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Quasars in a Control Field Far from Bright Galaxies

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Summary. In order to further investigate the background density of quasars, a field far from bright galaxies has been selected at R.A. $=15^{\mathrm{h}}49^{\mathrm{m}}$, Decl. $=+48°38'$. Adjacent ultraviolet and blue images were compared on three separate 48-inch schmidt plates. A total of 137 ultraviolet objects were found. Spectra of 25 of these candidates were obtained with the SIT spectrograph on the 5 m Palomar telescope. Twelve turned out to be quasars. This yields a value of $6.7\pm0.9\,\mathrm{deg}^{-2}$ quasars down to $B=20$ mag, over the $19.0\,\mathrm{deg}^2$ area of the field.

This value compares well with the original Sandage and Luyten value of 10, the Setti and Woltjer value of 8.5, the Arp, Sulentic, and di Tullio value of 7 ± 4 and the Arp and Hazard value of 6 for background density in other regions of the sky. Selection of the present control field far from bright Shapley-Ames) galaxies has not reduced the quasar density strongly. On the other hand large fluctuations of the quasar density (up to 100%) are present in this field over small areas approximately $1.5\,\mathrm{deg}^2$ in size and may be correlated with groups of intermediate brightness galaxies which are in this field.

Key words: Cosmology – quasi stellar objects Surveys

I. Introduction

In order to evalute quasar clustering on scales ranging from several arc min (Hazard et al., 1979; Arp and Hazard, 1980; Burbidge et al., 1980) to scales of up to two degress (Oort et al., 1981) it is necessary to have a reliable value for the average background density of quasars. It is particularly important to have accurate quasar background densities in order to evaluate the evidence for quasar associations with companions of large galaxies (cf. latest reviews by Arp 1980a, 1981).

But in addition to having an accurate general background density it is important to find out something about the variation of this background from region to region in the sky. In particular, if quasars (or a special class of quasars) are loosely grouped around relatively nearby galaxies, one may wonder how much the previous estimates of background quasar density have been affected by the presence of such galaxies in the original surveyed areas. For example, it has already been mentioned (Arp, 1980b) that the Braccesi field at R.A. $\sim 13^{\mathrm{h}}00^{\mathrm{m}}$ and Decl. $\sim +35\overset{\circ}{.}5$ has a high quasar density and contains five Shapley-Ames galaxies, including an $m_{\mathrm{H}}=11.3$ mag Sc. Nevertheless this field has for more than a decade been quoted as a definitive standard of quasar background density (Braccesi et al., 1970; Formiggini et al., 1979; Steppe et al., 1979). Furthermore, inspection of the field of quasars around and far away from NGC 5982 and from other galaxies (Arp, 1980b) has suggested that the quasar background may be variable over region to region in the sky.

All these considerations have led us to initiate a systematic search of quasars in a selected control field of the sky, i.e. a field chosen to be free of bright galaxies ($m_{\mathrm{H}}<13.0$), in order to derive an average density for the background quasars as well as to analyse the distribution of these quasars across the observed field.

Although the final objective of this project cannot be realized before several years because of the difficulty to gather all necessary spectroscopic and photometric data, preliminary results now in hand are of sufficient interest in themselves to be presented in this paper.

II. Observations

In the early spring of 1979, Arp obtained three Schmidt plates PS 25960/69/75 of a selected control field with the 48-inch (1.2 m) Palomar Schmidt telescope in both the ultraviolet and blue. The ultraviolet exposure was 60 min behind a UGI filter and the blue exposure, offset 12″ from the former one on the same 103a–0, baked emulsion, was 7 min behind a GG 13 filter.

The selected control field was centered around the SAO 45758 star [R.A. (1950) $=15^{\mathrm{h}}49^{\mathrm{m}}17^{\mathrm{s}}$, Decl. (1950) $=+48°37'59''$, $V=6.8$] and corresponds to a galactic field ($l^{\mathrm{II}}=76\overset{\circ}{.}98$, $b^{\mathrm{II}}=49\overset{\circ}{.}44$) completely empty of bright galaxies ($m_{\mathrm{H}}<13.0$), even of those galaxies included in the Second Reference Catalogue of Bright Galaxies (de Vaucouleurs et al., 1976).

By visual inspection of the blue and ultraviolet images of a same object located on a dual image (UB) plate, objects with ultraviolet excess ($U-B \lesssim -0.4$) could be identified down to blue magnitudes of around $B=20.5$ mag on both good quality PS 25960/69 Schmidt plates.

In the first phase of this program, in the spring of 1979, Arp identified by inspection with a hand held magnifier a sample of 50 ultraviolet-excess objects on plate PS 25969 within a radius of $1\overset{\circ}{.}5$ from the center of the control field. For 25 of these candidates located near the center, he obtained spectra with the sky-subtraction SIT spectrograph attached to the Cassegrain focus of the 200-inch telescope on Mount Palomar. In the remainder of

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this paper, these 25 observed UB-candidates are labelled *A* to *Y*. They are sketched in Fig. 1a–d, where the SAO 45758 central star has also been identified.

III. Spectroscopy of the 25 UB-Candidates

Although the redshifts obtained for some of the 25 UB-candidates need further confirmation, we are confident that the quasar or blue star nature of each object can be ascertained at this point. Table 1 summarizes this information altogether with the emission redshift of the identified quasars and an approximate $V(5000\,\text{Å})$ magnitude which was determined only for the objects observed during a photometric night.

As can be seen from that table, among the 25 selected ultraviolet-excess objects, 12 turn out to be quasars and 13 are found to be blue stars.

IV. Average Quasar Density over 19.0 Square Degrees

During June 1980, we made use of the blink comparator of the European Southern Observatory (Geneva) to make new scans of the entire plates of the two, dual-image, (UB) PS 25960/69 exposures. During this long survey, we quickly realized that a considerable number of objects appeared as UB-candidates on one plate but not on the other. After a careful analysis of such cases, it became clear that inhomogeneities in the emulsion, plate flaws, clumps of silver grains, etc. could appreciably contribute to the selection of more UB-candidates than actually did exist. Reciprocally, identification of a blue-excess object on one plate could receive an immediate confirmation on the basis of its same appearance on the second plate. These considerations clearly show that the use of two plates in a blink comparator enables one to select more readily good ultraviolet-excess objects as well as to eliminate very efficiently all those which are artifacts.

After carrying out two independent, careful scans of the $19.0\,\text{deg}^2$ field (10 inch × 10 inch), and excluding all non-stellar UB-candidates, we selected a total number of 158 QSO-candidates down to about $B = 20.5$ mag. However, because $B = 20.5$ mag appears as a limiting magnitude on both PS 25960/69 plates, we had, for the sake of completeness, to limit our sample down to $B = 20$ mag. This last selection was achieved by comparing the B images between some of the 25 spectroscopically observed UB-candidates and the 158 selected QSO-candidates. In doing so, we implicitly assumed that the color index of quasars is negligible in transforming from V_{5000} to B magnitudes. From this comparison results a final sample of 137 good UB-candidates down to about $B = 20.0$ mag. All of these are numbered 1 through 137 and are identified in Fig. 1.

At this stage, we were very impatient to compare our candidates to those first selected by Arp (see Sect. 2). It turned out that among the 25 spectroscopically observed candidates, 11 quasars out of 12 and 2 stars out of 13 were included in our newly selected sample (see Fig. 1 and Table 1). We also note that among the remaining 25 of Arp candidates, which had not been observed spectroscopically, a similar proportion (11 Arp candidates) was rejected from our final sample.

A few remarks should now be made. Indeed, a careful look at the rejected Arp candidates shows that most of them appear as possible UB-candidates on the PS 25969 plate and not on the PS 25960 one, but furthermore it is evident that the $U-B$ threshold adopted initially by Arp in order to select his 50 candidates led him to discover more objects (cf. the missed quasar *Y* in Fig. 1) with a less pronounced ultraviolet excess than those finally included in our sample. Consequently, the sample of 137 UB-candidates presented here certainly contains an important fraction of quasars (~11/13) but is more biased against quasars with $U-B \gtrsim -0.4 \pm 0.1$ than Arp's initial one. At the same time, this also probably means that our sample is biased against high-redshift quasars ($Z \gtrsim 2.5$) for which typically $U-B \gtrsim -0.3$ (Wills and Lynds, 1978).

Considering now that the fraction of quasars missed in our sample is of the order of 1/12, the total number of quasars we expect to find over the $19.0\,\text{deg}^2$ area of our control field is

$$N = \tfrac{12}{11} \cdot \tfrac{11}{13} \cdot 137 \sim 126 .$$

Assuming that the number of blue stars common to our sample and Arp's initial one has been underestimated (or overestimated) by a factor 2, one derives an average density

$$\bar{D} = 6.7 \pm 0.9\,\text{deg}^{-2}$$

for the background quasars down to the limiting magnitude $B = 20$ mag. This value is found to be in good agreement with the Sandage and Luyten (1969) value of 10, the Setti and Woltjer (1973) value of 8.5, the Arp et al. (1979) value of 7 and the Arp and Hazard (1980) value of $6\,\text{deg}^{-2}$ to the same magnitude limit.

Because the photometric standard stars were measured through an 8″ diameter aperture and the quasars through 3″ or 5″ diameters, aperture corrections had to be made on nights of poor seeing. On good seeing nights corrections were less than 0.1 or 0.2 mag and were generally not made. Some of the magnitudes may therefore be a few tenths brighter than listed and in any case

Table 1. Nature of the 25 spectroscopically observed UB-candidates

Object	Nature	Redshift z	Magnitude (V_{5000})
A	QSO	1.960 ± 0.010	19.8 ± 0.1
B	Star		18.7
C	Star		18.2
D	QSO	1.465	19.7
E	QSO	1.728	19.2
F	QSO	(1.878)	20.0
G	QSO	(1.100)	18.9
H	QSO	1.854	
I	QSO	2.045	20.0
J	Star		
K	QSO	(1.869)	
L	QSO	0.953	
M	Star		
N	Star		19.0
O	Star		19.2
P	Star		
Q	Star		
R	Star		17.8
S	Star		
T	Star		18.0
U	Star		
V	QSO	(0.858)	19.3
W	Star		
X	QSO	2.042	18.9
Y	QSO	1.737	19.5

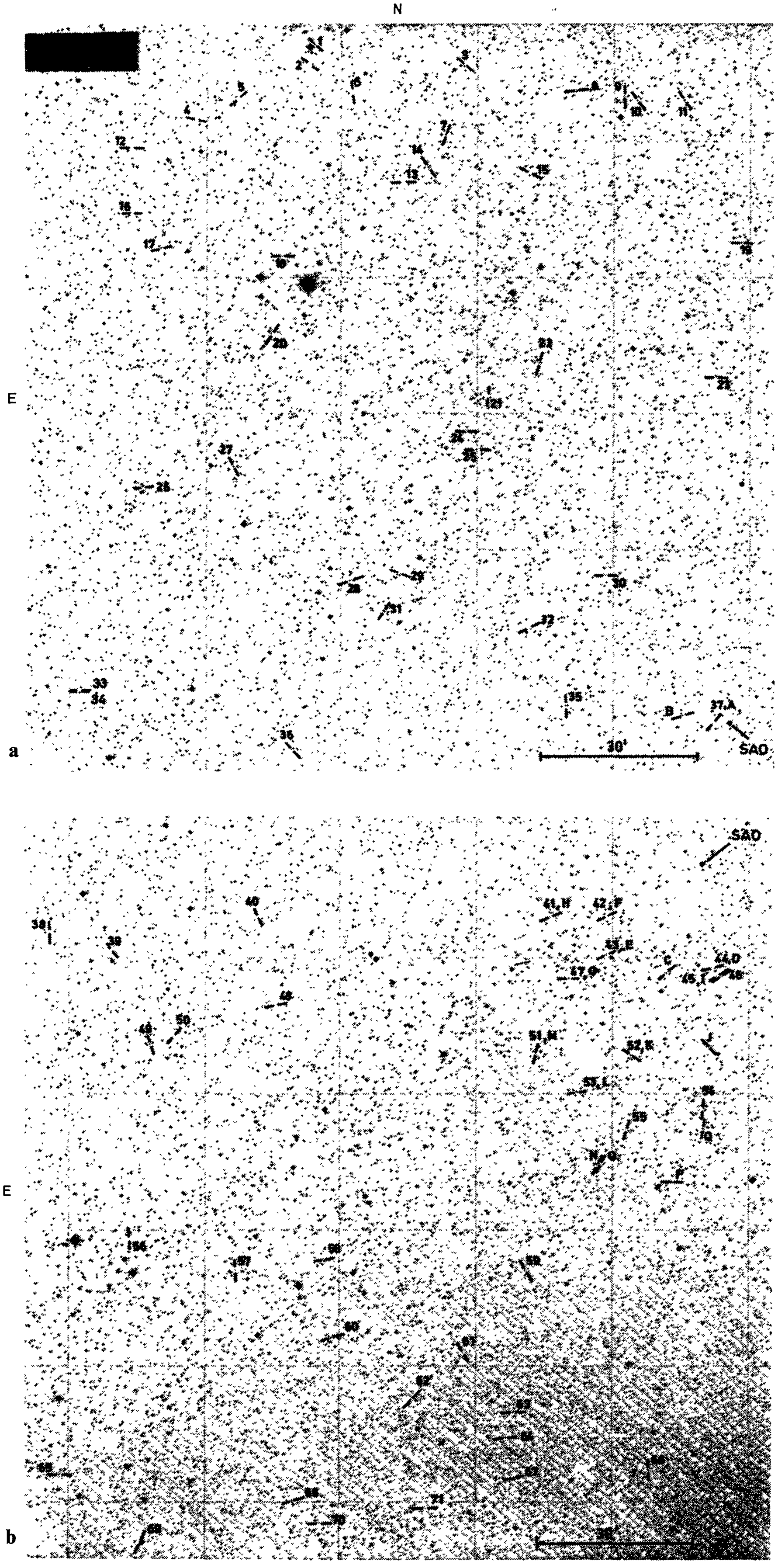
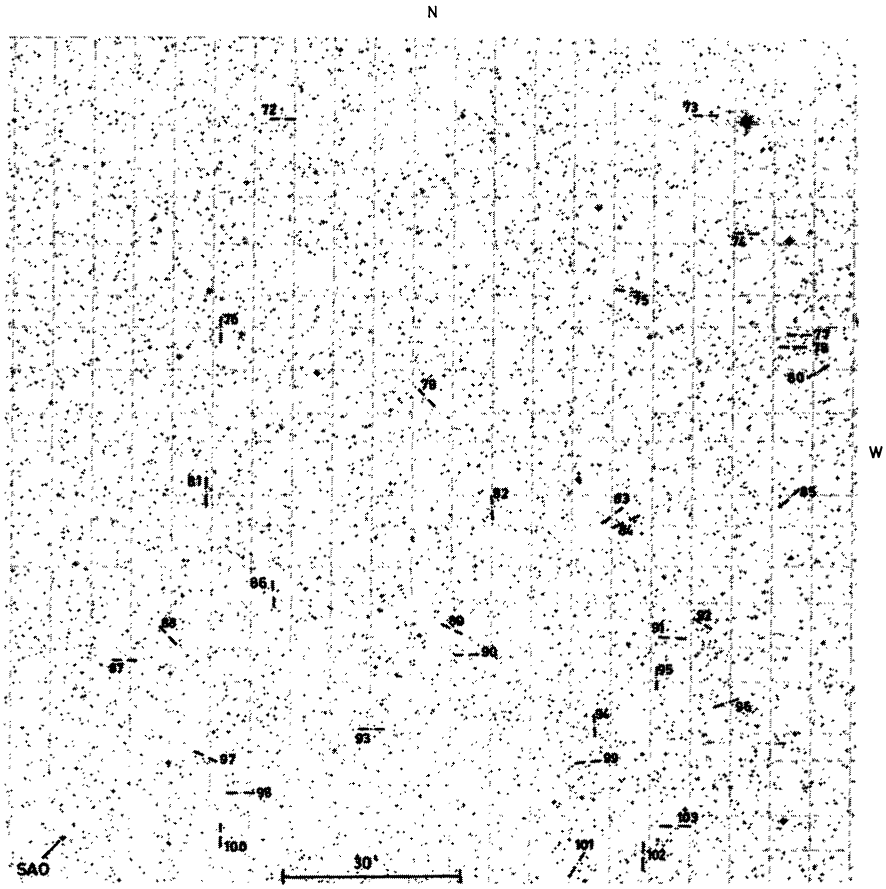


Fig. 1. a Photograph of the selected control field located NE of the SAO 45758 Star. Exposure is 1 h on IIIa–J + Wr 2c with the 48-inch (1.2 m) Palomar Schmidt telescope. All ultraviolet-excess candidates are marked 1 through 137, and the 25 spectroscopically observed UB-candidates are labelled A through Y. **b** Same as for **a** but SE of the SAO 45758 Star. **c** Same as for **a** but NW of the SAO 45758 Star. **d** Same as for **a** but SW of the SAO 45758 Star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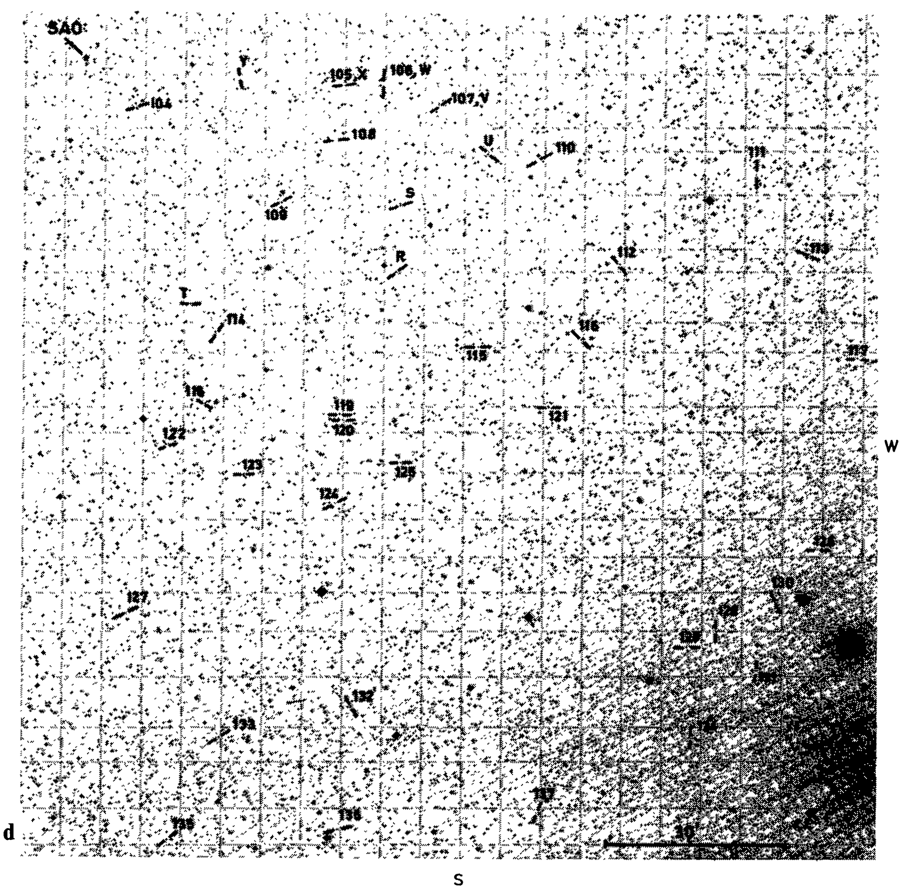
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the limiting magnitude is uncertain by several tenths of a magnitude. We actually plan to perform an accurate *UBV* photometry in order to check the completeness of the present survey of quasars down to $B=20.0$ mag with $U-B \lesssim -0.4$.

V. Fluctuations of the Local Density of the Quasar Background

In reality, before we estimated the average quasar density over the $19.0\,\mathrm{deg}^2$ of the control field, we had already calculated the local density of quasars within the area including the 25 spectroscopically observed UB-candidates. The selected polygonal area being $1.58\,\mathrm{deg}^2$ in size and the number of QSO-candidates identified there equal to 22, the local density of background quasars is found to be

$$D=12.9\pm1.0\,\mathrm{deg}^{-2}.$$

This is a value about twice higher than the average quasar density, and this result should be regarded as fully significant because it is free of any selection effects. An objection to this estimate could be that it is influenced by the choice of the polygonal area. Let us remark, however, that the polygonal area was constructed in such a way that the distance from any QSO-candidate to the polygonal line was kept equal or greater than the mean distance between the UB-candidates located inside that area.

The fluctuation of the quasar background can also be directly seen from the spatial distribution of the UB-candidates in Fig. 1a–d. For instance, in Fig. 1b, it is easy to see the apparent lack of UB-candidates along a strip oriented NE-SW and located SE of the SAO star (also approximately $1.5\,\mathrm{deg}^2$ in size).

This empty area was subsequently searched again for the presence of UB-candidates, but none was found.

VI. Conclusions

The optical UB-technique has enabled us to study the quasar background in a selected field ($19.0\,\mathrm{deg}^2$), empty of bright galaxies. We have derived an average quasar density $\bar{D}=6.7\pm0.9\,\mathrm{deg}^{-2}$ down to the limiting magnitude $B=20$ mag, a value which compares well with previous determinations in other regions. Let us recall, however, that the completeness of the present survey of quasars down to $B=20.0$ mag with $U-B \lesssim -0.4$ still needs further confirmation. As mentioned earlier, it is our intention to gather all necessary *UBV* photometric data in order to perform such a task. Nevertheless, we have confirmed the emphasis by Arp (1980a) that the quasar background may be variable over region to region in the sky and we could even present an example of a typical amplitude (up to 100%) and spatial scale ($\sim 1.5\,\mathrm{deg}^2$) for these fluctuations.

Let us remark that both these results do not alter the previous statistics in favor of physical associations of quasars with galaxies (cf. Arp 1980a, 1981) or quasar clustering (cf. Hazard et al., 1979).

One of the major reasons for undertaking the present work was to ascertain whether a field far from bright galaxies contained fewer than average quasars. The density we have derived, however, is not appreciably less than the density of other fields investigated with the same technique. More fields will have to be measured in this manner before definite conclusions can be made but a few preliminary comments can be made.

If the quasar density in galaxy free fields is not generally reduced, is there any reduction of some particular kind of quasar observed? There are two possible peculiarities noticeable in the field analyzed here. First the distribution of preliminary redshifts is unusual. There are no redshifts present below $z=0.8$, and only one between $1.2<z<1.7$. Quasars associated closely with bright galaxies or companion galaxies in the past have been strongly represented in those redshift ranges. If this pattern were to persist in other non galaxy fields it might establish that quasars of this redshift were the kind that were preferentially, or more closely, associated with bright galaxies.

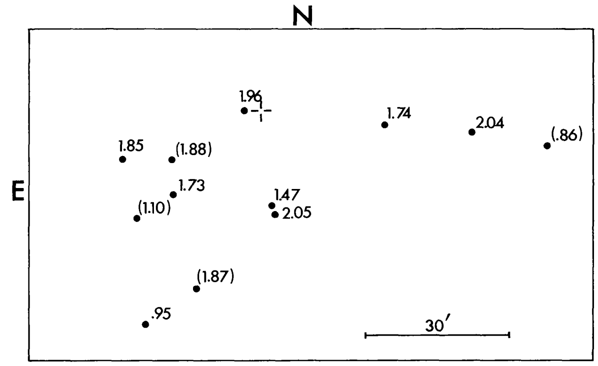

Fig.2 Arp & Surdej

Fig. 2. Those quasars which are presently known near the center of the control field are plotted with their best current redshifts. A tendency for similar values of redshifts to occur in pairs and triplets is evident

The quasars which are present in the present control field are very numerous near redshift $z=1.8$. This is a redshift which is not very common in fields previously investigated. As Figs. 1 and 2 show, however, these redshifts are very concentrated in one small area of the control field. In fact they are concentrated in that small area of the control field in which it was shown earlier that there is a 100% increase in density in what looks like a group or small clusters of quasars. Here, as in other fields (for example see Kunth et al., 1980), there are apparent groups of quasars within which there are redshifts which resemble each other much more closely than would be expected by chance. But even though the quasars are apparently grouped it is still not plausible to interpret them as arising in a distant, rich supercluster because there are different redshift groups within the same spatial group (in Fig. 2 we see a group $z=1.85$, 1.87, and 1.88 and pairs of $z=1.73$, 1.74 as well as 2.04, 2.05 and 0.95, 1.10). The only galaxies which are at all conspicuous on the plate is a chain of galaxies in the 17 mag range, showing some interaction. This chain of galaxies lies about 30′ East of the group of quasars and is a possible candidate for association with the group of quasars.

As mentioned in Sect. IV, it would also be desirable to obtain objective prism plates of the same control field to eliminate the observational bias against quasars with $z>2.5$. This material would also help in improving the sample of QSO-candidates. Finally, obtaining broad-band (*UBV*) photometry of all identified quasars would enable comparison of colors of quasars near bright galaxies with these quasars far from bright galaxies.

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Note added in proof: One further candidate (see Fig. 1b, No. 46) was measured on 24 April 1981. It is a quasar with a redshift $Z=0.968$.