General Relativity Since Einstein

General Relativity. An Einstein Centenary Survey. S. W. HAWKING and W. ISRAEL, Eds. Cambridge University Press, New York, 1979. xviii, 920 pp., illus. $74.50.

To celebrate the centenary of Albert Einstein Stephen Hawking and Werner Israel have gathered together 16 papers by leading authorities on general relativity. Their total impact is overwhelmingly powerful. Together they provide an outstanding modern account that covers all the important aspects: observational, mathematical, astrophysical, cosmological, and quantum mechanical. It shows very clearly that general relativity has come of age and is now part of the mainstream of science, rich in concepts and techniques and in consequences for the rest of physics and for astronomy.

The history behind this development is an interesting one. It took Einstein ten years of painful and essentially lonely effort to pass from special relativity to the general theory. Almost immediately thereafter some of the main consequences of the theory were established: the Schwarzschild solution, the three crucial tests, the cosmological models, gravitational waves. This was succeeded by a fallow period (which Einstein, sadly, did not outlive), resulting partly from the paucity of observations and partly from the rapid growth of quantum mechanics.

Then in the late '50's began the renaissance of general relativity. This was partly the consequence of a series of successful conferences, beginning with one held in Berne in 1955 to celebrate the 50th anniversary of the discovery of special relativity and continuing with the Chapel Hill conference of 1957 and the Texas conferences on relativistic astrophysics. But it was mainly the result of a series of spectacular discoveries in astronomy that were widely linked with cosmology and with general relativity: radio galaxies, quasars, x-ray sources, the 3°K background, and pulsars. In the '60's and '70's cosmology was transformed and black holes came into their own. Finally in 1974 Hawking discovered that quantum mechanical processes lead to thermal emission by black holes. This great discovery showed that there are deep, hitherto unsuspected, links between general relativity, quantum field theory, and thermodynamics. The discovery has led to a flood of new work on the connections between quantum field theory and general relativity and to renewed hope that a consistent quantum theory of gravity may be constructible.

The book itself begins with a survey by the editors that describes this history in detail. Then follows a discussion of the observational situation by C. M. Will based on the PPN (parametrized post-Newtonian) formalism. The paper is essentially complete up to 1977, but it is a testimony to the present rate of change of observations in gravitational physics that the possible evidence for damping of the orbit of the binary pulsar by the emission of gravitational radiation had to be inserted at the proof stage and that there was no opportunity for discussion of this potentially key result. For the same reason there is no mention of the newly discovered binary pulsar, of the two close quasars that may result from the action of a gravitational lens, or of the possibility that linear polarization of the x-rays from Cygnus X-1 may soon provide definite evidence of the presence of a black hole in this system and at the same time a strong field test of general relativity. In addition, neither in this paper nor in those on cosmology was there the opportunity to discuss recent work using grand unified theories to account for the baryon asymmetry of the universe, work that has at least two potential links with observation, namely the observed ratio of thermal photons to baryons in the universe ($\sim 10^9$) and the predicted half-life of the proton ($\sim 10^{32}$ years).

The next paper, by D. H. Douglass and V. B. Braginsky, should also be of wide interest to physicists and astronomers. It is an account of likely astronomical sources of gravitational radiation and of the basic principles underlying the design of the current generation of detectors. The pioneering work of J. Weber has certainly borne fruit; there are at least 14 experimental groups attempting to improve the sensitivity of detectors. I share the confidence of the authors that gravitational wave astronomy will one day be an observational science.

The style of the book changes abruptly at this point, becoming highly mathematical. There is a paper by A. E. Fischer and J. E. Marsden on the initial value problem, which is intended for specialists. Unfortunately it was written just too early to record the significant progress achieved by R. Schoen and S.-T. Yau, who have gone far toward proving the fundamental conjecture that a physically realistic system cannot evolve toward such a tightly bound gravitational state that its total energy becomes negative.

Another mathematical paper, by R. Geroch and G. T. Horowitz, is on the global structure of space-times. It makes a real attempt to convey modern topological studies in general relativity to the uninitiated. In view of the importance of these studies I would urge non-mathematicians to tackle the paper. I believe that they would find it difficult but rewarding.

Lovers of black holes will need no urging to study the chapters by B. Carter, S. Chandrasekhar, and R. D. Blandford and K. S. Thorne. Carter describes the general theory of the mechanical, electromagnetic, and thermodynamic properties of black holes, and Chandrasekhar gives a detailed account of the Kerr metric and its perturbations. By contrast Blandford and Thorne discuss the astrophysical aspects of black holes. These papers are written in the characteristic (and characteristically different) styles of their authors and together provide an excellent contemporary introduction to the subject.

We are still hardly more than halfway through the book, and now cosmology receives attention. First come two rather personal statements of point of view by leading cosmologists, one by R. H. Dicke and P. J. E. Peebles and the other by Ya. B. Zel'dovich. These are followed by a more objective and technical account of anisotropic and inhomogeneous cosmological models by M. A. H. MacCallum. A paper by R. Penrose on singularities and time asymmetry is another personal account. Penrose makes the intriguing proposal that one should impose on the initial singularity of the universe a time-asymmetric initial condition (namely the vanishing of the Weyl tensor) and that this is related to the second law of thermodynamics via the gravitational field's contribution to the total entropy density of the universe.

The last set of papers concern the relation between quantum field theory and general relativity. G. W. Gibbons describes the "halfway house" in which one attempts to construct a quantum field theory in a curved but classical background space-time. There are still some unsolved problems here, but Gibbons takes the discussion as far as it can be taken at the present time. The other

papers concern the full quantum theory of gravity. In fact a satisfactory theory of this kind does not yet exist, partly because when gravity is coupled to matter the usual quantization procedures lead to a nonrenormalizable theory. B. S. DeWitt reviews the present status of these problems, and Hawking and S. Weinberg offer accounts of their own proposals for solving them (Hawking using path integrals in a space-time with positive-definite metric, which he believes may be dominated by gravitational instantons, and Weinberg using renormalization group arguments in terms of which he proposes that the requirement of renormalizability may be adequately replaced by a weaker one of asymptotic safety).

The book is remarkably varied and the papers are of a consistently high quality and interest. Indeed, in their power and comprehensiveness they constitute a unique monument to the genius of Einstein, and, may I add, to the brilliant and profound work of the contemporary generation of relativists, many of whom are at once the creators of the present state of the subject and, in the pages of this marvelous book, its masterly expositors.

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Zooarcheology

Reindeer and Caribou Hunters. An Archaeological Study. ARTHUR E. SPIESS. Academic Press, New York, 1979. xiv, 314 pp., illus. $25. Studies in Archaeology.

No species evokes clearer images of windswept northern wastes than *Rangifer tarandus*, known popularly as the reindeer in Eurasia and as the caribou in North America. Over most of its arctic and subarctic range, this species is by far the most common large mammal and therefore a prime source of meat and skins for indigenous peoples. Anthropological interest in the relationship between these animals and people dependent on them is especially great because during Pleistocene glacial intervals the species extended its range far southward and was widely preyed upon by Paleolithic hunters in mid-latitude Eurasia.

Spiess has brought together a great deal of information on the distribution and ecology of recently observed reindeer/caribou and on the social organization and technology of the people who hunted and, in some cases in Eurasia, also herded them. He emphasizes that people exploiting these animals must be responsive to marked seasonal changes in the composition and distribution of the animals' social groupings. For archeologists, the seasonally changing age-sex composition of these groupings, combined with the fact that the great majority of the calves are born at more or less the same time (usually within a two-week period between mid-May and mid-June, depending on the place), means that the age-sex profile of the animals represented in a site can be used to establish the season when people were at the site, as well perhaps as the purpose for which (for meat or skins) and the methods by which people obtained the animals. These methods could range from selective stalking of individual animals to driving of whole groups into corrals or other traps.

Spiess shows that some previous attempts to determine the age and sex of archeological reindeer used methods of questionable accuracy or reliability, whereas the methods he employs have a high probability of providing meaningful results. To demonstrate the interpretative potential of caribou age-sex profiles from archeological bone assemblages, he uses his analyses of bones from various protohistoric North American sites to show that there is a reasonable fit between the human behavior inferred from the bones and behavior that could have been predicted from historic observations. He then undertakes the more ambitious task of drawing similar inferences from a Paleolithic reindeer sample, where of course no ethnohistoric check is possible. The Paleolithic sample was derived from layers dated between roughly 35,000 and 18,000 years ago ("early Upper Paleolithic") at the Abri Pataud in southwestern France, meticulously excavated over many years by Hallam L. Movius.

The most interesting and important inference that Spiess draws from his study of the Pataud materials is that people occupied the site between late fall and early spring. This appears to be true for the entire 17,000 years of occupation, although changes in artifacts indicate that the people who brought reindeer bones to the site at different times belonged to very different cultures.

Spiess's writing is very loose, and the presentation could have been substantially improved by greatly reducing the amount of detail about the recently observed hunters and replacing it with relevant background material on Paleolithic archeology and the place of the Abri Pataud in prehistory. Still, Spiess's work is a valuable contribution to archeology because it illustrates as clearly as any study to date the information about human behavior that can be obtained from careful determination of the ages and sexes of animals represented in ancient archeological sites. All that is necessary for this kind of study to burgeon now is the kind of thoughtful selection of sexing and aging methods exemplified in Spiess's work and the careful excavation of large bone samples, comparable in size and quality to the samples obtained by Movius at the Abri Pataud.

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Primate Behavior

The Great Apes. DAVID A. HAMBURG and ELIZABETH R. MCCOWN, Eds. Benjamin/Cummings, Menlo Park, Calif., 1979. xiv, 554 pp., illus. $18.95. Perspectives on Human Evolution, vol. 5; a publication of the Society for the Study of Human Evolution, Inc.

Long awaited and already widely cited, this volume consists of papers presented at a 1974 Burg Wartenstein conference, plus a few papers added later. The majority of the papers describe long-term, systematic field observations of gorillas, orangutans, and chimpanzees carried out under difficult conditions. Care was also taken to provide some representation of laboratory and theoretical perspectives, and there are several fine essays on communication and a detailed theoretical paper on aggressive competition in animals generally. No comparable body of reliable information about the natural history of great apes exists. Thus, the book suffers relatively little from its late publication, although an updated summary chapter would have been valuable.

The extraordinary biochemical similarities between humans and the terrestrial African apes (gorillas and chimpanzees) that have been investigated through DNA hybridization, protein sequencing, and immunological analysis will be well known to readers of *Science*. Less well known may be some of the recent findings that challenge old ideas about the behavioral differences that separate humans from other primates. This volume documents for other hominoids intercommunity killings, avoidance of inbreeding through female emigration (in two of the three great apes), face-to-face copulation and elaborate sexual foreplay (among wild orangutans;