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Nonlinear Physics of Ecosystems

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The allure of the aesthetic

A Beautiful Question
Finding Nature's Deep Design

Frank Wilczek
Penguin Press, 2015. $29.95
(430 pp.). ISBN 978-1-59420-526-2

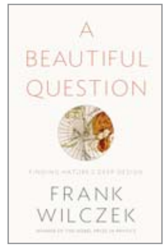
Reviewed by Sabine Hossenfelder

My four-year-old daughter recently discovered that equilateral triangles combine to form larger equilateral triangles. When I caught a distracted glimpse of her artwork, I thought she had drawn the baryon decuplet, an often-used diagram to depict relations between some of the particles composed of three quarks.

The baryon decuplet doesn't come easy to humans, but the beauty of symmetry does. And how amazing it is that physicists have found symmetry tightly woven into the fabric of nature itself: Both the standard model of particle physics and general relativity, currently our most fundamental theories, are in essence mathematically precise implementations of symmetry requirements.

Next to being instrumental for the accurate description of nature, symmetries are also universally appealing to humans, as reflected in art and design across cultures. For the physicist, it is second nature to see the equations behind the art. Indeed, having that ability may be considered either a curse or a blessing.

To Frank Wilczek, it clearly is a blessing. In *A Beautiful Question: Finding Nature's Deep Design* he highlights the success of symmetries in physics and goes on to answer the question of whether "the world embodies beautiful ideas" with an emphatic "Yes." Wilczek starts from the discovery of basic mathematical relationships like Pythagoras's theorem (and doesn't shy away from proving it!) and proceeds through the history of physics, stopping to consider such milestone topics as musical harmonies, the nature of light and the basics of optics, Newtonian gravity and



its extension to general relativity, quantum mechanics, and ultimately the standard model of particle physics. He touches briefly on condensed-matter physics—graphene in particular—and takes an interesting detour into the human eye's limited ability to decode visual information.

In the last chapters of the book, Wilczek goes into quite some detail about the particle content of the standard model and how, it seems, the model is not as beautiful as one may have hoped. He introduces the reader to extended theories such as grand unification and also supersymmetry, which was invented to remedy some of the supposed shortcomings of the standard model. The reader unfamiliar with the quantum numbers used to classify elementary particles will likely find some parts of that section a bit demanding.

But whether or not one makes the effort to follow the details, Wilczek gets his message across clearly: Striving for beauty in natural law has been a useful guide, and he expects it to remain one. He is, however, careful to note that relying on beauty has, on various occasions, led to plainly wrong theories, such as an explanation of planetary orbits in terms of Platonic solids or a theory of atoms based on the mathematics of knots.

A Beautiful Question is a skillfully written reflection, or "meditation," as Wilczek puts it. It is well structured and accompanied by many figures, including two inserts with color prints. The book also contains an extensive glossary, recommendations for further reading, and a timeline of discoveries mentioned in the text.

The content of the book is unique in the genre of popular works. Dave Goldberg's *The Universe in the Rearview Mirror: How Hidden Symmetries Shape Reality* (Dutton, 2013), for example, also discusses the role of symmetries in fundamental physics, but Wilczek gives more space to the connection between aesthetics in art and science. *A Beautiful Question* picks up and expands on the theme of Steven Weinberg's book, *Dreams of a Final Theory* (Pantheon, 1992), which also expounds on the relevance of beauty in the development of physical theories. More than 20 years have passed since Weinberg wrote his book, but the dream is still as elusive today as it was back then.

For all its elaboration on the beauty of symmetry, Wilczek's book falls short of spelling out a conundrum physicists face today: We have no reason to be confident that the laws of nature yet to be discovered will conform to the human sense of beauty. Nor does Wilczek spend many words on aspects of beauty beyond symmetry; he only briefly touches on fractals, and never goes into the rich appeal of chaos and complexity.

My mother used to say that "symmetry is the art of the dumb," a criticism perhaps too harsh to level at the standard model. But seeing that reliance on beauty has not helped us in the past two decades, maybe it is time to consider that a beautiful answer might not reveal itself as effortlessly as does the appeal of plane tilings to a four-year-old. Maybe the inevitable subjectivity in our sense of aesthetic appeal will turn out to be a curse, misleading us as to where the answers lie.

Wilczek's book contains something for every reader, from the physicist who wants to learn how a Nobel Prize winner thinks of the connection between ideas and reality to the layman who wants to know more about the structure of fundamental laws. *A Beautiful Question* reminds us of the many ways that science connects to the arts, and it invites us to marvel at the success our species has had in unraveling the mysteries of nature.

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Nonlinear Physics of Ecosystems

Ehud Meron
CRC Press, 2015. $89.95 (344 pp.).
ISBN 978-1-4398-2631-7

Many concepts and methods from nonlinear physics have proved to be useful for addressing important problems in ecology. Indeed, a growing number of physicists are working with ecologists and are making significant contributions to ecology. Pattern formation and spatial ecology—how those patterns are related to ecological phenomena—are particular research areas that benefit from the interdisciplinary interactions. For example, field observations of vegetation patterns in arid and semiarid regions have revealed patterns similar to ones found in fluid dynamics and nonlinear optics.

Any book that attempts to bridge ecology and nonlinear physics would be welcomed by scientists who work at the intersection of both fields. In my own work, I have collaborated with ecologists to develop quantitative methods and models to address biodiversity dynamics and spatiotemporal early warning signals of catastrophic shifts in ecosystems. I have also taught courses for mixed audiences of agronomists, ecologists, and physicists.

I was greatly impressed by the variety of topics covered in Ehud Meron's *Nonlinear Physics of Ecosystems* and by the depth in which they are discussed. The author's introduction to each topic is clear, and the book's overall organization makes it easily readable. At the beginning of each chapter is an outline of the major points treated, and at the end, a summary of the key ideas that were developed. The bibliography is extensive and comprehensive. I found few omissions. The most significant one would be James Murray's classic text *Mathematical Biology II: Spatial Models and Biomedical Applications* (Springer, 2003), which, although it does not focus on spatial ecology, has substantial overlap with this book. *Nonlinear Physics of Ecosystems* also contains many figures and photos that help readers to visualize spatial patterns in real ecosystems. All that makes Meron's book an important reference, particularly for researchers of spatial self-organization and spatial ecology.

The book is divided into three parts. The first begins with a quite standard presentation of the basics of self-organization in nonequilibrium systems. It then offers a qualitative review of spatial ecology and presents outstanding problems such as desertification and biodiversity loss. The concluding chapter for that section raises important and broadly relevant questions about ecosystem modeling: Why model? How should a model be set up? What is the significance of qualitative information? Such questions should be considered by anyone who conducts scientific research and uses models.

The second part is devoted to pattern formation theory, which, according to Meron, is a missing link in ecological research. In fact, the book's main purpose is to fill that gap; in essence, part two is the book's nucleus. The author presents basic and advanced methods related to the main types of pattern formation mechanisms. Among the plethora of structures are stripe and hexagonal patterns, scale-free patterns, and spiral waves.

The third part considers different applications of pattern formation theory to spatial ecology. The author explains the significance of self-organized vegetation patchiness to paramount ecological problems presented in the first part, including desertification and biodiversity loss in changing environments. I enjoyed reading the two final chapters—11 and 12—which cover topics I have been working on, namely, regime shifts, desertification, and species coexistence and diversity in plant communities. Particularly well done were the discussions on different early warning signals of regime shifts and their spatial aspects. I enjoyed the explanation of species coexistence induced by plants that act as ecosystem engineers by modifying their physical environment and in certain circumstances facilitating the growth of other species.

Nonlinear Physics of Ecosystems surely will contribute to the development of a newly emerging interdisciplinary research field at the interface of ecology and pattern formation. I would recommend it to graduate students who want to conduct research in mathematical ecology or physics applied to spatial-ecology problems. A minor caveat: I wish the book had included exercises to help students reinforce and test their understanding; maybe it will in the next edition.

Nonetheless, it could be used either as a main or supporting textbook in a one-semester course for advanced undergraduate or graduate students in physics or ecology or in a course with a mixed audience of students from both disciplines. I also warmly recommend the book for nonlinear physicists, applied mathematicians, and theoretical ecologists working on those cutting-edge environmental interdisciplinary problems.

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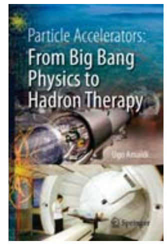
Particle Accelerators
From Big Bang Physics to Hadron Therapy

Ugo Amaldi
Springer, 2015. $34.99 (284 pp.).
ISBN 978-3-319-08869-3

Particle Accelerators: From Big Bang Physics to Hadron Therapy takes us on a fascinating odyssey of accelerator history and applications. Author and prominent CERN scientist Ugo Amaldi's principal aim is to highlight and praise the role of the machine builders. In doing so, he borrows a comparison made by particle theorist Victor Weisskopf, CERN director general from 1961 to 1965. Weisskopf likens accelerator builders to the creators and captains of the ships that brought Christopher Columbus and his crew to the Americas; experimentalists to those who set foot on the new lands and described them; and, somewhat self-mockingly, theorists to those who stayed behind in Europe and made the prediction that Columbus would arrive at India. Amaldi's book also confirms the view that developments in science are driven by the achievements of many people across many generations, and that we are indeed standing on the shoulders of giants.



The first version of *Particle Accelerators* was published in 2012 and written in Italian. In 2013 it won a science communication award from the Italian Book Association. Following that success, the author considerably expanded his text, adding many useful details. In its present form, the book contains many recollections of CERN; it would definitely warm the heart of anyone who worked and lived in that wonderful scientific mecca.

Particle Accelerators, which is aimed at the general public, is filled with intriguing analogies, metaphors, and humor. For example, the author describes the uncertainty principle as the process of taking a "loan of energy" from the "Heisenberg bank," with the unusual twist that the greater the loan amount, the earlier it matures. He compares the Bevatron at Lawrence Berkeley National Laboratory to a 10 000-ton "cracker of invisible nuts" and electron–positron annihilation to the disappearance of two colliding strawberries giving rise to a flood of bananas or apples. And he suggests what he considers a compact and more meaningful nomenclature for the three neutrinos: neutrino for the electron neutrino, neutretto for the muon neutrino, and neutrotto (or fatter neutrino) for the tau neutrino.

After telling the story of the early accelerator builders, the book goes on to particle physics, the field that has most benefited from the technology. Topics covered include the standard model and its extensions; dark matter; dark energy; supersymmetry; and string theory, which the author believes provides the most likely explanation for symmetry breaking. If a subsequent edition is written, I hope it includes brief and simple descriptions of the many phenomena and methods that are mentioned but never explained—for example, synchrotron radiation and the supernova standard candles that led to the idea of an accelerating universe.

Medical applications are featured in the book's concluding section, which describes in popular terms the basics of x-ray and particle imaging and tumor treatment. Readers will learn about many technical details and enjoy some intriguing stories along the way. For instance, the first—and for a long time, the only—interest in an early article outlining computerized tomography came from a Swiss center for avalanche research, which wanted to use the technology to find objects—like lost skiers—trapped in snow.

Amaldi captures the romantic spirit of the early days of particle physics experiments. He also touches on the cooperation and competition between the continents. Surprisingly, at least at the time this edition was published, all bosons since 1948 had been discovered in Europe and all fermions in America—a peculiar sort of symmetry breaking.

The author also occasionally makes what some readers may consider as frank and provocative remarks. For example, he states that the Large Electron–Positron Collider could have discovered the Higgs more than a decade ago had he and his colleagues convinced the CERN directorate to invest substantially in upgrading the superconducting RF cavities. Amaldi also laments that Bruno Touschek and Gersh Budker were not rewarded with the Nobel Prize for their role in the development of electron–positron colliders; he suggests that had the scientists been working in the US—where the main action was—they would have received the honor. In any case, such comments are nicely balanced by wonderful stories of cooperation, such as between Brookhaven National Laboratory and CERN during the building of the CERN Proton Synchrotron.

Particle Accelerators culminates with an inspiring story of the development and creation of the Italian National Center for Oncological Hadron Therapy, a great achievement for Amaldi, who put an enormous amount of effort and energy into its creation. He is now working to develop a novel linac for proton therapy. These initiatives prove the author's own maxim that "physics is beautiful and useful."

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Gravity
Newtonian, Post-Newtonian, Relativistic

Eric Poisson and Clifford M. Will
Cambridge U. Press, 2014. $80.00
(780 pp.). ISBN 978-1-107-03286-6

Gravity: Newtonian, Post-Newtonian, Relativistic is not the usual relativity text. But it's the one you need if you actually want to calculate something astrophysical without a supercomputer. I know of no other text that compares with this compendium of tricks for calculating observables in the large fraction of the universe that is not near an event horizon.