Astron. & Astrophys. 21, 169–184 (1972)

The Radio Emission of NGC 4258 and the Possible Origin of Spiral Structure

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Received March 3, 1972

Summary. The radio structure of the spiral galaxy NGC 4258 has been investigated with a beam of 24″ × 32″ at 1415 MHz. The radio structure shows two curved "ridges" of considerable intensity which differ in position, shape and continuity from the optical arms. They run straight across these arms and are remarkably smooth over their entire length. These radio arms, which lie probably in the same plane as the optical arms, are practically straight between 5 and 15 kpc from the centre. Inside 5 kpc they curve around and join the major axis of the galaxy. In this part they coincide precisely with the remarkable filamentary H_α-arms discovered on interference-filter photographs by Courtès and Cruvellier in 1961. These authors stressed the exceptionally smooth texture of the arms, differing so radically from that of ordinary spiral arms with their chains of H II regions. E. M. and G. R. Burbidge and Prendergast, as well as Chincarini and Walker have shown that large deviations from circular motion occur in this galaxy, indicating large-scale eruptive activity.

Radio emission has been measured in the "normal" arms, but it is considerably weaker than that of the "ridges". The radio ridges have steep edges on the sides which precede in the direction of the rotation. On the other side they merge into "plateaus" of lower intensity and considerable extent. Except perhaps for some condensations in the normal arms the radio emission is non-thermal.

The radio ridges and the accompanying filamentary H_α-arms are interpreted as the present location of "clouds" expelled from the nucleus in two opposite directions in the equatorial plane about 18 million years ago, at velocities ranging from about 800–1600 km/s. The clouds are braked by the interstellar medium, and have thereby acquired angular momentum. In the outer parts of their orbits the shocked interstellar gas has been able to cool and form a region of compressed gas; the corresponding compression of the magnetic field causes the enhanced synchrotron emission. The H_α-emission is ascribed to ionization in the shock front. The normal arms show evidence of having been affected by the expelled material; on the west side at least they appear to have much decreased in brightness in those parts where this material would have moved through.

The total ejected mass must lie between 10^7 and 10^8 solar masses; in due time most of this should be concentrated near the "ridges". By the differential rotation the latter will after some 100 million years develop into a normal spiral pattern extending over the whole system. The suggestion is made that processes like that which we suppose to be responsible for the radio arms of NGC 4258 may be the mechanism by which spiral structures are re-born at such intervals that they can replace structures that have become worn out.

Key words: radio continuum – galaxies – nuclear activity – spiral structure

1. Introduction

The observations of NGC 4258 form part of a programme for high-resolution mapping of the radio structure at 1415 MHz of the brighter spiral galaxies with the 12-element synthesis radio telescope (SRT) at Westerbork. Aims of the programme were to investigate the relation between synchrotron emission and spiral arms and to study the nuclear activity in ordinary spirals, and its relation to other properties of these galaxies.

Up to the present all spirals brighter than 11^m and lying north of +30° declination have been observed, except that in the Andromeda nebula only the south-preceding half was investigated, the entire galaxy having already been observed in detail at Cambridge. Observations of M101 are being discussed by Allen and others in Groningen.

Data on the distribution of radio emission were also obtained for about forty other bright spirals, among which were all the known Seyfert galaxies above +10° declination, and some galaxies in which strong activity

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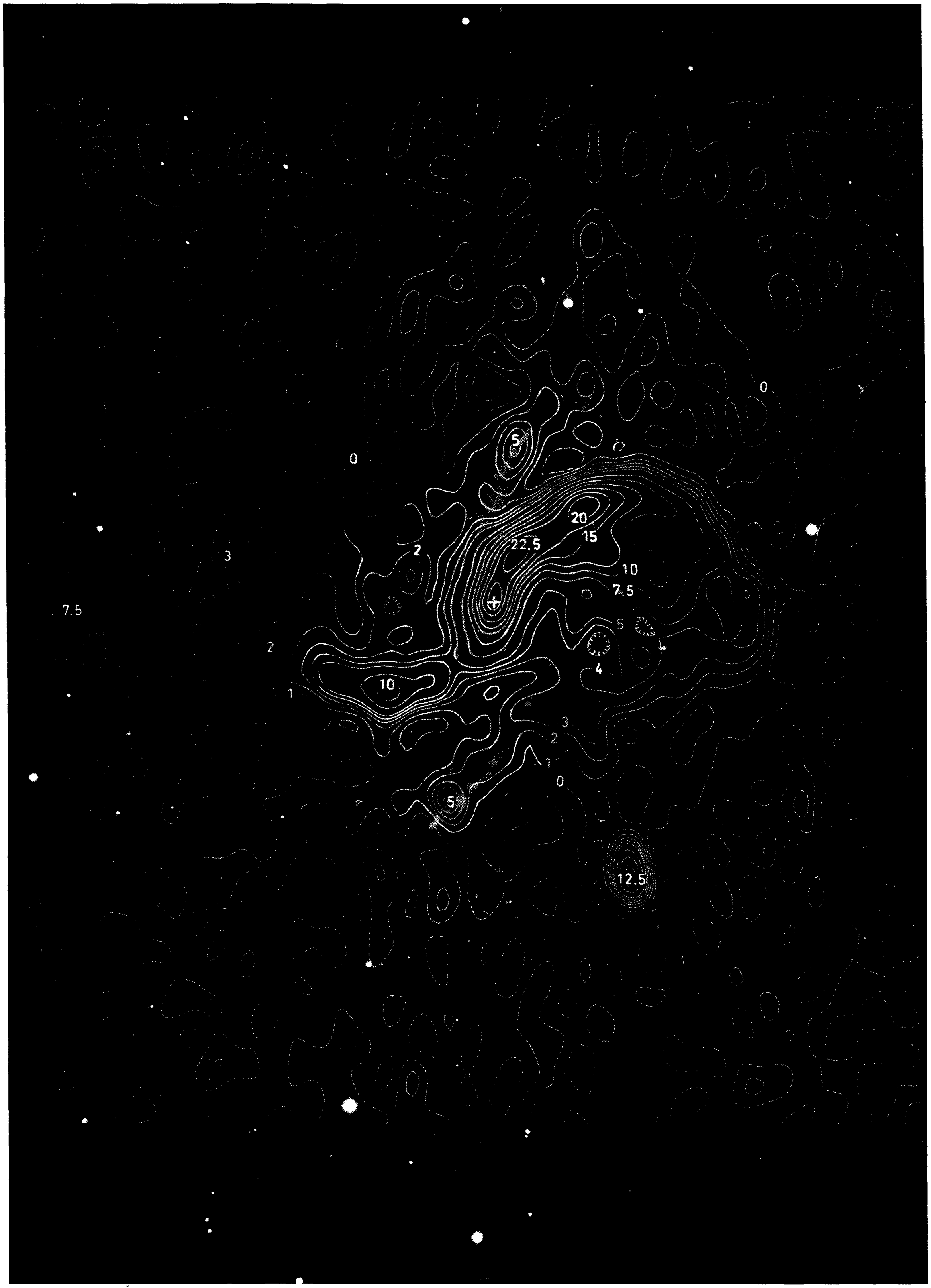

Fig. 1. Observed radio contour map of NGC 4258 superimposed on the optical photograph. The contour units are 1 m.f.u. per synthesized beam, or 0.9 °K brightness temperature. The optical photograph is a reproduction of a 200-inch IaO plate taken by A. R. Sandage kindly made available to us by him and through the help of Mr. William C. Miller, Scale 1 cm = 100″. The position of the optical nucleus is indicated by a white cross

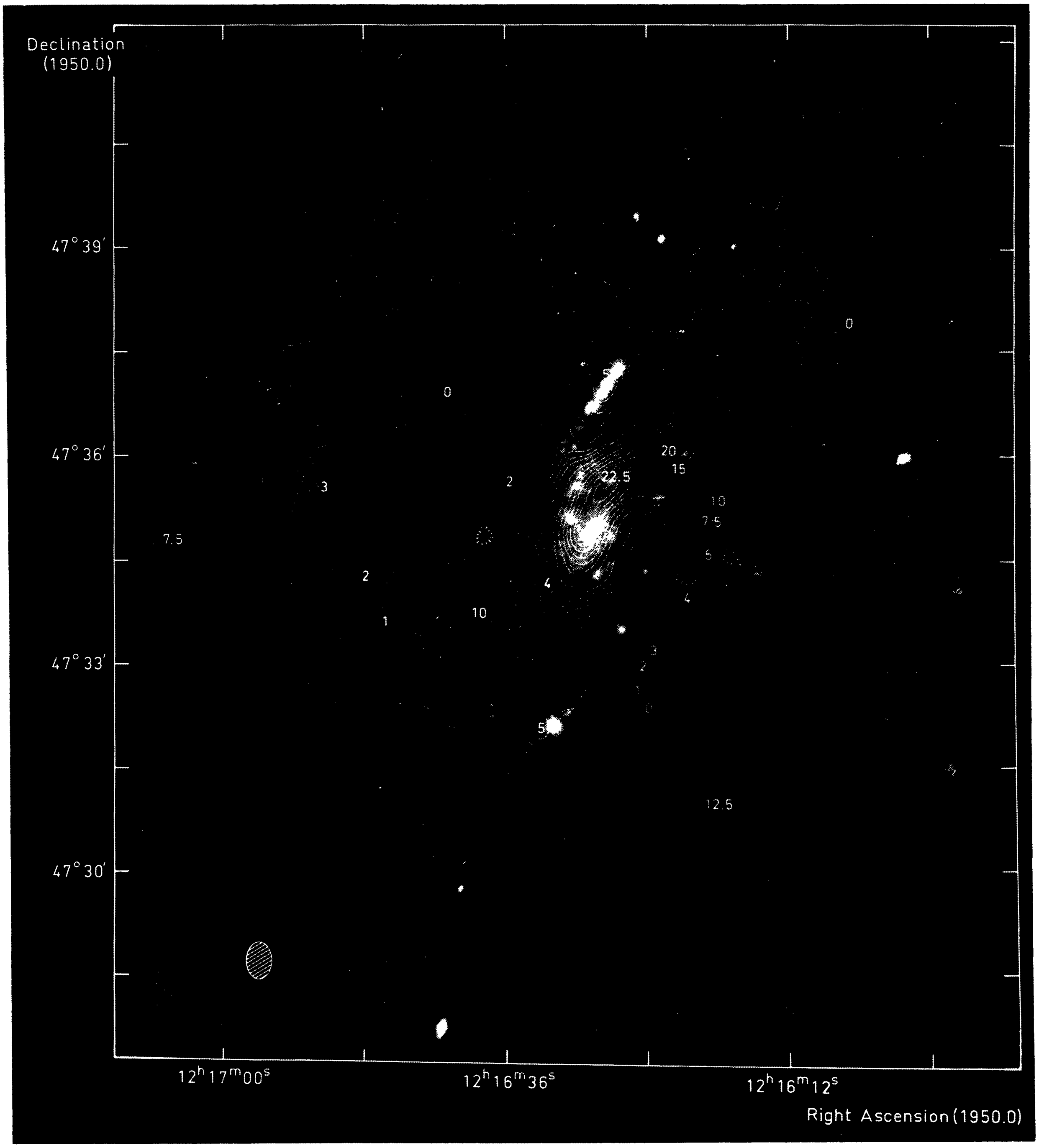

Fig. 2. The same contour map as in Fig. 1 superimposed on an H_α-photograph, taken by Deharveng and Pellet with the 193-cm reflector of the Observatoire de Haute-Provence through an interference filter of 10Å half-width transmitting velocities between −230 and +230 km/s relative to the velocity of the galaxy (half-width interval). Scale 1 cm = 100″

is indicated by striking deviations from circular motions in the optical observations, and galaxies in which bright supernovae have been observed. Results on the central sources of the Seyfert galaxies and of a dozen other spirals have been published by van der Kruit (1971b). An extensive study of the entire radio structure of M51 has been published by Mathewson, van der Kruit and Brouw (1972).

Unexpected features were encountered in some galaxies, like the triple radio source in NGC 4736. But the most important phenomena found would seem to be the radio arms in NGC 4258 discussed in the present article.

2. Optical Data

NGC 4258 (Fig. 1; cf. also Figs. 1 and 2 in Chincarini and Walker (1967) and p. 33 of the Hubble Atlas of

Galaxies (Sandage, 1961) is a bright Sb spiral galaxy ($m_B = 9.19$) with two prominent and fairly regular arms, which are well outlined by many strong HII regions, and extend to about 5 kpc. Fainter outer arms can be seen extending to at least 15 kpc. Following Sandage, as quoted by Burbidge, Burbidge and Prendergast (1963), the distance of NGC 4258 is taken to be 6.6 Mpc, so that $1'' = 32$ pc. The spiral has an inclination on the sky of about 65°. The central part, which can be fairly separated from the part where the arms become visible, appears to be lenticular in shape (cf. Chincarini and Walker, Fig. 1) and reaches to a distance of about 15″, or 500 pc. Except for the bright spiral arms the region outside the nucleus is extremely irregular and full of absorbing clouds (cf. Fig. 4), which are particularly conspicuous in the western half, which is the near side. NGC 4258 stands out from other spiral galaxies by the very large systematic deviations from circular motion shown by its emission regions. Attention was first drawn to this peculiarity by Burbidge *et al.* (1963) who found large deviations from circular motion in the principal arms at distances of about 4 kpc from the centre; the abnormal motions varied surprisingly rapidly with position angle. Chincarini and Walker found similarly striking deviations in the regions within 1′, or 2 kpc, from the centre. They found a quite complicated picture. Particularly large deviations from circular motion seem to occur on the NW part of the major axis, up to about 1′ from the centre. The radial components (presumably directed away from the centre) must in several regions be of the same order as the transverse (rotational) components. Motions in radial directions (away from or towards the nucleus) are also striking in their observations on the minor axis. If the gas observed lies in the plane of the spiral these observations indicate radial motions directed *towards* the centre. But they can equally well be interpreted as due to an *expulsion* of gas under a considerable angle with the plane of the galaxy. As Chincarini and Walker have remarked, the available data are still insufficient to construct a model. But they clearly show that over a large part of the galaxy the motions deviate widely from simple rotational motion, and that probably a great deal of the gas is being expelled outside the equatorial plane.

Notwithstanding the evidently disturbed state a rough idea of the rotational velocities may still be obtained. The rotation curve suggested by Burbidge *et al.* provides the following rough data for the velocity of rotation and periods of revolution at the distances from the centre specified in the first two columns:

40″	1.3 kpc	220 km/s	36 million years
80″	2.6 kpc	290 km/s	55 million years
120″	3.8 kpc	280 km/s	85 million years
200″	6.4 kpc	260 km/s	150 million years

From the data given by Chincarini and Walker we infer that the period of rotation in the nuclear region, up to 7″.5 from the centre, is around 11 million years.

Chincarini and Walker as well as Burbidge *et al.* have shown that fairly high "turbulent" motions occur in the nucleus. The velocity dispersion is estimated at ±350 km/s. The nucleus therefore shows *some* resemblance to a Seyfert nucleus. The galaxy was, in fact, included by Seyfert (1943) in his list of peculiar galaxies. However, the velocity dispersion is a factor three lower than in what are now defined as Seyfert galaxies.

A most interesting discovery was made by Courtès and Cruvellier (1961). With an H_α interference filter of 50 Å half-width they found that besides the striking arms in the ordinary optical pictures there exist two other arms emerging from the two extremeties of the central lens in a general direction which makes a large angle with that of the main arms. The authors especially noted the fact that the texture of these arms is entirely different from that of the principal arms. The structure is smooth, and shows no localized emission nebulae. Moreover there is no concentration of early-type stars in these arms, for they are invisible on plates taken in the blue optical continuum. The ionization seems therefore to be due to a mechanism other than the radiation of OB stars. The arms were again observed by Courtès *et al.* (1965) through a considerably narrower H_α-filter of 6 Å half-width and a central wavelength such that the half-width band transmitted extends from −330 to −50 km/s relative to the velocity of the centre, which on the basis of the observations by Burbidge, Burbidge and Prendergast and by Chincarini and Walker we assume to be +500 km/s. On this plate the northern half of the anomalous H_α-arms is invisible, which, as the authors remark, must be due to the rotation of the galaxy.

At our request Prof. Schmidt has measured the velocities of six points in the filaments with the image-tube spectrograph in the Cassegrain focus of the Hale telescope. He writes as follows about his measures: "The emission lines seen are [O III] $\lambda\lambda$4959 and 5007, H_α, [N II] $\lambda\lambda$6548 and 6583, and less frequently [S II] $\lambda\lambda$6717 and 6731, and H_β. The final radial velocities relative to the sun are

1	12ʰ16ᵐ33ˢ.5 + 47°33′48″	+190 km/s
2	12 16 30.4 + 47 34 09	+230
3	12 16 34.6 + 47 33 35	+230
4	12 16 35.1 + 47 33 55	+260
5	12 16 24.9 + 47 36 03	+630
6	12 16 22.6 + 47 36 11	+570

My impression of the uncertainty of these velocities is that they are of the order of 30 km/s, except for No. 4 where it would be 20 km/s, and No. 3 for which it might be 50 km/s. However, these "errors" are quite uncertain."

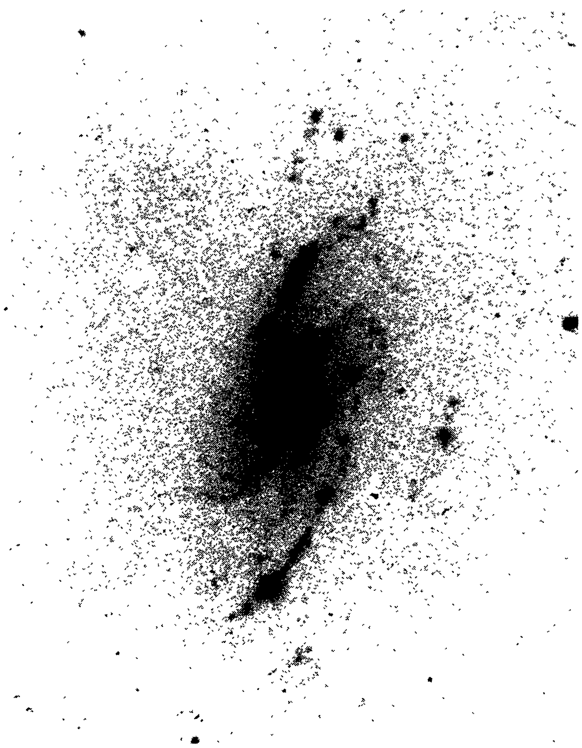

Fig. 3. The same exposure as in Fig. 2, without the radio contours. The reproduction was made from a film kindly put at our disposal by Mr. Deharveng. Scale 1 cm = 71″

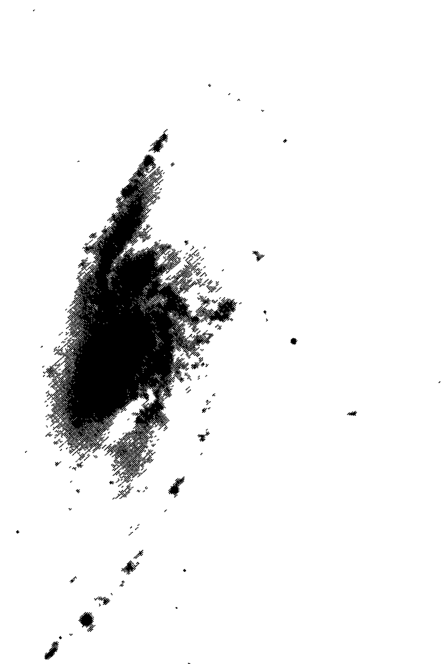

Fig. 4. The central region of NGC 4258, reproduced from the same plate as Fig. 1. Scale 1 cm = 51″

The first four points are in the southern filamentary arms, the first at the position where the arm forks into two branches (cf. Fig. 3), the third and fourth points lie on these branches. The last two points lie in the northern arm at 80″ and 110″ from the nucleus.

These observations confirm that no very high velocities occur in these arms. The difference from the central velocity are in the direction to be expected from the rotation of the galaxy and agree fairly well with what was known about the rotation curve. The uncertainty of the velocity of the centre is such that no conclusions can be drawn about the possible asymmetry between the velocities in the two arms.

From the fact that these arms appear to partake in the rotation we infer that they probably lie in the equatorial plane. In a third exposure, which was published by Deharveng and Pellet (1970) a filter of half-width 10 Å was used and a centre wave length such that the half-width of the transmitted region extends from -230 to $+230$ km/s relative to the velocity of the galaxy. This is reproduced in Fig. 3 of the present article. The fact that on this narrow-filter exposure the arms appear in virtually the same way as on the original 50-Å plate by Courtès and Cruvellier indicates that no large systematic radial motions, such as would be associated with a violent ejection, occur in these arms. Deharveng and Pellet state that the surface brightness over the arms is practically constant, which is another indication that the arms lie in the disk of the galaxy. In view of the strong absorption in the disk, which is especially striking on the SW front side of the nebula (cf. Fig. 4), one would expect to see a large difference in brightness between the northern and southern filaments if they would lie in a plane inclined to the equatorial plane. As there is no evidence for such a difference we conclude provisionally that they lie in this plane. Deharveng and Pellet noted further that each arm consists mainly of two more or less parallel filaments which can be followed over projected lengths of 120–175″; they state that the arms can already be distinguished from the central "lens" at 7″.5 from the centre. A striking phenomenon shown in all three interference-filter photographs is that the regions preceding the anomalous H_α-arms in the rotation direction are fainter than the regions following them. In particular in the southern arm the outer boundary is very sharp, and follows a remarkably smooth curve. The run of this curve is such that in the equatorial plane it must go out at a steep angle; in this respect it also differs radically from the normal spiral arms (cf. Fig. 6). The filaments in the south-eastern arm, which are particularly striking, were estimated to have a thickness of 3″. Deharveng and Pellet have measured the H_α surface brightness in the approximately uniform filaments, and find 7.7×10^{-5} erg cm^{-2} s^{-1} sterad^{-1}, corresponding with an emission measure of 850 cm^{-6} pc. If we would assume a homogeneous filling of the 100-pc wide filaments this would give $n_e = 3$ electrons cm^{-3}, which leads to a total ionized hydrogen mass of $3 \times 10^6 M_\odot$ in these arms.

We summarize those inferences from the optical observations of the anomalous arms which seem of direct importance for the interpretation of the phenomena:

1. Symmetry and participation in the rotation indicate that they lie in the galaxy's equatorial plane.
2. Velocities, also in radial direction, must be rather small.
3. Continuity and form may point to a fan-shaped ejection rather than, for instance, individual eruptions.
4. The probably large mass of H II suggests that they may have swept up a fair fraction of the interstellar gas.

3. Radio Observations

The observations have been made with the Westerbork Synthesis Radio Telescope which is operated at a frequency of 1415 MHz and has a bandwidth of 4 MHz. The telescope consists of twelve 25-m dishes along an east-west line. In four periods of 12 hours a total of 80 baselines can be measured. In these observations they ranged from 36–1458 metres at regular intervals of 18 metres. However, due to a failure in one of the fixed telescopes two baselines are missing (180 and 252 metres), but the effects for the synthesized beam are not very serious. The synthesized beam has a halfpower diameter of 24″ in right ascension and 32″ in declination. The system temperature is 240 °K and the r.m.s. noise in the map is about 0.3 m.f.u. (1 m.f.u. = 10^{-29} W Hz^{-1} m^{-2}). The beam solid angle measured to 5 halfpower radii is 0.215 square minutes, so that 1 m.f.u. in the centre of the beam corresponds to a brightness temperature of 0.9 °K. The reduction procedures are described by Brouw (1971).

Figure 1 shows the observed radio isophotes superposed on the optical photograph, which was kindly supplied to us by Miller of the Hale Observatories. The cross indicates the position of the optical nucleus, which is determined to be R.A. = $12^h16^m29\overset{s}{.}42$, Dec. = $+47°34'53\overset{''}{.}2$ (1950.0) by Schoenmaker with the Leiden Observatory 33-cm photographic refractor. The contour unit is 1 m.f.u. per beam, or 0.90 °K brightness temperature.

Figure 2 shows the same contour map superposed on the H_α-photograph, which was kindly supplied by Mr. Deharveng of the Marseille Observatory. An inspection of Figs. 1 and 2 shows the following five important points: (1) The dominant radio structure are two ridges of radiation, whose inner parts coincide with the anomalous H_α-arms. Their extent, however, is much larger. The boundaries of the ridges on the side preceding in the rotation are very sharp; they are unresolved. The western ridge is much stronger than the eastern one. This is very obvious in the radio picture shown in Fig. 5. (2) On the other sides of the ridges there is in both cases an extended plateau of radio radiation. This is

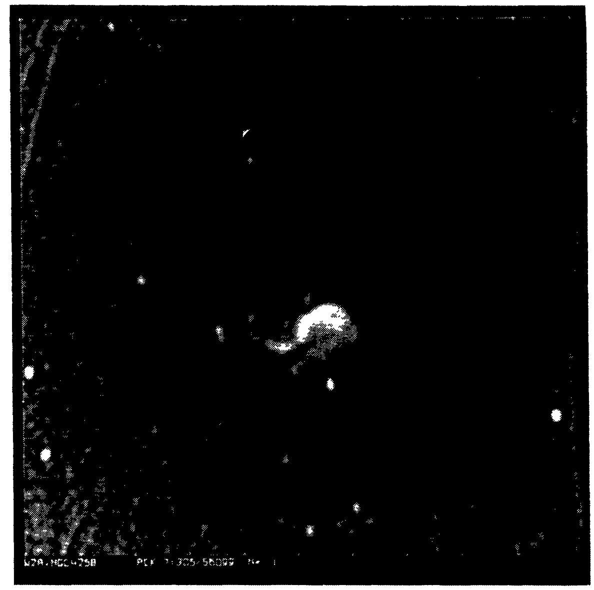

Fig. 5. Cathode-ray picture of the synchrotron emission from NGC 4258 and the surrounding field, made from the Westerbork data by W. J. Jaffe. Scale 1 mm = 32″. The orientation is the same as in Fig. 1–4. The picture gives a good representation of the lower intensity regions and of the surrounding field. The elliptical rings have been caused by the two missing interferometer distances (cf. p. 6)

most intense on the western side, where there is also evidence that the ridge splits in two (see Fig. 1). (3) The normal spiral arms, that are delineated by the bright H II-regions, are also visible. For the southern one the radio arm appears to be displaced from the young population in the bright arm, and to coincide rather with the dust lane on the inner side of the arm, in a similar way as was found in M51 (Mathewson *et al.*, 1972). In the northern arm the dust lane is not sufficiently well defined. The brightness temperature in the arms is about 3–5 °K. This is two times weaker than in the inner arms of M51, but an order of magnitude brighter than in M31. The differences are presumably due to differences in the general magnetic field strengths in these galaxies. Most of the condensations in the arms may be due to thermal radiation from H II regions. However, the pronounced maximum in the southern arm does not coincide with the bright H II region close to it. (4) There is presumably a source in the nucleus with a flux density of at most 25 m.f.u. This is several times weaker than the nucleus of M51 (Mathewson *et al.*, 1972) and only three times stronger than the Sgr A complex. It is at least an order of magnitude weaker than the nuclei of the Seyfert galaxies studied by van der Kruit (1971b). (5) Two radio sources are near to the galaxy on the sky, and it is noteworthy that both are resolved. To these observed properties a sixth item can be added, viz. that maps in the Stokes parameters Q and U show that the percentage of linear polarization (in the bright ridge) is less than 15%.

The emission measure of the anomalous H_α-arms, estimated in the foregoing section to be 850 cm^{-6} pc, is much too low for the observed radio emission to be thermal in origin. This is also evident from the spectrum of the integrated radio radiation. Table 1 gives the total flux densities available, and one can see that, as expected, this is a non-thermal spectrum. The spectrum flattens at lower frequencies; Lang and Terzian (1969) have noted that this is a phenomenon that is found in the spectra of most spiral galaxies.

Planimetry of the observed contours gives a value of 0.9 f.u. Comparison with the published flux densities in Table 1 shows that, within the error of about $\pm 10\%$, no large-scale structure has been missed by the Westerbork telescope because of lack of "zero-spacing" information.

Table 1. Spectrum of the integrated radio emission of NGC 4258

Frequency (MHz)	Flux-density ($10^{-26} WHz^{-1} m^{-2}$)	Source
178	<2	(4*C*) Gower *et al.* (1967)
408	1.3	Braccesi *et al.* (1967)
750	1.0	Heeschen and Wade (1964)
1400	0.9	Heeschen and Wade (1964)
1415	1.1	de la Beaujardière *et al.* (1968)
1415	0.93	Lequeux (1971)[a]
1420	0.88	Rogstad *et al.* (1967)
2695	0.42	De Jong (1967)

[a]) Lequeux finds a circular component of 3′ with 0.81 f.u. and a smaller component (1.′4) containing 0.12 f.u.

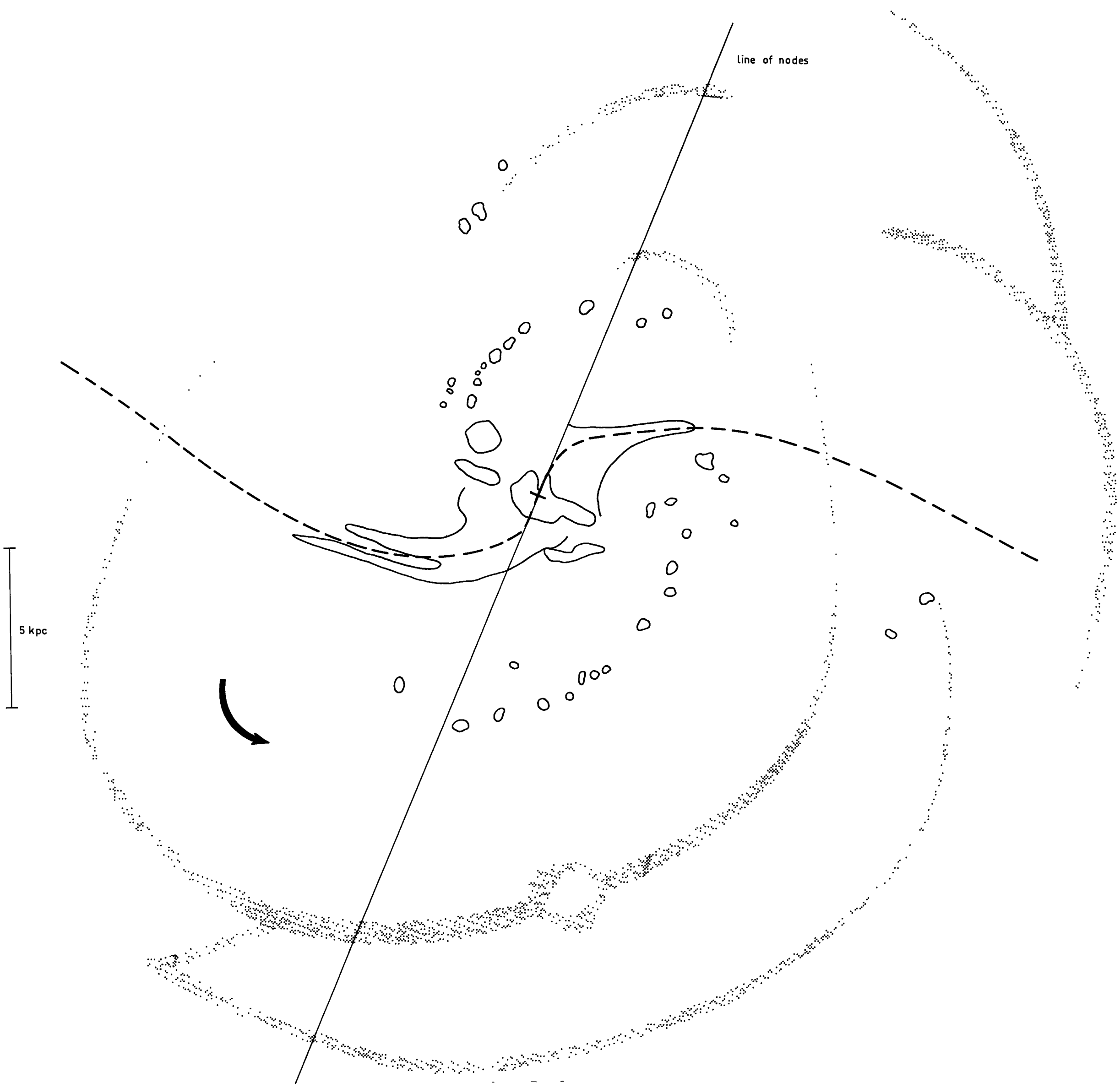

Fig. 6. Radio arms, anomalous H_α-arms and ordinary spiral arms drawn in the galaxy's equatorial plane on the supposition that all arms lie in this plane

4. The Plane of the Anomalous Arms and Their Shape

In the models discussed in the following sections we have assumed as a tentative working hypothesis that the H_α filaments and the strong radio ridges and plateaus are due to interaction between gas expelled from the nucleus with the interstellar gas in the disk of the galaxy, leading on one hand to ionization of the hydrogen and on the other hand to compression of the magnetic field, with consequent enhancement of the radio emission. This model requires that the expulsion has occurred mainly in the equatorial plane.

An alternative possibility would be that the emission comes from the expelled plasma without such interaction, as in the case of double radio galaxies. In this case the anomalous arms could lie in an arbitrary plane.

In the first model the shape of these arms finds a natural explanation in the rotation of the interstellar medium (cf. Sections 5 and 6). In the second model the shape must result from motion of the direction of eruption during the expulsion process, presumably due to the rotation of the nucleus.

Though we cannot yet decide definitely between the two alternatives there are several things which make it appear probable that the anomalous arms lie in the equatorial plane. Arguments tending to indicate that the filamentary H_α arms lie in this plane have been given in Section 2. There is one additional argument supporting the supposition that they lie in the disk: because of the absence of blue giants in these arms there must be another mechanism to ionize them. A plausible hypothesis is that they are being ionized by collision of the erupted gas with the disk medium, and must therefore lie in the disk. Because, so far as they are visible, the optical arms coincide precisely with the radio arms it is natural to assume that also the latter are situated in the galaxy's equatorial plane. As regards the radio emission a rather artificial model of expulsion would be required to explain the steepness of the preceding edges if they lay in a plane inclined to the disk of the galaxy, while these can be plausibly interpreted as the interaction front between the expelled gas and the interstellar medium if they lie in the equatorial plane.

Another argument favouring the hypothesis that the radio arms lie in this plane is that the *ordinary* arms appear to become fainter in the regions of strong radio emission, while normally one would have expected them to become *brighter* when followed inwards. This behaviour of the optical arms could be understood if the gas in these parts has been swept away by material expelled from the nucleus (cf. Section 7).

We hope that a more decisive check of our working hypothesis will be furnished by observations of the 21-cm hydrogen line which are now being made in Westerbork.

If the anomalous arms lie in the plane of the main spiral their run in this plane is roughly as indicated in Fig. 6. It shows the ridge lines of the radio arms and also the run of the anomalous H_α-arms. The assumed position angle of the line of nodes and the inclination were 157° and 64°.4, respectively, which are the values used by Burbidge *et al.* The inclination is from a determination by Danver (1942).

The figure illustrates again the close agreement between the radio arms and the H_α-arms, particularly in the south-eastern part, where the H_α-arms are best defined. But the most striking thing in the figure is the dissimilarity between the shapes of the "radio" arms and the "normal" arms; the latter have been sketched in with the aid of Sandage's 200-inch plate. The two sets of arms are also radically different in continuity. While the radio ridges – and in particular their steep edges – are smooth and continuous through the entire disk the normal arms are broken up into separate parts, and do not lie in a regular pattern. But the two systems of arms have two things in common, viz. that they are wound in the same sense, and that they end at virtually the same distance from the centre. This latter is rather important, because it suggests once more that the radio arms are in some way connected with the normal gas disk.

5. Expulsion Model

In the present state of our knowledge the most plausible explanation of the strong radioarms and the apparently connected H_α-arms appears to be that they have originated in an eruption of gas from the nucleus, possibly similar to the violent activity observed in the nuclei of Seyfert galaxies, although in the latter the matter may well have been expelled at considerable angles with the equatorial plane. Direct evidence that violent events have occurred is seen in the observations by Burbidge *et al.*, as well as by Chincarini and Walker; both of these investigations showed exceptionally large deviations from circular motion. Although part of the ejected matter apparently moved at considerable angles with the equatorial plane it may be that such vast eruptions as required for the formation of the radio arms take place *in* this plane.

We shall therefore use as a tentative working hypothesis that the peculiar phenomena observed in NGC 4258 are caused by a gigantic explosion in the nucleus which has thrown out gas in two opposite directions in the spiral's principal plane with such mass and velocity that it has moved through the entire disk. This gas, which we may picture as concentrated in clouds or filaments, is interacting with the quiescent gas in the disk. Ionization will occur in the shock front, thereby giving rise to the H_α-emission, while the accompanying compression of the disk magnetic field causes enhanced synchrotron radiation. The volume emissivity for a given density of relativistic elections is proportional to the $(1+\alpha)$th power of the compression, where α is the spectral index. As in NGC 4258 α is about 0.7 at 1415 MHz, the compression by a factor of about 4 in the shocked region of the interstellar gas would enhance the emission by a factor of about 10 if the relativistic-particle density would remain unaltered, or by a factor of 40 if this density is increased proportionally with the gas density.

We assume that relativistic electrons exist everywhere in the disk, being continuously replenished by supernovae or some other process. The total radio emission is comparable to that of other, "normal", spirals, so no extraordinary density of cosmic rays or exceptional magnetic field strength are required.

A quite possible alternative picture is that the gas ejected from the nucleus has already initially contained enough relativistic particles and magnetic field strength to explain the entire radio emission, and that the only role played by the interstellar medium has been to decelerate the clouds in such a way as to produce the observed shape and velocity of the arms. For the following computation it makes no difference which of the two pictures is adopted. But we do think that strong interaction with a pre-existing interstellar medium is essential.

We have considered, but rejected, the possibility that the arms would have been caused by beams of relativistic particles ejected from the nucleus. These would travel with the Alfvén velocity. This being of the order of only 100 to 200 km/s it would have taken such particles about 10^8 years to reach the outer parts of the radio arms. In this time the inner parts would have made several revolutions, so that the shape of arms formed in such a way could not resemble the observed pattern. Moreover, the beam of relativistic particles would have to contain an improbably high proportion of low-energy cosmic-ray electrons in order to provide the ionization of the H_α-arms.

The gas clouds hitting the interstellar gas do so with supersonic velocity, and will therefore create shocks. Before considering the results of the schematic calculations outlined above we must briefly discuss the consequences of the shock waves set up in this process. In the shock the interstellar gas will be heated to a very high temperature. The question is whether or not the shocked gas will cool fast enough for our snow-plow model to become an acceptable, though evidently crude, approximation.

The density in the shock will be $\sim 4\varrho(0)$. If we suppose the cloud to be much denser than the interstellar medium the initial temperature in the shock wave will be about $20\,V^2$ if V is the relative velocity in km/s (cf. Burgers, 1946, formula (16), in which ε has been taken zero, and a factor $\frac{1}{2}$ applied to T because of the complete ionization; cf. also Chow and Savedoff, 1972). Let us consider the time when the clouds were half way to the present ridge line, which may illustrate average conditions. In the models described below V at this time was generally in the range 500 to 1000 km/s, so that the temperature in the shock was between 5×10^6 and 20×10^6 degrees. The cooling coefficients, as given in a recent article by Cox and Daltabuit (1971; we are indebted to Dr. Habing for this reference) are shown below for velocities of 500 and 1000 km/s.

V km/s	T °K	Cooling coefficient	$\tau_{\mathrm{const.}\,\varrho}$ $10^6 y$	Z km/s
500	5×10^6	$2.4\times10^{-23} n_e$	$1.4 n_e^{-1}$	200
1000	20×10^6	$1.4\times10^{-23} n_e$	$9.0 n_e^{-1}$	400

If during the cooling process the density would remain constant the cooling times would be as given under $\tau_{\mathrm{const.}\,\varrho}$. If the undisturbed interstellar density would be of the same order as in the Galaxy, say 1 H/cm^3, n_e in the shock would be 4 cm^{-3}, and the cooling times would be short compared to the time of about 18 million years taken by the clouds to reach the ridge line. In this case the snow-plow model may give a fair approximation. The cooled interstellar gas would be heaped up against the clouds, its density becoming even higher than the density of $4\varrho(0)$ in the initial shock. As the magnetic field will be similarly compressed a considerable enhancement of the synchrotron emission should be expected near the contact surface between the cloud gas and the interstellar gas (cf. p. 8), which would explain the radio ridge. The cooling and compression phenomena are in this case rather similar to those of the high-velocity gas falling into the Galactic System and its interaction with the halo gas, a problem which has been discussed by Savedoff *et al.* (1967), and by Chow and Savedoff (1972). We refer to their articles for a detailed model of the evolution of the shock region.

Actually, the circumstances are complicated by the fact that the heated gas expands in the z-direction, perpendicular to the equatorial plane. The velocity of this expansion is of the order of that given under Z (in km/s, which is practically equivalent with pc/10^6y). If the gas layer had initially an equivalent thickness of 200 pc this would in the case $V=500$ be doubled in 0.5×10^6 years, i.e., in a time slightly longer than the cooling time for $n=4$ cm^{-3}. The real cooling time will therefore become only slightly longer if the expansion is taken into account. For $V=1000$ the conditions become radically different. Here the layer thickness would double in 0.25×10^6 years, and the density therefore decreases by a factor of 2 in a time of the order of only 1/10th of the cooling time for constant density. As the expansion will not halt until the layer has reached a thickness of the order of 10 kpc, and the cooling rate has gone down by a factor of the order of 100, the actual cooling time becomes long compared to the total traveling time of the clouds. This would generally hold for velocities above about 800 km/s. However, the clouds will gradually slow down in much the same way as in the snow-plow model, because they transfer roughly the same momentum to the shocked gas. In the model *B* considered below their final velocities are generally far below 500 km/s. In the last parts of their orbits they would therefore be accompanied by compressed interstellar gas, and our interpretation of the radio ridge as caused by compression of the disk magnetic field would remain generally valid. There would still be a hot shock region, but in particular for smaller *R*, where the final relative velocities are less than 200 km/s, it would be quite narrow, and might well have the appearance of the H_α-filaments.

6. Two Specific Models

In order to schematize the model as far as possible we have assumed that the expulsion took place in two opposite directions in the equatorial plane and was completed in a time much shorter than the time of revolution of the nucleus, so that all the matter was expelled in the same two directions. The computation of the orbits of the expelled clouds was made in the same way as in a former investigation by van der Kruit (1971a) on the expulsion of gas clouds from the nucleus of our own Galaxy. Because we have only very rough knowledge about the rotation curve and gravitational field in NGC 4258, and because over the optically observed region this does not seem to differ greatly from that in our Galaxy we have provisionally adopted the galactic gravitational field also for the calculations for NGC 4258. In further similarity to the computations for the Galaxy the orbit calculations were started at a distance *R* from the centre of 100 pc. In the present case this is an arbitrary radius. But as we know nothing about the mechanism of expulsion there was no particular ground for selecting another starting distance. In the orbit calculations a distance of 3.8 Mpc had been assumed for the galaxy (the value used by Rogstad *et al.* (1967) in their discussion of the HI line observations) while the distance finally adopted for the further discussions in the present article is 6.6 Mpc. The parameters for the orbits are the initial velocities V_0 (supposed to be directed radially away from the centre) and $d_0 = \sigma_0/\varrho(0)$ at $R = 100$ pc, where σ_0 is the column density of the cloud in the direction of motion and $\varrho(0)$ the average interstellar density in the central plane of the disk. d_0 is given in kpc; it is the length of a column with density equal to the general interstellar density having the same mass as a column of the same cross-section through the cloud. The parameter d_0 determines the braking effect of the interstellar medium. The interaction with the gas layer was estimated in a very crude way, with the "snow-plow"-model, assuming that the cloud simply sweeps up all the interstellar gas it meets. As a further simplification the gas density in the undisturbed disk was taken constant out to a radius of 4.2 kpc, which is the radius of the bright inner part of NGC 4258, and is also roughly where the H_α-arms fade out. The density was assumed to be zero outside this radius. In reality, as we see spiral arms out to about 15 kpc, there must be *some* gas in this outer region.

Clearly, the calculations are at best grossly schematic. But, as we cannot in any case hope to get more than order-of magnitude estimates, we have not attempted to improve on these first crude calculations, nor to repeat the calculation with the revised distance of 6.6 Mpc of the galaxy.

While moving through the gas disk the clouds will be braked in radial direction. But, as the medium through which they move is rotating, they will simultaneously be pushed in the direction of rotation, and acquire angular momentum. The orbits will therefore become curved in the direction of the rotation. Figure 7 illustrates this in some samples of trajectories, the parameters of which are indicated in the legend and in the figure. At the present moment the clouds all lie on the dashed curve. As will be shown below the expulsion parameters can be chosen in such a way that this curve will coincide with the ridge lines of the radio arms. The dashed curve would then be the frontier between the cloud gas and the interstellar medium. At each point of the orbit the direction of the braking force by the interstellar gas is opposite to the cloud's velocity *V* relative to this medium, which has been indicated by arrows in Fig. 7. Having lost no angular momentum to the ejected clouds the *stars* in the region of the disk through which these clouds have passed, and perhaps also a part of the interstellar medium which has not been "swept-up", must have advanced in front of the clouds. The region where these stars and this medium are at present is indicated by a dashed curve in Fig. 8 (see below); the other limit of this region lies along the ridge line in the figure. This region will be deficient in gas and young stars. This is confirmed in a striking manner by the observations. In particular Fig. 3 shows clearly that the regions preceding the H_α-arms emit less radiation than those behind them (cf. also Chincarini and Walker, 1967, Fig. 2).

We shall now consider the cloud orbits in two schematic models. In case A the clouds were assumed not to expand laterally during their motion. In case B they expand laterally in the direction parallel to the disk but *not* perpendicular to it. The expansion was taken proportional to the distance over which the cloud has traveled.

Case A

All expelled clouds were assumed to have the same column density; d_0 was taken equal to 1 kpc. The expulsion of all clouds was in the same direction and simultaneous, so that at any given moment the clouds all lie on one curve. If we consider the situation at the

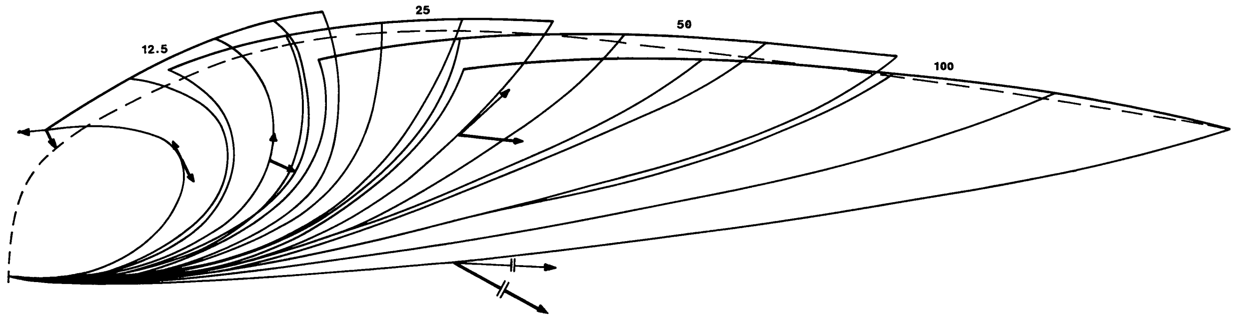

Fig. 7. Trajectories and isochrone of ejected matter in the equatorial plane, and comparison with radio arms. For data on the trajectories cf. Fig. 9. Thin arrows indicate the velocity of the cloud in the non-rotating frame of reference. Heavy arrows show the velocity relative to the undisturbed interstellar gas

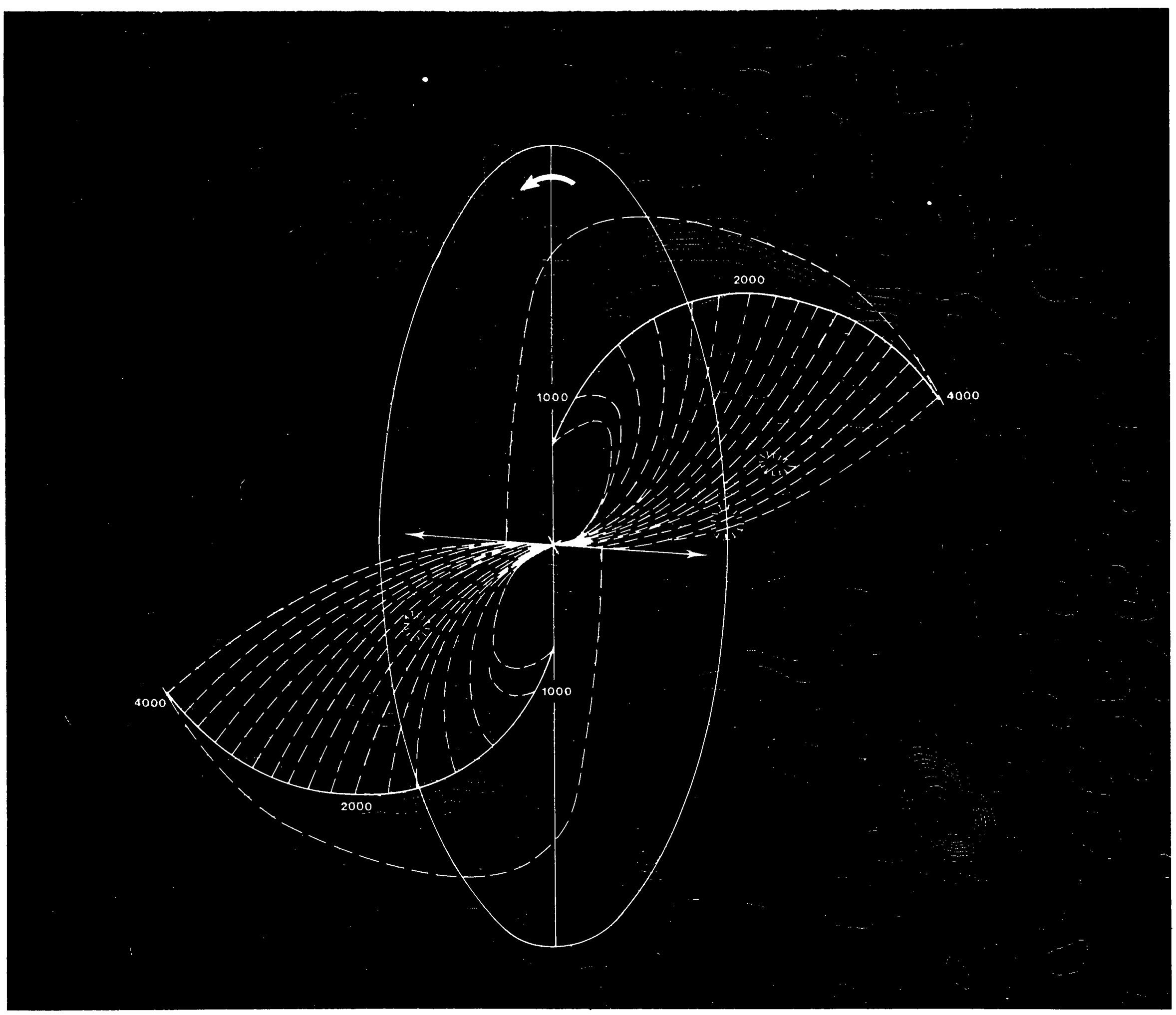

Fig. 8. Calculated trajectories and ridge line for case A superimposed on the radio contour map. The expulsion took place along the arrows, 17.5×10^6 years ago, with velocities V_0 ranging from 900 to 4000 km/s. The trajectories are calculated at intervals of 100 km/s in V_0. The inclination of the disk is 68°, and the deceleration parameter, d_0, 1 kpc. The region of the disk which was traversed by the gas is now, due to the rotation, situated between the dashed curve and the ridge line. The ellipse shows the assumed edge of the gas disk

present moment this curve may be identified with the H_α-arms and the radio ridge line. A good fit to these observed features was found to occur after 17.5 million years. To arrive at such a fit three more parameters have to be derived. These are the angle $\theta = 96°$ between the line of nodes (or the major axis) and the direction of expulsion, measured in the plane of the disk, the position angle of the line of nodes (this angle was

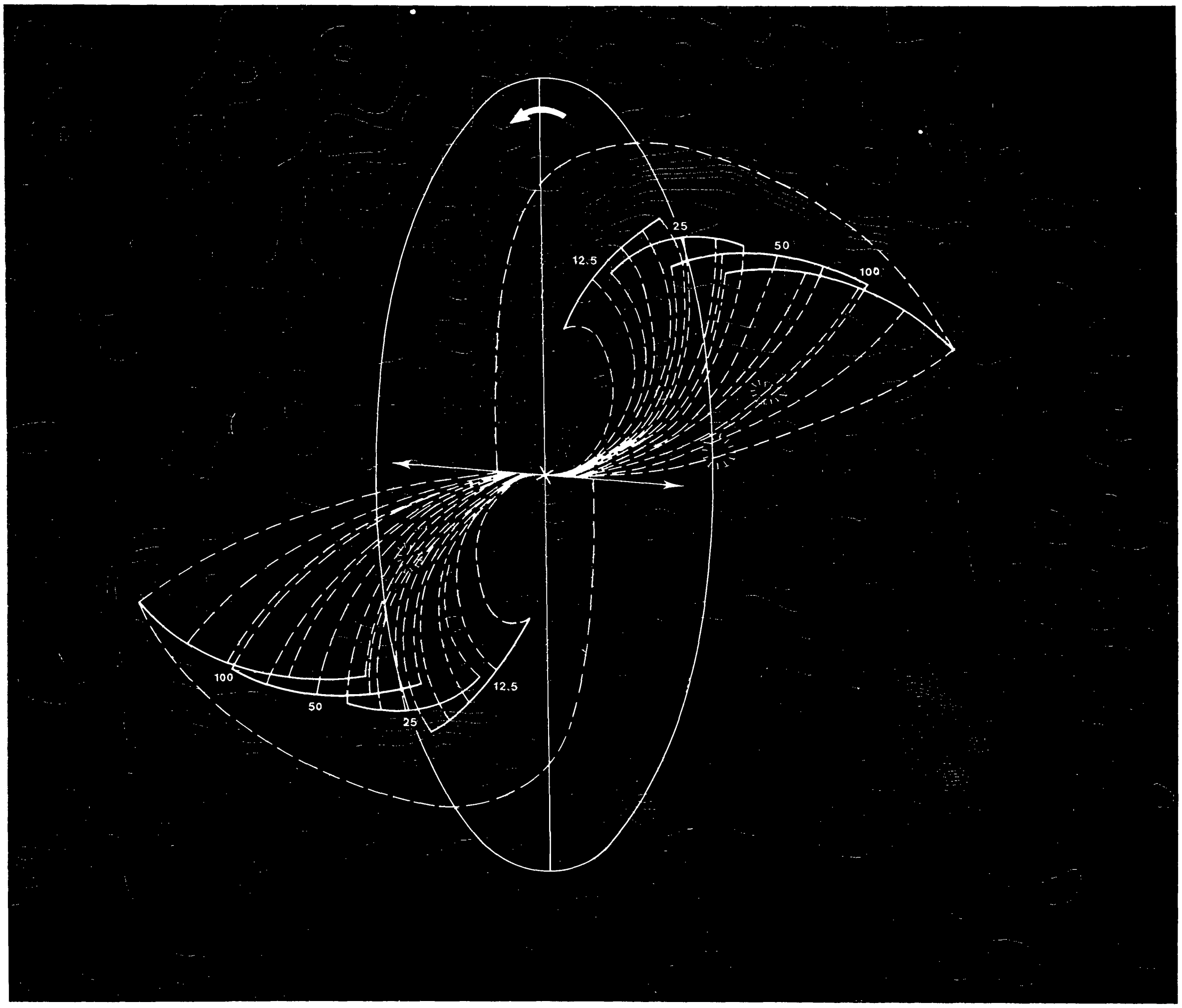

Fig. 9. The same as Fig. 8 for case B. Values along individual curves in the ridge give d_0 in kpc. Velocities range from 800–1600 km/s in steps of 200 km/s

$\Phi = 153°$ in the best fit) and the inclination of the disk ($i = 68°$). These last two are in good agreement with the values used by Burbidge *et al.* (1963), 157° and 64° and by Chincarini and Walker (1967), 155° and 64°. The projected trajectories and the predicted ridge lines are shown in Fig. 8 superimposed on the contour map. The assumed edge of the gas disk is also indicated, together with the sense of rotation. The dashed curve has been explained on *p.* 10.
The two opposite directions of expulsion are indicated by the arrows.

Case B

In the second case the clouds were taken as expanding in one direction, and different values of the deceleration parameter d_0 were taken ($d_0 = 12.5, 25, 50$ and 100 kpc). In this case a smaller range of V_0 suffices to give the total extent of the ridge line. V_0 ranges from 800 to 1600 km/s, and all combinations of d_0 and V_0 (V_0 in steps of 200 km/s) were calculated. The projected trajectories are shown in Fig. 9 in the same way as in Fig. 8. The time after the expulsion is again 17.5×10^6 years and the same values are used for $\theta(96°)$, $\Phi(153°)$ and $i(68°)$. In some cases the computation is unrealistic, e.g. the gas with $V_0 = 1400$ km/s, $d_0 = 12.5$ kpc moves in front of the cloud with $V_0 = 1000$ km/s, $d_0 = 25$ kpc, and therefore does not move through an undisturbed region. This results in a smaller increase in angular momentum for this cloud and it will therefore not rotate through such a large angle as indicated in the figure. It is then to be expected that it will more or less move along with the latter cloud. Thus the broken ridge-line in Fig. 9 will in reality be a smoother structure that is something like an average of the given curves.
There will presumably also be a dependence between V_0 and d_0. Clouds with high d_0's have generally relatively higher masses and might tend to have lower velocities.
To illustrate the velocities in the ridge line we use the second case. For the orbit giving the inner end of the calculated ridge line ($V_0 = 800$ km/s, $d_0 = 12.5$ kpc)

$V_{\tilde{\omega}} = -111$ km/s and $V_\theta = 224$ km/s. This gas rotates almost with the local circular velocity but is falling back in. For a point half-way to the ridge, at a time 6×10^6 years after the eruption, we have $V_{\tilde{\omega}} = 98$, $V_\theta = 117$ km/s. For the orbit with $V_0 = 1200$ km/s, $d_0 = 50$ kpc the velocities at the outer and mid-way points are $V_{\tilde{\omega}} = 191$, $V_\theta = 68$, and $V_{\tilde{\omega}} = 296$, $V_\theta = 106$, respectively. For the outermost orbit shown they are $V_{\tilde{\omega}} = 697$, $V_\theta = 48$, for mid-way and $V_{\tilde{\omega}} = 630$, $V_\theta = 25$ km/s at the present time.

The calculations show that the ridge line can in principle be represented by the kind of models used. The problem contains too many unknown parameters to calculate detailed models and to give accurate values of time scales, velocity range, and so on. The most serious simplifications in our calculations are (1) the mass model used, (2) the assumptions concerning the interaction with the quiescent gas layer, (3) the assumption that all gas was expelled in the same direction. The assumption that the gas density outside $R = 4.2$ kpc is negligible is also clearly unrealistic, for we see faint outer arms up to about 15 kpc from the centre, and – more important – the radio ridge extends to similar distances, indicating compression of an existing medium. However, with the little data we have, a more refined model seemed hardly justified. As regards (3) it is evident that in reality the expulsion must have subtended a finite cone. The width of the expulsion cone perpendicular to the plane of the disk will have caused some of the expelled gas to get out of the gas disk. However, as long as the Z-component of the initial velocity did not exceed 100 km/s, corresponding with an average angle of about 5° with the equatorial plane, the gas would fall back into the disk in a sufficiently short time, so that the present computations could still be applied.

7. The Radio Plateaus and Indications of Interaction with the Normal Arms

The general emission from the *radio plateaus* behind the ridge lines has been mentioned on p. 6. The emission from these plateaus is rather strong; the western plateau is even stronger than the brightest parts of the ordinary spiral arms in this galaxy as well as the base disks in other galaxies, which vary from a few tenths of a degree to a few degrees (2.5 °K in M51; cf. Mathewson *et al.*, 1972). Both plateaus extend over a large sector in position angle. The western plateau extends farther to the south than the expulsion direction found from the above model; similarly the eastern plateau extends much farther to the north. The plateaus are probably caused by clouds expelled in smaller position angles, the "ridge lines" of which would thus at present lie behind the main ridges. Such an extent in position angle in the equatorial plane is not unlikely, if only because the eruption process must have extended over a certain time. Since the rotation period of the nuclear region is at most 11×10^6 years (cf. Section 2) the nucleus, and with it presumably the direction of the expulsion, would have rotated over at least 30° if the activity has lasted a million years. The strongest burst and the largest velocities should then have come at the end of this period. The evident irregularities in the plateaus, and, for instance, the apparent splitting of the western ridge into two branches, may be indications of discontinuities in the eruptive process. It should be noted that because of the sensitivity of the synchrotron emission to changes in the compression factor, relatively small differences in the latter may cause appreciable differences in intensity. Thus, a small asymmetry in the expulsion properties or in conditions of the disk may well have been responsible for the origin of the radio asymmetry between the eastern and western sides.

A remarkable feature of NGC 4258 is that the normal optical spiral arms become weaker around the middle of the plateau. For instance, the bright south-western arm shows a striking decrease in intensity when followed to the north (and, therefore, inward, where arms normally increase in brightness). There is a similar weakening of the faint outer western spiral arm.

Now this is just what one should expect in our model. For those parts of the original spiral arms which were in the way of the expelled clouds must have weakened compared to the undisturbed parts. What remained of the arms after the passage of the clouds will by the rotation of the disk have been carried in front of the clouds; the weakening of the arms therefore becomes pronounced only around the middle of the plateau, and extends beyond the intense radio ridge into the region indicated by the dashed curve in Fig. 8.

8. Mass Estimate

We shall finally try to make an estimate of the total mass which has been expelled from the nucleus. The continuity of the H_α-arms and the similar continuity of the radio ridge might be taken as an indication of a fairly complete coverage of the ridge line by the expelled clouds. Should this inference be correct it would imply that the expelled gas had swept up a major part of the interstellar medium in the regions traversed by it. As these regions comprise nearly half of the entire disk it would follow that the swept-up gas might be of the order of half the total gaseous mass of the galaxy.

An order-of-magnitude estimate of the total mass that would have had to be expelled in order to completely cover the ridge line may be made in the following manner. Consider an interval of 1° on the 100-pc circle. In case B this would on the average ultimately fill about 1° of the sector subtended by a ridge line. With an average $d_0 = 50$ kpc, an assumed layer thickness of 200 pc and an assumed $\varrho(0) = 1$ H atom per cm^3, the mass of this 1° sector would be $4 \times 10^5\ M_\odot$. As each ridge covers about 80° in position angle the total expelled mass for the two ridges would have been about $7 \times 10^7\, M_\odot$. This is an upper limit, as we do not know whether the ridges are completely covered by the expelled clouds.

With an average expulsion velocity of 1200 km/s the corresponding upper limit for the kinetic energy at the expulsion is 10^{57} erg.

The expulsion can probably not have lasted more than about a million years. For, according to the optical observations, the rotation period of the innermost region is of the order of 10 million years, and, as the ejection has not extended over more than about 45° in position angle, the time interval should have been less than 1.2 million years. The rate of outflow must therefore during this period have been extremely high, at least of the order of 100 solar masses per year. With an initial thickness of the order of 10 pc for the ejected clouds these would have had densities ranging from about 10^3–10^4 atoms/cm^3, if d_0 ranges from 12.5–100 kpc as in our model B.

Observations of the distribution and motion of neutral hydrogen in NGC 4258 which are now being made in Westerbork may give information on the amount of cool gas connected with the radio arms, and may shed more light on the formation of these arms, as well as on the degree to which the sectors just mentioned have been swept clean of H I.

9. Remarks on Other Cases of Expulsion

Large-scale expulsion of mass from nuclear regions has been observed in a number of galaxies, though rarely on a similar scale. Beside Seyfert galaxies the most striking cases are presented by M82, NGC 1275 and by radio galaxies. In the latter the small widths of the cones in which the plasma eruptions have apparently been concentrated seem to indicate that the expulsion took place in the direction of the rotation axis. In NGC 5128 the radio structure indicates that there have been a number of distinct successive eruptions, all in the same two opposite directions, which seem to suggest rather forcibly that this direction must have been the rotation axis. In M82, likewise, the phenomena point to an expulsion in a general direction which made a large angle with the equatorial plane, and may well have been perpendicular to it. In NGC 1275, where the most violent expulsion known has taken place, the phenomena seem again quite different from any of the other known eruptive nuclei. In the case of our own Galaxy there is very direct evidence for ejection of large masses of gas from the nucleus at velocities of the order of 600 km/s at angles of 25–30° with the galactic plane (cf. van der Kruit, 1971a).

NGC 4258 gives the first clear evidence of a large-scale ejection which seems to have been roughly *in* the plane of rotation. On a small scale this may also have occurred in Walker's so-called "fan-jet" in M87 (Shklovsky, 1972).

Apparently, matter can be ejected from the nuclear regions of galaxies by various differing mechanisms.

10. Do the Phenomena in NGC 4258 Show the Birth of Spiral Structure?

It is tempting to speculate about the possibility that the radio arms and the peculiar H_α-arms might represent the birth process of normal spiral arms.

The radio arms, whose run in the equatorial plane is shown in Fig. 6, will after a time of the order of 100 million years (the rotation period at $R \sim 5$ kpc) develop into a regular spiral pattern extending over the entire system. We have seen that these radio arms can, and probably *will*, have been formed by expulsion of matter from the nucleus. Apparently, "grand-design" spiral structures can originate in this way. Whether these structures can be identified with normal spiral arms depends on the amount of interstellar gas that has been collected in them. They will develop into full-fledged arms only if, as suggested in the preceding section, a large fraction of the gas in the sector traversed by the expelled clouds has been swept up and has cooled sufficiently to be amassed near the radio ridges. The radio plateaus behind the ridges indicate that there must be much cooled compressed interstellar gas in these regions. Like the main ridges this gas must have less angular momentum than the undisturbed disk gas at the same R. It will therefore gradually be pushed forward by the undisturbed gas following behind it and may ultimately become concentrated into the embryo arms near the ridge line. This process may continue until the velocity of the new spiral feature has everywhere approached the circular velocity to within about 25 km/s, when the sweeping-up becomes too slow.

The total interstellar mass which can by this simple hydrodynamical mechanism in principle be collected in spiral arms formed by expulsion of mass from the central region is roughly ten times the mass expelled. This can be seen from a simple reasoning based on the conservation of angular momentum. The original disk gas can transfer angular momentum to the "jet" of expelled matter until the relative velocity becomes of the order of 1/10th of the velocity of rotation. At that stage the fraction of the disk that could catch up with the new arms in one revolution would have decreased to 1/10th, and would soon after become negligible. To form spiral arms with a mass of $10^9\, M_\odot$, about $10^8\, M_\odot$ would thus have to be expelled. It must, moreover, be expelled with such a momentum that, like in NGC 4258, it can reach the outer limit of the disk.

It has been felt for some time that spiral structures, though they can probably be maintained as waves during a few revolutions, need periodic renewal, or excitation. With an angular velocity of the wave pattern and density in the arms such as have been used for models of the spiral structure in our Galaxy, the energy transport in a density wave through a circle in the galactic plane calculated for a sound wave in an ideal gas, is of the order of 10^{46} erg/year. Explosive events of such magnitude as described in the present article, if taking place once every 10^9 years, could supply such an energy even if they had an efficiency of only 1%.

That there is need for a mechanism which can periodically (say, every 500 million years) put fresh order into spiral structure seems indicated in particular by the enormous irregularity of almost all spiral galaxies. This mechanism might well be the same as that which we have surmised for the explanation of the radio and H_α-arms in NGC 4258. As the life time of structures like these will be at most of the order of 50 million years (in which time the parts at $R \sim 5$ kpc will be carried forward by about 180° relative to the outer parts, so that the features might no longer be distinguishable from normal spirals) we might then expect that at most about 10% of all spirals should show such anomalous arms. Up to the present we have found no other similar case among several dozen suitable spiral systems observed with the Westerbork telescope. However, not all of these have been completely synthesized. NGC 4258 is among the 15 nearest giant spirals above +35° declination that have been fully observed. The only spiral in which *somewhat* similar phenomena have been found is our own Galaxy (cf. p. 14), and possibly also in NGC 4736 (van der Kruit, 1971b).

It might be that such a cleansing process as we have proposed for NGC 4258 would remain largely restricted to the interstellar medium, and that the main, *stellar*, density wave would not be drastically affected. The problem of the interaction between a newly formed gaseous wave and a pre-existing stellar density wave needs further study.

If masses of the order of $10^8 M_\odot$, as estimated in the case of NGC 4258, are periodically expelled from the nuclear region this gas must in some way be replenished. One of the most interesting difficulties in connection with these massive eruptions is the origin of the expelled gas. As explained below it appears improbable that the gas could be replenished in sufficient quantity by the evolution of the *stars* in the central region, and one is therefore led to consider the existence of a less conventional source.

The amount of interstellar gas produced by evolving stars in an old population I may be estimated with the aid of data derived by Sandage (1957) for the cluster M 67. From the evolution times given in his Table 5 for stars on the left side of the horizontal branch we infer that per 0.0944×10^9 years all the stars which had initial bolometric absolute magnitudes between +3.84 and +3.86 move toward the white-dwarf stage. With more recent estimates on the age of the cluster this time interval is increased to 0.19×10^9 years. As the initial mass of these stars was about $1.4 M_\odot$, and the average mass of a white dwarf has been estimated at about $0.5 M_\odot$, each of these evolving stars sheds perhaps about $0.9 M_\odot$ into interstellar space.

We next estimate which fraction of the total mass of the stars in an element of volume has an absolute magnitude between +3.84 and +3.86. From Van Rhijn's (1965) luminosity function, with a small correction to reduce to the initial luminosity function, we estimate that this fraction is roughly 9.4×10^{-5}. Per 10^9 years the fraction moving to the white-dwarf stage would then be 5×10^{-4}. In our Galaxy the total mass within $R = 100$ pc is estimated at $0.9 \times 10^9 M_\odot$, and within $R = 500$ pc at $8 \times 10^9 M_\odot$ (Rougoor and Ort, 1960). Within $R = 100$ pc the yield of gas per 10^9 years would thus be $4 \times 10^5 M_\odot$. Roughly 9 times more might be collected if all the gas produced within 500 pc of the centre could ultimately flow into the nucleus, but this is evidently a quite uncertain hypothesis. Even in this extreme case the amount of gas produced is an order of magnitude less than the mass we estimated as having recently been expelled from the nucleus of NGC 4258. Moreover, the above estimates may well be an order of magnitude too high, because judging from the M/L ratio in M31 (Rougoor and Oort, 1960; Oort, 1971) the central regions may contain a much greater proportion of faint dwarfs than given by Van Rhijn's luminosity function. These stars contribute to the mass but not to the production of gas.

A similar discrepancy between the quantity of gas apparently flowing out of the nuclear region and the quantity that can be produced by evolving stars has been noted for our own Galaxy (Rougoor and Oort, 1960).

Other possible sources that have been suggested by which exploding galactic cores might be replenished are stellar collisions and inflow of intergalactic gas. If the star densities in the nuclei of spiral galaxies are generally comparable to the density in the nucleus of our Galaxy, which is of the order of $10^6 M_\odot/\mathrm{pc}^3$ within 1 pc from the centre (Oort, 1971), the amount of gas that can be produced by collisions, even over periods as long as 10^{10} years, falls far short of what would be needed to provide for such ejections as we suppose to have occurred in NGC 4258, or even for the smaller masses of the expanding hydrogen in the central region of the Galactic System. Inflow of gas from intergalactic space cannot be dismissed as a possible source, if gas flowing into a central disk can in some way be concentrated into the nucleus. Estimates based on high-velocity hydrogen at high latitudes in our Galaxy indicate quantities that are at least an order of magnitude too low, but it is not unlikely that for NGC 4258, situated in a group where the density of galaxies, and probably also of intergalactic gas, may be an order of magnitude higher than in the Local Group, the inflow is much higher.

It seems that the hypothesis that spiral arms are transformed by an eruption from the nucleus involves the hypothesis of a still unknown source of replenishment of interstellar gas. Such a source might either be inflow of intergalactic matter in yet unprecedented strength, or one or more non-stellar bodies of large mass in the nucleus, such as were first surmised by Ambartsumian (1958, 1964), in order to explain the activity of galactic nuclei, or, perhaps, a much faster production of gas by stellar evolution than predicted by existing theories.

If explusion of matter from a nucleus can give birth to a spiral structure extending over an entire galaxy it should also be capable of producing a structure which is confined to the inner part of a galaxy. The process may explain the occurrence of nuclear spiral patterns which are unconnected with outer spiral arms. The most striking example is shown by the SBa galaxy NGC 4314. This has a bright small spiral of about 600 pc radius at the centre of a smooth and much larger bar, from the ends of which an outer spiral structure extends (cf. Sandage, 1961, p. 44).

The idea that the structure of a galaxy may have been strongly influenced by processes in the nucleus is not at all new. It has been advanced in particular by Ambartsumian, who has on many occasions stressed his opinion that the nucleus plays a decisive role in the formation and evolution of the entire galaxy (cf. especially his reports at the Solvay Conferences of 1958 and 1964; Ambartsumian, 1958, 1964). A suggestion that spiral arms might come from the nuclei has also been made by Arp (1969a and b).

NGC 4258 is at present being observed at Westerbork in the 21-cm line. These measures will provide information on the amount of neutral hydrogen near the radio ridges, and may show whether or not the above speculations have a basis of reality.

Acknowledgements. We are deeply indebted to the telescope group in Westerbork under the direction of Dr. Raimond and Dr. Weiler, and to Mr. van Someren Gréve and the computing division in Leiden for producing the observations on which the article is based. We thank Mr. Schoenmaker for determining an accurate optical position of the nucleus. Mr. Kleibrink's skill has contributed in an essential manner to the presentation of the results. We are obliged to Mr. Jaffe for the cathode-ray radio picture, to Dr. Courtès and Mr. Deharveng for enlargements on films of their interference filter photographs and for their permission to reproduce these, to Dr. Sandage and Mr. Miller for a film enlargement which has been used for the reproductions in Figs. 1 and 4. We have profited from discussions with various members of the staff of Leiden Observatory and with B. Burke.

The Westerbork Radio Observatory is operated by the Netherlands Foundation for Radio Astronomy with the financial support of the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

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