Results from the Stanford 10m all-reflective polarization Sagnac interferometer

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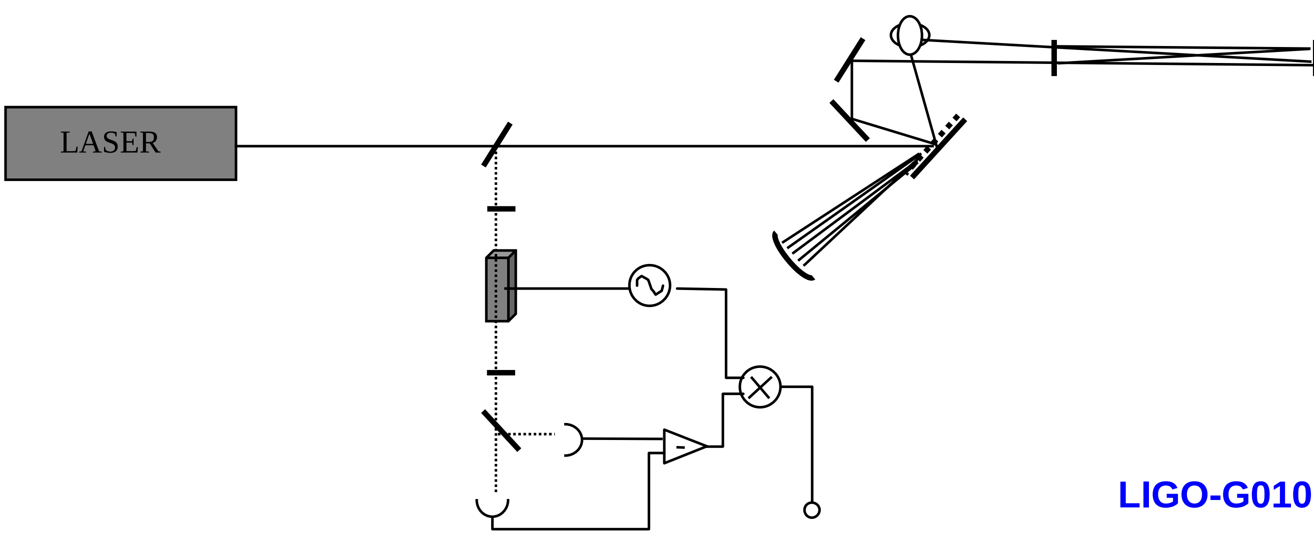


LIGO-G010100-00-Z

The Stanford 10m Sagnac interferometer

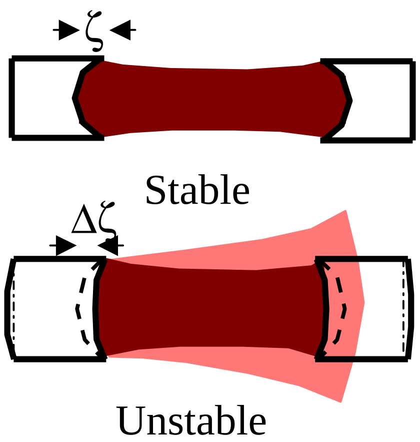
- Description of the interferometer
  - Delay line Sagnac interferometer
  - uncontrolled suspended optics
  - no transmissive optics
- Results
  - stable operation without active control
  - shot noise limited sensitivity at 1kHz

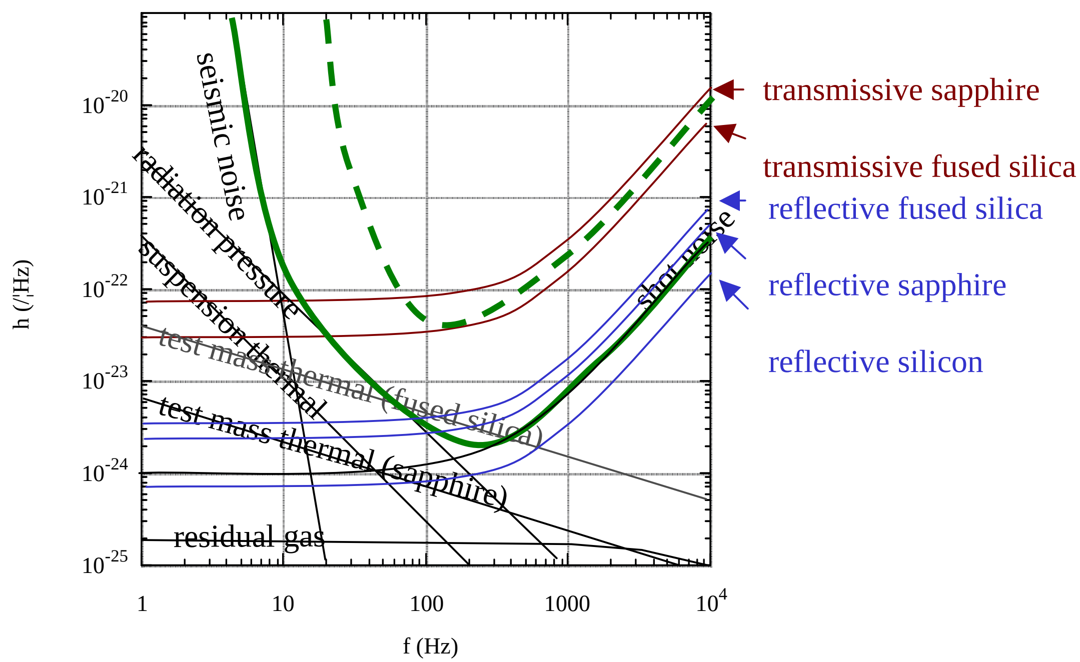
Q: Why the delay line Sagnac interferometer?

A: It is well suited to handle the high circulating power necessary for LIGO III

- Allows the use of all-reflective optics
- Beams travel a common path
  - -Simple control scheme
  - -robust operation in the presence of (dynamic) thermal effects

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

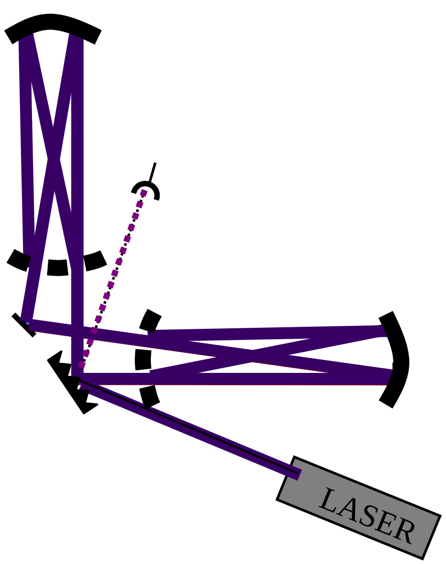
Design elements of the 10m prototype

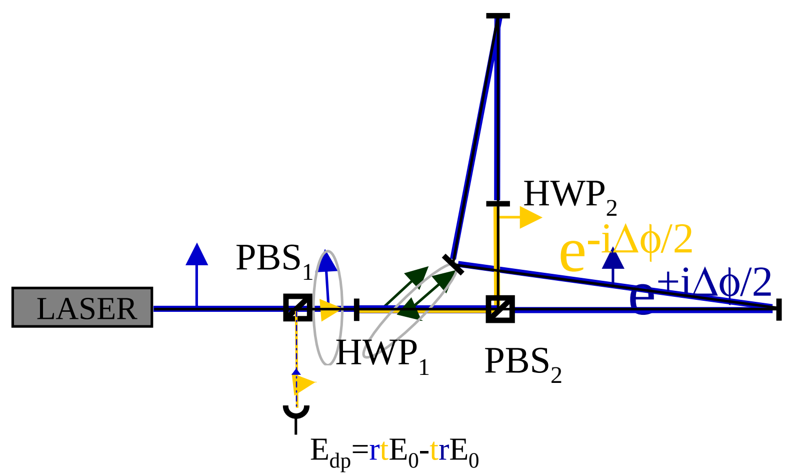
Straw-man design

- All reflective optics
  - grating beamsplitter
  - delay lines for energy storage

Stanford's 2m Sagnac interferometer

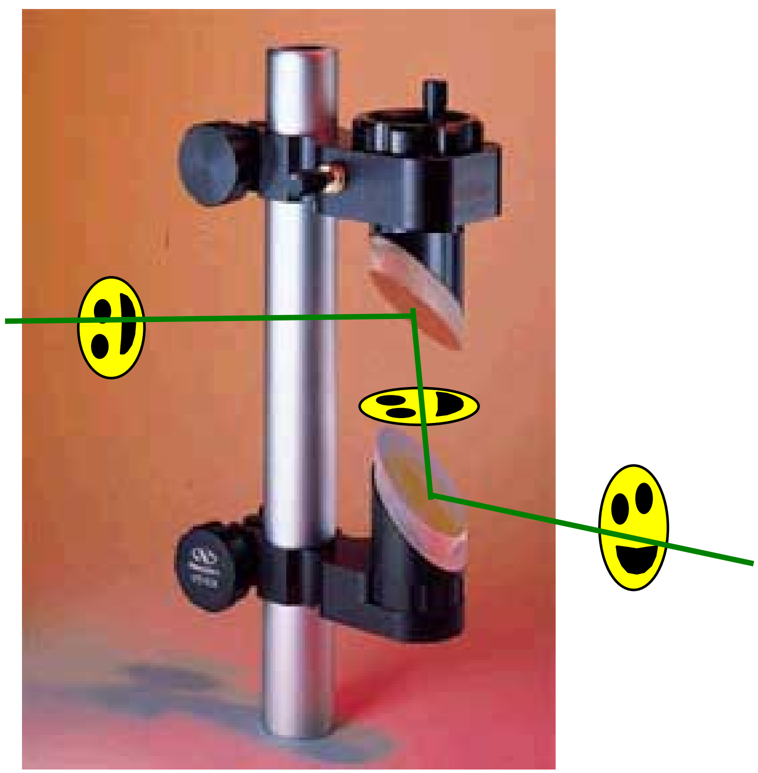
- Polarization control for operation on the symmetrical port of the beamsplitter
  - Polarizing beamsplitter
  - half-wave plate for polarization rotation





Reflective Waveplates

periscope

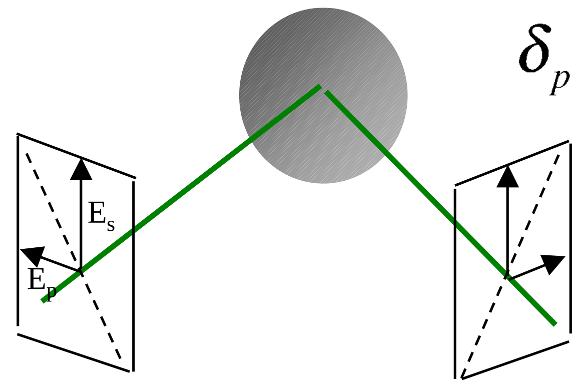


A periscope can rotate the spatial profile of a beam, thereby rotating the polarization

dielectric mirror

$$\delta_s = 0$$

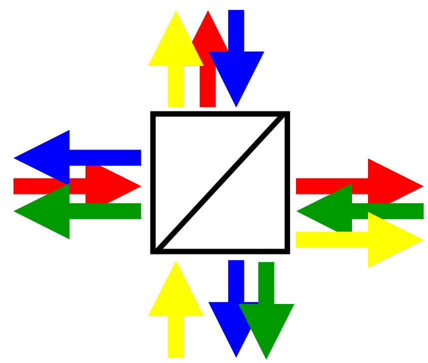
$$\delta_p = \pi$$

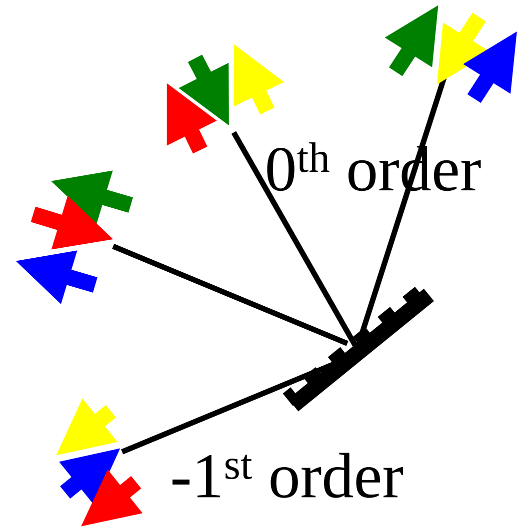


A dielectric mirror can introduce a phase shift between the s and p polarization components of a beam, thereby rotating the polarization

The Grating Beamsplitter

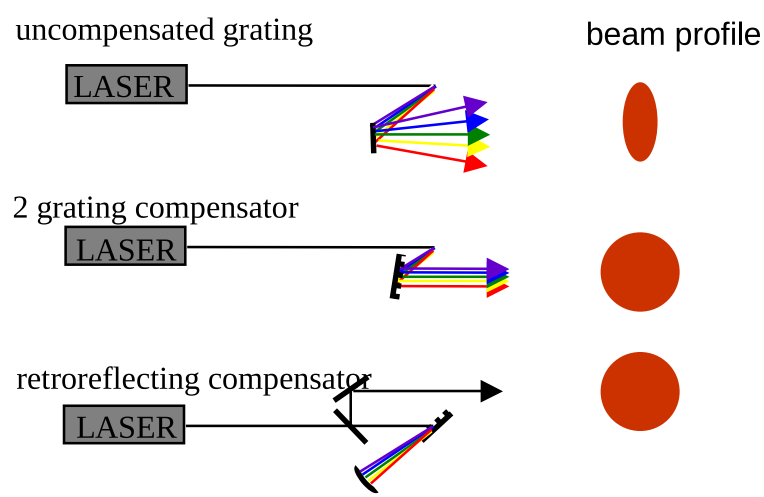
A transmissive beamsplitter and a grating are 4 port devices that are functionally equivalent



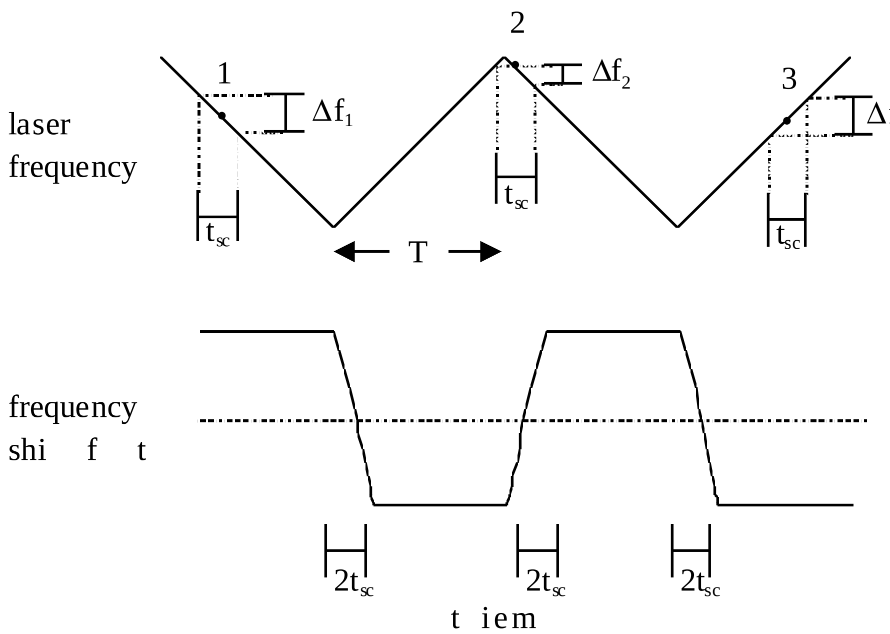


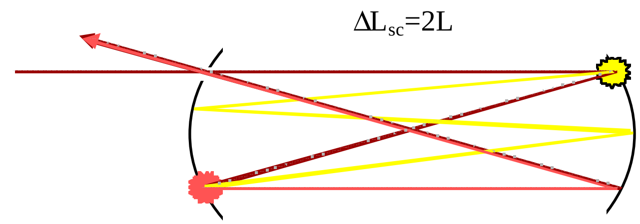
$$S_{bs} = \begin{bmatrix} 0 & r & it & 0 \\ r & 0 & 0 & it \\ it & 0 & 0 & r \\ 0 & it & r & 0 \end{bmatrix} \qquad S_{gr} = \begin{bmatrix} 0 & r & \eta & 0 \\ r & 0 & 0 & \eta \\ \eta & 0 & 0 & r \\ 0 & \eta & r & 0 \end{bmatrix}$$

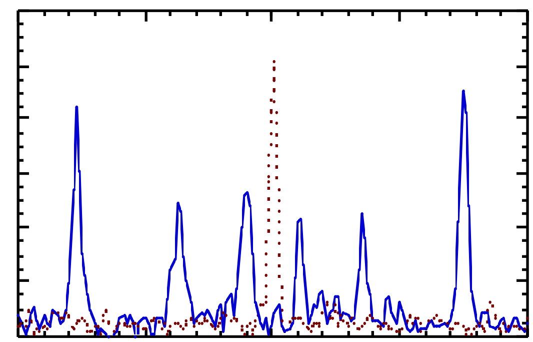
A grating has the undesirable effect of converting laser frequency noise to pointing noise and distorting the spatial profile of the diffracted beam. These effects can be compensated for:



Eliminating noise from scattered light

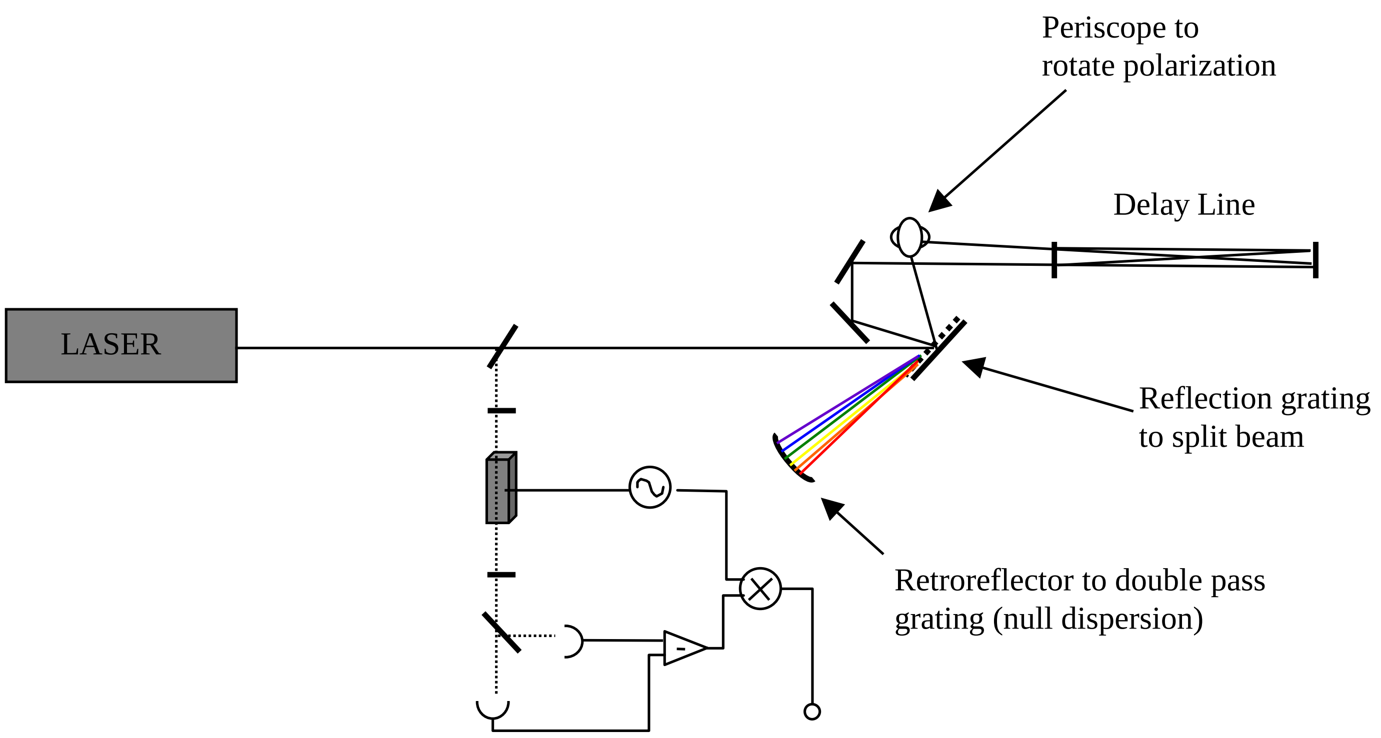




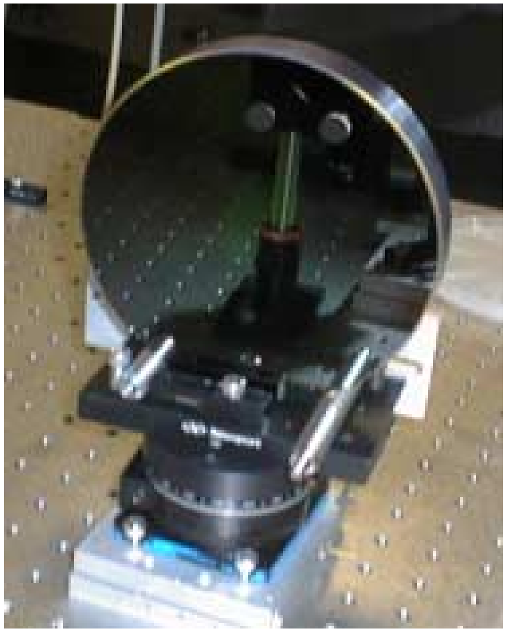


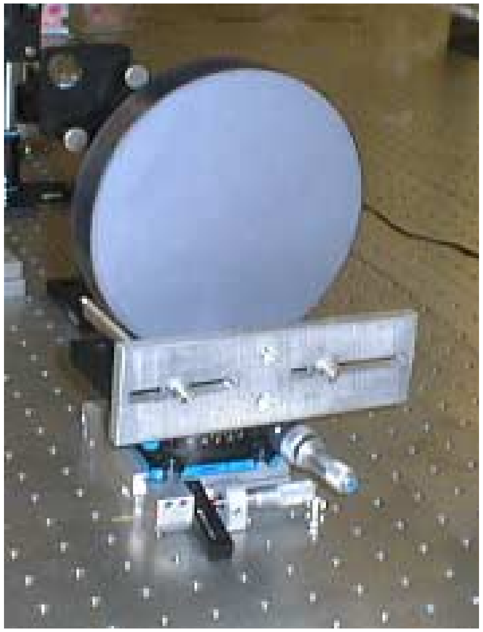
Any noise from scattered light with a delay, t_{sc}, much less than the modulation period, T, will be shifted

The Stanford all-reflective 10m delay-line Sagnac prototype



The 6” silicon delay-line mirrors



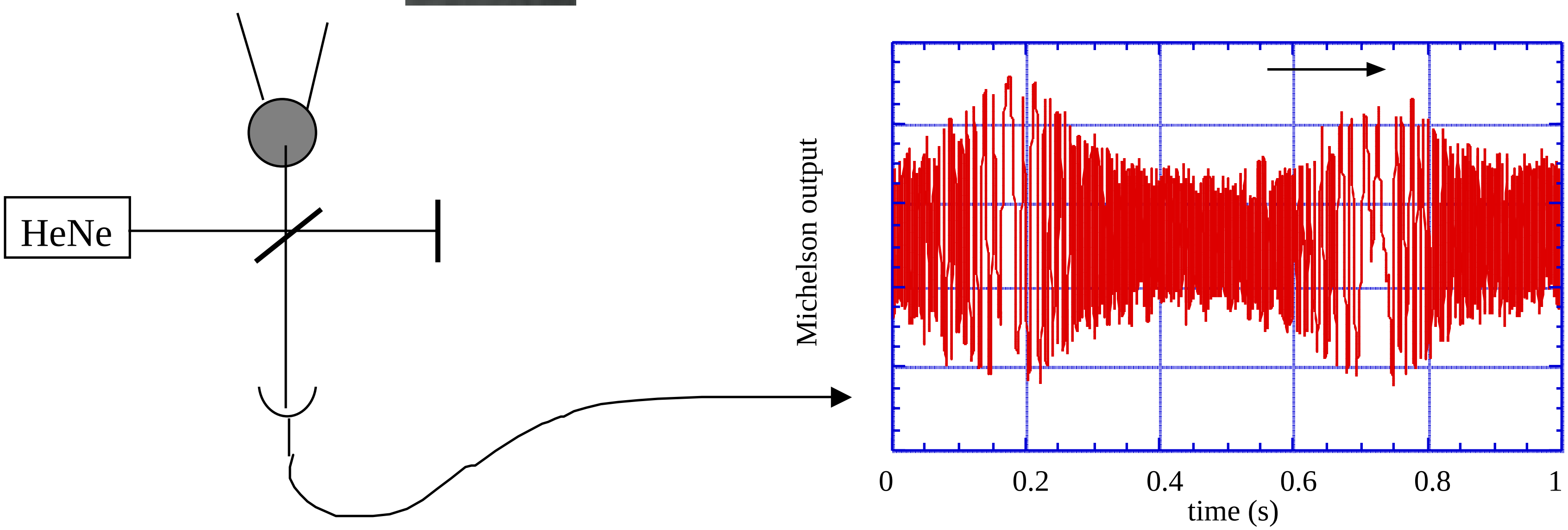


6 inch diameter (1 inch thick) silicon substrates, coated and polished cost $7,000 from General Optics. Only 15% more than fused silica

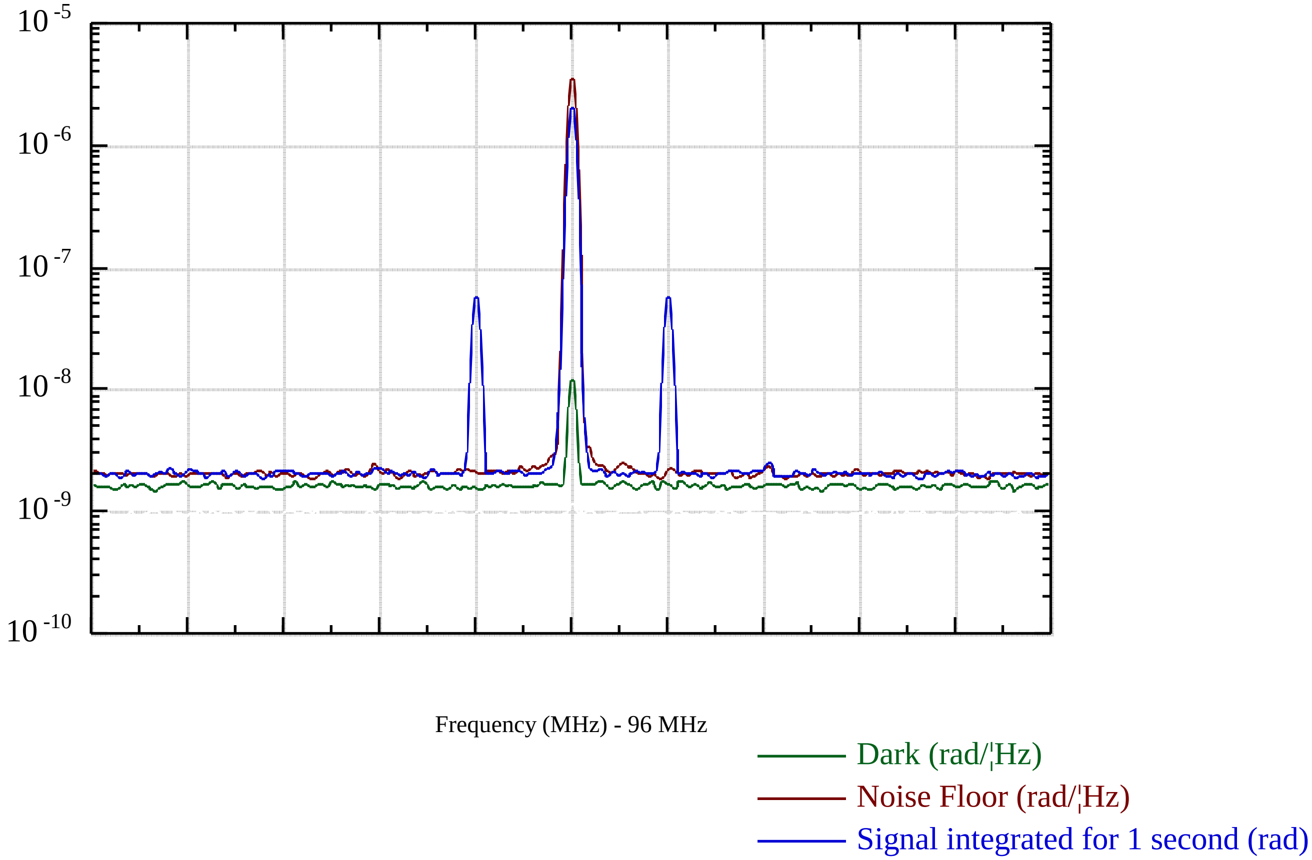
Motion of suspended mirrors

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

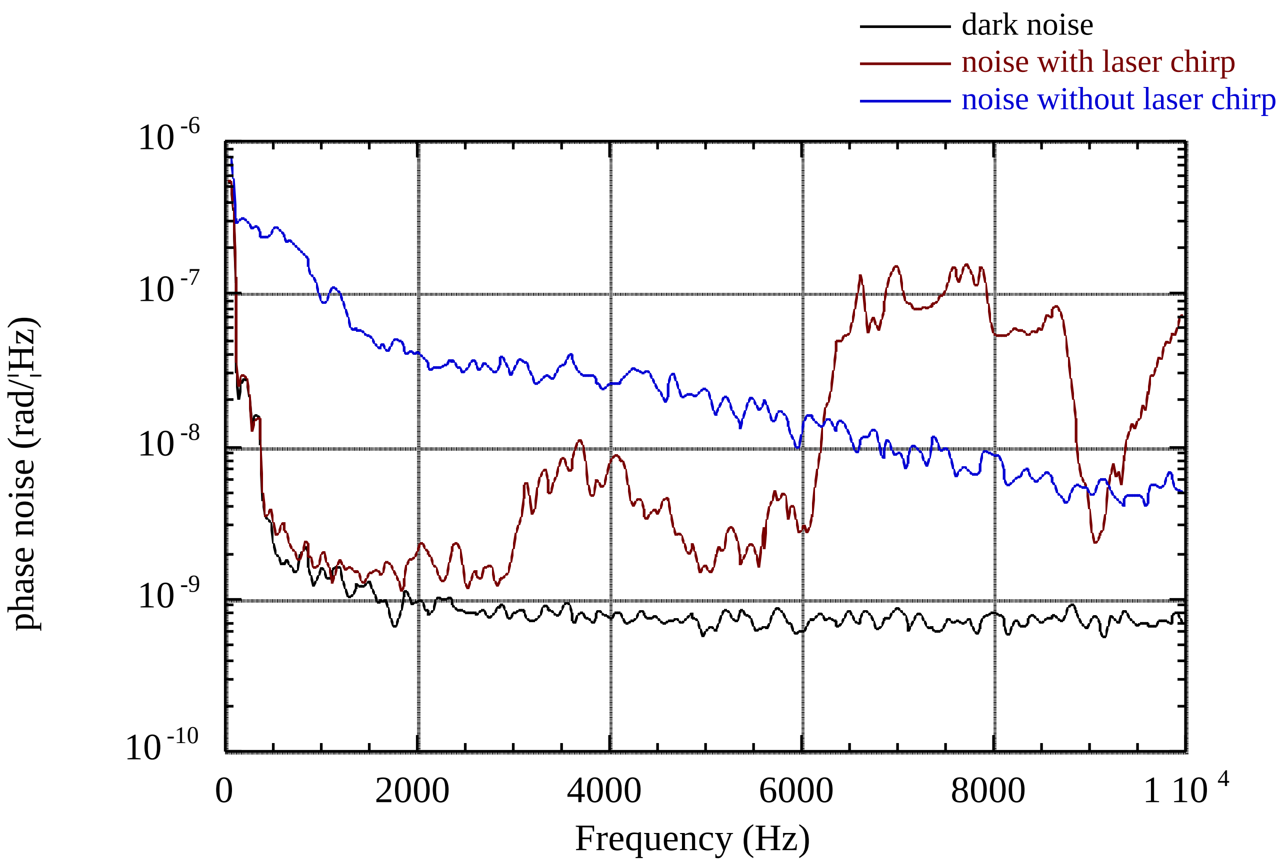
Mirror swings freely at 1Hz with A displacement of $\Delta X \approx 50\,\mu m$



100 kHz signal and noise floor of modulated output



Noise Floor of Demodulated Output



Facts of Interest

- Long term stability ~ 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

State of the Sagnac research

- The delay-line polarization Sagnac interferometer with a laser frequency chirp addresses the challenges of detection on the dark fringe and tuning to low frequencies
- The robustness of the design has been demonstrated on a 10m suspended interferometer
- The development of a high-powered green laser is necessary for implementation in LIGO III

Conclusion

- The Stanford 10m Sagnac interferometer was operated for many days at a time without active control of the optics.
- The scattered light noise was frequency shifted by using a laser frequency chirp so that shot-noise-limited operation was possible at 1 KHz.
- Phase sensitivity of $2 \cdot 10^{-9}$ rad/$Hz^{1/2}$ at 1 kHz was possible despite 50 micron motion of delay line mirrors at 1 Hz.