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The large globule Lynds 810 as a possible member of the Vulpecula OB1 complex

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Summary. A distance of 2.5 ± 0.2 kpc is derived for the dark globule Lynds 810 using photometric data for foreground stars and star counts. It is argued that this globule is likely to belong to the Vul OB1 complex. Its cometary structure, like certain other features of dust-related objects in Vulpecula, appears to be the shock signature of a past disturbance originating from a region near $l = 60°$, $b = +2°$, which lies within the fossil H II region Lynds 792.

Key words: clusters: associations – interstellar medium: clouds: Lynds 810

1. Introduction

Lynds 810 (Lynds, 1962) is a cometary dark cloud roughly $5' \times 10'$ in extent which is located on the Vulpecula-Cygnus border ($l = 63\overset{\circ}{.}5$, $b = +0\overset{\circ}{.}8$). The cloud is similar in appearance to many large Bok globules, but is distinct in containing a faint diffuse nebula near its centre (Herbst and Turner, 1976), implying that it is a site of recent star formation. Observations at infrared and radio molecular-line wavelengths by Neckel et al. (1985) confirm this suggestion and indicate that Lynds 810 is a dense molecular cloud containing an H_2O maser associated with a jet from the central nebula. The emission from the cloud appears to be generated by a faint, luminous (350 $L_\odot$), Orion population variable star located at one end of the nebular jet.

The distance to the cloud is of interest for determining its exact dimensions and for inferring its possible origin. At present three independent estimates for the cloud's distance are available, namely (i) 1.5–2.0 kpc (Herbst and Turner, 1976) based on star densities for foreground stars projected on the cloud, (ii) ~ 1.0 kpc (Bok, 1976, private communication) based on the density of faint stars projected on the cloud, and (iii) a kinematic distance of 1.5 ± 0.5 kpc (Neckel et al., 1985) determined from the cloud's radial velocity found from radio molecular-line observations. It is also possible to estimate the cloud's distance using photometry of foreground stars lying in the cloud's densest portions (cf. Herbst and Turner, 1976) or by applying an empirical relationship between distance and foreground star density derived by Herbst and Sawyer (1981). This paper presents a new distance determination for Lynds 810 which is based upon these last two methods as well as upon optical evidence related to the cloud's likely origin.

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2. Observations and analysis

Herbst and Turner (1976) presented photoelectric UBV photometry, supplemented by a few spectral types, for six of the brightest stars projected on the densest portions of Lynds 810. These stars were all considered to be foreground objects on the basis of reddenings and distances derived for them using the assumption that most were likely to be dwarfs. This assumption appeared to be justified for all but the brightest and reddest stars in the sample, and permitted a strict lower limit to be placed on the cloud's distance. Since the six stars observed by Herbst and Turner all lie closer than about 1 kpc, their photometry serves merely to confirm the validity of the three distance estimates quoted above.

An effort was made to search for more distant foreground stars in Lynds 810 by obtaining photoelectric UBV photometry for the nine brightest stars in the cloud. The observations were made on three nights in August 1979 using the 0.4-m telescope at Kitt Peak National Observatory. Special care was taken in the program to avoid possible systematic errors in the photometry of faint stars near the telescope limit (cf. Turner, 1981a) by making repeated observations of the stars and by using sky corrections appropriate for nearby opaque portions of Lynds 810. The photometry is presented in Table 1, where n represents the number of nights of observation for each star. The stars are identified in Fig. 1. A comparison with the photometry of Herbst and Turner (1976) for stars 1 to 6 reveals only small differences in colour that can satisfactorily be accounted for by the larger air mass corrections required for the earlier observations from Cerro Tololo Observatory. Also given in Table 1 are magnitude and colour estimates for the remaining objects identified in Fig. 1, as derived from image diameter measurements from the POSS plates.

The photoelectric data in Table 1 were dereddened to the intrinsic two-colour relation for dwarf stars using a reddening law appropriate for the region (Turner, 1980), and the different possible solutions for most stars were examined using the following considerations: (i) the field reddening in this region (Neckel and Klare, 1980) results mainly from obscuration by dust clouds which

Table 1. Photometric data for stars projected on Lynds 810

Star[a]	V	B-V	U-B	n[b]	$(B-V)_o$[c]	E_{B-V}[d]	d(pc)	Remarks
1	11.26	0.53	0.05	3	+0.43	0.11	640	Sp.Type = F5 IV
2	11.69:	0.41	0.31	3	+0.01	0.41	982^{+574}_{-393}	Sp.Type = A2 IV:
3	12.18	0.74	0.36	3	+0.74	0.00	213	Sp.Type = G
4	12.29	1.20	0.97	3	+1.01	0.21	...	
5	13.22	0.55	0.21	3	+0.33	0.23	776	
6	13.23	1.19	0.80:	3	+0.86	0.36	...	
7	16.5	1.4:	...	0	...	...	...	R ≃ 15.7 on POSS
8[e]	17.6:	0.2:	...	0	...	...	...	
9[f]	17.6:	3.9:	...	0	...	...	...	
10[f]	18.6:	2.9:	...	0	...	...	...	
11[e]	17.1	0.4	...	0	...	...	...	
12	16.2	1.3	...	0	...	...	...	
13	13.68	0.69	0.24:	3	+0.38	0.33	851^{+149}_{-127}	double, ΔR ≃ 0.1
14	13.80	0.37	0.23	1	-0.02	0.40	1722	1820 pc, class V
15	14.08	0.96	0.65	1	+0.87	0.10	...	

[a] Star numbering adapted from Herbst and Turner (1976) and Neckel et al. (1985)

[b] 0 = photometric data obtained from POSS plates

[c] Most likely value (see text)

[d] Equivalent reddening for a B0 star

[e] The blue colours and faint magnitudes of these objects cannot be reconciled with foreground status. The manner in which they bracket star 7 and the nebulous appearance of object 8 suggest that they are reflection nebulosities from star 7 (cf. Turner, 1986)

[f] These two objects (and others in their immediate vicinity) are not visible on the POSS blue plate, so the possibility arises that they are plate flaws. However, differences in their appearance from other plate flaws on the POSS red plate (cf. two non-stellar images on the right central edge of Fig. 1) and their location at the edge of the cloud are also consistent with objects lying on the far side of Lynds 810 (Turner, 1986)

lie at distances of about 500 to 900 pc, and generally is constant beyond this; (ii) even very distant stars in this field are not reddened by more than $E(B-V)=0.66$ (Turner, 1980). Adopted reddenings and distances for the program stars (assuming dwarf or subgiant luminosities) are presented in Table 1 and illustrated in Fig. 2.

The resulting variation of reddening with distance towards Lynds 810 seems to be relatively well-defined. No reddening is evident within about 500 pc, beyond which it increases to $E(B-V)=0.4$ at a distance of 1 kpc. and remains constant thereafter. Additional data which support this reddening trend are provided by a closely adjacent cluster of stars, ~650 pc distant and reddened by $E(B-V)=0.5$ (Turner et al., 1986), which surrounds the variable star S Vulpeculae. Star 14 in Table 1 is almost certainly more distant than ~1.7 kpc, which therefore specifies the minimum distance to Lynds 810.

Alternatively, the distance to Lynds 810 can be obtained from the star count method of Herbst and Sawyer (1981) since the central portions of the cloud are opaque to blue light on the POSS. In fact, the absorption by the cloud is finite (Neckel et al., 1985) yet large enough to make background stars stand out by their faintness and extremely red colours. A few embedded objects also appear nebulous on the POSS (Herbst and Turner, 1976; Neckel et al., 1985).

The technique adopted here was to first make a composite print of the cloud by superposing a negative of the POSS red plate with a positive of the POSS blue plate, and then to outline the cloud boundaries from the distribution of extremely red stars. The resulting outline of Lynds 810 was roughly circular in shape for the densest portions, but had a low density tail appended northeast of the cloud head (cf. Fig. 2). Star counts were made in both regions using a circular template of diameter 3.'2 (corresponding roughly to the dimensions of maximum formaldehyde absorption recorded by Neckel et al., 1985), and obvious background or embedded stars (or knots) were excluded. The resulting counts of foreground stars varied from 14 to 20 across the cloud, being largest in the cloud head. The average count across Lynds 810 was 16.6 ± 2.3 stars/3.'2

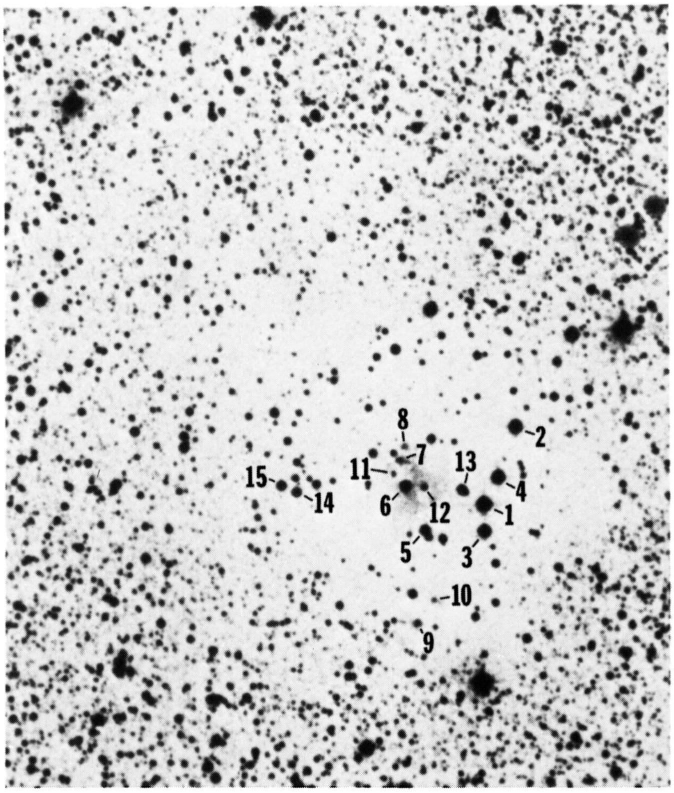

Fig. 1. Identification chart for Lynds 810 from the POSS E-plate of the region. The photograph is oriented with north up and measures roughly 10′ × 12′. *(Copyright: National Geographic Society – Palomar Observatory Sky Survey)*

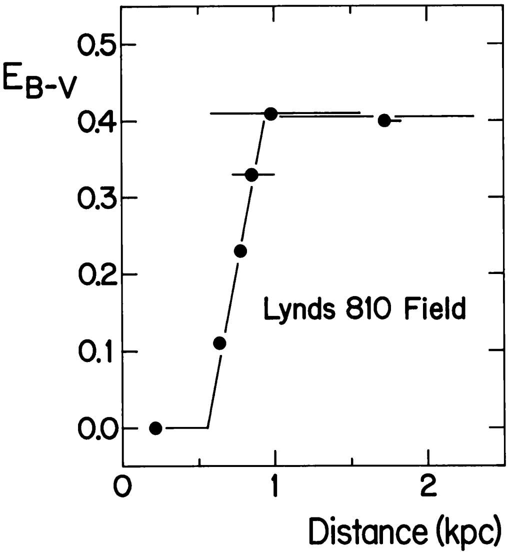

Fig. 2. Distance-reddening diagram for stars foreground to Lynds 810

diameter circle, which corresponds to 39.8 ± 5.5 stars/5′ diameter circle. The Herbst and Sawyer (1981) relation yields a corresponding distance of 2.6 ± 0.2 kpc for the cloud, but we have adopted here a value of 2.5 ± 0.2 kpc determined from a slightly modified distance-star density relation which incorporates new (unpublished) distance estimates for a few of the more distant clusters

Table 2. Velocities and orientation angles for Vulpecula clouds

Identification	V_{LSR}(abs)[a]	V_{LSR}(em)[b]	Θ[c]
NGC 6820	+27 km/s	+26 km/s	327°
Sharpless 87	+23 km/s	+17 km/s	...
Sharpless 88	+23 km/s	+15 km/s	278°
Sharpless 89	+26 km/s	...	...
Sharpless 90	+22 km/s	+23 km/s	243°
Sharpless 93	+21 km/s	...	...
Lynds 810	+16 km/s	+11 km/s	218°
Lynds 812	...	...	217°

[a] From Blitz et al. (1982) or Neckel et al. (1985)

[b] From Georgelin and Georgelin (1970), Georgelin et al. (1973) or Neckel et al. (1985)

c Estimated uncertainties ± 2°

serving as calibrators for Herbst and Sawyer's relation. A distance of 2.5 kpc for Lynds 810 is larger than previous estimates, but has interesting consequences regarding the cloud's possible origin.

3. Discussion

There appear to be only two dust complexes lying along the line of sight to northern Vulpecula, one immediately foreground to the stars of Vul OB4 (distance ~1 kpc) at a distance of roughly 500 to 900 pc (cf. Neckel and Klare, 1980), and one associated with the OB stars, clusters and emission regions of Vul OB1 at a distance of about 2.3 kpc (Turner, 1979, 1981b). Unless Lynds 810 is completely isolated from other dust complexes in the region, it must be part of the Vul OB1 complex as argued by its distance inferred from star counts and from the fact that a few foreground stars projected on the cloud lie beyond the nearer dust complex.

Certain pieces of evidence also indicate a more direct relationship between Lynds 810 and other dust-associated objects in the Vul OB1 complex. This evidence is summarized in Table 2 and includes similar radial velocities for the objects as well as orientation angles for optical components of some of them which are directed towards a common location near $l = 60°$, $b = +2°$ (see Fig. 3). The specific optical characteristics referred to here are summarized below.

(i) Lynds 810 and the less opaque Lynds 812 north of it share cometary head-tail structures of similar orientation suggesting formation through the compressional effects of a passing shock wave impacting from the southwest.

(ii) Sharpless 90 contains a cometary elephant trunk structure on its eastern edge which appears to have originated from a past disturbance from the southwest rather than from more recent H II region expansion.

(iii) Sharpless 88 is ionization bounded on its eastern side by a bow-shaped complex of dust oriented towards the west.

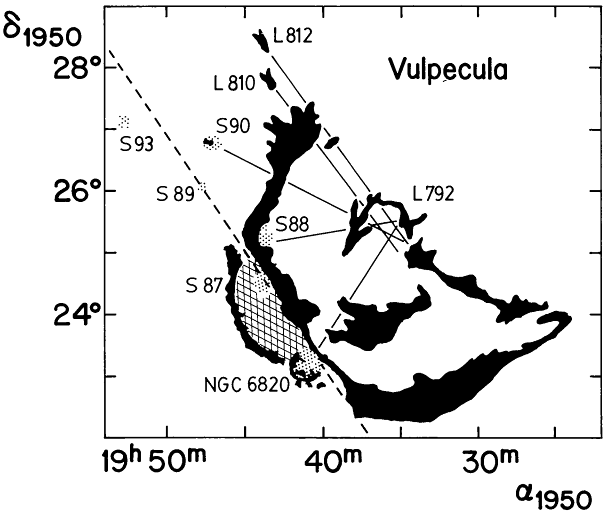

Fig. 3. A schematic representation of the Vulpecula complex of dust clouds and obscuration (solid and cross-hatched shading; L = Lynds) and emission nebulae (dotted shading; S = Sharpless) indicating the symmetry axes of features in Table 2 and their probable centre of origin. A broken line represents the galactic plane

(iv) NGC 6820 contains dust globules and elephant trunks which lie mostly to the southeast of the massive OB stars in NGC 6823 (Turner, 1979), while the bow-shaped complex of dust which runs across the northwest edge of this H II region suggests a similar orientation towards the northwest.

The common thread which seems to connect these features is their possible origin from the compressional or ram pressure effects of a passing shock front. Interestingly, the common point of intersection for the orientation vectors, which corresponds to the place of origin for this disturbance, lies within the dusty contails of Lynds 792, an inverted U-shaped dust cloud which has the appearance of a fossil H II region (van den Bergh, 1967, 1972).

The distribution of dust within Lynds 810 itself is analogous in appearance to the cometary globules of the Vela-Puppis complex, which Hawarden and Brand (1976), Sandqvist (1976), Zealey (1979), and Zealey et al. (1983) have noted are oriented with their tails directed away from the centre of the Gum Nebula. Similar cometary features have been found by Magakyan (1983) on the periphery of NGC 7129. However, there is a modest difference in scale for the features in Vul OB1, since Lynds 810 lies over 120 pc in projected distance away from the interior portions of Lynds 792 at the distance estimated above. The cometary globules in the Vela-Puppis complex generally have projected distances from their associated centre of only half this, while the cometary features near NGC 7129 lie even closer to this star formation region. This distance factor may place constraints upon the type of mechanism (stellar winds, H II region expansion, supernova shock wave) which is most likely responsible for the shock signatures of Lynds 810 and other dust-related objects in the Vul OB1 complex. In fact, a supernova shock wave appears most plausible in this instance.

New observational material for the Vulpecula region would help to provide a better picture of the actual spatial distribution of various features with respect to one another. A good example of a possible source of confusion is the elongated dust cloud which runs across the lower section of Vulpecula in Fig. 3. This appears at first glance to be part of the Vul OB1 complex, yet photometric and spectroscopic data for an F0 V: e star embedded in reflection nebulosity near its northwestern tip (Herbst et al., 1982) indicate that its distance is much less than that of Vul OB1.

The distance to Lynds 810 implied by star counts (2.5 ± 0.2 kpc) is probably the best estimate available at present. It is consistent with the photometric data for foreground stars to the cloud as well as with the radial velocity observations, provided that one accepts a peculiar velocity for Lynds 810 of about -10 km s^{-1} with respect to other objects in Vul OB1. The larger distance also leads to an upwards revision in the cloud dimensions. The diameter of the cloud head becomes $\sim 3^1/_2$ pc at this distance, rather than ~ 2 pc as quoted by Neckel et al. (1985).

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