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RADIO SOURCES AND THEIR GALAXIES OF ORIGIN

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Thirteen new associations of radio sources paired across central galaxies are presented. The separations of the radio sources range from 1° to 15°, with one association covering more than 10°. The spectral indices of the radio-pair members resemble each other, and the more distant member of the pair has a preferentially flatter and weaker radio spectrum. The majority of the new central galaxies are spirals, and the possibility is discussed that the ejection of their radio sources is connected with the formation of spiral-armlike features. The time since ejection is computed to be of the order of 10^7 years, and the speeds of ejection to be in the vicinity of 0.1 c. In some cases, smaller galaxies, including type 1 irregulars, are scattered along the line of ejection of the radio sources.

Twelve quasi-stellar objects are among the new radio-source associations. It is shown that the peculiar ellipticals in the *Atlas of Peculiar Galaxies*, which were previously associated with radio sources, have radio sources that are more widely separated from the parent galaxy and are composed predominantly of optical galaxies that emit radio radiation. The radio sources associated with the spirals in the present paper, however, are closer to the parent galaxy and contain a much higher percentage of quasi-stellar objects.

If the spiral and type 1 parent galaxies are taken to be less massive than the elliptical, one consequence of these observations is to suggest that quasi-stellar objects are preferentially less massive than ejected radio galaxies.

I. *Introduction*. Evidence has been presented [1, 2] (called Papers I and II here) that certain kinds of galaxies, usually large ellipticals with disturbed material in the vicinity, are likely to be the origin of ejected pairs and groups of radio sources. Of thirty-five candidates in the *Atlas of Peculiar Galaxies* [3] which could be formally tested, fifteen were found to be at the center of pairs of radio sources. Taking the distribution of radio sources as observed, and the stated prescription for finding associations, it was computed empirically that only 4.6 such associations should be found by accident. The probability that the number of associations actually found could be accidental can be computed from a binomial distribution to be less than 10^{-5}. Observations of streaks and shreds of luminous material near the galaxies which pointed in the direction of some of the radio sources led to the working hypothesis that the central peculiar galaxies had ejected the pairs of radio sources. If this hypothesis is correct, it implies that many of the remaining extragalactic radio sources distributed over the sky were also ejected from galaxies. A search was therefore undertaken to discover galaxies from which some of these other radio sources originated. The present paper describes thirteen new high-probability associations of radio sources with parent galaxies.

Methods of finding radio-source associations are first discussed. The reality of the new associations as a group is then analyzed and each new system described individually. The associations are arranged so that the discussion leads up to involvement of spiral galaxies and spiral armlike features with the ejection process. The culmination of the discussion of individual systems links some flat spectral-index sources with quasi-stellar objects relatively recently ejected from spiral galaxies. The relationship suggested between shredlike galaxies pointing along the line to radio sources, small irregular galaxies scattered along these lines, and type I spiral-armlike phenomena are discussed. The paper then relates the new results to the associations originally discovered around principally elliptical and type II galaxies. Finally, the possible evolution of a nonvelocity redshift from high to low values as the radio sources evolve through their various stages is considered.

II. *Remarks on Discovery of Radio-Source Associations.* The phenomenon of wide radio-source pairing across a central galaxy was first noticed when a certain class of unusual galaxy from the *Atlas* was seen to fall between apparent radio-source pairs in the sky. Because there were a limited number of peculiar galaxies in the *Atlas*, it was possible to investigate the distribution of radio sources around each one. The manner of finding the associations presented in the present paper had to be different because the list of peculiar ellipticals that had been discovered to be good candidates for radio-source ejection had been exhausted in the *Atlas* analysis. In order to find additional associations around possibly different kinds of central galaxies, and to investigate weak, small-seperation associations (presumably more distant), it was necessary to return to the very first method by which the associations were noticed. That is, we examine the distribution of radio sources, and where a pair of radio sources fall close together relative to the density of sources in the area, we look between this pair. If there is a galaxy in the region between them that is bright for the amount of area involved, i. e., does not appear to be an accidental occurrence, we consider that configuration to be a successful identification.

It was considered that the most pressing problem was to find a sample of the most probable radio pairs in order to find out more about what kind of galaxies fall between these pairs and what kind of material might extend in the direction of the radio sources. All the probability factors mentioned above can be visually integrated and high-probability associations selected. This sample of the most probable identifications was then studied in detail. Unexpectedly, it turned out that properties of the radio sources were related to the properties of the central galaxies. These properties can now be used to improve selection criteria for systematic analysis of the radio distribution as a whole. Positions of radio sources in various catalogues are being analyzed by computer (Jon Sharp, in preparation). That analysis will furnish the probability, relative to chance occurence, of each radio pair considered in the present paper. A systematic listing of all probable associations will also become available at that time.

Meanwhile, we can discuss the new associations prior to obtaining their formally computed probabilities by using the unexpected ralationships in the properties of the associations which emerged. We can show that, as a group, the new associations cannot be accidental because (1) central galaxies fall preferentially closer to the stronger radio source. Additional evidence for the reality of the whole group of associations is present in the tendency for (2) the radio pairs to have similar spectral indices, and (3) the more distant source to have the flatter spectrum. The validity of any individual association can usually be supported by (4) the peculiar appearance of the central galaxy, (5) shreds, jets, or luminous material pointing along the line of radio sources, or (6) smaller galaxies distributed along the line between the radio sources.

Going back to certain regions of the sky now with the knowledge that indices of pairs are correlated and that sources more distant from the central galaxy are weaker and have flatter spectra, it seems that we can begin to disentangle certain areas of confusion. It is possible that eventually in only a few areas of the sky will the separate distributions overlap in such a manner as to be inextricably confused.

III. *Reality of the New Group of Associations.* The radio sources listed in the *Parkes Catalogues* [4, 6] between Dec $= +20^\circ$ and -30°

were adopted as the distribution in which to search for new associations. These Parkes sources went to faint radio limits, about 1.5 flux units at the survey frequency of 408 *Mc/s*, but the biggest advantage was that here was a rather complete listing of radio sources in a region of the sky that had been so far essentially uninvestigated for associations. (The original *Atlas* identifications had mostly been made in the region of the 3C *R Catalogue*, between Dec $= 0°$ to $90°$). The present search has been confined to the region between R. A. $= 22^h$ to 4^h in the *Parkes Catalogues*. Table 1 lists all galaxies considered as probable origins of radio sources at the time of writing this paper. The table also collects data which are known for the radio sources themselves. The new associations are listed in the first thirteen entries in Table 1*a*, roughly in order of decreasing brightness of the central galaxy. Four previous identifications (Paper II) with Parkes sources are included at the end of Table 1*a*. Table 1*b* lists all the remaining sources previously indentified with 3C sources in Paper II. The first twelve are pairs of radio sources listed in order of the probability of the association as computed in Paper II. The last eight are multiple-source associations also listed in order of probability. Flux strengths and spectral indices of these 3C sources are taken from [7]. The data for 3C 274 (M 87) is from [8, 9].

a) *More Distant Source Tends to be Weaker*. By inspecting the first thirteen sources in Table 1*a*, it can be seen that where there is a difference in source strength at a wavelength of 22 *cm*, it is such that in eleven out of twelve cases the radio source that is at a greater separation from the central galaxy is the weaker source. In fact, only No. 13 violates this relation, and, since these associations are listed in order of fainter central galaxies, No. 13 is the least certain association. At 75 *cm* the more distant source is weaker in ten out of twelve cases. The first result we have established, then, is that this new group of associations is physically significant. We can argue very simply that if the associations were a result of a galaxy accidentally falling on a line between a pair of unrelated radio sources, we would expect the central galaxies to show no preference for falling closer to the stronger source.

The second important point that this result immediately relates to is the following: It is known that in the classical radio-galaxy identifications (radio pairs separated by less than 30′) the optical galaxy falls closer to the stronger radio source in about 75 per cent of the cases ([10] and Fomalont private communication). The same is true in the present identifications — which strongly suggests that a similar physical mechanism is responsible for both the large and small separations.

The situation with respect to the previous identifications of Paper II is not so clear-cut. It is difficult to be certain which are the pair members in the multiple-source distributions in Table 1*b*. Therefore, only the twelve pairs of the first part of Table 1*b* are considered. In that group, at 21 *cm* wavelength, seven out of twelve associations (or six out of the first nine most probable associations) show the central galaxy falling closer to the stronger radio source. About the same is true of the four previous identifications with Parkes sources from Paper II which are listed at the end of Table 1*a*. In the case of those previous identifications, however, the radio-source distributions were studied around specific galaxies; therefore, if bracketings of radio sources were accidental, we would expect the stronger radio source to fall more separated from the central galaxy than the weaker because a larger area must be searched to find a brighter radio source. Since the reverse is true, it constitutes an additional argument for their physical reality. But it is also clear that in the new identifications a much higher percentage of central galaxies are closer to the stronger sources than in the original identifications. We will discuss later the differences between radio sources in the old and new indentifications. There is an interesting feature of the first twelve associations in Table 1*b*, however, and that is that out of the five cases where the correlation is violated (and therefore the more distant source is stronger), the fluxes of the radio pair vary with frequency in such a way that four of them will probably reverse at frequencies slightly lower than 178 *Mc/s*. That is, *at long wavelengths* the original associations of Paper II more strongly favor the weaker source as being the more distant. (It will be argued later in this paper that radio sources involved in the original identifications around elliptical galaxies are more likely to have undergone secondary radio outbursts. Therefore, we might expect the shorter-wavelength radio regions to be distorted from their original strength, whereas the longer wavelength spectrum more nearly reflects the original relative strength of the pair. This is a possible explanation of why the newer identifications show the more distant source weaker at all observed wavelengths, while the original identifications show the effect best at long wavelengths).

That the more distant source should be in general weaker at longer wavelengths is supported in both groups by the data to follow on the indices, which shows that the more distant source in general has the flatter spectrum. This means, naturally, that as one goes to longer wavelengths the strength of the nearer source increases relative to the more distant one.

b) *More Distant Source Tends to Have Flatter Spectrum.* Considering first the thirteen new identifications, we find that of those with differences in their spectral indices, the source with the flatter spectrum is more distant in seven out of eleven cases. Considering next the previously identified pairs around elliptical galaxies listed at the end of Table 1*a* and the first part of Table 1*b*, we find the source with the flatter spectrum is more distant in ten out of fifteen cases. Altogether, the seventeen out of twenty-six cases in which this is true fall just short of statistical proof of non-randomness. But, if this same ratio of nearly two to one holds in further identifications, then this one property alone would furnish proof of the physical reality of these systems. The point is, of course, that in accidental associations we should have equal chances of the more distant source having either a flatter or steeper spectrum. The fact that the more distant source has a flatter spectrum in about two thirds of the configurations identified so far would have to be explained by any physical mechanism proposed for the ejection.

c) *Spectra of Sources in Identified Radio Pairs Tend to be Similar.* The average spectral index of Parkes sources in the area of the sky we are considering is about -0.86 (uncertainty of the average about ± 0.01). The average spectral index of 3C sources is about -0.85 ± 0.03 [7]. There is little apparent skewness in the distribution of these indices, so we can adopt an average of -0.86 and investigate whether the radio-source pairs have spectral indices which tend to be either both below or both above this average spectral index. Of the thirteen new identifications that have spectral indices appreciably different from this average (and omitting No. 1, which was detected on the basis of its flat spectral indices), in seven out of ten cases the spectral indices of both members of the pair are either both above or both below the average. In the remaining associations in Table 1*a* and the pairs in Table 1*b*, this situation pertains in nine out of fourteen cases. The total ratio of sixteen out of twenty four has just about four chances out of one hundred of occurring accidentaly. The trend is clearly for spectral indices of pairs picked by their geometrical associations with central galaxies to have spectra which are similar.

d) *Testing Correlation of Radio Properties in All Sources So Far Identified.* Table 2 summarizes the properties of the radio sources in the associations identified in Table 1. If the radio sources identified with each central galaxy were only accidentally associated, then we would expect each radio source not to have the stated property (*cross*) as often as it did possess the stated property (*check*). We see that Table 2 contains 53 checks out of 78 entries, which is a statistically significant number.

IV. *Remarks on Individual New Associations.* Many of the arguments concerning the nature of the radio sources and their relation to their central galaxies which will be used to suggest an over-all picture at the end of this paper will be developed here in the analysis of individual associations. The less important associations will be considered first and the more illuminating cases later, arranged so as to clarify certain ideas about the ejection process. A radio flux ratio is written next to the 21-*cm* flux strength of each filled-circle radio source in the diagrams. This flux ratio is simply obtained by dividing the 21-*cm* flux by the 75-*cm* flux. It has the advantage of being derivable for sources with only these two spectral measures and avoids the problem of quantitatively designating a curved spectrum. The numbers used in the following sections refer to numbers in Table 1*a*.

a) *No. 13.* Although the 3°.4 separation of this pair of radio sources is small compared to identifications made in Paper II, it is rather large for the identifications made in the present paper. The diagram of the configuration is shown in Fig. 1. As mentioned previously, the central galaxy is faint and the identification is the least secure of any suggested here. Both radio flux ratios are very near the average, which is about 0.36. The galaxy itself is a small, low-surface-brightness spiral with a very sharp stellar nucleus. There is a more compact galaxy south of it along the line to the 4.7 unit source, which is indicated by a dot in Fig. 1. Another small galaxy along this same line, but lying closer to the central object, is not indicated on the drawings.

b) *No. 12.* Fig. 2 shows a pair of radio sources of similar flux strength separated by only 1°.3 on the sky. The spectral indices are almost identical and slightly flatter than normal (Table 1*a*). The central galaxy is more like a bona fide E galaxy than any of the remaining new identifications made in this paper. There may be small, very faint extensions from the photographic image of the E galaxy. The two smaller E-like galaxies in the region seem to be significantly placed along the line to the northern radio source. They are sketched in the diagram of Fig. 2. In the 200-inch photograph, two very faint additional galaxies are also seen to lie northward along this line (actually all these galaxies are in the direction to the centroid of the radio pair).

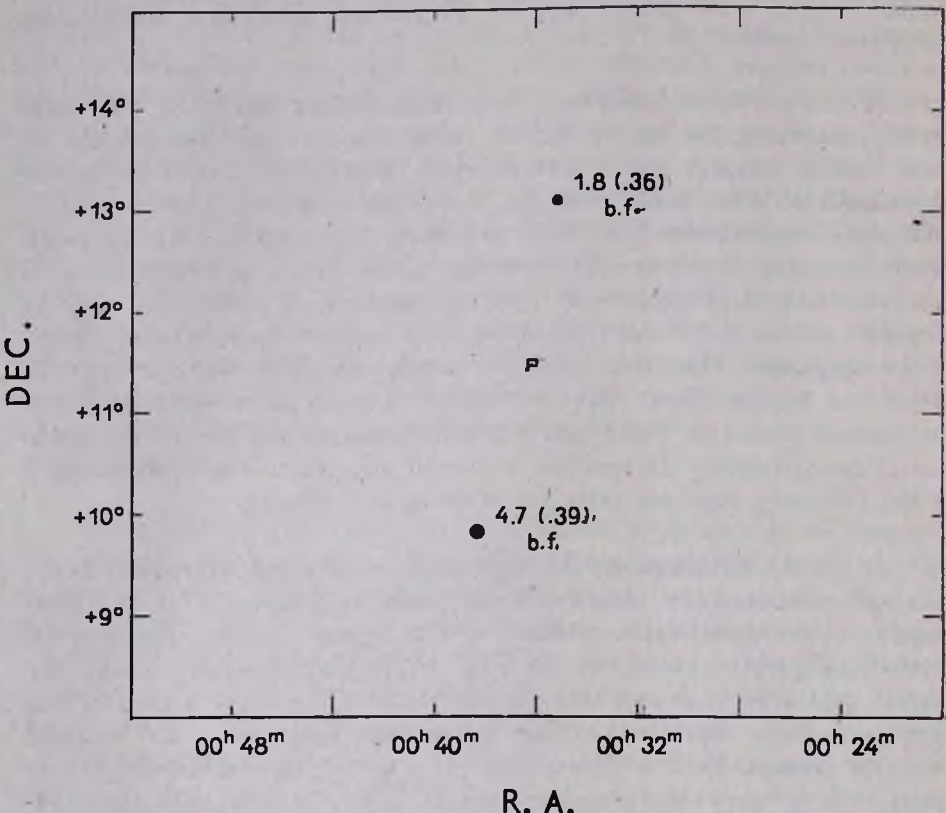
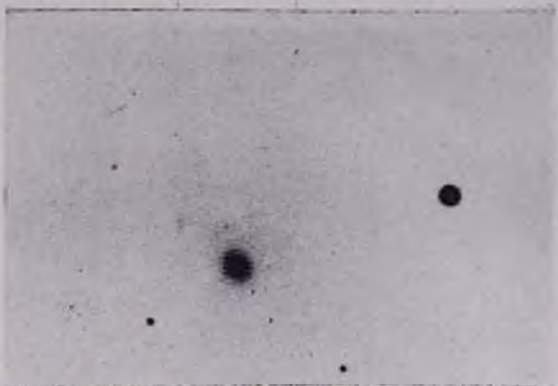


Fig. 1. New identification No. 13 in Table 1*a*. Parkes radio sources indicated by filled circles with 21-*cm* flux strength and ratio of 21 *cm* to 75 *cm* flux in parenthesis. All Parkes sources above 1.5-flux units plotted. Both radio sources are optically blank fields. Central object is small spiral galaxy with bright, sharp nucleus.

This identification seems to be most like the previous identifications made in Paper II. The radio sources are much closer together, but the central E galaxy is much fainter. Presumably the whole association is at a greater distance. The radio sources are of surprisingly large flux strength, however, and the central galaxy, although offset toward the stronger source, is the most offset of any of the other associations.



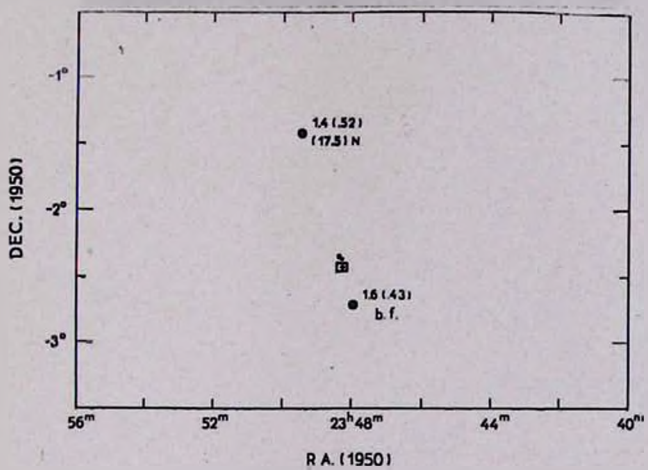


Fig. 2. Identification No. 12 in Table 1*a*. All Parkes sources greater than 0.7-flux units in area are plotted. Central galaxy (*in box*) is an E, possibly peculiar. Two smaller E-type galaxies are indicated in diagram to fall along line to northern radio source, which is identified as a 17.5-*mag* N galaxy. Note also two very faint galaxies in the photograph stretching up along this line.

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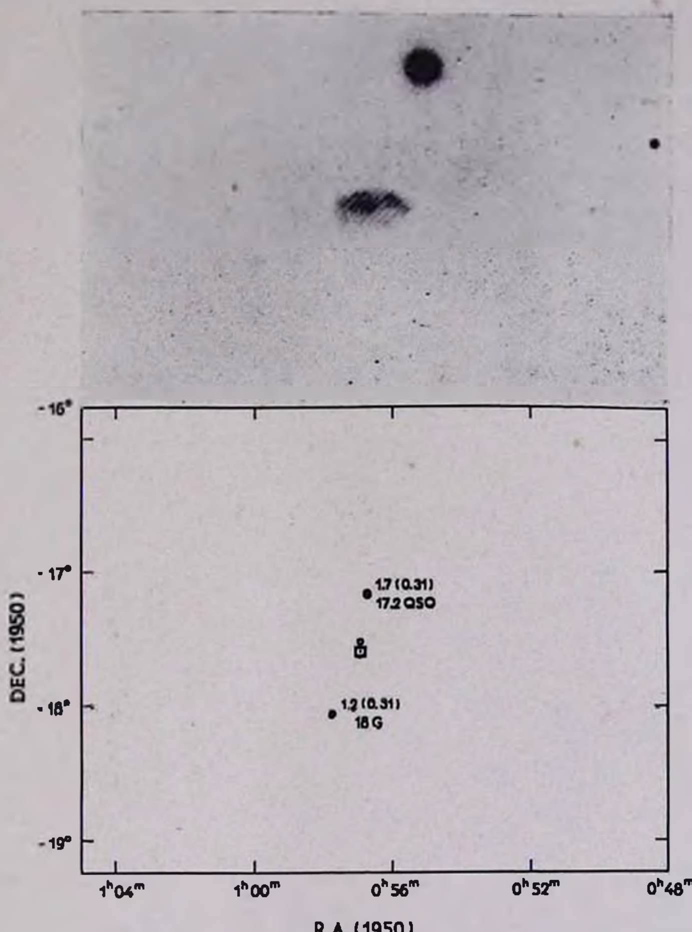

Fig. 3. Identification No. 11. All Parkes sources in the area have been plotted A blue starlike image and a fairly large E are indicated to lie in this order along the line to the quasi-stellar object to the north. A 200-inch plate of the peculiar spiral within the box in the diagram is shown.

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This identification is also most like the conventional radio galaxy identifications because of the small angular separation of the radio pair. One of the radio sources is a blank field, but, unlike the conventional identifications, the other is a 17.5-*mag* N galaxy.

c) *No. 11.* This rather strong pair of radio sources is less than a degree apart in the sky. Between them lies a small peculiar spiral. Like many of the spirals found between radio sources (e. g., NGC 5055, IC 1767), the peculiarity consists of a bar or bright segment out toward the rim of the spiral, but not connected with the spiral pattern. The spectral indices of the two radio sources are very similar, and both steeper than normal. An E galaxy—brighter than the spiral and only slightly smaller in apparent diameter—lies on a line toward the brighter radio source. A very blue, faint starlike image also lies along this line. It is possible that the E galaxy is the origin of the radio pair, but there seems to be nothing conspicuously peculiar about it so the peculiar spiral has been preferred.

This association appears to be a very certain one. It also seems to be a relatively distant one.

d) *No. 6.* No diagramm is shown here, but the two radio sources listed opposite No. 6 in Table 1*a* are the only Parkes sources in an area $3^\circ \times 4^\circ$ in the sky. Spectral indices of both sources are very close to average. Closest to stronger source and fairly well aligned between them is a very high-surface-brightness spiral, NGC 62. (Even though its diameter is very small, it was bright enough to be included in the NGC catalog). The disk of the galaxy is burned out on the *Sky Survey* prints of this system, and on the blue plate a very faint, narrow ring is seen to encircle the galaxy (diameter of ring about $1\overset{'}{.}5$).

e) *No. 5.* No diagram is shown here, but there is an area of the sky near R. A. $= 4^h30^m$ and Dec $= -1^\circ$ in which two very flat-index quasi-stellar objects are found (0420—01 and 0440—00). This pair cannot as yet be assigned with certainty to a galaxy of origin. But, if we consider the remaining radio sources a degree north of this pair, we find an obvious bracketing of a group of NGC galaxies by a pair of radio sources. (Actually the southwest member of the pair consists of two radio sources close together, which are tentatively treated as one source here).

The largest galaxy in the cluster of inferred origin is an elliptical (NGC 1588), with a smallar galaxy (NGC 1587) due west of it. This second galaxy looks like an elliptical with diffuse „S“—shaped material emanating from it. The second galaxy is a particularly good example of type numbers 167 through 172 in the *Atlas of Peculiar Galaxies.* In fact, when this galaxy was scheduled to be photographed in order to study the nature of the origin of the radio pair, it was discovered that a plate was already on file in the *Atlas* supplement series that is now being gathered.

f) *No. 10.* A strong radio pair separated by only $1^{\circ}\!.35$ on the sky is shown in Fig. 4. Both sources have flatter than normal radio indices, and between them lies the conspicuous spiral galaxy IC 1767. The peculiarity in the spiral lies on its southwest rim. This luminous patch, with a suggestion of a nucleus, is slightly elongated along the direction of the radio-source line. This patch is also very red in color. Over-all, this peculiarity is reminiscent of the activity on the rim of NGC 5055 (Paper II), which is apparently associated with ejection of a quasi-stellar object. The present case involving IC 1767 is the first where both members of the bracketing pair are quasi-stellar objects.

The optical identification of Parkes 0159—11 as a quasi-stellar object has been confirmed by spectra. The identification of 0155—10 has not, but the measured optical position is in excellent agreement with the radio position (Bolton, private communication). Both quasi-stellar objects have similar optical magnitudes, and the brighter optical magnitude goes with the brighter radio flux.

Fig. 4 also shows a sketch of all galaxies on a 200-inch plate centered on IC 1767. The two largest galaxies (excepting the central one) lie on a straight line through IC 1767, which coincides very closely with the line between the radio sources. (The dashed lines in Fig. 4*c* point to the quasi-stellar objects. The southeast QSS deviates slightly from the direction to the southeast companion galaxy). The remainder of the smaller galaxies in the field are also distributed preferentially along this line.

Considering the closeness and alignment of the configuration, similarities of the radio sources, and nature of the central galaxy, this is one of the most impressive identifications so far found. The distribution of the smaller galaxies in the area suggests strongly that they are connected with the ejection of these radio sources. We will continue to see examples of luminous matter along the radio source paths.

g) *No. 4.* Fig. 5*a* shows a $25^{\circ} \times 30^{\circ}$ area of the sky in which all radio sources greater than 4.7 flux units at 21 *cm* have been plotted. This diagram is shown in order to emphasize the isolation and relative closeness of this pair of radio sources. Fig. 5*b* shows an enlarged

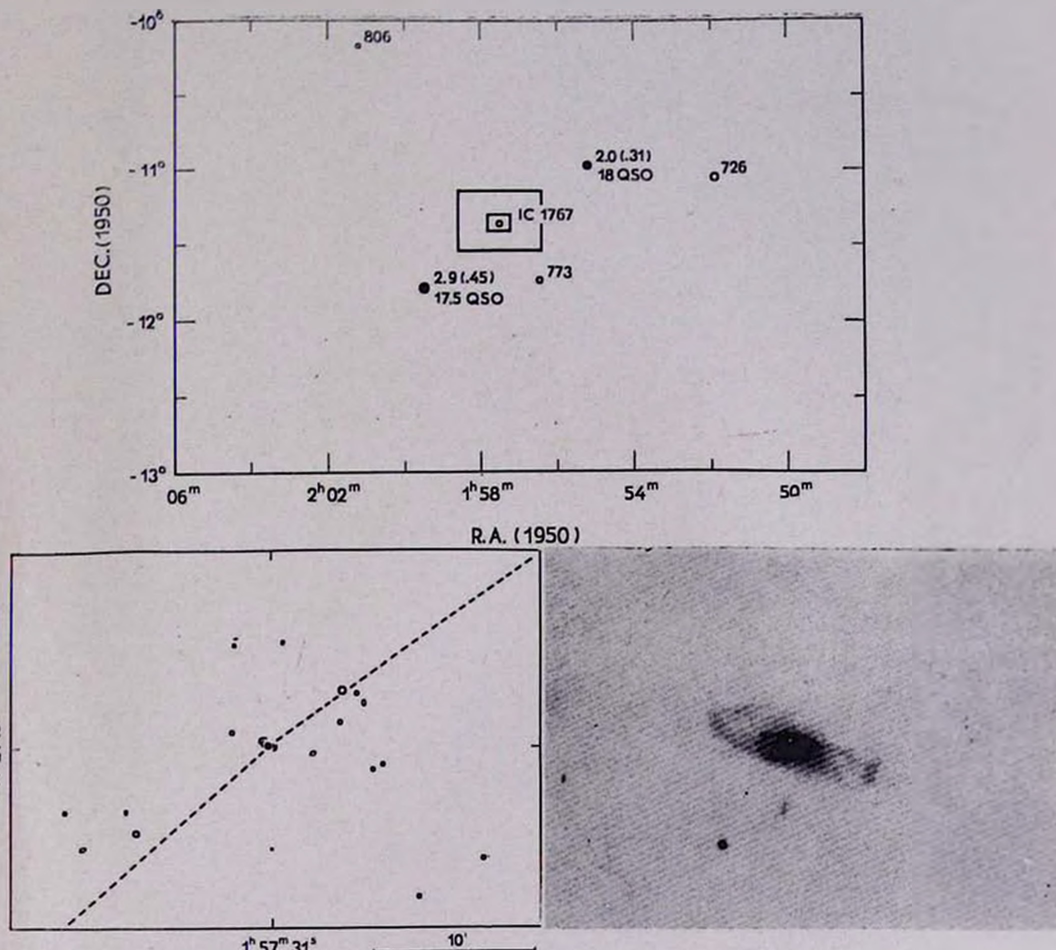

Fig. 4. (*a*) *Above*: All radio sources greater than 0.5 flux units at 21 *cm* are plotted. All NGC and IC galaxies in the area are also plotted. (*b*) *Below, right*: A 200-inch photograph of the peculiar spiral IC 1767 in the inner square is shown. (*c*) *Below, left*: All the conspicuous galaxies on the 200-inch plate (area of large square in diagram) are sketched. Dashed lines in drawing indicate direction of the two quasi-stellar objects.

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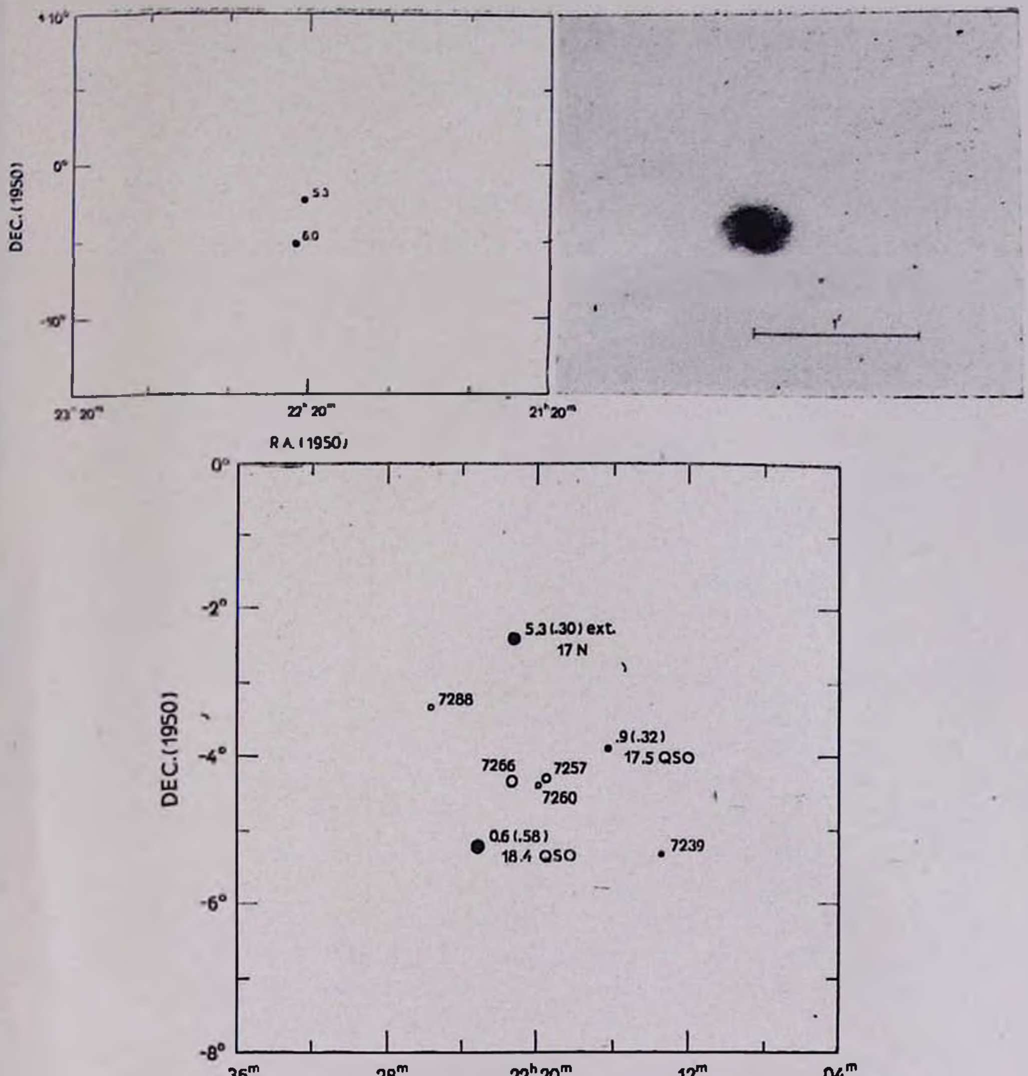

Fig. 5. (*a*) ***Above, left:*** Shows all radio sources brighter than 4.6 flux units at 21 *cm* plotted in a 25° × 30° area of the sky. (*b*) ***Below, center:*** An 8° × 8° area centered on bright radio pair in which all radio sources and all NGC galaxies are plotted. Northern strong radio source is 3C 445; southern is 3C 446. (*c*) ***Above, right:*** Photograph of NGC 7266.

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portion of sky around this pair ($8^\circ \times 8^\circ$). All radio sources, to limiting faintness, are plotted. Also plotted — as open circles with size according to brightness — are all the NGC objects which are in this area. (NGC 7260 cannot be found on the *Sky Survey* and may be an error in the NGC catalog).

The important result that emerges from Fig. 5*b* is that here is an isolated group of (three) radio sources which is coincident with an isolated group of (four) bright galaxies. Just the visual evidence for physical association as shown in Fig. 5 is very strong.

NGC 7266 (as shown in the photograph) is a high-surface-brightness spiral with peculiar, rudimentary arms. Since it is more peculiar than NGC 7257 and closer to a line between the two bright radio sources, it has been identified as the origin of the radio pair. But it is highly suggestive that the two smaller galaxies, NGC 7239 and NGC 7288, lie at apposite ends of a diameter passing through NGC 7257 and NGC 7266. It is as if these fainter outer galaxies had been ejected earlier, perhaps accompanied by fragmentation of the central galaxy, and had subsequently reached their present distance and evolved into their present form. They are class Sa (peculiar) and peculiar, respectively.

The bright radio sources are well known and interesting. The northern one, 3C 445, is an N galaxy with a redshift of $z = 0.0568$ [11]. Although this has not been stressed in the past, it is visually so compact that it is barely distinguishable from a QSS. Its radio diameter is $1'.9 \pm 1'.0$ and it is a double radio source. The small flux-unit radio source is a quasi-stellar object optically brighter than the-bright radio source to the south, which is 3C 446. This latter quasi-stellar object has been observed recently to undergo a large optical outburst [12, 13] and to show rapid change of optical polarization [14]. Only 46′ southeast of 3C 446 is another unusually blue, compact object with a large redshift, PHL 5200 [15].

h) No. 2.

i) The association and central galaxy. Fig. 6 shows one of the most important configurations to be found to date. All radio sources greater than 1.7 flux units at 21 *cm* have been plotted in a sky area $7^\circ \times 7^\circ$. The strong radio pair is obvious. Between it falls the bright ($m_{pg} = 12.8$) Shapley-Ames spiral, NGC 7541. The photograph in Fig. 6 shows this galaxy to be a fairly tightly wound, multi-armed Sc spiral.

Fig. 7 shows a shorter, blue-sensitive exposure in order to exhibit more clearly the extremely unusual feature on the west side of the spiral. This feature is a very high-surface-brightness, apparently tubular feature which leads from the center toward the edge of the galaxy.

Since the origin of the radio-source associations is consistently implied as one of ejection from the central galaxy, it is obvious that we should investigate this unusual linear feature to test whether it could be the result of the ejection of a radio source. Because of the obscuration by the near side, it is clear that the south side of the galaxy is nearest to us. Therefore, because of the curvature of the spiral arms in NGC 7541, it is clear that the spiral is rotating clockwise, as projected on the plane of the sky in Figures 6 and 7. We assume that a fraction of a revolution earlier the radio source was ejected to the northwest, either leaving material in a trail behind it or disturbing the material in the galaxy along its wake. About one sixth of a revolution subsequent to that ejection, the feature has rotated around to its observed direction from the radio source. In support of this hypothesis we can point to the luminous feature itself, as shown in Fig. 7. It can be seen that the feature is not perfectly straight, but has acquired a slight curvature in the expected direction, and by just about the amount that would be caused by differential rotation in the disk of the galaxy during a fraction of a revolution.

Fig. 7 also exhibits a spectrum of this luminous feature. The spectrum shows only absorption lines and is remarkably early in spectral class. The Balmer series of absorption lines can be seen strongly, and the K line of neutral calcium is very weak compared to $H + H_\varepsilon$. The spectrum appears to be that of a composite late A or early F. They are clearly stars whose age must be less than 10^8 years. (An integrated spectrum of a cluster of the age of the Hyades would be of later type). Possibly the best match in integrated spectral type would be some of the blue globular clusters in the Magellanic Clouds, like NGC 1866, which have A-type composite spectra [16] and ages of a few times 10^7 years [17]. The stars could be younger as well, since it only requires a small percentage of evolved supergiants to give an integrated spectrum a later appearance. But we shall adopt an age of the order of a few times 10^7 years for the age of this group of stars.

Now we can note that the typical rotation period for a spiral galaxy is about 3×10^8 years. Since we originally estimated that the luminous feature under discussion has existed for the order of one sixth of a revolution, we therefore compute its age to be a few times 10^7

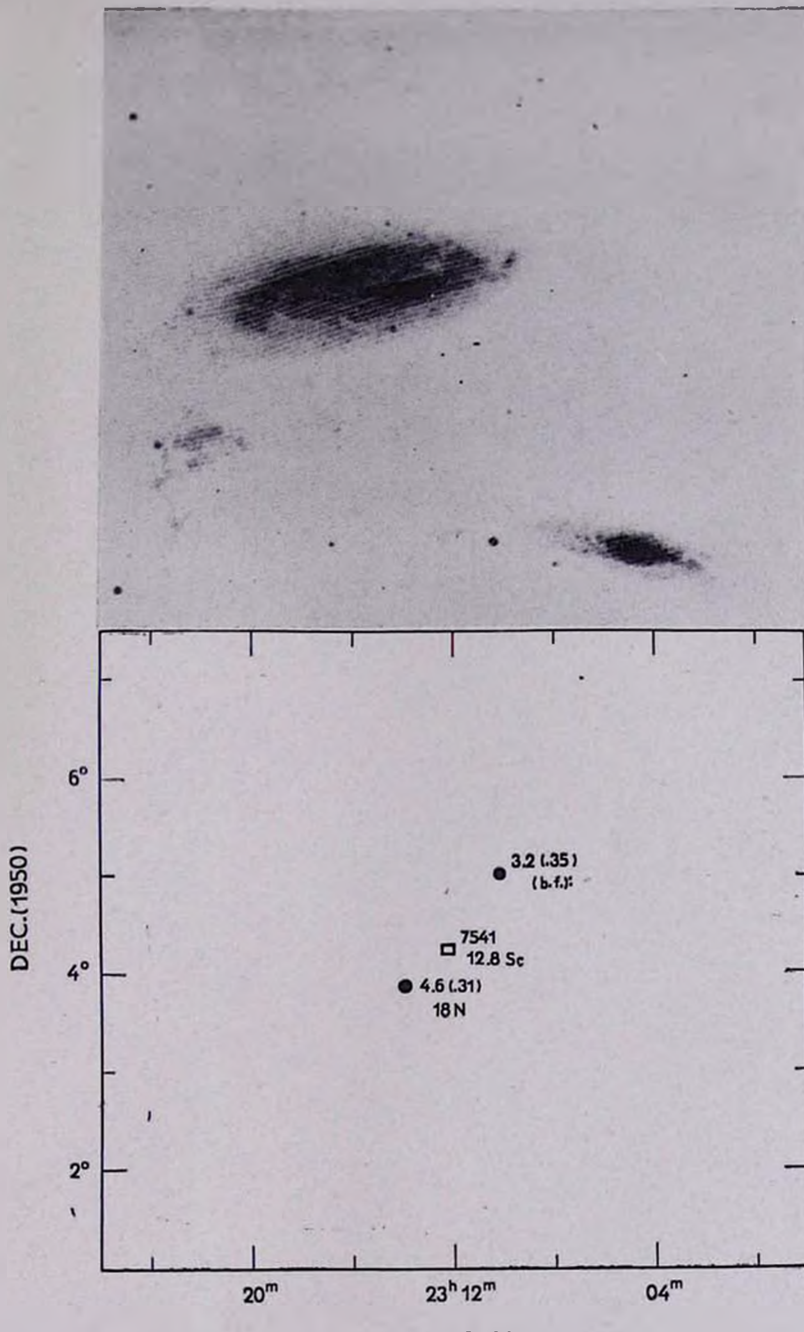

Fig. 6. All radio sources greater than 1.7 flux units at 21 *cm* are plotted in diagram. All galaxies greater than about $m_{pg}=13$ *mag* are also plotted (Shapley-Ames catalogue). Photograph, on 103a-J emulsion, of central galaxy is shown above diagram.

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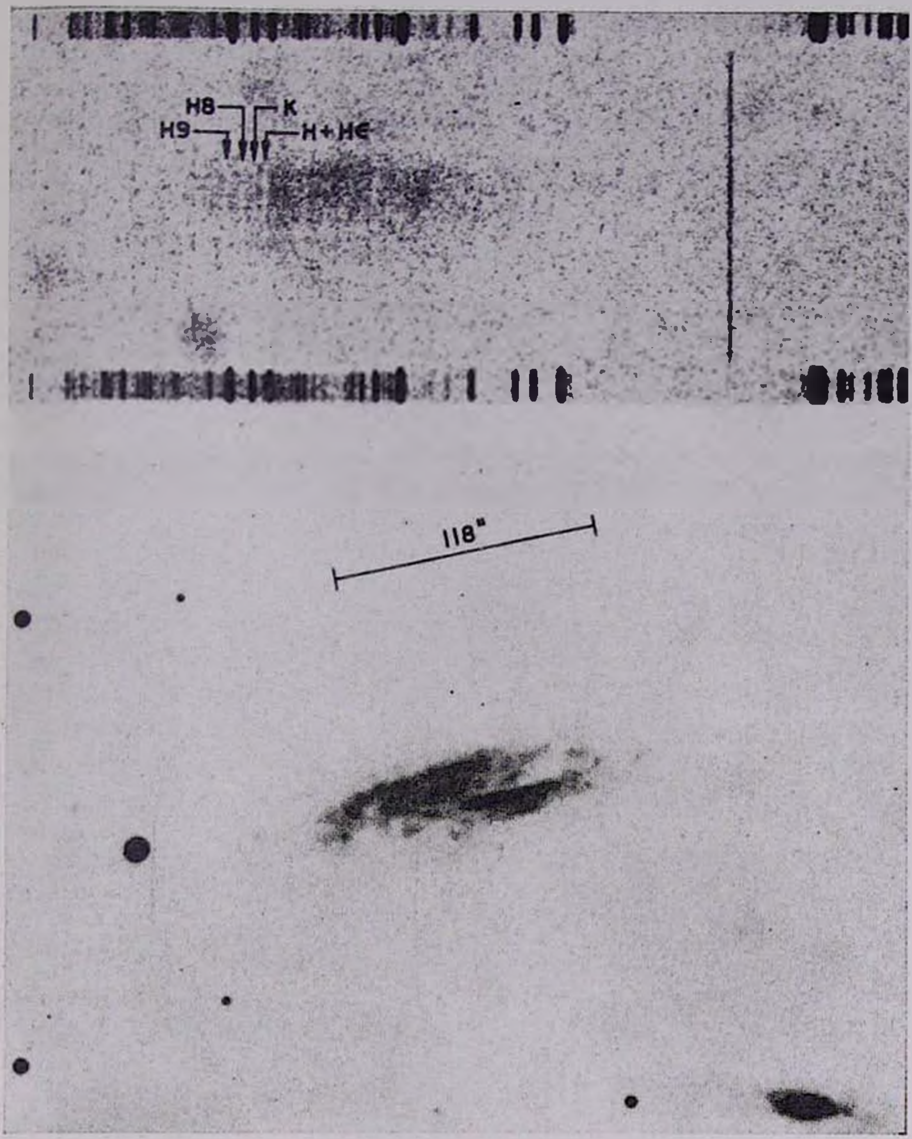

Fig. 7. Lighter exposure on blue-sensitive IIa-O emulsion shown to bring-out luminous streak pointing northwest from center of galaxy. Spectrum of feature shown on 103a-F emulsion, original dispersion 400 Å/*mm*. Orientation and length of spectrograph slit is shown on photograph above luminous streak.

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years. This age checks very well with the age of the stars as indicated by their composite spectrum. We provisionally conclude that the stars that make up the feature started to form at the time of the ejection of the radio source.

The feature is evidently young, blue, and has many characteristics in common with what we would call a spiral arm. We will see in the next two associations that spiral-arm phenomena may be associated with other ejected radio sources and will discuss at the end the relation of type I features, in general, to the lines of ejection. But, to conclude discussion of the present association, a few remarks should be made about the radio sources themselves.

ii) *The radio sources.* Since both radio sources are bright, there is considerable data available on them. The one closer to NGC 7541 is 3C 459, and it has the strongest flux and steepest index. It is a small-diameter radio source identified with an N galaxy that has a redshift of $z = 0.22$ [11]. As in a number of other cases, the optical appearance of the N galaxy is so compact that it is scarcely distinguishable from a star, and, therefore, is very close to what we would have to term a low-redshift quasi-stellar object.

The northwest radio source of the pair is 3C 458, which was identified by Wyndham [18] with an $m_{pv} = 20$ *mag* red galaxy. A position from Parkes (Bolton, private communication), however, places the radio-source position about 20″ north of this red galaxy in a blank region on the 48-inch prints. Four photographs of this field were taken with the 200-inch with the following results:

1. A 45-min exposure, seeing 2 on 103a-O plate, shows not much more than the 48-inch exposures.

2. A 120-min exposure, seeing 1 on 103a-F experimental plate behind an RG2 filter, shows that the original Wyndham galaxy is indeed very red.

3. A 25-min exposure, seeing 3 on 103a-J, shows that 17″ southwest of the red galaxy are three condensations connected together in a „V“ form by faint narrow filaments. The object is very unusual in appearance.

4. A 180-min exposure on III-a-J baked plate goes about a magnitude fainter than normal limiting photographs and reveals a very faint, diffuse object of about 11″ diameter north of the red galaxy near the Parkes position. It is tempting to conclude that this last object is the source of the radio radiation. But the extent of the radio emission is about $4' \times 30''$ and shows multiple structure [10]

so that the coincidence of the exact center with an optical object may not be of significance, and, in fact, more than one of the unusual optical objects might be associated with the source of the radio radiation. If the faint surface-brightness feature is responsible for the radio source, it would represent a new kind of radio-emitting galaxy, one with very low optical surface brightness. It should be noted that a similar investigation has been carried out on another supposed „blank-field" radio source, 3C 65. A similar very faint, very low-surface--brightness galaxy has been tentatively identified.

i) *No. 3.* Fig. 8 shows all Parkes sources inside an area $7° \times 8°$. All NGC galaxies within this area are also plotted. It is apparent that the two strongest radio sources in this region pair very accurately across the $m_{pg} = 13.1$-*mag* spiral, NGC 7309. There is a third radio source in this region, however, which at 0.9 flux unit is not very much weaker than the main pair and is about the same distance from the central galaxy. There seems to be no way to avoid considering that third source along with the slightly stronger other two. The photograph of the central galaxy, however, surprisingly shows a nearly flat-on, striking example of a three-armed spiral. Not only are three-armed spirals quite rare, but the symmetry and balance of these three arms is additionally exceptional.

It is difficult to avoid the inference that each of the three arms is associated with the ejection of one of each of the three radio sources. In the previous case, we found evidence connecting a spiral-armlike feature and ejection of a radio source, and we shall see more in the final case to follow. But there is further independent evidence in the present case that ejection has taken place from the central spiral out along the line of at least the major pair of radio sources.

That evidence is shown in the sketch of all prominent galaxies present on the 200-inch plate of the area. Fig. 8 shows that most of the remaining galaxies on the plate are distributed along the line between the major radio pair. This is the strongest evidence that could be presented, in addition to statistical proofs, that the associations are real.

One important point should be borne in mind, and that is that an initially straight luminous track in the direction of a radio source will be wound up into a spiral form only within the differentially-rotating disk of the galaxy. Outside the gravitational or viscous influence of the galaxy, it should remain more or less straight in space until it dissipates.

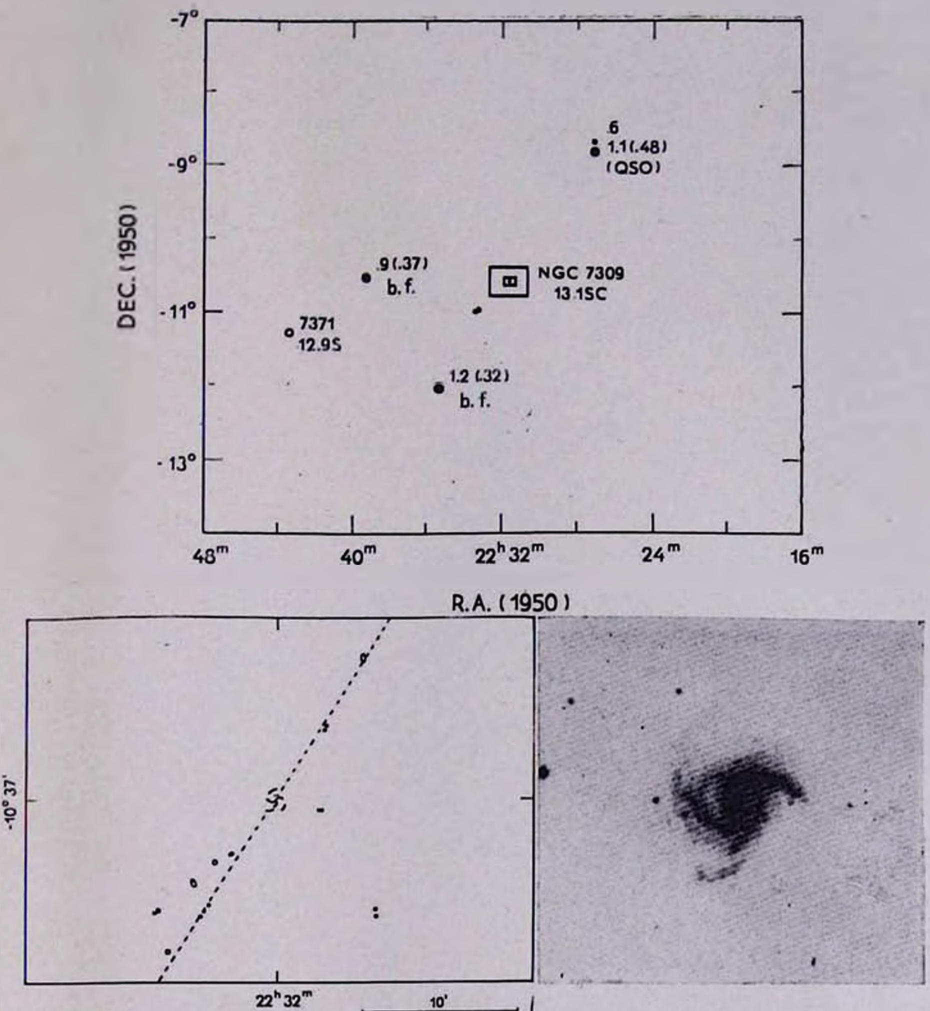
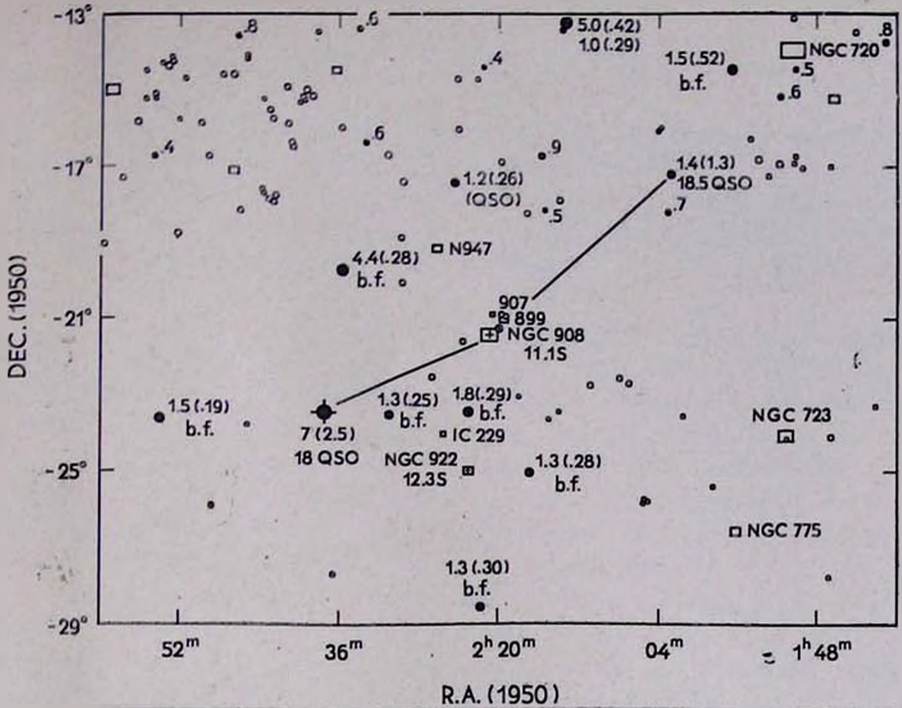


Fig. 8. All Parkes radio sources in 7° × 8° area are shown in diagram at left. All Shapley-Ames galaxies in same area are also plotted. Photograph of area inside small rectangle is shown at right. All conspicuous galaxies on 200-inch plate (inside bigger rectangle in diagram) are shown on drawing below. Dashed line indicates line between main radio pair.

К статье Г. Арпа



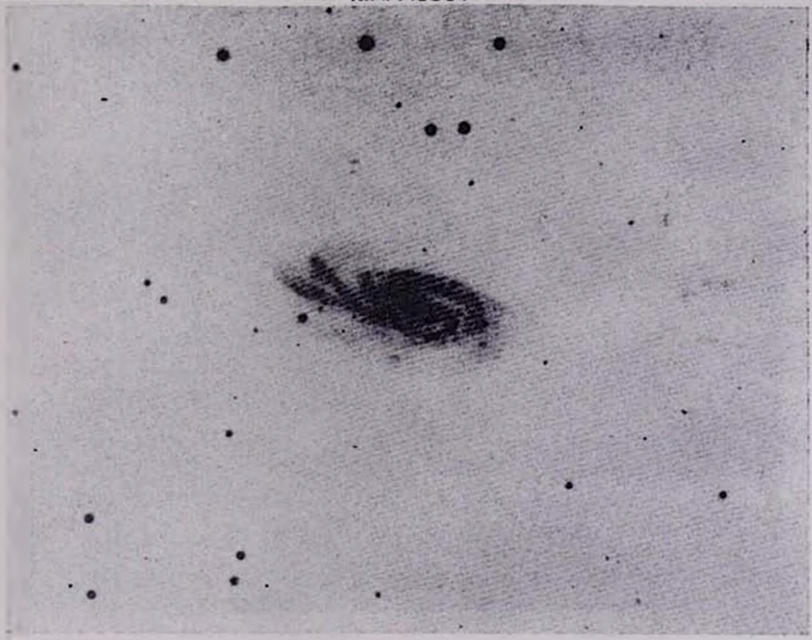


Fig. 9. All Parkes sources in a $16^\circ \times 20^\circ$ area of the sky are plotted as filled circles. Flux strength at 21 *cm* is written to the side and ratio of 21- to 75-*cm* flux in parenthesis. All NGC and IC galaxies in the region are as open symbols, and the size of the symbol is proportional to their brightness. Small circles with dots represent dwarf type I galaxies on either side of NGC 908. High-redshift quasi-stellar object Pks 0237—23, is southeast of pair acrossNGC 908.

Fig. 10. *Below:* Photograph of NGC 908, central galaxy located between the flat index QSO's shown in the upper diagram. Exposure, 20 min on 103a-J film.

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There are several good examples of the tubelike filaments which proceed outward from galaxies into space. No 188 in the *Atlas of Peculiar Galaxies* is a good example. Examples of what might happen sometime later, when rotation has wound the inner filament but left the outer still straight, are given by Nos. 65 and 296 in the *Atlas*.

i) No 1. In a survey at short wavelengths, Bolton discovered a flat-spectrum quasi-stellar object (Pks 0237—23) with a very shortwavelength synchrotron self-absorption cut off [19]. Because of the exeptional nature of this object, the sky in this general region was searched for a possible galaxy of origin. A second flat-index quasi-stellar object (0202—17) was found on the side of NGC 908 opposite from the first quasi-stellar object. Fig. 9 shows how this very flat-index pair of radio sources brackets the $m_{pg}=11.1$-*mag* Sc spiral.

All the radio sources in this $16^\circ \times 20^\circ$ area of the sky are plotted in Fig. 9. It is apparent from the flux ratios written by the side of each radio source how the flat-index pair stands out from the remaining sources in the vicinity. Also plotted in this area of the sky are all the NGC and IC galaxies. It is seen that these galaxies extend east and slightly north of the 12-flux unit quasi-stellar object, and west and slightly south of the 7-flux unit quasi-stellar object. This distribution of radio sources and galaxies (in this case a „*Z*“ shape) is reminiscent of the spiral distribution observed around NGC 5128 and in the Virgo cluster in Paper II. If an appreciable number of these galaxies are at the same distance as NGC 908, then the explanation suggested in Paper II — rotation of an ejection axis with time— can be applied here. In that kind of picture the two flat-index quasi-stellar objects would be the most recent ejecta. But, because the short-wavelength synchrotron radiation decays rapidly, we might expect flat-index quasi-stellar objects to be very young in any case.

Within this inferred distribution of ejected galaxies we can for the first time attempt to answer the question of whether the remaining radio sources are as old as the galaxies and are distributed along with the galaxies by the original ejection, or whether the remaining radio sources are recent, secondary ejecta from the galaxies within the distribution. The answer appears to be the latter, because most of the remaining radio sources can be paired across galaxies within the distribution. For example, the 4.4-and 1.2-unit sources can be paired across NGC 965 (No. 7 in Table 1*a*). Fig. 11 shows the subregion of the distribution west and slightly south of 0237—23. There are only four radio sources in this area and only two conspicuous galaxies. The radio sources pair beautifully across the two galaxies, following almost all the rules indicated in § II.

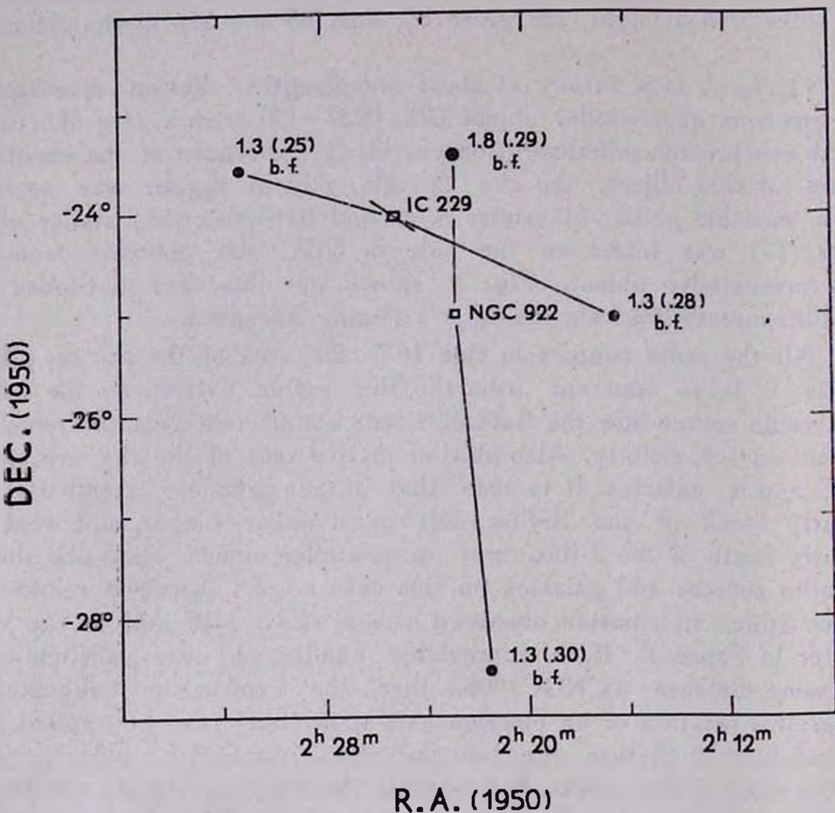

Fig. 11. Subregion of Fig. 9. All radio sources and brightest NGC galaxies plotted in area 7° × 7°. Lines indicate presumed association of pairs of radio sources with central galaxies.

There are several more very important features of this association. One is that just north of NGC 908 are three very peculiar galaxies. These are NGC 907, NGC 899, and IC 223. They are disturbed galaxies in the sense that their forms indicate that they cannot represent equilibrium configurations. The suggestion is that they are „fragment" galaxies resulting from the disruptive process taking place in the central galaxy that is responsible for the ejection of the quasi-stellar objects and galaxies distributed around it. We have encountered similar cases more or less clearly in *Atlas* No. 55 in Paper II No. 5 in Table 1*a* of the present paper.

Another important point if that there are two type I irregular dwarf galaxies close to NGC 908. Fig. 9 shows that one lies just northwest along the line to the northwest quasi-stellar object, and the second dwarf lies just to the southwest along the line to the southwest quasi-stellar object. Now type I dwarfs are an infrequently discussed paradox in that they represent a system of very young type I stars, but the density of the systems appears so low that the origin of these stars so recently formed is puzzling. If star formation cannot replenish a type I dwarf, it must fade in the order of 10^8 years. The present results then may have some implications for the origin and persistence of type I dwarfs in general. But those around NGC 908 remind us of another point; namely, that a type I dwarf is, in material content and optical appearance, like a spiral arm. If we could see a detached piece of spiral arm, we would surely classify it as a type I dwarf. Therefore, Fig. 9 implies that part of the trail toward the ejected quasi-stellar objects consists of type I material. Where it becomes isolated, and before it fades and dissipates, it would be expected, in fact, to resemble what we see on either side of NGC 908. This idea at once relates the spiral arms — which were suggested by the last two associations to be a result of the radio-source ejection — to the shredlike and fragment galaxies scattered along the line to the radio sources outside the edges of the central galaxies. It is quite clear that much of the galaxy material distributed along these lines would have to be classified as type I or type I irregular and dwarf.

There is one final striking prediction we can make and test with this very important association. Fig. 10 shows a photograph of NGC 908, the large central spiral. It is a very large two-armed spiral with one outstandingly unusual feature. That feature is the conspicuous bifurcation of one of those arms at the end. The prediction we would make, if the ejection of radio sources were really somehow connected with the formation of spiral arms, would be that there should be two radio sources ejected out of that bifurcated arm. Fig. 12 shows that when we extend our area of search slightly we encounter another flat-index quasi-stellar object, almost identical in character to 0202—17, just 30^m west in right ascension. We measure the angle from 0202—17 to NGC 908 to 0130—17, and it turns out to be 25°. We measure the angle between the fork at the end of the NGC 908 spiral arm, and it turns out to be 23°.

V. *Difference Between Radio Sources Associated with Ellipticals and Those Associated with Spirals.* It is clear from the discussion of the new associations that a higher percentage of spiral galaxies have now been found as the origins of radio pairs than were originally discovered in Papers I and II. The reason seems to be that the *Atlas of Peculiar Galaxies* included a group of peculiar ellipticals that had a very high probability of being associated with radio sources. In the analysis of the *Atlas,* then, many ellipticals turned out to be the center of radio distributions. But, although such galaxies have a high probability of producing sources, they are numerically rare, and apparently many radio sources come from other kinds of galaxies. When we look between pairs of radio sources, as we have done here, we find these

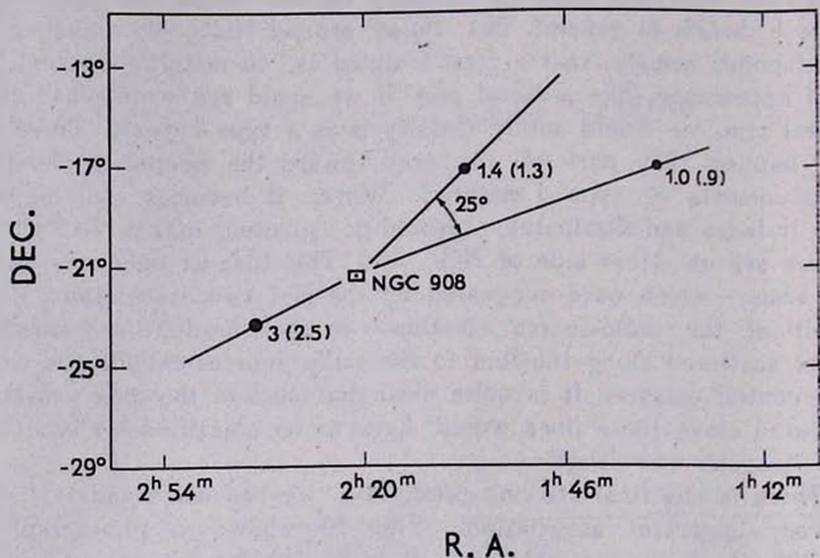

Fig. 12. Plot of all flat-index radio sources (ratio of 21- to 75-*cm* flux greater than 0.7) in area around NGC 908. All galaxies brighter than $m_{pg} = 11.7$ *mag* in area are also plotted. Angle between NGC 908 and the two flat-index radio sources to the northwest is 25°.

other kinds of galaxies in larger numbers. Mary of them turn out to be spirals. Particularly, apparently bright sources that are close together turn out to be preferentially associated with spiral galaxies. This is a fortunate situation, because, by studying the difference in the radio sources around the different central galaxies, we can hope to learn something more about the nature of the radio sources and the mechanism of their production.

a) *Separation of Radio Sources in Units of Diameter of Central Galaxy.* It would be desirable to obtain the absolute projected distance of the radio sources away from their central galaxies. Redshifts of all the central galaxies are not known, however, and, even if they were, it is not completely certain that the derived distances would be trustworthy. We can, on the other hand, form the ratio of the apparent projected separation of the radio sources to the apparent diameter of the central galaxy. If individual distances — and therefore absolute individual diameters — become available later, these ratios can readily be converted into absolute separations. Meanwhile, approximate diameters for individual galaxies, or classes of galaxies, can be used to obtain an estimate of the real projected separations.

Table 1 lists the diameters of all the central galaxies as measured on the blue 48-inch *Sky-Survey* prints. In order to avoid tilt effects, the diameter d is taken as the maximum diameter across the apparent limits of the image. These diameters are listed in the third column (d''), and the projected separations of the radio sources are listed in the fifth column. We designate the ratio of the latter to the former as $(r_1 + r_2)/d$. Table 3 lists the separation/diameter ratio for all associations in Table 1, where a dominant central galaxy is clearly classifiable as either spiral (type I) or elliptical (type II).

Assuming that the intrinsic diameters of spirals and ellipticals are roughly comparable, one can readily see that the radio sources associated with type I systems are, on the average, much closer to their parent galaxy. Either the radio sources are not ejected to as great distances from spirals, or we are seeing these systems at an early stage when the sources are still travelling outward.

b) *Speeds of Ejection.* Half of the type I systems in Table 2 have peculiarities in their disks which are apparently associated with the radio-source ejection (NGC 5055, NGC 908, NGC 7541, NGC 7309, IC 1767, No. 11 Sp). As discussed previously, if we assign a few times 10^7 years as the time for differential rotation to disturb these features, we have an estimate of the time since the ejection event. Table 2 shows that for these six systems the average distance of the radio sources from the central galaxy is a little over 40 galaxy diameters. If we take 15 *kpc* for the average spiral diameter, we get 600 *kpc* projected distance for the average radio source. For our estimated time we get average projected speeds of around 20 000 *km/sec*, or true space velocities of about 0.1 c. This is from 3 to 30 times faster than the original ejection speeds estimated in Paper I. But, in those original, wider identifications there was evidence for slowing down of ejecta after they had reached a certain distance. We can try to check on this effect by looking at the relative accuracy of the alignment exhibited in the close and in the more distant sources.

c) *Accuracy of Alignment.* The angular deviation from a straight line, $\Delta\theta$, is listed in the third column of Table 3. It is seen that there is a trend in both the type I and type II associations (with the type II offset to wider seperations) for wider relative separations to be worse aligned. This result has connection with the conclusions in Papers I and II; namely, that the ejected sources slow their outward velocity rapidly after a certain point. If their angular velocity also slows, and at different rates and at different distances from the central galaxies, then any initial alignment would be expected to be progressively destroyed.

d) *Proportion of Quasi-Stellar Objects Associated with Spiral Galaxies.* Listed in Table 3 are the kinds of radio sources that are associated with each central galaxy. A striking difference in the kinds of radio sources associated with the spiral galaxies as opposed to those associated with the ellipticals is evident. Although there are about the same number of blank fields in each set, there are twice as many quasi-stellar objects as radio galaxies (12 Q, 6 G) associated with the spiral galaxies. The group of ellipticals, on the other hand, has associated radio sources which turn out to be radio galaxies three times as often as quasi-stellar objects (4 Q, 12 G). There is a clear tendency for spiral galaxies to be associated with quasi-stellar objects, whereas ellipticals are associated with radio galaxies.

A significant difference emerges when the above distribution of properties is compared to that of the radio sources just as they are listed in the catalogues. In the *3 CR Catalogue* about 40 per cent of radio sources are blank fields (no probable optical identification; [18]. In the *Parkes Catalogues* about 70 per cent are blank fields [20, 21]. But, in all these catalogues the percentage of optically identified radio sources that are QSS, or suspected QSS, runs very close to 30 per cent. It is clear that the radio sources associated with spiral galaxies, as shown in Table 3, are running instead about twice as many QSS as radio galaxies. That is, if we were to pick random radio sources from the *Parkes Catalogues*, we would expect 26 radio sources to distribute 2.5 Q, 5.5 G, 18 b. f. We actually observe the sources associated with spirals — primarily Parkes sources in Table 3 — to distribute themselves 12 Q, 6 G, 8 b. f. The sense of this result has already been anticipated by Wagoner [22], who showed that it was the optically identified radio sources that fell closest, on the average, to *Atlas* peculiar galaxies, and that the quasi-stellar objects fell, by a little, the closest of all.

e) *Flat-Index Radio Sources.* Associated with the spiral and type I systems in Table 3 are eight radio sources that have spectral indices as flat or flatter than —0.71. Seven of these eight are members of pairs with the smallest separation to diameter ratios (170 or less). The eighth is a member of an association (NGC 7266) where $(r_1 + r_2)/d$ would be smaller if the central galaxy is taken to be one of the fragments of an originally larger galaxy. Just as the data stand, however, and despite the small numbers involved, there is a tendency evident for the flat-index radio sources to appear in associations with the smallest relative separations. Since there is some reason for believing the flat-index sources are younger than the steep, this is a preliminary indication of a correlation between age of the association and its separation, with the smallest separations being the youngest and the sources aging as the separation increases.

VI. *The Problem of the Interpretation of the Redshift.* Since the first announcement of the association of radio sources and peculiar galaxies (Paper I), there have been a number of investigations of the statistical significance of the correlation between these two groups of objects [22—24]. The *least* favorable finding was that there was only a 99 per cent probability that the two groups were associated ([23], "one sky out of a hundred„). The present paper outlines additional specific properties of radio sources which are associated with different kinds of central galaxies. Aside from furnishing clues to the physical nature of the associations, these correlations naturally furnish additional proof that the associations are real.

The simplest summary of the observational paradox is the following: One group of objects, the central galaxies, has redshifts of the order of $z = 0.01$ to 0.03. The other group of objects, the radio sources, has redshifts in the range $z = 0.05$ to 0.2 (radio galaxies as a class) and $z = 0.2$ to $2+$ (QSS's as a class). The problem is simply that we cannot have groups with such divergent redshift values physically associated together in the same volume of space and still interpret the redshifts as all due to velocities of recession.

The difficulties of alternative interpretations of redshift are well known. Scattering processes which degrade the energy in emergent photons also spread the spectral lines more than is observed. Gravitational redshifts could only give narrow spectral lines for light originating within a region of small gradient of high gravitational potential. Radio galaxies which appear to emit light from more or less extended regions of fairly low density would seem to be certainly excluded from gravitational redshift effects.

The objects indicated in the present papers to have excess redshifts are generally characterized by radio emission, optical emission, and compact structure or compact components. As time proceeds, the electrons giving rise to the radio emission will tend to decay, the atoms giving rise to the emission lines will recombine, and the excited compact regions will expand. Unless the object is reexcited or reconcentrated, we will fairly quickly be left with an apparently normal galaxy with a presumably normal redshift. Empirically, then, the only suggestion this evidence holds for me is that the relatively recent emergence of matter into a dense, excited state, or the conditions connected with that state, is the most promising clue for discerning a redshift mechanism.

On the observational side, a few general remarks need to be made as to whether a non-velocity redshift for certain extra-galactic objects, as required by the present results, can be reconciled with classically observed redshift-apparent-magnitude relations. Specifically, there exists a narrow redshift-apparent-magnitude relation for radio galaxies which is supposed to be a result of their velocity-distance relation [12]. The first point that should be mentioned is that the term „radio galaxy" is currently used to designate a number of different kinds of objects. The most common type is an E or D galaxy, which is found between adjacent regions of radio emission. The redshift-apparent-magnitude relation for this type of radio galaxy is like that of the peculiar E galaxies found between wide radio-source pairs in Paper II—that is, it is the normal Hubble relation for E galaxies shifted about one magnitude brighter. In fact, this is a strong argument that the identifications in Paper II are just an extension of the accepted identifications to wider pairings, and that the central galaxies are similar. (The parent galaxies in Paper II could even be called radio galaxies, as far as present usage goes).

But there are also E and D galaxies in which the radio emission appears to emanate directly from the optical object. There are also galaxies which are associated with radio emission that are not E's or D's, but range from normal galaxies to galaxies almost as compact as quasi-stellar objects, These latter are usually called „N" galaxies. It is mainly the latter two catagories of radio galaxies which in Paper II and the present paper appear to have varying degrees of non-velocity redshifts. It would be of crucial importance to construct a redshift-apparent-magnitude relation for just the N and compact radio galaxies or for just the radio galaxies identified as ejecta in the present papers. If a relation shows considerable scatter, then only the interpretation of redshift as velocity in these particular objects need be abandoned. If the relationship for ejecta is narrow, however, and the results of the present papers are still accepted, then a more fundamental reconsideration of the interpretation of redshift would be necessary.

The redshift-apparent-magnitude relation for quasi-stellar objects, however, shows great scatter. In the picture that has developed in the present series of papers, the quasi-stellar objects appear to represent an extreme where almost their entire redshift is non-velocity. But, if their lifetimes are only of the order 10^6 to 10^7 years [11], they must evolve rapidly into something else. Because their observed excitation and temperature is very high, we would predict that they get less compact with time and evolve into more quiescent objects. These latter properties are characteristic of N and compact radio galaxies. Since observationally the redshifts are less, we would have to conclude that they generally lose their non-velocity redshift in this evolution. But, if there were still any component left, we would predict that some N and compact radio galaxies would lie to a varying extent above the normal Hubble relation, particularly for nearby objects where the expansion redshift is low. If these objects evolve further into normal galaxies, it would be expected that they would then obey the normal redshift-apparent-magnitude relation except when actually undergoing secondary activity.

VII. *The Significance of Different Types of Parent Galaxies.* An unexpected result of the present paper was that galaxies other than large peculiar ellipticals could eject radio sources. In fact, we have found a number of spiral galaxies that have ejected radio sources. Probably the most fundamental difference between the kind of elliptical that emits radio sources and a spiral galaxy or type I system is that the mass of the former is considerably greater. Therefore, we might consider, as a start, that the masses of the radio sources ejected from ellipticals would be, in general, larger than those ejected from spirals. This prediction is then roughly confirmed by the fact that we can observe objects of the order of size of small galaxies to be ejected from the ellipticals, whereas the spirals eject quasi-stellar objects and N galaxies. At the distances derived here, these latter objects are less luminous and, therefore, presumably less massive than even small galaxies. (Since the quasi-stellar objects and N galaxies are in a highly energized state, their mass-to-luminosity ratio is also probably much lower than that of more normal galaxies). As an example we might cite NGC 5128, probably the most massive of well-known elliptical galaxies. Each member of the wide pair of radio sources ejected from it consists of a fairly bright galaxy in its own right (Paper II). The spiral galaxy NGC 908 (discussed in § IV, No. 10); on the other hand, has apparently ejected quasi-stellar objects of $M_v = -14$ mag and fainter.

The blank fields are a puzzle in that they are distributed in Table 2 about equally between spiral and elliptical parents. One possibility is that a blank field is a different kind of radio source that is ejected from a galaxy and never becomes optically visible. This, however, is no assurance that the blank-field radio emissions conventionally identified close to E and D galaxies are the same kind of blank fields as identified in the wider pairs across the present galaxies. On the other hand, the ejecta may generally start out as blank-field radio emissions and, as they move outward, evolve into something optically visible. This is in agreement with the fact that quasi-stellar objects and radio galaxies are so far not found to *closely* bracket parent galaxies, as in the conventional identifications with blank fields.

We have mentioned that apparently very large ellipticals can sometimes eject amounts of matter which are fairly large-size galaxies in their own right. These secondary galaxies, in turn, appear to be able to eject smaller amounts of material. Evidence for this is given in Paper II and in § IV, NGC 908, of the present paper. These smaller amounts of material are seen closer to their parent galaxy, since Table 3 shows that the relative separation of radio sources around spirals is about a factor of 5 less than around ellipticals. As the ejecting galaxies become smallar and more recently active, we appear to encounter more frequently what we call type I characteristics, that is, young blue stars, gaseous emission, and non-equilibrium configuration of material.

The suggestion has been advanced in this paper that the ejection of radio sources from spiral galaxies is sometimes associated with spiral arms or spiral-armlike features. This suggestion would now interlock with the results on the ellipticals that had associated type I material. In the peculiar-elliptical case it was just the presence of such type I material emanating from or in the vicinity of elliptical galaxies that defined the group of peculiar ellipticals originally identified as associated with radio sources. Apparently in the peculiar-elliptical case the explosion or process of ejection of the radio sources also formed

Table 1a

GALAXIES WITH ASSOCIATED PARKES RADIO SOURCES

Central Galaxy	m_{pg}, Class d'', $\Delta\theta^{\circ}$	Radio Source	Distance	S_{408}	S_{1410}	S_{2650}	Index	Identification
			i) New Identification with Parkes sources					
NGC 908	11.1 Sc	0237—23	—4.5°	≲3	7	5	— .5	16.6 Q
	275″, 17°, 8°	0202—17	6.2	1.1	1.4	1.3	— .1	18.5 Q
		0130—17	15.2	1.1	1.0	1.2	— .4	(19 Q)
NGC 7541	12.8 Sc	2313+03	.56	14.8	4.6	2.3	— .9	18 N 3 C 459
	71″, 15°	2310+05	.92	9.1	3.2	1.7	— .7	22 G ext:3 C 458
NGC 7309	13.1 Sc	2235—12	1.70	3.8	1.2	0.4	—1.01	b. f.
	80″, 1°	2239—10	1.85	2.4	0.9		— .8	b. f.
		2227—08	2.12	2.3	1.1		— .64	(Q)
		2227—08	2.22		.6			
NGC 7266	15 Sp	2223—05	1.00	10.3	6.0	4.4	— .51	18.4 Q 3 C 446
	28″, 25°	2216—03	1.35	2.8	0.9	1.0		17.5 Q scint
		2221—02	1.93	17.5	5.3		— .81	N 3 C 445 d -1.9
NGC 1587 and 1588	15 Ep	422+00	1.46	(4.8)	1.4	1.3	— .1	b. f.
	(15 Ep	421+00	1.70		1.7	1.1	— .7	b. f.
	54″, 12°)	439+01	-2.92	4.4	1.0	0.6	—1.0	b. f. 3 C 124
NGC 62	14 Sp	0016—12	.86	7.8	2.3	1.3	— .91	b. f.
	27″, 16°	0013—14	1.11	2.1	0.8		— .84	—
NGC 965	17 Sp	0235—19	1.7	15.7	4.4	2.4	— .91	b. f.
	40″, 17°	0224—17	1.9	4.7	1.2	0.5	—1.22	(Q)
NGC 922	15 Sp	0222—23	1.8	6.2	1.8	1.0	—1.0*	b. f.
	80″, 5°	0221—28	3.55	4.3	1.3	1.6	—1.0*	b. f.

Table 1a (cont'd)

Central Galaxy	m_{pg}, Class d'', $\Delta\theta°$	Radio Source	Distance	S_{408}	S_{1410}	S_{2650}	Index	Identification
IC 229	16 Ir	0231—23	[1.59	5.2	1.3	0.6	—1.1*	b. f.
	188", 8°	0216—25	2.35	4.7	1.3	0.7	—1.1*	b. f.
IC 1767	16 Sp	0159—11	[0.65	6.5	2.9	2.0	— .61	17.5 Q
	84", 7°	0155—10	0.70	6.5	2.0	1.3	— .71	(18 Q)
Anon	17 Sp	0056—17	0.43	5.5	1.7	0.9	—1.01	17.2 Q
	27", 17°	0057—18	0.50	3.9	1.2	0.7	— .92	18 G
Anon	17.5 E	2347—02	[0.28	3.7	1.6	0.9	— .82	b. f.
	17", 1°	2349—01	1.05	2.7	1.4	0.9	— .81	17.5 N
Anon	18 N?	0035+13	1.63	5.0	1.8	1.1	— .9	b. f. 3 C 16
	27", 8°	0038+09	1.72	12.2	4.7	3.0	— .8	b. f. 3 C 18
ii) Previous Identifications with Atlas of Peculiar Galaxies								
NGC 5128	7.2 Ep	1302—49	[7.4	14	7.4	4.4	—	9.2 S NGC 4945
(Atlas 153)	400", 15°	1332+33—33	9.5	32	7.0	4.6	—	11.9 E IC 4296
NGC 7609	18 Ep	2318+07	1.3	(4.0)	0.8	0.5	— .7	12.8 E NGC 7626
(Atlas 150)	11", 16°	2313+10	[1.4	2.2	1.2	0.9	— .5	b. f.
		2319+07	1.5	(4.0)	1.1	1.0	— .2	b. f.
NGC 3303	15 pec	1044+15	[3°.4	5.4	1.0	0.6	—1.2	b. f.
(Atlas 192)	107", 10°	1022+20	3 .6	3.6	1.3	0.5	—1.1	b. f. 3C 242
Atlas No. 149	18 Ep	1233+16	[0.8	8.8	2.2	(0.8)	—1.1	II ext.
	9", 16°	1241+16	1.2	9.4	2.9	1.6	— .9	Q 3C 275.1

* Sp. index from 75 to 21 *cm*

Table 1b

GALAXIES WITH ASSOCIATED 3C SOURCES

Central Galaxy	m_{pg}, type d'', $\Delta\theta°$	Radio Source	Distance	S_{178}	S_{750}	S_{1400}	Index	m_V	Ident.
			i) Paired Sources						
NGC 4472	10.1 E 214″, 1°	3C274 3C273	4.4 6.0	970 67	320 46.0	200 39.6	−0.81 − .24	10.8 E 12.8 Q	NGC 4486
Atlas No. 55	15 pec 34″, 4°	3C219 3C216	1.6 1.8	44 18.5	14.0 6.6	8.0 3.8	− .91 − .89	17.5 G 18.3 Q	
Atlas No. 145	16 Ep 80″, 6°	3C65 3C66 3C73	1.3 1.7	27 33	5.7 15.4 3.6	3.2 9.7 1.9	− .92 − .74 −1.04	22G 12.3 G	$d=3.'0$ $d=5.'5$
NGC 5223+ 28+33	14, 14, 15 E E, E, 40″,34″,40″, 1°	3C288 3C286	4.1 4.4	14.5 21	6.1 19.2	3.6 15.2	− .87 − .38	16.5 G 17.4 Q	
Atlas No. 102	15 E+Sp 27″, 3°	3C356 3C352	2.1 3.4	14.5 11.0	2.8 3.5	1.5 1.9	−1.07 − .96	15.3 (N) b. f.	
NGC 5055	10.5 Sp 429″, 4°	3C285 3C280.1	1.3 3.6	10.5 11.0	3.1 2.6	2.3 1.5	− .53 − .92	15.5 S 19.4 Q	$d=2.'7$
Atlas No. 96	E+S 34″, 9°	3C61.1 3C220.3	4.1 4.6	29 14.5	11.2 5.9	6.1 3.0	− .50 −1.10	18.5 G 18.5 G	
IC 982 +983 Atlas No. 117	14.6, 14.3 —, 10°	3C300 3C293.1	3.6 4.0	16.0 9.5	6.4 2.3	3.6 1.1	− .93 −1.15	18.0 G 19.0 G	
Atlas No. 141	15 Ep 17″, 16°	3C173.1 3C184	1.4 3.6	12.0 11.0	4.7 4.2	2.8 2.6	− .85 − .78	18.5 G b. f.	

Table 1b (cont'd)

Central Galaxy	m_{pg}, type d'', $\Delta\theta^\circ$	Radio Source	Distance	S_{178}	S_{750}	S_{1400}	Index	m_v	Ident.
NGC 5421	17,16 E+Sp	3C294	1.1	9.0	2.4	1.4	— .95	b, f.:	
Atlas No. 111	—26°	3C293	3.1	12.0	7.2	4.5	— .75	13.0 G	
NGC 5820	14 Ep	3C303	3.0	12.5	4.1	2.3	— .90	16 G or 20 G	
Atlas No. 136	30", 30°	3C319	3.8	17.0	4.6	2.5	— .99	18.5 G	
Atlas No. 201	16,16½ pec	3C15	3.4	14.5	6.6	4.4	—0.65	15.5 G	
		3C2	4.3	15.0	6.0	3.6	—0.80	20 Q	
			ii) Multiple Source						
IC 701	14.7 Sp	3C258	1.9	9.0	1.6	1.1	—0.55	19.5 G	
Atlas No. 197	40". 6°	3C263.1	3.3	17.5	5.7	3.0	—1.02	3 Parkes Sources	
		3C264	3.6	24	9.6	5.9	—0.78	13.0 G d=3.'0	
		3C256	4.0	9.5	2.7	1.4	—1.05	17 G	
Atlas No. 125	16, 17 Sp	3C345	2.3	10.0	7.9	6.4	—0.34	15 Q	
	—, 11°	3C337	3.0	17.0	5.2	3.3	—0.76	b. f.	
		3C338	3.1	41	9.2	3.6	—1.51	12 G	
Atlas No. 139	16 Ep	3C284	1.1	10.5	3.1	2.0	—0.75	18.5 G	
	10", 2°	3C277.3	3.1	11.5	4.3	3.1	—0.54	15.5 G	
		3C287	5.5	14.0	9.7	7.0	—0.52	17.5 Q	
Atlas No. 148	15 pec	3C254	2.1	19.0	5.4	3.1	—0.91	17.5 Q	
	30", 6°	3C247	2.4	15.5	4.8	2.9	—0.81	b. f.	
		3C252	5.4	12.0	2.7	1.2	—1.28	b. f.	
Atlas No. 109	16. 16 E+Sp	3C314.1	3.5	9.0	3.0	1.7	—0.91	17 D	
	20", 22°	3C330	4.0	24	10.9	7.4	—0.61	b. f.	
		3C309.1	4.6	17.0	11.5	8.5	—0.48	16.8 Q	

Table 1b (cont'd)

Central Galaxy	m_{pg}, type d'', $\Delta 0^\circ$	Radio Source	Distance	S_{178}	S_{750}	S_{1400}	Index	m_v	Indent.
NGC 2444+45	13 Ep	3C186	– 1.3	13.5	2.7	1.3	—1.19	17.8 Q	
Atlas No. 143	—; 27°	(3C189)	(2.8)		Parkes sources				
		(3C183)*	(5.2)		1.5	0.6	—1.34		
		3C194	– 5.5	9.0	3.3	2.1	—0.73	b. f.	
NGC 4194	14 pec	3C266	5.8	9.0	2.8	1.5	—0.95	18.4 N	
Atlas No. 160	40", 20°	3C277.1	6.4	12.0	3.6	2.5	—0.57	18.0 Q	
		3C277	7.0	12.5	2.2	1.3	—0.79	b. f.	

* Amended

Optical identifications from [18, 20, 21] and in a few cases unpublished identifications by author.

Table 2

PROPERTIES OF RADIO SOURCES IN ASSOCIATIONS

№	Distant source Weaker at 21 *cm*	Distant source Has flatter spectrum	Spectral indices Same side of average
		Table 1*a* (i)	
1	√	√	√*
2	√	√	....
3	√	√	×
4	√	×	√
5	√	×	×
6	√	√	×
7	√	×	√
8	√	....	√
9	....	....	√
10	√	×	√
11	√	√	√
12	√	√	√
13	×	√	....
		Table 1*a* (ii)	
14	√	....	....
15	√	√	√
16	×	√	√
17	×	√	....
		Table 1*b* (i)	
1	√	√	√
2	√	√	√
3	×	√	×
4	×	√	×
5	×	√	√
6	√	×	×
7	√	×	×
8	√	×	√
9	√	√	√
10	×	√	×
11	×	×	√
12	√	×	√

* Selected by flat indices

Table 3

RELATIVE SEPARATIONS FROM CENTRAL GALAXIES, ANGULAR DEVIATIONS AND KINDS OF RADIO SOURCES

Spiral and Type I Systems				Elliptical and Type II System			
Central Galaxy	$\frac{r_1+r_2}{d}$	$\Delta\theta$	Radio Sources	Central Galaxy	$\frac{r_1+r_2}{d}$	$\Delta\theta$	Radio Sources
NGC 5055	40	4°	E, Q	NGC 5128	150	15°	G, G
IC 1767	60	7	Q, Q	NGC 4472	175	1	G, Q
IC 229	75	8	b. f., b. f.	New No. 12	280	1	b. f., N
NGC 7541	80	15	N, G:	Atlas No. 145	600	6	G, G:
No. 11, Sp	120	17	Q, G	NGC 1587	700	12	b. f., b. f.
NGC 908	140	12	Q, Q, Q	Atlas No. 149	800	16	b. f., Q
NGC 7309	170	1	b. f., b. f., (Q)	NGC 5820	800	30	G, G
NGC 922	240	5	b. f., b. f.	NGC 7609	1000	17	E, b. f., b. f.
NGC 62	270	16	b. f., — —	Atlas No. 141	1000	16	G. b. f.
NGC 965	320	17	b. f., (Q)	NGC 2444+45	1000	27	Q, b. f.
Atlas No. 55	360	4	G, Q	Atlas No. 139	3000	2	G, G, Q
NGC 7266	380	25	Q, Q, N				
	Total:		12 Q, 6 G, 8 b. f.		Total:		4 Q, 12 G, 8 b. f.

Q = quasi-stellar object, N=N galaxy, G=galaxy, b. f.=blank field

spiral-armlike or type I features; but, because of lack of rotation or some other differences, the material did not take up a very precise spiral geometry. We generally conclude now that the term "peculiar" as used to characterize parent ellipticals in Paper II means physically that recent disruptive activity associated with the ejection of radio sources has taken place. We suggest in the present paper that in some similar sense spirals may be non-equilibrium galaxies, but less massive and with more rotation.

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РАДИОИСТОЧНИКИ И ПОРОЖДАЮЩИЕ ИХ ГАЛАКТИКИ

Г. АРП

Приводятся тринадцать новых ассоциаций радиоисточников, расположенных в виде пары по обе стороны от центральных галактик. Разнесение радиоисточников составляет от 1° до 5°, а в одном случае оно превышает 10°. Спектральные индексы членов радиопар сходны, причем более далекий член пары имеет предпочтительно более плоский и более слабый радиоспектр. Большинство новых центральных галактик является спиралями, и обсуждается возможность того, что выброс их радиоисточников связан с формированием спиралеобразных деталей. Вычисляется время, прошедшее с момента выброса, оказавшееся порядка 10^7 лет, а скорости выброса оказываются порядка 0.1 *c*. В некоторых случаях вдоль линии выброса радиоисточников рассеяны меньшие по размерам галактики, включая иррегулярные типа I.

Среди новых ассоциаций радиоисточников имеются двенадцать квазизвездных объектов. Показано, что пекулярные эллиптические галактики Атласа Пекулярных Галактик, ассоциированные ранее с радиоисточниками, имеют радиоисточники, которые более широко разнесены от родительской галактики и состоят преимущественно из оптических галактик, испускающих радиоизлучение. Радиоисточники, ассоциированные в настоящей статье со спиралями, расположены, однако, теснее к родительской галактике и содержат гораздо больший процент квазизвездных объектов.

Если спиральные и иррегулярные типа I родительские галактики считать менее массивными, чем эллиптические, то эти наблюдения указывают на то, что квазизвездные объекты преимущественно менее массивны, чем выброшенные радиогалактики.

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