The Discovery of 3C 273
and the Road to Quasars

Ken Kellermann, Marshall Cohen, Barbara Harris, Dave Jauncey, Dan Harris (foreground from left to right) at social dinner

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Extragalactic jets from every angle
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The sequence of events that led to the 1963 publications in *Nature* of 3C273, the first quasar and the first extragalactic radio jet

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Abstract. We are undertaking a detailed investigation, based on the available evidence, of the sequence of events that led to the historical discovery of the first quasar, 3C273.

Keywords. history and philosophy of astronomy, quasars: individual (3C273), occultations

1. Introduction

The pages of *Nature* for March 16 1963 carried two short papers which announced the precise position, structure, and the optical identification and redshift measurement of the radio source 3C273, the first quasar. These were closely followed by the recognition of the high redshift in the existing spectrum of the radio source 3C48. These discoveries irreversibly changed our understanding of the Universe.

Fifty years later we are undertaking a detailed examination, based on available evidence, of the circumstances surrounding the observations that led to the publications in *Nature* in 1963 by Cyril Hazard *et al.*, and Maarten Schmidt, of the radio position and structure and the optical identification of 3C273. This source occupies an iconic place in extragalactic astronomy. This presentation is an as yet incomplete version of what took place those 52 years ago, and we remain optimistic that a more complete account will soon be forthcoming.

The 3C273 discovery was an international effort, made by an Englishman working in Australia and a Dutchman working in the United States, and was made using two of the world's largest telescopes at that time, the Parkes 210 ft. Dish and the Palomar 200 inch. We are fortunate in our investigations in that fifty years ago international communication was essentially by letter. Many have remained accessible through archives and collections available today, and a number are reproduced here.

2. The occultation observations

In Australia, Cyril Hazard was working on the Brown-Twiss interferometer at Narrabri, as a member of the Chatterton Astrophysics Department of Sydney University. Earlier, while at Jodrell Bank, he had successfully observed the occultation of 3C212 (Hazard

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1961). After giving an occultation talk at Sydney University, he had been invited by Joseph Pawsey, of CSIRO Radiophysics, to use the Parkes telescope as a Guest Observer to make further observations. At Parkes, Hazard was well supported by Brian Mackey and John Shimmins as well as by the Parkes Director, John Bolton.

Hazard's motivation for the occultation work was to provide precise, arcsecond radio positions for high Galactic latitude radio sources in order to establish their nature, which he had strong evidence for being extra-galactic. Hazard had noted that the radio source 3C273 would be occulted by the moon several times that year. Moreover, these occultations would be visible at the newly completed Parkes 210 foot radio telescope. The importance of these occultations was that they were capable of yielding a precise radio position with arcsecond accuracy, and that the position was in the optical reference frame.

In 1962, the year of these dramatic observations, Maarten Schmidt had taken on the optical identification and spectroscopy of the objects identified based on radio positions measured with the Owens Valley interferometer (e.g. Read 1963). In this he was ably supported by Tom Matthews who made the essential optical position measurements on the Palomar Schmidt plates (e.g., Matthews & Sandage 1962).

The first occultation observation took place at 410 MHz on May 15 1962, when only the emersion was visible. The emersion occurred as the moon was entering the field of view of the telescope with the telescope stationary at the elevation limit. The record was complicated by the presence of the rapid increase in level as the moon entered the beam. But what was interesting was the clear presence of two well-defined diffraction fringes. This was the first time that these had been seen, and clearly identified the presence of a component of diameter no more than ~ 2 arcseconds. Such small components implied that the necessary arcsecond position would be attainable. Unfortunately, the record was unsuitable for a more detailed analysis. But it did make clear the importance of the August 5 occultation, for which both immersion and emersion would be visible. However, the emersion was scheduled to occur at an elevation close to the 30 degree limit of the Parkes telescope.

Before the scheduled August 5 observations Bolton was concerned about the possible low elevation and undertook significant surgery on the telescope. As it happened, it was unnecessary, but it made a great story (c.f. comments by Frank Kerr in Serendipitous Discoveries in Radio Astronomy, p 174, 1983). The "problem" was that the predictions from HM Nautical Almanac Office were given not for Parkes, but for the Fleurs Field Station 275 km east-south-east of Parkes.

The August 5 occultation was undertaken with concentric feeds at 410 MHz and 136 MHz where the telescope half-power beamwidths are 48 arcminutes and three times this, respectively (Bolton *et al.* 1964). The telescope was unable to track the moon, and could only track the radio source. Both immersion and emersion were observed and the records showed clearly the presence of two components in the source. The immersion and emersion records at both 136 and 410 MHz are plotted as Figure 1; time increases from right to left, and the motion of the moon is also from right to left.

3C273 is clearly a double source at 410 MHz, aligned so that both components reappear together along P.A. 45 degrees. However, the immersion record at 136 MHz shows no evidence for a second component as is shown at 410 MHz. Hazard started his preliminary analysis of the records immediately after the occultation.

On August 20, while Hazard was still involved in his analysis, Bolton wrote a letter to Maarten Schmidt (section reproduced below) about a separate potential Parkes identification. He also asked "would you also pass on to Tom (Matthews) the following position

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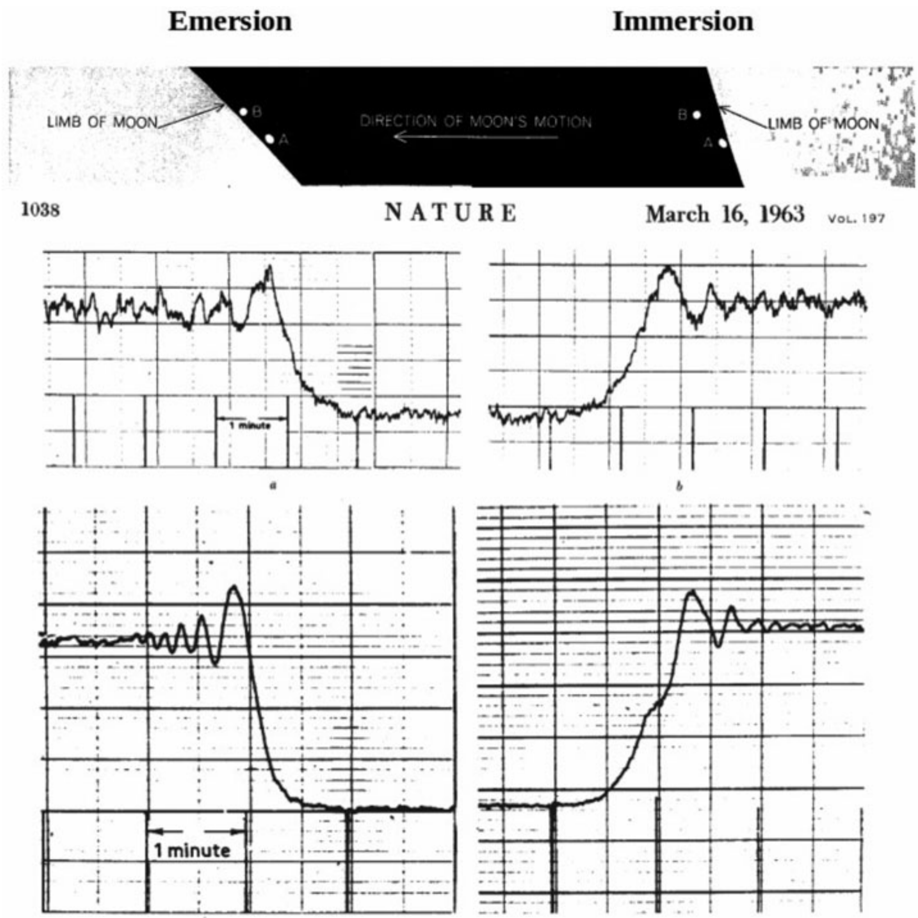

Figure 1. The August 5 immersion and emersion records at 136 MHz, top, and 410 MHz, bottom, taken from Hazard *et al.* (1963). Note that time increases from right to left.

for 3C273", but gave no reference as to its origin. He also added a P.S. saying "The position of 3C273 is subject to arithmetic errors as yet undetected!"

(a)	12^h	26^m	$32.^s1$	$\pm\ 0.^s1$
	02°	$19'$	$30.''1$	$\pm\ 0.''2$
(b)	12	26	$32.^s5$	$\pm\ 0.^s1$
	02	19	$37''.3$	$\pm\ 0.''2$

It is noticeable that the positions given to Schmidt for the two components differ noticeably from the final position given by Hazard *et al.*, in their later *Nature* paper.

Figure 2 suggests that the optical identification for 3C273 was most likely what we now know as the jet; the radio source is at exactly the same position angle, 45°, and has the same length, ∼ 10 arcseconds, but displaced laterally by about 5 arcseconds. Such a coincidence would otherwise be most unlikely. However, the exact nature of the bright, ∼ 13th magnitude "star", is clearly uncertain; is it merely a random background star, or, alternatively, is it somehow associated with the "jet"? This situation posed a serious

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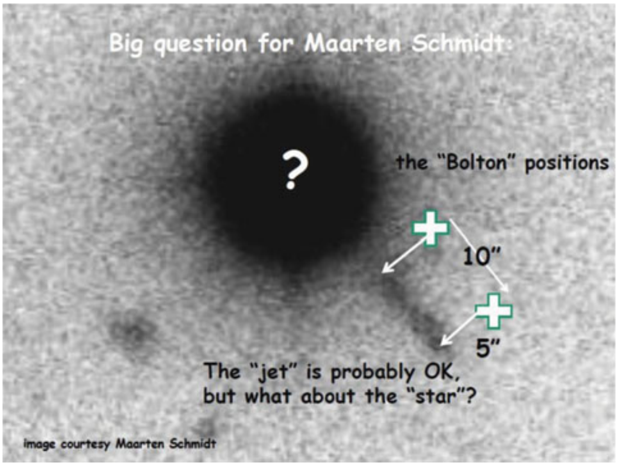

Figure 2. Palomar Sky Survey plate image of the vicinity of 3C273. Superimposed are the "Bolton" positions sent to Schmidt on August 20. Right ascension increases from right to left.

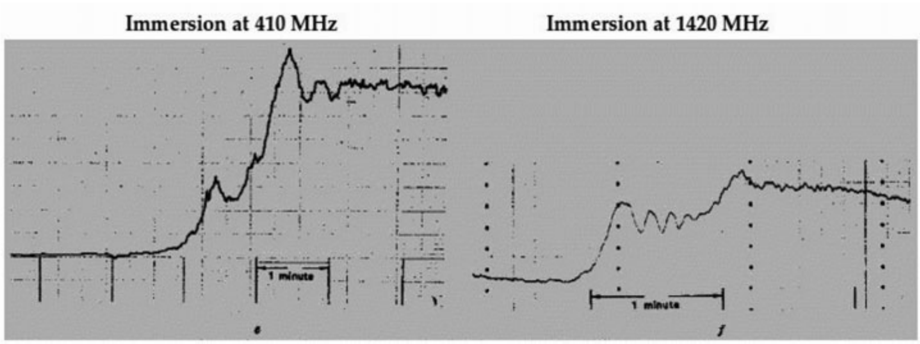

Figure 3. The immersion records from the October 26 occultation observations at Parkes, taken from Hazard *et al.* (1963). Again, time increases from right to left.

question for Schmidt, as well as for us now. Why did this position differ from that given later in the *Nature* paper?

Bolton's letter is dated August 20, barely two weeks after the occultation, and Hazard was still engaged in his analysis. As this was the first time that diffraction fringes had been seen, their presence presented a new challenge, and the analysis was complex. The most likely reason for Bolton passing on this position is that Hazard's analysis was still incomplete. At 136 MHz component B has effectively disappeared. At 410 MHz the separation between the components is 20 arcseconds, so a possible solution could be to put component B half way between the 410 MHz positions. Alternatively, Bolton may have misread the numbers. However, at the time the question for Schmidt was not pressing, because for the next four months, 3C273 was up only in daylight hours, and so was inaccessible at the 200 inch.

In the meantime the October 26 immersion observations were undertaken successfully at Parkes, this time at 410 and 1,420 MHz, as this was the standard concentric feed configuration in use at that time for the Parkes Sky Survey. The October occultation results are shown in Figure 3.

At 410 MHz both components show clear fringes, indicating angular sizes of 1-2 arcseconds for both. At 1420 MHz, where the Fresnel scale is much smaller, component A

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shows at best a small bump, while B exhibits strong fringes. Component B is significantly smaller than A at the sub-arcsecond scale. A detailed analysis of these observations was later undertaken (Scheuer (1965)) showing that both components at 410 MHz have diameters less than 2 arcseconds, while at 1420 MHz component B is less than 0.5 arcseconds in diameter.

Also interesting is the relative increase in source fraction at 1420 MHz. The spectral index of the more compact component B is now flat at 0.0, whereas that of A is steep at -0.9. The August 1962 record shows component A totally dominates at 136 MHz with $\sim 95\%$ of the total. Here was the first concrete evidence for an inverted-spectrum, sub-arcsecond component, B, in a radio source. The low-frequency surveys of the 1950s and '60s preferentially found the steep-spectrum sources. It would be for the later high-frequency surveys to uncover these compact, flat-spectrum sources.

For both the August and October 1962 occultations, Hazard's 3C273 analysis had revealed a "core-jet" structure with "normal" steep-spectrum component A and an inverted-spectrum, very compact component B. The final image and positional information was determined by Hazard in collaboration with Nicholson, and the detailed arcsecond resolution image is given here in Figure 4, taken from Hazard *et al.* (1963). In January 1963 Hazard wrote to Schmidt with the correct occultation structure and positions for A and B, and suggested a joint publication. On January 26, Bolton also wrote to Schmidt giving the positions.

In the meantime, Schmidt had undertaken spectroscopy at the 200 inch on the nights of 27 and 29 December, his first opportunity to do so. He was faced with a practical dilemma. He assumed that the bright "star" was merely a confusing background very bright 13th magnitude Galactic star. To obtain a spectrum of the faint jet, which was by far the most likely identification based on the information he had received from Bolton, he had to place the slit of the spectrograph along the extended jet for a long exposure. In doing it was inevitable that the bright confusing star 10 arcseconds away, would spill over into any spectrum of the jet he would obtain.

To offset this, he had decided to first obtain a spectrum of this bright star. His first attempt on the night of December 27 was overexposed. Although he had the world's largest optical telescope at his disposal, his detector was a photographic plate with efficiency no more than a few percent, so exposure times were not always easy to determine. On the night of December 29 he managed to obtain a spectrum of the "star" that was not overexposed, and which showed some faint emission lines, but with no obvious explanation in terms of any expected stellar lines.

There it stayed until February 6th, as outlined in the paper presented to the American Philosophical Society (Schmidt 2011). He wrote:

"It happened on 6 February 1963. In response to Hazard's letter I decided to have another look at the spectra... For reasons that I don't remember I tried to construct an energy-level diagram. When the energy levels did not come out regularly spaced, I was annoyed... To check on the regularity of the observed lines, I decided to compare them with the Balmer lines of hydrogen... Specifically, I took for each line in 3C 273 the ratio of its wavelength over the wavelength of the nearest Balmer line. The first ratio was 1.16, the second was... also 1.16.
It suddenly struck me that I might be seeing a redshift. When the third and fourth ratios were also close to 1.16, it was abundantly clear that I was seeing in 3C 273 a redshifted Balmer spectrum."

It was indeed fortunate that the 3C273 redshift was small enough that the Balmer series was there and would be readily recognised.

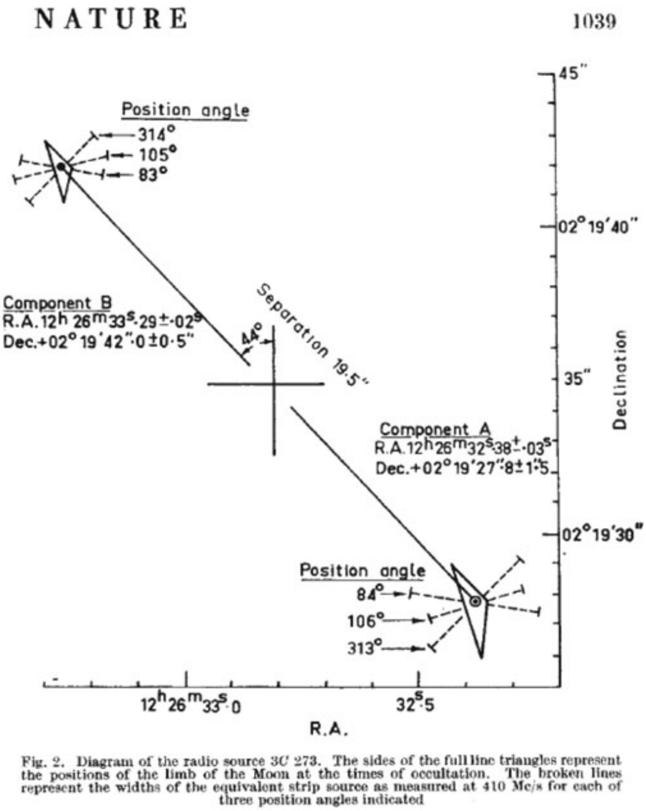

Figure 4. The occultation structure and position from both the August and October Parkes occultations of 3C273, from Hazard *et al.* (1963).

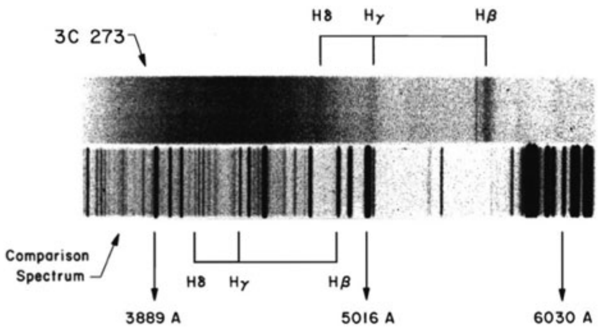

Figure 5. Maarten Schmidt's 200" spectrum taken on the night of December 29, with the identified Balmer lines at a redshift of 0.16 (figure courtesy of Maarten Schmidt).

In our discussions since, Maarten has raised the question as to who had actually identified 3C273. It is clear that it was only when faced with Hazard's final radio structure and position as shown in Figure 4, that it was finally possible to make the correct identification. The bright star and the faint jet were co-incident with the radio components B and A respectively, as shown below.

The consecutive papers in *Nature* of March 16 1963 followed. With the discovery of the first quasar our knowledge and understanding of the Universe changed forever.

3C273 had become:

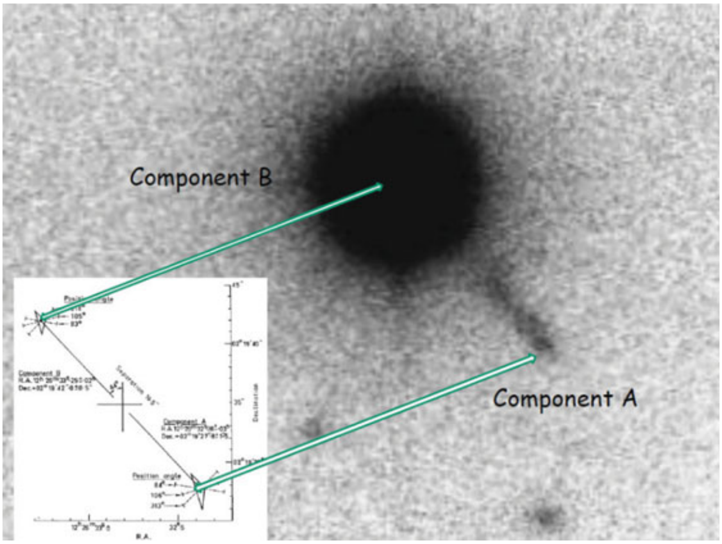

Figure 6. The culmination of the Parkes positions and the Palomar redshift.

- the first Quasar
- the first radio and optical Jet
- the first inverted spectrum radio source
- the first sub-arcsecond radio position
- the first sub-arcsecond radio structure
- the first radio-optical reference frame tie
- the first optical and radio variable extragalactic source
- the first black hole.

Acknowledgements

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