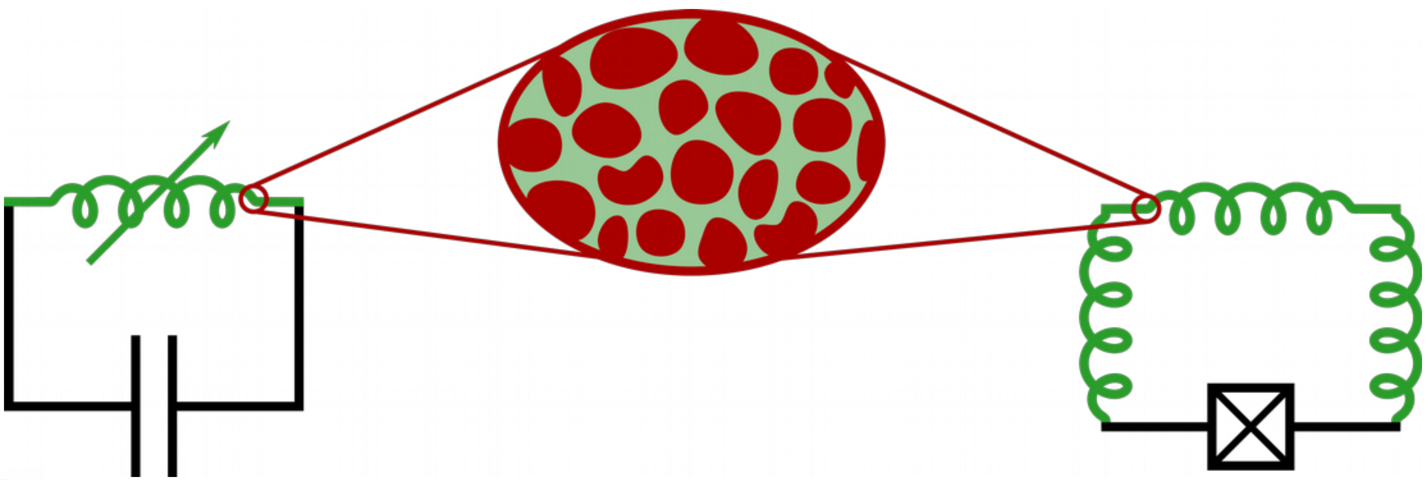
Karlsruhe Institute of Technology

Physikalisches Institut

Granular aluminum

A versatile material for superconducting detectors and quantum circuits

Lukas Grünhaupt



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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Karlsruhe Institute of Technology

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M. Martinez

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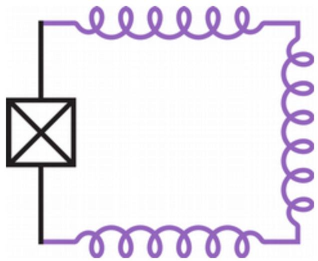
G. Catelani

High kinetic inductance materials for...

Superconducting qubits

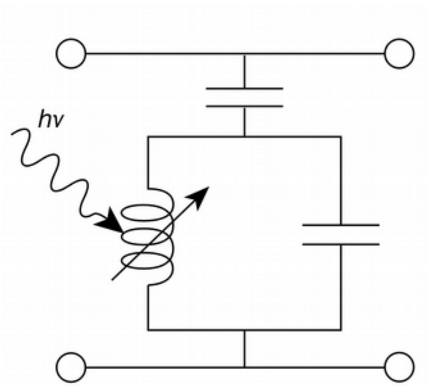


V. Manucharyan *et al.*, Science 326 (2009)
S. Gladchenko *et al.*, Nat. Phys. 5 (2009)
P. Brooks *et al.*, PRA 87 (2013)
S. Richer *et al.*, PRB 96 (2017)
L. Nguyen *et al.*, arXiv:1810.11006 (2018)
T. Hazard *et al.*, PRL 122 (2019)

Strong spin – photon coupling

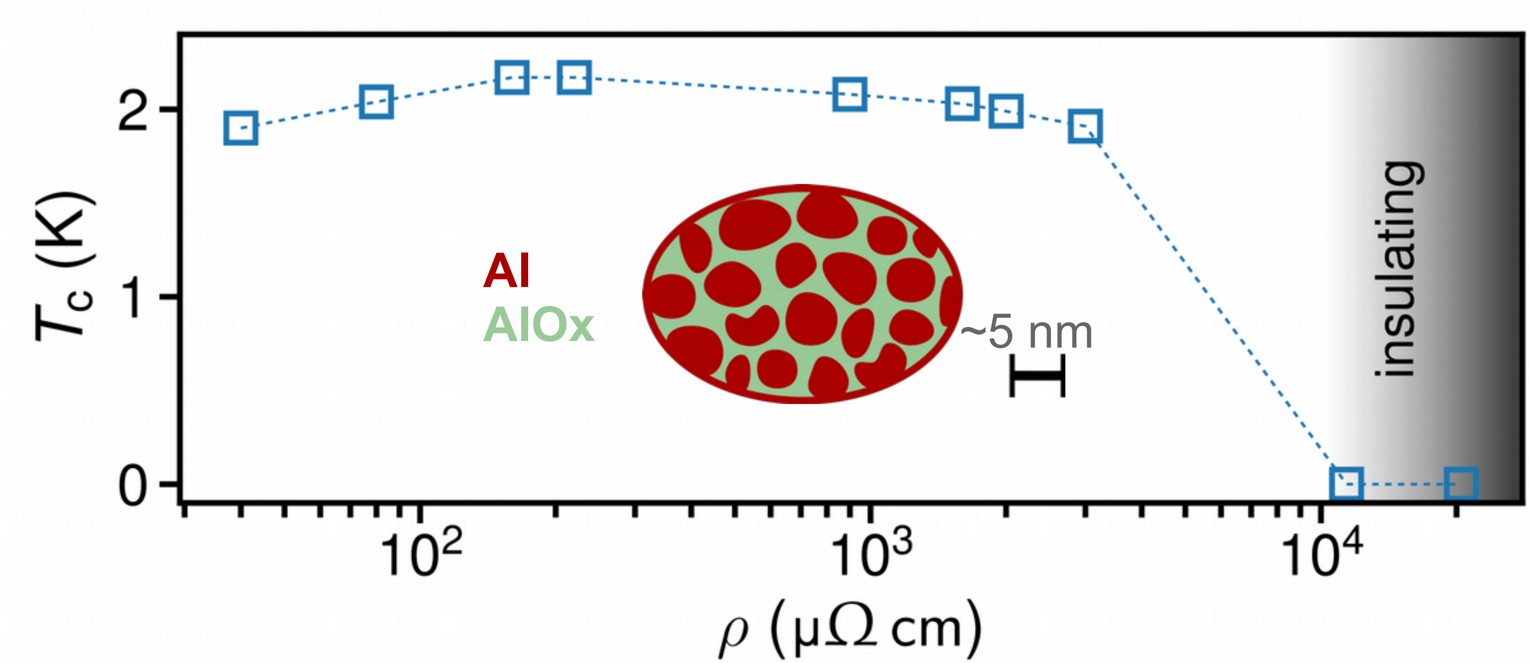
N. Samkharadze *et al.*, Science 359 (2018)
A. J. Landig *et al.*, Nature 560 (2018)

Kinetic inductance detectors



P. Day *et al.*, Nature 425 (2003)
B. Mazin *et al.*, APL 89 (2006)
L. Swenson *et al.*, APL 96 (2010)
J. Gao *et al.*, APL 101 (2012)
P. J. de Visser *et al.*, Nat. Commun. 5 (2014)
P. D. Mauskopf, PASP 130 (2018)

Granular aluminum



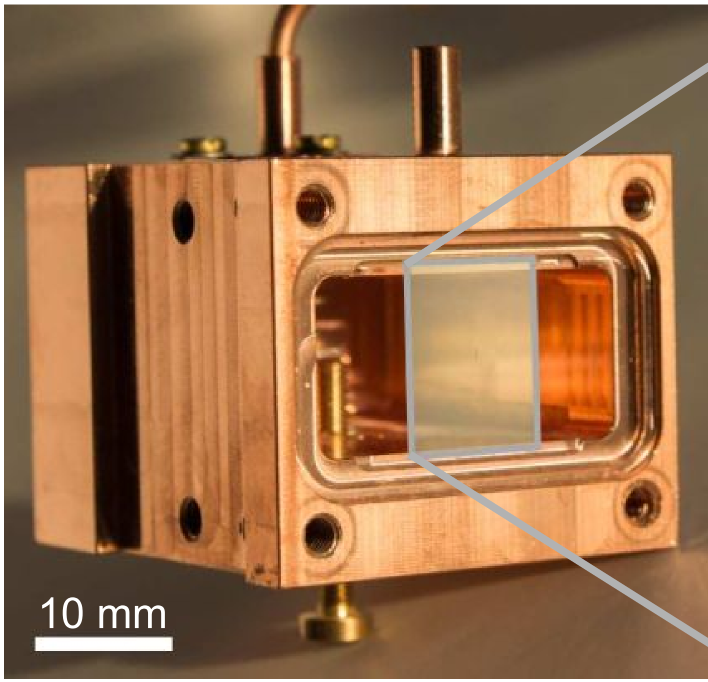
ρ tunable by control of oxygen pressure during evaporation

⬇

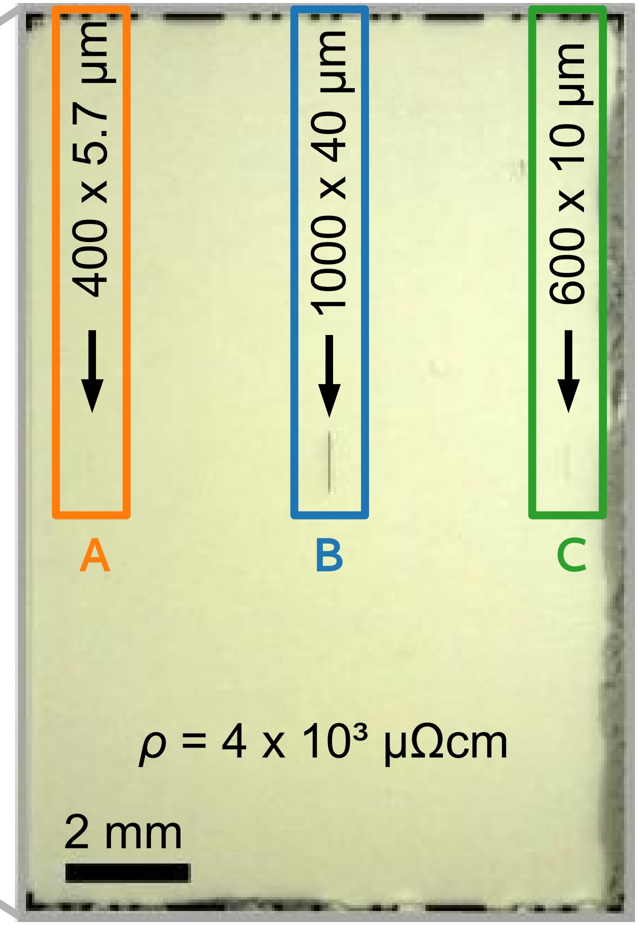
$L_{kinetic}$ from ~ pH/sq up to ~ nH/sq

R. W. Cohen and B. Abeles, Phys. Rev. 168 (1968)
G. Deutscher *et al.*, J. Low Temp. Phys. 10 (1973)
U. Pracht & N. Bachar *et al.*, PRB 93 (2016)
H. Rotzinger *et al.*, SuST 30 (2016)
F. Valenti *et al.*, PR Appl. 11 (2019)
F. Levy-Bertrand *et al.*, PRB 99 (2019)

Granular aluminum kinetic inductance



A. Kou *et al.*, Phys. Rev. Appl. 9, (2018)



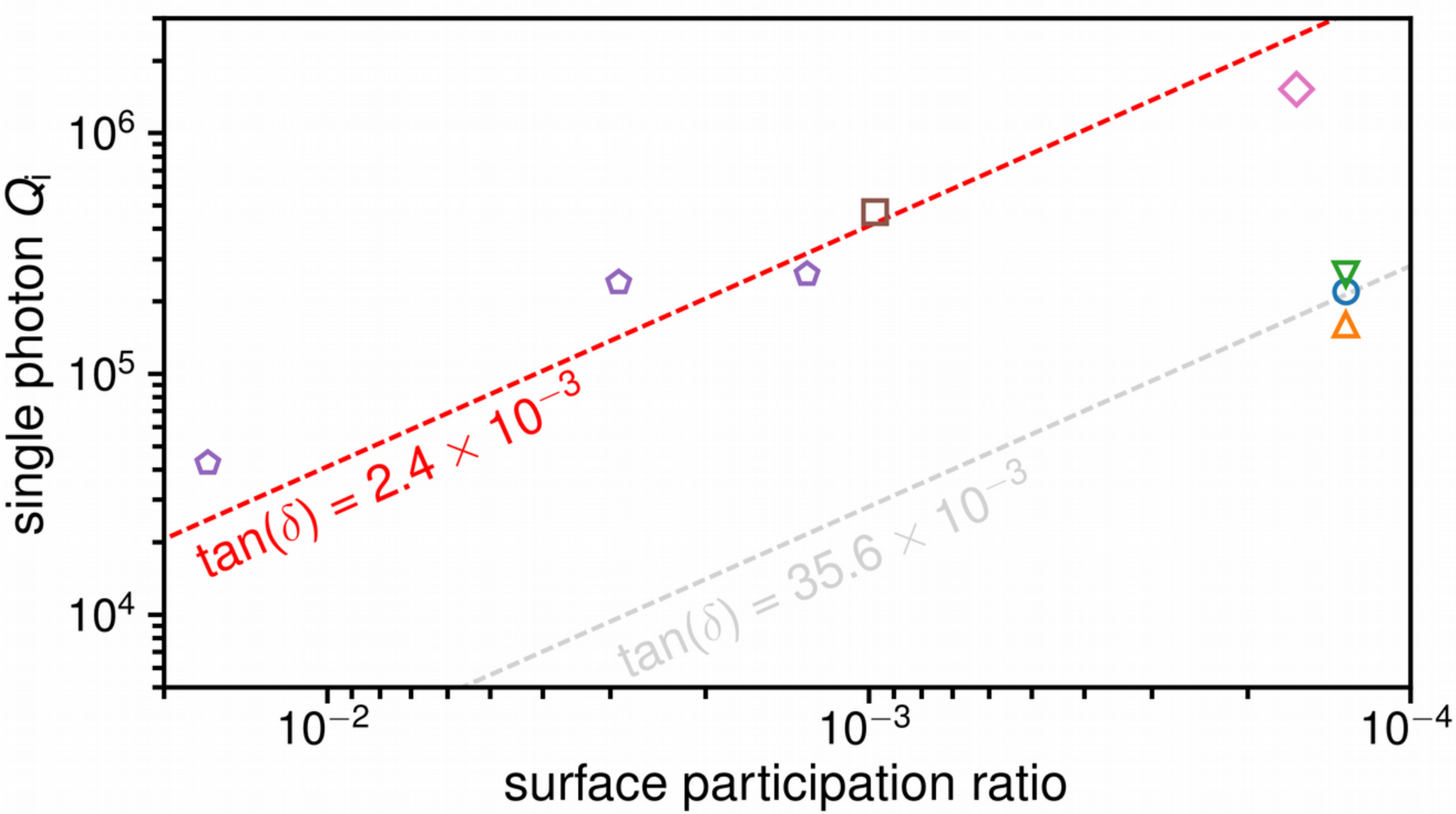
A: f_0 = 6.994 GHz

B: f_0 = 6.025 GHz ➡ $L_{kinetic}$ ≈ **2 nH/sq**

C: f_0 = 6.287 GHz

L. Grünhaupt *et al.*, PRL 121 (2018)

Granular aluminum coherence



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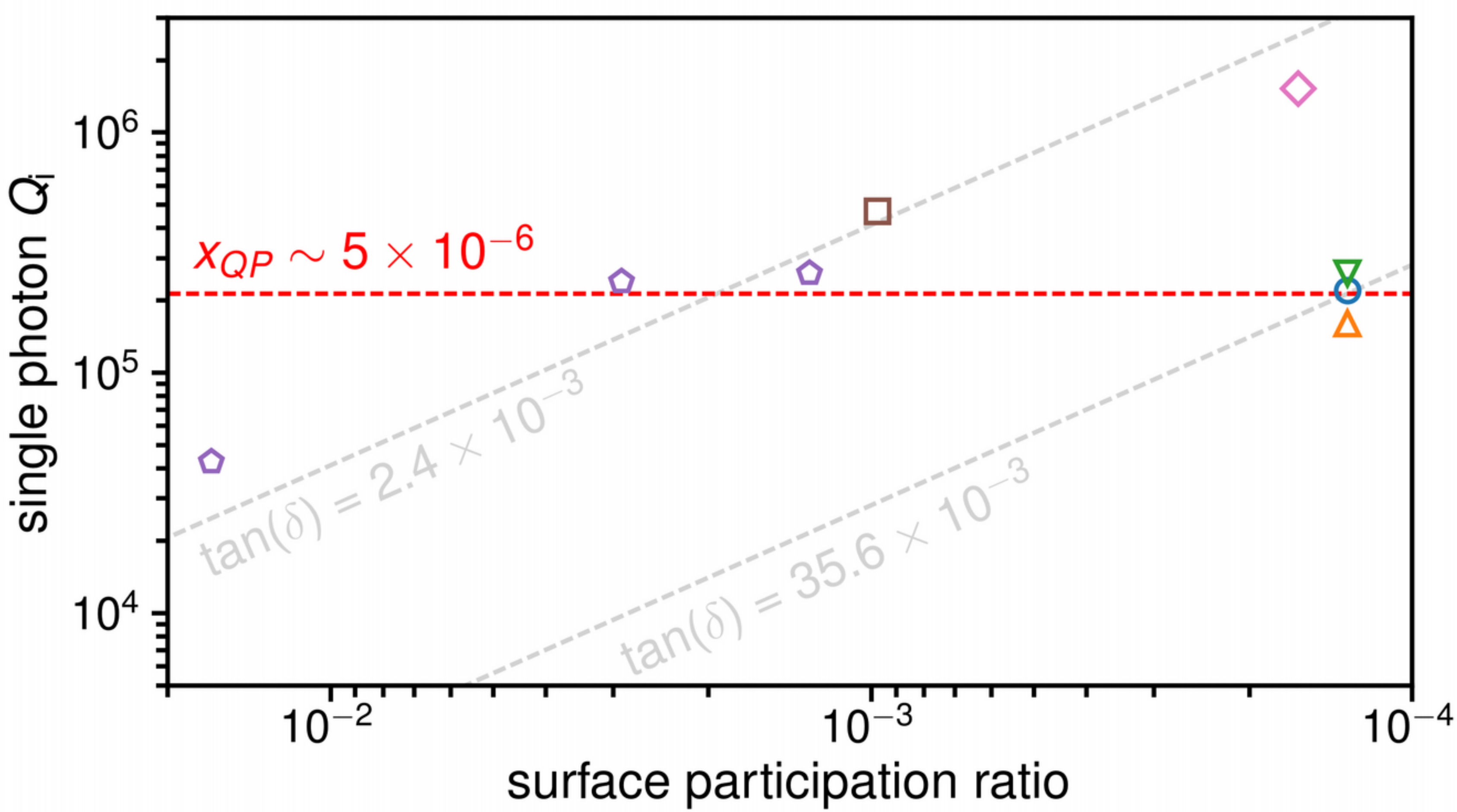
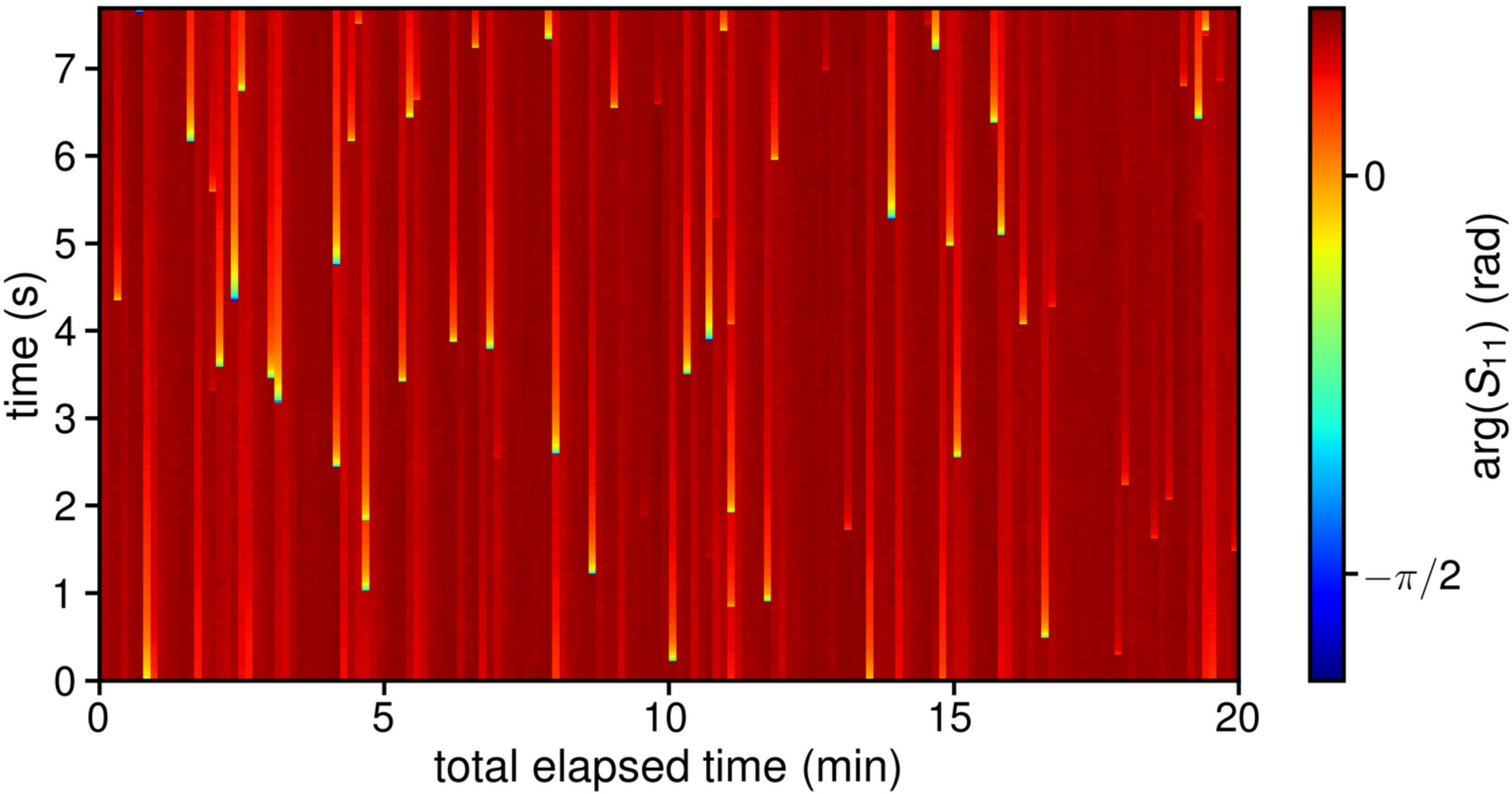
Granular aluminum coherence



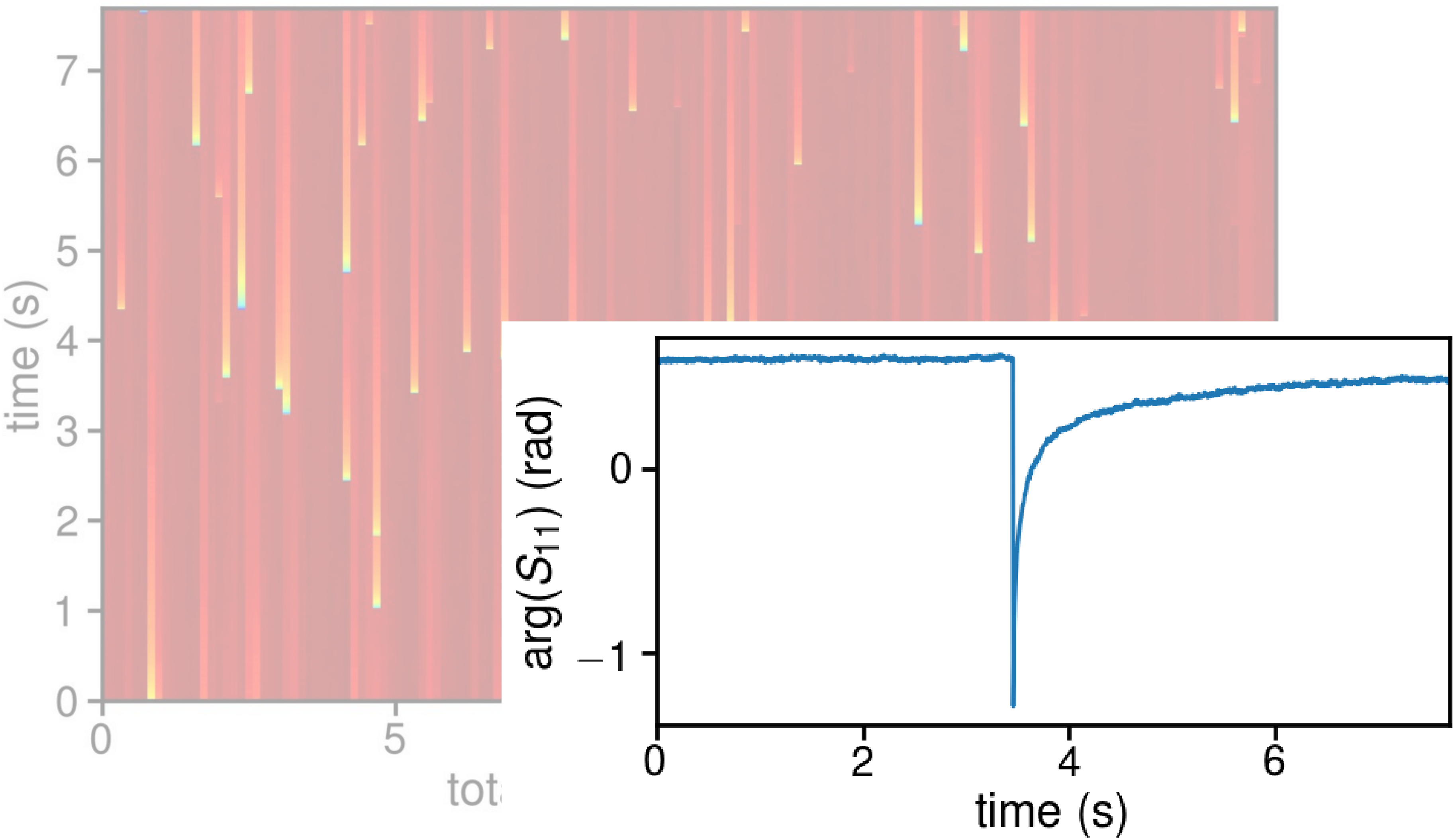
J. Wenner *et al.*, APL 99 (2011)
C. Wang *et al.*, APL 107 (2015)
W. Woods *et al.*, PR Appl. 12 (2019)
L. Grünhaupt *et al.*, PRL 121 (2018)
F. Valenti *et al.*, PR Appl. 11 (2019)
L. Grünhaupt *et al.*, APL 111 (2017)

Quasiparticle bursts in granular aluminum



L. Grünhaupt *et al.*, PRL 121 (2018)

Quasiparticle bursts in granular aluminum



L. Grünhaupt *et al.*, PRL 121 (2018)

The fluxonium

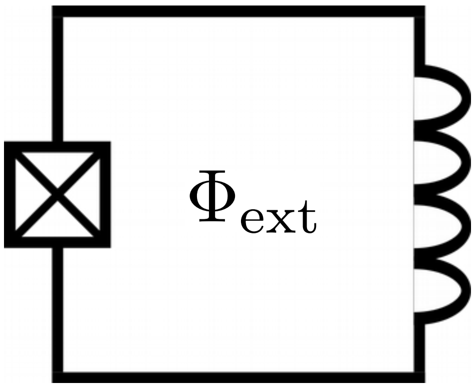
Small **Josephson junction**

$A \sim 0.1\ \mu m^2$

High impedance inductance

Superinductor

$L_S \sim 300$ nH



$$\hat{H} = \frac{1}{2C}\hat{q}^2 + \frac{1}{2L}\hat{\phi}^2 - E_{\rm J}\cos\left(\hat{\phi} - \frac{2\pi}{\Phi_0}\Phi_{\rm ext}\right)$$

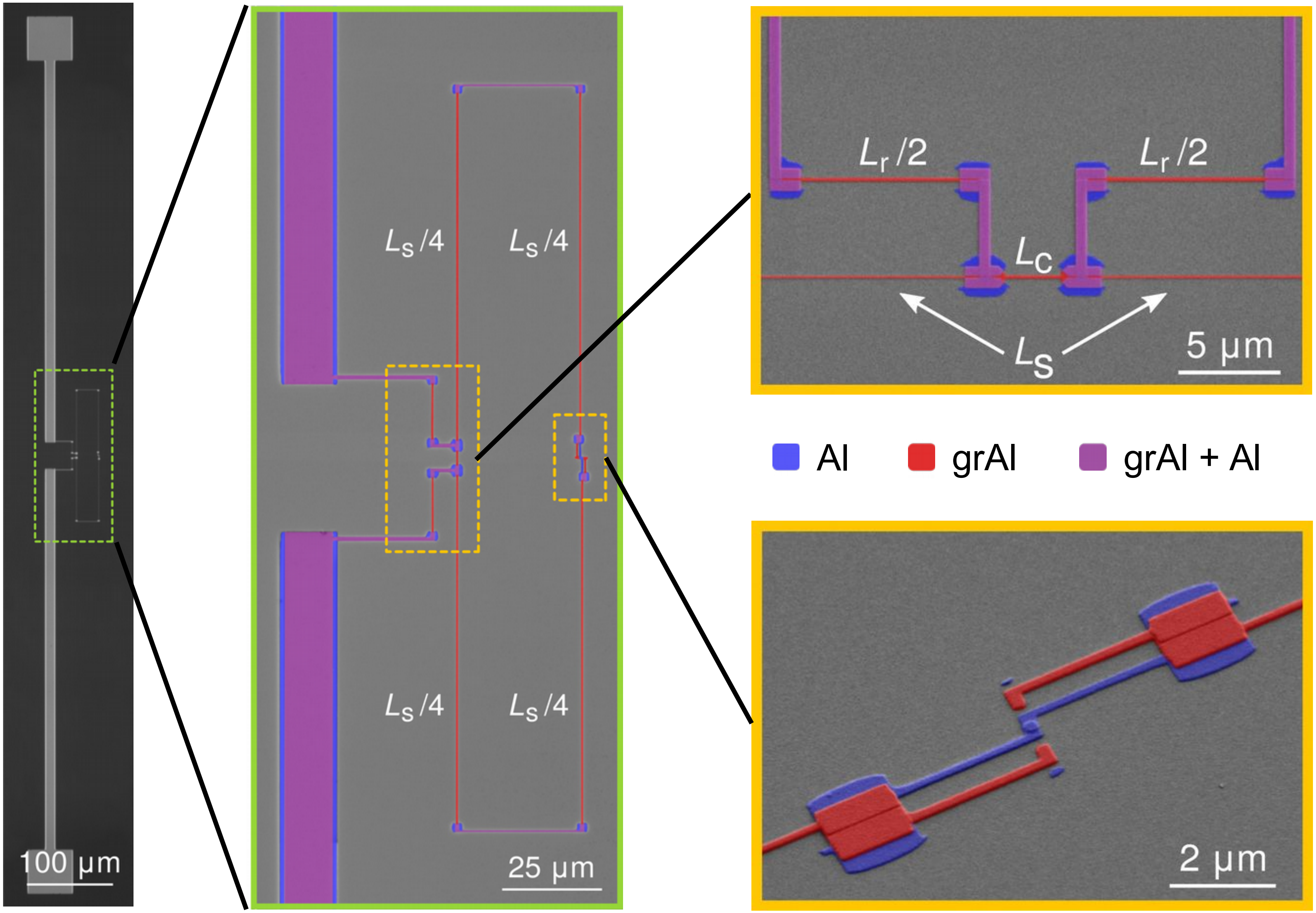
Charge fluctuation insensitive qubit

with

large anharmonicity

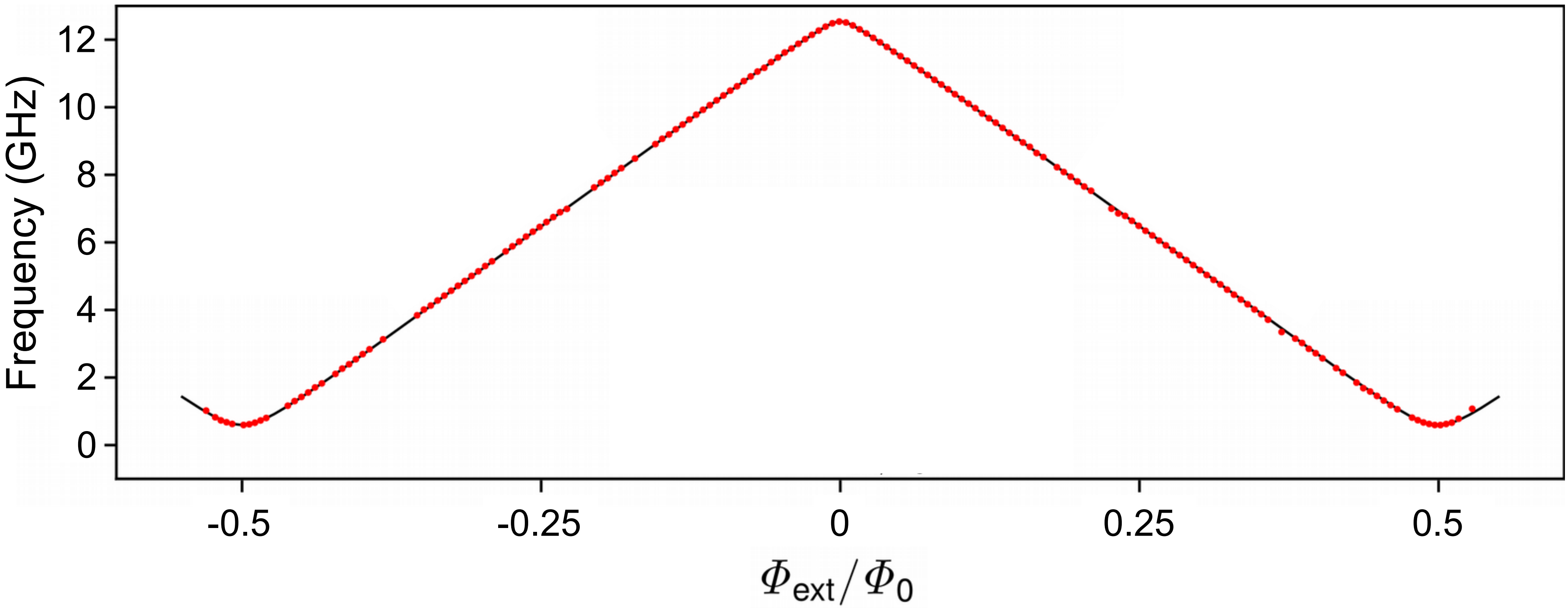
V. Manucharyan *et al.*, Science 326 (2009)

Granular aluminum fluxonium design



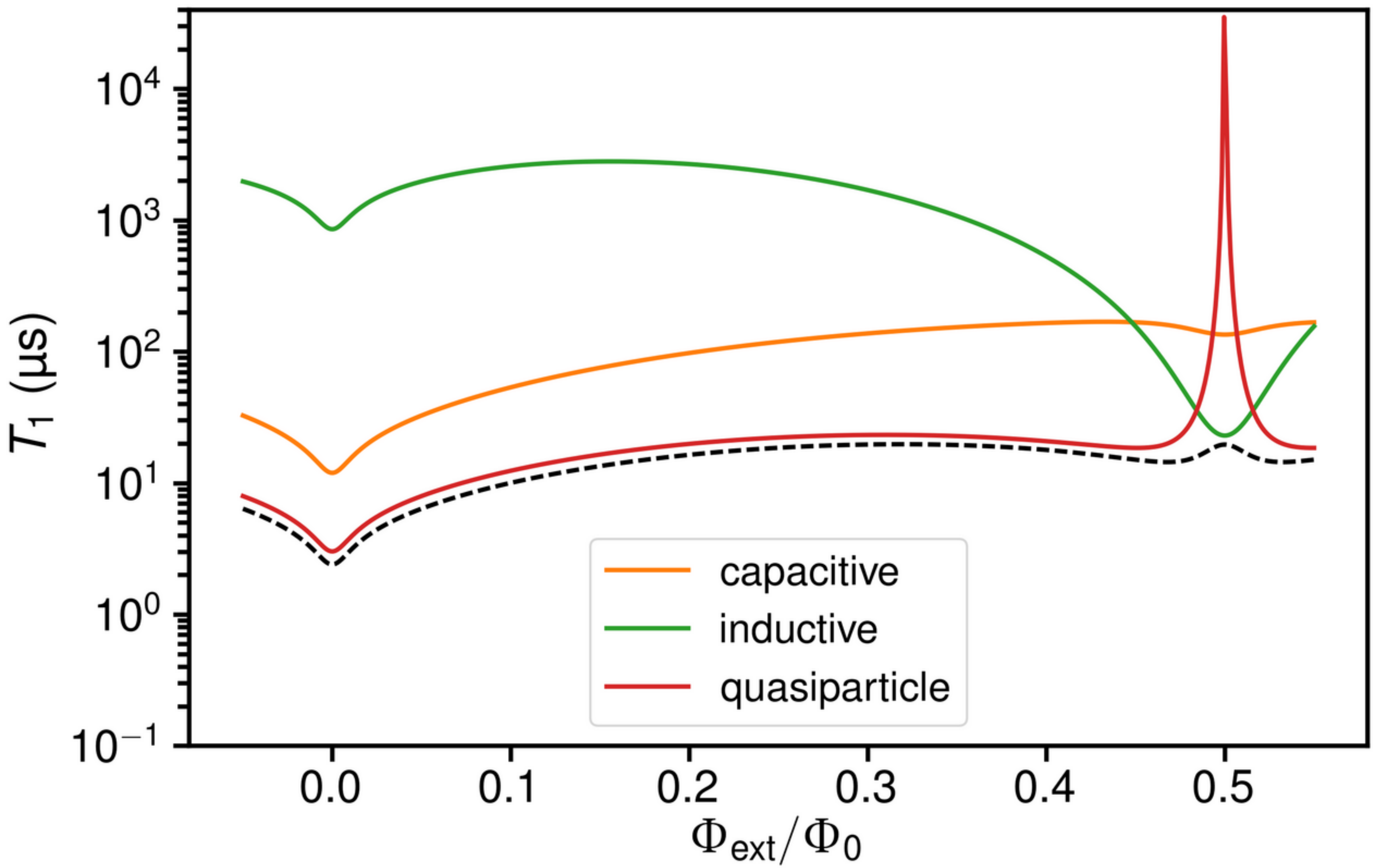
L. Grünhaupt & M. Spiecker *et al.*, Nature Materials (2019)

Granular aluminum fluxonium spectrum



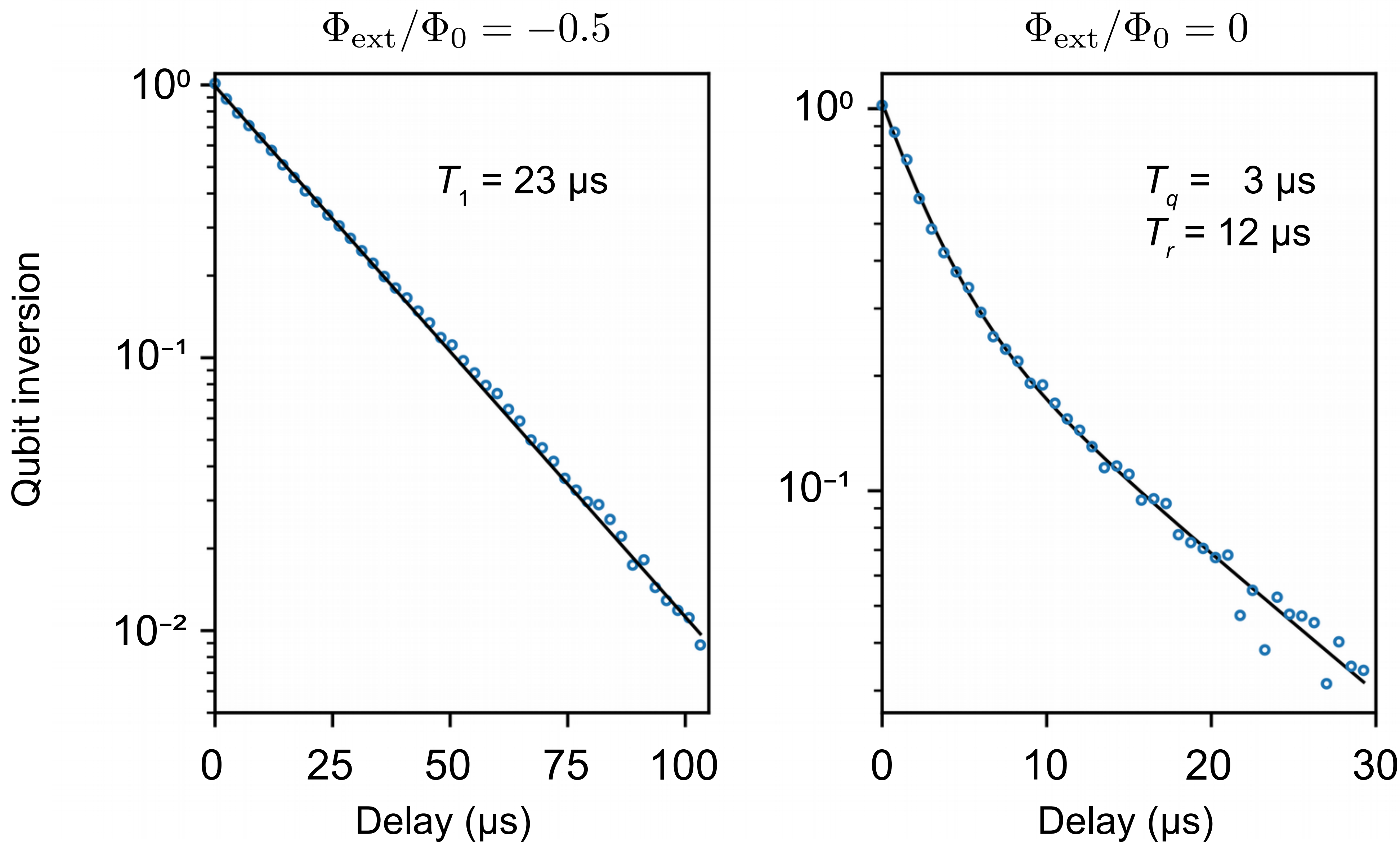
L. Grünhaupt & M. Spiecker *et al.*, Nature Materials (2019)

Fluxonium as a quasiparticle sensor



L. Grünhaupt & M. Spiecker *et al.*, Nature Materials (2019)

Granular aluminum fluxonium coherence



L. Grünhaupt & M. Spiecker *et al.*, Nature Materials (2019)

Conclusion

Granular aluminum is suited for superconducting quantum circuits

$L_{kinetic}$ ~ nH/sq, $Q_i \geq 10^5$, tunable nonlinearity

N. Maleeva *et al.*, Nat. Commun. 9 (2018)

L. Grünhaupt *et al.*, PRL 121 (2018)

Successful realization of fluxonium qubit with grAl superinductor

T_1 = 23 µs, T_2^* = 28 µs

L. Grünhaupt & M. Spiecker *et al.*, Nature Materials (2019)

Promising performance of grAl MKIDs

F. Valenti *et al.*, PR Appl. 11 (2019)

Talk [59] by F. Valenti 12:30 PM on Friday

Reduce influence of excess quasiparticles in quantum circuits

Investigate quasiparticle dynamics