

A unique source in a unique location

Revealing the Heart of the Galaxy

The Milky Way and Its Black Hole

Robert H. Sanders
Cambridge U. Press, 2014. \$39.99
(197 pp.). ISBN 978-1-107-03918-6

Reviewed by Matthew Walker

The greatest astrophysical discoveries come in two flavors: those that fundamentally alter the human perspective and those that cannot be adequately explained by conventional physics. Discoveries of the first kind have displaced our planet, our sun, and our galaxy from presumed central locations and might eventually include the detection of extraterrestrial life. Dark matter, dark energy, and other discoveries from the second category point the way toward new physics. In his latest book, *Revealing the Heart of the Galaxy: The Milky Way and Its Black Hole*, veteran astrophysicist Robert Sanders tells the story of a discovery that combined both qualities during its long development over most of the past century and culminated with a consensus among astrophysicists that the center of the Milky Way is home to a giant black hole.

An expert in stellar and gas dynamics, Sanders narrates an often personal account of observational results and theoretical ideas (with several wrong turns along the way) behind the discovery of that “unique source in a unique location.” He traces the story’s origins to heroic efforts during the early 20th century to determine the size and structure of the sidereal system composed of point-like stars and fuzzy or spiral-shaped nebulae. Clever techniques for measuring distances to those objects soon yielded perspective-altering results: Many of the nebulae lie far beyond the stars, proving that our Milky Way is but one of many galaxies in a gigantic universe. Furthermore, like all galaxies, ours has a center, but one that is far from the Sun.

Matthew Walker is an assistant professor of physics at Carnegie Mellon University in Pittsburgh, Pennsylvania. He uses large optical telescopes to investigate the properties of galaxies and dark matter.

Sanders links those results as the foundation for studying galactic nuclei, a topic he proceeds to cover with a detailed seriation of results spanning the 1963 discovery of quasars to the recent detection of huge gamma-ray bubbles rising from the Milky Way’s center. The driving question is: What mechanism can be responsible for the emission of extremely powerful radiation from relatively tiny regions at the centers of many galaxies (typically about 10^{40} W from within the innermost light-year)? In its most illuminating passages, *Revealing the Heart of the Galaxy* explains how some of the world’s most distinguished scientists systematically identified



and ruled out various candidates. The review is pedagogical and introduces the reader to a rich variety of astronomical phenomena, both observed and hypothesized. It also develops the thesis that “astrophysics is, in a real sense, applied physics: the concepts of modern physics are applied to astronomical problems. Moreover, explanations of astronomical phenomena are sought in terms of *known* physics.”

So it is only after careful elimination of conventional explanations that the astrophysicist can justify resorting to the exotic. That principle becomes the source of dramatic tension when the frontier of physics evolves as rapidly as that of observational astronomy. Indeed, in the late 1960s, just months after general relativity’s curious spacetime singularities were first dubbed “black holes,” it was shown that the energy liberated during the accretion of gas onto a sufficiently large one—that is, a black hole with a mass hundreds of millions of times greater than the Sun’s—could plausibly power even the most luminous galactic nuclei. With that idea came the bold prediction that the Milky Way itself hosts a dormant (because gas is not accreting), and hence less conspicuous, supermassive black hole. In its climactic sections, *Revealing the Heart of the Galaxy* gives a blow-by-blow account of the race among teams of astronomers as they vie for time on the world’s largest telescopes to find unambiguous evidence for that black hole’s existence.

According to the preface, the book is “aimed at nonspecialist readers and

students and historians of astronomy.” But the content eventually veers toward the technical. Early chapters focus on the contributions and even personalities of individuals, with particular emphasis on pioneering observers like Jacobus Kapteyn and Jan Oort. In later chapters, such character studies give way to detailed descriptions and interpretations of an ever-growing body of astronomical data. There the storytelling often seems to labor under the weight of more than 100 references to published work. Toward the end, the nonspecialist will find it challenging to navigate among so many interconnected results.

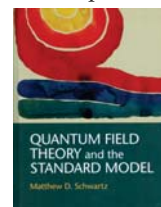
Yet it is refreshing to see an author err on the side of rigor instead of oversimplification. Moreover, Sanders restores balance by inserting helpful summaries after particularly dense sections. Those interludes contain charmingly personal reflections on both the practice and development of astronomy and help to ensure that interested readers of all backgrounds can share in the thrill of a wondrous discovery.

Quantum Field Theory and the Standard Model

Matthew D. Schwartz
Cambridge U. Press, 2014. \$90.00
(850 pp.). ISBN 978-1-107-03473-0

Well before two research teams at CERN’s Large Hadron Collider announced the discovery of a Higgs-like boson, the standard model of particle physics had been validated by data collected across a broad range of energies. Theory—in particular, the formulation of the standard model as a relativistic quantum field theory (QFT)—played a significant role in that success. To be sure, a QFT is an abstract and highly mathematical construct, but it offers a calculational framework from which can be derived predictions that can be tested to high precision.

To this day, QFTs are the primary theoretical tools for advancing the frontiers of knowledge about the basic principles underlying the behavior of matter. For



that reason, it is important that the theories be presented in a modern context. That's what Matthew Schwartz's *Quantum Field Theory and the Standard Model* attempts to do. The voluminous text provides an inspiring tour of theoretical particle physics, from the very basics, to the detailed formulation of the standard model, to advanced concepts of present-day research. The book is at a level appropriate for students who have had a solid undergraduate course in quantum mechanics. The overall format of relatively short sections, underlined headings with large fonts, and highlighted boxes helps to make the book user friendly. A bit annoying, though, is the lax handling of upper and lower Lorentz indices, which sometimes leads to confusion.

Schwartz, an associate professor at Harvard University, is an experienced researcher and an expert in applying QFT to experiments for testing the standard model. His book covers the grand ideas that feed into the standard model: relativistic QFTs, including gauge theories; symmetries; and symmetry breaking. But consistent with the spirit of Schwartz's research, it is a pragmatic text that primarily focuses on the theory's perturbative aspects, teaching ideas and methods of relativistic QFTs so that the reader can perform practical calculations.

Quantum Field Theory and the Standard Model moves from the fundamental Lorentz symmetry to the various kinds of fields and particles and their interactions in the Lagrangian and Hamiltonian approaches. It discusses perturbation theory, Feynman diagrams, the path-integral formulation, loop calculations and renormalization, broken and unbroken gauge theories, and tests of quantum chromodynamics and the electroweak theory—the sectors of the standard model that describe the strong force and electromagnetic-plus-weak forces respectively. The last part of the book is concerned with more advanced topics, such as heavy-quark effective theory and soft-collinear effective theory, which are important in current standard-model tests in flavor physics and at high-energy colliders. Schwartz's introduction to them will be useful for more sophisticated readers. Throughout, the author maintains the connection between theory and experiment; he also includes interesting historical references.

The book is full of explicit derivations and concrete calculations that will allow readers to dig into the subjects, provided they are willing to invest suf-

ficient time. Its derivation of Feynman graphs through the Hamiltonian formulation, for example, shows the pedagogically helpful relationship between the Feynman graphs and the conventional perturbation theory of nonrelativistic quantum mechanics. The more formal Lagrangian and path-integral approaches, on the other hand, are more elegant and efficient pathways to that central tool of particle physics.

Quantum Field Theory and the Standard Model may be considered a successor to Michael Peskin and Daniel Schroeder's *An Introduction to Quantum Field Theory* (Westview Press, 1995), which for almost 20 years has been a standard reference. Schwartz's book is similar in its selection of themes and presentation, yet with more details, different viewpoints, and broader introductory material. Unlike Peskin and Schroeder's, it covers new developments and modern topics, including spinor-helicity methods, heavy-quark effective theory, and soft-collinear effective theory, and it offers a modern point of view on the use and relevance of nonrenormalizable theories. Schwartz's section about tests of the standard model includes the recently measured Higgs boson properties in electroweak precision tests. That discussion, however, does not go beyond the one-loop level and gives the misleading impression that one-loop calculations are sufficient to get agreement between theory and experiment. In fact, important higher-order calculations not discussed by Schwartz have been done in the past two decades.

Overall, *Quantum Field Theory and the Standard Model* is a balanced and comprehensive text. I recommend it for beginners in particle physics and its theoretical foundations. Containing a rich collection of information in a single volume, it will also be a useful reference for lecturers and researchers.

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Astronomical Measurement A Concise Guide

Andy Lawrence
Springer, 2014. \$89.99 (192 pp.).
ISBN 978-3-642-39834-6

In *Astronomical Measurement: A Concise Guide*, Andy Lawrence, the Regius Professor of Astronomy at the University of Edinburgh, provides a delightfully

comprehensive summary of the essential information the budding observational astronomer needs to know. This elegantly succinct textbook—just 143 pages long, plus two appendices—is an inclusive overview of the issues a serious astronomy student should understand to plan science observations. It is aimed at the advanced undergraduate and the beginning graduate student, but it can also serve as an engaging refresher for the working astronomer who wants to venture into a new wavelength regime. For a practical handbook on observational strategies, challenges, and tactics, look no further.

We astronomers live at a time in which all sorts of ground- and space-based astronomical facilities are available to us. Lawrence makes it clear, though, that the problems of signal-to-noise ratio, atmospheric distortion, imaging resolution, detector efficiency, and spectroscopy are analogous across wavelength regimes and that basic observation strategies can be duplicated or adapted to various instruments. What's required is for astronomers to know what celestial phenomena we want to study and what physical properties will help us understand them.

While reading *Astronomical Measurement*, one thought kept coming back to me: Where were books like this when I was an astronomy student? As a professional who has worked across the electromagnetic spectrum but trained with a bias toward optical astronomy, I am thrilled to see this text. No longer will the student need to struggle through separate introductory textbooks to learn about observing with optical, radio, and high-energy telescopes. *Astronomical Measurement* covers them all. I would even recommend it as background for proposal writing, provided the writer is already familiar with the physics of radiative processes, which is not covered in detail.

Lawrence's book is clear about what it is not: a lengthy tome of technical details. For every concept introduced in a chapter, the "Further Reading" and "References" sections at the chapter's end direct the reader to more thorough discussions in relevant technical books, articles, and manuals. Consequently, *Astronomical Measurement* will also serve as an excellent reference. Lawrence places his discussion of statistics and orbital mechanics into the appendices, thus making them crucial

