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Geoffrey R. Burbidge (1925–2010)

ARTHUR M. WOLFE
Department of Physics Center for Astrophysics Space Sciences; University of California, San Diego
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Geoffrey R. Burbidge, one of the principal architects of 20th century astrophysics, died in La Jolla, California, on 2010 January 26. Together with his wife and lifelong collaborator, Margaret Burbidge, and several leading astrophysicists, he originated ideas that remain at the core of current astrophysical research. He was, of course, coauthor of B^2FH (Burbidge, Burbidge, Fowler, & Hoyle 1957), one of the most influential scientific papers ever written, which explained how elements heavier than helium are synthesized in the interiors of stars. Geoff's research interests spanned a wide range of topics. He was the first to estimate the colossal energetics of extragalactic radio sources. Together with Margaret and Kevin Prendergast he initiated the first systematic program to measure the masses of galaxies from their rotation curves. He published research that effectively began the field of "active galactic nuclei," and he made the fundamental suggestion that galactic X-ray sources were powered by viscous transport of energy in accretion disks surrounding neutron stars or black holes in binary star systems. After the discovery of quasars in 1963, Geoff wrote influential papers on gravitational collapse as their energy source and an excellent book summarizing research on this subject. During the latter part of his career Geoff became known as the "great contrarian" who remained skeptical about the cosmological origin of quasar redshifts and rejected the big bang theory. He was author of 355 publications.

Geoff was born in 1925 September in Chipping Norton Oxfordshire, where he grew up and developed a lifelong passion for tennis. He attended the yearly matches at Wimbledon with his father, a ritual he maintained for most of his life. In 1946 he got his undergraduate degree in physics at the University of Bristol. After graduating he was assigned for 18 months to a government ballistics laboratory in London, where he became an expert in testing penetration bombs and other types of demolition devices, and where he decided to pursue a graduate career in physics. In 1947 he began studying theoretical physics with H. Massey at University College London and received his Ph.D. in physics in 1950 with a thesis concerning capture of muons by atoms. During his stay in London, Geoff's interest in astronomy was sparked upon meeting his future wife, Margaret Peachey, who was the Assistant Director of the University of London Observatory; they married in 1948. Margaret was working on spectral variations in Be stars, and Geoff collaborated with her by participating in her observing runs and in performing theoretical analysis, beginning a unique and famous scientific partnership that lasted over 60 years.

After Geoff obtained his Ph.D., he and Margaret went to the US in 1951, he to Harvard and she to Yerkes Observatory. Between 1951 and 1957 the Burbidges held research appointments at Cambridge University, Carnegie Observatories, and Caltech. During this period their work on the peculiar abundances of magnetic variable stars attracted the attention of the Caltech nuclear physicist Willy Fowler, who was visiting Cambridge. They were soon collaborating with him on the general problem of the origin of the elements and on the s process in particular. Fred Hoyle, who had been advocating stellar interiors as the sites of element production, joined the collaboration, and after a few preliminary papers Fowler invited the group to Pasadena. Between 1955 and 1957 the group worked on various aspects of nucleosynthesis. The culmination of these efforts was the publication of B^2FH in 1957. The significance of this paper is that by shifting the site of element production from the primordial universe, as advocated by George Gamow and colleagues, to stellar interiors, B^2FH provided compelling evidence for a new way to understand the origin of the elements. The authors gave an exhaustive account of the processes that go into building elements lighter than ^{56}Fe (nuclear fusion) and elements heavier than ^{56}Fe (s process, r process, p process, etc.). They showed that the variety of physical conditions in stars resulting from their evolution naturally explained the variety of temperatures and densities required to produce the diversity of chemical abundances measured in stellar atmospheres. Their work also explained the peaks in the abundance curves, i.e., chemical abundance versus atomic weight, and identified supernovae and red giant stars as production sites for heavy elements. Publication of this paper resulted in the demise of the competing primordial theory and widespread acceptance of B^2FH as the gold standard for explaining the origin of the elements heavier than ^7L. While the authors ran into difficulties explaining the origin of elements with masses equal to or lighter than ^7L, which they attributed to an unknown x process, the consensus view today is that these elements do have a primordial origin. However, Geoff argued that all the elements were synthesized in stellar interiors.

While he was working on nucleosynthesis, Geoff became interested in the physics of the newly detected radio sources. He was convinced that they were emitting incoherent synchrotron

Courtesy of Sarah Burbidge. Credit: NOAO/AURA/NSF.

radiation, which was far from obvious at this time. In a highly influential paper published in 1956, the year his daughter Sarah was born, he showed that the condition for a minimum total energy in relativistic particles and magnetic fields occurs when the two are in approximate equipartition. Applying these ideas to radio galaxies and later on to quasars, he determined total minimum energies as large as 10^{60} ergs. The need to find a "machine" efficient enough to generate such colossal energies led Geoff, Hoyle, and several other theorists to turn from the release of nuclear binding energy, which powers the energy output of stars, to gravitational binding energy as the source of these energetic events. Accretion of matter onto black holes is the modern version of these ideas.

Between 1957 and 1962 Geoff and Margaret held faculty positions at the University of Chicago Yerkes Observatory in Wisconsin. During this period Geoff became interested in the properties of galaxies. In the late 1930s Horace Babcock of Carnegie Observatories had deduced the mass of the giant nearby spiral galaxy M31 by measuring its rotation curve, but otherwise little was known. Between 1959 and 1969, Geoff, Margaret, and their Yerkes colleague Kevin Prendergast carried out the first comprehensive investigation of galaxy masses. In all, they obtained spectra for about 30 spiral and barred spiral galaxies. They deduced rotation curves from velocity displacements of $\mathrm{H}\alpha$ and N II emission lines with respect to the systemic motion of the Galaxy. The measurements were carried out with a Cassegrain spectrograph attached to the 82 inch telescope at McDonald Observatory in west Texas. Besides being the first of its kind, the work was groundbreaking for the following reasons: First, the techniques introduced by the Burbidges were ultimately used to discover the presence of dark matter in galaxies. Second, during the course of their work, they discovered noncircular motions near the centers of a subset of the galaxy sample, which led to the idea of activity at the centers of galaxies. Recognizing the similarity between the velocity fields of these active galaxies and quasars, Geoff, Margaret, and Alan Sandage wrote an important review article in 1963 entitled, "Violent Events in the Nuclei of Galaxies," thus giving birth to the research field of "Active Galactic Nuclei," which has remained vibrant to this day.

Geoff, along with Margaret, joined the faculty of the University of California, San Diego (UCSD) in 1962, where, except for short stints back in the UK and his directorship of Kitt Peak National Observatory, he stayed until he passed away. Geoff's research focused on quasars after their discovery in 1963. Geoff maintained that the quasar redshifts were not due to the expansion of the universe, but rather were intrinsic to the quasar. In this case the quasars would be relatively nearby, rather than at cosmological distances, which he argued would help to alleviate the enormous energetic requirements arising from their high luminosities. He participated in the discovery of quasar absorption lines in 1966, which led to much fruitful research concerning the foreground absorbing gas. Because of his position on quasar redshifts, Geoff believed that the difference between the absorption redshift and the higher emission redshift of the quasar was due to the velocity of the absorbing gas being ejected from the quasar. But, the consensus view today is that quasars are at cosmological distances and, in most cases, the absorbing gas coincides with intervening matter that has lower redshifts because it is nearer to us than the background quasar. Later in his career Geoff became an adherent of the modified steady-state cosmology, i.e., the quasi–steady-state theory, arguing for an alternative explanation for the cosmic microwave background radiation, helium production, etc. In my opinion, Geoff's contrarian views reflected his distrust of the bandwagon phenomenon, which he interpreted as the uncritical behavior of scientists following what he regarded as the wrong-headed views of a few elite leaders.

Geoff also contributed in many other ways to the astronomical community. He was editor of *Annual Reviews of Astronomy and Astrophysics* (*ARAA*) from 1973 to 2004. The editorial committees regarded him as an excellent editor who kept his scientific prejudices out of the discussions and who was mainly responsible for the superb reputation of this journal. Geoff was Director of Kitt Peak National Observatory from 1978 to 1984, where he carried out much needed reforms, and scientific editor of the *Astrophysical Journal* from 1995 to 2001. Geoff also served on several committees, including chairmanship of the Astronomical Advisory Committee for the National Science Foundations from 1966 to 1967. He was on the board of the Association of Universities for Research in Astronomy from 1970 to 1974, the organization that administers Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, and Sacramento Peak Observatory. From 1972 to 1982, he was a board member of the Associated Universities Inc., which administers the Brookhaven National Laboratory and the National Radio Astronomy Observatory.

Geoff and Margaret were recipients of the Gold Medal of the Royal Astronomical Society in 2005. He received the Catherine Bruce Gold Medal of the Astronomical Society of the Pacific in 1999 and the Jansky Prize of the National Radio Astronomy Observatory in 1985. In 1959, he and Margaret received the Warner Prize of the American Astronomical Society. He was also a fellow of the Royal Society, the American Academy of Arts and Sciences, the American Physical Society, and the University of London.

Finally, some personal recollections: Geoff had an imposing charismatic personality as well as a dynamic wit. Both of these characteristics were on display at the weekly astrophysical seminars held at the Center for Astrophysics and Space Sciences at UCSD. On many occasions Geoff's booming voice could be heard, well outside the seminar room, expressing some of his favorite themes. For example, despite all the claims about mass infall into galaxies, as far as he was concerned the data showed evidence for just the opposite: i.e., for mass being ejected from the galaxies. Geoff could sometimes be heard complaining about the praises heaped on modern cosmology, which he termed as "big bangery." In most cases the seminar speaker would be forewarned that there was nothing personal in these outbursts, but rather it was just Geoff venting. Once the seminar got underway, Geoff would inevitably fall asleep. But, at the end of the talk, just as inevitably, he would wake up with a start and ask questions indicating that not only had he fully understood the talk, but that he usually brought a fresh perspective to the subject that few in the audience had appreciated.

Geoff exhibited two outstanding traits. First, he had a high sense of personal integrity. This was evident in the editorial sessions of the *ARAA*. When deciding who should be asked to write a review article about a specific topic, he would usually favor the person with the best scientific reputation, even if he disagreed with the scientific opinions of that individual. When adjudicating personal conflicts, Geoff was neither swayed by institutional prestige nor the seniority of the participants. Rather, he tried to get at the core of the truth, even if that meant sticking up for the underdog against more powerful voices. Geoff had another admirable quality: he was loyal to his friends. He could always be counted on for support, no matter how difficult the circumstances. This is the characteristic that I will miss the most.