History of Australian Astronomy

The Fortieth Anniversary of Extragalactic Radio Astronomy: Radiophysics in Exile

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In 1931 Karl Jansky established that radio noise was associated with our own galaxy—the Milky Way. For a decade and a half there was little follow-up; those of us who were associated with low frequency radar during the war regarded it as a nuisance which could limit the detection range of enemy aircraft. Grote Reber was the first to make a detailed but fairly low resolution map of the radiation from the galaxy showing, for the first time, some detailed structure. The event which we celebrate today occurred when Gordon Stanley, Bruce Slee and I showed that three of the discrete sources that we had discovered could be identified with visual objects. One was with the Crab Nebula, a supernova remnant within our own galaxy and the other two with galaxies, far beyond our own system, in the constellations of Virgo and Centaurus. Thus began extragalactic radio astronomy. In 1982 at the Noosa meeting of the ASA, I gave an account of those early years, later to be published in the ASA Proceedings. As I don't wish to repeat myself, I propose to speak on my involvement in a later development which was to extend the observable scale of the universe to look-back times as great as the age of the oldest stars in our own system. The first important step was Graham Smith's identification of Cygnus A with a galaxy that was much fainter than our two. The spectrum by Minkowski revealed an intrinsically highly-luminous galaxy with strong emission lines and opened up the possibility of discovering similar objects at significantly greater distance. This was achieved nine years later with the building of the Owens Valley Observatory and my title of ‘Radiophysics in Exile’ comes from the fact the observatory owed its existence and early successes very largely to past and future staff members of Radiophysics. They were, in order of appearance, J. G. Bolton, G. J. Stanley, K. C. Westfold, J. A. Roberts, V. Radhakrishnan, D. Morris and K. I. Kellermann. Some still bear the scars—Westfold left the tip of one index finger in the Owens Valley!

I was the first to arrive at Caltech, one weekend in January 1955. At 9 am on the Monday morning Rudolph Minkowski appeared in my office. He had come, he said, not to try and influence me in any way, but to suggest that anything I built should offer the possibility of second-of-arc positions of radio sources to combine with the facilities he had access to, those of the Palomar 200 inch telescope. Each succeeding Monday, when possible, for the following four years he made a check to see that his suggestion was being followed up! Stanley arrived a few months later, and with the very significant contribution of Bruce Rule on the engineering side and the Office of Naval Research on the financial side, the installation in the Owens Valley was dedicated in November 1958. Superficially it bore some resemblance to the Australia Telescope. It only had two dishes instead of five and the dishes were larger, prime focus instead of Cassegrain, and equatorially mounted rather than alt-az. It had a shorter East-West baseline with fewer stations, but it also had a North-South line. Originally it had been planned to operate at 400 MHz with a buried waveguide linking the two dishes. Developments during the construction years had a 750 MHz receiver on the first telescope at dedication, to be replaced with 960 MHz during commissioning. This choice was to fit in with JPL and their Explorer Satellites and ground stations which used Stanley-designed receiver front-ends.

At that stage I returned to Australia for a month's break, then to Europe and the eastern USA to catch up on developments in Radio Astronomy. At NRL, I spent an afternoon with Russell Sloanaker who had not been able to convince his colleagues that his painstaking observations of Jupiter indicated a disk temperature (equivalent black body) of around 400 K at 10 cm. I was convinced and that night rang Gordon, who began observations with Jim Roberts. Jupiter was close to the galactic plane and could only be detected against its small scale structure by subtracting observations a week apart as the planet moved. They found a disk temperature of around 6000 K. We let Russell know the result and also Frank Drake at Greenbank who easily made the detection against a much lower galactic background at 1400 MHz.

1959 saw the first telescope used at 960 MHz for a variety of programmes. Jim Roberts and Dan Harris used it to find sources to fit the numbers in the original 3C catalogue. Many of the 3C positions were lobe-shifted and we wished to have a finding list with an accuracy of a few minutes of arc for later interferometry. A number of the objects which could be identified showed that radio galaxies were at the upper end of the luminosity function for galaxies. Dan Harris looked at all the known supernova remnants for his thesis material. Bob Wilson and I mapped the region of the galactic plane. Barry Clark and I made drift scans of Centaurus A as a dinner-hour project to provide the then best map of its outer structure. Rad and I got the second telescope going mid-year with a narrow band H-line receiver. Rad made the first detection of the H-line in self-absorption in a region near IC443 and thus began a mammoth project that was not to end until ten years later at Parkes.

Dave Morris and I finally installed a second 960 MHz receiver and linked the two dishes at Christmas, 1959. Although sources could be seen on each dish, we had no trace of interferometer patterns for four agonising days, during which we pulled the whole system apart. Finally we found that two drums of cable were to provide the IF paths to the central portable building at all the spacings were not identical as ordered from the supplier but differed by 500ft! Bandwidth dispersion did the rest! For the first six months the baseline was steadily increased. Each move first involved the more technically minded staff—Gordon, Rad, Dave Morris and me, and graduate students Bob Wilson and Dick Read—in solving the problems that accompanied the move and trying to anticipate those of the next. Observing sessions followed: Al Moffet and Dave Morris made observations of sources at transit and various hour angles for determination of source structure, Rad and Jim Roberts made their famous observations, including polarimetry, of Jupiter which were to show synchrotron radiation from a van Allen-type belt as the source of the excess radiation, and Tom Matthews and Dick Read made some preliminary observations on the stability of the system for positional work.
After six months we had reached the end of the baseline. Quite a number of sources had been resolved, some of which showed double structure, similar to Cygnus A and Centaurus A. Identified sources confirmed what we already suspected: galactic sources had radio diameters about the same as optical, while extragalactic radio diameters were much larger than optical. Obviously good extragalactic calibrators required identification of very small diameter sources. Such objects would also satisfy Minkowski's ambition to obtain the line spectrum of an object which could not be detected against the background on a direct photographic plate. Amongst the sources not resolved at the longest baseline were four relatively strong objects which were also not resolved at Jodrell Bank's longest baseline; moreover they were not lobe-shifted in the 3C catalogue which indicated to us that they were in relatively unconfused locations. A special set of position observations were undertaken in which the dishes were maintained within a few degrees of the meridian. The Crab, M 87, Cygnus A and NGC 1275 were used as calibrators. The first reduction by Matthews was of 3C 295, which had the highest declination and potentially the lowest error in the fringe period method used to measure declination. I had the task of locating the position on the Palomar Schmidt plate, which was by no means easy in the days before computer-generated overlays and two-coordinate measuring machines. I was fortunate that the relevant Schmidt plate had a quality in the top one percent of the Palomar collection for otherwise the object in Matthews' 25 square arc second error box would not have been visible and Minkowski in his last run on the 200 inch would not have got a redshift of \( z = 0.46 \), roughly three times the highest then known and a record which would be to stand for fifteen years. The redshift was only based on the identification of the single emission line as [OII] X3727, but it was consistent with accurate photometry of the continuum, made by Bill Baum. I gave the result at the London URSI meeting in September 1960 and Rudolph published it in the Astrophysical Journal (1960, 132, p. 908). Shortly after the result was known Milt Humason came into my office. He said "I want to congratulate you. You have succeeded in doing what I spent the last ten years of my life trying—and failed." In a way it was a very sad moment, for Milt was one of the real gentlemen of astronomy. As some consolation, I pointed out that, in contrast to his own efforts, there was a good chance that our faint galaxy was at a great distance and should have an emission spectrum and, for me, it had represented six years of effort.

Later, in October, Matthews gave me the position of 3C 48 which unequivocally fitted a 16th magnitude star. I made a finding chart and took it straight to Jesse Greenstein who had promised me a case of Scotch for the first radio star (incidentally never paid). Jesse took the chart to Palomar where he had the next dark run, but was clouded out. He passed the chart on to Allan Sandage who obtained the first spectrum, and also from visual examination under good seeing felt there might be a little 'fuzz' in spite of a largely stellar appearance. Guido Munch followed, agreed with Allan, and got a confirming spectrum. The spectra were measured by Jesse. Tom Matthews and I both felt that we had a galaxy in which we were seeing an explosion in the optical range which later led to the extended double radio sources—not too inconsistent with today's thinking. A stellar object four or five magnitudes brighter would be needed to blot out the parent galaxy making it around 21st magnitude. The two lines, in the blue, would then be in the ultra-violet in the rest frame. Ike Bowen, the director of Palomar, was a physicist, renowned as an optician, but who as a graduate student of Millikan built the first vacuum spectograph to measure UV spectra. He had also worked on the spectra of planetary nebula—high excitation objects. I had several afternoons of tuition in which Bowen compiled the most likely lines of common elements at high excitation in the ultra-violet. The best fit that I could find for the one broad line and one narrow line which Jesse had measured were with Mg II \( \lambda 2798 \), and [Ne V] \( \lambda 3426 \), and a redshift of around 0.37. Unfortunately there was a four angstrom discrepancy in the fit of the rest wavelengths. Jesse had me re-measure the spectra and I agreed that the discrepancy was real. At the time it was too large for my spectroscopic peers, particularly Jesse, to tolerate. The identification of 3C 48, the first quasar, went public without a redshift in a late paper given by Allan Sandage at the Christmas, 1960 meeting of the American Astronomical Society, with the authors T. A. Matthews, J. G. Bolton, J. L. Greenstein, A. R. Sandage and G. Munch—the chronological order in which they were involved. Looking back it is ironic that what would now be considered an excellent fit between permitted and forbidden lines in quasars stopped the clock for nearly three years. I did not pursue the matter further, for the interferometer still had to undergo tests on the newly completed north-south baseline; my personal affairs in California wound up and my family embarked on the S. S. Orcares for the journey back to Australia in mid-December for the start of the first steelwork construction at Parkes.

The other two of the four selected sources also turned out to be stellar, and a further two or three were found at Caltech and 3C 279 at Parkes before the 3C 273 occultation. Before the results of this were known the consensus view in Pasadena was that these objects were galactic and Greenstein had a paper in press (subsequently withdrawn) which interpreted the spectrum of 3C 48 as a supernova remnant.

The observation of lunar occultations of radio sources had been prominent on the list of suggested programmes for the 64 m telescope drawn up by Frank Kerr and predictions had been made by the RGO for several years. Jim Roberts attempted an occultation of an MSH source with the OVRO interferometer—unfortunately it was not one of the better quality MSH sources. It was Cyril Hazard who made the first successful occultation observation (of 3C 212) at Jodrell Bank. Cyril joined Hanbury Brown's group at Sydney University and I invited him to take part in the Parkes programme, with John Shimmins and Brian Mackey for telescope and receiver support. There were five occultations of 3C 273 predicted for 1962, but only in two cases were immersion and emersion to be visible. The first full attempt failed when Cyril fell victim to the then horror stretch of road between Narrabri and Coonabarabran; however, the other full and two partial occultations were successfully observed. The second full occultation on August 5 was the most critical and required an extension of the existing zenith angle coverage of the telescope, achieved by grinding off a considerable amount of metal from the zenith angle bearing housings. By the time of the second attempt, positional measurements by me and John Shimmins, made to determine the best position for tracking the source, had almost established the identification for it was mid-way along the jet extending from a 13th magnitude stellar object. This jet, although apparent on the 48 inch Schmidt survey, showed very clearly on a 200 inch plate which Rudolph Minkowski brought with him on a three month visit to Radiophysics and Mount Stromlo that winter. The real interest in the occultation was "was it the star or was it the jet?" Two minutes of the occultation, where the limb of the moon was perpendicular to the jet provided the answer. There were two sources, the star and the jet, and as observations
were made at 136 and 400 MHz, differences in their radio spectra were immediately apparent—flat for the star and steep for the jet. I believe that it was Minkowski who communicated the position to Maarten Schmidt, who established the redshift almost as quickly as Cyril Hazard completed the occultation calculations. Radio and optical results were published simultaneously in *Nature*. Second thoughts on the spectrum of 3C 48 led Greenstein and Matthews to publish its redshift of 0.37 in a following paper.

From then on, for a period in the mid-sixties, quasars really took off. On the identification side a major contribution was made by Allan Sandage who noticed their power-law spectra, resulting in an ultra-violet excess. The absence of a minus-UV filter in the Palomar 48 inch blue survey and the fact that the telescope was out-of-focus in the UV made quasars look blue. John Shimmins first noted a similar effect in the radio spectrum in that objects with spectral indices flatter than −0.5 were almost exclusively identified as stellar. The Parkes surveys at higher than previously used frequencies contained a considerably higher proportion of such sources which were suggested as quasar identifications on the basis of minute-of-arc positions and confirmed by photometry or two-colour photography by Tom Kinman at Lick Observatory. On the spectroscopic side, Schmidt's remarkable effort in the interpretation of spectra rapidly extended the known redshift range to in excess of 2 and the advent of the Carnegie image tube and its use with the prime focus spectrograph on the Lick 120 inch gave Lick an edge over Palomar and gave Margaret Burbidge and others a field day.

It all began near that plaque at Dover Heights!

Editors' note: On Thursday 1989 November 2, a symposium to commemorate ‘40 years of Radio Galaxies’ was held at the Epping, CSIRO Radiophysics headquarters of the ATNF (Australia Telescope National Facility) and, at dawn on the same day, a plaque was placed near the site of an historic radio telescope at Dover Heights (see J. G. Bolton, 1982, *Proc. Astron. Soc. Aust.*, 4, 349-358). The above article is the text of a talk at the symposium by John Bolton, who was the initiator of the Dover Heights telescope and subsequently, for many years Director of the Parkes radio telescope. John expresses thanks to colleagues who assisted him by providing some historical material, particularly John Whiteoak, Jim Roberts and Woody Sullivan.