Stanford University and Lockheed are developing Gravity Probe B, a satellite gyroscope experiment scheduled for launch in 1998 at an estimated total cost of at least $500 million. Its goal is to measure one parameter that characterizes the spin of a gravitational field predicted by general relativity. Some scientists consider that the result is already known; others doubt that the degree of accuracy required for the gyroscope to remain stable—a thousandfold better than has been achieved on the ground—can be attained in space; and still others note that even if Gravity Probe B were to find a discrepant result, the only sensible reaction would be to lobby for funds to refly an independent experiment. So complex is Gravity Probe B that only if the anomaly were confirmed would it be believed.

These tests of Einstein's theory are beautiful in concept. The reality is that in times of budget compromise and cuts, more tangible science is being sacrificed to test fundamental ideas that no one really disputes. Of course, finding a nearby wormhole would circumvent all of these concerns. One could bypass the budgetary pains of development and deployment and, with a single bound through time, go straight to the ultimate goal. *Black Holes and Time Warps* combines no-holds-barred propaganda for Einstein's dream with science writing at its lucid best. One does not have to concur with its precepts to enjoy a book that is definitely worth reading.

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Gravimetrists in Action

The Rise and Fall of the Fifth Force. Discovery, Pursuit, and Justification in Modern Physics. ALLAN FRANKLIN. American Institute of Physics, New York, 1993. viii, 141 pp., illus. $29.95 or £25.

"In the case of news, we should always wait for the sacrament of confirmation," declared Voltaire in 1760. Scientists cling to Voltaire's recommendation very tightly, especially when news arrives that heralds the possible breakdown of an established scientific paradigm. A well-known case in point was the widely publicized announcement in January 1986 of the possible discovery of a new force in nature that was slightly weaker than gravity, of an intermediate range, and dependent on the composition of the interacting masses. It was economically dubbed the "fifth force."

To the physics community, and to gravitational physicists in particular, this was a rather jolting event—so much so that in the years since then literally scores of individuals have felt compelled to investigate for themselves the theoretical and experimental foundations of the conjectured force. Enthusiasm both for and against its existence ran high during the first few years of study, but around 1990 the preponderance of evidence began to favor conventional physics. The fifth force, as originally conceived, was no longer a viable candidate as a new physical interaction, and most of the excitement originally associated with it gradually began to fade from the scene.

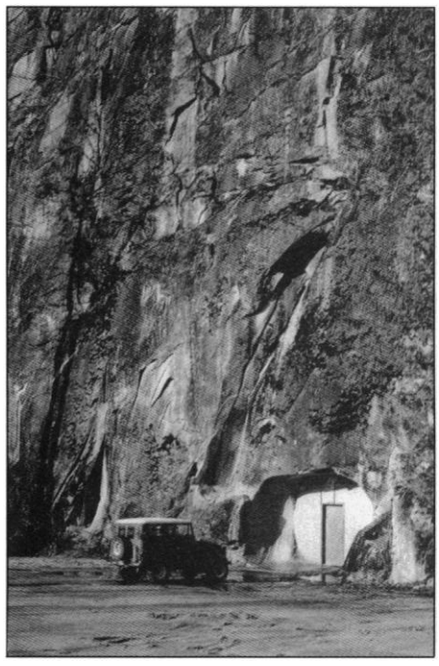
From at least two perspectives, however, this was not the end of the story. First, most of the data from the experimental side of the effort were generated by techniques originally introduced one or more centuries ago to study Newtonian gravitation. These techniques included gravimetry up and down mine shafts and towers, torsion pendulum observations of the attraction between test masses, and Galileo-type falling body experiments, among others. The sudden and intense interest in the fifth force caused a resurgence of interest in gravitational phenomenology, and especially in the development of advanced versions of each of these different types of measurement scheme. General relativity and gravitation as a whole have benefited greatly from this impetus. Apparatus and techniques capable of performing more precise tests of the weak equivalence principle have been introduced, and their use has placed very stringent limits on the parameters in the Yukawa form of violation of the inverse-square law of gravitation.

A second and more subtle point (but one that has not gone unnoticed) is that the case of the fifth force presents a well-documented vignette of physics as it is practiced today that is of great value to those who study the philosophy and history of science. Allan Franklin is one of those who saw things this way. With *The Rise and Fall of the Fifth Force* he has provided a most interesting look at this episode in modern science.

The book actually serves two distinct purposes. First, it is a thorough, well-referenced scientific review of the fifth-force saga. It delves deeply into the physical arguments that led Ephraim Fischbach and his colleagues to hypothesize the existence of the force and goes on to describe the evolution of their thinking as events unfolded. The story of the fifth force is very much that of the interplay of results from various experimental searches for it, and the author has taken great care to sort through the original conflicts that fueled much of the subsequent debate. The book is richly illustrated with graphical data and photographs of the experimental arrangements. All of this helps the reader follow the path taken by the research community in pursuit of the hypothesized force.

What makes this book unique, though, is the way it opens windows on the methods by which scientific inquiry proceeds by introducing the reader to historical analysis techniques. We are shown that there are many levels at which scientific evidence is evaluated and significantly different contexts within which decisions are made about whether confirmation of particular observations has occurred.

Another interesting feature of the book is its incorporation of selected records from several months' worth of electronic mail exchanged between the principal figures in the story. Not only does this provide insight into the day-to-day thinking that went into the research, it plays up the way in which "private communications" are now quite often exchanged by colleagues. In addition, the inclusion in the discussion section of a Bayesian analysis of the plausibility of the fifth force as proposed in its original form helps the reader see how one could arrive at probabilistic predictions of the force's chances of existing, given some quantitative information about the experimental evi-



"The entrance to the tunnel in the cliff near Index, Washington, the site of [Paul] Boynton's experiment." With this experiment, which used a torsion pendulum made of aluminum and beryllium, Boynton found a positive result for the presence of the fifth force. The experiment was conducted in the tunnel to maximize the effect of a composition-dependent force. [From *The Rise and Fall of the Fifth Force*; courtesy of Paul Boynton]

dence on which the conjecture was based.

Although the pages of *The Rise and Fall of the Fifth Force* contain interesting and useful lessons for all scientists, this is very much a book about physics written for physicists. Those at the postgraduate level will probably get the most out of it, but the extensive footnotes and thorough referencing make it accessible to those with less knowledge of the field.

Voltaire has provided us with sound advice that seems self-evident. Franklin has shown by specific example, however, that scientific confirmation is a phenomenon that is context-dependent and deserving of careful thought.

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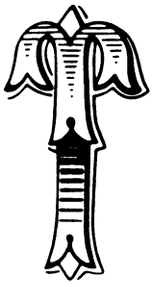
Southernmost Fauna

Antarctic Fish Biology. Evolution in a Unique Environment. JOSEPH T. EASTMAN. Illustrations and graphics by Danette Pratt. Photographs by William Winn. Academic Press, San Diego, CA, 1993. xiv, 322 pp., illus. $74.95 or £57.

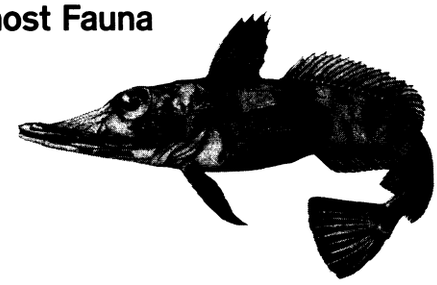
Antarctic Fish and Fisheries. KARL-HERMANN KOCK. Cambridge University Press, New York, 1992. xvi, 359 pp., illus. $110 or £60. Studies in Polar Research.

History and Atlas of the Fishes of the Antarctic Ocean. RICHARD GORDON MILLER. With contributions by Philip A. Hastings and Josette Gourley. Foresta Institute of Ocean and Mountain Studies, Tucson, AZ, 1993. xx, 792 pp., illus. $95; laminated cover, $78.



The Antarctic Ocean is a cold and difficult place. The water temperature is as low as −1.86°C even in summer; there is no intertidal ecosystem because ice covers and scours the shoreline and coastal waters to depths of 30 meters or more; the winter night lasts for months at the higher latitudes, just as the summer day does; and the narrow southernmost tip of the closest major landmass (South America) is about 1000 miles from the narrow northernmost tip of the Antarctic Peninsula. Yet for people who love fishes and the polar regions—there are some—studying antarctic ichthyology is a dream come true. These three comprehensive books take three quite different approaches to describing that dream, focusing to varying degrees on evolution, physiology, ecology, history, morphology, and fisheries.

Antarctica's marine fish fauna (there are no freshwater species, because there is no permanent liquid water on the continent) comprises approximately 275 species, 95 of which belong to the perciform suborder Notothenioidei. This one group of largely antarctic fishes has received a great deal of attention, for its species have a variety of unusual adaptations. Some of them have glycoprotein antifreezes in their blood, some have no hemoglobin, some have so small a temperature tolerance that they die at temperatures above 4°C, some are neutrally buoyant despite lacking swimbladders, and some live as deep as 2950 meters. The suborder has no known fossils, largely because no bony feature—indeed, no single character of any sort—can be used to define it. How did these animals arrive there, what are their ancestors, how do they make a living in such an environment, and can they support commercial harvests?

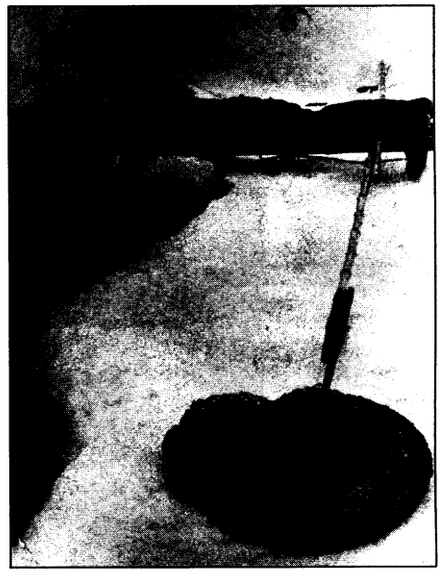


A representative notothenioid fish from Antarctic waters, *Chaenocephalus aceratus*. [From *Antarctic Fish Biology*]

Eastman's book—the most technically demanding of the three—focuses on the evolution and physiology of the notothenioids. It provides a thorough review of the geologic history of Antarctica, tracing its development from the time it finally broke away from the other tectonic elements of Gondwana about 25 million years ago. The icy climate probably had developed by that time, although there were milder periods; "the latest expansion of the ice sheet [probably] commenced 2.5 [million years ago] during a period of gradual marine and terrestrial cooling, and the present Antarctic climate is as severe as it has ever been." Antarctica's ocean is effectively separated from other world oceans by the circumpolar Antarctic Convergence, so it appears that a substantial part of the fish fauna became isolated there from relatives in warmer seas and underwent an adaptive radiation somewhat reminiscent of that of the cichlid fishes in Africa's Great Lakes. In this respect, Antarctica differs from the Arctic: the arctic fish fauna consists mainly of species found also in adjacent subarctic waters.

Having set the stage, Eastman describes the fish fauna, with an emphasis on the six families of notothenioids. Not an illustrated key, this section nonetheless provides some idea of the morphological diversity of these fishes: that diversity is not great, and the external morphology of most of the species would not cause surprise in a bottom-trawl off the U.S. west coast. The obvious exceptions are the enormous toothfish (*Dissostichus mawsoni*), which can reach nearly 2 meters and more than 70 kilograms; and the hemoglobinless icefishes (family Channichthydae), whose creamy-white gills, pale blood, and yellow muscles would surely draw attention anywhere. Eastman then discusses the group's evolutionary history, pointing out that "the radiation of whales, seals, and penguins, like that of fishes, is roughly coincident with the Miocene events producing [oceanic] features similar to those of the modern Southern Ocean." Despite this long period of isolation in the cold seas, notothenioid ancestry is still uncertain. Eastman's analyses and literature review of these topics are detailed and scholarly (despite his misspelling of "plesiomorphic"), and he grounds them in clear questions about how things came to be as they are today.

The second half of Eastman's book, focusing on what must be his first love, physiology, would be hard going without advanced study; examples include passages about "aglomerularism [being] apomorphic in notothenioids" and the "drag-based labriform swimming cycle of notothenioids." Indeed, much of the sec-



"Observer at 'Bergy Bit' fishing hole at tidal Cape Hallett, 1959. Antarctic ichthyologists use ladders horizontally." [From *History and Atlas of the Fishes of the Antarctic Ocean*]