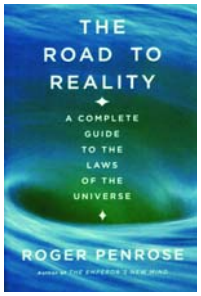
about dissecting JPL's personality and its belated acceptance of late-20th-century cultural norms. Women scientists and engineers, and later managers, broke into the intensely male culture at JPL and became role models for the women who followed them. The issues of homosexual lifestyle finally became publicly acknowledged in the 1990s with the debate over health benefits for JPL workers and their partners. Lord uses her knowledge of the lab and insights from her father's professional life to add depth and color to the ongoing evolution at JPL. This part of her story is unfinished and perhaps not completely circumspect. Her discussion of women in the JPL workforce and their successes and failures is largely anecdotal. The anecdotes are valuable, but there must be more to the picture. Likewise, the issues of ethnic diversity at JPL are in transition and continue to evolve. But then JPL is still a work in progress, and only time may allow us to look back at this epoch of change with greater clarity.

Astro Turf is an interesting read and filled with intriguing insights into the inner workings of JPL, the people who work there, and the history that contributes so richly to its unique character. Lord successfully accomplishes her mission in writing this story, which also serves as a memoir about her father. She comes to closure with a more complete understanding of his life, a life so inextricably woven into rocket science that to understand him she had to understand his work.

Douglas P. Blanchard
Johnson Space Center
Houston, Texas

The Road to Reality: A Complete Guide to the Laws of the Universe

Roger Penrose
Alfred A. Knopf, New York, 2005.
$40.00 (1099 pp.).
ISBN 0-679-45443-8



Roger Penrose is very possibly the most creative and independent thinker working in theoretical physics today. It can be fairly said that he has contributed more to our understanding of general relativity than anyone since Albert Einstein. He is also the originator of several important and influential ideas that have been widely used. For example, he invented a simple model of quantum spacetime, called spin networks, that now underlies much work in quantum gravity. But he went on to develop his own approach to quantum gravity, called twistor theory. Although twistor theory has played a role in mathematics and, recently, in string theory, most physicists have not followed Penrose's explorations of the subject. And Penrose's views on quantum mechanics are decidedly original and heterodox: He believes that quantum mechanics is an approximation of a more complete theory in which the wavefunction will evolve nonlinearly as a result of gravitational effects.

In addition to writing *The Road to Reality: A Complete Guide to the Laws of the Universe*, Penrose, a distinguished professor emeritus in the mathematics department at the University of Oxford, is the author of two previous books that present his vision of the future of physical theory. Although those books have inspired a few physicists, most working theorists have rejected Penrose's vision in favor of a research program that aims to go beyond the standard model of particle physics without modifying any aspect of quantum theory. That dominant view has lasted for more than 30 years and has led from grand unified theories to supersymmetry, higher-dimensional theories, and string theory. Penrose's book appears at a moment when the dominant view faces a crisis following the discovery that any string theory compatible with the observed positive cosmological constant offers such a vast number of possible universes—at least 10^{500}—that it may never be able to make any falsifiable predictions. This has recently led great physicists like Leonard Susskind and Steven Weinberg to declare the dawning of an age of anthropic physics, in which a theory is to be believed even if it is untestable and there are to be no first-principles explanations for most properties of the elementary particles.

I mention the above crisis because it is the context in which Penrose's new book must be understood. Penrose's treatise is two books in one. The first is a pedagogical introduction to the main ideas of mathematics and physics sufficient, according to Penrose, to take lay readers from the integers to twistor spaces and Calabi–Yau manifolds. The second is a strongly argued critique of the dominant research approach, followed by a formi-

dable argument in favor of his alternative view.

Penrose's critiques of string theory and other popular ideas are carefully and respectfully presented. He is a lover of beautiful mathematics, and he writes very sympathetically about the aesthetic attractions of string theory. Nevertheless, his criticisms are formidable. For example, he invokes a singularity theorem that he was the first to prove, and he uses it to argue (convincingly to me) that all higher-dimensional theories suffer instabilities that will lead them to collapse quickly to singularities. To my knowledge, his critique has not been answered. If he is right, the idea of unification of gravity with other forces through higher dimensions is doomed. Penrose also explains why he finds supersymmetry disappointing; he correctly points out that it does not unify any known particle with any other known particle but that it does lead to a huge expansion in the number of free parameters.

Other approaches to unification receive equally balanced treatment. Penrose is uniquely honest in mentioning the weak points and gaps in his own favored ideas. He reminds us of an earlier era before physicists learned to aggressively hype their ideas, an era in which the prevailing ethic called for honestly explaining the pros and cons and letting the ideas and results speak for themselves.

At the core of Penrose's thinking are arguments that lead him to believe that quantum mechanics must be modified to be unified with gravity. This idea leads him to reject both string theory and such competing approaches as loop-quantum gravity. More than that, he rejects a governing assumption of almost all post–standard model theorizing, which is that such foundational challenges as the measurement problem and quantum gravity can be ignored while physicists work on the problem of unification. Although Penrose's proposal for modifying quantum theory may or may not succeed, it has a feature string theory so far lacks: a doable experiment to test it.

Penrose's case for his ideas is sufficiently strong that it raises the question of why more physicists do not follow him in investigating the possibility that gravity limits the applicability of standard quantum theory. My guess is that most physicists are trained to be problem solvers rather than visionaries, and it is easier for them to work on research programs that offer well-defined problems to solve. To follow Penrose is to engage in a much more risky and challenging activity: a search for a new theoretical framework. But the longer time goes on without clear evidence for the success of other approaches, the more pressing will be the need to take Penrose seriously.

At the very least during this moment of crisis for string theory, a thoughtful critique by someone who has himself achieved so much is something that no working physicist should ignore. Unless the crisis is quickly resolved, physicists will see in the next few years a more public argument between the radicals who argue that science must be modified to allow belief in a theory that may never make a falsifiable prediction and conservatives who say that the mainstream took a wrong turn somewhere after the standard model. The conservatives will argue, as Penrose convincingly does in *The Road to Reality*, that the reason theoretical physics lost touch with experiment after the standard model was that physicists had by then gone as far as they could go without solving such deep foundational problems as quantum gravity and the interpretation of quantum mechanics.

It is ironic that one of the most radical and independently minded thinkers we have in modern physics, Roger Penrose, will be a leading inspiration for the conservatives who will try to bring physicists back to a physics based on sticking closely to the phenomena experiments observe. Physicists who care about the future of our science should read his book and consider what this careful and creative man has to say.

Lee Smolin
Perimeter Institute for Theoretical Physics
Waterloo, Ontario, Canada

New Books

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