Future limits to sensitivity

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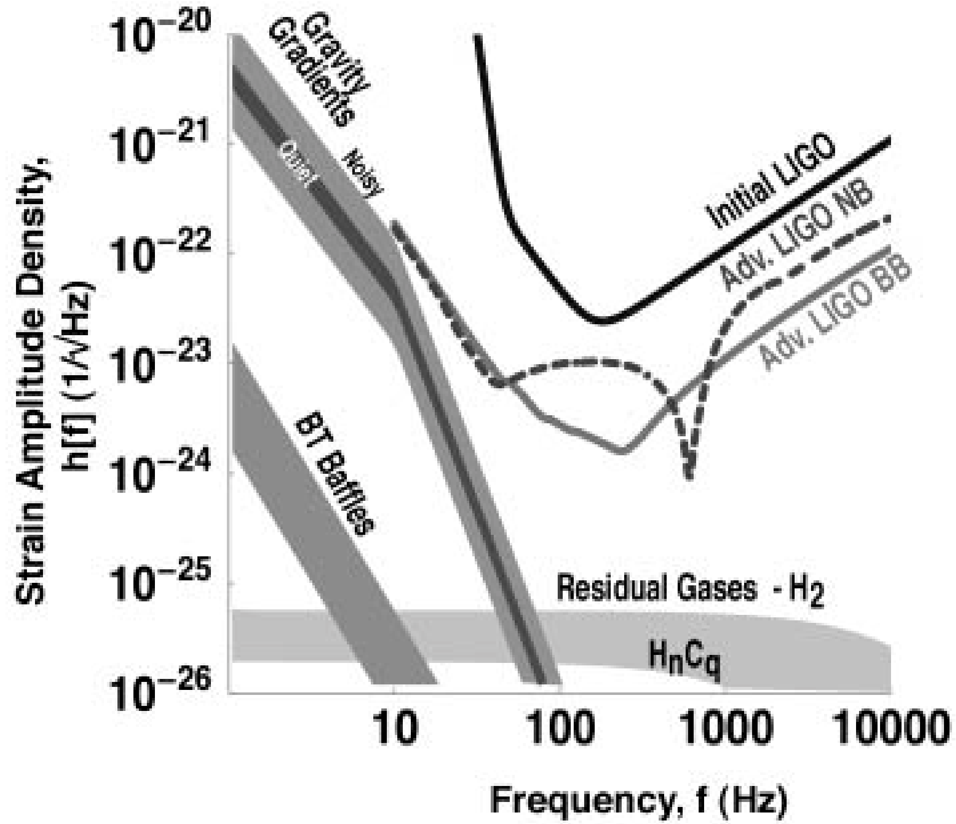
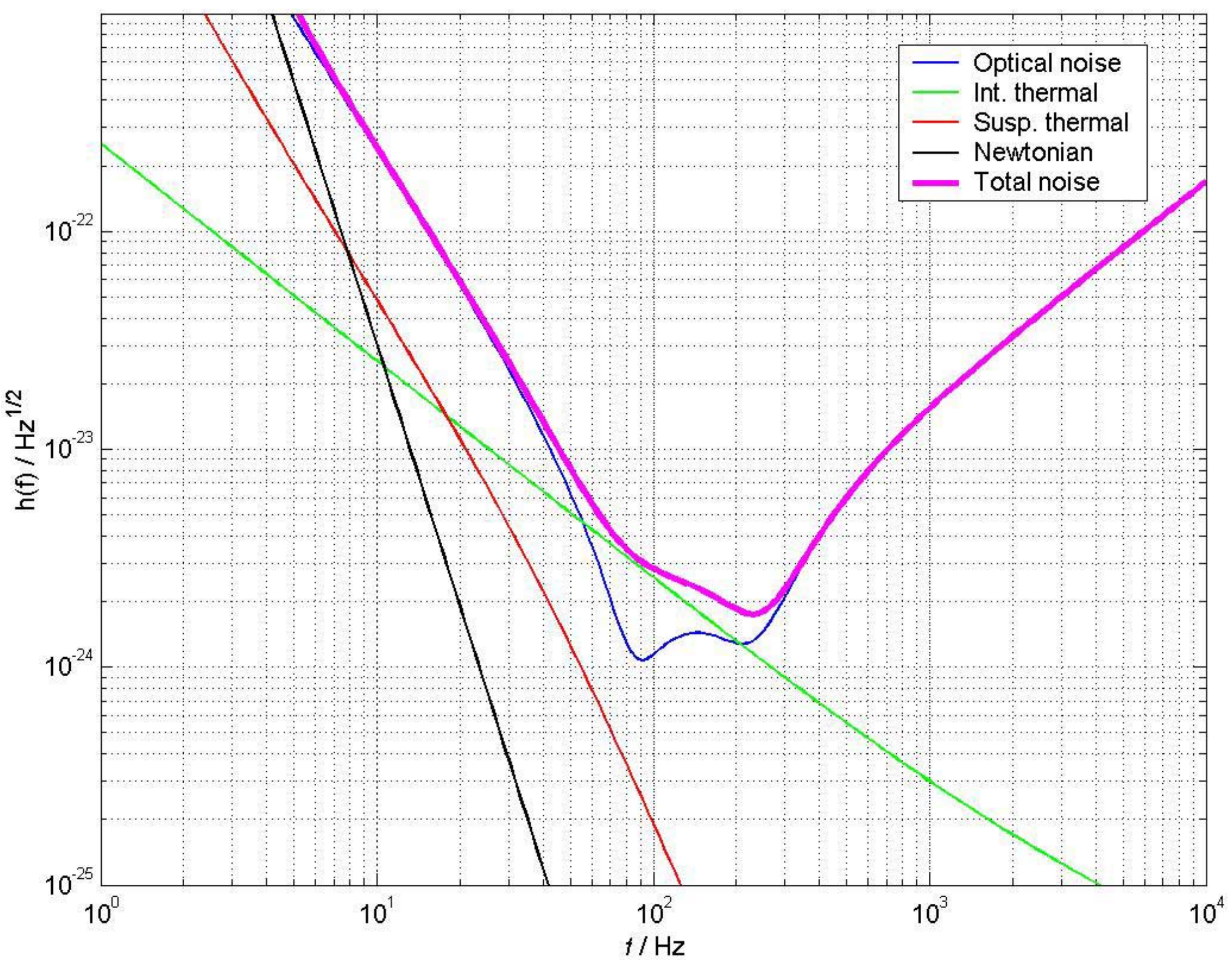
- Facility limits
  - » Gravity gradients
  - » Residual gas
  - » (scattered light)
- Beyond Adv LIGO
  - » Thermal noise: cooling of test masses
  - » Quantum noise: quantum non-demolition
  - » Configurations: non-transmissive systems



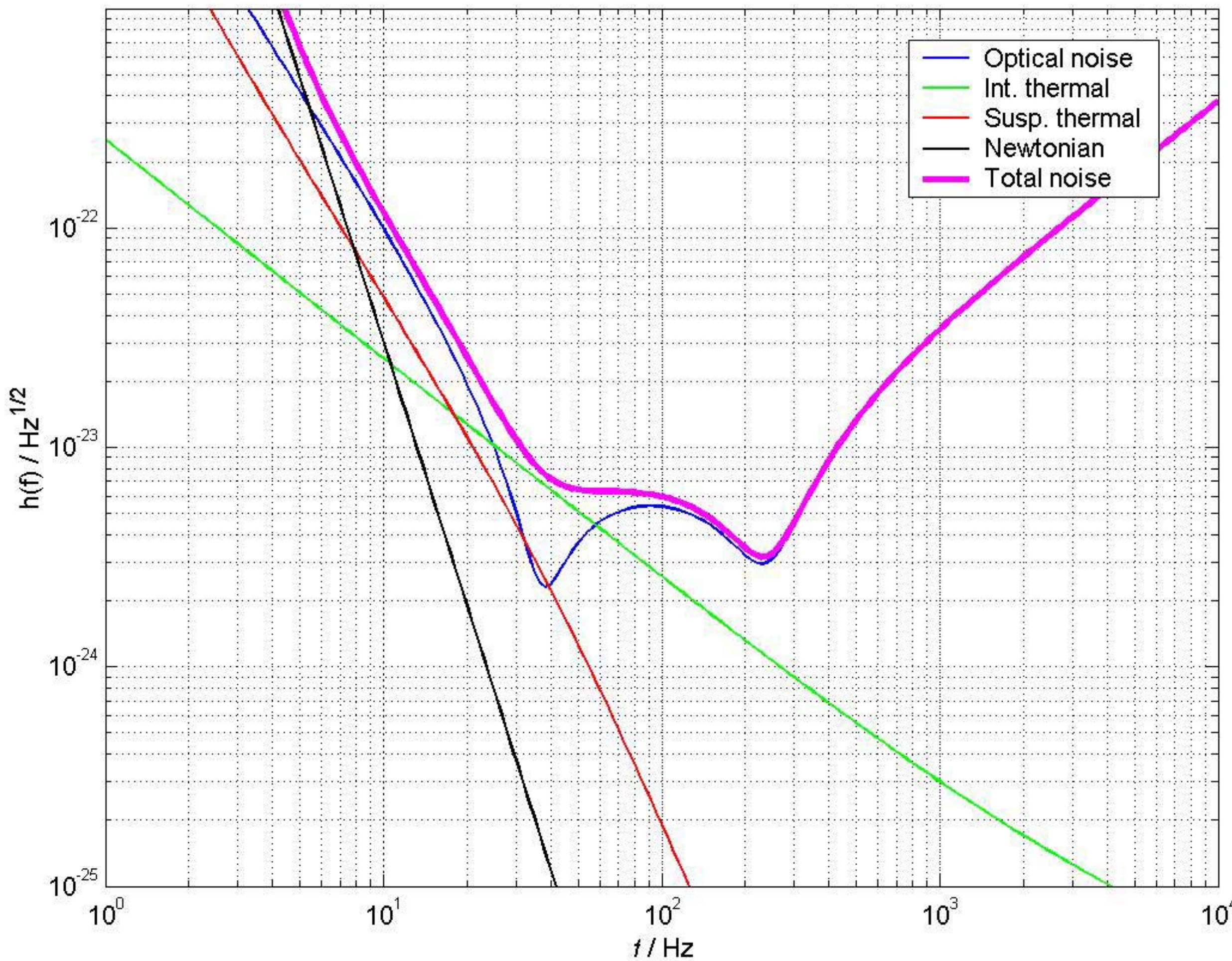
Future System trades

- Lower frequency 'cutoff'
  - » Newtonian background
  - » Possibly susceptible to engineering – for ground, not for air…
- Thermal noise
  - » Both suspension and internal thermal noise have $1/f^{n}$ character
  - » However well we choose materials and cool, quantum noise floor less demanding at low frequencies
- Quantum noise
  - » Larger masses help hold down 'radiation pressure' noise
  - » May be reduced through QND;AND/OR reductions in laser power
- Laser power
  - » Trade between improved readout resolution, and momentum transfer from photons to test masses
  - » Heating of test masses in cryogenic environment
- Numbers and types of interferometers
  - » May well choose to separate low- and high-frequency interferometers to manage power loading, facilitate targeted searches

Adv LIGO parameters – 120 W (200 Mpc)

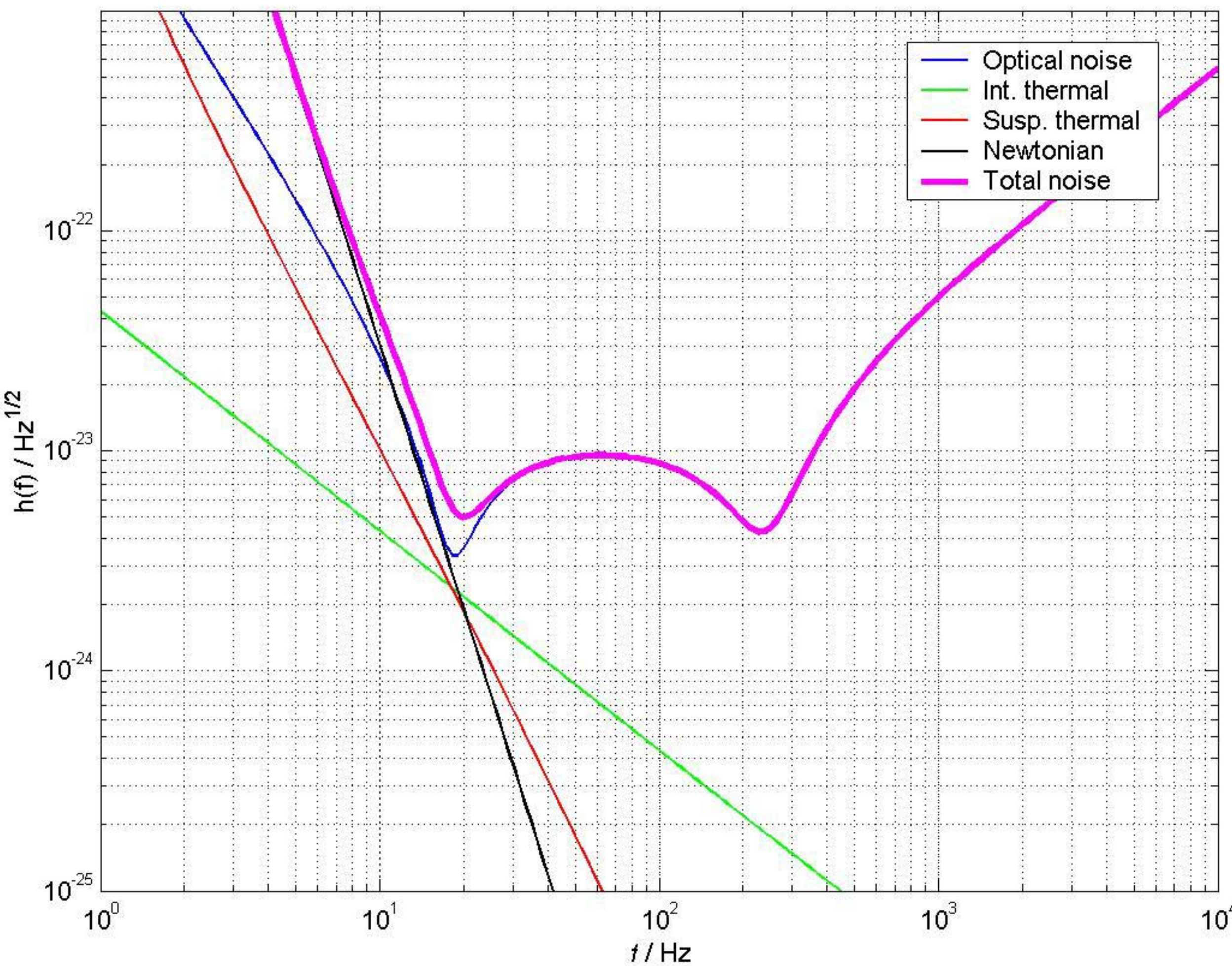


Adv LIGO, 12 W (120 Mpc)

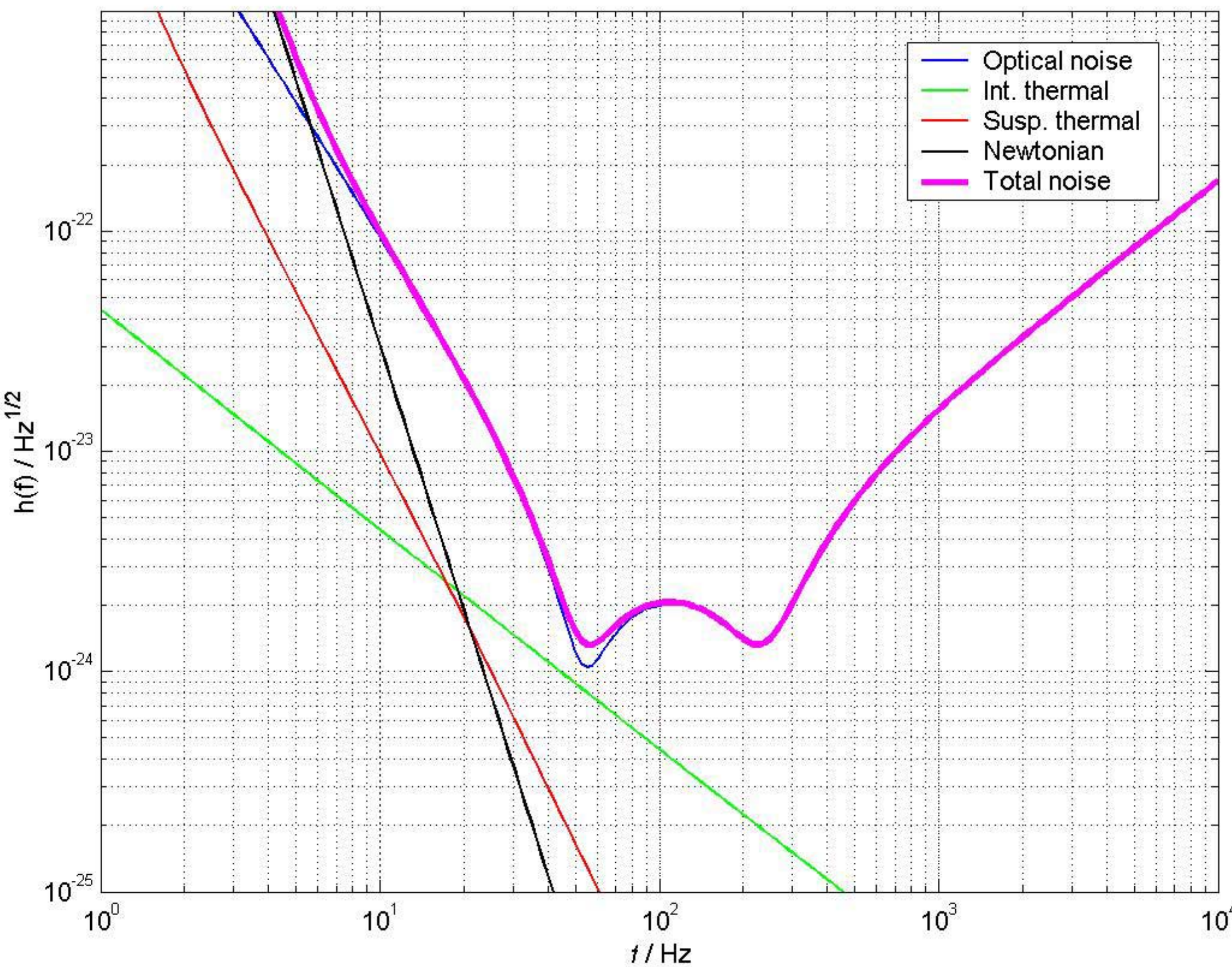


12W, 100 kg, ‘cooled’ (260 Mpc)

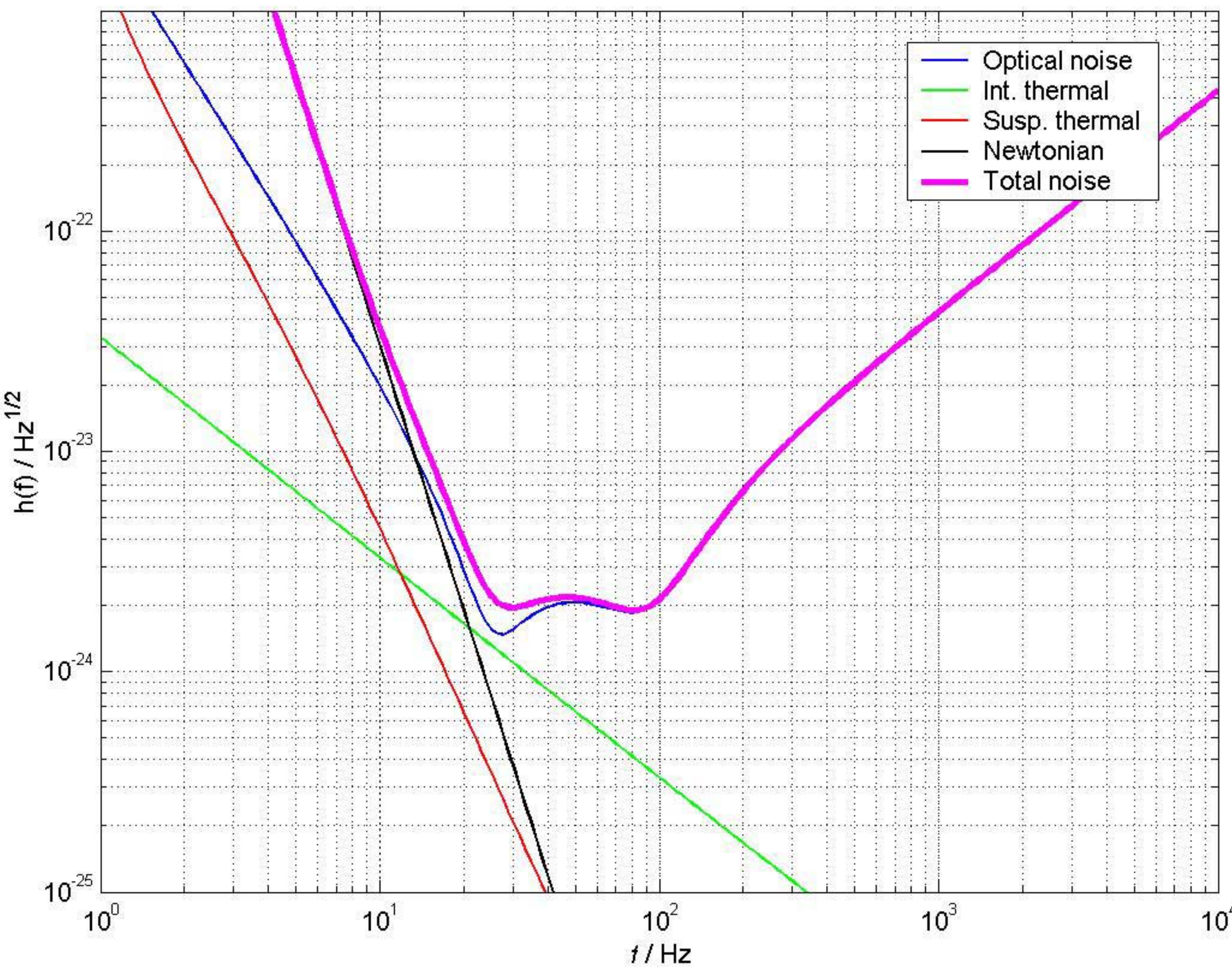
(factor 10 reduction in thermal noise)



120W, 100 kg, ‘cooled’ (420 Mpc)



30W, 230 kg 'cooled' (505 Mpc, 1 ifo)
(RSE optimized, large beams)



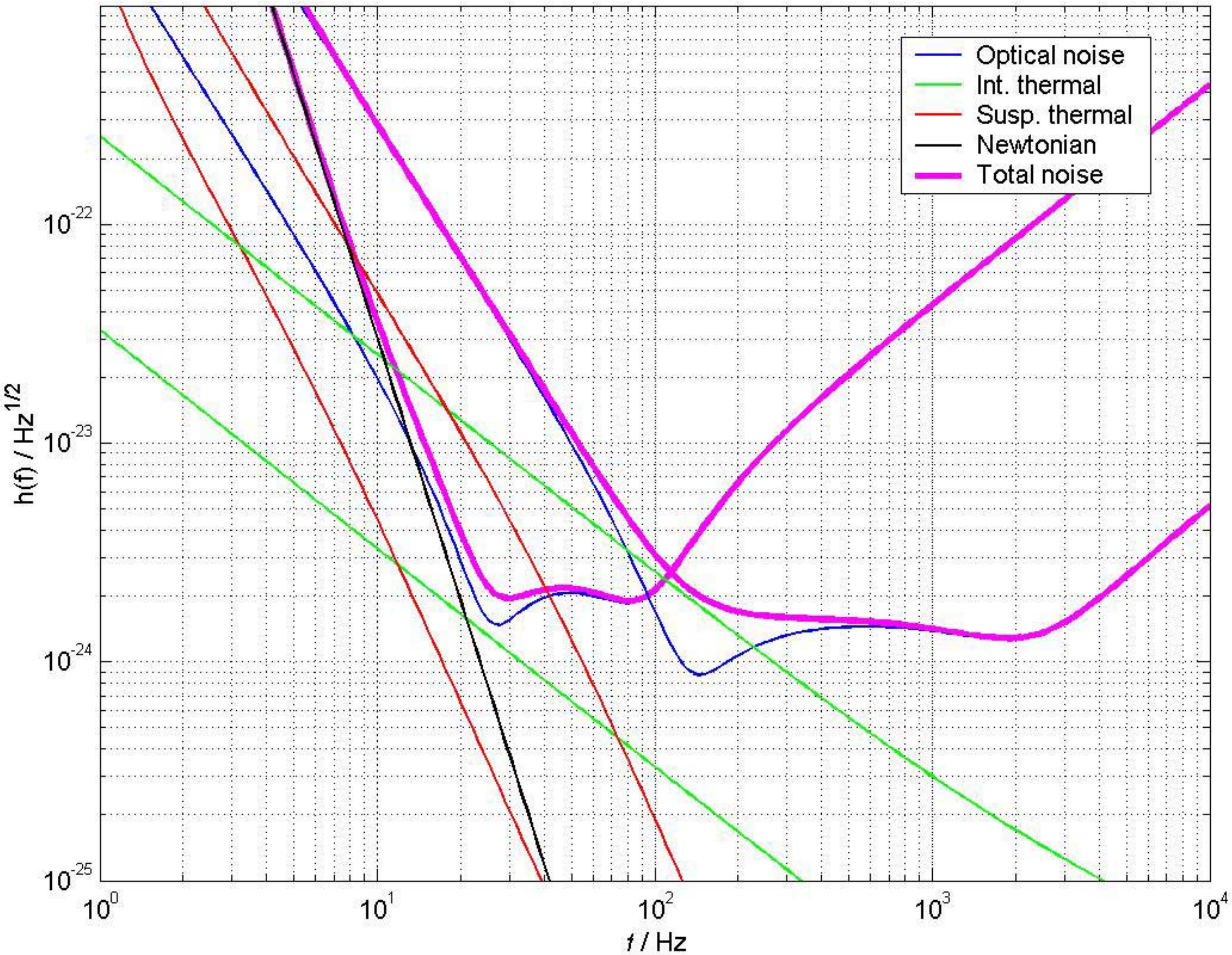
Thoughts on low-frequency interferometers

- Clearly desirable to reduce thermal noise
  - » Cooling is one evident solution
  - » May be susceptible to sensing/feedback schemes as well
  - » Would need to reduce by factor ~100 to reach facility limit
  - » Only need 30 K to drop below reasonable quantum noise
- Low-frequency quantum noise (‘radiation pressure’ regime) a significant noise term; can handle via any combination of:
  - » Increased mass (may also allow better cooling through larger suspension cross section) – 230 kg is 60cm x 20cm sapphire…
  - » Low laser power for low-frequency interferometers – a compromise, but possibly the right one; helps with cooling too
  - » Cleverer readout – advantages for both power dissipated, and for low-frequency quantum noise

Thoughts on high-frequency interferometers

- Frequency dependence of internal thermal noise delightful viewed from this perspective
- If sapphire thermoelastic noise dominates, ~present room temperature performance may suffice for ‘initial beyond advanced’ interferometers
- Low coating and substrate absorption is the key
  » (which can then be applied to cooled interferometer as well)
- Clearly readout schemes are the focus in this regime

Two-interferometer broad-band solution



Parameters

	Low-frequency system	High-frequency system
Fabry-Perot arm length	4000 m	
Laser wavelength	1064 nm	
Optical power at interferometer input	30 W	2500 W
Power recycling factor	17	17
FP Input mirror transmission	0.5%	0.5%
Arm cavity power	200 kW	1.7 MW
Power on beamsplitter	0.5 kW	42 kW
Signal recycling mirror transmission	20.0%	15.0 %
Signal recycling mirror tuning phase	0.3 rad	0.01 rad
Test Mass mass	230 kg	40 kg
Test Mass diameter	60 cm	32 cm
Test Mass and Suspension temperature	30 K (~10 mW load)	300 K
Substrate and coating absorption	2ppm/cm, 0.025 ppm	2ppm/cm, 0.025 ppm
Beam radius on test masses	12 cm	6 cm
Neutron star binary inspiral range (3 ifos)	760 Mpc	340 Mpc
Stochastic GW sensitivity (Bench units)	6 x 10-11	1 x10-8

Lessons

- Mass is critical for low-frequency ifo
  - » 230 kg just enough for 30 W – bigger masses realistic?
- Temperature is not so important
  - » 30 K fine for 230 kg
  - » Larger beams on larger mass help internal noise
  - » Suspension noise goes quickly with temperature (?), low anyway
- Absorption in coating, substrate critical for high-frequency ifo
  - » 0.025 ppm/bounce, 2 ppm/cm for 2500 W
  - » Makes heat load for cooled interferometer very small
  - » For all, assume that coating excess thermal noise is negligible (!)
- Sensing still not at beam-tube index fluctuations facility limit
  - » need a miracle (QND?)
  - » Sidestep brute-force mass, photon needs