Atomtronics

A Very Short Introduction

Charles W. Clark
Joint Quantum Institute

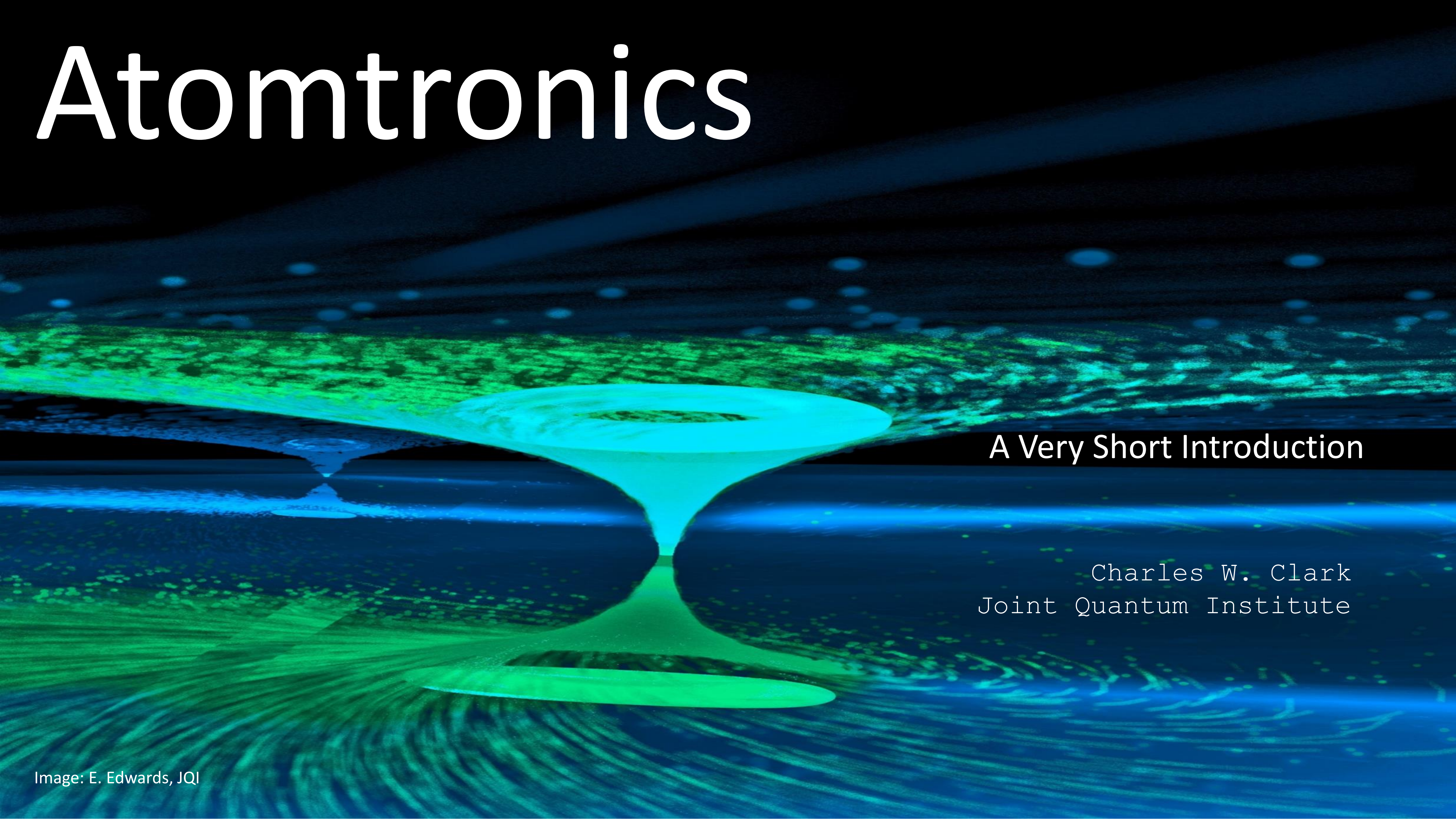

Image: E. Edwards, JQI

Atomtronics

Internet electronics and photonics

Quantum computers and atomic clocks

Atomtronic concepts and devices

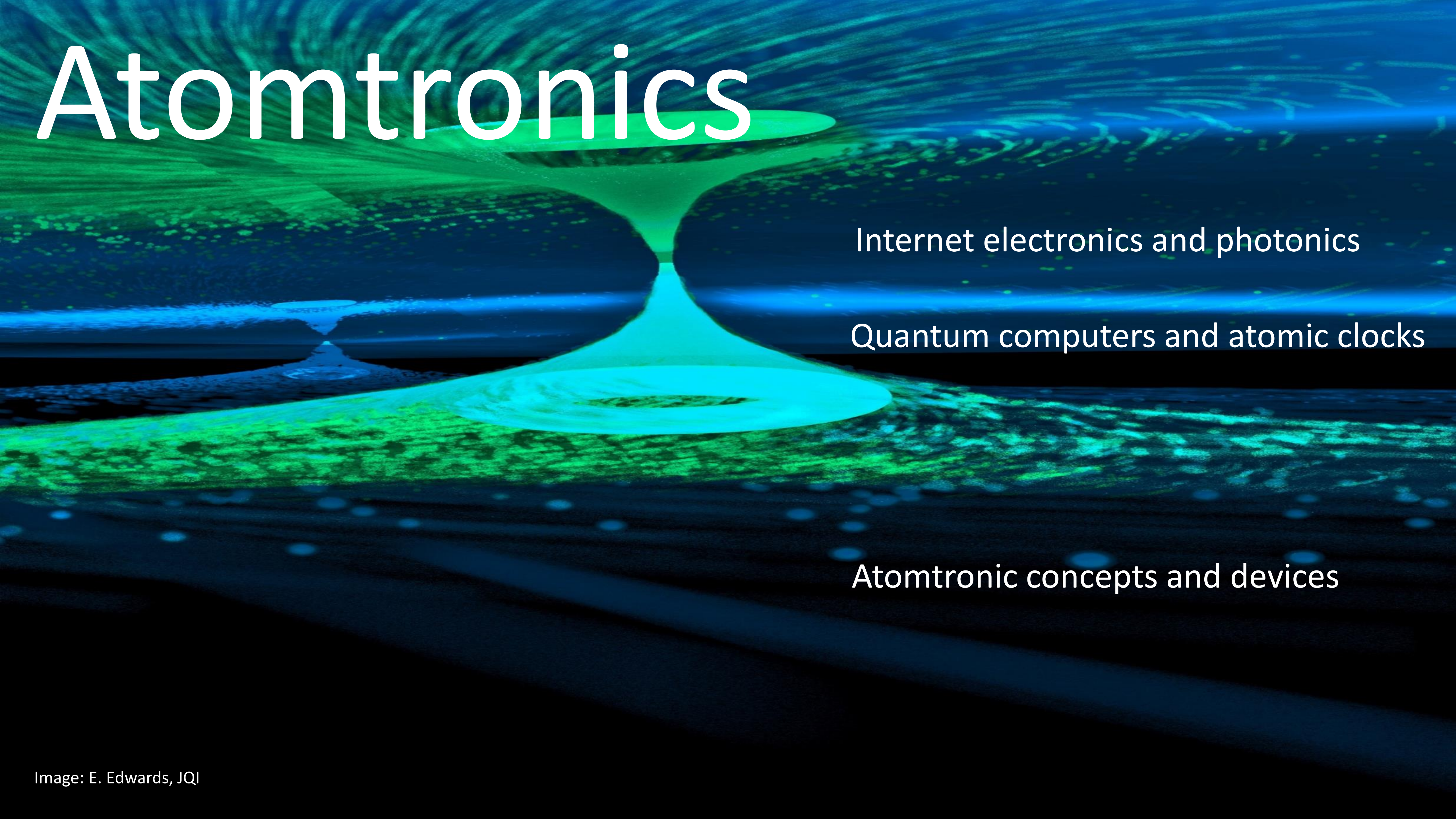

Image: E. Edwards, JQI

Internet

Is it just a flash in the pan . . .

. . .or could it be REALLY BIG, someday?

Image: E. Edwards, JQI

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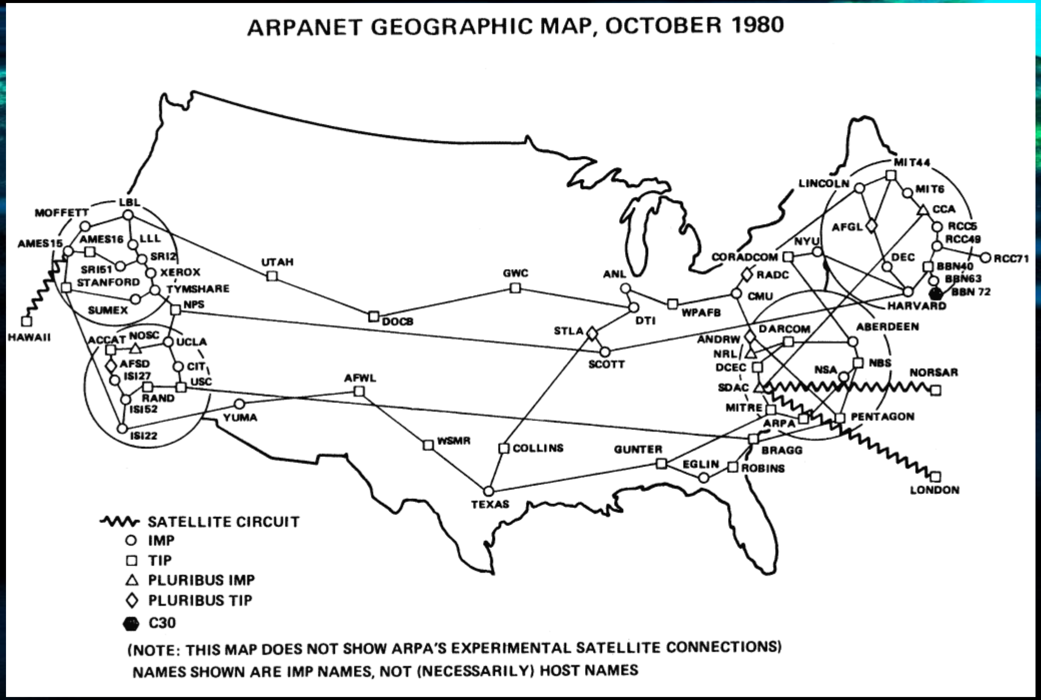

ARPANET 1980
Computers connected by telephone lines and satellite links

Image: E. Edwards, JQI

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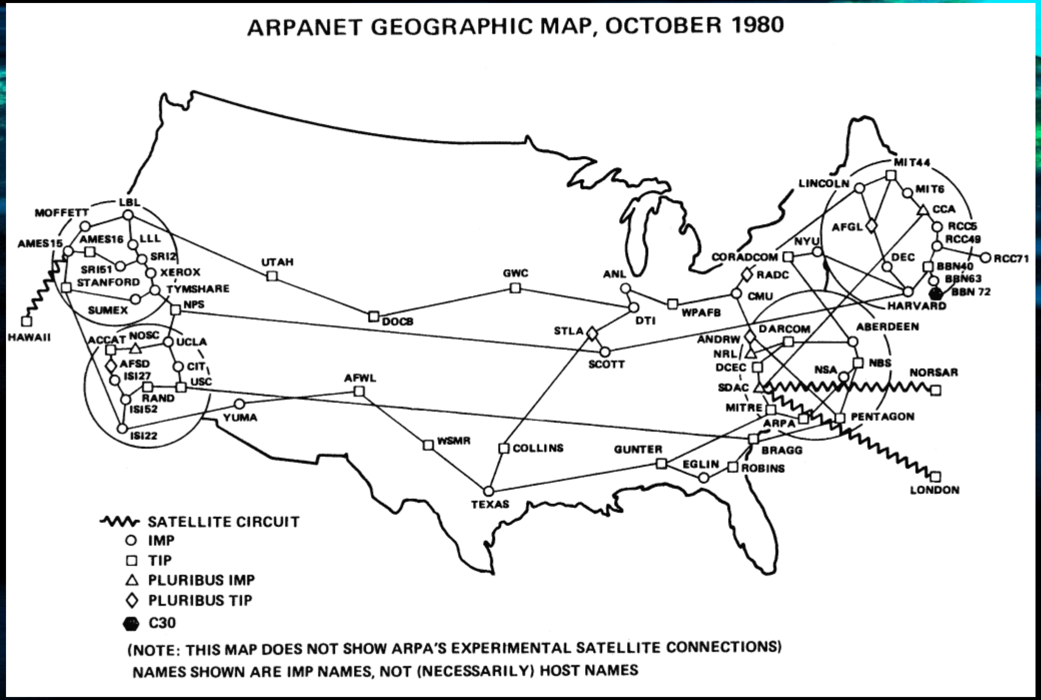

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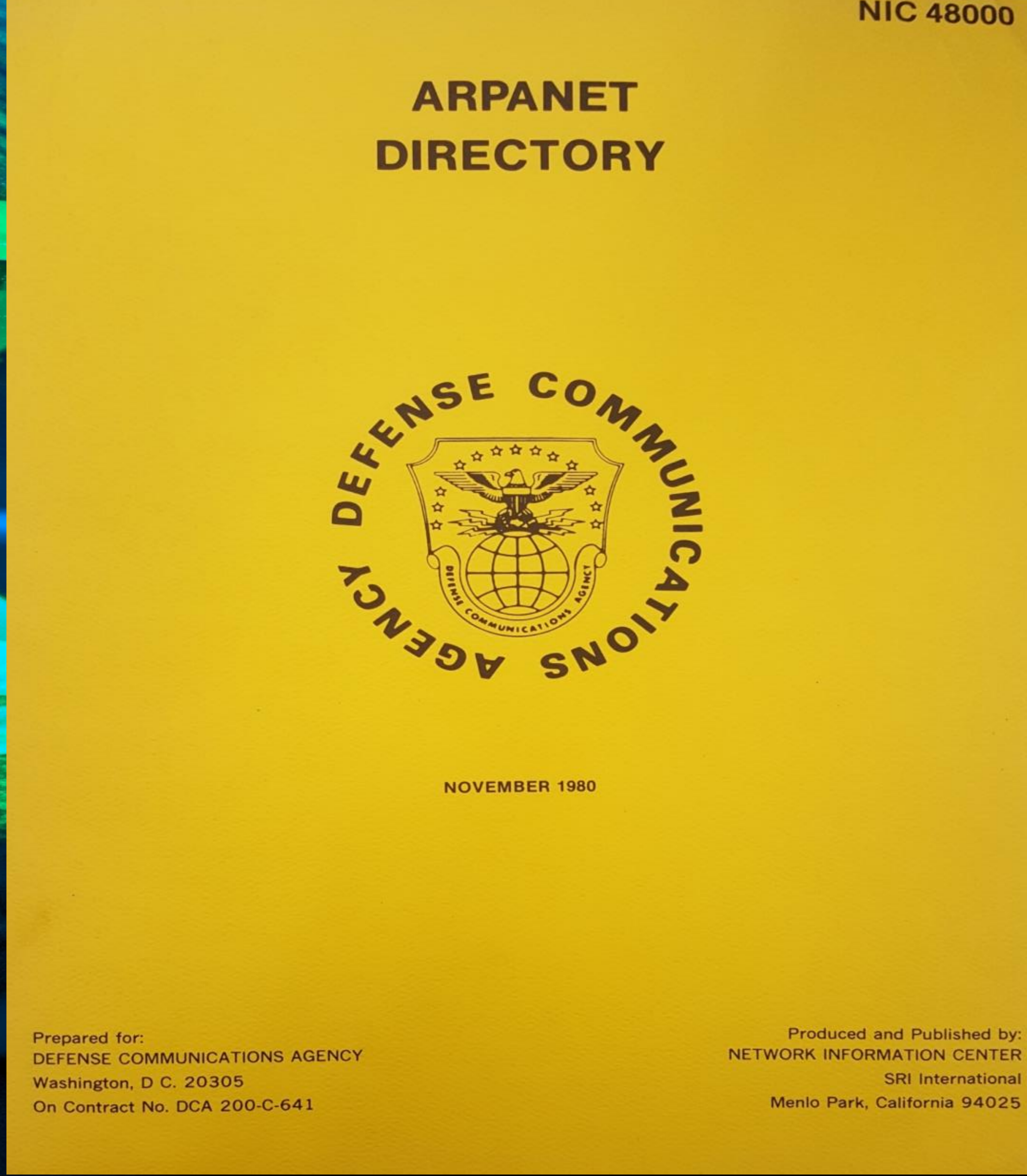

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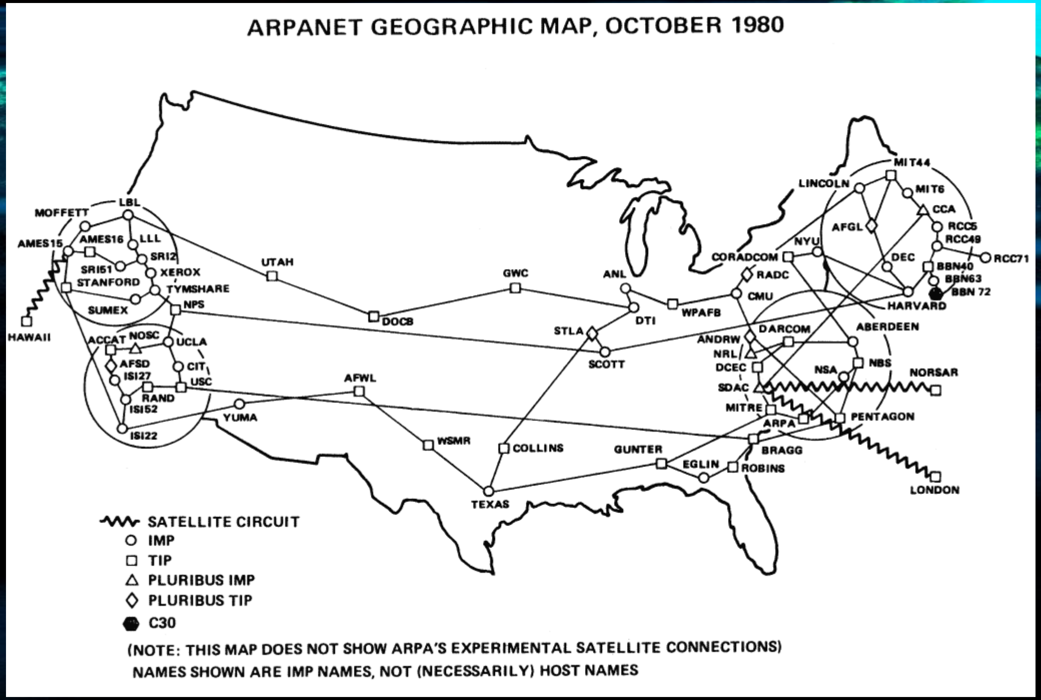

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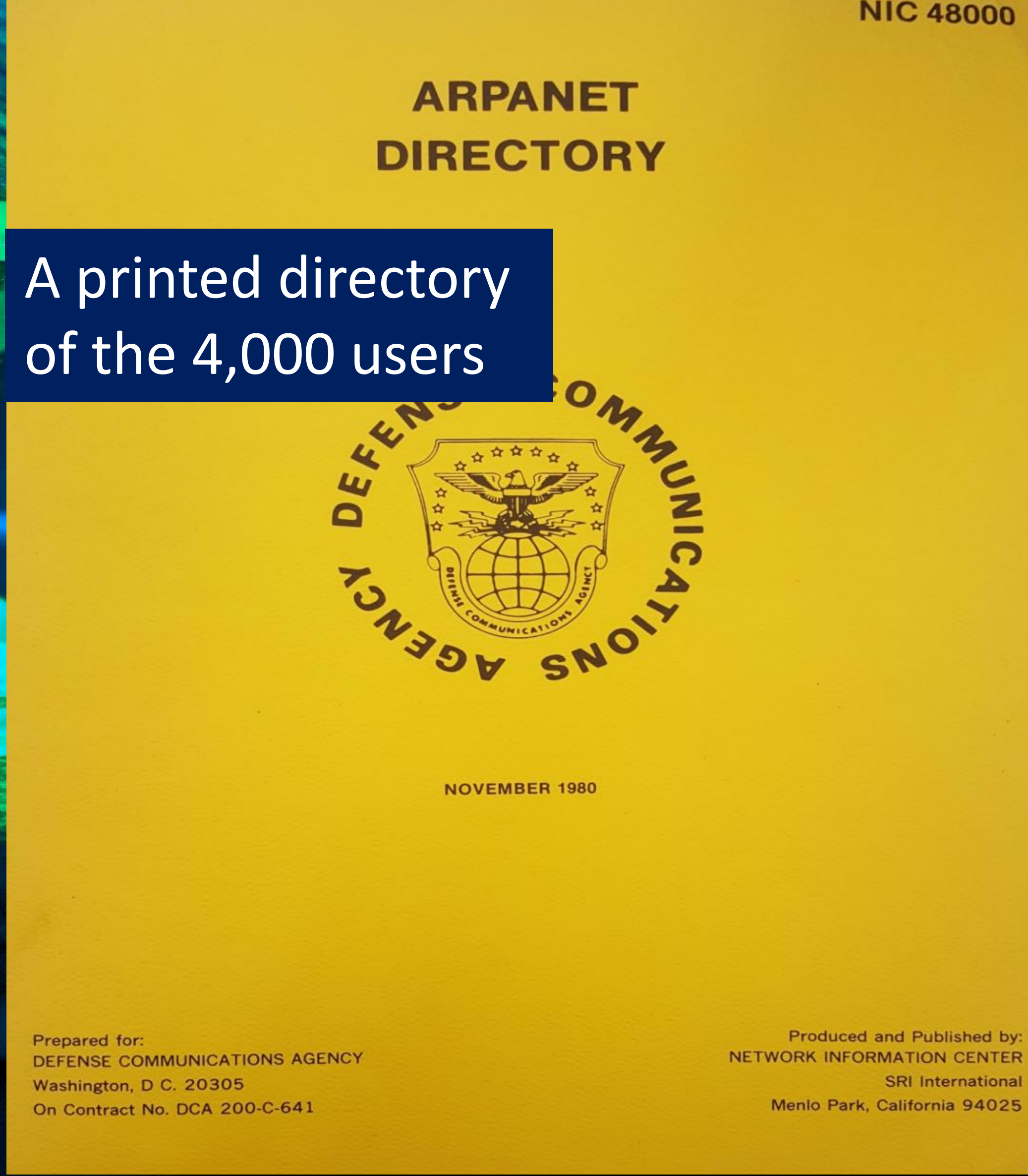

A printed directory of the 4,000 users

Internet

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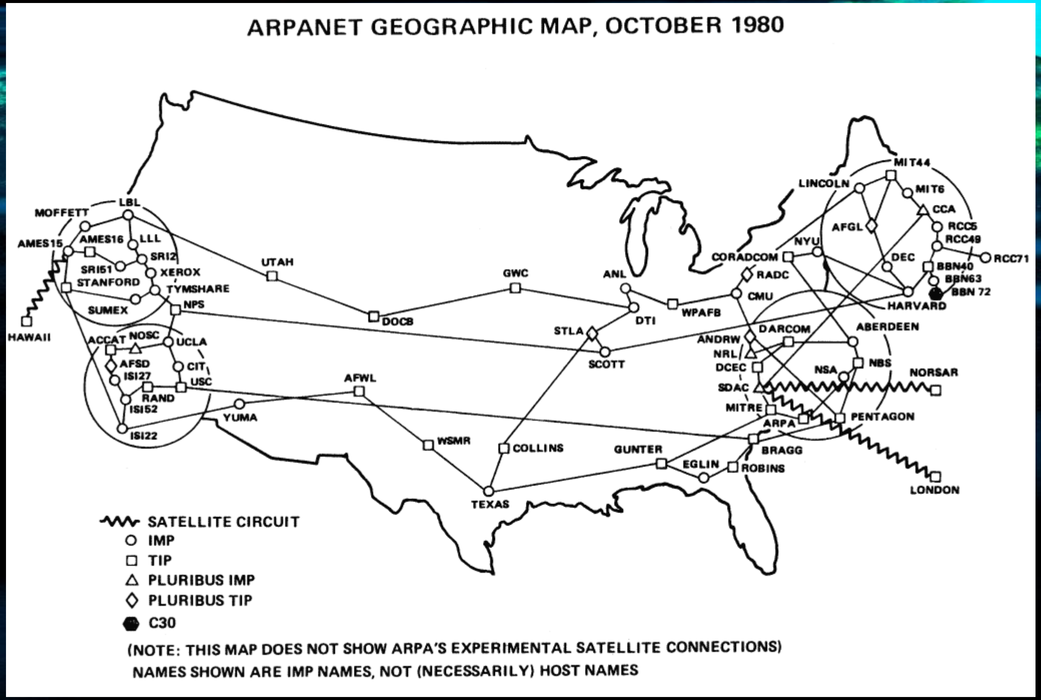

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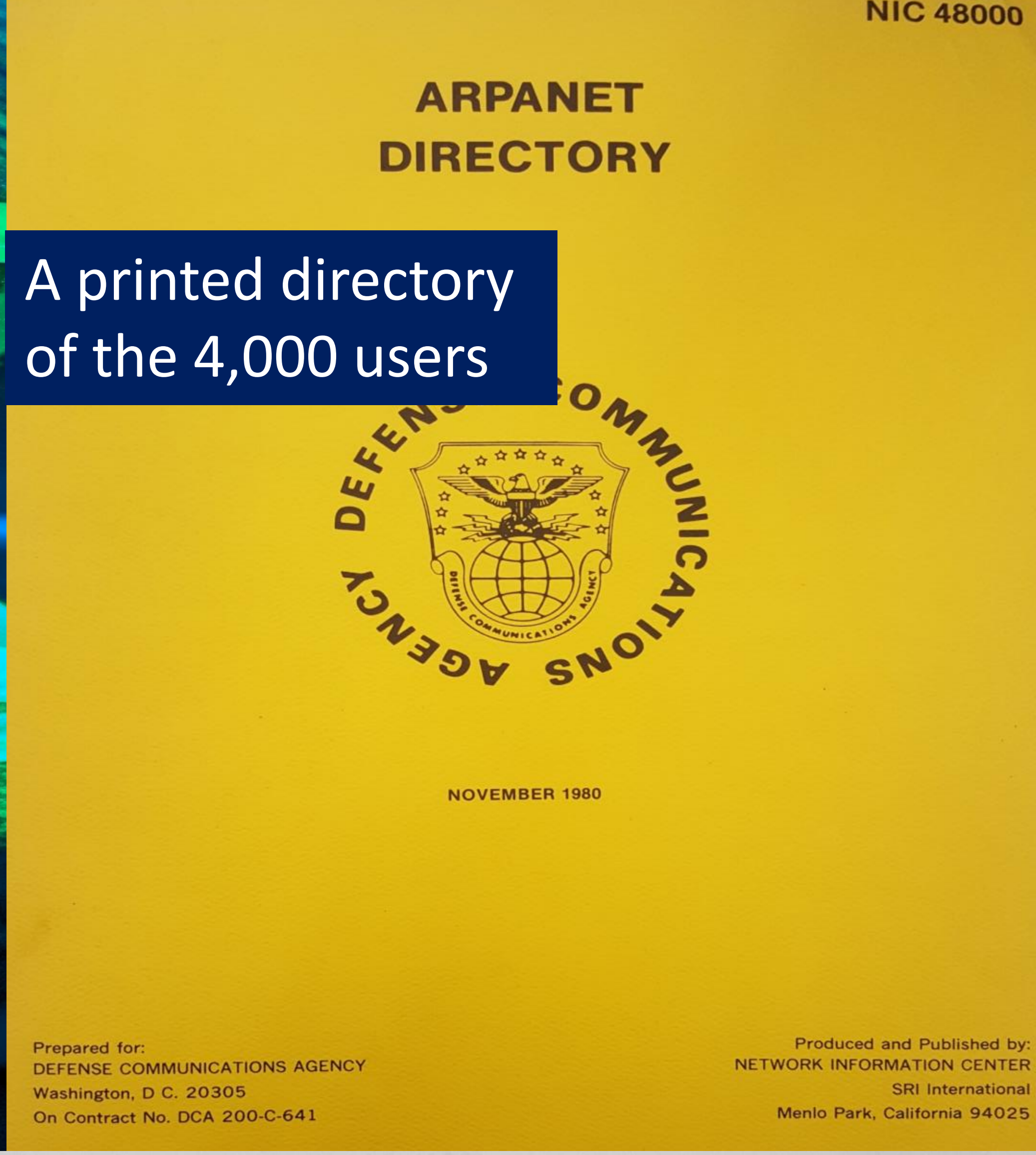

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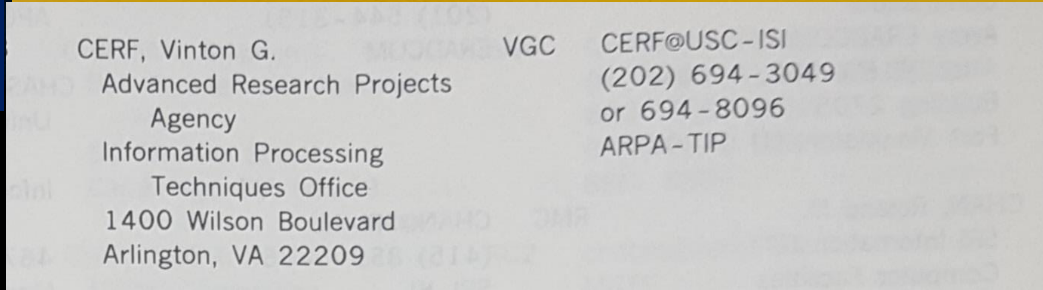

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or 694-8096
ARPA-TIP

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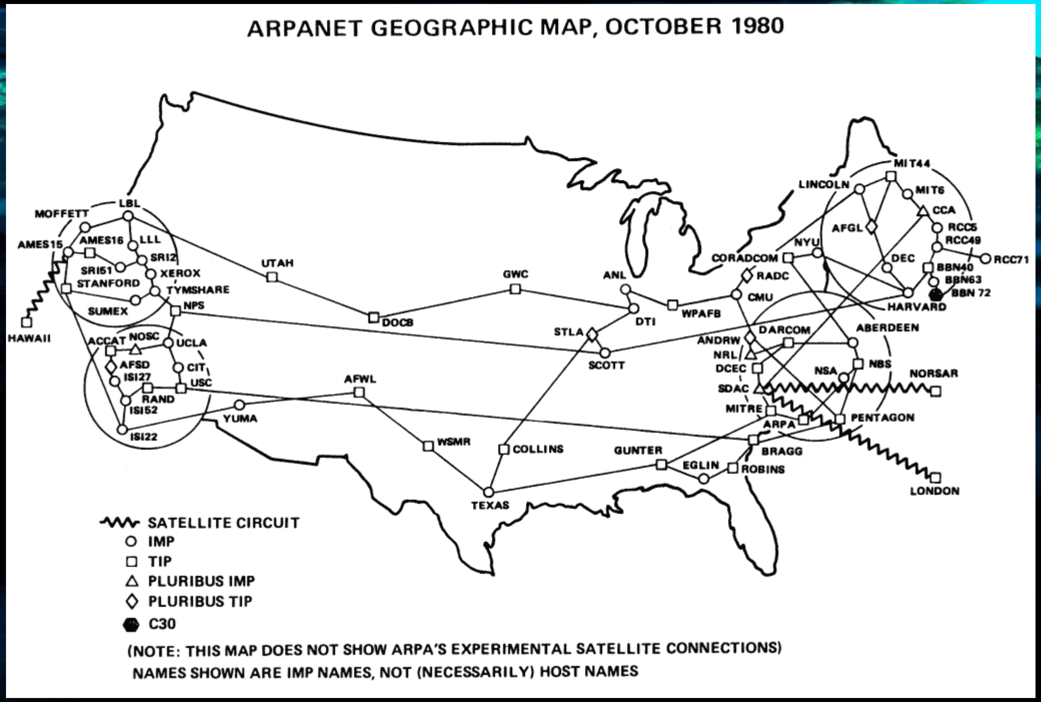

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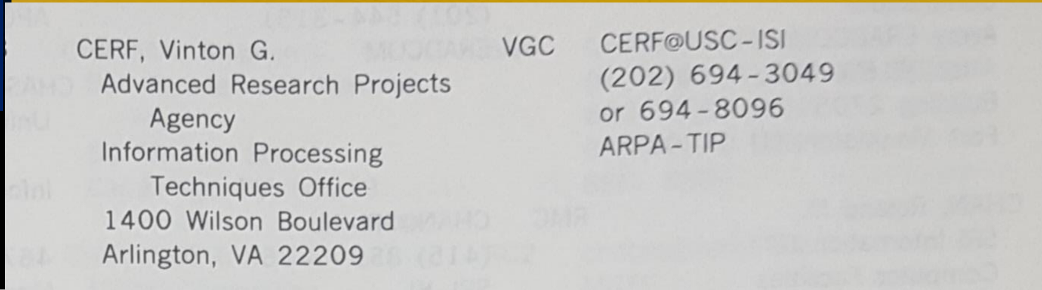
The Electronic Age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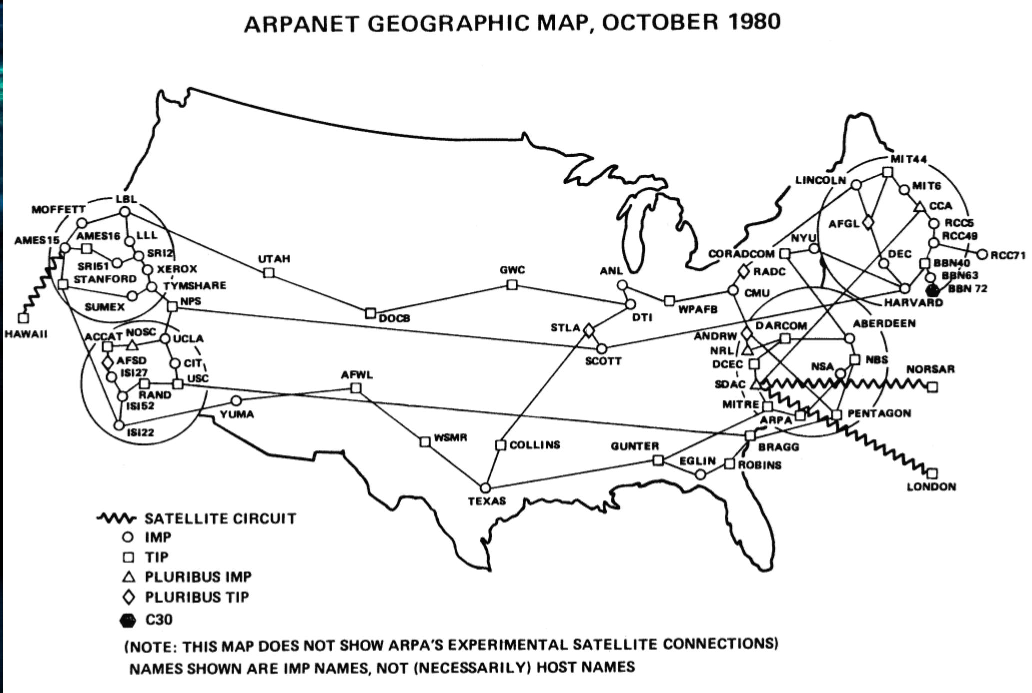

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The Electronic Age

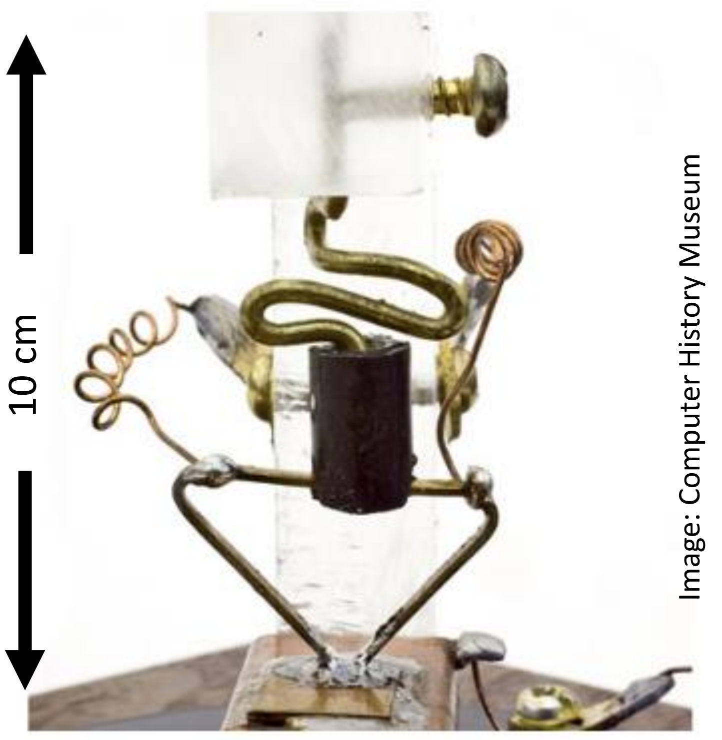
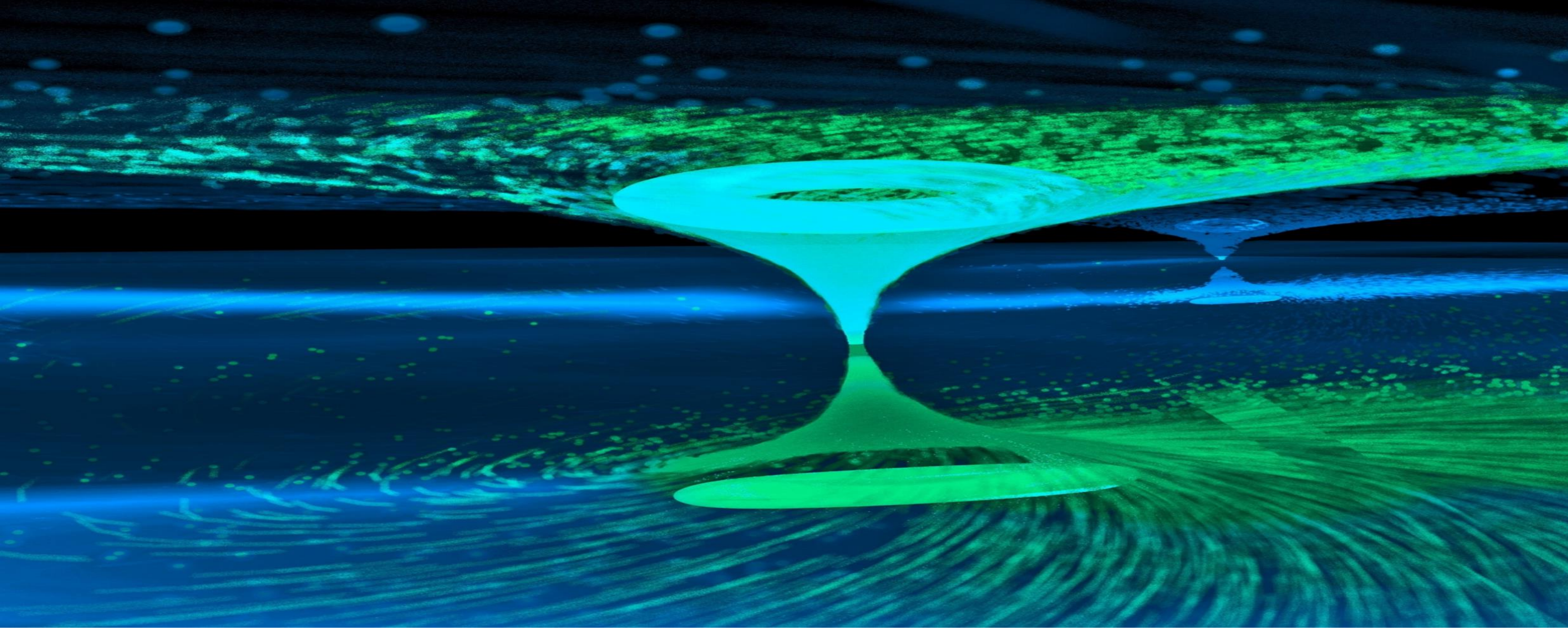


Image: Computer History Museum

Enabling technology of electronics:
The Transistor
Bell Laboratories 1947

Internet today

The Electronic Age



Internet today

2 billion smartphones worldwide; *each contains ~ 1 billion transistors* = 10^{18}

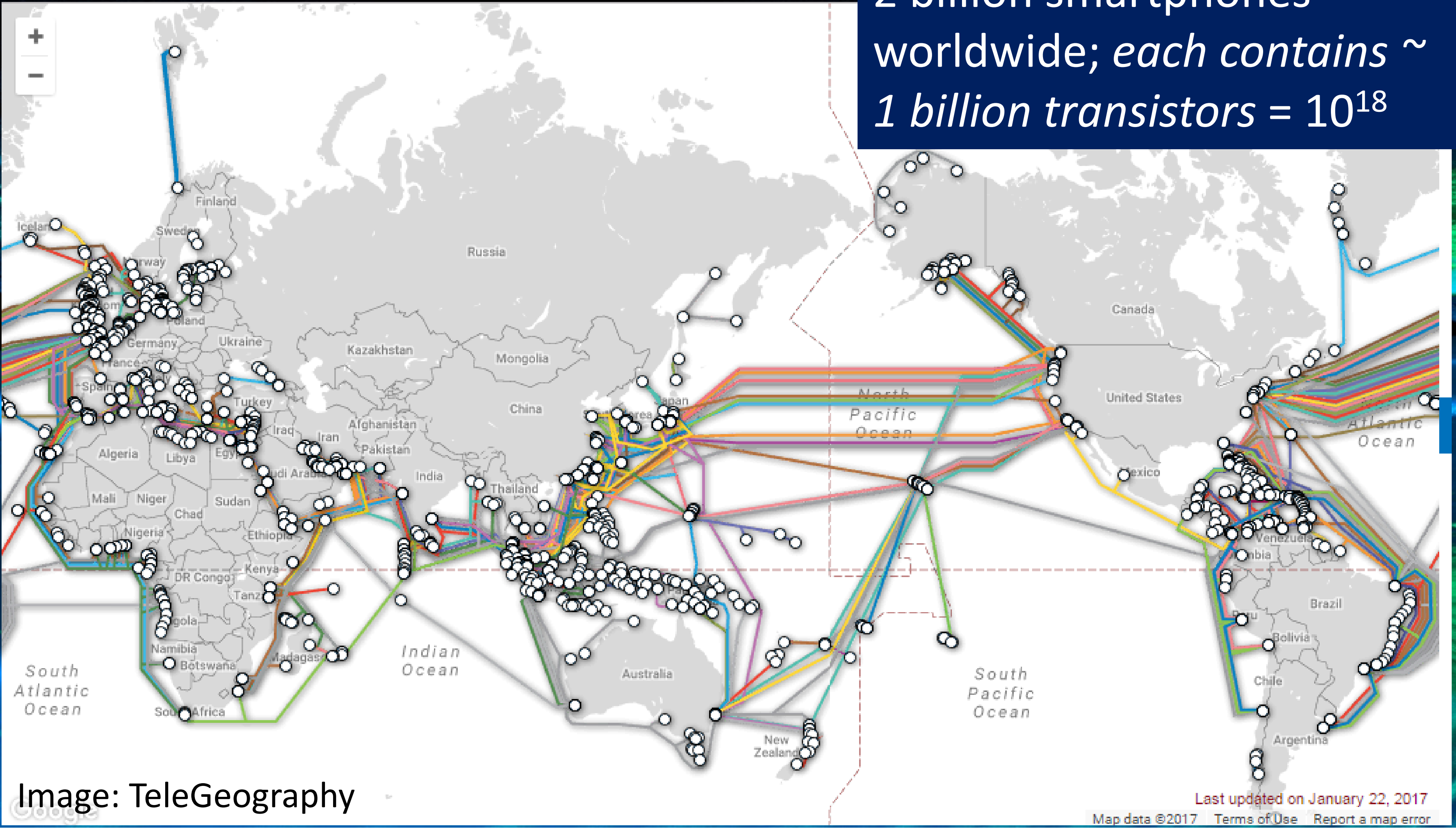


Image: TeleGeography

The Electronic Age

Vast global flow of data requires high-speed optical communication: ***Photonics***

Global reach requires precise network synchronization: ***Atomic clocks***

Internet today

1.3 million kilometers of submarine fibre-optic cables

2 billion smartphones worldwide; *each contains ~ 1 billion transistors* = 10^{18}

Atomic clock timing

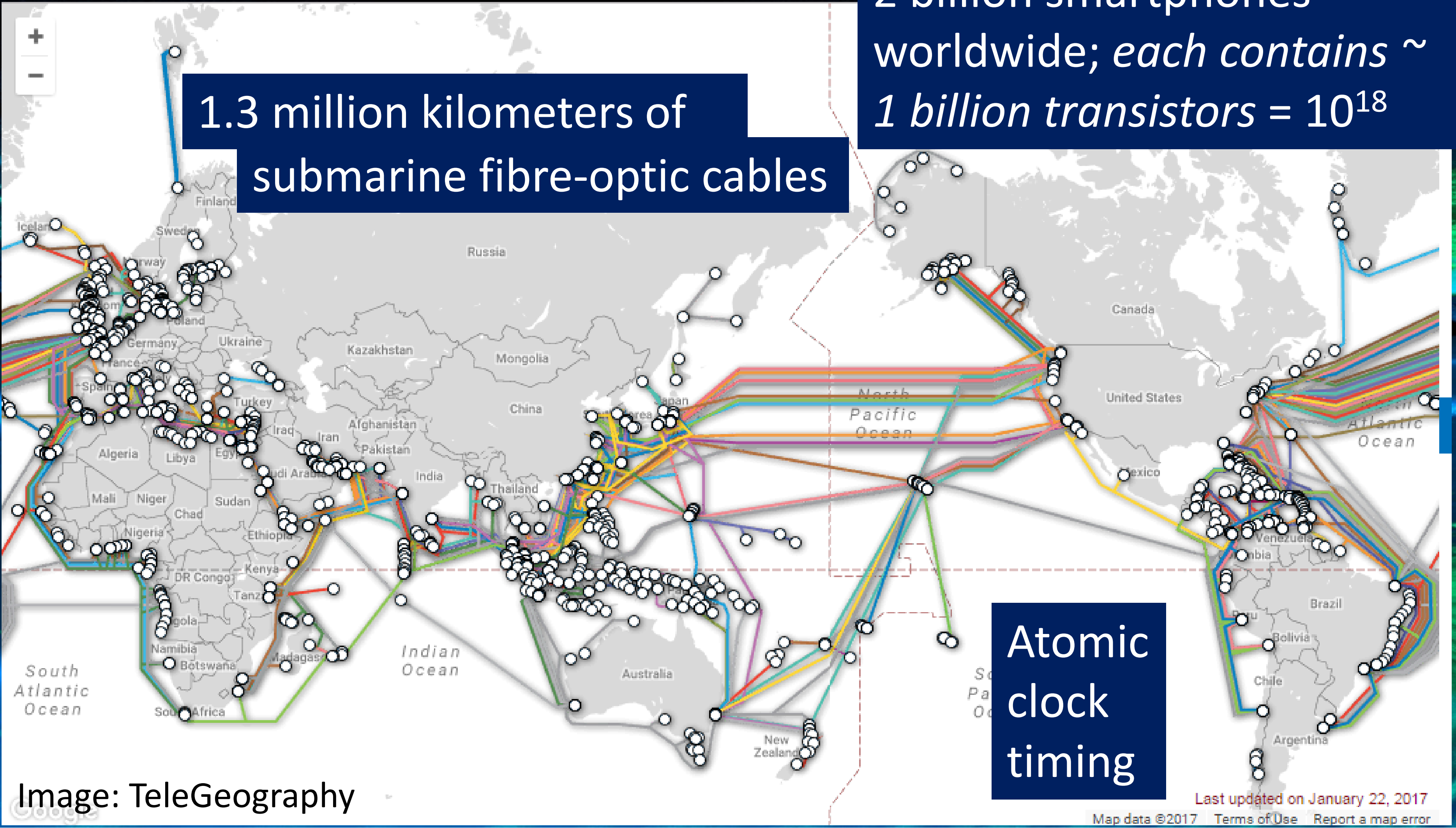


Image: TeleGeography

The Electronic Age

Vast global flow of data requires high-speed optical communication: ***Photonics***

Global reach requires precise network synchronization: ***Atomic clocks***

Atomic Clocks

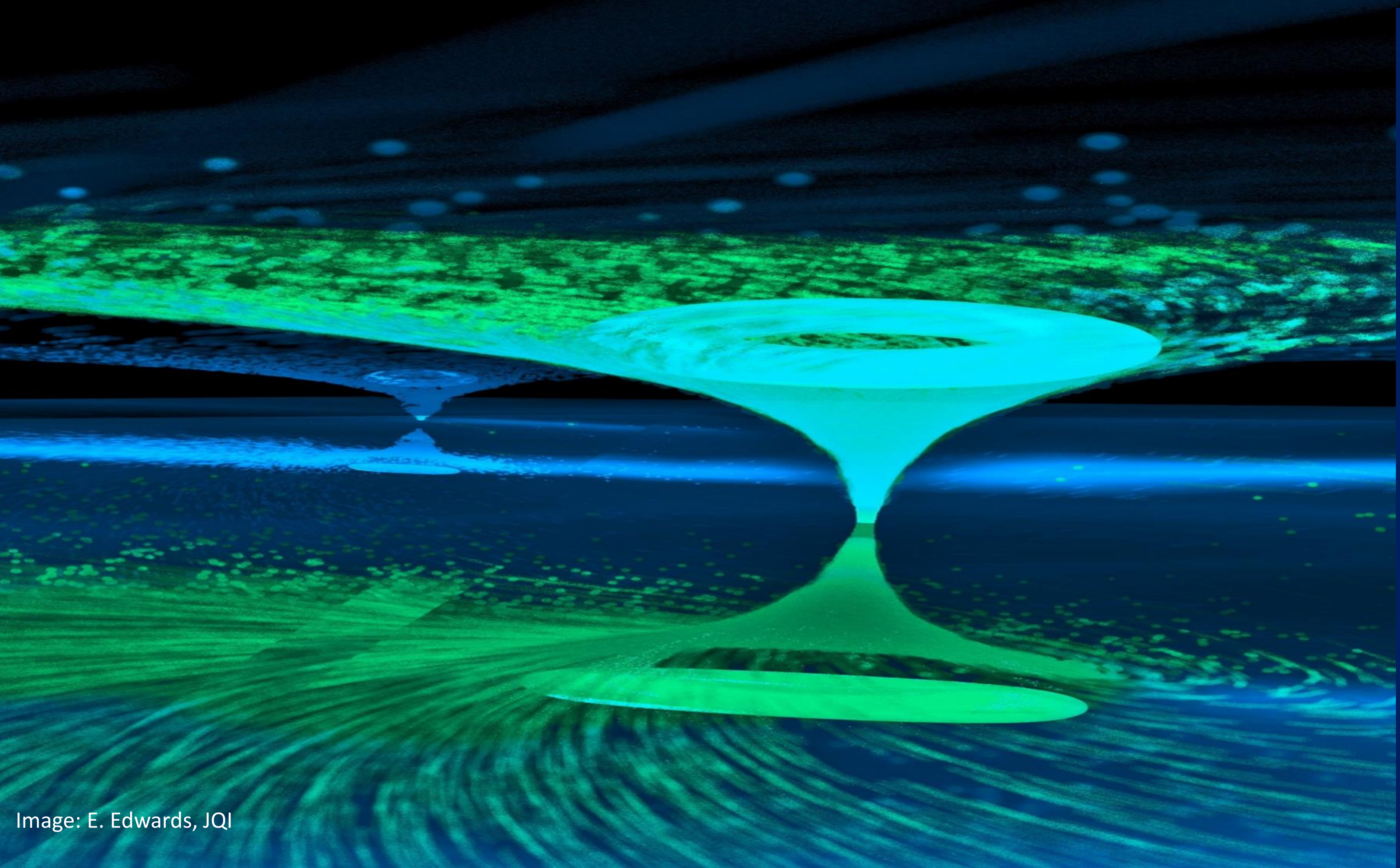


Image: E. Edwards, JQI

The Electronic Age

Vast global flow of data requires high-speed optical communication: ***Photonics***

Global reach requires precise network synchronization: ***Atomic clocks***

Atomic Clocks

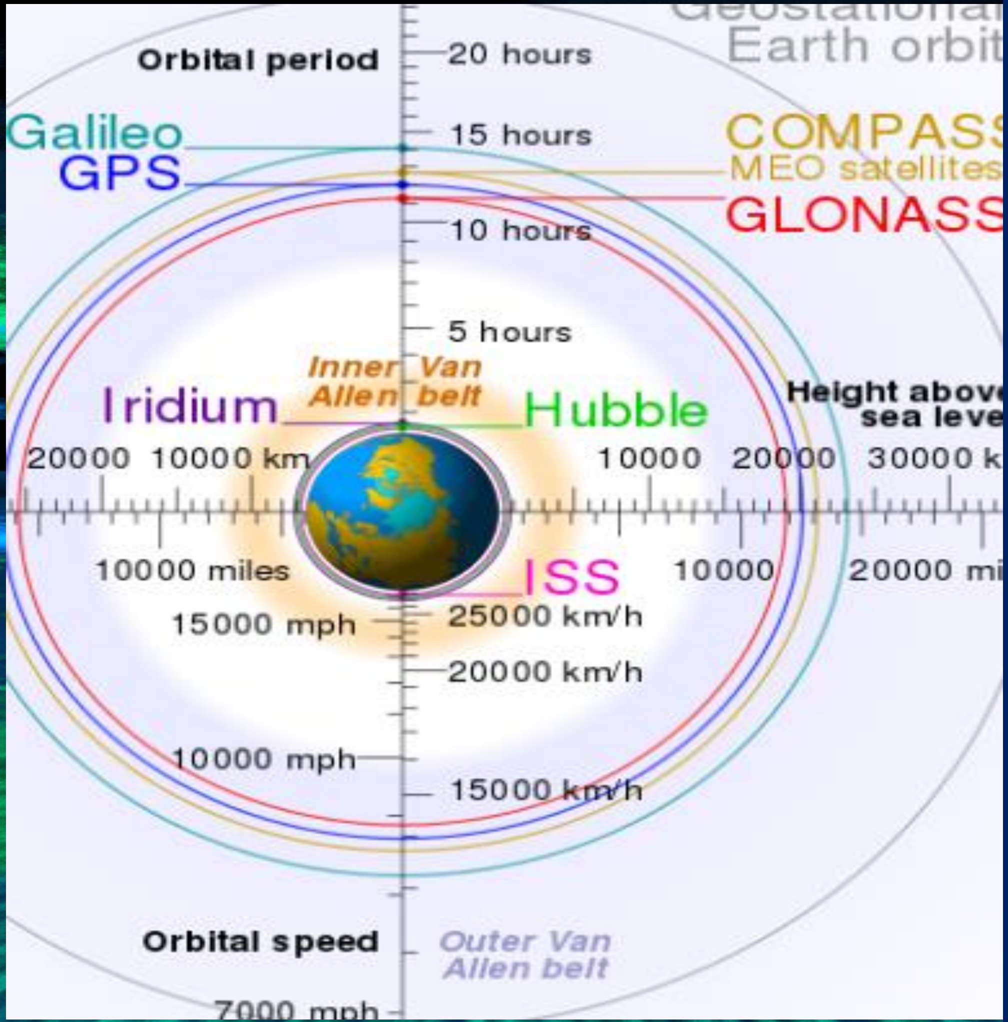


Image: Geo Swan

Constellations of Atomic Clocks Aboard Earth Satellites

Global Navigation Satellite Systems (GNSS):

- Global Positioning System GPS (USA)
- GLONASS (Russia)
- Galileo (Europe)

Regional coverage:

- BeiDou (China)
- NAVIC (India)

Vast global flow of data requires high-speed optical communication: ***Photonics***

Global reach requires precise network synchronization: ***Atomic clocks***

Atomic Clocks

The original atomtronic devices

Atom – most precise oscillator

– sets the standard of time

Image: C. Suplee, NIST

Global reach requires precise network synchronization: ***Atomic clocks***

The clock in the control room of the Laser Interferometer Gravitational-Wave Observatory at Hanford, WA, displays PST and GPS Time (in seconds).

Shown on a GPS-enabled smartphone.

Atomic Clocks

The original atomtronic devices

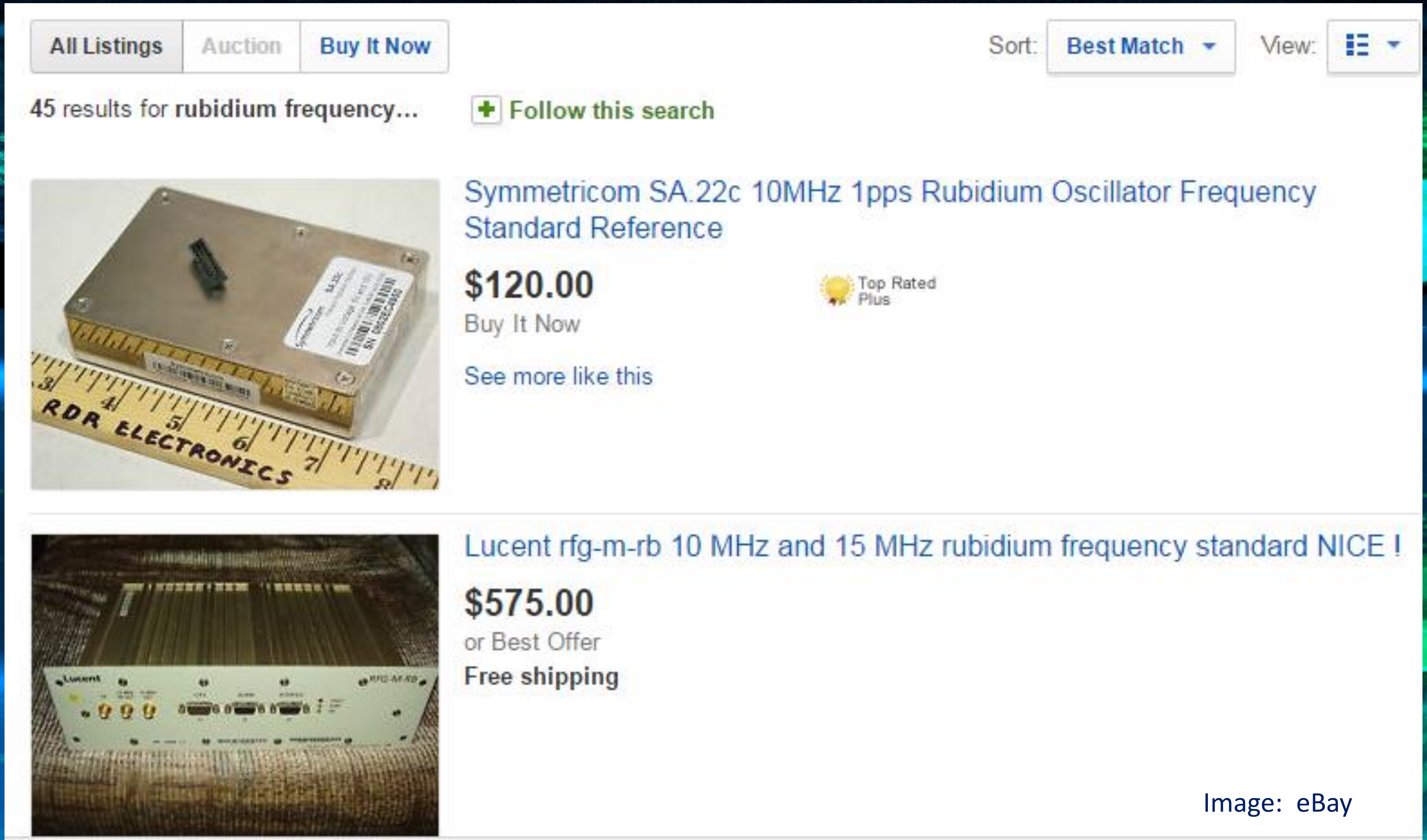
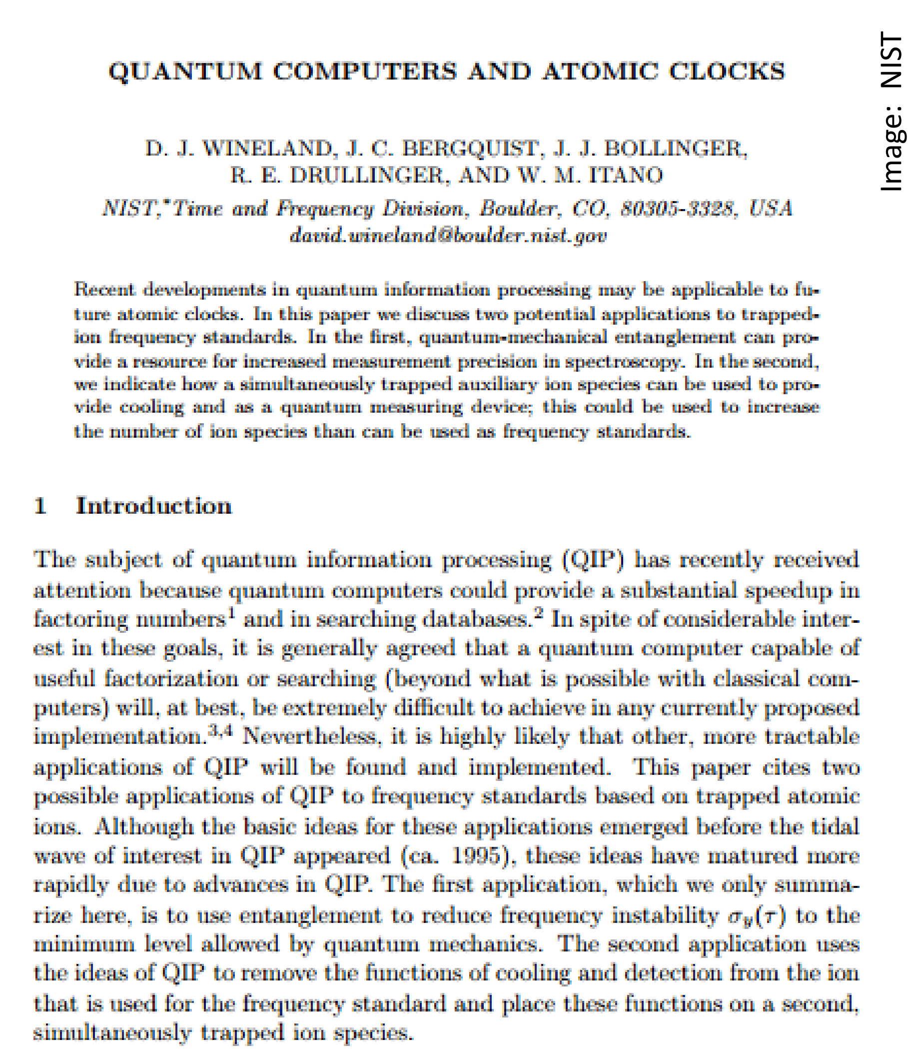


Image: eBay

Global reach requires precise network synchronization: ***Atomic clocks***

Get your own atomic clock on eBay for about a hundred bucks (plus shipping)

Quantum Computers and Atomic Clocks



QUANTUM COMPUTERS AND ATOMIC CLOCKS

D. J. WINELAND, J. C. BERGQUIST, J. J. BOLLINGER,
R. E. DRULLINGER, AND W. M. ITANO

*NIST,*Time and Frequency Division, Boulder, CO, 80305-3328, USA*
david.wineland@boulder.nist.gov

Recent developments in quantum information processing may be applicable to future atomic clocks. In this paper we discuss two potential applications to trapped-ion frequency standards. In the first, quantum-mechanical entanglement can provide a resource for increased measurement precision in spectroscopy. In the second, we indicate how a simultaneously trapped auxiliary ion species can be used to provide cooling and as a quantum measuring device; this could be used to increase the number of ion species than can be used as frequency standards.

1 Introduction

The subject of quantum information processing (QIP) has recently received attention because quantum computers could provide a substantial speedup in factoring numbers[1] and in searching databases.[2] In spite of considerable interest in these goals, it is generally agreed that a quantum computer capable of useful factorization or searching (beyond what is possible with classical computers) will, at best, be extremely difficult to achieve in any currently proposed implementation.[3,4] Nevertheless, it is highly likely that other, more tractable applications of QIP will be found and implemented. This paper cites two possible applications of QIP to frequency standards based on trapped atomic ions. Although the basic ideas for these applications emerged before the tidal wave of interest in QIP appeared (ca. 1995), these ideas have matured more rapidly due to advances in QIP. The first application, which we only summarize here, is to use entanglement to reduce frequency instability $\sigma_y(\tau)$ to the minimum level allowed by quantum mechanics. The second application uses the ideas of QIP to remove the functions of cooling and detection from the ion that is used for the frequency standard and place these functions on a second, simultaneously trapped ion species.

Image: NIST

http://bit.ly/AtomQC

Only have time to read just one atomic physics paper in your life?

← Try this.

David J. Wineland
2012 Nobel Prize in Physics

"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"

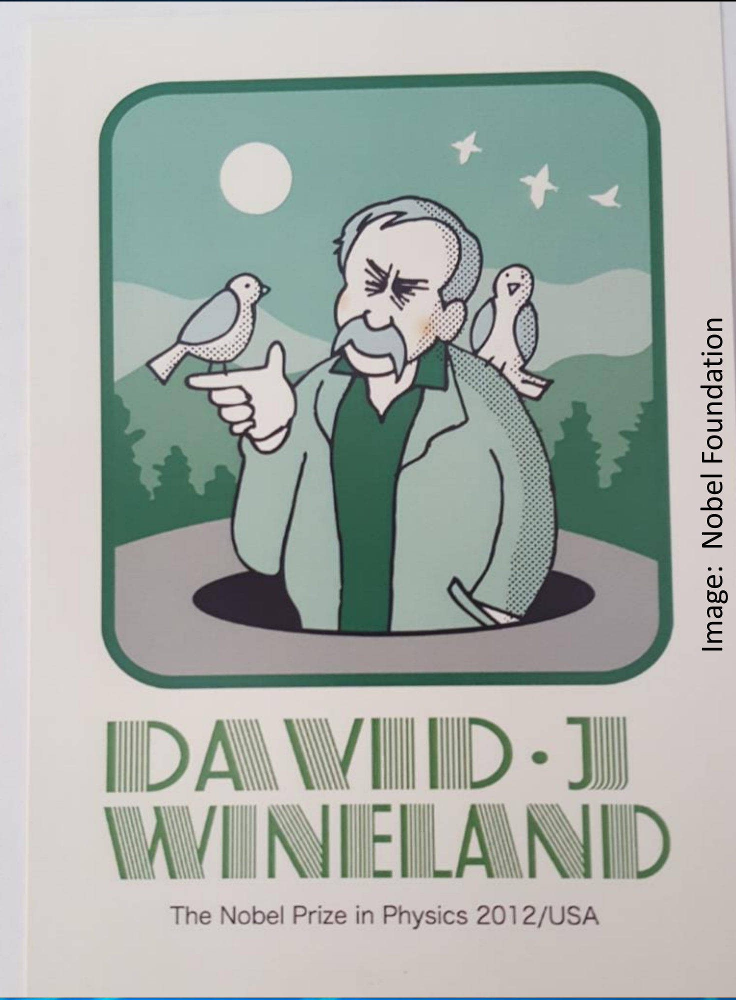
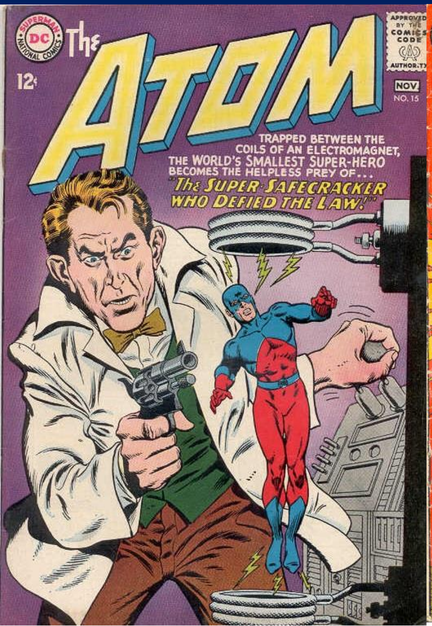
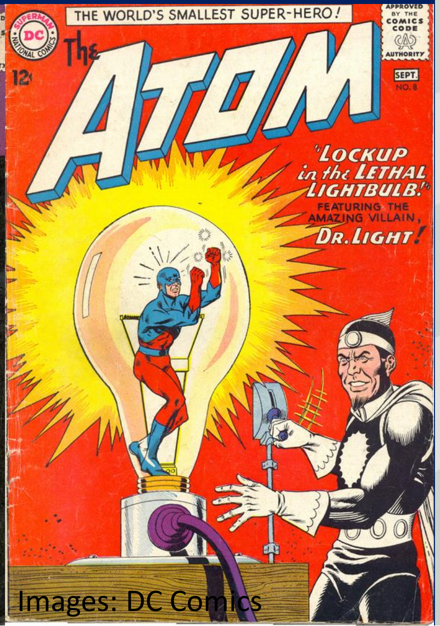


Image: Nobel Foundation

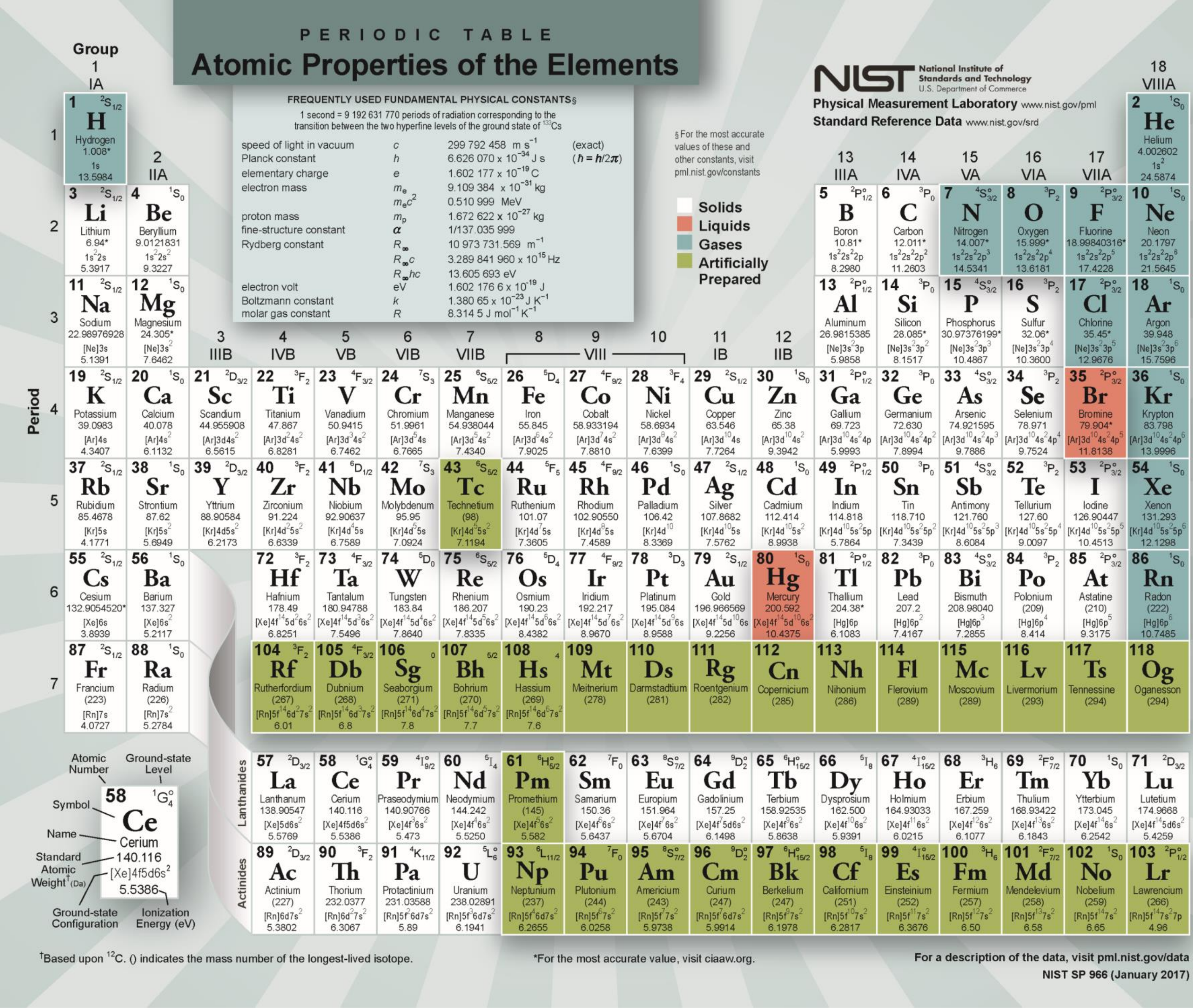
Atoms

- Identical
- Stable
- Quantum
- Diverse



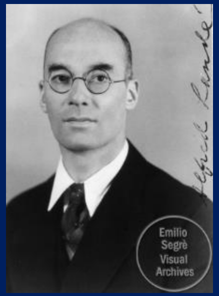


Images: DC Comics



Atoms

- Identical
- Stable
- Quantum
- Diverse
- Electronic "vibrations"
- Light excitations



Alfred Landé
1888-1976

The "virtual orchestra" of atomic oscillators in the Sun's atmosphere.

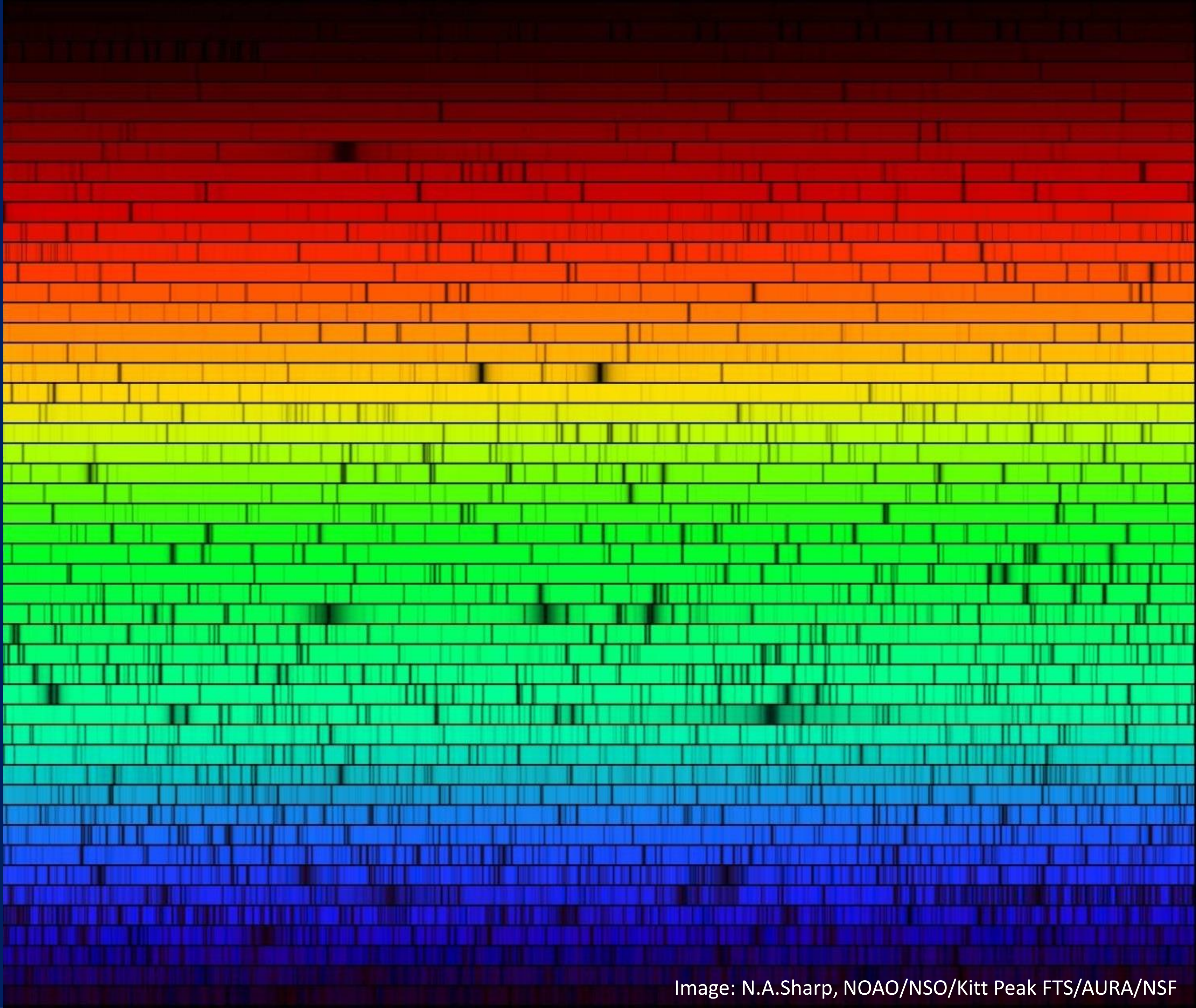


Image: N.A.Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF

Atomtronics timeline

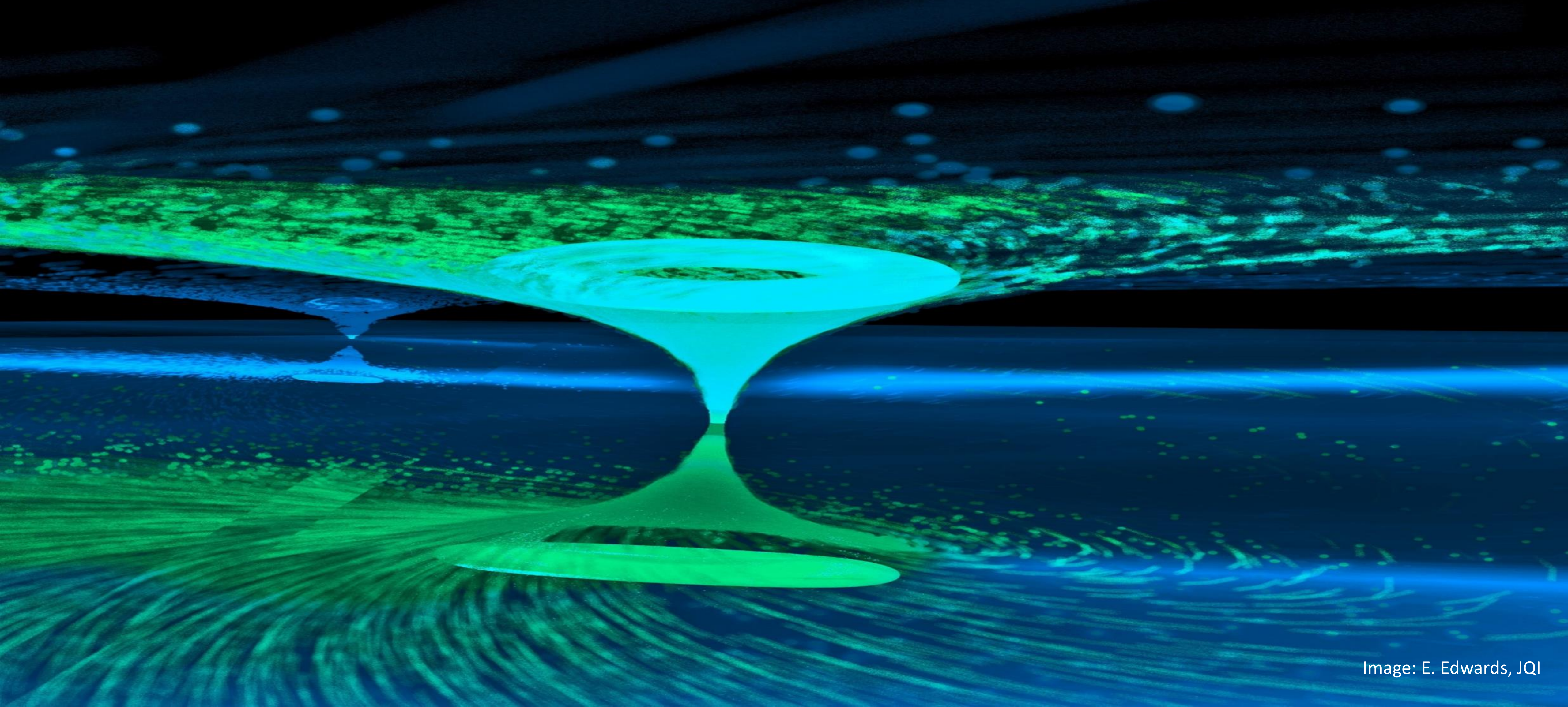
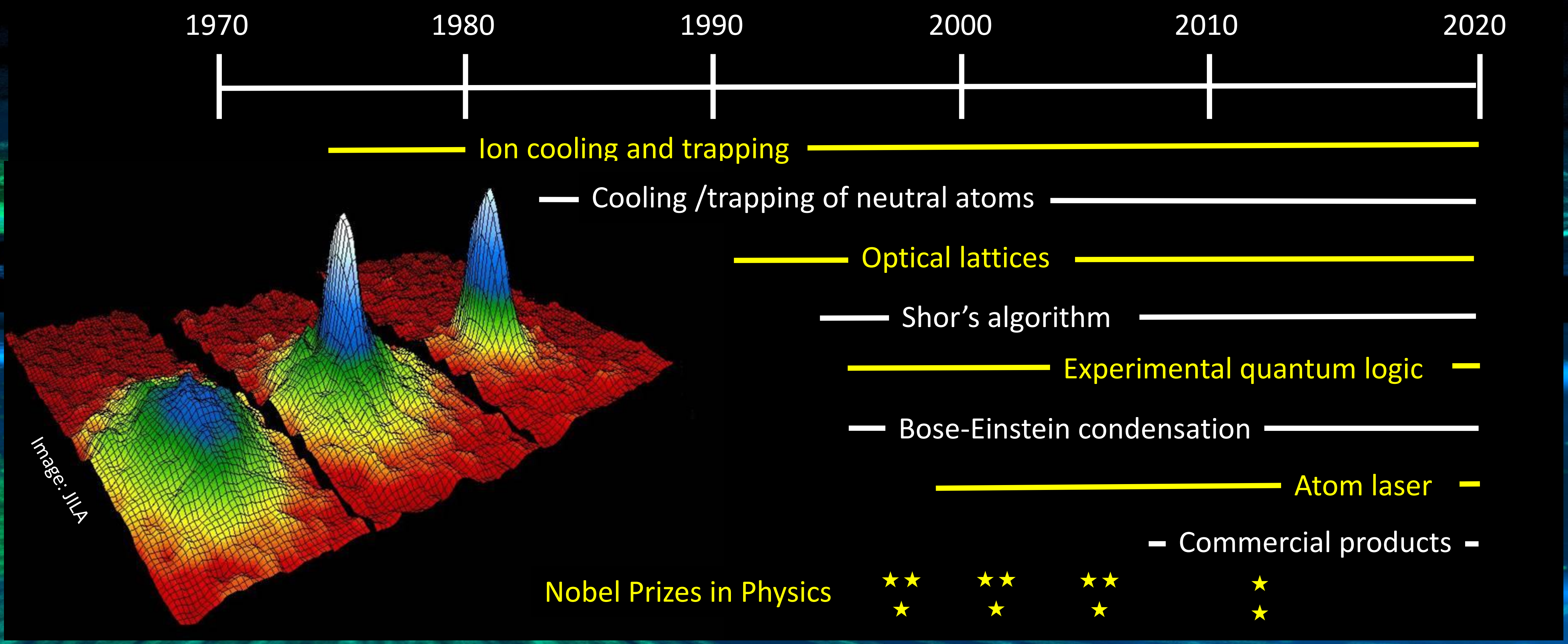


Image: E. Edwards, JQI

Atomtronics timeline



Atomtronics applications

New Journal of Physics Focus on Atomtronics-enabled Quantum Technologies

http://j.mp/At0mtr0nics

Precision measurement – quantum-enhanced clocks, matter-wave interferometry

Sensing: magnetometry, gravity/gradiometry, rotation, acceleration

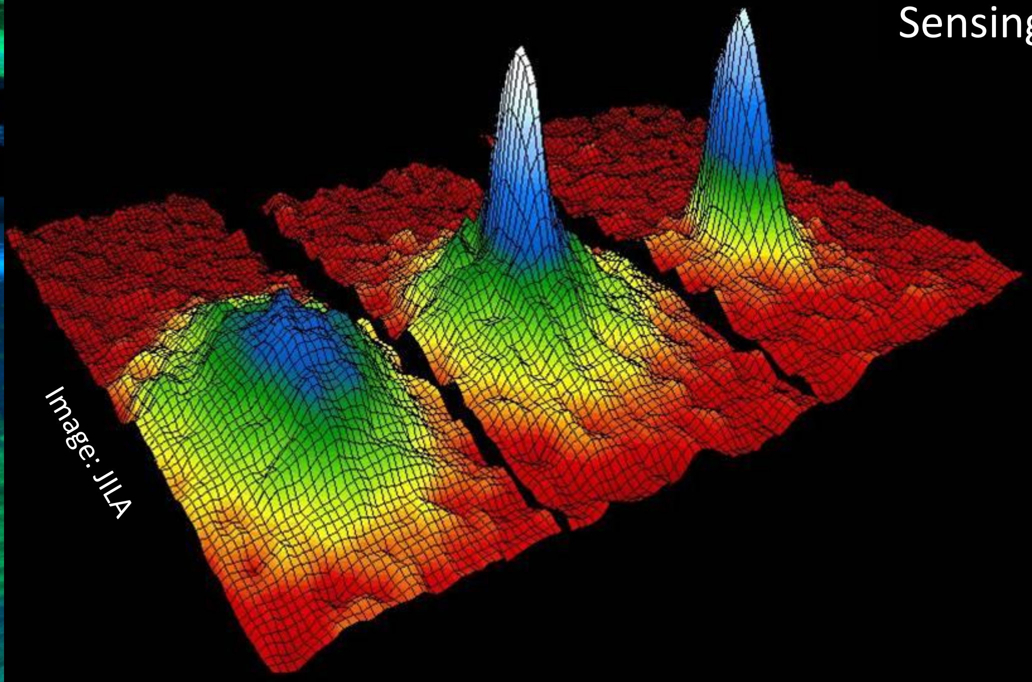
Novel scanning probe microscopy

Novel superconductivity and superfluidity

Experimental quantum logic

Novel magnetism and synthetic magnetic fields

Simulating complex quantum systems



Recent atomtronic devices

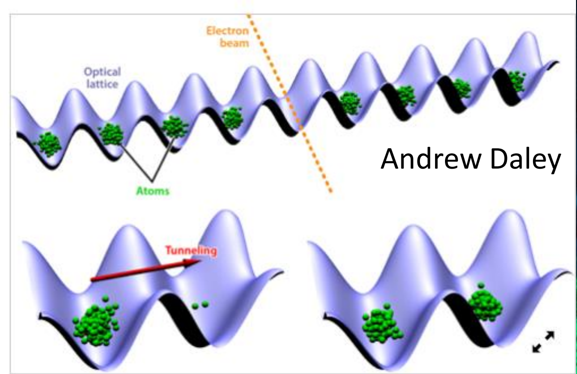
Portable BEC chamber (2014)

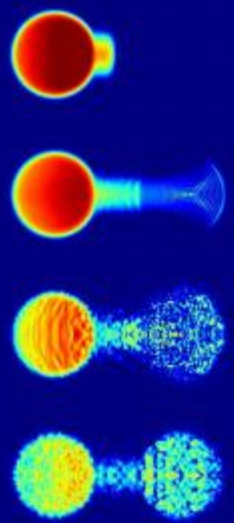
ColdQuanta

Atom SQUID (2014)

NIST

Diode (2015)

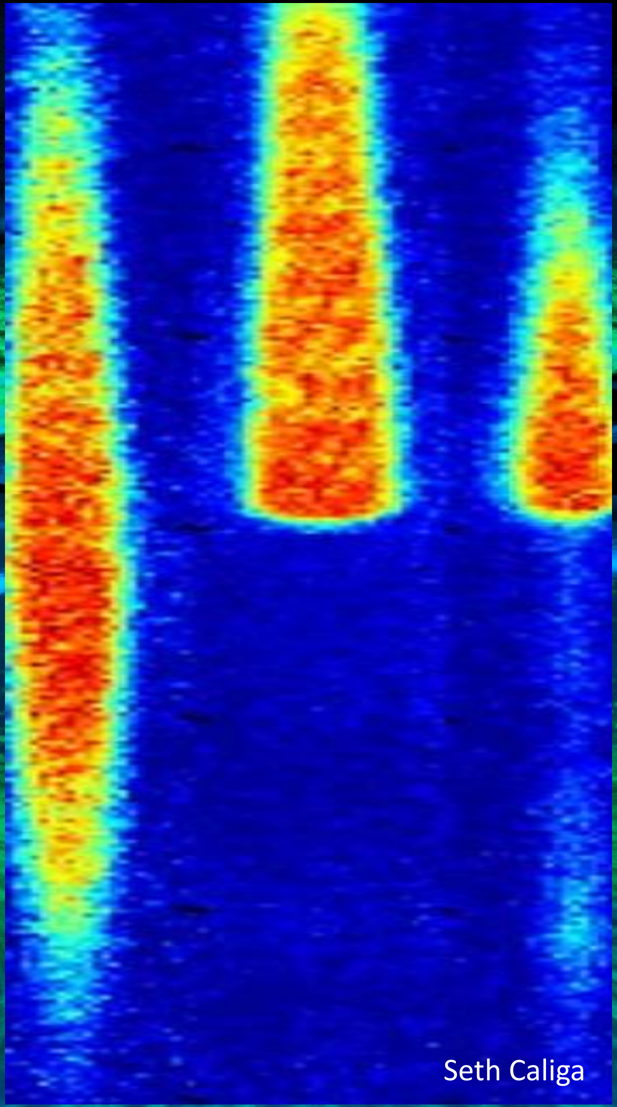




Tank Circuit (2016)

Mark Edwards

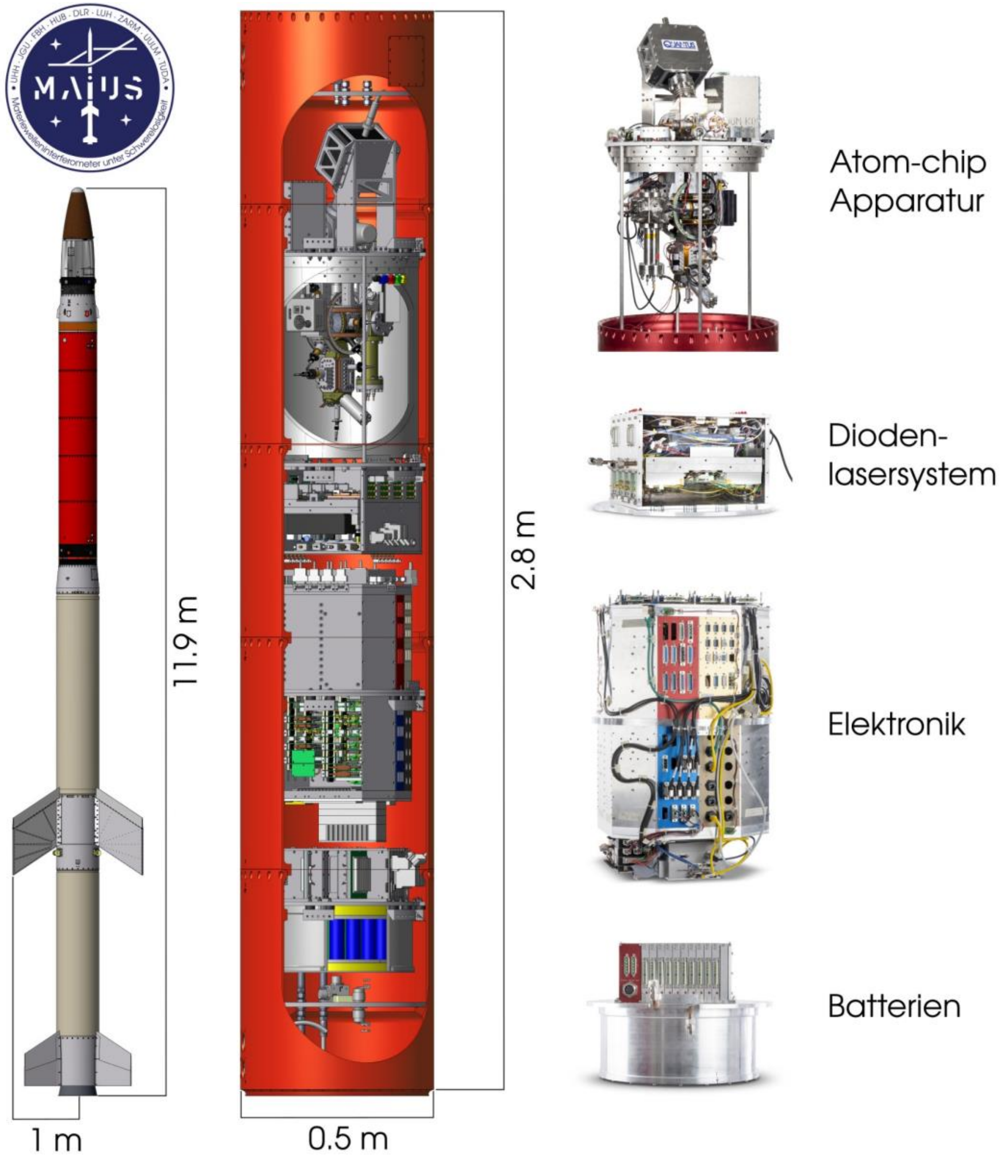
Battery (2017)



Seth Caliga

Atomtronics today

First Bose-Einstein condensate in space



Images: DLR

MAIUS 1 Sounding Rocket Mission

- MAIUS: Matter-Wave Interferometry in Microgravity
- Launched 23 January 2017 in northern Sweden
- Produced Bose-Einstein condensate on board
- Performed 100 experiments in matter-wave interferometry