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RED AND NEBULOUS OBJECTS IN DARK CLOUDS: A SURVEY

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ABSTRACT

A search on the NGS-PO Sky Survey photographs has revealed 150 interesting nebulous and/or red objects, mostly lying in dark clouds and not previously catalogued. Spectral classifications are presented for 55 objects. These indicate a small number of new members of the class of Herbig–Haro objects, a significant number of new T Tauri stars, and a few emission-line hot stars. It is argued that hot, high-mass stars form preferentially in the dense cores of dark clouds. The possible symbiosis of high and low mass stars is considered. A new morphology class is defined for cometary nebulae, in which a star lies on the periphery of a nebulous ring.

I. INTRODUCTION

Even a cursory survey of the nearest stellar nursery, namely the Taurus-Auriga dark clouds, reveals many nebulous objects embedded in the clouds. Subsequent spectroscopy and infrared photometry indicates their pre-main-sequence nature. The survey described here was designed to extend our knowledge of nebulous young objects to fainter limits in previously studied dark cloud complexes, and to provide a sample of such objects in hitherto uninvestigated dark clouds. It was motivated by the questions of how many faint nebulous T Tauri stars had eluded inclusion in the catalogue by Herbig and Rao (1972), and where stars of intermediate mass (~ 5 $M_{\odot}$) form.

II. THE SURVEY

The search was made on the National Geographic Society-Palomar Observatory Sky Survey photographs. It is impossible to make claims of completeness in such a search, for selection and recognition of interesting objects are often highly subjective. I have attempted to examine the entire area of every photograph although in dense star fields the survey must, of necessity, be more complete in dark clouds than in the general field. All photographs were surveyed between declination zones +90 and +6°. Between zones 0 and −42° I selected somewhat in favor of photographs covering the galactic plane. Criteria sufficient for inclusion in Table I were any of the following: extreme redness in association with nebulosity; location apparently within small dark clouds; totally nebulous character, either amorphous or cometary; location apparently on bright emission rims or at the focus of roughly parabolic arcs of nebulosity; a compact group of very red stars seemingly embedded in a common cloud. Table I presents 150 objects giving running number in this list, in order of increasing right ascension; approximate 1950 coordinates (±3 arcmin); and an abbreviated description of morphology. A number of objects found during this survey have been discussed already in the literature, individually, and were omitted from Table I. Gyulbudagyan and Magakyan (1977) have carried out similar surveys of the Sky Survey photographs and objects common to our lists are referenced with their designation too in Table I, as are some nebulae first noted by Parsamyan (1965).

III. SPECTROSCOPY

Since I wished to locate young objects in this survey, optical spectra were obtained of a hopefully representative sample of objects. These covered the range λλ4270–6700 with 7 Å resolution and all were acquired with the Cassegrain image-tube scanner (Miller, Robinson, and Wampler 1976) on the Lick Observatory 3-m telescope in the periods 1976 December 14–17 and 1977 January 12–15. Spectral classification was with respect to a library of 90 spectral standards observed with the same instrumentation. Luminosity discrimination is poor due to the low resolution of the spectra and the faintness of many of the stars (except at late spectral type where molecular features provide ready discriminants). Narrowband color indices between 5400, 6000, and 6700 Å yield total visual extinctions by comparison with the indices for unreddened standard stars (Cohen and Kuhi 1976). Table II summarizes all these data for the sample of 55 objects. Included are very brief descriptions of the emission-line spectra.

IV. NOTES ON INDIVIDUAL OBJECTS

a) 2

This is the planetary nebula BV2, listed by Perek and Kohoutek (1967), despite the irregular morphology (a bright elliptical patch with diffuse extension to the north).

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TABLE I. The catalogue.

RNO	α (1950)	δ (1950)	Description[a]
1	0h 3m4.0	63° 14′	s, cl, 2-33[b]
2	0 37.0	62 36	P, a, planetary
3	0 46.5	50 29	f, a, r, P
4	1 03.7	59 25	arc n
5	1 16.0	72 54	dP, vR
6	2 13.2	55 10	P, C, B, 1-4
7	2 24.0	72 24	s, b, R, cl
8	2 25.5	72 52	P, f
9	2 26.5	72 25	2s, b-R, vfnS; f-R
10	2 37.6	69 37	P? dh, vRc
11	2 53.9	60 27	s, cl, F, =LW Cas
12	2 57.0	60 28	s, cl, F
13	3 22.0	30 35	s, vf, vR, C, 2-55
14	3 22.3	30 34	bs, an, dark cloud edge
15	3 24.7	30 05	s, vf, vR, C, 2-13
16	3 25.6	31 08	2s, vR, an
17	3 25.7	30 21	s, R, cl
18	3 26.0	30 50	s, cl, vf, 3-3
19	3 39.8	31 49	G, 3s, cl, R, i
20	3 40.9	31 51	P, vvf, R
21	3 42.8	37 02	s, vR, cl
22	3 52.8	53 45	s, vR, cl
23	4 07.5	85 50	P, vf, an, vRc
24	4 10.5	28 15	s, cl
25	4 11.5	55 08	2s, f, cl, i
26	4 23.0	54 45	2s, f, vvR
27	4 25.2	26 12	G, 5P, vR, vvf-HH 31-A
28	4 27.0	35 44	fs, cl
29	4 27.3	35 50	s, cl (several s, cl nearby)
30	4 32.0	36 10	2P, e, vR
31	4 38.0	28 34	s, R, cl
32	4 52.5	5 28	2P, S, vf, vR, eg?
33	4 53.5	51 27	C, f, vRs (Cohen 1978), 2-3
34	5 01.3	25 13	2s, f, R, cl
35	5 04.4	−3 25	P, a, vvf, D large nebula
36	5h 04m.4	−7° 14′	2s, vvf, vR, er, vfg
37	5 05.0	−6 13	G, ~18s, vf, vR, 2 dominant cl
38	5 14.5	34 21	2s, vf, vR, cl, g
39	5 19.8	−3 42	2s, er, vR
40	5 17.15	−5 56	P, e, vR, 2-38
41	5 28.1	34 10	s, B, C, S part NGC 1931 = Parsamyan 1
42	5 29.4	6 01	bs, pseudo-rectangular dn
43	5 29.6	12 49	P, vf, vR, e, 2-16
44	5 30.1	12 51	s, vf, cl, ~6′ E of 43
45	5 32.0	−3 01	3s, vf, R, er
46	5 33.8	−6 30	s, cl, g
47	5 33.8	−6 27	P? vvf, R
48	5 35.1	35 50	s, cLn
49	5 35.9	35 45	G, 3s, cl, vR, vf
50	5 36.8	36 20	s, vR, mRln
51	5 37.05	−3 38	s? vvf, R, er
52	5 37.5	35 40	G, 4P, D big n, 3-5, 3-6, 2-65, 2-66
53	5 37.5	23 50	s, R, C, 2-64=3-4
54	5 39.3	22 36	C, Rs, ring nebula
55	5 40.0	−8 09	G, 5s, cl, 3-7?
56	5 40.7	−3 40	2s, er, f, vR
57	5 48.4	3 06	P, fc, vfh; 3′ NE s, R, cl, 3-8
58	5 55.5	−14 07	Several vRP patches
59	5 57.2	31 57	s, vR, fC, see notes, 2-5
60	5 58.3	−9 50	G, i
61	6 01.1	−9 45	s, C?
62	6 03.3	−7 20	s, vR
63	6 05.4	−5 15	s, cl, aneSvR, 2-41
64	6 05.7	18 10	s, f, vR
65	6 06.0	21 40	s, vvR, cl
66	6 06.1	−6 55	2s, cl, vR, 2-70
67	6 06.1	−6 16	P, vvf, ln, 2-69=3-11
68	6h 09m.6	17° 59′	s, cl, g, 2-19, 2-42
69	6 10.6	17 56	s, cl, an
70	6 21.3	−10 15	eg?
71	6 22.9	−10 30	G, Bs, i
72	6 29.2	10 30	s, f, vR, cl
73	6 30.9	4 02	G, 4s, 2vR, cl, i
74	6 35.3	−10 17	Bs, cl, N end of cloud

TABLE I. (Continued).

RNO	α (1950)	δ (1950)	Description[a]
75	6 38.0	9 08	s, vR, cl, S of NGC 2264, g
76	6 44.5	1 20	2s, f, vR, cl
77	6 54.8	−8 06	s, R, cl, = Parsamyan 16
78	6 54.8	−8 16	s, cl, ane W
79	6 55.5	−8 46	s, B, cl
80	6 56.6	−11 55	G, fs, i
81	6 57.2	−4 47	Rs, cl
82	6 58.5	−8 50	s, vR, cl, an
83	7 01.7	−11 15	bBs, cl
84	7 02.0	−11 00	P, a, f, vvR, g
85	7 03.6	−10 50	2Bs, cl
86	7 04.6	−11 15	G, fvRs, i
87	7 06.1	−8 54	s, cl
88	10 18.3	35 05	Rectangular n (plate flaw)
89	10 34.3	18 24	2 interacting galaxies?
90	16 31.0	−15 41	Bs, cl, 2-48=3-24
91	16 31.6	−15 44	vvRs, C
92	17 12.8	−20 53	bs, cl
93	17 13.0	−20 59	bs, cl
94	17 47.8	25 49	eg? bs + galaxy?
95	17 48.1	−14 15	bs, cl
96	17 50.0	−8 30	fs, vvR
97	18 08.8	−15 31	C, 2-9
98	18 17.8	−15 36	an
99	18 21.5	−1 02	vRs, cl, 2-49
100	18 25.6	−0 06	G3, fRs, one cl
101	18 27.2	−0 20	vRs, cl
102	18 27.2	0 44	vRs, cl
103	$18^h 28^m.8$	−2° 23′	Rs, cl
104	18 46.5	5 25	P, qb
105	18 52.0	0 52	bs, R, cl
106	18 56.7	0 49	G4, fs, vR
107	18 58.6	9 11	vRs
108	19 06.3	5 33	fs, vvR, cl
109	19 18.0	11 17	vRs, an, 2-76
110	19 24.6	23 49	Rs, cl, edge of dark cloud
111	19 24.8	22 37	vRs, f, cl
112	19 46.3	11 35	s? neutral, cl
113	19 47.9	34 16	Bipolar, planetary
114	20 03.0	29 05	Near small H II region
115	20 06.8	35 06	vr, vvRs
116	20 06.8	35 06	vf, vR, P?
117	20 08.4	27 17	2s, one R, one neutral, both cl
118	20 19.0	41 05	Rs, C, fan shaped
119	20 19.5	37 40	vfRs, in tiny circle of red Nebulosity
120	20 22.9	35 56	Rs, cl
121	20 23.2	39 03	C, vvRs + RP condensations, 3-31
122	20 30.3	40 07	C, bipolar
123	20 33.1	41 09	vRs, C + dn
124	20 35.9	67 46	C, vfvRs, ring nebula, 1-12
125	20 45.4	67 47	New fan C, fRs, Cohen, Kuhi & Harlan 1977, 2-29
126	20 54.7	52 30	fBs, cl
127	20 59.0	52 18	2 vvfs
128	20 59.0	38 35	C? bipolar, or overlapping star images
129	21 00.0	78 10	fvvRs, D Rd with starlike Rc
130	21 01.5	59 18	2s, neutral, cl, 2-54
131	21 02.4	67 55	Rs, D an
132	21 03.0	76 54	f, vvRs, cl
133	21 05.5	41 48	2 fRs, cl
134	21 20.2	46 43	fRs, C (fan-tip), 2-51
135	$21^h 32^m.9$	76° 10′	vf, vRs, cl
136	21 36.6	42 50	vvf, RP
137	21 37.8	42 57	fRs, cl
138	21 41.8	65 51	Near core of NGC 7129, s, cl, 2-57=3-32
139	22 12.0	70 00	bs, g
140	22 15.5	61 30	C? (bipolar) or 2s, one vR, cl
141	22 15.5	61 30	2s, f, cl
142	22 27.5	65 00	vf, vRsc, ln
143	22 31.9	65 04	Rs, cl
144	22 36.5	75 00	2s, vR
145	23 35.0	80 35	W component of pair, vRs
146	23 43.0	80 37	2s; b-vR, g; f-R, cl, g

TABLE I. (Continued).

RNO	α (1950)	δ (1950)	Description[a]
147	23 43.5	63 07	s, f, vR, cl, i 148, 1-15
148	23 43.5	63 07	s, vR, cl, i 147, 1-15
149	23 50.5	62 27	P, vf, an
150	23 59.2	47 50	P, vf, R, h, fc, eg?

[a] Explanation of abbreviations used in the descriptions: a = amorphous; b = bright; B = blue; c = core; C = cometary; cl = closely nebulous; d = diffuse; D = detached from; e = elongated; eg? = possibly extragalactic; er = on emission rim; f = faint; F = at focus of emission rim; g = general background nebulosity present; G = group; h = halo; i = involved in common nebulosity; l = linear; L = large ($\gtrsim$1 arcmin); m = in the middle of; n = nebula; P = purely nebulous; q = quite; R = red; s = star; v = very; the cardinal directions are rendered NSEW.

[b] References 1, 2, 3-n designate object numbers in the following lists: 1 Gyulbudagyan and Magakyan 1976; 2 Gyulbudagyan and Magakyan 1977; 3 Gyulbudagyan, Glushkov and Denisyuk 1978.

TABLE II. Spectroscopy.[a]

Object	V	Spectrum	A_V	Emission lines
1	14.1	F5	2.4 ± 0.1	Hα
2	21.5			planetary
6	13.9	B1	2.7 ± 0.1	Hα
9f	18.5	—	—	Hα
9b	14.5	F5	1.8 ± 0.1	Hα
10	18.3	—	—	—
11	17.9	AO III	5.5 ± 0.1	—
12	14.9	F1	2.1 ± 0.1	—
13	19.5	—	—	Hα, Hβ, [O I], [S II], Ca II(IR)
15	19.6	—	—	Hα, [O I], Ca II(IR)
16N	18.6	M4.5	2.1 ± 0.3	Hα, Hβ, [O I]
16S	17.7	K7	2.5 ± 0.3	Hα, Hβ, [O I]
17	14.8	M0.5	0.4 ± 0.1	Hα
18	18.7	K7	3.3 ± 0.6	Hα, Hβ
22	15.3	F5	3.3 ± 0.1	—
27				HH object = HH 31-A
31	14.9	M1.5	0.9 ± 0.3	Hα
33	15.6	M2	2.2 ± 0.4	Hα, Hβ, Hγ, Fe II, Na I, He I, [O I]
group: 37	15.0	K5	2.4 ± 0.1	Hα, Hβ, Hγ, [O I]
	14.5	K5	2.0 ± 0.1	Hα, Hβ, Hγ
	18.5	—	—	—
	18.5	M5	0.6 ± 0.3	Hα, Hβ
	17.4	K5	1.2 ± 0.2	—
	17.5	K7-M0	3.2 ± 0.1	Hα, Hβ, [O I]
	18.6	—	—	—
39f	15.8	M1	0.3 ± 0.3	Hα
39b	13.8	K6	0.0	Hα
40				HH Object
41	10.9	B1	1.3 ± 0.1	—
43				HH Object
45	17.6	M1	0.9 ± 0.3	Hα, Hβ, Hγ, [O I]
46	11.3	G1	1.6 ± 0.1	—
47	19.5	—	—	Hα, Hβ, [O I]
50	16.6	F0:	5.2 ± 0.1	Hα
51	19.0	—	—	Hα, Hβ, Hγ
53	16.4	G0	4.4 ± 0.1	Hα
54	12.8	F5 II	3.8 ± 0.3	Hα
56N	17.9	K2	1.4 ± 0.2	—
56S	17.9	K3	1.0 ± 0.1	Hα
59	16.3	—	—	Hα
63	13.3	F6	2.2 ± 0.1	Hα (P Cyg profile)
65	16.2	B2	6.6 ± 0.1	weak Hα
66f	17.5	K7	3.8 ± 0.1	Hα
66b	16.5	K6	3.2 ± 0.1	Hα, Hβ
67	21.3	—	—	—
73f	16.8	G:	4.9 ± 0.4	Hα, [N II]
73b	15.7	K0	0.2 ± 0.2	Hα, [N II]
75	16.1	K3	0.4 ± 0.1	Hα
83	11.5	B3	2.1 ± 0.1	—
84	17.4	F0	4.3 ± 0.1	Hα, [N II]
122	18.2	F0:	7:	Hα, Hβ
123	14.5:	A5:	8:	rich spectrum of H, Fe II
129	15.8	G:	0:	Hα
146b	17.2	K7	0.4 ± 0.1	—
147	19.1	—	—	—
148	16.3	F:	4.3 ± 0.2	Hα

[a] When more than one star is present, b and f denote brighter and fainter stars, respectively; N and S are similarly used to distinguish between stars in pairs.

b) 11

This small, nebulous object (LW Cas) was suggested for infrared observation by Herbig. It is a parabolic nebulosity, at whose tip lies an infrared source, projected against a small dusty region near the center of the bright emission nedula IC 1848. Broadband infrared photometry of the source is presented in Table III. Cohen (1979) has observed high frequency radio continuum emission from the direction of LW Cas. It is possible to reconcile radio, infrared, and optical observations of LW Cas (Cohen 1979) with an early B star of class V (for a distance to IC 1848 of 2.7 kpc, cf. Georgelin and Georgelin 1970).

c) 33

Cohen (1978) has described this very young T Tauri star, associated with an arcuate cometary nebula, which faded in the 1950s.

d) 54

Fawley (1974) discovered this relatively bright star on the rim of an incomplete nebulous ring. The star is a bright infrared source (Table III). A red plate, taken with the Crossley reflector at Lick Observatory on 1977 February 14, shows no obvious changes compared with the nebula's appearance in the Sky Survey.

e) 59

This star and its detached, very faint, nebulous arc are included on two adjacent Sky Survey pairs of photographs. Both the star and its nebula faded between 1951 and 1955. The optical spectrum now reveals no unusual feature, save emission at Hα.

f) 111

This bipolar nebula is totally invisible on the blue photograph, whereas it is well-exposed and striking in appearance on the red. A 1977 Crossley plate reveals a structure quite different from bipolar, however. The nebula has the appearance of a faint elliptical ring (with major axis north-south) on this plate, as if defined by two intersecting arcs. No central star is obvious. The spectrum is pure emission-line in nature and the object is in fact the planetary nebula K 3-46 (Perek and Kohoutek 1967).

g) 123

Cohen, Kuhi, and Harlan (1977) and Gyulbudagyan, Magakyan, and Amirkhanyan (1977) have described this strange nebula that has radically altered its structure since 1955. The spectrum continues to change. A rich Fe II spectrum has been in emission even at the shortest wavelengths observed (~3500 Å). The nebular structure was stable over the past two years, although there is a definite suggestion that the original nebular "streak" reappeared in early 1979.

h) 27, 40, 43

These three objects reveal spectra typical of Herbig-Haro objects. All are purely nebulous. 1976 Crossley plates of the two brighter (40 and 43) show no changes compared with the Sky Survey. 27 shows emission lines of Hα, Hβ, and Hγ, [N II], [S II]. [O I], [N I], and has log I(Hα)/I(Hβ) = 0.57, log I(Hβ)/I(Hγ) = 0.54. 40 shows all the lines of 27, together with [O III] and He I, and has a Balmer decrement (as defined for 27) of 0.70, 0.62. 43 shows no [O III] and resembles 27 although weak He I emission is seen. Its Balmer decrement is 0.78, 0.75.

V. COMETARY NEBULAE

Cometary nebulae as a class have been discussed in detail elsewhere (Cohen 1974). During the course of this survey, a new morphology was found that seems to be related to the cometaries and to represent if not a new type then at least a modification of one of the existing four types. The object Haro 2-249 is well-shown on a photograph by Strom, Grasdalen, and Strom (1974: their Fig. 5, just west of the bright star). This is an obvious, complete nebulous ring on whose periphery lies a star (Haro 2-249) with a very rich emission-line spectrum, resembling that of a T Tauri star (see Cohen and Kuhi 1979 for details). Object 122 is a very faint star slightly

TABLE III. Infrared photometry (in magnitudes with photometric errors, 1 rms of the mean) for cometary nebulae included in Table I, or relevant to the newly designated morphology, "Type V."

Object	[1.6]	[2.3]	[3.5]	[4.9]
LW Cas (22)	10.31 ± 0.07	9.11 ± 0.02	7.95 ± 0.05	6.58 ± 0.02
Haro 2-249	9.54 ± 0.02	8.31 ± 0.02	6.94 ± 0.03	
54[a]	7.76 ± 0.01	6.96 ± 0.01	5.96 ± 0.03	
Parsamyan 21	10.46 ± 0.02	9.89 ± 0.02	8.51 ± 0.05	
V1515 Cyg	7.74 ± 0.01	7.15 ± 0.01	6.33 ± 0.01	5.97 ± 0.23

[a] Another set of data obtained for object 54 on 1976 December 27 yields: [2.3] = 6.97 ± 0.01, [3.6] = 5.75 ± 0.03, [4.9] = 4.87 ± 0.11, [8.6] = 3.48 ± 0.17, [10] (broad filter) = 3.02 ± 0.20, [10.3] (narrow filter) = 2.96 ± 0.14, [11.3] = 2.70 ± 0.17, [12.8] = 2.30 ± 0.17, [18] = −0.25 ± 0.17.

offset from (to the outside) a faint complete ring of nebulosity. Object 54 represents a star on the rim of an almost complete nebulous ring. It would appear that there are sufficient of these rings with associated stars on their peripheries to define a morphology class of cometary nebulae, "Type V."

Cometary nebulae of type IV are defined to be those which show a small nebulous appendage attached to the image of the allied star (cf. Z CMa, Herbig (1960), his Fig. 10). The object V1515 Cyg, a possible emulator of FU Ori (Herbig 1977), was ascribed to class IV by Cohen (1974: V1515 Cyg is the star marked by lines in the chart for Parsamyan 22, which is the object labeled "a" by Cohen; his Plate I). However, Gyulbudagyan *et al.* (1977) have presented a recent picture of V1515 Cyg that reveals an extended elliptical ring structure that overlies the location of both star and nebulous bar on the Sky Survey. It does not appear that Z CMa, the prototypical type IV nebula, has ever appeared within such a ring. But it may be that type IV cometaries evolve into type V with the passage of sufficient time.

Type V, therefore, represents cometaries with complete or almost complete rings whose stars lie sensibly on the periphery of their nebulae, as opposed to within them. The class at present includes: Haro 2-249, objects 54 and 122, Parsamyan 21, V1515 Cyg, objects 13(?) and 15(?). All (except 122 which has not yet been observed in the infrared) are bright infrared sources (Table III).

VI. GLOBAL ISSUES

It is of great interest to ask what is the nature of the typical red and/or nebulous objects in dark clouds.

a) *Herbig-Haro-Type Objects*

These nebulous emission-line objects, without optical continua, are generally believed to have some connection with star formation. They are typically extremely faint and it would appear that the highest probability of detection arises when they are both close to the solar neighborhood and possess some photographically compact, relatively bright core (e.g., object 43). Gyulbudagyan, Glushkov, and Denisyuk (1978) have also sought these nebulosities in the Sky Survey. Several objects are common to Table I of these authors' paper and the catalogue (Table I) of the present paper. However, it should be noted that these authors obtained spectra of only a handful of their 37 objects. My own spectra of common objects reveal an obvious continuum in their candidates 3, 4, and 11, as well as a complete lack of emission lines in the spectrum of object 11 (and object 14). It is therefore probable that their list includes much less than 37 *bona fide* members of the HH class. The overall fraction of dark cloud objects known to be HH objects is thus small, although the question of incomplete sampling must certainly arise in connection with distant ($\gtrsim 1$ kpc) clouds.

b) *T Tauri Stars*

By far the largest proportion of objects in Table II is the group of cool stars, types G, K, and M, with hydrogen emission lines. Several objects (13–18) lie within the NGC 1333 dark cloud complex, for which Strom, Vrba, and Strom (1976) estimate a distance of 500 pc. The values of M_V derived for objects 16 *N/S*, 17, and 18 show them to be overluminous for dwarfs by 1–3 mag, arguing that they are T Tauri stars. It is likely that there is an appreciable number of young, low mass stars represented in Table I, for the T Tauri population is known to be abundant in dark clouds.

c) *High Mass Versus Low Mass Star Formation*

Table IV summarizes the spectral content of Table II. It is apparent that there is a surprising paucity of hot stars. Suppose we assume that Table I presents a representative sample of the general population of dark clouds, and that Table II is an unbiased cross section of the stars in Table I. Then we would expect to see OBA stars in clouds to a much greater distance than the T Tauri stars, and certainly there should not be clouds with visible T Tauri stars that do not also reveal young (probably nebulous) hot stars. That this is not the case (cf. object 33, Cohen 1978) argues that some basic assumption is unfounded. The likeliest false suppositions are that "high mass" (for our purposes $\gtrsim 5\ M_\odot$) form at the same time/in the same location as "low mass" ($\lesssim 1\ M_\odot$) stars in a complex.

Cohen and Kuhi (1979) have completed a massive study of 450 young stars with emission-line spectra, very few of which are hot stars. Several OBA stars that they did investigate are deeply embedded in the cores of clouds (where the reddening is anomalous due to the presence of large grains) in which T Tauri stars are readily visible. This indicates that while low mass stars may form throughout clouds, higher mass stars have a preference for their dense cores. (Lada, Blitz, and Elmegreen (1978) concluded that stars of high mass, which produce appreciable H II regions, are found at the surfaces of large molecular clouds. However, it is likely that even these stars originally formed within the clouds and subsequently dispersed the surrounding material. The difference between the locations of hot stars in, say, W3 and the Taurus-Auriga complex would then be a function of the evolutionary phase of star formation within regions in the different complexes.) It is entirely possible that the "unclassifiable" spectra of Table IV represent hot stars, in which case they too are heavily reddened (on the basis of their continuum slopes). Furthermore, some of these potential high mass stars lie in associations of known distance (e.g., object 15, in NGC 1333 clouds), yet the combination of V, A_V, and M_V yields extreme

TABLE IV. Distribution of spectra of objects in Table II.

Herbig-Haro	3
Planetary nebulae	2
Unclassifiable	9
O-type	0
B	4
A	2
F	10
G	4
K	14
M	7

distances, one or two orders of magnitude larger than the known values. This could be evidence either for strong neutral extinction (due to large grains), or for compact nebulosities that merely reflect the light of an otherwise invisible hot star (object 67, lying in Mon R2, is a good candidate for this latter hypothesis). Consequently, there is mounting evidence that high mass stars do not form in every location in which low mass star formation has occurred.

A temporal separation between high and low mass stars is much more difficult to establish. The major problem is that the richest OB-associations are so distant that their low mass stellar components are quite unknown from preliminary Hα-emission surveys (e.g., typical T Tauri stars at the distance of W3 would have V ~ 18–19). Orion provides a simultaneous view of O- and T-associations, although it is not yet clear, due to the complex structure of this volume, if these have arisen in common regions of space. One may speculate on the symbiosis of high and low mass stars, but clues are scarce. It could be that energetic stellar winds from very young T Tauri stars are necessary to support large clouds against collapse and fragmentation to so small a scale that high mass stars could not be formed (cf. Silk and Norman 1979). Subsequently, the strong winds from high mass stars formed within the dense cores of clouds could sweep clean a significant volume of the clouds, switching off the formation of low mass stars, and eventually dispersing totally the remnant cloud.

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