MICHELSON INTERFEROMETER WITH 3-PORT GRATING COUPLED ARM CAVITIES

Michael Britzger, Max Wimmer, Daniel Friedrich,

Karsten Danzmann, and Roman Schnabel

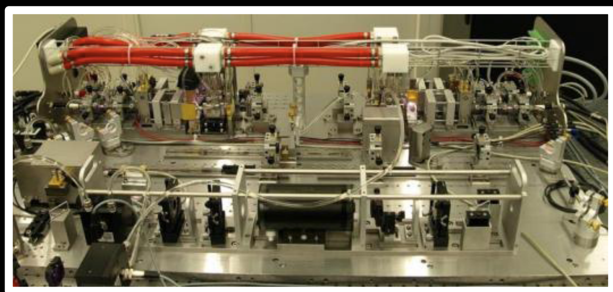
Max-Planck Institute for Gravitational Physics

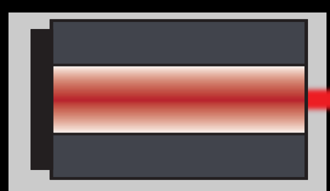
Albert Einstein Institute

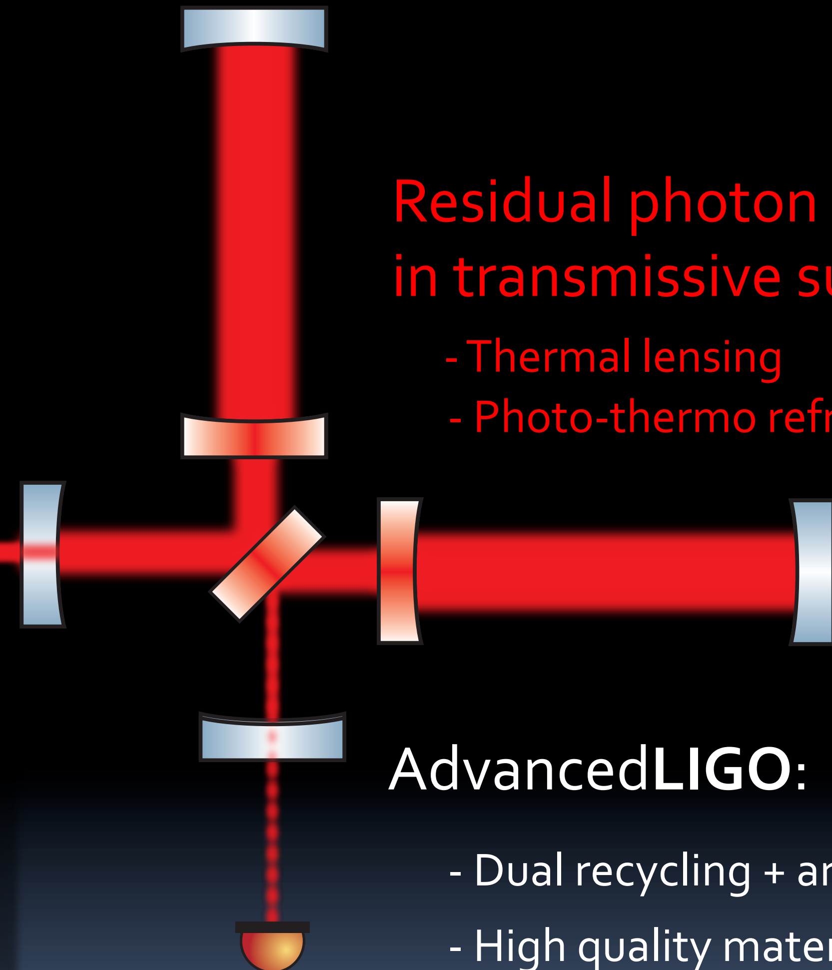
OUTLINE

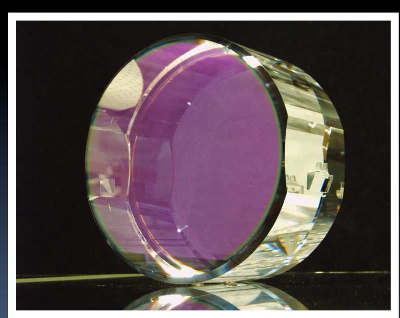
- Motivation
- Diffractive optics for future GWDs
- 3-port grating cavities
- Michelson interferometer with 3PG-coupled arm cavities
  - set up
  - results
- Outlook and summary

MOTIVATION









Residual photon absorption in transmissive substrates

- Thermal lensing
- Photo-thermo refractive noise

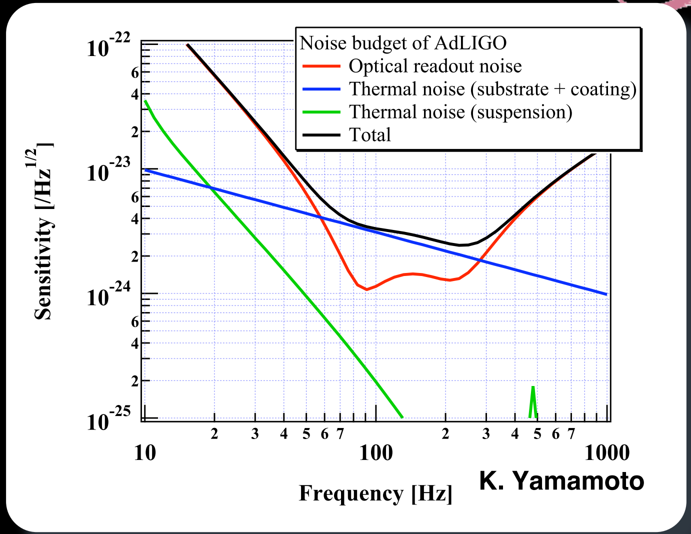
Advanced**LIGO**:

- Dual recycling + arm resonators
- High quality materials
- 200W Laser input

MOTIVATION

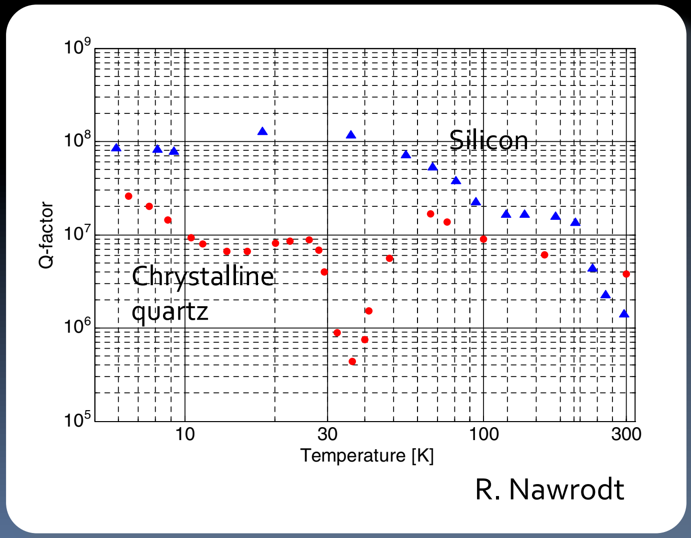
Problem:

Sensitivity of future generations will be limited by thermal effects due to stored laser power of up to the megawatt-range.



Solutions:

1. Trade-off
2. Cryogenic cooling
3. Other materials

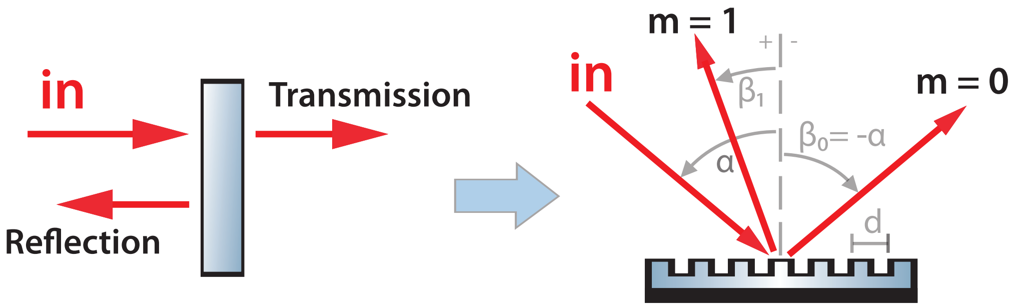


But:

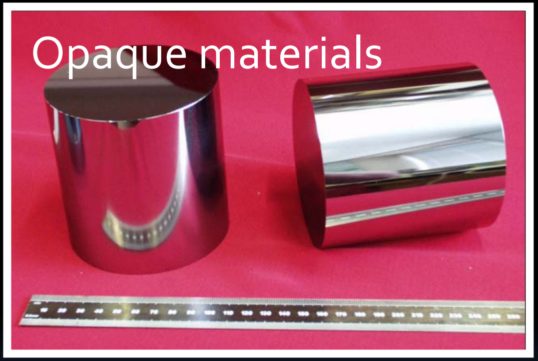
1. that's no solution
2. Decreasing quality factor of fused silica
3. Materials must be highly transparent

DIFFRACTIVE ALTERNATIVE

Replacing the transmissive components that are exposed to high thermal load



Transmissive Component | Diffractive Component

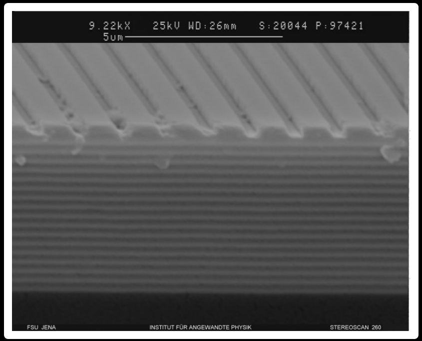


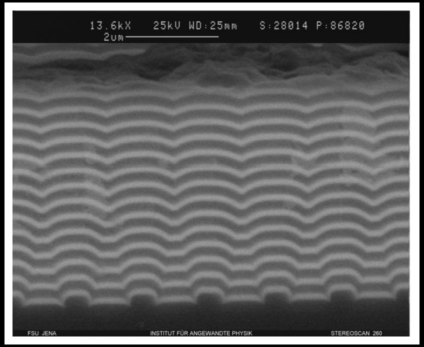
- described by the grating equation for monochromatic light
- R, T correspond to diffraction orders with certain diffraction efficiencies

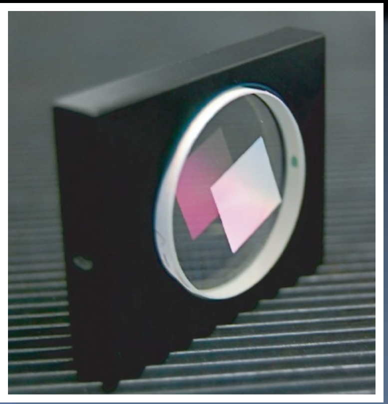
Grating Equation

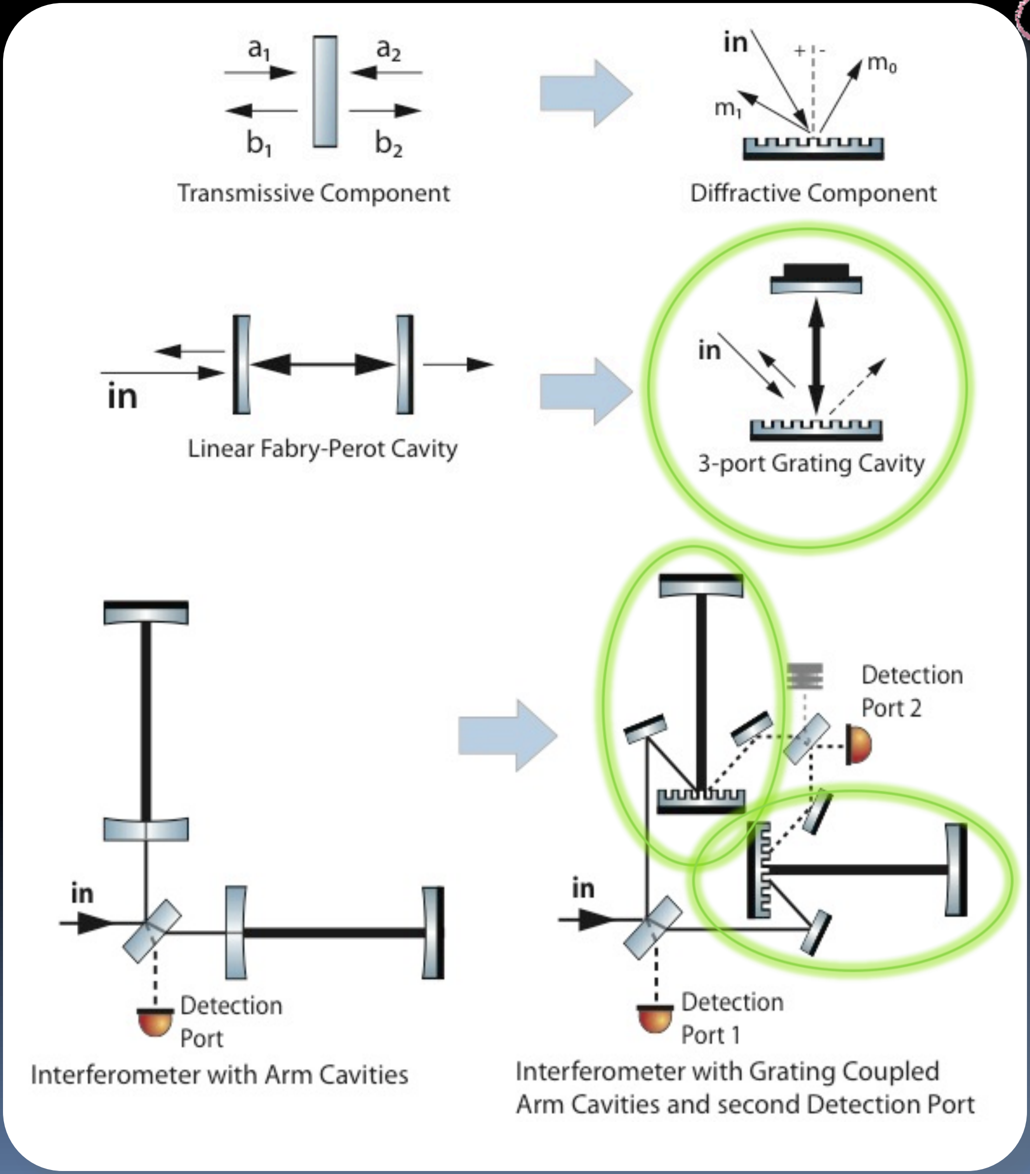
$$\sin\,\alpha + \sin\,\beta_m = \frac{m\lambda}{d}$$

NEW TOPOLOGIES

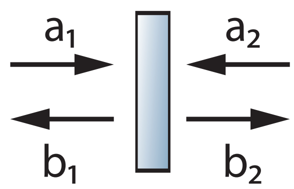








3-PORT GRATING

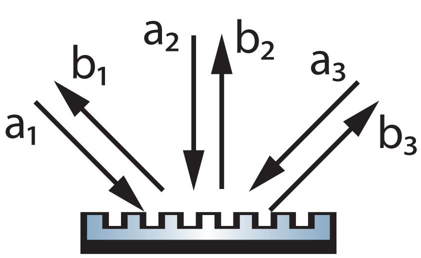


Transmissive Component

- Two light fields
- Phases are constant
- 2x2 Scattering Matrix

$$\mathbf{S}_{2p} = \begin{pmatrix} \rho & \tau \\ \tau & -\rho \end{pmatrix}$$

$$\mathbf{b} = \mathbf{S} \times \mathbf{a}$$



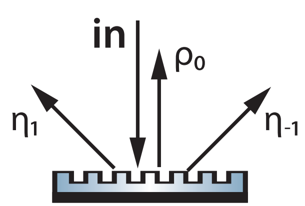
3-port Grating:

- Three light fields
- Phases: Φ(η0, η1, η2)
- 3x3 Scattering Matrix
- non-vanishing matrix elements

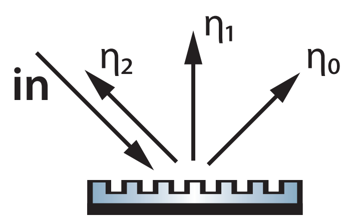
$$S_{3p} = \begin{pmatrix} \eta_2 e^{i\phi_2} & \eta_1 e^{i\phi_1} & \eta_0 e^{i\phi_2} \\ \eta_1 e^{i\phi_1} & \rho_0 e^{i\phi_0} & \eta_1 e^{i\phi_1} \\ \eta_0 e^{i\phi_0} & \eta_1 e^{i\phi_1} & \eta_2 e^{i\phi_0} \end{pmatrix}$$

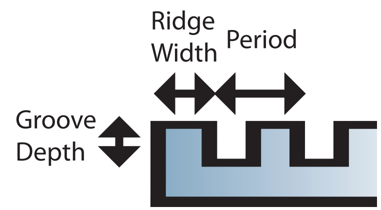
$$\eta_n \neq 0$$

Normal incidence



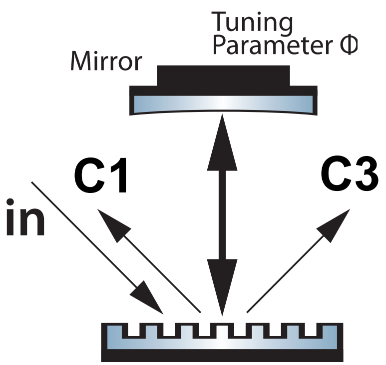
2nd order Littrow





$$\sin\,\alpha + \sin\,\beta_m = \frac{m\lambda}{d}$$

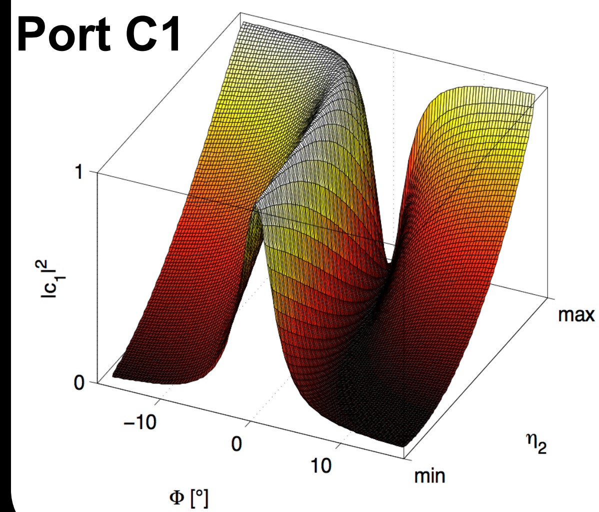
3-PORT GRATING CAVITY



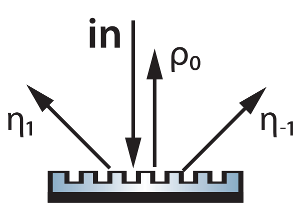
- Coupling via 1st order
- low coupling -> high finesse
- Two correlated Ports C1 and C3

Grating design defines ratio of the radiation at the two output ports

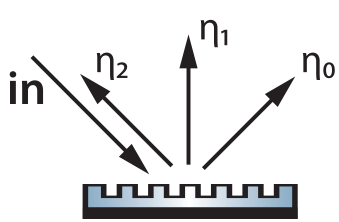
$$\eta_{0\,\substack{\min\\\max}} = \eta_{2\,\substack{\min\\\max}} = \frac{1 \mp \rho_0}{2}$$

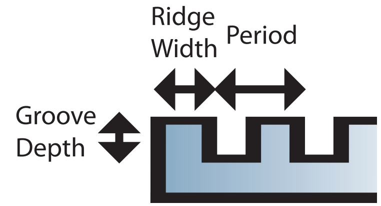


Normal incidence



2nd order Littrow

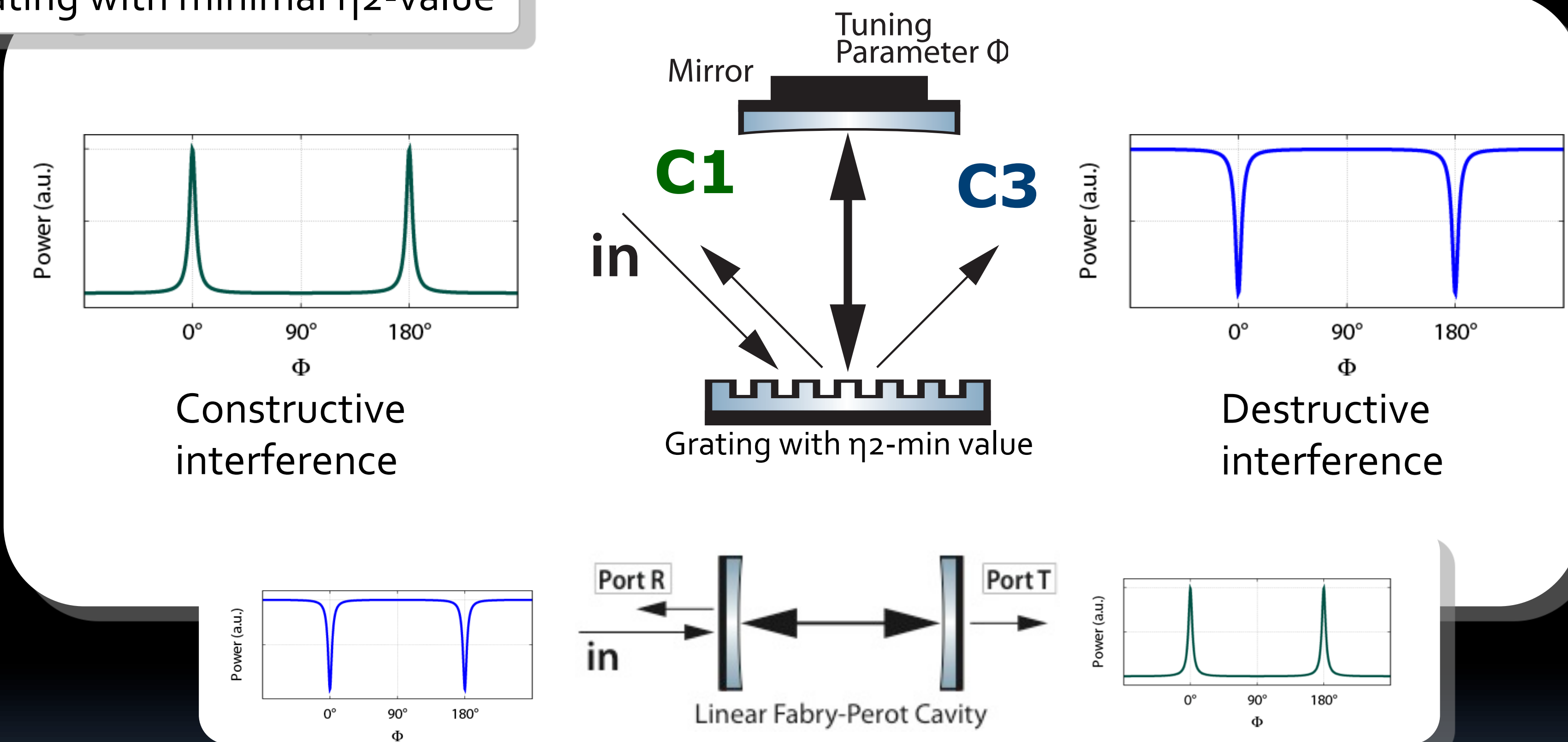




$$\sin\,\alpha + \sin\,\beta_m = \frac{m\lambda}{d}$$

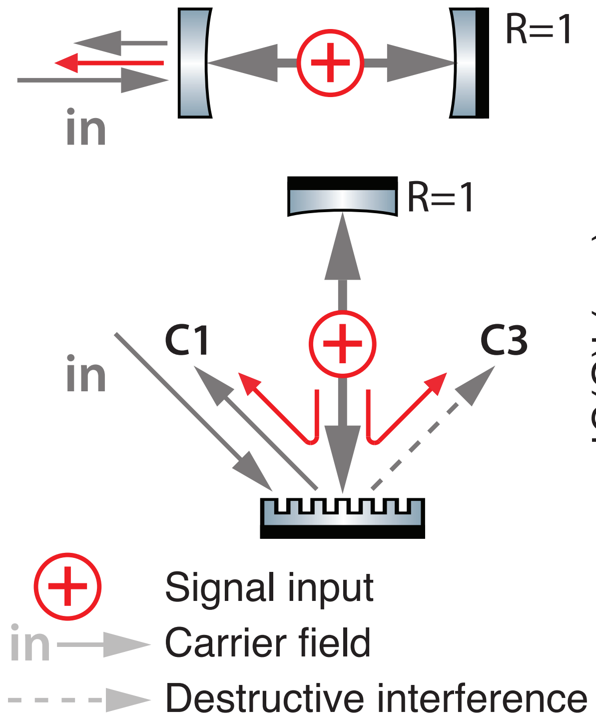
3-PORT GRATING CAVITY

Grating with minimal η_2-value

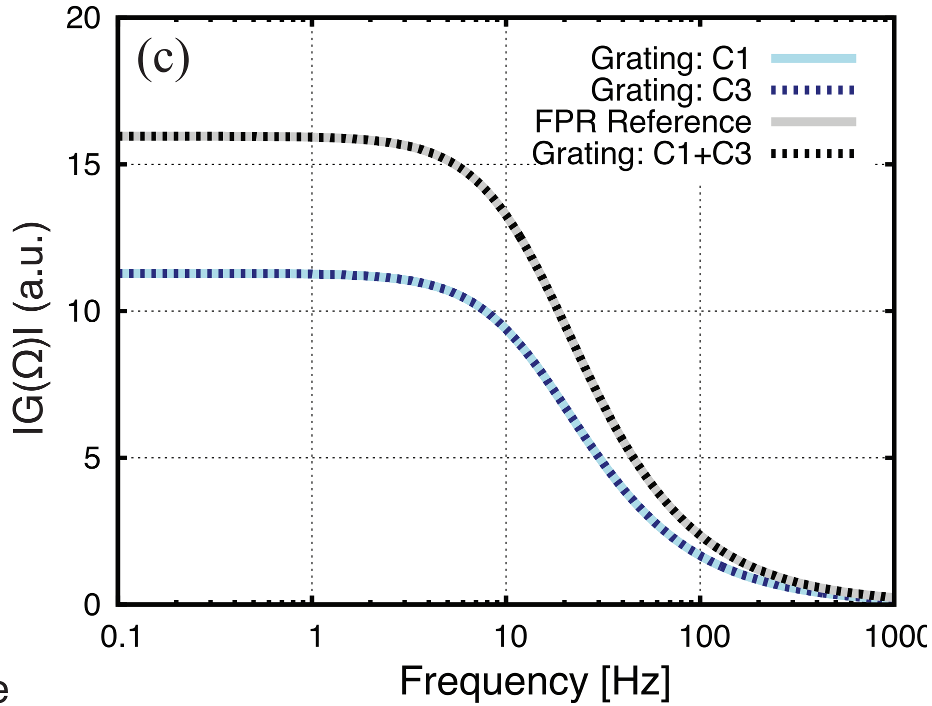


- Constructive interference at C1 and destructive interference at C3
- Light is retro reflected towards the laser source
- 'Modecleaner in reflection'

SIGNAL RESPONSE

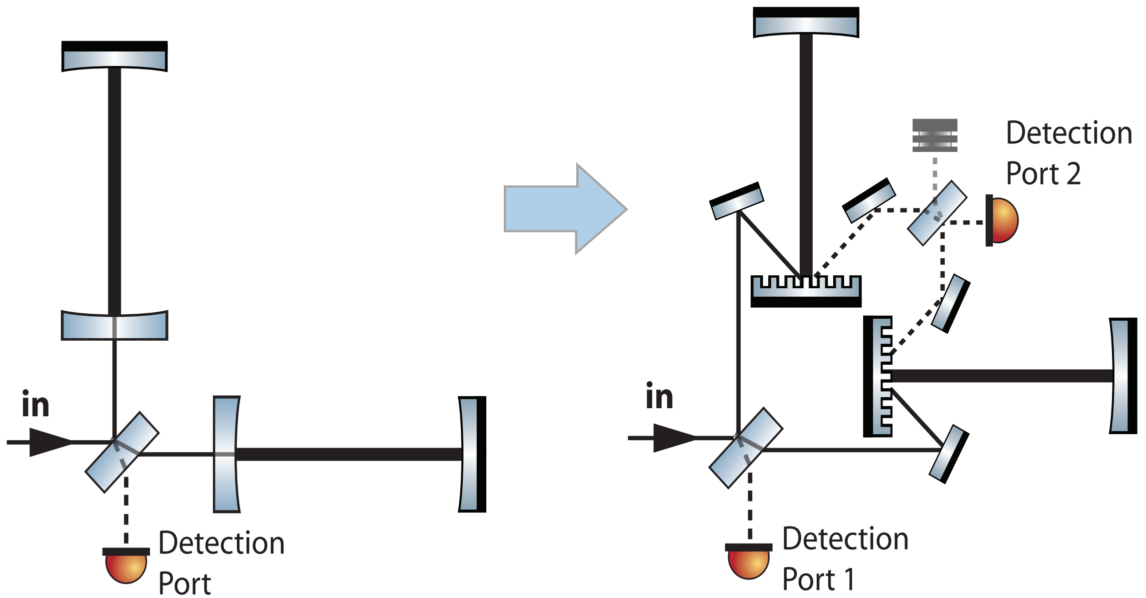


Phase quadrature readout at the detection ports for both cavities on resonance



Second detection port required to gain full signal information

TWO DETECTION PORTS

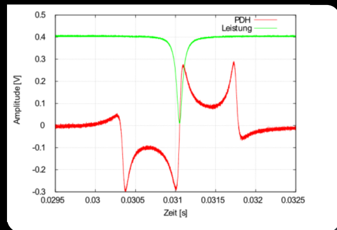


Interferometer with Arm Cavities

Interferometer with Grating Coupled Arm Cavities and second Detection Port

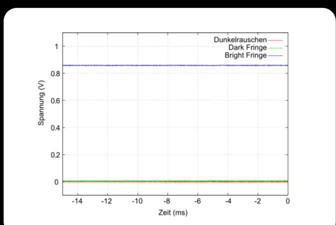
SET UP

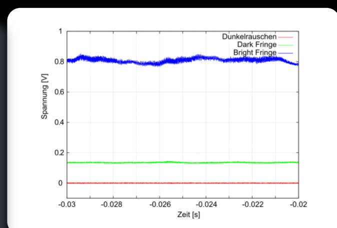
Cavity lock with standard PDH



Main IFO lock with internal modulation

Detection 2 lock with DC lock

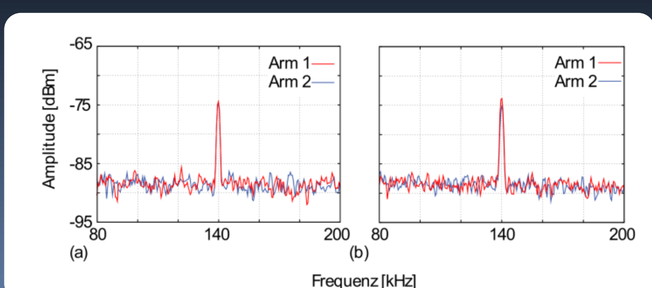


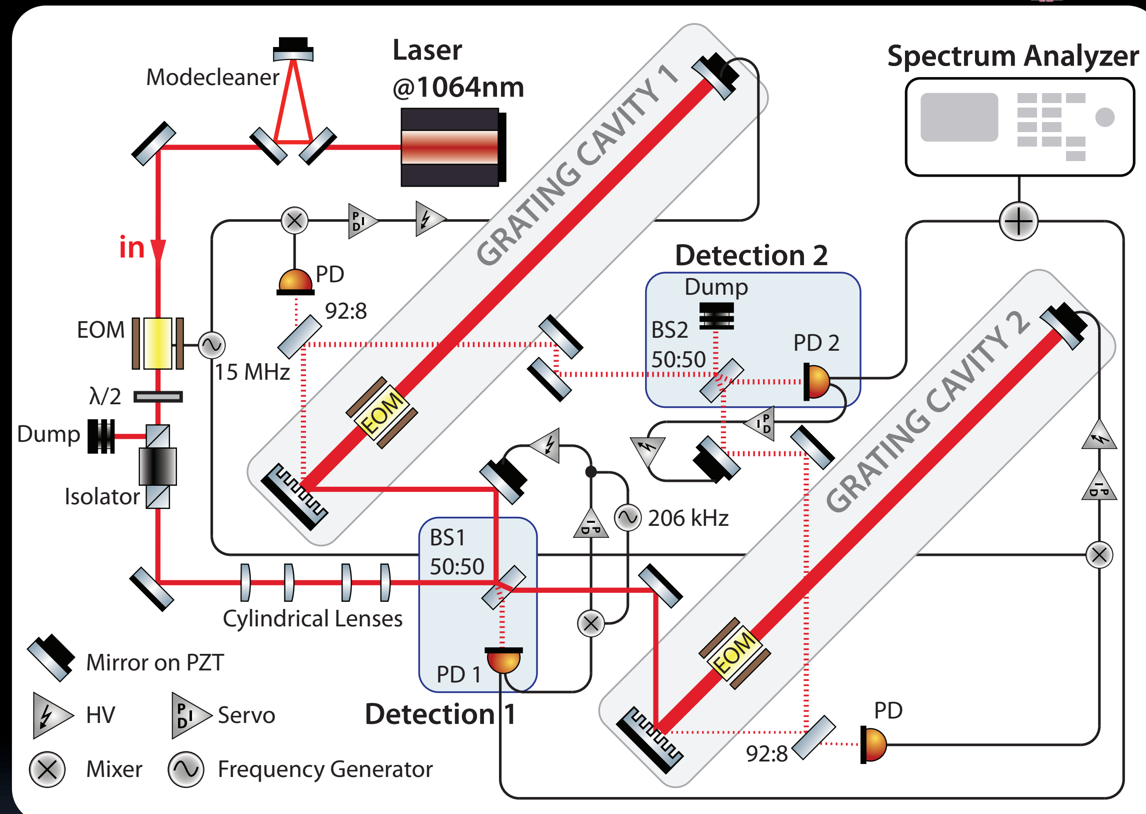


Contast = 98%

Contast = 80%

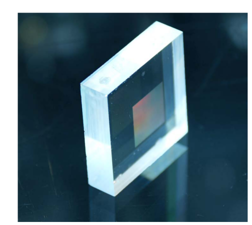
Signal adjustment for both cavities





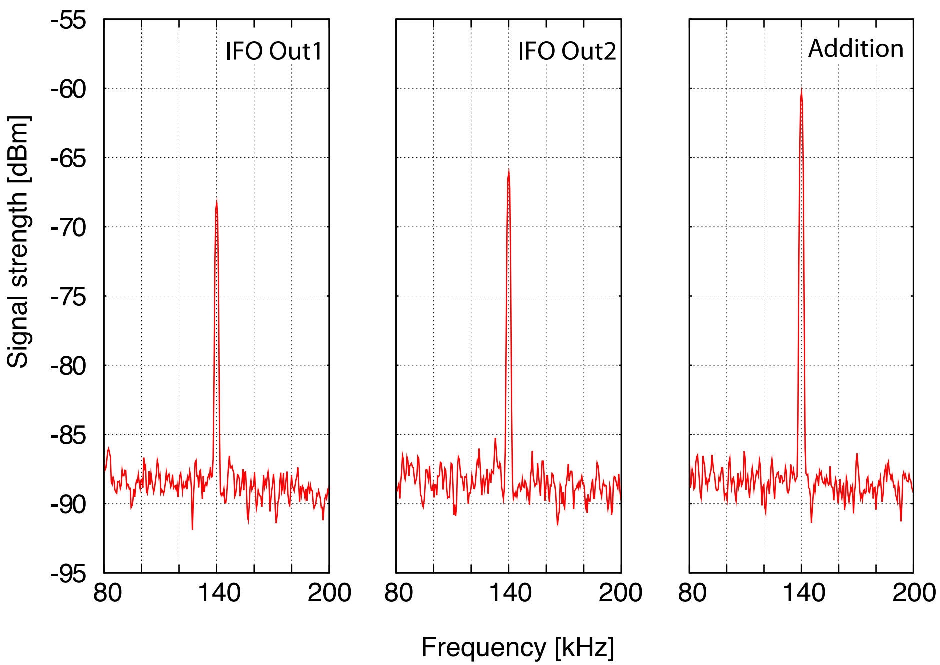
Structure-on-top grating characterized and split

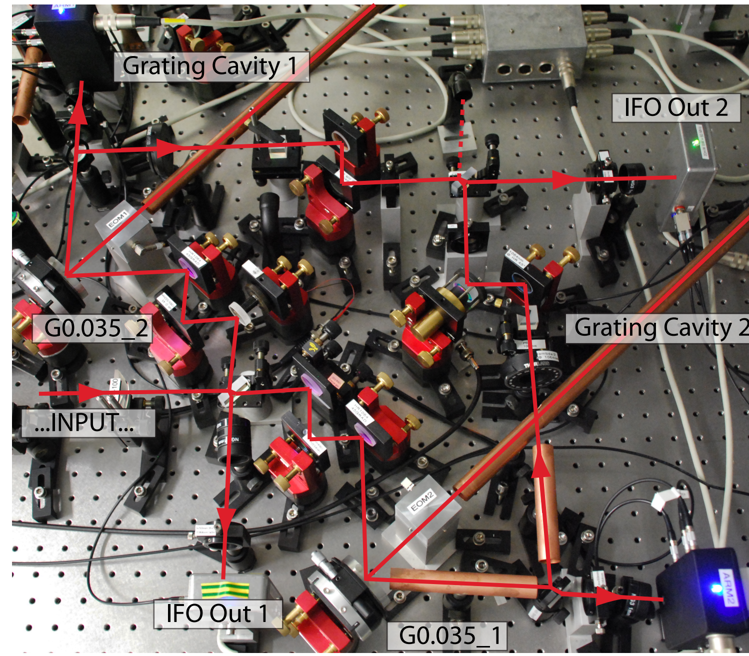
Gitter	η_0^2 [%]	η_1^2 [%]	η_2^2 [%]
$G0.035_{3.1}$	96,24 (±2,3)	3,04 (±0,23)	0,04 (±0,02)
$G0.035_{3.2}$	96,01 (±2,3)	3,30 (±0,23)	0,04 (±0,02)

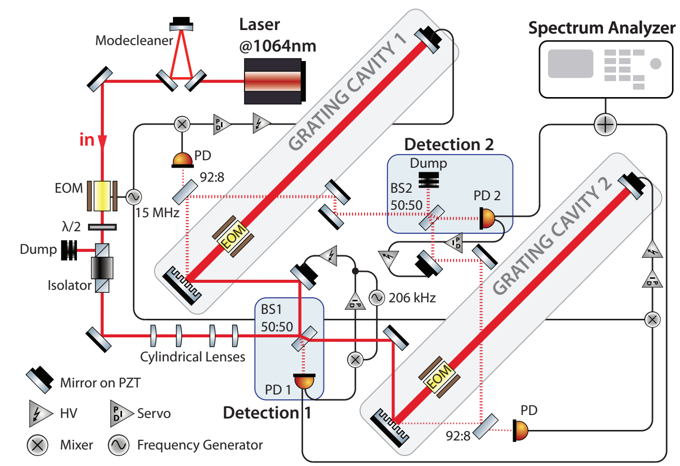


FIRST RESULTS

Signal addition:



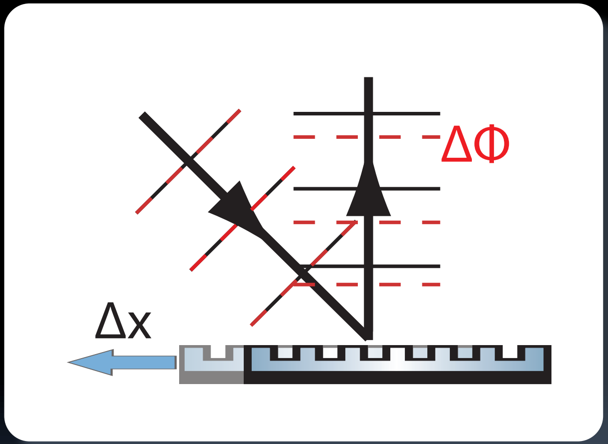




OUTLOOK

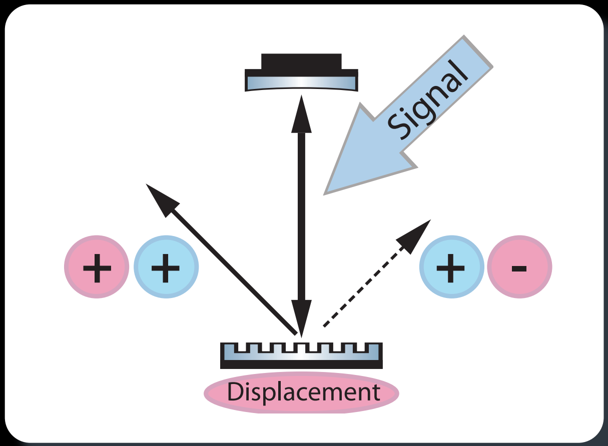
Lateral Displacement noise

- Side motion induced phase noise
- Additional noise source
- Experimental verification in Glasgow



A.Freise et al. , New Journal of Physics 9, 433 (2007)
J. Hallam et al. , J. Opt. A: Pure Appl. Opt. 11 (2009)

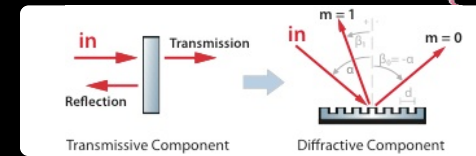
'Uninvite the uninvited guest'



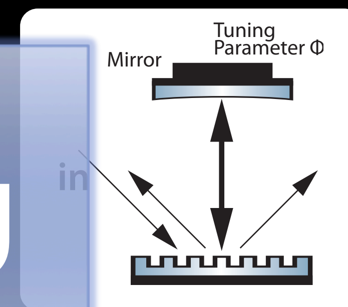
- Alternative read-out scheme at IFO
- GW signals are correlated
- Displacement induces anti-correlated signals
- Current investigations

SUMMARY

- Gratings avoid transmission induced thermal effects in the substrates



- 3-port grating cavity (η_2-min) retro-reflects the light field towards the source



- 3-port arm cavities require 2nd detection port

THANK YOU

- IFO with signal injection realized