very strong and brilliant scientist she has succeeded in writing a first-rate cultural and scientific account of one of the most exciting periods in physics.

Gravitation and Inertia

Ignazio Ciufolini
and John A. Wheeler
Princeton U. P., Princeton, N.J., 1995. 498 pp. $49.50 hc
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Mathematicians, astronomers and mathematical physicists were the principal investigators of Einstein's theory of gravitation for some four decades, until a full-blooded physicist went relativistic and transformed the field into a prime part of physics. John Wheeler of Princeton University inspired experiments in relativity and created a large school of followers who, together with his grandstudents, may count in the hundreds. (Wheeler students are easily recognized by the bound notebooks they carry around.)

As Einstein's apostle, Wheeler has fertilized relativity with many ideas, often intriguing and bizarre, that through their succinct formulation spread his gospel beyond physics and made "black hole" a buzz word in all major languages. It was thus with great interest that I read the newest Wheeler text written with Ignazio Ciufolini, research associate at Consiglio Nazionale (delle) Ricerche in Rome.

The authors state: "This book is on Einstein's theory of general relativity, or geometrodynamics. It may be used as an introduction to the *foundations* and *tests* of gravitation and geometrodynamics, or as a monograph on the meaning and origin of inertia in Einstein Theory." The authors' catholic touch and multifaceted approach, however, turn the book into a veritable encyclopedia of Einstein's theory of gravitation, listing 1041 papers and ending with 56 pages of indexes—a whole sky catalog of relativity. Although the book is perhaps not optimal as an introduction, it is a treasure trove of information and should be consulted by all workers in relativity as a signal contribution to the literature. Due to Ciufolini's expertise in satellite experiments, we obtain here a rich account of relativistic tests and designs for ambitious future experiments.

One of the authors' goals was for their book to be a monograph on the meaning and origin of inertia in Einstein's theory. Here the Austrian philosopher and experimental physicist Ernst Mach casts a long shadow over the pages. The skeptical Mach, who didn't believe in atoms (he used to needle colleagues with the Viennese *Ham's eins g'sehn?* Did you see one?), absolute space or other Newtonian "absurdities," thought that rotation was relative, that the flattening of Earth at the poles and the inertia of particles might both be due to distant masses.

But atoms exist, and spin is not relative but absolute, given by the length of the Pauli–Lubanski vector divided by the mass of the particle. Very little of Mach's program, however nebulous, survived in Einstein's theory—like the dragging of inertial frames—since gravitation is definitely not the source of the local Minkowski metric, while some extension of the Higgs field might well be. Also, modern gauge theories are local and hold local fields responsible for what is going on, and they do not put the blame on the dark matter at the edge of the observable universe.

Mach's principles—whatever they may be—will always find their defenders and believers. When one of its promoters, Dennis Sciama, slammed on the brakes of his car, propelling his girlfriend, seated next to him, toward the windshield, she was said to be heard moaning, "All those distant galaxies!"

The modern interpretation of Einstein's gravitation theory pioneered by Hermann Weyl in the (still untranslated) fifth edition of *Space-Time-Matter* (Springer, 1923) is well represented in Michael Friedman's *Foundations of Space-Time Theories* (Princeton U. P., 1983), but is not among the Wheeler–Ciufolini references. Ciufolini and Wheeler do not even mention the Higgs field as having something to do with inertia but state their credo as the Machian mantra: "Inertia here arises from mass there." The proof of this statement would involve observing a change in the mass of an electron due to the removal of a substantial part of the universe, the ultimate challenge to the experimentalist. I think it's nonsense, but, okay, let them try!

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Quaternionic Quantum Mechanics and Quantum Fields

Stephen L. Adler
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The basic equations of classical physics involve real numbers only. Heisenberg's and Schrödinger's, however, use an imaginary unit i. Many researchers, including Lawrence Biedenharn, Garrett Birkhoff with John Von Neumann, Gerhard Emsch, Feza Gürsey, L. P. Horwitz, Josef Jauch, David Speiser and Abraham Pais, have studied quantum theories with two or more independent anticommuting i's. Von Neumann pointed out that quantum transition amplitudes could be drawn from any regular *-algebra, so the lode of possible number systems has hardly been tapped. For example, supersymmetric quantum theory adjoins anticommuting square roots of 0 instead of square roots of −1.

In *Quaternionic Quantum Mechanics and Quantum Fields*, Adler moves the whole quantum world—nonrelativistic one-body theory, scattering theory, many-body theory and relativistic quantum field theory—from its complex foundations to quaternionic with elegance, grace and minimum casualties. He suggests that the new theory might apply to subquarks like the rishons of Haim Harari.

In quaternion space, the imaginary number i is no longer a linear operator. Can we still do quantum dynamics? Most theories postulate not only three imaginary numbers i, j and k to replace the one complex number i, but also three "quaternionic imaginary operators" I, J and K to replace the one complex operator i. Adler especially develops the scattering theory for Hamiltonians with these imaginary operators, which break time reversal invariance in a natural way special to quaternionic quantum mechanics.

Quaternionic spaces have no tensor product. Can we still do quantum physics? Quaternionic wavefunctions for composite systems need not factor into cluster wavefunctions when the particles form widely separated clusters. In the chapters on many-body theory, Adler proves that, when the system is infinite, any finite part of it clusters in the way that is familiar from the complex theory, at least to first order in perturbation theory. The loss of tensor product may not be as fatal for causality as it first appeared.

Adler develops a quaternionic gauge field theory somewhat along lines once suggested by C. N. Yang. Curiously, he postulates that the quaternionic imaginary operators are constant throughout spacetime. This remote quaternionic comparison conspicuously violates Einsteinian locality and gauge invariance at the start. He copes with this to some extent by dropping the Dirac–Schwinger–Feynman action principles of present-day quantum mechanics for a principle that he proposed in 1979: His variables are not the true quantum ones but the totality of their numerical matrix ele-