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Direct Broadband Measurement of Advanced Coating Noise

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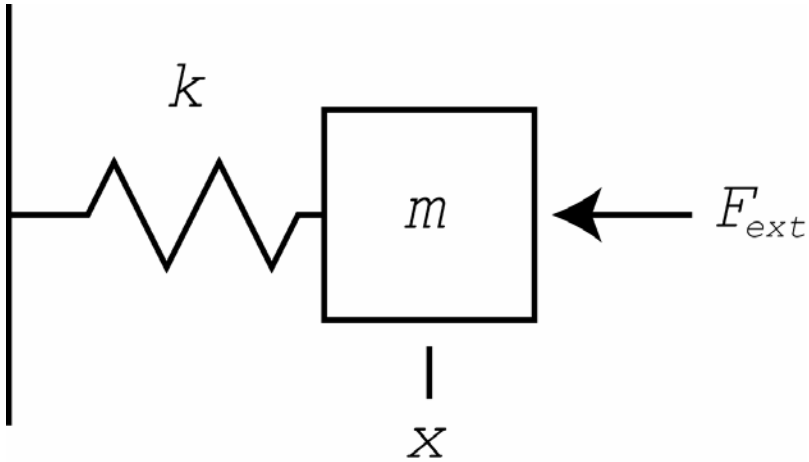
Noise Prediction

- Fluctuation-dissipation theorem relates mechanical properties of a system (internal friction) to the thermal noise *spectrum*.

$$x_{Th}^2(\omega) = \frac{4k_B T}{\omega^2}\,\mathrm{Re}\left\{\frac{v}{F_{ext}}\right\}$$

Example: Simple Harmonic Oscillator



$$ma = -kx + f_{friction} + F_{ext}$$

$$f_{friction} = -ik\phi(\omega)x$$

$$ma = -k(1 + i\phi(\omega))x + F_{ext}$$

- General function $\phi(\omega)$ is called the "loss angle"
- For viscous drag (air friction),

$$f_{friction} = -\gamma v$$

$$\phi(\omega) = \frac{\gamma}{k}\omega$$

- Most materials have internal friction, with a loss angle that is independent of frequency.

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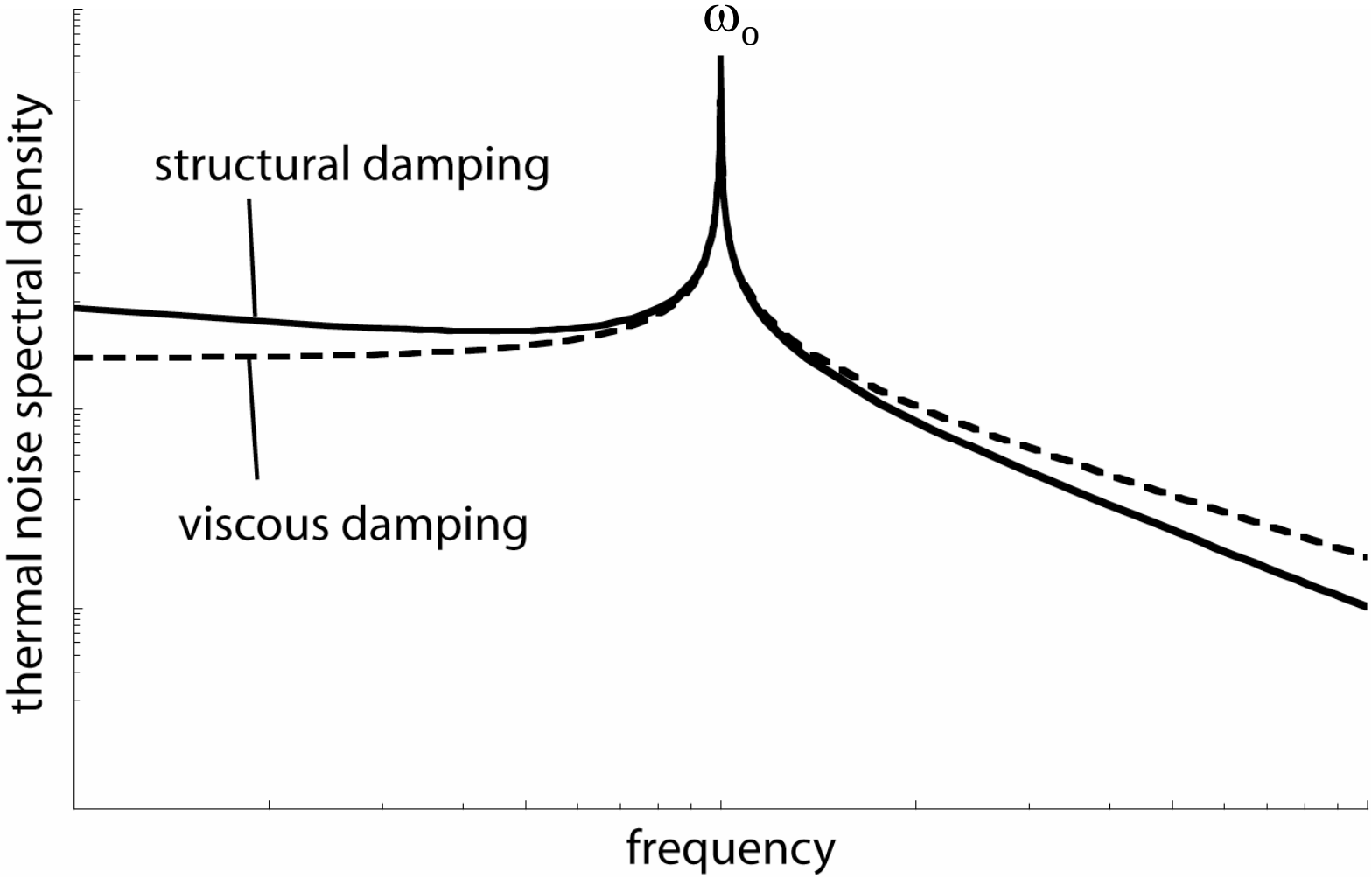
How does loss angle affect thermal noise?



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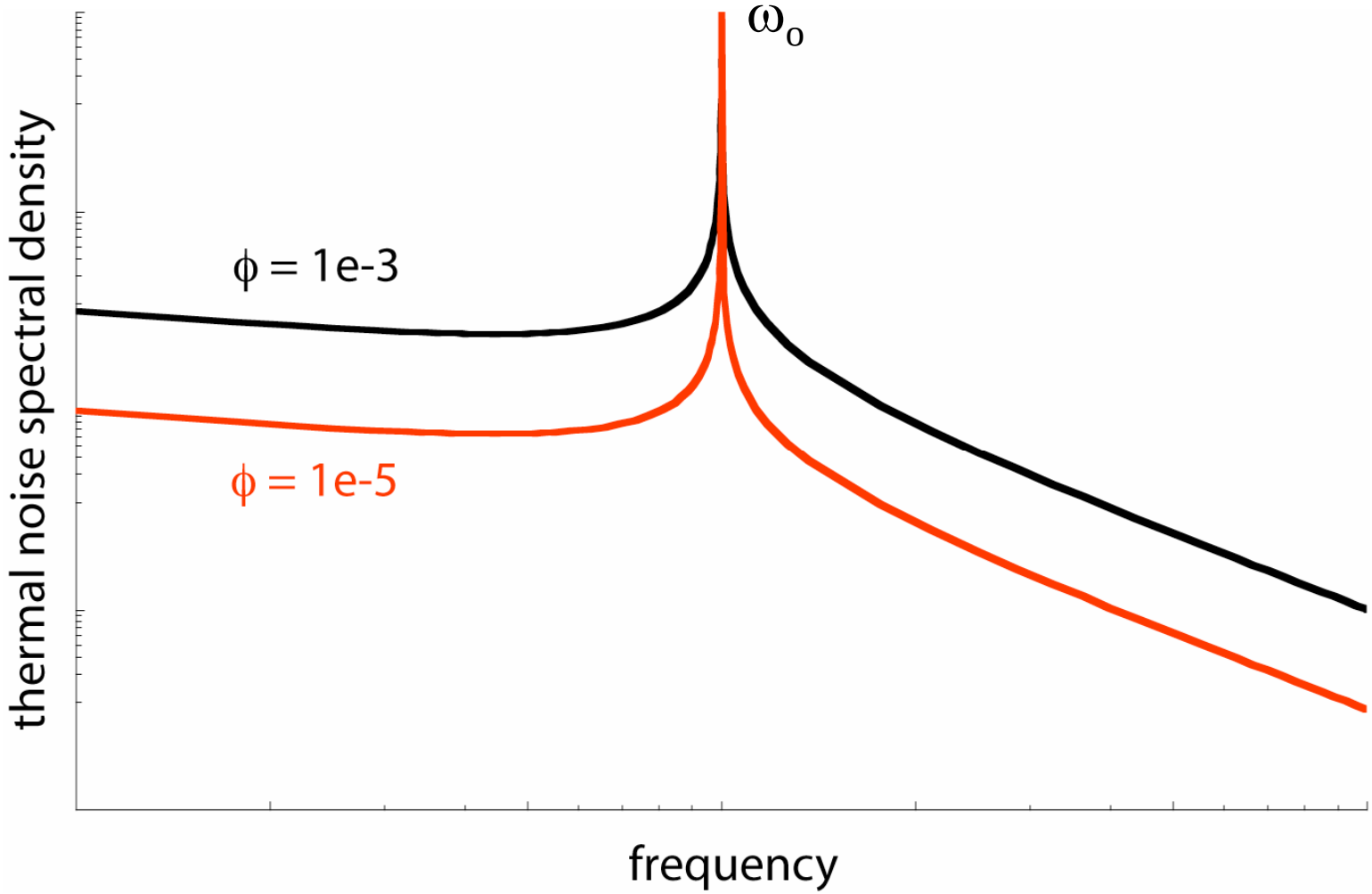
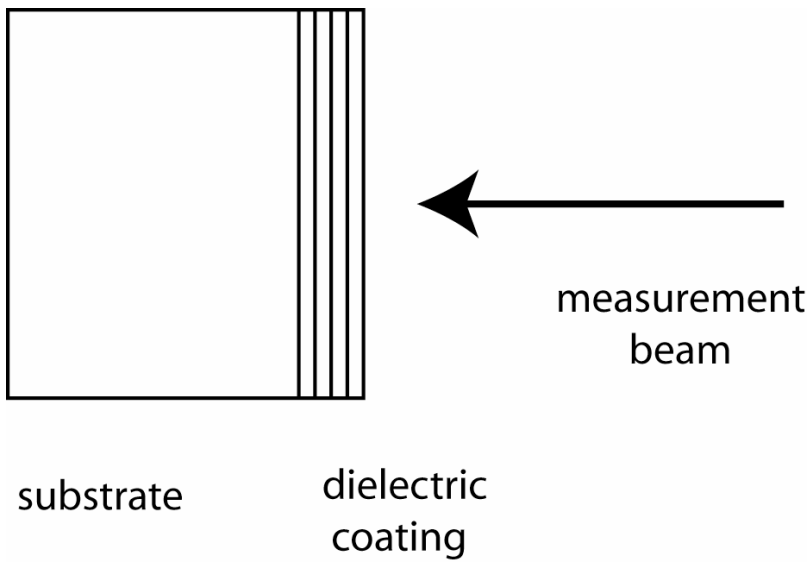
How does loss angle affect thermal noise?

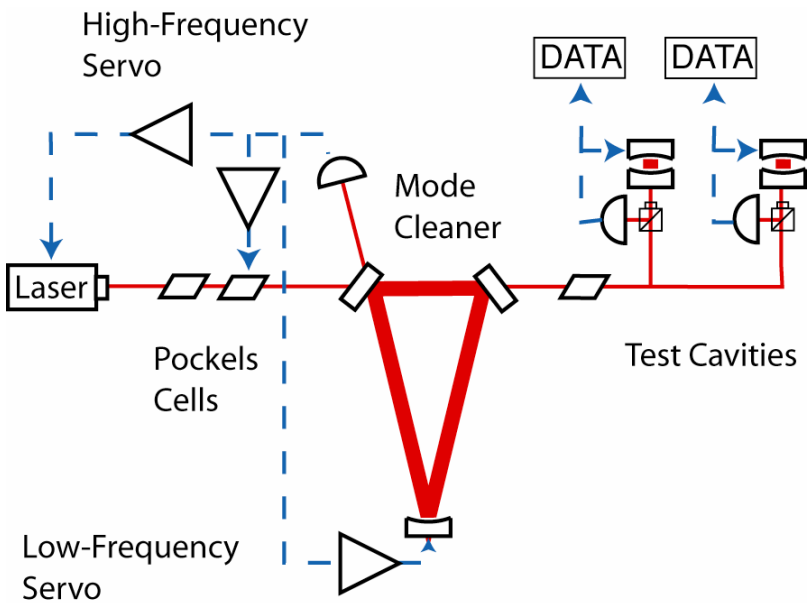


What does a mirror look like?



- Dielectric mirror is made up of many layers of alternating high-index-of-refraction layers and low-index-of-refraction layers.
- Because the coating is on the surface we are measuring, its noise matters most.
- LIGO-I coatings use SiO2 (low-index) and Ta2O5 (high-index).
- Most mechanical loss is in the Ta2O5 layers, therefore they are the source of most of the noise in our measurement band.
- Doping Ta2O5 with TiO2 appears to reduce its mechanical loss, but does is really reduce its broadband noise?
- Must do a direct measurement to find out.

Thermal Noise Interferometer (TNI)



- Fundamental-noise limited interferometer (thermal and shot).
- Pockels Cells: create reference sidebands on carrier beam
- Servo: sends feedback to laser and mirrors to maintain ideal system
- Mode Cleaner:
  - removes laser frequency noise
  - sets proper Gaussian beam profile
  - Filters all but TEM00 mode

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Installing Mirrors

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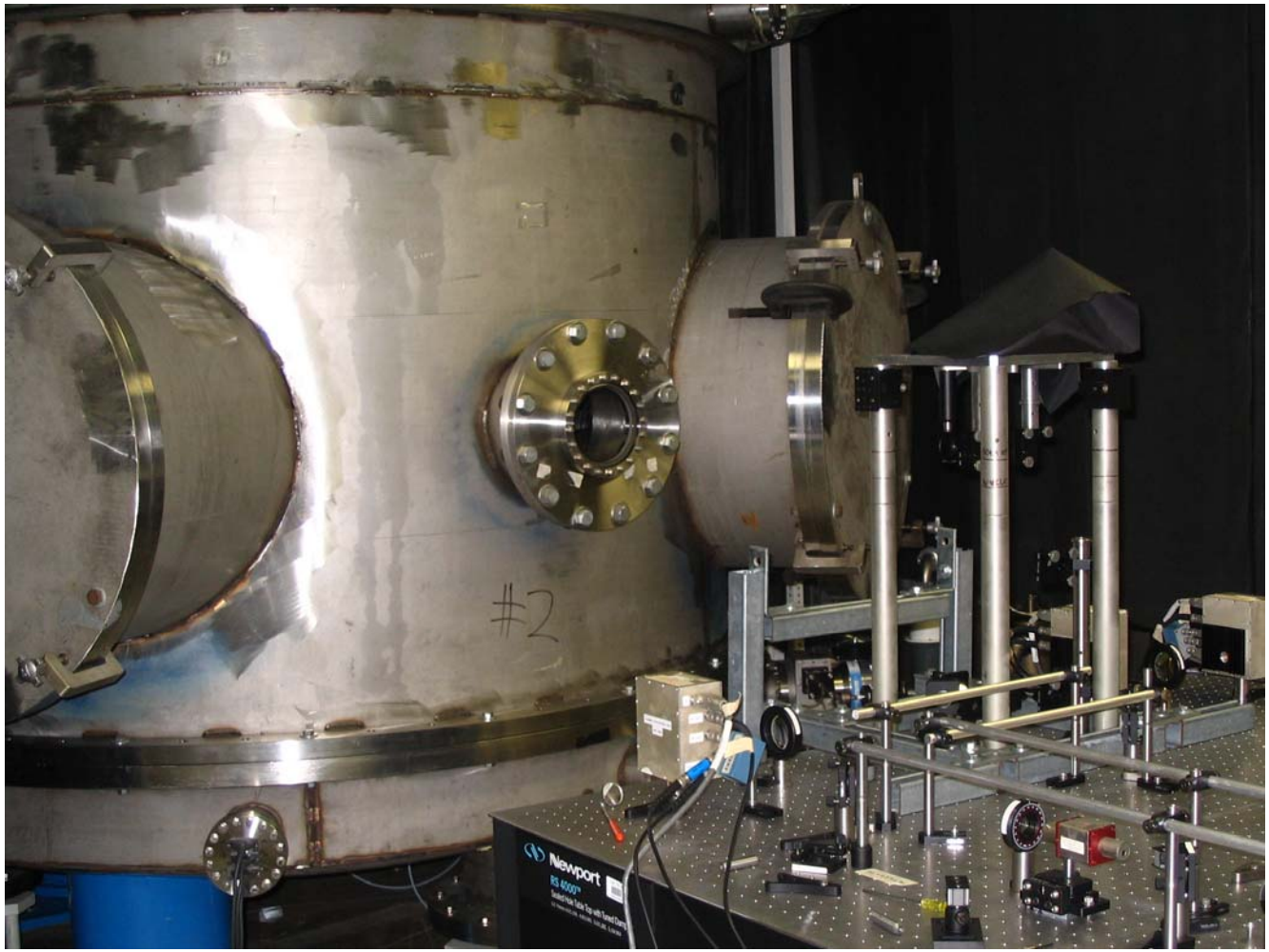
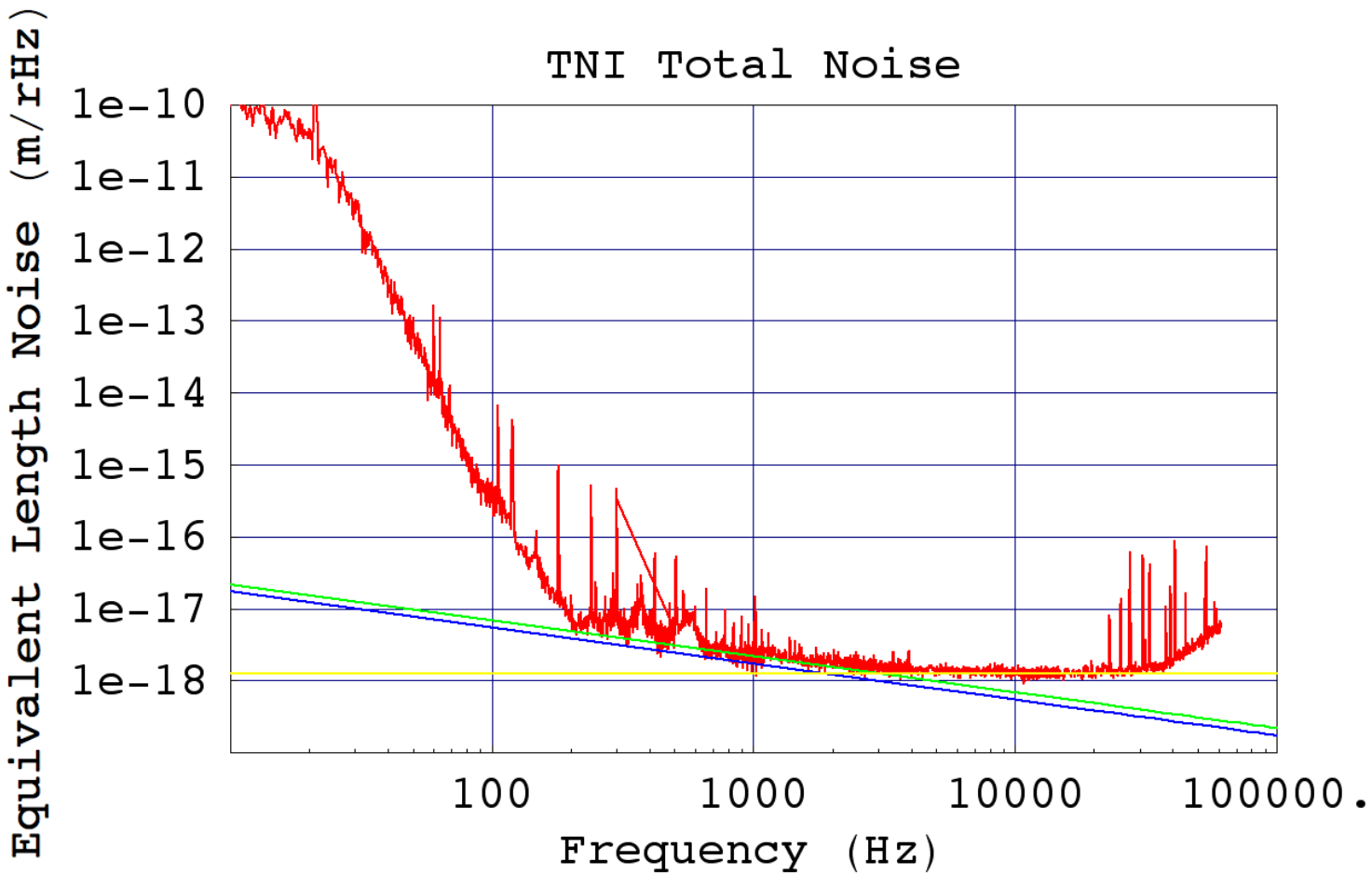
Vacuum Chamber



Advanced Coating Noise Curve



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Thank you!

- Eric Black
- Akira Villar
- Chinyere Nwabugwu
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- Rick Kirian
- Ken Libbrecht
- NSF