Cryogenic LIGO Upgrade

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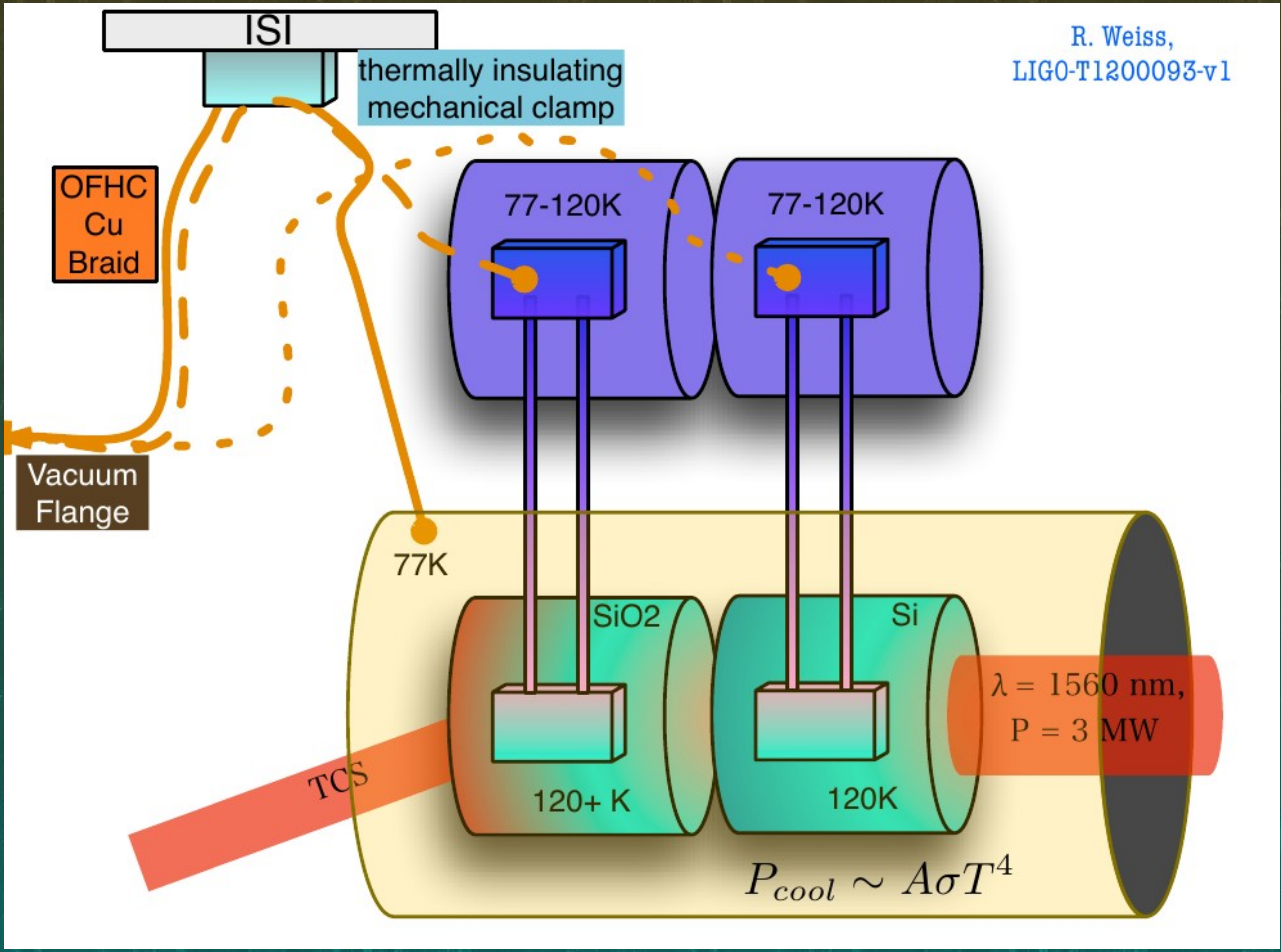
Conclusions

- Cryogenic Silicon allows for high stored arm power not just thermal noise benefit
- We have ideas for the 140kg test mass
- We are still learning about the behavior of Silicon optics
  - 2 photon induced free carrier absorption is not a problem
  - Carrier density thermal noise may be very important, more work needed

Cryogenic LIGO

- 3-fold broadband sensitivity improvement over aLIGO goal
- Pure silicon test masses
  - Cryogenically cooled (124K)
  - 150kg mass
- Squeezed light at 1550nm



Design features

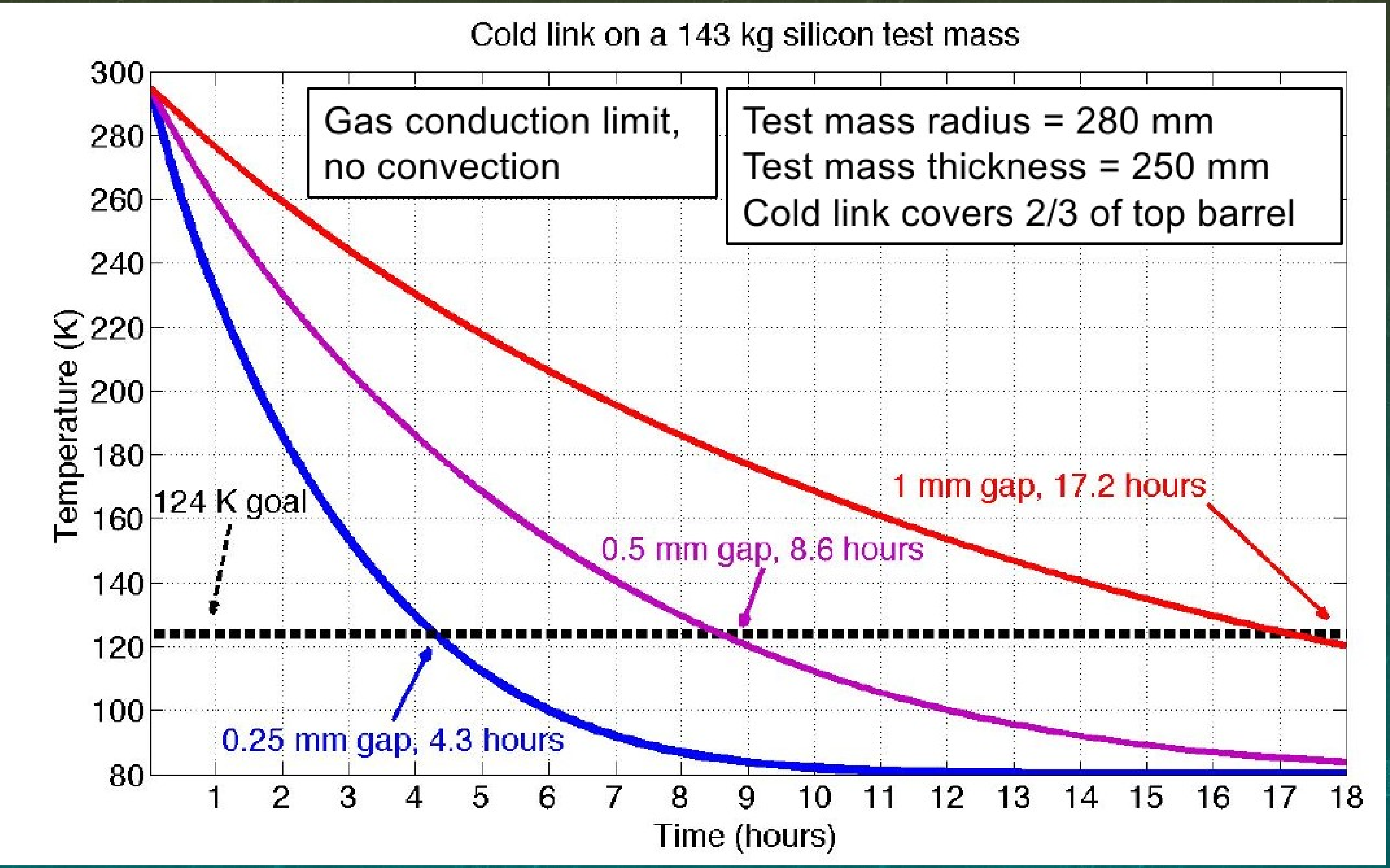
- High thermal conductivity of silicon suppresses thermal gradients
  - High power circulation in arm cavities, shot noise reduction
- Cryogenic suspension and crystalline mirror coatings
  - Reduces thermal noise
- "Generic" features
  - Frequency dependent squeezed light injection
  - Larger masses

Challenges

- Radiative cooling system
- Production of large silicon test masses
- Absorption
  - Substrate and coating
- 1550nm quantum optics
  - Intrinsic QE of InGaAs improves compared to 1064nm
  - 12dB squeezing already demonstrated down to ~10kHz

Initial cool-down simulation

- B Shapiro

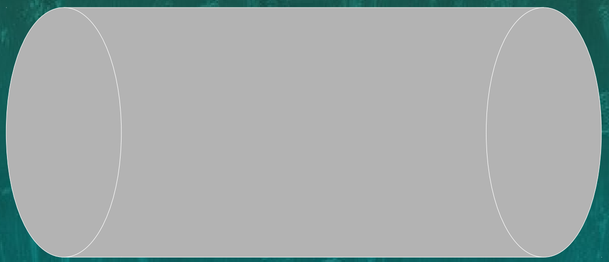


Steady state test mass cooling/heating

- Radiative cooling capacity
  - About 10W
- Heating
  - Cavity power absorption ~6W (assuming 2ppm abs.)
  - 300K radiation through 10m cryogenic duct <10mW
  - ITM substrate absorption ~few W
- More detailed thermal model is needed
  - Emissivity of test mass coatings is not known

Test mass geometry

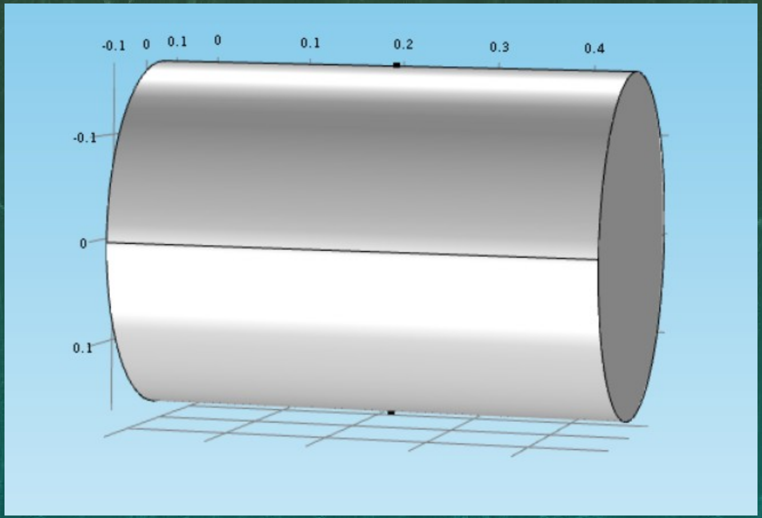
- Float zone purity required, but not currently available in pieces with 0.5m diameter
- Possible solutions
  - Composite test mass with FZ in the center, and surrounded with CZ
  - All FZ, log shaped test mass

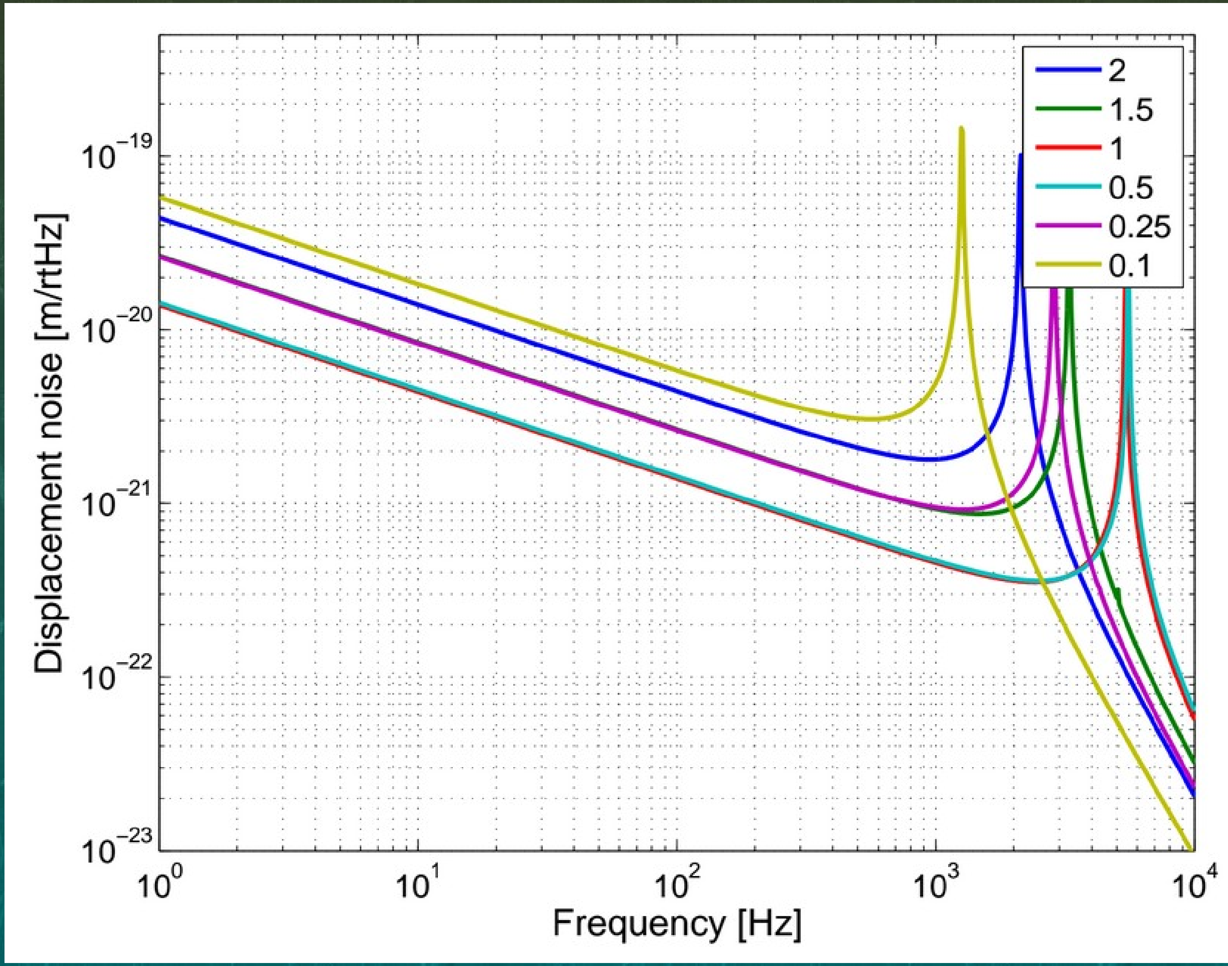


Thermal noise of a log

- How does TM thermal noise scale with aspect ratio?

TM with r/t = 0.5





2 photon induced carrier absorption

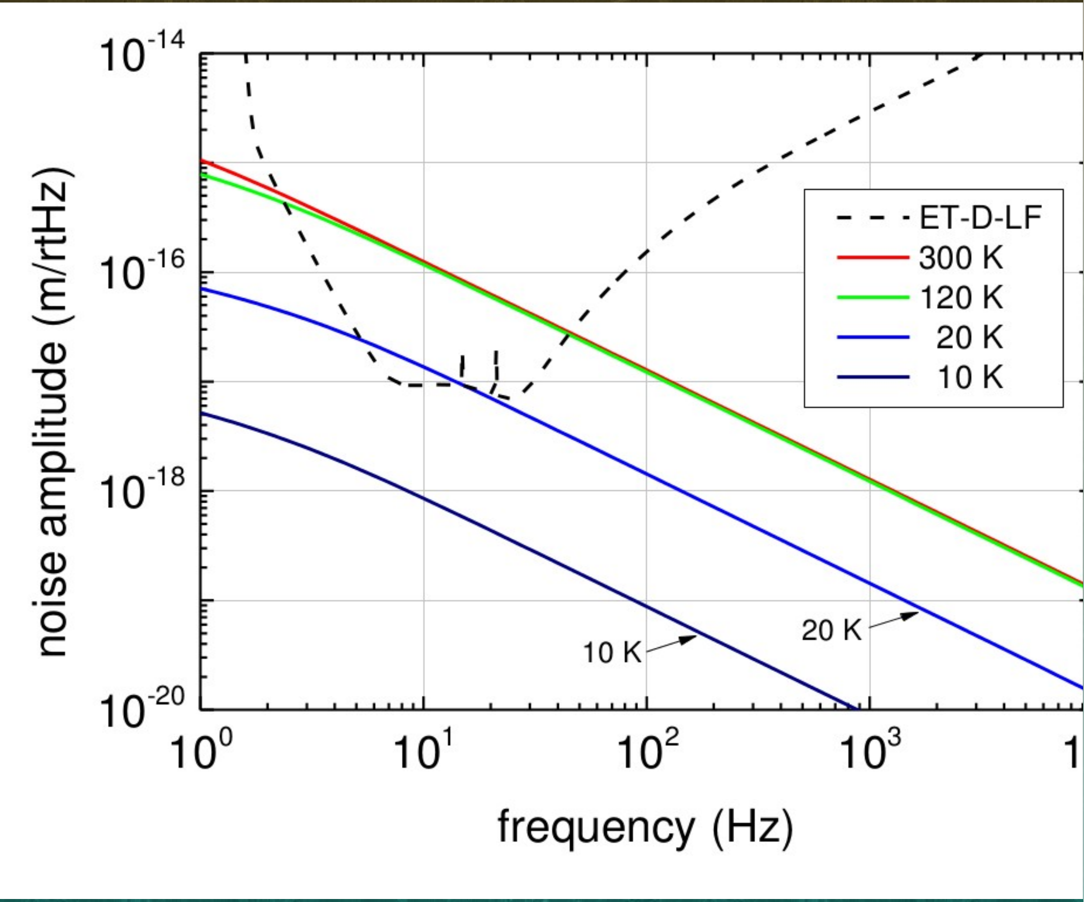
- Visit from Stanford group (Shapiro, Lantz, Fejer)
- Intensity in ITM is: 100W/cm^2

$$\alpha = 3000 \frac{\text{ppm}}{\text{cm}} \times \left(\frac{I}{10\text{kW}/\text{cm}^2} \right)^2$$

- Absorption = 0.3 ppm/cm
- This absorption mechanism is not a problem

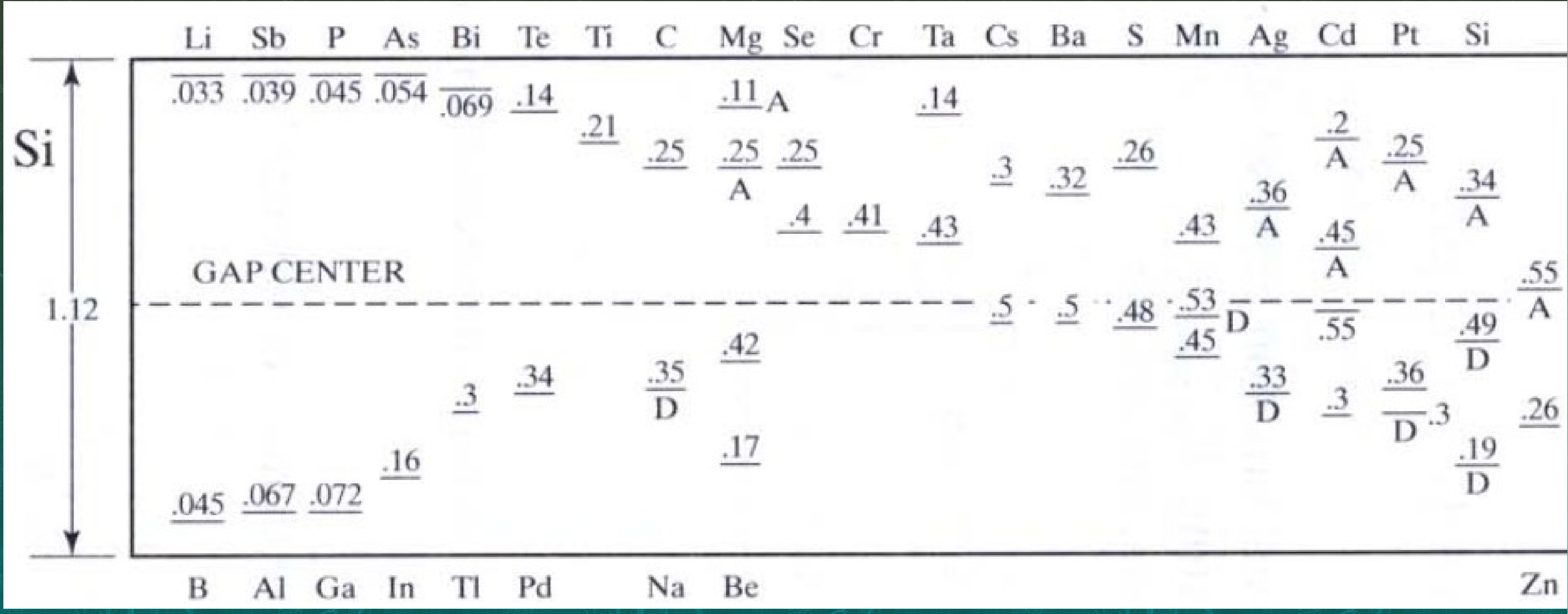
Carrier density thermal noise

- Talk by D. Heinert
- Theoretically, pure silicon would not be a problem, but realistic impurity levels lead to high noise
- Full calculation still needs to be done, but basic scaling from plot on the right does not change much for 120K LIGO case



How can we reduce CD noise?

- Temperature dependence depends on donor dopant energy.



- Doping compensation is an idea, but not clear how to do this on large crystal

Conclusions, again

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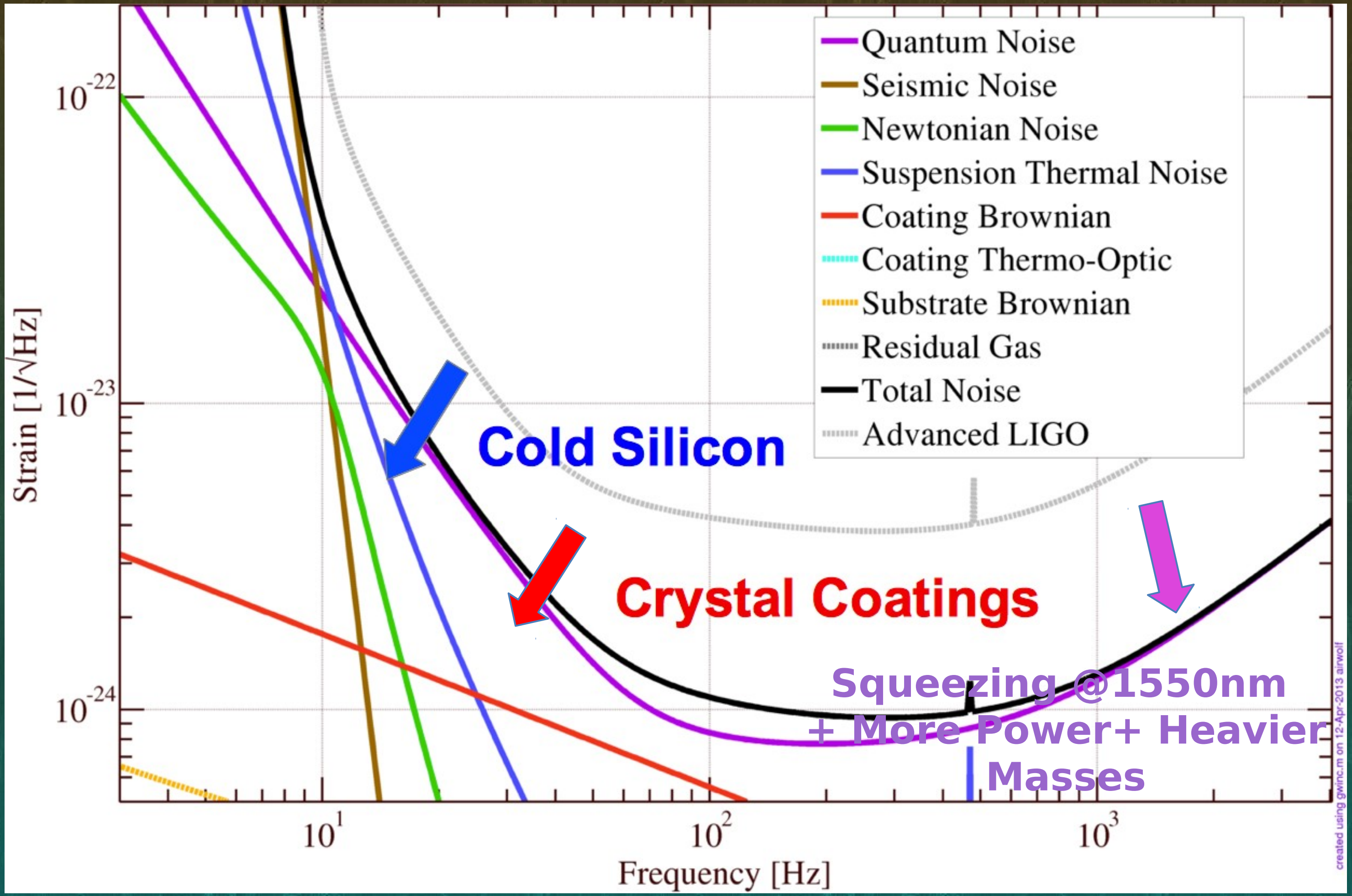
Cryogenic LIGO III Sensitivity



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