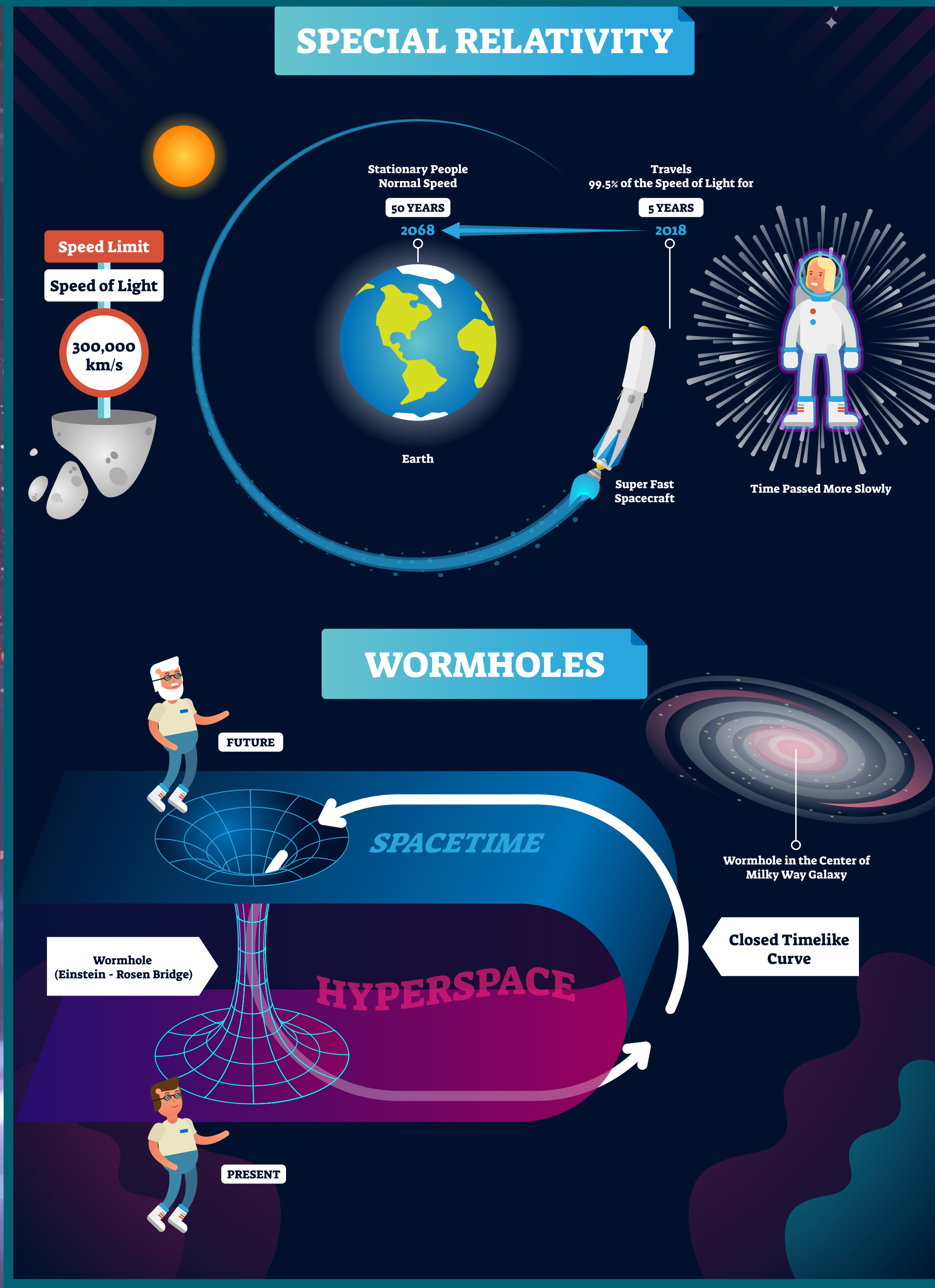
Revisiting the legacy of Michelson's interferometer experiment



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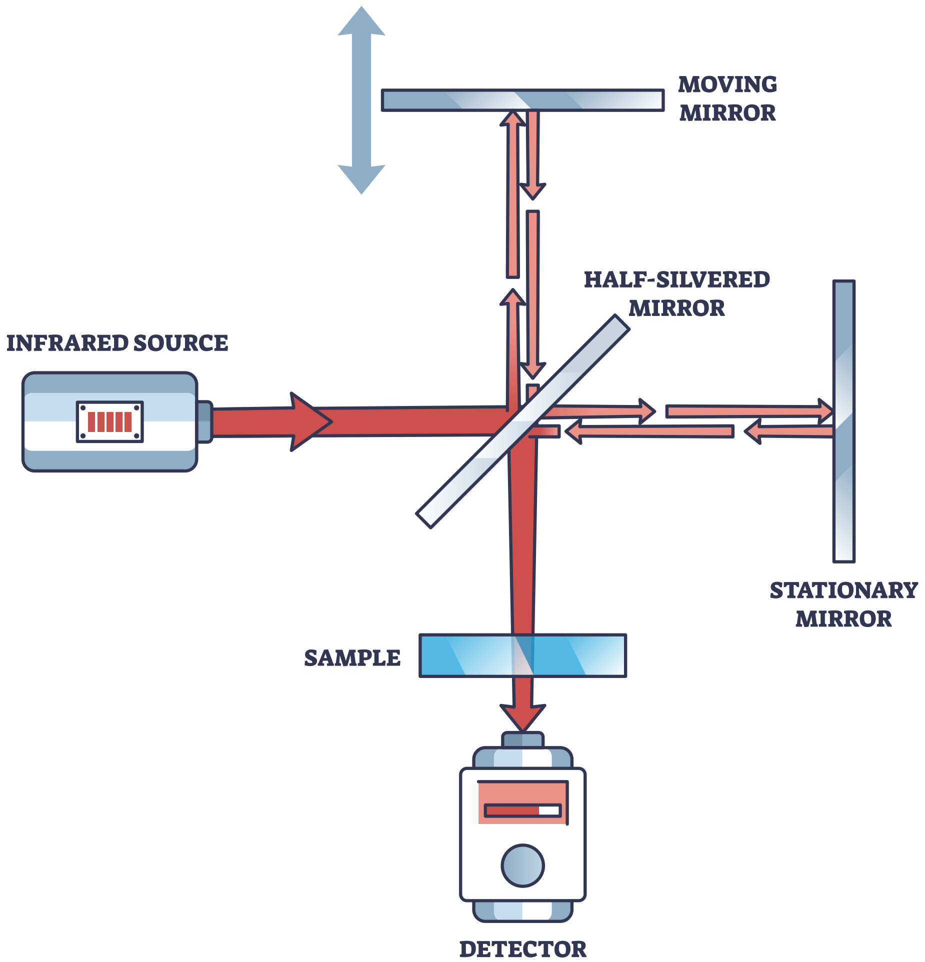
- In 1881, Albert Michelson's interferometer experiment would forever alter our understanding of the Universe.
- Today, it is one of very few experiments widely cited in textbooks as being foundational for modern physics.
- In his new paper, Hans Haubold reflects on the findings of the International Michelson Colloquium held in 1981, a century after Michelson's original experiment.

Prior to Michelson's experiment, the theory of 'luminiferous aether' was widely accepted by physicists. It suggested that much like the propagation of sound waves through matter, light waves must also travel through a fixed medium named the 'aether', which permeates all of space. This would mean that as Earth travels through the aether, the speed of light measured from its surface should vary, depending on the direction in which it is measured.

With his interferometer, Michelson fully expected to measure these differences in speed. His instrument worked by splitting a beam of light into two parts, which would each travel down separate paths with identical lengths before being reflected back to their starting point.

If one part of the light beam took longer than the other to travel down its path, it would affect the interference pattern observed in the recombined light beam. According to the aether theory, any light travelling against Earth's motion would be slower compared to light travelling with it, creating a measurable difference in these patterns.

However, contrary to his expectations, Michelson observed no significant difference in the speed of light travelling on each path. This now-famous 'null result' meant one of two things: either the aether had



Interferometer design.

Haubold's new paper highlights how Michelson's experiment was much more than just a technical achievement: it was a pivotal moment in the history of science.

no detectable effect on the speed of light, or, as physicists soon came to accept, it didn't really exist after all. The result was revolutionary: providing the experimental foundations which would soon lead to Einstein's theory of special relativity.

The 1981 colloquium

To commemorate the centenary of Michelson's groundbreaking experiment, an international colloquium was held in April 1981 at the Astrophysical Observatory Potsdam, Germany, where the experiment first took place.

The gathering was organised by the Academy of Sciences of the Central Institute for Astrophysics (GDR) and was sponsored by institutions including the Einstein Laboratory for Theoretical Physics, the Physical Society of the GDR, and the Humboldt University Department of Physics. It brought together several prominent scientists and science historians to reflect on Michelson's work and its enduring impact.

During the colloquium, participants discussed the broader implications of Michelson's findings. The lectures spanned a variety of topics, from the experimental nuances and historical context of Michelson's work to its philosophical and educational significance. Notable speakers included Dorothy Michelson Livingston, Michelson's daughter, who highlighted her father's artistic and scientific legacy.

Michelson's synergy with Einstein

One of the colloquium's key points of discussion was the impact of Michelson's results on Einstein's theory of special relativity, which he published in 1905. Drawing from Michelson's results, Einstein posited that the speed of light must remain the same regardless of the motion of the frame of reference from which it is measured. This led to his revolutionary idea that space and time are not absolute but relative and interconnected – a concept which has stood firm to this day.

To highlight this synergy even further, Haubold's paper includes letters addressed to Dorothy Michelson from two highly prominent figures: Max Born, a physicist whose work was instrumental in the development of quantum mechanics, and Helen Dukas, who served as Einstein's personal secretary from 1928. Showcased for the first time in this paper, these exchanges shed new light on the profound influence of Michelson's work on Einstein's thinking, which wasn't originally discussed in the 1981 colloquium.

Reflections on education

In his recollection, Haubold also reflects on the educational value of Michelson's experiment, which has withstood even since the 1981 colloquium. Today, it is one of very few experiments which are widely cited in textbooks as being foundational for modern physics, helping students to understand critical concepts such as the constancy of the speed of light and the nature of scientific inquiry.

Philosophically, the paper also highlights how the null result of Michelson's experiment invites reflection on the nature of scientific progress itself. According to Haubold, the result exemplifies how experimental data can challenge prevailing theories and lead to paradigm shifts. The shift from the aether theory to the theory of relativity underscores the dynamic and self-correcting nature of science, which may one day prove to disprove other scientific theories which have withstood to this day.

The legacy of precision

Following his initial experiment in Germany, Michelson refined his methods even further. In 1887, he designed a new interferometer in collaboration with fellow American physicist Edward Morley, this time at Case Western Reserve University in Cleveland, Ohio. In his paper, Haubold reflects on how the duo's meticulous approach and innovative techniques set new standards for experimental physics. Even today, interferometers based on their design remain a fundamental tool across a diverse array of fields in science and technology.

Altogether, Haubold's new paper highlights how Michelson's experiment was much more than just a technical achievement: it was a pivotal moment in the history of science, whose full implications have continued to reverberate across history, research, and education.

Even since the exhaustive discussions of the 1981 colloquium, the paper shows that Michelson's experiment has remained a fascinating and engaging topic of continuing discussion, which will likely continue to guide and inspire the course of physics for many more years to come.

Personal response

Are there any other cases in physics where a null result has led to revolutionary discoveries?

A search for sterile neutrinos with the IceCube detector has found no evidence for the hypothetical particles, significantly narrowing the range of masses that a new kind of neutrino could possibly have.

Although only three types of neutrinos are known to exist, hints of a new kind of neutrino that solely interacts with matter through gravity have appeared in several experiments. If such a 'sterile' neutrino does indeed exist, it might also play an important role in the evolution of the Universe. The hunt for sterile neutrinos has gone on for decades and has been full of twists and turns, with tantalising positive signals that were later found to be in tension with null results in follow-up experiments. Now the world's largest neutrino detector, the IceCube experiment at the South Pole, has released an analysis that eliminates a large portion of the parameter space in which sterile neutrinos could exist.

What do you find especially interesting about the letters to Dorothy Michelson from Max Born and Helen Dukas?

The experiment did not play any role in the formulation of Special Theory of Relativity by Albert Einstein.

Was Michelson's experiment decisive for the creation of the Special Theory of Relativity? An article by R. Shankland, published in 1963, the following excerpt from his interview with Einstein dating back to 1950:

"When I asked him how he had learned of the Michelson–Morley experiment, he told me that he had become aware of it through writings of H.A. Lorentz, but only after 1905 had it come to his attention! 'Otherwise', he said, 'I would have mentioned it in my paper!' Indeed, Einstein's 1905 paper contains no mention of Michelson's experiment or references to Lorentz's papers."

What fields of research are currently being influenced by the interferometer?

At their cores, the US National Science Foundation Laser Interferometer Gravitational-Wave Observatory detectors are Michelson interferometers, similar to the device that was invented in 1881. They are similar in that:

- They are L-shaped with two equal-length arms
- A mirror at the vertex of the arms splits a single light beam into two, directing each beam down an arm of the instrument
- Mirrors at the ends of the arms reflect the beams back to their origin point where they are recombined to create an interference pattern called 'fringes'

But this is where the similarities end!

Details

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Bio

Hans J Haubold is a professor of theoretical astrophysics at the Office for Outer Space Affairs of the United Nations, New York and Vienna. His research focuses on the internal structure of the Sun, solar neutrinos, and special functions of mathematical physics. Additionally, he is interested in the history of astronomy, physics, and mathematics.

Further reading

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- Lucas, A, (2023) Albert A. Michelson and his Interferometer: Lord of the Spinning Worlds, Master of Light. Newcastle upon Tyne: Cambridge Scholar Publishing.
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UNITED NATIONS

Michelson's experiment took place at the Astrophysical Observatory Potsdam, Germany.