Reports

Peculiar Galaxies and Radio Sources

Abstract. *Pairs of radio sources which are separated by from 2° to 6° on the sky have been investigated. In a number of cases peculiar galaxies have been found approximately midway along a line joining the two radio sources. The central peculiar galaxies belong mainly to a certain class in the recently compiled* Atlas of Peculiar Galaxies. *Among the radio sources so far associated with the peculiar galaxies are at least five known quasars. These quasars are indicated to be not at cosmological distances (that is, red shifts not caused by expansion of the universe) because the central peculiar galaxies are only at distances of 10 to 100 megaparsecs. The absolute magnitudes of these quasars are indicated to be in the range of brightness of normal galaxies and downward. Some of the radio sources which have been found to be associated with peculiar galaxies are galaxies themselves. It is therefore implied that ejection of material took place within or near the parent peculiar galaxies with speeds between 10^2 and 10^4 kilometers per second. After traveling for times of the order of 10^7 to 10^9 years, the luminous matter (galaxies) and radio sources (plasma) have reached their observed separations from the central peculiar galaxy. The large red shifts measured for the quasars would seem to be either (i) gravitational, (ii) collapse velocities of clouds of material falling toward the center of these compact galaxies, or (iii) some as yet unknown cause.*

A 4-year study of peculiar galaxies has been recently completed (*1*). This *Atlas of Peculiar Galaxies* was compiled in order to systematically study physical processes in galaxies and relationships between different kinds of galaxies and to gain a more realistic picture of the contents of space. At the end of the project, positions of *Atlas* objects were compared to positions of radio sources. Aside from a few well-known identifications, there was no significant number of coincidences in position. Shortly after the *Atlas* had been submitted for publication in January 1966, however, a remark by J. L. Sérsic (*2*) caused me to reexamine the relation between radio sources and peculiar galaxies.

At first, only radio sources of greater than 9 flux units in the *3CR Catalogue* (*3*) were considered. The numbers of these radio sources are such that if they were distributed at random in the northern sky (excluding the area of the Milky Way) we would have to draw a circle of 4.°6 radius, on the average, in order to include one radio source within it. Peculiar galaxies from the *Atlas*, however, fell significantly closer than this to the radio sources on the average. It was also noticed that radio sources of similar flux densities tended to form pairs separated by from 2° to 6° on the sky. A certain class of peculiar galaxy, Nos. 100 through 150 in the *Atlas*, often fell approximately midway along a line joining these pairs. To date, out of 27 peculiar galaxies in the *Atlas* which have so far been assigned as probable or possible origins of radio sources, 23 are numbered between 100 and 200, and 18 of these are numbered between 100 and 150. Other kinds of galaxies of this brightness do not fall between pairs of radio sources. This can be demonstrated by referring to *Atlas* galaxies Nos. 1 through 50 and 200 through 338. Of these, only three fall between radio-source pairs or groups. Peculiar galaxies numbered 102 through 145 in the *Atlas* are characterized as elliptical galaxies with either disturbed spiral galaxies nearby or disturbed material which appears in many cases to be ejected from these ellipticals. The typical distance from one of these kinds of central peculiar galaxies to the nearest radio source is about 2°. The distance to the second radio source is 4° on the average. The direction from the peculiar galaxy to the second source agrees with the direction of the line joining the two sources to within ±5°. The probability that any single configuration like this could be accidental is less than about one part in 1500.

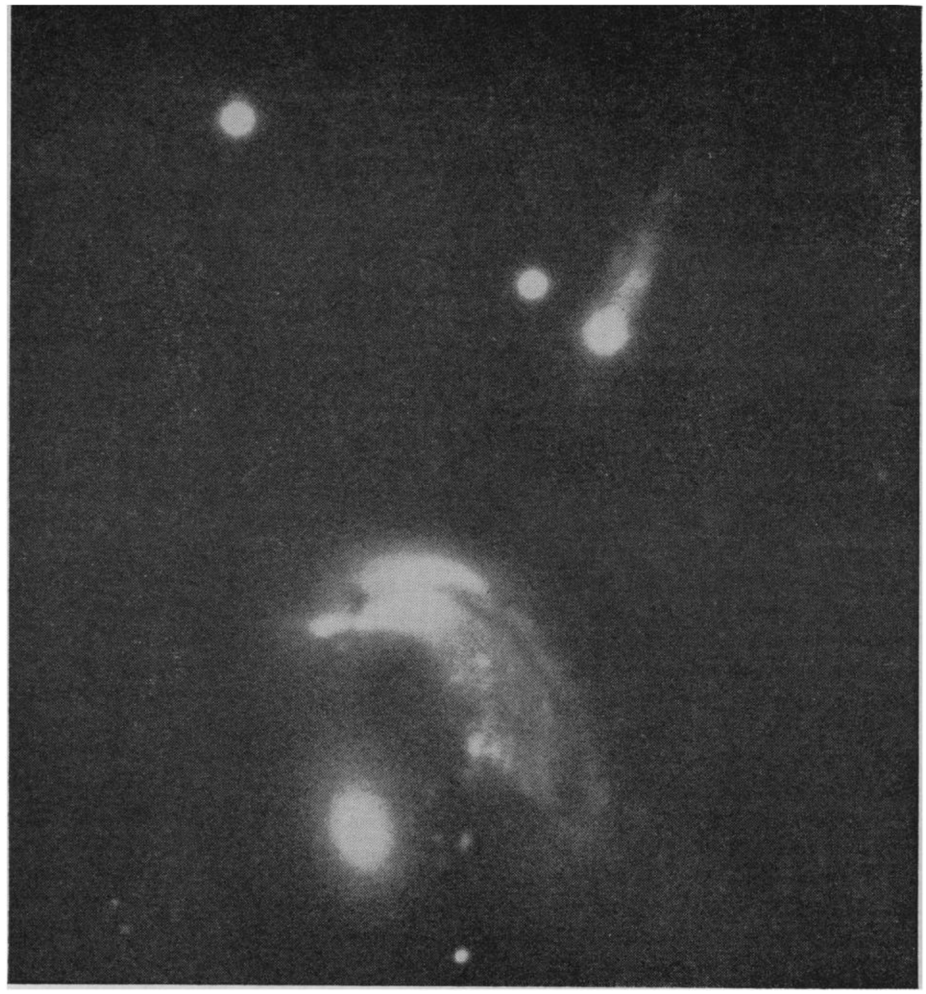
In the peculiar galaxies Nos. 145, 127, and 142 there are elongated shreds of material in the vicinity which point in the direction of the line joining the pair of radio sources. In Nos. 148, 125, 139, and 160 there is a third nearby radio source which is in an opposite direction to the material which appears to be being ejected from the central elliptical galaxy. In general, there is a tendency for filaments and axes within the peculiar galaxies to point toward the radio sources. Some peculiars have four neighboring radio sources tending to be paired oppositely, and No. 108 in the Southern Hemisphere is surrounded by five Mills, Slee, and Hill sources (*4*).

Systematic spectroscopic and photometric observations on the central peculiars remain to be made. Fragmentary data presently available, however, indicate that these galaxies have apparent magnitudes in range $m_{pg} = 13$ to 15. Five red shifts indicate recession velocities of the order of 2 to 10×10^3 km/sec. The velocity-distance relation would give distances from 10 to 100 megaparsecs and absolute magnitudes for the peculiar galaxies themselves of $M_{pg} = -18$ to -20. Such magnitudes would place these central peculiar galaxies among the brighter known galaxies.

As radio observations continue to improve their resolution and positioning accuracy, some radio sources will probably continue to remain optically unidentified, whereas other sources will become identified with optical galaxies of varying degrees of compactness. As far is known now, the list of radio sources associated here with peculiar galaxies (Table 1) contains at least five quasars in the probable category and three others in the possible category. Association of these quasars with the class of peculiar galaxies just discussed would indicate that the quasars are not at cosmological distances (that is, expansion of the universe only accounts for a small part of their observed red shifts). Since the apparent magnitudes of quasars is in the $m_{pg} =$ 15 to 19 range, their absolute magnitudes would appear to be in the range of that of normal galaxies and fainter. The quasar 3C273 is identified here as belonging to the bright Virgo-cluster elliptical NGC 4472. Using a distance modulus of $m - M = 30.3$ magnitudes gives $M_B = -17.4$ magnitude for 3C273 (average over light variations).

At the distances estimated for these peculiar galaxies, the radio sources spread out in space for a distance of

Fig. 1 (right). A giant elliptical galaxy, NGC 2937, and strongly disturbed matter around it. The galaxy is No. 142 in the *Atlas of Peculiar Galaxies* (*1*). This type of galaxy seems now to be preferentially located between pairs of radio sources widely spaced in the sky. Note the shred of luminous matter pointing up and to the right—within 8° of the direction to the radio source 3C222, which is 1°.7 away.



from 1 to 10 megaparsecs around them. The implication is that the radio sources were ejected from within or near the central galaxy at some time in the past. This has been the model for previous radio sources identified with galaxies (radio sources which show a strong tendency to pair across the center galaxy). Maltby, Matthews, and Moffat (*5*) have indicated that for radio sources heretofore identified with optical galaxies the sources probably originate near the nucleus with diameters of the order of 10^3 parsecs. As the two components of the source move away from the nucleus out to distances of the order of 200×10^3 parsecs, they reach diameters of the order of 100×10^3 persecs. The results here open up a whole new class of identifications, similar in the pattern of opposing pairs of radio sources but with separations ranging from 5 to 50 times larger. The diameters of the radio sources in the new, wider identifications, however, are smaller and sometimes associated with luminous matter of varying degrees of compactness, including quasars. The question is what velocities and what flight-travel times are involved for the much larger angular separations here identified. There are two ways I have estimated the time since the ejection event. One is that the central galaxies are not exactly at the point of inferred origin. They lie very roughly between 0.1 and 1 megaparsec from that origin. At 300 km/sec, a reasonable peculiar velocity for a galaxy to have, they would have to have been traveling for about 10^9 years. Another estimate comes from the rotation period of the galaxies, which is characteristically a few times 10^8 years. In order to have approximate, but still not exact, alignment of shreds and filaments and axes, and opposition of ejected material, then the time since the event must be over 10^8 years from this estimate also. In order to reach the observed distances, the ejected material would then have to be traveling around 3000 km/sec. These kinds of velocities of ejected material have been observed from exploding galaxies (*6*).

Among the radio sources listed in

Table 1. Probable associations of peculiar galaxies and radio sources.

Central galaxy (*Atlas* Nos., NGC Nos., and other designations and sources)	Radio sources (Cambridge Survey Nos. and Mills, Slee, and Hill Nos.)
......, NGC 62, ...	MSH 00–16, MSH 00–17
No. 127, NGC 191, ...	MSH 00–07(NGC 157), MSH 00–011
No. 140, NGC 274, 75, VV 81	MSH 00–013, MSH 00–010
No. 157, NGC 520, VV 231	3C39, 3C44, MSH 01+03, MSH 01+06 (last two may be redundant)
No. 166, NGC 750, 51, VV 189	3C46, 3C67
No. 145, ..., Minkowski, Gates, Reaves	3C65, 3C66 (galaxy) (3C73 ?)
No. 131, ..., VV 336	MSH 02–111, MSH 02–114, MSH 02–116 MSH 02–113 (perhaps more to south)
No. 141, ..., VV 123	3C173. 1, 3C184
No. 108, ..., VV 346	MSH 02–218, MSH 02–219, MSH 02–220 MSH 03–21, MSH 03–22
No. 143, NGC 2444, 45, VV 117	3C183, 3C186, (3C189), 3C194
No. 55, ..., VV 155	3C216 (QSS), 3C219 (two galaxies)
No. 142, NGC 2936, 37, VV 316	3C222, MSH 09+04, MSH 09–07, MSH 09+06
No. 148, ..., VV 32	3C247, 3C252, 3C254 (QSS)
No. 197, IC 701, VV3	(3C256 ?), 3C258, 3C263.1, 3C264 (galaxy)
No. 160, NGC 4194, ...	3C266, 3C277, 3C277. 1
No. 134, NGC 4472, ...	3C273 (QSS), 3C274 (M87)
Nos. 139, 196, ..., Herzog	3C277.3, 3C284, 3C287 (QSS)
No. 125, ..., A. Wilson	3C337, 3C338 (NGC 6166), 3C345 (QSS)
No. 102, ..., Zwicky, VV 10*	3C352, 3C356
No. 130, , VV 263	3C467, 3C1, 3C9 (QSS)
Nos. 35, 201, ..., ..., VV 257, VV 38	3C2 (QSS), 3C15, 3C17 (galaxy)
No. 282, NGC 169, A. Wilson	3C14, 3C19, 3C28 (galaxy)
Pec., ..., ...	3C16, 3C18
No. 121, ..., A. Wilson	Nearby MSH sources
......, NGC 5223, 28, 33, ...	3C286 (QSS), 3C288
No. 117, IC 982, 83, ...	3C293.1, 3C300
No. 111, NGC 5421, VV 120	3C293, 3C294
Pec., , ...	3C437, 3C437.1, 3C442
No. 110, ..., ...	Numerous MSH sources between declination −10° and −20° and right ascension 22^h20^m and 23^h24^m

* Below No. 102 the associations are classed as possible rather than probable.

Table 1 are nine previously identified with optical galaxies (5). Since they are at approximately the same distances from the parent peculiar galaxies as the radio sources in general, there is no reason to believe that the luminous material is traveling with any different velocity than the plasma which emits the radio signals. In particular, the quasars in Table 1 are essentially the same distance as the radio sources and luminous matter and, therefore, must be traveling with spatial velocities of the order of 10^3 km/sec.

Two very approximate direct checks are available. First, M87, the opposite particle to 3C273, is traveling away in our line of sight, relative to the central elliptical NGC 4472, with a velocity of 300 km/sec. Symmetry implies that 3C273 is approaching with this component of velocity in the line of sight. Its true space velocity must be somewhat higher, depending on the projection factor. The second piece of evidence comes from a triplet of peculiar galaxies studied by Zwicky (7). Two ellipticals traveling at +7000 km/sec are seen attached to a spiral traveling at +100 km/sec. It appears now that this spiral is being ejected with a velocity of about 7×10^3 km/sec. Order of magnitude limits to the ejection velocities of the radio sources then seem to lie between 10^2 and 10^4 km/sec.

The nature of the large red shifts observed in the quasars then remains unexplained. We have shown here that neither cosmological recessional velocities nor large Doppler velocities can be the answer (the latter is also doubtful because of the failure to observe blue shifts). As discussed by Greenstein and Schmidt (8), line shifts in the gravitational field of a very dense body should be the only remaining possibility. I would like to add one other possibility: that of high collapse velocity of material toward the center of these very compact objects. The region radiating the emission lines would have to be opaque to obscure the blue shifts from the back side. A hotter surface below should produce absorption lines on the red side of the emission lines (reverse P Cygni effect). That surface might, however, be red-shifted out of visibility—or possibly the emitting material might actually form a hollow shell collapsing from a larger spherical shell distribution. If only parts of that shell were luminous at a given time, fairly narrow emission lines could possibly result. Since there are objections to both the gravitational and collapse explanations of the large red shifts, however, the true explanation may lie in a direction so far not considered.

The results so far open up a number of possibilities. Among them are: (i) If it is possible to observe large spectral red shifts which are noncosmological, then the velocity-distance relationship for ostensibly normal galaxies should be regarded with slightly more caution. (ii) If material in galactic amounts can be ejected from other galaxies, the possibility is raised that certain kinds of galaxies, particularly spiral galaxies, can be much younger than other kinds of galaxies. (iii) If ejection from a center can take place more slowly, with differential rotation, then spiral galaxies themselves may be a manifestation of this phenomenon. (iv) Very small, compact dwarf galaxies with emission lines recently discovered (9) appear to be characteristically double. It may be possible to show that these also represent fairly recent ejections from nearby galaxies. (v) The cause and mechanism of the ejection of material from galaxies becomes an even deeper puzzle which may be connected with the formation of galaxies. (vi) The ejection of material into intergalactic space must affect the composition of that space. If the ejected plasma is ultimately controlled by the conditions it finds there, then we have experiments which connect the galaxies with the conditions in the space in which they are imbedded.

HALTON ARP

Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena

References

1. H. Arp, *Atlas of Peculiar Galaxies* (California Institute of Technology Bookstore, Pasadena, 1966); *Astrophys. J., Suppl.*, in press.
2. J. L. Sérsic, National University, Cordoba, Argentina, privately remarked that a peculiar galaxy he had been studying in the southern hemisphere had three radio sources within 1½° (NGC 6438).
3. "The revised 3C (3d Cambridge) catalogue of radio sources," A. S. Bennett, *Mem. Roy. Astron. Soc.*, vol. 58, p. 163 (1962).
4. B. Y. Mills, O. B. Slee, E. R. Hill, *Australian J. Phys.* **11**, 360 (1958); *ibid.* **13**, 676 (1960); E. R. Hill and B. Y. Mills, *ibid.* **15**, 437 (1962).
5. P. Maltby, T. A. Matthews, A. T. Moffett, *Observations of the California Institute of Technology Radio Observatory* **4**, IV. "A discussion of 24 identified sources" (1962).
6. C. R. Lynds and A. Sandage, *Astrophys. J.* **137**, 1005 (1963); E. M. Burbidge, G. R. Burbidge, V. C. Rubin, *ibid.* **140**, 942 (1964); E. M. Burbidge and G. R. Burbidge, *ibid.* **142**, 1351 (1965).
7. F. Zwicky, *Ergeb. Exakt. Naturw.* **29**, 344 (1956).
8. J. L. Greenstein and M. Schmidt, *Astrophys. J.* **140**, 9 (1964).
9. H. Arp, *ibid.* **142**, 402 (1965); F. Zwicky, *ibid.* **143**, 197 (1966).

25 February 1966

Mars: Upper Atmosphere

Abstract. *The thermal structure of the upper atmosphere of Mars has been theoretically investigated. The exospheric temperature, for a pure CO_2 model atmosphere, lies between 400° and 700°K. The origin of the Martian atmosphere is discussed in the light of these results.*

Recent spectroscopic measurements (1) and results of the Mariner IV occultation experiment (2) indicate that the atmosphere of Mars may be mainly composed of CO_2 with a total atmospheric pressure at the surface of 5 to 10 mb. Using this model we have calculated the thermal structure of the upper atmosphere. The results indicate that the exospheric temperature of Mars may be 550° ± 150°K (Fig. 1). The temperature profile is consistent with the temperatures deduced from the Mariner IV occultation experiment.

The method of computation and the basic assumptions made for these calculations are as follows: It is assumed that the average surface temperature is 200°K, and that the lower atmosphere, up to 80 km, is in radiative equilibrium; the temperature profile for this region has been calculated from the method described by Prabhakara and Hogan (3). At this level the dissociation of CO_2 by solar ultraviolet radiation becomes effective; we assume that, above 80 km, the dissociation products of CO_2, CO and O, are in diffusive equilibrium.

The temperature structure in the thermosphere and exosphere is calculated by the method described in detail by Chamberlain (4), McElroy, L'Ecuyer, and Chamberlain (5), and Rasool, Gross, and McGovern (6). The input of energy in this region is mainly in the far ultraviolet, through the ionization of atomic oxygen, while the emission is by CO_2 and CO. The presence of CO in the upper atmosphere is extremely effective in reducing the exospheric temperature, mainly because the emission is proportional to the square of the temperature T (5). For this reason the exospheric temperature (T_{ex}) on Mars is as low as about 550°K, whereas T_{ex} for Earth is approximately 1500°K. The large uncertainty of ±150°K in the value of T_{ex} for Mars (Fig. 1) results from the uncertainties in the value of the solar flux in the extreme ultraviolet, the exact fraction of solar energy that goes into heating, and also the altitude at