The Physics of Black Holes

Black Holes. The Membrane Paradigm. KIP S. THORNE, RICHARD H. PRICE, and DOUGLAS A. MACDONALD, Eds. Yale University Press, New Haven, CT, 1986. xiv, 367 pp., illus. $40; paper, $14.95.

Until now, essentially all books devoted to the subject of black holes have been either popularizations or sophisticated treatises dealing mainly with their mathematical structure. *Black Holes: The Membrane Paradigm* is undoubtedly the first major volume to treat black holes from the point of view of "applied physics." Its main aim is to provide a practical formalism for describing phenomena around black holes that can be used by non-experts in general relativity. It proceeds by recasting the equations describing these phenomena—such as the structure of electromagnetic fields produced by plasmas around a black hole or the evolution of a black hole perturbed by an external tidal gravitational field—in a form closely resembling the equations describing similar phenomena in ordinary three-dimensional space. A key step in this procedure is to endow the horizon of the black hole with attributes such as surface charge, electrical conductivity, and temperature. (Actually, for reasons having to do with the fact that the authors use spatial surfaces that intersect the horizon at the bifurcation two-sphere [where the "time translation" isometries vanish], they choose to work with a timelike surface displaced slightly outward from the horizon—the so-called "stretched horizon.") In this manner, the black hole horizon is treated as though it were an ordinary physical surface. This accounts for the subtitle of the book, "The Membrane Paradigm."

The book is actually a collection of eight separate chapters by different authors. Nevertheless, it has the unity and coherence of a singly authored volume. Undoubtedly, this is at least partly explained by the fact that Thorne is not only an editor of the volume but a coauthor of every chapter. Numerous interesting model problems are worked out throughout the book, and the discussion is uniformly clear, with many well-labeled diagrams and figures. There is, however, little discussion of purely theoretical issues such as why the membrane paradigm exists, that is, why it should be possible to rewrite equations so that the horizon can be treated as an ordinary surface.

As already indicated above, the main intended readership of the book is astrophysicists and other physicists who are not expert in general relativity. However, unless such a non-expert reader wishes only to obtain some "cookbook" prescriptions for solving certain problems, it is necessary that his or her knowledge of general relativity be at least equivalent to what would be obtained from an introductory graduate course at the level of the Misner, Thorne, and Wheeler textbook *Gravitation*. Indeed, that book is cited frequently throughout *Black Holes* for explanations of such things as the sources of the various equations, and the non-expert reader undoubtedly would need to keep a copy of it handy in order to follow the discussion.

I believe that the book is quite successful in its treatment of electrodynamic phenomena around black holes in the first four chapters. The membrane paradigm formalism is sufficiently similar to standard electrodynamics that all readers should be able to gain understanding and intuition about these processes. In particular, the Blandford-Znajek process for extracting rotational energy from a black hole surrounded by a magnetized plasma is well explained in this formalism. The experts in general relativity will also learn much from these chapters.

Although the next four chapters, on gravitational interactions involving black holes, are as well written as the preceding four, I believe the book is considerably less successful here. This is largely because the intuition of the non-expert reader will be much poorer for these phenomena. In addition, much more detailed and technical results are employed in the analysis; the references for explanations or derivations of equations no longer are to *Gravitation* but now are mainly to the current research literature. Thus, in particular, I find it difficult to picture a non-expert reader making it through chapter 6 unscathed. On the other hand, the expert readers probably would want to make their own favorite gauge choices and probably would be more comfortable thinking about null geodesics than the behavior of a (fictitious) "fiducion fluid." Nevertheless, these chapters will at the very least serve as a useful guide to the literature for non-expert readers who are trying to become experts, and the solutions to the numerous model problems will provide a useful reference for the expert readers.

The final chapter of the book concerns black hole thermodynamics, specifically the thermal properties of the region around the black hole (its "atmosphere") as measured by stationary (as opposed to freely falling) observers. The entropy contributed by layers of this "atmosphere" is calculated and used to justify the validity of the generalized second law of thermodynamics and the idea that the entropy of a black hole corresponds to the logarithm of the number of its possible "internal states." Both experts and non-experts should find the points of view introduced in this chapter to be of interest.

In summary, non-experts in general relativity should find this book a very useful guide to analyzing astrophysical phenomena around black holes, although they may not have an easy time with some of the later chapters. The experts will find it a valuable reference, mainly on account of the numerous model problems that are analyzed. Undoubtedly, both will wish to own copies of the book.

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Group Selection Reiterated

Evolution through Group Selection. V. C. WYNNE-EDWARDS. Blackwell Scientific, Palo Alto, CA, 1986. xii, 386 pp., illus. $58; paper, $29.

Group selection may be thought of as a change in gene frequencies within a population resulting from the differential reproductive success of local subgroups of that population. The concept becomes controversial when it is postulated to cause the evolution of traits, such as sacrifice of personal reproduction, that are unfavorable in terms of individual selection. Although he was not the first to propose that group selection has shaped the social world of animals, Wynne-Edwards triggered two decades of substantive debate about the topic with his 1962 book, *Animal Dispersion in Relation to Social Behaviour*. No sooner did he make group selection an everyday expression in biology than it was denounced by a host of biologists as impossible and unnecessary as an explanation of social (or other) adaptations. The concept has undergone a steady renaissance over the past decade, having once "rivaled Lamarckianism as the most thoroughly repudiated idea in evolutionary theory" (D. S. Wilson, *Ann. Rev. Ecol. Syst.* **14**, 159 [1983]).

Wynne-Edwards's early, vigorous exposition on group selection caused evolutionary biologists to broaden and sharpen their reasoning about mechanisms of natural selection. Unfortunately, the present work is not likely to produce similar results. The author

remains stoutly convinced that virtually all of animal behavior stems from the necessity for populations to regulate their own numbers in order to avoid overexploitation of the food resources. This theme underlies all 20 chapters of the book, and it is essentially unchanged since 1962. The book opens with six chapters on animal nutrition, then proceeds through seven interesting chapters summarizing the social biology of the red grouse (*Lagopus lagopus scoticus*). This game bird of the heather moors of Great Britain is used explicitly as a paradigm for the entire animal world. For this reason, readers who intend to study carefully the author's reasoning about group selection should examine chapters 7 through 13 in detail. Chapters 14 through 20 generalize the red grouse example into a broad discussion of animal population structure and the author's perspective on the mechanisms and implications of group selection.

Although the author includes discussions of Wright's shifting-balance theory of genetic population structure, Wade's laboratory experiments on *Tribolium* beetles, and D. S. Wilson's group selection models, he provides no new theoretical insight into how these results relate to the natural biological world of animal social systems. Evolutionary theorists have shown that group selection depends upon the combination of limited dispersal among populations with small effective sizes and high among-population variance in average reproductive success. Yet Wynne-Edwards musters little quantitative evidence that in nature these necessary ingredients indeed characterize the animals he describes. In short, he fails to demonstrate that in any widespread species locally adapted populations (his "in-groups") can serve as units of selection. Possibly, his difficulty in this respect reflects the fact that birds are among the most uniformly distributed and mobile of all animals, and therefore perhaps the least likely taxon in which group selection could be expected to operate.

As in 1962, the crux of Wynne-Edwards's hypothesis is that those in-groups whose members are genetically disposed toward good behavior (that is, regulating their numbers to match the food supply) produce a disproportionately large fraction of the total pool of offspring. These offspring in turn disperse to found new, equally cooperative in-groups. In contrast, groups consisting of "non-cooperatives," "self-seeking individualists," or "freeloaders" end up "ravaging their environment" and "strip[ping it] of renewable assets in ruthless pursuit of personal fitness" (p. 13). Colorful language of this sort makes for lively reading. The prose is excellent, but in the absence of rigorous theoretical underpinnings it often comes across as more amusing than persuasive.

Wynne-Edwards views population homeostasis as an adaptation that has arisen because of the common good it confers upon the group. The alternative interpretation is that it is a byproduct of individual strategies and constraints in survival and reproduction. In the red grouse, the well-documented relationship between population size and food supply is not at all inconsistent with the latter. Wynne-Edwards describes surviving individuals who are unmated as having "declined the opportunity to mate" (p. 161), but the idea that they have simply lost the competition for mates and resources is not even mentioned, much less repudiated. The failure to cast his discussion in terms of rigorously defined alternative explanations is the single greatest weakness of Wynne-Edwards's treatment of group selection.

Theorists and empiricists alike have rescued the concept of group selection from a premature death. Whether group selection has been of major evolutionary consequence in the real world is once again an open and fruitful biological question. Wynne-Edwards remains a strong voice in support of its importance, but as in 1962 his case appears overstated and lacks the theoretical footing to contribute substantial new understanding to the problem.

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Physiological Diversity

Adaptational Biology. Molecules to Organisms. C. LADD PROSSER. Wiley-Interscience, New York, 1986. xii, 784 pp., illus. $99.50; paper, $49.50.

Over his illustrious career C. Ladd Prosser has been instrumental in persuading comparative physiologists to adopt an evolutionary perspective. His book *Comparative Animal Physiology* (Saunders, 1973) documented functional differences between species and stimulated an entire generation of comparative scientists to seek explanations for these differences. In *Adaptational Biology* he provides a clear statement of his scientific philosophy and attempts to place the extensive database of comparative physiology into an evolutionary perspective.

The work can be divided into three major sections. The first examines adaptation in detail, identifying the sources of adaptive diversity through chapters on the origin of life and metabolic pathways, genetics, biological variations, and enzyme kinetics and protein structure. These chapters may be too detailed for many readers, but they provide a solid grounding in the bases of adaptational processes. The presentation makes it obvious that only an integration of disciplines will provide adequate answers to the important evolutionary questions at issue.

The second section examines the four environmental factors—oxygen, temperature, hydrostatic pressure, and water and ions—that have been exhaustively studied by comparative physiologists. The diverse adaptations shown by organisms are selectively documented. The theme dominating these chapters is that the genome limits the ability of the organism to adapt, and the reader is given an insight into the extent of change necessary to separate organisms from extreme environments (as evidenced for example by the difference in the number of sulfhydryl groups in the enzyme fructose diphosphoaldolase in an Antarctic fish and the domestic rabbit). The most fascinating chapter in this group is that on water and ions. The treatment of ion pumps and gradients is excellent and perceptive. The referencing in each chapter is extensive and up-to-date, and points where data are lacking are identified.

The final section deals with animal behavior, nervous systems, electrical transduction, and excitability of cells. The discussion throughout is informative and challenging, and the reader is introduced to subjects not usually found in general works in comparative physiology (for example, audioreception and vision). Even familiar subjects such as membrane potentials are handled in a new and fascinating manner. This section crystallizes the book's prevalent theme, that by examining a diversity of organisms it is possible to identify a tentative evolutionary progression for certain functions. Prosser cautions the reader that it is not possible to answer all questions and that without speculation many of the voids in our understanding cannot be filled, but the relationships developed are compelling in spite of these caveats.

Prosser has succeeded in a formidable task. He has both informed and challenged the reader, while describing functional diversity in evolutionary terms. Prosser states in the preface that this book is not a textbook. Instead, it is a book to be read by comparative biologists working at any level of organization who are interested in how organisms and environments evolve. It is the