Sonification of Squeezed Vacuum State of Light

Unveiling Quantum Dynamics through Sound

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CREDO workshop

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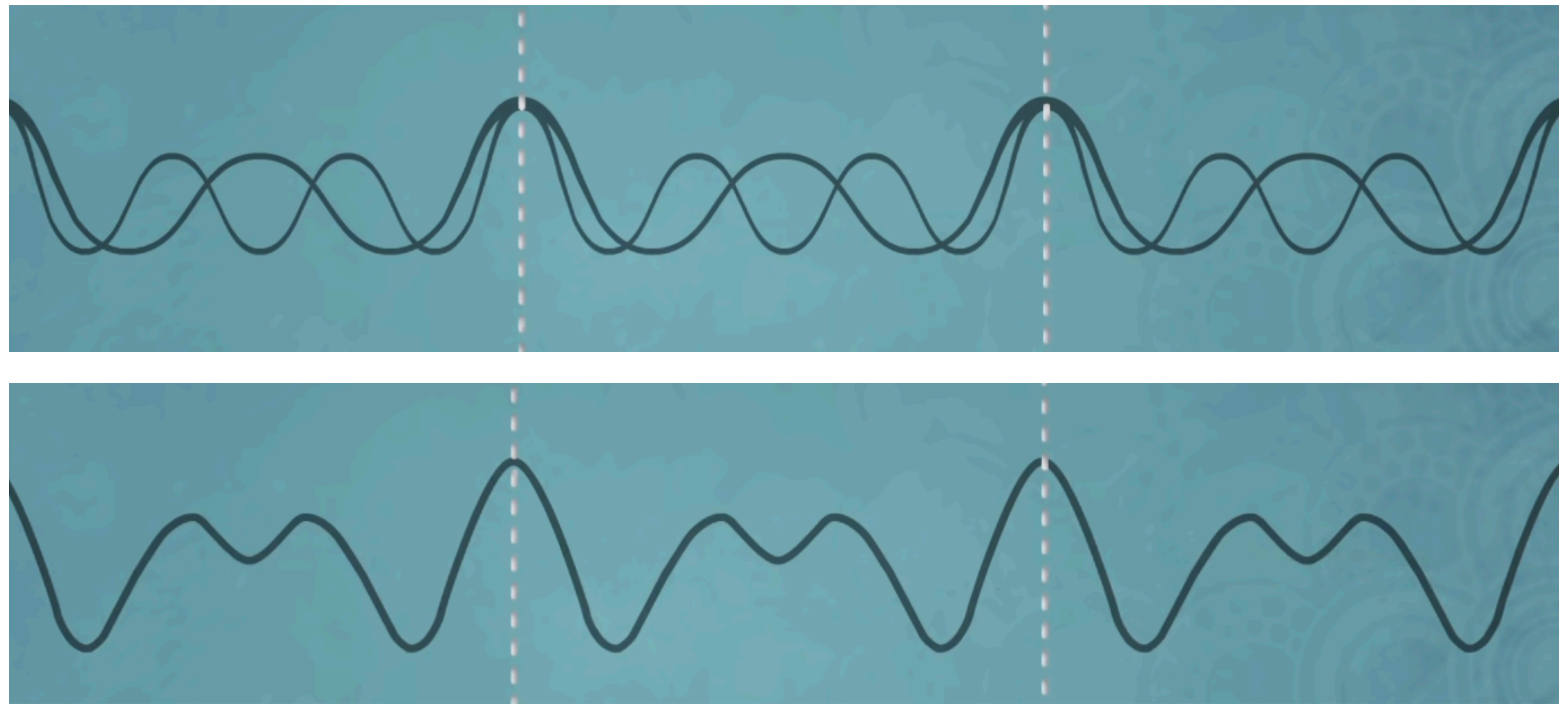
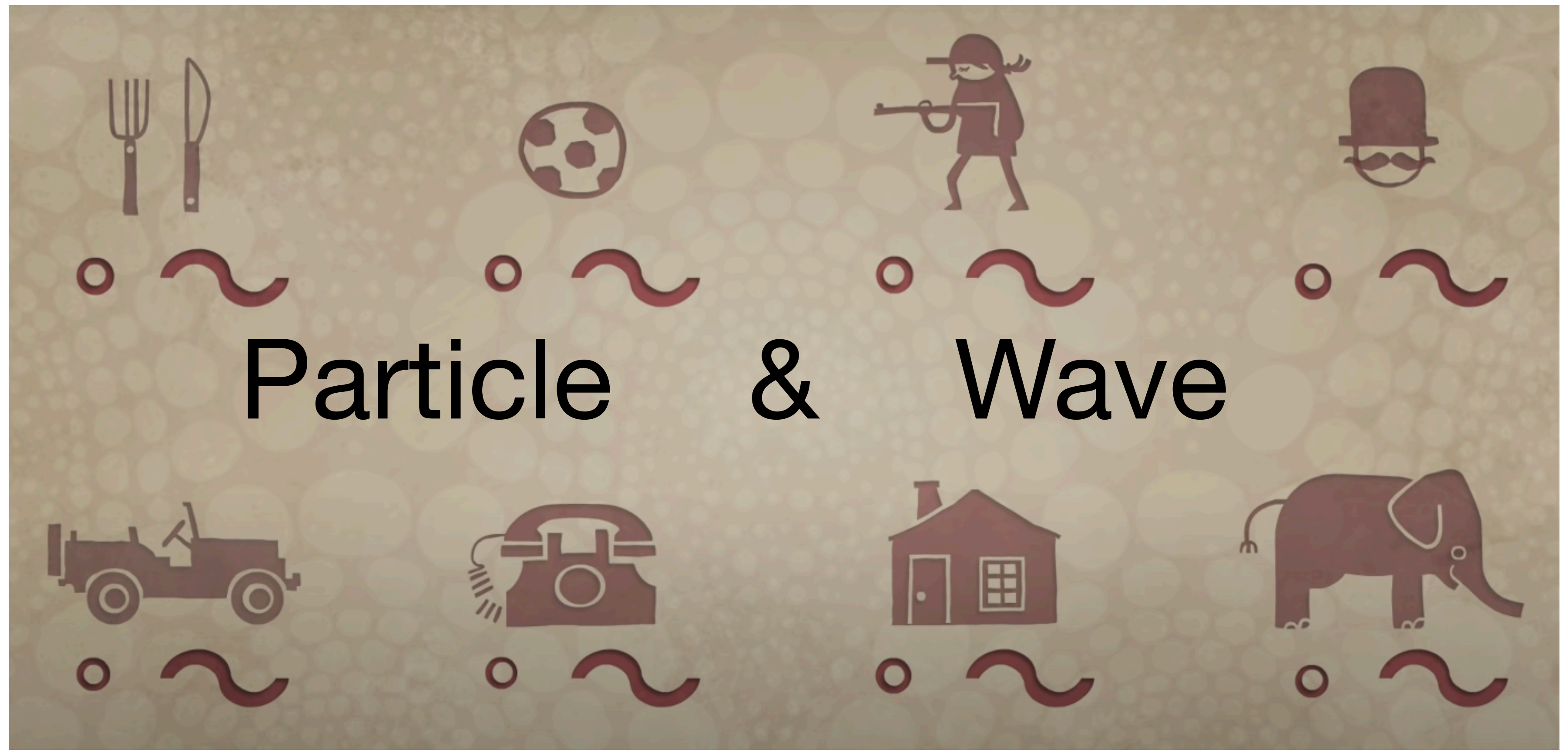
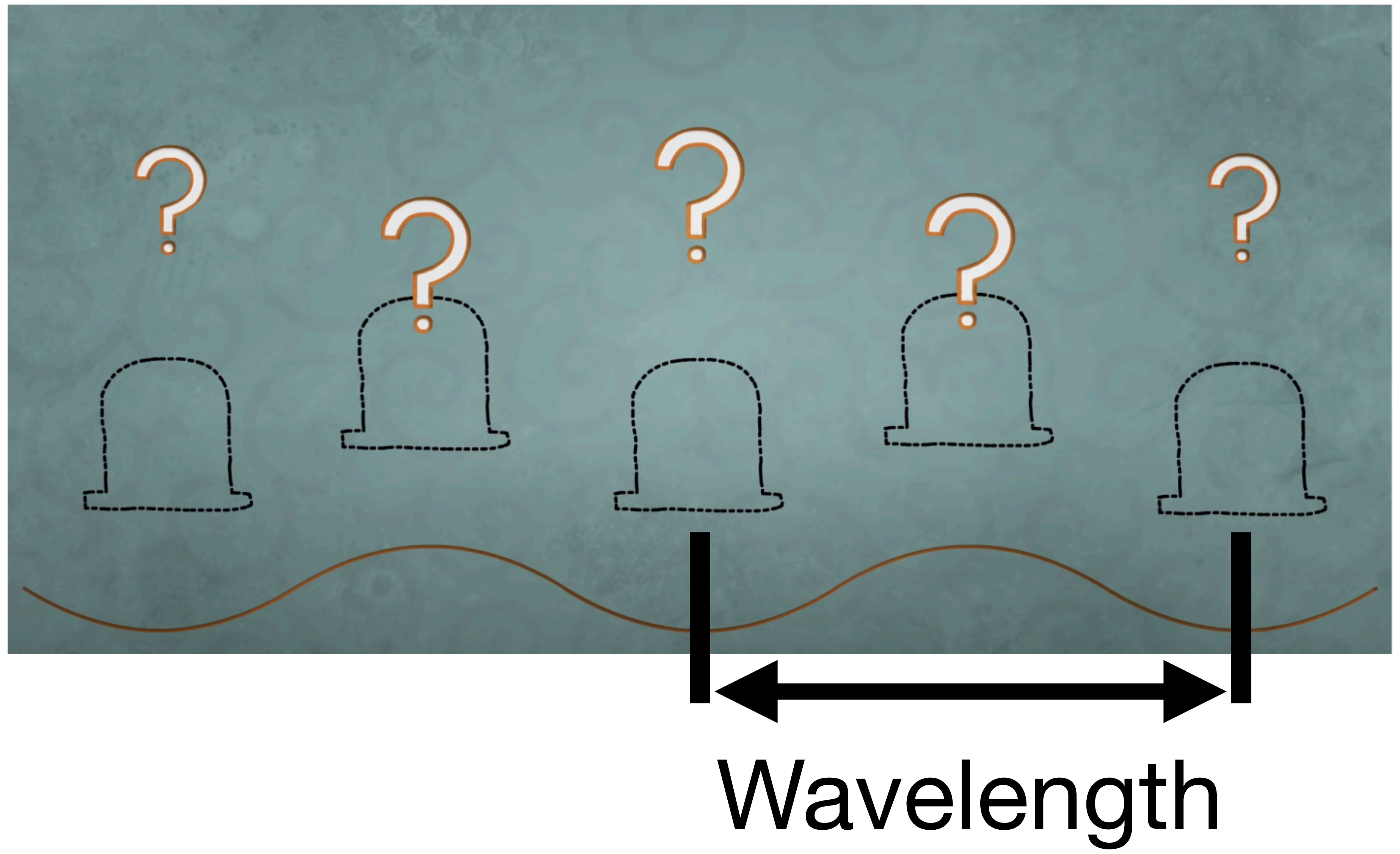
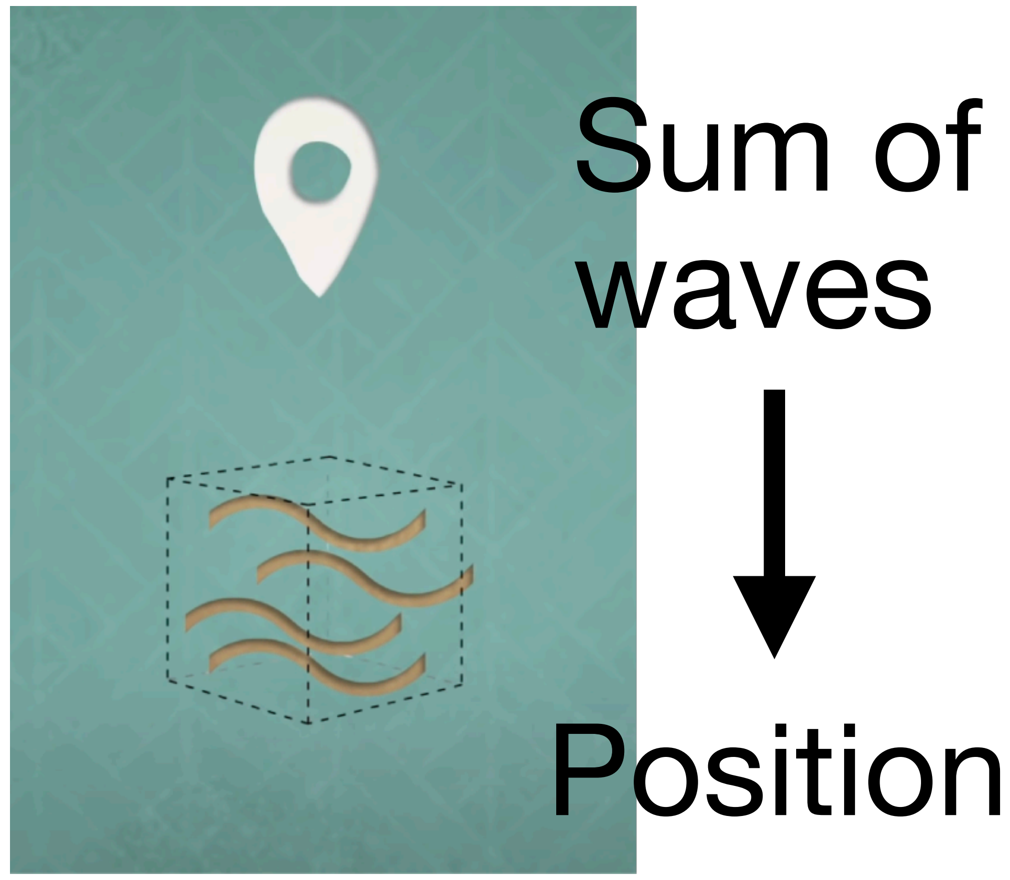
Heisenberg uncertainty principle and vacuum fluctuation

- Heisenberg uncertainty principle gives zero point energy, putting limit on measurement

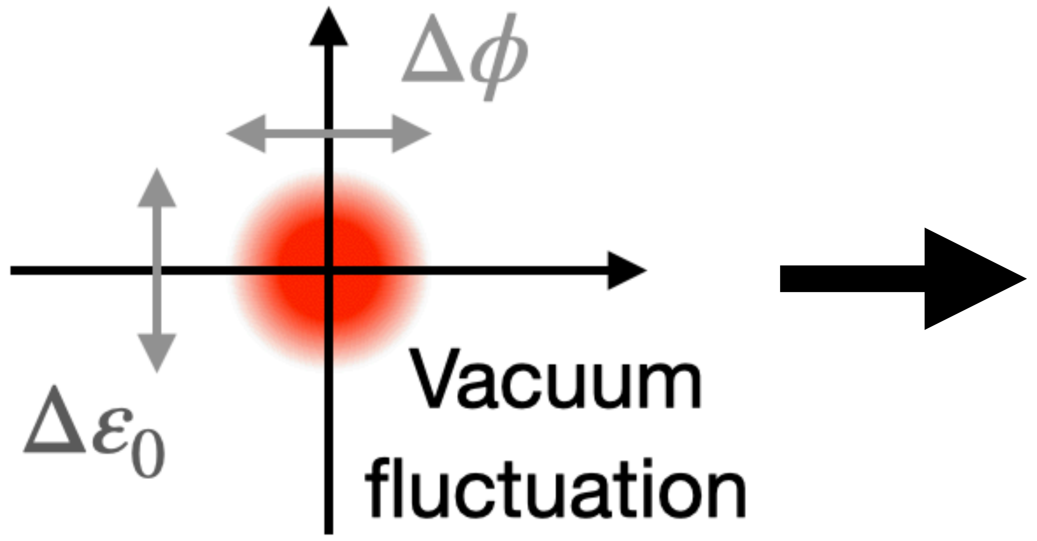








Credit: https://www.youtube.com/watch?v=TQKELOE9eY4&t=11s



- This zero point energy leads to the fluctuation of amplitude and phase for the concept of electro-magnetic field, coined as **vacuum fluctuation**

The reduction of vacuum fluctuation

- The parametric down conversion causes phase-sensitive generation of photons which reduces vacuum fluctuation

Credit: Am. J. Phys. 81, 767-771 (2013)

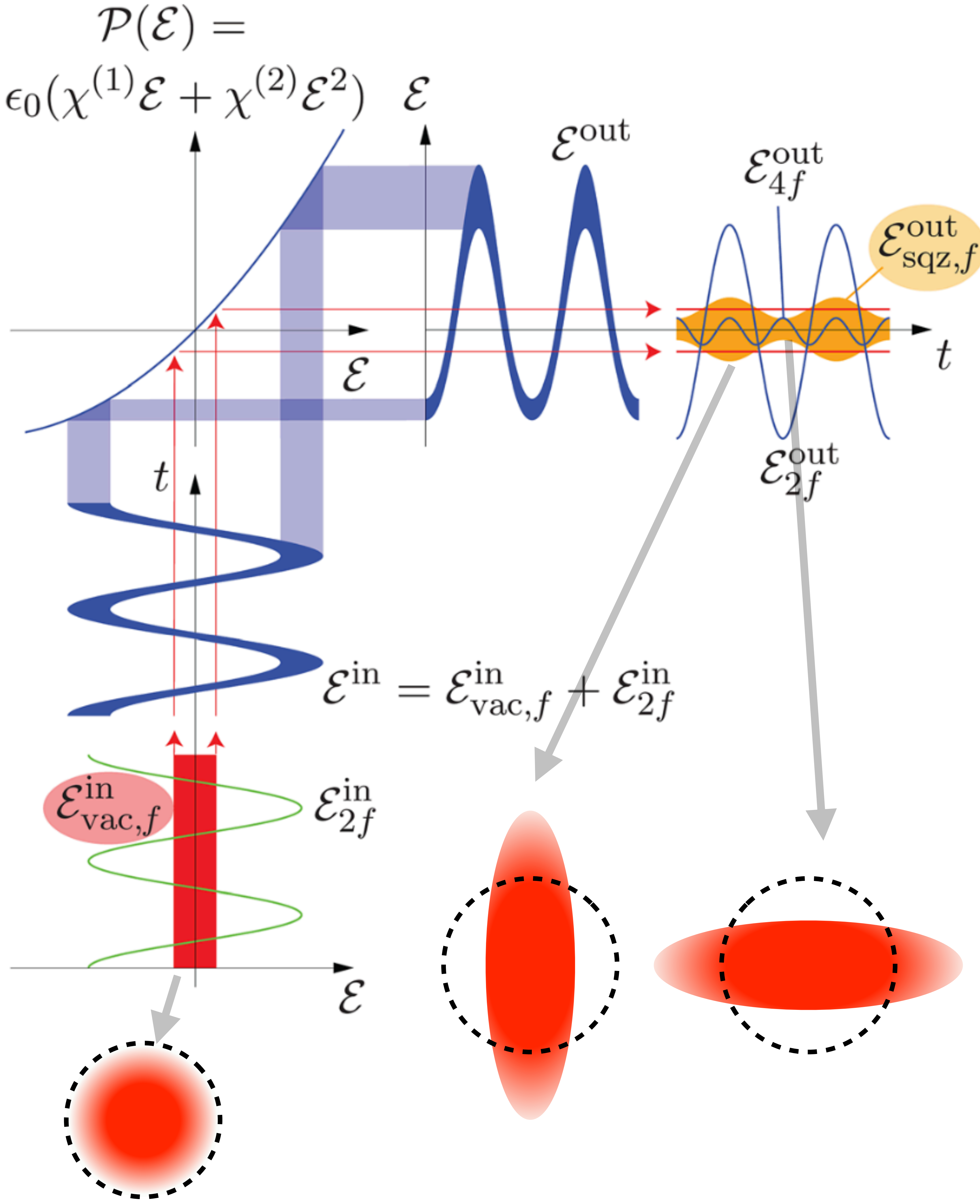
$$\mathcal{P}^{(2)}(\mathcal{E}) = \epsilon_0\chi^{(2)}\{A^2\cos^2(\omega t+\phi) + B^2\cos^2(2\omega t) - 2AB\cos(\omega t+\phi)\cos(2\omega t)\}$$

$$= \epsilon_0\chi^{(2)}\left\{\frac{1}{2}A^2[1+\underbrace{\cos(2\omega t+2\phi)}_{\propto 2\omega}] + \frac{1}{2}B^2[1+\underbrace{\cos(4\omega t)}_{\propto 4\omega}] - AB[\underbrace{\cos(\omega t-\phi)}_{\propto\omega} + \underbrace{\cos(3\omega t+\phi)}_{\propto 3\omega}]\right\}$$

Parametric down conversion

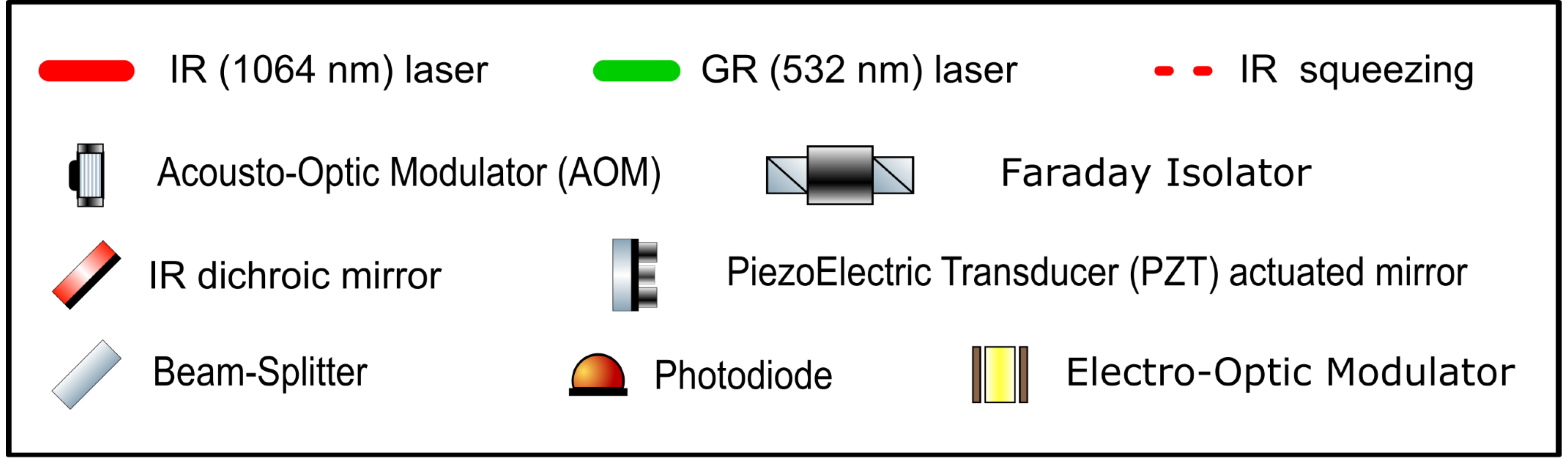
$$\mathcal{E} = A\cos(\omega t+\phi) - B\cos(2\omega t)$$

Pump

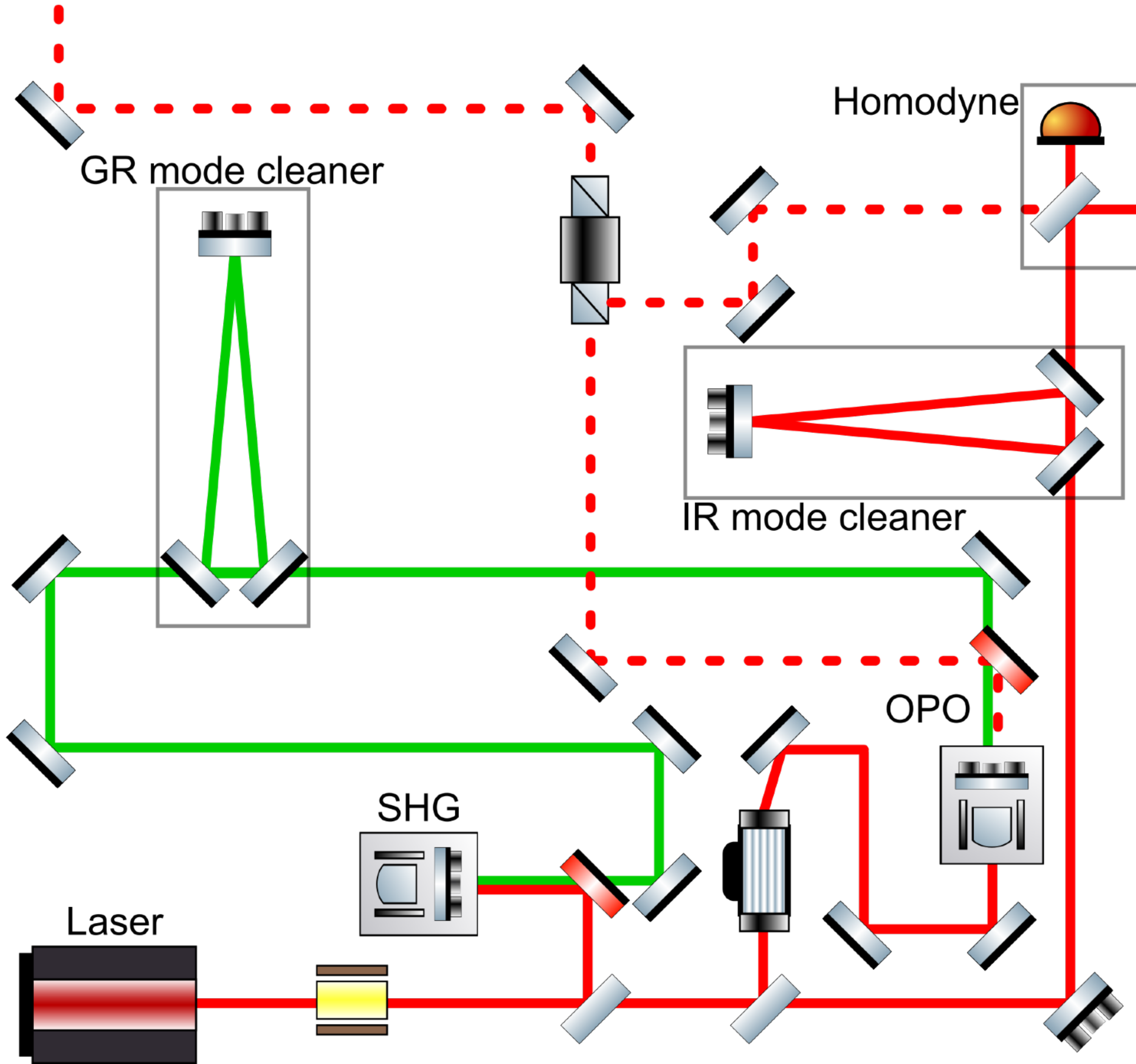


- Key ingredients:
  - Pump (2f field)
  - Non-linear effects (for parametric down conversion)

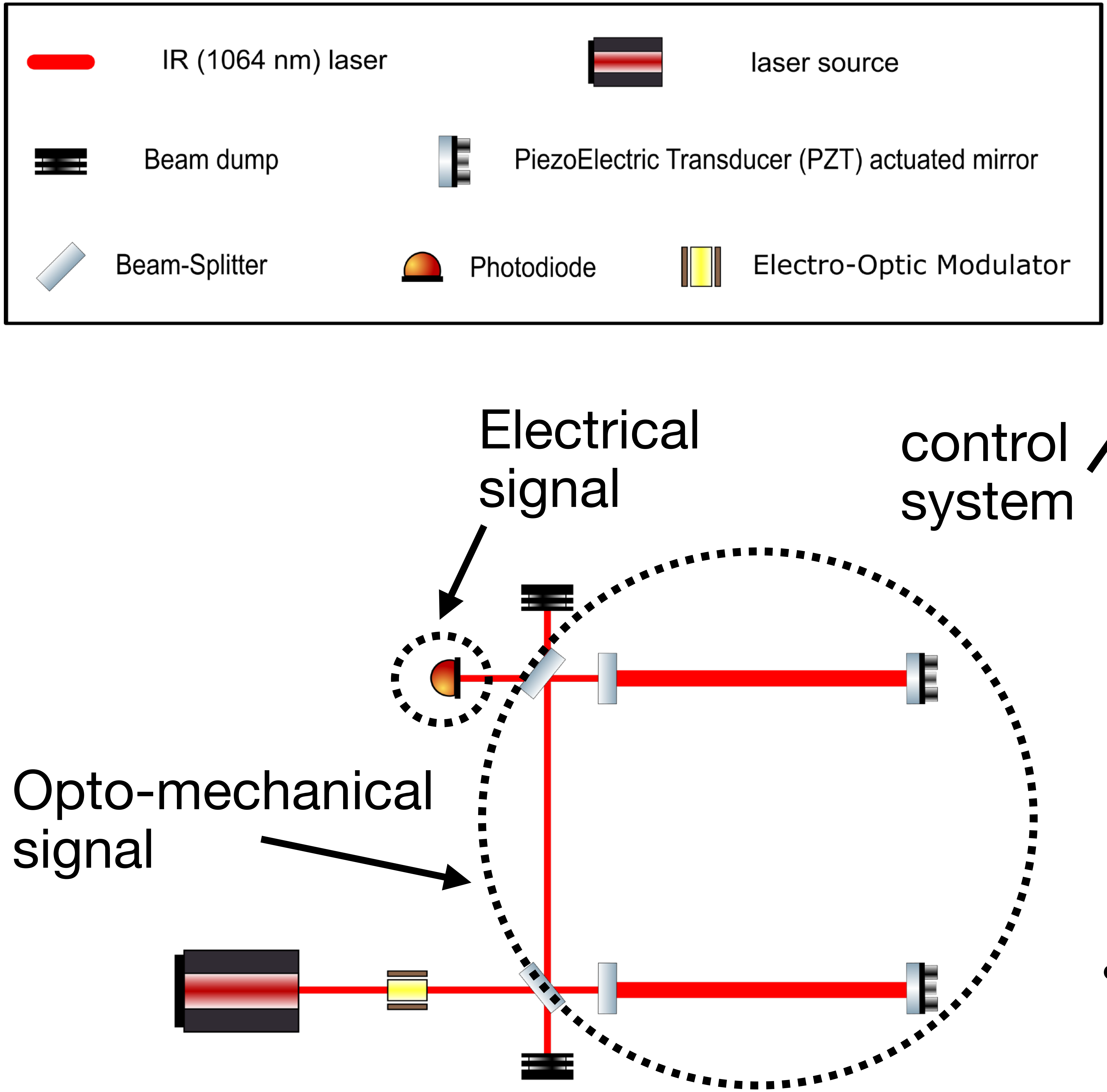
Simplified experimental setup

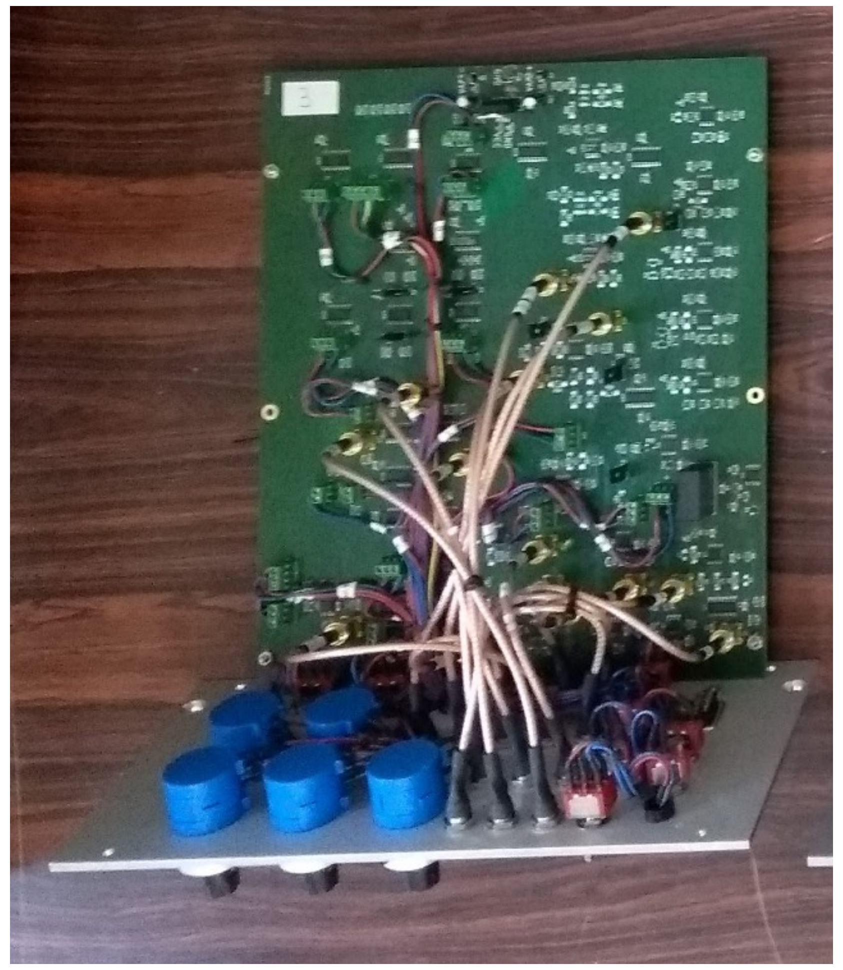


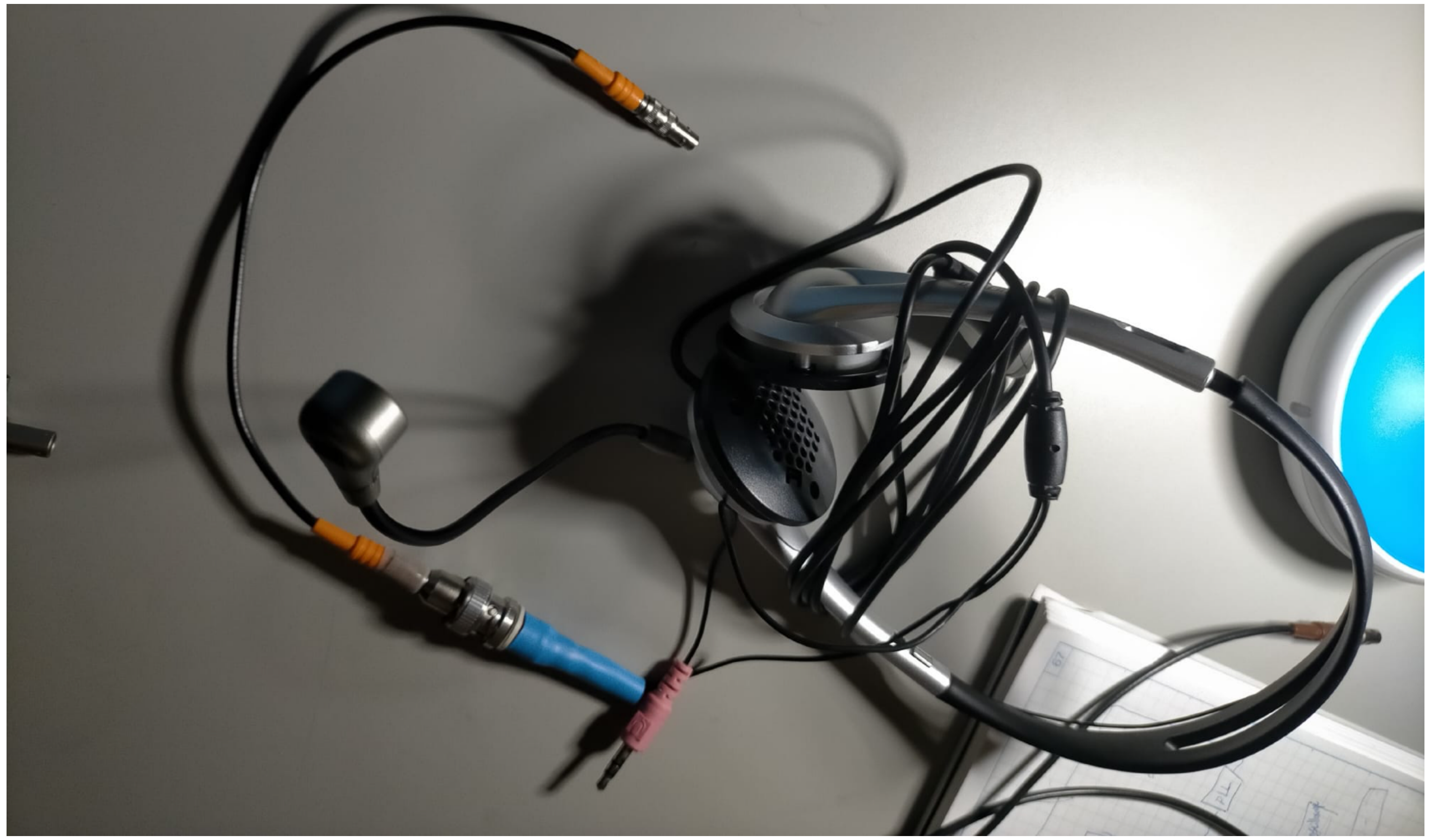
- This set-up is based on the key ingredients (pump and parametric down conversion)
- Additional components are used to guarantee the performance of squeezed vacuum generation
- Phase sensing is based on beam coming from AOM



Sonification method

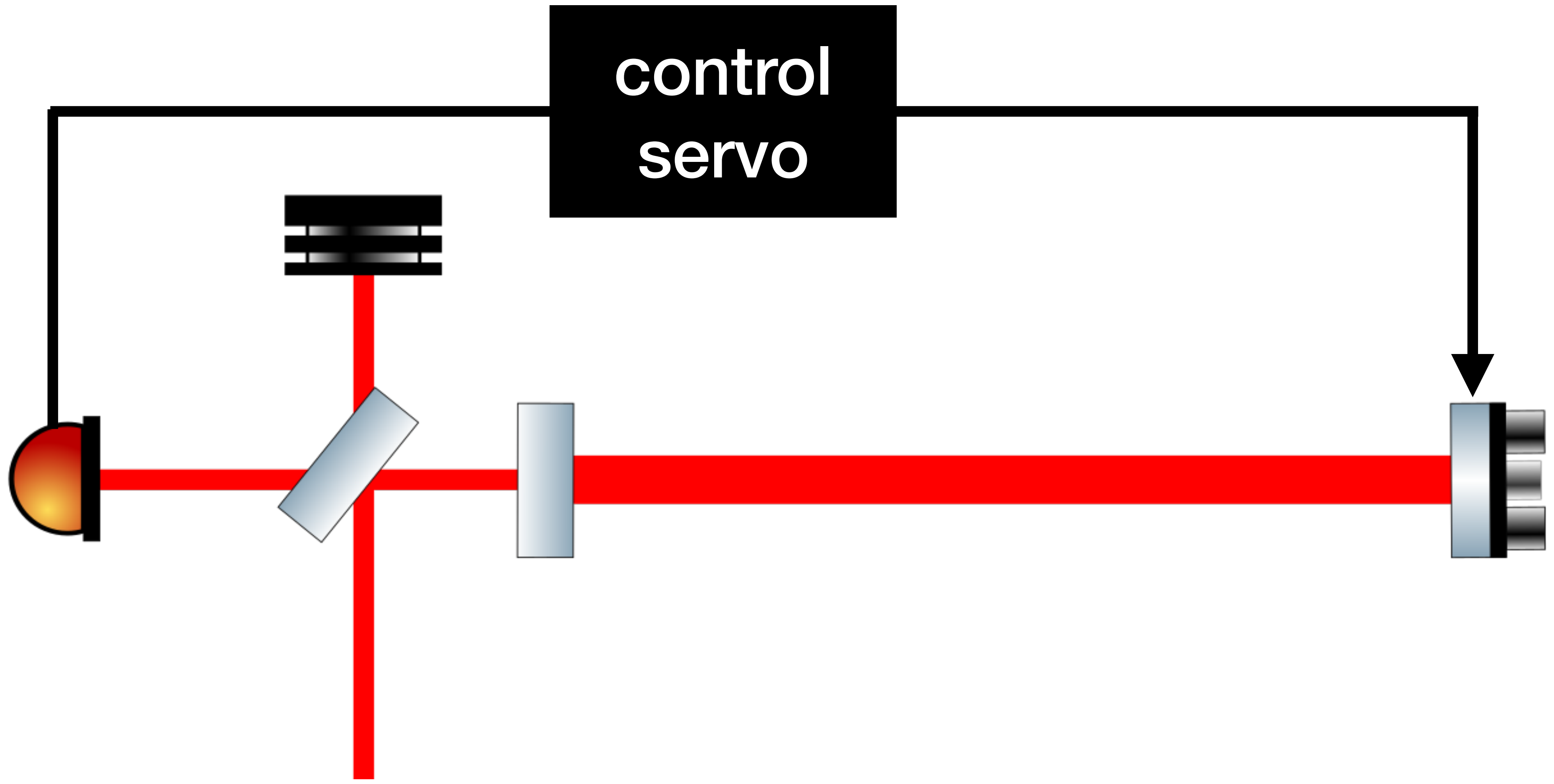


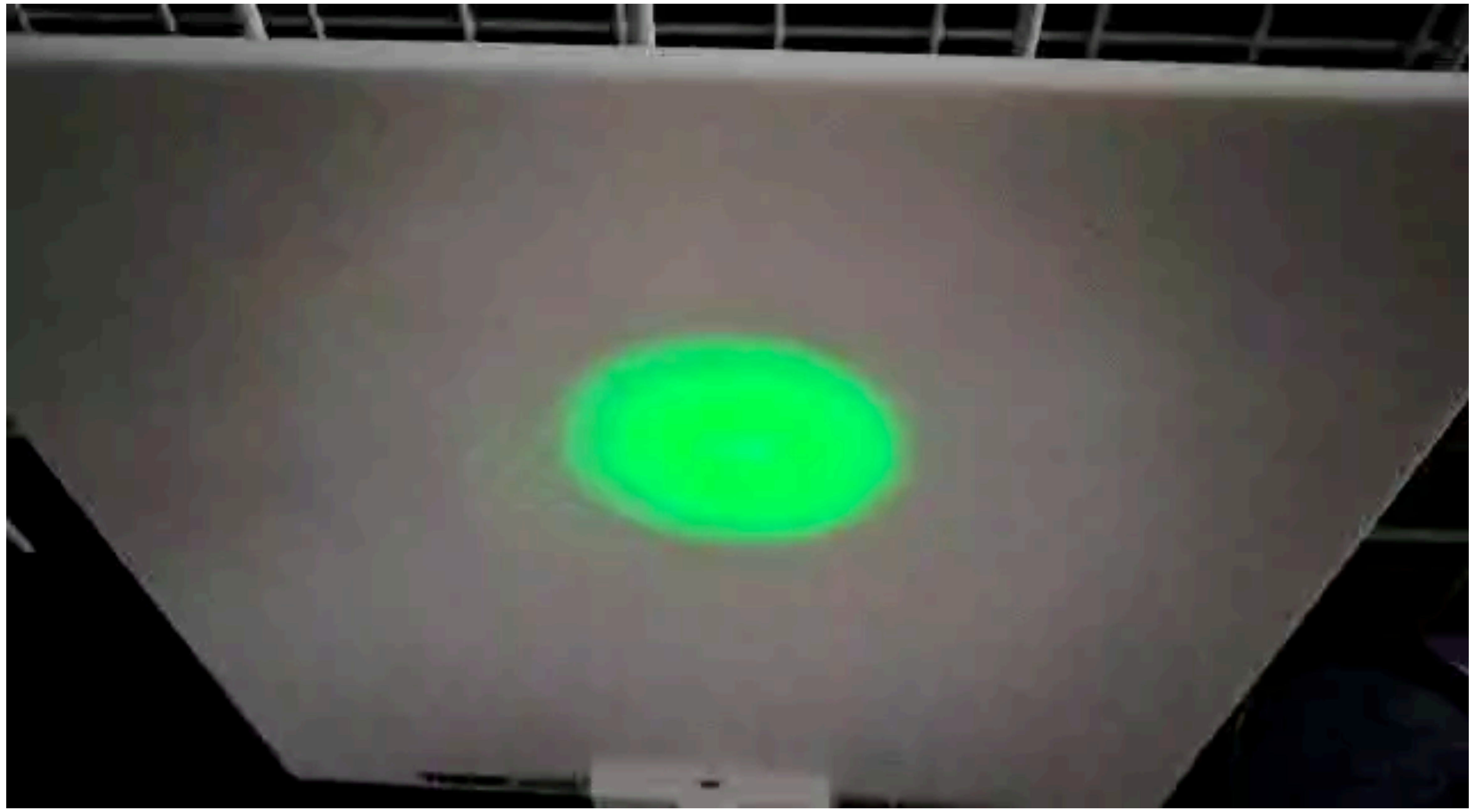


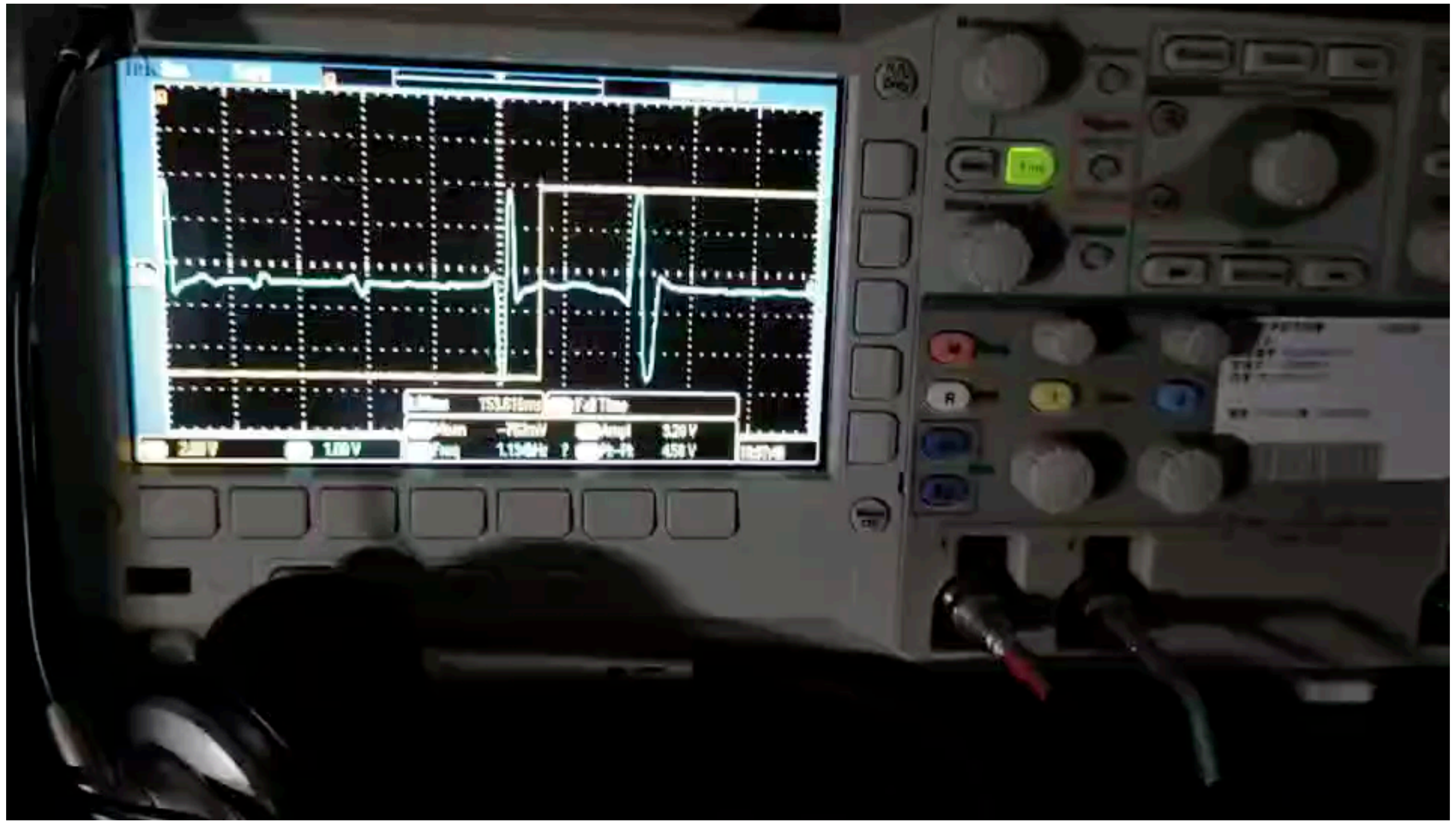


- We took a headphone, whose speaker wire is soldered with a BNC connector

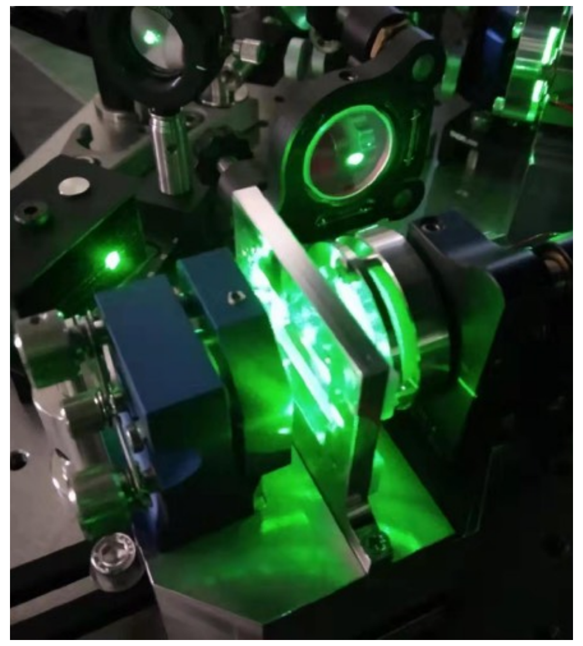
Control of interference



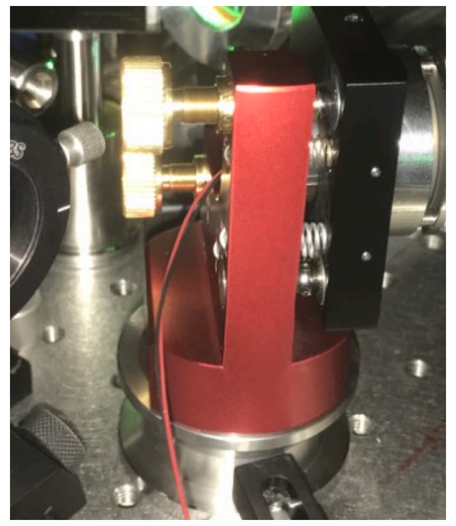




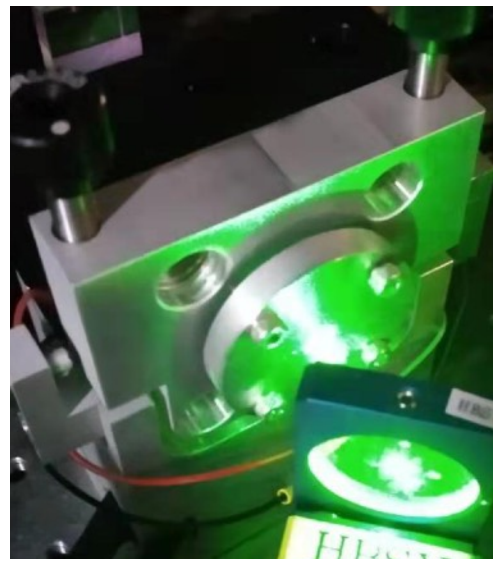
Experimental setup



Mach-Zehnder

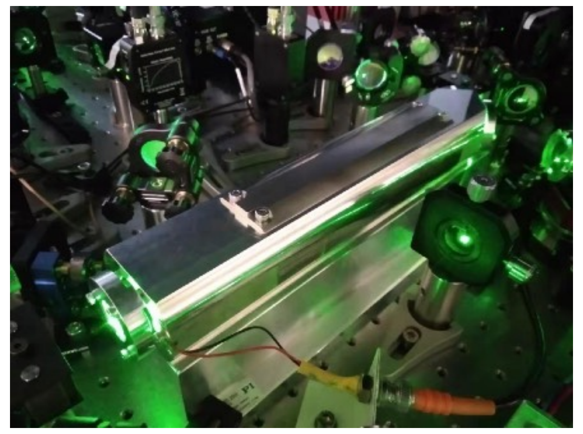


Green phase shifter

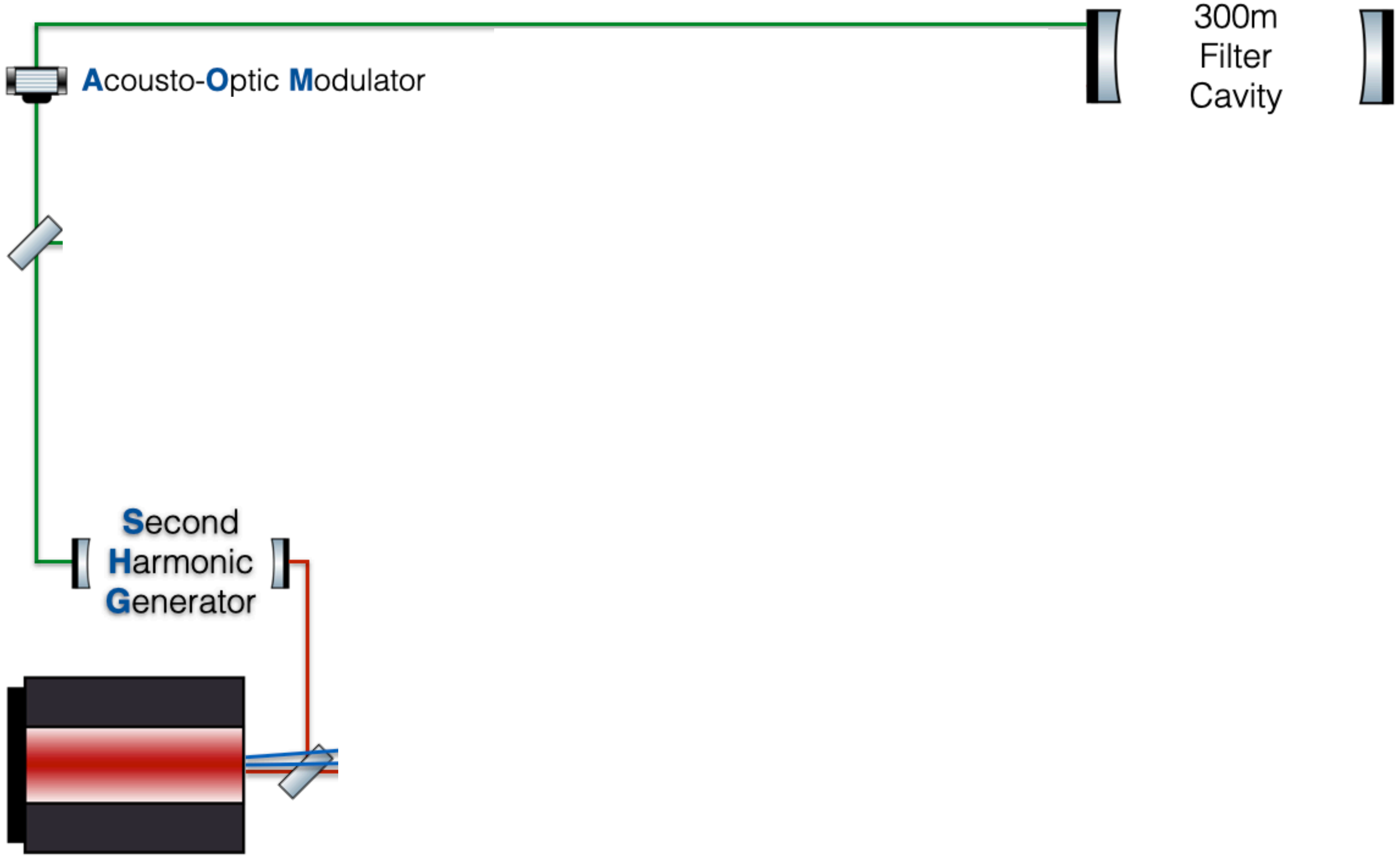


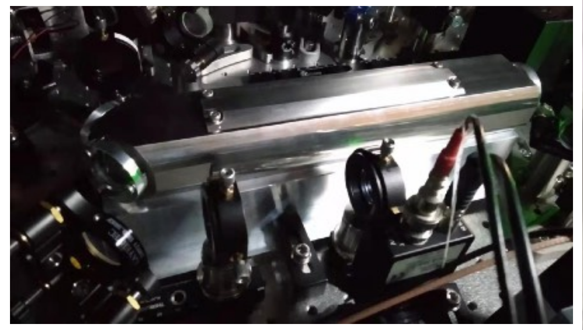
Optical parametric oscillator (OPO)

Homodyne detector

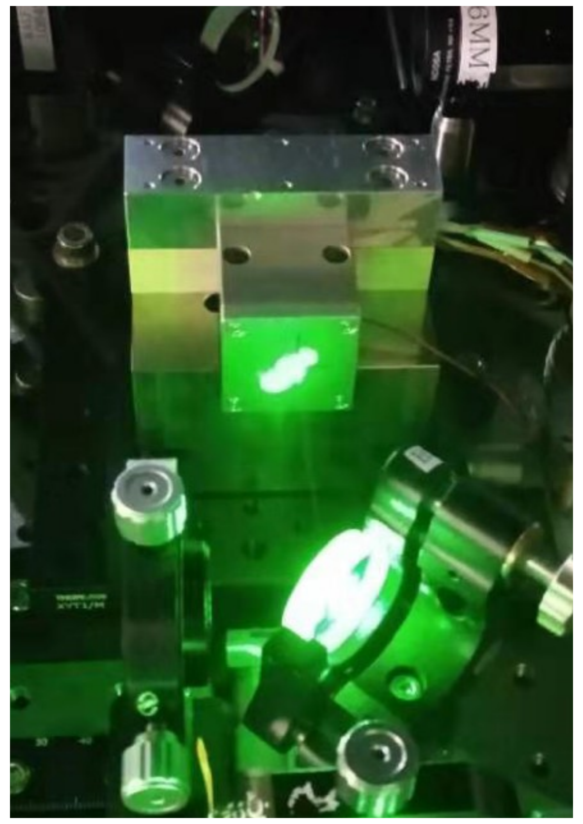


Green Mode cleaner

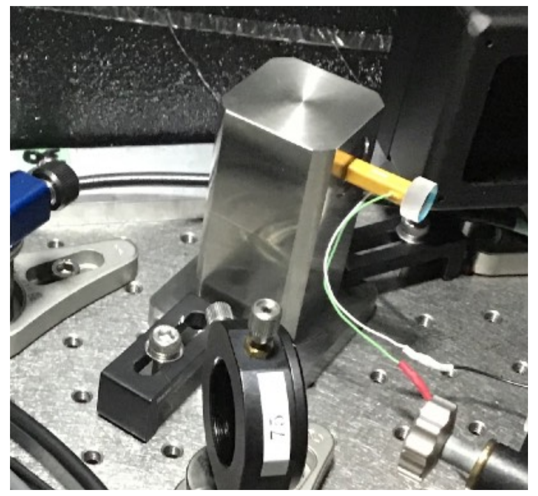




Infrared Mode cleaner



Second harmonic generator (SHG)



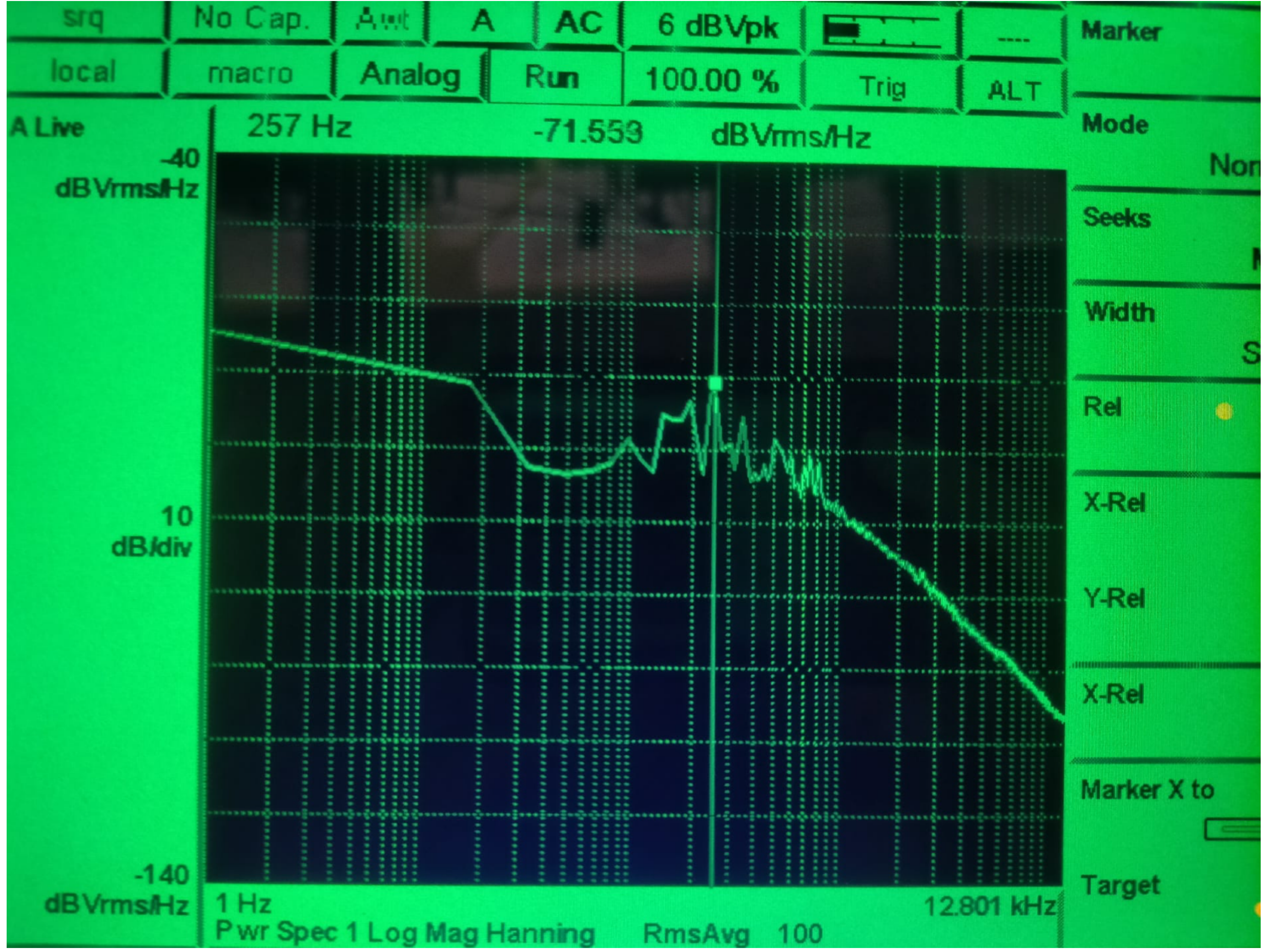
Infrared phase shifter

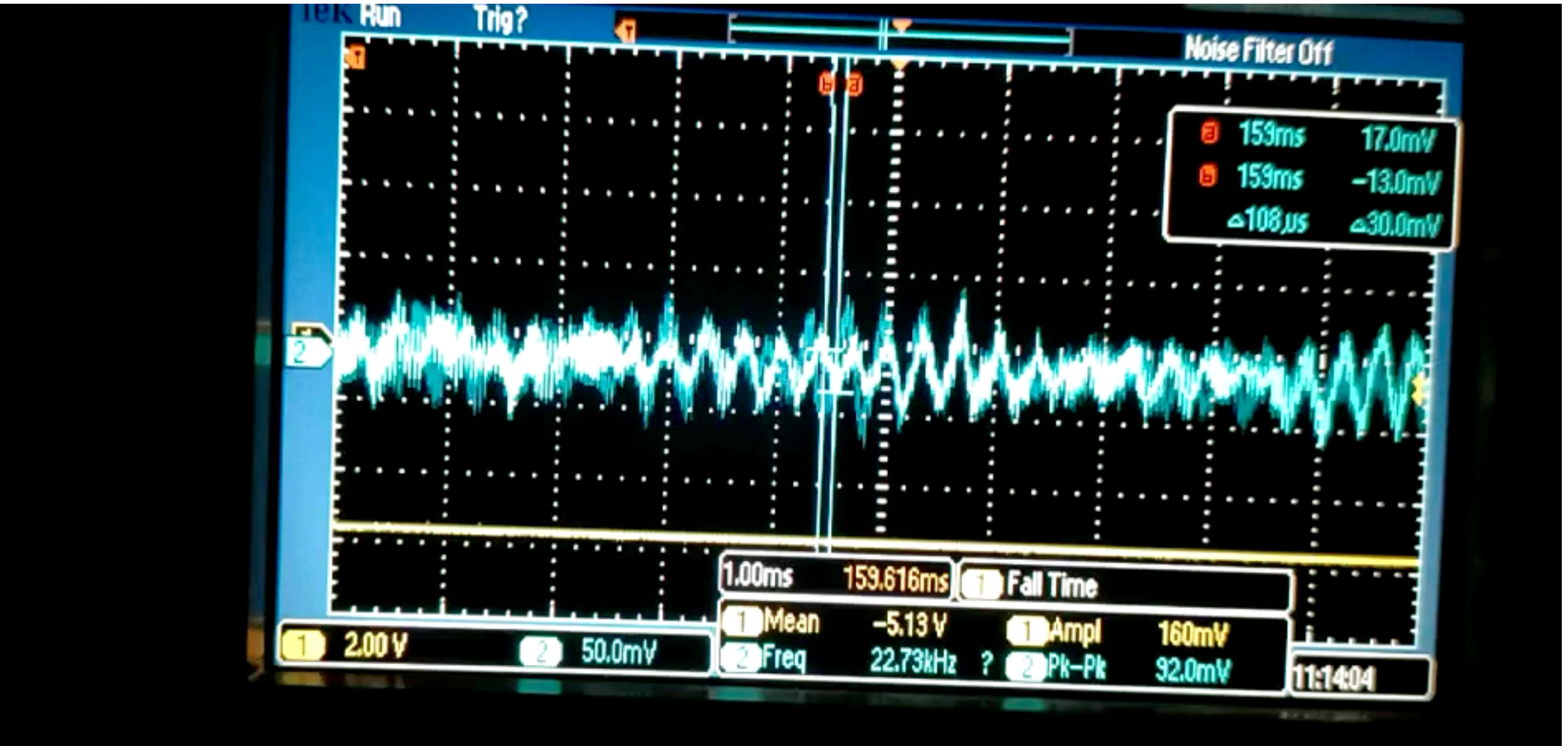
Control servos and monitors

Some sounds in the lab

Lab is in a very noisy environment (listen to the sound)

- Some control loops can get unstable depending on the opto-mechanical and loop-design structures

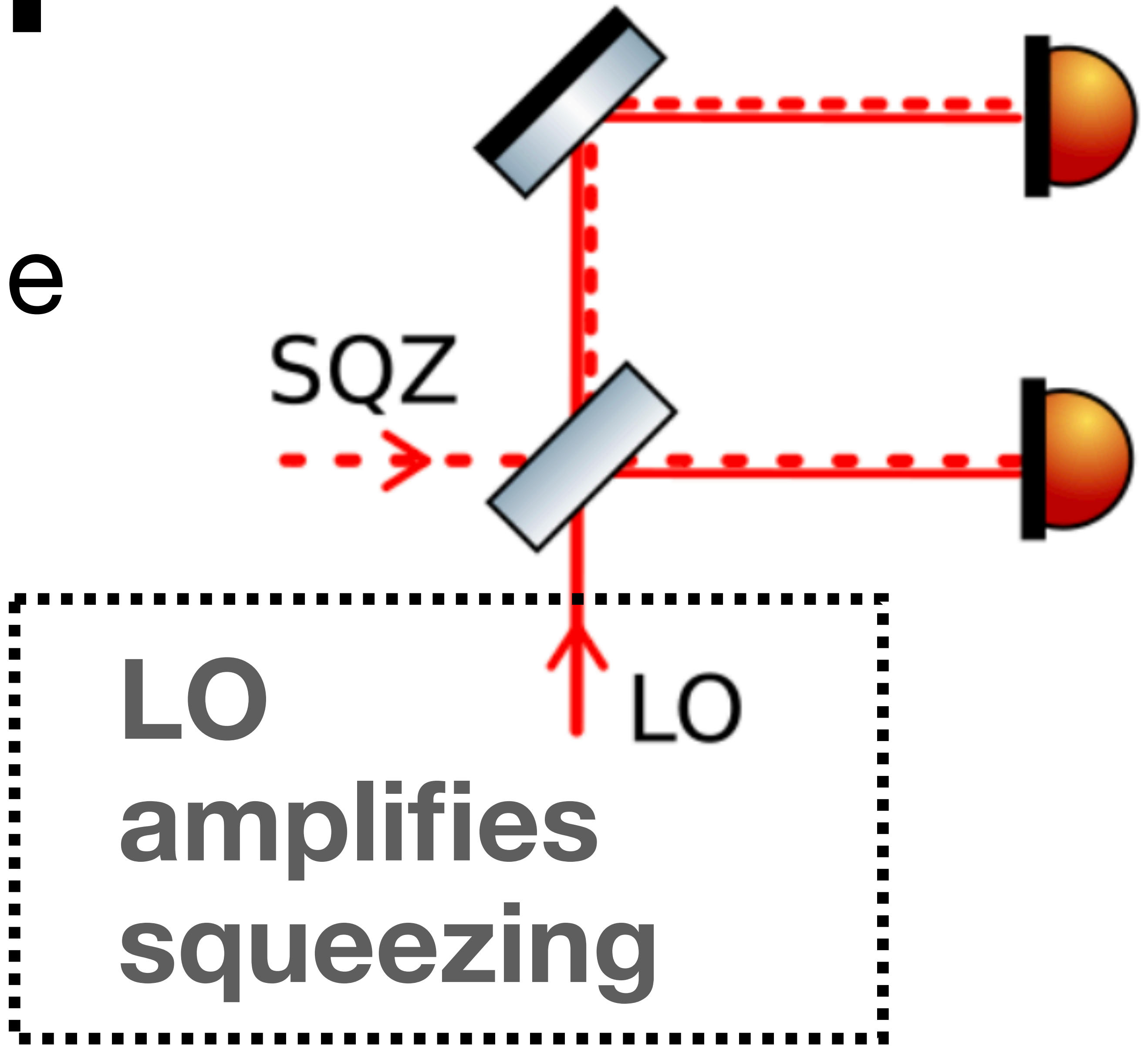




A control loop with resonances

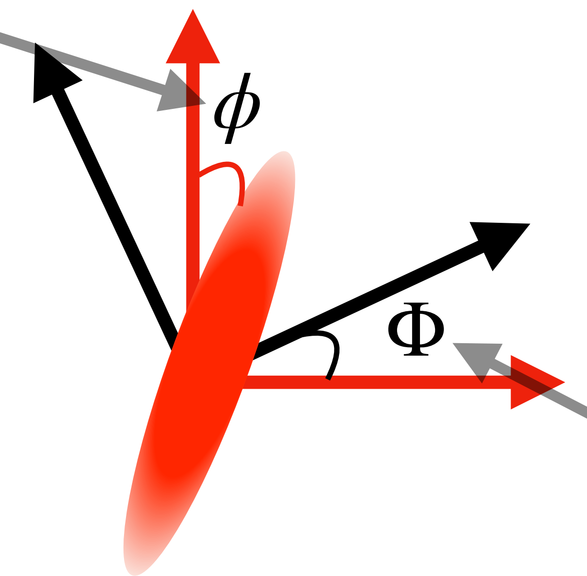
A better control loop with less resonances

The detection of squeezed vacuum



- Squeezed vacuum is only few photons, we need either single photon detections or homo-dyne detections

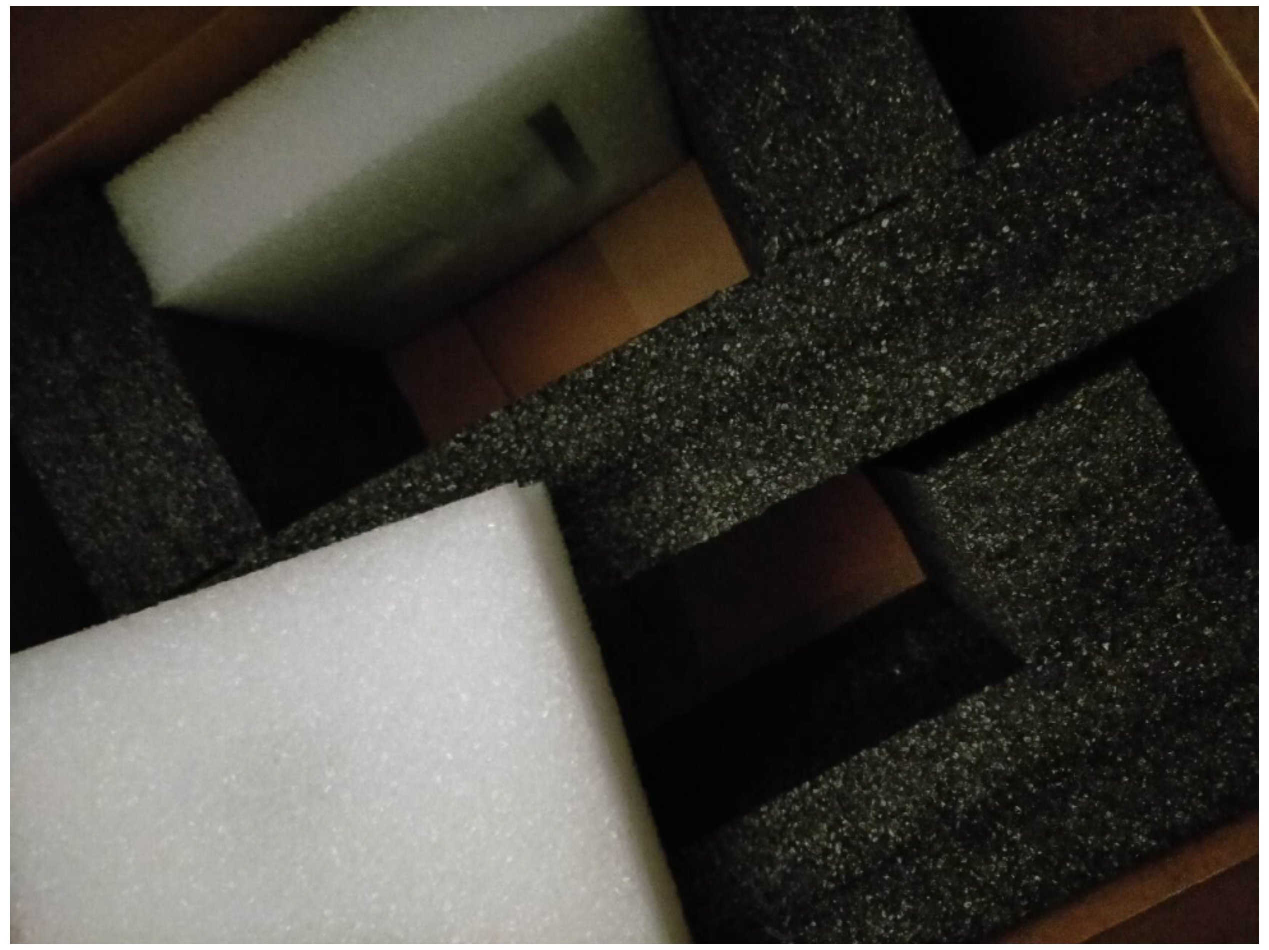
- In our experiment, we use homo-dyne detection



Some similarity

- You can feel how quiet the squeezed vacuum is, even though we are in a noisy environment

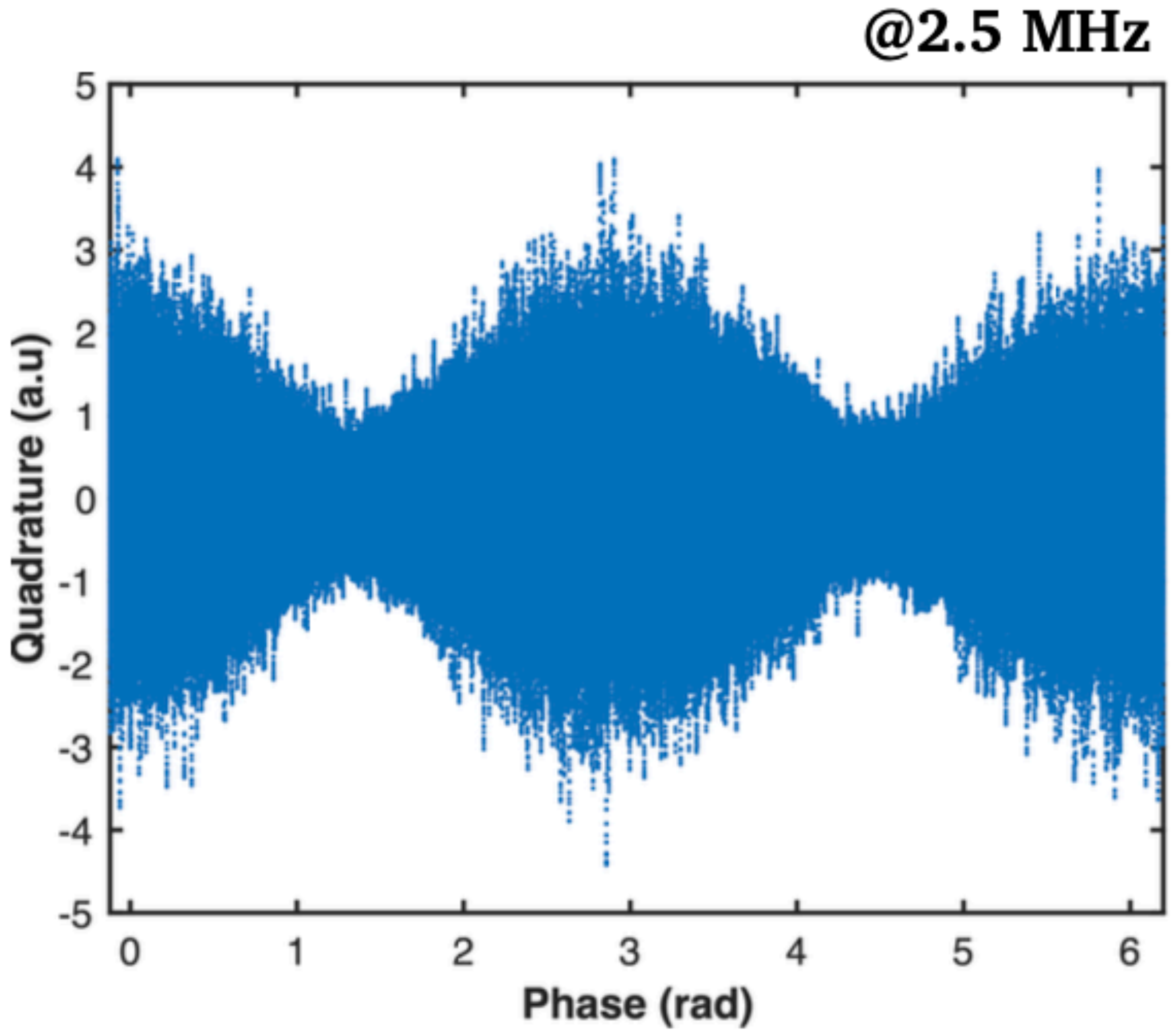
Sound is taken inside this box

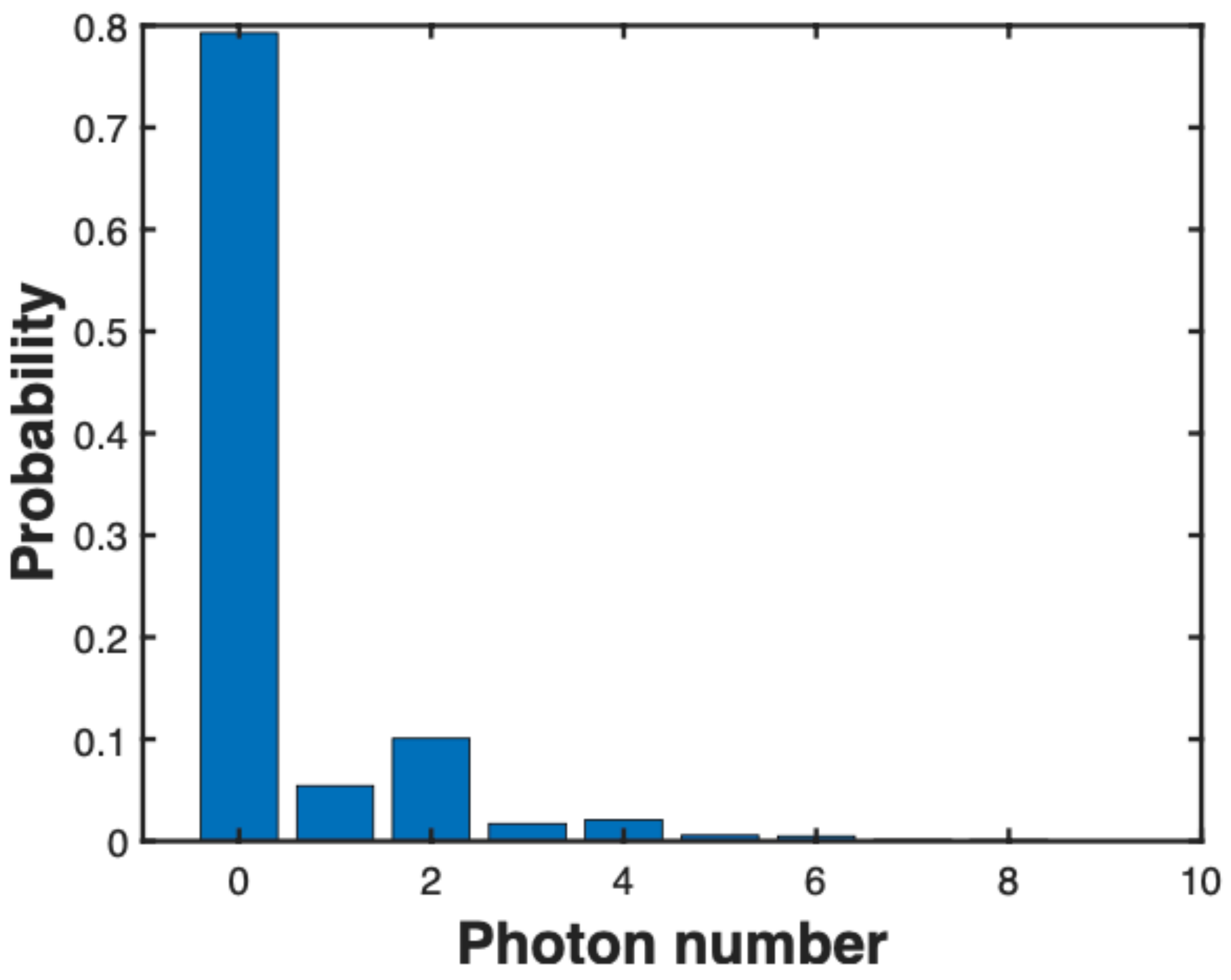


The structure of squeezed vacuum

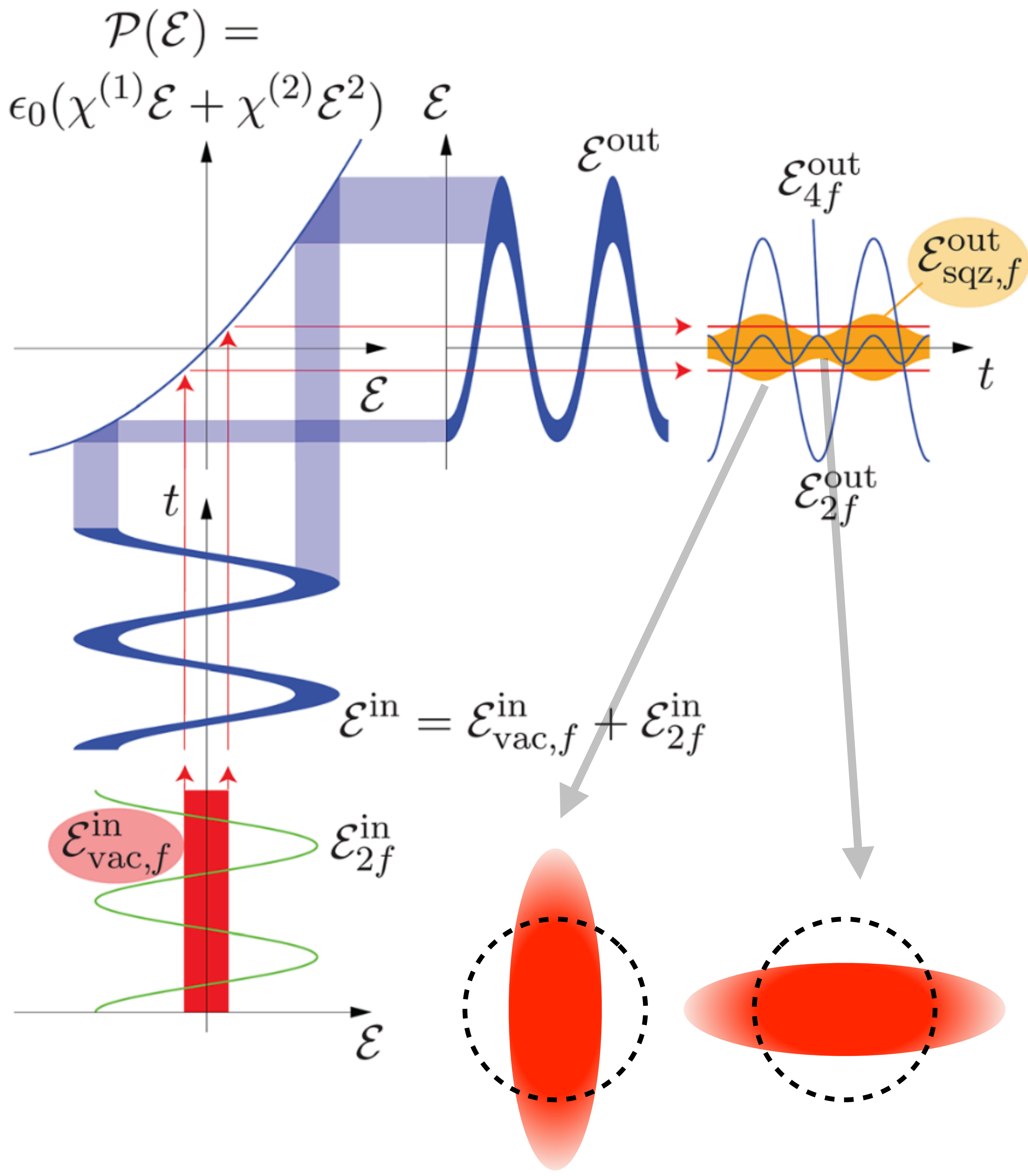
Credit: Am. J. Phys. 81, 767-771 (2013)

- As we introduced, the generation of photons is phase sensitive
- By scanning the phase of the local oscillator, we reveal the structure of squeezed vacuum





Credit: Yiru Chen



I hope you had fun when listening to squeezed vacuum!

https://gwpo.mtk.nao.ac.jp/wiki/FilterCavity