Light Sources and Interferometer Topologies

- Introduction -

Roman Schnabel

Albert-Einstein-Institut (AEI)

Institut für Gravitationsphysik

Leibniz Universität Hannover

Light Sources and Interferometer Topologies

8:30 Roman Schnabel (AEI) "Introduction to the session”

9:00 John Miller (MIT) "Decoherence and degradation of squeezed states in quantum filter cavities”

9:30 Andreas Sawadsky (AEI) "Dissipative opto-mechanical coupling”

10:00 BREAK

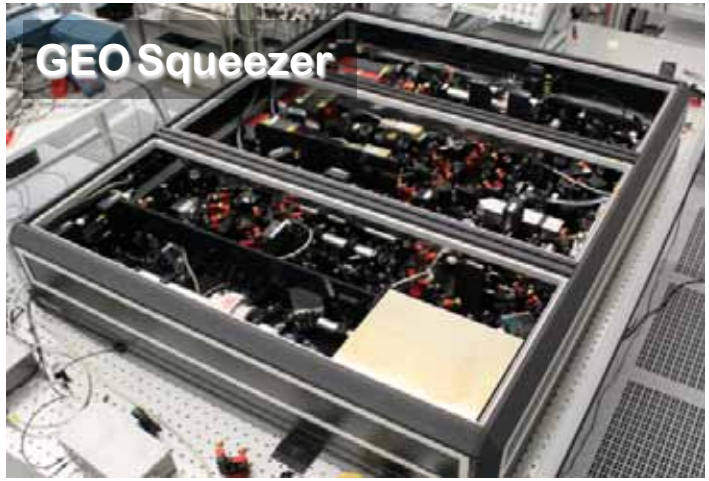
10:30 Nobuyuki Matsumoto (U Tokyo) "Classical Pendulum Feels Quantum Back-Action”

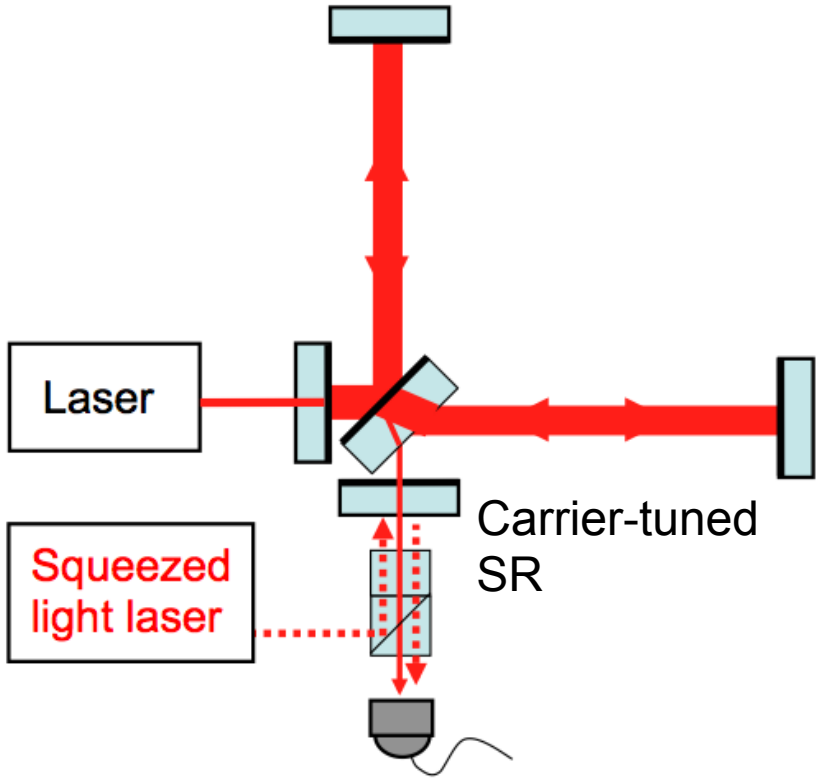
11:00 Haixing Miao (Birmingh.) "Intra-cavity filtering scheme for detecting gravitational waves”

11:30 Georgia Mansell (ANU) "In-vacuum OPO squeezer”


GEO 600
Coherent
Squeezed

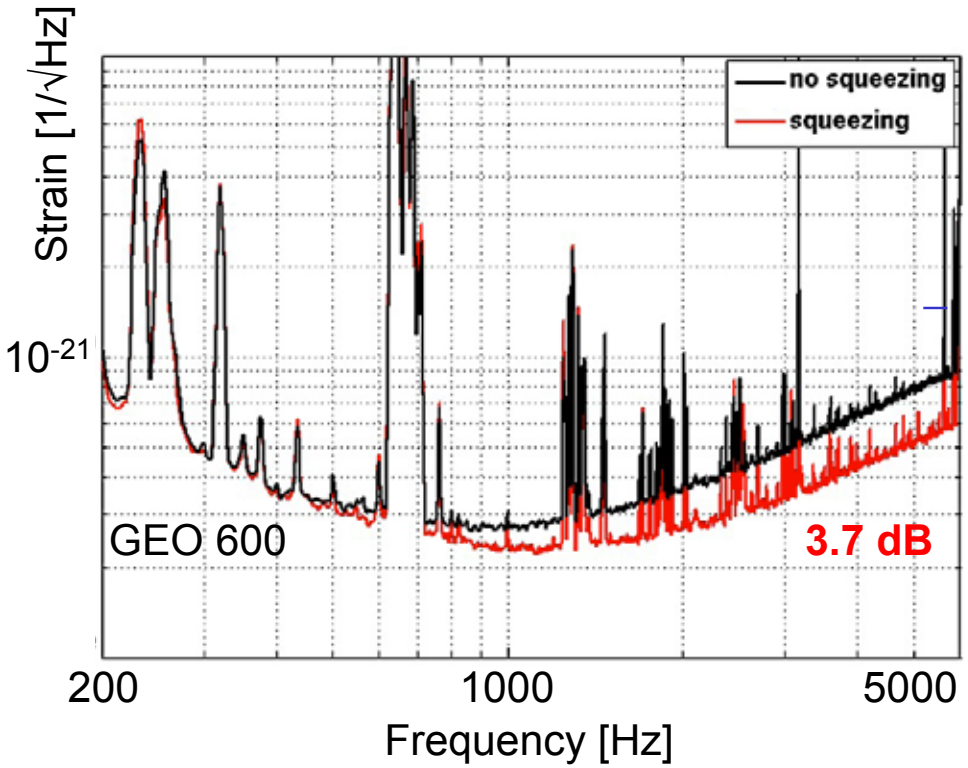
Squeezed Light in GW Detection

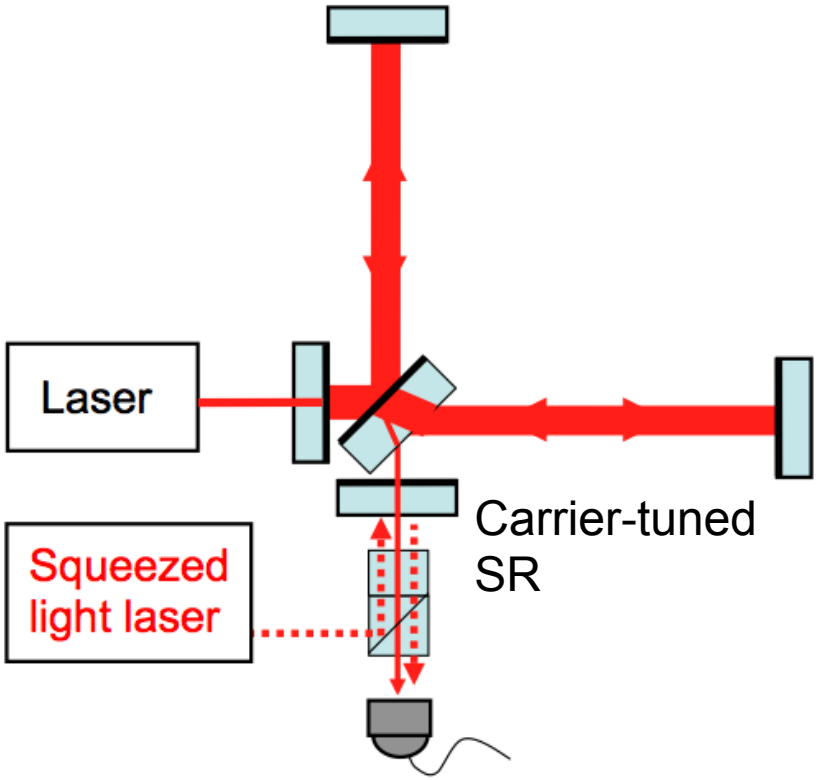




Squeezed Light in GW Detection

Squeezing the shot noise

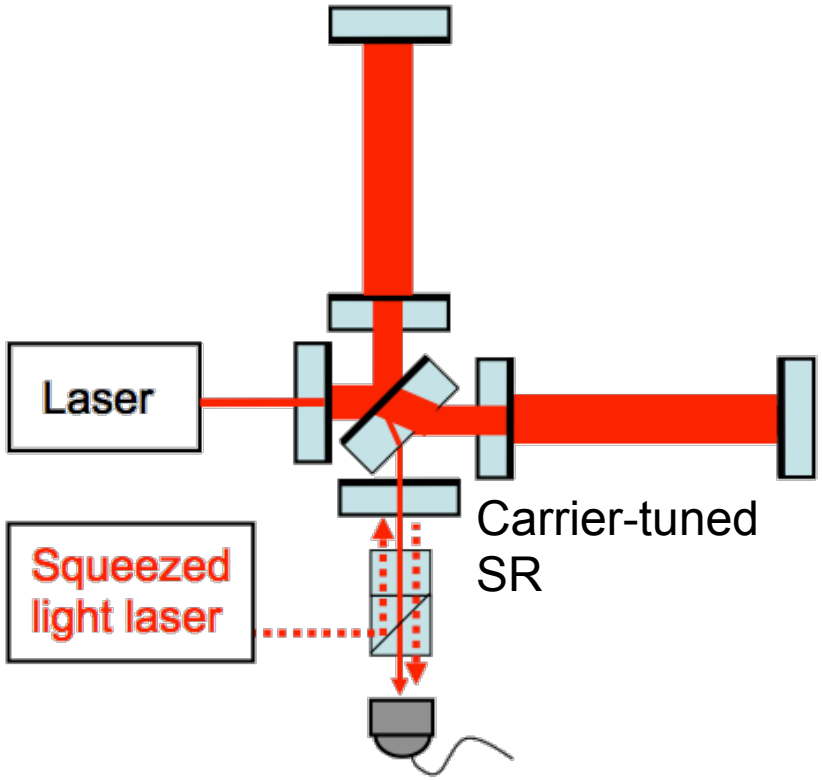




Squeezed Light in GW Detection

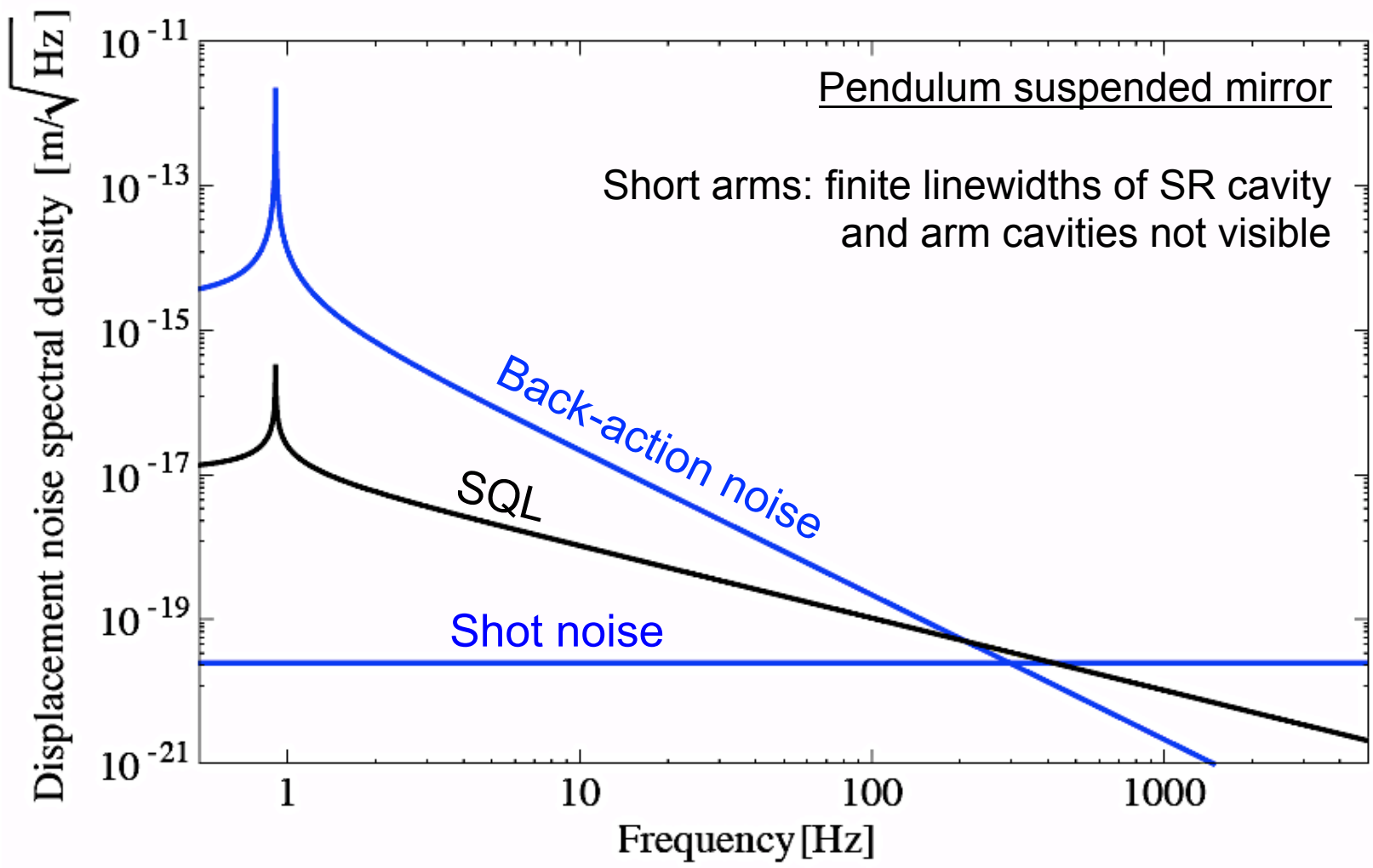
Squeezing the shot noise in Advanced Detectors (Dual-recycled Fabry-Perot Michelson interferometers):

No filter cavities required in the shot noise limited regime for tuned SR.



But: Advanced detectors will be (almost) back-action-noise limited at low frequencies ➔ Filter cavities are required.

Back-Action (Radiation pressure) Noise



Back-Action (Radiation pressure) Noise

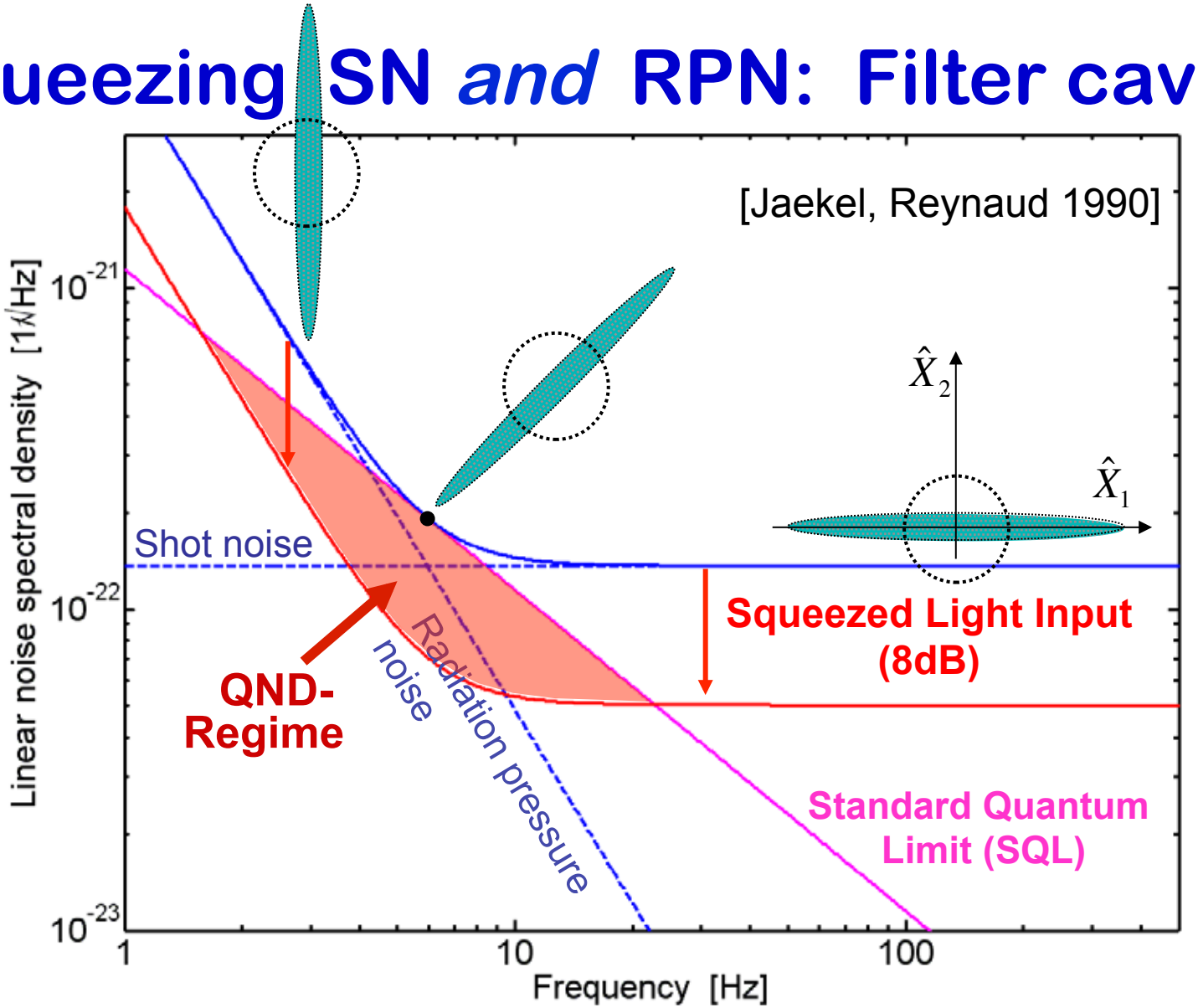
Only recently, back-action noise was observed for the first time.

- Observation of radiation pressure noise on a membrane
  [T. P. Purdy, R. W. Peterson, C. A. Regal, Science **339**, 801 (2013)]
- Observation of ponderomotive squeezing
  [A.H. Safavi-Naeini, S. Gröblacher, J.T. Hill, J. Chan, M. Aspelmeyer, O. Painter, Nature **500**,185 (2013)]
- Classical Pendulum Feels Quantum Back-Action
  [N. Matsumoto, Y.Michimura, G.Hayase, Y.Aso, K.Tsubono, arXiv:1312.5031]

Back-Action: Talk by Nobuyuki Matsumoto

Poster by Shiori Konisho

Squeezing SN *and* RPN: Filter cavities



EUROPHYSICS LETTERS 15 October 1990

Europhys. Lett., 13 (4), pp. 301-306 (1990)

Quantum Limits in Interferometric Measurements.

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4 place Jussieu, F-75252 Paris Cedex 05

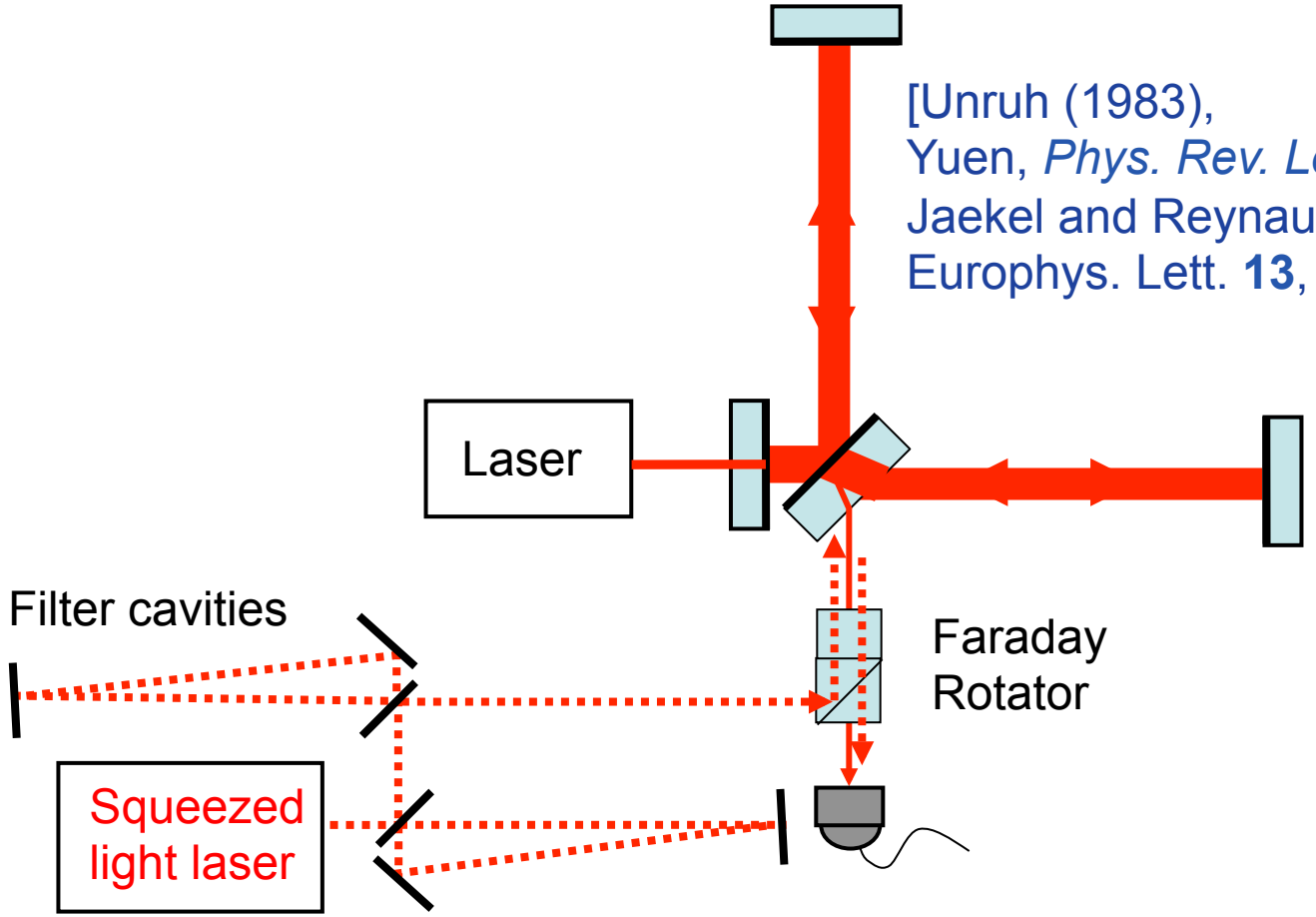
"Photon counting noise and radiation pressure noise in a GW detector can ***both*** be squeezed!"

First doubts on the free-mass SQL as the ultimate limit:

W. G. Unruh, in *Quantum Optics, Experimental Gravitation, and Measurement Theory* 647–660 (Plenum, 1983),

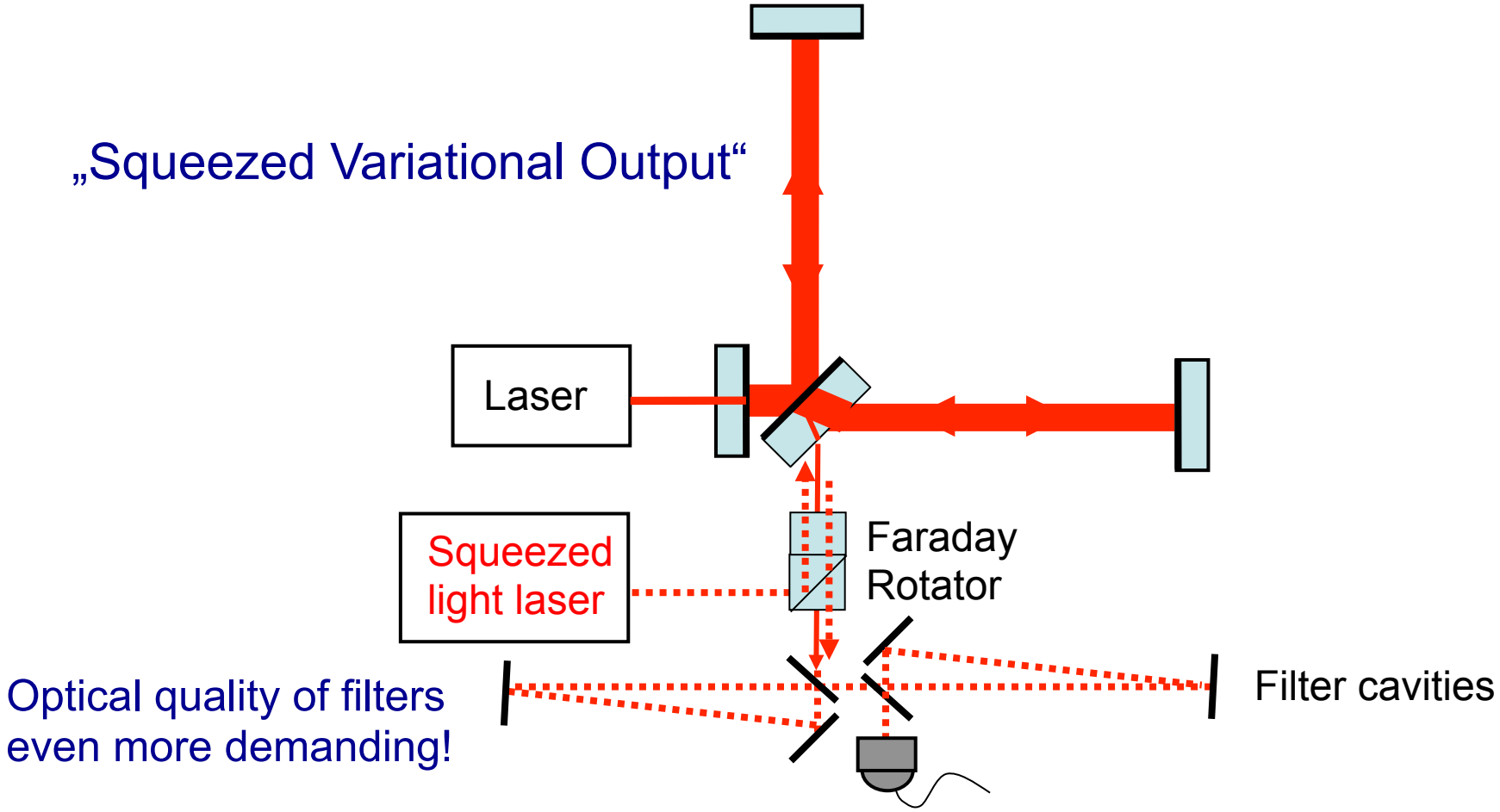
H. P. Yuen, Phys. Rev. Lett. **51,** 719 (1983)

Squeezing SN *and* RPN: Filter cavities



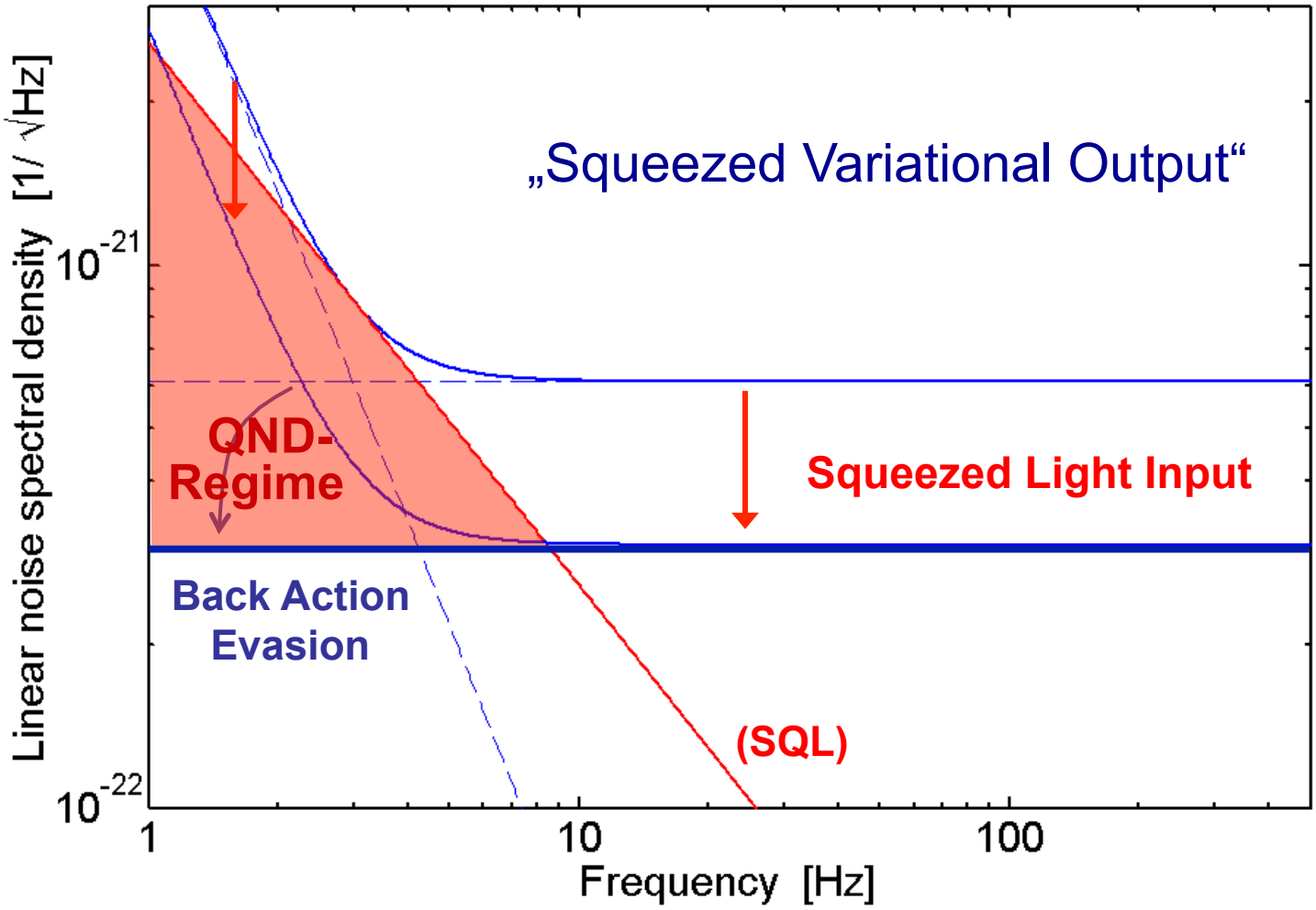
[Kimble *et al.*, Phys. Rev. D **65**, 022002 (2001)]

Squeezing and Full Evasion of RPN



[Kimble *et al.*, Phys. Rev. D **65**, 022002 (2001)]

Squeezing and Full Evasion of RPN



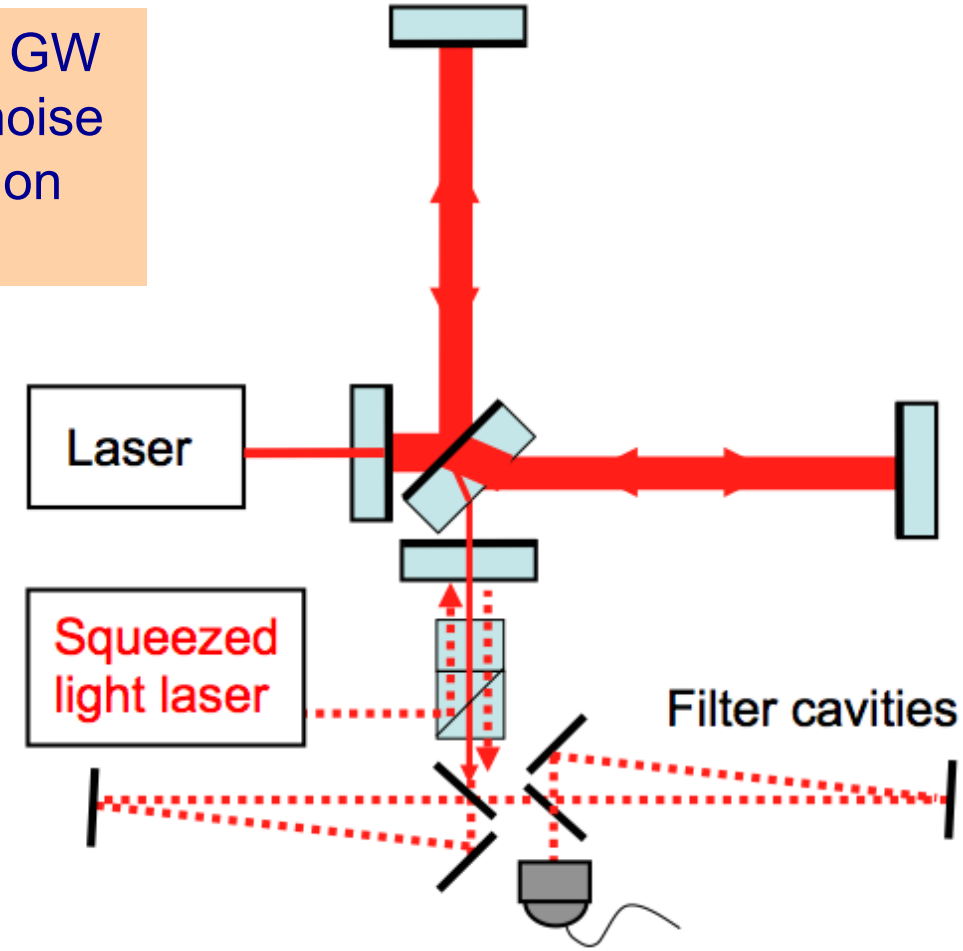
Squeezed-Light Filter Cavities

"Filter cavities are necessary in GW detectors to squeeze the shot-noise without increasing the back-action (radiation pressure) noise."

Filter cavities:

Talk by John Miller

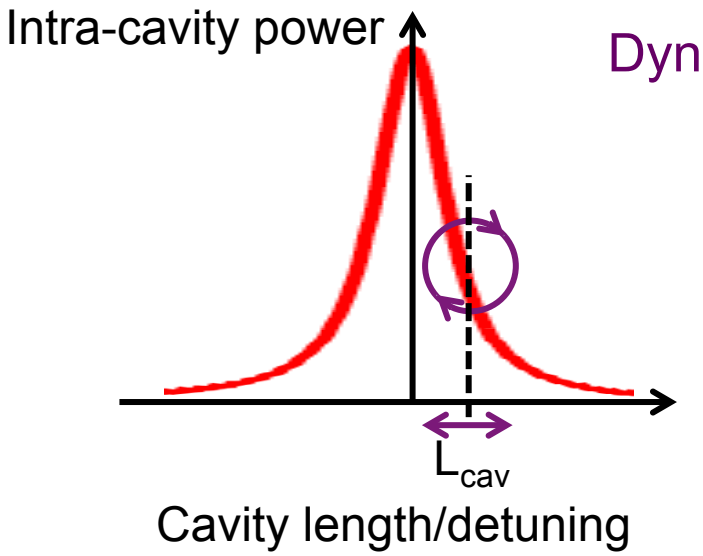
Poster by
Tomoki Isoqai



Dynamical Back-Action

…describes a macroscopic laser power change of a cavity mode that is caused by and couples back to the mechanical motion, thereby creating an opto-mechanical oscillator.

Example: “Optical Spring”



Dynamical back-action ➔ Spring constant
No damping ➔ Instability

[Dorsel, McCullen, Meystre, Vignes, Walther, Phys. Rev. Lett. 51, 1550 (1983)]

[Sheard, Gray, Mow-Lowry, McClelland, Whitcomb, Phys. Rev. A, 69, 051801 (2004)]

Dynamical Back-Action

If the mechanical motion causes a cavity length change:
"*Dispersive coupling*" (e.g.: optical spring in a GWD at dark port)

If the mechanical motion causes a cavity linewidth change:
"*Dissipative coupling*" (partially e.g.: optical spring in a GWD off dark port)

The combination of dispersive and dissipative couplings produces unexpected instabilities.

[Tarabrin *et al.*, PRA 88, 023809 (2013)]

Dynamical back-action:

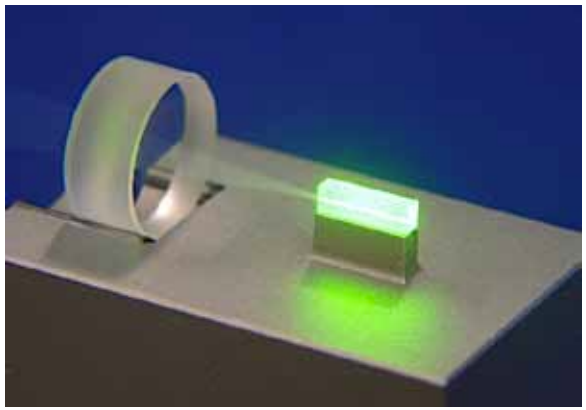
Talk by Andreas Sawadsky

Posters by Chunnong Zhao and by Jonathan Cripe

Squeezed Light Sources

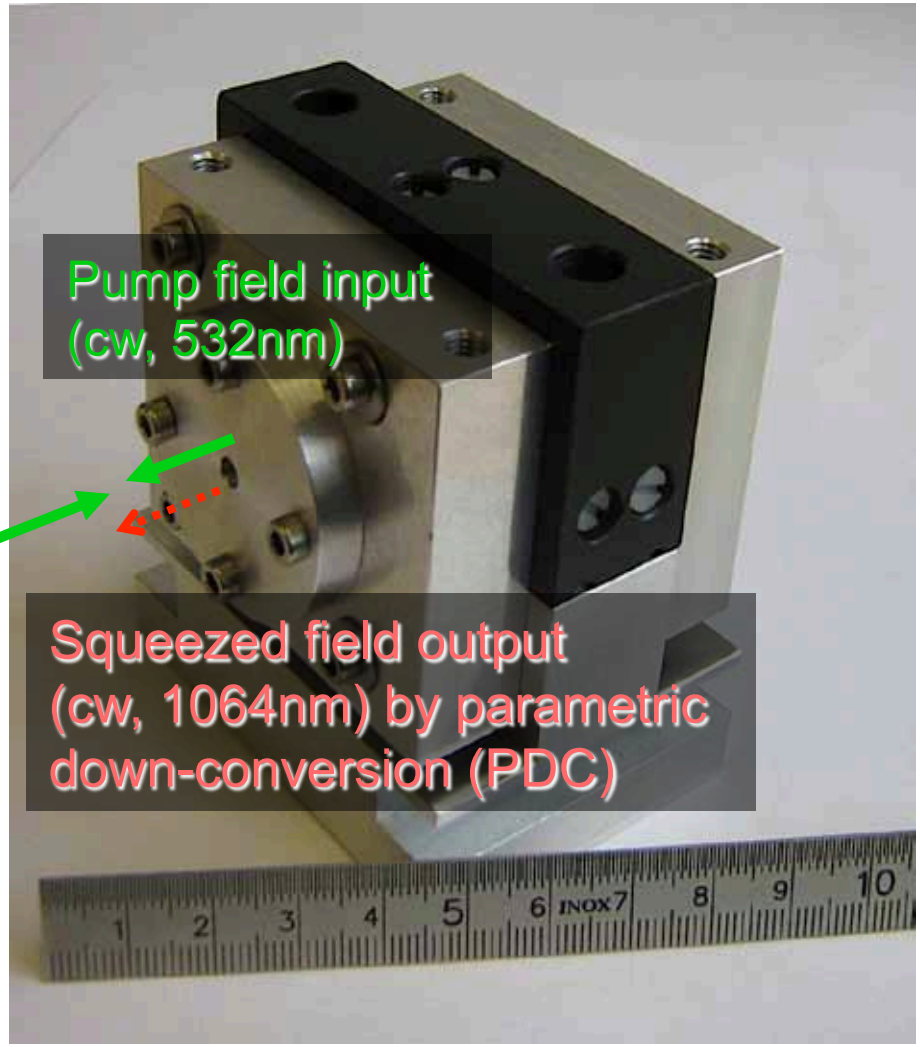
Mechanism:

Cavity enhanced parametric down-conversion in a χ_2-nonlinear crystal, such as periodically poled KTP



Standing-wave cavity (AEI)

Alternatively:
Travelling-wave cavity (ANU)



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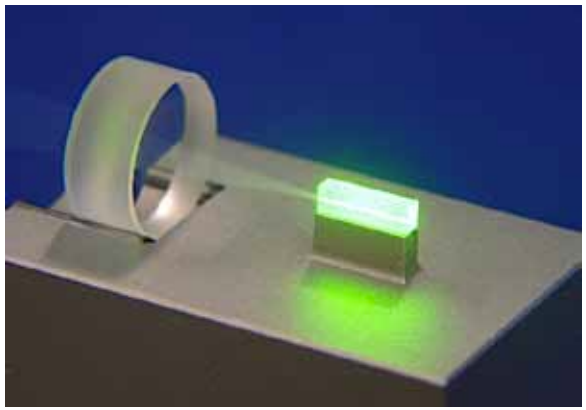


Standing-wave cavity (AEI).
Alternatively:

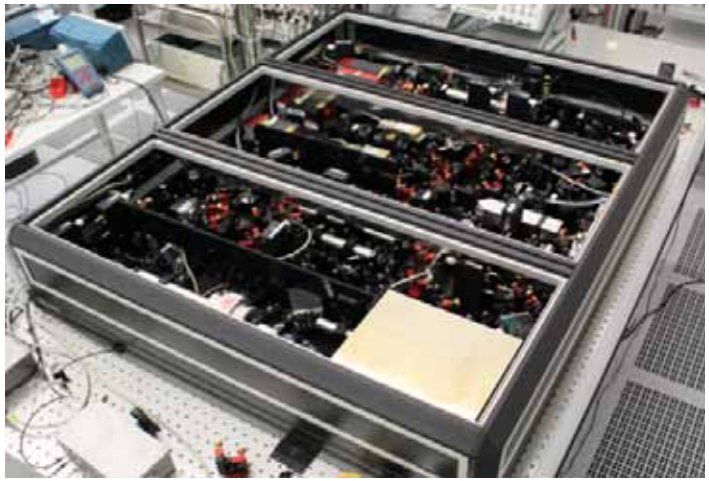
Travelling-wave cavity (ANU)

Strongest directly observed squeezing so far:
12.7 dB (@1064nm),

including all losses, also loss at photo diode, as well as phase noise [T. Eberle *et al.*, PRL **104**, 251102 (2010)] :

To achieve a 10 dB improvement in ET, maximally another 4% loss (at zero additional phase noise) is allowed to be imposed by the GW detector.

Squeezed Light Sources



Optical components, loss and phase noise of the GEO squeezer are already good enough for ET.

A major Goal:
Realisation of a smaller and more compact design.

Squeezers:

Talk by Georgia Mansell

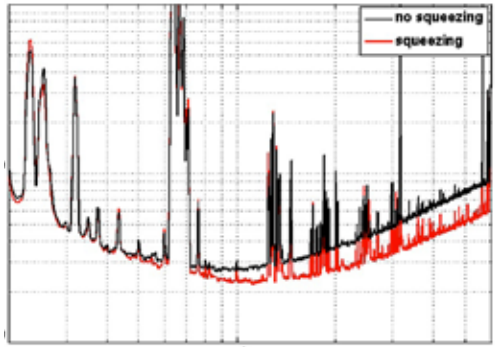
Poster by Eric Oelker

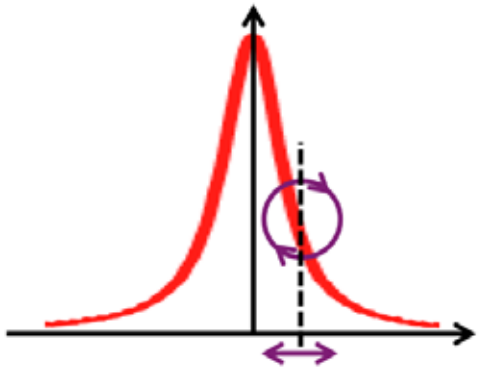
Summary and Outlook

- "The combination of intense coherent light and squeezed vacuum is the optimum quantum approach for GW detectors
  ➔ filter cavities are required to avoid increase of back-action noise."

- "Experiments on back-action and dynamical back-action are required to verify our models (for the design of GWDs)."

- "Smaller (and possibly cheaper) squeezed light sources would be great."





DFG SFB TR7 cQOM