Squeezed Light for the Low-Frequency Interferometers of ET

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Squeezed Light Source at 1550 nm Wavelength

- Squeezed vacuum states of light are used to reduce quantum noise.
- In current and future gravitational wave detectors this helps to improve their sensitivities.
- Ideally the frequency independent squeezed state is converted via filter cavities into a frequency dependent state that matches the dual recycled interferometer topology.

Stabilized laser system at 1550 nm wavelength for future gravitational-wave detectors
https://doi.org/10.1103/PhysRevD.105.122004

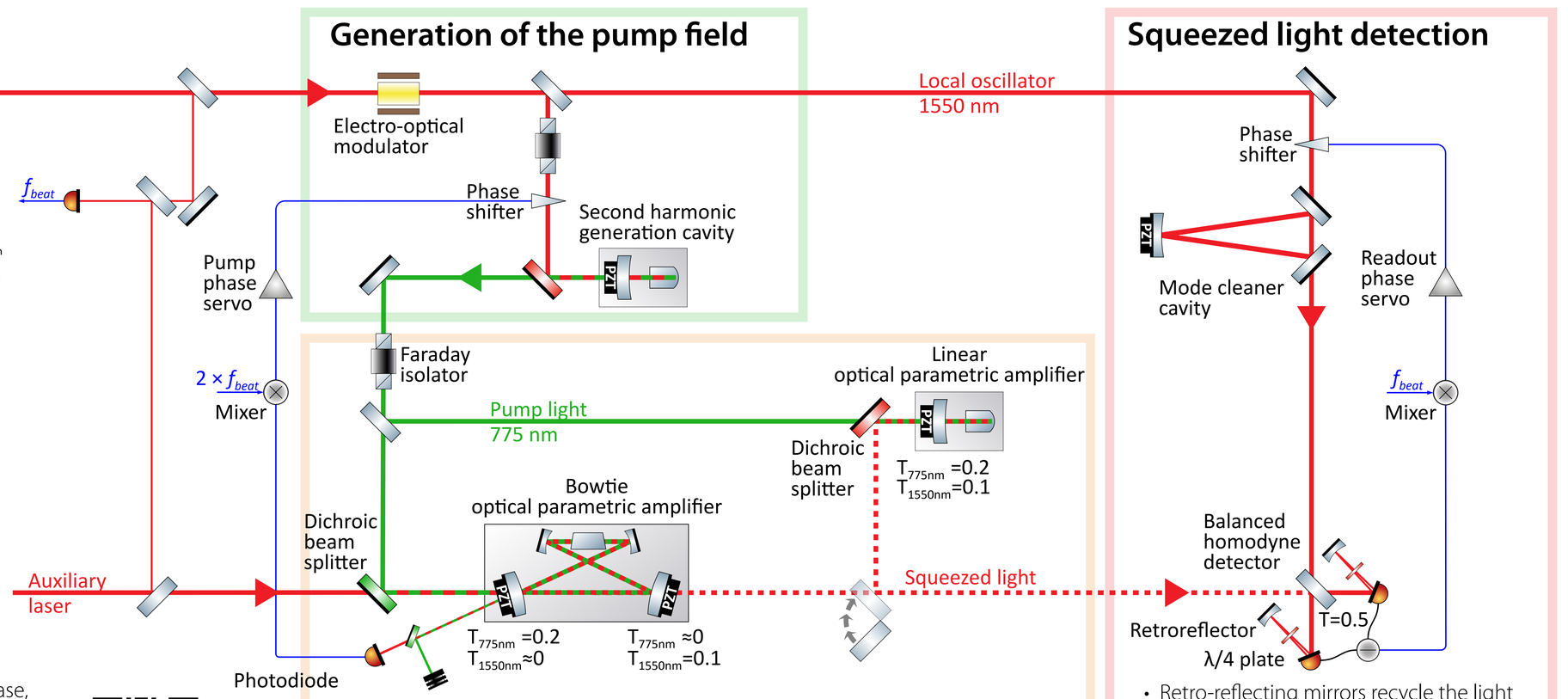
Squeezed light source

- Light from the main laser is frequency doubled.
- This light is used to pump the optical parametric amplifier.
- Here the vacuum state at 1550 nm is "squeezed".
- The balanced homodyne detector enables to measure each quadrature of the squeezed state of light.

Coherent control of the phases

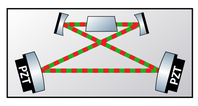
- An auxiliary laser is used to sense the readout and pump phase,
- This allows to fully control the generated squeezed state of light.
- For electronic demodulation the beat frequency between the main and the auxiliary laser is used.

PhD thesis, Fabian Meylahn
https://doi.org/10.15488/13109

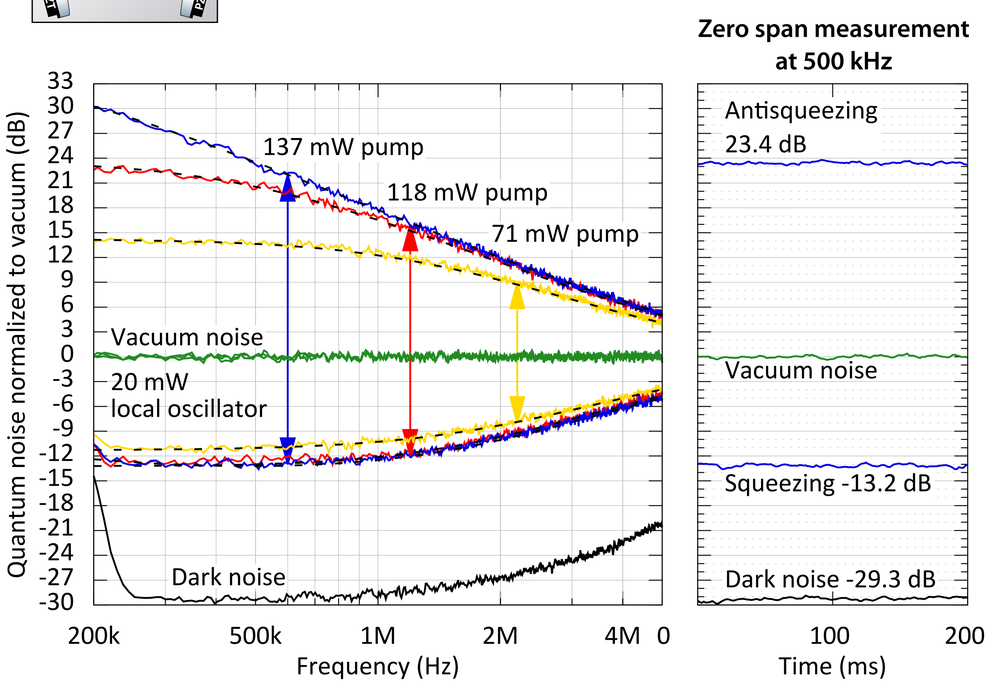


- Retro-reflecting mirrors recycle the light
- λ/4 plates turn this reflected light in the orthogonal polarization to reduce disturbances by back-scattered light.

Characterization of the Optical Parametric Amplifiers



Bowtie optical parametric amplifier



Total optical loss: 4 %
Phase noise: 4 mrad
Free spectral range: 0.45 GHz
Pole frequency: 4.1 MHz

- Bowtie cavity design for low astigmatic beams with convex and concave mirrors
- Doubly resonant to enhance pump intensity and interaction time
- **Less sensitive to backscattered light** because of the two distinct traveling wave directions inside the cavity

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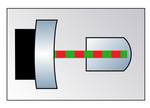
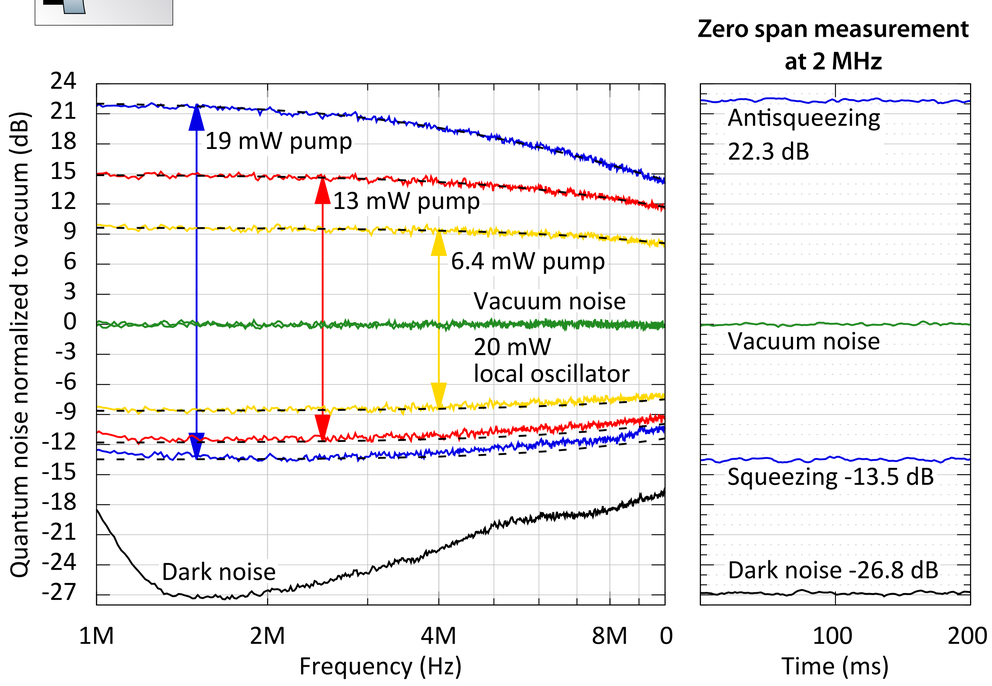


Linear optical parametric amplifier



Total optical loss: 3.5 %
Phase noise: 5 mrad
Free spectral range: 3.4 GHz
Pole frequency: 30 MHz

- Doubly resonant half monolithic cavity design for simultaneous resonance of pump and squeezed field
- Full characterization of optical loss contributions enables the estimation of the **photodiode quantum efficiency** to **98.5 % ± 0.7 %** including the enhancement in sensitivity of 0.5 % gained with the retroreflectors.

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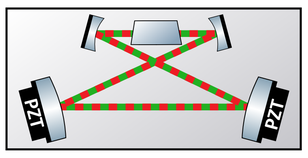
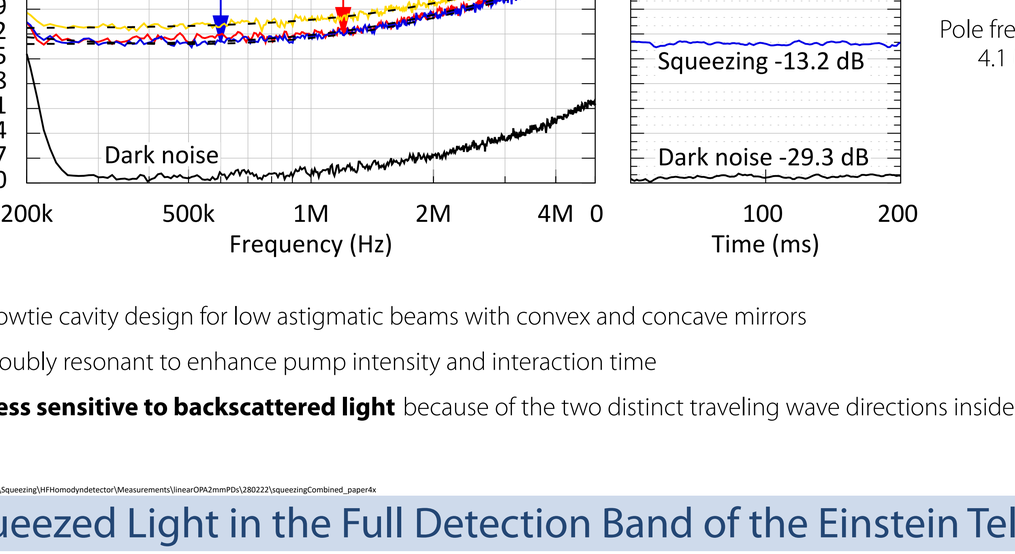
Squeezed Light in the Full Detection Band of the Einstein Telescope

Audio-band squeezing and sub-audio-band squeezing

- Coherent control of readout and pump phase required.
- Low frequency performance can easily be limited by laser noise coupling.
- Back-scattered light has to be minimized.

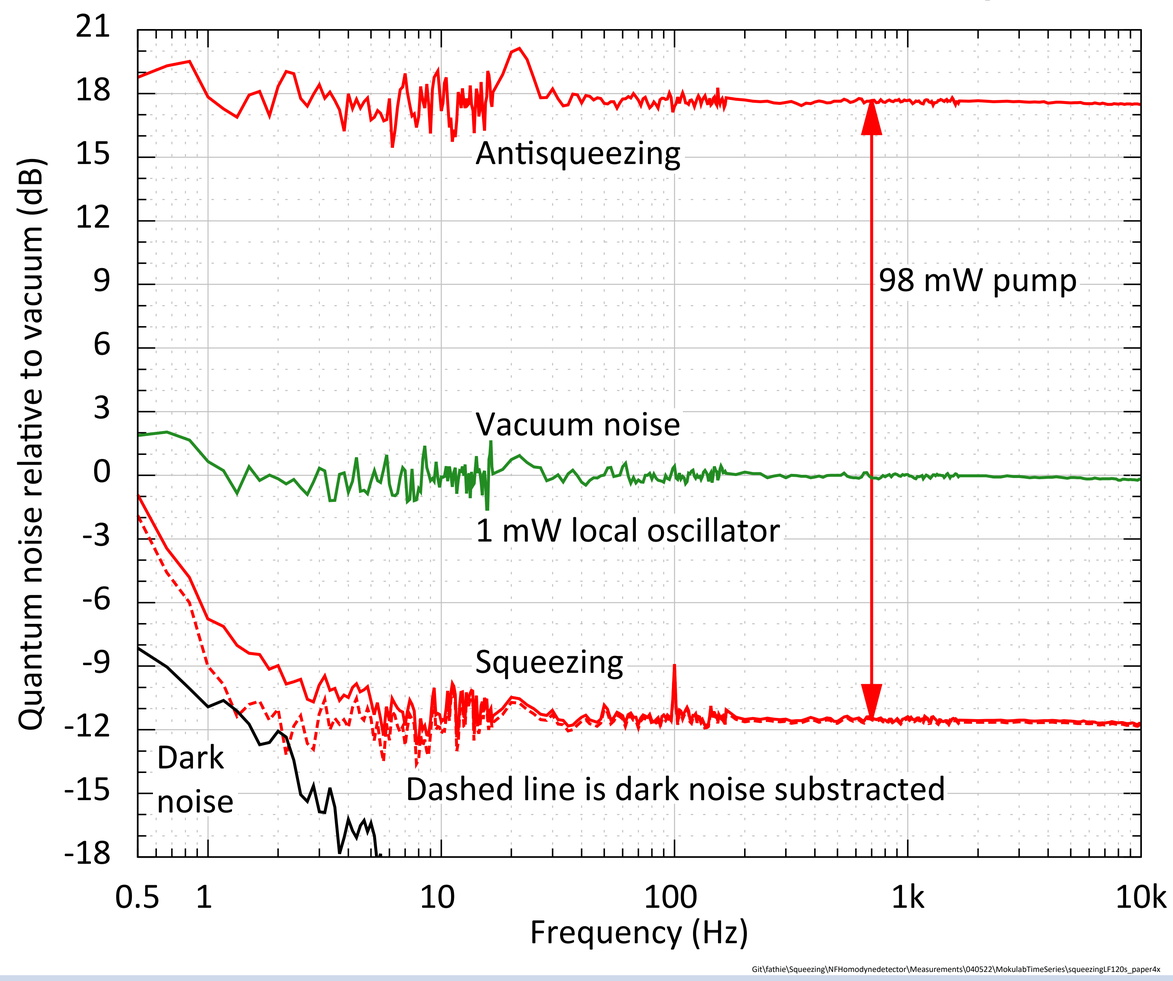




- First demonstration of **squeezed light at 1550 nm** below 500 Hz and **down to 0.5 Hz**.
- **11.5 dB quantum noise reduction** in the ET-LF detection band
- Highest noise reduction shown at 1550 nm so far!
- Current limits: Noise of the auxiliary laser, particles passing one homodyne detector arm, and power noise below 1 Hz

Squeezed states of light for future gravitational wave detectors at a wavelength of 1550 nm
https://doi.org/10.1103/PhysRevLett.129.121103

Quantum noise measurements with the bowtie squeezer



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https://gitlab.aei.uni-hannover.de/lasergroup/fathie/-/tree/master/Vorstellungen/GWADW2023/Poster2/GWADW2023squeezing