Responses to Review Questions

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NSF Review of Advanced LIGO

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G0300294-00-M

Plan for choosing substrate

- Basic notion:
  - » Sapphire development for the downselect close to completed; some measurements remain
  - » Silica development still being pursued
  - » Continue analysis of impact of current material properties on performance
  - » Continue coating development in parallel
  - » Downselect at latest time compatible with other schedule constraints

Sapphire

- Further characterization:
  - » Absorption, scattering (level, spatial scale) on additional samples: 6 months
    - – Caltech scanning setup to be built, and/or SMA Lyon contracted for measurements
    - – Billingsley, Armandula
  - » Homogeneity – confirmation of positive results
  - » Birefringence – characterization of large pieces
  - » Mechanical Q on additional samples: 6 months
    - – Additional existing samples of sapphire – disks, rods
    - – Harry, Willems, Rowan
  - » Trace element analysis – neutron activation, precision spectroscopy
- Experiments
  - » Annealing to reduce absorption: ongoing
    - – Route et al
- Analysis: 6 months
  - » Optics simulation with absorption profiles
    - – Kells, d'Ambrosio
- Times in parallel, data in ~6 months

Silica

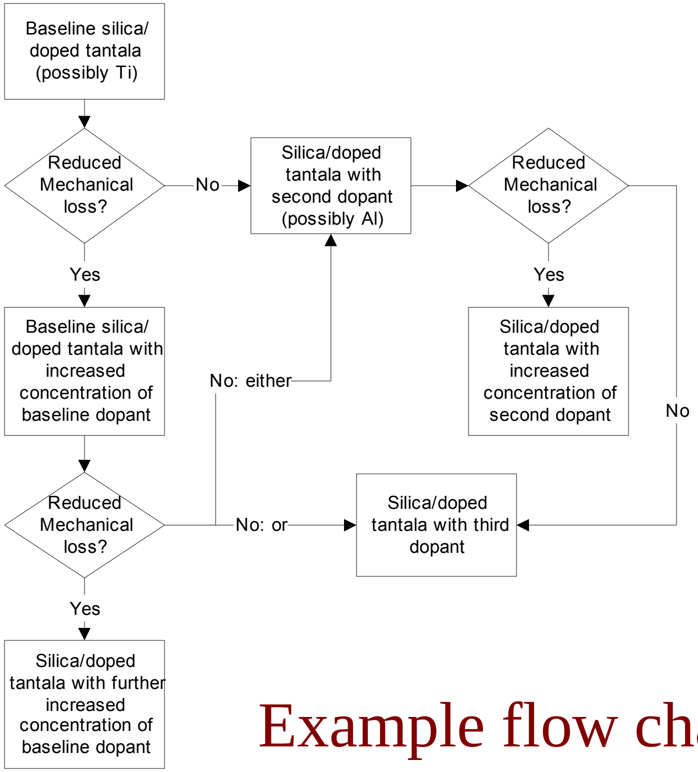
- Measurements to be made
  - » Mechanical Q in input test mass material ('Suprasil 311 SV')
    - – Measure additional existing samples, Acquire additional samples
    - – Harry, Penn, Ageev
- Experiments
  - » Annealing
    - – Oven time to be rented (near term), oven acquired (Penn)
    - – Regimes of time and temperature to be explored, Effect of polishing to be explored
    - – Characterization of sample before and after for optical, mechanical properties
- Polishing test, 3 months, small samples
  - » Ion beam and superpolishing of surfaces, anneal, characterize
- Surface character test, 3 months
  - » Repolish after anneal, characterize
  - → Initial results for comparison with Sapphire
- Scaling of annealing process, 6 months
  - » Scale up to midsize piece
  - » Scale to initial LIGO piece
- Results in ~1 year

Downselect Plan

- Downselect team : Jordan Camp, Marty Fejer, Peter Saulson, Phil Willems, Jim Hough, Peter Fritschel, Sam Finn, David Shoemaker (chair)
- Team meets monthly to discuss progress, choose directions, brainstorm
- Document, web site tracks status –
  - » http://www.ligo.caltech.edu/~gari/LIGOII/Downselect/index.htm
- Downselect Date is April 04
  - » Allows both Sapphire and Silica evaluation to make good progress

Plan for Coating development

- Coordinated trials and characterization
  - » Advanced LIGO Coating Development Plan, LIGO-C030187-00-R
- RFP out,
  - » multiple vendors interested, anticipate selecting 2
  - » Informal responses encourage our approach
- Motivated by experiments to date, perceived expertise in coating vendors
- 8 coating runs anticipated, ~8 months for complete cycle
- Continue with one vendor, refining concept
- Encouraged to pursue program with university materials science expertise – will integrate into program



Example flow chart from plan

Coating Characterization

- Measurements
  - » Internal friction (LIGO, Stanford, Glasgow, HWS)
  - » Optical absorption (LIGO, Stanford, vendors)
  - » Birefringence (LIGO)
  - » Young's modulus (Stanford, vendors)
  - » Thermal expansion (Stanford)
- Team
  - » MIT - Gregg Harry, David Shoemaker
  - » Caltech - Helena Armandula, GariLynn Billingsley, Dennis Coyne, Eric Black, Riccardo DeSalvo
  - » Livingston - Andri Gretarsson
  - » LSC Collaborators
  - » Stanford University - Sheila Rowan, Martin Fejer, Roger Route, Vlad Kondilenko, Alex Alexandrovski
  - » Glasgow University - Jim Hough, Peter Sneddon, David Crooks
  - » Hobart and William Smith College - Steve Penn
  - » University of Florida - Dave Reitze
  - » TAMA collaborators
  - » University of Tokyo - Kenji Numata(GSFC), Masaki Ando

Recovery scenario

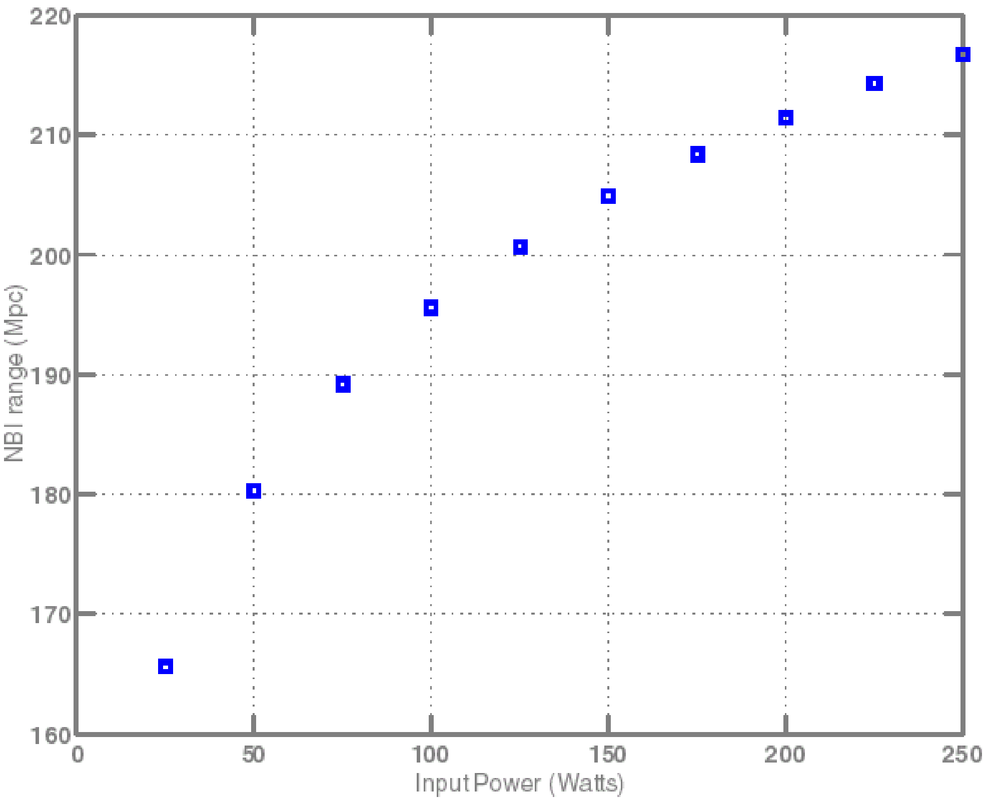
- Suppose no improvement in coatings found before coatings must be applied (in ~2006), BUT then a better coating is developed at a later time (e.g., 2010)
- Spares for test masses would be coated with improved coating; sufficient spares exist to replace all masses in one interferometer
- Old coated masses swapped out for new coated masses
  - » Opening vacuum, but minor activity – down time of ~1 month
- Old coated masses repolished, coated, installed in second ifo
  - » ~6 month turnaround
- Process repeated for third interferometer
- …gradual upgrade of all interferometers over ~1.5 years, minimal down time (~3 months out of ~18 months), cost ~$2M

What are the big steps leading to the Advanced LIGO sensitivity?

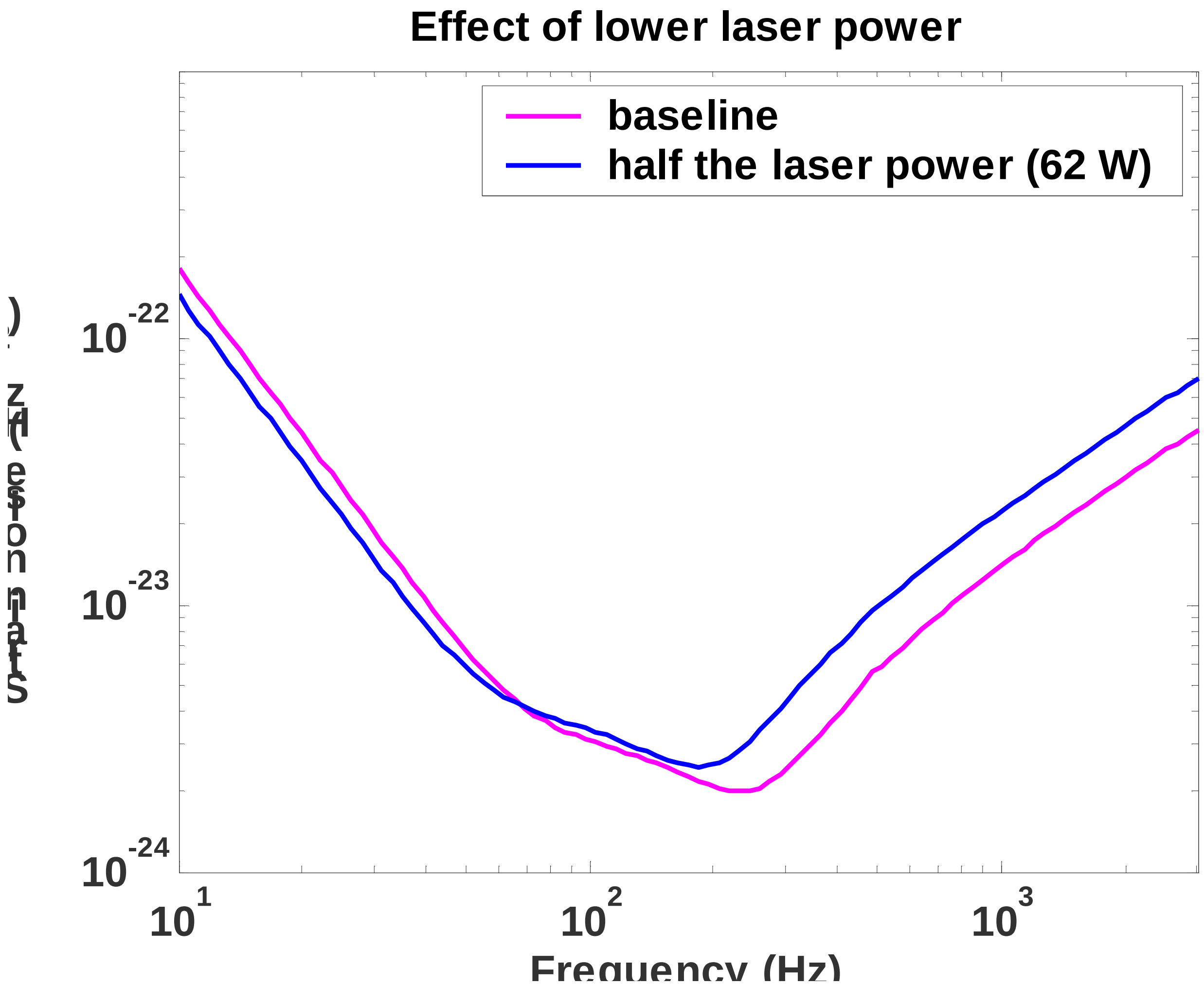
- Seismic noise rendered negligible through a combination of Active Isolation systems, and multiple-pendulum suspensions
  - » Moves wall from 40 Hz to 10 Hz, below Newtonian background
- Thermal noise reduced by materials, assembly techniques
  - » Suspensions of fused silica, monolithic construction lowers suspension noise below Newtonian Background
  - » Choice of low-loss sapphire substrates to minimize internal thermal noise
  - » Development of low-mechanical-loss coatings
- Quantum noise reduced by significant increase in power
  - » Factor of 20 over initial LIGO
- Quantum noise, power "managed" with signal recycling
  - » Optimization of response for given laser power, thermal noise, and astrophysical signal signatures

Risk Items

- Laser power
  - » Plan calls for 180 watts
  - » If do not improve over present 87 W, 32 Mpc instead of 350 Mpc
- Laser intensity noise
  - » Plan calls for 2e-9 ΔP/P (to make contribution 1/10 of other noises)
  - » If do not improve over present 1e-8, nois level increases by 1.11 in amplitude
- Modulators/Isolators
  - » Plan calls for handling 180 W
  - » If can only handle half power, 322 Mpc instead of 350 Mpc
- Sapphire absorption
  - » Plan calls for 40 ppm/cm, irregularities 'moderate'
  - » If do not improve over present average (60 ppm, reduce input power to (40/60), 332 Mpc
  - » If do not improve over present irregularity of pk-pk ~130 ppm and spatial scales of ~0.5 cm, guess 10% power loss, or ~340 Mpc

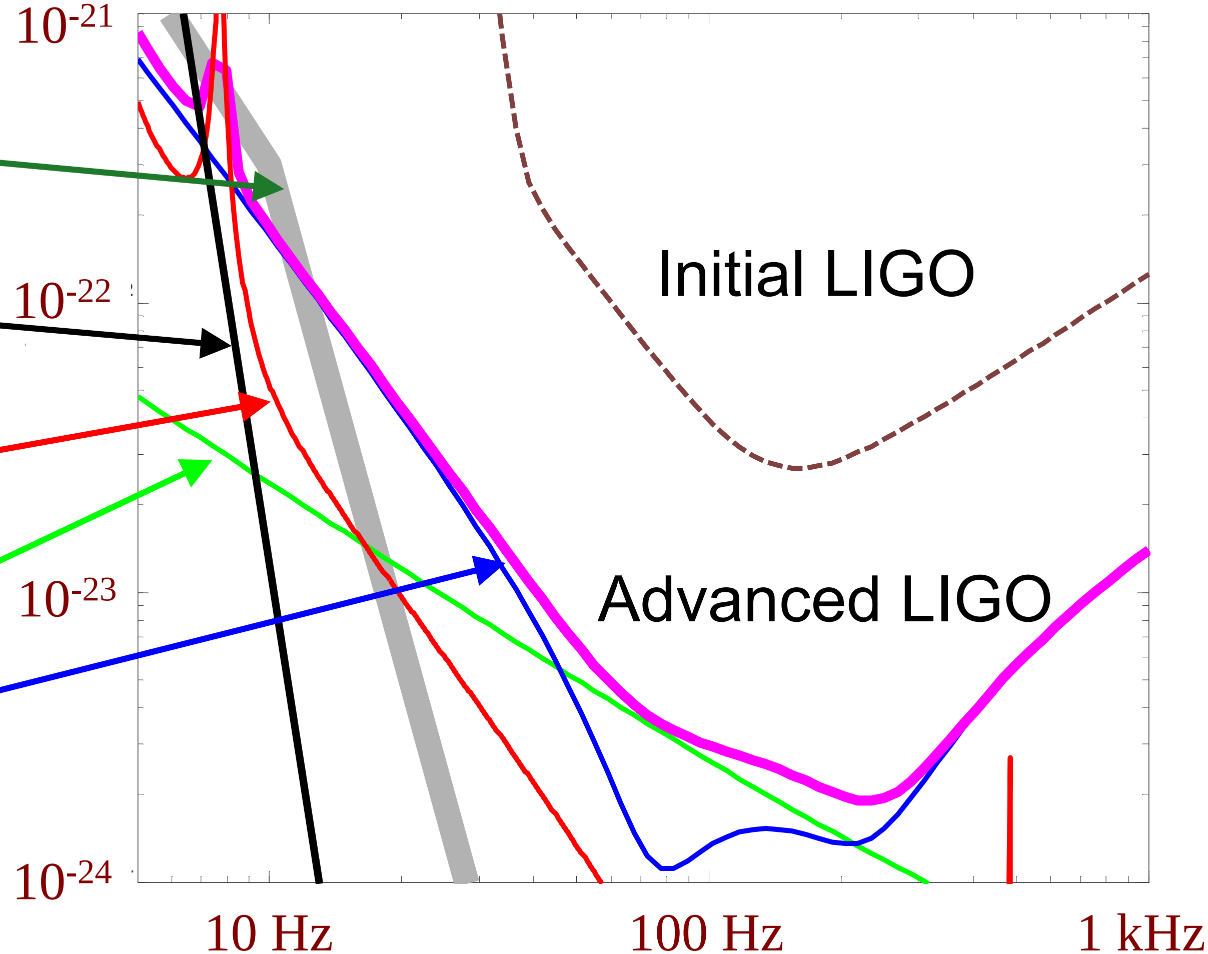


- Impact of reduced laser power or sapphire absorption losses



Anatomy of the projected Adv LIGO detector performance

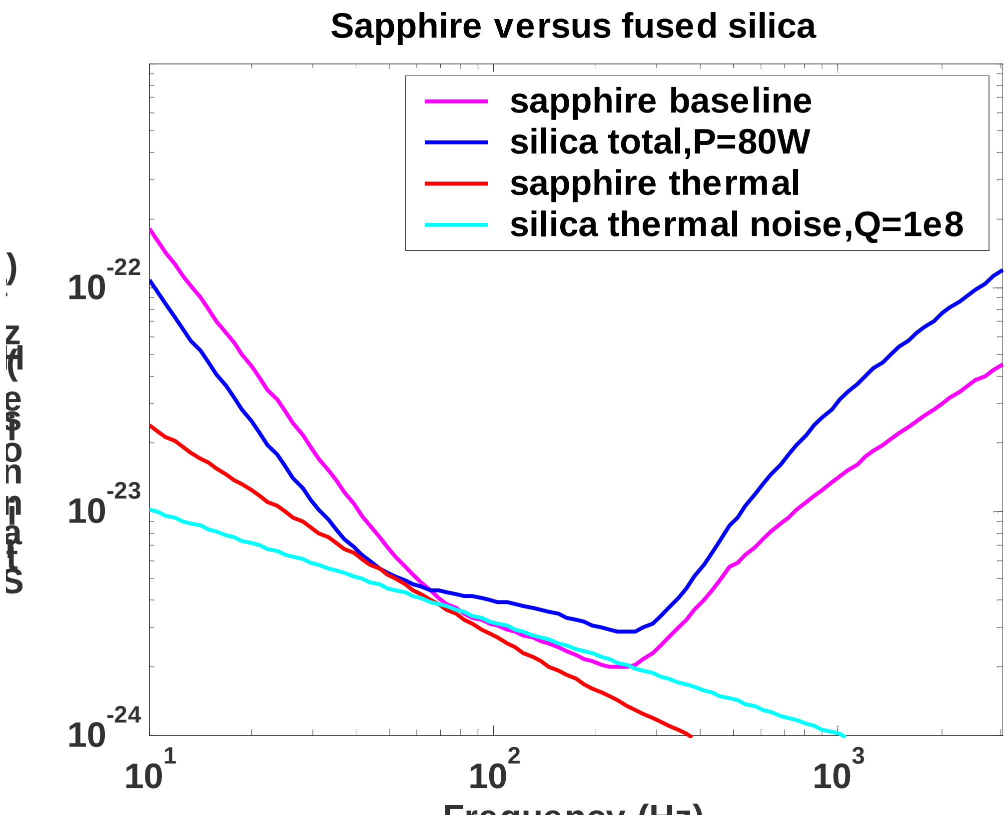
- Newtonian background, estimate for LIGO sites
- Seismic 'cutoff' at 10 Hz
- Suspension thermal noise
- Test mass thermal noise
- Unified quantum noise dominates at most frequencies for full power, broadband tuning



- Advanced LIGO's Fabry-Perot Michelson Interferometer is a platform for all currently envisaged enhancements to this detector architecture

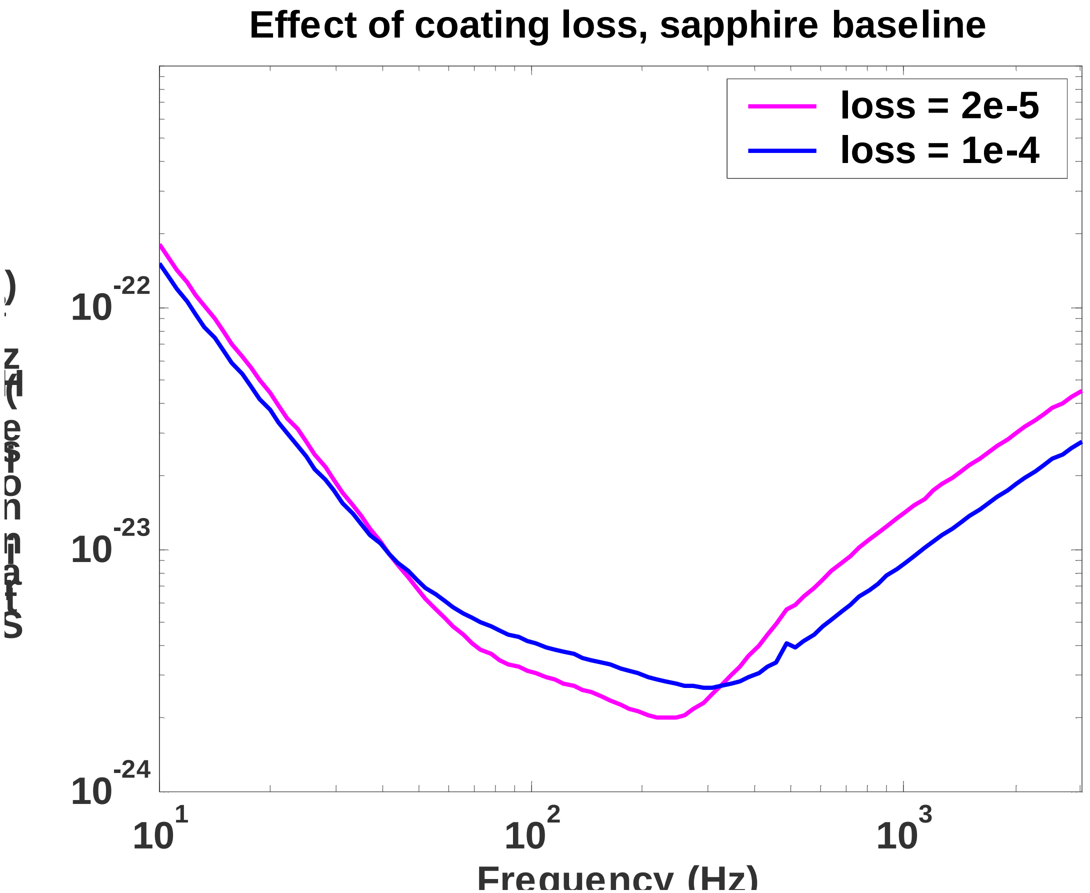
Risk Items

- Test Masses
  - » Plan calls for sapphire
  - » If choose fused silica, good coatings, ~ worst case 300 Mpc



Risk Items

- Coatings
  - » Plan calls for losses of ~2e-5 phi on sapphire
  - » If do not improve over present best 1e-4 phi, 314 Mpc



Risk Items

- Suspension thermal noise
  - » Losses in fiber could be greater than anticipated
  - » Factor 10 increase would give small change in NS seeing
  - » Impact on stochastic background, BH – TBD
- Seismic Isolation
  - » Noise in system could be greater than anticipated, or gains lower
  - » Raises low-frequency limit of interferometer; very hard to raise to 20 Hz, small change in NS seeing
  - » Impact on stochastic background, BH – TBD

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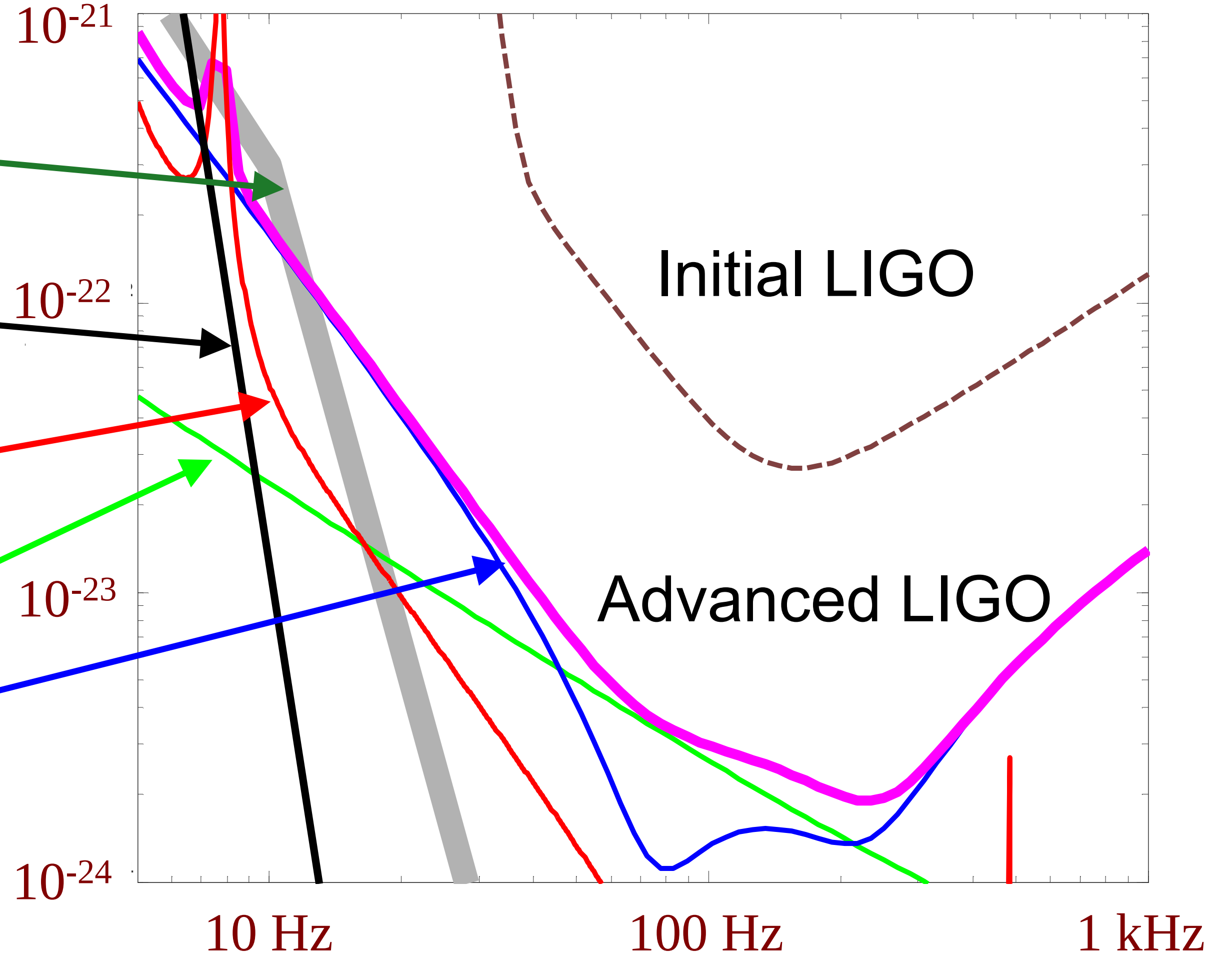

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Risk Items: summary

- Seeing distance for NS binaries, linear noise robust against most shortcomings
- 10-20% losses in sensitivity if we are “stuck” at the present levels of R&D progress
- Most potential risks considered small
- Coating may be a difficult problem to solve –
(but only) 10-20% loss in sensitivity if we find no improvement over current best levels of coating loss