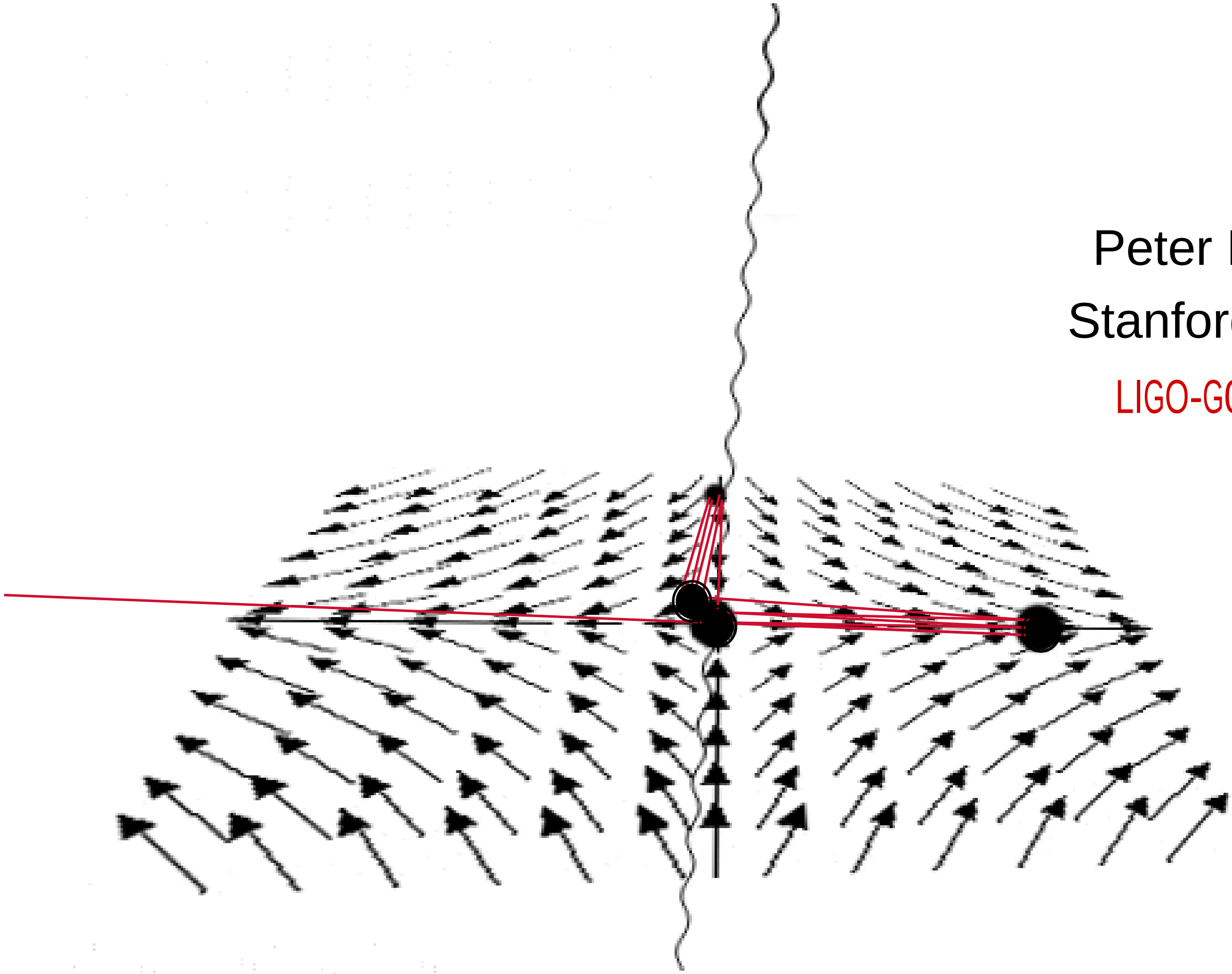
The Stanford 10m All-Reflective Sagnac



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Stanford University

LIGO-G000279-00-D

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The 10m all-reflective Sagnac interferometer

- Motivation for using an all-reflective Sagnac
- The interferometer design
  - The grating beamsplitter
  - Controlling polarization
  - The delay lines
- Results
  - Measurements of the effect of stray light
  - Demonstration of the robustness of the Sagnac interferometer
- Conclusion

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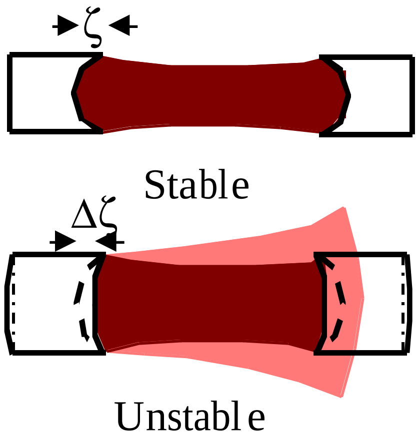
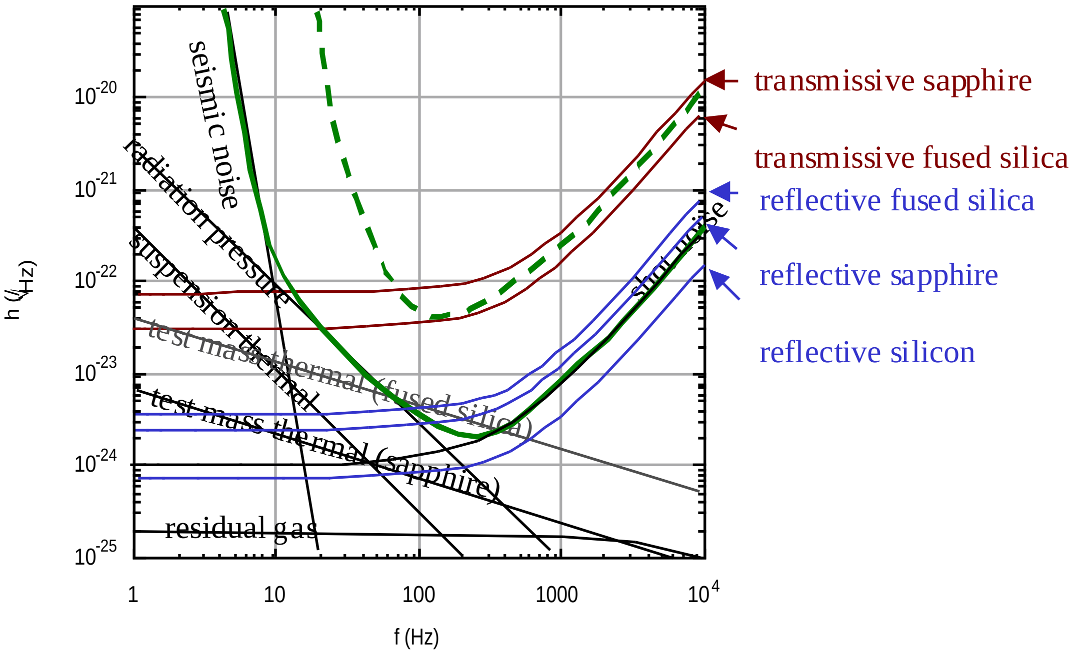
LIGO III thermal distortion limited sensitivity



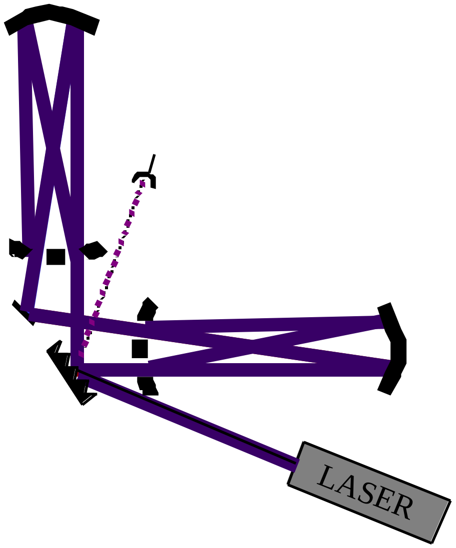


The thermal deformation is

$$\Delta\zeta = \left[\frac{\alpha / \kappa}{4\pi}\left(a_{coating} + a_{bulk}\right) + \frac{\beta / \kappa}{4\pi} a_{coating} + 1.3\frac{\beta / \kappa}{4\pi} a_{bulk}\right] P_{inc}$$

Stability requires $\Delta\zeta < \dfrac{\omega_{max}^2}{2R_{\max}}$

Straw-man design based on an all-reflective Sagnac



- All reflective optics
  - grating beamsplitter
  - delay lines for energy storage
- Robust control scheme
  - dynamically stable(No out-of-band control effort is necessary)
  - soft failure mode (interferometer is passively locked)

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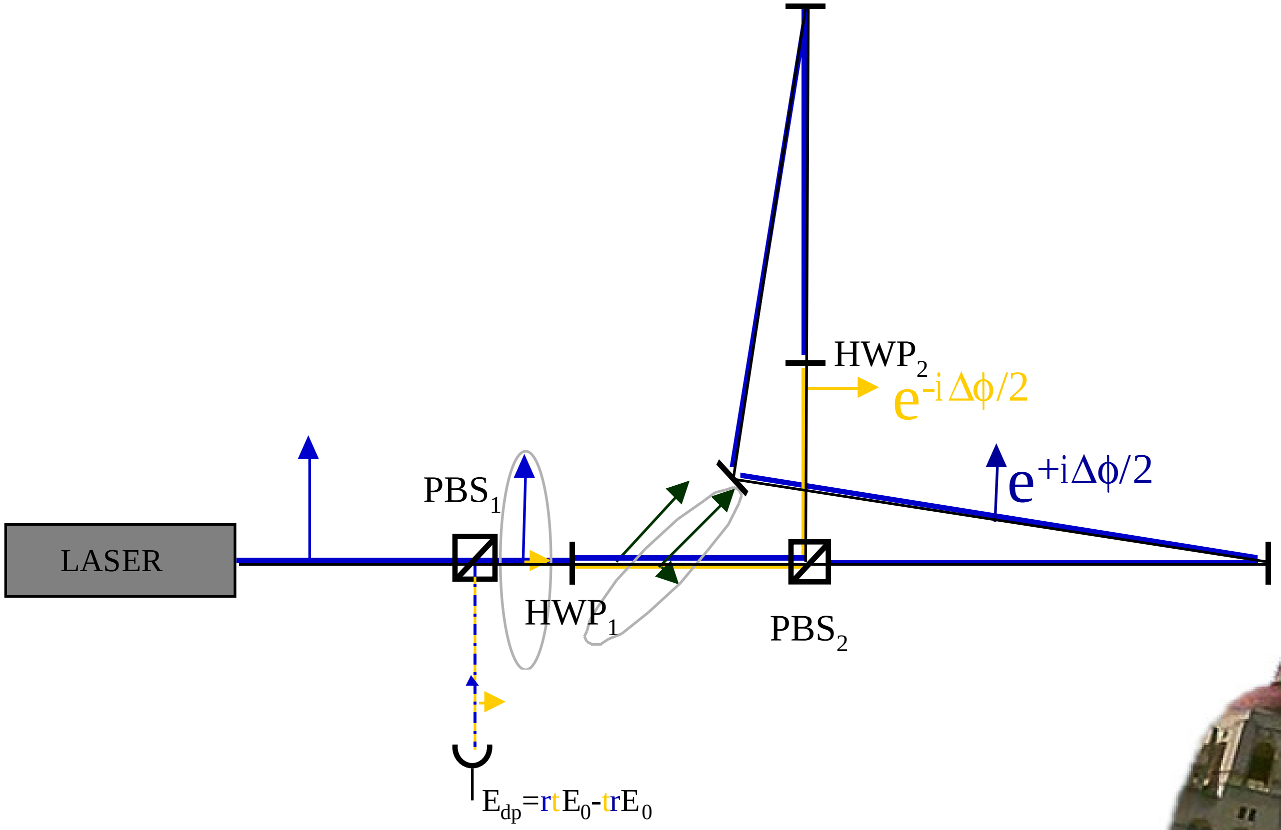
The Polarization Sagnac Interferometer

Reflective beamsplitters and waveplates must be used



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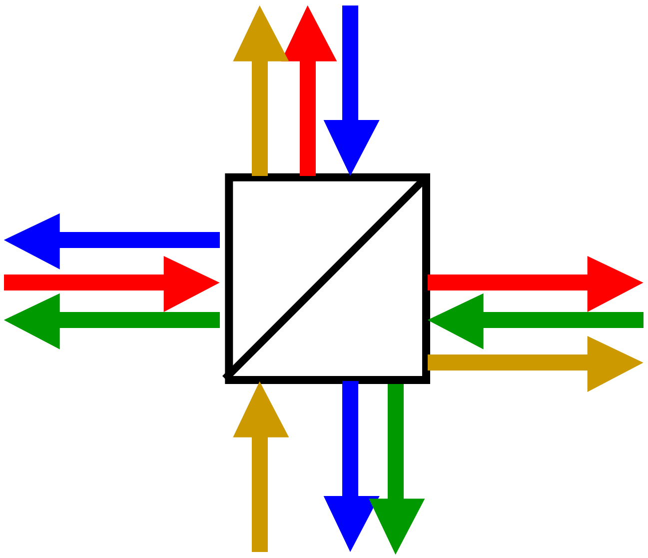
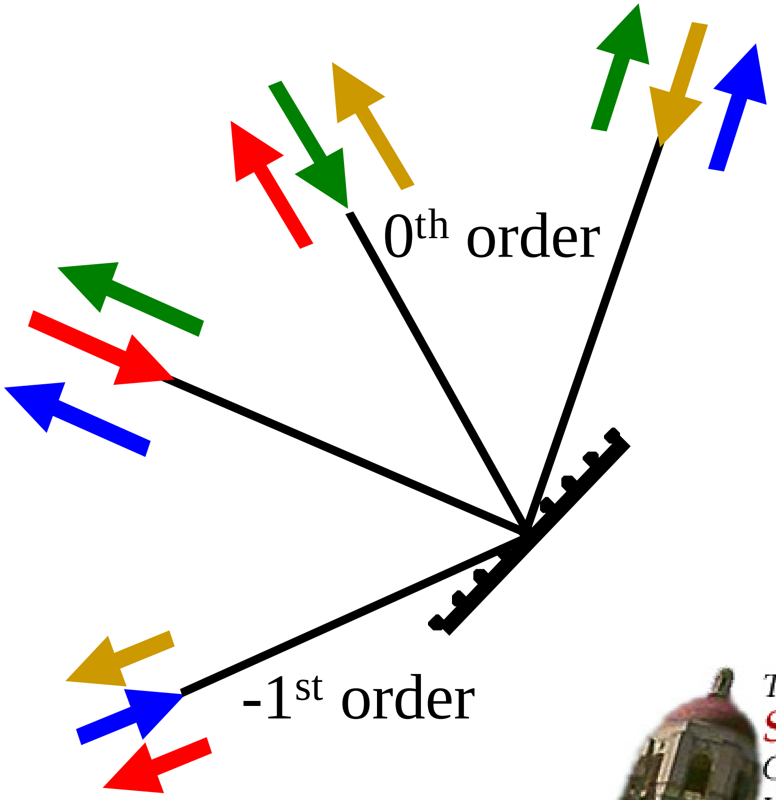
A grating as a reflective beamsplitter

A transmissive beamsplitter and a grating are 4 port devices that are functionally equivalent

$$S_{bs} = \begin{bmatrix} 0 & r & it & 0 \\ r & 0 & 0 & it \\ it & 0 & 0 & r \\ 0 & it & r & 0 \end{bmatrix} \qquad S_{gr} = \begin{bmatrix} 0 & r & \eta & 0 \\ r & 0 & 0 & \eta \\ \eta & 0 & 0 & r \\ 0 & \eta & r & 0 \end{bmatrix}$$

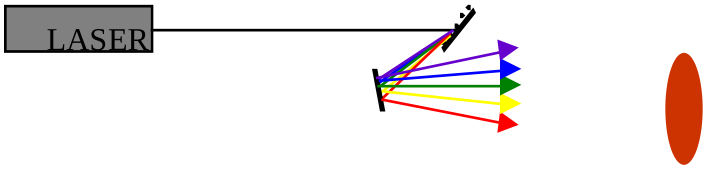




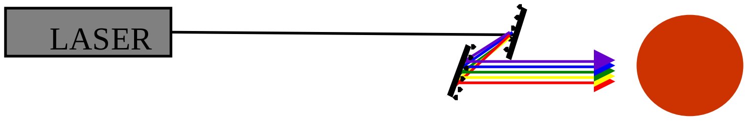
Compensating for grating dispersion

Uncompensated grating

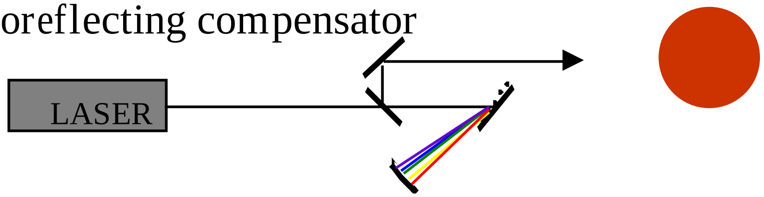
beam profile



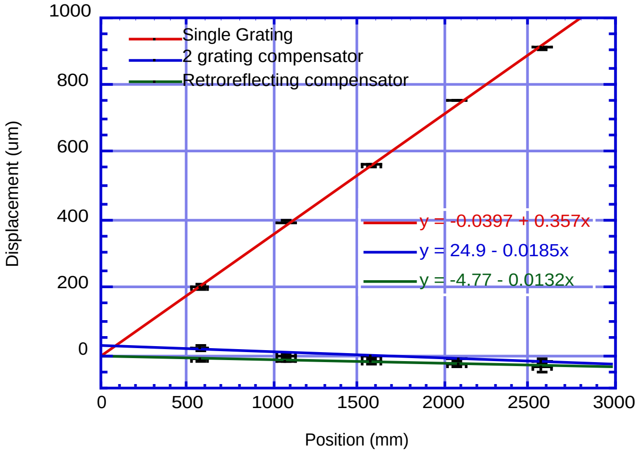
2 grating compensator



retroreflecting compensator



Beam displacement vs. position for a 20 GHz laser frequency change



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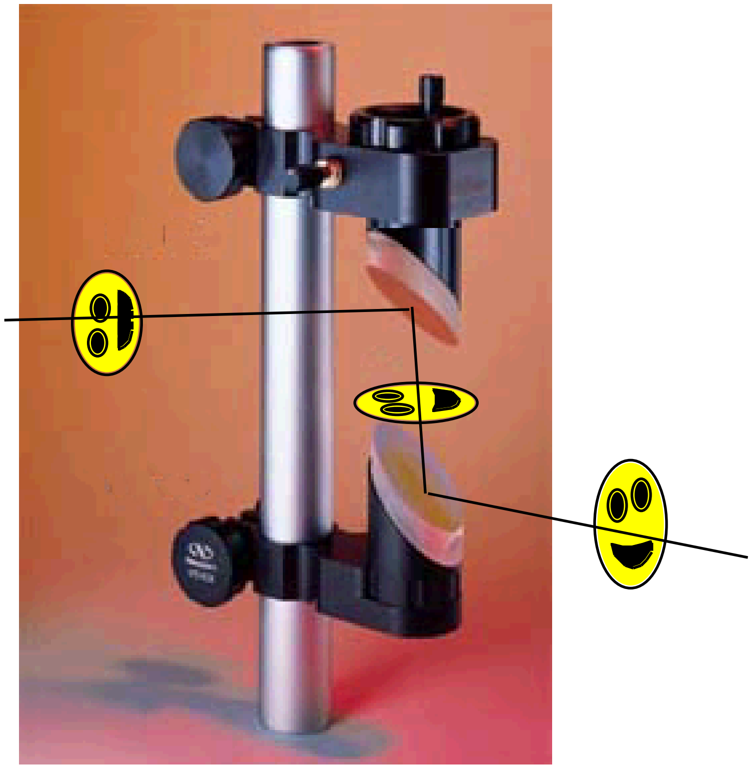
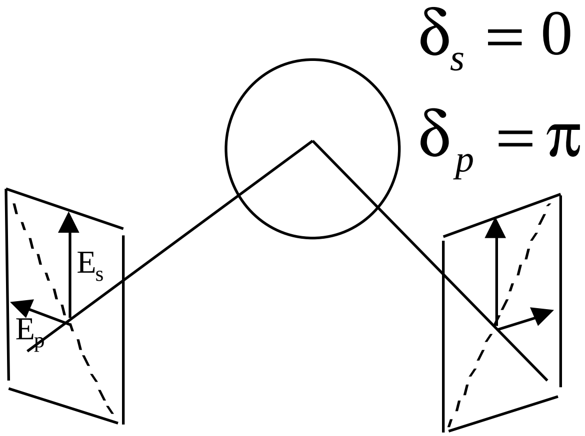
Polarization rotation without transmissive waveplates

Periscope



Dielectric Mirror



$$\delta_s = 0$$

$$\delta_p = \pi$$

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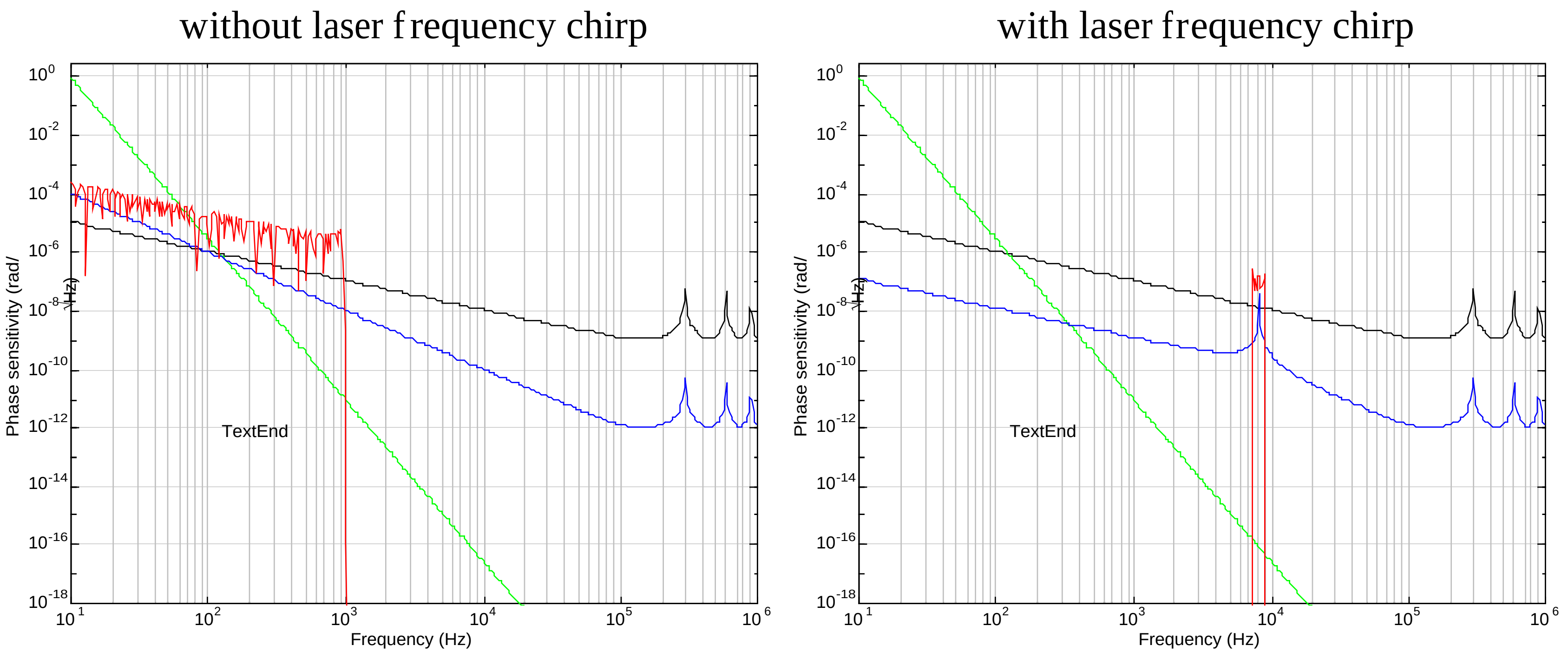
Expected Sensitivity of Prototype Sagnac



⬛ shot noise
🟩 seismic noise
🟦 laser frequency noise
🟥 upconverted mirror noise

$P=300\text{mW}$ $f_o=1$
$\lambda=1.064\mu\text{m}$ $\Delta x_{max}=1\text{mm}$

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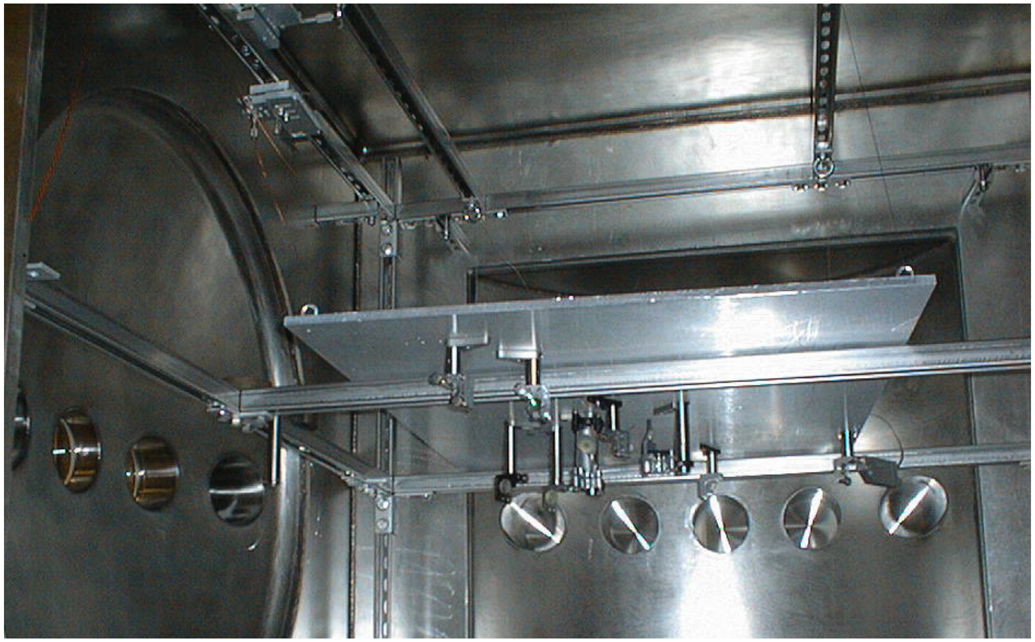
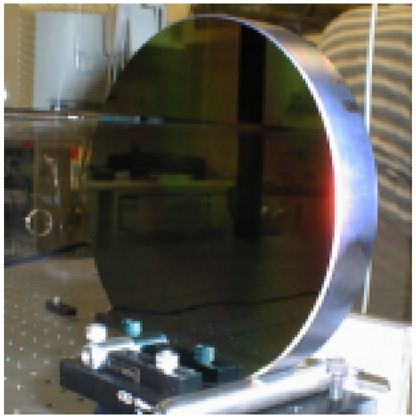
√Hz)

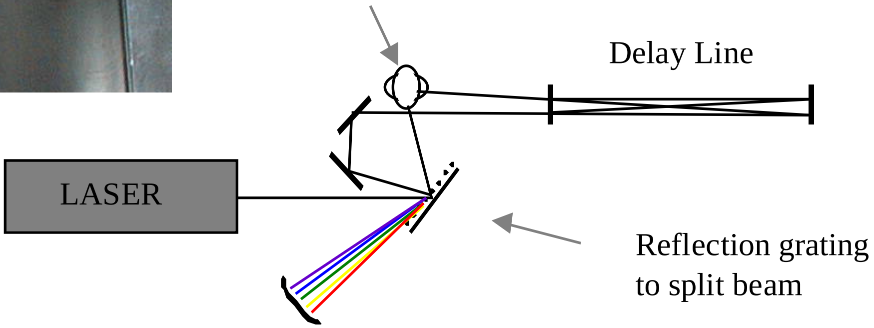
Layout of 10m suspended prototype all-reflective polarization Sagnac



The suspended table in the vacuum system holds most of the components of the interferometer

The delay line mirrors are dielectric coated 6” silicon substrates.





Periscope to rotate polarization

Delay Line

LASER

Reflection grating to split beam

Retroreflector to double pass grating (null dispersion)

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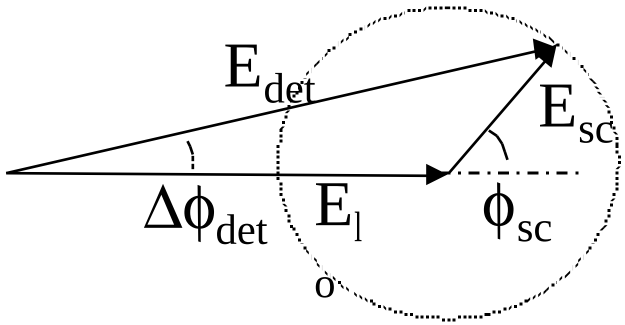
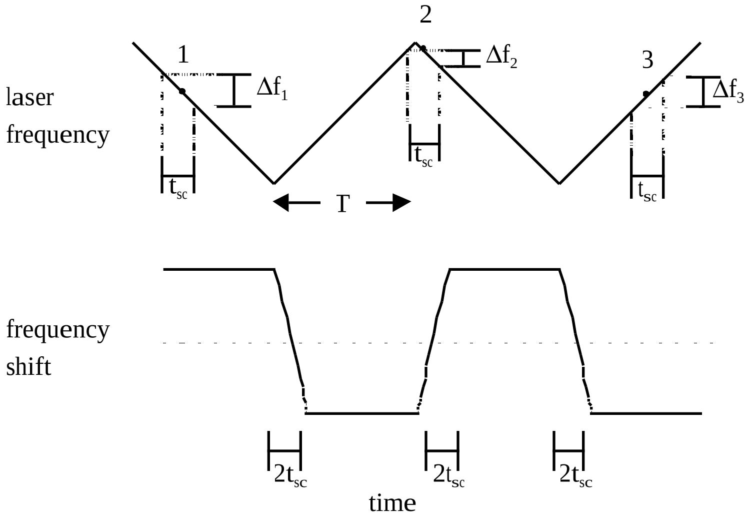
Reducing scattered light noise with a laser frequency chirp





Use large, slow modulation which is easy to produce

-Nd:YAG laser frequency is tunable over 50 GHz in 10 seconds by temperature tuning the crystal

The Frequency of the output light is a function of the light's transit time in the interferometer

-Scattered light will have a different frequency than the signal and local oscillator

Scattered light beats with the local oscillator at a frequency outside of the measurement band

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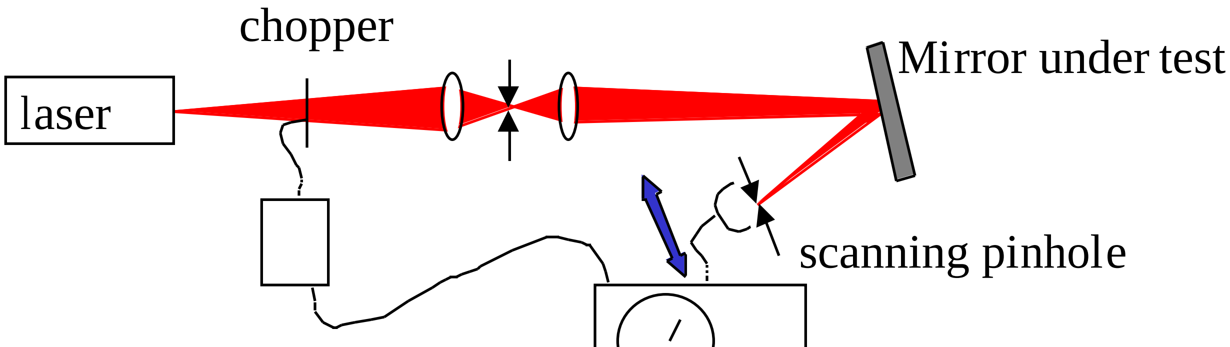
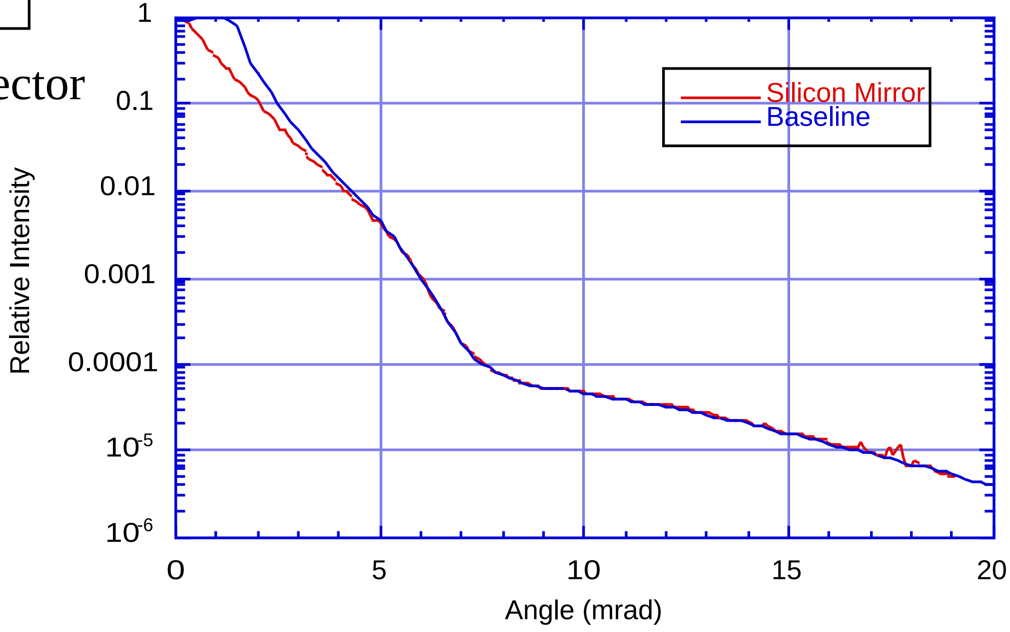
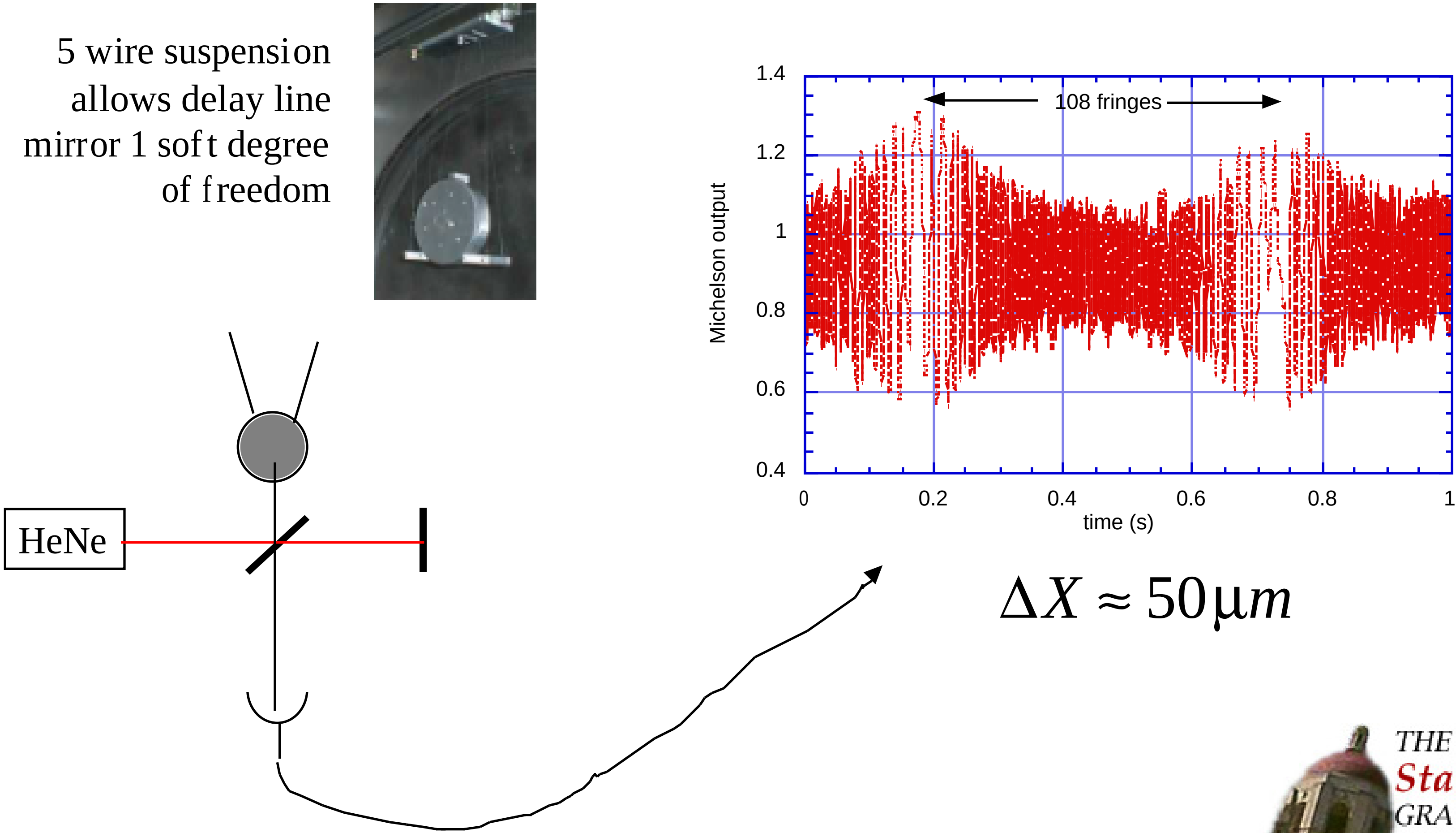
Experiment to measure scattering from mirror





Motion of suspended mirrors

5 wire suspension
allows delay line
mirror 1 soft degree
of freedom



$$\Delta X \approx 50\mu m$$

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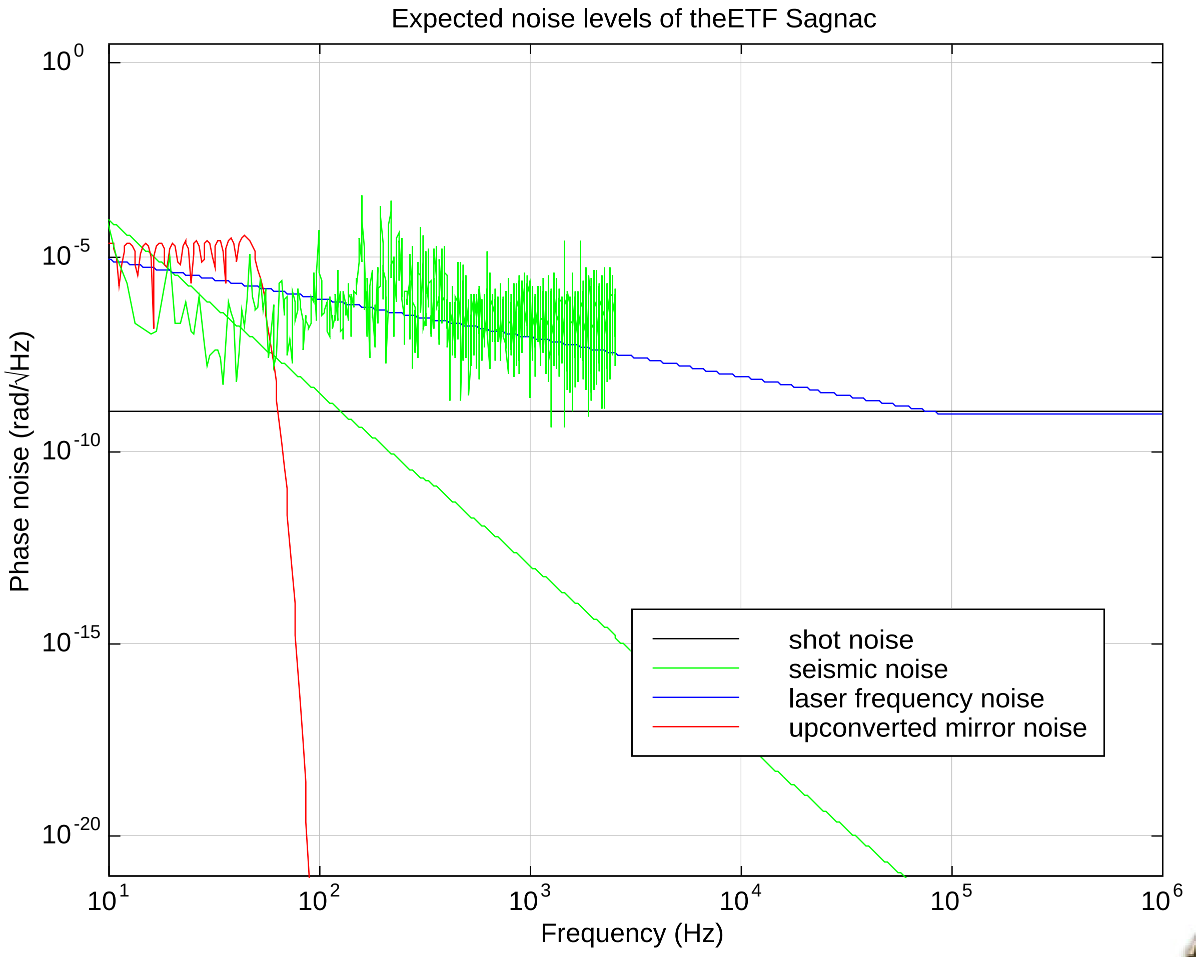
Noise level of Prototype Sagnac



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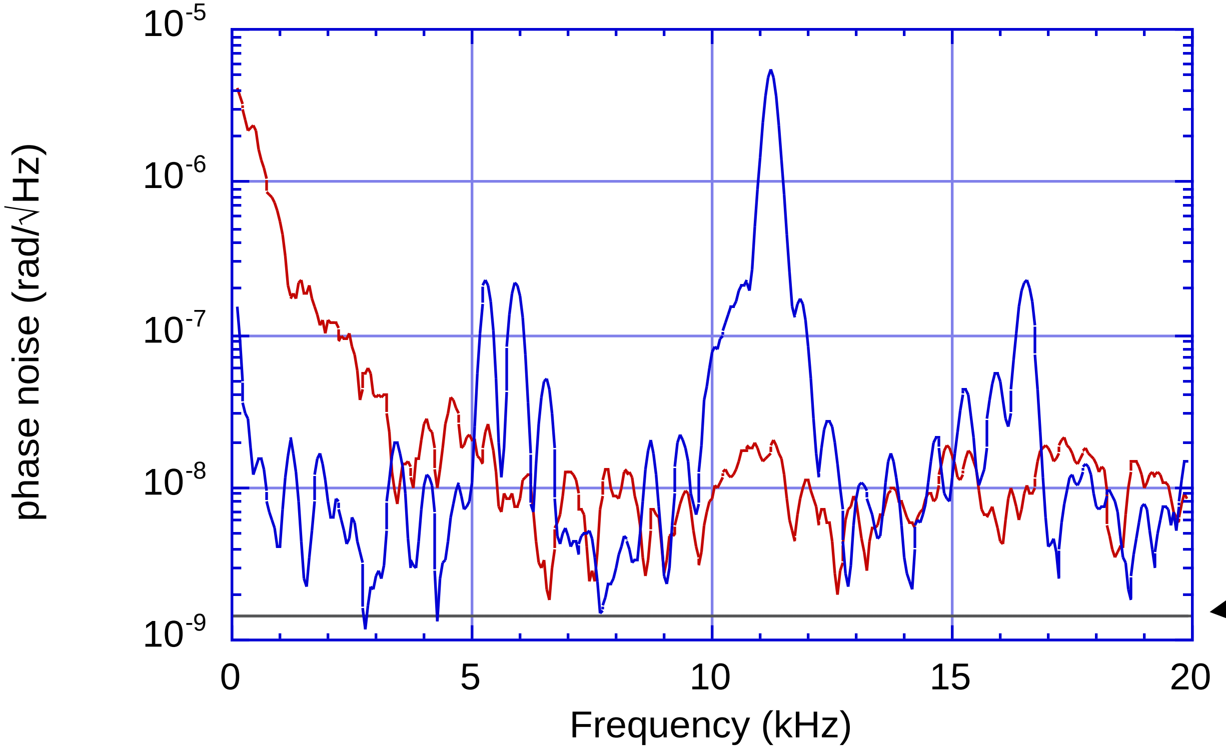
Effect of laser frequency sweep



Shot noise

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Facts of Interest

- Long term stability (drift < beam diameter) ~ 5 days
- Average time to realign ~2 minutes
- Vacuum Pressure $<10^{-6}$ torr
- Time to cycle vacuum system ~6 hours
- Fringe contrast 42 dB
- Clipping factor 2.5
- Peak of frequency Response 217 kHz
- Circulating Power 150 mW
- Local Oscillator power 2mW

Conclusion

- An all-reflective interferometer will allow power scaling necessary for LIGO III
- Many necessary features of an all-reflective interferometer have successfully been implemented in the Stanford 10m Sagnac

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