# Real Cavity Design Basics

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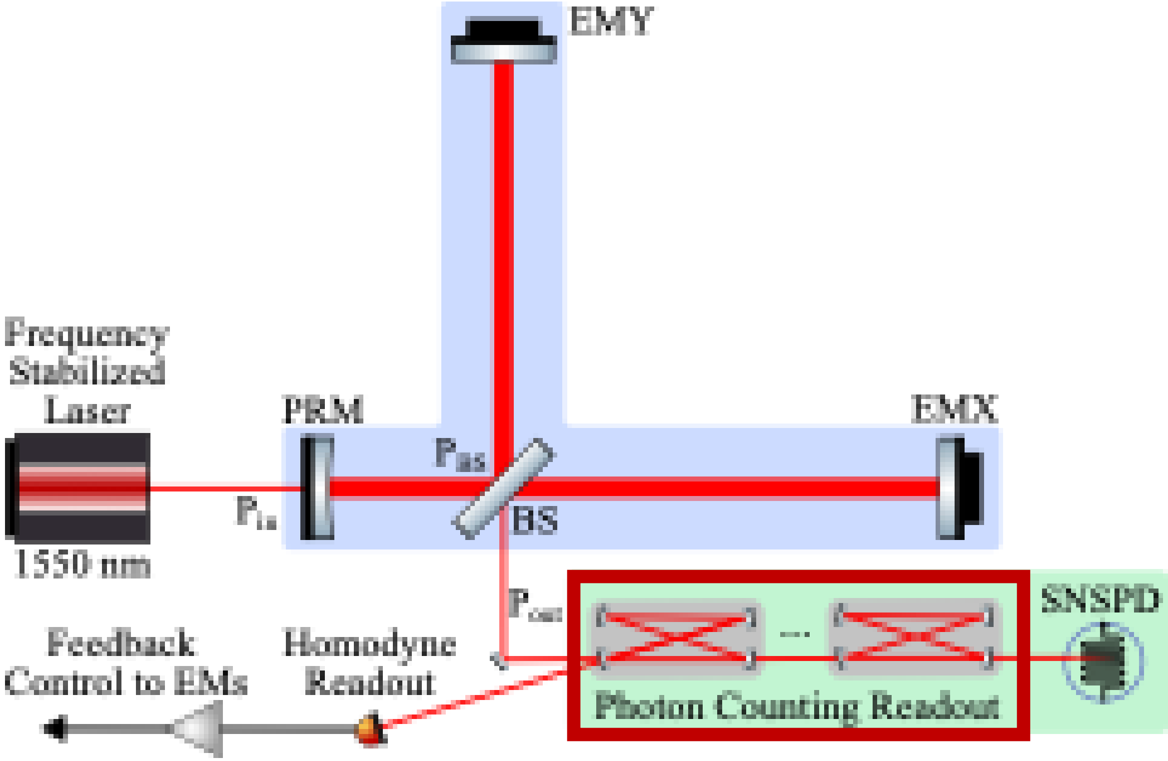
# GQuEST Review

- Michelson Interferometer to detect (tiny) quantum spacetime fluctuations
- Novel "Photon Counting Readout" requires filtering out "carrier" and passing signal with ~18 MHz sideband
- Using 4 Optical Cavities to do this filtering



# Optical Cavity Review

- Electric Field incident on system of mirrors that circulates light
- Get field buildup inside cavity that depends on the spacing, mirror reflectivity, and loss

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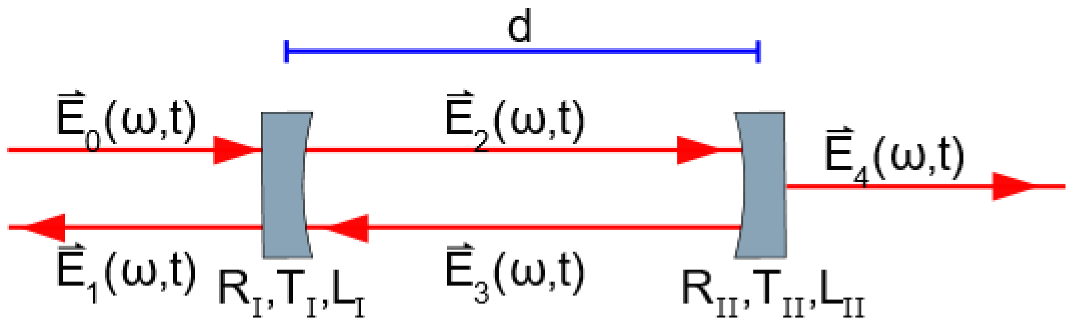


# Optical Cavity Math

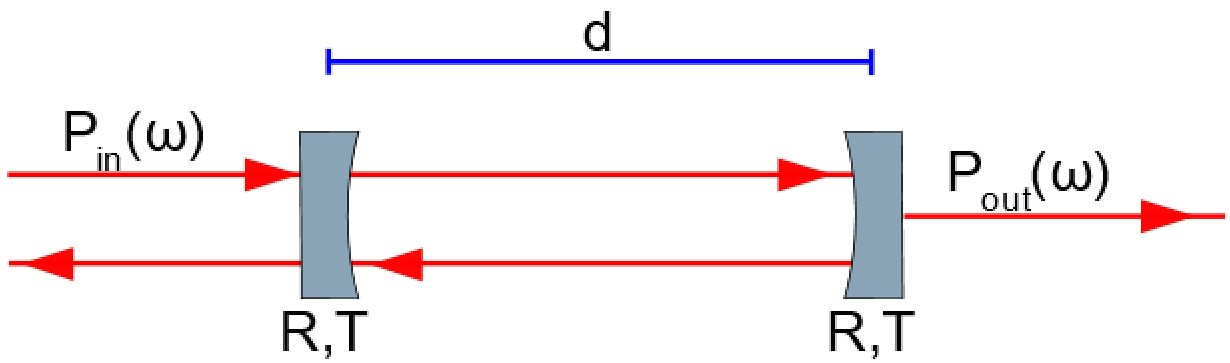
- Assume 2 mirror cavity with lossless mirrors and equal reflectivities

$$T_{\text{cav}} = \frac{P_{\text{out}}(f)}{P_{\text{in}}(f)} = \frac{1}{1 + (\frac{2\mathcal{F}}{\pi})^2 \sin^2(\frac{\pi f}{\text{FSR}})} \approx \frac{1}{1 + (\frac{2f}{\delta f})^2}$$

$$\mathcal{F} = \frac{\pi\sqrt{r}}{1 - r} \approx \frac{2\pi}{T}$$

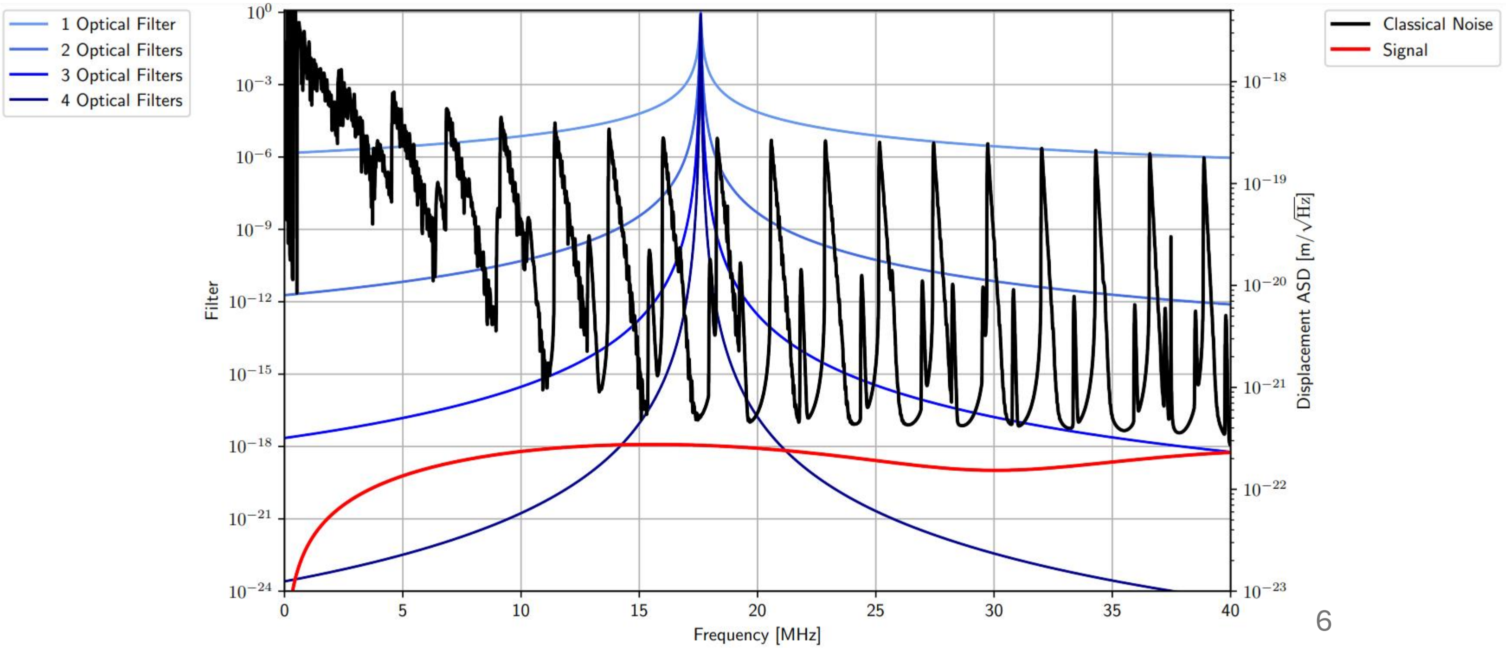
$$\text{FSR} = \frac{c}{\text{path length}} = \frac{c}{2d}$$

$$\delta f = \frac{\text{FSR}}{\mathcal{F}} = \frac{c}{2d\mathcal{F}}$$



# How GQuEST uses Cavities

- Use the frequency selectivity of optical cavities to pass signal and filter out carrier
- Have to filter carrier power by 22 orders of magnitude and still pass a meaningful amount of signal
- Use multiple cavities: passband width minimally reduced while carrier filtered by more



# Finesse and Length Choice

$$\dot{N}_{\text{carrier}} < \dot{N}_{\text{signal}}$$

$$\text{Filter}(f_{\text{signal peak}})\frac{P_{\text{carrier}}}{\hbar\omega} < \frac{\delta f_1}{2} S_{\dot{N}}^{\text{signal}}$$

$$\left(\frac{\delta f_1^2}{\delta f_1^2 + 4 f_{\text{s.p.}}^2}\right)^4 \frac{P_{\text{carrier}}}{\hbar\omega} < \frac{\delta f_1}{2} S_{\dot{N}}^{\text{signal}}$$

$$\frac{\delta f_1^8}{256 f_{\text{s.p.}}^8} \frac{P_{\text{carrier}}}{\hbar\omega} < \frac{\delta f_1}{2} S_{\dot{N}}^{\text{signal}}$$

$$\delta f_1 < 2(S_{\dot{N}}^{\text{signal}} f_{\text{s.p.}}^8 \hbar\omega / P_{\text{carrier}})^{1/7}$$

$$\frac{c}{\mathcal{F}L} < 2(S_{\dot{N}}^{\text{signal}} f_{\text{s.p.}}^8 \hbar\omega / P_{\text{carrier}})^{1/7}$$

$$\frac{c}{2(S_{\dot{N}}^{\text{signal}} f_{\text{s.p.}}^8 \hbar\omega / P_{\text{carrier}})^{1/7}} < \mathcal{F}L$$

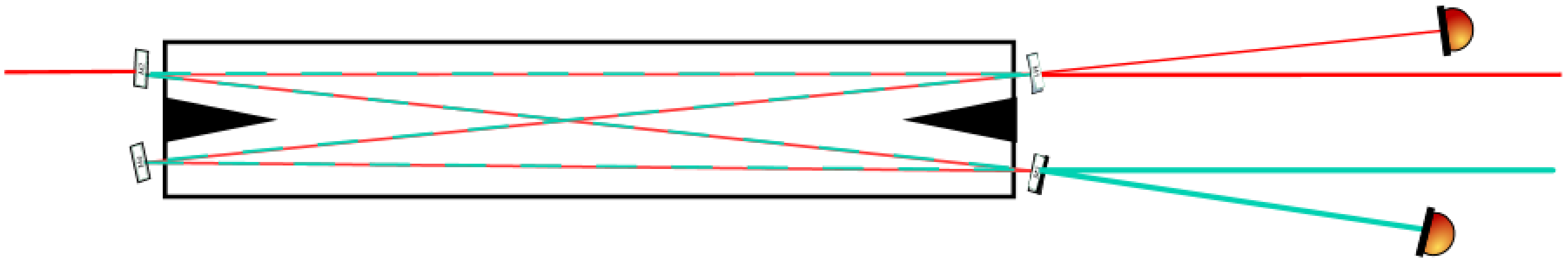
$$\boxed{4000\ \text{m} < \mathcal{F}L}$$

# Finesse and Length Choice pt 2.

- To suppress the carrier below signal => 4000 m < $\mathcal{F}L$
- Finesse chosen to be large (3000), but it becomes infeasible to keep the cavity at the operating point with too high a Finesse
- Requiring high mode spacing means the FSR cannot be too small
- Thus, length cannot be too large
- Additional practical concern with too long a length

# More high-level design choices

- Controlled with PDH technique on frequency doubled light
- 4 mirrors to allow for more inputs into cavity
- $2\pi/3$ round trip Gouy phase to help with (HG) mode separation
- Low Angle of Incidence (AOI) to avoid astigmatism from curved mirror
- Want AOI large enough to separate incident and reflected beams



# Practical Design Choices

- Solid body to accurately set cavity length and reduce vibration noise
- “Flexure mounts” to align mirrors
- Enclosed body and black coating (not shown) to reduce stray and scattered light
- Controlled with a piezoelectric chip (cannot use laser)
- Novel design to avoid gluing ($1,000) mirrors to piezo