THE SPECTRA OF Be- AND Ae-TYPE STARS ASSOCIATED WITH NEBULOSITY*

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ABSTRACT

An argument based on the relative rates of contractive and nuclear (hydrogen-burning) evolution for stars of masses 3 to 20 $m_{\odot}$ enables an estimate to be made of the number of still-contracting stars of these masses within an observable distance of the sun. For example, within 1 kpc of the sun and 100 pc of the galactic plane one would expect there to be, somewhere in their contractive phase, about 18 stars that will in time reach the main sequence at types B2 and B3. A purely empirical attempt was made to identify some of these objects by examining in detail a list of 26 Be- and Ae-type stars that both lie in obscured regions and illuminate nearby nebulosity. The list contains such well-known variables as T Ori, AB Aur, RR Tau, Z CMa, and R Mon, as well as some newly found emission-line stars. In the course of the investigation two new variable nebulae were found. Two main types of stars were encountered: one with emission lines mainly of hydrogen plus absorption features due to a weak overlying shell; and another group with higher velocities of ejection, stronger emission lines, and line structure of the P Cygni type. Although it is entirely possible that this list of peculiar objects does contain examples of still-contracting stars of large mass, no convincing proof of this supposition could be found. The essential reason was that, although there are some striking spectroscopic peculiarities among the stars examined, at the dispersions employed in this investigation the peculiarities did not appear to be unique to this group: they may be found as well in stars that are not associated with nebulosity.

I. INTRODUCTION

Over the past decade the accumulation of observational material, together with a growing understanding of some of the processes of stellar evolution, have led many astronomers to the belief that the T Tauri stars are young stars still in the stage of gravitational contraction toward the main sequence. If this belief is correct, then the luminosities of the T Tauri stars indicate that they are objects of small to intermediate mass that will in time become main-sequence stars of type F and later. The next step is to inquire whether some newly formed stars of still larger mass may be identified in a similar manner. The aim of this paper is to investigate that question.

It is obvious that contracting stars of large mass will be much rarer in a given volume of space than will the T Tauri stars, because their contraction times are much shorter and their numbers smaller. On the other hand, if the search is extended to a given apparent magnitude, the higher luminosity of the stars of large mass will help to compensate for these effects. An estimate of the number of stars of large mass that are in the contractive phase at any one time may be made in the following manner.

If t_N is the nuclear time scale (i.e., the interval spent on or very near the main sequence) for a star of mass $\boldsymbol{m}$, and t_C is the time required for it to contract to the main sequence, then the ratio of the number of stars in the contractive phase to those on the main sequence is

$$\frac{N_C}{N_{MS}}=\frac{t_C}{t_N}, \qquad (1)$$

provided that t_N is small in comparison to the time interval in which star formation has been under way in the Galaxy. This last condition is unnecessary if star formation has been going on at a constant rate since the beginning. Now, t_N is approximately the time required for the star to reduce the hydrogen content of its convective core to zero, and hence it can be estimated from data tabulated for various masses by Henyey, LeLevier,

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and Levee (1959); values of t_N are given in Table 1. It is assumed for the present purpose that t_C is equal to the gravitational Kelvin contraction time,

$$t_K = 5 \times 10^7 \frac{m^2}{LR} \text{ years}, \tag{2}$$

where mass, terminal luminosity, and terminal radius are all in solar units. Values of t_K computed in this way from the main-sequence (MS) values of m, L, and R used by Henyey *et al.* are given in Table 1, as well as the ratio $(t_K/t_N)^{-1}$. A value of N_{MS} (per cubic parsec) can be found from integrating the Van Rhijn luminosity function for main-

TABLE 1

THEORETICAL NUCLEAR (t_N) AND CONTRACTIVE (t_K) TIME SCALES AS A FUNCTION OF STELLAR MASS ($m/m_\odot$)

$m/m_\odot$	Main-Sequence Spectral-Type Corresponding to $m/m_\odot$	t_N (years)	t_K (years)	$(t_K/t_N)^{-1}$
1.5.......	F0	1.1×10^9	1.2×10^7	92
2.0.......	A5	5.2×10^8	5.8×10^6	90
3.5.......	B9	1.1×10^8	1.4×10^6	79
6.0.......	B5	3.7×10^7	4.4×10^5	84
11.0.......	B1	1.3×10^7	1.5×10^5	87
20.0.......	O9.5:	6.4×10^6	4.5×10^4	140

TABLE 2

PREDICTED NUMBERS OF STILL-CONTRACTING STARS OF LARGE MASS

Spectral-Type Interval	Adopted Value of $(t_K/t_N)^{-1}$	N_{MS}: Number of Main-Sequence Stars pc^{-3}	N'_C: Numbei of Contracting Stars within 1 kpc	N'_C, but Corrected to Limit of $m_v=13.0$
B0–B1 V.....	100	4.6×10^{-7}	2.9	40.
B2–B3 V.....	85	2.5×10^{-6}	18.	155.
B5–B8 V.....	80	1.7×10^{-5}	130.	660.
B9–A0 V.....	80	3.5×10^{-5}	280.	780.

sequence stars (Sandage 1957) over the M_v intervals corresponding to the spectral-type intervals listed in Table 2; the luminosity calibration of Keenan and Morgan (1951) was used. Table 2 also lists N'_C, the number of contracting stars within 1 kpc of the sun and within 100 parsecs of the galactic plane; this number was obtained by multiplying N_{MS} by an average value of t_K/t_N for each M_v interval, and by the volume 6.3×10^8 psc^3. Now, if beyond 1 kpc the survey extends to $m_v = 13.0$ for all M_v's, and an allowance is made for a visual absorption of 1 mag/kpc, the corrected N'_C's of the last column of Table 2 are obtained; they assume that the terminal M_v's are a suitable index of the detectability of these stars during contraction and ignore the fact that these objects are confined to the spiral arms.

These are the number of stars within the observed volume that are somewhere in their contractive phases, but, judging from experience with the T Tauri group, one expects that during only a fraction of their contractive careers will these stars show any strikingly peculiar characteristics, if at all. Furthermore, it is also to be expected that such stars will be formed in regions of high gas and dust density, where they will be very heavily obscured. Consequently it is anticipated that, even if the numbers in the last column of Table 2 are correct, the number of such stars that are both observable and obviously peculiar will be much smaller.

But the point is that the numbers are not negligible, and hence there is some chance that a certain number of objects of this kind can be found. This paper is an account of the examination of a number of stars, selected by presumption as to the circumstances in which one might expect to find newly formed early-type objects, to see whether any distinctive spectroscopic characteristics exist.

Consideration was limited to stars of spectral type A and earlier, that is, to stars that are presumed to be not far from their terminal points on the main sequence. Objects that are still farther to the right in their contractive movement leftward across the H-R diagram are excluded from the present study; it is hoped to discuss such stars at a later time. One expects that the objects being sought will be closely associated with nebular material, so the further condition is imposed that the star illuminate nearby nebulosity; this condition will act to exclude objects only projected on the obscured field.

The stars listed in Table 3 were chosen for study because they met the following conditions: (*a*) The spectral type is A or earlier, with emission lines. (*b*) The star lies in an obscured region. (*c*) The star illuminates fairly bright nebulosity in its immediate vicinity.

Condition *b* is intended to exclude those nebulous stars with envelopes probably produced by ejection; examples are planetary nebulae, some Wolf-Rayet stars, and old novae. Even so, the conditions are loose enough that some extraneous objects may be included. The most frequent interlopers will be ordinary Be stars, but among these the nebulosity is rarely very bright or closely condensed around the star, so that many Be stars will be eliminated by condition *c*. A list of stars that may be related to those of Table 3 is given in Table 4, which also lists several objects that, from published information, may belong in Table 3 but are too far south for observation from Mount Hamilton.

The limitation of this study to stars with emission lines comes entirely from analogy with the T Tauri stars, although it is clear that the same spectroscopic criteria that have been devised for membership in the T Tauri class (Herbig 1958) will not be useful in the early spectral types, because no clear-cut examples of T Tauri stars (as defined by these criteria) have been found earlier than about type F8 (although V380 Ori, described later in this paper, may be such an object). Some such preliminary screening is necessary if distinguishing spectroscopic criteria are to be found at all because, so far as is known, the absorption spectra of nebulous early-type stars without bright lines look very much like their counterparts outside nebulosity. (For a possible exception to this statement see Morgan 1956.) But it is recognized from the beginning that the emission-line condition imposed here may effectively limit consideration to a rather special minority of "new" early-type stars.

The present investigation is intended to be no more than a reconnaissance of the field. Therefore, no effort has been made to obtain first-class observational data purely for its own sake, and no apology is offered for the approximate nature of some of the magnitude and color data employed. Because of the exploratory nature of the investigation, a considerable amount of information was collected that, in retrospect, appears to have had little direct bearing on the main issue. Its omission would have resulted in a more concise presentation; but, nevertheless, a considerable amount of this material is included here on the chance that it may prove useful or relevant in the future.

Finally, it should be emphasized that the stars studied here have not been found as the result of a systematic survey of the sky, so that they must be regarded as a very incomplete sampling of the volume of space corresponding to the most distant member. A closer scrutiny of the Mt. Wilson lists of emission-line stars would certainly turn up additional objects of the type under discussion.

TABLE 3

Be AND Ae STARS ASSOCIATED WITH NEBULOSITY

	Star	Other Designation	α(1900)	δ(1900)	Magnitude*	Spectral Type	Nebula†
1....	LkHα 198	....	$0^{h}06^{m}1$	+58°17′	*15*	A:eα	Anon.
2....	BD+61°154	MWC 419	0 37.5	+61 22	10.6	B2–B5 eq	Anon.
3....	AB Aur	HD 31293	4 49.4	+30 23	*7.2– 8.4*	B9e+shell	Anon.
4....	HK Ori	MWC 497	5 25.9	+12 05	*11.4–12.5*	Ae	Bar. Atlas no. 100
5....	T Ori	MWC 763	5 30.9	− 5 32	9.5–12.6	B–Aeα+shell	(Orion)
6....	V380 Ori	−6°1253	5 31.6	− 6 47	9.7–10.3	B8–A2e	NGC 1999
7....	RR Tau	AS 103	5 33.3	+26 19	10.2–14.2	B8–B9e+shell	Anon.
8....	HD 250550	MWC 789	5 56.2	+16 31	*9.7*	B9eq	Anon.
9....	LkHα 208	....	6 02.1	+18 42	*13.0*	B5–B9e+shell	Hubble anon.
10....	LkHα 215	....	6 27.2	+10 14	10.7	Be+shell	NGC 2245
11....	HD 259431	MWC 147	6 27.6	+10 24	8.7	B5:e	NGC 2247
12....	R Mon	MWC 151	6 33.7	+ 8 50	*11.3–13.8*	e+shell	NGC 2261
13....	LHα 25	....	6 35.2	+ 9 53	13.0v?	B8pe+shell	(NGC 2264)
14....	Z CMa	MWC 165	6 59.0	−11 24	*8.8–11.2*	eq	Anon.
15....	HD 53367	MWC 166	6 59.7	−10 18	7.0	B0 IV:e	IC 2177
16....	MWC 297	....	18 22.4	− 3 55	*11.0*	?	Anon.
17‡....	R CrA	....	18 55.2	−37 06	*10.0–13.6*	Ae	NGC 6729
18‡...	T CrA	....	18 55.2	−37 06	*11.8–13.9*	F0eα	(NGC 6729)
19....	BD+40°4124	MWC 340	20 17.0	+41 03	10.6	Be	Anon.
20....	BD+41°3731	....	20 20.8	+41 58	9.9	B2–B3e	NGC 6914*b*
21‡...	HD 200775	MWC 361	21 00.4	+67 47	7.4	B3e+shell	NGC 7023
22....	BD+65°1637	AS 475	21 40.6	+65 39	11	B5e	NGC 7129
23....	LkHα 234	....	21 40.8	+65 39	*13*	Aeβ	NGC 7129
24....	BD+46°3471	AS 477	21 48.7	+46 46	10.1v?	A0e+shell	(IC 5146)
25....	LkHα 233	....	22 30.3	+40 08	*14.5*	A7eα	Anon.
26....	MWC 1080	....	23 12.9	+60 18	*13.0*	eq	Anon.

* Taken from Kukarkin *et al.* (1958) for the variable stars; slightly different values have on occasion been used in the text.

† If the name of the nebula is in parentheses, it means the star only lies within or near that nebula, and that there is an uncatalogued nebulosity more closely associated with the star.

‡ See notes below.

NOTES TO TABLE 3

17 R CrA.—This star, imbedded in the head of the variable nebula NGC 6729, has been observed spectroscopically in recent years by Joy (1945), Greenstein and Aller (1947), and Greenstein (1948*a*). The star was observed fairly extensively both at McDonald and at Lick in 1946, when it showed H and Fe II emission upon an absorption spectrum featured by strong Balmer lines together with weaker lines of He I, Ca II, and perhaps Mg II. On the Lick plates, NGC 6729 showed essentially the same spectrum as did R CrA, but the description by Greenstein and Aller suggests that sharp, strong higher members of the Balmer series were more conspicuous in the nebula. The absorption spectrum observed in R CrA and NGC 6729 is very much like that of an absorption shell, as has also been observed in R Mon and NGC 2261 near maximum light. It is the writer's opinion that in neither object (R CrA–NGC 6729 or R Mon–NGC 2261) has there been a convincing demonstration of a permanent, intrinsic difference in spectrum between star and nebula, except for an effect involving Ca II (see the discussion of V380 Ori in this paper). However, the matter deserves re-examination with modern equipment.

18 T CrA.—This variable lies in the outer edge of NGC 6729 and may itself be involved with a wisp of nebulosity. According to Joy (1945), the type is F0 with no emission in the photographic region. Lick slitless plates show that Hα is in emission.

21 HD 200775.—This reddened B3e (Mendoza 1958) shell star illuminates NGC 7023, around which a number of emission-Hα stars have been found at Michigan (Weston 1953) and at Lick. HD 200775 has rather narrow hydrogen emission lines that are cut by approximately central reversals. Weak [Fe II] emission lines appear to share the velocity of the underlying star, rather than that of the absorption cores. The cores may vary in displacement (Weston 1949, 1950).

II. OBSERVATIONAL DATA

In Table 3 are listed 26 stars that meet the conditions already described. Twenty-three are discussed in some detail in this section; for three stars marked by double daggers, no new material was collected. The notes to Tables 3 and 4 contain summaries of the published data on stars that were not investigated anew.

1. *LkHα 198*

Several years ago, Dr. C. D. Shane called to my attention a pair of faint nebulous stars that he had noticed on a plate taken with the 20-inch Astrograph. These two stars, 37″ apart, lie about 26′ southeast of β Cassiopeiae in a small dark nebula. Crossley plates taken in 1952–1958 show that the southern star (= LkHα 198), of about m_{pg} = 15,

TABLE 4

EMISSION-LINE STARS THAT MAY BE RELATED TO THOSE IN TABLE 3

	Star	α(1900)	δ(1900)	Magnitude	Spectrum
27*......	HR Car	$10^h19^m.4$	−59°07′	*8.2– 9.6*	B2eq
28*......	Anon.	10 50.0	−59 55	*10.5*	eq
29*......	GG Car	10 52.0	−59 52	*9.1– 9.5*	e
30*......	AG Car	10 52.2	−59 55	*7.1– 9.0*	eq
31*......	KK Oph	17 03.9	−27 08	*11.9–12.7*	B–Aeβ
32*......	VV Ser	18 23.7	+ 0 05	*11.4–12.7*	A2eβ
33*......	MWC 300	18 24.0	− 6 09	*10.0*	eq

* See notes below.

NOTES TO TABLE 4

27 HR Car.—The magnitude variation is slow and irregular (Hoffleit 1940). Henize (1952) reports that H, He I, [Fe II], and Fe II are in emission, with P Cygni structure at Hγ and Hδ. He states that "the absorption spectrum appears to be about that of a B2 supergiant." Interstellar λ 6284 can be seen on objective-prism plates, so the star is likely a high-luminosity object.

28 Anon.—Henize (1952) found very broad P Cygni-type lines of H, He I, and N II. The star is central in a small round nebula about 1′ in diameter (Hoffleit 1953).

29 GG Car.—This star may be a peculiar eclipsing variable with a period of 62^d (Greenstein 1938). It is located in the η Carinae region, but it is not individually nebulous according to Thackeray (1950). A slit spectrogram reproduced by Smith (1955) shows strong narrow H and Fe II emission, but without P Cygni structure. No stellar absorption spectrum is apparent.

30 AG Car.—The light variation is irregular and usually is slow (Greenstein 1938; Gaposchkin 1946; Mayall 1955). A nebulous ring about the star, of outer diameters 30″ × 39″, was discovered by Thackeray (1950). The spectrum of AG Car has been discussed very briefly by Smith (1955), Thackeray (1956), and Gratton (1957); strong H and He I emission is present, many lines being accompanied by P Cygni-type components. The spectrum is variable.

31 KK Oph.—Nothing is known about the type of light variation of this star. It lies at the edge of the dark cloud B59, which contains a number of emission-Hα stars, but it is not clear whether KK Oph is associated with the cloud or is a background object. Hα is in emission, but no bright lines—except for a filling-in of absorption Hβ—appear in the photographic region on 430 A/mm plates obtained in 1949 and 1951. Strong hydrogen lines, as well as a few faint late-type features, are present in absorption but the K line is not visible.

32 VV Ser.—This star lies in heavy obscuration and illuminates a faint elongated nebulosity of dimensions about 0′.5 × 3′ centered at the star. The nebulosity is brighter on blue exposures than on red, and hence is probably reflection. Hα emission in the star was found by Iriarte and Chavira (1956). Two Lick slit spectrograms obtained in 1946 show the type to be A2, with weak emission in Hβ. Little is known about the variability of VV Ser: both a short period and one of about $43^d.5$ have been suspected.

33 MWC 300.—This object lies in a dark region of the Aquila rift, but no bright nebulosity has been found in the vicinity, despite careful examination. The star is quite red. The emission-line spectrum of MWC 300 in 1951 has been described by Merrill and Bowen (1951): rather weak, narrow lines of H, Fe II, [Fe II], and [S II] were present, while [O I] had been found earlier. A Lick plate (130 A/mm) obtained in 1952 shows sharp shortward absorption components at the Balmer lines, as well as broad dark lines of Ca II. Except for these H and K lines, no stellar absorption spectrum is visible.

has nebulosity extending from it in position angles from about 30° to 160°. This rather bright fan-shaped nebula can be traced to about 35″ southeastward of the star (see Fig. 1).

The northern star of the pair is variable in light, between approximately $m_{pg} = 16$ and 18, and in the quadrant from northwest to southwest is surrounded by faint nebulosity with considerable structure. The nebulosity sets in about 5″ from the star and extends to about 15″. The star was bright in 1952, and at that time it exhibited a bright but very short nebulous tail that projected to the southeast for about 3″. This tail could still be seen in 1954 when the star was near mag. 18, but in 1955 the tail had disappeared and the star appeared only as a round, diffuse spot (Fig. 1). By 1958 the star had brightened somewhat, and the elongation of the image toward the southeast was again apparent. The brightness of the more distant nebulosity also varied on these plates, being relatively bright in 1952 and quite faint in the other years; it therefore may be correlated with the brightness of the star.

TABLE 5

APPARENT MODULUS OF THE GROUP BD+57°18,19,22

BD	HD	MK Type	M_v	M_{pg}	m_{pg}	$m_{pg}-M_{pg}$
+57°18.......	594	B3 V	−2.0	−2.2	7.85	10.0
+57 19.......	....	B5n	−1.3*	−1.5	8.32	9.8
+57 22.......	627	B6 V	−1.1	−1.2	8.8†	10.0

* It is assumed that the luminosity class is V.

† The star is ADS 129, with $\Delta m = 0.3$ mag. The Rutherfurd m_{pg} of 8.24 has been corrected by + 0.6 mag. to allow for the companion.

A slitless grating spectrogram of the field obtained in 1951 showed Hα emission of moderate intensity in LkHα 198, but neither that plate nor a subsequent exposure showed any emission in the northern (variable) star of the pair, although its continuous spectrum is well above the plate limits. Slit spectrograms (dispersion 430 A/mm at Hγ) of LkHα 198 in the photographic region show strong hydrogen absorption lines and possibly a trace of the K line; no emission is visible. If a stellar K line is indeed present, the type is about A5; if not, the strength of the Balmer lines corresponds to a late B or A type. Both the spectrum of LkHα 198 and the appearance of its nebula are reminiscent of R CrA and NGC 6729.

The spectrum of the northern star was observed in the photographic region in 1950 and 1954; only strong Balmer absorption lines could be seen, so that the type is B or A. No adequate spectrogram of the nebulosity at either star has been obtained, but what evidence there is indicates that both nebulae have spectra of the "continuous" rather than the emission-line variety.

About 7′ southwest of LkHα 198, at the edge of the same obscured area, is a group of three B-type stars lying in rather bright reflection nebulosity. The appearance of this nebulosity on direct photographs (Fig. 1) leaves little doubt that BD+57°19 and +57°22 are responsible for the illumination of the nebulosity in their immediate vicinity, but it is not obvious whether +57°18 is also involved. Nevertheless, the spectroscopic information (see Table 5) supports the idea that all three stars are at about the same distance. The bright nebulosity around the B-type stars is undoubtedly part of the dark cloud that contains LkHα 198 and its companion, and hence an apparent distance modulus derived from the bright stars will be applicable to the faint objects, except for differences in absorption.

The spectral types and luminosity classes of the three BD stars have been obtained from spectrograms of 75 A/mm dispersion by comparison with MK standards. The photographic magnitudes were taken from the work of Schilt and Hill (1937), and the normal absolute magnitudes and colors were taken from Morgan and his collaborators (Keenan and Morgan 1951; Johnson and Morgan 1953). The details and the results are contained in Table 5. The mean *apparent* modulus is about 9.9 mag. Therefore the M_{pg}'s of LkHα 198 and its variable companion are about +5 and +6 to +8, respectively, minus any correction for extra absorption. If LkHα 198 is a main-sequence star of type somewhere in the interval B5 to A5, it therefore appears at least 2.5 mag. too faint. If this discrepancy is due to ordinary absorption near the star, a color excess of at least 0.6 mag. should be present. The object deserves a photoelectric observation of color and magnitude.

The slitless spectrograms of the field show only one other emission-line star in the dark area: LkHα 197, of $m_{pg} \sim 17$, which lies near the western edge (see Fig. 1). The emission at Hα is very strong, but a slit spectrogram of the photographic region shows only rather weak bright Hβ and Hγ. The star is quite red, but no spectral type can be assigned with confidence. One other star having Hα in emission, LkHα 196, was found still farther to the westward. It lies 0ʹ.2 west and 2ʹ.7 south of BD+58°2, in an area of moderate obscuration, but its spectrum has not otherwise been observed.

2. *BD+61°154*

The rather sparse cluster NGC 225, containing about 15 stars of magnitude 10 or brighter, has on its northwestern edge the star BD+61°154 (= MWC 419), of type Beq. The cluster lies partly in a dark lane, but +61°154 is the only star in the group that is surrounded by bright nebulosity. Faint extensions of the nebulosity can be traced on a Crossley plate 4ʹ to 5ʹ east and south of the star, but the brightest features are a pair of parallel streamers extending to about 1ʹ from +61°154 (see Fig. 2). The nebulosity is much brighter on the blue than on the red exposure of the Palomar Sky Survey, and it very likely has a reflection spectrum.

Bright Hα was discovered in the spectrum of +61°154 by Merrill, Burwell, and Miller (1942). They stated that "the spectrum bears a general resemblance to that of HD 51480 . . . but the bright lines of Fe II are more distinct, and other differences are present. The P Cygni character of the lines of H and Ca II is well marked; the centers of the dark components of these lines are displaced about 2A to the violet from their normal positions. The stronger bright lines of Fe II appear to have weak dark components on their violet edges." Later, Merrill, and Burwell (1949) stated that the spectrum was probably the same four years later (in 1944).

Four Lick spectrograms of +61°154 taken at 75 A/mm dispersion in 1954 confirm the description of the spectrum given by the Mt. Wilson observers (see Fig. 14). The intensity maxima of the bright components of the hydrogen lines have only a small displacement; the mean for Hβ, Hγ, and Hδ is +7 km/sec, although the displacement of Hβ seems to be systematically more positive than that of the other lines. The shortward absorption components, on the other hand, show mean displacements of −240, −190, and −160 km/sec, respectively, for the same three lines. The emission lines of Fe II are somewhat diffuse but probably in their mean give a value less affected by systematic shifts than any of the other measurable features; the mean Fe II velocity is −12 km/sec. The general character of the spectrum did not change during the period of observation (about 4 months) except that the strength of both bright and dark components of the H lines varied somewhat from plate to plate. An increase in the strength of the shortward absorption borders was reflected in a shift of their minima still farther shortward. The Fe II emission lines also fluctuated in intensity along with the H lines, but neither their displacements nor those of the H emission components showed any obvious correlation with intensity.

It is clear from their large negative displacements that the shortward absorption fringes at the H lines originate in an expanding atmosphere and not in the underlying star. However, the He I lines λ 4026 and λ 4471 are present in absorption without conspicuous emission components and in the case of λ 4026, at least, with only a small displacement. Furthermore, at Hδ the P Cygni structure is superimposed on a wider absorption line, whose wings can be seen on either side. Presumably these wings and the He I lines arise in the underlying star; their intensities suggest a spectral type in the interval B2 to B5.

A provisional magnitude and color of +61°154, as measured on only one night in 1958 with the 22-inch reflector, are: $V = 10.64$, $B - V = +0.52$, $U - B = -0.33$. If the deviation of these colors from normal main-sequence values is due only to ordinary interstellar reddening, then +61°154 can be represented by a B2 V star with 2.3 magnitudes of visual absorption superimposed. If the Keenan and Morgan (1951) calibration of the MK luminosity-class system is assumed, then the distance modulus is 10.9 mag. However, although the underlying star in +61°154 may be of type B2, it is doubtful whether one can safely assume either that its intrinsic color is that of a normal non-emission star or that it lies on the main sequence, because Mendoza (1958) has found that the ordinary Be stars of a given type show a substantial scatter in intrinsic color; he also found that several B1e-B2e stars of well-determined M_v are 0.4 to 1.0 mag. brighter than the Keenan-Morgan main-sequence values.

If +61°154 is a physical member of NGC 225, its absolute magnitude is probably best determined from the color-magnitude diagram of the cluster, although there may be difficulty with local reddening corrections. The only evidence available at the present time regarding its membership in NGC 225 comes from the proper motions of a number of stars in the region that have been determined by Lee (1926). The curious rotational character of the published motions causes one to regard the details of those results with some reserve; but *in amount* the proper motion of +61°154 does not differ markedly from those of many cluster stars.

Two exposures of the region of NGC 225 with the slitless spectrograph showed 7 stars within 22′ of +61°154 that have the Hα line in emission; they are marked in Figure 2 and are listed in Table 6. The notes to the table contain the information obtained from slit spectrograms of the photographic region.

3. *AB Aurigae*

The spectrum of AB Aurigae is that of a B9 star plus a shell whose emission and absorption features vary, usually slowly but sometimes quickly, with time. The spectrum has been described by Merrill and Burwell (1933*a*, 1943), by Swings and Struve (1943*b*), and by Sanford and Merrill (1958). The most recent observations known to the writer are a number of McDonald and Lick spectrograms obtained in 1949–1958. On these plates the spectrum agrees with the description by Swings and Struve of their 1943 spectrogram. Strong, somewhat diffuse, emission components are present in the Balmer lines as far as H10 or H12, while the hydrogen absorption lines are individually distinguishable as far as H15. A weak, narrow K line is present, and faint absorption lines are visible at Mg II λ 4481, Fe II λ 4233, Ca I λ 4226, and Fe I λ 4383 on the 1949 McDonald plate; a number of still fainter metallic lines are probably present, and possibly He I λ 4026 as well. The spectrum of the star is B9, and the luminosity class is either IV or V. The Mount Wilson plates of 1928–1930 showed sharp absorption cores in the Balmer lines, while longward emission fringes were usually conspicuous at Hβ. The dark K line was strong and probably had a core similar to the hydrogen lines, but it showed no emission. The shell that was so prominent at that time is clearly weaker now.

The brightness of AB Aurigae is approximately constant near $m_{pg} = 7.3$ for most of the time. Minima occur infrequently; the faintest observed by S. Gaposchkin (1952) in a survey of the Harvard plate material was near mag. 8.4. Despite the superficial resemblance of the light variations of AB Aur to those of stars of the R CrB type, it is certain that this variable is an object of quite different character. Shapley (1924) noted that AB Aur was situated near the edge of an obscured region, and he speculated that "probably . . . its abnormal variability is to be attributed to occultations by cosmic dust clouds." Several years ago the writer noticed that the image of AB Aur on a 20-inch plate was nebulous, and subsequent Crossley photographs show that the variable is the center of a system of streamers and arcs of rather faint nebulosity (see Fig. 3). Two extensions reach to the east as far as the irregular variable SU Aurigae, 3′ away, which itself has a small but much brighter curved nebulous tail. This appendage opens clockwise from SU Aur and ends abruptly about 13″ away. A much fainter arc emerges from the image of AB Aur and extends for about 35″ to the northeast. It is perhaps significant that the appendages to AB and SU Aur each extend approximately in the direction of the other star. There have been too few observations as yet to establish whether or not these nebulae are variable.

TABLE 6

EMISSION-Hα STARS NEAR BD+61°154

LkHα	Approximate m_{pg}	Hα Intensity	LkHα	Approximate m_{pg}	Hα Intensity
199	14	m	203	17	m
200*	14	m	204	17	m
201*	14	s	205*	16	s
202	13	s			

* See notes below.

NOTES TO TABLE 6

LkHα 200.—An early K-type absorption spectrum is present; the energy distribution is approximately that of a dK0 star. Weak emission is present at H and K, and possibly at Hβ. It is probably a T Tauri-like star associated with the dark cloud.

LkHα 201.—The spectrum appears continuous on narrow 430 A/mm spectrograms of the photographic region. The energy distribution is about like that of a dK0 star.

LkHα 202.—This is a background Be star. Absorption Hβ is absent, presumably due to superimposed emission. The energy distribution is like that of a star much later than class B. LkHα 202 is outside the area shown in Fig. 2; it is 4′.6 north, 4′.4 west of LkHα 203.

LkHα 205.—Only one underexposed plate is available; no emission lines are visible in the photographic region.

The color of AB Aur was measured on three nights by Stebbins, Huffer, and Whitford (1940); the mean value of C_1 was +0.01 mag. The intrinsic C_1 color of a non-emission B9 V star is about −0.14 mag. (Morgan, Harris, and Johnson 1953), so that the mean E_1 for AB Aur is +0.15 mag. and the visual absorption, 0.9 mag. If AB Aur at maximum light has the luminosity of a normal B9 V star, its distance modulus is then about 6.2 mag. If the star in reality lies above the main sequence, this distance of 175 parsecs is to be considered a lower limit, although it is reasonable in view of the fact that the dark nebula in which AB Aur lies is part of the extensive Taurus obscuration, for which a mean distance of about 150 parsecs is usually quoted.

Several other emission-line stars lie in the same dark cloud and are listed in Table 7.

4. *HK Orionis*

The variability of HK Orionis (= 43.1939 Ori = MHα 265-13 = MWC 497) was discovered by Morgenroth (1939), who believed it to be an eclipsing variable. Hoffmeister (1949*a*) found that the variations were irregular and stated that the star was probably like R CrB. Irregular fluctuations between m_{pg} = 11.4 and 12.5 were also observed by Kurokin and Kholopov (Kholopov 1951); their data indicated that the star varies on both sides of an intermediate magnitude, near 12.0, which is maintained most of the time.

Hoffmeister remarked that HK Ori lay at the south end of a small, bright triangular nebula. This nebulosity, first noticed by Barnard (1927), is shown in Figure 4. The nebulous fan can be traced for over 3′ north and west of the star, and a fainter streamer extends over 5′ to the south. This reflection nebulosity is quite blue and is obviously illuminated by HK Ori. The area is covered by an intricate mass of emission nebulosity (see the excellent photograph in Haro *et al.* 1953) that is excited by λ Ori, about 2°.4 to the south.

The spectrum of HK Ori has been described briefly by Joy (1949); in what follows, Joy's remarks have been supplemented by new Lick and McDonald material (see Fig. 14). In the photographic region, Hβ is a moderately strong emission line with faint absorption wings. At Hγ, the emission is inconspicuous upon a strong absorption line, and higher Balmer lines show little or no emission. A narrow K absorption line is present. Nearly as strong as Hβ are the [Fe II] emission lines at λλ 4243, 4287, 4359, and 4416. Permitted Fe II appears weakly, as does [S II]. The strength of the H absorption lines

TABLE 7

EMISSION-LINE STARS NEAR AB AURIGAE

Star	Mag.	Spectral Type
AB Aur	*7.2– 8.4*	B9e+shell
SU Aur	*9.7–11.3*	G2ne III
UY Aur	*11.6–14.0*	dG5:e+?
GM Aur	*13.1–13.9*	dK5e
Haro 6–39*	*17.5:*	eα

* Haro, Iriarte, and Chavira (1953).

corresponds to an early A type, but on some spectrograms a few faint lines of Fe I and Ca I can be seen. If these arise in the atmosphere of the star and not in a shell, they indicate a later type for the underlying star than do the Balmer lines. It should be clear that the H lines, unlike the shell-type features observed in RR Tauri and other objects described in this paper, have extensive wings and appear quite normal except for the presence of emission in the low series members.

Joy assigned a type of A4 to HK Ori, and the luminosity of the variable is approximately in accordance with that type. The evidence is as follows. HK Ori lies in the H II ring excited by λ Ori, for which a distance modulus of about 8.5 mag. is appropriate. The magnitude and color of HK Ori were measured by O. J. Eggen and the writer on two nights in 1949; reduced to the B,V system, the mean values are: $V = 11.52$, $B - V = +0.41$. If the intrinsic color is that of an A4 V star, or $B - V = +0.12$, then the color excess corresponds to a visual absorption of 0.87 mag., and thus $M_v = +2.2$, compared to a value of +2.0 for a normal A4 V star (Keenan and Morgan 1951).

The surrounding dark cloud contains many emission-Hα stars; about 30 have been discovered as a result of the surveys of Joy (1949), Haro *et al.* (1953), Manova (1959), and the writer (unpublished). A few non-emission variables are known as well. A few of the emission objects lie in the fan-shaped nebulosity illuminated by HK Ori and are indicated in Figure 4.

5. *T Orionis*

T Orionis is the classical example of the association of an early-type irregular variable star with nebulosity. It lies in the Orion Nebula about 10′ southeast of the Trapezium. Photographs taken in yellow light, with the strong nebular emission lines filtered out, show that a faint fan of nebulosity extends for about 10″ westward of the variable (see Fig. 5). Exposures in blue and red light also show the fan, but in those spectral regions the brilliant Orion emission nebulosity is dominant. The presence of this reflection nebula at T Ori demonstrates that the star actually lies in or very near the nebular material.

The most complete study of the light variations of T Ori has been made by Parenago (1950, 1954), whose work should be consulted for a thorough account of the photometric behavior of the star. He found a visual range of 9.4 to 12.2 mag.; the variable is more often near maximum brightness than faint, but the fluctuations are completely irregular.

TABLE 8

MEASURED RADIAL VELOCITIES OF T ORIONIS

Mean (based only on 2- and 3-line plates) = +64 km/sec*

Date (U.T.)	Radial Velocity (km/sec)	No. Lines	Estimated m_{vis}
1944 Jan. 19, 8^h09^m......	(+109)	1	10.0:
1945 Jan. 23, 7 24.......	+ 73:	3	10.7
Oct. 3, 11 18.......	+ 36	3	....
1949 Sept. 30, 11 40.......	(+ 80)	1	9.9
1950 Feb. 26, 5 54.......	+ 73	2	9.8
Sept. 28, 12 46.......	+138	2	10.1
Nov. 26, 7 02.......	(0)	1	9.8
1951 Jan. 28, 4 53.......	+ 46	3	9.8
Mar. 12, 4 24.......	+ 48:	2	9.8
Oct. 22, 12 33.......	− 8	3	10.0
Oct. 23, 9 08.......	+ 13	3	....
Oct. 23, 12 33.......	+ 9	3	....
Nov. 2, 9 44.......	+ 72:	3	10.2
Nov. 7, 10 12.......	+ 48	3	9.8
Nov. 17, 9 46.......	+ 61	2	10.1
Dec. 15, 8 19.......	+114	2	9.8
1953 Feb. 24, 3 45.......	+ 46	3	9.8
1955 Feb. 7, 3 53.......	+ 84	3	9.9
Feb. 8, 3 23.......	+ 86	3	9.9
Feb. 9, 3 45.......	+119	2	10.0
Mar. 6, 3 57.......	+ 90	3	10.0
Mar. 7, 3 55.......	+ 77	3	10.1

* The radial velocity of the emission nebulosity in the region of T Orionis is +22 km/sec (Campbell and Moore 1918).

A spectral type of A0: was assigned by Trumpler (1931), but the first published description of the spectrum of T Ori was by Greenstein and Struve (1946), who gave a type of B8–A3 V; the uncertainty arose from the presence of He I λ 4471 in a spectrum that was otherwise about type A3. Greenstein and Struve found the mean absorption-line velocity to vary from +13 to +91 km/sec over an interval of 24 hours. A series of 26 spectrograms of T Ori was obtained at Mt. Hamilton in 1944–1955 with a dispersion of 75 A/mm at Hγ; those measurable for radial velocity are listed in Table 8. A plate of the red region obtained in 1945 showed that Hα was a narrow, rather strong, emission line, but otherwise the spectrum is very much as described by Greenstein and Struve, except that He I does not appear on the Lick plates. The strength of the Ca II lines corresponds to type A3. There is no emission in the photographic region at maximum light, and the spectrum appears normal except for narrow cores in the H lines, noted also by Greenstein and Struve (see Fig. 14). These cores are sometimes shifted well to longward of the line centers, causing the lines to have a markedly asymmetric appearance. The measured radial velocity varies over a range of about 150 km/sec. It is not clear whether the velocity changes are due entirely to variations in the position or strength of the cores or whether the whole line shifts as well. But one has the impression that the large shifts toward positive velocity, at least, are accompanied by a longward shift of the cores. In view of the composite structure of the Balmer lines, it would not be safe to attach much significance to the fact that the mean velocity from Table 8 is about 40 km/sec more positive than the velocity of the Orion Nebula in the vicinity of the star.

The K line of Ca II does not vary in velocity over so large a range as the H lines, and fragmentary measures on weak metallic lines tend to confirm the statement by Greenstein and Struve that "the absorption velocities from the various elements differ significantly." The velocities given in Table 8 are straight means of the Hβ-, Hγ-, and K-

TABLE 9

MEASURED RADIAL VELOCITIES OF V380 ORIONIS FROM EMISSION LINES

Plate No.	Date (U.T.)	Radial Velocity† (km/sec)	No. Lines
30906........	1946 Jan. 11.25	+24	28
30908........	Jan. 12.26	+15	22
30924........	Jan. 15.23	+20	28
30940........	Jan. 21.20	+17	39
30957........	Jan. 31.16	+18	35
31067........	Apr. 15.17	+31	27
32347........	1948 Jan. 13.31	+24	30
....	1949 Dec. 2.40	+38	23
Ce 6099*	1950 Jan. 28.24	+20.7	23
Ce 6714*.......	Dec. 2.37	+20.4	13
38331........	1955 Feb. 7.23	+26	22

* Mount Wilson coudé spectrograms, dispersion 10 A/mm; each of these velocities received 3 times the weight of a 75 A/mm result.

† Weighted mean = +22 km/sec.

line displacements on 22 of the better plates. No period that would consistently represent all the radial velocities has been found, although there is a suggestion of a cycle length of 100 to 200 days. More rapid changes also take place. No correlation could be found between the velocity and the brightness of the star, the latter being estimated at the finder with respect to AAVSO comparison stars when the spectrograms were taken.

The general spectroscopic features of T Ori are obviously due to the superposition of a rather weak shell spectrum, of variable displacement, upon a spectrum of late B or early A type. The predominantly longward displacement and the variable velocity of the shell features find precedents in the behavior of "normal" shell stars such as Pleione. Although the velocity range of T Ori is larger than in such shells, the suggestion of a time scale of the order of a few hundred days in the velocity variation also is matched by the cycle lengths observed in some B-type shells (Struve and Swings 1943). This analogy, if correctly drawn, is important because it appears to suggest that, however stimulated, the shell of T Ori is due to activity controlled by the properties of the underlying star and not by the nebular environment of T Ori. However, the large light variations of T Ori are certainly not characteristic of shell stars.

Little is known about the spectrum of T Ori when it is very faint. A rather weak spectrogram taken on October 3, 1950, when the star was near mag. 11.2 shows no apparent change in the spectrum except that a narrow, fairly strong emission component has appeared near the center of Hβ. This emission line arises in the star and not from the nebular background since, despite the faintness of the variable, the exposure time was not prolonged to the point where the spectrum of the nebulosity would appear.

6. *V380 Orionis*

The emission lines in V380 Orionis (= BD − 6°1253) were discovered by Morgan and Sharpless (1946) on a Case objective prism plate and independently by the writer (Herbig 1946) in a search of the Orion Nebula region for emission-line stars. Brief descriptions of the spectrum have also been published by Greenstein (1948*a*, *b*) and Joy (1949). The Lick spectrograms are listed in Table 9, together with two 100-inch coudé plates obtained by the writer through a guest investigator arrangement with the Mt. Wilson and Palomar Observatories. Several McDonald spectrograms of the ultraviolet region to λ 3250 are also avilable, but they will not be discussed here.

Emission lines of H, Ca II, Fe II, Ti II appear strongly in V380 Ori, together with weaker lines of many other ions (see Fig. 14). A list of the lines measured in the region λλ 3905–6563 appears in Table 10. The bright H lines are superimposed upon the broad absorption lines of a star whose type, judged from the strength of the Balmer wings, must be between B8 and A2. An absorption fringe is visible also just shortward of the bright K line. It is unlikely that this is entirely P Cygni structure, since no such absorption is seen elsewhere in the spectrum. If it is the K line of the underlying star, then that star must have a type, if it is a main-sequence object, of A0 to A2.

The bright-line spectrum of V380 Ori is much like those of "advanced" T Tauri stars, except in certain details; but the level of ionization is distinctly higher because the lines of Fe I and other neutral metals are much weaker than in objects like RW Aurigae. It is perhaps surprising that the difference is not even greater, since here the underlying star is probably an early A, as compared to type G in ordinary advanced T Tauri stars. The lines of [S II] are not present in V380 Ori, but the fluorescent Fe I line at λ 4063 is suspected to be faintly present on a few plates. The star thus satisfies marginally one of the formal spectroscopic criteria for membership in the T Tauri class (Herbig 1958) and, if admitted on this very slender evidence, it is the only member now recognized whose type is earlier than about F8.

The emission lines in V380 Ori are rather diffuse. Simple micrometer measurements on the 10 A/mm coudé plates give a total half-width (from the line center to the "edge") of 66 km/sec for Fe II, 95 km/sec for Hβ and Hγ, and 125 km/sec for K of Ca II. Despite these width differences, which are intrinsic in the sense that they are not due to differences in line intensity, all elements yield essentially the same radial velocity. The mean emission-line velocity from all the material listed in Table 9 is +22 km/sec. Although the velocity from one plate stands 16 km/sec, or 4 times the probable error of a single 75 A/mm spectrogram, off this mean, there is no clear-cut evidence for variable radial velocity, nor has any change in the spectrum been observed on the Lick plates.

Rather weak, narrow absorption components are present in the Ca II emission lines. They are probably interstellar in origin. The mean radial velocity derived from the line at K is +21 km/sec.

V380 Ori is the illuminating star of NGC 1999, a round mass of reflection nebulosity about 1ʹ.5 in diameter (Fig. 6). It lies in the broad lane of obscuration, strewn with feebly luminous nebulosity, that extends several degrees south and eastward of the Orion Nebula. A striking feature of NGC 1999 is an extremely dark triangular cloud silhouetted against the bright nebulosity. V380 Ori lies on the edge of this marking, and a C-shaped arc of very bright nebulosity extends from the star around the northeast corner of this triangle. The arc and the dark marking are surrounded by fainter nebulosity. The structure is shown in the exposures reproduced in Figure 6.

The surface brightness of NGC 1999 is surprisingly high, and a number of slit spectrograms (dispersion 430 A/mm) have been obtained of various parts of the nebulosity. The line spectrum of the bright inner arc is, on these plates, identical with that of V380

TABLE 10

THE STRONGER EMISSION LINES IN V380 ORIONIS

λλ 3905–6563*

Laboratory Wave Length of Major Contributor	Identification	Estimated Intensity
3905.53	Si I (3)	3:
3913.46	Ti II (34)[+Fe II (2)?]	4:
3933.66	Ca II (1)	35
3938.29	Fe II (3)+Fe II 38.97 (190)	0
{3968.47 {3970.07	Ca II (1)} Hε}	35
4012.37	Ti II (11)	1
4024.55	Fe II (127)?	2
4028.33	Ti II (87)	2
4045.82	Fe I (43)	1
4053.81	Ti II (87)	1
4063.60	Fe I (43)	0?
4101.74	Hδ	15
4122.64	Fe II (28)	2
4128.74	Fe II (27)	2
4163.64	Ti II (105)	4
{4171.90 {4173.45	Ti II (105)} Fe II (27)}	15
4178.86	Fe II (28)	18
4215.52	Sr II (1)	0
4226.73	Ca I (2)	2
4233.17	Fe II (27)	20
4242.38	Cr II (31)	1
4246.83	Sc II (7)	2
{4273.32 {4275.57	Fe II (27)} Cr II (31)}	2n
4290.22	Ti II (41)	2
{4294.10 {4296.57	Ti II (20)[+Sc II 94.77 (15)?]} Fe II (28)}	3
{4300.05 {4301.93 {4303.17	Ti II (41)} Ti II (41)} Fe II (27)}	8
4307.90	Ti II (41)	2
{4312.86 {4314.08 {4314.98	Ti II (41)} Sc II (15)[+Fe II 14.29 (32)?]} Ti II (41)}	4
4320.74	Sc II (15)	0
4325.01	Sc II (15)	1
4331.53	Fe II (uncl.)?	0
{4337.92 {4340.47	Ti II (20)} Hγ}	20
4351.76	Fe II (27)	12
{4367.66 {4369.40	Ti II (104)} Fe II (28)}	1
4374.46	Sc II (14)	1
4385.38	Fe II (27)[+Ti II 86.86 (104)?]	6
4395.03	Ti II (19)	6
{4399.77 {4400.36	Ti II (51)} Sc II (14)}	2
4416.82	Fe II (27)[+Sc II 15.56 (14)?]	10
4443.80	Ti II (19)	5
4450.49	Ti II (19)	2
4468.49	Ti II (31)	5
4480:	Mg II 81.2 (4)?	2

* The braces inclose lines that were measured as one; the numbers in parentheses are the multiplet numbers of the *Revised Multiplet Table*. The estimated intensities longward and shortward of λ 5100 are probably not on the same scale, since they were estimated on plates taken with different emulsions and optics.

TABLE 10—*Continued*

Laboratory Wave Length of Major Contributor	Identification	Estimated Intensity
{4489.18	Fe II (37)}	20n
{4491.40	Fe II (37)}	
4501.27	Ti II (31)	6n
4508.28	Fe II (38)	10
4515.34	Fe II (37)	8
{4520.22	Fe II (37)}	25
{4522.63	Fe II (38)}	
4528.6:	Ti II 29.46 (82)?	1
4533.97	Ti II (50)+Fe II 34.17 (37)	5
4541.52	Fe II (38)	2
{4549.47	Fe II (38)}	20
{4549.62	Ti II (82)}	
{4555.89	Fe II (37)}	20n
{4558.66	Cr II (44)}	
4563.76	Ti II (50)	3
4571.97	Ti II (82)	4
4576.33	Fe II (38)	1:
4583.83	Fe II (38)[+Fe II 82.84 (37)?]	25
4589.96	Ti II (50)[+Cr II 88.22 (44)?]	2
4620.51	Fe II (38)[+Cr II 18.83 (44)?]	8
4629.34	Fe II (37)	20
4635.33	Fe II (186)+Cr II 34.11 (44)	0
4656.97	Fe II (43)+?	2:
4670.40	Sc II (24)+Fe II 66.75 (37)	3n
4731.44	Fe II (43)	4
4824.13	Cr II (30)	5
4848.24	Cr II (30)	3
4861.33	Hβ	40
4923.92	Fe II (42)	30
5018.43	Fe II (42)	35
5169.03	Fe II (42)[+Mg I 67.32, 72.68 (2)?]	40
5188.70	Ti II (70)[+Mg I 83.60 (2)?]	3n
5197.57	Fe II (49)	10
5226.53	Ti II (70)	2
5234.62	Fe II (49)+Cr II 37.34 (43)	15n
5264.80	Fe II (48)	1
5275.99	Fe II (49)+Cr II 74.99 (43)	10
5284.09	Fe II (41)	2:
{5316.61	Fe II (49)}	25
{5316.78	Fe II (48)}	
{5325.56	Fe II (49)}	2n
{5334.88	Cr II (43)}	
{5336.81	Ti II (69)}	
5362.86	Fe II (48)	5
5425.27	Fe II (49)	1
5534.86	Fe II (55)	2
{5889.95	Na I (1)}	5n
{5895.92	Na I (1)}	
{6147.74	Fe II (74)}	2
{6149.24	Fe II (74)}	
6238.38	Fe II (74)	2:
6247.56	Fe II (74)	10
6347.09	Si II (2)	1
{6369.45	Fe II (40)}	2
{6371.36	Si II (2)}	
6416.90	Fe II (74)	2:
6432.65	Fe II (40)	2
6456.38	Fe II (74)	10
6516.05	Fe II (40)	10
6562.82	Hα	200

Ori. But the Ca II lines in the spectrum of the faint outer envelope do not match those in the star. In V380 Ori, the K emission line is quite strong, and, although the λ 3968 line of Ca II is weaker than K, it is almost enough to fill in the center of the Hε absorption line. In the spectrum of the outer nebulosity, however, K is quite weak in emission, and the contribution of the Ca II line at λ 3968 has diminished to the point that Hε is a conspicuous absorption line (Fig. 6). This phenomenon is probably the same as observed by Greenstein (1948*a*, *b*) in the spectrum of the outer parts of NGC 2261. There seems no way for these Ca II emission lines to be weakened in the outer parts of such nebulae other than by a self-absorption process.

There can be no doubt that V380 Ori is imbedded in the same dark cloud that contains the Orion Nebula. This is demonstrated by the following facts. First: NGC 1999 cannot be a foreground object since the Hβ and λ 3727 emission lines of the field nebulosity overrun its spectrum and can be observed crossing the triangular dark patch close by V380 Ori. This is probably the source of the λ 3727 emission observed by Greenstein (1948*a*) in the outer parts of NGC 1999. And it is obvious that V380 Ori cannot be very deeply imbedded in the dark cloud because of the rather moderate amount of absorption indicated by its color (see below).

Second: the spectroscopic distance modulus of V380 Ori is very nearly equal to that of the Orion aggregate of early-type stars, on the basis of the following considerations. The spectral type of the star underlying the emission spectrum is probably A0 to A2. A normal A1 V star has $M_v = +0.8$ (Keenan and Morgan 1951). The color of V380 Ori was measured photoelectrically by Eggen and the writer on two nights in 1949; the mean value, reduced to the B,V system, is $B - V = +0.34$, which yields a visual absorption of 0.9 mag. Consequently, at the distance of the Orion aggregate, such a star should appear as $m_v = 10.2$, on the basis of Sharpless' modulus (1952). Actually, V380 Ori is slightly variable, between $m_v = 9.7$ and 10.1, but the agreement is satisfactory, thus demonstrating the point.

Third: the radial velocity of +22 km/sec observed for V380 Ori agrees very well with the peak 21-cm velocity for the H I cloud at that position, +24 km/sec (Menon 1958). However, one would feel more respect for this correspondence if the stellar velocity had not been obtained from the emission spectrum.

V380 Ori was reported as a double star (= ADS 4209) by Jonckheere (1917); the magnitudes were given as 8.9 and 13.0, separation about 3″, position angle about 220°. In addition, Jonckheere suspected a third star of mag. 15 at about 5″ in 40°. No further observations have been published. Neither companion has been seen during the present investigation. The positions given by Jonckheere both lie in the C-shaped arc of bright nebulosity passing through V380 Ori, and it may be that it was parts of this nebulosity that were measured.

Many T Tauri stars as well as a few non-emission variables have been found in the region of NGC 1999, and three Herbig-Haro Objects are located nearby. These are all outlying members of the large group of such objects associated with the Orion Nebula. The majority of the emission-Hα stars in this area were found initially by Haro (1953).

7. *RR Tauri*

Although the location of the irregular variable RR Tauri in a small dark cloud was noticed some years ago by Hoffmeister (1949*b*), the bright nebulosity immediately around the star apparently was not discovered until 1952, on Lick photographs (Herbig 1953, 1954*a*). It is shown on the Crossley photographs reproduced in Figure 7. The brightest feature of this nebulosity is a knot about 14″ east of the variable star; from this knot and from the star, two arcs of nebulosity run to about 50″ northward of RR Tau. In addition, a faint S-shaped mass of nebulosity appears to the south and west of the variable and extends southward for about 3′, beyond the star BD+26°887, which is surrounded by a close nebulous envelope of its own about 20″ in radius. Crossley plates obtained in 1952–1956 show that the appearance of details in the nebulosity near RR Tau are subject to change with time. Most conspicuous are variations in the brightness of the nebulous knot to the east of the variable, but the appearance of the narrow isthmus of nebulosity that connects the knot with the star also seems to change. Nebulosity lying very close to the image of RR Tau on the southeast cannot be seen on all the plates. Changes are also suspected in the streamer of nebulosity extending northwestward from the image of the variable. More extensive material than is now available will be required to determine whether or not there is any relationship between the changes in the nebulosity and the variations in light of RR Tau.

The light changes of RR Tau are quite irregular, with a visual range of mag. 10.2 to 14.2. (See, for example, the light curve for 1928–1936 given by Campbell [1937] and that for 1929–1930 by Jacchia [1933].) The variations may range from very rapid to rather slow, as evidenced by the fact that various early observers suggested widely different periods, from 2 to 210 days. The most detailed study of the light variation, based on all published photometric material covering the interval 1900–1942, is by Starikova (1951), who applied the statistical method used by Parenago for T Ori. Although the appearance of the light curves of T Ori and RR Tau differs (particularly in that RR Tau shows fluctuations of considerable amplitude with little apparent preference for any level in its range while T Ori gives the impression of having mainly downward variations from maximum light), Starikova considered that the variations of the two stars show significant similarities.

The impression exists in the literature that the spectral type of RR Tau is G1, but this is only the color class (color index = $+0.62 \pm 0.18$) as determined by Parenago (1933) from simultaneous comparisons of the photographic and visual magnitude. Joy (1945) commented that RR Tau was of earlier spectral type than the T Tauri stars, but no actual classification has apparently been published other than that by the writer (Herbig 1954*a*) of A2 II–III. The spectrum (see Fig. 14) is actually somewhat peculiar: the strength of the K line and of a few weak metallic lines correspond to A2 or a slightly later subclass, but the best plates show rather faint He I lines as in type B8 or B9. The cores of the H lines are narrow and deep. Since emission is present at Hα and Hβ (see below), it is more probable that RR Tau is a late B-type star plus a shell, rather than an early A-type star of intermediate luminosity as stated earlier by the writer.

An emission line at Hα was discovered in RR Tau by Merrill and Burwell (1950) and has since been amply confirmed on Lick plates. A sharp emission component is usually present at Hβ and may lie on either side of the absorption core, as if exposed by relative shifts of the absorption and emission. Its position is noted in Table 11 for each of the Lick spectrograms. On a few plates, weak shortward absorption components are present at the Balmer lines. With the exception of the change in the structure of the H lines, the Lick plates (of dispersions 75 and 130 A/mm) show no variation in the spectrum of RR Tau over a light range of 2 magnitudes.

The nebulous star BD$+26°887$ lies 3′ from RR Tau, at the edge of the same dark cloud so that it is very probable that the two stars are at essentially the same distance. The magnitudes and colors of RR Tau and of $+26°887$ have been measured on the U,B,V system by Walker (1958) and by Lenouvel (1957). The observations of RR Tau by Walker, which were made at my request, are contained in Table 12. For $+26°887$, Walker obtained: $V = 10.47$, $B - V = +0.42$, $U - B = +0.11$. The spectral type of $+26°887$ is B8; a reddening path of normal slope in a $U - B$, $B - V$ diagram does indeed intersect the main-sequence line at B8. A color excess of $E_{[B-V]} = +0.50$ mag. is indicated, from which $A_V = 1.5$ mag. The corrected m_v of $+26°887$, when compared to the normal main-sequence luminosity for a B8 star, yields a distance modulus of 9.5 mag. Lenouvel's photometric data for $+26°887$, treated in the same manner, also give a modulus of 9.5 mag.

Walker's and Lenouvel's data show that the color of RR Tau bears no simple relationship to the magnitude, nor is it a unique function of the magnitude. The variation of $U - B$ and $B - V$ is shown in Figure 15, where the points that represent observations by Lenouvel on successive nights are connected. It is clear that the variations of RR Tau cannot be explained by variable amounts of normal interstellar reddening. So, in the absence of any understanding of the phenomenon, we proceed blindly from the mean values of magnitude and color to estimate the amount of reddening of RR Tau. Walker's mean values, from Table 12, indicate a main-sequence type of B9, and a value of $\langle E_{[B-V]}\rangle = +0.75$ mag., so that $\langle A_V\rangle = 2.25$ mag., and $\langle V_0\rangle = 10.00$. At this mean magnitude, the modulus of the dark cloud obtained from $+26°887$ indicates that $\langle M_V\rangle = +0.5$. Similarly, the variation of RR Tau from $m_v = 10.2$ to 14.2 corresponds to a variation of M_v from -1.6 to $+2.4$.

In the same way, Lenouvel's mean results from 9 nights' observations ($\langle V\rangle = 11.84$, $\langle B - V\rangle = +0.60$, $\langle U - B\rangle = +0.37$) correspond in color to a B9.5 V star with $\langle A_V\rangle = 1.89$ mag., and $\langle V_0\rangle = 9.95$. At this mean magnitude, $\langle M_V\rangle = +0.4$, and the total range in M_v is -1.2 to $+2.8$. The agreement between the two ranges in absolute magnitude is probably all that one could expect in view of the limited number of observations and the large color variation of RR Tau.

But it must not be forgotten that the assumption made in deriving the above results, that the mean color of RR Tau is determined entirely by interstellar reddening, is certainly not entirely true because the data plotted in Figure 15 show that the process responsible for the light fluctuations enters into the colors as well. A second serious uncertainty in the derived absolute magnitude of RR Tau comes from the necessity of

TABLE 11

SLIT SPECTROGRAMS OF RR TAURI

Date (U.T.)	m_{vis}	Position of Hβ Emission with Respect to Absorption Core	Date (U.T.)	m_{vis}	Position of Hβ Emission with Respect to Absorption Core
1944 Oct. 17	10.8	Longward	1954 Feb. 8	11.1	Absent
1945 Dec. 6	10.9	Longward?	1954 Sept. 4	11.5	Longward
1949 Oct. 15	12.3	Longward?	1955 Mar. 16	11.0	Absent
1952 Oct. 27	10.3	Shortward	1956 Nov. 9	10.7	Longward

TABLE 12

PHOTOELECTRIC OBSERVATIONS OF RR TAURI BY M. F. WALKER*

Date (U.T.)	V	$B-V$	$U-B$
1953 Nov. 12	12.29	+0.71	+0.47
Nov. 13	12.13	+ .63	+ .31
Nov. 16	11.86	+ .71	+ .40
1955 Dec. 15†	12.49	+ .73	+ .35
Dec. 16	12.72	+ .70	+ .31
Means	12.25	+0.69	+0.37

* The 1953 observations were made with the 20-inch reflector at Mt. Palomar; the others were made with the 60-inch reflector at Mt. Wilson.

† Low weight; this observation is not included in the mean.

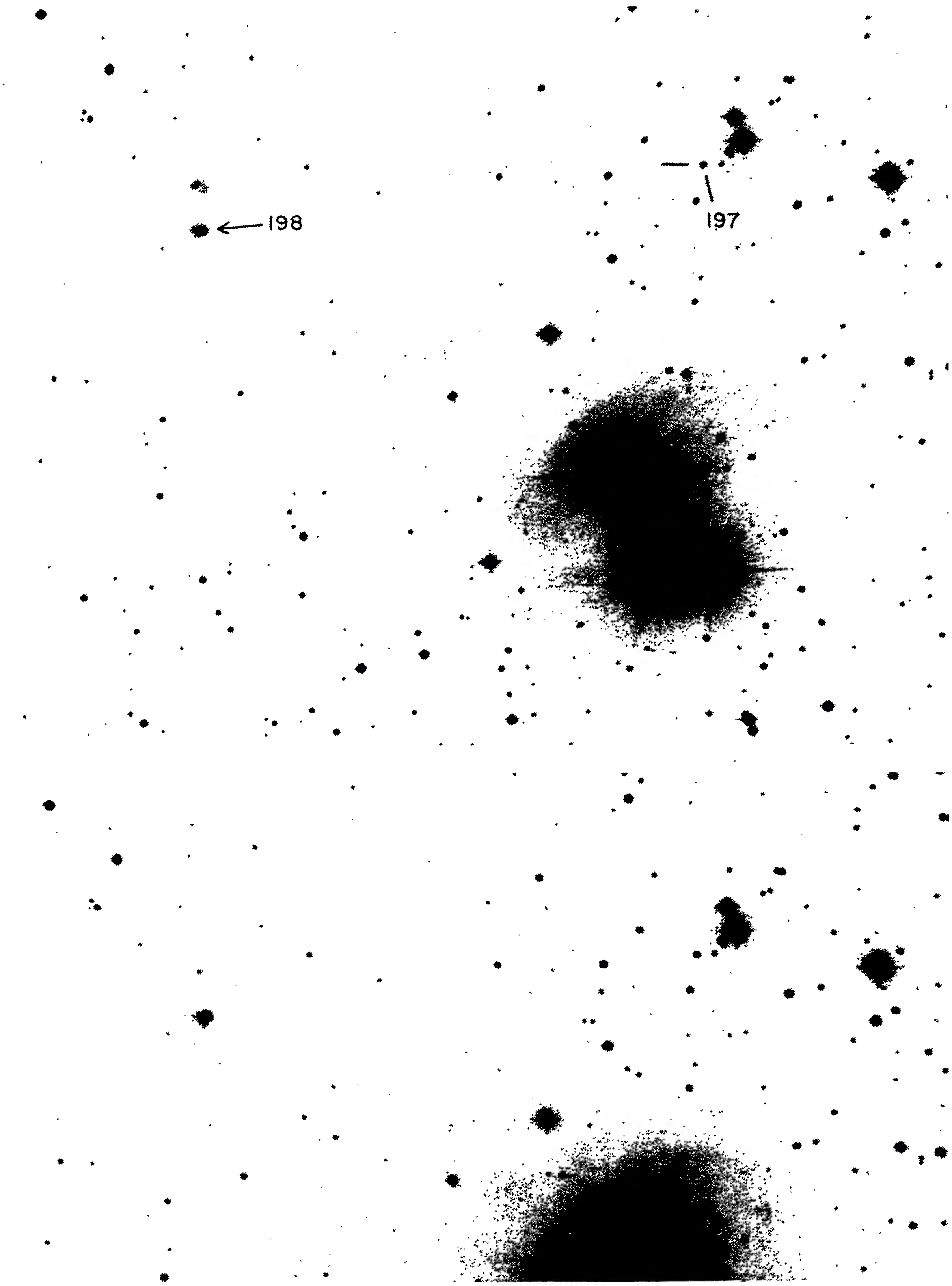


FIG. 1.—*Above:* The regiōn of LkHα 198 on September 17, 1952. The nebulous star north of LkHα 198 (and the nebulosity near it) is bright. The reflection nebulosity around +57°18, 19, 22 appears in the lower right. (Crossley reflector, 60^{m} exposure on Kodak II*a*-O; the scale is 5".0/mm; north is at the top and east to the left.) *Below:* The same area on September 23, 1955. The star north of LkHα 198 is faint and non-stellar; the nebulosity to the west of it is quite faint. There is another variable star 14 mm north, 7 mm east of this nebulous object (Crossley, 30^{m} on 103*a*-O).

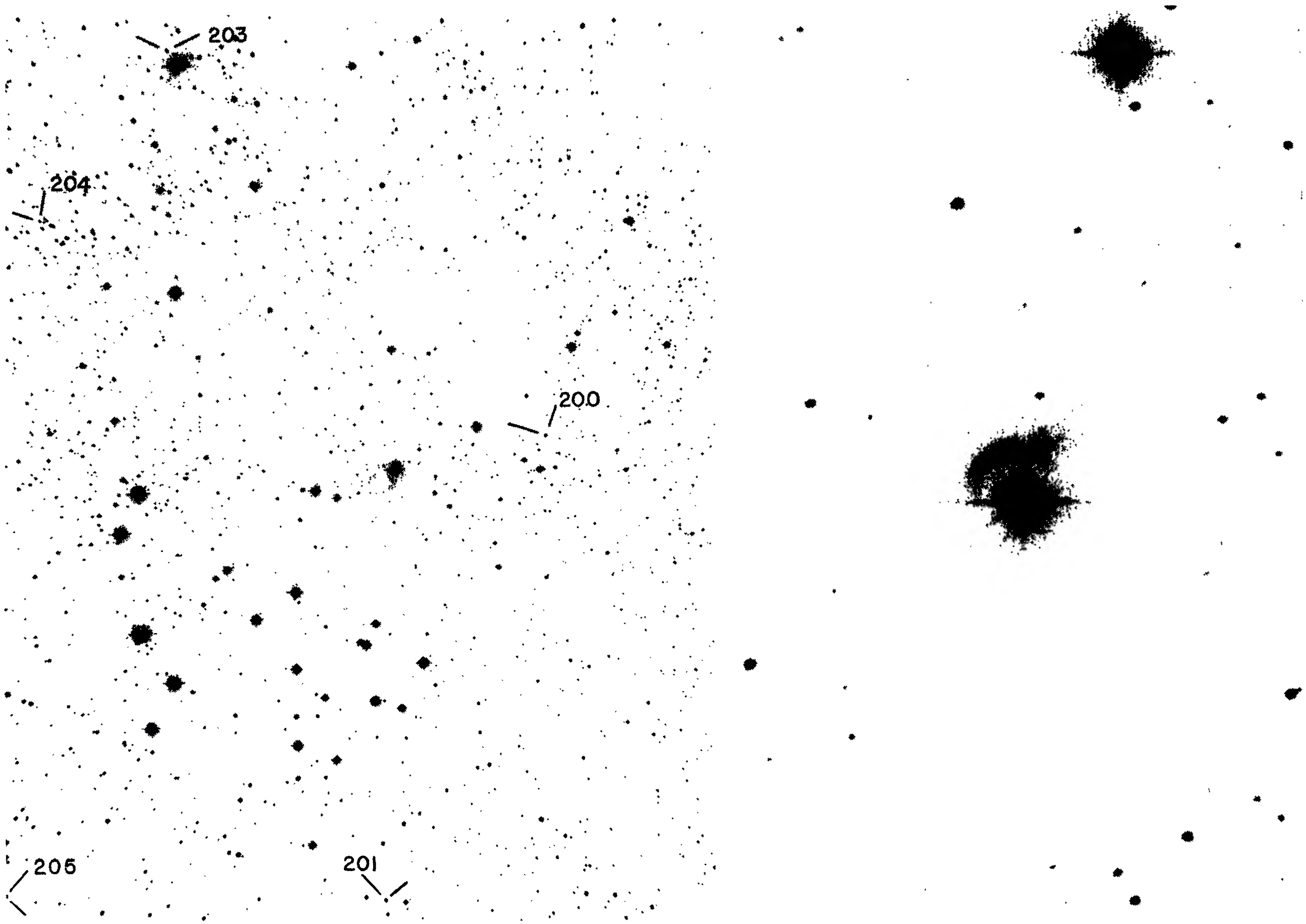


FIG. 2.—*Left:* The region of NGC 225; BD+61°154 (= MWC 419) is the nebulous star near the center. Emission-Hα stars are marked with their LkHα numbers. (Crossley, February 21, 1954; 28^m on 103*a*-O. The scale is 15″/mm, and orientation as in Fig. 1.) *Right:* The nebulosity at HD 250550 (= MWC 789). (Crossley, November 9, 1958; 30^m on 103*a*-O. The scale is 2″.7/mm, the orientation as in Fig. 1.)

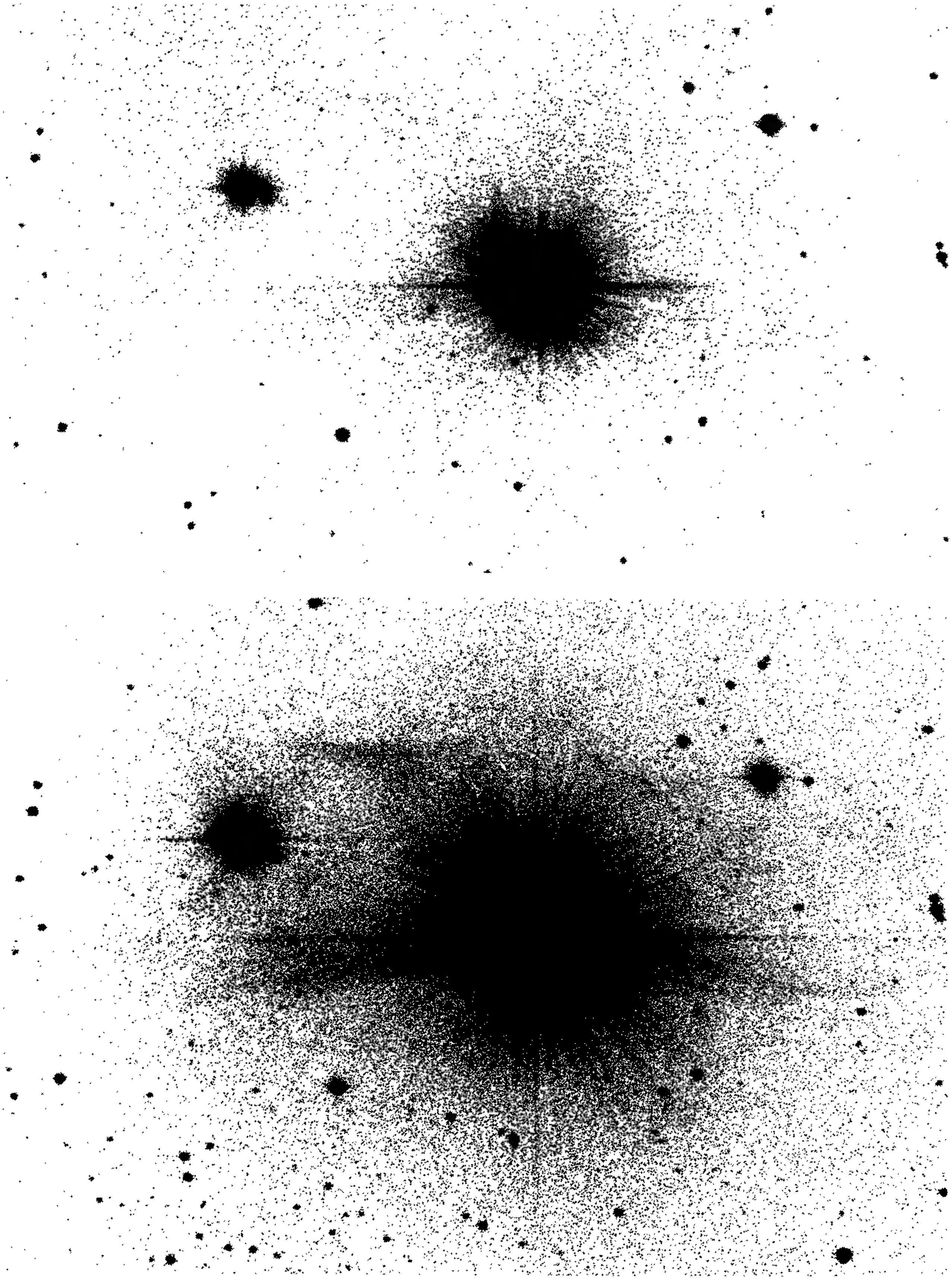


FIG. 3.—Two exposures of the nebulosity at AB Aurigae (*center*) and SU Aurigae (*upper left*). The upper exposure was with the Crossley on February 2, 1953 (II*a*-O, 15^m), the lower on February 10, 1951 (II*a*-O, 60^m). The scale is 3″.8/mm, the orientation as in Fig. 1.

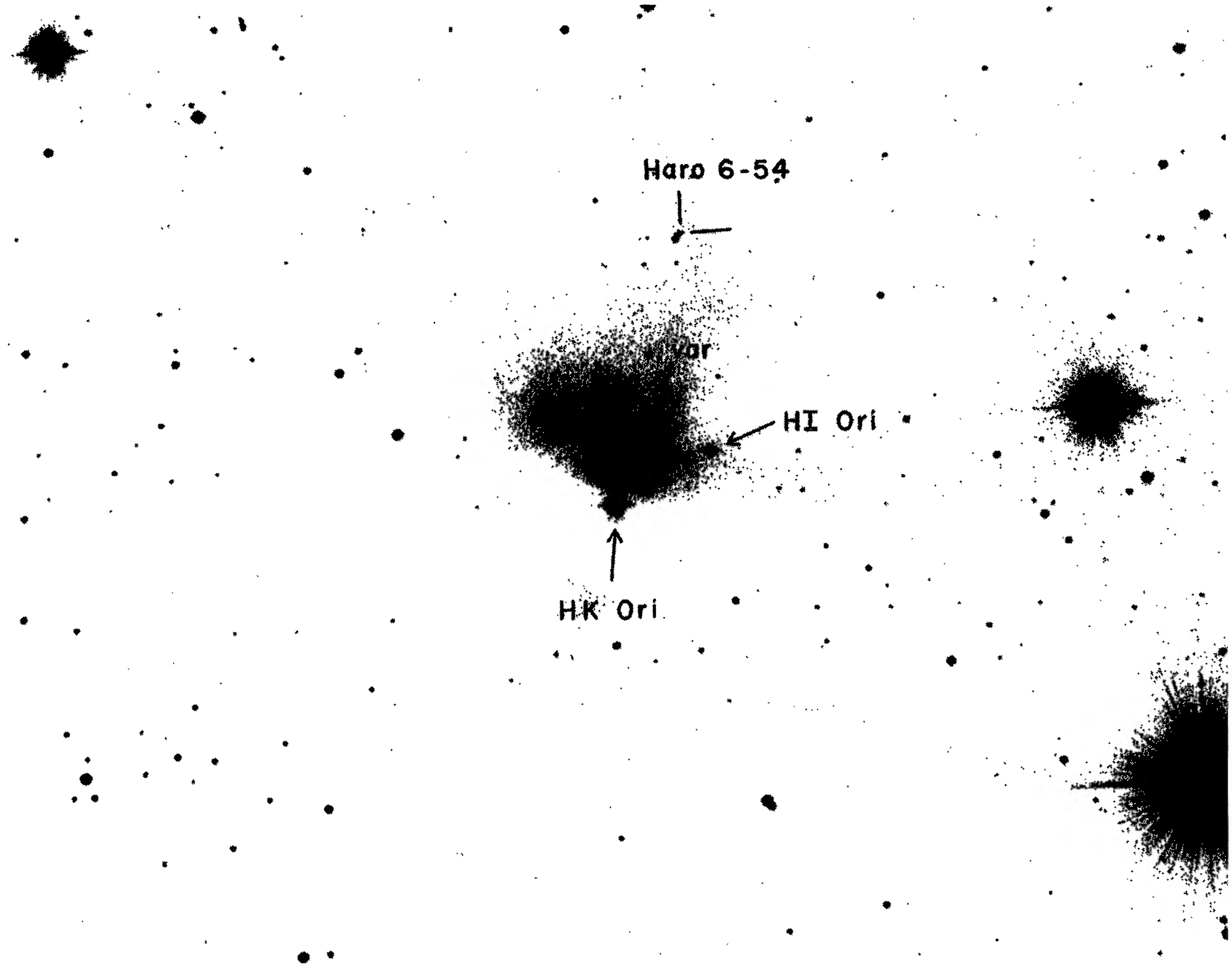


FIG. 4.—The nebulosity at HK Orionis. (Crossley, February 3, 1953, 60^{m} on IIa-O. The scale is 4ʺ.6/mm, orientation as in Fig. 1.)

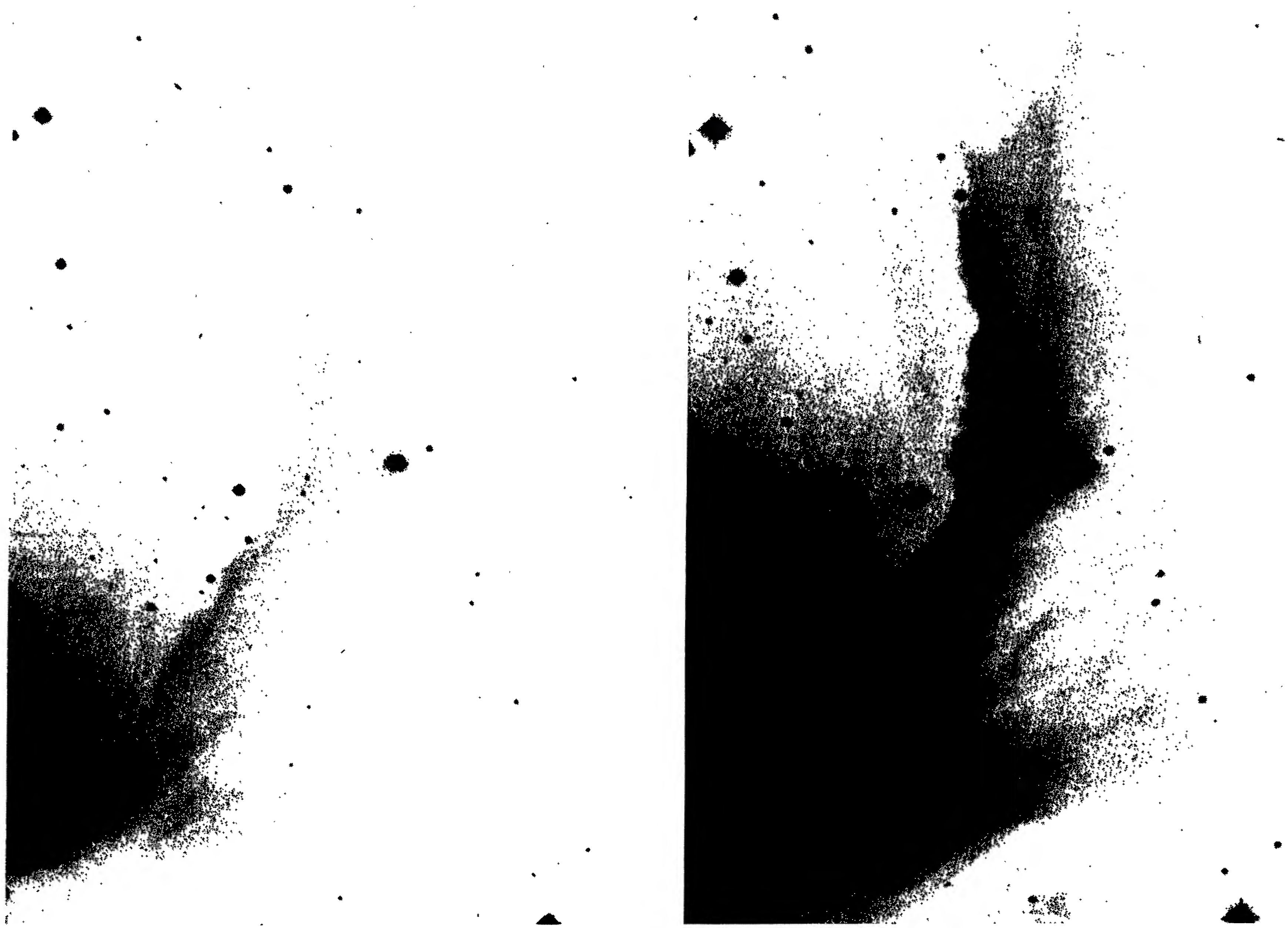


Fig. 5.—The nebulosity at T Orionis (the bright star near the center) extends only a very short distance to the left of the star image. Both photographs were filtered for the λλ 5250–5850 region so as to minimize the contribution of the Orion emission nebulosity. (Crossley, February 5, 1954, 10^m and 30^m on Kodak 103*a*-G plus 2 mm of Schott OG-1. The scale is 5″.1/mm; south is at the top and west to the left.)

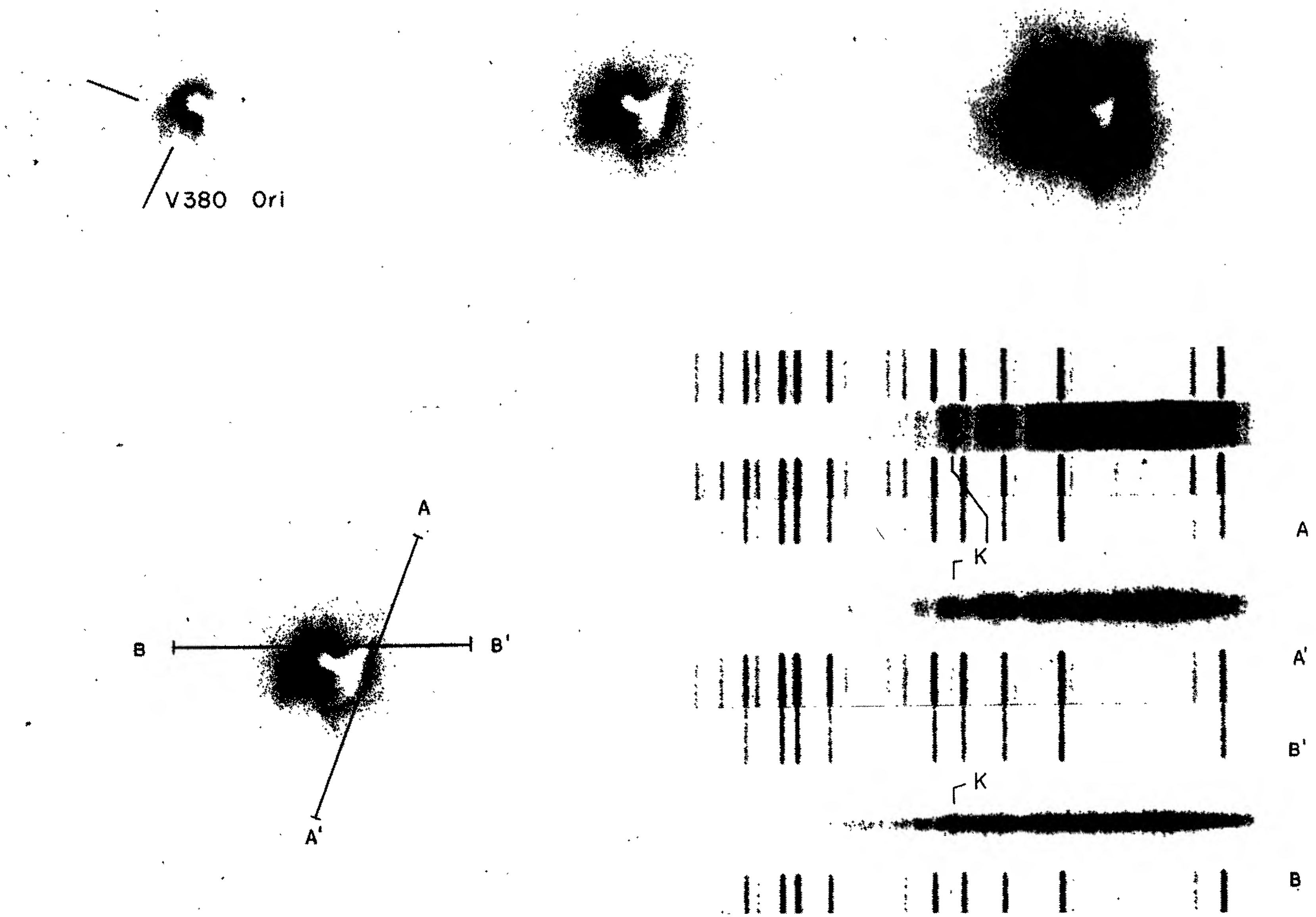


Fig. 6.—NGC 1999. *Top:* Three Crossley exposures of different length (IIa-O, scale: 3".3/mm). *Bottom right:* the spectrum of V380 Orionis (*top*) compared to the spectra of two parts of NGC 1999, all with 430 A/mm dispersion. The different strength of Ca II emission, and other details, in the two areas of the nebula is striking. *Bottom left:* The slit positions for the two spectrograms of NGC 1999.

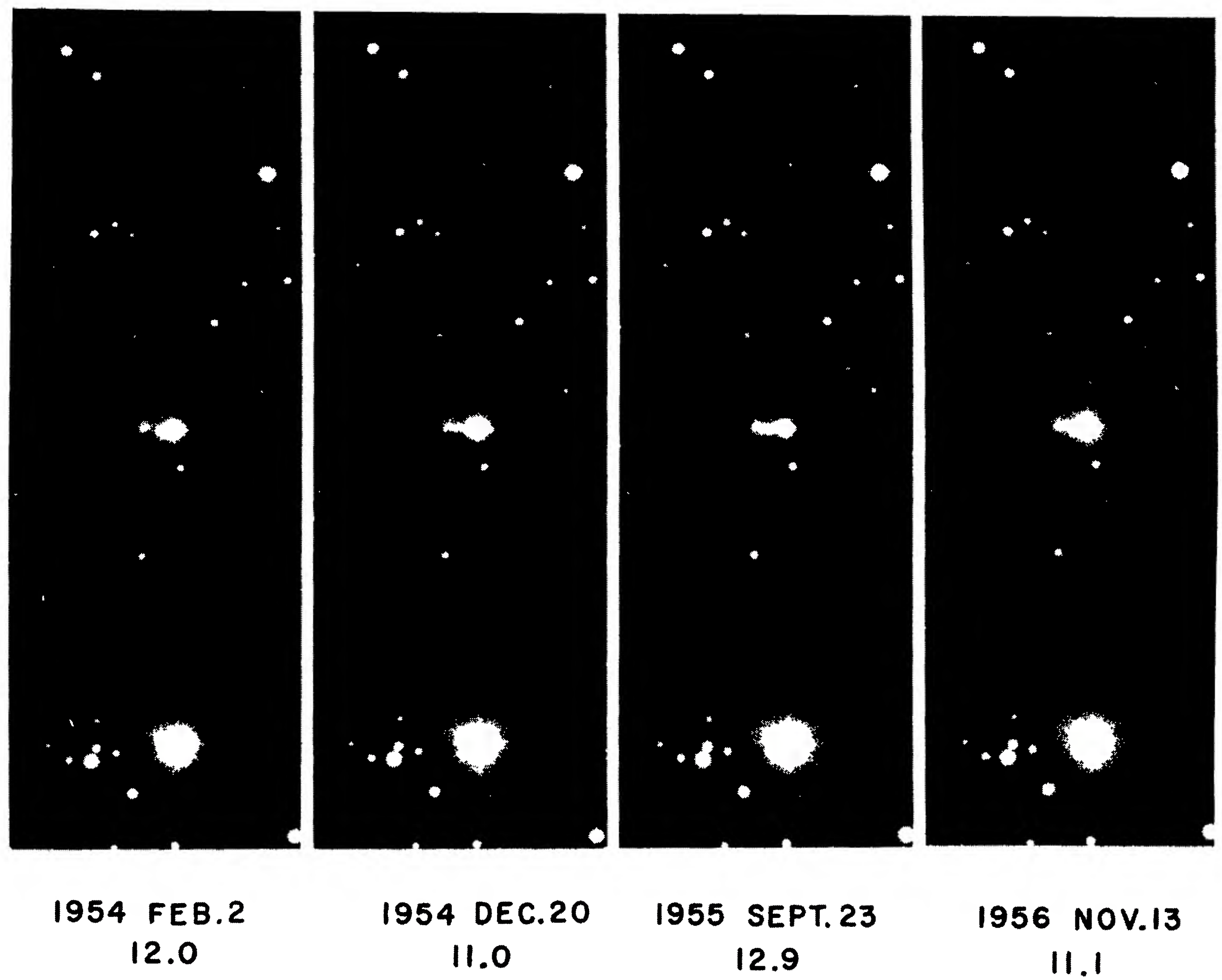


FIG. 7.—The variable nebulosity at RR Tauri. (All four exposures were made with the Crossley, 30^m on 103*a*-O; scale 4″.0/mm, orientation as in Fig. 1.) The magnitudes of RR Tauri are visual estimates, made at the telescope when the plate was taken. The bright star near the bottom is BD+26°887, referred to in the text; the star 2 mm south, 11 mm east of it is LkHα 206.

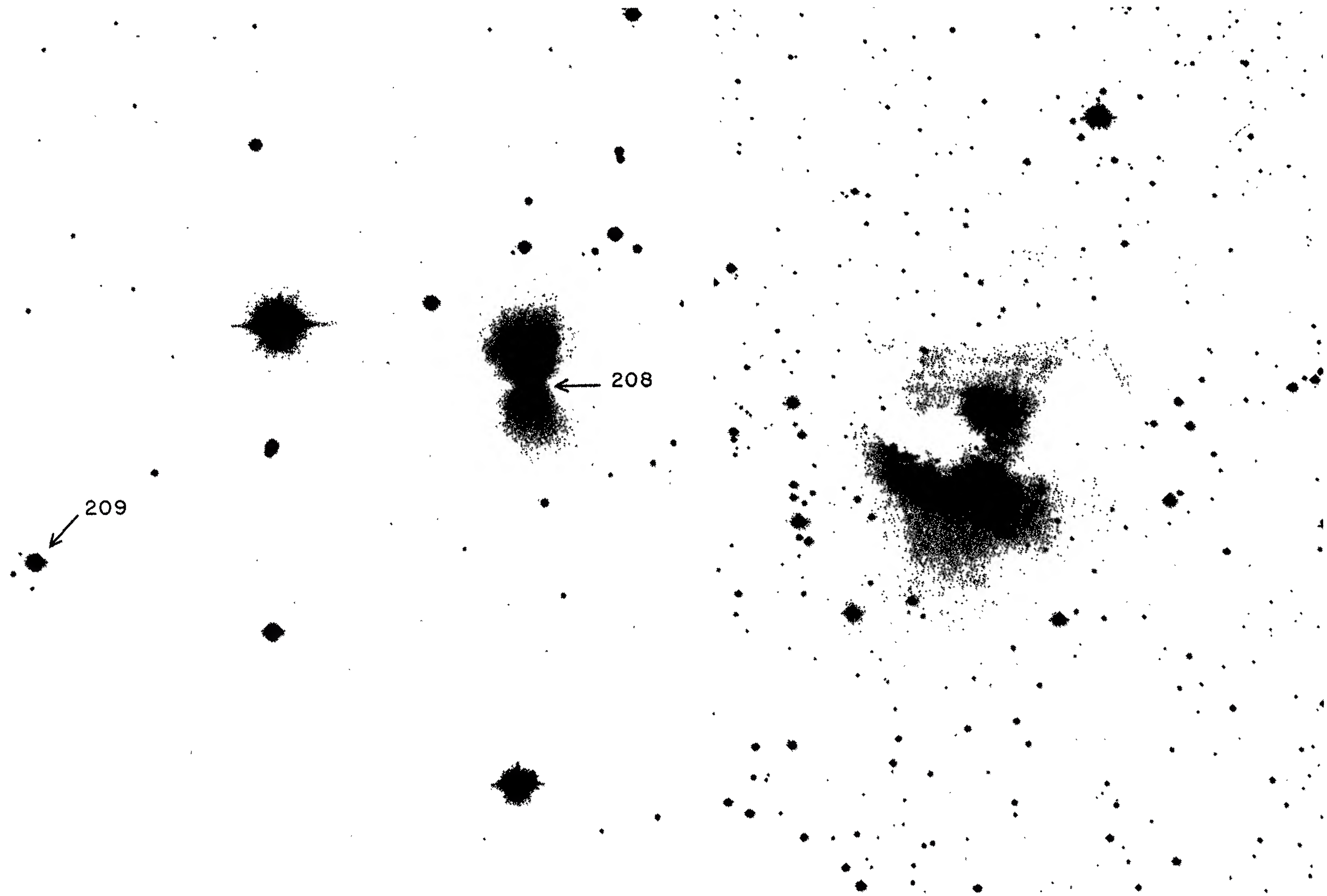


FIG. 8.—*Left:* The nebulosity at LkHα 208. (Crossley, February 2, 1953; 45^m on II*a*-O. The scale is $4''.6$/mm, the orientation as in Fig. 1.) *Right:* IC 2177, the nebulosity around HD 53367. (Crossley, January 12, 1956, 28^m on 103*a*-O. The scale is $14''$/mm, the orientation as in Fig. 1.) The star in the nebulosity 12 mm south, 8 mm west of HD 53367 is the foreground proper motion star Ross 54.

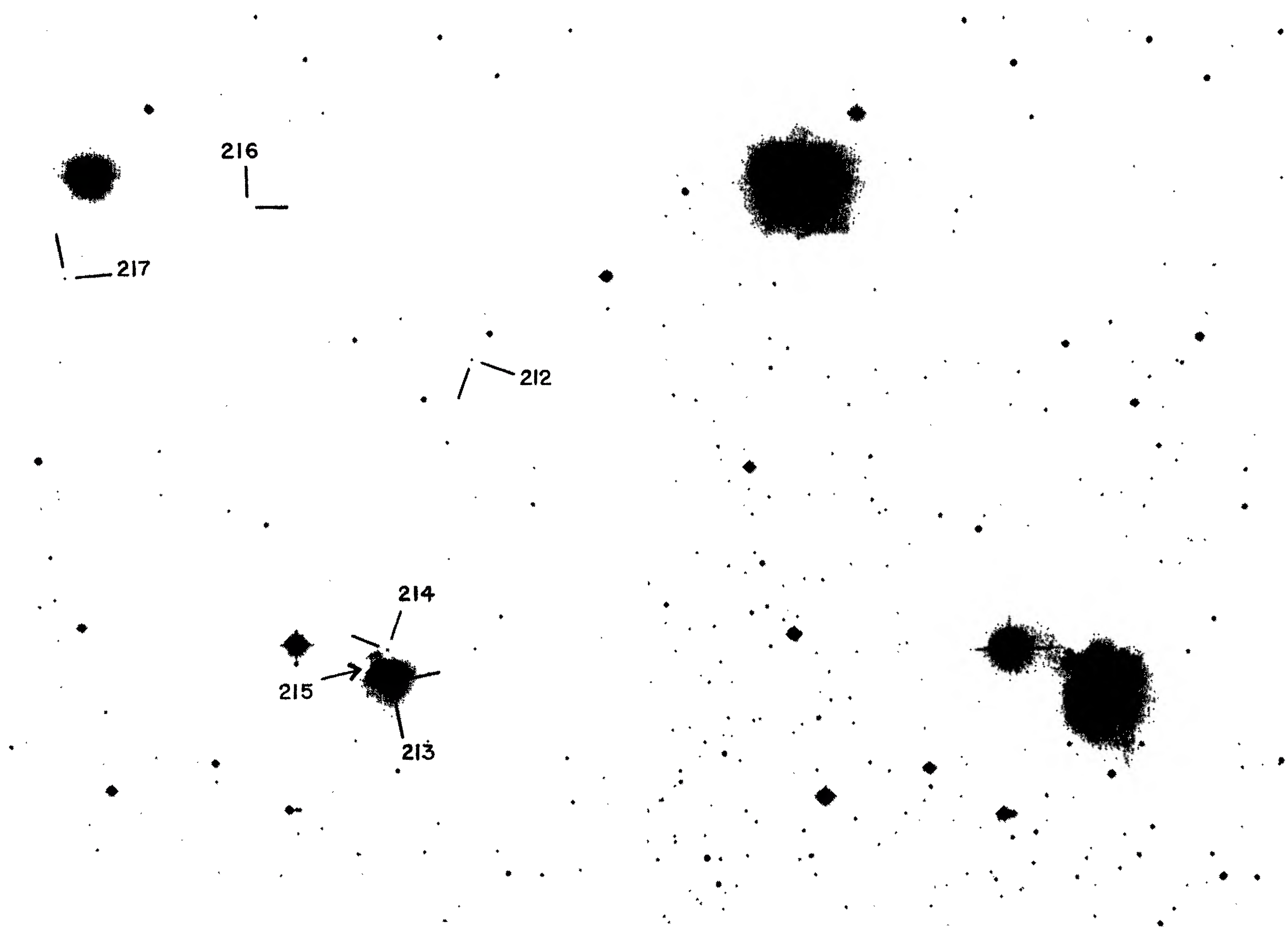


FIG. 9.—Two exposures of the region of NGC 2245 (*lower right*) and NGC 2247 (*upper left*). (Crossley, December 20, 1954, 5^m and 30^m on 103*a*-O; scale 7″.8/mm, orientation as in Fig. 1.) Emission-Hα stars in the area are marked with their LkHα numbers. HD 259431 is lost in the overexposed image of NGC 2247.

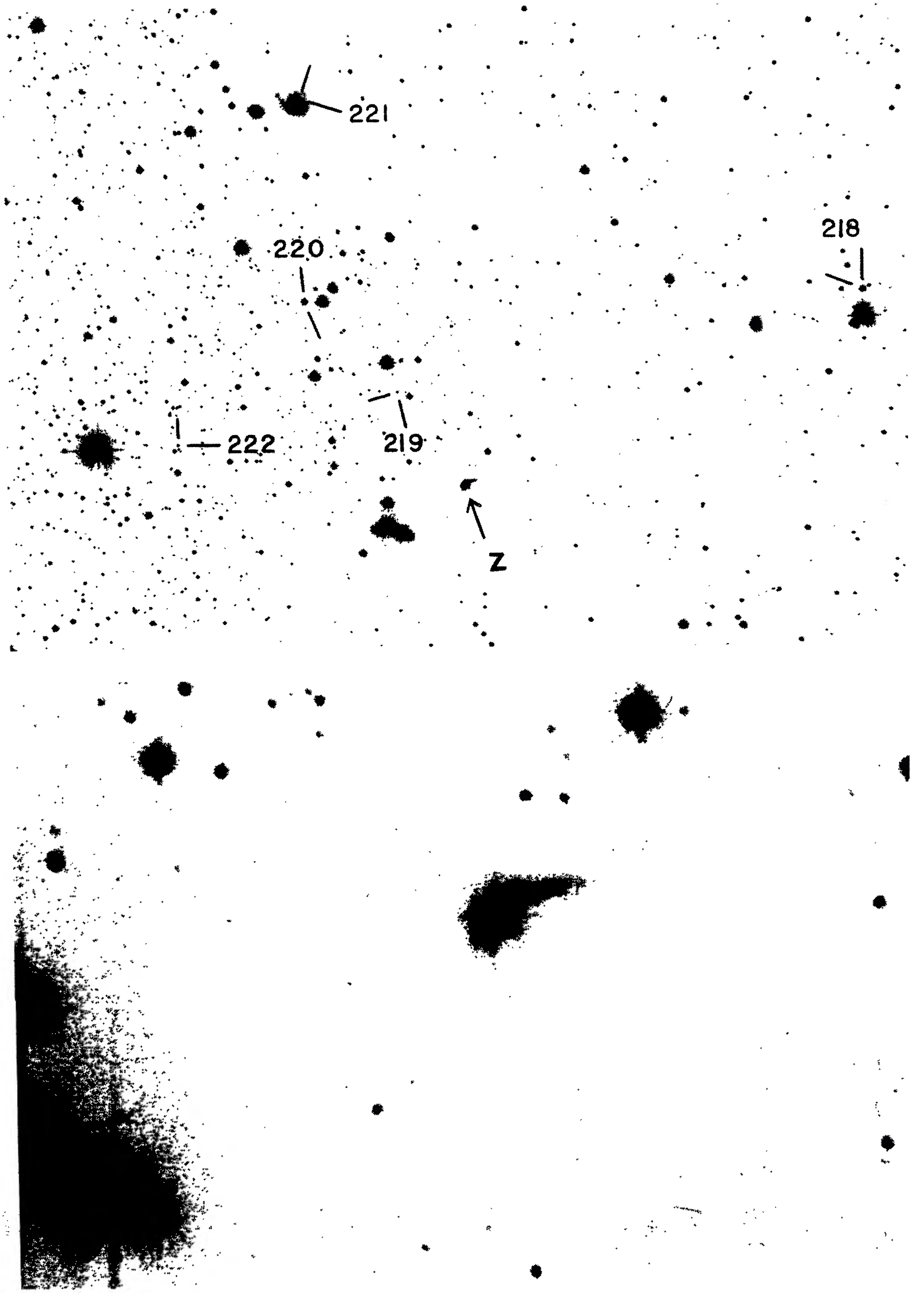
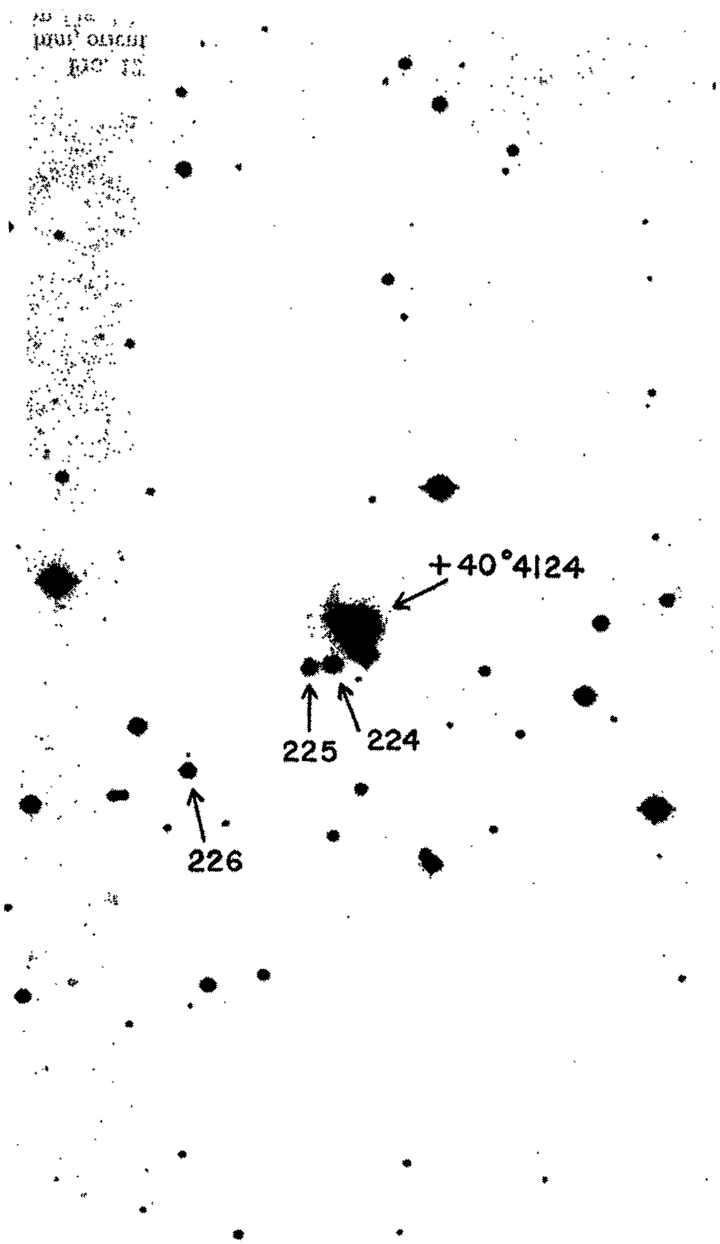


FIG. 10.—*Above:* The region of Z Canis Majoris, with emission-Hα stars identified. The nebulosity near LkHα 221 is NGC 2327. (Crossley, January 1, 1957, 30^m on 103*a*-O; the scale is 14″/mm, orientation as in Fig. 2.) *Below:* The nebulosity near Z CMa. (Crossley, December 5, 1953, 30^m on 103*a*-O; scale 2″.2/mm, orientation as above.)



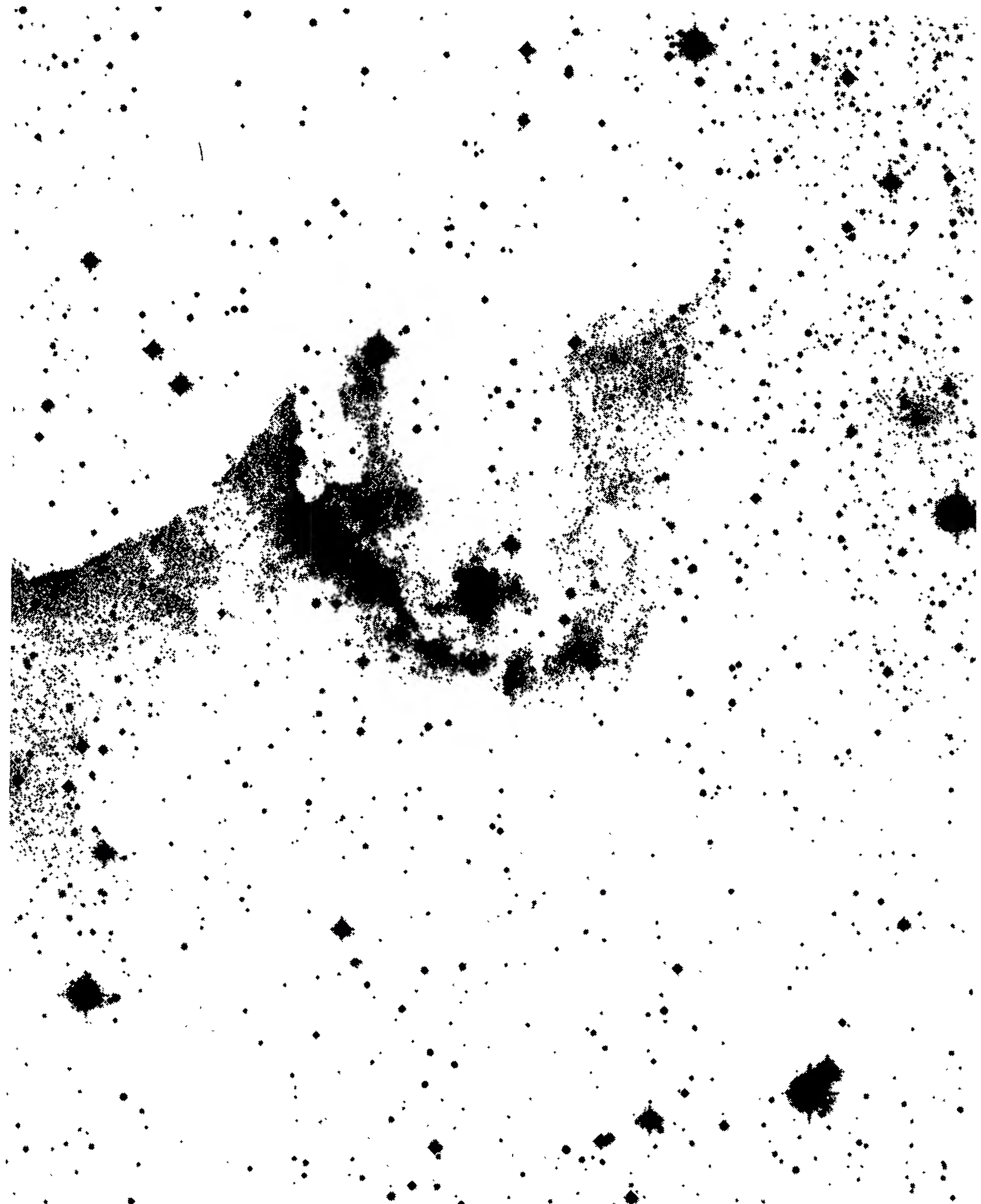


FIG. 11.—*Left:* The region of BD+40°4124 (= MWC 340) from a Crossley red exposure. (July 1, 1956, 60^m on 103*a*-E(2) plus 2 mm Schott RG-1; the scale is 5″.0/mm, orientation as in Fig. 1.) Emission-Hα stars are identified with their LkHα numbers. *Right:* The region of +40°4124 in red light, copied from plate E754 of the Palomar Sky Survey. (The scale is 13″/mm, orientation as in Fig. 1.) (Copyright National Geographic Society—Palomar Observatory Sky Survey.)

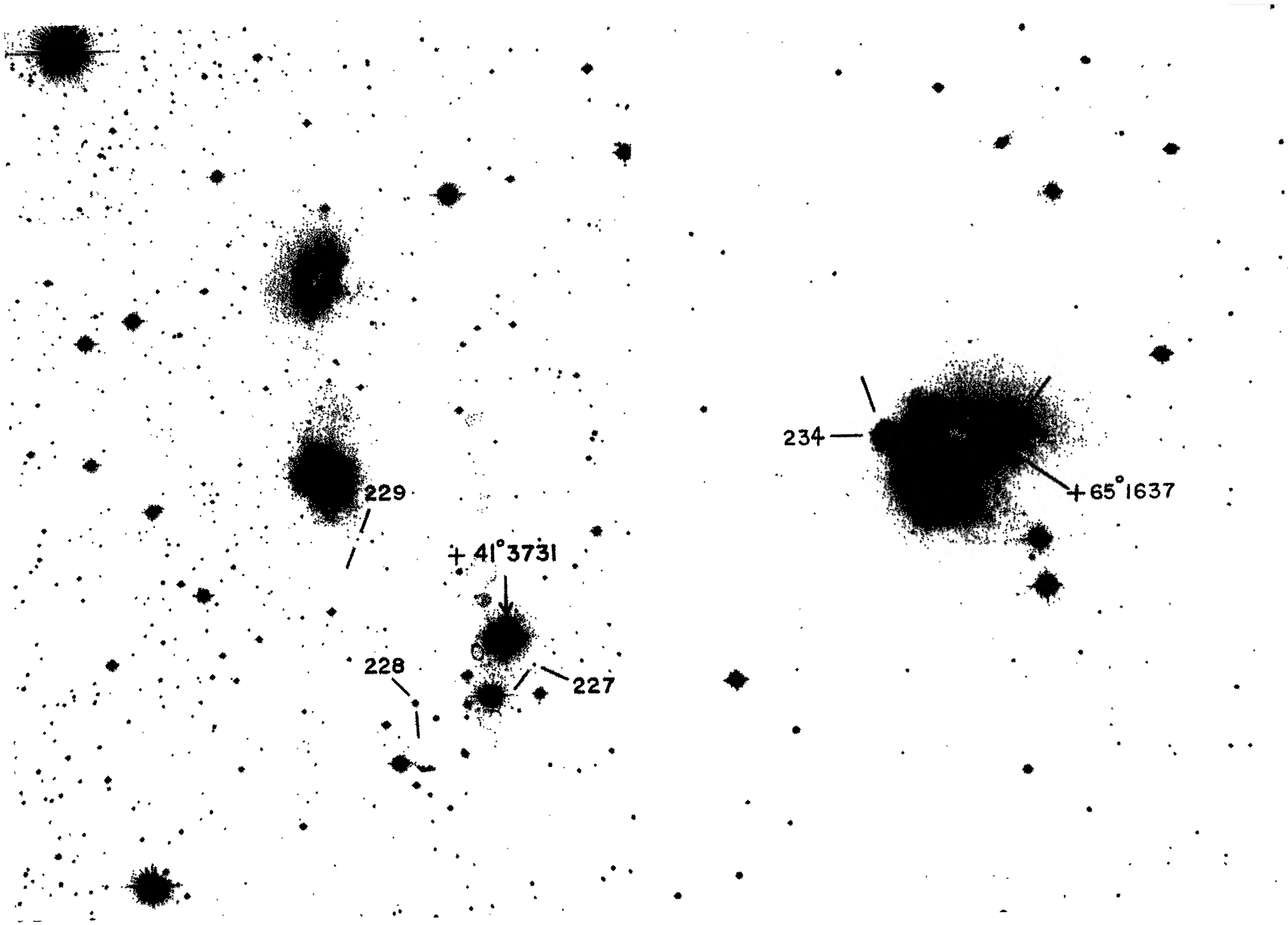
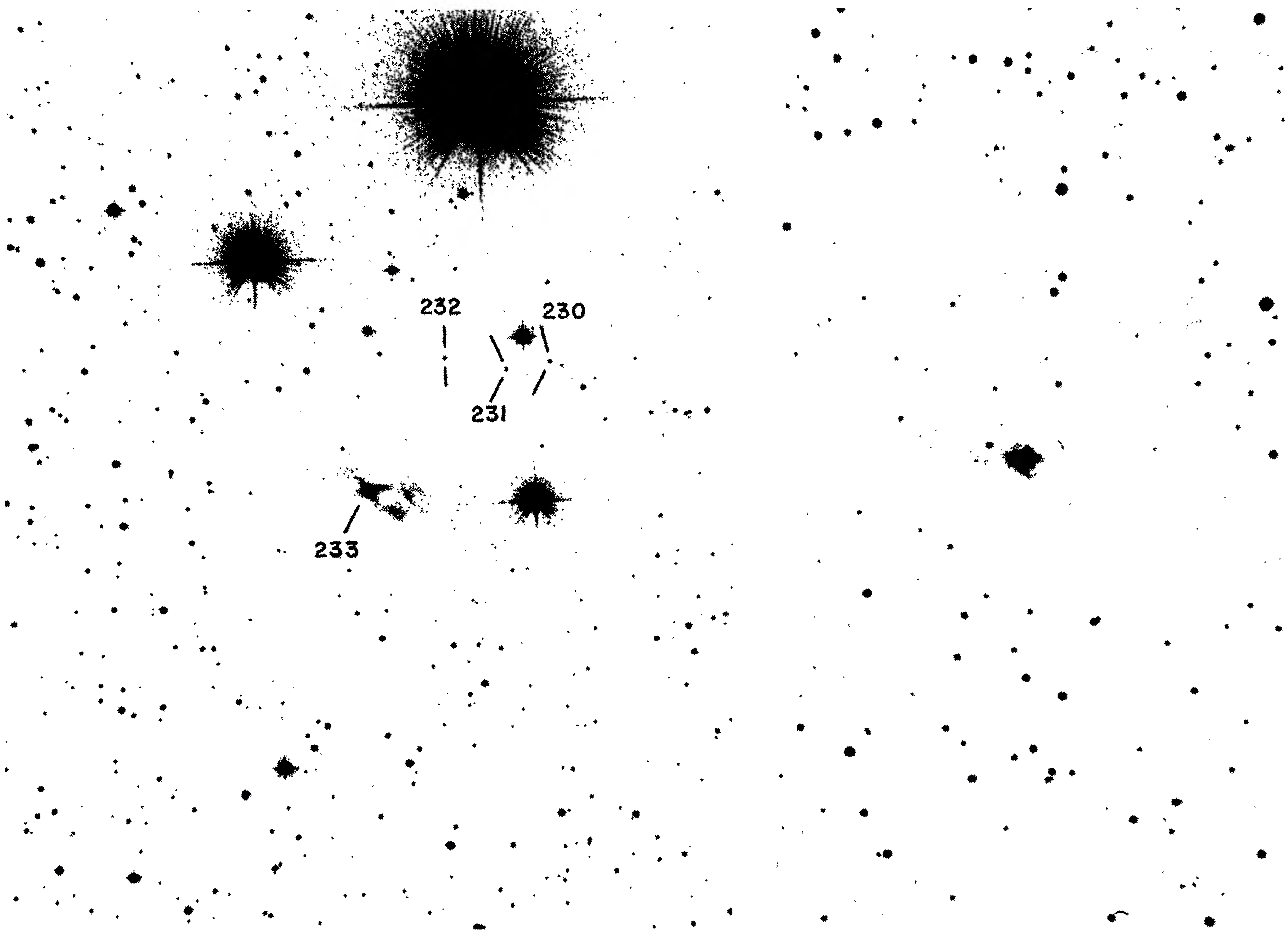


FIG. 12.—*Left:* The nebulae NGC 6914, 6914*a*, 6914*b*. Stars having Hα in emission are identified. (Crossley, September 27, 1954, 30^m on 103*a*-O; the scale is 12″/mm, orientation as in Fig. 1.) *Right:* NGC 7129, with emission-Hα stars identified. (Crossley, September 27, 1954, 30^m on 103*a*-O; the scale is 5″.4/mm, orientation as in Fig. 1.)

1960ApJS....4..337H

FIG. 13.—*Left:* The region of LkHα 233; the brightest star is HD 213976. (Crossley, July 17, 1953, 60^m on IIa-O; the scale is 6."5/mm, the orientation as in Fig. 1.) *Right:* MWC 1080, from a Crossley red exposure (November 9, 1958, 30^m on 103a-E[2] plus 2 mm Schott RG-1; the scale is 4."1/mm, the orientation as in Fig. 1.)



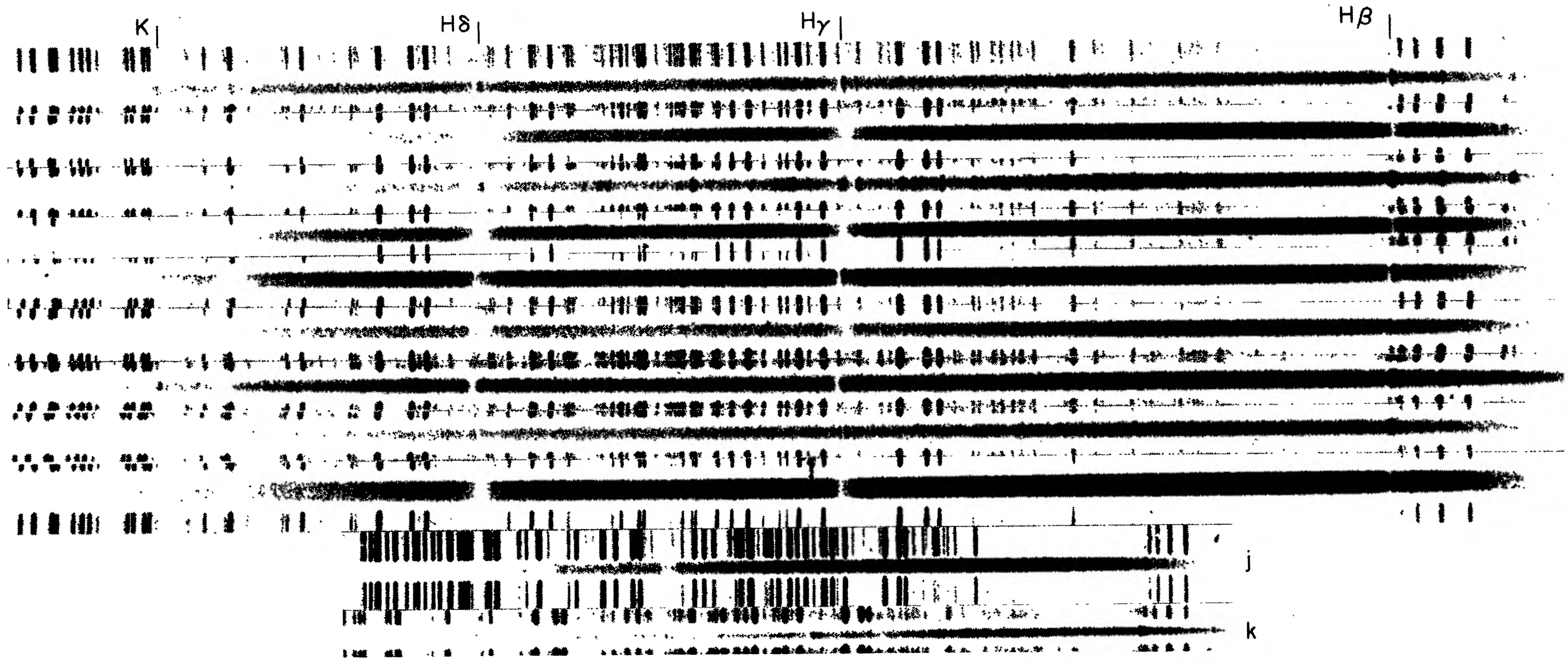


FIG. 14.—The spectra in the photographic region of Be- and Ae-type stars associated with nebulosity. The first 9 and the 11th spectrum were obtained with the Lick 36-inch refractor with dispersions of 75 and 130 A/mm, respectively. Spectrum *j* was obtained at 150 A/mm with the 82-inch McDonald reflector. *a:* +61°154 (July 9, 1954); *b:* T Orionis (February 8, 1955); *c:* V380 Orionis (February 7, 1955); *d:* RR Tauri (October 17, 1944); *e:* HD 250550 (February 26, 1959); *f:* LkHα 215 (October 30, 1954); *g:* Z Canis Majoris (February 7, 1955); *h:* +40°4124 (April 30, 1956); *i:* +46°3471 (July 16, 1954); *j:* MWC 497 (January 3, 1949); *k:* MWC 1080 (August 3, 1958).

estimating the distance modulus from +26°887, itself involved in nebulosity and hence possibly having a luminosity different from a normal B8 V star.

A few faint stars having the Hα line in emission have been found in the same dark cloud as RR Tau. The brightest of these is LkHα 206, of $m_v \sim 13.5$, which lies about 1′ east of +26°887 and is involved in the faint nebulosity between RR Tau and +26°887. The emission at Hα is quite weak, and no bright lines are visible in the photographic region. The spectral type is early K. The star LkHα 207 is the fainter component of a double 2′ west of RR Tau; it is conspicuously variable in light.

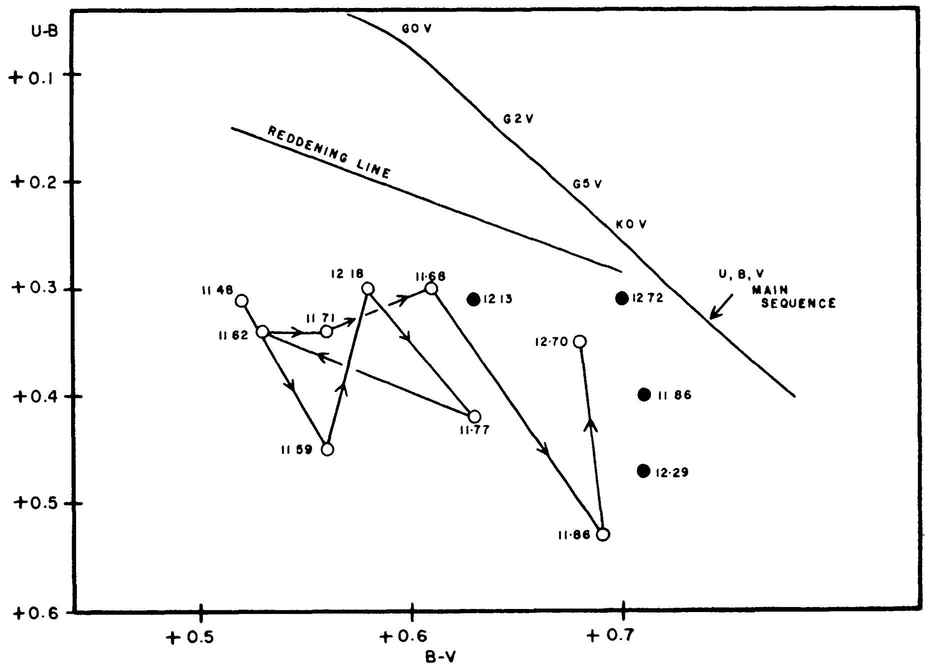


FIG. 15.—The variation of $U - B$ versus $B - V$ in RR Tauri. The open circles represent observations by Lenouvel, the filled circles those by Walker; the V magnitude at the time of each observation is indicated. Lenouvel's observations were made on successive nights; the time sequence is shown by the arrowed lines.

8. *HD 250550*

HD 250550 (= MWC 789) is located centrally in a small obscuring cloud (about 5′ by 8′) which is connected by a dark lane with more extensive obscuration to the north and east. The star is the center of a bright, 120° arc of nebulosity with a radius of 20″ to 25″. Fainter nebulosity lies just outside this arc and to the northwest (see Fig. 2). The nebulosity is brighter in the blue than in the red and hence is probably reflection.

Emission at Hα was discovered in HD 250550 by Merrill and Burwell (1949); the type was given as A0e with the remark that "Hβ consists of a strong dark core with emission on the longward side." Later (Miller and Merrill 1951) it was noted that the spectrum was about the same in 1950 as in 1946. Lick 75 A/mm plates taken in late 1958 and early 1959 (see Fig. 14) show a B9 spectrum plus rather narrow Balmer emission lines that have strong shortward absorption components. The emission is strong at Hβ but quite weak at Hδ; the absorption fringes, however, remain strong. The bright hydrogen lines have only a small displacement: the mean of Hβ, Hγ, and Hδ is +14 km/sec on three spectrograms. The P Cygni-like absorption fringes at the same lines have mean displacements of −285, −260, and −210 km/sec, respectively, on the same plates. Merrill and Burwell reported a mean displacement of −159 km/sec on a 1946 spectrogram. The lines He I λ 4026, λ 4471, and Mg II λ 4481 of the B9 star are sharp and strong; they have small velocity shifts. A few faint Fe II lines may also be present. The edges of the Balmer lines of the B9 star can be seen longward of the P Cygni structure.

A single slit spectrogram (88 A/mm) of the visual region, obtained in February, 1959, shows Hα as a strong emission line with shortward absorption. The [O I] line at λ 6300 appears rather weakly in emission; λ 6363 may also be present.

The area has not been examined for faint emission-Hα stars.

9. *LkHα 208*

In his survey of galactic nebulae, Hubble (1922*a*) mentioned briefly "a bright uncatalogued nebula similar to NGC 2245. A thirteenth-magnitude star is at the apex of the cometary form." He gave for the star (= LkHα 208) $m_{pv} = 13.5$; the spectrum of the nebulosity was "continuous," i.e., presumably a reflection of the star.[1]

The nebula consists of two lobes in the form of an hourglass; the northern is the brighter, and the star lies precisely between the two (see Fig. 8). These lobes are but the brighter portions of the larger masses of nebulosity whose outlines, where they can be seen dimly, are roughly circular. They are about 3′ in diameter and approach tangency very near the star. (It is interesting that the same double-lobed appearance is found in NGC 2261, but in that case one-half is very faint.) Hubble (1922*b*) followed the nebula for variability, but with no positive results.

Hubble gave the spectral type of the nuclear star as B1. McDonald and Lick spectrograms obtained by the writer, however, suggest an early to intermediate A type on the strength of the K line, but He I λ 4471 is present. Emission of moderate intensity is present at Hα, and absorption Hβ is filled in. The McDonald negative, obtained in 1948, shows, in addition, several weak emission lines of [Fe II]. The spectrum of LkHα 208 appears in reality to be that of an extended envelope, clearly evidenced in absorption only at K, superimposed upon a rather late B-type star. The spectrum of the northern lobe of the nebulosity shows strong absorption lines of H, and thus appears to be purely a reflection spectrum.

LkHα 208 is located near the edge of a dark cloud whose extensions can be traced for approximately 1° to north and south. About 1°8 to the north of LkHα 208 is the large H II region NGC 2175, excited by the O6 star HD 42088. If the two nebulae are actually associated in space, the distance modulus of 11.5 mag. for HD 42088 obtained by Hiltner (1956) indicates that LkHα 208 is at least as luminous as $M_v = +2.0$.

About 2′ south and 6′5 east of LkHα 208 is LkHα 209, a star of the same photographic magnitude with a strong Hα emission line. Two slit spectrograms of dispersion 130 A/mm show an absorption spectrum of late G or early K type, with emission at Hβ and Hγ.

10. *LkHα 215*

The reflection nebula NGC 2245, together with NGC 2247 (see below), IC 446, and IC 2169, lies in an extensive obscured area that is connected by a dark lane with the cloud containing the nebulous cluster NGC 2264. NGC 2245 has been described by Pease (1920); its brighter parts form a rough parallelogram, with LkHα 215, of $m_{pv} =$ 10.7 according to Hubble, set just within the northeastern corner (see Fig. 9). The surface brightness of NGC 2245 declines with distance from the star, giving it an appearance similar to fan-shaped nebulae such as NGC 2261. About 25″ north of the star, across a gap relatively free of nebulosity, is a short bar that is but the brightest part of a nebulous arc, convex toward the star, that suggests the outline of a mirror image of the fan-shaped nebulosity. Similar structure has already been mentioned in connection with

[1] The star was later measured for parallax by Van Maanen (1928). He derived a relative parallax of $+0''.004 \pm 0''.003$, but with respect to comparison stars some of which are projected on the surrounding heavy obscuring cloud, and hence may be foreground objects.

NGC 2261 and the nebula at LkHα 208. Faint nebulosity containing considerable structure can be traced as far as 3′ to the north and south of LkHα 215.

The spectrum of LkHα 215 was assigned to type B1 by Hubble (1922*a*, 1922*b*) with the remark "bright Hβ suspected," and to type A0 by Sanford (1920). Slitless plates of the field taken at Lick in 1953 show a bright Hα line of moderate intensity in the star; it was found independently by González and González (1956). Slit spectrograms (dispersion 75 A/mm) obtained in 1953, 1954, and 1959 show very sharp, deep H absorption cores, except at Hβ, which is partially obscured by emission. In 1954, a strong narrow emission line was present near the center of absorption Hβ, while at Hγ the absorption core had only weak emission edges (see Fig. 14). A narrow K line and several Fe II absorption lines were present. Wide dark lines of He I were visible, and the sharp core of Hδ was superimposed on broad absorption wings. The hydrogen emission lines and absorption cores, and the metallic lines, are produced in a shell overlying an absorption spectrum of early to intermediate B type.

TABLE 13

EMISSION-Hα STARS NEAR NGC 2245, 2247

LkHα	Approximate m_{pg}	Hα Intensity	LkHα	Approximate m_{pg}	Hα Intensity
210*	16	w	215	11	m
211*	15	m	216	17	m
212	17 var	s	HD 259431	9	s
213	18:	m	217	17	m
214	16	s			

* These two stars are outside the area shown in Fig. 9. LkHα 210 is 3$'$.1 south, 0$'$.7 east of BD+10°1161. LkHα 211 is 2$'$.3 north, 2$'$.4 west of +10°1165.

No modern photometric observations of LkHα 215 are available, but the early exposure-ratio results of Seares and Hubble (1920) indicate that its color is approximately that of an an F-type star. This corresponds to a visual absorption of 1 to 2 mag. If the distance modulus of NGC 2245 is equal to that of NGC 2264 (Walker 1956), then the M_v of LkHα 215 is 0 to -1. In view of the large uncertainties involved, this is perhaps not an unreasonable result as far as one can judge from the spectral type of the underlying star.

The spectrum of NGC 2245 has long been known to be "continuous" (Hubble 1916, 1922*a*). Actually it is very similar to that of LkHα 215: a 430 A/mm spectrogram taken in 1950 with the slit along the axis of symmetry of the nebula shows H absorption lines on a strong continuous background, except for Hβ which is not visible, presumably due to filling-in by emission.

Two other emission-line stars have been found within NGC 2245. The brighter of these, LkHα 214, is located just beyond the west end of the bar of nebulosity mentioned previously. The fainter, LkHα 213, is in the bright nebulosity 25″ southwest of LkHα 215. A few isolated emission-Hα stars have been found in the surrounding obscured area and are marked in Figure 9. None of these objects have been observed in the photographic region. They are all listed in Table 13.

Less than 2′ northeast of the nucleus of NGC 2245 is HD 46265, which was suspected of variability by Seares and Hubble but never confirmed. The star is superimposed on faint nebulosity, but this appears to be entirely an extension of NGC 2245. The MK type is G8, and the luminosity class III, or possibly somewhat brighter. The star is most probably a foreground object.

11. *HD 259431*

The Be star HD 259431 is located 11′.5 northeast of NGC 2245, in the same dark cloud (see Fig. 9). HD 259431 is surrounded by NGC 2247, an approximately circular envelope of nebulosity whose brightness drops off rather quickly and uniformly in all directions from the star. Very faint extensions of the nebulosity can be traced as far as 4′ to 5′ from the star on a Crossley negative. The Mount Wilson photographs of NGC 2247 have been described by Pease (1920).

The spectrum of HD 259431 has been discussed briefly by Hubble (1922*a*), by Sanford (1933), and by Swings and Struve (1943*b*). Eight Lick spectrograms of dispersion 75 A/mm were obtained by F. J. Neubauer, in 1944–1946, and another by the writer, in 1954. The Lick plates show an apparently normal absorption spectrum of type B5 or possibly B3, with somewhat diffuse lines, and with rather fuzzy emission components placed centrally in the Balmer lines. The emission decrement is slow; Swings and Struve observed emission as far as H15. There is no indication of any change in the spectrum between 1943 and 1954, but on Sanford's 1920–1928 plates, "double bright lines appear at Hβ and Hγ, and there is some evidence of variability in their intensity." The structure of the hydrogen emission therefore changed sometime between 1928 and 1943.

The magnitude and color of HD 259431 have been measured by Hiltner (1956); his values, when shifted along a reddening path of the conventional slope in a $U - B$, $B - V$ diagram, reach the main sequence at type B1.5. But the underlying star is not as early as B1.5; the Lick plates suggest B5 or perhaps B3, while Morgan, Code, and Whitford (1955) give B6pe. This appears to be an example of the phenomenon found by Mendoza (1958): the colors of Be stars differ substantially from those of non-emission stars of the same type, in the sense that the emission-line stars most often lie higher in the $U - B, B - V$ diagram. Consequently, the intrinsic color of HD 259431 is unknown and an accurate allowance for reddening cannot be made, but it is likely that M_v is not far from -2.0.

In any case, despite its involvement in NGC 2247, there is no indication that HD 259431 is anything but an ordinary Be star.

12. *R Monocerotis*

R Monocerotis is the diffuse, semistellar object at the apex of NGC 2261, Hubble's Variable Nebula. There may be a faint star imbedded in this brilliant nuclear nebulosity, but, as has been emphasized by W. Baade (unpublished), all spectrograms of "R Mon" reported thus far, as well as ordinary photometric observations, refer essentially to the nuclear nebulosity within a few seconds of the star.

The extensive observational material available on R Mon and NGC 2261 will not be discussed at this time. To summarize briefly the spectroscopic characteristics of R Mon, a strong emission spectrum consisting of lines of H, Ca II, and Fe II has been observed near minimum light. Sharp, rather weak absorption reversals appear in the early Balmer lines and become more conspicuous with increasing quantum number. The bright K line of Ca II is very strong, but the H line is hidden by Hϵ absorption. The spectrum is obviously that of a low-excitation emission source overlaid by a rather weak absorption shell. Near maximum light, the emission spectrum is much weaker, the intense K emission line has vanished, and the spectrum is dominated by very strong, deep, narrow Balmer absorption lines that can be seen far into the ultraviolet. The spectrum variations thus seem to be an interplay between the emission and shell features, whose intrinsic strengths appear to bear inverse relationships to one another.

In the writer's opinion, no normal absorption-line stellar spectrum has as yet been observed in R Mon. The absolute magnitude of "R Mon" (not of the presumed stellar nucleus) can be inferred approximately from the fact that at maximum light, m_v is about 10, and so, since NGC 2261 is associated with the dark nebulosity around the cluster NGC 2264, the M_v of R Mon must be about +0.5, less any correction for local absorption. If the brightness of R Mon is due to scattered light from a heavily obscured central star, then this value should be a better index of the luminosity of the star than one would obtain directly from its apparent magnitude, which has been estimated to be about 14 or 15.

The emission spectrum of R Mon is of the low-excitation chromospheric variety, but it does not meet the critical requirements for inclusion in the T Tauri class: the fluorescent Fe I lines at λλ 4063, 4132 have not been observed, and [S II] is not seen with certainty, if present at all. Furthermore, R Mon is set apart also by the fact that it is about 3 magnitudes more luminous than the brightest members of the T Tauri group (with the possible exception of V380 Ori: see above).

13. *LHα 25*

A strong Hα emission line was detected in this thirteenth-magnitude star in NGC 2264 by the writer (Herbig 1954*b*). Low-dispersion (430 A/mm) spectrograms of the photographic region showed no other emission lines except a possible filling-in of Hβ. A type of A2 or A3 was assigned from the relative strengths of K and the Balmer lines. A plate of LHα 25 was obtained at Mount Wilson in 1955 by Walker (1956) with a dispersion of 83 A/mm; a type of A2p was given. This plate, which I have examined through the kindness of Dr. Walker, shows indeed that the spectrum is somewhat peculiar. The Ca II and H lines indicate a type of A2, but He I λ 4026 and λ 4471 are present. The near equality of λ 4471 and Mg II λ 4481 corresponds to about B8, and the absolute strength of He I is in approximate agreement. The H lines are rather narrow and lack the wings of other NGC 2264 stars of about the same type. Walker noted that rather weak [Fe II] emission was also present on this plate. The simplest interpretation of the spectrum is, as Walker suggested, in terms of a weak shell. This would account for the narrow H cores, the strength of Ca II, and the presence of emission [Fe II]. However, it is unlikely that a normal B8 star plus a shell would look entirely like LHα 25 in regard to the absence of Balmer wings.

LHα 25 was measured photoelectrically on 3 nights by Walker; a small variation in visual light of 0.3 mag. was suspected. The mean V was 13.0. If Walker's three-color observations are interpreted as being affected solely by normal interstellar reddening, it is clear that the displacement of LHα 25 off the normal main-sequence line in a $U - B$, $B - V$ diagram is from the vicinity of B9, not A2, in essential agreement with the remarks of the preceding paragraph. The corrected V magnitude of LHα 25 corresponds to $M_V = +2.8$. This value is 2.8 mag. fainter than an average B9 V star, or 1.8 mag. below the "age zero" main sequence at B9 (Johnson and Hiltner 1956). The position of LHα 25 in the color-magnitude diagram of NGC 2264 is thus very puzzling if one attempts to account for its position in terms of initial contraction. If it cannot be explained away in terms of abnormal local absorption in the surrounding nebulosity, an alternative explanation is that LHα 25 might be the remnant of a once-massive star that is now moving to the left in the color-magnitude diagram for the second time.

LHα 25, unlike all the other stars in Table 3, does not itself illuminate any nebulosity but lies in the strong reflection nebulosity around HD 47755. There can be little doubt that LHα 25 lies in the NGC 2264 cluster, because of the moderate amount of reddening despite its superposition on very heavy obscuration. Furthermore, the relative proper motion measured by Van Maanen (1930) does not differ significantly from that of the cluster as a whole.

14. *Z Canis Majoris*

Z Canis Majoris is located in a lane of mingled bright and dark nebulosity nearly 3° long (see Plate 26 of Fesenkov and Rozhkovskii 1953). Several early-type stars are imbedded in this cloud and excite local nebulae; NGC 2327, Cederblad 90, and IC 2177 are the brightest, but fainter nebulosity is present around HD 52721, HD 52942, and a few other B-type stars. The eastern side of the lane is an intricate mass of emission nebulosity; the orientation of emission edges indicates that HR 2694 (= HD 54662, MK type O6) and HR 2678 (= HD 53974, B0.5 IV) are responsible for a major part of the excitation.

Z CMa itself is superimposed on an area of rather weak emission nebulosity near the boundary between the luminous and the dark material of the lane. Direct photographs obtained with the Crossley reflector, first in 1953, show that this star possesses a peculiarity shared by no other stars in the region: a narrow, nearly straight bar of bright nebulosity emerges from the north edge of the overexposed image of Z CMa and extends for about 35″ in about p.a. 290° (see Fig. 10). A fainter arc runs to about 2′ west of the star, and several faint detached scraps of nebulosity lie from 1′ to 2′.5 southwest of Z CMa. Two slit spectrograms of the bright bar have been obtained. Although the plates may be somewhat contaminated by scattered light from Z CMa, the spectrum is certainly not that of an emission nebula. It is essentially continuous and may be identical with that of the star.

The first slit spectrograms of Z CMa were obtained in 1925 and 1927 and have been described by Merrill (1927). More recent observations of the spectrum have been discussed by Swings and Struve (1940, 1942) and by Merrill and Burwell (1949). Lick plates (dispersion 75 A/mm) were obtained in 1933 and 1936 by F. J. Neubauer and in 1954–1955 by the writer (see Fig. 14). All this material confirms the remark of Merrill and Burwell that "the spectrum . . . has retained its chief characteristics for more than twenty years." The 1933–1955 Lick spectrograms look very much like the 1942 plate reproduced by Swings and Struve. A spectral type of B was assigned in the *Henry Draper Catalogue* since dark lines of hydrogen and helium were present, but this is misleading since no normal stellar absorption spectrum has been seen on slit spectrograms. The bright H lines have marked P Cygni structure, and their shortward absorption components are indeed comparable in strength to the Balmer lines of a B-type star. The H emission decrement is rapid; emission can be seen clearly only as far as Hδ. The higher Balmer lines appear entirely in absorption. He I lines were not mentioned by Merrill or by Swings and Struve, nor are they present on the Lick plates, so that if the remark in the *HD* that "[dark] helium lines are certainly present" in Z CMa is correct, the spectrum has changed at least to this extent. Strong, wide absorption lines with weak longward emission are present at H and K and at the D lines. No unique spectral type can be given to the absorption spectrum of the expanding shell, but it clearly corresponds to a level of excitation considerably later than that of a B-type star.

The shortward shifts of the absorption fringes are not the same for all lines, so it is likely that the absorption features originate at different levels in the shell. Thus, on a Lick plate of February 7, 1955, the H absorption components are displaced by −350 km/sec, while Ca II is shifted only −145 km/sec. The Fe II absorption lines suggest an intermediate value. Similar discrepancies were found by Swings and Struve (1940). The emission lines of H, Ca II, Fe II, and Ti II show better agreement among themselves, but there is still a substantial scatter. There is no doubt that the displacements, and possibly the intensities, of the various spectral features vary somewhat with time, but the details are obscure. A Lick spectrogram of the red region taken in 1957 shows that [O I] λ 6300 is present in emission with moderate intensity, as suspected by Swings and Struve, and, possibly, λ 6363 as well.

The visual range of Z CMa is from mag. 8.5 to 11.1 (Beyer 1931, 1937, 1950), the photographic from 9.0 to about 11.3 (Payne-Gaposchkin 1952). The light variations are quite irregular but are not rapid; changes of 1 to 2 mag. over intervals of a few months were representative in 1924–1930, when the variable was quite active, but in recent years the variations have been less conspicuous. There is no clear indication of spectral changes correlated with the light fluctuations, although slit spectrograms do not seem to have been taken at any time when the variable was at full maximum light. This matter deserves investigation when the star again becomes photometrically active.

A rough estimate of the luminosity of Z CMa can be made from the modulus of HR 2678, which is about 8.5 mag. if one adopts the Keenan-Morgan calibration of the MK system. On this basis, at maximum Z CMa must be brighter than $M_v = 0.0$. Reliable correction for absorption is not possible since the normal color is unknown, but a rough upper limit on the luminosity can be set in the following way. The C_1 color of Z CMa has been measured (Stebbins, Huffer, and Whitford 1940) as +0.24 mag., about that of a late F-type star. The bluest stars known have intrinsic C_1 colors of about −0.29 mag.; if it is assumed that Z CMa is intrinsically this blue, an overcorrection for absorption will certainly result. In this way, one obtains an upper limit on the luminosity of Z CMa at maximum of $M_v = -3.2$.

Slitless spectrograms show 6 stars within 20′ of Z CMa that have the Hα line in emission; they are marked in Figure 10. (LkHα 223 lies just outside Fig. 10; it is 4$'\!.$5 north, 0$'\!.$8 west of BD−11°1775). The two brightest (LkHα 218 and 220) have been observed in the photographic region and appear to be ordinary early-type stars. Three of the others lie in the rich star field east of Z CMa, beyond the dark nebulosity, and are probably distant Be stars. LkHα 221, however, lies in the bright nebulosity of NGC 2327 and might be a T Tauri-like object. The limit of these slitless survey spectrograms is estimated as about $M_{pg} = +8$ for bright-Hα objects in the obscured region around Z CMa, so it is obvious that the dark nebulosity in this area is for some reason very poor in T Tauri stars.

15. *HD 53367*

The bright-line character of HD 53367 was discovered at Mount Wilson, and very brief descriptions of the spectrum have been given by Merrill and Burwell (1933*b*) and by Swings and Struve (1943*a*). Lick plates obtained in 1954 and 1957 show that no obvious change had taken place in the spectrum since 1920. The spectral type according to Morgan, Code, and Whitford (1955) is B0 IV:e. Hα is a moderately strong emission line with a faint, nearly central reversal. A rather weak emission line is present shortward of the center of absorption Hβ, and can be faintly seen in Hγ. As noted by Swings and Struve, the He I lines are sharper than is usual in Be stars. Otherwise, the spectrum is quite unexceptional, and spectroscopically there is no reason to regard HD 53367 as other than an ordinary Be star.

HD 53367 is located nearly centrally in the bright nebula IC 2177 (see Fig. 8), part of the large complex of early-type stars and nebulosity in Canis Major that was described in connection with Z CMa. The transition between emission and reflection nebulae occurs with exciting stars near type B0, and in IC 2177, a slit spectrogram indeed shows the continuous component of the light of the nebulosity to be very strong, particularly south and southeast of HD 53367. The intensity of the strong hydrogen and [O II] lines of the emission nebulosity seems to be independent of the increased strength of the continuum in that area. The western edge of IC 2177 contains considerable filamentary structure, strong in Hα light, which presumably arises from some interface phenomenon at the boundary between the luminous region and the dark material farther to the west.

16. *MWC 297*

The Hα emission in MWC 297 was discovered in the Mount Wilson survey (Merrill, Humason, and Burwell 1932). A slit spectrogram obtained in 1931 showed emission at Hβ and Hγ, and a type of Be was assigned. No further observations have been reported. Lick spectrograms obtained in 1955 and 1958 showed the emission at Hβ to be very strong, but bright Hγ was weak, and Hδ was very faint if present at all. Although the star is very red, this steep Balmer decrement is intrinsic. The Ca II lines are very strong in absorption, and no other absorption features can be seen.

MWC 297 is located in one of the darkest areas of the Aquila rift. On blue photographs, it is only feebly nebulous. In red light, however, moderately bright nebulosity can be traced out to about 5′ from the star. Although considerable structure is present, the absence of the sharp details that one usually finds in emission nebulae indicates that this is probably a heavily reddened reflection nebula.

The star is obviously deeply imbedded in the dark cloud and probably owes much of its large color index to this fact. The presence of strong H and K lines in absorption conflicts with an assignment to class B, and MWC 297 may resemble Z CMa in this respect. The star is too faint and too red for one to determine, with Crossley equipment, whether the ultraviolet Balmer lines appear in absorption.

19. *BD+40°4124*

A very strong emission Hα line was discovered in BD+40°4124 (=MWC 340) by Merrill, Humason, and Burwell (1932); Hβ was also bright. A type of B(2)e was assigned, with the remark that "the dark lines are very weak and the type is uncertain." Swings and Struve (1943*a*) concurred in this description of the emission spectrum. A Lick spectrogram, taken with 75 A/mm dispersion in 1956 (see Fig. 14), shows Balmer emission as far as Hδ, but the bright H lines are divided centrally by sharp, very deep absorption components. Although this spectrogram does not extend into the ultraviolet, it is probable that the higher Balmer lines occur entirely in absorption. No other absorption features due to the shell can be seen. Rather diffuse He I absorption lines of an early B-type star are present, but no accurate type can be assigned to the spectrum underlying the emission.

A provisional magnitude and color were obtained with the 22-inch reflector on two nights in 1958: $V = 10.64$, $B - V = +0.78$, $U - B = -0.37$. On the usual assumptions, these data translate to a main-sequence star of MK type somewhat earlier than B0; the indicated visual absorption is 3.3 mag. If +40°4124 does have an absolute magnitude near that of an O9.5 V star, $M_v = -4.4$ (Johnson and Hiltner 1956), the corrected distance modulus is about 11.7 mag.

On direct photographs, +40°4124 is a most interesting object (see Fig. 11). It lies about 70′ north of γ Cygni, in a region filled with emission nebulosity. The star is near the focus of a roughly parabolic arc of emission nebulosity approximately 5′ across, which seems to have "broken through" the relatively regular boundary between a large dark cloud to the north and a region of smoothly luminous nebulosity to the south. +40°4124 itself is closely nebulous out to a distance of about 20″. The nebulosity immediately around the star is bluer than that in the more distant arc and hence may be reflection. A determination of the direction of the proper motion of +40°4124 would indicate whether or not one should consider seriously the possibility that the extraordinary arc of nebulosity around the star might have been produced by the motion of +40°4124 out of the dark cloud to the north.

Although the vicinity is not rich in stars, +40°4124 has four companions within 35″. Interestingly, the two of these to the southeast (LkHα 224: $\Delta\alpha \cos \delta = +12''$, $\Delta\delta = -23''$; LkHα 225: $+26''$, $-25''$) show the Hα line in emission, although not strongly; there is only one other emission-Hα star within 22′ of +40°4124. Both of these companions are quite red. Neither have emission lines in the photographic region; LkHα 224 has Balmer absorption lines as in a B- or A-type star, while no lines can be seen on two 430 A/mm spectrograms of the fainter and redder LkHα 225. The companion of +40°4124 at $-7''$, $-18''$ is about type F0 and is not particularly red; presumably it is a foreground star.

20. *BD+41°3731*

The reflection nebulae NGC 6914, 6914*a*, and 6914*b* (in the notation of Hubble 1922*b* and Collins 1937) surround B-type stars that lie in a dark cloud superimposed on the extensive emission nebulosity in the vicinity of γ Cygni (see Fig. 12).

NGC 6914*b* is the rather faint aureole of nebulosity around +41°3731. The brightest part is circular in outline with a radius of about 1′, but faint extensions go out to almost 3′. Lick spectrograms of the star taken in 1954 show rather weak emission at Hα and that the spectral type is B2 or B3n. Faint, approximately central emission components are present in Hβ and Hγ. The spectrum is entirely that of an ordinary Be star.

Provisional 3-color photoelectric measurements made with the 22-inch reflector of +41°3737, the star in NGC 6914*a*, and of +41°3731 indicate $B - V$ color excesses of 1.0 and 0.9 mag., respectively. Reduced to the main sequence, the colors of both stars correspond to MK types of B3 to B4. The resulting distance moduli (on the basis of the MK calibration by Keenan and Morgan 1951) are 10.1 and 10.8 mag.

Three faint stars in the obscured area near NGC 6914*b* that have Hα in emission are marked with their LkHα numbers in Figure 12. Only the spectrum of the brightest, LkHα 228, $m_{pg} = 14$, has been observed in the photographic region; it is near G0, with no strong line emission.

22, 23. *BD+65°1637 and LkHα 234*

NGC 7129 consists of a small group of early-type stars surrounded by very bright reflection nebulosity and seen against a small but dense obscuring cloud (Fig. 12). The bright nebulosity has been described by Pease (1917). The brightest star of the group is BD+65°1638, for which Hubble gives $m_{pv} = 10.2$ and type B3. Of the stars within 6′ of +65°1638, there are six around which the bright nebulosity condenses in such a convincing manner that there can be no doubt of their association. Two of the brightest of these six, +65°1637 and LkHα 234, have emission at Hα.

BD+65°1637, Pease's star b, is 1′ northwest of +65°1638. Emission Hα of medium intensity was found in this star by Merrill and Burwell (1950) and on Lick plates. Spectrograms of 75 A/mm dispersion indicate a type of B5n, or somewhat earlier. Narrow emission components are present near the centers of the H lines from Hβ through Hδ and possibly Hε. Interstellar Ca II is present. The spectrum is entirely like that of an ordinary Be star.

LkHα 234, Pease's star c, is 62″ from +65°1638 in p.a. 50°. It is closely involved in bright nebulosity containing much intricate structure. The bright Hα line is fairly strong, and emission of moderate intensity is present at Hβ. A single plate of 430 A/mm dispersion shows a late A-type absorption spectrum.

A few very faint stars having Hα emission are suspected near the limit of the slitless exposures in the bright nebulosity of NGC 7129.

24. *BD+46°3471*

The nebula IC 5146 and the cluster of stars associated with it have recently been described by Walker (1959). The main mass of bright nebulosity is illuminated by BD+46°3474, of MK type B1 V; the nebular spectrum contains emission lines on a strong continuous background, as expected from the transitional spectral type of the illuminating star. About 10′ west of the center of IC 5146, beyond the bright nebulosity and just within the boundary of the heavy obscuring cloud against which IC 5146 is projected, is + 46°3471, which is surrounded out to 1′ or 2′ by fairly bright nebulosity whose spectrum in the photographic region is a faithful replica of that of the star.

A bright Hα line of medium intensity was discovered in +46°3471 at Mount Wilson (Merrill and Burwell 1950) and independently at Mount Hamilton. In the photographic region, the spectrum is that of a star about type A0 plus sharp, deep, shortward-displaced shell components in the Balmer lines (see Fig. 14). At Hβ, a moderately strong emission line lies longward of the absorption core; at Hγ the emission component is very weak, and it is absent at the higher Balmer lines. Two 75 A/mm plates taken in 1951 and 1954 show no change in the appearance of the spectrum. Walker suspected that the star was slightly variable in light. His results show also that +46°3471 lies above the cluster "zero-age" main sequence by about 2 magnitudes, the precise amount depending upon how correction for reddening is made.

Beginning near $m_{pg} = 16$, stars with Hα emission begin to appear in considerable numbers in IC 5146, although there are a few brighter. The brightest, after +46°3471, is Walker No. 76, a late B- or early A-type star with $m_v = 13.2$, and rather weak Hα emission. The fainter emission-line stars are discussed in another paper (Herbig 1960).

25. *LkHα 233*

During an examination of several obscured areas near the Lacerta I association for faint emission-line objects, stars having Hα emission were found in the small dark cloud extending to the west and south of HD 213976 ($m_v = 7.0$, MK type B1.5 V). The brightest of these, LkHα 233, is a closely nebulous star of about $m_{pg} = 14.5$. Four streamers of nebulosity in the form of a flattened letter X extend from 20″ to 75″ from the star (see Fig. 13). The somewhat elongated nebulosity closely surrounding LkHα 233, from which the streamers extend, becomes increasingly brighter down to distances of about 1″.5 from the star, below which the Crossley scale is inadequate. Both the close nebulosity and the streamers are fainter on red exposures than on the blue; both this fact and the lack of emission lines in the immediate vicinity of LkHα 233 indicate that the nebulosity is reflection. No changes in the appearance of the nebulosity have been observed on Crossley plates taken in 1953–1957. The writer's results on this field, as well as some additional Harvard material, have been described by Howard (1958).

The dark cloud in which LkHα 233 is located lies behind the brightest area of one of the bands of emission nebulosity that overlie the Lacerta association (Johnson 1953; Morgan, Strömgren, and Johnson 1955). On slit spectrograms of LkHα 233, a strong [O II] λ 3727 from the field nebulosity runs the entire length of the slit.

Two 430 A/mm spectrograms of LkHα 233 were widened by drifting so that they include the contributions of both the star and the bright nebulosity very near it. Hα is in emission with moderate intensity on slitless plates, but no stellar emission lines appear in the photographic region. The Balmer lines appear in absorption, together with a rather weak K line; the spectral type is about A7.

Three considerably fainter emission-Hα stars lie near the center of the dark cloud, about 3′ northwest of LkHα 233. Their m_{pg}'s are about 17, but LkHα 230 is conspicuously variable; it is markedly bluer and has much stronger Hα emission than LkHα 231 or 232. No obvious light changes have been noticed in the latter two stars, but the intensity of Hα emission in LkHα 231 is variable, so it may vary in magnitude as well.

26. *MWC 1080*

MWC 1080 lies in a small dark cloud, about 4′ by 7′, in a rich section of the Milky Way in Cepheus. It falls within the triangle defined by the spectacular H II regions NGC 7538, Simeis 14, and NGC 7635 (see Fig. 6*b* in Gaze and Shajn 1955). MWC 1080 is very closely nebulous, especially on the south and east, this structure terminating in a short bar of bright nebulosity 5″ to 10″ southeast of the star (see Fig. 13). An intricate mass of fainter nebulosity lies about 30″ to the north and northeast, while still fainter nebulosity surrounds the star on all sides except the north.

The Hα emission in MWC 1080 was found by Merrill and Burwell (1949); a Mt. Wilson low-dispersion plate showed Hβ to be in emission, and the spectrum was classified Be. Lick spectrograms (130 and 430 A/mm) obtained in 1957 and 1958 show Balmer emission lines with a rapid decrement and strong P Cygni absorption fringes (see Fig. 14). Many emission lines of Fe II are prominent, but only $\lambda\lambda$ 4923, 5018 show absorption components. Strong dark lines are present at H and K, but it is uncertain from these plates whether the lines originate in the star or in the expanding shell. With this possible exception of the Ca II lines, no stellar absorption spectrum can be seen. MWC 1080 thus resembles Z CMa rather strongly. The spectrograms show also that MWC 1080, like Z CMa, is quite red.

III. DISCUSSION

The aim of the present investigation is to attempt to identify the hypothetical still-contracting stars of large mass with some type of observable object. A statistical comparison of the observed data with the predicted numbers in Table 2 would not be conclusive even under ideal circumstances; it would be quite meaningless here because, as mentioned before, the stars of Table 3 were not collected as the result of a systematic search, and also because the effect of local obscuration on the predictions might be very large.

There appear to be two ways in which one might proceed with this identification problem: (1) by taking advantage of some known property of the contractive phase or (2) by purely empirical means. Consider these two possibilities.

(1) If a detailed theory of contractive evolution existed, one would in principle be able to predict the observable properties of contracting stars and to compare these with observation. In the absence of such a theory, one can only expect these stars to lie somewhere above the main sequence, but this is a rather loose condition since stars can lie above the main sequence for other reasons as well. Even if this were not so, only a few objects of the present list could be located on a color-absolute magnitude diagram, since most are not associated with appreciable numbers of normal stars.

But it is possible that the early-type stars just above the main sequence in young clusters might possess some distinguishing spectroscopic characteristic that would serve to identify their counterparts elsewhere. The most suitable cluster for an investigation of this question is NGC 2264; the three brightest stars on the "hump" in the color-magnitude diagram are types A3–4 III, A5 III, and A7 III, IV and, according to Walker (1956), show no spectral peculiarities in the photographic region at a dispersion of 83 A/mm. The photographic region has not been re-examined here, but the interval $\lambda\lambda$ 5500–6800 in these stars has recently been observed at Mt. Hamilton with a grating dispersion of 88 A/mm, and the spectra compared with A3 III–A7 III MK standards. The only marked peculiarity observed in these three stars is at Hα in the brightest, HD 261736 (=Walker No. 46): the line consists of a quite narrow absorption core with a fringe of emission on the longward edge. The effect is that expected of a very weak shell, but the phenomenon is neither an obvious consequence of the youth of the star nor so striking as to make it of any use in the present context. Since the first approach has failed, at least for the moment, a less direct way to identify the massive stars still in contraction is to ask:

(2) Do any of the objects listed in Table 3 form a spectroscopically unique group that can be found only in association with nebulosity? If so, it might then be possible to develop certain further arguments which, although they would not result in an iron-clad identification, would at least render identification with the contracting stars plausible. It is essentially in this way that the T Tauri stars have been related to still-contracting stars of small to intermediate mass. The common spectroscopic properties of the objects described in Section II can best be summarized by arranging them in the following rough scheme of classification. Those that seem most probably to be ordinary Be stars have been excluded.

1*a:* B- or early A-type star plus a rather weak absorption shell; usually there are no strong emission lines except those of hydrogen; there is often a conflict in spectral criteria (as between He I and Ca II) that presumably arises from the contribution of the shell:

AB Aur	LkHα 215
T Ori	LHα 25
RR Tau	+46°3471
LkHα 208	

1*b:* Probably similar to 1*a*, but with a stronger emission spectrum:

HK Ori	R Mon

1*c:* Apparently rather conventional Be shell stars, but possibly related to 1*a:*

+40°4124	HD 200775

1*d:* Possibly members of 1*a*, or related to it, but observations are inadequate:

LkHα 233	R CrA
LkHα 198	T CrA ?

2: Strong hydrogen emission lines with P Cygni structure:

+61°154	MWC 1080
HD 250550	MWC 297 ?
Z CMa	LkHα 101 ? (Herbig 1956)

3: An A-type star with superimposed emission spectrum that marginally meets T Tauri criteria:

V380 Ori

To summarize still further, the criteria for inclusion in this investigation that are listed in Section I have resulted in a collection of emission-line stars most of which are distinguished by one of these characteristics: the possession of a weak absorption shell or the presence of marked P Cygni structure at the stronger lines. The distinction between the two is probably that the amount of material involved, and the velocity of expansion of the envelope, are greater in the members of the P Cygni-like group.

But the answer to question (2), whether any unique spectroscopic characteristics exist, is in the negative: at the dispersion employed here, the spectra are distinctive but not unique. Shell stars and stars with P Cygni structure entirely similar to those described in Section II can be found elsewhere in the sky, entirely free of association with nebulosity. It might be argued that many such nebulosity-free stars could also be young objects, which differ from the stars in Table 3 only in having had the initial velocities, and the times, to have moved far from their places of formation. This proposal might be correct, but it requires proof.

The only firm large-scale conclusion that can be reached is an obvious one that could perhaps have been drawn at the outset. Assuming, first, that an appreciable number of still-contracting stars of larger mass exist, as indicated by the calculations of Section I; second, that not all such stars are buried in heavy obscuration; third, that such stars, like the T Tauri stars at lower masses, will show emission lines and variability as an unexplained consequence of contractive evolution; then certainly one must conclude that the objects described in Section II (excluding the ordinary Be stars) are at the present time the outstanding candidates for identification with these still-contracting stars. It is known that +46°3471 lies above the main sequence, as would be expected if it is still contracting (Walker 1959). It will be interesting to see if T Ori and V380 Ori also do so when a precise color-magnitude diagram of the Orion Nebula region becomes available. It will also be interesting to see if +61°154 lies above the main sequence of NGC 225. But the well-determined subluminous character of LHα 25 indicates that a complete explanation of the stars in Table 3 may involve more than simple Kelvin-style contractive evolution.

It might be that a closer examination with high dispersion of some of the stars described in Section II would modify the negative conclusion reached above. It is my intention to explore this possibility in a few stars. But it seems clear that further study of these particular objects at low dispersion does not appear promising as far as the general evolutionary problem is concerned, unless some new approach can be devised. However, there are certainly many details in individual objects that could well be clarified by further work of the general type described here. It is hoped that this detailed presentation of the results of the Lick program will be of use to others in planning such observations.

REFERENCES

Barnard, E. E. 1927, *A Photographic Atlas of Selected Regions of the Milky Way* (Washington: Carnegie Institution of Washington), Pt. II, Table 6, object No. 122.
Beyer, M. 1931, *Astr. Abh.*, **8**, C72.
———. 1937, *A.N.*, **263**, 76.
———. 1950, *Astr. Abh.*, **12**, B18.
Campbell, L. 1937, *Pop. Ast.*, **45**, 152.
Campbell, W. W., and Moore, J. H. 1918, *Pub. Lick Obs.*, **13**, 96.
Collins, O. C. 1937, *Ap. J.*, **86**, 529.
Fesenkov, V. G., and Rozhkovskii, D. A. 1953, *Atlas Gazovo-Pylevykh Tumannostei* (Acad. Sci. Kazakh S.S.R.).
Gaposchkin, S. 1946, *Harvard Ann.*, **115**, 67.
———. 1952, *ibid.*, **118**, 126.
Gaze, V. F., and Shajn, G. A. 1955, *Izv. Crim. Ap. Obs.*, **15**, 11.
González, G., and González, G. 1956, *Bol. Obs. Tonantzintla y Tacubaya*, Nos. 14, 19.
Gratton, L. 1957, *Trans. I.A.U.*, **9**, 412.
Greenstein, J. L. 1948*a*, *Centennial Symposia* (Cambridge, Mass.: Harvard Observatory), p. 19.
———. 1948*b*, *Ap. J.*, **107**, 375.
Greenstein, J. L., and Aller, L. H. 1947, *Pub. A.S.P.*, **59**, 139.
Greenstein, J. L., and Struve, O. 1946, *Pub. A.S.P.*, **58**, 366.
Greenstein, N. K. 1938, *Harvard Bull.* No. 908, p. 25.
Haro, G. 1953, *Ap. J.*, **117**, 73.
Haro, G., Iriarte, B., and Chavira, E. 1953, *Bol. Obs. Tonantzintla y Tacubaya*, Nos. 8, 3.
Henize, K. G. 1952, *Ap. J.*, **115**, 133.
Henyey, L. G., LeLevier, R., and Levee, R. D. 1959, *Ap. J.*, **129**, 2.
Herbig, G. H. 1946, *Pub. A.S.P.*, **58**, 163.
———. 1953, *A.J.*, **58**, 249.
———. 1954*a*, *Trans. I.A.U.*, **8**, 805.
———. 1954*b*, *Ap. J.*, **119**, 483.
———. 1956, *Pub. A.S.P.*, **68**, 353.
———. 1958, *Étoiles a Raies d'émission* (Cointe-Sclessin: Institut d'Astrophysique, 1958), p. 251 = *Mém. 8° Soc. Roy. Sci. Liège*, quatr. sér., Vol. **20**; *Contr. Lick Obs.*, Ser. II, No. 82.
———. 1960, *Ap. J.*, **131** (in press).
Hiltner, W. A. 1956, *Ap. J. Suppl.*, **2**, 389 (No. 24).
Hoffleit, D. 1940, *Harvard Bull.* No. 913, p. 4.
———. 1953, *Harvard Ann.*, **119**, 37.
Hoffmeister, C. 1949*a*, *Astr. Abh.*, **12**, No. 1.
———. 1949*b*, *A.N.*, **278**, 24.
Howard, W. E. 1958, *A 21-cm. Study of the Stellar Association I Lacertae* (thesis, Harvard University), p. 22.
Hubble, E. P. 1916, *Ap. J.*, **44**, 196.
———. 1922*a*, *ibid.*, **56**, 162.
———. 1922*b*, *ibid.*, p. 400.

Iriarte, B., and Chavira, E. 1956, *Bol. Obs. Tonantzintla y Tacubaya*, Nos. 14, 31.
Jacchia, L. 1933, *Pubb. Bologna*, **2**, 191.
Johnson, H. L., and Hiltner, W. A. 1956, *Ap. J.*, **123**, 267.
Johnson, H. L., and Morgan, W. W. 1953, *Ap. J.*, **117**, 313.
Johnson, H. M. 1953, *Ap. J.*, **118**, 162.
Jonckheere, R. 1917, *Mem. R.A.S.*, **61**, 57.
Joy, A. H. 1945, *Ap. J.*, **102**, 186.
———. 1949, *ibid.*, **110**, 424.
Keenan, P. C., and Morgan, W. W. 1951, *Astrophysics*, ed. J. A. Hynek (New York: McGraw-Hill), p. 12.
Kholopov, P. N. 1951, *Variable Stars*, **8**, 83.
Kukarkin, B. P., Parenago, P. P., Efremov, Yu. I., and Kholopov, P. N. 1958, *General Catalogue of Variable Stars* (Moscow: Acad. Sci. U.S.S.R.).
Lee, O. J. 1926, *M.N.*, **86**, 645.
Lenouvel, F. 1957, *J. d'obs.*, **40**, 37.
Manova, G. A. 1959, *A.J. U.S.S.R.*, **36**, 187.
Mayall, M. W. 1955, *J. Roy. Astr. Soc. Canada*, **49**, 166, 212.
Mendoza, E. E. 1958, *Ap. J.*, **128**, 207.
Menon, T. K. 1958, *Ap. J.*, **127**, 28.
Merrill, P. W. 1927, *Ap. J.*, **65**, 291.
Merrill, P. W., and Bowen, I. S. 1951, *Pub. A.S.P.*, **63**, 295.
Merrill, P. W., and Burwell, C. G. 1933*a*, *Ap. J.*, **77**, 103.
———. 1933*b*, *ibid.*, **78**, 87.
———. 1943, *ibid.*, **98**, 153.
———. 1949, *ibid.*, **110**, 387.
———. 1950, *ibid.*, **112**, 72.
Merrill, P. W., Burwell, C. G., and Miller, W. C. 1942, *Ap. J.*, **96**, 15.
Merrill, P. W., Humason, M. L., and Burwell, C. G. 1932, *Ap. J.*, **76**, 156.
Miller, W. C., and Merrill, P. W. 1951, *Ap. J.*, **113**, 624.
Morgan, W. W. 1956, *A.J.*, **61**, 358.
Morgan, W. W., Code, A. D., and Whitford, A. E. 1955, *Ap. J. Suppl.*, **2**, 41 (No. 14).
Morgan, W. W., Harris, D. L., and Johnson, H. L. 1953, *Ap. J.*, **118**, 92.
Morgan, W. W., and Sharpless, S. 1946, *Ap. J.*, **103**, 249.
Morgan, W. W., Strömgren, B., and Johnson, H. M. 1955, *Ap. J.*, **121**, 611.
Morgenroth, O. 1939, *A.N.*, **268**, 273.
Parenago, P. 1933, *Veränderliche Sterne*, **4**, 226.
———. 1950, *Variable Stars*, **7**, 169.
———. 1954, *Pub. Sternberg Astr. Inst.*, **25**, 214.
Payne-Gaposchkin, C. 1952, *Harvard Ann.*, **118**, 21.
Pease, F. G. 1917, *Ap. J.*, **46**, 24.
———. 1920, *ibid.*, **51**, 276.
Sandage, A. 1957, *Ap. J.*, **125**, 422.
Sanford, R. F. 1920, *Ap. J.*, **52**, 13.
———. 1933, *ibid.*, **78**, 104.
Sanford, R. F., and Merrill, P. W. 1958, *Pub. A.S.P.*, **70**, 602.
Schilt, J., and Hill, S. J. 1937, *Contr. Rutherfurd Obs.*, No. 30.
Seares, F. H., and Hubble, E. P. 1920, *Ap. J.*, **52**, 8.
Shapley, H. 1924, *Harvard Bull.* No. 798.
Sharpless, S. 1952, *Ap. J.*, **116**, 251.
Smith, Henry J. 1955, *Southern Wolf-Rayet Stars* (thesis, Harvard University), p. 156.
Starikova, G. A. 1951, *Variable Stars*, **8**, 244.
Stebbins, J., Huffer, C. M., and Whitford, A. E. 1940, *Ap. J.*, **91**, 20.
Struve, O., and Swings, P. 1943, *Ap. J.*, **97**, 426.
Swings, P., and Struve, O. 1940, *Ap. J.*, **91**, 576.
———. 1942, *ibid.*, **96**, 258.
———. 1943*a*, *ibid.*, **97**, 194.
———. 1943*b*, *ibid.*, **98**, 91.
Thackeray, A. D. 1950, *M.N.*, **110**, 524.
———. 1956, *Vistas in Astronomy*, **2**, ed. A. Beer (London and New York: Pergamon Press), p. 1380.
Trumpler, R. J. 1931, *Pub. A.S.P.*, **43**, 255.
Van Maanen, A. 1928, *Mt. W. Contr.*, No. 356.
———. 1930, *ibid.*, No. 405.
Walker, M. F. 1956, *Ap. J. Suppl.*, **2**, 365 (No. 23).
———. 1958, private communication.
———. 1959, *Ap. J.*, **130**, 57.
Weston, E. B. 1949, *Pub. A.S.P.*, **61**, 256.
———. 1950, *A.J.*, **55**, 82.
———. 1953, *ibid.*, **58**, 48.