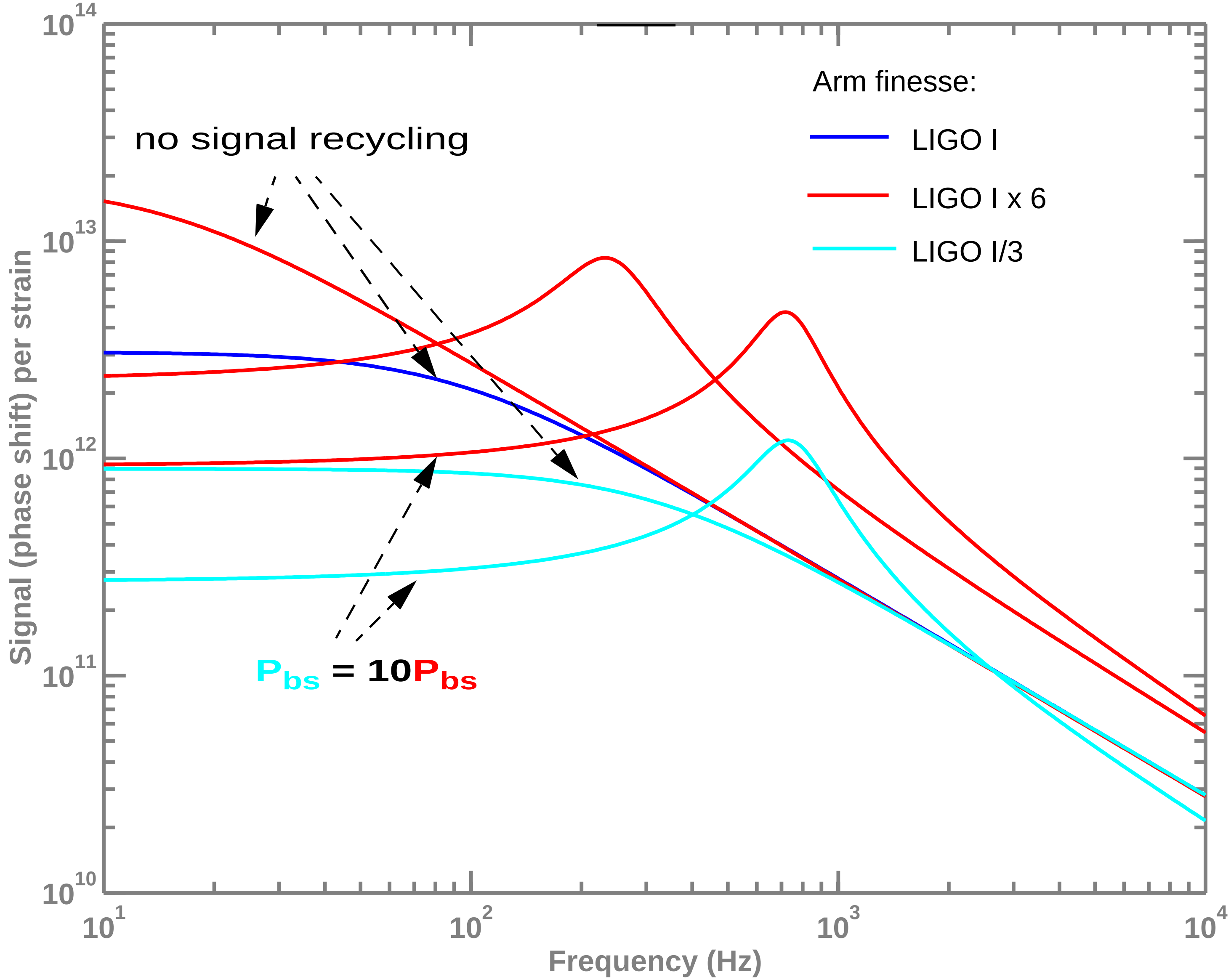


compound output coupler for the GW signal, whose reflectivity depends on:

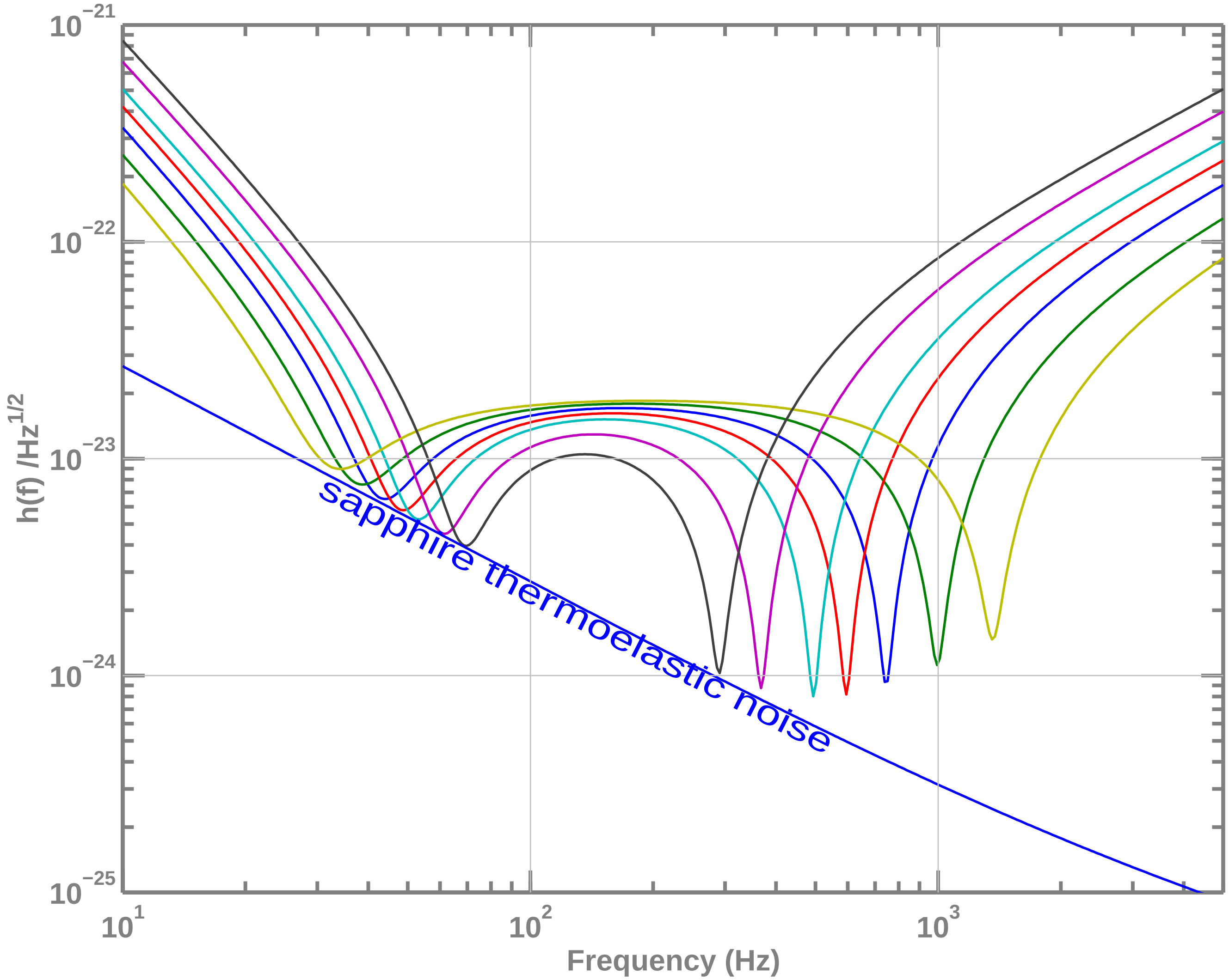
r_{ITM} , r_{SRM} , l_{src}

two more parameters to choose; response can be tailored

Response Functions



A Narrowband Interferometer: 2nd WA IFO?



Example tuning curves for a fixed transmission signal recycling mirror

LIGO II DATA

- Sampling rate
  - no increase over present 16384 S/sec for the GW channel; upper cutoff frequency is 1.5-2kHz for LIGO I & II
- Number of channels:
  - increases due to added complexity: 2-3 x ?
- Number of bits/dynamic range
  - determined by (quasi)-periodic signals (violin modes of fibers), relative to the broadband background (shot noise)
  - thermal motion from a single suspension fiber:

$$x^2 = \frac{k_B T}{2M\omega_v^2(\omega_v/\omega_p)^2} \quad \rightarrow x_v \approx 3\times10^{-18}\text{m-rms, from 500 Hz mode}$$

  - rss all 16 wires: $x_v/x(f) \approx 10^{-17}\text{m}/3\times10^{-20}\text{m}/\sqrt{\text{Hz}} = 300\sqrt{\text{Hz}}$
  - present 16-bit ADCs are OK: $1 - 5\times10^{6}\sqrt{\text{Hz}}$, ~3 orders of mag. from rms to peak (~2 orders for a narrow-band ifo)

SUMMARY

- In its first few hours of operation, the physics reach of LIGO II will exceed that of the 1 year initial LIGO science run
- Much R&D still to be done!
  - sapphire materials development
  - operation at high power: thermal compensation
  - control and readout systems for signal recycling