DISCOVERY OF QUASARS

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Quasars are hard to find in the optical sky; there are as many as 3 million stars brighter than the brightest quasar, 3C 273. The situation is radically different at radio wavelengths. In the 3C catalogue 3C 273 is the sixth strongest source above galactic latitude 15 degrees. In hindsight, then, it is clear why radio astronomy was destined to lead us to the first quasars. If radio astronomy had developed much later, X-ray astronomy would have played the same role for the same reasons.

Historically, the epoch of the discovery of quasars must have been set by the gradual improvement of radio source positions coupled with the accuracy needed to select a relatively undistinguished looking star as a likely identification. I will use this occasion to chronicle the optical work that was carried out, once this stage was reached in 1960.

I am least familiar with the beginning since I was not directly involved. It all started with 3C 48 for which Thomas A. Matthews had obtained an accurate radio position with the twin 90-foot interferometer at the Owens Valley Radio Observatory. This source had a small angular diameter according to long baseline interferometry carried out at Jodrell Bank and it was expected to be a distant cluster of galaxies. However, when Allan R. Sandage took a direct plate of the field in September 1960 it showed a stellar object with faint fuzz at the radio position. Sandage obtained the first spectra of the stellar object in October 1960 which showed it to be extremely peculiar, the only prominent features being strong, broad emission lines. Photometry by Sandage of the 3C 48 stellar object showed that it had a strong ultraviolet excess, such as exhibited by white dwarfs. Guido Münch and Jesse L. Greenstein obtained further spectra in subsequent months. The results of the joint effort were presented in an unscheduled paper at the 107th meeting of the American Astronomical Society in New York in December 1960 (Matthews, Bolton, Greenstein, Munch, and Sandage 1961).

Further photometry of the 3C 48 stellar object showed it to be variable and the general impression in 1961 was that this was probably the first radio star (see Matthews and Sandage 1963).

My own work on optical objects identified with radio sources started after the retirement in 1960 of Rudolph Minkowski, following his remarkable determination of a redshift of 0.46 for the radio galaxy 3C 295. Tom Matthews supplied me with optical identifications of radio sources. Initially these were mostly radio galaxies. I am giving in Table 1 a list of first spectroscopic observations of optical objects with those radio sources that eventually turned out to be quasi-stellar radio sources.

TABLE 1

Initial Spectra of Optical Objects Identified with
Quasi-Stellar Radio Sources, 1961-1962

Date	Radio Source	Optical Object
Apr 1961	3C 286	misidentification
Jun 1961	3C 280	misidentification
Jun 1961	3C 298	misidentification
May 1962	3C 196	quasar
May 1962	3C 286	quasar
May 1962	3C 273	misidentification
May 1962	3C 254	misidentification
Oct 1962	3C 147	quasar
Dec 1962	3C 273	quasar

All three objects observed in 1961 were spectroscopically uninteresting and eventually turned out to be misidentifications due to radio lobe shifts. It was not until May 1962 that two further quasars-to-be were observed spectroscopically. 3C 196 showed a continuum without emission or absorption lines. 3C 286 exhibited one broad emission line at 5170 A. I noted in a brief Letter that this line was not observed in any other astronomical object, including 3C 48 (Schmidt 1962). I also obtained in May 1962 a spectrum of a galaxy mistakenly identified with 3C 273.

The spectrum of 3C 147 observed in October 1962 showed several emission lines in the red part of the spectrum. I obtained several further spectra and discussed the material at a conference on extragalactic radio sources held at the Goddard Space Science Institute in New York in December 1962. I attempted to explain the spectrum in terms of helium emission from an expanding shell, but did not publish this interpretation as it was soon overtaken by further developments.

The next object among quasars-to-be was 3C 273. Cyril Hazard et al. had been observing lunar occultations of this strong source in April, August and October 1962, and found that it was a double. John Bolton sent us the first accurate positions obtained in August 1962. Tom Matthews found that the two sources coincided to within a few arcseconds with a thirteenth magnitude star and a nebular wisp or jet. I suspected that the jet was a peculiar nebula associated with the radio source and that the 13th mag. star was a foreground object. Since the jet was exceedingly faint and would require long exposures, I decided to take a spectrum of the bright star so that it could be eliminated from consideration.

The first spectrum of the star taken at the end of the night of December 27/28, 1962 was badly overexposed - I was not used to observing such bright objects. In the far ultraviolet the spectrum showed a broad emission line, at 3250 A. In addition, I saw emission lines at 5650 and 5820 A and suspected the presence of others. Two nights later I obtained a spectrum with the correct exposure and found several more emission lines. It was clear that 3C 273 belonged to the class of 3C 48.

Subsequently, J. B. Oke observed 3C 273 spectrophotometrically at the 100-inch telescope on Mount Wilson and detected a strong emission line in the infrared, at 7600 A. A total of seven emission lines was now known in 3C 273 and in hindsight it seems strange that with so much information no larger effort was undertaken to identify the lines. I showed the list of lines to I. S. Bowen and B. Baschek, but besides incomplete identifications with parts of the helium spectrum, no progress was made.

It was on February 5, 1963 that the puzzle was suddenly resolved. Cyril Hazard had written up the occultation results for publication in Nature and suggested that the identification results be published in an adjacent article. It was in the process of writing the article that I took another look at the spectra. I noticed that four of the six lines exhibited increasing spacing and strength toward the red. I attempted (not necessarily for any good reason) to construct an energy-level diagram based on these lines, then made an error which seemed to deny the regular pattern. I remember being slightly irritated by that, because it was clear the lines were regularly spaced - and to check on that I started taking the ratio of the wavelength of each line to that of the nearest Balmer line. The first ratio was 1.16, the second 1.16, the third .... 1.16!

Realizing that this was a redshift, I divided the wavelengths of the other two lines by 1.16 and found that they landed near those of the Mg II doublet at 2800 A and forbidden [O III] at 5007 A. Oke's line observed at 7600 A came close to the wavelength of H-alpha. Clearly, a redshift of 0.16 explained all the observed emission lines!

The extraordinary implications of a "star" of 13th magnitude having a redshift of 0.16 were immediately clear. When I told Jesse Greenstein what had happened, he produced a list of emission line wavelengths from a just completed manuscript about the spectrum of 3C 48. Within minutes, we had derived a redshift of 0.37 from the emission lines which mostly turned out to be forbidden lines. Most importantly, one of the emission lines turned out to be Mg II at 2800 A. This provided strong confirmation for the redshift of 3C 273, since the Mg II doublet had never been observed yet in an extragalactic object.

The results for 3C 273 and 3C 48 were published in four consecutive articles in Nature six weeks later (Hazard, Mackey, and Shimmins 1963; Schmidt 1963; Oke 1963; Greenstein and Matthews 1963).

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