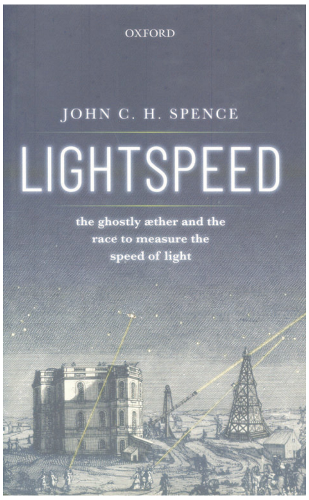


Light Speed: The Ghostly Aether and the Race to Measure the Speed of Light. John C. H. Spence. Oxford University Press, Great Clarendon Street, Oxford, OX2 6DP, United Kingdom. 2020. viii + 244 pages. Price: £25.00.

The driving force of all knowledge, as the Greeks pronounced, is being curious and having a sense of wonder. Amidst all other things light in itself is an amazing phenomenon that invokes awe-inspiring curiosity and a profound sense of wonder. What is it? – a volley of questions spring up: a particle or wave, or both, is its speed finite, how does it move from one place to another, and in what medium? As a matter of fact the two great revolutions of the twentieth century were propelled by the realization that light's motion could not be incorporated in the Newtonian framework. It could be reined in only by enlarging the existing framework. One of these led to the theory of relativity and the other to the quantum theory.

Ever since Newton's time, the question of its nature, particle or wave, had been the greatest puzzle which persisted through the last century, and even today it keeps on raising questions now and then. Newton thought it to be a particle and propounded the corpuscular theory while his contemporary, Huygens, thought it to be a wave and subscribed to the wave theory. In either case, it raised some formidable questions. If it is a particle, its speed could be changed by its collision with other particles. On the other hand, a wave's speed is determined by the medium in which it propagates. The two conceptions offer opposite – dual behaviours. The observations supported both perceptions, it is sometimes a particle and other times a wave.

In the first quarter of the previous century, it was the most challenging and consuming of all the questions to all the leading physicists, so much so that it was said that it was a particle on Monday, Wednesday and Friday; and a wave on Tuesday, Thursday and Saturday; and on Sunday they all prayed to get some revelation! It was so difficult and involved because its speed was so high – almost thought to be infinite, and that in itself held a special fascination.

The book under review is a very passionate and insightful account of attempts made to measure light speed by extraordinarily talented and highly passionate and profoundly creative people. It is a story of painstaking observations, ingenious and imaginative experiments and creative inventions of new instruments and devices.

The story was set in motion by a Danish astronomer, Ole Roemer, who observed successive eclipses of Jupiter's moon Io and found that light would take about 22 minutes to travel across the diameter of earth's orbit around the Sun. This turned out to be 26% lower than the present value, and the discrepancy was largely due to errors in distance estimates at that time.

He made this discovery in 1676 when he was assistant to Giovanni Cassini, the first Director of the recently founded Paris Observatory. Cassini however did not accept his estimate but it was accepted by Newton, Huygens, Leibniz and Edmund Halley of Halley's comet. So much so that Newton in his book *Optics* mentioned that light took 7–8 minutes to travel from Sun to earth and credited the value to Roemer. For a protestant with an important discovery it was not very promising for his future scientific career in catholic France, so he moved first to the UK and then to his home country Denmark where he was warmly welcomed by the Danish King. Besides academic honours and positions he was made senator, chief justice of the Supreme Court of Copenhagen and Prefect of Police.

In 1729 James Bradley while sailing on a ship on the river Thames made a remarkable observation that when the ship turned, the vane attached to the mast at the top shifted even though the wind had not changed. He argued that the apparent position of a star should similarly suffer a shift due to the earth's motion in its orbit. This is how he discovered the phenomenon of light aberration, and employing that made an accurate measurement of the speed of light which was closer to the present value. He independently and with greater precision verified Roemer's discovery 19 years after his death. Bradley's observations were so persuasive and solid that even French astronomers gave in and accepted. He was appointed to the Savilian Chair of Astronomy at Oxford on Newton's recommendation and succeeded Halley as Astronomer Royal.

Francois Arago was the first to devise terrestrial experiments with his extraordinarily gifted students Hippolyte Fizeau and Leon Foucault (of Foucault pendulum fame) in an attempt to measure the speed of light on earth by sending a light beam over Paris rooftops to a nearby hill and getting it reflected and then measuring the time taken. He also gave the theory of diffraction which established the wave theory of light. One of his other students, Augustine Fresnel, developed the mathematical framework for the wave theory. Following that the wave theory was accepted on both sides of the Channel.

Fizeau's measurement was further refined by Foucault who made the reflecting mirror rotate to achieve greater accuracy. They verified Bradley's value in a terrestrial experiment. The science historian, G. Sarton, opined that the story of the Arago–Fizeau–Foucault experiments would always be one of the most beautiful in the history of mankind.

Napoleon wanted students to sign a petition that he be appointed as Emperor, but Arago refused. When Napoleon was told that he was the top student at the prestigious Ecole Polytechnique, he only mused, had he been at the bottom … This reminds of the Charles de Gaulle–Sartre event during the students unrest in late 1960s. Sartre, who was spearheading the protests, would distribute protest pamphlets in Paris cafes and crowds of students would surround him. Soon the police would round off all the students leaving Sartre alone. When de Gaulle was questioned about it, he simply said, you couldn't arrest a Voltaire. There is something in the French that always respects and bows to scholarship and intellect.

Faraday and Maxwell synthesized electric and magnetic forces into one. It is the same force which is called electric when it is due to electric charges at rest and magnetic when charges are moving. Maxwell synthesized the laws of Coulomb, Ampere and Faraday to formulate the equations of electromagnetic theory. The most revolutionary prediction of the theory was that light was an electromagnetic wave that propagated in vacuum and had a universally constant velocity.

True, the wave's speed remains the same irrespective of observer's motion so long as the medium in which it propagates does not change or move. Thus a hypothetical medium called the aether was proposed for light to propagate in. Does it remain stationary or is it dragged along partially or fully by the earth as it moves in its orbit around the Sun? The question was to devise an experiment to measure the earth's motion relative to the aether.

Albert Michelson conceived a beautiful interferometric experiment in which a light beam was split into two; one part follows the original horizontal path and the other goes in an orthogonal direction. At equal distances on either side, mirrors are placed from which light got reflected back. By observing interference fringes it could be determined whether the reflected light arrived at the same time or there was a time-lag.

Michelson collaborated with Edward Morley for a decade repeating this experiment, every time getting the same null result that light arrived at the same time. There was no relative motion detected between the earth and the aether. This was the famous Michelson–Morley experiment. It was hugely frustrating for Michelson who expected that the earth's motion should show up.

It is the greatest salute to Michelson's ingenuity that one of the greatest discoveries of all times – gravitational waves – was made by the instrument (Laser Interferometer Gravitational wave Observatory, LIGO, one of which is also being built in India), a laser powered and enormously refined version of his interferometer. Michelson toiled over a decade while the present team of international scientists has taken more than half a century to detect gravitational waves by a terrestrial experiment.

On the other hand Maxwell's theory predicted that light velocity was always constant irrespective of whether the observer moved towards or away from it. The null result of the Michelson–Morley experiment was a positive result for Maxwell's theory, verifying one of its most outrageous predictions – velocity of light is constant.

This conflicted with Newtonian mechanics where velocities added up as $w = u + v$, implying no velocity could be constant for all observers. Thus there was a serious and irreconcilable conflict between Newton and Maxwell. The best of the minds including the great Henri Poincaré and Hendrik Lorentz were entirely taken up by this conflict. So much so that they worked out various properties and effects like length contraction and slowing down of clocks if light's speed were constant. Sadly they hesitated to declare that light speed was a universal constant. They hesitated because they were the two greatest scientists of the day and had a great reputation earned over a lifetime that was at stake. That cost them heavily, a rightful claim on discovery of one of the fundamental theories of physics.

At this juncture when the atmosphere was fully charged and pregnant for a new discovery, there came a young man, a clerk in the patent office in Bern, who pronounced that the velocity of light was a universal constant that bound space and time into one whole, space–time. That was Einstein and so was born his famous theory of special relativity – a new theory of mechanics. It shook our concepts of space and time, and a new paradigm of four dimensional space–time had to be adapted in place of three space and one time without any connection between them.

(The simplest common sense way to understand all this is to appreciate that space and time are both universal entities which means they are the same for all and equally shared by all. All universal entities must be related through a universal relation. What relates space and time is speed and hence it should be universally constant. Maxwell's theory identifies this with the speed of light.)

What else is universal which could be further synthesized? The answer is gravity which is felt by all massive particles by Newton's famous inverse square law. Include light as well in the gravitational interaction, i.e. light must also feel it like any other particle. Light moves freely in space with constant speed which cannot change, so the only way it can feel gravity is that gravity must bend/curve space. The contribution that singles out Einstein from all other great scientists is his theory of general relativity in which gravity is described by curvature of space–time – Einstein's theory of gravitation. It is not for nothing that Paul Dirac said: it was the greatest feat of human thought!

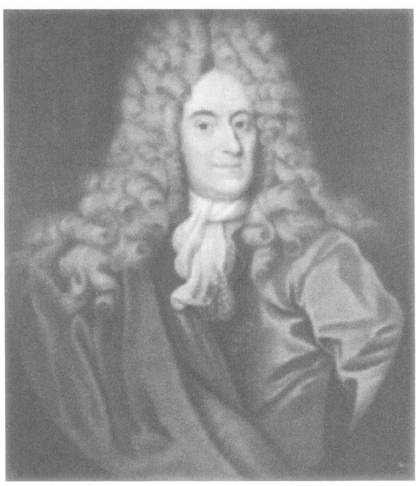
Aether was hypothesized as a medium for light to propagate in. Then arose the question of measuring the motion of objects like the earth relative to the aether. The famous Michelson–Morley experiment showed that there was no relative motion between the aether and the earth. And hence it was concluded that there was no aether.

(Against the popular belief and unquestioning general audience, we would like to say that this is an erroneous inference. True, what the experiment showed was that one could not measure earth's motion relative to the aether. That was simple because aether was present everywhere, it could not be separated from the earth. Therefore it could not serve as a reference frame to measure any motion. On the other hand, it was a universal medium which could neither be changed nor moved and hence any wave that propagated in it would have universal speed.

This however does not mean aether does not exist, all it says is that it is no good to measure motion relative to it.)

In more sophisticated physical theories, the term being used is vacuum. Presence of matter produces quantum fluctuations in it and hence it has physical structure. Like the aether this is omni present, and hence cannot serve as a reference frame to measure motion.

All general relativity literature has one profoundly wrong statement, as Sun



Ole Roemer (From Google Images)

moves around earth, bending of light. What bends is space not light, light freely floats on it and hence we measure bending of space by means of light. Though wrong, it has got currency and so we carry on with it.

Another misconception is that in a strong gravitational field light slows down. That too is utterly wrong. What slows down is the clock in strong gravity and that would result in increasing light frequency and thereby energy but its speed remains the same universal constant. When light is tunnelling out of a strong gravitational field, it loses energy through decrease in its frequency or increase in wavelength. This is the phenomenon of gravitational red-shift.

This otherwise excellent book, I have to say, suffers from this misconception.

Let me also underline one of the profound statements the author makes: light travels as a wave but arrives as a particle. It should rather be enlarged to say that not only does it arrive but it also departs as a particle. It is a wave through the journey while it is a particle at both ends.

At first sight, I must confess I was a bit taken aback, why should such a fascinating book end with such a speculative note? What the author is seeking is further synthesis between gravity and quantum theory. We are again faced with the wave–particle like duality. Gravity is described by curvature of space–time which is a continuum while the basic elements of quantum theory are discrete. How to make the two compatible is the most challenging question over half a century discrete/digital nature of events induces non-locality and acausal transmission of information. What is hinted at is that new synthesis would arise as and when we have quantum theory of gravity or space–time.

In other words, how do we synthesize Planck's constant, which is universal like velocity of light, with space–time? All universal entities must be related and synthesized. This is the most profound open problem over half a century, and we are nowhere near the solution.

As I said in the beginning, it is a fascinating and engaging story of one of the most exciting and challenging feats of observation and experiment. It is being told with a lot of feeling, insight and care, and it is indeed a must read for not only physicists but scientists in general as well as curious audience at large.

Let me close with an apology. I have taken liberty in discoursing on some issues of concepts and principles (enclosed in parentheses) that could though be construed as transgressions but at the same time that may perhaps be illuminating.

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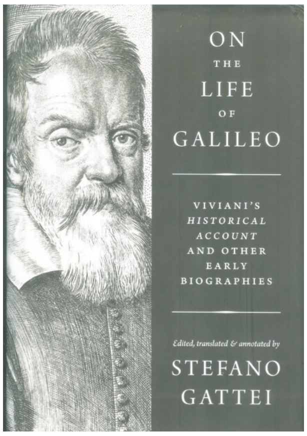

On the Life of Galileo: Viviani's Historical Account and Other Early Biographies. Edited, translated and annotated by Stefano Gattei. Princeton University Press, 41 William Street, Princeton, New Jersey 08540. 2019. lxviii + 348 pages. Price: US$ 49.95/£42.00.

Galileo Galilei (1564–1642) is one of the most well-known scientists as the father of mechanics and dynamics; however a commoner would identify him as an 'eye-opener' for astronomy by the introduction of telescope. It provided a turning point for the observations of the night sky, and for a strong foundation for a heliocentric planetary model. His biography is so well publicised that we imagine that his life story was created rather easily as he left behind his own works. Some documents (for example, letters) would have supplemented the write ups with many ifs, buts and may be's, providing scope to classify some anecdotes to 'hero worship' category. Thus it becomes all the more important to know what his contemporaries felt about him and their reactions to the good and the bad events of his life. However, as we see in this latest compilation, the contemporary biographies unfold his potential as an untiring seeker of truth; his mind and hands worked brilliantly leaving us wonder if some unpublished material may still be hiding somewhere escaping the eyes of historians.

Stefano Gattei is a well-known name among the historians. The book was eagerly awaited by historians as the publications of a series of papers on Galileo, especially the one[1] in 2017. This critical edition comprises the biographical sketches of Galileo during his life time or just after his death by people within his circles. Some of them are translated into English for the first time opening up our views on his public image – his life which was entangled in controversies of science and religion.

Stefano Gattei gives a detailed introduction clearing our blurred views of the contemporary society. The original Italian, French and Latin texts follow with a very faithful translation and abundant notes. The resources available (in English) hitherto, were mainly based on the book by Viviani Vincenzo, the last student of Galileo. Thus historians were longing for access to other original resources providing the historical context of the making of Galileo.

The introduction titled 'Shaping the myth' begins with the poem by Primo Levi in 1984, with '*Before the Sun burned my eyes/I had to yield and say/I did not see what I saw*', a very concise picture we have of Galileo. The 'Galileo affair'[2] gained enough publicity especially after the church vindicated him in 1992. He was well respected for his engaging thoughts on the experiments with the inclined plane, the introduction of the ideas on gravity, the analysis of tidal motions. His books on physics were popular all over Europe and therefore, one would be curious to know how this 'affair' was treated. Segre[3] made an effort on these lines to analyse the context in light of limited tools accessible to Galileo.

Gattei narrates the individual texts of this volume, fourteen in all. Viviani's original biography (1654), the 'Letter to the Prince Leopoldo de Medici on the Application of the Pendulum Clock' (1659) and 'Report on Galileo's Later Works' (1674) are reproduced with translations and comparison of the style of writing with other contemporary