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MIT Radiation Pressure Experiment Optical Coatings: Noise and Other Issues

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Workshop on Optical Coatings in Precision Measurements
March 20-21

Outline

- Optical Springs
  - Some Results
- Experimental Setup
- What we want to do.
  - Standard Quantum Limit
- Coating Issues: Needs and Requests

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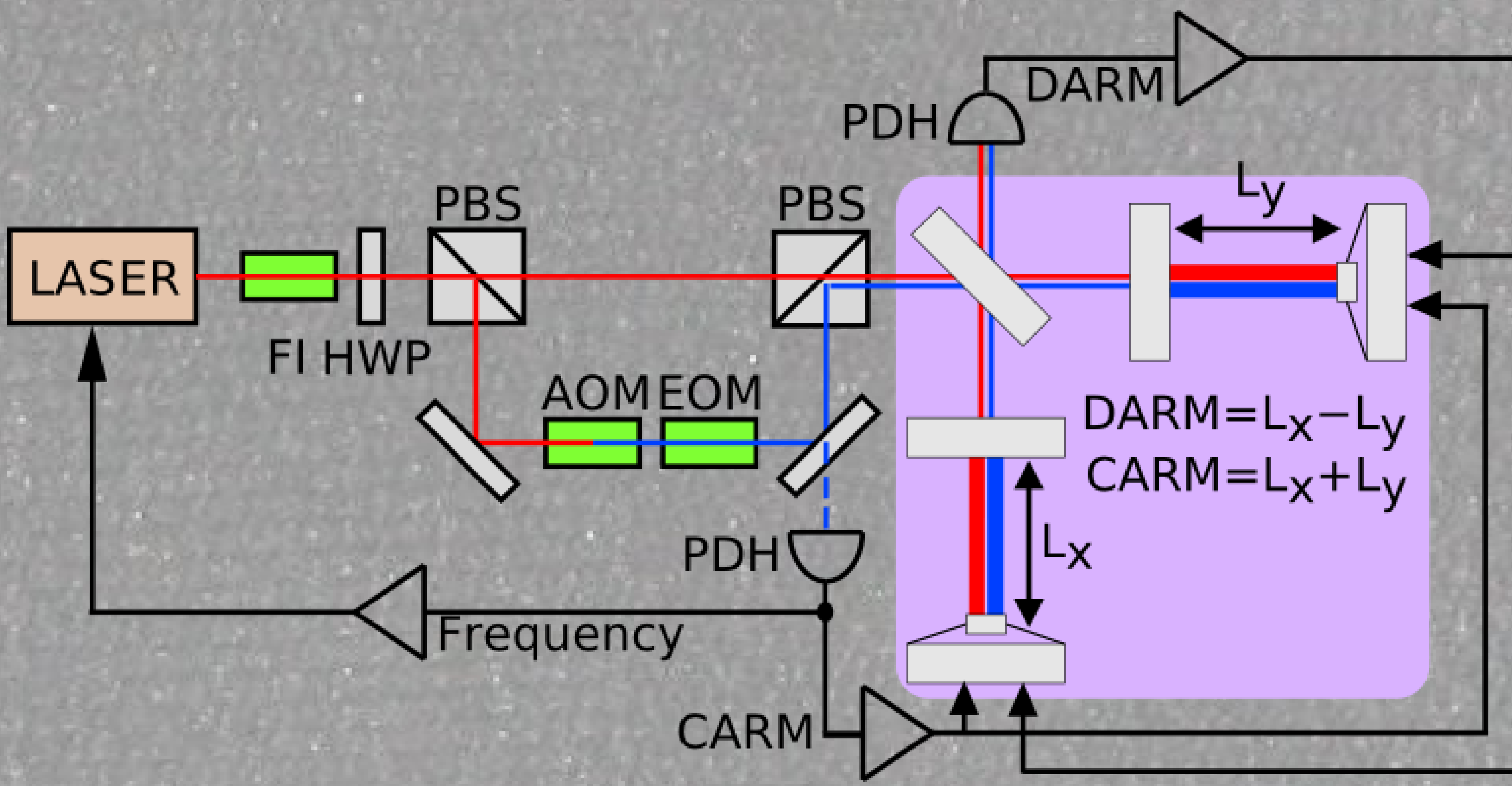
Experiment



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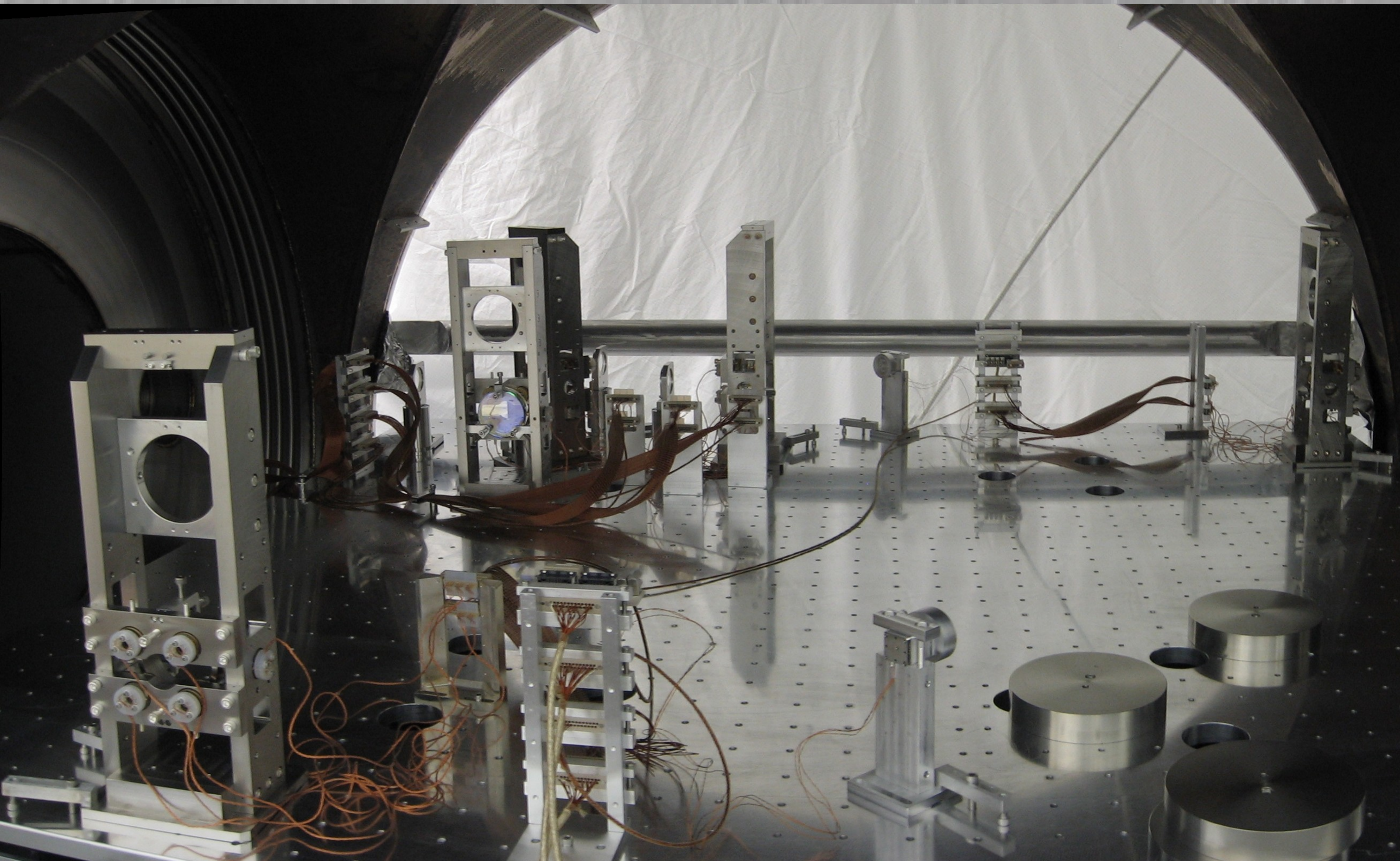
Experiment



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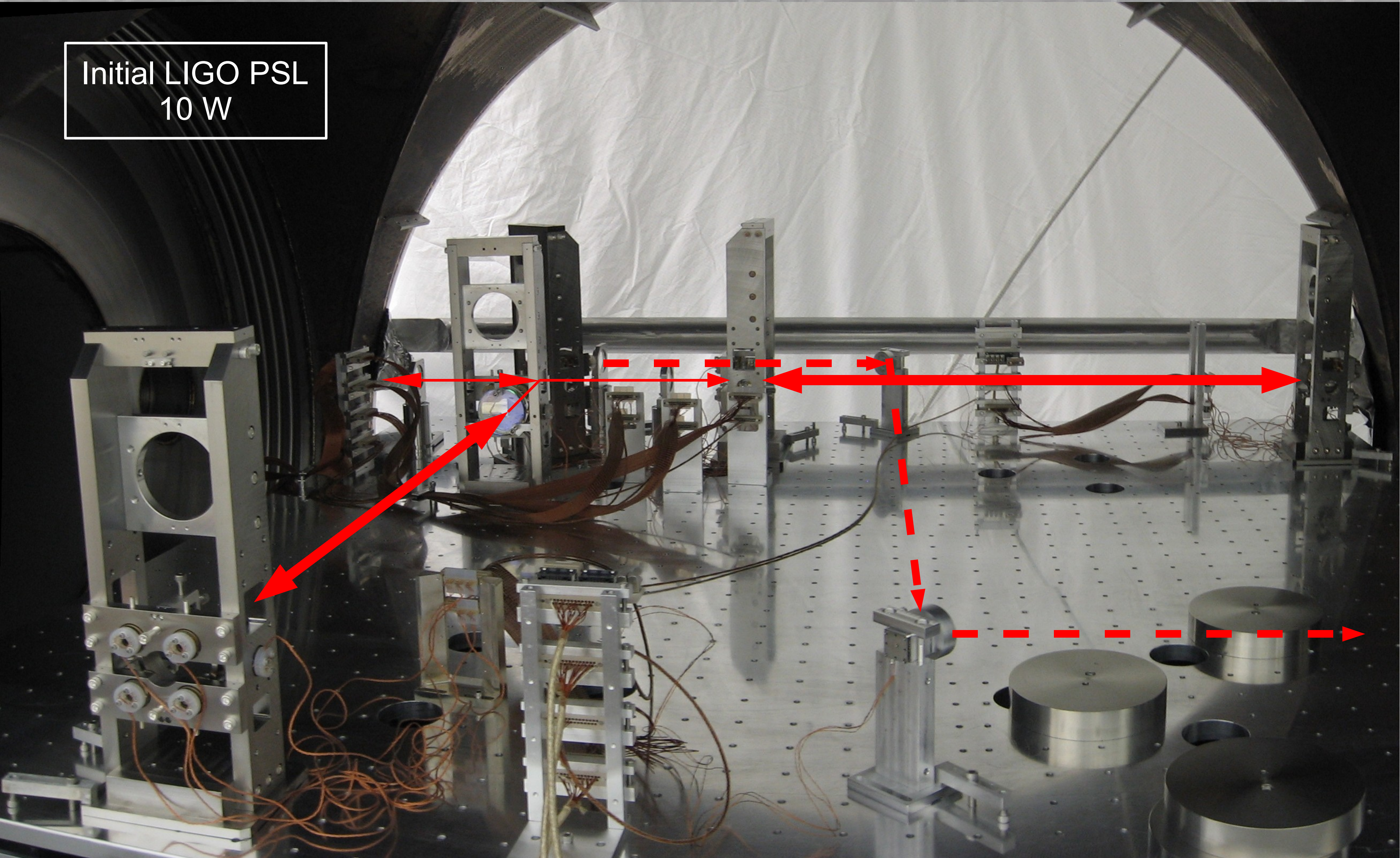
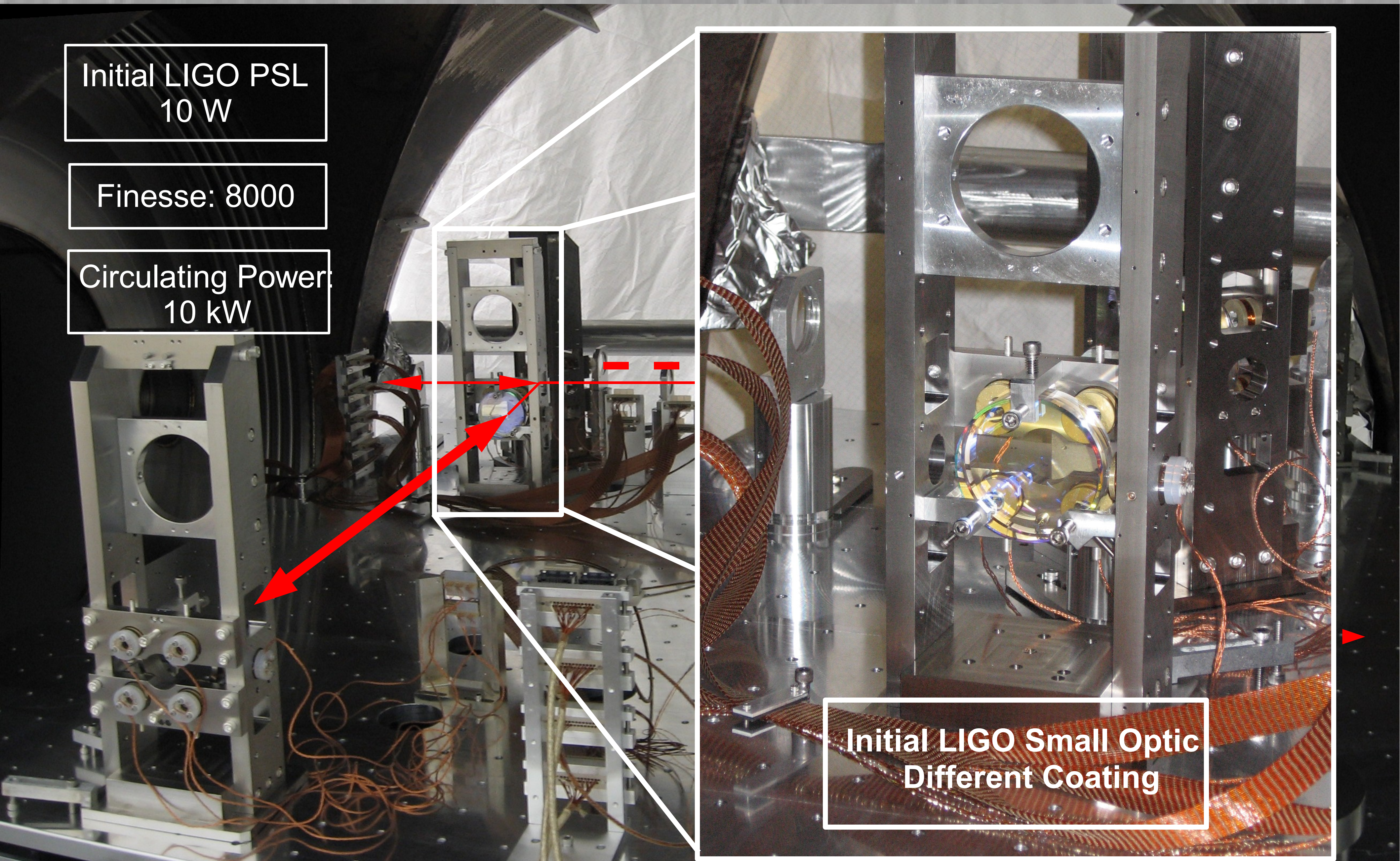


Experiment



Initial LIGO PSL
10 W
Finesse: 8000
Circulating Power
10 kW
Initial LIGO Small Optic
Different Coating

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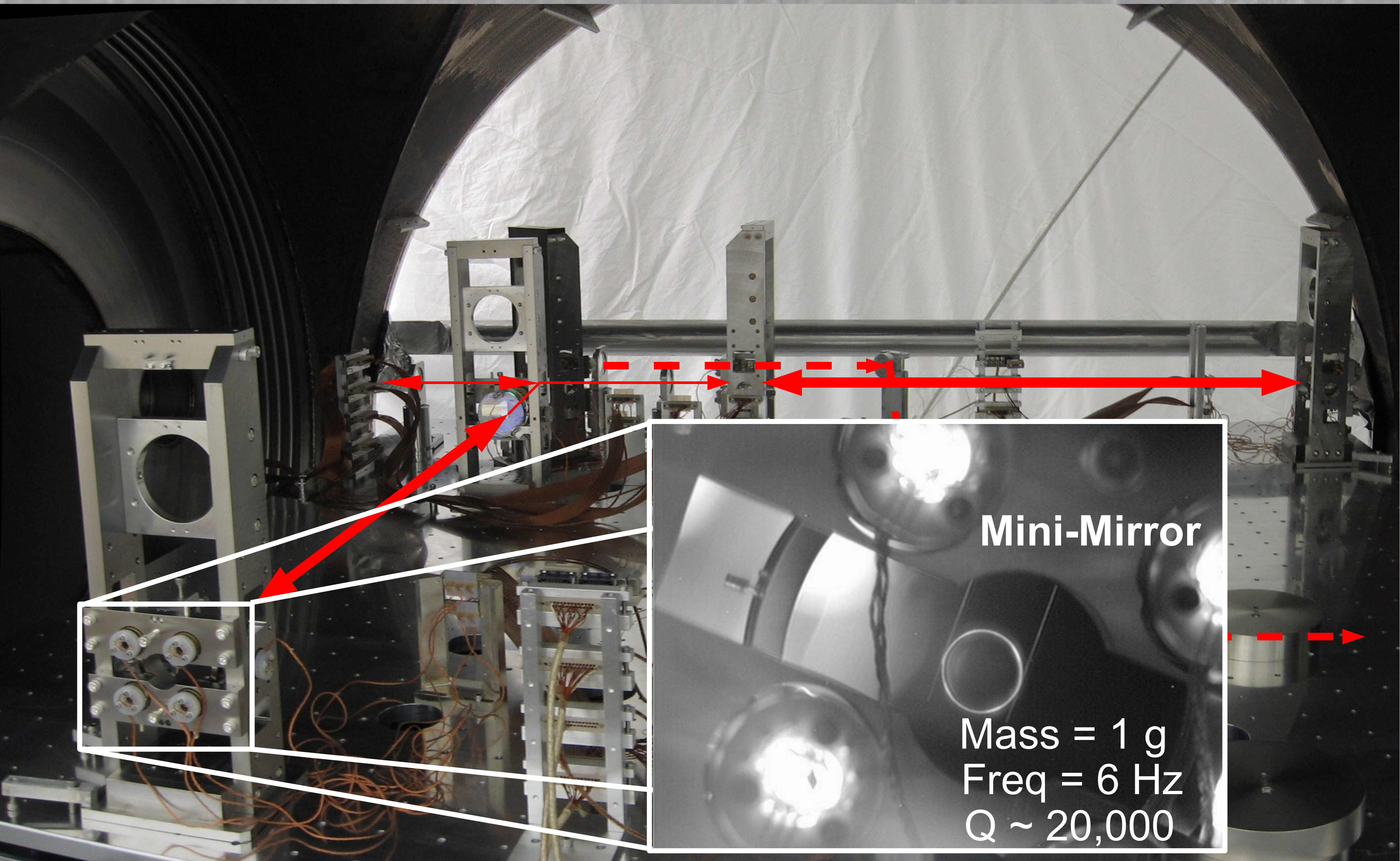
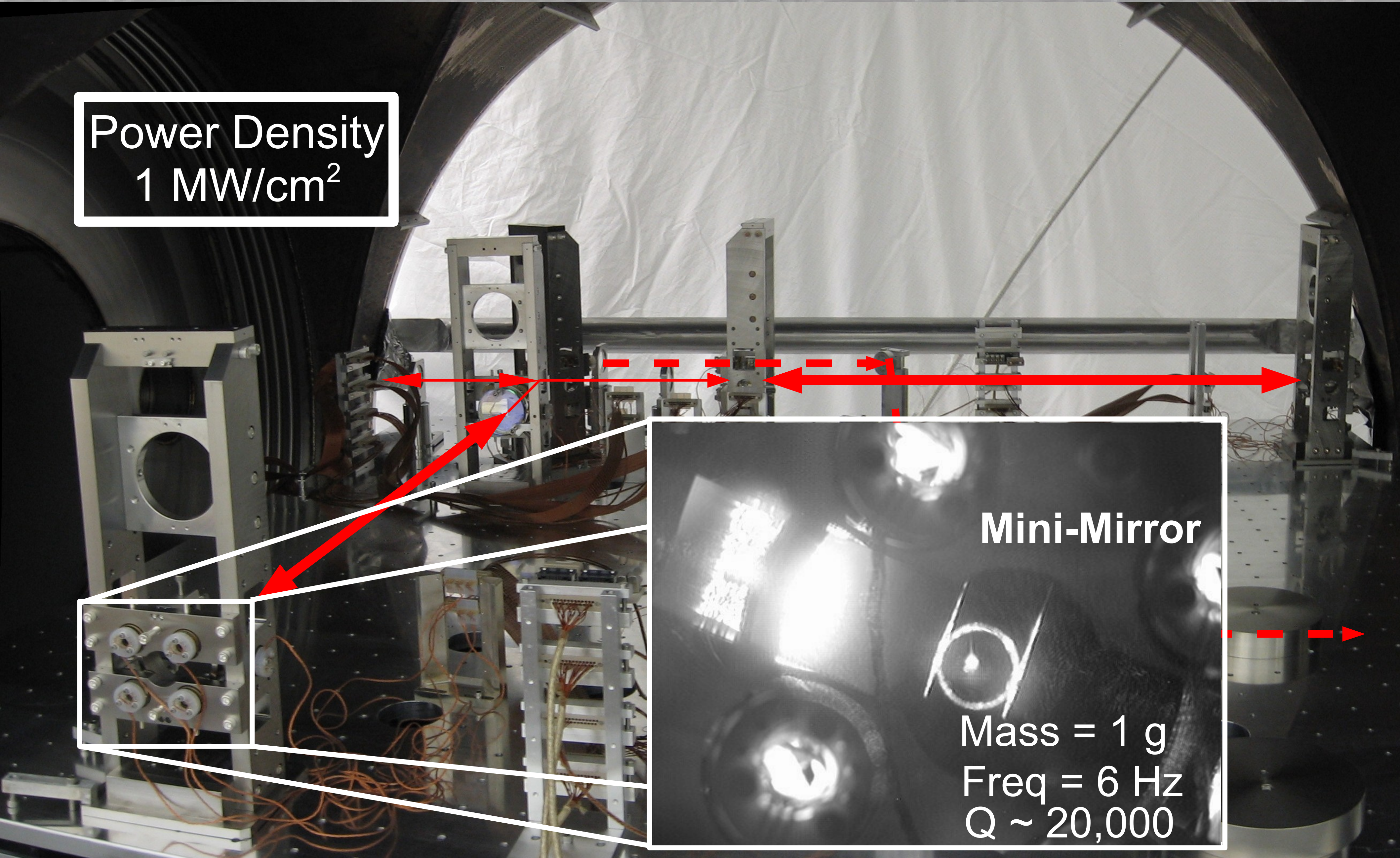
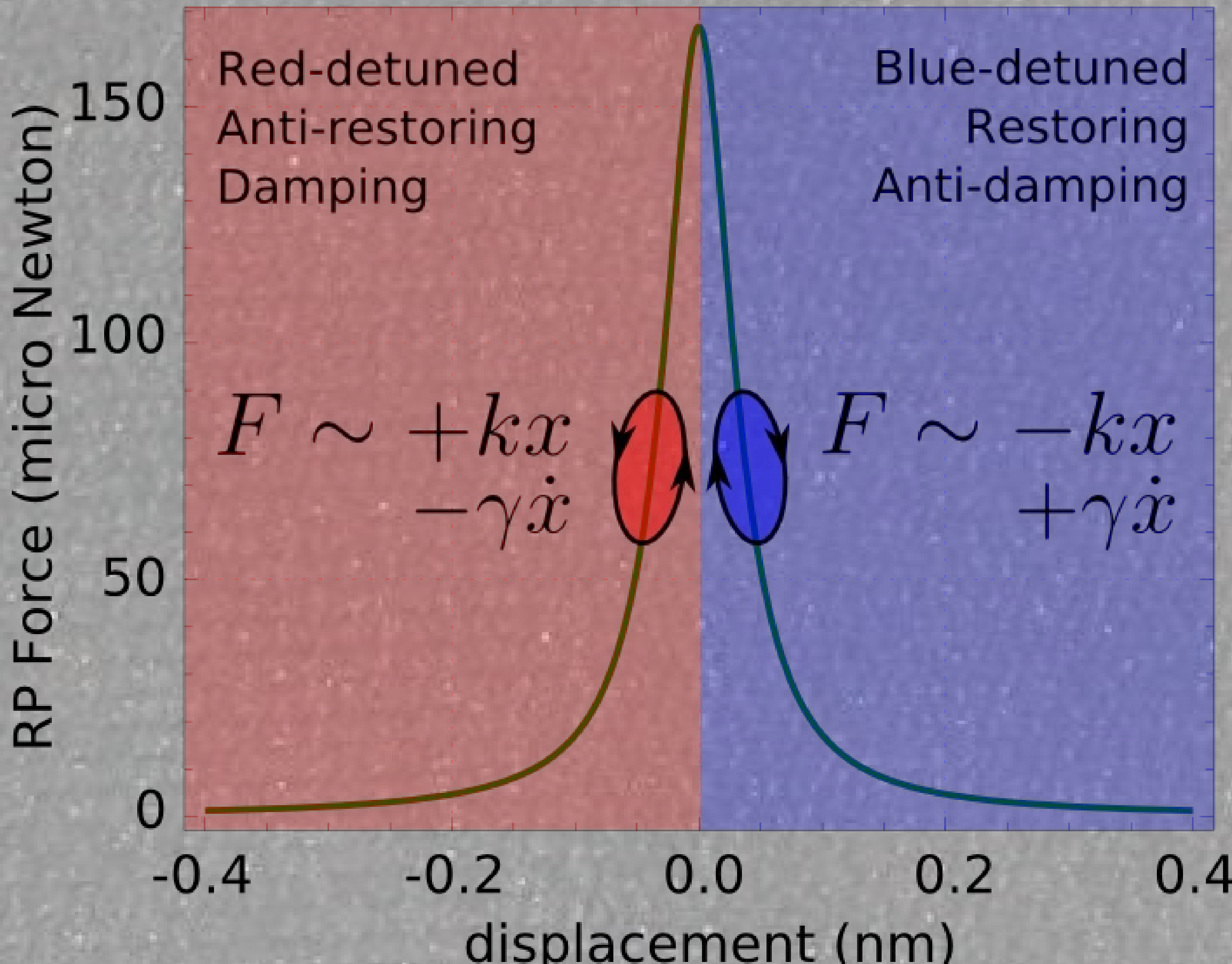
Experiment



Experiment



Optical Springs



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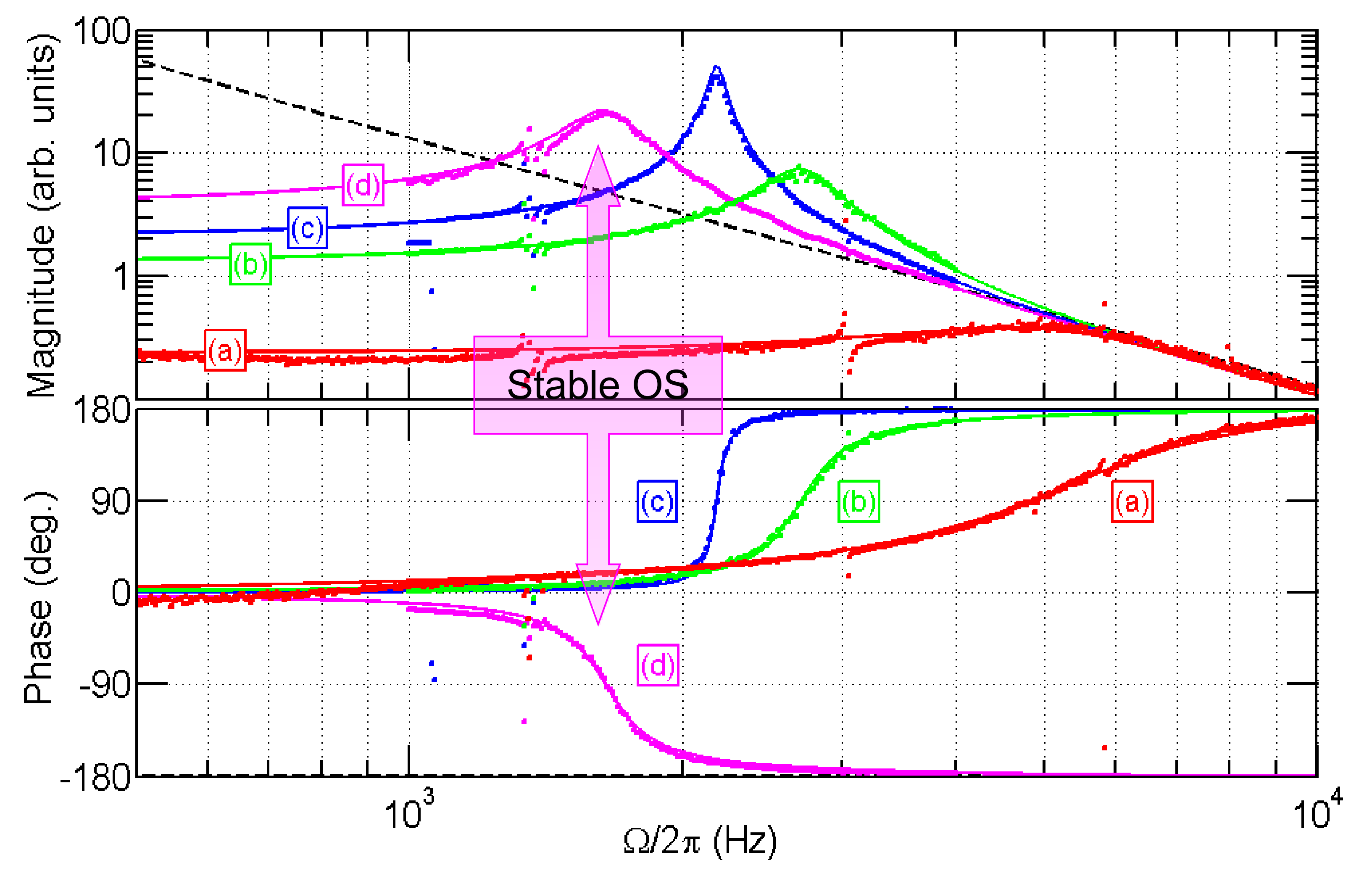
Optical Springs



T. Corbitt et al., PRL (2007)

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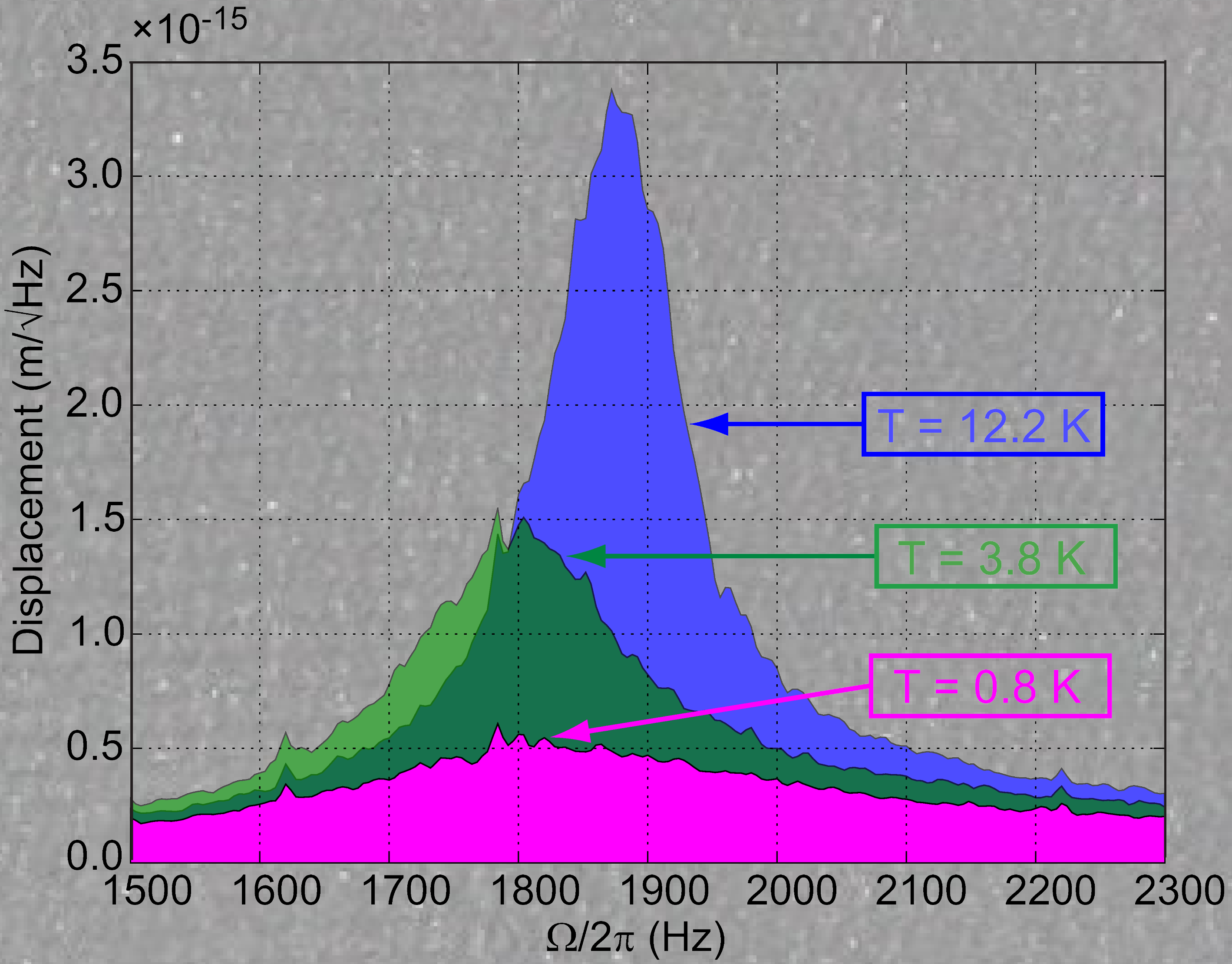
Optical Cooling



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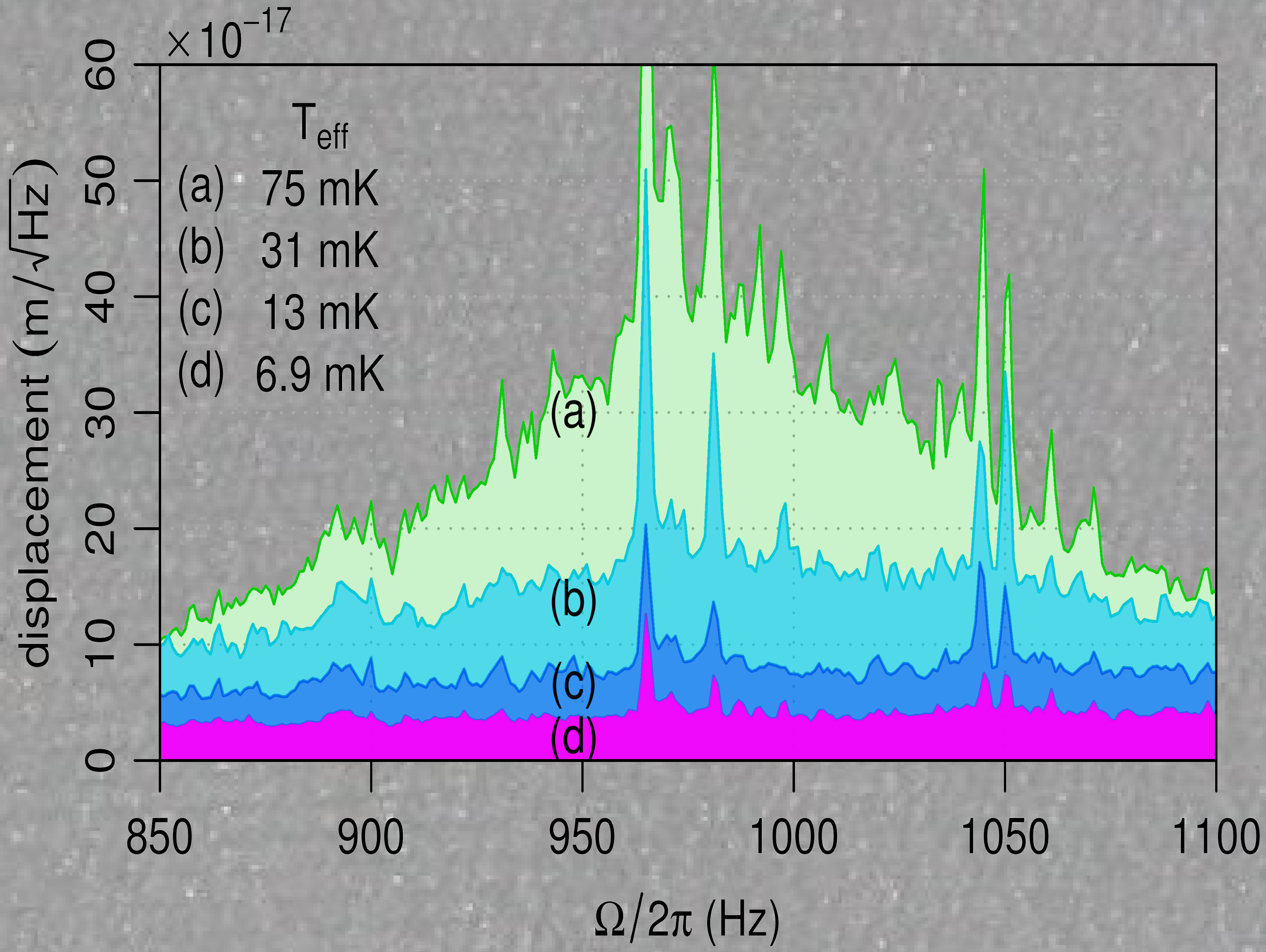
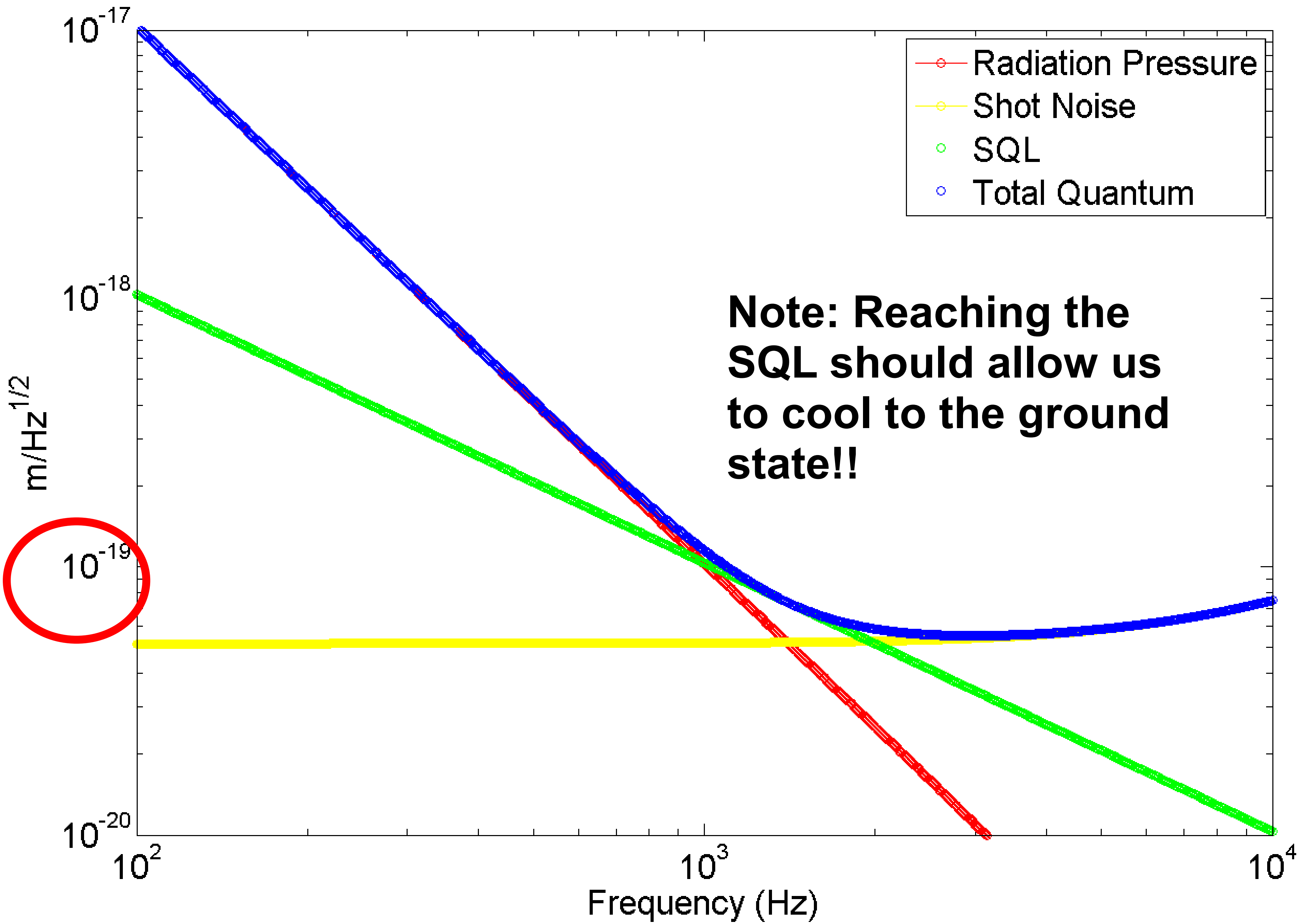
Optical Cooling



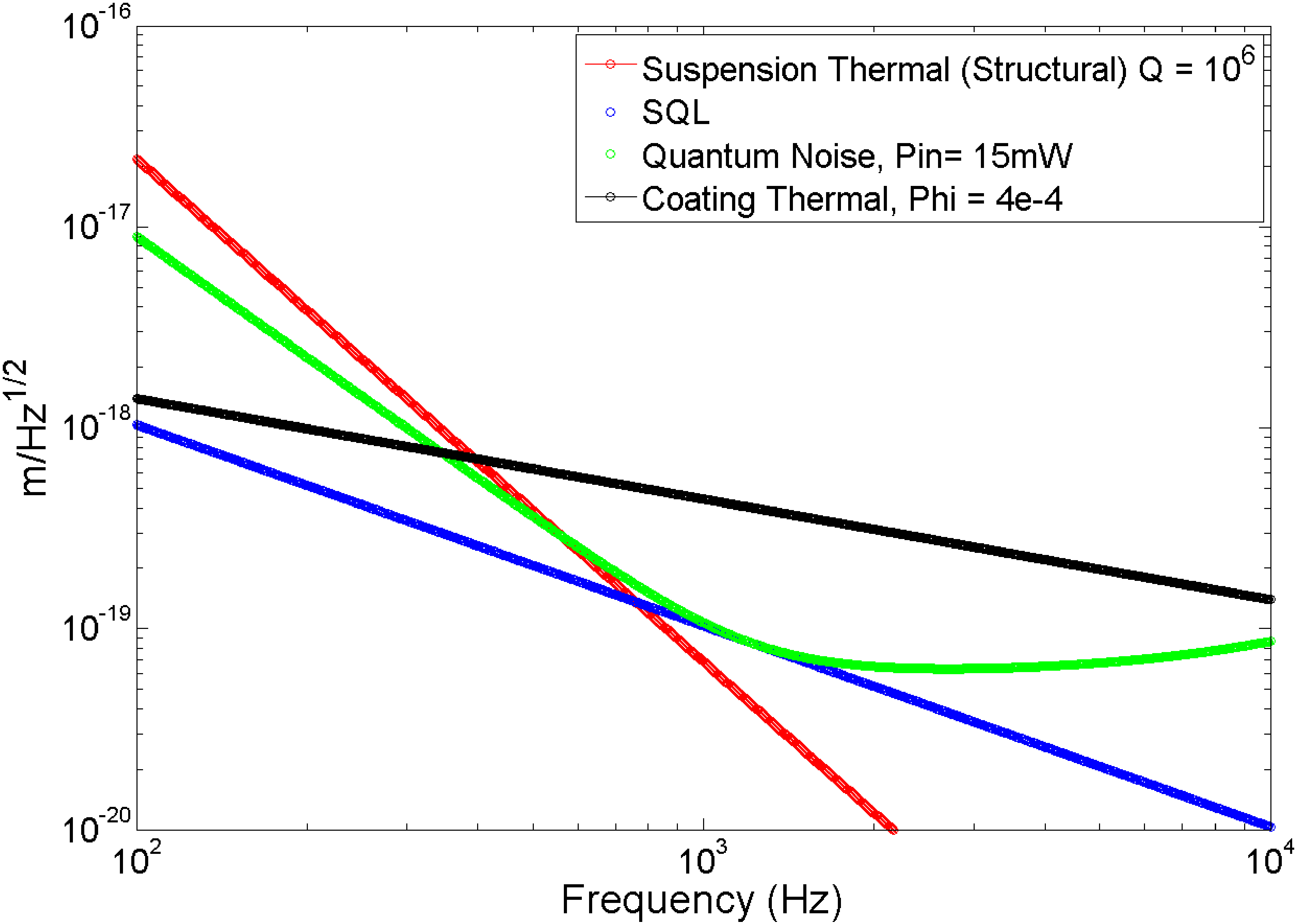
The Standard Quantum Limit

- Heisenberg: When you measure an object you disturb it.
- Example: If you try to localize the position of a particle (to some precision), it's momentum becomes more uncertain . Then the next time you look at it, the momentum uncertainty will have fed back to the position. And around we go.
- The SQL occurs when your initial position precision is equal to the noise from the momentum feedback.

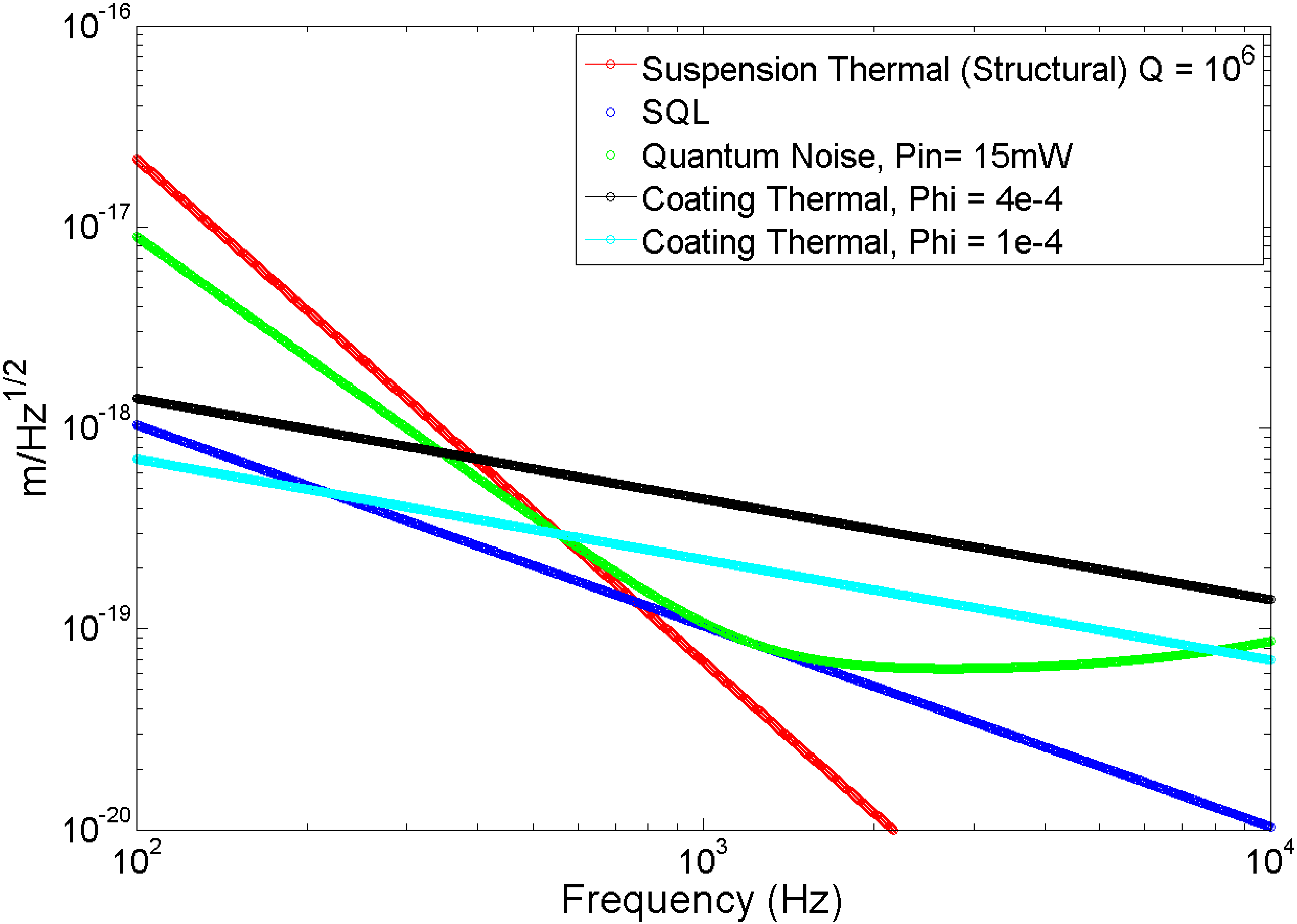


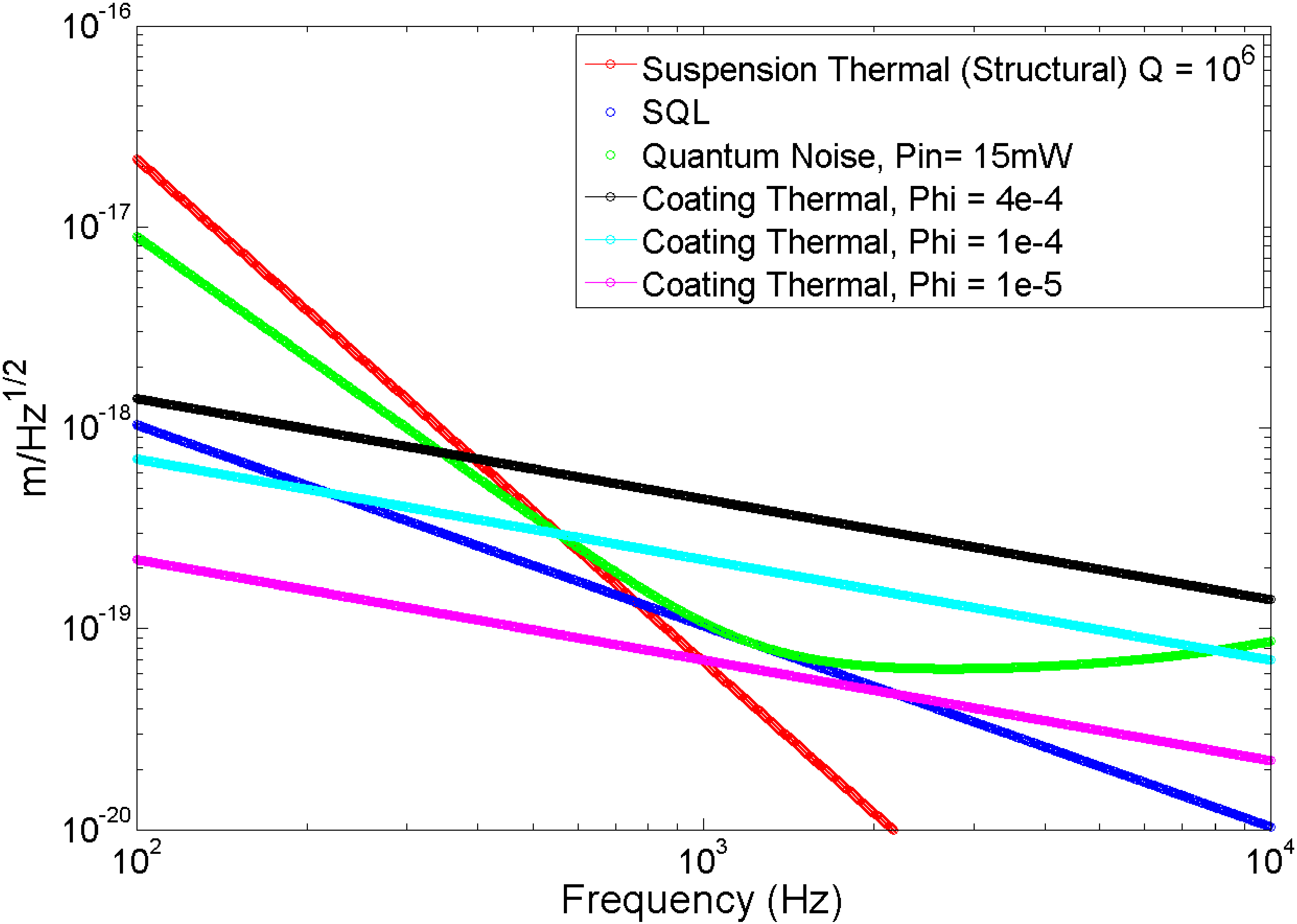
Radiation Pressure
Shot Noise
SQL
Total Quantum
Note: Reaching the SQL should allow us to cool to the ground state!!
m/Hz^1/2
10^-17
10^-18
10^-19
10^-20
10^2
10^3
10^4
Frequency (Hz)

What do we need?



Suspension Thermal (Structural) Q = 10^6
SQL
Quantum Noise, Pin= 15mW
Coating Thermal, Phi = 4e-4
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
m/Hz$^{1/2}$
10^2
10^3
10^4
Frequency (Hz)


Suspension Thermal (Structural) Q = 10^6
SQL
Quantum Noise, Pin= 15mW
Coating Thermal, Phi = 4e-4
Coating Thermal, Phi = 1e-4
m/Hz^1/2
10^-16
10^-17
10^-18
10^-19
10^-20
10^2
10^3
10^4
Frequency (Hz)



Suspension Thermal (Structural) Q = 10^6
SQL
Quantum Noise, Pin= 15mW
Coating Thermal, Phi = 4e-4
Coating Thermal, Phi = 1e-4
Coating Thermal, Phi = 1e-5
m/Hz^1/2
Frequency (Hz)
10^-16
10^-17
10^-18
10^-19
10^-20
10^2
10^3
10^4

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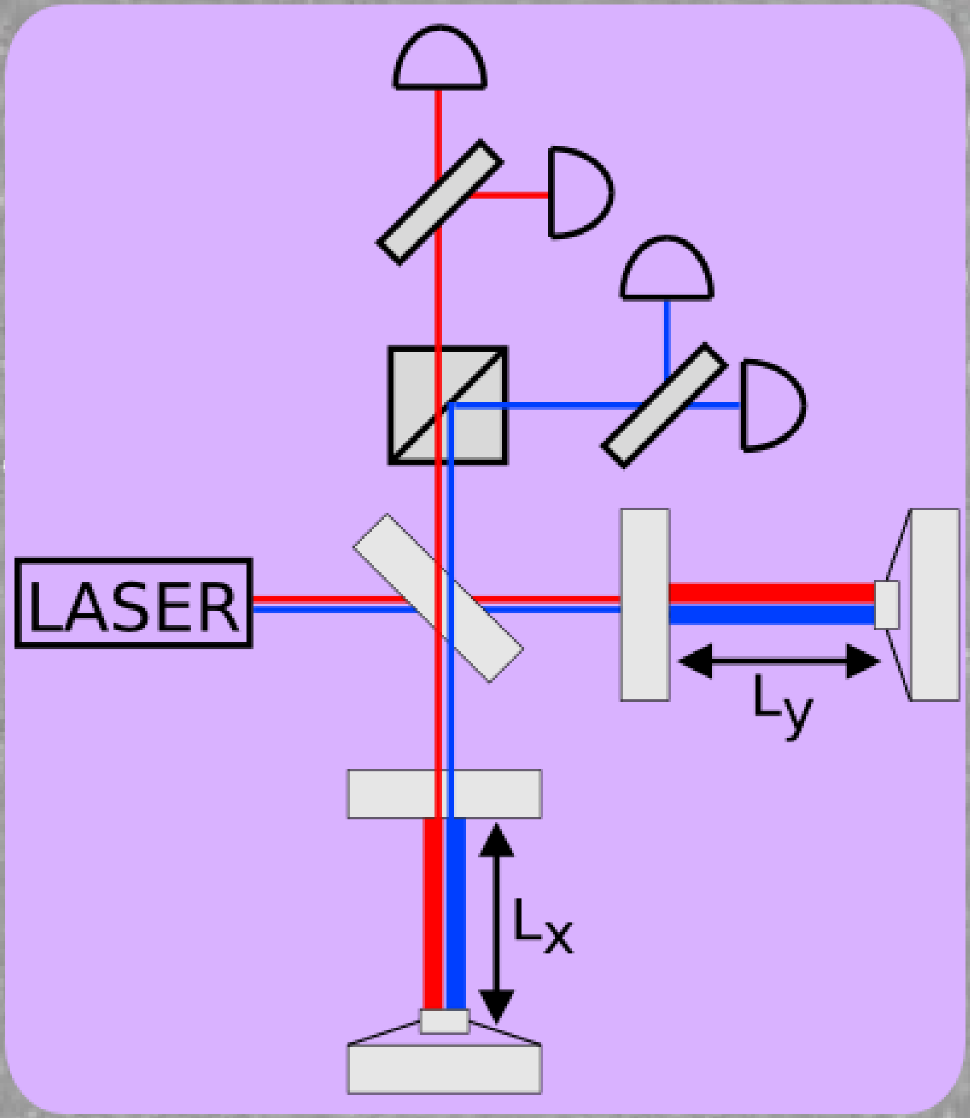
Double Optical Spring

- Better from a controls perspective.
- Useful for ponderomotive squeezing.
- Needed for entanglement of light beams.
- Ground state cooling.



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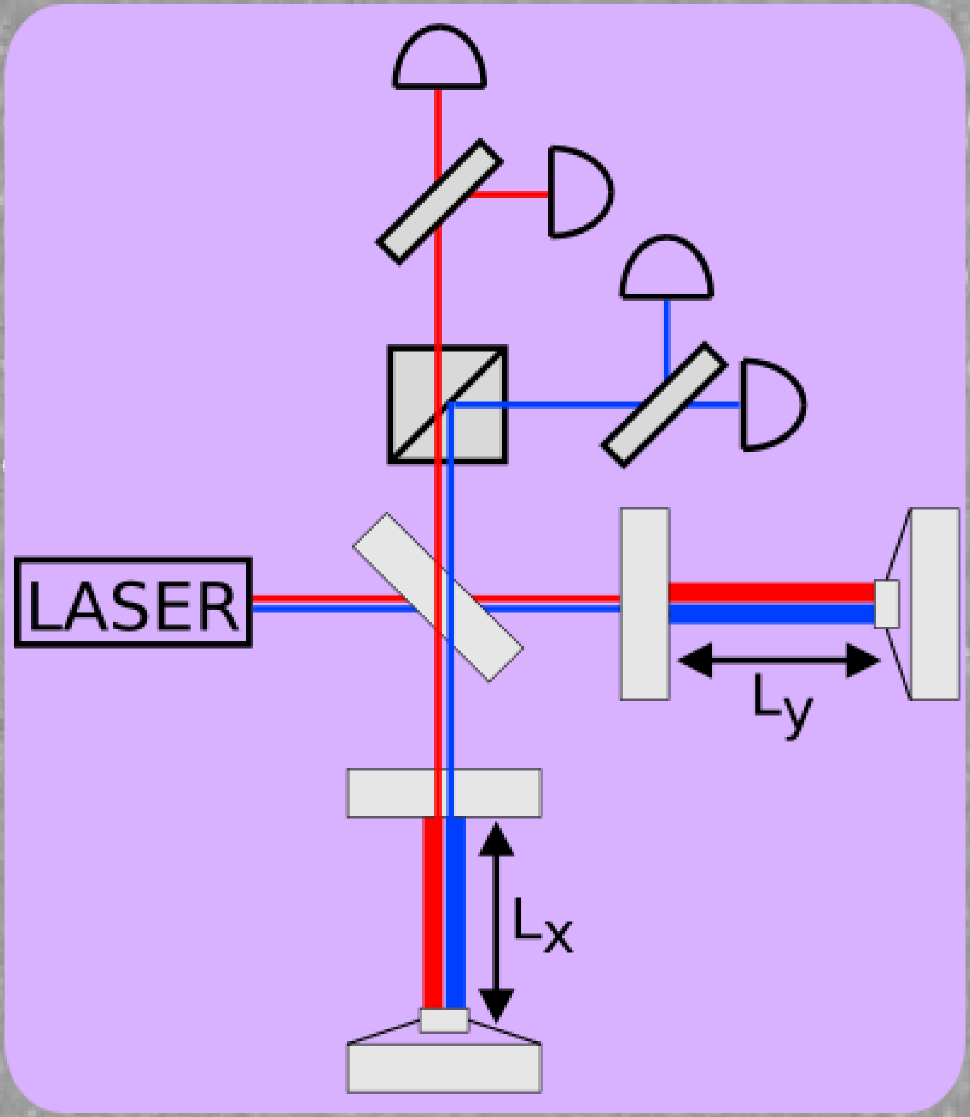
Double Optical Spring

- Need a BS that is 50/50 to 1 % in two orthogonal polarizations.



Summary

- Loss angles needed:
  - Standard Quantum Limit: phi = 1e-5
- Double Optical Spring: Beamsplitter 50/50 to 1% in two orthogonal polarizations.
- Within the next year we will hopefully measure coating thermal noise. A new testbed for coating characterization.

Entanglement

- Entanglement is like factoring.
- If a joint quantum state cannot be factored into two smaller quantum states then the joint state is entangled.
- The "more" entanglement that a system exhibits is quantified by the logarithmic negativity (Larger = "more")
- "More" implies that the entanglement could be "more" useful for some quantum task.

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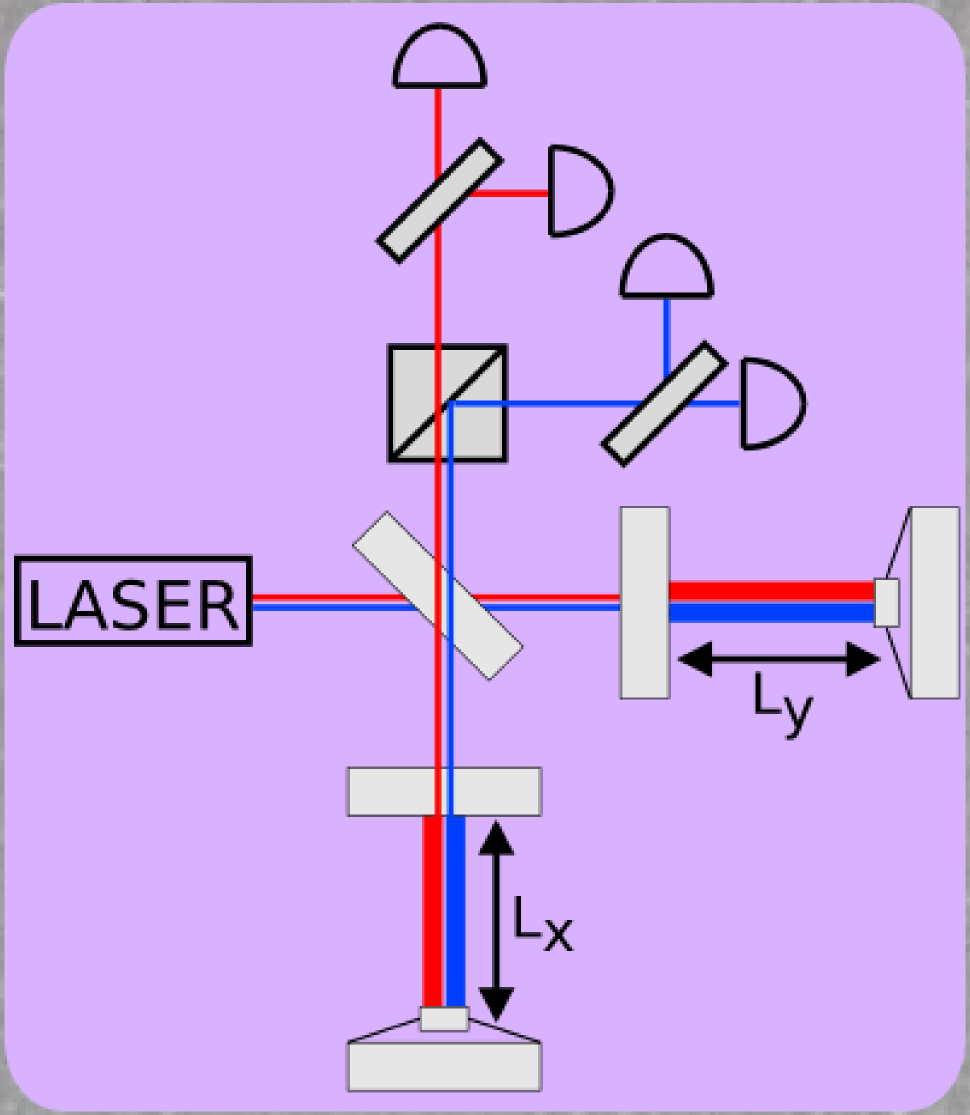
Entanglement

- Have two light fields in the interferometer. (carrier and sub-carrier in different polarizations)
- The amplitude fluctuations of the carrier imprint on the phase of carrier and sub-carrier!
- Same for fluctuations of sub-carrier.
- These correlations give rise to entanglement.



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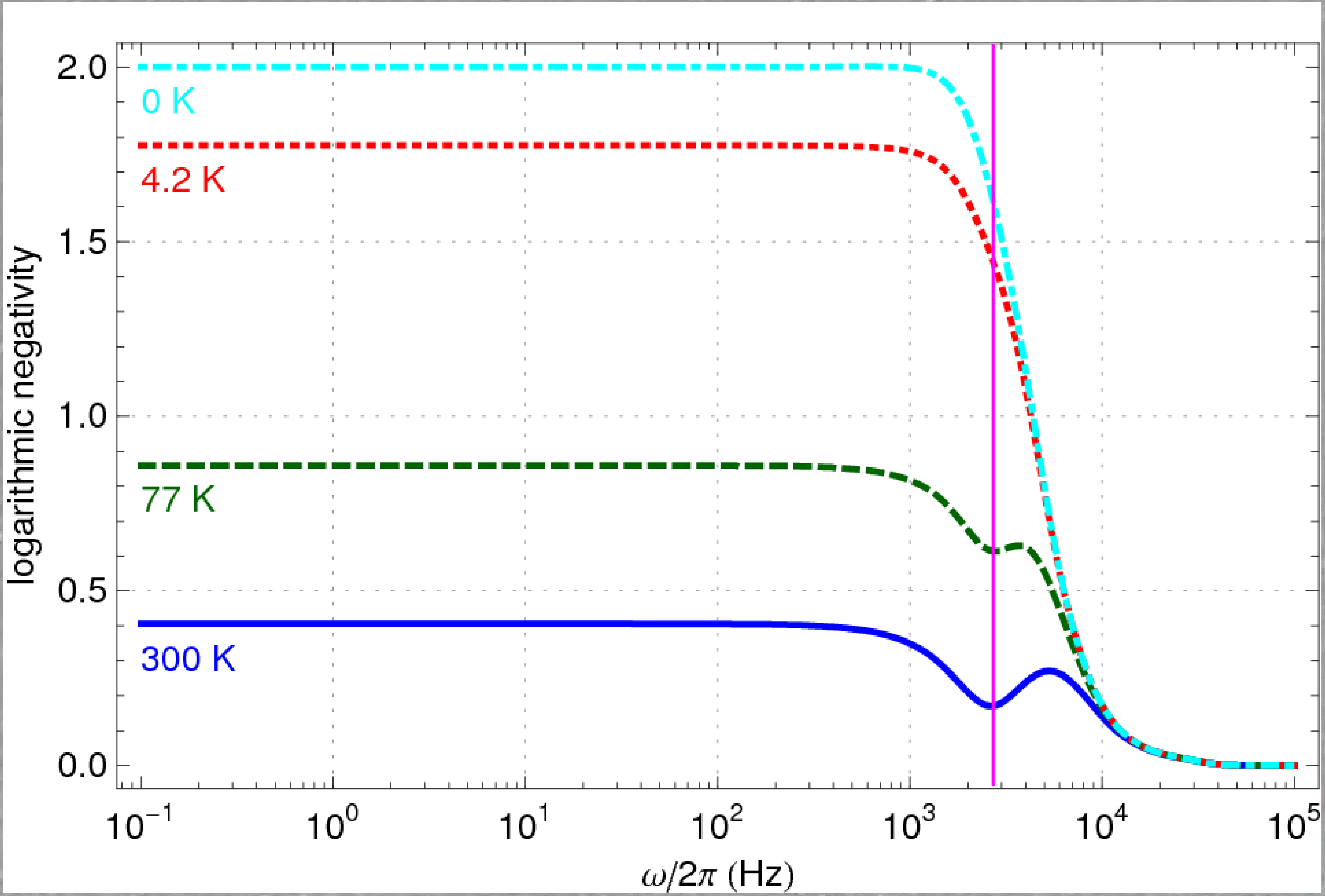
Entangled



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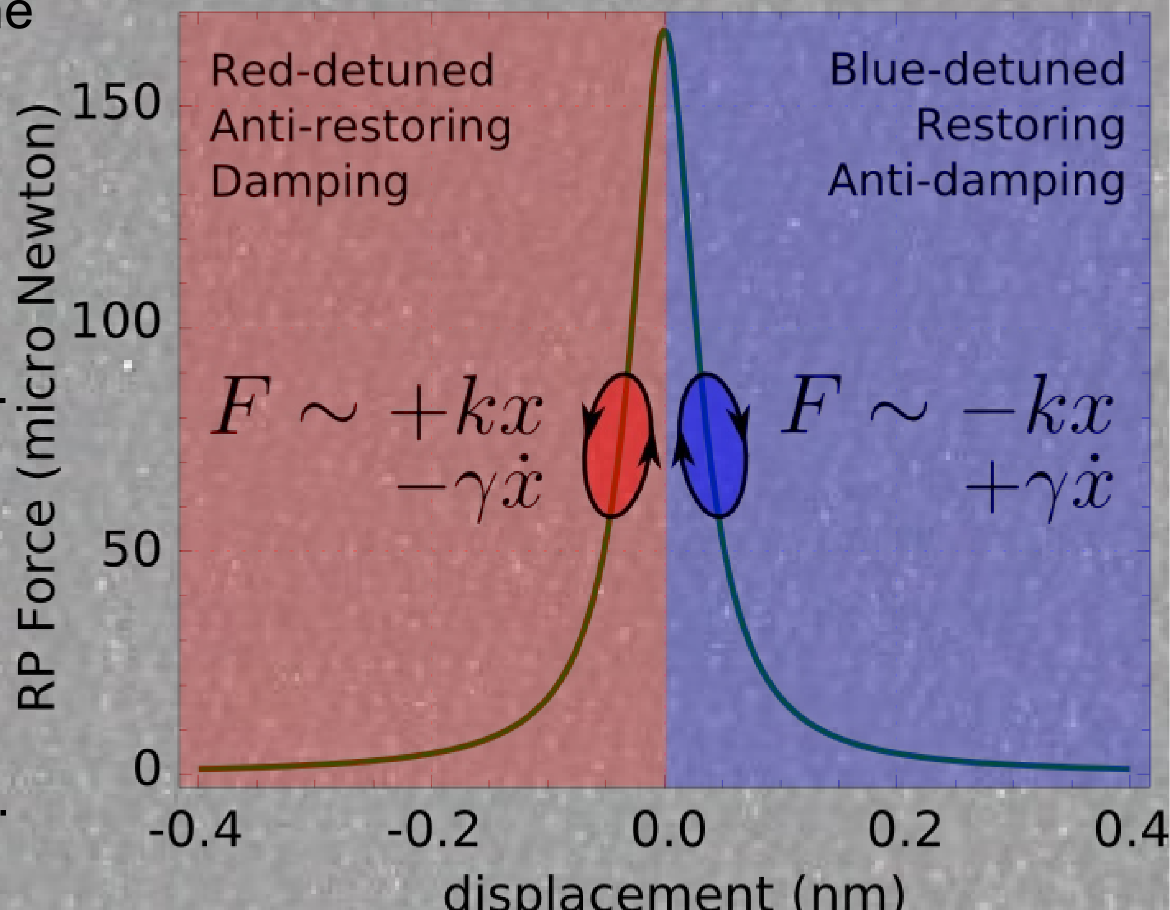
Optical Springs

- Detune the cavity blue or long.
- The length fluctuates causing the detuning to change.
- Cavity gets longer, detuning increases, power drops.
- Radiation pressure decrease mirror move back to equilibrium.
- Cavity get shorter, detuning decrease, power increases.
- RP force increase and restores the mirror to original position.
- Restoring Force! Optical Spring.



SQL

$$\sqrt{S_x}(SQL) = \sqrt{\frac{4\hbar^2}{m\Omega^2}}$$

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$$S_{coating}(f) = \frac{2k_BT}{\pi^{\frac{3}{2}} f} \frac{1}{wY} \left(\frac{d}{w\sqrt{\pi}} \left(\frac{Y'}{Y}\phi_{||} + \frac{Y}{Y'}\phi_{\perp} \right) + \phi_{substrate} \right)$$