

## Quantum Computing

Is that the real and only technology  
we will need for the future?

prof.dr. K. Bertels  
UGhent (BE)

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## Some important questions...

- What is happening in the world?
- How important are computers?
- Who needs computers?













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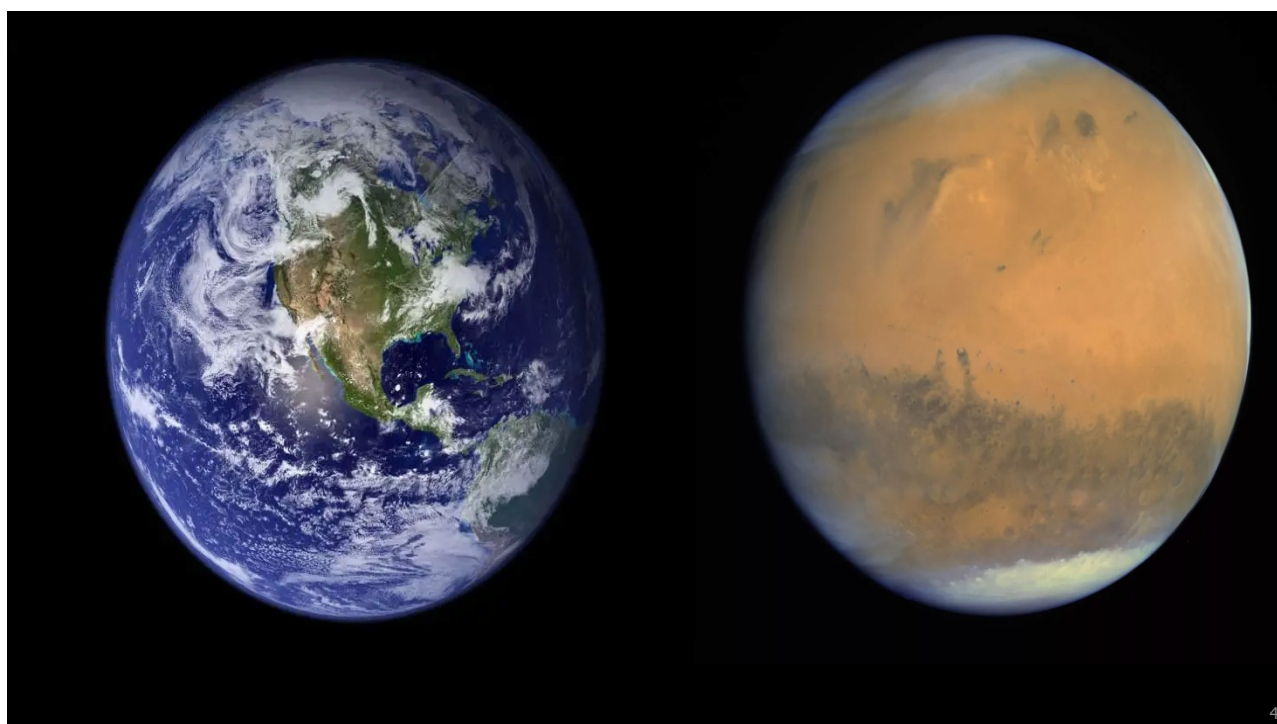
## Koen Bertels

- Built upon 10+ years of research, led by Prof. Dr. K. Bertels, on Quantum Computing and DNA data storage
- Collaboration with top universities, research centers and industrials
- QBee<sup>2</sup> is the fourth company Bertels created**
  - Nr. 3 QBee went bankrupt, January 2024
  - Nr. 2 BlueBee bought by the US-company Illumina
  - Nr. 1 Upsilon bought by its largest client in Belgium
- Member of**
  - Member of Quantum Business Network (QE)
  - Qflagship gave birth to QuIC QC architecture expert group
  - IEEE - Involved in re-structuring IEEE for QC
  - Will apply for membership to DNA-data storage Alliance

- 2012 Research program in Quantum Computer Architecture in Delft University of Technology initiated
- 2014 Quantum Computer Architecture vision defined
- 2015 Intel funds QuTech with \$50m for full-stack quantum accelerator
- 2016 Open-source QX simulator on HPC
- OpenQL quantum programming language
- 2017 cQASM/eQASM based QISA and QuMA for both super/semi-conducting QPUs demonstrated
- Neural-network based surface-code QECC decoder
- Lattice-surgery on surface codes
- Mapping and routing of quantum circuits
- 2018 Quantum accelerated genomics (sequence reconstruction) + IBM
- 2019 Quantum Accelerator Infrastructure
- 2020 Sabbatical at University of Leuven
- 2021 Creation of QBee in Leuven
- 2022/3 Part-time Full professor at UGhent
- Invited talk at ESA conference
- Creation of QBee<sup>2</sup>
- DNA data storage development
- 2024 Full Stack DNA data storage device

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## Outline

- **Why?**
- What?
- Which?
- How?
- Who?

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## Why the interest in Quantum Computing?

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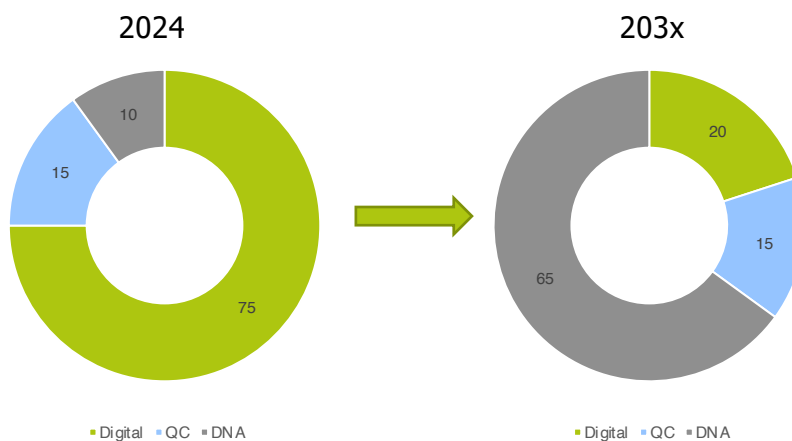
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## WHY?

- **CMOS-transistors**
  - **For computing**
    - 2nm size → classical computers will NOT get more powerful
    - Below 1nm → quantum properties
  - **Data Storage**
    - 2nm also holds here
    - **Too much digital data** to be **saved** and **processed**
- **Quantum Computing**
  - A couple alternatives exist but QC has the largest **potential** for **computing**
  - Q hardware needs **10-15+ years** to mature
  - **Analogue** and **digital** combined
- **DNA-Data Storage**
  - The only **scalable** and **robust** alternative to digital and quantum storage

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Computer Platform Evolution

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# Scientific Revolution...

Not by an individual, but by **international collaboration** with people **from industry, universities, research centres**

Different **competences** need to be combined  
A **new way of thinking and reasoning** is needed!






DIGITAL DATA    ARTIFICIAL INTELLIGENCE


QUANTUM COMPUTING

DNA DATA STORAGE

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TABOR NETWORK:  DATANAMI  ENTERPRISEAI  HPCWIRE JAPAN  QCWIRE  HPC & AI WALL STREET



Since 1987 - Covering the Fastest Computers in the World and the People Who Run Them

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## Crossing the Quantum Threshold: The Path to 10,000 Qubits

By Yuval Boger, QuEra Computing

April 15, 2024

*Editor's Note: Why do qubit count and quality matter? What's the difference between physical qubits and logical qubits? Quantum computer vendors toss these terms and numbers around as indicators of the strengths of their systems. For seasoned quantum computing watchers, the rationale behind the*

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DOI:10.1145/3571725

**What are the promising applications to realize quantum advantage?**


BY TORSTEN HOEFLER, THOMAS HÄNER, AND MATTHIAS TROYER


# Disentangling Hype from Practicality: On Realistically Achieving Quantum Advantage

COMMUNICATIONS OF THE ACM | MAY 2023 | VOL. 66 | NO. 5


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**Our analysis shows a wide range of often-cited applications is unlikely to result in a practical quantum advantage without significant algorithmic improvements.**



**Our suggestion**

Perfect (Qubit) Intermediate Scale Quantum (**PISQ**)

VS

Noisy Intermediate Scale Quantum (**NISQ**)

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# Quantum Computing

1. The Quantum Physics community drives it
  - Physicists are absolutely needed
  - But...they monopolise the budgets in Europe
2. Unsolved challenges in Q Physics
  - What **kind of qubits** can we use?
  - How **many qubits** are needed?
  - How **many quantum gates** do we need?
    - 20 (now) or 10.000?
3. QC applications –
  - What **kind of quantum gates** are needed?
  - Increase the **number of quantum gates**
  - How to make a **good logical qubit**?
    - How many qubits are needed for that?
  - How to **program qubits**?
4. Physics based metrics
  - T1 = thermal relaxation time or lifetime of the qubit
    - Go from high energy  $|0\rangle$  to low energy  $|1\rangle$
  - T2 = qubit coherence time
    - Go from  $|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$
    - To  $|-\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$

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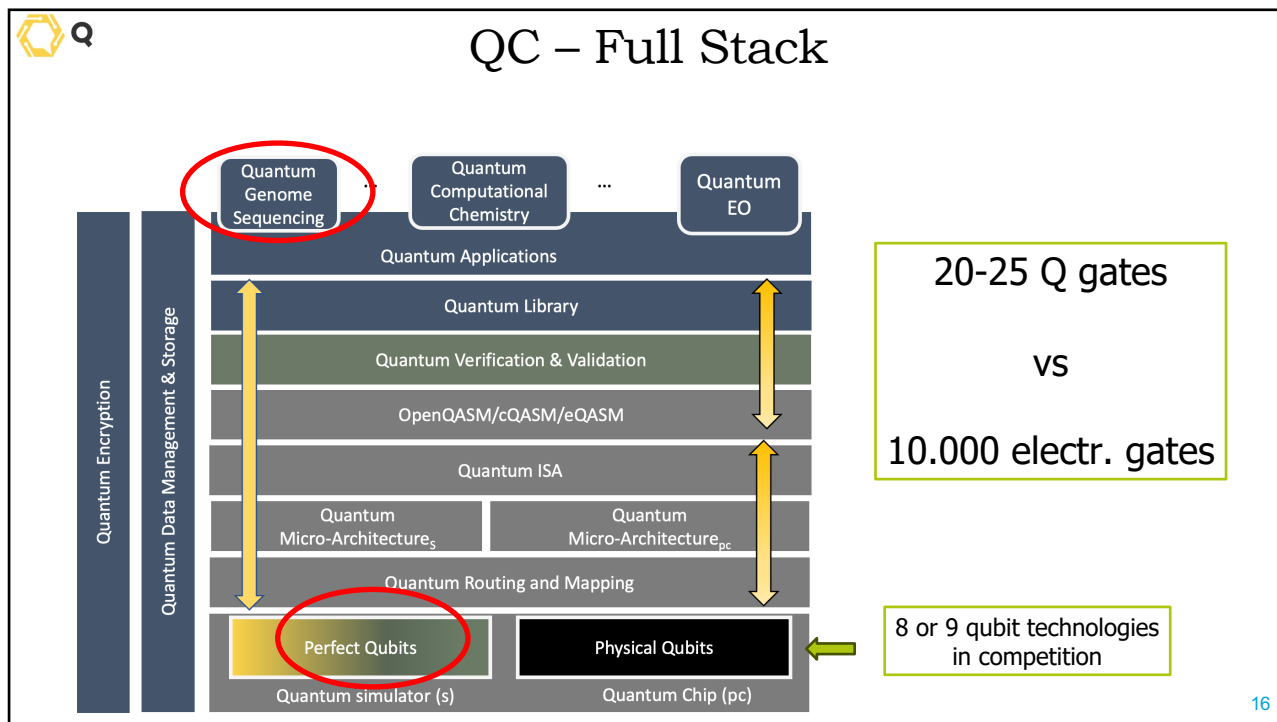
But....what about data storage?

**Data storage → Not clear!**

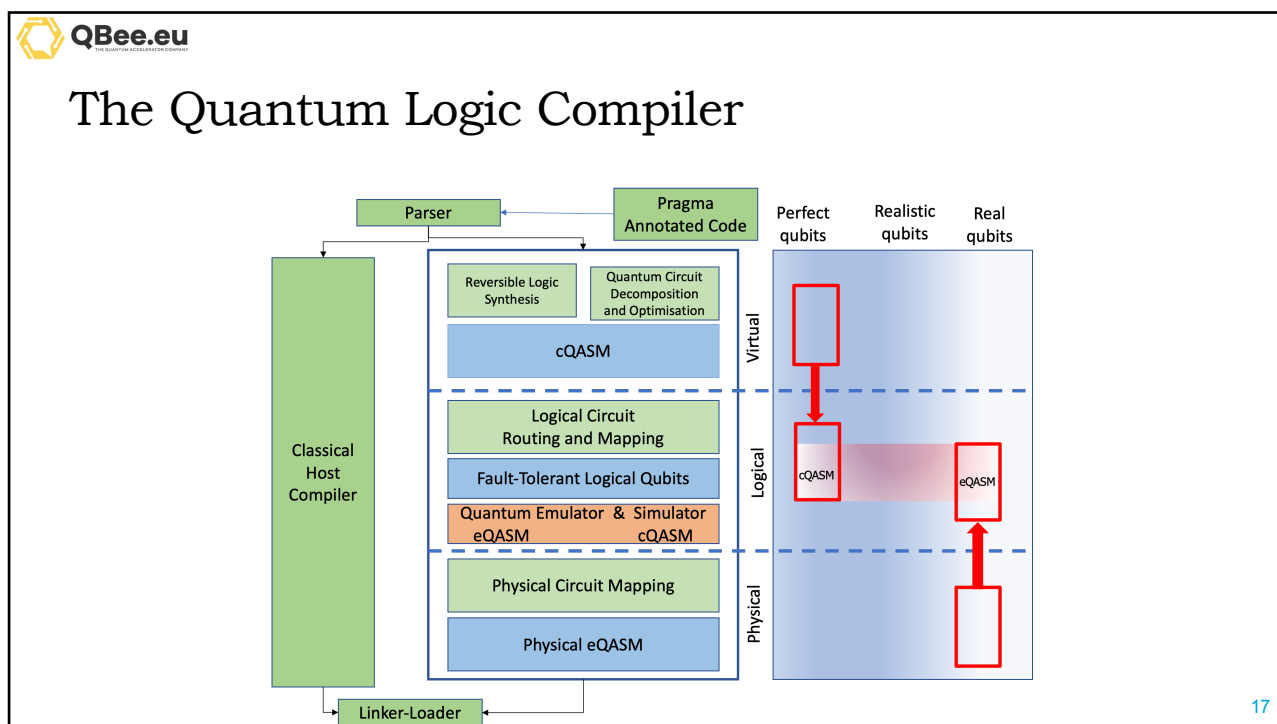
- How **many data items** represented in a QC-logic way?
- How to **store the results** in a scalable and long-term way?

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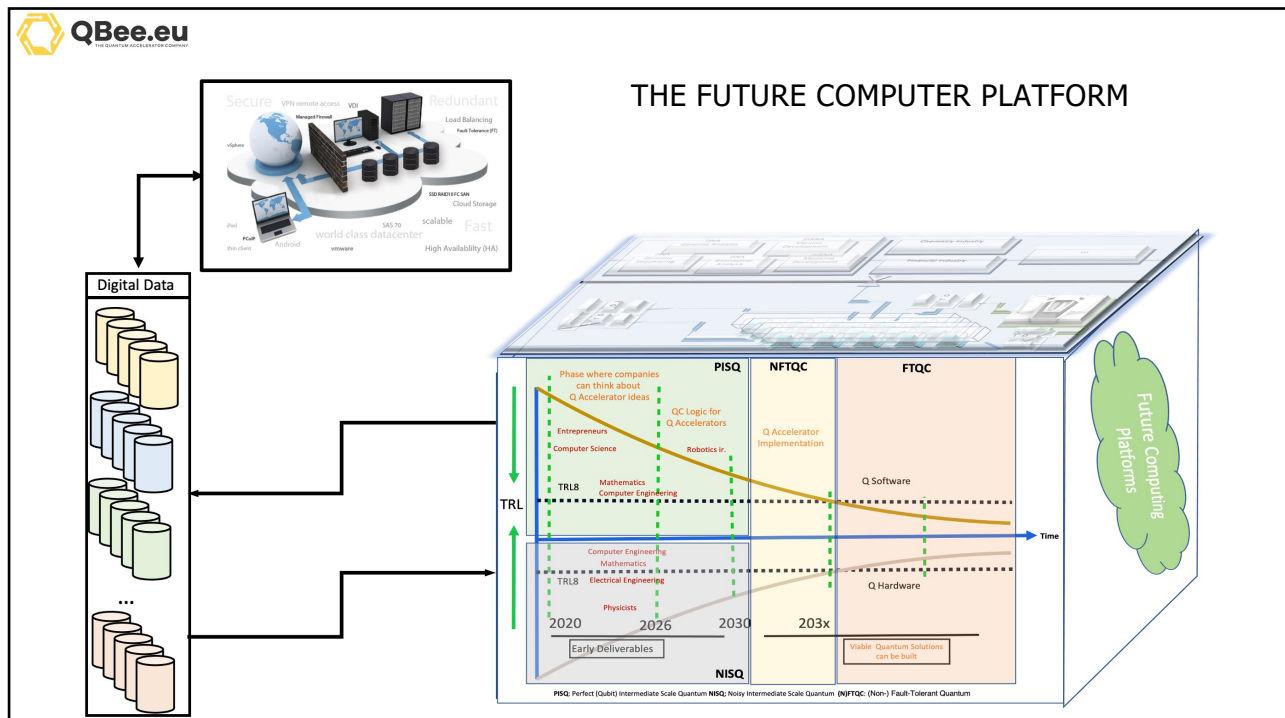


## Outline

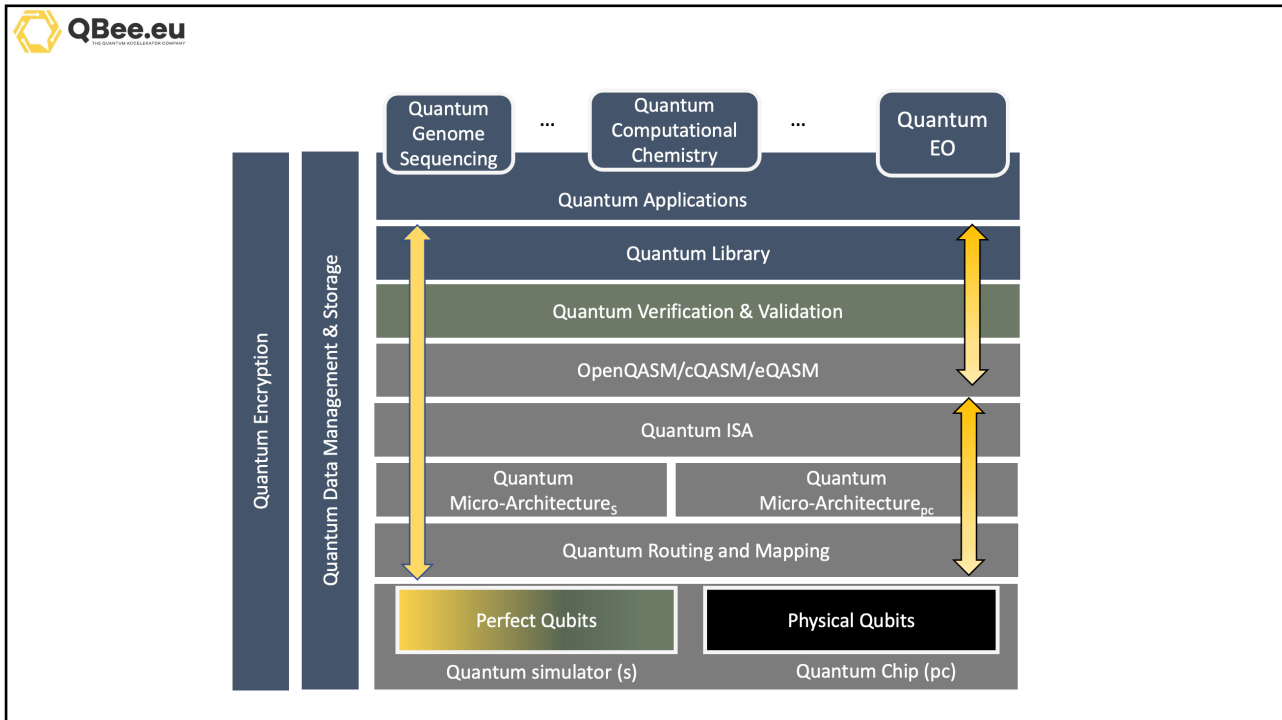
- Why?
- **What?**
- Which?
- How?
- Who?

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## WHAT? FUTURE COMPUTER & DATA STORAGE PLATFORMS

• **FOR COMPUTING**

• **FOR DATA STORAGE**

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## Data needs for our planet

By 2025...

- Per day – 250 zettabytes ( $10^{21}$ ) are generated on our planet
  - **1 gram of dried DNA= 455 exabytes of data**
    - Exabyte= $10^{18}$ , petabyte= $10^{15}$
  - 66% of this data - needs to be saved for around 20 years
  - 27% of this data – needs to be saved for longer than 100 years

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## DNA advantages

- **Durability** – days to millions of years
- **Density** – 215 million GB in DNA size 50% of sugar cube
- **Sustainability and energy efficient** – 1 base pair degrades per 6.830.000 years
- **Format Immutability** – stable structure
- **Cost effective** – negative exponential lowering of costs
- **Parallel computing** – can also be used for computing

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## DNA-Storage and Quantum Computing Application A very interesting and completely new scientific direction

K. Bertels<sup>1</sup><sup>1</sup>University of Ghent

June 25, 2024

### Abstract

This paper proposes a new approach to build a scalable way of doing in-depth analysis of the large amounts of digital data we produce on daily basis. It is a combination of existing and still growing digital data, quantum computing applications and a DNA-based way of storing information. The content of the paper is to sketch the state of the art in Quantum Computing and will introduce the huge amounts of existing and future digital data. The paper also presents also a new full-stack for any new DNA-data storage device. This full stack is based on the published DNA-data storage Alliance but makes the explicit link with quantum data, digital and DNA-data storage. Such a DNA-device already exists but this paper makes the link between digital data, quantum results and DNA data storage. There are still open issues such as operating temperature and operational speed. Important to know is that temperatures around -5 Celsius are needed and no extremely low temperatures such as millikelvin are needed to store DNA-based information. Evidently, DNA-data storage is also applicable for pharmaceutical and medical purposes.

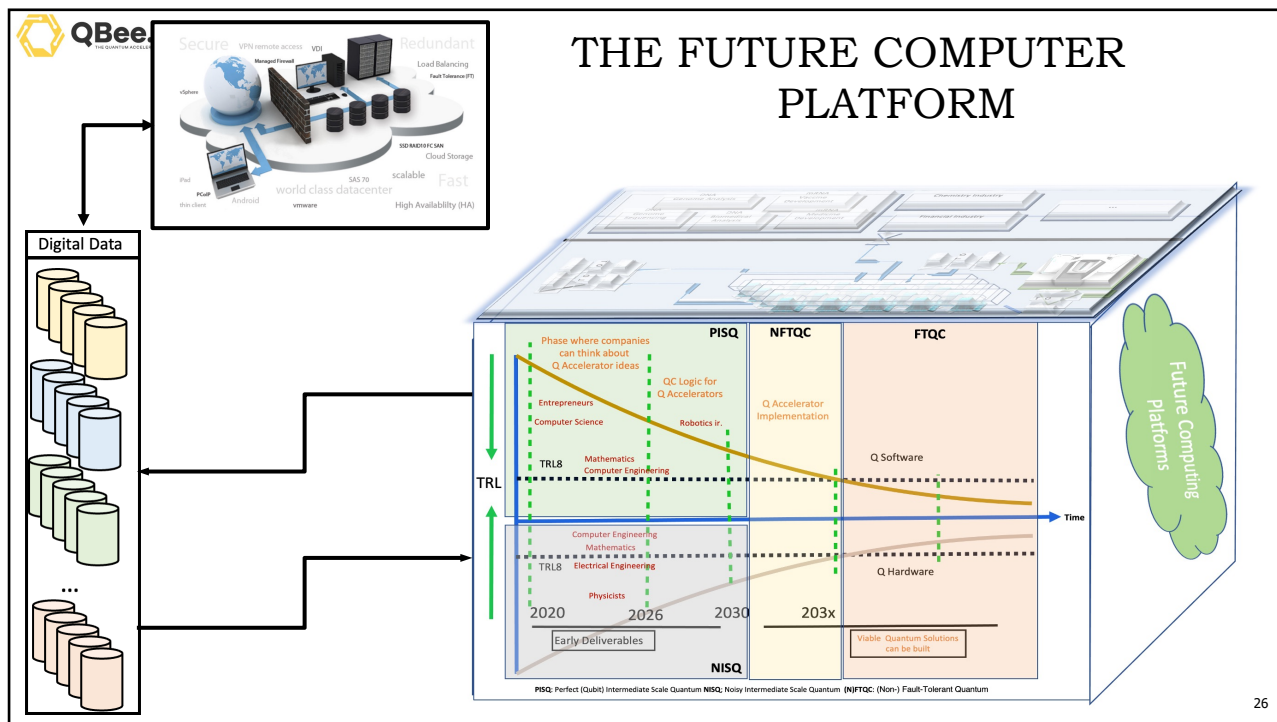
### 1 Introduction

The computer hardware technology is reaching the limits of the size of CMOS-transistors, used to make computer chips. Some authors call this the information catastrophe. [1] The current size of such transistors is at 2nm, and once they become smaller than 1nm, they enter the quantum mechanical universe, with direct implications. This universe makes them behave in completely different ways such that quantum elementary computations are done in a probabilistic rather than deterministic way. [2][3] A second important challenge is to store all the digital data we generate on a daily basis. Not many humans are aware of the fact that the CMOS-transistor size cannot provide enough storage space for any kind of classical and digital data. This is where DNA as a storage technology pops up. The goal of this paper is to introduce the complete innovative way of doing scientific research, by focusing on DNA-based storage technology to save huge amounts of digital data we have on our planet. We will also explain how this device can be combined to store computing or experimental results that can be further analysed using quantum computing technology. It is all very experimental but very needed.

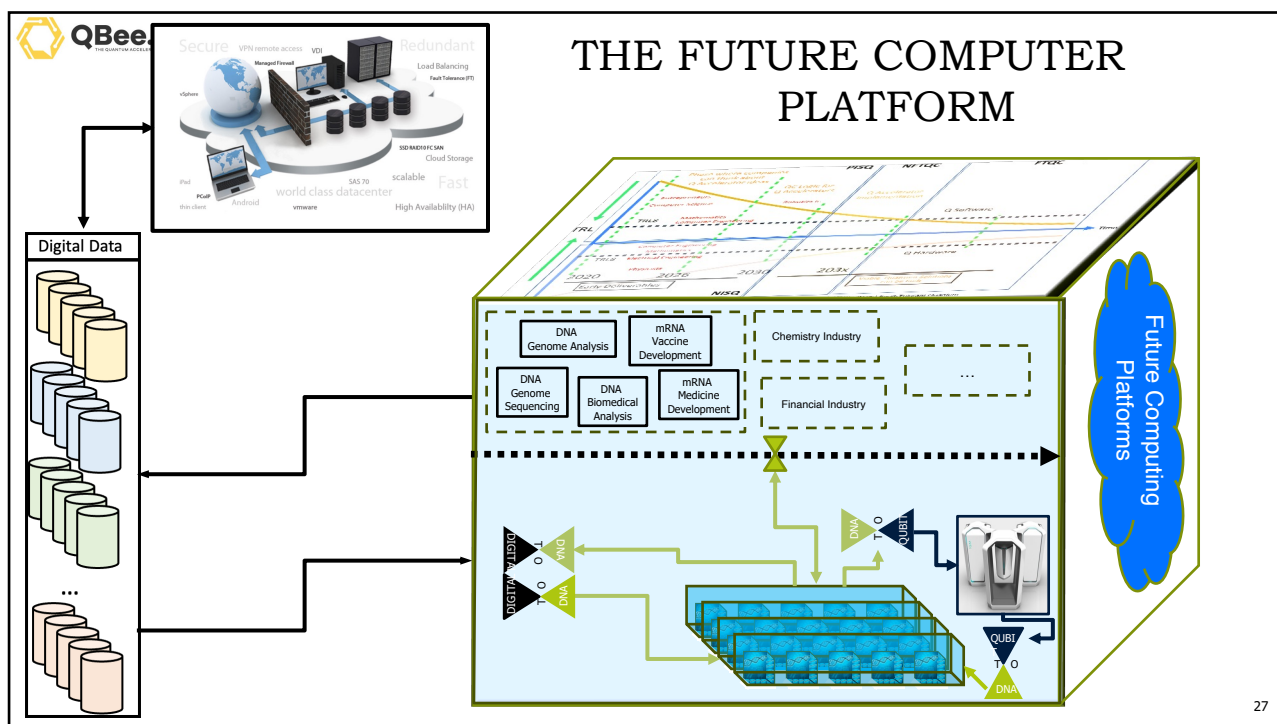
Deoxyribonucleic acid, commonly known as DNA, is the fundamental molecule of life, encoding the genetic instructions used to develop and operate living organisms. DNA is composed of molecules called nucleotides, which include a nitrogenous base, a pentose sugar, and phosphate groups. These nucleotides are arranged in sequences of four bases: adenine (A), thymine (T), cytosine (C), and guanine (G), which are the core components that store genetic information

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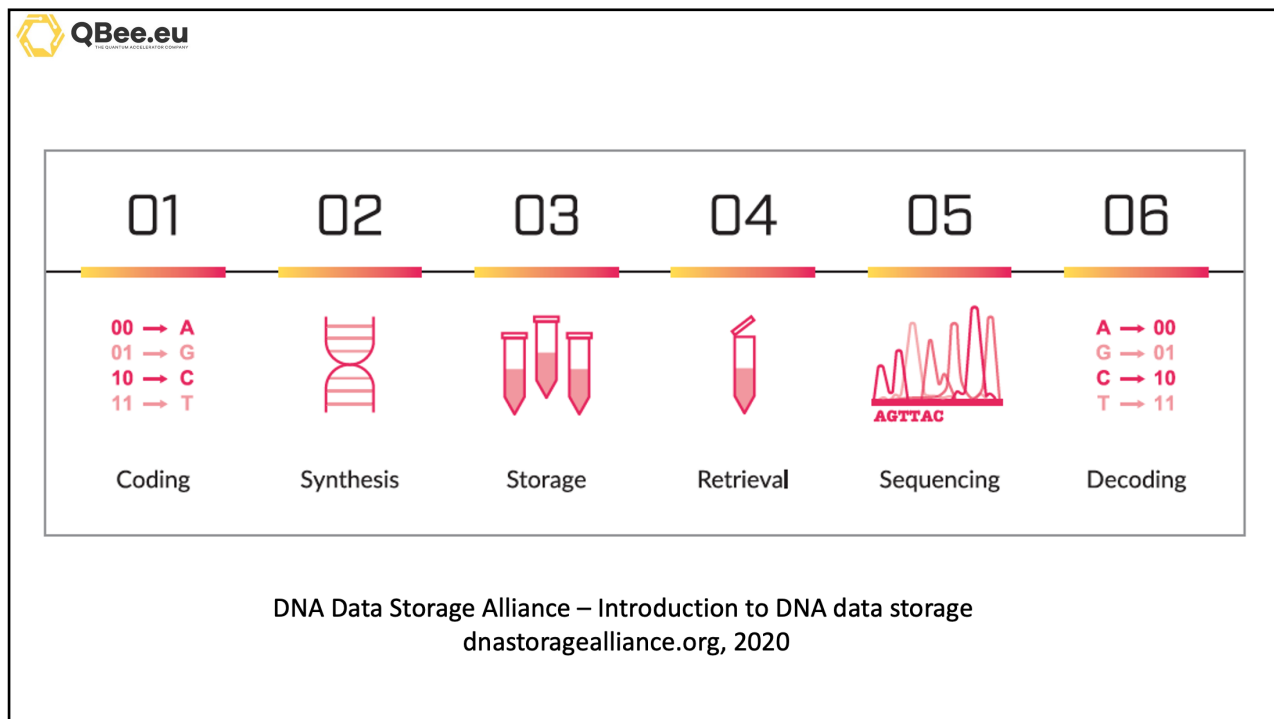
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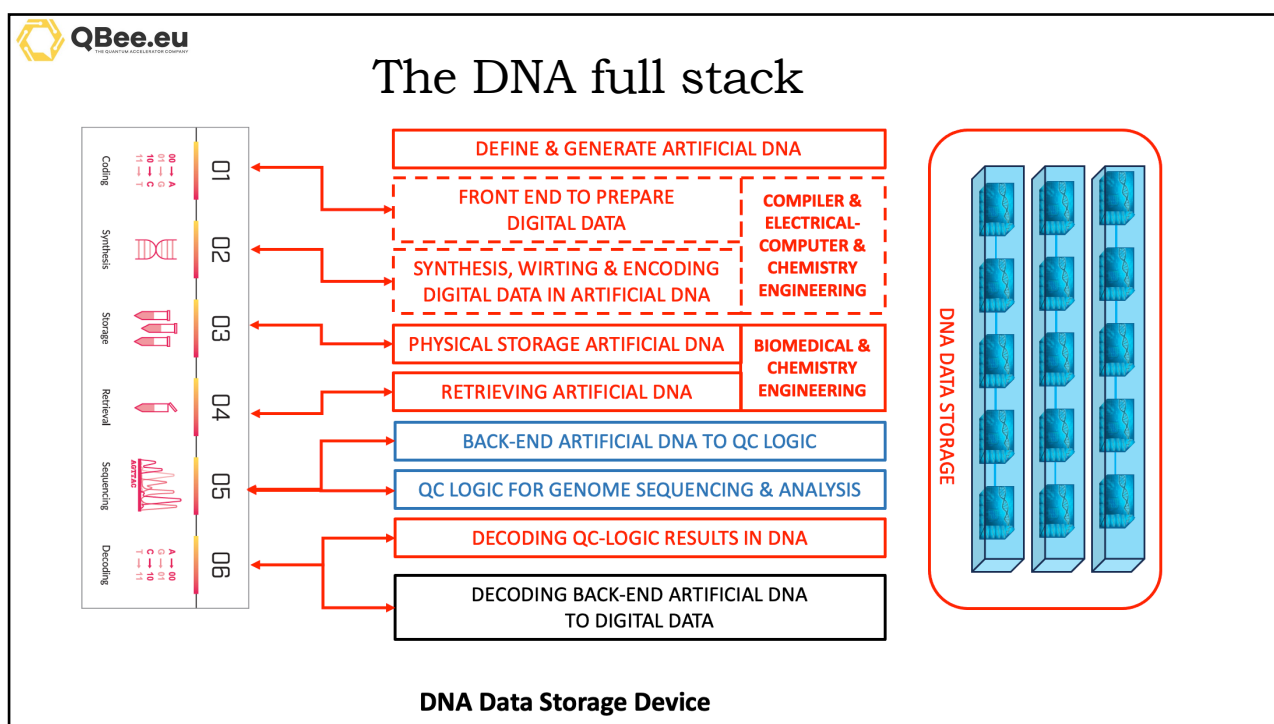
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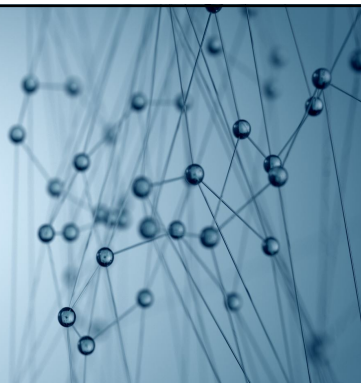


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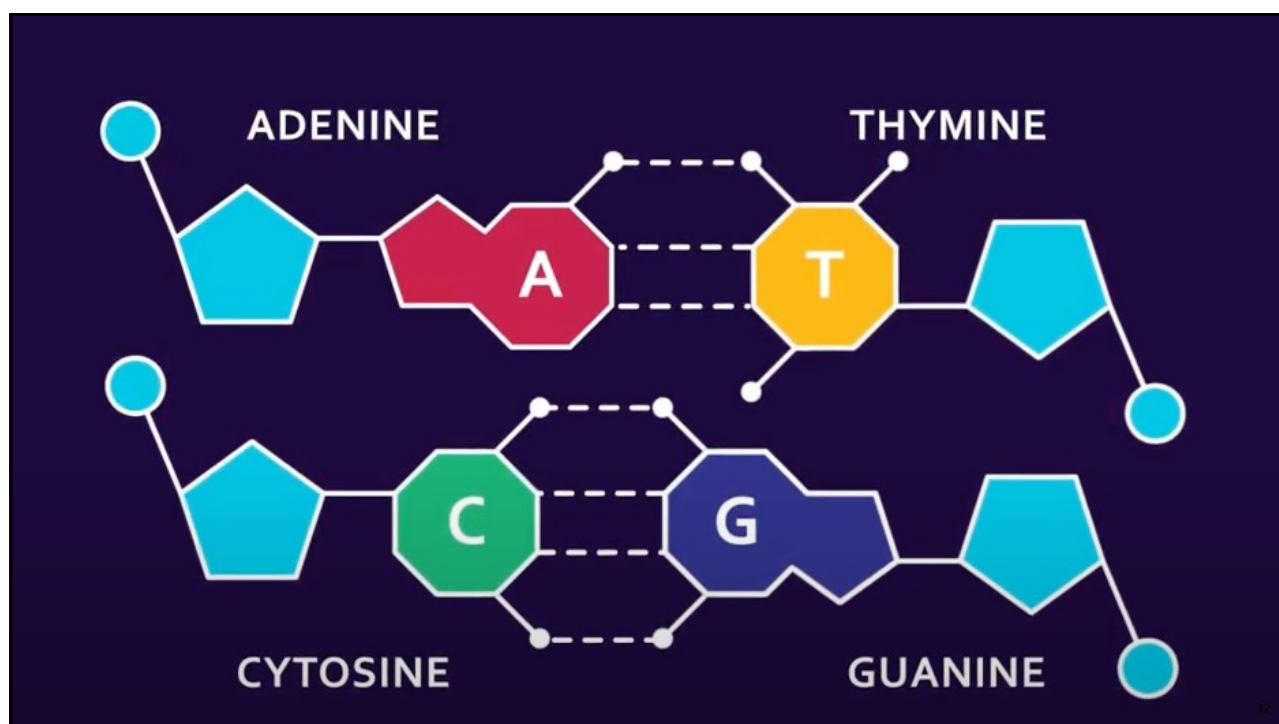
## DNA basics and DNA Storage

**Francis Crick, Rosalind Franklin, James Watson, and Maurice Wilkins**

These four scientists—Crick, Franklin, Watson, and Wilkins—codiscovered the double-helix structure of DNA, which formed the basis for modern biotechnology.

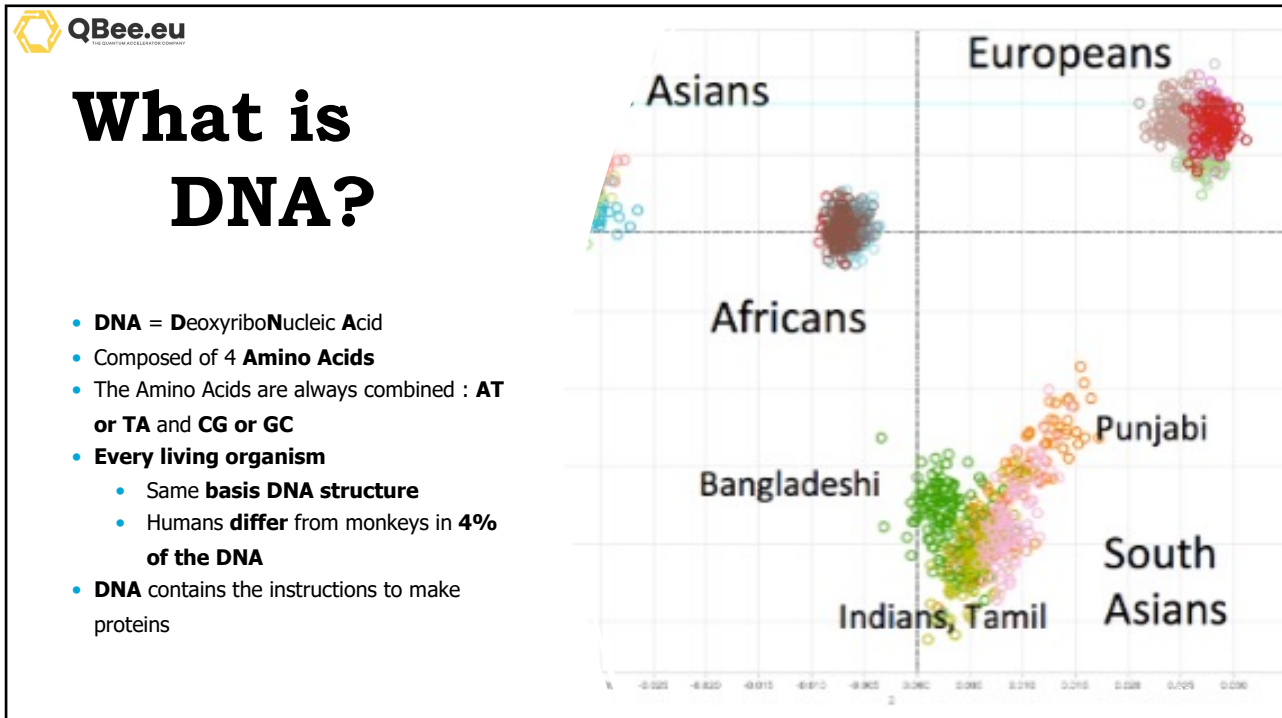


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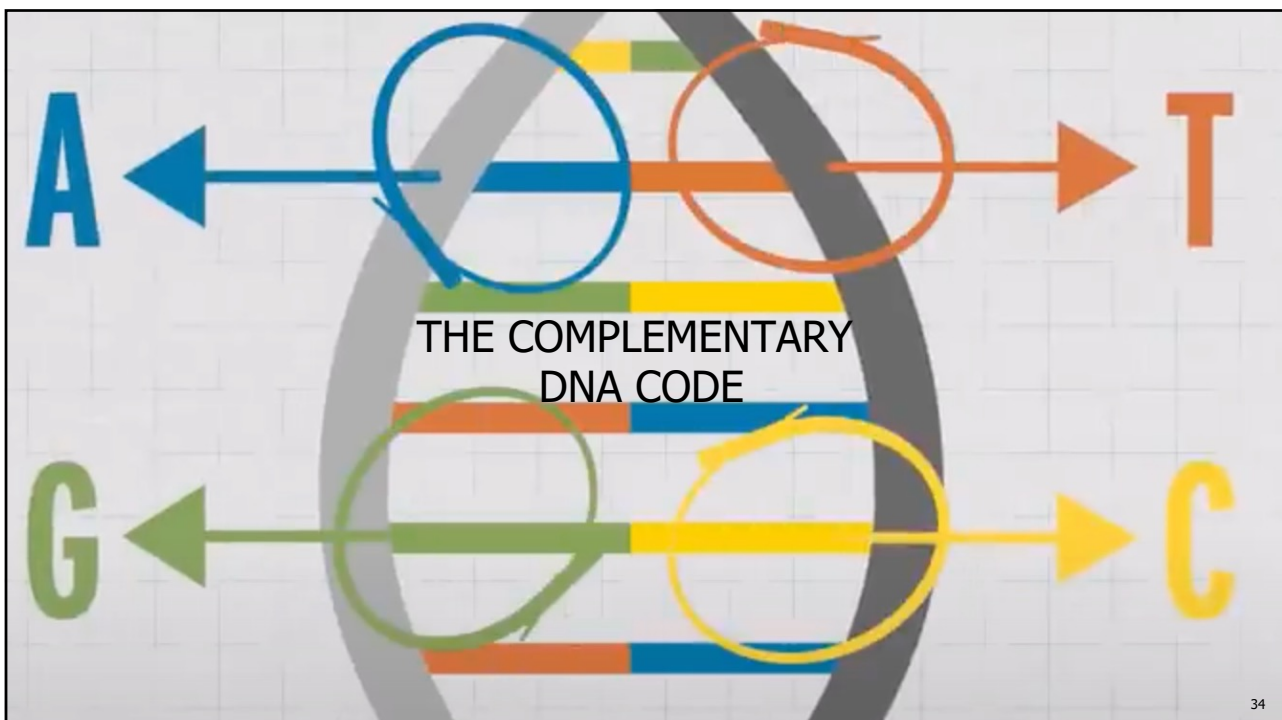


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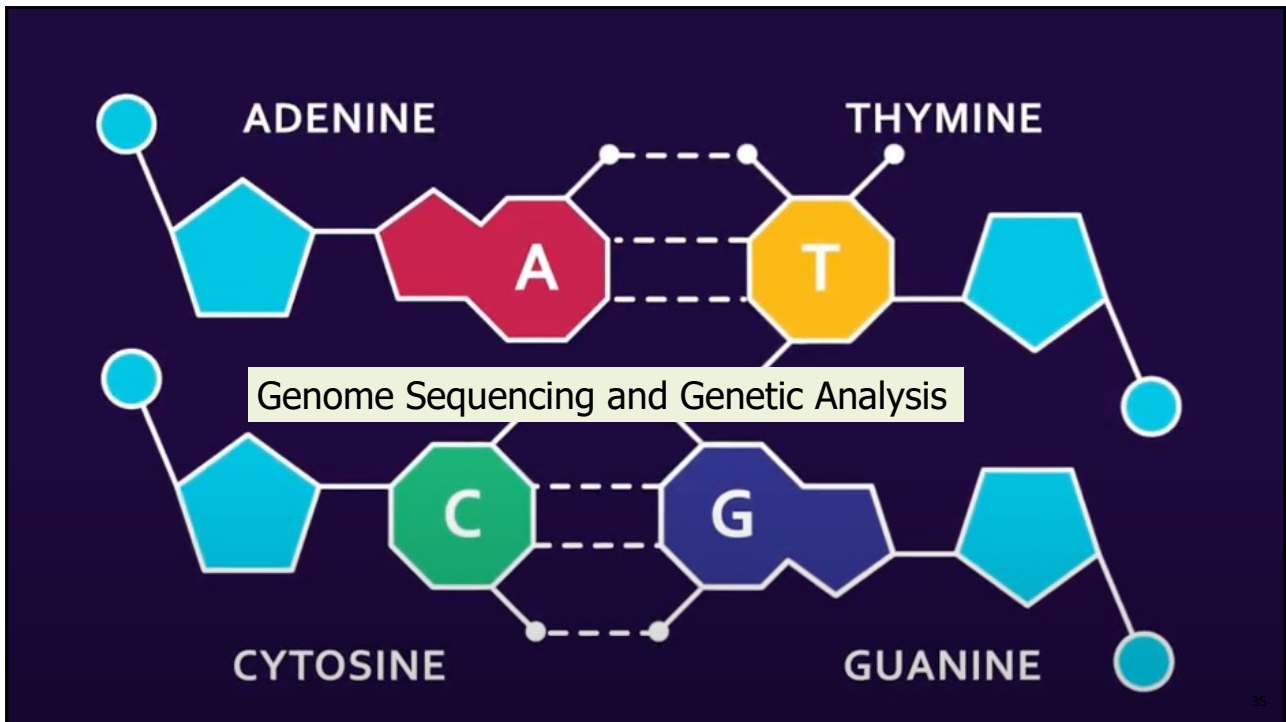


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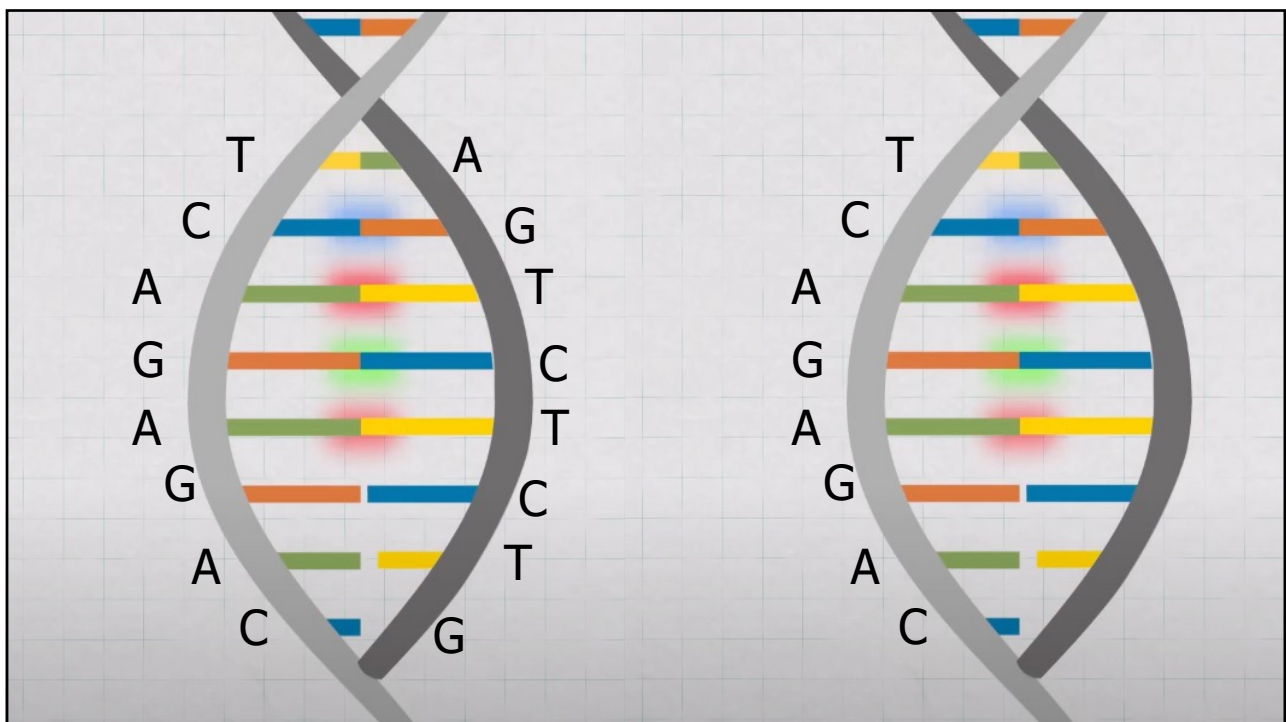


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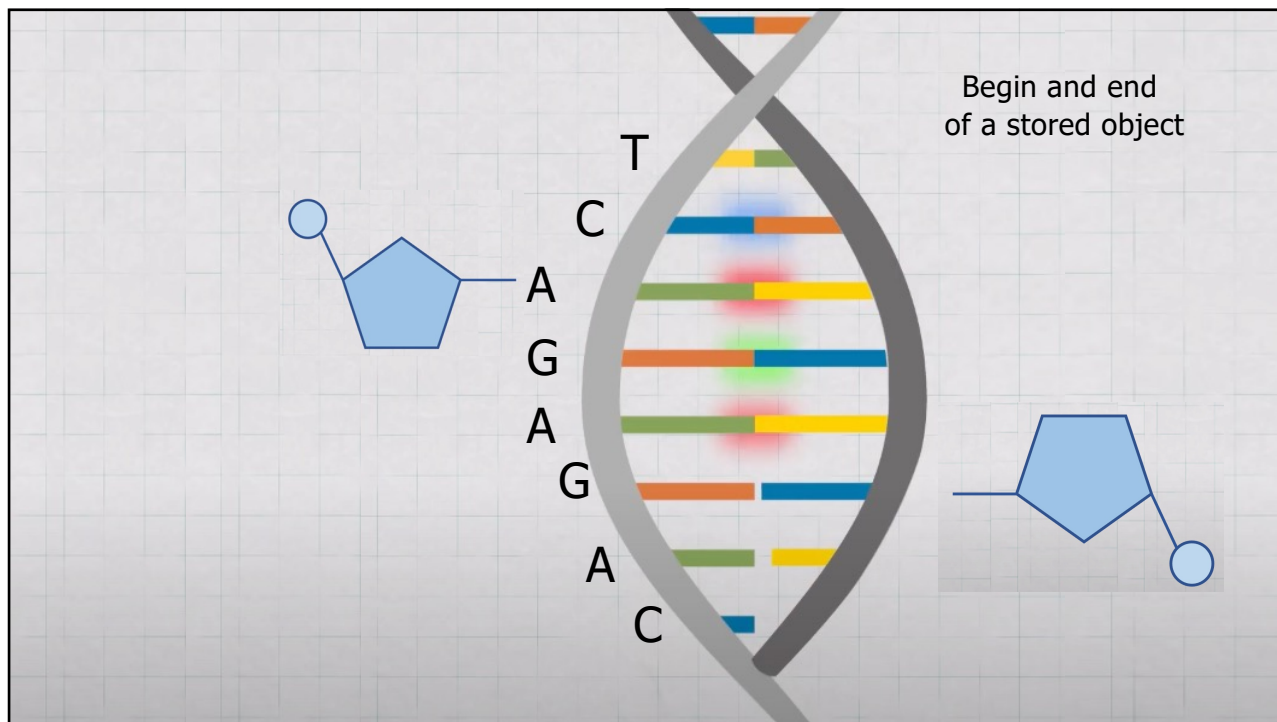




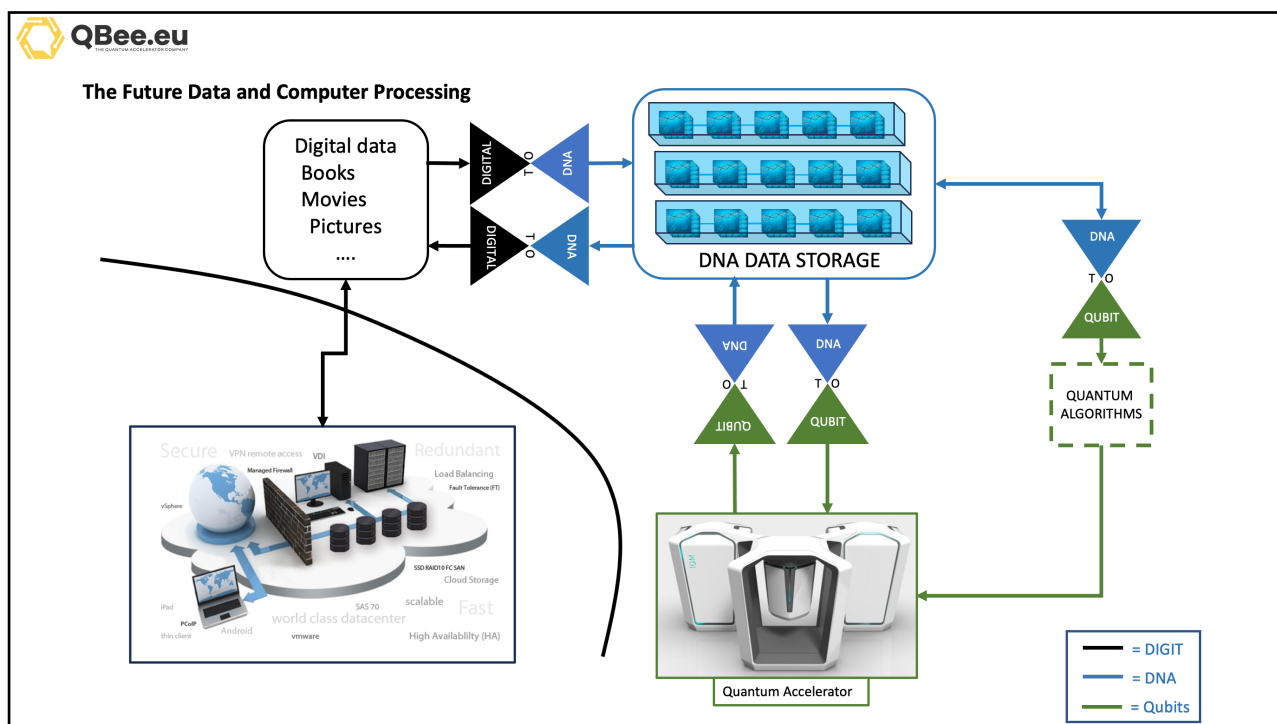
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## Frequency of use of DNA-based data

Daily frequency

Digital Data Storage

Monthly and yearly frequency

DNA Data Storage

Multiple years frequency

DNA Data Storage

DNA Data Storage for MARS

Resistant to radioactivity

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## Outline

- Why?
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 **WHAT? FUTURE COMPUTER PLATFORMS**

<ul style="list-style-type: none"> <li>• <b>Innovative approach for Q Software Development</b> <ul style="list-style-type: none"> <li>• <b>Perfect (qubits) Intermediate Scale Quantum – PISQ</b></li> <li>• Other complementary approaches <ul style="list-style-type: none"> <li>• Noisy Intermediate Scale Quantum –NISQ</li> <li>• (Non-) Fault Tolerant Quantum Computing</li> </ul> </li> <li>• PISQ-simulators &amp; NISQ-based execution</li> </ul> </li> <li>• <b>Contributions</b> <ul style="list-style-type: none"> <li>• <b>New Q software</b> for applications, with IP</li> <li>• <b>New Q gates</b>, with IP</li> <li>• <b>New Q methods</b>, with IP</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Scalable and Robust DNA-Data Storage</b> <ul style="list-style-type: none"> <li>• Huge amounts of digital data</li> <li>• Can be stored in DNA-format</li> </ul> </li> <li>• <b>Contributions</b> <ul style="list-style-type: none"> <li>• IP</li> <li>• <b>Scalable storage space &amp; low energy consumption</b></li> <li>• <b>Speed for storage and retrieval needs to be faster</b></li> <li>• Can be <b>combined</b> with QC</li> </ul> </li> </ul>
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**Quantum Computing Logic and DNA data storage are the birth of a new way of thinking scientifically and technically**

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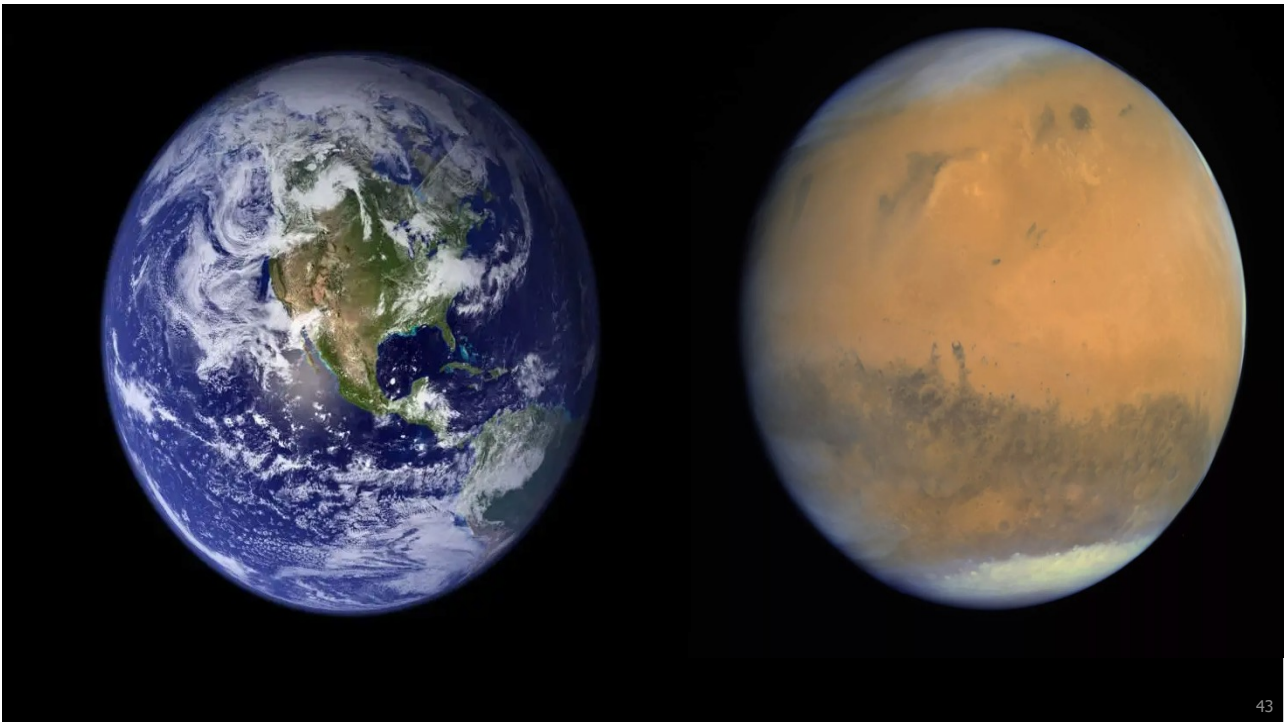
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**COLLABORATION WITH UNIVERSITIES  
AND INDUSTRIAL COMPANIES, such as Thales,  
IS SUPER IMPORTANT**

**Quantum Computing Logic and DNA data storage are the birth of a new way of thinking scientifically and technically**

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## QBEE<sup>2</sup> WILL DEVELOP 2 KINDS OF QC PRODUCTS & 1 DNA PRODUCT

- **QC-Logic algorithm for breast cancer research**
- **QC-Logic algorithm for mRNA based vaccine development**

### • **DNA-data storage device**

- Designed for DNA-storage of all kinds of **data, ranging from digital data to natural DNA**, for which
  - The already available quantum genome sequencing version will be executed, including
  - **Digital data** that will be stored to **DNA** and converted back, when needed
- All **genetic results** from the QC-logic development will be stored on that device

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## QBEE<sup>2</sup> WILL DEVELOP 2 KINDS OF QC PRODUCTS & 1 DNA PRODUCT

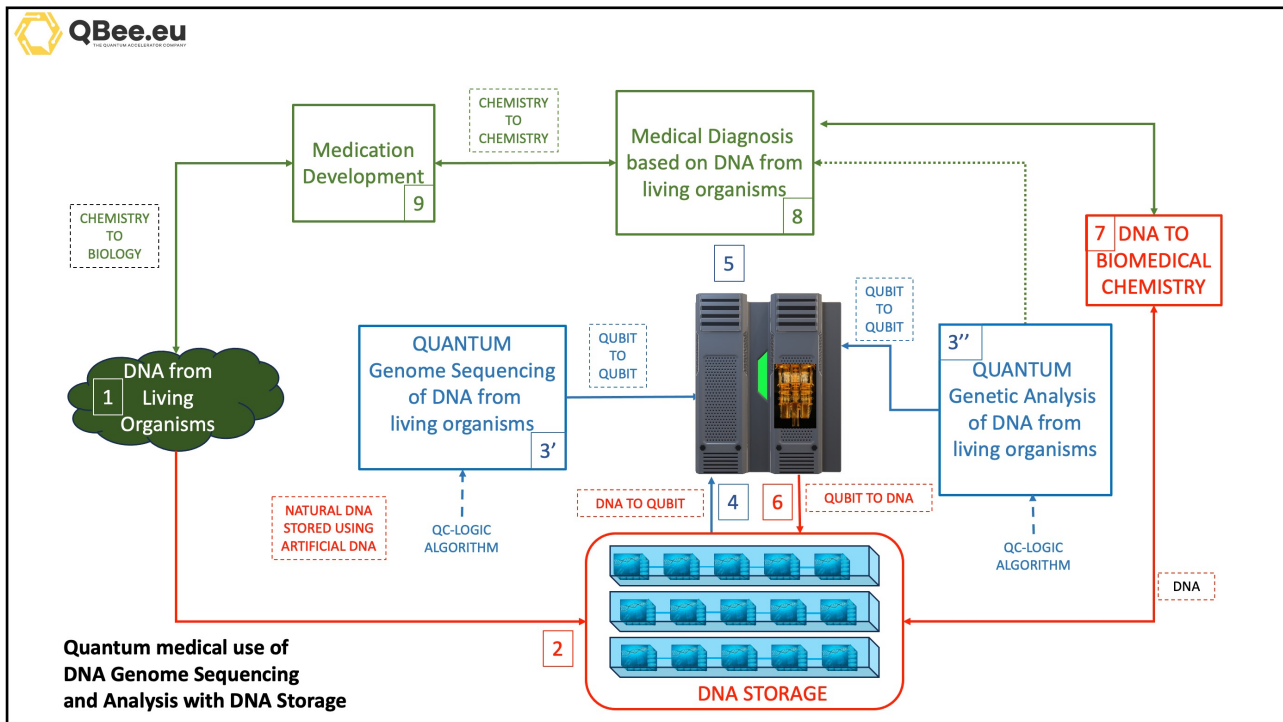
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Meant for **Biomedical Chemistry, Electrical & Computer Engineering**

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## WHO? QBee team




Prof. Dr. Koen Bertels  
Founder  
past Prof. QCE TUD  
past PI QCA QuTech  
Prof. UGhent

**Full-stack Q  
accelerator  
Quantum genomics  
DNA data storage**




Prof. Dr. Emma Turki  
Lead in coastal  
dynamics & EO  
Assoc. Prof.  
Un. Rouen  
Normandie

**Quantum Earth  
Observation**



Dr. Ir. Aritra Sarkar  
Lead Q Applications  
Post-Doc TUD

**Quantum  
genomics  
Quantum AI  
Author of QGS  
Moves to India but will  
collaborate remotely**




Dr. Tamara Sarac  
QC Chemistry  
researcher

**Quantum  
computational  
chemistry  
DNA data storage**

**+ 1 new CEO**  
**+ 2 researchers on genetics topics**  
**+ 2 researchers on DNA-data storage**

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## Conclusion

- **Large changes** in all scientific and technology based fields....so everywhere !
- **Classical and digital data** will keep on growing, including classical computers
- But we need **additional computer platforms...**
- Because the problems on our planet become **larger** and more **complicated**
- **Two possible solutions**
  - **Quantum Computing** and QC-logic applications
  - **DNA-data storage devices** need to be made better
- Read the DNA&QC paper you received and talk to your promoters!

Important for space  
but also for our  
planet

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