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RADIAL VELOCITIES AND SPECTRAL TYPES OF T TAURI STARS*

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ABSTRACT

Absorption-line radial velocities have been measured for about 50 T Tauri stars on 34 Å mm^{-1} spectrograms of the 5850–6700 Å region; the standard deviation of the velocity from an average plate is 4 km s^{-1}. Only emission lines were measurable in about 10 other stars. The scatter of the absorption velocities with respect to the molecular cloud velocities is small, but the true dispersion is concealed by errors of measurement; an upper limit on the intrinsic dispersion of about 3 km s^{-1} is estimated. Single spectrograms of three stars do show larger velocity discrepancies, and require further investigation. One fairly well-observed star (RY Tau) may be a single-line spectroscopic binary. The number of large residuals is about as expected if the proportion of spectroscopic binaries in the sample is the same as is found among F3–G2, IV and V stars near the Sun. The T Tauri velocities in the mean indicate no systematic radial motion of stars with respect to the molecular clouds. Velocities from emission lines on the average seem to agree with those from the absorption-line spectra, but there is a substantial scatter. The displacement of the absorption reversal in Hα, with respect to the stellar velocity, ranges between about -300 and $+60$ km s^{-1} in different stars, with a frequency peak near -80 km s^{-1}. Although a few mildly positively shifted reversals do occur in the sample, no "reversed P Cygni" structure of the YY Orionis type is seen at any star, including YY Ori itself. The spectral types of these stars range from G to M4. With a few exceptions, they are mostly of luminosity class V. A few T Tauri stars are observed to lie outside cloud boundaries, but it is not yet clear how they have escaped.

Subject headings: interstellar: molecules — stars: emission-line — stars: pre-main-sequence — stars: spectral classification — stars: stellar dynamics

I. INTRODUCTION AND OBSERVATIONS

One expects that stars formed from interstellar clouds would show only a small velocity dispersion with respect to the cloud material. The very limited information available on proper motions of T Tauri stars in the Taurus-Auriga dark nebulae, as well as the relatively accurate radial velocities for a very few bright objects (both discussed by Herbig 1962), appeared to support a velocity dispersion in those clouds of about 2 km s^{-1}. Radial velocities for many more faint T Tauri stars were published by Joy (1945, 1949). However, these were measured at very low dispersion in spectra often confused by emission lines, and are of insufficient accuracy for this purpose.

The radial-velocity problem was taken up recently for two reasons: the availability of red-sensitive image intensifiers which make it possible to observe faint stars with moderate spectroscopic dispersion in a spectral region where the stellar absorption lines are relatively free from emission-line interference; and the availability of radial velocities for the dark clouds upon which these T Tauri stars are superposed, obtained from radiofrequency lines of H_2CO and CO. This new program concentrated upon the brighter objects in the Tau-Aur nebulae, but similar spectrograms were obtained for stars elsewhere in the sky, as time permitted. Preliminary results from the first season's work have been reported (Osterbrock 1976).

The spectrograms were obtained at the coudé spectrograph of the Lick 120 inch (3 m) reflector. The dispersion of 34 Å mm^{-1} was produced in the first order of a 600 groove mm^{-1} Babcock grating by the 20 inch (51 cm) camera, with a 40 mm Varo electrostatic image intensifier having extended S-20 sensitivity mounted at its Newtonian focus. Originally the cooling arrangement was as described by Zappala (1970), where the intensifier is cooled by thermal contact with cold boxes that were changed when the cathode temperature rose to about 0° C. That system in effect allowed the temperature to cycle between about $-8°$ and 0°, and although no thermal shifts in the spectrum were observed, this seemed an undesirable arrangement for a radial-velocity program. In early 1976 it was therefore replaced by a system in which cold nitrogen gas, boiled off liquid N_2 and carried to the spectrograph in a vacuum-jacketed line about 7 m long, is forced continuously through a porous copper block that surrounds the cathode end of the intensifier. The cathode temperature can now be held to a few tenths of a degree for hours at a time (usually near $-8°$ C) by adjusting the N_2 boil-off rate. However, no improvement was detected in the internal or external errors of velocities measured on spectrograms obtained with the new system.

The emulsion employed throughout was Kodak

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103a-D, which was pressed into contact with the rear fiber-optic faceplate. A projected slit width of 36 μm (0".94 in the coudé focal plane) was generally used, wider than usual in order to reduce exposure times. There is no indication that velocities obtained with this wide slit differ systematically from those with a width of 21 μm, although the difference in definition of the spectrograms is apparent. The plates were widened to 0.6 mm for the brighter stars, but only to 0.25 mm for the faintest. At the narrower width, a spectrogram well exposed in the 6000–6600 Å region could be obtained for a star of $V = 13.5$, $B - V = +1.8$ in about 20 minutes, in fair seeing. All the exposures were guided with the aid of a three-stage Varo intensifier that replaced the usual slit-viewing system. Some 90 spectrograms of about 50 T Tauri stars were obtained in this program. The plates were centered at 6350 Å, and were of adequate definition for measurement between about 5850 and 6700 Å. In addition, Dr. L. V. Kuhi very kindly lent about 40 additional spectrograms, mostly of the same stars, that had been taken for another purpose with the same equipment but at a slit width of 21 μm and with central wavelength 6200 Å.

II. RADIAL VELOCITIES

a) *Absorption-Line Velocities*

Standard-velocity stars were usually observed on the same nights as the T Tauri stars; their brightness was reduced when necessary by neutral filters. A number of G5 to M2 dwarfs having velocities of quality *a* or *b* in Wilson's *General Catalogue of Radial Velocities* were used to establish the velocity system. The wavelengths of all reasonably strong lines in these spectra were measured and corrected for the *Catalog* velocity. About 15 lines were retained whose positions showed an acceptably small scatter and no obvious dependence on spectral type. It is upon this short list of empirical wavelengths that the present velocities depend. All the measurements were made in two coordinates on a digitized Grant comparator, and were reduced with a program (developed by Mr. Douglas Duncan) that corrected for the asymmetric pincushion distortion of the image-intensifier field. The individual plate velocities are given in Table 1. Also listed is the formal standard deviation of this value, calculated from the scatter of individual lines, and the number of lines measured. All plates have, however, been regarded as having the same weight in forming the mean velocities for each star given in Table 1. The emission-line and other velocities given in Table 1 will be discussed later.

The differences between the measured velocities of 19 spectrograms of 10 standard stars and their *Catalog* values scatter symmetrically about zero; the mean is 0.0 ± 1.0 (s.d.) km s^{-1}. This shows that in the mean, the present velocities lie quite near the *Catalog* system.[1] The standard deviation of the individual residuals, which measures the external error of an individual velocity together with the contribution of *Catalog* velocity errors, is 4.4 km s^{-1}. As usual, this is larger than the internal error inferred from the agreement of individual lines on the same plate. For these same 19 spectrograms, that is 1.8 km s^{-1} on the average.

Molecular velocities have been measured in these same dark clouds by a number of radio observers, but here attention is restricted to H_2CO absorption velocities by Dieter (1975) and ^{12}CO emission velocities determined by Knapp (1976, private communication). Both these lists were generously furnished in advance of publication. In both series, the radio observation was made at the optical position of the T Tauri star.

For the Tau-Aur cloud stars, the residuals, ΔV, of measured absorption-line star velocity *minus* molecular-line cloud velocity, scatter symmetrically about a mean of $\langle \Delta V \rangle = +0.2 \pm 0.9$ km s^{-1}, if each of the 26 stars is given equal weight regardless of the number of spectrograms measured. If the individual stars are weighted in proportion to number of plates, then $\langle \Delta V \rangle = +0.4 \pm 0.5$ km s^{-1}. The corresponding external error of the average plate is 3.9 km s^{-1}, which essentially agrees with that obtained from the standard stars. Omitted from these means are four stars for which no molecular velocities are available (VY, DK, DM, and GG Tau) and three for which single spectrograms indicate a major difference between star and cloud (DQ and DS Tau, GM Aur), discussed in note 4. Also omitted are stars for which only emission lines could be measured either because the absorption spectrum was veiled or because the spectrograms were underexposed. A number of spectrograms, arranged in order of increasing visibility of the absorption spectrum on account of decreasing strength of the veiling continuum, are shown in Figure 1 (Plate 6).

Several interesting conclusions can be drawn from these results.

1. Within the uncertainty of the present velocities, a close kinetic association is demonstrated between T Tauri stars and dark clouds. There is no indication of any systematic motion of these stars as a group; for example, they are not all being ejected from the nebulae, at least at velocities in excess of a few km s^{-1}. One observes that there is also no evidence for significant radial motion in the absorption-line regions of these T Tauri stars, such as a general rising or falling of those layers (unless, of course, these two hypothetical effects are both present and fortuitously cancel one another).

The first serious attempt to compare T Tauri star velocities with cloud velocities from molecular lines was made by Gahm and Winnberg (1971), on the basis of a small number of stellar velocities by Joy (1945)

[1] Nine additional spectrograms of HD 95735, type M2 V, were also obtained. Their mean measured velocity is -91 ± 2 km s^{-1}, which lies well off the *Catalog* value of -86.5 km s^{-1} (quality *b*). It is even farther from the more recent single 10 Å mm^{-1} velocity of -85.5 km s^{-1}, and that from seven 38 Å mm^{-1} plates of -82.9 km s^{-1}, published by Wilson (1967). The star was discovered to be an astrometric binary by Lippincott (1960), but more recent measurements do not support the period of 8 years found at that time (Lippincott 1976, private communication).

TABLE 1

RADIAL VELOCITIES OF T TAURI STARS

HRC (1)	STAR (2)	JD⊙ 2440000.+ (3)	V* (4)	σ (5)	n (6)	Hα VELOCITY Em. (7)	Abs. Rev. (8)	Peaks (9)	V_{LSR}* (10)	V_{LSR}^{mol} (11)	ΔV (12)
10.....	Lk Hα 264	2296.89†	+9	2	8	...	...	...	...	...	...
		2731.72	e (a)			−2:	−154	−205 +52			
			+9	...	...	...	...	...	+1	...	...
11.....	Lk Hα 325	2405.75†	−13:	6	8	−6	...	...	...	...	...
20.....	Lk Hα 330	2296.93†	+20	4	5	+2	...	...	...	...	...
									+14		
...* ...	Anon.	1348.71	+12	2	13	+5 *S*	...	...			
									+3	+6.8	−3
... .	HD 283447	1318.74	+18	1	14	+18	...	...	...	...	...
		1318.85	+19	2	18	+17	...	...	...	...	...
		1639.75	+11	3	16	+29	...	...	...	...	...
			+16	...	...	...	...	...	+7	+6.8	0
23.....	FM Tau	2770.69	e	...	...	+1	...	...	...	...	...
25.....	CW Tau	2296.96†	+28	2	9	...	−18	−155 +140	...	...	...
		2770.67	e	...	...	−14:	−27	−149 +114	...	...	...
			+28	...	...	...	...	...	+19	+6.9	+12
26.....	FP Tau	1618.85	+22	1	6	+43	−19	...			
									+12	(+8.2)	(+4)
28.....	CY Tau	1581.94	+18	2	6	+20 *S*	...	...			
									+9	+7.1	+2
29.....	V410 Tau	1318.78	+16	2	12	−6 *S*	...	...	...	...	...
		1580.93	+22	2	12	+3 *S*	...	...	...	...	...
		2295.96†	+22	1	11	...	...	...	...	...	...
		2415.69	+20	2	12	...	...	...	...	...	...
			+20	...	...	...	...	...	+11	+7.4	+4
...* ...	Hubble 4	1318.82	+13	2	13	+15 *S*	...	...	...	...	...
		1580.97	+15	1	16	+12 *S*	...	...	...	...	...
		2851.63	+10	2	9	+5 *S*	...	...	...	...	...
			+13	...	...	...	...	...	+4	+7.3	−3
32.....	BP Tau	1582.99	+13	3	13	+15	...	...	...	...	...
		2295.99†	+23	2	10	−8	...	...	...	...	...
		2297.91†	+22	2	12	+19:	...	...	...	...	...
		2377.76†	+1	2	7	−12	...	...	...	...	...
		2405.86†	+18	2	9	+18	...	...	...	...	...
		2434.62†	−10	4	5	−21	...	...	...	...	...
		2436.61†	+12	4	9	+11	...	...	...	...	...
		2675.86†	+23	2	7	−12	...	...	...	...	...
		2676.95†	+15	3	6	−26	...	...	...	...	...
		2767.80†	+15	2	5	+3	...	...	...	...	...
		2798.64†	+15	2	9	+14	...	...	...	...	...
			+14						+5	+7.1	−2
33.....	DE Tau	2297.96†	+16	5	5	+6	...	...	...	...	...
		2731.89	+9	3	7	+3	...	...	...	...	...
		2770.76	+21:	4	4	−1	+58	...	...	...	...
			+15	...	...	...	...	...	+6	+7.0	−1
34.....	RY Tau	1581.01	+23	3	13	+15	−67	...	...	...	...
		2297.94†	+30	2	9	...	−27	−145 +119	...	...	...
		2474.68	+29	3	11	+26	−41	−164 +150	...	...	...
		2675.99‡	+12	1	10	...	−52	−174 +144	...	...	...
		2824.68	+12	2	11	+4	−40	−141 +111	...	...	...
			+21	...	...	...	...	...	+12	+7.1	+5
35*....	T Tau	0556.66	+20	2	13	+15	...	...	...	...	...
		1581.03	+24	2	14	+20	...	...	...	...	...
		2297.04†	+26	2	12	+18	...	...	...	...	...
		2325.98†	+24	2	11	+18	...	...	...	...	...
		2675.92‡	+18	1	9	...	...	...	...	...	...
			+22	...	...	...	...	...	+11	+8.1	+3
36.....	DF Tau	2296.02†	+18	2	6	−1:	−92:	...	...	...	...
		2713.97	+11	5	6	+7	−94:	...	...	...	...
		2770.81	+8	3	8	−1	−94:	... +25	...	...	...
			+12	...	...	...	...	...	+3	+6.7	−4
37.....	DG Tau	2085.67	e	...	...	...	...	...	...	...	...
		2297.01†	e	...	...	...	...	...	...	...	...
38.....	DH Tau	2298.00†	+21	2	12	+13	...	...	...	...	...
		2770.72	+14	3	10	−7 *S*	...	...	...	...	...
			+18	...	...	...	...	...	+8	+6.4	+1
39.....	DI Tau	2298.03†	+19	4	4	−5	...	...	...	...	...
		2713.91	+18	2	13	+9 *S*	...	...	...	...	...

TABLE 1—*Continued*

HRC (1)	Star (2)	JD⊙ 2440000.+ (3)	V^* (4)	σ (5)	n (6)	Hα Velocity: Em. (7)	Hα Velocity: Abs. Rev. (8)	Hα Velocity: Peaks (9)	V_{LSR}^* (10)	V_{LSR}^{mol} (11)	ΔV (12)
39.....	DI Tau	2770.74	+8	2	12	−2 *S*	...	...	...	...	...
			+15	...	...	...	...	...	+5	+6.3	−1
42.....	UX Tau B	2415.85	+18	4	9	+9 *S*	...	...	...	...	...
									+6	+7.2	−2
43.....	UX Tau A	1619.88	+21	1	16	+6	−42	...	...	...	...
		2377.83	+23	2	9	+12	...	...	...	...	...
		2769.90	+15	2	15	−13	+75	−84 +159	...	...	...
			+20	...	...	...	...	...	+8	+7.2	0
45.....	DK Tau	2713.99	+17	3	11	−37	+23:	...	...	...	...
		2770.78	+5	3	9	−14	+104:	...	...	...	...
			+11	...	...	...	...	...	+1	...	...
49*....	HL Tau	2415.80	e (u)	...	...	+5	...	...	...	...	...
50.....	XZ Tau	2415.80	e (u)	...	...	−6	−91	−230 +130	...	...	...
53.....	UZ Tau W	2730.87	e (u)	...	...	+4	−76	−96 +30	...	...	...
52.....	UZ Tau E	1380.65	e (a)	...	...	+2	−94	...	...	...	...
		2731.94	e (a)	...	...	+10	−64	−134 +63	...	...	...
54.....	GG Tau	2713.87	+15	2	12	+5	...	...	...	...	...
		2769.85	+14	2	12	−2	...	...	...	...	...
			+14	...	...	...	...	...	+2	...	...
55.....	GH Tau	1639.80	+12	4	9	+16	−52	...	+1	+6.6	−5
...*....	SVS 1849	2850.72	+22	4	9	+20 *S*	...	...	...	...	...
		2851.65	+30	3	7	+33 *S*	...	...	...	...	...
			+26	...	...	...	...	...	+16	...	...
56.....	GI Tau	2732.03	+10	3	8	+13	...	...	...	...	...
		2769.75	+22	3	7	−11	−58	−94 +21	...	...	...
			+16	...	...	...	...	...	+5	+6.6	−1
57.....	GK Tau	2731.97	e (u)	...	...	−12	+6	−97 +89	...	...	...
		2769.68	e (u)	...	...	...	−28	−108 +81	...	...	...
		2769.70	+16	4	9	...	−30	−113 +76	...	...	...
									+6	+6.5	−1
58.....	DL Tau	2085.76	e (a)	...	...	+1	−94	...	...	...	...
61.....	CI Tau	2085.70	+9	4	9	+12	...	...	−2	+5.6	−8
62.....	DM Tau	2769.81	+11	5	5	+10	+8	...	−1	...	
63.....	AA Tau	2377.93	+19	5	6	+24	−7	−81 +106	...	...	...
		2731.86	+9	3	8	−43	+9	−117 +72	...	...	...
			+14	...	...	...	...	...	+4	+5.2	−2
65.....	DN Tau	2714.02	+17	2	11	...	+75:	−5 +137	...	...	...
		2770.83	+11	2	10	+7	...	...	...	...	...
			+14	...	...	...	...	...	+3	+5.6	−2
67.....	DO Tau	2085.64	+20	4	6	+21	−93:	...	+10	+6.4	+3
...*....	Comp DO Tau	2086.71	+11	6	5	+15 *S*	...	...	+1	+6.4	−5
68.....	VY Tau	2416.69	+16	2	13	+7 *S*	...	...	+6	...	...
72.....	DQ Tau	2850.70	−4	5	6	+2:	...	...	−17	+9.6	−27
74.....	DR Tau	2824.75	e	...	...	...	−211	−371 +98	...	...	...
75.....	DS Tau	2770.92	0	3	8	−8	−51	−118: +35:	−10	+7.7	−18
76.....	UY Aur A	2474.72	+21	4	7	+18	...	...	...	...	...
		2824.73	+14:	6	9	−11	−10	−162 +41	...	...	...
			+18	...	...	...	...	...	+9	+6.5	+2
77.....	GM Aur	2851.66	−12	2	12	−22	−27	−111 +61	−21	+6:	−27:
79*....	SU Aur	2325.90†	+22	5	7	...	−44	−154 +71	...	...	...
		2474.70	+25	3	9	+41	−60	−157 +94	...	...	...
		2824.66	+26	2	10	...	−61	−165 ...	...	...	...
			+24	...	...	...	...	...	+15	+6.1	+9
80.....	RW Aur A	1619.91	e	...	...	...	−78	−239 +132	...	...	...
		2824.66	+18:	1	4	...	−57	−191 +138	+8:	...	...
84.....	CO Ori	2732.05	+28	5	8	...	−48	−263 +100	...	...	...
		2769.97	+17	2	10	...	−59	−220 +125	...	...	...
			+23	...	...	...	...	...	+8	...	...
85.....	GW Ori	2326.91†	+37	3	8	+36	...	...	...	...	...
		2732.06	+34	3	8	+50	...	...	...	...	...
		2769.96	+32	2	11	+38	...	...	...	...	...
			+34	...	...	...	...	...	+20	...	...

TABLE 1—*Continued*

HRC (1)	STAR (2)	JD⊙ 2440000.+ (3)	V^* (4)	σ (5)	n (6)	Hα VELOCITY: Em. (7)	Hα VELOCITY: Abs. Rev. (8)	Hα VELOCITY: Peaks (9)	V_{LSR}^* (10)	V_{LSR}^{mol} (11)	ΔV (12)
86.....	V649 Ori	2326.94†	+34	2	13	+45	...	...	+19	...	...
113.....	P 1404	2326.99†	+29	2	11	...	...	...	+11	+8.9	+2
116.....	IU Ori	2326.06†	+35	2	14	abs	...	...	+17	+8.2	+8
119.....	YY Ori	2086.77	+12:	5	7	+9	−81:	−153 +101:	−6:	+8.1	−14:
121.....	P 1649	2327.02†	+38	2	13	...	...	...	+20	+8.3	+12
164.....	V380 Ori	1619.95	e	...	...	+22	...	...	...	...	...
248.....	CoD−33°10685	2239.75	−12	2	8	−51	−17?	−110 +19	−6	+4.7	−11
250.....	CoD−35°10525	2239.77	−5	2	10	−46	−15	−136 +73	+1	...	...
252.....	RY Lup	1131.74	+1	2	16	−73	−90	...	+6	...	...
253.....	EX Lup	2205.80	−8:	5	7	−33	...	...	−3:	...	...
254*....	AS 205	1088.81	e (u)	...	...	...	−210	−285 −18*	...	...	...
		1132.75	−25	3	9	...	−247:	−312 −48*	...	...	...
		2504.87	e (a)	...	...	...	−245	...	−14	...	...
259.....	S-R 4	2198.81†	−3	2	11	...	...	...	+7	+3.2	+4
270.....	V1121 Oph	1088.88	−10	3	10	−5	...	...	...	...	...
		2297.65†	−10	3	8	...	...	...	+3	...	...
286.....	S CrA	1132.87	e (a)	...	...	−22:	−133	...	...	...	...
292.....	AS 353 A	2202.94	e	...	...	...	−165	−364 +73	...	...	...
		2295.75†	e	...	...	...	−196	−308 +81:	...	...	...
302.....	V1331 Cyg	2289.88	e	...	...	...	−365	... +69	...	...	...
315.....	DI Cep	1995.68	−10	2	11	...	−309	−378 +21	+1	+1.2	0
... .	AS 507	1348.62	−10	3	12	−5	−90	−152 +303	+1	...	...
318.....	BM And	2295.89	−24	4	7	−55	−34	−164 +81	...	...	...
		2770.58	−30	2	7	−102	−63	−176 +49	...	...	...
			−27	...	...	...	...	...	−18	−7.4	−11

Col. (1): The numbers are from the Herbig-Rao (1972) Catalog; an asterisk indicates that a note follows.
Col. (3): The heliocentric JD of the spectrogram is followed by a dagger (†) if the spectrogram is one of the 34 Å mm^{-1} Kuhi series (see § I). A double dagger (‡) indicates a Kuhi spectrogram of dispersion 17 Å mm^{-1}.
Cols. (4), (5), (6): V^* is the mean heliocentric absorption-line velocity measured on that spectrogram, and σ is the formal standard deviation of that mean, all in km s^{-1}; n is the number of lines measured. If there is more than one plate, the mean is given as the last entry in col. (4). The following abbreviations are used:
e: only emission lines are present;
e (a): a few weak absorption lines can be seen;
e (u): the plate is underexposed so that only emission lines can be measured.
Cols. (7), (8), (9): Velocities of structure in the Hα emission line: Em. is the position of the point in the line midway between the steepest points in the wings. This velocity is followed by an *S* if the line is narrow. Abs. Rev. is the position of the reversal. Peaks are the positions of the intensity maxima on either side of the reversal.
Cols. (10), (11), (12): On the last line for each star, V_{LSR}^* is the mean velocity of col. (4) corrected for a solar motion of 20 km s^{-1} toward 18^h +30° (1900). V_{LSR}^{mol} is the velocity of the molecular cloud at the position of the star from H_2CO, CO, or a mean of both. ΔV is V_{LSR}^* *minus* V_{LSR}^{mol}; since the ΔV's were computed with one more significant figure than tabulated here, round-off sometimes causes an apparent discrepancy of one unit in ΔV.

... *Anon.*—This nebulous star is 11′ in 300° from HD 283447. Photoelectric observations by R. Stone on two successive nights in 1972 gave: V = 13.58, 13.46; $B - V$ = 1.79, 1.92.
... *Hubble 4.*—1922, *Ap. J.*, **56**, 162, Table 3. Photoelectric measurements by R. Stone on single nights in 1972 Feb. and Sept. gave: V = 12.78, 12.68; $B - V$ = 1.72, 1.64; $U - B$ = 1.33, 1.06.
35 T Tau.—On these 34 Å mm^{-1} spectrograms, the reversal was lost in the overexposed image of Hα. Two 11 Å mm^{-1} plates obtained on JD 1582.0 showed the reversal at −53 km s^{-1}, and the two emission peaks at −77 and about +12 km s^{-1}.
49 HL Tau.—Only emission lines are measurable on this plate. Five lines of [O I], [S II], and He I give $V = -15 \pm 2$ km s^{-1}, which does not agree with the velocity of −122 km s^{-1} reported by Strom, Grasdalen, and Strom (1974).
... *SVS 1849.*—See the note to Table 2.
... *Comp DO Tau.*—This nebulous star is about 1′.5 east of DO Tau.
79 SU Aur.—There is apparently a weak longward reversal in Hα as well as the strong one shortward.
254 AS 205.—On the first spectrogram, the velocity of −18 km s^{-1} refers to the point of maximum intensity in the longward component; the center of gravity of that component is at about +89 km s^{-1}. On the second plate, the same displacements are −48 and +50 km s^{-1}, respectively.

and cloud velocities from OH 1667 MHz. It is now apparent that their result, namely that (in the present notation) $\langle \Delta V \rangle \approx +9$ km s^{-1}, arose from the large contribution by RY Tau and SU Aur, two stars which indeed do have large positive ΔV's when the present velocities are substituted for Joy's: $\Delta V = +5$ and $+9$ km s^{-1}, respectively. A smaller velocity residual was later obtained by Gahm *et al.* (1974) for RU Lup, $\Delta V = -2.0$ km s^{-1}, but in that case the stellar velocity was obtained from emission lines, and the significance of the small residual was hence not quite obvious.

2. The true dispersion of the star velocities with respect to the clouds is lost in the errors of the present observations. Since the standard stars give $\sigma(V) =$ 4.4 km s^{-1}, while $\sigma(\Delta V) = 3.9$ km s^{-1}, the true σ for stars with respect to clouds must be less than about 3 km s^{-1}. Such a velocity dispersion (in one coordinate) is compatible with the old estimate of about 2 km s^{-1} mentioned in the first paragraph of this paper.

3. There has been occasional interest in the wavelength of the Li I λ6707 line, which is so prominent in T Tauri–type spectra. The line is measurable on most of the spectrograms centered at λ6350, although it lies in a region where the image-intensifier definition has begun to deteriorate. With this reservation, the mean wavelength from 47 plates is 6707.785 ± 0.03 Å, when reduced in each case with the stellar velocity from the same spectrogram. The line is a close doublet; the stronger ^{7}Li component is at 6707.761, the weaker at 6707.912 Å. The wavelength of the unresolved blend in terrestrial lithium depends upon the optical thicknesses of the components and other conditions in the source; values sometimes quoted are 6707.81 (King 1916) and 6707.844 Å (*MIT Tables*). All uncertainties considered, the measured wavelength in T Tauri stars does not seem inconsistent with those values.

b) *Emission-Line Velocities*

The physical significance of emission-line velocities in T Tauri stars has never been clear. In the blue-ultraviolet region of stars like RW Aur, there seems to be a real scatter in the velocities given by different lines and ions. To the extent that blending in these complicated spectra can be excluded, the effect may be caused by asymmetric self-reversal in varying degree. Velocities that have been measured in less crowded spectra but at low dispersion probably are affected by inclusion of the H, Ca II, and Na I lines, all of which can have complex structure. On the present series of 34 Å mm^{-1} plates in the red, the emission spectra are rather simple, and it is possible to measure the structure of Hα and the position of the bright He I lines fairly well. In several stars, lines of Fe II can also be measured. The [O I] lines λλ6300, 6363 are also present in many stars, and Na I λλ5889, 5895 in a few, but these can be affected by airglow line emission. The spectra shown in Figure 1 are representative. In the remarks that follow, laboratory wavelengths have been used for the emission lines.

The Hα emission line in many stars is divided by a deep absorption reversal, but the position of the whole emission line can be measured with some consistency on the Grant comparator, by ignoring the reversal and the point of peak intensity, and locating the midpoint between the steep sides of the profile. (This, however, has not been attempted with the very wide lines.) On the average, the Hα emission velocity agrees rather well with the absorption lines; a mean Hα shift of -11 ± 3 km s^{-1} is obtained from 71 spectrograms, although on individual plates the shift ranges between about $+5$ and -30 km s^{-1}. The nonzero value for the mean shift may reflect only the problem of locating the midpoint of such a wide and often somewhat asymmetric line; on these plates, the wings of emission Hα often can be traced to ±500 km s^{-1}. The situation is most safely described by the statement that there is no evidence for a shift of emission Hα in excess of about 10 km s^{-1}. An equally interesting point is that the presence or absence of an absorption reversal seems to have no effect upon the measured shift of the whole Hα emission line, unless of course the entire wing of the emission line is obliterated, as happens in a few cases.

One or both of the He I lines λλ5875, 6678 could be measured on 34 plates, from which were excluded those stars that have strong [S II] emission in which the He I lines might contain a contribution from a low-density envelope. The mean He I shift is $+7 \pm$ 2 km s^{-1}. This result ought to be more reliable than that from Hα. Lines of Fe II could also be measured in several stars, but in those cases, the absorption-line spectrum is usually obliterated by continuous emission. Probably the only significant result comes from DG Tau, in which four unblended Fe II lines give a (heliocentric) velocity of $+14$ km s^{-1}, as compared with the $+16.4$ km s^{-1} from H_2CO and CO at that point. In this one instance, at least, there is no evidence for any large shift of Fe II.

It is concluded that the emission lines in the red reproduce the absorption-line velocities of the T Tauri stars quite well, in the mean. What is not clear from these measurements is whether the rather substantial scatter between emission and absorption lines on individual spectrograms is real or not.

c) *Absorption Reversals in* Hα

As is well known, the Balmer emission lines (as well as lines of Ca II and Na I) in T Tauri stars are frequently cut by what appear to be absorption reversals, usually but not always having shortward displacements. It is these reversals that constitute the evidence for an outflowing "T Tauri solar wind." In the better-observed stars, the positions and finer structure of these reversals are subject to some variation. On the present series of spectrograms, there is a large range in strength of the Hα reversal among the stars observed: from examples in which no reversal at all can be seen to those, such as V1331 Cyg, AS 353A, and DR Tau, in which it is very strong and deep (see Fig. 1). In these latter stars, there can be no doubt that the structure is of the conventional P Cygni type. Unfortunately, since these plates were generally exposed for the continuum and absorption lines, the Hα emission is often too dense for the detection of weak absorption reversals, so that the sample is as a consequence somewhat biased.

Several qualitative statements can be made about the reversals observed in this sample of T Tauri stars. In all cases, the reversal displacement is given with respect to the absorption-line velocity on the same spectrogram, or, in a few, with respect to the molecular-line velocity. It refers to the minimum-intensity point in the feature, not to the center of gravity of the absorption profile.

There is a large range in the measured displacement; see the histogram, Figure 2. The distribution peaks near -80 km s^{-1}, but the spread is from -300 to about $+60$ km s^{-1}. There are only a few stars that have positive displacements. None of these longward reversals is very strong, but there seems no reason to doubt their reality. On none of these spectrograms was there any evidence for "reversed P Cygni structure" of the type described by Walker (1972) in YY Ori and other stars. The one red spectrogram of YY Ori available here showed only a conventional absorption reversal at about -90 km s^{-1}.

No convincing correlation has been found between the displacement or the strength of the reversal and such quantities as the amount of extinction, spectral type, or emission-line width. It is possible that reversal displacement is weakly correlated with the ultraviolet excesses measured by Kuhi (1974), in the sense that some of the stars which have the largest negative displacements also have large ultraviolet excesses. But some stars with large excesses have no detectable reversals at all. It is also possible that the stars which have the largest negative displacements tend to have the stronger reversals, but to be sure of this, one must await a proper determination of the equivalent width of the reversals on these plates.

d) *Forbidden Lines*

Lines of [S II], [O I], and [O II] occur in the spectra of a number of T Tauri stars. In T Tau and HL Tau, these lines largely (or perhaps entirely) originate in small emission nebulae, closely surrounding the stars, which can be photographed directly. The [S II] lines λλ6716, 6730 appear also in several other stars on plates on the present series: CW Tau, DO Tau, DG Tau, and less strongly in DL Tau. The [S II] lines λλ4068, 4076 had already been discovered by Joy (1949) in the first three stars. He also noted [S II] in DN Tau and DQ Tau, but the red [S II] lines are not apparent in either object on the present spectrograms. Possibly the emission nebulae at these stars are variable, as is the case at T Tau. The images of several of these stars are diffuse on the Palomar Atlas plates; close examination at high resolution might reveal the nebulae directly.

III. SPECTRAL CLASSIFICATION

For types K0 and later, spectral classification can be performed with some confidence in this spectral region

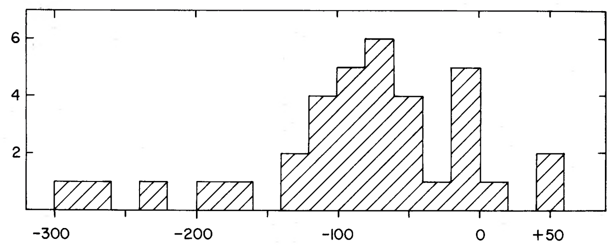

FIG. 2.—The frequency distribution of displacements of the absorption reversal in Hα with respect to the stellar absorption-line velocity, for all stars listed in Table 1. (In a few cases, the molecular cloud velocity was used as reference instead.) UX Tau A is not included because of the disagreement of the displacement as measured on two different spectrograms: -63 and $+60$ km s^{-1}.

on the basis of metallic line ratios, by reference to MK standards. Earlier than K0, however, the metallic lines are weak and change only slowly with temperature. Later than about M3, bands of TiO and MgH become strong, and classification depends increasingly upon band strengths, which is not very satisfactory when continuous emission is present. Except for a few luminous objects of types G and early K, all these spectra resemble luminosity class V, a fact recognized long ago by Joy. Most of these stars lie several magnitudes above the main sequence, but there is no suggestion of that fact in the luminosity-sensitive lines in the red, although, since class IV is not defined in the MK system later than K1, one must make do by comparison with class III and V standards.

Classifications for all the T Tauri stars observed in this program are given in Table 2, together with earlier types assigned by Joy, by Rydgren, Strom, and Strom (1976), and by others. The frequency distribution of types in Tau-Aur is shown as a histogram in Figure 3. It is uncertain whether the decline in numbers of stars later than M1 is real, or an effect of selection because the later types become increasingly fainter. The observed lack of types later than about M4 in Figure 3 is expected qualitatively in both the Hayashi and Larson pictures of pre-main-sequence evolution. In the former, it is a consequence of the region forbidden to fully convective stars cooler than about $T_{\rm eff} =$ 3500 K. In the Larson (1972) view, the cores of young stars do not become visible through their infalling envelopes until substantial surface temperatures are

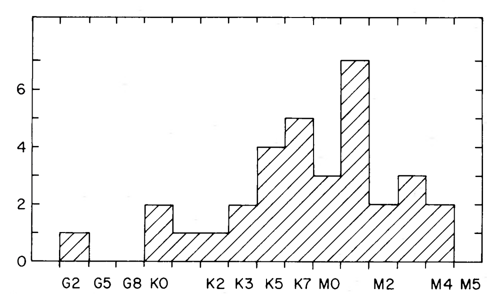

FIG. 3.—The frequency distribution of spectral types for stars in the Taurus-Auriga clouds, from Table 2.

TABLE 2

SPECTRAL CLASSIFICATIONS OF T TAURI STARS

		CLASSIFICATION FROM		
HRC (1)	STAR (2)	Joy or HRC (3)	Rydgren *et al.* (4)	This Paper (5)
10	Lk Hα 264	...	...	K5e V(Li)
11*	Lk Hα 325	K2eα	...	~K5eα
20*	Lk Hα 330	G2eα	...	~F6eα
23*	FM Tau	...	?	...
...*	Anon.	...	...	M0eα V(Li)
...	HD283447	...	K2	K3eV (Li)
25	CW Tau	dK5e	?	K0e V(Li)
26	FP Tau	dM2.5e	M2+	M4e V(Li)
28	CY Tau	dM2e	...	M1e V(Li)
29	V410 Tau	dK5	...	K3eα V(Li)
...*	Hubble 4	dK8	...	K7eα (Li)
32*	BP Tau	dK5e	?	K5,7e V(Li)
33	DE Tau	dM1e	M1	M3e V(Li)
34	RY Tau	dG0	~G5	K1e IV,V(Li)
35	T Tau	dG5	~K1	K0e IV,V(Li)
36*	DF Tau	dM1e	?	M3e V(Li)
37*	DG Tau	Ge	?	...
38	DH Tau	dM0e	~M0	M1e V(Li)
39	DI Tau	dM1e	M0	M0eα V(Li)
42	UX Tau B	dM2.5e	...	M1eα V(Li)
43	UX Tau A	dG5	G5	K2e V(Li)
45	DK Tau	dM0e	K7:	K5,7e V(Li)
52*	UZ Tau E	dM1.5e	...	M1,3e V(Li)
53*	UZ Tau W	dM3e	...	M4e V(Li)
54	GG Tau	dK6e	K7	K5e V(Li)
55	GH Tau	M2eα	...	M3e V(Li)
...*	SVS 1849	...	...	M3eα V
56	GI Tau	K5e	K7	K5e V(Li)
57	GK Tau	K5(e)	K5	K7:e V(Li)
58	DL Tau	Ge	?†	K7e V(Li)
61	CI Tau	Ge	?†	K7e V(Li)
62	DM Tau	dK5e	M?	M2e V(Li)
63	AA Tau	dM1e	?	K5e V(Li)
65	DN Tau	dK6e	M0:	M1:e V(Li)
67	DO Tau	Ge	?†	M1e V(Li)
...*	Comp DO Tau	...	...	M1eα V(Li)
68*	VY Tau	...	...	M0eα V(Li)
72	DQ Tau	dM0e	...	M1e V(Li)
74*	DR Tau	dK5e	...	...
75	DS Tau	dK4e	...	M0:e V(Li)
76	UY Aur A	dG5:e	...	K7:e V(Li)
77*	GM Aur	dK5e	...	K3e V
79*	SU Aur	G2 III	~G2 III	Geα (Li)
80*	RW Aur	dG5e	?	...
84*	CO Ori	Gpeα	...	F8:neα V(Li)
85	GW Ori	dK3e	...	G5,8eα V(Li)
86	V649 Ori	dK3e	...	G8eα III,V(Li)
113	P1404	G5:eα	...	G5eα III,V(Li)
119*	YY Ori	G-Ke	...	M0:ne V
...*	BD+1°1156	...	...	K2:n
121*	P1649	K0–2 III,IV	...	G2 III,IV
248	CoD−33°10685	Geα	...	K2eα V(Li)
250	CoD−35°10525	...	...	K7e V(Li)
252	RY Lup	G0eα V	...	K1:eα V(Li)
253*	EX Lup	...	...	M0:e V(Li)
254	AS 205	...	...	M0:e V(Li)
259*	S-R 4	K5e	~K7	K0:e V
270	V1121 Oph	K0±	...	Ke V(Li)
286*	S CrA	...	...	...
292*	AS 353A	...	...	...
302*	V1331 Cyg	...	...	...
315*	DI Cep	dK3e	...	G8:e V:(Li)
...	AS 507	...	...	G5,8eα V(Li)
318*	BM And	F8:eα	...	K5eα V(Li)

NOTES TO TABLE 2

Col. (1): The numbers are those of the Herbig-Rao (1972) Catalog. An asterisk indicates that there is a note, below.

Col. (3): These classifications are usually taken from Joy (1945, 1949) or Joy and Abt (1974); otherwise the type is that given by Herbig and Rao.

Col. (4): The type assigned by Rydgren, Strom, and Strom (1976); a question mark means veiled by continuous emission. For the stars marked by daggers, Rydgren *et al.* quoted a type attributed to Herbig (private communication); those were preliminary estimates from these same plates.

Col. (5): A type such as K5,7 means that it could lie anywhere between K5 and K7; "eα" means that Hα was the only emission line detected in the yellow-red region; (Li) means that Li I λ6707 is present.

11 Lk Hα *325*.—The single spectrogram is underexposed; λ6707 would have been undetectable even if present.

20 Lk Hα *330*.—It is not certain whether λ6707 is present or not.

23 FM Tau.—Only Hα and He I are in emission. The spectrum is nearly continuous, but a few very faint, unclassifiable absorption lines are present.

... *Anon*., *Hubble 4*.—These stars are identified in Table 1.

32 BP Tau.—Types estimated on individual spectrograms range between K3 and M0. Emission of variable intensity and structure at the Na I lines on these plates has been described by Kuhi (1975).

36 DF Tau.—The [O I] lines are very strong, but [S II] is not present.

37 DG Tau.—The emission-line spectrum is very rich, including strong He I, Fe II, Na I, [O I], [S II]. Continuous emission is also very intense; a few vague minima are probably the stronger absorption lines of a late-type star, but no type can be assigned.

52, 53 UZ Tau.—It is the *eastern* star of this pair that exhibited a major flareup in 1921 (Herbig, unpublished). In the red, both stars have veiled M-type absorption spectra with Hα and He I in emission, but only the eastern shows strong [O I].

... *SVS 1849*.—This flare star, discovered by Tsessevich (1972), lies at the edge of a dark cloud that contains a number of T Tauri stars. The star is certainly a dwarf and has narrow emission at Hα, but the radial velocity differs by about 10 km s^{-1} from that of the molecular cloud, and in addition the Li I λ6707 line is absent. Probably SVS 1849 is a foreground object.

... *Comp DO Tau*.—See Table 1.

68 VY Tau.—This spectrum was observed near minimum light.

74 DR Tau.—Hα is very intense, with classical P Cygni structure. Slightly diffuse emission lines of He I, Fe II, Na I, [O I] are present. No absorption spectrum can be seen with certainty.

77 GM Aur.—The spectrogram is too underexposed to determine whether λ6707 is present or not.

79 SU Aur.—Classification of early G-type spectra is very uncertain in this spectral region at this resolution. The type of G2 III assigned from the photographic region could well be correct.

80 RW Aur.—The bright-line spectrum is very rich, and continuous emission strong. Traces of a few late-type features are present but unclassifiable. These spectrograms were taken when the variable was bright, so contamination by the companion is unlikely.

84 CO Ori.—The star was near maximum when these plates were obtained. The star is a close double ($\sim 1''$), but unfortunately the seeing was not good enough to determine which component was bright.

119 YY Ori.—The absorption spectrum is diffuse and difficult to classify; λ6707 may be present.

... *BD+1°1156*.—This bright nebulous star, with several much fainter T Tauri stars lying nearby, has such very broad absorption lines that the classification is uncertain. Hα is in absorption with a weak shortward emission fringe. A weak λ6707 may be present.

121 P1649.—The Hα emission is from the superposed H II region. λ6707 does not appear to be present.

253 EX Lup.—This spectrum was observed at minimum light.

259 S-R 4.—This spectrogram is defective near λ6707.

286 S CrA.—The Hα emission is very strong; He I, Fe II, Na I, [O I] are also present. A few faint unclassifiable absorption features are visible under the strong continuous emission.

292 AS 353A.—Powerful P Cygni structure is present at Hα. The emission spectrum is very rich, and includes Na I. No stellar absorption lines are present.

302 V1331 Cyg.—Hα shows classical P Cygni structure (see Fig. 1). Many emission lines are present, including Fe I in unusual strength. No stellar absorption spectrum can be seen.

315 DI Cep.—Hα is strong, with a weak shortward absorption fringe. He I and Na I are also in emission.

318 BM And.—This new classification conflicts with that of F8 assigned from the photographic region. The three original Lick spectrograms (dispersion 130 Å mm^{-1}) taken in 1949, upon which that type was based, have been reexamined. It is clear that the F8 classification rested almost entirely upon the strength of the Balmer lines in absorption; they are much too strong for a K star. This effect, namely, that the H lines are too strong for the metallic spectrum, has been noted in other T Tauri stars; it is quite conspicuous at high dispersion. Presumably it is due to the contribution of a shell. It was the realization that the Balmer lines are best ignored that was responsible for the change in the classifications of RY Tau and T Tau, from Joy's original assignments of dG0 and dG5, respectively, to early K (Kuhi 1964).

achieved. For example, the surface of a star of mass 0.25 $M_\odot$ should become visible at about type M1, of 0.5 $M_\odot$ at M0, of 1.0 $M_\odot$ at K5, and 1.5 $M_\odot$ at K3. The existence of T Tauri stars at types M3 and M4 would thus imply very small masses, but presumably Larson's early calculations are to be regarded as only indicative.

A striking characteristic of the spectra of T Tauri stars is the presence of the Li I λ6707 line in considerable strength. The notation (Li) has been added to the types in Table 2 whenever λ6707 was clearly present. The line is ordinarily undetectable at this resolution in conventional main-sequence stars later than about K0

(Herbig 1965, 1973). Yet it is so universally present in T Tauri–type and other Orion population stars that it must now be considered a primary criterion for their identification. Its application to the task of identifying post–T Tauri stars will be discussed in another paper.

Four T Tauri stars (CI, DG, DL, and DO Tau) which have very crowded emission spectra were classified simply as Ge by Joy (1949), from 220 Å mm^{-1} spectrograms in the blue. It has here been possible to assign better types in three of these cases, from the absorption spectra in the red; they are in fact types K7 to M1. It is obvious in this spectral region and at this resolution that in such stars the late-type lines are truly "veiled," and not simply blurred or broadened: they remain narrow as their equivalent widths are reduced by the superposed continuous emission.[2] This can be seen from the spectra shown in Figure 1. From these spectrograms it is also apparent that the famous "blue continuum" extends through the red region as well, and is there a smooth continuum rather than a lumpy mass of imperfectly resolved emission lines.

IV. DISCUSSION

If stars form from the material of a dense cloud which is itself gravitationally bound, then one would expect that those stars would lack the energy to escape.[3] The observed concentration of T Tauri stars within the Tau-Aur cloud boundaries (see Fig. 4) would then appear understandable. The binding is, however, very weak: the velocity of escape from the surface of a spherical cloud of radius R and mean density of ρ is $(8\pi G\rho/3)^{1/2}R$. For $R = 2$ pc and $\rho = 100$ H atoms cm^{-3}, reasonable values for Tau-Aur, v_{esc} is only 0.6 km s^{-1}.

There are a few stars that lie outside the main masses of the Tau-Aur clouds: RW Aur is the best example (Fig. 4). SU Aur is a well-observed star that seems to have a residual velocity ($\Delta V = +9$ km s^{-1}) sufficient for escape. RY Tau may be another ($\Delta V = +5$ km s^{-1}), but it appears to have a variable velocity, so that its correct mean V may not have been measured. There are thus a few objects that seem to defy elementary expectation.[4] A future paper will discuss other examples elsewhere in the sky.

[2] Possibly stimulated by the familiar broadening of the absorption lines in some T Tauri stars, there had been speculations that the weakening of the absorption spectra in stars like DG Tau might be due to a similar effect, perhaps by the diffusion of a narrow-lined spectrum through a blanket of high-speed scatterers.

[3] If the clouds were instead contained by external pressure, then the internal motions would be more indicative of the stellar velocities to be expected. In the dense clouds where T Tauri stars are found, the widths of molecular lines show that internal velocities are very small.

[4] Large residual velocities were measured on single spectrograms of three other stars: DQ Tau ($\Delta V = -27$ km s^{-1}), DS Tau (-18 km s^{-1}), and GM Aur (-27 km s^{-1}). The plates of the latter two stars are underexposed, and the velocities somewhat uncertain. Judgment is best reserved on the reality of these discrepancies until additional spectrograms have been obtained.

One can imagine several ways that stars might be able to escape, short of dispersing the cloud itself, as follows: (1) Some stars might be accelerated as part of the process of formation, as, for example, the ejection of one component of a multiple star system. (2) One observes that the real Tau-Aur clouds are not even approximately spherical: they project upon the sky as irregular masses with ropy, extended tentacles or streamers (Fig. 4). It is possible that, in such complex configurations, there will be points where the local velocity of escape is low, and a low-velocity star could leak away. (3) The present geometry of the Tau-Aur clouds is not permanent. Over an extended period, the clouds could be reconfigured in such a way as to spill out some of the stars contained within them. There seems little one can do to clarify such questions observationally.

An original aim of this radial-velocity program has not been achieved for lack of sufficient accuracy, but the idea deserves mention because it is probably still attainable. Basically, it was that, since the observable T Tauri stars are on the near side of the clouds, two situations can be imagined. If the stars are all trapped, then they will all be located near the outer turning points of their orbits, and their radial velocities should show a small symmetric dispersion about the cloud velocity. But if some or all of these stars were able to move radially outward and escape immediately following formation, then there would be a preponderance of negative residual velocities. The present observations have shown that no major effect of this second kind is present, but the errors are too large for a critical test. It is technically feasible with existing equipment to improve the accuracy of these velocities by a factor of about 3, and still be able to reach a substantial number of the Tau-Aur cloud stars. This may be just enough of an improvement to make the results interesting.

Another question of some importance is whether spectroscopic binaries exist among the T Tauri stars. Although only one spectrogram is available for about half the stars observed, one has now the advantage of having demonstrated that the normal stellar velocity should lie very near that of the molecular cloud, so that in principle a variable velocity T Tauri star could be detected from one observation alone. To predict the number of detectable binaries in this particular sample of Tau-Aur cloud stars, the two assumptions are made at the outset that (i) these objects will eventually reach the main sequence as normal stars approximately in the 1–2 solar mass range, and (ii) they will have a normal complement of binaries. To test the second assumption, we proceed to compare them *en masse* with the collection of bright stars between F3 and G2, luminosity classes IV and V, that has recently been examined for spectroscopic binaries by Abt and Levy (1976). It is thus assumed that the binary frequency, masses, orbital dimensions and orientations, etc., are the same in the two groups. We expect that, on these particular T Tauri spectrograms, a velocity more than 10 km s^{-1} off the cloud velocity would have been suspect. Similarly, a double-line binary with a splitting of more than 100 km s^{-1} would

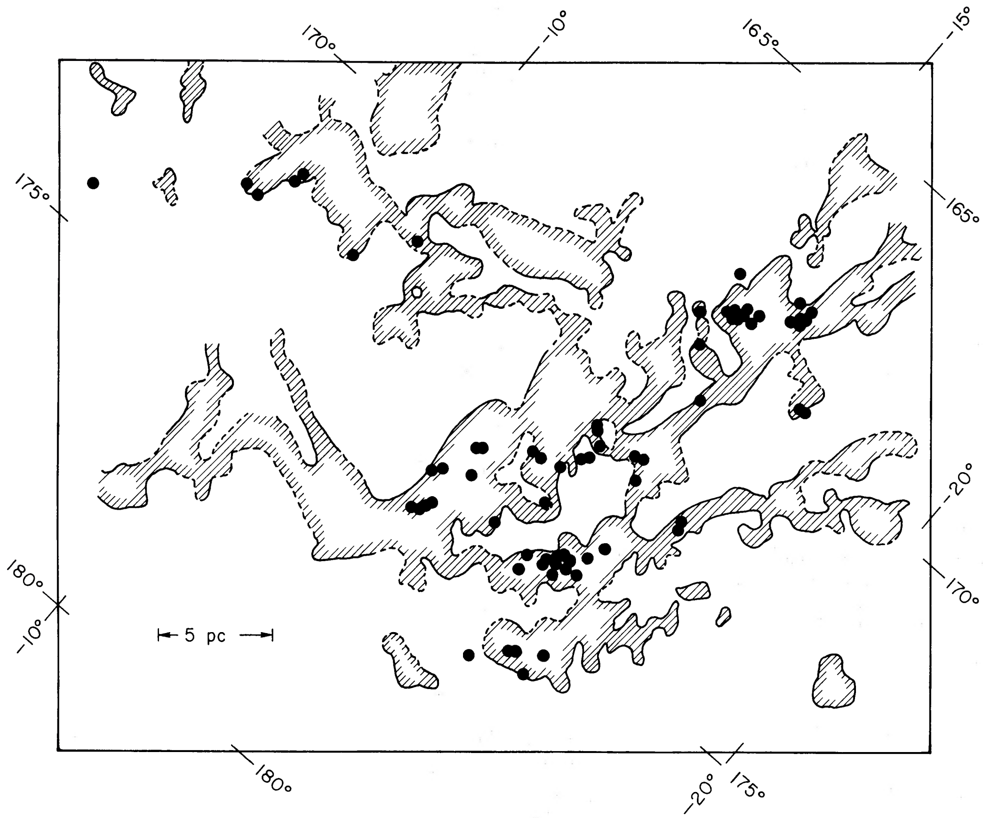

FIG. 4.—The optical boundaries of the Taurus-Auriga dark clouds; they are approximately the contours of $A_{pg} = 1.5$ mag. The positions of all confirmed T Tauri stars are plotted (*solid circles*); in some crowded regions, the scale is expanded for clarity. RW Aur is the point well outside the cloud boundaries in the upper left. Galactic coordinates are indicated along the margins.

have been noticed. Fortunately, Abt and Levy tabulate the individual velocities for all their spectrograms. One finds that, among the 131 stars they observed, 198 velocities out of 2704 exceed our velocity tolerances. Only 69 spectrograms are available for 29 Tau-Aur stars for which the absorption-line velocity as well as cloud velocity is known, and therefore among these one expects to find $198 \times 69/2704 = 5.1$ similarly discrepant velocities. In addition, since 10 km s^{-1} is 2.3 times the standard deviation of a standard star velocity (§ II), if the errors are distributed normally then $0.022 \times 69 = 1.5$ additional velocities should lie outside the $\Delta V = 10 \text{ km s}^{-1}$ limits, for purely accidental reasons. Thus one expects about seven Tau-Aur velocities to violate that tolerance. The actual number of deviant spectrograms in Table 1 is nine, which is acceptably close to expectation. But of these, three represent the widely discrepant stars mentioned in note 4; if those are provisionally set aside for reobservation, the agreement with expectation is still good.

It is concluded that there is no reason to question assumption (ii); i.e., the proportion of variable velocities among these T Tauri stars does not differ obviously from that on the main sequence, although a number of binaries will have to be detected and studied before much more can be said. It may be noted that, since the probability of eclipses for a given separation of centers increases in proportion to the radii of the components, more eclipsing variables should be detectable among these objects while they are T Tauri stars than after they reach the main sequence. The discovery of close binaries is of some importance, because in no other way will there be a convincing mass determination for one of these objects.

Finally, it will be noted that the small velocity dispersion of the T Tauri stars is in sharp contrast to that of the Herbig-Haro objects, where one velocity of -150 km s^{-1} is well established, and two cases are known of objects having cross-motions of that same order (Cudworth and Herbig, unpublished). It is thus difficult to defend the notion that such isolated Herbig-Haro objects (as distinct from the spectroscopically similar forbidden-line envelopes at some T Tauri stars) are the evolutionary precursors of T Tauri stars.

V. SUMMARY

The principal conclusions of this investigation are as follows.

1. The absorption-line velocities of the T Tauri stars examined here are the same, within the errors of measurement, as the velocities of the molecular clouds upon which they are projected. There is thus no

evidence that newly formed stars are systematically being ejected from these nebulae, although the velocity of escape would be well below the threshold of these observations. As expected, any intrinsic dispersion in the stellar velocities is hidden in the errors, and must be less than about 3 km s^{-1}.

2. Emission lines in the red give velocities that are, in the mean, not far from the absorption-line values. The absorption reversals seen against Hα in many stars have displacements that in different stars range from −300 to about +60 km s^{-1}, but are predominantly negative.

3. Spectral types of the Tau-Aur stars range from early G to about M4, with a frequency peak near M0. All except a few of the earliest are of luminosity class V. Unfortunately the cutoff near M4 does not provide a critical test of evolutionary theories.

4. The fraction of stellar velocities that lie well off the molecular cloud velocity is about that to be expected if the normal main-sequence fraction of spectroscopic binaries exists among these T Tauri stars.

I am very grateful to Dr. L. V. Kuhi for allowing me to measure the radial velocities of his collection of T Tauri star spectrograms, and to Drs. N. H. Dieter and G. R. Knapp for providing me with their formaldehyde and CO velocities, respectively, in advance of publication. I am also much indebted to Dr. D. M. Rank for advice on cryogenic problems, to Mr. R. Stone for *UBV* photometry, to Mr. Douglas Duncan for his development of the two-coordinate reduction program for image-intensifier spectrograms, and to him and Mr. David Soderblom for assistance at the telescope. I am also very appreciative of the hospitality of Professor Dr. H. Elsässer and the Max-Planck-Institut für Astronomie, Heidelberg, where this paper was written. Crucial support for the entire investigation has been provided by the National Science Foundation.

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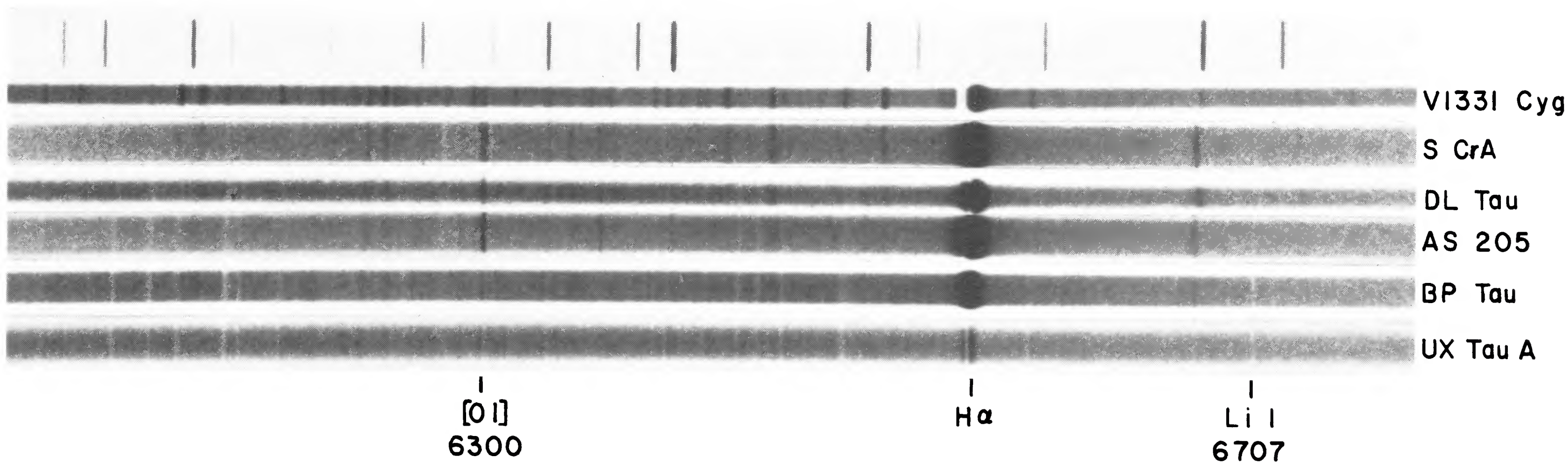

FIG. 1.—Representative 34 Å mm^{-1} spectrograms of T Tauri stars between about 6050 and 6750 Å. They are arranged from top to bottom in order of increasing visibility of the underlying absorption spectrum, which is also the order of decreasing strength of the emission lines. (The erratic ordering of [O I] λ6300 is caused by the airglow contributions; the absorption feature just shortward is atmospheric.) The prominence of Li I λ6707 is also to be noted. V1331 Cyg clearly shows classical P Cygni structure at Hα; in some of the other stars, the absorption reversals in Hα are suppressed by overexposure.

HERBIG (*see* page 748)