Symmetry in Mesoscopic Conductance and Rectification

International Conference on Nanoelectronics
Lancaster University, UK, Jan. 5, 2003

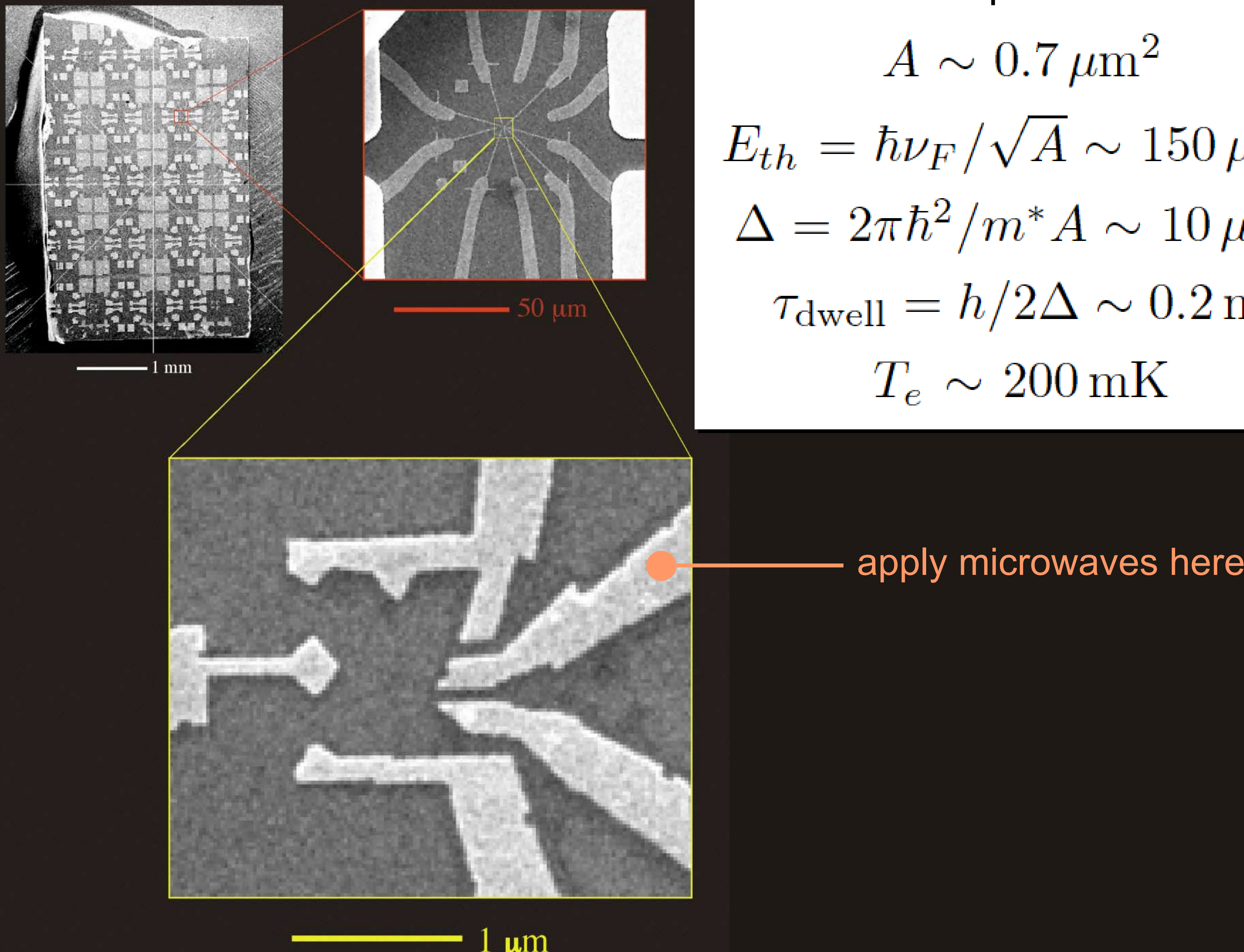
AG Huibers, M Switkes, L DiCarlo, CM Marcus,
Harvard University

Maxim Vavilov
University of Minnesota

Discussion with
Piet Brouwer, Markus Büttiker

Supported by ARO-MURI, DARPA, NSF

Device: GaAs Lateral Quantum Dot



Device Specifications

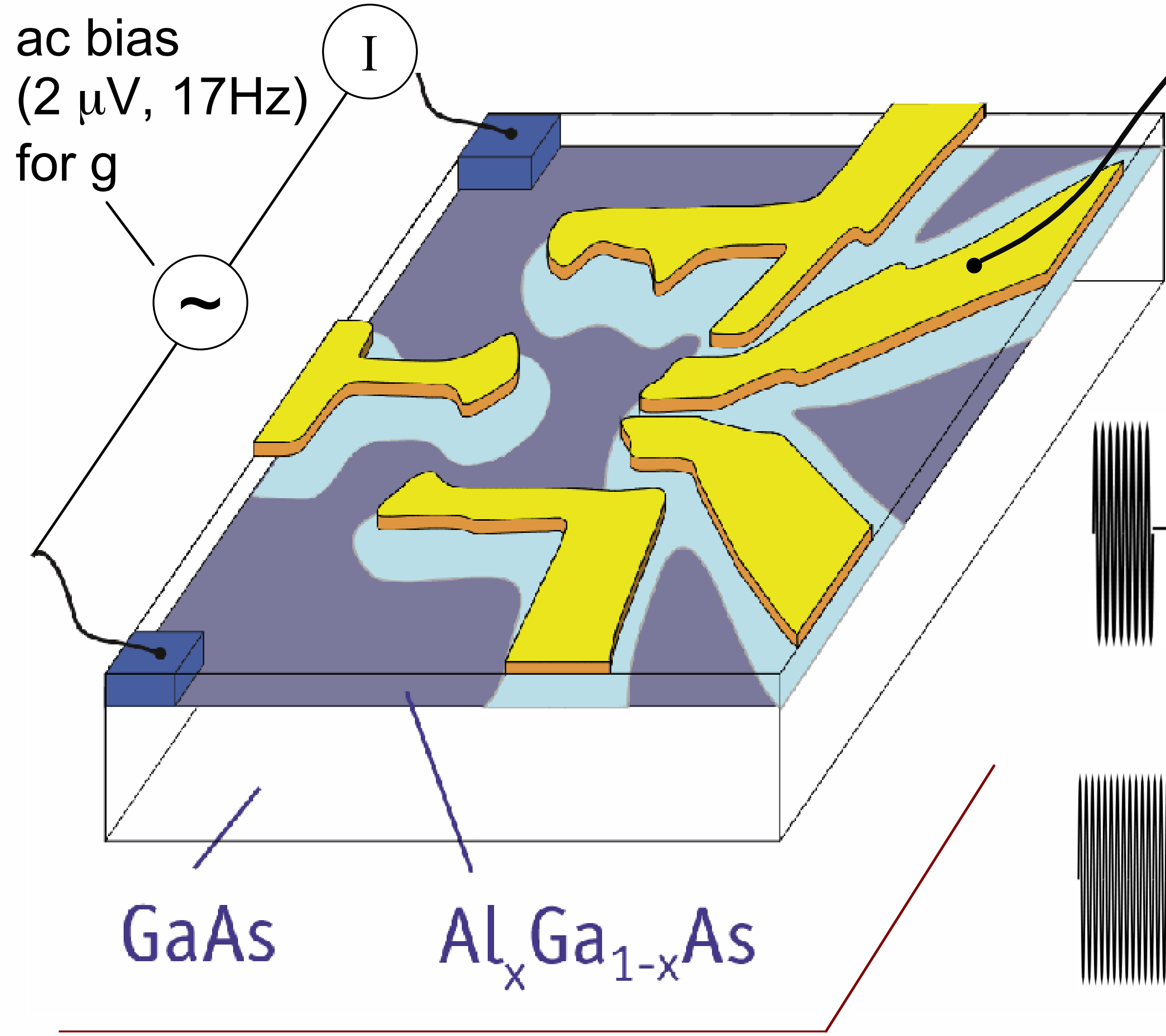
$$A \sim 0.7\,\mu\mathrm{m}^2$$

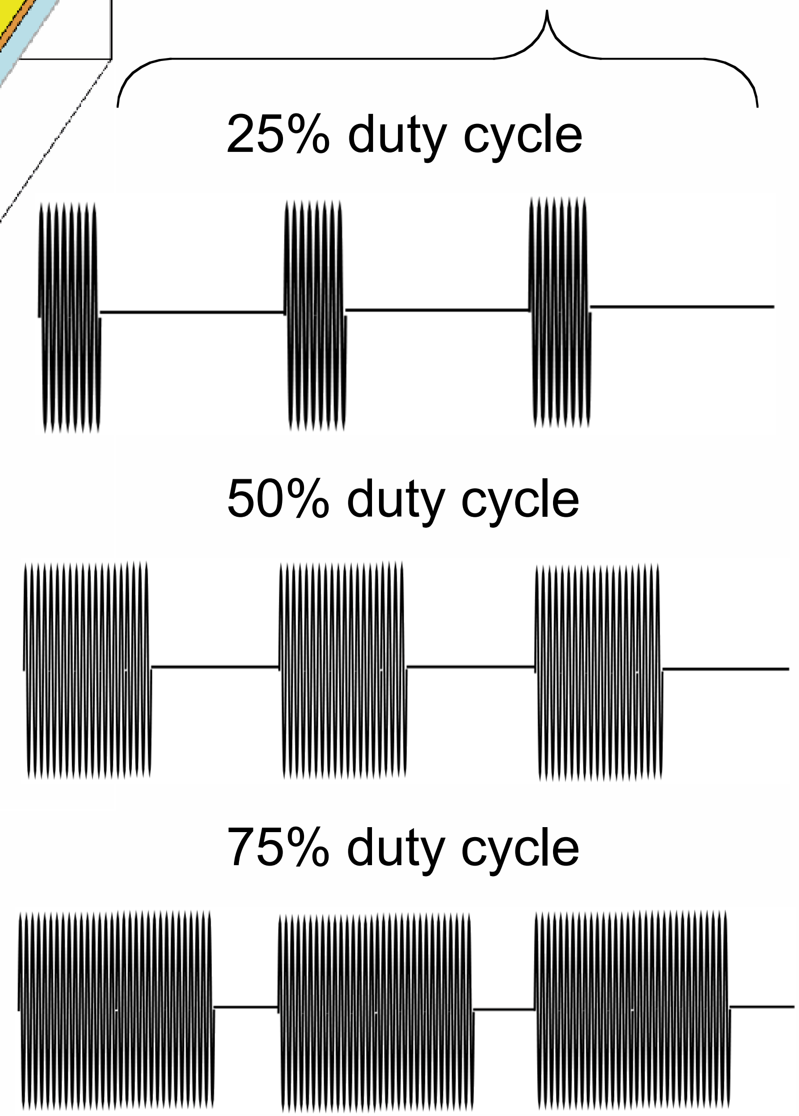
$$E_{th} = \hbar v_F/\sqrt{A} \sim 150\,\mu\mathrm{eV}$$

$$\Delta = 2\pi\hbar^2/m^* A \sim 10\,\mu\mathrm{eV}$$

$$\tau_{\mathrm{dwell}} = h/2\Delta \sim 0.2\,\mathrm{ns}$$

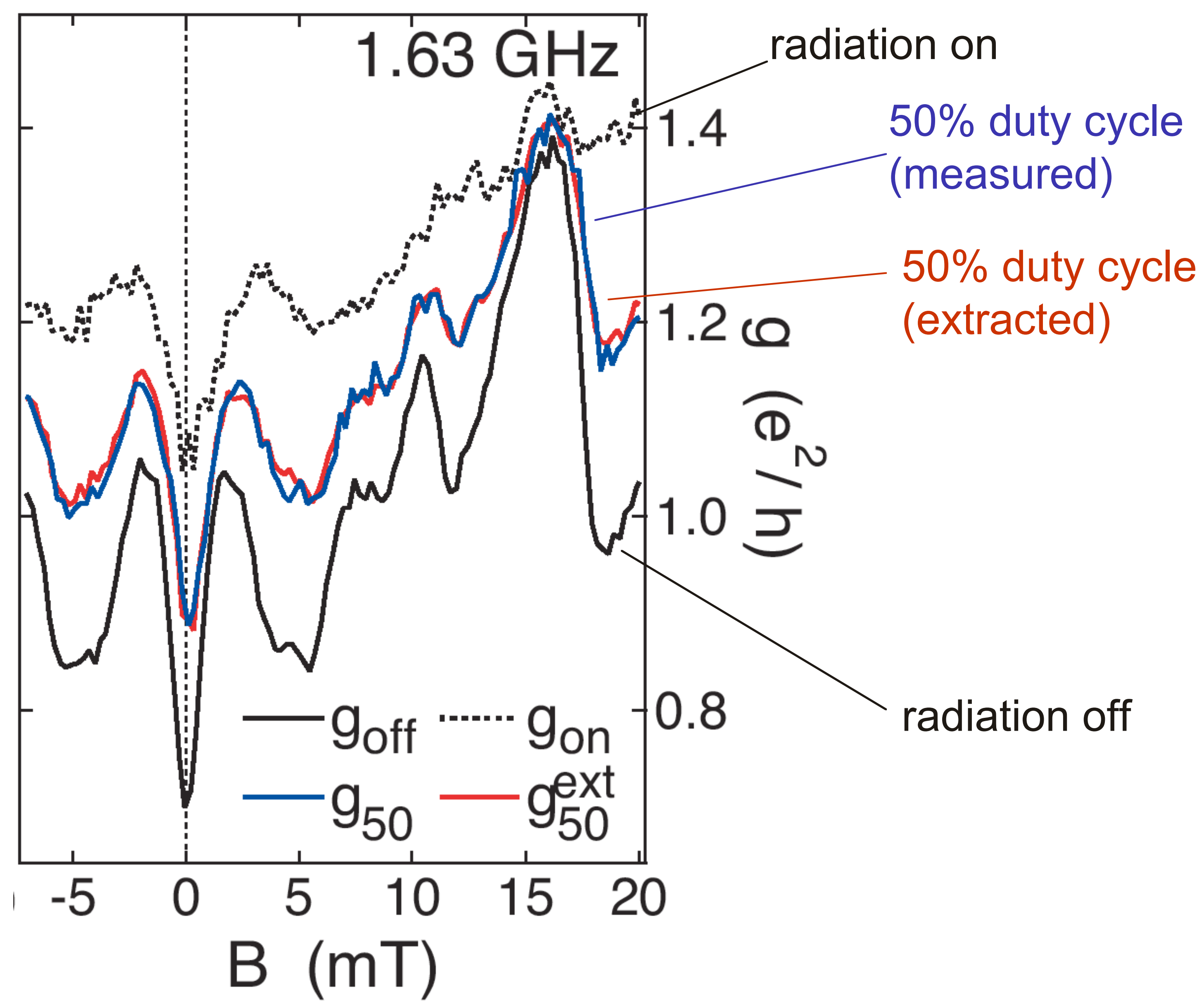
$$T_e \sim 200\,\mathrm{mK}$$



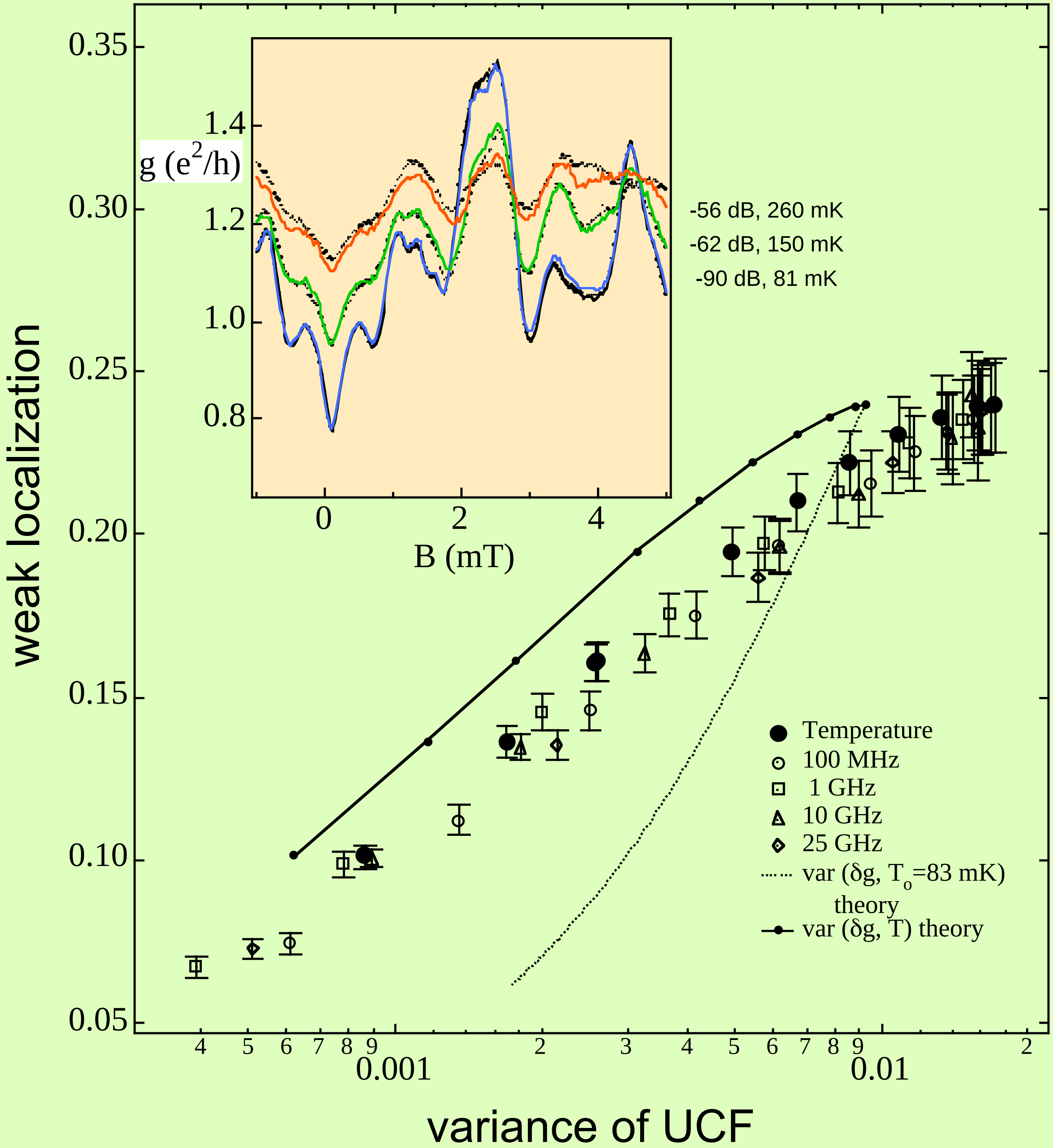


radiation:
10MHz -
10GHz

lock in to
modulated rf (at 153Hz)
for sensitive current
measurement



1.63 GHz
radiation on
50% duty cycle
(measured)
50% duty cycle
(extracted)
radiation off
g (e²/h)
1.4
1.2
1.0
0.8
-5
0
5
10
15
20
B (mT)
g_{off}
g_{on}
g_{50}
g_{50}^{ext}



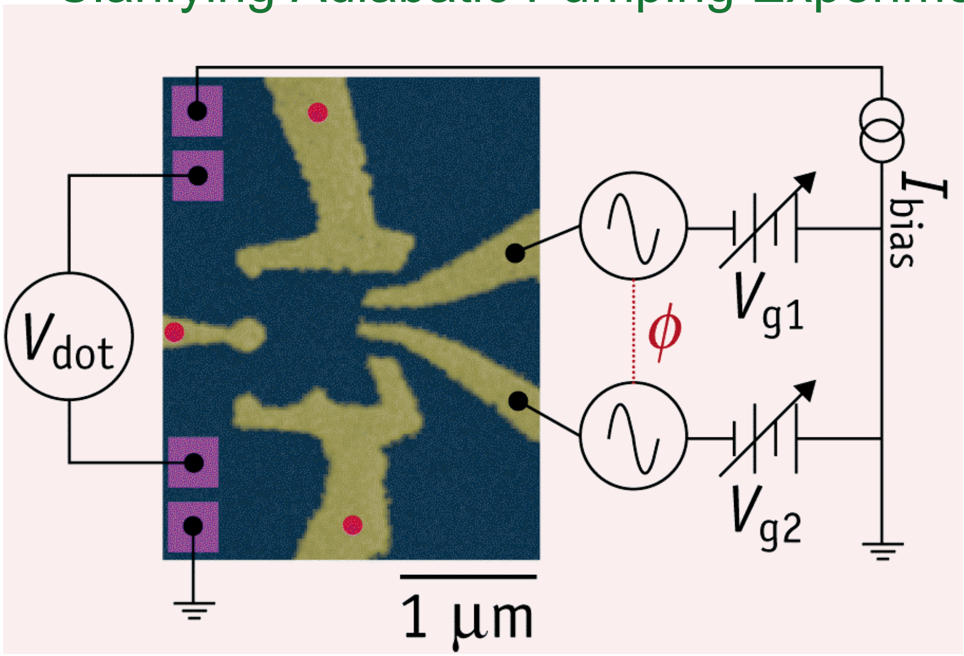
Motivation #1:

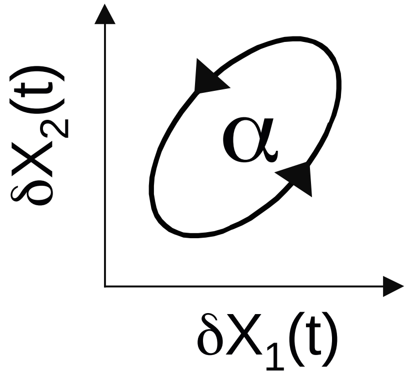
Previously found radiation looked like pure heating

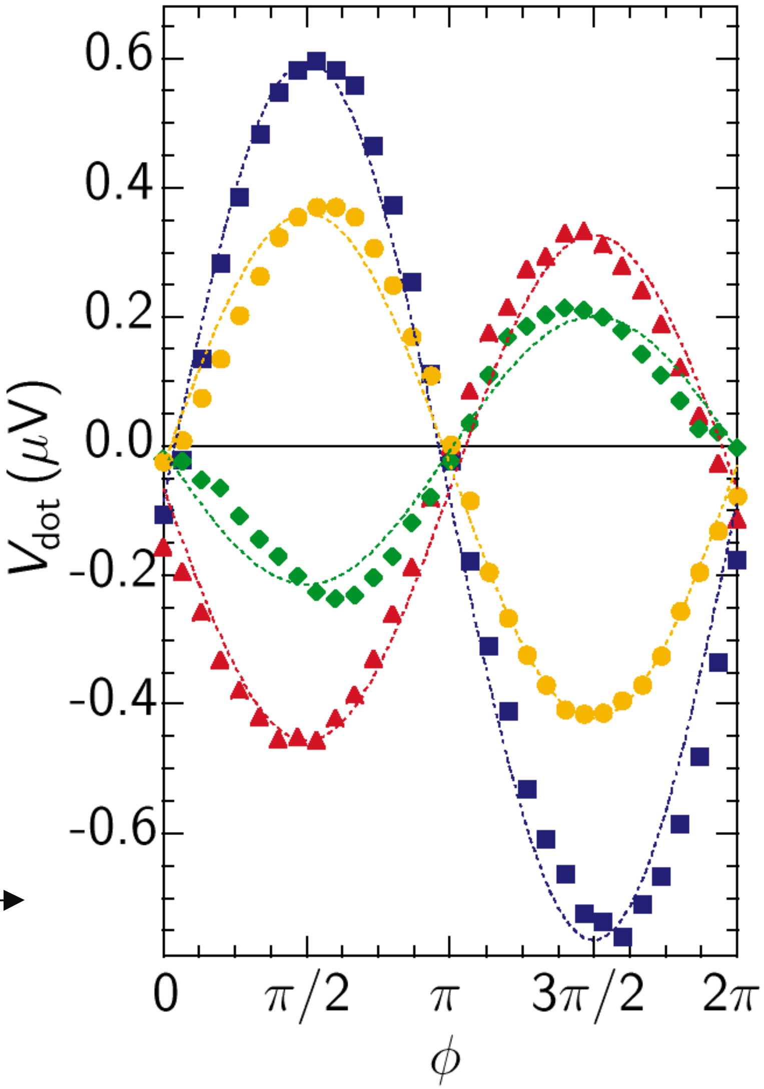
Huibers, CMM et al PRL **83** 5090 (1999).

Motivation #2:

Clarifying Adiabatic Pumping Experiment

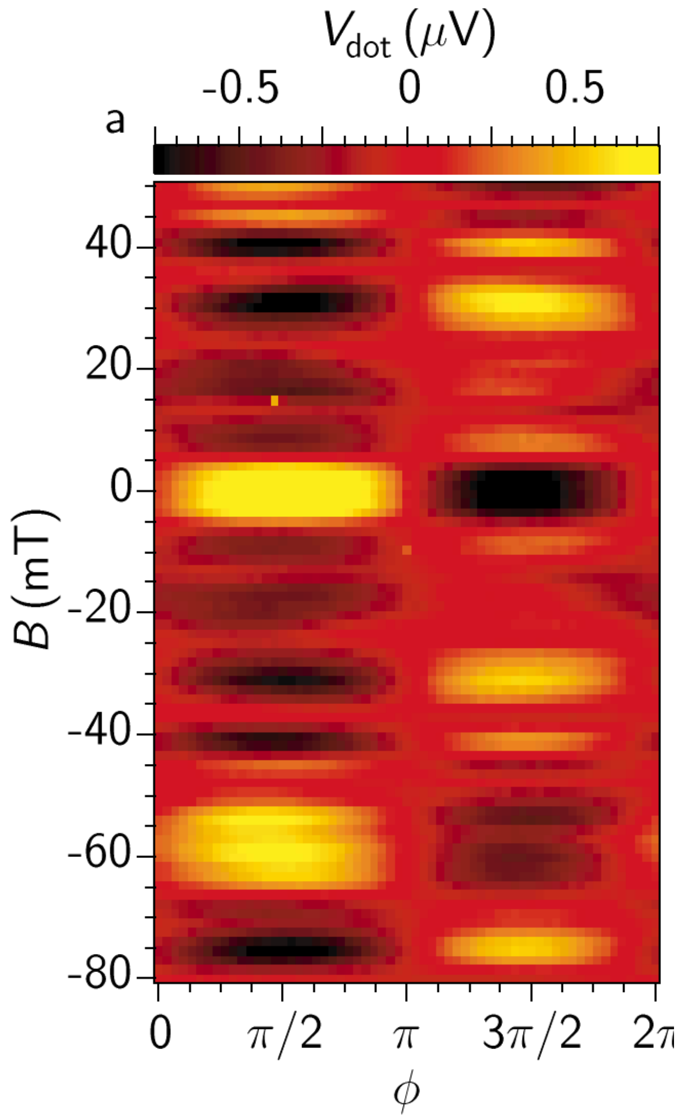


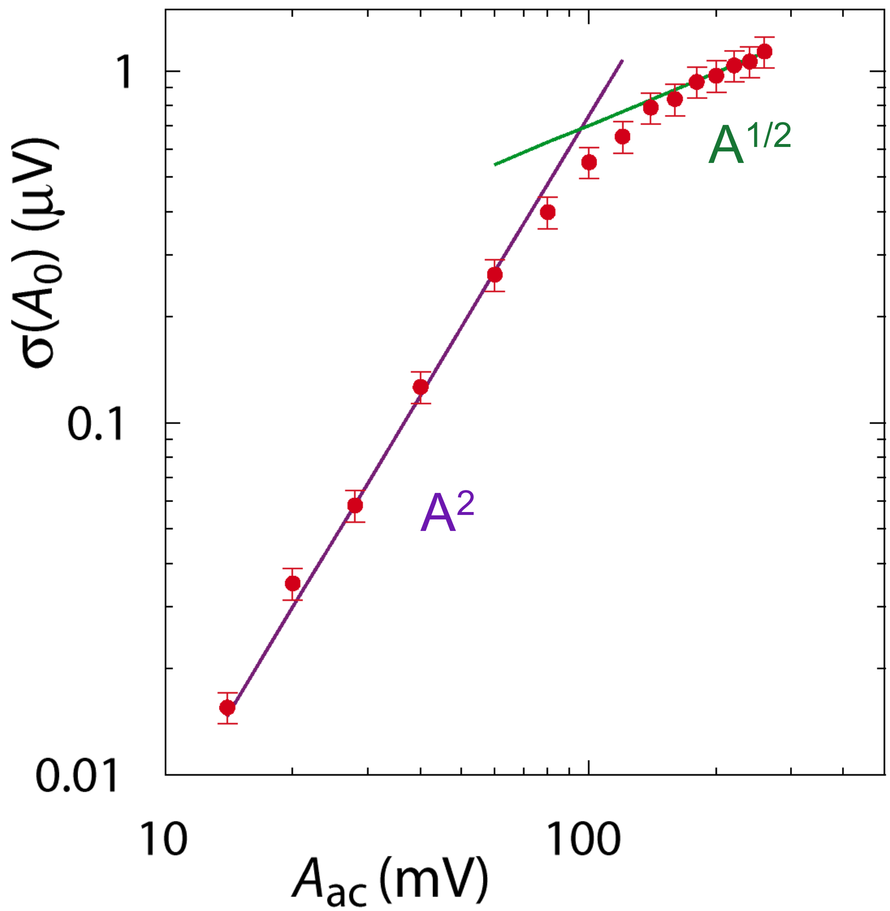




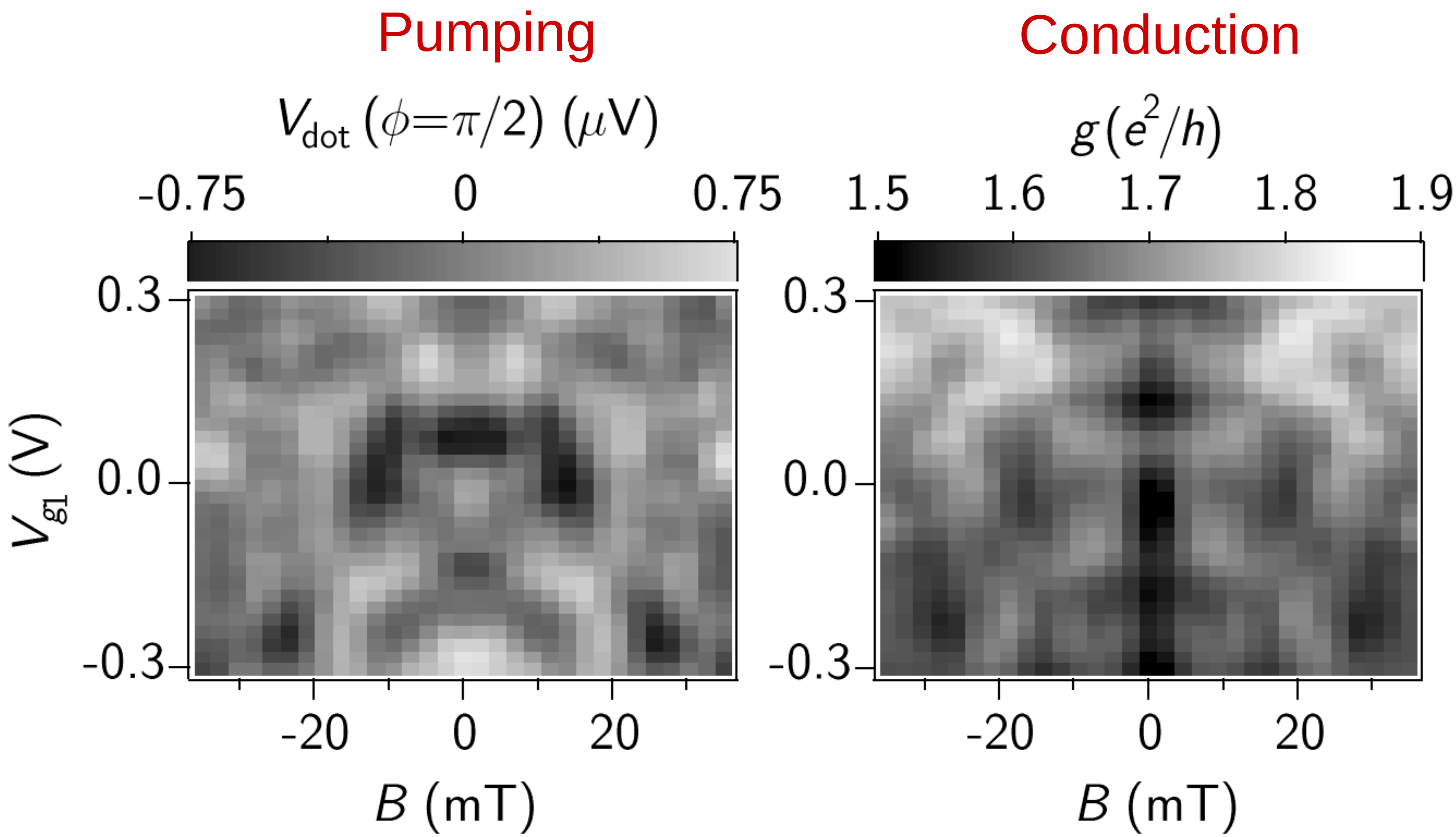
M. Switkes, CMM, et al
Science, 1999

Adiabatic pumping experiment agrees with theory in many respects….





….but not all!



M. Switkes, CMM, et al
Science, 1999

Mesoscopic Fluctuations of Adiabatic Charge Pumping in Quantum Dots

T.A. Shutenko
Physics Department, Princeton University, Princeton, NJ 08544

I.L. Aleiner
Department of Physics and Astronomy, SUNY at Stony Brook, Stony Brook, NY 11794

B.L. Altshuler
Physics Department, Princeton University, Princeton, NJ 08544
NEC Research Institute, 4 Independence Way, Princeton, NJ 08540

cond-mat/9911019 2 Nov 1999

Effect of the magnetic field — We have demonstrated in Sec. III A that there is no fundamental reason for the pumped current to be symmetric with respect to the magnetic field reversal, in a sharp contrast with the dependence of conductance on the magnetic field. The corresponding correlation functions were calculated in Sec. III B. It is demonstrated there that $\langle Q(B)Q(-B)\rangle \propto B^{-6}$ at large B. These conclusions contradict to Ref. 12 where the symmetry with respect to magnetic field reversal was reported. We can not explain this symmetry within the framework of our theory.

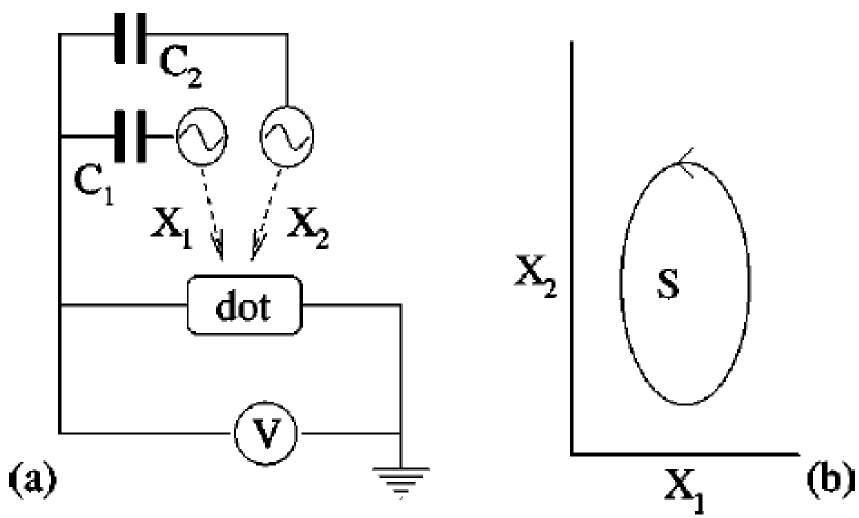
RAPID C

PHYSICAL REVIEW B, VOLUME 63, 121303(R)

Rectification of displacement currents in an adiabatic electron pump

P. W. Brouwer
Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, New York 14853-2501
(Received 14 December 2000; published 5 March 2001)

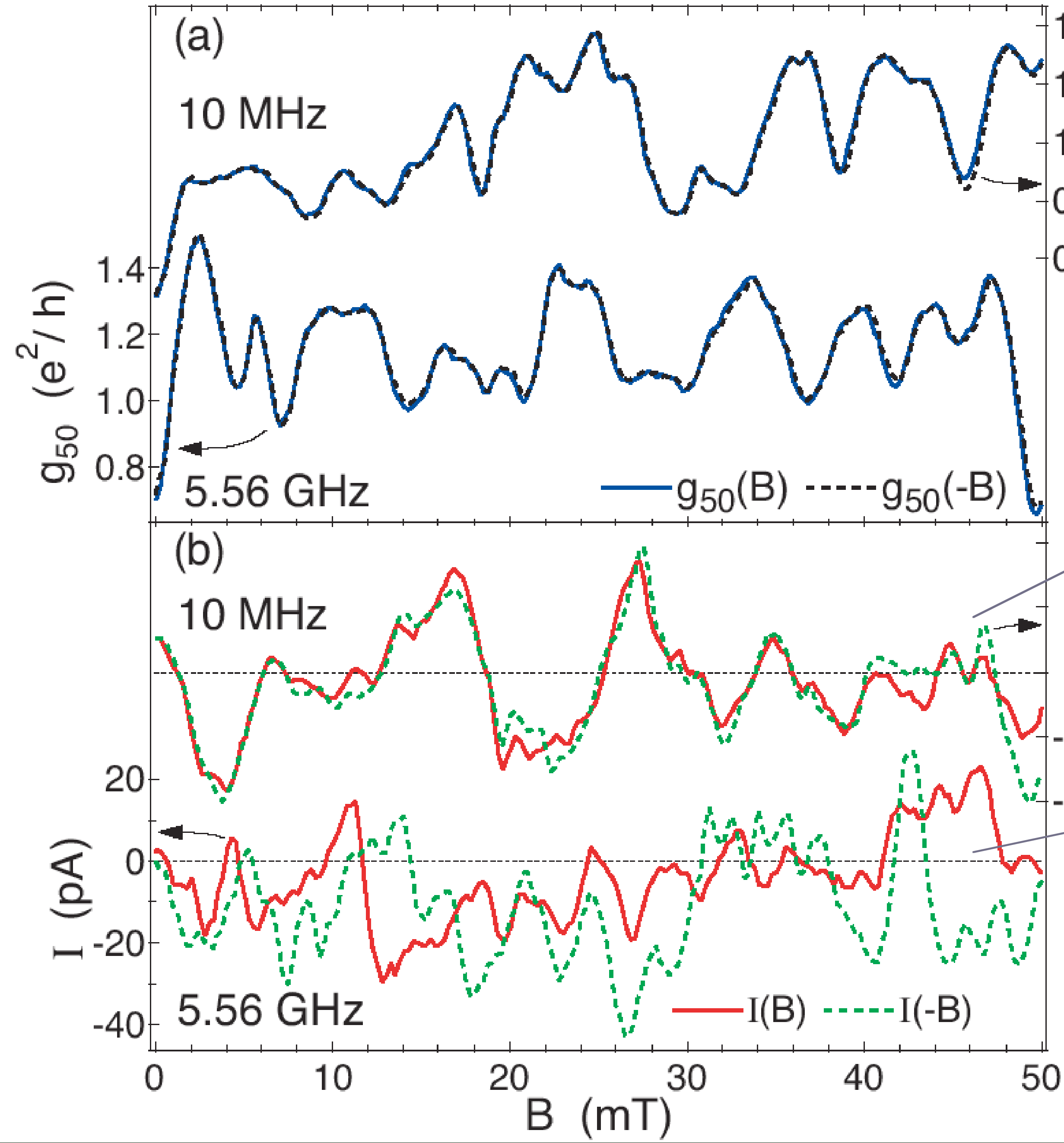
Rectification of ac displacement currents generated by periodic variation of two independent gate voltages of a quantum dot can lead to a dc voltage linear in the frequency ω. The presence of this rectified displacement current could account for the magnetic field symmetry observed in a recent measurement on an adiabatic quantum electron pump by Switkes *et al.* [Science **283**, 1905 (1999)].



Rectification Current

$$I_{\text{rect}} = \frac{\omega}{2\pi} \int_0^{2\pi/\omega} \alpha V_g^{ac} \sin(\omega t + \phi) g(V_g(t)) dt$$

When the peak ac gate voltage is small relative to the gate voltage correlation length ($\sim 10\,\text{mV}$), we can approximate $I_{\text{rect}} = \frac{\alpha \cos(\phi)}{2} (V_g^{ac})^2 \frac{dg}{dV_g}$.



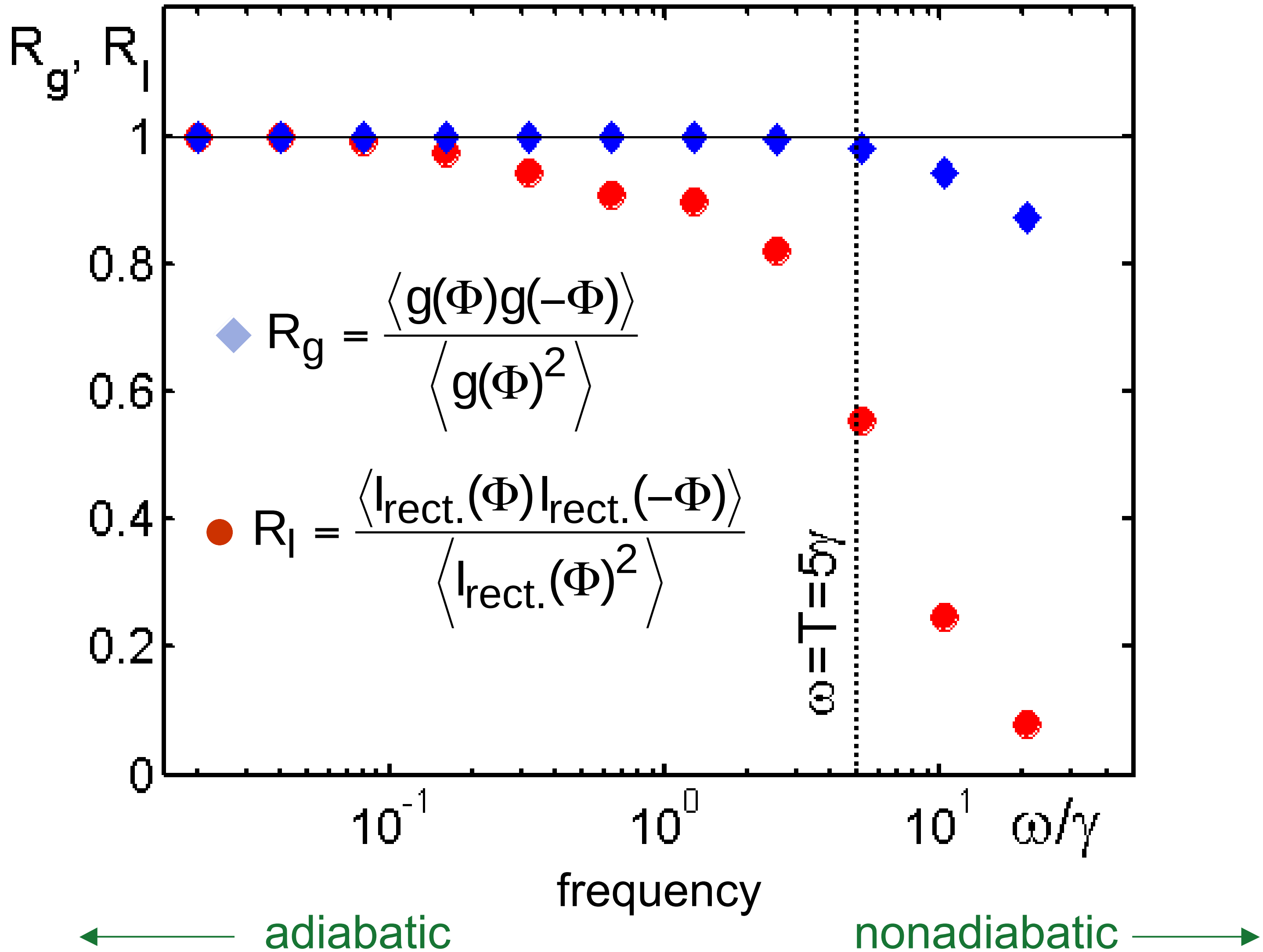
symmetric

nonsymmetric

L. DiCarlo
CMM
(in prep.),

Theory:

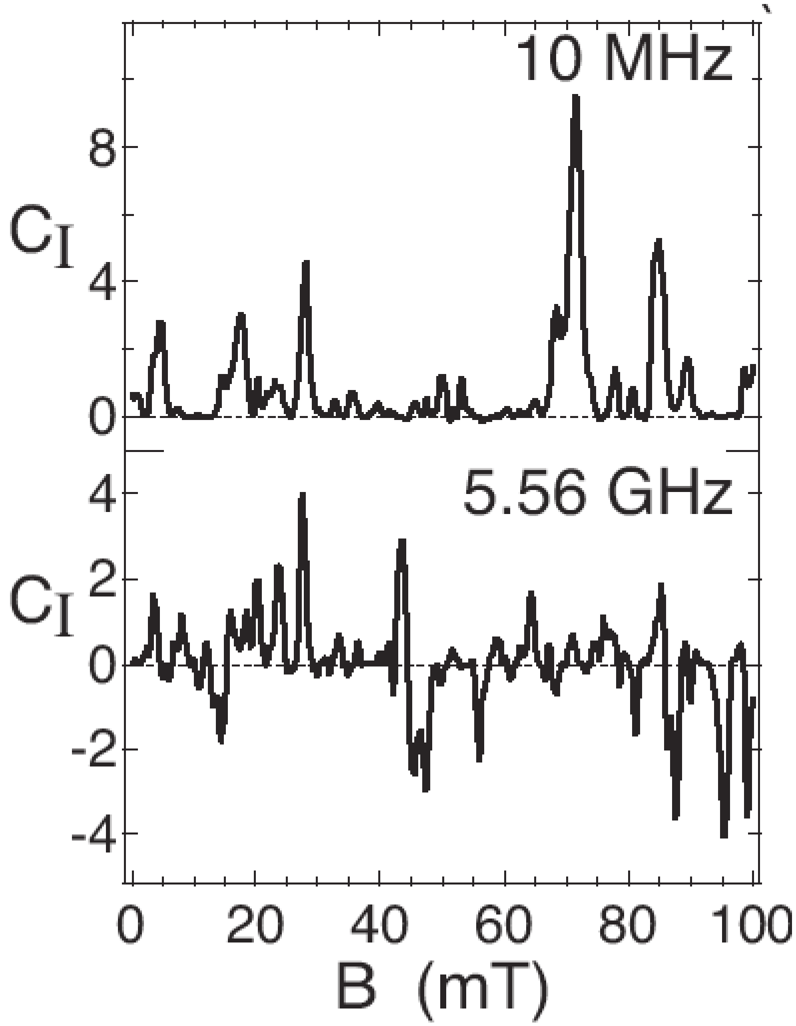
Symmetry of dc conductance, symmetry of rectification current



M. Vavilov, unpublished

rectification

photocurrent

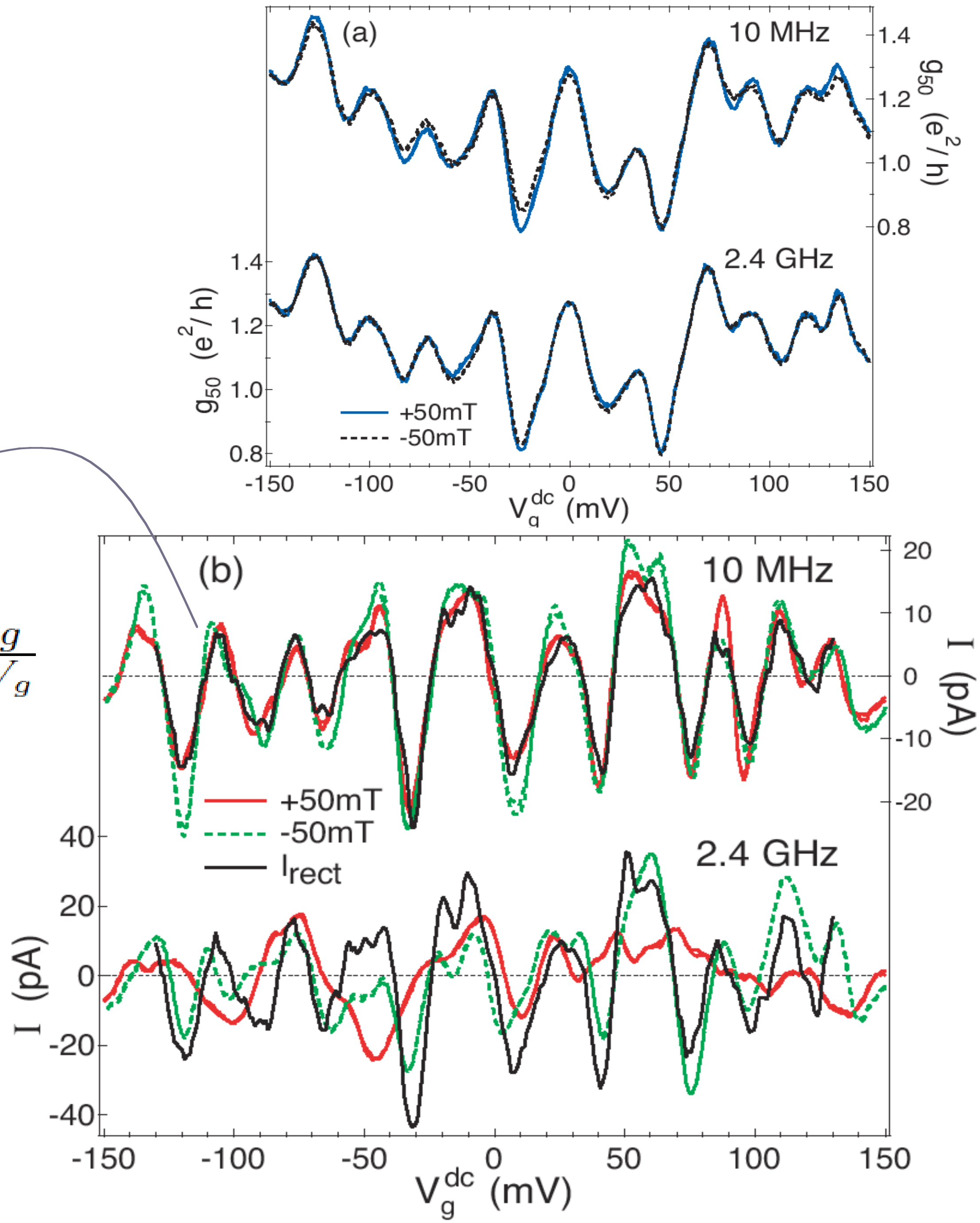


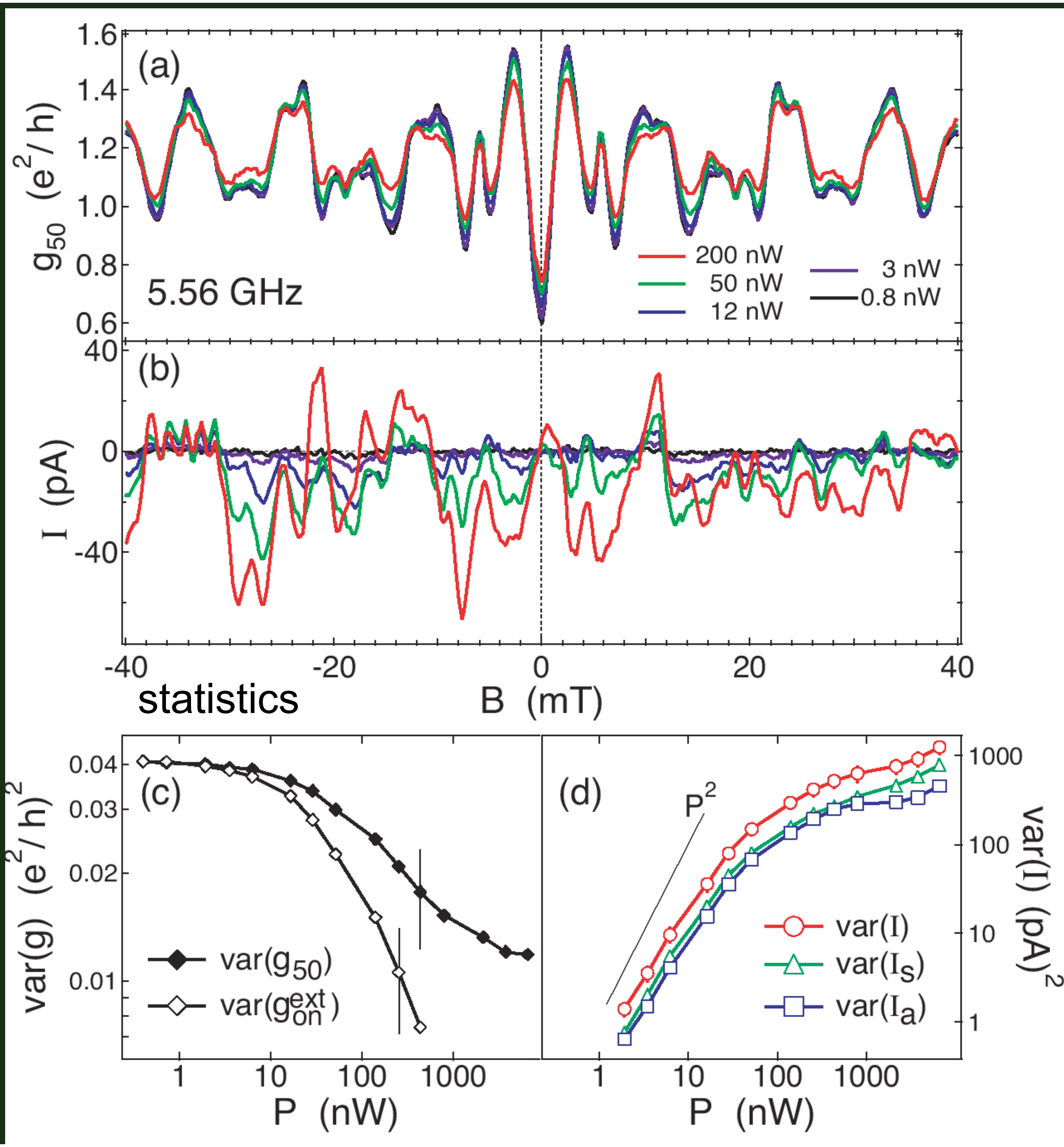
$$C_I(B) = (\delta I(B)\delta I(-B))/\langle \delta I(B)\delta I(B)\rangle_B$$

conductance fluctuations from shape distortion

rect. model

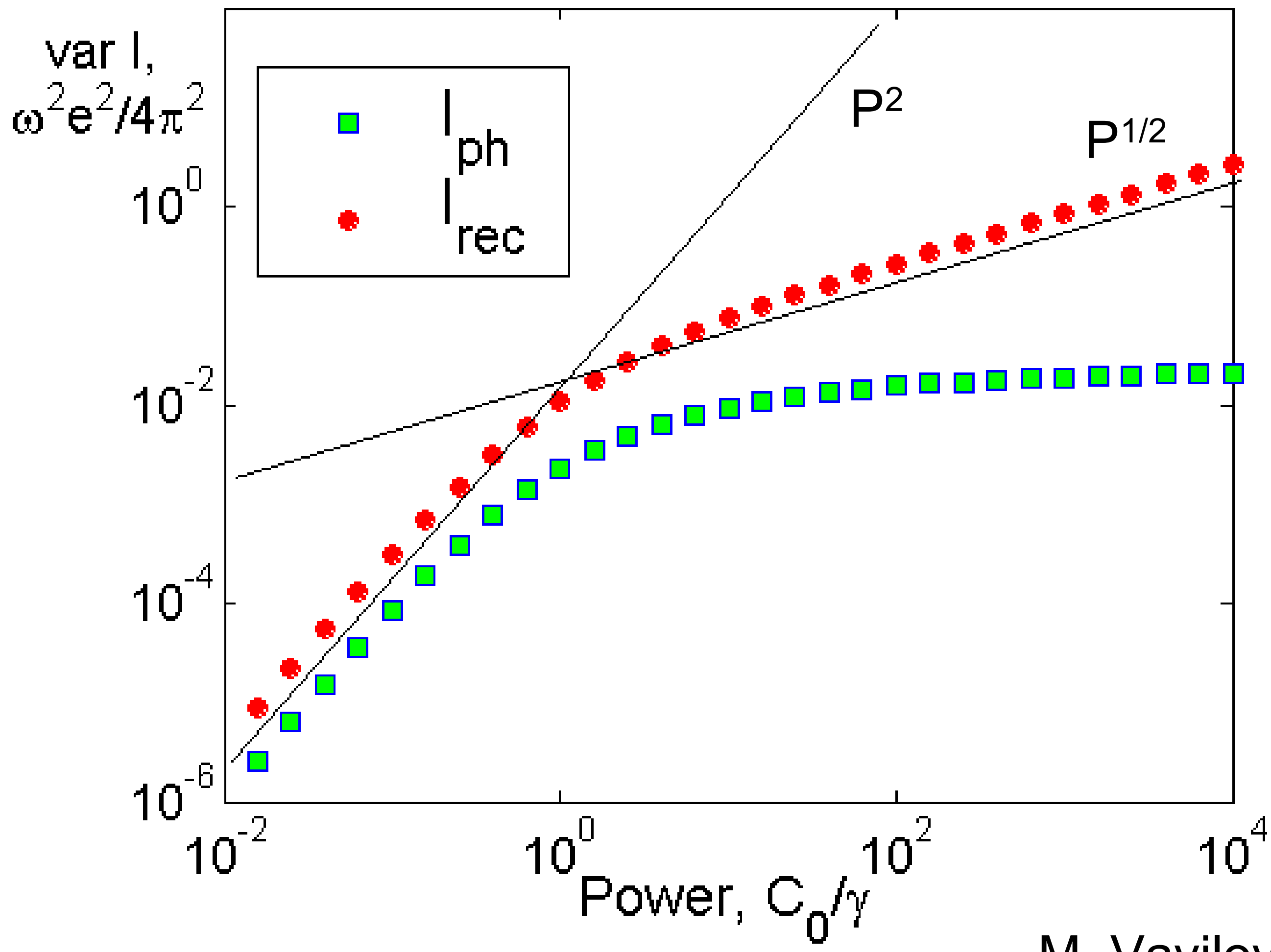
$$I_{\text{rect}} = \frac{\alpha\cos(\phi)}{2}(V_g^{ac})^2\frac{dg}{dV_g}$$



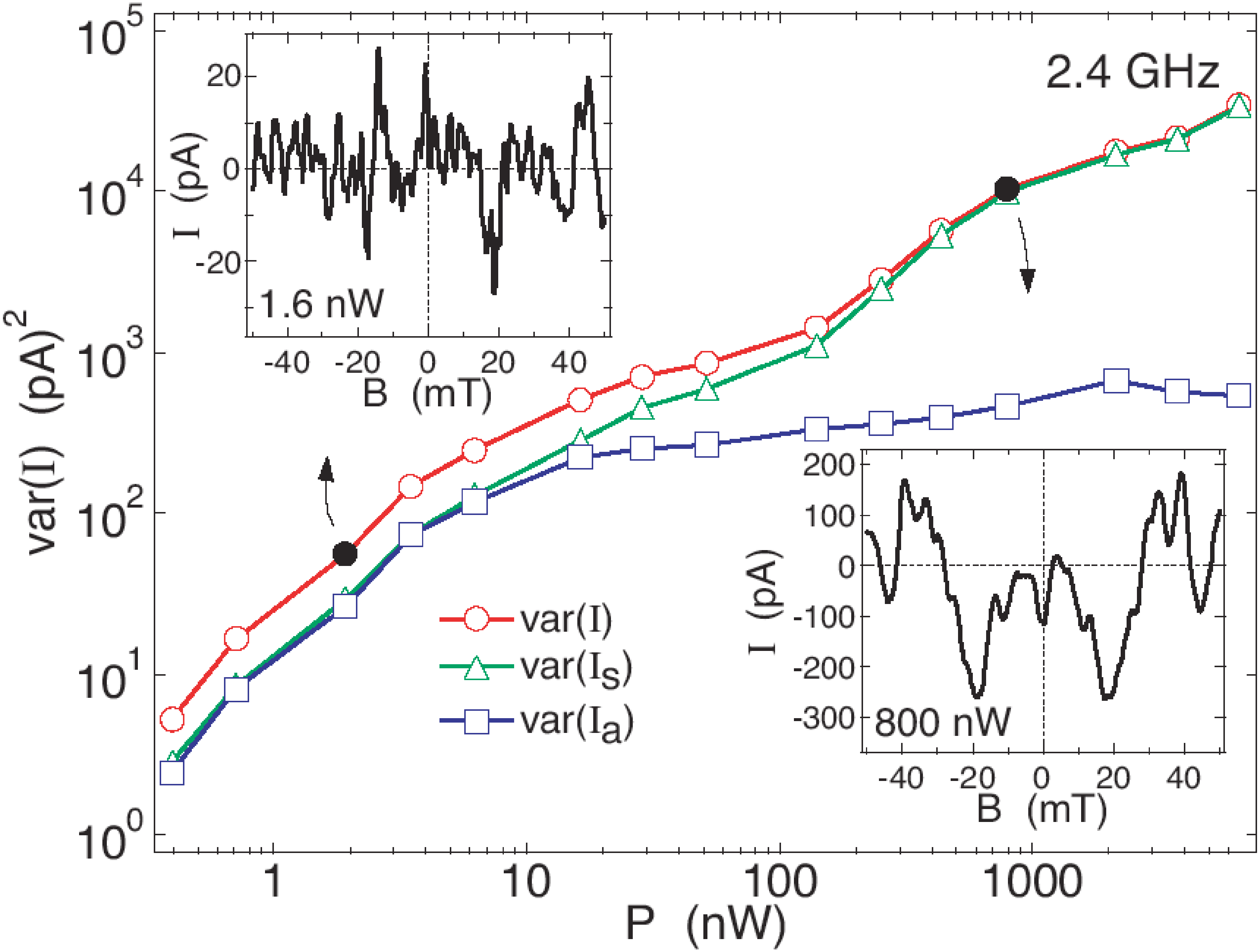


(a)
5.56 GHz
200 nW
50 nW
12 nW
3 nW
0.8 nW
g50 (e2/h)
(b)
I (pA)
B (mT)
statistics
(c)
var(g50)
var(gonext)
var(g) (e2/h)2
P (nW)
(d)
P2
var(I)
var(IS)
var(Ia)
var(I) (pA)2
P (nW)

Theory: rectification versus photocurrent



M. Vavilov
(unpublished)



2.4 GHz
var(I) (pA)^2
P (nW)
1.6 nW
I (pA)
B (mT)
800 nW
I (pA)
B (mT)
var(I)
var(I_s)
var(I_a)