IDENTIFICATION OF THE RADIO SOURCES IN CASSIOPEIA, CYGNUS A, AND PUPPIS A

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ABSTRACT

The radio sources in Cassiopeia and Puppis A are identified with a new type of galactic emission nebulosity. The outstanding features of these nebulosities are very large internal random velocities. The radio source Cygnus A is an extragalactic object, two galaxies in actual collision.

Only very few individual sources of cosmic radio emission have been identified with conspicuous astronomical objects.[1] Although the sources in Cassiopeia[2] and Cygnus A[3] are among the brightest and earliest-known radio sources of the sky, all attempts to identify them with astronomical objects in the visible range have failed so far. In the fall of 1951, F. G. Smith, of the Cavendish Laboratory, communicated to us in advance of publication new positions for both sources which were very much more accurate than any previous data. Using an interferometric method, Smith had reduced the uncertainties in the positions to $\pm 1^s$ in right ascension and $\pm 40''$ in declination. As it turned out, the new positions were accurate enough for an unambiguous identification of both radio sources on plates taken in September, 1951, at the 200-inch telescope. The Cassiopeia source coincides with a galactic-emission nebulosity of a new type, whereas Cygnus A is an extragalactic affair, two galaxies in collision. Quite similar to Cassiopeia is one of the fainter radio sources, Puppis A.

THE CASSIOPEIA SOURCE, RYLE 23.01[4]

On blue-sensitive plates, only an archlike nebulosity, $2\overset{'}{.}8$ long, appears. Its detailed structure hardly leaves any doubt that we are dealing with an emission nebulosity (see Fig. 1). It is close to, but does not coincide with, the radio position which lies some $2'$ farther to the south.[5] Much more revealing are the red-sensitive plates (Fig. 2) which cover the $H\alpha$ region ($\lambda\lambda$ 6400–6700). They show, besides the arc and mainly to the south of it, broken bits of nebulosity of a most remarkable kind. Some are elongated streaks up to $25''$ long, others have almost stellar appearance. In intensity they range from very bright objects to mere smudges just above the limit of the plates. Not a single one of these broken bits of nebulosity registers on the blue-sensitive plates. Although there are strong indications that interstellar reddening affects the field, there can be no doubt that the broken bits of nebulosity are intrinsically very red. A good illustration is the brightest of these, marked *2* on Figure 3. Not a trace of it appears on the blue-sensitive plate,

[1] For a general discussion see the following paper by the authors (p. 215).

[2] M. Ryle and G. Smith, *Nature*, **162**, 462, 1948.

[3] J. G. Bolton and G. J. Stanley, *Nature*, **161**, 312, 1948.

[4] Since no generally accepted system exists, the designation of the sources in the list of Ryle, Smith, and Elsmore (*M.N.*, **110**, 508, 1950) and in the list of B. Y. Mills (*Australian J. Sci. Res., A*, **5**, 266, 1952) will be given.

[5] About an attempt by D. W. Dewhirst to identify the Cassiopeia source see *Observatory*, **71**, 212, 1951. The object noted as peculiar by Dewhirst is actually a blend of a star and some brighter spots of the northern arc of nebulosity.

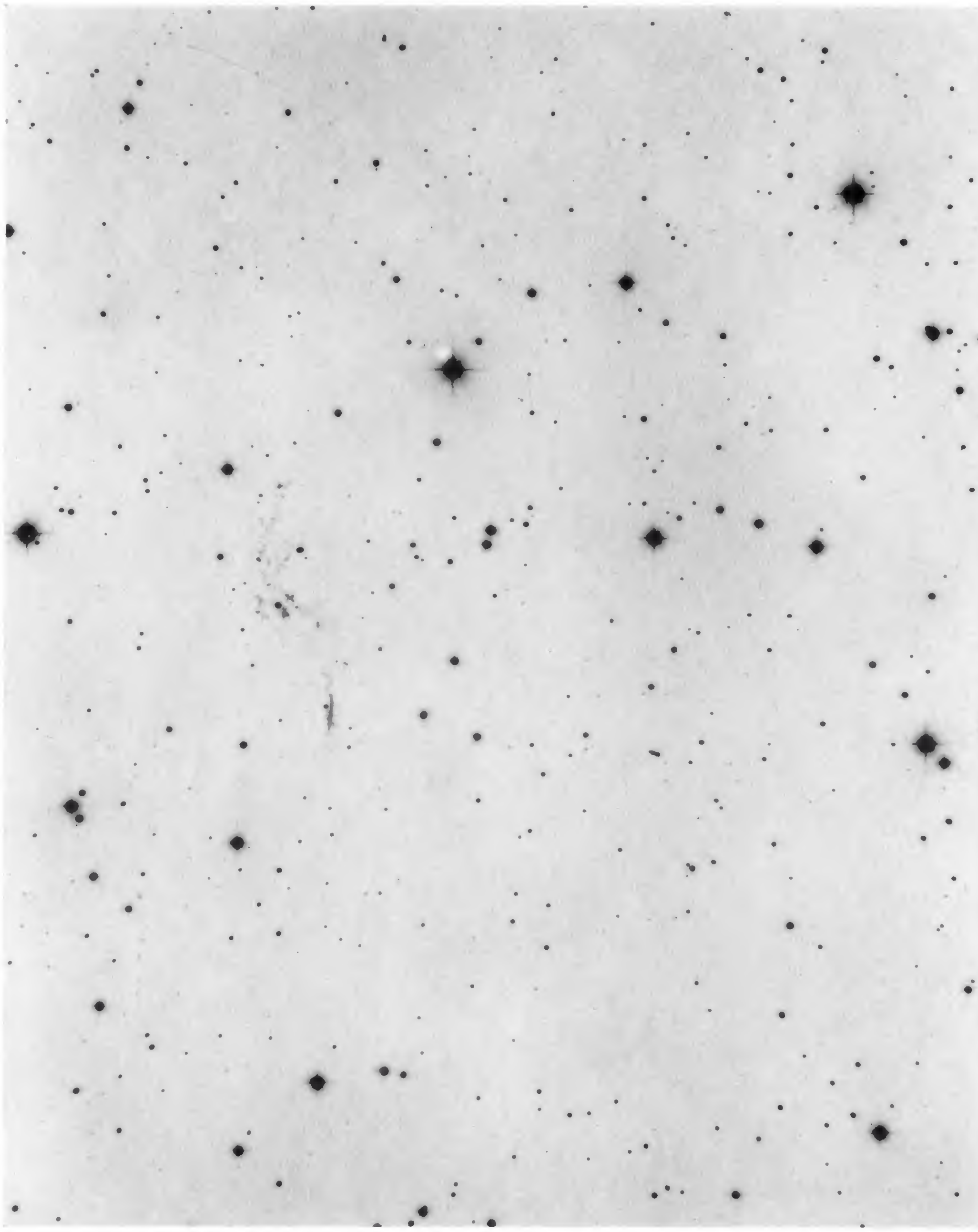

FIG. 1.—Nebulosity in Cassiopeia. λλ 3600–5000; 200-inch; 1 mm = 4″.8

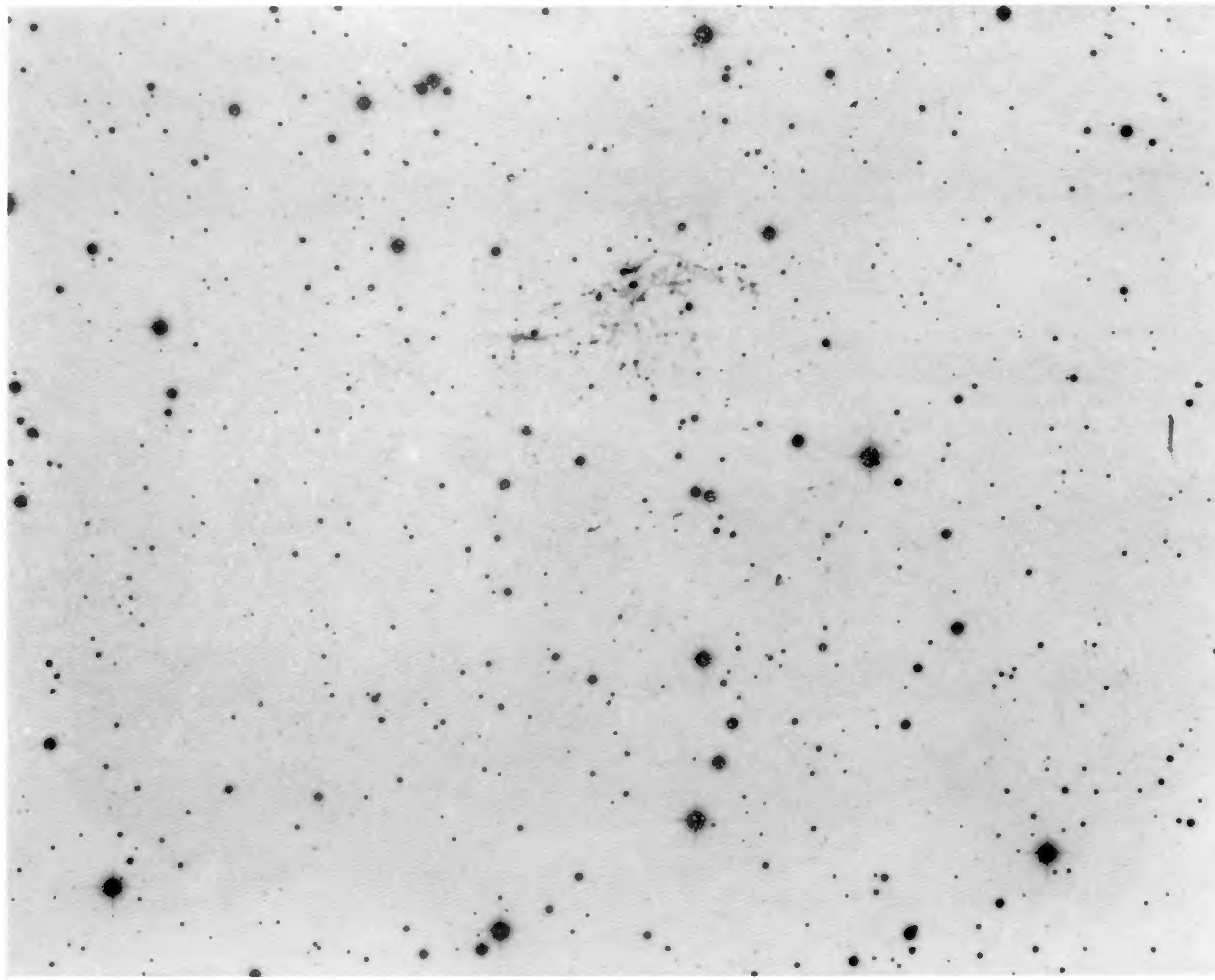

FIG. 2.—Nebulosity in Cassiopeia. λλ 6400–6700; 200-inch; 1 mm = 4″.8

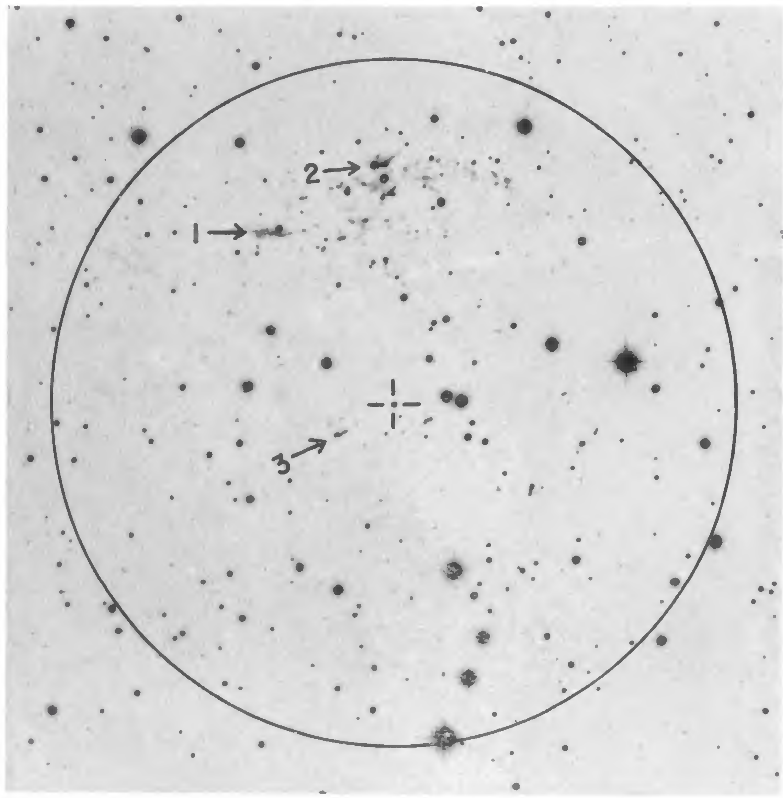

FIG. 3.—Nebulosity in Cassiopeia. λλ 6400–6700; 200-inch; 1 mm = 4″.9

whereas the nebulosity of the arc in which it is imbedded appears almost equally bright on the blue and the red plates. There can be no doubt, therefore, that in these broken bits of nebulosity the emission in the blue is abnormally faint compared to that in the $H\alpha$ region. So far as we know, it is for the first time that we encounter the type of nebulosity just described. The total area covered by these nebulosities is the circle of $6'.3$ diameter in Figure 3. Its center, marked by a cross, has the position 1950.0, $23^h21^m11^s.38$, $+58°31'52''.9$, compared with F. G. Smith's radio position[6] of 1950.0, $23^h21^m12^s.0 \pm 1^s$, $+58°32'.1 \pm 0'.7$. Within the uncertainty of the present radio position, visible nebulosity and radio source coincide perfectly. All positions which have been obtained for the source are in Table 1.

TABLE 1

POSITION OF THE SOURCE IN CASSIOPEIA, RYLE 23.01

α (1950)	δ (1950)	Method	Observer
$23^h21^m12^s \pm 10^s$	$+58°32' \pm 4'$	Radio interferometer	Ryle, Smith, and Elsmore*
$23^h21^m12^s.0 \pm 1^s$	$+58°32'.1 \pm 0'.7$	Radio interferometer	Smith†
$23^h21^m36^s \pm 30^s$	$+58°38' \pm 10'$	Radio paraboloid	R. Hanbury Brown‡
$23^h21^m11^s.38$	$+58°31'52''.9$	Photographic	Baade

* *M.N.*, **110**, 508, 1950.
† *Nature*, **168**, 555, 1951.
‡ *M.N.*, **113**, 123, 1953.

Although the center of the visible nebulosity closely coincides with a star of photographic magnitude 18.9, there is no reason to identify this star with the exciting source of the nebulosity, since in no way does it stand out by its color. The same is true of the other stars near the center, so that there is no visible source of excitation for the nebulosity.

Obviously, the identification of the radio source with the nebulosity just described would be strengthened very much if it could be shown that the radio source has the same diameter as the visible nebulosity. At our request, F. G. Smith[7] measured the diameter of the Cassiopeia source interferometrically. It turned out that the radio source has indeed a measurable diameter. From his measures Smith derived $d = 5'.6 \pm 0'.2$ under the assumption of a uniformly radiating disk, or $d = 5'.0 \pm 0'.2$ if the shell is optically thin. Observations by Hanbury Brown, Jennison, and Das Gupta[8] indicate a slightly elliptical area of $3' \times 4'$, with the major axis approximately in position angle 25°. The values for the diameter of the radio source are in such good agreement with the diameter of the visible nebulosity that there can be no further doubt about the identification. Both in position and in diameter the two objects agree within the errors of measurements.

Exact agreement of the radio position with the center of the nebulosity and of the radio diameter with the diameter of the nebulosity can be expected only if all parts of the nebulosity contribute equally to the radio emission. The present evidence suggests strongly that this is true and that no direct relation exists between optical and radio emission. But the accuracy of the radio measures does not yet seem to be adequate to draw final conclusions. Of all sources identified until now, the Cassiopeia source seems to offer the best opportunity for studying this question.

[6] *Nature*, **168**, 555, 1951.

[7] *Ibid.*, **170**, 1064, 1952.

[8] *Nature*, **170**, 1060, 1952.

Added October, 1953: Interferometric measures by Jennison and Das Gupta, reported at the Symposium on Radio Astronomy at the Jodrell Bank Experimental Station in July, 1953, show that the source emits as a uniformly radiating disk with some limb darkening.

That in the Cassiopeia source we have for the first time come across a galactic nebulosity of extraordinary properties was strikingly shown by the spectroscopic investigation. Spectra of three filaments, marked on the chart in Figure 3 by arrows in the position angles of the slit, have been obtained with the nebular grating spectrograph at the prime focus of the 200-inch telescope.[9] A grating with 7500 lines/inch blazed for the third-order red was used with the 1.4-inch camera; for emission objects this grating can be used to observe the third-order red together with the overlapping fourth- and fifth-order green and violet, respectively, without serious interference by blending of lines from different parts of the spectrum. The dispersion is 220 A/mm in the third-order red, 165 A/mm in the fourth-order green, and 132 A/mm in the fifth-order blue.

The spectrum of filament *1* in Figure 4 is unique in regard to composition and to internal motions. The only lines recorded are λ 4959 and λ 5007 of [*O* III] and λ 6300 and λ 6364 of [*O* I]. The absence of *Hα* indicates a large intensity ratio [*O* III]/*Hα*, but not necessarily a larger one than that found in those planetary nebulae which show the highest value of this ratio. The [*O* I] lines, however, are abnormally strong relative to *Hα* as well as to [*O* III]. The unusual weakness of the hydrogen lines relative to the forbidden lines may be explained by the assumption that the excitation is by collisions rather than by radiation.[10] It should be noted that the situation is different from that in the Crab Nebula, where the relatively low intensity of the *H* lines compared to the permitted lines of both *He* I and *He* II suggests low hydrogen abundance.[11,12]

Even more peculiar than the composition of the spectrum are the internal motions in the filament. Each line appears to have one strong component with three fainter components of greater wave lengths. Closer inspection suggests that these components are merely intensity maxima in a broad band. The velocities within this band range from −1000 to at least +2200 km/sec; faint extensions to about +3000 km/sec are suspected for λ 5007. Details of the intensity distribution are not the same in the [*O* I] lines as in the [*O* III] lines. This suggest differences of excitation in different parts of the filament.

A possible interpretation of the line structure is that the apparent filament is really a thin sheet of matter which is spreading out rapidly in the radial direction. The maxima in the lines would then correspond to regions of high intensity within this sheet. If this interpretation is correct, high tangential velocities comparable to the radial velocities should be expected, and, unless the object is at a distance larger than 500 psc, changes in the appearance of the filament should become noticeable after a few years. But other models for the motions in the filament are kinematically possible.

The spectrogram of filament *2* is in Figure 5. It shows *Hα* flanked by the [*N* II] lines λ 6548 and λ 6584. The relative intensities are 6548:*Hα*:6584 = 1.5:1:4.5. The [*O* I] line λ 6300, blended with the same line from the sky, is present. Spectra of this composition and with similar relative intensities are shown by some planetary nebulae. The radial velocity is −45 km/sec at the east end and +36 km/sec at the west end of the filament. The width of the lines corresponds to a velocity spread of about 400 km/sec.

Filament *3* shows a similar spectrum as filament *2*. Owing to the faintness of this filament, only the condensation of the southeast end is recorded in all three lines, and the rest shows only faintly in λ 6584 [*N* II]. The radial velocity is −170 km/sec at the southeast end. The values for the center and the northwest end, based on measures of one line and correspondingly uncertain, are −125 and −170 km/sec, respectively. The spectrogram is too faint to permit a reliable estimate of the width of the lines.

Filaments *1* and *2* are near the edge of the nebulosity; filament *3* is near the center. There are no indications that the nebulosity as a whole is expanding. Any possible veloci-

[9] J. S. Bowen, *Ap. J.*, **116**, 7, 1952.

[10] See the following paper by R. Minkowski and L. H. Aller, *Ap. J.*, **119**, 232, 1954.

[11] R. Minkowski, *Ap. J.*, **86**, 199, 1942; *Mt. W. Contr.*, No. 666.

[12] R. Minkowski and J. L. Greenstein, *Ap. J.*, **119**, 238, 1954.

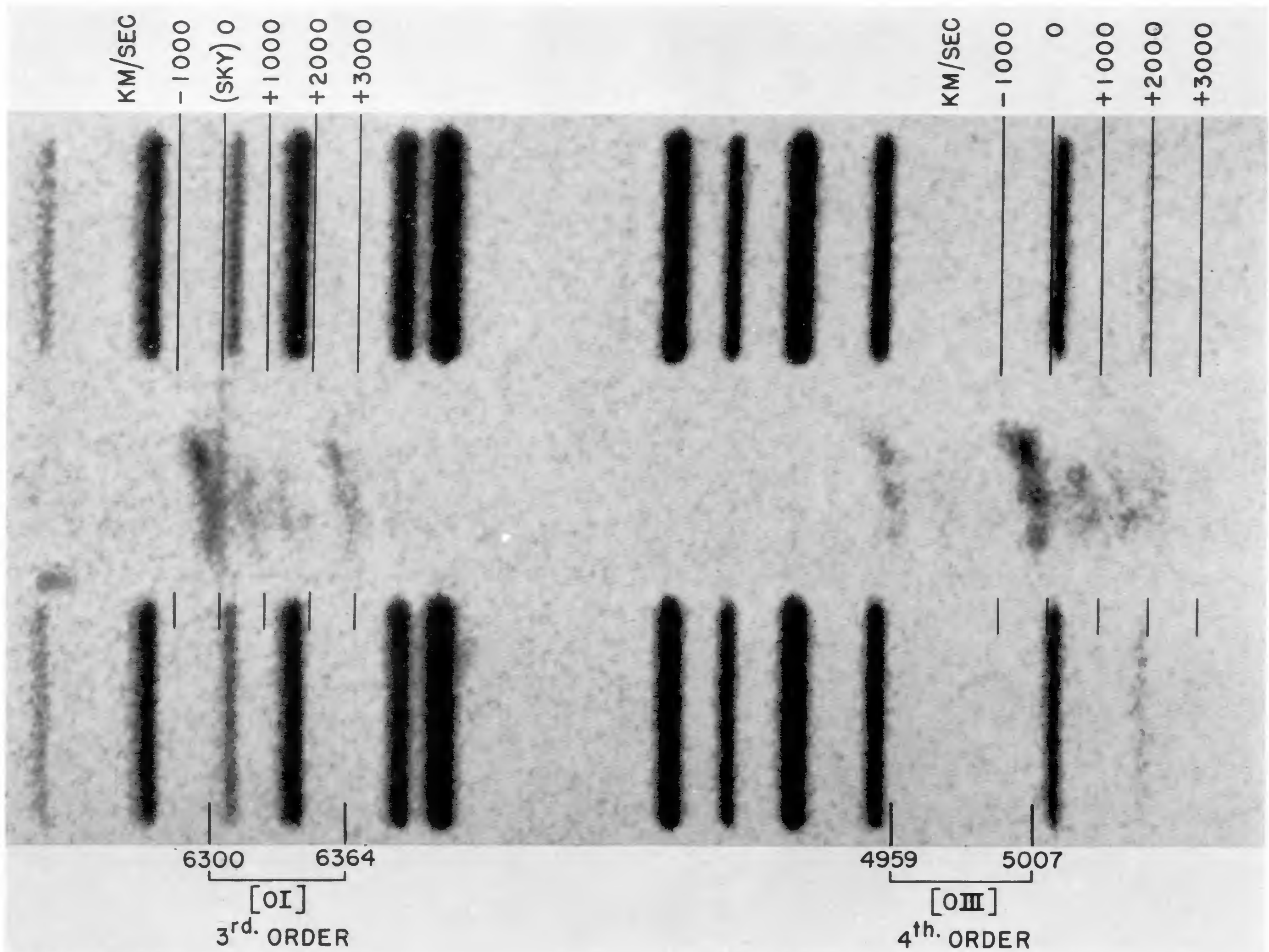

FIG. 4.—Spectrum of filament 1 of the nebulosity in Cassiopeia

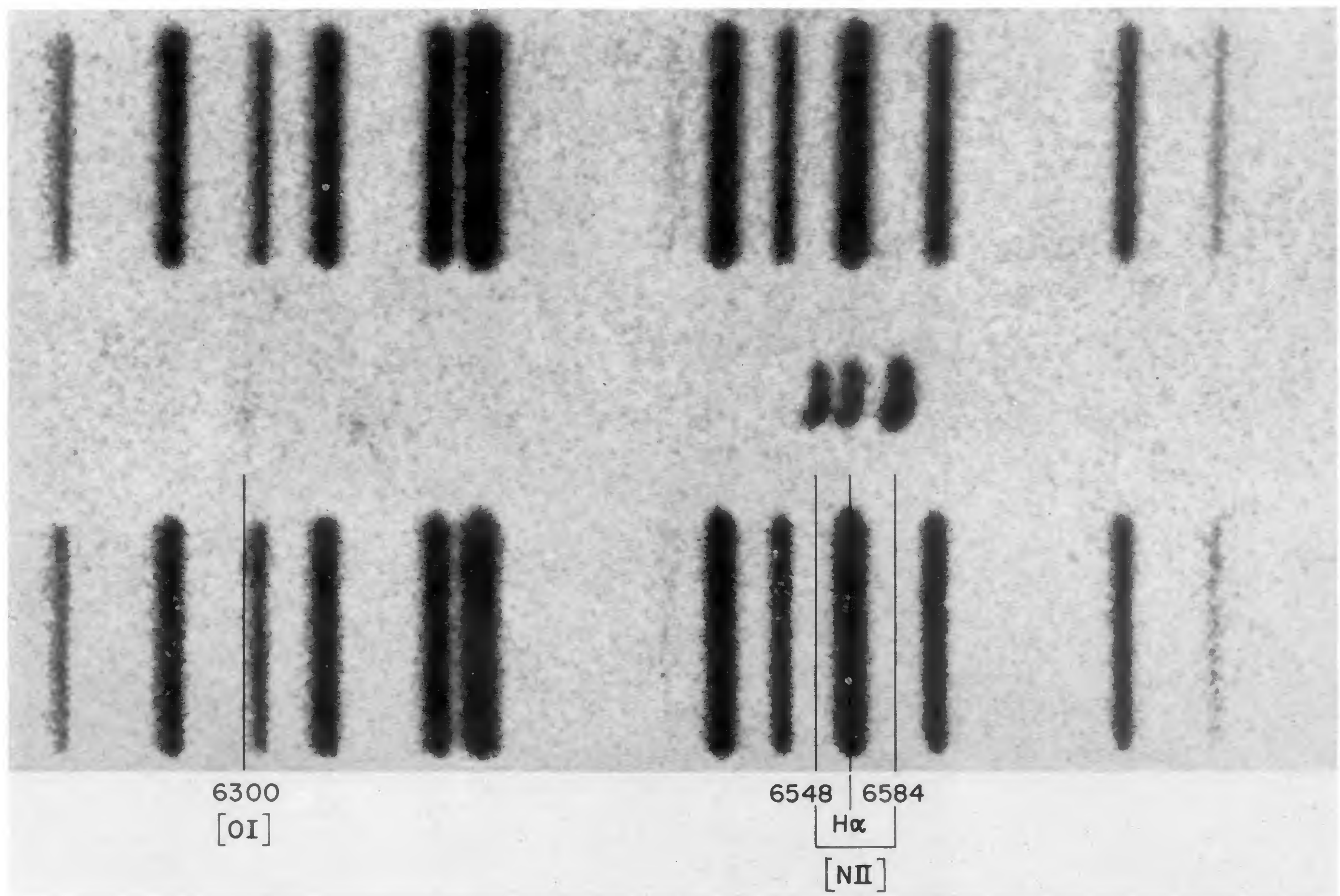

FIG. 5.—Spectrum of filament 2 of the nebulosity in Cassiopeia

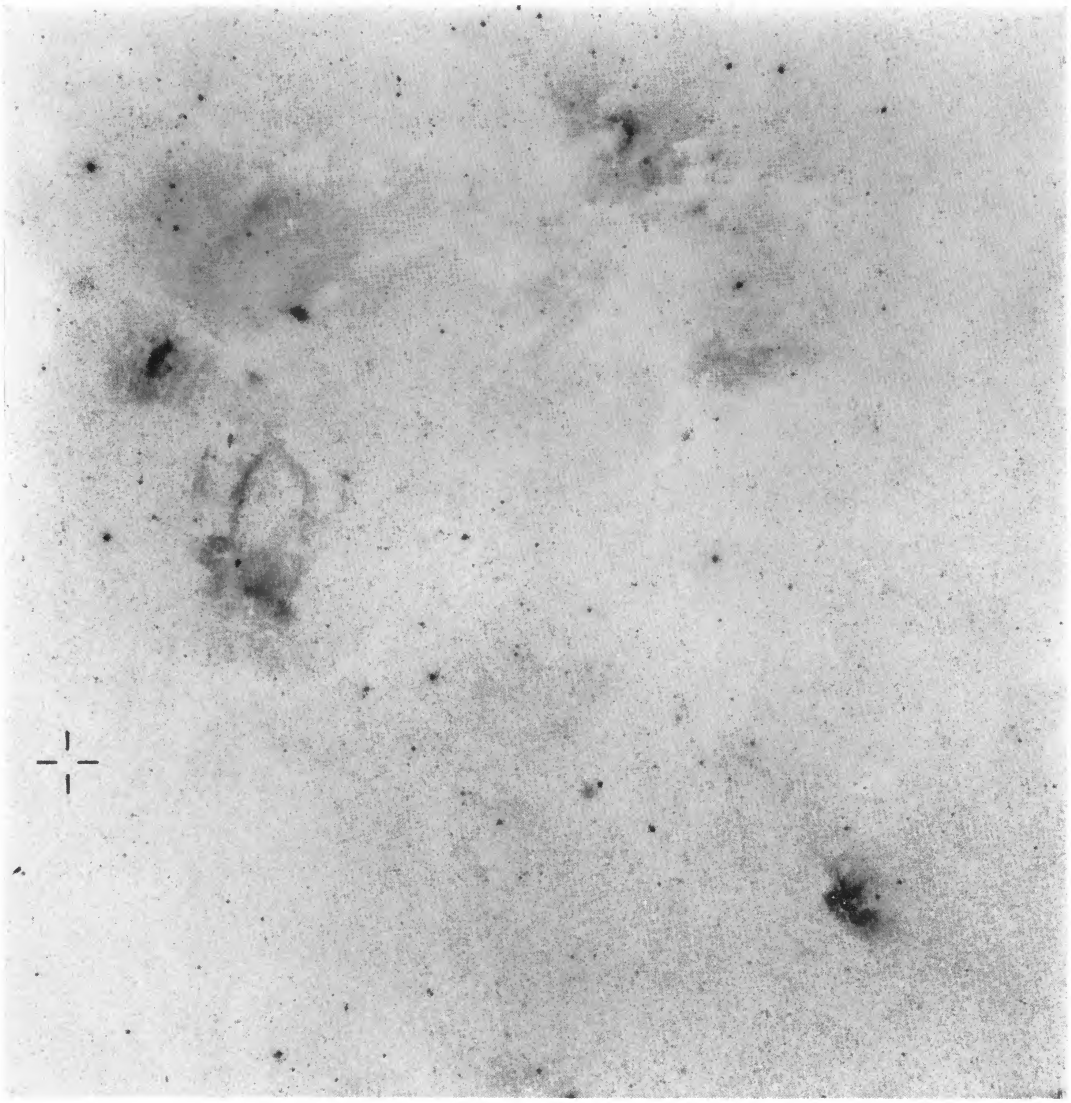

FIG. 6.—Field in Cassiopeia. Center (1950) 23^h40^m, $+61°24'$; λλ 6300–6700; 48-inch; 1 mm = 3′.1

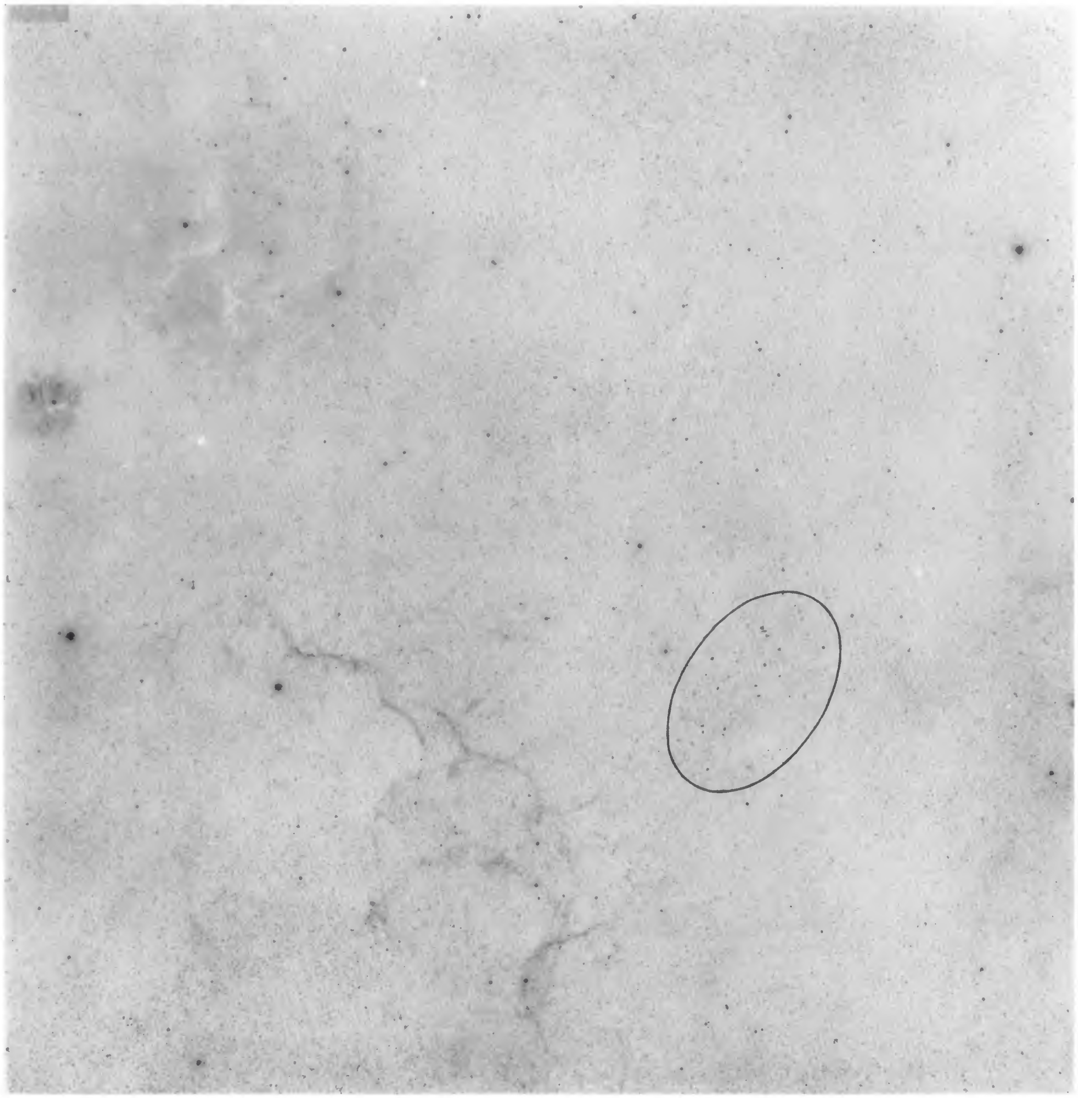

FIG. 7.—Field in Puppis. Center (1950) 8^h27^m, $-42°0'$; λλ 6300–6700; 48-inch; 1 mm = 3'.1

1954ApJ...119..206B

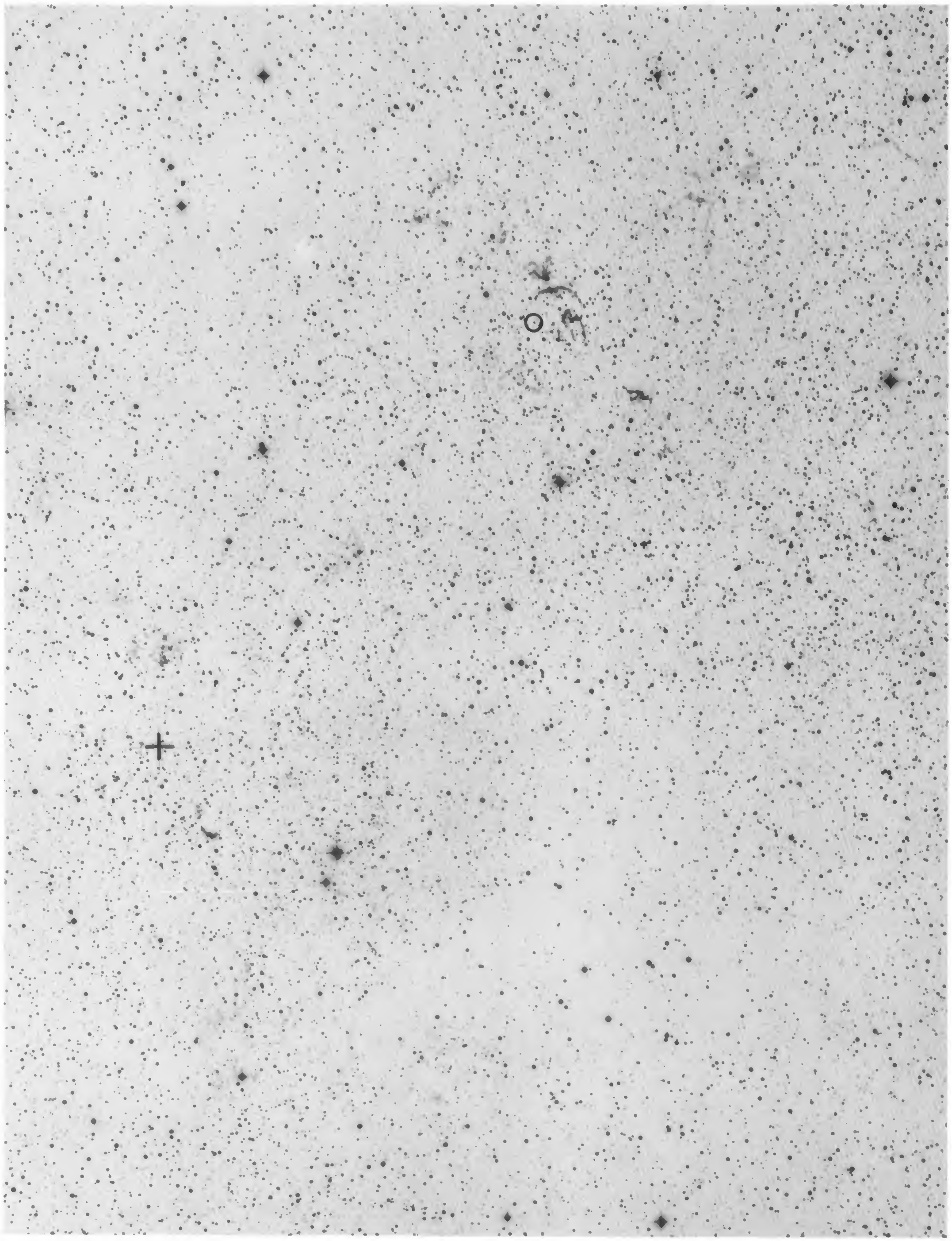

FIG. 8.—Filaments in Puppis. λλ 6200–6700; 48-inch; 1 mm = 29″

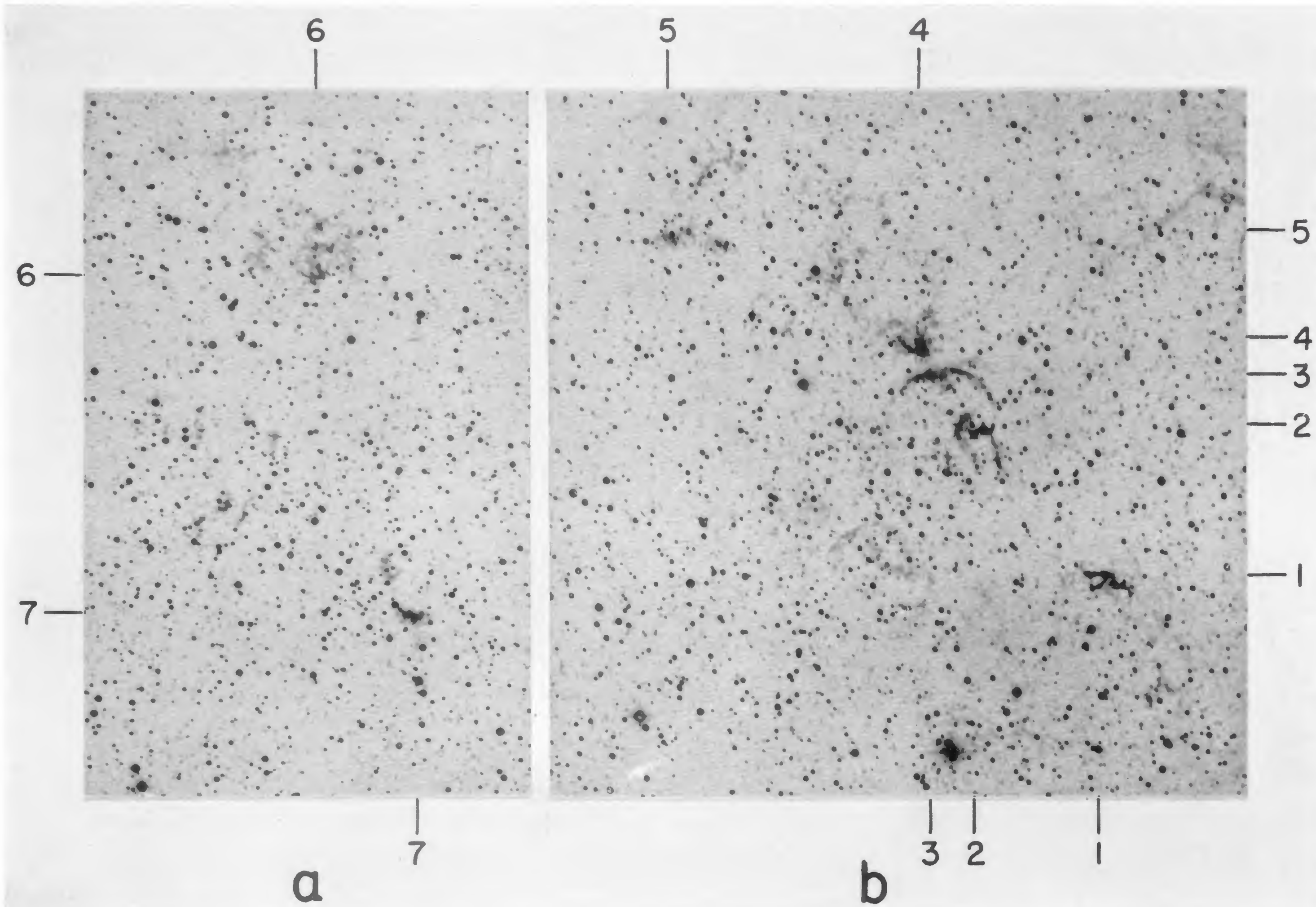

FIG. 9.—Filaments in Puppis. λλ 6200–6700; 48-inch; 1 mm = 15″

ty of expansion is obviously small compared to the random motions. This is quite different from the conditions found in shells of novae and supernovae and clearly shows that the nebulosity is not a shell of this type.[13]

The outstanding characteristic of the filaments is the large internal velocity dispersion. It seems plausible to assume that the unusually large internal motions in this nebulosity are directly connected with the strong radio emission. The present observations leave open the question of whether the filaments are being formed or dissolved. Unless the distance of the source is much larger than 500 psc, it should be possible after a few years to decide by observation between the alternatives.

The field containing the source is shown in Figure 6, reproducing a plate taken with the 48-inch Schmidt telescope. The position of the source is marked by the cross in the lower left corner; owing to the reduced scale, the faint nebulosity is not visible in Figure 6. The field is rich in large diffuse nebulosities and obscuring clouds, but none of these features coincides with the radio source, which is strikingly inconspicuous.

Added October, 1953: Intercomparison of plates taken in the fall of 1953 with the earlier plates of 1951 show marked motions and intensity changes in the filaments making up the northern arc of the nebulosity. In contrast, the red broken bits of nebulosity, such as filaments *2* and *3* in Figure 3, show neither perceptible motions nor intensity changes. Additional spectra have been obtained of seven more condensations. The diffuse filaments of the arc all have large radial motions of the order of 2000 km/sec, while the sharp red bits of nebulosity have small radial velocities around 50 km/sec.

PUPPIS A (MILLS 08−4)

When, in November, 1951, J. G. Bolton sent a list of certain sources with appreciable angular diameters, a search for these sources was made by Minkowski on 48-inch Schmidt plates. An extended visual object was found only in one of the positions, that of Puppis A.

A Schmidt plate containing the source is shown in Figure 7, reduced 2.8 times. The field is rich in large diffuse nebulosities. Not connected with these conspicuous nebulosities is a loose mass of filaments which greatly resemble the filaments of the Cassiopeia source. These filaments are within an approximately elliptical area of about $50' \times 80'$, with the major axis in position angle 145°; this area is marked in Figure 7. The filaments are not visible in Figure 7, owing to the reduced scale. The area containing the filaments is shown in Figure 8 on a larger scale. Parts of this area are still more enlarged in Figure 9, where those filaments are marked of which spectra have been observed. The centers of Figure 9, *a* and *b*, are marked in Figure 8 by a cross and a circle, respectively.

The two radio positions of the source in Table 2 agree in declination but not in right ascension. According to private communications from J. G. Bolton and B. Y. Mills, the position by Stanley and Slee may be more nearly correct. The position of the filamentary nebulosity, whose center cannot be determined with high accuracy, agrees with that by Stanley and Slee in right ascension, but the center of the nebulosity is 48′ south of the radio position. The northern border of the nebulosity at −42°13′ is, however, close to the radio position. Mills[14] found 33′ for the equivalent angular size of the source in right ascension. This is somewhat smaller than the extent of the nebulosity, but of the correct order. Radio source and nebulosity seem to overlap. In view of the faintness of this radio source and the low accuracy of its position, the agreement in regard to both position and size may be considered satisfactory. The possibility that the radio emission is stronger near the northern end of the nebulosity should not be disregarded. Exact agreement between optical and radio postion is therefore not to be expected.

[13] Since there is every reason to believe that the Cassiopeia source has nothing to do with supernovae, the attempt by I. S. Shklovsky (*Astr. J. U.S.S.R.*, **30**, 26, 1953) to identify the source with a new star of A.D. 369 is beside the point.

[14] *Australian J. Sci. Res.*, *A*, **5**, 266, 1952.

Spectra of seven filaments marked in Figure 9 have been obtained with a nebular spectrograph at the Newton focus of the 100-inch telescope. The spectrograph is similar to that used at the 200-inch telescope.[9] The same grating was used with a $F/0.67$ thick-mirror Schmidt camera; the dispersion at $H\alpha$ is 238 A/mm. Owing to the large zenith distance and the consequent high intensity of spectral features from city lights, only the strongest lines, $H\alpha$ and the [*N* II] lines λ 6548 and λ 6584, were observed; the presence of other lines is possible. The velocities and relative intensities are in Table 3. In several

TABLE 2

POSITION OF THE SOURCE IN PUPPIS, MILLS 08−4

α (1950)	δ (1950)	Method	Observer
$8^h18^m \pm 13^m$	$-42° \pm 40'$	Radio interferometry	Stanley and Slee*
$8^h35^m \pm 4^m$	$-42° \pm 20'$	Radio interferometry	B. Y. Mills†
$8^h20^m.3$	$-42°48'$	Photographic	Minkowski

* *Australian J. Sci. Res.*, *A*, **3**, 234, 1950.
† *Australian J. Sci. Res.*, *A*, **5**, 266, 1952.

TABLE 3

VELOCITIES OF FILAMENTS IN PUPPIS

FILAMENT	KM/SEC $H\alpha$	KM/SEC [*N* II]	6548/$H\alpha$	6584/$H\alpha$	REMARKS
1	+ 8	− 47	1.5	4.5	
2	− 12	− 18	3	9	Lines diffuse
3	+113	+124	0.5–1.5	1.5–4.5	Lines wavy
4	+ 57	+ 76	2	6	*
5	− 19	− 8	1.5	4.5	Lines diffuse
6*a*	+ 84	+ 70	1.5	5	Lines diffuse†
6*b*	....	+124	....	....	
7	+ 22	− 9	0.8	2.5	

* The tabulated velocity is for the strong condensation. Velocity at the east end of the filament is +42 km/sec; at the west end, +87 km/sec.

† Filament 6 contains a sharp filament approximately in position angle 20° superposed on fainter, more irregular, filaments. The velocity for 6*a* is for the sharp filament, that for 6*b* for the background. $H\alpha$ is present in 6*b* but is too faint to be measured.

filaments the lines are noticeably diffuse; the velocity dispersion indicated is of the order of 150–200 km/sec.

The conditions shown by the spectra resemble greatly those in the Cassiopeia source, but on a reduced scale in regard to the velocities. The velocity dispersion is large, and any possible velocity of expansion is smaller than the random velocities. If the radio emission is connected with large velocity dispersion in filaments, a smaller velocity spread in Puppis A than in the Cassiopeia source is to be expected, since the radio emission of Puppis A is substantially smaller than that of the Cassiopeia source. The general similarity of the conditions in the Puppis nebulosity to those in the Cassiopeia nebulosity in regard to appearance, spectrum, and motions strengthens the identification as the radio source.

CYGNUS A (RYLE 19.01; MILLS 19 + 4)

Except for the first positions by Bolton and Stanley,[15] all positions of the source given in Table 4 are within an area of 18′ in right ascension and 10′ in declination. This area

[15] *Nature*, **161**, 312, 1948.

is marked in Figure 10, which shows the field surrounding the source. No bright star or any other conspicuous object is near the position of the source. Faint outlying parts of the nebulosities near γ Cygni cover the field. But interstellar absorption is low, as shown by the fact that numerous faint galaxies appear in the field.

Previous observers[16] had already noted that the region around Cygnus A must be quite transparent in spite of its low galactic latitude ($b = -4°$), because extragalactic nebulae shine through in large numbers. The 200-inch exposures clearly show the reason why, aside from the general transparency of the field, extragalactic nebulae are so frequent. The radio source lies amid a rich cluster of galaxies, the brightest members of which are of about the seventeenth photographic magnitude. In conformity with the general rule, the dominating nebular types in the cluster are E- and So-systems. The radio source

TABLE 4

POSITION OF CYGNUS A (RYLE 19:01; MILLS 19+4)

α (1950)	δ (1950)	Method	Observer
$19^h58^m47^s \pm 10^s$	$+41°41' \pm 7'$	Radio interferometry	Bolton and Stanley*
$19^h58^m14^s \pm 60^s$	$+40°36' \pm 10'$	Radio interferometry	Stanley and Slee†
$19^h57^m46^s \pm 5^s$	$+40°30' \pm 7'$	Radio interferometry	Ryle, Smith, and Elsmore‡
$19^h57^m37^s \pm 6^s$	$+40°34' \pm 3'$	Radio interferometry	Mills and Thomas§
$19^h57^m44^s \pm 2^s.5$	$+40°35' \pm 1'.5$	Radio interferometry	Mills‖
$19^h57^m22^s \pm 25^s$	$+40°22' \pm 16'$	Radio paraboloid	Hanbury Brown and Hazard#
$19^h57^m45^s.3 \pm 1^s$	$+40°35'.0 \pm 1'$	Radio interferometry	Smith**
$19^h57^m44^s.49$	$+40°35'46''.3$	Photographic	Baade

* *Nature*, **161**, 312, 1948. This position has been superseded by the value given by Stanley and Slee.
† *Australian J. Sci. Res.*, *A*, **3**, 234, 1950.
‡ *M.N.*, **110**, 508, 1950.
§ *Australian J. Sci. Res.*, *A*, **4**, 158, 1951.
‖ *Australian J. Sci. Res.*, *A*, **5**, 456, 1952.
M.N., **111**, 576, 1951.
** *Nature*, **168**, 555, 1951.

coincides in position with one of the brightest members of the cluster:[17] Cyg A (radio position by F. G. Smith[7]), 1950.0, $19^h57^m45^s.3 \pm 1^s$, $+40°35'.0 \pm 1'$; position of nebula, 1950.00, $19^h57^m44^s.49$, $+40°35'46''.3$.

In the center of this nebula (Fig. 11, *a*) are two bright condensations separated by about 2″ in position angle 115°. The bright central region of about 3″ × 5″ is surrounded by much fainter outer parts of elliptical outline, about 18″ × 30″, with the major axis in position angle 150°.

At first sight, this nebula is a very curious object which seems to defy classification. The clue to a proper interpretation lies in the fact that it has two nuclei which are tidally distorted and that hence we are dealing with the superimposed images of two galaxies. Both are late-type systems, judging by the low density gradients of the two disks. Spatially they are oriented face to face, they are slightly decentered, and we look upon them

[16] B. Y. Mills and A. B. Thomas, *Australian J. Sci. Res.*, *A*, **4**, 158–171, 1951.

[17] This coincidence was already noted in 1951 by Mills and Thomas (see n. 16), who had obtained for the radio position of Cyg A: 1950.0, $19^h57^m37^s \pm 6^s$, $+40°34' \pm 3'$; but it seemed unlikely at that time that a distant galaxy could be the radio emitter. Moreover, the coincidence established by them was not convincing, since, besides the nebula in question, three of the brighter members of the cluster fall into the area defined by the uncertainty of the position. Minkowski therefore wrote Mills that he did not think it was permissible to identify the source with one of the faint extragalactic nebulae in the area and emphasized that what was wanted was a more accurate radio position. The accuracy of Smith's position was needed to make the identification among the cluster members unambiguous. After Smith's position became known, the coincidence of the nebula with the radio source was also noted by D. W. Dewhirst (*Observatory*, **71**, 212, 1951). B. Y. Mills later gave the improved position: 1950.0, $19^h57^m44^s \pm 2\frac{1}{2}^s$, $+40°35' \pm 1\frac{1}{2}'$.

at an angle not far from 45°. Actually, the two systems must be in close contact because of the strong signs of tidal distortions which the nuclei show. This suggests that we are dealing with the exceedingly rare case of two galaxies which are in actual collision. The main features of such a collision have been discussed by Spitzer and Baade.[18] On the cosmical time scale, collisions of galaxies are a rather frequent phenomenon in the rich clusters of galaxies. As far as the stars of the colliding systems are concerned, such a collision is an absolutely harmless affair. The average distance between two stars is so large that the two galaxies penetrate each other without any stellar collisions. The situation is very different for the gas and dust imbedded in the two systems. Because of the much shorter free paths of the gas and dust particles, the collision of the two galaxies means a real collision of the imbedded gas and dust, which are heated up to very high temperatures, since the collisional velocities range from hundreds to thousands of kilometers per second.

It is obvious that this behavior of the gas and dust provides a beautiful test of our hypothesis that the two galaxies which we identify with the radio source Cygnus A are actually colliding; for we should expect a very unusual spectrum for our nebula. Besides the continuous spectrum provided by the stars of the two systems, the emission spectrum of the colliding gases should be visible. In fact, this emission spectrum should be quite strong, since we are dealing with a face-on collision of the two galaxies, which makes it certain that maximum amounts of the gas are in collision simultaneously. Moreover, on account of the high velocities involved in the collision of two galaxies, the resulting emission spectrum should be one of unusually high excitation and the lines themselves should show broadening. Spectra taken at the 100-inch and 200-inch telescopes largely confirmed these predictions.

Spectra of the bright nuclear region have been obtained with the nebular spectrographs at the prime focus of the 200-inch telescope and at the Newtonian focus of the 100-inch telescope. The spectrum in Figure 12 was obtained with the grating mentioned earlier, which permits the simultaneous observation of the third-, fourth-, and fifth-order red, green, and violet, respectively. For the photographic region, a grating with 15,000 lines/inch blazed for violet has also been used with a dispersion of 435 A/mm.

The spectrograms show that the nebula is indeed a very peculiar, if not unique, object. Strong forbidden-line emission is recorded, while the continuous spectrum barely shows. Photoelectric measures by Dr. W. A. Baum indicate that more than 50 per cent of the total light of the condensations is in the emission lines. The emission lines and the nebular red shift derived from them are in Table 5. From the red shift, the distance of the nebula is 3.3×10^7 psc, with the value 540 km/sec per 10^6 psc for the red-shift constant.

The large red shift of 16,830 km/sec places all lines in regions of the spectrum where the plate sensitivity differs from its normal values for the lines; reliable estimates of relative line intensities, therefore, cannot be given at this time. It is obvious that $H\alpha$ is relatively faint compared to the adjacent [*N* II] lines. The absence of $H\beta$ from the observed lines indicates relatively low intensity compared to the neighboring [*O* III] lines. The lines are diffuse, but the dispersion is too low to determine reliable values of the width. Individual lines seem to differ in width, but at least part of this is caused by intensity differences. The velocity spread is of the order of 400 km/sec.[19] The [*O* II] line λ 3727 extends through the full length of the slit in Figure 12. The corresponding diameter of more than 30″ in position angle 90° is slightly larger than the visible size of the nebula.

[18] *Ap. J.*, **113**, 413, 18, 1951.

[19] The spectrum of the nebula resembles to a certain degree the spectra of those relatively rare nebulae whose nuclei show strong emission lines (C. J. Seyfert, *Ap. J.*, **97**, 28, 1943; *Mt. W. Contr.*, No. 671), but there are marked differences. In NGC 1068 and NGC 4151, the outstanding representatives of the emission nuclei, only 13 and 22 per cent of the light of the nucleus, respectively, is in the emission lines. The outstanding difference between Cygnus A and the nebulae with emission nuclei is that in Cygnus A the area of very strong emission has a diameter of 800 psc, whereas in the other nebulae the emission is restricted to diameters of the order of 25 psc.

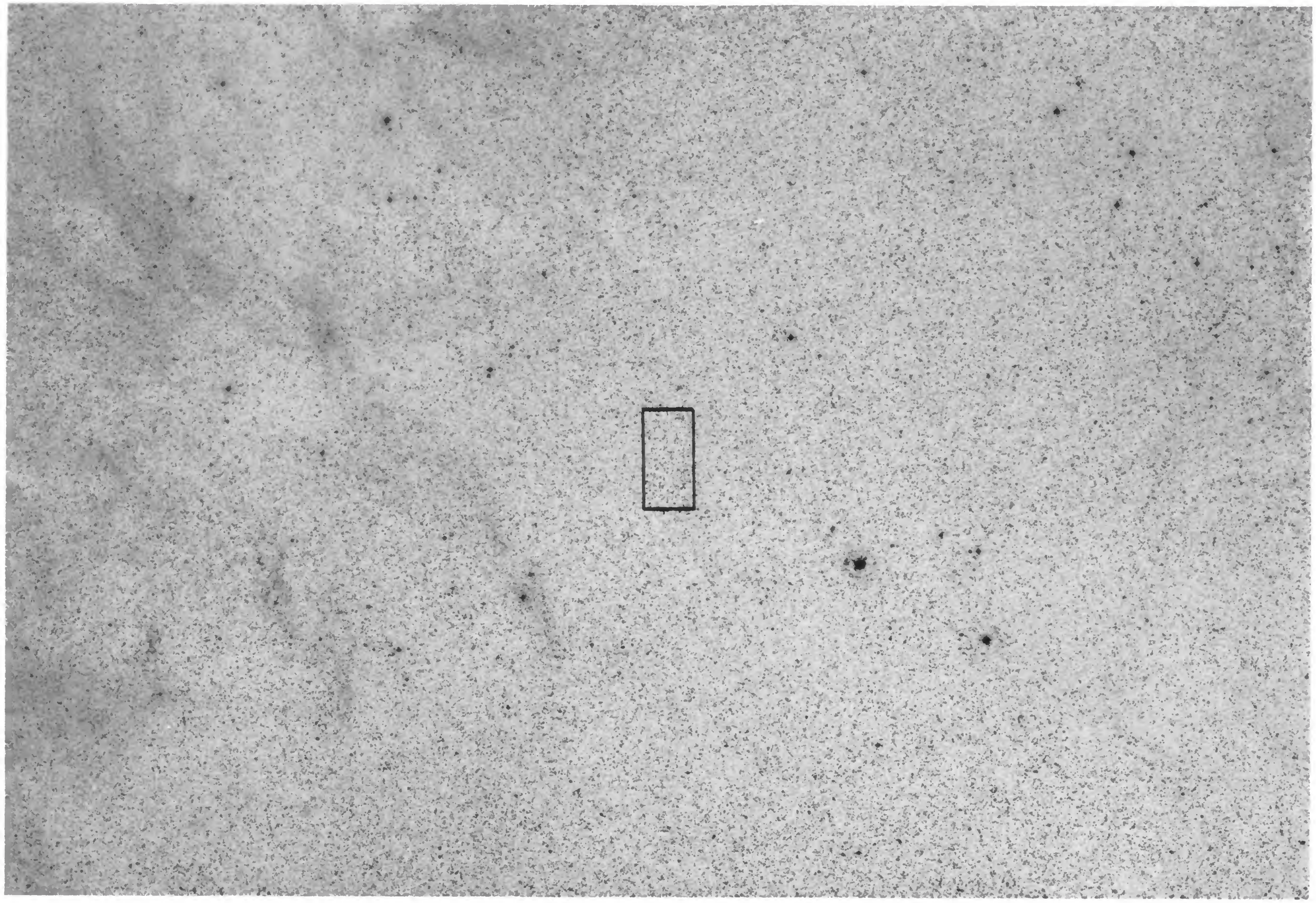

FIG. 10.—Field in Cygnus. Center (1950) $19^{h}57^{m}.6$, $+40°35'$; 48-inch; 1 mm = 67″

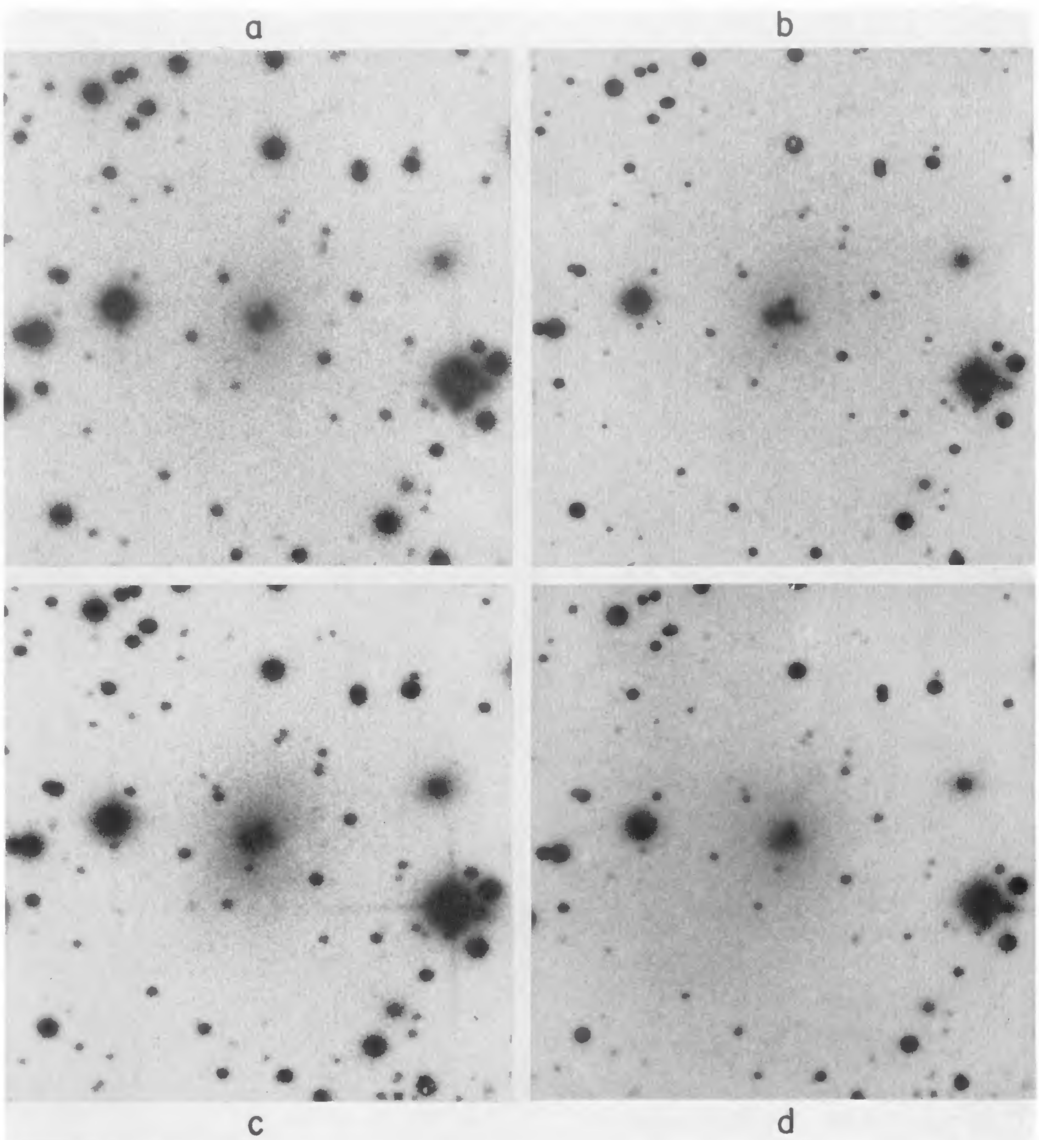

FIG. 11.—Extragalactic nebula in Cygnus. 200-inch; 1 mm = 1″.2. *a*, λλ 3600–5000 [*Ne* v], [*O* II], [*Ne* III]; *b*, λλ 5000–5400 [*O* III]; *c*, λλ 5000–6200 [*O* III]; *d*, λλ 6700–7500 *Hα*, [*N* II].

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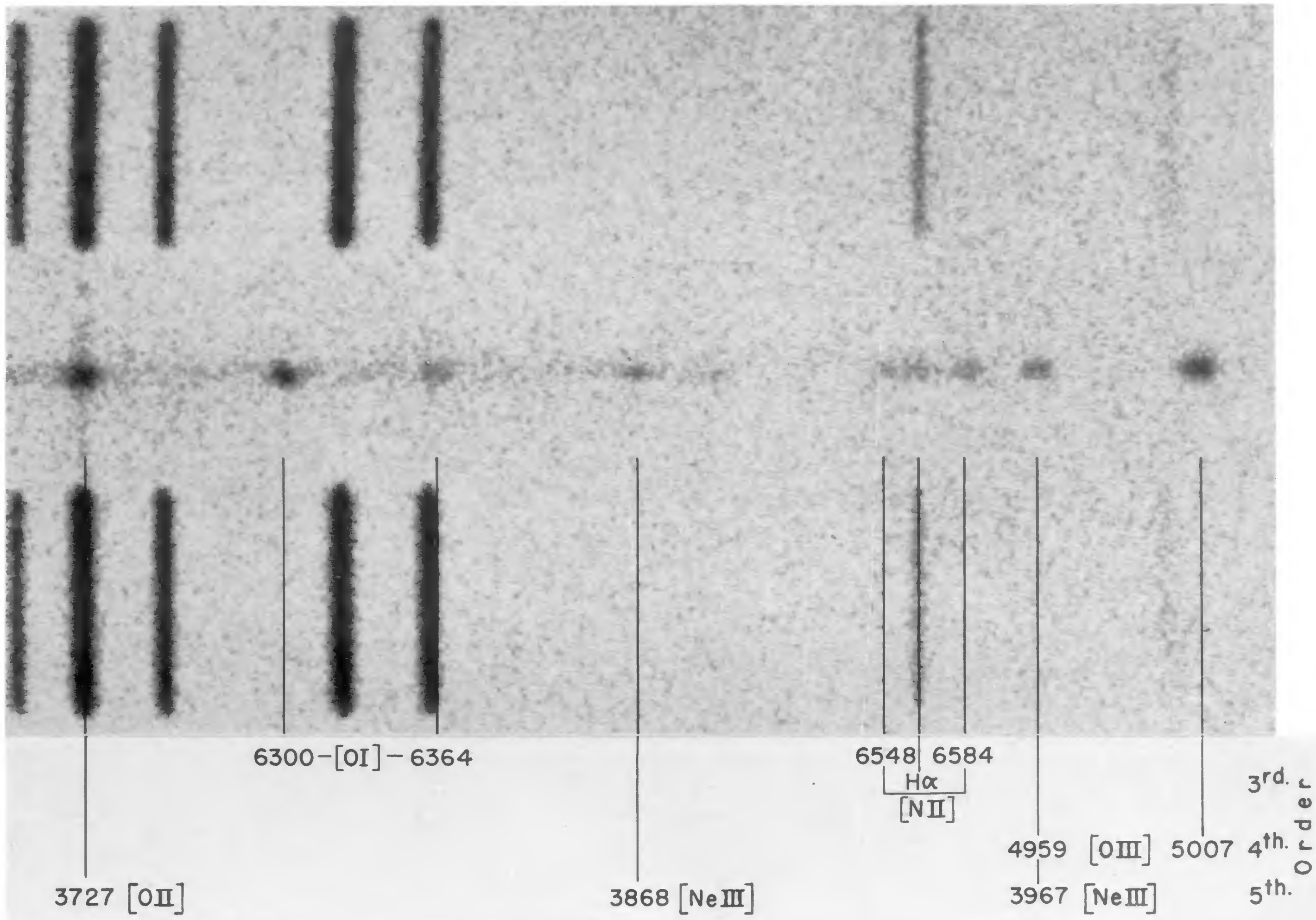

FIG. 12.—Spectrum of the extragalactic nebula in Cygnus

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Inclination of the line indicates rotation of the nebula; the south-following side is receding relative to the center.

On account of the great intensity of some of the emission lines, it is possible, by selecting sufficiently narrow filter ranges, to photograph the emission regions. As Figure 11 shows, there are marked differences in the pictures, depending on the emission lines selected. Owing to the nebular red shift, the emission lines do not appear in their normal wave-length region; the main lines contained in each photograph are listed in the caption of Figure 11.

The determinations of the size of the radio source confirm that the source is not stellar, as had been assumed originally, but has a small diameter measurable with refined interferometric methods. Measures by Mills[20] give an effective size of 1′.1. Smith[21] finds a diameter of about 3′.5. Both values should apply to the east-west direction. Measures by Hanbury Brown, Jennison, and Das Gupta[22] suggest an elliptical outline of about

TABLE 5

EMISSION LINES IN CYGNUS A

λ Observed	Identification		$cd\lambda/\lambda_0$ (Km/Sec)
3619.9......	3425.86	[*Ne* V]	17,010
3937.2......	3726.06/8.82	[*O* II]	16,930
4087.5......	3868.77	[*Ne* III]	16,930
4189.6......	3967.48	[*Ne* III]	16,820
5234.3......	4958.91	[*O* III]	16,660
5284.6......	5001.85	[*O* III]	16,955
6642.5......	6300.27	[*O* I]	16,770
6718.6......	6363.88	[*O* I]	16,720
6916.6......	6548.06	[*N* II]	(16,870)*
6928.0......	6562.66	*H*α	(16,300)*
6949.2......	6583.43	*N* II]	16,670
Mean...	....		16,830

* λλ 6916.6 and 6928.0 are blended: the accuracy of the measured wave lengths therefore is low, and the values of the red shift for both lines have been excluded from the mean.

1′ × 2′.1, with the major axis in a position angle close to that of the major axis of the nebula. This is three to four times larger than the visible size, which, as is usual for faint nebulae, is only that of the main body of the nebula. The emission line λ 3727 [*O* II] extends beyond the main body, and it is quite possible that the fainter outer parts may have a diameter much larger than the main body. If, however, a large part of the disagreement has to be explained by an essential contribution of the outer parts to the radio emission, the radio and the optical emission cannot be related. It seems improbable that this assumption entirely suffices to explain the discordance. In view of the difficulty of the radio measures, however, the lack of agreement in regard to the precise extent seems less important than the agreement as to the order of magnitude of the size.

Photoelectric magnitude and color of Cygnus A have been measured by Dr. W. A.

[20] *Nature*, **170**, 1063, 1952.

[21] *Nature*, **170**, 1064, 1952.

[22] *Nature*, **170**, 1060, 1952.

Added October, 1953: Interferometric measures by Jennison and Das Gupta, reported at the Symposium on Radio Astronomy at the Jodrell Bank Experimental Station in July, 1953, show that the radio emission originates in two areas separated by 82″ and 43″ long in position angle 95° with a width of 30″. No object of this description can be seen on any of our plates which cover the wave-length range from the ultraviolet to the infrared.

Baum. With a diaphragm of 11".5 diameter, the magnitudes and colors reduced to the international system are $m_{pg} = 17.90$; $m_{pv} = 16.22$; $CI = +1.68$. To determine the absolute magnitude, corrections have to be applied for interstellar absorption and for the size of the diaphragm. By comparison with nebulae of similar appearance, a conservative estimate is that the nebula is 0.75 mag. brighter than the part admitted by the diaphragm. The interstellar absorption cannot be determined from the color index of the nebula, since the color is affected by the emission lines. But, on the assumption that the elliptical nebula 25" north-preceding is a member of the cluster to which Cygnus A belongs and therefore at the same distance, this apparently normal nebula may be used. Its magnitudes and colors are $m_{pg} = 18.95$; $m_{pv} = 17.42$; $CI = +1.53$. The color of an elliptical nebula with a red shift of 17,000 km/sec is[23] $CI = +1.08$. The color excess of $+0.45$ mag. between this value and the measured color index is due to interstellar reddening. The ratio of photographic absorption to international color excess is[24] somewhat less than 5. The photographic absorption, therefore, is 2.1 mag. Thus we have for Cygnus A the values in the accompanying tabulation.

	Mag.	
Apparent m_{pg}	17.90	
Correction for incompleteness	0.75	
Photographic absorption	2.1	
Corrected m_{pg}	15.05	
Distance modulus $m - M$	32.6	(from red shift)
M_{pg}	-17.5	

The system, therefore, is a giant system which may be expected to have a diameter of more than 10,000 psc. The major axis of 30" of the visible main body of the nebula is only 5000 psc. The assumption is justified that the nebula has a larger diameter than this; but a diameter of 20,000 psc, which would correspond to the radio interferometer measures, would call for strong radio emission from the outermost parts of the nebula, where the average density is exceedingly low.

Since the distance of the nebula is known, the total energy emitted in the radio region may be computed. The flux received from the nebula is of the order of 1.3×10^{-22} watts m^{-2} $(c/sec)^{-1}$ in a band of an equivalent width of 500 Mc/sec. The total flux, therefore, is of the order of 6×10^{-14} watts m^{-2} or 6×10^{-11} ergs cm^{-2} sec^{-1}. With the source at the distance of 3.3×10^{7} psc, the total energy emitted in the radio region is 8×10^{42} ergs/sec. This is larger than the total optical emission of 5.6×10^{42} ergs/sec and larger than the energy contained in the line emission. The source of energy for the radio emission may be the relative kinetic energy of the colliding nebulae, which is of the order of 10^{59} ergs for a relative velocity of 500 km/sec.

We want to express our sincere thanks to all members of the radio-groups in Sydney, Cambridge, and Manchester for their generous co-operation.

[23] J. Stebbins and A. E. Whitford, *Ap. J.*, **108**, 413, 1952.

[24] J. L. Greenstein, in *Astrophysics: A Topical Symposium*, ed. J. A. Hynek (New York: McGraw-Hill Book Co., 1951), chap. xiii, p. 538.