which is that Einstein, with help from Michele Besso, first calculated the perihelion in the summer of 1913, and found a result that was too small. I believe Renn is correct, while Howard's aim is to collect various problematic issues that had been accumulating from 1913 to 1915.

Howard writes that Einstein, like everyone else at the time, "… routinely conflated frames of reference with systems of coordinates." (page 162). Once he overcame this obstacle, and discarded other fallacious reasoning, Einstein recalculated the perihelion precession. His correct explanation was quickly published on 18 November 1915. Less than a month later, on 14 December 1915, he penned a letter to Moritz Schlick which Howard identifies as having a profound influence on the philosophy of science ever since:

> The new finding is the result that a theory exists that agrees with all previous experience whose equations are covariant with arbitrary transformation in the space-time variables. Thus time & space lose the last vestiges of physical reality. (page 165).

Schlick was the first to expound on the philosophical significance of relativity, and it even merited approbation from Einstein, who wrote to Schlick on 14 December 1915: "From the philosophical side, nothing at all appears to have been written on the subject that is nearly so clear." (page 164). Einstein became intimately involved on the philosophical developments over the next few years. It might seem odd that he would be so concerned about the views of Immanuel Kant, from the late eighteenth century, but such was the case, and it gave him a chance to exercise his wit in this line from 1919:

> Kant's celebrated view on time reminds me of Andersen's tale about the emperor's new clothes, except that instead of the emperor's clothes, it concerns the form of intuition. (page 174)

Relativity in its early years was assailed by neo-Kantian writings, which Einstein and his philosophical supporters were determined to fight off. Schlick realised that if the distinction between proper empirical judgments and definitions were merely a relative one, a neo-Kantian could threaten GR by asserting it is a "… fixed element in scientific theory, one that cannot be impugned by the results of observation and experiment." (page 184). Howard's explanation of how the verificationist version of empiricism arose to defend GR, and why Einstein (one of its founders) then repudiated it in the 1930s, is a tour de force. This chapter alone makes the book most worthwhile, and an essential read for any historian of astronomy (or science, more generally).

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Lightspeed: The Ghostly Aether and the Race to Measure the Speed of Light, by John C.H. Spence. (Oxford, Oxford University Press, 2019). Pp. 256. ISBN 9780198841968 (hardback), 140 × 220 mm, US$32.95.

The late John C. H. Spence was the Richard Snell Professor of Physics at Arizona State University and the Director of Science at the National Science Foundation BioXFEL Science and Technology Center. His research focused on the application of X-Ray Free-electron lasers to structural biology.

Lightspeed is rich in the history of physics and astronomy. It provides a detailed background of the early ideas concerning light as well as biographical information of many scientists and their attempts to measure the speed of light. Originally, these attempts involved the search for an absolute frame of reference in the Universe, the aether, which was the term used to refer to the 'invisible stuff' throughout the Universe that allowed light waves and gravitational forces to travel through vast distances (page 5). Spence examines in detail the ways in which experimental outcomes, successful or not, influenced Einstein's theories leading to the equivalence of mass and energy. Spence does include mathematics, but understanding it is not essential to the main points of this book. It can be fun to follow the mathematics used to show the reader why a small velocity, V, gives nearly the same answer as the Galilean rule of velocity vector addition, but a velocity near the speed of light results in the mathematical conclusion that V cannot exceed the speed of light. More mathematics is included in the appendices for interested readers.

Spence traces out the history chronologically starting with ancient Greek astronomers and their insights into mathematics, such as Eratosthenes using shadows and geometry to calculate the Earth's circumference with surprising accuracy. He also extensively explores the concept of aether. Early opinions were divided as to whether light travels instantaneously or at some finite velocity. James Bradley provided irrefutable proof that light travels at finite speed through his discovery of the aberration of starlight. Augustin Fresnel then concluded that only a wave theory for light supported Bradley's results as long as an aether medium filled all space in order to support light-waves. In contrast, Rene Descartes considered light to be a particle that traveled at a finite velocity because its velocity changes when light crosses a boundary into a different medium. Here readers are given a glimpse into the early discussions that led to the wave-particle duality concept of light.

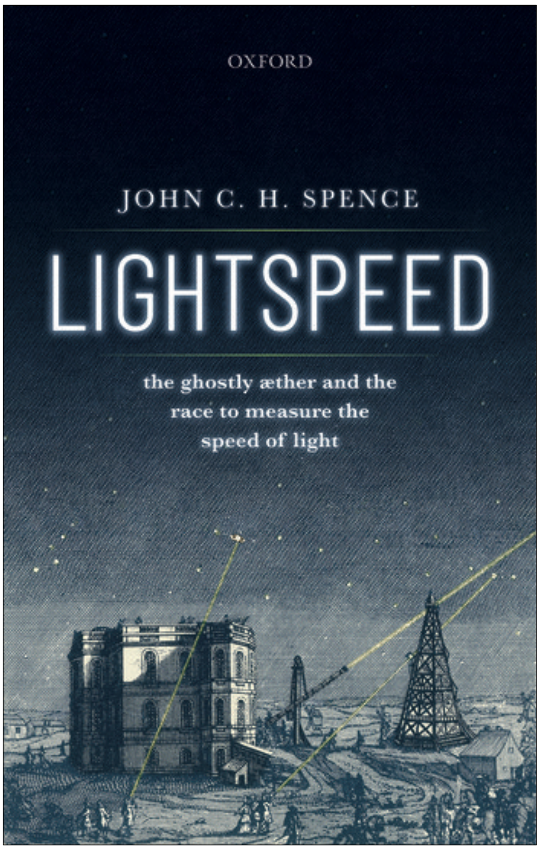
In this book, Spence nicely describes the "… intense creative turmoil and debate among scientists … [and the] unsettling effect …" that unexpected results can have on a field of study (page 112). However, it is often the experiments considered at the time to be "… the greatest negative result in the history of science …" that later turn out to be the exciting key to the next major step in the advancement of science (page 112). For example, the first American to win a Nobel Prize (1907) in science, Albert Michelson, performed "… one of the most important experiments in the history of physics …" but failed to detect the aether (page 2). This was "… a result that no one wanted …" (page 2), however, it eventually led to Einstein's breakthrough connection of "… space and time through the speed of light …" (page 158). Einstein noted that Michelson put "… much effort into his tedious measurements …" over many years and stated (page 141):

> You, my honored Dr. Michelson, began when I was just a youngster. It was you who led physicists into new paths, and through your marvelous experimental work paved the way for the theory of relativity.

The contradictions found in competing hypotheses that were supported by experimental interpretation are readily seen in the chapter concerning Michelson and his search for the Aether. Spence points out that several experimental outcomes and ideas, later shown to be correct, were largely ignored at the time. "If this agreement between experimental results and a theory based on the nonsense of the aether theories gives you a headache …" (page 120) don't worry, the correct answer is discussed at length in a subsequent chapter.

The real fun starts in the chapter focusing on Einstein. Observations of binary stars displayed the expected Doppler Shift, but without the expected change in the speed of light as the stars orbit one another due to the fact that the speed of light is independent of the speed of the source or the detector. Good examples, humor, and explanations are used in this chapter to help readers understand the basic idea of Einstein's Theory of Relativity. "Time slows down, not only at traffic lights and boring meetings, but also if you go really fast, relative to the people at home …" (page 139). The chapter summarizes the complex "… intellectual journey of ideas …" (page 157) that eventually led to Einstein's theory in 1905 that extended "… Newton's laws to the very high energies and speeds of nuclear physics …" (page 158). It is this theory that "… connects space and time through the speed of light …" (page 158). As Spence states, though, "… It was easier to understand the mathematics of special relativity than the physics of it." (page 157).

The last chapter focuses on universal constants, the most important of all being the speed of light which recent results show has not changed within error. Spence details the changes that have been made in the standards of the international metric system that were formerly based on measurements of our planet's dimensions, motion, mass, and "… unique preserved artifacts …" (page 185). The standards have now "… been re-defined



in terms of fixed physical constants …" of the Universe (page 185). Last of all, Spence discusses the combination of quantum mechanics and special relativity that has led to quantum field theory, replacing the idea of aether with the concept of universal background energy. Olber's paradox, Bell's theorem, entanglement, and quantum weirdness are a few of the topics explored in this chapter. The statement that "Physics attempts to derive predictive mathematical metaphors for an underlying reality which we don't understand …" (page 216) is followed by the warning that … "mathematics can never be a substitute for thought in Physics." (page 219).

Lightspeed provides a good summary of the scientists and historical advances involved in determining the speed of light. Readers with some background knowledge of optics, electricity and magnetism will have an easier time digesting all of the information Spence has included such as light ray diagrams. In addition, Spence gives descriptions of many of the instruments that were developed in order to investigate the behavior of light. Ingenious designs of instruments that could make precise measurements were needed to fine tune the mechanical methods required for speed of light measurements such as the extensive use of rotating mirrors.

Spence delves into lives of some of the lesser known scientists, several almost forgotten today, giving credit to those who did important research but have historically not been given the credit they deserved. Quite a few specific suggestions of books and research papers are given for those wishing to dig more deeply into specific topics or learn more about the contributions of specific scientists. For example, Spence points out that while Michael Faraday was an excellent experimentalist who contributed much to the study of electromagnetism using clear and simple language, it was James Clerk Maxwell who summarized Faraday's work in a set of equations that are now the basis of modern electromagnetic theory. Maxwell also demonstrated that magnetic and electric fields travel as waves at the speed of light.

Spence brings to light many insufficiently appreciated achievements such as those of Oliver Heaviside, who rewrote Maxwell's equations in the late 1800s in the form used today. In doing so, Spence nicely paints a detailed picture of the way that scientists build on the knowledge gained from previous observations and experiments to keep adding to the total body of knowledge. He also shows that the process is often not linear and can take many years to complete. When discussing radio and telecommunications, he notes the contributions Heinrich Hertz made and points out that "Modern attempts to reproduce his work have shown how difficult it must have been." (page 170).

The only real problem with reading *Lightspeed* is that Spence packs so many details concerning specific scientists, experiments, instruments, and equations in each chapter that it can overwhelm anyone not already familiar with the topics covered. The background history is fun, but plowing through all the experimental and biographical details may cause some to not continue reading to the end. No matter how far one reads, though, be sure not to miss the explanation in Appendix 5 of "… how to measure the speed of light with a Microwave oven and pizza dough …" on page 229.

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***Heavenly Numbers: Astronomy and Authority in Early Imperial China*, by Christopher Cullen. (Oxford, Oxford University Press, 2017). Pp. xiv + 426. ISBN 9780198733119 (hardback), 234 × 156 mm, £78.**

Heavenly Numbers: Astronomy and Authority in Early Imperial China by Christopher Cullen provides an overview of the role of astronomers and astronomy in early imperial China at court and everyday life. Cullen describes China as a "… distinctly astronomical empire …" (page 19), in which rulers claimed legitimacy, in part, by demonstrating their comprehension of cosmic patterns. *Heavenly Numbers* serves, to an extent, as a companion volume to Cullen's 2016 monograph, *The Foundations of Celestial Reckoning*, in which he translates three Han astronomical systems (*li* 曆). While *Foundations* is directed at specialists of early Chinese history and contains translations of highly technical texts, *Heavenly Numbers* is written for a broader audience, speaking both to historians of non-Chinese astronomy, as well as to historians of early China who have some interest in astronomy and astronomers in the early imperial period. It is largely successful in this endeavour; enough basic astronomical information is presented to accommodate Han specialists without any technical background, and sufficient cultural history is provided for historians of astronomy who are not familiar with the early imperial context. The book also includes technical discussions of Han astronomical systems, usually presented in boxes inset in the text, for those who wish to have a more detailed understanding of the constants and calculations employed by Han astronomers.

Cullen centres his narrative on individual astronomers and their work during the Western and Eastern Han periods (206 BCE–220 CE). During this period, a narrative was created wherein sage rulers of antiquity observed the heavens and established calendars for the people. This narrative contributed to Han legitimacy, and established the importance of astronomy and astronomers at Court. It was during this early period, Cullen argues, that the foundations for astronomical debate at Court were laid, as was the precedent of rulers establishing astronomical syst-