The discovery of Quasars

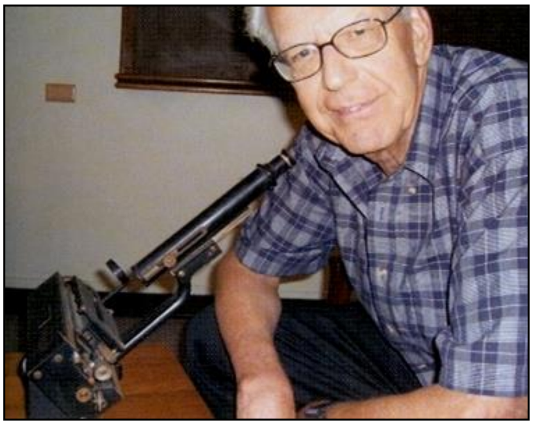
John Gatenby Bolton (1922-1993), seen squatting at right with Mike Jeffery and Taffy Bowen at the hub of the under-construction Parkes Dish) was seconded from the CSIRO at the end of 1954 to introduce the new science of radio astronomy to Caltech at Pasadena, but returned to Australia in January 1961 after six years to supervise the completion and become the first Director of the 64 metre (210 feet) Parkes Radio Telescope. There were a number of teething problems with the new telescope that occupied some months as solutions were found. Once it was operating perfectly, Bolton immediately began work on a new radio survey of the sky. Eventually, the Parkes Catalogue listed more than 8000 radio sources. It led to the discovery of many quasars and pulsars, and greatly increased the interaction between optical and radio astronomers. Bolton's students became leaders in radio astronomy in the USA and the UK as well as in Australia.

Early radio telescopes detected some sources in the sky that appeared to be quite compact. These were called 'radio stars', and were thought to be located inside the Milky Way. Larger sources were thought to be probably extragalactic, and became known as 'radio galaxies'. The new, powerful radio telescopes being built in the 1950s had much better resolution than the earlier ones, and soon some radio galaxies were identified with optical galaxies, (Bolton devised the names for Cygnus A, Centaurus A and Virgo A), but they were still not able to pinpoint the small areas of sky where the 'radio stars' were, and the equipment was certainly not precise enough to identify any one of them with a single optical star.

In 1959 **Alex Shain** and **Joe Pawsey** thought of a way to use lunar occultations to fix the positions of these sources, and two years later Pawsey calculated that the 'radio star' 3C 273 (No. 273 in the Third Cambridge catalogue of radio sources) would be occulted by the Moon on 15 May, 5 August and 26 October 1962. **Cyril Hazard** (born 1928), late of Jodrell Bank but now employed at the University of Sydney's new Chatterton Astronomy Department, had independently devised a similar procedure. (Cyril was pleased to be joined at Chatterton by his Jodrell Bank friend Hanbury Brown in early 1962.) Joe Pawsey invited Hazard as a guest observer to assist with the timings of these occultations with the Parkes Radio Telescope.

Cyril and **John Bolton**, Brian Mackey and John Shimmins used them to pinpoint the sky location of 3C 273 to an accuracy of one arcsecond. This was possible because the radiation from such a tiny source was interrupted instantaneously by the Moon's limb, revealing it to be from a virtual point in space. In this work, Bolton used his experience gained on eclipse expeditions in 1948 and 1949. In the event, 3C 273 turned out to be a double source, the two components being 6 x 2 arcseconds in size and 20 arcseconds apart. By coincidence, **Rudolph Minkowski**, recently retired from the Hale Observatories, visited Parkes in January 1963. He had been watching with interest the developments in Australian radio astronomy for over a decade, and had brought a number of plates from the 200 inch telescope with him, including one of the area of 3C 273. Examining the plate at the newly-found position of 3C

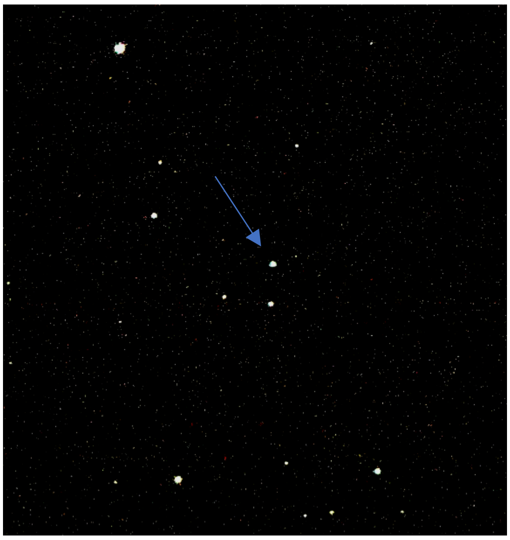
273, they detected an unusual image of a point-like 13th magnitude blue ‘star’ with a peculiar jet extending out from it.



Maarten Schmidt (1929-2022, *right*) who had been a student of Jan Oort and had taken over from Minkowski at Mount Palomar, visited Parkes a few weeks later as part of an IAU-URSI Symposium. He was shown the results, and was asked to acquire a spectrum of the faint ‘star’ with the 200 inch as soon as he returned to California. He did this in December 1962, but found the seven faint spectral lines that were recorded to be incomprehensible. There was no trace of the hydrogen lines, and numerous emission lines appeared as well, so how could it be a star?

Unable to decipher 3C 273’s lines, Schmidt worried about the problem for six weeks, but then had the inspiration to take another spectrum using an infrared photographic plate. To his amazement, he found that the familiar lines of hydrogen, oxygen and magnesium usually seen at optical wavelengths were redshifted to such an extraordinary extent that they now appeared in the infrared band. Such a redshift indicated an extremely high recessional velocity, and application of the **Hubble-Lemaître Law** showed that this particular star-like object was exceedingly remote, further away than any known galaxy. He reported this finding in March 1963.

The significance of the Parkes radio observations combined with Minkowski’s plate and Schmidt’s spectra was immediately recognised. The large redshift indicated that 3C 273 was receding at 16% of the speed of light (47 400 kilometres per second) and was now 1000 times further away than the Great Galaxy in Andromeda. To shine at 13th magnitude at that great distance, it had to be an enormously powerful yet compact source of energy. Such an object was much too powerful to be a star, or even a large galaxy – it was something entirely new. More of these radio sources were optically identified with faint, blue ‘stars’ in the years that followed. Their spectra, though, were like 3C 273’s – the lines were shifted far to the red, quite unlike the patterns seen in normal stellar spectra. They were therefore named **Quas**i-stel**lar** Radio Sources or **Quasars**. As we have found that they are nothing like stars, they are now called **Quasi-stellar Objects** or **QSO**s. Only 10% are radio powerful. In fact, most small sources (the erstwhile ‘radio stars’) are galaxies or QSO’s at exceedingly remote distances.



[We now know that 3C 273 has the highest apparent magnitude of all the QSOs. Even though it lies at a distance of 2.443 billion light-years or 749 mega-parsecs, it is one of the closest, as its redshift z is only 0.158. Also one of the most luminous QSO’s, it has an absolute magnitude of -26.7, making its light and heat output 4 trillion times greater than that of the Sun. If it were located at the same distance as the star Pollux (33 light-years or about 10 parsecs), it would still appear star-like but its light intensity would be so great that it would be as bright as the noon-day Sun, turning night into day. The mass of 3C 273 is 886 ±187 million solar masses.]