2026: Celebrating FERMI

PROGRAMME

The Enrico Fermi paper "Sulla Quantizzazione del gas perfetto monoatomico" was presented to the Academia Nazionali dei Lincei by Antonio Garbasso at the Session of February 7, 1926. Franco Rasetti, In the "Collected Papers" by Enrico Fermi, mentions this paper as "probably his most famous theoretical contribution, when he formulated the theory ...of particles...now designated in his honour as fermions"

Thursday 5 February

10.00 *Welcome address*

Carlo DOGLIONI (Presidente della Classe di Scienze Fisiche, Matematiche e Naturali dell'Accademia Nazionale dei Lincei)

Angela BRACCO (Presidente della Società Italiana di Fisica e del Centro Enrico Fermi)

Chair: Massimo INGUSCIO (Linceo, UCBM-Roma, LENS-Firenze)

10.20 Klaus VON KLITZING (Max Planck Institute for Solid State Research): *A Century of Fermi Energy: Quantum Hall Physics and Metrology*

11.00 Leonardo FALLANI (Università di Firenze): *New quantum simulations with ultracold Yb fermions*

11.40 Coffee break

Alessandro Volta: building the future with science

International Conference
Villa Erba, Cernobbio, 14-15 April 2025

Opening event of the celebrations for the bicentenary of the death of Alessandro Volta

From scientific discoveries and research to new technologies and innovation for the benefit of human kind

Program

April 14, 2025 (International World Quantum Day)

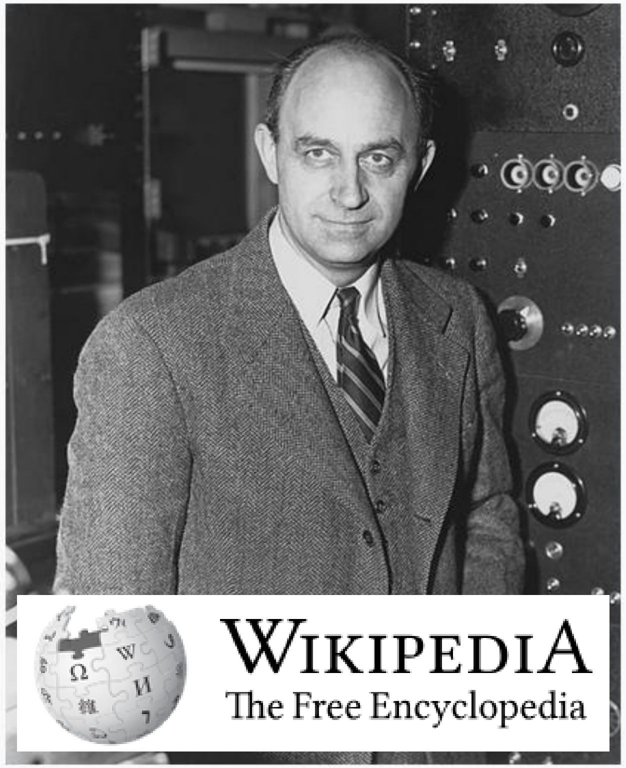
15:00 Institutional greetings and introduction

*Chair **Massimo Inguscio**, Accademia Nazionale dei Lincei*

15:30 **Klaus von Klitzing**, *Nobel Prize in Physics 1985, Max Planck Institute*
Electrical Measurements and Quantum Physics

2026: Celebrating FERMI

Enrico Fermi
ForMemRS



Fermi in 1943

Born	29 September 1901 Rome, Italy
Died	28 November 1954 (aged 53) Chicago, Illinois, U.S.

125th birthday

1901: the year of the first Nobel Prize

Nobel Prize Physics 1938

FERMIONS
FERMI-DIRAC DISTRIBUTION
FERMI-ENERGY
FERMIOLOGY
Composite FERMIONS
……

Nobel Lecture, December 12, 1938
Artificial Radioactivity Produced by Neutron Bombardment

FERMI unexpectedly saw FISSION

VON KLITZING unexpectely saw QUANTUM HALL EFFECT

On the Quantization of the Monoatomic Ideal Gas

2026: Celebrating FERMI

"Rend. Lincei 3, 145-149 (1926).
presented by the Associate A. Garbasso at the meeting of 7 February 1926

On the Quantization of the Monoatomic Ideal Gas

E. Fermi

Introduction

A recent experiment [1] has brought a nearly-ideal gas of Fermi-Dirac particles (^{40}K atoms) to the condition of *quantum degeneracy*, in which the symmetry of the many-particle wavefunction has a dominant effect on the equation of state of the gas.

In the above-mentioned experiment, the gas atoms were confined by a magnetic field, whose effect is expressed by the harmonic potential,

$$V(x, y, z) = \frac{M}{2}\left(w_r^2(x^2 + y^2) + w_z^2 z^2\right)$$

where x, y, z are Cartesian particle coordinates, M is the particle mass, $\omega_r = 2\pi\,137$ Hz, and $\omega_z = 2\pi\,19.5$ Hz. This situation is close to that portrayed in the

FERMIONS
FERMI-DIRAC DISTRIBUTION
FERMI-ENERGY
FERMIOLOGY
Composite FERMIONS
……

QUANTUM Hall Effect
*** 5 February 1980**

February 5, 2026:
A conference day to celebrate TWO birthdays

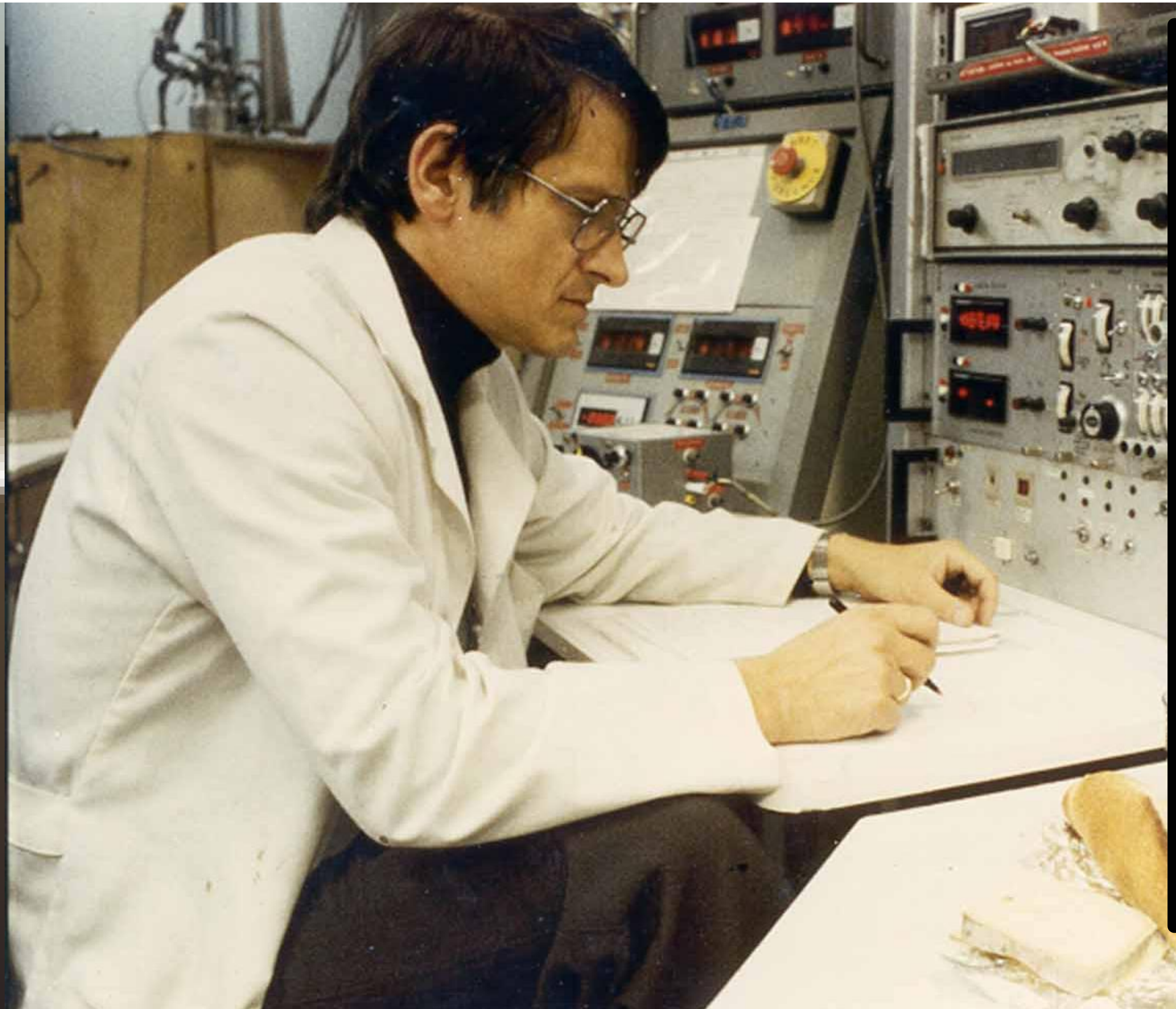
100th birthday of Fermi-Dirac statistic

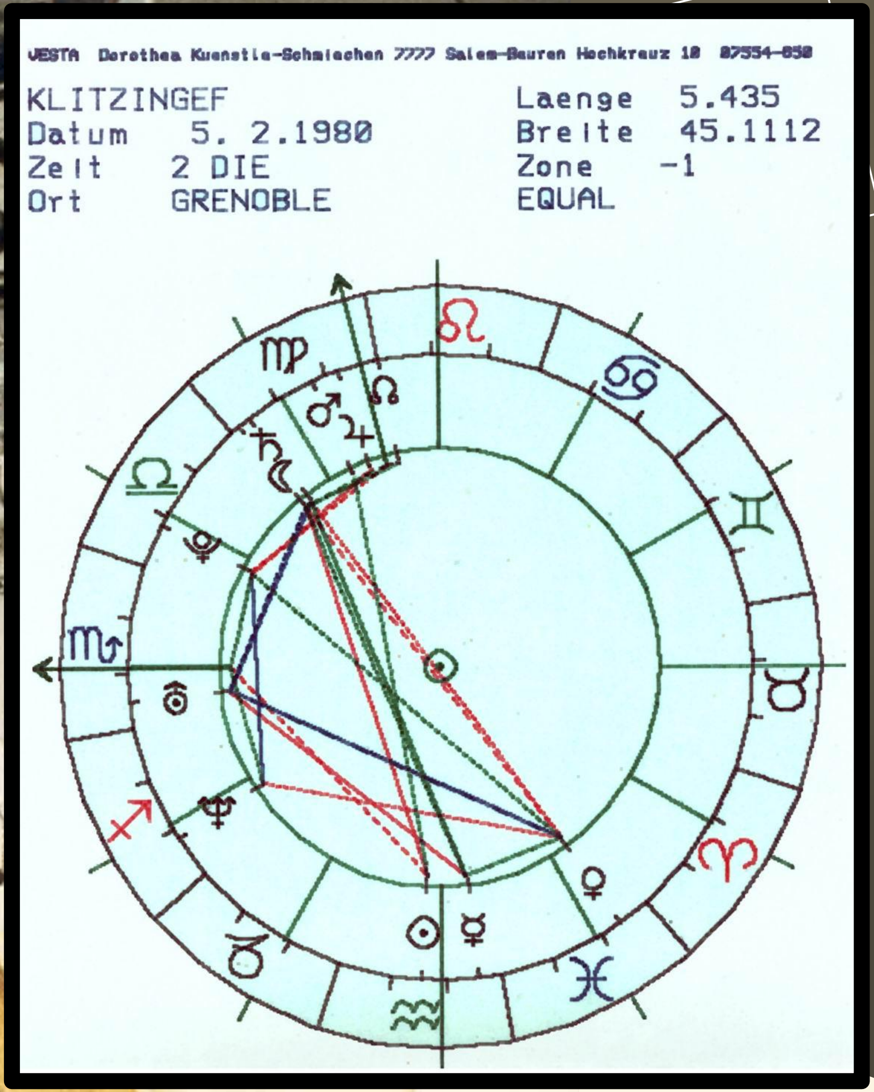
46th birthday of Quantum Hall Effect with the consequence of a new SI system

Since 20.5.2019:

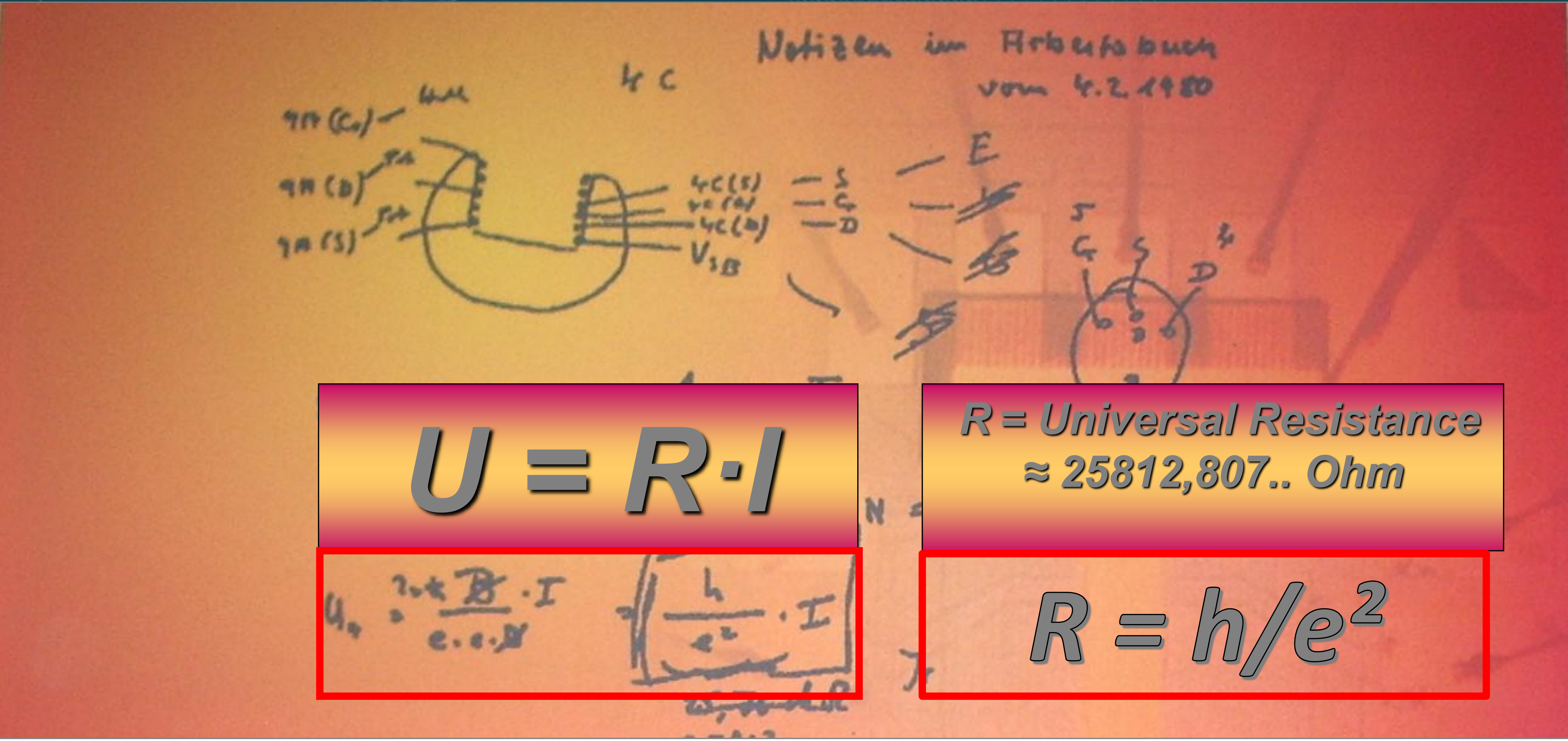
New Kilogram
New Ampere
New Kelvin
New Mole

Birth of the Quantum Hall Effect *2/5/1980 at 2 a.m.





Copy of my Notebook



$$U = R \cdot I$$

R = Universal Resistance
≈ 25812,807.. Ohm

$$R = h/e^2$$

Application of QHE:

A New Electrical Resistor with a value R = h/e²

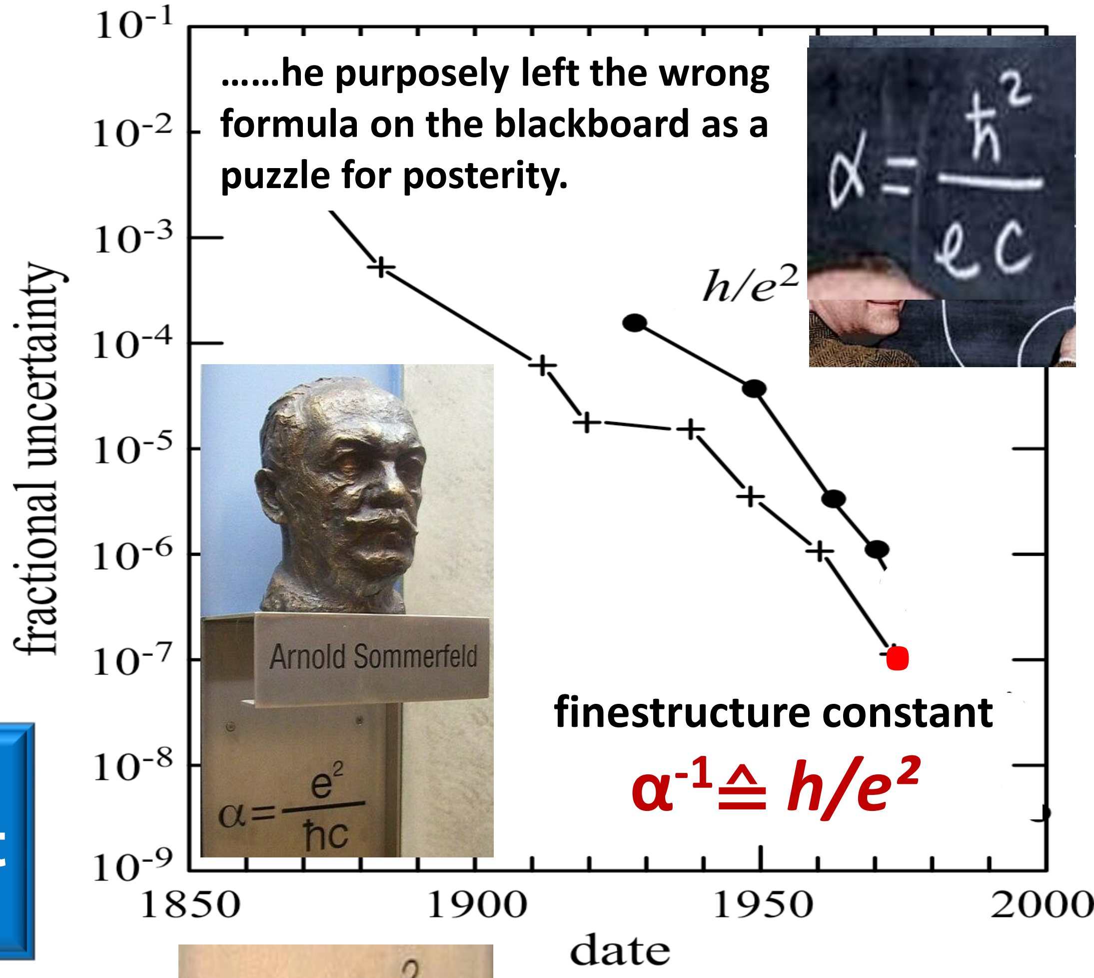
Realization of a Resistance Standard

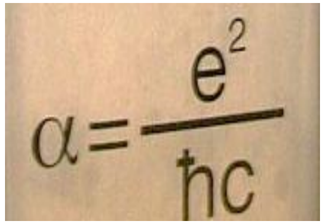
If h/e² is known

Determination of the Fundamental Constant R = h/e²

If calibrated Ohm available

Application 1980





Remarks on the quantum theory of the absolute zero of temperature

G.Beck, H. Bethe, and W. Riezler

Die Naturwissenschaften 2, 38-39, (1931)

"Correction"

Die Naturwissenschaften, March 6, 1931

The note by G. Beck, H. Bethe and W. Riezler, published in the January 9 issue of this journal, was not meant to be taken seriously. It was intended to characterize a certain class of papers in theoretical physics of recent years which are purely speculative and based on spurious numerical agreements. In a letter received by the editors from these gentlemen they express regret that the formulation they gave to the idea was suited to produce misunderstanding.

$$T_0 = -(2/\alpha - 1) \text{ degrees.}$$

Putting $T_0 = -273°$ we obtain for $1/\alpha$ the value 137 in perfect agreement within the limits of accuracy with the value obtained by totally independent methods. It can be seen very easily that our result is independent of the particular crystal lattice chosen.

G. Beck, H. Bethe, W. Riezler

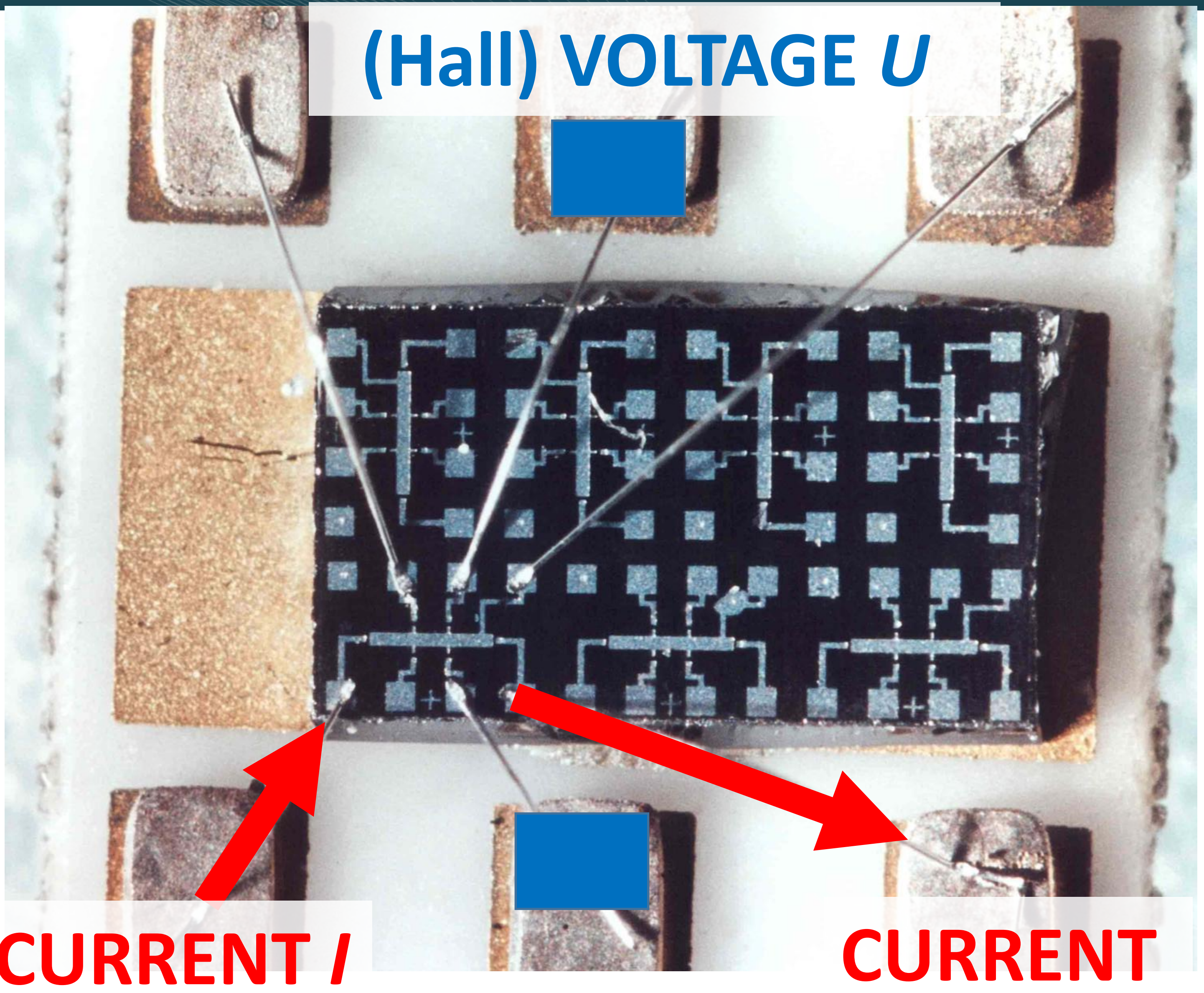
Cambridge, 10 December 1930

Nobel Prize for RAMAN

Discovery of the Quantum Hall Effect

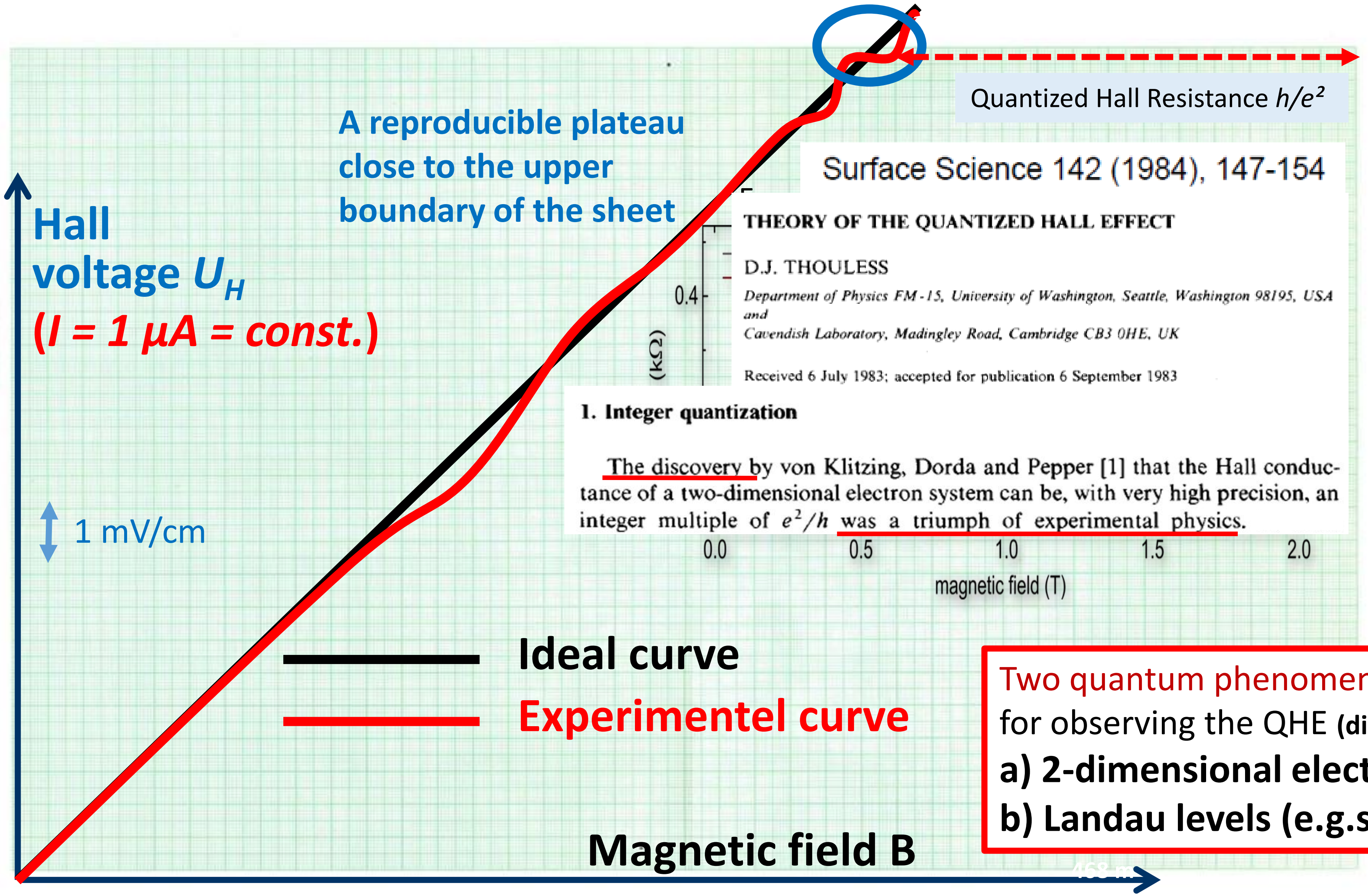
My field of research:
How to understand the movement of electrons in MOSFETs for smaller and faster devices

<u>Basic research on the most important device in microelectronics (silicon field effect transistor = MOSFET) led to the unexpected discovery of the quantized Hall effect</u>



From the work of an experimental physicist….

HALL EFFECT



Two quantum phenomena necessary for observing the QHE **(discrete energies):**

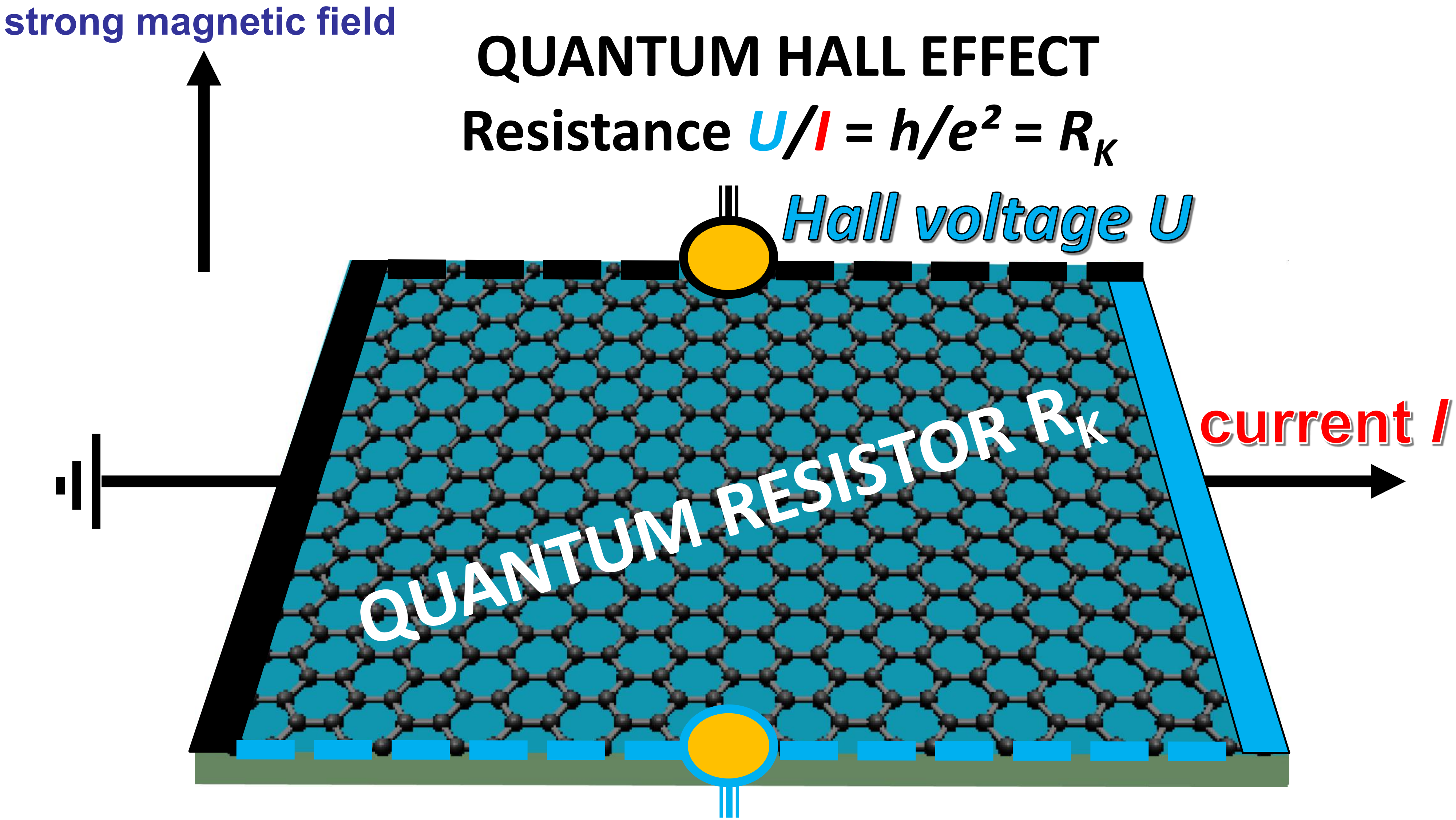
a) 2-dimensional electron system

b) Landau levels (e.g.strong B)

GRAPHENE (atomic layer of Carbon)
(ideal 2-dimensional conductor):

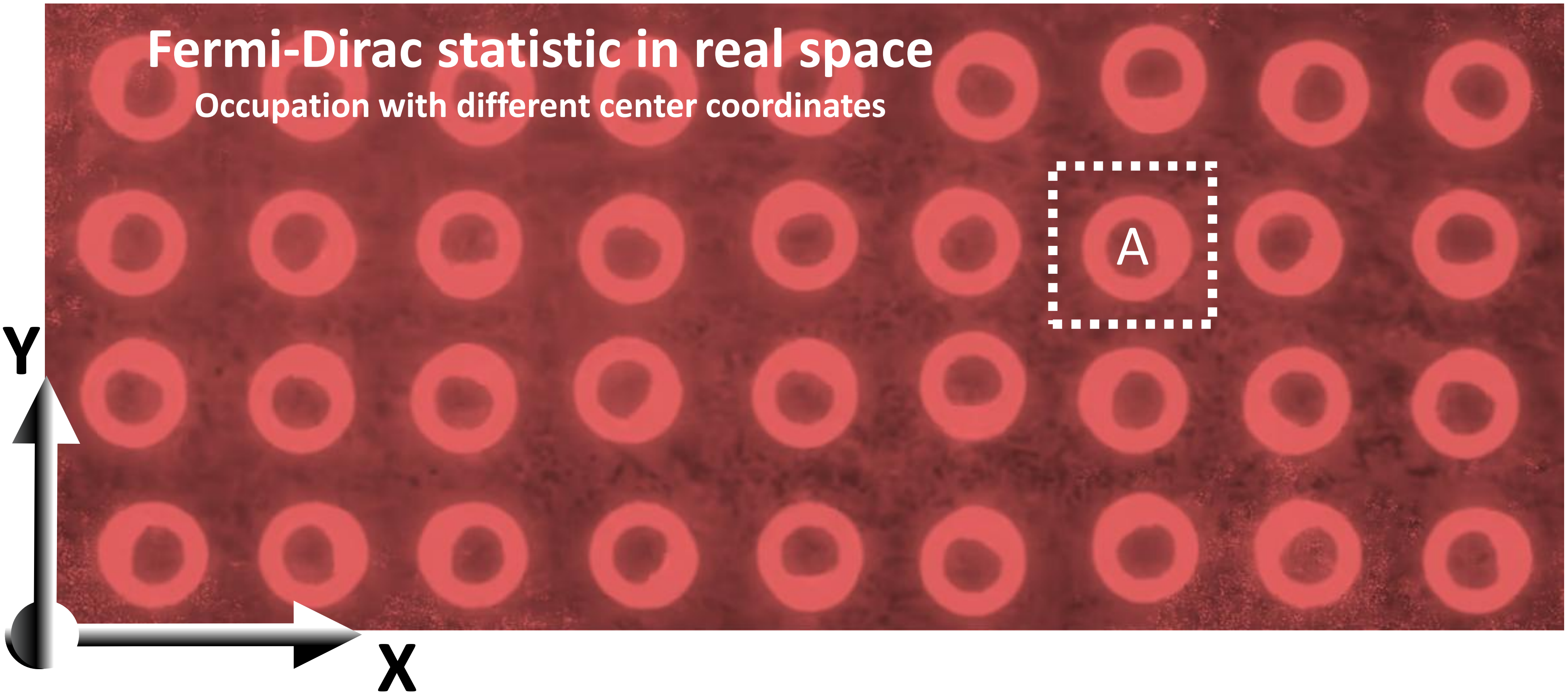
QUANTUM HALL EFFECT

Resistance $U/I = h/e^2 = R_K$



2-dim. electron system + strong magnetic fields:

Electrons move on closed cyclotron orbits (like in atomic physics)



Area A for one cyclotron orbit:

$A = \Delta X \cdot \Delta Y = h/eB$

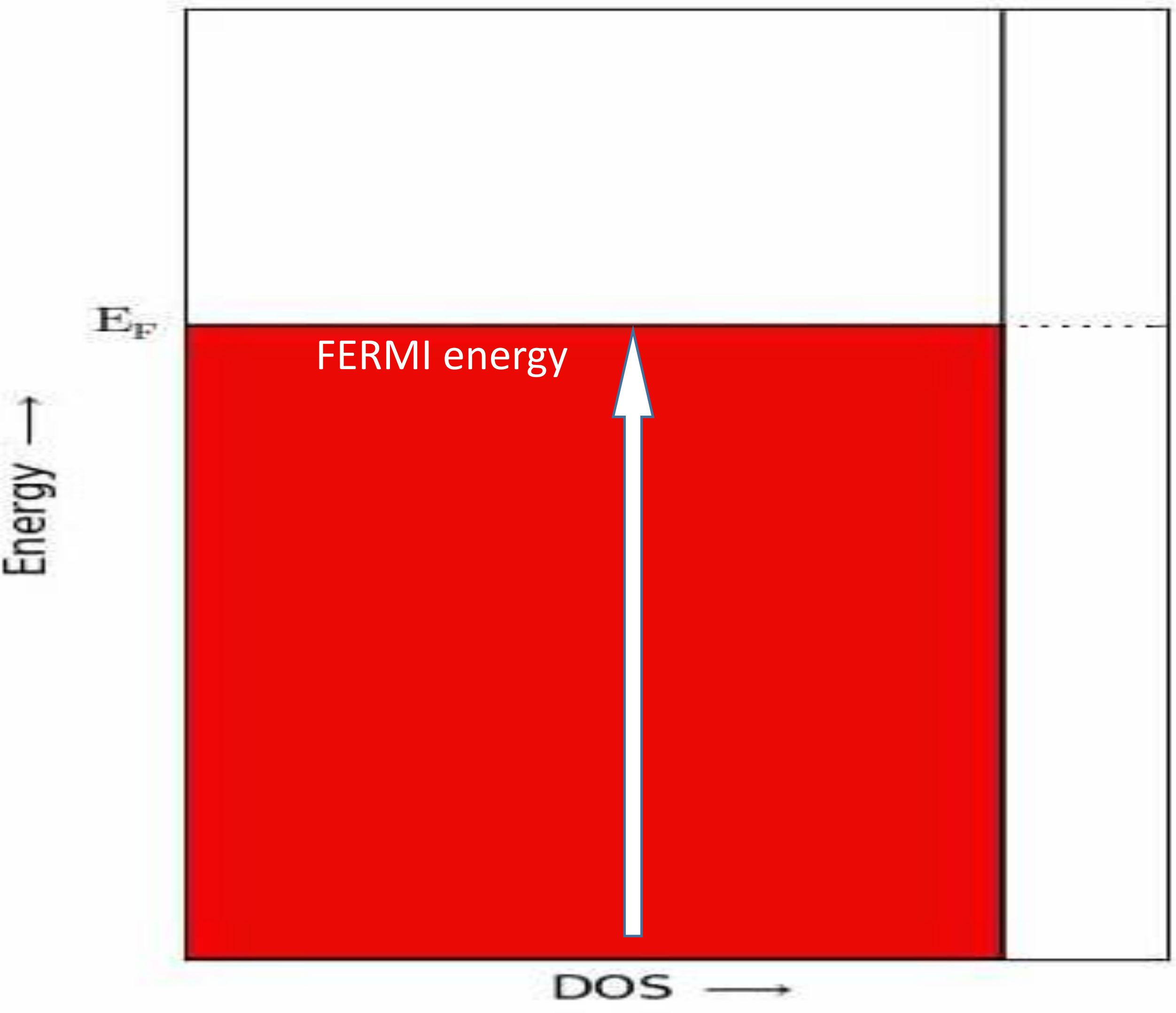
= area of 1 flux quantum

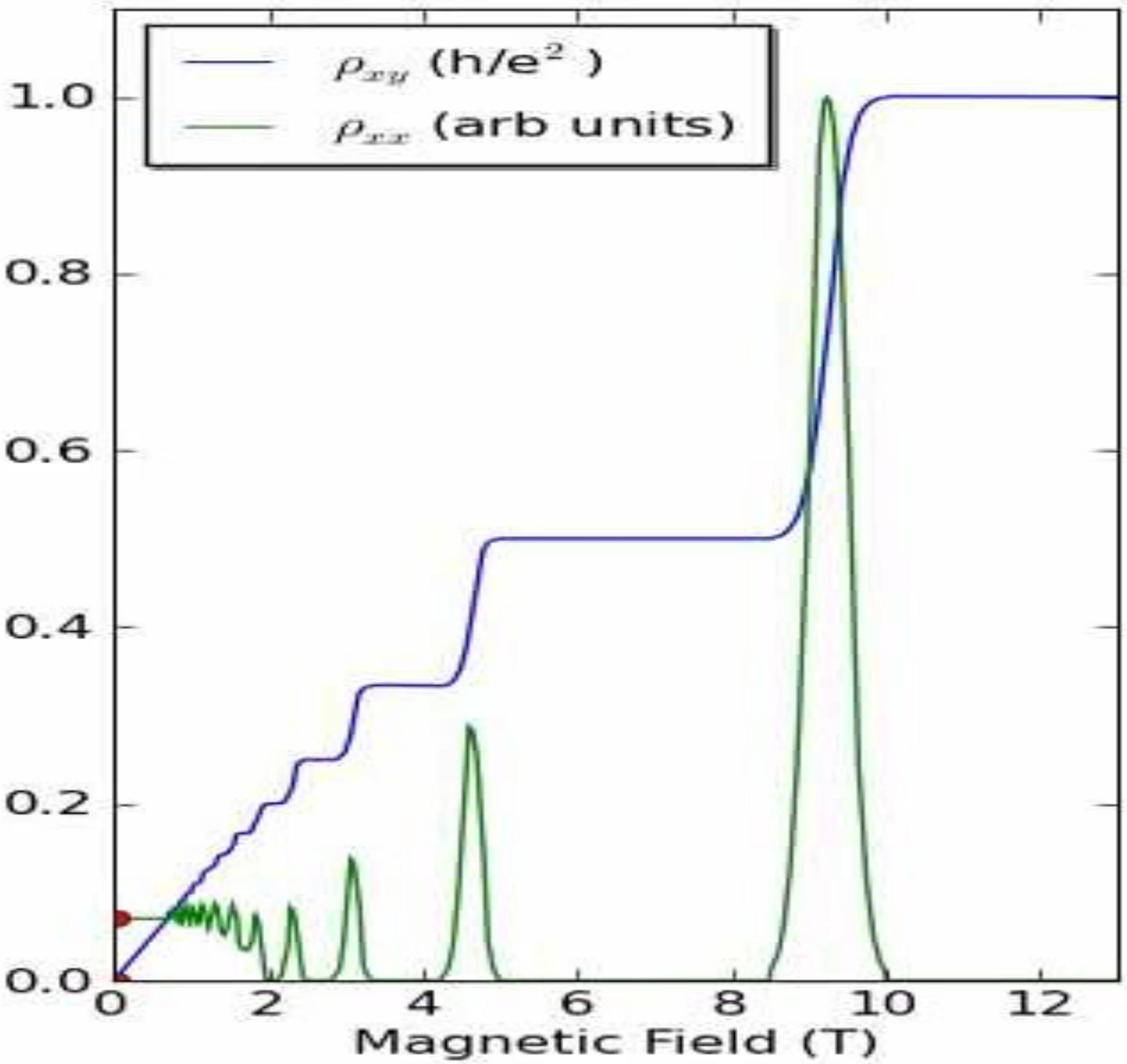
(uncertainty relation in REAL SPACE !)

QHE =
closely packed
electron orbits
(incompressible)

Wikipedia Explaination of QUANTUM HALL EFFECT

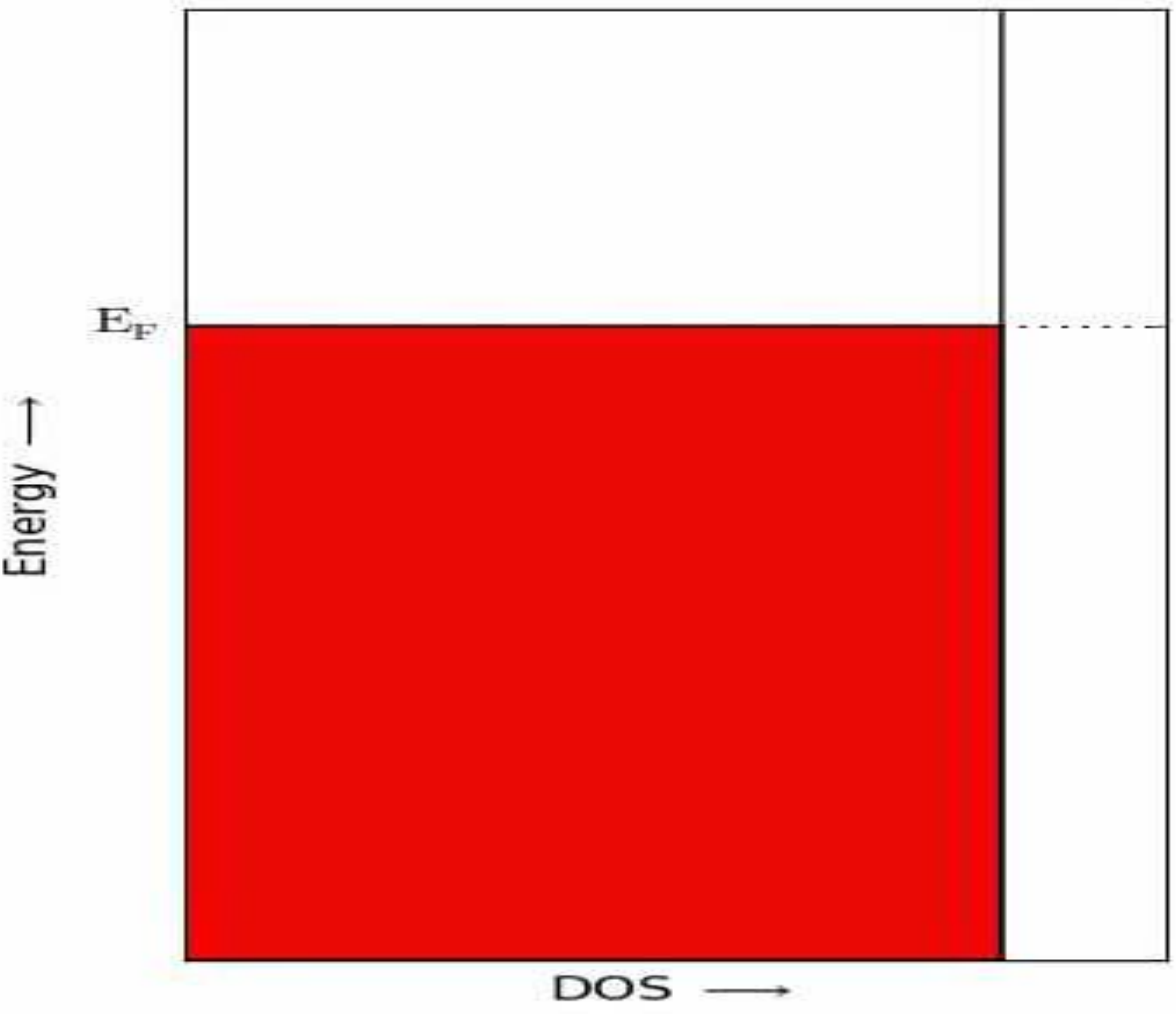
B=0: constant density of states

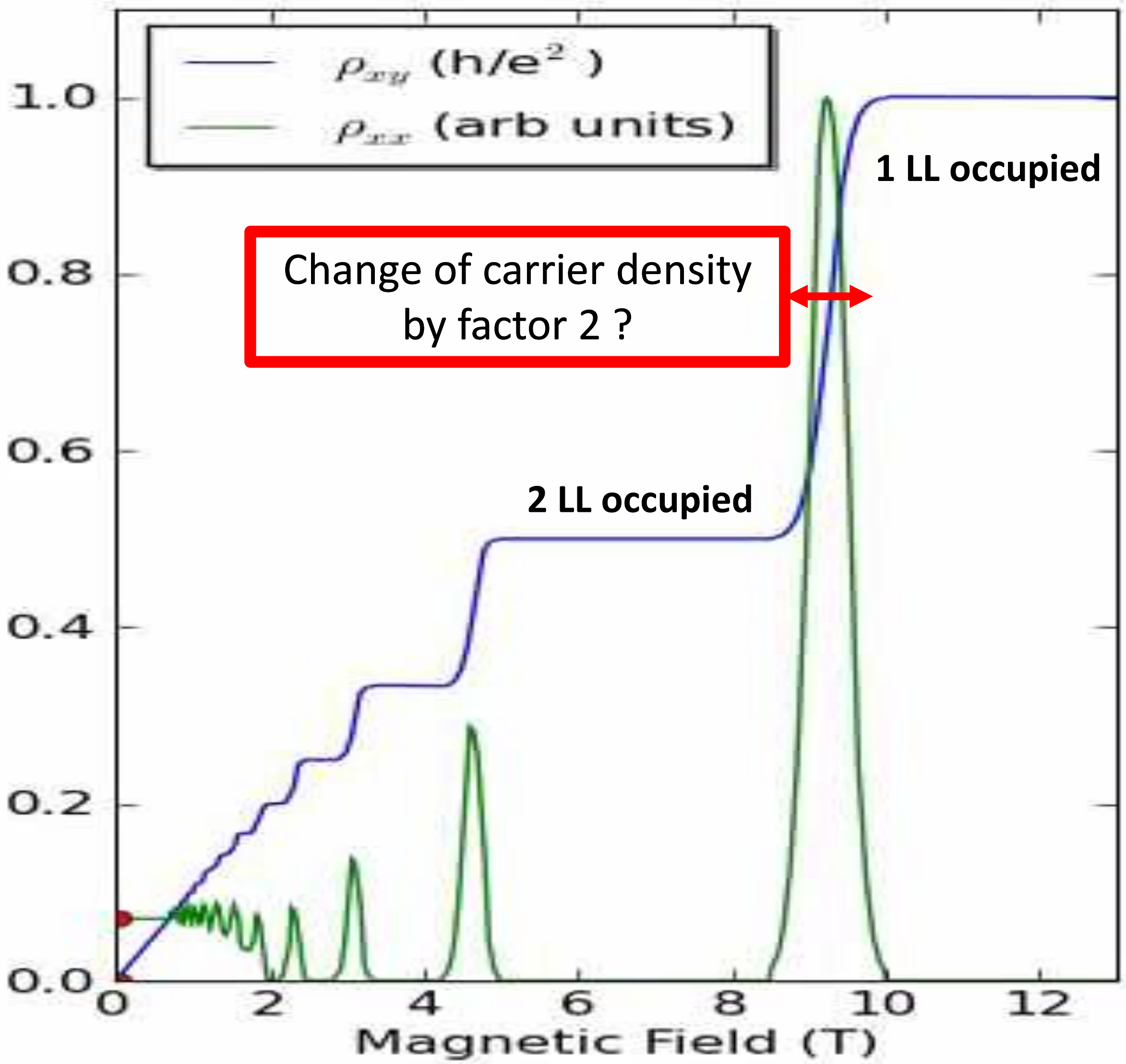




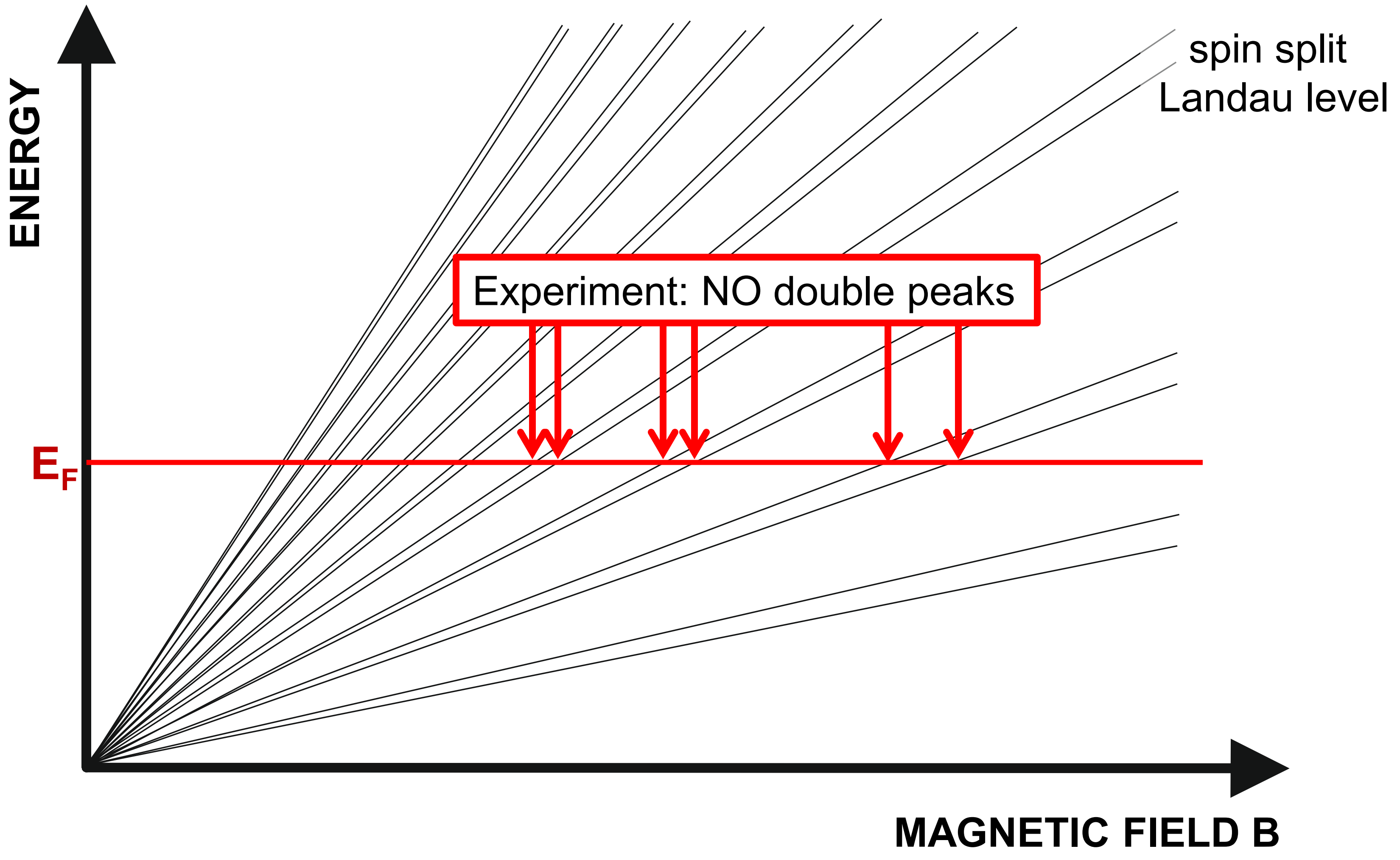
Wikipedia Explaination of QUANTUM HALL EFFECT

B=0: constant density of states

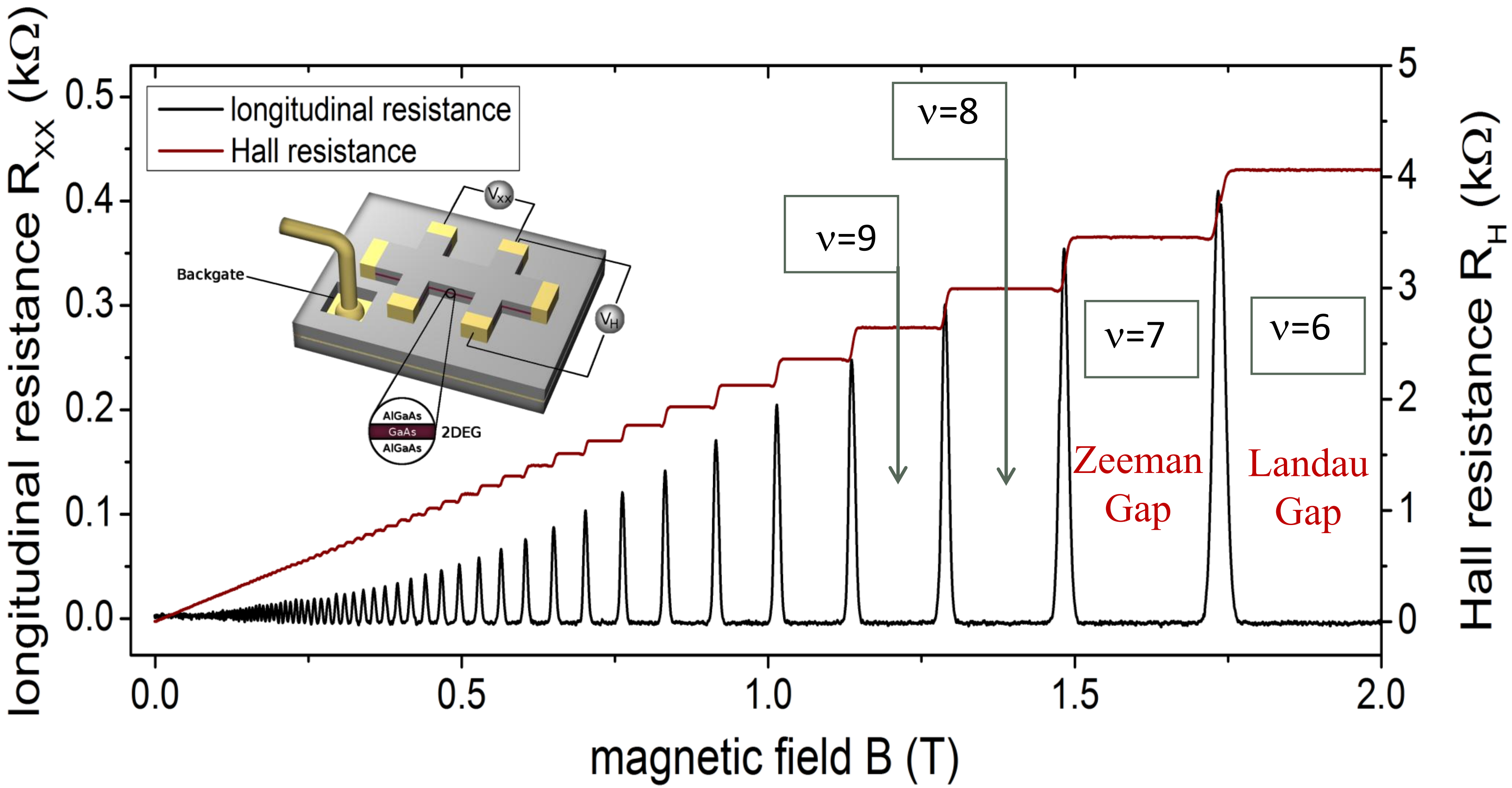




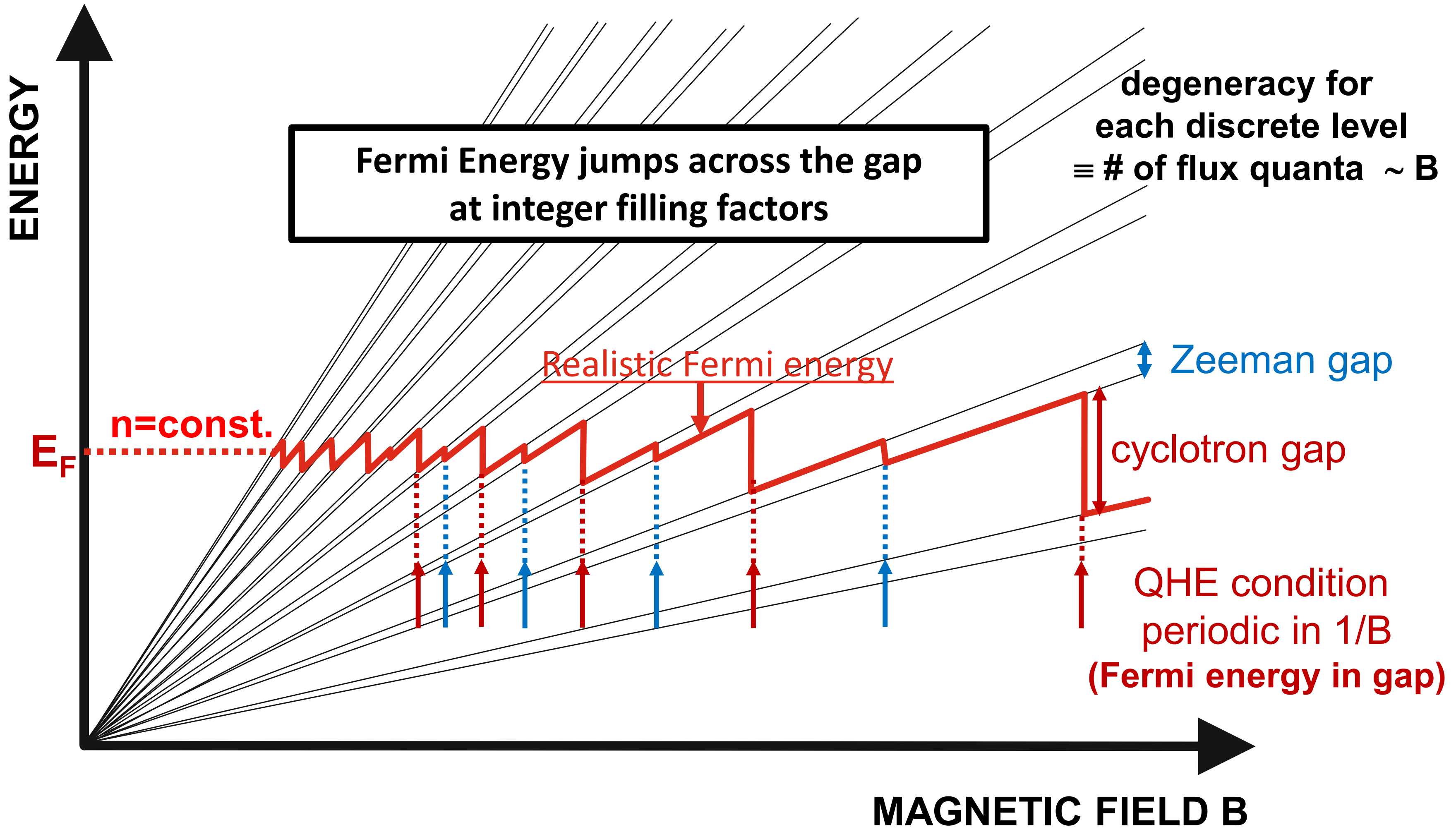
Quantum Hall Devices (GaAs): Spin Splitting of Landau Levels



Integer Quantum Hall Effect for High Mobility GaAs/AlGaAs Heterostructure



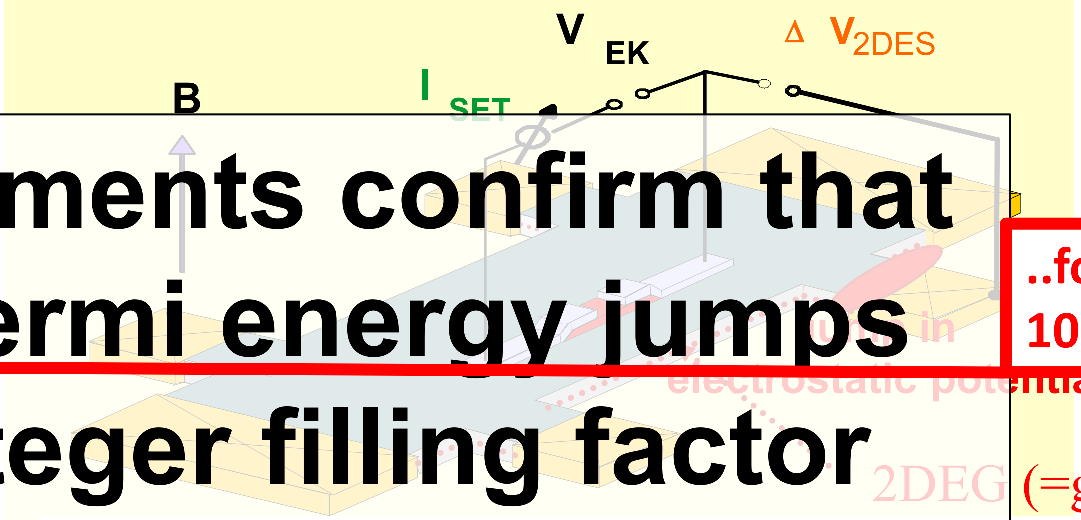
Quantum Hall Devices (GaAs): A System with Many Energy Gaps



Jump in Fermi Energy Observable?

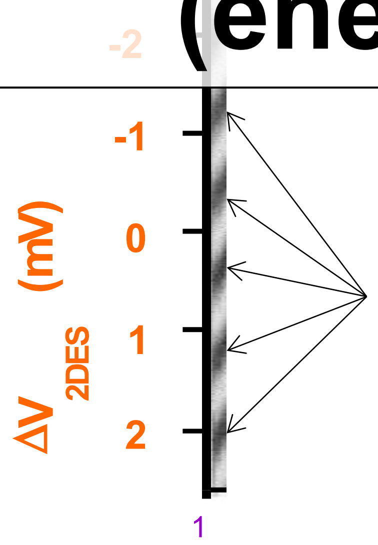
Single Electron Transistor (SET)

as an extremely sensitive electrometer for measurements on a 2DEG



Experiments confirm that the Fermi energy jumps at integer filling factor (energy gap!)

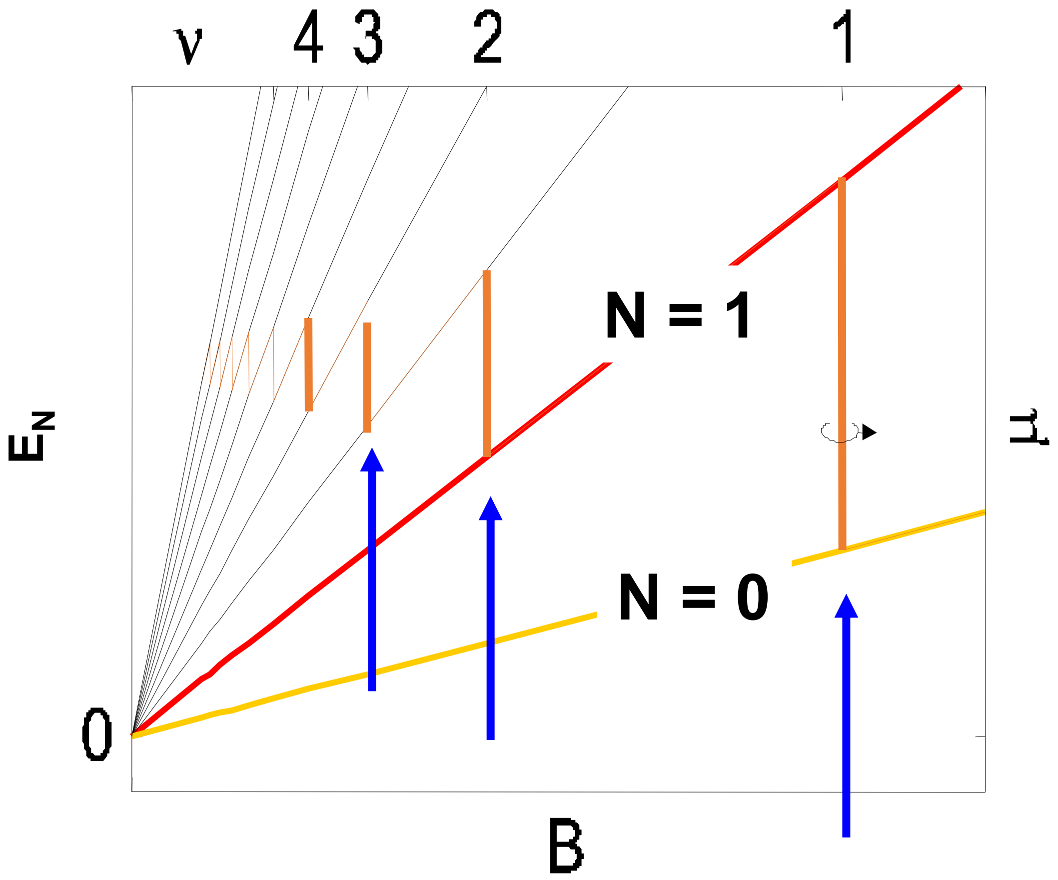
..for the 100th anniversary



Coulomb blockade oscillations (black: conductivity peak)

PROBLEMS with „jumping“ Fermi energy

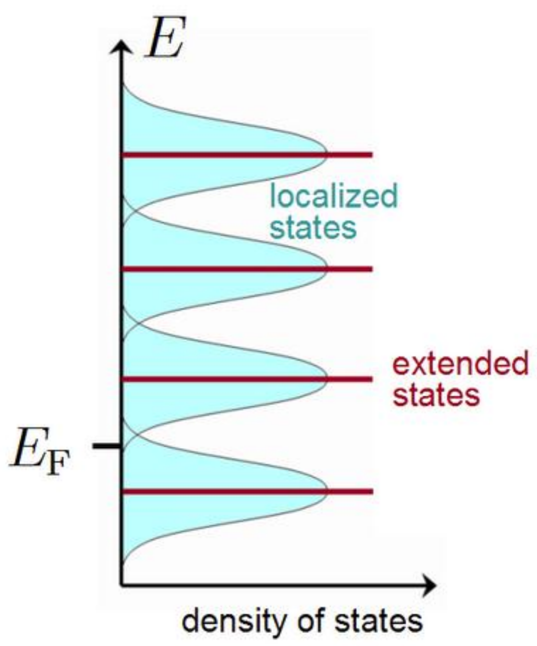
NO quantum Hall **plateaus** since the condition of fully occupied Landaulevel is fulfilled only for very special magnetic field values!



Localized States in Tails of Landaulevels stabilize the Hallvoltage

A remark must be made on the Hall conductivity σ_{xy}. Even if the Fermi level lies in the Anderson-localized region in the tail of the N-th subband ($N \geq 1$), there exist the extended states in the sub-band ... E_F. Since the relative coordinates (ξ_+, ξ_-) of the cyclotron motion contribute[5] to the Hall cond... as the correlation function of $\langle \xi_+(t)\xi_-(0) \rangle$, the states below E_F give rise to the Hall conductiv... $-(nec/H)$, where n is the number of mobile carriers below E_F. This is consistent with the experimental

Localized states in the tails of Landaulevels are missing in the Hall effect !?



Experimental Facts:

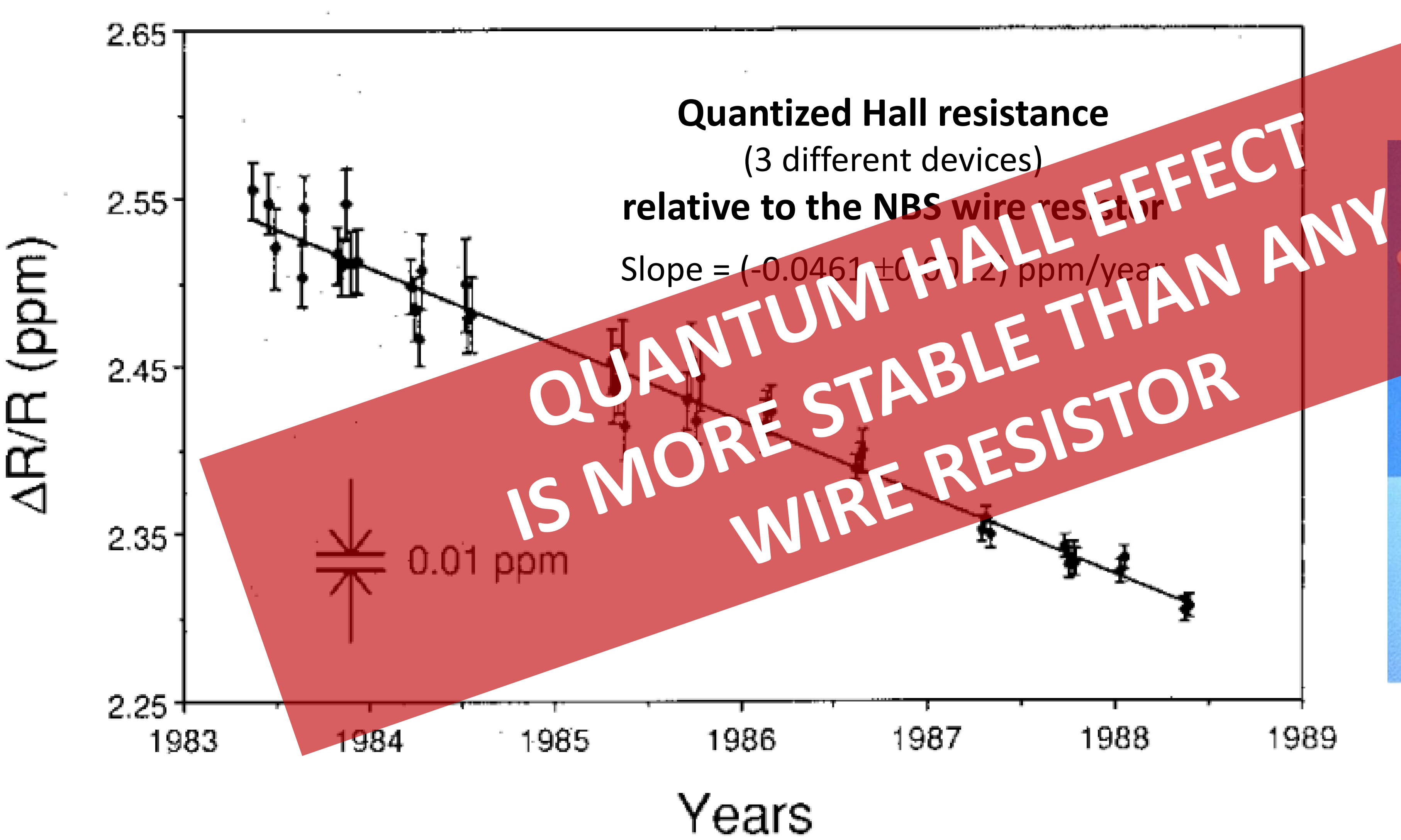
The quantized Hall resistance is extremely reproducible !

von Klitzing, K. et al. (1980)	25812.68 (8) Ω
BIPM (France)	25812.809 (2) Ω
PTB (Germany)	25812.802 (3) Ω
NBS (USA)	25812.807 (1) Ω
LCIE (France)	25812.802 (6) Ω
NRC (Canada)	25812.814 (6) Ω
NPL (UK)	25812.809 (1) Ω
ETL (Japan)	25812.806 (7) Ω
IMS (Russia)	25812.807 (8) Ω
VSL (The Netherlands)	25812.802 (5) Ω
NIM (China)	25812.806 (16) Ω
EAM (Switzerland)	25812.809 (4) Ω

Task Group "Quantum Hall" at NBS

Monitoring the U.S. Legal Unit of Resistance via the Quantum Hall Effect

IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. IM-36, NO. 2, JUNE 1987



From Basic Research to Applications

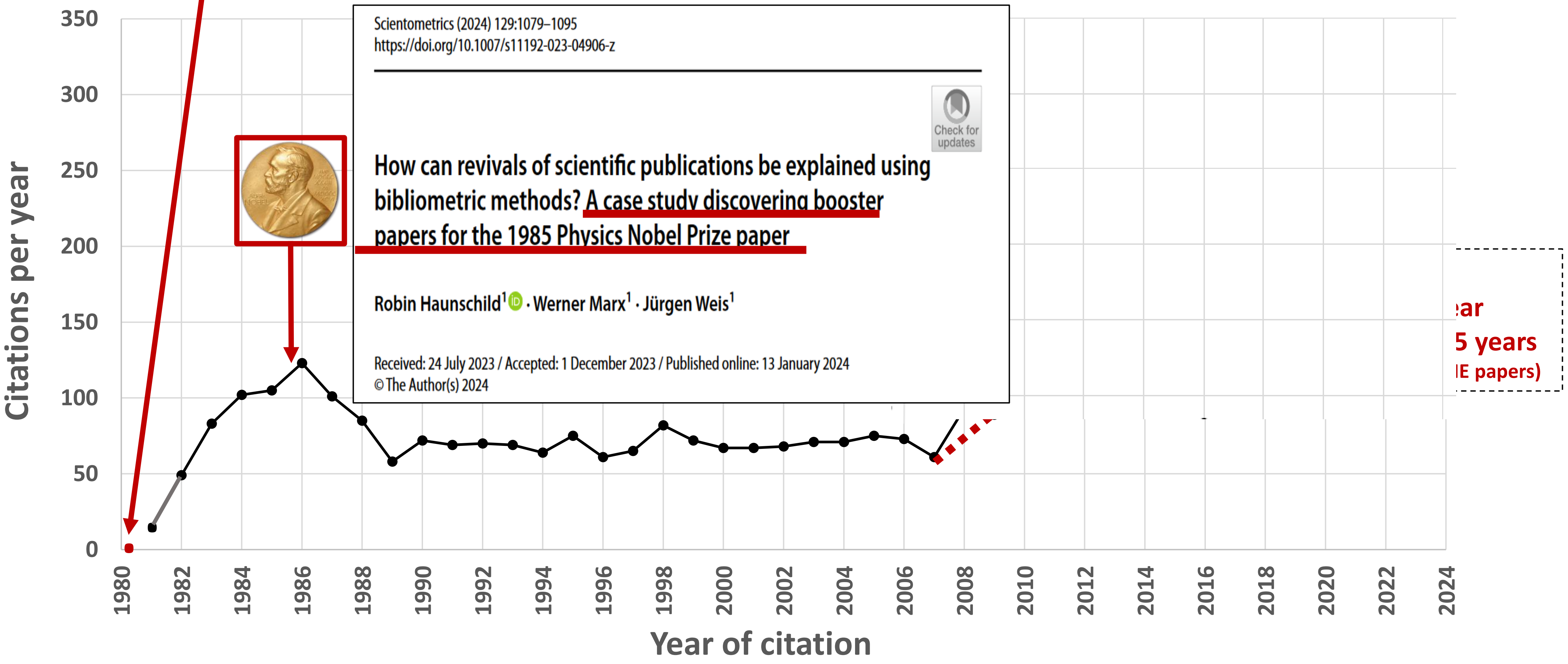
QUANTUM HALL EFFECT

Opened a new research field

(including application in metrology)

First Quantum Hall Publication: 11.8.1980

von Klitzing et al., PRL V45 P494
5,543 citations (30.04.2025)



Scientometrics (2024) 129:1079–1095
https://doi.org/10.1007/s11192-023-04906-z

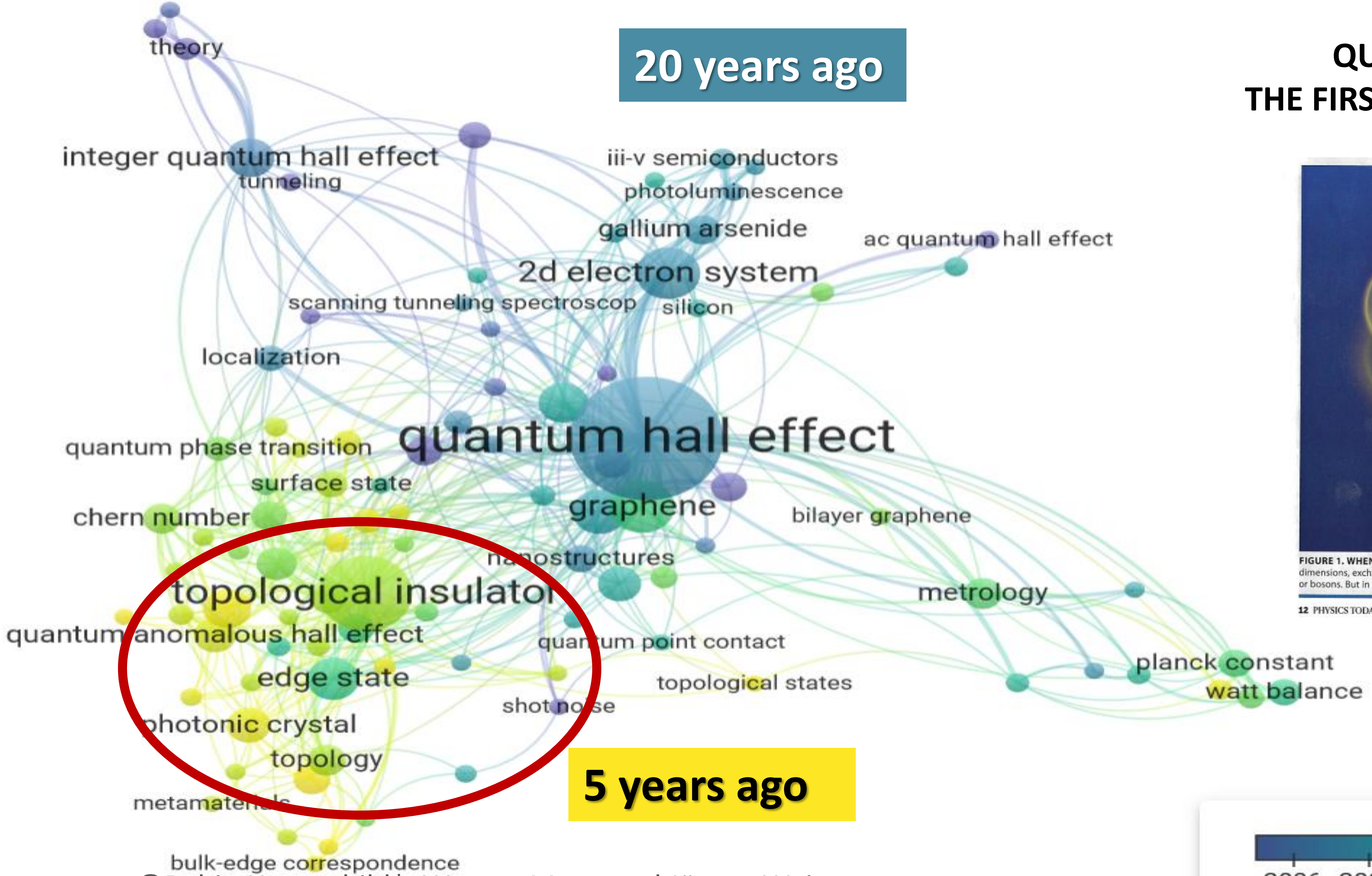
Check for updates

How can revivals of scientific publications be explained using bibliometric methods? A case study discovering booster papers for the 1985 Physics Nobel Prize paper

Robin Haunschild[1] · Werner Marx[1] · Jürgen Weis[1]

Received: 24 July 2023 / Accepted: 1 December 2023 / Published online: 13 January 2024

Impact of the Original QHE Publication



QUANTUM HALL EFFECT:
THE FIRST TOPOLOGICAL INSULATOR

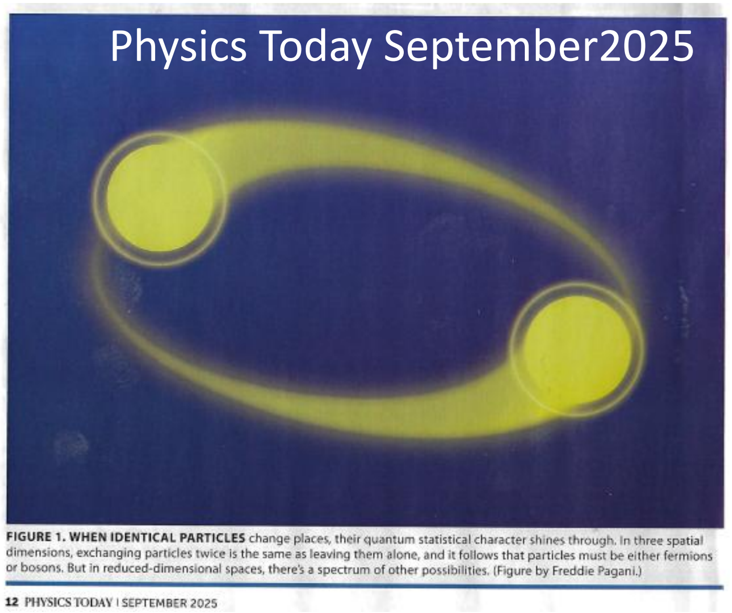


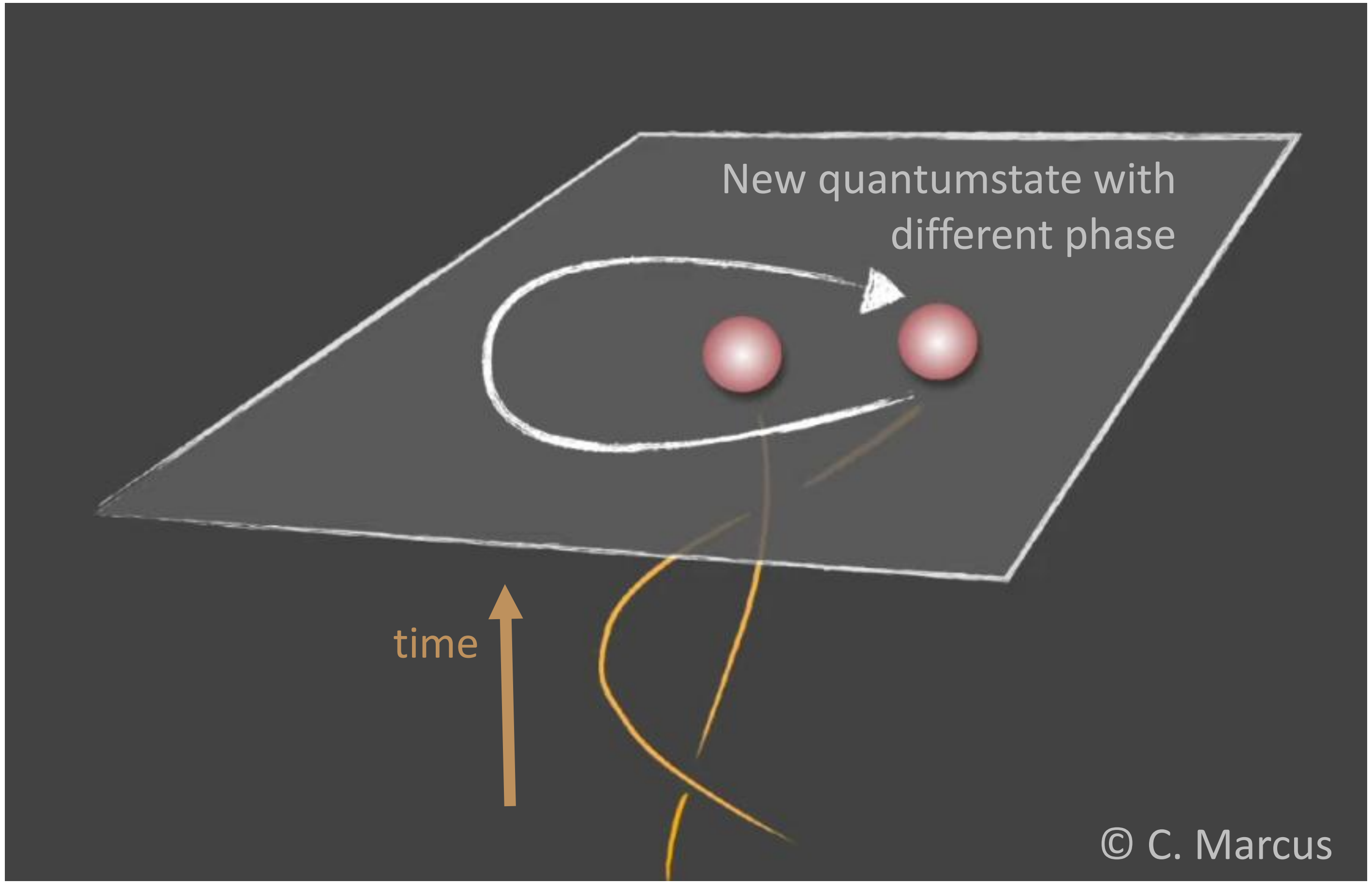
FIGURE 1. WHEN IDENTICAL PARTICLES change places, their quantum statistical character shines through. In three spatial dimensions, exchanging particles twice is the same as leaving them alone, and it follows that particles must be either fermions or bosons. But in reduced-dimensional spaces, there's a spectrum of other possibilities. (Figure by Freddie Pagani.)

12 PHYSICS TODAY | SEPTEMBER 2025

©Robin Haunschild*, Werner Marx, and Jürgen Weis

Speciality of 2-dimensional systems:

Particles behave not only as **FERMIONS** or BOSONS but also as **ANYONS** (any-ons)



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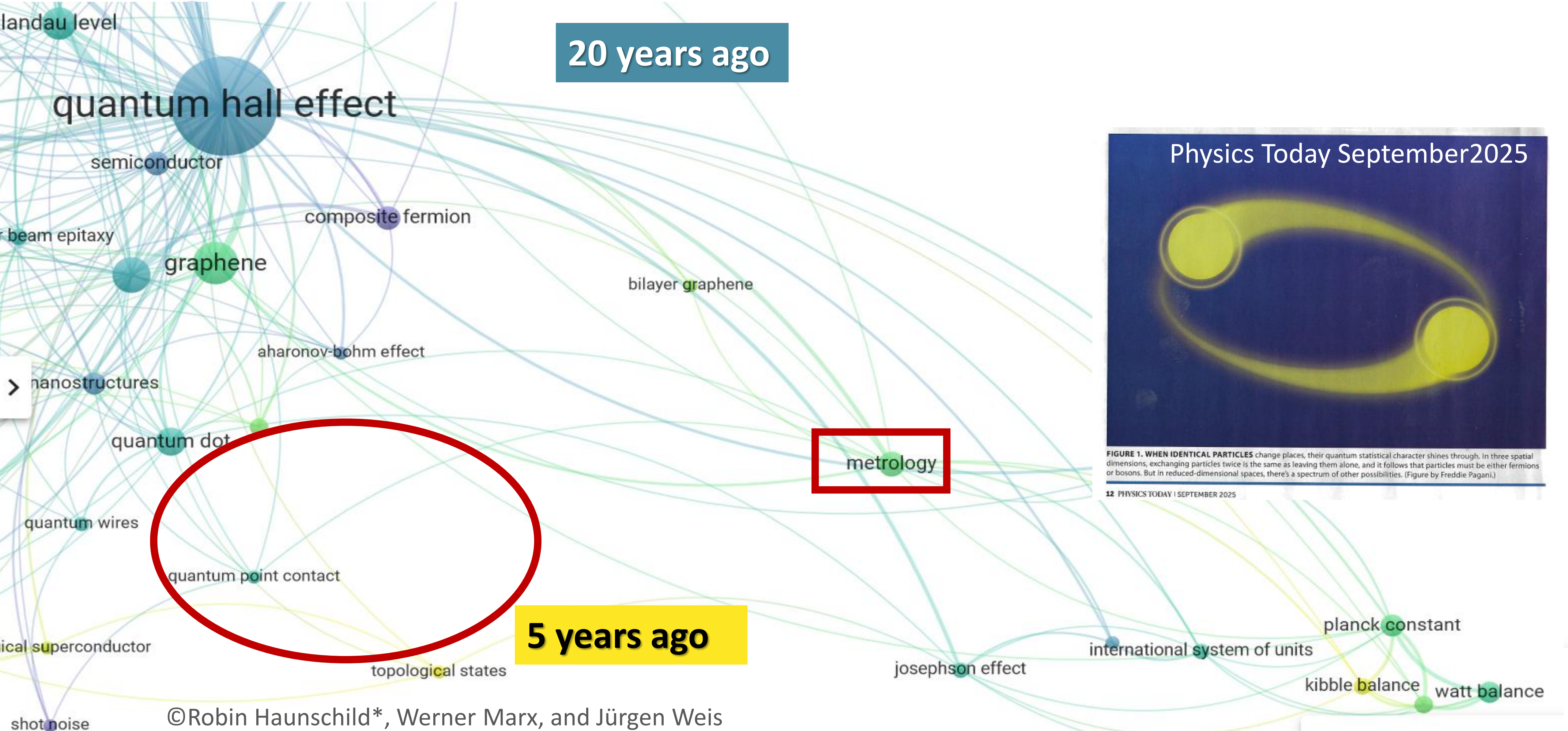

FIGURE 1. WHEN IDENTICAL PARTICLES change places, their quantum statistical character shines through. In three spatial dimensions, exchanging particles twice is the same as leaving them alone, and it follows that particles must be either fermions or bosons. But in reduced-dimensional spaces, there's a spectrum of other possibilities. (Figure by Freddie Pagani.)

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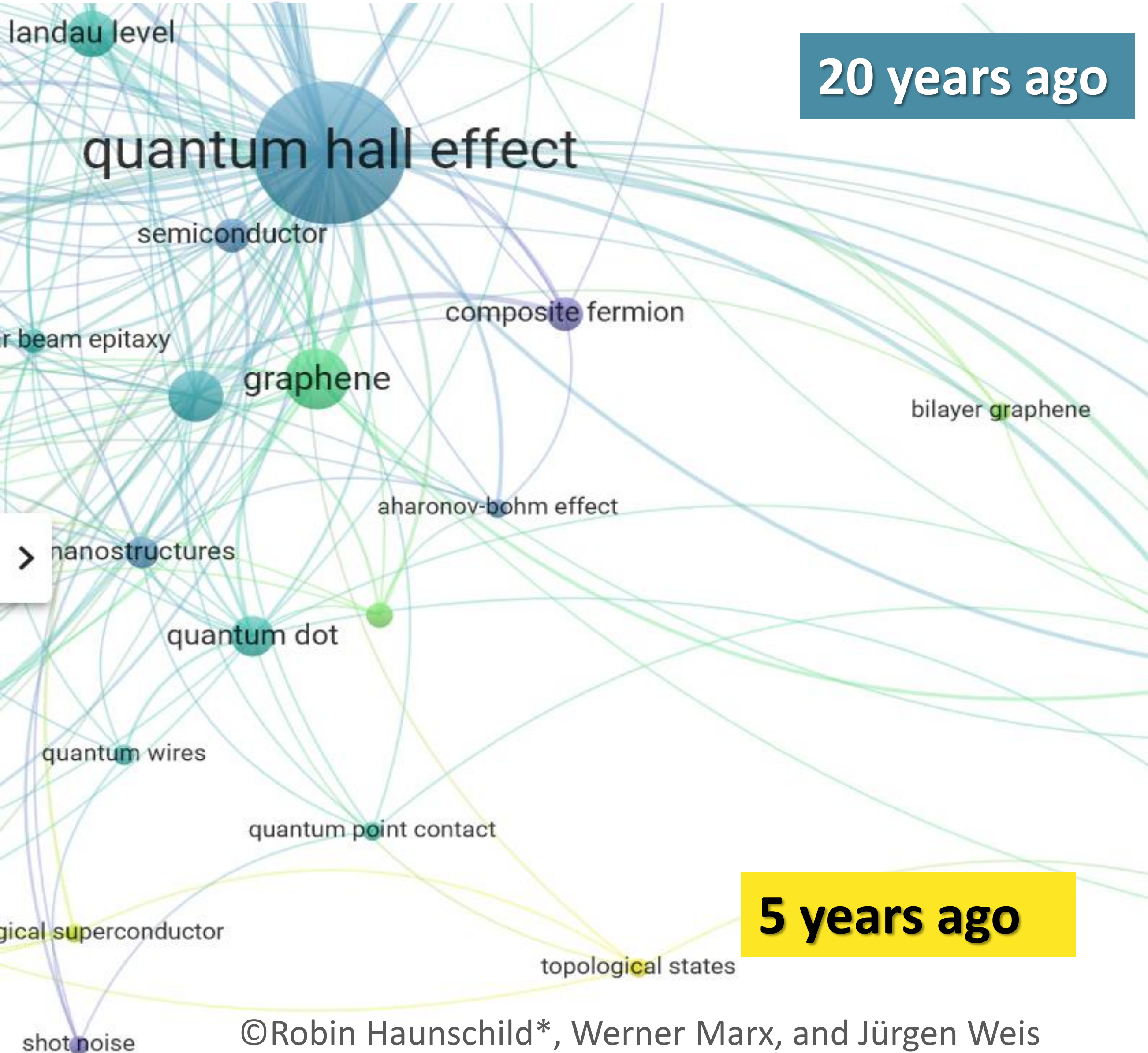


QHE and Metrology

Quantized Hall resistance revolutionized
(≈ 40 years after the discovery)
our *International System of Units*

©Robin Haunschild*, Werner Marx, and Jürgen Weis

INTERNATIONAL SYSTEM OF UNITS

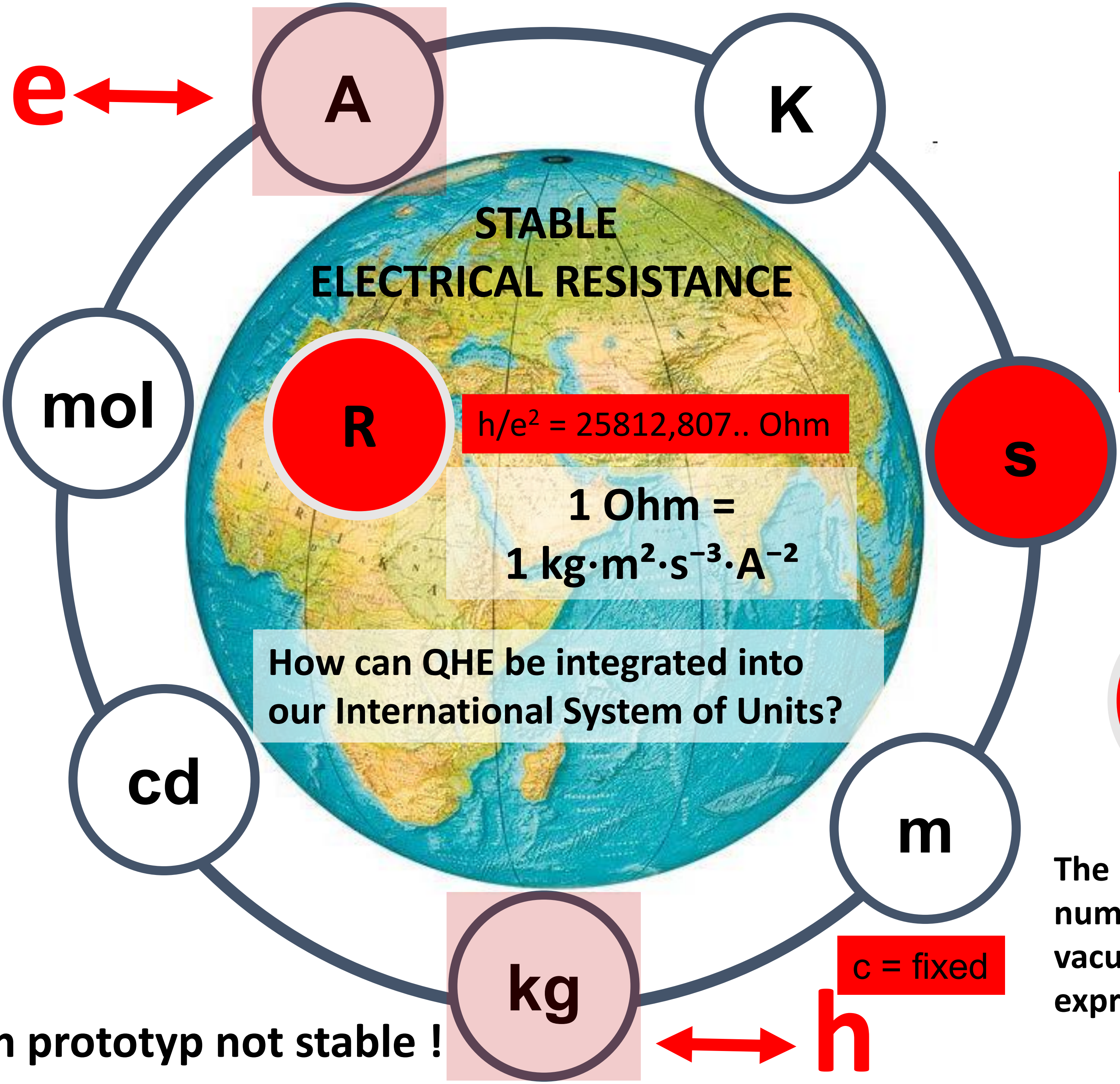
ALL MEASUREMENTS IN OUR UNIVERSE CAN BE TRACED BACK TO THE 7 BASE UNITS OF OUR *SI* SYSTEM:

KILOGRAM, METER, SECOND, AMPERE, KELVIN, MOL, CANDELA

May 20, 2019,
worldwide change in measurement laws

7 SI base units

Situation 10 years ago



atomic clock (since 1967)

c

Fixed value for velocity of light (since 1983)

The metre is defined by taking the fixed numerical value of the speed of light in vacuum, c, to be 299 792 458 when expressed in the unit m/s.

Kilogram prototyp not stable !

A Historical Event

26th Meeting of the International Committee of Weights and Measure

Report of the *The New York Times*

Representatives of the Meter Convention voted unanimously to redefine four basic units of measurement: the kilogram, the mole, the kelvin, and the ampere. Among them was Klaus von Klitzing, front row, taking a picture, discoverer of the von Klitzing constant in 1980, for which he received a Nobel Prize.

Credit...Matt Roth for The New York Times

Standing Ovation

A Historical Event!

Quantum metrology united all countries

New Definitions of SI Units

KILOGRAM

~~prototype~~

Quantum Kilogram

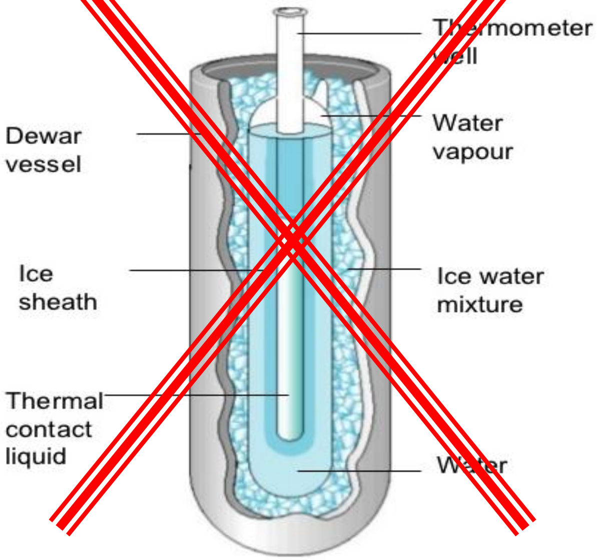
$h \equiv$

6.626 070 15 × 10^{-34}J s

KELVIN

~~triple point cell~~

273.1575 K



$k \equiv$

1.380 649 × 10^{-23} J/K

AMPERE

~~force between 2 wires~~

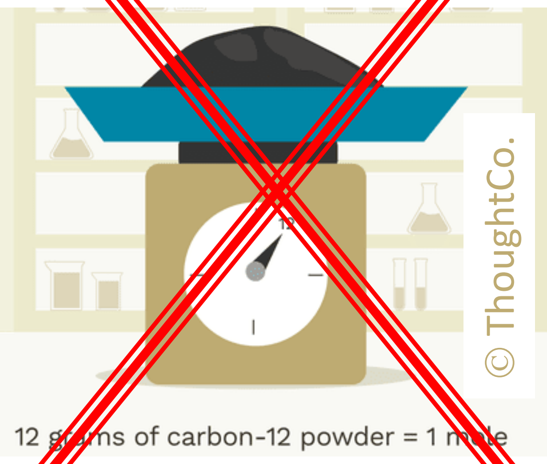
$e \equiv$

1.602 176 634 × 10^{-19} C

MOLE

~~# of atoms~~

in 12 g C^{12}

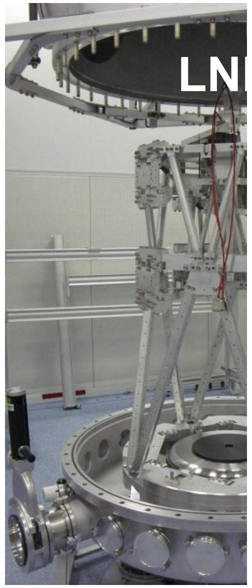


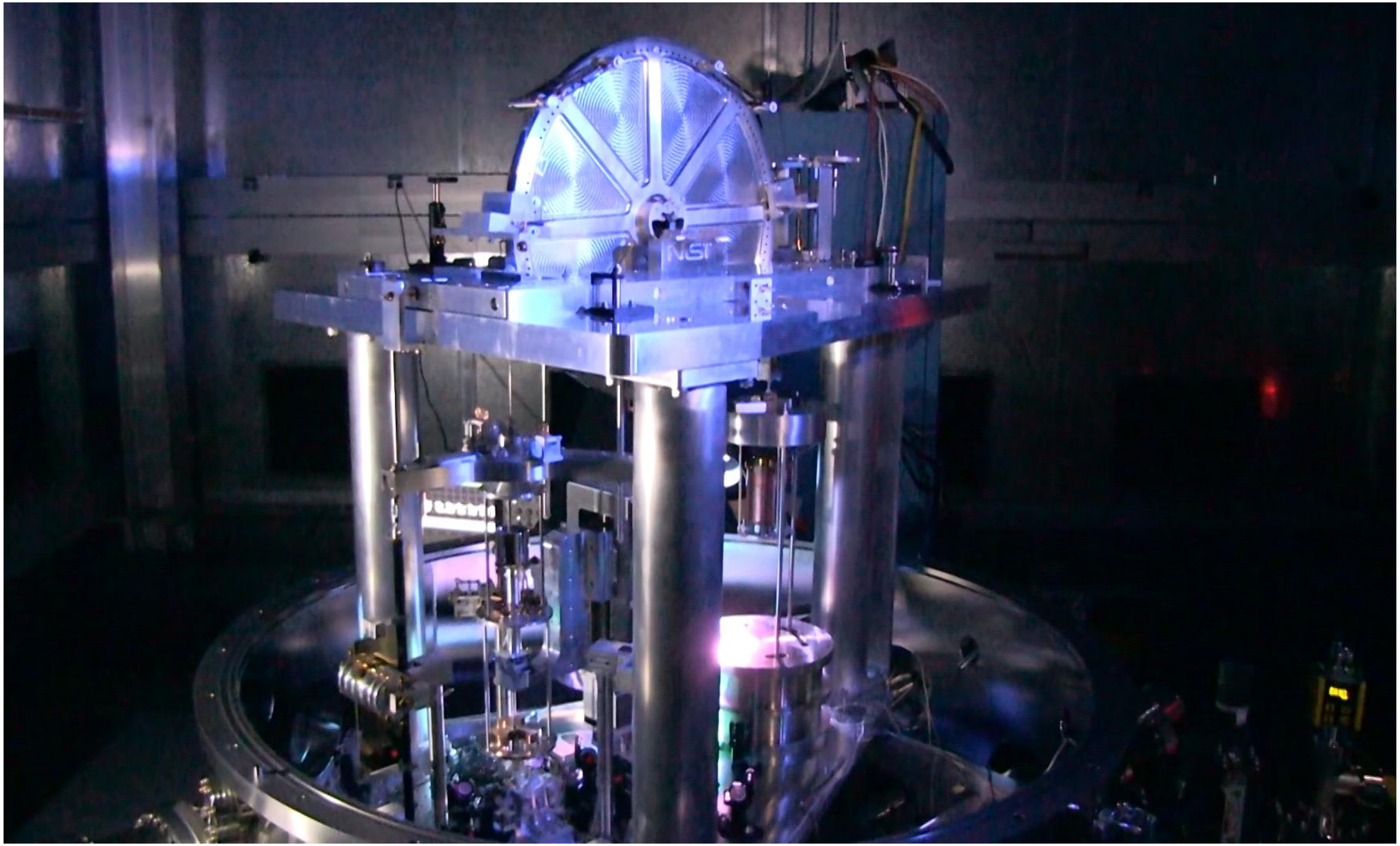
$N_A \equiv$

6.022 140 76 × 10^{23} mol^{-1}

From a fixed value of *h* to a new kg

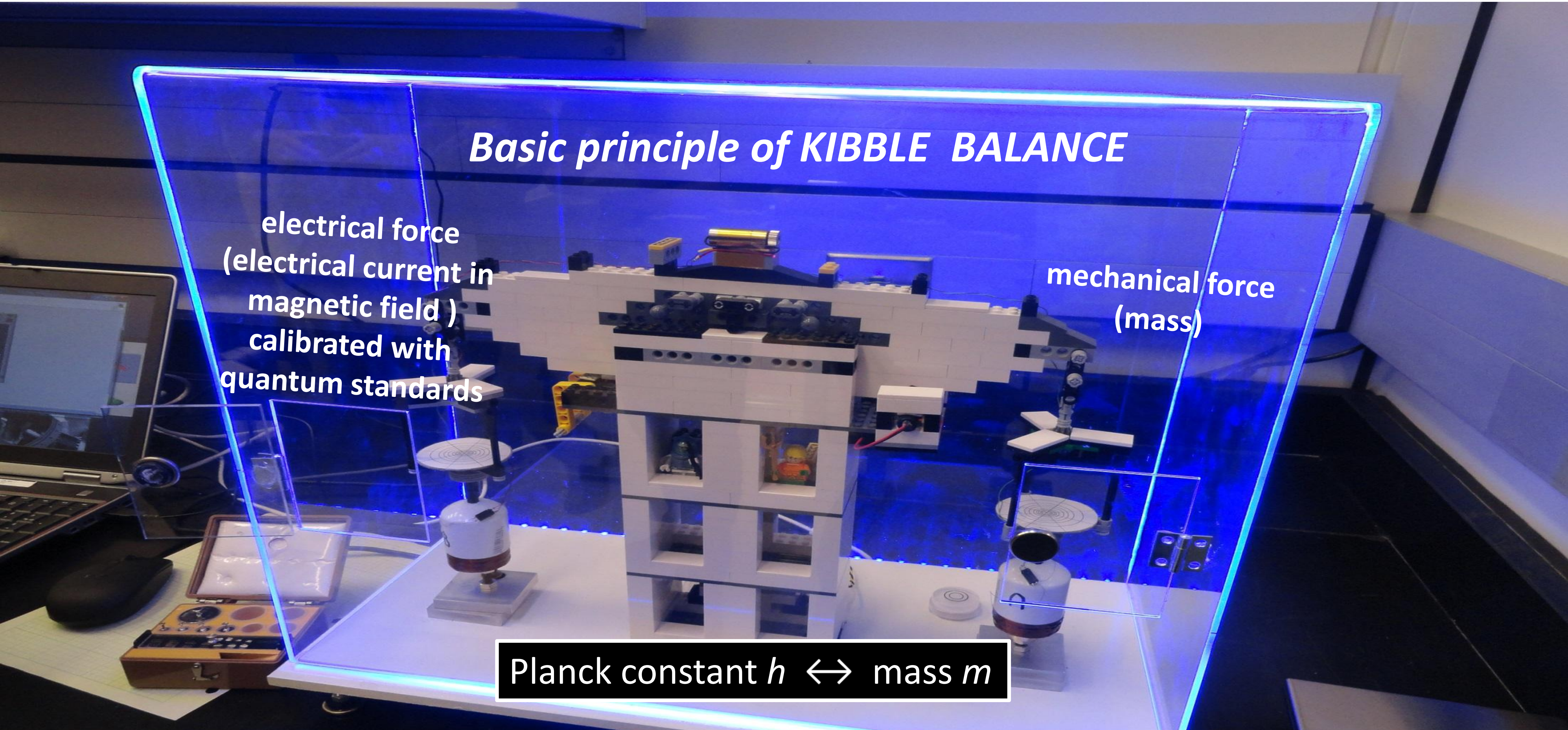
(KIBBLE BALANCE)



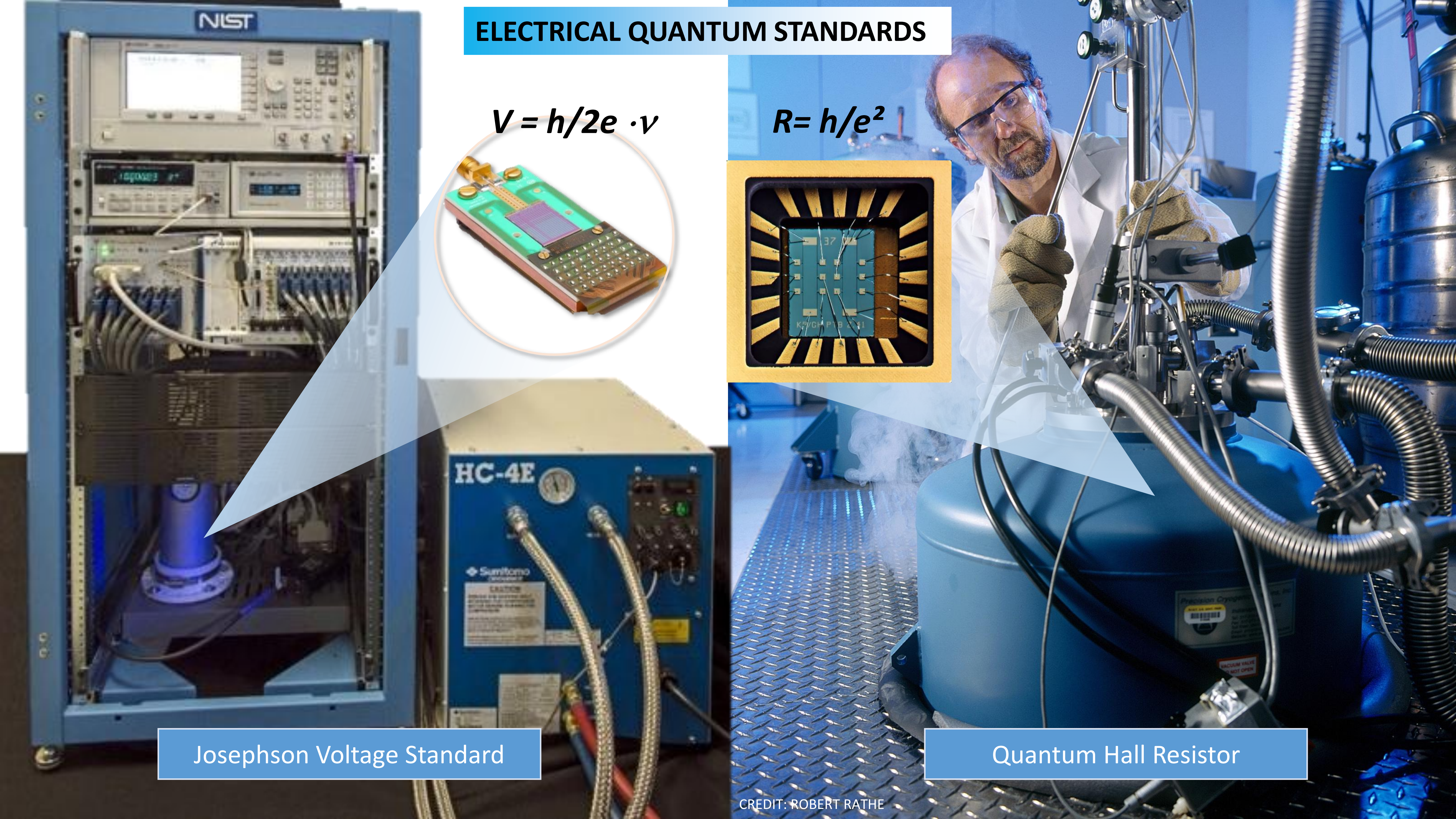


From a fixed value of *h* to a new kg

(KIBBLE BALANCE)



ELECTRICAL QUANTUM STANDARDS



CREDIT: ROBERT RATHE

Industrial Prototype: Planck Balance

Credit: TU Ilmenau

Our New SI System

CODATA RECOMMENDED VALUES OF THE FUNDAMENTAL CONSTANTS OF PHYSICS AND CHEMISTRY NIST SP 959 (June 2019)

An extensive constants list is available at physics.nist.gov/constants.

Quantity	Symbol	Numerical value	Unit
*^{133}Cs hyperfine transition frequency	$\Delta\nu_{Cs}$	9 192 631 770	Hz
*speed of light in vacuum	c	299 792 458	$m\,s^{-1}$
*Planck constant	h	$6.626\,070\,15 \times 10^{-34}$	$J\,Hz^{-1}$
	$\hbar$	$1.054\,571\,817\ldots \times 10^{-34}$	$J\,s$
*elementary charge	e	$1.602\,176\,634 \times 10^{-19}$	C
*Avogadro constant	N_A	$6.022\,140\,76 \times 10^{23}$	mol^{-1}
*Boltzmann constant	k	$1.380\,649 \times 10^{-23}$	$J\,K^{-1}$
*luminous efficacy	K_{cd}	683	$lm\,W^{-1}$
electron volt (e/C) J	eV	$1.602\,176\,634 \times 10^{-19}$	J
Josephson constant $2e/h$	K_J	$483\,597.848\,4\ldots \times 10^{9}$	$Hz\,V^{-1}$
von Klitzing constant $2\pi\hbar/e^2$	R_K	$25\,812.807\,45\ldots$	Ω
molar gas constant $N_A k$	R	$8.314\,462\,618\ldots$	$J\,mol^{-1}\,K^{-1}$
Stefan-Boltzmann const. $\pi^2k^4/(60\hbar^3c^2)$	σ	$5.670\,374\,419\ldots \times 10^{-8}$	$W\,m^{-2}\,K^{-4}$

*Defining constants of the International System of Units (SI).

Calculated von Klitzing constant

Corrections to $R_{QHE} = h/e^2$?

$R_K = 6.62607015 \cdot 10^{-34} / (1.602176634 \cdot 10^{-19})^2$ OHM

25812,807459304506660045516706087443042457273221403421768329716073228965768572716532282171634884319000217144421378765742752959413401835729968409387997331598962806948332670845532197863625428172849465833207123385987

QED corrections?

1950559470887042232733954593703467654262471394789675144427161191665010557967339586991450015258157073019680779452392228657121962603968873783682884290631160482581812243967142718840153390647445805580452450994080904786483167432221924416385739262708991096954452328562893763279

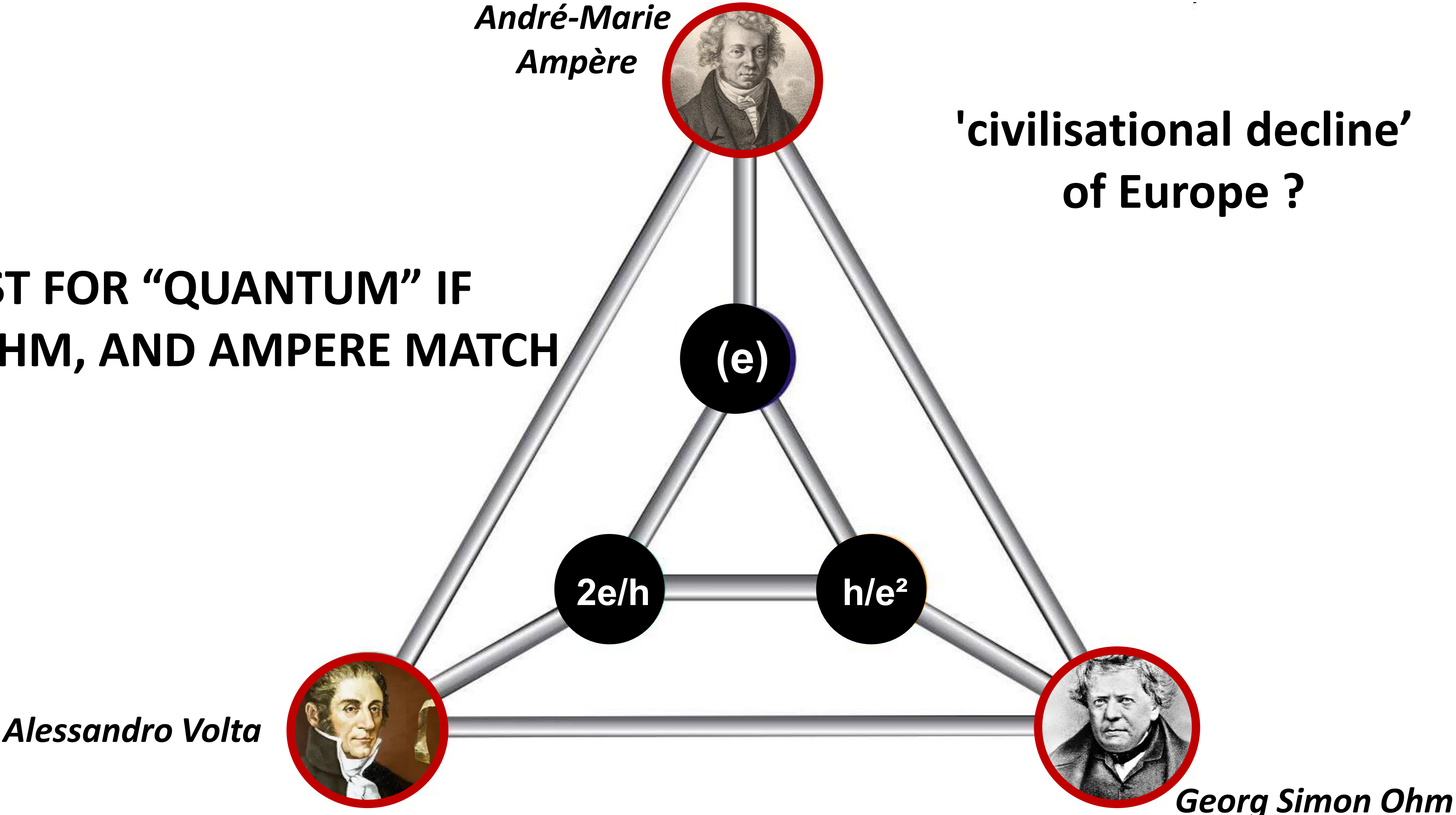
Gravitational Field ?

6454192845324325022435473419950615225717011556725719264967368864934837307547633083732603235857721511497472131407816403408083174577608067015120709426900536754291769658409620096382313783177238953315269366720535728752400531769855897217630973638284031650531224506513133579539977578601888366615661488411328887258453446957649806326110774356647198468501493799207694968420235100990563478004022880597341004501448391508825110664870070345622581265244927824436 5....**Ohm**

Consistency Check of Quantum Standards

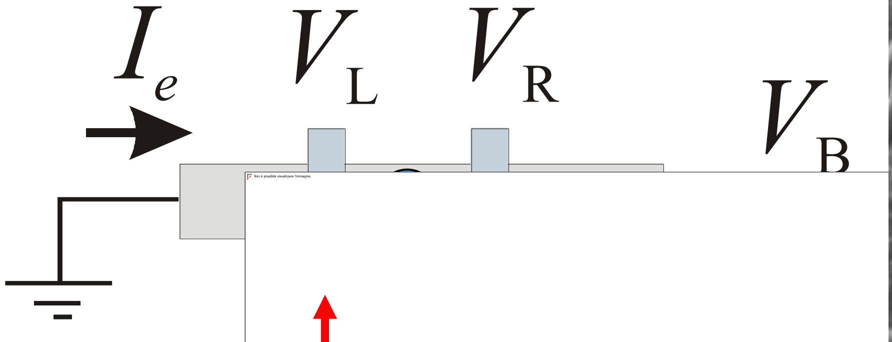
'civilisational decline' of Europe ?

A TEST FOR "QUANTUM" IF VOLTA, OHM, AND AMPERE MATCH



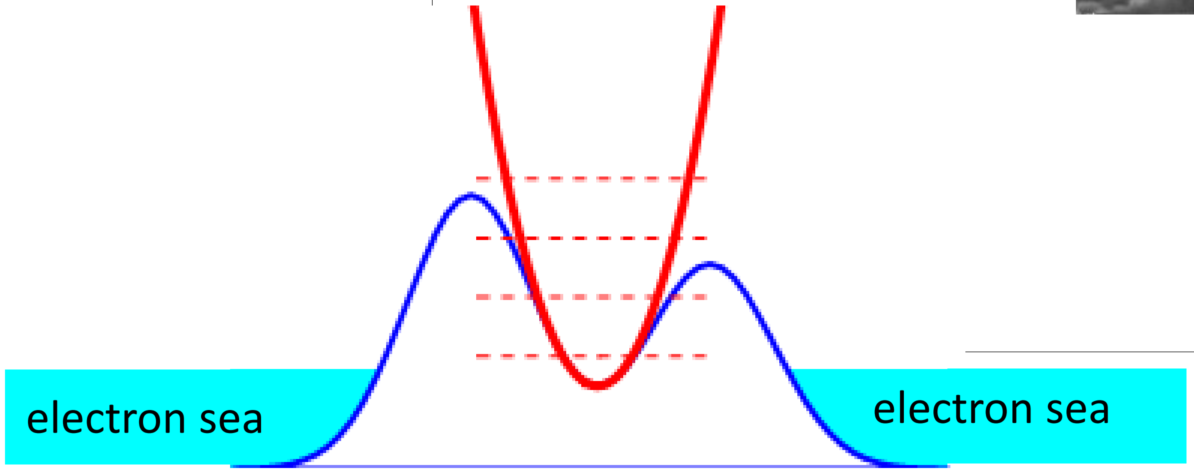
Realisation of the ELECTRIC BASE UNIT AMPERE

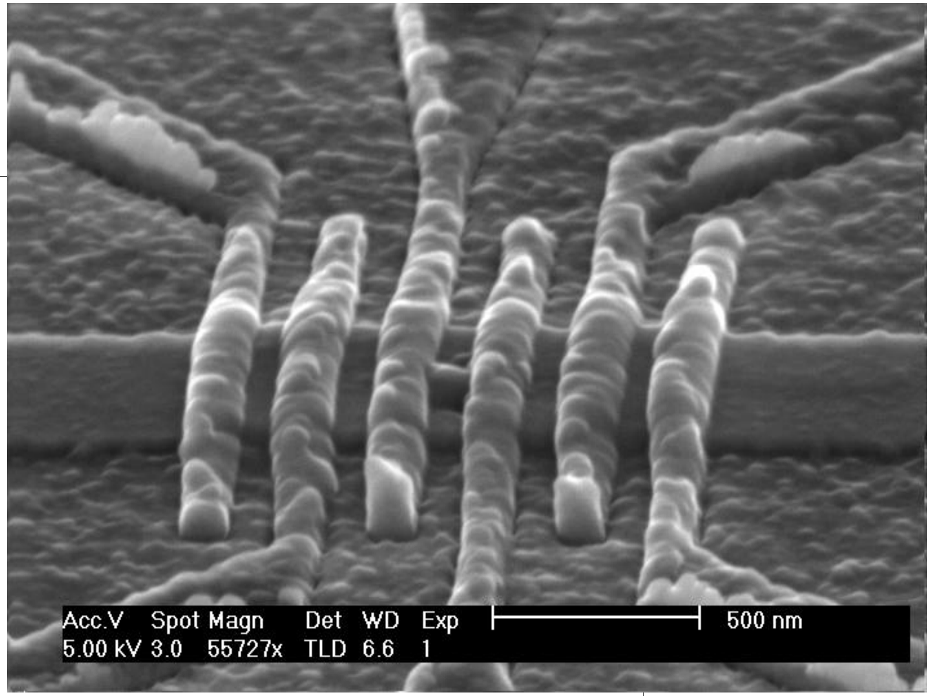
SINGLE ELECTRON PUMP



$$V_L = V_0 + V_1 \cos 2\pi f t$$

$$I_e = f \cdot e$$



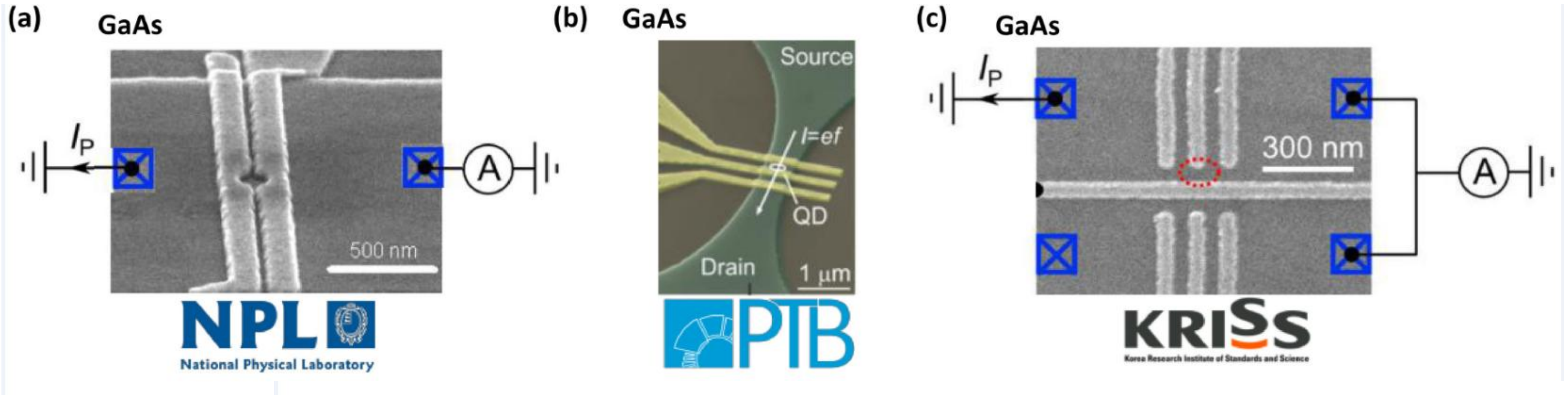


Robust single-parameter quantized charge pumping

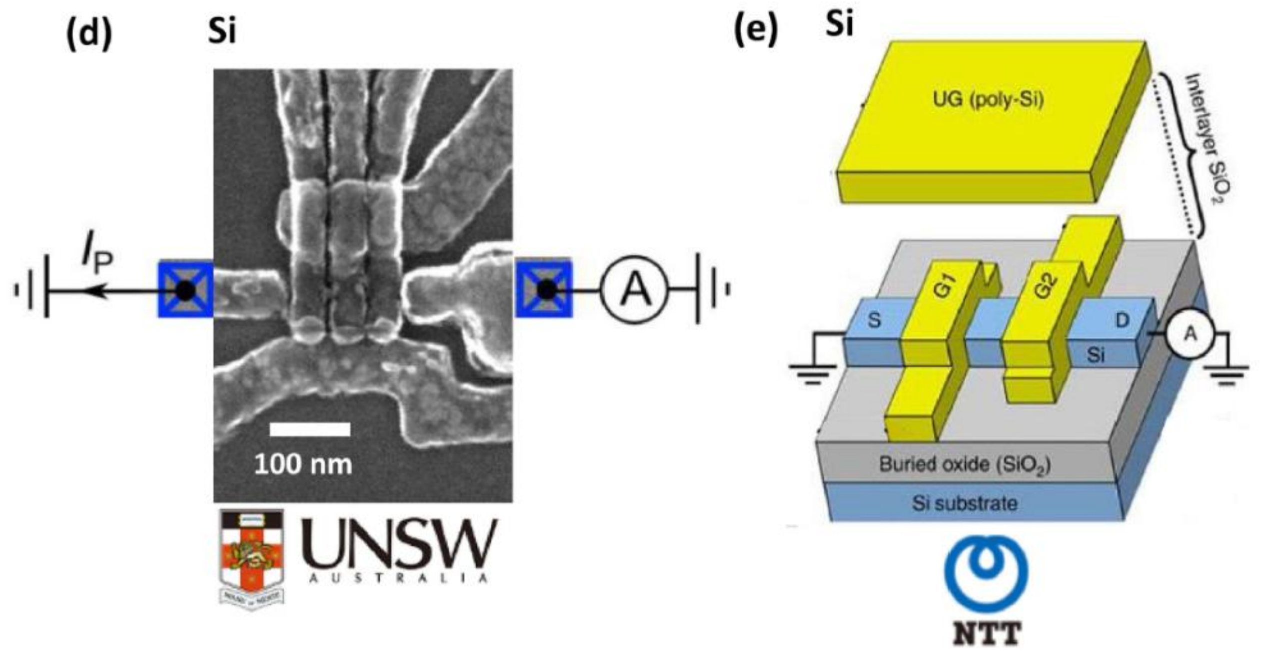
B. Kaestner et. al. (PTB Braunschweig)

APL 92, 192106 (2008)

Typical Single Electron Pumps…



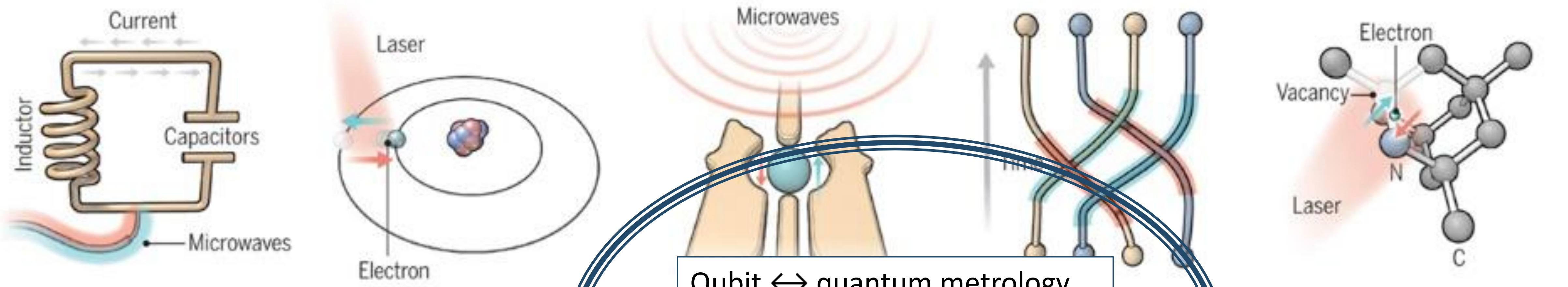
…with connections to quantum dot qubits



QUANTUM BITS- the building blocks of quantum computer

A bit of the action

In the race to build a quantum computer, companies are pursuing many types of quantum bits, or qubits, each with its own strengths and weaknesses.



Qubit ↔ quantum metrology

Superconducting loops

A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into super-position states.

Trapped ions

Electrically charged atoms, or ions, have quantum energies that depend on the location of electrons. Tuned lasers cool and trap the ions, and put them in superposition states.

Silicon quantum dots

These "artificial atoms" are made by adding an electron to a small piece of pure silicon. Microwaves control the electron's quantum state.

Topological qubits

Quasiparticles can be seen in the behavior of electrons channeled through semi-conductor structures. Their braided paths can encode quantum information.

Diamond vacancies

A nitrogen atom and a vacancy add an electron to a diamond lattice. Its quantum spin state, along with those of nearby carbon nuclei, can be controlled with light.

	Superconducting loops	Trapped ions	Silicon quantum dots	Topological qubits	Diamond vacancies
Longevity (seconds)	0.00005	>1000	0.03	N/A	10
Logic success rate	99.4%	99.9%	~99%	N/A	99.2%

FERMI and QUANTUM HALL SCIENCE

FERMIONS:

FQHE = QHE of COMPOSITE FERMIONS *(1 electron + 2 flux quanta)*

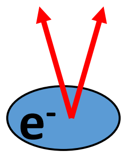
BOSONS:

QHE = *COMPOSITE BOSONS (1 electron + 1 flux quantum) IN 2-D SYSTEMS*

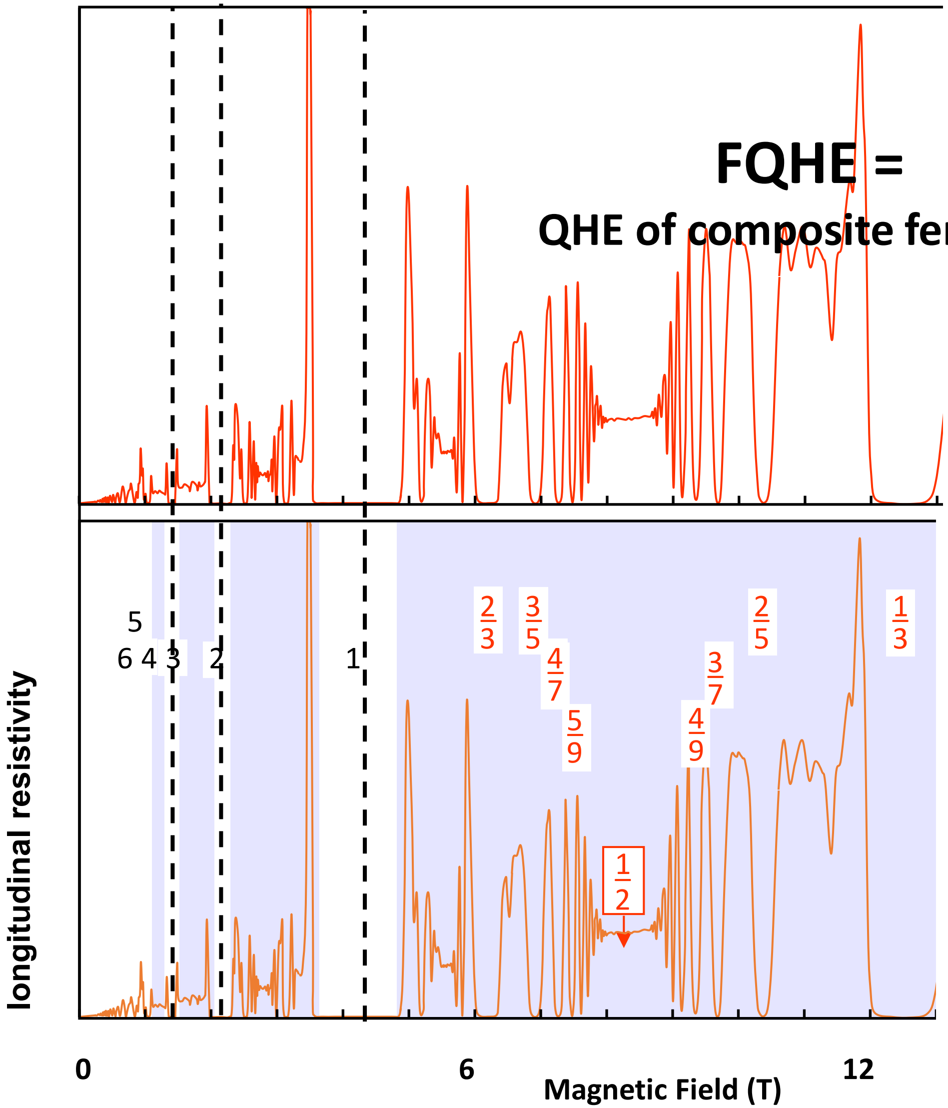
ANYONS: ↔ Two-dimensional system (2-D SYSTEM)

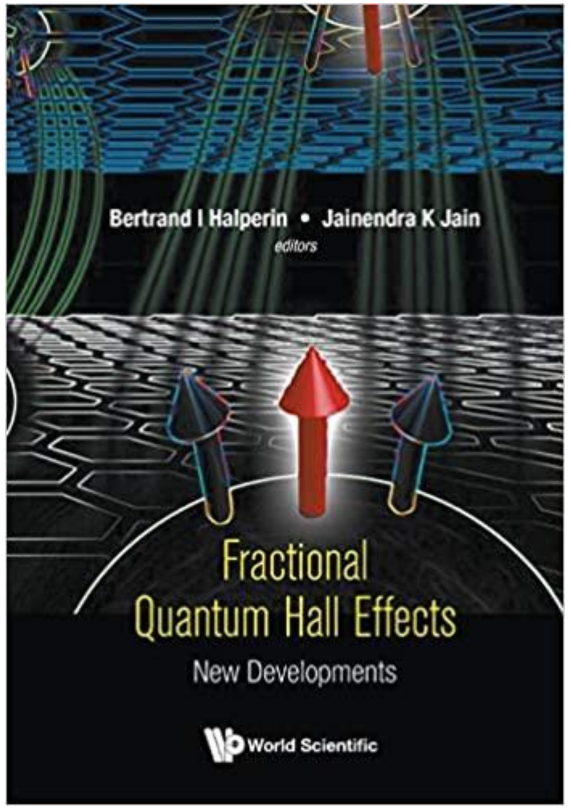
Quantum Hall Physics

A very powerful quasiparticle
(introduced by Jainandra Jain)
h/e h/e



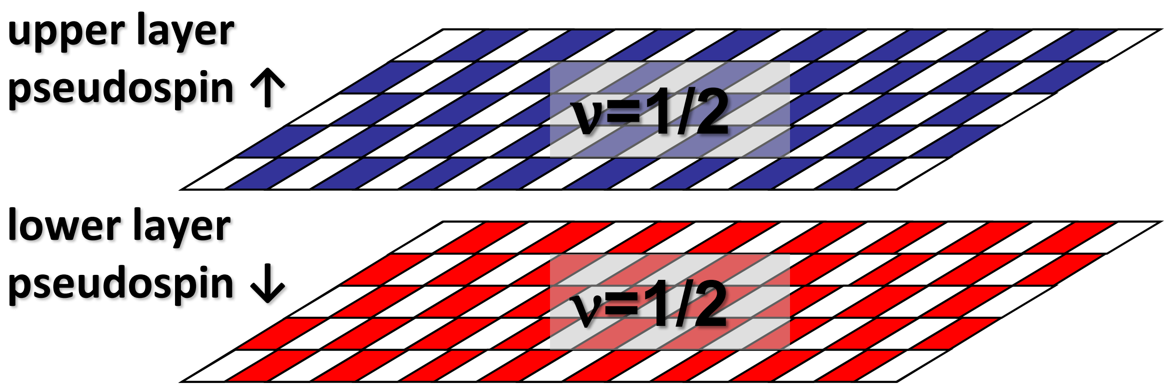
FQHE =
QHE of composite fermions

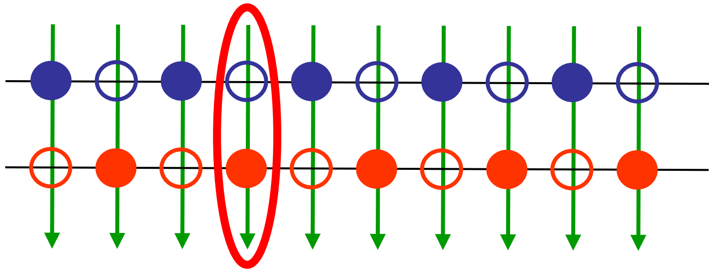




data of Pan et al., $\mu=10^7 cm^2/Vs$, T=30 mK

Bose Condensate of Excitons





Ground State at n_{tot}=1:

exciton

$$|\Psi\rangle = \prod_k (a + b c^\dagger_{k,\downarrow} d^\dagger_{-k,\uparrow}) (\prod_k c_{k,\uparrow}|0\rangle).$$

Bose-Einstein Condensate of Excitons (with *inter-layer* phase coherence) in the ground state

H. A. Fertig, *Phys. Rev. B* 40, 1087 (1989)

A Success of Global Cooperation

The constants of nature are the most stable basis for a UNIVERSAL SYSTEM OF UNITS *"for all times, for all people"*.

OPEN QUESTION

HOW CONSTANT ARE FUNDAMENTAL CONSTANTS ?

Suffiently constant for metrology: applications

$$\frac{1}{\alpha}\cdot\frac{\Delta\alpha}{\Delta t} < 10^{-18}\ \text{/year}$$

inverse finestructure constant : $\alpha^{-1} = \frac{h}{e^2} \cdot \frac{2}{c \cdot \mu_0}$