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INTERNAL MOTIONS IN H II REGIONS. III
THE NEBULAR COMPLEX NGC 2467

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RESUMEN

Se ha determinado la velocidad radial en 625 puntos del complejo H II NGC 2467 en la constelación de Puppis con un equipo Fabry-Pérot fotográfico. La región estudiada cubre alrededor de 400 minutos de arco cuadrado. Dos cúmulos galácticos, H 19 y H 18ab, están asociados con el complejo H II. Una distancia cinemática de 4.2 kpc se ha obtenido usando el promedio de las velocidades de Hα. Esta distancia es exactamente el valor dado por Havlén para la asociación Pup OB2 en la dirección de NGC 2467.

Se concluye por lo tanto que el complejo nebular NGC 2467 está dentro de la asociación Pup OB2, la cual delinea un brazo espiral. Se han detectado velocidades relativas entre las diferentes secciones de la nebulosa que llegan a tener en la dirección radial, valores hasta de 10 km s^{-1}. Hay indicación de que el gas circundante a la estrella O6, HD 64315, la cual es la fuente de la excitación de la parte más densa de la región H II, está en expansión. Asimismo se ha detectado una expansión en el nudo H II compacto que envuelve una estrella B1 V del cúmulo H 18ab. El complejo en su totalidad es un objeto joven con una edad alrededor de $2 - 3 \times 10^6$ años.

ABSTRACT

Radial velocities from the Hα line using a photographic Fabry-Pérot equipment are obtained at 625 points of the H II complex NGC 2467, in the constellation of Puppis. The region studied covers around 400 sq. arcminutes. Two galactic clusters, H 19 and H 18ab, are associated with the H II complex. A kinematic distance of 4.2 kpc is derived using the mean of the Hα velocities. This distance is exactly the value given by Havlén for the Pup OB2 association which delineates a spiral feature. Relative velocities are detected between the different sections of the nebula, up to 10 km s^{-1} in the radial direction. There is indication that the gas surrounding the O6 star HD 64315, the main source of excitation of the densest part of the H II region, is expanding. An expansion is also detected of the compact H II knot surrounding the star B1 V in the cluster H 18ab. The whole complex is a young object with age around $2 - 3 \times 10^6$ years.

Key words: H II REGIONS — INTERFEROMETRY — RADIAL VELOCITIES.

I. INTRODUCTION

NGC 2467 (1950 $\alpha = 7^h50.^m5$ $\delta = -26°15'$) is a conspicuous H II region in the constellation of Puppis. It is described in the New General Catalogue as "pretty bright, very large, round, easily resolvable, an 8th magnitude star in the middle". There is no mention of a star cluster within it. However Alter *et al.* (1958) include NGC 2467 in their catalogue of star clusters. To the best of our knowledge the existence of a cluster within this H II region is considered doubtful (Havlén 1972). Two stellar groups Haffner 19 and 18ab fall in the region of NGC 2467 at large and are shown by FitzGerald and

Moffat (1974) to be star clusters. It is the whole emission complex including the two open clusters which is often loosely referred to as NGC 2467.

II. DESCRIPTION OF THE REGION

Figure 1 (Plate 76) is an enlargement of a red plate (exposure 27 min) taken with the Tonantzintla Schmidt telescope (on 103aE emulsion through a Wratten 29 filter). The two clusters mentioned above are marked on it. The main source of excitation of the densest part of the nebula is HD 64315, also marked on the figure, of spectral type O6n, V = 9.24, B-V = +0.25, U-B = −0.73 (Lodén 1966). In Figure 2 (Plate 77) we give an enlargement of an Hα plate with a focal reducer attached to the 1-meter reflector of the University of Mexico installed at Tonantzintla. The Strömgren sphere around H 19 is well defined. Involved in nebulosity is also H 18ab. To show the total extent of the nebular complex we give in Figure 3 (Plate 78) a reproduction of a red print from the Palomar Sky Survey. The largest dimension of the H II region is around 32 arc minutes.

III. OBSERVATIONAL MATERIAL

The H II complex NGC 2467 appeared to us sufficiently interesting to include it in our program on the internal motions in galactic nebulae. Six interferograms were obtained, covering most of the brighter parts of the complex, with the Fabry-Pérot equipment attached to the 1-meter reflector at Tonantzintla. The étalon used has a central interference order of 1060, finesse around 10, and a free spectral range of 283 km s^{-1} at Hα. An interference filter of 10 Å halfwidth isolates the Hα line.

The interferograms were obtained on Kodak Special 098-01 plates. Calibration for Hα at rest was obtained by photographing on the same plate, before and after the field exposure, the light of a hydrogen lamp diffused by a screen. The list of the interferograms is given in Table 1. The number of the plate and the equatorial coordinates (1970) of the field center are given in the first three columns while columns four and five list the exposure lengths and the date of observation. The last column gives the number of points measured on each interferogram. To serve as a sample for our observational material, we reproduce in Figure 4 (Plate 79) an enlargement of F 42. The remaining interferograms listed in Table 1 are of a quality comparable to that of F 42.

The measurement of the interferograms was carried out on the Mann comparator of the Applied Physics Branch of the NASA Johnson Space Center. The procedure for measuring and reducing the material is that given by Courtès (1960).

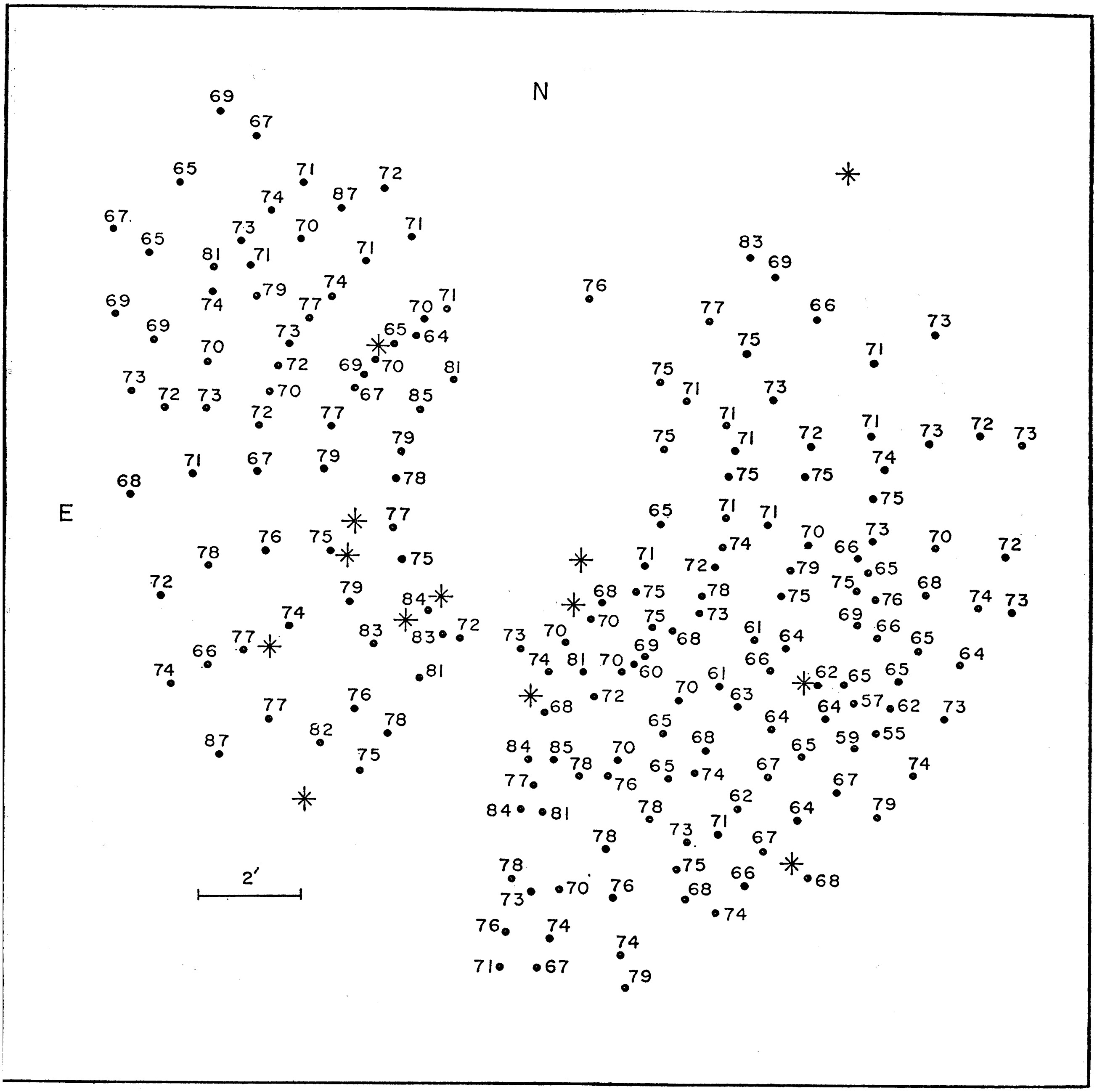
IV. PRESENTATION OF THE RADIAL VELOCITY DATA

Radial velocities from the Hα at 625 points were obtained from the six interferograms. We do not present the velocities of individual points from each interferogram separately. Instead, the data are combined over small regions common to three interferograms at a time. Average velocities of such regions are displayed in Figure 5 for F 42, F 45 and F 53. All velocities are referred to the Sun.

TABLE 1

Observational Material
Fabry-Pérot Interferograms of NGC 2467

Plate Number	α(1970)	δ(1970)	Length of exposure	Date	Points measured
F 38	$7^h52^m13^s$	−26°22′	45 min	January 29, 1973	74
F 42	7 52 34	−26 18	90	February 2, 1973	250
F 45	7 52 33	−26 17	60	February 3, 1973	132
F 53	7 52 26	−26 19	120	March 1, 1973	61
F 56	7 51 56	−26 18	90	March 4, 1973	56
F 57	7 52 11	−26 25	45	March 4, 1973	52



'IG. 5. Display of radial velocities averaged over small regions from interferograms F 42, 45 and 58.

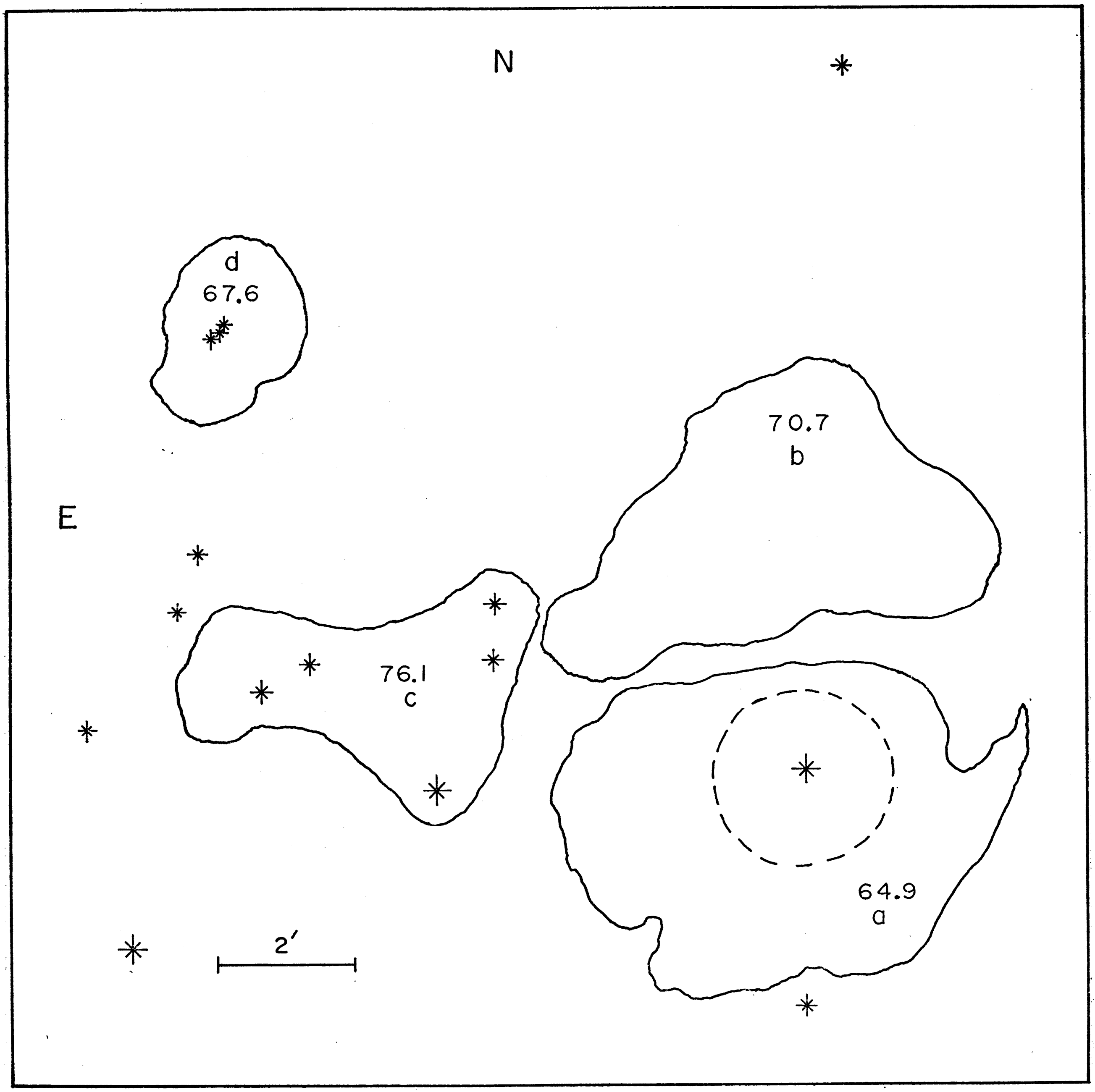


FIG. 6. Scheme for the division of the H II complex into sub-regions. The numbers within the sub-region are the mean velocities of the points measured on interferograms F 42 and F 45 which include the largest number of the points falling within the sub-regions.

TABLE 2

Mean Radial Velocities of Subregions

Region	*a*	*b*	*c*	*d*	*e*
Mean radial velocity km s^{-1}	64.9	70.7	76.1	67.6	73.5
Standard deviation km s^{-1}	± 9.6	± 5.3	± 6.4	± 7.6	± 7.6

The overall morphology of the H II complex suggested to us that the velocity structure could best be studied by subdividing the complex into regions such as *a*, *b*, *c* and *d* as shown in Figure 6 by full lines. In that figure we also indicate the mean velocity of each region. These mean velocities are listed in Table 2 together with their standard deviations. An "*e*" stands for the general background outside the marked areas.

V. DISCUSSION OF THE VELOCITY FIELD

The mean velocity over all measured points is 73.0 ± 6.3 km s^{-1} (625 points). This we adopt as the velocity of the NGC 2467 complex. Region *a*, the densent area where HD 64315 is located, has the lowest velocity. With respect to the standard of rest defined by the whole complex it is approaching us with a radial velocity of 8 km s^{-1}, whereas region *c* is receding at the rate of 3 km s^{-1}, to mention only the extremal values. The appearance of the nebular complex on direct photographs particularly that in Figure 2 makes the assumption quite plausible that the different parts of the H II complex are spatially related and that the differences in radial motion are not differential rotation effects; rather they are peculiar motions of the clouds that constitute the complex.

The standard deviations around the mean radial velocities are quite large; these are in the range $5 - 10$ km s^{-1}. A substantial amount of the standard deviation should arise from the circumstance that the interference rings, of which the point of maximum intensity is measured, is the convolution, of the fringe profile and the image in Hα of the region. If the intensity distribution of the nebula presents inhomogeneities, particularly on a scale small compared to the instrumental profile, the standard deviation of the mean is expected to be large. The observed standard deviation is thus a combination of this "instrumental" effect and the physical effect —random mass motions and thermal motions— within the nebula.

It is interesting to note that the relative velocities of approach in *a* are highest around the exciting star. If the region is optically thick —a very likely situation— this could be interpreted as an expansion of the gas surrounding the star. Within the region *a* we have encircled by dashed lines the vicinity of the exciting star; the mean radial velocity of this region is 62.1 ± 4.7 km s^{-1} while outside it —again within region *a*— the mean velocity is 66.7 ± 8.2. The mean velocity of approach of the gas around HD 64315 is thus 4.6 ± 9.4 km s^{-1} which is not significantly different from zero. However, accepting this difference at face value, for isotropic expansion the velocity will be of the order of 9 km s^{-1}.

Georgelin and Georgelin (1970) derive 64.4 km $s^{-1} \pm 9.5$ (standard deviation) for the velocity of NGC 2467. Their value is based on one interferogram (22 points) and it is likely that they observed the brightest region only; if so our values are in excellent agreement with the Georgelins'.

On the interferogram F 42 a branching of the innermost interference ring was observed (marked by an arrow in Figure 4). The velocity of the branch pertaining to region "*b*" is by 45 km s^{-1} larger than that of region "*a*". Most of this difference is evidently spurious and is caused by the convolution of the fringe with the discontinuity between regions *b* and *a* seen in the direct plates. The real difference, though in the same sense, should be much smaller and close to the difference of the average velocities —region *b* minus region *a*— which is $\simeq 5$ km s^{-1}.

VI. THE DISTANCE TO THE H II COMPLEX

Kinematic: as mentioned earlier we adopt the overall average 73.5 km s^{-1}, as the radial motion of the NGC 2467 complex. The component of solar motion in this direction is in 18.4 km s^{-1} (adopting a solar motion of 20 km s^{-1} towards $\alpha = 18^h$ and $\delta = +28°$); the velocity of the H II complex referred to the LSR is thus 55.7 km s^{-1}. This value and the Schmidt rotation curve yield a kinematic distance of 4.2 kpc. Georgelin and Georgelin (1970) obtain a kinematic distance of 3.83 kpc which is smaller than ours since the velocity they use is too small by 8.6 km s^{-1}.

Stellar: Information on the physical properties of HD 64315, the source of excitation of NGC 2467 proper, is scanty. Crampton (1972) from the velocity variation from 4 spectra suspects the star to be a binary. The radial velocities range from +10 to +61 km s^{-1}. If the star is indeed a binary the determination of a velocity curve is necessary in order to obtain a reliable value for the velocity of the system. The radial velocity of the star is given as +28 km s^{-1}, the mean of the 4 spectra. Cruz-González *et al.* (1974) compute a photometric distance of 3.75 kpc for HD 64315. At this distance the star should show a radial velocity of 49 km s^{-1} due to differential rotation. These authors suggest therefore that HD 64315 is a runaway star, a suggestion that does not appear to be very attractive. This star is located only one arc minute (~1 pc) from the center of the nebula. At a velocity of 100 km s^{-1}, which is more or less typical for runaway stars, it would have reached its present position from the center of the nebula in only ten thousand years. If the runaway started so recently then there should be evidence for a supernova remnant. The low velocity dispersion found by the authors excludes this possibility.

The spectrum of the star has "nebulous" lines and is difficult to classify particularly in luminosity. Furthermore one cannot exclude the possibility that the star is not a normal main sequence object and that the observed variations are intrinsic to the star. Assuming a spectral class of O6 IV, V and (B-V) values by Lodén (1966), calibrations for visual absolute magnitude and intrinsic colors by Cruz-González *et al.* (1974), we obtain a distance of 4.1 kpc for HD 64315, in good agreement with our kinematic distance of NGC 2467. For a luminosity class III the distance would be 4.7 kpc.

VII. THE H II EMISSION COMPLEX AND THE ASSOCIATION PUP OB2

Münch (1951, 1954) and Markarian (1952) called attention to the existence of an OB association around NGC 2467. Based mainly on UBV photometry, Lodén suggested that there is more than one association in the direction of NGC 2467. Havlén (1972) confirmed the existence of two associations, Pup OB1 and Pup OB2 by the UBV photometry of OB stars between $l = 240°$ and 250°. The distance obtained for the association Pup OB1 is 2.5 kpc while for Pup OB2 it is 4.2 kpc. Furthermore Havlén points out that the two associations fall near the two successive maxima of the hydrogen distribution providing thus support to the reality and the location of the associations.

A more recent and extensive investigation of this region was carried out by FitzGerald and Moffat (1974) including the clusters H 19 and H 18ab, essentially by UBV photometry, both photoelectric and photographic. Their study includes 584 stars covering a total area of 0.065 square degress. HD 64315 and the stars in its vicinity, in the densest part of the nebular complex, are left out since no reliable photographic photometry could be performed in such a region. FitzGerald and Moffat reach the conclusion that H 19 and H 18ab are indeed star clusters and are both at a distance of 6.9 ± 0.9 kpc. The reddening is found to vary within the clusters but the mean color excesses are 0.45 and 0.70 magnitudes respectively while the color excess of the O6 star is intermediate between these values. These reddening values are less than the average value of 0.90 magnitude of the surrounding region; the smaller reddening suffered by H 19 and H 18ab and their large distance leads them to suggest that these two clusters lie at the inner edge of a third arm. In this picture Pup OB1 is in the spiral arm nearest the Sun, and Pup OB2 in the second farther spiral arm to which NGC 2467 belongs. We do not agree with their conclusions. We shall emphasize below that the star clusters H 19 and H 18ab and the nebular complex

NGC 2467, together with the association Pup OB2 are at a distance of 4.2 kpc and belong to one and the same spiral feature.

From our kinematic data (Table 2 and Figure 5) we feel quite justified in stating that H 19 and H 18ab are at comparable distances from the Sun and that both are within the nebular complex NGC 2467. That the two clusters are at the same distance is also shown by the photometric study of Fitz-Gerald and Moffat (1974). But the value of the common distance they derive, 6.9 kpc, appears to be overestimated by some 2 kpc.

The kinematic distance of the OB2 association, based on five stars with mean radial velocity of 71 ± 3.7 km s^{-1} by Bok *et al.* (1967) is estimated as 4.2, using a Schmidt rotation model; this distance is in surprisingly good agreement with our value of 4.2 of the kinematic distance of NGC 2467 complex. We recall that Havlén obtains a photometric distance of again 4.2 kpc for the OB2 association. Thus, the kinematic data —both stellar and nebular— and the photometric data provide ample evidence that the complex NGC 2467 which includes the clusters H 19 and H 18ab is embedded in the Pup OB2 association and is at a distance of 4.2 kpc from the Sun.

VIII. IS THERE A DISCREPANCY BETWEEN THE PHOTOMETRIC AND KINEMATIC DISTANCES?

Georgelin and Georgelin (1970) from the analysis of their Fabry-Pérot radial velocities of H II regions have encountered a discrepancy between the kinematic distances derived by these velocities (assuming the Schmidt model) and the photometric distances of the exciting stars of these regions. In certain regions particularly in the anti-center direction they find that kinematic distances are smaller than the photometric ones. In the present study of NGC 2467 as well as in a study from Fabry-Pérot velocities of S 254, 257 and 255 Pişmiş and Hasse 1976) we have not detected any discrepancy of the kind. In all of these nebulae the Georgelins do find a discrepancy. A thorough check on radial velocities of H II regions and attempts to obtain more reliable photometric distances will be necessary to find out if such a discrepancy does exist at all. If with better velocity data of the gas and with more reliable photometric distances the discrepancy is not removed, one may suspect that the Schmidt rotation curve in the anti-center direction has to be revised. Meanwhile Pişmiş (unpublished) using all available Fabry-Pérot velocities of H II regions and the photometric distances to the regions (Georgelin and Georgelin 1970) obtained a galactic rotation curve which shows a wavy form; but the mean curve to a distance of 15 kpc from the galactic center is flatter than the Schmidt curve; it does not bend down as rapidly. Such a tendency does not seem at all unlikely; recent studies of rotation curves from the 21-cm H line indicate that the rotation curve in M 31 and in other galaxies continues to be flat to larger distances than previously believed (Roberts 1974).

IX. SOME COMMENTS ON H 19 AND H 18ab

The star cluster H 19 is particularly interesting in having a rather neatly defined Strömgren sphere associated with it (Figure 2, Plate 77). It is a young cluster with an estimated age of $4 - 8 \times 10^8$ years. The brightest star is of spectral type BO V. Very close to this star are two stars of spectral type b1 and b1.5, so close as to appear as a blob in Figure 2. A third member star has a spectral type of b1.5. (Fitz Gerald and Moffat 1974). Our average Fabry-Pérot velocities yield a value of $+67.4 \pm 7.6$ km s^{-1} for tre Strömgren sphere; no expansion is detected with the present data.

The cluster H 18ab appears to be younger still with an estimated age of $\simeq 10^6$ years (FitzGerald and Moffat 1974). An O9 IV and an O7 star are among its members, which stars doubtless contribute to the ionization of the complex. The most interesting object however is a bright round H II condensation, with a diameter of 1.3 arcminute (1.9 pc) surrounding a B1 V star. The object shows a striking similarity to the H II condensation within the H II region NGC 2175, also associated with a B1 V star (Garnier & Zuckermann 1971, Pişmiş 1974, Grasdalen and Carrasco 1975). However the diameter of the latter (0.5 pc) is about one fourth of that of the knot in NGC 2467. The object happened to fall on the interference rings of F 42 and F 38. The knot shows, aside from a large dispersion, a negative velocity with respect to the H II complex. Thus there is indication that the gas around the star is expanding, a circumstance that attests to the young age of the cluster to which the object belongs. The positive component of the expansion —if it exists— has not been observed due probably to the fact that the knot did not fall exactly on an interference ring but was slightly displaced towards the outer edge of the ring where the relative velocities are negative. Consequently the knot, which has a diameter of the order of the half width of the interference fringes, did no extend far enough from the inner edge of the fringes where the relative velocities are positive. Thus no positive expansion velocities could be recorded. The expansion velocity is of the order of 20 km s^{-1}. A more definite value cannot be given at this stage without carrying out a deconvolution of the interferograms. Spectral studies of the H II knot and the exciting star should be rewarding.

Summarizing, we may state with considerable certainty that NGC 2467, its two galactic clusters H 19 and H 18ab all within the association Pup OB2 are at a distance 4 – 5 kpc. The source of excitation of the densest part of NGC 2467 is HD 64315 around which we have detected an expansion of the gas, of the order of 9 km s^{-1}. There exist considerable relative motions up to 10 km s^{-1}, in the radial direction, between the clouds which constitute the H II complex.

The H II complex is a young object with an age around $2 - 4 \times 10^6$ years (Havlén 1972, FitzGerald and Moffat 1974).

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