Squeezed Light for Gravitational Wave Interferometers

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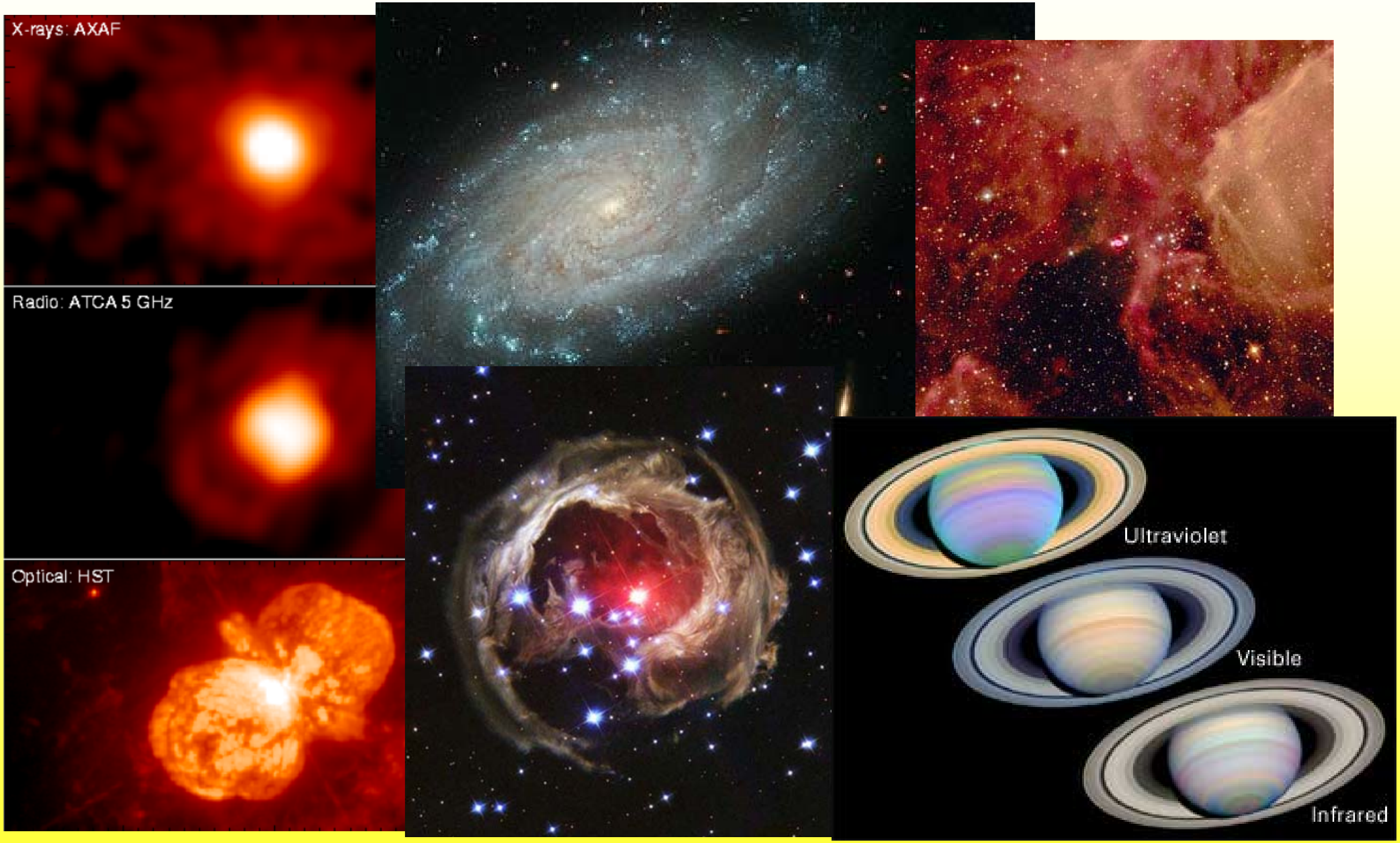
Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut),

Light : Our Picture of the Universe

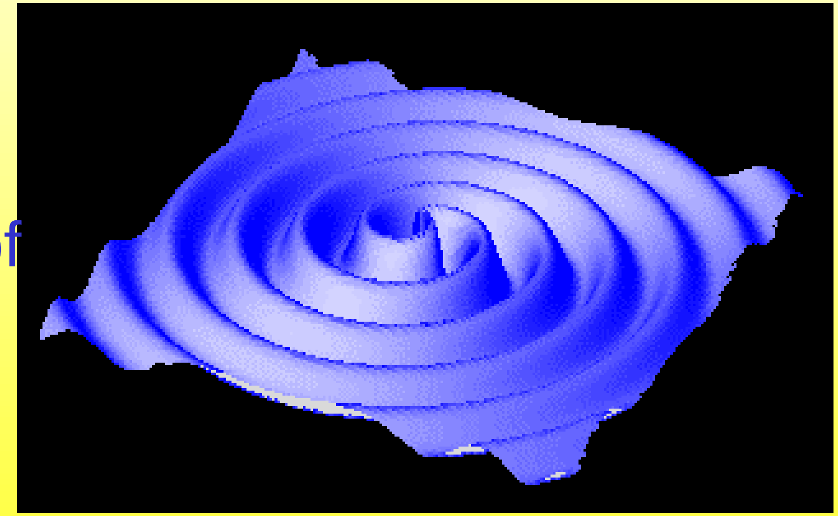


By detecting gravitational waves we do not look at the universe but we listen to it.

What are gravitational Waves ?

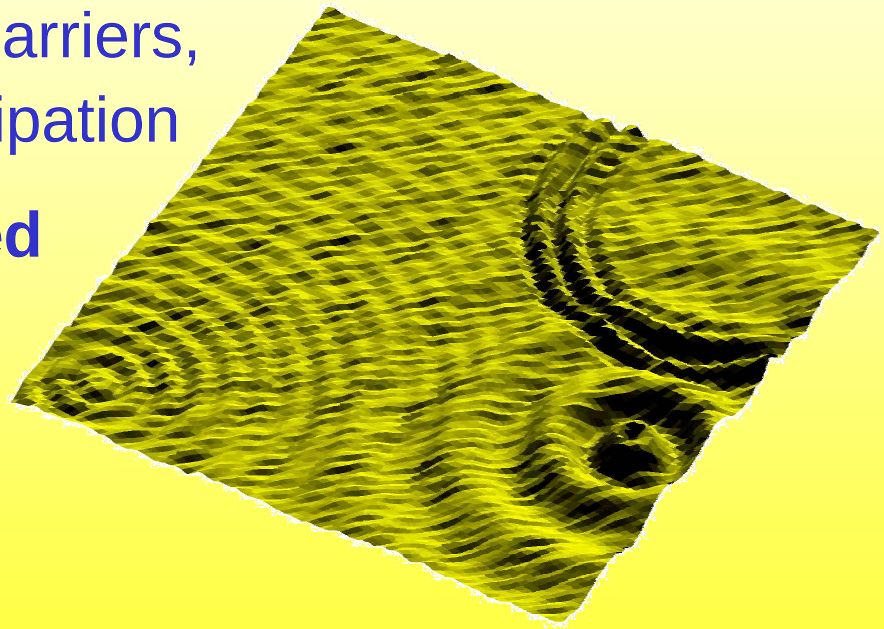
By detecting gravitational waves we do not look at the universe but we listen to it.

Gravitational Waves are distorsions of space and time which propagate with speed of light and are caused by accelerated masses



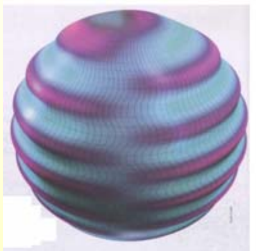
Gravitational Waves

- GWs are the dynamical part of gravitation
- They carry hugh energies but hardly interact with anything
- They are ideal information carriers, almost no scattering or dissipation
- **The whole universe is filled with GWs and has been transparent for them shortly after the big bang**

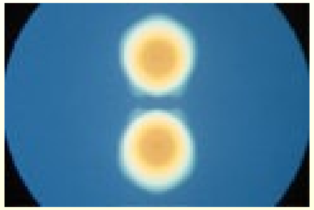


Sources of Gravitational Waves

Supernovae

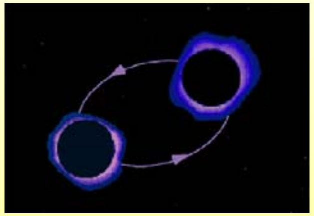


Big Bang
Inflation



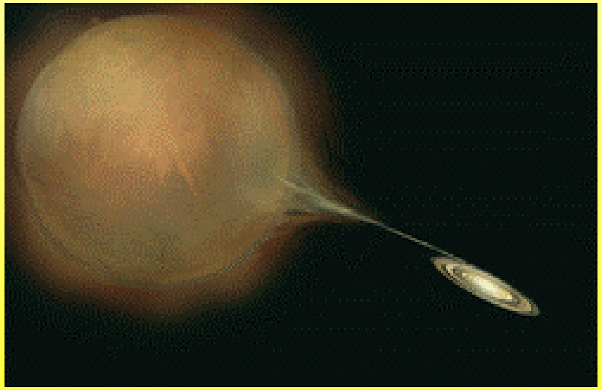
NS

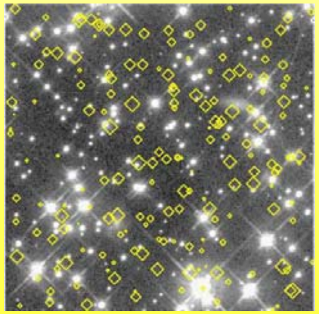
Binary systems



BH

Accreting neutron stars

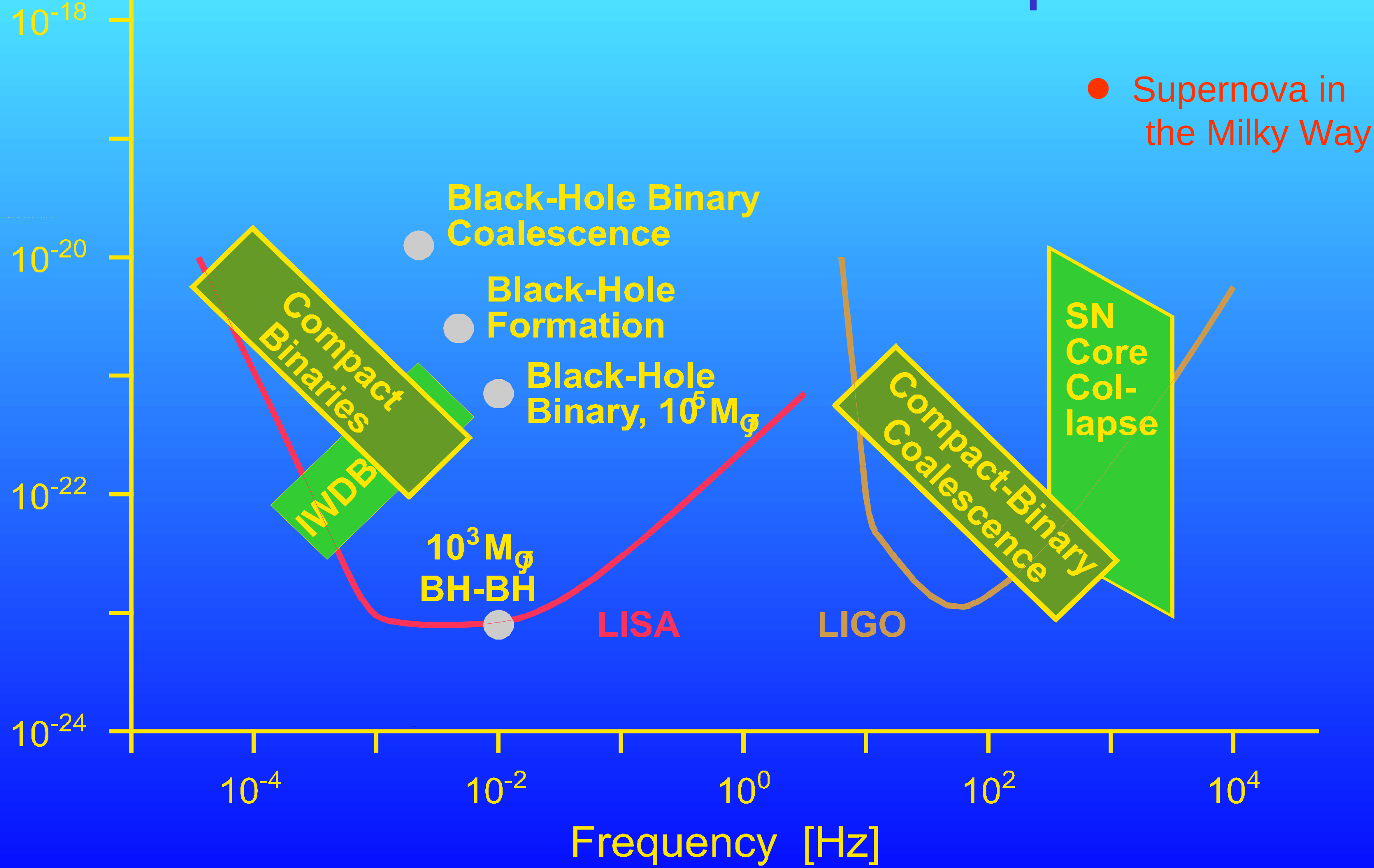




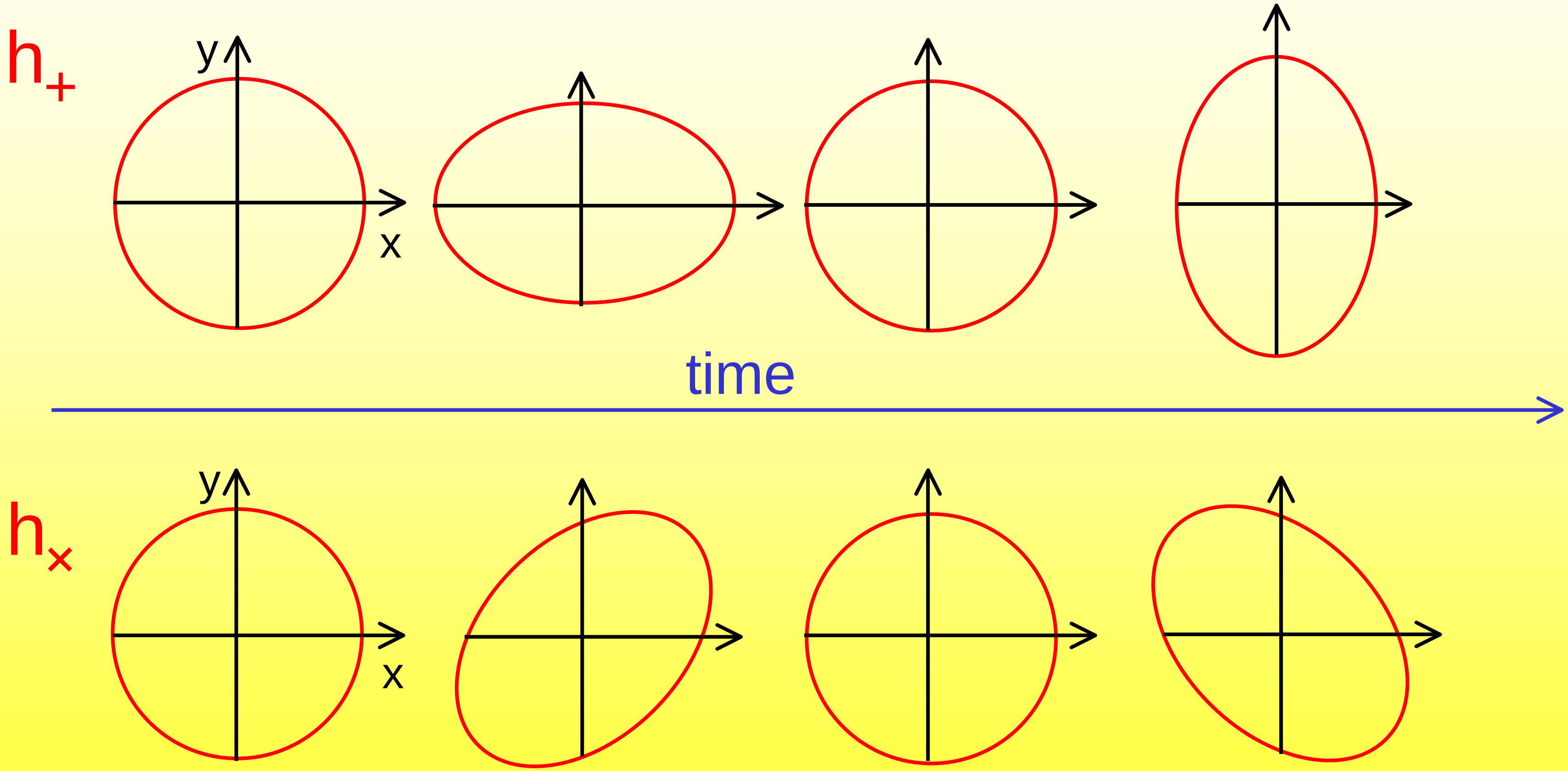
Dark matter ?

Colliding supermassive Black Holes in Galaxies

The Gravitational Wave Spectrum

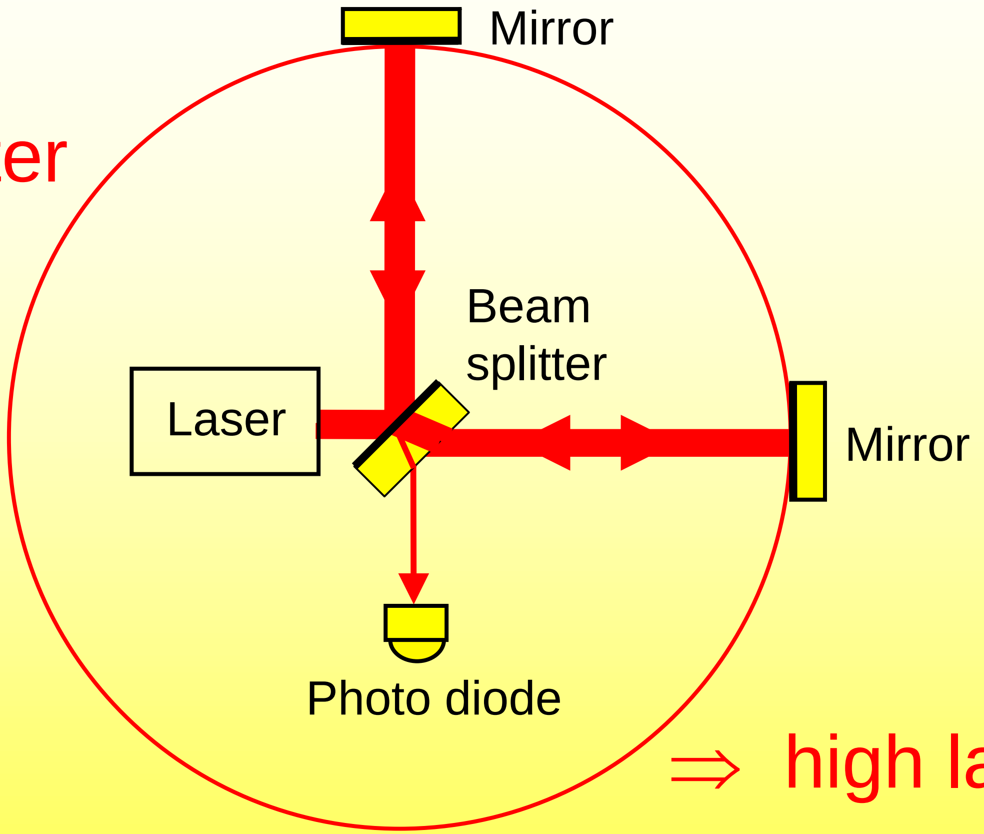


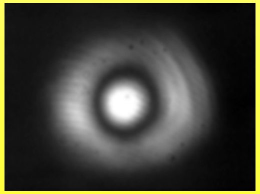
Gravitational Waves



Gravitational Wave Interferometers

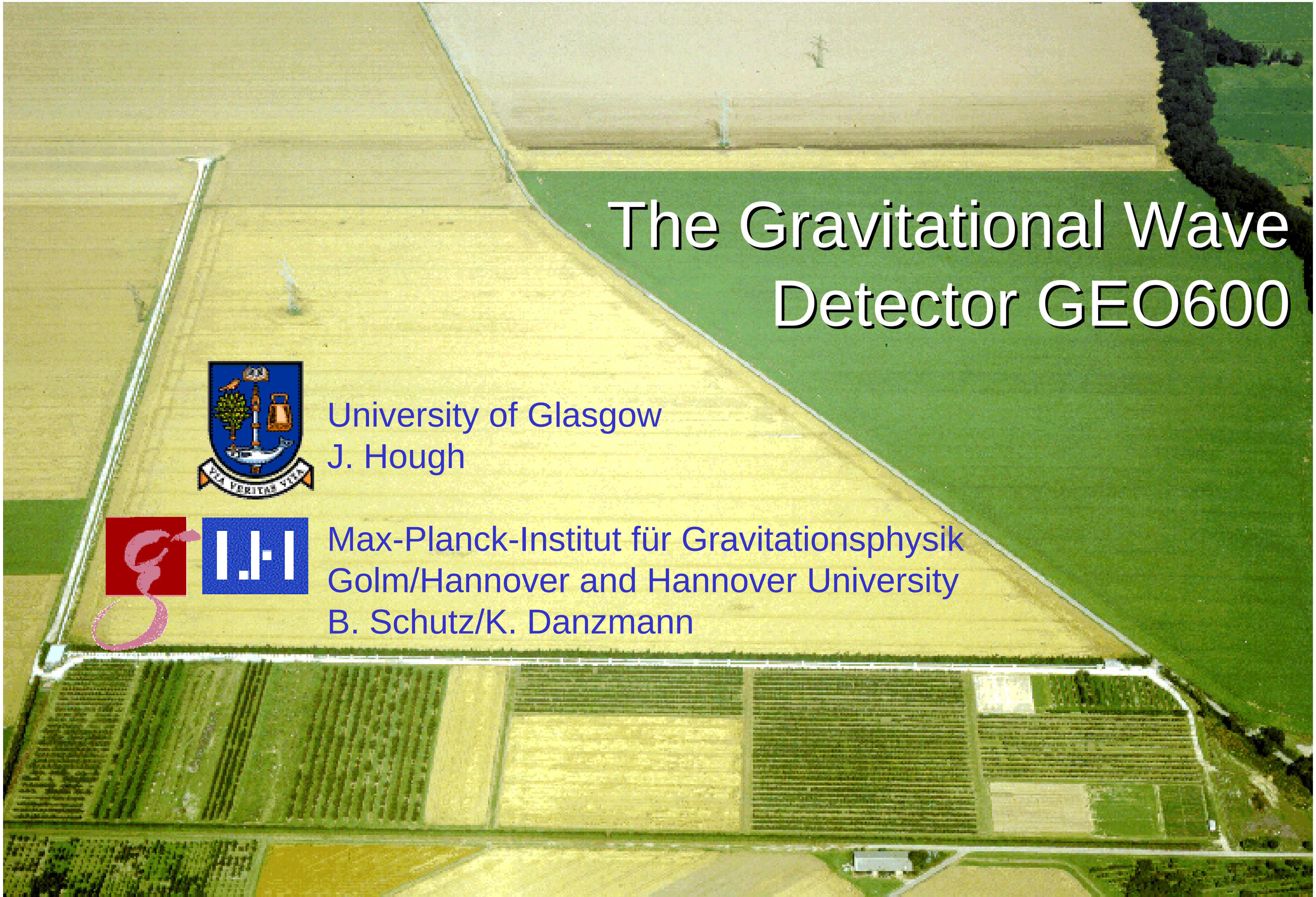
Michelson Interferometer





⇒ high laser power

⇒ long arms

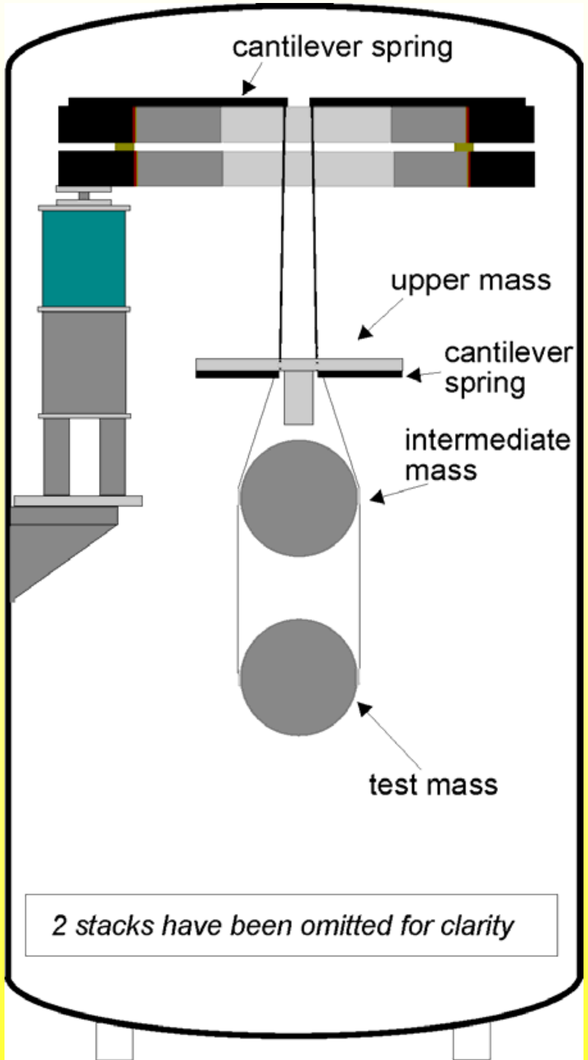


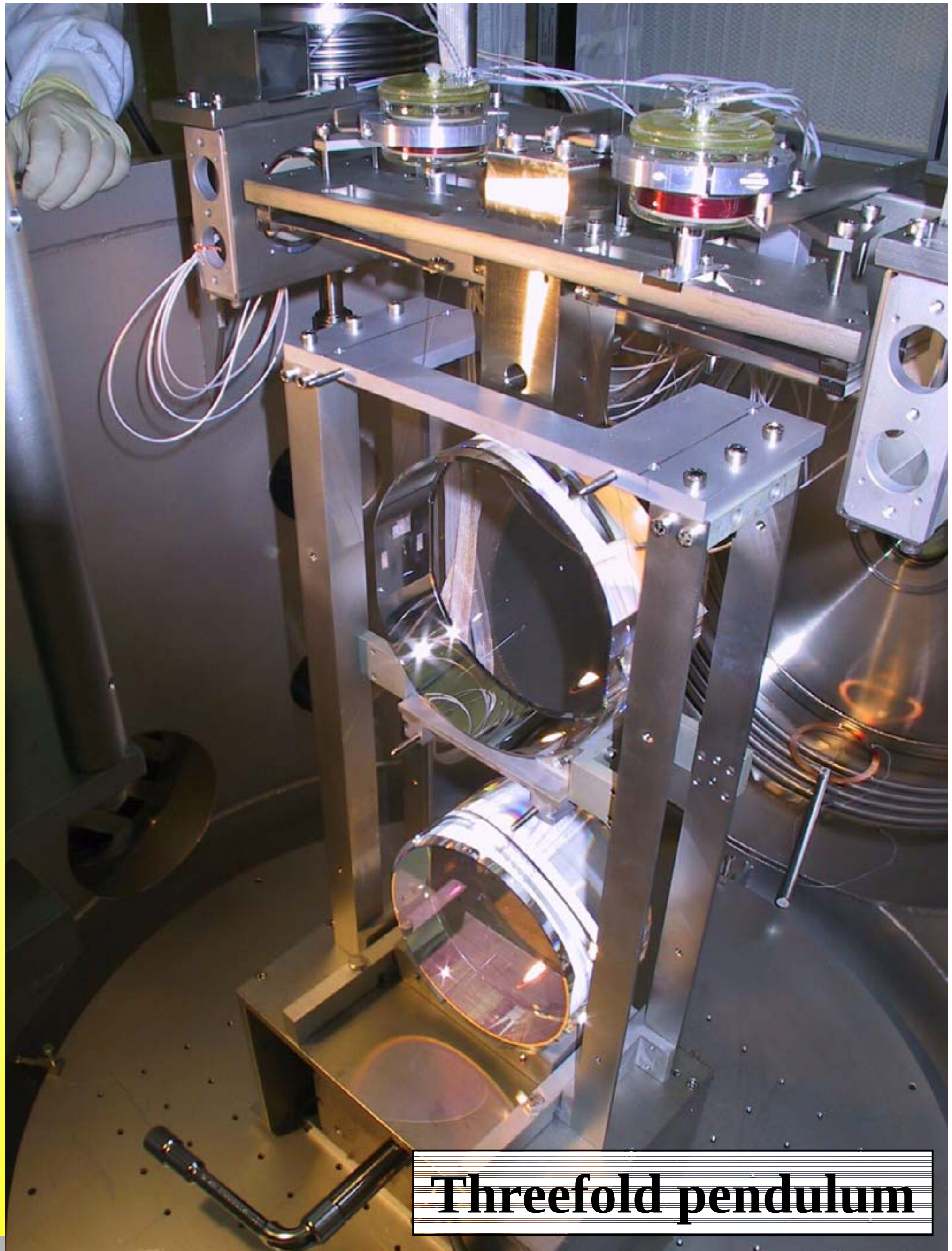
The Gravitational Wave Detector GEO600

University of Glasgow
J. Hough

Max-Planck-Institut für Gravitationsphysik
Golm/Hannover and Hannover University
B. Schutz/K. Danzmann

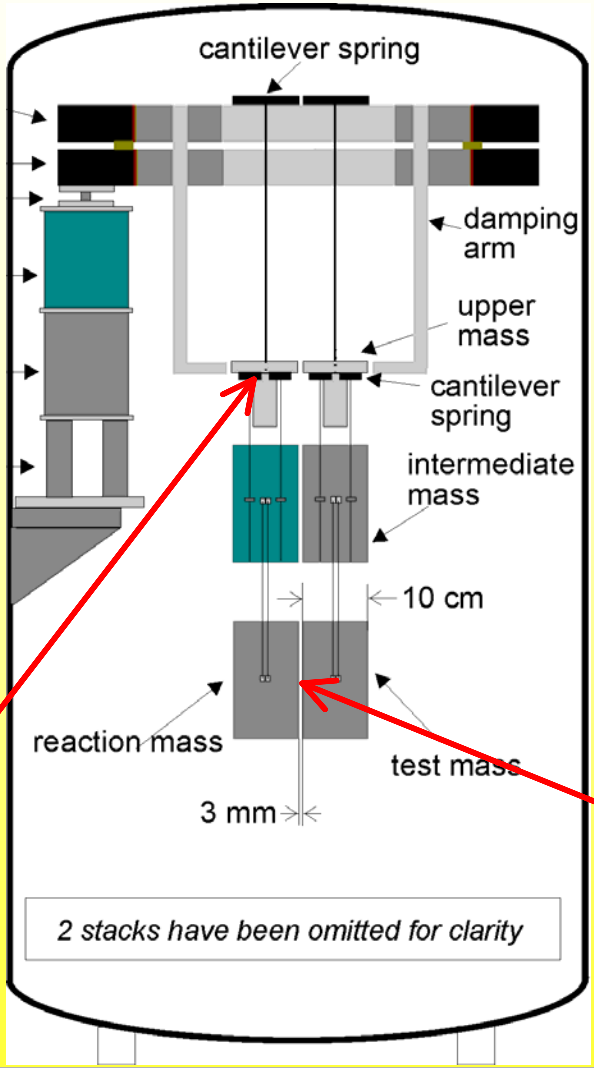
Seismic Isolation





Threefold pendulum

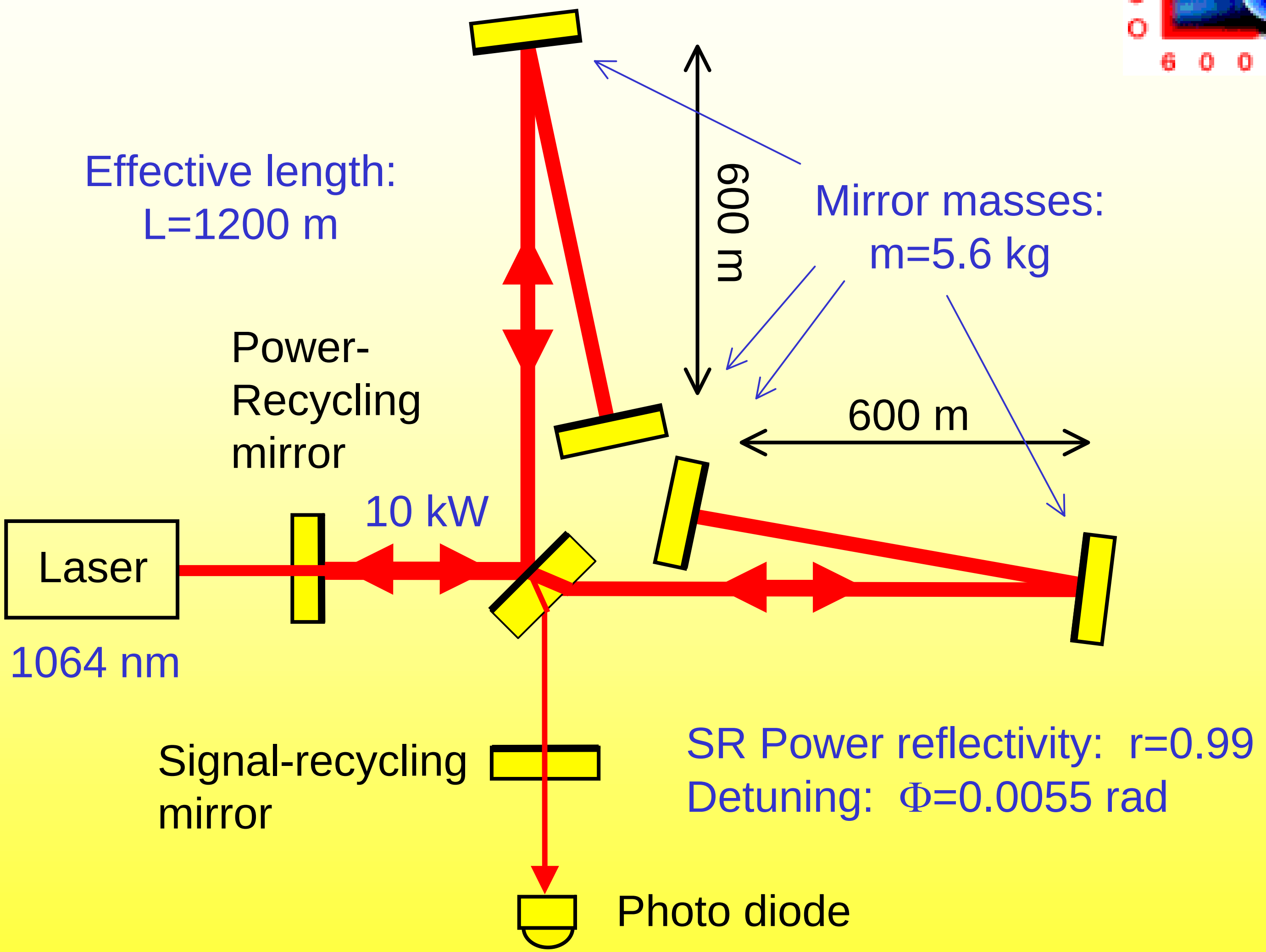
Position Control



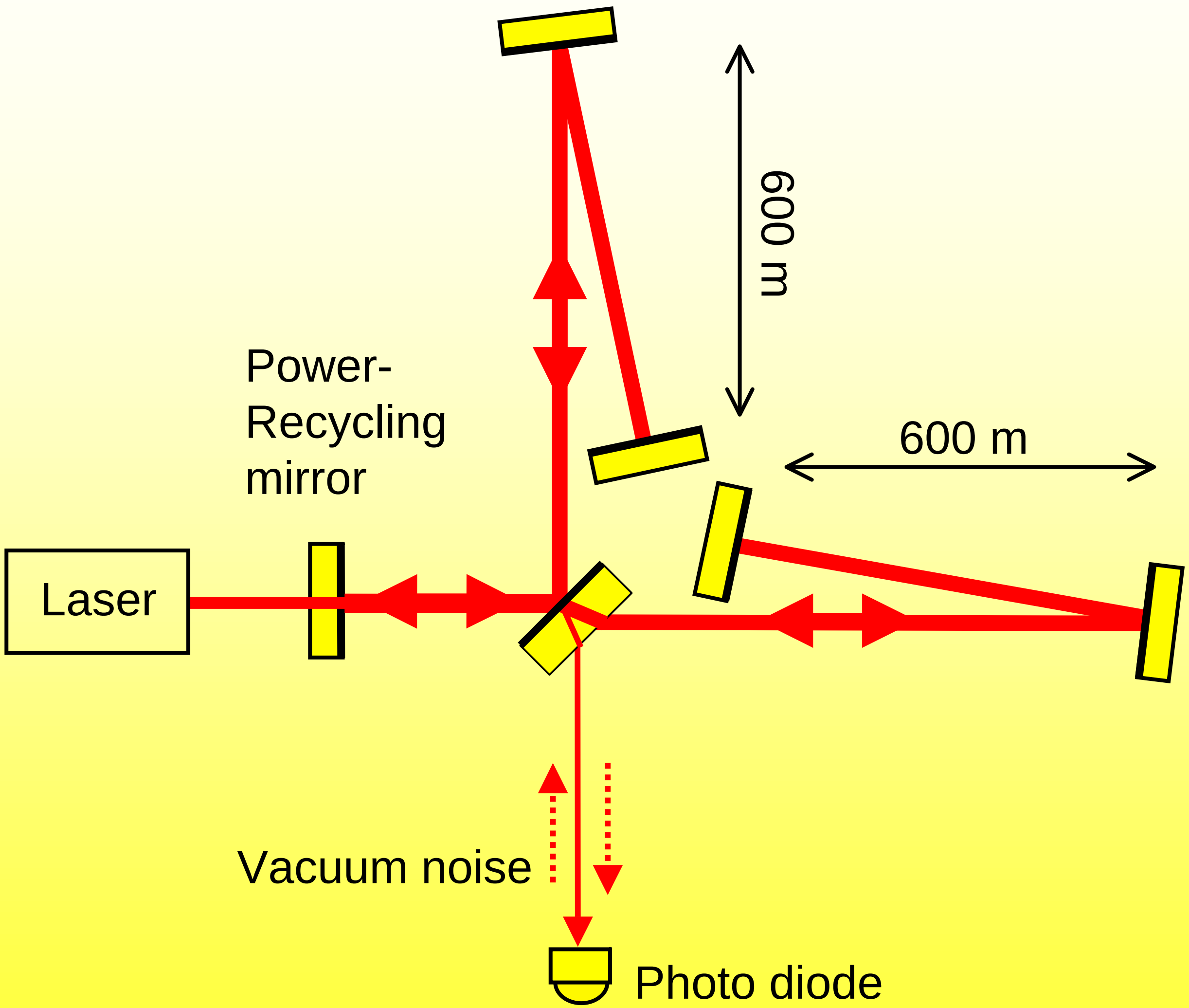
Coil magnets

Electrostatic drive

Optical Layout of GEO 600



Quantum Noise of a Conventional MI



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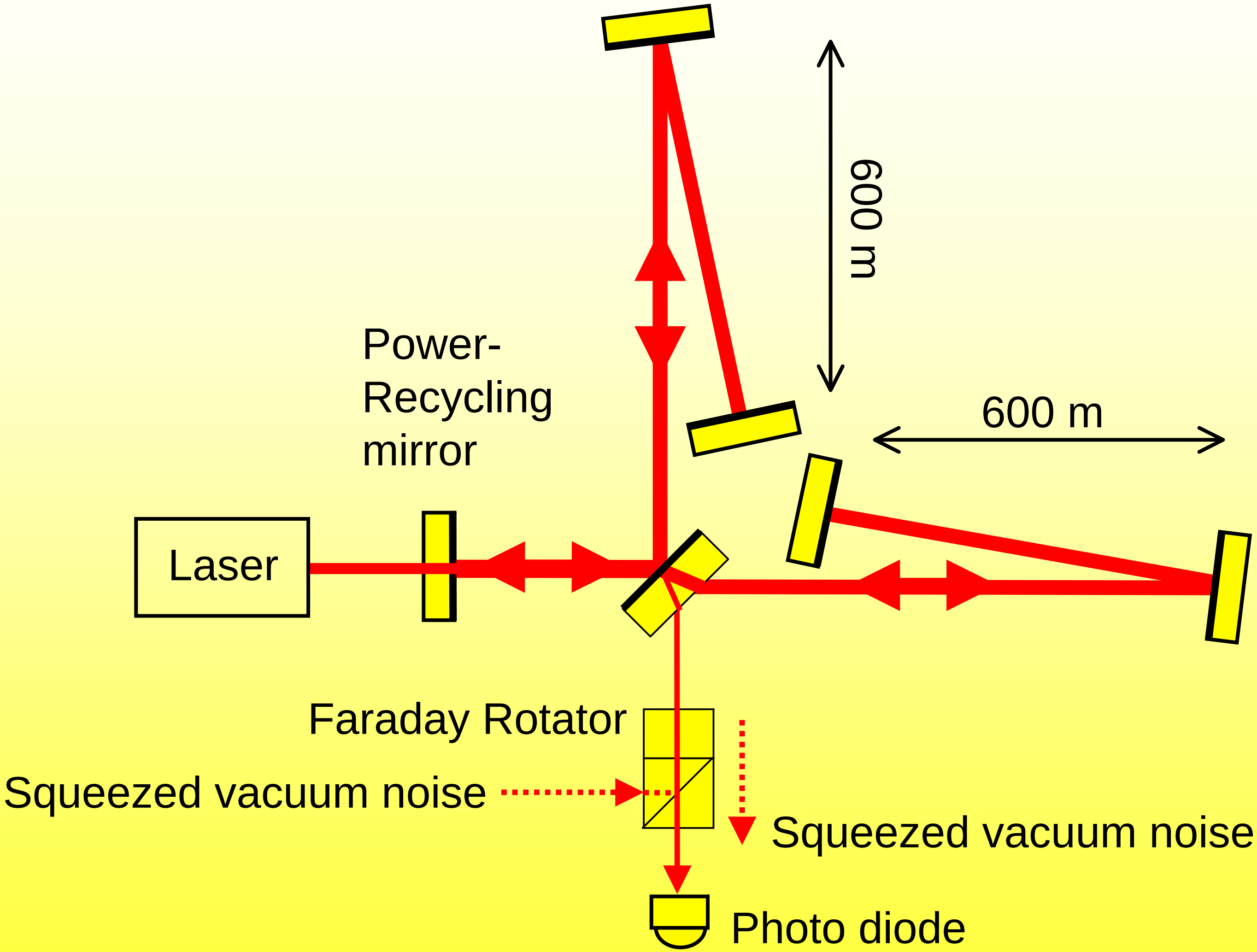

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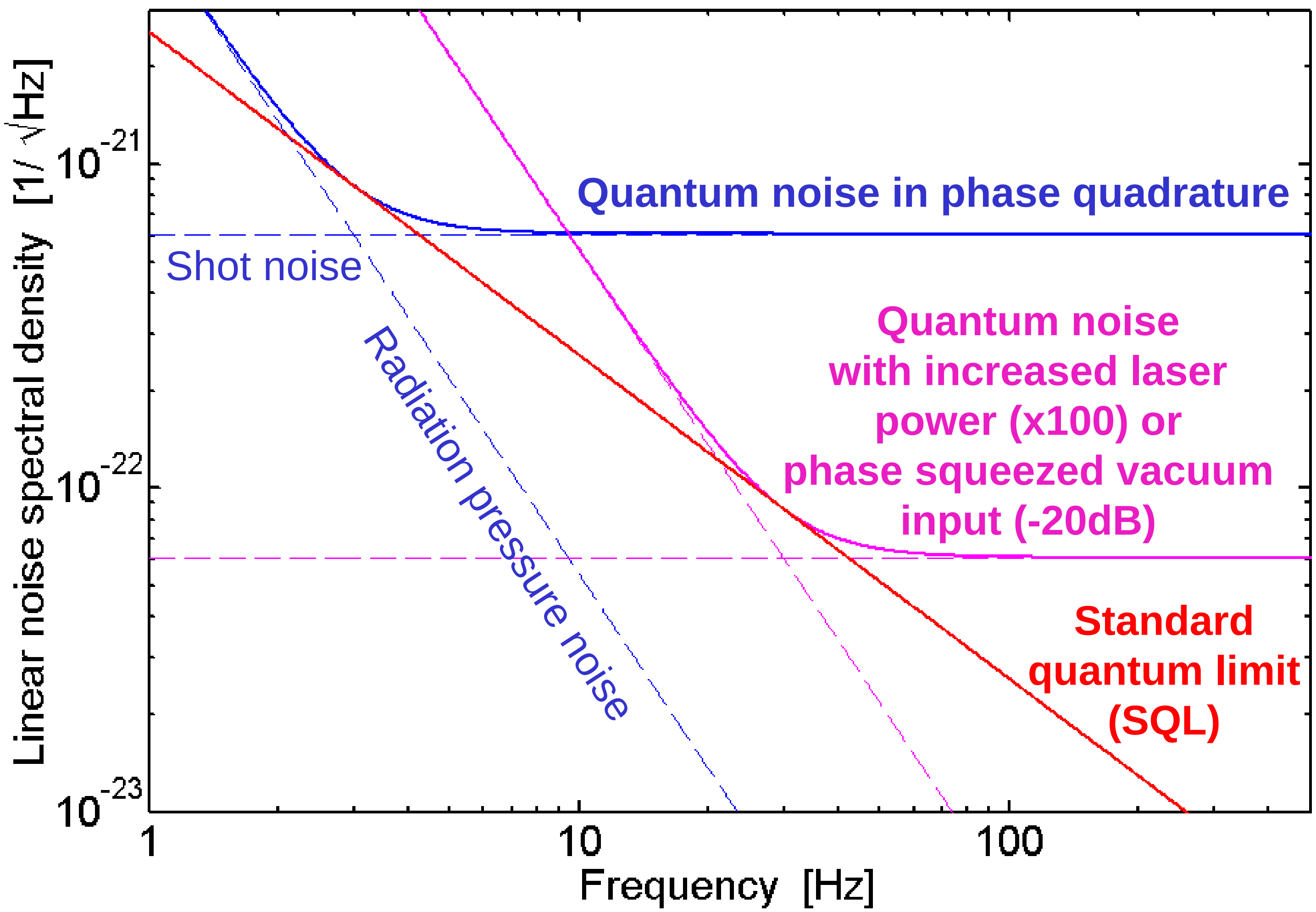
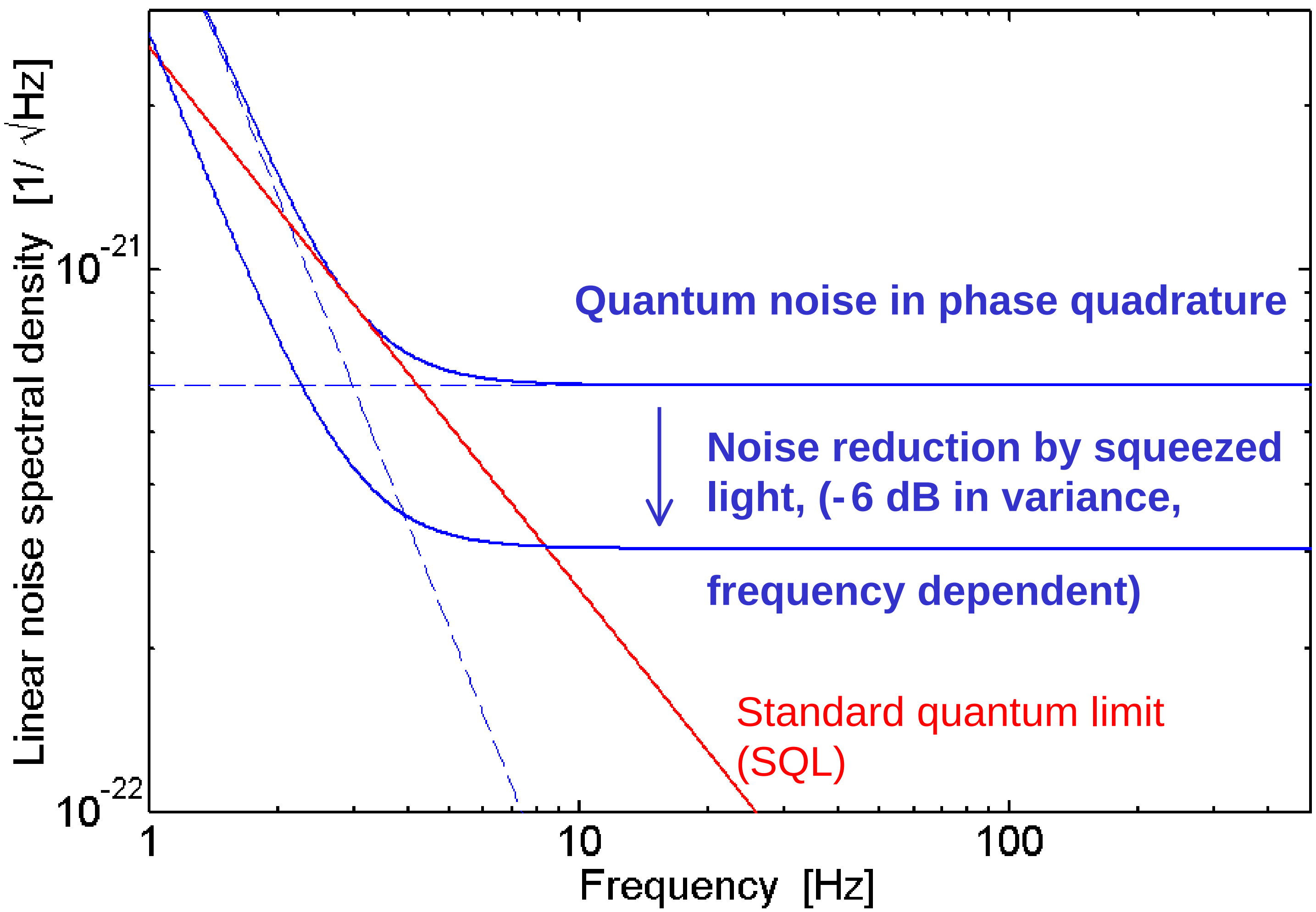
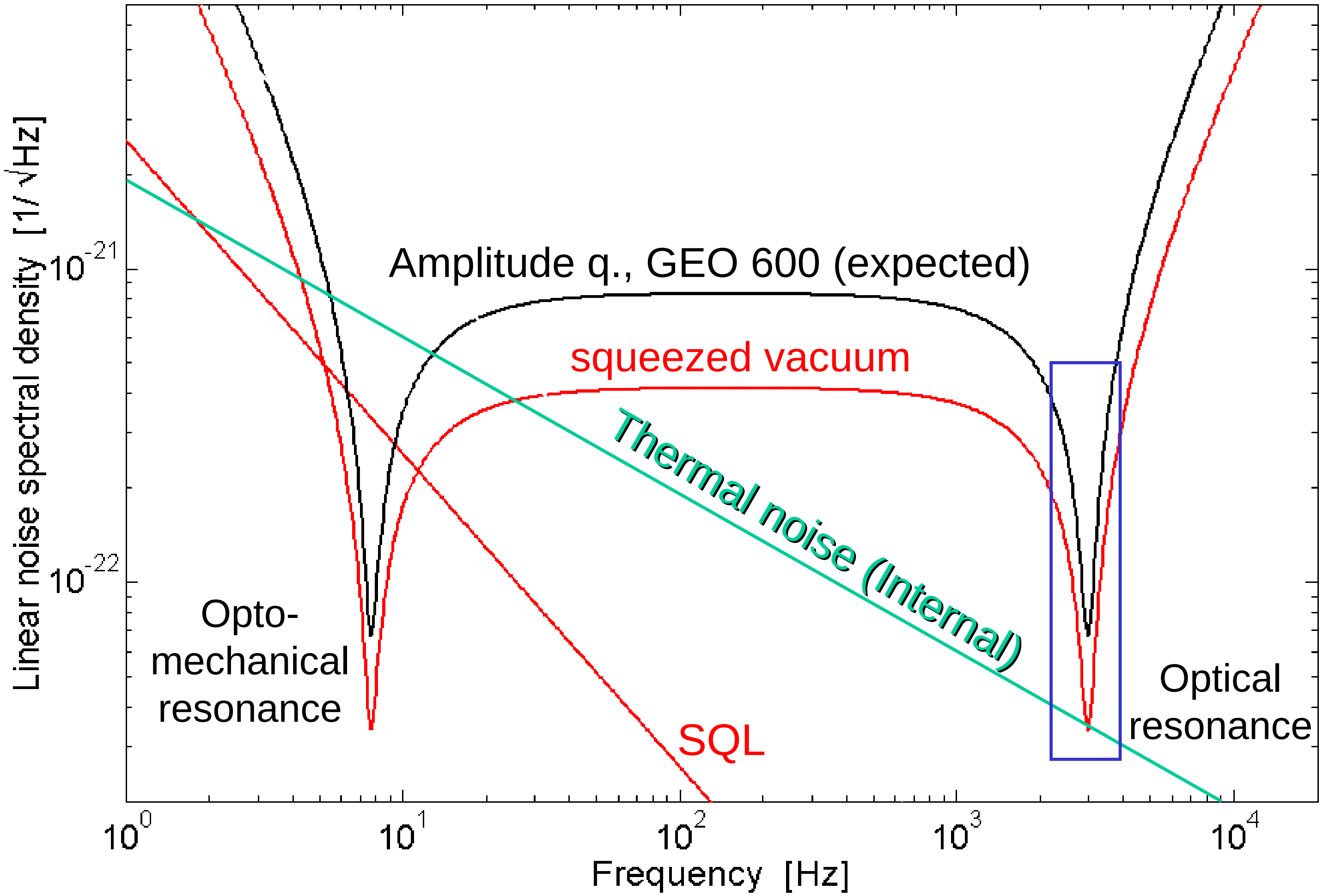


Simple MI plus Squeezed Light Input



Signal Recycled MI plus Squeezed Light Input



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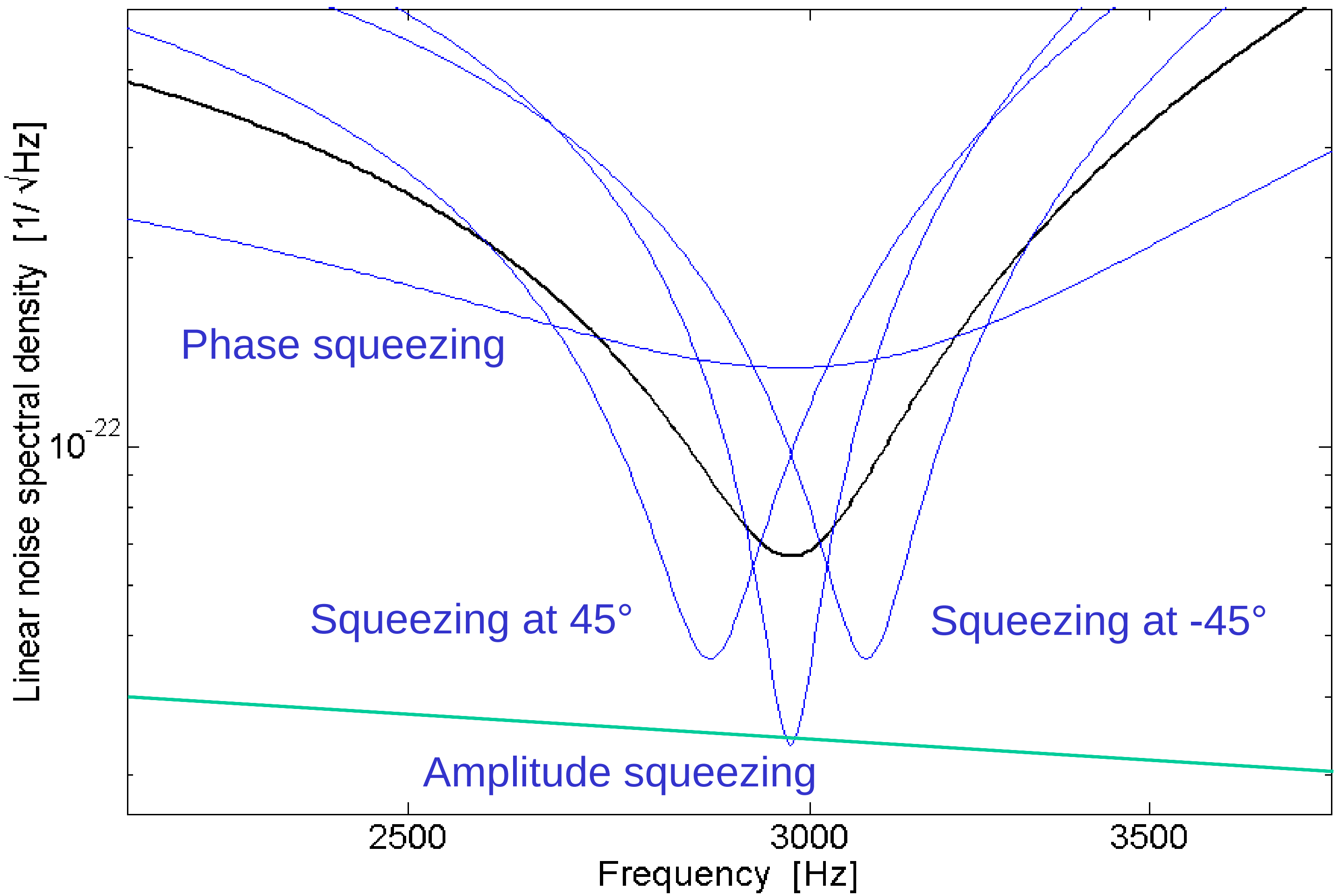

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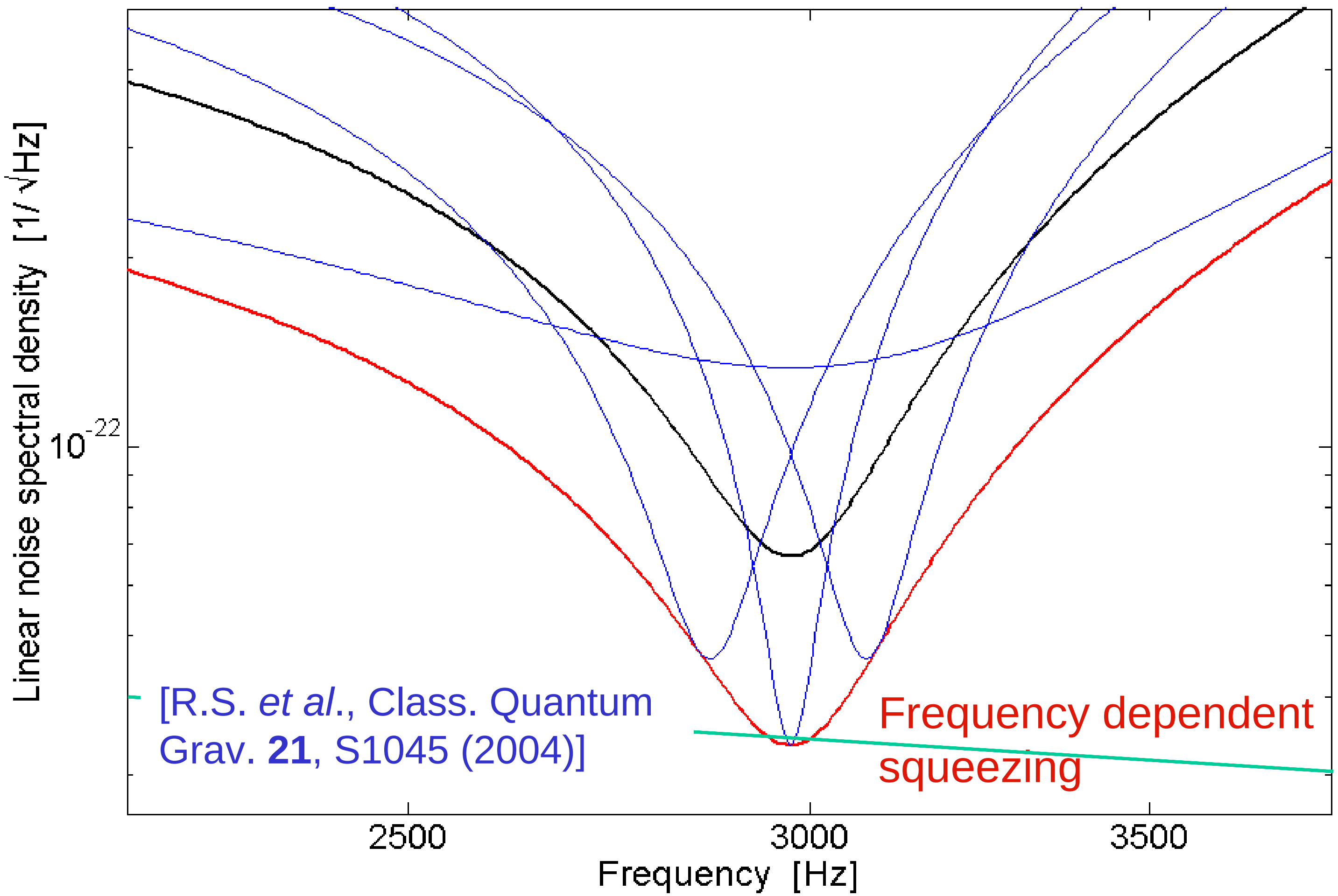


Rotation of Quadrature Amplitudes

$$\hat{a}_1 = \frac{\hat{a}(\omega_0+\Omega)+\hat{a}\ (\omega_0-\Omega)}{\sqrt{2}}$$ Amplitude quadrature

$$\hat{a}_2 = \frac{\hat{a}(\omega_0+\Omega)-\hat{a}\ (\omega_0-\Omega)}{i\sqrt{2}}$$ Phase quadrature

$$\hat{a}_\theta = \frac{\hat{a}(\omega_0+\Omega)e^{+i\theta}+\hat{a}\ (\omega_0-\Omega)e^{-i\theta}}{\sqrt{2}}$$ θ quadrature

$$\Delta^2\hat{a}_1 \cdot \Delta^2\hat{a}_2 \geq \frac{1}{4}$$

$$\hat{a}_{\theta'} = \frac{\hat{a}(\omega_0+\Omega)e^{+i\theta}+\hat{a}\ (\omega_0-\Omega)e^{-i(\theta+\Phi)}}{\sqrt{2}}$$ Angle rotated by $\Phi/2$

$$= \frac{e^{-i\Phi/2}}{\sqrt{2}}\left(\hat{a}(\omega_0+\Omega)e^{+i\theta'}+\hat{a}\ (\omega_0-\Omega)e^{-i\theta'}\right) \quad , \quad \theta' = \theta + \Phi/2$$

To lower quantum noise in GW inter-
ferometers we need

- vacuum states, squeezed at detection frequencies (1 Hz to 10 kHz)

- orientation of squeezing ellipse needs to be of specific frequency dependence !

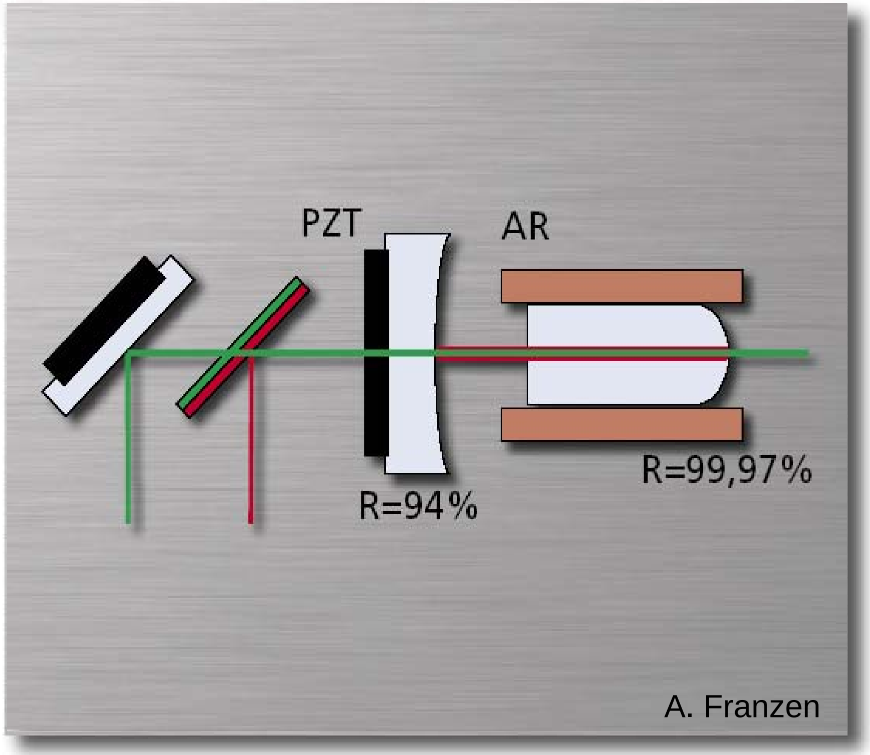
Squeezed Light Generation

OPA layout

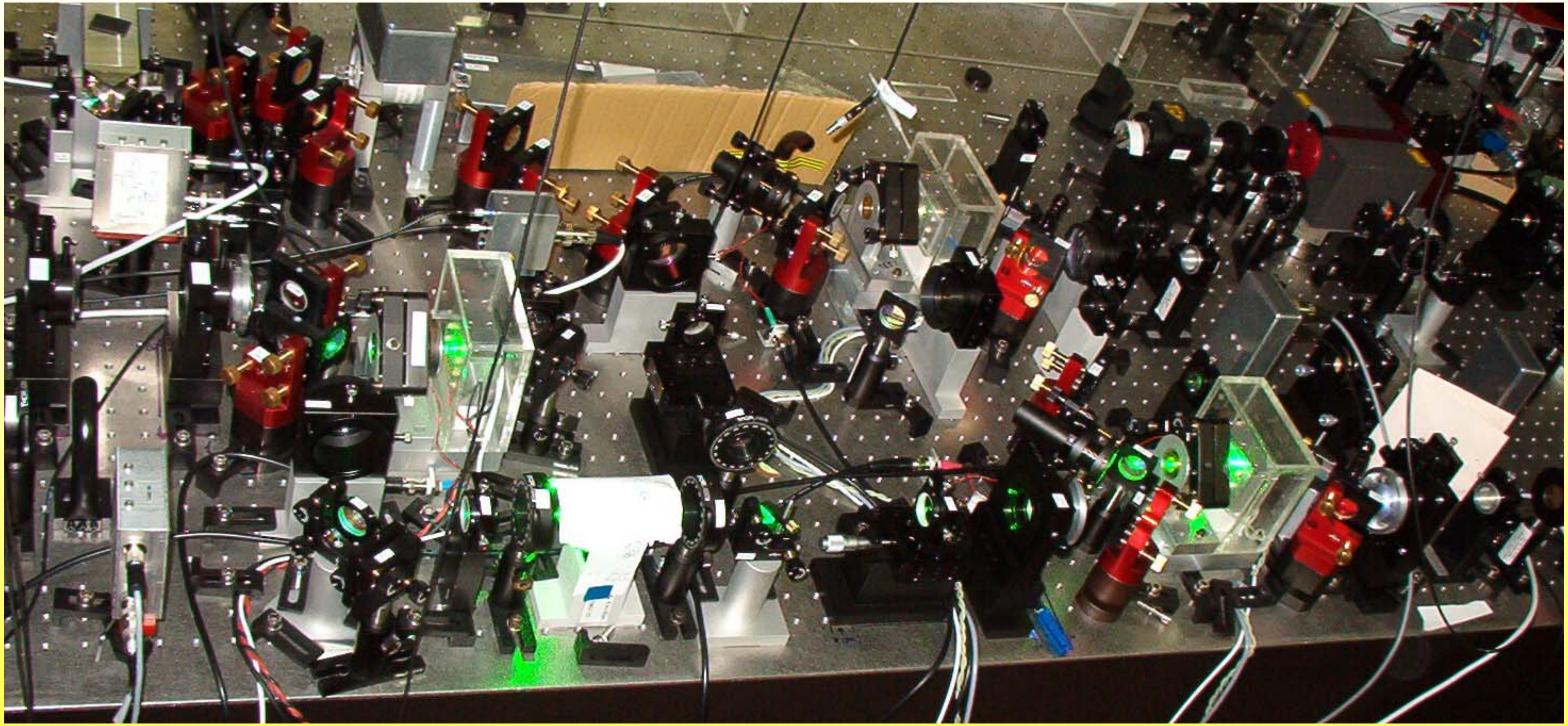
MgO LiNO – hemilithic crystal
7.5mm x 5mm x 2.5 mm

Radius of curvature: 10 mm
HR=99.97% at 1064 nm
Flat surface
AR at 1064 nm and 532 nm

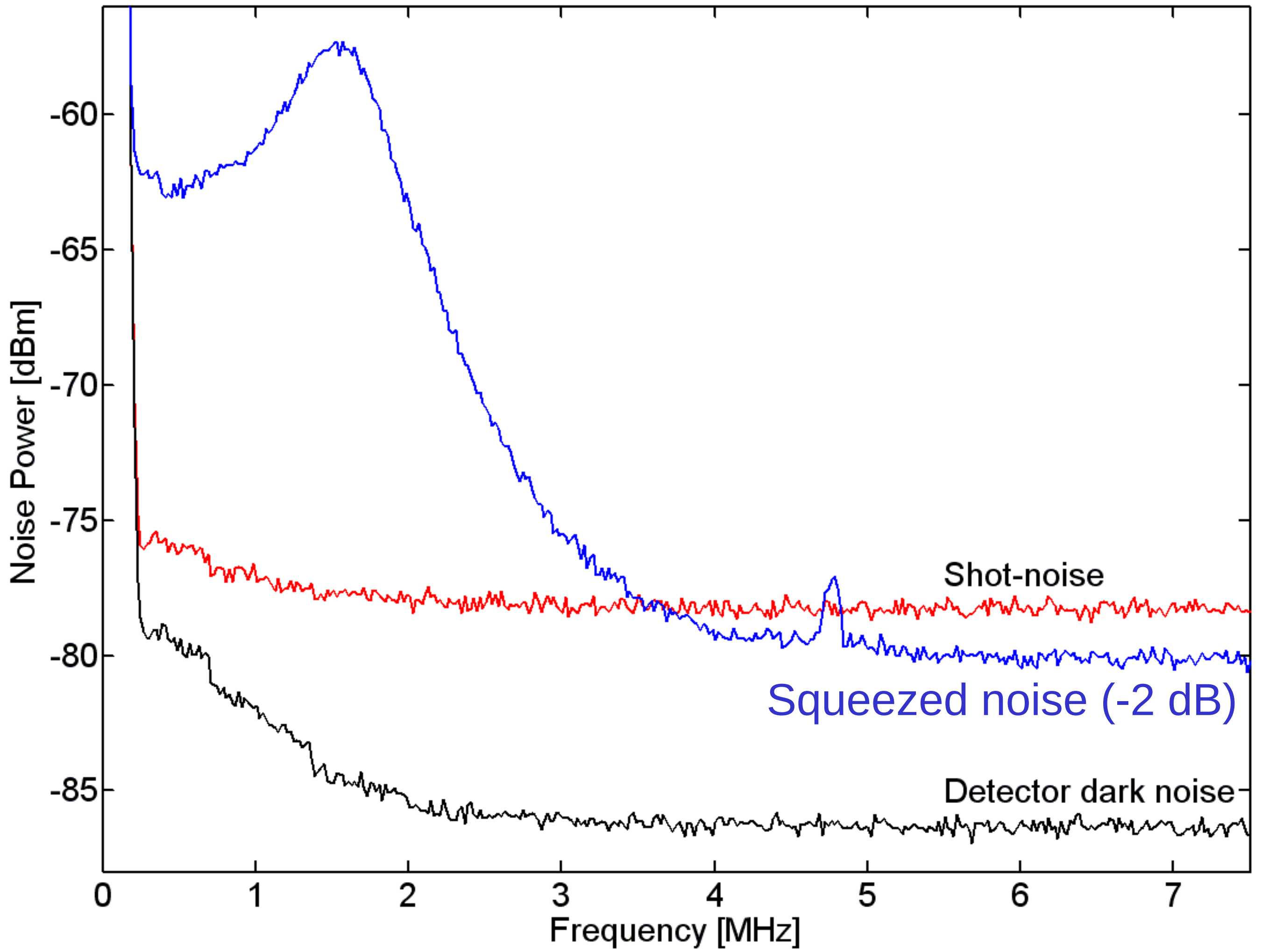
Output coupler:
R=94% at 1064 nm
Finesse ~ 100
Waist ~ 32 μm
FSR ~ 3 GHz
γ = 30 MHz



Squeezed Light Generation



Locked Amplitude-Quadrature Spectra



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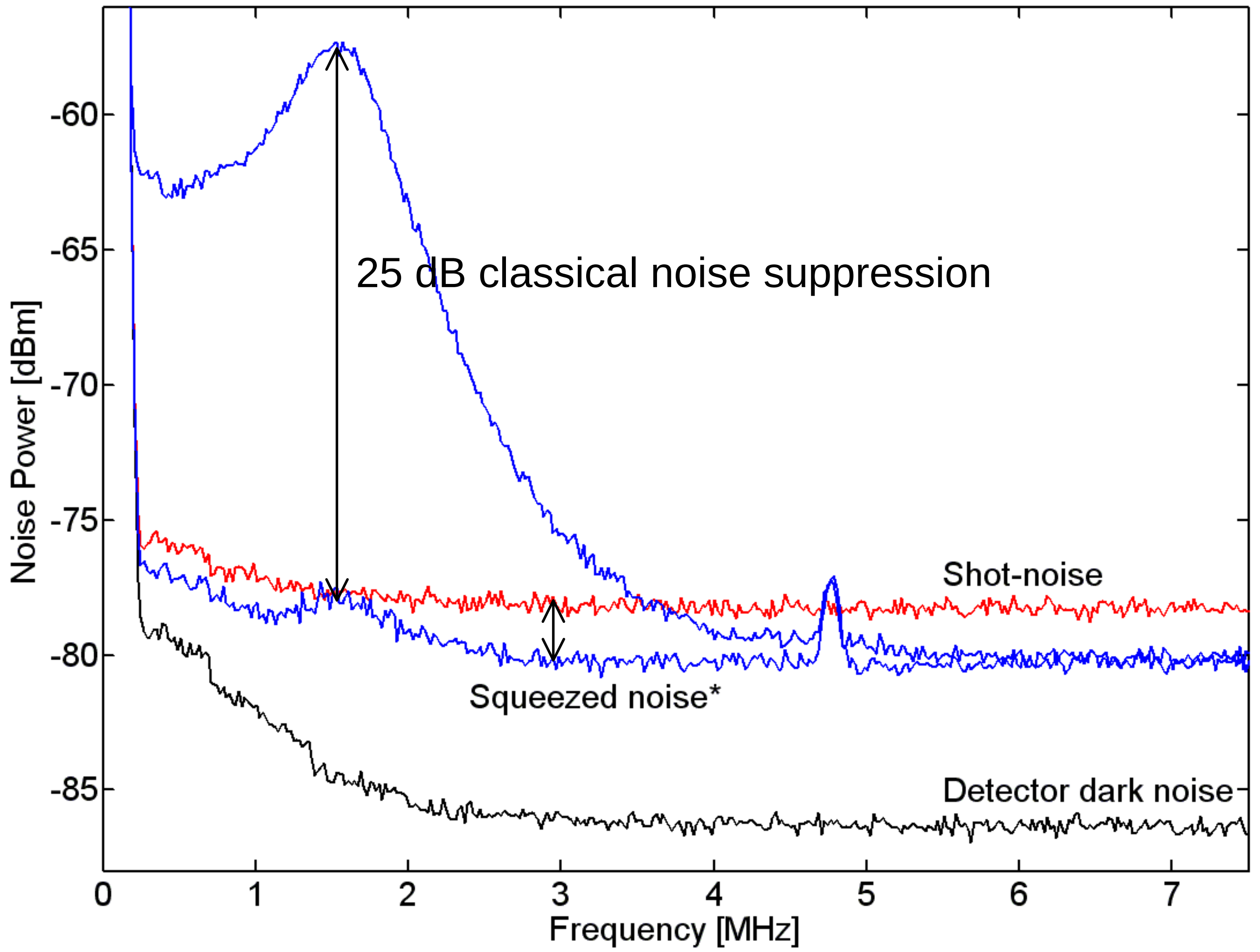
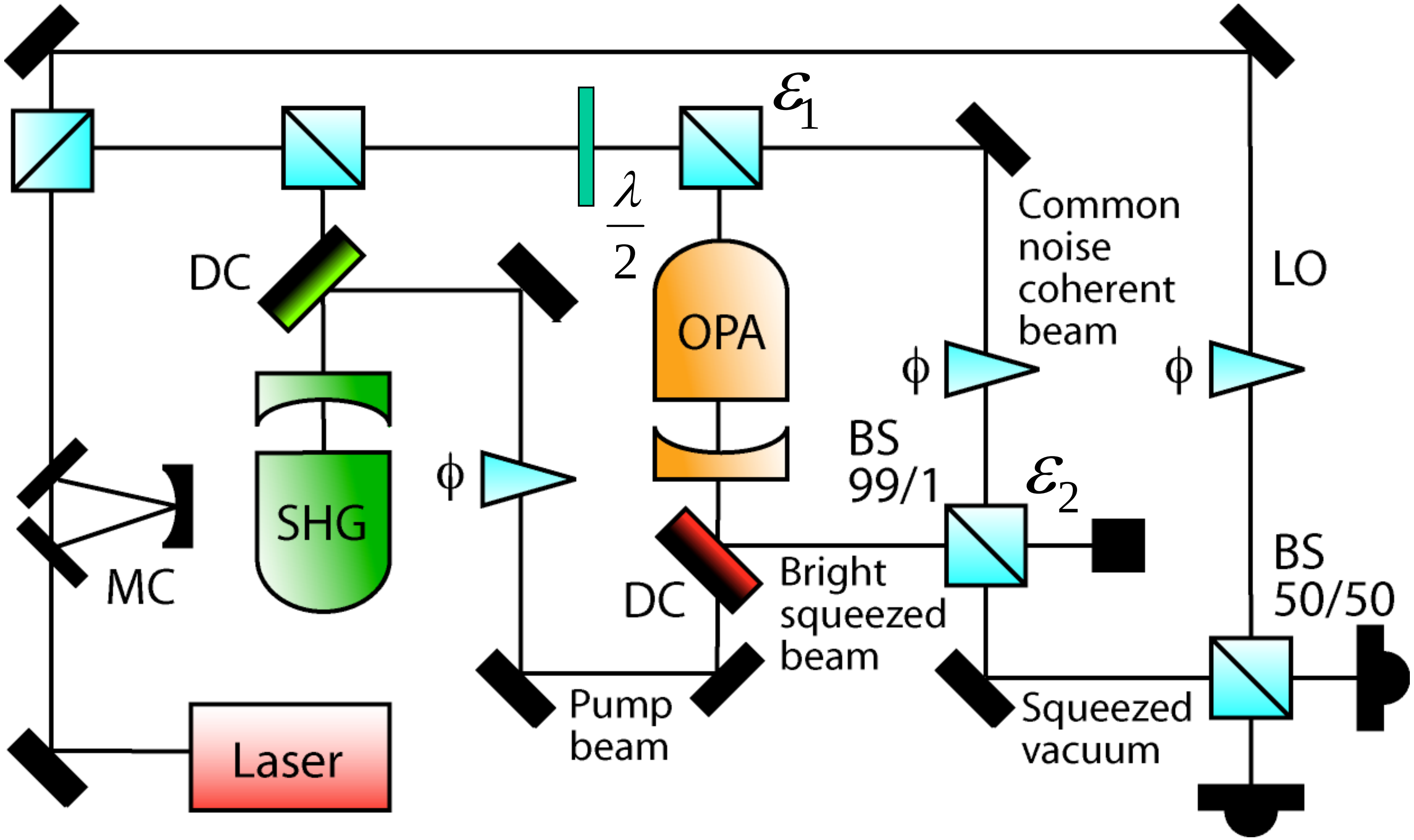
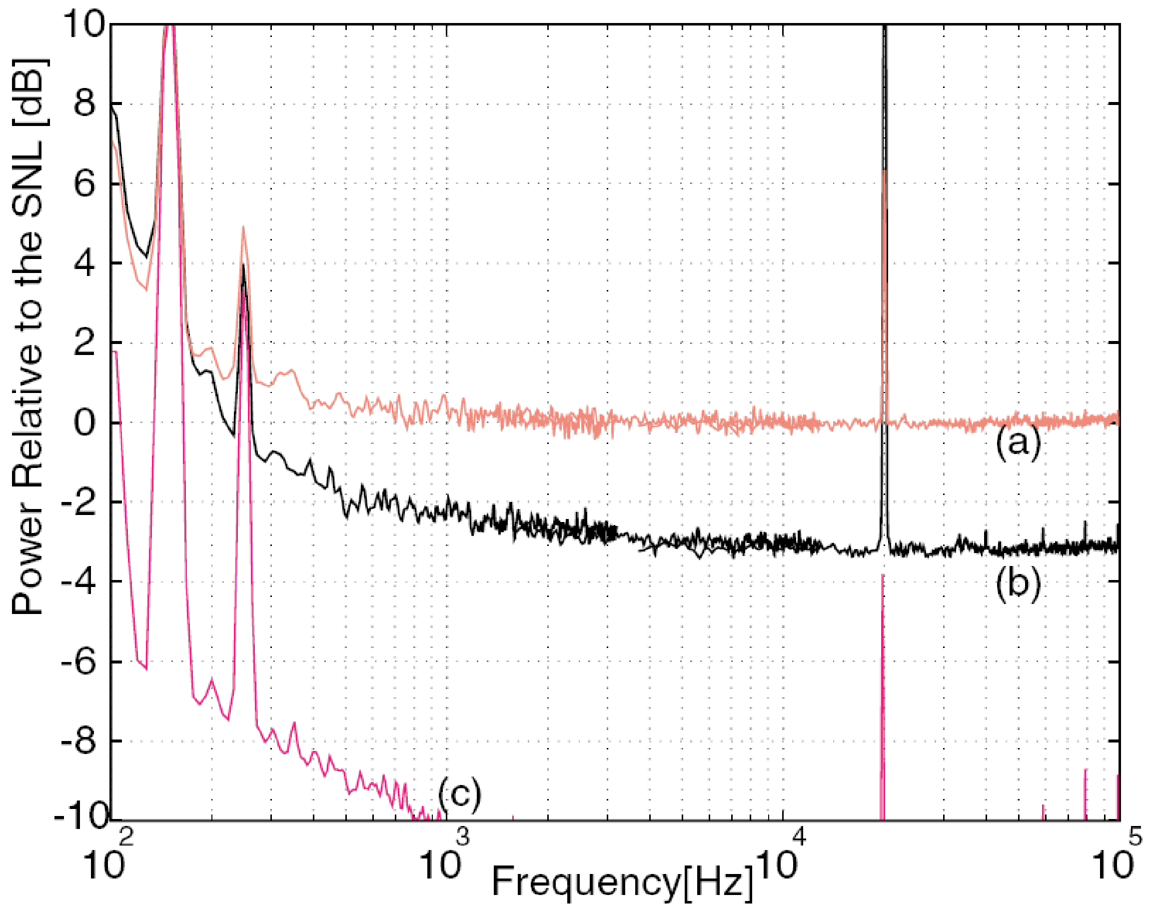


Common Mode Noise Cancellation



Squeezing Spectrum at Low Frequencies

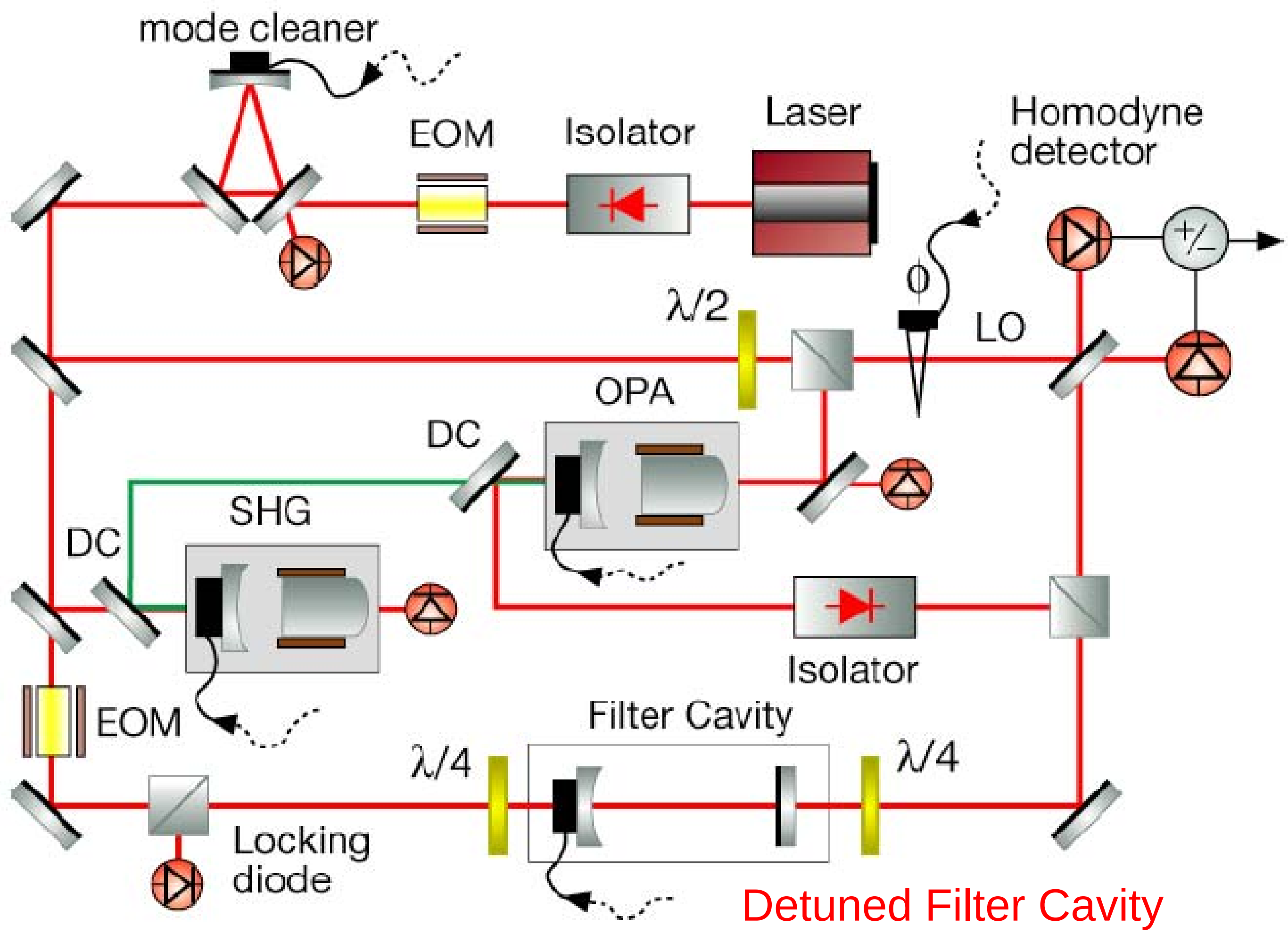


Vacuum noise

Squeezed vacuum noise

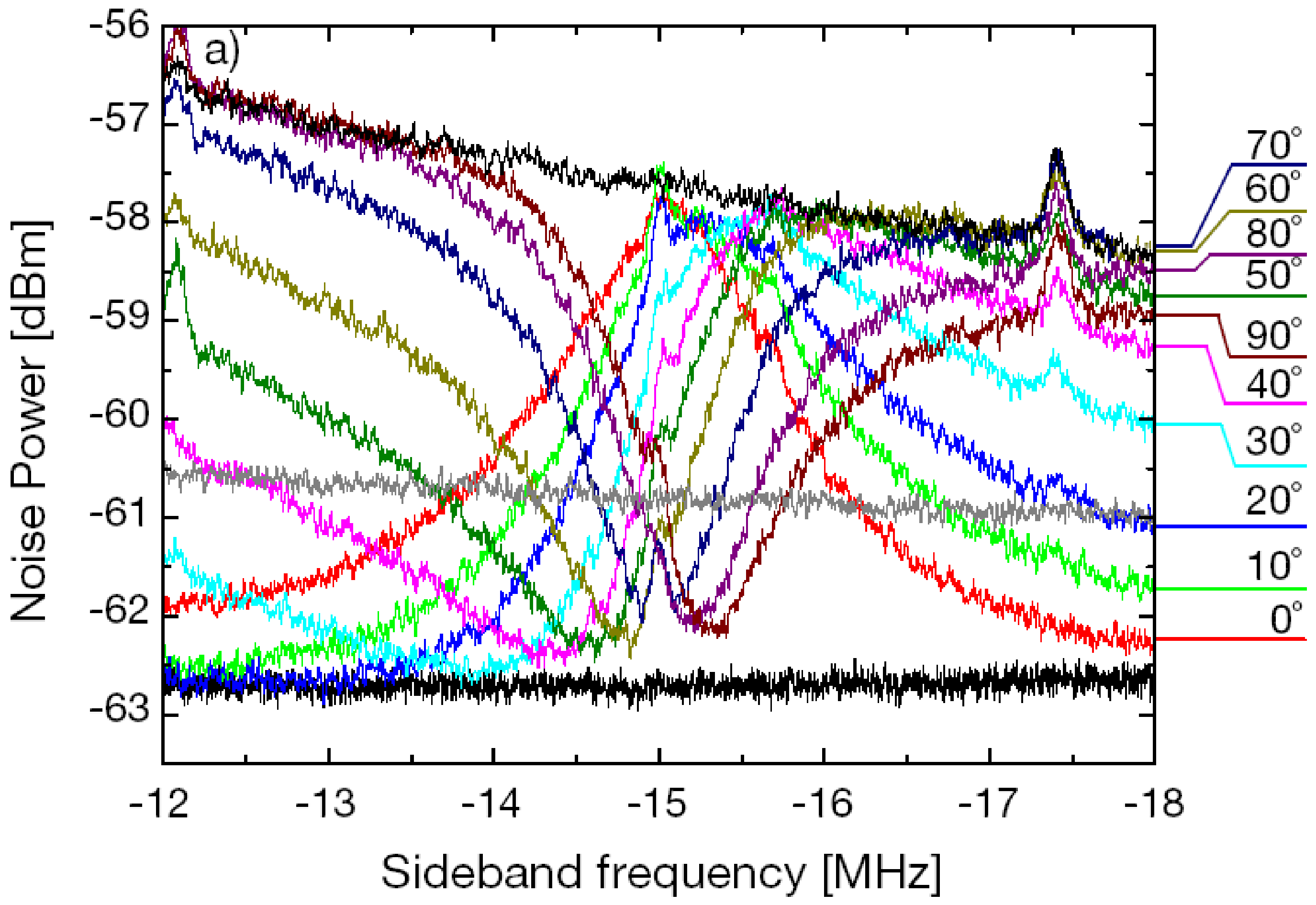
[McKenzie *et al*., Phys. Rev. Lett 93, 161105 (2004)]

Generation of Frequency Dependent SQZ

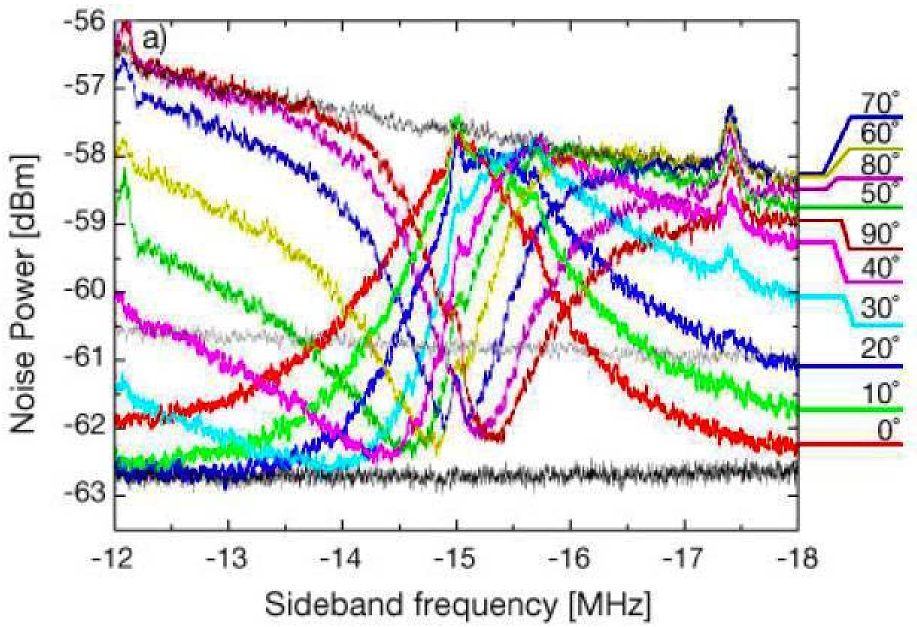


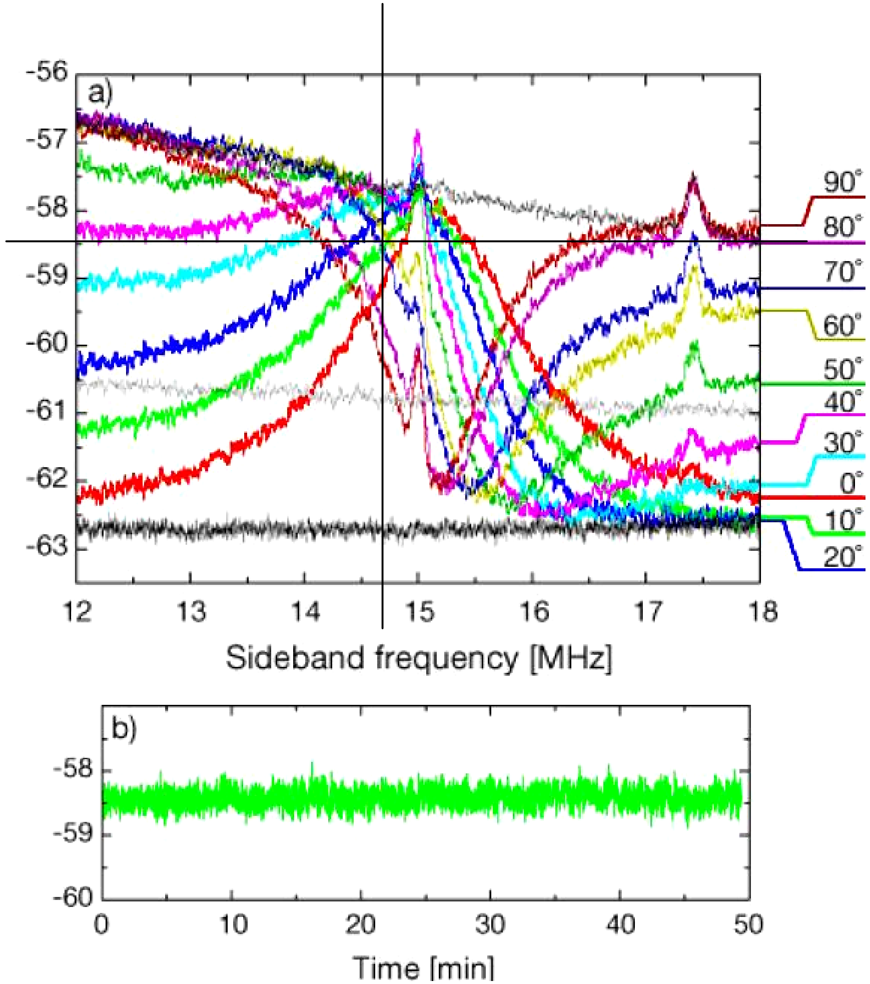
Detuned Filter Cavity

Frequency Dependent Squeezing Spectrum

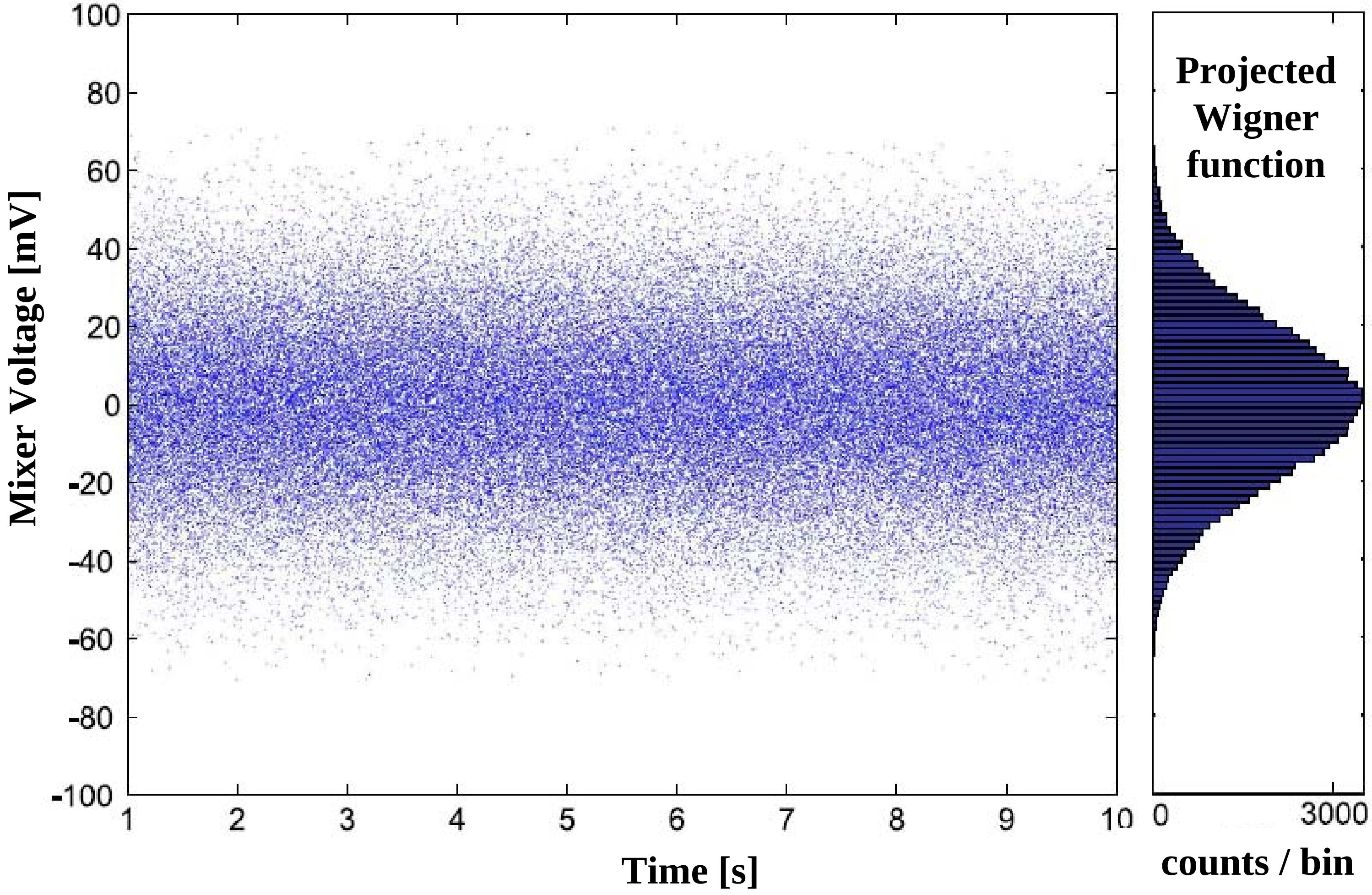


Frequency Dependent Squeezing Spectrum

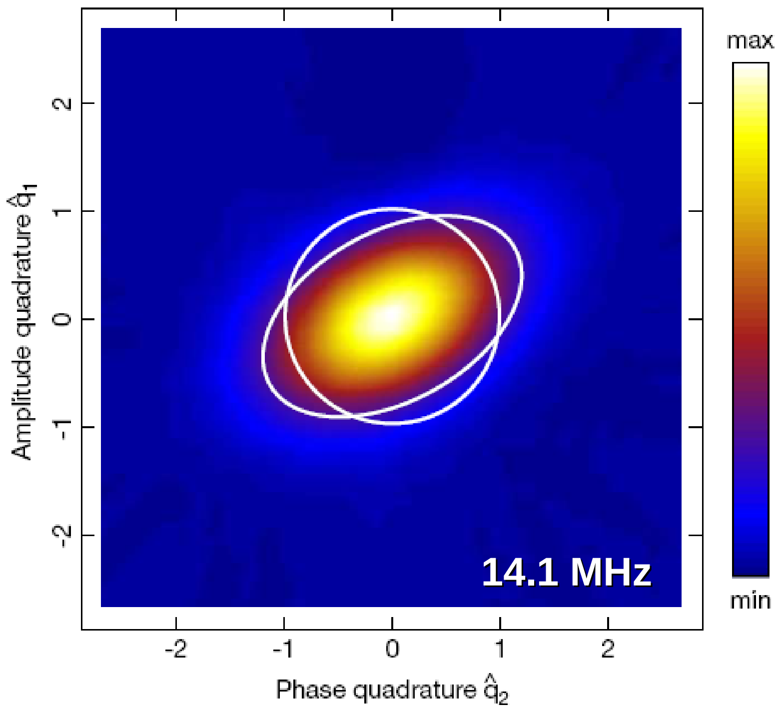


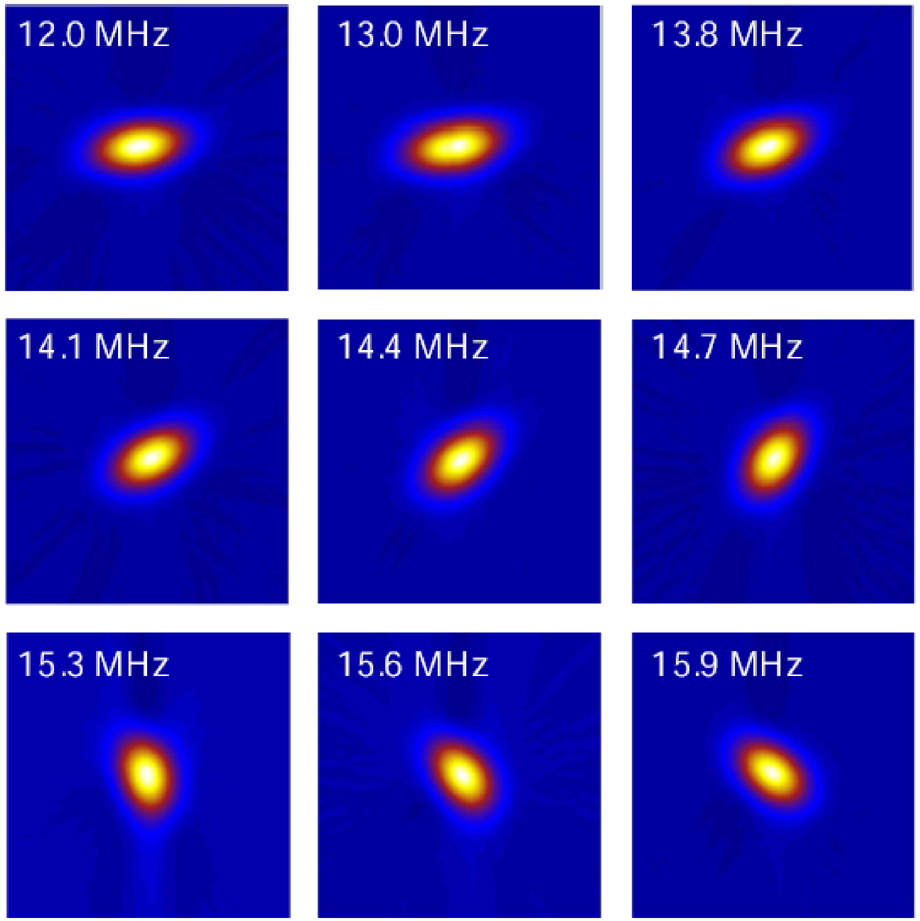


Tomography - Quadrature Noise Histogram



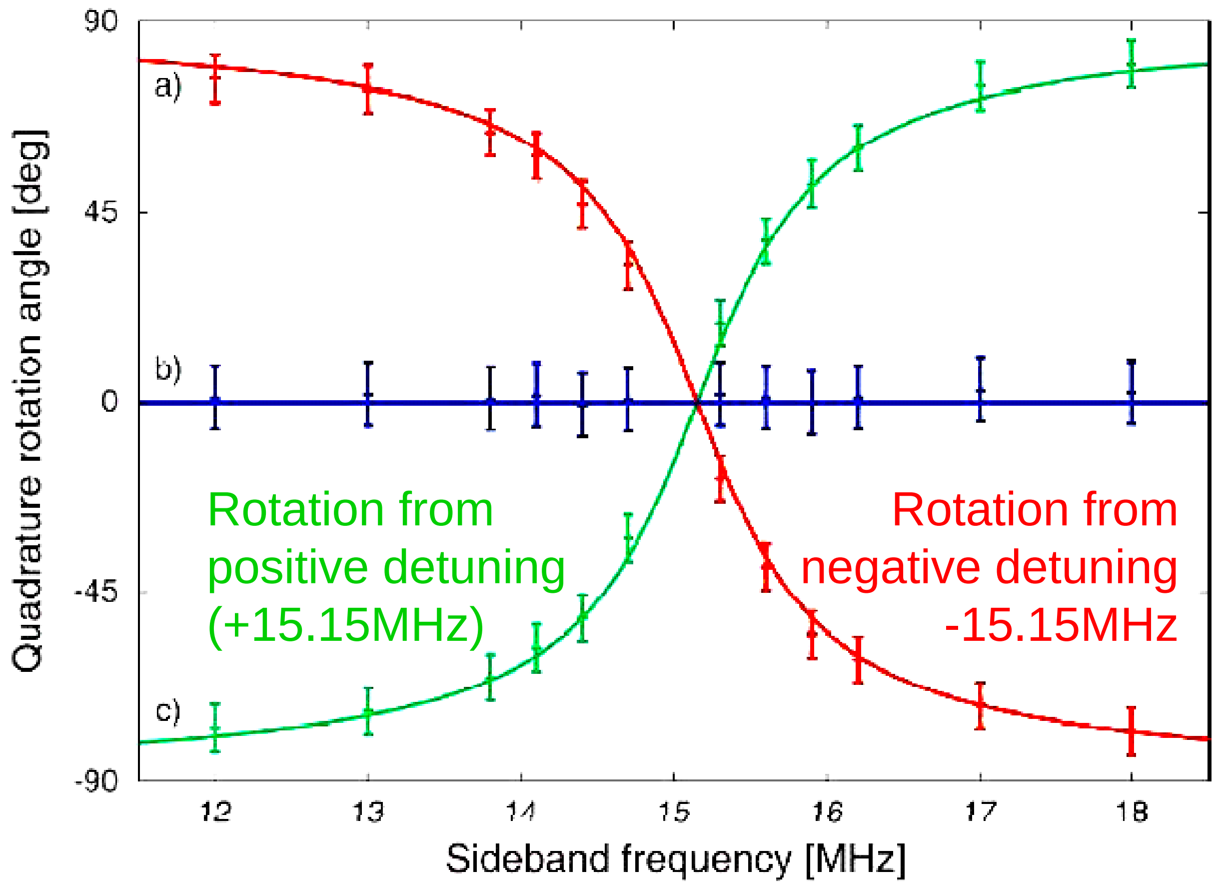
Tomography - Wigner Function Plots





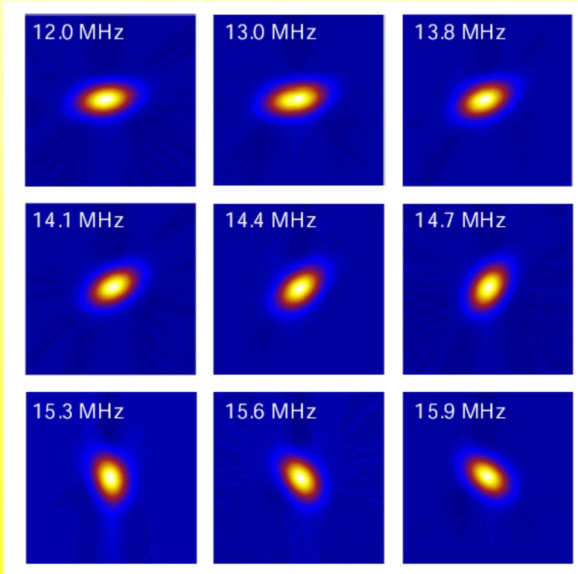
[Chelkowski *et al*., Phys. Rev. A 71, 013806 (2005)].

Cancellation of Frequency Dependence



Summary

- Squeezed light is capable of improving the quantum noise performance of GW interferometers.
- Generally squeezed light in the acoustic band of GW interferometers is required with frequency dependent orientation of the squeezed quadrature.
- Demonstration of frequency dependent squeezed light in a fully controlled (locked) setup, characterization using quantum state tomography.
  [Chelkowski *et al*., Phys. Rev. A 71, 013806 (2005)].



Gravitational Wave Interferometers