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The Scientific Legacy of Fred Hoyle

Fred Hoyle was a remarkable scientist, and made an immense contribution to solving many important problems in astronomy. Several of his obituaries commented that he had made more influence on the course of astrophysics and cosmology in the second half of the twentieth century than any other person. This book is based on a meeting that was held in recognition of his work, and contains chapters by many of Hoyle's scientific collaborators. Each chapter reviews an aspect of Fred Hoyle's work; many of the subjects he tackled are still areas of hot debate and active research. The chapters are not confined to the discoveries of Hoyle's own time, but also discuss up-to-date research that has grown out of his pioneering work, particularly on the interstellar medium and star formation, the structure of stars, nucleosynthesis, gravitational dynamics, and cosmology. This wide-ranging overview will be valuable to established researchers in astrophysics and cosmology, and also to professional historians of science.

Douglas Gough is the Professor of Theoretical Astrophysics, and Director of the Institute of Astronomy, at the University of Cambridge. He is an honorary professor at the University of London, an adjunct fellow at the University of Colorado, and a visiting professor of physics at Stanford University. His main research interest is the internal dynamics of stars.

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Sir Fred Hoyle 1915–2001

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Foreword

MARTIN REES

Fred Hoyle's varied and prolific output spanned more than 60 years. Indeed, throughout the entire period 1945–70 he was preeminent among astrophysicists in the range and influence of his contributions. This one-day memorial meeting focused on his research contributions, but of course all those who knew him – and, indeed, the wide public – admired him for other reasons too. His engaging wit and relish for controversy, retained throughout his long life, gained him a high public profile. He had a wide following as a popularizer of science and as a successful writer of science fiction. He also played an active organizational role in UK science. Fred died on 20 August 2001 in Bournemouth, England. He was physically and mentally robust until the year before his death, during which he suffered a series of strokes.

Born on 24 June 1915 in Bingley, Yorkshire, he was the son of a wool merchant. He attended the local grammar school, from which he gained a scholarship to Emmanuel College, Cambridge, where he read mathematics. He graduated with a BA in mathematics in 1936, winning the Mayhew Prize for his outstanding performance. He was elected to a fellowship at St John's College, Cambridge, in 1939 for work on beta decay. His shift towards astrophysics was stimulated by his colleague Raymond Lyttleton, with whom he wrote papers on accretion and stellar evolution. Although accretion plays such a great role, few of the younger generation of astrophysicists will have read these papers. I certainly was unaware of the remarkably detailed discussion of cooling processes involving molecular hydrogen in a 1940 paper by Hoyle and Lyttleton, described in Phil Solomon's contribution.

During the years of the Second World War, Fred was engaged mainly on technical problems related to radar. He found himself working with Hermann Bondi and Thomas Gold; in spare moments the trio discussed astronomy. The most celebrated outcome of this collaboration was the steady-state cosmology, put forward in two papers in 1948. Bondi and Gold's arguments were general

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(almost philosophical). But the Hoyle model was more specific: he introduced a negative-pressure *C*-field into Einstein's equations. As Fred enjoyed pointing out, this formulation was, in some sense, a precursor of currently fashionable inflationary models. The steady-state theory was a serious contender for 15 years. (Its three promoters were articulate and effective advocates. However, it is fair to say that their voices did not carry across the Atlantic, where the theory never acquired the visibility it had in the UK). It had the virtue of being testable, and was the focus of often acrimonious controversy, especially with Martin Ryle and other radio astronomers. Fred held out against Big-Bang theory, even post-1965, when the discovery of the microwave background led most cosmologists to favour it. He nonetheless contributed important studies of Big-Bang nucleosynthesis with Roger Tayler, Willy Fowler, and Bob Wagoner.

From 1945, Hoyle was based in Cambridge, first as lecturer in mathematics, and subsequently, from 1958, as the Plumian Professor of Astronomy. But he derived stimulus from frequent visits to the USA. He was one of the early users of Cambridge's EDSAC computer for his studies of red giants and stellar evolution. At Princeton University, he and Martin Schwarzschild modelled the evolution of low-mass stars right through to the red-giant branch. He spent much time at Caltech, where he followed up the ideas adumbrated in his famous 1946 paper, 'The synthesis of the elements from hydrogen', in a long and fruitful collaboration with Willy Fowler on nuclear processes in stars and supernovae. This research was codified in a classic 1957 article, universally referred to as 'B^2FH' (published in *Reviews of Modern Physics*), which he and Fowler coauthored with Geoffrey and Margaret Burbidge. Many of us felt that Fred should have shared Fowler's 1983 Nobel Prize in Physics, but the Royal Swedish Academy of Sciences later made partial amends by awarding him, with Edwin Salpeter, its 1997 Crafoord Prize.

Throughout the 1950s and 1960s Fred kept up his wide-ranging interests in solar physics, the origin of the Solar System, the structure of galaxies, and the nature of gravity. The discovery of quasars in the 1960s led to a stream of stimulating papers, many coauthored with the Burbidges, on supermassive objects and various aspects of high-energy astrophysics. Fred was at the leading edge of all these developments. As Malcolm Longair describes in this book, those who attended his lectures had the privilege of following the development of his theories in 'real time'.

Committee work and administration held little attraction for Fred. Nonetheless, especially during the 1960s and early 1970s, he served effectively on the Science Research Council and the Council of the Royal Society, among other UK bodies. In Cambridge, his energetic advocacy and fundraising led to the creation, in 1966, of the Institute of Theoretical Astronomy. Its main building, now named

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after him, was modelled on the University of California's Institute of Geophysics and Planetary Physics in La Jolla, California, although it overlooks a field of cows rather than the Pacific Ocean. He had a remarkably 'hands on' role in the detailed design, and all the occupants of this building have cause to be grateful to him. (He believed that wide corridors were not a waste of space but would encourage an interactive atmosphere. He even convinced the budgeters that it was 'economical' to carpet the building throughout, since otherwise acoustic cladding would be needed, which would be more expensive.) It was specially timely that this memorial meeting was the first conference to be held in the Hoyle Building after its renovation and extension – it is now substantially enlarged, but in a style which fully maintains the environmental qualities that Fred valued and created. The Institute of Theoretical Astronomy opened in 1967 and quickly made an international mark. Key ideas on supernovae and explosive nucleosynthesis were developed by Willy Fowler, David Arnett, Don Clayton, Stan Woosley and other colleagues during their regular summer visits.

Fred's regular collaborators Jayant Narlikar and Chandra Wickramasinghe were part of the Institute's full-time staff. In addition, a lively group of postdoctoral scientists benefited from the stimulating environment of the Institute. I was privileged to be one of these, along with Brandon Carter, Stephen Hawking, Joe Silk and many others. A lot of our research was orthogonal (or even contradictory) to his own. At a Vatican 'Study Week' in 1970, my talk, given immediately after his, was quite out of line with his interpretation of radio source counts, but scientific disagreements did nothing to diminish his friendly support. On the broader UK scene, Hoyle's role was pivotal in establishing the Anglo-Australian Observatory, in the early 1970s. As a result, for the first time, UK astronomers had guaranteed access to a world-class optical telescope.

The dispute that led to Fred's premature retirement from Cambridge in 1972 was deeply regrettable. He thereafter based himself for many years in a remote part of the Lake District (hill-walking being one of his lifelong enthusiasms) before moving to the more sedate environs of Bournemouth. His consequent isolation from the broad academic community was probably detrimental to his own science; it was certainly a sad deprivation for the rest of us. But there was no let-up in his productivity. His scientific writings continued throughout the 1980s and 1990s, and dealt, often controversially, with topics as disparate as Stonehenge, panspermia, Darwinism, palæontology, and viruses from space. It was perhaps unfortunate that he gained more public attention for these excursions than he ever had for his work on nucleosynthesis. But he never lost his focus on cosmology, nor the hope of achieving a deeper synthesis: his book *A Different Approach to Cosmology: From a Static Universe through the Big Bang towards Reality*, coauthored with G. Burbidge and Narlikar, appeared in 2000.

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His lifelong success as a popularizer started in 1950 – in the pre-Sagan era, long before the dominance of television – with a celebrated series of radio talks. Huge numbers of people (including many who later achieved scientific distinction) were inspired by these talks, by books such as *Frontiers of Astronomy*, and by his lectures. Throughout his life, he retained the distinctive accent of his native Yorkshire.

Fred's first novel, *The Black Cloud* (Harper 1957), about an alien intelligence embodied in a cloud of interstellar gas, has achieved classic status. It was followed by a dozen others, including *A for Andromeda*, coauthored with John Elliot, which was dramatized as a television series, *Ossian's Ride* (1959) and *October the First is Too Late* (1966). Some of his books, including those he wrote for children during his later years, were coauthored with his son Geoff. His autobiography *Home Is Where the Wind Blows: Chapters from a Cosmologist's Life* (University Science Books 1994) sensitively evokes his early life in Yorkshire and offers entertaining perspectives on later academic disputes.

The memorial meeting in Cambridge offered a chance to review and celebrate Fred's enduring insights into stars, nucleosynthesis, and the large-scale universe. Some of these rank among the great achievements of twentieth-century astrophysics. Most of us were aware of his 'highlight' contributions, but (along, probably with most of the audience) I learnt about diverse aspects of his work which were completely new to me. His theories were unfailingly stimulating, even when they proved transient. He will be remembered with fond gratitude not only by colleagues and students, but by a much wider community who knew him through his talks and writings.

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Preface

Fred Hoyle was one of the great figures in twentieth-century theoretical astrophysics. His many scientific writings on an extremely wide range of astronomical subjects, from solar and stellar physics to cosmology and panspermia, bear witness to his penetrating mind and his remarkable versatility. In addition, he captured the imagination of the public with his popular books, his radio broadcasts and his public lectures. A great deal of what Fred did was controversial at the time, but is becoming less so as the years go by, as generally accepted scientific wisdom moves more and more towards the essence of his ideas, if not necessarily the details of his application of them to astronomy: an example, discussed in this book, is the introduction of his *C*-field into the dynamical equations describing the evolution of the Universe, a negative-energy field which has subsequently reappeared in the currently almost universally accepted inflationary scenario. Yet much of Fred's work was quite obviously sound from the outset, such as his pioneering monumental study, with Willy Fowler and Geoff and Margaret Burbidge, of the creation of the chemical elements, and his seminal work with Martin Schwarzschild on the evolution of low-mass stars and on the structure of red giants.

For three decades of his scientifically most productive life, Fred was based in Cambridge. He was a Fellow of St John's College from 1939 and, after intermission for the Second World War, became a lecturer in applied mathematics in the Department of Applied Mathematics and Theoretical Physics in 1945, and subsequently Plumian Professor of Astronomy and Experimental Philosophy. In 1966 Fred founded the Institute of Theoretical Astronomy (which subsequently amalgamated with the University Observatories to form the Institute of Astronomy), and was its Director until his departure from Cambridge in 1972. It was fitting, therefore, that an international meeting to honour his scientific life should take place in Cambridge. The meeting was held on 16 April 2002, at the Institute of Astronomy and St John's College. It was attended by Fred's friends and

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collaborators, by younger scientists some of whom had not known Fred personally, and also by many of Fred's family. It was not merely retrospective, but looked forward to new advances. This book is a record of the proceedings of that meeting. It contains discussions not only of work carried out by Fred and his collaborators in the context of present-day thinking, but also of up-to-date developments in astronomy and cosmology that have grown out of Fred's ideas.

I thank all those who have helped with the production of this book, particularly Bob Carswell, who wrote the first chapter with the help of his video recording of Wal Sargent's talk, to Di and Richard Sword who polished the LaTeX and the diagrams, to Mark Hurn who assembled the index, and to Jacqueline Garget of Cambridge University Press whose patience was truly tried by delays in receiving the final text.

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