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Wild, Woolley and Savage —or how John Bolton and I went hunting for Quasars and QSOs*

Ann Savage

UK Schmidt Telescope, Anglo-Australian Observatory,
Private Bag, Coonabarabran, N.S.W. 2357, Australia.

Abstract

This paper is about how I met John Bolton and includes some highlights of the four years I took compiling my Ph.D. at the Parkes Observatory. It is strongly linked to the discovery of quasars (quasi-stellar radio sources) and QSOs (quasi-stellar objects, not necessarily radio sources)—John being dedicated to discovering quasars and I to discovering QSOs. I hope my perception of John Bolton as a person comes through as it seems I was fortunate in meeting him at a time when, according to some, he had mellowed!

1. Introduction

In 1974 my husband and I flew to Australia, where I was to work as a Ph.D. student for John Bolton. On our arrival in Sydney, Richard and I naively asked about trains to Parkes. We learnt that, in Australia, you drove or flew, since the only train available was the 'Milk Run' which took close to 24 hours. We caught the plane to Parkes, but inclement weather diverted it to Cowra from whence, after a very long wait, a coach took us to Parkes. We were met at Parkes by an exceptionally irate John Bolton. You see, John, as well as seeing war service in the Navy, had spent some time working in the Radiophysics Lab's Rain and Cloud Physics Section, studying the effects of seeding clouds to produce rain. In his estimation, the cloud ceiling at Parkes had been at least 2000 feet and the plane could have landed easily. Despite his best efforts to persuade the airport staff to this view, they persisted in reporting a visibility less than 1000 feet; so the plane went to Cowra.

Letty Bolton, however, had prepared us an excellent lunch and by the time we finally arrived, she had some very hungry diners. I was to experience Letty's hospitality many times. Whenever the Parkes team went optical observing to either Mount Stromlo or Siding Spring, Letty provided John with a rich fruit 'Observing Cake'.

* Refereed paper based on a contribution to the John G. Bolton Memorial Symposium held at the Parkes Observatory, 9–10 December 1993. To explain the title of this paper: Paul Wild is an astronomer, a former chief of the Radiophysics Laboratory and later chairman of CSIRO Australia. Sir Richard Woolley was director of a number of observatories, including the Mount Stromlo Observatory now operated by the Australian National University. It was mooted at one time that these two be invited to become patrons of the North Goobang Philosophical Society, so that the said Society could refer to its patrons as 'Wild and Woolley' (see Price 1994). John Bolton always hoped I could write a paper with them—but this is the best I can do (AS).

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2. The Discovery of Quasars

My meeting with John Bolton is strongly linked to the discovery of quasars and QSOs; John was dedicated to discovering quasars and I to discovering QSOs. To relate the discovery of quasars, I am relying on the book by Robertson (1992) which contains John's recollections of what happened. The discovery began in 1960 when Tom Matthews, an astronomer from the California Institute of Technology, measured an accurate position for 3C 48, one of the sources listed in the third Cambridge Catalogue. Subsequent Jodrell Bank interferometer observations by Henry Palmer showed that the angular diameter of 3C 48 was less than 4 arcsec, making it an exceptionally compact source compared with the usual 30 to 60 arcsec for most radio galaxies.

John, then at Caltech's Owens Valley Observatory, examined the POSS (Palomar Observatory Sky Survey) prints and found that 3C 48 coincided with a 16-mag star. Observations with the 200-inch Hale telescope, by Allan Sandage, Jesse Greenstein and Guido Munch, showed the star to have an unusual blue colour and a spectrum made up of a combination of strong emission and absorption lines unlike that of any star known.

At the same time Cyril Hazard from Jodrell Bank was pioneering the method of lunar occultation to pinpoint accurate positions of radio sources—in this case 3C 212. In 1962, while in Australia, Hazard was able to use this method to pinpoint a position for 3C 273. Using the Parkes 64-m radio telescope, the first occultation in April 1962 proved inconclusive, but that of 5 August by Hazard working under the auspices of the University of Sydney, and John Shimmins and Brian Mackay from the Radiophysics Laboratory, went according to plan.

The immersion and emersion times as the source passed behind the Moon were then sent to the Nautical Almanac Office (NAO) of the Royal Greenwich Observatory (RGO) in Sussex. These were then turned into one-dimensional cuts on the sky which, in turn, gave accurate radio positions for the source. Rudolph Minkowski, who was visiting Australia from Caltech, made the identification on Hale plates of a peculiar blue star with a jet. In December 1962 Maarten Schmidt measured the optical spectrum and found six strong emission lines in the spectrum of the blue star. Finally Schmidt twigged that these were indeed lines of ionised hydrogen but were redshifted by 16%. 3C 273 therefore was very distant (assuming this to be a cosmological redshift), radiating at least 100 times more energy than the most luminous galaxy. I remember John telling me he had suggested to Schmidt that he try the lines of ionised hydrogen, many months before Schmidt actually did it. I have not seen this information written down anywhere, nor have I heard it from anyone else.

Interestingly, when I did finally arrive at Parkes, I was carrying with me a large number of spectra of 3C 273, taken on the small 98-inch Isaac Newton Telescope with a new-fangled photon-counting device with better quantum efficiency than conventional photographic emulsion. I was a small, junior, part of a large team (Boksenberg *et al.* 1975) making a systematic spectroscopic study of 3C 273 which yielded improved spectra, particularly in the blue region which showed previously undetected features! John was very interested in these tracings which, of course, appeared very different from the photographic spectra he was used to peering at.

In April 1964 Hazard and Mackay in collaboration with Bill Nicholson at the NAO announced the discovery of three further quasars detected by the lunar occultation technique and, by the end of the year, a total of 40 quasars had been reported. Coincidentally, I started work at the RGO in December 1964, actually working on the prediction of lunar occultations for certain stars, and Bill Nicholson was one of my bosses. Suffice to say that even though I was at the Nautical Almanac Office then, sharing a flat with Margaret Evans (now Penston), I never heard a whisper of any of these newly discovered astronomical objects—quasars!

3. Meeting John Bolton

I did not go to university straight from school because the offer I received was not in my preferred field. However, once I had started at the NAO, I realised how necessary a degree was to further my career. I embarked on a series of day-release courses, and was eventually invited to do a part-time sandwich course leading to an Applied Physics degree. I gained a first-class honours degree in that and, this time, the RGO invited me to do the part-time M.Sc. course in astronomy, run in conjunction with the University of Sussex. I received my M.Sc. with special merit and this prompted Michael Penston to encourage me to do a part-time Ph.D., again under the auspices of the University of Sussex.

I started with Margaret Burbidge as a supervisor. This was my first introduction to quasars and QSOs, since my first task was to trace all her photographic spectra on the RGO's Joyce Loebl machine. When Margaret notified her intention to leave the RGO, I expressed an interest in going to South Africa to continue my Ph.D., in this case with Sir Richard Woolley who had been asking for a British Ph.D. student. At about this time the photographic sky survey plates had started to come from the UK Schmidt Telescope. John Bolton wrote to Russell Cannon asking for a British Ph.D. student to work on a project to identify sources from the Parkes (Australian) catalogue on this British plate material. Cannon discussed this request with his old friend and my Head of Department, Bob Dickens. I was asked if I would like to go, because I was already doing a Ph.D. and had expressed a willingness to work abroad. By that time I had heard of John Bolton and knew that Margaret was a collaborator of his.

One of my memories of John is that he went to a lot of effort for me, telling me about different people and teaching me to appreciate people for their strengths, and to use these strengths to the best advantages for both person and team. For example, he told me that he always sent Jasper Wall in a car to pick up Fred Hoyle at Sydney airport, because that way they would be obliged to talk to each other and, I deduce, learn more about each other and about cosmology. This I feel is a very devious tactic, which I have adopted but adapted; I almost always let my visiting students live with our family.

Michael Penston was going to train me to identify some of the 5C radio sources before I left for Australia. However, he finally decided that it might be best if I learnt the identification procedure from John himself, presumably uncontaminated by any prior doctrine. With hindsight, the one 5C area that Michael had already looked at (Parkes and Penston 1973), 5C3, covered a very small area of only 4×4° at 408 MHz, and only 1×1° at 1407 MHz, compared with half the sky covered by the Parkes catalogue. All the Cambridge radio surveys were made at low frequency and the sources had steep radio spectra, so flat-spectrum quasars were comparatively rare in the Cambridge catalogues. The first part of the Parkes Catalogue of Radio Sources (Bolton *et al.* 1964) was also a low-frequency survey compiled from 408-MHz scan records, but with sources confirmed or rejected as such by scans at 1410 MHz. This process selected a disproportionately large number of flat- or inverted-spectrum sources which we now know are more normally identified with quasars. Thus, to find quasars, later Parkes surveys were done at high frequency. The Parkes 2700-MHz survey began in 1967 (Shimmins *et al.* 1968) specifically to find flat-spectrum quasars in large numbers. The 5C sources had radio positions with a much higher accuracy than was being achieved at Parkes (Pooley 1969). Identifications could then be made on positional coincidence alone. The radio identification content would have been very different from that from the Parkes surveys, and the techniques would have been totally alien to John. It was to be many more years before he was finally convinced that one needed arcsecond positional accuracy to find the rarer higher redshift quasars! This then is how John and I came to meet.

4. The Discovery of QSOs

Once astronomers recognised the peculiar blue colours of quasars, searches were made through the earliest catalogues of blue stars to find the optically quiet equivalent of quasars and QSOs. Most of the early catalogues were concerned with stars brighter than 16 mag. Among the surveys to a deeper limiting magnitude, that of Sandage and Veron (1965) was the first deliberate attempt to find QSOs by means of their ultraviolet excess (uvx), since they realised that there might be a large population of QSOs which did not show a detectable radio emission.

Sandage (1965) announced that from photometric, spectroscopic and number-count evidence most blue objects in high Galactic latitudes fainter than 16 mag were extragalactic and resembled the quasars. However, this was a very controversial statement. Sandage's estimates were based on the evidence that most of the blue objects occupied the same region in the two-colour diagram (U-B) versus (B-V) as the quasars, and that the observed integral count curve of $\log N(m)$ for objects in the PHL (Palomar–Haro–Luyten, see Haro and Luyten 1962) catalogue had a change of slope between mpg $= 12 \cdot 0$ and 15, steepening and reaching a constant slope for mpg > 16. Sandage attributed the increase in slope to the QSOs. Subsequently, it was shown that his $\log N(m)$ result could also be explained by a large proportion of Galactic stars and a small fraction of extragalactic objects. Kinman (1965) proposed that the combination of horizontal-branch (HB) stars and white dwarfs could account for at least 75% of the PHL objects brighter than mpg $= 16 \cdot 5$. Lynds and Villere (1965) synthesised counts of white dwarfs and came to much the same conclusion as Kinman. Greenstein (1966) obtained spectra of 100 'faint' blue stars with mpg $< 16 \cdot 5$. He found no rapid transition to a QSO population at $15 \cdot 5$ mag, nor was it indicated by $16 \cdot 5$ mag. The high percentage of white dwarfs at $15 \cdot 5$ mag suggested that they would dominate until $19 \cdot 0$ mag, but that the HB stars would disappear at about $17 \cdot 5$ mag. Schmidt (1974) made a spectroscopic survey of 120 faint blue objects selected from the PHL and LB catalogues and this selection yielded 44 QSOs, seven objects with continuous spectra and 69 Galactic stars. These early results on 'blue' stars suggested that almost all brighter than mpg $= 16$ are stars, but the fraction fainter than 16 that are QSOs could lie between a quarter and a half.

Braccesi *et al.* (1968) tried a different method, the forerunner of multicolour searches, of selecting QSOs from the catalogue of uvx objects compiled by Braccesi *et al.* (1970). In this catalogue there are 165 uvx objects to mpg $= 19\cdot4$ in a 36-square-degree area, and of these objects 99 also have an infrared excess (IRX). Braccesi *et al.* obtained spectra for 16 of the latter and confirmed 15 of them as QSOs, which led them to propose that most of the IRX objects were QSOs, i.e. 60%. Further work on the sample by Wills and Wills (1976) suggested that perhaps the fraction of uvx objects that are QSOs is actually between 50% and 60% to mpg $= 19\cdot4$.

At the time I was researching my thesis, most investigators agreed with these results, namely that Galactic stars dominate the population at, say, mpg $= 17\cdot0$, but no really definitive answer existed on the relative content of the population fainter than $17\cdot0$.

5. The Birth of My Ph.D. Project

John drove me from the township out to the Parkes Observatory nearly every day, and the first glimpse I had of the telescope was while it was parked at the zenith. I remarked that it did not appear to be pointing exactly at the zenith. I learnt that it parked 5° away from the zenith; my observation earned me some 'brownie points'. I also wore sensible shoes and handled the SERC administrator in charge of me with great aplomb; these earned me many more points. Some time later I also learnt that the enigmatic illness John had, while he was corresponding with me before I arrived in Australia, was 'mumps', caught from his grandsons. I think this caused him some embarassment; it seemed to me that John was a very shy person.

It was Jas Wall who taught me how to identify each radio source on both the Palomar 'E' and 'O' prints. For the first three weeks I went home seeing stars in front of my eyes as I tried to remember the appearance of the O field to compare with the E field. Things got gradually better, and John was relieved that I could tell the difference between a star and an extended object on the plates; apparently some of his past students had never mastered this art. Once Jas departed, John seemed quite content to work on the identifications with me.

My initial task was to help with the continuing 2700-MHz survey and then to check all the existing (~8000) Parkes survey radio sources on the new SERC J and the long-awaited ESO R southern sky surveys. To relieve the tedium of identifying sources on separate plates in two colours, and to minimise plate handling, John built a closed-circuit TV, combined blink and two-coordinate measuring machine. John and the Parkes staff designed and built the machine—a product of the 'Goobang Construction Company' (see Price 1994). This was the type of construction project John really enjoyed, second to none, except perhaps radio or optical observing. It was unfortunate that in all the time I was at Parkes, the ESO R plates never eventuated.

The radio positions measured at Parkes were not very accurate, but by then it was known that the larger family of radio-quiet quasars/QSOs were always recognised as blue objects, exhibiting uvx. Because such stellar objects are rare, identifications with such uvx stellar objects, even with imprecise radio positions, could be made with a high degree of reliability, such that subsequent optical spectroscopy would confirm the candidate identification as a quasar.

The confirmation was done by means of two-colour (B/UV) photography at the Cassegrain focus of the Mt Stromlo 74-inch reflector (see Shimmins *et al.* 1971). The image tube operated at f/8 and covered a field of only 4 arcmin, but in many cases a second uvx object was seen. Out of 138 fields investigated, 11 ($\sim$10%) were found to have a second uvx object (the final paper in the series was that by Peterson *et al.* 1976). No magnitudes were noted for these second objects, but it was assumed that they were bright because the image tube plates were thought not to go very deep; nor were the numbers of optically selected QSOs particularly well known. At this time a very heated controversy arose amongst all the collaborators in the Parkes group about the significance of these results (Bolton 1977), since Derek and Bev Wills, making similar observations, did not find the same high numbers of pairs (Wills and Wills 1977). They suggested that the probability of the QSO pairs found by John arising from chance associations of quasars and background QSOs was 1 in 1000, using the background QSO counts of Setti and Woltjer (1973) based on the searches of Braccesi *et al.* (1970). They also suggested that their result could be made consistent with that of John's at the expense of increasing the current estimates of the surface density of QSOs by a factor of about 4.

I have since spent ages searching the literature for an account of this controversy, forgetting that Jas Wall used to complain that John always published the controversial snippets in conference papers and that they never appeared elsewhere, or else he delegated someone else to include such items in his/her conference paper. This eccentricity of John's (and now mine) is mentioned later.

In any event, the controversy decided me on my Ph.D. project. I would try to determine the surface density of optically selected QSOs so that the significance, or otherwise, of this result could be determined. Once I had decided on this course, John was adamant that I should research early blue-star catalogues, proper-motion catalogues and the beginnings of optical searches for the optical equivalent of the radio quasars, as mentioned earlier in this paper.

John and I put in a request for our own pairs of B and U UK Schmidt Telescope (UKST) plates and the blink comparator, or 'Bolton Machine' as it became fondly known, came into its own. Using the electronic gadgetry of the 1970s, parts of the plates were displayed side by side and those stars having a uvx were immediately obvious.

On reading the first draft of this paper, Russell Cannon asked me to include the following. John originally insisted that he did not need ultraviolet (U) plates because he could spot quasars on the unfiltered Palomar blue (O) by comparing them with the Palomar red (E) plates. Russell added that he and John had had long arguments about this since the BR (O–E) colours of quasars are not exceptional. Additionally, the same technique did not seem to work on UKST plates. In the end they decided that this was because the UKST had an achromatic corrector which made the UKST unfiltered blue plate (U+B) images of quasars too good. The quasars showed up on the Palomar unfiltered blue plates because the ultraviolet image recorded on the blue plate was out of focus and larger in diameter than the blue image, making quasar images apparently much bigger, and thus brighter, in B than normal blue stars.

At this time confirming each candidate by low-resolution spectroscopy was slow and painstaking work. In July 1976 a full aperture objective prism was commissioned on the UKST. I decided that I would like to use this prism to take plates to determine the nature of at least some of my sample of uvx QSO candidates. John was adamant that such plates would not be at all useful as they would not go faint enough. However, I stood my ground and argued that even if they helped us classify one or two of the brighter objects as white dwarfs it would be useful. Neither of us was familiar with Malcolm Smith's pioneering work on the 61-cm (24-inch) Curtis Schmidt telescope, and the success he was having in searching for emission-line objects on its objective prism plates (Smith 1975; since publication was December, and close to Christmas, perhaps we can be forgiven this oversight). This is one of the drawbacks of working at an isolated site away from an interacting group of astronomers, lecturers and students.

The UKST objective prism plates and the IIIa J direct plates which were taken in superb seeing conditions were examined at the positions of all the uvx objects and at the positions of the independent deep radio surveys we had made in the two areas (Savage 1978). With the aid of reference objects for which the Anglo-Australian Telescope image dissector scanner (IDS) spectra had been obtained (Robinson and Wampler 1972), we found it relatively easy to classify about 80% (and, with some difficulty, a further 10%) of the objects as either stars, QSOs or galaxies. Thus it turned out that the UKST prism plates were ideally suited to classifying many of the uvx candidates and to producing a new medium for searching for emission-line QSOs which did not have a uvx. These were found by scanning the prism plates on the Bolton Machine also. I learnt that Ph.D. supervisors are not always correct and that one should pursue one's own ideas, even in the face of adversity, although I was never sure whether this was just another of John's teaching/training exercises.

We also found that one of the fields contained a very high number of non-uvx QSOs (Bolton and Savage 1978—you've guessed it, IAU Symposium 79). Independently, it was also being gradually realised that QSOs could be neutral or red and, because red stars are very common, precise arcsecond radio positions are needed before reliable identifications can be made. This added a devastating radio-selection effect to the Parkes identified quasars which exhibited a redshift cutoff at about $z \sim 2{\cdot}2$. Even with these results Alan Wright and I had a great deal of difficulty convincing John that quasars could be other than blue. In addition, I was convinced that we now needed precise positions (see the saga in Savage *et al.* 1984) and was quick to collaborate with Dave Jauncey when the offer was made to identifiy radio sources with precise Tidbinbilla positions (Jauncey *et al.* 1982). Eventually this work led to the discovery of the not-blue PKS 2000–330, the then most distant radio quasar (Peterson *et al.* 1982). However, Hook and McMahon (1993) have since reported the discovery of two more distant radio quasars ($z = 3{\cdot}9$ and $4{\cdot}3$), also drawn from 5-GHz radio samples but to a fainter flux limit of $0{\cdot}2$ Jy, relegating PKS 2000−330 to the third most distant radio quasar.

To demonstrate how anecdotal accounts turn into imprecise myths with the passage of time, let me refer you to Murdoch (1993, p. 348), who recounts the discovery of PKS 2000−330. The text says: 'On such an occasion Savage chose, in desperation, an object which was five hours ahead of transit.' In fact, what happened was that Peterson and I went outside to inspect the weather. Water was pouring off the side of the AAT dome although the skies were clear.

We decided that the conditions were too dangerous to open the Dome and so went back into the control room, silent. However, the power to decide to *open* (normally *close* in the face of recalcitrant astronomers) is vested in the night assistants. Frank Freeman went outside, came back and said: 'I'm going to open the Dome; give me an object at a large zenith angle love.' Stunned into further silence, we obeyed immediately. I do not translate this into 'Savage chose, in desperation...'. Alan Wright later provided a bottle of scotch for Frank. The episode was a triumph for John Bolton and the Parkes 2·7-GHz surveys of many years of painstaking effort.

6. Results

In the end I forgot, when I wrote up my thesis, what it was that had originally triggered me to try to determine more precisely the surface density of QSOs. It may well have been the evidence for incompleteness even in our new sample which dissuaded me from using the results (see Morton and Tritton 1982), or the fact that my thesis was written up in the Parkes maternity hospital!

Recent investigations (Savage *et al.* 1993) confirm that only 6% of uvx objects brighter than $B = 16 \cdot 16$ mag are QSOs. Even to $B = 18 \cdot 0$ mag, the QSOs still only comprise a small proportion, 20%, of a uvx-selected sample. Most of this sample will comprise a mixture of white dwarfs, CVs, blue horizontal branch stars and rarer types of blue stars. Boyle *et al.* (1987) confirmed as QSOs about 40% of uvx objects with $B < 21 \cdot 0$, with a surface density of about 20 QSOs per square degree to $B = 20 \cdot 0$. One would therefore expect to find ten QSOs by chance in the area covered by the Mt Stromlo two-colour comfirmation project; in fact, 11 were found, provided that the two-colour plates reached about this limiting magnitude (John had estimated 19 to 19·5). This confirmed that the fields containing both a radio quasar and a radio-quiet QSO were no more than chance coincidence and had no special significance.

I regret that it should take this memorial issue to solve this enigma at long last, but am pleased at the opportunity to present the results—and it may well be best that John is not here, or he would probably try to box my ears again, as he tried to do once before when I was using the Bolton Machine and made a derogatory comment to him about it.

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