

# Programmieren mit Qiskit

PC-Treff-BB VHS Aidlingen

Ingolf Wittmann

# Agenda

- Qubit Physik
- Quantum Gate Operatoren
- Guided Workshop

# Bits versus Qubits

**Bit** 2 Zustände 0 oder 1  
 Multi-bit Effekte: keine



Silicon  
 Struktur  
 < 20 nm



$\infty$

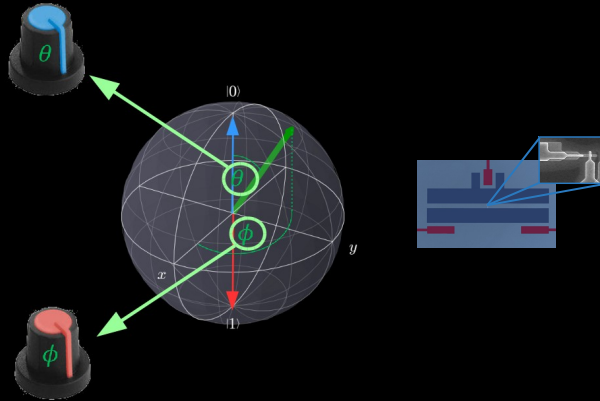


0 - 50° C

**Klassisch**

**Qubit** beliebige Zustände zwischen 0 und 1, zur selben Zeit  
 (= Superposition) repräsentiert als Punkt auf der Bloch-Kugel

Multi-qubit Effekte: Entanglement



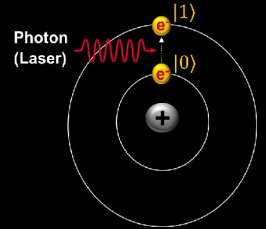
70 - 100  $\mu$ s



15 mK

**Quantum**

Atome  
 Elektronen  
 Photone



N bit input 100110...

Quantum  
 Computer  
 N qubits  
 $2^N$  paths  
 $|100000 \dots\rangle + |010010 \dots\rangle +$   
 $|101000 \dots\rangle + \dots$

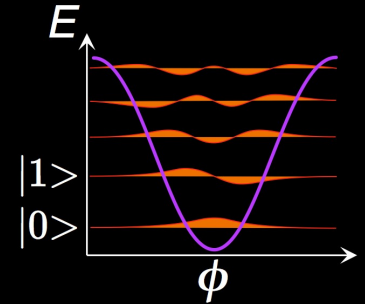
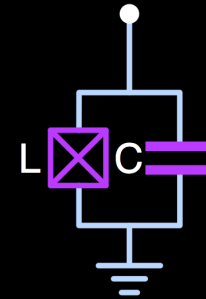
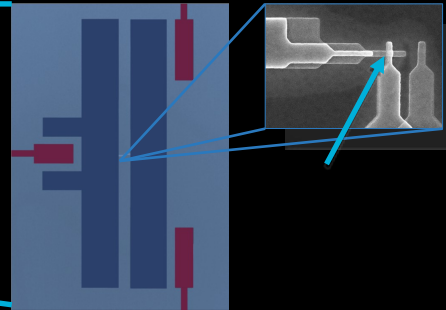
N bit output 010101...

# Anatomie eines supraleitenden Quantumprozessors



## Supraleitendes Qubit:

- Josephson Junction als eine nicht lineare Spule



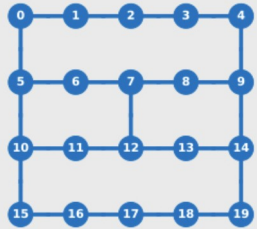
$$E_{01} \approx 5 \text{ GHz} \approx 240 \text{ mK}$$

## Supraleitender Mikrowellenschwingkreis:

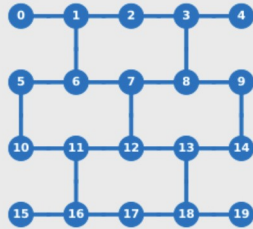
- Auslesen der Qubits
- Verbindung von Qubits
- Rauschfilter

# Topologie von IBM Quantumprozessoren

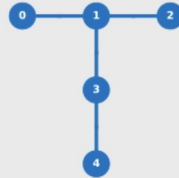
## IBM Quantum Prozessoren



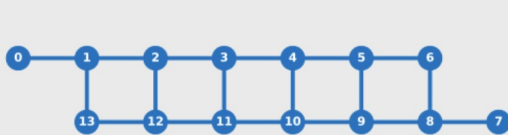
Johannesburg  
Poughkeepsie



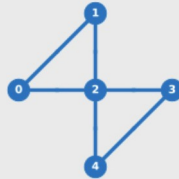
Almaden  
Boeblingen  
Singapore



Ourense  
Valencia  
Vigo

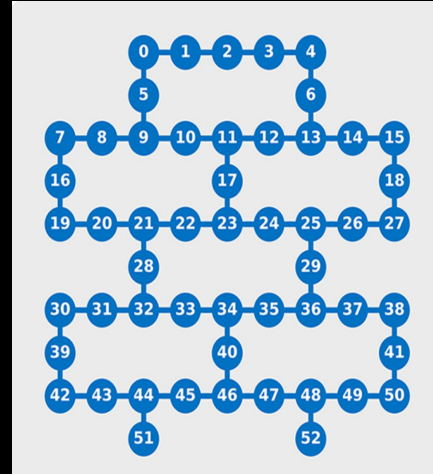


Melbourne

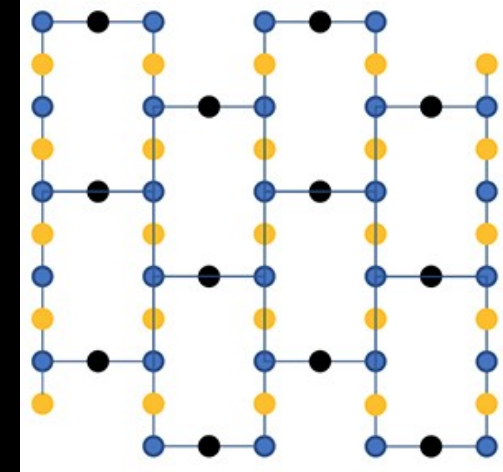


Yorktown

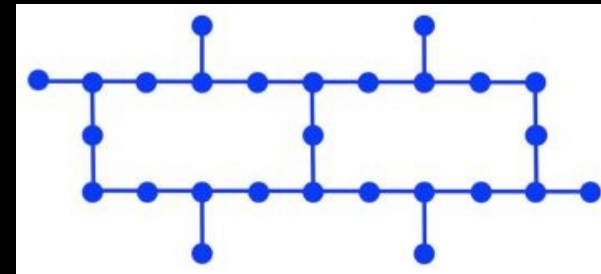
53 Qubit Prozessor  
[Rochester]



65 Qubit Prozessor  
[Hummingbird]

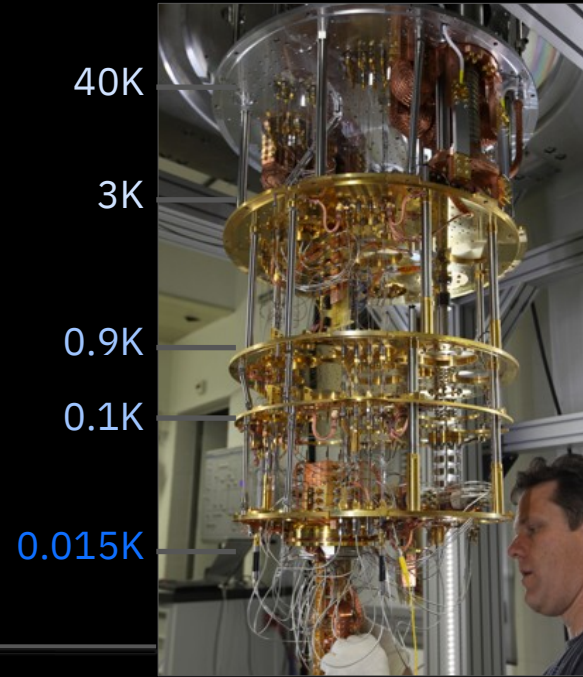
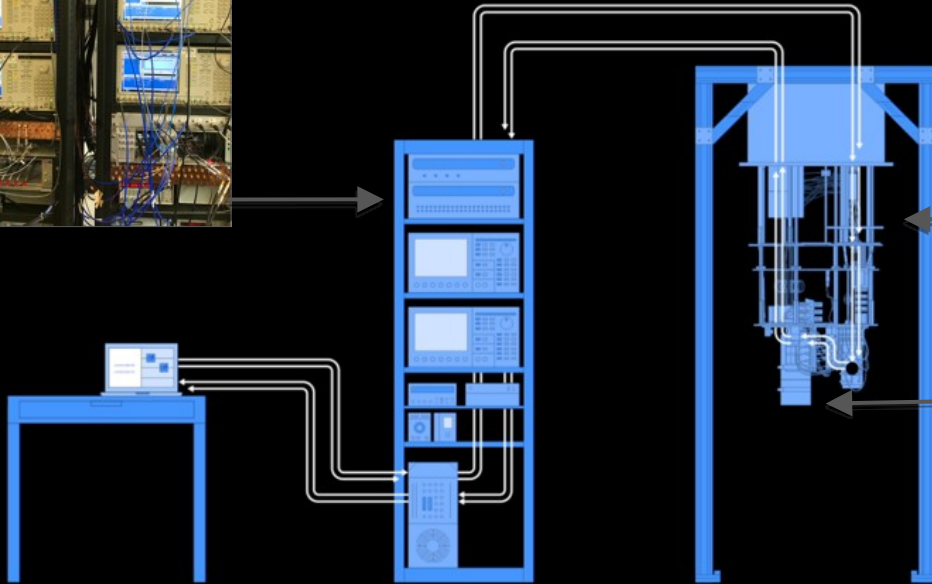
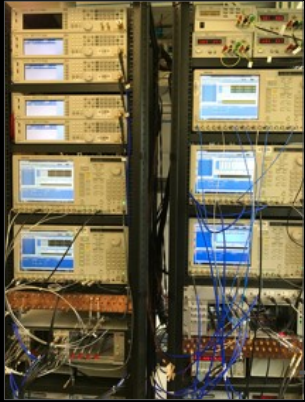


27 Qubit Prozessor  
[Falcon]

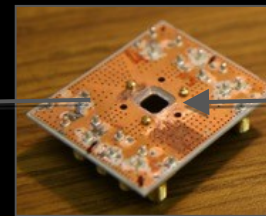


# Aufbau eines IBM Quantum Computing Systems

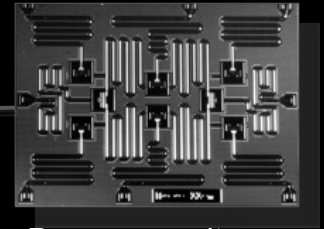
Mikrowellenelektronik



Kryograph um die Qubits auf 10 - 15 mK mit den Isotopen von  $^3\text{He}$  und  $^4\text{He}$



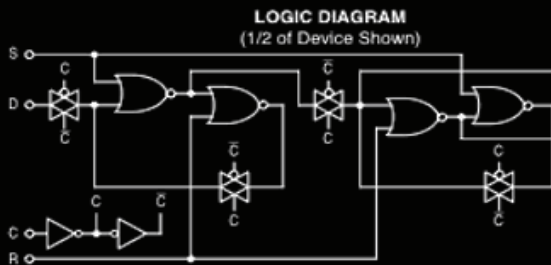
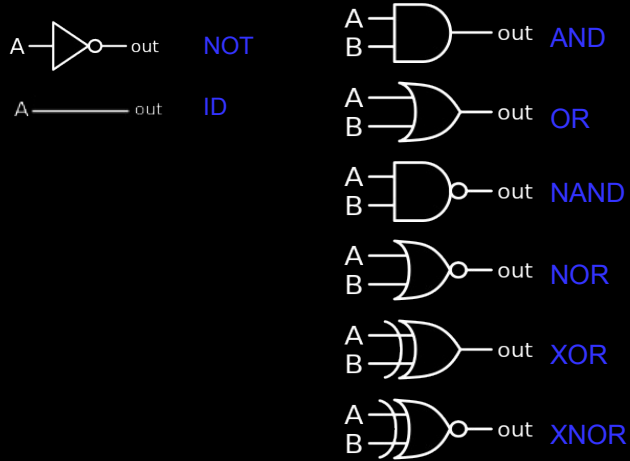
Leiterplatte mit dem Qubitprozessor bei 15 mK geschützt von der Außenwelt mit mehreren Abschirmungen



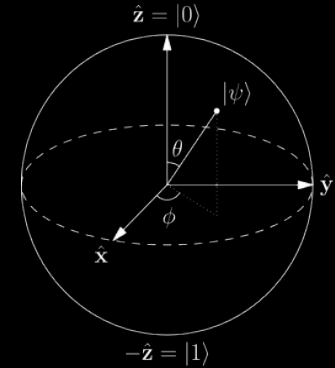
Prozessor mit Superconducting Qubits und Resonators

# Quantum Logik ... wie man Quantencomputer programmiert

## Bit

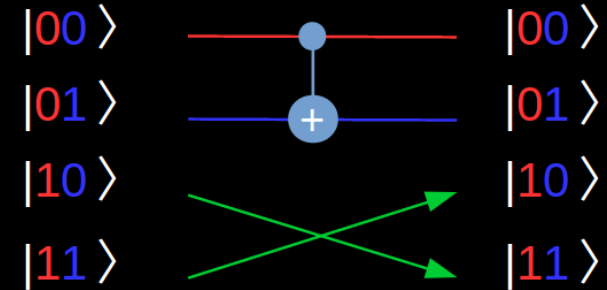


## Qubit



**1-qubit Gate**  
 → Rotation of Bloch-Sphere  
 → Adding to length and latitudee

**2-qubit Gate: CNOT**  
 → Controlled NOT  
 → Exchange of  $|10\rangle$  and  $|11\rangle$



# Hamiltonoperator

$$H_{eff} = \sum_i (\omega_i b_i^\dagger b_i + \frac{\delta_i}{2} b_i^\dagger b_i b_i^\dagger b_i) + \sum_{i,j} J_{ij} (b_i^\dagger b_j + b_i b_j^\dagger)$$

»[...] I think I can safely say that nobody understands quantum mechanics.«

*Richard P. Feynman*  
The Character of Physical Law (1964)



# Lineare Superposition für ein Qubit

## Bloch Kugeldarstellung

ein klassisches Bit

0, 1

ein Qubit

$|0\rangle, |1\rangle$

ein Qubit: in Superposition

$$|\psi\rangle = \alpha_0|0\rangle + \alpha_1|1\rangle = \cos\left(\frac{\theta}{2}\right)|0\rangle + e^{i\phi}\sin\left(\frac{\theta}{2}\right)|1\rangle$$

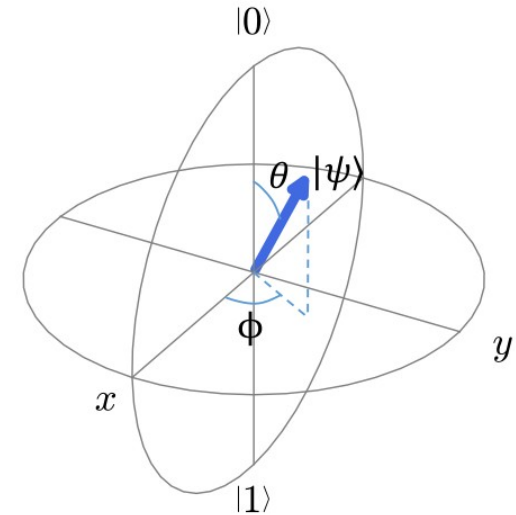
mit

$$|\alpha_0|^2 + |\alpha_1|^2 = 1$$

entsprechend hier angezeigt

$$|\psi\rangle = 0.95|0\rangle + (0.18 + 0.25i)|1\rangle$$

90.25 % der Messungen ergeben  $|0\rangle$  und 9.75 % sind  $|1\rangle$



# Unitäre Quantengatter

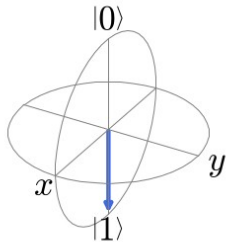
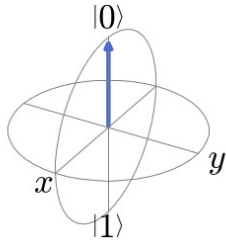


X gate ( $\sigma_x$  matrix)

bit-flip:

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad \begin{array}{l} |0\rangle \rightarrow |1\rangle \\ |1\rangle \rightarrow |0\rangle \end{array}$$

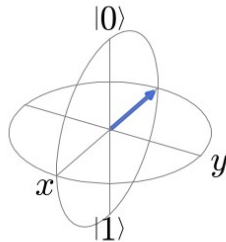
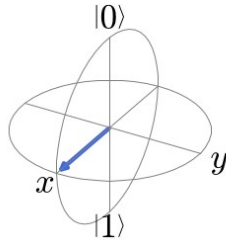
$$|0\rangle \equiv \begin{pmatrix} 1 \\ 0 \end{pmatrix}; |1\rangle \equiv \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$



Z gate ( $\sigma_z$  matrix)

phase-flip:

$$Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \quad \begin{array}{l} |0\rangle \rightarrow |0\rangle \\ |1\rangle \rightarrow -|1\rangle \end{array}$$

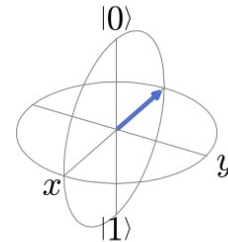
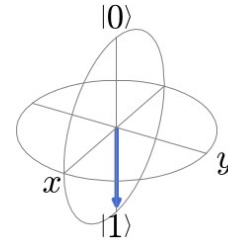


Hadamard gate

(superposition):

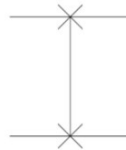
$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$\begin{array}{l} |0\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \\ |1\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle) \end{array}$$



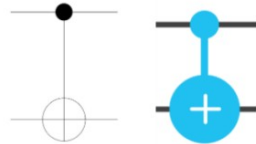
# Binäre Quantengatter

## SWAP gate

$$\text{SWAP} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$


$$\begin{aligned} |00\rangle &\rightarrow |00\rangle \\ |01\rangle &\rightarrow |10\rangle \\ |10\rangle &\rightarrow |01\rangle \\ |11\rangle &\rightarrow |11\rangle \end{aligned}$$

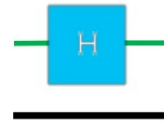
## controlled NOT gate (CNOT)

$$\text{CNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$


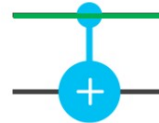
$$\begin{aligned} |00\rangle &\rightarrow |00\rangle \\ |01\rangle &\rightarrow |01\rangle \\ |10\rangle &\rightarrow |11\rangle \\ |11\rangle &\rightarrow |10\rangle \end{aligned}$$

## Vorbereiten des Bell States

$$|00\rangle \rightarrow \frac{1}{\sqrt{2}} (|00\rangle + |10\rangle) \rightarrow \frac{1}{\sqrt{2}} (|00\rangle + |11\rangle) = |\psi_{\text{Bell}}\rangle$$



Hadamard  
auf dem ersten qubit

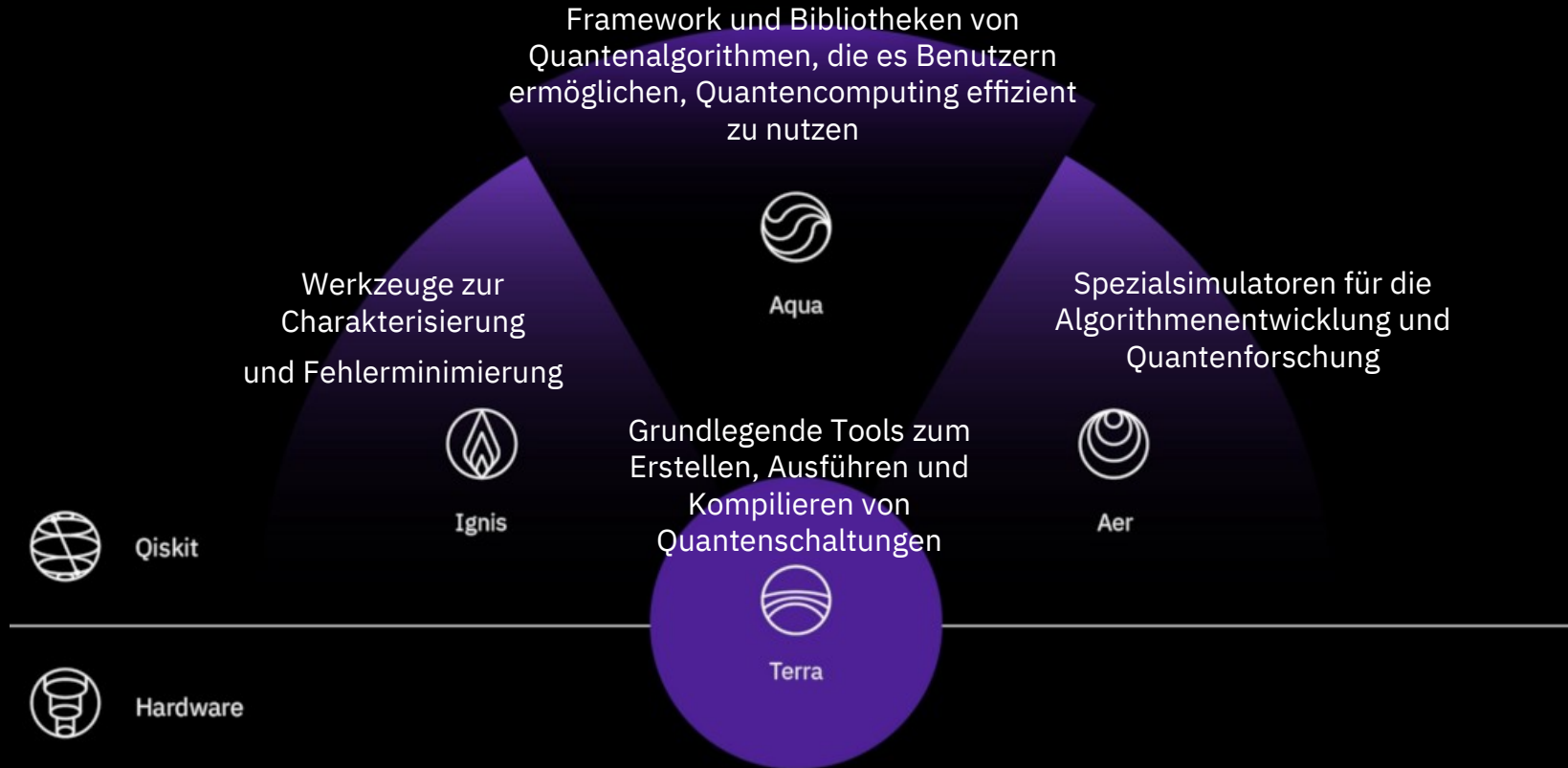


CNOT  
1 auf 2

Gegeben zwei qubits  $|\psi_1\rangle = \alpha_0|0\rangle + \alpha_1|1\rangle$  und  $|\psi_2\rangle = \beta_0|0\rangle + \beta_1|1\rangle$  ein Bell Status kann nicht als **Produkt** dargestellt werden

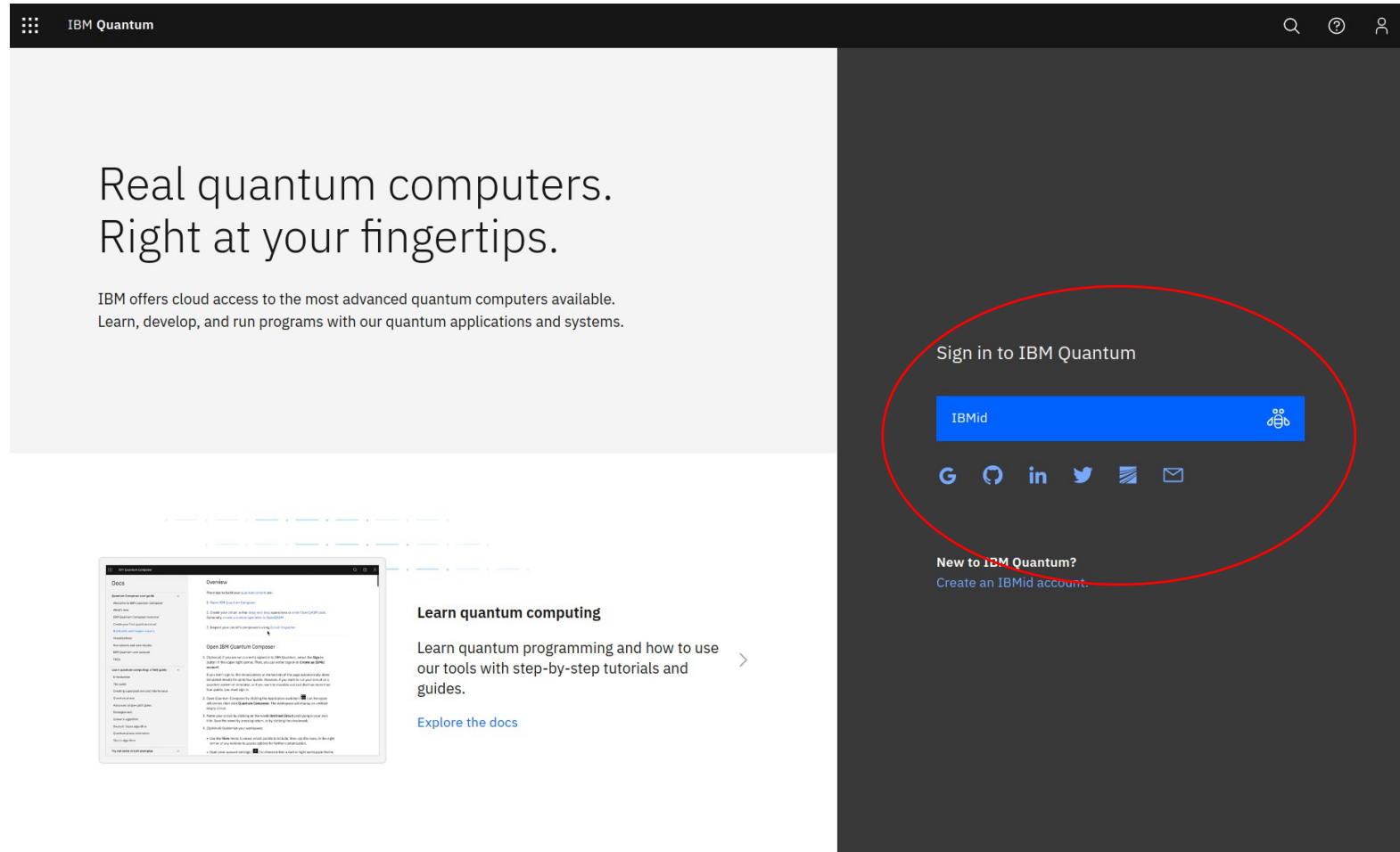
$$|\psi_1\rangle \cdot |\psi_2\rangle = \alpha_0\beta_0|00\rangle + \alpha_0\beta_1|01\rangle + \alpha_1\beta_0|10\rangle + \alpha_1\beta_1|11\rangle \neq |\psi_{\text{Bell}}\rangle$$

# Qiskit Softwarestack



# Hands On

<https://quantum-computing.ibm.com/>



The screenshot shows the IBM Quantum website interface. At the top, the navigation bar includes the IBM Quantum logo, a search icon, a help icon, and a user profile icon. The main content area features the headline "Real quantum computers. Right at your fingertips." followed by the text "IBM offers cloud access to the most advanced quantum computers available. Learn, develop, and run programs with our quantum applications and systems."

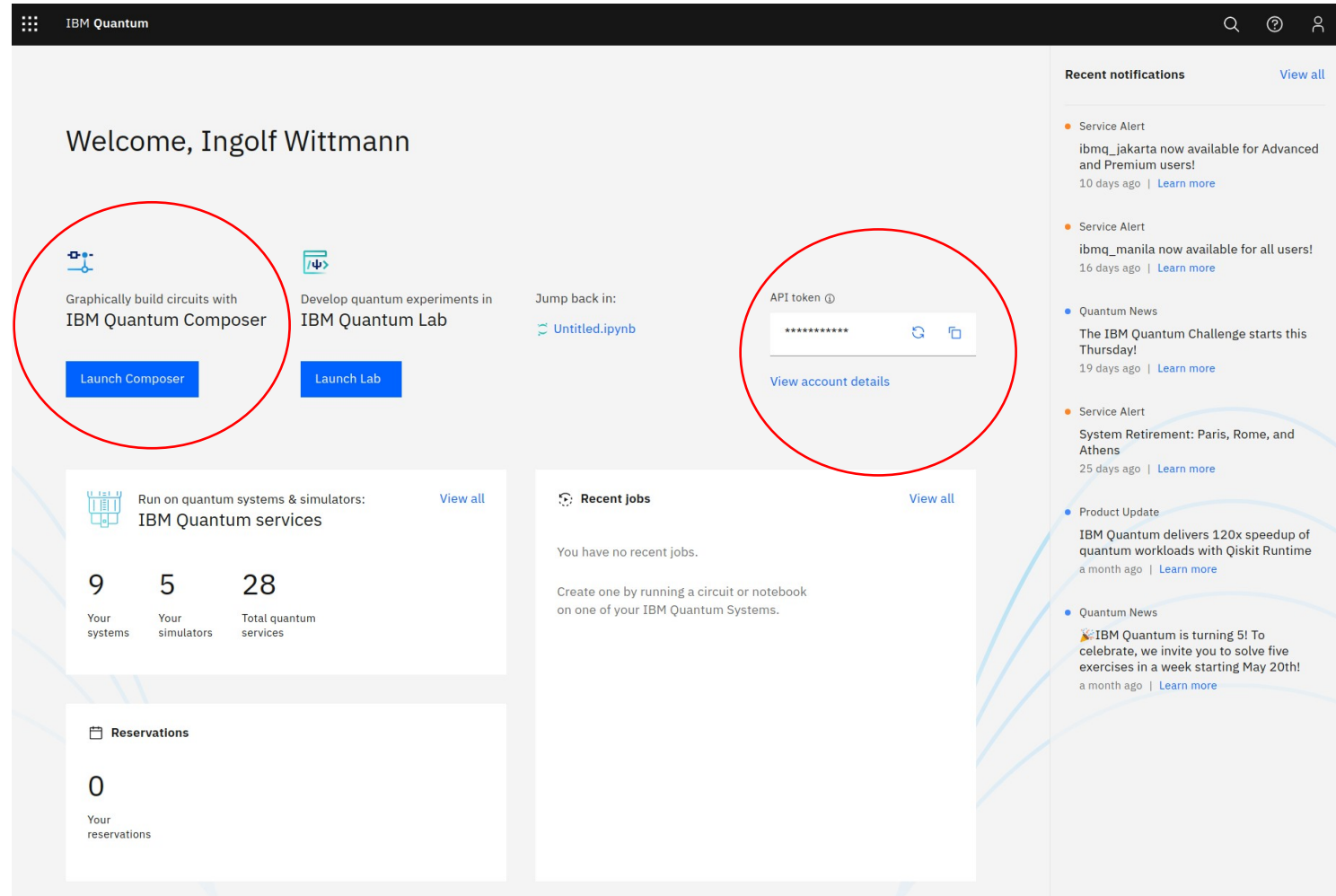
Below the main text, there are three primary navigation options:

- Learn quantum computing**: A link to "Learn quantum programming and how to use our tools with step-by-step tutorials and guides." with a right-pointing arrow.
- Explore the docs**: A link to "Explore the docs".
- Sign in to IBM Quantum**: A prominent blue button for signing in, which is circled in red. Below it are social media icons for Google+, GitHub, LinkedIn, Twitter, YouTube, and Email.

At the bottom right, there is a section for "New to IBM Quantum?" with a link to "Create an IBMid account."

In the bottom left corner, there is a small inset image of a document titled "Docs" with a table of contents. The table of contents lists sections such as "Overview", "Open IBM Quantum Composer", and "Get started with Qiskit".

# IBM Quantum Experience





IBM Quantum

Welcome, Ingolf Wittmann

Graphically build circuits with IBM Quantum Composer

Develop quantum experiments in IBM Quantum Lab

Jump back in: Untitled.ipynb

API token  

View account details

Run on quantum systems & simulators: IBM Quantum services [View all](#)

9	5	28
Your systems	Your simulators	Total quantum services

Recent jobs [View all](#)

You have no recent jobs.

Create one by running a circuit or notebook on one of your IBM Quantum Systems.

Reservations

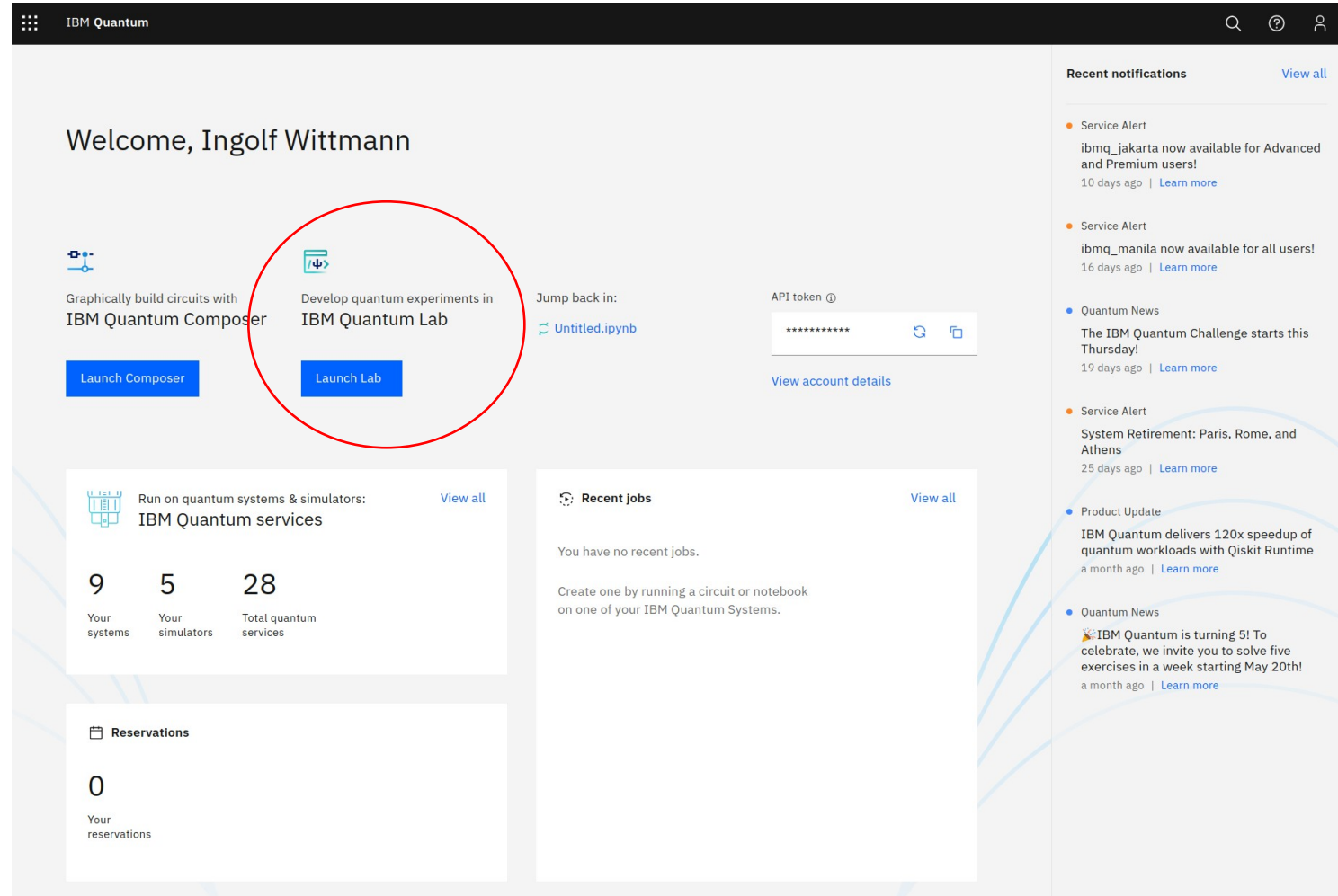
0

Your reservations

Recent notifications [View all](#)

- Service Alert  
ibmq\_jakarta now available for Advanced and Premium users!  
10 days ago | [Learn more](#)
- Service Alert  
ibmq\_manila now available for all users!  
16 days ago | [Learn more](#)
- Quantum News  
The IBM Quantum Challenge starts this Thursday!  
19 days ago | [Learn more](#)
- Service Alert  
System Retirement: Paris, Rome, and Athens  
25 days ago | [Learn more](#)
- Product Update  
IBM Quantum delivers 120x speedup of quantum workloads with Qiskit Runtime  
a month ago | [Learn more](#)
- Quantum News  
IBM Quantum is turning 5! To celebrate, we invite you to solve five exercises in a week starting May 20th!  
a month ago | [Learn more](#)

# IBM Quantum Experience & Jupyter Notebook



IBM Quantum

Welcome, Ingolf Wittmann

Graphically build circuits with IBM Quantum Composer [Launch Composer](#)

Develop quantum experiments in IBM Quantum Lab [Launch Lab](#)

Jump back in: [Untitled.ipynb](#)

API token [View account details](#)

Run on quantum systems & simulators: IBM Quantum services [View all](#)

9	5	28
Your systems	Your simulators	Total quantum services

**Reservations**

0  
Your reservations

**Recent notifications** [View all](#)

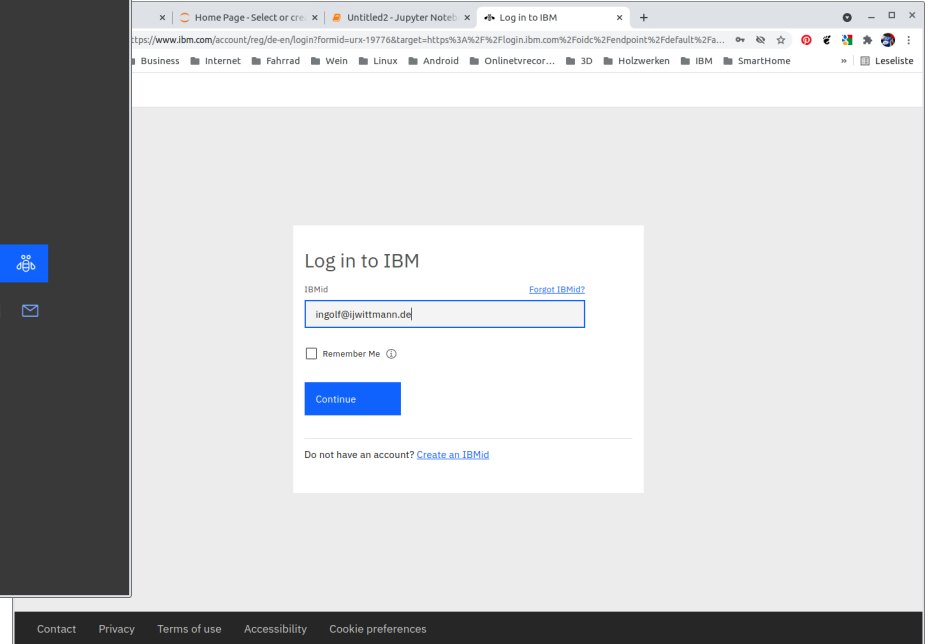
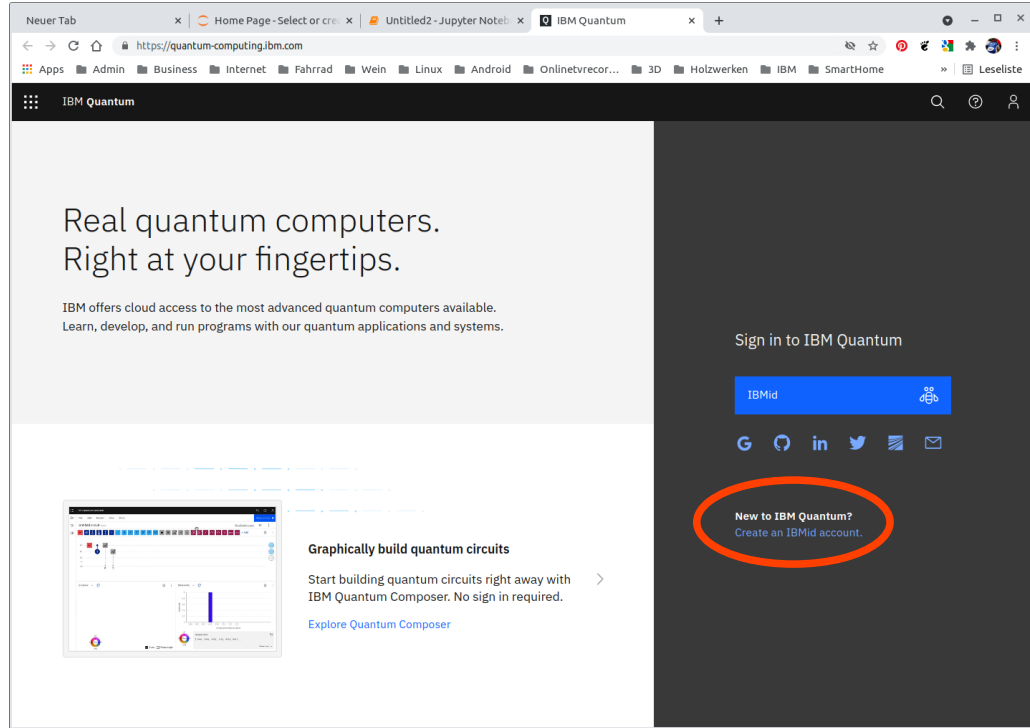
- Service Alert  
ibmq\_jakarta now available for Advanced and Premium users!  
10 days ago | [Learn more](#)
- Service Alert  
ibmq\_manila now available for all users!  
16 days ago | [Learn more](#)
- Quantum News  
The IBM Quantum Challenge starts this Thursday!  
19 days ago | [Learn more](#)
- Service Alert  
System Retirement: Paris, Rome, and Athens  
25 days ago | [Learn more](#)
- Product Update  
IBM Quantum delivers 120x speedup of quantum workloads with Qiskit Runtime  
a month ago | [Learn more](#)
- Quantum News  
IBM Quantum is turning 5! To celebrate, we invite you to solve five exercises in a week starting May 20th!  
a month ago | [Learn more](#)

**Recent jobs** [View all](#)

You have no recent jobs.

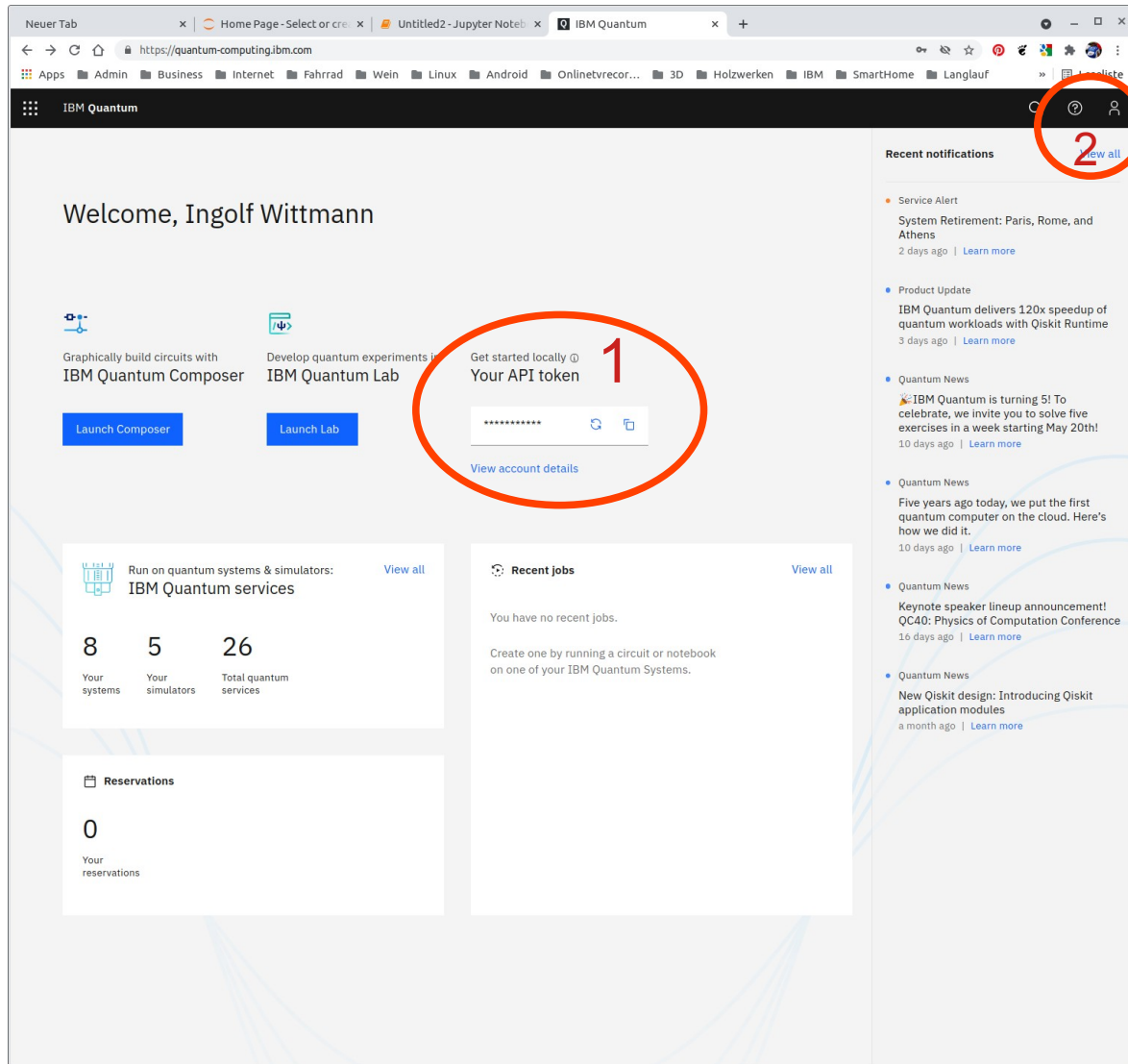
Create one by running a circuit or notebook on one of your IBM Quantum Systems.

# IBM Q Account und API Token erstellen





# Qiskit API Token



The screenshot shows the IBM Quantum user interface. The browser address bar displays `https://quantum-computing.ibm.com`. The page header includes navigation links for Apps, Admin, Business, Internet, Fahrrad, Wein, Linux, Android, Onlinetrecor..., 3D, Holzwerken, IBM, SmartHome, Langlauf, and a user profile icon. The main content area is titled "Welcome, Ingolf Wittmann" and features two primary actions: "Launch Composer" (for graphically building circuits) and "Launch Lab" (for developing quantum experiments). A red circle highlights the "Get started locally @ Your API token" section, which includes a text input field containing a masked token (represented by asterisks) and a "View account details" link. A red circle with the number "1" is placed next to the "Your API token" text. Another red circle with the number "2" is placed over the user profile icon in the top right corner. Below the main content, there are three summary cards: "Run on quantum systems & simulators: IBM Quantum services" (with 8 systems, 5 simulators, and 26 total services), "Reservations" (with 0 reservations), and "Recent jobs" (with no recent jobs). A "Recent notifications" sidebar on the right lists several updates, including a service alert, a product update about a 120x speedup, and various quantum news items.