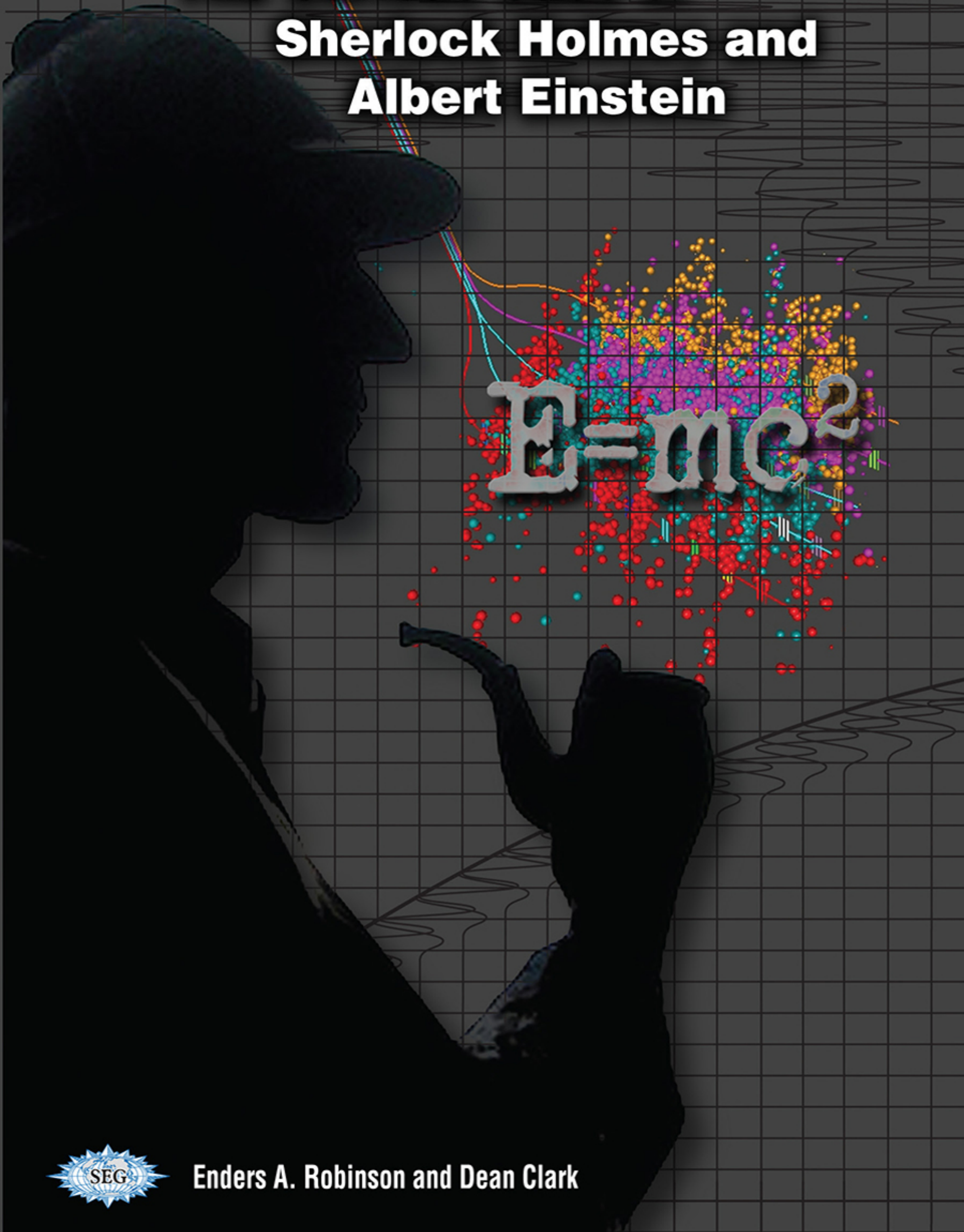
Remote Sensing in Action:

The Curious Case of Sherlock Holmes and Albert Einstein



Enders A. Robinson and Dean Clark

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REMOTE SENSING IN ACTION: THE CURIOUS CASE OF SHERLOCK HOLMES AND ALBERT EINSTEIN

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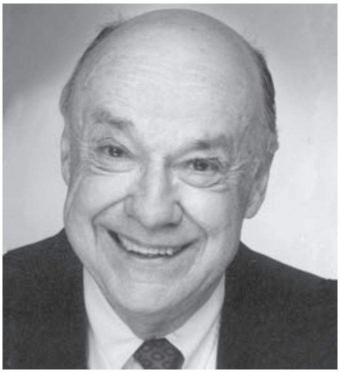
About the authors



Enders A. Robinson is professor emeritus of geophysics at Columbia University in the Maurice Ewing and J. Lamar Worzel Chair. He received a B.S. in mathematics in 1950, an M.S. in economics in 1952, and a Ph.D. in geophysics in 1954, all from Massachusetts Institute of Technology. As a research assistant in the mathematics department at MIT in 1950, Robinson was assigned to seismic research. Paper-and-pencil mathematics on the analytic solution of differential equations was expected. Instead, Robinson digitized the seismic records and processed them on the MIT Whirlwind digital computer. The success of digital signal processing led to the formation of the MIT Geophysical Analysis Group in 1952 with Robinson as director. Almost the entire geophysical exploration industry participated in this digital enterprise. In 1965, Robinson and six colleagues formed Digicon, one of the first companies to do commercial digital seismic processing. In 1996, Digicon and Veritas combined to form VeritasDGC, which combined with CGG in 2007.

With Sven Treitel, Robinson received the SEG award for best paper in GEOPHYSICS in 1964, the SEG Reginald Fessenden Award in 1969, and the Conrad Schlumberger Award from the European Association of Exploration Geophysicists, also in 1969. In 1983, Robinson was made an honorary member of SEG. In 1984, he received the Donald G. Fink Prize Award from the Institute of Electrical and Electronic Engineers. In 1988, he was elected to membership in the National Academy of Engineering. He received the SEG Maurice Ewing Medal and the SEG award for best paper in GEOPHYSICS in 2001, the Blaise Pascal Medal for Science and Technology from the European Academy of Sciences in 2003, and the Desiderius Erasmus Award from the European Association of Geoscientists and Engineers in 2010. Robinson is the author of 20 books and the coauthor of 13.

Dean Clark joined the publications department at SEG in 1981 as associate editor of THE LEADING EDGE (TLE). He became TLE's editor in 1984 and served in that capacity until retiring in 2013. He served as a U. S. Army officer in Vietnam from 1966 to 1969. He then joined the sports department of the newspaper *Tulsa World* where he spent 12 years as a reporter and columnist. Clark has written one hundred scientific and literary articles covering all phases of exploration geophysics including the history of geophysics, biographies of leading geophysicists, expositions of current developments and new trends, and mathematical tutorials. He has also written short stories and short plays based on characters in the Sherlock Holmes stories of Sir Arthur Conan Doyle. Four of his plays have been performed in New York during the annual January gathering of the Baker Street Irregulars to celebrate Holmes' birthday.

Clark is a graduate of Phillips Exeter Academy and the University of Oklahoma, where he earned a bachelor of science degree in journalism in 1966. He is a founding member of the Afghanistan Perceivers of Oklahoma and a member of Circulo Holmes, the Sherlock Holmes club in Barcelona, Spain.

Preface

This book takes you on an exciting journey of scientific discovery. The foundation resides in the fictional detective work of Sherlock Holmes and the scientific genius of Albert Einstein. This narrative, purportedly an unpublished account by Dr. John Watson, is set entirely at 221B Baker Street in London in 1905, the year in which Albert Einstein published his special theory of relativity. Dr. Watson and Sherlock Holmes had spent many years at that address. Characters of every type would frequent the place, entreating Holmes for assistance on mysteries that only he could solve. By 1905, Dr. Watson still lived at the Baker Street residence, but Holmes had retired and lived by himself on a small farm on the South Downs of England.

The narrative is a story within a story, a literary device in which one narrative is presented during the action of another narrative. The outer story consists of conversations between Holmes and Watson at 221B Baker Street in the course of a few days in the fall of 1905. In their dialogues, they construct the inner story, which is a retelling of their journey from London to Switzerland. The inner story takes place during 11 days, from Friday, 24 April 1891, to Monday, 4 May 1891. In 1905, Sherlock Holmes undertook the biggest challenge of his career — to explain to Dr. Watson, who had little understanding of physics, how a recently published paper by a virtually unknown Swiss patent clerk had radically changed the fundamentally important subject of remote sensing (and just about everything else).

Animals have five direct senses: sight, hearing, smell, touch, and taste. However, the effectiveness of direct sensing quickly falls off with distance. Bats in flight primarily use echolocation to navigate and avoid obstacles. Echolocation is a form of *remote sensing*, that is, sensing at a distance. Remote sensing (also known by the older designation, *remote detection*) depends on the use of signals that allow communication between the observer and the remote object. The most important type of signal is the traveling wave, whether mechanical (as in sound) or electromagnetic (as in light). The Doppler effect is fundamental to remote sensing. For this reason, much of the science in this book is concerned with the Doppler effect.

Many methods of remote sensing have been developed over the years. With telescopes, the astronomer can look outward to the stars and galaxies and determine that the universe is expanding. With microscopes, the biologist can look inward to the microorganisms that exist throughout the biosphere. Ground-control radar provides safe landings for airplanes. Doppler radar provides weather maps. An echocardiogram lets a doctor see the internal movements of the heart and blood without penetrating the skin. A satellite can monitor the features on the earth's surface and determine the environmental status of land cover, land use, and natural resources. Reflection seismology yields accurate 3D images of the underground structure of the earth. Ground-penetrating radar reveals buried archaeology without digging. Nondestructive testing finds hidden defects without taking the airplane apart.

A textbook is a manual of instruction. This book, which belongs to the genre of scientific fiction, is a science textbook embedded in a fictional story. (We acknowledge the contemporary scientist/novelist John Casti for introducing us to the term *scientific fiction*, but the genre itself dates back centuries, at least as far as Galileo.) We feel that presenting these advanced concepts in this form makes the book an ideal supplement to the standard texts for high-school and college students and will let them grasp the ideas more easily.

The book can also be used by someone entering science or as a refresher for seasoned scientists. In fact, much of the material will be of use to the general reader with an interest in detecting the unknown. No trigonometry, no analytic geometry, and no calculus are used. The highest level of mathematics in this book is high-school algebra and plane geometry. However, the more mathematics that one has studied, the easier the book will be to understand. The book is intended to show how useful mathematics is to science and to induce students to pursue further studies.

The scientific method is one of humankind's greatest creations. However, it is built around the assumption that new ideas, theories, and experimental results are always communicated effectively by the traditional methods. In essence, it is assumed that "communication" has been accomplished once the theory or experimental results are published (mainly in a respected peer-reviewed journal). We feel that this assumption is wrong and, in fact, unscientific. In addition, we further propose that what needs to be done is to apply the scientific method to the scientific method to find out what communicates scientific theory most effectively.

This book is an experiment along the lines that we propose. We use the techniques of fiction to "communicate" the essential ideas of remote sensing. We have done so because we feel that humans are innately attracted to stories (an assumption that probably also needs to be subjected to scientific research). We use the Sherlock Holmes stories as our basis. The Holmes-Watson framework is extremely popular worldwide with all age groups, and it has been for well over a century. Sherlock Holmes is the first and foremost detective in literature to use scientific principles consistently. Thus it is fitting that Sherlock Holmes be the detective to explain things and lead this journey.

The book is designed for the attentive reader who wants to learn about remote sensing. It is a detective story set in 1905. In that year, Einstein published the theory of special relativity in analytic form. It changed the understanding of space, time, and matter. A few years later, Hermann Minkowski gave geometric meaning to special relativity as a theory of 4D space-time. Minkowski's words, given in an address in 1908, are now classic: "The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth, space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

According to that viewpoint, it is necessary to express both distance and time in the same unit. For example, we are expressing distance in terms of time (years) when we say that the star Vega is 25 light-years away. In this way, the same unit, namely the year, is used for both time and distance. The appreciation of this fact is the first and most vital step in the understanding of relativity theory. In this book, we deal only with special relativity, which applies only to coordinate systems that correspond to inertial frames. We never mention general relativity, which applies to all coordinate systems.

In Chapter 1, Holmes explains relativity theory to Watson. More of this explanation is given in Appendix A. In the rest of the chapters, Holmes goes on to teach Watson about many other remarkable and essential techniques of remote sensing. This intellectual exertion occurs while Holmes and Watson review their famous 1891 escapade through Europe, in which they played a cat-and-mouse game with the notorious criminal Professor Moriarty.

Because this book is an experiment, several preliminary drafts went to a variety of people (ranging from students to much respected senior scientists) who were asked for comments. A very interesting response came from Claire Michel, a graduate of the University Jean Moulin in Lyon, France, who lives within a few miles of one of the settings in this story — the house on Lake Geneva in which Lord Byron spent the summer of 1816. Michel wrote:

> In Chapter 1, I was intrigued by the conversation between Dr. Watson and Sherlock Holmes. Clearly, Watson does not understand relativity theory, but he listens intently to various explanations given by Holmes. Watson keeps trying because normally he is able to follow the way that Holmes solves a case. I found that Watson's feeling entirely mirrored my own. In the end, Watson had a better understanding, and so did I. This entirely new way to understand relatively theory is great. I quickly realized that the most difficult part of the book was over. At this point, the stage is set for the rest of the story.
>
> I began Chapter 2 with Lady Anne, and I find it even more captivating because it has less mathematics and theory and more story and action. However, I do totally understand the need for Chapter 1 in relation to the entire story. I realized that the concept of the story is really brilliant, and most of all, it would certainly have pleased Conan Doyle. Indeed, this entire story is so fascinating that I can easily imagine going on the same path in Bruxelles, where Holmes and Watson have been, and afterward to Strasbourg and then to Geneva. I am sure I will not see the clock of Strasbourg in the same way any more (as now I see it in terms of Einstein's theory).

Although this Sherlock Holmes story is fiction, the science described is accurate — with one important caveat. The drawings purportedly discovered by Holmes in Brussels and Strasbourg, which demonstrate how Christiaan Huygens developed Huygens' principle, are fictitious. They are our attempt to explain Huygens' reasoning. Huygens must have worked with something like these drawings, but no extant document supports that contention. Huygens' principle is a fundamental building block of wave theory, which underpins such important scientific advances as electromagnetism and relativity. Amazingly and surprisingly, however, the way Huygens came upon this fundamental concept remains a mystery more than three centuries later.

Our story is a battle of wits between Sherlock Holmes and Professor Moriarty, who has prodigious mathematical ability. Lady Anne is our counterpoint to Professor Moriarty. We demonstrate the mathematical prowess of Lady Anne throughout the book. It is she who makes two new discoveries at Stonehenge. One is an explanation of why the number of Aubrey holes is 56 and the other is that ancient builders located the position of the heelstone by means of the stereographic projection.

Lady Anne also shows how ancient astronomers could have used the stereographic projection in conjunction with the stone circle to map the position of the stars. Our story, through Lady Anne, traces the use of the stereographic projection from Stonehenge to the ancient Egyptians to the ancient Greeks to the Renaissance and finally to the relativistic Doppler effect. Those readers who want to learn more of the mathematics of the Doppler effect can continue to Appendices B, C, and D.

Appendix B gives a musical explanation of the "classical" Doppler effect, otherwise known as the acoustic Doppler effect. The signals are mechanical waves such as sound waves or seismic waves. The speed of a mechanical wave is very much less than the speed of light. The word *classical* refers to the fact that familiar Newtonian mechanics is used. Pythagoras originated the theory of musical harmony, basing it on his scheme of means and extremes. Our presentation of the Doppler effect, not found in physics books, makes use of the simpler tools of Pythagoras.

We take an additional step. Zeno's famous paradox of Achilles and the tortoise states that the swiftest racer can never overtake the slowest. We show how this paradox explains why there is a need to have two classical Doppler factors instead of just one. The classical Doppler effect from a fixed source to a moving receiver is essentially the arithmetic mean, whereas the classical Doppler factor from a moving source to a fixed receiver is essentially the harmonic mean. The fact that both the arithmetic mean and the harmonic mean are required represents a fundamental asymmetry in the classical Doppler effect.

Appendix C uses intuitive methods originating in antiquity and in the Renaissance to explain the "relativistic" Doppler effect, otherwise known as the optical Doppler effect. The word *relativistic* refers to the fact that the relativistic mechanics of Einstein are used. The signals are electromagnetic waves, such as light waves or radar waves. The speed of an electromagnetic wave is equal to the speed of light. The relativistic Doppler factor from a fixed source to a moving receiver is essentially the geometric mean, whereas the relativistic Doppler factor from a moving source to a fixed receiver is also the geometric mean. The fact that only the geometric mean is required represents a fundamental symmetry in the relativistic Doppler effect.

Appendix D gives a geometric treatment of Einstein's theory of special relativity. The underlying mathematical trappings of special relativity should not be difficult for a student who wants to learn. The mathematics is essentially the same as that of the relativistic Doppler effect. Both can be expressed in terms of the geometric mean of Pythagoras and the stereographic projection of Hipparchus. However, the ramifications of Einstein's special relativity go well beyond mathematics into the previously unknown domain of space-time. We give some outstanding examples conceived in the fertile mind of Albert Einstein, such as Einstein's train, the dilation of time, and the light clock.

We built our story around the timeline that Conan Doyle established in the stories "The Final Problem" and "The Adventure of the Empty House." Lady Anne, the hereditary Duke of Burgundy with residence at Coudenberg Castle, and a few minor characters are our own fictional creations. In actuality, the real Coudenberg Castle burned down on the night of 3 February 1731; its ruins are now a museum. The present king of Spain, Juan Carlos, claims the title of Duke of Burgundy.

Finally, this book would not have been possible without the contributions of two men of genius — Sir Arthur Conan Doyle for creating the world's most popular fictional character and Christiaan Huygens for his supremely important contributions in many areas of physics. We enthusiastically thank the late Conan Doyle, whose writings have entertained and inspired people for more than a century. Sherlock Holmes, Dr. Watson, Mrs. Hudson, Mycroft Holmes, and Professor Moriarty are his original creations. We are extremely grateful to the Conan Doyle Estate Ltd. for its kind permission to use these copyrighted characters. It is our strong opinion that Christiaan Huygens unquestionably ranks with the greatest scientists of all time. However, his reputation among the general public and even among some scientists is not commensurate with his astonishing achievements, many of which are at the very foundation of modern physics. We hope this book helps in some small way to correct this injustice.

Acknowledgments

Because this book is an experiment in scientific communication, it underwent several revisions before achieving its final form. Various drafts of the manuscript were sent to many friends and acquaintances, most of whom willingly played the long-established "game" among fans of Sherlock Holmes (i.e., that this was a long-lost manuscript by Dr. Watson that we were going to "edit" for publication). We are grateful for their comments and criticism, much of which resulted in extensive reworking of the material.

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