dynamical casimir effect using SQUIDS

DYLAN MAHLER

GROUP MEETING

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Dynamical Casimir Effect in a Superconducting Coplanar Waveguide

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We investigate the dynamical Casimir effect in a coplanar waveguide (CPW) terminated by a superconducting quantum interference device (SQUID). Changing the magnetic flux through the SQUID parametrically modulates the boundary condition of the CPW, and thereby, its effective length. Effective boundary velocities comparable to the speed of light in the CPW result in broadband photon generation which is identical to the one calculated in the dynamical Casimir effect for a single oscillating mirror. We estimate the power of the radiation for realistic parameters and show that it is experimentally feasible to directly detect this nonclassical broadband radiation.

LETTER

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Observation of the dynamical Casimir effect in a superconducting circuit

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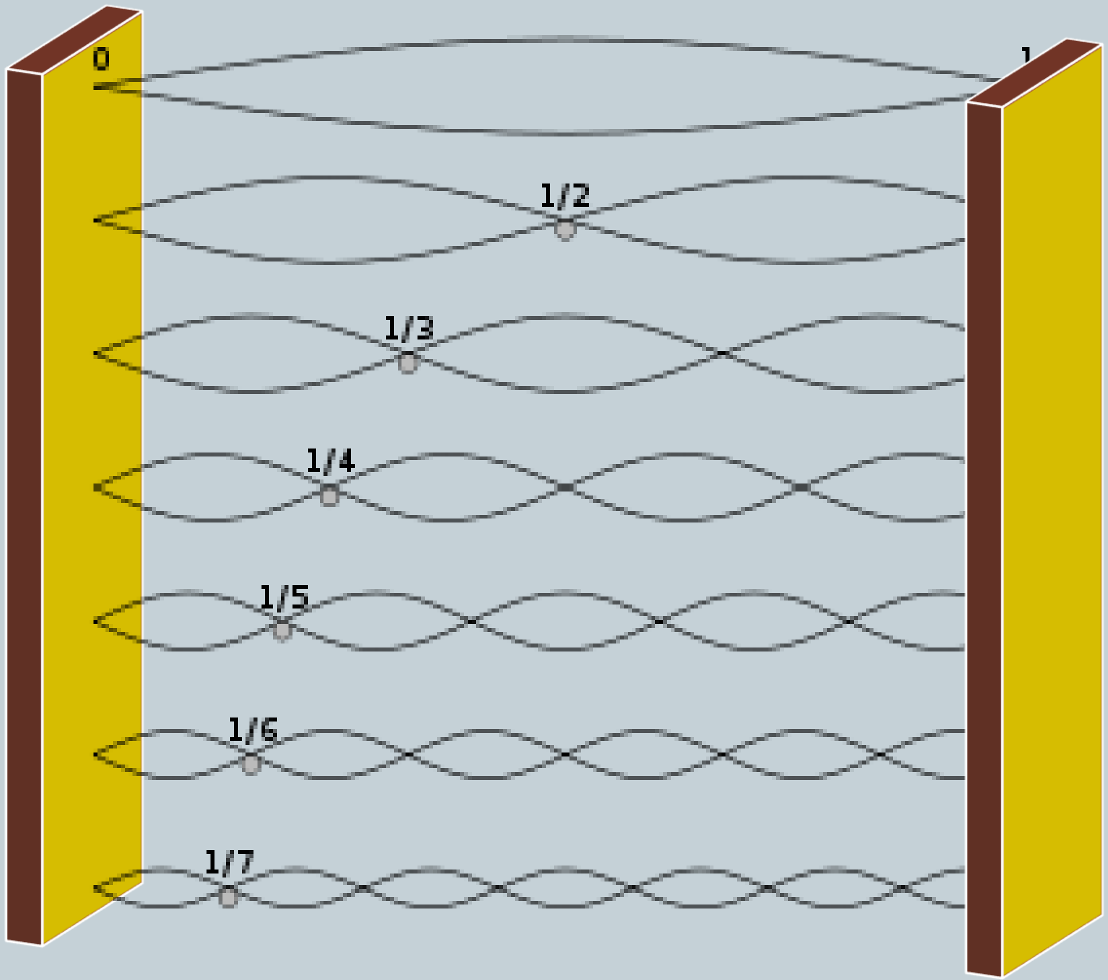
outline

- Casimir effect
- Dynamical Casimir Effect
- SQUIDS as mirrors
- The Experiment

the casimir effect



casimir effect

- Energy:

$$\langle E \rangle = \frac{1}{2} \sum_n E_n$$

- Space dependant energy implies a force!

$$F(p) = - \left. \frac{\delta \langle E(s) \rangle}{\delta s} \right|_p$$

- Vacuum states yield a force?!

casimir effect

- Hilariously enough,

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Extracting electrical energy from the vacuum by cohesion of charged foliated conductors

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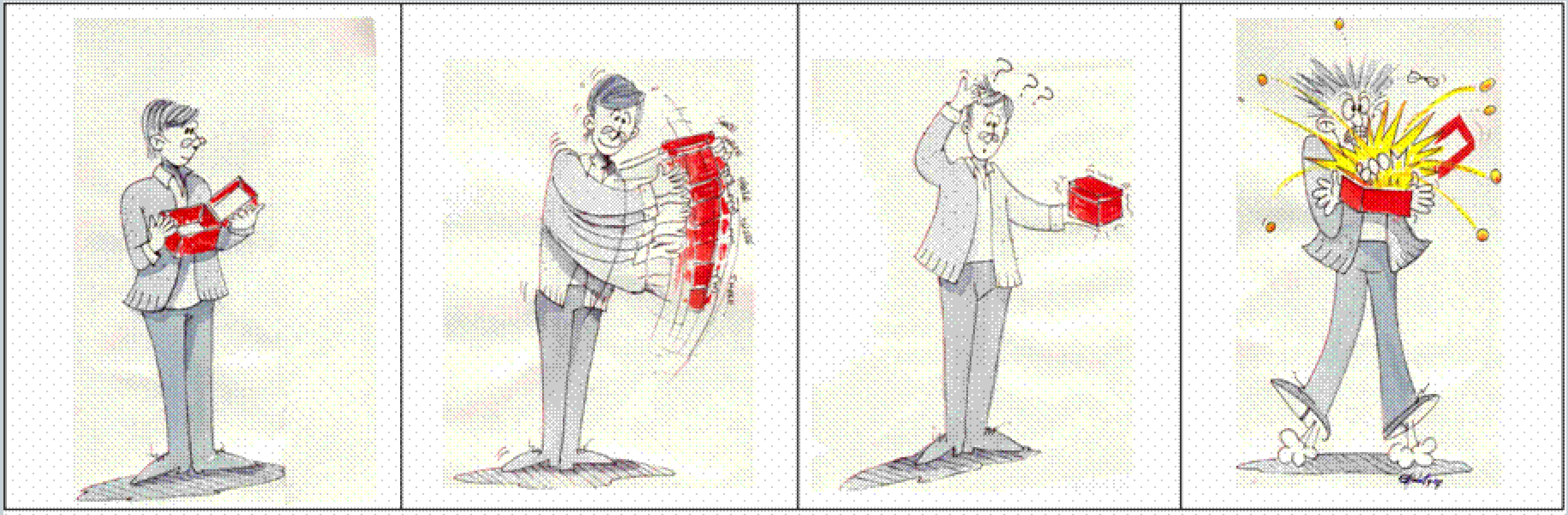
(Received 23 November 1983; revised manuscript received 16 April 1984)

Any pair of conducting plates at close distances ($<1\ \mu$m) experience an attractive Casimir force that is due to the electromagnetic zero-point fluctuations of the vacuum. A "vacuum-fluctuation battery" can be constructed by using the Casimir force to do work on a stack of charged conducting plates. By applying a charge of the same polarity to each conducting plate, a repulsive electrostatic force will be produced that opposes the Casimir force. If the applied electrostatic force is adjusted to be always slightly less than the Casimir force, the plates will move toward each other and the Casimir force will add energy to the electric field between the plates. The battery can be recharged by making the electrical forces slightly stronger than the Casimir force to reexpand the foliated conductor.

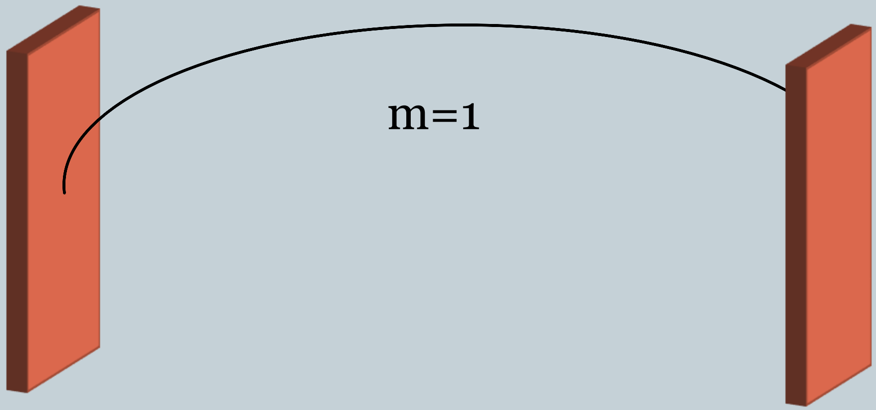
(the casimir spaceship!)

dynamical casimir effect

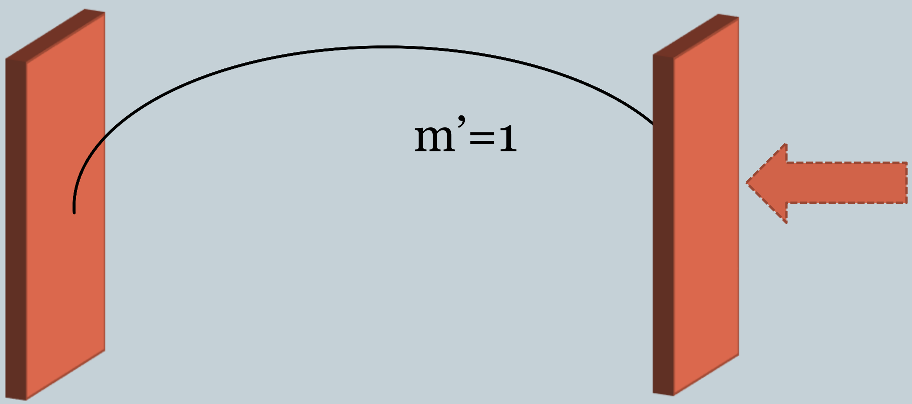


dynamical casimir effect

- At t=0



- At t=t'



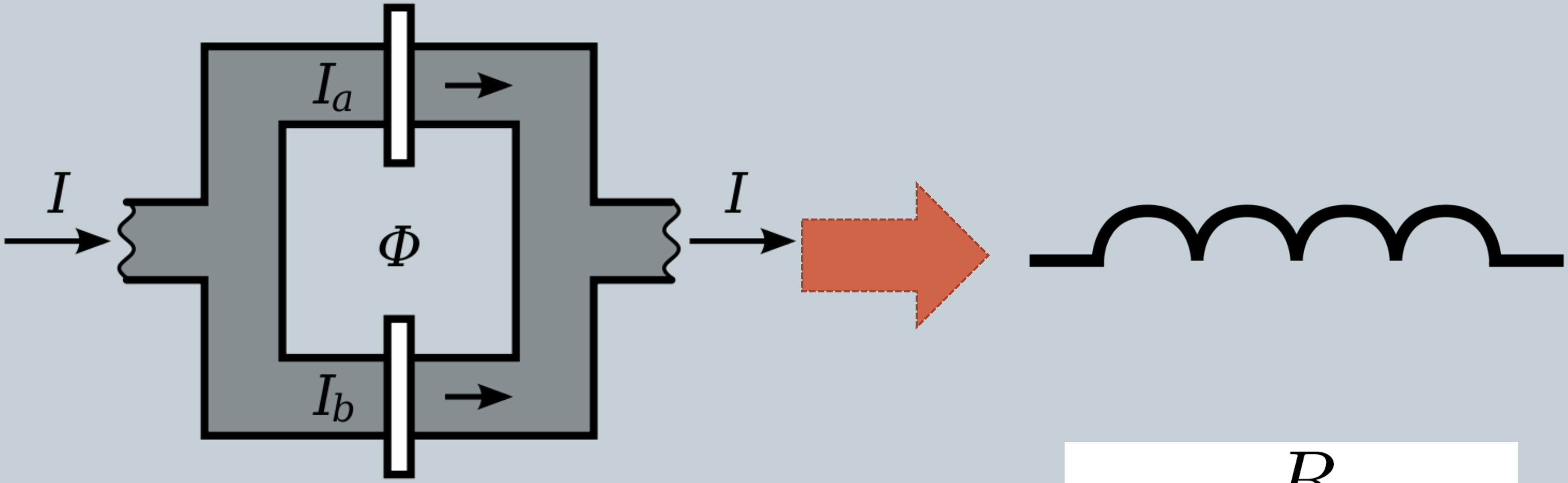
dynamical casimir effect

- Non-zero overlap between vacuum and first excited state at difference times
- Do this non-adiabatically (v~c) and

$$P(|0\rangle \rightarrow |1\rangle) \neq 0$$

- Can create real photons from vacuum!
- CAVEAT: Must be able to move mirror at v~c

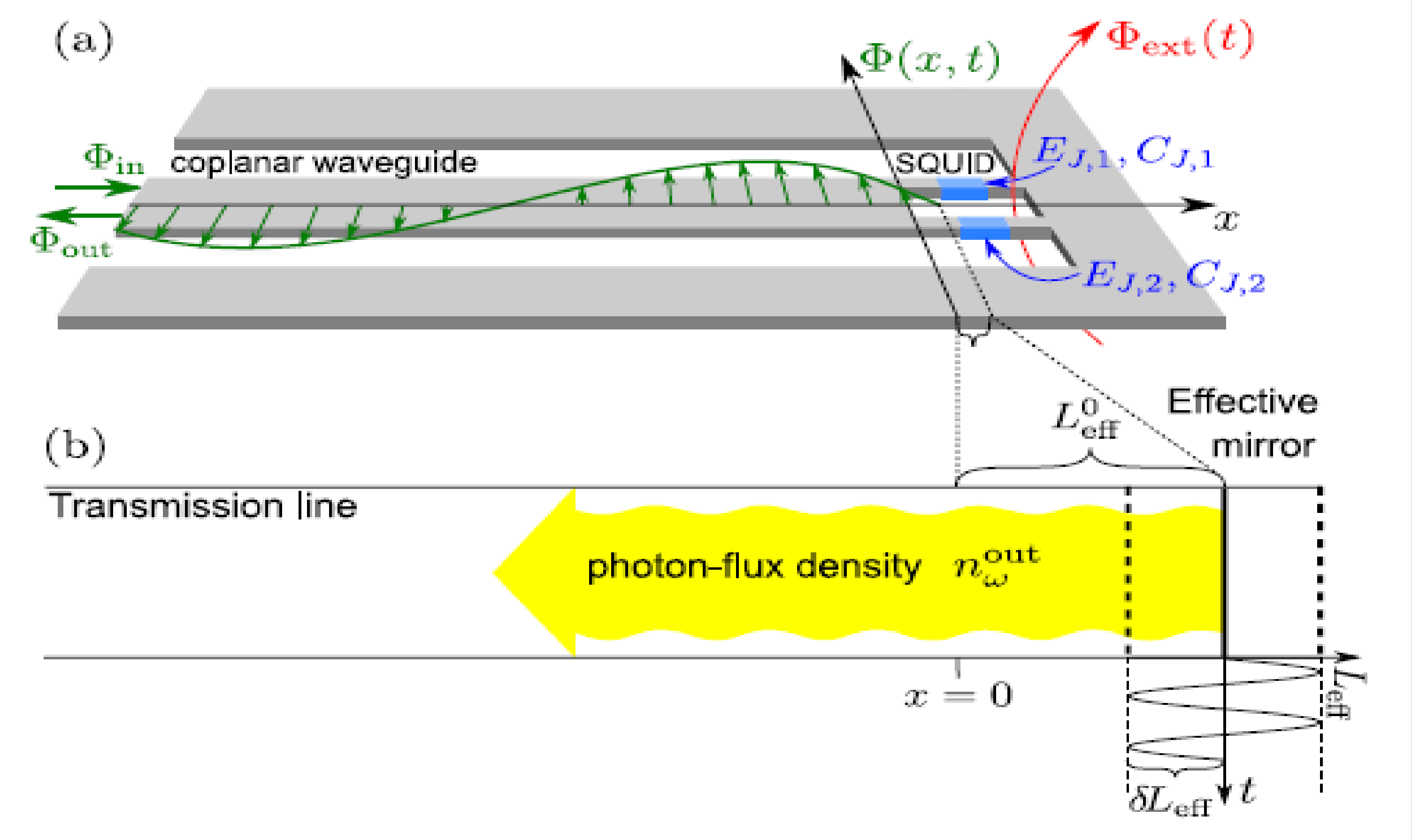
SQUIDS



$$L = (\frac{R}{V})\Delta\phi$$

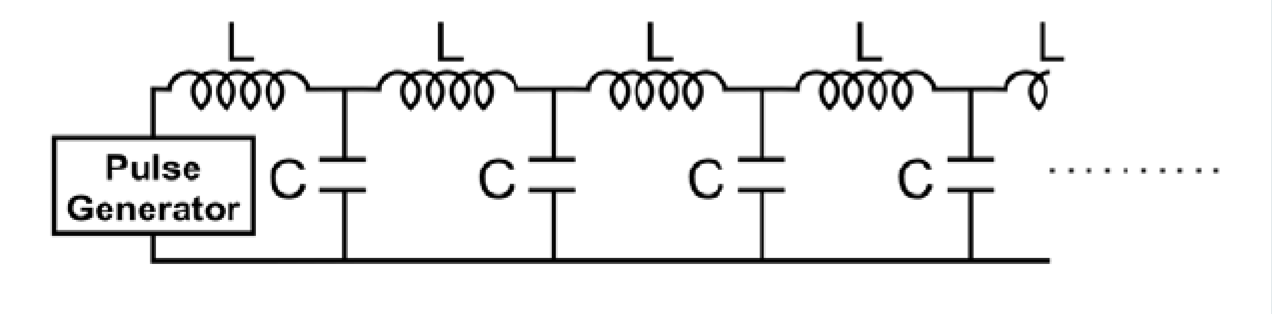
SQUIDS as mirrors

- The set-up:



SQUIDS as mirrors

- A fact that I can't really explain:
  - The SQUID terminated to ground acts as a single JJ, with a tuneable Josephson energy and therefore a tuneable inductance
  - This changes the boundary conditions of the light hitting the SQUID, as a function of the applied flux
- Model as an ideal transmission line:



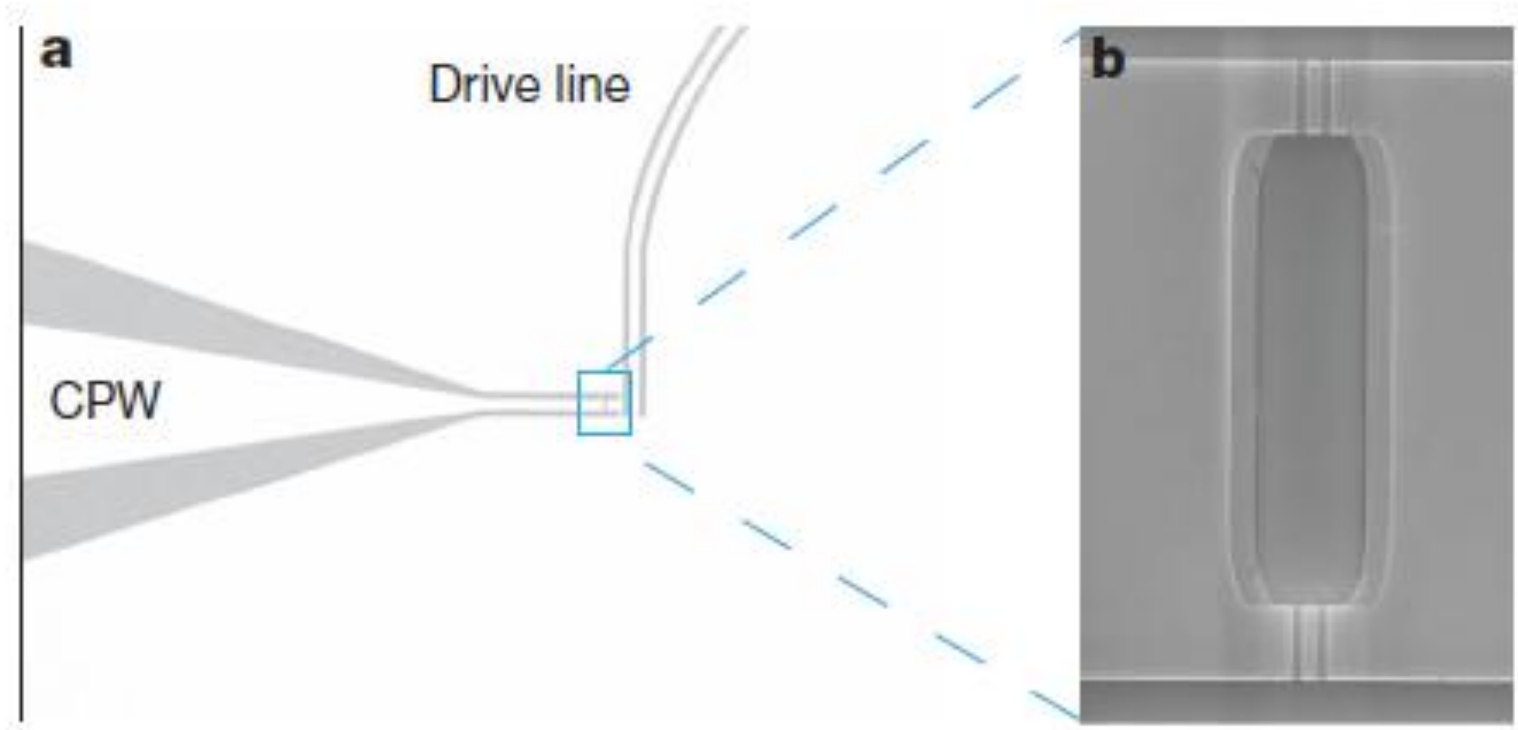
SQUID as a mirror

Assume the end is terminated by a ***load of impedance Z***. If we take into account the two opposite directions of wave propagation (+, -), we may write a boundary condition at Z:

$$V_+ + V_- = V$$
$$I_+ + I_- = I$$

Which can be combined with: $$\frac{V_+}{I_+} = Z_0 = -\frac{V_-}{I_-} \quad and \quad \frac{V}{I} = Z$$

A change in the boundary conditions (Z=L for a SQUID) yields a change in the effective length of the transmission line!


a
Drive line
CPW
b

How to measure it?

- Output spectral distribution is different than the input!

$$n_{\text{out}}(\omega) = n_{\text{in}}(\omega) + |S(\omega)|^2 n_{\text{in}}(\omega_{\text{d}} - \omega) + |S(\omega)|^2$$

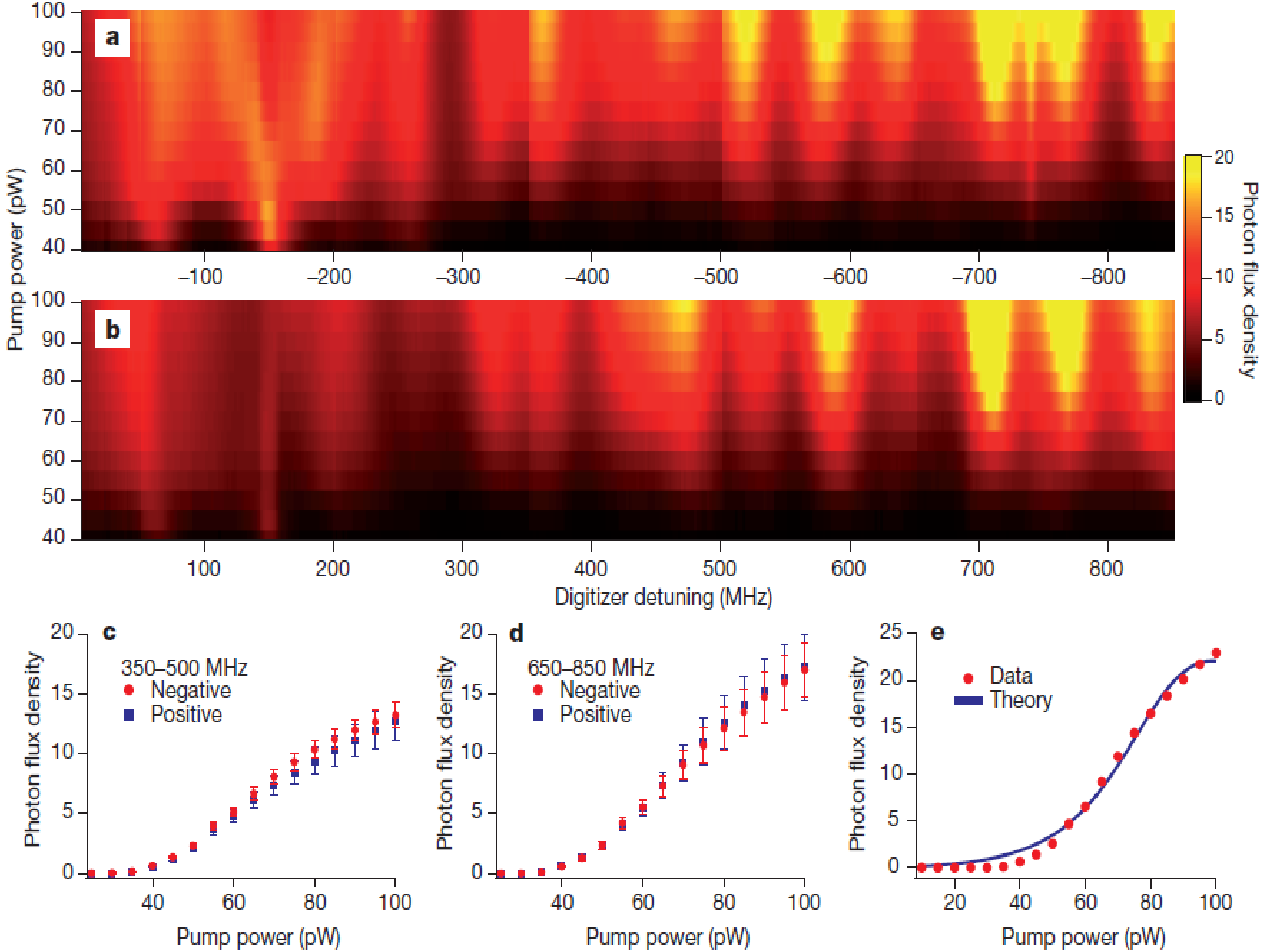
Reflection Of thermal radiation

upconversion

DCE (downconversion?!)

How to measure it?

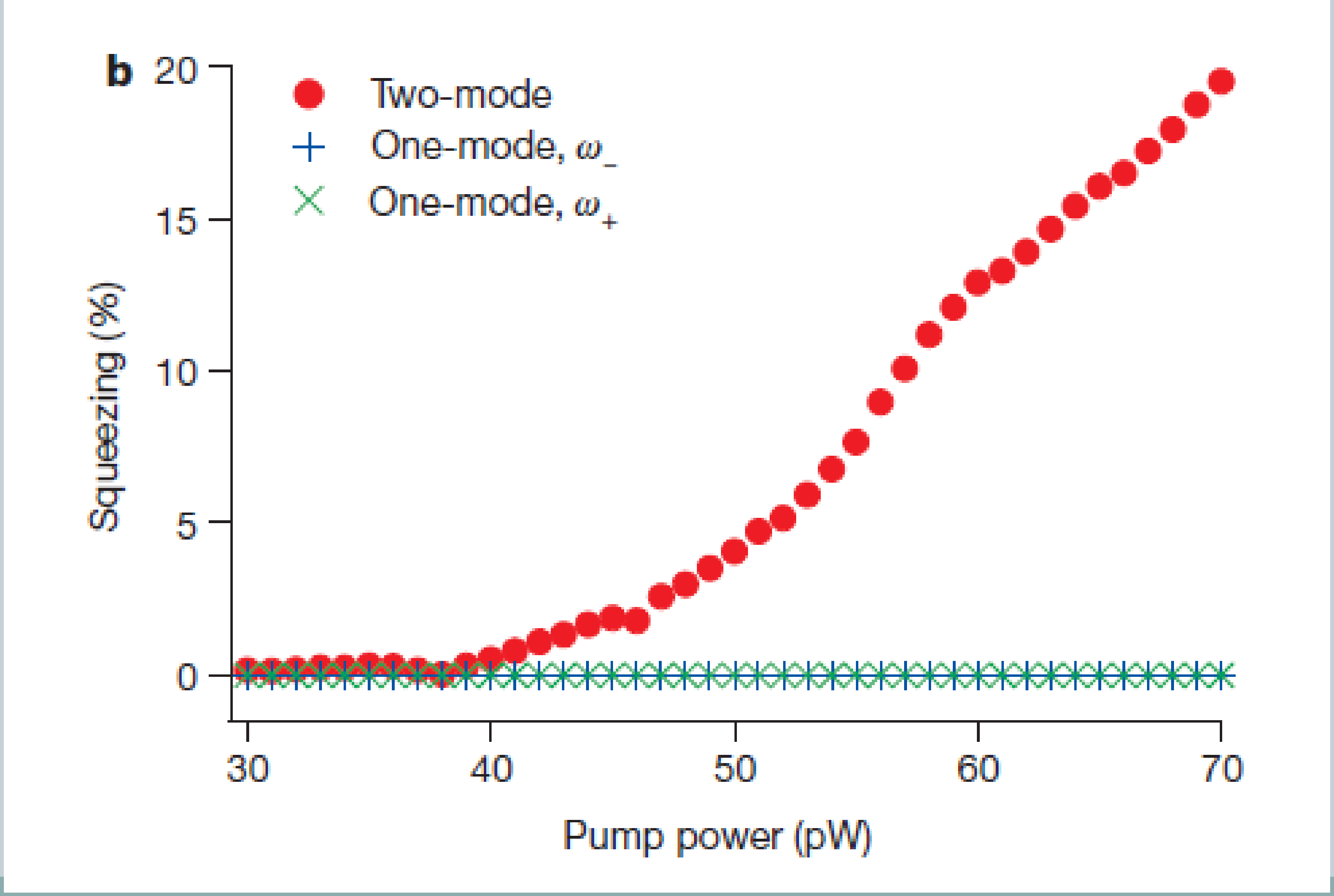
- Similarly to SPDC, emission exhibits correlations:
- Symmetric around half the drive frequency
- Photons produced in pairs!!



a
b
Pump power (pW)
Digitizer detuning (MHz)
Photon flux density
c
350–500 MHz
Negative
Positive
Pump power (pW)
Photon flux density
d
650–850 MHz
Negative
Positive
Pump power (pW)
Photon flux density
e
Data
Theory
Pump power (pW)
Photon flux density

Correlations

- 2 mode squeezed, same as SPDC



conclusions

- Demonstrated, for the first time, the dynamical Casimir effect
- Cool.