Experimental Methods in Physics

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Moodle: https://moodle.epfl.ch/course/view.php?id=15458#section-1

Goals of the MEP course

1. Learn some interesting experimental methods:
   1. Noise and interference reduction techniques
   2. Scanning probe microscopy: STM, AFM, etc.
   3. Electron microscopy: SEM, TEM, EDX, etc.
   4. Optical spectroscopy

2. Learn some critical thinking:
   1. Critical evaluation of experimental methods
   2. Critical reading of scientific papers

Weekly exercises: Presentation of a scientific paper (with criticism)

Exam: 10' presentation of a scientific paper on a subject related to the course (after 1h preparation, course material allowed), followed by questions on the techniques discussed in the course

What is critical thinking?

Here are some short presentations that you can watch:

- https://www.youtube.com/watch?v=dItUGF8GdTw
- http://fr.slideshare.net/zollnera/critical-thinking-in-high-school-physics

It's important not only in science, but in life in general !

The importance of critical thinking

Robert Park, American Physical Society representative in Washington DC:

“Of the major problems confronting society- problems involving the environment, national security, health, and the economy - there are few that can be sensibly addressed without input from science. As I sought to make the case for science, however, I kept bumping up against scientific ideas and claims that are totally, indisputably, extravagantly, wrong, but which nevertheless attract a large following of passionate, and sometimes powerful, proponents. I came to realize that many people choose scientific beliefs the same way they choose to be Methodists, or Democrats, or Chicago Cubs fans. They judge science by how well it agrees with the way they want the world to be.”

“A best-selling health guru insists that his brand of spiritual healing is firmly grounded in quantum theory; half the population believes Earth is being visited by space aliens who have mastered faster-than-light travel; and educated people wear magnets in their shoes to restore natural energy. Did we set people up for this? In our eagerness to share the excitement of discovery, have scientists conveyed the message that the universe is so strange that anything is possible? What can we tell people that will help them to judge which claims are science and which are voodoo?”

For scientists, critical thinking is an essential part of the scientific method !

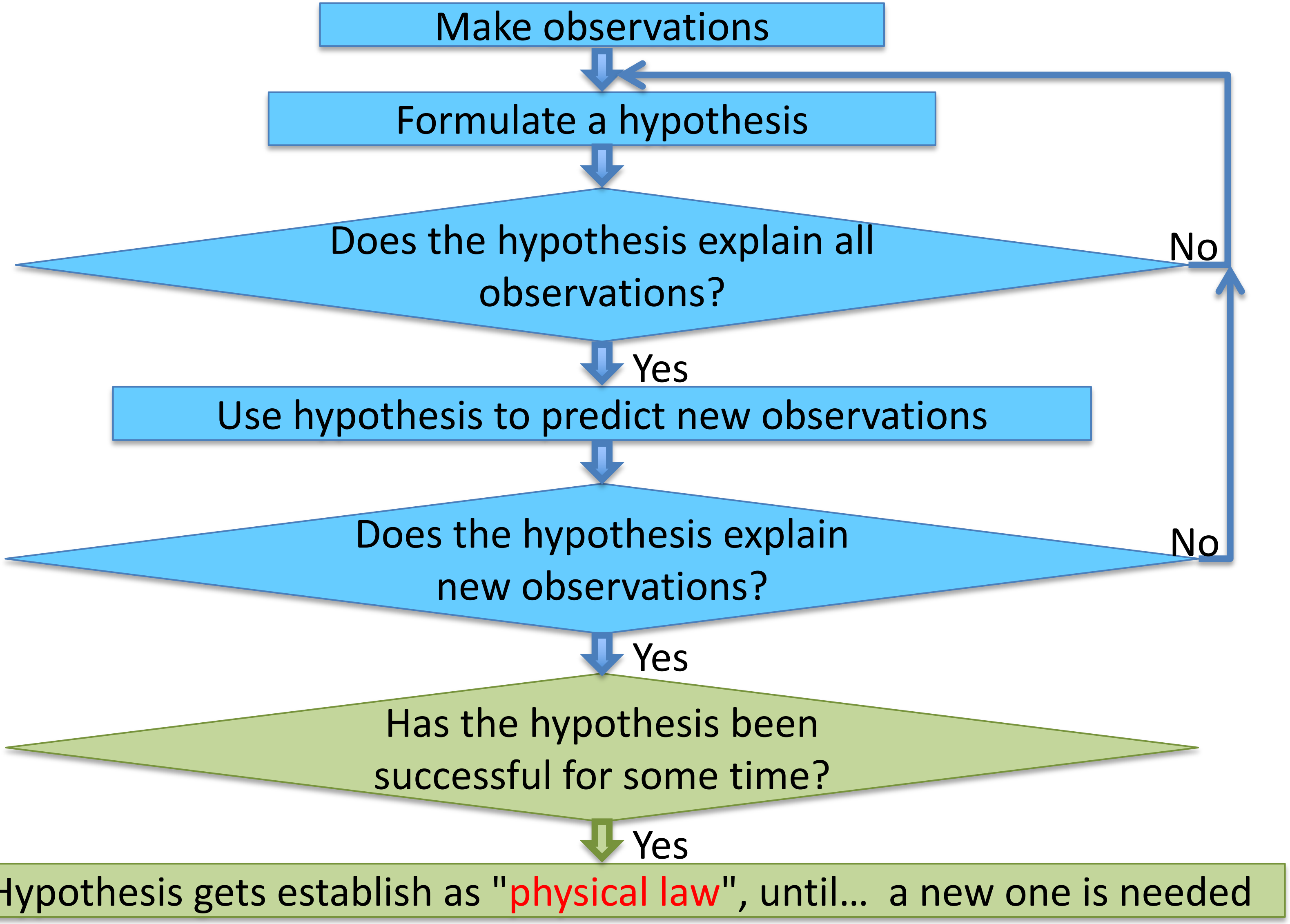
Robert Park, “VOODOO SCIENCE: The Road from Foolishness to Fraud”, Oxford university press, 2000, pp VIII-IX

The scientific method:

The foundations of the scientific method were laid out in the renaissance, following pioneers during the Arab "age of gold"

Alhazen, ~1000

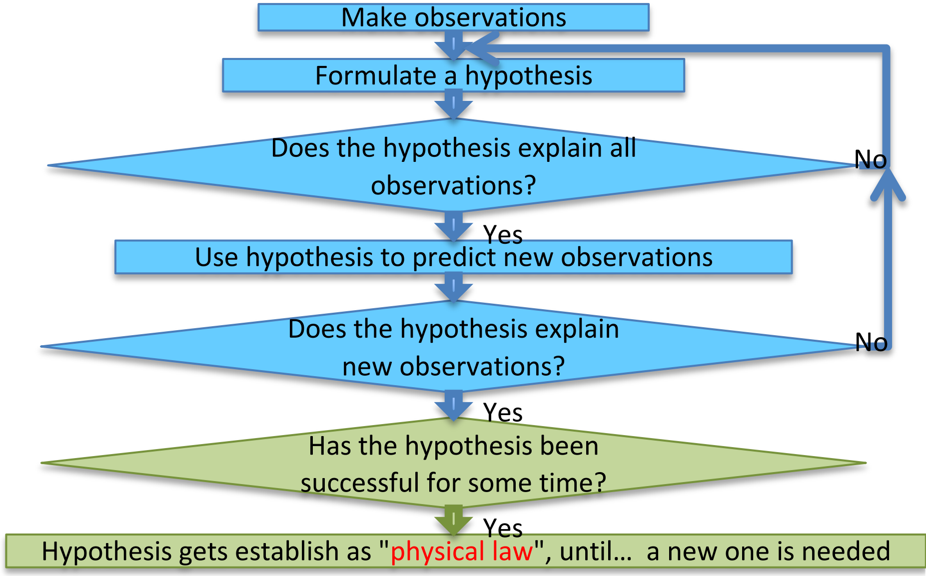
F. Bacon, ~1600



This process approaches the full understanding of nature by "successive approximations"
It's important to understand that although we can never get "all the truth", we're very close…

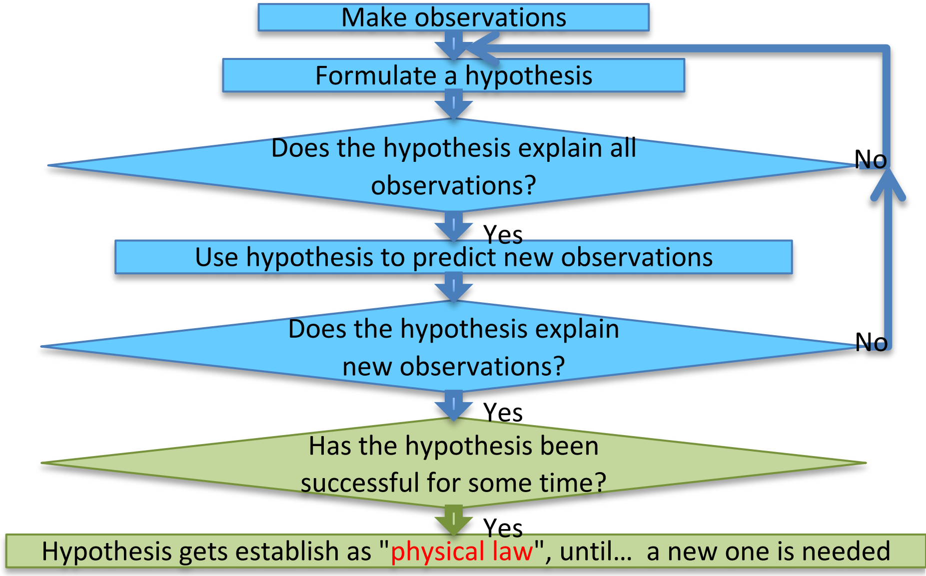
Examples of correct scientific development of theories:

- The theories of Newton about movement and gravitation:
  - Developed in 1687, it explains the movement of both everyday objects and the planets in a simple way.
  - Only in 1905, following some experimental discrepancies and contradictions, Einstein developed the theories of special and general relativity, which replace Newton's theories (which remain a good approximation in everyday life).
- The theory of the Ether:
  - During the 19th century, scientists imagined that light (electromagnetic waves) must propagate in a medium (like sound waves), called the Ether, which fills all space.
  - Following experiments by Michelson-Morley (1887) and others (including Einstein), the Ether theory was abandoned. It was recognized that electromagnetic waves can propagate in vacuum.



How would critical thinking help:

- When formulating the hypothesis:
  - Check that it explains ALL relevant results
  - Prefer hypotheses that are simple and predictive
- When designing experiments:
  - The experiments should check if the hypothesis is true or false
  - ALL aspects of the hypothesis should be checked, and against competing hypotheses. Control experiments should be designed
- When interpreting results:
  - Be as objective as possible towards the results
  - Check that ALL results are taken into account, not only supporting ones
  - Check that other hypotheses can not explain results
- When reviewing / reading about experiments:
  - Check that published results are plausible and consistent with what we know
  - Check that results are consistent with the author's hypothesis, but not with competing ones
  - Had others tried to confirm the results? or the hypothesis?



It's always easier to be critical towards others than towards oneself ...

The pitfalls (1)

"Science fascinates us by its power to surprise. Unexpected results that appear to violate accepted laws of nature can portend revolutionary advances in human knowledge. In the past century, such scientific discoveries doubled our life span, freed us from the mind-numbing drudgery that had been the lot of ordinary people for all of history, revealed the vastness of the universe, and put all the knowledge of the world at our fingertips. As a new century begins, molecular biology is unravelling the secrets of life itself, and physicists dare to dream of a "final theory" that would make sense of the entire universe.

Alas, many "revolutionary" discoveries turn out to be wrong. Error is a normal part of science, and uncovering flaws in scientific observations or reasoning is the everyday work of scientists. Scientists try to guard against attributing significance to spurious results by repeating measurements and designing control experiments. But even eminent scientists have had their careers tarnished by misinterpreting unremarkable events in a way that is so compelling that they are thereafter unable to free themselves of the conviction that they have made a great discovery. Moreover, scientists, no less than others, are inclined to see what they expect to see, and an erroneous conclusion by a respected colleague often carries other scientists along on the road to ignominy. This is pathological science, in which scientists manage to fool themselves.

Robert Park, "VOODOO SCIENCE: The Road from Foolishness to Fraud", Oxford university press, 2000, pp 9-10

The pitfalls (2)

If scientists can fool themselves, how much easier is it to craft arguments deliberately intended to befuddle jurists or lawmakers with little or no scientific background? This is junk science. It typically consists of tortured theories of what could be so, with little supporting evidence to prove that it is so.

Sometimes there is no evidence at all. Two hundred years ago, educated people imagined that the greatest contribution of science would be to free the world from superstition and humbug. It has not happened. Ancient beliefs in demons and magic still sweep across the modern landscape, but they are now dressed in the language and symbols of science: a best-selling health guru explains that his brand of spiritual healing is firmly grounded in quantum theory; half the population believes Earth is being visited by space aliens who have mastered faster-than-light travel; and educated people wear magnets in their shoes to draw energy from the Earth. This is pseudoscience. Its practitioners may believe it to be science, just as witches and faith healers may truly believe they can call forth supernatural powers.

What may begin as honest error, however, has a way of evolving through almost imperceptible steps from self-delusion to fraud. The line between foolishness and fraud is thin. Because it is not always easy to tell when that line is crossed, I use the term voodoo science to cover them all: pathological science, junk science, pseudoscience, and fraudulent science."

Robert Park, "VOODOO SCIENCE: The Road from Foolishness to Fraud", Oxford university press, 2000, pp 9-10

Critical thinking helps to detect and avoid important pitfalls:

- Scientific fraud (rare, but exists)
- Scientific mistakes (can happen to anyone)
- Illusions and Self-deceptions (rare, take time to find)

"But this long history of learning how to not fool ourselves—of having utter scientific integrity—is, I'm sorry to say, something that we haven't specifically included in any particular course that I know of. We just hope you've caught on by osmosis.

The first principle is that you must not fool yourself—and you are the easiest person to fool. So you have to be very careful about that. After you've not fooled yourself, it's easy not to fool other scientists. You just have to be honest in a conventional way after that."

R. P. Feynman, Cargo Cult Science, 1974

US NSF : Responsible Conduct of Research (RCR)

Statutory Requirement
"The Director shall require that each institution that applies for financial assistance from the Foundation for science and engineering research or education describe in its grant proposal a plan to provide appropriate *training* and oversight in the responsible and ethical conduct of research to undergraduate students, graduate students, and postdoctoral researchers participating in the proposed research project."

http://www.nsf.gov/bfa/dias/policy/rcr.jsp

Scientific fraud

Distribution of recent fraud cases according to fields:

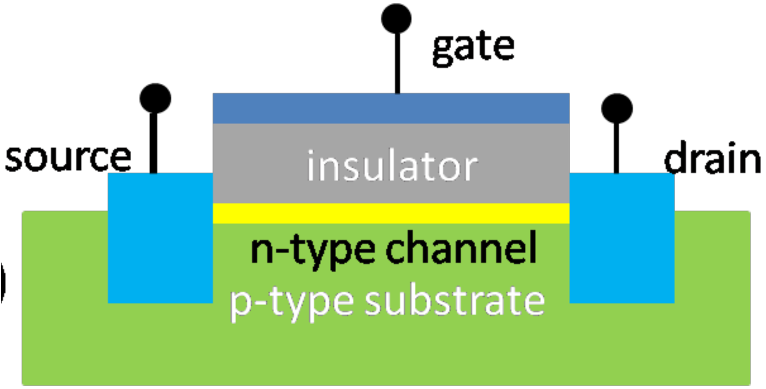
Field	Number of cases
Biology/Medicine	60
Physics	3
Chemistry	5
Math/Computers	3

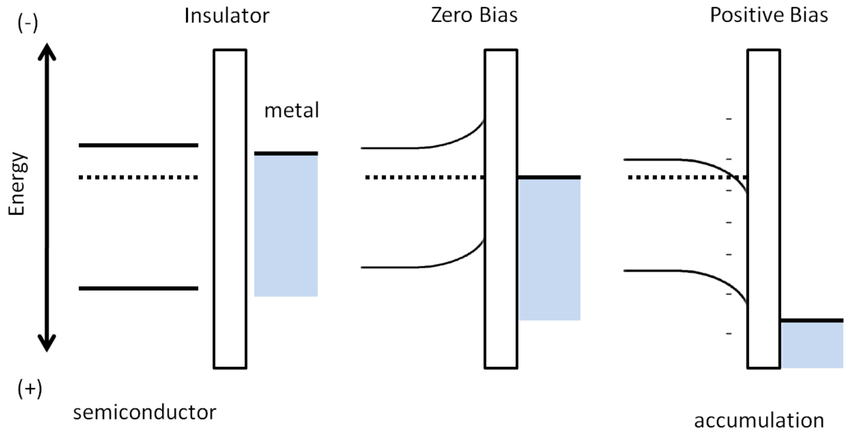
(Source: https://en.wikipedia.org/wiki/List_of_scientific_misconduct_incidents)

Scientific fraud

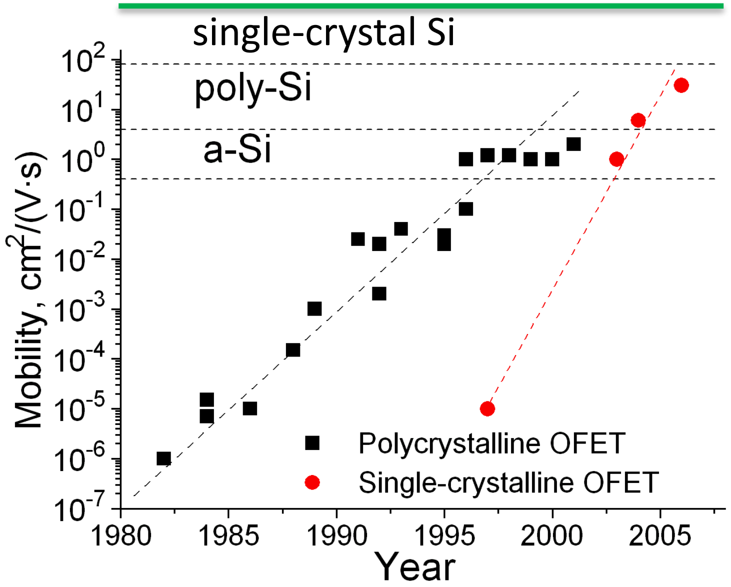
The most important case in physics - the H. Schön scandal (Bell labs, 2002): 32 retracted papers!

- The background: Research on organic conductors, as potential replacement for semiconductors in novel electronic circuits. These materials have an energy gap similar to conventional semiconductor, and can be doped (p and n types). They have several advantages:
  - Cheaper materials, no need for single-crystal growth.
  - Can be deposited by simple coating techniques over very large surfaces.
  - Many materials exist with different electronic properties, that can be combined to form new devices.
- However, they also have some important limitations:
  - Making good electrical contacts to these materials is not simple.
  - Relatively poor charge mobility.
  - Transistors made from these materials need high electric fields in order to create the charge carrier "channel". This implies that the gate dielectric layer must be of a very high quality.
- Currently such devices are used in displays (TFT, OLEDs), and in flexible electronics.





https://en.wikipedia.org/wiki/Organic_field-effect_transistor



Scientific fraud

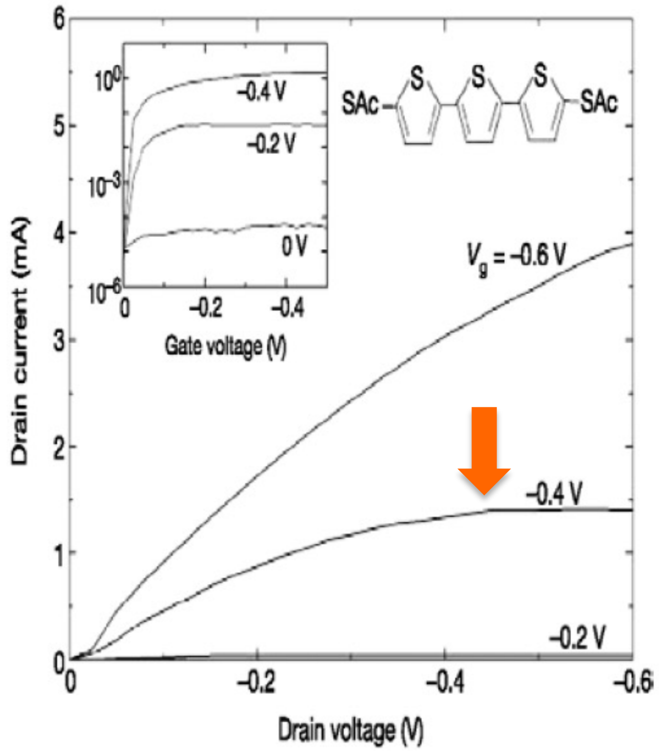
The most important case in physics - the H. Schön scandal (Bell labs, 2002): 32 retracted papers!

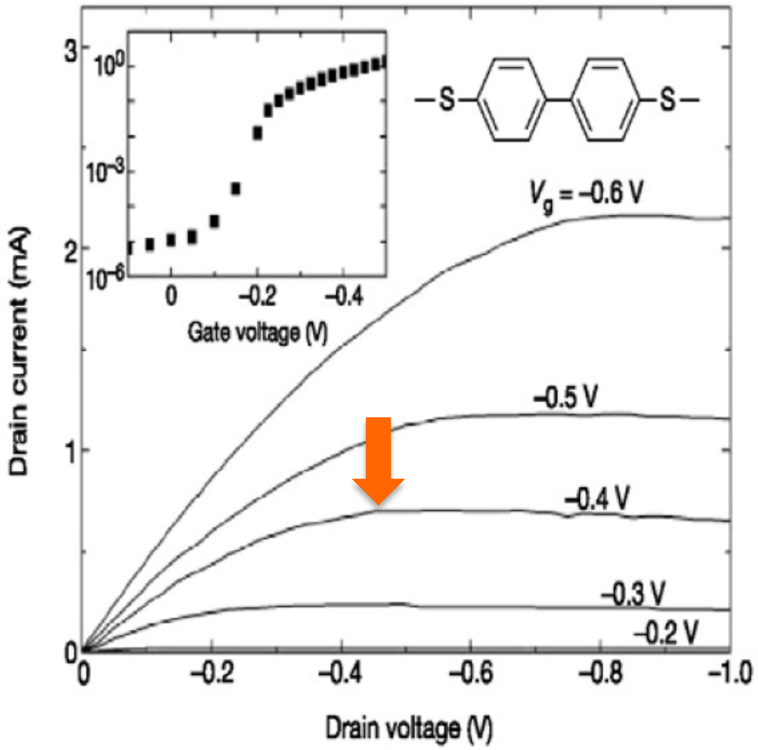
- Using crystals of organic conductors, and claiming to have developed an excellent gate insulator, H. Schön produced many new results in a record time, covering many phenomena: transistor action, superconductivity, light emission. He demonstrated many devices: logic gates, oscillators, LEDs, Lasers, …
- All these resulted in 9 Science and 7 Nature papers published in 2000-2001.
- Overall publishing speed of 1 paper / 8 days (!)
- End 2001: the scandal started! Following lack of success in reproducing these results by other scientists, followed by criticism (led by L. Sohn and P. McEuen) of some of the published data
- Beg. 2002: Bell labs appointed an investigation committee, led by M. Beasley, which report was issued end 2002 and pointed out to many cases of “scientific misconduct”, and even "data fabrication and falsification".

Some examples of data falsification:

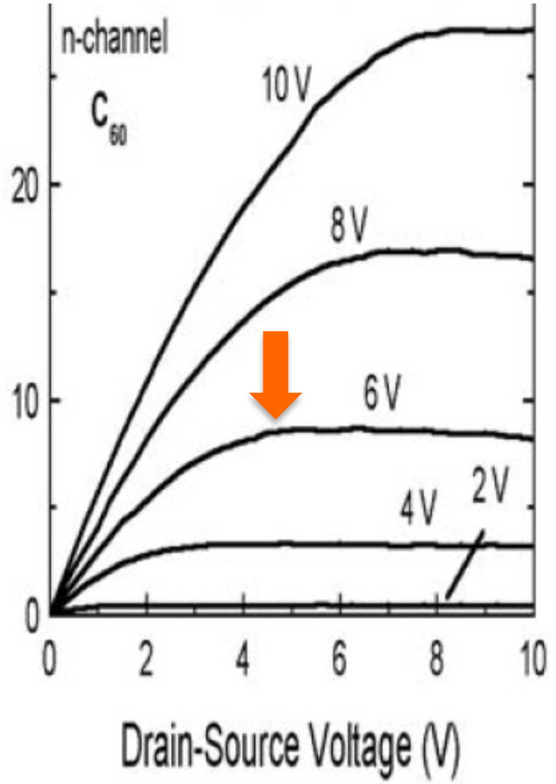
1. Same data, different scales…

- Two I/V curves, taken from different papers, and representing different molecules: There is an exact correspondence of the data in these curves (with x2 y-axis scaling between them):



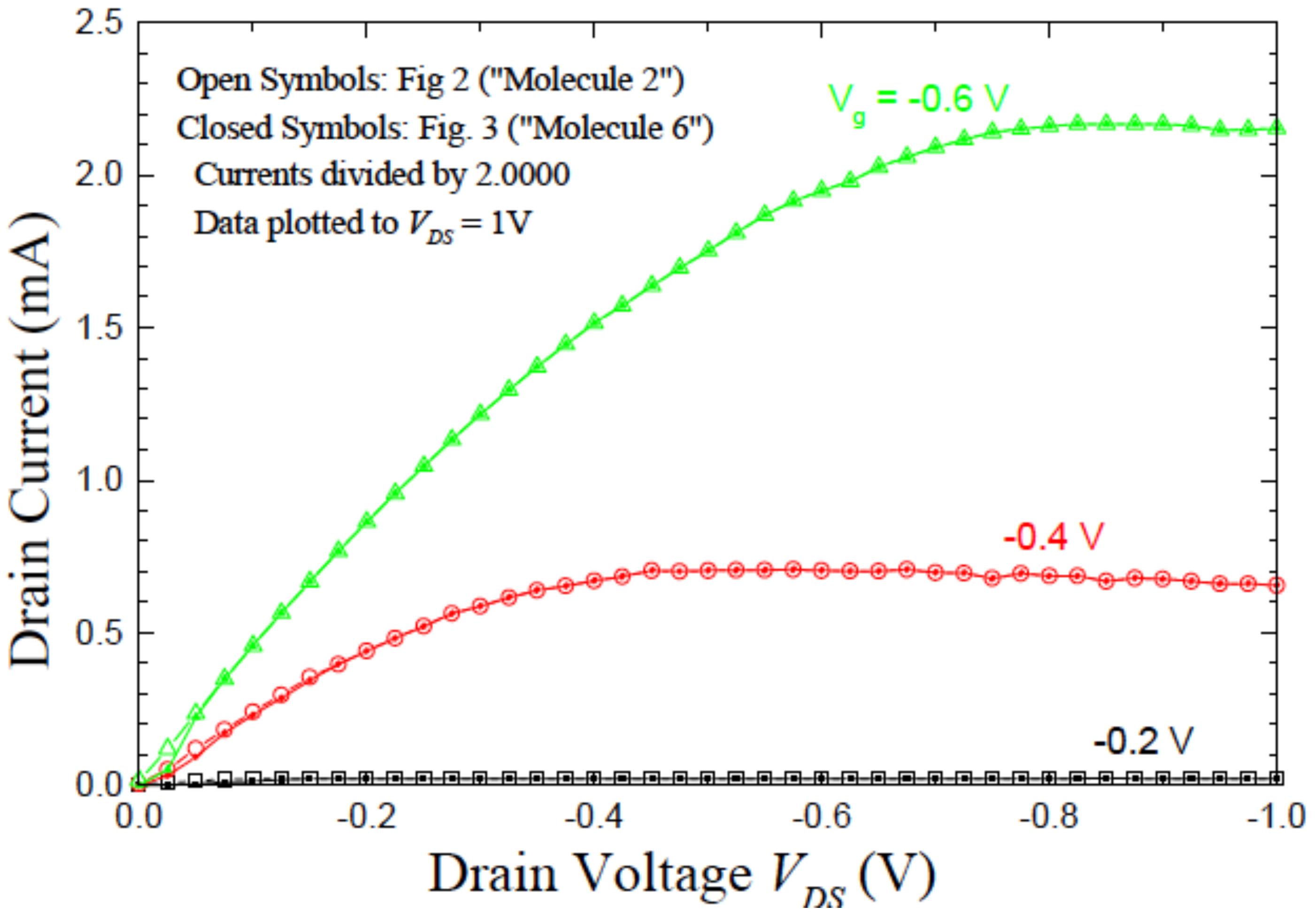


- These curves seem to match a 3rd graph from an older paper, representing yet another material:
- Each graph has different scales and extent, but all have the same shape (incl. noise) !



1. Same data, different scales… details of the proof:

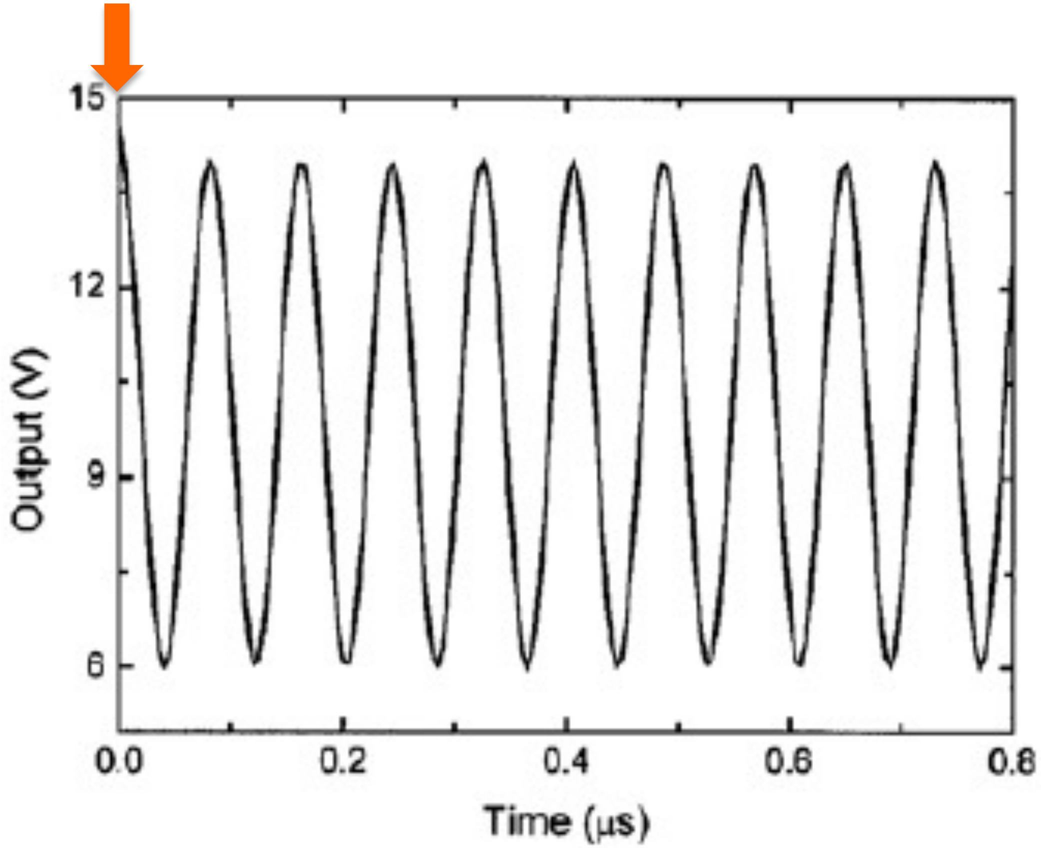
- Plotting the two sets of 3 I-V curves (at 3 different gate voltages), supposedly from two devices using different organic conductors (one set of data has the current divided by 2) on the same graph shows exact correspondence.
- Here the same data (perhaps real ?) has been copied and scaled to represent different results.

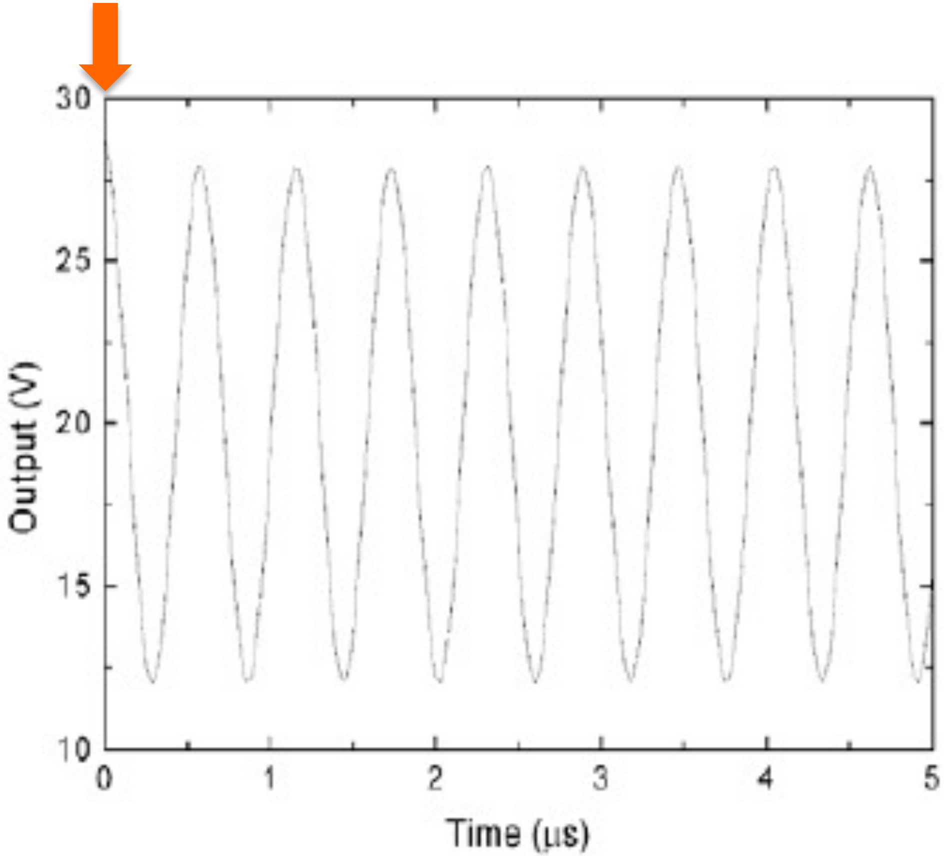


Some examples of falsification:

2. Almost ideal oscillations…

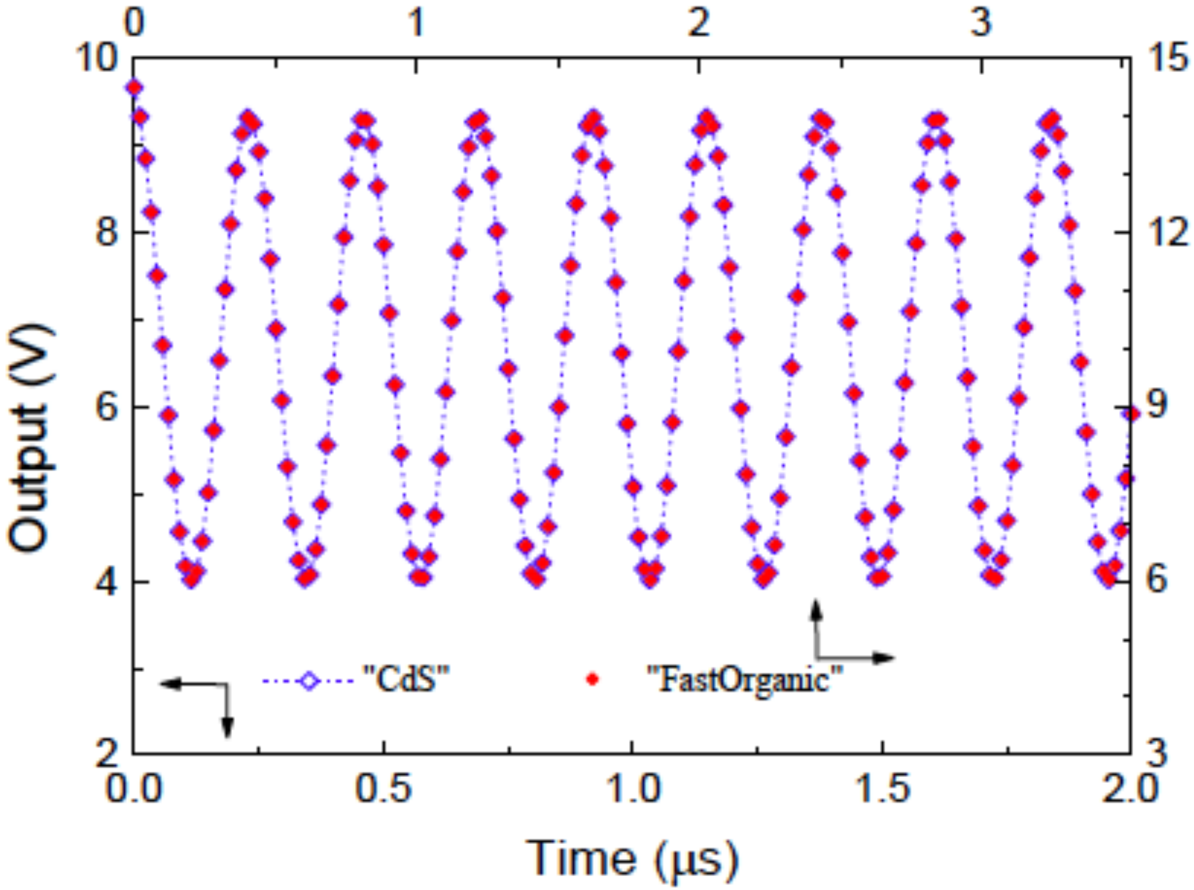
- To show the speed of organic-semiconductor transistors, a "ring oscillator" is built. It uses positive feedback to make the transistor amplifier oscillate, and the period of oscillations reveals the time response of the transistor.
- Two curves showing the output of a ring oscillator, using different molecules: Both voltage and time scales are related by an exact scaling factor: it's the same data!
- Plus, a strange extra peak at t=0 … appears in both graphs !

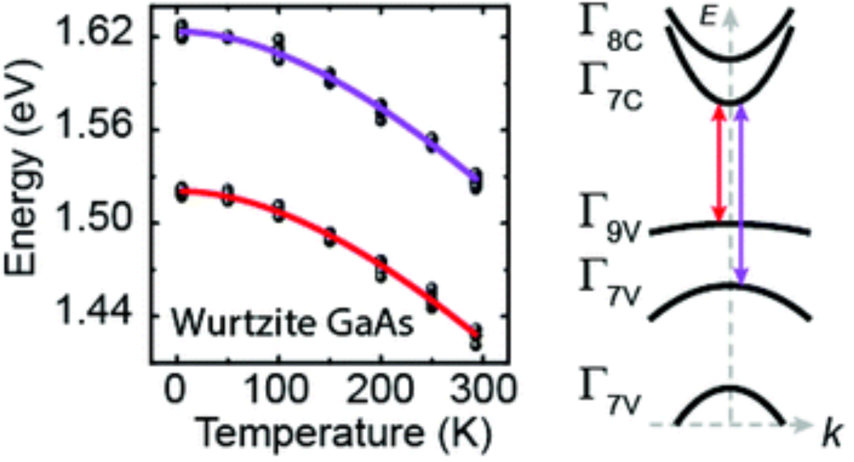




2. Almost ideal oscillations… details of the proof

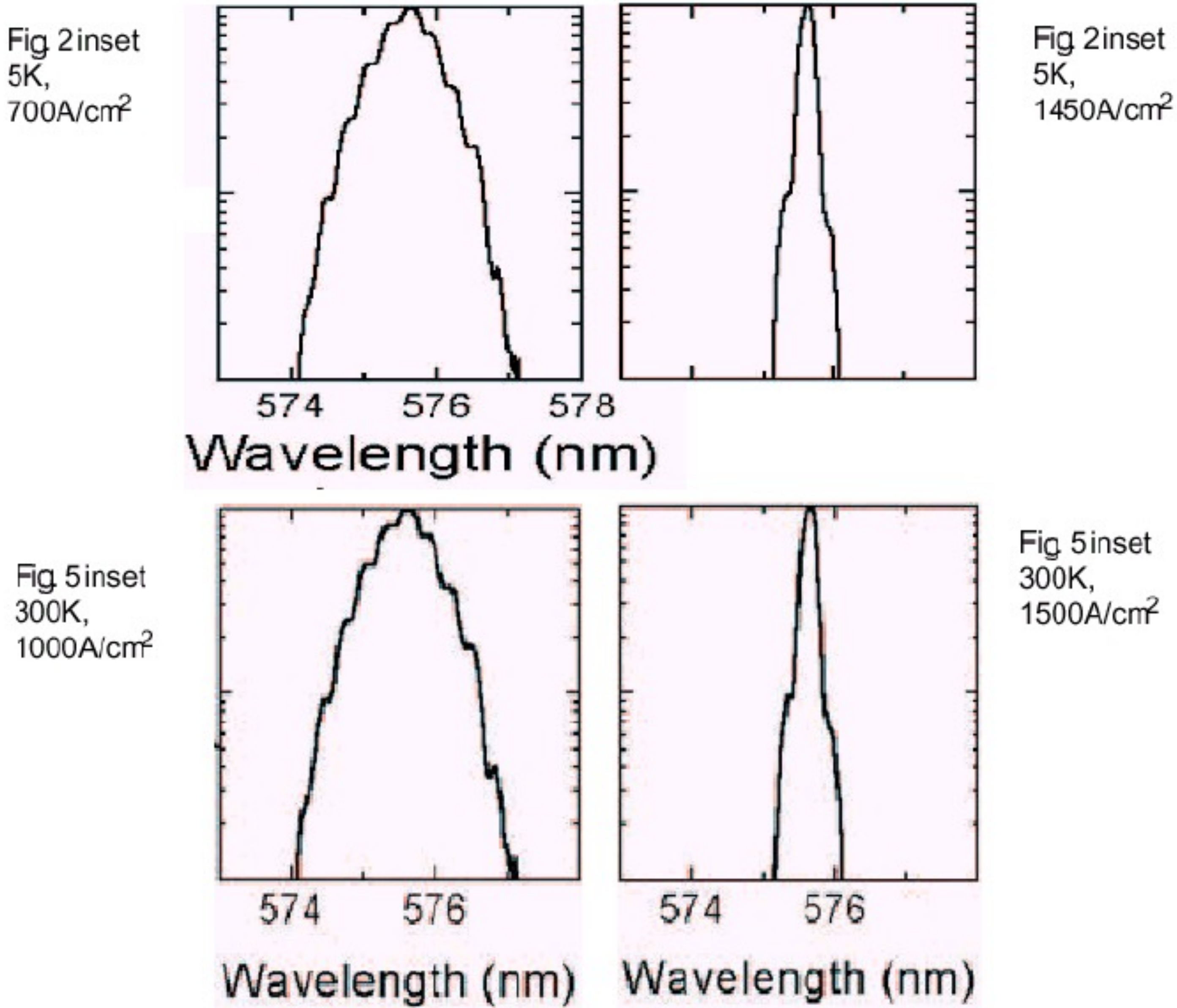
- "Original" data files were found later by the committee. Plotting the two curves on the same graph, using different voltage and time scales, show their precise matching
- Here the "data" was obtained artificially by calculating a sine function, then adding the pulse at time t=0.





Some examples of falsification:

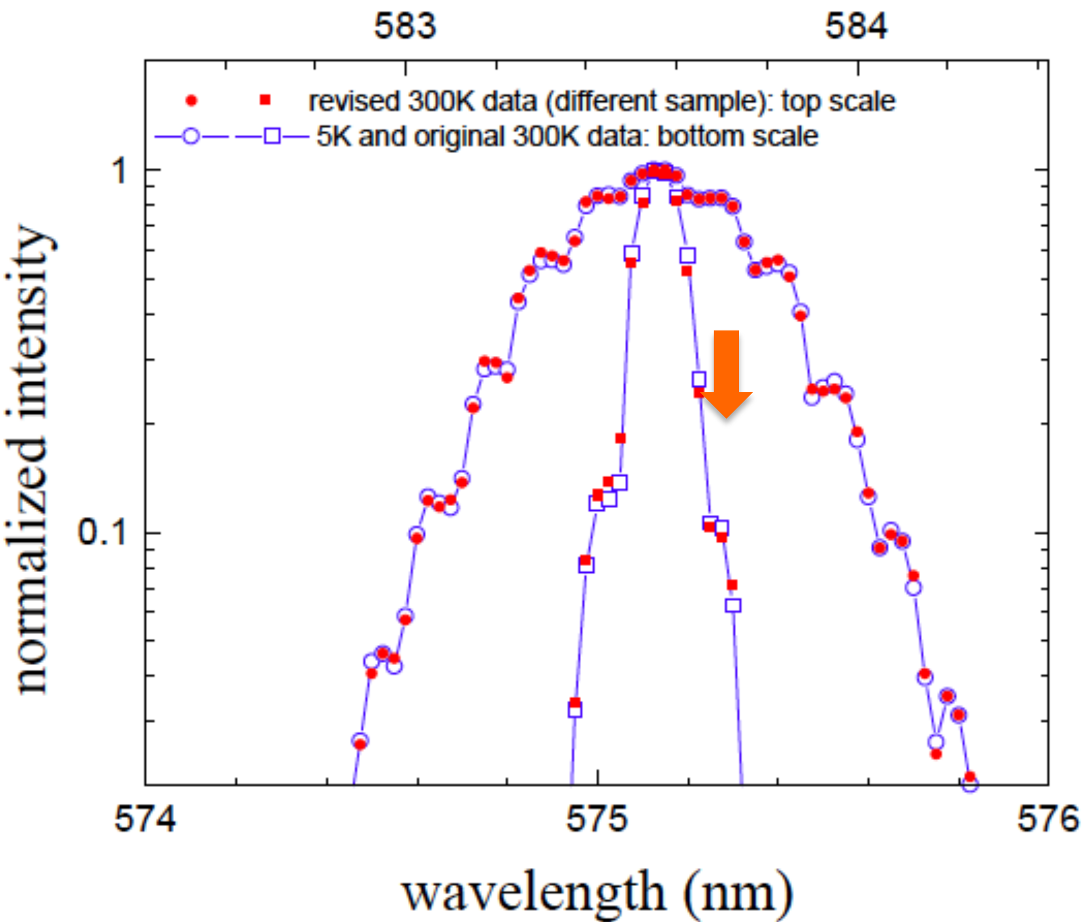
3. Ideal Gaussian as data

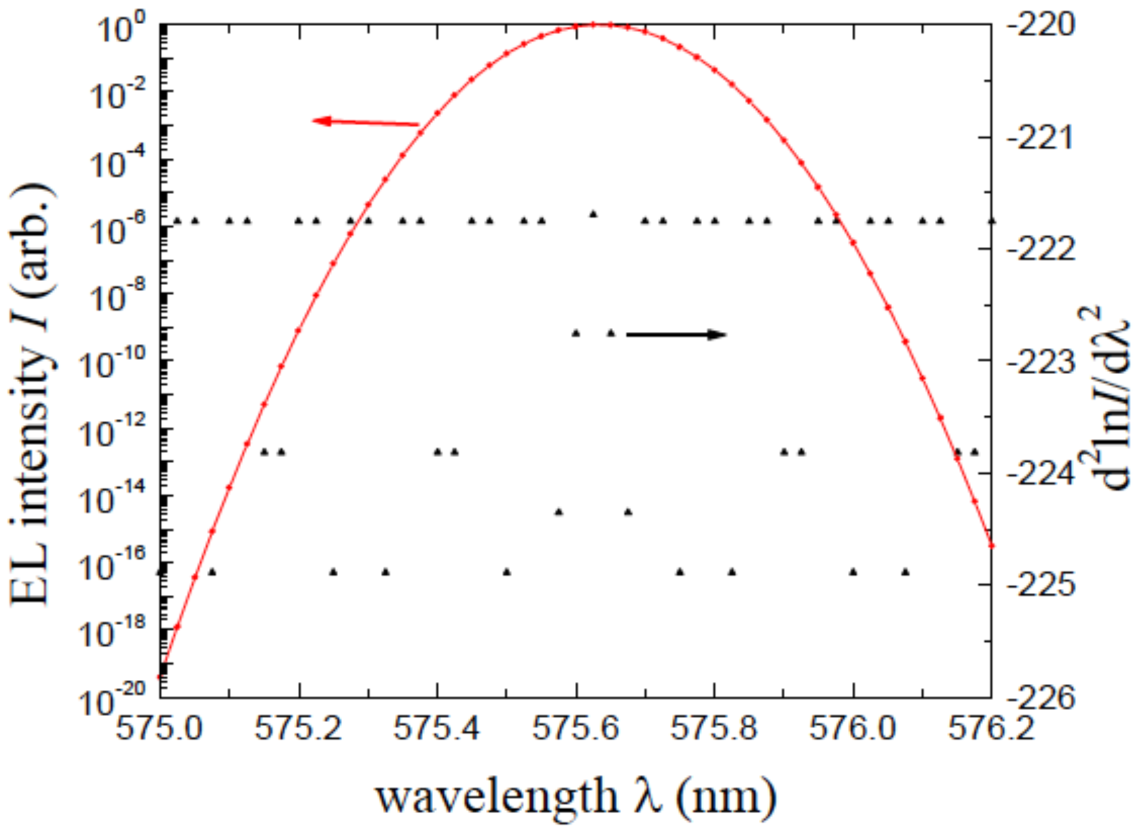


- Optical spectra of laser emission at different temperatures and currents, are essentially the same: This is not physical!
- Optical emission of semiconductors in general, and especially laser diode emission, should vary with temperature. This is due to:
  - Bandgap energy is temperature-dependent
  - Index of refraction changes with temperature
- Moreover, carrier concentration (related to current) changes the emission energy as well.
- Conclusion: It isn't possible to have a spectral peak at exactly the same wavelength for different temperatures and currents!

3. Ideal Gaussian as data: The proof

- Actually, all "data" comes from a perfect Gaussian function, as shown in an extended plot found later in the original file:





- By limiting the numerical precision, one obtains the steps seen in the curves
- Same thing happens with data from "another sample", which is the same curve, only shifted in wavelength…

Scientific fraud

- Luckily, it doesn’t happen often!
- Usually the scientific journal's peer review process is enough to detect problematic data and claims
- How to detect:
  - Identical data in different graphs (perhaps with different scaling), different articles (not to confound with multiple publications, which could be an ethical issue but not fraud)
  - Precision which is “too good to be true”, usually isn’t!
  - Lack of statistically reasonable data spread and noise hints to artificial data

Scientific mistakes

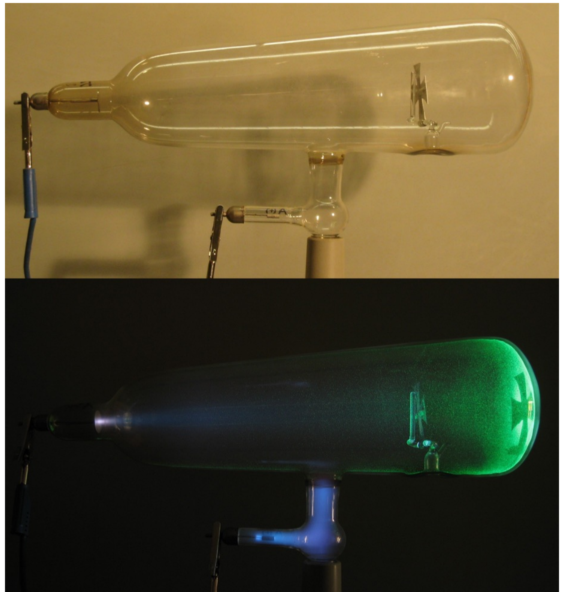
- These can happen to anyone!
- Usually detected by the student, the supervisor, or a referee, before publication – or (in the worst case) by peers after publication
- Examples showing how to reduce the chances of a mistake:
    - Test a new experimental setup with no sample (measure the noise level, then the excitation signal feed-through, then the effect of changing temperature, magnetic field, or other parameters).
    - Test the new experiment with known samples. Sometimes it's possible to compare different parts of a sample, e.g. modified/unmodified parts.
    - Test numerical simulations by doing manual (order-of-magnitude) or analytical calculations in simplified cases.

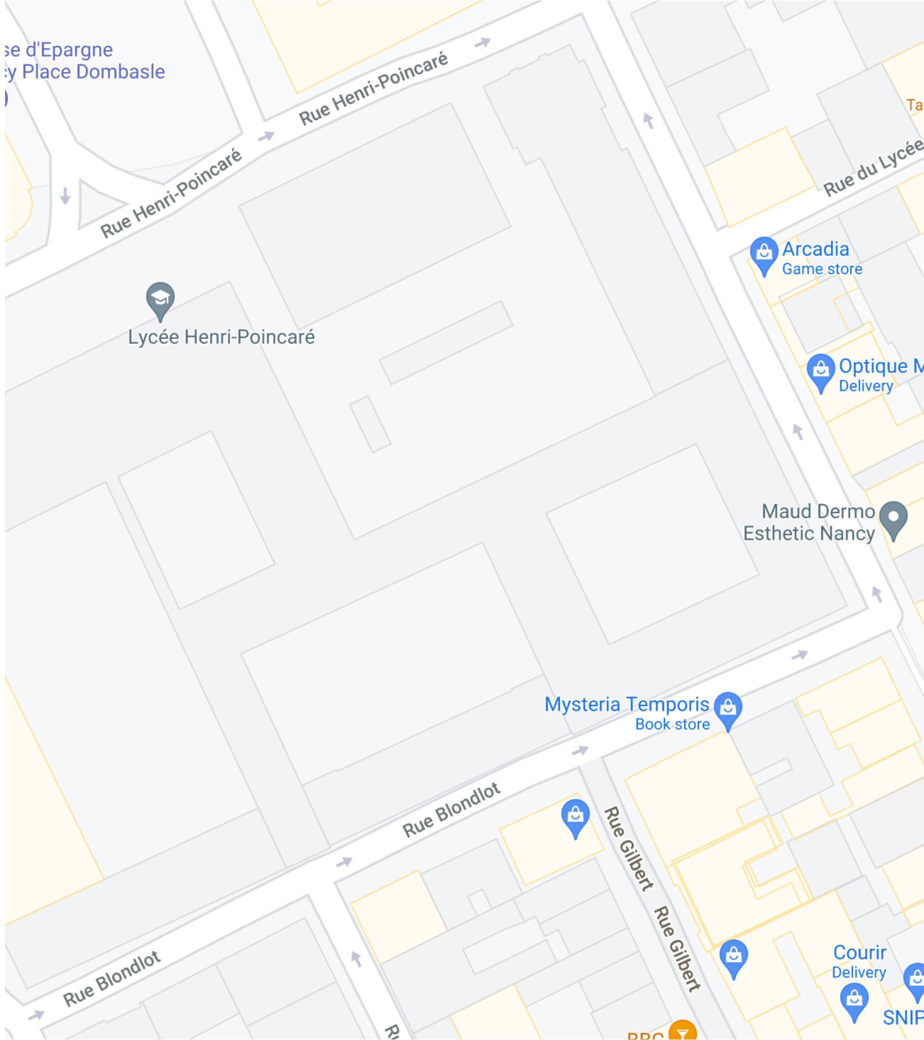
Scientific illusions and self-deceptions

- Also known as “Pathological science” (Langmuir, 1953), and “cargo Cult Science” (Feynman, 1974)
- Unlike fraud, these are real theories and experiments published in good faith by well-known researchers
- The main problem is self-deception: The belief in a pet theory, based on marginal (and often partial) data
- Not many such cases exist in physics, but they’re very instructive

Scientific illusion example: The N-rays (1)

- The prof. Prosper-René Blondlot (1849–1930) was an eminent physicist at the university of Nancy, France.
- In the 1880-1990s, he was the first to measure the traveling speed of electric pulses in cables and the propagation speed of radio waves, in relation with the recent electromagnetic theory of Maxwell (1862). For these he received many distinctions.
- In the years 1993-1999, many discoveries were made concerning radiation: short-wavelength UV, X-rays, the electron (cathode rays), alpha, beta and gamma rays. That was the frontline of physics!
- In many cases, these rays were detected by weak fluorescence of a screen, forming a shadow image, or by counting individual scintillations, by an observer in a dark room. Sometimes a sensitive (thick) photographic plate was used.





https://en.wikipedia.org/wiki/Prosper-Ren%C3%A9_Blondlot

https://en.wikipedia.org/wiki/Crookes_tube

Scientific illusion example: N-rays (2)

- In 1903, Blondlot claims to discover a new type of rays, which he names N-rays.
- They were detected as an increase of brightness of a small electric spark, or of a weekly illuminated fluorescent screen, but the brightness difference was always minimal.
- In many scientific papers by Blondlot and others, These rays were claimed to have many properties similar to light:
- They could go through wood and non-ferrous metals, but were blocked by water.
- They were emitted by the sun, gas burners, and human presence; could be stored in a brick (covered by black paper and put in sunlight, then brought into the dark lab to test).
- They could be polarized, reflected, refracted.
- Spectroscopy was tried using an Al prism, showing on a phosphorous screen regions of different brightness claimed to show spectral peaks.

Photo of barely illuminated screen (left) and with N-rays (right):

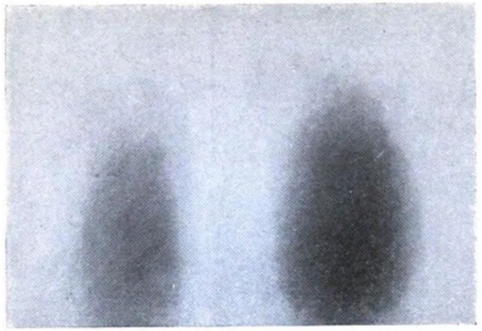


Fig. 6.

Without "N" rays. With "N" rays proceeding from a Nernst lamp.

Images from Blondlot's report: photos of an electric spark with N-rays (right) and without (left)

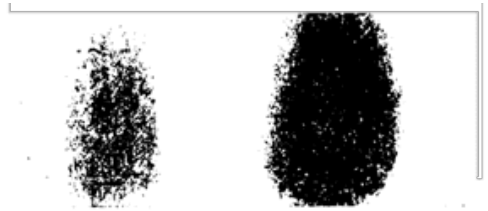


Fig. 6.

Without "N" rays. With "N" rays proceeding from a Nernst lamp.

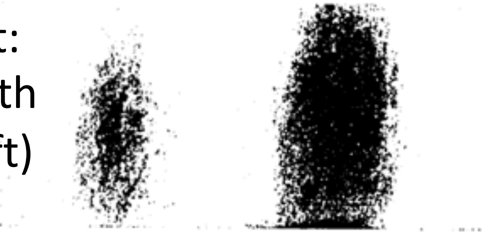


Fig. 7.

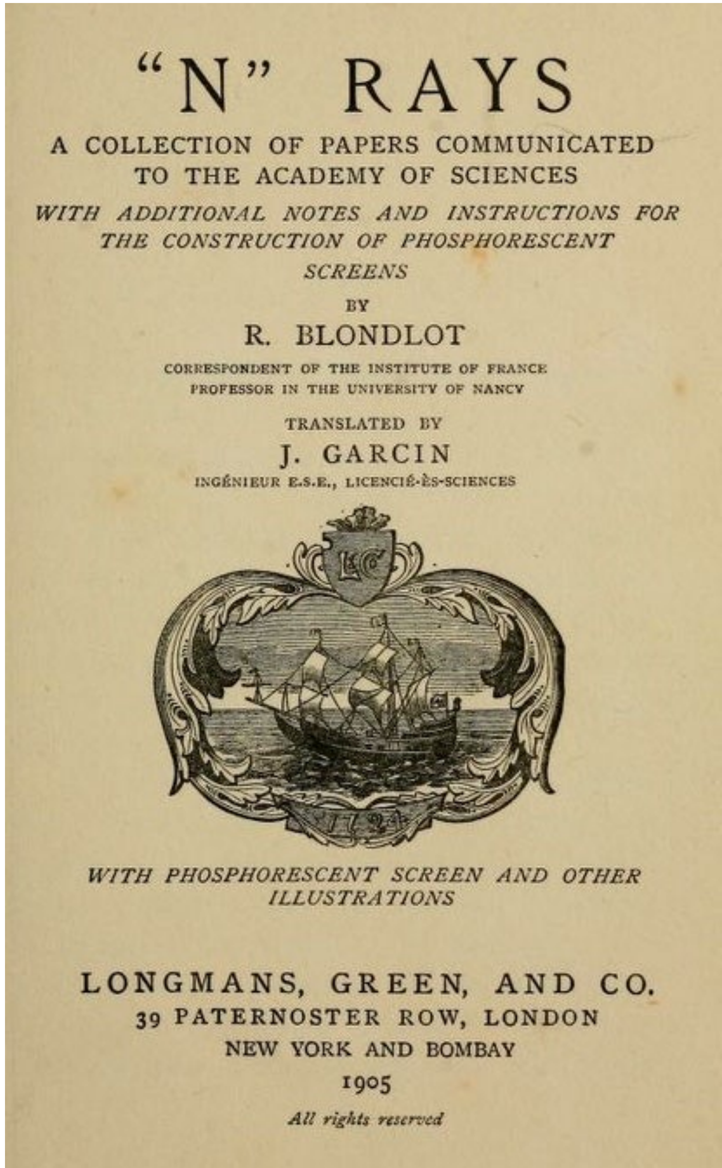
Without "N" rays. With "N" rays produced by two large files.

[To face p. 66.

N.B.—The striæ and most of the spots in the figures do not exist in the original photograph, but are the result of the inability of the photogravure process to reproduce images of this kind.

https://phoenixwi.com/neutron-radiography/n-rays-vs-n-rays/

https://www.wired.com/2014/09/fantastically-wrong-n-rays/



"N" RAYS

A COLLECTION OF PAPERS COMMUNICATED TO THE ACADEMY OF SCIENCES

WITH ADDITIONAL NOTES AND INSTRUCTIONS FOR THE CONSTRUCTION OF PHOSPHORESCENT SCREENS

BY

R. BLONDLOT

CORRESPONDENT OF THE INSTITUTE OF FRANCE
PROFESSOR IN THE UNIVERSITY OF NANCY

TRANSLATED BY

J. GARCIN

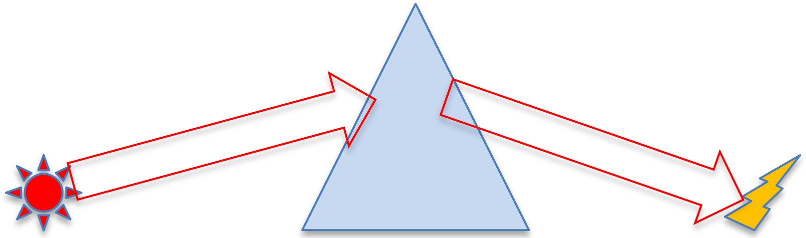
INGÉNIEUR E.S.E., LICENCIÉ-ÈS-SCIENCES

WITH PHOSPHORESCENT SCREEN AND OTHER ILLUSTRATIONS

LONGMANS, GREEN, AND CO.
39 PATERNOSTER ROW, LONDON
NEW YORK AND BOMBAY
1905

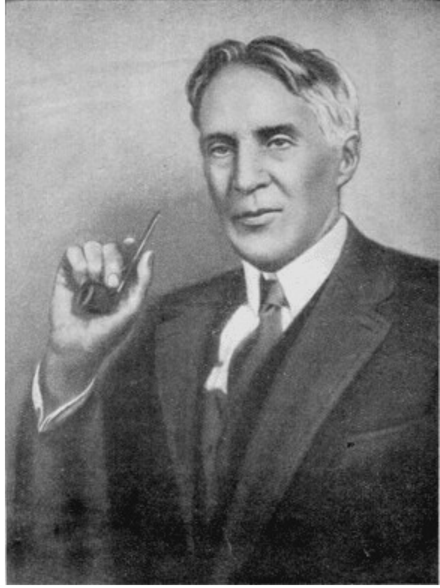
Scientific illusion example: N-rays (3)

- Following skepticism in the scientific community, R. W. Wood visits Blondlot's lab in 1904 and sees the experiments, including the Al-prism spectroscopy experiment.
- He asks to repeat the experiment, and Blondlot gets exactly the same results.
- However, in the dark room, between the two measurements, Wood has removed the prism used in the experiment!
- After publication of these results, this is the end of N-rays…



Wood's explanation of the photographic plates:

purely imaginary. It seems strange that after a year's work on the subject not a single experiment has been devised which can in any way convince a critical observer that the rays exist at all. To be sure the photographs are offered as an objective proof of the effect of the rays upon the luminosity of the spark. The spark, however, varies greatly in intensity from moment to moment, and the manner in which the exposures are made appears to me to be especially favourable to the introduction of errors in the total time of exposure which each image receives. I am unwilling also



Parts of Wood's letter to Nature: R. W. Wood, Nature 1822, Vol.70 p.530 (1904):

The *n*-Rays.

THE inability of a large number of skilful experimental physicists to obtain any evidence whatever of the existence of the *n*-rays, and the continued publication of papers announcing new and still more remarkable properties of the rays, prompted me to pay a visit to one of the laboratories in which the apparently peculiar conditions necessary for the manifestation of this most elusive form of radiation appear to exist. I went, I must confess, in a doubting frame of mind, but with the hope that I might be convinced of the reality of the phenomena, the accounts of which have been read with so much scepticism.

After spending three hours or more in witnessing various experiments, I am not only unable to report a single observation which appeared to indicate the existence of the rays, but left with a very firm conviction that the few experimenters who have obtained positive results have been in some way deluded.

Scientific illusions: How to tell

Langmuir's analysis of "pathological science" (Physics Today, 1989):

Symptoms of Pathological Science

▷The maximum effect that is observed is produced by a causative agent of barely detectable intensity, and the magnitude of the effect is substantially independent of the intensity of the cause.

▷The effect is of a magnitude that remains close to the limit of detectability or, many measurements are necessary because of the very low statistical significance of the results.

▷There are claims of great accuracy.

▷Fantastic theories contrary to experience are suggested.

▷Criticisms are met by *ad hoc* excuses thought up on the spur of the moment.

▷The ratio of supporters to critics rises up to somewhere near 50% and then falls gradually to oblivion.

More scientific illusions

Other scientific illusions in the 20th century:

- B. Davies and A. H. Barnes (1930): resonant electron capture by α-particles with extraordinary precision (again depends on marginal detection of scintillations by human eye)
- F. Allison (1927): detection of isotopes by time-resolved polarization rotation in solutions
- A. Gurwitsch (1923): "Mitogenetic rays": influence of living matter, at a distance, on growth of plants
- N. Fedyakin, B. Derjaguin (1960) "Polywater": water condensed through capillaries shows unusual viscosity (found out to be due to contamination)
- M. Fleischmann, S. Pons (1989): "Cold fusion": Nuclear fusion at room temperature, brought about by electrolysis of heavy water using Pd sponge electrode. They claimed positive heat output (in an energy balance which is a small difference of big numbers), but no neutron flux was detected, so the subject has since become exotic

Global warming: a case study of science and society (1)

Currently a huge debate, with both scientific and political aspects. We should distinguish between:

- Facts
- Theories and models
- Recommendations for policy change (not science!)

Source: IPCC technical report 2021
https://www.ipcc.ch/report/ar6/wg1/#TS

- Facts:
  - We know the temperatures and atmospheric CO_2 concentrations between 1850-2020 (direct measurements).
  - We know the temperatures and atmospheric CO_2 concentrations in prehistoric times (inferred from tree rings, polar ice etc.).
  - We see clear correlation between them in all times.

Three selected global climate indicators covary across multiple paleoclimate reference periods

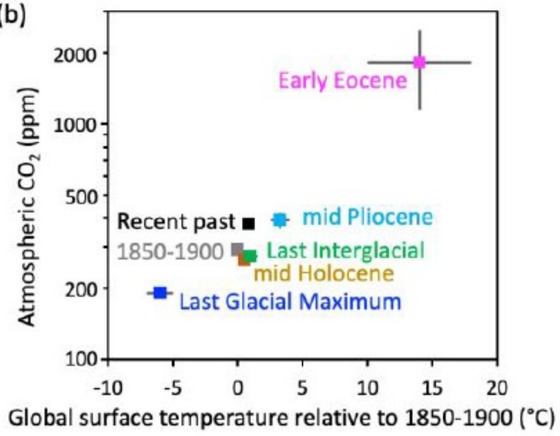
(a)

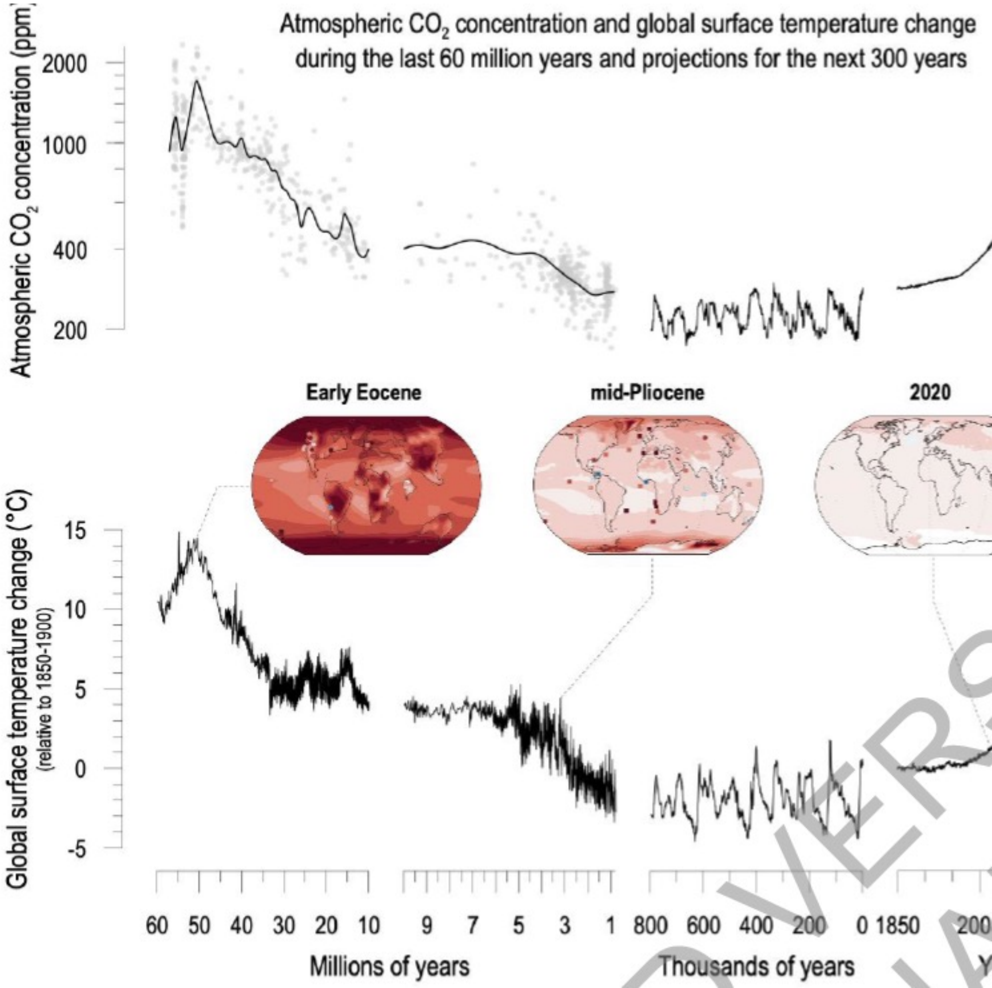
Reference period (*See Interactive Atlas for climate model output)	Age	CO_2 (ppm)	Temperature (°C)	Sea level (m)
Recent past	1995-2014 CE	360 → 397	0.66 to 1.00	0.15 to 0.25
Approximate pre-industrial	1850-1900 CE	286 → 296	-0.15 to +0.11	-0.03 to 0.00
Last Millennium	850-1850 CE	278 to 285	-0.14 ~ 0.24	-0.05 to 0.03
Mid-Holocene*	6.5-5.5 ka	260 to 268	0.2 to 1.0	-3.5 to +0.5
Last Deglacial Transition	18-11 ka	193 → 271	not assessed	-120 → -50
Last Glacial Maximum*	23-19 ka	188 to 194	-5 to -7	-134 to -125
Last Interglacial*	129-116 ka	266 to 282	0.5 to 1.5	5 to 10
Mid-Pliocene Warm Period*	3.3-3.0 Ma	360 to 420	2.5 to 4.0	5 to 25
Early Eocene	53-49 Ma	1150 to 2500	10 to 18	70 to 76
Paleocene-Eocene Thermal Max	55.9-55.7 Ma	900 → 2000	10 to 25	not assessed

X to Y: *very likely* range (caveats in Figure 2.34)
X → Y: start to end of period, with no stated uncertainty
X ~ Y: lowest and highest values, with not stated uncertainty

lower 1850–1900 higher

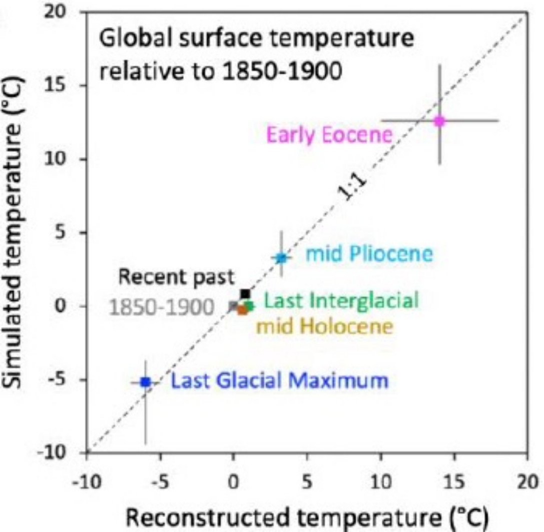
(b)

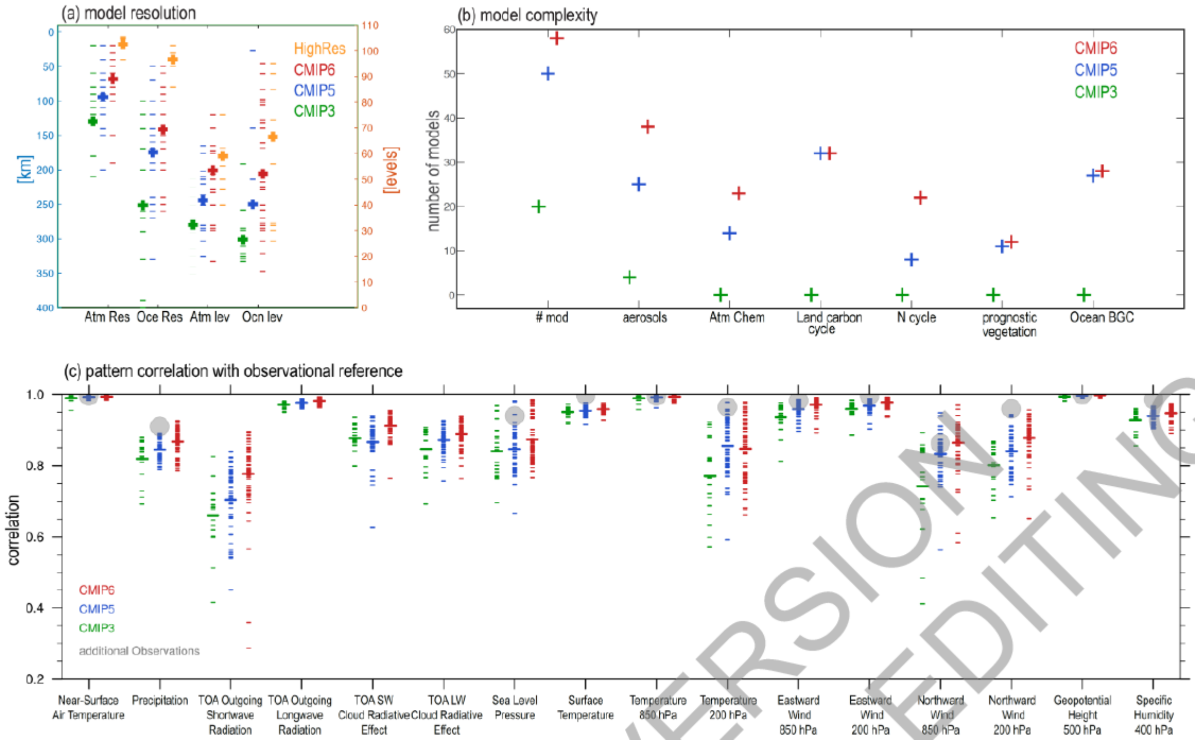


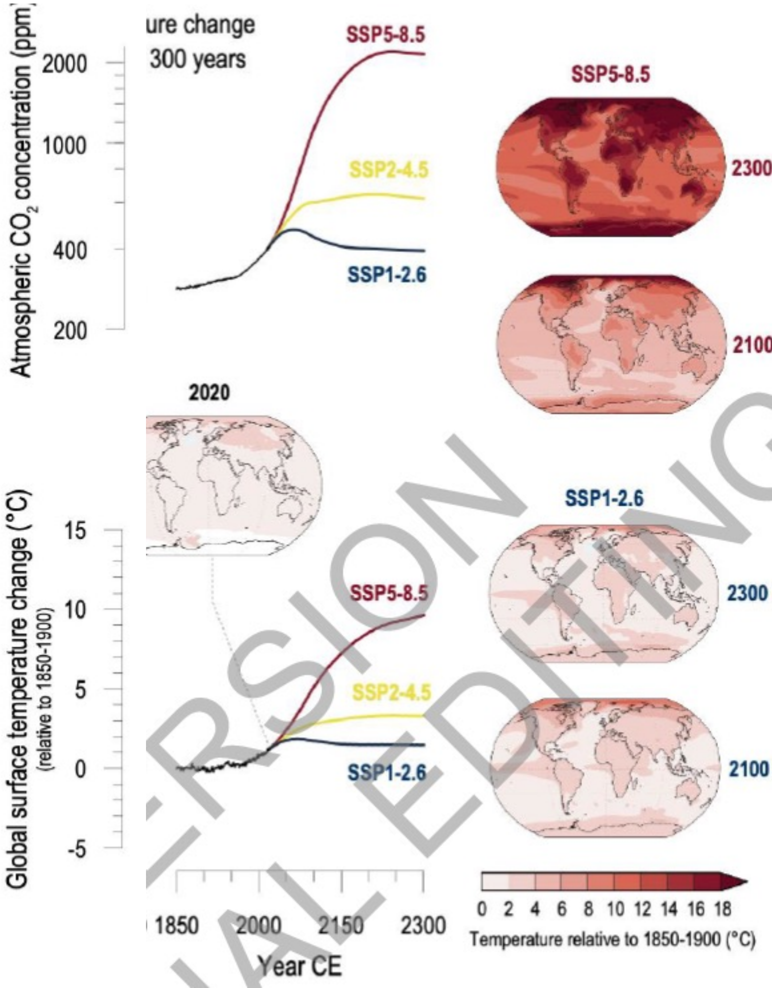


Global warming: a case study of science and society (2)

- Theories and models
- As all scientific models, meteorological models are constantly improving in accuracy, matching more closely the observed data.
- This is the result of more efforts and computing power becoming available for these complex calculations.
- As a result, their predictive power also improves.
- They predict a warming of 1-7 degrees, depending on future CO_2 emission levels.

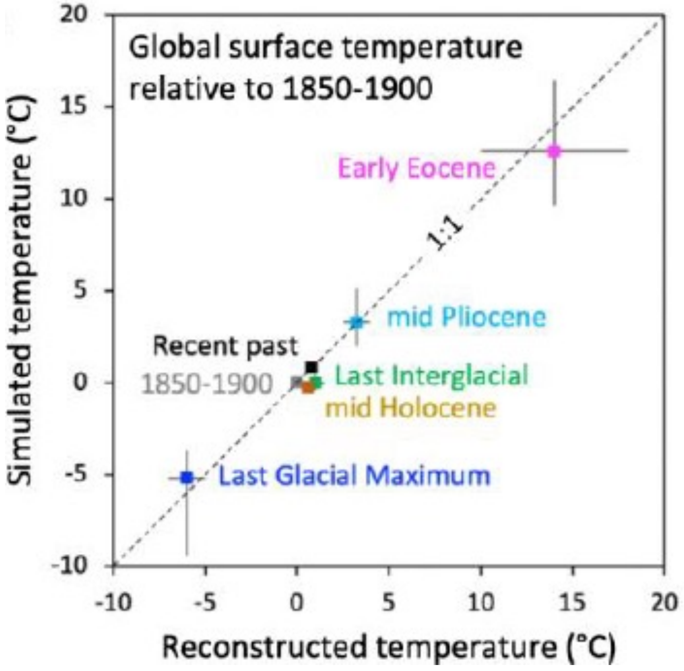


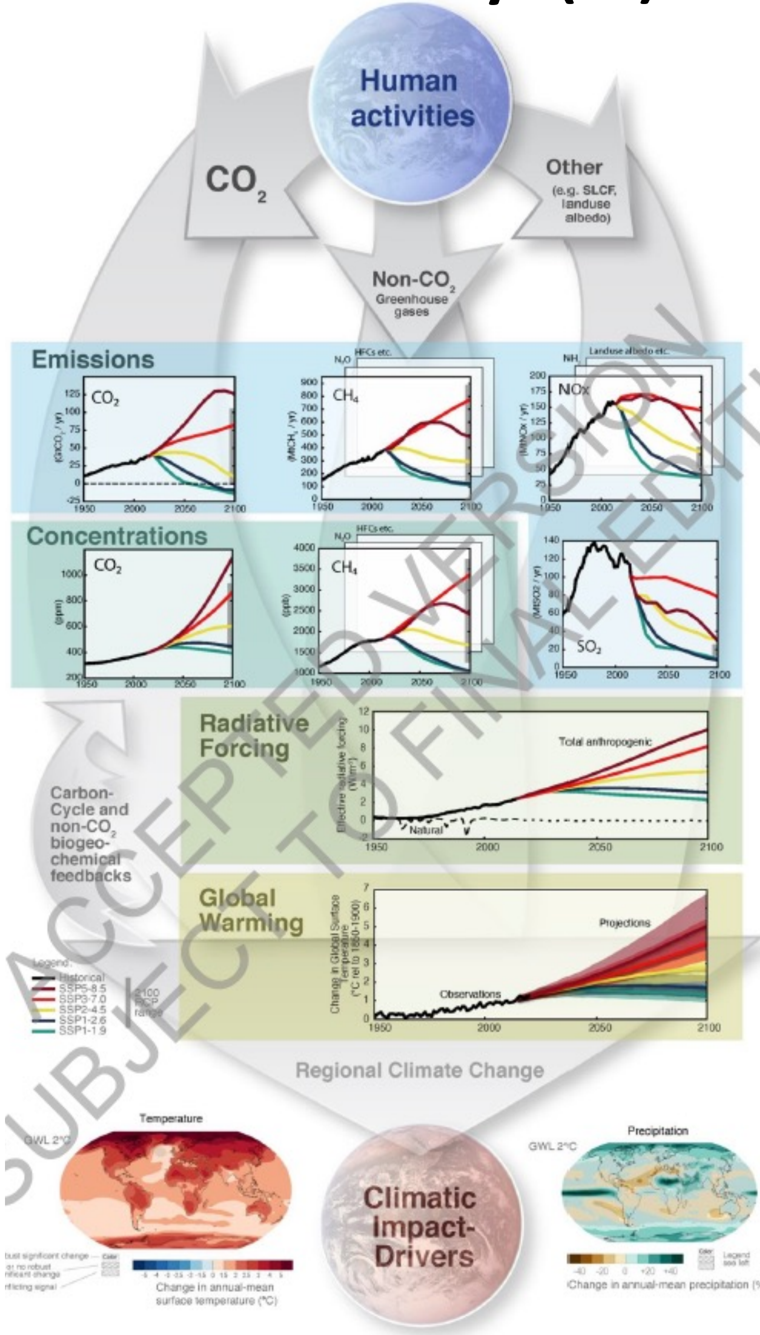




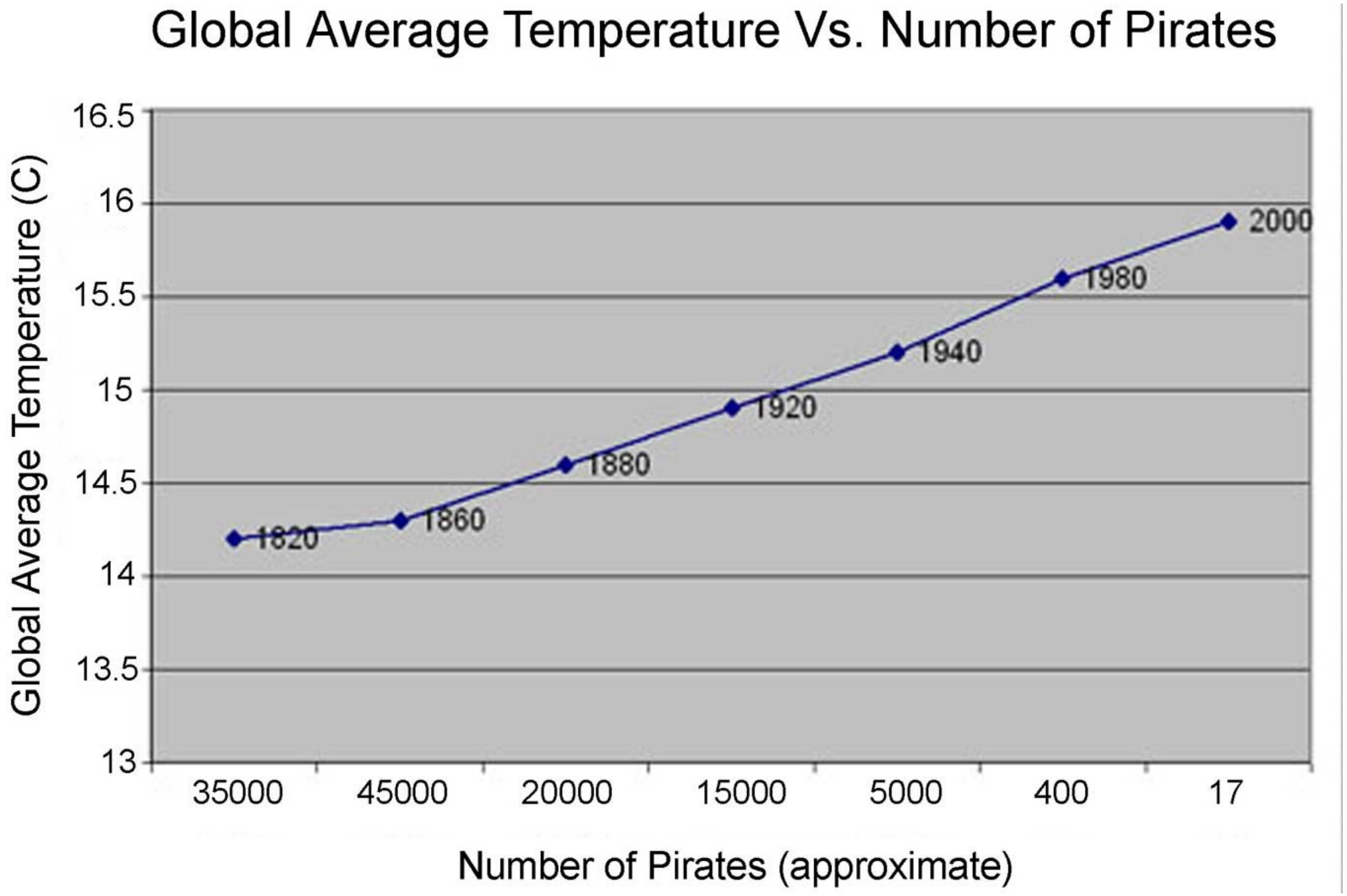
Global warming: a case study of science and society (3)

- Recommendations for policy change (not science!)
- We must understand that the scientific process improves the models (always with some remaining error margins!), but can not dictate our actions, nor predict everything.
- Another important issue: correlation is not always causality!
- Here critical thinking is important





An example of a common pitfall: Correlation is not causality !



The Covid pandemics: a case study of science and society

- The recent vaccination debate shows many pitfalls related to the comprehension of scientific data:
  - The difference between probabilities to transmit an infection, to be infected, and to develop a serious illness
  - How to interpret published data, e.g. percentage of hospitalized persons that are vaccinated or not
  - How to understand test protocols (e.g. of a vaccine), trade-offs between time, budget and number of tests
  - How to understand the medical priorities when recommending vaccination
  - On the social level, we've seen everything – including many non-rational responses, fake, and pseudoscience.
  - Again, some critical thinking could have helped, not only scientists but the population in general…

The publication trap

- In the "publish or perish" race, we have to be critical about the journal we choose!
- There exist many "predatory journals" that can actually harm the author's reputation. Their main interest is financial (publication fees), some such editors have more than 100 journals.
- They have been denounced by many scientists, the most famous of whom being Jeffrey Beall (U. Colorado), who have compiled lists of such publishers and published criteria showing how to identify them.
- Typical characteristics of predatory journals:
  - Many journals belonging to the same editor, appearing and disappearing quickly.
  - Accepting articles quickly with little or no peer review or quality control.
  - Notifying academics of article fees only after papers are accepted.
  - Communication with the editor/referee always passes by some unknown secretary.
  - Aggressively campaigning for academics to submit articles or serve on editorial boards.
  - Listing academics as members of editorial boards without their permission, not allowing academics to resign from editorial boards, appointing fake academics to editorial boards.
  - Citing fake or non-existent impact factors.
- Here you can find Beall's list: https://beallslist.net

https://en.wikipedia.org/wiki/Predatory_publishing

Hoaxes that expose "black sheep" journals

- The Sokal affair: Alan Sokal, NY university and U. of London (mathematical physics), published in 1996 a hoax (pseudo-scientific) article in the social science journal Social Text. He then exposed it in an article in Lingua Franca.
- The "Sokal squared" affair: In 2017-2018, a team (James A. Lindsay, Peter Boghossian, and Helen Pluckrose) created and sent 20 hoax papers to social studies journals with peer review; out of these, 4 were published, 3 more were accepted… then they stopped the experience. They wanted to expose the "grievance studies" in social sciences.
- Closer to home, at UNIL (see pdf on the Moodle site): A fake article on Chloroquine, with flagrant mistakes and nonsense, was published very quickly (3 days) in "Asian Journal of Medicine and Health", after an alleged review by several referees... and payment of publication fees, of course.

Sokal A. (1996). "Transgressing the Boundaries: Toward a Transformative Hermeneutics of Quantum Gravity". Social Text. 46/47 (46/47): 217–252. [doi:10.2307/466856](doi:10.2307/466856)

Sokal A. (1996). "A Physicist Experiments with Cultural Studies" (PDF). *Lingua Franca*: 62–64

Pluckrose, Helen; Lindsay, James A.; Boghossian, Peter (October 2, 2018). "Academic Grievance Studies and the Corruption of Scholarship". *Areo Magazine*. Archived from the original on October 10, 2018.

Jillian Kay Melchior (October 2, 2018). "Fake news comes to academia". *The Wall Street Journal*. New York. Archived from the original on October 5, 2018.

https://www.theatlantic.com/ideas/archive/2018/10/new-sokal-hoax/572212/

https://www.letemps.ch/sciences/chloroquine-trottinette-un-article-delirant-sest-retrouve-un-journal-scientifique

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Our best friend can lead us in error!

Or, Dr. Google can sometimes be mistaken…

- We all have the habit of searching the internet for knowledge
- Unfortunately, the available data is not classified according to its reliability, nor is there any selection of sources
- Result: anybody can put anything on the internet!
- We can easily find sites preaching for fake science: anti-immunization, flat-earth, UFO, etc.
- This problem has also touched Wikipedia, where political sources try to change items that they don't like, or fabricate false items.
- Be critical!

Example of fake science on the internet:

The flat-earth theory

- One can easily find the site: https://www.tfes.org
- It's vary well-produced, citing experiments, alternative gravitation theories, and of course the idea of conspiracy
- It has developed to large extent, especially in California…
- …That even National Geographic had to produce a refuting test: https://www.youtube.com/watch?v=06bvdFK3vVU

… and what about AI?

- New AI tools (ChatGPT and others) can produce text, images, video clips of amazingly realistic quality, and imitate human style in an increasingly reliable way.
- On the "lower level": how to distinguish between genuine students' reports and artificially generated ones? And what about scientific publications?
- On the "higher level": AI could help science and technology in the future, to design better experiments, analyze big data in new ways and produce better electronics. But will it have the insight and intuition of human researchers?

- Two SciFi stories that discuss this last point: "Profession" (1957) and "All the Troubles of the World" (1958) from the book "Nine tomorrows" (1959) By Isaac Asimov.

Doubt is important for science

A citation from R. Feynman:

"What, then, is the meaning of it all? What can we say to dispel the mystery of existence? If we take everything into account - not only what the ancients knew, but all of what we know today that they didn't know - then I think we must frankly admit that we do not know.

But, in admitting this, we have probably found the open channel.

This is not a new idea; this is the idea of the age of reason. This is the philosophy that guided the men who made the democracy that we live under. … This method was a result of the fact that science was already showing itself to be a successful venture at the end of the eighteenth century. … If we want to solve a problem that we have never solved before, we must leave the door to the unknown ajar.

We are at the very beginning of time for the human race. It is not unreasonable that we grapple with problems. But there are tens of thousands of years in the future. Our responsibility is to do what we can, learn what we can, improve the solutions, and pass them on. It is our responsibility to leave the people of the future a free hand. In the impetuous youth of humanity, we can make grave errors that can stunt our growth for a long time. This we will do if we say we have the answers now, so young and ignorant as we are. If we suppress all discussion, all criticism, proclaiming "This is the answer, my friends; man is saved!" we will doom humanity for a long time to the chains of authority, confined to the limits of our present imagination. It has been done so many times before.

It is our responsibility as scientists, knowing the great progress which comes from a satisfactory philosophy of ignorance, the great progress which is the fruit of freedom of thought, to proclaim the value of this freedom; to teach how doubt is not to be feared but welcomed and discussed; and to demand this freedom as our duty to all coming generations."

Know to reject pseudo-science

Watch out that being “open-minded” does not mean “accept anything”!

Examples:

- The demand to teach creationism and “intelligent design” at schools as “another scientific discipline”, equal to evolution theory
- Confound the SETI and similar projects with UFOs
- Give astrology the weight we give to astronomy

Conclusions

1. Be critical!
2. Try to design experiments, modeling programs and data analysis with critical thinking in mind
3. When reading or reviewing scientific articles, check the plausibility, compare with literature
4. Try to communicate that in science there is no single answer, but a process of gradually approaching the objective truth, usually resulting in very high accuracy, but always open to new scientific ideas

References

- I. Langmuir, and R. N. Hall, "Pathological science" lecture (1953), transcribed and reprinted in Physics Today 42(10), 36 (1989); doi: 10.1063/1.881205
- R. P. Feynman, "Cargo Cult Science" lecture (1974), reprinted in "Surely You're Joking, Mr. Feynman!" Norton Publ. (1985)
- M. R. Beasley, S. Datta, H. Kogelnik, H. Kroemer, D. Monroe "Report of the Investigation Committee on the possibility of Scientific Misconduct in the work of Hendrik Schon and Coauthors" (2002): http://www.alcatel-lucent.com/wps/DocumentStreamerServlet?LMSG_CABINET=Docs_and_Resource_Ctr&LMSG_CONTENT_FILE=Corp_Governance_Docs/researchreview.pdf
- M. Gardner, "Fads and Fallacies in the Name of Science" Dover Publ. (1957)
- Robert Park, “VOODOO SCIENCE: The Road from Foolishness to Fraud”, Oxford university press, 2000
- A new EPFL internal course on research integrity: https://www.epfl.ch/campus/services/internal-trainings/keep-learning-en/trailers-en/