

was unable to see it at the time. As he says, "most of one's time is spent in confusion, much in error, and a little with truth". This honest book is Chitty's sacrificial lamb.

The volume is dedicated to the late Helen Chitty, and is a valuable reminder of her significant contribution to the study of population cycles. Among other duties, she organized much of Elton's data by doing what Dennis Chitty calls "mail order zoology", including the Canadian Arctic Wildlife Enquiry and the Snowshoe Rabbit Enquiry, two important sources of information on spatio-temporal ecological variation.

There are, unfortunately, too many ugly, out-of-date 'facts' in the book that are not really synthesized into an integrated whole. The book could have done with further critical scrutiny and the use of an editor's red pen. Another problem is that it was written for three very different kinds of readers: those seeking what Chitty refers to as the ecological Holy Grail ("to understand the 10-year cycles in numbers of animals such as lemmings, voles, snowshoe hares, game birds and

defoliating insects"); scientists, whatever their speciality, who may be interested in the principles of scientific inference; and "anyone interested in mysteries, whether scientific or otherwise". Chitty is certainly aware of the difficulty of combining these three kinds of books into one: "in trying to kill two birds with one shot I here run the risk of merely wounding both". Perhaps he should have focused on just one type of reader: the scientist with an interest in the history of ecology and the development and discussion of his hypothesis.

The Chitty hypothesis may not be as beautiful as many long believed, and Chitty still does believe, but he has produced a very beautiful book. It is well written and full of interesting historical information. To give it colour there are quotations and references from a variety of sources, including the Bible and philosophy texts; indeed, seeing who he quotes is a fascinating exercise in itself. □

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## Full circle

H. K. Moffatt

**Turbulence: The Legacy of A. N. Kolmogorov.** By Uriel Frisch. Cambridge University Press: 1995. Pp. 296. £45, \$80 (hbk); £15.95, \$29.95 (pbk).

THE phenomenon of turbulence holds a peculiar fascination both for physicists, who, like Einstein, still see it as the most challenging unsolved problem of classical physics, and for mathematicians, who see it as presenting the ultimate problem in the theory of dynamical systems. But for the meteorologist, oceanographer or engineer, turbulence holds a rather different kind of fascination as usually the unavoidable and intractable phenomenon at the heart of a given physical situation. It must be modelled through judicious approximations, based at best on physical insight or at worst on the need to come up with numbers, or through predictions, which may be no better than 'best guesses' in the absence of a satisfactory underlying theory for turbulent flow. In practical engineering, any small improvement in the modelling of turbulence could have important economic consequences, and this lends an edge to the urgency and competitiveness of research on turbulence. Nevertheless, progress at a fundamental level has been slow over the past 40 years, a reflection of the intense difficulty of the subject.

Uriel Frisch takes as his focus the theory of turbulence put forward by A. N. Kolmogorov in a famous series of three short papers that appeared in 1941 in *Comptes Rendu de l'Académie des Sciences de l'U.R.S.S.* These papers, published in Russian, were translated into English for the Aeronautical Research Council, and were 'discovered' by Batchelor shortly after the Second World War. He reviewed them, together with the almost parallel theories of Onsager, von Weizsacker and Heisenberg, at the Sixth International Congress of Theoretical and Applied Mechanics, held in Paris in 1946 (see *Nature* **158**, 883).

Kolmogorov's theory is based on two general hypotheses concerning the statistics of the relative velocities at a set of points in a turbulent flow. The net effect of these hypotheses is to identify a single dimensional parameter, namely the mean rate of dissipation of energy per unit volume, denoted  $\varepsilon$  by Kolmogorov (a notation that was subsequently adopted universally), as the key parameter that, together with the kinematic viscosity of the fluid  $\nu$ , determines all the statistical properties of the small-scale ingredients of the turbulent flow. This theory flourished during the 1950s and early 1960s, when observational evidence from studies of turbulence in the atmosphere and ocean was found to agree substantially with the theory, at least as far



An arctic loon or diver, *Gavia arctica*, surveys a northern lake. The picture is one of more than 120 that appear in *Loons* by Aubrey Lang and Wayne Lynch. In the accompanying text the authors examine the scientific facts behind the many myths that have long surrounded these birds. Firefly, \$19.95 (pbk).

as the energy spectrum of turbulence governed by Kolmogorov's  $k^{-5/3}$  law was concerned.

But Kolmogorov's theory contained the seeds of its own destruction, as was apparently recognized by Landau in discussions following the presentation of Kolmogorov's papers to the Russian Academy. The local rate of dissipation of energy per unit volume  $\bar{\epsilon}$  is itself subject to spatial fluctuations, and, in subregions of the flow where  $\bar{\epsilon}$  is much greater than its spatial average, the local statistics should reflect this local value rather than the mean value  $\bar{\epsilon}$ . Indeed, in regions where  $\bar{\epsilon}$  is large, the process of cascade of energy from large to small scales is more intense, smaller scales of motion are generated, and the rate of viscous dissipation becomes even larger. This leads to the problem of intermittency of turbulent dissipation, a problem that was recognized by Kolmogorov himself in 1962 (*Journal of Fluid Mechanics* 13, 82–85) and has since attracted increasing attention.

All of this is discussed by Frisch in a stimulating and imaginative manner. He begins with a qualitative discussion of symmetry-breaking instabilities of a typical flow as the Reynolds number ( $Re$ ) is increased from small values, and argues that in the asymptotic turbulent regime of very large  $Re$ , although all symmetries are broken in detail, a new statistical symmetry (essentially homogeneity and isotropy) emerges in relation to the small scales of motion. He then presents a novel discussion of the vital process of energy transfer (or 'cascade') from large to small scales. This leads to a discussion of the seeds of chaos in simple dynamical systems, and to a sophisticated introduction to some of the probabilistic techniques used in the theory of turbulence.

In the heart of the book, Frisch presents and develops his own reinterpretation of Kolmogorov's theory and contemporary theories incorporating the effects of intermittency. He bases his presentation on two empirical laws, the famous 'two-thirds law' relating to mean-square of the velocity difference between two points in the flow, and the 'law of finite energy dissipation', which states that  $\bar{\epsilon}$  tends to a constant independent of  $\nu$  as  $\nu$  tends to 0. The first law is well supported by experiments, the second less so; if this second law is not valid — a possibility that Frisch does not care to contemplate — the whole Kolmogorov construction is a house built on sand.

One of the most illuminating discussions of intermittency is that involving the ' $\beta$ -model' introduced by Frisch, Sulem and Nelkin in 1978. As the energy cascades, the volume in which 'active eddies' are present is supposed to reduce each step of the cascade by a factor  $\beta < 1$ ; this leads to a fractal distribution for  $\epsilon(x)$  from which higher-order statistics can also be deduced. Unfortunately, the theory is not in accord with subsequent experiments; to achieve agree-

ment, as Frisch shows, it is necessary to adopt a 'multifractal' rather than a simple fractal viewpoint, involving a continuum of coexisting fractal dimensions. At this point, many more earth bound researchers will part company with Frisch (and other multifractalists), unprepared to accept that the ultimate nature of turbulence may hinge on such an alien concept.

Much more promising, I believe, is the more conventional and physically appealing picture of turbulence as a random superposition of stretched vortex filaments, the 'sinews of turbulence'. Direct numerical simulations have been pointing in this direction for some years, and experiments by Couder and others (Douady, Couder and Brachet, *Physical Review Letters* 67, 983; 1991) lend credence to this view. The wheel of turbu-

lence is coming full circle as we witness a return, albeit at a highly sharpened level, to a consideration of concepts (vortices and vortex interaction) with which Kelvin would have felt at ease.

Frisch concludes his monograph with a long chapter providing a guided tour of further reading in the subject, an extremely useful aid for students whose appetites may have been whetted by this personal, highly unconventional and provocative account. This book will be a source of inspiration for theoretically inclined researchers, but will provide little comfort for practising engineers. □

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## Holes unearthed

Stephen Battersby

**Gravity's Fatal Attraction: Black Holes in the Universe.** By Mitchell Begelman and Martin Rees. *W. H. Freeman: 1996.* Pp. 246. £19.95, \$32.95, £19.95.

*"It's black, and it looks like a hole. I'd say it's a black hole."*

SIDNEY Harris's white-coated cartoon astronomer makes this deadpan satire on scientific coinage and deduction while showing her colleague a picture of a star field with a big round gap in it. Although we do not yet have any images that are so

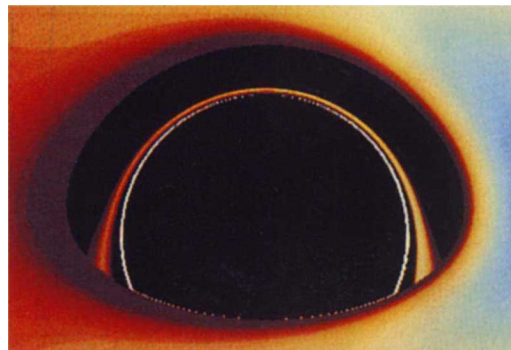
Exemplifying the book's confident stance, they say: "But we now know that black holes are not mere theoretical constructs; they exist in profusion and account for many of the most spectacular astronomical discoveries of recent times".

This certainty is prompted by a discovery that was made shortly before the book went to press. In the nucleus of the galaxy NGC4258, there are gas clouds in which water vapour forms natural masers. They trace out a warped disk of material orbiting at enormous velocities, betraying such a dense central concentration of mass that "the only plausible alternative is a single massive black hole". Unfortunately, the figures that illustrate this are by far the most confusing in the book; perhaps the news was so hot that they had to be printed at high speed. A few minutes of sweaty decipherment smudged the ink on two of them, strengthening my suspicion.

Other than this, there is little to criticize here and plenty to delight in, from the history (apparently one Revd John Michell was the first to postulate black holes in 1784, beating Laplace by ten years) to the well illustrated oddities of general relativity. Rigorous and thorough but not dry, the book describes holes of all shapes and sizes — all sizes, anyway — from the still-improbable primordial subatomic holes, shining by Hawking radiation, to the billion-solar-mass holes that power quasars.

Black holes have lost part of their traditional mystique — the question of their existence — but I am sure there is plenty left to keep them popular. □

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**Simulated close-up view of a black hole and its disk of accreting gas, relativistically distorted by gravity and the high orbital speeds.**

unequivocal, most astronomers assume that black holes probably do exist, either on the weight of circumstantial evidence or because their colleagues tell them so. But since 1963, when Roy Kerr calculated the properties of spinning black holes, we have been in the odd position of knowing exactly what a whole class of objects is like without knowing whether a single one exists.

When will the evidence accumulate to a point beyond reasonable doubt? It already has, according to Begelman and Rees.