GEOFFREY RONALD BURBIDGE
24 September 1925 — 26 January 2010
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Elected FRS 1968

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Geoffrey (Geoff) Burbidge’s career spanned the tumultuous years when astronomy was transformed from a purely optical science to a multi-wavelength discipline through the development of new types of astronomy—radio, X-ray, γ-ray, cosmic ray physics. These offered new astrophysical and cosmological challenges, which he grasped with relish. To all of these disciplines, Geoff, often in collaboration with his wife Margaret Burbidge (FRS 1964), made pioneering contributions, particularly in the areas of the synthesis of the chemical elements, the physics of extragalactic radio sources, the rotation curves of galaxies, the dark matter problem in clusters of galaxies, the physics of accretion discs and the origin of cosmic rays. He also espoused less popular causes such as the non-cosmological nature of the redshifts of quasars and was sceptical about the standard Big Bang picture of the origin of the large-scale structure and dynamics of the Universe. He was a flamboyant and outspoken astrophysicist who challenged his colleagues about their deeply held views on all aspects of astrophysics and cosmology. His service to the community included five years as director of the US Kitt Peak National Observatory, based in Tucson, Arizona, and as a most effective editor of Annual Review of Astronomy and Astrophysics for over 30 years and the Astrophysical Journal.

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Biographical Memoirs

EARLY LIFE

Geoff Burbidge\(^1\) was born in the small market town of Chipping Norton in the Cotswolds, roughly halfway between Oxford and Stratford-on-Avon. The families of both his parents had lived in Chipping Norton for many generations. His father, Leslie Burbidge, was a partner with his two brothers, Fred and Percy, in a small building firm, Burbidge and Sons, which covered a large rural area, where they built, renovated and repaired many types of Cotswold buildings using Cotswold stone. His mother, Evelyn Beechey, was a milliner who had three sisters and two brothers. Geoff was an only child, but had five uncles, one of whom had died during the war, and two aunts. The Burbidges were well known in the town and were prominent in local affairs, particularly in the local Baptist Chapel, in managing the local hospital, in horticulture and in musical activities.

His father was a very good sportsman who had played football as a young man. He became the manager and the secretary of the local football team and later a long-serving member and sometime secretary of the Oxfordshire Football Association. Leslie’s greatest ability was in lawn tennis and he won all the local club competitions many times. He taught Geoff to play and turned him into a reasonable player. He used to take Geoff to Wimbledon for a day every year and this led to Geoff’s lifetime interest in tennis. His father imbued in him a very strong sense of fair play, which according to Geoff was ‘something that in the cut and thrust of academic politics and science has turned out to be a mixed blessing’ (24)\(^2\).

His uncle, Fred Burbidge, was extremely versatile. He ran a small market garden in which he grew tomatoes and other vegetables. He and his daughter Hilda had a thriving apiary, and there was a small shop attached to the house where they sold their produce, only about half a mile from where Geoff lived.

Geoff was educated at the local primary school and then at Chipping Norton Grammar School, in which only about 250 pupils were taught. The school was a good one, the subjects in which he excelled being history and mathematics. He was lucky in having an extremely good mathematics master, Leonard Miles. Outside school, he read voraciously including many classics, thrillers, the plays of George Bernard Shaw and many other contemporary writers. He discovered T. E. Lawrence, and found his *Seven pillars of wisdom* ‘a marvellous and rather mysterious book’.

In his teenage years he spent some time helping in the building office and accompanied his uncles to many jobs in the local villages. He learned about business, the building industry, dealing with banks and awkward clients, and paying and looking after the employees. This was his only experience of personnel management until he took over as Director of the Kitt Peak National Observatory more than 35 years later.

BRISTOL UNIVERSITY AND BOMB TESTING

In 1942 the war was at its height and Geoff realized that he would soon be called up to join the armed forces. Since he excelled at mathematics and was competent in physics, he won

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\(^1\) Much of the biographical material in this Memoir, especially with regard to his early life, has been derived from Geoffrey Burbidge’s opinionated, but characteristically honest, autobiographical prefatory essay in the 2007 volume of *Annual Review of Astronomy and Astrophysics* (24).

\(^2\) Numbers in this form refer to the bibliography at the end of the text.
a scholarship to Bristol University, which would enable him to study for a Pass Degree in Physics and then to take up a short service commission. The armed forces were desperate for physicists and mathematicians to take up this opportunity because of their urgent need for expertise in ballistics, radar, explosive events, nuclear weapons and so on. Geoff was the first of his family to go to university.

He was fortunate that Bristol University had one of the strongest physics departments in the country. The head of department was Arthur M. Tyndall FRS who had been responsible for the building of the H. H. Wills Physics Laboratory, which was opened in 1927 by Ernest Rutherford FRS Geoff was taught by two physicists who later won Nobel prizes, Nevill Mott FRS and Cecil Powell (FRS 1949), as well as taking lecture courses given by a number of distinguished physicists, including Herbert Fröhlich (FRS 1951), Frank Nabarro (FRS 1971) and others. He also got to know Giuseppe (Beppe) Occhialini (ForMemRS 1974) and his associate, later his wife, Constance Dilworth, who were both working in Powell’s Cosmic Ray Group. Geoff states that he learned a great deal of physics from Occhialini—he must have awakened Geoff’s future interest in the origin of cosmic rays.

After his two-year physics course and with the war drawing to a close, he stayed at Bristol for a further year to complete a special honours degree, graduating in 1946 with outstanding results. The Ministry of Supply then appointed him to work in a ballistics laboratory which had originally been the Road Research Laboratory in Hounslow in West London.

For the next 18 months he worked on two programmes. The first was related to the attempts started during the war to provide the Royal Air Force with bombs that could penetrate the caves where the U-boats docked and were refuelled under the cliffs near Brest in France. The bombs were designed to penetrate to great distances through rock and then explode. Various bomb configurations were calculated theoretically and then tested. Scaled-down bomb cases were made at the Woolwich Arsenal and then loaded into large bore naval guns that were fired horizontally through thick sheets of steel. To carry out these experiments, Geoff and his colleagues went down to the Naval Firing Range at Shoeburyness. The second programme was concerned with demolition. A scaled-down model of a ballistics laboratory was built at the Road Research Laboratory and then Geoff and his colleagues systematically blew it up, section by section, using the latest plastic explosives. As Geoff recalls in his autobiographical essay (24):

During this period of working in the lab two things happened to me. (a) I learned more than I could ever have imagined about guns and explosives. The lab had a long history of experiments throughout the war so that all types of guns were available there: Webley automatics, machine pistols, submachine guns, large machine guns, anti-aircraft guns (Bofors, in particular), and everything up to light artillery. There was a range on which you could try things out, and some of us did. (b) I concluded that physics is a completely fascinating field, and I became determined to become a graduate student, get a PhD, and do research.

LONDON

In 1947 Geoff received a bursary to study for a PhD under Harrie Massey FRS, who was head of the Department of Mathematics at University College London (UCL). Massey suggested that he work on the capture of μ-mesons by atoms. This led to his first publication in the Physical Review jointly with A. H. de Borde (1). At the same time, he became
extremely interested in the new developments in quantum electrodynamics. There was no-one at UCL working in this area, but Massey encouraged him to travel regularly to Cambridge and attend the theoretical seminars in field theory that were being run under the direction of Paul Dirac FRS, Nicholas Kemmer (FRS 1965) and J. Hamilton. The Cambridge colloquia adopted a much more mathematical approach to field theory than most theorists were used to. Experimental data relating to theory were rarely, if ever, discussed.

He also attended a variety of lecture courses in London, including a course on the atomic and molecular physics of the upper atmosphere of the Earth. Here he met Margaret Peachey, who was six years his senior and already had a PhD in astronomy from UCL. She was assistant director of the University of London Observatory at Mill Hill. In April 1948 they were married and began an extraordinary lifetime of joint research and publication which was to continue until his death. Margaret Burbidge (FRS 1964) was a brilliant observational astronomer who was to become one of the foremost of her generation and an outstanding role model for women astronomers. Geoff learned to assist Margaret in her observing programme during their time at UCL.

While working on his PhD, Geoff was appointed as an assistant lecturer in mathematics at UCL, but he soon realized that he had no talent for teaching. As he remarked in 2007, ‘I was, and am, too impatient’ (24). Geoff called his autobiographical essay An accidental career, reflecting the fact that he had had little interest in astronomy until his marriage. This was to change very rapidly as he and Margaret attended numerous astronomical meetings over the next few years. In August 1948 they attended the seventh General Assembly of the International Astronomical Union in Zurich, where they were introduced to many of the leading astronomers. The following summer, 1949, they went to France, first to the Observatory at St Michel in Haute Provence and then to Paris to reduce the data. There they met some of the leading French astrophysicists, including Daniel Chalonge and Evry Schatzmann. By good fortune, the Paris meeting on Astronomical Turbulence was taking place at that time and Geoff learned a great deal about the subject. Among the English astrophysicists present were Fred Hoyle (FRS 1957) and Ray Lyttleton (FRS 1955). Hoyle debated every issue with Carl Friedrich von Weizäcker and Geoff learned a great deal about the basic problems concerning the condensation of the interstellar gas and the problems of spiral structure.

In the following year, 1950, Geoff obtained his PhD in theoretical physics at UCL and remained on the staff until 1951. Massey had organized a meeting at UCL that concerned, among other things, the nature of the recently-discovered discrete extraterrestrial sources of radio emission. At that time, apart from the Sun, the only optically identified radio source was the supernova remnant known as the Crab Nebula. The most popular idea was that the unidentified radio sources were flare stars. Hannes Alfvén (ForMemRS 1980) and Nicolai Herlofson had proposed that the radiation mechanism was non-thermal incoherent synchrotron radiation (Alfvén & Herlofson 1950). On the other hand, Martin Ryle (FRS 1952) and his colleagues in Cambridge believed that some form of coherent plasma oscillation was involved. The young Thomas (Tommy) Gold (FRS 1964) suggested that, since the unidentified sources showed a roughly isotropic distribution, they might either be quite close to us—as flare stars would be—or they might be very far away, at cosmological distances. The latter proposal, Gold’s preferred option, was vehemently opposed by Ryle and by the general relativist and cosmologist George McVittie. It turned out that Gold was correct. This episode soured the
relations between Ryle and Gold, and Geoff never forgot what he perceived to be inappropriate behaviour on Ryle’s part. This was the beginning of acrimonious relations with Ryle.

The peripatetic years

The United States, 1951–1953

In 1951 Margaret was offered an appointment at the Yerkes Observatory in Williams Bay, Wisconsin, part of the University of Chicago, enabling her to obtain observing time on the 82-inch telescope of the McDonald Observatory in West Texas. At the same time, Geoff was awarded the Agassiz Fellowship at the Harvard College Observatory in Cambridge, Massachusetts. Geoff very much enjoyed the atmosphere at the Harvard College Observatory. Harlow Shapley was the director and other prominent astronomers included Fred Whipple, Donald Menzel and Bart Bok as well as Dave Heeschen and Ed Lilley, who were radio astronomers. Since he had been introduced to observational astronomy through Margaret’s stellar spectroscopy, he became interested in stellar atmospheres and radiative transfer; the senior person closest to his interests was Menzel. In the second part of the academic year, 1951–1952, Geoff spent time at the Yerkes Observatory, while in 1952–1953 Margaret came to Harvard. There were also several observing runs using the coudé spectrograph of the 82-inch telescope in Texas.

Back to the United Kingdom, 1953–1955

Margaret and Geoff held exchange-visitor visas to the United States and had to return to England in 1953. On their way back they attended a summer school on astrophysics at the University of Michigan in Ann Arbor organized by Leo Goldberg. The lecturers included Walter Baade, George Gamow, Edwin Salpeter (ForMemRS 1993) and George Batchelor (FRS 1957), and special seminars were given by Allan Sandage (ForMemRS 2001) and others. For the first time, he met, and argued with, Sandage, who remained one of his best friends, exemplifying his lifelong capacity to sustain personal friendships despite deep scientific divergences.

On his return to the UK, Geoff accepted a research appointment at the Cavendish Laboratory at Cambridge, working as a theorist in Ryle’s Radio Astronomy Group. He was given free rein to carry out theoretical work on the basic mechanism that gives rise to the non-thermal radio emission of the Galaxy, of supernova remnants and of distant radio galaxies. He was soon convinced that the mechanism was the incoherent synchrotron process, which had been extensively studied by the Soviet theorists Vitali Ginzburg (ForMemRS 1987) (Ginzburg 1951), Sergei Syrovatskii and Josef Shklovsky. He and Ryle still did not get on well, Ryle still believing that the radiation mechanism was coherent plasma oscillations. One issue was, however, resolved with the discovery of the extragalactic nature of the radio sources in directions away from the Galactic Plane, following the identification by Baade and Rudolph Minkowski of the radio source Cygnus A with a distant galaxy (Baade & Minkowski 1954).

The main work of the radio astronomy group was the construction and operation of new types of radio telescope and making deep surveys of the radio sky to understand the nature of the radio source population. The results of the surveys were kept under very close wraps until Ryle’s announcement of the results of the 2C survey of the radio sky in his 1955 Halley Lecture at Oxford (Ryle 1955). In anger at not being made privy to these results, Geoff
refused to go to Oxford. Ryle’s claim to have disproved the Steady State Theory of Gold, Hermann Bondi (FRS 1959) and Hoyle was a further cause of friction. Despite the differences with Ryle, Geoff was on good terms with many members of the Radio Astronomy Group, particularly with John Baldwin (FRS 1991), John Shakeshaft, Peter Scheuer and Tony Hewish (FRS 1968).

Of special importance for their future research, Margaret had obtained at the McDonald Observatory high dispersion spectra of one of the well-known magnetic variable stars, $\alpha^2$ Canum Venaticorum, which has an extremely rich spectrum with hundreds of lines of the rare earth elements and other heavy elements (2). Their derivation of the abundances of many of the heavy elements was the first time that the spectrum of such a star had been analysed in detail. The results showed that when averaged through the magnetic cycle, the abundances of many of the rare earth elements were $10^3 - 10^4$ times greater than the abundances of these elements in a normal star like the Sun.

Geoff gave a colloquium on this topic in Cambridge at one of the evening meetings of the Kapitsa Club, after which the distinguished experimental nuclear physicist William (Willy) Fowler introduced himself. He was very interested in the Burbidges’ results—this was the beginning of their collaboration on the problems of stellar nucleosynthesis.

Until 1955, Geoff’s publications, nearly all co-authored with Margaret, had dealt with individual peculiar stars. But this was crucial groundwork for the epochal achievement during the next two years, when the Burbidges’ collaboration with Fowler and Hoyle led to a great synthesis of nuclear physics and astrophysics. They identified the processes whereby stars, in their fusion-fuelled lives and violent deaths, synthesized elements all the way up the periodic table. In this collaboration, all the ingredients were there: Margaret, a stellar observer; Fowler, the nuclear experimentalist; Hoyle, who had proposed seminal ideas in the 1940s, and had discovered the crucial triple-$\alpha$ resonance (Hoyle 1954); and Geoff, by now a well-informed theoretical nuclear physicist.

**Pasadena and stellar nucleosynthesis**

Fowler arranged for the four of them to pursue their detailed investigations at Pasadena, California. Margaret was given a research post supported by the Atomic Energy Commission in the Kellogg Radiation Laboratory at the California Institute of Technology (CalTech) while Geoff was awarded a Carnegie Fellowship at the Mount Wilson and Palomar Observatories, the first to be awarded to a theorist (figure 1). From mid 1955 to early 1957, Margaret, Geoff, Fowler and Hoyle worked intensively on the many different aspects of stellar nucleosynthesis. Following earlier ideas of Hoyle, they showed how the elements up to the ‘iron (Fe) peak’ could be created by the successive stages of nuclear fusion that occur during the processes of stellar evolution. The production of heavier elements beyond the iron peak requires endothermic reactions. Fowler, Margaret and Geoff began by exploring the build-up of heavy elements by the slow (s) neutron capture process.

As a further clue to the location of these processes, in 1956 Geoff noticed a paper in *Physical Review Letters* in which it was announced that the transuranic isotope Californium 254 had been detected in the Bikini nuclear bomb test. Its half-life of 55 days agreed with the decay timescale of the light curve of the supernova in the galaxy IC4182, discovered by Baade. If correct, this coincidence connected supernova explosions to the rapid build-up of heavy nuclei by the rapid (r) process in stellar nucleosynthesis (3). It turned out later that the agreement was spurious and the light curve is due to other isotopes, namely radioactive nickel.
decaying to cobalt and then to iron; nonetheless, this result was a great stimulus to their work. They showed how fast and slow neutron capture, the r- and s-processes, could explain the observed abundances of elements heavier than iron.

By the first months of 1957 the team had begun to pull together the vast amount of observational and experimental data as well as their many detailed calculations. They showed that the variety of physical conditions that stars of different masses experience during their evolution could generate the range of temperatures and densities needed to synthesize the elements—and, moreover, these could be matched to the observed chemical abundances of the elements. They could account for the peaks in the abundances of elements around iron with atomic number 26 and they identified supernovae and red giant stars as the production sites for the heaviest elements.

The monumental 104-page paper by Burbidge, Burbidge, Fowler & Hoyle, universally known as B²FH, was published in the Reviews of Modern Physics in late 1957 (4). In it, they showed how the heavy elements, though not He and Li, could be built up by successive generations of stars: the planets, and we ourselves, are the ‘nuclear waste’ from the fuel that makes the stars shine.

During the 1930s there were two reasons why the synthesis of the chemical elements in the hot early stages of the Friedman world models was taken seriously. First, the
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abundances of the elements in stars were remarkably uniform, suggesting they had a common origin. The second consideration was that the interiors of stars did not seem to be hot enough for the nucleosynthesis of the chemical elements to take place. The equilibrium theory predicted abundances in gross disagreement with the observed abundances of the elements (Chandrasekhar & Henrich 1942). In contrast to this equilibrium picture, Georges Lemaître proposed in 1931 that the Friedman world models had evolved from an initial state which he termed a ‘primaeval atom’ (Lemaître 1931a,b). George Gamow’s attack on the primordial origin of the chemical elements began immediately after the War. He extrapolated the Friedman models back to very early cosmological epochs, at which the densities and temperatures were high enough for nucleosynthesis to take place. By the early 1950s, his colleagues Robert Alpher, Robert Herman and James Follin had shown that only about one part in $10^7$ of the initial mass was converted into elements heavier than helium, far less than the cosmic abundances of the heavy elements (Alpher & Herman 1948, 1950; Alpher et al. 1953). They had come very close to the modern picture of the thermal and nuclear evolution of the early Universe, including the important result that about 25% of the primordial material by mass was converted into helium and that the cooled remnant of these hot early phases should be present in the Universe today with radiation temperature about 5 K, which was to be discovered by Penzias and Wilson in 1965 (Penzias & Wilson 1965). With the dramatic results of the B2FH paper, Bondi asked what evidence there was for any relics of the hot early phases of the Universe. With the new insights provided by B2FH, the abundances of the chemical elements disappeared as evidence (figure 2).

The scenario expounded in B2FH has been firmed up in later decades. It constitutes the most important and durable work of each of the four authors—though we note that many of the ideas were developed in parallel, and independently, by the Canadian physicist Alastair G. W. Cameron (Cameron 1957).

In the midst of all of this frantic activity, Margaret and Geoff’s daughter, Sarah, was born in August 1956, the many well-trained, and distinguished, babysitters including Baade and his wife.

Radio astronomy and high energy astrophysics

In Pasadena Geoff continued his studies, begun in Cambridge, of the physics of radio sources. By 1955 it was known that the extragalactic radio sources tended to have double radio structures, with very large lobes on either side of the optical galaxy that had to be the primary energy source. The Soviet theorists had suggested that the optical continuum radiation of the Crab Nebula and the optical jet in M87 were also incoherent synchrotron radiation and this was confirmed by Baade, who detected the predicted polarized optical emission (Baade 1956).

Geoff’s major contribution to these studies was the calculation of the minimum amount of energy in relativistic electrons and magnetic fields required to produce the observed radio emission, which occurs when there is roughly equipartition between the energy in the electrons plus protons and the energy contained in the magnetic fields. The minimum amounts of energy in the form of highly relativistic particles and fields had to be very large indeed ranging from $\sim 10^{56}$ erg ($\sim 100 M_\odot c^2$) for M87 to $\sim 10^{61}$ erg ($\sim 10^7 M_\odot c^2$) for more distant sources such as Cygnus A (7). These were startling results. There was a popular speculation that the phenomenon was a consequence of a high-speed collision between two galaxies. The origin of this energy, and of other manifestations of ‘violent activity’ in galaxies, remained controversial.
for a further 20 years; Geoff remained a prominent contributor to the debates throughout that period.

The realization that these extragalactic sources involved stupendous amounts of energy led Geoff to believe that they might be the origin of the primary cosmic rays (5)—ultra-relativistic particles pervading our Galaxy, whose properties had already been well studied, partly because they provided physicists with a ‘cosmic laboratory’ offering far higher energies than could be generated in terrestrial accelerators. A consequence of this hypothesis was that cosmic rays would pervade all intergalactic space. An alternative view, promoted by Soviet theorists, was that the cosmic rays detected on Earth originated in supernova explosions and their remnants in our own Galaxy. They would then pervade the Galaxy, but they would be confined by the Galactic magnetic field so that their density in intergalactic space would be far lower. This hypothesis, somewhat more ‘economical’ in energy requirements, has become widely accepted today. But from the beginning Geoff stuck to his different view. This led to a strong divergence of opinion between Geoff (16) and Ginzburg (Ginzburg 1970). One of us (MSL)
remembers vividly Ginzburg telling him in Moscow in 1968: ‘I know of twenty reasons why Burbidge is wrong. Of course, if I was really sure, I would only need one!’

Over the next decade or more Geoff developed this line of reasoning in several papers, culminating with a long paper with Kenneth Brecher in 1972 (17). Ginzburg and Geoff did agree that the very highest energy cosmic rays, if they are protons with energies greater than about \(10^{19}\) GeV, cannot be contained or accelerated in our Galaxy.

**Chicago and Yerkes, 1957–1962**

In autumn 1957 Geoff and Margaret, now with their daughter Sarah, moved to Williams Bay, Wisconsin, where they had both been given long-term appointments. They also became members of the Fermi Institute on the university campus in Chicago. The senior astronomers were Gerard Kuiper as Director, Bengt Strömgren, Subrahmanyan Chandrasekhar FRS, William Morgan and Albert Hiltner; among the younger staff members were Robert Kraft, Kevin Prendergast and Joseph Chamberlain.

Geoff realized that the astrophysics of galaxies was in a remarkably primitive state. Very little was known about the basic parameters, such as the rotation curves of spiral and irregular galaxies, the velocity dispersions of stars in elliptical galaxies and the properties of the interstellar gas in these systems. Margaret and Geoff started a programme to measure the rotation curves of disc galaxies. In 1939 Horace Babcock had built a very fast, low dispersion spectrograph for use at the prime focus of the McDonald 82-inch telescope. The spectrograph had a long slit and was ideal for measuring the rotation curves of galaxies. Despite being a very difficult instrument to use, Margaret managed to obtain good spectra during the period 1957 to 1962. Geoff acted as night assistant, carrying out all the darkroom work, cutting film, plates, developing, and so on. They measured the rotation curves of many normal and barred spiral galaxies, and also showed that in some cases there were non-circular motions, which they interpreted as the ejection of gas close to the nuclear regions of the galaxy. Prendergast contributed in a major way to the project. He had devised a technique for solving numerically the integral equation involving the rotation curve so that the mass distribution as a function of radius could be determined and, hence, the total mass and the mass-to-light ratio could be found out to the furthest measurable radius (see, for example, (8)).

Over about 10 years from 1959, they measured the rotation of some 30 Sb, SBb, Sc and SBc galaxies and a few irregulars, more than had ever been studied before (for details, see the full list of papers published in the major journals). The type of analysis which became possible through these efforts is illustrated by their paper of 1965 entitled ‘Ionized gas in the nuclei of elliptical, S0, spiral, and irregular galaxies’ (10). The limitations of the spectrograph and detectors at that time meant that we were not able to measure the rotation curves much beyond their peak velocities. It was only later that Morton Roberts and other radio astronomers used the 21-cm line of neutral hydrogen to demonstrate that the rotation curves nearly all tend to become flat, rather than decreasing, beyond the peak of the rotation curve. Corroborative results were found by Vera Rubin, who had worked with Margaret and Geoff in San Diego, but using more modern spectrographs and image tubes (Rubin et al. 1980). The consensus of opinion is that these later data provide compelling dynamical evidence that the galaxies contain large amounts of dark matter in a ‘halo’ extending out beyond their visible boundaries.

Geoff and Margaret also became involved in the issue of the stability of clusters of galaxies in their studies of the Hercules cluster of galaxies (6). They found the same result already
established by Zwicky in his study of the Coma cluster in the 1930s that there must be some form of ‘dark matter’ present to bind the cluster gravitationally. Notably, they advocated a model in which the clusters were not bound but were expanding or disrupting systems, following the proposal of positive energy systems advanced by Ambartsumian in earlier years.

The discovery of non-circular motions, the most extreme of which were referred to as explosive events, led them to infer that matter was being ejected from the centres of galaxies. At the same time, Allan Sandage and Roger Lynds had shown that a major outburst had taken place in the nearby irregular galaxy M82 (Lynds & Sandage 1963). Putting all of these data together, and including the distant radio sources, Burbidge, Burbidge and Sandage published in 1963 an influential review article in *Reviews of Modern Physics* entitled ‘Evidence for the occurrence of violent events in the nuclei of galaxies’, just predating the discovery of the quasi-stellar objects (QSOs) in 1963 (9).

**University of California, San Diego**

In 1962, following a significant managerial crisis at the Yerkes Observatory, Margaret and Geoff finally left Chicago and moved to the physics department of the newly-established La Jolla campus of the University of California (UCSD). This was to be their base for the rest of their careers. Almost immediately after their arrival, the quasi-stellar radio sources were discovered thanks to precise radio positional measurements by Cyril Hazard (Hazard *et al.* 1963) and the consequent securing of the spectrum of the optical counterpart of 3C 273 by Maarten Schmidt (Schmidt 1963). The very large redshifts of the quasars implied that these objects were exceedingly distant, and therefore had to be ultra-luminous. Even more dramatically, these enormous luminosities were found to vary over timescales of months and years (Smith & Hoffleit 1963)—nothing like this had been observed before in extragalactic astronomy. Geoff took the point of view that the large redshifts must have some other cause: QSOs, then, need not be at the vast distances implied by the cosmological interpretation of their redshifts. If they were much more nearby, their luminosities would be much less extreme and the variability would be more easily understood. Geoff and Margaret became deeply involved in the study of quasars and in 1967 published the first monograph on *Quasi-stellar objects* (13), in which all their then-known properties were described and discussed.

Early attempts to model QSOs revealed other seeming paradoxes. In 1966, Hoyle, Geoff and Wallace (Wal) Sargent (FRS 1981) showed that the rapid variability of the optical synchrotron radiation in these objects led to what is called the ‘inverse Compton catastrophe’ if the QSOs were at cosmological distances (12). This and the other problems could be avoided if the radiating sources were expanding at highly relativistic speeds, an approach advocated by Lodewijk Woltjer (Woltjer 1966) and one of us (MJR) (Rees 1966,1967). In 1966, Hoyle and Geoff wrote a further paper making the case that the QSOs might well be comparatively nearby objects shot out of nearby galaxies at relativistic speeds (11). Geoff was sympathetic to this as it was related to the radical ideas of the influential Armenian astronomer Viktor A. Ambartsumian (ForMemRS 1969), who envisaged the centres of galaxies as places where new matter was created. However, Peter Strittmatter, then a postdoc at UCSD, noted that the redshifts could not be due to Doppler motions, because if they were, blueshifts would predominate—but no blueshifted quasars had been observed, even though even one would have discredited the ‘cosmological’ interpretation. Moreover, Jesse Greenstein and
Schmidt had shown that the redshifts could not be gravitational either (Greenstein & Schmidt 1964). So, if the redshifts were not cosmological, they would signal the need for new physics.

In 1970 Geoff published a massive and influential survey in the *Annual Review of Astronomy and Astrophysics* with the title ‘The nuclei of galaxies’ (15). This review of 91 pages and 442 references brought together all the work he and Margaret had carried out on the central regions of galaxies with the vast amount of new material which had become available during the 1960s. The assessments were fair and authoritative, setting active galactic nuclei in the more general observational and theoretical contexts. But he was reluctant to concede that the quasars were the hyperactive nuclei of active galaxies. No mention was made of the fact that quasars with redshifts as large as two had already been discovered.

A further line of argument was advanced by Halton (Chip) Arp: in the late 1960s he claimed to find evidence that high redshift QSOs and radio sources often appear so close on the sky to low redshift bright galaxies that they must be physically associated (see, for example, Arp 1970). Arp had earlier noted that some groups of galaxies displayed ‘anomalous’ redshifts, for example in Stephan’s quintet which consists of a compact group of five galaxies in which four have similar redshifts but the fifth has a very much lower redshift (Arp 1973). He and Geoff were reluctant to dismiss these phenomena as chance superpositions. A further issue was the presence of absorption lines in QSO spectra with many different redshifts, all smaller than the emission-line redshift of the QSO itself. These are now convincingly attributed to intergalactic clouds and filaments along the line of sight. But Geoff attributed these all to ejected clouds. There were examples of quasar absorption lines with typical P-Cygni profiles which undoubtedly provided evidence for the ejection of matter from quasars, but the character of these was quite different from the narrow absorption features which had the same clustering properties as galaxies on the large scale.

When the first few QSOs were discovered, they were sufficiently bewildering that the kind of open-mindedness displayed by Geoff was surely salutary. But over the next decade, evidence accumulated that suggested how QSOs could be incorporated into a general scheme, and be interpreted, as were the giant radio sources, as extreme instances of activity in galactic nuclei, powered (probably) by processes around a supermassive black hole. As the evidence piled up, a diminishing number of astronomers were willing to take the so-called ‘non-cosmological redshifts’ as serious evidence for new physics.

The late 1960s was an exciting time for other aspects of ‘high energy astrophysics’, quite apart from the QSOs. Geoff was at the cusp of these developments, following the discoveries eagerly and contributing to the ensuing debates. In particular, radio astronomers discovered pulsars, which were soon interpreted as rotating magnetized neutron stars, and X-ray astronomers discovered compact sources in binary stellar systems, soon identified as accreting neutron stars and black holes. Geoff wrote, with Prendergast, a prescient paper interpreting these X-ray sources in terms of accretion discs—they attributed the intense and rapidly-varying emission to gas captured from the companion, swirling down onto a compact object and heated by viscous dissipation (14). Such ideas were applied soon afterwards by Donald Lynden-Bell (FRS 1978) to the larger-scale high energy phenomena in galactic nuclei, and have formed the basis for modelling that is ongoing to this day (Lynden-Bell 1969). It is ironic—and, in retrospect, sad—that, despite the head-start offered by his collaboration with Prendergast, Geoff never contributed to this endeavour.
Geoff’s involvement with QSOs continued for the next 20 years. He was assiduous in attending conferences, giving reviews and summary lectures. Although these gave him the opportunity to promote his distinctive theoretical ideas, he continued to stay close to the data, producing, jointly with his long-time assistant Adelaide Hewitt, expanded and updated catalogues of the QSOs that had been identified since the publication of his 1967 monograph (see, for example, (19), (20), (21), (22)).

Geoff’s almost undistracted immersion in innovative and highly-regarded research for almost 30 years resulted in major contributions to stellar, galactic and extragalactic astronomy. But gradually, from the mid 1960s onwards, the controversies over the nature of quasar redshifts and his adherence to Steady State cosmology, in the face of overwhelming evidence in favour of the standard Big Bang picture, dominated his thinking. He just would not let go of non-cosmological redshifts, which would require new physics, and non-primordial origins for the cosmic microwave background radiation.

From the 1970s onwards, however, his career developed in somewhat different directions with his involvement in the UK’s efforts to rejuvenate its heritage in optical astronomy and his future role as Director of the Kitt Peak National Observatory in the USA. His distinguished editorship of *Annual Review of Astronomy and Astrophysics* began in 1973.

**CAMBRIDGE, HERSTMONCEUX AND BRITISH ASTRO-POLITICS**

In the 1960s, Geoff, Margaret and Sarah spent parts of the summer in Cambridge, where they were regular visitors to Hoyle’s Institute of Theoretical Astronomy (IoTA; founded in 1966). Hoyle had based his design of the building—with wide corridors, and French windows in all rooms—on the Institute of Geophysics and Planetary Physics at UCSD, where the Burbidges at that time had their offices. For the next five years, the period for which the funding was guaranteed from a number of sources, IoTA was a magnet for the very best astrophysicists from around the world (figure 3). Margaret and Geoff continued their collaboration with Hoyle, Fowler and their numerous associates.

The European astronomers realized that there was a pressing need to construct more large reflecting telescopes in good climates, similar to those that existed in the United States at the Palomar, Mount Wilson, Lick and Kitt Peak observatories. In continental Europe, plans were being developed under the leadership of distinguished astronomers such as Jan Oort ForMemRS from the Netherlands and Baade and Otto Heckmann from Germany, for a European Southern Observatory (ESO) to be built in Chile.

In the 1960s Hoyle had a major role in planning for the future of UK optical astronomy as chairman of the Northern Hemisphere Review Committee. The committee consisted of Hoyle as chairman, Astronomer Royal Richard Woolley FRS, Astronomer Royal for Scotland Hermann Brück, several professors of physics, the director of Jodrell Bank, Bernard Lovell FRS, and two expatriate British astronomers, Sargent and Geoff. James (Jim) Hosie, an able and experienced civil servant with a mathematical background, was also a member.

A long series of two-day meetings was held. Possible sites discussed included the southwest United States, Hawaii, northern Chile, southwest Africa, the Canary Islands and Australia. The majority of the members favoured a northern hemisphere observatory to be operated independently of the Royal Observatories by the university community. The final majority report, which described how the new structure could be set up, was accompanied by a minority report from Woolley and Brück advocating that any new telescopes should be operated by the
Figure 3. Participants in the 1971 IoTA symposium to celebrate the sixtieth birthday of Willy Fowler. Many of the protagonists in this Memoir are present in this remarkable picture. The identifications are by row number (R) from the front row and from the left (l) or right (r). Thus, Geoff is (R2, l5). He is standing next to Martin Ryle (R2, l6). In the front row, there are Donald Lynden-Bell (R1, L2), Stephen Hawking (R1, l6), Fred Hoyle (R1, l8), Margaret Burbidge (R1, l9), Willy Fowler (R1, l10), Sarah Burbidge (R1, l11), Wal Sargent (R1, r6), and Roger Penrose (R1, r7). Further back there are Kip Thorne (R3, r6), John Archibald Wheeler (R4, l7), Bob Wagoner (R4, r4), Tony Hewish (R5, r7), and Al Cameron (R6, r8). The authors of this Memoir are at: MSL (R5, r5) and MJR (R1, r7). (Photography by Edward Leigh, 1971. Reproduced by courtesy of Lafayette Photography, Cambridge and the Institute of Astronomy, Cambridge University.)
existing Royal Observatories. Stalemate was reached and the report was never published by the Science Research Council (SRC).

A year or two after this episode, Woolley, the Astronomer Royal and director of the Royal Observatory at Greenwich (RGO), retired. Brian Flowers FRS, the chairman of the SRC, nominated Margaret, as the leading expatriate observational astronomer, to be the next director. She reluctantly accepted the appointment which, for the first time in 300 years, did not carry the title of Astronomer Royal. Martin Ryle was appointed Astronomer Royal, which thereafter has been simply an ‘honorary’ position. Geoff was promised a senior civil service appointment at the RGO. Unfortunately, the SRC was not prepared to support most of the changes Margaret wanted to make.

In the summer of 1972, the frustrations associated with the reception of the Northern Hemisphere Review Committee report and the difficulties in Margaret’s attempts to improve the situation at the RGO led Geoff to go public. He published a highly critical analysis of British astronomy in a letter to *Nature* (18) and also in a letter to *The Times* of London. This led to a great deal of publicity and great anger from the establishment.

After spending one summer in Herstmonceux Castle, Geoff returned with Sarah to La Jolla for domestic reasons. Margaret remained as director of the RGO for two and a half years and returned to California in 1972. In addition to the problems at the RGO, there were changes at IoTA in Cambridge. After five years of undoubted success and independent existence, it was amalgamated with the Cambridge Observatories to create the Cambridge Institute of Astronomy (IoA). As a result of the differences of opinion and fierce arguments over many aspects of the proposed changes, Hoyle resigned from the Plumian Chair and the directorship of IoTA and left Cambridge for good.

A positive legacy of this tortuous history was that the Burbidges and Hoyle were influential in the planning, construction and staffing of the 3.9-metre Anglo-Australian Telescope (AAT) and the associated Anglo-Australian Observatory (AAO), which was the first modern major venture for UK optical astronomy after World War II. Together with Hosie and Edward (Taffy) Bowen (FRS 1975), they pushed through major design changes for the AAT and appointed the first director, Joseph Wampler from Lick Observatory. Thus an outstanding observational and instrumental astronomer became the first director of a modern observatory that was half British in a good climate (Gascoigne et al. 1990). The Observatory played a major role in the regeneration of UK optical astronomy.

**DIRECTOR OF THE KITT PEAK NATIONAL OBSERVATORY**

In 1978, Geoff took a five-year leave of absence from UCSD to become the director of the Kitt Peak National Observatory (KPNO). As he notes in his reminiscences: ‘I remained director until 1984 and it was the hardest job, but in some ways the most satisfying job that I have done so far in my life’ (24).

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3 It is understood that the posts of Astronomer Royal and Director of the Royal Greenwich Observatory had been split prior to Margaret’s appointment to make possible the appointment of a non-UK citizen as director of the RGO.

4 An account of the events leading to the creation of the Institute of Astronomy and Hoyle’s resignation is contained in the book *Fred Hoyle’s Universe* by Jane Gregory (Gregory 2005).
Operating the 4-metre (Mayall) telescope together with the 2.2-metre and numerous smaller telescopes, the Observatory could provide excellent observing opportunities to the large community of astronomers who did not have access to large optical telescopes. They could now compete on roughly equal terms with the private observatories such as the Mount Wilson and Palomar and the Lick and McDonald University observatories. His instructions from the Board of the Association of Universities for Research in Astronomy (AURA), the managing entity contracted to the US National Science Foundation to operate the telescopes, were to convince the non-privileged astronomical community that it really was a national observatory for their benefit. Geoff succeeded in doing this by appointing new professional managers for the different divisions. The technical staff were the backbone of the operation and so he did everything he could to improve their morale and conditions.

For a year or so after his appointment, his decisions were fully supported, but, inevitably, as the operating budget did not keep pace with inflation, hard decisions had to be taken and preserving staff morale proved an increasingly difficult challenge. There were many crises. At one stage the Air Force announced that they planned to build a new airstrip very close to Kitt Peak. Fortunately, the Observatory had a good friend in Senator Barry Goldwater, who at that time was the senior senator from Arizona and chairman of the Senate Armed Services Committee. As a last resort, Geoff appealed to Goldwater for assistance and this was successful—the runway was not built.

During his period as director of KPNO, the observatory was involved in plans to build a much larger national telescope. A great deal of effort was spent on this. The final report advocated the construction of a giant 15-metre multiple mirror telescope (MMT) as the US national telescope, but it did not materialize. The National Optical Astronomy Observatory (NOAO), now overseeing all the national optical astronomy facilities, finally decided to build two 8-metre telescopes, one in Hawaii and one in Chile—the Gemini project, with the UK and Canada as major partners.

The budget cuts meant that the staff had to be reduced from more than 350 in 1978 to about 260 in 1984. There had been some overstaffing, but nothing approaching 20–25%. Understandably, Geoff states (24): ‘the trauma associated with firing good people involving a face-to-face discussion was to me the most painful thing I ever had to do. But I felt that in many cases I had to do it myself, and so I did.’

At the end of five years he was reappointed for a second term as director of Kitt Peak National Observatory, but AURA was planning a reorganization of the managerial structure of the observatories. The three observatories—KPNO, Cerro Tololo Inter-American Observatory (CTIO) and the Sacramento Peak National Solar Observatory—were to be placed under a single director who would decide how to allocate the resources. Although Geoff was an obvious candidate for the position, he was not selected. John Jeffries was chosen and Sidney Woolf worked under him as KPNO director. In 1984 Geoff resigned as director and returned to UCSD.

**Later Years**

The Burbidges were inveterate travellers, almost always to attend conferences or interact with collaborators. Geoff became specially fond of India, and made the first of many visits in November 1963 when he attended the International Cosmic Ray Conference in Jaipur. He
returned frequently, giving summer school lectures and seminars in Bangalore, Goa, Uddar Pradesh and elsewhere. On visits to Cambridge he continued his interaction with Fred Hoyle and began a long collaboration with Fred’s former student, Jayant Narlikar.

In 1972, Narlikar returned to India to become head of the Astrophysics Group at the Tata Institute in Mumbai and Geoff made frequent trips there to further their joint work. In 1988, Narlikar was appointed the founding director of the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in Pune. The institute was set up and funded by the Indian government to engage in frontier research in astrophysics and cosmology and to build connections with the Indian universities. This became Geoff’s regular destination for their collaboration in cosmology on alternatives to the standard Big Bang cosmology. The culminations of these efforts were two books entitled *A different approach to cosmology* with Narlikar and Hoyle (23) and *Facts and speculations in cosmology* with Narlikar (25). The basic concept of their different approach was that of an oscillating Steady State Universe, designed and tuned to mimic the many successes of the standard Big Bang picture.

A particularly notable part of Geoff’s later activities was in editorial work, both for *Annual Review of Astronomy and Astrophysics*, of which he was an editor-in-chief from 1973 to 2004, and for the *Astrophysical Journal*. It has been remarked by all his colleagues that, despite his controversial views on many astronomical and cosmological topics, he was scrupulously fair in ensuring that the reviews and articles spanned the whole gamut of research in all areas, allowing the individual voice of the writer to be heard. During the 1970s, he introduced the practice of inviting a distinguished astrophysicist to write an introductory review, the first one, by Ernst Öpik, being published in 1977. Geoff’s own essay appeared in the 2007 edition of the series (24).

In 1995 Geoff volunteered to become one of the scientific editors of the *Astrophysical Journal*, a role which he carried out until 2001, with Helmut Abt as editor-in-chief. Again, his integrity was impeccable. He wrote (24):

> This is where my very strong belief in fair play enters in. As an editor I always tried to be fair, even in situations in which my own interests were involved. If the editor allows his own point of view to enter and sends the paper to a referee who agrees with him, this is the kiss of death for any authors who don’t also agree with the editor and referee.

**SUMMARY—APPRECIATION**

Geoff’s most important and durable scientific achievement was his contribution to the 1957 B²FH paper (4), a work rightly regarded as a classic. Hoyle perhaps deserves credit as the instigator of this extraordinarily ambitious programme, but Geoff had not only a thorough understanding of nuclear physics, supplementing Fowler’s expertise, but also a comprehensive knowledge of stellar spectroscopy and phenomenology which he shared with Margaret. The four of them constituted a ‘dream team’. It seemed to many an injustice that only Fowler received recognition with a Nobel prize for this work.

This was the last project in which Geoff deployed his expertise in nuclear physics. His later work focused on non-stellar energy sources—those that produce high energy phenomena in many wavebands—radio galaxies, compact X-ray binaries and quasars. He was a prominent figure in many debates for four decades, but, in his later work, became typecast as a maverick.
He deserves uncontroverted credit for two contributions to high energy astrophysics. First, he appreciated very early the crucial role of synchrotron radiation for cosmic radio emission. This was in itself important, but he then made the spectacular inference of the energy content in the lobes of giant radio sources. This realization led to a focus on the centres, or ‘nuclei’, of galaxies. The 1963 paper, with Sandage, on violent events in galaxies gathered together the phenomenology. Among the ‘events’ studied were those in the Seyfert galaxies, where the emission lines of highly excited gas are detected. These emissions are now recognized to be either ‘starburst’ galaxies or to involve some non-thermal compact source in their centres.

Our understanding might have developed in a less confrontational fashion if these ‘violent events’ had been more fully studied and better understood by the time the QSOs were discovered. It would then have been natural to infer that they resembled Seyfert galaxies, but were systems in which the ‘wick’ had been turned up to such an extent that the non-stellar central emission swamped that from the entire galaxy. They appeared point-like in the early observations simply because the underlying host galaxy was too faint to be seen. But, despite these earlier premonitions that galaxies were more than assemblages of stars, and the pioneering work of Fritz Zwicky in cataloguing several categories of ‘active galaxies’, the QSOs, when first discovered, were treated as suis generis. Most astronomers made no immediate link with Seyferts, nor with the strong double radio sources associated with radio galaxies. That is why there was exaggerated worry about the energy, which Geoff should have been relaxed about because of his work on the extreme energy requirements of the double radio sources, and a greater willingness than in other astronomical contexts to be open-minded about the need to invoke new physics.

When the Burbidges’ monograph on QSOs was written, the nature of their redshifts was regarded as open. It took more than a decade before it was generally accepted that quasars were hyperactive galactic nuclei.5 What Geoff derided as a bandwagon seemed to nearly all of us a compellingly convincing set of arguments, and his views became marginalized.

The same happened with his post-1990 work with Hoyle and Narlikar on cosmology. Unlike the slow and tentative firming-up of QSO models, the cosmic microwave background (CMB) was accepted very quickly as the thermal radiation left over from our Universe’s hot, dense beginning, close to the prediction of Gamow and his colleagues in the late 1940s. Moreover, an important paper of 1967 by Fowler and Hoyle with Robert (Bob) Wagoner offered remarkable independent quantitative corroboration of the ‘Big Bang’ picture (Wagoner et al. 1967). The authors showed how helium, deuterium and lithium could be synthesized in the first three minutes of the cosmic expansion, a result that beautifully complemented the stellar nucleosynthetic processes discussed in B²FH. The latter theory could not account for the high measured helium abundance in even the oldest stars, nor for the other light elements.

But even in the 1990s, Geoff still held out against the standard ‘Big Bang’. He chaired a conference session when John Mather announced the first results from the COBE spacecraft, presenting the CMB spectrum that fitted that of a black body with a precision of one part in 10,000. But even this did not clinch the case for Geoff—he expressed surprise when the audience applauded this magnificent result. He still preferred the conjecture that the radiation

5 Some appreciation of the nature of the discussion over the origin of the redshifts of QSOs may be obtained from the book The redshift controversy (Field et al. 1974)
was starlight that had been thermalized by dust grains, even though an accurate black body spectrum is hard to achieve with plausible parameters.

Throughout his Kitt Peak years, and indeed for the rest of his life, he continued to be extremely critical of a blinkered ‘establishment’, as he saw it, for its reluctance to embrace new physics. He claimed that younger scientists were discouraged from exploring non-mainstream ideas and denied telescope time to do so. Despite his own prominence, these pronouncements gained declining traction: young astronomers, disregarding his advice, continued to vindicate the standard cosmological picture that he disparaged and through large-scale surveys, numerical modelling and measurements of the CMB have firmed up its quantitative details to an astonishing degree; the case for ‘anomalous redshifts’ has wilted completely.

There is a telling comment in Geoff’s autobiographical article explaining his motivations for exploring unconventional cosmology (24):

...there were two factors that I thought were very important. The first was the observational evidence and how it was interpreted. The second was the view of Fred Hoyle who I worked with on so many astrophysical problems.

Hoyle was not only Geoff’s long-time friend and collaborator, but someone whose leaps of the imagination merited special respect because of his near-unparalleled record of original insights from the 1940s to the 1960s. It was a sad loss for the rest of the community that so much of their later years were spent in controversies where their views, although a salutary antidote to complacency, became no more than diverting footnotes to the history of the advance of astrophysics and cosmology.

But, quite apart from the towering achievement of B²FH, Geoff Burbidge will be remembered as one of the polymaths of our subject—and especially for all he did to illuminate, and promote, the whole range of phenomena that go under the name of ‘high energy astrophysics’ when the subject was first opening up. Quite apart from his research, he served the community in many ways—through his lectures and reviews, his editorial work and his directorship of a leading publicly-funded observatory in the USA. He was a fine expositor, with infectious enthusiasm, and his influence on the astronomical community was worldwide.

In addition, he was a passionate supporter of gender equality for women astronomers. Among his earliest experiences of the problems facing women in astronomy was the bar on women using the telescopes at the Mount Wilson Observatory. He went along so that Margaret could make her observations. This advocacy for women in astronomy was the reason he encouraged Margaret to accept the directorship of the Royal Greenwich Observatory. Besides Margaret, distinguished astronomers such as Sandra (Sandy) Faber, Vera Rubin, Anneila Sargent and many others all benefited from Geoff’s unswerving support for the advancement of their careers.

Those who were privileged to know him speak of his loyalty to his friends, his honesty and his integrity. And they will all recollect his extraordinarily close and creative partnership with Margaret—in both scientific and practical life. She was, incidentally, elected a Fellow of the Royal Society four years before him. Their personalities, scientific styles and expertise were contrasting, but symbiotic. Indeed, this complementarity extended to their everyday life. For instance, Geoff would plan their schedule and their travel, but he never learned to drive—this was left to Margaret, who for many years had a Jaguar of the ‘Inspector Morse’ variety.
This collaboration of two exceptional scientists, sustaining an intense focus on discovery and service over more than 50 years, had a huge influence on the astronomical community.

Geoff died on 26 January 2010 at the age of 84 after a prolonged illness. As Jayant Narlikar writes:

Although physically debilitated for many months, Geoff retained the mental and intellectual sharpness that had been so effective in critical appraisal of his field: astrophysics and cosmology.

He is survived by Margaret, their daughter Sarah and his grandson Connor Loeven.

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AWARDS AND RECOGNITION

1959 Helen Warner Prize of the American Astronomical Society (with Margaret Burbidge)
1968 Fellow of the Royal Society of London
1985 Jansky Prize, National Radio Astronomy Observatory
1989 Vainu Bappu Memorial Award, Indian National Science Academy
1999 Bruce Medal of the Astronomical Society of the Pacific
2005 Gold Medal of the Royal Astronomical Society (with Margaret Burbidge)
2007 National Academy of Sciences Award for Scientific Reviewing of the National Academy of Sciences

REFERENCES TO OTHER AUTHORS

Bibliography

The following publications are those referred to directly in the text. A full bibliography is available as electronic supplementary material via http://dx.doi.org/10.1098/rsbm.2017.0002 or via https://doi.org/10.6084/m9.figshare.c.3782258.


