

BOOK REVIEWS

Reaching Farther in Physics

Cosmic Strings and Other Topological Defects. A. VILENKIN and E. P. S. SHELLARD. Cambridge University Press, New York, 1995. xx, 517 pp., illus. \$100 or £60. Cambridge Monographs on Mathematical Physics.

One of the most exciting twists of 20th-century science has been the merging of the study of the very large and the very small—the unification of particle physics and cosmology. Particle physics addresses the structure of matter at the shortest accessible distances (or, equivalently, at the highest possible energies). Cosmology concerns the structure and the evolution of the whole universe. Particle physics has had great success over the past 30 years. A “standard model” is now firmly in place that can account for all of the available experimental evidence. But the standard model is not a final theory; it leaves unanswered too many fundamental questions. Only by pressing on to study physics at still shorter distances and higher energies can these mysteries be resolved. Cosmology has had comparable success. Here too a “standard model” is in place that gives a reasonable account of the available observations. But again the standard model leaves unanswered too many questions, especially about “initial” conditions in the universe. Only by pressing on to study the universe at still earlier times can these mysteries be resolved. But at earlier times the universe was hotter, and we can extend the study of the universe to the very earliest times only by considering the behavior of matter at the very highest energies. Thus the study of the elementary particle meets the study of the universe.

The essential thrust of this unification is twofold. In particle physics, the most energetic current accelerator experiments can resolve the structure of matter at a distance scale of 10^{-16} cm. But particle theorists boldly speculate about the properties of the fundamental interactions down to distance scales of 10^{-33} cm. We crave experimental evidence to constrain these speculations, but no accelerator in the foreseeable future will be sufficiently energetic to provide it. Instead, particle physicists look to the early universe as their accelerator. The universe was once so hot as to evidence the behavior of

matter at exceedingly short distances, and we can hope to detect relics of that fiery past in today’s universe.

Conversely, ideas from particle physics can illuminate the central questions of cosmology: Where did the matter of the universe come from? Why is the universe so large, so nearly isotropic, and so nearly homogeneous? What explains the origin of galaxies, of clusters of galaxies, of superclusters? What is the nature of the “dark matter” that dominates the halos of spiral galaxies? Particle physics has offered a wealth of appealing answers to these questions. The trouble is that there are too many answers; they cannot all be right.

A central theme of modern cosmology is the study of “large scale structure”—the way the galaxies are distributed in the universe. The very early universe was much more homogeneous than the present universe. But small inhomogeneities in the matter density were present even then and, owing to their gravitational attraction, grew, eventually condensing into the galaxies and other structures we see today. The most fundamental question about the formation of galaxies is: What was the origin of these initial perturbations? Recent measurements of the microwave radiation left over from the big bang allow us to estimate their size. The typical variation of the density about its mean value was only about one part in 10^5 , and it is the task of fundamental theory to explain why this variation was so small.

Two major competing models for the origin of the density perturbations have been proposed. In the “inflationary” model, the perturbations arose from quantum fluctuations and can be understood as a consequence of the Heisenberg uncertainty principle. These quantum fluctuations are almost certainly present at some level, but so far theorists have not offered any unambiguous prediction of their magnitude. (The “natural” assumption seems to be that the fluctuations would be of order 1, and we don’t understand why they should be so small as 10^{-5} .) The second model of the origin of large-scale structure is the “cosmic string” model, and it provides the motivation and central focus for Vilenkin and Shellard’s *Cosmic Strings and Other Topological Defects*. In this picture, the perturbations arose from a network of

linear defects that were created during a phase transition that took place during the first 10^{-37} after the big bang. Vilenkin is one of the originators of this scenario, and Shellard has been a leading contributor to its development. Their book is a remarkably complete and authoritative review of the broad range of physics issues underlying it.

Cosmic strings are closely analogous to the vortex lines that are seen in laboratory experiments with type-II superconductors, but with two important differences: the cosmic strings are defects in the vacuum rather than in a bulk state of matter, and their diameter is only of order 10^{-30} cm. Correspondingly, the strings are enormously heavy—with a mass per unit length of order 10^{22} g/cm or, in units better suited to astrophysics, about 10^{10} solar masses per kiloparsec. These numbers are obtained under the assumption that cosmic strings are indeed responsible for the primordial density perturbations, by fitting to the cosmic microwave observations.

The chain of ideas connecting cosmic strings with the large-scale structure of the universe is intricate, and Vilenkin and Shellard are compelled to cover a lot of terrain in this treatise. They discuss, for example, the classification of topological defects, the theory of phase transitions and of defect formation in a quench how strings move and what happens when they collide, the gravitational effects of strings and the gravitational radiation they emit, and, of course, the effect of strings on the microwave background and on the formation of structure.

Indeed, the physics of the cosmic string scenario is so complicated that even after 15 years of intensive study, it is difficult to extract precise predictions that can be compared with the observations of the astronomers. Even the qualitative picture of how the scenario works has evolved substantially, especially as a result of improved numerical simulations. Vilenkin’s original idea was that each galaxy was seeded by a closed loop of string, but the simulations showed that the loops that branch off of the string network are smaller than originally assumed, and this proposal became untenable. Another idea was that gravitational focusing behind a moving open string would cause matter to accrete onto a sheet in the string’s wake, enhancing the abundance of galaxies on the sheet. But the simulations showed that the open strings wiggle much more than originally expected, and that picture also had to be modified. Current comparisons of the scenario with observation are still inconclusive, but the situation is bound to be clarified as both the simulations and the observations improve. Actually, what

surprised me most about this book is that so little is said about the confrontation of the scenario with the data. I suppose the authors were worried that any detailed discussion would rapidly become obsolete.

The proposal that cosmic strings guided the formation of the large-scale structure of the universe is boldly speculative, and, like most speculative ideas, it is likely to be wrong. But there are several potential observations that could provide persuasive evidence in support of the scenario within the next decade—strings could be detected either through their influence on the microwave background anisotropy or as a result of their gravitational lensing properties. Such a discovery would be extraordinarily exciting for both particle physicists and cosmologists: for the particle physicist, the universe would provide us with a glimpse of short-distance physics well beyond the standard model; for the cosmologist, the structure of matter at 10^{-30} cm would explain the structure of the cosmos.

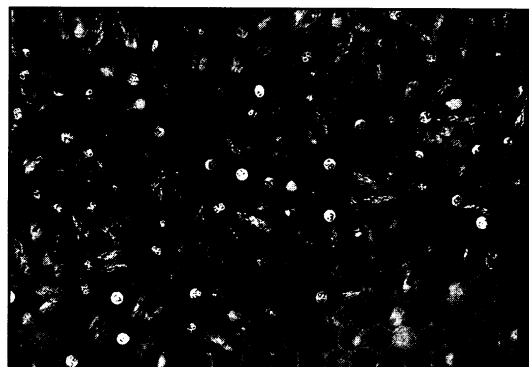
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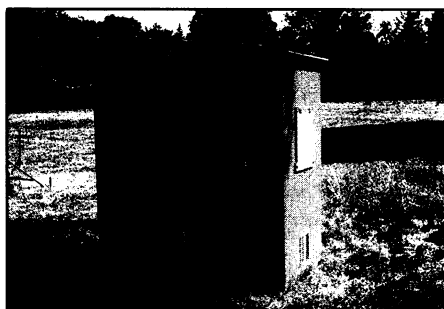
Bee Work

The Wisdom of the Hive. The Social Physiology of Honey Bee Colonies. THOMAS D. SEELEY. Harvard University Press, Cambridge, MA, 1996. xiv, 295 pp., illus., + plates. \$49.95 or £31.50.

This book addresses the deceptively simple question of how worker honey bees acquire information and organize their work. It records its author's 15-year re-



Members of a colony of bees that have been individually labeled for identification. The labeling system used "makes possible the discrimination of 4000 individuals, which is a convenient population size for colonies used in experimental studies." [From the dust jacket of *The Wisdom of the Hive*]



Observation hive in portable hut. Bees enter the hive, which is suspended from a metal bar, through a tunnel leading from the window in the far wall of the hut. The hut's roof is constructed of translucent fiber glass, and shuttered windows can provide additional light. Fresh air enters through louvers at the base of the hut, and the hut's roof can be tilted open to provide further ventilation. The hut is bolted together and hence can easily be dismantled for transport. [From *The Wisdom of the Hive*]

search odyssey to determine how honey bees use the dance language, interactions between workers, and information about colony conditions to meet immediate and long-term colony needs. This work begins where the pioneering dance language and communication research of Karl von Frisch, Martin Lindauer, and their students left off. Seeley goes well beyond the dance language to explore how bees acquire and integrate information about conditions inside the colony and the location and quality of resources in the field. He discusses how worker bees make decisions about foraging and food storage tasks, as well as how comb construction is regulated. These are marvelous stories of adaptation, made vibrant by comparisons with other levels of biological organization such as individual cells, multicellular organisms, and other animal societies, with reference also made to economic theory and ergonomics.

Seeley's main point is that individual bees can perceive only a small amount of the total information available in a colony, yet the hive's "wisdom" lies in worker bees following simple rules to determine and accomplish work priorities. For example, a colony can increase its nectar-collecting rate when returning foragers perform waggle dances to recruit nonforagers to begin foraging. When the nectar supply in

the field diminishes, decreased dancing shuts off the system. Similarly, more bees are recruited to receive and store nectar when returning foragers perform a different dance, the tremble dance. This dance occurs when the returning foragers have to conduct overly long searches before encountering nectar-receiving bees in the hive. As Seeley puts it, "Waggle dances and tremble dances play complementary roles in keeping a colony's rates of nectar collecting and processing well matched, for the former enables a colony to boost its collecting rate while the latter enables it to boost its processing rate."

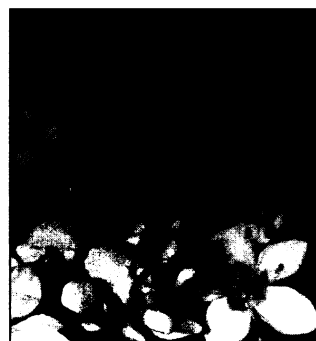
In physical design and chapter organization *The Wisdom of the Hive* is structured to recall von Frisch's *The Dance Language and Orientation of Bees*, also published, in its first English edition (1967), by Harvard University Press. This approach was risky, since it invites comparison with the earlier book, but the quality of Seeley's writing and the significance of his findings justify the analogy. His book is a worthy successor to von Frisch's classic and a landmark synopsis of how social insect colonies integrate complex information.

Seeley's writing is clear and eloquent, but this is not a light, coffee-table book, and concentration is required to follow the experimental detail he presents. Nevertheless, the dedicated reader will be rewarded with a rich and flowing portrait of a scientist at work as well as with a remarkable account of what a worker bee does and how she knows when, where, and how often to do it.

Another pleasing aspect of the book is that it shows that good science does not require expensive, high-technology equipment: a simple sugar-water feeder, a glass-walled bee hive in a hut, a set of artist's paints, and a camel's hair brush can still tease out wonders of nature. Seeley's book reminds us that probing questions, rigorous experimental design, careful observations, long hours of data collection, and keen intuitive insights still have a place in today's fast-paced, tool-driven scientific world. It is especially fitting that he has used the honey bee, a paradigm of hard work and cooperation, to remind us of how rewarding scientific endeavor can be.

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"A worker honey bee foraging on buckwheat flowers. Note the proboscis, which is unfolded to probe for nectar, and the load of pollen packed on the outer surface of the hind leg." [From *The Wisdom of the Hive*]