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FURTHER OBSERVATIONS OF STARS IN THE FIELD OF THE COMETARY GLOBULE NGC 5367

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ABSTRACT

UBVRIβ photometry and unfiltered polarimetry were obtained for a group of stars in the field of the reflection nebula NGC 5367, which is the head of a cometary globule more than 1° long. The observations are used to derive the distance and to discuss the magnetic field in the core of the globule.

Subject headings: nebulae: individual — polarization

I. INTRODUCTION

NGC 5367 is a reflection nebula at considerable galactic latitude ($l = 316\overset{\circ}{.}5$, $b = 21\overset{\circ}{.}1$) and out of the band covered by the catalog of van den Bergh and Racine (1973). The morphology of the brightest region of this nebula resembles that of Lynds 810 (Herbst and Turner 1976), one of the few known cases of stars probably associated with a Bok globule. However, in this case, the association of stars and nebular material is well supported by the local CO heating (Van Till, Loren, and Davis 1975), which is absent in Lynds 810 (Dickman 1978). These kinds of objects may be the linking step between globules and protostars and deserve particular attention.

Hawarden and Brand (1976) noted that this particular globule has a nebular tail more than 1° in length and directed toward the galactic plane, which gives a cometary appearance to the complex.

Later, Williams *et al.* (1977, hereafter WBLH) presented *UBV* observations of 11 stars in the field of NGC 5367 and *JHKL* of one star, obtaining a distance of 630 pc for the group.

The CO observations by Van Till, Loren, and Davis (1975) allow one to perform a comparison between radio and optical results and to derive the nebular mass. Moreover, the recently proposed identification by Cooke (1976) of NGC 5367 with a source of transient X-ray bursts adds more interest to the study of this object, as was thoroughly discussed by WBLH.

This paper is an attempt to clarify the association of stars and nebular material, as well as the magnetic field role in relation to the shape of the globule.

II. THE OBSERVATIONS

Multicolor *UBVRIβ* photometry of the brightest stars has been carried out at La Plata and Cerro Tololo observatories since 1974. The results are listed in Table 1; the identification numbers are those of WBLH, and *n* is the number of independent observations. Comparison with their *UBV* photometry shows the following systematic differences (WBLH—this work): $\Delta(V) = -0.045 \pm 0.010$ mag, $\Delta(B - V) = 0.028 \pm 0.011$ mag, and $\Delta(U - B) = 0.052 \pm 0.014$ mag, with no obvious color term. The same comparison but with Van Till *et al.* (only stars 1 and 2) gives almost null differences in the colors and the same discrepancy (0.24 mag) in the *V* of star 1 that WBLH found.

Two 30 minute exposure Hα plates were obtained with the Cerro Tololo Curtis Schmidt camera in 1976 July with the aim of searching for emission-line stars. The 4° prism was employed with 127-04 emulsion

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TABLE 1

UBVRIβ OBSERVATIONS

Star*	*V*	*B* − *V*	*U* − *B*	*n*	*V* − *R*	*R* − *I*	*n*	β	*n*
1.....	9.77	0.32	−0.19	6	0.46	0.45	3	2.651	2
2.....	10.11	0.12	−0.28	6	0.23	0.15	2	2.758	3
3.....	12.43	0.54	+0.01	3	...	...	0	...	0
4.....	9.15	1.00	+0.79	4	0.79	0.49	2	2.583	2
5.....	12.82	0.88	+0.55	4	...	...	0	...	0
6.....	13.88	0.46	+0.14	3	...	...	0	...	0

* Numbers from WBLH.

plates (baked N_2) plus an RG-630 (2 mm) filter and a 0.2 mm widening. No additional emission-line star was found in a 3° × 3° region centered on the star CD −39°8581 (WBLH no. 1), which is itself an emission double star cataloged as He 3-949 by Henize (1976). The limiting magnitude of this survey was estimated as $R = 15.0$ mag from a comparison with calibrated plates taken in Corona Austrina.

The polarimetric observations were obtained during 1977 at La Plata Observatory with the single-channel rotating-analyzer polarimeter developed by Marraco and Marabini (1978). The polarimeter was employed without filters and the response function corresponds to the combination of a KN-36 Polaroid sheet and an S-4 photocathode. The results are tabulated in Table 2.

III. THE ASSOCIATED STARS

The identification of the stars associated with the nebula can be readily made in the cases where the light is scattered by the nearby dust. According to this criterion, and after the POSS Whiteoak Extension (R) and the ESO (B) Survey have been examined, stars 1, 2, 6, and 8 are members of this complex. The first of these stars is a double, with a separation of 3".7, known as h4636 (Herschel 1847).

The distance determination for NGC 5367 relies on the observed β index of star 2, which Van Till, Loren, and Davis (1975) have shown is probably associated with the globule. From the measured *UBV* colors this star is a B6 dwarf with a color excess $E_{B-V} = 0.25$ mag. An absolute magnitude $M_v = +0.2 \pm 0.3$ mag was derived by means of Crawford's (1976) (β, M_v) calibration, and, adopting $R = 3$ for the ratio of total to selective absorption, this leads to $V_0 - M_v = 9.1$ mag. The corresponding distance is 660 ± 100 pc, while the height of the globule above the galactic plane is $z = 240 \pm 40$ pc. It should be noted that this distance is in remarkable agreement with that obtained by WBLH despite the small number of stars used in their ZAMS fitting.

The adoption of a normal value for the ratio of total to selective absorption is supported by the color excess ratio $E_{V-I}/E_{B-V} = 1.88$ for star 2. This value is not significantly larger than 1.7, the value suggested by Johnson and Borgman (1963) for normal interstellar matter.

WBLH interpreted the difference of color excesses of the components of the double star h4636 as evidence for a circumstellar dust shell around the northern star. However, this difference may also arise as an effect of the gas envelope ultraviolet excess on the *UBV* colors. In turn, the infrared energy distribution can be explained by free-bound and free-free radiation arising from the same gas envelope that produces the Balmer-line emission (Dyck and Milkey 1972). This picture avoids the need of a high-temperature circumstellar dust shell with its very restrictive chemical composition.

A strong Hα absorption line is evident in star 6 and also (stronger) in star 8 on inspection of the objective prism plates. None of the remaining stars (3, 4, 5, 7, 9, and 10) shows this line, either in absorption or (as already reported) in emission. In light of this result, the values of $(B - V)_0$ adopted by WBLH for stars 6 and 8 appear to be correct and confirm that the former is placed below the ZAMS like W90 in NGC 2264, but without emission lines (Warner, Strom, and Strom 1977). Conversely, the colors of stars 3, 5, 7, 9, and 10 are most easily understood as those from little-reddened, main-sequence, foreground stars. If this were not the case, and these stars were provisionally identified as pre–main-sequence objects, one would be faced with the problem of explaining why none of these stars shows the Hα emission typical of T Tauri–like stars.

The spectral type of star 4 may be G8 III or K5 V from the *UBV* colors, but the $V - R$ and $V - I$ colors favor the former identification. The amount of reddening is relatively low but still enough to produce measurable polarization, while the distance modulus is about $V_0 - M_v = 10.0$ mag, placing this star as a background object. Stars 9 and 10 may also be considered, alternatively, as background, little-reddened giants.

TABLE 2

POLARIZATION OBSERVATIONS

Star*	Polarization (%)	Position Angle (°)	n
1.....	0.83 ± 0.20	161 ± 7	6
2.....	1.25 ± 0.12	146 ± 3	4
4.....	0.46 ± 0.09	135 ± 6	5

* Numbers from WBLH.

IV. COLOR EXCESSES AND ^{13}CO COLUMN DENSITIES

The total absorption along the line of sight is derived as

$$A_v = (3.0 \pm 1.2 \text{ mag}) \times 10^{-18} N_{CO} \qquad (1)$$

from the relation between ^{13}CO column densities and A_v obtained by Tucker *et al.* (1976) and the relative isotopic abundance $^{12}C/^{13}C = 89$ used by Van Till *et al.* The CO column densities from Figure 1*d* of Van Till *et al.* were converted into visual absorption (in magnitudes), and Figure 1 shows the results on the stellar field.

The comparison of the absorptions derived from the color excesses with those obtained from equation (1) shows that the former account for only about 25% of the total absorptions derived from the CO column densities.

This can be understood by assuming that the embedded stars are not in the center but located near the nebular front edge, as in the large molecular complexes where star formation seems to be confined to the edge of dense regions.

The possibility of a selection effect, in the sense that only near-side embedded stars were found, can

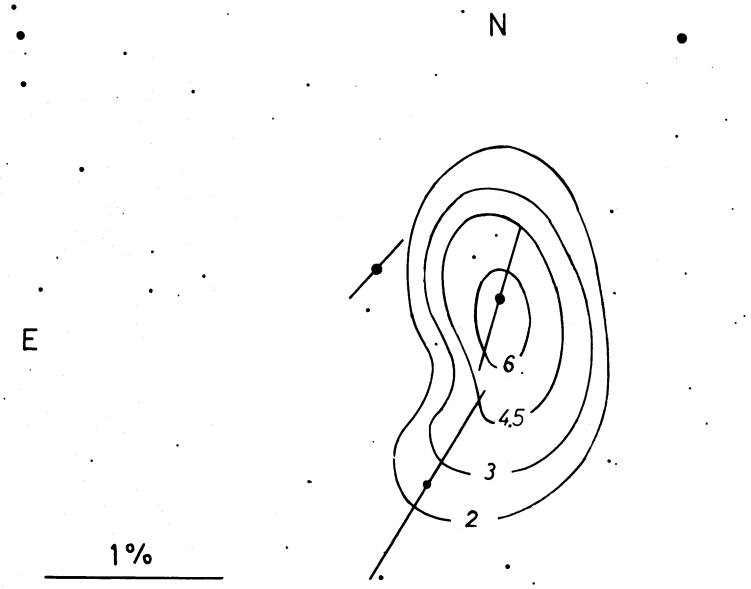

FIG. 1.—A plot of the visual absorption (in magnitudes) derived from CO column densities superposed on the stellar field. The straight lines represent the polarization vectors.

be ruled out, taking into account the limiting magnitude of the POSS Whiteoak Extension. This magnitude is close to $R = 19$ mag, faint enough to show zero absolute magnitude stars at the distance of NGC 5367 with more than 10 mag of visual absorption.

V. POLARIZATION

The polarization vectors are shown in Figure 1. It is interesting to note that the observed stars are beyond the Scorpius-Centaurus association, which is nearer to the Sun. This association was studied by Gutiérrez-Moreno and Moreno (1968), who showed (Figs. 5–9 of their work) that the largest color excesses in the neighborhood of NGC 5367 are about $E_{B-V} = 0.08$ mag. According to Serkowski, Mathewson, and Ford (1975), this implies $P \leq 0.7\%$, the inequality holding for all the cases but the one of perfect grain alignment. Besides, 10 stars were found within 5° of NGC 5367 whose polarization had been measured by Mathewson and Ford (1970). All these stars have $P_B \leq 0.2\%$ and most of them show $P_B \leq 0.07\%$.

From the preceding data it is very probable that the observed polarization arises almost completely from the dust associated with the globule. The alignment of the polarization vectors is near P.A. = 140° for stars 2 and 4, while it is slightly larger for the emission-line star 1, where some intrinsic polarization may be present.

An examination of the ESO (B) Survey shows that the reflection nebula around star 2 has a filamentary structure oriented with the same position angle. The cometary tail associated with the globule also points in the same direction, according to Hawarden and Brand (1976), who obtained P.A. = 135°. It is also interesting to note that 4.°6 away from NGC 5367 at P.A. = 135° there is a small patch of dark material. This 6′ × 18′ nebulosity ($\alpha_{1950} = 14^h12^m3$, $\delta_{1950} = -43°9'$; $l = 318.°7$, $b = 16.°9$), apparently overlooked by Hawarden and Brand, is seen at $X = 103$ mm and $Y = 140$ mm in the POSS chart ($-42°$, 14^h00^m), which also shows NGC 5367.

VI. CONCLUSIONS

The results presented in this paper further support the physical association of the globule with a number of early-type stars, as well as with stars apparently placed below the ZAMS. A regular magnetic field seems to be related with the gross morphology of the nebula (the cometary tail); moreover, if the nebular patch placed on the nebular tail extension is actually associated with the globule, it suggests that the magnetic field is spatially regular over a projected length scale of 4.°6 (about 50 pc).

The total cloud mass as estimated by Van Till, Loren, and Davis (1975) and corrected to the distance obtained in this paper turns out to be $M_{\rm cloud} = 140\ M_\odot$, still low in comparison with the masses of several times $10^3\ M_\odot$ found in other dark cloud complexes (Vrba 1977). However, this mass is a lower limit because the sampling of Van Till *et al.* is restricted to a small area near the nebular head.

The apparent lack of T Tauri–like objects, often found in very young associations, suggests a relatively advanced evolutionary stage for this complex. Nevertheless, it might also be possible that these kinds of stars are not formed in low-mass clouds.

Conversely, early-type pairs similar to h4636 seem to be common objects in very young associations, like

HD 176386–TY CrA in Corona Austrina. The latter was classified as Allen type F (IR excess caused by free-free emission) by Glass and Penston (1975).

WBLH proposed that star formation in NGC 5367 was triggered by a supernova explosion at $l = 320°$, $b = 30°$. This picture, which is adopted by Vrba (1977) for the ρ Ophiuchi cloud, is sustained by the following features: Star formation occurs in a small high-density region in the edge of the cloud first hit by the shock wave. The efficiency of star formation (as defined by Vrba) is quite high: 14%, taking into account only the embedded stars. If this is so, then the magnetic field *cannot* inhibit cloud collapse even in this case, where the projected angle between shock propagation velocity and field direction is about 50°.

Finally, there remains the possibility that some hidden source might be spotted by raster scanning in the infrared. In this connection one should remember that the densest part of the nebula, similar to the zone near HH 100 in Corona Austrina where a strong IR source was found (Strom, Strom, and Grasdalen 1974), is the center of the triangle formed by stars 1, 6, and 8.

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REFERENCES

Cooke, B. A. 1976, *Nature*, **261**, 564.
Crawford, D. L. 1976, private communication.
Dickman, R. L. 1978, private communication.
Dyck, H. M., and Milkey, R. W. 1972, *Pub. A.S.P.*, **84**, 597.
Glass, I. S., and Penston, M. V. 1975, *M.N.R.A.S.*, **172**, 227.
Gutiérrez-Moreno, A., and Moreno, H. 1968, *Ap. J. Suppl.*, **15**, 459.
Hawarden, T. G., and Brand, P. W. J. L. 1976, *M.N.R.A.S.*, **175**, 19p.
Henize, K. G. 1976, *Ap. J. Suppl.*, **30**, 491.
Herbst, W., and Turner, D. G. 1976, *Pub. A.S.P.*, **88**, 308.
Herschel, J. F. W. 1847, *Results of Astronomical Observations Made during the Years 1834, 5, 6, 7, 8 at the Cape of Good Hope* (London: Smith, Elder).
Johnson, H. L., and Borgman, J. 1963, *Bull. Astr. Inst. Netherlands*, **17**, 115.
Marraco, H. G., and Marabini, R. 1978, in preparation.
Mathewson, D. S., and Ford, V. L. 1970, *Mem. R.A.S.*, **74** 139.
Serkowski, K., Mathewson, D. S., and Ford, V. L. 1975, *Ap. J.*, **196**, 261.
Strom, K. M., Strom, S. E., and Grasdalen, G. L. 1974, *Ap. J.*, **187**, 83.
Tucker, K. D., Dickman, R. L., Encrenaz, P. J., and Kutner, M. L. 1976, *Ap. J.*, **210**, 679.
van den Bergh, S., and Racine, R. 1973, in *IAU Symposium No. 52, Interstellar Dust and Related Topics*, ed. J. M. Greenberg and H. C. van de Hulst (Dordrecht: Reidel), p. 123.
Van Till, H., Loren, R., and Davis, J. 1975, *Ap. J.*, **198**, 235.
Vrba, F. J. 1977, *A.J.*, **82**, 198.
Warner, J. W., Strom, S. E., and Strom, K. M. 1977, *Ap. J.*, **213**, 427.
Williams, P. M., Brand, P. W. J. L., Longmore, A. J., and Hawarden, T. G. 1977, *M.N.R.A.S.*, **181**, 709 (WBLH).

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