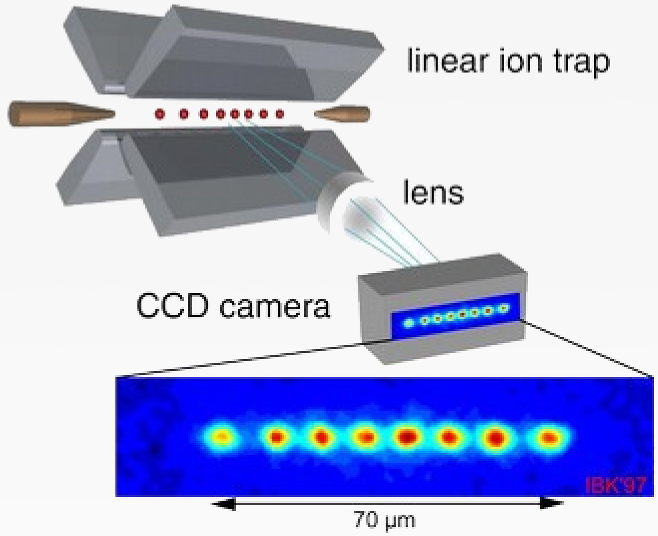
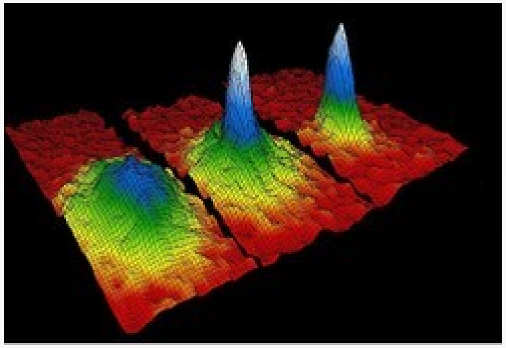
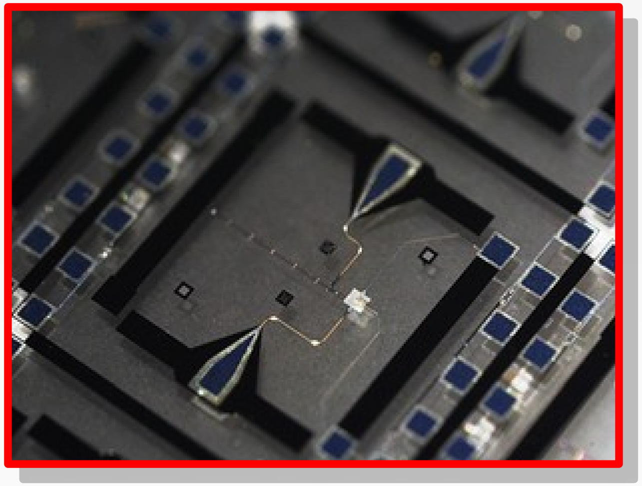
Day I

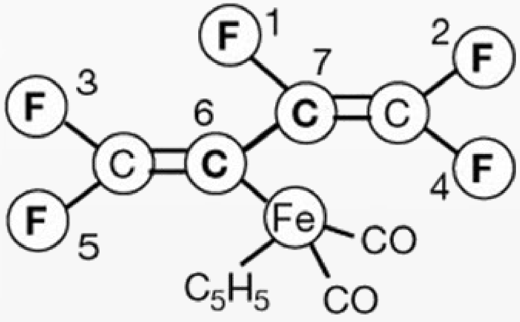

http://quinfog.hbar.es
Toulouse
Carcassonne
San Sebastián
Vitoria-Gasteiz
Pamplona
Andorra
Girona
Porto
Salamanca
Toledo
Castellón de la Plana
Balearic Sea
Portugal
Spain
Valencia
Palma
Lisbon
Badajoz
Benidorm
Alicante
Córdoba
Almería
Málaga
Alboran Sea
Oran
وهران
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

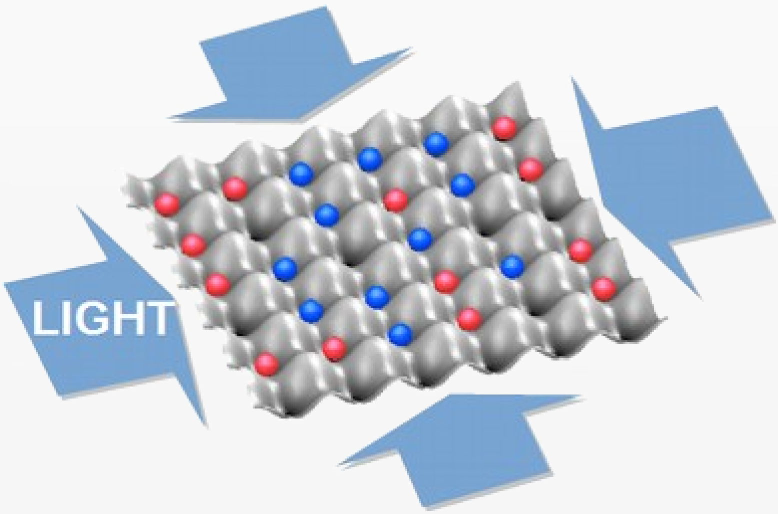






1	10	100	1000	10^4	10^5		10^{25}



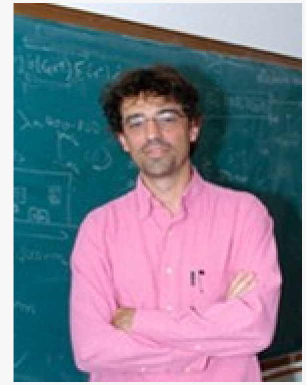


Favourite topics

B. Peropadre
Harvard

D. Porras
Univ. Sussex, UK

D. Zueco
U. Zaragoza



L. Martín-Moreno
ICMA, Zaragoza

E. Sánchez-Burillo
ICMA, Zaragoza

VE RI TAS

US
University of Sussex

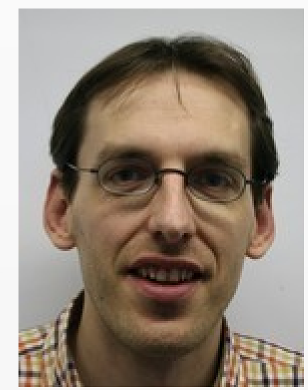
icma
Instituto de Ciencia
de Materiales de Aragón

A. Lupascu
IQC, Waterloo

Pol Forn-Díaz
IQC, Waterloo

C. Wilson
IQC, Waterloo

M. Häberlein
WMI, Garching

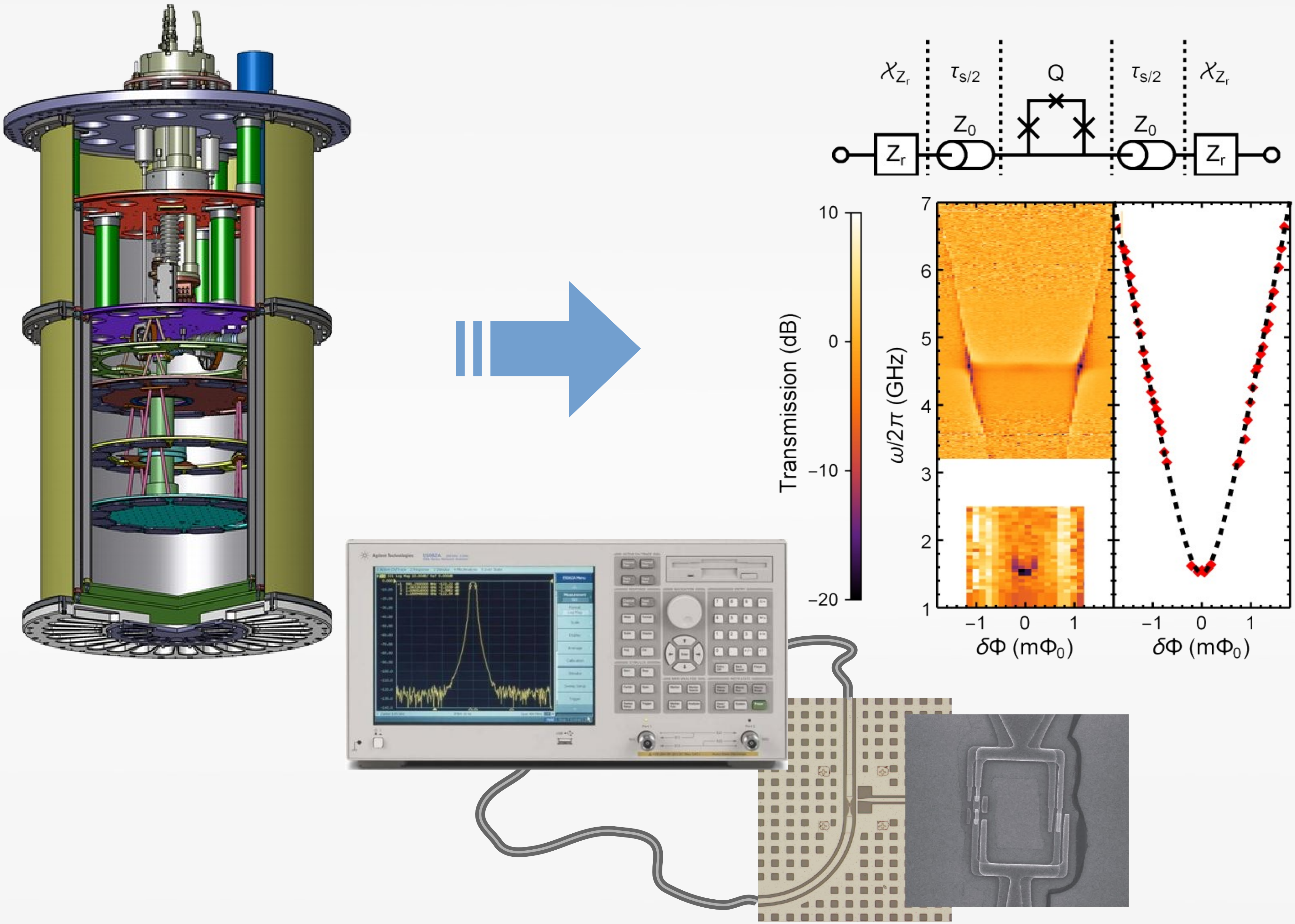


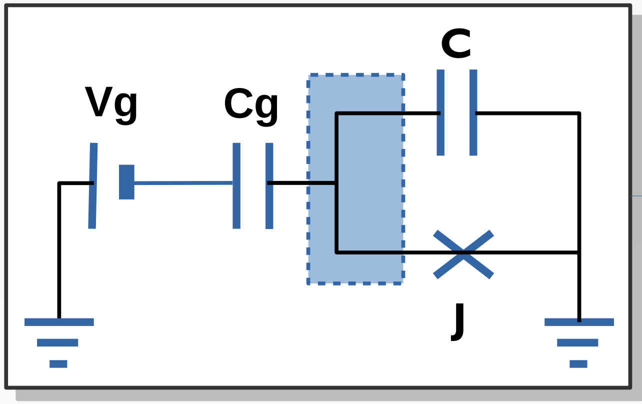
F. Deppe
WMI, Garching

UNIVERSITY OF
WATERLOO

IQC Institute for Quantum Computing

WMI


χ_{Z_r}
$\tau_{s/2}$
Q
$\tau_{s/2}$
χ_{Z_r}
Z_0
Z_r
Z_0
Z_r
Transmission (dB)
10
0
−10
−20
$\omega/2\pi$ (GHz)
7
6
5
4
3
2
1
−1
0
1
$\delta\Phi$ (mΦ_0)
−1
0
1
$\delta\Phi$ (mΦ_0)



Kirchoff theory

$$C_{ij}\dot{V}_j = \frac{1}{L_{ij}}(V_i - V_j)$$

$+\ldots$

Flux variables

$$V = \frac{d\varphi}{dt}$$

Lagrangian

$$S = \int_{t_0}^{t_f} L(\varphi, \dot{\varphi})\, dt$$

Hamiltonian

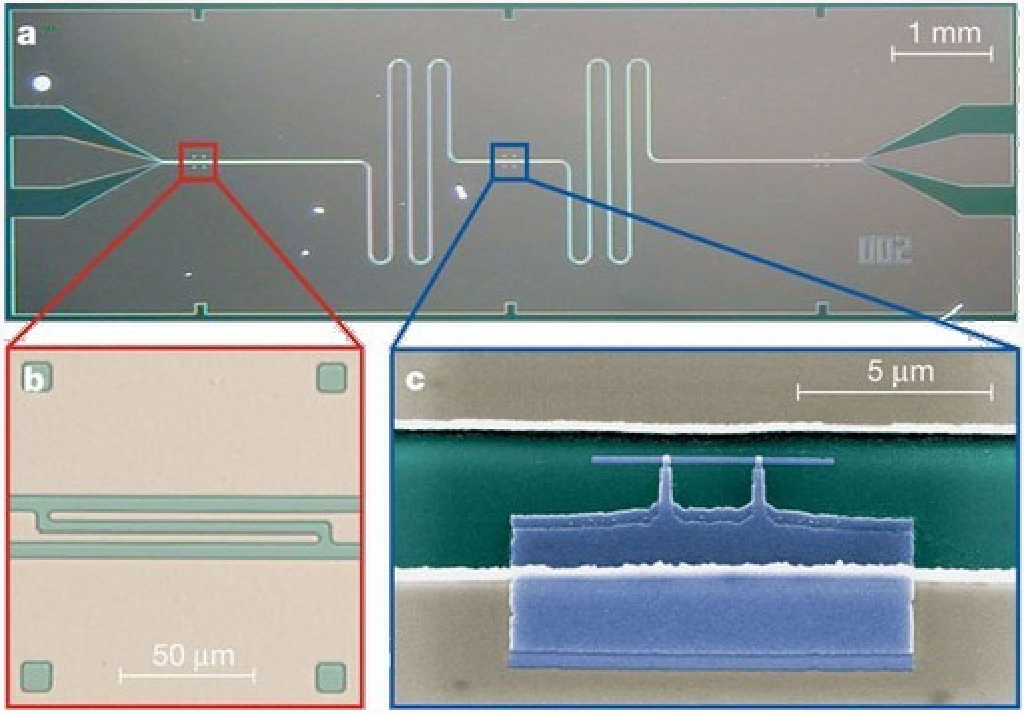
$$H = H(q, \varphi)$$
$$q = \partial L / \partial \dot{\varphi}$$

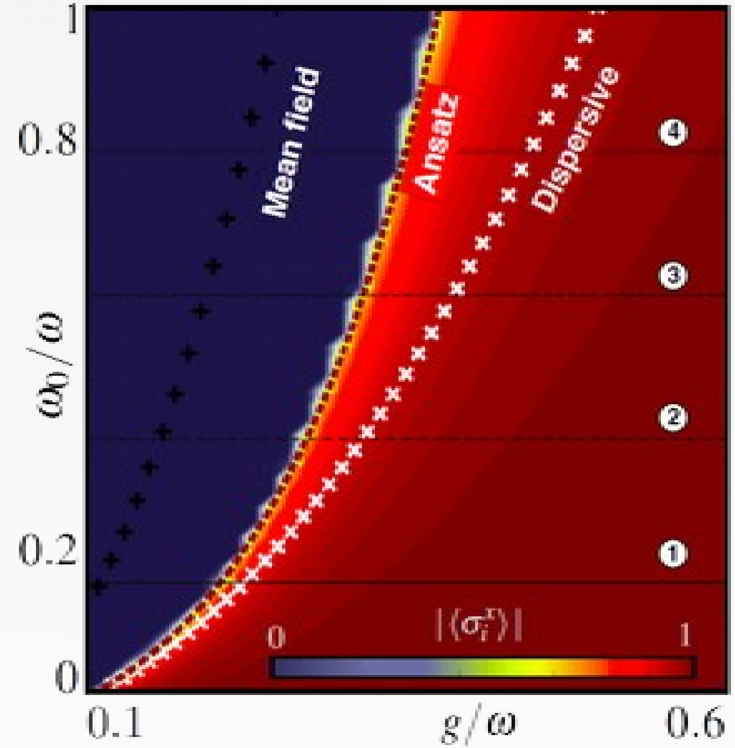
Quantization

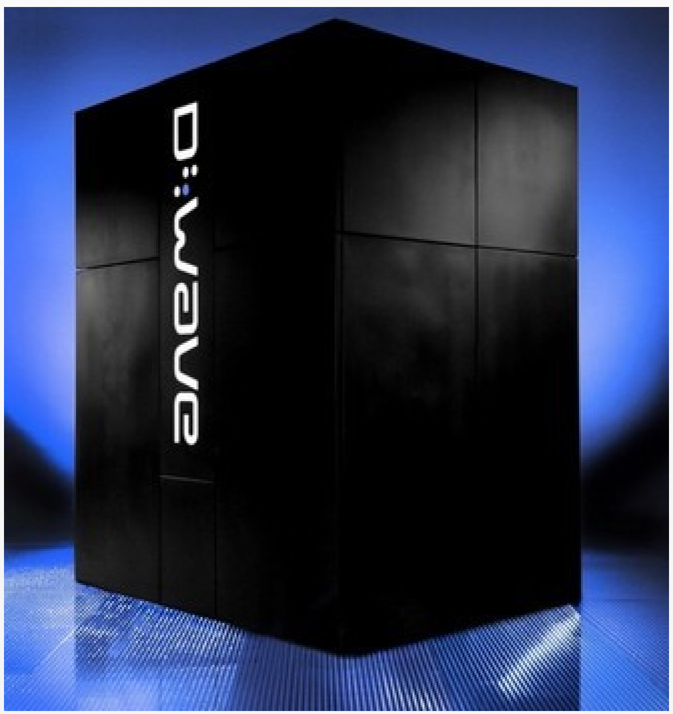
$$[\varphi, q] = i\hbar$$

$$H = \frac{1}{C_g + C} q^2 + V_g q + \frac{1}{2L}\phi^2 + J\phi_0 \cos(\phi/\Phi_0)$$

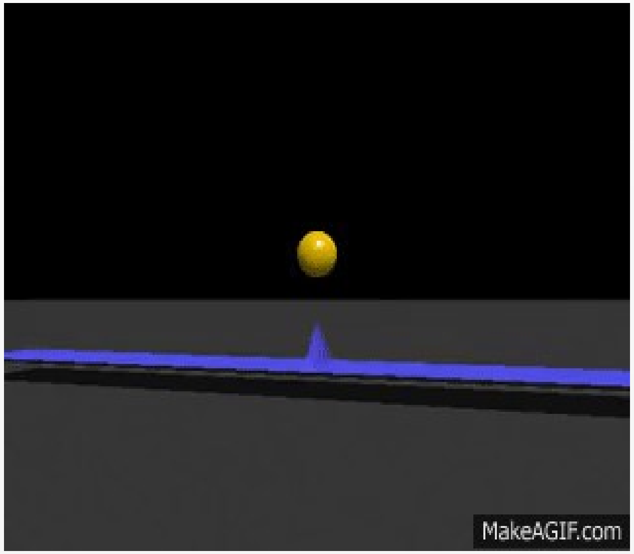
http://juanjose.garciaripoll.com/lectures-quantum-circuits

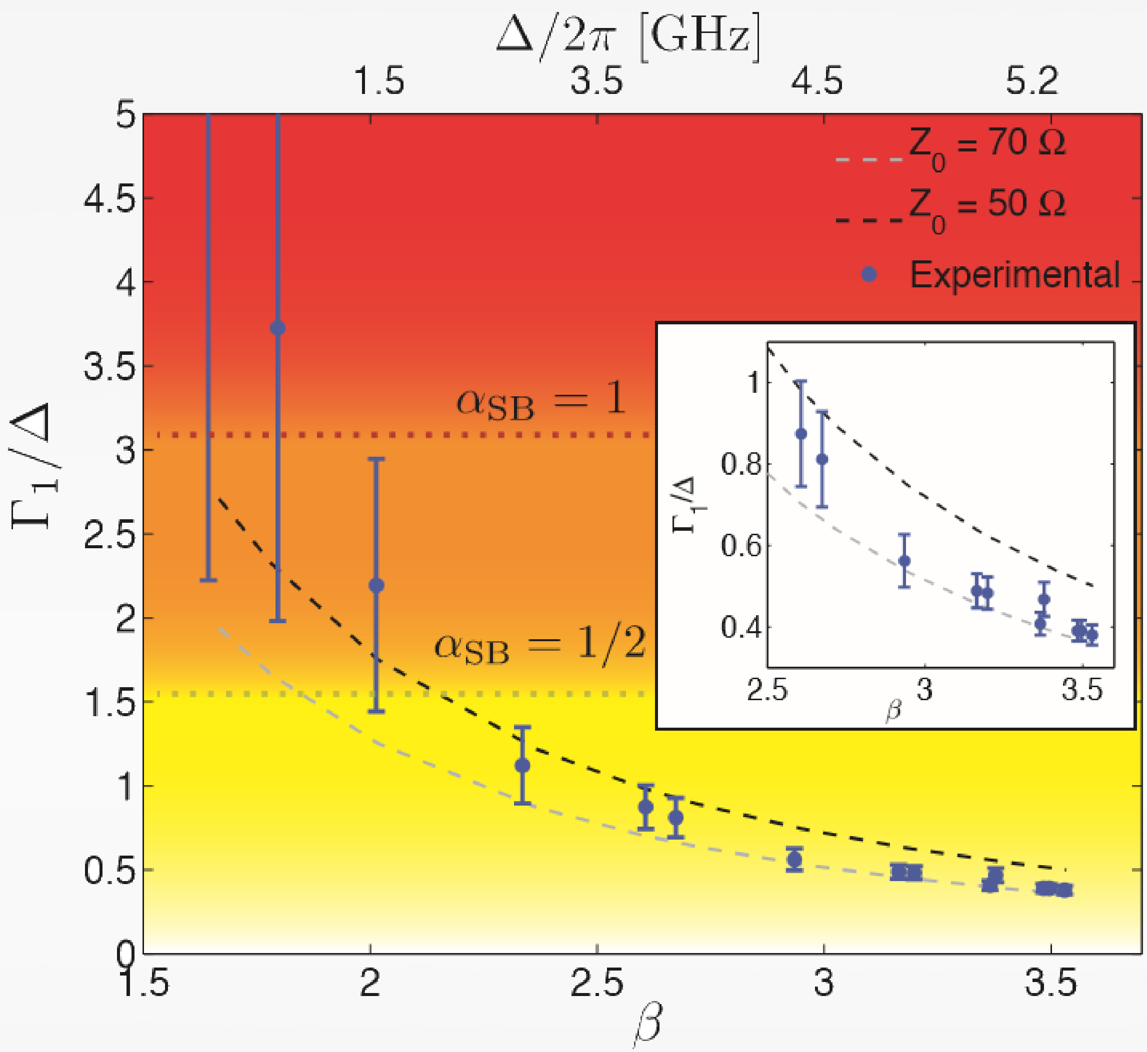






A bit of everything





http://arxiv.org/abs/1602.00416

Pet topics

Week 1		
	03/02/16 Wednesday	Instroduction and setup
		Basic elements and notions
Week 2		
	08/02/16 Monday	Circuit theory: rules
		Circuit theory: basic examples
	10/02/16 Wednesday	Circuit theory: squids
		Charge qubit
	12/02/16 Friday	Transmon
		Flux qubit
Week 3		
	15/02/16 Monday	Transmission line quantization
		Circuit-QED setup
	17/02/16 Wednesday	Cavity-QED model & strong coupling
		Cavity spectroscopy
	19/02/16 Friday	Dispersive limit: QND measurements & Hamiltonian
		Dispersive limit: photon state preparation
Week 4		
	24/02/16 Wednesday	Three-dimensional cavities and transmons
		Parity measurements & Schroedinger cats
	26/02/16 Friday	D-Wave machine I: adiabatic QC
		D-Wave machine II: setup & annealing
Week 5		
	29/02/16 Monday	Tuneable coupling
		UCSB quantum processor: g-mon, x-mon
	04/03/16 Friday	Qubit in open line: Ohmic spin-boson model
		Single-photon, single-qubit interaction
Week 6		
	07/03/16 Monday	Ultrastrong coupling

Tight schedule

Flexible in time and content

Organizational issues

Location: IQOQI, entrance left, 1st office

Email:

jj.garcia.ripoll@csic.es

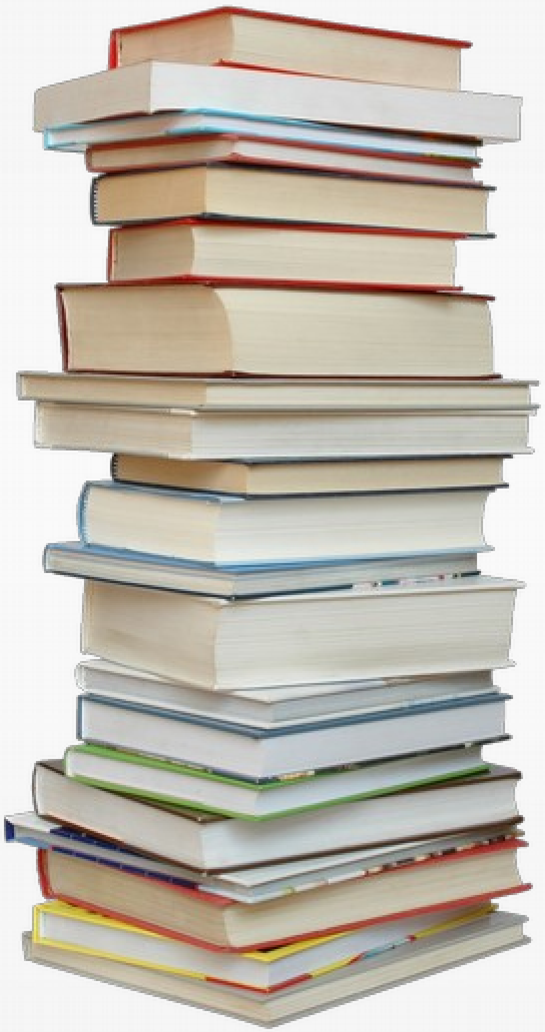
Material: will be uploaded to my homepage

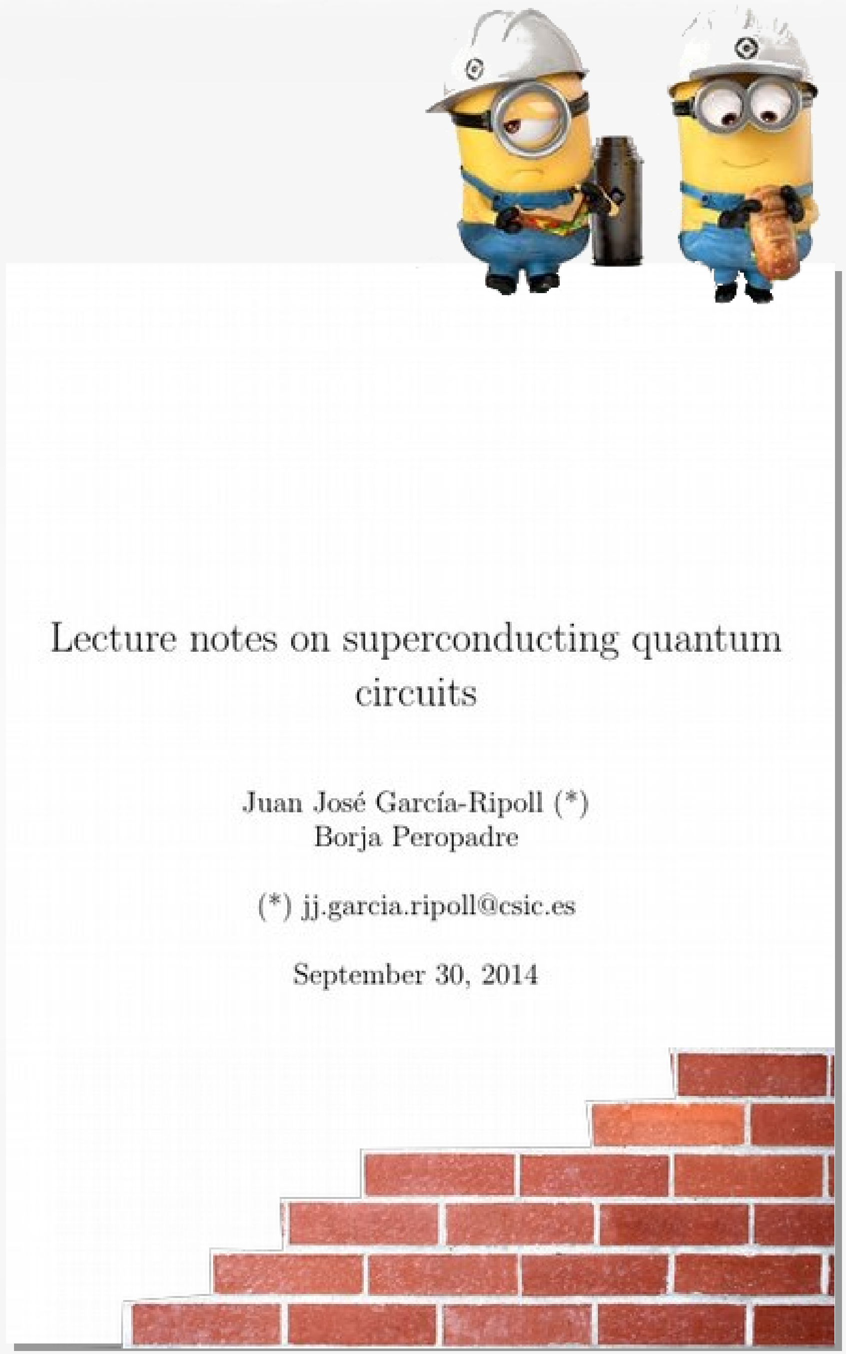
http://juanjose.garciaripoll.com

after curation

Will announce topic of the lectures there and 30'

@jjgarciaripoll





Lecture notes on superconducting quantum circuits

Juan José García-Ripoll (*)
Borja Peropadre

(*) jj.garcia.ripoll@csic.es

September 30, 2014

http://juanjose.garciaripoll.com/lectures-quantum-circuits

Also:

M. Devoret's Les Houches Lectures
http://qulab.eng.yale.edu/documents/reprints/Houches_fluctuations.pdf

S. Girvin Lecture notes on circuits

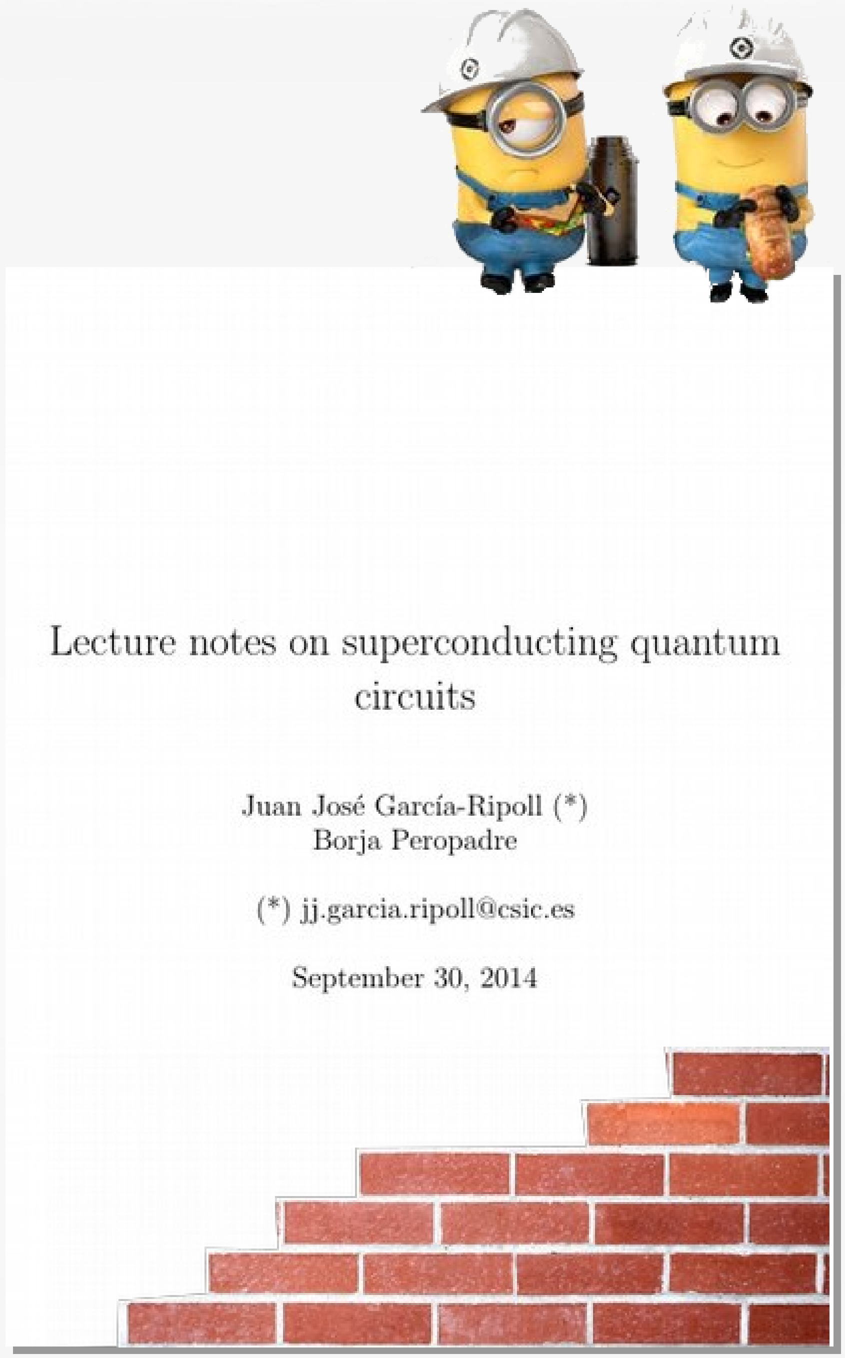
A. Blais, PRA 69 062320 (2004)

T. Orlando's book on superconductivity

…

always growing list of papers

Feedback appreciated!



Lecture notes on superconducting quantum circuits

Juan José García-Ripoll (*)
Borja Peropadre

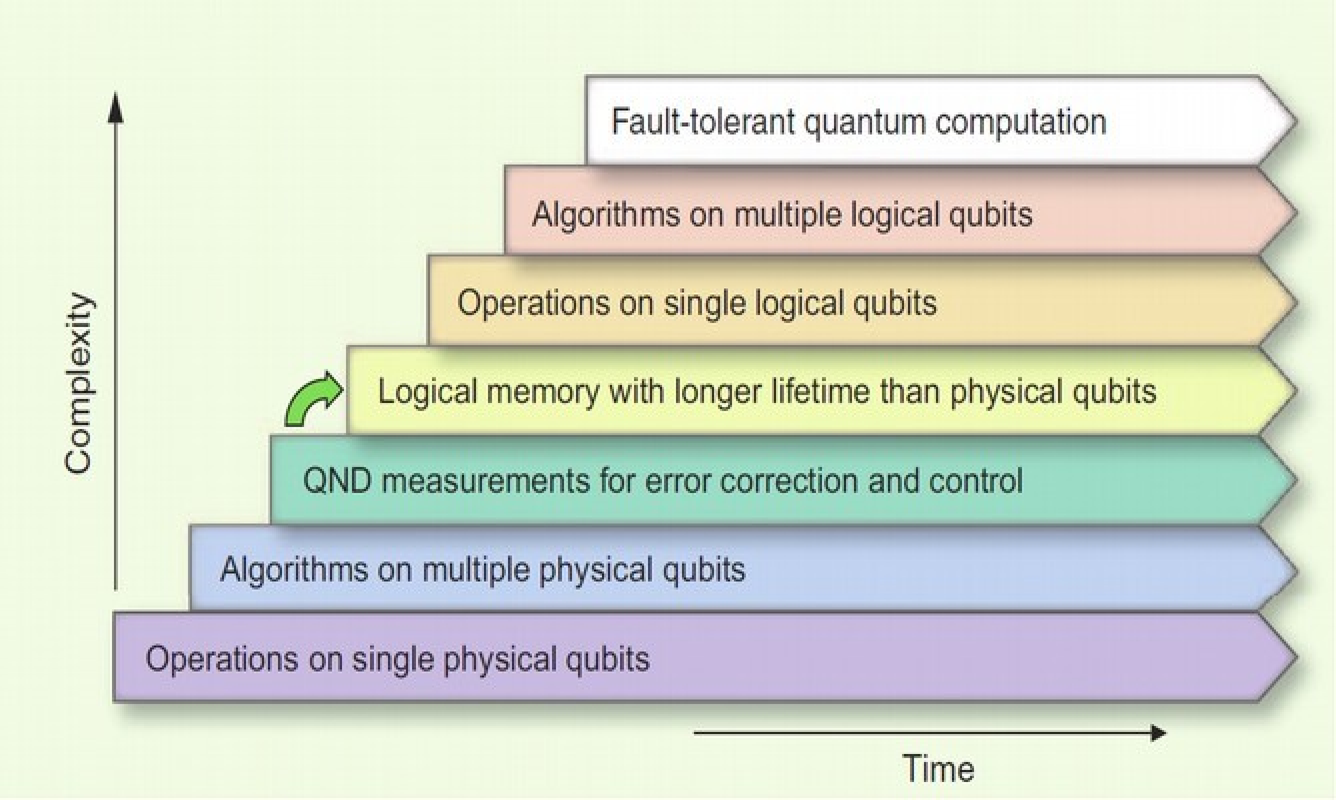
(*) jj.garcia.ripoll@csic.es

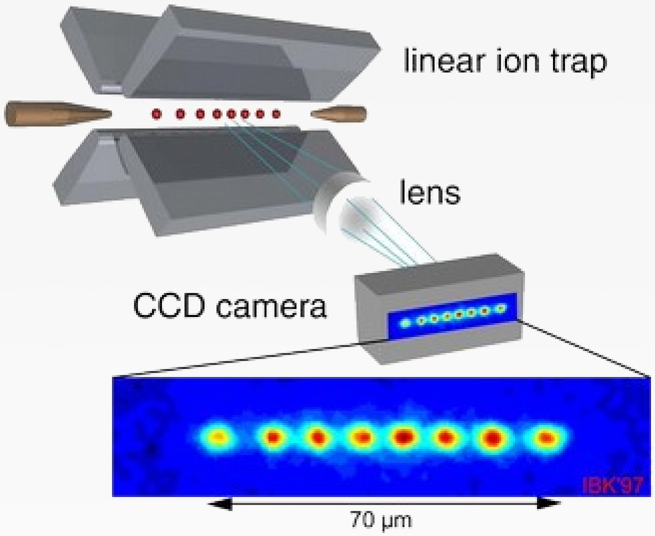
September 30, 2014

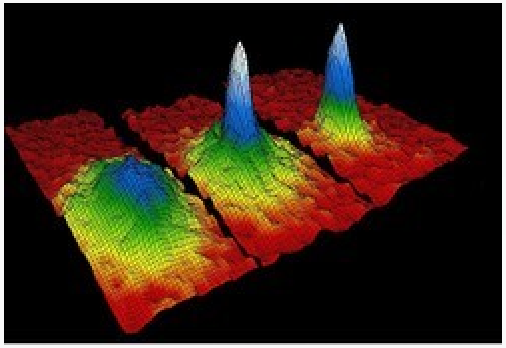
http://juanjose.garciaripoll.com/lectures-quantum-circuits

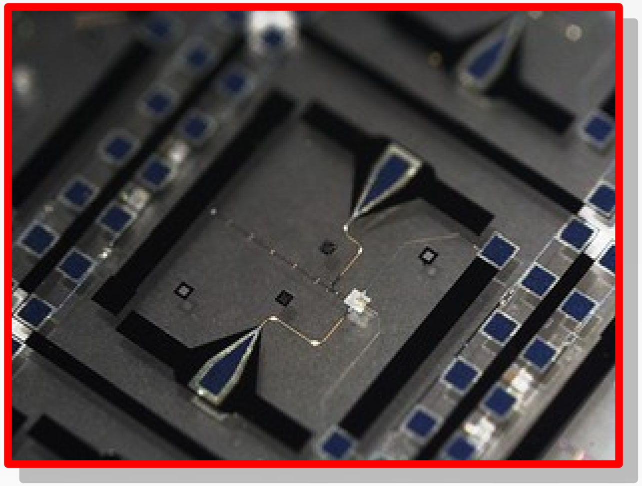
1. Find a qubit
    - Discrete coherent degrees of freedom
    - Preparation of some initial state
    - Measurements
2. Enable computation
    - Arbitrary local unitaries
    - One universal two-qubit unitary
3. Scale up with error correction

1. Find a qubit
    - Discrete coherent degrees of freedom
    - Preparation of some initial state
    - Measurements
2. Enable computation
    - Arbitrary local unit
    - One universal two
3. Scale up with er

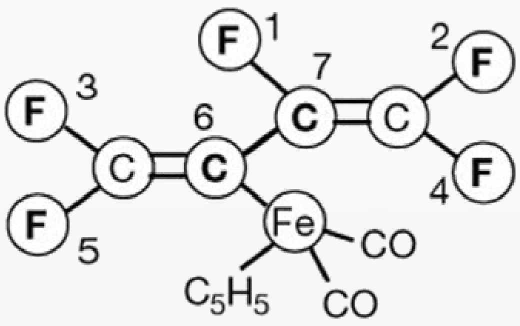


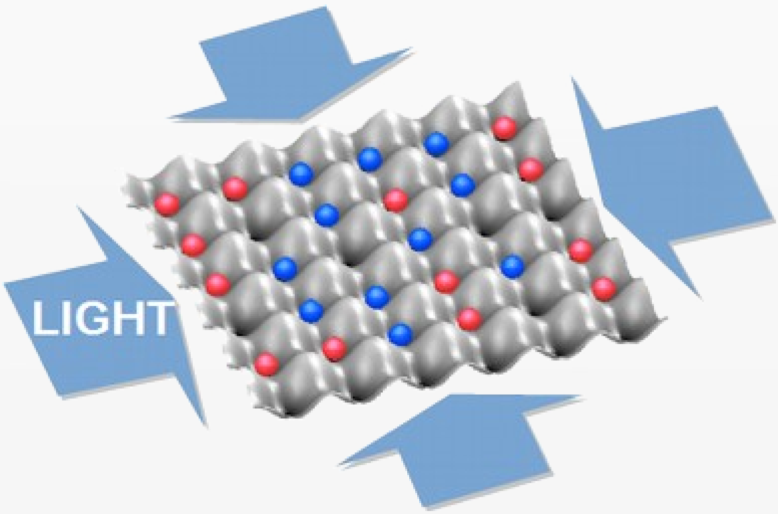


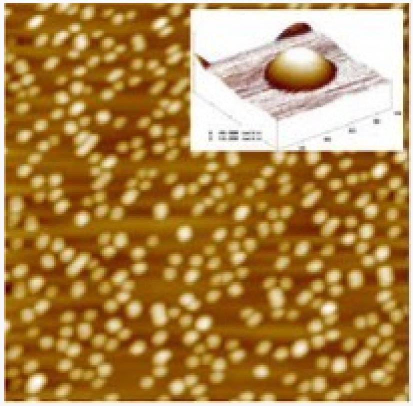


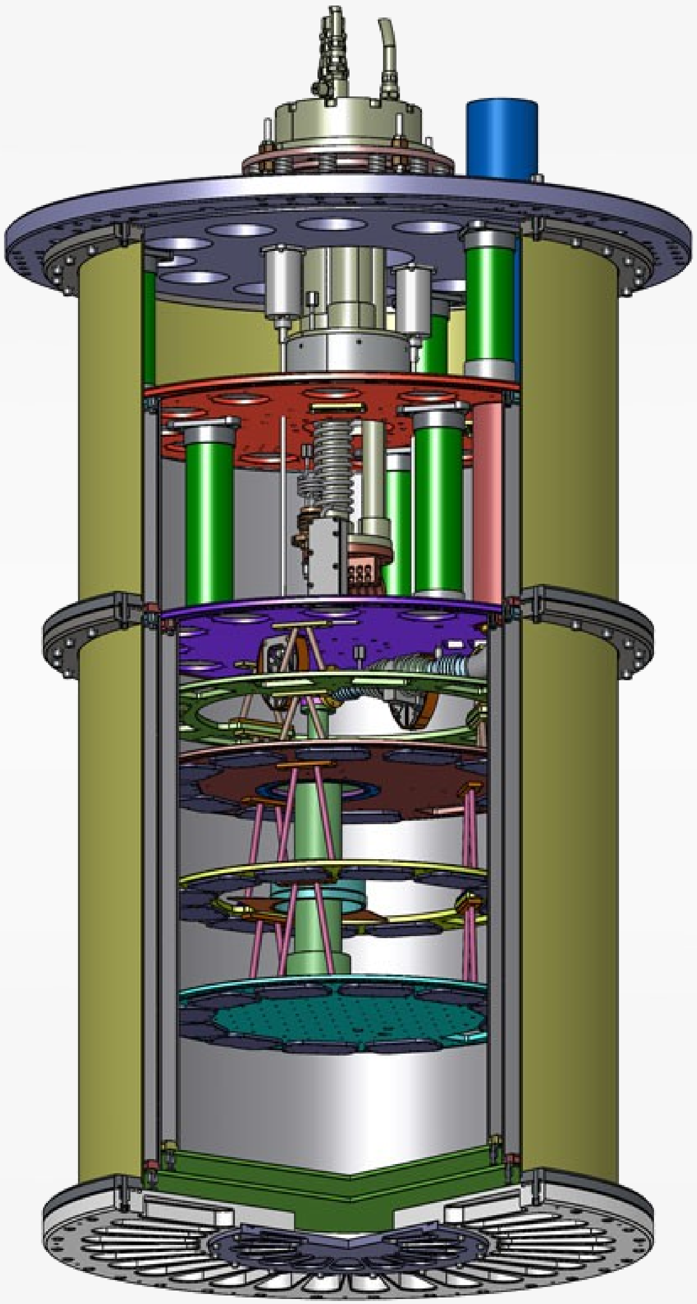


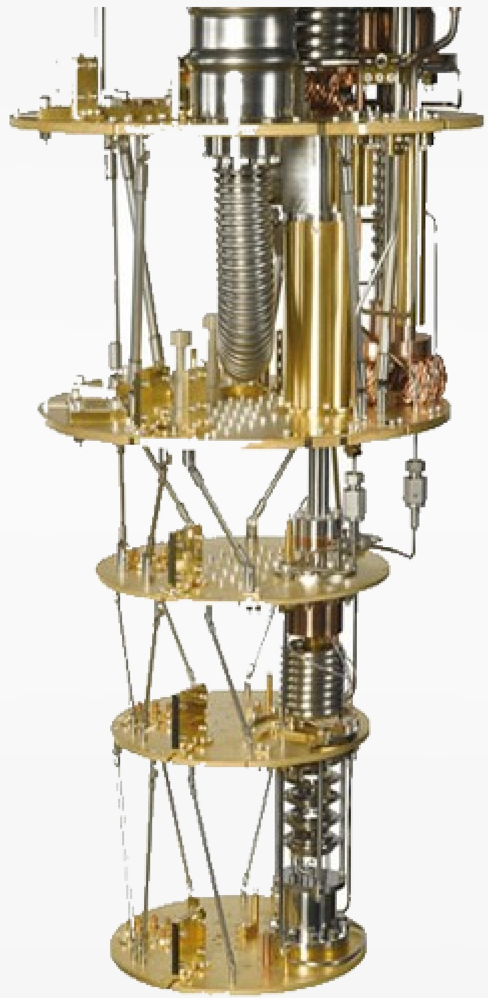
1 | 10 | 100 | 1000 | 10^4 | 10^5 | 10^{25}











(dedicated to the memory of Bernd Matthias; compiled by James S. Schilling)

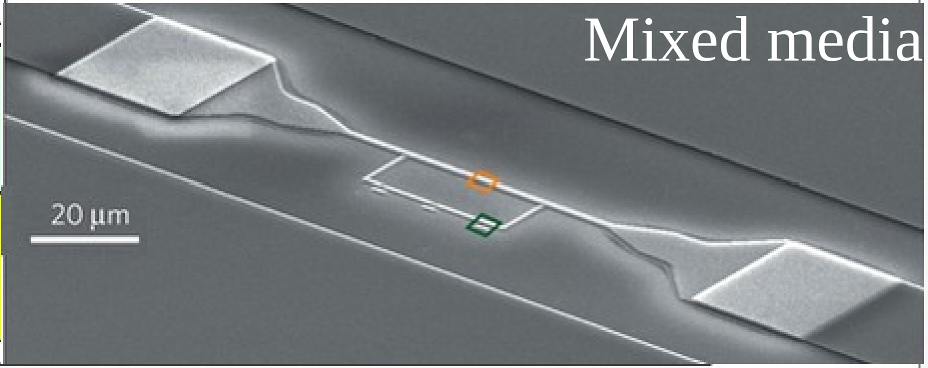
30 elements superconduct at ambient pressure, 23 more superconduct at high pressure.

ambient pressure superconductor: T_c(K)
T_c^{max}(K)
P(GPa)

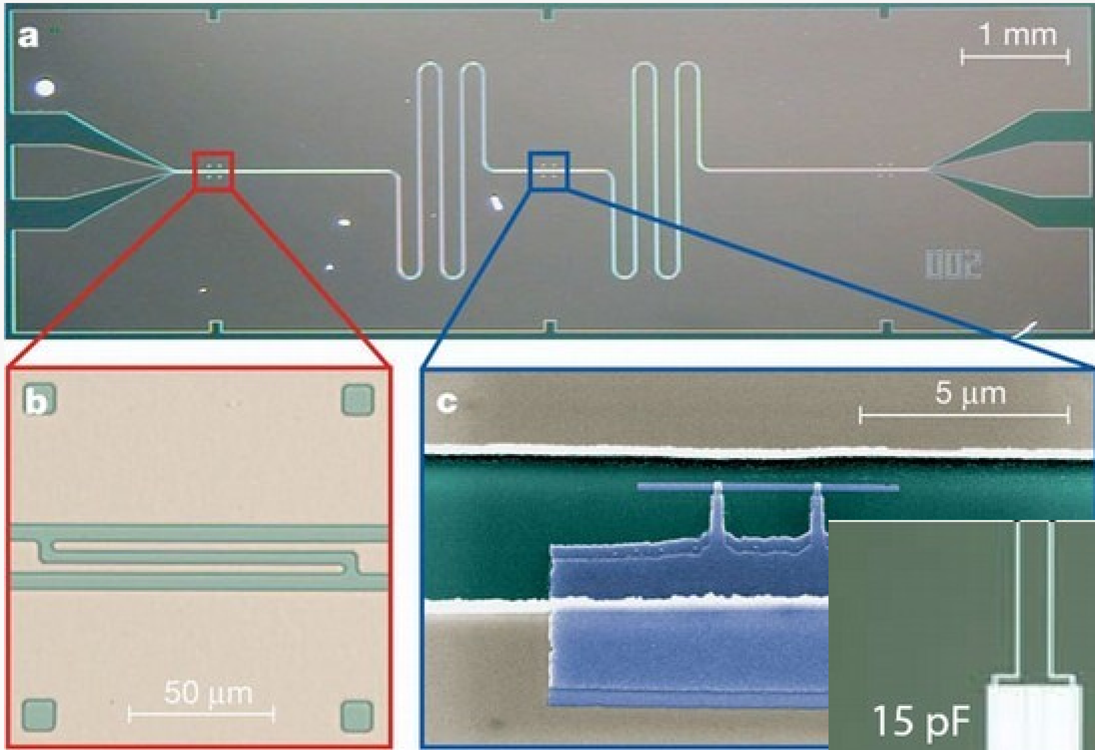
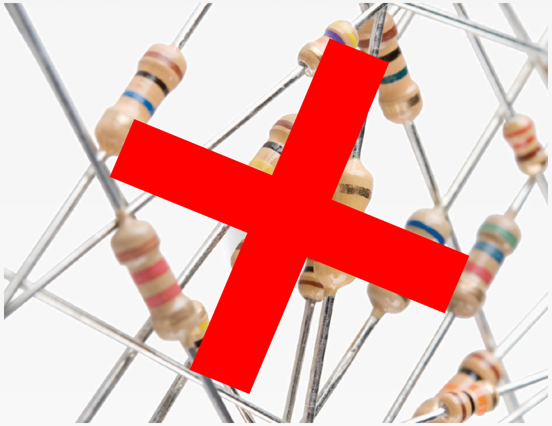
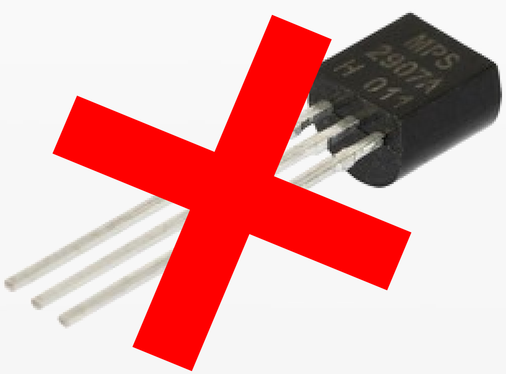
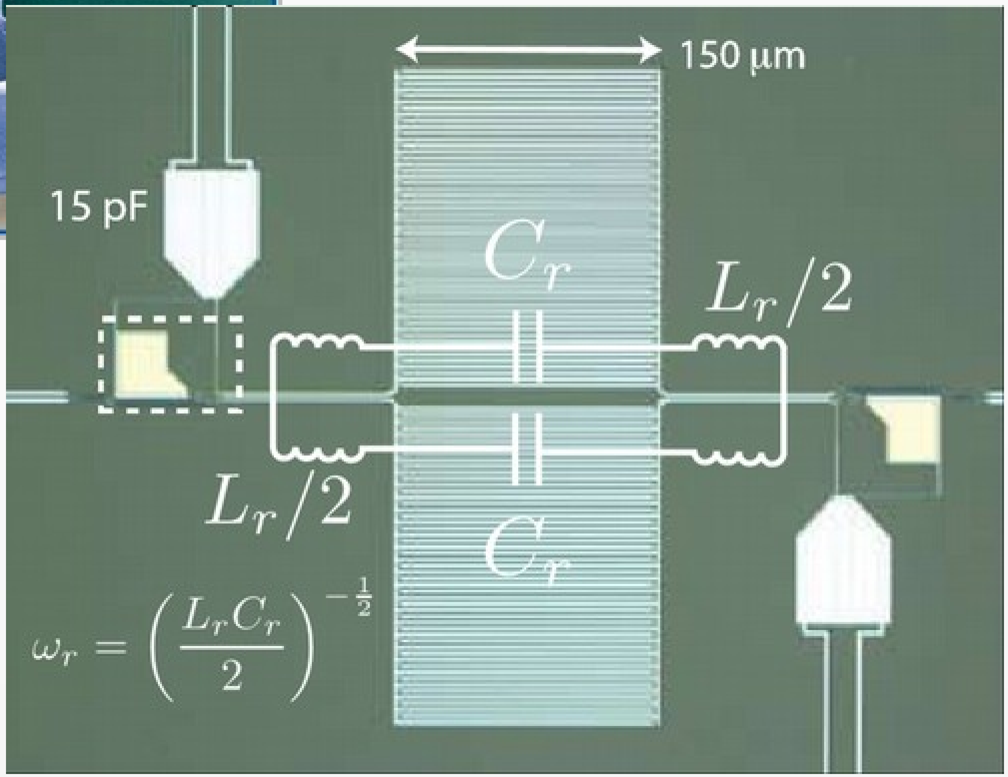
high pressure superconductor: T_c^{max}(K)
P(GPa)

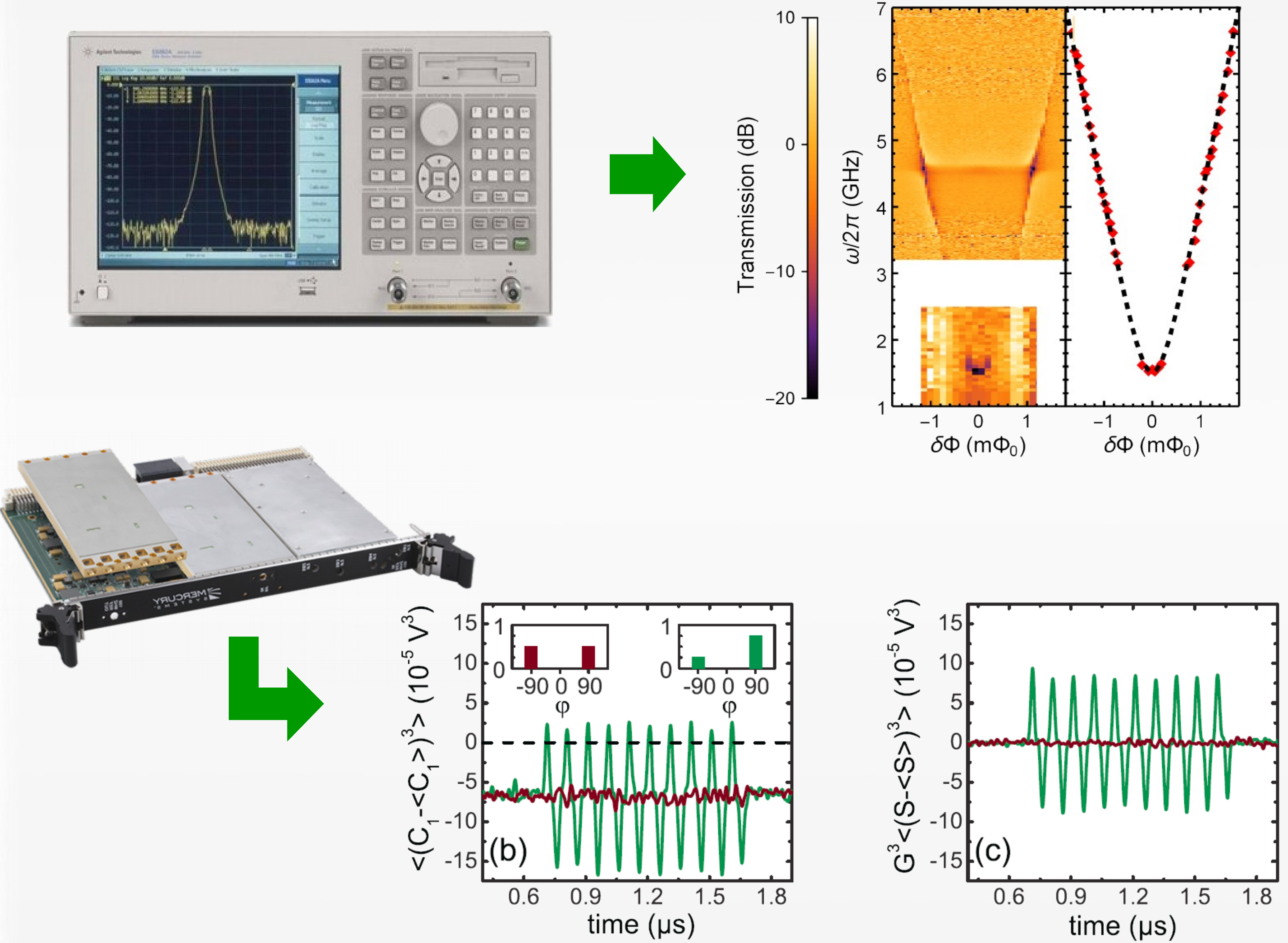
H																	He
Li 0.0004 14 30	Be 0.026 3.7 30											B 11 250	C	N	O 0.6 100	F	Ne
Na	Mg											Al 1.14	Si 8.2 15.2	P 13 30	S 17.3 190	Cl	Ar
K	Ca 29 217	Sc 19.6 106	Ti 0.39 3.35 56.0	V 5.38 16.5 120	Cr	Mn	Fe 2.1 21	Co	Ni	Cu	Zn 0.875	Ga 1.091 7 1.4	Ge 5.35 11.5	As 2.4 32	Se 8 150	Br 1.4 100	Kr
Rb	Sr 7 50	Y 19.5 115	Zr 0.546 11 30	Nb 9.50 9.9 10	Mo 0.92	Tc 7.77	Ru 0.51	Rh .00033	Pd	Ag	Cd 0.56	In 3.404	Sn 3.722 5.3 11.3	Sb 3.9 25	Te 7.5 35	I 1.2 25	Xe
Cs 1.3 12	Ba 5 18	insert La-Lu	Hf 0.12 8.6 62	Ta 4.483 4.5 43	W 0.012	Re 1.4	Os 0.655	Ir 0.14	Pt	Au	Hg-α 4.153	Tl 2.39	Pb 7.193	Bi 8.5 9.1	Po	At	Rn
Fr	Ra	insert Ac-Lr	Rf	Ha													

La-fcc 6.00 13 15	Ce 1.7 5	Pr	Nd	Pm	Sm	Eu 2.75 142
Ac	Th 1.368	Pa 1.4	U 0.8(β) 2.4(α) 1.2	Np	Pu	Am 0.79 2.2 6



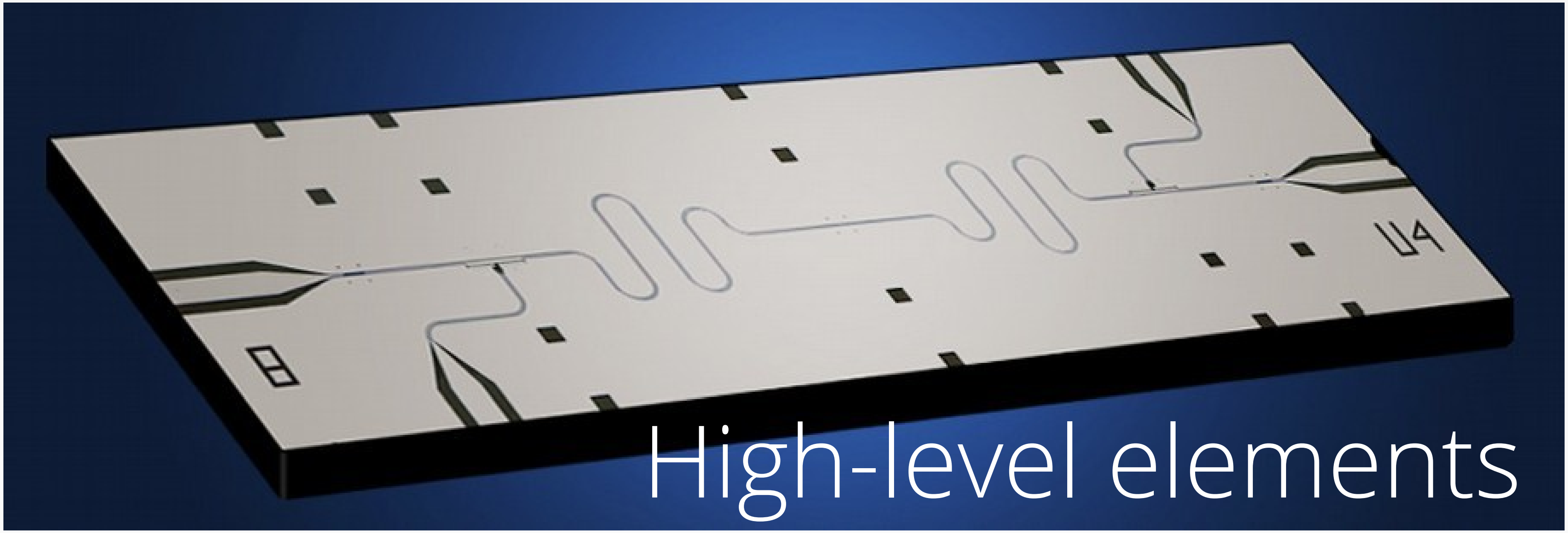
M. Debessai, T. Matsuoka, J.J. Hamlin, W. Bi, Y. Meng, K. Shimizu, and J.S. Schilling, J. Phys.: Conf. Series **215**, 012034 (2010).
High pressure data for Ca and Be: K. Shimizu email from 9 Dec 2013.

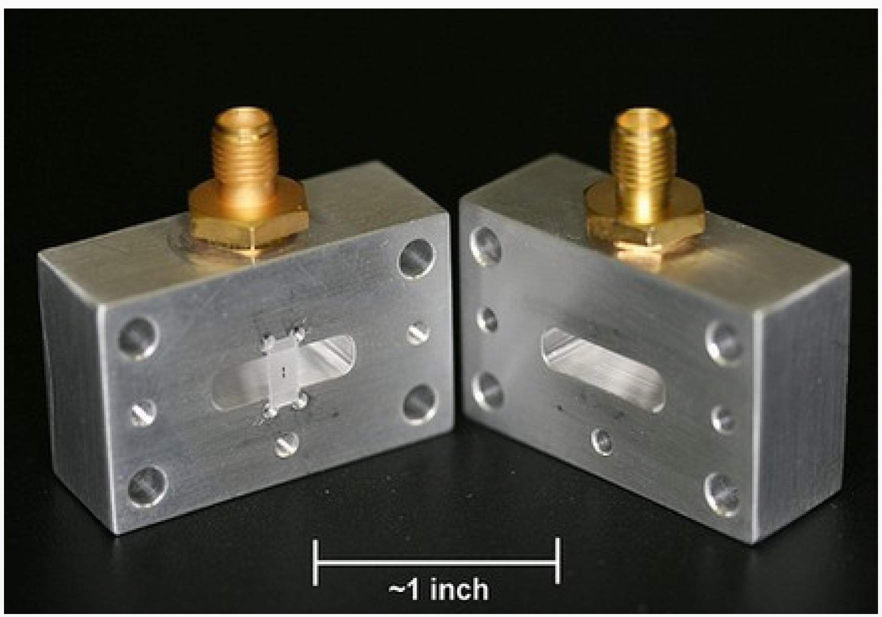

a
1 mm
b
50 µm
c
5 µm


MPS
2907A
H 011

150 µm
15 pF
C_r
$L_r/2$
$L_r/2$
C_r
$\omega_r = \left(\frac{L_r C_r}{2}\right)^{-\frac{1}{2}}$

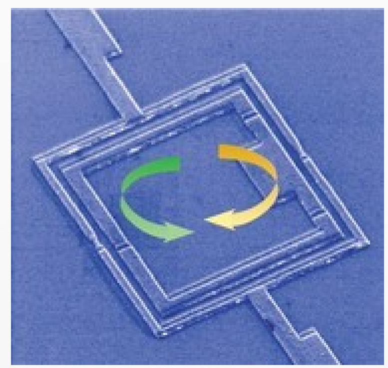


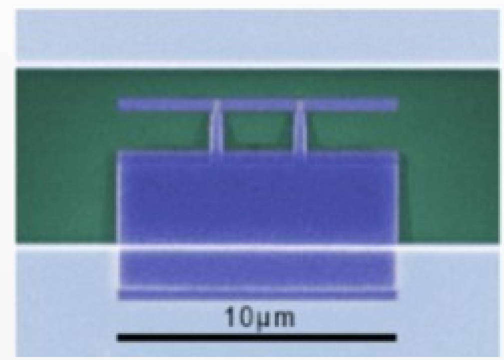
Transmission (dB)
10
0
−10
−20
ω/2π (GHz)
δΦ (mΦ0)
(b)
(c)
<(C1-<C1>)3> (10-5 V3)
G3<(S-<S>)3> (10-5 V3)
φ
-90 0 90
time (μs)
0.6
0.9
1.2
1.5
1.8
MERCURY SYSTEMS

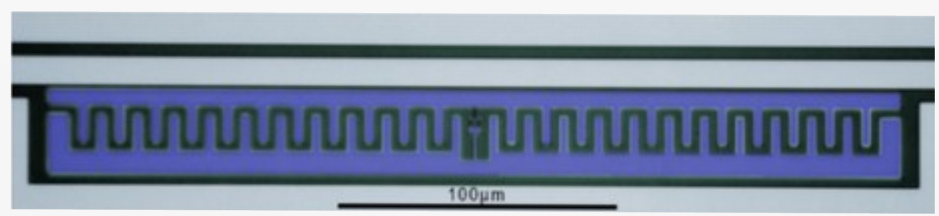
High-level elements

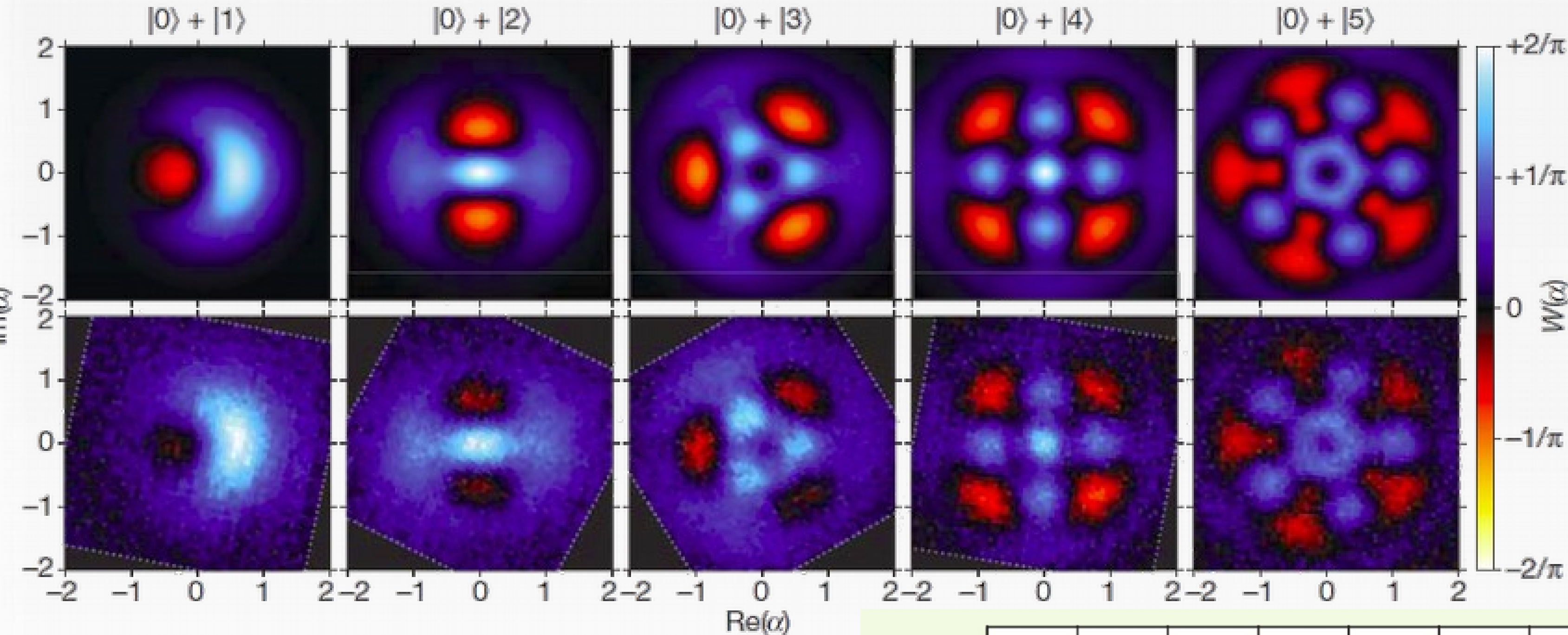




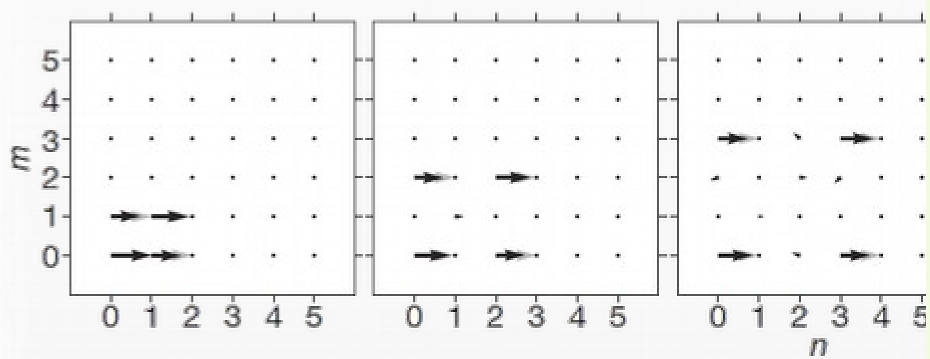




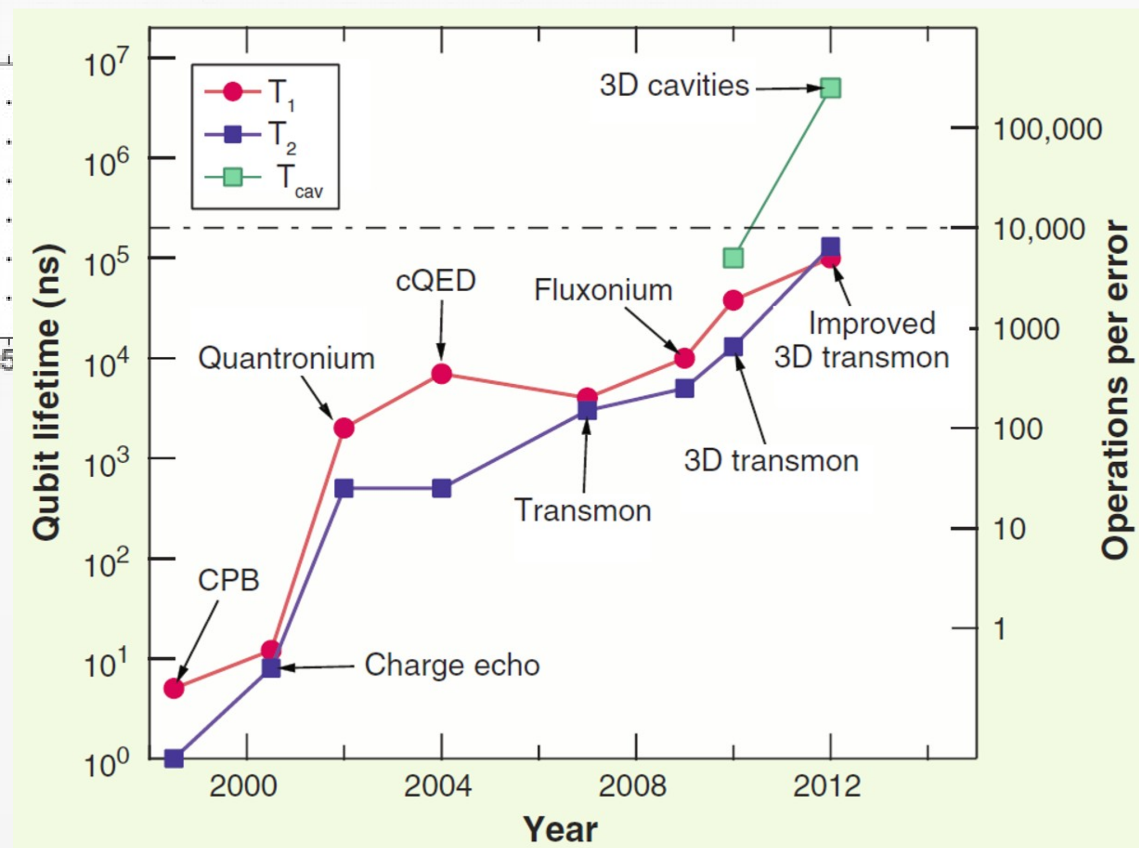




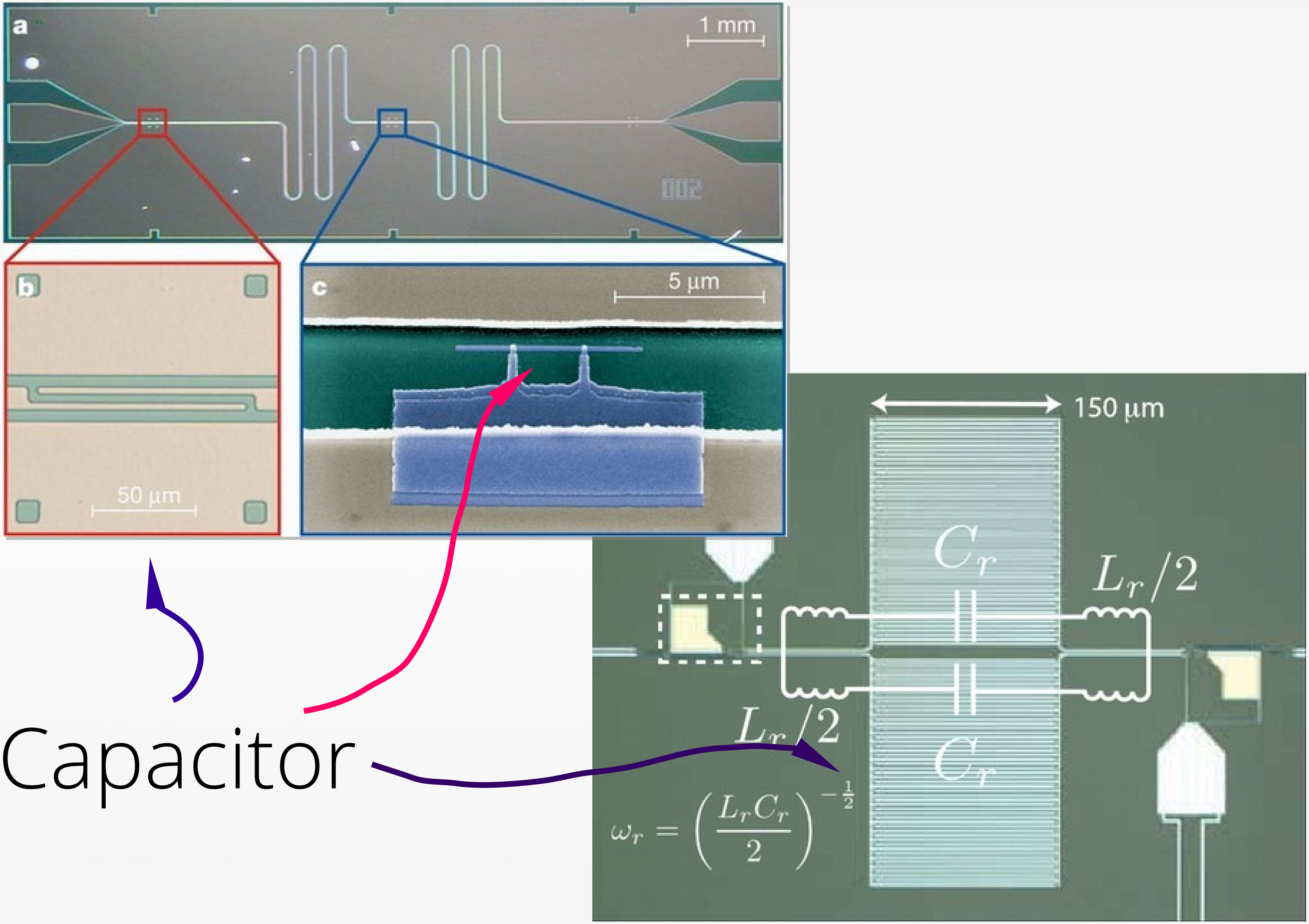
|0⟩ + |1⟩
|0⟩ + |2⟩
|0⟩ + |3⟩
|0⟩ + |4⟩
|0⟩ + |5⟩
+2/π
+1/π
0
−1/π
−2/π
W(α)
Re(α)



m
n

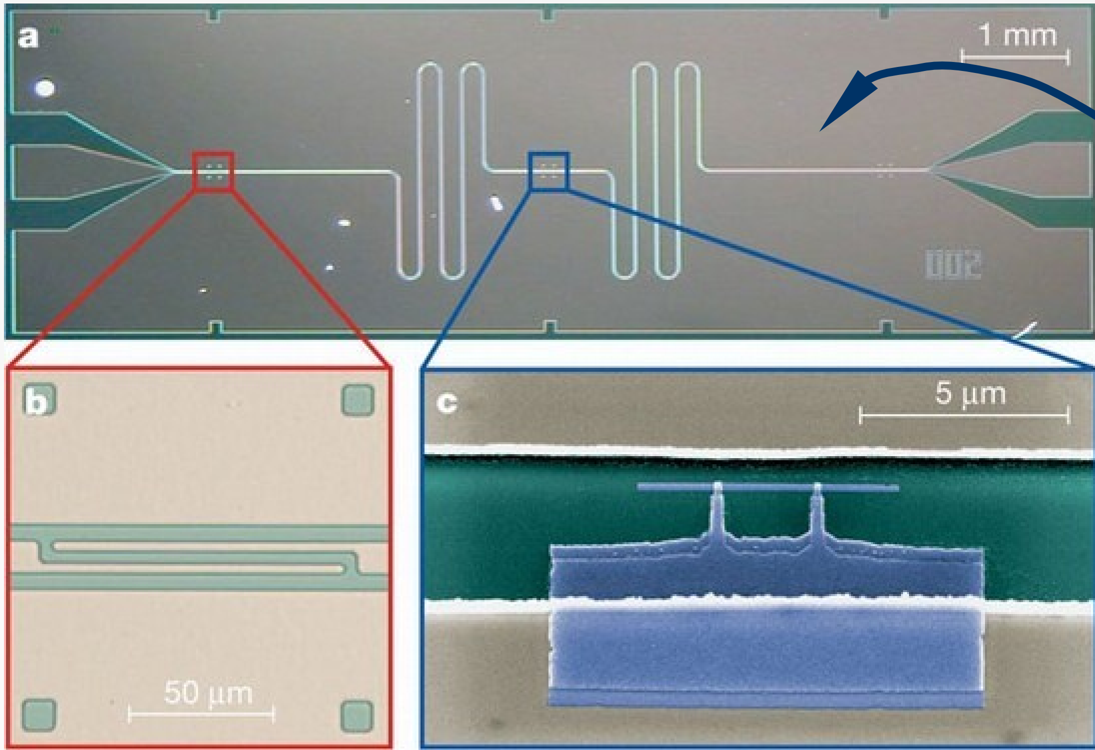


T1
T2
Tcav
3D cavities
100,000
10,000
1000
100
10
1
cQED
Fluxonium
Improved
3D transmon
Quantronium
3D transmon
Transmon
CPB
Charge echo
Qubit lifetime (ns)
Operations per error
2000
2004
2008
2012
Year

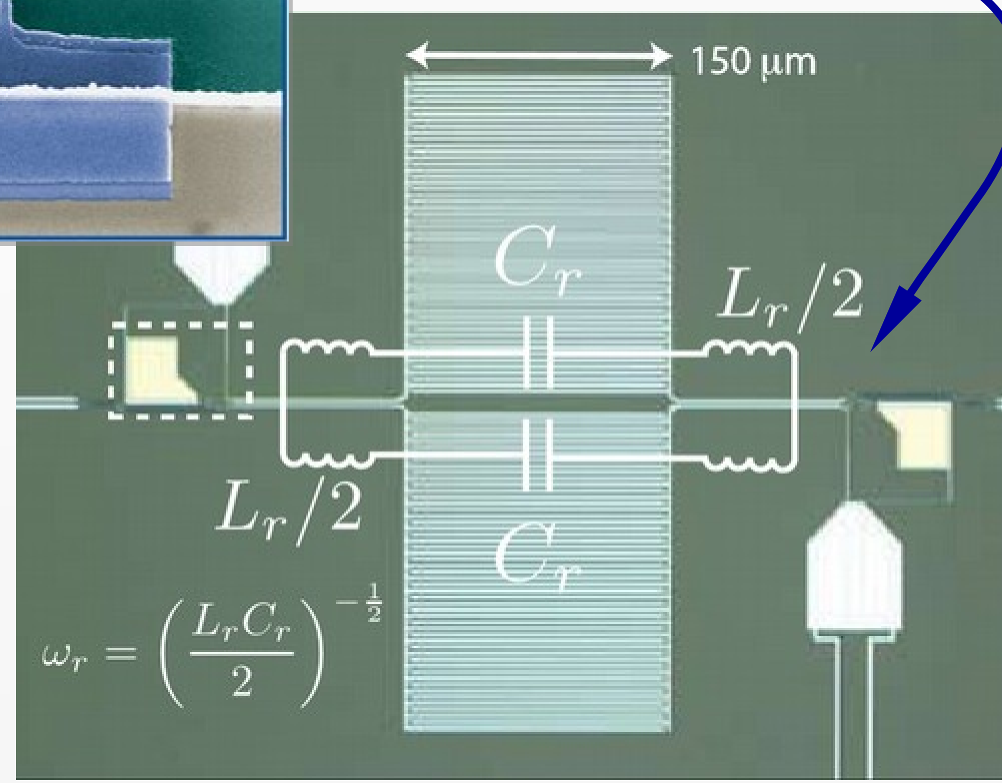


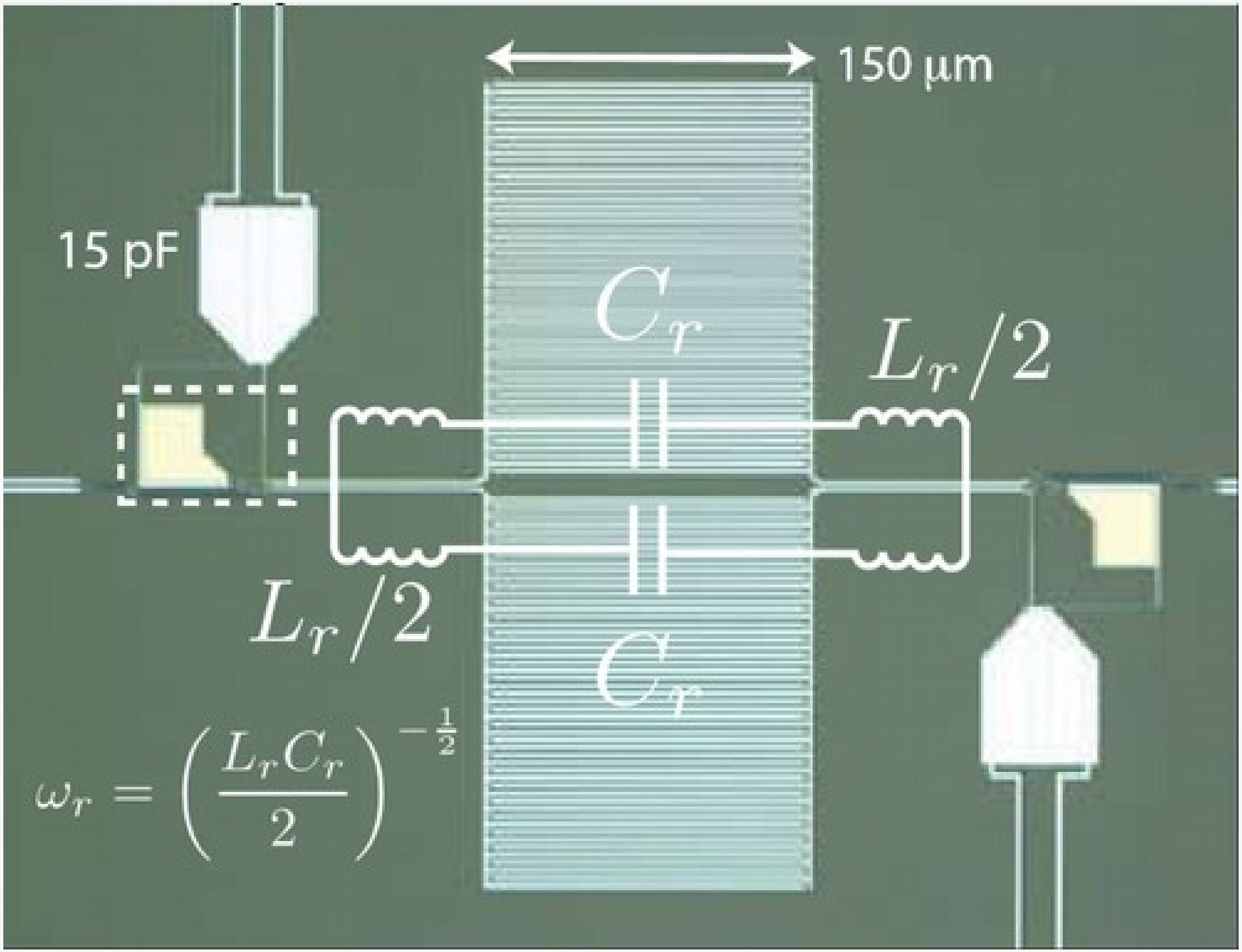
a
1 mm
b
50 µm
c
5 µm
150 µm
C_r
$L_r/2$
$L_r/2$
C_r
$\omega_r = \left(\frac{L_r C_r}{2}\right)^{-\frac{1}{2}}$

Capacitor


a
1 mm
b
50 μm
c
5 μm

Inductor


150 μm
C_r
$L_r/2$
$L_r/2$
C_r
$\omega_r = \left(\frac{L_r C_r}{2}\right)^{-\frac{1}{2}}$



P. Forn-Díaz et al, Phys. Rev. Lett. 105, 237001 (2010)