vanced students in the expanding and important field of statistical physics.

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## What Remains To Be Discovered: Mapping the Secrets of the Universe, the Origins of Life, and the Future of the Human Race

John Maddox
*Free Press, New York, 1998. 434 pp. $26.00 hc*
*ISBN 0-684-82292-X*

Although John Horgan's book *The End of Science* (Helix Books, 1996) is nowhere mentioned in John Maddox's *What Remains To Be Discovered*, the latter is clearly a reply to Horgan's contention that the most important scientific discoveries are behind us. Maddox summarizes many of the questions that will keep researchers busy for decades or centuries to come, and he is surely correct in saying that "the record of the past shows that novel conundrums are forever treading on the heels of those that still perplex." Maddox's book is engagingly written and clearly organized. But there are serious problems with it.

Maddox is amazingly opinionated about the directions in each field that are most and least ready for progress—a confidence in his own judgment that perhaps comes from his more than two decades as editor of *Nature*. The three parts of his book are titled Matter, Life, and Our World (the chapters of the third part are titled Thinking Machines, Mathematics, and The Avoidance of Calamity), but in this brief review I will concentrate on its discussion of physical science. I disagree with many of his predictions regarding the future of physics and astronomy. Among them:

▷ Einstein's hunch that a black hole is metaphysical (and thus intolerable) will be proved correct.

▷ By extension, the idea that the universe began in a single event, the big bang, will be found false. . . .

▷ [H]alf a century from now, cosmologists will have a much better idea of what kind of universe they are expected to explain. The once-and-for-all universe of Genesis, or of [Alan] Guth's [cosmic inflation] equivalent, is an improbable outcome.

I question whether Maddox understands enough about these subjects to render a thoughtful opinion. Consider, for example, his description of the Big Bang:

"What was the universe like at the very beginning? It was simply a tiny bubble of space-time packed with energy. . . . But energy is equivalent to mass, which means that space-time in the nascent universe would have been tightly curved, following Einstein's theory of gravitation. . . . The result is that, one microsecond after the big bang, the observable universe would have been just 300 meters in radius . . .but would have been embedded in a much larger structure, the parts of the larger universe that are permanently beyond our ken."

Every single statement cited here is wrong, or at best misleading: The energy of relativistic particles is not gravitationally equivalent to mass. Spacetime was not curved in the early universe but perfectly (or at least nearly) flat. At one microsecond, the radius of the presently observable universe was not 300 m, the distance light covers in a microsecond, but a hundred billion times larger. The mismatch between these two scales is known as the "horizon problem" in cosmology: Since the distance light could have covered in the early universe is so small, even after taking into account the expansion of the universe, how could different regions have come to the same temperature to within about a part in $10^5$? The only answer that has yet been found is cosmic inflation, which also solves other problems concerning the initial conditions.

To be sure, Horgan's scientific understanding appears to be no deeper than Maddox's. For example, his book says that, "Astronomers may find that the cosmic microwave background stems not from the flash of the big bang, but from some more mundane source, such as dust in our own Milky Way. . . . We humans may never see directly into the dust-obscured heart of our own galaxy, let alone into any other galaxy, but we may learn enough to raise doubts about the black hole hypothesis."

That the cosmic microwave background originates inside the Milky Way has been rather convincingly ruled out, while increasing evidence is being found for black holes. Infrared light penetrates interstellar dust, and recent infrared observations of stars orbiting very close to the center of the Milky Way have not only confirmed that a black hole is lurking there but also given a fairly precise value for its mass.

Let us hope that scientists do not leave entirely to journalists and editors the debate over the future of science!

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## Galactic Astronomy

James Binney and Michael Merrifield
*Princeton U. P., Princeton, N.J., 1998. 796 pp. $99.50 hc ($35.00 pb)*
*ISBN 0-691-00402-1 hc (0-691-02565-7 pb)*

James Binney and Michael Merrifield's *Galactic Astronomy* is one of the most important astronomy books of this decade. Within its nearly 800 pages it details almost every aspect of the nature and content of galaxies. Every astronomer will want to have it on his or her bookshelf as a reference work. As a textbook, however, it has severe shortcomings: many students will find it difficult and frustrating, and many instructors will find it unsatisfactory.

This is not a revision of a book of the same name by Dimitri Mihalas and Binney (W. H. Freeman, 1981); the authors describe it rather as a "replacement." What they mean by this is that they have drastically changed the point of view, aiming at the study of galaxies in general and touching on the Milky Way only as our local example. To support this aim, they have created an invaluable compendium of much of astronomy, not only detailing the facts about galaxies and the effort to understand them but also delving into related topics, such as nuclear astrophysics, radio-astronomy observations, and the physics of interstellar material.

It is this very wealth of factual detail that may render this book disappointing to teachers and students; the reader is presented with fact upon fact, but is not given the logical framework on which to hang them, a framework that would allow the facts to be remembered easily as parts of a coherent picture. Such a framework indeed exists in the form of our understanding of stellar structure, stellar evolution, and stellar populations. But these topics are not introduced until chapter 5; the properties of stars and the morphology of galaxies—introduced earlier—would have been so much more easily absorbed if the reader were first given the milieu in which so much about these topics is understood.

In a parallel way, the components of the Milky Way—disk, bulge, and halo—are held back until the tenth of the book's 11 chapters, thus passing by the possibility of interpreting corresponding components in other galaxies, rather than just cataloguing them and describing them. Strangely, interstellar material is discussed in earlier chapters, thus dividing the stellar inhabitants of chapter 10 from the material with which they share their lives. Furthermore, the dark matter that far exceeds the total mass of the stars and totally dominates their motions is dealt with, separately, hundreds of pages earlier.

Although the book begins with a brief historical overview, it does not convey the flavor of historical development of its topics. Seminal papers are often overlooked in favor of references to more recent papers that merely give more extensive data sets. And more flavor is lost when the actual diagrams from the astronomical literature are not reproduced; instead, new diagrams have been adapted from the originals.

After the introductory chapter, the authors take up observational quantities, stellar properties, galaxy morphology, and then, at last, stellar evolution and populations. They devote a chapter to star clusters and another to the cosmic distance scale. Interstellar material is then discussed in detail, with excellent discussions of the observations and their interpretation. Other galaxies are taken up first, and then the interstellar material of the Milky Way. The final chapters describe the components of the Milky Way and internal motions in other galaxies. Four appendices take up gravitational lensing, catalogs, Richardson–Lucy deconvolution, and a list of useful numbers. All references are collected at the end, and the book is well indexed. Factual errors are few, but this first printing has numerous typos and other copyediting oversights.

As would be expected in a book that covers as many topics as this one does, there are many cross-references. Unfortunately, these lack page numbers; in one case it took me several minutes to find a numbered equation in an earlier chapter that has 113 pages and 57 equations.

This review has dwelt on the imperfections of the book, while its virtues were quickly stated. To set a proper perspective, however, I wish to close by saying that this is a comprehensive and valuable book that nearly every astronomer will want to own and use.

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## The Deep Hot Biosphere

Thomas Gold
*Copernicus (Springer-Verlag), New York, 1999. 235 pp. $27.00 hc ISBN 0-387-98546-8*

Three hundred sixty million years ago, near what is today the city of Rättvik in central Sweden, the collision of a large meteorite with the Earth generated a huge pile of granitic rubble and built a crater 44 km in diameter. Not only were the beautiful lakes of the Siljan Ring thus formed, but the rough terrain at this site created an unprecedented opportunity for Cornell University astronomer Thomas Gold: a laboratory in the field awaited his unique insight. Gold's great enthusiasm induced the Swedish parliament, Chicago's Gas Research Institute, and other donors to support the drilling—between 1986 and 1990—of a skinny but very deep hole in Rättvik's crystalline bedrock.

In *The Deep Hot Biosphere*, Gold details the reasons for instigating the expensive dig. He believes that a source of hydrogen equal to the mass of a small planet, plus methane and other reduced carbon compounds, including a diverse supply of hydrocarbons, abounds in the bowels of Earth. He claims that these powerful gaseous chemicals react to generate earthquake-size forces; that they concentrate heavy metals such as copper, zinc, lead, silver, and gold; and, astoundingly, that the reduced carbon compounds, entirely independent of life, account for coal deposits! This primordial carbon chemistry, he insists, even now supports a chemolithotrophic, nonphotosynthetic biosphere that equals or exceeds in size our familiar light-driven biosphere here at Earth's surface. In short, Gold combines the theory of a deep-Earth biosphere with that of a deep-Earth gas repository. To test his double-barreled concept, four branches radiate from the hole, which has a 6.7 km maximum depth. The theory, the drilling exercise, and other possible tests of its validity, and the theory's possible repercussions, form the core of the book's narrative. Gold's imaginative and potentially lucrative deep-Earth concept upset such traditionally-isolated scientists as, at least, astronomers, geologists, geophysicists, paleobotanists, and biogeochemists.

Although a water-based drilling fluid was used to produce the shaft, Gold insists that it could not possibly have contaminated the hole with oil or reduced carbon gases. Gold tells us that "good measurements of hydrogen, helium, methane and other hydrocarbon gases up to pentane ($C_5H_{12}$)" were indeed made at the drill site (page 111). The volumes of these gases increased as a function of depth, he says, and an oil-based sludge was recovered, replete with magnetite, of which the particle size was in the micron range. The observation of a 250-times excess of iridium relative to magnetite (page 117) implies a primordial source.

A downhole pump was installed in the first hole in April 1990. (Earlier samples had been taken from drilling-generated fluids and sludge.) The result was a resounding success: Some 24 000 pounds of what looked "like ordinary crude oil" and 30 000 pounds of fine-grained magnetite came with the pumped extract (page 121). All the extremely high values of organics, samples of which were taken at 5-foot intervals, were recovered from places where the drill hole crossed volcanic intrusive rock (dolerite), presumably generated as magma at great depth.

The book champions two of Gold's fundamental, intrinsically connected, and, to many, shocking ideas. His first, that of deep gas, was so strongly supported by the studies in Sweden, Gold states, that the data "confirmed the abiogenic theory of petroleum formation and supported my view that enormous quantities of hydrocarbons were still streaming up from a primordial source in the deep crust and upper mantle" (page 112). By "primordial," I think Gold means that these hydrocarbons were generated at depth early in Earth's history and have never interacted with the surface in any way. The deep-Earth gas theory posits huge quantities of hydrocarbons, both gas and liquid, at depth. This organic matter, unrelated to photosynthate at the surface, is inferred to have supplied the origin and early evolution of life with sustenance.

This gas is the basis for Gold's second contention: that an unknown realm of life, his "deep, hot biosphere," existed and still exists. Deep because the strange life forms may thrive 10 km or more below Earth's surface, and hot because, as a result of the natural thermal gradient of Earth, temperatures in that realm can exceed 100 °C.

As Freeman Dyson says in his foreword, "Gold's wrong ideas are insignificant compared with his far more important right ideas." Among his array of revolutionary and correct ideas, Gold numbers (1) pulsars as neutron stars, (2) a theory of hearing that involves inner-ear resonance, and (3) a 90° flip of the axis of Earth's rotation! Dyson's belief, "based on fifty years of observation of Gold as a friend and colleague, that the deep hot biosphere is . . . original, important, controversial—and right" (p. xi) inspires confidence. Like Gold, Dyson is a member of the National Academy of Sciences, and his statements tend to be firmly grounded and trustworthy. For readers, the implications are clear: Gold's claims must be debated, evaluated, tested, and understood rather than rejected out of hand. If correct, his grand scheme will fundamentally alter the depth of our relationship to prodigious Mother Earth.

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