PART II

POINT SOURCES: INDIVIDUAL STUDY AND PHYSICAL THEORY

PAPER 17

OPTICAL INVESTIGATIONS OF RADIO SOURCES

INTRODUCTORY LECTURE BY

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Loose agreement of a radio position of low accuracy with that of some object listed in the NGC is not sufficient to provide the identification of a radio source. Even satisfactory coincidence of a precise position with that of an astronomical object requires supporting evidence. Agreement of the size of the source with that of the visible object, at least in order of magnitude, is an important argument in favour of an identification; exact agreement of sizes can be expected only where radio and optical emission are physically connected. The radio spectrum, the optical spectrum, and the physical characteristics of the visual object also have to be taken into account. Observations of the radio spectrum should be particularly useful to support the identification of sources with H II regions which can be recognized from their thermal emission even if they are obscured and optically inaccessible. If all data are available, satisfactory agreement exists between optical and radio observations. The best example of this kind at the moment is perhaps NGC 2237, the Rosette nebula, reported as a source by Ko and Krauss (1955) [1] and also observed by Mills, Little and Sheridan (1956 [11]; see also paper 18).

The number of positions observed with adequate accuracy has increased considerably during the last year. But for very few sources has it been possible to make identifications or even to find objects worthy of the detailed optical investigation necessary to support a possible identification. Since the optical investigations usually require the use of a large telescope, almost regularly the 200-inch telescope, their cost in observing time is high. Work of this type appears justified only for sources with positions whose uncertainty is of the order of a minute of arc. High positional accuracy is therefore of basic importance.

The reasons why a high percentage of the sources cannot be seen or identified will depend upon the various types of sources. Extended sources should be easy to identify. But among twenty-five extended sources for which positions were communicated by Ryle in advance of publication there is only one which is perhaps not too far removed from some recently discovered peculiar filaments to assume that this source is due to a filamentary nebulosity; most of this nebulosity could be obscured and the few visible filaments could be near its edge [12]. Of these twenty-five sources ten are in more or less heavily obscured areas at low galactic latitudes. That they cannot be seen is not particularly surprising. Some may be H II regions which should be established by investigation of the radio spectra.

The remaining fifteen sources in unobscured areas at high latitudes are a group of considerable interest. Objects of this kind have also been found by several other observers. These objects cannot be H II regions, nor can they be nearby extra-galactic systems of any known type. Since they are invisible, radio observations will have to find an answer to the puzzle. Some of the sources may represent blends of several objects, but it does not appear statistically reasonable to assume this explanation for more than a small fraction. The question thus arises whether they are really extended, in which case gas clouds with non-thermal radio emission unaccompanied by optical emission are at this moment the only plausible explanation, or whether the extent is not intrinsic, but due to some scattering effect, e.g. in interstellar clouds. This question is also raised by the excess of the radio dimensions of some extra-galactic objects over their optical size.

The situation is quite different for small sources which may be optically inconspicuous objects, such as peculiar galaxies and possibly stars. Cygnus A is near the limit where a peculiar object of this type can still be recognized by simple *inspection* with the 200-inch telescope. Another source of this type is Hercules A which has quite recently been found to be a double galaxy with high-excitation forbidden line emission at a distance of $1\cdot4 \times 10^8$ parsecs, about $1\cdot5$ times the distance of Cygnus A. More distant objects of this type might provide many identifications, but positions of the accuracy achieved by F. G. Smith and considerable work with the 200-inch telescope are required. The limit at which objects of the Cygnus A type can still be recognized should be at a distance of $\cdot1$ to 2×10^9 parsecs.

Much less conspicuous than the peculiarities of colliding galaxies is that of M87. This galaxy would be very difficult to recognize as containing a peculiarity if seen from another direction or at a much greater distance. The nature of the peculiarity is still not understood. But M87 demonstrates

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clearly that even relatively nearby galaxies might have peculiarities which are very difficult to observe, if at all. It is therefore impossible to deny that an apparently normal distant galaxy might be the proper identification for a radio source. However, an identification requiring strongly enhanced radio emission from a normal-appearing galaxy seems acceptable only if based on a position of the highest accuracy.

To identify stars as sources requires impossible positional accuracy. At the moment, the best hope to identify stars as radio sources is offered by the observation of variability of certain sources by Slee and by Kraus. Intrinsic rapid variability is conclusive proof for the stellar character of an object. However, radio variability does not necessarily imply observable optical variability.

I. SINGLE GALAXIES

Even now a considerable variety of objects have been identified as sources which offer diverse observational problems. Normal galaxies are safely established as sources. One main problem at the moment is the relation between optical and radio magnitude. The present observations are not sufficient to decide how much of the scattering around a constant difference between the two magnitudes is intrinsic and how much of it is due to differences between the various types of galaxies. Results by Mills (1955 [13]; see also paper 18) favour the point of view that such differences exist, but the material has to be substantially increased before a final conclusion seems permissible. The two main difficulties met by such an investigation arise from optical absorption effects and from weak peculiarities. As an example of the first difficulty one may consider NGC 891 which is seen edge-on and has a very heavy absorption lane. Some part of the excess radio emission which follows from the observation of this nebula by R. Hanbury Brown is obviously due to the reduction of optical brightness by the absorption lane. It is, however, hardly possible to explain in this way a magnitude discordance of about 2 mag. But the absorption lane may also hide a peculiarity; it is not possible to be certain that NGC 891 is a normal galaxy. Obviously, objects of this type are not suitable samples. The second difficulty may be illustrated by NGC 1068 which Mills finds about 1 mag. brighter than the average Sb galaxy. Actually, NGC 1068 is long known to be one of the otherwise normal appearing galaxies whose small and bright nuclei emit a spectrum similar in its composition to that of a planetary nebula but with lines of great width corresponding to velocities of several thousand km./sec. This phenomenon is as yet unexplained. If the peculiar state of the nuclear gas involves radio emission with a volume emissivity equal to that in the Crab nebula, the excess radiation would be more than fully explained. In any case, NGC 1068 is not a good sample of a normal nebula.

It has already been mentioned that the peculiarity of a galaxy may evade optical observations. A good example is NGC 1316 which also serves well to demonstrate the complexity of the identification problem. The survey position (Mills, 1952) [2] and the precise position (Mills, 1952) [3] of the source in question were communicated in 1952 in advance of publication. The proximity of NGC 1316 to the source was noted, but the suggested identification did not seem acceptable to the Australian observers who considered the positional agreement in declination as inadequate. Moreover, Bolton and Mills were unable to agree on the exact right ascension and the intensity measured on different interferometers and on this suggested an extended source. Shklovsky (1953) [4], knowing only the survey position by Mills but not the later precise position, suggested again the identification with NGC 1316 and tried to support it by claiming similarity of NGC 1316 to NGC 5128. This similarity was also suggested by de Vaucouleurs (1953) [5]. However, there can be no doubt that the impression of similarity was due to an over-interpretation of a small-scale photograph. Actually, NGC 1316 (see Baade and Minkowski, 1954) [6] is an early-type galaxy with some absorption patches which suggest the beginning of spiral formation, possibly of a barred spiral. NGC 5128 (see Baade and Minkowski, 1954) [7] seems to be a combination of an early-type system with the major axis in position angle about 45° and a late system containing much gas and dust in position angle about 135°. Moreover, NGC 5128 has a G-type absorption spectrum with emission lines strong enough to have been seen by Hubble on objective prism exposures. Its spectrum shows considerable internal motions which support the point of view that two galaxies are in interaction. On the other hand, NGC 1316 has a G-type spectrum without emission lines; not even [O II], λ 3727 is observable. The similarity of the two systems cannot be maintained. This does not imply, however, that NGC 1316 has to be a normal galaxy. Actually, a recent position by Mills with the cross shows the presence of a source in excellent positional agreement with NGC 1316. This seems to admit no other conclusion than that NGC 1316, probably as part of a blend giving the appearance of an extended source, is actually a galaxy with fairly strong enhanced radio emission but without obvious strong optical peculiarity other than the appearance of a few absorption patches in an early-type galaxy.

The identification of a source due to a collision between galaxies presents relatively little difficulty. Large nearby systems of this kind can easily be recognized from their appearance. Actual collisions seem to lead to conspicuous emission of forbidden lines of high excitation which can still be observed in objects too distant and thus too small to reveal their nature from their appearance. While it seems not yet possible to predict the strength of the radio emission from the appearance of a given object, the sequence of conditions seems basically clear. Close pairs of galaxies, such as NGC 4575/4576, without visible signs of interaction do not show enhanced radio emission. Close pairs with large tidal interactions, such as NGC 4038/4039, may give somewhat enhanced emission. Unpublished observations by Mills suggest that this object may be an emitter of somewhat more than normal intensity. Spectroscopic observations of NGC 4038/4039 show that the radial-velocity difference between the systems is small. The interaction would thus be expected to be weak, but at the same time of long duration favouring strong distortion. A strongly distorted galaxy such as NGC 2623 might be of somewhat similar kind. This system coincides closely with a source observed by Ryle. Spectroscopic observations show little gas, revealed by faint emission of [O II], λ 3727, but a spectrum of type A, a relatively rare type for galaxies. It might be that the other system is now on the far side and hidden. The interaction might be near its end and could have removed most of the gas from NGC 2623, while still-surviving early-type stars of population I could explain the early spectral type.

Strong interaction is represented by systems like Cygnus A, Hercules A, and NGC 1275. The most powerful source of this type, Cygnus A, is unfortunately too distant, thus too small and faint to permit a detailed optical investigation. The radio interferometric results suggest that the radio emission arises in outlying parts of this system which are optically unobservable. The full dimensions of the system indicated by the radio results are large, but tidal filaments in some systems extend much farther. There is thus no obvious contradiction to astronomical facts.

NGC 1275 is the only known sample of colliding galaxies which is suitable for a detailed optical investigation. That this object and not the Perseus cluster of galaxies is to be identified with the small source in its position is now safely established. The system consists of a tightly wound spiral of early-type and a strongly distorted late-type spiral. Inspection of blue and red exposures shows some unusual features regarding the colours

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and distribution of emission patches connected with the distorted spiral arms of the late-type system. A detailed spectroscopic investigation leads to the surprising results shown in Fig. 1. Spectrograms were obtained with the positions of the slit indicated on the left half of the figure. To the right are shown the sections of these spectrograms which contain the [O II] lines. In the northern part of the object, two sets of lines appear, separated by about 3000 km./sec., which show unmistakably the presence of two separate gas masses. Comparison of the structural details on the direct photographs with the spectrograms shows that the velocities of the early spiral and of the late-type system are about +5200 km./sec. and +8200 km./sec. respectively. Since the absorption patches of the late-type systems are obviously in front, the northern part of the late-type system moves toward the early spiral. Going from the north towards the nucleus of the early spiral one finds this same condition, but a fundamental change occurs between the nucleus and the nearest position to the north of it which has been investigated until now. Superposed on the nucleus, and extending beyond it into the object, appears a spectrum containing one set of high excitation emission lines of very great width, slightly asymmetrical towards the violet, which were first observed by Humason and later investigated in some detail by Seyfert (1943) [8]. This same spectrum appears also to the south of the nucleus. It should be noted that this is an important difference from the nebulae with nuclei containing emission lines in which the high excitation spectrum is confined to the nucleus.

The interpretation of these results is obvious. The two galaxies, which are seen nearly face on, are in collision. They are inclined towards each other in such a way that originally the southern part of the late system was closer to the early spiral. As the galaxies moved towards each other, the collision started in the south and progressed to the north, where interaction between the separate gas masses of the two galaxies is now going on. Farther to the south, probably from some line slightly to the north of the nucleus on, the collision is over, leaving the combined gas mass formed by the collision in a highly heated and excited condition. The velocity of the combined gas differs little from that of the early spiral; this requires that the mass of the gas in this system was considerably higher than that in the late-type galaxy. This result does not appear improbable. The early spiral is a system of very high luminosity having an absolute magnitude $M_{pg} \approx -19$ and may be expected to contain a correspondingly large mass of gas. More detailed discussions of the conditions in this system have to wait for additional observations.

If one uses a crude model in which the gas masses are considered as

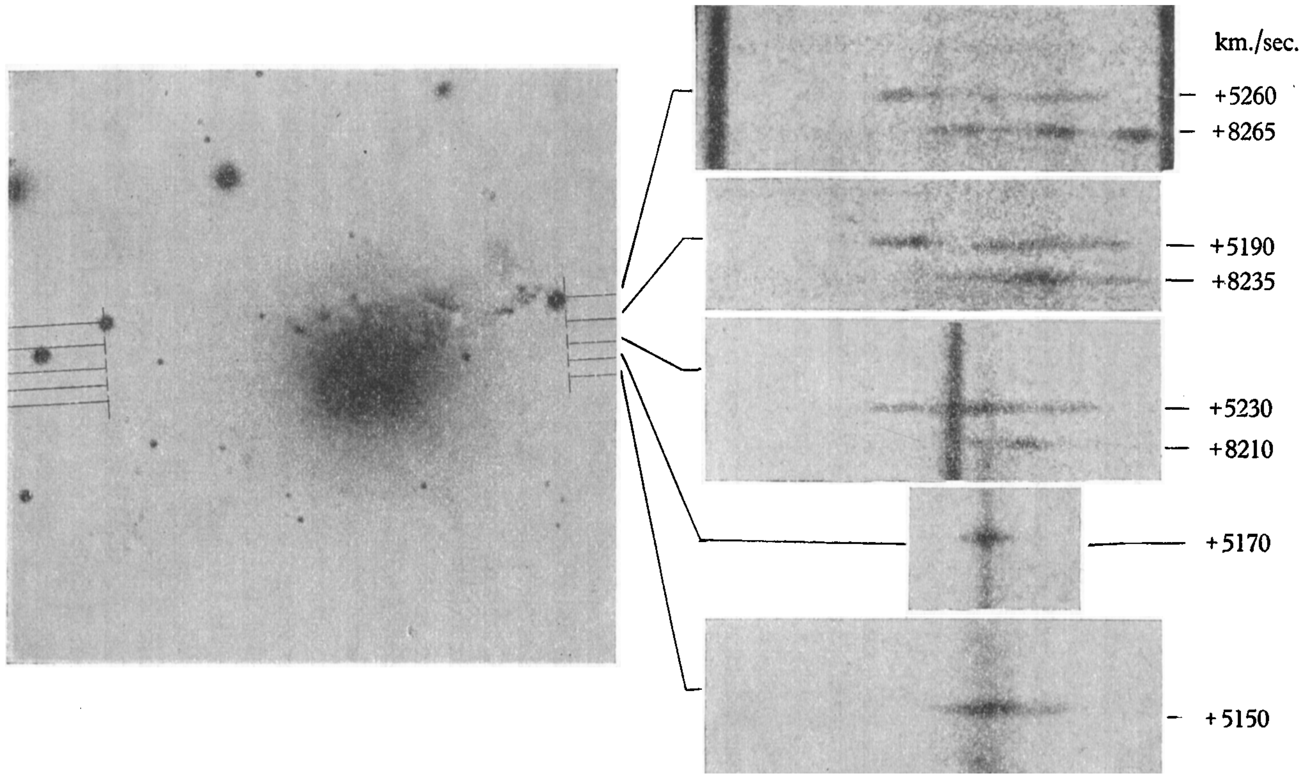

Fig. 1. Spectroscopic evidence that NGC 1275 consists of two galaxies in collision.

plane parallel layers of 500 parsecs thickness, one finds that the observed conditions require an angle of 15° to 20° between the galactic planes of the two systems. On this basis, the total duration of the collision is of the order 10^6 years. The intensity of the radio emission during this period should first increase, reach one or possibly several maxima depending on the distributions of gas in the two galaxies, and finally decline. If the present power represents about the average, the total energy emitted during the collision must be of the order 10^{47} erg, still a small fraction of the total kinetic energy of 10^{49} to 10^{50} erg available in a collision between galaxies with a relative velocity of 3000 km./sec.

3. GALACTIC NON-THERMAL SOURCES

Except H II regions which are thermal sources, only six galactic non-thermal sources have been definitely identified. They comprise apparently different objects of which it is not known whether and how they are related [14].

Remnants of supernovae of type I are represented by the Crab nebula. A source found by Hanbury Brown near the position of Tycho's nova may not be connected with this object; the Cambridge position of this source is too far from Tycho's position to admit this identification [15]. The investigation of the Crab nebula has brought most important progress in the discovery of polarization in the central region which emits a continuous spectrum. This discovery by Vashakidze and Dombrovsky is now being followed up by Oort and Walraven with most interesting results which leave no doubt that the optical continuous spectrum and the radio emission have a common origin, being produced by radiation of relativistic electrons in a magnetic field, as was suggested by Shklovsky (1953) [9].

Three sources have been identified with IC443, the big loop in Cygnus and a very faint nebulosity in Auriga which might be similar in character to the first two nebulae [16]. The first two are definitely similar. They are slowly expanding with relatively high internal motions; the velocities are of the order 50 to 100 km./sec. The large size of these objects, which have diameters larger than a degree, involves slow progress for a detailed investigation such as is now under way for the Cygnus loop. The nature of these objects is obscure. Oort has suggested that they may be supernova shells slowed down by interaction with the interstellar medium. At this time, no data exist which support or disprove the suggestion.

The Cassiopeia source has been identified with a remarkable nebulosity with unique characteristics [10]. Puppis A seems to be connected with a

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nebulosity of similar kind. The investigation of the Cassiopeia nebulosity has been continued with interesting results the most important of which are measures of proper motions of the diffuse condensations by Baade which establish beyond doubt that the nebulosity is a rapidly expanding object. The sharp bits, however, do not show any observable trace of motion.

The nebulosity consists of two different types of filaments which are so drastically different in every way that it is hard to avoid the conclusion that two masses of gas are involved in some way. Sharp broken bits, ranging down to condensations of almost stellar appearance, can be photographed only in the red. Diffuse condensations are seen both in the blue and the red. As can be expected from this, the spectra are radically different. The sharp bits show H_α, the neighbouring [N II] lines with intensities comparable or slightly larger than H_α and very faintly the [O I] auroral lines. The diffuse condensations show lines of [O I], [O II], [O III], [S II], [Ne III], but no trace of H_α or [N II]. The red lines of [S II] are the most intense lines in some of the diffuse filaments. The interpretation of the line intensities meets difficulties which are most probably due to the fact that the ionization is not in equilibrium. From estimated values of the surface brightness and intensity ratios of lines belonging to the same ion, such as [O III], λ4363 and λ4959/5007 and [S II], λ4067/78 and λ6713/31, one may conclude that the sharp bits have relatively low electron temperature, possibly below 10,000° K., and moderately high electron density; if, as seems likely, the excitation is collisional, the ionization is incomplete and the total density may be very high, of the order 10^6 atom./cm.$^{-3}$. The diffuse filaments have high electron temperature, 20,000° K. or higher, and moderate electron density of the order 10^3 cm.$^{-3}$. To understand the relative line intensities it is necessary to assume a colour excess due to interstellar reddening of the order of 1 mag., corresponding to a total absorption $A_{ph} \approx 4$ mag., for the brightest northern region of the nebulosity. If the faint diffuse filaments near the centre are intrinsically as bright as those in the northern arch, the total absorption here may be about 6 mag. That the interstellar absorption in the field is large and spotty is obvious from its appearance. From star counts on the 48-inch Schmidt plates Greenstein finds that the total absorption exceeds $2^{m}.5$ by an undetermined amount; this supports the conclusions drawn from line intensities.

The radial velocities observed until now are plotted in Fig. 2 as a function of the distance of the condensations from the centre of expansion. The velocities of the broken bits cover a range more than an order of magnitude smaller than that for the diffuse condensations. The broken bits nearest to the centre show somewhat higher velocities than those farther away. This could represent a small systematic expansion, but the scatter is too large and the number of measured points too small to permit any definite conclusion. The diffuse condensations show velocities which seem to

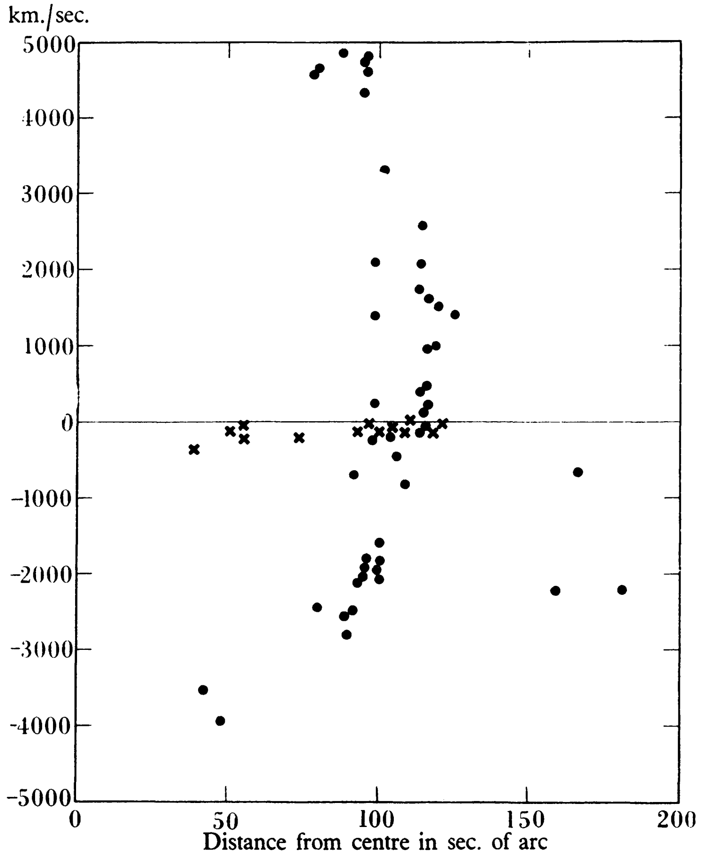

Fig. 2. Radial velocities in the Cassiopeia source as function of distances from the centre.

scatter without any regular arrangement. The highest velocities are not nearest to the centre, the smallest velocities are at an intermediate distance and the most distant condensations have still very high velocities. If the object were a complete expanding shell of some thickness, all points should lie between two ellipses; their axes in the velocity direction would represent the minimum and maximum velocities while the axes in the distance direction would give inner and outer diameters. Thus, the points with low velocities at about 110″ from the centre may represent the inner diameter of the shell, but the outer diameter and the maximum and minimum velocities cannot be found since the limiting ellipses cannot be determined. It is clear, however, that the maximum velocity is not very much larger than 5000 km./sec.

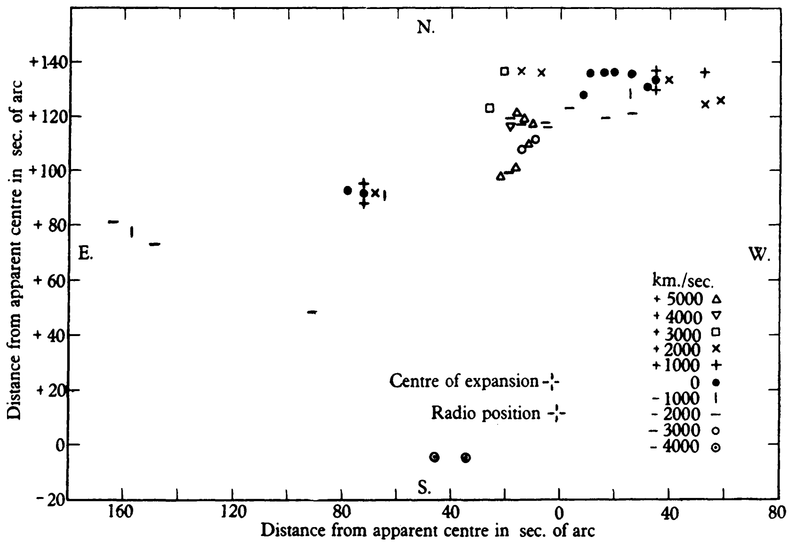

Fig. 3. Distribution of radial velocities in the Cassiopeia source.

What has happened becomes clear when the distribution of observed velocities over the area of the object is inspected. As can be seen in Fig. 3, the velocities are not scattered at random over the nebula, but velocities in certain ranges are grouped in certain regions. For instance, only velocities between +1500 and +2500 km./sec. occur in a region centred about 130″ N. and 45″ W. from the apparent centre of the nebulosity. Five such groups can be recognized in the region of the bright northern arch of the nebulosity. Their mean velocities and approximate co-ordinates in Fig. 2 are:

+4585 km./sec.,	α +15″,	δ +110″
+2430	+15″	+135″
+1305	−45″	+130″
+ 60	−20″	+135″
−2130	− 5″	+120″

Obviously, each group represents a cloud of condensations moving in a certain direction. It is not impossible, but not very probable that the original process has resulted in the ejection of a few batches of material in some directions. It seems much more likely that the gas was originally ejected in all directions with more or less spherical symmetry and that interstellar material in the region in which the explosion occurred has stopped most of the ejected shell. On this assumption the two gas masses whose presence is so strongly suggested by the existence of two distinctly different types of condensations are an expanding shell and interstellar gas.

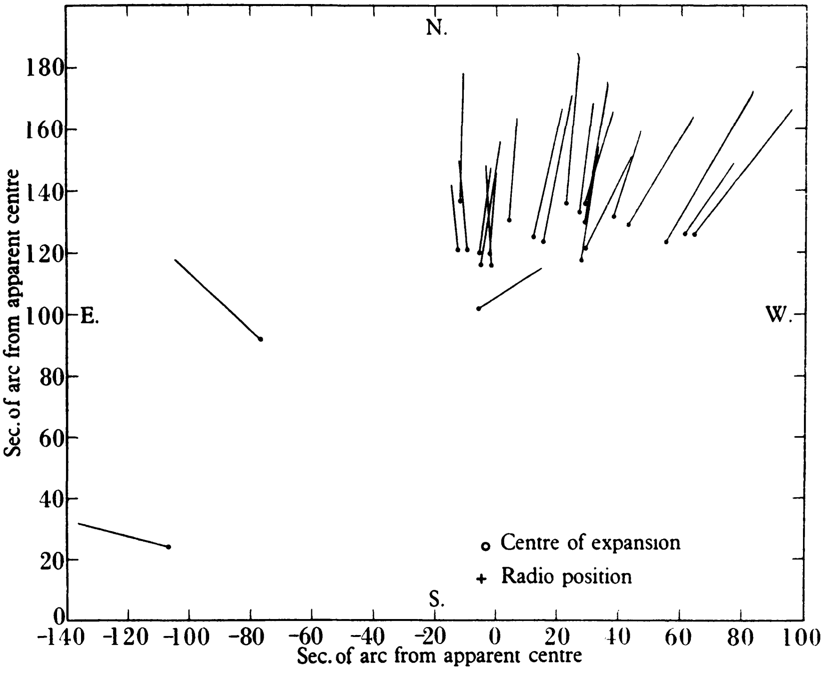

Fig. 4. Proper motions of diffuse condensations in the Cassiopeia source.

The fast-moving condensations which are now still visible must have moved through parts of the interstellar gas with lower than average density where they have lost little of their initial velocity. The sharp bits represent the effect of stopping of ejected material; at this time the question has to be left open whether they are compressed parts of the original ejected material which have lost their outward motion almost completely or whether they represent phenomena such as shock zones in the interstellar material caused by the braking of parts of the moving gas.

As mentioned earlier, the proper motions of the diffuse condensations have been measured by Baade with an interval of three years. The results of these measurements are shown in Fig. 4, where the length of the lines extending outwards from the positions of the condensations gives the motion for 100 years in the direction of the lines. The systematic expansion is obvious. The position of the centre of expansion determined by a least squares solution agrees well with the position of the radio source; it is, as a matter of fact, just about as far north preceding of the radio position as the apparent centre of the visible nebulosity is south preceding. The error of measurement is about 2 % of the average motion. Obviously there are noticeable random components superposed on the regular expansion; these might have been produced if the moving condensations had been braked in varying degrees by the interaction with the interstellar gas. The existence of velocity groups is not directly visible in Fig. 4 for the very simple reason that not all velocity groups are represented. For instance, all of the condensations in the cloud closest to the centre with an average velocity of +4585 km./sec. have changed so much in three years that their motions, while clearly visible, cannot be measured accurately. Actually, only three velocity groups are represented: the groups with mean radial velocities −2132, +59, and +1307 km./sec. Radial velocities are not yet available for all points for which the motion could be measured

If the absolute values of the motions are plotted as a function of the distance from the centre (Fig. 5), one finds considerable scatter around the straight line through the origin which would correspond to a simple expansion. The increase of motion with distance is, however, obvious and the mean values for points with more and less than the average distance, plotted as large full circles in the figure, are quite close to the line. The velocity groups appear separated to some degree. The straight line

$$s = 3{\cdot}52 \times 10^{-2}\, r,$$

where r is in sec. of arc and s in sec. of arc per year, describes the mean expansion satisfactorily. The time elapsed since the start of the expansion is then 280 years. If the material observed today has been slowed by interaction with interstellar gas, the time actually elapsed would be shorter.

If velocity of expansion and motion are known for an expanding shell, the distance can be determined. For the Cassiopeia nebulosity, such a determination is not possible in the usual way which requires essentially that the major and minor axis of a velocity ellipse in a plot like that in Fig. 2 be known. Since this is not the case, arbitrary assumptions would have to be made to apply the usual computation. Almost any value of the distance can be obtained in this way. It is therefore necessary to attack the problem differently. It seems reasonable to assume that in each velocity group the random velocities, which appear clearly both in radial velocities and motions, are independent of the direction from which the object is viewed. The distance can then be determined from the dispersions in radial velocities and in motions. If the random velocities in a group have spheroidal distribution, one has

$$d = \frac{\overline{(v-\bar{v})}}{4{\cdot}73 \times \frac{\pi}{2}\,\overline{(s-\bar{s})}} \text{ parsecs.}$$

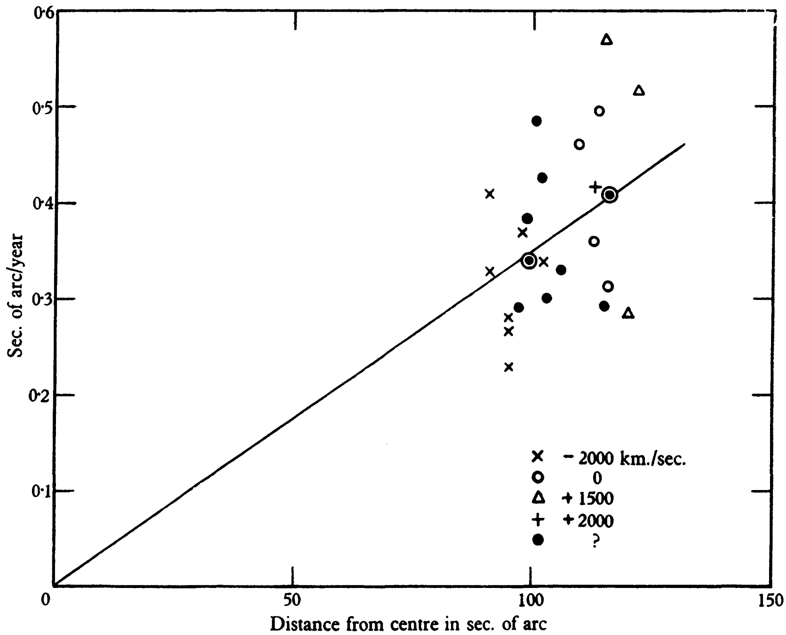

Fig. 5. Proper motions of diffuse condensations in the Cassiopeia source as function of distances from the centre.

Here, v is the velocity in km./sec. of a point of a group with the mean velocity $\bar{v}$, s the absolute motion in sec. of arc of a point of this group whose mean motion is $\bar{s}$. The values for the three groups for which data are available are given in Table 1. The three independent values agree satisfactorily. Thus, the mean value of the distance 540 parsecs seems to deserve some confidence [17]. From the apparent diameter of about 6′, the linear diameter of the nebulosity is then about 1 parsec. To reach this diameter in 280 years, a velocity of about 4000 km./sec. is needed. This is the velocity of gas seen near the edge of the object. It should be noted that distance values of the same order are also obtained if one assumes that the first and third group move at an angle of 45° to the direction of vision. This assumption, however, is entirely arbitrary. It can certainly not be applied to the second group for which a distance of a few parsecs would follow; this group seems to represent a cloud near the inner edge of the shell.

Table 1. *Distance of the Cassiopeia source*

Km./sec.		″/year		Parsecs
$\bar{v}_r$	$(v-\bar{v})$	$\bar{s}$	$(s-\bar{s})$	d
−2132	274	0·318	±0·051	715
+ 59	311	0·407	0·074	575
+1307	248	0·446	0·098	340

A considerably larger distance has been derived from observations of 21-cm. absorption which show the presence of a very small interstellar cloud with a velocity of about −40 km./sec. in front of the object. If this velocity is interpreted as due to the effect of galactic rotation, one has to conclude that the object is at least in, if not behind, the second spiral arm, at a distance of more than 2000 parsecs. Such a distance would lead to an implausibly large linear size, about 5 parsecs, and velocity of expansion about 20,000 km./sec. As a matter of fact, there is no reason to believe that the velocity of a small cloud such as that seen in absorption represents the average velocity of the gas in any spiral arm; the concept of galactic rotation could at best be applied to that average velocity.

Finally the question as to the origin of the object has to be raised. Only one type of astronomical object is known at present in which expansion velocities of the order 5000 km./sec. have been observed: supernovae of type II. The average absolute photographic magnitude of this class of supernovae is near −14 mag. (new scale). If the photographic absorption near the centre of the object is 6 mag., the apparent brightness of such a supernova at 540 parsecs becomes $-0^{\mathrm{m}}\!\cdot\!4$. No nova like this has been recorded for about 280 years. An object of this brightness would certainly not go unnoticed today. However, no record of any nova exists in the period from the second half of the seventeenth century to the end of the eighteenth century. It seems not unreasonable to assume that this indicates a general lack of interest in novae; several ordinary novae of comparable brightness have occurred in the first half of the present century and it does not seem likely that the phenomenon was missing for more than a century. It is, of course, not impossible that the interstellar absorption is even heavier than assumed and that the nova was fainter. For the time being the assumption that the Cassiopeia source is the remnant of a supernova of type II seems to be the most plausible interpretation.

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[12] Photographs with the 48-inch Schmidt telescope and a plate-filter combination with a narrow passband for Hα have shown that the filaments are indeed part of an extremely faint nebulosity which coincides in position and size with the radio source HB 21 (R. Hanbury Brown and C. Hazard, *M.N.R.A.S.* **113**, 123, 1953).

[13] Mills, B. Y., *Aust. J. Phys.* **9**, 368, 1955.

[14] The number of identified galactic non-thermal sources has now increased to nine.
[15] An extremely faint nebulosity which is the remnant of Tycho's nova has recently been found. The approximate centre of the nebulosity follows by about 30 sec. the accepted position of the nova. It now appears probable that this position is less reliable than was formerly assumed and that the source is to be identified with Tycho's nova. Since a radio source in the position of Kepler's nova of 1604 has been found by Mills, Little and Sheridan [11] the remnants of all three known galactic supernovae of type I are now identified radio sources.
[16] The nebulosity with which the source HB 21 has been identified [12] also belongs in this group.
[17] If changes of shape of the diffuse filaments with time make a noticeable contribution to the random components of the proper motions, the distance of 540 parsec is only a lower limit for the true distance.