thermore, 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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