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INTERNAL MOTIONS IN H II REGIONS. XIII. THE VELOCITY FIELD OF SHARPLESS 184

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RESUMEN

La región H II S184 (NGC 281), que se supone que se encuentra en estado evolucionado, está situada en el Brazo de Perseo a una distancia de aproximadamente 2 kpc. La extensión óptica de la región de unos 5 pc, nos muestra un complejo de diferentes capas de gas y nubes alrededor de la región central. Este complejo ha sido objeto de estudios detallados anteriormente. Hace poco se detectó un maser de H_2O y de este descubrimiento sugirió que podría ser el lugar de formación de estrellas.

En este trabajo damos un extenso campo de velocidades radiales, que cubre toda la región.

ABSTRACT

The H II region S184 (NGC 281), presumed to be an evolved one, is situated in the Perseus Arm at a distance of about 2 kpc. The optical extension of the region of around 5 pc shows in projection a complex of different layers of gas and clouds around the central region. This complex has been object of detailed studies before. An H_2O maser discovered earlier has suggested that it marks the site of star-formation.

In this paper we give an extensive radial-velocity field covering the region.

Key words: RADIAL VELOCITIES – H II REGIONS

I. INTRODUCTION

S184 (NGC 281; l = 123.1; b = –6.3), has an almost circular form in radio continuum (Davis 1967; Caswell 1968; Israel 1977), but optically the south-west corner is cut off by heavy obscuration. In Figure 1 (Plate) an enlargement of the region from the Palomar Sky Survey print in the blue is given. The nebula at a distance of about 2.0 kpc is ionized by a trapezium-like cluster of O stars, ADS 719 (Ambartsumian 1954; Sharpless 1954; Allen, Poveda, and Worley 1974) dominated by HD 5005 A, a type O6.5((7)) star, and HD5005 C, of type O8V(n); the latter is classified by Walborn (1973). The kinematic distance of about 2 kpc is slightly larger than the photometric distance of the exciting star (Georgelin, Georgelin, and Roux 1973). We note that this is to be expected since previous investigations have shown that in the Perseus Arm, to which S184 belongs, there is a systematic tendency for the kinematic distances to be larger than the stellar photometric ones (see for example Pişmiş and Hasse 1982). The cluster is situated almost at the center of the nebula, slightly north of the obscuration zone.

Velocity-measurements of S184 have been carried out by Courtès, Cruvellier, and Georgelin (1966), Miller (1968), and Williamson (1970). Riegel (1967) detected a cloud of atomic hydrogen of about 1°, associated with the nebula and with a mass of 16000 $M_\odot$, but more extended than the optical region, especially to the south; later, Roger and Pedlar (1981) scanned a field of 2° around S184 both, in the continuum and in H I at λ21 cm.

CO observations were made by Wilson *et al.* (1974), Israel (1980), Elmegreen and Lada (1978). The latter reported the detection of two fragments of a CO cloud in front of the nebula, apparently separated by a channel of ionized gas. The larger of the two clouds lies east of the nebula and the smaller one directly in front of the south-west corner, nearly coincident with the obscuration bay. These authors and Elmegreen and Moran (1979) discovered and investigated at the same time the only H_2O maser zone of the region, situated between the western cloud and the nebula, at a linear distance in the range of 3 - 9 pc from it. It is not clear what the origin of the water maser may be.

The 21-cm radio map of Israel (1977) shows two emission peaks, *A* and *B*. *A* coincides almost with the H_2O maser position, while *B* lies between the two cloud fragments, mentioned earlier. Israel detected a low surface brightness, especially in the obscured region and rather low r.m.s. electron density (Ne $\sim$ 50 cm^{-3}). The total flux density observed is 6.2 f.u. and the excitation parameter, 39 pc cm^{-2}. Apart from the two radio peaks Israel did not find much small-scale structure over the nebula.

The most recent and detailed studies on the S184 complex have been done by Roger and Pedlar (1981) and Johnson, White, and Pedlar (1981). Both teams investigated the association of H II with H I and [N II],

TABLE 1

THE OBSERVATIONAL MATERIAL

Interf.	Coordinates (1980) α	δ	Telesc. (cm)	Obs.[1]	V_{LSR} (km s^{-1})	Standard Deviation (km s^{-1})	n	Exposure time (min)	Hα Filter	Date of observation
FI 557	0^{h}51^{m}27^{s}5	+ 56°27′	100	TON	− 29.05	± 6.04	64	20	Hα	23.I.1979
SN 150	0 51 53	+ 56 16.3	84	TON	− 28.57	± 3.1	71	20	Hα	14.XII.1980
SN 151	0 51 33.7	+ 56 39	84	TON	− 30.16	± 4.5	42	22	Hα	14.XII.1980
SN 158	0 51 9.6	+ 56 26.3	84	TON	− 30.35	± 3.07	37	15	Hα	15.XII.1980
SN 159	0·51 48	+ 56 29.4	84	TON	− 30.40	± 3.85	66	15	Hα	15.XII.1980
FI 822	0 51 39	+ 56 29.7	210	SPM	− 27.96	± 5.82	73	10	Hα	30.VIII.1981
FI 824	0 51 52	+ 56 30	210	SPM	− 28.72	± 6.8	54	12	[N II]	30.VIII.1981

1. TON = Tonantzintla, SPM = San Pedro Mártir.
2. $V_{LSR} = V_{Hel} + 6$ km s^{-1}.

CO and H_2; Johnson *et al.* found a splitting of the [N II] line of up to 19 km s^{-1}. We will return to this point later.

II. THE OBSERVATIONS

The observational material on NGC 281 discussed in this paper consists entirely of Fabry-Pérot interferograms, taken with a focal reducer and a one-stage Varo image intensifier. In the observation two étalons were used both of them having a "finesse" of about 10. The étalons have a free spectral range of 283 km s^{-1} (for the FI plates) and 190 km s^{-1} (for the SN plates).

The calibration is done by a hydrogen lamp attached to the focal reducer. The exposures are made on 103 a G films. Further details of the interferograms are given in Table 1:

Colum 1 gives the plate designation. Columns 2 and 3, the equatorial coordinates of the plate center. Column 4 indicates the telescope used and column 5 the observatory where the interferograms have been taken. In columns 6, 7 and 8 we give the LSR radial velocity with its standard deviation and the number of measured points, respectively. The next column (9) gives the exposure time and the two last ones the filter used and the observation dates. All filters have halfwidths of 10 Å.

The FI interferograms were measured by Pişmiş on the Mann Comparator at the Johnson Space Center, NASA, and the SN interferograms were measured by Rosado, at the Observatory of Marseille, using the vibrating mirror comparator. The reductions are carried out following the scheme of Courtès (1960); for further details about the reductions of the SN interferograms we refer to Rosado *et al.* (1982). The estimated errors of the velocities are about 1 to 2 km s^{-1}.

III. THE VELOCITY FIELD

A total of 407 velocity points were obtained on the overall region from the combined data of Pişmiş and Rosado; the average velocity over all these yielded −29 ± 5.6 km s^{-1} in good agreement with other authors. (Table 2). Using the Schmidt rotation curve we found a distance of 2.1 kpc. Figure 2 (Plate) shows two direct images of the inner part of S184, obtained through Hα and [N II] filters, respectively.

TABLE 2

PREVIOUS OBSERVATIONS

Feature	V_{LSR} (km s^{-1})	References
Hα	− 27.7; − 29.6	1,3
	− 31.2; − 26.7	4,5
	− 27.7; − 29.2	6,12
HI	− 30; − 30	2,11
CO	− 30; − 31; − 30.5	7,8,9
H_2O	− 31.3; − 32.9	7,8
[N II]	− 26 and − 7	10,12
	− 28.7	12

1) Courtès *et al.* 1966 2) Riegel 1967 3) Cruvellier 1967 4) Miller 1968 5) Williamson 1970 6) Georgelin and Georgelin 1970 7) Elmegreen and Lada 1978 8) Elmegreen and Moran 1979 9) Israel 1980 10) Johnson *et al.* 1981 11) Roger and Pedlar 1981 12) this paper.

The two dark spots at the north-east and the ionization front, extending in the east-west direction, are visible in both figures, however, with the [N II]-filter more details, bright rims (Pottasch 1956) and a great many stellar images can be seen.

The points measured and reduced by Rosado spread out over all of the region (Figure 3), while the velocity-points measured by Pişmiş and reduced by the writer, are largely in the center and in the southern part (Fig-

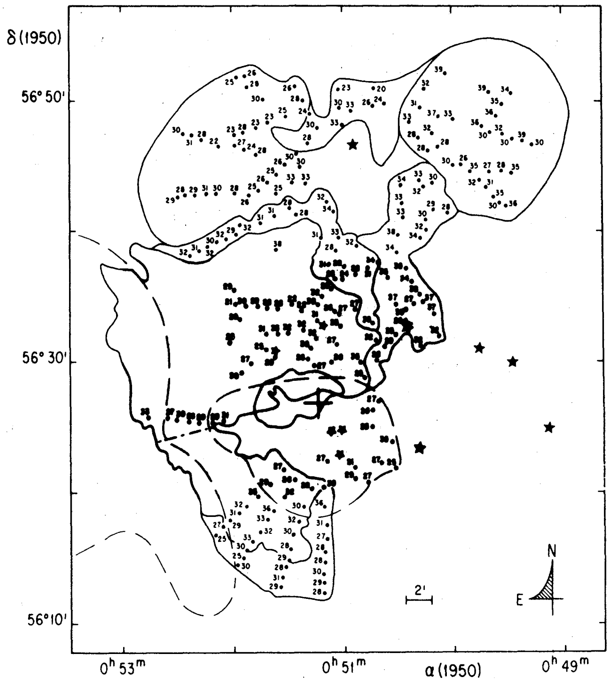

Fig. 3 Individual velocity-points, measured by M. Rosado, covering the overall region. The square outlined in the center represents the area enlarged in Figure 4. In Figures 3, 4 and 5: The CO cloud fragments (Elmegreen and Lada 1978) are marked by dashed lines and the H_2O maser by a cross. All velocities should be taken with a negative sign.

ure 4). The high inhomogeneity of these latter regions is manifested by the large standard deviation (Table 1).

We divided the overall region into subgroups, taking into account the morphological details, and to a certain extent the velocity structure. The scheme of the subdivisions is given in Fig. 5, where the overall motion of the different subgroups is manifested, with the average velocities inscribed in each sub-region.

The north-west regions (F and G) show a relative approach, a result that confirms earlier ones (Williamson 1970; Israel 1980). The southern border is also blueshifted. We call attention particularly to some emission "clouds", visible within the absorption zone (Fig. 5 and Fig. 6 Plate).

It seems that the inner part of S184 in general is receding with respect to the rest; we can describe the projected picture in the following way: around the O star cluster and the surrounding gas, which are moving together at a velocity of -26 ± 4.3 km s^{-1} there is a second zone, encircling the central region with a slightly approaching velocity of around -29.8 ± 4.7 km s^{-1}. Already Riegel (1967) found a similar tendency, a "dip" at the optical center of the nebula. Elmegreen and Lada (1978) measured a relative redshift of about 5.9 km s^{-1} around the cluster. Regions marked by M, D, E, which seem to lie along a half-ring, surrounding the strongest emission zone mentioned above yield a mean velocity of -30.6 ± 4.5 km s^{-1}. It should be emphasized that the differences of the mean values of the velocity

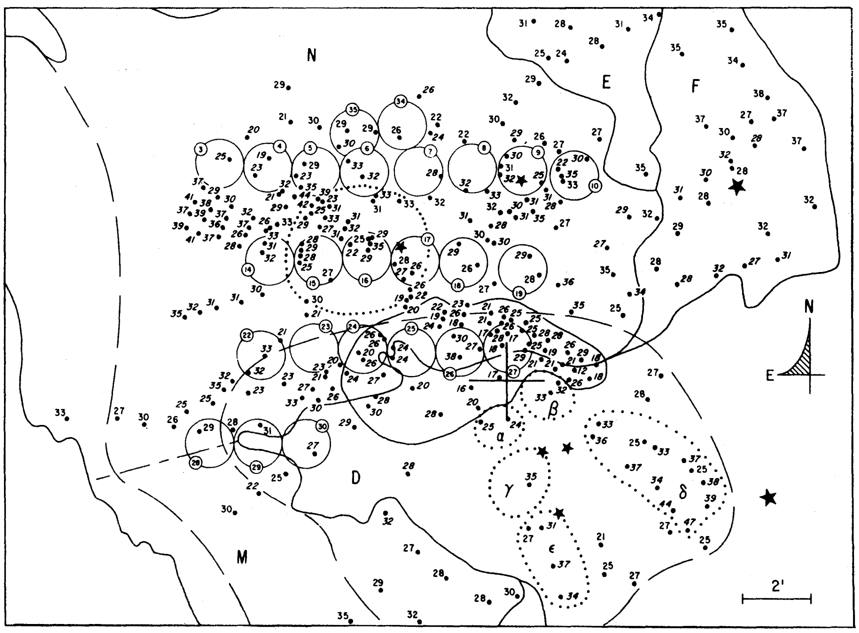

Fig. 4. LSR velocities treated by Pişmiş and Hasse, and plotted on the enlargement of the square indicated in Figure 3. The approximate positions of Johnson's velocity-points are marked by circles in order to compare them with our velocities. All velocities should be taken with a negative sign.

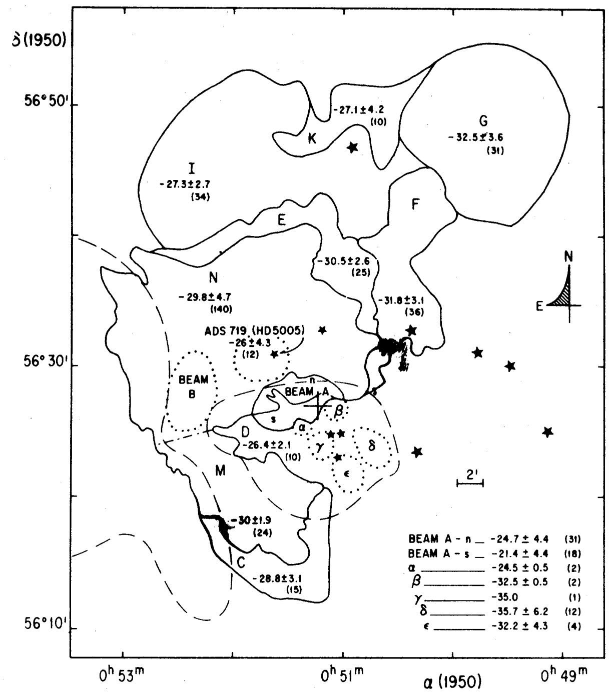

Fig. 5. A sketch of the subregions of S184, drawn following the optical structure (see Figure 1) and labeled with letters. The dotted lines encircle the following regions (from north to south): the O star cluster, ADS 719 with the surrounding gas; beam B of Israel (1977), situated between the two CO cloud fragments; and the emission "clouds", marked by α, β, γ, δ, ϵ, visible on the obscured region in the south. Beam A of Israel (at center) is divided into two zones marked by n and s, (north and south), following the outline of the ionization front. Average LSR velocities as well as standard deviation and the number of velocity points are inscribed within almost each subregion.

groups may not be too significant, since these differences lie within the standard deviation of the mean of each group.

We did not include here beam A (Israel 1977) as we shall treat it later. The blueshifted groups (F, G) with velocity around -32.1 ± 3.3 km s^{-1} located almost outside of strongest optical emission, seem to lie in front of group I, K, which represent more redshifted velocities (-27 ± 3.1 km s^{-1}). The PSS red print shows here an extension of optically visible emission in form of two horns.

IV. DISCUSSION

In the past few years different models have been proposed to explain the observational findings on the S184 complex. It is suggested that it is a typical case of an H II region, colliding with a molecular cloud, which contains an H_2O maser, comparable with the W3 complex (Goudis 1980; Johnson *et al.* 1981). But in the latter case the complete picture of evolution appears to be spread out along the plane of the sky, while in the case of S184 the different constituents are presumably projected along the line of sight. On the other hand S184 is a much smaller region than the W3 complex.

Elmegreen and Lada (1978) give a projected distance between the nebula and the molecular cloud of about 3 pc, and a real distance of at most three times larger. Starting from this assumption they deduce a maximum age of 2×10^6 years for the nebula, a result that is in good agreement with earlier estimates of the dynamical age of the cluster, ADS 719 (Mirzoyan and Mnatsakanyan 1975).

Johnson *et al.* (1981) suggested that the extended H I shell observed to expand with velocity of around 4 km s^{-1} encloses an also expanding, wind-driven inner shell of H II, radiatively ionized at its inner surface by HD5005 and its companios (ADS 719). Their conclusions are based on a splitting of the [N II] 6584 Å line. They obtained emission line profiles at 35 points in a systematic scanning over the optical region. Almost at every position they found a splitting, obtaining thus two different velocity-groups of average velocities of -22.9 km s^{-1} and -6.8 km s^{-1} respectively (see Table 3).

Johnson *et al.* interpreted these results as an expansion of the inner shell of H II around the exciting star cluster: one velocity group representing the far-off surface, going away from us, and the other approaching us. Unfortunately we could not detect any line-splitting in our data. Comparing our velocity-points whenever possible with those of Johnson *et al.*, and particularly around the 35 positions, we found our results more negative by 4.1 km s^{-1} (-27 ± 4.4 km s^{-1}) than the mean value of his blueshifted velocities (-22.9 ± 3.9 km s^{-1}), all corrected to the local standard of rest. Our velocities around the maser position are systematically redshifted. Their average is around -23 km s^{-1}, but we integrated them for comparison with beam *A*, one of the two regions singled out by Israel (1977), where he found high surface brightness. It will not be possible to do the same comparison for peak *B* as we have too few points, which cover only an insignificant part of *B*. Taking strictly the coordinates of beam *A* given by Israel we found a mean velocity of -23.7 km s^{-1}. Including all our points in the neighborhood, the average remains almost the same, namely -23.5 ± 4.7 (49 points). We have also divided region A into northern and southern portions, following the ionization front that passes almost through the center of A. We found in the northern, bright emitting part a velocity of -24.7 ± 4.4 km s^{-1} (31 points) while in the obscured region, south of it, we measured -21.4 ± 4.4 km s^{-1} (18 points; see Figure 5). In contrast, Elmegreen and Lada (1978) find a more negative velocity (-31.03 km s^{-1}) of the H_2O maser itself.

In our [N II] filter photographs, where the structure of the optical region is better defined, we found that the dark spots seem to approach us, while the brighter part, specially in the center around the exciting cluster, recedes relative to the rest, a fact we mentioned earlier.

TABLE 3

COMPARISON OF VELOCITIES

Position	V_{LSR} (km s^{-1}) Johnson *et al.* splitting		This paper No splitting	No
1	– 26	...	...	...
2	–29	–17	...	...
3	– 23	...	– 25	1
4	– 20	+ 1	– 21±2	2
5	– 25	– 8	– 29±4.9	3
6	– 27	– 1	– 32.5±.5	2
7	– 31	–10	– 25.5±2.5	2
8	– 25	– 10	– 32	1
9	– 22	...	– 29.5±2.7	4
10	– 31	– 10	– 30±4.9	4
11	– 18	...	...	...
12	– 23	– 4	...	...
13	–25	– 9	...	...
14	– 23	–8	– 1.5±1	2
15	– 26	–11	–27.1±7	5
16	–24	–7	– 28±4.7	5
17	– 26	– 11	– 27±.8	3
18	– 16	– 2	– 27.5±15	2
19	–24	–8	– 28.5±.7	2
20	– 29	– 12	...	...
21	–24	–5	...	...
22	– 27	– 14	– 32±64	3
23	– 26	– 9	...	...
24	– 15	...	– 24.5±2.6	4
25	–20	...	–24±0	2
26	– 18	...	–31.6±4.6	3
27	– 18	...	– 22.7±4.8	7
28	– 24	– 6	–29	1
29	– 21	– 4	– 31	1
30	– 19	– 4	– 27	1
31	– 19	...	...	...
32	– 19	...	...	...
33	– 19	...	...	...
34	– 21	+ 2	– 26	1
35	– 20	+ 2	– 263±3,1	3

In 1978 Elmegreen and Lada proposed that the maser zone, very near to the ionization-front, seems to progress into the backside of the molecular cloud. Probably this is another case, where in well evolved H II regions, stimulated by certain physical processes dense conglomerations give rise to new star-formation. In fact, Elmegreen and Moran (1979) suggest that the maser source associated with this region should be a B-star formed in the shock-compressed gas.

Considering our results and the overall situation, the model Johnson *et al.* (1981) proposed, seems to fit the observational picture satisfactorily.

I wish to thank P. Pişmiş and M. Rosado for proposing the study of S184 and for providing me with the observational data on which this paper is based. Their help and encouragement is particularly appreciated.

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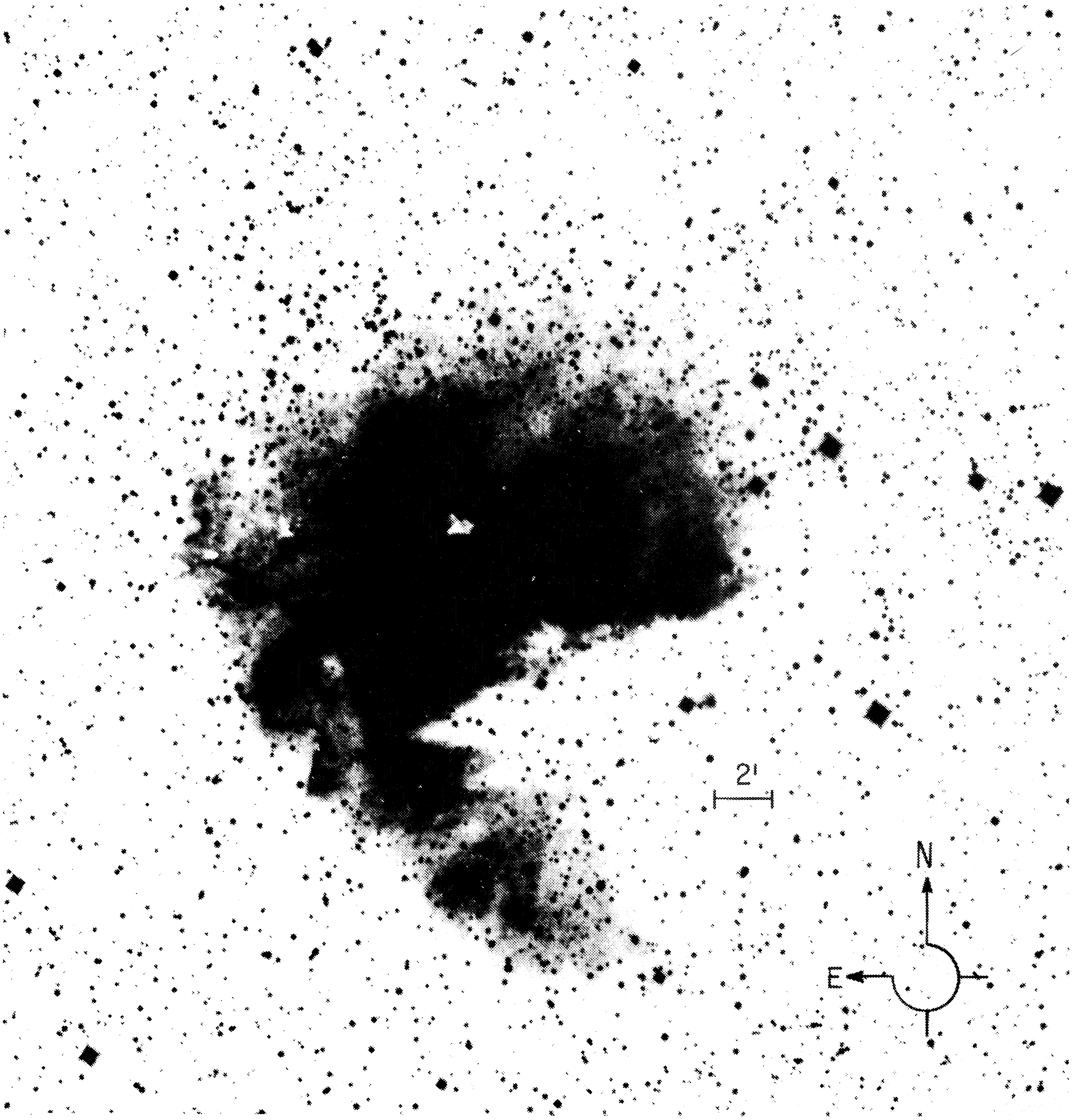

Fig. 1. Enlargement of the optical region from Palomar Sky Survey Print in the blue.

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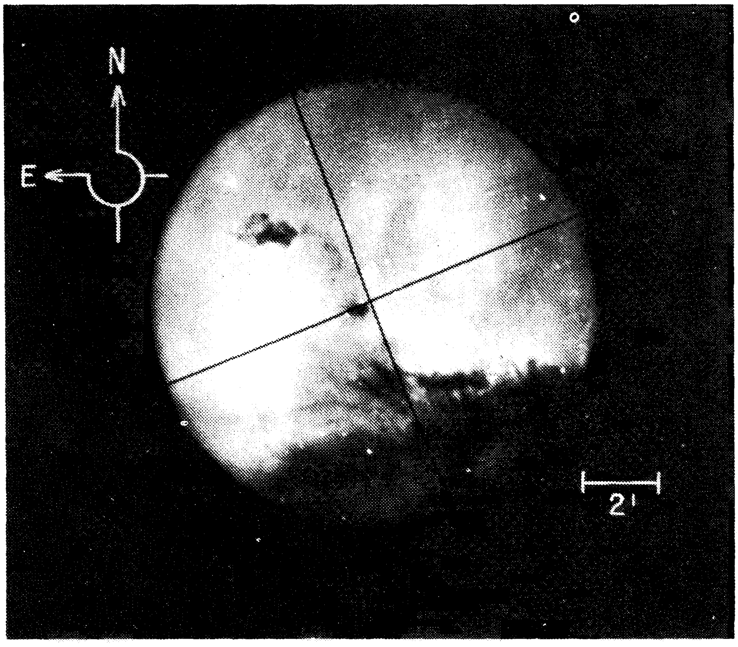

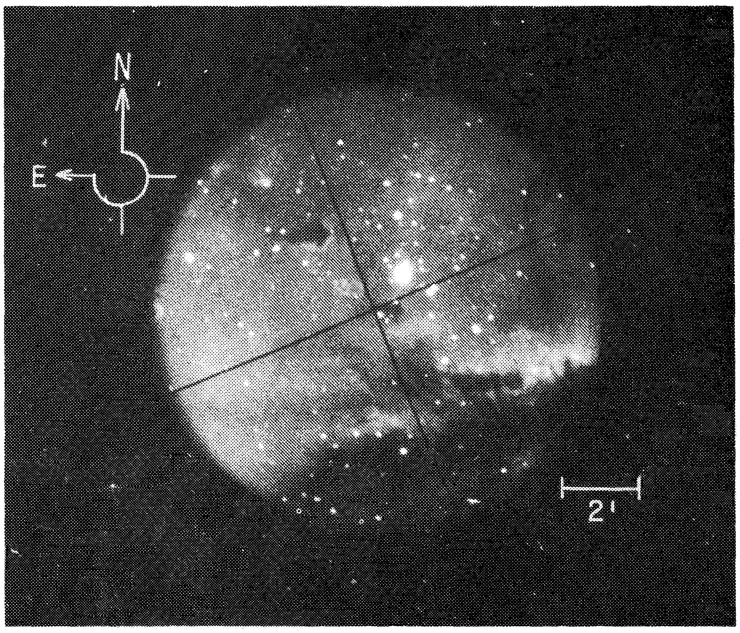

Fig. 2. Two direct photographs of the inner part of S184 with Hα and [N II] filters respectively. Taken with a focal reducer attached to the 2.1-meter reflector of the Observatory at San Pedro Mártir.

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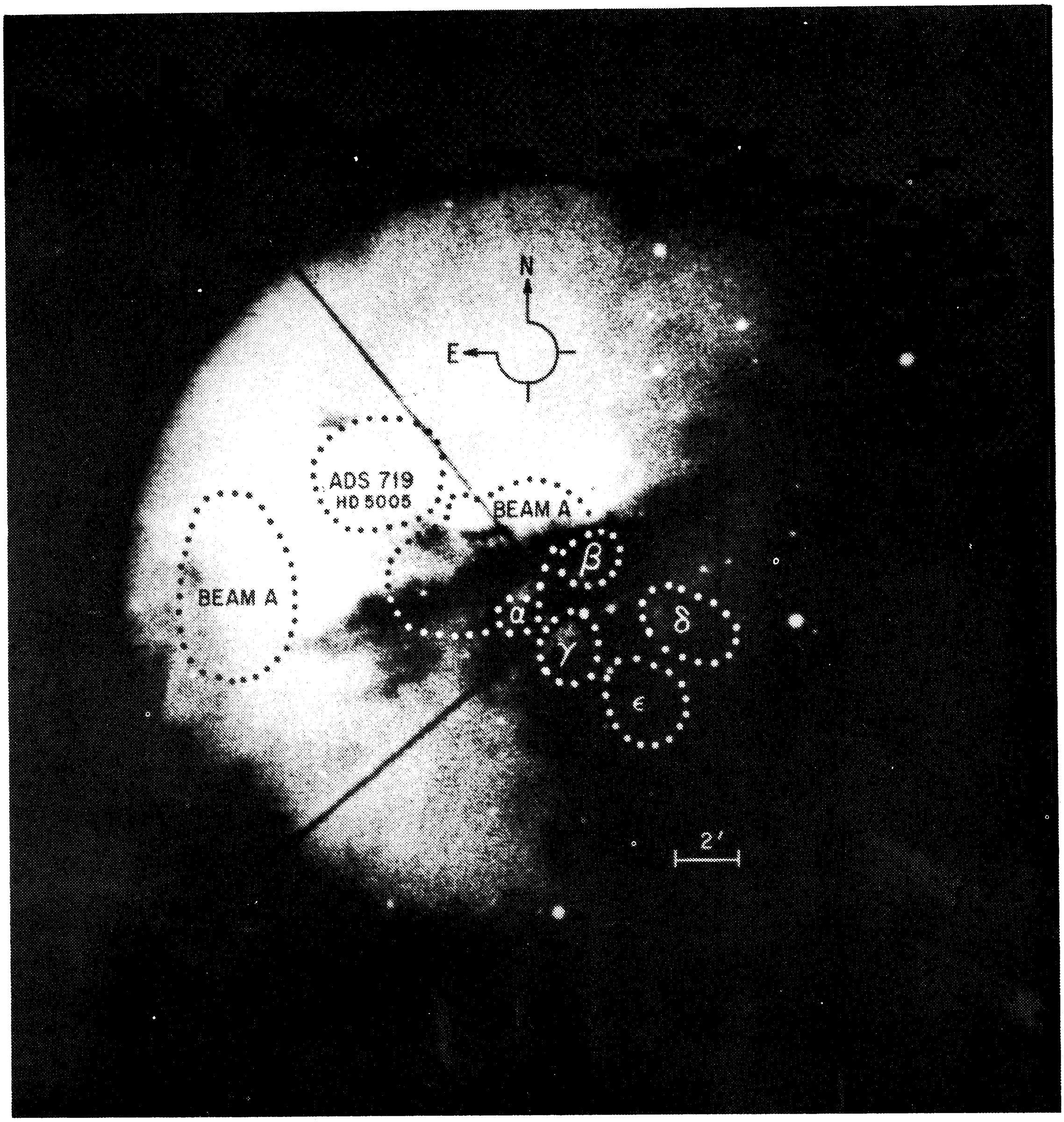

Fig. 6. A separate presentation of the center of S184. Beam A and B of Israel, the optical "dip" around ADS 719, and the faint emission "clouds" in the south are outlined with dotted circles.

I. HASSE (See page 83)