A look at interferometer topologies that use reflection gratings

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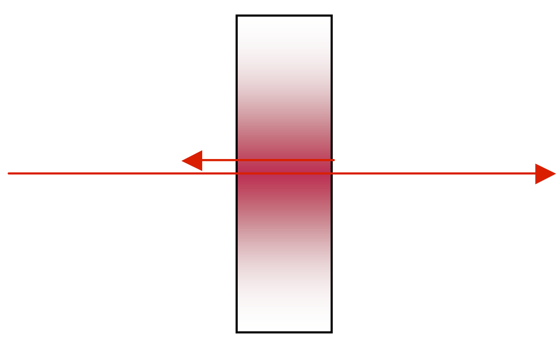
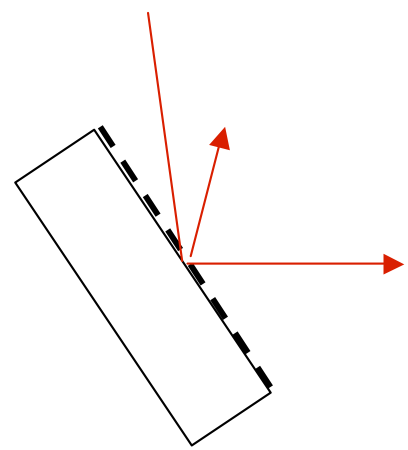
Outline

- Motivation for considering reflection gratings
- Configurations that use gratings
  - Reflective RSE
  - Reflective power recycled Fabry-Perot Michelson interferometer
- Issues with seismic noise that are unique to gratings

Motivation for considering reflection gratings

- Reflection gratings can be used as beamspliters or cavity couplers without the thermal deformation issues associated with absorption in the transmissive substrates of conventional beamsplitters or cavity couplers

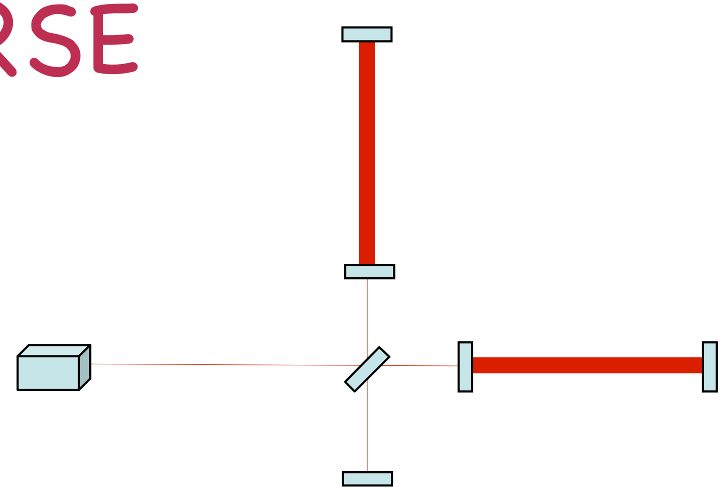




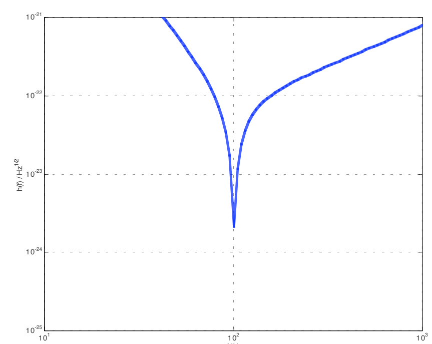
Revisiting RSE

Bandwidth enhancement is limited by loss in the signal extraction cavity

$$\Delta BW = \frac{r_{ETM} t^2_{ITM}}{1 - r_{ITM} r_{SEM}} \; 1 - \frac{r_{ITM} r_{SEM}}{1 - r_{ITM} r_{SEM}} \; a$$



RSE interferometer

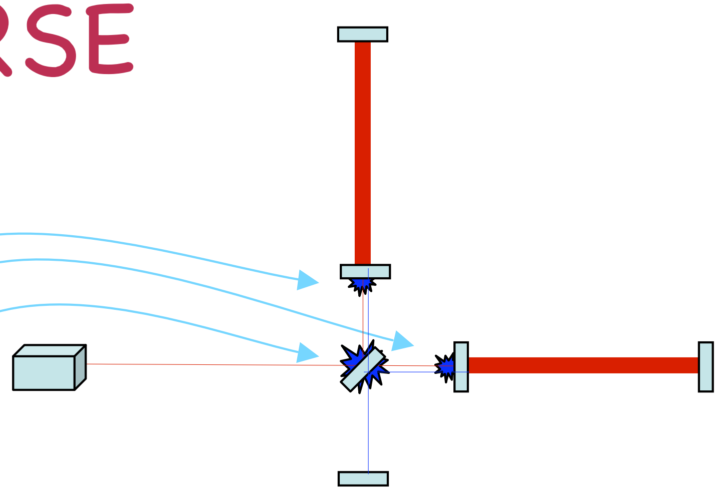


Revisiting RSE

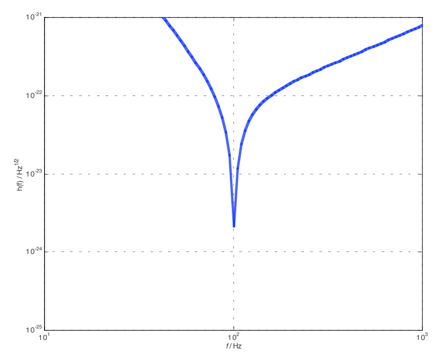
Bandwidth enhancement is limited by loss in the signal extraction cavity

$$\Delta BW = \frac{r_{ETM} t^2_{ITM}}{1 - r_{ITM} r_{SEM}} \left(1 - \frac{r_{ITM} r_{SEM}}{1 - r_{ITM} r_{SEM}} a \right)$$

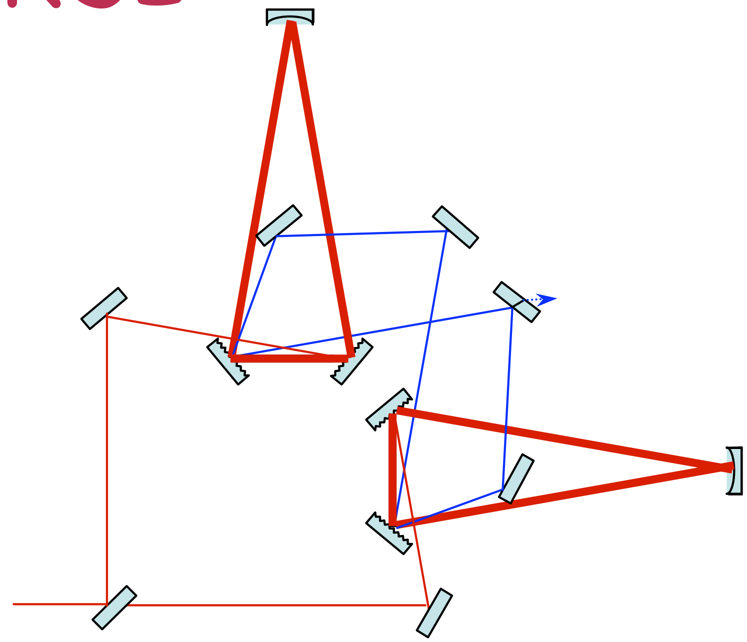
Loss in the signal extraction cavity is dominated by absorbtion in the optical substrates



RSE interferoemter



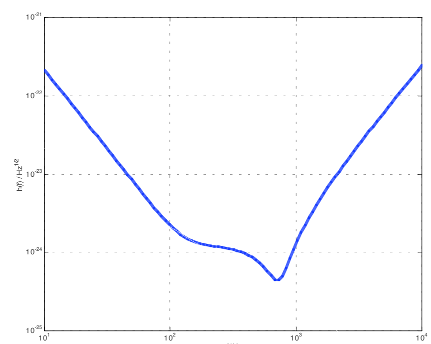
Revisiting RSE



Rather than modify design to increase the bandwidth of the arm cavities (power recycled RSE), modify it to reduce the loss in the signal extraction cavity

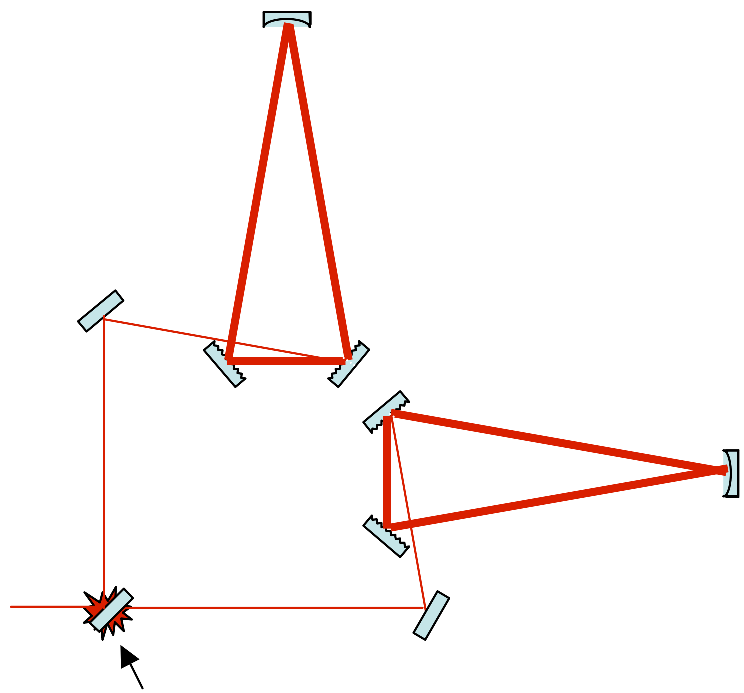
- Take advantage of low-loss reflection gratings to eliminate ITM substrate absorption

- Reconfigure geometry to separate signal extraction cavity from the beamsplitter



RSE with reflection gratings

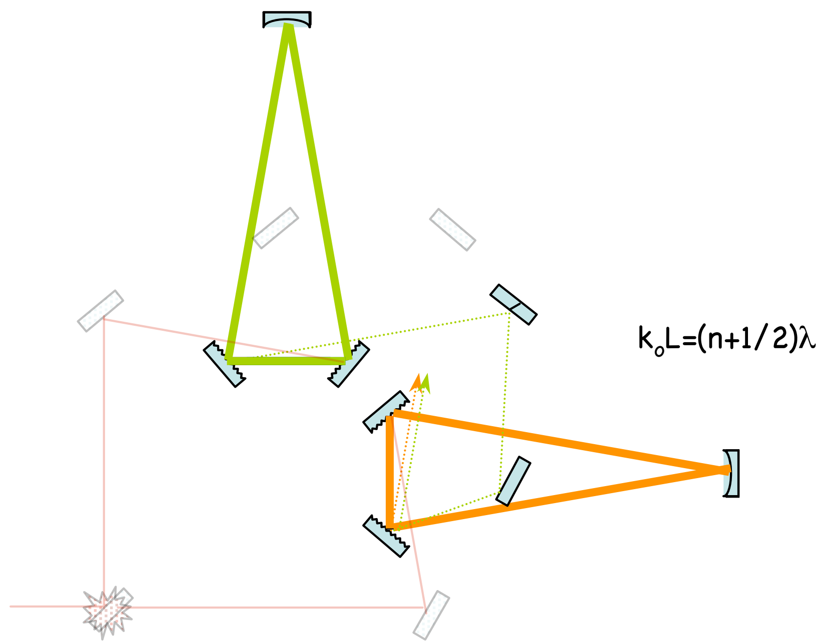
- Input power is split and critically coupled into arm cavities



Lossy beamsplitter is not inside a cavity

RSE with reflection gratings

- Input power is split and critically coupled into arm cavities
- Carrier exiting arm at output coupler is cancelled by carrier from other arm



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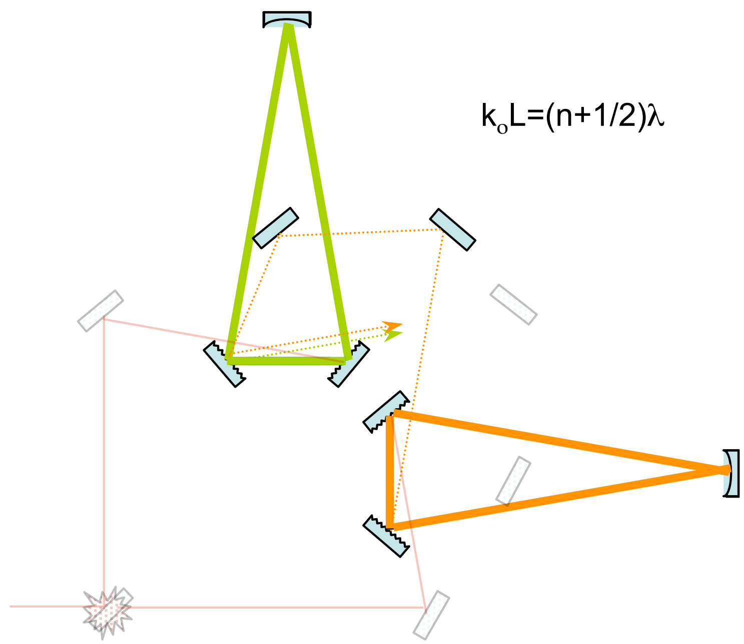
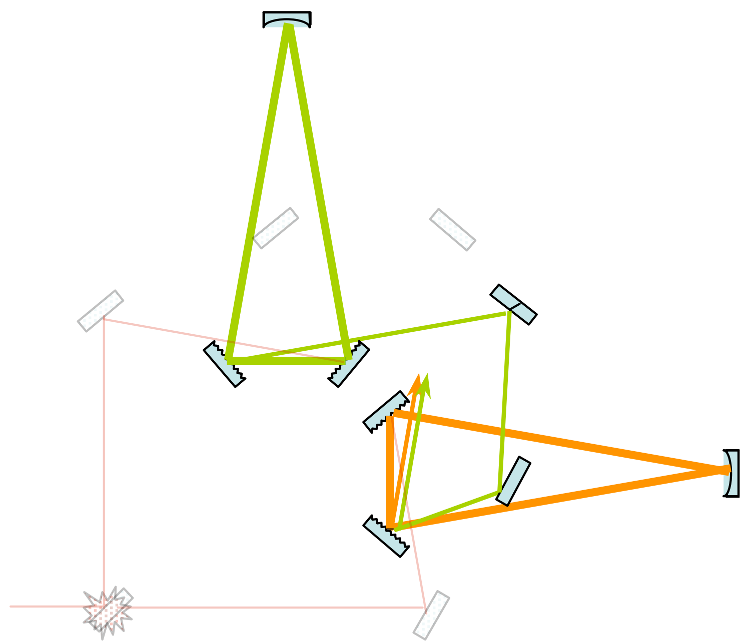


RSE with reflection gratings

- Input power is split and critically coupled into arm cavities
- Carrier exiting arm at output coupler is cancelled by carrier from other arm
- Signal exiting arm at output coupler is enhanced by signal from other arm



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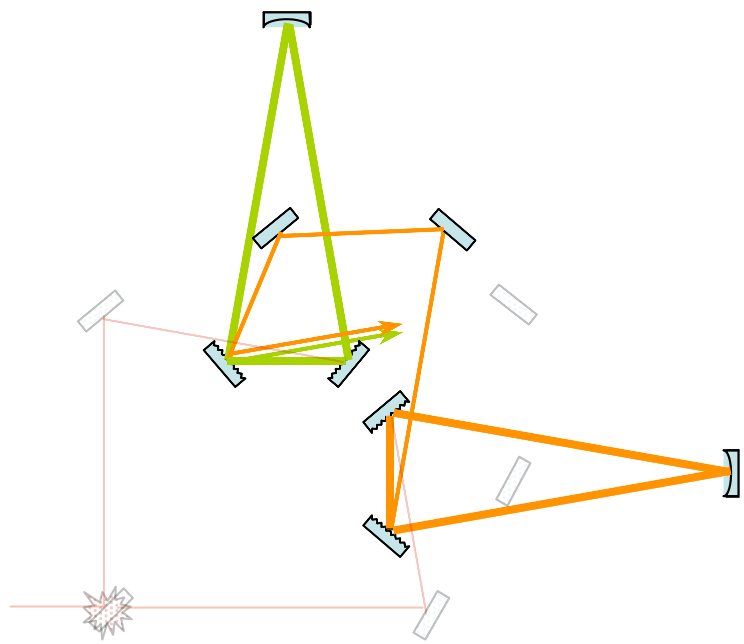

RSE with reflection gratings

- Input power is split and critically coupled into arm cavities
- Carrier exiting arm at output coupler is cancelled by carrier from other arm
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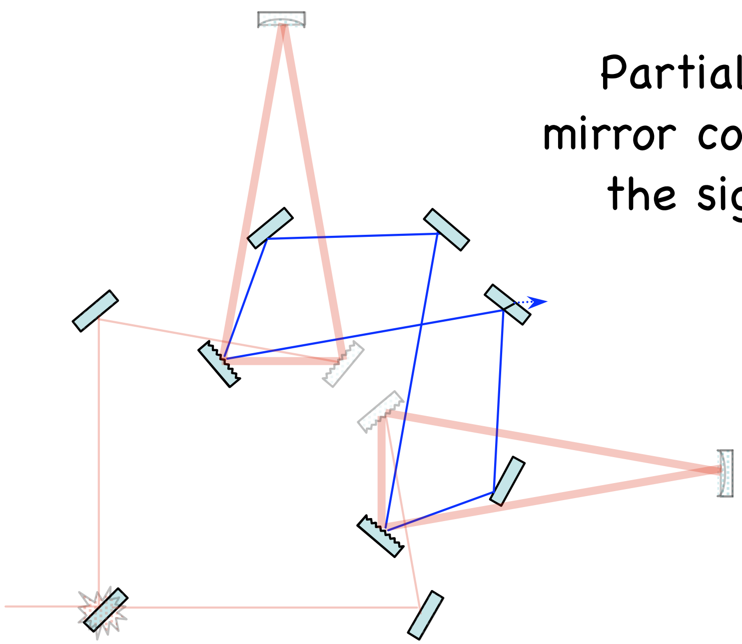
- Signal extraction cavity has no lossy elements inside of it



Partially transmissive mirror couples light out of the signal extraction cavity

RSE with reflection gratings

- Input power is split and critically coupled into arm cavities
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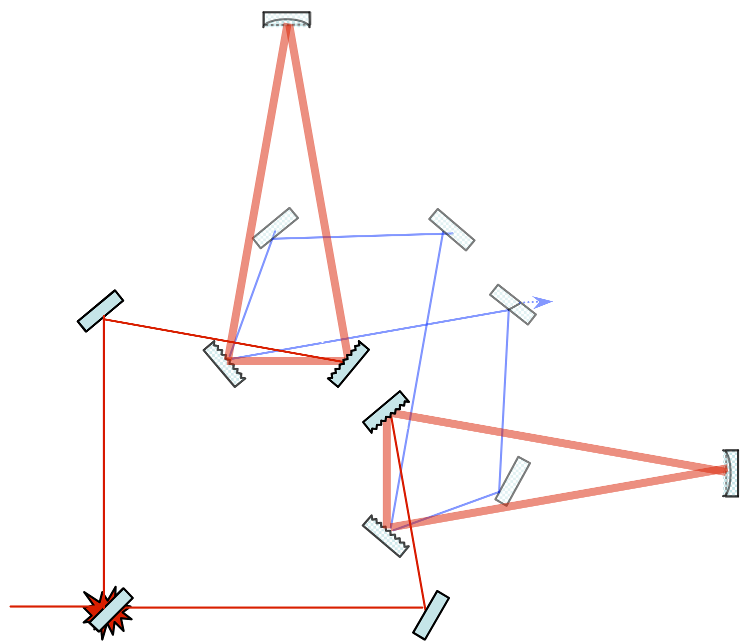
- Signal exiting arm at output coupler is enhanced by signal from other arm
- Signal extraction cavity has no lossy elements inside of it
- Laser noise is filtered by arm cavities



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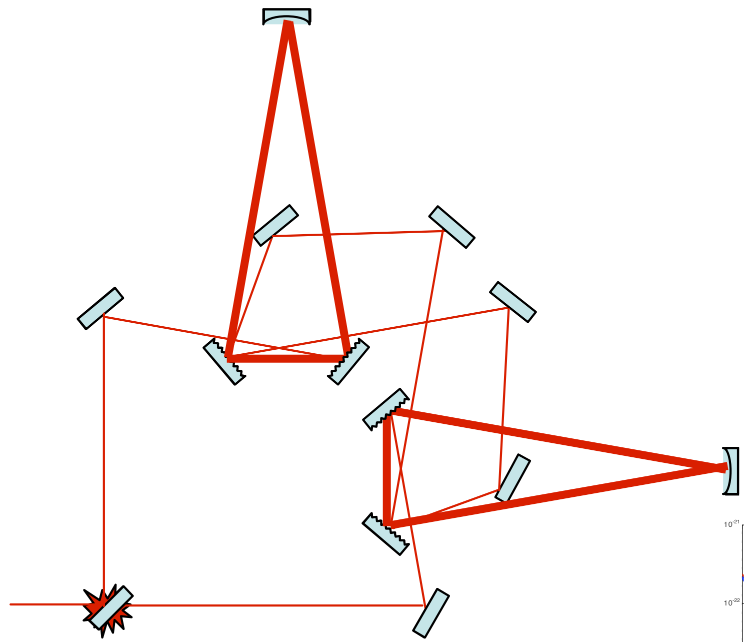
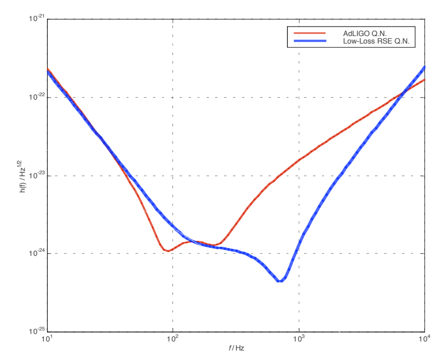
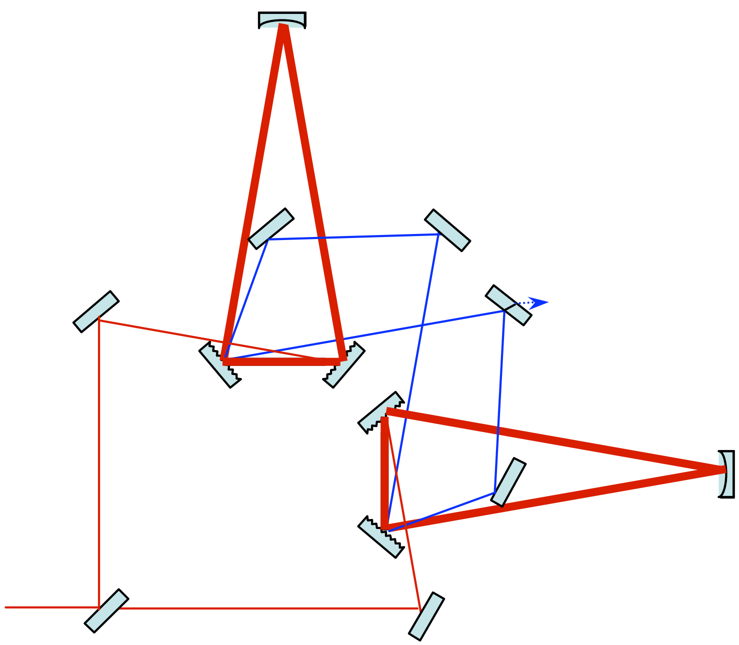


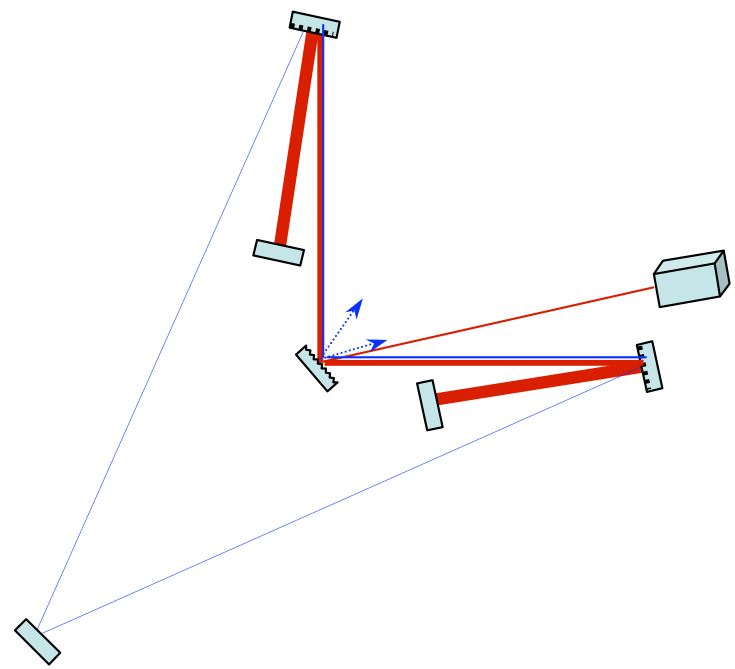
NS-NS inspiral range
187->236 MPc



Other configurations with reflection gratings



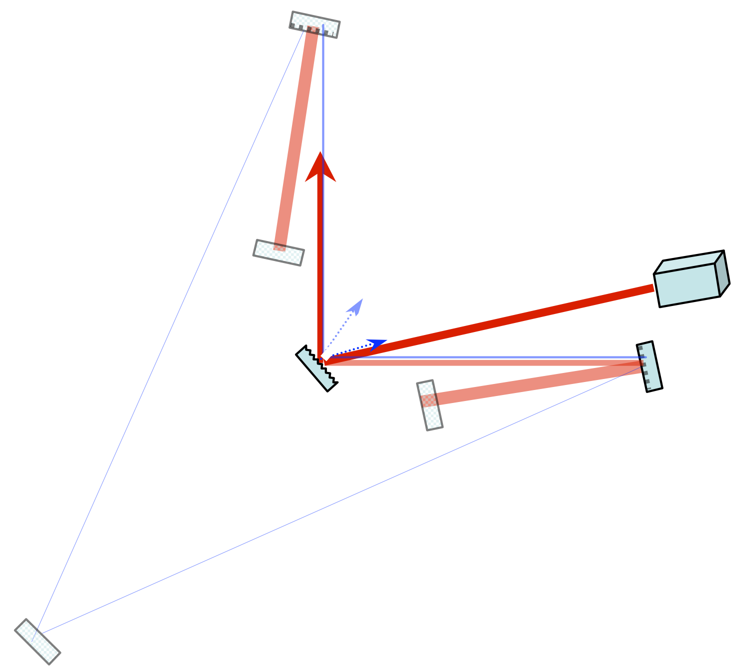
reflective RSE



reflective power recycled RSE
(Drever 1995)

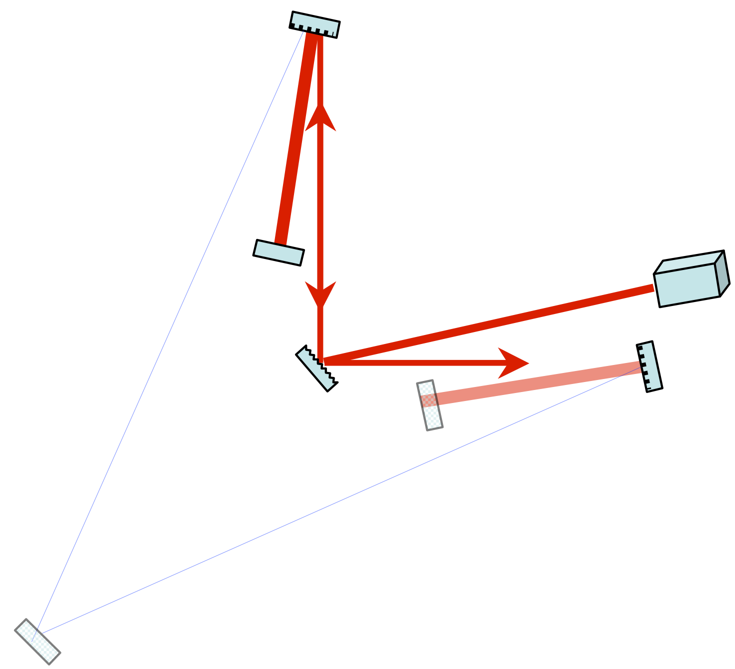
Power recycled RSE with reflection gratings

- Input power is diffractively coupled into the middle of the power recycling cavity



Power recycled RSE with reflection gratings

- Input power is diffractively coupled into the middle of the power recycling cavity
- Each grating arm cavity forms one end of the recycling cavity



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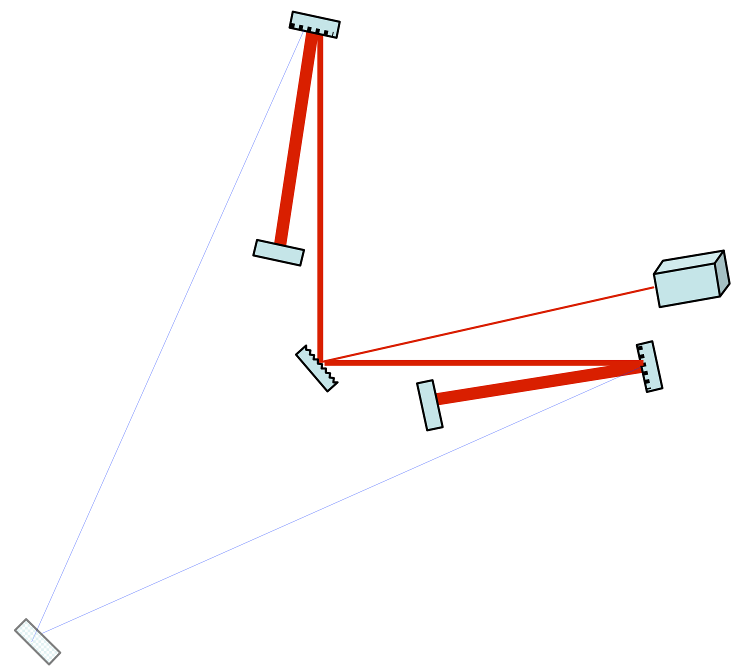
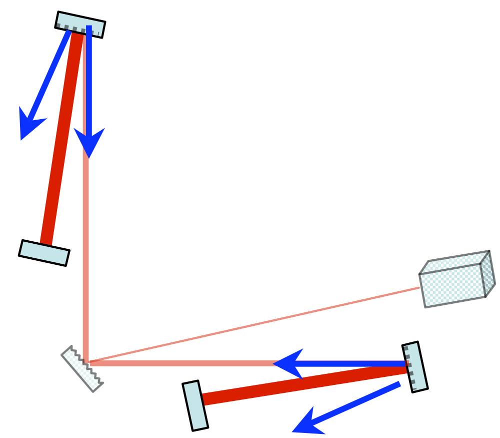


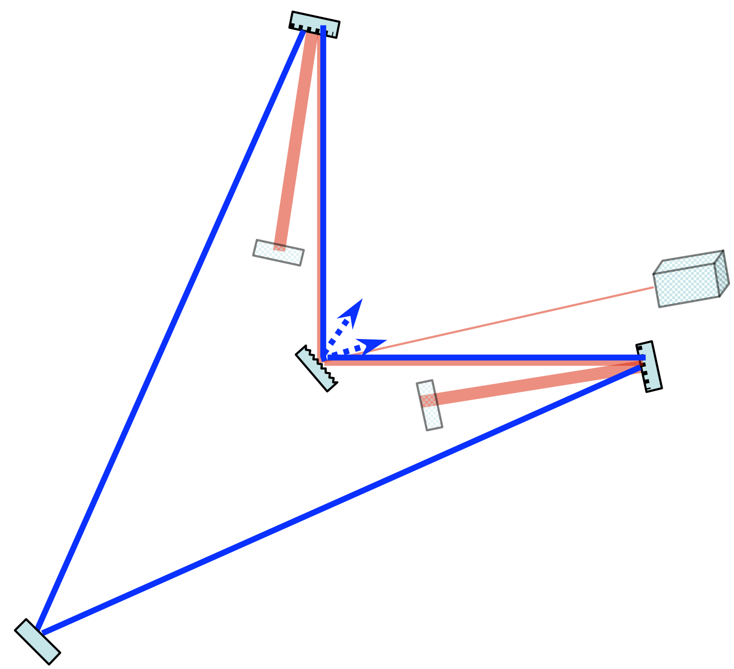
Power recycled RSE with reflection gratings

- Input power is diffractively coupled into the middle of the power recycling cavity
- Each grating arm cavity forms one end of the recycling cavity
- Signal sidebands from arm cavities exit the arms in two directions



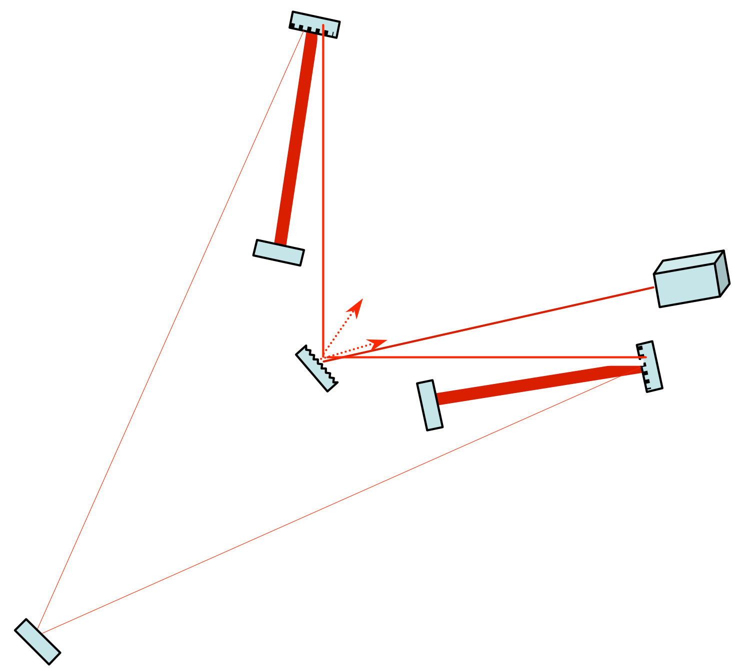
Power recycled RSE with reflection gratings

- Input power is diffractively coupled into the middle of the power recycling cavity
- Each grating arm cavity forms one end of the recycling cavity
- Signal sidebands from arm cavities exit the arms in two directions
- Signal extraction mirror closes the signal extraction cavity path



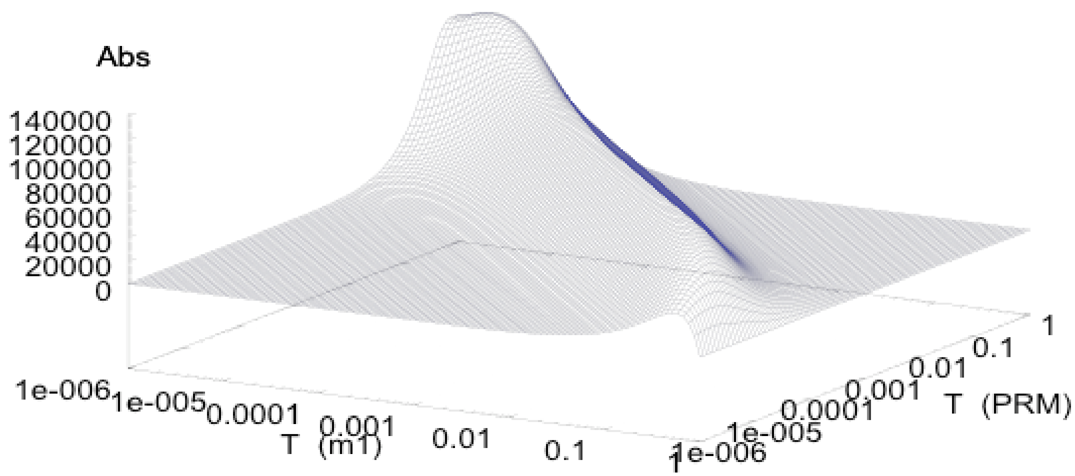
Power recycled RSE with reflection gratings

- Input power is diffractively coupled into the middle of the power recycling cavity
- Each grating arm cavity forms one end of the recycling cavity
- Signal sidebands from arm cavities exit the arms in two directions
- Signal extraction mirror closes the signal extraction cavity path
- Laser technical noise follows the signal everywhere



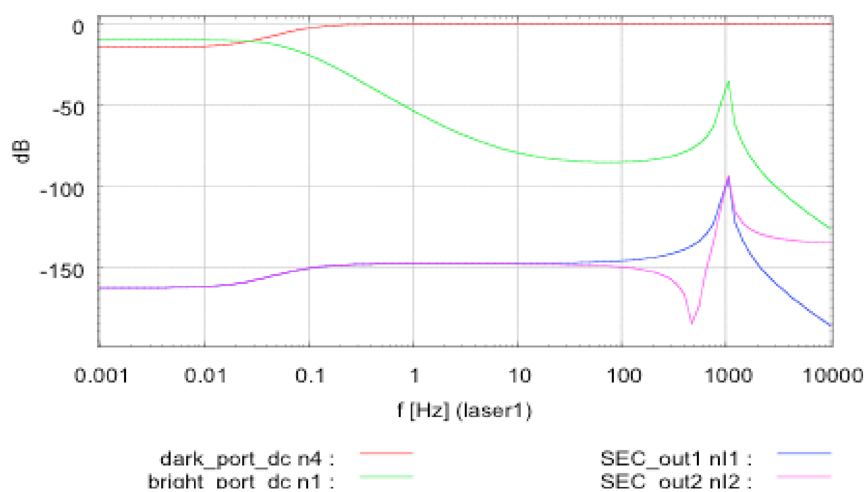
Power gain dependence on diffraction efficiency

The total power gain in the arms of the grating ring RSE
(loss of 1ppm per mirror and a signal tuning of 20 degrees)

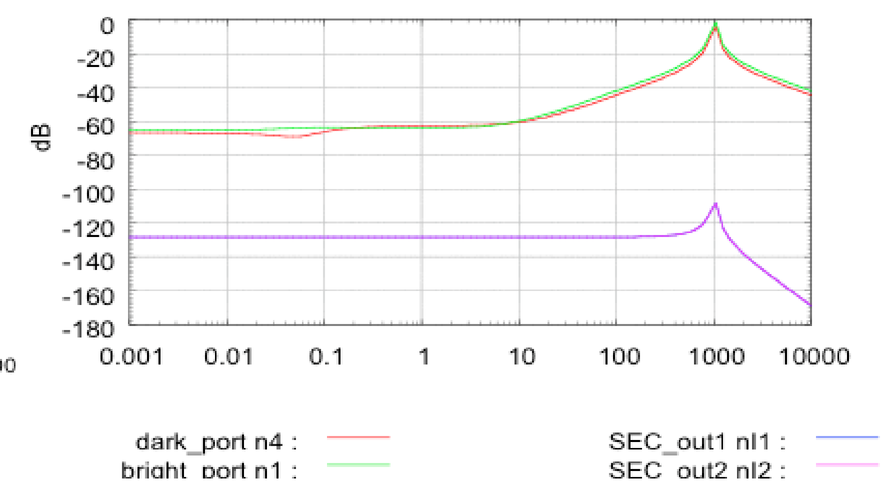


The left-most axis is the diffraction efficiency of the arm cavity gratings, the right-most axis is that of the recycling cavity grating

Laser noise coupling to output

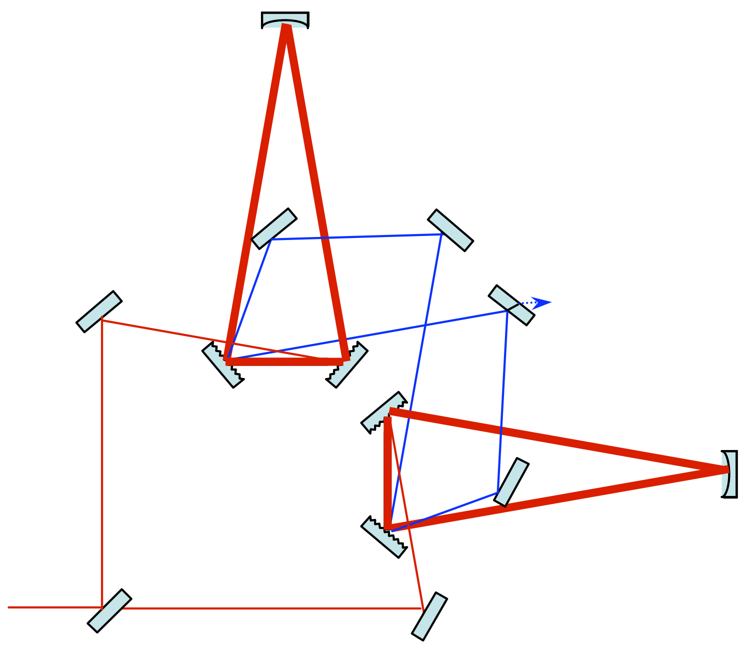


Laser noise coupling



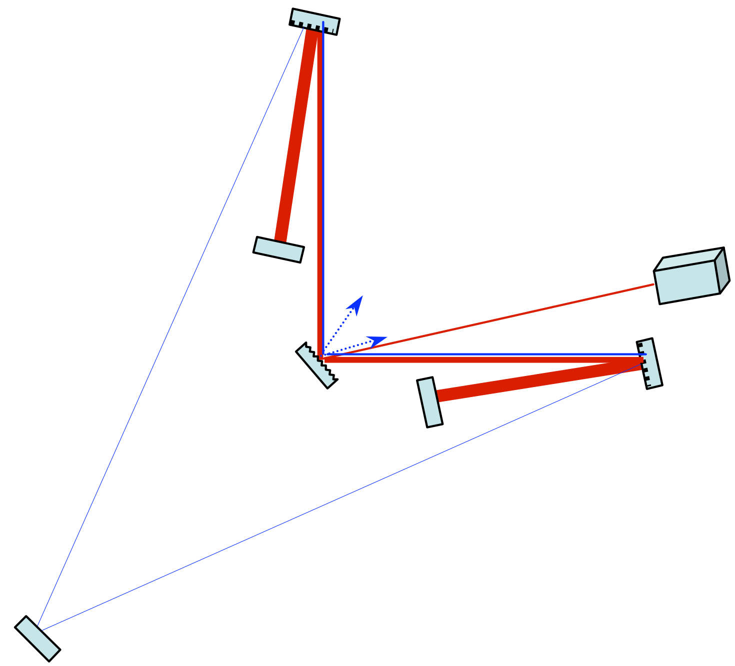
Signal transfer function

Reflection grating interferometer comparison



reflective RSE

- Grating efficiency 10ppm
- Laser power 50W
- Good separation of signal and laser noise

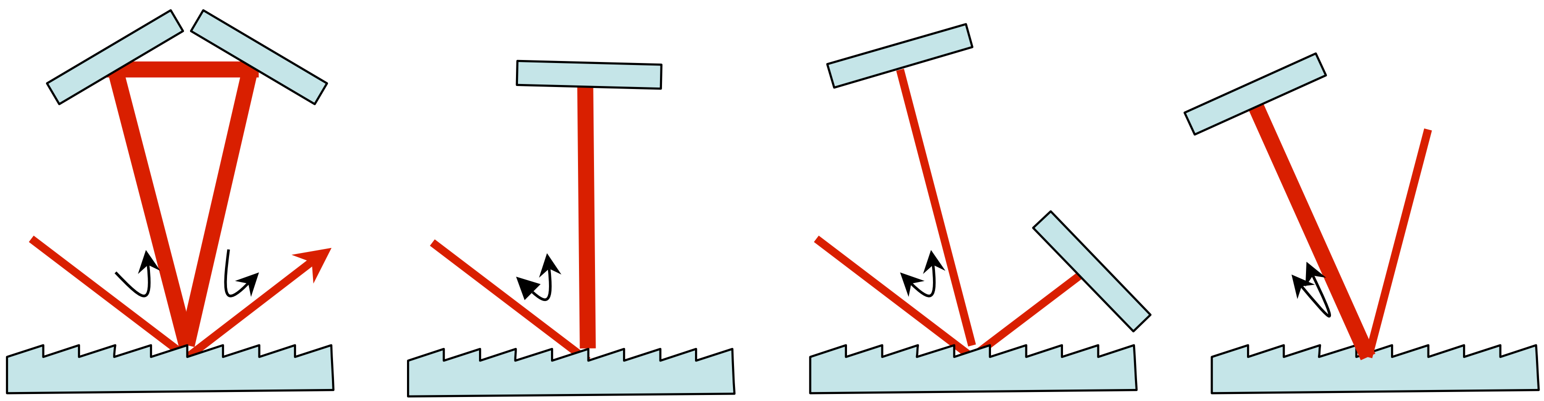


reflective power recycled RSE

- Grating efficiency 0.001
- Laser power 25W
- Poor separation of signal and laser noise

Geometry of various grating arrangements

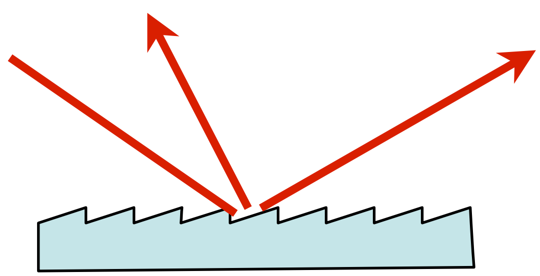
Four basic geometries that use reflection gratings



ring cavity   2nd order Littrow   beamsplitter   1st order Littrow

Effect of seismic noise with gratings

Effect of the grating's displacement noise depends on the geometry; it is different for reflected and diffracted beams



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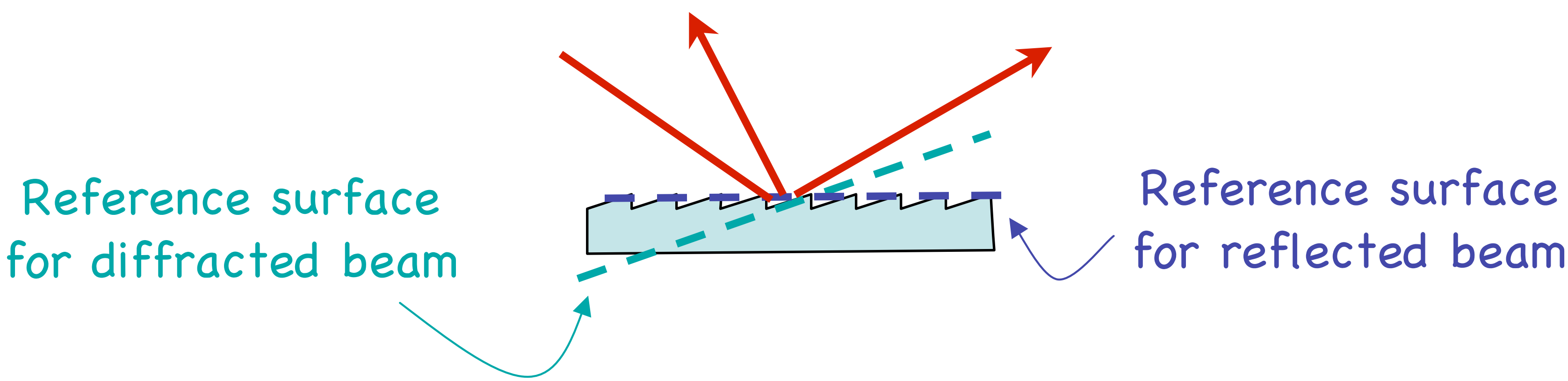
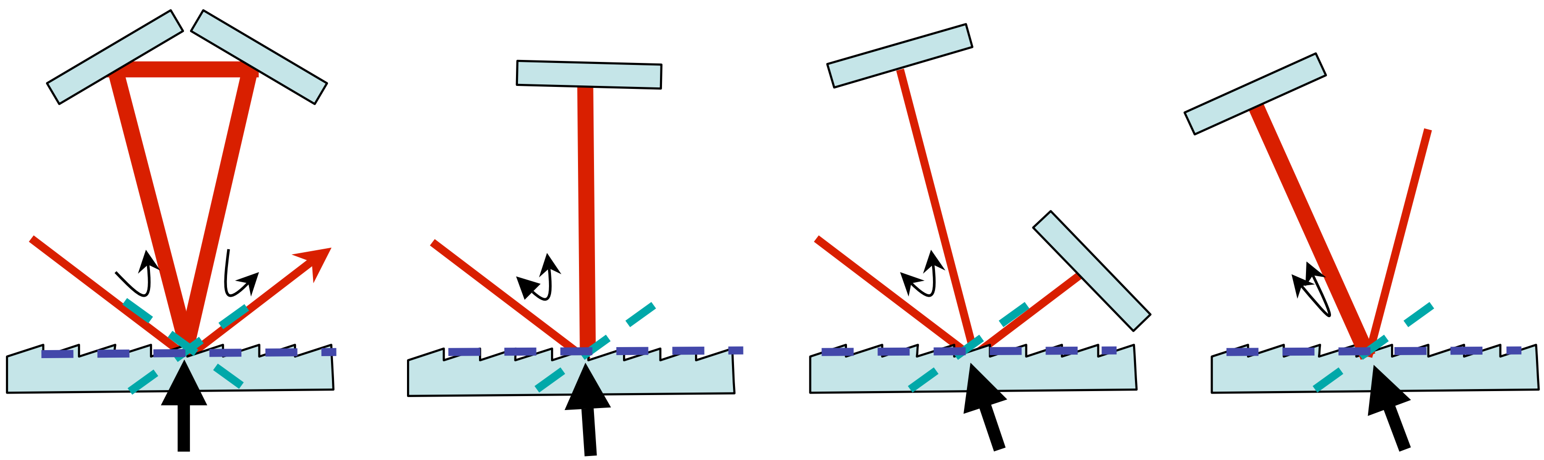


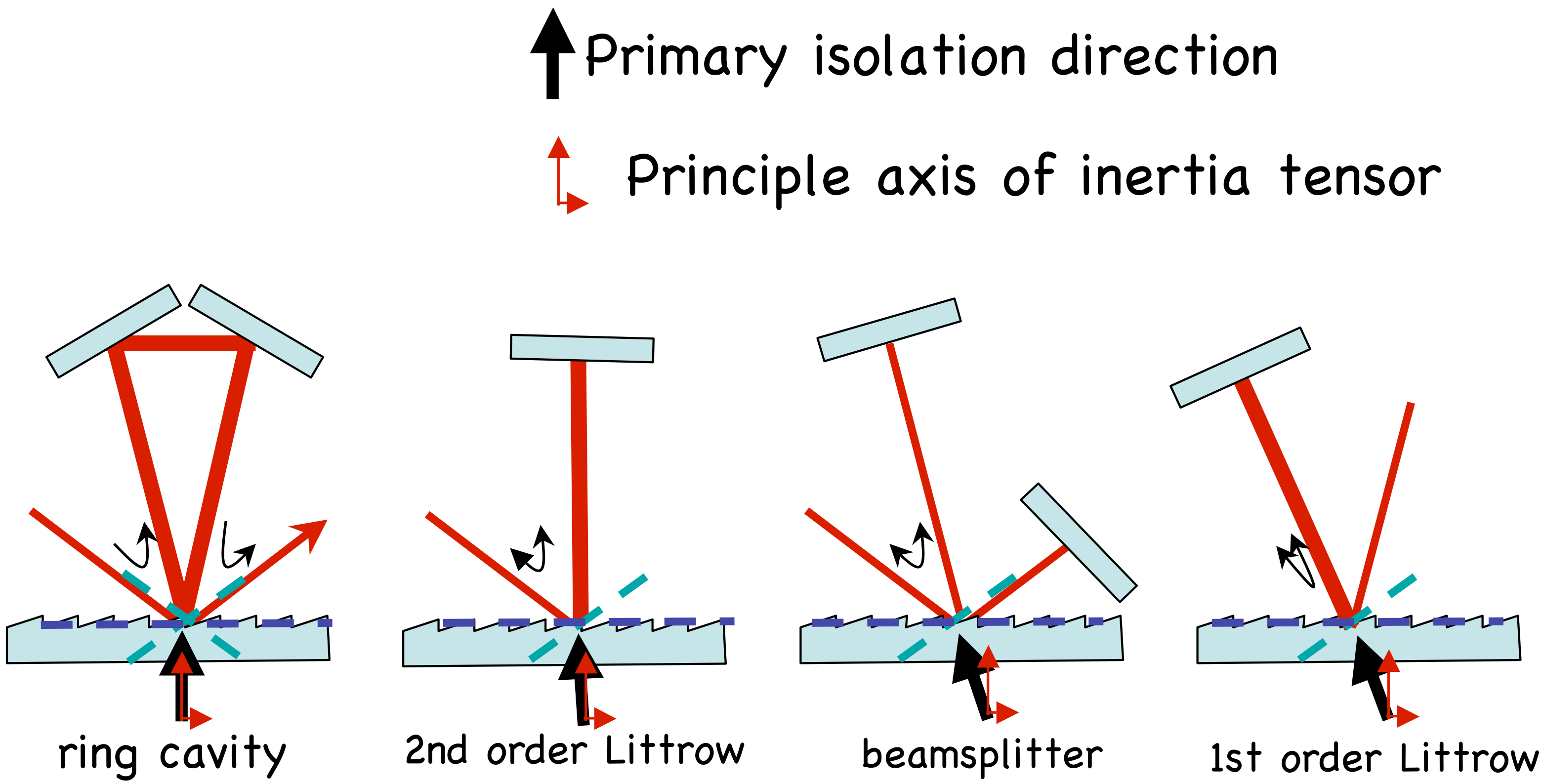
Effect of seismic noise with gratings

Primary isolation direction



ring cavity | 2nd order Littrow | beamsplitter | 1st order Littrow

Effect of seismic noise with gratings



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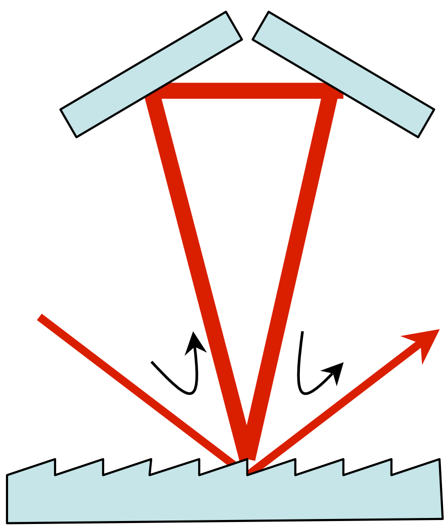
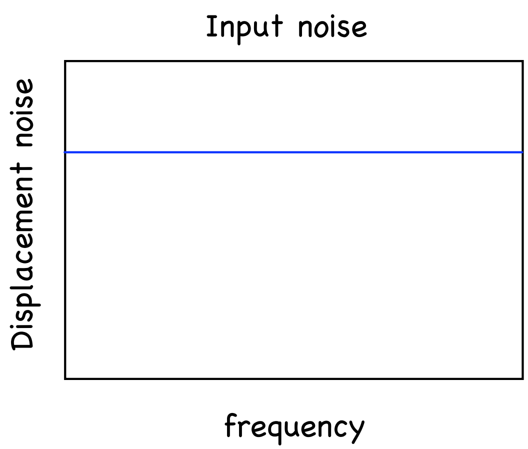


Ring cavity configuration seems best suited for use in a detector:

- Phase noise due to lateral displacement of grating can be cancelled to first order at low frequencies
- Direction of maximum isolation requirement is aligned to principle axis of inertia tensor of the mass
- Holds promise of low-loss

Cancellation of phase noise from transverse motion



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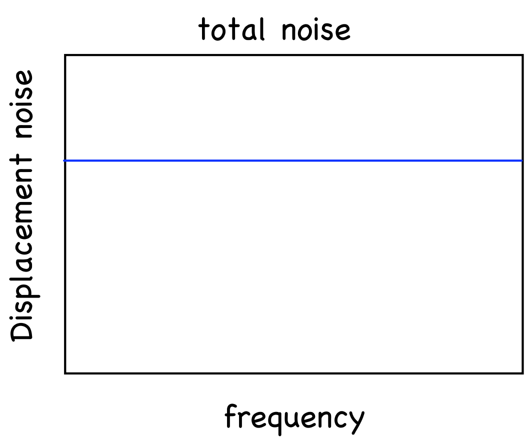

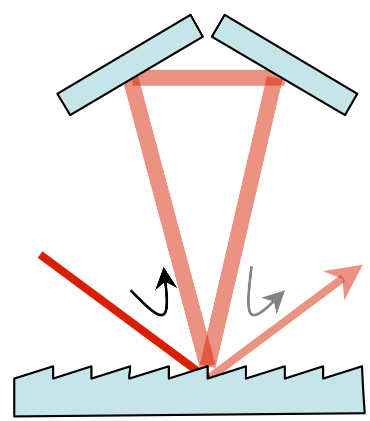

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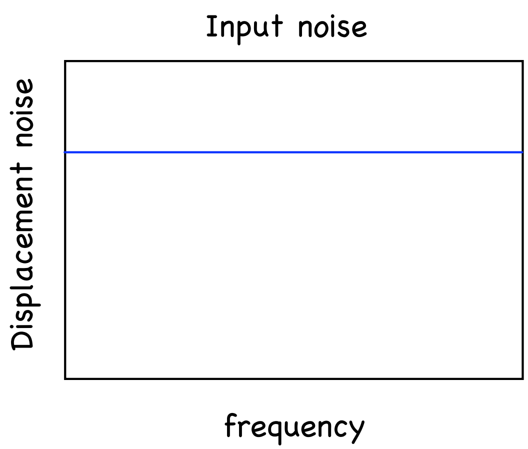

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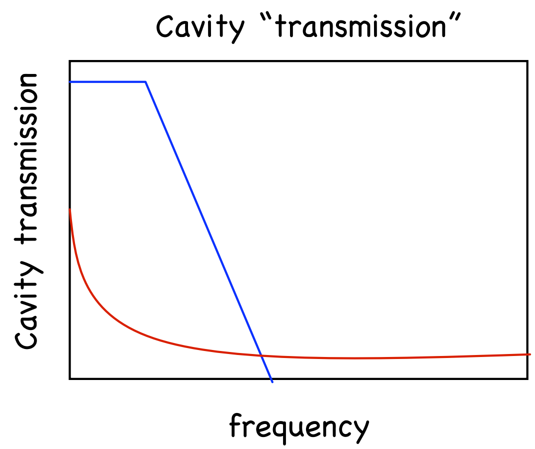

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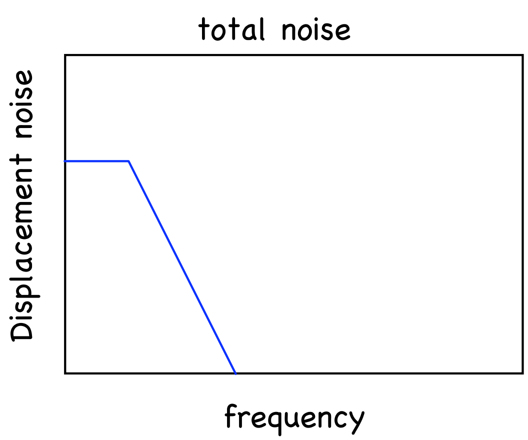

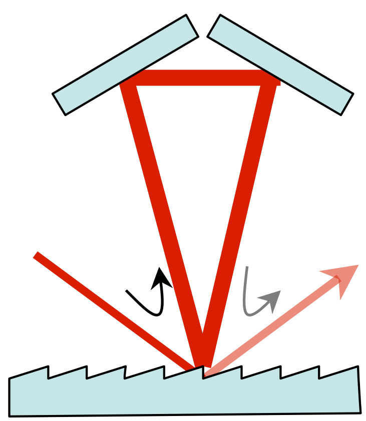

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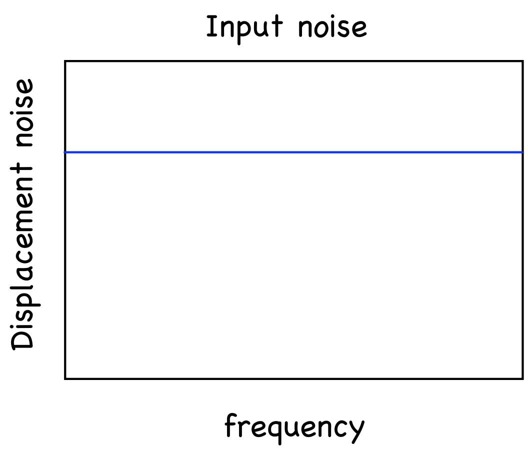

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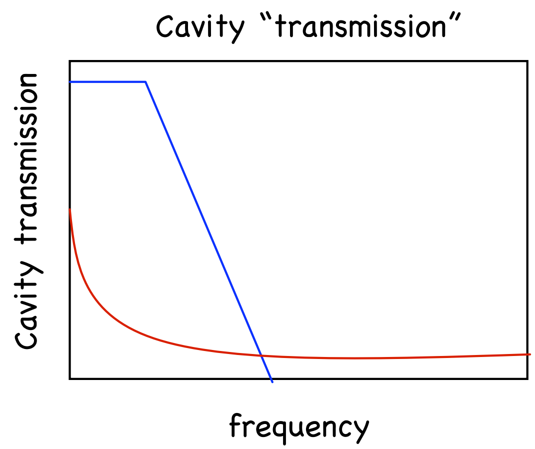

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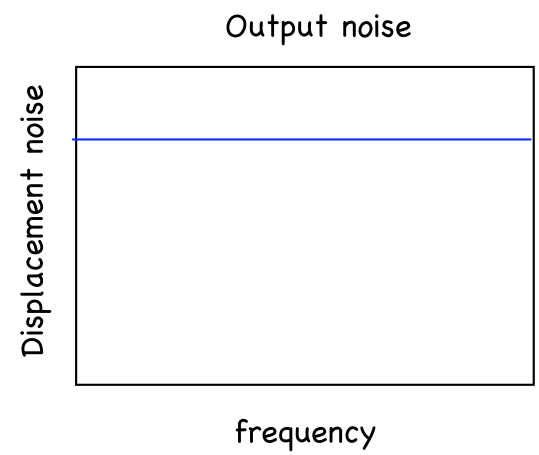

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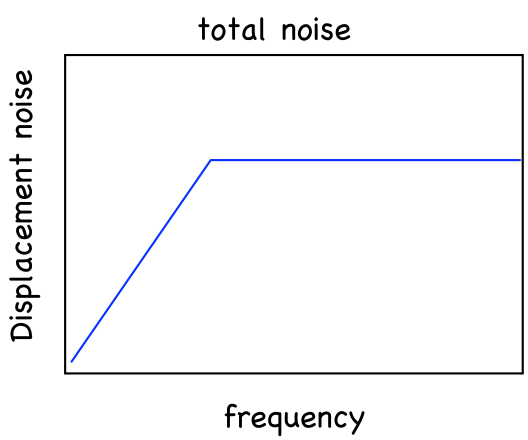
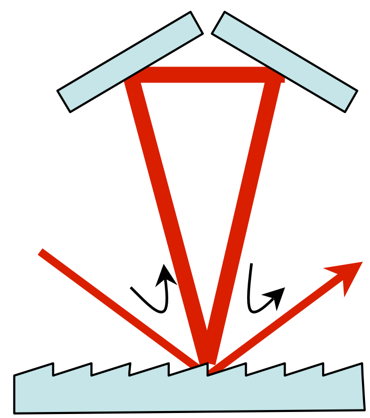
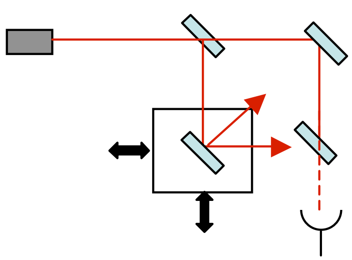


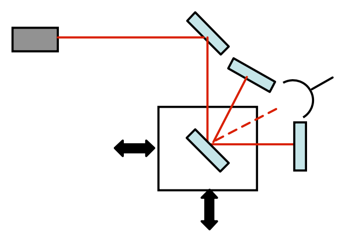


Upcoming experiments

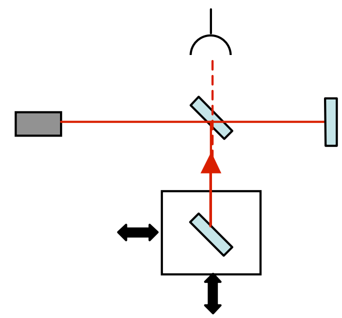
- Quantify effect of lateral displacement noise on phase shift in various configurations



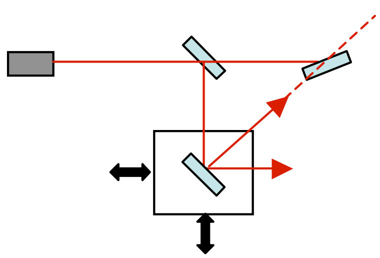
phase of specular order



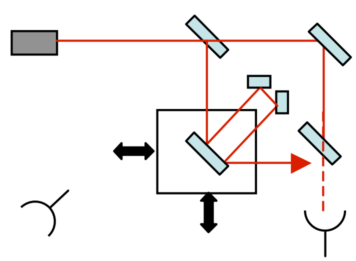
phase of specular order relative to diffracted order in grating beamsplitter



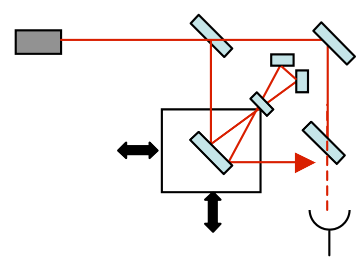
phase of diffracted order in Littrow-mount grating



phase of diffracted order



phase of twice-diffracted order



phase of twice-diffracted order with time delay

Upcoming experiments

- Quantify effect of lateral displacement noise on phase shift in various configurations
- Determine constraints for grating suspension
  - longitudinal noise performance
  - transverse noise performance
  - roll noise performance
  - roll positioning accuracy and range
- Compare suspension requirements to Advanced LIGO suspension performance

Summary

With reflection gratings on core optics comes:

- Promise of low loss
- Capability of very high power storage
- Possibility of lower loss in the signal extraction cavity
- Possibility of higher storage-time arm cavities
- New suspension design requirements