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Observational Paradoxes in Extragalactic Astronomy

For some extragalactic objects evidence contradicts the usual assumptions about red shifts, ages, and origins.

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According to the present astronomical picture of the universe, all the galaxies condensed out of a diffuse medium about 10^{10} years ago. This picture arises out of the general belief that we live in an expanding universe. Extrapolating backward in time, it is inferred that the galaxies were all compressed at a beginning epoch into some sort of hot, gaseous medium.

The belief in an expanding universe in turn dates from about 1922, when it was found that there was instability in Einstein's (*1*) general relativistic description of the universe and that the universe would naturally either expand or contract. Astronomers at that time were discovering that the fainter the galaxy they measured spectroscopically, the greater, in general, were the shifts of its spectral lines toward the red end of the spectrum. This observed relation between the red shift and the apparent magnitude of the galaxy was interpreted to mean that there was a velocity-distance relation in which the most distant galaxies were expanding away from each other with the greatest velocities.

As larger telescopes yielded data on the red shifts and magnitudes of fainter galaxies, it became possible to compute more accurately the time at which the galaxies had been compressed back at their singular origin. This so-called expansion age of the universe has been most recently estimated to lie in a range from about 7×10^9 to 11×10^9 years ago (*2*). Another age which can be measured is the age of our galaxy. As inferred from the age of the oldest stars, it is 11×10^9 to 13×10^9 years old (*3*). The uranium-lead content of material in the planetary system yields an age of 7×10^9 to 12×10^9 years (*4*). There are important uncertainties associated with the geometric model of the universe, the chemical composition of the oldest stars, and the exact process of the original heavy-element production. But the present order-of-magnitude agreement of these independent methods of measuring ages is impressive and lends support to the idea that the universe has been expanding from a singular stage for the order of 10^{10} years.

If this "big bang" picture of the universe is adopted, it means, of course, that galaxies that are appreciably distant from each other will be receding from each other with velocities proportional to their separation. An approximate upper limit to the random velocities of galaxies is about 1000 kilometers per second. Therefore, red shifts, if they are interpreted as velocities, should be meaningful measures of the distance from our galaxy when the red shifts are greater than a few thousand kilometers per second.

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Quasi-Stellar Radio Sources

When starlike sources of radio noise were discovered, the feature that made these "quasars" so remarkable was their very high red shifts. Estimating their distances from the relation between red shift and distance for normal galaxies yielded luminosities that were of the order of hundreds to thousands of times brighter than those of normal galaxies. The brightest quasar in apparent magnitude, 3C 273, for example, was calculated on this basis to be radiating about 10^{47} ergs per second, an amount that would be generated by converting completely into energy 1 solar mass per year. At their red-shift distances some quasars would be even more luminous. Known energy-generation mechanisms, of course, are much less efficient than any hypothetical total conversion of mass to energy.

An additional difficulty is that some quasars are observed to vary in optical and radio brightness. This observation means that the amount of energy that undergoes a time fluctuation must be enclosed within a region that has a maximum diameter of, in some cases, no more than a few light-days. This limitation leads to exceedingly high energy densities and difficulties in getting the photons of light out of the object without excessive numbers of collisions with electrons.

It is just possible to construct models of synchrotron energy generation that work under such restrictions, but these models require very special assumptions. Most recently (*5*), very-long-base-line radio observations of the quasar 3C 279 have indicated two equal sources of radio emission which appear to be separating at the rate of about ten times the velocity of light if the red-shift distance to the quasar is assumed to be valid. Here again, very special models are required to explain such results without calling into question the values for certain accepted physical constants, such as the velocity of light.

Astronomers were aware, almost from the outset, that these energy requirements could be lessened and the special requirements eased if the quasars were closer than the distances indicated by their red shifts. However, models in which known physical principles were used to give intrinsic red shifts, for example gravitational red shifts, worked even less satisfactorily. As a result, most astronomers have preferred to retain the initial assumption that the quasar red shifts indicate great distances.

There is one way, however, in which it is possible to demonstrate the actual distances of quasars. That way would be to find quasars associated with objects at known distances. For quasars with red shifts less than $(\Delta\lambda/\lambda) = 0.2$, any associated normal galaxies of the same red shift should be readily visible. On the other hand, if quasars are generally closer than their red-shift distances would indicate, it should be possible to demonstrate observationally their association with galaxies of lower red shift.

Clusters of Galaxies

Normal galaxies are strongly associated in groups and clusters. In a census of the 60 nearest galaxies, de Vaucouleurs (*6*) finds only eight galaxies that are not probable group members. Some of the remaining are possible group members. On the whole, probably well over 50 percent of all galaxies belong to clusters and, in fact, the Lick survey of nebulae (*7*) is compatible with a model in which all galaxies belong to clusters. Many astronomers believe that clusters of galaxies are the fundamental condensations of matter in the universe. One well-known catalog of clusters of galaxies was compiled by Abell (*8*), who listed the 2712 richest clusters of galaxies in the sky. These clusters include on the order of several hundred thousand galaxies to as faint an apparent magnitude as those that would normally have a red shift of $(\Delta\lambda/\lambda) = 0.2$.

Burbidge and Burbidge (*9*) listed 11 quasi-stellar objects with red shifts of $(\Delta\lambda/\lambda) = 0.2$ or less. At least two of those objects do not have the unresolved stellar appearance that is necessary to fit the quasar definition (*10*). Others on the list do fit the definitions of quasars very well, and some, in addition, are radio sources (making them quasi-stellar radio sources). Of the nine remaining, presumably bona fide quasars on that list with $(\Delta\lambda/\lambda) \leq 0.2$, none falls in Abell's clusters of galaxies. In fact, even after the cluster diameters listed by Abell are doubled, "no quasi-stellar objects with redshifts less than 0.2 are found to lie in the direction of rich clusters of galaxies" (*11*). Other selected quasars with low red shifts have been investigated to distances as deep as the largest telescopes will photograph, and no conspicuous clusters of associated galaxies have shown up. Gunn (*12*) showed that one of several objects around a quasar with a red shift of 0.3 had essentially the red shift of the quasar. But, even if these objects were galaxies and the whole group had this same red shift, they are by no means numerous enough to be designated as a cluster. This is a very controversial subject, but I think it can be fairly said that, of all the quasars now known, not one has been proved to be associated with a faint, rich cluster of galaxies.

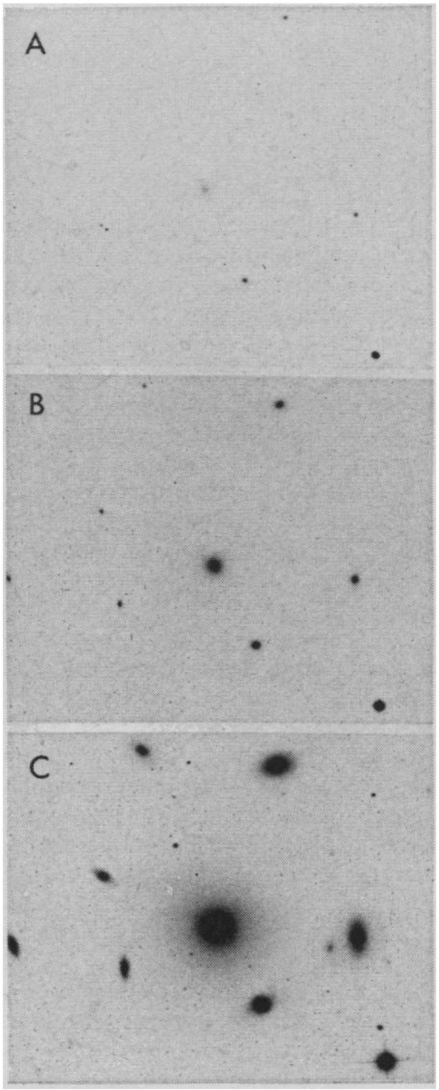


Fig. 1. A short (A), medium (B), and long (C) exposure of the Coma Cluster of galaxies by Zwicky (*13*). The series illustrates how the compact galaxies (those with high surface brightness) are generally the faintest. [Courtesy of *Science Journal*, London]

The paradox then is: If the quasars are at their red-shift distances, why do they not fall in the major concentrations of mass in the universe? Why do they seem to "avoid" clusters of galaxies at the same red-shift distance?

I shall show in the following sections that there is some evidence that the quasar distribution on the sky is not homogeneous and isotropic, as one would expect of objects near the edge of the observable universe, but instead shows clumpings on a scale and in directions coincident with nearby clusters of bright galaxies. But first I would like to make one point about the kinds of galaxies that make up a cluster.

Kinds of Galaxies in Clusters

Figure 1 shows a series of photographs of the Coma Cluster, one of the best-known rich clusters of galaxies. Most rich clusters are dominated by one or two giants, so-called cD galaxies, which have large tenuous extensions that make the galaxy appear very large in long-exposure photographs. Figure 1 shows, however, that, as shorter exposures are taken, these outer regions with low surface brightness are no longer recorded and the largest galaxies shrink in apparent size. The smaller, fainter galaxies in the cluster, however, are generally more compact (higher surface brightness), and their loss of apparent dimension is less. Zwicky (*13*) first used this technique to demonstrate the correlation between intrinsic luminosity and average surface brightness in a typical cluster of lenticular or elliptical galaxies.

This observation affects my discussion in the following way: There is a class of galaxies variously called compact galaxies, radio compact galaxies, or N galaxies (disks with bright sharp nuclei) which generally have active nuclei showing emission lines of excited elemental gases, sometimes nonthermal emission, and sometimes variable light and radio emission. Most astronomers agree that physical continuity is present between the normal galaxies, which are quite extended objects with fairly low surface brightness, through the compact, N, and similar kinds of galaxies, and the very compact (optically unresolved) and predominantly nonthermal quasars. The question is: How does intrinsic luminosity progress along this sequence? Does the intrinsic luminosity decrease from the giant galaxies through the compact galaxies, as observed in the clusters, a result which implies a low intrinsic luminosity for the quasars? Or does there discontinuously appear a class of objects, the quasars, which are enormously compact but which are greatly more luminous than the giant cD galaxies? The latter is the paradoxical conclusion to which the assumption of cosmological distance for the quasars leads.

Distribution of Quasars on the Sky

Figure 2A shows the distribution of all faint ($m_v \geq 17.0$ magnitude) quasars above the plane of the Milky Way in the north galactic hemisphere (*14*). These quasars are not distributed homogeneously over the unobscured fields of high galactic latitude, as we would expect of a very distant population of galaxies. Instead they are almost completely absent in the regions where right ascensions = 15^h to 17^h and are most heavily concentrated in the region where right acsension = 12^h to 13^h. Even more startling, however, this particular distribution of faint quasars closely resembles the distribution of brightest galaxies in the sky. Figure 2B shows how the bright galaxies, $9.0 \leq m_{pg} \leq 11.0$ magnitude, are distributed in generally the same peculiar way, perhaps only slightly more confined, like a core of the quasar distribution. Those bright galaxies, of course, are, for the most part, at distances of 10 to 100 megaparsecs (the order of a few hundred million light-years) and form a cluster of clusters or what de Vaucouleurs has called the "local supercluster" (*15*).

We may quantitatively test the significance of this distribution by measuring the distance from each galaxy in Fig. 2B to the nearest quasar. The average distance is less than 6° of arc. We can use the computer to distribute the same number of quasars randomly throughout the area and find that the average distance to the nearest randomly placed quasar would be about 11° of arc. The chance of finding a distribution like the real one by accident is less than 2 percent. The same association between the galaxies and quasars can be demonstrated in the south galactic hemisphere, except that there the brightest galaxies are fainter and the faint quasars are also, on the average, fainter.

An important further demonstration of this association is the tendency for quasars, such as those analyzed above, to align themselves on either side of the bright galaxies. This same pairing across the central galaxy is characteristic of the so-called "blank-field" radio sources paired across normal radio galaxies. In the case of these normal radio galaxies it is generally supposed that the radio sources are radio-emitting plasmoids and generally accepted that they are ejected in opposite directions from the central galaxy.

What of the quasars of brightest apparent magnitude ($m_v \lesssim 16.2$ magni-

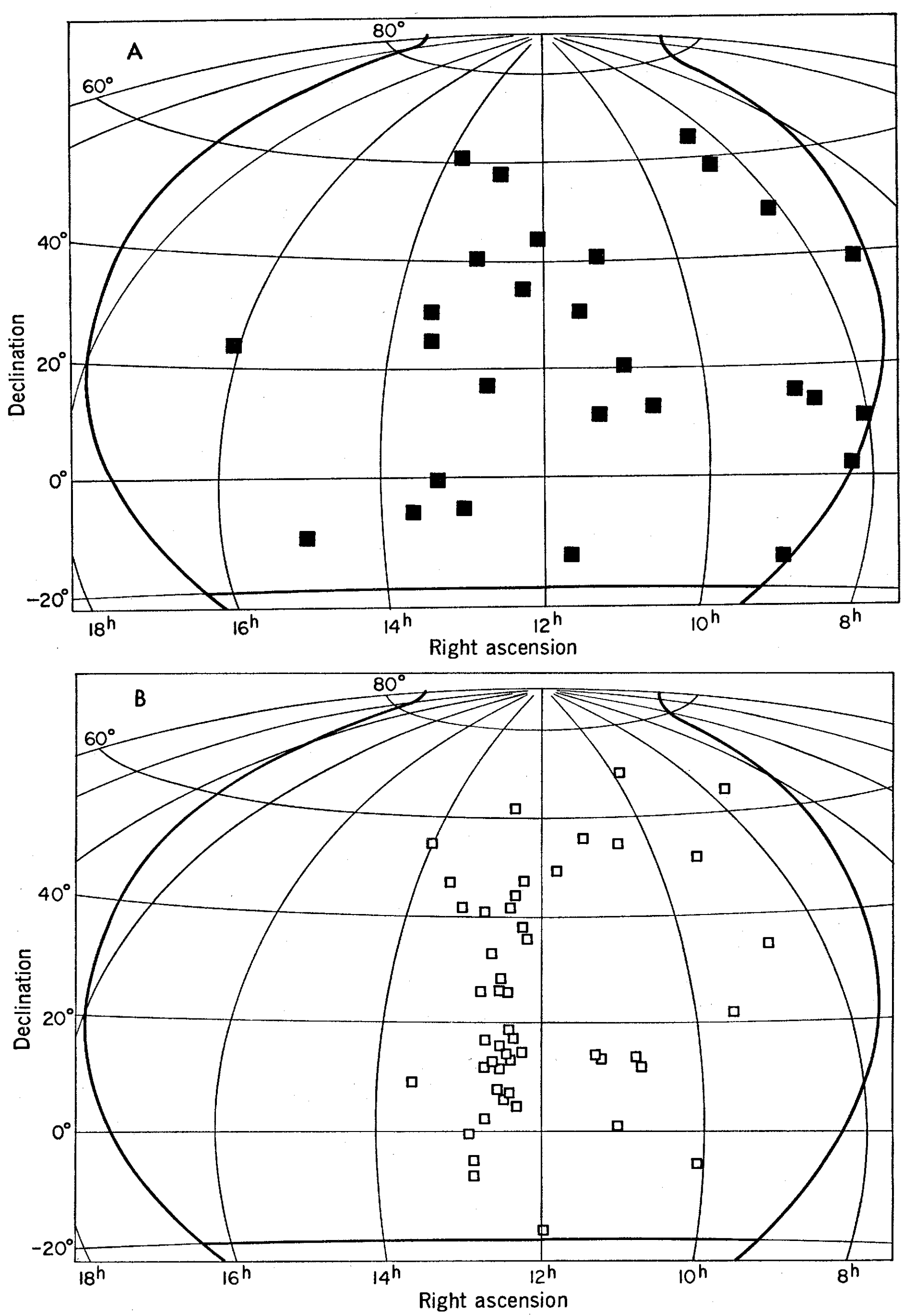


Fig. 2. That portion of the sky which lies in the direction of the north galactic pole and which is essentially unobscured by the plane of our own galaxy. In (A) the solid squares show the distribution of all faint quasars in this region; in (B) the open squares show the distribution of bright galaxies in the same region.

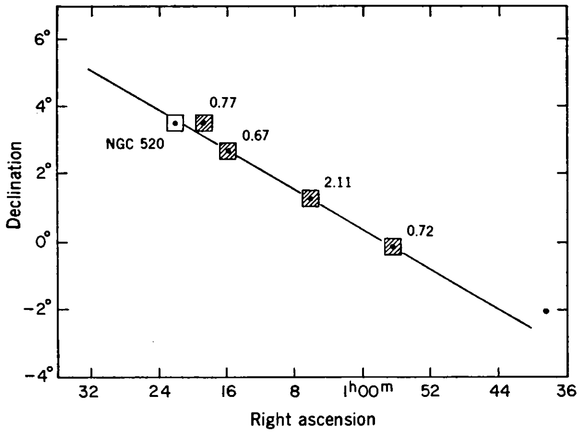


Fig. 3. Quasars on a straight line from an exploding galaxy. All faint quasars are plotted in this section of sky as shaded squares. Red shifts are labeled to the upper right of each shaded square. Galaxy NGC 520 is a violently disrupted galaxy, number 157 in the *Atlas of Peculiar Galaxies* (*20*) and has a red shift of 0.007.

tude)? It happens that a majority of these fall in that half of the sky nearest M31, the dominant galaxy in our local group of galaxies. They tend to pair in properties and position across M31 and fall at projected distances of from 40° to 80° away, as if they had been ejected from 0.5 to 2 megaparsecs from that galaxy. Finally, there are two quasars that fall about 150° opposite each other as we see them on the sky. They are among the apparently brightest quasars and have almost identical red shifts. They represent the most likely candidates to have been ejected in roughly opposite directions from our own galaxy. Recent measures by G. K. Miley (*16*) show that these two quasars have the largest angular radio structures among quasars, both about 140 arc seconds.

This completes my brief review of the distribution of quasars on the sky from available data. (The quasar data used here are taken only from identifications confirmed by red-shift measures in radio catalogs complete to a given flux limit.) Analysis of these data shows that quasars are not associated with distant clusters of galaxies, nor are they distributed as distant galaxies are. Instead the evidence shows that the distribution on the sky of quasars of the brightest apparent magnitude is associated with the local group of galaxies, and also that the distribution of fainter quasars is associated with more distant but still relatively nearby galaxies in the local supercluster.

Distribution of Quasars in Red Shift

Inhomogeneities and anisotropies of the quasar distribution have been noted elsewhere. In 1966 Strittmatter *et al.* (*17*) pointed out that the concentration of quasars with the highest red shift is located in the galactic polar regions. It seems from the considerations presented here that this concentration is most likely associated with the concentration of the nearby galaxies in the general regions of the galactic poles. Miley has recently pointed out an excess number of quasars with large angular radio structures in the north galactic hemisphere (*16*). As I indicated in the preceding section, there is a larger number of relatively nearby galaxies in the north galactic hemisphere than there is in what we can observe of the south galactic hemisphere.

Schmidt and others (*7*) have calculated that, if the quasar red shifts are assumed to be a measure of the distance of the quasars, the spatial densities of quasars increase steeply out to red-shift distances of about $(\Delta\lambda/\lambda) = 2$ and then diminish abruptly. This sudden drop in density, implied to be a function of the time since the creation of the quasars, does not seem to me a very plausible model for large regions of the universe. If, however, as the results presented in the next section indicate, the intrinsic luminosity of quasars drops rapidly for red shifts greater than 2, then we see smaller volumes of space and the cutoff in the number of quasars on the sky at this red shift is a natural expectation.

Burbidge (*18*) has pointed out that excess numbers of quasars occur at certain values of red shift, for example, around 1.95 and 0.6, as well as at other values. It has been debated whether the favored values of red shift form a numerical sequence (*19*). Regardless of the sequence, however, the very existence of favored discrete values of red shift would be important. It would seem that, if the quasar red shifts were a measure of the distance of the quasars, there would be no reason for them to group at discrete values. If quasars were associated with the local supercluster, on the other hand, it might be natural to expect associated groups of intrinsic red shifts which reflected the nearby hierarchical structure.

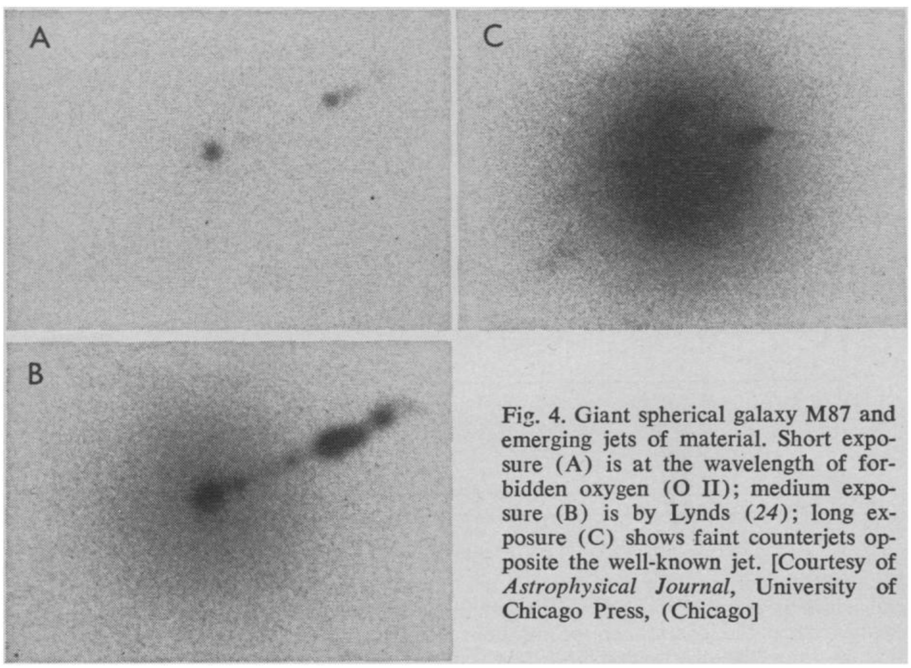


Fig. 4. Giant spherical galaxy M87 and emerging jets of material. Short exposure (A) is at the wavelength of forbidden oxygen (O II); medium exposure (B) is by Lynds (*24*); long exposure (C) shows faint counterjets opposite the well-known jet. [Courtesy of *Astrophysical Journal*, University of Chicago Press, (Chicago]

A Line of Quasars from an Exploding Galaxy

If we examine the distribution of faint quasars in the sky, it is apparent that the most conspicuous single grouping occurs in a small region of the south galactic hemisphere. It turns out, as shown in Fig. 3, that the four quasars in this region fall very accurately on a straight line. The terminus of this straight line falls on the second brightest and the most violently disrupted galaxy that is known, NGC 520 (the brightest exploding galaxy is M82). Galaxy NGC 520 is number 157 in the *Atlas of Peculiar Galaxies* (*20*) and is known from earlier work to have lines of radio sources emerging from it (*14, 21*). It happens that many of these radio sources are quasars. The four quasars in this region, of course, have high red shifts: $(\Delta\lambda/\lambda) = 0.67, 0.72, 0.77$, and 2.11. Galaxy NGC 520, on the other hand, has a red shift of only $(\Delta\lambda/\lambda) = 0.007$.

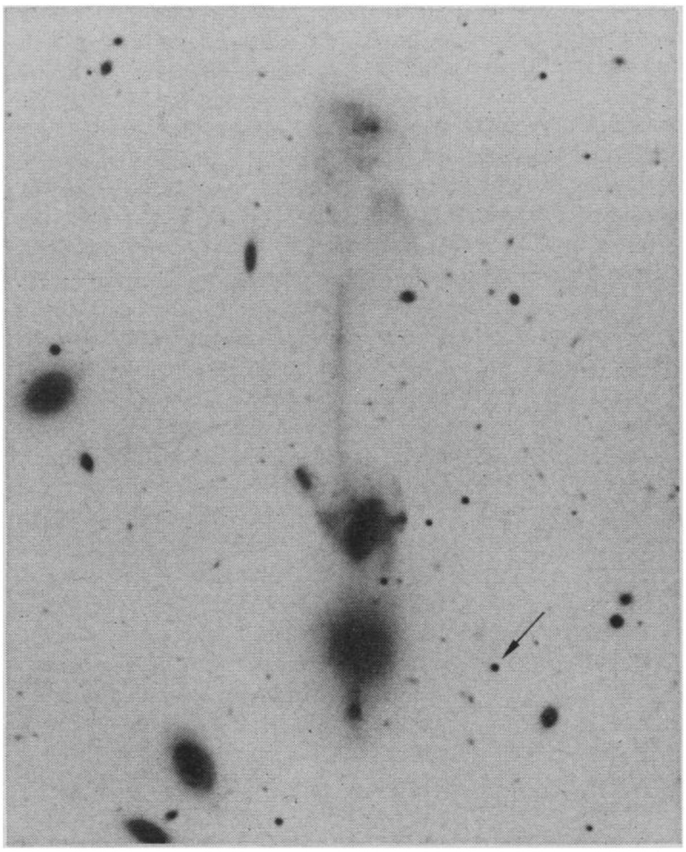
The quasar in the straight line with the highest red shift has the faintest apparent magnitude and illustrates the drop in intrinsic luminosity with red shifts greater than 2 that I discussed earlier. But for the three remaining quasars, the close similarity in the values of their red shifts would be very difficult to achieve by random selection among the red shifts of the quasars in the south galactic hemisphere. The progression of radio characteristics along the line, that is, the diminishing flux strength and the flattening radio spectral index as we go away from NGC 520, had been previously established as a property of radio sources associated with galaxies (*22*).

If we compound the improbabilities of finding four quasars so close together and in such a straight line, and also of finding that this line originates in a galaxy as peculiar as NGC 520, that the red shifts of the quasars resemble each other this closely, and that their radio properties progress away from the ejecting galaxy in the previously established way, we arrive at a truly astronomical improbability—of the order of much less than one chance in 10^6—that the configuration could be accidental. This association would seem to be an *experimentum crucis* on whether quasars are at their red-shift distances. There are only two possibilities: either the configuration is an accidental arrangement of foreground and background objects, or it is not. All the independent tests we can apply, however, indicate that the quasars originating in NGC 520 are actually associated with that exploding galaxy with a relatively low red shift.

Ejection from Galaxies

Figure 4 shows the giant spherical galaxy in the Virgo Cluster, M87. Since 1918 it has been known that a luminous jet extends out from the nucleus of M87 (*23*). The jet is blue, has high surface brightness, and is composed of a string of compact condensations, possibly just resolved with the largest telescopes. These compact knots are polarized and show a featureless continuum, usually assumed to be synchrotron emission. (As with quasars, the model for energy generation is very complicated, and it is somewhat doubtful in the case of the knots in the jet whether synchrotron emission from a plasmoid is a satisfactory explanation.) Since the spectrum of the knots is featureless, we cannot measure any red shift, but, with this exception, the observed characteristics of these knots are very similar to those of quasars.

Astronomers generally believe that the jet in M87 represents the ejection of material (*24*), and it is impressive to see what a good physical analog this jet furnishes for the four or five quasars that lie on a line out of NGC 520. As



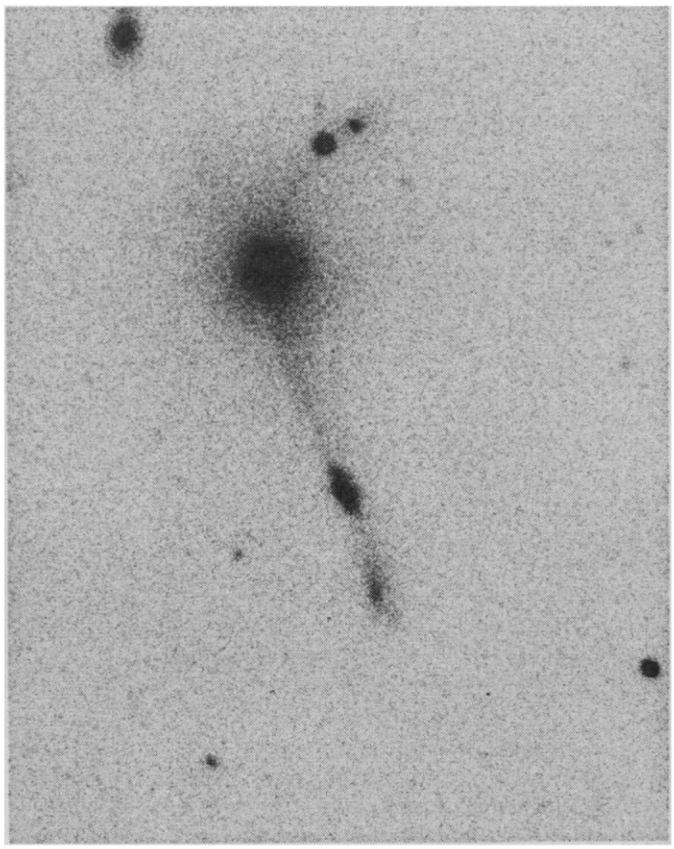


Fig. 5 (left). Ejection of luminous material from NGC 3561. Ambarzumian's knot is directly south (down) from the spherical galaxy. The quasar discovered by Stockton with a red shift of 2.19 is the nearest star to the west (right) from the spherical galaxy (see arrow). Fig. 6 (right). Line of compact galaxies and luminous material originating from the spherical galaxy I Zwicky 96.

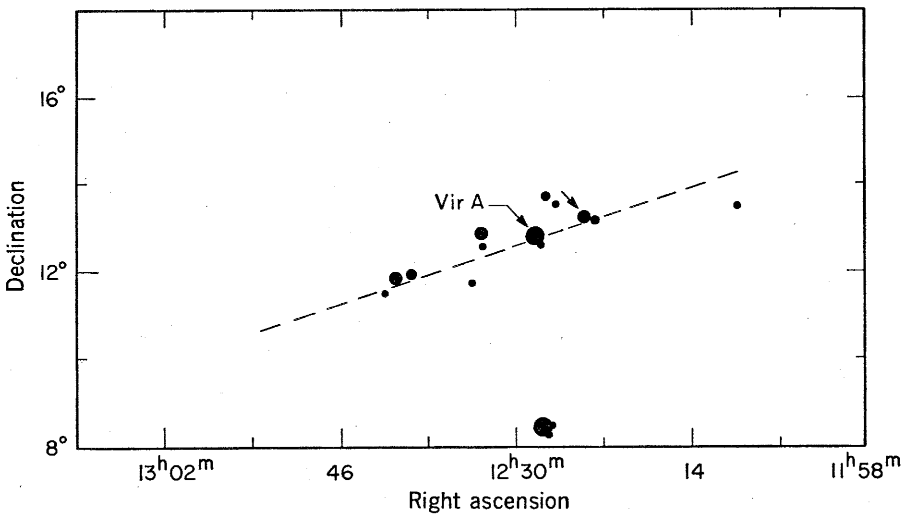


Fig. 7. Line of galaxies through the giant spherical galaxy M87 (called radio source Virgo A). Dashed line shows the direction of the jet and the counterjet. All galaxies classified as E galaxies by de Vaucouleurs (*40*) in this section of the Virgo Cluster are plotted. Strong radio sources are marked by arrows.

for the ejection of luminous material and luminous bodies from galaxies, the evidence has, in the last few years, become very strong.

In 1957 the Soviet astronomer Ambarzumian noted that luminous material appears to be ejected from galaxies (*25*). Figure 5 shows one of his earliest examples and is a good illustration of the various kinds of ejection. In this pair of galaxies, diffuse luminous matter is erupting upward from the disturbed spiral. A compact-appearing body, known as Ambarzumian's knot, is projecting downward, just on the other side of the E galaxy. On this especially deep plate taken with the 200-inch telescope, a small galaxy is connected on one side of the spiral and another compact object is connected on the other side. The nearest bright star in this magnitude range, a few minutes of arc to the southeast of the interacting pair, is not visibly connected by any luminous material to either galaxy but is nevertheless a quasar of red shift $(\Delta\lambda/\lambda) = 2.19$.

In Fig. 6 another peculiar object, first located by Zwicky on wide-field survey plates (*13*) and later observed spectroscopically by Sargent (*26*), is shown. The large-scale photograph shown here reveals a thin, luminous filament emerging from either side of the central E galaxy. Four condensations occur in this filament, two on each side of the central galaxy. One of these condensations is a galaxy with low surface brightness, one is a galaxy with high surface brightness, one is a compact galaxy, and one is a galaxy whose image is photographically indistinguishable from that of a fairly bright star. The spectra of this last object show that its red shift is large, only a few percent greater than that of the central galaxy, and it therefore clearly appears to be an object ejected along with the other material. The spectra of this last object exhibit absorption lines presumably due to stars that are closely packed together in this very compact galaxy.

The characteristics of this important example typify the four conclusions to which observations of ejection in galaxies have led me, namely:

1) Galaxies eject matter. (The matter can be in a variety of physical states—gaseous, radio-emitting, in the form of stellar masses, or possibly states

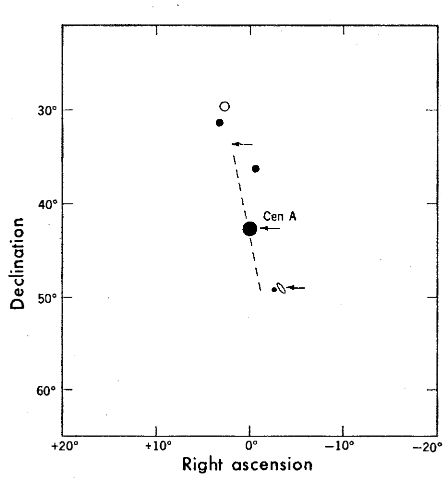


Fig. 8. Line of galaxies though the giant radio spherical galaxy NGC 5128 (Centaurus A). The dashed line is the direction of the inner ejected radio pair. Other strong radio sources in the vicinity are marked by arrows; solid circles, E galaxies; open circles, spirals.

with which we have thus far had no experience.)

2) The quantities of matter tend to be ejected in approximately opposite directions. (This observation is most clearly seen in the cases of radio sources paired across a central galaxy, but it also can be seen in the cases of the ejected luminous matter shown here.)

3) When the ejected matter is in the form of a smaller, companion galaxy, that companion tends to have a high surface brightness. (The corollary to this conclusion is that in associated groups of galaxies the more compact galaxies tend to be fainter.)

4) Compact companion galaxies generally have higher red shifts than the galaxies from which they were ejected.

In the next section I shall consider companion galaxies in the surroundings of active galaxies like M87 and consider whether there is further evidence for ejection having the properties just described in rules 1 through 4.

Lines of Galaxies

Quite surprisingly, it turns out that, when the larger area around M87 is studied, all the reasonably bright E galaxies fall on a line on either side of M87. This area of the sky is shown in Fig. 7. Also shown in Fig. 7 is the extraordinary coincidence of this line of galaxies with the line of the jet and the counterjet in M87. [The counterjet was discovered in 1967 (*27*) and consists of two faint emission filaments pointing away from the center in the opposite direction to the jet.] As I stated above, it is generally assumed that the jet represents the ejection of material. Therefore it is implied that the line of galaxies through M87 originated in some kind of ejection process.

In the case of the giant, peculiar radio E galaxy NGC 5128, a similar situation prevails. There are two strong radio sources about 3° apart which fall on either side of NGC 5128. This is the classical case of a pair of blank-field radio sources that are believed to have been ejected in opposite directions from the central galaxy. But, as Fig. 8 shows, almost all the bright galaxies in this general region of the sky are aligned out along this same axis of ejection. Along this NGC 5128 line there is a second strong pair of radio sources about 17° apart. One of them is identified with NGC 4945, for which I know no red shift. The other member of the radio pair is identified with IC 4296, itself a triple radio source. Galaxy IC 4296, however, has the relatively high red shift of $(c\Delta\lambda/\lambda) = +3700$ kilometers per second (where c is the speed of light) as compared to a red shift of $(c\Delta\lambda/\lambda) = +400$ kilometers per second for NGC 5128 and $(c\Delta\lambda/\lambda) = +1141$ kilometers per second for the member of the chain with the next largest red shift after IC 4296.

Essentially the same configurations have been encountered in the larger areas around both M87 and NGC 5128. It is striking that radio astronomers call M87 by the name Virgo A and NGC 5128 by the name Centaurus A, in virtue of their having been the first radio sources discovered in their respective constellations. In fact, because of their enormous strengths, they were among the first radio sources discovered anywhere in the sky. Acting on this clue, I studied all of the 13 E galaxies brighter than $m_{pg} = 15$ magnitude that were known to be strong radio sources. I found that all but two occurred in lines, the remainder in elongated clusters, and evidence in support of the idea that the radio components and galaxy components defined the same line was present in a number of cases (*28*).

Figure 9 shows a closely spaced chain of five galaxies first cataloged by Vorontsov-Velyaminov and later studied spectroscopically by Sargent (*29*). The red shifts of four of the members of the chain are all around $(c\Delta\lambda/\lambda) =$ 16,000 kilometers per second. One of the galaxies, however, has a red shift of $(c\Delta\lambda/\lambda) = 37{,}000$ kilometers per second. It is extremely unlikely that one of the links in this chain is missing and that its place just happens to be filled by a more distant background galaxy accidentally falling exactly in that position. Recent photographs (*30*) show that the galaxy with the high red shift is slightly peculiar and possibly bluer than the rest. Therefore, it is even more unlikely to be a field galaxy. Instead, it appears to be one of those peculiar galaxies of the sort that appear in other lines of galaxies and that have mysteriously discordant red shifts.

The physical difficulties of ejecting galaxies from other galaxies will be discussed in one of the final sections of this article. However, I would like to comment here on another paradox which the very existence of the chains of galaxies presents. The paradox is that if the dispersion in velocities of the members of this chain is greater than about 100 kilometers per second, then the chain will break up in less than 10^9 years. Yet the galaxies in the chain are all supposed to be of the order of 10^{10} years old! If the red-shift differences are interpreted wholly as velocity differences, they are of the order of thousands of kilometers per second, and therefore even shorter dissolution times for the chains, of the order of 10^8 years, are indicated. Even if there is a component of nonvelocity red shift, however, it is unlikely that the real dispersion in velocity in these lines of galaxies is much below 100 kilometers per second; therefore, regardless of red-shift anomalies, the ages of these companion galaxies are indicated to be less than the usually assumed 10^{10} years.

Companion Galaxies

So far we have discussed giant E galaxies and active disrupted galaxies that are at the centers of lines of objects. The lines appear to be associated with ejection processes and confirm the empirical rules of ejection given above. In all cases, however, the associated objects could be classified as companion galaxies, and I now ask the question of whether companion galaxies as a general class could originate from ejection processes.

A surprisingly definite answer to this question comes from a recent study by Holmberg (*31*). By comparing areas around nearby spiral galaxies with control fields many degrees away, he was able to show that there is a statistical excess of apparently small galaxies around these nearby galaxies. The unexpected result was that this excess occurred only in a wide cone along the projected minor axis of the large galaxy. Holmberg postulated that these companions were ejected isotropically from the central galaxy, but that the disk of the central galaxy prevented their emergence in directions along the projected major axis. This model seems to be the only possible explanation for the observations. In addition, it predicts a very specific kind of event that should be observed. In order to see what this is, we must ask the question: What happens to ejected companions that try to get out through the disk of the galaxy but are stopped? The answer is that we should see some young companion galaxies with disturbances leading from the nucleus of the main galaxy out through the disk to the companion. But this is, in fact, an excellent description of the whole

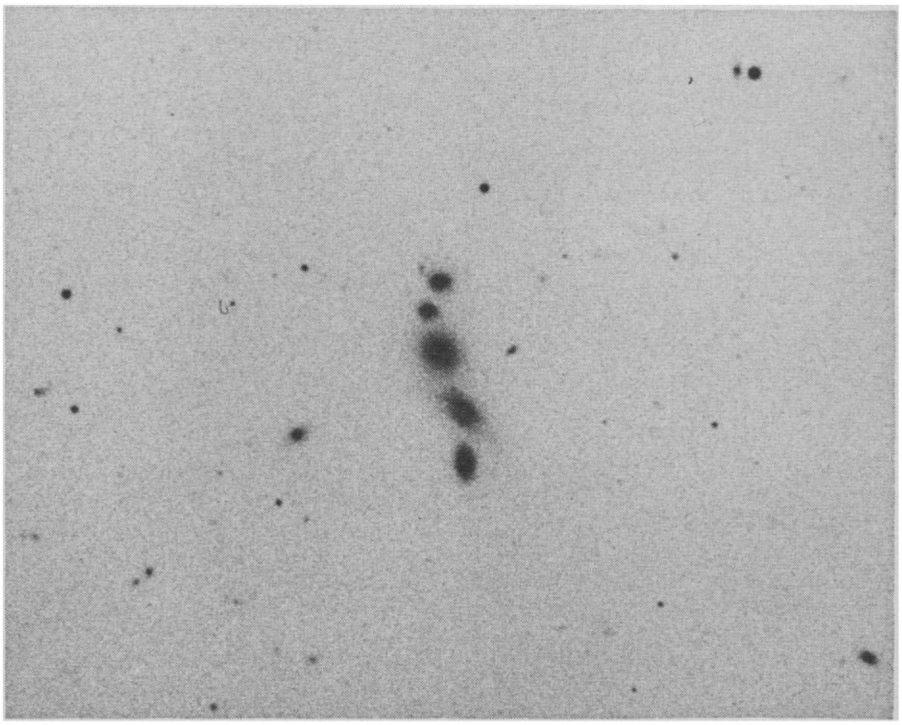


Fig. 9. Close chain of galaxies called Vorontsov-Velyaminov 172. The compact member of the chain, one down from the top, was discovered by Sargent (*29*) to have a much higher red shift than the remaining members. This photograph taken on red-sensitive plates with good seeing.

class of peculiar galaxies known as "spirals with companions on the ends of arms" (*20, 32*).

Can this hypothesis be supported by other characteristics of these systems? It should be noted first that the luminous matter ejected in the objects discussed earlier is predominantly in compact form. Aside from the fact that matter in diffuse form could hardly penetrate very far through the disk of a galaxy, it is also true that the small, active galactic nuclei would be very unlikely to eject objects bigger than themselves. Therefore, on the basis of both observation and logical reasoning, the matter should be compact as it is first ejected, and subsequently it should expand. In this respect it is not surprising that the luminous filament which leads to the companion is narrower than the companion. The picture would be that a compact object emerged from the nucleus, plowed through the disk of the galaxy, slowing down and then expanding. The companions, in fact, give evidence of being young and unstable, and, in the one case in which I could measure it, the companion was expanding on a time scale of 10^7 years.

The second point of interest is that the ejection of material tends to take place in opposite directions (the second rule of ejection). Since most spiral galaxies are symmetrical two-armed spirals, if we look opposite to the spiral arm with the companion on its end, we see another, similar spiral arm. Could this opposite spiral arm represent the ejection or track of the ejection in the opposite direction to the companion? Perhaps it could, if the opposite ejection had already expanded, had not yet expanded, or had not been stopped within the bounds of the disk.

The implication of this hypothesis would be that spiral arms were caused by ejection (in opposite directions) from galactic nuclei. Can this hypothesis be reconciled with the currently held view that spiral arms represent density waves (young star condensation) traveling through the disk of a galaxy? At first sight, these would seem antithetical mechanisms, but it should be stressed that the density-wave theory only deals with the problem of sustaining a spiral arm in the disk as opposed to its being wound up by differential rotation. The theory says nothing about the important question of how a two-armed density perturbation is caused in the first place. A spiral arm embedded in the disk of a differentially rotating galaxy would be wound up in the order of less than 10^9 years. The primary purpose of the density-wave theory is to sustain an open spiral structure for the order of 10^{10} years. Of course, the additional longevity for the spiral structure furnished by the density-wave theory would only be needed if some spirals are 10^{10} years old and have retained the same form for their entire lifetime. In any case, it is no contradiction, and possibly may be a complementary feature, to have the initial density perturbation established by ejection and then sustained by the density-wave mechanism if it is to be of significant physical effect.

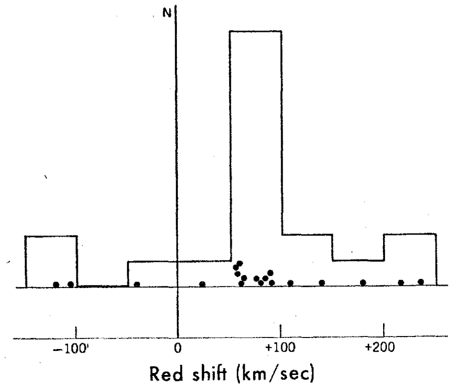


Fig. 10. Red shifts of 19 accepted companion galaxies (solid dots) with respect to the red shift of the central galaxy (heavy line).

So far the evidence of Holmberg and the evidence from companions on the ends of spiral arms point to an ejection origin for companion galaxies. If spiral arms are associated with ejection tracks, they fulfill the rule about ejection in generally opposite directions. Since the companions on the ends of spiral arms have strikingly higher surface brightnesses than the central galaxies, they fulfill well rule 3 for ejected material. This result leads us to test further rule 4, which predicts that the companions should have systematically higher red shifts than the central galaxies.

Table 1. Galaxies known to be companions of larger galaxies.

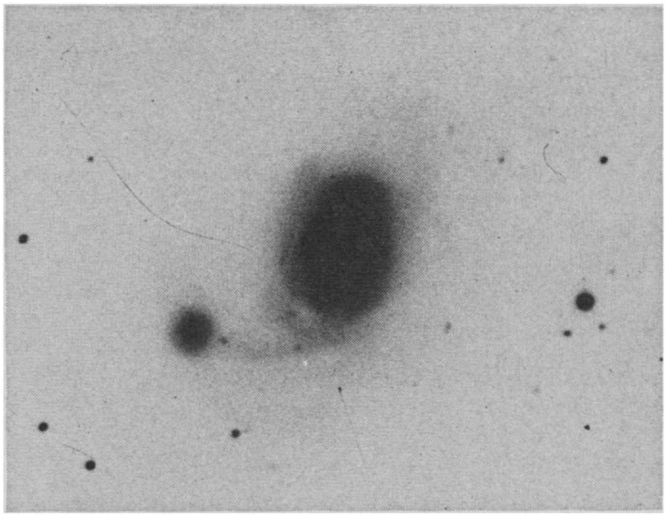
Dominant galaxy	Companion galaxy	Differential red shift (km/sec)
M31	M32	+85
	NGC 205	+62
	NGC 185	+58
	M33	+57
M81	M82	+234
	NGC 2976	+81
	NGC 3077	−104
	IC 2574	+91
	HO II	+215
NGC 5128	NGC 5102	+77
	NGC 5236	+64
	NGC 5253	−42
	NGC 5068	+139
M51	NGC 5195	+109
No. 48 (*20*)	Companion	−120
No. 58 (*20*)	Companion	+60
No. 82 (*20*)	Companion	+90
No. 86 (*20*)	Companion	+23
No. 87 (*20*)	Companion	+180

Red Shifts of Companion Galaxies

In order to investigate this matter it is necessary to start from very conventional knowledge about small companion galaxies which belong to M31 and other nearby, intrinsically large galaxies. Table 1 lists all the galaxies that have been, over the years, accepted by astronomers as companions of the dominant galaxy in the group. The last column indicates the measured red shift of the companion relative to that of the large galaxy. Eleven out of 13 of these companions have higher red shifts than that of their parent galaxy. We can add the results from a sample of companions on the ends of spiral arms because there the connection assures us that the smaller galaxy is at essentially the same distance as the larger galaxy. Altogether, then, in this complete sample of galaxies for which we have the greatest assurance that they are companions, a total of 16 out of 19 cases show red shifts of companions higher than those of their central galaxy. Figure 10 shows how the distribution of these red shifts is significantly greater than zero. Of those three companions that show negative relative red shifts: for one the red shift is probably not the red shift of the underlying compact body and the red shift for another is assignable to an ejection velocity toward the observer (*33, 34*).

The excess red shifts of these companions average only between +70 and +80 kilometers per second. But, because they are so nearby and so well studied, the red shifts are accurate and the excesses well established.

Of all the surprising observational results we have so far encountered, this result is the most startling. The reason is that, regardless of whether the companions are in orbit around the main galaxy or are still receding from it as a result of ejection, we should expect to see as many negative as positive velocities, on the average, with respect to the central galaxy. If, in fact, we are seeing a significant predominance



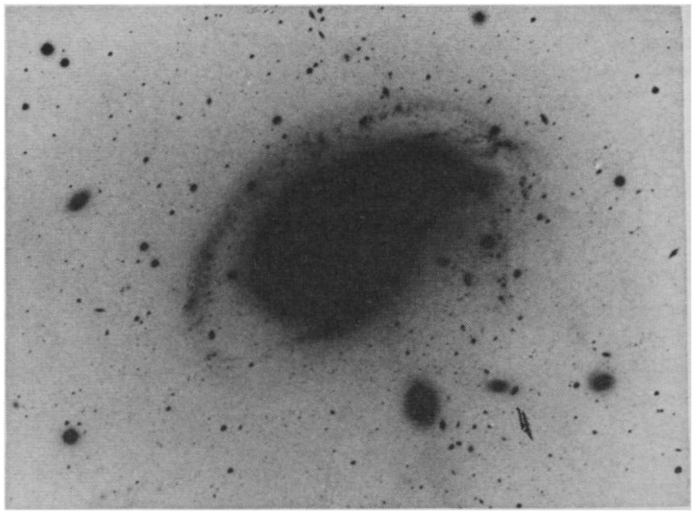


Fig. 11 (left). Companion galaxy connected to the disturbed spiral NGC 7603. The companion has a red shift 8000 kilometers per second higher than that of the spiral. Fig. 12 (right). Companion galaxies connected to the disturbed spiral NGC 772. The two smaller companions have red shifts 17,300 and 17,800 kilometers per second greater than that of the central disturbed galaxy.

of positive red shifts, then we must be seeing the effects of some nonvelocity red shift.

Although I predicted this result and was led to look for it because of the results obtained on other, more peculiar companion galaxies (*33*), it is still startling to find in view of the nature of the companions that I am discussing here. They are not excessively peculiar nor are they characterized by nonthermal emission. It is true that in my ejection picture the companions are second-generation objects from the nucleus of the parent and that there is an inferred physical continuity going back through the compact galaxies to the quasars. Nevertheless, the small excess red shift of the companions presumably arises from the integrated light of an aggregate of stars that we have no reason to believe are very different from the stars in the main galaxy.

I shall discuss these difficulties in greater detail at the end of this article, but at this point I would like to examine further the observational evidence and see if there is any way to confirm or deny the extremely difficult result that the companion galaxies show systematically higher red shifts.

Galaxies Connected to Companions of Much Larger Red Shift

The positive red-shift residuals discussed so far are primarily in the range from +50 to +300 kilometers per second. It is clear that any small galaxies in the area of larger galaxies that have red-shift residuals much in excess of this range would, under conventional assumptions, be automatically considered to be unrelated background galaxies. There are only two ways in which it could be demonstrated that companions of very much larger red shift are associated with central galaxies. One is a statistical method, essentially the clustering of fainter galaxies around larger galaxies, which will be discussed in the next section. The second way is to find galaxies of much different red shift either interacting or actually connected together by luminous filaments. Some examples of connected galaxies will be given in this section.

In 1956 an example of discordant red shifts was given by Zwicky, who pointed out a connected triplet of galaxies in the projected area of the Virgo Cluster (*7*). There one member of the triplet had a red shift about 7000 kilometers per second different from the other two. In Fig. 11 we see NGC 7603, a galaxy recently discovered to have a Seyfert-type nucleus in a disk which was connected to a peculiar companion (*35*). The companion has a core with a high surface brightness inside a halo with a low surface brightness. Only absorption lines are visible in the companion, and they give a red shift 8000 kilometers per second greater than that of the central galaxy. Figure 12 shows NGC 772, which has two faint companions attached to it by luminous filaments and protuberances. In this case the two connected companions have red shifts 17,300 and 17,800 kilometers per second greater than that of the central galaxy. Even by conventional interpretation such high differences in red shift could not be readily attributable to velocity differences because perturbing passages of companions at such high velocities would not have time to gravitationally perturb out the connecting filament observed. In any case, the discordances seem always to be in the positive direction, and either orbital interaction or ejection should give as many negative as positive differential velocities. Particularly for NGC 7603, which is a typical case of a peculiar companion on the end of a spiral arm, the only interpretation available is that the companion has been ejected. But the actual outward velocity of ejection is now probably only of the order of hundreds of kilometers per second, whereas the nonvelocity red-shift effect is at this time of the order of thousands of kilometers per second.

Small Galaxies Grouped around Large Galaxies

In the preceding sections I mentioned Holmberg's identification of a statistical excess of small galaxies around larger galaxies (*31*). I am now investigating these groups, and, since there are large numbers of these companions, it will take time to complete that observational project. But some preliminary results can be reported which seem to indicate that the excess red shift of the physical (real) companions will almost certainly be confirmed.

I have investigated the area around one nearby spiral, NGC 2403, out to a projected distance of 50 kiloparsecs.

Of the six small galaxies in this area, Holmberg's counts indicate that, statistically, five should be physical companions. Of the six small galaxies around NGC 2403 so far measured, however, all have a red shift of the order of 6000 kilometers per second greater than that of the central galaxy. Other cases that I have investigated so far are similar. In particular, the case of NGC 7331, the large, nearby Sb spiral, deserves mention.

Figure 13 shows a number of smaller galaxies grouped conspicuously along the eastern minor axis of NGC 7331. It can be seen from the visual appearance of the field that it would be a considerable coincidence if these companions were background galaxies accidentally projected around the Sb galaxy. Indeed, Holmberg's statistics show that more than four out of seven of the nearest companions should be physical members of the system. Recent red-shift measures by Lynds, however, show that all seven of these companions have red shifts from 6000 to 8000 kilometers per second greater than that of the large, nearby NGC 7331 (*36*).

Stephan's Quintet

Now, curiously enough, about three galaxy diameters to the southwest of NGC 7331 is located one of the most famous groups of interacting galaxies in astronomy. In 1877 Stephan pointed out this group (*7*), and it has been studied intensively since then. It was studied first for the extreme interaction of some of the galaxies in the group, and later because of the discordant red shifts of these galaxies. Four of the members have red shifts between 5700 to 6700 kilometers per second, and the fifth member has a red shift of about 800 kilometers per second.

But NGC 7331, just 0.5° to the northeast, itself has a red shift of 800 kilometers per second. The three brightest companions on the other side of NGC 7331 from Stephan's quintet, which were discussed in the preceding section, have red shifts of from 6300 to 6700 kilometers per second. Apart from arguments about whether all members of Stephan's quintet are actually interacting, the quantitative coincidence of the high and low red shifts in the NGC 7331 system and in Stephan's quintet would make it very improbable that they were chance coincidences of background and foreground galaxies.

Actually, the position of Stephan's quintet relative to NGC 7331 is just about that at which we would expect, on the basis of the results discussed above, to find ejected companion galaxies. Ordinarily we would not be able to check further the ejection hypothesis for Stephan's quintet. We are fortunate in this case, however, to be able to consult radio measures made in this region in 1966 by De Jong (*37*). The radio measures are shown in Fig. 14. Because the object being mapped was NGC 7331 and the presence of Stephan's quintet was not considered, the radio map cuts off at a declination about 10 arc minutes north of the quintet. But, from the radio measures that are available, it is clear that the radio emission extends northeast of NGC 7331, encompasses the three nearby companions with high red shift, and extends in a roughly opposite direction to a greater distance to the southwest. There the isophotes appear to be heading directly toward Stephan's quintet. [Very recent radio measures by Roberts (*38*) indicate that there is in fact additional radio emission south of the cutoff in Fig. 14 in the direction of Stephan's quintet.] This picture would seem to furnish evidence that there had been ejection from NGC 7331 and support for the idea that the companions of NGC 7331 with the higher red shifts (including Stephan's quintet) were in fact associated with that ejection and conform to the four rules of ejection established in preceding sections of this article.

Summarizing the Discordant Evidence

The first point that should be stressed is that, even though the observations contradict some of our basic assumptions about galaxies, the contradictions so far involve only special kinds of objects: quasars, compact galaxies, peculiar galaxies, and ejected material. There is no evidence to indicate that the brightest E galaxies in clusters or the largest Sb galaxies which dominate groups are not normal. There is no reason to believe that these two types of galaxies have not condensed at an early epoch and that they have red shifts which conform perfectly well to the relation between red shift and distance. If we come to understand the paradoxical observations about the younger, more compact classes of galaxies, this new understanding may modify to a great or small extent our estimates of the expansion rate of the universe. On the other hand, it is possible that a component of nonvelocity red shift might pertain to special objects without changing at all the presently accepted expansion rate.

With that introductory reservation I would summarize the discordant observational evidence on the objects I have discussed as follows:

1) Quasars with lower red shift are not found in any of a large sample of rich clusters of galaxies. Quasars are not distributed on the sky, or in red shift, in a way in which we would expect a very distant population of galaxies to be distributed.

2) Quasars and compact objects are associated with nearby galaxies and have moderately low luminosities.

3) A whole class of objects, including quasars, compact galaxies, blank-field radio sources, luminous material, lines of galaxies, and companion galaxies appear to be ejected in opposite directions from the nuclei of large active galaxies.

4) Lines of galaxies and compact galaxies give evidence of being stable only on time scales hundreds of times less than the normally accepted ages of galaxies and therefore are presumed to be quite young.

5) There appears to be a continuity of physical characteristics going from quasars through compact galaxies to companion galaxies. Quasars seem to have very large nonvelocity red shifts, but companion galaxies also have nonvelocity red shifts. The nonvelocity red shifts of the companion galaxies, although very small, are systematically positive and characteristic of a wide range of kinds of companion galaxies.

Fundamental Paradoxes

One paradox that these observations present is that of the ejection of galaxies from nuclei of other galaxies. Obviously a normal assemblage of stars cannot be hurled about like a snowball because the members of such an assemblage do not have the cohesion to stick together. Thus either the ejected galaxy must emerge as a compact coherent body from which stars later differentiate and separate, or some diffuse, gaseous material must emerge, at which point there must take place very rapid condensation of stars within the emerging gas. Both of these models would seem very strange in view of current assumptions about star formation in the present epoch by condensation in rather quiescent, outer regions of galaxies.

Another, perhaps more fundamental, paradox is: What is the cause of the nonvelocity red shift? It may be possible, by using known physical mechanisms, to explain this type of red shift. The models, however, would probably be very complicated. For example, Sisteró showed that collimated photons overtaking and scattering off relativistic electrons will give red shifts where $(\Delta\lambda/\lambda)$ is constant throughout the spectrum (*7*). Since relativistic electrons are very forward-scattering, this mechanism would also circumvent the usual second objection to variants of the "tired light" theory, namely, that the apparent angular diameter of the source is enlarged appreciably by numbers of scatterings. Some support for Compton scattering models might be forthcoming from the fact that, in order for photons to penetrate the densities of relativistic electrons that are derived on the assumption of cosmological distances, the electrons and photons would indeed have to be moving in closely similar directions. But a difficulty arises in that the nucleus or source of the spectrum must be shielded from direct view by the observer. This restriction suggests that the nucleus is shielded by nondiscrete blue scattering from electrons in other directions. Another possibility is that the nucleus is shielded by dust. This mechanism in turn introduces the possibility that a nucleus seen reflected from a dust cloud moving away from the observer would be shifted by the velocity of the moving reflector. Rees has mentioned the additional possible mechanism of red-shifting within an optically thick, expanding shell around a spectral source (*39*). He has also mentioned the possibility that we see objects ejected with high velocities but that, for some reason, possibly dust obscuration in front of the objects, we do not "see" the approaching velocity.

In fact, it seems that there are a number of possible explanations that can be derived from conventional physics. Although these explanations could give only very complex and intricate solutions, they cannot at the present time be ruled out as solutions. It would be of utmost importance to see if these models could all be demonstrated to be very unlikely explanations (as the gravitational red-shift models were shown to be). The importance of this step would lie in the existence of new physics which would then be implied. It is possible that in the year 1971 we do not know all the physics there is to know. Perhaps in the nucleus of a galaxy or in the process of ejection physical conditions are encountered that are so extreme that local geometry is affected or clocks run slow. If there were, in fact, new physics to be discovered, it would most naturally be in the realms where observations most fundamentally contradict the current theoretical expectations. But, of course, before we consider seriously new physics, we must first exhaust the more conventional alternatives.

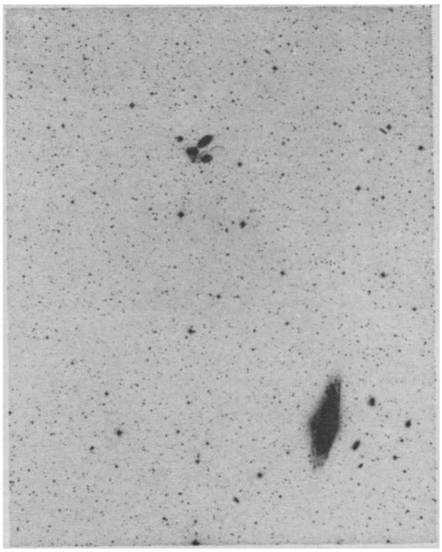


Fig. 13. Region aound the large Sb spiral galaxy NGC 7331. Stephan's quintet is shown about 30 arc minutes southwest.

Whose Move Now?

Most of the evidence that I have reviewed here is in the literature in various places. The reason for bringing it all together here and trying to evaluate it on more than a purely technical level is that there seems to have been some sort of impasse reached in astronomy with regard to this evidence, and it is of interest to examine why this is so and how the deadlock might be broken.

As I have stressed throughout this article, if the observations are correct, some of our fundamental assumptions are wrong. The only escape from this conclusion is to say that each association of discordant red shifts and observed ejection phenomena is accidental. For example, if the string of quasars coming out of the exploding galaxy is not accidental, then quasars are closer than cosmological distances and their red shifts are due to some other cause. I have tried to reduce these questions to crucial sets of associations—either "yes" or "no," with the decision hinging on the facts of the observation. Many astronomers either reject these cases as "selected" accidents or adopt a neutral attitude. But it seems to me that the accumulation of evidence is now very difficult to either reject or ignore.

It could be argued that each case is somewhat different—that sometimes quasars, sometimes compact radio galaxies, sometimes companion galaxies are involved in associations. The answer to this argument is that all these objects are varieties of galaxies and that there is a continuity of attributes involving all these various kinds of extragalactic objects. In these associations it is usually the most extreme and peculiar objects that have the most discordant red shifts. Actually this observation strengthens the conclusion that the associations are significant, because, if there were accidental associations, they should, for the most part, involve normal objects, which are the kinds of objects most frequently observed. Instead they tend to involve peculiar ob-

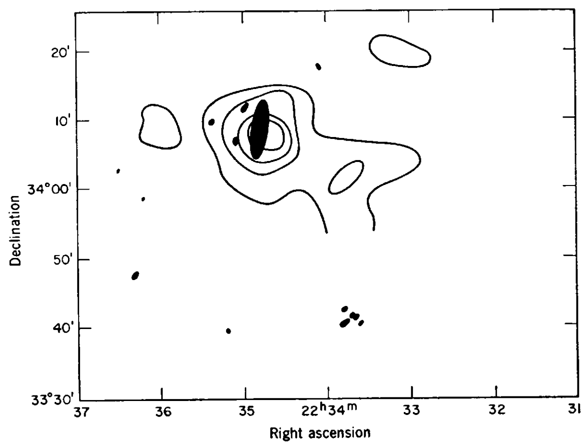


Fig. 14. Radio map of the region around NGC 7331 [adapted from De-Jong (*37*)]. The map stops just north of Stephan's quintet. [Courtesy of *Astrophysical Journal*, University of Chicago Press, Chicago]

jects—objects that are the least likely to be involved accidentally. But physically we know the least about these peculiar objects, and they are the ones for which there is the greatest a priori chance that new and unknown physical mechanisms are at work.

In the end, however, we must all agree that the ultimate criterion for science is experiment and observation. If the observational paradoxes discussed in this article can be demonstrated to be false or accidental, then we can say that the paradoxes are solved on the basis of our present knowledge. If the observations stand, then we must conclude that something new of vast importance is happening and we should get on with the exciting job of finding out more about it.

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Heterochromatin, Satellite DNA, and Cell Function

Structural DNA of eucaryotes may support and protect genes and aid in speciation.

Jorge J. Yunis and Walid G. Yasmineh

The term heterochromatin was first introduced by Heitz (*1, 2*) to denote chromosomes or chromosome regions that are condensed in interphase and prophase and do not unravel in telophase like the rest of the chromosomes. Although Heitz made his initial observation in primitive plants (liverworts and mosses), his definition of heterochromatin generally holds true for most organisms. In mammals two main types of heterochromatin are recognized: constitutive heterochromatin, or the heterochromatin that is present in homologous chromosomes, and facultative heterochromatin, or the heterochromatin that results from the inactivation of one of the two X chromosomes in females. This inactivation is an effective mechanism to reduce the number of functional X chromosomes to one in both sexes (*3*).

Recent reports indicate that the DNA of constitutive heterochromatin is composed to a large extent of short repeated polynucleotide sequences, termed satellite DNA. This discovery has necessitated a critical review of current ideas concerning the origin and function of this portion of the genome of higher organisms (*4–12*). A careful appraisal of the information that has accumulated about heterochromatin since the time of Heitz (*1, 2*) and on satellite DNA during the last decade suggests that these entities have vital structural functions: they maintain nuclear organization, protect vital regions of the genome, serve as an early pairing mechanism in meiosis, and aid in speciation.

Satellite DNA

Satellite DNA was first detected in the early 1960's by the technique of density gradient centrifugation. When DNA of the mouse, guinea pig, calf, and crab was centrifuged in neutral CsCl, a minor component or components differed in buoyant density from the bulk of the DNA (*13–15*), and the DNA of different density was termed satellite DNA. The observation a few years later that the complimentary strands of mouse satellite DNA reassociate rapidly after denaturation by heat (*16, 17*), strongly suggested that satellite DNA is composed of relatively short, repeated polynucleotide sequences.

The relation in many organisms between repetitiveness and rate of strand reassociation was investigated soon thereafter by Britten and Kohne (*17*). They introduced the variable *Cot* (where *Co* equals the initial concentration of DNA in moles of nucleotide per liter and *t* equals the reassociation time in seconds) to estimate

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