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ON THE NEBULOSITIES ASSOCIATED WITH THE EXTREME Of STAR HD 148937

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ABSTRACT

The extreme Of star HD 148937 and its associated nebulae, including NGC 6164–5, a 2° diameter H II region, and an outer dust shell, plus a newly identified interstellar bubble, are studied to understand their interrelations and thereby to understand the origin of HD 148937. Information from far-ultraviolet spectroscopy of the central star, narrow passband emission-line photography, and broad-band survey plates is assembled into a self-consistent model describing the interaction of HD 148937 with the surrounding interstellar bubble–H II region complex. The star HD 148937 is found to be quite young, less than 350,000 years in age. Constraints on its luminosity suggest it is still in the pre-main-sequence contraction phase.

Subject headings: nebulae: H II region — nebulae: individual — stars: individual — stars: pre-main-sequence — stars: Of type

I. INTRODUCTION

The spectroscopically peculiar Of star, HD 148937 [$\alpha = 16^h30^m$, $\delta = -48°0'$ (1950)] is one of the most intriguing objects in the sky. This star is surrounded by a highly unusual set of related nebulosities. Centered upon HD 148937 is the well-known **S**-shaped nebular complex NGC 6164–5. Both HD 148937 and NGC 6164–5 are centered within an apparent cavity, devoid of diffuse emission. This cavity has a well-defined boundary delineated by a shell of sharp filaments most easily seen in [O III] λ5007. This is situated within a large, nearly circular H II region which in turn is bounded by a thin, outer dust shell.

Although these peculiar nebular structures have been noticed previously (Longmore 1977; Westerlund 1960; Henize 1959), new observational data (both narrow bandpass emission-line photographs of the nebulosities and high-dispersion far-ultraviolet spectroscopy of the central star) considerably extend information on both HD 148937 and the surrounding nebular complex. This paper presents this new information and attempts to establish a consistent interpretation of HD 148937 and its associated nebulosities.

II. THE CENTRAL STAR: HD 148937

a) *Previous Spectral Data*

This star was first classified by Westerlund (1960) who assigned a tentative class of O6f. He noted that the spectral lines are apparently variable. Practically all (five) spectrograms show He II λ4686 in emission, most of them also showed N III λ4641 and a few C III λ4651. He also noted that the Balmer lines show fairly broad, shallow absorption with, in some cases, a sharp central core, thus suggesting a rapidly rotating star with an outer shell. A luminosity was derived by Westerlund by using the radial velocities of the Ca II interstellar lines to give a minimum distance. Assuming the star to be located in the inner spiral arm, Westerlund estimated a distance of 1400 pc which yielded $M_v = -6.2$.

HD 148937 is listed as Ofp by Smith and Aller (1969) who include it in a listing of planetary nebula nuclei. The peculiarity which they noted is the presence of C III λλ4647, 4650–4651 emission. This C III emission does not appear in "normal" Of spectra of Population I stars. They noted that only two Population I stars of spectral type Ofp are known—HD 108 and HD 152408. Both stars are also unusual in that P Cygni line profiles are present. They also note that, by contrast, Of stars showing C III emission are frequent among planetary nebula nuclei. If HD 148937 is excluded, 4 of the 27 planetary nuclei classified in that paper fall in the Ofp group.

Walborn (1972) has classified the star as O6.5fp. He noted the peculiarity to be both the presence of well-marked emission in C III λλ4647, 4650, 4651 and the large value of the λλ4640–4642/λ4634 intensity ratio of N III emission, neither of which is a property of normal Of stars. He notes that one other O star has similar characteristics—HD 108.

Hutchings (1976) assigned a classification of O7f to HD 148937 and, on the basis of the Hγ equivalent width, derived a very luminous $M_v = -7.2 + 0.4$, consistent with the star being a supergiant. Hutchings (1978) has included HD 148937 among the five "very extreme" Of stars, with absolute magnitudes near $M_{bol} = -10.5$. All five of these stars are characterized by He II λ4686 emission and emission in the λλ4630–4650 region. At least four of these stars, HD 148937, HD 108, HD 152408, and HD

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151804, show C III emission at λλ4647, 4650–4651 (Smith and Aller 1969; Conti, Garmany, and Hutchings 1977). These are the same characteristics of the Ofp stars noted by Smith and Aller.

Mass-loss rates for HD 148937 have been determined using both visual and ultraviolet data. On the basis of the Hα emission Hutchings (1976) determined a mass-loss rate of $7 \times 10^{-6} M_\odot \text{ yr}^{-1}$. More recently, Hutchings and von Rudloff (1980) used the ultraviolet N V, C IV, and Si IV resonance profiles from high-dispersion *IUE* spectra to derive mass-loss rates for O stars. They found anomalously low rates ($\sim 2 \times 10^{-7} M_\odot \text{ y}^{-1}$) in contrast to the Hα results for both extreme Of stars HD 108 and HD 148937. These rates are two orders of magnitude lower than normally expected for extreme Of stars. This result is supported by Conti and Garmany (1980) who also investigated mass loss in Of stars using similar *IUE* spectral data. Hutchings and von Rudloff reference a private communication of Walborn noting that both HD 148937 and HD 108 display a very different spectral morphology compared to other Of stars. The anomalously low mass-loss rate of HD 148937 deduced from *IUE* data, in contrast to that deduced from the Hα emission, is certainly an aspect to be explained by any model of this object.

b) *New UV Spectral Data*

One of the biggest problems encountered with the visual stellar classification Of stars is the difficulty in establishing reliable luminosities for these objects. However, the ultraviolet spectra of these stars have provided very useful information leading to much improved classification.

It has been shown, from low-resolution *Skylab* S-019 objective-prism data, that the C IV and Si IV resonance features provide an excellent luminosity criterion for O stars (Henize *et al.* 1975, 1977). All of the O supergiants with Walborn classifications exhibit pronounced Si IV P Cygni profiles in addition to the C IV P Cygni profiles characteristic of most O stars; whereas neither Si IV absorption nor emission is seen in main-sequence O stars earlier than O8 at low resolution. A low-dispersion spectrum of HD 148937 obtained with *IUE* shows little or no Si IV present, while C IV shows a strong P Cygni profile. These characteristics are typical of luminosity class V stars and some luminosity class III stars, but not of a supergiant.

Although such a classification might be considered controversial, since it is based upon lines arising primarily in the stellar wind, it is supported by photospheric features in an *IUE* high-dispersion spectrum loaned to us by Peter Conti. This spectrum shows the presence of many strong high-excitation photospheric lines of Fe V. These Fe V transitions have been previously identified in *IUE* spectra of the low-gravity O subdwarf HD 49798 and the main-sequence spectral standard 15 Mon (O7 V) by Bruhweiler, Kondo, and McCluskey (1981). These features become noticeably weaker and more diffuse in stars of higher luminosity but of similar spectral type. In the spectral tracing loaned by Peter Conti and in a follow-up exposure by one of us (F. C. B.), the entire ultraviolet photospheric spectrum of HD 148937 is strikingly similar to that of HD 49798 and 15 Mon (see Fig. 1). These similarities support the contention that HD 148937 lies near the main sequence. Although the features in HD 148937 are broader or slightly more diffuse than in 15 Mon, which may or may not indicate a slightly higher luminosity, they are markedly less diffuse than supergiants of similar spectral type. It is also noteworthy that the low mass-loss rate of $2 \times 10^{-7} M_\odot \text{ yr}^{-1}$ determined by Hutchings and von Rudloff (1980) is more in line with those of main-sequence stars (Conti and Garmany 1980).

Due to the similarity of the spectrum of HD 148937 to an O subdwarf and its association with the planetary-like nebulosities NGC 6164–5, it is important to consider whether HD 148937 is actually a subdwarf. Although there are marked similarities among the spectra discussed, there should be definite differences in features arising from the elements C, N, and O between the nitrogen-rich, carbon- and oxygen-weak O subdwarfs and the extreme Population I stars. In the subdwarf HD 49798 the features of O IV λ1338, and the C IV resonance lines of λλ1548.8, 1550.2 are pronouncedly weaker. While the profiles of C IV in HD 148937 and 15 Mon show skewed absorption indicating expansion velocities of 2600 and 1950 km s^{-1}, respectively, only narrow unshifted photospheric features are found in the O subdwarf. Further, the ultraviolet spectrum of the star HD 150136 (O5 III), one of the exciting stars of NGC 6193 and a member of the Ara OB1 association, shows that the interstellar features most likely formed along the entire line of sight (C II, Si II, and O I) exhibit similar profiles and equivalent widths to those in the spectrum of HD 148937. (The interstellar line results of these and other stars will appear elsewhere.) It is clear that HD 148937 cannot be a nearby O subdwarf, nor a luminous supergiant, but must be a relatively unevolved Population I O star similar to 15 Mon.

III. THE SURROUNDING NEBULOSITIES

The nebulosities NGC 6164–5 have long been recognized to be associated with HD 148937. Henize (1959), in interpreting the Michigan–Mount Wilson Southern Hα Survey, noticed a faint symmetrical, but diffuse, structure of nebulosity in the form of a figure eight. He further noted that within the nebulosity were "small knots placed with central symmetry" about HD 148937.

The detailed structure of NGC 6164–5 is astonishingly symmetrical as the photographic data reveal in Figure 2 (Plate 2). These data were obtained using interference filters with 6–10 Å wide bandpasses and the CIT (C 33011) camera behind the Yale 1 m telescope at Cerro Tololo Inter-American Observatory. In both [O III] λ5007 (Fig. 2*a*) and Hα (Fig. 2*b*), a general diffuse but symmetrical structure is noticeable. This does not seem to be present in [N II] (Fig. 2*c*), but may not be detected because the [N II] image is not exposed as deeply as the

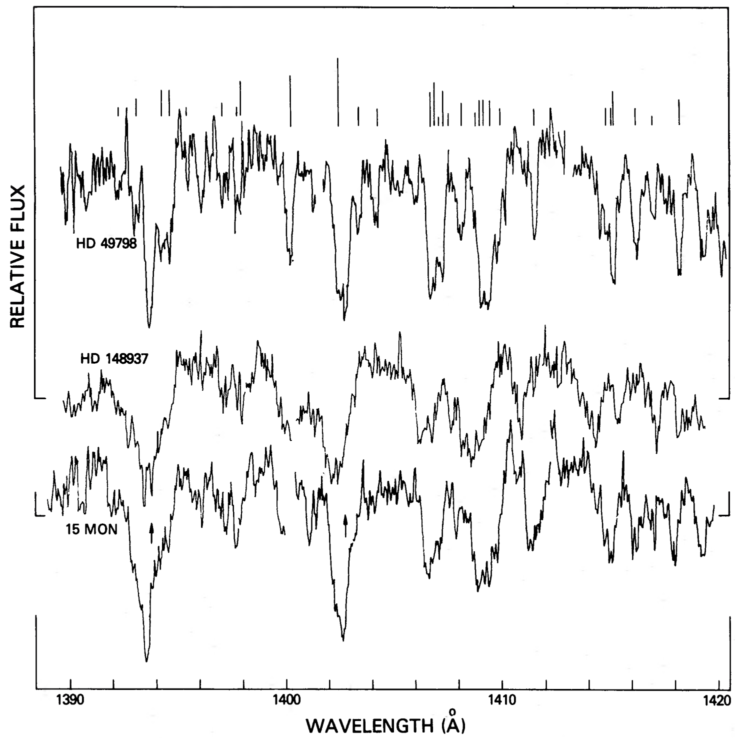

FIG. 1.—The spectrum of HD 148937 (O6f–O7f) compared to HD 49798 (O6p) and 15 Mon (O7 V). The spectral region is near 1400 Å. Arrows indicate wavelength positions of Si IV lines. The lines above the spectra indicate wavelength positions of Fe V lines; the physical line lengths are proportional to relative intensities published by Ekberg (1975). Any apparent velocity shifts between spectra are arbitrary for plotting purposes.

[O III] image. In Figure 2*d*, we have sketched the important portions of the nebulosity. The bright knots, as labeled, consist of a pair of elongated bright knots (A, A′) and two pairs of fainter, smaller knots (B, B′ and C, C′). The ionization structure indicates that a neutral core exists within each knot. We note from the scale in Figure 2*c* that the maximum extent of this structure is 370″ in a northeast–southwest direction.

Radial velocities from slit spectra (Catchpole and Feast 1970) and from Fabry-Perot studies (Pismis 1974) are consistent with the emission nebulosity expanding symmetrically from HD 148937. However, the measured line profiles indicate a rather complex velocity pattern.

The Hα plates obtained by Westerlund (1960) using the Uppsala Observatory Schmidt telescope show additional nebular structures around HD 148937: (a) an arc 13′.5 to the southeast and (b) a nearly circular H II region extending 44′ to the northeast and 64′ to the west.

More recently, IIIa-J plates in the ESO/SRC Survey (Longmore 1977) show a filamentary "halo" with a major axis of 20′.5 and a minor axis of 15′ (Fig. 3 [Pl. 3]). These axes are aligned with the major and minor axes of the inner nebulosities, NGC 6164–5. The 13′.5 arc noted by Westerlund in Hα is one of the brighter portions of this halo. The filamentary nature of this halo and the detection of strong [O III] as presented here in these filaments are very reminiscent of filaments commonly associated with supernova remnants.

HD 148937 has been identified as a possible runaway star (Cruz-Gonzales *et al.* 1974). Such an identification tempts speculation that a supernova event is responsible for the present filamentary structure. While such is not the case, it is these filaments noted in wide-field [O III] imagery that stimulated the initial research leading to this paper.

The wide-field narrow passband imagery came from an emission-line survey of the Milky Way recently completed by Parker, Gull, and Kirshner (1979). From the original plate data, we present in Figure 4 (Plate 4) enlargements of the region surrounding HD 148937 as imaged in the light of blue continuum λ4215 (Fig. 4*a*), [O III] λ5007 (Fig. 4*b*), Hα + [N II] λ6570 (Fig. 4*c*), and [S II] λ6730 (Fig. 4*d*). The following features of special interest are evident on the plates.

1. The filamentary halo is most easily seen in [O III]. This is probably due to an abrupt change in ionization plus an abrupt increase in density at the wind-shocked interface compared to the background H II region.

2. The circular symmetry of the background H II region, noted by Westerlund, is confirmed. Its overall diameter is 110′. However, HD 148937 is displaced 7′ east of the geometric center. This may be due to an apparent

density gradient increasing toward the east suggested by the increased Hα emission and the possible interaction with the NGC 6193 dust complex.

3. The total extent of the H II region is well defined in Hα + [N II] and in [S II], but is poorly defined in [O III]. In particular, [O III] is essentially absent in the vicinity of the western and northeastern rims. If we ignore the southeastern portion, which is back-illuminated by the NGC 6193 complex, the [O III] surface brightness is strongest near the center of the H II region whereas the [S II] and, to a lesser extent, Hα + [N II] are strongest near the outer rim. This is consistent with this region being photoionized by the central star.

4. The volume interior to the filamentary halo is devoid of any detectable diffuse emission except for the compact nebulosities NGC 6164–5 as Figure 4 shows. Westerlund previously noted this "hole." Neither the ESO/SRC plate data (Fig. 3) nor the blue continuum photograph (Fig. 4) show any evidence of decreased star counts interior to the filamentary halo compared to the immediate surroundings. This clearly indicates that the "hole" is an actual cavity and is not due to a dust cloud. This cavity is most likely maintained by the high-velocity mass loss from the central star which we will discuss further in § IV. A thin circular dust shell bounding the 110′ diameter H II region is evident in Figure 5 (Plates 5 and 6). This shell is most easily recognized on the eastern boundary, but can be traced in detail around the full perimeter.

The adjacent cluster NGC 6193 and its nebulosity can be used to derive an upper limit to the distance and luminosity of HD 148937. Near the region of strong, diffuse [O III] emission of NGC 6193 lie the two O stars HD 150135 (O6.5 V) and HD 150136 (O5 III). There can be but little doubt that one or both of these stars are the exciting stars of this nebulosity. Judging by the back-illuminated dust geometry, NGC 6193 must be a background object to HD 148937 and its associated nebulosities. The increased observability of dust and its mottled appearance at the eastern rim of the large H II region around HD 148937 implies a physical interaction with NGC 6193. However, this mottled appearance may only be a result of back illumination by NGC 6193. Both HD 150135 and HD 150136 are separated by approximately 15″ and have nearly identical extinctions (A_v). The information for these two stars and HD 148937 is given in Table 1. The data for HD 150136 combined with absolute magnitude-spectral type calibration of Panagia (1973) yield a distance estimate (1200 pc) in close agreement with the independently determined distance of the Ara OB1 association. Assuming an interaction of the large circular H II region and NGC 6193 then implies that $M_v = -5.7$ for HD 148937. The star HD 150136 was not used here since it is a suspected binary (Humphreys 1978), but if duplicity were to be taken into account a distance close to HD 150135 would result. However, it may be preferable to use the adopted distance (1380 pc) to the Ara OB1 association (Humphreys 1978). Doing this yields $M_v = -6.0$ for HD 148937.

An upper limit of $M_v = -6.0$ does not conflict with the luminosity derived from the ultraviolet stellar spectrum. This is consistent with HD 148937 being a star of luminosity class V or III.

TABLE 1

HD 148937 AND THE EXCITING STARS OF NGC 6193

Star (HD)	Sp. Type	V	A_V
148937	O6–O7	6.71	1.98
150135	O6.5 V	6.89	1.47
150136[a]	O5 III	5.62	1.44

[a] Humphreys (1978) lists this as a possible binary. The data entries for HD 150135 and HD 150136 as given by Humphreys (1978) are reversed.

IV. THE PHYSICAL CONDITIONS AND AGES OF THE NEBULOSITIES

a) The H II *Region*

The geometrical bounds of the H II region and the thin dust shell enclosing the H II region and HD 148937 are, in general, clearly defined and permit a detailed analysis of the H II region and its history. Assuming a spherical Strömgren sphere and ignoring the inner cavity and NGC 6164–5, the tables from Panagia (1973) enable us to determine the electron number density n_e inside the H II region. The electron number density was calculated for two extreme limits for the absolute magnitude of HD 148937: case A ($M_v = -4.7$) corresponding to a star on the zero-age main sequence (ZAMS), and case B ($M_v = -6.0$) corresponding to our previously determined upper limit. The results of these calculations are given in Table 2. The reasoning for considering a very low luminosity for case A will be made clear shortly in our present analysis.

As an H II region around a star expands outward, a weak R-type ionization front develops. At some point it becomes R-critical and the ionization front will trail behind the propagating shock front. A compressed neutral shell then forms immediately ahead of the ionization front (Lasker 1966). This neutral shell formed by the shock front corresponds to the dust shell bounding the H II region.

TABLE 2

PHYSICAL CONDITIONS OF THE H II REGION

Parameter	Case A	Case B
M_v (HD 148937)..............	−4.7	−6.0
Distance........................	790 pc	1380 pc
(r_i) ionization radius..........	12 pc	21.2 pc
(n_e) electron interior number densities...........	10 cm^{-3}	7.8 cm^{-3}
Shell density	58–99 cm^{-3}	46–77 cm^{-3}
(n_0) initial number density	14.6–24.7 cm^{-3}	11.4–19.2 cm^3
$1-(r_i/r_s)$	0.05–0.09	0.05–0.09
t_{char}[a]	1.7–3.9 × 10^5 yr	3.0–7.0 × 10^5 yr
S_0	6.6–9.3 pc	11.6–16.4 pc

[a] See text for ages for the interstellar bubble.

The relative thickness of the neutral shell $(1 - r_i/r_s)$ is defined by the visible dust ring, where r_i is the radius of the H II region and r_s is the outer radius of the compressed neutral shell. Visual examination of the available photographic data shows the relative shell thickness to be between 0.05 and 0.09. The outer boundary of the shell is not well defined at all position angles, but 0.09 represents a realistic upper limit to the relative thickness.

In order to estimate the age and physical parameters of the H II region, we can assume the neutral shell is formed by a strong adiabatic shock and take from Lasker (1967)

$$n = n_0 s_0^{3/2} r^{-3/2} , \tag{1}$$

$$r_i = (\tfrac{7}{4} c s_0^{3/4} t + s_0^{7/4})^{4/7} , \tag{2}$$

$$\Delta r = \tfrac{1}{6}[(\tfrac{7}{4} c s_0^{3/4} t + s_0^{7/4})^{6/7} - s_0^{3/2}] \times (\tfrac{7}{4} c s_0^{3/4} t + s_0^{7/4})^{2/7} . \tag{3}$$

These expressions represent the number density, n, the radius of the H II region, r_i, and the thickness of the neutral shell, Δr. By using these equations we can solve for the three unknown quantities: s_0, the initial radius of the Strömgren sphere, n_0, the initial undisturbed interstellar medium, and t, the age of the H II region.

The isothermal sound speed c in the H II region is calculated here assuming a temperature of 10,000 K. In Table 2, the physical conditions in the neutral shell and the H II region as well as the characteristic ages of the H II region are given using the above formulations. This is done both for case A and case B, where for each case a range of shell number density, shell thickness, and ages are presented based upon the limits of the relative shell thickness $(1 - r_i/r_s)$.

The characteristic ages (1.7–7.0×10^5 yr) found for the H II region are short compared to the main-sequence lifetime of an O6–O7 star ($t_{ms} \sim 5 \times 10^6$ yr). This implies a young age for HD 148937. Even though the characteristic age of the H II region is based upon a somewhat heuristic treatment by Lasker (1966, 1967), the thinness and sharpness of the dust shell, unlike the thicker, more diffuse dusty regions around other H II regions, testifies to its youth.

b) The Filamentary Halo and the Inner Cavity

The pronounced filamentary nature of the halo and its enhanced [O III] emission strongly suggests a shocked interface as in the case of supernova remnants. However, such shocked interfaces, marking boundaries of interstellar bubbles, are expected due to the interaction of the high-velocity stellar winds of OB stars and the surrounding interstellar medium. Since it is known that HD 148937 possesses such a high-velocity wind, we have interpreted the halo as due to this physical process. Models for interstellar bubbles by Weaver *et al.* (1977) predict low densities of 10^{-2} to 10^{-3} cm^{-3} and temperatures on the order of 10^5 to 10^6 K for the interiors of these cavities and can explain the lack of observed diffuse emission.

We have not overlooked that the observed filamentary interface might be, in part, a consequence of an explosive event. The inner nebulosities, NGC 6164–5, do in fact suggest such an event. No doubt the inner nebulosities have affected the structure of the halo. Witness the alignment of the major and minor axes of the filamentary halo with NGC 6164–5 (see Fig. 3). For the time being, however, we will ignore other contributions and will consider only the effects of the observed stellar wind.

If the cavity around HD 148937 is an interstellar bubble, then it must be quite young, as in an older bubble the shock front defining the boundary of the bubble is expected to overtake the shell surrounding the expanding H II region (Weaver *et al.* 1977). In this sense, the 2° diameter thin dust shell can in no way be interpreted as the shell of an interstellar bubble. The very presence of visible emission in the H II region implies densities far in excess of those expected in interstellar bubbles (10^{-2} to 10^{-3}cm^{-3}).

We can estimate the age of the bubble by using the expression for the radius of an interstellar bubble from Weaver *et al.*

$$R_s = 27 n_T^{-1/5} L_{36}^{1/5} t_6^{3/5} \text{ pc} . \tag{4}$$

The parameters are n_T, the total number density in the surrounding H II region, L_{36}, the kinetic energy of the stellar wind in units of 10^{36} ergs s^{-1}, and t_6, the age of the bubble in units of 10^6 years.

The terminal velocity based upon the C IV resonance profiles is 2600 km s^{-1} as measured from *IUE* spectrum SWP 9717. However, the ultraviolet mass-loss rate of $2 \times 10^{-7} M_\odot$ yr^{-1} by Hutchings and von Rudloff (1980) assumes a $M_v = -7.2$. Scaling the mass loss to a star of smaller radius corresponding to a lower luminosity, but with identical observed profiles, yields scaled mass-loss rates of 1.2×10^{-7} and $6.3 \times 10^{-8} M_\odot$ yr^{-1} for M_v equal to -6.0 and -4.7, respectively. We choose to take the semiminor axis as the radius of the interstellar bubble, because the nebulosities NGC 6164–5 which are possibly linked to an explosive event producing anisotropic mass loss seem to have altered the structure of the bubble in the northwest–southeast direction. The semiminor axis corresponds to 1.7 and 3.0 pc for case A and B, respectively. By solving for t_6 in the above expression, we derive 5.1×10^4 to 1.4×10^5 years as the age of the bubbles in our two respective cases. These ages for the interstellar bubble assume that the mass-loss rate and terminal velocity has been constant over the lifetime of the bubble. Yet, if we do allow a lower mass-loss rate in the past, since $r \propto L_{36}^{1/5} \propto \dot{m}^{1/5}$ where $\dot{m}$ is the mass-loss rate, it is still difficult to increase the age of the bubble to greater than 5×10^5 years. We might add that if we were to also allow some contribution due to an explosive event, the age of the bubble can only be younger than that calculated by stellar winds alone.

Since we might expect a stellar wind to exist throughout the main-sequence lifetime of an O star, and possibly even in the later pre-main-sequence phase, both the age of the bubble and the implied age of the H II region are in good agreement in that they both indicate a very young age; an age no older than 5×10^5 years for HD 148937.

c) *The Inner Nebulosities: NGC 6164–5*

These nebulosities, NGC 6164–5, show striking symmetry indicating this gas has been ejected from HD 148937. Catchpole and Feast (1970) confirmed that the elongated bright knots are expanding outward from the central star, finding radial velocities of +21 and −43 km s^{-1} for NGC 6164 and 6165, respectively. The ejection seems clearly to be nonisotropic with no indication of matter moving along the line of sight; then the time interval since ejection becomes large ($\sim 2 \times 10^5$ yrs if $i = 80°$). It then becomes difficult to understand how the ejected knots could have maintained their compactness over such a period. The compactness of the knots of NGC 6164–5 is perhaps unique among observed stellar ejecta. Perhaps we should not be too quick in ruling out some plasma confinement mechanism such as magnetic fields. However, barring such a mechanism, it seems more plausible that the nebulosities were ejected at angles of $i \approx 10°$. The ages of NGC 6164–5 are, then, on the order of 5×10^3 years. Even though the mechanism responsible for the origin of NGC 6164–5 is extremely uncertain, we are compelled to at least speculate about the nature of these phenomena.

One model suggested to explain the inner nebulosities is that of Pismis (1974). In this model a magnetic field is postulated that is not aligned with the axis of rotation of HD 148937. Starting at times of 4×10^3 years ago, material was ejected at the magnetic poles in several outbursts creating the nebulosities we now see. Yet, the **S**-shape, or possibly figure-eight shape, which extends all the way to the central star (Fig. 2), strongly suggests a continuous mass outflow upon which is superposed sporadic mass ejection throughout this time period.

A "lawn sprinkler model" with jets at the stellar poles would produce a helical or **S**-shaped nebulosity. If the **S**-shaped pattern is indicative of continuous ejection, then it requires a nutation or precession mechanism with a period on the order of the age of the nebulosities to produce the required helical pattern. Generally, nutation or precession requires the presence of a close stellar companion. However, Conti, Garmany, and Hutchings (1977) from extensive spectroscopic coverage at high dispersion find no evidence of a companion. They estimate that any velocity amplitude greater than 20 km s^{-1} would have been detected. Yet it is not clear that this completely rules out presence of a companion which could cause the necessary precession or nutation. One might add that an extensive protostellar disk around a young HD 148937 can also lead to precession or nutation. A young star undergoing internal instabilities resulting in mass ejection at the poles could lead to the currently observed nebulosities NGC 6164–5.

We emphasize that the ejection mechanism giving rise to the inner nebulosity may be quite different from that responsible for the ultraviolet stellar wind features commonly seen in all Population I O stars. We emphasize that large amounts of material preferentially ejected at the stellar poles and not along the line of sight, in our model, would explain the anomalously strong Hα emission when compared to the mass-loss rate derived from the ultraviolet resonance features of N V, C IV, and Si IV.

V. DISCUSSION

The low ultraviolet mass-loss rate for HD 148937, the similarity of the ultraviolet stellar spectrum of HD 148937 with the main-sequence star 15 Mon, the back-illuminated geometry involving NGC 6193, and the young characteristic ages, derived for both the H II region and the interstellar bubble, all present strong evidence that HD 148937 is not an evolved O star, but instead is an extremely young object. We parenthetically comment that monochromatic imagery reveals a similar but more evolved interstellar bubble–H II region around 15 Mon; these results will be presented elsewhere.

Taking our presult results at face value, the absolute magnitude of HD 148937 lies between $M_v = -4.7$ and -6.0. The lower limit is derived from the extremely youthful ages of the H II region and the interstellar bubble, and the upper limit from the possible association with NGC 6193. The ultraviolet spectra are in agreement with these limits. The similarities of the ultraviolet interstellar lines in HD 150135 and HD 148937, membership in Ara OB1 association, and the implied interaction of the spherical H II region around HD 148937 with the NGC complex indicate that HD 148937 may be slightly evolved with $M_v = -5.7$ to -6.0. Yet, at the same time, the sharply defined neutral dust shell around the H II region and the derived ages of both the H II region and the interstellar bubble strongly argue for HD 148937 being young. These young ages ($t < 5 \times 10^5$ yr) do not allow enough time for HD 148937 to evolve away from the ZAMS. The models of Stothers (1972) indicate the total main-sequence lifetime or the elapsed time for evolution from the ZAMS through the tip of the main-sequence "turn-up" is approximately 5×10^6 yr. If the absolute magnitude of HD 148937 is $M_v = -5.7$ or brighter and an evolved O star, it must be older than 5×10^6 yr.

One way to rectify what may be a paradox is to accept that HD 148937 is indeed extremely young and is in a pre–main-sequence evolutionary phase.

As protostars in the H-R diagram evolve to the left then finally down to the ZAMS, extensive mass ejection is expected (Bodenheimer and Black 1978; Westbrook and Tarter 1975; Iben 1965). If HD 148937 were still evolving toward the ZAMS, the young ages of the interstellar bubble and the H II region, the "likely" luminosity ($M_v = -5.7$ to -6.0) of HD 148937, and the formation of NGC 6164–5 present a single, coherent interpretation.

Admittedly, the extremely short pre–main-sequence phase ($t = 2 \times 10^4$ yr) makes the odds of detecting a O star in such a phase quite low. However, if the formation of the interstellar bubble resulted from the combined effects of explosive mass ejection and continuous mass loss, then the age estimates, calculated in § III, for the bubble are likely upper limits.

We certainly cannot rule out a lower luminosity and smaller distance for HD 148937 commensurate with a main-sequence or ZAMS star. Of course, this would also imply smaller ages of the interstellar bubble and the H II region. By adopting a smaller distance, we must then question whether the H II region around HD 148937 is interacting with NGC 6193 and also whether it is a member of the Ara OB1 association. Regardless of what absolute magnitude is chosen for HD 148937, the thin, sharply defined boundary of the H II region and the age deduced for the interstellar bubble point to an extremely young age for the central star HD 148937.

The star HD 148937 has been labeled at different times as a luminous extreme Of star and a nucleus of a planetary nebula. HD 148937 is the brightest O star ($m_v \sim 6.71$) known to have an associated nebulosity that mimics a planetary nebula. The nebula is also fairly bright and thus is easily studied. We raise the question whether there are other similar but fainter objects masquerading as nuclei of planetary nebulae.

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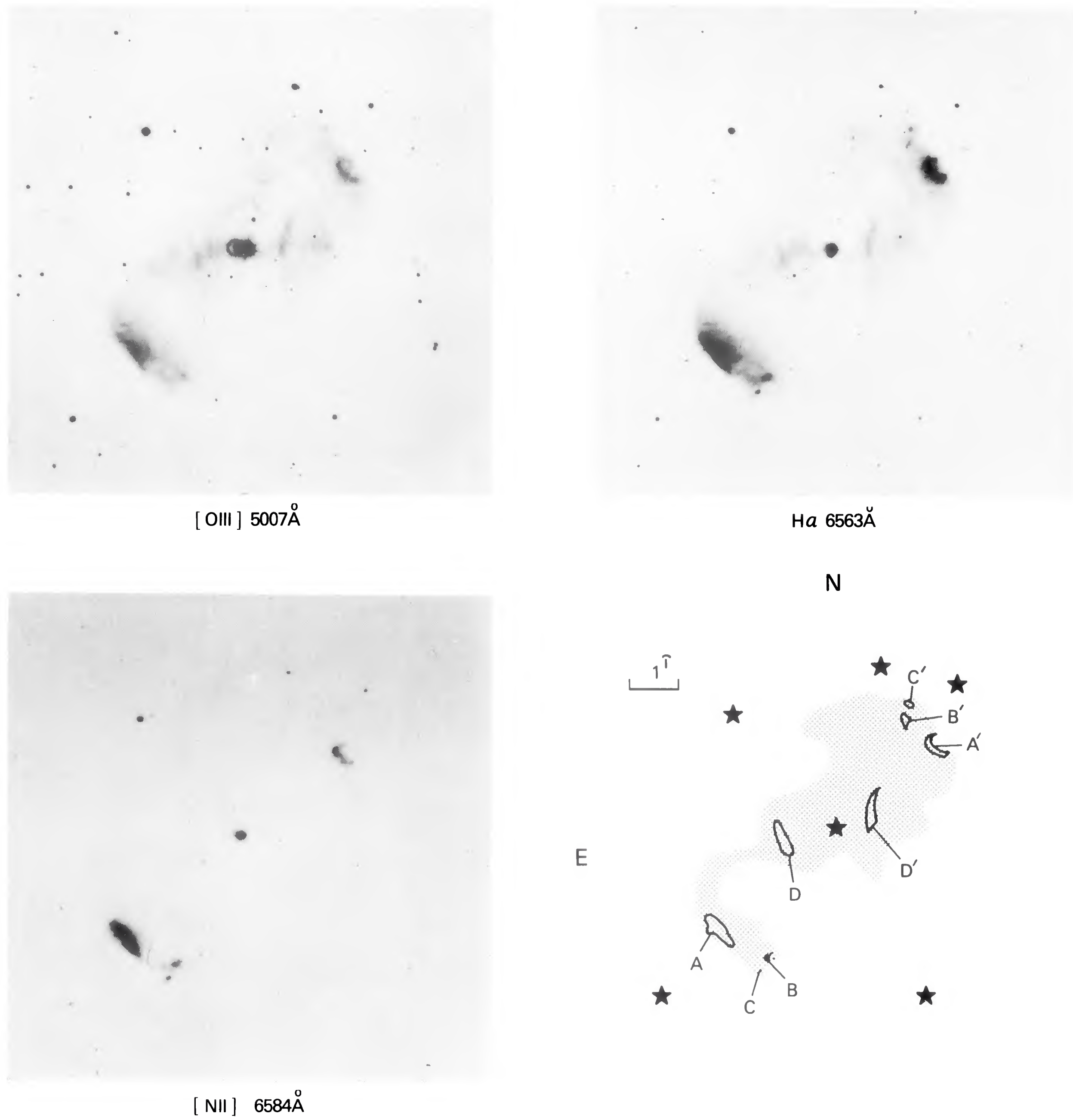

FIG. 2.—Narrow passband photographs of HD 148937 + NGC 6164–5. The [O III] 5007 Å emission (*upper left*) is diffuse and faint, extending across the figure-eight region of emission normally seen in deeply exposed broad bandpass photographs. The Hα 6563 Å structure (*upper right*) has two distinct components: a diffuse emission distributed like the [O III] emission, and pairs of bright knots diametrically distributed about HD 148937. The [N II] 6584 Å structure (*lower left*) is confined to the bright knots. This structure seems to describe high-density material surrounded by a hotter gas. Stability of such a structure should be short-lived, implying that the condensations are fairly recent ejecta. The original plates were recorded using a two-stage image intensifier mounted behind the Yale 1 m telescope located at Cerro Tololo Inter-American Observatory.

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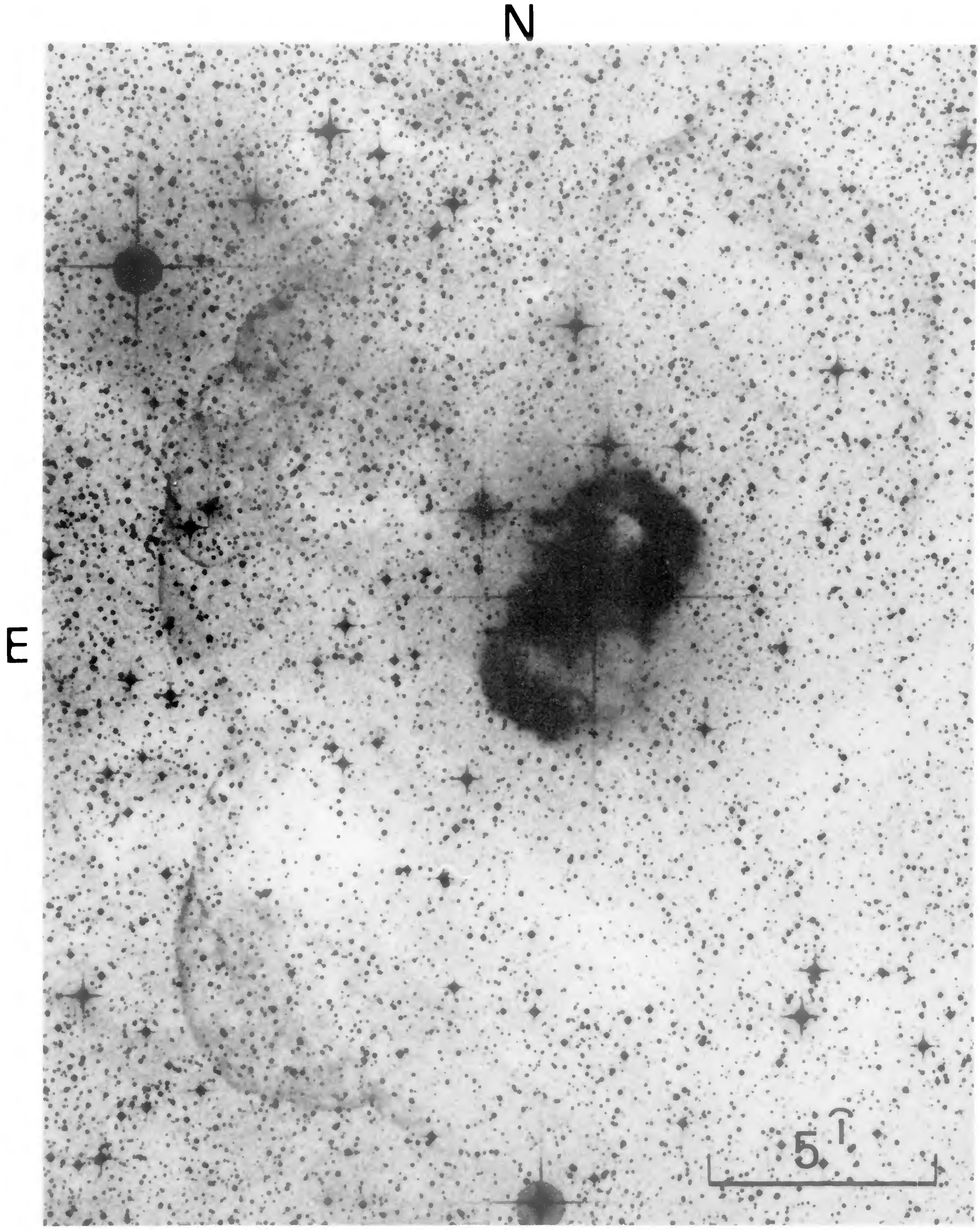

FIG. 3.—The shell nebulosity surrounding HD 148937 and NGC 6164–5. The original plate, J1486, was a 60 min exposure recorded by the UK 1.2 m Schmidt Telescope using a GG395 filter and IIIa-J emulsion ($\lambda\lambda$3950–5400). Narrow passband imagery reproduced in Fig. 4 shows these structures to be primarily [O III] emission. This shell nebulosity is interpreted to be the boundary between the interstellar bubble driven by the wind of HD 148937 and the H II region ionized by HD 148937.

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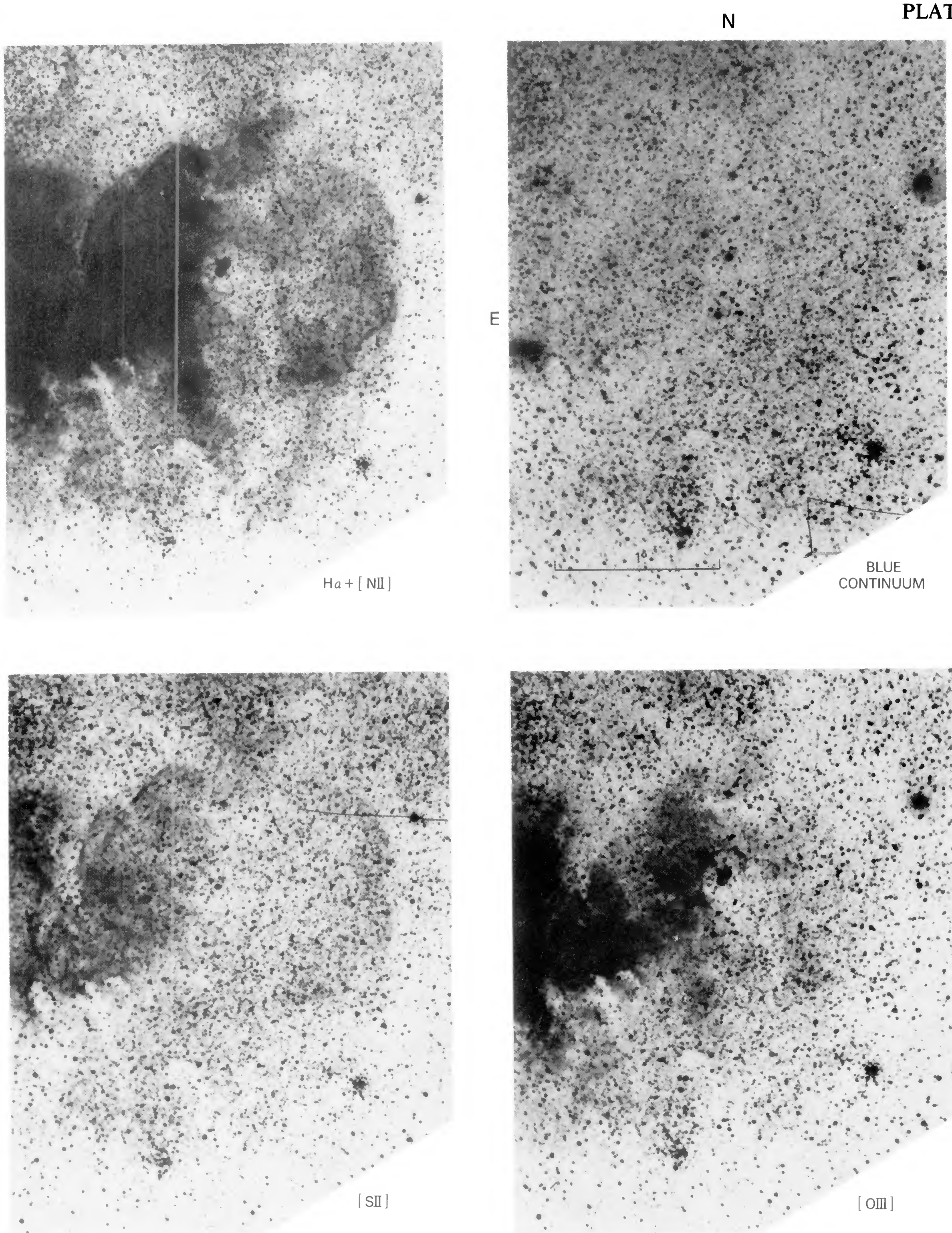

FIG. 4.—Imagery of the galactic plane in the direction of HD 148937. The ionized structures are most easily identified in the Hα + [N II] frame (*upper right*). A 2° diameter H II region surrounds HD 148937 and is presumably ionized by HD 148937. Off to the east is the cluster association NGC 6193. A dust cloud, noted in blue continuum (*upper left*), is between the nebulosity excited by NGC 6193 and the HD 148937 nebulosities. Ionization structures in Hα + [N II], [S II] (*lower right*), and [O III] (*lower left*) are consistent with the dust cloud separating such. The H II region surrounding HD 148937 has only weak, diffuse [O III] except near HD 148937. There exists an apparent hole in Hα + [N II] and [O III] plus a filamentary boundary in [O III]. These filaments are the same structures imaged with higher angular resolution in Fig. 3.

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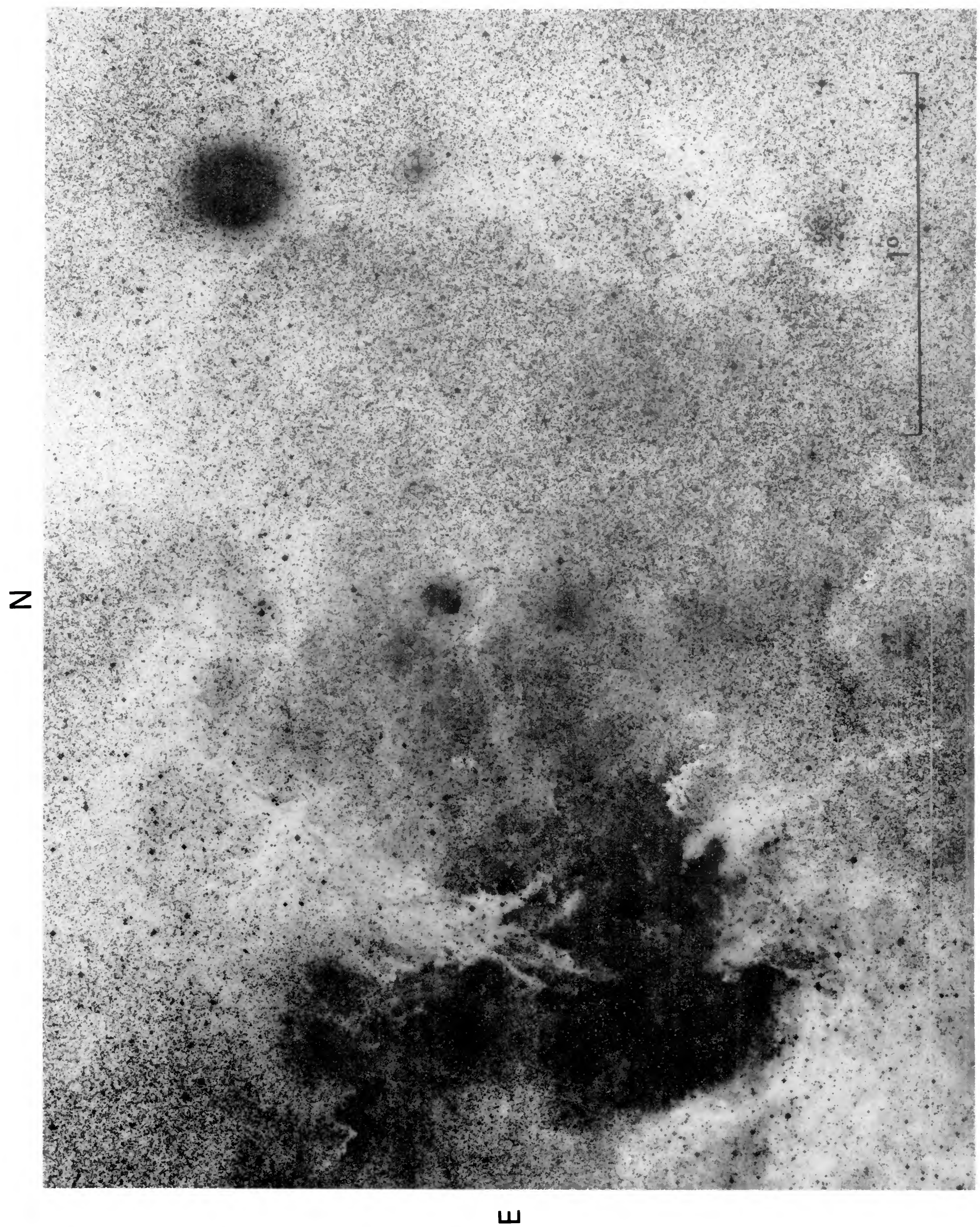

FIG. 5a.—Broad bandpass imagery of the HD 148937 region, reproduced from the UK Schmidt plate J1486, taken with a GG395 filter and IIIa-J emulsion. It is particularly good in showing the dust shell surrounding the H II region ionized by HD 148937. The thickness of this dust shell, relative to the radius of the H II region was used to estimate the evolutionary age of the H II region.

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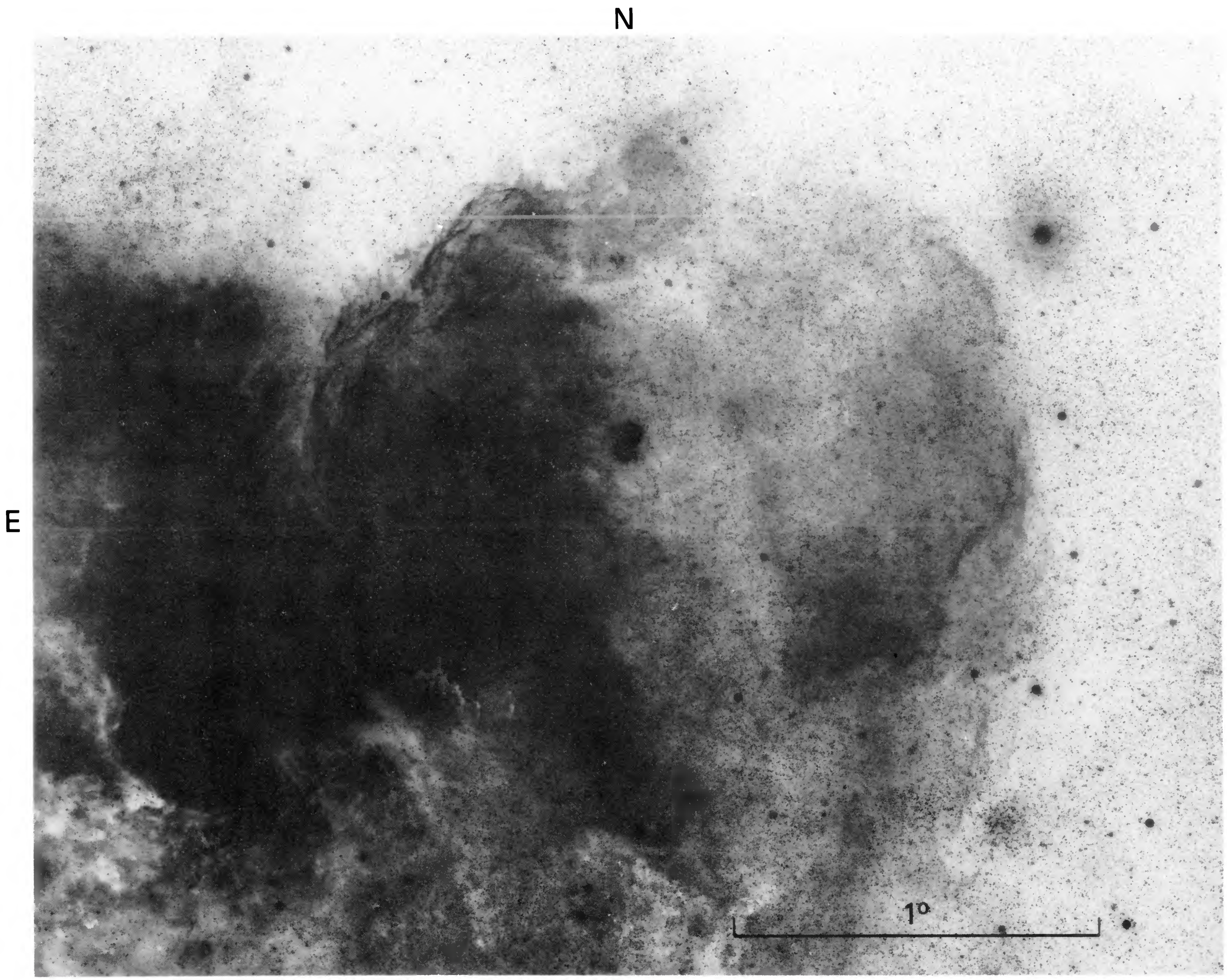

FIG. 5b.—Reproduced from UK Schmidt plate Hα 4361, a 240 min exposure taken by W. J. Zealey. It was recorded on IIIa-F emulsion with the Anglo-American Observatory's 100 Å bandpass filter. The location of the ionized gas and its boundaries related to dust are well defined here.

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