McKinsey & Company

McKinsey Quantum Computing Monitor

FACTS & FIGURES

DECEMBER 2020

What is the Quantum Computing Monitor?

- Dynamic overview of industries‘ **maturity toward quantum computing,** based on the current application of the technology
- Continuously evolving overview of the **global quantum computing player & investment space,** updated 6-monthly

… and what it is not:

- **Definitive & exhaustive list** of the start-up and funding activities in the quantum computing realm as it evolves too rapidly

Key Facts

60% of start-ups and incumbent companies in the G7 are located in North America

G7 members account for more than 70% of quantum computing startups worldwide[1]

Investments in the past 5 years show a compound annual growth rate of 80% with 0.5 billion USD in 2020 alone representing about one third of all investments so far

About 90% of investment is focused on hardware manufacturers

~60% of quantum computing players are active in the systems and algorithm layers

Quantum computing hardware manufacturers are 35-40 globally

1. Excluding China, due to a lack of data

NOT EXHAUSTIVE

Quantum technologies are accelerating

Not Exhaustive

Quantum computing | Quantum communications | Quantum sensing | Quantum overall

2000

1999

EU invests €50-75 million in quantum technologies via Future and Emerging Technologies (FET) program over next 7 years (EU Flagship program)

1999

D-wave is founded

2001

SK Telecom starts R&D on quantum communication

2003

DARPA launches the first quantum network; it becomes fully operational in October 2003

2007

ID Quantique starts commercially offering quantum key distributions services

2007

The local government of Geneva protects voting systems with quantum key distribution for a federal election

2011

Lockheed Martin enters a contract with D-Wave, including the sale of a D-Wave One for $10M

2012

1Qubit is founded

July 2014

IBM invests $3 B in research initiative that includes quantum computing

2015

2015

Intel invests $50 M in QuTech Delft to develop a quantum computer

2016

IBM starts making their quantum computers available to the public for the first time with the IBM Q program

2016

KPN starts testing quantum key distribution on commercial fiber lines

2016

Canadian government commits $ 76 millions to the University of Waterloo for quantum hardware and software

2017

Volkswagen announcing co-development with Google

Several dozens of startup are founded

2018

MuQuans develops first commercial Quantum 2.0 sensor, a gravity sensor

2018

DowDuPont announce co-development with 1QBit to develop quantum tools in the areas of chemicals and material science

IBM and Google start to incubate and consolidate the start-up ecosystems

2018

EU commission announces a €1 billion project for support of quantum researchers over the next ten years (EU Flagship program)

Today

2019

IBM launches online platform IBM Q Experience via the cloud

2019

Google claims the achievement of 'quantum supremacy'

2019

Microsoft announces Quantum cloud service "Azure Quantum" in cooperation with Honeywell, IonQ and QCI

2019

Amazon announces Quantum cloud service "Amazon Braket" in based on HW from D-Wave, IonQ and Rigetti

2020

Honeywell announces world's most powerful quantum computer (volume 128)

Source: McKinsey analysis, expert interviews, press search

Public funding for quantum computing

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2.5 bn USD p.a.

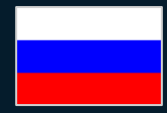
2.7 bn USD

2.2 bn USD

1.2 bn USD

1.2 bn USD

0.9 bn USD



0.8 bn USD

0.8 bn USD

0.5 bn USD

0.1 bn USD

Less than **0.1** bn USD

Source: CSIRO, McKinsey analysis

Several industries are already working in “stealth mode” on competitive applications of quantum computing

Adoption of quantum computing technology, by industry vertical

Bystanders

- No explorative activities in the realm of quantum computing have publicly been announced by the industry’s players so far

Beginners

- Industry players formed first partnerships and/or consortia to explore first quantum computing use cases (pre-competitive)

Amateurs

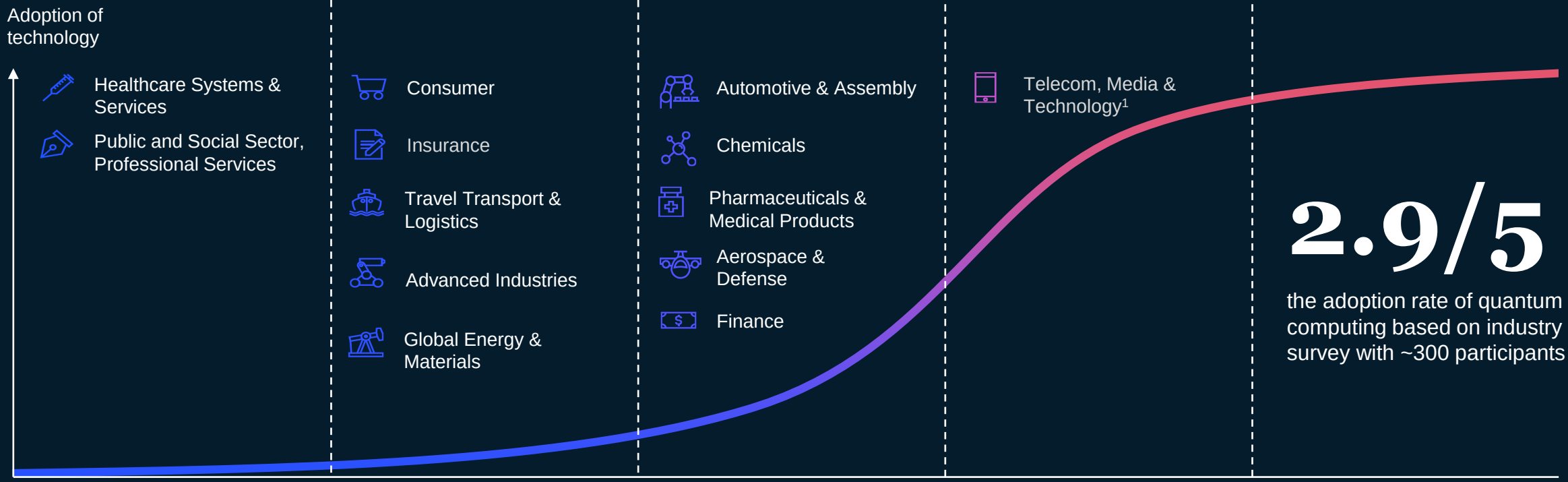
- Several pre-competitive activities have moved to a competitive stage and industry players start to hire quantum scientists

Professionals

- Industry players start to realize business impact via proprietary quantum computing applications and adhere to a strategy

Legends

- Innovation related to the applications of quantum computing in an industry plateaued but use cases continue to create value



2.9/5

the adoption rate of quantum computing based on industry survey with ~300 participants

1. Technology companies are quantum computing hardware manufacturers and software developers

Source: McKinsey analysis

Experts expect the impact of quantum computing in the mid-term to be greatest in AI, GEM, Finance and TTL

Horizons: Primary value pools (until ~2025) | Secondary value pools (beyond ~2025)

Economic value: + Low ++ Medium +++ High

Value share: Low Medium High

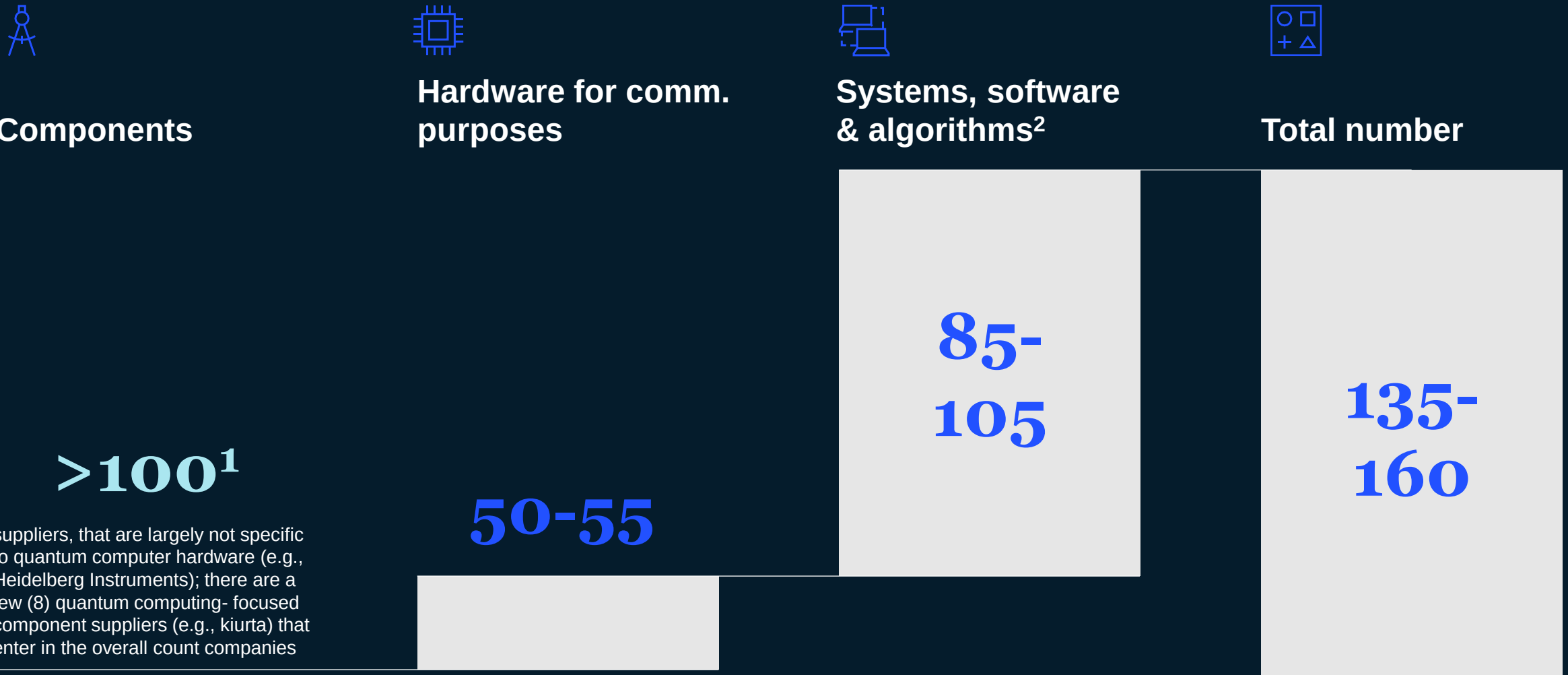
	Economic value		Economic impact share			
	~2025	~2035	Quantum simulation	Optimization	Quantum AI/ML	Prime factorization
Advanced Industries	+	++	Low	Medium	High	Low
Consumer	+	+	Low	High	High	Low
Global Energy & Materials	++	+++	High	Medium	Medium	Low
Telecom, Media & Technology	+	++	Low	Medium	High	Medium
Finance	++	++	Low	High	Medium	Medium
Insurance	+	++	Low	Medium	High	Medium
Healthcare Systems & Services	+	+	Medium	Medium	High	Low
Pharmaceuticals & Medical Products	++	+++	High	Medium	Medium	Low
Travel Transport & Logistics	+	++	Low	High	High	Low
Public and Social Sector, Professional Services	+	++	Low	High	High	Low

Source: McKinsey analysis

NOT EXHAUSTIVE

Most players are active in the systems, software & algorithms layer

Number of quantum computing players, by value chain segment



1. Only 8 of these companies counted in the overall number of quantum computing players
2. Does not include end-users with their own quantum computing teams, e.g. the Volkswagen Data:Lab or Airbus

Source: McKinsey analysis, web research

NOT EXHAUSTIVE

The US and Canada are most active around quantum computing

Number of quantum computing players (excl. China), by country and origin

Geographic details on next slide

Number of QC players, by country		Start-ups	Incumbent companies	Public- /gov.-organizations	Academic groups
Top 7		36	13	14	38
		20	0	1	9
		13	0	1	7
		7	0	2	4
		7	1	0	5
		7	1	3	1
		6	0	2	1
… and elsewhere[1]		31	3[2]	19	24
Σ		**127**	**18**	**43**	**89**

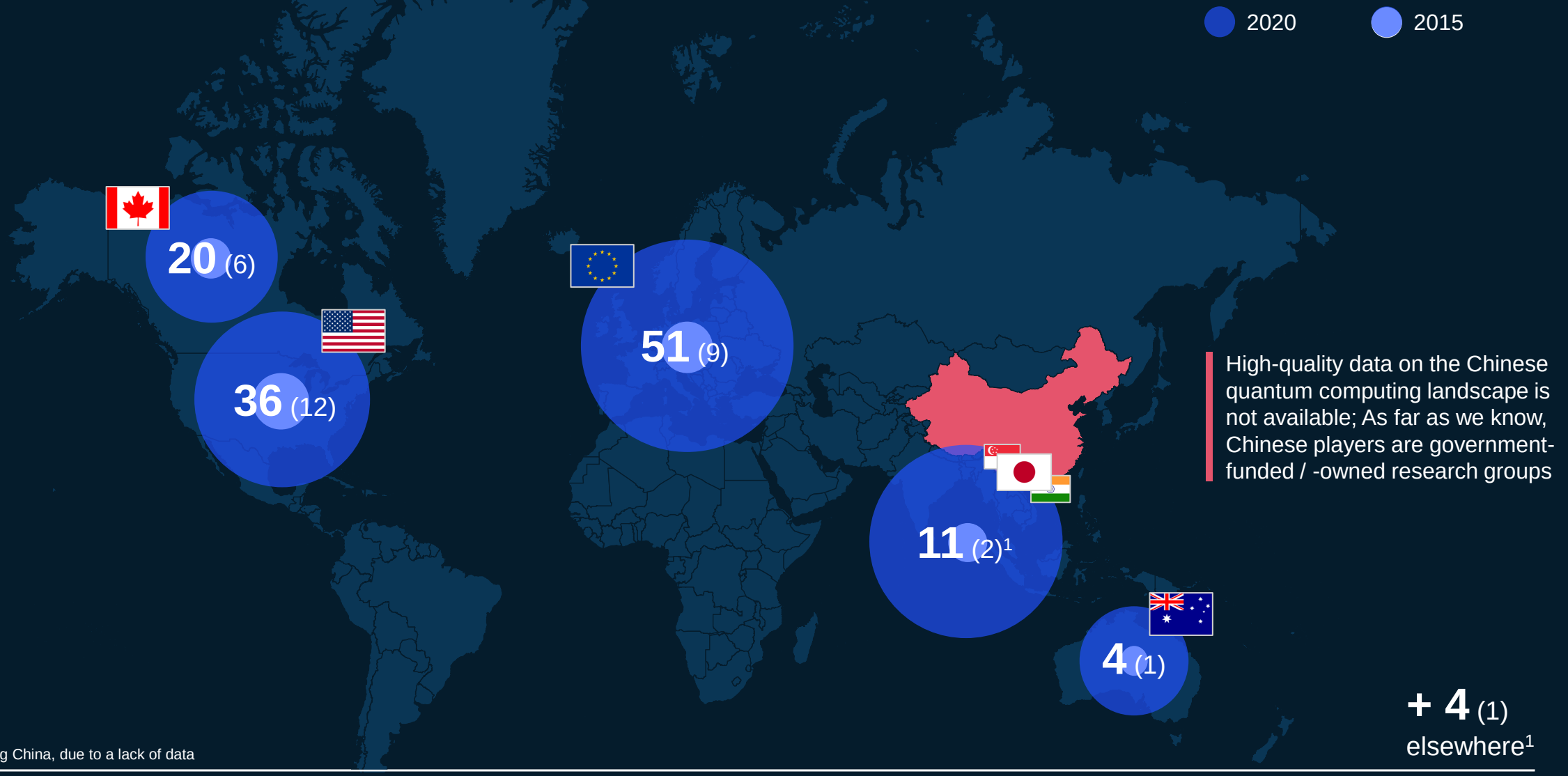
1. Excluding China, due to a lack of data
2. Includes Chninese companies Baidu and Alibaba

Source: McKinsey analysis, web research

NOT EXHAUSTIVE

We have seen a stark rise in quantum computing start-ups globally

Number of quantum computing start-ups (excl. China), by region (today, and 2015 in brackets)



1. Excluding China, due to a lack of data

Source: McKinsey analysis, Pitchbook, Crunchbase

NOT EXHAUSTIVE

The top 10 investments have been directed at hardware players

Top 10 VC/PE investments in quantum computing start-ups, ordered by deal size (descending)

	Company	Country	Value chain pos.	Deal size, Million USD	Deal year	Lead investors
1	PsiQuantum		Hardware mfg.	230	2019	Playground Global
2	PsiQuantum		Hardware mfg.	215	2020	Atomico
3	Xanadu		Hardware mfg.	100	(2021)	-
4	Rigetti		Hardware mfg.	79	2020	Bessemer Venture Partners
5	Silicon Quantum Computing		Hardware mfg.	66	2017	University of New South Wales Endowment
6	IonQ		Hardware mfg.	55	2019	Samsung Catalyst Fund
7	D-Wave		Hardware mfg.	52	2017	PSP Investments
8	D-Wave		Hardware mfg.	50	2016	-
9	Psi-Quantum		Hardware mfg.	50	2017	Playground Global
10	Rigetti		Hardware mfg.	50	2017	Alumni Ventures

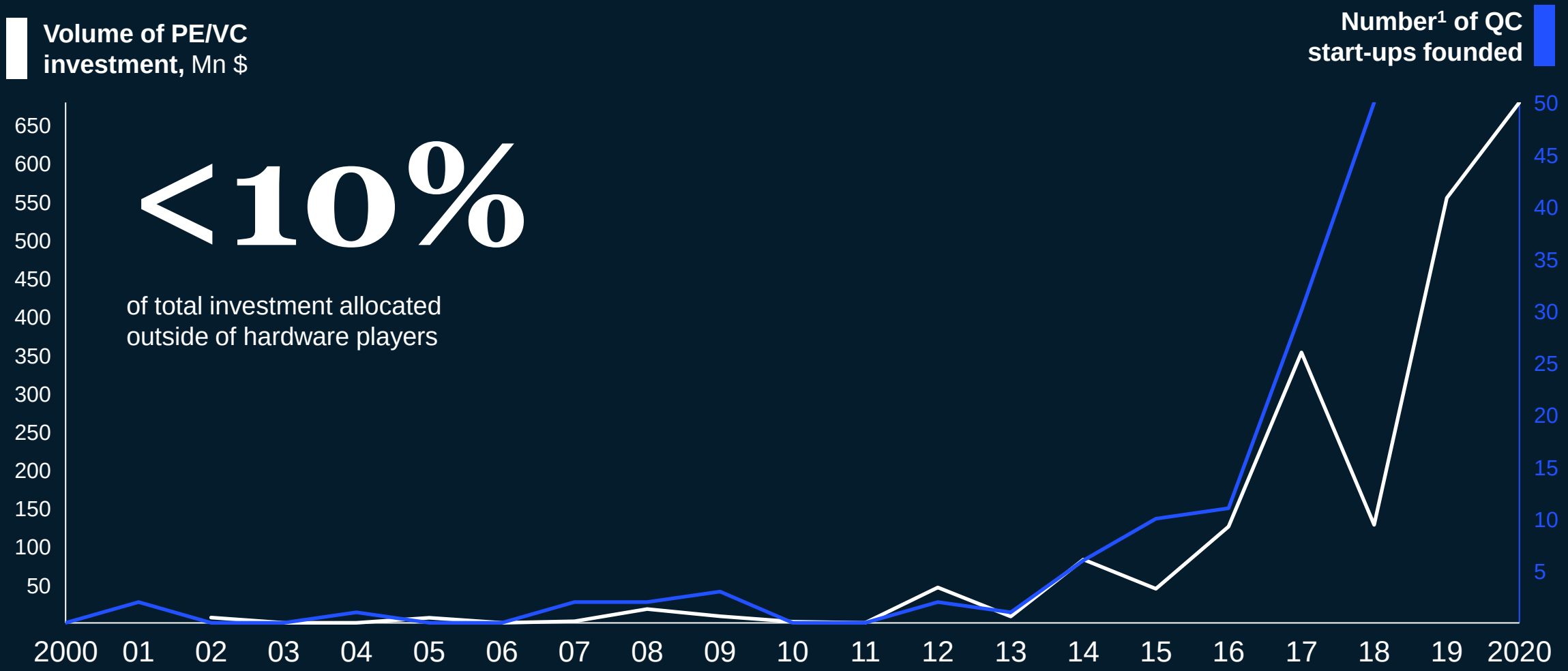
1. Number only quoted until 2018, since start-ups with a later founding date may still be in "stealth" mode, i.e. they have not disclosed their activity publicly

Source: McKinsey analysis, Pitchbook, Crunchbase

NOT EXHAUSTIVE

Founding & investment activity has grown rapidly in the last 5 years

Number new foudings / investment volume, by year



<10%

of total investment allocated outside of hardware players

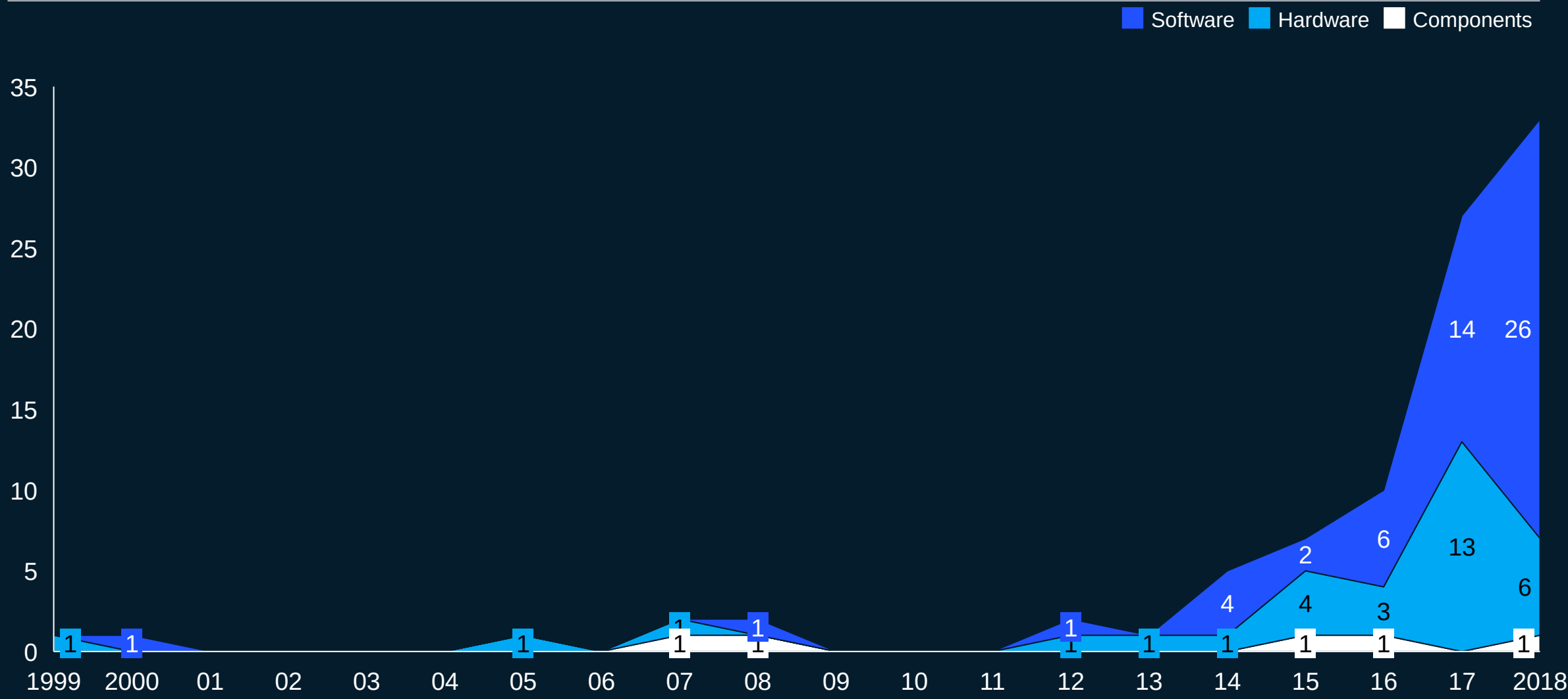
1. Number only quoted until 2018, since start-ups with a later founding date may still be in "stealth" mode, i.e. they have not disclosed their activity publicly

Source: McKinsey analysis, Pitchbook, Crunchbase

NOT EXHAUSTIVE

Most newly founded start-ups are software & algorithm developers

Founding activity[1] in quantum computing (excl. China), by new founding volume per year



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Source: McKinsey analysis, Pitchbook, Crunchbase

Development of QC in China is driven by start-ups and researchers linked to the government

~1

Billion USD Funding for a governmental laboratory

National Quantum Information Sciences Laboratory

First provincial and ministerial level key laboratory in the field of quantum information in China

Focus on theoretical and experimental research on quantum communication and quantum computing

The project is invested in total 7 billion RMB, and is completed and delivered by September 30, 2020

In December 2020, researchers from the Hefei National Laboratory claimed quantum supremacy with a photonic prototype

3

Startups are active in commercial quantum computing

Origin Quantum Computing

Founded in 2017 by a research team of the quantum information lab at the Chinese Academy of Sciences

Offers QCPU, quantum controlling hardware, quantum software, quantum cloud. In Sep 2020, Origin began to operate China's first superconducting quantum computer outside the lab

Qasky

Founded in 2016 to commercialize quantum cryptography research at the Academy of Sciences

Plan to offer products and services for integrated solutions for quantum information security systems

QuantumCTek

First Chinese provider of multi-protocol network security products and services based on quantum

517

Patents related to quantum computing filed in China in 2018 (twice as many as US)

Related activities

Large Chinese companies are interested in quantum products:

Baidu 百度

Search engine provider Baidu engages in Quantum AI and the design of computing architecture

Alibaba Group 阿里巴巴集团

The Alibaba Group hosts a quantum computing cloud qbit an 11 qubit computing device backend

Source: Press clippings, web research

Where is quantum headed?

- The race for technological leadership will continue between photonic, trapped-ion, and superconducting qubit devices
  - IBM announced a ~103 qubit superconducting chip by 2023, more than an order of magnitude larger than the current Hummingbird chip
  - Honeywell aims to gradually scale its ion trap technology and manufacture large-scale quantum computers for commercial applications by 2030
  - PsiQuantum announced that it will manufacture a commercially-viable quantum computer with ~10^6 qubits by 2025
- More players across industries will move from pre-competitive explorations of quantum computing into competitive research (partly in “stealth-mode”)
- Several large investment rounds have already been announced for 2021 (e.g. Xanadu, ~100 mn USD), suggesting that the investment activity around quantum computing will continue to rise despite the COVID-19 pandemic
- Chinese researchers have made a claim to quantum supremacy (for a boson-sampling problem) in December 2020, and local research is expected to yield more breakthrough results backed by the ~10 bn USD government fund for quantum computing

What will the Quantum Computing Monitor include next

Quantum computing talent pools

- Where is talent emerging or lacking
- What are typical talent flows from academia to industry

Quantum computing figures of merit

- What are the standards on qubit count, gate depth, or quantum volume and how do they relate with each other
- How close are today's quantum computers from demonstrating quantum advantage in solving real business problems?

…and provide further deep-dives on current content

The team behind the Monitor

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Appendix

Classical computing

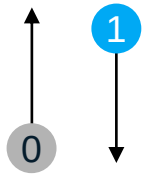
Alan Turing

"Father" of
classical computing

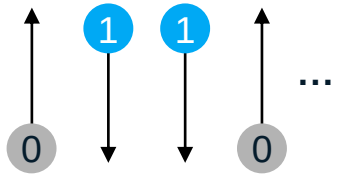
1 classical bit

Bit can store
zero or a one

2 classical bits



N classical bits



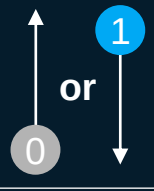
Source: McKinsey analysis, expert interviews, press search

Quantum computing

Richard Feynman

"Father" of
quantum computing

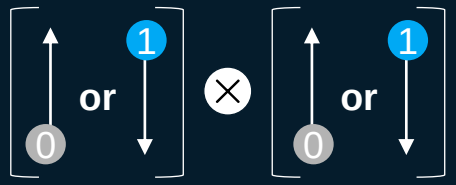
One quantum bit



Superposition state of two quantum states 0 and 1

2 (complex) coefficients are required to describe the superposition

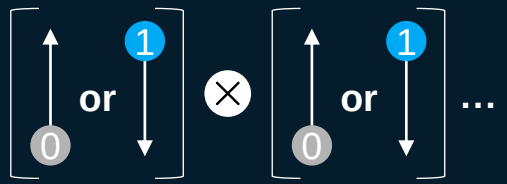
2 quantum bits



Superposition state of 4 quantum states 00, 01, 10, 11

4 (complex) coefficients are required to describe the superposition

N quantum bits



Superposition state of N quantum states 0000…, 1000…, 01000…, etc.

2N (complex) coefficients are required to describe the superposition

Exponential complexity to leverage as computational power

Simplicity of read-out

Methodology

Quantum computing temperature and industry positioning (pp 6-7)

- The quantum computing temperature (pp 6) is based on a survey across +300 industry leaders globally and their opinion on the impact of quantum computing on their respective industry
- The impact estimation and impact share across quantum capabilities (pp 7) is based on a survey across +100 McKinsey experts and industry leaders

Quantum computing player landscape and investment (pp 3, 4, 8-14)

- To obtain the Quantum Computing player landscape, we considered the following entities
  - Startups: founded in the last 25 years with estimated revenues below 200 million USD
  - Incumbent companies: companies with revenues above 200 million USD
- *Hardware manufacturers* are considered such, if they have already demonstrated the creation of a quantum computer or have announced efforts in this direction
- *Systems, software and algorithms* include all companies and startups which develop dedicated software or applications for quantum computing. Hardware manufacturers which also develop dedicated software solutions are also included in this group
- Investments in startups has been extracted from Pitchbook and Crunchbase and amended by McKinsey analyses
- We could not obtain high-quality data on the quantum computing landscape in China due to most quantum efforts being kept secret.