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Festschrift on an Astronomical Scale for Stephen Hawking

The Future of Theoretical Physics and Cosmology: Celebrating Stephen Hawking's 60th Birthday. *G.W. Gibbons, E.P.S. Shellard, and S.J. Rankin, editors, Cambridge University Press, Cambridge, UK, 2003, 906 pages, $60.00.*

Two years ago Cambridge University celebrated Stephen Hawking's 60th birthday with a workshop and symposium on an astronomical scale. The galaxy of distinguished speakers . . . but let's let the numbers talk: lecturers, 42; lectures, 44; pages in the resulting festschrift, 879; weight, 5 pounds. The book is meant to lie open on a desk, with paper, pencil, and library nearby.

BOOK REVIEW

By David Park

The book's title suggests a predictability that isn't really there. As long as cosmologists and particle physicists can't identify or even find 95 percent of the matter and/or energy that the universe seems to contain, and physicists at the grade of the contributors to this book nibble around the edges of a logical structure called M-theory, which may or may not be reducible to any presently known mathematics, prediction would require clairvoyance. So readers should be thankful that the present (with a two-year offset) keeps creeping into this book, while the future, as usual, is postponed.

Experts will be able to go as deep as they like, but even those with only a "popular science" interest in recent developments in particle physics, astrophysics, and cosmology will find much to interest them. A useful introduction by Gary Gibbons and Paul Shellard situates Hawking's work in these fields, and Part I continues with five "popular" lectures on those subjects, along with autobiographic remarks by Hawking, who has made contributions to each.

Astronomer Royal Martin Rees (paper #2) sketches recent observations of the cosmic background radiation and some of the conclusions that have followed from those observations, with a parental boost for the idea that our universe may not be alone in the . . . well, never mind. Rees's word is "multiverse," and he deftly argues that it may not be crazy to talk of similarities and differences among the universes that compose it. James Hartle (#3) talks wisely about fundamental physical laws in a quantum-mechanical universe and concludes that in such a universe "a theory of everything is not (and cannot be) a theory of everything." Roger Penrose and Kip Thorne (##4 and 5) write about singularities and curvature of space–time, and Hawking (#6) contributes a few pages of scientific autobiography that are useful as historical background.

With the conclusion of Part I the symposium takes off its coat, loosens its tie, and starts to talk shop. From the reader's perspective, the rest of the book is a continuation of a conversation among Hawking and his friends that has been going on for years and is not easy to plug into. Instead of trying to say something encyclopedic about the remaining 38 papers, I have taken a single theme, Hawking radiation, and indicated how a few of the contributors hitch onto it.

Gibbons, Shellard, and Hawking (##l and 6) outline Hawking's scientific career. In the early 1960s it became clear, largely through the work of Hawking and Roger Penrose (#4), that a black hole, as seen from outside, is an extremely simple thing: spherically symmetric if nonrotating, axially symmetric if rotating, characterized by only three numbers: mass, angular momentum, and electric charge (if any). When something drops into a black hole and arrives inside a mathematically defined surface called the "event horizon," it disappears forever; if you drop in an encyclopedia, the information in it, factual plus thermodynamic, vanishes, and the entropy of the universe correspondingly decreases, apparently violating the second law of thermodynamics (Israel, #11). Otherwise, it might not seem that black holes have much to do with thermodynamics.

In 1970, however, Hawking and Demetrios Christodoulou independently proved that one can't do anything to a black hole that decreases the area of its event horizon—their example was to imagine dropping another black hole into it. Since irreversible processes like this always increase entropy, Jacob Bekenstein was led to propose that a black hole has an entropy related to the area of the event horizon. If a black hole has an entropy, it has a temperature and should therefore emit radiation; Hawking was soon able to show that it does so and that the entropy (in bits) is equal to 1/4 of the area of the black hole's event horizon measured in Planck units $G\hbar/c^3$ (G = gravitational constant, $\hbar$ = Planck's constant divided by $2/\pi$, c = speed of light). Because bits come in integers, the area is quantized; the unit is about 10^{-66}cm^2. A question follows: How could anything as simple as a black hole have a temperature and such an enormous entropy?

Enter superstrings and their later development as supermembranes in multidimensional space. What drew people to replace particles with strings in the first place was that the resulting theory not only accommodated Einstein's theory of gravity, it also required the existence of associated quanta known as "gravitons" (Witten, Gross, Green, and Townsend, ##25–28). Think of the intense gravitational field within an event horizon not in terms of a static gravitational field but as full of writhing superstrings. It can then have both temperature and entropy, and calculation from that point of view (Perry and Polchinsky, ##16 and 17) gives exactly Hawking's result. The calculation shows that in some sense superstrings in 10 or 11 dimensions are physically the same as a static gravitational field in 4.

How many dimensions are there really? What's "really"? If by any chance a superstring physics evolves that gives the same answers as quantum field theory, how are we ever going to know? The most important conclusion that comes from this work is that space and time are not foundation stones of physics, but concepts that emerge from even more fundamental machinery. The lack of an a priori geometric base on which to erect theoretical structures is only one reason for the difficulty of calculating anything in string theory.

Hawking's formula suggests something else: In ordinary thermodynamics the entropy of a system depends on what is going on inside it and is proportional to its volume; for black holes the entropy formula ignores the volume and looks only at the surface. How can you know what's going on inside a volume by looking at a surface? Well, there is a familiar situation in which you can—a hologram (Penrose, Giddings, Susskind, Warner, and Binetruy, ##10, 15, 19, 29, and 44). Here, people find themselves trying to explain what dimension means when changing the number that defines the strength of an interaction changes the number of dimensions (Gross, #26).

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What do these dimensions have to do with what our senses tell us? Four dimensions are enough for the electromagnetic field, which is, among other things, the vehicle that carries all our sensory inputs. Field-theoretical calculations of the properties of electrons and atoms succeed with fantastic accuracy, and there is no sign that more dimensions are needed. From the holographic perspective, these fields and particles inhabit a four-dimensional membrane ("brane" for short) in a wider world.

For gravitons the situation is different. They are required by string theory, but to understand them as electrons are understood would seem to require situating them in a world very different from the one we normally think we inhabit. One thing is clear: Experiments are essential. Gravitons are not yet open to experiment and will not be for some time, but within a few years (Thorne and Rees, ##5 and 12), detectors of gravitational waves may be bringing messages that originated very close to the beginning of everything. They will surely tell cosmologists things they do not now know, and they may also illuminate the world outside the brane we seem to live in.

This walk along a winding path has touched on several of the essays in the Hawking festschrift. It has led to questions much bigger than any answers that have been found, so this seems an appropriate place to stop. The essays have not much to say about future developments in theoretical physics or cosmology, but they show people looking for that future in directions that will surprise many who thought that the foundations of physics were secure. For a while, at least, it may be a mistake for anyone to dismiss branes and superstrings as fringe physics.

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