BIPM

C.-É. Guillaume and the scientific bubbling of the early XXth century (1900-1925)

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1920

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OF
THE ROYAL SOCIETY

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AN UNUSUAL NOBEL PRIZE

by

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SUMMARY

C.-E. Guillaume received the Nobel Prize for Physics in 1920 for the discovery and development of a pair of alloys that had characteristics invariant with temperature: one had constant length near ambient temperature, the other had constant Young's modulus. A recent analysis expresses retrospective surprise at this award: the objective of this short paper is to justify the award retrospectively, in terms of the continuing and impressive consequences of Guillaume's discoveries.

Nobels of the early XXth

<u>1901-1925</u>:

All European at the exception of Millikan and Michelson

<u>New physics is rare</u>:

Quantum mechanics (Planck/Bohr/Einstein)+radioactivity

<u>No mention of relativity</u> (special or general)

Gravitation came into the list only in 1993 (*Taylor-Hulse*) and then 2017 (*Weiss-Barish-Thorne*), 2019 (*Peebles*),

2020 (*Penrose, Genzel, Ghez*)

(fundamental) Physics of the early XXth

Lord Kelvin speech (April 27th, 1900)
"*Nineteenth-Century Clouds over the Dynamical Theory of Heat and Light* »

1.The inability to detect the luminous ether, specifically the failure of the Michelson-Morley experiment
2. The black body radiation effect

On this period,

1905: special relativity
1915: general relativity
1900-…: rapid development of quantum mechanics

All are *Frame Theories* in the sense that they define the theortical frameworks to include

causality, matter, measurement limitation, gravitation

independently of a given phenomena.

They are related to conceptual and technical revolution.

These facts draw several thoughts about the way we conceive and talk about science.

1. Dichotomy between « *pure science* » and « *applied science* » as 2 modes of production of knowledge.

2. Emergence of Relativity and why it took so long for it to be widespread

3. Guillaume / Einstein contributions and styles

4. Implication of the theoretical shift of the XXth century on physics and metrology.

5. What about today.

Modes of production of science

Distinction of a « *classical mode* » and a « *new mode* » of production of scientific knowledge.

This is more of a myth, or an ideology but it plays a entral role in the debates about the autonomy of science and its relation with society.

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Emma Spary (2000)

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XVI-XVIII:

« *practical mathematics* » include astronomy, cartography, navigation but also artillery and the art of fortification and the art of instruments (astrolabe, clocks…)

Science contributed to abadon Aristotlician view of the world but also answered the economical and social changes as well as the politics and military developments.

e.g. Newton/Boyle – implication with the East India Compagny

Modes of production of science

XIX:

structuration of the disciplines
the disciplinary knowledge is developed in universities

Transatlantic telegraph: Lord Kelvin / Maxwell

competition in the development of precision instrument

XX:

emergence of a reductionist physics at odd with the phenomenology and physics of precision that dominate universities.

AT&T (1920+) and Bell Labs

Fabry-Perot [1899]

…

Science

Science (or more precisely sciences) is not a circumscribed and stable object in time

This is more a vast ensemble of relations with

- productions of many kind *(texts, results, techniques,…)*
- practices *(instrumental, computational, simulations,…)*
- values and norms *(epistemological, ethical, behavioral,…)*
- institutions *(laboratories, universities, private companies, start-up,…)*
- social and political modes *(salons, clubs, professional societies, academies,…)*
- economics and *law (fundings, modes of appropritations, industrial properties,…)*

The slow emergence of relativity

1905. Galilean relativity vs electromagnetism: call for reconciliation

1907. gravity. A long-standing insatisfaction

That gravity is innate, inherent and essential to matter, so that one body can act on another at a distance through the void, without the mediation of anything else, by which and through which their action and force can be communicated from one to the other is for me an absurdity of which I believe that no man, having the faculty of reasoning competently in philosophical matters, can ever be guilty.

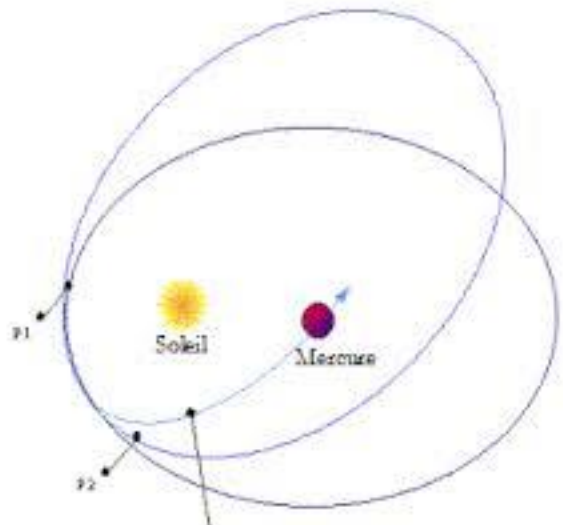
Lettre de Newton à Richard Bentley en 1692

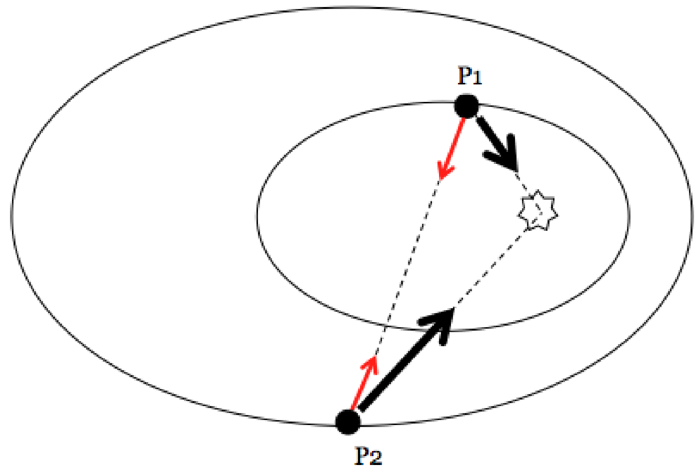
The vision

... I was sitting at my desk at the Berne Patent Office; suddenly I thought that if someone was falling down, he wouldn't feel his own weight. I was surprised. This simple thought made a kind of impression on me (...) Because for an observer falling from a roof, there is no gravitational field. If he drops objects, they will remain at rest in relation to him, or in uniform motion (...) He is therefore entitled to rest.

(A. Einstein, cited by A. Pais, *Subtle is the Lord*, pp. 178-179)

Mercury perihelion





Causes de l'avance du périhélie de Mercure (en secondes d'arc par siècle)

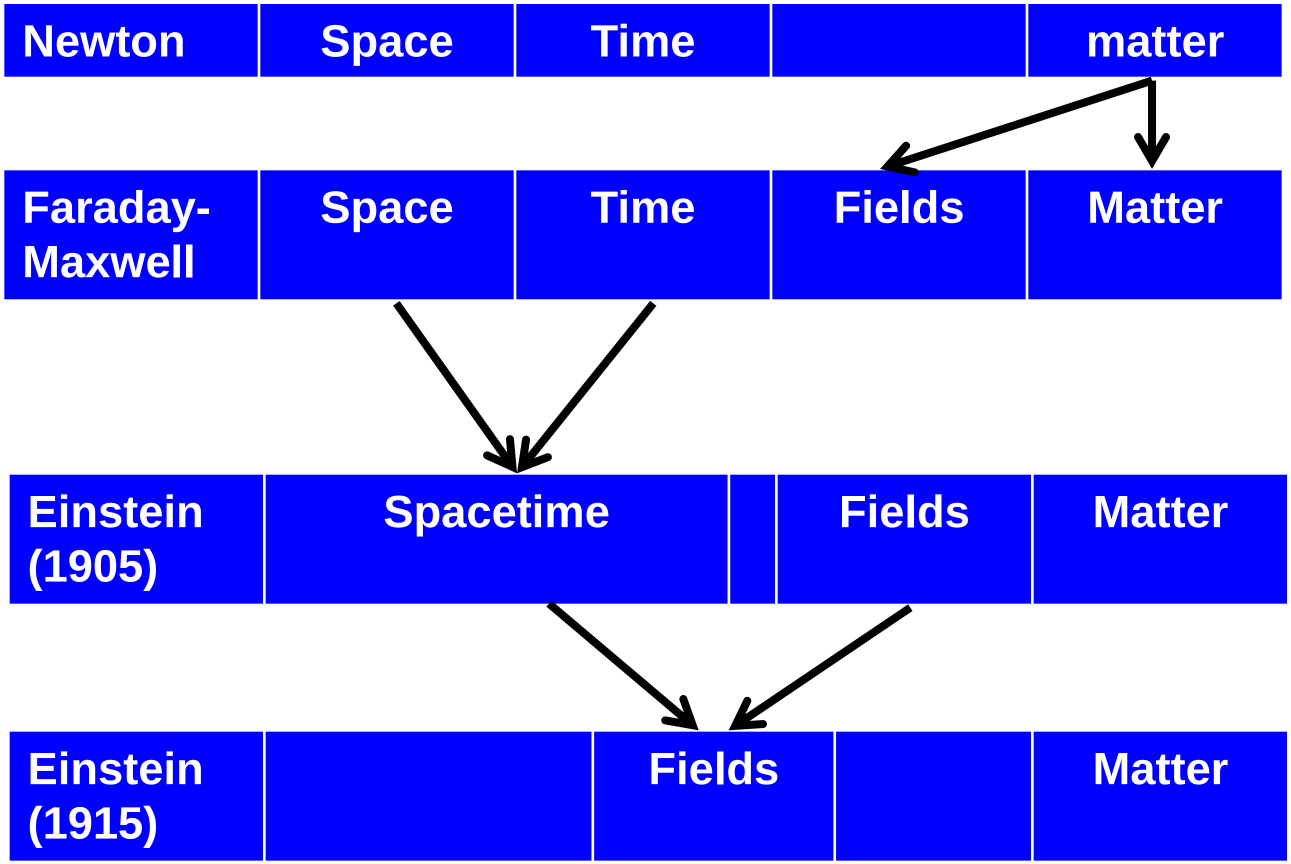
Équinoxes	Vénus	Terre	Mars	Jupiter	Saturne	Autres	Total	Observé	Anomalie
5025″.6	277″.8	90″.0	2″.5	153″.6	7″.3	0″.2	5557″.0	5599″.7	42″.7

$$\Delta\omega = \frac{6\pi GM}{pc^2}$$

Mercury: *$a = 58.10^6$ km,*
$e = 0{,}21$

ω = 42''.7

It changes our ideas on what does exist



Gravitation newtonienne	Gravitation relativiste
Absolute space and time	*Dynamical spacetime*
Force	*curvature*
Acceleration, speed	*Geodescis, worldline,…*

2 maps of « reality » with different resolutions

- *different ontology*
- *need to be related (continuity)*
- *Sometimes impossible to express properties of a finer theory in terms of pre-existing concepts.*

LIGHTS ALL ASKEW IN THE HEAVENS

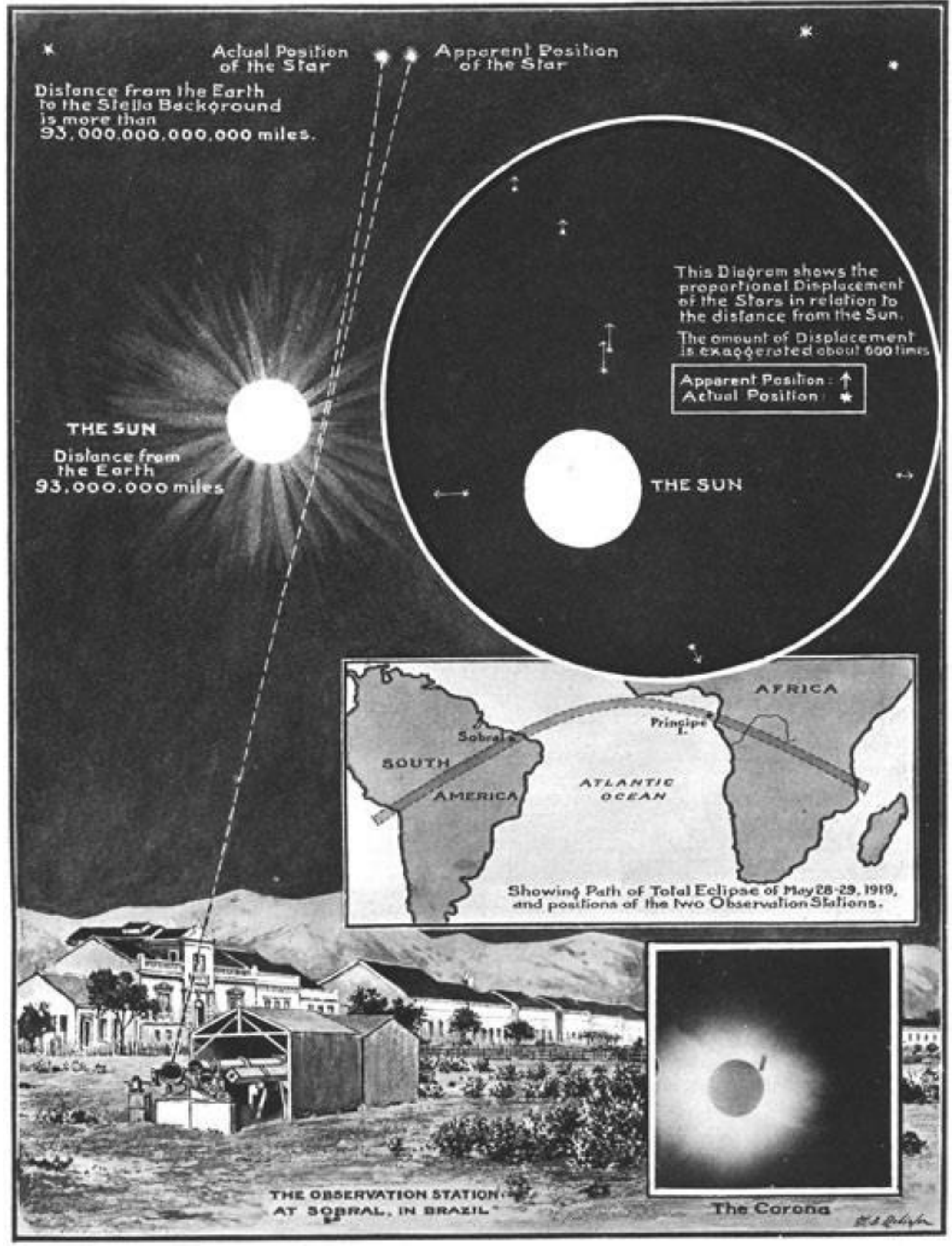
Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.



But still....

The theory has 2 great experimental successes from its beginnings.
It solves the "absurdity" mentioned by Newton.

But

- The young generation of physicists is mainly interested in quantum mechanics,
- relativistic effects remain small in the solar system and on Earth,
- the theory is based on poorly taught mathematics that few physicists can understand.

So one adopts a neo-Newtonian attitude:

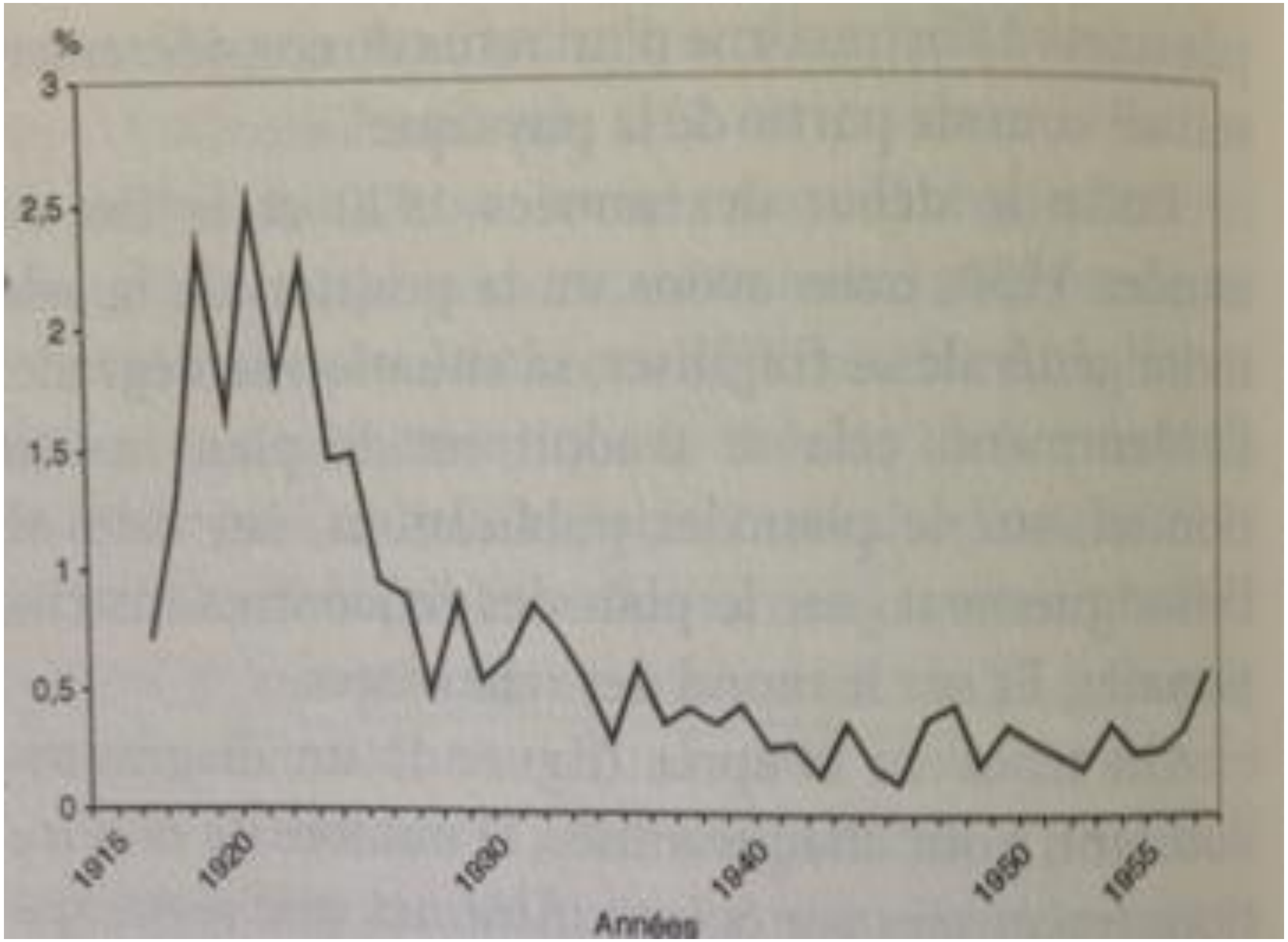
- we take into account some small modifications to Newton's physics,
- there is no change in the way of conceiving space and time.

The true scope of the theory therefore remains unknown!

… it remains ignored

Despite the fact that

- it is based on 2 experimental successes,
- it resolves the absurdity mentioned by Newton,



Guillaume

Discovery of alloys with special thermo-mechanical properties

Invar – Elinvar - …

CGPM (1889) –Imphy alloy

Systematic research program: 600 alloys provided by Imphy

Precision Metalurgy

Important for

- métrology et cryogeny (realisation of a standard meter with smaller T-sensitivity)
- Application to watch-making, geodesy

Unexpected long term applications

- integrated circuits, TV tubes, plane cables, optical systems fir spacecraft, Cassini mission…

But he was also interested by problems with less application:

- Temperature of space
- Xray and photography of opaque astre

Guillaume

Properties of Invar had theoretical consequences:

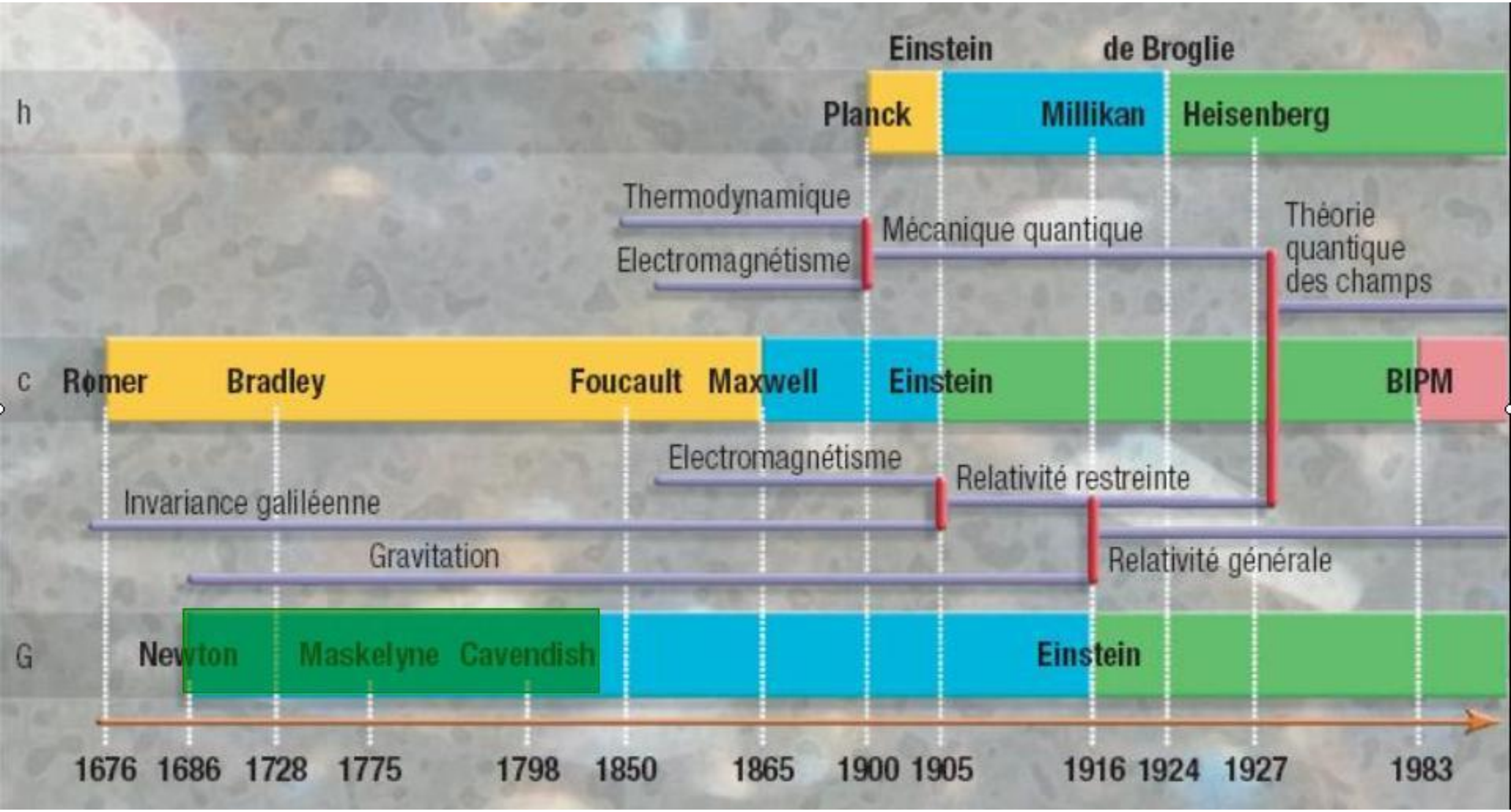
- link to disappearance of ferromagnetism
- but no model before quantum model for ferromanetism (1928)
- ….

> A man of ideas can be likened to a racehorse and the metrologist to a plough-horse. When the race is over, all that remains is a cloud of dust and a bit of noise, which soon die down, and a certain amount of money has changed hands. In contrast, a nourishing harvest arises in the wake of a plough-horse. Metrology is the nourishment of science and *there is scarcely any original idea in the field of pure science that has not grown out of a measurement more precise than its predecessors*. [My italics.]

The guideline

In dealing with the particular object of the theory of relativity, I would like to make it clear that this theory has no speculative basis, but that its discovery is based entirely on the persevering will to adapt, as well as possible, the physical theory to the observed facts. There is no need to speak of a revolutionary act or action since it marks the natural evolution of a line followed for centuries.

(A. Einstein, *Comment je vois le monde*)


h
Einstein
de Broglie
Planck
Millikan
Heisenberg
Thermodynamique
Electromagnétisme
Mécanique quantique
Théorie quantique des champs
c
Rømer
Bradley
Foucault
Maxwell
Einstein
BIPM
Electromagnétisme
Relativité restreinte
Invariance galiléenne
Gravitation
Relativité générale
G
Newton
Maskelyne
Cavendish
Einstein
1676
1686
1728
1775
1798
1850
1865
1900
1905
1916
1924
1927
1983

Guillaume / Einstein

While Guillaume may be seen as an experimenter, he explored some astrophysics and fundamental questions

While Einstein is the archetype of the theoretical physicist, his Nobel recognized a prediction for photo-electic effect,

- maybe the less conceptual of his work (because it is not for his contribution in quantum mechanics)
- was realised in the laboratory by Millikan (1922).

Two profiles and maybe the end of the universal scientists.

- Phenomenology driven / large program / goals / collaboration in and out the academic world /
- principle driven / person-centered research / not-application driven

Two very different ways of being involved in the scientific community.
Two styles and modes of doing research
Two ways of being modern

Implications of the theoretical shift

Golden age because the theory was dealing with energy scales that could be accessed in the laboratory.

1. **Special relativity:**
   * Notion of distance is not well-defined [No solid object]
   * Proper time is the important quantity
   * speed of light in vaccum is a fundamental constant

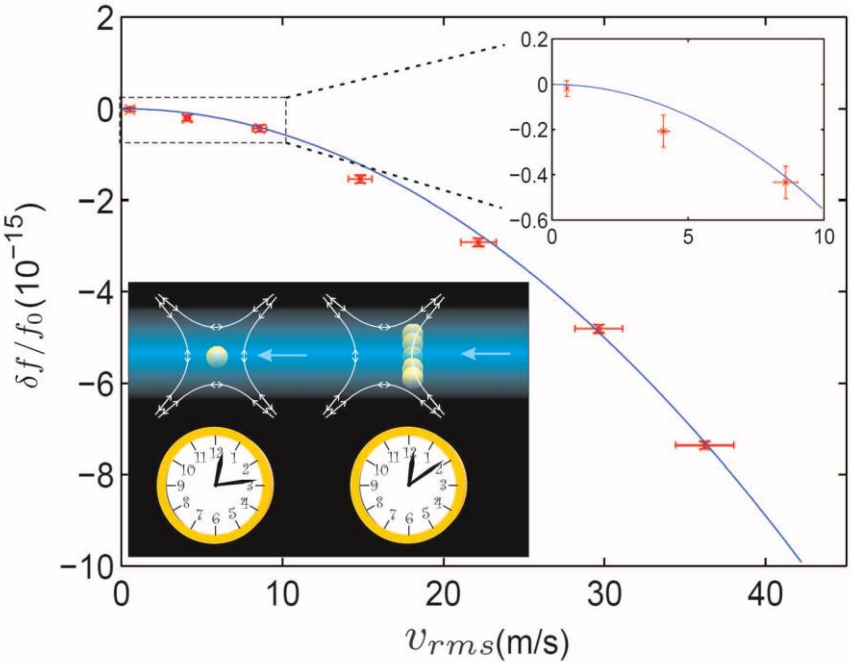
2. **General relativity**
   Limitation by environment (Einstein effect, decoherence,...)

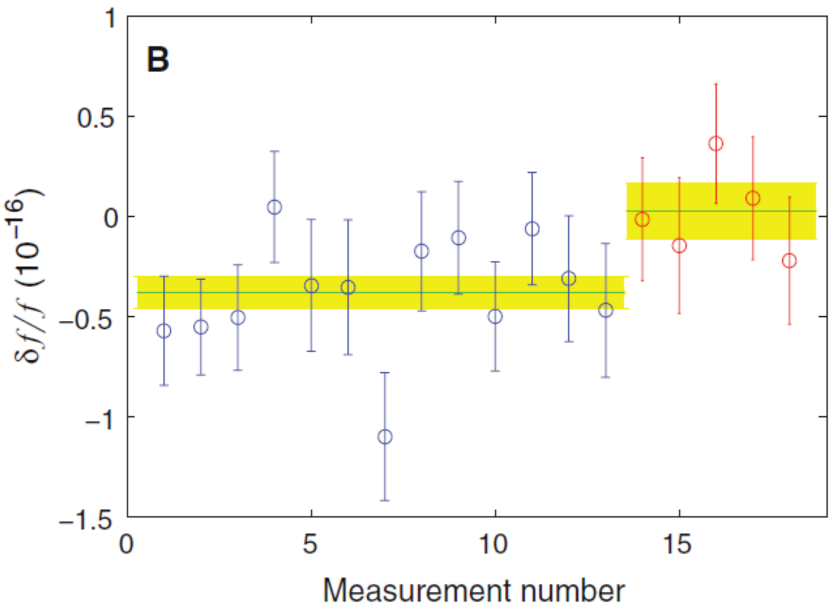
3. **Quantum mechanics**
   the theory is transformed in tools very quickly, i.e. we do not even question it. It becomestandard lore physcis.

4. **Implications**
   * Interferometry is central
   * 1983 definition of the meter.
   * Quantum with new metrological techniques

Time and clocks

C. W. Chou, D. B. Hume, T. Rosenband, D. J. Wineland, Science 329, 1630, (2010)





Dilatation du temps

(*relativité restreinte*)

Effet Einstein

L'horloge B est montée de 33 cm.

Sa fréquence augmente de 3. 4 10^{-17}

What about today?

1. Theory tells us what are the most fundamental objects of nature. Those that cannot be altered: best candidates to define unpearishable systems if units [cf. Maxwell]

2. e.g. atoms: you need QM to understand the spectra / constants

3. Fondamental frontiers:
   1. Gravity (equiv. Principle) – quantum
   2. Particle physics (DM, mass of neutrinos)
   3. Energy gap between theory and metrology

4. Conceptual revolution vs revolutions driven by tools.
   coincidence during the early XXth.

5. Structuration de la recherche

We cannot plan discovery – only research can be but that starts to be politics.

Limitations of disciplines for the questions we are facing today