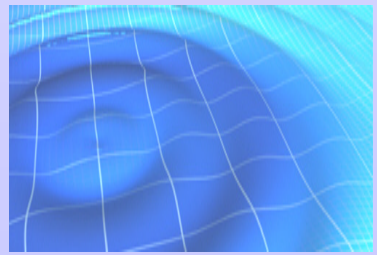
Generation of squeezed states for Gravitational Wave detectors

Simon Chelkowski, Henning Vahlbruch, Roman Schnabel
and Karsten Danzmann

Albert-Einstein-Institut Hannover,
Max-Planck-Institut für Gravitationsphysik
and Universität Hannover

LIGO-G070056-00-Z

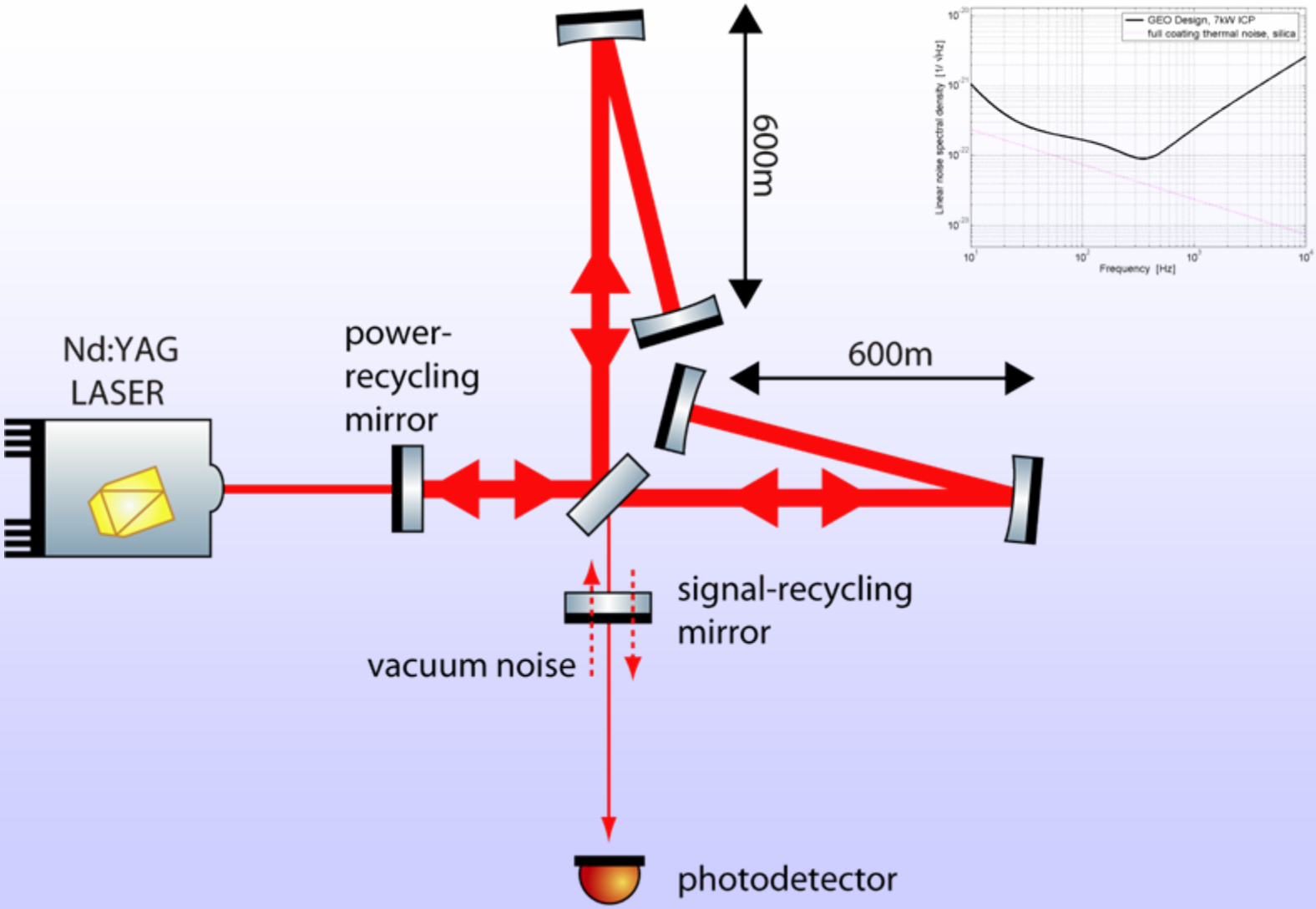


Outline

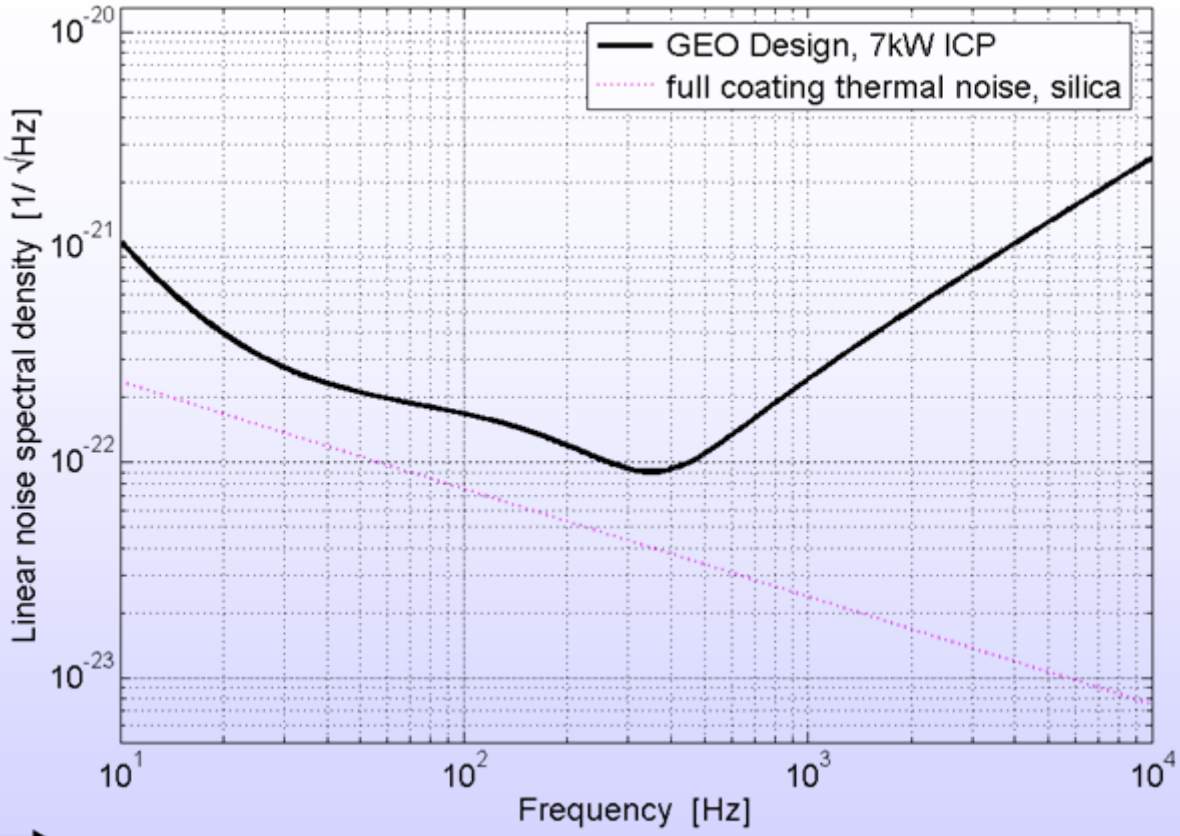
- Quantum Noise in an Interferometer
  - Frequency dependent squeezed light
  - GEO HF upgrade possibilities
- Low Frequency Squeezing

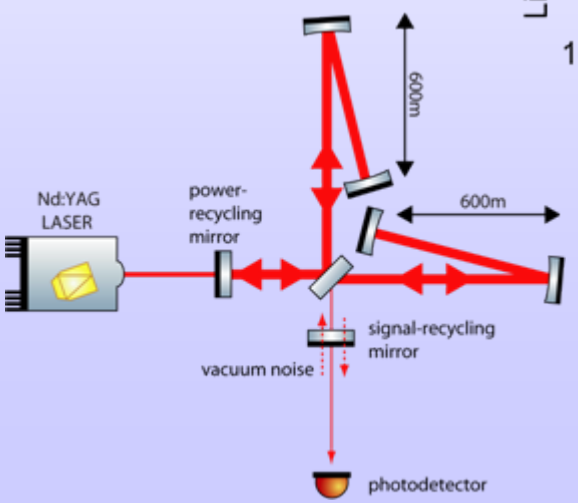
Quantum Noise inside Interferometers

The GEO600 Gravitational Wave Detector

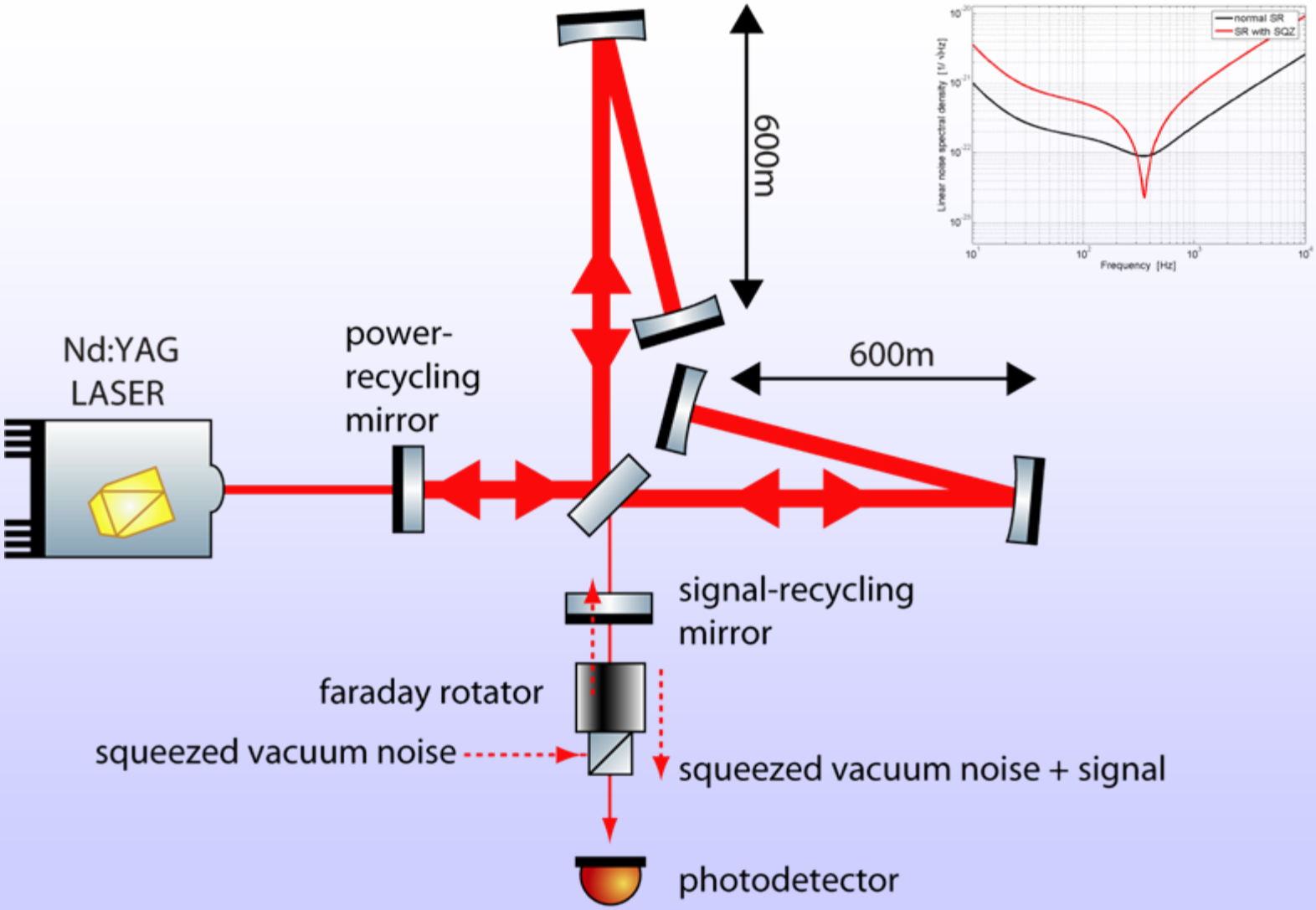


Quantum Noise in a modern Interferometer

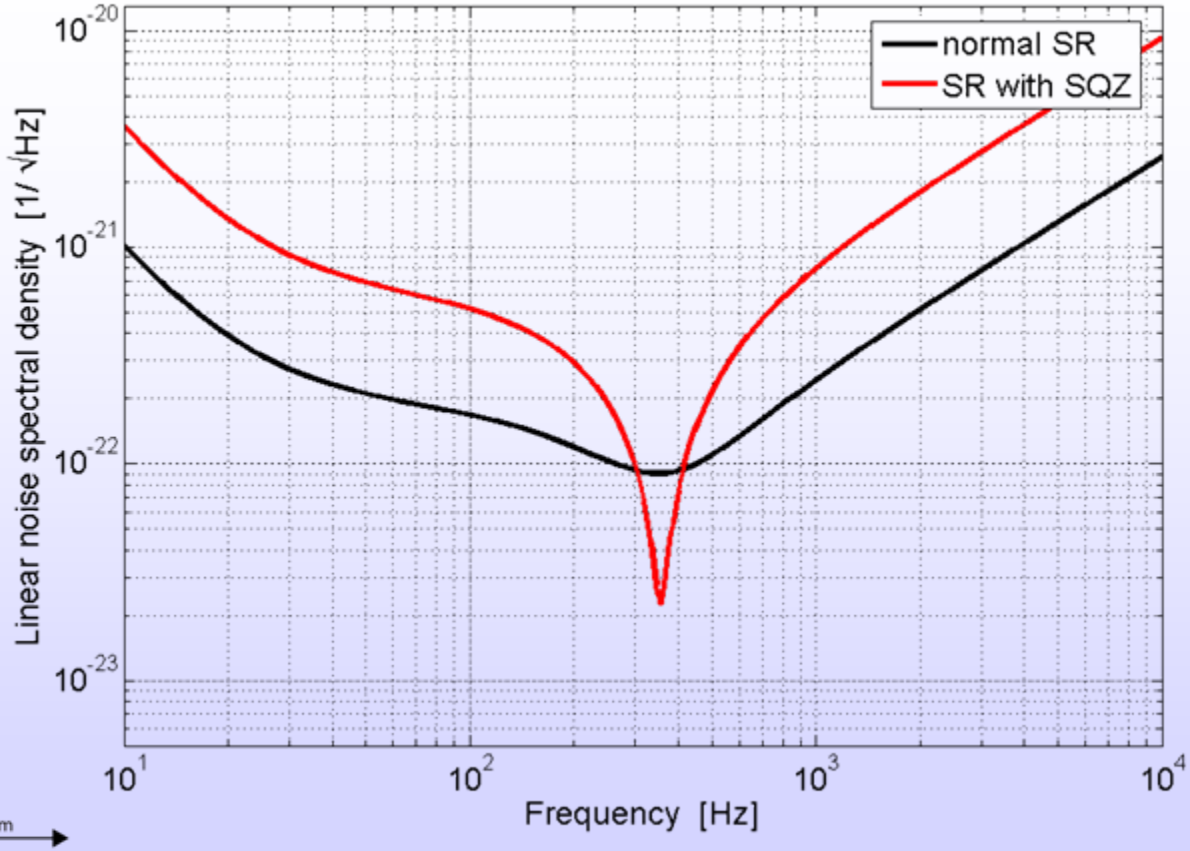


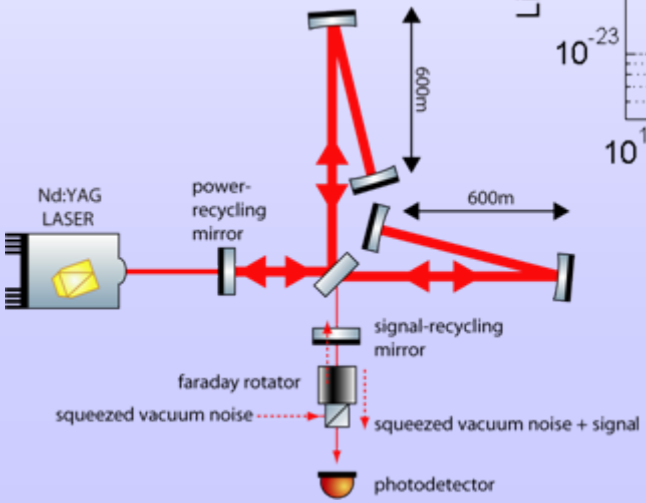


Reducing the Quantum Noise

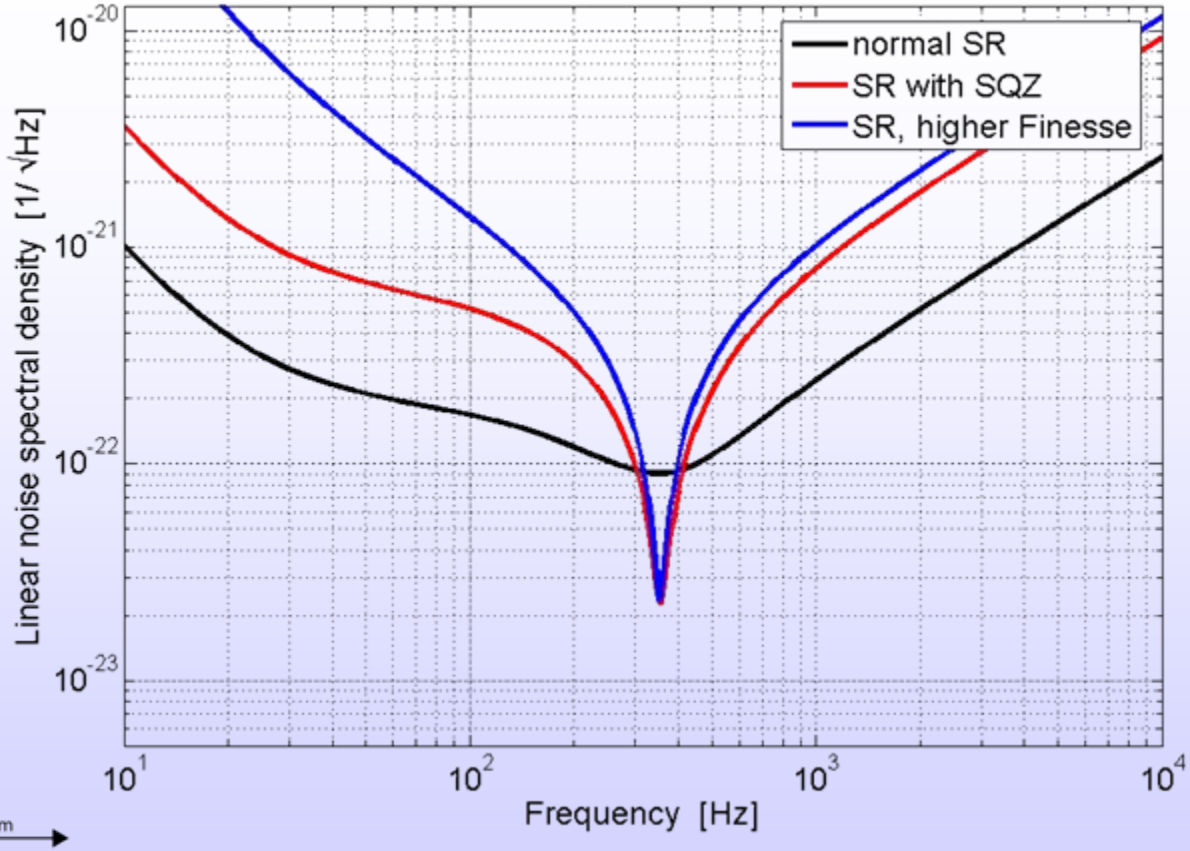


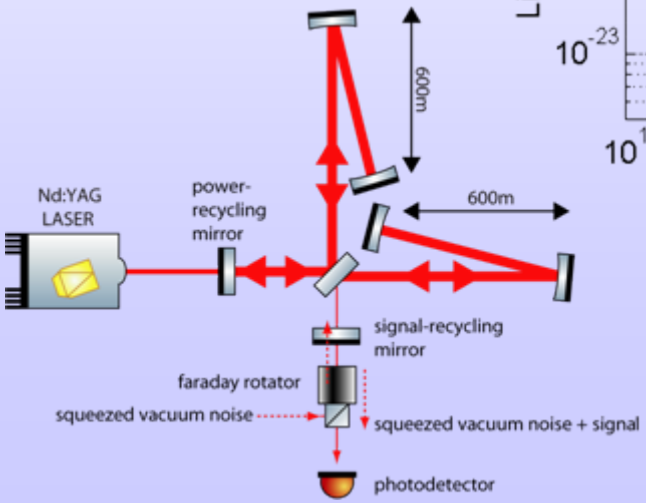
Reducing the Quantum Noise



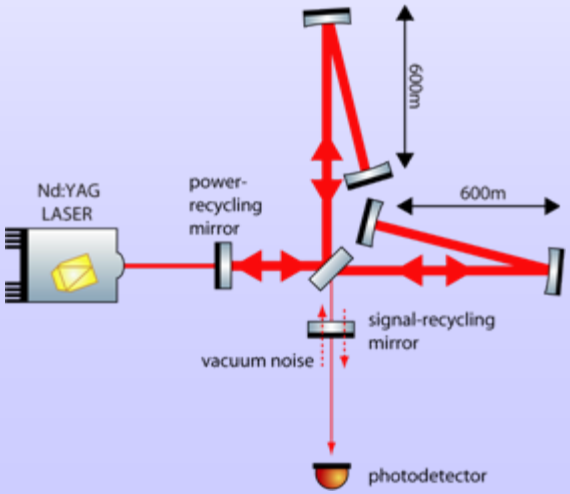


Reducing the Quantum Noise

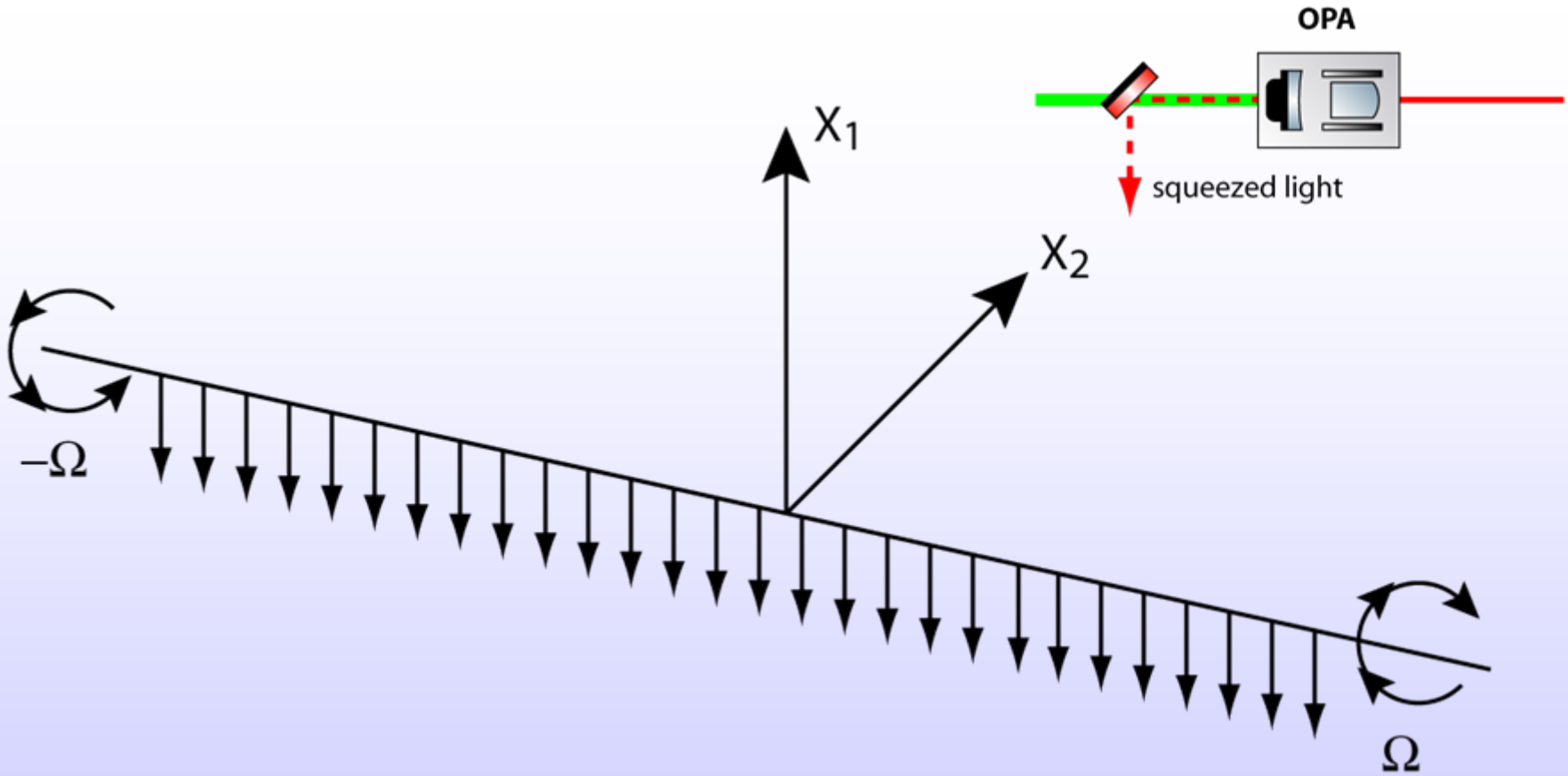




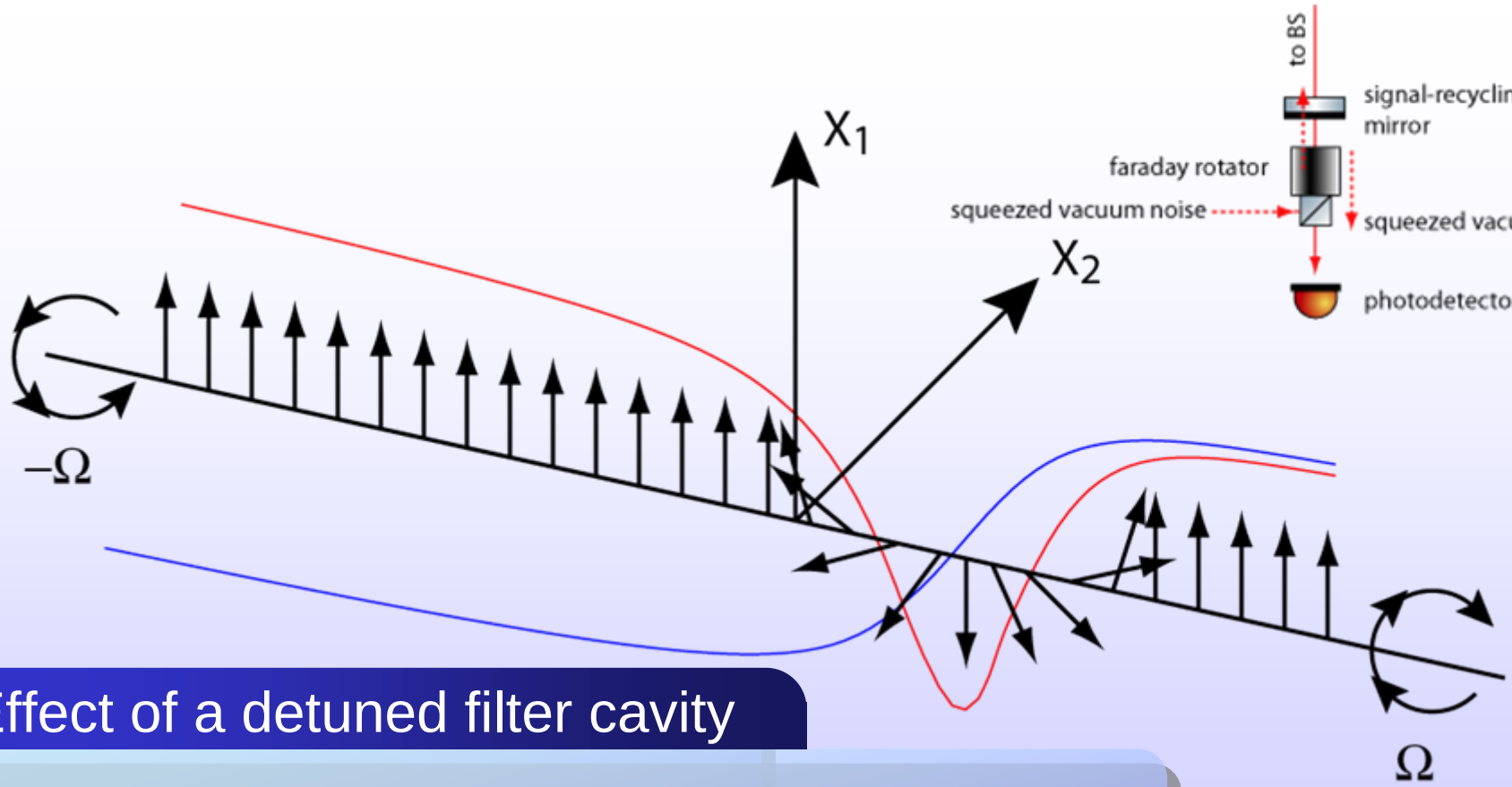
Quantum Noise



Squeezed Vacuum



Squeezed Vacuum Interaction with a cavity

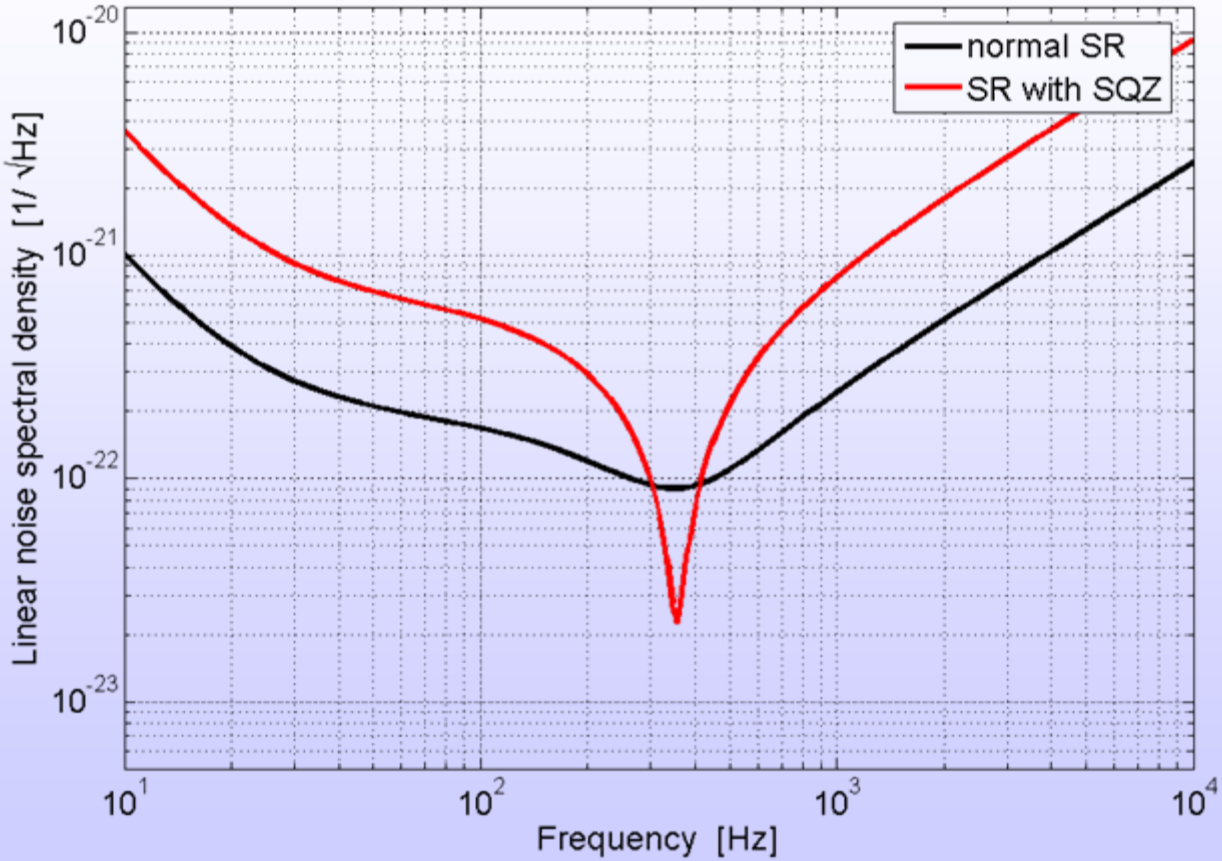


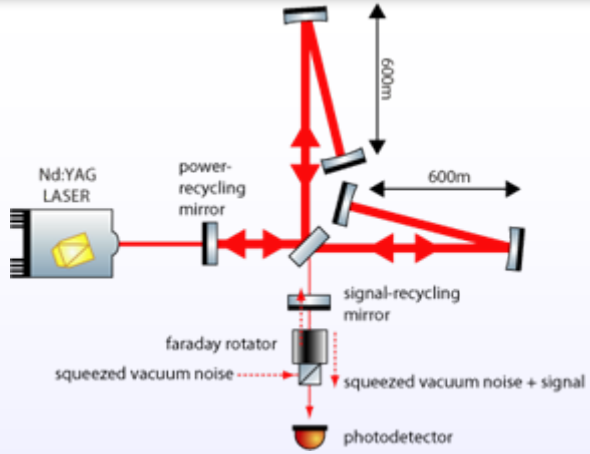
Effect of a detuned filter cavity

$$\hat{a}_{\theta'}(\Omega) = \frac{1}{\sqrt{2}}[\hat{a}(\omega+\Omega)e^{-i(\theta+\phi)} + \hat{a}^\dagger(\omega-\Omega)e^{i\theta}]$$

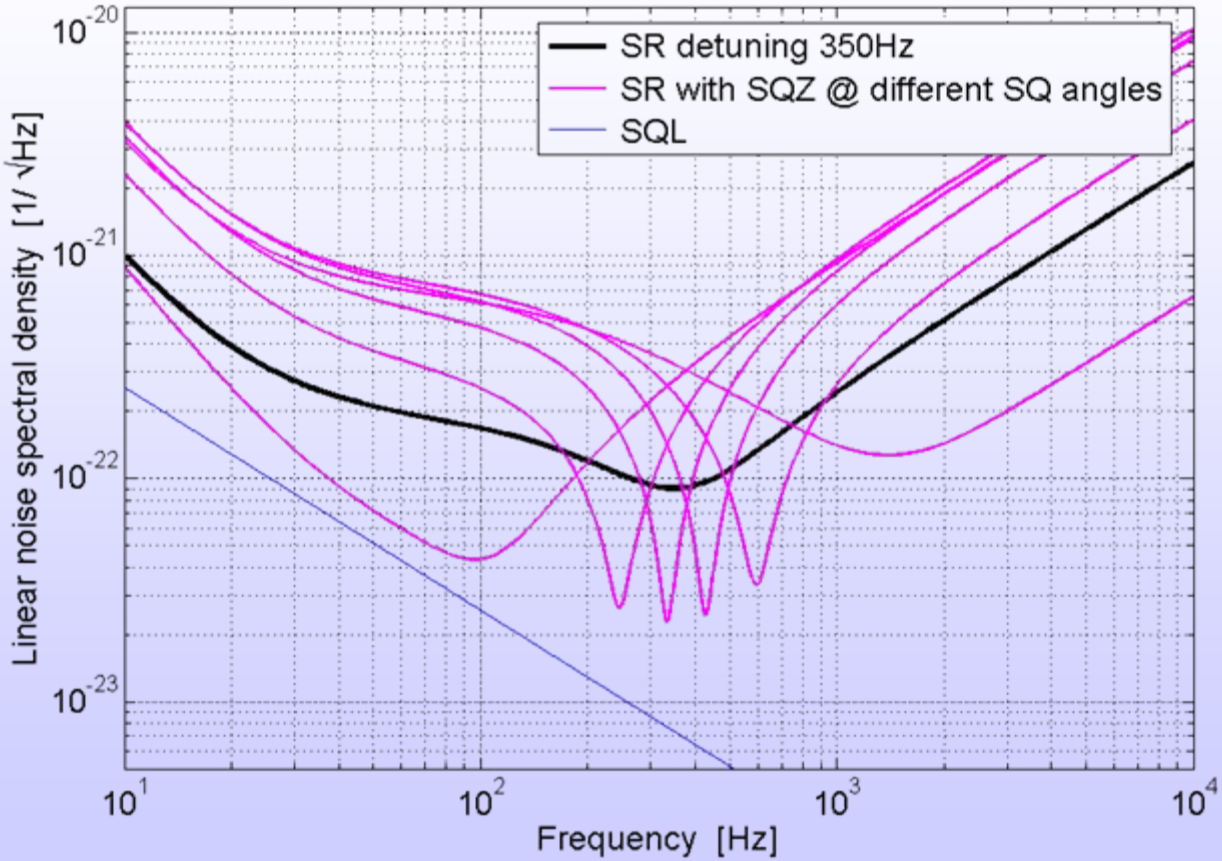
$$= \frac{e^{-i\phi/2}}{\sqrt{2}}[\hat{a}(\omega+\Omega)e^{-i\theta'} + \hat{a}^\dagger(\omega-\Omega)e^{i(\theta')}]$$

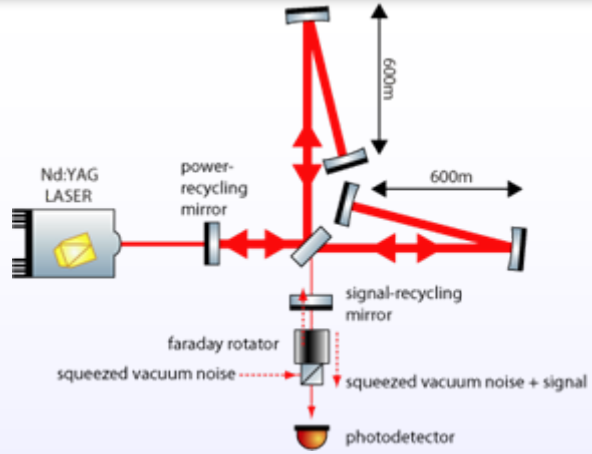
$$\text{mit } \theta' = \theta + \phi/2$$


normal SR
SR with SQZ
Linear noise spectral density [1/ √Hz]
Frequency [Hz]
10^-20
10^-21
10^-22
10^-23
10^1
10^2
10^3
10^4

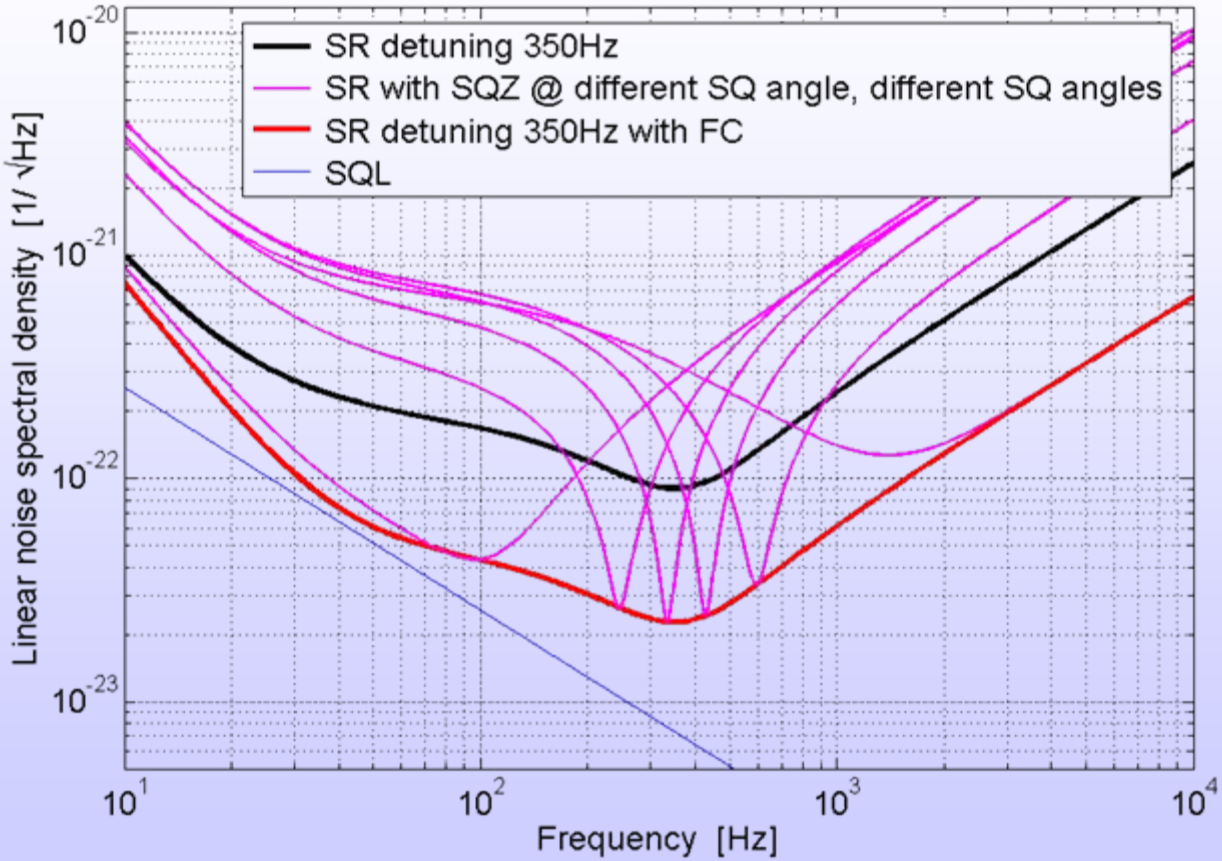

600m
Nd:YAG
LASER
power-
recycling
mirror
600m
signal-recycling
mirror
faraday rotator
squeezed vacuum noise
squeezed vacuum noise + signal
photodetector

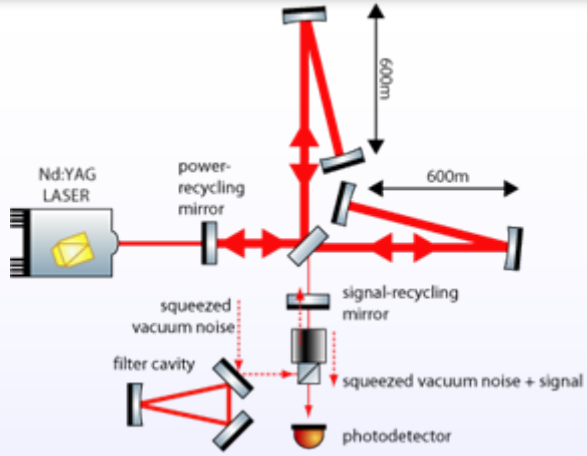
GEO 600 with Squeezed Vacuum and Filter Cavity



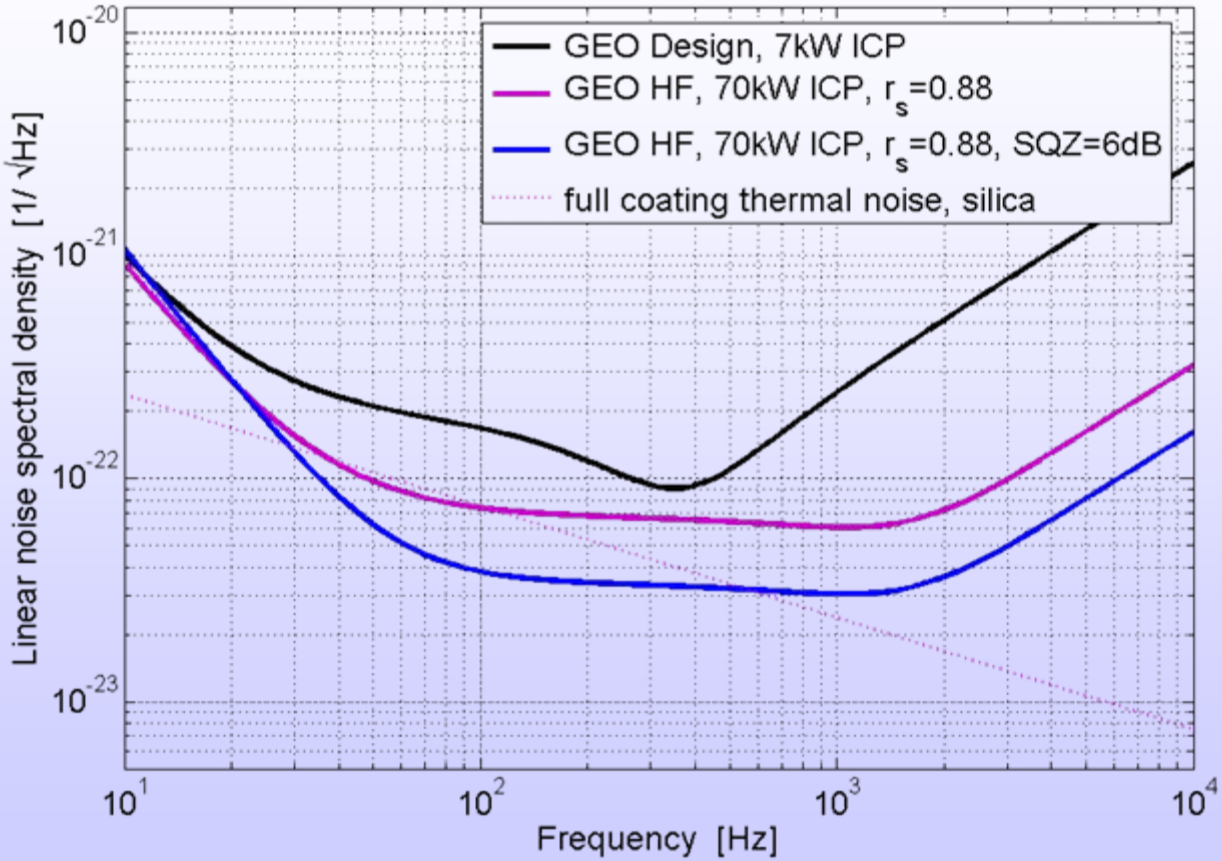


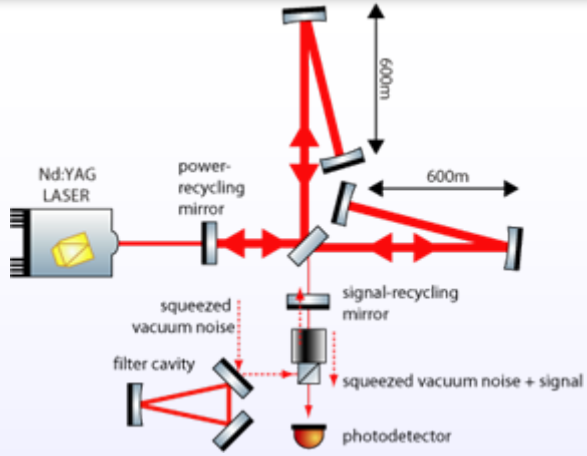
GEO 600 with Squeezed Vacuum and Filter Cavity



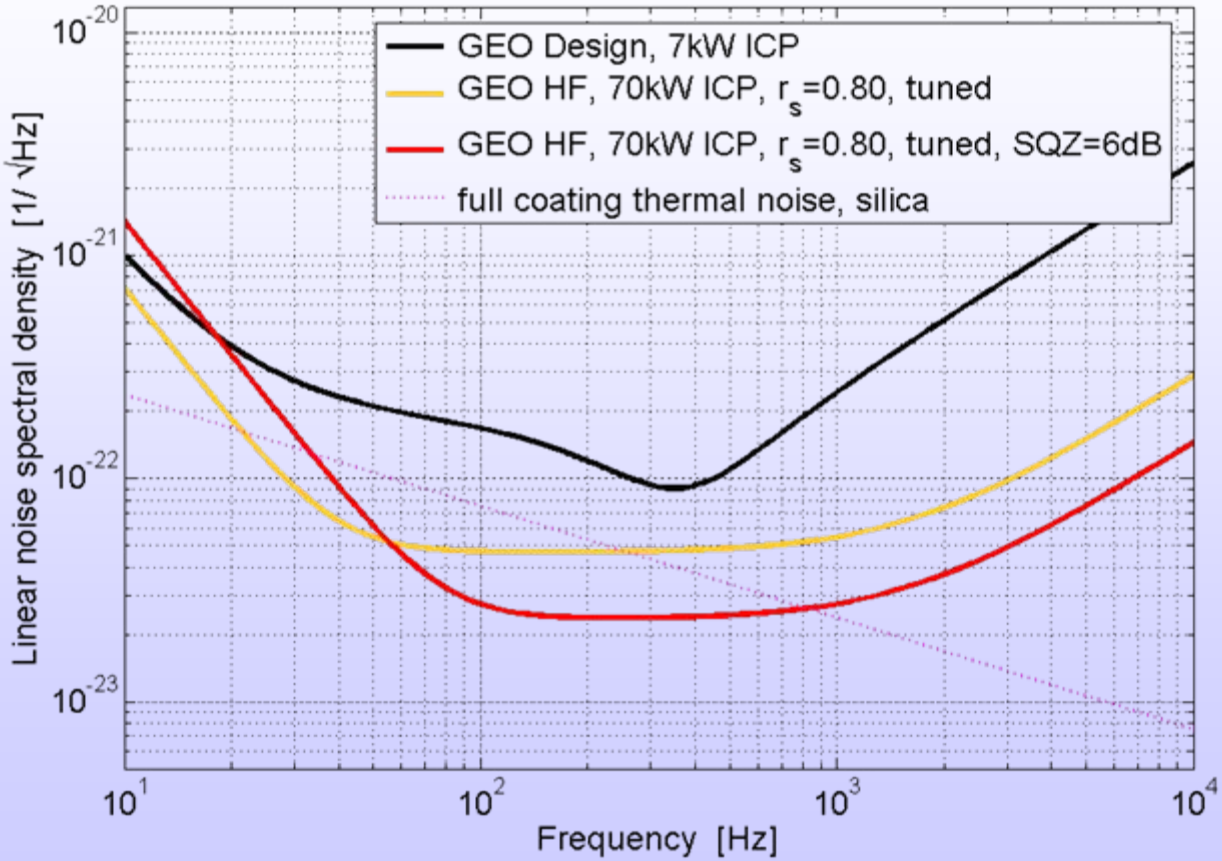


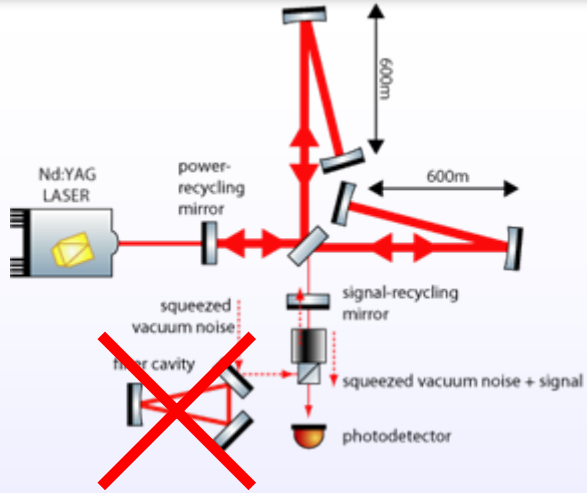
GEO HF: Detuned Signal Recycling



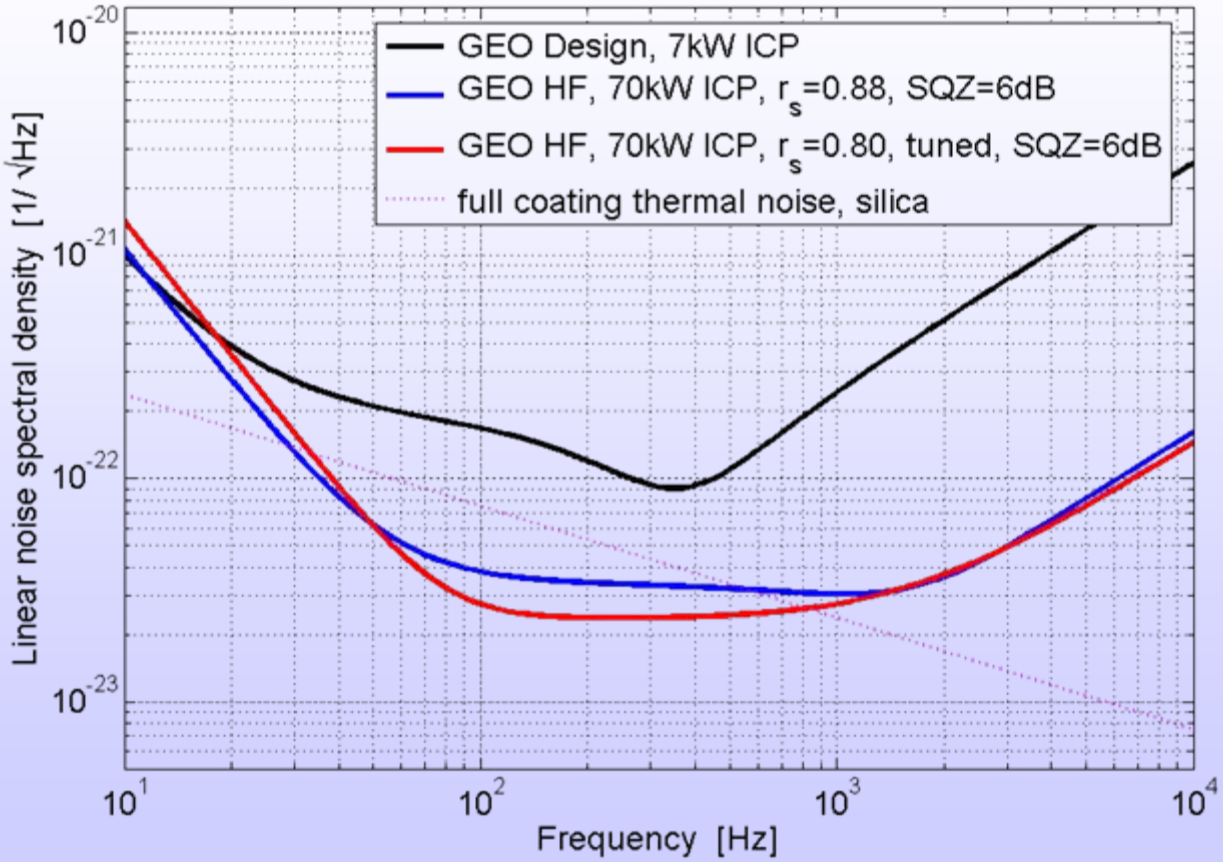


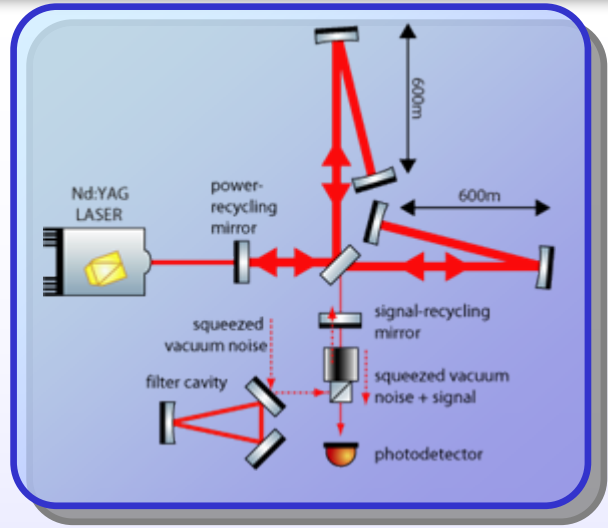
GEO HF: Tuned Signal Recycling

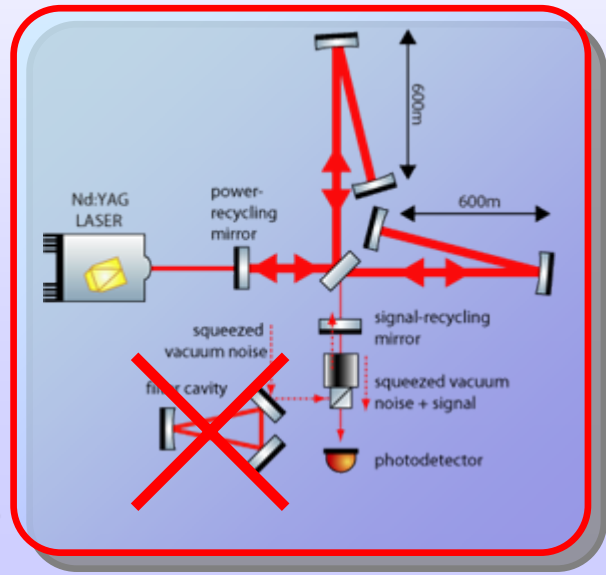




Do we need a filter cavity?

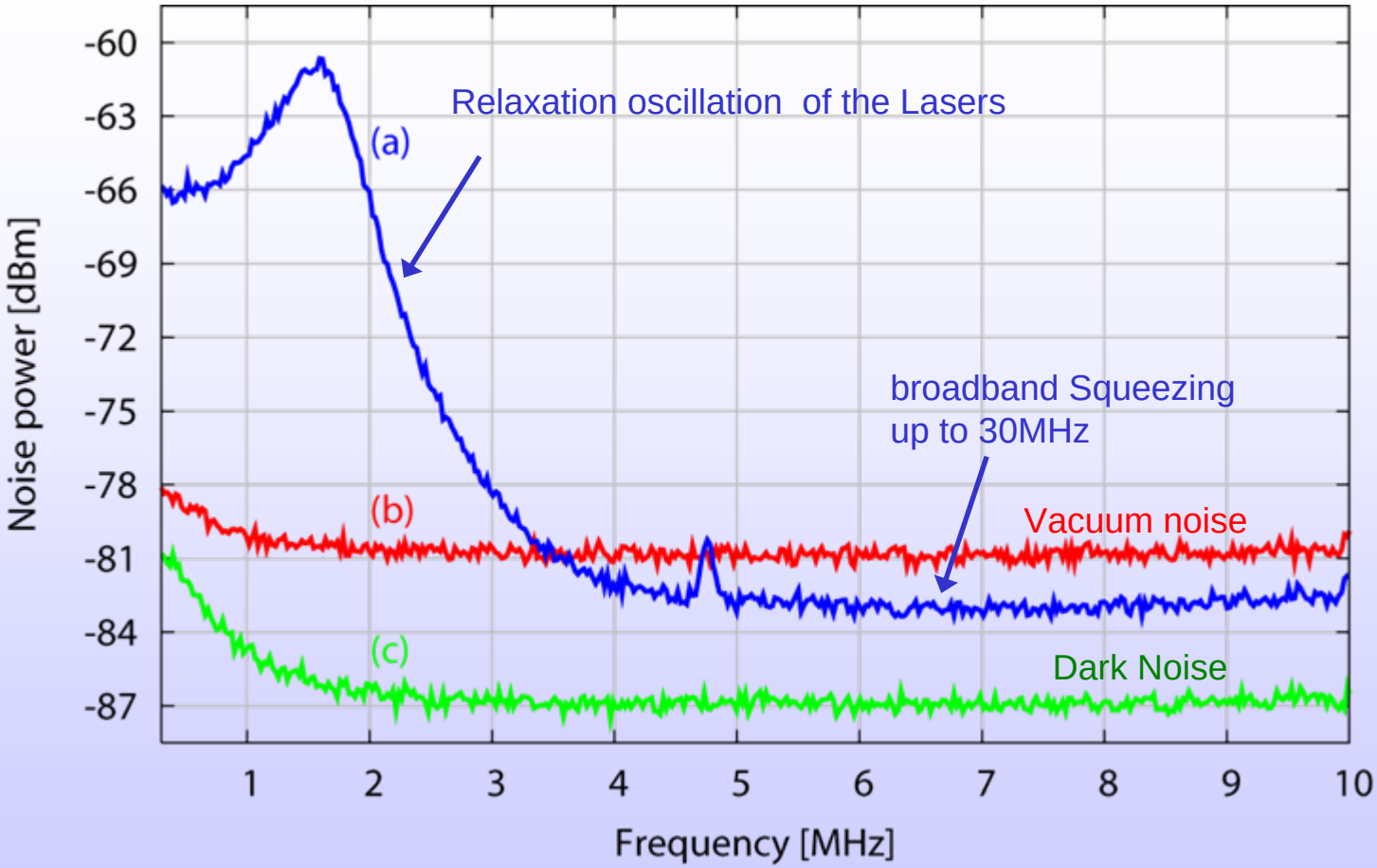




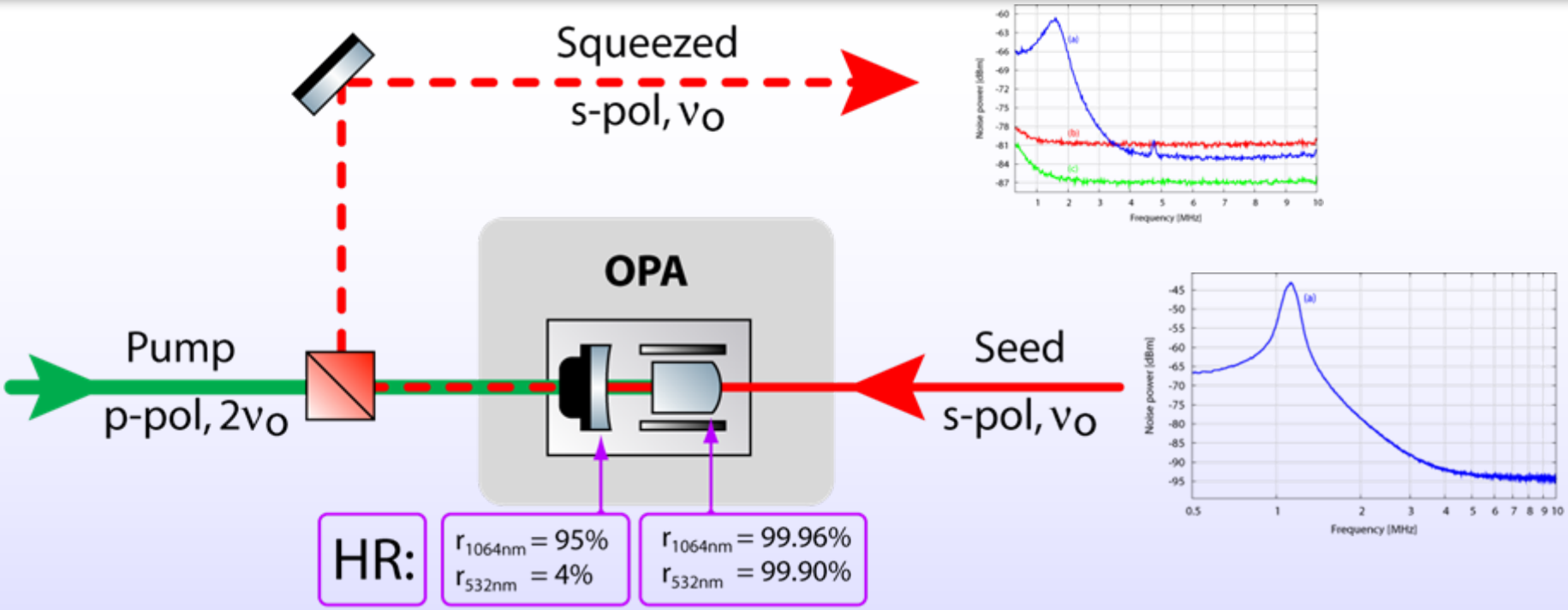


Low frequency squeezing

Generic squeezing from an OPA

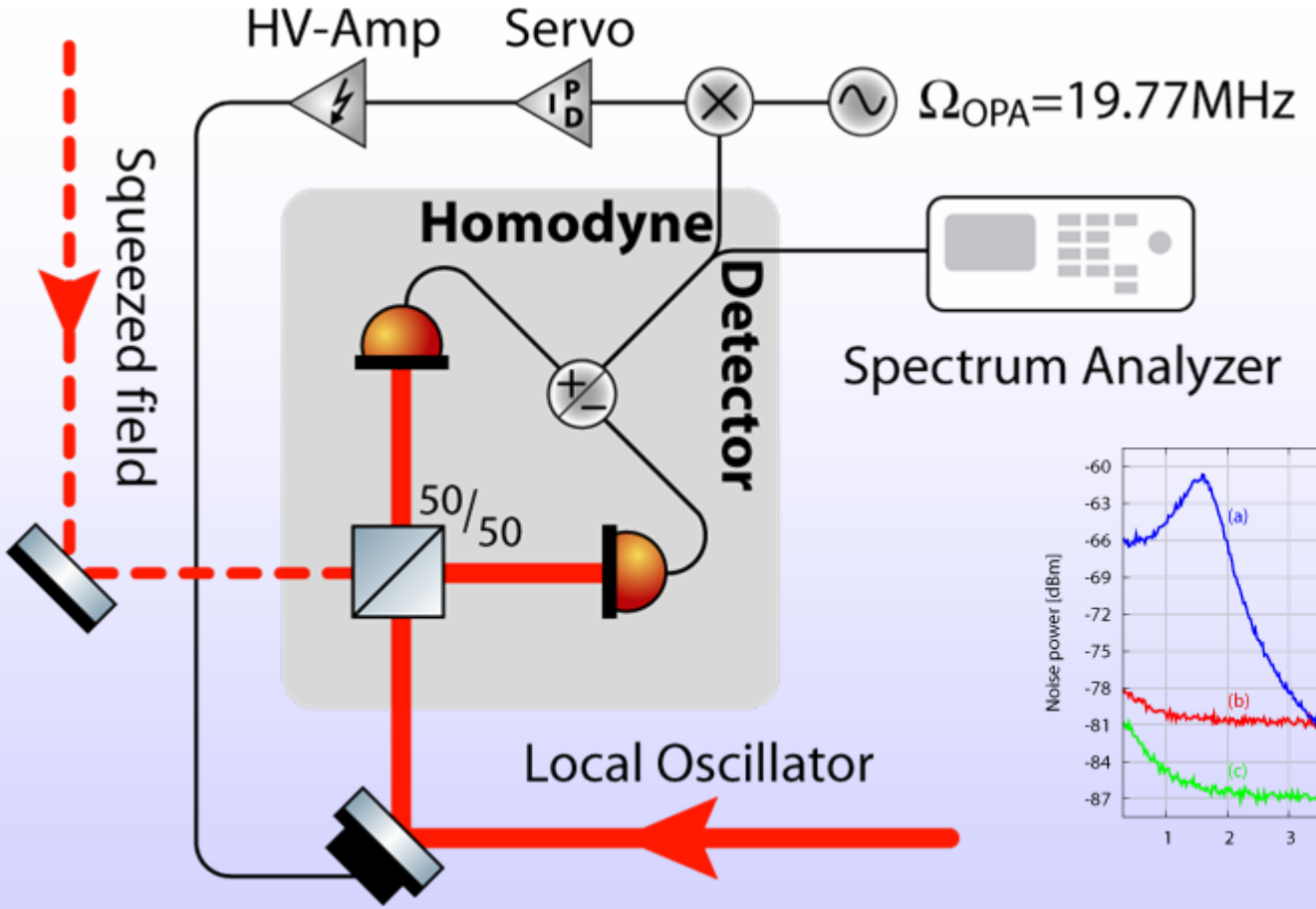


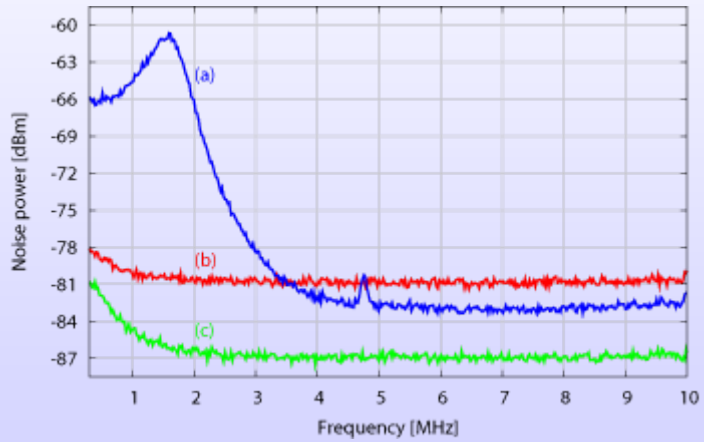
OPA – Optical Parametric Amplification



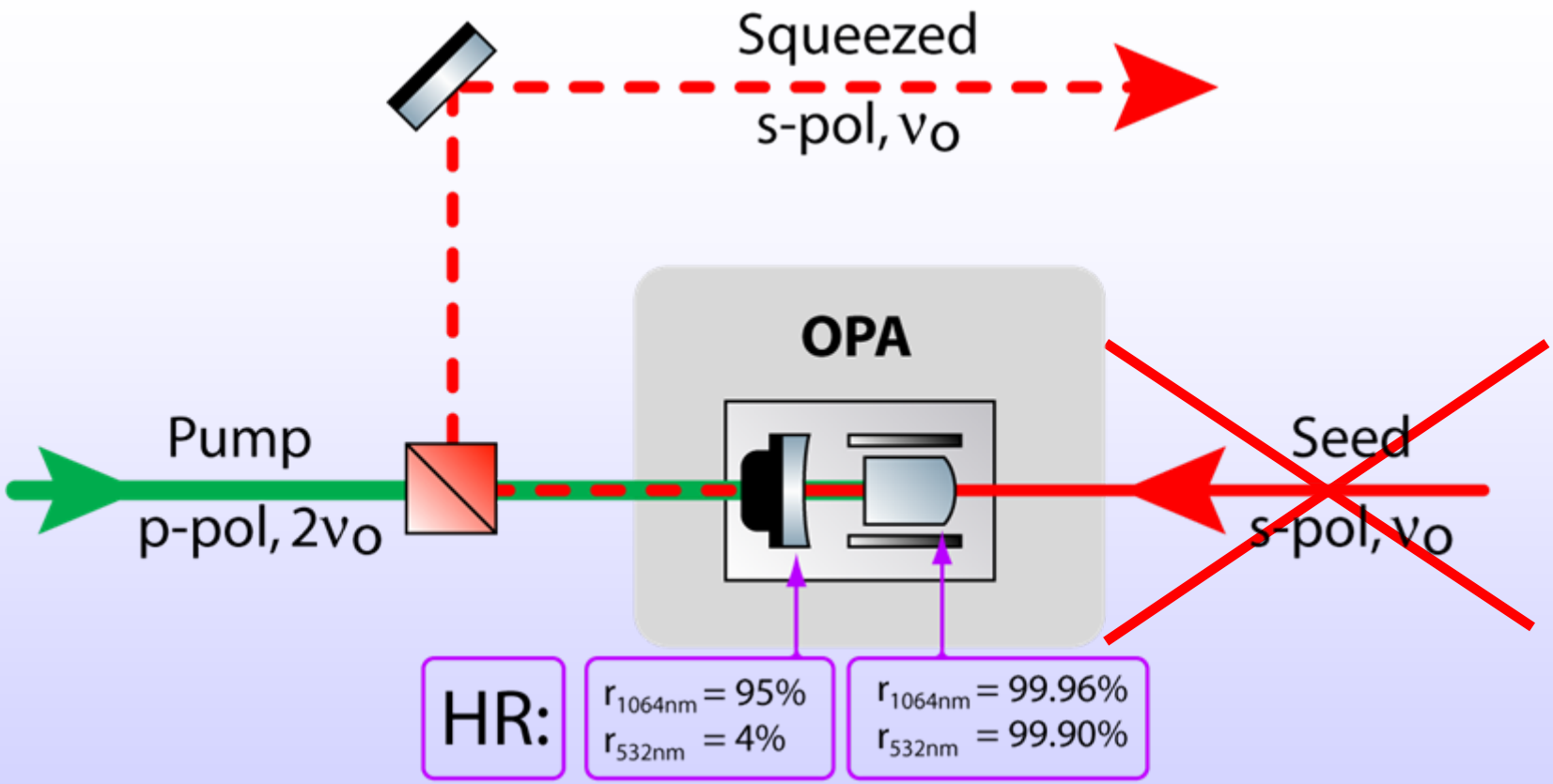
- hemilithic cavity
- $MgO:LiNbO_3$ – crystal as nonlinear material
- strong interaction between Seed- und Pump
- fractions in phase get amplified

Seed field is a control field

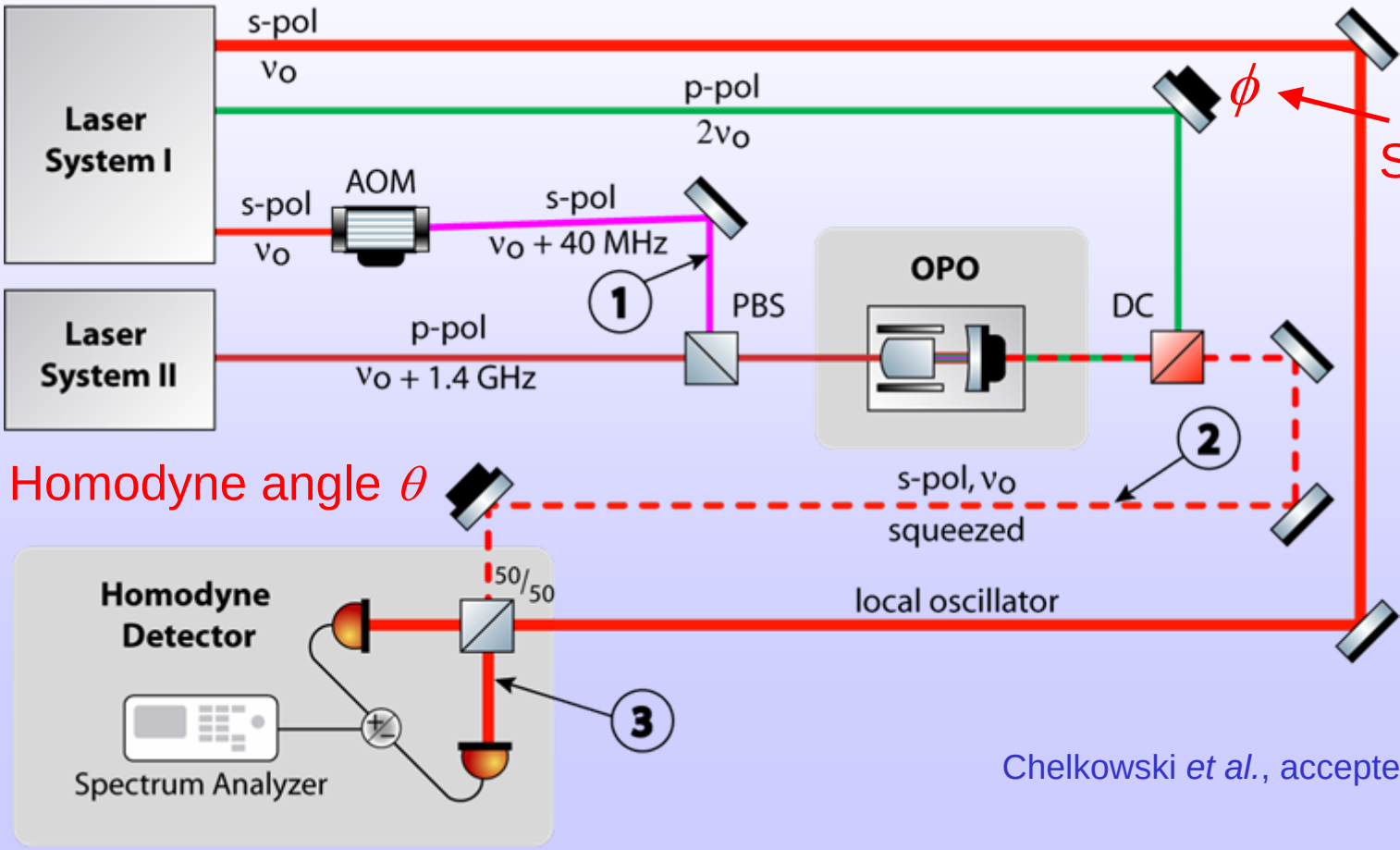




OPA without seed turns into an OPO

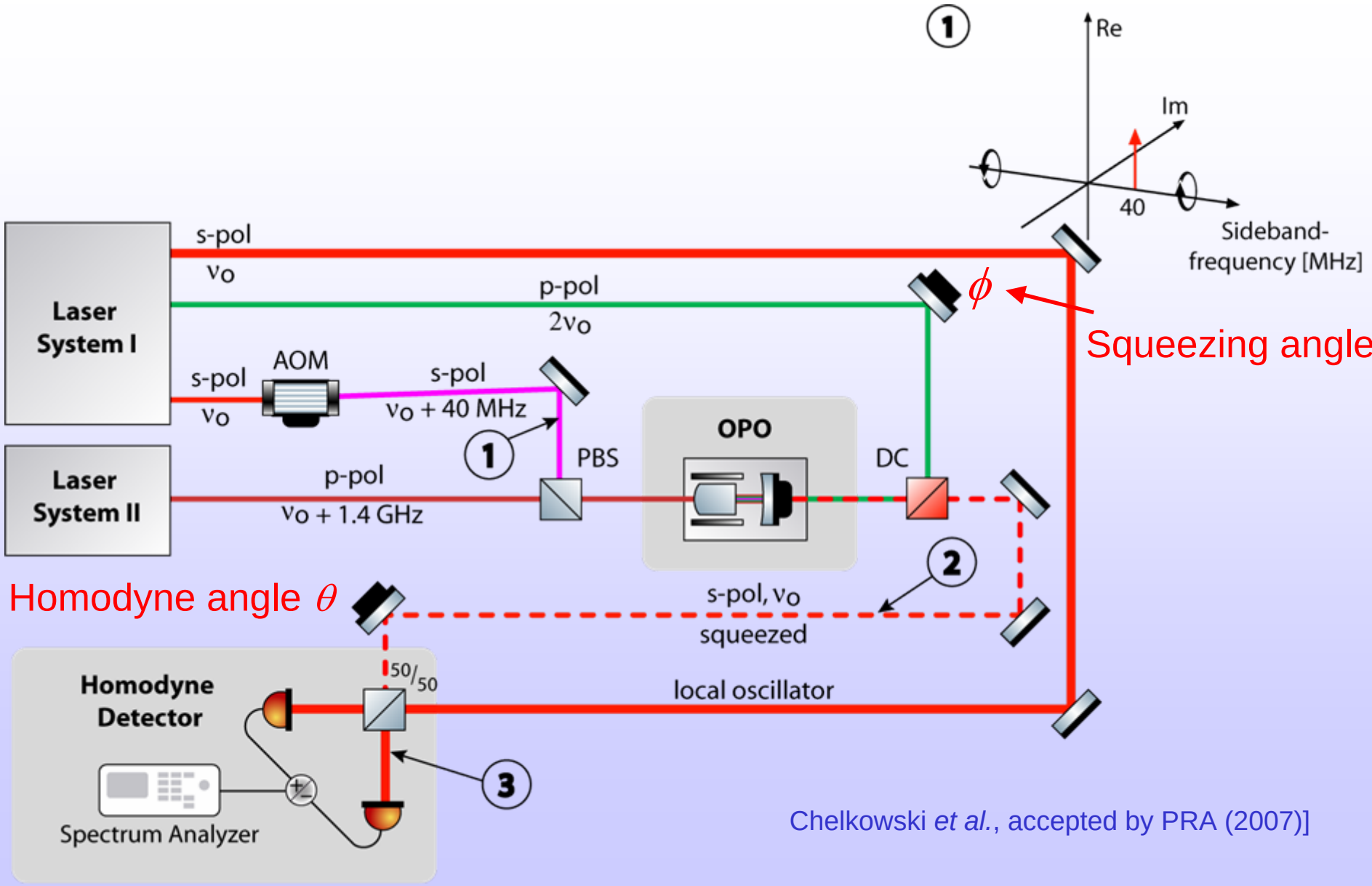


Setup for low frequency squeezing



Chelkowski *et al.*, accepted by PRA (2007)]

Setup for low frequency squeezing

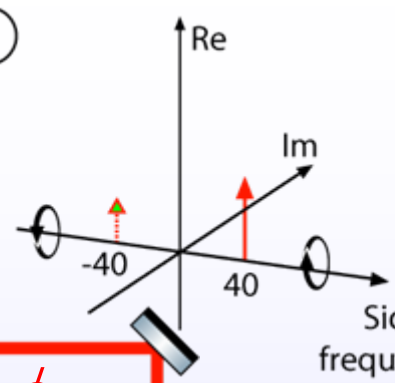


Chelkowski *et al.*, accepted by PRA (2007)]

Setup for low frequency squeezing

$$E^{QCF}(t) \propto \frac{1+g}{\sqrt{2}g}\alpha_\Omega \cos(\omega_0 t + \Omega t) - \frac{1-g}{\sqrt{2}g}\alpha_\Omega \cos(\omega_0 t - \Omega t - 2\phi)$$

$$S_{Err}^{QCF/P} \propto \frac{(-1+g^2)\alpha^2 \sin(2\phi)}{4g}$$



Laser System I

Laser System II

s-pol
ν_0

p-pol
$2\nu_0$

ϕ

Squeezing angle

AOM

s-pol
ν_0

s-pol
$\nu_0 + 40$ MHz

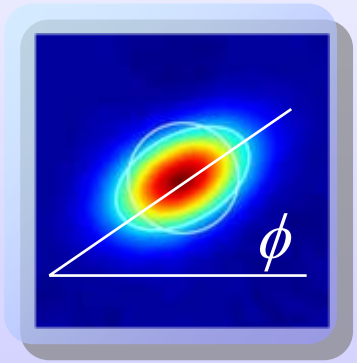
1

PBS

OPO

DC

p-pol
$\nu_0 + 1.4$ GHz



Homodyne angle θ

2

s-pol, ν_0
squeezed

local oscillator

Homodyne Detector

50/50

3

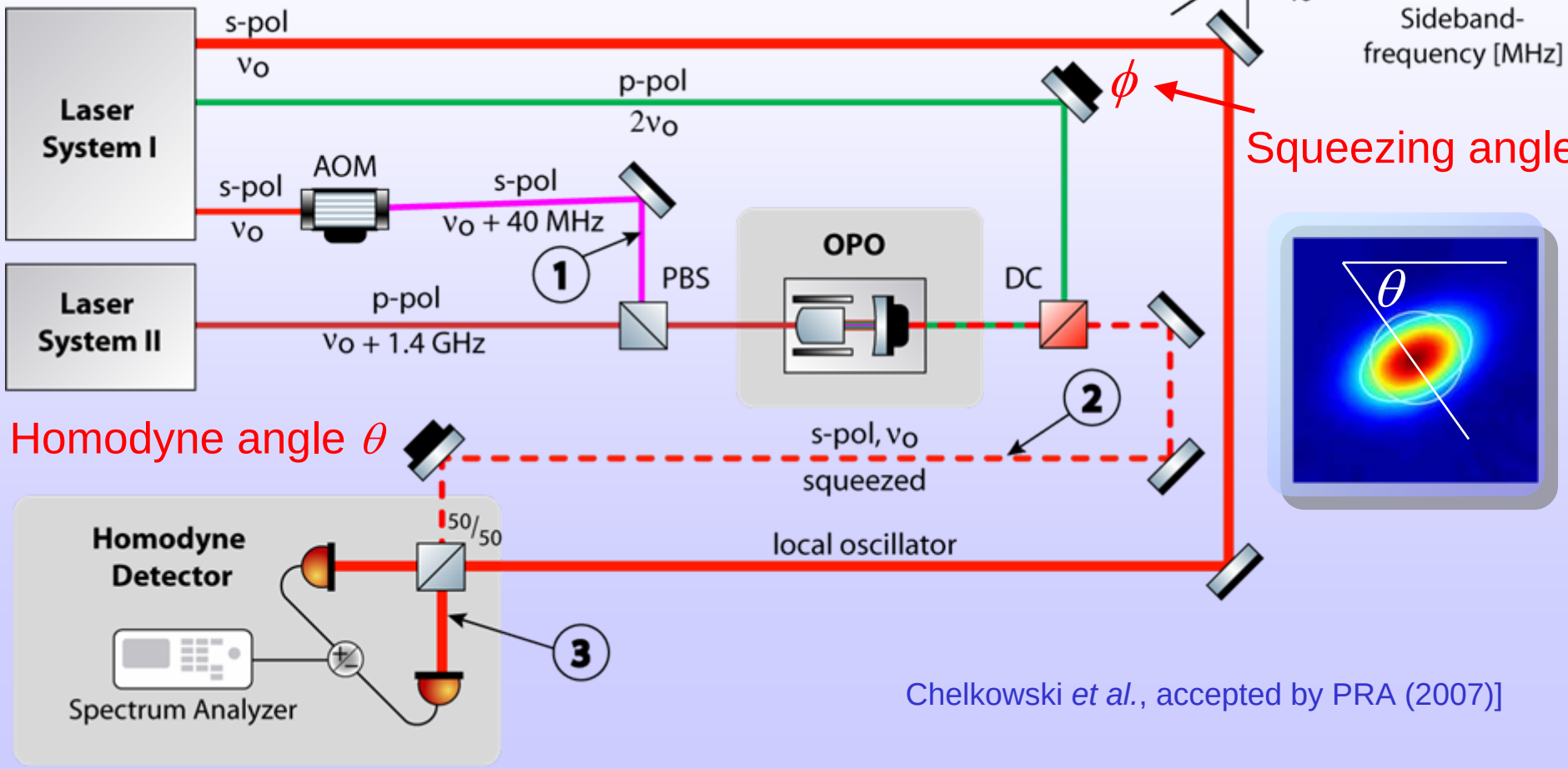
Spectrum Analyzer

Chelkowski *et al.*, accepted by PRA (2007)]

Setup for low frequency squeezing

$$E^{HD1} \propto \frac{1}{\sqrt{2}}\left(\alpha_{LO}e^{-i(\omega_0 t+\theta)} + \left[\frac{1+g}{\sqrt{2g}}\alpha_\Omega \cos(\omega_0 t+\Omega t) - \frac{1-g}{\sqrt{2g}}\alpha_\Omega \cos(\omega_0 t-\Omega t-2\phi)\right]\right)+\text{c.c.}$$

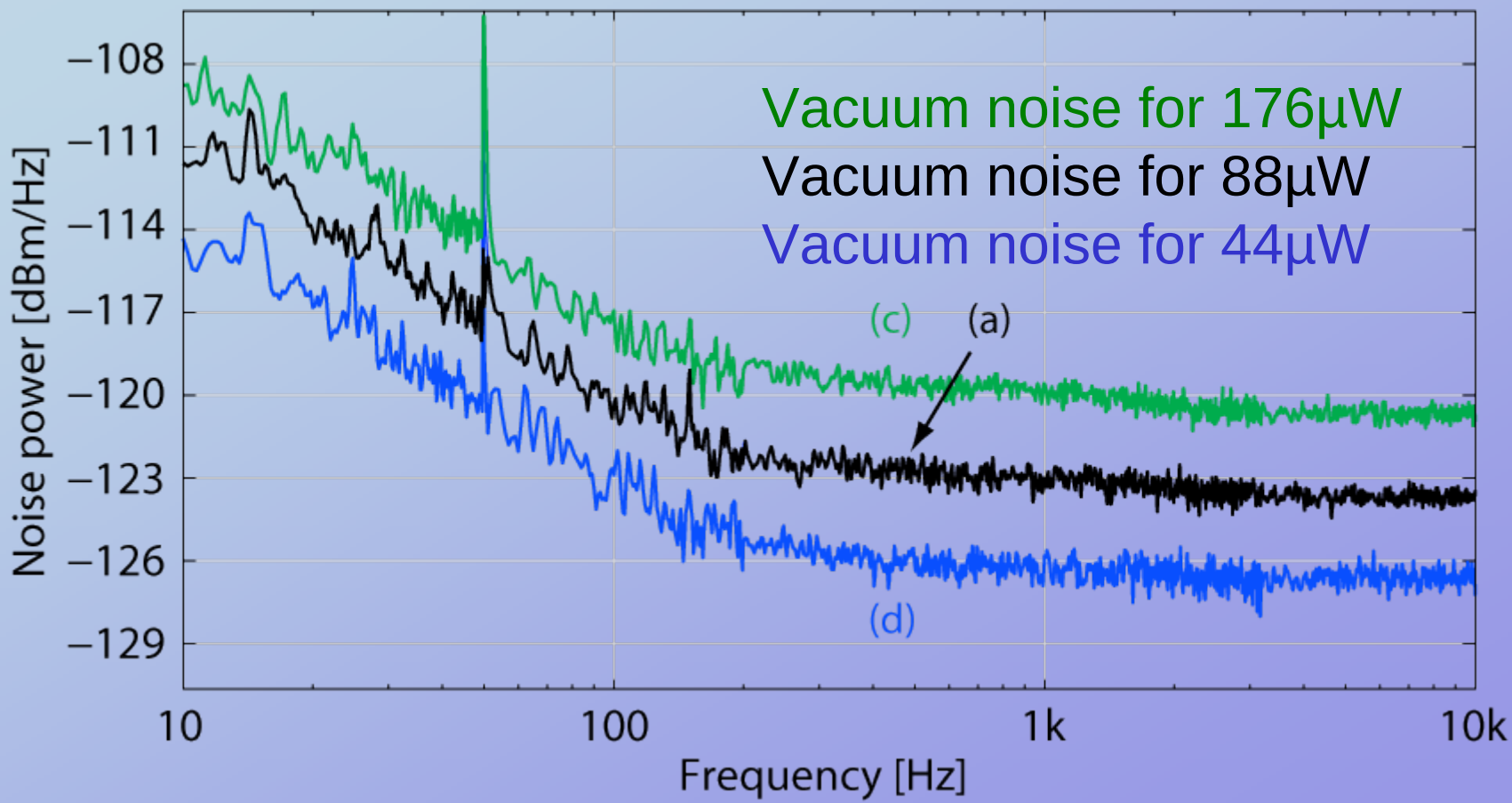
$$S_{Err}^{QCF/LO} \propto \frac{\sqrt{2}\alpha_{LO}\alpha_\Omega(-1+g)}{\sqrt{g}}\sin(2\phi+\theta)$$



Chelkowski *et al.*, accepted by PRA (2007)]

First low freqeuency squeezing results

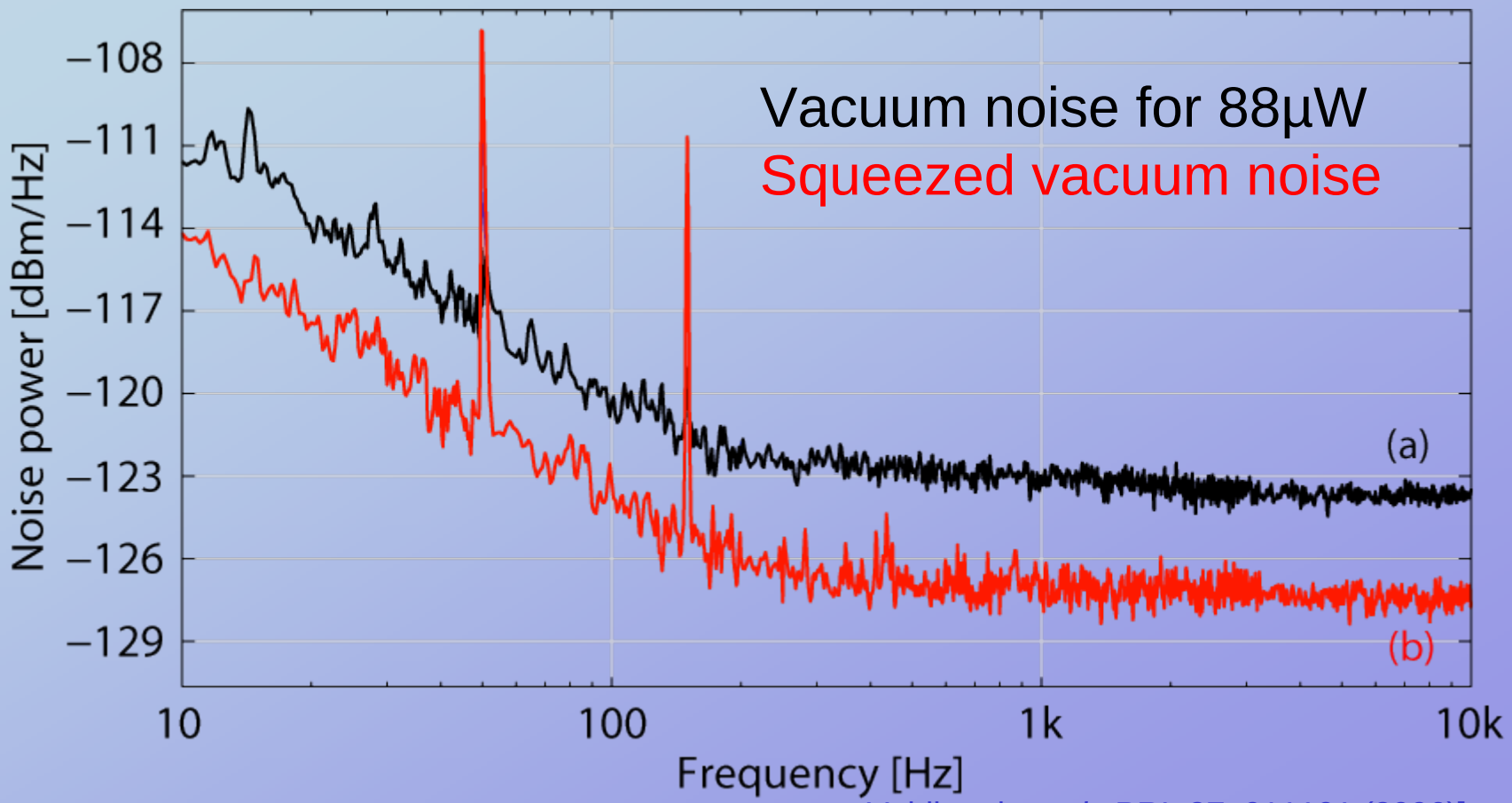
Measured vacuum noise



Vahlbruch *et al.*, PRL **97**, 011101 (2006)]

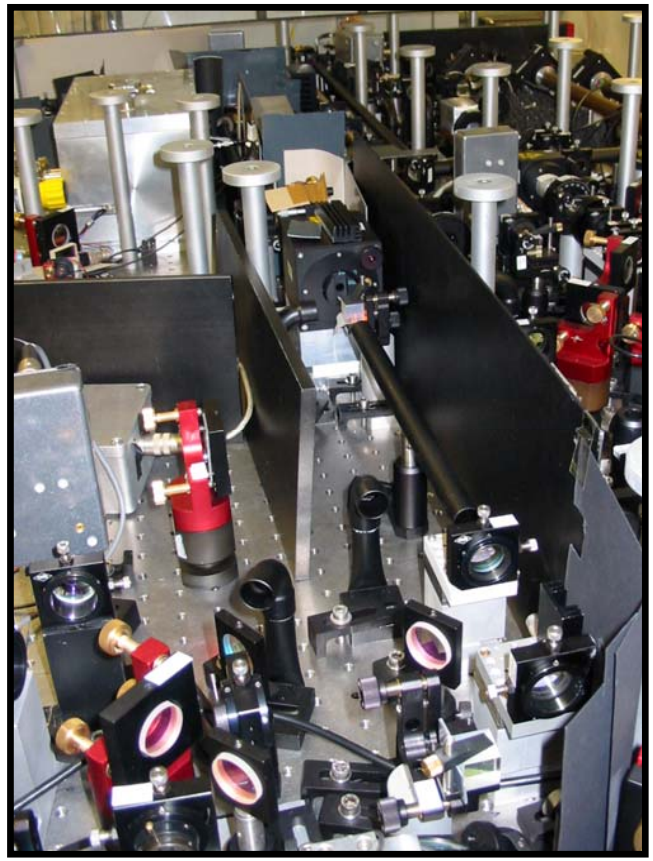
First low freqeuency squeezing results

Measured squeezed vacuum noise

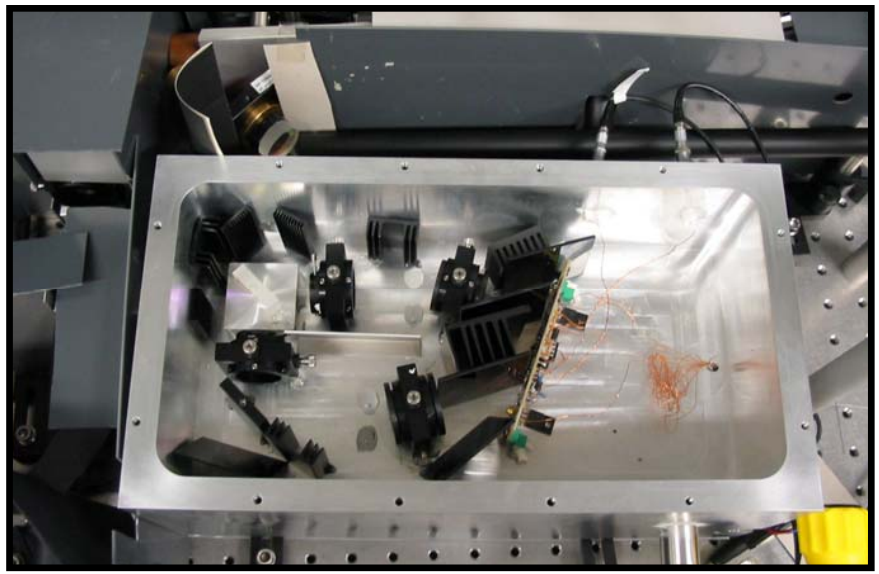


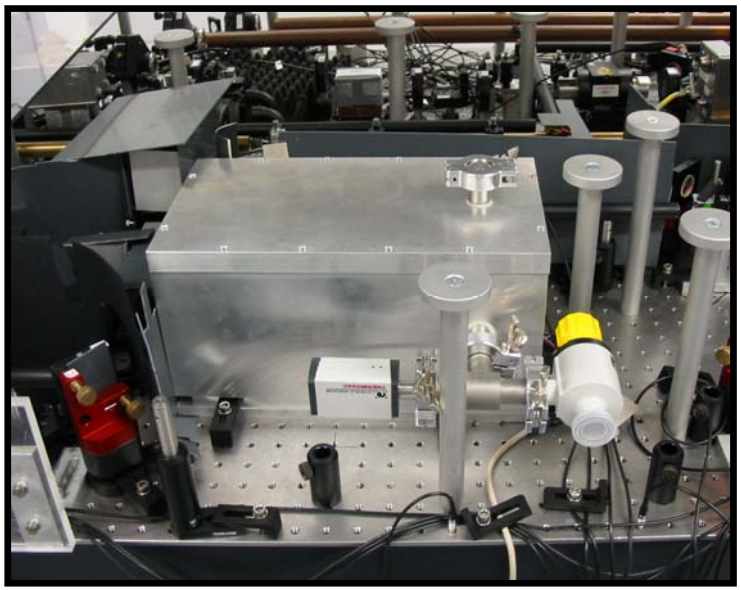
Vahlbruch *et al.*, PRL **97**, 011101 (2006)]

Enhancements of the setup



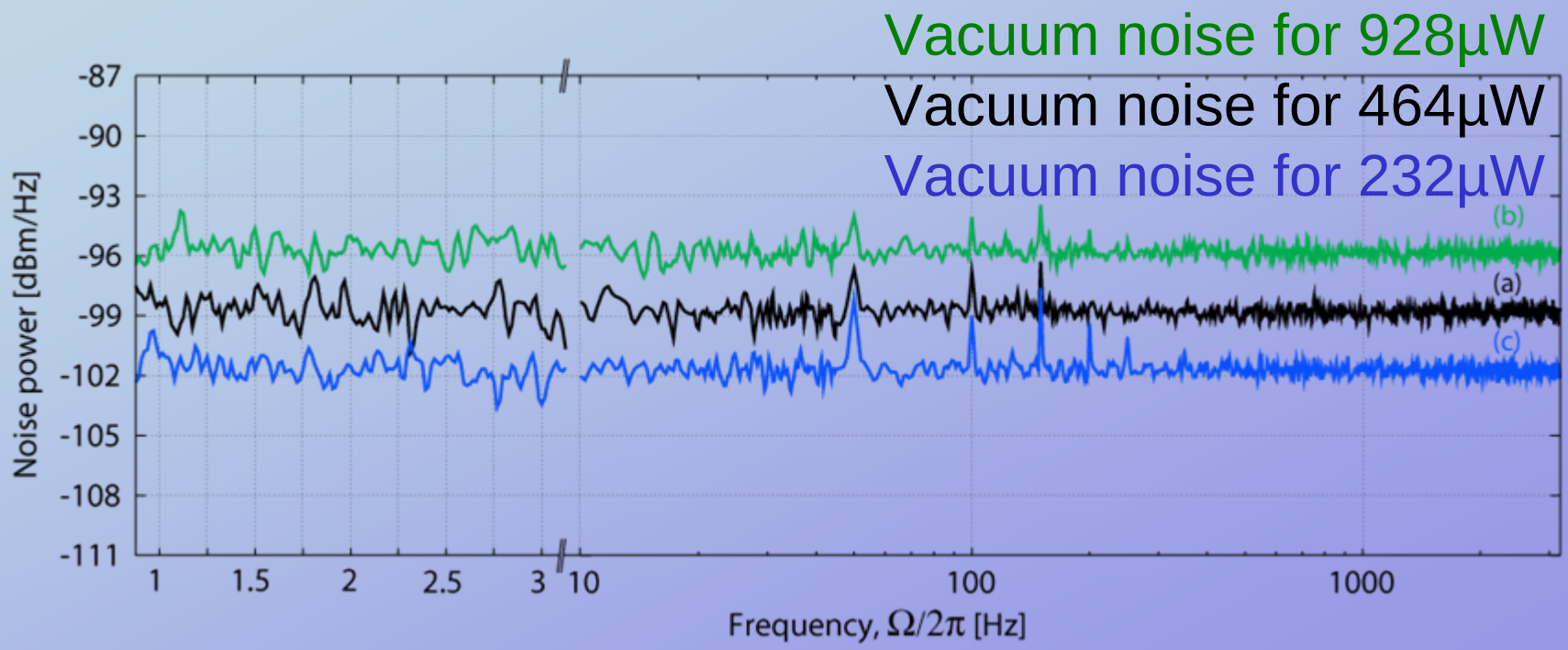
Enhancements of the setup





Latest low freqeuency squeezing results

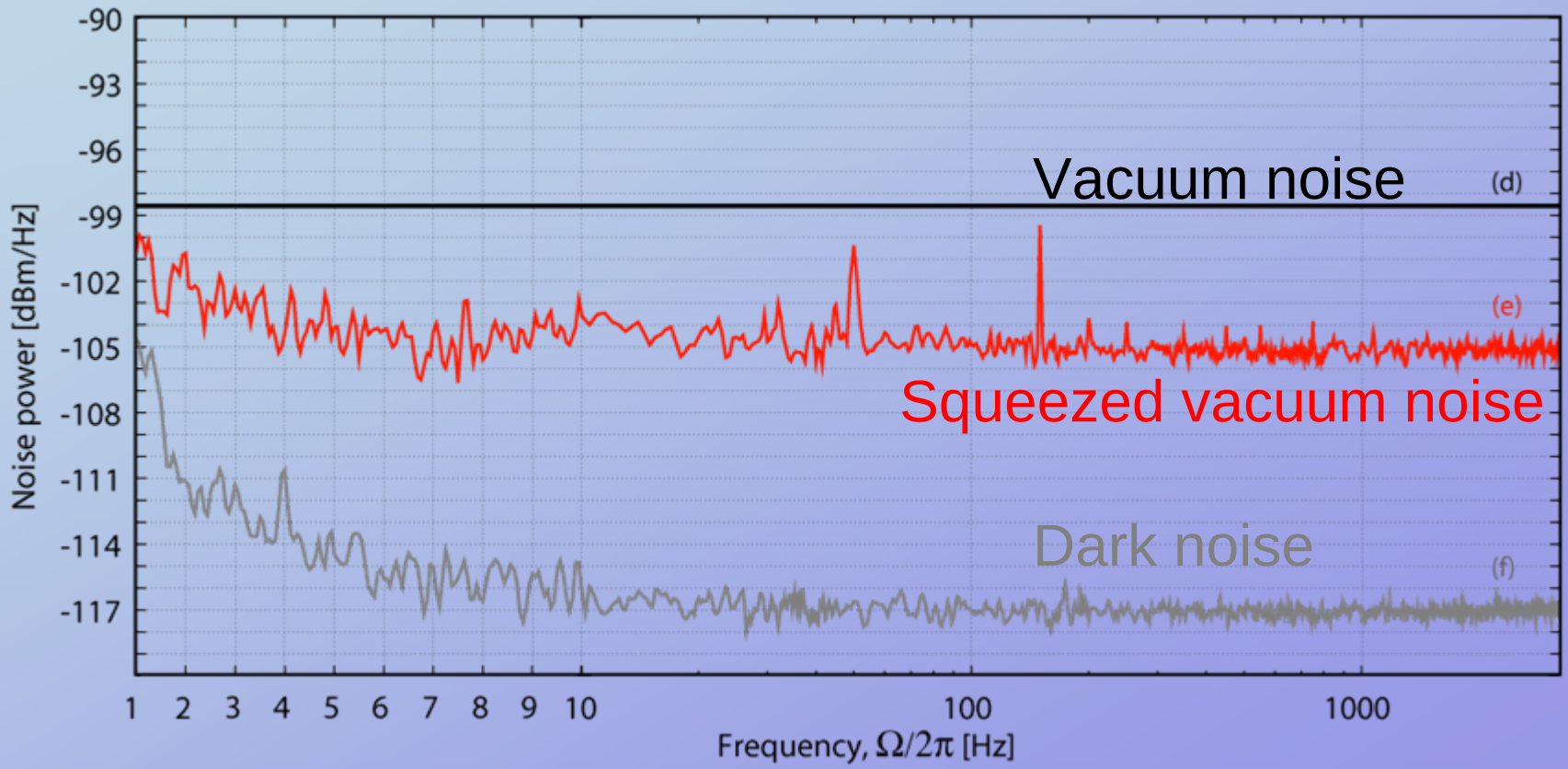
Measured vacuum noise



To be published

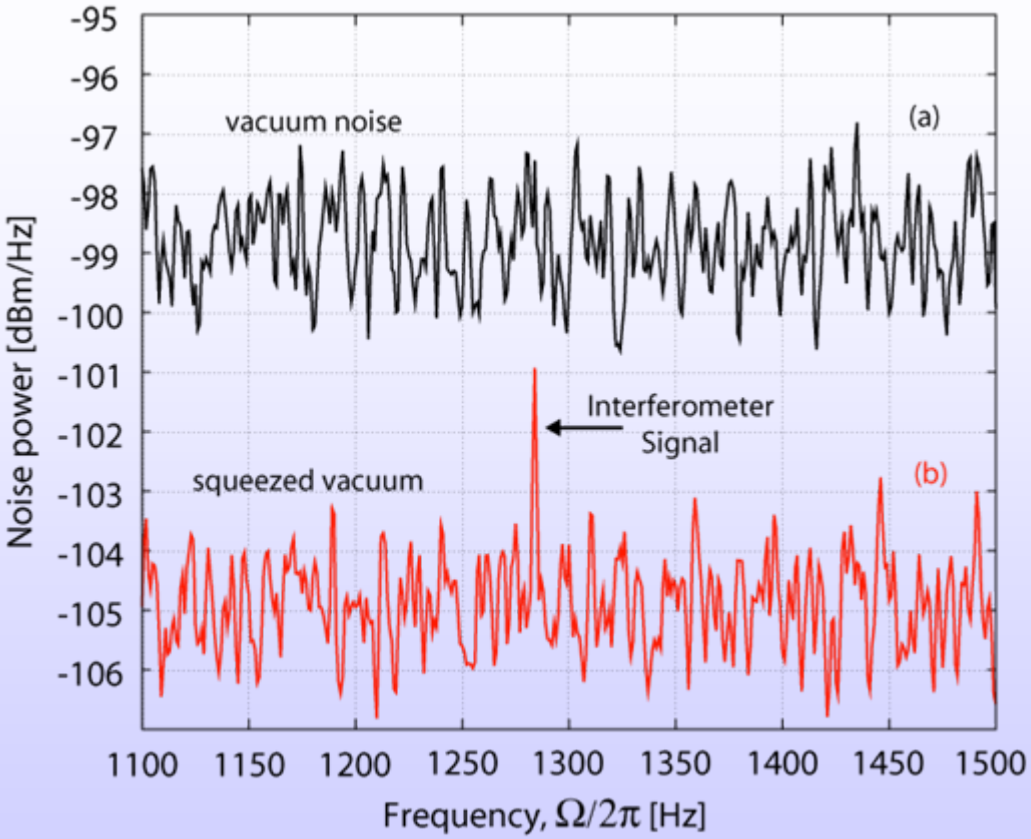
Latest low freqeuency squeezing results

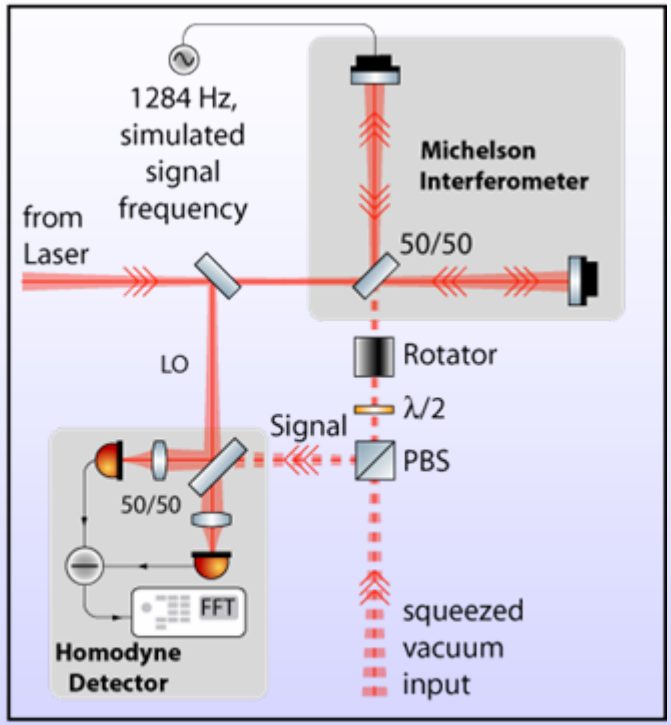
Measured vacuum noise



To be published

Squeezed vacuum enhanced Michelson Ifo





Conclusion

- We understand the quantum behaviour of Interferometers
- Low frequency squeezed vacuum can be stably generated
- More than 6dB of squeezing available
- Frequency dependent light eventually not needed for GEO600


The
end