COMETARY GLOBULES IN THE ORION SUPER-BUBBLE

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1. Introduction

Interstellar clouds with a cometary appearance (a compact "head" with a wider diffuse "tail") are likely artifacts of interactions of winds, shocks and ionization fronts with molecular gas. As such they represent a means of tracing the history of massive star associations. The first catalogue of such objects was described by Odenwald (1988). Since then, theoretical works by Dyson (1993) on mass-loaded flows, and by Bertoldi (1989) and Bertoldi & McKee (1989) on photo-evaporation of neutral globules have suggested mechanisms for generating their morphologies and make predictions of their kinematics. With the increased understanding of the formation of these objects it may become possible to use them as "fossil records" of the 10 Myr history of their local ISM.

There is a large body of evidence that the interstellar medium around the Orion Molecular Cloud has been affected significantly by stellar winds, ionizing radiation, and past supernovae from stars in the Orion OB1 association. Fig. 3 (from Reynolds & Ogden 1979) shows the radial velocities of diffuse Hα components across the Orion-Eridanus region. Reynolds & Ogden postulated that the loop-like filaments in Hα and H I were the result of a cavity of hot gas ionized by UV flux from the early-type stars in Orion OB1, surrounded by expanding shells of H I produced from supernovae. The shells could also be the result of the radiative shock of a supernova with higher column density structures the result of older supernovae (Cowie, Songaila, & York 1979). Brown, de Geus, & de Zeeuw (1994) have shown that the winds from the Orion OB1 stars also contribute a significant amount of energy into the region.

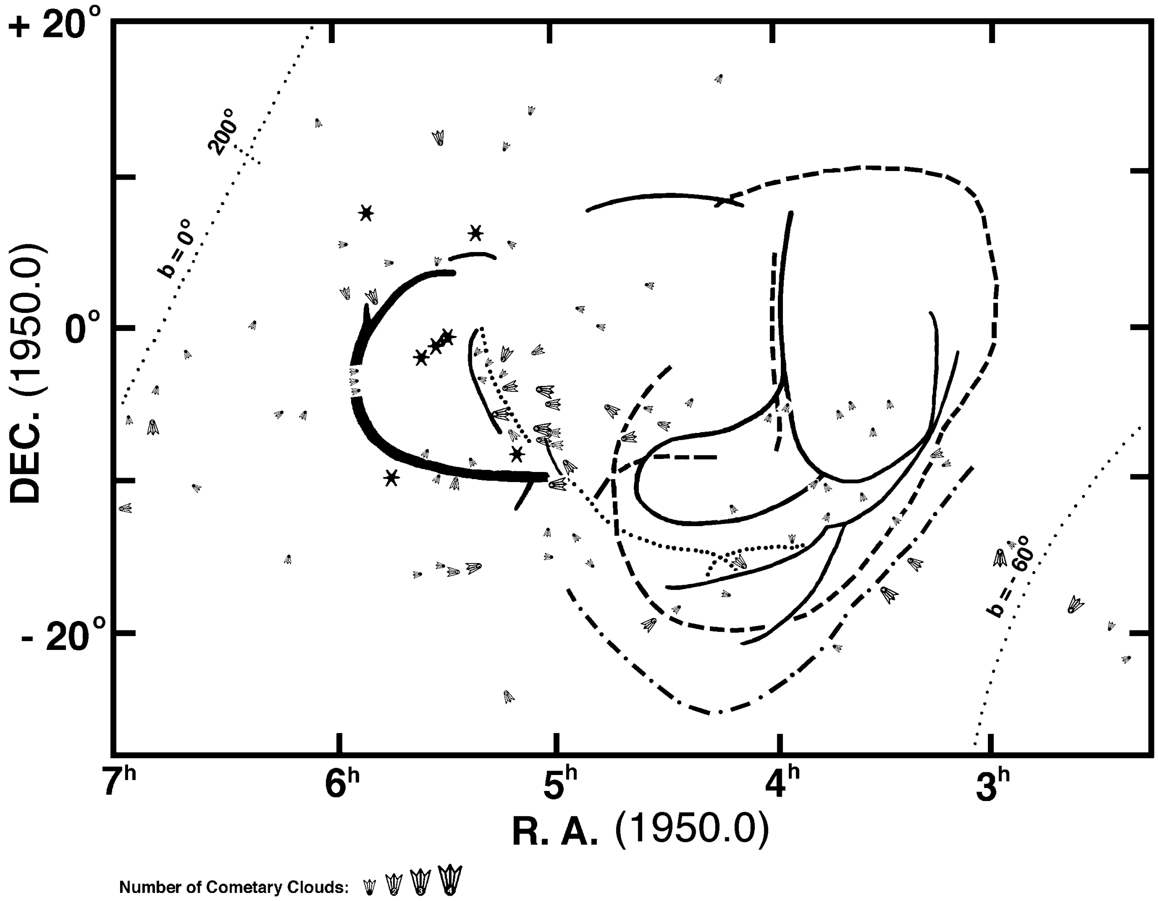

Figure 1. The approximate positions and orientations of the cometary globules identified in our survey. Larger symbols denote more objects in the immediate area. The orientation was defined by the position of the most compact and bright region relative to the rest of a given object. The *solid* lines show Hα emission with Barnard's Loop as the thick loop on the left; *dotted* lines show 21 cm emission from −12 to −9 km s^{-1}; the *dot-dashed* line shows 21 cm features from +3 to +6 km s^{-1}; the *dashed* line shows 21 cm features in the +18 to +21 km s^{-1} interval.)

2. Procedure

We searched for possible cometary globules by visually examining the IRAS Sky Survey Atlas (ISSA) plates at 100, 60 and 25 μm, around the Orion region [R.A. range 7^{h} to 2^{h}, and Dec. range −24° to +20°] for clouds with morphologies that could be loosely described as cometary. We also looked for shock morphologies around globules in this region since they can be indicative of rapidly expanding ionized gas. The results of our search are

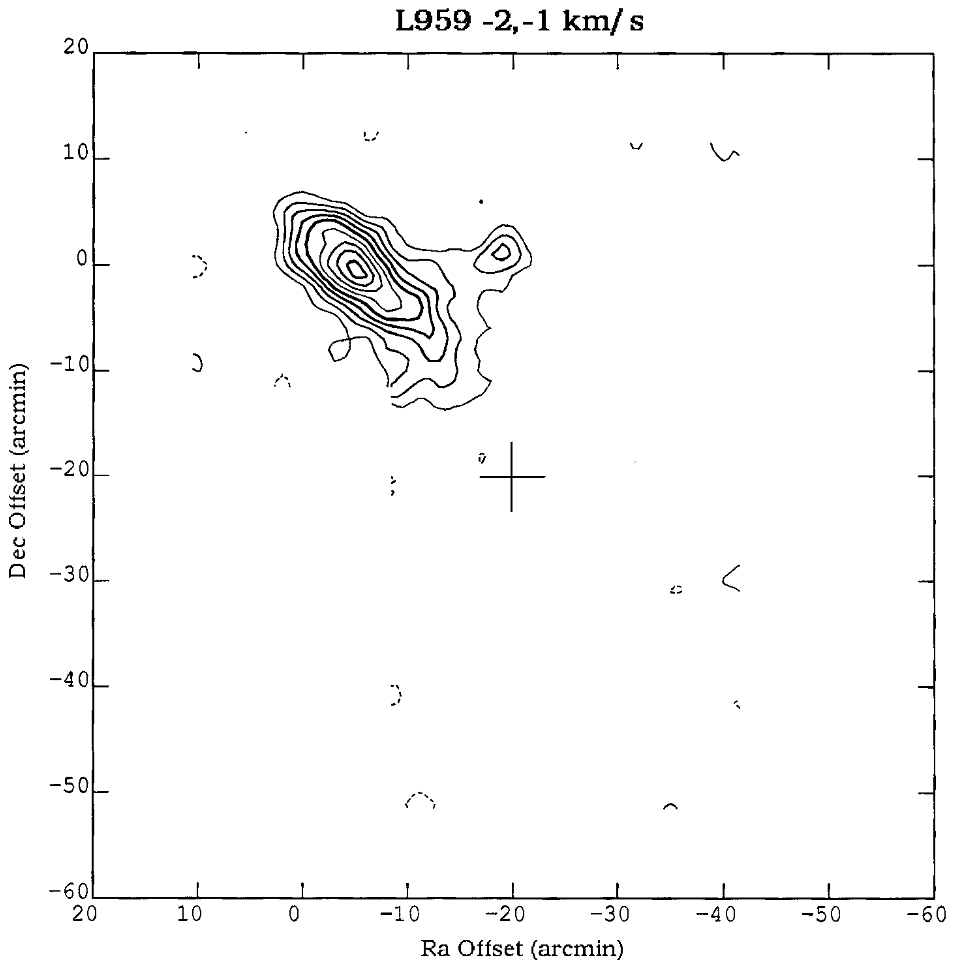

Figure 2. (Fig. 2-4) These maps of L959 in $C^{13}O$, J=2-1 show a relationship between VLSR and position along the object's axis. v_{tail}-v_{head} increases with distance along the axis of the object. The estimated time of expansion assuming constant velocity in time is $\sim$ 10 Myr. This figure shows $C^{13}O$ emission with -2 < VLSR < -1 km/s.

shown in Fig. 1, with the symbols representing potential cometary globules.

We then searched an Orion $C^{13}O$, J=2-1 data archive for scans that were coincident with our selected cometary globules. These observations were made by J. Bally during 1986–1991 using the AT&T Bell Laboratories 7 m offset Cassegrain antenna and a liquid helium-cooled SIS receiver with a single side-band receiver temperature $T_{\rm SSB} \sim 200$ K (Pound, Bania, & Wilson 1990). The observations were made using in-band frequency-

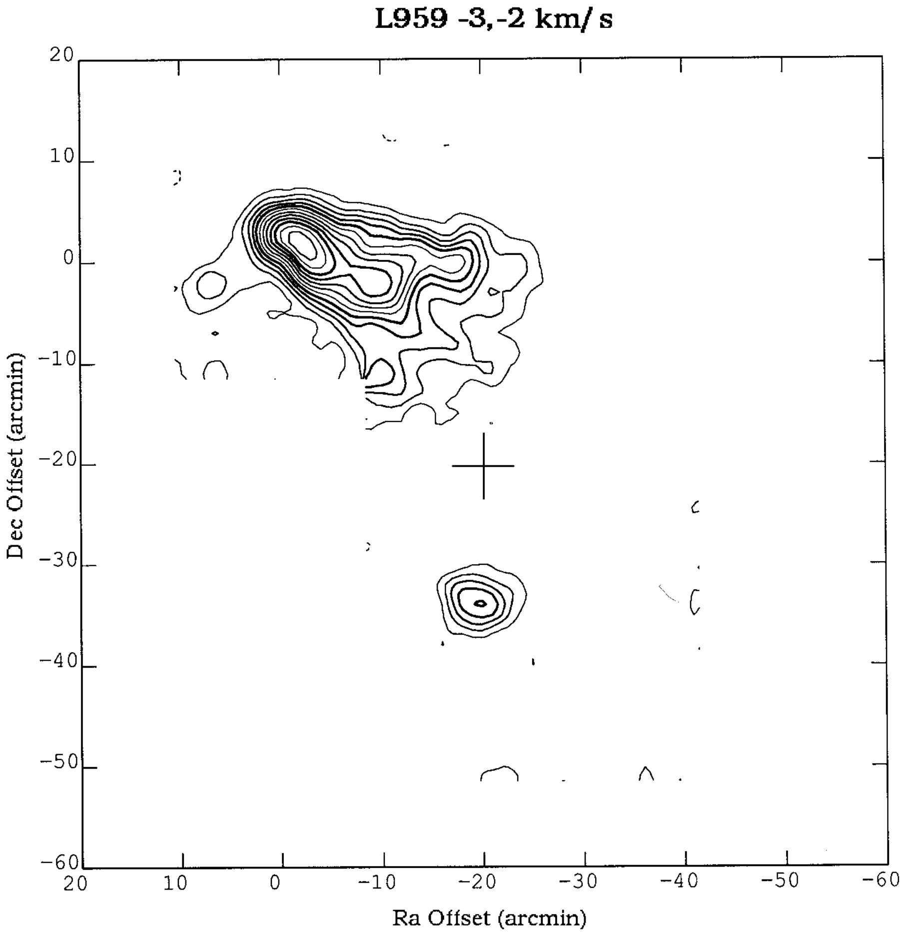

Figure 3. L959 $C^{13}O$ emission with -3 < VLSR < -2 km/s.

switching in which the reference frequency is displaced from the signal by 6.4 MHz. The 20 second integration scans were taken with a 250 kHz filter bank with 256 channels, one half of which were sent to a spectrum expander to give a resolution of 100 kHz or 0.26 km s^{-1} at 115 GHz. The data were reduced with the COMB spectral line reduction package, using a third-order polynomial fit to remove baseline.

Out of the 60 scans located in the area of our search around the Orion region, we found 23 that were coincident with a pre-selected cometary globule. Table 1 presents the B1950.0 R.A. and Dec. coordinates for the 23 scans, as well Gaussian fitted center $V_{\rm LSR}$ s and line widths.

We also located spectral maps of areas coincident with two of the glob-

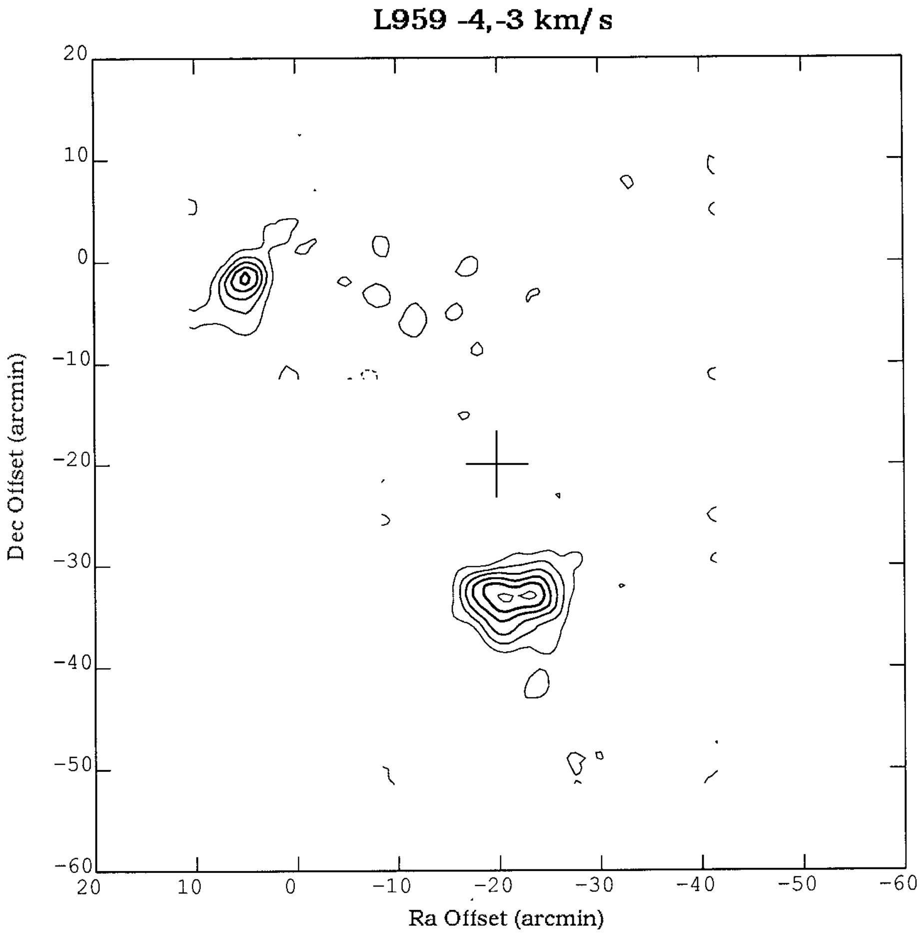

Figure 4. L959 $C^{13}O$ emission with -4 < VLSR < -3 km/s.

ules identified in the ISSA plates, L1662 and L959. We present maps of L959 in this work (fig. 2-4).

3. Discussion

The locations and directions of the "tails" in our selected sample of cometary globules (Fig. 1) suggest that the morphologies of the molecular clouds in the region have been processed by radiation or stellar winds originating near the center of Barnard's Loop. Figures 2-4) show how mass lost accelerates as it moves away from a globule. This is consistent with the description of photo-evaporation of equilibrium cometary clouds presented in Bertoldi

TABLE 1. Scans Coincident with Cometary Globules

R.A. (1950.0)	Dec. (1950.0)	V_{LSR} (km s^{-1})[a]	FWHM (km s^{-1})[a]
$4^h\ 59^m\ 23^s$	-8° 57′ 36″	+4.854 ± 0.012	1.101 ± 0.027 [b]
$5^h\ 02^m\ 17^s$	-8° 15′ 33″	+4.271 ± 0.009	0.710 ± 0.021
$5^h\ 02^m\ 00^s$	-7° 26′ 20″	-3.604 ± 0.046	1.037 ± 0.126
$5^h\ 03^m\ 16^s$	-7° 07′ 45″	-4.094 ± 0.089	2.013 ± 0.233
$5^h\ 03^m\ 38^s$	-6° 52′ 39″	-3.211 ± 0.016	1.692 ± 0.037
$5^h\ 04^m\ 46^s$	-6° 18′ 36″	-2.332 ± 0.004	1.609 ± 0.007
$5^h\ 03^m\ 37^s$	-6° 31′ 40″	-2.876 ± 0.063	1.703 ± 0.148
$5^h\ 03^m\ 15^s$	-4° 01′ 38″	+8.788 ± 0.239	1.383 ± 0.436
		+9.473 ± 0.024	0.796 ± 0.057
$5^h\ 02^m\ 58^s$	-3° 26′ 42″	+7.145 ± 0.068	1.411 ± 0.123
		+7.738 ± 0.028	0.796 ± 0.065
$5^h\ 04^m\ 16^s$	-3° 24′ 56″	+8.093 ± 0.014	2.677 ± 0.037 [c]
$5^h\ 16^m\ 42^s$	-5° 59′ 55″	+8.771 ± 0.012	1.143 ± 0.028
$5^h\ 18^m\ 08^s$	-5° 48′ 32″	+10.279 ± 0.010	1.375 ± 0.027
$5^h\ 16^m\ 49^s$	-5° 27′ 05″	+9.080 ± 0.052	1.305 ± 0.130
$5^h\ 19^m\ 09^s$	-4° 38′ 50″	+14.258 ± 0.150	1.500 ± 0.000
$5^h\ 18^m\ 05^s$	-4° 07′ 33″	+14.375 ± 0.021	1.387 ± 0.047
$5^h\ 19^m\ 39^s$	-3° 46′ 12″	+11.144 ± 0.013	1.310 ± 0.031
$5^h\ 12^m\ 08^s$	-1° 53′ 53″	-7.214 ± 0.033	1.106 ± 0.08
$5^h\ 26^m\ 30^s$	-3° 58′ 27″	+10.465 ± 0.074	1.06 ± 0.18
$5^h\ 28^m\ 14^s$	-4° 12′ 16″	+10.508 ± 0.066	1.745 ± 0.109
		+12.074 ± 0.014	0.688 ± 0.034
$5^h\ 38^m\ 25^s$	-9° 21′ 09″	+11.139 ± 0.027	1.156 ± 0.064
		+1.920 ± 0.017	1.632 ± 0.044
		+4.205 ± 0.056	2.161 ± 0.138
$5^h\ 35^m\ 24^s$	-9° 43′ 44″	+4.203 ± 0.020	1.147 ± 0.048
		+5.721 ± 0.039	0.862 ± 0.094
$5^h\ 35^m\ 16^s$	-10° 34′ 29″	+0.489 ± 0.021	1.220 ± 0.056
$6^h\ 06^m\ 42^s$	2° 46′ 52″	+8.704 ± 0.292	3.290 ± 0.517
		+11.260 ± 0.065	2.179 ± 0.231
		+9.703 ± 0.062	0.799 ± 0.147

[a] Line centers and FWHMs are from gaussian fits done in the COMB package.
[b] Same object as G64-26 in Odenwald, 1988.
[c] L959

(1989) and Bertoldi & McKee (1989). More globules should be mapped to test if this is a general characteristic of this class of objects.

The relationship between spatial position and velocity along the tails of both L1662 and L959 suggest that the material has been in motion for roughly 10 Myr, assuming a constant velocity and a distance to the globules of 500 pc. This is consistent with the age of the Orion OB1a association (Brown et al. 1994).

Using an Orion molecular cloud velocity relative to our local standard of rest of $\sim$ 5 km s^{-1}, we see that many of the Hα filaments with R.A. $> 5^{\rm h}$ are approaching us with $v \lesssim 25$ km s^{-1}. This timescale is consistent with numerical simulations (e.g., Mac Low & McCray 1988; Tenorio-Tagle & Bodenheimer 1988) of "blow out" phenomena, where super-bubbles are larger in the direction perpendicular to the Galactic plane instead of being spherically symmetric due to density gradients in the interstellar medium perpendicuar to the galactic disk. This work suggests that the Orion OB1 association is generating a disk "blow out."

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