Review of “Quantum Legacies: Dispatches from an Uncertain World”
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The stories of real humans involved in the discovery of secrets of the quantum realm are highlighted by David Kaiser's book "Quantum Legacies: Dispatches from an Uncertain World." Kaiser is both an accomplished theoretical physicist and a historian of science, holding a dual professorship at MIT. The book is a collection of his essays written for a popular audience knit into a theme of how discovery of quantum ideas has taken place in a changing world by intriguing personalities.

Scientific discovery never takes place in a vacuum, but rather is guided and spurred on by the very pressures experienced by its human discoverers, including personal family tragedies such as the suicide of Paul Dirac's brother or societal upheavals such as the Nazi takeover in Germany leading to World War II. Kaiser describes his own journey and how it was affected by the politics and pressures of the Cold War. Indeed, as a particle physicist who also grew up during the Cold War, I could relate to many of the dynamics described by Kaiser. He notes that funding for the Superconducting Super Collider project in the 1990's was canceled partly because the Cold War ended, and the U.S. funding for "world prestige" projects was cut, in favor of more "world collaborative" projects, such as the International Space Station. Given that my own career trajectory was influenced by this decision, reading this book certainly caused some personal reflections.

The book is divided into four sections: Quanta, Calculating, Matter, and Cosmos. The essays on Quanta include the early years of quantum mechanics, highlighting the lives of Paul Dirac, the Briton who discovered the equation describing electrons, Erwin Schrödinger, the Austrian who used a half-dead, half-alive cat in a box to describe the bizarre idea of quantum mechanical superposition, and Bruno Pontecorvo, the Italian who applied Schrödinger's idea to the ghostly neutrino particle to predict its spontaneously changing identity. The interesting personal lives of these men and the historical context in which their scientific pursuits took place provide a dramatic reading. Indeed, the probabilistic aspects of the quantum mechanics they studied reflected the uncertainty of the world they lived in. The final essay on Quanta describes an experiment that Kaiser personally participated in, proving that entangled photons obey the probabilistic predictions of quantum mechanics, and not deterministic laws proposed by Isaac Newton through Albert Einstein. Enriching the story, Kaiser connects quasars from the remote edges of our visible universe to the Roque de los Muchachos Observatory on the Canary island of La Palma to show that the world of physics involves interesting physical settings.

Calculating is an interesting collection of essays on how national defense priorities from the end of World War II through the Cold War drove university physics enrollments, the development of atomic bombs and computers, and even the personal lives of the contributing physicists. For example, David Bohm, whose textbook "Quantum Theory" took great pains to explain its conceptual and philosophical foundations, was forced to flee the U.S. to Brazil during the

Communist purges. No updated editions of his textbook followed, a rather unusual history for an initially very popular textbook. Nearly all other textbooks on quantum mechanics emphasized its calculational properties, relegating subtle conceptual points to lie outside the domain of physics. Kaiser finds this rather unfortunate, since these very points are where several key questions in quantum theory remain unanswered. And this is what draws students to physics. Kaiser ends this discussion with an essay on Frithof Capra's "The Tao of Physics", a bestselling popular book on physics and Eastern philosophy, showing that the mystical elements of quantum theory are precisely what many people find so fascinating about it.

Matter is a collection of stories on the discovery of elementary particles with a focus on the Higgs particle. The Standard Model of elementary particles grew out of Murray Gell-Mann's idea from symmetry arguments that fundamental particles lie inside the neutrons and protons of the atomic nucleus. He gave them the name quarks. The quark model quickly became very successful at predicting the existence of other quark bound states. However, the theoretical model worked only if the quarks and all other particles in nature were massless. This quandary could be resolved, claimed several physicists, including the Scotsman Peter Higgs, if there existed a field permeating all of space which caused particles to become massive. Higgs also predicted that this field would have its own associated particle. Since the Standard Model successfully met every other test, the search for the Higgs particle became the driving force behind new experimental designs, including the Superconducting Super Collider project that was ultimately canceled in 1993. However, the Large Hadron Collider at CERN (the European Organization for Nuclear Research), located in Geneva, would be the project that successfully found the Higgs particle in 2012. Kaiser uses this as a bridge to his final set of essays on the Cosmos, since the Higgs field itself leads naturally to an idea that explains the weakness of gravity compared to other fundamental forces, and how one might understand the earliest moments of the cosmos.

Cosmos is an appropriate final set of essays for Kaiser's book, since the quantum ideas prove to have profound implications for the entire history of the universe. This is also the most colorful set of essays from Kaiser, since he includes discussions on the search for extraterrestrial life, gravitation and black holes, the Big Bang Theory and even creation and evolution. The chapter on "The Other Evolution Wars" is particularly interesting in its descriptions of the interactions between science and religious faith. While Kaiser points out that some cosmologists beginning with the Belgian priest Georges LeMaître found a satisfying fit between their growing scientific view of an evolving cosmos with their theology, the situation changed to an acrimonious one with the advent of the modern creation science movement. Kaiser discusses the resurgent biblical literalism that denies an older cosmos and the Big Bang Theory and then briefly mentions "intelligent design". Unfortunately, Kaiser seems to lump the critics together rather haphazardly. Concerning his internet perusal of critiques from creationist web sites, he writes:

> I found plenty of sites eager to sell the recent anti-big-bang books, along with DVDs such as "The Privileged Planet", proffering "evidence" of supernatural intelligent design. (pp. 248-249)

This statement implies he assumes the authors of "The Privileged Planet" are anti-big-bang, which they are not. The issues of purpose, design and intentionality are certainly at stake. It is noteworthy to me that the book by Peter Ward & Donald Brownlee (Rare Earth) and that by Guillermo Gonzales & Jay Richards (The Privileged Planet) are very similar in thrust, emphasizing aspects of planet Earth that appear rather unique in the cosmos, but because they diverge on the question of purpose, design and intentionality, one is considered mainstream science (Rare Earth) and the other creationist literature (The Privileged Planet). Although I personally do not promote apparent design in nature as an argument for supernatural design, I am saddened by all the harsh critiques, whether it is leveled against those who hold that science is in support of faith or whether it is leveled against good science in order to protect doctrinal positions. There doesn't need to be a combative relationship between scientists and Christians, but scientists like Kaiser are very aware of such.

Cosmos includes a chapter on the amazing developments in modern cosmology. Since I did a book review in 2017 of Roger Penrose's "Fashion, Faith and Fantasy in the New Physics of the Universe", I was happy to see a discussion of his Conformal Cyclical Cosmology. Theoretical physicists respect the contributions of Roger Penrose, given his and Stephen Hawking's contributions to our understanding of space-time from General Relativity. But the elegant ideas offered by Penrose in his CCC appear to not withstand the exacting toll of precision data in modern cosmology, and we await further ideas that will.

The book wraps up with some recent noteworthy events: the discovery of gravitational waves in 2015 and the death of Stephen Hawking in 2018. While the former heralded in a new age in modern multi-messenger astronomy, the latter has brought us to the end of an era in which one of the most brilliant minds took on the challenge of understanding the universe, overcoming incredible odds and challenges. Again, the experience of personal struggles of one person did not prevent great accomplishments in scientific thought, and in fact may have contributed to it. Quantum Legacies ends with a positive note. Overall, despite the sometimes awkward collection of essays, the book is an enriching read.