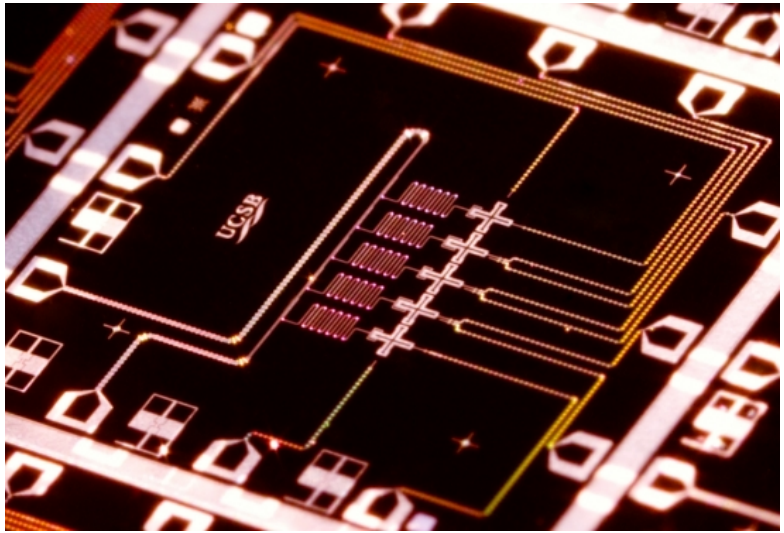
Zusammen gegen Corona

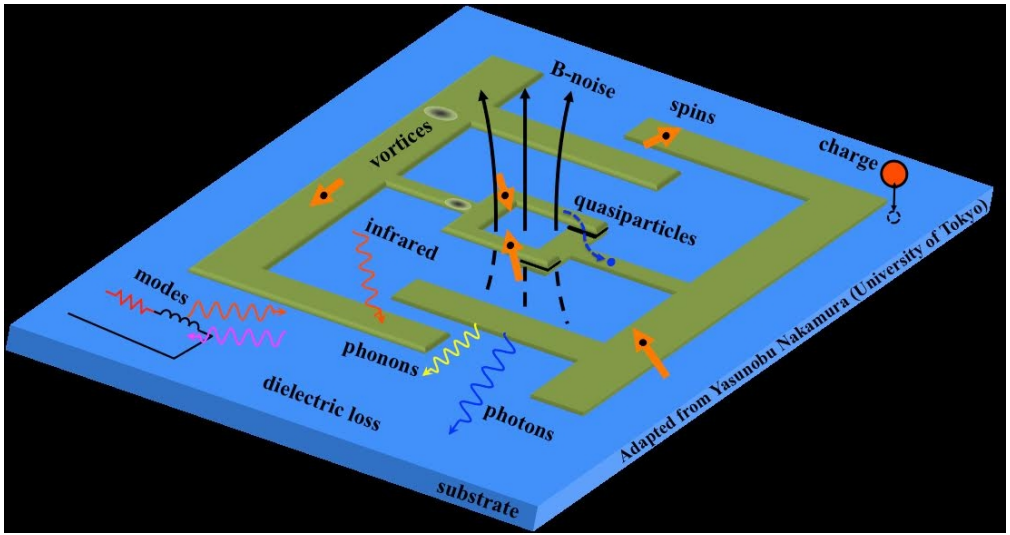
#WIRBLEIBENZUHAUSE

Universität Konstanz

Theory seminar:
Superconducting quantum hardware for quantum computing

Dr. Amin Hosseinkhani
Florian Ginzel
Research Group of Prof. Guido Burkard

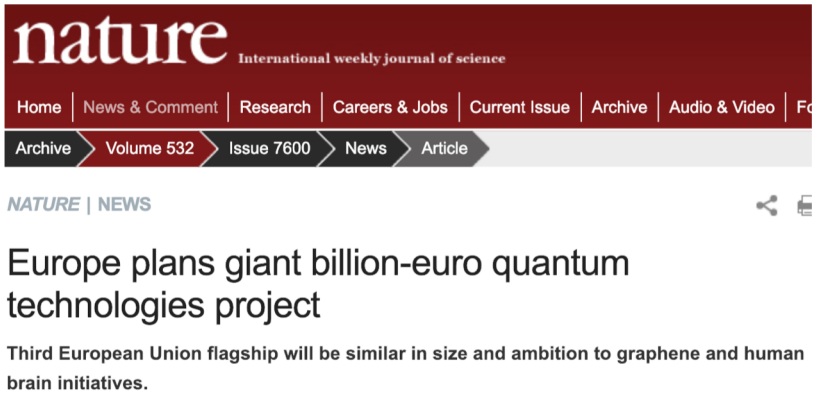




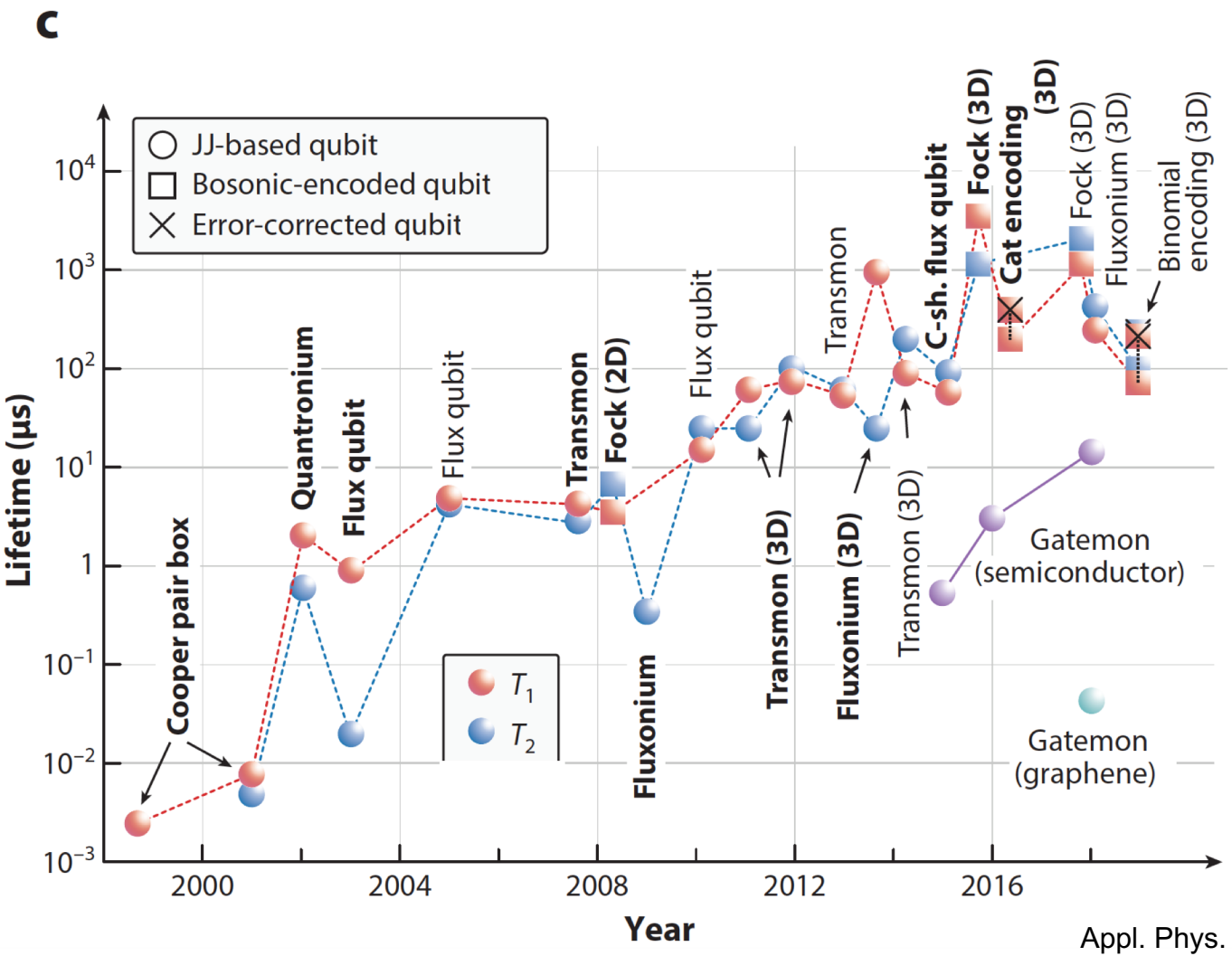
April 23, 2020

- Huge investment in developing quantum science and technology.
- EU Quantum Flagship

- **Superconducting qubits: one of the most promising candidates to encode quantum information**
- Technology companies:



Google	IBM	intel	Microsoft	D-Wave	rigetti
SC Qubits (Transmon qubit)	SC Qubits (Transmon qubit)	SC and spin Qubits (Transmon qubit)	Topological qubits	SC Qubits (Transmon qubit)	SC Qubits (Transmon qubit)



We study various types of superconducting qubits and their coherence properties.

Appl. Phys. Rev. 6, 021318 (2019)

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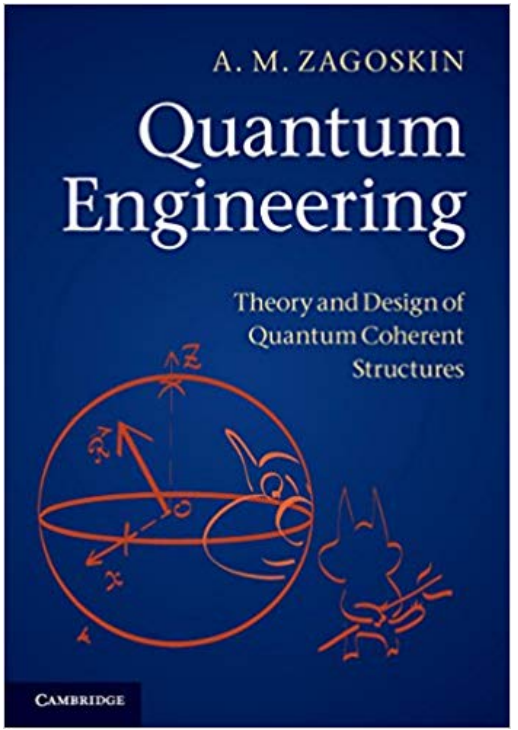
- Main literature:

Quantum Engineering: Theory and Design of Quantum Coherent Structures
by Alexandre Zagoskin, Cambridge University Press 2011



- Review articles:

Rev. Mod. Phys. **73**, 357 (2001)

Appl. Phys. Rev. 6, 021318 (2019)

- Original publications:

Science **326**, 113 (2009).

Phys. Rev. B **84**, 064517 (2011)

Nature Comm. **5**, 5836 (2014)

Phys. Rev. B **94**, 104516 (2016)

Science **354**, 1573–1577 (2016)

And etc.

Online access is made possible by the library of Universität Konstanz

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We start by 4 introductory lectures

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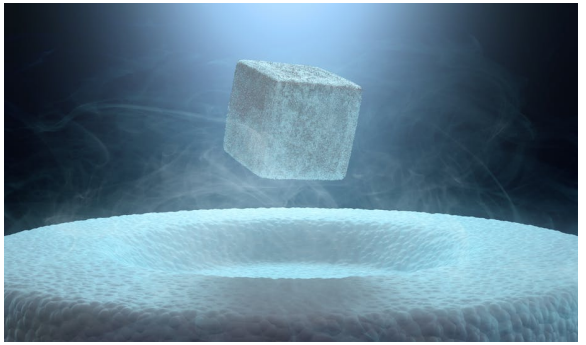
➔ Lectures + Seminars

- **Lecture 1: Physics of BCS superconductors**
  By Amin Hosseinkhani

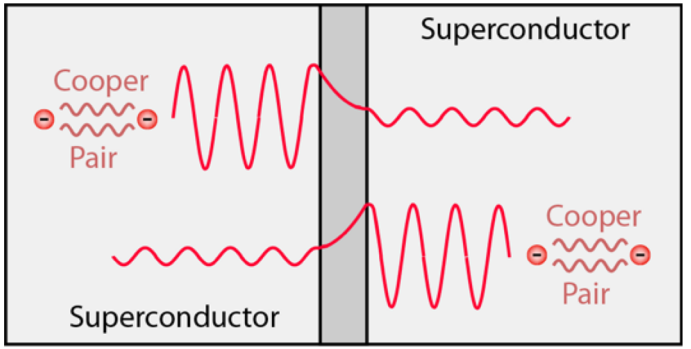


➔ Formation of superconductivity

➔ The ground state condensate; *single quantum phase*

➔ Quasiparticle excitations; *gapped* from the ground state condensate.

➔ Josephson Junctions; building blocks of SC



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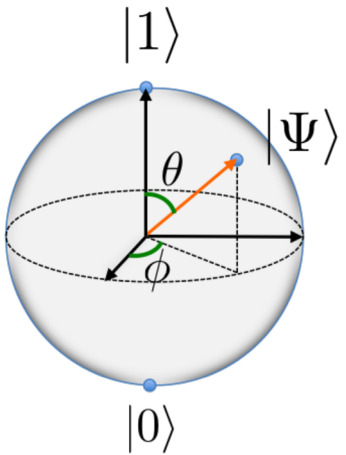
- Lectures + Seminars

- **Lecture 2: Characterizing qubit coherence times**
  By Florian Ginzel
  - Environment watching the qubit ⇨ decoherence.
  - Density matrix formalism
  - Tracing out the environment
  - Energy relaxation and pure dephasing

Environment



$$\frac{1}{T_2} = \frac{1}{2T_1} + \frac{1}{T_\phi}$$

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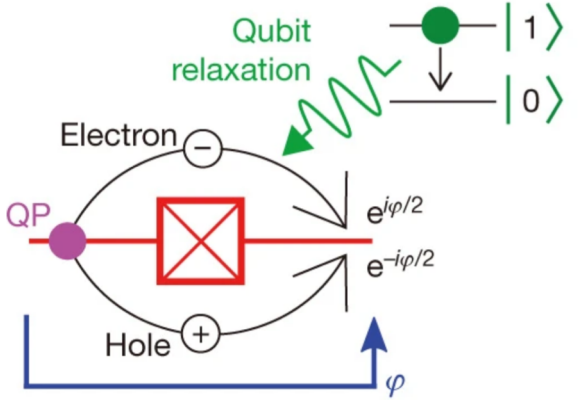
➔ Lectures + Seminars

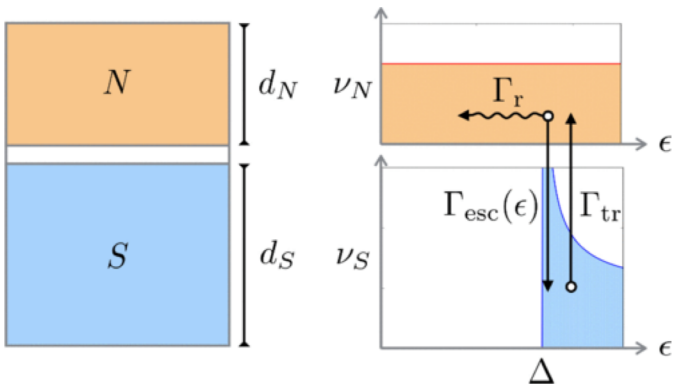


- **Lecture 3: Superconducting intrinsic noise: Quasiparticle (QP) poisoning**
  By Amin Hosseinkhani

  Phys. Rev. Lett. **106**, 077002 (2011)
  Phys. Rev. B **84**, 064517 (2011).
  arXiv:2003.04366

- **Lecture 4: Suppressing QP-induced relaxation in superconducting qubits:** **normal-metals, vortices, pulse injection, etc**
  By Amin Hosseinkhani

  A. Hosseinkhani, PhD thesis, DOI: 10.18154/RWTH-2018-226909
  Nature Comm. **5**, 5836 (2014)
  Science **354**, 1573–1577 (2016)



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The student seminars then begin

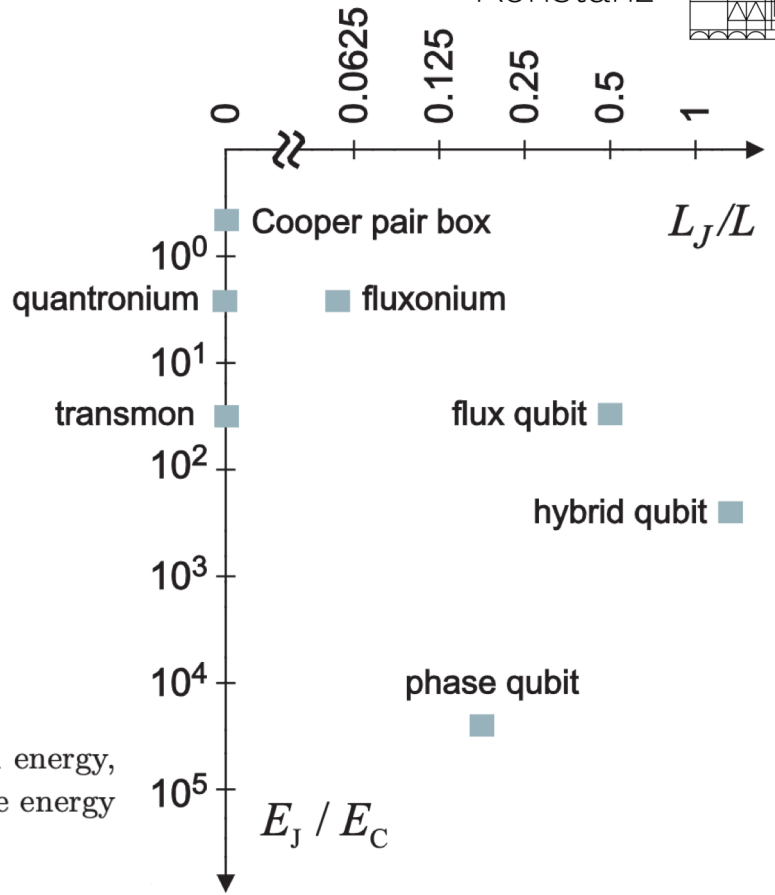

Fig. 4.4 'Periodic Table' of superconducting qubits. E_J is the tunneling Josephson energy, $4E_C$ is the energy cost to charge the junction with one Cooper pair, and $E_L/2$ is the energy cost to 'charge' the shunt inductor with one flux quantum. (Courtesy M. Devoret.)

S.M. Girvin, Les Houches lecture notes, 2011

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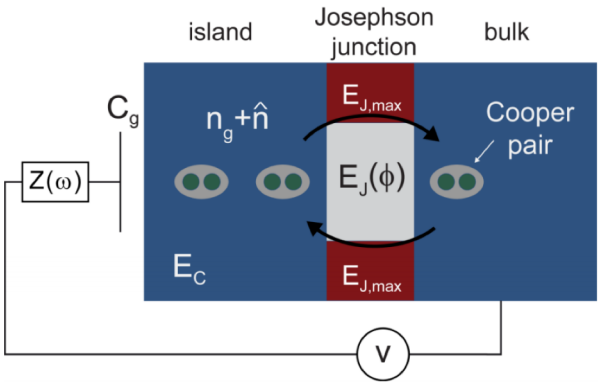
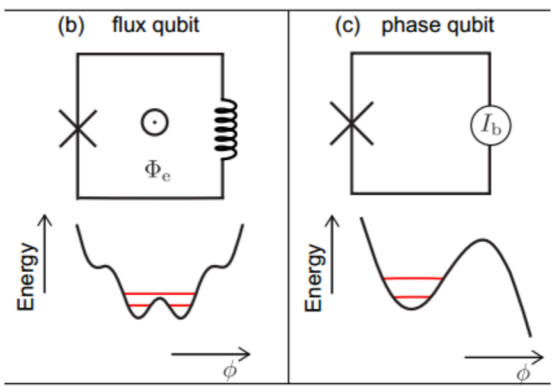
➔ Lectures + Seminars



- **Student Seminar 1: Cooper-pair box and Quantronium**

  Suggested references:

- Zagoskin, Sections 2.2.1 and 2.4
- Nature **398**, 786-788 (1999).
- Science **296**, 886-889 (2002).



- **Student Seminar 2: Flux and Phase qubit**

  Suggested references:

- Zagoskin, Sections 2.2.2- 2.2.3 and 2.3.5
- Science **285**, 1036-1039 (1999).
- Phys. Rev. Lett. **89**, 117901 (2002).

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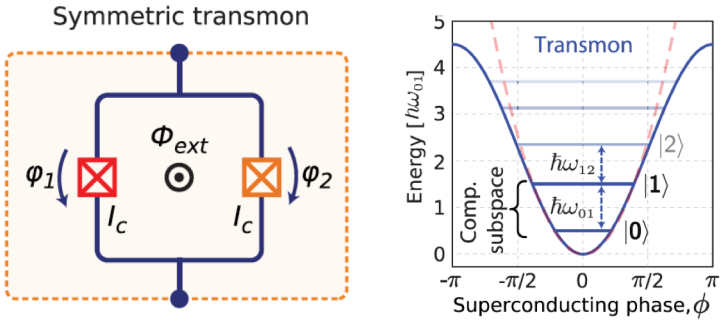
- **Student Seminar 3: Transmon and Fluxonium qubit**

Suggested references:

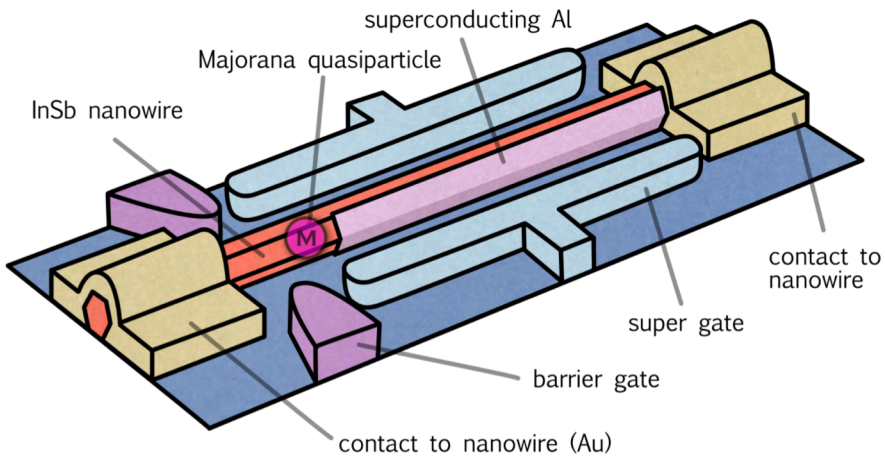
- Phys. Rev. A **76**, 042319 (2007).
- Science **326**, 113-116 (2009).



- **Student Seminar 4: Majorana fermions and the prospect of qubit application**

Suggested references:

- Semicond. Sci. Technol. **27**, 124003 (2012)
- arXiv:1404.0897
- Science **336**, 1003 (2012).



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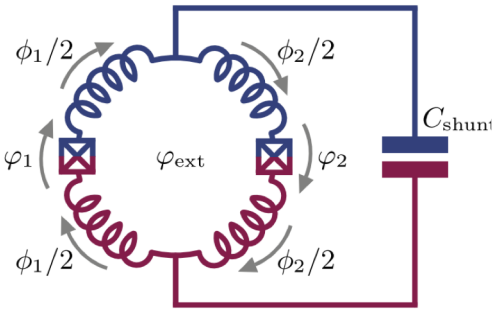
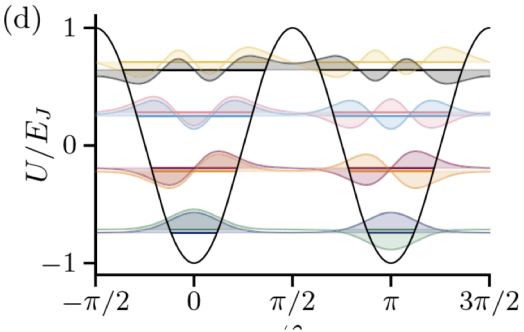
➔ Lectures + Seminars

- **Student Seminar 5: Superconducting circuit protected by two-Cooper-pair tunneling**

  Reference: • npj Quantum Information 6, 8 (2020)





$$H = 4E_C(N - N_g)^2 - E_J \cos 2\varphi,$$

- **Student Seminar 6: Multiqubit devices; capacitive and inductive coupling**

  Suggested reference:
  Zagoskin, Sections 4.1.1., 4.1.2 and 4.1.3

- **Student Seminar 7: Coupling qubits to resonators**

  Suggested reference:
  Zagoskin, Sections 4.2.2., 4.2.3 and 4.2.4, 4.3.1 and 4.3.2

- Please choose your topic by Friday, May 8, 2020 and send me an email with your chosen topic (first come, first served.)
- Grading is based on your given seminar as well as your written report.
- Seminars should take ~ 45 to maximum 60 minutes
- The report must be handed in ***no later than 3 weeks*** after the seminar is given.
- Should you have questions about the topics you picked, you can discuss them with us. Just send an email and make an appointment.
- Any question?