Microdictyon, are respectively spicules from organisms that look suspiciously like amphineuran molluscs (although he does not say so) and plates from the sides of onychophorans.

The strangest of the Cambrian wonders, *Hallucigenia*, turns out to be an onychophoran too, not immediately recognized because it was interpreted upside down. In his earlier book, *Wonderful Life*, Gould argued that the Cambrian fauna, with extraordinary creatures such as *Hallucigenia*, displayed a level of anatomical diversity unequalled thereafter, and that the persistence of modern phyla was a matter of historical 'contingency'. Now, he uses the relegation of *Hallucigenia* to a modern phylum in making a case for the same view. One cannot avoid discomfort with a theory that seamlessly accommodates so complete a reversal of fact. Elsewhere there are other weaknesses. He does not realize that duplicating a gene can be favoured by natural selection either through a need for more of its product or as an escape from heterozygous advantage. He falls into the common trap of supposing that only the neutral theory predicts a faster evolutionary rate for smaller changes of phenotype, whereas selective theories do so too.

Gould is very good at finding sense in the work of scientists whose ideas have now been abandoned and who are often ridiculed in textbooks. The pieces on William Paley and Archbishop James Ussher stand out, but he is palpably ill at ease trying to justify Goethe's amateurish theories about the structure of plants. There are also some fine essays on general subjects, including a heartfelt and perceptive celebration of authenticity. Having read the piece, and mentally applauded, I chanced to look more carefully at the dustjacket. Here, in the US edition, there is a picture of some snails and the caption: "These sixteen Partula snails from Moorea . . . have all become extinct in the last ten years". The shells illustrated are *Partula nodosa* from Tahiti. So much for authenticity. Another piece tells how Gould was dismayed to find that he had misremembered the place of treasured meetings with his grandfather. It is true and touching, but in an earlier collection of essays he accused Teilhard de Chardin of the Piltdown forgery because of a lapse no greater than his own. These peccadillos, however, are forgiveable in one who writes so well. Gould has given us a feast, and the reader should enjoy it, taking some of the arguments with a pinch of salt. After all, a little salt improves the savour. □

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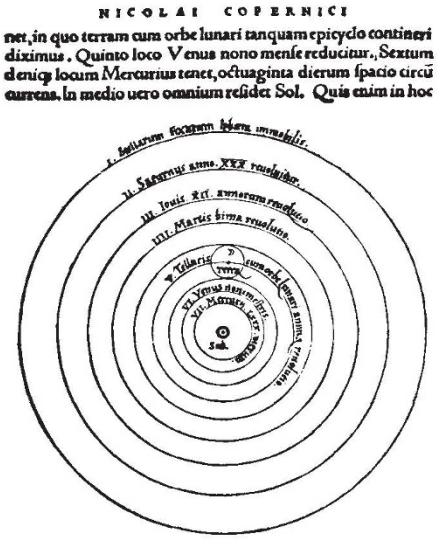
Heavenly works

Fred Hoyle

Nicholas Copernicus: Complete Works in Two Volumes*. *Johns Hopkins University Press: 1993. Pp. 452/373. Each volume $48, £30 (pbk).*
Johannes Kepler: New Astronomy†. *Cambridge University Press: 1992. Pp. 665. £85, $140.*

BOTH publishers are to be congratulated on making these works, which form the foundations of modern astronomy, available to English readers uneasy with mediaeval Latin. Those who venture


NICOLAI COPERNICI
net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum deniq; locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc

pulcherimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra inuentẽ omnia. ita profecto tanquam in solio regali Sol residens circumagentem gubernat Astrorum familiam. Tellus quoq; minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximã Luna cũ terra cognationẽ habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

The first printed representation of the Copernican system as it appears in *De revolutionibus* (1543). Picture taken from *Early Physics and Astronomy* (2nd edn) by O. Pedersen. CUP, £50, $75 (hbk), £19.95, $27.95 (pbk).

between the covers of any of the volumes will be surprised to find out how much more complicated the work looks than popular potted versions would have it. Compilers of the popular versions, I suspect, do not really understand what the original authors sought to explain. But seen as the pioneers had to see it, the situation was devilishly complicated, as much so as any of the puzzles of recent science.

Two versions of *On the Revolutions* exist, one made in Copernicus's last years by Rheticus, a visitor from Germany whose copy was used for the printed book set in Nürnberg in 1543; the other Copernicus's own autograph. Both versions were used to obtain what the translator, Edward Rosen, believes to be a superior rendering than either alone. Frankly, I would have preferred Copernicus's own manuscript, since it is not clear that the Rheticus copy ever had Copernicus's full approval.

It is scarcely possible to consider the constructions of Copernicus without comparing them with those of Ptolemy, who seems to me to have been dealt with more than harshly by scientific history. Copernicus discovered a geometrical construction for obtaining the motion of a planet, correct in the main to the first order in the eccentricity of its orbit, working in heliocentric coordinates. Then, to obtain a planet's position with respect to the Earth, in order to compare theory and observation, a subtraction had to be made, the planet's position minus the Earth's position. Ptolemy, on the other hand, discovered a construction that both gave the planet's position and made the subtraction with respect to the Earth, all in the same process. The outcome, so far as comparing theory and observation was concerned, was essentially the same. The science was the same. It was the inconsequential philosophy that people attached to the theory that was different.

Two small mistakes in the constructions of Copernicus provided the springboard for Kepler. In his construction for planets other than the Earth, Copernicus used a point related to the Earth when he should have used the Sun, a strangely non-copernican oversight. Kepler, when he had withstood the insults of Tycho Brahe and had eventually secured access to Brahe's observations, soon put the mistakes right, and might have rested content there. But discrepancies remained for Mars. Because the eccentricity of Mars is comparatively large, errors due to second-order terms were showing through in Brahe's data. How Kepler solved this problem is one of the great early stories of science, on a par with the "Eureka!" of Archimedes. Just what the solution was remains unexplained in Dreyer's classic *History of Astronomy*. Nor does it appear in Kaspar's biography of Kepler. And the avid reader will have a high old time digging it out of *New Astronomy*. Some hints may help.

Kepler's first move was to use an opposition of Mars (a situation when the terrestrial observer knows the heliocentric direction of Mars with respect to the distant stellar background) together with routine observations of Mars, to obtain the relative shape of the Earth's orbit to the highest possible accuracy. Then other oppositions of Mars, making use of

* *On the Revolutions* edited by J. Dobrzycki, translation and commentary by E. Rosen; *Minor Works* edited by P. Czartonyski, translation and commentary by E. Rosen with E. Hilfstein. † Translated by William H. Donahue.

the accurately known sidereal period of Mars, gave heliocentric directions and distances for a number of points on the martian orbit. And the last step, the one that commentators tend to feel more comfortable with, was to decide the nature of the curve determined by the points. The usual story is that Kepler found the curve to be an ellipse, to which the mention of 'perfect ellipse' in the title of Chapter 59 of *New Astronomy* gives credence. But with a proper measure of respect, this was an exaggeration. The martian orbit could be said to be an ellipse only to within the accuracy of Brahe's observations, and these were far from perfect.

Underlying every investigation by all the pioneers was the hypothesis that the planetary orbits (neglecting mutual interactions) were closed curves, requiring a unique relation between direction and distance as viewed by the Sun. It was just lucky that the pioneers did not have to cope with a world in which the post-newtonian relativistic approximation was important, when this hypothesis would have been untrue.

Quite possibly, Newton and Halley were aware of this point. Then one can readily understand the excitement over the orbits of comets of large eccentricity, which really did require the close perfection of the elliptic orbit. This matter of deep principle is surely the reason why comet Halley was so important to the newtonian world. For the perfect ellipse implied the inverse-square law of gravitation, and with that relationship firmly established, the march of science had become essentially unstoppable. It was in these books that it all began. □

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The shape of things to come

John L. Casti

Predicting the Future. Edited by Leo Howe and Alan Wain. *Cambridge University Press: 1993. Pp. 195. £18.95, $29.95.*

WITHOUT too great an exaggeration, I think it's fair to say that the *raison d'être* of intellectual endeavour in general — art, literature, religion, music and all the rest — is to offer convincing answers to the eternal question: "Why do we see what we do and not see something else?" And science is no exception, being distinguished only by the form of the answers the scientist provides. The scientific answers come wrapped up in a set of rules, usually encapsulated in the form of a mathematical model or, more common nowadays, a computer program. And the purpose of these rules? Basically, to do two things: to explain past observations and to predict the results of new ones. So prediction and explanation are the twin pillars upon which the scientific enterprise rests. But, as this book makes clear, prediction and explanation are not concerns of the scientist alone, but lie at the centre of all types of intellectual life ranging from astrophysics to the Holy Scriptures.

Predicting the Future arose out of a series of lectures on the topic of "Predictions" given at Darwin College, Cambridge, in 1991. But from a glance at the table of contents, the volume might have been better titled "Predictions, Prophecies and Futurology". The book opens well enough, with thoughtful and informative accounts of the long-term behaviour of the Universe by Stephen Hawking and the mysteries of chaotic dynamical processes by Ian Stewart. Both of these well-written essays are firmly centred in the scientific tradition of prediction by rule, showing that the rules we currently have at hand leave a lot to be desired when it comes to addressing the questions we most want to ask of nature.

Following a historical essay on the role of comets in prophecy through the ages by Simon Schaffer, the distinguished economist Frank Hahn offers probably the best account of the ins and outs of prediction in the book with his chapter on divining the mysteries of economic processes. Along the way to his almost foreordained conclusion that the predictive powers of economists are pretty feeble, Hahn brings out an important although often neglected aspect of prediction: namely, that not all predictions involve the future. He supports this claim with several convincing examples from the area of rational choice theory. Hahn ends with a general discussion of the possibility of effective predictions in the social sciences in general, a discussion that should sober up just about anyone infected with the germ of the idea that there's anything even remotely scientific about the social 'sciences'.

At this point, the book veers off the path of anything even faintly resembling prediction — scientific-style — flying off into the realms of futurology, historicism and prophecy. The first entry in this direction is an account of the possible future of medicine by Ian Kennedy. In pondering the medical frontier, Kennedy focuses on the bioethical dilemmas that the medical community is likely to face in coming years, including such things as the complex questions of care for an ageing population, how to handle developments in human genetics and the control of access to information about patients and their medical care.

The final three chapters abandon completely any pretence at prediction as that term is used in everyday speech, giving the floor over to religion, science's main competitor in the reality-generation game. Averil Cameron fires the opening salvo with his account of divine providence in late antiquity. This turns out to be a not very convincing attempt to show how late antiquity was characterized by a hierarchical Christian worldview that claimed to offer answers to a wide spectrum of human problems and was an infallible guide to predicting the future. The next chapter by Richard Gombrich on the role of prediction in the Buddhist scheme of things is a bit more satisfying, mostly because the author restricts his attention to a simple question: how open is the future from a Buddhist's perspective? Gombrich offers a threefold answer, in which the future can be both open and closed depending on whether or not an individual is one of the 'enlightened'. Lastly, there is the Last Judgement, the theme of the book's final chapter by Don Cupitt. In this strange chapter, the author traces the history of the almost universal belief that there is a moral providence in the world ensuring that we will eventually get exactly what we deserve.

So what is one to make of this potpourri? To begin with, it's difficult to think of any single individual short of a reincarnation of Leonardo da Vinci whose intellect could simultaneously encompass the wide variety of views espoused here on the nature and effectiveness of prediction. Most scientists will find the second half of the book distinctly odd, if not completely eccentric, in treating prediction as more of a kind of religious and/or historical experience than as the working out of a set of scientific rules, or a computer progam, to get at the why and the when of things. All in all, this seems to be a volume more for browsing than for line-by-line reading. While the editors are to be commended for bringing such a disparate collection of views together within a single volume, it remains a volume in which the whole is somehow less than the sum of the parts. □

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