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The Early Years of Radio Astronomy at Caltech*

Jesse L. Greenstein

Department of Astronomy and Palomar Observatory,
California Institute of Technology, Pasadena, CA 91125, U.S.A.

Abstract

By the early 1950s astronomy in the United States was under pressure to embrace radio astronomy, which was being developed largely outside the USA. Much of the motivation derived from the need for accurate radio source positions, so that optical telescopes like the California Institute of Technology's giant Palomar Telescope and the nearby Mt Wilson Telescope could identify these sources with astronomical objects. To lead Caltech's move into radio astronomy its president, Lee DuBridge, realised that he needed a leader from a country with more practical experience than the USA. He turned to his wartime friend E. G. 'Taffy' Bowen, chief of the CSIRO's Radiophysics Laboratory in Sydney, who 'loaned' him John Bolton. John stayed at Caltech for a bare five years, but it was a time of inspired guidance that helped to secure a place in radio astronomy, not only for Caltech, but for the USA.

1. Introduction

To honour John Bolton is a pleasant, but sad duty. I knew him for some years, when he contributed greatly to the growth of radio astronomy in the United States. Given my present ancient age (84) it seems particularly sad that we should lose younger men of such great talent and charm. Through John Bolton many Americans had the opportunity to meet those who helped place Australia in the forefront of a new science. The excitement generated by the successful identification of several classes of radio sources with astronomical objects, by the year 1951, had placed irresistible pressures on US astronomy. Physicists and engineers involved in military radar and other electronics-driven projects saw a new field in which their talents would find ample scope. Among the US institutions involved were the Naval Research Laboratory (which expanded also into rocket astronomy) and the Massachusetts Institute of Technology's Lincoln Laboratory (inheritors of the wartime Radiation Laboratory). University-based groups (from Cornell, Harvard, Michigan, Ohio State) built on what their local talents encouraged. Funding from US military research organisations (especially

* Refereed paper based on a contribution read on the author's behalf to the John Bolton Memorial Symposium held at the Parkes Observatory, 9–10 December 1993. This paper is based on a scientific autobiography now being written, with some deletions and additions. I hope that this material will be included in a book giving an account of my involvement with the early years of radio astronomy, as part of my story of sixty years in American astrophysics (JLG).

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the Office of Naval Research) was easy, since high-frequency and low-noise technology were related to their missions.

Several Pasadena optical astronomers were convinced that we needed a radio observatory close to the Mount Wilson and Palomar Observatories. Active protagonists included Walter Baade and Rudolph Minkowski (from the Carnegie Institution of Washington, i.e. Mt Wilson) and myself (from the California Institute of Technology, i.e. Palomar). But we lacked the local radio engineering talent which existed at other universities. Our administrative structure was also quite complex. I. S. Bowen, Director of the Mt Wilson and Palomar Observatories, was responsible for optical astronomy. Bowen, a physicist with expertise in spectroscopy and optics, was by nature conservative. The Observatory Committee (on which I served as Caltech's representative) was sympathetic, but decided that radio frequencies were not 'light' and therefore lay outside the charter of the Mt Wilson and Palomar Observatories. A radio observatory could be within Caltech's Division of Physics, Mathematics and Astronomy. I ran (insofar as anyone ran anything in a good university) the latter 'department' (or option, since separate departments did not exist). It was planned that any radio-astronomy faculty should hold appointments, and students receive degrees, in either astronomy or physics. This flexibility eventually brought some of our best students and staff into radio astronomy.

Positive factors minimising the possible organisational mess were the people to whom I was responsible. Robert F. Bacher (who had been at both the MIT Radiation Laboratory and Los Alamos, and was an Atomic Energy Commissioner) was Division Chairman, and Lee A. DuBridge (who had headed the MIT Radiation Laboratory) was Caltech's energetic President. They were well-informed and influential in Washington. The country owed them a good deal. Although I made as strong a scientific case as I could, they raised a question valid for that time. Did radio astronomy have an important scientific future? In retrospect, this may seem an odd concern, but the future is never easy to predict. Conceptual difficulties then were: (a) the low angular resolution of any conceivable single-dish antenna, (b) the apparent paucity of spectral lines, negating measures of composition or velocity, and (c) the gap between information and interpretation. A senior administrator often copes with such questions by 'calling a meeting'. They did and I became secretary of the organising committee; its other members were Bart Bok, John Hagen, Merle Tuve, Jerome Wiesner, and Charles Seeger of the newly established National Science Foundation.

The international conference, held in Washington in January 1954 and sponsored by the NSF, the Carnegie Institution and Caltech, was a success. One consequence was the birth of the US National Radio Astronomy Observatory. Only a résumé was published (see *J. Geophys. Res.* **59**, pp. 149–201, 1954). Attendees were a Who's Who: from Australia, E. G. (Taffy) Bowen and B. Y. Mills; from Great Britain, R. Hanbury Brown, C. G. Little, F. Hoyle and F. Graham Smith; and from the Netherlands, H. C. van de Hulst, who earlier had predicted the pivotal spectral line of hydrogen. At the conference Charles Townes reviewed other lines expected from laboratory studies, giving us our first introduction to microwave spectroscopy. By then the 21-cm hydrogen line had already been used to map the velocity and concentration of Galactic hydrogen. The science of radio astronomy proved itself clearly here to stay.

2. Birth of the Owens Valley Radio Observatory

Caltech needed a working leader and Bacher and DuBridge felt assured that money would be obtainable to employ such a person. It appeared that the leader had to be from outside the US, from a country with longer practical experience. The 'brain drain' was actively flowing; much of my own 5-year-old astronomy department had foreign origins. DuBridge and Taffy Bowen (head of CSIRO's Radiophysics Laboratory in Australia) were old friends, with Taffy providing the first link between British radar and the Radiation Lab early in World War II. Taffy strongly recommended a young Englishman, John Bolton, then resident in Australia. He had been radar officer on a British aircraft carrier during the war and joined CSIRO for its breadth of opportunities at the war's end. Added to his self-reliance, imagination and scientific skills was his ability to pour concrete and weld steel. To obtain improved positions of radio sources Bolton, with others, had designed and built an interferometer on a cliff top at Dover Heights in Sydney. The radio beam, passing over the ocean, interfered with its reflected image, giving a baseline twice the cliff height; the diurnal motion of the sky carrying the radio sources through the fringe pattern. A similar device was later transported to the west coast of New Zealand, to observe a source as it sets (see the paper by Orchiston in this issue, p. 541). Differences between the Bolton and Stanley cliff-top interferometer positions and British measurements at first were several degrees; some were suspected to be in rapid motion!

But after ironing out the difficulties, the Dover Heights interferometer permitted Bolton to make the first believable identification of three radio 'sources' with strange objects in the optical sky. They were the Crab Nebula (a supernova remnant), M87 (a giant elliptical galaxy with a central jet) and NGC 5128 (a nearby, highly disturbed, interacting spiral). So, attracting Bolton to build, and lead, our radio observatory sounded fine to me. What did optical astronomers want from radio at first? They hoped for radio source positions sufficiently accurate for Minkowski or Baade (and later others) to point the new 200-inch Palomar reflector and to discover with which optical object the radio source was identified. At the time, that goal (better than 60, and possibly 10, arcseconds) seemed remote, requiring that the errors be reduced by more than an order of magnitude. However, such precise positions became the first goal of the instruments that were built—the two- and three-element interferometers at Owens Valley, with variable baselines near a kilometre, and then the multi-element interferometers at higher frequency. The pursuit of resolution eventually culminated in the Very Large Array in New Mexico, with 27 antennae and 40-km baselines, and more recently to the proposed Very Long Baseline Array. In Australia, large Southern-Hemisphere arrays were also built and made strategic surveys. A dividend that Bolton and collaborators eventually provided was the size and shape of large radio sources, by using antennae at variable spacing.

An opportunity to spend some time with John Bolton appeared in the summer of 1955. I ordered a car for delivery in Glasgow and then made plans to attend the IAU Symposium at Jodrell Bank near Manchester, where Bernard Lovell's large steerable antenna was being built. It worked out beautifully. I picked up the new car, a green MG Magnette sedan, and we toured the long narrow lanes of Scotland. John and I visited pub after pub, sampling the varied, local, single-malt whiskys. We agreed on his scientific plans for Pasadena, gave our scientific papers in Manchester, and then I delivered John (from memory to a sister in Leeds). I drove the MG to London, where it performed a four-wheel 90° skid at the bottom of a hill to miss a bus on the wrong side of the road (wrong, even as defined in England!).

The 1955 IAU Symposium was probably radio astronomy's coming-of-age party. It was a quite an international meeting which brought definitive agreement that non-thermal, electron-synchrotron radiation dominated strong radio sources. The Shklovskii–Ginzburg model triumphed. Cosmic-ray electrons at relativistic energies (although rare in our Galaxy) radiated copiously in the magnetic fields of radio sources, from X-rays to radio frequencies. In the Crab Nebula they emit highly polarised blue light! I gave what was to be my last paper on thermal sources, in which I evaluated the total energy involved in the strong radio sources. Thermal radiation from ionised gas clouds, or galaxies in collision, proved too small. Thus, 1955 marked the realisation that enormous violence dominated the cosmos. In Manchester, I also saw a laboratory demonstration of the quantum nature of light by Robert Hanbury Brown (and Richard Twiss), which led to the building of his unconventional stellar intensity interferometer in Australia. Hanbury was not only a devotee of sports cars (I believe he owned a monstrous Alvis), he had an unusually broad-ranging mind.

My MG was a joy in California for many years, as was John Bolton, but alas for only a few years. He came to Pasadena and established his operation in the astronomy building (Robinson Lab). He built a 32-foot antenna for 21-cm observations on Palomar, while surveying southern California for a radio-quiet, accessible location. Some of us had hoped at first that a similar mountain top near Mt Palomar would be suitable to provide mutual support in the expansion of electronics for astronomy. Unfortunately, the aerospace industry had made Mt Palomar into a radio-noisy location; the 200-inch dome was used as a target by pilots learning blind navigation, bathing the mountain with high-frequency beams. The nearest, large, radio-quiet site provided to be in the Owens Valley, a sink between the Sierra Nevada and the White Mountains, both about 14,000 feet high. With 5-hour commuting, it was not too remote to be supported from Pasadena; its low humidity also permitted later work down to millimetre wavelengths. The isolated and large area of land needed was available because the valley, and the water drainage from the mountains, had been pre-empted by the Metropolitan Water District of the City of Los Angeles. There Bolton created the Owens Valley Radio Observatory (OVRO) with its tradition of multi-element, variable-spacing interferometers. At first it was a home-made and inexpensive construction—2000 feet of track built east–west and a similar north–south leg to carry the moveable antennae. The levelling and grading were the summer task of a first-year graduate student, R. R. Wilson, a quiet Texan who could drive a caterpillar tractor. (Bob Wilson later shared the Nobel Prize for Physics with Arno Penzias for the discovery, at the Bell Telephone Laboratory, of the 2·7-K background radiation.)

The members of the frame supporting the antenna skin needed miles of precision welding, and Bolton's proverbial skill was a not trivial factor. I remember John, sprawled high in the spidery steel framework, bossing older, redneck American welders. Waving the noisy torch, in his curious, quiet, Anglo-Australian accent, he lectured them with something like: 'So many inches one side, then the other, front and back! No slop, no breaks!!'. The students received invaluable hands-on training—building receivers, digging the desert floor, laying cable, pouring concrete and climbing steelwork. John's policy was that students help build or test their own equipment, do their own observing and write their theses with a good deal of independence.

3. Operations

Bolton was a most successful and inspiring guide for our first graduate students. Letty, John's Australian wife (formerly a nurse) was very sociable. She ran the numerous dinners, thesis celebrations, parties and picnics with skill from their small house. The students found a friendly centre; much of the present US leadership in radio astronomy came from among those early students. They remained intensely loyal to the Boltons. At one of those parties, personal disaster loomed for me. In a (unspokenly competitive) display of masculinity, I tried to match drinking straight scotches (without food) against the redoubtable Taffy Bowen, there on a visit. I found out later that he was negotiating for Bolton's return to Australia to head the 210-foot project. The noisy crowd of students eating dinner at Letty's house had, as desert, fresh strawberries and cream. They looked irresistible but made me deathly ill. I should have known that I was no match for Taffy, as the outcome of high-level science politics soon proved. My surfeit of strawberries and scotch was as much a mistake as my belief that radio astronomy had become a firmly established part of Caltech's graduate instruction and research program. Nevertheless, the important fact is that early students under Bolton were among our most successful. Many became leaders in world radio astronomy.

Optical astronomers expected, and got, invaluable information from Bolton's improved apparatus. One of the most important gifts of the two-element interferometer working at 960 MHz was a particularly accurate position of the source 3C 295; from a Tom Matthew's position with a 25-square arcsecond error box, John had the pleasure of being the first to search an excellent 48-inch Schmidt photograph provided by Rudolph Minkowski. He found that there was a faint galaxy, the now precise position of which permitted Minkowski to observe it with the 200-inch telescope. Based on only one emission line at first, 3C 295 had a redshift of 46%, much higher than any previously known, and triple the highest z found after years of search by Hubble and Humason. Radio galaxies were shown to be extraordinary luminous!

In return, some radio astronomers became optically oriented. In particular, John Bolton himself later became an optical observer, specialising in the search for large redshifts of galaxies and quasars. He returned from Australia to Berkeley and to the Lick and Mt Palomar Observatories as a welcome guest observer for many years. Less well known was his involvement in the early work on 'radio stars', now called quasars. Tom Matthews had optical-telescope experience, and John and Tom cooperated with Allan Sandage by providing accurate radio positions for what became known as radio stars, compact or unresolved radio sources. At the 1960 Christmas meeting of the American Astronomical Society, a paper presented by T. A. Matthews, J. G. Bolton, J. L. Greenstein, A. R. Sandage and G. Munch discussed 3C 48 for which the last three authors, optical astronomers, had all obtained spectra that showed unidentifiable lines. Matthews was so closely linked with that object that, with the emission lines at last identified as at redshift 37%, he was co-author with me of a paper published in *Nature* (Greenstein and Matthews 1963).

There is often much more to a story than is apparent when it happens. My experiences with the Establishment have had many hidden turnings, revealed to me only in hindsight. It is rather like peeling an onion, except that this onion had no finite core. Bolton did not really enjoy being a professor. He had done what he had promised at Caltech in starting radio astronomy and, to my unhappy surprise, he resigned in 1960, soon after he became a professor. Only after he left to take charge of the 210-ft dish in Australia did I learn that his Caltech stay had been an arranged 'loan' between DuBridge and Taffy Bowen (for more detail see Roberts in this issue p. 561). Gordon Stanley stayed in Pasadena and succeeded Bolton as Director of the Owens Valley Radio Observatory (see p. 507).

Bolton's story involves other major historic events, but these must be left for others to tell. I salute his memory.

References

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