Cold-Electron Bolometers

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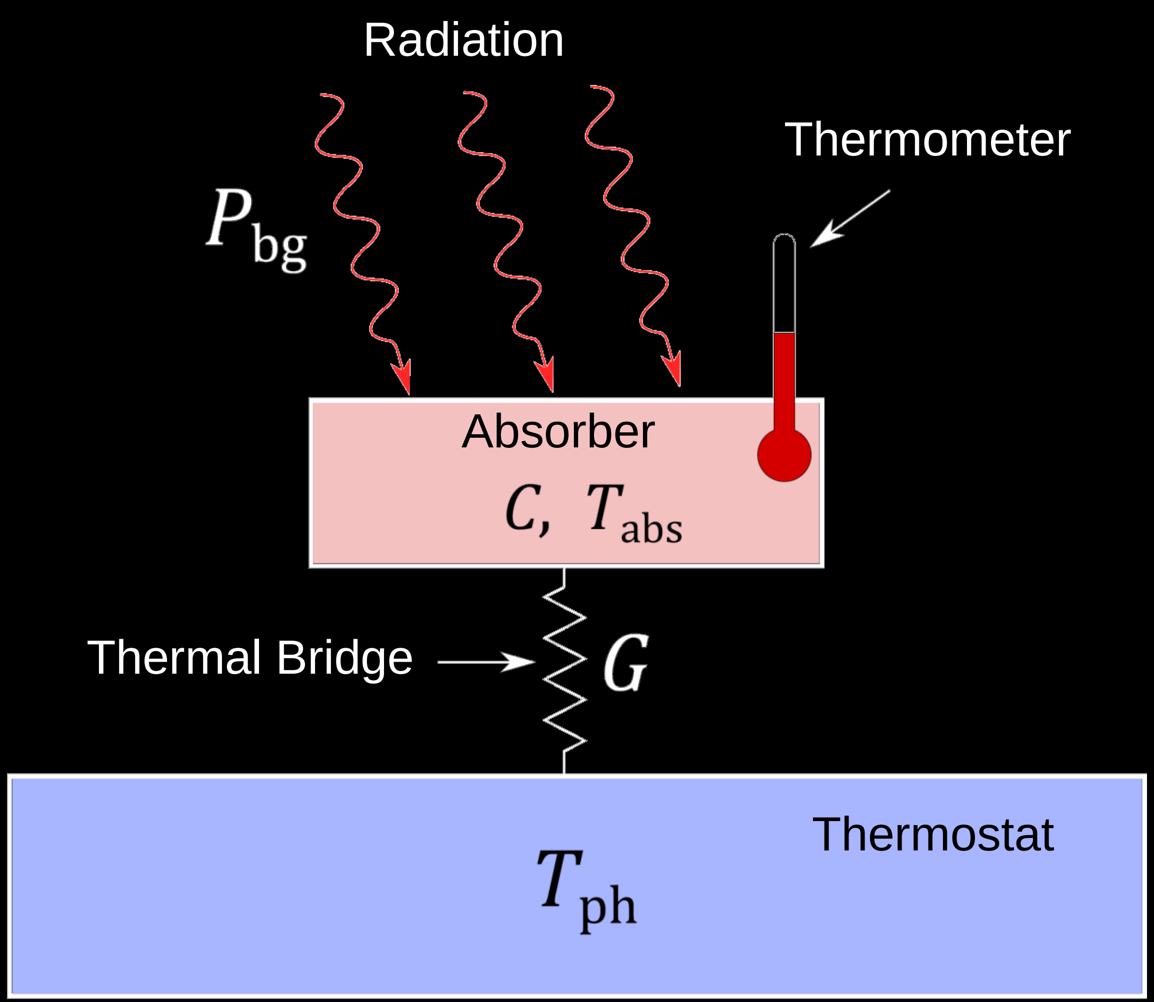
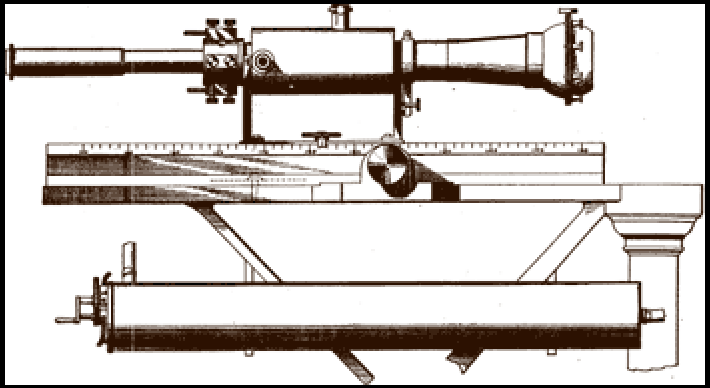
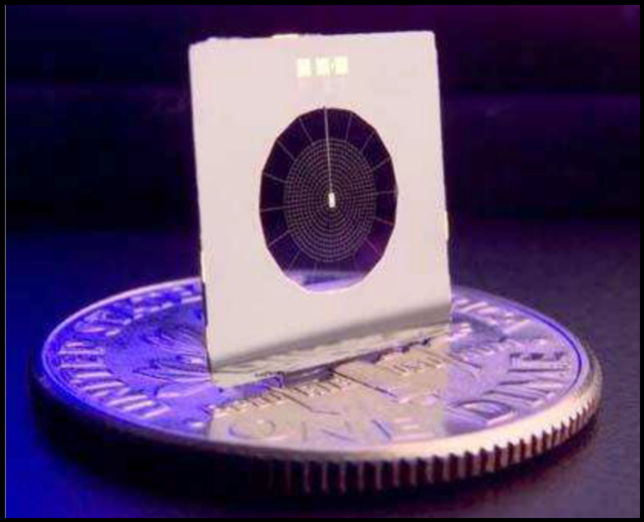
Bolometers



$$\tau = C/G$$

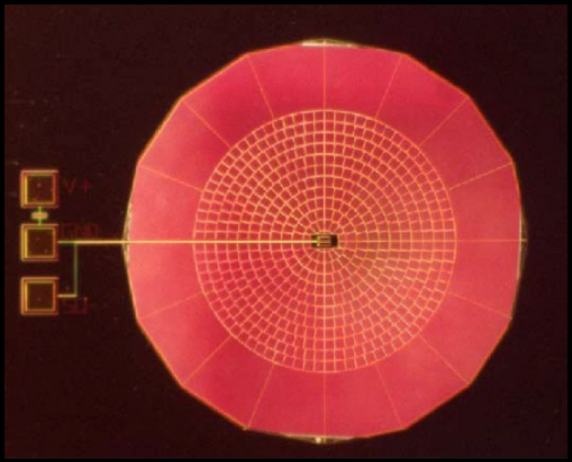


1878

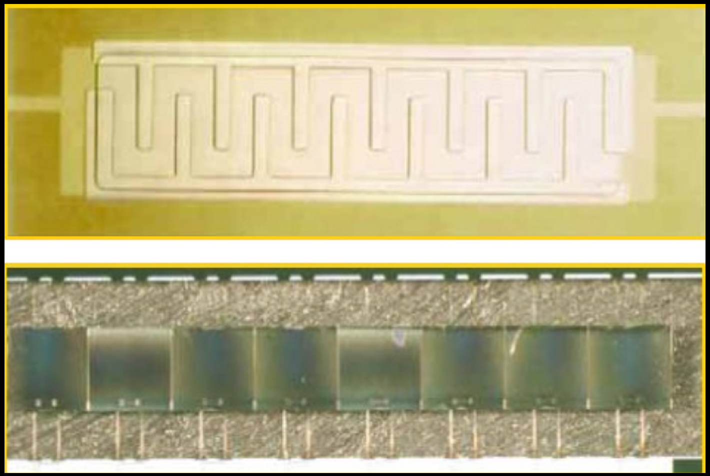


2016

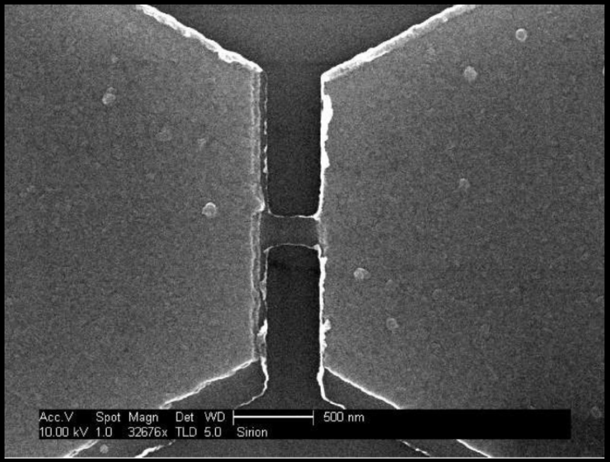
Bolometers



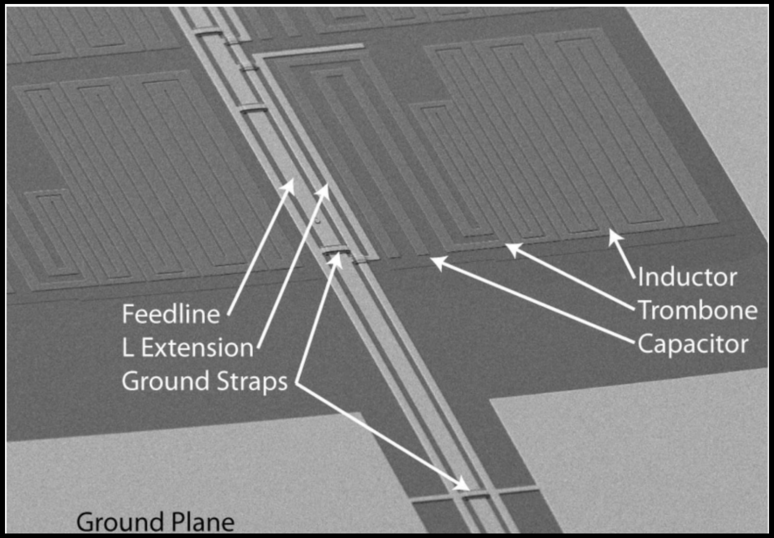
Semiconductor



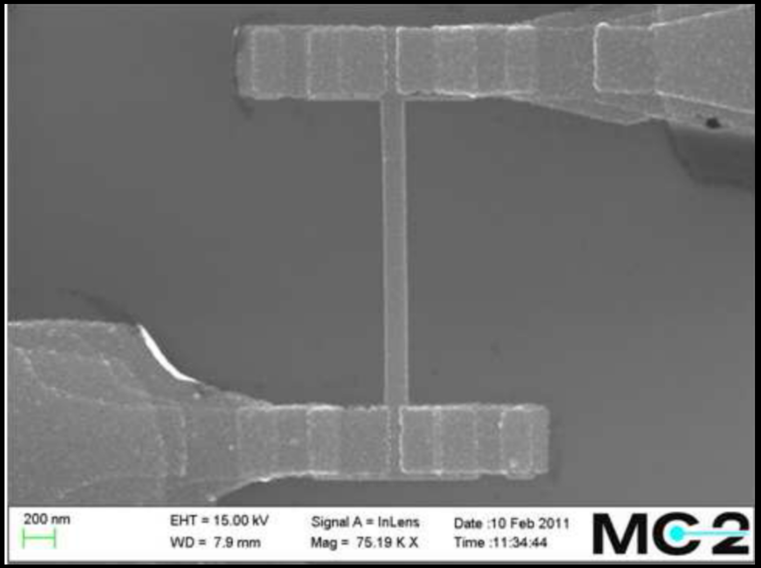
Transition Edge Sensor



Hot-Electron Bolometers

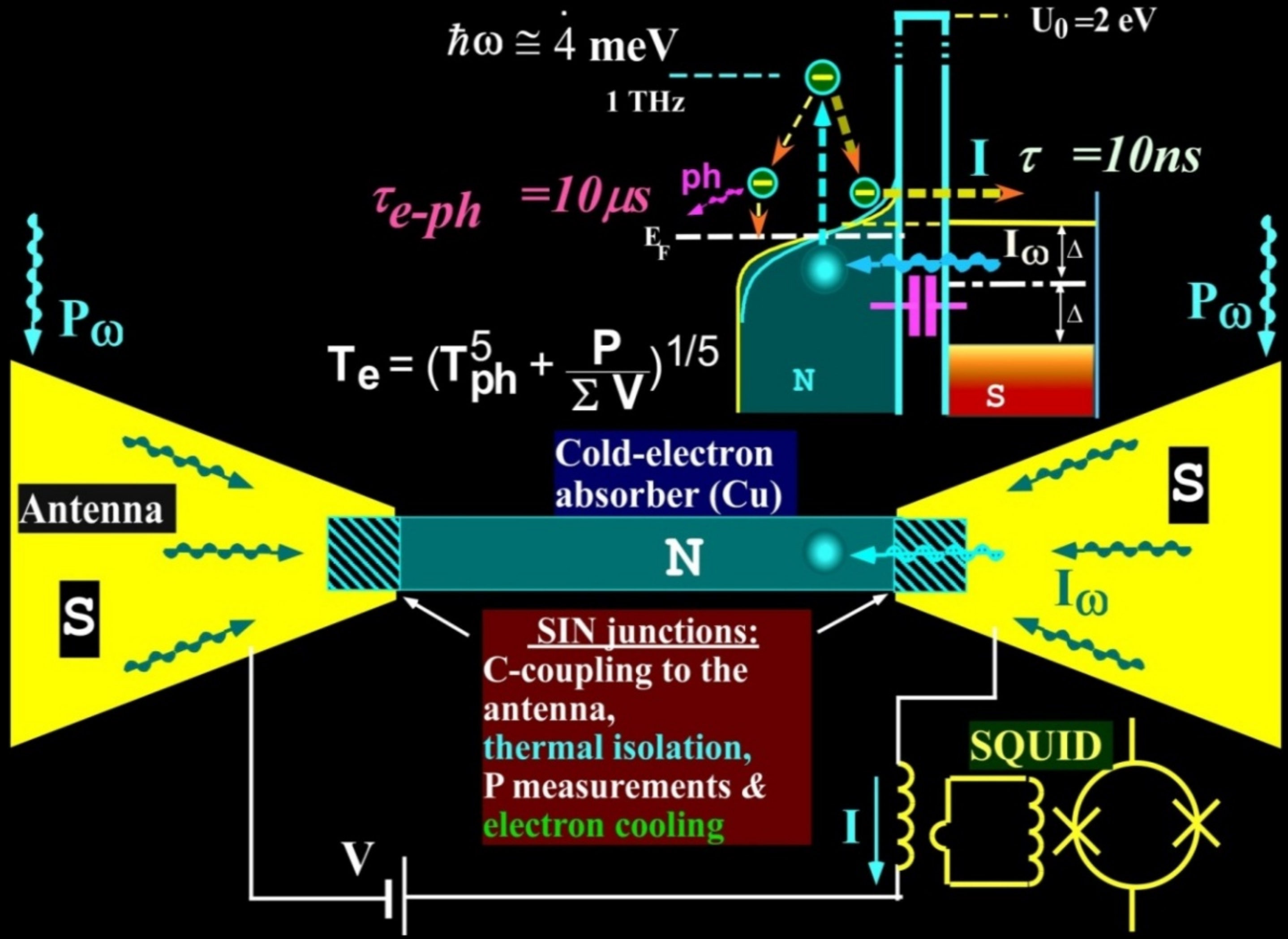


Kinetic Inductance Detector



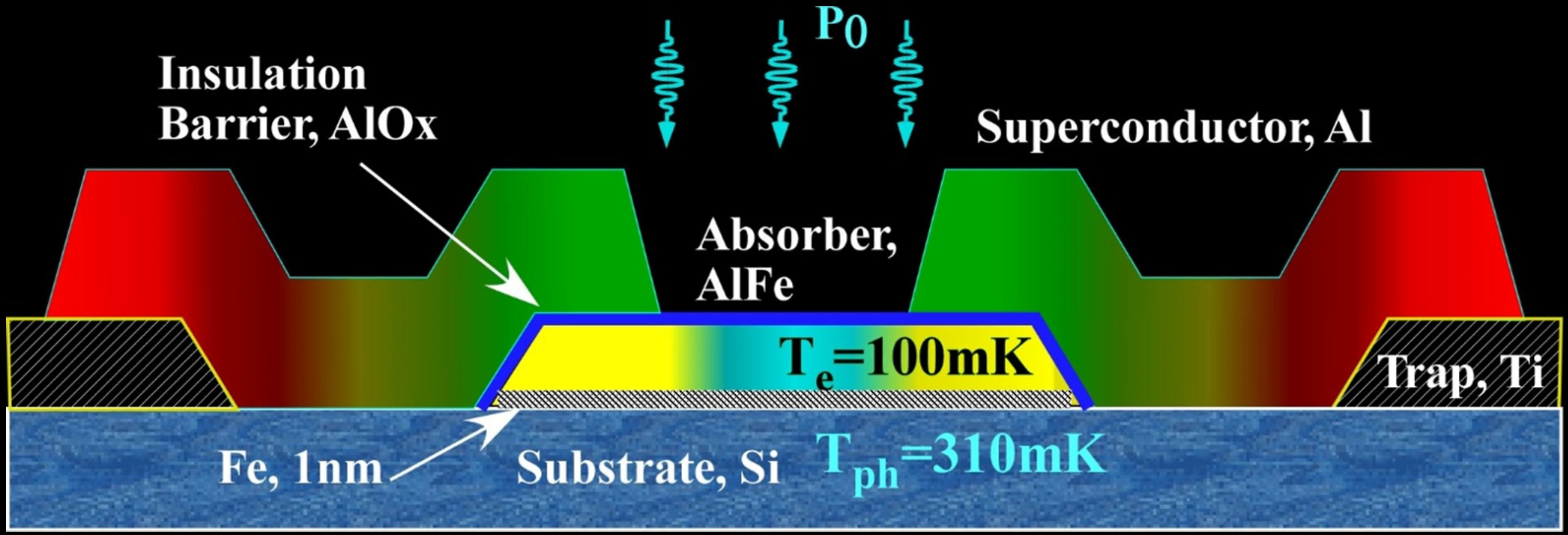
Cold-Electron Bolometers

Structure



ħω ≅ 4 meV
1 THz
U0 =2 eV
I τ =10ns
τe-ph =10μs
ph
EF
Iω
Δ
Δ
Pω
Pω
Te = (T5ph + P/ΣV)1/5
N
S
Cold-electron
absorber (Cu)
S
Antenna
N
S
Iω
SIN junctions:
C-coupling to the
antenna,
thermal isolation,
P measurements &
electron cooling
SQUID
I
V

Structure



P_0
Insulation Barrier, AlOx
Superconductor, Al
Absorber, AlFe
T_e=100mK
Trap, Ti
Fe, 1nm
Substrate, Si
T_{ph}=310mK

Record Electron Cooling

Very small volume of the absorber (0.02 um^3) and large relative area of tunnel junctions (80% of the absorber).

Efficient removing of hot quasiparticles by double stocking them at both sides of the junctions.

Suppression of Andreev Reflection by a thin layer of Fe in AlFe absorber.

Result: unique bolometers operating at T_e less than T_{ph}.

Direct Electron Cooling vs Platform Phonon Cooling

Direct electron cooling

Kuzmin et al., 2002–2019

Direct electron self-cooling of the absorber at 300 mK to reach 70 mK or 170 mK under 20 pW radiation.

The cooler size is 1×1 um².

Result: photon noise limited system of 194 CEBs for OLIMPO Balloon Telescope.

Cooling Platform

Pekola et al. 1997–2019

Phonon cooling of a membrane from 300 to 200 mK.

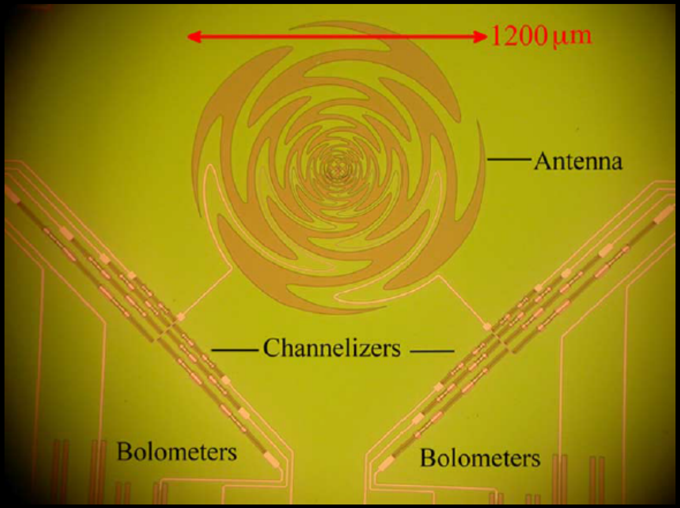
The cooler size is 2×2 mm².

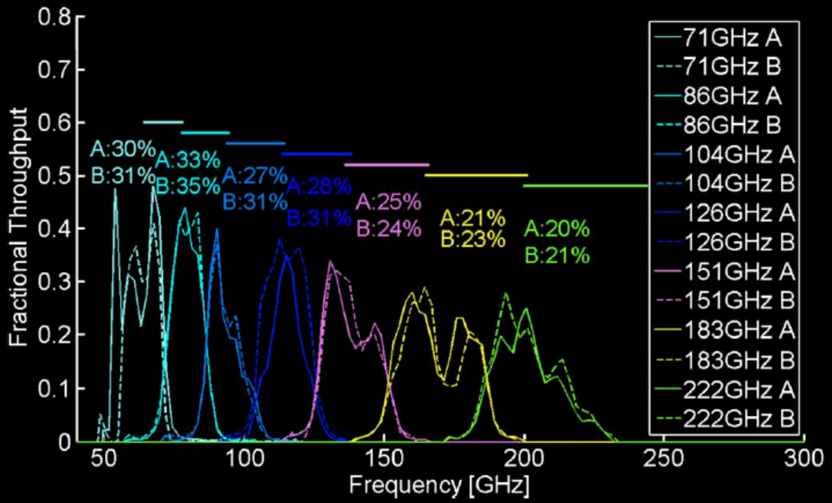
Result: no tests of bolometers on the platform so far.

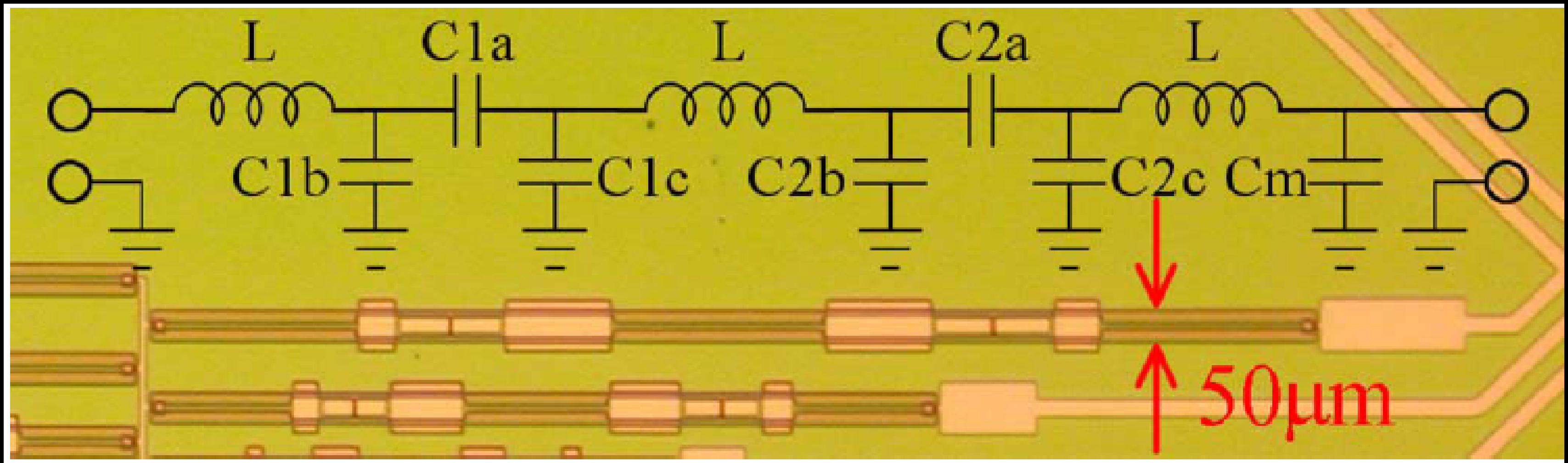
A. J. Manninen, M. M. Leivo, J. P. Pekola, “Refrigeration of a dielectric membrane by SIN tunneling”, Appl. Phys. Lett. 70, 1885 (1997).

Sinuous Antenna

R. O'Brian *et al.*, IEEE Appl. Sc. (2011)

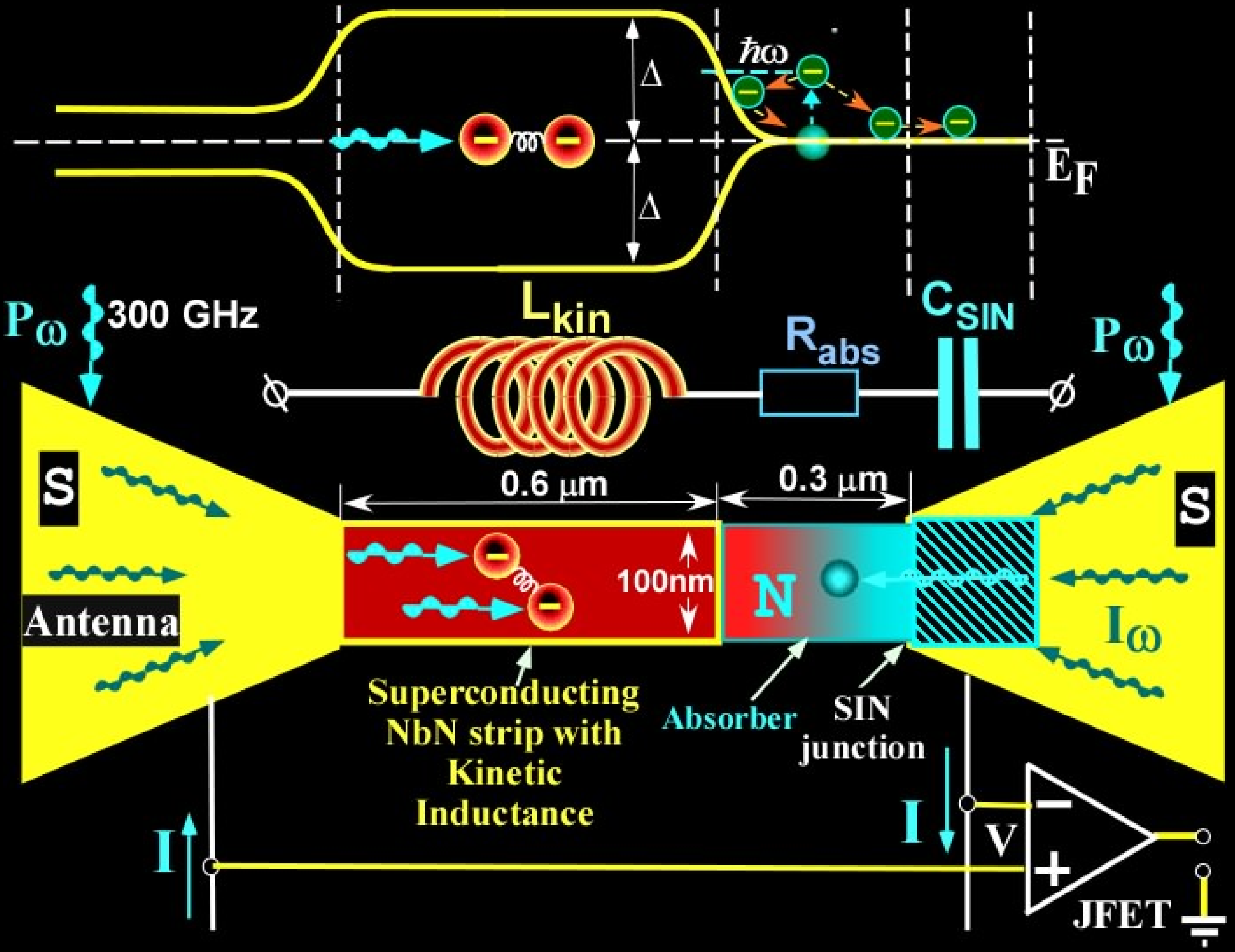




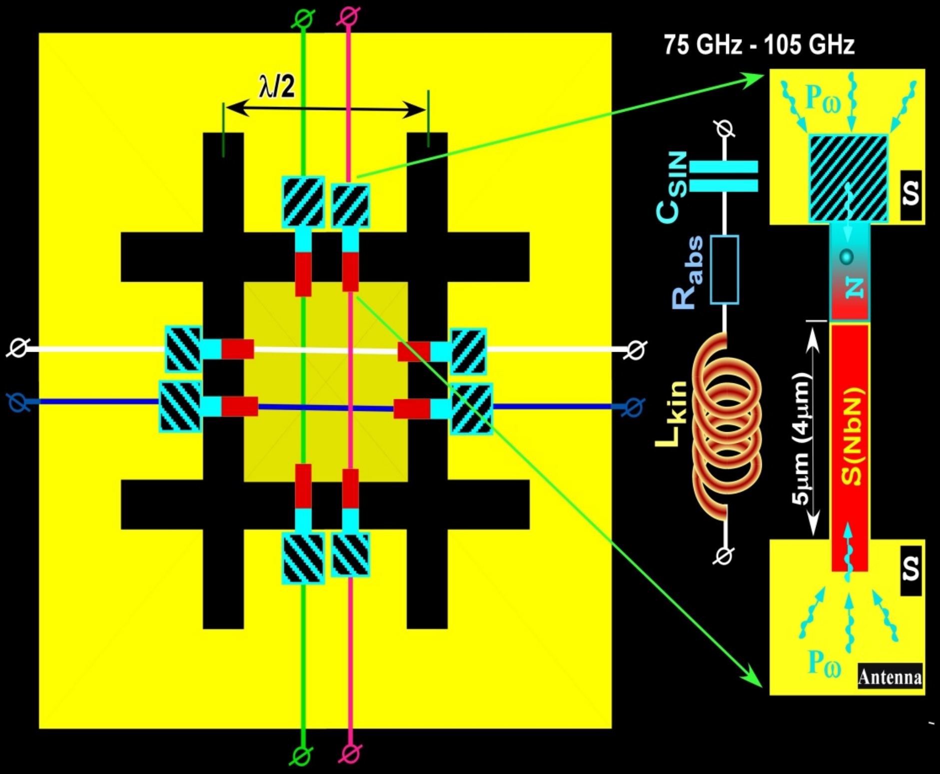


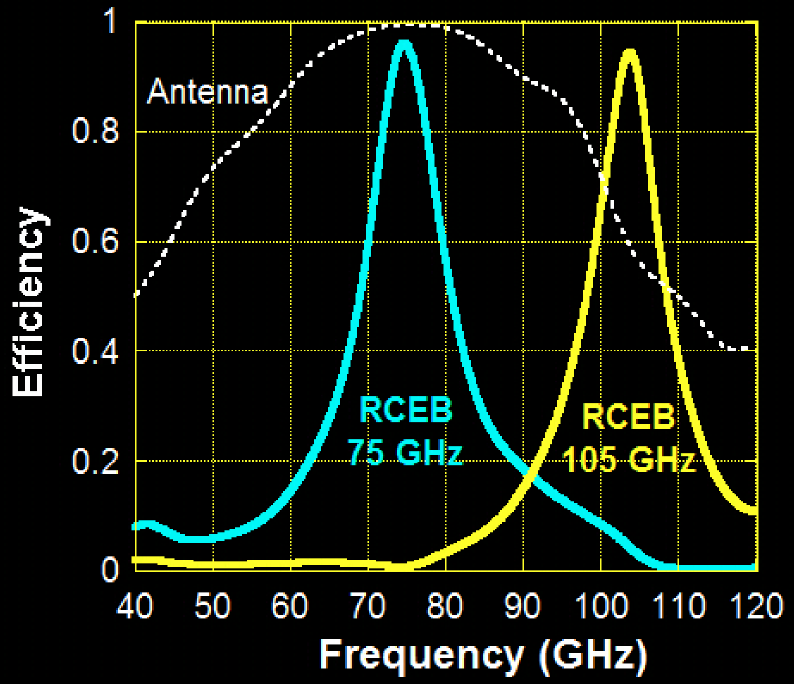
L. Kuzmin, ISSTT, 2013; IEEE TST, 2014

Nanofilter by a Kinetic Inductance of the NbN Strip



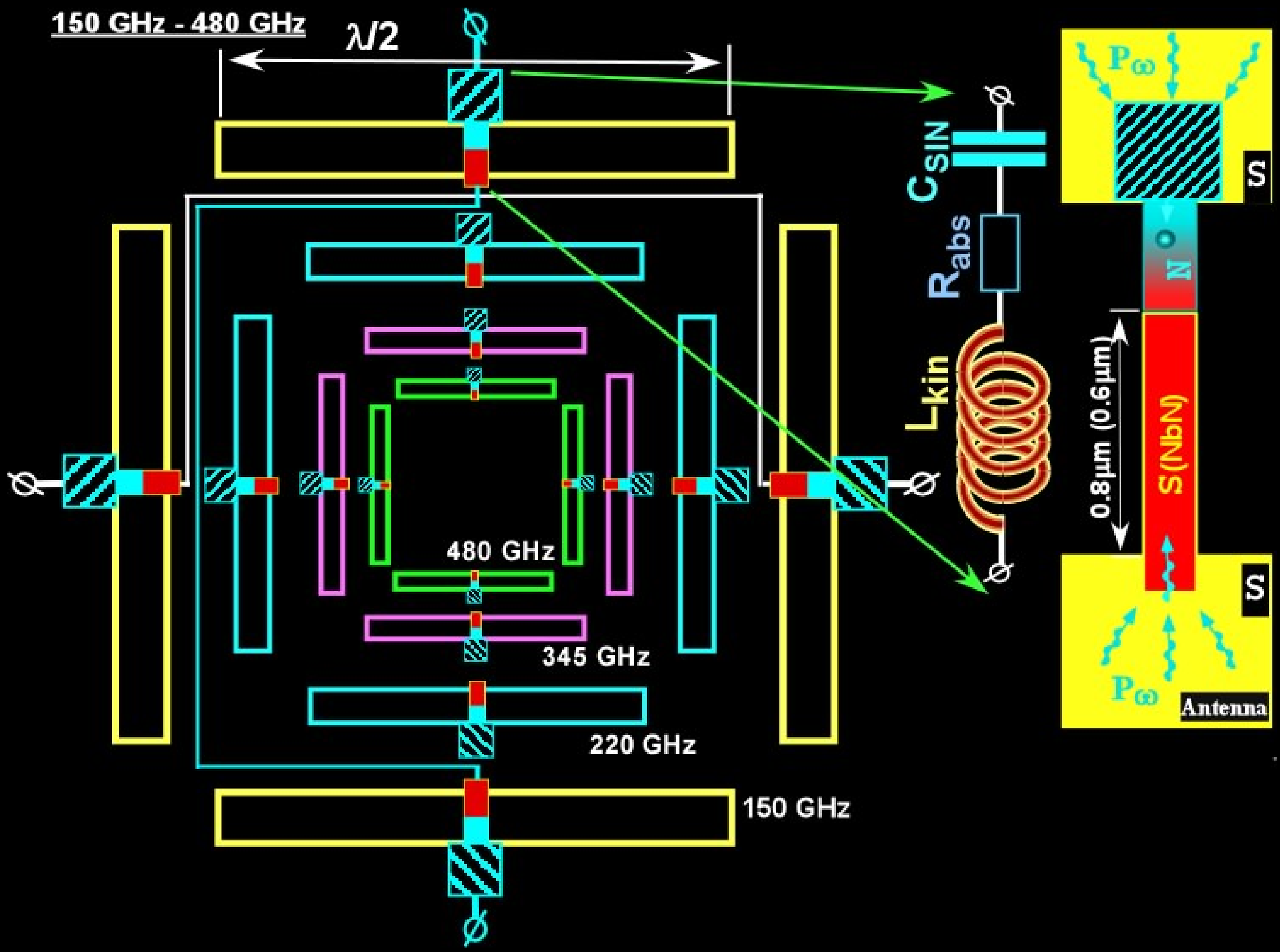
Cross-Slot Antenna





“Seashell” Slot Antenna

Leonid Kuzmin, Rome, 21 Sept 2013
stimulative discussions with Paolo de Bernardis are acknowledged



Seashell Antenna with Resonant Slot Antenna and w/o RCEBs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Featured article

Multichroic seashell antenna with internal filters by resonant slots and cold-electron bolometers

L S Kuzmin, A V Blagodatkin, A S Mukhin, D A Pimanov, V O Zbrozhek, A V Gordeeva, A L Pankratov and A V Chiginev

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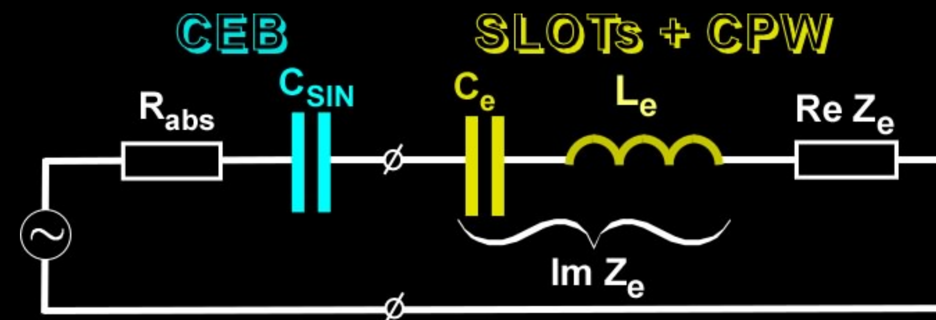
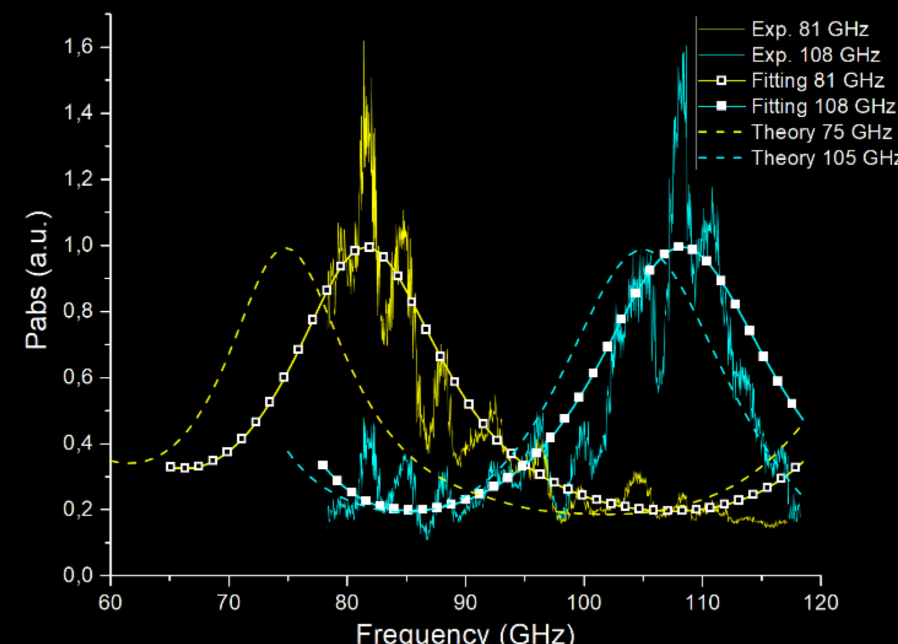
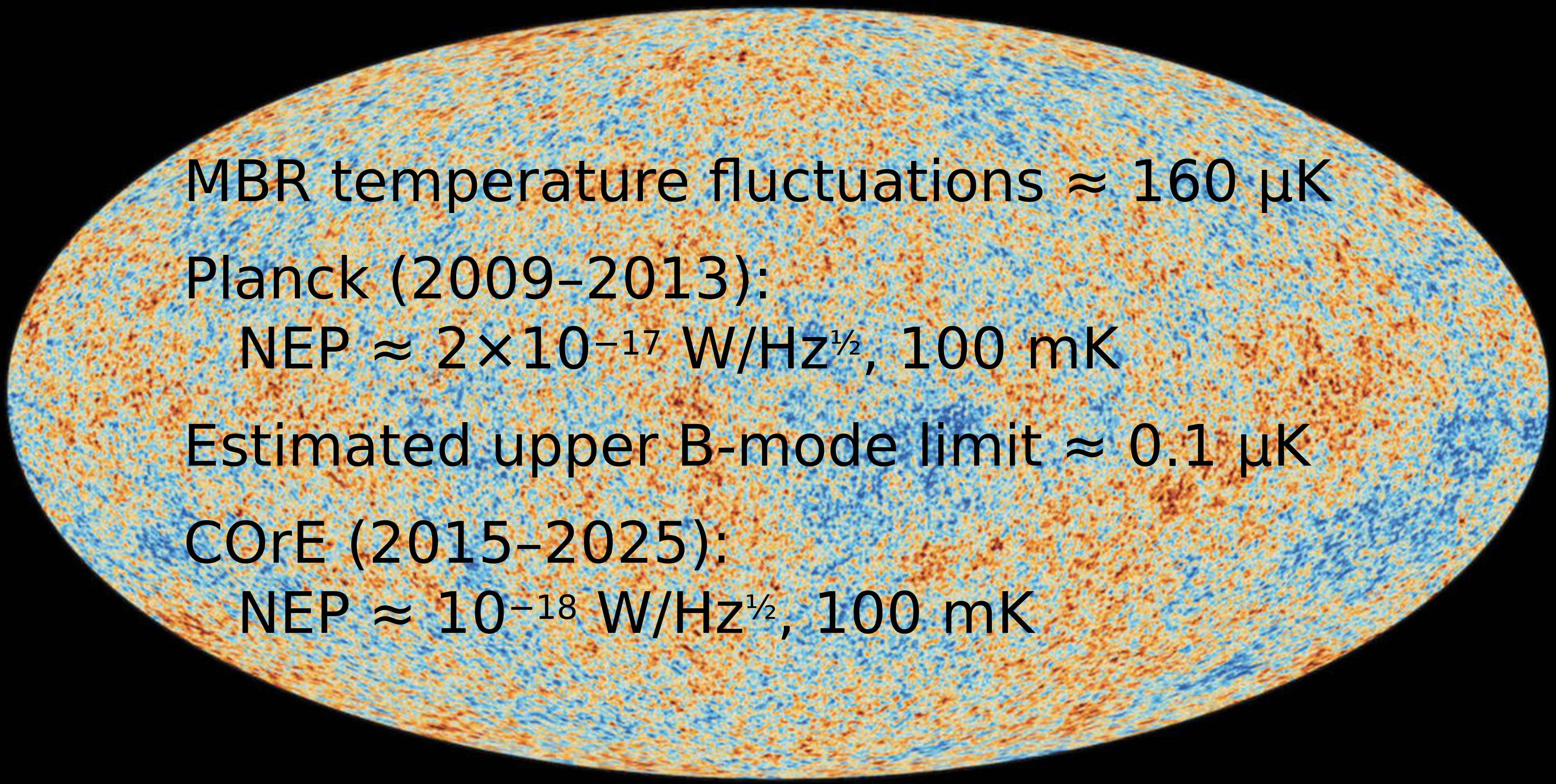




Application



MBR temperature fluctuations ≈ 160 μK

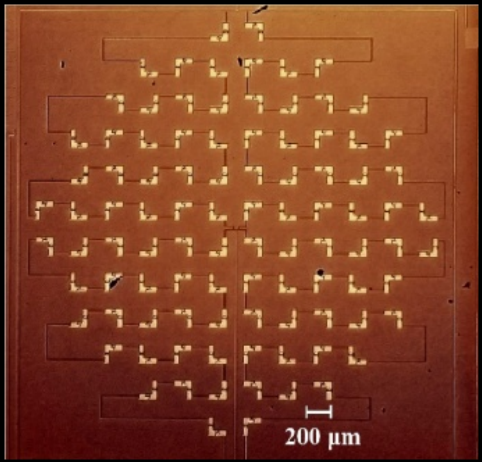
Planck (2009–2013):
NEP ≈ 2×10^{-17} W/Hz$^{1/2}$, 100 mK

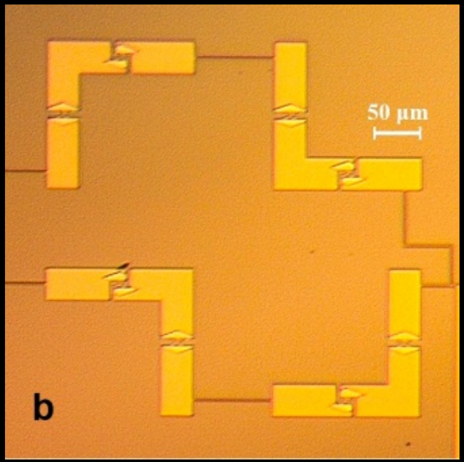
Estimated upper B-mode limit ≈ 0.1 μK

COrE (2015–2025):
NEP ≈ 10^{-18} W/Hz$^{1/2}$, 100 mK

Credit: ESA, Planck Collaboration

Application:
OLIMPO Receiver Pixel

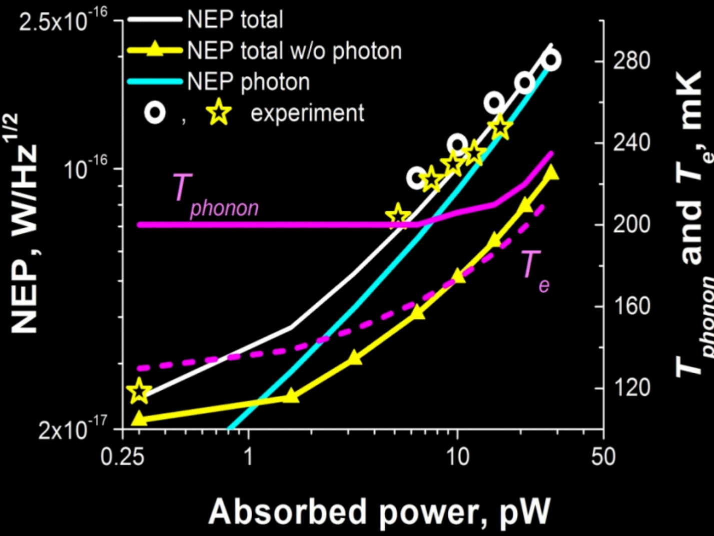


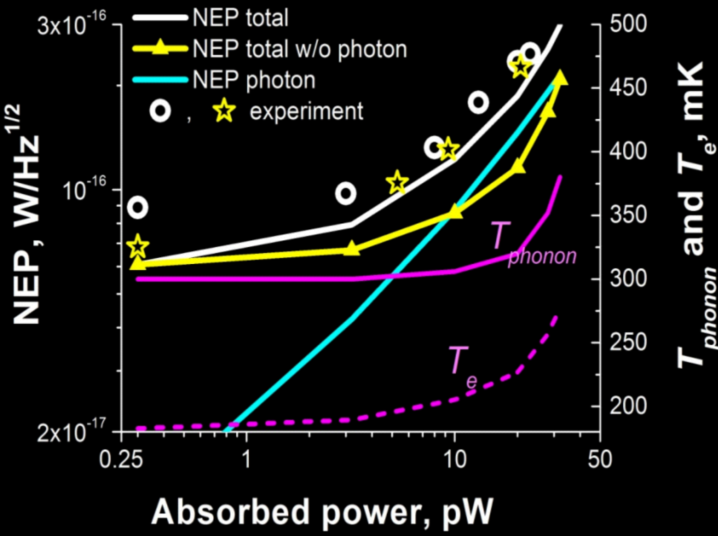


OLIMPO, channel III:
350 GHz, df = 33 GHz

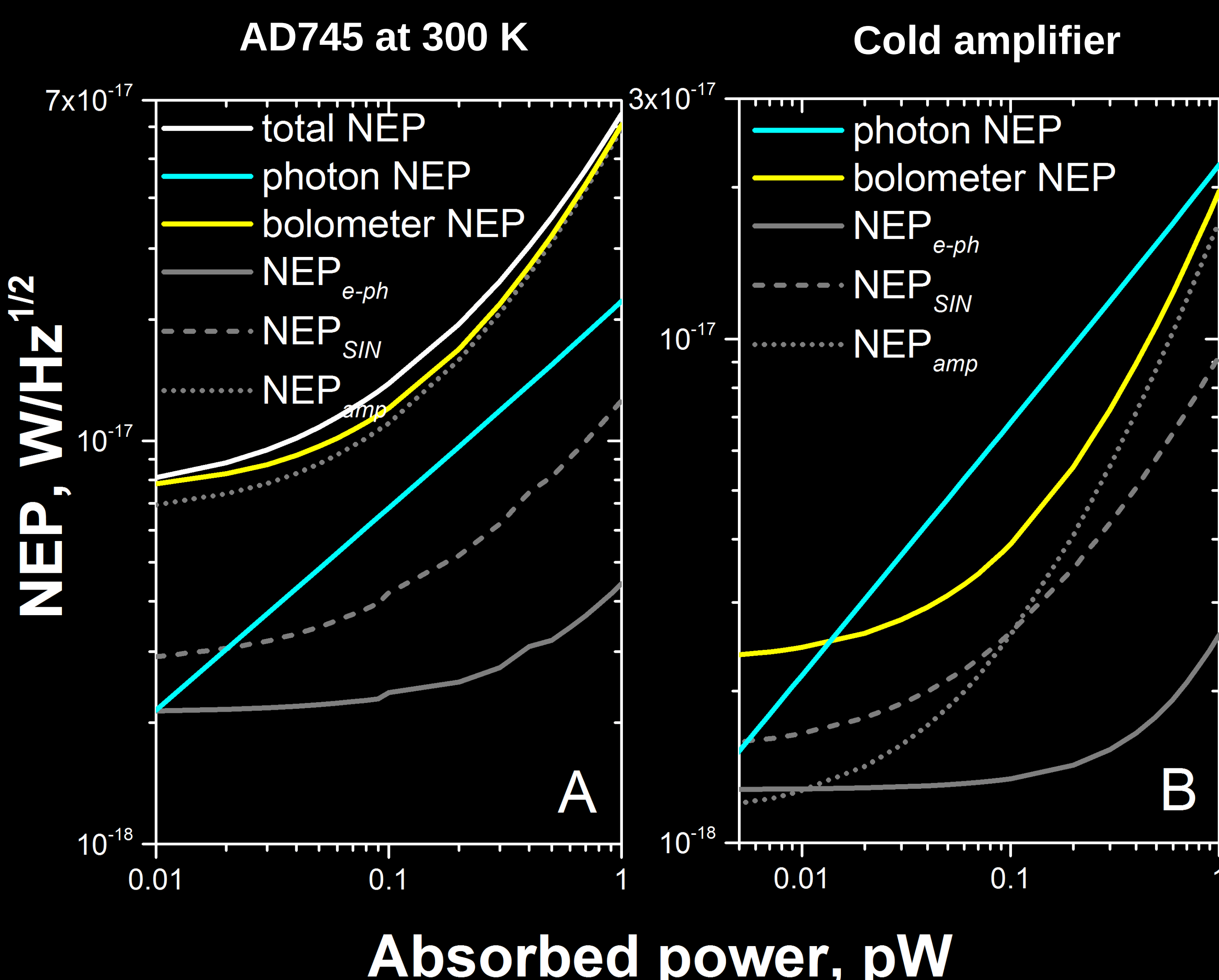
Load: P = 38 to 66 pW

Photon noise limit:
$NEP_{bol} < NEP_{ph} = 10^{-16}$ W/Hz^{½}

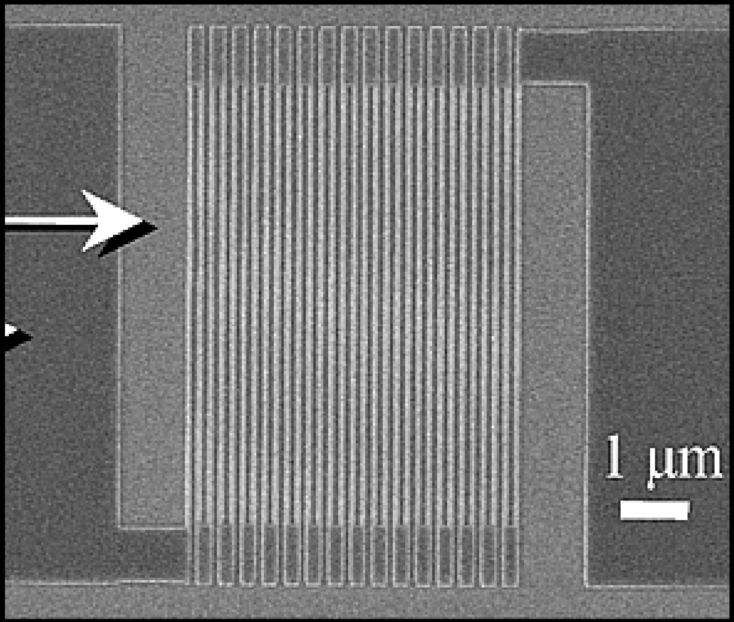




Single Bolometer NEP

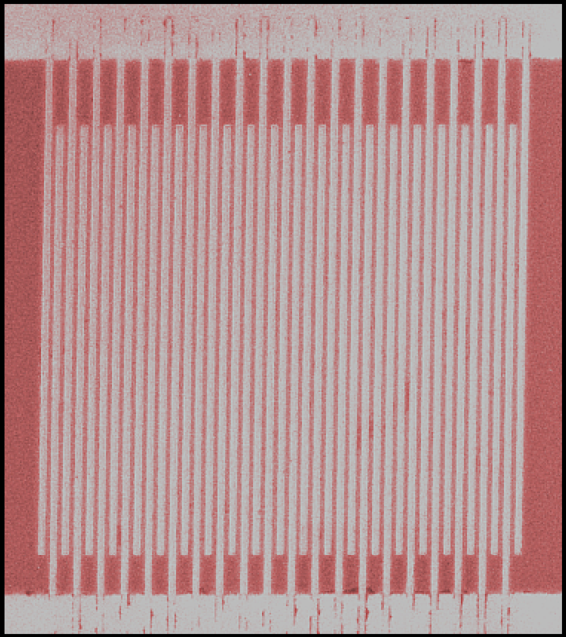


Weak Signals Detector



SEM of a nanowire pattern

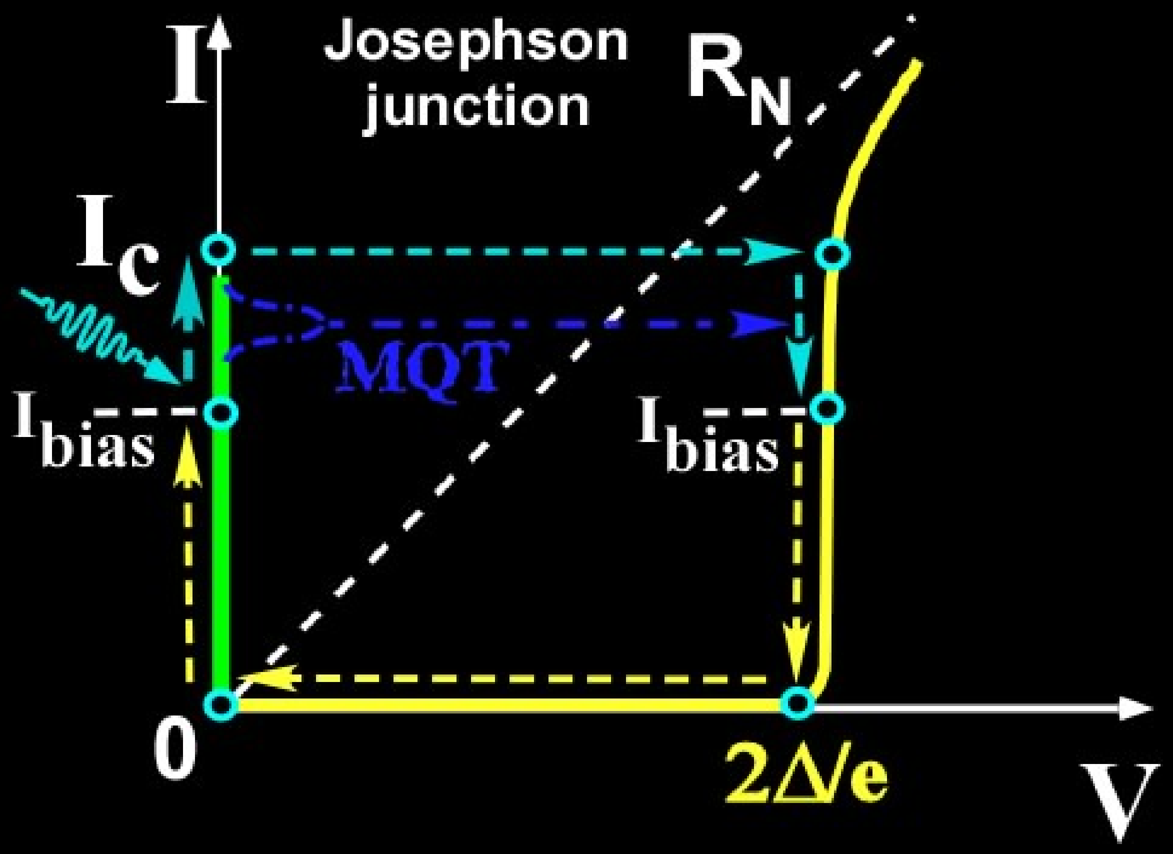
G. Gol'tsman et al.



WSi nanowire with a detection energy threshold of 0.8 eV

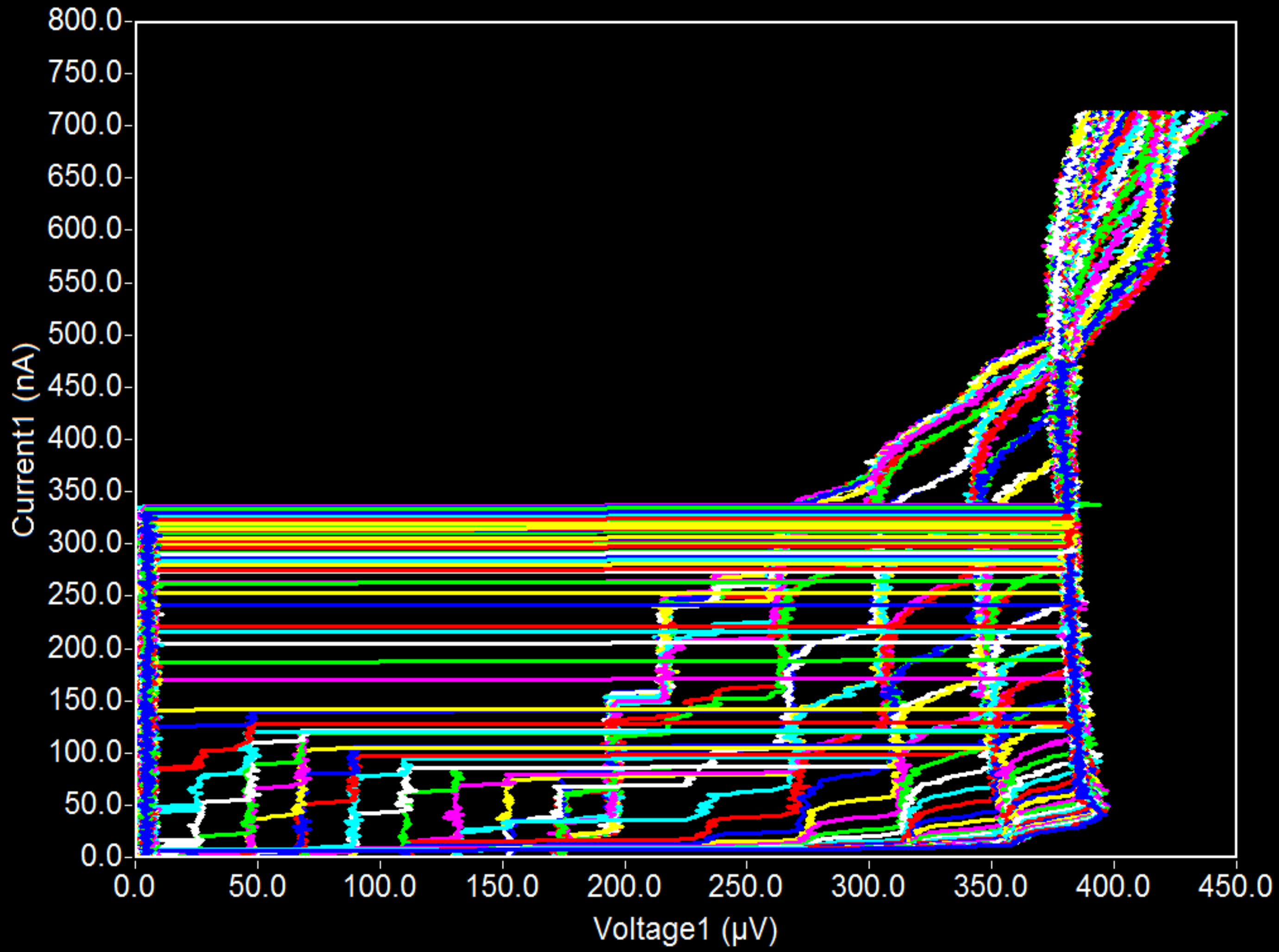
Y. Hochberg et al.

Weak Signals Detector



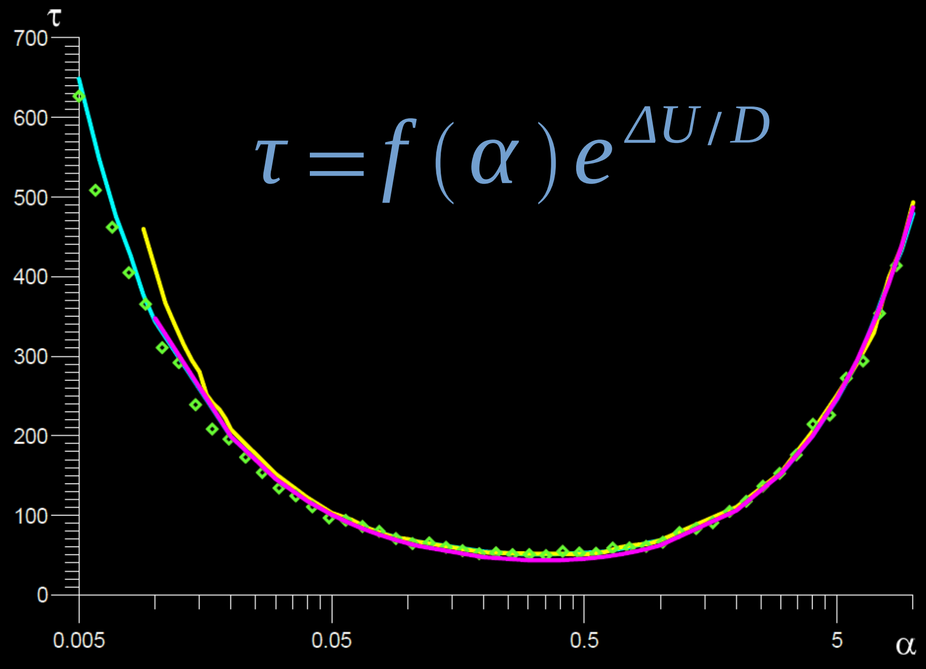
G. Oelsner, L. S. Revin, E. Il'ichev, A. L. Pankratov, H.-G. Meyer, L. Gronberg, J. Hassel, L. S. Kuzmin, Appl. Phys. Lett. 103, 142605 (2013)

9 GHz Signal Response

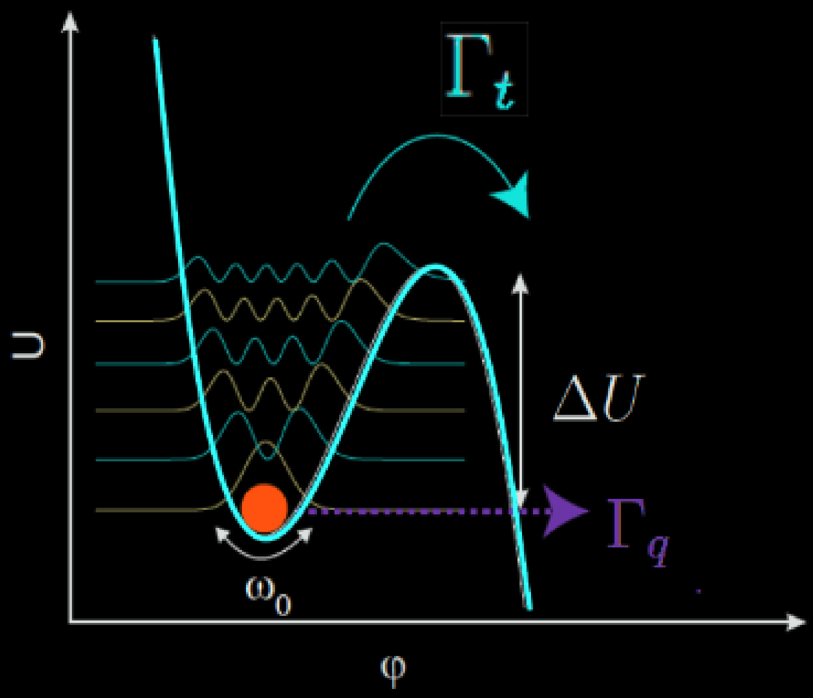


Theory

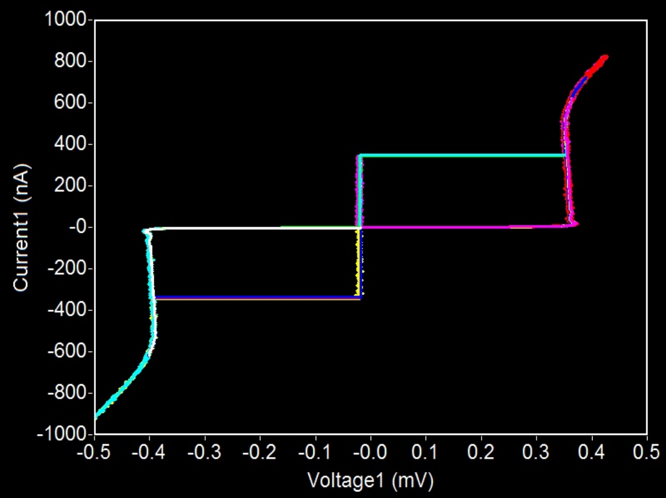
$$\frac{d^2\varphi}{dt^2}+\alpha\frac{d\varphi}{dt}=\eta-\sin(\varphi)+\sqrt{2D}\,\xi(t)$$

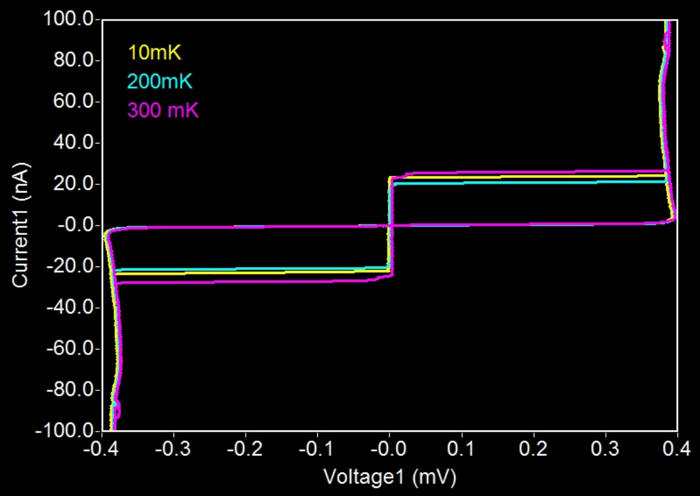


$$\tau=f(\alpha)\,e^{\Delta U/D}$$



Измерение ВАХ образцов Al SIS контактов





SIS1

I_c = 0.328 uA

S = 7 um^2

C = 0.315 pF

Rn = 470 Ohm

α = 0.1

SIS2

I_c = 0.025 uA

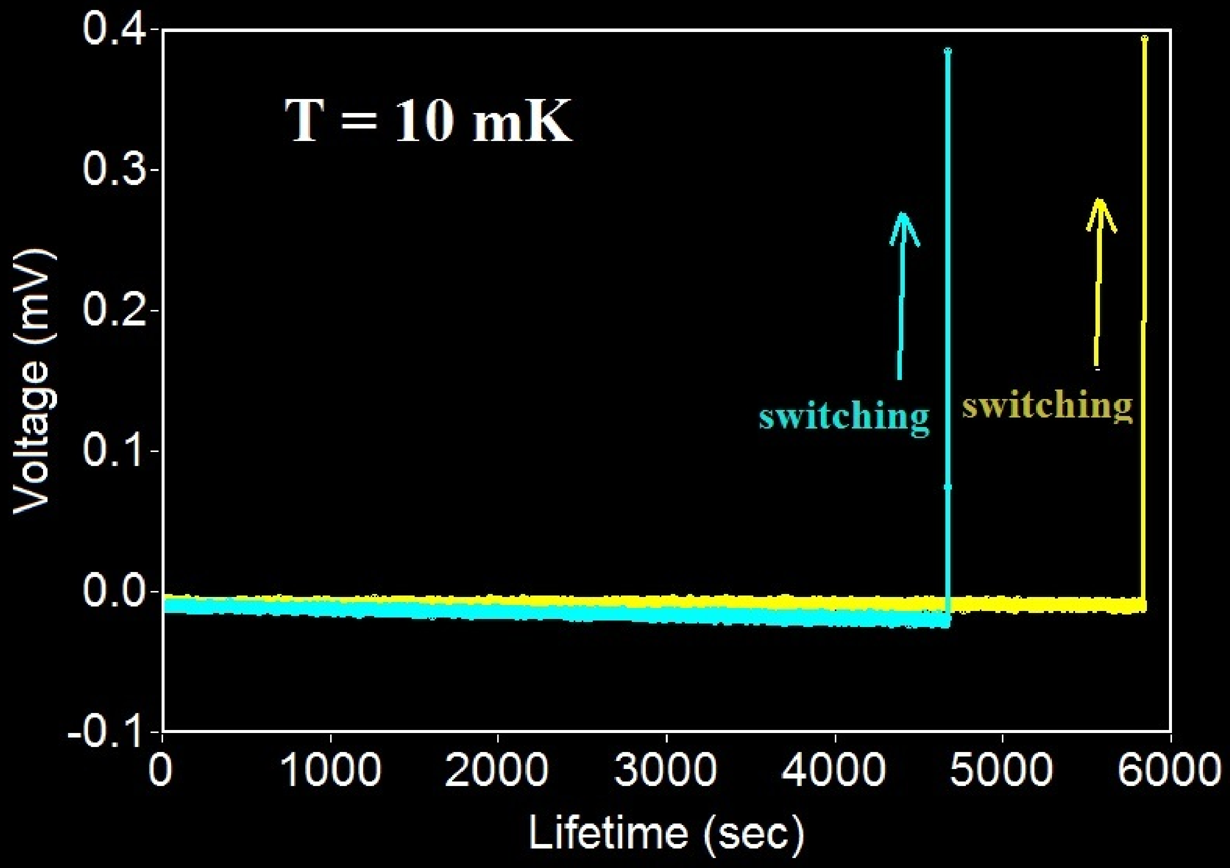
S = 0.8 um^2

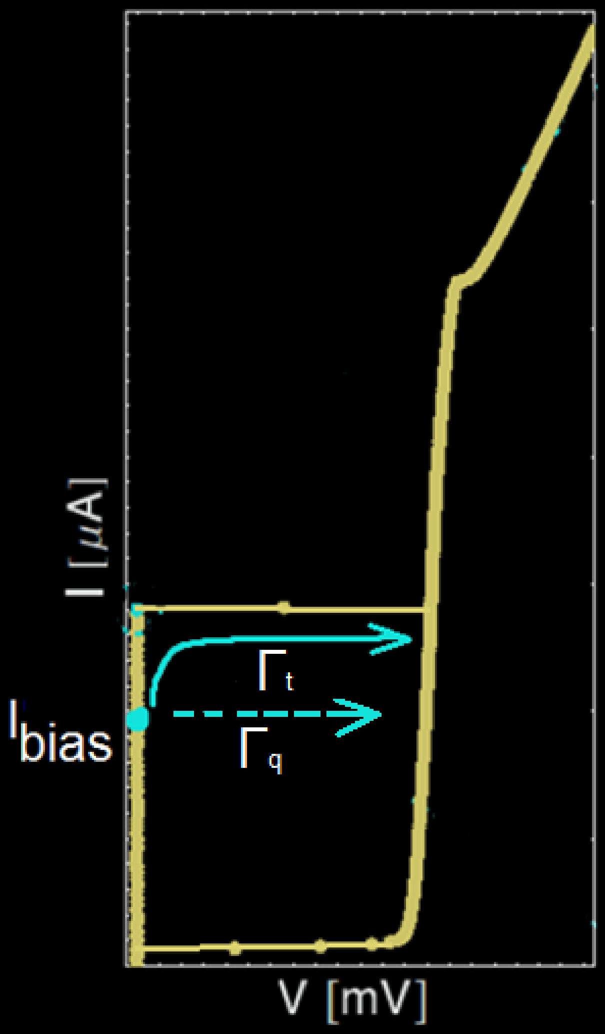
C = 0.036 pF

Rn = 2000 Ohm

α = 0.3

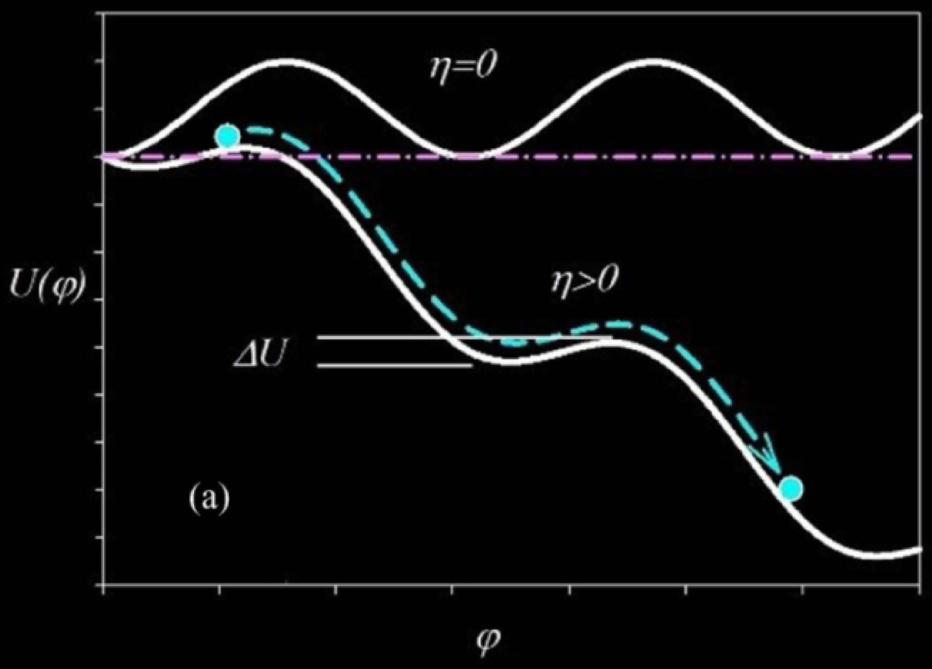
Lifetime: Dark Counts Rate



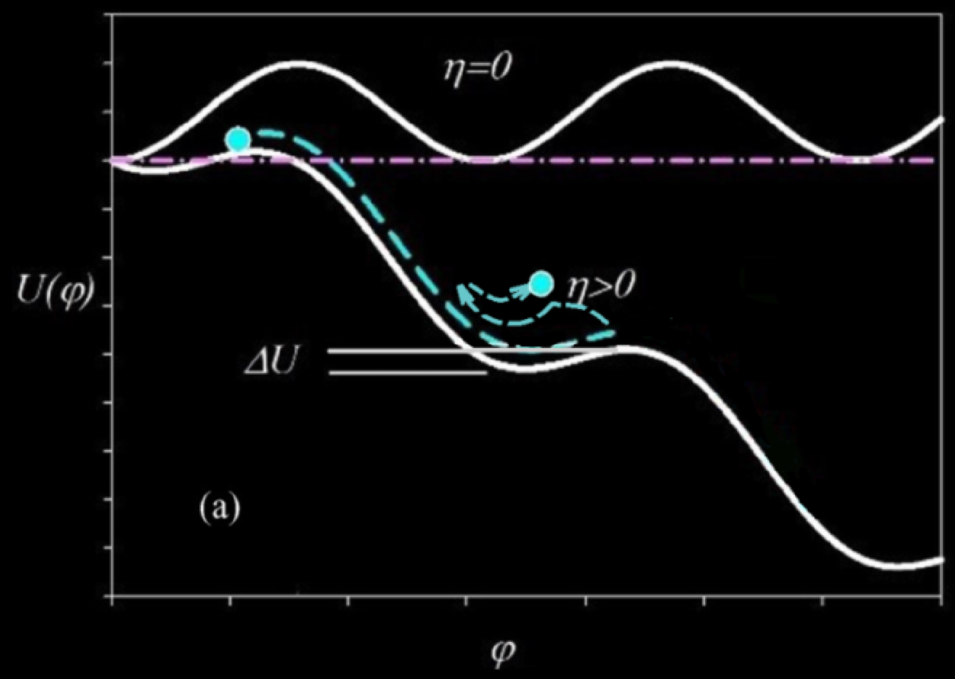


Running State vs Phase Diffusion State

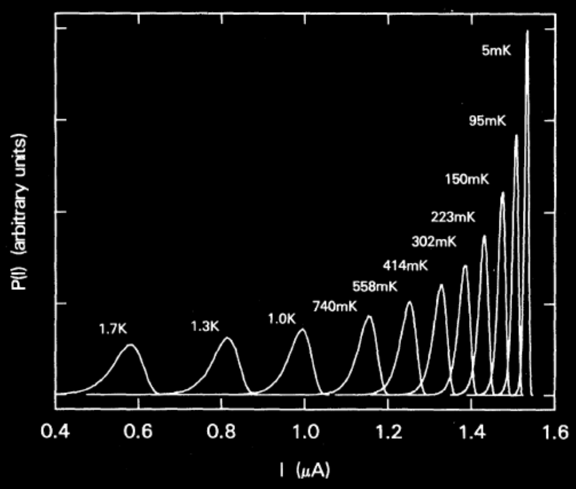
Running State:

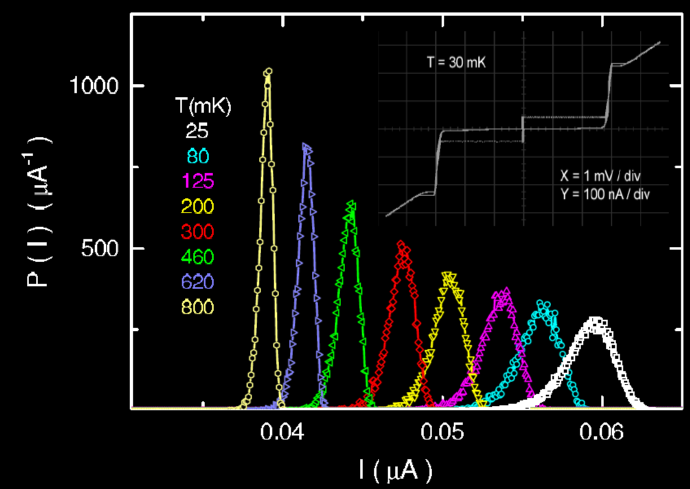


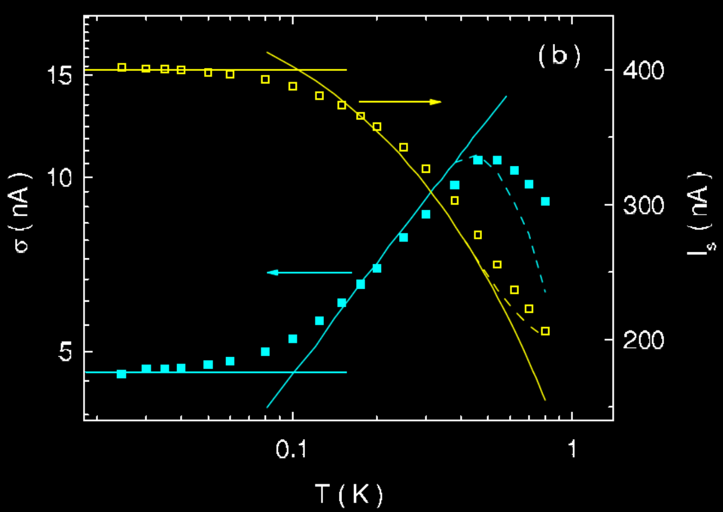
Phase Diffusion:

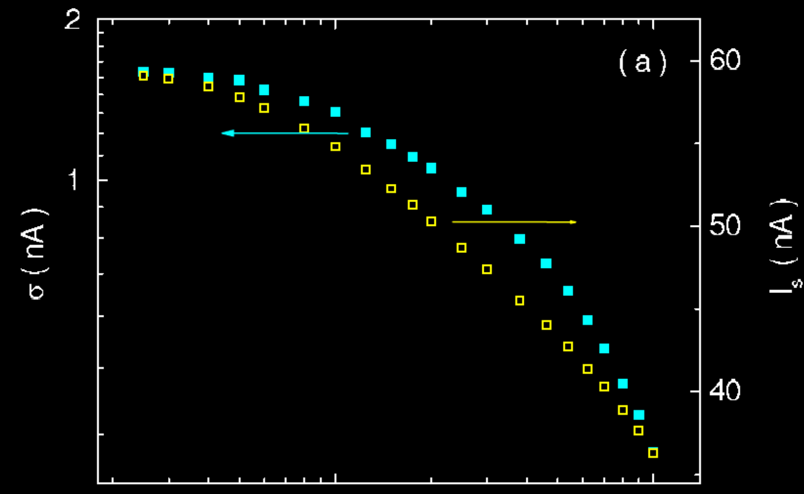


Running State vs Phase Diffusion State





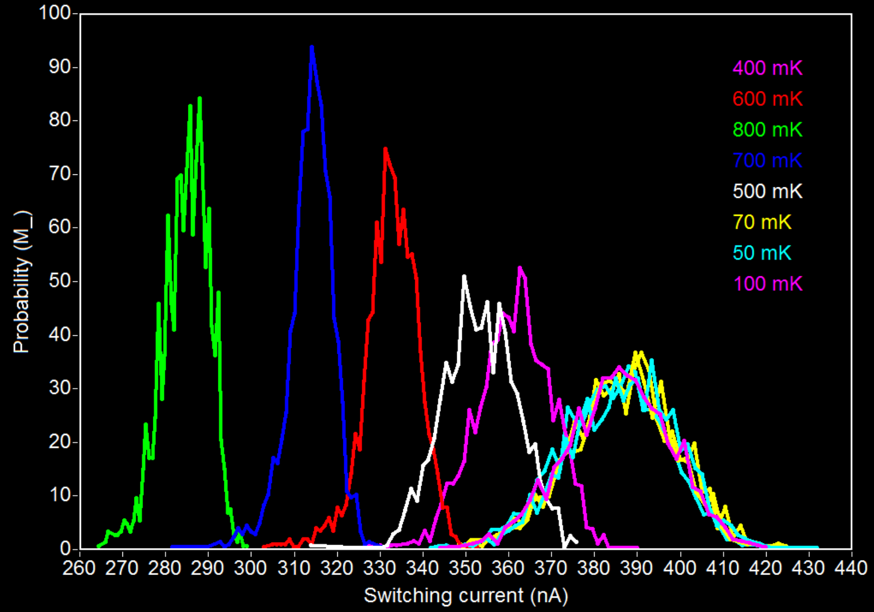


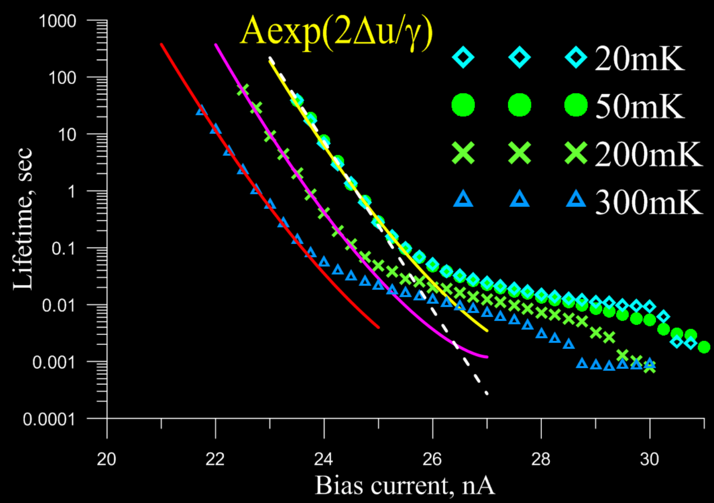


Running State

Phase Diffusion

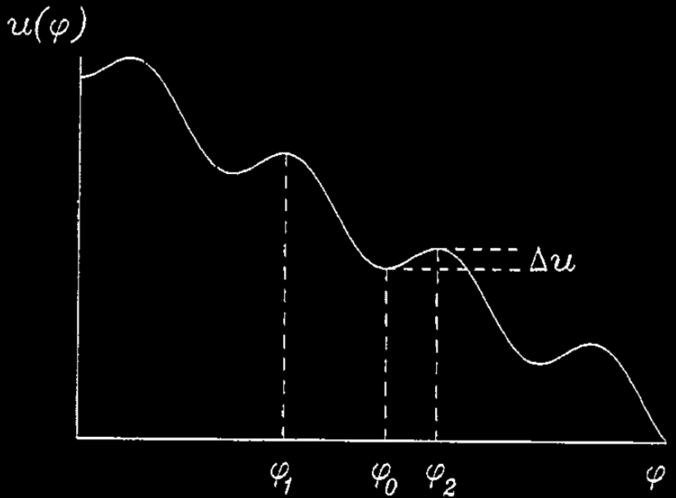
Lifetime Distribution



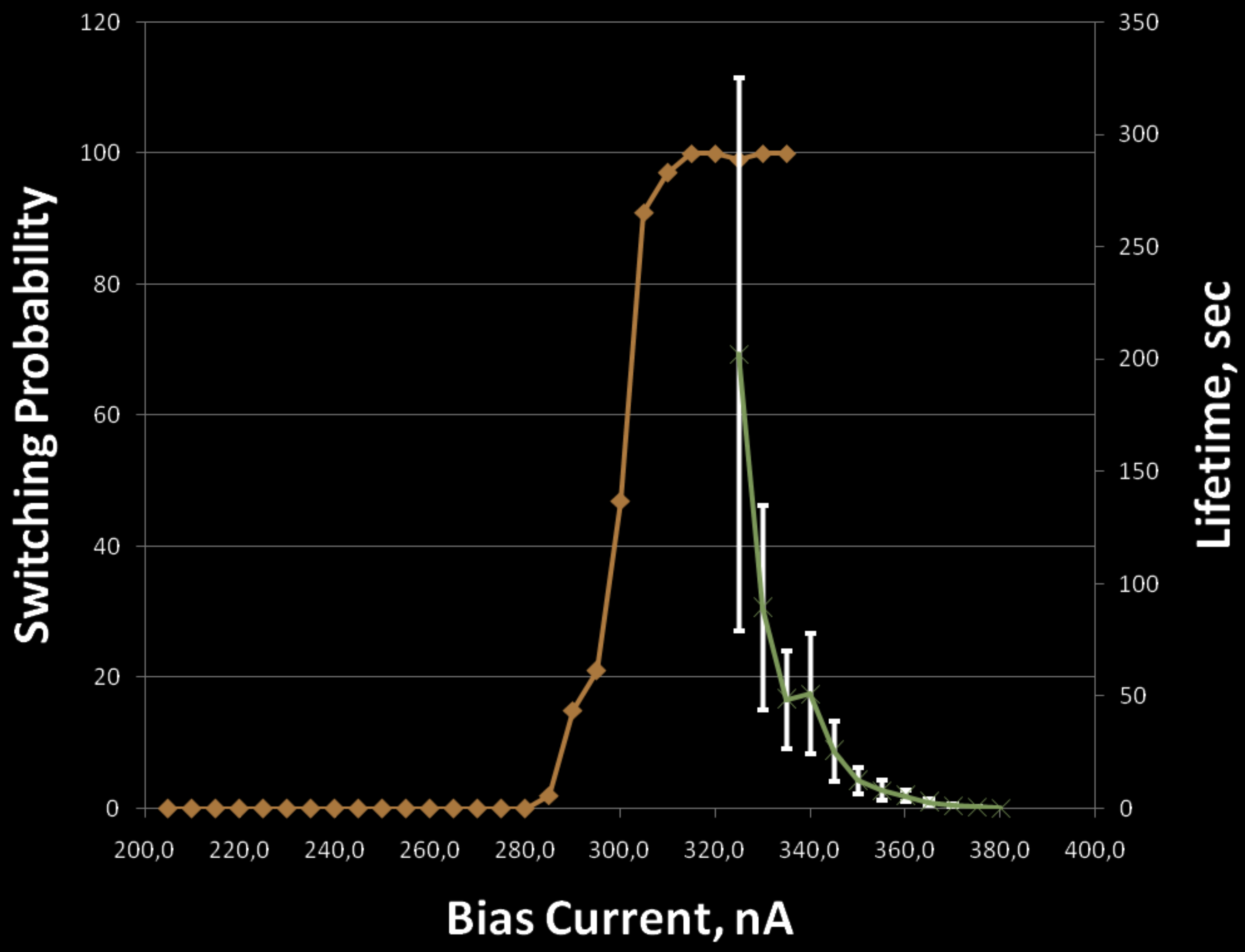


$$\Delta u/\gamma = (2\sqrt{1-i^2} + 2i(\arcsin i - \pi/2))/\gamma$$

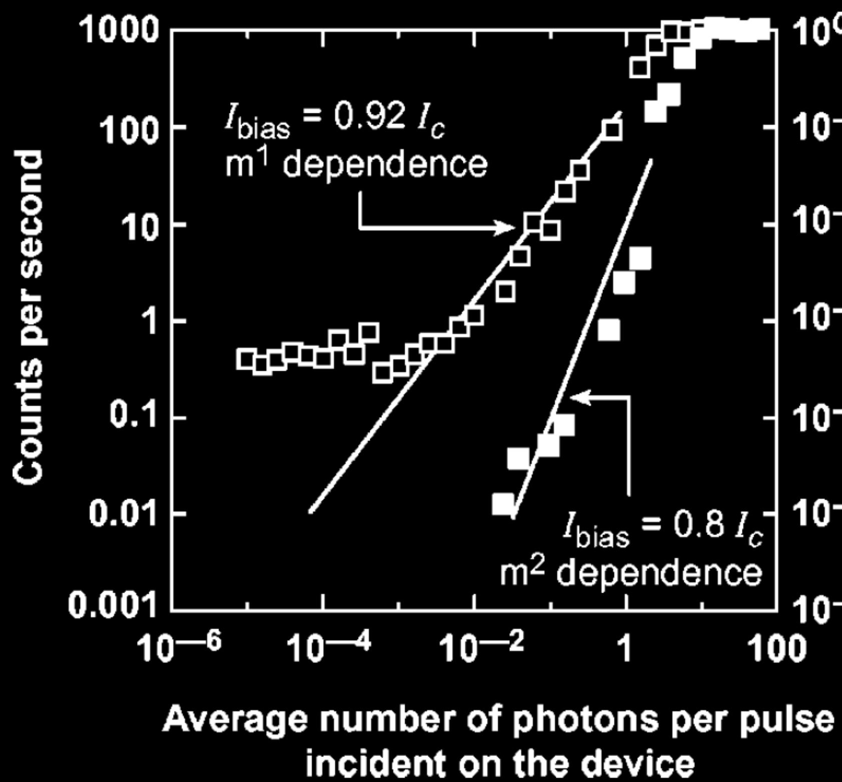
$$\gamma = 2ekT/\hbar I_c = I_T/I_c$$

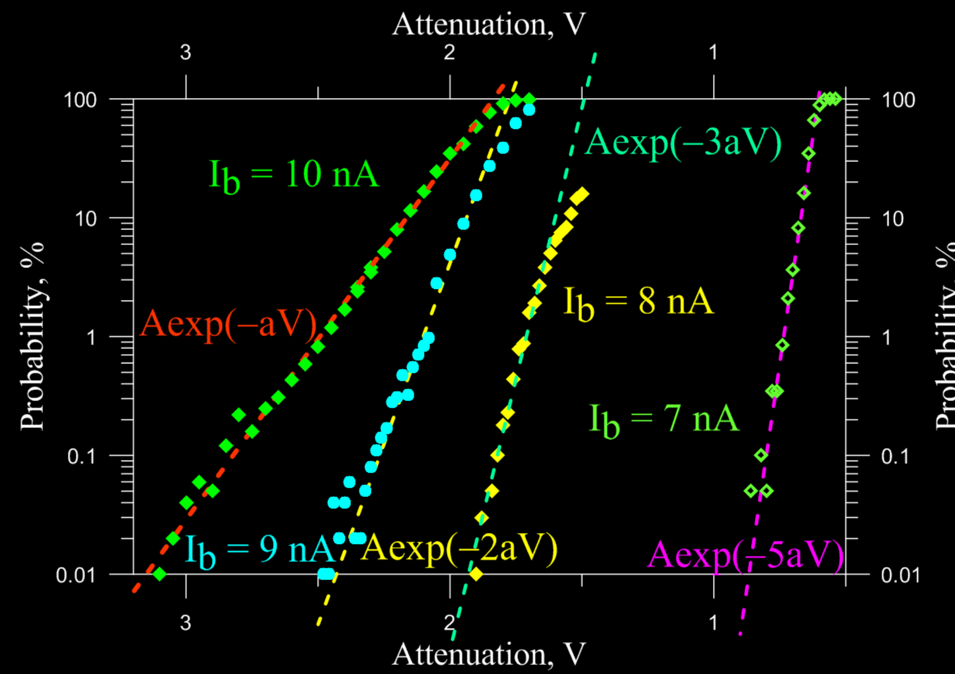


9 GHz Signal Response



9 GHz Signal Response





G. N. Gol'tsman, O. Okunev, G. Chulkova, A. Lipatov, A. Semenov, K. Smirnov, B. Voronov, and A. Dzardanov, Appl. Phys. Lett., 79, 705 (2001).

Conclusions

- A detector of an ultimate sensitivity has been created.
- There are many more mysteries to deal with.