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Companion Galaxies on the Ends of Spiral Arms

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Photographic and spectroscopic observations are presented which show that companion galaxies on the ends of spiral arms of normal galaxies tend to have (1) high-surface brightness, (2) emission lines characteristic of excited gaseous material, and (3) early-type stellar absorption lines in their nuclei. One companion is shown to be expanding. Another is shown to be probably receding from the center of the larger galaxy.

The hypothesis advanced is that these companions have been recently ejected (10^7—10^8 years ago) from the parent galaxy. It is concluded that they are short-lived, and that many are now in the process of expanding and ejecting secondary material. Holmberg previously concluded that small companions were found only along the minor axis of spiral galaxies because their disks stopped ejection in the plane. The companions on the ends of spiral arms in the present paper are considered to be examples of this stopping mechanism. It is further suggested that ejection of material through the disks of rotating galaxies is generally important in the formation of spiral arms.

Key words: galaxies — spectra of galaxies — companion galaxies — peculiar galaxies — ejection

1. Introduction

In all the visual observations made by the Herschels, no galaxy was ever seen to be of spiral form. It was not until the large reflector built by Lord Rosse that the spiral structure was first perceived in M 51, the so-called whirlpool nebula in Canes Venatici (sketches by Lord Rosse in 1845). This prototype spiral galaxy, however, was known from the outset to have a large, irregular galaxy apparently attached to one arm. The problem posed by actual physical attachment is twofold: (1) how could two galaxies either be formed with a connection between them or later establish such a connection? (2) even given such a connection, it is well established now that spiral galaxies are in differential rotation. In a few rotations – of the order of 10^8 to 10^9 years – such a connection would be wound up. But galaxies in general are supposed to be older than 10^{10} years! These difficulties were undoubtedly responsible for Walter Baade's opinion that the companion was not physically attached to the end of the arm, but that it only appeared to be projected there from somewhere above or below the plane of M 51.

Since then, however, a long-exposure photograph in a wavelength interval slightly to the blue of Hα (Arp, 1966) showed luminous streamers extending from the companion to the side away from M 51. Recently a photograph by van den Bergh (1969) shows these streamers reaching out to an even greater distance away from M 51. Although the nature of these features is not known, they do establish that the companion is actually interacting with the main galaxy and that its apparent closeness is not merely an accident of projection.

In considering the question of whether the material in the arm of M 51 is actually mingled with the material in the companion, the answer at first sight may appear negative. There is no large deformation apparent in that part of the arm which terminates at the companion. It might be argued that one would expect appreciable gravitational perturbation if the arm and the companion were close together in space. On the other hand, looking carefully at Figs. 1 a and b we see that the whole M 51 outer arm which leads into the companion is longer and less curved, particularly at the end, than the opposite arm. The noncompanion arm is also pulled out somewhat and is heavy in emission at a point which is near its closest approach to the companion and the arm as it enters the companion. In the Hα line photograph of Fig. 1 a there also seems to be some diffuse emission at the end of the arm which tends to envelop the companion. Finally, the continuum photograph in

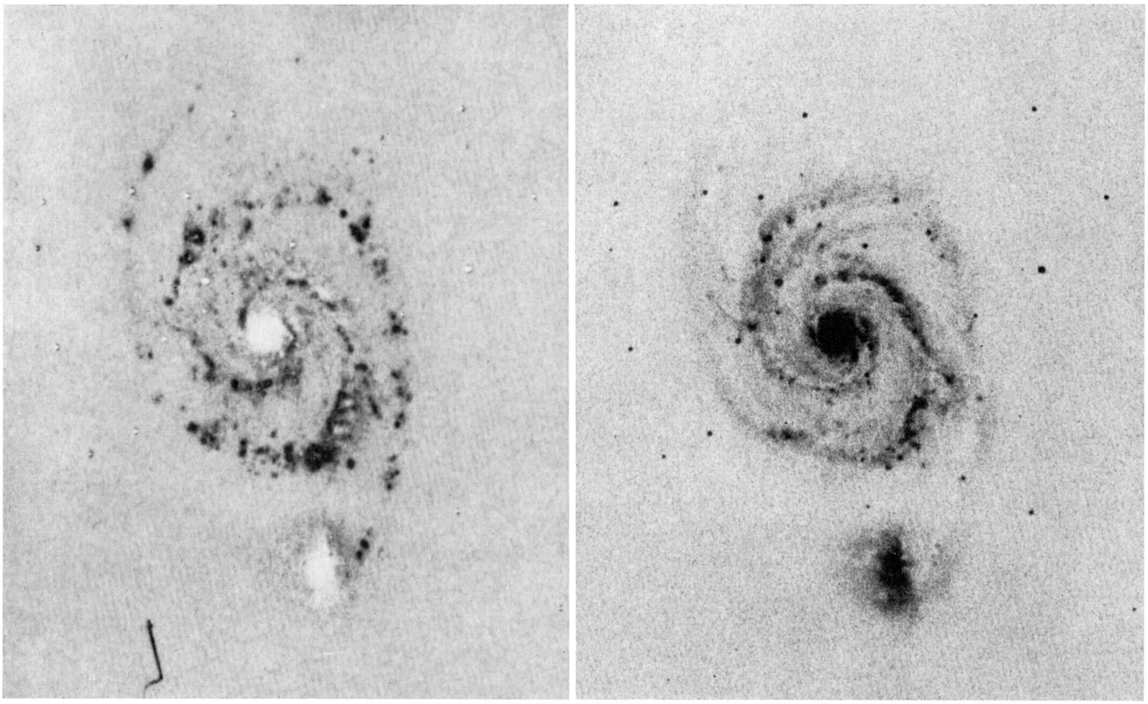

Fig. 1 a and b. Photographs of NGC 5194 and 5195 with the 48-inch Schmidt telescope on Palomar. On left, Fig. 1 a shows a long exposure through a 100 Å band pass filter centered on Hα. A similar photograph taken in the continuum just to the blue of Hα has been photographically subtracted leaving a picture in the pure hydrogen line. (The high surface brightness areas in the nucleus are saturated and subtract to white). Fig. 1 b on the right is a normal photograph in blue wavelengths for comparison. Note doubling of arm as it enters the companion as in *Atlas* 86 (Fig. 11)

Fig. 1 b shows that the arm, as it enters the companion, is broad and somewhat double in appearance. In this respect it closely resembles *Atlas* 86 which is discussed in the body of the present paper.

Red shift measures indicate the companion to have a velocity near +100 km/s and the arm on that side of the galaxy to have about −100 km/s. Carranza, Crillon and Monnet (1969) comment that this either suggests a lifetime of the companion less than 2×10^8 years or a model in which the companion has an orbit inclined 45° to the plane of M 51. Warren and Roberts (in press) suggest either a relative inclination of 90° or a velocity of separation of the companion out along the arm of something greater than 200 km/s. The latter model is of interest for the hypotheses of the following paper.

M 51 has been discussed in this introduction because it is the best known and therefore the prototype for galaxies with companions on the ends of arms. Because no spatial and kinematic model can be settled on at the moment however, it is of interest to see whether other systems like NGC 5194−5195, in fact, exist. Direct evidence on this problem became available with the publication of *Atlas of Peculiar and Interacting Galaxies* (Voronstov-Velyaminov, 1959) and the *Atlas of Peculiar Galaxies* (Arp, 1966). While statistical analysis of the frequency of such systems would be difficult, the high-resolution photographs in the latter reference (*Atlas* No. s 37−101) show that in most of these cases the arm leading to the companion is disturbed in such a way as to leave no doubt that the companion galaxy is, in fact, physically connected to the spiral arm. Not only does this situation now furnish precedent for the connection of NGC 5194 and 5195, but, over and beyond that one case, it now makes it necessary to face the difficult problem, in the entire class of galaxies, of why differential rotation does not wind up the connecting arm in a time short compared to the presumed age of the galaxies.

In order to gather as much data as possible on a representative sample of such objects, six of the most favorable cases were selected from the *Atlas of Peculiar Galaxies* for study here. In order to understand the relationship between knots in spiral arms and full-fledged companions, the *Atlas* has been ordered in a more or less continuous sequence between these two extremes. Therefore, in the present paper the first two cases, *Atlas* 49 and 58, involve companions that, relative to the main galaxy, are only slightly more conspicuous than large H II regions or knots in spiral arms. *Atlas* 82 and 86 have intermediate-size companions, and in *Atlas* 84 and 87 the size and brightness of the companion begin to approach that of the parent. Spectroscopic and some new photographic data are reported in the present paper in the following major categories: (1) the optical form and surface brightness of the companion and the nature of the connecting spiral arm; (2) the redshifts of identified spectrum lines in the companion and central galaxy; and (3) the kind of lines identified in the spectra and the physical state of the galaxies which these lines imply.

How the new data presented in this paper relate to the problem of the origin and stability of such configurations will be discussed at the end of the paper. In that conclusion a picture will be outlined in which these companions are ejected from their central galaxies and then undergo secondary and sometimes tertiary ejection (see also the present results abstracted in Arp [1968c]). In the analyses of the individual systems which precede the final section, however, this result will be anticipated to some extent in order to be able to discuss some of the otherwise apparently unconnected details of each individual system.

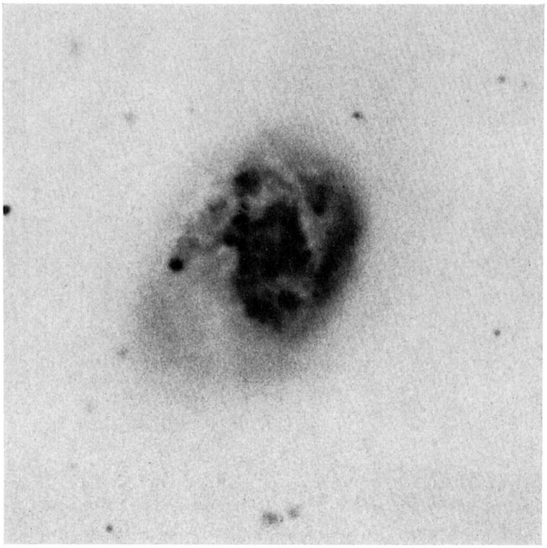

Fig. 2. Photograph of *Atlas* 49 (NGC 5665). Stellar-appearing object on east of galaxy is the compact companion. (Exposure 25 m on 103a-J emulsion at $f/3.7$ focus of 200-inch telescope)

2. *Atlas* 49 (NGC 5665)

Figure 2 shows a late-type spiral galaxy, classification about Sd, with broad spiral arms comprised of large, irregular patches of luminous and dark material. On the east side of the galaxy there is a relatively bright, stellar-appearing object. The spiral arm on this side of the galaxy seems to trail out behind this semistellar knot like a broadening wake. The existence of this turbulent-appearing wake suggests that this small, high-surface-brightness object is travelling through the medium of the galaxy. It is of considerable interest, therefore, to investigate its spectroscopic appearance and its redshift relative to the main galaxy.

The spectrum shown in Fig. 3a is at an original dispersion of only 400 Å mm^{-1}, but it does show significant redshift differences for the various luminous patches over which the slit passed. (These regions are indicated in the schematic diagram of Fig. 4). In Table 1 the first plate, obtained with the 200-inch prime-focus nebular spectrograph, is listed as N 2445. Later a plate was taken with the Cassegrain image-tube spectrograph, and it is listed as Q 547. Table 1 shows that there is a small systematic redshift difference between N 2445 and Q 547. In order to eliminate this systematic component, the difference in redshift, Δz, between the companion and the parts of the main galaxy to the west were computed separately for each spectrogram. These redshift differences were averaged and plotted in Fig. 5. It is seen that the companion has about 100 km s^{-1} smaller redshift than the average of the main galaxy.

Considering the small magnitude of the difference between the redshift of the companion and the redshift of the main galaxy, it is difficult to conclude with certainty that the companion is not bound to the galaxy. Pending a more precise determination of the rotation curve, however, it can be argued that it is unlikely that the redshift difference between the companion and the galaxy is due to rotational velocity of the companion as, for example, a knot in the disk of a spiral galaxy that is rotating at a fixed radius about a nucleus.

The reasons are the following: first, the galaxy is a small one, presumably of low mass, and we would not expect very high rotational velocities. In fact, late-type spirals of the lower luminosities rarely have rotational velocities greater than $V_0 \sim 100$ km s^{-1} at distances of $R_0 = 5$ kpc or less from the center

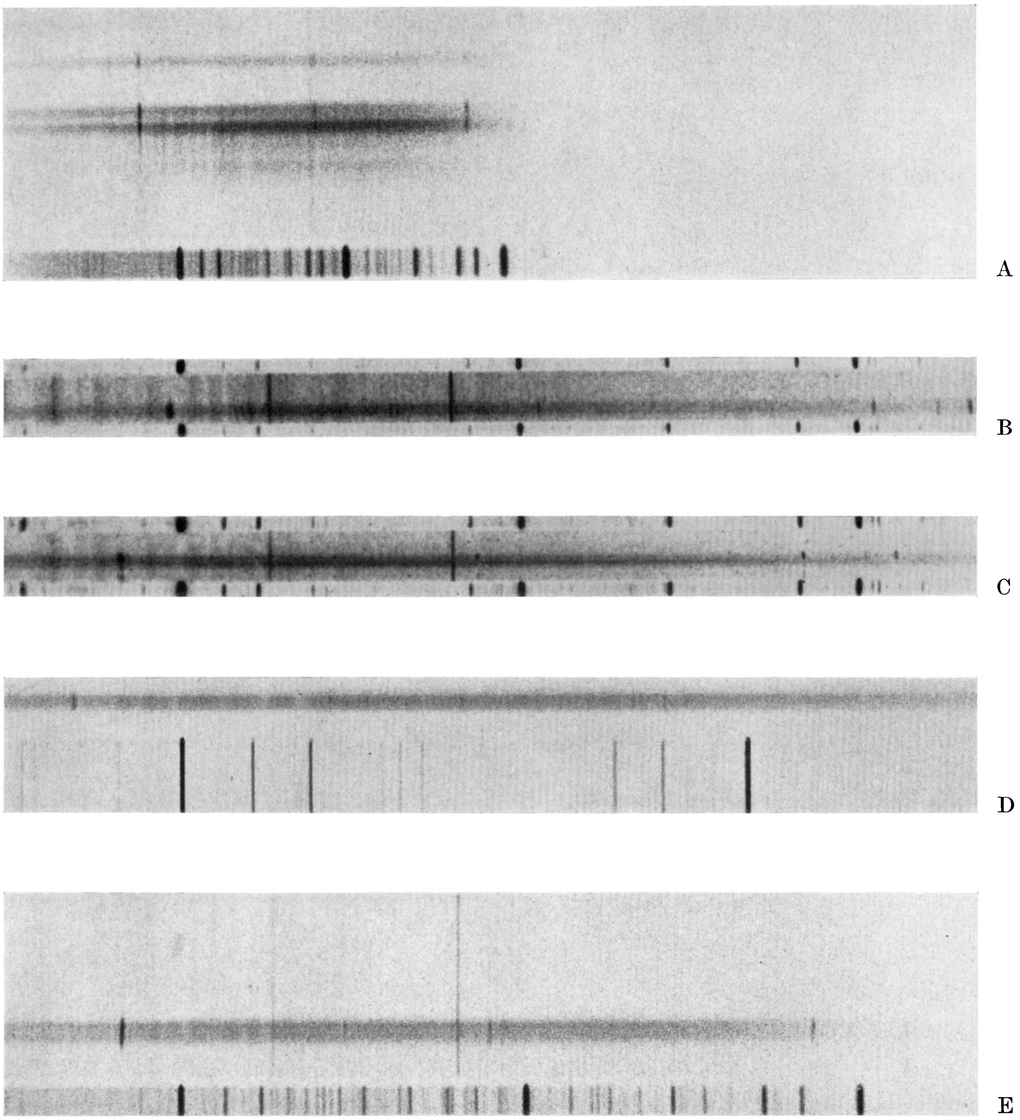

Fig. 3. Representative spectra of five of the companions in present paper. The bright helium comparison line 3888 Å in each spectrum has been aligned vertically, but the dispersions are generally different for different objects. A) *Atlas* 49 with spectrum of companion separated from galaxy at top of spectrum. See Fig. 4 for orientation of slit. Original dispersion 400 Å/mm with prime-focus nebular spectrograph at 200-inch. B) *Atlas* 58 companion taken with Image Tube Spectrograph at Cassegrain focus of 200-inch telescope; original dispersion 85 Å/mm. C) *Atlas* 82 companion. Strong emission lines come from knot 5″ northeast of nucleus. Same dispersion as B. D) *Atlas* 84 companion (compact nucleus). Original dispersion 90 Å/mm with high resolution of the 200-inch nebular spectrograph. (Spectrum courtesy Greenstein.) E) *Atlas* 86 companion. Slit in this case was aligned along minor axis of companion. Original dispersion 190 Å/mm with prime-focus nebular spectrograph

(see, for example, M 33, Carranza *et al.*, 1968). Second, *Atlas* 49, as we observe it, is not anywhere near edge-on, and the geometrical projection factor would reduce any true rotational component that we observe. Last, but most important, placing the slit in the east-west direction as we have done here, we are aligned almost exactly along the minor axis of the galaxy (particularly as judged by the inner, brighter ring of material). In all, although it should be checked by an actual rotational curve for the galaxy, we must conclude that probably most of the 100 km s^{-1} red-shift difference between the companion and the main galaxy found here represents motion away from the center of the main galaxy.

Table 1. *Lines measured in Atlas 49* (NGC 5665)

Ident.	λ_0	Companion (knot) N 2445	Companion (knot) Q 547	Main gal (18″ West) N 2445	Main gal (18″ West) Q 547	Main gal (24″ West) N 2445	Main gal (24″ West) Q 547	Main gal (30″ West) N 2445
[O II] em	3727.5	3754.6	3756.4	3755.4	3756.8	3757.0	3756.7	3758.5
H9 abs	3835.4	...	...	3865.7	...	3865.7	...	3865.7
He I em[a])	3888.6	...	3920.1	...	3920.0	...	3919.4	...
H8 abs	3889.1	...	...	(3924.4)	...	(3924.4)	...	(3924.4)
K abs	3933.7	...	...	3961.3	3967.0	3961.3	3965.3	3961.3
H abs	3968.5	...	...	3998.8	...	3998.8	...	3998.8
Hε em	3970.1	...	...	...	4000.4	...	...	...
Hδ em	4101.7	...	4132.7	...	4133.4	...	4132.8	...
... em	4135.7	...	...	...	4168.8	...	4168.4	...
... em	4240.9	...	...	...	4273.9	...	4273.4	...
Hγ em	4340.5	4369.8	4373.3	4373.0	4373.7	4371.7	4372.7	...
Hβ em	4861.3	4895.8	4898.0	4896.3	4897.5	4895.4	4897.1	...
Mean z	0.0071	0.0071	0.0076	0.0075	0.0079	0.0074	0.0077	0.0077
Mean em	$\pm$0.0001	$\pm$0.0001	$\pm$0.0001	$\pm$0.0001	$\pm$0.0001	$\pm$0.0002	$\pm$0.0001	$\pm$0.0002

[a]) This emission line in Q 547 is somewhat stronger than one would predict from the decrement of the longer wavelength Balmer lines. It has been identified with He I in analogy with *Atlas 82.*

Since 100 km s^{-1} traverses 1 kpc in 10^7 years, the compact companion galaxy would require no more than of the order of a few $\times 10^7$ years to have come out the nucleus of the main galaxy, if that is where it originated. This is of the order of time required for about one tenth of a revolution in an average spiral galaxy. Therefore, an object traversing the disk of NGC 5665 with a velocity of the order of 100 km s^{-1} would be expected to show roughly some curvature of track due to differential rotation of the disk. In fact, we observe in the photograph some curvature of the wake behind the compact object.

Two qualifying factors, however, should be appreciated. One is that if the intepretation of a turbulent wake behind the object is correct, then this may indicate that kinetic energy from the object is being

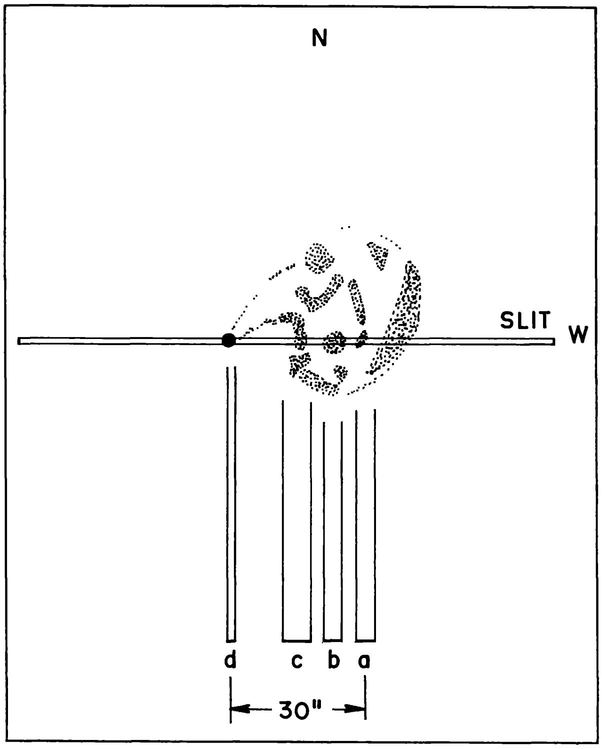

Fig. 4. Schematic representation of *Atlas* 49 showing placement of slit and identification of features measured in Table 1 and illustrated in Fig. 5

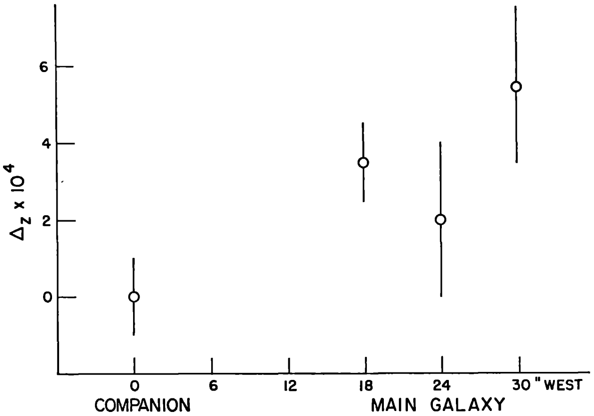

Fig. 5. Redshift differences for features measured in *Atlas* 49. Differences are differential to redshift of companion. Points are mean from two spectra with range in values shown

transferred into the medium, in which case the object could now be moving more slowly than it was at the beginning of its interaction. Second, in this intepretation we may be seeing to a large extent the medium of the galaxy which the object has excited. Naturally, that material would have predominantly the motion of the underlying galaxy. The object responsible for the excitation might itself be moving much faster.

The spectrum in Fig. 3a shows that the knot is characterized by [O II] and hydrogen emission lines superposed on a blue continuum. Again, the emission lines may be due to excited material in NGC 5665, while the compact source itself, beyond being compact and blue, gives no obvious spectral clue as to its nature.

Table 7 shows that the main galaxy is a near dwarf of absolute magnitude $M_B = -18.7$ mag and has a diameter to the outermost faint material of about $D = 5$ kpc. At this distance the compact companion is $M_B \approx -13$ mag and $D \lesssim 200$ pc.

With respect to the question of ejection for this galaxy, it is of great interest to note a recent radio observation by Varsavsky with the Arecibo telescope (kindly communicated in advance of publication). Varsavsky finds in this region a pair of faint radio sources separated by 45′ aligned almost exactly across NGC 5665.

The luminosities, dimensions, and other characteristics of both the main galaxy and the companion will be discussed, together with the five cases to follow, in Section 8.

3. *Atlas* 58

Figure 6 shows a spiral galaxy with arms that are not very tightly wound. One arm curves out far away from the center of the galaxy, while the other is shorter and terminates in a bright, extremely compact companion. The spiral arm connecting the companion to the main galaxy is disturbed and either partially malformed or disrupted. From the companion itself, a short fan of luminous material emanates outward in a direction apparently unrelated to the direction of the spiral arm.

At a distance corresponding to a Hubble constant of 100 km s^{-1} Mpc^{-1}, the luminosity of the main galaxy is derived to be $M_{pg} = -20.4$ mag, and its diameter to be about $D = 60$ kpc. Unlike the galaxy discussed in the preceding section, *Atlas* 58 turns out to be a giant galaxy with an outstandingly large diameter. If *Atlas* 58 is really at the distance indicated by its redshift, it is interesting to note the absence of a strong disk component in the outer portions and its small degree of winding, which is in strong contrast to the structure of a galaxy like M 31 which is usually considered a prototype giant galaxy.

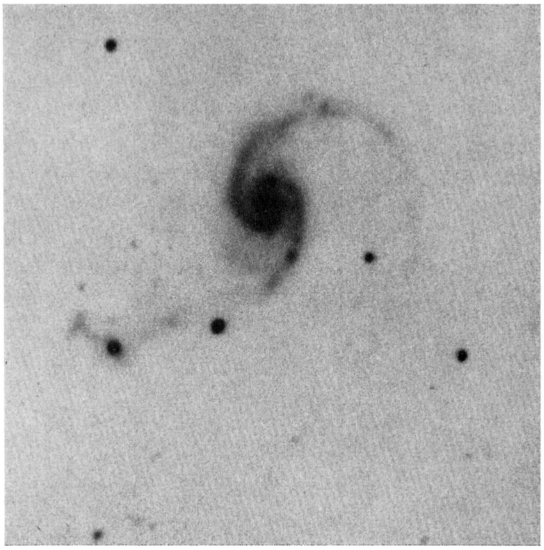

Fig. 6. Long exposure photograph of *Atlas* 58 (see Arp, 1966)

The companion has an apparent diameter of about 3″ on a long exposure plate, and nearly as high surface brightness as stars with the same size seeing disks. Its apparent magnitude is estimated at $m_{pg} \approx 18.5$ mag. At the assumed redshift distance, the companion therefore has a diameter $D = 1.5$ kpc and an absolute magnitude near $M_{pg} = -17$ mag. What appears on first inspection to be a large H II region or knot in a spiral arm turns out, therefore, to be a compact but quite luminous galaxy in its own right.

The high-surface brightness of the companion galaxy enables its spectrum to be easily observed (Fig. 3b). Spectrogram Q 151 (slit E–W) shows strong [O II] and narrow hydrogen emission lines which are appreciably slanted. Spectrogram Q 253 (slit N–S) was taken in very good seeing and is very narrow. It shows the same lines as Q 151, but is too narrow to reveal any slant to the lines if any is present. The presence of K and H absorption lines supports the classification of the companion as a galaxy with a stellar component and indicates that, if it were seen isolated in the sky, it would certainly be classified as a compact galaxy like the group studied and discussed by Zwicky (1964, 1966).

The very-low-surface brightness of the main galaxy makes it difficult to register a spectrum, and

Table 2. *Lines measured in Atlas 58*

Ident.	λ_0	Nucleus (Q 261)	Nucleus (Q 275)	Nucleus (Q 288)	Comp. (Q 151)	Comp. (Q 253)
Ne II: em	3694.2	...	3832.2	...	...	...
[O II] em	3727.5	3866.2	3867.2	3866.5	3867.7	3866.9
Si II em[a])	3854.9	...	...	...	3999.1	...
[Ne III] em	3868.7	...	...	...	4013.5	...
H8 abs	3889.1	...	...	4031.9	4034.8	...
H abs	3968.5	4117.0	4116.8	4112.8	...	...
H δ em	4101.7	...	...	...	4256.4	4256.0
...[b]) em	4233.6	...	...	4391.5	...	...
...[c]) em	4287.0	4447.3	...	...	...	...
...[d]) em	4331.5	...	...	4493.1	...	...
H γ em	4340.5	...	...	...	4502.8	4504.4
H β em	4861.3	...	...	...	5043.4	...
[O III]: em	4931.8	...	...	5114.5	...	...
[O III] em	4958.9	...	...	...	5145.1	...
[O III] em	5006.8	...	...	...	5195.7	...
Mean redshift $z =$		0.0373 $\pm$0.0005	0.0374 $\pm$0.0005	0.0371 $\pm$0.0002	0.0375 $\pm$0.0003	0.0376 $\pm$0.0005

[a]) Probable blend of Si II 3856.0 and 3853.7; see *Atlas 82* and Aller, Bowen and Wilson, 1963.
[b]) Possibly [Ni XII] 4231.4.
[c]) Possibly [Fe II] 4287.4.
[d]) Possibly [Ni IX] 4331.7.

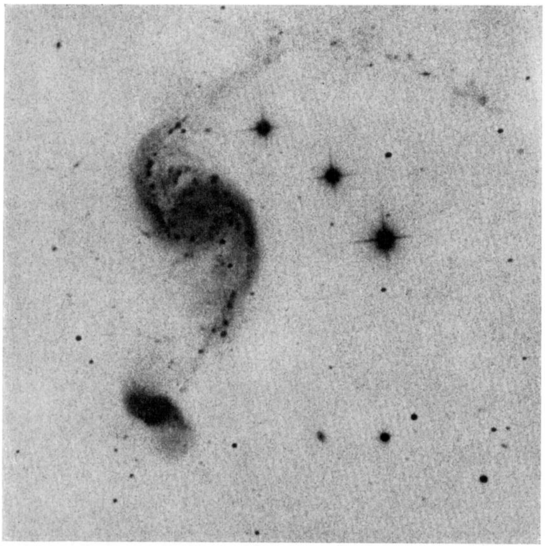

Fig. 7. Long exposure photograph of *Atlas* 82 (see Arp, 1966)

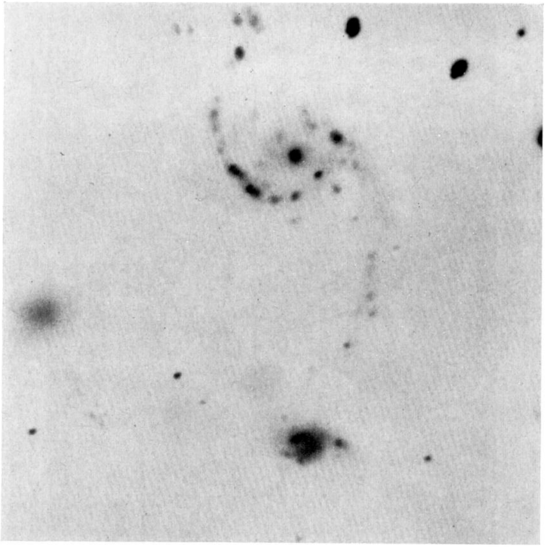

Fig. 8. Exposure on *Atlas* 82 by Vaughan and Arp with 100 Å band-pass filter centered on the hydrogen-α line as redshifted for the velocity of the system. Exposure of 1 h at prime-focus of 200-inch with the Carnegie Image Tube, S-20 surface. Note structure of companion in hydrogen-α showing two knots on either side of nucleus

a number of spectrograms were taken with the slit in different orientations. The three spectra which showed the most lines are listed in Table 2. Although no line has been listed that does not appear to be real, there are several lines that appear on only one plate – possibly because the slit passed over slightly different areas of the galaxy for different plates (all plates were taken with the slit passing through the nucleus).

The mean difference between the redshift of the companion and the central galaxy is 84 km s^{-1}, with the companion being the more redshifted. On two of the spectra, one taken with the slit north-south and one east-west, the central galaxy appears to have strongly tilted lines, suggesting rapid rotation. The projected shape of the galaxy, however, does not indicate that it is very close to being edge-on to our line of sight. Because of the very low-surface brightness of this galaxy, it would be difficult to determine a rotation curve to appreciable distances out from the center. Therefore, it will be difficult ever to determine whether the companion has the same redshift as the spiral arm to which it is attached.

The nebulous material which emerges from the companion in a direction to the northeast was not recorded spectroscopically. The configuration of this material relative to the companion, however, suggests strongly that this material has been ejected from the companion.

4. *Atlas* 82 (NGC 2535 and 36)

Figure 7 shows another open spiral with very long arms. The companion on the end of the one arm, however, is larger relative to the central galaxy than in the previous case of *Atlas* 58. The surface brightness of the companion, as in all cases investigated here, is conspicuously higher than the average surface brightness of the central galaxy. In this particular case, however, the central galaxy has a small, nearly stellar nucleus and the companion has a less concentrated nuclear luminosity.

The redshift of the central galaxy NGC 2535 is determined here as $cz = 4110$ km s^{-1}, with an uncertainty of about 30 km s^{-1}. The redshift of the companion, NGC 2536, is derived here to be $cz = 4200$ km s^{-1}, with the same uncertainty. These redshifts may be compared to those obtained previously by Humason and Page of $cz = 4135$ km s^{-1} for NGC 2535 and $cz = 4072$ km s^{-1} for NGC 2536 (de Vaucouleurs and de Vaucouleurs, 1964). The new redshift for NGC 2535 agrees well with the older determination. There is a disagreement, however, in the redshifts determined for NGC 2536. The explanation for this disagreement is the bright knot which appears in the high-surface-brightness region of NGC 2536, a little less than 5″ northeast of the nucleus (see hydrogen-α exposure in Fig. 8). The spectrum of the true nucleus of NGC 2536 consists primarily of K and H absorption and weak [O II], which gives a redshift of $cz = 4200$ km s^{-1}. The spectrum of the knot, however, has many conspicuous emission lines that give a redshift of $cz = 4080$ km s^{-1}. If the slit is placed across the general center of NGC 2536, the spectrum of this knot will dominate. This is demonstrated by plate Q 283 in Table 3, which was taken in poor transparency conditions. Only the spectrum of the knot was visible in Q 283. The specific emission lines which were originally reported in NGC 2536 (Page, 1961) indicate that it was indeed this knot that Page observed, and not the true nucleus. If we identify the previously recorded redshift as belonging to the knot, the redshift reported, $cz = 4072$ km s^{-1}, agrees very well with the redshift of $cz = 4080$ km s^{-1}, which was measured for the knot in the present paper.

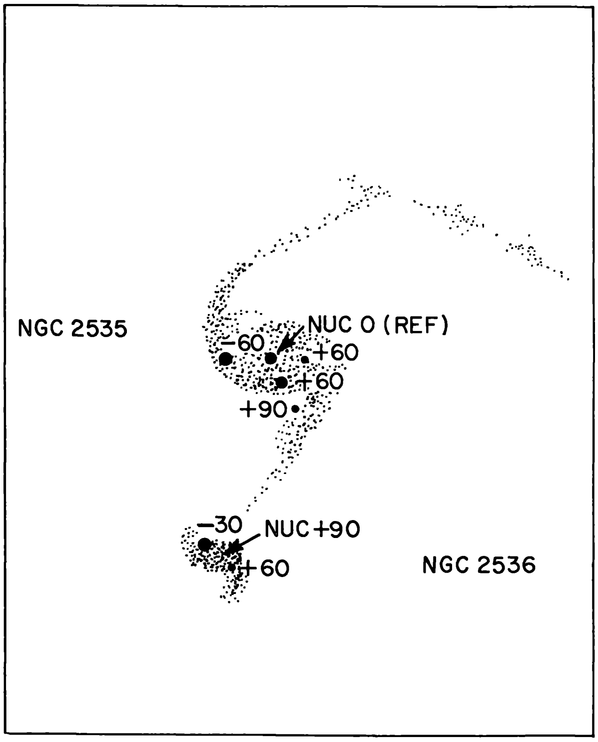

Fig. 9. Schematic representation of *Atlas* 82 shows the redshifts (in km/s) measured for various bright knots within each galaxy. The nucleus of NGC 2535 is labeled as 0 km/s for reference. The accuracy of each redshift is about ±30 km/s. The bright red star immediately southwest of the nucleus has low redshift-absorption lines and is presumably a foreground star. Enhancement of the nebular [O II] line by this star's continuum, however, enables a redshift to be measured at this point

Figure 9 gives a schematic picture of the two galaxies and the redshifts, relative to the nucleus of NGC 2535, which were measured for various knots within the galaxies. The redshift differences which are indicated within the main galaxy could be attributed to rotational motions within the spiral. The

Table 3. *Lines measured in Atlas 82* (NGC 2535 *and* 36)

Ident.	λ_0	Main Galaxy						Companion Galaxy			
		Q 287[d]			Q 285[e]			Q 289[f]		Q 283[g]	
		21″ E	Nucleus	16″ W	Nucleus	11″ SW	20″ SW	Knot 5″ NE	Center	Knot 12″ SW	5″ NE
[O II] em	3727.5	3778.0	3780.5	3780.0	3779.0	3778.9	3779.4	3779.4	3781.0	3780.2	3778.3
Si II[a]) em	3853.0	...	...	...	3906.2	...	...	...	...	...	...
Si II[b]) em	3862.0	...	...	...	3915.3	...	...	...	...	...	...
He I em	3888.6	...	...	...	...	...	...	3942.6[c])	...	...	...
K abs	3933.7	3987.8	3987.4	3988.2	...	...	...	...	3987.7	...	...
H abs	3968.5	(4019.2)	(4020.5)	(4024.4)	...	...	...	...	4023.4	...	...
Hε em	3970.1	...	...	...	...	...	...	4024.1	...	...	...
Hδ em	4101.7	...	...	...	...	...	...	4156.8	...	...	...
Hγ em	4340.5	4398.8	4400.5	4402.0	...	...	...	4398.7	...	4400.0	...
[O III] em	4363.2	...	4422.7	(4422.1)	...	...	...	...	...	...	...
Hβ em	4861.3	4927.4	(4927.4)	4928.7	...	...	...	4927.0	...	4928.4	...
[O III] em	4958.9	...	...	...	...	...	...	5026.2	...	...	...
[O III] em	5006.8	...	...	...	...	...	...	5074.3	...	5076.1	..
Mean redshift $z =$		0.0136 $\pm$0.0001	0.0138 $\pm$0.0001	0.0140 $\pm$0.0001	0.0136 $\pm$0.0001	0.0138 ...	0.0139 ...	0.0136 $\pm$0.0001	0.0140 $\pm$0.0002	0.0139 $\pm$0.0001	0.0136 ...

[a]) Probably Si II 3856.0 and 3853.7; *see Atlas 58* and Aller Bowen, and Wilson 1963.
[b]) Probably Si II 3862,6; see *Atlas 58* and Aller, Bowen, and Wilson 1963.
[c]) Too strong to be H8 in emission.
[d]) Position angle of slit Q 287 = 90°.
[e]) Position angle of slit Q 285 = 39°.
[f]) Position angle of slit Q 289 = 60°.
[g]) Position angle of slit Q 283 = 57°.

redshifts measured within the companion, however, are indicated to have at least some component over and above any components that might be due to rotation. There are two indications of this: first, the difference in redshift of 120 km s^{-1} between the nucleus and the knot to the northeast is a difference between two parts of the nebula that are extremely close together. Second, of the two knots on roughly opposite sides of the nucleus, both have more negative redshifts than the nucleus.

Although the nucleus of the main galaxy, NGC 2535, is extremely compact, the K and H absorption lines are strong, and the hydrogen emission lines are weak and are not visible later than Hγ (Plate Q 287 in Table 3.) On spectrogram Q 285, which was guided during very good seeing, the absorption lines in the nucleus do not show, possibly because of the absence of any widening in the very narrow spectrum. Two unusual emission lines register weakly but clearly in this spectrum. They have been tentatively identified with the permitted Si II lines, as indicated in Table 3. As described earlier, the knots in the companion galaxy, NGC 2536, give very strong emission, particularly the bright knot to the northeast of the nucleus. The nucleus itself, however, gives a spectrum similar to the nucleus of NGC 2535.

The redshift distance for this system yields a modulus of $m - M = 33.0$ mag. The modulus is therefore about 2 mag closer than *Atlas* 58, which was analyzed in the previous section. Corroborating this closer distance for *Atlas* 82 is the increased resolution in the latter object. A number of small, almost stellar knots are resolved throughout the main galaxy and companion. Estimating these knots as apparent magnitude $V \sim 20$ mag yields an absolute magnitude of about $M_V \approx -13$ mag, which is about a magnitude brighter than we would normally expect for a bright H II region (see Section 8). At this redshift distance the luminosities of NGC 2535 and 36 become $M_B = -19.5$ mag and $M_B = -18.0$ mag, and the diameters become $D = 50$ kpc and $D = 7$ kpc, respectively.

It is interesting to note that the size and brightness of the companion, NGC 2536, are very similar to the size and brightness of the whole of *Atlas* 49, which was discussed in Section 2. The knots in NGC 2536 are also just about the same size and brightness as the knot companion in *Atlas* 49. The knot in *Atlas* 82 companion lies near a diffuse, luminous extension of the nucleus, and there is an irregular luminous filament extending out from the knot itself.

The characteristic that makes all of the cases investigated in the present paper of special interest is the fact that the companions are connected to the central galaxies by luminous filaments. *Atlas* 82 represents an especially interesting case of connections and subconnections. To summarize the situation with respect to *Atlas* 82, we can say that the largest concentration of luminosity represents the main galaxy, NGC 2535. The next largest concentration of luminosity is the companion, connected to the main galaxy by the luminous filament of the spiral arm. Close to the nucleus of the companion lie two smaller, still higher-surface-brightness concentrations of luminosity, which we have called knots. These knots, in turn, are connected to the nucleus by luminous extensions of the nucleus. Finally, there is a narrow irregular filament emanating from the brighter knot itself. Thus we see a series of objects of increasing compactness, each connected to the previous, larger object by a luminous filament. The most obvious interpretation of these features would seem to be to consider this an example of primary, secondary, and tertiary ejection.

It is also informative to carefully study the spiral arms in the photograph of *Atlas* 82. The arm that leads to the companion is perfectly straight between the companion and the point where it leaves the thick inner spiral arm of the main galaxy. From this latter point there is another, fainter spiral arm, but it curves away in a nearly circular arc inside the radius of the companion. Coming from inside the main galaxy to this point of departure for the southern outer arm there are narrow dust lanes which fan into an extended portion of the arm. There are short, bright, linear segments pointing along the arms at the ends of the bright portions of both the northern and southern arms of the central galaxy. There is a thick segment of the northern arm which is, again, perfectly straight out to a point comparable in position with the companion on the south arm. At this point there is a break, the northern arm is offset and resumes in a considerably different direction with a slight curvature. The behavior of this northern arm raises the possibility that a body comparable in size to NGC 2536 existed at least temporarily, and was then disrupted in the event that gave rise to or affected the direction of the outermost segment of the northern arm. A comparable symmetrically situated break in the arm opposite the companion is apparent in the previous example of *Atlas* 58.

For the main galaxy, the straight arms in the exterior and the slight degree of winding in the interior would suggest recent formation of the arms, on the principle that they have not as yet been much curved by differential rotation.

5. *Atlas* 84 (NGC 5395 and 94)

Figure 10 shows the fourth case analyzed in the present paper. The large, tightly wound and nearly edge-on central galaxy is NGC 5395. The smaller, open spiral is NGC 5394, and has a bright, nearly stellar nucleus. On the northeast side of this nucleus there is a very-high-surface-brightness arc. On the southwest there are two smaller bright arcs. From these arcs extend fainter, slightly curved spiral arms. The southern arm of the companion appears, in projection, to be attached to the disturbed western arm of the central spiral. Actually, the whole western side of the parent spiral is displaced outward and widened to many times its normal width along just a line joining the centers of the larger and smaller galaxies (or a little ahead in the direction of rotation of that line). Also along that line but slightly further out is an elongated-appearing galaxy that points back to the center of the larger galaxy. Since the one side of the central galaxy is so badly disturbed just along the general direction to the companion, one interpretation could be that the companion was ejected out along this line and disrupted the disk of NGC 5395 as it

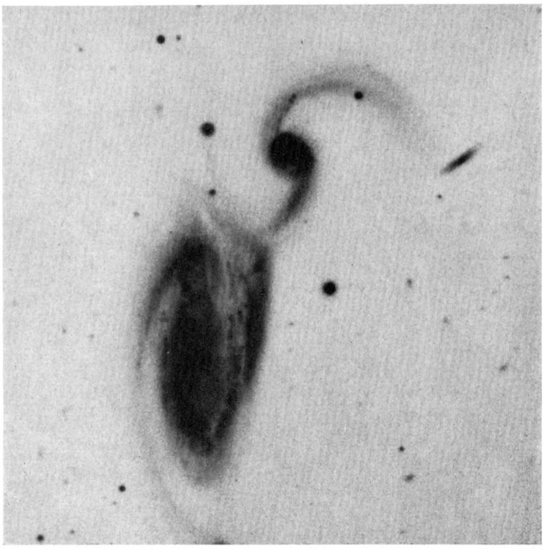

Fig. 10. Long exposure photograph of *Atlas* 84 (see Arp, 1966)

Table 4. *Lines measured in Atlas 84 companion* (NGC 5394)

Ident.	λ_0	Q 280	Q 300	N 2393	N 2398
[O II] em	3727.5	3771.0	3772.2	3769.6	3769.7
H 13 abs	3734.4	...	...	3776.5	3776.5
H 12 abs	3750.2	...	...	3792.7	(3793.0)
H 11 abs	3770.6	...	...	(3814.5)	3812.6
H 10 abs	3797.9	3840.3	...	3839.8	3841.0
H 9 abs	3835.4	3881.6	...	3876.0	(3878.6)
H 8 abs	3889.1	3932.5	...	(3930.4)	(3934.8)
K abs	3933.7	3976.0	...	3977.4	3976.1
(H + Hε) abs	(3969.3)	4014.3	...	4013.7	(4012.1)
Hγ em	4340.5	...	...	4390.2	4389.9
Hβ em	4861.3	4916.7	4916.8 em	4915.6	...
Mean z =		0.0114 ±0.0001	0.0117 ±0.0003	0.0112 ±0.0001	0.0113 ±0.0001

passed through. Since only one side of the disk of NGC 5395 is disrupted, this interpretation seems preferable to gravitation perturbation due to the consideration that an encounter, however brief, might be expected to deform the whole galaxy more than is pictured.

In either interpretation we must ask why the companion galaxy is not itself more deformed. This seems to require a very recent origin of the arms of the companion. The high surface brightness arcs which appear like rudimentary spiral arms close to the sharp center of the companion galaxy are very unusual. It would seem difficult to understand them as equilibrium configurations and this would, of course, point to their recent origin in the companion. There is an unusually sharply defined string of condensations coming out of the companion on the inside of the northern arm. The rest of the northern arm of the companion is diffuse and more curved than this string of condensations which, except for its slight curvature, could be classified in the group of features in galaxies which are usually called "jets".

Through an oversight, no spectra exist of the main galaxy, NGC 5395. The bright, sharp nucleus of the companion, NGC 5394, however, has enabled unusually good spectra to be obtained. J. L. Greenstein has kindly loaned me two relatively high-dispersion spectra of the companion, NGC 5394. The first (N 2393) was taken at an original dispersion of about 200 Å mm^{-1}, and the second (N 2398) at about 90 Å mm^{-1}. Fig. 3d shows that the latter spectrum shows the unusual result for a galaxy that the hydrogen absorption lines can be seen clearly down to H 13. The absorption lines are fairly narrow, but the emission lines are even narrower. In Fig. 2d, Hγ emission can be seen sharp and narrow inside the Hγ absorption line. A previous example of such sharp hydrogen emission lines in a galaxy was the isolated pair of compact galaxies described by Arp (1965). The hydrogen emission lines in the present case have perhaps an even steeper Balmer decrement.

The interpretation of this spectrum is not obvious. The blue continuum and absorption lines apparently come from the bright compact nucleus of NGC 5394. Precedent for such spectra is seen in the non-emission blue compacts of Zwicky (1964, 1965), Arp (unpublished), and Sargent (unpublished). The emission lines may come from more rarified regions exterior to this, or there may be other models which will be required. The early-type stellar-absorption spectrum implies a concentrated group of young stars at the center, of the order of 10^7 years age, in analogy with the young Magellanic Cloud cluster, NGC 1866 (Arp and Thackeray, 1967). This latter interpretation is, however, simply the most obvious assumption in view of the lack of detailed information and models tested against these observations.

6. *Atlas* 86 (NGC 7753 and 52)

Figure 11 shows one of the most striking examples, next to M 51, of a companion galaxy on the end of a spiral arm. It also furnishes one of the best illustrations of the tendency for the companion galaxy to have the higher surface brightness of the two. The surface brightness of the companion galaxy, NGC 7752, is so high that when the photographic plate is exposed long enough to register the main galaxy clearly, the companion is too burned out to register details. On such long exposures the companion has a roughly

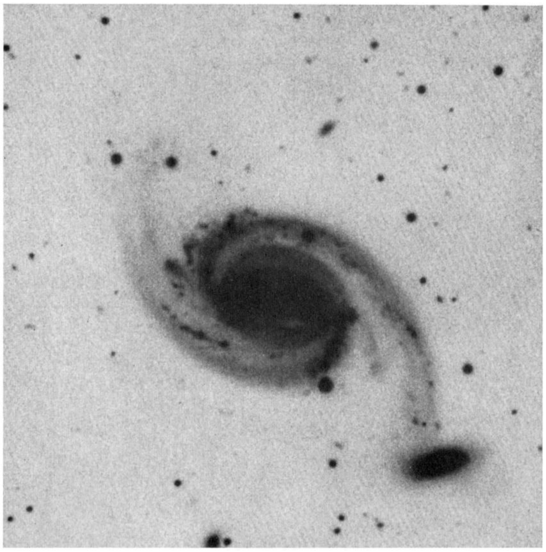

Fig. 11. Long exposure photograph of *Atlas* 86 (see Arp, 1966)

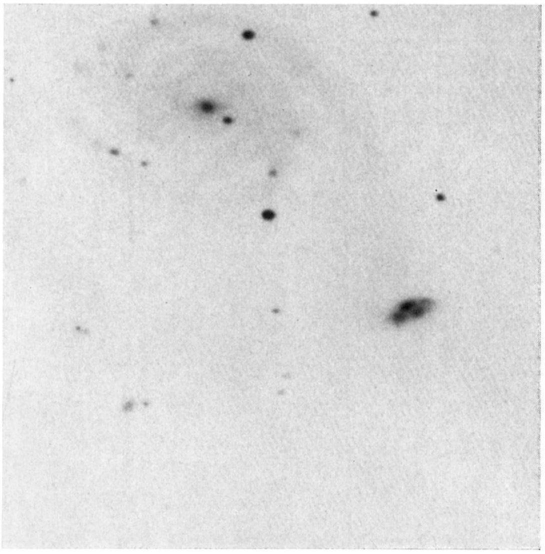

Fig. 12. Short exposure good-seeing photograph in order to show interior detail in companion of *Atlas* 86

elliptical outline, which suggests that it is a typical, rotating, flattened spiral seen partially edge-on.

When the slit of the spectrograph is placed along the major axis and the minor axis, however, it is immediately apparent that the spectral lines appear slanted in both of these slit orientations. Redshifts measured along both the major and minor axes are listed in Table 5. As Fig. 13 shows, the gradient of redshift in km s^{-1} per arc second is just about the same along either the major or minor axis. The simplest modification of the usual galaxy model would be that the companion is a rotating, flattened system (giving a redshift gradient along the major axis), and at the same time is expanding away from its own center (giving a redshift gradient along the projected minor axis). A glimpse into the interior structure of NGC 7752, however, is afforded by the light-exposure good-seeing plate shown in Fig. 12. That picture shows that far from being a uniform disk, the companion contains a few relatively bright

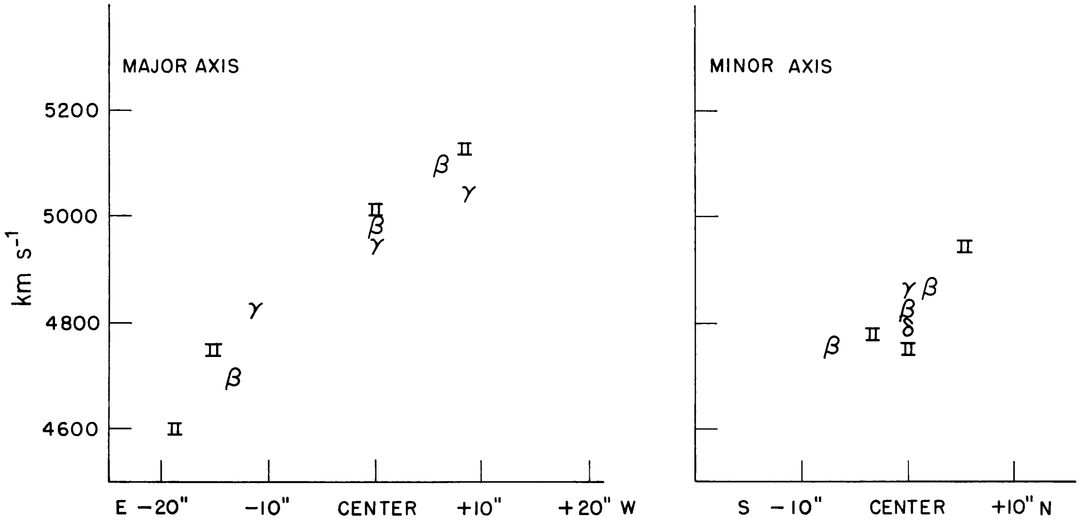

Fig. 13. Redshifts measured at various distances along the major axis (*left*) and minor axis (*right*). Symbols stand for the various lines measured, the hydrogen emission lines (β, γ, δ), and forbidden oxygen (II)

Table 5. *Spectrum of Atlas 86 companion* (NGC 7752)

	Line	λ (Å)	Ident.	λ_0	$c\,\Delta\lambda/\lambda_0$ (km s^{-1})
	Major axis (Plate N 2337, 190 Å mm^{-1} original dispersion)				
Distance along major axis					
8.″5 W	em	3791.3	[O II]	3727.5	5130
Center	em	3789.8	[O II]	3727.5	5010
15.″1 E	em	3786.5	[O II]	3727.5	4746
18.″9 E	em	3784.6	[O II]	3727.5	4596
8.″9 E	em	4413.5	Hγ	4340.5	5045
Center	em	4412.2	Hγ	4340.5	4955
11.″1 W	em	4410.3	Hγ	4340.5	4825
6.″3 E	em	4944.0	Hβ	4861.3	5103
Center	em	4942.1	Hβ	4861.3	4985
13.″5 W	em	4937.4	Hβ	4861.3	4691
	Minor axis (Plate N 2345, 190 Å mm^{-1} original dispersion)				
Distance along minor axis					
5.″3 N	em	3789.1	[O II]	3727.5	4950
Center	em	3786.6	[O II]	3727.5	4755
3.″1 S	em	3787.0	[O II]	3727.5	4787
	abs	3857.0	H10	3797.9	4668
	abs	3896.8	H9	3835.4	4803
	abs	3995.8	K	3933.7	4736
	abs	4027.3	H	3968.5	night-sky interference
	em	4167.1	Hδ	4101.7	4783
	em	4410.9	Hγ	4340.5	4866
1.″9 N	em	4940.2	Hβ	4861.3	4864
Center	em	4939.7	Hβ	4861.3	4837
7.″0 S	em	4938.5	Hβ	4861.3	4760

condensations or knots. In this respect it resembles NGC 2536, discussed in Section 4. Like NGC 2536, the center of NGC 7752 also contains some early-type absorption lines (spectrogram N 2345 taken along the minor axis). It may be then, like NGC 2536, that these condensations are being ejected outward from their own nucleus, thus giving rise to the slanted emission spectrum lines in various orientations of the slit. The emission lines which are measured in NGC 7752 appear smooth and continuous, but it would be necessary to obtain spectra in very good seeing conditions in order to be certain that these are not simply the discrete condensations shown in Fig. 12 melding into a continuous line under less than the best resolution. But, whichever of these models is the more pertinent, it still is clear that the redshift gradients imply an expanding system.

Using only the redshift gradient along the minor axis, we see from Fig. 13 that there is an expansion gradient of 100 km s^{-1} per 6″ projected distance along the minor axis. The redshift distance to this pair of galaxies is about 50 Mpc; therefore, the projected diameter along the minor axis is about 3 kpc, and the implied time since the start of the expansion is about 1×10^7 yr. As the companion expands, its surface brightness should decrease roughly with the square of its dimensions. Therefore, in a few times 10^7 years the companion should be more spread out, disrupted, and, since the young stars and emission would also decay appreciably in times of this order, the companion could be characterized as having a lifetime of the order of a few times 10^7 years. This is a very important result since it indicates that the lifetime of this companion is enough less than the average rotation period of a spiral galaxy, so that the spiral arm leading to it would not be wound up in a near circle. An age of a few times 10^7 years also agrees with the general dynamical and physical ages derived for the individual cases discussed in previous sections.

The redshifts previously published for NGC 7753 and 52 are 4845 and 4868 km s^{-1} (de Vaucouleurs and de Vaucouleurs 1964). The latter redshift agrees with the redshift measured here for the central regions of the companion. Since the exact point at which the previous measure was made is not certain, a more exact comparison with the present measures is not possible. The redshift distance to the system yields a modulus of $m - M = 33.4$ mag. No apparent magnitudes are given in the literature. We estimate $m_{pg} = 14$ and 15 mag for the main galaxy and companion, which gives absolute magnitudes near $M_{pg} = -19$ and -18, respectively.

The difference in redshift between the main galaxy and the companion is so small as to shed no light on whether the companion is escaping or not. A number of spectrograms have been obtained by Bertola (unpublished results) for the purpose of deriving the rotation curve of the main galaxy. When that curve is available, it will be very important to carefully compare the redshift of the companion to the rotational velocity of the main galaxy at that point on the arm of the main galaxy.

7. *Atlas* 87 (NGC 3808 and Companion)

Figure 14 shows one of the most curious cases of a companion galaxy on the end of a spiral arm. In this particular case, the spiral arm appears to actually approach the companion in a helical fashion. This in turn gives the impression that the companion is a spindle-shaped body rotating about its long axis. It is reminiscent of NGC 2685, which is a well known case of a galaxy rotating about its long axis. Just to the northeast of the companion is a fainter but even more elongated galaxy at only a very slightly different projected angle of its long axis. Although no spectra exist for this latter galaxy, it is, by its appearance, not a distant edge-on system. It may be of common origin and associated with the brighter companion. This faint shred near the *Atlas* 87 companion is very similar to the shred that pointed back to the center of NGC 5395 in *Atlas* 84. As in the latter case, the shred near *Atlas* 87 companion also may have been recently ejected. Because of its orientation, however, it is more likely in the present case to have been ejected from the companion galaxy.

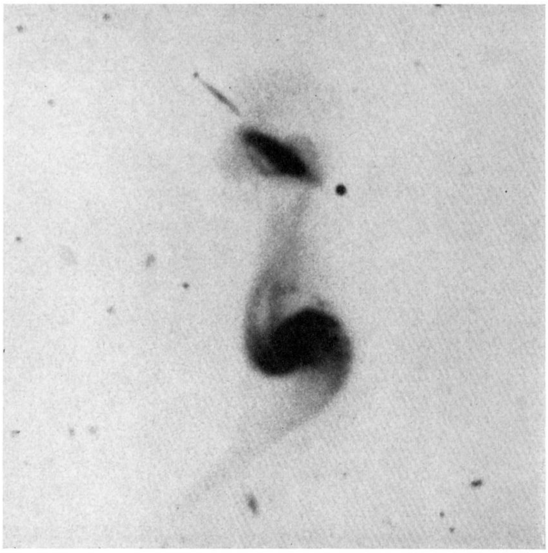

Fig. 14. Long exposure photograph of *Atlas* 87 (see Arp, 1966)

If, as it appears, the arm of the main spiral actually has been deformed into a helix around the companion, it poses a very difficult problem as to what are the actual physical properties of that spiral arm.

Atlas 87 represents another case of a very high-surface-brightness galaxy, as can be seen from the photograph in Fig. 14. The spectra show, as listed in Table 6, that this companion has also a very large number of hydrogen absorption lines visible. As in the case of *Atlas* 84 companion, they can be seen all the way to H 13. There are no previously recorded redshifts for this system. The companion has a redshift of +180 km s^{-1} relative to the central galaxy. This is the largest difference of redshift between main galaxy and companion that has been recorded in this paper. Since the main galaxy appears more or less face-on, it probably represents a velocity of separation between the two galaxies.

8. Group Characteristics and Physical Nature of the Companions

The summary of properties in Table 7 shows that the main galaxies range all the way from near dwarf systems up to giant systems having as large diameters and luminosities as known among any galaxies. The property which all the main galaxies do have in common, however, is that they are all classified Sc or later. In every case the arms are quite open, conspicuous dust and emission clumps are present, and there is no sign of a large nuclear bulge, which is characteristic of Sa and Sb galaxies. This result

Table 6. *Atlas 87 and companion* (NGC 3808 *and companion*)

Ident.	λ_0	Nuc Q 265	Nuc Q 277	Comp. Q 264	Comp. Q 266	Comp. Q 276
[O II] em	3727.5	3815.4	3814.7	3816.7	3818.2	3816.6
H 13 abs	3734.4	...	...	3825.0	...	3826.5
H 12 abs	3750.2	...	...	3840.4	...	3841.1
H 11 abs	3770.6	3858.8	3854.2	3861.4	...	3861.3
H 10 abs	3797.9	3890.7	3885.3	3888.1	3890.4	3889.5
H 9 abs	3835.4	3927.9	3929.7	3928.9	...	3926.7
H 8 abs	3889.1	...	....	3985.2	...	3983.2
K abs	3933.7	4025.2	4024.0	4027.2	...	4029.1
H abs	3968.5	4063.9	4064.4	4063.8	...	4062.0
Hδ abs	4101.7	4194.2	...	4202.1	...	4197.0
... em	4316.4	...	...	...	...	4420.0
(He II): [a])em	4338.7	...	...	....	4442.1	4442.2
Hβ em	4861.3	4975.3	...	...	4976.4	4976.1
Average $z =$		0.0236	0.0234	0.0242	0.0240	0.0240

[a]) Probably confused with some Hγ emission.

Table 7. *Derived properties of main galaxies and companions*

Name	Class	$m—M$[a])	M_{pg}	D(kpc)	Name	M_{pg}	D(kpc)
NGC 5665	Sd III	31.8	—18.7	5	Companion	—13	0.2
Atlas 58	Sc I	35.3	—20.4	60	Companion	—17	1.5
NGC 2535	Sc I	33.0	—19.5	50	NGC 2536	—18.0	7
NGC 5395	Sc I	32.6	—20.1	29	NGC 5394	—18.7	17
NGC 7753	Sc I	33.4	—19	49	NGC 7752	—18	5×3
NGC 3808	Sc I	34.2	—20	56	Companion	—19	11×3

[a]) Computed with a Hubble constant of $H = 100\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$.

would seem to be a significant one from the standpoint of the young stellar population which characterizes this class of spirals. The general youth of such stellar components would correspond well to the small dynamical and physical ages that have resulted from our analysis of the companions.

As to the exact physical nature of the companions themselves, considerably more detailed study will be required before a picture can be derived in which we can place confidence. At this time only a few general comments can be made about the companions. The first concerns their relationship to H II regions. Normally what we consider as typical H II regions are emission regions that appear as bright knots in the arms of spiral galaxies. An estimate of their luminosities can be made from a statement by Humason, Mayall and Sandage (1956). On page 160, they state concerning the galaxy NGC 4321 that "stars can be resolved . . . . about 2 magnitudes fainter than the [H II] knots". Using a modern value for the brightest stars in galaxies of about $M_{pg} = -10$ mag, this would make the brightest H II regions about $M_{pg} = -12$ mag. The least luminous companion studied here is about $M_{pg} = -13$ mag, and it resembles quite closely, both spectroscopically and photographically, a H II region. The remaining companions are brighter, $M_{pg} = -17$ mag and up, but it should be recalled that NGC 2536 itself is like NGC 2565 and the large knots in it are in a similar role of small companions. Sersic (1960a, b) gives slightly less than 0.3 kpc as the diameter of a large H II region, and it is seen that the sizes here again go upward from about this dimension.

If we consider the nature of a so-called H II region, a volume of gas with an exciting star at the center, then there is a natural upper limit to its size because of the upper limit or stellar luminosity. But, as happens often in young stellar populations, there can be two, three, or a small cluster of stars at the center of the gas, a larger amount of gas can be excited, and the region can be more luminous. (In this respect the galaxies studied here, and particularly their companions, are again indicated to be related to the Sc-type galaxies, where the H II regions reach their largest relative size.)

There is conceptually no limit to the number of exciting stars and their distribution and, therefore, the mass of gas one could ionize with them. Hence there is no obvious theoretical dividing line between a large H II region and a small galaxy. It is also interesting to note the companions of *Atlas* 49 and *Atlas* 58, the least luminous in Table 7, seem, as well as can be determined, to be more or less a single body. The next brighter companions, NGC 2536 and NGC 7752, are to some extent small associations of H II regions with a small amount of absorption-line continuum visible spectroscopically. The largest companions, *Atlas* 84 and 87 companions, have a strong non-emission-line continuum and conspicuous absorption lines.

The second preliminary comment that can be made concerns the nuclei of the companions. We suspect the nuclei are kinetically exciting to some extent the surrounding companions by gross ejection, but we do not know to what lower limits in size these ejections might go. Also, it is not clear whether the nuclei are radiationally exciting their surroundings as well. The A-type absorption spectra so conspicuous in the companions of *Atlas* 84 and 87 do not imply a very high radiation temperature. The best guess would seem to be that the hot OB-star continuum was an earlier stage and that most of the stars in the nucleus are old enough to have evolved into a composite A spectrum. Perhaps only in the most recently ejected material – whether it be primary, secondary, or tertiary – can the stars be young enough to give a hot OB-star excitation typical of H II regions seen in more local galaxies. Spectral scans, emission- and absorption-line studies, and high-resolution photography on these nuclei would seem a very promising way to get sufficient observational data on which to build a more accurate working model for the nuclei of these companions.

Table 8 lists the spectral lines observed in both the main galaxies and the companions. There are some interesting lines present in the companions, for example, He I and possibly He II. The data are insufficient to indicate whether this is due to excitation mechanisms or abundance variations.

Table 8. *Summary of lines observed*[a])

Main galaxies (4)		Companions (6)	
Emission	Absorption	Emission	Absorption
[O II] (4)		[O II] (6)	H13 (2)
			H12 (2)
	H11		H11 (2)
	H10		H10 (3)
	H9 (2)		H9 (3)
	H8 (2)		H8 (4)
	K (3)		K (4)
Hε	H (3)	Hε	H (5)
Hδ	Hδ	Hδ (4)	Hδ
Hγ (2)		Hγ (5)	
Hβ (3)		Hβ (5)	
[O III] (2)		[O III] (2)	
He I		He I (2)	
Si II		Si II	
Ne II:		[Ne III]	
[Ni IX]:		He II:	
[Ni XII]:			
[Fe II]:			

[a]) Number of separate objects in which line was observed, if greater than 1, is in parentheses.

9. Origin of Companions

Enough evidence that galaxies eject luminous material has now accumulated (Ambartsumian, 1958, 1961; Arp, 1966, 1968a, b) that we might be led to look for and to try to identify ejected material around certain given classes of galaxies. This was the motivation for Holmberg's (1968) study of the nearby large-apparent-diameter spiral galaxies. He found a significant excess of smaller galaxies associated with these large spirals at many diameters distance from them. But the companions existed only in directions along the minor axis of the central galaxy. Holmberg concluded the companions were ejected isotropically, but that material in the plane of the parent spiral prevented their escape into regions which would be seen projected along the major axis.

If this were true, it would imply that companions ejected in the plane would have an energy exchange with the medium which would slow them down and stop them. In some cases where the event was recent enough, we should expect not only to be able to observe the effect of these ejected bodies on the material in the plane of the parent, but we should expect also to see nearby the ejected galaxy connected with this disturbance. It is clear that the class of galaxies investigated in the present paper, companion galaxies on the ends of spiral arms, fulfills all these criteria. It is considered here that the very existence of this class of objects confirms Holmberg's hypothesis, and that the observations presented in this paper can be used to begin to study the details of this process.

Since most of the companions studied here are galaxies in their own right, they undoubtedly contain mixtures of stars, dust, gas, magnetic fields, etc. Perhaps the proportions are different and the amount scaled down, but there is no reason to doubt that if the companions have been ejected from the main galaxy that their material is essentially the same kind as in the galaxy of origin. Therefore, it would be natural to expect this ejected material to be also capable, at some time, of a similar kind of ejection, but perhaps scaled down. We have seen in a number of cases studied here just this expected phenomenon of secondary and tertiary ejection.

The most interesting additional conclusion of the present paper is that if bodies are ejected in these cases then these ejected bodies must be initially very compact. This circumstance is almost *a priori* necessary because the sizes of the companions considered to have been ejected are often larger than nuclei of the galaxies from which they are supposed to have sprung. This necessitates some expansion or unfolding of the ejected material as it progresses outward. It is just this quality of initial compactness that is so well illustrated by the systems discussed in the present paper (particularly in the first two sections). The disturbed wake or luminous filament which the ejected bodies leave behind them is quite narrow in relation to the central galaxy. After reaching a certain point along their tracks, we observe that these ejected bodies sometimes expand. At least to some extent, this expansion takes the form of secondary and tertiary cascading ejection. This sequence of events is supported by the observations in the present paper which show that the smallest companions have the highest surface brightnesses, for example, *Atlas* 49 and 58. The larger companions have lower surface brightness, until companions nearly the size of the parent approach the surface brightness of the parent galaxy. Again this behavior would be required by the expansion or unfolding of an initially compact (in luminosity) body.

It should be recalled once more that we may be observing, in the initial stages particularly, only the effect on the surrounding medium of a very compact body within. Its passage through the medium may excite the medium, or perhaps its radiation or secondary ejections. Perhaps not all ejections are initially in compact form, but, in that case, it might be more difficult to recognize them or their effect on the galaxy.

It was accepted almost from the outset that the so-called "blank-field" (plasmoid) radio sources had been ejected from galaxies. Even more interesting is the very strong tendency for these ejected radio sources to appear in pairs aligned across the galaxy (Maltby, Matthews and Moffet 1963). Considerable evidence has also been adduced that luminous material identified with radio sources is also ejected in pairs oppositely from the central galaxy (Arp, 1968a, b). It is not surprising to see in NGC 2536, then, the two knots which were considered to have been ejected appear on roughly equal sides of the nucelus of this galaxy.

Another interesting example of pairing phenomena is encountered in the Magellanic Clouds. The importance of a possible link between our own Galaxy and these nearest neighbors has been attested to by the numerous searches for such a link, starting with John Herschel. Such a connection was never established optically, but the radio observations of Turner and Varsavsky (1966) now suggest the existence of a narrow hydrogen arm from our own Galaxy out toward the Clouds. It is significant to note that the Clouds are themselves double galaxies within a common envelope. Moreover, the work of Hindman (1964) shows that an appreciable amount of hydrogen in the Small Cloud is separated into two masses that are receding from each other with a velocity of the order of $30-40$ km s^{-1}.

The most intriguing property of the ejection of material from galaxies is the general tendency for this ejection to take place in pairs oppositely directed from the ejection point. The general implication for the objects studied in the present paper is that, if the companion we observe on the end of a spiral arm has been ejected, there should be a balancing counter-ejection in roughly the opposite direction. There is, of course, the spiral arm opposite the one to which we see the companion attached. There are four general possibilities for this opposite arm on which there is no companion: (1) the ejected body could have passed beyond the end of the arm and escaped interaction with the system; (2) the ejected body has expanded and dissipated; (3) the ejected body has not yet expanded; or (4) the ejection could be of a somewhat different nature in the two opposite directions (e.g. the jet and counterjet in M 87).

It is suggested in this paper that the spiral arms of galaxies in general need not necessarily be stable equilibrium features that will last 10^{10} years. If they wind up into tight circles in a few times 10^8 years, the bright supergiant stars which mark these arms will have already decayed in luminosity and the arm would fade rapidly into the disk of the galaxy. New arms can be reestablished periodically by opposite ejections through the disk, gradually building up by this process a larger and larger component of disk material in the galaxy.

The most important implication, however, and one that might be profitably tested by calculation and observation, is that spiral arms in general might be the result of opposite ejection of material from the nucleus of a galaxy.

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