University of Basel

PHYSICAL REVIEW A

covering atomic, molecular, and optical physics and quantum information

Laboratory of Artificial Quantum Systems

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Editors' Suggestion

Access by University of
Memes

Light dressing of a diatomic superconducting artificial molecule

G. P. Fedorov, V. B. Yursa, A. E. Efimov, K. I. Shiianov, A. Yu. Dmitriev, I. A. Rodionov, A. A. Dobronosova, D. O. Moskalev, A. A. Pishchimova, E. I. Malevannaya, and O. V. Astafiev

Phys. Rev. A **102**, 013707 – Published 7 July 2020

\+ Superconducting qubits basics

Speaker: Artemii Efimov

10/02/2023, Basel

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Charge-insensitive qubit design derived from the Cooper pair box

Jens Koch, Terri M. Yu, Jay Gambetta, A. A. Houck, D. I. Schuster, J. Majer, Alexandre Blais, M. H. Devoret, S. M. Girvin, and R. J. Schoelkopf

Phys. Rev. A **76**, 042319 – Published 12 October 2007

Bible of Transmons

Handbook

Applied Physics Reviews REVIEW scitation.org/journal/are

A quantum engineer's guide to superconducting qubits

Cite as: Appl. Phys. Rev. **6**, 021318 (2019); doi: 10.1063/1.5089550
Submitted: 20 January 2019 · Accepted: 3 May 2019 ·
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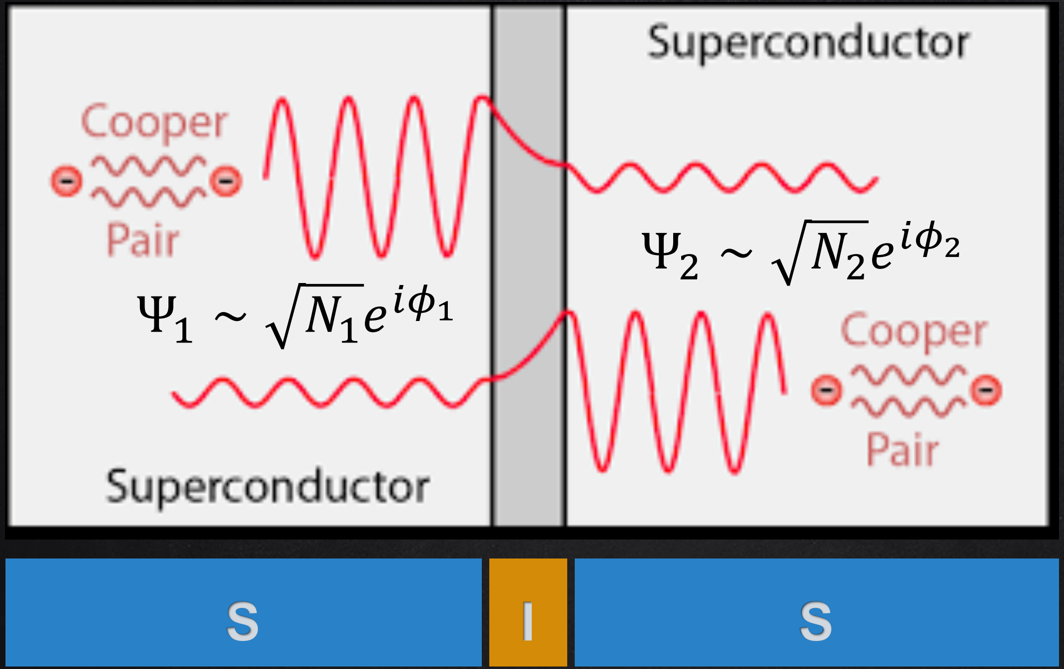
P. Krantz,[1,2,a] M. Kjaergaard,[1] F. Yan,[1] T. P. Orlando,[1] S. Gustavsson,[1] and W. D. Oliver[1,3,b]

AFFILIATIONS

[1]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
[2]Wallenberg Centre for Quantum Technology (WACQT), Chalmers University of Technology, Gothenburg SE-41296, Sweden
[3]MIT Lincoln Laboratory, 244 Wood Street, Lexington, Massachusetts 02420, USA



Josephson junction

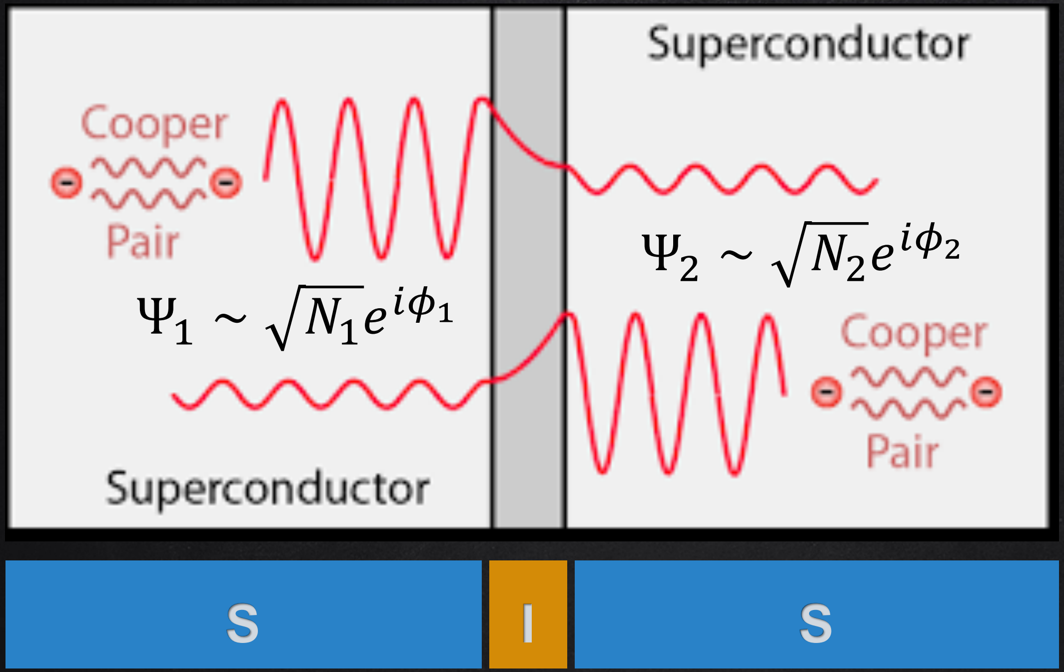
1st Josephson relation:

$$I = I_c \sin \phi$$

2nd Josephson relation:

$$2eV = \hbar \frac{\partial \phi}{\partial t}$$

Charge or Phase?



Josephson junction

$$[e^{i\phi}, n] = e^{i\phi}$$
$$[\phi, n] = \phi$$

$$\boldsymbol{\Delta\phi\Delta Q \geq e}$$

$$I = I_c \sin\phi$$

$$2eV = \hbar \frac{\partial\phi}{\partial t}$$

Josephson energy

$$E_J = \frac{\Phi_0 I_c}{2\pi}$$

$$U_J = \int_0^{t_0} I_c sin(\tilde{\phi}) \left(\frac{\Phi_0}{2\pi}\frac{d\tilde{\phi}}{d\tilde{t}}\right) d\tilde{t} = \frac{\hbar I_c}{2e}(1-\cos\phi) = E_J(1-\cos\phi)$$

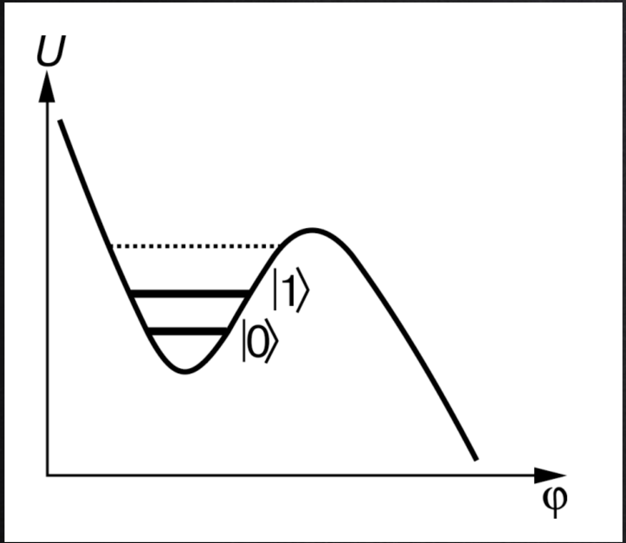
Charging energy

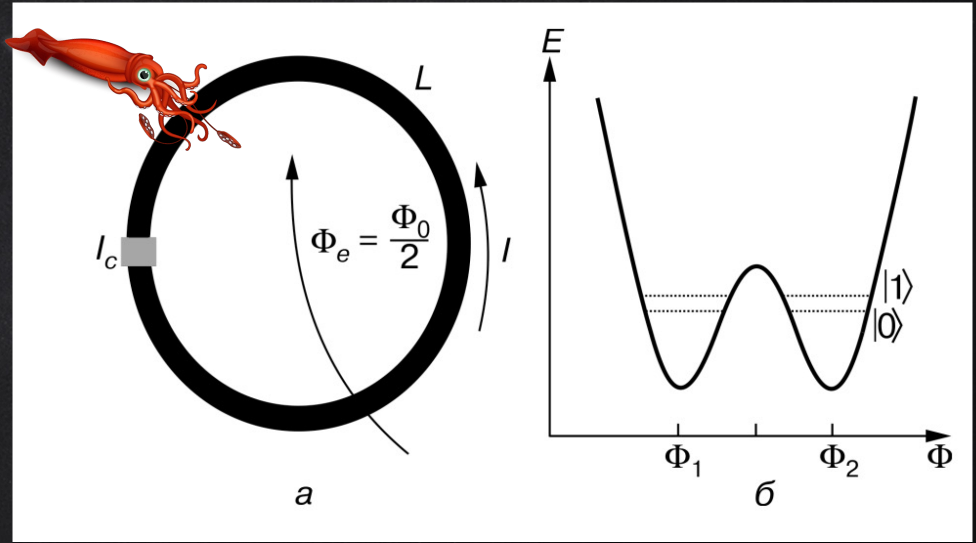
$$E_C = \frac{e^2}{2C}$$

$$U_C = \frac{CV^2}{2} = \frac{Q^2}{2C} = \frac{(2en)^2}{2C} = E_c\left(\frac{Q}{e}\right)^2 = E_c(2n)^2$$

Phase qubit: $E_J \gg E_c$

Flux qubit: $E_J \gg E_c$



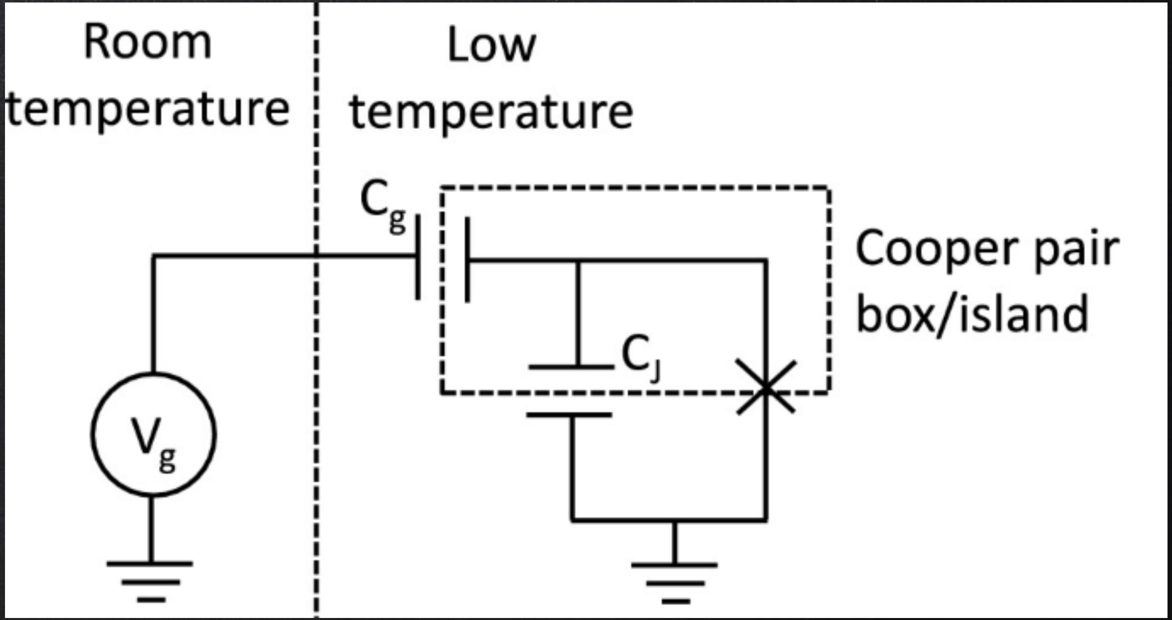


$$H = -Ec\frac{\partial^2}{\partial\phi^2} - E_J\cos\phi - \frac{\hbar}{2e}I\phi$$

$$H = E_c\left(\frac{\Phi_0}{2\pi}\right)^2\frac{\partial^2}{\partial\Phi^2} - E_J\cos\left(2\pi\frac{\Phi}{\Phi_0}\right) + \frac{1}{L}(\Phi - \Phi_0)^2$$

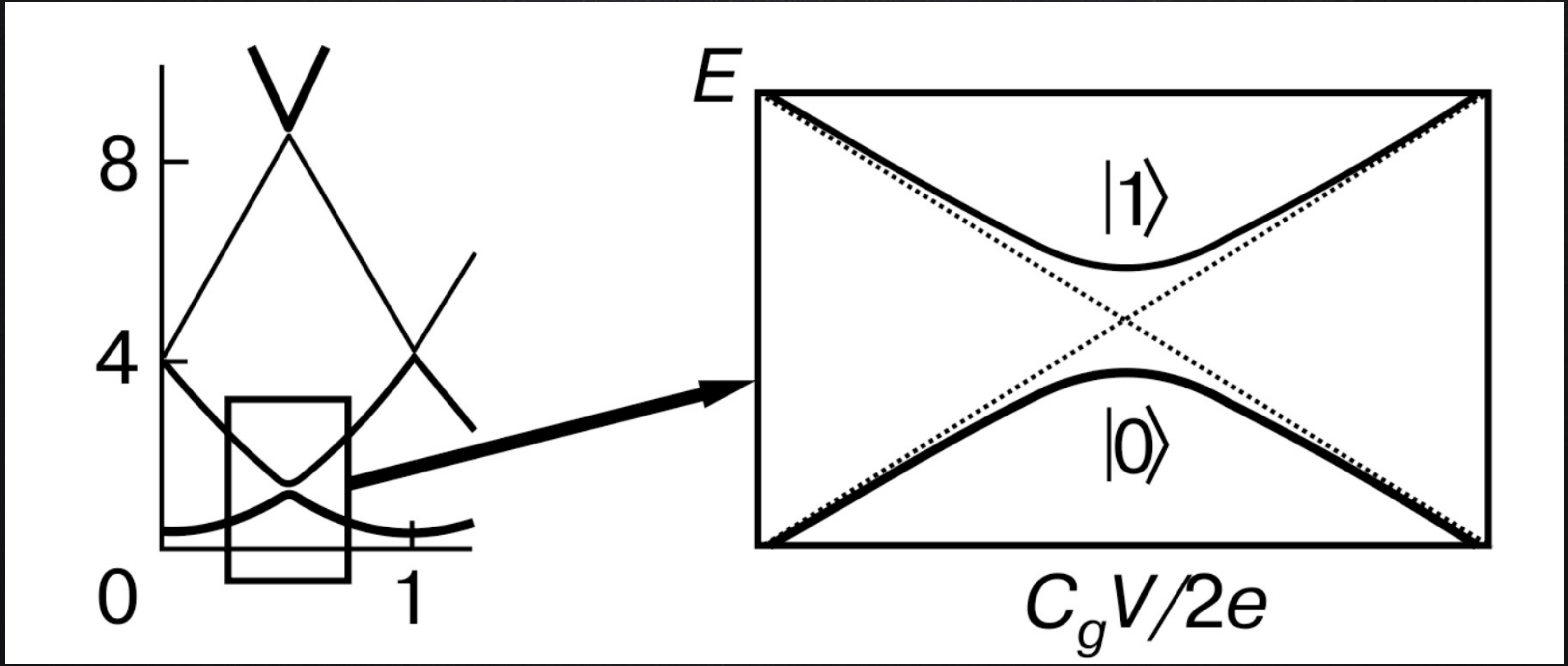
Simple realization: Josephson junction at I = const

Charge qubit $E_J \ll E_c$

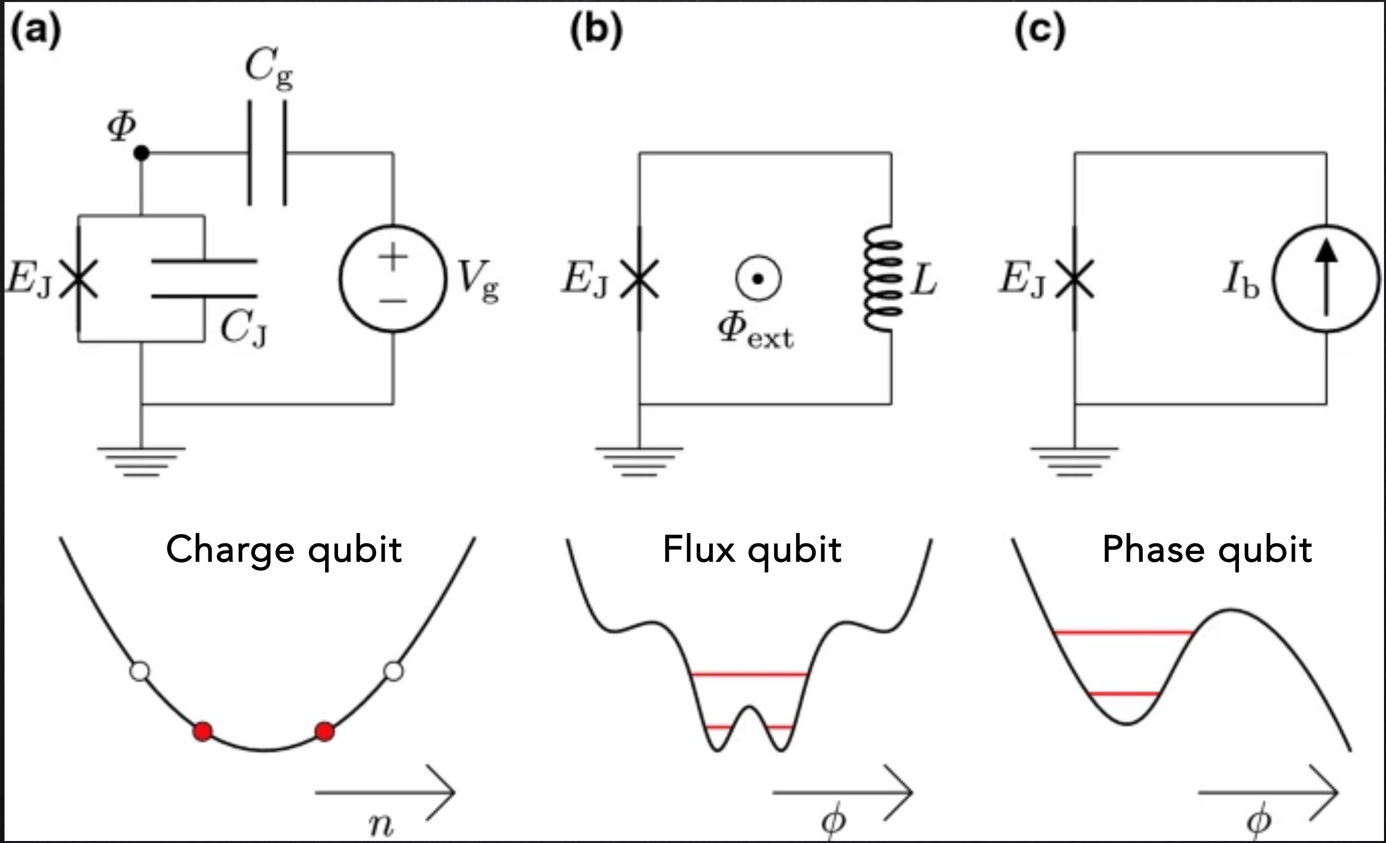


$$H = Ec(n - n_g)^2 |n\rangle\langle n| - \frac{1}{2} E_J (|n\rangle\langle n+1| - |n+1\rangle\langle n|)$$

Charge qubit $E_J \ll E_c$



$$H = Ec\left(n - n_g\right)^2 |n\rangle\langle n| - \frac{1}{2} E_J(|n\rangle\langle n+1| - |n+1\rangle\langle n|)$$



Kockum, A.F., Nori, F. (2019). Quantum Bits with Josephson Junctions.

Transmon qubit

$E_J > E_c$

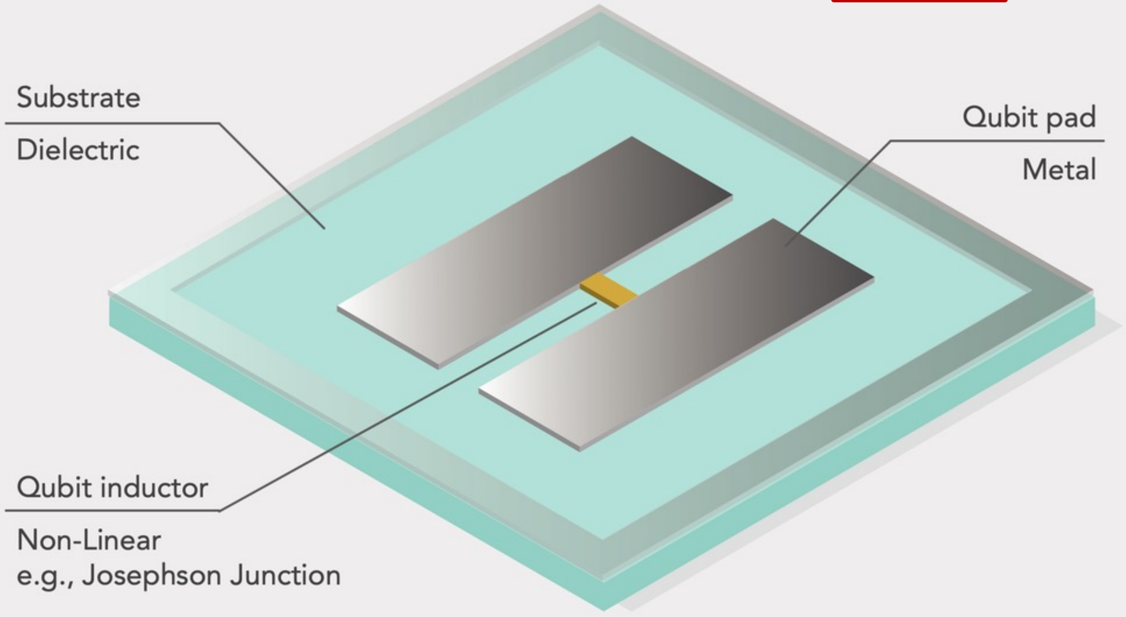
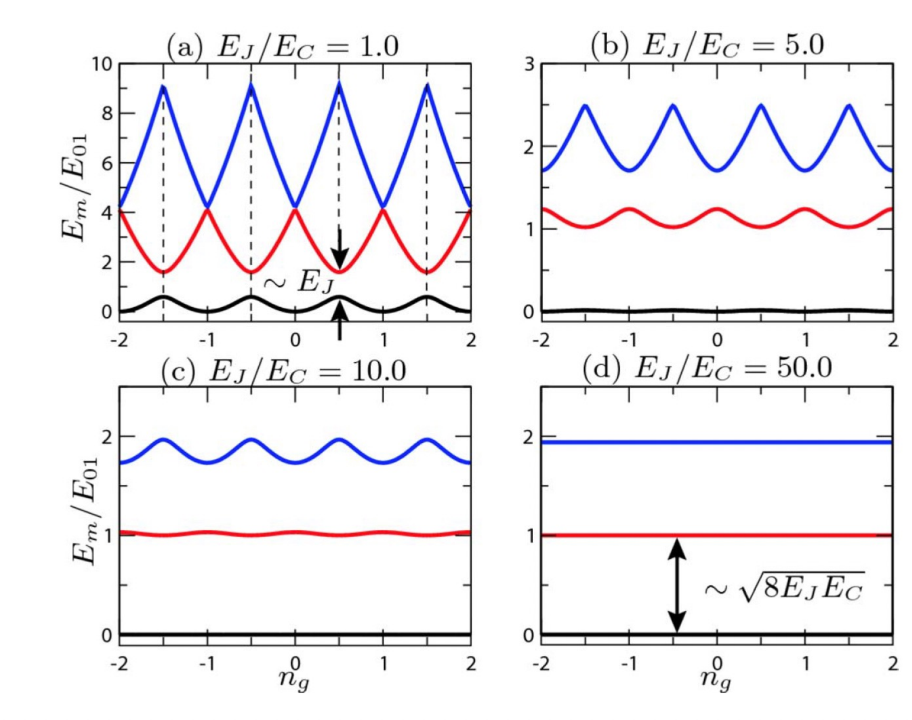
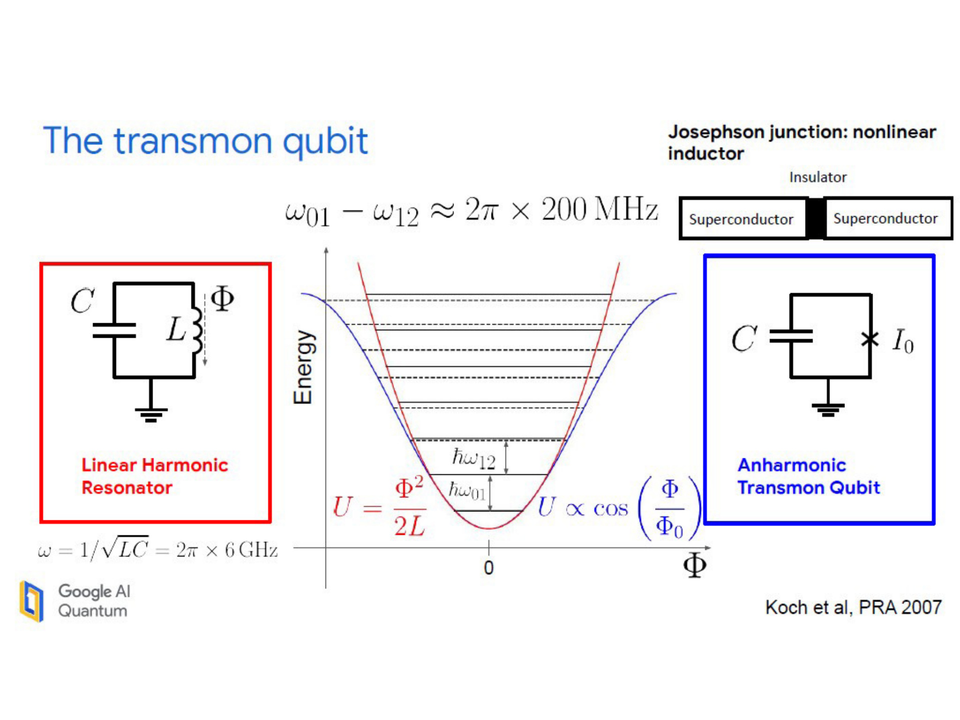


Image: Zlatko Minev

It is just a Cooper pair box but with a big shunted capacitance.

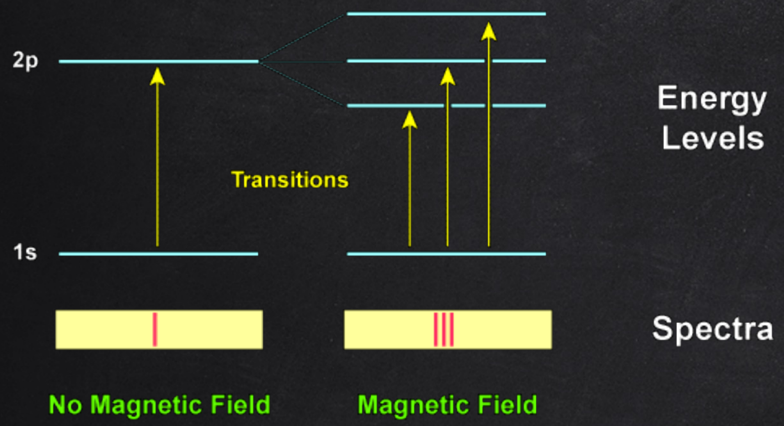
Anharmonicity vs dispersion of charge





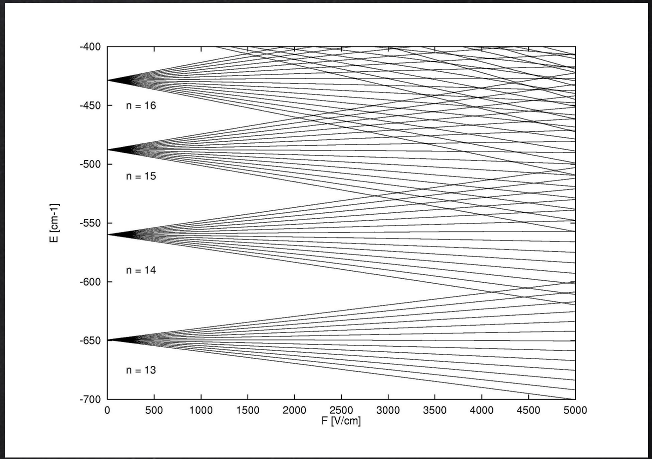
Koch et al, PRA 2007

DC effects



Zeeman splitting

(dc Magnetic field)



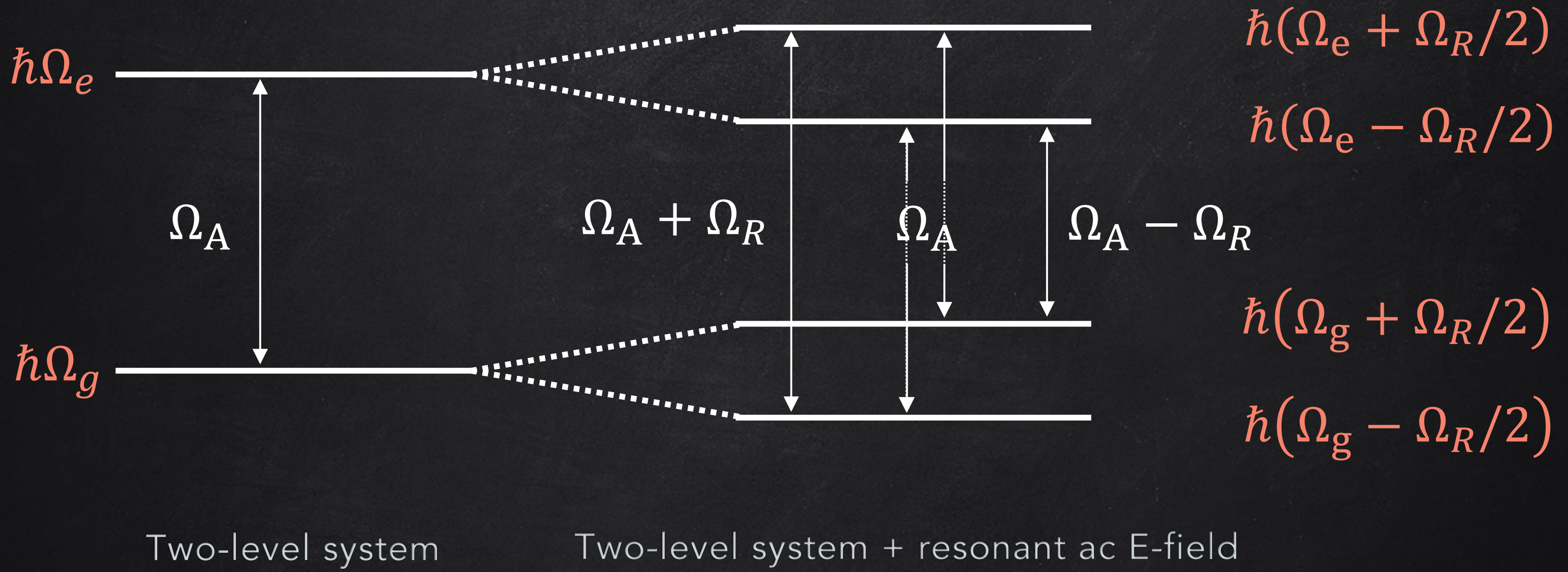
Stark splitting

(dc Electrical field)

http://www.pas.rochester.edu/
Wikipedia/Stark effect

AC Stark effect

For small detuning!!



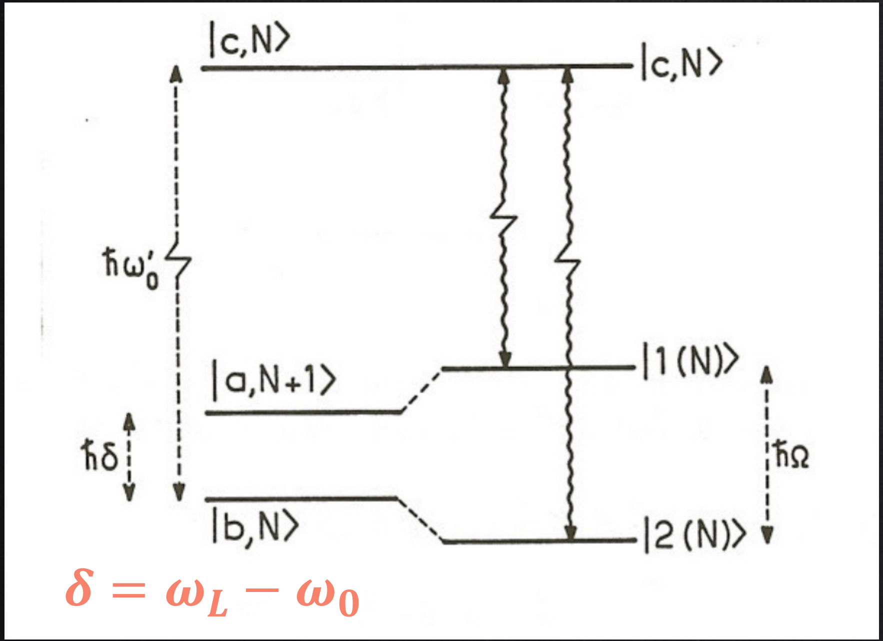
$$H = H_A + H_{int}$$

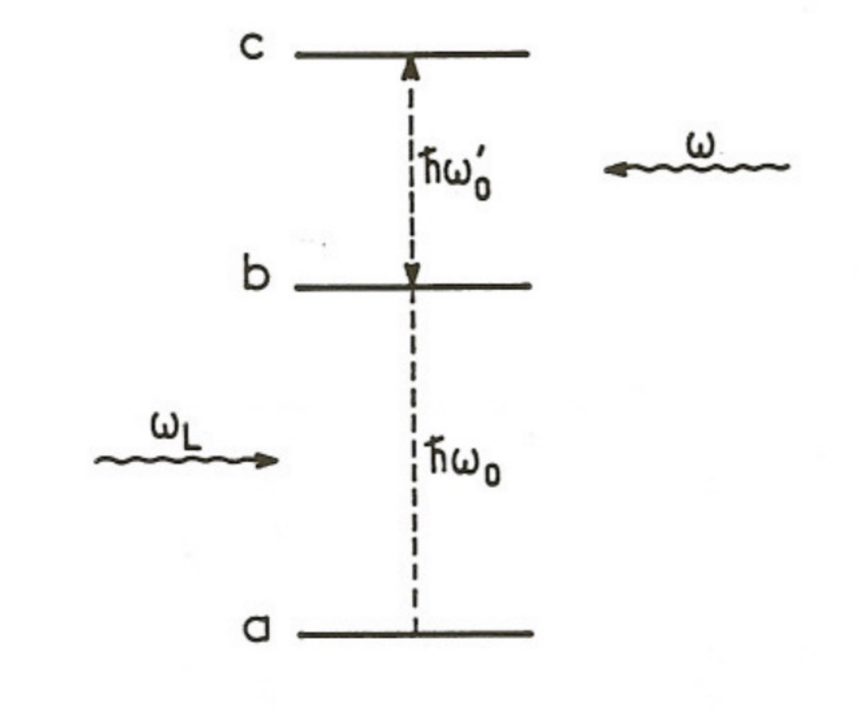
$$H = \hbar\Omega_A|e\rangle\langle e| + \frac{\hbar\Omega_R}{2}(|g\rangle\langle e| + |e\rangle\langle g|)$$

AC Stark effect

↓

Pump-probe experiment



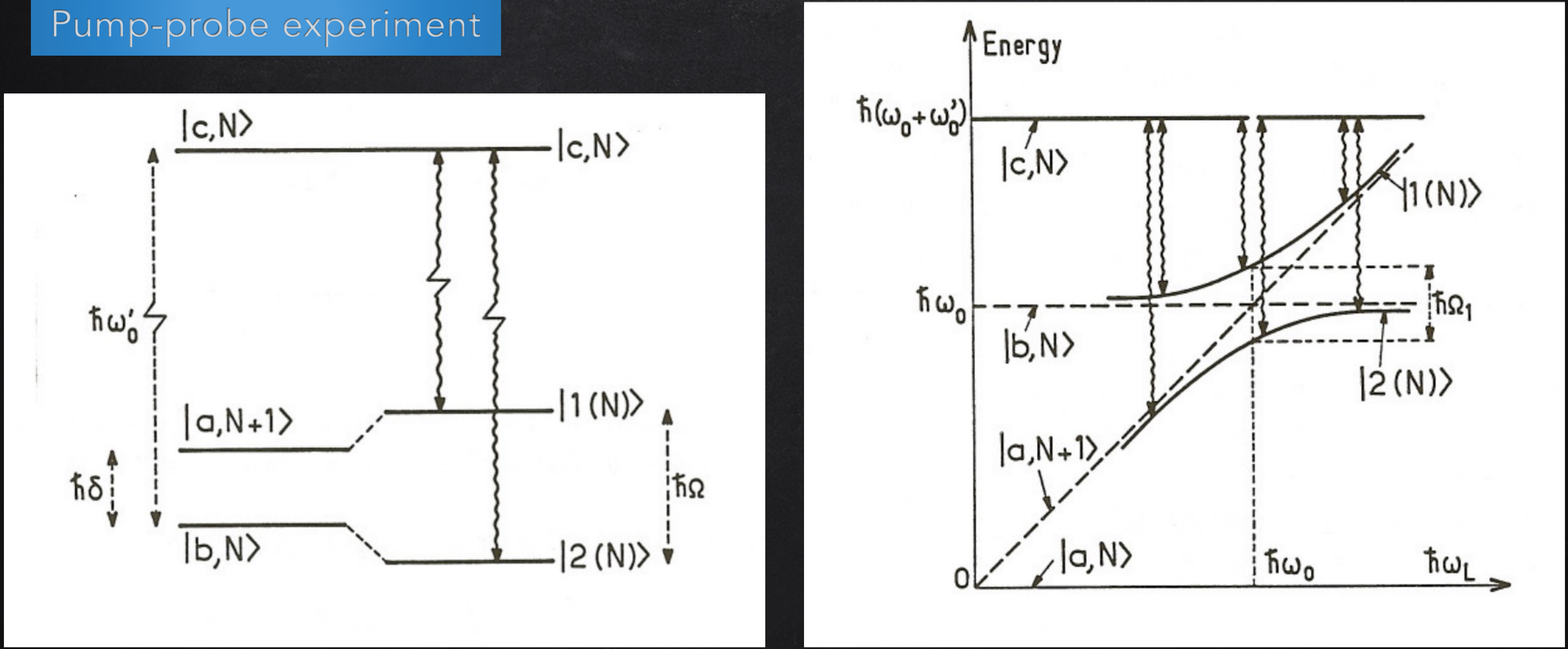


Claude Cohen- Tannoudji,
Collège de France et Laboratoire Kastler Brossel
de l'Ecole Normale Supérieure*

AC Stark effect

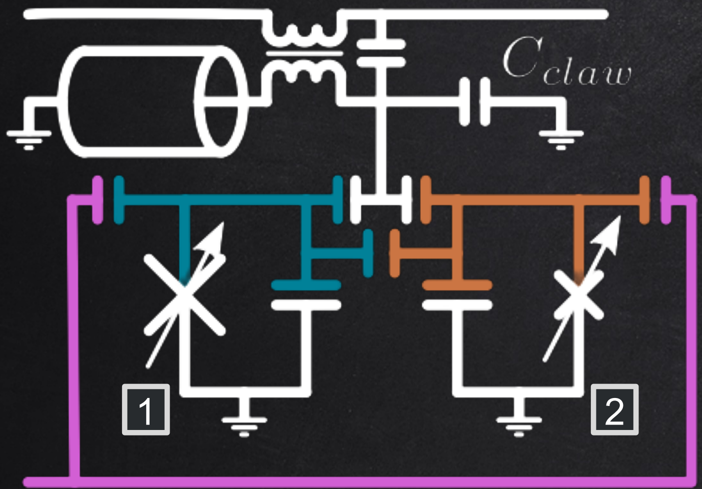
↓

Pump-probe experiment



Claude Cohen- Tannoudji,
Collège de France et Laboratoire Kastler Brossel
de l'Ecole Normale Supérieure*

The paper

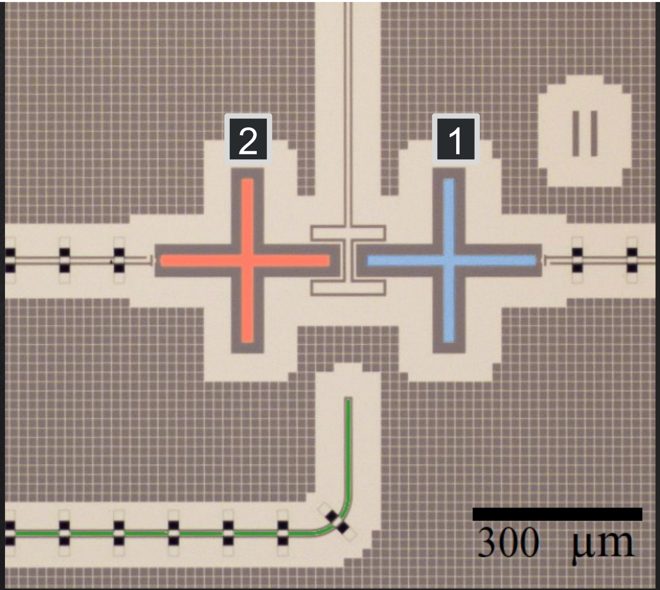


The dc-SQUID setup

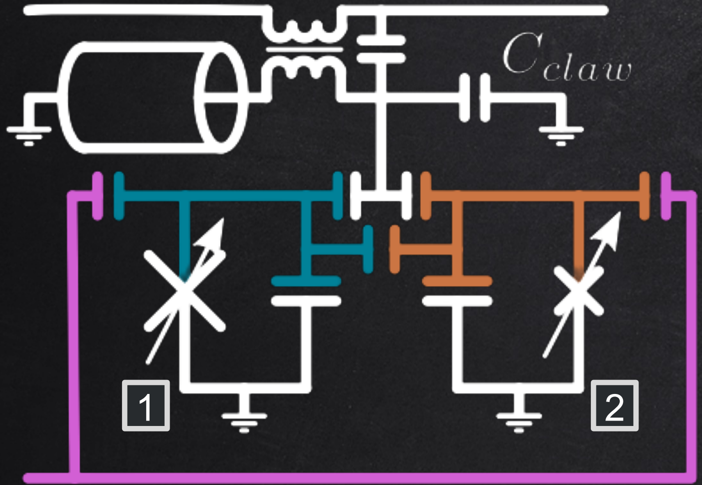
$$E_J = E_{J,max} \cos\left|\pi \frac{\Phi}{\Phi_0}\right|$$

$$\omega = \omega(\Phi_{ext})$$

Parameter	Transmon 1	Transmon 2
$\omega/2\pi$	5.12–6.30 GHz	4.00–5.45 GHz
$\alpha/2\pi$	−220 MHz	−220 MHz
T_1	6.82 μs	4.41 μs
T_2^*	5.14 μs	3.33 μs
$J/2\pi$	8.69 MHz	



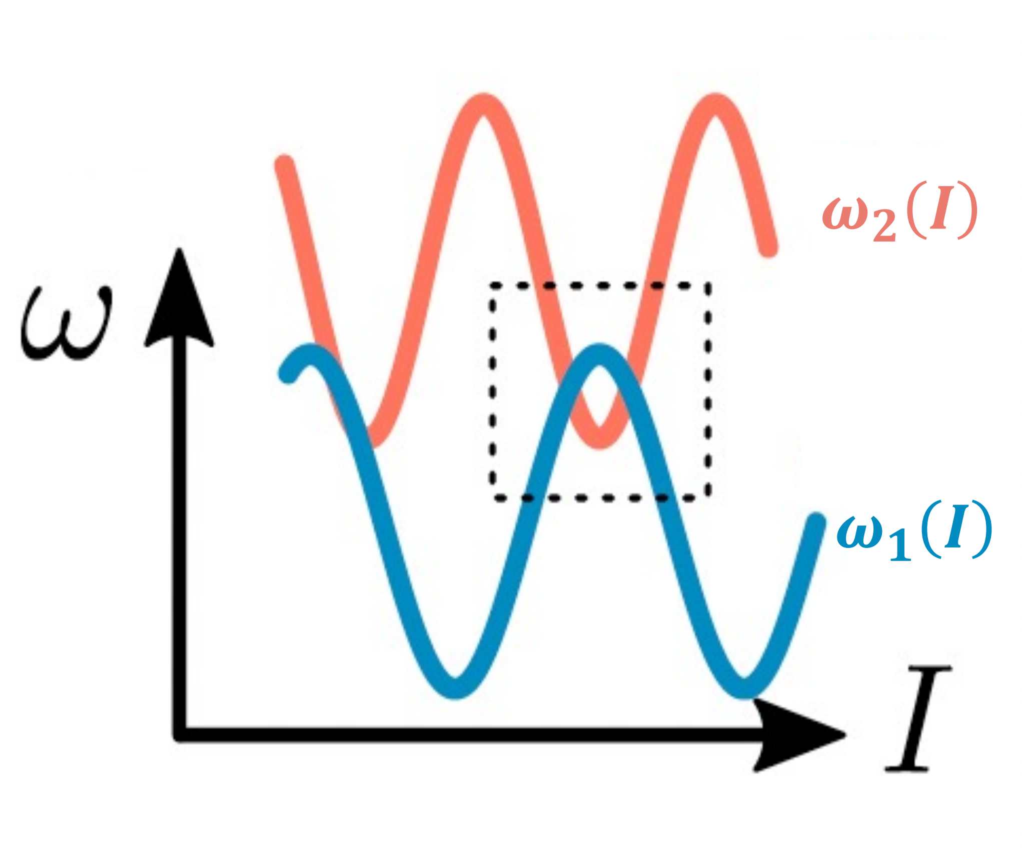
The paper



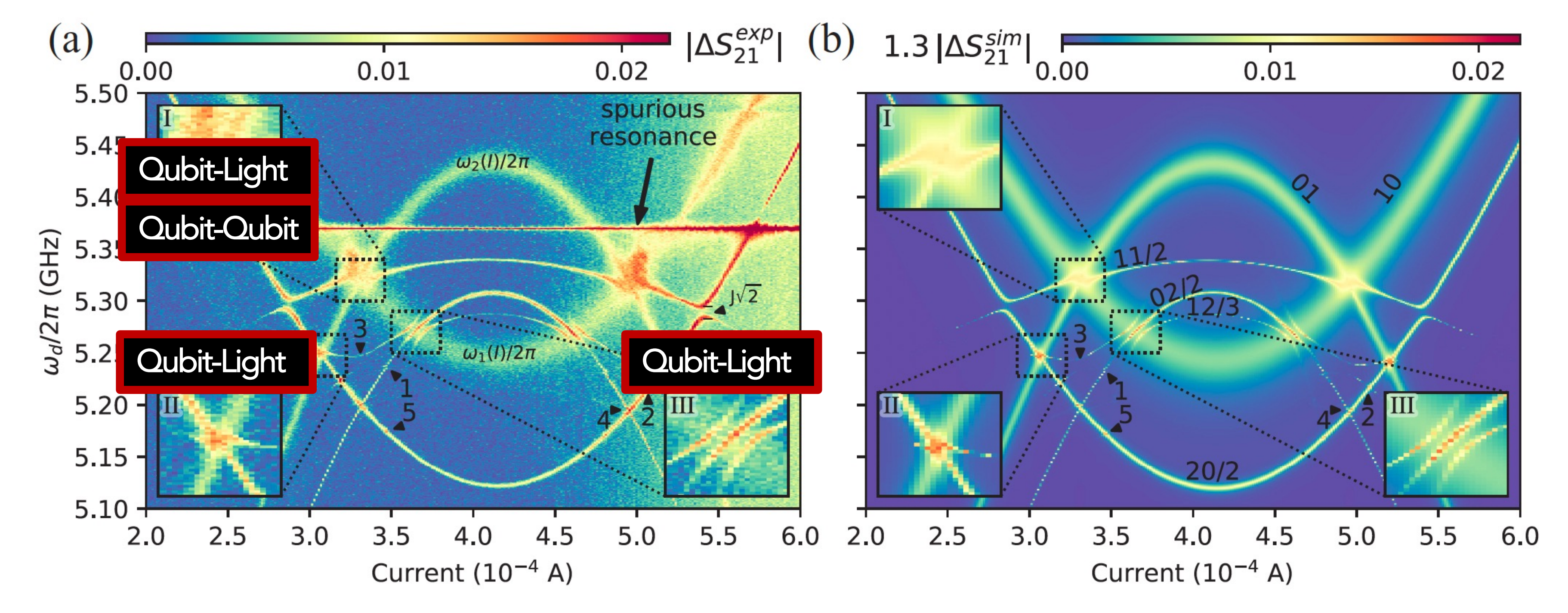
The dc-SQUID setup

$$E_J = E_{J,max} \cos\left|\pi \frac{\Phi}{\Phi_0}\right|$$

$$\omega = \omega(\Phi_{ext})$$

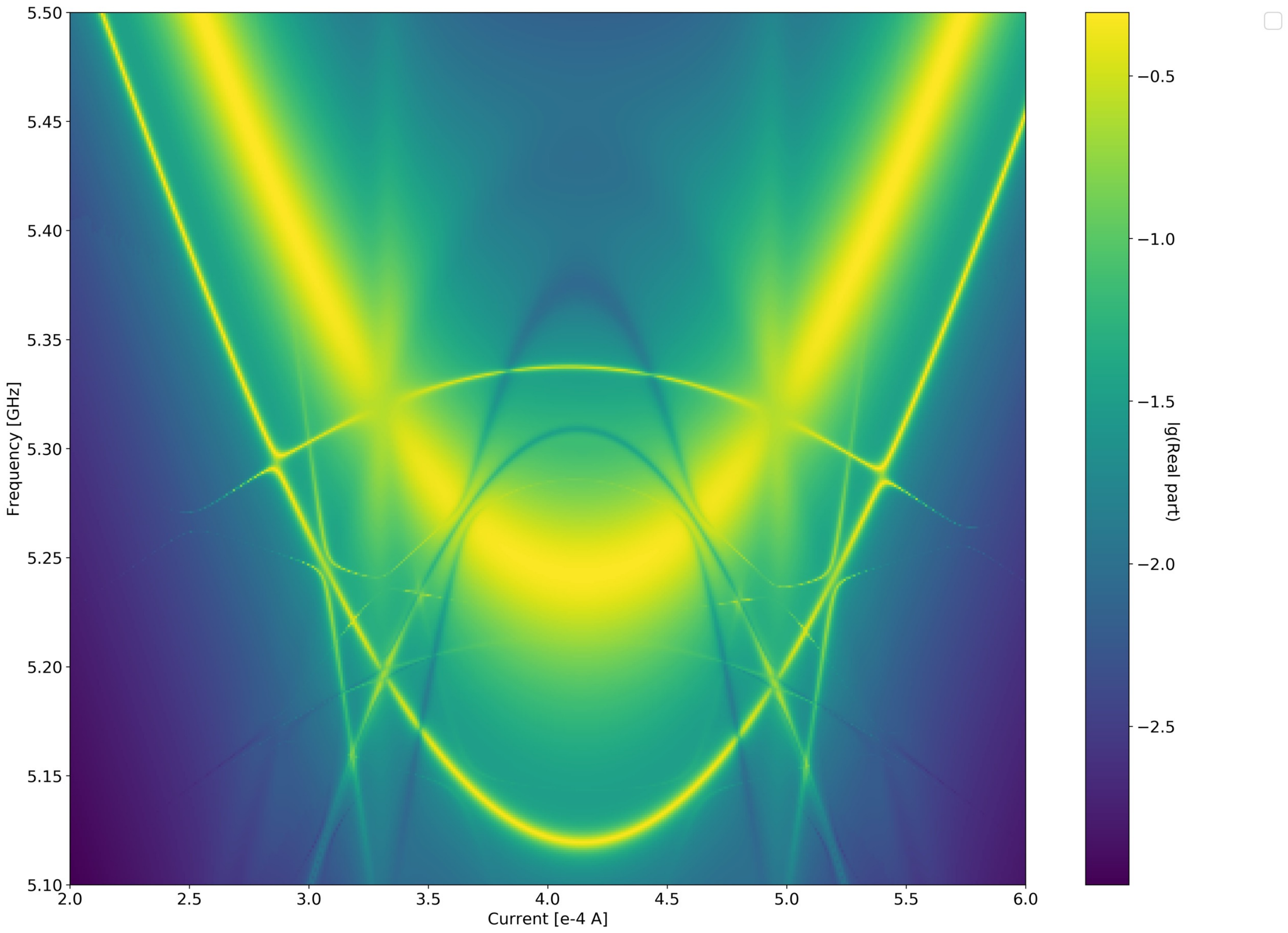


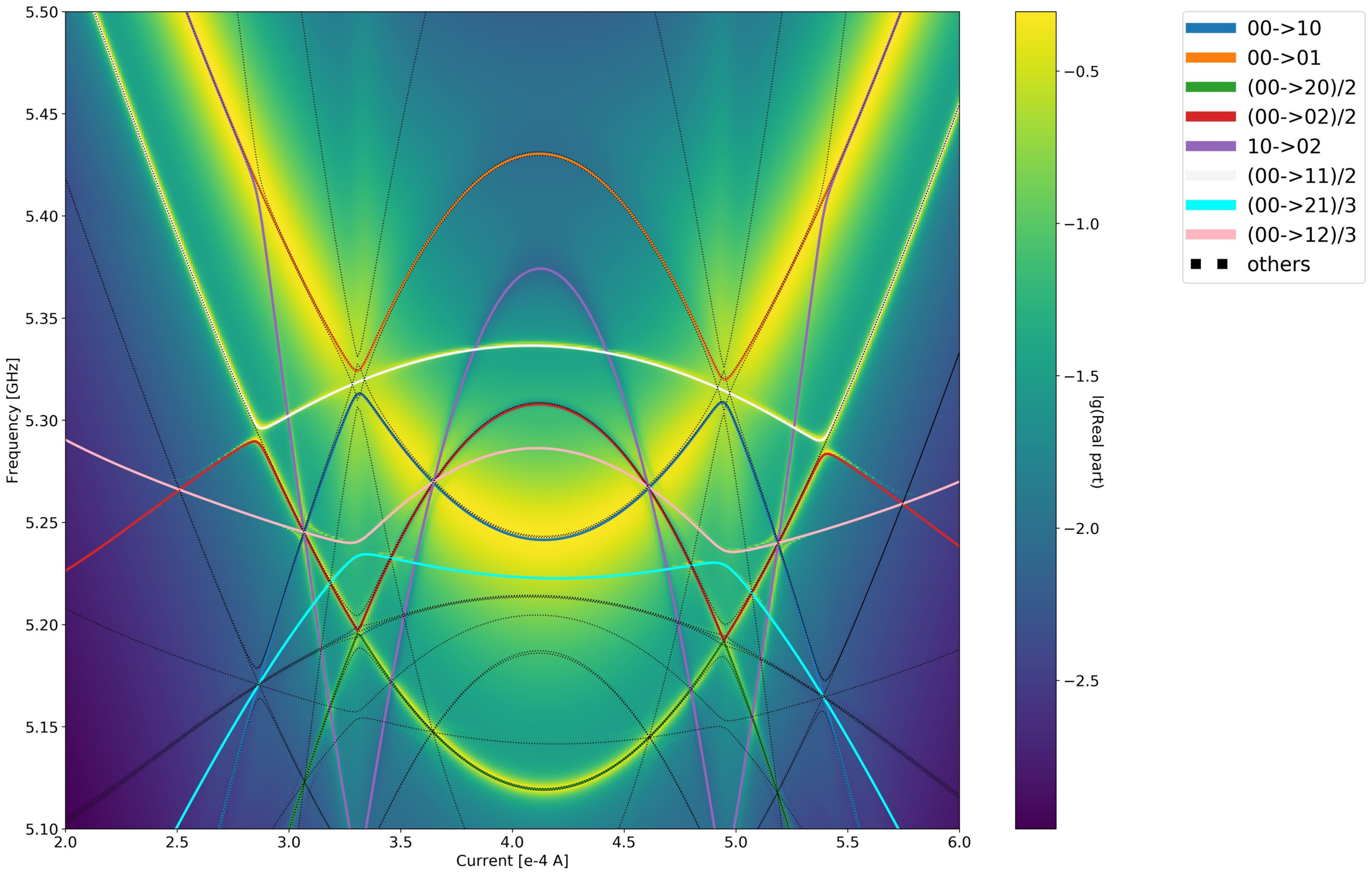
Two-tone spectroscopy



From the experiment

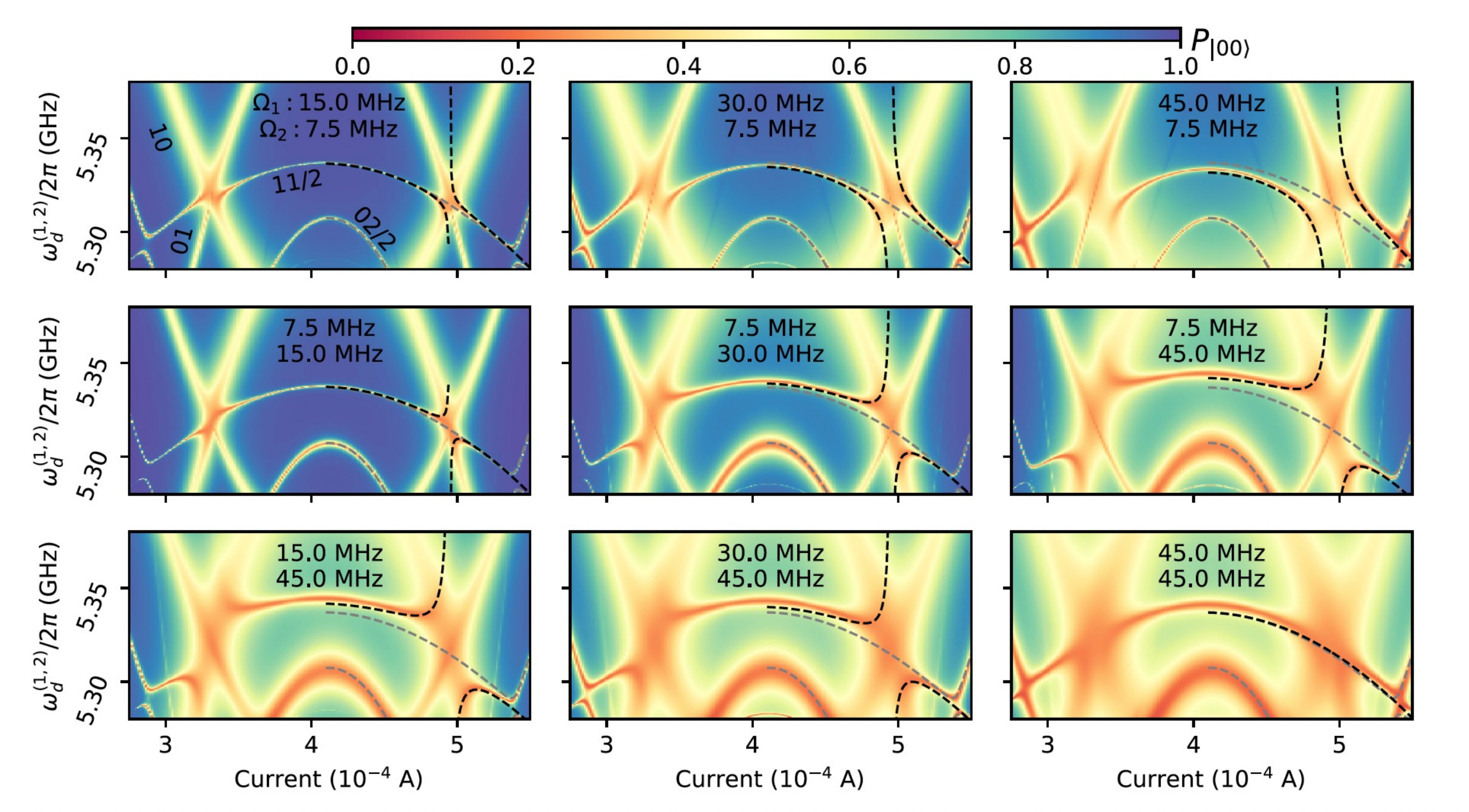
From the simulations


5.50
5.45
5.40
5.35
5.30
5.25
5.20
5.15
5.10
Frequency [GHz]
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Current [e-4 A]
−0.5
−1.0
−1.5
−2.0
−2.5
lg(Real part)



00->10
00->01
(00->20)/2
(00->02)/2
10->02
(00->11)/2
(00->21)/3
(00->12)/3
others
Frequency [GHz]
Current [e-4 A]
lg(Real part)
5.50
5.45
5.40
5.35
5.30
5.25
5.20
5.15
5.10
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
−0.5
−1.0
−1.5
−2.0
−2.5

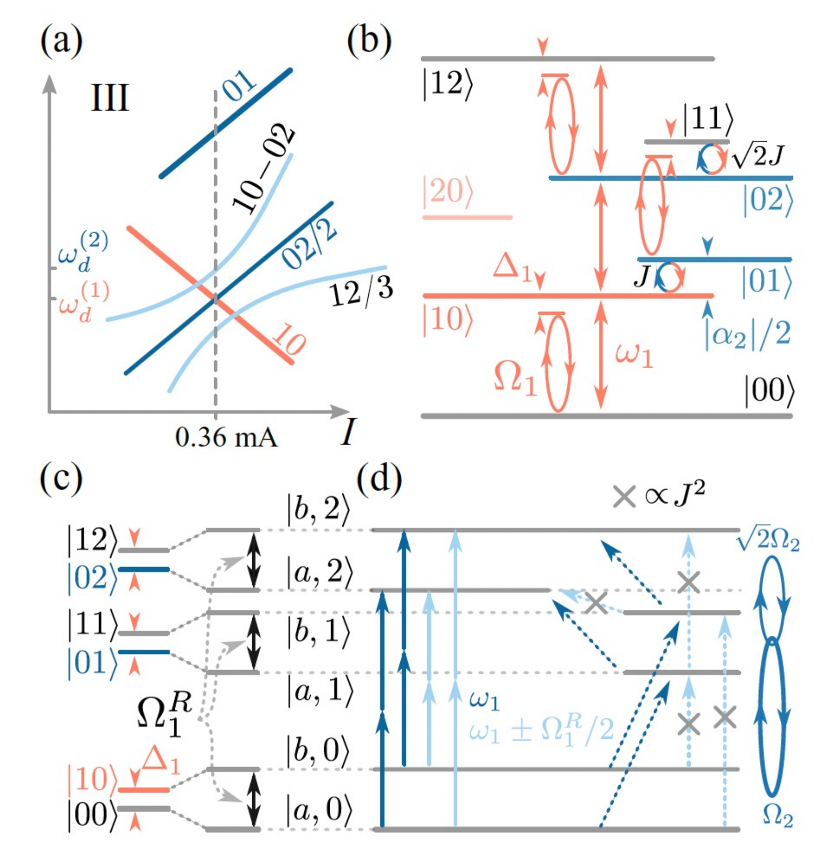
Different driving

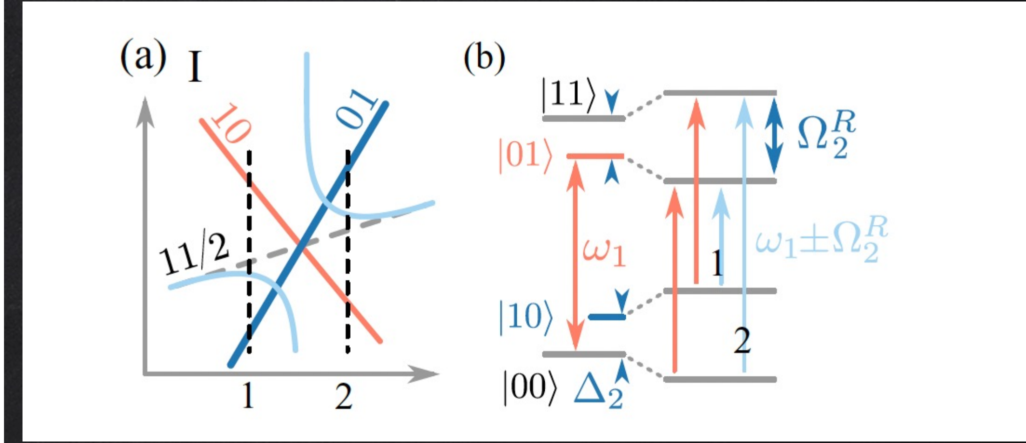


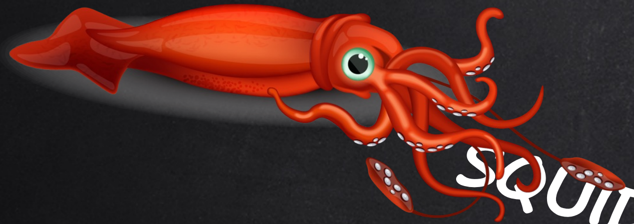
Summary

- Basics in Superconducting qubits
- Autler-Townes effect - Light dressing
- Two qubit system + classical/quantized light

Thank you for your attention!


(a)
III
01
10−02
02/2
12/3
10
$\omega_d^{(2)}$
$\omega_d^{(1)}$
0.36 mA
I
(b)
$|12\rangle$
$|11\rangle$
$\sqrt{2}J$
$|20\rangle$
$|02\rangle$
$|01\rangle$
Δ_1
J
$|10\rangle$
$|\alpha_2|/2$
Ω_1
ω_1
$|00\rangle$
(c)
$|12\rangle$
$|02\rangle$
$|11\rangle$
$|01\rangle$
Ω_1^R
Δ_1
$|10\rangle$
$|00\rangle$
$|b,2\rangle$
$|a,2\rangle$
$|b,1\rangle$
$|a,1\rangle$
$|b,0\rangle$
$|a,0\rangle$
(d)
$\times \propto J^2$
$\sqrt{2}\Omega_2$
ω_1
$\omega_1 \pm \Omega_1^R/2$
Ω_2


(a)
I
10
01
11/2
1
2
(b)
$|11\rangle$
$|01\rangle$
$|10\rangle$
$|00\rangle$
Δ_2
ω_1
Ω_2^R
$\omega_1 \pm \Omega_2^R$
1
2



SQUIDS