ETA CARINAE. I. THE NEBULOSITY

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ABSTRACT

A series of photographs taken with the Córdoba 61-inch reflector discloses the complex structure of the nebula surrounding η Car. Isophote-curves are drawn for a wide scale of exposure times. The blending of the star's nebula with the galactic nebulosity is shown. Identifiable parts of the nebula, measured previously as stellar components, are shown to be moving radially away from the nucleus at speeds compatible with the assumption that they were ejected from the star in 1843 or later.

INTRODUCTION

Two different clouds are called "the nebulosity surrounding Eta Carinae"; one is Herschel's "Key-Hole Nebula," NGC 3372, which covers many square degrees of one of the two brightest parts of the southern Milky Way; this I shall call the "galactic nebulosity." The other is the group of nubeculae measured repeatedly since 1914 as a multiple-star system by southern double-star observers; the latter covers a disk not larger than about 10″ in radius around the star;[1] this group I shall call the "star's nebulosity." There is no positive evidence of a physical or causal relation between the galactic nebulosity and the star η Car. In spite of the fact that the latter has changed in magnitude from -1 (1843) to about 8.4, the luminosity of the galactic nebulosity seems not to have decreased. B. A. Gould wrote[2] in 1871: "But such observations of the nebula around η Argus as I have been able to make, compared with Sir John Herschel's drawings, have tended strongly to impress me with the conviction that the alleged change is altogether imaginary." B. J. Bok[3] accepts "this verdict as final." There is, on the other hand, evidence that the star's own nebulosity undergoes relatively rapid changes, as we shall see in this paper.

OBSERVATIONAL RESULTS

The complex structure of the brighter part of the star's nebulosity—within 6″ of the center—was observed at Bosque Alegre with the 61-inch reflector the first time the star was put on the slit of the new spectrograph in the early morning of January 9, 1944. Under a power of 1200 diameters and star images not larger than 1″ a shape resembling a "homunculus," with its head pointing northwest, legs opposite and arms folded over a fat body, could be clearly seen.

Many attempts were made afterward to obtain on a plate the same clear detail observed visually. A special camera was built for the Cassegrain focal plane of the 61-inch reflector, with an equivalent focal distance of about 33 meters, mounted in such a way that it can be put into operation—whenever the star images seen on the slit jaws of the spectrograph are fine enough—by turning a plane mirror into the light beam. Fourteen months later, on March 7, 1945, two excellent plates were obtained. Each has nine

[1] A series of photographs appeared in the *Memoria* of the Córdoba Observatory for the years 1944 and 1945, published by *Revista astronomica*, Vol. **18**, No. 5, 1946; one reproduction was printed in *Nature*, **158**, 403, 1946; a composite sketch, based on photographs, and a description have been published by A. D. Thackeray in *Observatory*, **69**, 31, 1949.

[2] *M.N.*, **32**, 16, 1871.

[3] *A Study of the η Carinae Region* ("Harvard Reprints," No. 77 [Groningen: Hoitsema Bros., 1932]), p. 71.

images, the times starting with 1 second and doubling for each successive exposure. Stellar images were small—1″ or less—and steady. No guiding was necessary, and none was used. Figure 1 reproduces the images of one of these plates.

The original plate—Ilford HP2—was enlarged first on Kodak Lantern Slide Medium plates; these were enlarged on contrast paper. As the reproductions are negatives, west is at the left and north is at the top. The enlargements were carried out with the same exposure and developing times, so that the series of pictures can be used as an approximate photometric scale, since the original exposure times were rather short (less than 5 minutes). Details of the exposures are described below.

Figure 1a.—1-second exposure. The image is not stellar (compare with *F* in Fig. 1*f*) or round: it has a prominence pointing to the northeast. The two components observed by van den Bos[4] (195°, 0″.2) cannot be seen.

Figure 1b.—2-second exposure. The northeast prominence has grown; two others, one to the northwest and one to the south, appear. They are perhaps already present in the previous picture.

Figure 1c.—4 seconds. The northeast and northwest prominences are growing equally, but the first still keeps the lead. They correspond to the supposedly stellar components C and B measured by Innes, van den Bos, and others (*Southern Double Star Catalogue* [Johannesburg, 1927]). No separation from the nucleus can be seen on the enlargements or on the original plates. The two prominences appear rather as eruptions coming from the center.

Figure 1d.—8 seconds. The northwest eruption has taken the lead. The northeast one appears rotated toward the south, at a position angle of about 90°.

Figure 1e.—16 seconds. The last eruption has grown and rotates still farther, pointing toward 102°. The whole looks like an inverted conventional heart. The legs of the homunculus are appearing.

Figure 1f.—32 seconds. The eruption at 102° of the previous picture has rotated farther (to 112°, 3″.8) and extends to form the upper part of the right leg of the homunculus. Two other nubeculae appear that may be separated from the main body by a zone of lesser density: *b* (175°, 2″.6) and *c′* (147°, 3″.1). Their separation is not definitely proved by the photographs; they may still be prominences or eruptions growing out of the main body. This is made probable for *b* by the rotation of its center of density in the next picture to 187°, 2″.9, agreeing better with van den Bos's *b* (195°, 1″.9)—at least in position angle. The condensation *c* measured at Johannesburg shows a dispersion in distance of nearly 1″.5. The measurements refer, probably, to *c′* and to *c* (141°, 4″.7), which can be seen better in the next picture. The stars *E* and *F* show clearly. The diameter of *F* is less than 1″. The distances $\eta - F = 13''.5$ and $E - F = 5''$ furnish the scale of the enlargements. That they are stars and not parts of the complex nebulosity is indicated by their unchanging distance[5] and by their spectra (Part II of this paper).

Figure 1g.—64 seconds. Three nubeculae appear that seem to deserve the name of local condensations: *c*, *d*, and *g* (see Fig. 5). The first two complete the left and right legs of the homunculus; *g* forms the left shoulder. The position of *d* agrees fairly well with that of van den Bos. A new eruption appears at *i* (30°, 2″.8). The head is inclined toward the northwest.

Figure 1h.—128 seconds. The shape of the head is now revealed, showing a condensation, *h* (310°, 4″.9), well separated from the body by a zone of lesser photographic density. The symmetrical position of *h* in relation to (*c* + *d*) should be noted.

Figure 1i.—256 seconds. Nothing new is added; the close isophote-curves indicate a steep gradient in intensity. This gives the impression, by visual inspection, that the nebulosity ends here; photographs show that it extends farther. The star showing about

[4] *Union Obs. Circ.*, No. 100, p. 522, 1938; No. 106, p. 207, 1948.

[5] Mr. J. Bobone has measured the following values on a plate taken by Dartayet on February 18, 1945: $\eta - E$(59°.5, 13″.62); $\eta - F$ (39°.7, 13″.85); $E - F$ (d = 4″.72).

3″ north of the head in Figure 1*h* and *i* does not belong there; it belongs to Figure 1*f* and *g*, respectively (successive images were displaced from south to north).

The "halo" of the homunculus is shown in Figures 2*a*, *b*, and *c* and 3*a*. They were taken with the Newtonian camera of the 61-inch reflector ($F = 748$ cm). Figures 2*a*, *b*, and *c* are 15-second, 1-minute, and 3-minute exposures on the same plate, Ilford HP2, taken on February 1, 1944.

The sensitivity of the plates seems to have been much greater than one year later, as a 15-second exposure appears several times denser than one exposed over 4 minutes at the Cassegrain focus (Fig. 1*i*). The ratio of light-concentration for extended objects is about 19. By equal seeing and plate sensitivity the density of the 15-second image (Fig. 2*a*) should be only slightly larger than that of Figure 1*i*. Comparison with other plates (not reproduced here) allows one to estimate the density ratio to be about 4.

Figure 2a.—15 seconds at Newtonian focus. Three new prominences appear faintly (curve *10′*). The first has a peculiar shape; starting from the main body at p.a. 248°, it spreads out at about 8″ from the center toward the southeast and mainly toward the northwest. This spreading has suggested to Thackeray[1] the presence of an elliptical shell. The pictures show no further evidence for it. Thackeray appears not to have noticed the cylindrical radial column.

The second prominence—seen by Thackeray as part of the elliptical shell—appears as a system of curved streamers coming from the central body between p.a. 160° and 185°. The third points a little to the north of star *F* (p.a. 28°). The star just east of η Car does not belong there.

Figure 2b.—1-minute exposure. The prominences have grown in outline without changing their general appearance. Some of the streamers due south curve to the east.

Figure 2c.—3 minutes. The two first prominences (*k* and *l*, Fig. 5) adopt the shape of hammerheads; the third appears conical. The diffraction due to the diagonal supports begins to show, particularly east. The peculiar arch formation at the north may be due in full or in part to diffraction. There may be a fourth prominence pointing east (*n* in Fig. 5).

Figure 3a.—This is an enlargement of a 20-minute exposure on an Ilford Ortho Process plate taken on June 21, 1944. The limits of the nebulosity are pushed to between 9″ and 10″ from the nucleus. The somewhat square shape is due to the diffraction-cross, in addition to prominences *k*, *l*, and perhaps *n*.

Figure 3b.—This is a 30-minute exposure on Ilford HP2 emulsion taken on March 18, 1944. New streamers in addition to the diffraction-cross appear. Some of them probably belong to the star's nebulosity, others to the galactic nebulosity. A discrimination is difficult because their densities are of the same order of magnitude. This is shown in Figure 3*c*, which is a smaller enlargement of the same plate used for Figure 3*b*. Herschel's "Key-Hole" shows on the left, also parts of the very bright nebulosity flanking it.

Figure 4.—This figure shows the brightest part of the galactic nebulosity. It is a 60-minute exposure on Eastman 103-O emulsion taken on April 25, 1944, at the Newtonian focus of the reflector. The rectangle indicates the extent of the previous figure. West is now at the right, since the reproduction is a positive.

ISOPHOTE-CURVES

Enlarging Figures 2*a*, *b*, and *c* and 3*a* to the same scale as the others and using a pantograph, I have obtained the series of isophote-curves reproduced in Figure 5. The numbers of the curves correspond to the figures as given in Table 1, with the exception of *10* and *10′*. These two were drawn from the same picture, *10′* following a line of weak and *10* one of larger density. The exposure times grow geometrically with a ratio of 2 from curve *1* to curve *9*. The density ratio between *10′* and *9* is estimated—as explained above—to be about 4. Further, $t\,(11)/t\,(10) = 4$ and $t\,(12)/t\,(11) = 3$. The density ratio between *13* and *12* cannot be given, as a different type of plate was used.

1950ApJ...111..408G

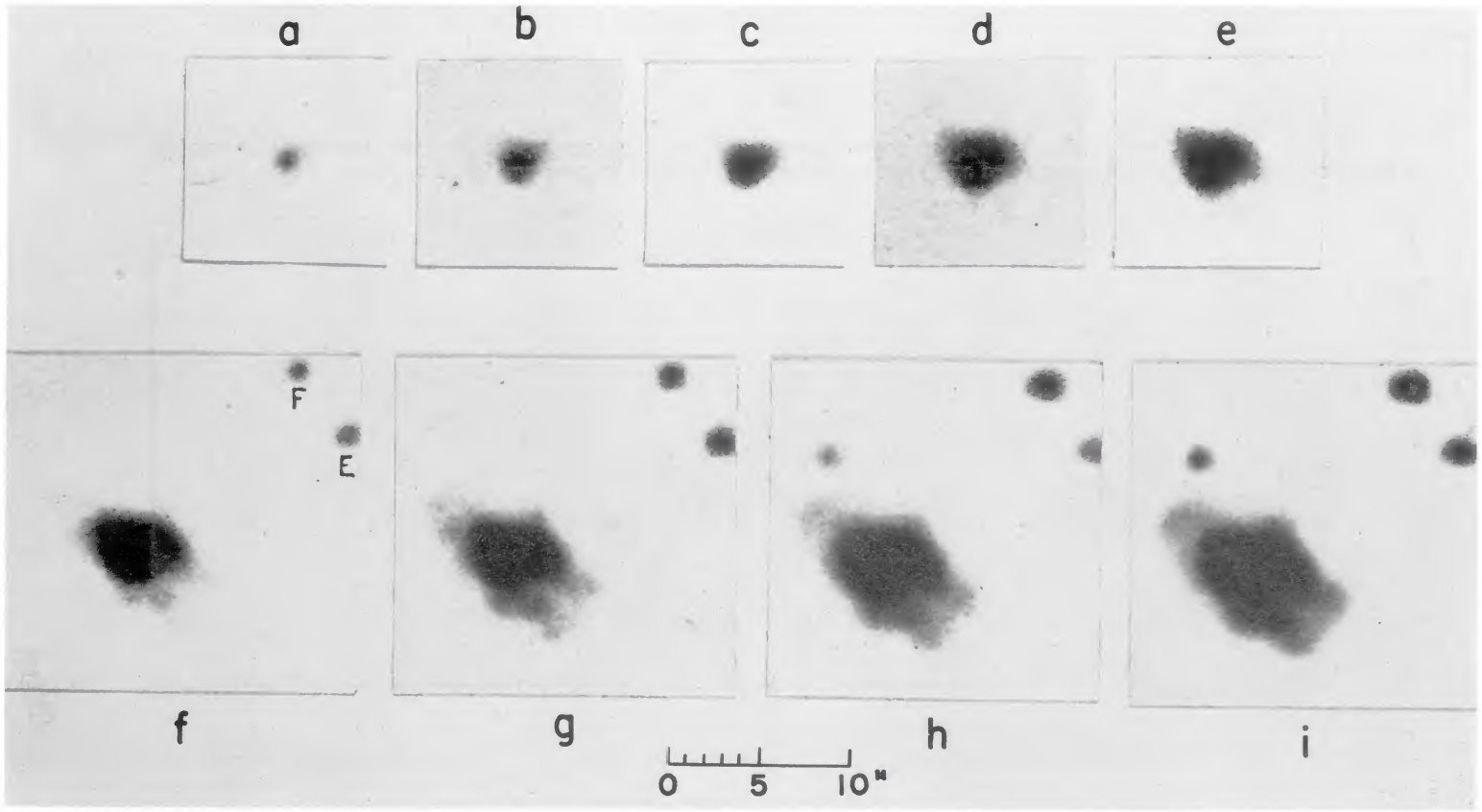

FIG. 1.—Series of photographs of η Car, taken on the same plate and night at the Cassegrain focus on Ilford HP2 emulsion, doubling the time on successive exposures—1–256 seconds. North is at the top; west at the left.

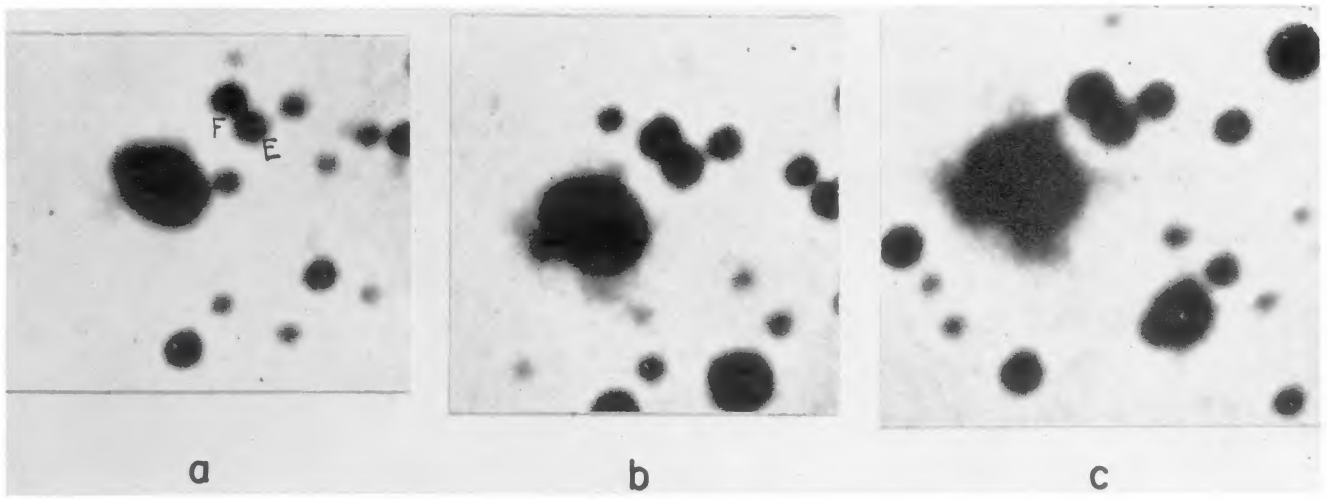

FIG. 2.—15-second, 1-minute, and 3-minute exposures on η Car on the same plate and night at the Newtonian focus on Ilford HP2 emulsion. A number of spurious images are present. Orientation is the same as in Fig. 1.

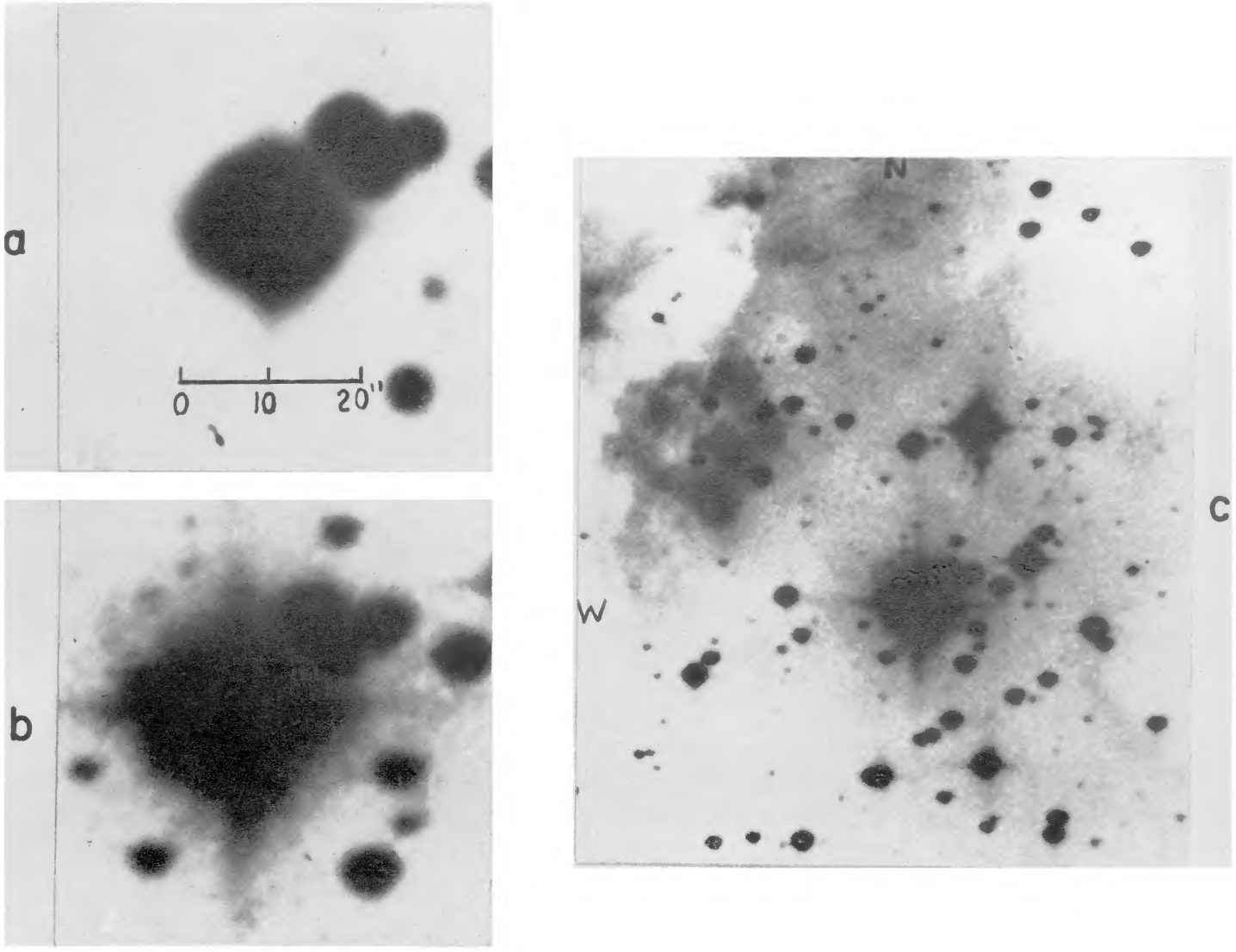

FIG. 3.—*a*, 20-minute exposure on Ilford Ortho Process plate at Newtonian focus; *b*, 30-minute exposure on Ilford HP2 emulsion, Newtonian focus; *c*, same as *b*, showing blending of the star's nebula with the galactic nebulosity.

FIG. 4.—The galactic nebulosity. Positive print indicating the extent of Fig. 3*c*. A 60-minute exposure on Eastman 103-O emulsion at the Newtonian focus.

The stars *F* and *E* are plotted for orientation. The letters designate eruptions, prominences, condensations, or nubeculae that have a certain individuality. I have kept, as far as possible, the letters used by van den Bos. Table 2 gives position angles and distances of the formations listed for the years 1945.2 and 1944.1.

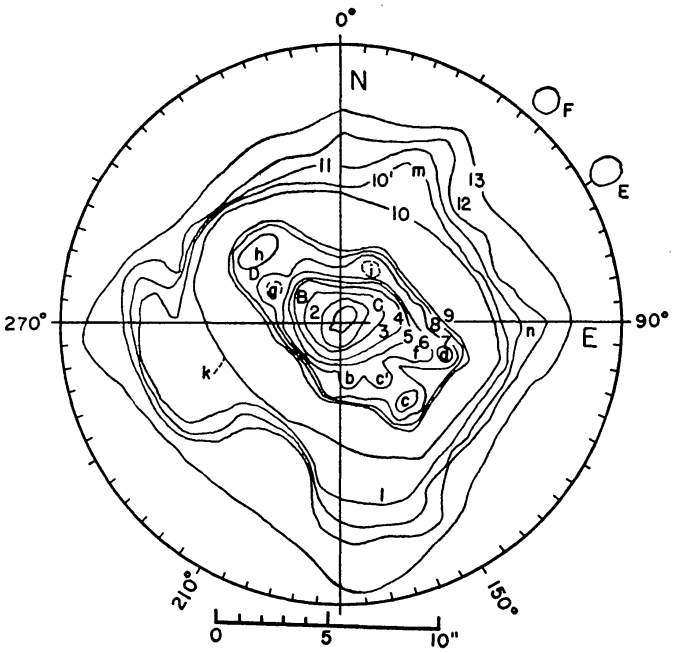

FIG. 5.—Isophote-curves

TABLE 1

Curve	Figure	Curve	Figure	Curve	Figure	Curve	Figure
2	1*b*	5	1*e*	8	1*h*	11	2*b*
3	1*c*	6	1*f*	9	1*i*	12	2*c*
4	1*d*	7	1*g*	10	2*a*	13	3*a*

TABLE 2

POSITION ANGLES AND DISTANCES FOR FORMATIONS

Date	Name	p.a.	*d*	Date	Name	p.a.	*d*
1945.2.....	B	312°	2".0	1945.2.....	*d*	108°	4".9
1945.2.....	C	65	1.9	1945.2.....	*f*	112	3.8
1945.2.....	*g*	296	3.4	1945.2.....	*i*	30	2.8
1945.2.....	*h*	310	4.9	1944.1.....	*k*	250	7.5
1945.2.....	*b*	{188	2.9	1944.1.....	*l*	173	7.0
		{175	2.6	1944.1.....	*m*	25	7.5
1945.2.....	*c'*	147	3.1	1944.1.....	*n*?	90	8.2
1945.2.....	*c*	141	4.7				

DISCUSSION OF RESULTS

Eta Car has been measured repeatedly as a multiple-star system since 1914; estimates date from John Herschel. Van den Bos expressed in 1938[4] his doubt about the stellar character of the components: ". . . nebular character of this unusual multiple system. . . . The companions may be nebular nuclei or involved stars." Thackeray considers the Radcliffe observations[1] as not "settling the question whether the components are truly stellar or nebulous condensation," but he favors the latter. A comparison of distances and position angles measured at different dates throws new light on the subject.

Table 3 contains the available data collected from the *Southern Double Star Catalogue* and the *Union Observatory Circulars*, adding the values of Table 2.

TABLE 3

MEASURES OF COMPONENTS

Name	Date	p.a.	*d*	Observer	Name	Date	p.a.	*d*	Observer
AB	1915.3	311°.8	0″.87	Innes	AD*	1926.3	269°.9	2″.04	B
	1915.3	319.4	0.82	Voute	*g*	1945.2	296	3.4	
	1917.1	312.5	0.98	I	AD†	1934.05	305.8	4.44	B
	1921.5	316	1.04	Bos	*h*	1945.2	310	4.9	
	1922.4	320.0	1.02	I					
	1926.3	216.6	1.40	I	Ab	1933.24	194.6	1.86	B
	1933.24	316.6	1.65	B		1945.2	175–188	2.6–2.9	
	1945.2	312	2.0						
					Ac	1933.24	141.3	3.98	B
AC	1914.4	74.4	1.07	I		1945.2	141	4.7	
	1914.4	75.3	0.80	V					
	1915.3	72.2	1.07	V	Ad	1934.79	103.3	4.45	B
	1915.3	74.2	1.06	I		1945.2	108	4.9	
	1916.4	72.1	0.98	I					
	1918.4	70.2	1.02	I					
	1921.5	70.0	1.08	B					
	1922.4	70.6	1.12	I					
	1926.3	69.0	1.12	I					
	1933.24	64.2	1.53	B					
	1945.2	65	1.9						

* Refers to *g*?
† Refers to *h*?

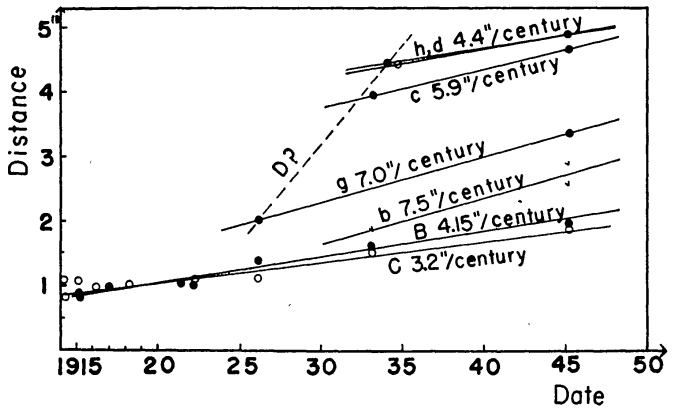

FIG. 6.—Motions of nubeculae

An inspection of the distances shows that they grow with time in a systematic way, while the position angles do not, or vary slowly. If we plot the distances of the components from the nucleus as a function of time, we obtain Figure 6.

The values given for D in the *Southern Double Star Catalogue* and in the *Union Observatory Circulars* are discordant in position angle and in distance. If we assume that the first measurement refers to our g and the last to our h, the changes fall in line with the others, although the position angles do not agree well in the first case. There is, therefore, evidence that the nubeculae forming the complex system move radially with speeds ranging from $3''.2$ to $7''.5$ per century. Not too much weight should be given to the individual values, as the objects measured are nebulous and not always easy to identify, but the order of magnitude is certainly significant: $5''$ per century or less could be taken as a weighted mean motion; the main eruption happened in 1843, just over a century before the last measurements, and the distances of the nubeculae concerned are about $5''$ or less.

Eta Car's own nebulosity as far as $5''$ from the nucleus is formed, therefore, by clouds ejected by the star around 1843 or later. The spectra—whose description will form Part II of this report—confirm this assertion. The radial velocities measured allow calculations of parallax. Objects E and F are stars, since their distances from η Car have not varied since Herschel estimated them in 1834, and their spectra are stellar.

It is a pleasure to thank Mr. Martin Dartayet for taking the plates at the Newtonian focus; Dr. Ricardo Platzeck for his constant help and for making possible the completion of this work; and M. Leon Fourvel Rigolleau for generously supporting part of it.