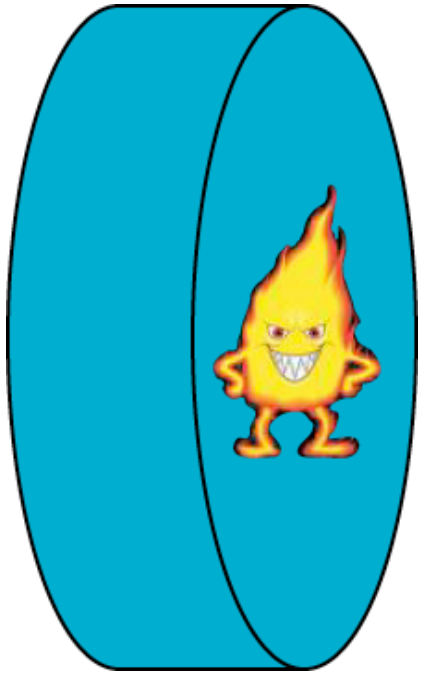
Thermal Noise in Optimized Coatings



Thermal Noise Interferometer

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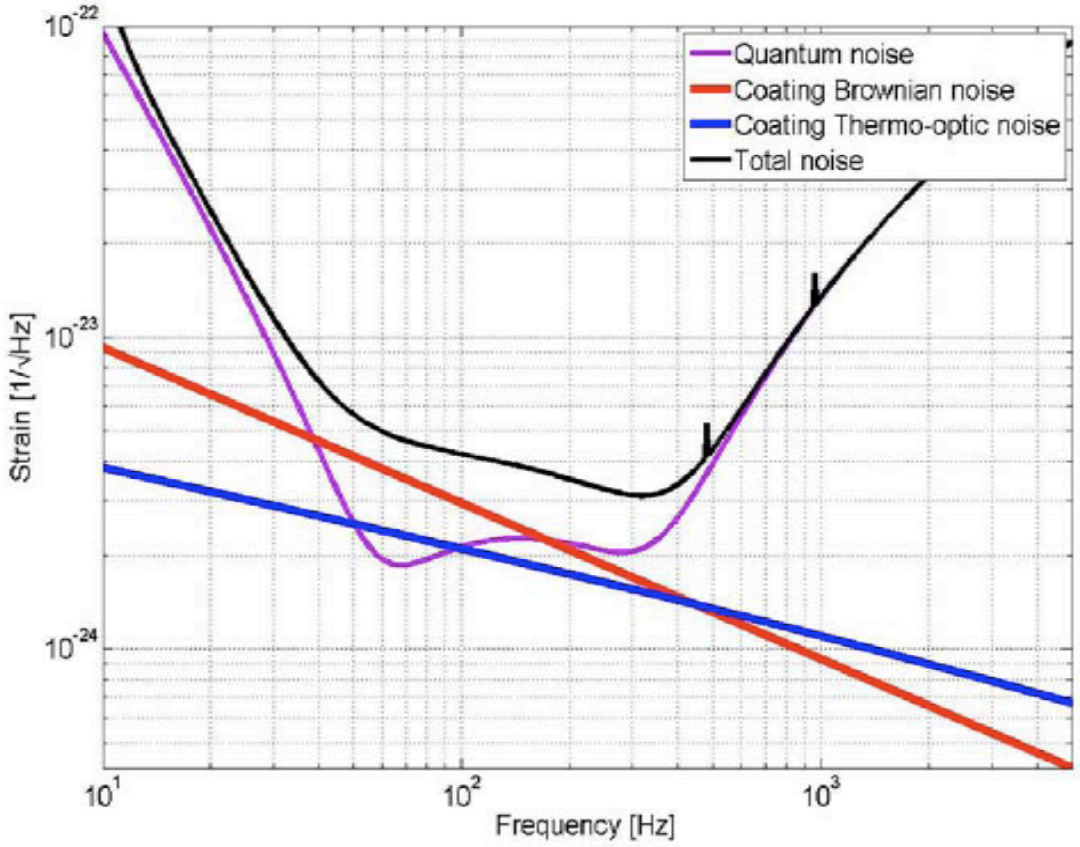
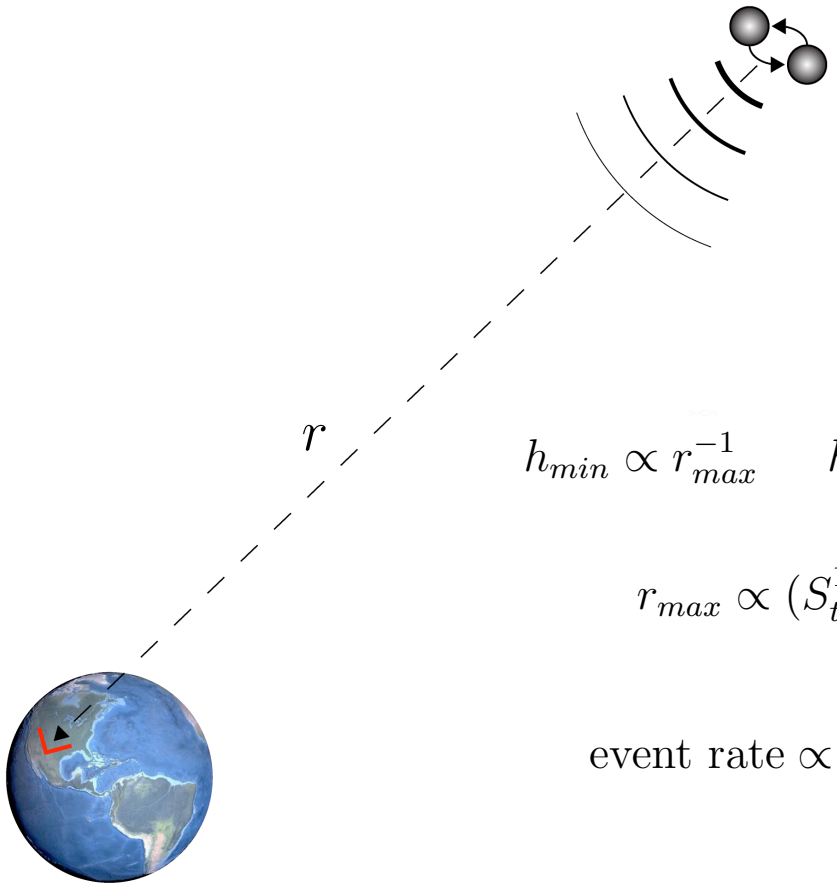
Innocenzo Pinto

Advanced LIGO Noise Floor



- Coating thermal noise will limit sensitivity around 100 Hz
- Reductions in coating noise lead directly to improvements in sensitivity

Lower Noise Floor Means More Events



$$h_{min} \propto r_{max}^{-1} \qquad h_{min} \propto S_{therm}^{1/2}$$

$$r_{max} \propto (S_{therm}^{1/2})^{-1}$$

$$\text{event rate} \propto V \propto r_{max}^{3}$$

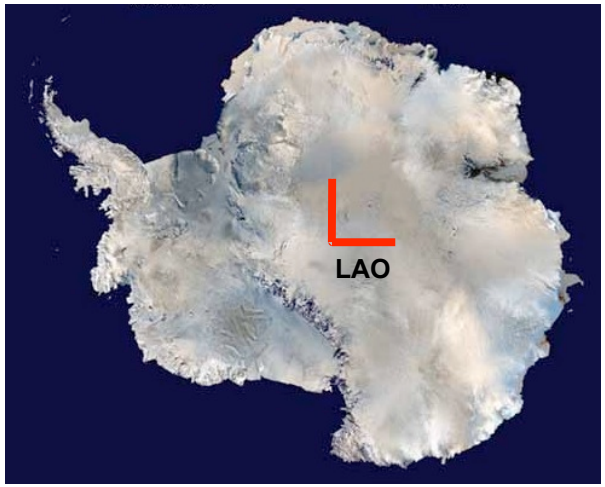
$$\text{event rate} \propto (S_{therm}^{1/2})^{-3}$$

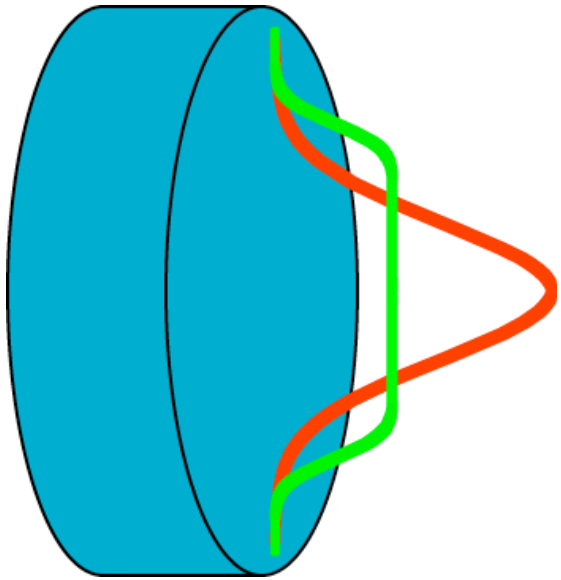
- Small improvement in thermal noise floor means big gain in event rate

Reducing the Thermal Noise

$$S_x(f) = \frac{2k_B T}{\pi^{3/2} f} \frac{(1-\sigma^2)}{wY} \phi_{eff}$$

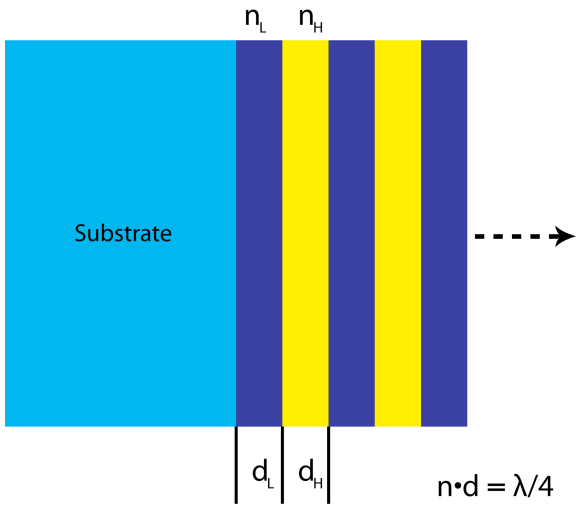
Cryogenics ➔



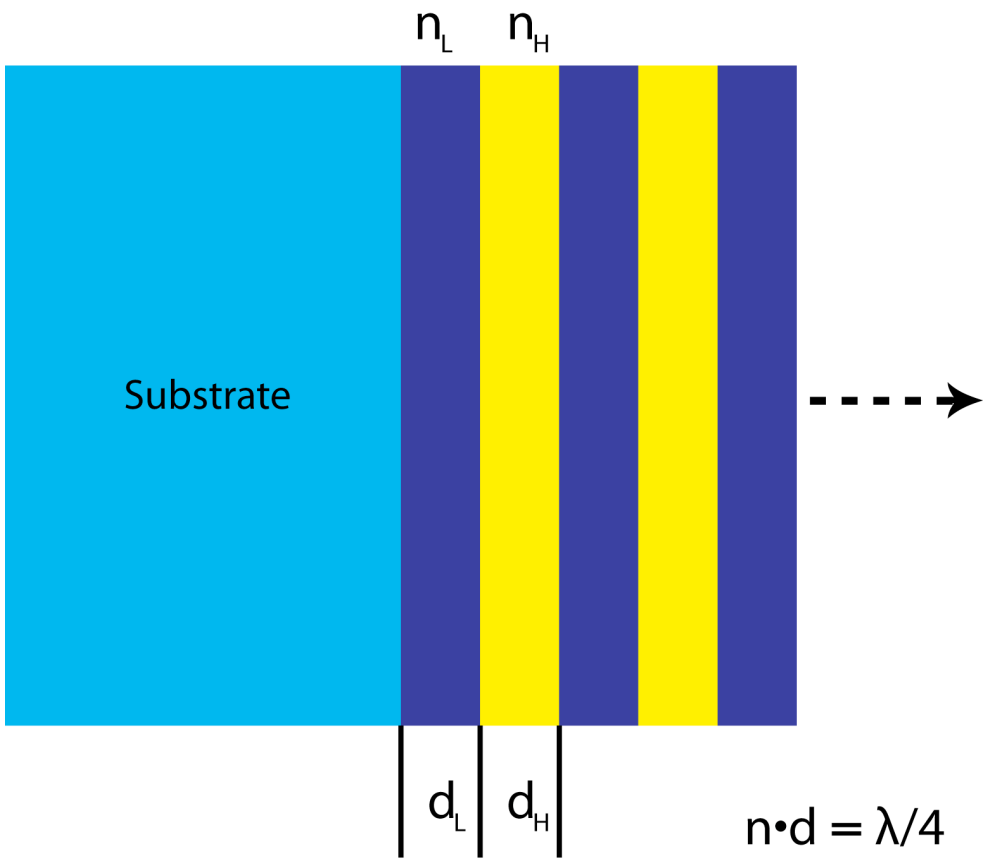


➔ Mesa Beam

Redesigned Coatings ➔

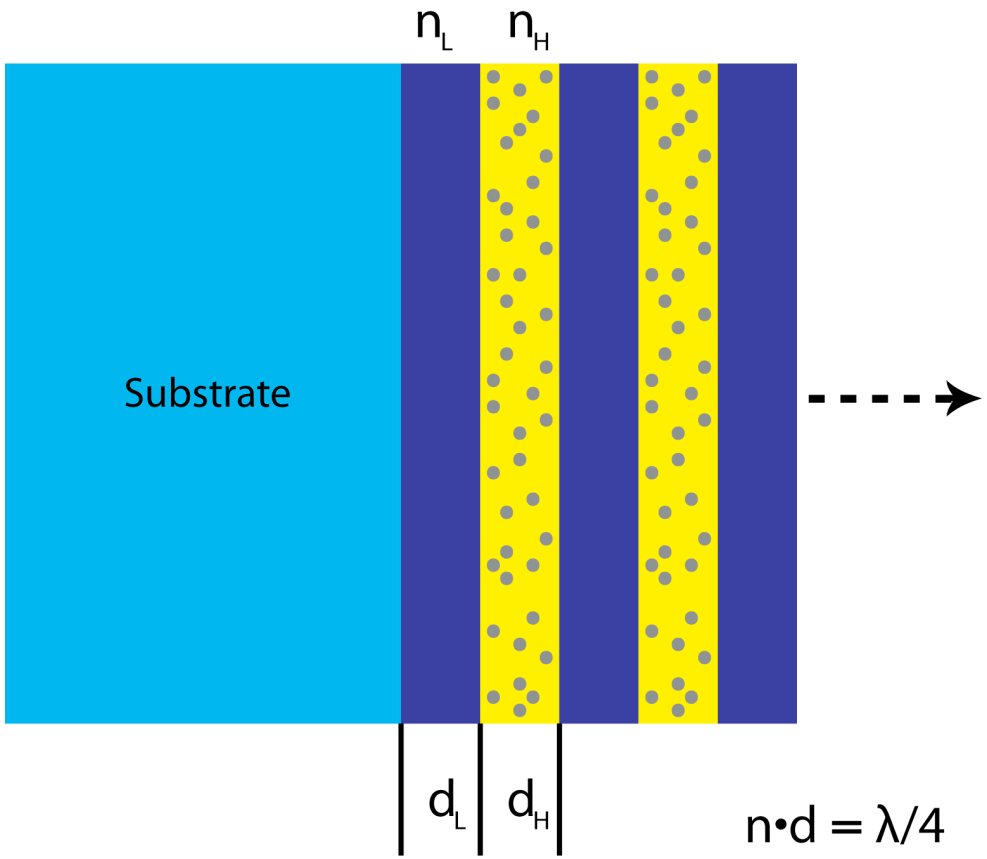


Multilayer Dielectric Coatings



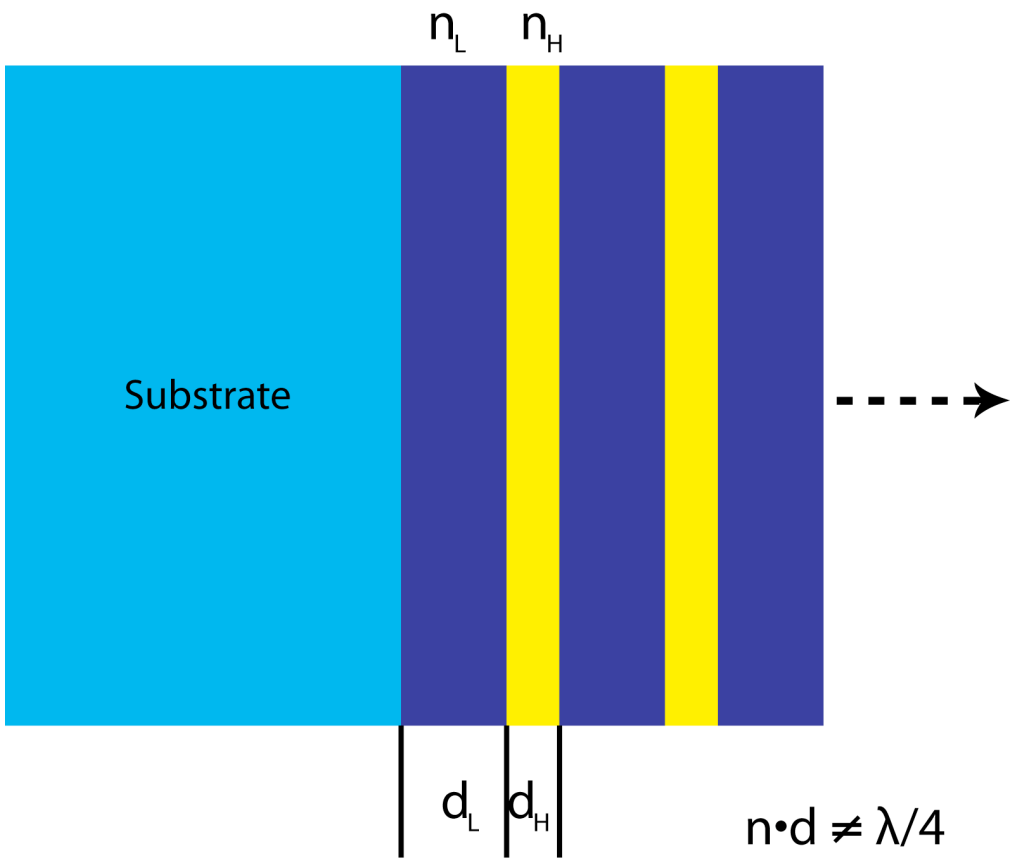
- Alternating layers of high and low index materials
- Quarter wavelength optical thickness for best reflectivity
- Thermal noise arises from internal friction in the coatings

Doped Coatings



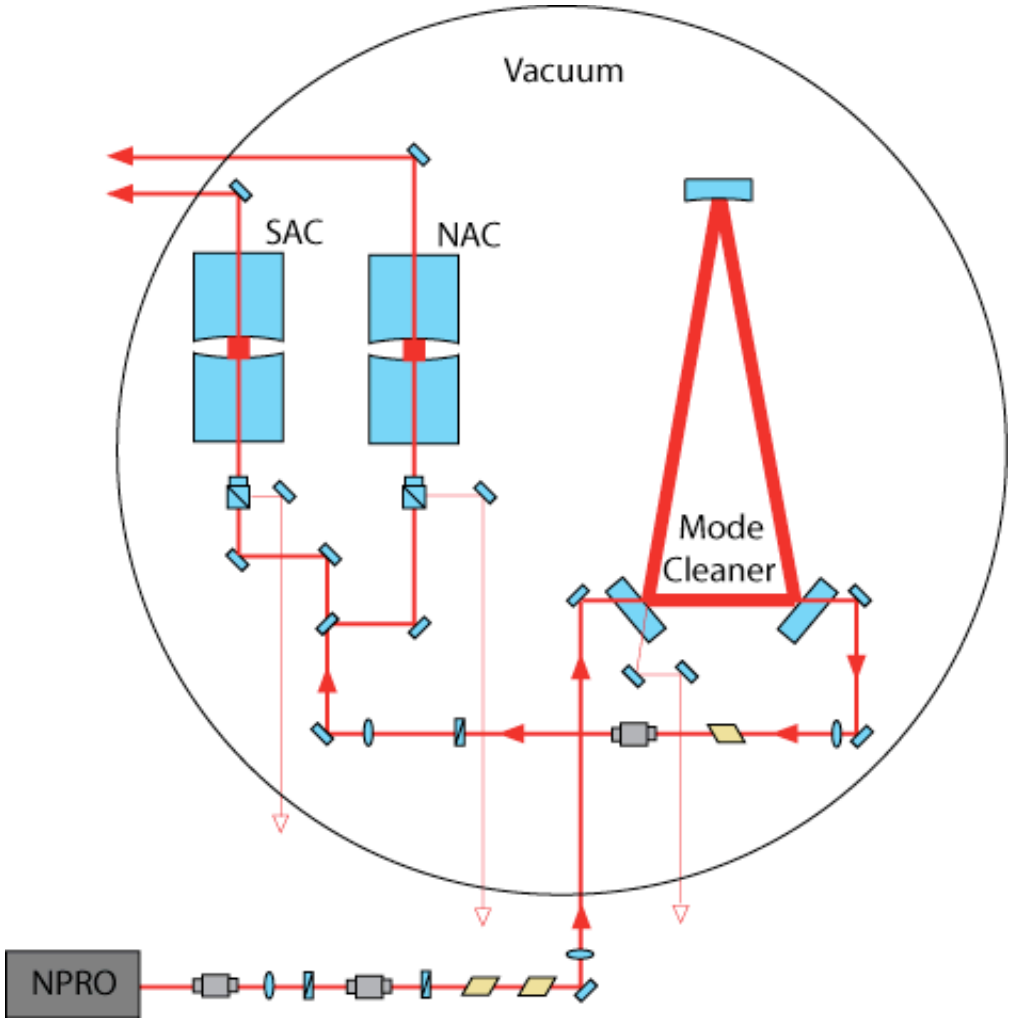
- Tantala layers are doped with Titania
- Lossiness of coating should decrease

Optimized Coatings

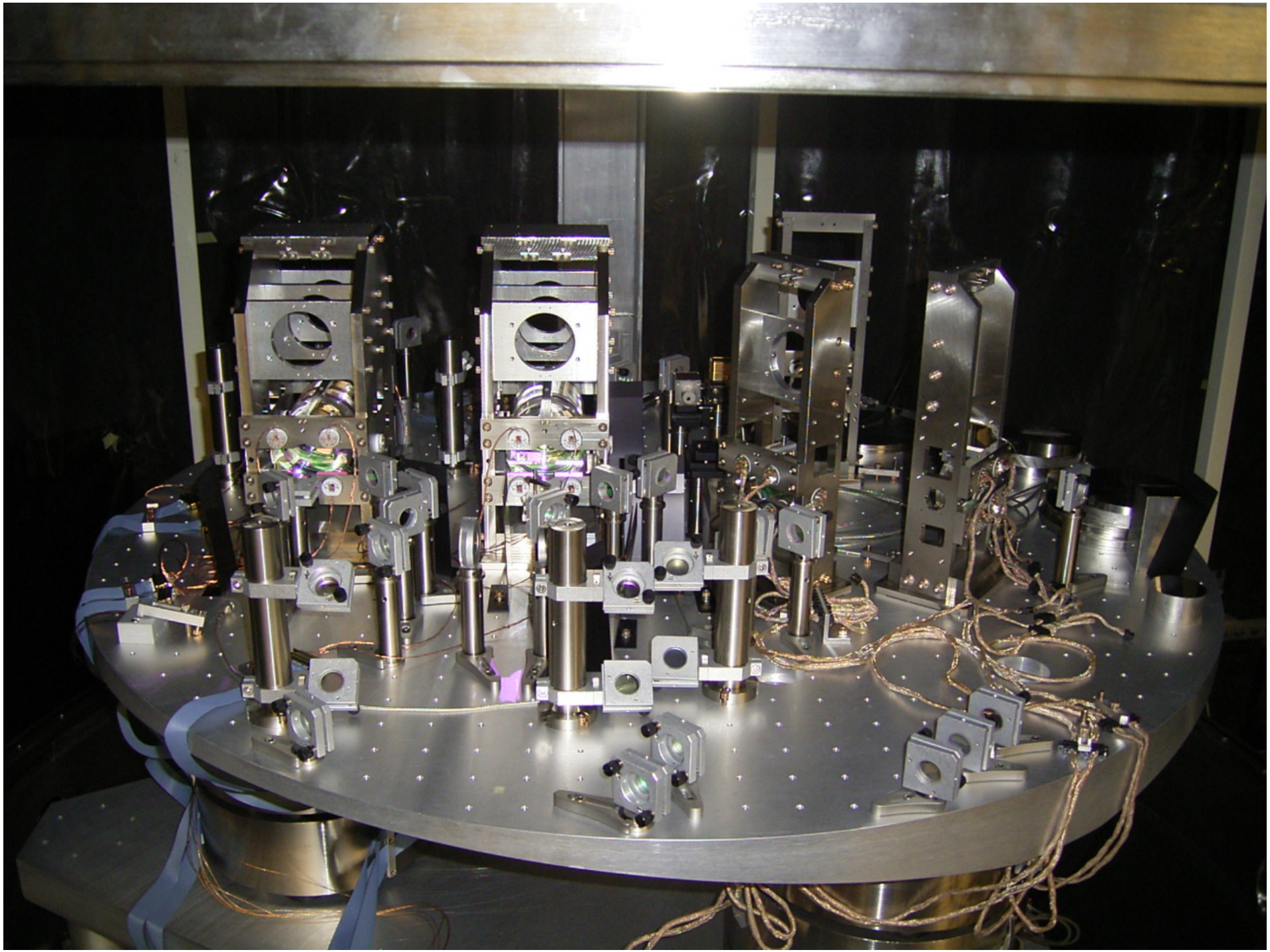


- Tantala thickness reduced
- Silica thickness increased
- Layer pairs have λ/2 optical thickness

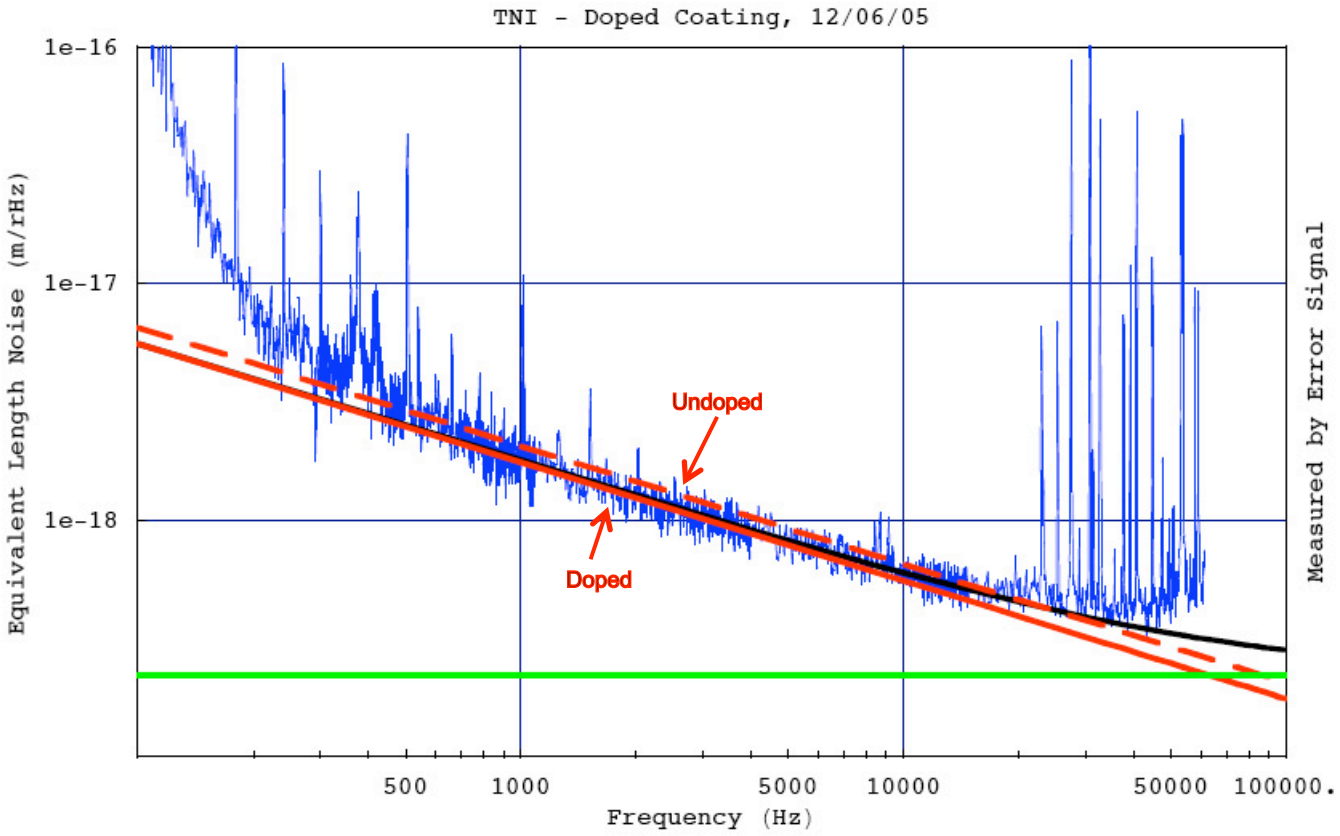
Thermal Noise Interferometer



- Testbed interferometer designed to measure thermal noise in optics
- Short test cavities reduce laser frequency noise
- Small spot size increases thermal noise
- Two test cavities permit CMR



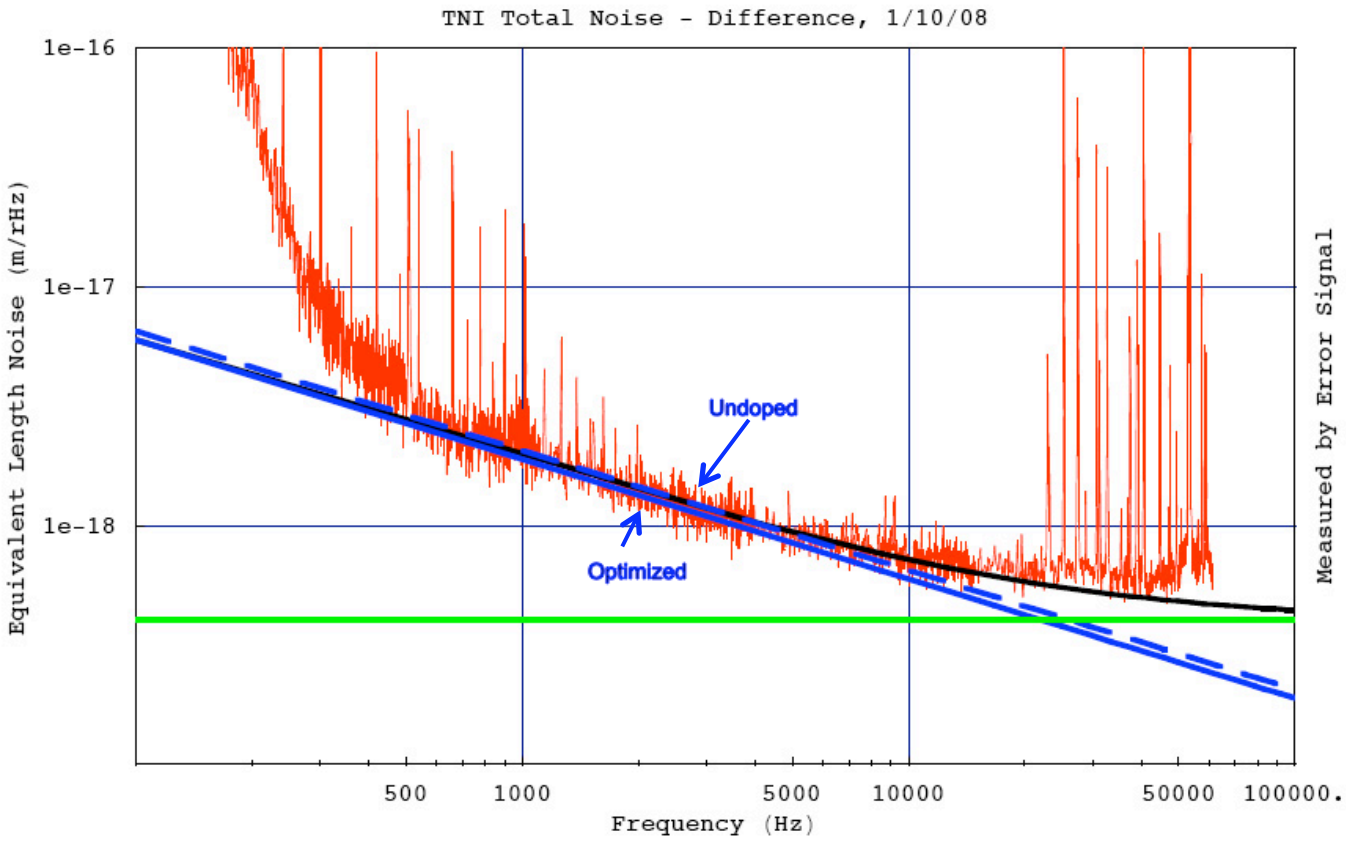
Doped Coating Measurement



- Undoped coatings: Layers of SiO_2 and Ta_2O_5
- Doped Coatings: Ta_2O_5 layers doped with TiO_2
- A 27% reduction in loss angle
- 60% increase in event rate

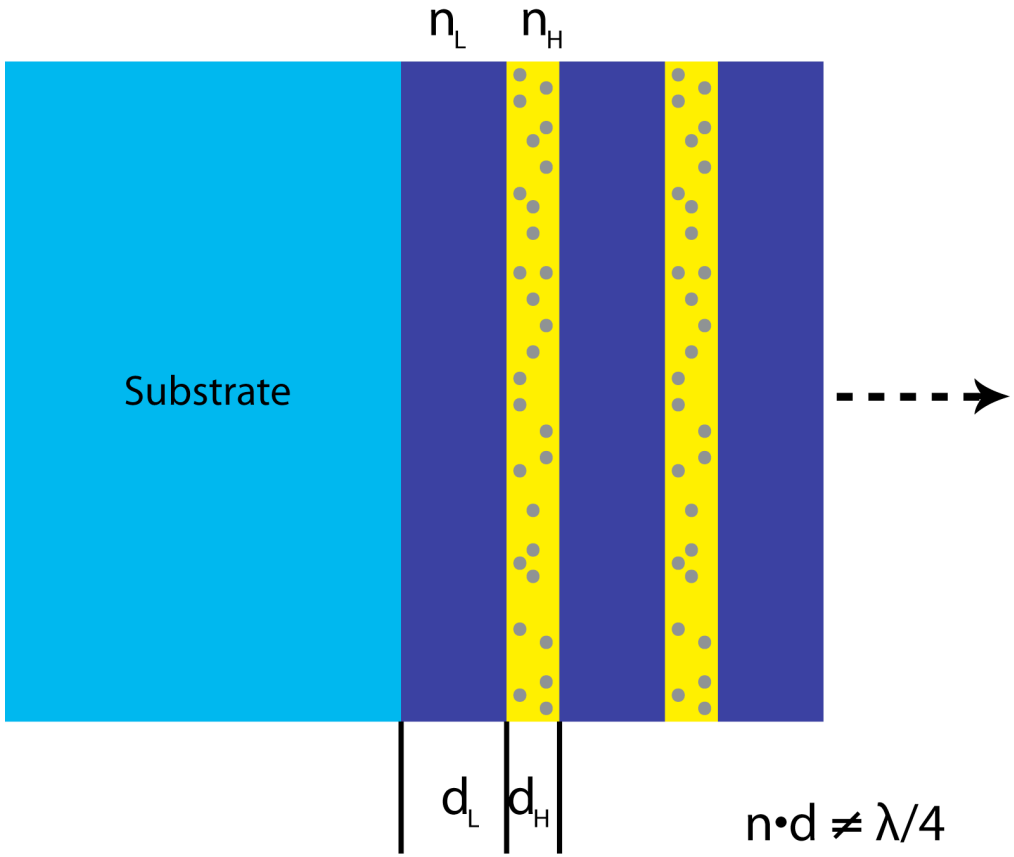
$$S_x(f) = \frac{2k_B T}{\pi^{3/2} f} \frac{\left(1-\sigma^2\right)}{wY} \phi_{eff}$$

Optimized Coating Measurement



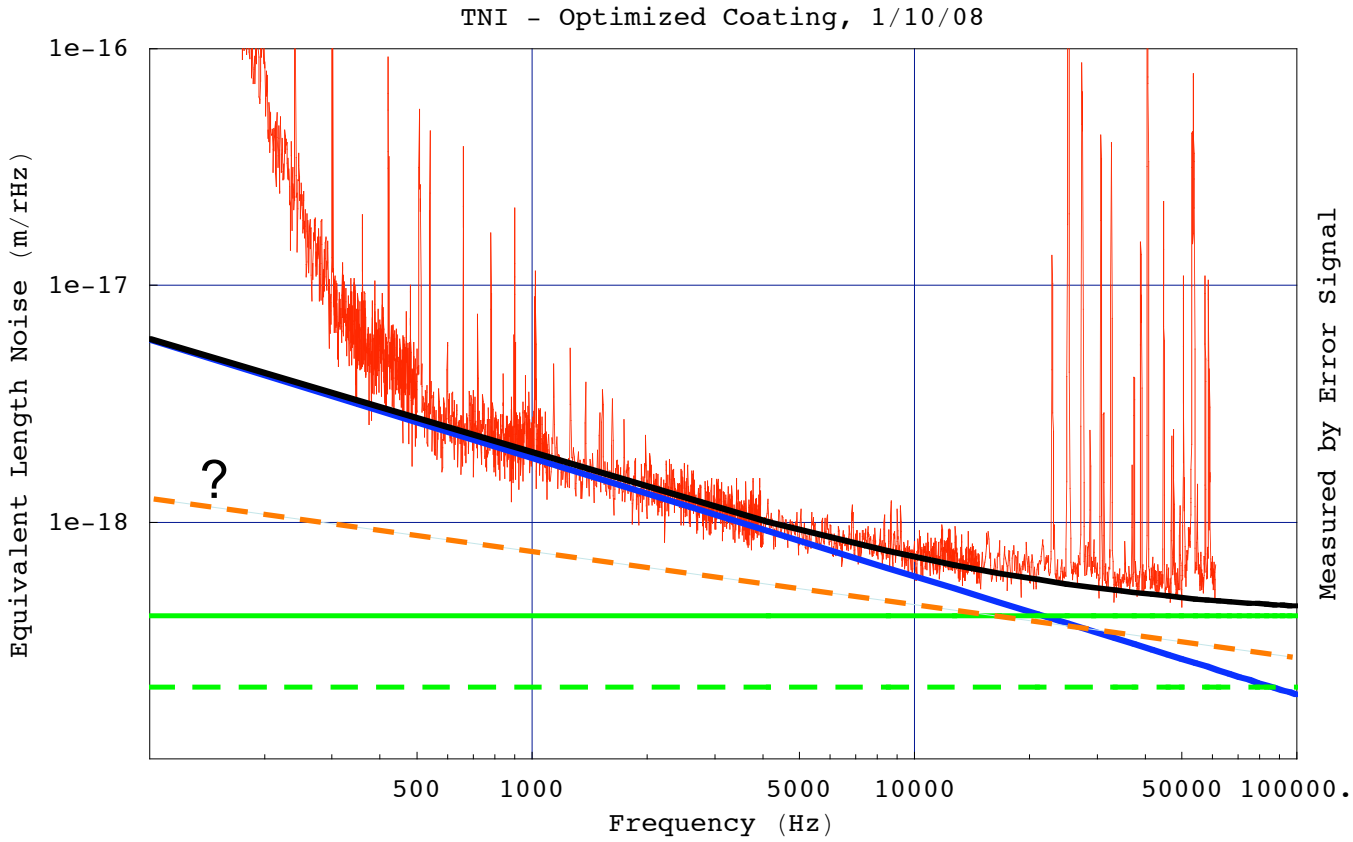
- 16% reduction in loss angle
- 29% increase in event rate

Next: Doped *and* Optimized Coatings



- Titania-doped Tantala for high index layers
- Layer thicknesses optimized to reduce thermal noise

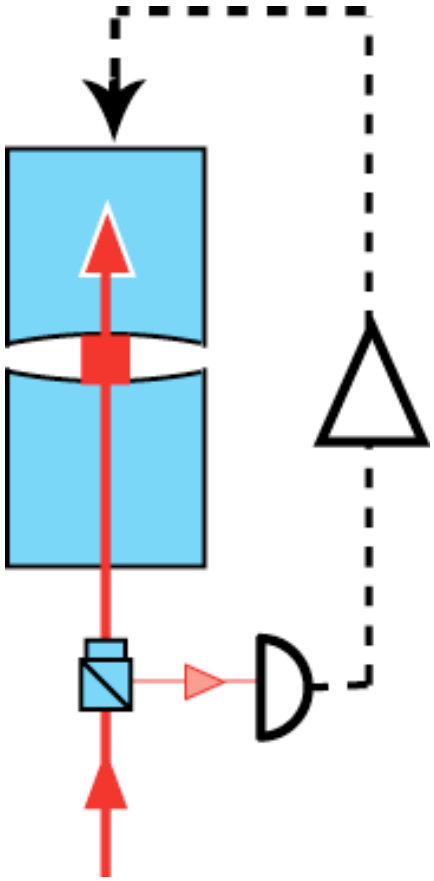
Thermo-Optic Noise?

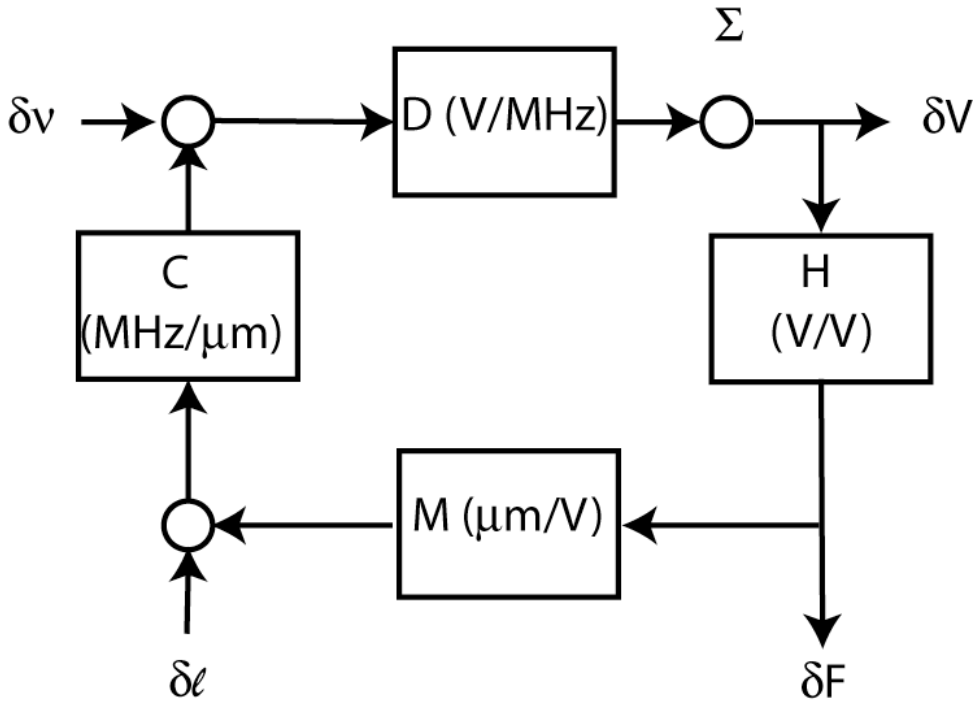


- Shot noise at the TNI should be reduced soon
- Chance of uncovering thermo-optic noise

LIGO

Test Cavity Servo





$$\delta\ell = \frac{1 + DHMC}{DC}\delta V$$