THE QUASARS FROM THE PARKES 2700-MHz SURVEY

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In 1967 we began a 2700-MHz survey for extragalactic sources at Parkes. By the middle of last year catalogues for the entire extragalactic sky available to the 64-m telescope, about 6·9 sterad in all, were either published[1–9] or in press[10]. These catalogues reach different intensity levels; a total of 3·9 sterad is complete to a source surface density of ~150 sources per sterad, and the other 3·0 sterad to between 500 and 1000 sources per sterad. Six selected areas, totalling 240 square degrees, are complete to 2500 sources per sterad. The survey has added about 5000 sources to the Parkes lists.

The accuracy of the radio positions obtained varies between better than 8″ arc rms in each coördinate to worse than 20″ arc, depending on survey zone and intensity level. Programmes to obtain optical identifications on the basis of these positions are carried forward with the survey. Of course, it is recognized that the identifications from these positions will be neither complete nor fully reliable, even in regions of high galactic latitude, and any analysis on the resultant identifications must be carried out with this in mind.

I want to discuss first (and briefly) the procedures used to identify the quasars, and secondly some results, both radio and optical.

About 75 per cent of the quasars or possible quasars found in the survey were identified using the standard "overlay" technique, in which a transparent computer-drawn overlay showing 10 reference-star positions and an error box at the radio position is placed on top of a plate/print, and the field is examined under perhaps 5 or 10× magnification to see if it contains objects of obvious interest. Blue stellar objects at the source positions are suggested as quasar identifications. Of course, quasars are *not* particularly blue in terms of the $B-V$ colour; and there are two reasons why the selection criterion works. First, quasars *are* bluer than the great majority of high-latitude field stars past which one is looking to make the identification. Second, if the Palomar Survey plates/prints are being used (or a set of blue and yellow plates with the same filter combination), the lack of a −UV filter for the blue plate means that the image of an object with an ultraviolet excess is somewhat enhanced.

The plates/prints used in this standard approach (together with references to the results of the programmes) are as follows:

(i) Palomar Sky Survey Prints. Of the objects suggested as quasars from examination of these prints, about 65 per cent are genuine quasars, according to subsequent optical observations. For most zones of the survey covered by Palomar prints, the results of the print examination are included with the catalogue[4,5,6,9]; for two of the zones the results are reported separately[11,12].

(ii) Double exposure (B–UV) Palomar Schmidt plates, taken by J. G. Bolton in 1966–67. These plates were obtained for our first zones of the 2700-MHz survey, and cover 0·5 sterad in the declination range ±4°. The plates provide a measure of UV excess, and subsequent observations, mostly by Roger Lynds and Derek Wills, have shown that >95 per cent of the objects suggested as quasars from these plates[13] are genuine.

(iii) *B*,*V* plate pairs, Uppsala Southern Schmidt. To obtain some identifications at declinations further south than reached by the Palomar Sky Survey, *B*,*V* plate pairs (using standard filter combinations) were taken on the Uppsala Southern Schmidt telescope at Mount Stromlo Observatory. These plate pairs cover about 0·3 sterad in the declination range $-33°$ to $-75°$, and reach within 1^m of the Palomar Survey prints. We expect that about 65 per cent of the 40 objects suggested as quasars in this programme[14] will prove to be genuine when the optical observations are undertaken.

An optical survey such as this requires a large amount of telescope time, but can, of course, be used to make both quasar and galaxy identifications. By confining themselves to a hunt for quasars only, Bruce Peterson and John Bolton undertook a programme of southern identifications which was highly effective in terms of telescope time per identification made. The technique they used I term the "pot shot" method, and it consists of carefully selecting the radio-source candidates on the basis of their radio properties. The programme has produced 25 per cent of the published Parkes quasars[15–18], and I return to a discussion of it shortly.

These programmes have added a total of 450 quasars and suggested quasars to the literature. It is thus imperative that I quickly present some results from studies of these objects, albeit very preliminary ones, in an attempt to convince you that this is not an exercise in stamp-collecting.

The essential point is that these quasars were selected by a survey at a relatively high frequency. If all radio sources were to have identical radio spectra, the survey frequency would make no difference. But they do not. It is well known that most sources found in low-frequency surveys ($\leqslant$408 MHz) have radio spectra which in the conventional log S–log ν plane appear as straight lines of slope $-0{\cdot}8 \pm 0{\cdot}2$, or as straight lines at the lower frequencies bending to a somewhat steeper slope at the higher frequencies. However, a small proportion of sources found in these surveys had "unusual" spectra, showing enhancement at the higher frequencies, or cut-offs to the lower frequencies. A relatively high survey frequency will serve to select such sources at the expense of those with "normal" spectra, and a prime reason for carrying out the Parkes 2700-MHz survey was to determine the extent of this "flat spectrum" source population.

I shall show the extent of the change in spectral content by means of an α–α diagram, first used by George Brandie and Alan Bridle in describing the spectra of sources in the Michigan 8-GHz survey[19]. Fig. 1 shows how the diagram works. Three flux densities, at frequencies ν_1, ν_2, and ν_3, are measured for each source, from which two spectral indices are computed, a low-frequency index $\alpha(\nu_1, \nu_2)$ and a high-frequency index $\alpha(\nu_2, \nu_3)$. These two indices define a point in Fig. 1 for each source; the lines in the diagram are schematic representations of the type of spectrum (log S vs log ν) represented by each region of the diagram. If the indices are equal, then the point representing the source falls on the diagonal, and the spectrum is a simple power law. Points above the diagonal correspond to radio spectra for which the high-frequency spectrum is flatter than the low-frequency spectrum, *i.e.* the source shows high-frequency enhancement due to one or more compact components. Points below the diagonal indicate that the low-frequency

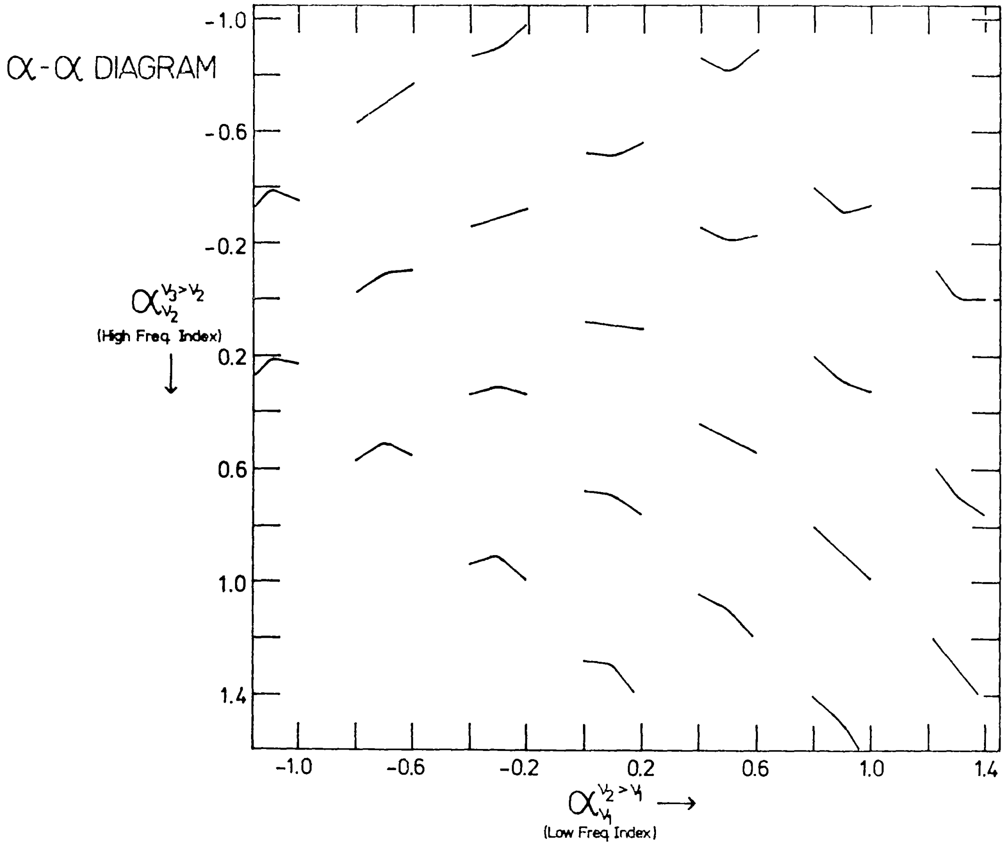

FIG. 1

The α–α, or two spectral index diagram. The lines in the diagram are schematic representations of the radio spectra (in the standard log S vs log ν plot) to which each region of the α–α plane corresponds. The indices are in the sense $S = K\nu^{-\alpha}$.

spectrum is flatter than the high-frequency spectrum, *i.e.* either the spectrum steepens with increasing frequency or it shows a cut-off to the lower frequencies. The lower right-hand corner of the diagram is the region in which we find the "normal spectrum" sources with power-law exponents of $-0{\cdot}8$.

(The diagram is the radio analogue of the two-colour diagram $(U-B)$ vs $(B-V)$. To make the analogy precise, the ordinate runs *downward*, as a concession to the optical astronomers at this meeting. It will not do so in future versions.)

Fig. 2 shows real data in this presentation—the identifications from the 3CR catalogue of radio sources. The flux densities measured by Kellermann, Pauliny-Toth, and Williams[20] were used to compute the indices, interpolation between their observations at 178 and 750 MHz yielding intensities at 318 MHz. The most obvious feature is how little of the diagram is populated—most 3CR sources have spectra of the common or garden variety power law or power law steepening with increasing frequency. The quasars and radio galaxies are clearly completely and inextricably mixed up in this plot, and I doubt that any statistical test could be devised to demonstrate a significant difference between the radio spectra of 3CR quasars and radio

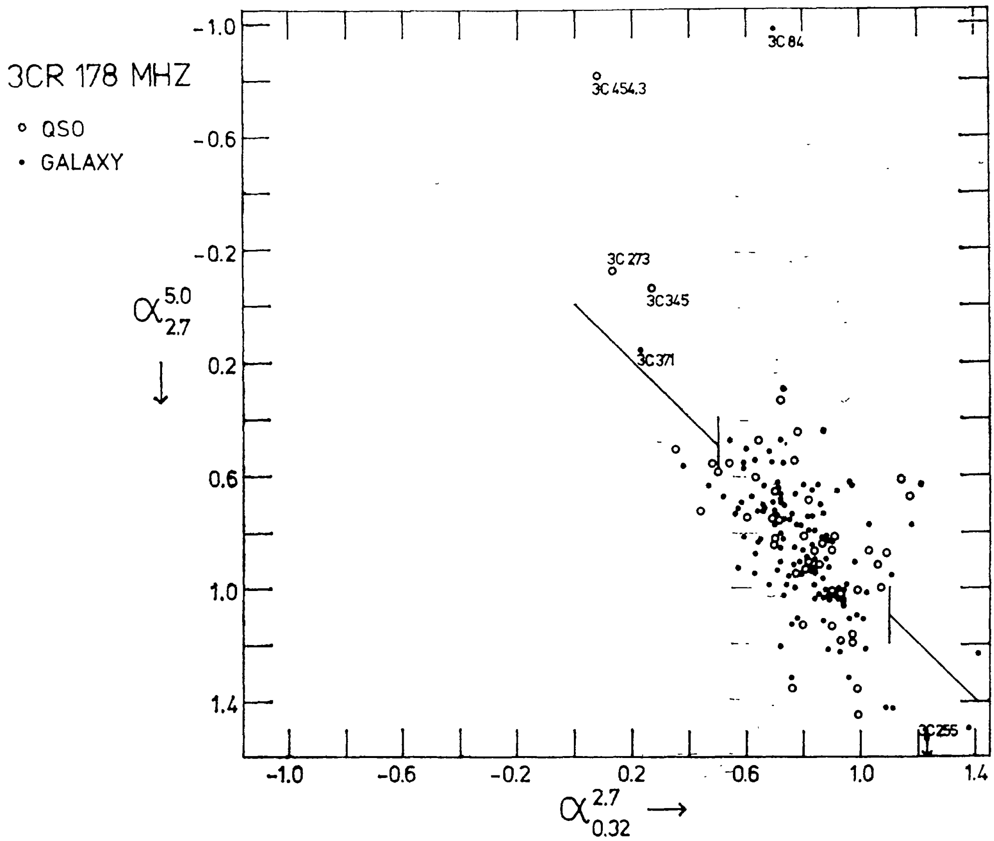

FIG. 2

The α–α diagram for the identifications from the 3CR (178 MHz) survey; data references in text.

galaxies. The survey frequency for the 3CR catalogue is relatively low, 178 MHz, and it is this which results in the selection of the steep-spectrum objects. These have consequently come to be considered as the "normal spectrum" objects, while the few objects in other regions of the diagram, all well known, have been considered as having "unusual" spectra.

The identifications from a high-frequency survey present a picture which is vastly different. Fig. 3 shows all the identifications from the Parkes 2700-MHz survey which are north of declination $-2°$. These identifications are all from the Palomar prints or two-colour plates; I stress that no "pot shot" results of carefully-selected radio sources are included to bias the picture. The indices were computed from the 318-MHz flux densities of Condon and Jauncey[21,22], and the 2700 and 5000-MHz flux densities obtained at Parkes.

A number of points should be made here. First, note the enormous range of spectral types which are represented in the diagram. The "normal spectrum" population is still present, galaxies and quasars mixed up as in Fig. 2. But the remainder of the diagram, almost blank in the previous figure, is populated *almost solely by quasars*. In particular, there are *no* radio galaxies showing low-frequency cutoffs, and relatively few showing enhancement due to compact components self-absorbing at high frequencies.

Most quasars shown in Fig. 3, then, are of spectral types which are not

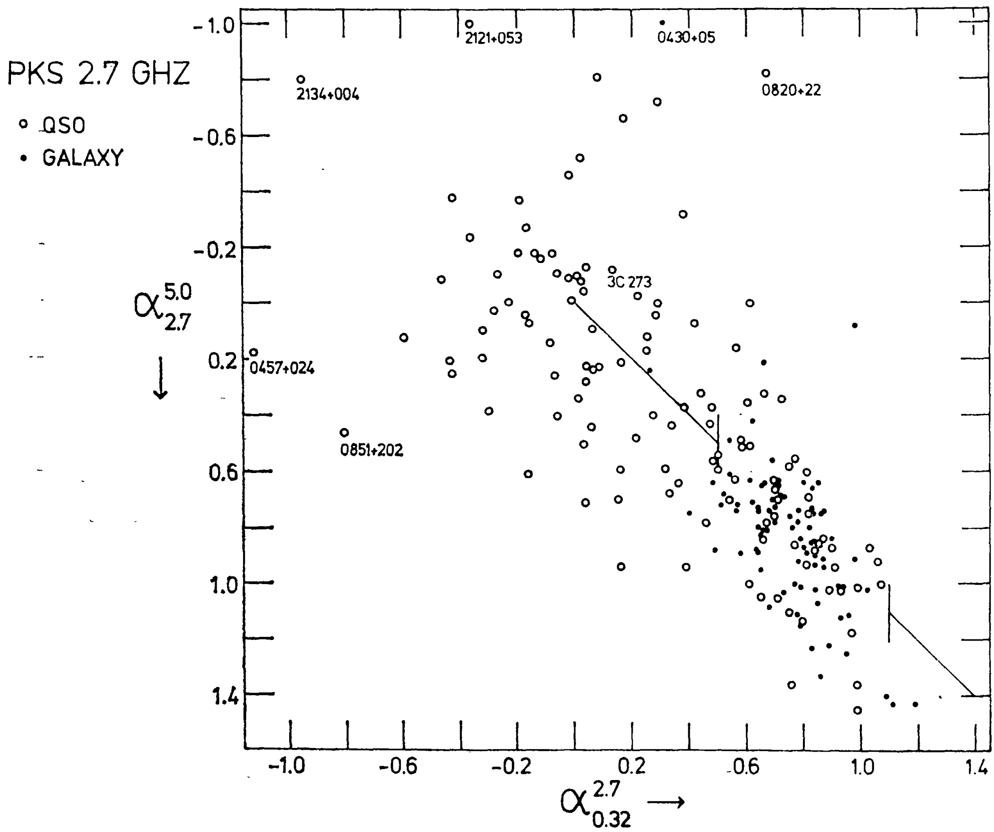

FIG. 3

The α–α diagram for the identifications from the Parkes 2700-MHz survey at declinations north of $-2°$; data references in text.

detected in the low-frequency surveys. The sample of radio-active quasars which has received most attention to date is the "normal spectrum" sample, which does appear in Fig. 3, but which does not dominate the diagram as it does in Fig. 2. In particular, studies of structure have indicated that these quasars frequently resemble radio galaxies in showing double structure with a weak and compact third component coincident with the optical object. This resemblance has been used to argue that quasars and radio galaxies are closely related objects. However, the structures of quasars in Fig. 3 which are *not* in the "normal spectrum" region of the diagram are generally dominated by one intense and compact component of radio emission, coincident with the optical object. The radio morphology of these objects does *not* resemble that of the majority of radio galaxies; and the large numbers of quasars recently identified from high-frequency surveys means that this dissimilarity is true of the majority of radio-active quasars now catalogued.

Before further consideration of the relationship between radio galaxies and quasars, it seems to me to be essential that "unusual spectrum", or "flat spectrum", quasars be studied as extensively as the "normal spectrum" sample. The low-frequency surveys have, by virtue of survey frequency, selected those quasars whose radio properties are most likely to resemble those of radio galaxies.

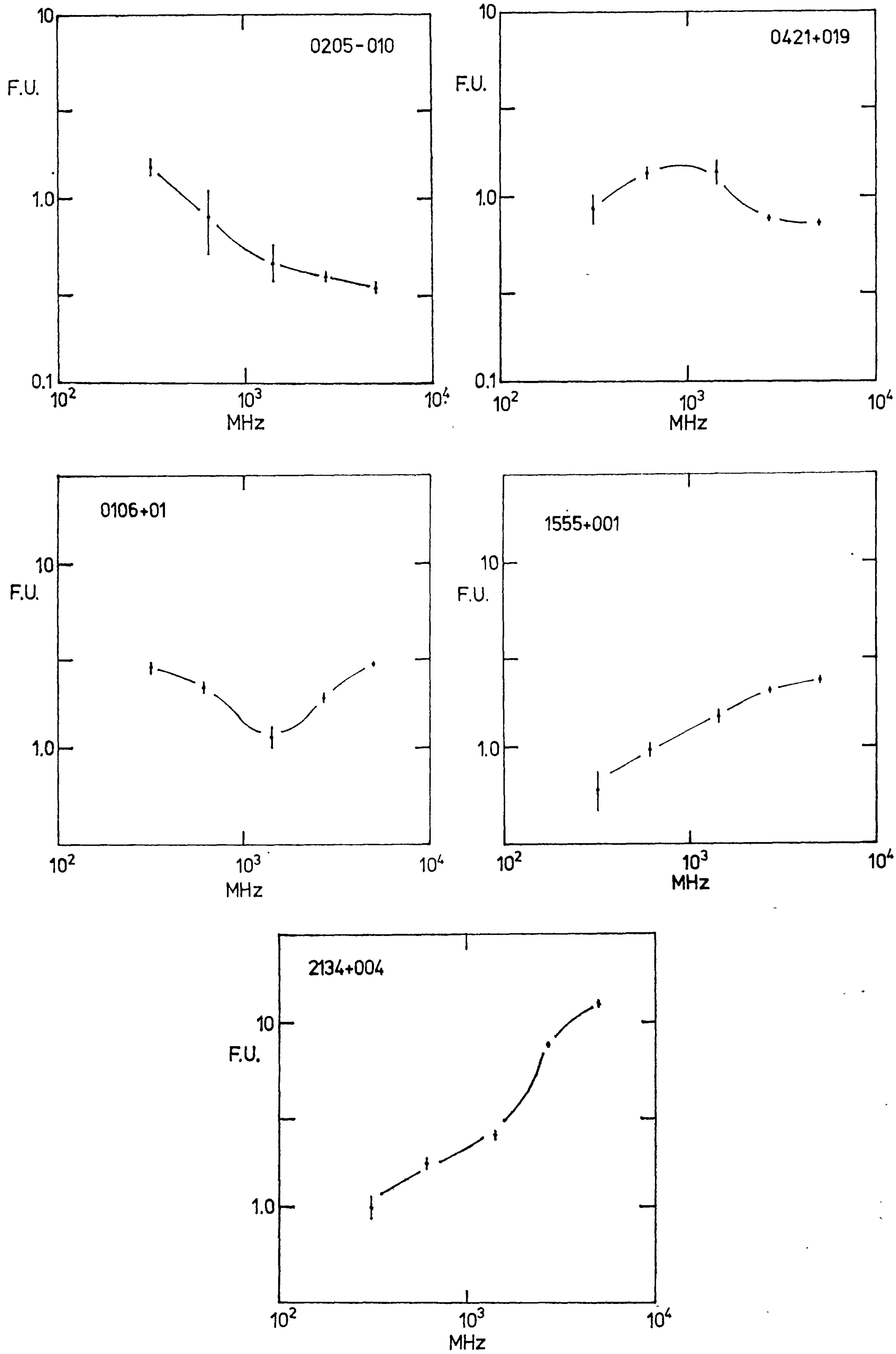

FIG. 4

The radio spectra for five quasars from the Parkes 2700-MHz survey. Flux densities at 318 and 610 MHz are from measurements at Arecibo[21], while those at 1410, 2700 and 5000 MHz are from measurements at Parkes[26].

Fig. 4 shows the radio spectra for a few quasars which do not lie in the "normal spectrum" region of Fig. 3. The plots are in order of increasing dominance of the spectrum by a compact component. For PKS 0421+019, the "low-frequency" component appears to show self-absorption as well as the "high-frequency" component. Flux densities at the higher frequencies for PKS 0106+01 are known to vary[23], while those for PKS 2134+004 are suspected to vary slowly[24]. The latter source was detected in 1968 at a 2700-MHz flux density of 7·5 f.u., and at that time was not reported in any other catalogue. The radio spectrum peaks at ~8 GHz (~12 f.u.)[25].

The clear spectral distinction between radio galaxies and quasars opens up several possibilities. Obviously, if sources are selected with radio spectra which place them outside the "normal spectrum" region of Fig. 3, one can be confident of dealing with quasars with little intrusion of radio galaxies into the sample. (This requires the single assumption that all radio sources can be identified, on deep enough plates, with either quasars or radio galaxies.) Hence, for example, one can do source-count analyses on the flat-spectrum sources, and be satisfied that it is quasars which are being counted. Likewise, one can look at the distribution of flat-spectrum sources on the sky, and be certain that it is quasar isotropy which is under examination. Any attempt to do such analyses on sources which are *identified* with quasars runs in to optical selection effects which are terrifying. The preliminary results of both these analyses are interesting—the flat-spectrum sources show a *flatter* source count than the steep-spectrum sources[21,26,27], and the distribution on the sky of the flat-spectrum sources suggests some lack of isotropy[27,28]. However, the statistical significance (aside from the cosmological significance) of these results is still under consideration, and I shall not discuss them further here.

Peterson and Bolton have used the spectral distinction in a more direct way in the "pot shot" approach to making quasar identifications. To obtain a large sample of quasars for study with the new optical telescopes coming in to operation in the southern hemisphere, they selected relatively strong sources from southern zones of the 2700-MHz survey for which $\alpha(2{\cdot}7, 5{\cdot}0) < 0{\cdot}4$ (see Fig. 3). They took plates at the positions of these sources with the Cassegrain image-tube camera of the Mount Stromlo 74-inch reflector. The plates reach $\sim 19^m$, and were double exposures in B and UV with these images displaced. Objects with UV excess were detected at the position of more than 100 radio sources[15–18], while galaxies did not appear at any of the source positions. This result was anticipated from the appearance of Fig. 3; very few galaxies lie in the region of the diagram occupied by the Peterson–Bolton sample. But the programme yielded other results which could not have been so easily foreseen.

The first such result is the very high success rate—plates obtained for ~95 per cent of the sources in unobscured regions showed an object with UV excess at the radio position. I believe this to be the highest success rate obtained for any class of extragalactic radio source, and it resulted from taking second-epoch plates in the small proportion of cases for which the first-epoch plates showed no object at the radio position. Moreover, about 20 per cent of the sources identified in this programme are in regions covered by the Palomar Survey prints, on which no object was apparent at the radio source position. The optical variability of these objects indicates that plates at several epochs are needed to approach completeness for quasar identifications; in particular, very accurate radio positions alone cannot produce complete identification statistics. Extreme cases of optical variations were observed for the quasars identified with PKS 0537−441 (18^m to 13^m over a period of several months[16]), and 2315−404 ($\sim 2^m$ variation in three weeks[17]).

The second result is more contentious. The two-colour plates are 4′ arc in diameter, and 80 of them form a uniform sample on which objects with UV excess appear at the radio source positions. Ten of these 80 show a *second* UV-excess object, either brighter or fainter than the radio source identification. (Forty two-colour plates taken at the positions of sources with steep ("normal") radio spectra form a control sample; none of these shows a UV excess object at any position on the plate.) Derek Wills has recently been working on a programme to obtain spectra of the Peterson–Bolton optical pairs, and I want to conclude this contribution with Wills's preliminary results[29] which I give with his kind permission.

The spectroscopy at McDonald Observatory of four of the radio-quiet objects confirms three of them as quasars, with inconclusive results for the fourth. The known density of radio-quiet quasars is about two per square degree at $B = 19^m$, leading to an expectation of $\sim 0{\cdot}5$ radio-quiet quasars in the *total area* covered by the 80 Peterson–Bolton plates. If all ten of the objects turn out to be quasars, the level of significance is thus about 1 in 10^9; *i.e.* there is one chance in 10^9 that the "pairing" could arise from a random distribution. Confirmation of the three as radio-quiet quasars results in a significance level of about one in fifty. However, the probability of finding the *only* three quasars in the ten from the first four tries is only 3 per cent. The significance level of one in fifty is thus a "low" lower limit.

Finally, Wills comments on the meaning of the results should the pairings turn out to be significant. If the redshifts of both pair members are the same, the cosmological hypothesis for the redshift can survive since angular separations of $\sim 1'$ arc lead to physical separations of ~ 100 kpc at $z = 2$. Differing redshifts will obviously run the cosmological hypothesis into severe difficulties. Good spectra were obtained for both objects in two of the three pairs, and again the results are ambiguous: in both cases the radio-emitting object shows a single emission line, while the radio-quiet object shows two emission lines, one of which lies near the single line of the radio-emitting object. In the first case, the radio-quiet object has lines at 3750 ± 10 Å (Ly-α) and 4760 ± 20 Å, giving a redshift of 2·08. The radio-active object has a single line at 4765 ± 10 Å, but if it has a redshift of 2·08, the Ly-α line should be clearly visible at ~ 3750 Å. It is not apparent; hence it is unlikely that the objects have the same redshift. In the second case, the radio-quiet object has lines at 3735 ± 10 Å (Ly-α) and 4700 ± 20 Å, giving a redshift of 2·04, while the radio-active object shows a line at 3735 ± 10 Å (Ly-α?), but no definite line at 4700 Å. More observations of these and the other pairs are obviously imperative.

I have attempted to show that preliminary results from the studies of the flat-spectrum quasar population are as unpredictable as results from studies of any quasar population. But clearly if our understanding of the radio-emitting quasars is to be advanced, then the flat-spectrum population, which now comprises the majority of quasar identifications, requires at least the sort of observational effort (at all wavelengths) which has been devoted to the "normal-spectrum" population.

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THE RÔLE OF ELECTRICAL DISCHARGES IN ASTROPHYSICAL PHENOMENA

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Electrical discharges may occur on stellar and galactic scales. They almost certainly contribute to the phenomena observed in solar flares; and they offer a ready explanation of some aspects of novae, radio-galaxies, and the "jet" of M87.

1. *Introduction*

Electrical breakdown is a commonly witnessed phenomenon in the Earth's