BOOKS: ASTRONOMY

Time, Space, and Us

William G. Unruh

What is now proved was once only imagin'd.
–William Blake

In the early years of the 20th century, Ernest Rutherford, the great experimental physicist at Cambridge, was reputed to have thundered, "If anyone in my laboratory begins to speak of the Universe, I tell him it is time to leave." Since its beginnings, cosmology, the study of the universe as a whole, has been characterized by a mixture of seemingly outrageous speculation and subsequent verification. Einstein founded his 1915 theory of gravity on one unexplained experimental fact—that all objects fall in exactly the same way in a gravitational field—and a demand for consistency with his theory of special relativity. Through an unparalleled intellectual tour de force, he created a theory in which the flow of time from place to place and the creation and destruction of space depend on matter. Shortly thereafter, the Russian physicist Alexandr Friedman and the Belgian priest Georges Lemaître each pointed out that this theory implied that the universe is dynamic and had a beginning. Einstein found this conclusion sufficiently repugnant to try to change his theory. Only a few years later, Edwin Hubble showed that faint smudges of light in the telescope were distant galaxies whose distance from us increases faster the further they are from us, just as had been predicted. Space really does grow, and time has a beginning.

The second half of the 20th century saw a dazzling increase in the ability of astronomers to make observations of the remotest reaches of the universe. The new technologies were manifold. Radio communications gave us radio astronomy and the detection of the cosmic background radiation from the earliest days of the universe. Consumer electronics provided the charge-coupled device camera, which enabled the imaging of galaxies hundreds of times dimmer than the night sky itself. High-precision spectroscopy allowed the detection of the small changes in the motion of distant stars (a few meters per second) due to planets orbiting those stars. Cosmology has thus changed from a field dominated by speculation and unconstrained theoretical extrapolation to an observational science. Now cosmological theories can die because of disagreement with observation and not just due to the death of their proponents.

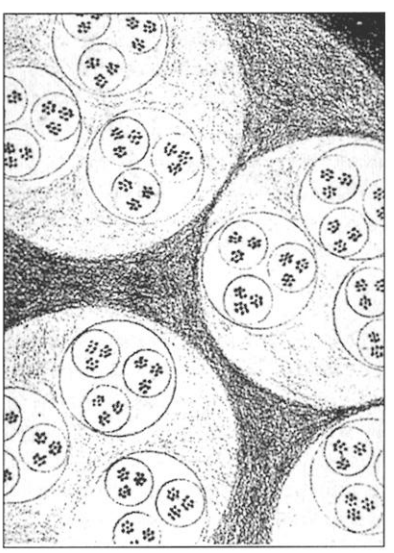
Our Cosmic Habitat
by Martin Rees
Princeton University Press, Princeton, NJ, 2001. 223 pp. $22.50. ISBN 0-691-08926-4. Weidenfeld and Nicolson, London, 2002. £14.99. ISBN 0-297-82901-7.

Humans are physical and, as such, must live in a universe which is consistent with that physical existence. How stringent are the conditions required of the universe in order that we could exist? Had gravity been slightly stronger or weaker with respect to the other forces, the resultant nature and lifetime of the stars would have precluded our existence. Had the nuclear force been slightly different, no elements heavier than carbon would have been created and no planets like Earth would exist. Had the cosmological constant (misleadingly called dark energy or false vacuum energy) been much larger, galaxies would not have been able to form.

This link between the cosmos, the subatomic scale, and human existence is the main theme of *Our Cosmic Habitat* by Martin Rees, the Astronomer Royal of Great Britain and former director of the Institute for Astronomy at Cambridge. This nontechnical account, an expansion of the Lippincott Lectures Rees presented at Princeton at the end of the millennium, has an informal style and breadth of coverage that make it a joy to read.

Rees begins by describing the discovery of planets in orbit about stars other than the sun and discussing the conditions needed for life to have formed on some of those. As Rees emphasizes, it is at the human scale where our science is most inexact. At the largest scale (the universe as a whole) and the smallest (the subatomic realm), the world appears to be simple; at these extremes it seems most easily described and understood. But in between, at the scale of planets and the life they might carry, our theories are at their most impotent and the current state of the world is most contingent on historical accident and complex, unanalyzable interactions. He shows that stars are simpler. Through their dependence on the interplay between gravitational and nuclear interactions, they illustrate the close dependence of the macroscopic on simple features of the microscopic worlds. On larger scales, gravity instability dominates, at least after the first few months of the universe's lifetime. The first part of the book closes with a digression on black holes and the possibility (very remote) of time machines as consequences of Einstein's theory of gravity.

The balance between observation and speculation begins to tilt in the book's second part. Here Rees's excursion first visits the very early universe, where fossils like the light element abundances and the fluctuations in the cosmic microwave background give clues to the nature of that early universe. The author uses theoretical extrapolations and hopes to trawl for a description of the very birth of the universe. Turning his attention to the other end of time, he shows how observations of early supernovae suggest that the universe will "end...in ice" (in Robert Frost's words), with the universe expanding and cooling forever at an increasing rate.



Too rough for cosmology. Rees notes that cosmology would not be tractable in a fractal-like universe of clusters within clusters ad infinitum, such as Carl Charlier envisaged early in the 20th century.

CREDIT: RICHARD SWORD/FROM *OUR COSMIC HABITAT*

Rees ends his tour with speculations as to why the universe seems to be so closely adapted to human existence. If, as our hubris would suggest, any life would have to share many of our physical features, why is the universe so well adapted to life? Although his argument (that current attempts to answer this question are real science) is unconvincing, his display of the possibilities not ruled out by theory or observation is still fascinating.

As is usual in accounts written for nonscientists, the book has its small share of infelicities. For example, the nuclear model for the atom was established by 1913, not 1930. To an outside observer, an astronaut

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approaching a black hole would rapidly vanish and would not, as Rees states, appear to be frozen at a horizon. And using "cycles/cm" as units for frequency is unusual in a book for laics. But such examples are rare and minor. And in almost all cases, Rees's explanations are exactly right—as in his emphasis that the expansion of the universe is due to the creation of space, not due to a primeval explosion.

So would Rutherford show Rees out the door of his laboratory? Perhaps, but I suspect that he would be astonished to see that much of what he had regarded as arrant, unproductive speculation has now been proved. He might also wonder whether some of the current speculations, which form part of the fascination of *Our Cosmic Habitat*, will share that same fate.

BOOKS: BIOMECHANICS

Marvelous Machines Made of Meat

Sharon Swartz

Few scholars have had so profound an impact on a contemporary biological discipline as Steven Vogel has had on biomechanics, particularly that of the basic, organismal variety rather than the applied, biomedical one. Most of my "biomechanician" colleagues have at one time or another worked with or been taught by Vogel, one of his students, or a student of one of his students. I suspect that all of the remaining few have read or, more accurately, studied his work. Happily for us academic practitioners, his influence has spread beyond the narrow confines of university departments through his writings for scientifically curious general audiences. Who could ask for a better ambassador than Vogel? Few among us can explain the often slightly mysterious physical phenomena so central to the biological world with such clarity and exuberance, and fewer yet leave us chuckling as we go.

Prime Mover
A Natural History of Muscle
by Steven Vogel
Norton, New York, 2002. 384 pp. $25.95, C$37.99, £19.95. ISBN 0-393-02126-2.

Prime Mover: A Natural History of Muscle is Vogel's newest compendium of biological phenomena packaged for both the diversity of biologists and the far greater diversity of other thoughtful people with at least passing interest in the natural world. Vogel offers to "take a piece of our biological nature, the 'flesh' of our 'flesh and blood' and explore how it works and how we work with it." In the course of this exploration, he manages to educate, enlighten, and entertain. The book begins with a whirlwind tour of muscle mechanics and physiology at a variety of levels—molecular, cellular, organ, and organismal. We are treated to splendidly lucid explanations and discussions of a wide range of topics relevant to understanding muscle. Vogel covers efficiency, thermodynamics, solid mechanics of the materials of muscle and the tissues attached to it (bone, tendon), contractile mechanics, and much more. His signature flair and wit run throughout the text: "No muscle can make ends meet"; "negative work is more negatively efficient than positive work is positively efficient"; "ecology orders, physiology delivers."

But *Prime Mover* is far more than an account of muscle physiology. Vogel argues that human history, culture, and technology can be interpreted from a perspective anchored in the biology of this one peculiar tissue, making his more general point that "biology, physiology, biomechanics...matter in context far beyond their immediate scientific domains." He reminds us that until a few decades ago the work of the world was done by muscle, the engine of zoology for roughly a billion years. Next, he illustrates the remarkable diversity of muscle function in creatures as diverse as flies, clams, and whales, in organs from tongues to timbals. Then we go much farther afield, into the worlds of the history and design of hand tools, the origin and development of human exploitation of animal muscle power, muscle-powered weaponry, and even (to the delight of those among us who would rather cook than fight) muscle as meat. Before *Prime Mover* concludes, we have been treated to explanations of the muscular basis of cursive handwriting, why people of different body sizes should use tools of different sizes, and a bioengineering view of why men rather than women should be the default openers of doors. Along the way, Vogel seamlessly draws history, industrial engineering, and fine art into his discussions. And, in case we are inclined to follow a path to which we've been newly introduced, he points us toward an astonishing variety of references, both printed and electronic.

The book also manages to vividly portray the scientists who have helped unravel the puzzles of muscle biology. We are given a veritable phylogeny of physiologists as Vogel traces the scientific and personal relationships among investigators as well as their classic experimental work. We meet the key architects of our modern understanding of muscle not only as names associated with achievements and awards, but as real people who learned from the natural world and from each other. This, surely, is the paradigm of scientific conduct we should communicate to our students and to the general public. It is also fascinating reading.

My gripes are few and small. This and Vogel's other works clearly demonstrate that he understands and interprets the world through the lenses of language and mathematics. Accordingly, here, as in his earlier books, the quality of the illustrations simply does not match his prose, and some figures are more confusing than enlightening. In places, Vogel explains biological processes by reference to background that he assumes to be much more familiar, such as the workings of automobile engines or phonographic cartridges. This approach is sometimes difficult for those who cartoonist Gary Larsen once designated "the mechanically disinclined." In fairness, however, Vogel's writing offers abundant opportunity for physics and engineering insight to even the least mechanically minded reader. I also miss one of Vogel's distinctive scholarly niceties; the reference sections of some of his earlier books include indications of the pages where particular works are cited in the text, which permit readers browsing the references to re-enter the relevant discussions.

Striated skeletal muscle.

CREDIT: QUEST/PHOTO RESEARCH

Many of us who teach undergraduates perpetually seek ways to go beyond imparting specific scientific knowledge; we believe that scientific inquiry shapes our understanding of our complex present-day world, helps guide our interpretations of human history, and inspires our visions of the future. Vogel's latest success informs and delights, and in the process, exemplifies this approach. He tells us, "Writing the predecessor of this book hooked me on the seductive pleasure of moving out of my scientific box." *Prime Mover* demonstrates how very lucky we are that he has been so seduced.

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