EVIDENCE FOR NON-VELOCITY REDSHIFTS – NEW EVIDENCE AND REVIEW

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Abstract. Evidence for non-velocity redshifts in quasars and galaxies is reviewed. It is shown that all current statistical tests favour the association of at least some quasars with relatively nearby galaxies. It is shown that a statistically significant number of quasars falling close to faint galaxies have intermediate redshift (between $z = 0.4$ and 1.8). This confirms the previous result that those are the intrinsically most luminous quasars and keeps open the possibility that less luminous quasars can appear projected at large distances around very nearby galaxies.

It is shown that in four individual cases where quasars fall, projected, closest to bright galaxies, the galaxies show evidence of physical interaction. New evidence for perturbations of the inner isophotes of NGC 4319 by Markarian 205 and by a radio source on the opposite side is presented.

Evidence for systematically higher redshifts for compact and peculiar companion galaxies is reviewed. The intrinsic redshift-morphology relation for clusters of galaxies is commented upon and the relation to Tifft's work is noted. As a summarizing diagram, the individual associations of high redshift quasars and companions are used to show an empirical continuity of observed characteristics between compactness (taken to be a measure of youth) and excess redshift.

Finally some possible theoretical explanations foι intrinsic redshifts are mentioned.

1. Introduction

One of the first and major results of radio astronomy was to show that many radio sources tended to pair across galaxies from which, it was presumed, they had been ejected. (The original paper is Jennison and Das Gupta (1953), but for summaries see Maltby *et al.* (1963) and Matthews *et al.* (1964)). When some individual radio sources identified with optical objects were claimed to be associated with galaxies of brighter apparent magnitude, however, considerable scepticism was encountered. The difficulty was that the optically-identified radio sources were characteristically quasars or galaxies of much higher redshift than the galaxy with which they were supposed to be associated (for summary see Arp, 1971a).

Because the quasars are the highest redshift objects now known, they pose in the purest form the problem of whether the conventional redshift-distance relation is applicable to all celestial objects. Therefore the following review will examine first the current evidence for and against quasars being at cosmological distances.

2. Associations of Quasars with Galaxies

There are two kinds of evidence associating quasars with nearby galaxies: (a) statistical and (b) individual connections to, or perturbations of, adjoining galaxies.

2.1. Statistical evidence

The first evidence suggested that some quasars were associated with violently dis-

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rupted or exploding galaxies (Arp 1966, 1967). Subsequently analysis of a complete and homogeneous sample of 3 CR and Parkes quasars (QSRs) indicated that these radio bright QSRs (down to 5.0 and 1.5 f.u. at 408 MHz) were associated with bright Shapley-Ames galaxies (Arp, 1970).

Most recently, an extremely thorough statistical analysis of the relation of QSRs and bright galaxies was made by Burbidge *et al.* (1971) and Burbidge *et al.* (1972). My own evaluation of the present situation would be that the density of QSRs has been investigated preliminarily out to the order of 20° around bright galaxies. Bright here means objects in the *Shapley-Ames Catalogue* (1932) which is complete to about $m_{pg} = 12.5$ mag and the *Reference Catalogue of Bright Galaxies* (de Vaucouleurs and de Vaucouleurs, 1964), which is complete to about $m_{pg} = 13.0$ mag. Arp (1970) showed that the faint ($m_v \geqslant 17.0$ mag) QSRs, from the complete 3CR and *Parkes Catalogue* identifications, fell on average 5°.8 away from galaxies brighter than $m_{pg} = 10.5$ mag, whereas the same number of QSRs randomly distributed on the sky fell an average of 10°.7 from these bright galaxies. Since both the bright galaxies and the faint QSRs were distributed in roughly similar and distinctive patterns over the north galactic hemisphere, it was assumed in that study that this was the reason for the smaller average distance between the two sets of objects. But Burbidge *et al.* (1971) showed that essentially just four QSRs which fell very close ($<7'$) to bright galaxies represented a very strong excess over that predicted on the basis of a random distribution of QSRs with respect to those galaxies. It is not clear, therefore, without additional investigation, whether the 3CR and Parkes QSRs are significantly associated out to distances of, say, 6° or more, or whether the association is primarily caused by a relatively few QSRs associated very closely, say within 7′, where Burbidge *et al.* (1971) found such an outstandingly high density of QSRs.

In later papers, Bahcall *et al.* (1972), Hazard and Sanitt (1972), and Burbidge *et al.* (1972) tested associations of QSRs with fainter galaxies. No statistically significant correlations were found. The latter paper pointed out, however, that several selection effects, such as faintness and closeness of QSRs to faint galaxies, might bias against discovery and fail to reveal an association if it were present.

Most recently Browne and McEwan (1973) have used improved optical identifications for Parkes radio sources greater than 0.35 f.u. Two new QSRs found within 1′.7 and 1′.2 of Zwicky Catalogue galaxies (Zwicky *et al.*, 1961, 1965) lower the probability of finding accidentally the observed number of QSRs close to these galaxies to something less than 5%. Although this is of marginal significance, the new quasars are found less than 2′.5 from galaxies, which gives weight to the view that they are like the examples of 3C quasars physically associated within 7′ of bright galaxies but just removed to greater distances.

I would like to discuss further this question of why a greater percentage of QSRs are not found close to fainter galaxies. In the first place, even on conventional grounds, the figure of 1.79 galaxies/sq. deg. as bright as 15.7 mag (Browne and McEwan, 1973) must overestimate to some extent the number of *distant* galaxies. In the light of Section 3 to follow – where a number of faint, high-redshift systems are indicated to be relatively nearby – the areal density of distant galaxies in fact might be reduced appreciably. Secondly I note that a large percentage of QSRs may be extremely close to us and be projected at relatively large distances from very bright galaxies. In the original Arp (1970) paper, evidence was found for the QSRs in the apparent magnitude range $m_v = 14$ to 16 mag to be associated with very nearby, Local Group galaxies. The QSRs in the $m_v = 17$ to 19 mag range were primarily associated with galaxies in the $m_{pg} = 9$ to 11 mag range. Therefore it is clear that if one investigates galaxies in the $m_{pg} = 13$ to 15 mag range, as in these later studies, one would only expect QSRs generally in the $m_v = 21$ to 23 mag range – beyond the usual discovery capability for QSRs.

Looked at from the standpoint of redshifts, that early paper showed the low redshift QSRs ($z = 0.2$ to 0.4) to have generally low luminosities, then higher luminosities in the $z = 0.4$ to 1.5 range, and drastically lower luminosities again in the $z = 1.8$ to >2 range. It is interesting to note in this respect that the five QSRs in the paper by Burbidge *et al.* (1972) are associated with what would be termed fainter galaxies in the present context. Everyone of them falls between $z = 0.5$ to 1.4 in redshift. If the distribution of QSR redshifts is taken from Barbieri *et al.* (1967), the probability of getting a redshift in this range by accident is 0.47, and the chance of getting all five in this range is only 0.02. In Table I of the present paper we have added,

TABLE I

Close association between quasars and galaxies

Object Pair	m	z	$r(')$
3C 455	19.7	0.543	0.4
NGC 7413	15.2	0.033	
3C 232	15.8	0.534	1.9
NGC 3067	12.7	0.005	
3C 268.4	18.4	1.400	2.9
NGC 4138	12.1	0.004	
3C 275.1	19.0	0.557	3.5
NGC 4651	11.3	0.003	
3C 309.1	16.8	0.904	6.2
NGC 5832	13.3	0.002	
2020-370	–	–	0.3
Spiral galaxy	–	1.1	
PHL 1226	–	0.404	0.9
IC 1746	14.5	–	
3C 270.1	18.6	1.519	5.1
pec ring galaxy	(17)	–	
0159-11	16.4	0.68	39
IC 1767	(15)	–	
Mark 132	15	1.75	45
NGC 3079	11.9	0.041	
3C 254	18.0	0.734	126
Mayall's pec. object	(15)	0.035	

below these five associations, seven more associations of QSRs with individual galaxies, which the author thinks are among most probable associations. Now the redshifts are still all restricted between $z=0.4$ and 1.8, or just in the brightest luminosity range for QSRs as was discussed earlier. The chance of the entire list of twelve being drawn accidentally between the above redshift limits from a list containing the normal distribution of redshifts is less than 0.007.

In summary then, the question of why every QSR is not associated closely with some galaxy seems to be answered by the result that many QSRs are relatively close to us and are projected at considerable distances on the sky from the galaxies from which they originate. This is particularly true of the fainter QSRs where we find an increasing percentage of redshifts $z>1.8$ which represent QSRs of drastically lower luminosity and therefore considerably closer by.

As for the important, and by now much investigated, question of whether the quasars are associated with clusters of galaxies, a brief summary of the current situation might be the following: A number of searches have been made around quasars of low redshift ($z<0.36$) for clusters of galaxies at the same redshift. Three possible examples of bona fide quasars near groups or clusters of the same redshift have been found, but Burbidge and O'Dell (1973) claim that, in view of the uncertainty in number density of less populous clusters, these cases are not statistically significant. On the other hand, two independent investigations have turned up evidence that quasars with redshifts $z>0.3$ are slightly correlated with clusters of redshift $z<0.2$ (Bogart and Wagoner 1973; Bahcall *et al.*, 1973). This correlation was not considered statistically significant, but it would be of interest to see whether the significance would be improved by taking only nearer clusters or more luminous quasars, as discussed above.

2.2. Association of individual quasars with galaxies

In order to search for evidence of a perturbation or connection, it is necessary to look carefully at those cases where the quasar falls closest to an adjoining galaxy. The four cases currently known of closest association are:

(1) 2020–370, where the quasar falls 21″ from a small spiral galaxy (Peterson and Bolton, 1972); (2) 3C 455, where the quasar falls 23″ from NGC 7413 (Arp *et al.*, 1972); (3) Markarian 205, where the quasar falls 42″ from the large spiral NGC 4319 (Weedman, 1970); and (4) PHL 1226, which falls 55″ from the spiral galaxy IC 1746 (Burbidge *et al.*, 1971). Of these cases, the first is unfavourable for study because the galaxy is small and, due to its extreme southern declination, good plates are not available.

In the second case, an isodensity tracing of the galaxy, NGC 7413, and the quasar 3C 455 is shown in Figure 1. Even though the galaxy looks like a dynamically relaxed, regular E galaxy, there is a conspicuous (and very unusual) perturbation of the inner isophotes of the galaxy in a northeasterly direction, the same approximate direction as the quasar. As we will discuss in the succeeding cases, the amount of rotation expected in the time since ejection from the inner regions of the galaxy would easily account for this displacement in direction. As far as the direct photographs show, the object is a normal, Population II galaxy in which it is not usual to find elongated luminous forms (although, as the jet from the nucleus of M87 demonstrates, some E galaxies at some times appear to be capable of ejecting luminous matter, which is in a physical state not well understood at present.)

In the third case, the quasar Mark 205 (at $z=0.07$) is close to a spiral galaxy NGC 4319 ($z=0.006$). Arp (1971b) claimed there was a luminous filament connecting the two objects both in the continuum and in Hα. Lynds and Millikan (1972) found a feature in continuum light but doubted its interpretation as a connection. Both Lynds and Millikan, and Adams and Weymann (1972), did not find a connection in Hα, while Ford and Epps (1972) not only did not find a feature at Hα but also concluded that none existed. Arp (1973b) showed that the Lynds-Millikan continuum feature coincided exactly in position and shape with the claimed emission connection. Figures 2 and 3 show two more Hα photographs I have just obtained, each of which reveals the luminous connection.

Another new result of considerable interest concerns a radio source found just north of NGC 4319 by van der Kruit (1971). He originally identified the radio source

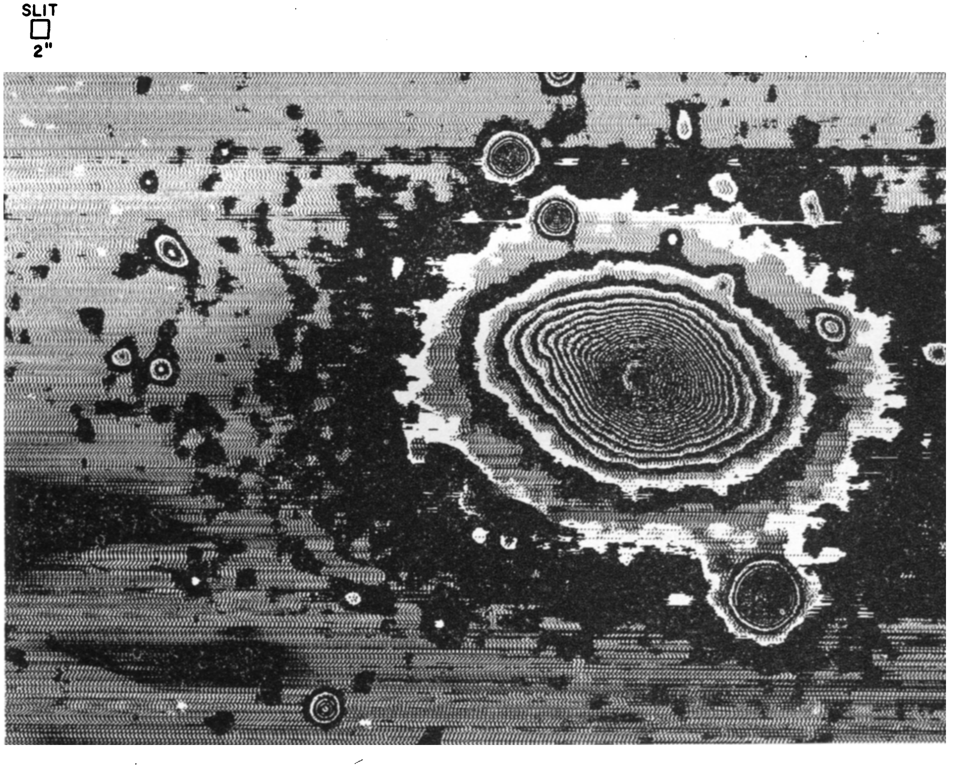

Fig. 1. **Isodensity tracing of NGC 7413 (E galaxy) and the QSR, 3C 455 (star image immediately north-east of galaxy).** Perturbation of isophotes is seen in general direction of QSR but slightly offset in direction. North is at the top and east at the left, as also in Figures 2–8.

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with an optically-bright star, but measures of photographic plates by Sulentic (unpublished) establish the radio source actually to be 1.2 s east and 15″ south of that star. Figure 4 shows, by a small cross, the location of the radio source relative to NGC 4319. The new position of the radio source places it within a few arc seconds of a moderately small galaxy, which then is possibly close enough to be a candidate for an optical identification. The existence of this radio source, however, takes on added significance when the following new results on the inner isophotes of the spiral galaxy are considered.

Initial isophotal analysis of the interior regions of NGC 4319 with GALAXY at Edinburgh (Arp and Pratt, unpublished) showed that a perturbation of the interior regions pointed in the general direction of Markarian 205. Figure 5 gives the result of further analysis with a Joyce-Loebel isodensity tracer at the Jet Propulsion Laboratory in Pasadena on a 20-minute exposure, 103a-J plate obtained with the 200-in. reflector (Arp and Sulentic, unpublished). It is seen that the major axis of the projected inner regions of NGC 4319 deviates considerably from that of the outer regions. It is seen further that from the inner regions, roughly along the line of

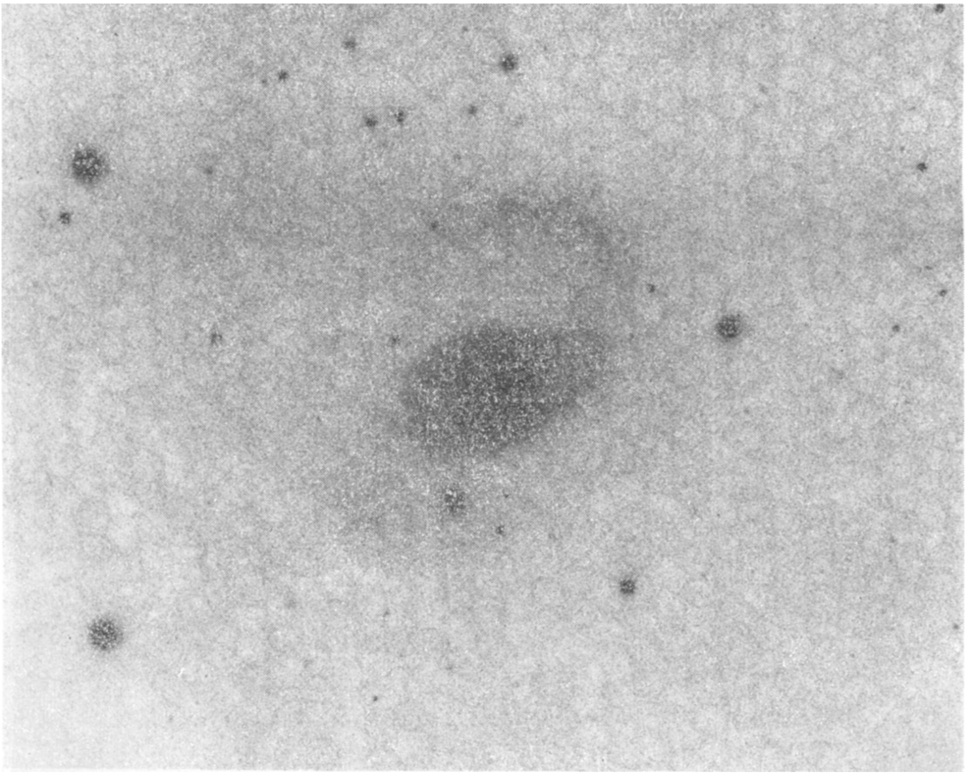

Fig. 2. Photograph of NGC 4319 (S galaxy) and Markarian 205 (compact object 42″ south). Hα interference filter with new 90mm image tube on 200-in. Palomar reflector. Faint luminous feature confirmed going north from Markarian 205 to galaxy in same place as previous connections photographed.

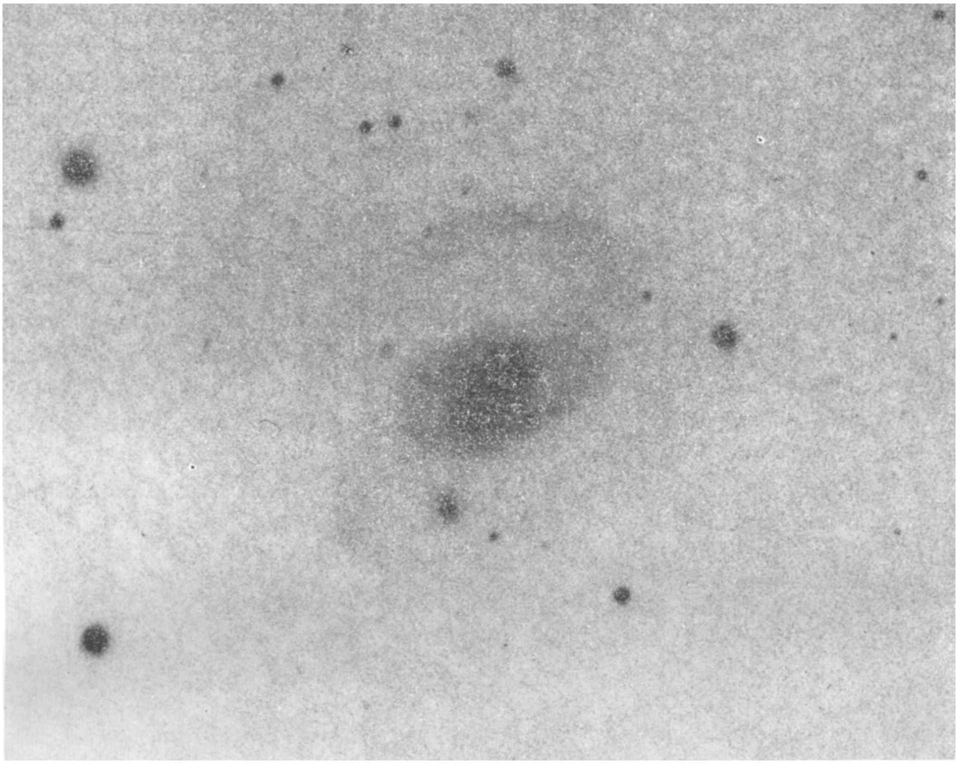

Fig. 3. A different photograph with same technique as in Figure 2 to show how a second, independent plate registers the feature.

elongation, there are perturbations throughout a number of contour lines extending both north and south-east. In Figure 5 we have drawn dashed lines from the centre of the galaxy southward to Markarian 205 and north-eastward to the radio source on the other side of the galaxy. Then we have rotated these lines clockwise (in the direction of the rotation of the galaxy as projected on the plane of the sky) by 30°. Figure 5 enables the viewer to judge how accurately these lines now pass out from the centre of NGC 4319 directly along the disturbances in the isocontour lines in both directions.

The interpretation of these observations fulfils earlier conclusions that material objects are ejected outward from galactic nuclei in roughly opposite directions (see Arp, 1972a for summary). In the present case the model is one in which the quasar and the radio source were ejected 10^7 yr ago with a velocity of about 1000 km s^{-1}. Passage outward perturbed the inner regions of the galaxy in a direction which has now swung around about 30° in the direction of rotation. We hypothesize that the ejection was somewhat out of the plane of the spiral so that the outer regions of NGC 4319 are not much disturbed. (It should be noted that the connection to Markarian 205 discussed initially does not necessarily have any physical relation to the perturbation of the inner regions. The connection could, for example, be a small

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amount of material drawn out behind Mark 205 and seen projected down onto the plane of NGC 4319.)

The fourth case mentioned in the introduction to this section was that of PHL 1226 and IC 1746. The initial discovery of this quasar, which lies less than 1′ from a moderately bright spiral galaxy, was made on *Palomar Sky Survey prints* (Burbidge *et al.*, 1971). On those prints the quasar seems attached to the galaxy by a luminous bridge. But later photographs with the 200-in. telescope in good seeing showed that a small galaxy image lay between the quasar and the large galaxy. Although a very suspicious configuration, no continuous connection was apparent between the quasar and galaxy. Now, however, new and extensive isodensity traces of two different photographic plates (Figures 6 and 7) reveal a number of significant features (Arp and Sulentic, unpublished):

(a) Again, the major axis of the inner isophotes of the spiral galaxy is considerably rotated from the axis of the outer isophotes.

(b) The inner spiral arm of the main galaxy, and the fainter continuation of that arm, seem to be extended toward the peculiar galaxy and the quasar.

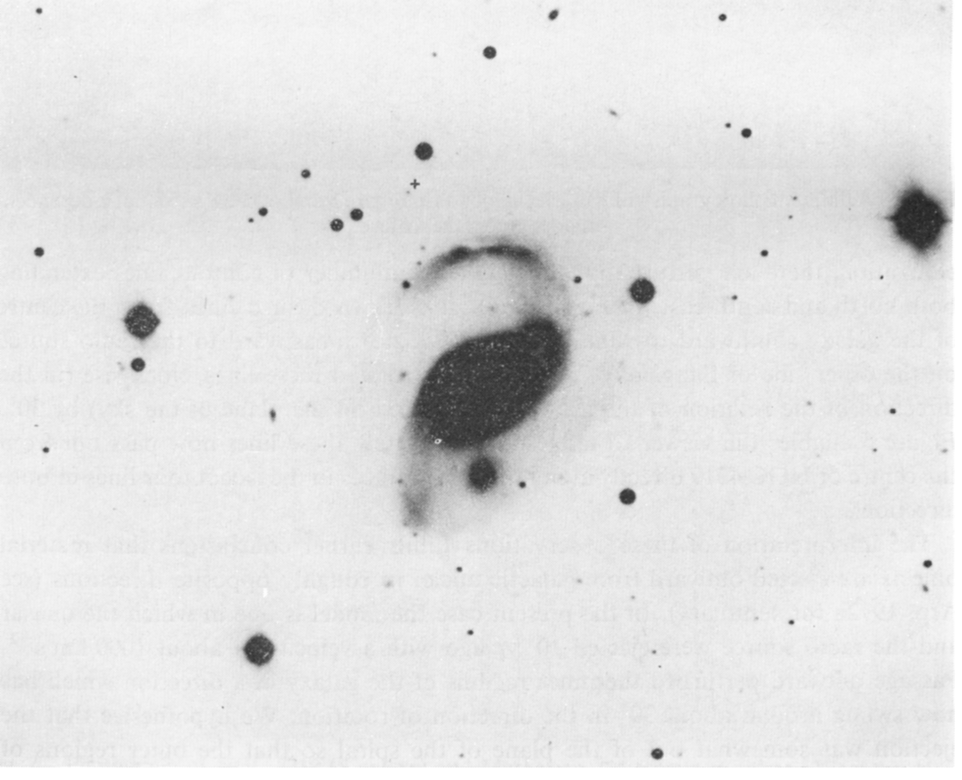

Fig. 4. Deep photograph of NGC 4319 and Mark 205 in continuum wavelengths (IIIa-J plate with no filter). Photograph shows connection and also position of radio source north-east of NGC 4319 (marked by a cross).

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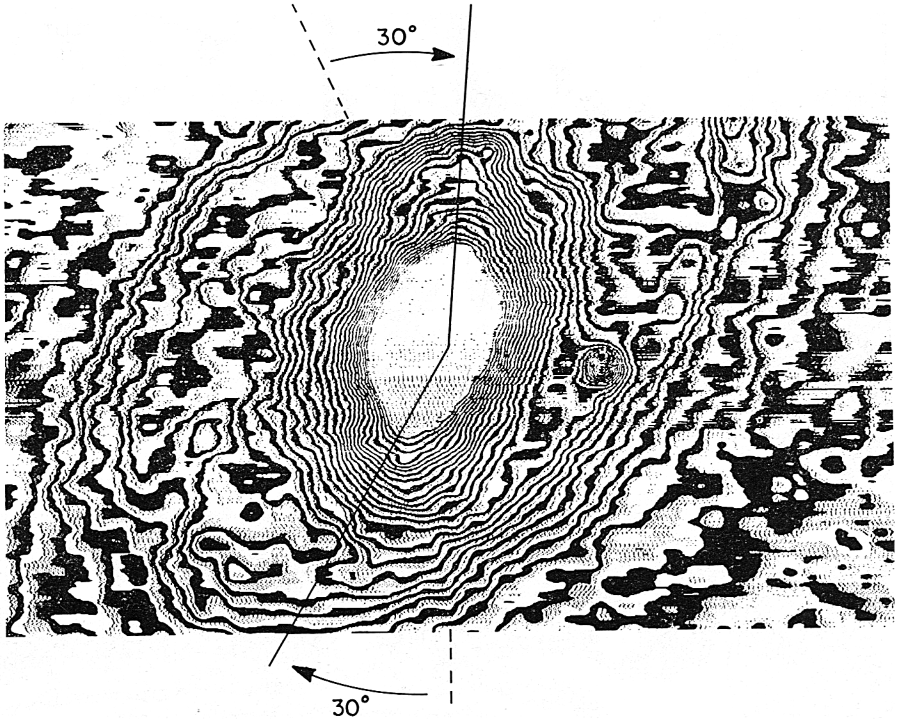

Fig. 5. Isodensity trace of short exposure of NGC 4319 showing perturbation of inner isophotes. Dashed line to north-east is drawn to radio source, dashed line south drawn to Mark 205. After rotation by 30° in direction of rotation of galaxy, the dashed lines are then drawn in solid. Note extension of innermost isophotes along solid lines.

(c) The outer isophotes of the spiral galaxy appear to envelop the peculiar galaxy and the quasar.

(d) A small, peculiar 'line'-like galaxy just north-west of the quasar has wings coming off on either side both toward and away from the quasar, suggesting some form of interaction.

(e) Finally, but most important, on both plates though particularly on the short-exposure plate taken in good seeing conditions, a connection of luminous material can be seen between the quasar and the small peculiar galaxy lying in the direction of the spiral.

Figure 6 shows the isophotal traces of the deepest plate, which illustrates conclusions (b), (c), (d), and (e). Figure 7 presents the lighter exposure, which illustrates conclusions (a), (b), and (e).

The redshifts of the small peculiar galaxies which seem to be interacting with the quasar are not known. But there would be no precedent for their having redshifts as high as $z=0.404$, which would be necessary in order to match that of the quasar. The importance of the result, therefore, is that once more we have observational evidence for the physical association of quasars with objects of much smaller redshift.

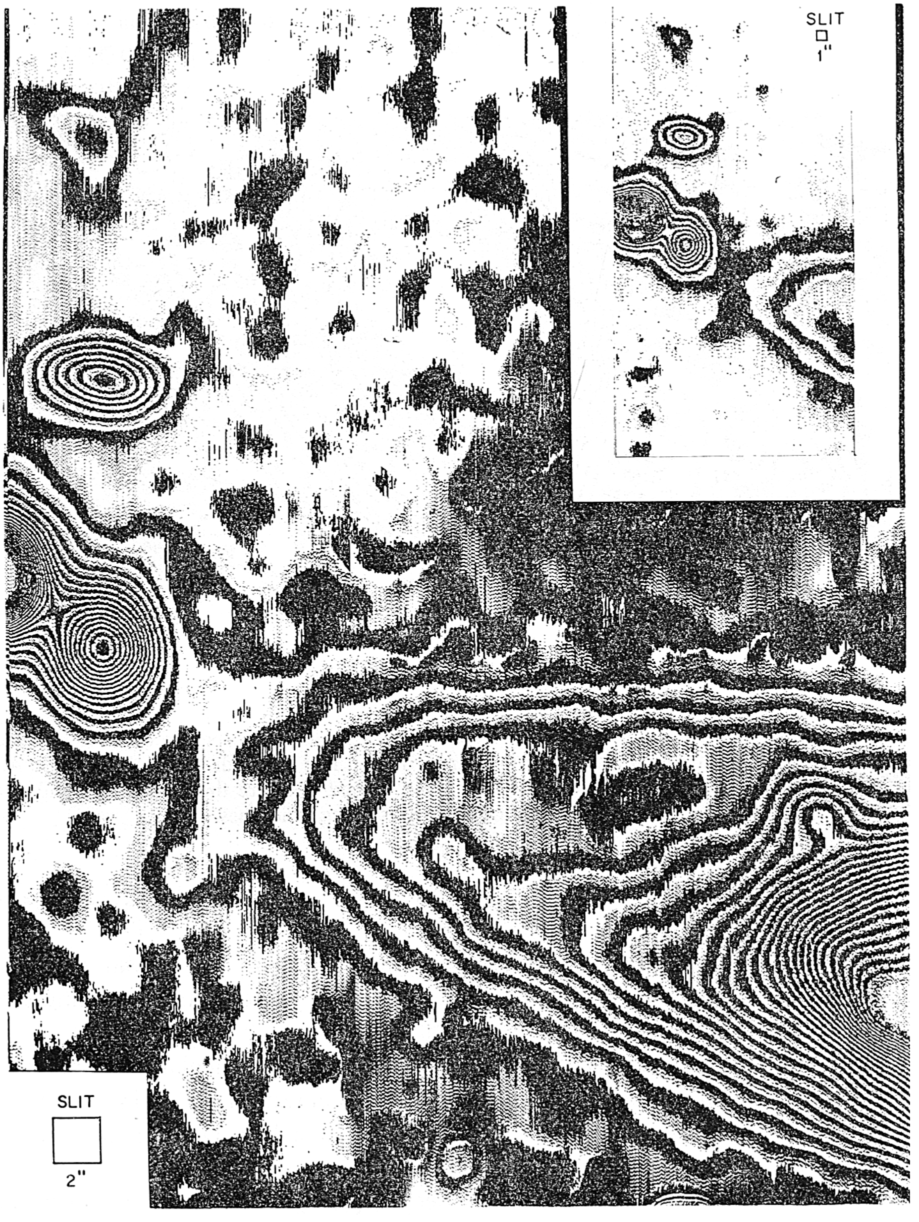

Fig. 6. Isodensity trace of photograph of region between the edge of the spiral galaxy (IC 1746) and the quasar PHL 1226 and peculiar galaxy. Note appearances of connection between latter two objects, envelope connecting the two to IC 1746 and perturbation of small galaxy north-west of the quasar.

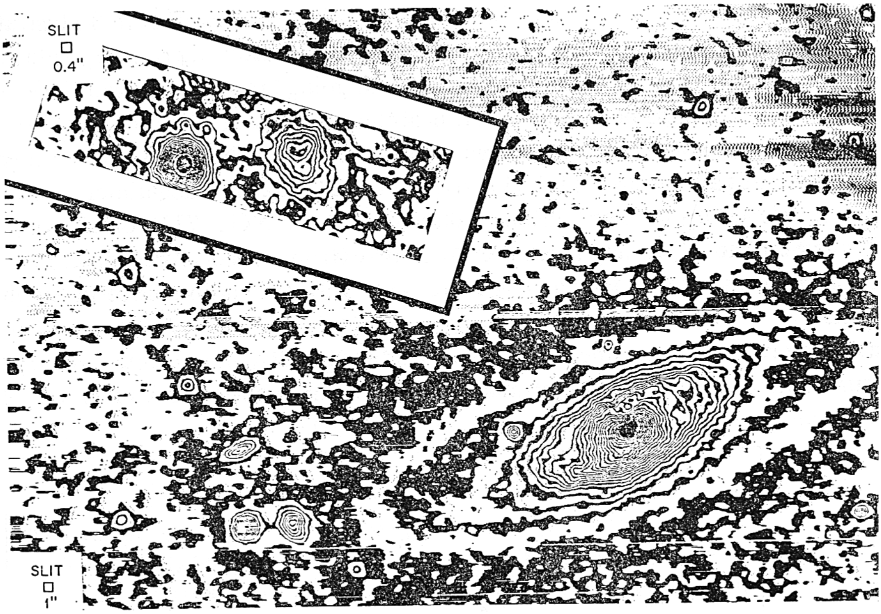

Fig. 7. Isodensity trace of shorter exposure shows bridge between quasar and peculiar galaxy more clearly.

In summary, therefore, we can state that of the three closest cases which could be investigated in detail, all reveal evidence for interaction of the quasar with the galaxy.

3. Association of High Redshift Galaxies with Low

Further compelling evidence for the existence of anomalous redshifts is the association of small, high-redshift galaxies with nearby, low-redshift systems. There are many examples of high-redshift companions (see reviews by Arp, 1971a and 1973b) but only a few individual associations will be discussed here, and the rest summarized.

3.1. Multiple interacting systems

The most famous case of a multiple interacting system is Stephan's Quintet. A series of papers (summarized in Arp, 1973a) provides evidence that all members of the Quintet, including NGC 7319 at $z = 6700$ km s^{-1} and other members to $z = 5700$ km s^{-1}, are associated with the large, nearby Sb spiral NGC 7331, which has a redshift of $z = 800$ km s^{-1}. The observational evidence is in the form of visible interaction between high and low redshift members (NGC 7319 and NGC 7320), identically-sized H II regions in high and low redshift members (NGC 7318 and NGC 7320), luminous filaments in the region between NGC 7331 and Stephan's Quintet, and excessive numbers of radio sources in the region between NGC 7331 and Stephan's Quintet. In connection with this latter point, and in consonance with the introductory remarks

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about conventional associations of radio sources with galaxies, Figure 8 illustrates a particularly strong line of radio sources, probably unresolved, running southward from NGC 7331, including Stephan's Quintet and going beyond to the south (Kaftan-Kassim and Sulentic, to be published). It is also clear from the diagram of this region that there is a group of high-redshift galaxies right around NGC 7331, then a group of high-redshift galaxies around the low-redshift NGC 7320 in the Quintet, and finally a comparable group of high-redshift galaxies north of NGC 7331 on the opposite side from Stephan's Quintet. There is even a fairly strong radio source in the northern group that forms a radio pair across NGC 7331 with the radio source in Stephan's Quintet.

In an attempt to determine the distance independently of redshift, two separate measurements have recently been made of H I in the high-redshift members of the

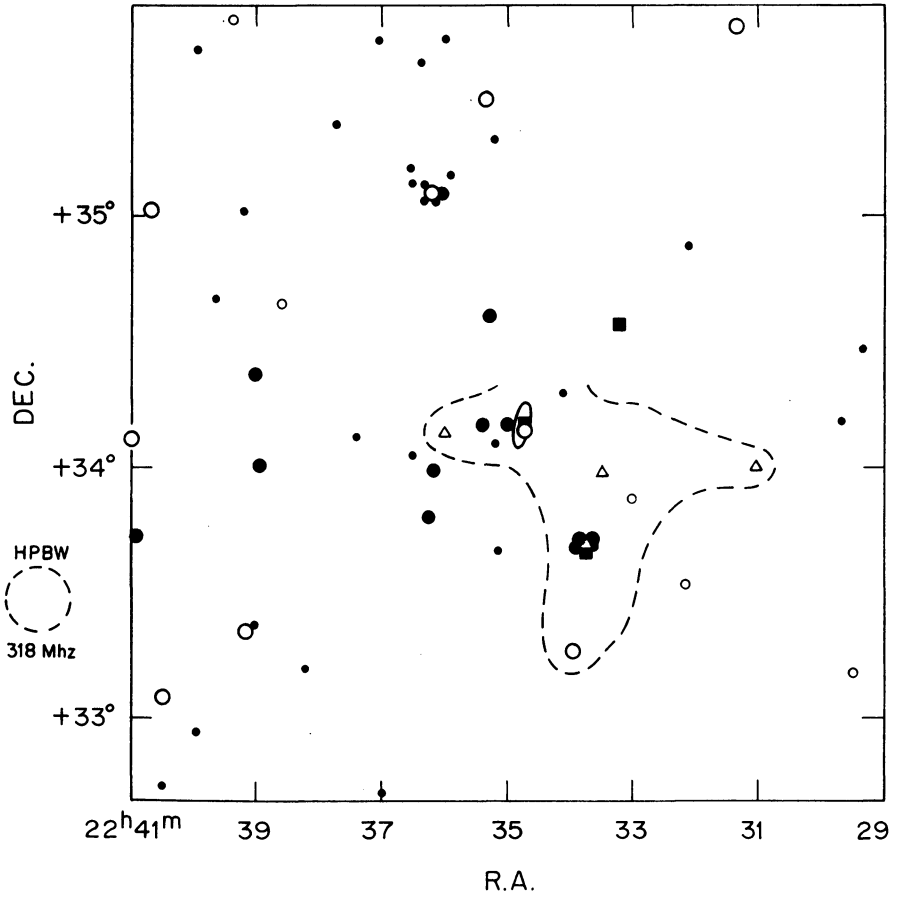

Fig. 8. NGC 7331 region: Open circles represent Bologna 408 MHz sources (small $S < 0.5$ f.u.; large $S > 0.5$ f.u.). Solid boxes, circles, and dots represent Zwicky catalogue galaxies brighter than 14, 15, and fainter than 15 magnitudes, repectively. Triangles and dashed line are the preliminary results of observations of Kaftan Kassim and Sulentic at Arecibo at 318 MHz.

Quintet. (H I in the low-redshift member, NGC 7320, was measured by Allen in 1970.) Everyone agrees that NGC 7320 is at the distance of the low-redshift NGC 7331. But Balkowski *et al.* (1973; see also Balkowski *et al.*, this volume, p. 237) claim that the H I measures with the Nançay radio telescope indicate that the high-redshift NGC 7319 cannot be at its conventional redshift distance but is probably at the closer distance of NGC 7320. They get $D=22^{+15}_{-9}$ Mpc. From a quite similar H I signal observed with the NRAO 300-ft radio telescope, Shostak (1974) gets NGC 7319 at a larger distance, $D=47^{+55}_{-26}$ Mpc, possibly at the conventional redshift distance. (The distance of NGC 7319 with the new Hubble constant of $H=50$ km s^{-1} Mpc^{-1} would be about $D=120$ Mpc.) Although the NRAO and Nançay determinations of the distance to NGC 7319 agree within their own quoted probable errors, there is considerable disagreement as to whether the object is more likely to be at the 10 or 11 Mpc distance of NGC 7331 and NGC 7320 or at the redshift distance of 120 Mpc.

The major difference between the two studies of NGC 7319 seems to be the body of data against which the NGC 7319 measures were calibrated. It is not clear which body of data is to be preferred, but it should be mentioned that Shostak calibrated against Roberts' (1969) H I measures of nearby galaxies, whereas the French project used data by Balkowski (1972). Roberts took distances for nearby galaxies from de Vaucouleurs' group membership assignments or values based on the assumption of a Hubble constant of 100 km s^{-1} Mpc^{-1}, whereas none of Balkowski's (1972) distances were based on the Hubble law. The distance for NGC 7319 derived in the French study should, therefore, be independent of the assumption of the validity of the Hubble law.

This point is particularly significant when one considers that the distance derived for NGC 7319 depends on the morphological classification assigned, i.e., Sb, Sbc, Sc, etc. Not only is there uncertainty in this assignment, but there is uncertainty about the standard Sc galaxies against which it would be calibrated if it were so classified. Recent work has raised some question as to whether Sc galaxies have generally a component of intrinsic redshift (Jaakkola, 1971). Also Sc I (luminosity class I) galaxies show very peculiar redshift distribution properties (Rubin *et al.*, 1973). We shall proceed to the discussion of these effects, but they are mentioned here in order to introduce the question of whether there might be systematic errors in the parameters of the Sc or Sc I classes.

To finish the discussion of multiple interacting systems, it can be stated that there are other groups like Stephan's Quintet, which may be used to test the proposition that such groups are *characteristically* associated with large, low-redshift galaxies. A list of the best examples has been assembled by Arp (1973a). Depending on whether we choose bright galaxies to a limit $m_H=12.2$ mag or galaxies out to 75′ from the disturbed groups, or include the first six or seven most interacting groups, it is found that, omitting Stephan's Quintet, the remaining systems have a probability of only 10^{-4} to 10^{-6} of being accidental. In other words, if these high-redshift systems are not characteristically associated with large, low-redshift galaxies, then we should be able to find about one thousand multiple interacting systems not near large galaxies. It is my belief that anyone familiar with the frequency of these peculiar groups will realize that this is clearly not the case.

3.2. Double interacting and peculiar companions

It has been reported (Arp, 1972b) that double interacting galaxies, as a simpler and more common case of multiple interacting galaxies, also occur characteristically in the neighbourhoods of large, low-redshift galaxies. The interpretation given in the above reference is that compact bodies have been fairly recently ejected from the parent body and are in the process of evolving, as a function of time, from peculiar, disturbed objects with high intrinsic redshift to older, more relaxed objects with a lesser component of intrinsic redshift. The early stages of evolution are apparently characterized by secondary ejection, fission, and disruption. Therefore the double and multiple interacting systems fit very well into this evolutionary scheme as young objects.

It is consequently of great interest to note the recent results of Heidmann and Kalloghlian (1973) in a paper titled 'Evidence for the recent Production of Markarian Galaxies', results undoubtedly related to the doubleness of compact galaxies earlier reported by Bertola *et al.* (1971). From the number of pairs of Markarian galaxies which are observed, it is clear that many Markarian galaxies exist as pairs at the same

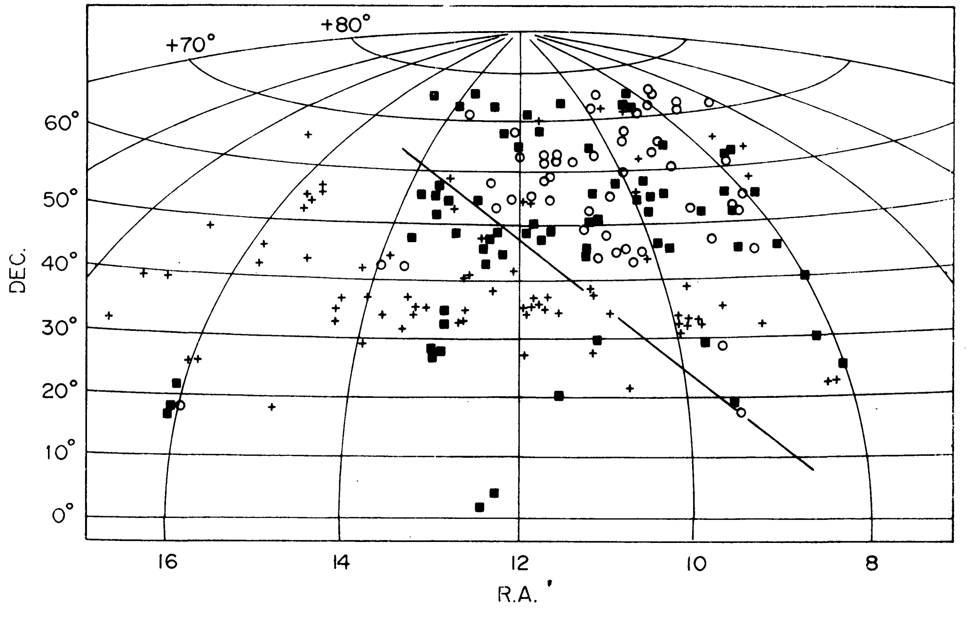

Fig. 9. Distribution of bright Markarian non-Seyfert galaxies ($\leqslant$ 15.5 mag) of differing redshifts: Open circles represent Markarian objects with $0.008 \leqslant z \leqslant 0.014$, and solid squares other objects with known redshifts not in the above range. Plus signs represent those objects for which a redshift is unavailable. The line is the same as used by Rubin *et al.* (1973) to divide the areas of their Sc I galaxies of 0.013 to 0.018 redshift (upper area) from their 0.020 to 0.025 redshifts (lower area).

distance from the observer. It is also clear that many pairs have positive energy and are flying apart on time scales of the order of 10^8 to 10^9 yr. On the idea that these Markarian objects are related to the interacting double companions discussed in the previous paragraph, their surroundings have been studied by Arp and Sulentic (unpublished). Preliminary results indicate that, within the area where Markarian galaxies have been most searched for, they are associated with galaxies brighter than 12 mag, the probability of which is estimated to be 0.09 of being accidental. Although the point remains to be formally investigated, presumably most of these Markarian galaxies have considerably higher redshifts than the larger galaxies with which they are associated.

In a further investigation of the distribution of Markarian galaxies on the sky, Arp and Sulentic have noted that Markarian objects of redshift between 0.008 and 0.014 occur predominantly in the area of the sky shown in Figure 9 as occupied by open circles. Curiously, this is the same area in which Rubin *et al.* (1973) found their Sc I galaxies of redshift 0.013 to 0.018 to fall preferentially.

The implication, from the close distance for NGC 7319, the association of the companion Sc I with NGC 4151, and the general correlation of youth with small luminosity and high redshift, is that the ScI's may have some component of intrinsic redshift, lower luminosities, and be associated with more nearby classes of galaxies.

3.3. Redshifts of Companion Galaxies

To complete the discussion of anomalous redshifts in galaxies, two important and recent results need to be described. The first is a study by Bottinelli and Gouguenheim (1973) of groups of galaxies identified by de Vaucouleurs in which the main galaxy is at least 50% more luminous than the others. The result is that the companions show an average residual redshift of +90 km s^{-1}. The conclusion that there is some residual redshift for these companions is significant at about the 1% level. The Bottinelli and Gouguenheim study repeats the original Arp analysis, which derived a mean residual of 80 km s^{-1}, but has a much larger number of companion galaxies (52), more accurate redshifts, and more stringent inclusion criteria. Therefore this exceedingly surprising and important result appears to be on a much sounder basis at present.

The second important result is a recent study by Jaakkola (1973). As in his previous studies (Jaakkola 1971), he investigates the associations of galaxies in clusters, groups, and pairs, dealing in all with about a thousand galaxies. This time he shows that the residual redshifts are higher for elliptical galaxies with high surface brightness, galaxies with high surface brightness and steep edge gradient of intensity, and galaxies compact in the sense of Zwicky's definition, as well as several other categories of galaxies. The significance of his result lies at the 98 to 99% significance level. The result is important because it independently cross-checks the higher intrinsic redshifts for companion galaxies since it is just the kind of galaxies mentioned above to which the companions tend morphologically. The result also pegs a strong observational confirmation to the hypothesis that the intrinsic redshifts are correlated with the youth of the object, since compactness and high surface brightness are nonstable stages preceding older morphological forms.

The evolutionary age of the system will be an important consideration in the following section where we discuss some analyses of clusters of galaxies.

3.4. Redshift-morphology relationships in clusters of galaxies

We have just considered the neighbourhoods of bright galaxies, typically about a degree radius around a bright Shapley-Ames spiral galaxy, and have reviewed evidence that these companion galaxies are smaller, have higher surface brightness, tend to be multiple and interacting, tend to be emission objects and also be radio sources or be associated in the vicinity of radio sources. All of these characteristics can be subsumed under the loosely descriptive term of young, and most of these objects have redshift excesses of varying amounts with respect to the central dominant galaxy.

The only other independent set of data by which we can test these conclusions is from rich clusters of galaxies. Because the clusters are rich there is greater statistical confidence in demonstrating that the various galaxies are at the same distance. However, it has been known since Hubble's (1936) studies that rich clusters of galaxies tend to be made up of older types of galaxies (E's and S0's) and to lack spirals which are more spread throughout the field. The reason for this may become clearer as we examine the nature of the rich clusters but let us look first at the classical case of a high-density cluster of glaxies.

Tifft (1972 and 1973a) shows that, if the previously established morphological types in the Coma Cluster of galaxies (principally E and non-E classification) are examined as a function of their listed redshifts, the non-E galaxies have a mean redshift about 700 km s^{-1} greater than the E galaxies. Pineau des Forêts and Schneider (1973) confirm that this situation pertains in the core of the Coma Cluster but that the difference diminishes further out in the cluster. The reason for this behaviour becomes clear if one looks at another recent paper by Tifft and Gregory (1973). There he shows that as one goes to the outer regions of the Coma Cluster a greater and greater percentage of blue ellipticals, faint galaxies, and emission galaxies are encountered. This situation was already clear from the work of Sastry (1970) who showed that blue galaxies, and therefore galaxies presumably related to spirals, occurred in a rough ring outside the central regions of the Coma Cluster. (It may be remarked in passing that this kind of structure for a cluster of galaxies implies that the large old galaxies are in the centre and the smaller, younger galaxies around the edge. This explains the previously mentioned tendency for spiral galaxies to be field galaxies, and at the same time is strong evidence for ejection or cascading ejection as the origin of galaxies and clusters of galaxies.)

Recently Tifft (1972) has claimed that the redshift vs. apparent-nuclear-magnitude diagram for rich clusters of galaxies like Coma shows a banded structure. Power spectrum analysis yields significant bands at a given slope. Tifft (this symposium

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p. 243) has now analyzed a third cluster in addition to Coma and Virgo, namely A2199. He finds significant banded structure at the same slope of the redshift in these bands, structure which would, of course, be vitiated by even small dispersions in real velocities.

Ignoring the reality or nonreality of the bands for a moment, it is clearly noted in Tifft's work that as one passes towards fainter magnitude and later Hubble type that one encounters increasing amounts of intrinsic redshift. In this respect his results on clusters give direct confirmation of my earlier results for groups and associations of galaxies. But if one accepts the band structure, the confirmation of increasing redshifts with fainter intrinsic magnitudes and younger morphologically type is much stronger. The previous results on correlation of excess redshift with various properties of galaxies are then supported in detail.

If, in fact, the apparent-magnitude vs. intrinsic-redshift plane is banded, this would imply some quantization of the properties of galaxies in different bands and might help selection between the various physical explanations briefly reviewed in Section 5.

4. Frequency Distribution of QSR Redshifts. Periodicity and Grouping

Considerable debate has taken place in the astronomical literature as to whether or not there exists periodicity or clumping at certain redshifts in the total sample of known quasar redshifts. Recently Tifft (1973b) has examined the known quasars in the redshift vs. apparent-magnitude plane and has claimed that the groupings in the distribution become more conspicuous – and significant – when the distribution is projected along a certain angle in the $\log z - m_v$ plane. That angle corresponds to just the angle of the redshift-apparent magnitude bands which he has found in his analyses of clusters of galaxies. He concludes that the major component of quasar redshift is intrinsic and is quantized. Véron and Véron (1973) have criticized Tifft's work and in redoing his analysis have excluded many quasars as photometrically unreliable, and have corrected for galactic absorption. Their results do not confirm the quasar bands.

Without taking any stand as to the reality or non-reality of the quasar bands, however, it is again possible to point out an interesting feature of Tifft's analysis. That feature is illustrated if we assume for the moment that some real grouping actually does take place in the frequency distribution of redshifts. Then we would expect quasars of the same redshift group to have some kind of relation between intrinsic luminosity and z, and some spread in distance (i.e. they would not form horizontal lines in the z-m diagram.) In that case there would be some angle in the z-m plane at which the grouping would appear maximally conspicuous. Projected against the z axis, as has been done heretofore, we would still expect to find some evidence of groupings but weaker, and more subject to contention as to its reality.

Therefore regardless of the actual reality of the Tifft bands, this approach is interesting from the standpoint of the reality of the groupings in redshift, and if it produced a significant improvement in the groupings would be an empirical proof of quantization in the quasar redshifts and therefore compelling evidence for non-velocity redshifts in quasars.

5. Theoretical Explanations of Non-Velocity Redshifts

Until the results on anomalous redshifts became more observationally established and accepted, the author has considered theoretical explanations to be premature. But several groups have now started working on the explanation of the effects reviewed here and for the sake of completeness I will briefly summarize these theories:

(1) *Gravitational redshifts.* Although it was not possible to build plausible models for quasars in which the redshift was gravitational, some investigators still believe in the possibility of such redshifts. There are even a few who believe that anomalous redshifts in galaxies could be due to high gravitational fields, although the fact that redshifts are not observed to vary across resolved regions in galaxies is strong evidence against this latter view. A variant of the gravitational redshift mechanism is the gravitational lens argument – advanced most strongly by Barnothy and Barnothy – that high redshift objects are merely distant objects seen through a relatively nearby gravitational lens.

(2) There are at least two investigators who claim that the difference between co-ordinate time and proper time will give anomalous redshifts at large light-time distances in the universe. Greenberger argues this directly (1970a, b; 1973), and Segal (1974) through a development of special relativity called 'Chronogeometry'. I cannot offer an opinion as to whether these separate authors' claim is true that their results are a natural consequence of currently accepted physics.

(3) *Photon-photon scattering.* Attempts by Sistero, Kierein, the author and others to account for redshifts by means of photons scattering off electrons usually foundered on, among other things, the prohibitive mass of electrons needed. Pecker *et al.* (1973), however, postulate emergent photons scattering off a sea of photons which are involved in the objects which have anomalous redshifts. They have impressively extended their predictions to account for redshift anomalies in binary stars in our own Galaxy (Kuhi *et al.*, 1974) and to a claimed anomalous redshift observed in a Pioneer-6 passage behind the sun (Merat *et al.*, 1973). Their type of anomalous redshift increases generally with temperature as T^3. A criticism of this explanation would therefore be that we would expect anomalous redshifts to vary according to the temperature in various parts of a resolved galaxy.

The most sensible comment on this whole proposal from the observational side of the anomalous redshifts, as reviewed here, is that it is very difficult to distinguish between galaxies which have a high temperature ambience and those which are very young. We would expect young galaxies to be generally composed of hotter objects and hence it is phenomenologically difficult to distinguish between the photon-photon scattering explanation and that below, which depends on differences in the fundamental structure of matter at different places in the Universe and at different epochs of creation (i.e. upon the ages of the galaxies concerned).

(4) The final explanation I mention is that put forward by Hoyle and Narlikar (1971). They postulated that matter of different ages and at different places in the Universe could be made of particles of lower mass. The lower mass of the electron in the Rydberg constant would therefore give lower frequency (redshifted) photons from the usual astrophysical radiative transitions. This explanation agrees with my earlier conclusion that the anomalous redshift was a function of the youth of the Galaxy, but it would introduce new physics in other places and times in the Universe.

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DISCUSSION

Heidmann: Arp (H.) showed us a very nice picture of Stephan's quintet in red light. But I know of a still nicer one (Figure A), in full colour. It is by Arp (J.) and is in the Tate Gallery, London, with a caption "Constellation of forms according to the laws of chance". Although in 1930 Arp (J.) did not know about the work of Arp (H.), you see that he made the quintet to be a sextet by including NGC 7320 C. I think the high redshift members are even painted red.

From the caption it appears that Arp (J.) knows about astronomy and statistics but that he (Arp, J.) is not completely convinced about the interpretation by Arp (H.)

E. M. Burbidge: Two comments and one question:

(i) Although the faint galaxy between the QSO PHL 1226 and IC 1746 looks compact, it has no central concentration and is hard to observe. I initially took conventional spectrograms and saw only a bluish continuum. Wampler and I then tried scans; it has no emission lines, so we looked for the H and K break where you have to integrate for long times to beat the noise. Preliminary indications were for a redshift about $z = 0.15$, but we must get more observations.

(ii) One of the troubles facing the cosmological redshift interpretation has been, since 1968, the knowledge of multiple absorption redshifts in QSOs. It's been clear for some time that it's highly unlikely that the absorptions can arise in intervening matter (G. Burbidge discussed this, p. 93), and we have to produce a theory to account for them. The radiation-pressure-driven outflow hypothesis has its own problems, and you actually predict a non-negligible (though fairly small) component of gravitational redshift in the emission lines. We started looking again at the possibility of a gravitational redshift model for the absorption lines in regions of different gravitational potential, but no satisfactory model has emerged.

Regarding the absorption line in Wampler *et al.*'s object B in the double QSO, it will be very interesting when he resolves its doublet structure. It coincides with Mg II em in object A, but one is

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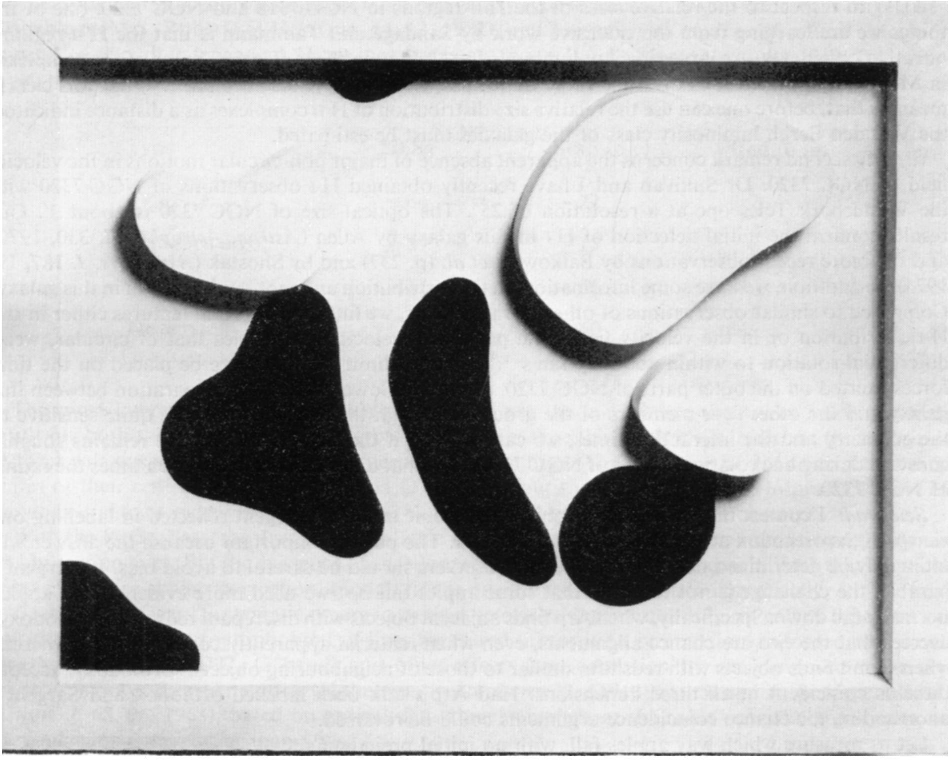

Fig. A. Jean Arp: Constellation according to the laws of chance. *Circa* 1930, The Tate Gallery, London. © *by ADAGP, Paris,* 1974.

constantly being surprised by QSOs and I wouldn't like to predict whether it should be C IV λ 1549 absorption or Mg II λ 2798!

(iii) Chip Arp mentioned Rubin and Ford's discovery of a velocity anisotropy in the Sc I redshifts over the sky. I'd like to ask Wal Sargent whether Sandage has considered this effect in the new calibration of the Hubble plot and what does it do?

Sargent: Sandage's view is that the observation by Rubin and Ford results from a very large scale inhomogeneity in the distribution of Sc I galaxies. Since only a 1 magnitude interval was involved in their work, it does not alter the recent determination of the Hubble constant based on Sc I galaxies.

Arp: A difficulty with this interpretation of the Rubin and Ford results is the sharpness of the velocity peaks.

Abell: One observational datum of possible significance that you discussed is the comparison of the frequency distributions of angular sizes of H II regions in NGC 7318 and NGC 7320. Both seemed similar on the slide you showed, and were peaked around one or two arc sec with tails extending to about 4 or 5″. Now for $H = 50$ km s^{-1} Mpc, at the implied cosmological distances of both galaxies, H II regions of diameter 100 pc would subtend angles of only 1″ or less. Seeing at Palomar is seldom that good, and with photographic effects combined with seeing, it seems to me one could expect to find measured diameters of up to several arc sec. In other words, can the frequency distributions you showed actually be describing the frequency distribution of seeing at Palomar?

Arp: I can answer that question quite definitely. I find H II regions in both the high and low redshift systems ranging from apparent diameters of 1″ (the seeing limit) to 5″, the diameter of the largest observed H II regions. Some of the large, high redshift H II regions are of low surface brightness and the observed apparent diameters are clearly the real apparent diameters.

Allen: Two comments:

(i) With respect to the relative sizes of the H II regions in NGC 7318 and NGC 7320, one of the things we are learning from the extensive work by Sandage and Tammann is that the H II regions, or rather complexes, are larger in giant luminous spirals than in other galaxies. Some of the complexes in M101 attain dimensions of order 1 kpc quite easily, on the new distance scale. What this clearly means is that, before one can use the relative size distribution of H II complexes as a distance indicator, the Van den Bergh luminosity class of the galaxies must be estimated.

(ii) My second remark concerns the apparent absence of major non-circular motions in the velocity field of NGC 7320. Dr Sullivan and I have recently obtained H I observations of NGC 7320 with the Westerbork Telescope at a resolution of 25″. The optical size of NGC 7320 is about 2′. Our results confirm the initial detection of H I in this galaxy by Allen (*Astron. Astrophys.* **7**, 330, 1970) and the more recent observations by Balkowski *et al.* (p. 237) and by Shostak (*Astrophys. J.* **187**, 19, 1974). In addition, we have some information on the distribution and motions of the H I in this galaxy. Compared to similar observations of other spiral galaxies, we find no abnormal features either in the H I distribution or in the velocity field. The pattern of velocities resembles that of circular, weak differential rotation to within about 20 km s^{-1}. An upper limit can therefore be placed on the tidal forces exerted on the outer parts of NGC 7320, and thus a lower limit to the separation between this galaxy and the other four members of the group. Although these calculations are quite sensitive to the geometry and the interaction times, we can say that if the separation distance remains roughly constant during one rotation period of NGC 7320, then that distance must exceed ten times the radius of NGC 7320.

Seielstad: I contest the initial philosophical viewpoint taken by Sargent reflected in labelling one viewpoint as orthodox and the other as unorthodox. The point is important because the answer will ultimately be determined observationally, and observers should be careful to avoid bias. In Sargent's parable, the challenge is not to prove that some apples fall up; we need more evidence that apples normally fall down. Specifically, when Arp finds adjacent objects with discrepant redshifts, 'orthodoxy' decrees that the two are chance alignments, even when material apparently connects them, whereas when Gunn finds objects with redshifts similar to those of neighbouring objects, 'orthodoxy' accepts these as coincident in all three dimensions. Had Arp's talk been labelled orthodox and Sargent's unorthodox, the chance coincidence arguments could be reversed.

Let us measure which way apples fall, with no initial prejudgment.

G. Burbidge: The situation is one that is summarized in England by calling it 'a lack of fair play'.

Sargent: Two comments: first on the size of H II regions. The orthodox view has to be that H II regions can be larger in interacting systems than in normal systems, and I think there is evidence for this from the Arp Atlas of Peculiar Galaxies where you often find resolved H II regions in galaxies with redshifts far too big for them to be resolved in normal galaxies if the upper limit to the size is 600 pc as Sandage believes. In the Hercules cluster, IC 4182 is an interacting system with H II regions 2 kpc across.

On the philosophical point, the redshift-distance law is not in dispute. What is in dispute is whether there are exceptions to it, and the exceptions have to be proved.

Seielstad: There seems to me to be a circular argument here, in that the redshift-distance law depends on the existence of 'standard candles', but if an object does not fit the law it is described as 'non-standard'.

G. de Vaucouleurs: We have re-analyzed the data regarding velocity residuals in the Virgo cluster (*Astron. Astrophys.* **28**, 109, 1973) and find that in the *true* Virgo I cluster, i.e. the 12° diameter classical cluster as defined by Hubble and Shapley, the mean velocity of the E, L-cloud is $+1000$ km s^{-1}, that of the S-cloud is $+1300$ to $+1400$ km s^{-1} (depending on whether spirals are subject to systematic corrections or not) and, that within each group, the mean velocity is independent of magnitude over a 4–5 mag interval, as it should be in a bona fide cluster. Objects outside the 12° cluster follow the usual *V-m* relation and should not be included since they are evidently not cluster members. Either the two clouds are at different distances and accidentally aligned or – if there is only one Virgo cluster – there are systematic non-cosmological velocity components.

Lewis: I can add a few comments to the anomalous redshift case, which are appropriate when evidence is to be adduced from small groups (cf. Bottinelli and Gouguenheim, *Astron. Astrophys.* **26**, 85, 1973) or from pairs and large clusters (Jaakkola, T., *Nature* **234**, 534, 1971). All optical velocities appear to be subject to substantial errors, which are demonstrable for all galaxy types and most velocity ranges (Lewis, *Observatory* **94**, 9, 1974). Perhaps the best independent estimate of errors is to compare the 21-cm velocities with the optical velocities, as the 21-cm line frequency is known and the measurement procedure is constant from one galaxy type to another. Using the sample of galaxies available to M.S. Roberts (*IAU Symp.* **44**, 12, 1972), and averaging *all* sources of optical velocities to get V_{opt} and all independent 21-cm measurements to get V_{21}, I obtain the results of the following table, in which all the units are km s^{-1}.

Type	S0/Sa	S(ab to c)	S(cd to m)	Im
$\langle V_{21} - V_{opt} \rangle$	−64	−22	+2	−33
Standard error	±29	±15	±8	±11
No. of objects	12	36	58	8
Dispersion	99	60	64	30

The most interesting features of this comparison are the large overestimates of velocity which result for both the Im and the S0/Sa types. For the Im type the result is a surprise as the velocities of these galaxies are observed from numerous emission lines. The deviation, if due to mistaken estimates of their centres, would be expected to scatter about the true value, while in practice most of the objects show a negative residual $V_{21} - V_{optical}$, for all of the independent observers.

With the S0/Sa class, the discrepancy is liable to be in part a reflection of an increasing dependence on absorption lines. But the existence of such large corrections for S0/Sa makes it likely that elliptical galaxies require similar correction, though this is much harder to estimate numerically.

G. de Vaucouleurs: Systematic errors in optical velocities depend not only on galaxy type, but on velocity, type of spectrograph, kind of lines measured (absorption or emission), adopted rest wavelengths of blends (λ3727, G band) and other effects (e.g. confusion by superimposed night sky spectrum). Several earlier studies (Holmberg, *Arkiv Astron.* **2**, 559, 1961; G. and A. de Vaucouleurs, *Astron. J.* **68**, 96, 1963), based on optical data alone, supplement the radio-optical comparisons, in particular for types earlier than S0/a.

B. Peterson: With regard to QSOs in the fields of clusters of galaxies, John Bolton and I have found two QSOs, out of about 100 identifications we have made, that are within ½′ of 15 mag galaxies in groups or small clusters. In the case of 2020-370, the $17^m.5$ QSO is 21″ from an S-type galaxy (Figure B). The QSO has a redshift of 1.05 while the galaxy has a redshift of 0.029. The projected distance of the QSO is 18 kpc from the nucleus of the galaxy. In the case of 1953–325, the QSO is 32″ from an E-type galaxy (Figure C). We do not have any redshifts for this system. The QSO appears to be double, or near a faint star, or to have a jet. The ultraviolet excess of this object is entirely due to the brighter component.

The probability of finding a 15^m (or brighter) galaxy within one square arc min of a given position is $\sim 10^{-4}$. In ~ 100 QSO fields we have found two cases when 10^{-2} would be expected. If the area is increased to 100 square arc min, the number of QSO fields containing galaxies $< 15^m$ increases from two to about six.

Ekers: I have used the Westerbork telescope to obtain an upper limit of 5×10^{-29} W m^{-2} Hz^{-1} on the 1415 MHz continuum radiation from any galaxy in the VV 172 chain. This observation was part of an unsuccessful search for other chains of the 3C31 (NGC 383) type.

Arp: It is interesting to note that the QSO 2020–320 shown by Peterson and Bolton lies in a chain of galaxies.

G. de Vaucouleurs: Would Arp care to comment on Holmberg's statistics of companion galaxies?

Arp: Holmberg concluded that the ejection from the nucleus is isotropic but that material in the plane prevents companions from escaping in this direction, hence causing the observed concentration of companions along the minor axis. If this is so, then one might expect to find objects in the plane which are trying to get out and I suggest that these are the companions one finds on the ends of spiral arms. It all fits together very well.

G. de Vaucouleurs: This could be checked by a spectroscopic survey to see if there are systematic differences in redshift between companions near the plane and companions near the poles.

Arp: Yes, I've been doing that every time I get an observing night – every once in a while – and am finding that I get much higher redshifts for the companions, for instance, the 6 companions of

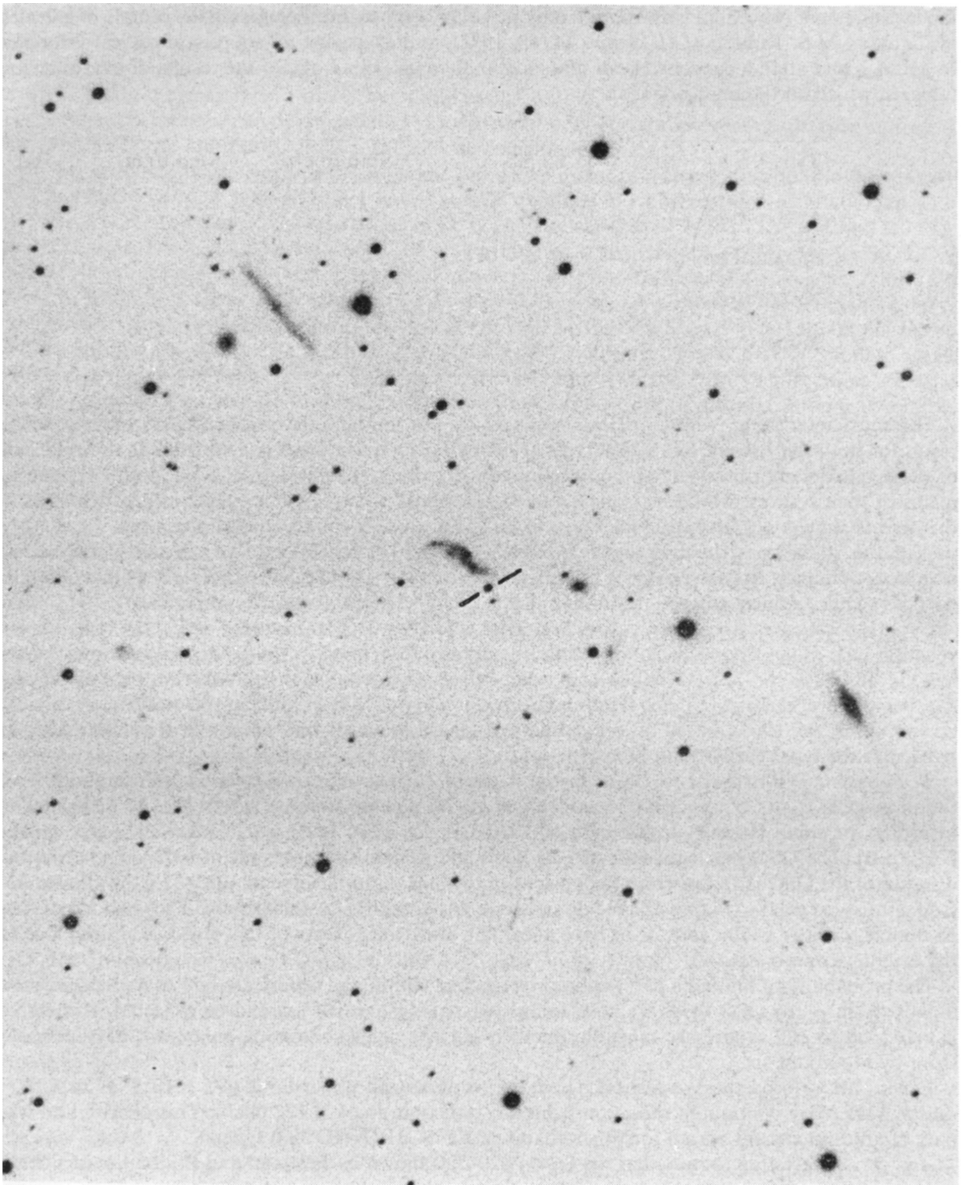

Fig. B.

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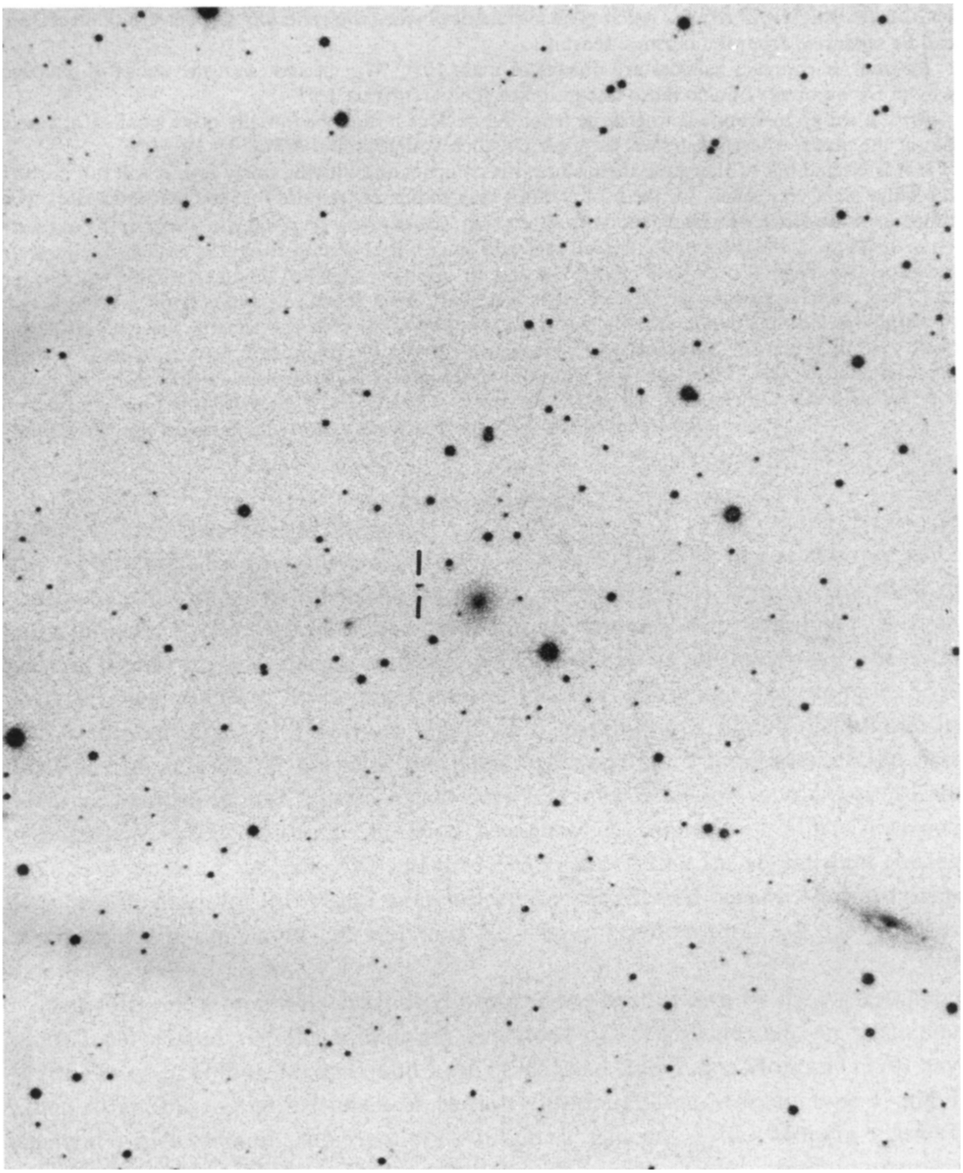

Fig. C.

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NGC 2403. But it will require much greater statistics before the generally smaller ejection redshifts can be separated from the intrinsic redshifts.

Rickard: If compact galaxies are objects of mass $10^{6-7}\ M_{\odot}$ ejected from the nuclei of galaxies, why don't we observe much more disruption of the parent galaxies?

Arp: If the ejected body is to emerge from the nucleus it must be initially quite small. If it comes out in the plane, where it burrows through gas, then you get spiral arms.

If it is ejected out of the plane then, since it is compact and moving fairly fast, it will not perturb the bulge stars very much. Or the observations may ultimately require that the mass increases with time, as in the Hoyle-Narlikar theory.