

about computational simulation.

Winsberg adopts the methods of philosophy of science to pose questions about how computational simulations relate to physical reality. His goal is not to answer all such questions but rather to frame some of them and suggest paths for investigation. He does not try to explain why, for example, the generation of random numbers can tell us something about particulate aggregation; his intent is to locate the question on the landscape of philosophical inquiry.

Philosophical investigation of how mathematics relates to physical reality has had a long history. At first glance, computer simulations may seem to consist merely of mechanical implementations of mathematical models. However, one of Winsberg's main points is that the methods and approaches used in simulation are more than just numerical evaluations of formulas implied by mathematical analysis of a theory. Here I wish he had said something about the formal meaning of "implications" of a mathematical formulation. The claim that statement A implies statement B does not mean that B is somehow contained in A. In fact, it means that A is contained in B. Therefore, mathematical deduction locates a theory in the universe of mathematical truths, but it does not reveal the theory's content.

In contrast, computational simulation produces knowledge different from that obtainable via deductions from theory; mathematical theory guides but does not determine how numerical models are constructed. Computational formulations are often amalgams of several theories, and they include various manifestly unphysical tricks—for example, adding artificial viscosity. Such techniques, however, generate epistemological questions about the relation between results of a simulation and the physical reality.

The distinction between facts obtained via deduction and those obtained via computation is treated well in Winsberg's book. Chapter 4 discusses the difference between real and computational experiments. A particularly nice example given is the use of physical experiments as a kind of analogue computation—for example, using Bose–Einstein condensates to study the behavior of black holes. Chapter 5 discusses so-called multi-scale computations, which rely on unphysical computational tricks to meld two or more incompatible theories, such as molecular dynamics and computational fluid dynamics (CFD).

Parts of the book seem to indicate a

lack in the author's background in applied mathematics and computational science. One example is the discussion of "exact" solutions of a differential equation. Winsberg appears to believe that numerically evaluating the closed-form solutions to the equation provides the best results. However, it's well known that for some functions, including the Airy functions and the Hankel functions, approximating the differential equation is more numerically precise than evaluating the closed-form function directly. In general, closed-form solutions won't give more insight than will the differential equation itself. In a similar vein, the author appears to expect too much from CFD. The reader may be led to believe that computational tricks are introduced because the partial differential equations cannot be indefinitely discretized. But, of course, CFD is itself an approximation. The Navier–Stokes equations are a versatile and powerful method for modeling fluids; but fluids are, in reality, ensembles of particles.

In spite of those quibbles, *Science in the Age of Computer Simulation* is an interesting and valuable book. I hope that it will stimulate more discussion and investigation of philosophical questions engendered by the enormous role that computational simulation plays in science.

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The Dark Matter Problem

A Historical Perspective

Robert H. Sanders
Cambridge U. Press, New York,
2010. \$60.00 (205 pp.).
ISBN 978-0-521-11301-4

"The prevailing view of the Universe now is radically different than it was 40 years ago when I began my career as a professional astronomer," says Robert Sanders in *The Dark Matter Problem: A Historical Perspective*. In this readable and enjoyable book, Sanders takes us through the historical development of the theory of dark matter, including attempts at its direct detection, and up to the present state of affairs in astronomy, cosmology, and particle physics. And he does so with a sympathetic nod toward an unpopular competing theory.

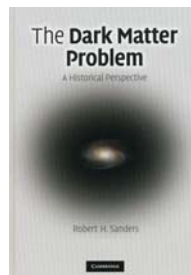
I found the first half histor-

ically informative. It was fascinating to learn that the instability of rotationally supported disks of spiral galaxies was one of the earliest pieces of evidence for dark matter. The author deftly discusses the post–World War II emergence of radio astronomy and weaves that story into the history of spiral galaxy rotation-curve observations. He also carefully presents the roles played by those involved in the discovery process. For example, the contributions of radio astronomers Morton Roberts, Albert Bosma, and others appear alongside those of Vera Rubin, whose name is most strongly associated with the optical observations of rotation curves in the 1970s.

Several chapters in the second half of the book contain an overview of early-universe physics, cosmology, and particle physics. Those chapters are terse and technical, providing neither explanations nor equations. They belong to a category of writing that won't satisfy any audience. A reader already familiar with the topics they discuss will not learn much, and I doubt a nonspecialist will either. Some topics, it seems, are resistant to intermediate-level expositions. Sanders also includes a discussion of dark energy, which is generally viewed as a separate problem. I found it unnecessary and a little distracting.

In an idiosyncratic twist, the book offers a detailed treatment of dark matter versus modified Newtonian dynamics, or MOND, an alternative hypothesis to explain galaxy rotation curves. A chapter is devoted to MOND, and references to MOND are ubiquitous throughout the book. The author presents many arguments for and against both dark matter and MOND, with varying degrees of emphasis. In his thorough coverage of galaxy rotation curves, Sanders emphasizes that dark matter has yet to explain their small-scale features, the "conspiracy" of maximum disks, or the slope of the Tully–Fisher relation, while MOND, apparently, fares well in addressing those observations.

But MOND's weak spots—explaining the mass content of clusters and the observations of the colliding clusters of the Bullet and other systems where mass and light are separated on the sky—are presented as problematic, although potentially explainable. Sanders also notes that various, sometimes unrelated observations can be explained by dark matter. To most cosmologists, that is a powerful and persuasive argument for



the yet-to-be-detected particles. To the author, it is a convenient compilation of problems forced together under the leaky umbrella of dark matter.

Given that the book is sympathetic toward modifications of Newtonian gravity, I would have liked to see more details about MOND. What is the form of the function that interpolates between Newtonian and MOND regimes in the force law? Can MOND account for the observed temperature fluctuations in the cosmic microwave background? How does the cosmic network of galaxies and clusters develop in MOND? What about the extra fields introduced in the tensor-vector-scalar theory, a relativistic version of MOND?

On the whole, *The Dark Matter Problem* will benefit advanced undergraduates, graduate students, and some researchers. I can imagine two different ways in which the author's nonstandard view of dark matter will play out with the reader. Nonspecialists might buy the narrative wholesale and believe that MOND is a competitive alternative—a conclusion at odds with the consensus of researchers. (Although the fraction of MOND papers has tripled since tensor-vector-scalar theory was introduced in 2004, they still make up only 3% of the papers that deal with the same “problems” addressed by dark matter.) Students and professionals working in the field may receive this book as a training tool that highlights the current deficiencies of the dark-matter paradigm. Understanding those deficiencies is an important part of the learning process.

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K. Bjørlykke. Springer, Berlin, 2010. \$99.00 (508 pp.). ISBN 978-3-642-02331-6

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\$17.00 *paper* (189 pp.). ISBN 978-1-61614-216-2

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Visions of Discovery: New Light on Physics, Cosmology, and Consciousness. R. Y. Chiao et al., eds. Cambridge U. Press, New York, 2011. \$85.00 (794 pp.). ISBN 978-0-521-88239-2

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