Material Downselect
Rationale and Directions

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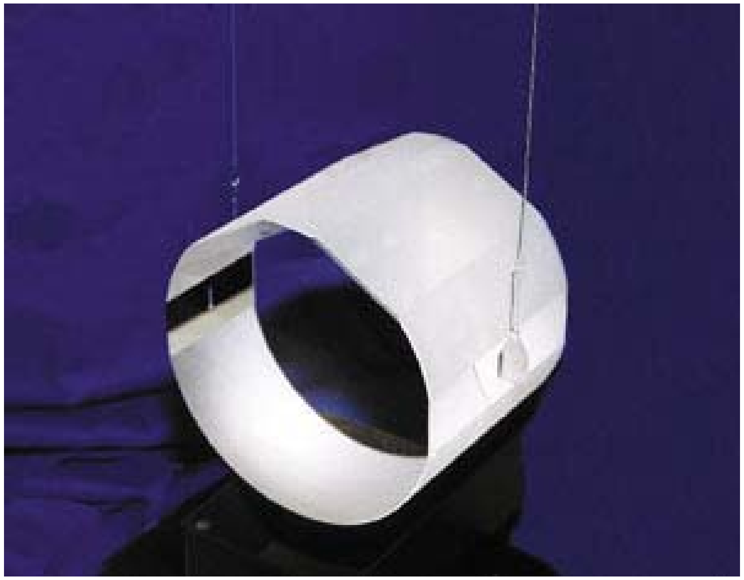
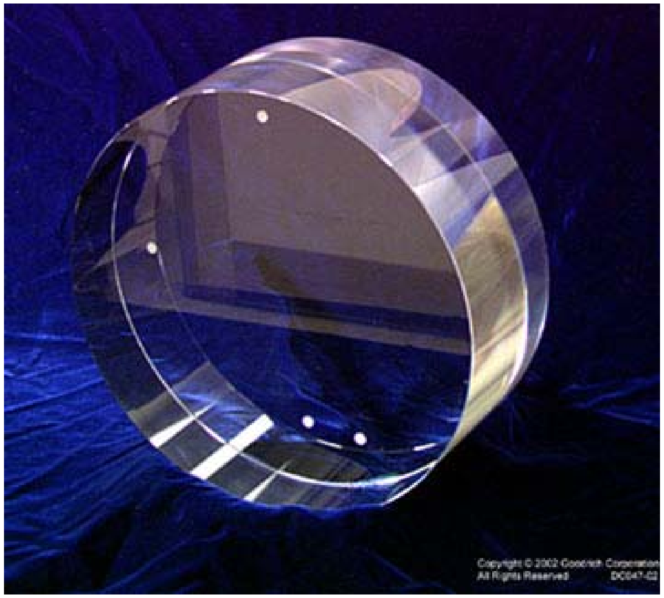
Choice and Rationale
Overview

Silica has been chosen

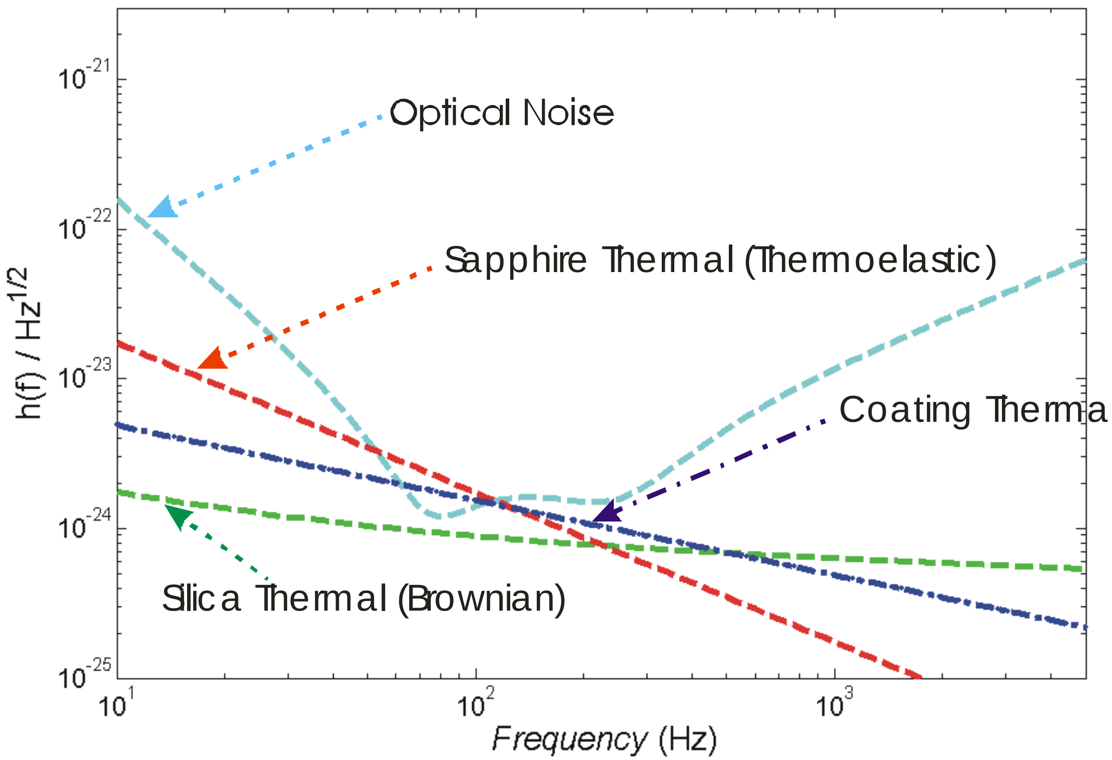
- Astrophysical reach
- Mechanical properties
  - » Thermal noise
- Optical and thermal properties
  - » Thermal compensation and absorption
  - » Polishing and coating
- Integration with suspensions
- Incremental improvements
- Cost and schedule
  - » Risk





Astrophysical Reach

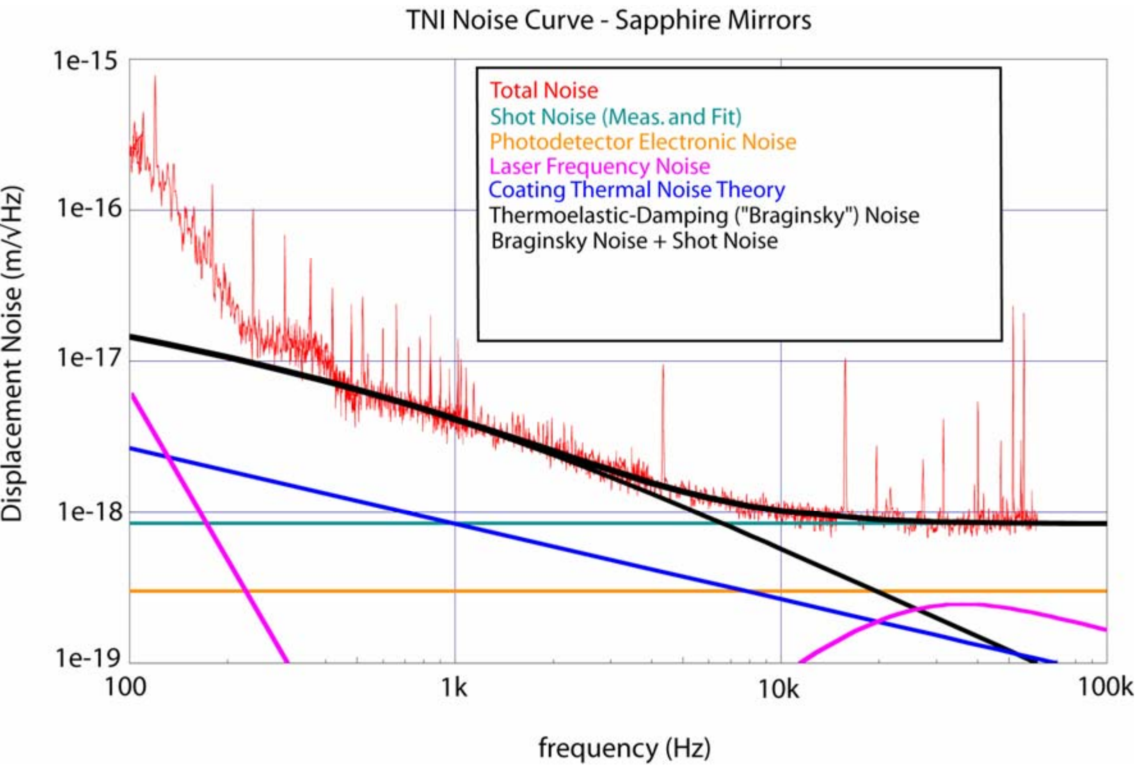
- Both reach goal
  - ~ 200 Mpc BNS range
  - Depends on coatings
- Clear difference
  - Silica – Low frequency
  - Sapphire – High frequency
- High frequencies
  - LMXB – difficult, requires narrow banding, may be coating limited
  - Neutron star mergers
- Low frequencies
  - High mass black hole binaries – should have high rate with either silica or sapphire



	Silica	Sapphire
BNS	191 Mpc	191 Mpc
BBH	1050 Mpc	920 Mpc
Stoch	2.6×10^{-9}	4.8×10^{-9}

Mechanical Properties

Thermoelastic Noise in Sapphire



Excitation of mirror modes

- Not much information
- May be better in sapphire
    - More widely spaced modes
    - Modal Q's probably similar to silica

Thermal noise

Thermoelastic in sapphire

- Well understood
- Observed in TNI, Japan

Brownian in silica

- Mechanical loss data down to 300 Hz
- Frequency dependence
    - loss is less at low frequencies
- Good agreement with theory

Coating thermal noise

- Important for both materials
- More impact on silica
- Less data on sapphire
- Sapphire has higher Young's modulus

Optical and Thermal Properties

Thermal compensation

Sapphire

- Optical absorption
  - Annealing has reached 10 ppm/cm in small samples
  - Concerns about scaling to full size
  - Spatial variation of absorption
- Some concern about effects of crystal structure

Silica

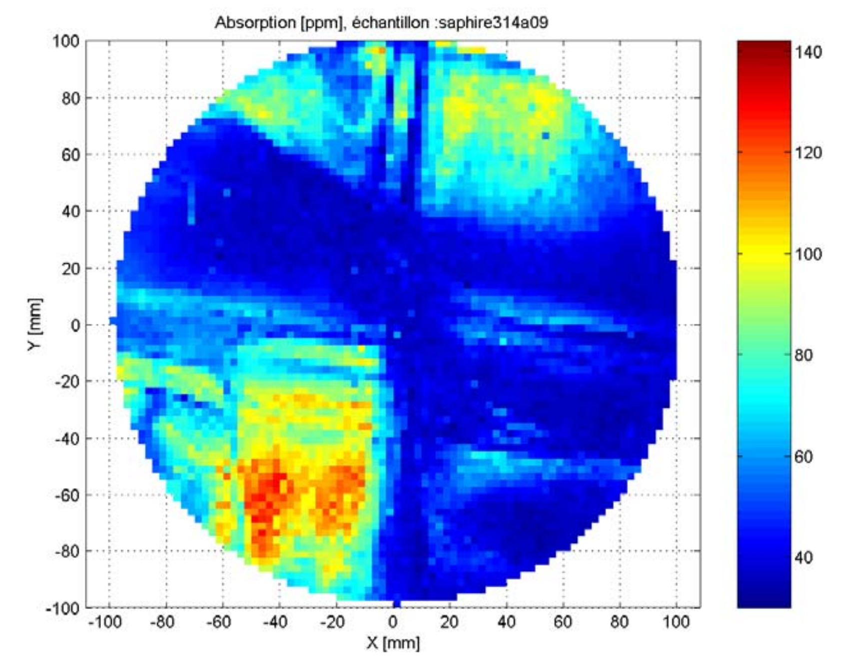
- Lower thermal conductivity
- Experience in compensation with initial LIGO
- Substrate absorption probably not a problem - will be dominated by coatings

Polishing and Coating

- Some problems with sapphire barrel polish
- Some problems with coatings on sapphire
- Need more data on both

Inhomogeneous sapphire absorption

(20 cm diameter)



Integration and Improvement

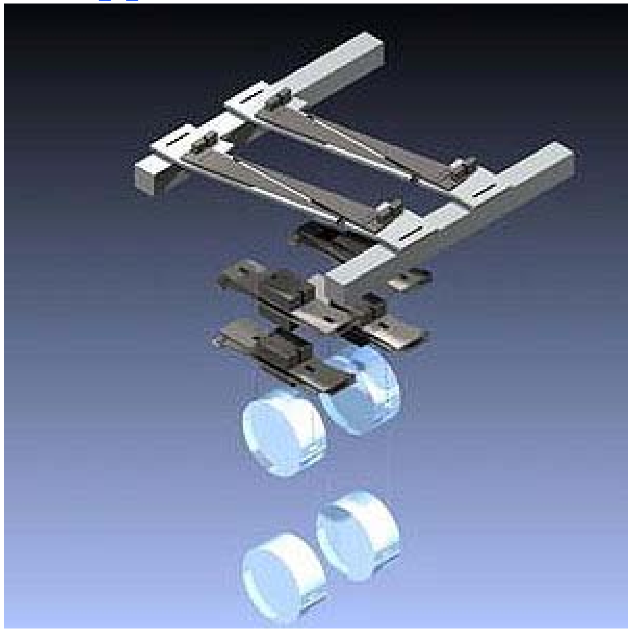
Improvement

Sapphire

- Sensitivity set by thermoelastic noise
- Hard to improve - flat topped beams

Silica

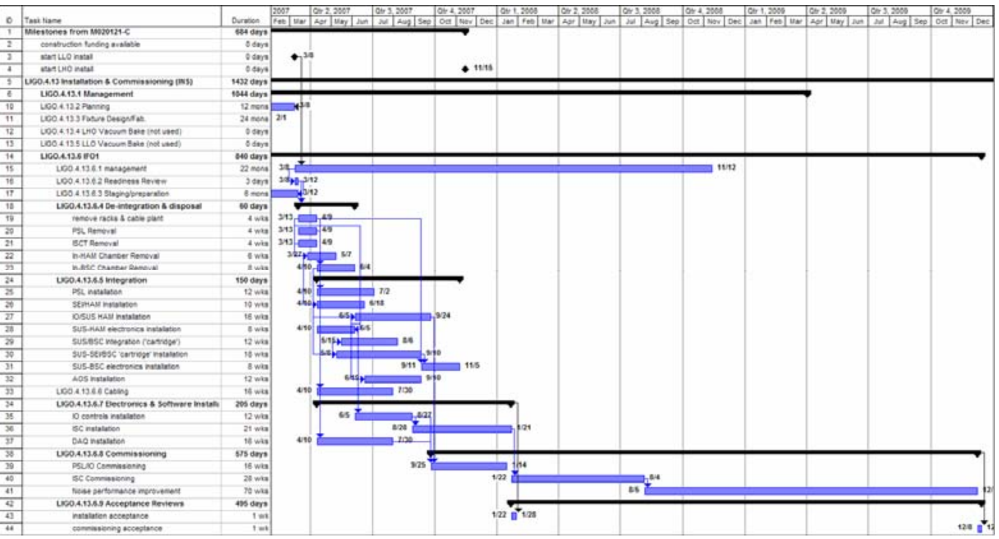
- Sensitivity set by coating
  - Vigorous research effort
- Flat topped beams



Integration with Suspensions

- Sapphire optic smaller
  - Higher density than silica
  - Helpful but not crucial
- Silicate bond
  - Sapphire-silica bond shows creep with annealing
    - Non-Gaussian noise?
  - Silica-silica bond better behaved
- Convertible design
  - Suspension design will allow a change to sapphire optics
  - Can also be used for additional sapphire interferometers

Cost and Schedule



Costs

- Basic costs are (roughly) the same
  - Single (small) vendor for sapphire
  - Two (large) vendors for silica
    - Heraeus preferred

Schedule

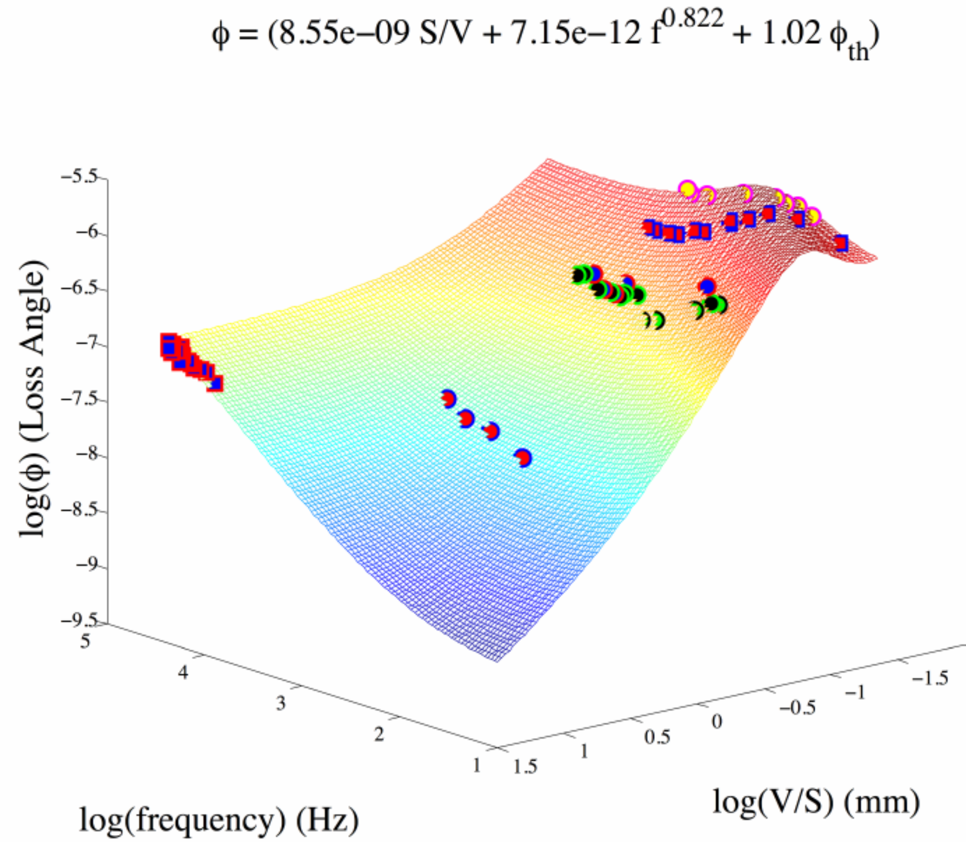
- Both likely to be able to be delivered to specifications
- Concerns about growing, polishing, and coating experience
  - Large LIGO-quality sapphire optics would be new both to us and the industrial community
  - Silica used in initial LIGO and years of industry experience
- Concerns with throughput
  - Single sapphire vendor
  - Greater risk of schedule slip with sapphire

Research Directions
Silica

Thermal Noise

- Annealing effects loss in silica (Numata, Ageev, Penn, Willems, Harry, etc.)
  - Not thought to be necessary
  - Not well understood in theory or model
- Frequency dependence - $\phi \sim f^{0.8}$
  - Big benefit at ~100 Hz
  - Data only down to ~ 300 Hz
- Separation of bulk and surface data
  - Model incorporates both
  - Data is segregated
  - Work is ongoing to fill in parameter space
- Data on larger, full sized, optics
- Flat topped beams
  - Reduces coating thermal noise
  - Direct payoff in sensitivity

Loss In Fused Silica



Other Issues

- Need experience handling large optics
- Possible problems with scatter

Research Directions
Sapphire

Optical Absorption

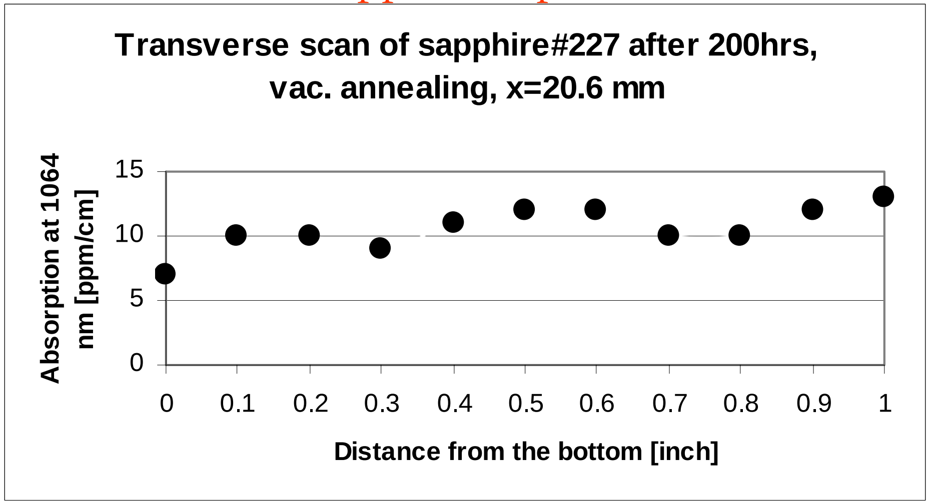
- Annealing is showing results!
  - Both homogeneous and inhomogeneous
  - Study kinetics for scaling to larger optics
  - Stanford to continue low level studies
    - Cost leveraged off other program
- Thermal compensation work
  - Gaining experience with initial LIGO
  - Perhaps can handle higher absorption

Thermal Noise

- Flat topped beams
  - Reduces thermoelastic noise
- Some concern about crystal structure
  - Multiple loss angles
  - Complicated and poorly understood

Sapphire absorption (1 inch scan)

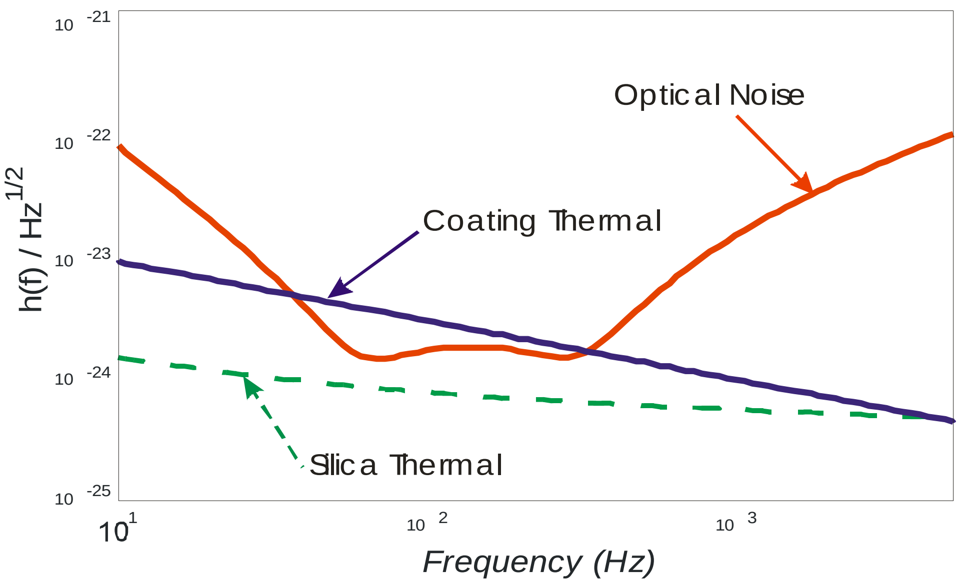
50-100 ppm/cm pre-anneal



Other Issues

- LIGO Lab funding focused on silica
  - A number of sapphire samples in stock
- Collaboration with TAMA
  - Already committed to sapphire
- Develop polishing techniques
- Find other credible vendors

Research Directions
Coatings



Thermal Noise

- Coatings dominate thermal noise for silica optics
- Helps with sapphire as well
- Continue to develop lower mechanical loss coatings
  - Direct sensitivity payoff

Optical Absorption

- Coatings dominate heating for silica optics
  - Need sub-ppm absorption
  - Need homogeneous absorption
- Thermal compensation work
  - Initial LIGO experience

Other Issues

- Scatter
  - Problems seen in initial LIGO
- Reproducibility of properties
- Reflectivity matching between arms

Research Directions
Other

Cleaning and Handling

- Could be limiting issue on optical absorption and scatter
- Upgrade procedures
- May need to upgrade facilities at sites

Astrophysics

- Need more information on high vs low frequency sources
- Benefits of extra sapphire interferometers

Other Issues

- Effects of charging
- Further work on silicate bonds
- Excitation of mirror modes by light pressure

Conclusions

- Silica selected for advanced LIGO
  - Experience from industry, initial LIGO
  - Good thermal noise performance
  - Good thermal and optical behavior
  - Thermal compensation challenges (from coatings)
- Sapphire is solid fall-back (or –forward)
  - Thermal compensation challenges (from substrate)
  - Higher uncertainties in schedule and costs
  - Less possibility to improve sensitivity
- Continuing work is crucial
  - Coating issues dominant in thermal noise and thermal compensation
    - Research effort should provide real payoffs
  - Some questions remain with silica thermal noise
  - Progress is being made on sapphire absorption
  - Engineering may be crucial – handling, cleaning