# Balanced homodyne detectors and Casimir energy densities

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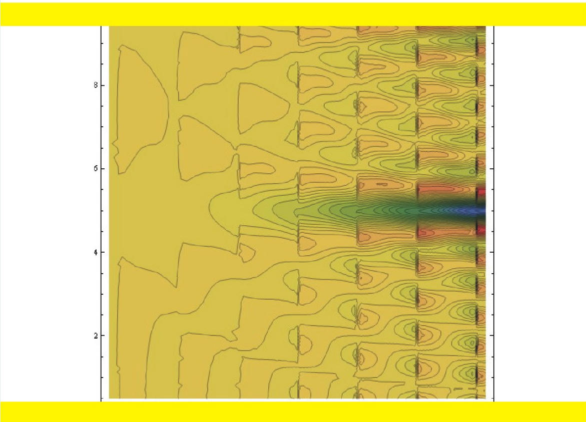
# Outline:

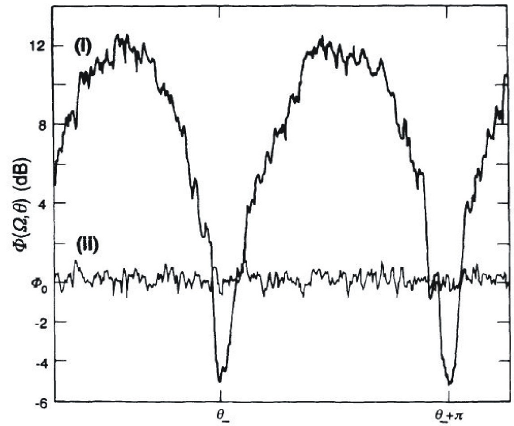
1. Photodiodes in QFT
2. Model of a balanced homodyne detector
3. Application to Casimir setups

# Motivation:

Energy densities in QFT $\langle \Omega | T_{00}(t, \vec{x}) | \Omega \rangle$



$E^2(x)$ for Casimir geometries



$E^2(x)$ for squeezed states

## (1) Description of photodiodes in QFT

- PIN junction; an electron in a localized bound state $|0\rangle$ is excited by the quantum filed to a scattering state $|\vec{q}\rangle$
- Simplification: linear interaction

$$V_{int} = ex^i \otimes E_i(t, \vec{x}) \cdot g(t)$$

- Perturbative calculation of the response. First order result:

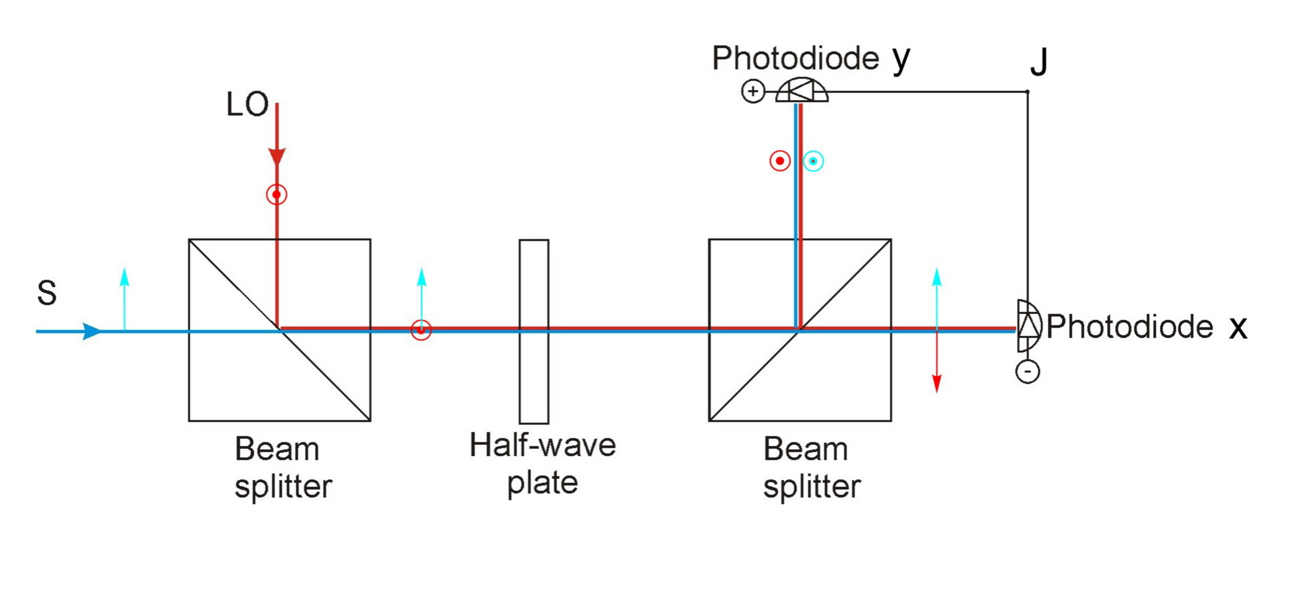
$$P_{exc}(g) = \underbrace{\int d\tau\, ds\, g(\tau) g(s)}_{\text{temporal sensitivity}} \underbrace{\int dq\, \langle 0|x^i(\tau)|\vec{q}\rangle\langle\vec{q}|x^j(s)|0\rangle}_{\text{electronic correlation funct.}} \underbrace{\langle E_i(\tau) E_j(s)\rangle_S}_{\text{field correlation funct.}}$$

  Here $S$ is the initial state of the quantum radiation field.

- The probability $P_{exc}(g)$ is negligible for vacuum and ground states

## (2) Balanced homodyne detector with a local oscillator

- Two photodiodes with their output subtracted
- Additional coherent light of frequency $\omega$ ("Local Oscillator")
- The quantum field (S) de-balances the detector (stochastic process of measurement)



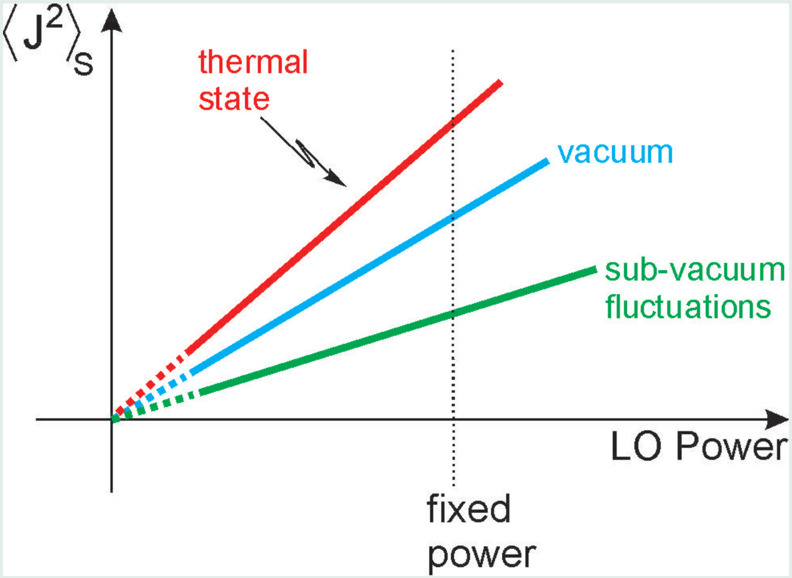

State $S$ is arbitrary (can be vacuum, ground, squeezed or thermal).

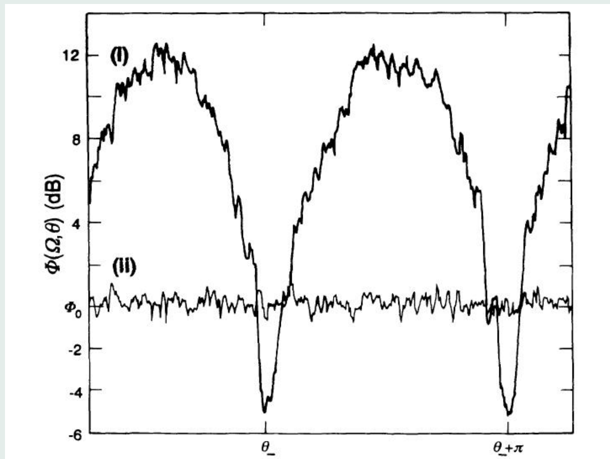
## BHD with LO: output

$$\langle J \rangle = \alpha_{el} \cdot E^i_{LO} \cdot \langle E_i(t, \vec{x}) \rangle_S$$

$$\langle J^2 \rangle = \alpha^2_{el} \cdot \underbrace{E^i_{LO} E^j_{LO}}_{LO\ power} \cdot \underbrace{\langle E_i(t, \vec{x})\, E_j(t, \vec{x}) \rangle_S}_{Quantum\ field\ 2pt\ funct.}$$

- all field operators are restricted to the frequency of the LO
- $\langle J^2 \rangle$ is proportional to LO power



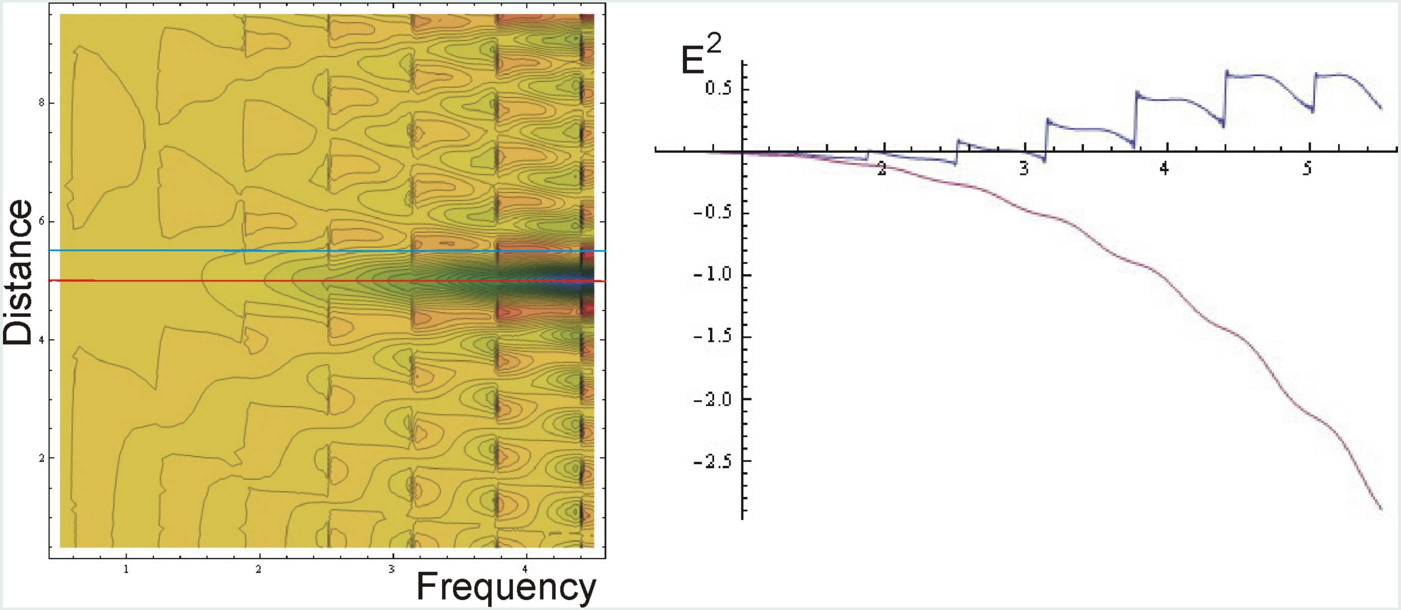




Various states of Quantum Fields (with $\langle J \rangle = 0$) on BHD with LO

## (3) Application to Casimir setups

Spectrum of the fluctuations (Hacyan et al, 1990; Ford, 1988-present) of the electric field:

$$\sigma(\omega, \vec{x}) = \int_{-\infty}^{\infty} e^{i\omega t} \langle E_y(t, \vec{x}) E_y(0, \vec{x}) \rangle_{Ground\, state}$$




$$\langle J^2 \rangle = \alpha_{el}^2 (E_{LO}^y)^2 \int d\tilde{\omega}\, \sigma(\tilde{\omega}, \vec{x})\, |\hat{g}(\tilde{\omega} - \omega)|^2$$

for ground states; $\hat{g}(\omega)$ is sharply peaked around $\omega = 0$.

## Summary

- BHDs with local oscillators provide detailed measurements of n-point functions of states of the quantum electromagnetic field
- These measurements have already shown sub-vacuum expectation values of $E^2$ for squeezed states (states darker than vacuum)
- Casimir geometries provide environmets with non-trivial, $\vec{x}$ and $\omega$ dependent, often sub-vacuum, $E^2$

Details in **quant-ph/0703076**