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HIGH-RESOLUTION SPECTROSCOPY OF SOME VERY ACTIVE SOUTHERN STARS

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ABSTRACT

We have obtained high-resolution echelle spectra of 18 solar-type stars that an earlier survey showed to have very high levels of Ca II H and K emission. Most of these stars belong to close binary systems, but five remain as probable single stars or well-separated binaries that are younger than the Pleiades on the basis of their lithium abundances and Hα emission. Three of these probable single stars also lie more than 1 mag above the main sequence in a color-magnitude diagram, and appear to have ages of 10 to 15 Myr. Two of them, HD 202917 and HD 222259, also appear to have a kinematic association with the pre–main-sequence multiple system HD 98800.

Key words: binaries: spectroscopic — stars: abundances — stars: chromospheres — stars: kinematics — stars: late-type — stars: rotation

1. INTRODUCTION

Two years ago we published a survey of Ca II H and K emission strengths in more than 800 southern solar-type stars (Henry et al. 1996, hereafter Paper I), determined from low-resolution ($R \approx 2000$) spectra obtained at Cerro Tololo Inter-American Observatory (CTIO). The purpose of the survey was to provide at least rough estimates of the ages of the individual stars, and to examine the distribution of emission strengths in a large and unbiased sample. The very existence of a simple or single relationship between chromospheric emission (CE) and age is debatable, but there is ample evidence that CE declines steadily with age (Skumanich 1972; Soderblom, Duncan, & Johnson 1991). In other words, we are confident of a general decline of CE with age because of observations of stars in clusters, and also because CE is so intimately tied to stellar rotation (and we know that rotation declines with age in solar-type stars). But we also know that the CE levels of individual stars vary as a result of rotational modulation of active regions, long-term cycles, and other phenomena, and that not all stars reach the zero-age main sequence (ZAMS) with the same angular momentum, and thus we are not so sure that there is a unique CE-age relation that applies to all stars.

The survey of Paper I included stars from a G dwarf sample defined using the combination of two-dimensional spectral types (Houk & Cowley 1975; Houk 1978, 1982; Houk & Smith-Moore 1988) and Strömgren photometry (Olsen 1988, 1993), and it turned up two groups of stars that we have studied further. The first group we called "very active" (VA), because they exhibited CE levels well above any seen in the field stars of the earlier survey of Vaughan & Preston (1980). The second group is called "very inactive," and consists of stars that appear to have activity levels well below the Sun's. The very inactive stars will be the subject of a future paper.

Here we concentrate on the VA stars, and we are led to examine them in detail for several reasons. First, stars with very high levels of activity are that way because they rotate rapidly, and they rotate rapidly either because they are very young (and have not yet lost much of their initial angular momentum) or because they are in a close binary system (where the companion's tidal forces lead to synchronous rotation). Both types of systems are interesting, and both types offer laboratories for the study of the rotation-activity relation.

A second reason for undertaking this detailed study is to find very young stars in the immediate solar neighborhood (i.e., within about 50 pc). Even if they were evenly mixed in the Galaxy, very young stars would be rare simply because their ages ($\lesssim 100$ Myr) represent such a small fraction of the age of the Galactic disk. But such stars are *not* evenly mixed, because they form in discrete regions and take time to be dispersed into the field. There may be a few stars near the Sun that are as young as, say, the Pleiades, but they are few indeed. However, even small numbers matter, since they imply that many more such stars lie in the much vaster volume of the greater solar neighborhood (i.e., within ~ 100 pc). Some of these very young field stars, such as the HD 98800 system, may be examples of the elusive post–T Tauri star class (see, e.g., Soderblom et al. 1998).

The moderate-resolution spectra obtained for Paper I were centered on the Ca II H and K lines to determine the level of CE. We have obtained higher resolution echelle spectra to confirm their high activity levels (at Hα), to test for youth (with Li), and to observe each star several times to search for radial velocity changes indicative of close companions.

2. OBSERVATIONS AND DATA ANALYSIS

We obtained high-resolution spectra of our VA sample members over four nights in 1996 April using the CTIO 1.5 m telescope, the fiber-fed bench-mounted echelle spectrograph, and a Tektronix 2048 × 2048 CCD. We observed 18 stars in 16 systems that were accessible at that time, taken from Table 6 of Paper I. This instrument, with a 45 μm slit, yielded a dispersion of 0.051 Å pixel^{-1} and a measured

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resolving power (from the FWHM of ThAr lines) of approximately 60,000. A 2 × 1 binning across the dispersion reduced readout time and read noise. The spectra are centered near Hα, with coverage from 5600 to 7750 Å after discarding the lowest signal-to-noise ratio (S/N) orders that are farthest from the center of the CCD. During the first night a different cross-disperser was used, and the wavelength coverage was somewhat less: from 5900 to 7110 Å. Table 1 contains a summary of the observations and achieved per-pixel S/N in the Hα and Li regions.

TABLE 1

Observations of Southern Very Active Stars

HD	HJD (2,450,000+)	t_{exp} (s)	S/N	$v \sin i$ (km s^{-1})	v_{rad} (km s^{-1})
		Program Stars			
37572A	201.453	900	82	7 ± 2	+28.9 ± 0.8
	201.464	900	81		
	202.440	300	46		
41824AB	200.470	900	101		+2.7 ± 3
	201.476	300	64	4, 7 (±2)	Δ = 23.8 ± 0.4
54579	201.480	900	67		
	201.491	900	68		
	201.502	900	67		
	202.533	300	32	≤140	
102982...........	200.692	900	41	≤100	
106506...........	200.708	900	42	70 ± 8	
	201.681	300	31		
119022...........	199.670	900	77	120 ± 25	+20 ± 5
	200.732	300	44		
	201.685	300	48		
123732...........	199.684	900	82	≤150	
	200.720	900	85		
151770...........	200.737	900	66		
	200.753	900	66		
	200.764	900	67		
	200.775	900	67		
	201.729	300	37		
155555AB	199.767	600	93		
163029 NE	199.791	600	35		
	199.815	600	36		
	200.787	900	49	≤3, ≤4	−28 ± 3
	201.837	300	27		
163029 SW......	199.799	600	40	10 ± 3	
	199.807	600	39		
	200.799	900	57		−26 ± 3
	201.841	300	34		
174429...........	199.889	600	46	58 ± 7	−13.5 ± 3.0
175897...........	199.898	600	43	≤190	
	200.810	900	58		+20.7 ± 4.5
	201.846	300	31		
177996...........	199.906	600	62		−38.4 ± 1.5
	200.822	300	45	≤4, 4	Δ = 35.2 ± 0.6
	201.896	300	45		Δ = 20.3 ± 0.5
180445...........	199.914	600	47	8 ± 3	
	200.827	600	50		Δ = −105 ± 7
	201.900	300	34		Δ = +85 ± 5
202917...........	200.898	900	55	12 ± 4	−5.3 ± 1.0
	200.909	900	56		
	201.905	300	31		
222259A	201.910	900	57	13 ± 3	+5.2 ± 1.0
	201.921	500	41		
	202.924	300	32		
222259B	201.927	900	33		+3.5 ± 0.8
	201.938	630	33		
	202.928	600	28		
		Inactive Comparison Stars			
38392	200.453	600	144		
38393	200.448	300	254		
45067	200.461	600	139		
76151	200.528	600	133		
81809	200.537	600	176		
	201.559	600	198		
115617...........	199.658	600	237		
	202.668	600	277		
158614 N........	199.824	600	109		
158614 S	200.921	300	141		

TABLE 2

SPECTROSCOPIC RESULTS

HD	ID	$B-V$	$T_{\rm eff}$ (K)	$\log R'_{\rm HK}$	$W_\lambda({\rm H}\alpha)$ Å	$F_{{\rm H}\alpha}$ (10^6 ergs cm^{-2} s^{-1})	$\log R_{{\rm H}\alpha}$	W_λ(Li) (mÅ)	$\log N$(Li)	[Fe/H]	Notes
Known or Probable Short-Period Binaries											
41824A	A1	0.680	5580	−4.17	…	…	…	≤16	≤1.57	…	1
41824B	A2	0.720	5440	…	…	…	…	…	…	…	1
54579	B	0.585	5940	−4.07	…	…	…	…	…	…	2, 3
102982	C	0.641	5720	−3.86	…	…	…	…	…	…	4, 5
106506	D	0.605	5860	−3.97	…	…	…	…	…	…	4, 6
119022	E	0.743	5360	−4.00	…	…	…	350:	3.9:	…	6, 7, 8, 9
123732	F	0.568	6020	−3.93	…	…	…	…	…	…	2, 3, 10
151770	G	0.676	5600	−3.90	…	…	…	yes	…	…	11
155555AB	H	0.798	5180	−3.67	…	…	…	Strong	…	…	12
163029 NE	J	1.082	4420	…	…	…	…	≤26	≤0.35	…	2
163029 SW	K	0.808	5140	…	0.65	2.59	−4.19	41	1.51	−0.05 ± 0.2	13, 14, 15
177996	L	0.877	4940	−4.17	…	…	…	25:	1.04	…	2, 15
180445	M	0.809	5140	−3.96	…	…	…	≤50	≤1.61	…	2, 16
222259B	N	1.078	4420	−3.99	…	…	…	193:	1.58:	…	2, 7, 17
Apparently Single Stars											
37572A	P	0.845	5040	−4.10	0.43	1.55	−4.37	253	2.78	−0.02 ± 0.1	
174429	Q	0.784	5220	−3.77	0.63	2.69	−4.20	267	3.16	…	
175897	R	0.649	5700	−3.87	0.35	3.08	−4.29	…	≤3.6	…	18
202917	S	0.682	5580	−4.06	0.69	3.86	−4.15	227	3.28	+0.06 ± 0.1	
222259A	T	0.679	5580	−3.97	0.60	3.26	−4.23	207	3.15	+0.06 ± 0.2	17
Inactive Comparison Stars											
38392		0.94	4760	−4.50	…	…	…	≤17	≤0.63	…	
38393		0.481	6380	−4.94	…	…	…	46	2.74	…	
45067		0.564	6040	−5.09	…	…	…	33	2.31	…	
76151		0.661	5660	−4.67	…	…	…	17	1.65	…	
81809		0.642	5720	−4.92	…	…	…	≤8	≤1.38	…	
115617		0.709	5480	−5.00	…	…	…	≤3	≤0.70	…	
158614 N		0.72	5440	−5.03	…	…	…	≤8	≤1.09	…	
158614 S		0.72	5440	−5.03	…	…	…	≤10	≤1.19	…	

NOTES.—(1) Multiple; (2) SB2; (3) broad-lined; (4) probable SB2; (5) Photometric variable?; (6) circumstellar/interstellar features; (7) Variable Hα; (8) SB?; (9) reddening; (10) W UMa system; (11) SB3 or SB4?; (12) Hα emission, triple?; (13) SB; (14) SB2?; (15) intermediate age?; (16) very weak Hα; (17) asymmetric CCF; (18) Very broad-lined.

Data reduction used standard IRAF[2] tasks and the specialized routines in the ECHELLE package. Preliminary processing consisted of overscan subtraction, trimming, and debiasing. After flat-fielding with a nightly master flat, the orders were identified and traced using the APALL package. Smoothed scattered-light corrections were made with the APSCATTER package on the two-dimensional frames. The resulting frames were then extracted to one-dimensional orders. Finally, we applied dispersion solutions that were determined by fitting the positions of about 600 lines with low-order polynomials in similarly reduced ThAr frames; these solutions had rms residuals of approximately 3 mÅ.

We sought to determine the following from these spectra: a normalized Hα emission index, a Li abundance, an estimate of [Fe/H], $v \sin i$, and the radial velocity ($v_{\rm rad}$), and evidence for variability in $v_{\rm rad}$ (Tables 1 and 2). The spectral features we used are the usual ones for our analyses: Hα as an activity indicator; Li I λ6708 as a test of youth; the Na I D lines as an indicator of circumstellar or interstellar material; lines of Fe I to determine metallicity; and moderate-strength lines of Fe and Ca to measure radial velocity.

[2] IRAF is distributed by the National Optical Astronomy Observatories.

For Hα, we followed the procedure described by Soderblom et al. (1993b, hereafter SSHJ). First we co-added the available spectra and then smoothed them slightly with a $\sigma = 2$ pixel Gaussian. The Hα profile of a star of the same $B-V$ color and known to have little activity was then subtracted to yield the net emission equivalent width; that was then converted to a flux ($F_{{\rm H}\alpha}$) and a flux ratio ($R_{{\rm H}\alpha}$), which is the ratio of the net Hα emission flux to the stellar bolometric flux. We estimate the uncertainty in $R_{{\rm H}\alpha}$ to be 0.2 dex. We measured the Li feature with both direct integration and profile fitting. We corrected for the nearby Fe + CN feature at 6707.4 Å by either fitting a symmetric profile to the red side of the line or using the empirical correction of Soderblom et al. (1993a). Both procedures agreed to within a few milliangstroms. W_λ(Li) was transformed to $A_{\rm Li} \equiv \log N({\rm Li})$ using Table 2 in Soderblom et al. (1993a). $B-V$ colors were used to determine $T_{\rm eff}$ values using equation (3) in SSHJ. The $B-V$ colors are taken from the Tycho Catalogue (ESA 1997) for the most part. For the inactive comparison stars we have worked with ground-based $B-V$ colors, but those differ little from the Tycho values. The only significant exceptions are HD 163029 NE/SW, for which we used ground-based photometry for reasons explained in § 3.

We derived Fe abundances for the more slowly rotating VA stars in our sample that did not show evidence of double lines. These values were calculated from the measured equivalent widths of a few Fe I lines in each spectrum using an updated version of the MOOG LTE analysis package (Sneden 1973; R. L. Kurucz 1992, private communication) model atmospheres. The atomic data were taken from Thévenin (1990). Solar abundances were calculated for the same lines using our sky spectrum and employing the same atomic data. The errors are dominated by those in the measurement of the line strengths. The Fe abundances for the four stars that could be measured reliably are all within 0.1 dex of solar, though slightly larger excursions are allowed by the uncertainties.

Rotational velocities for the five apparently single stars and some of the probable binaries were estimated from measured breadths of selected metal lines. Measurements were not made for the other binary stars, because of line blending. However, one may easily gauge the qualitative nature of rotation in these stars from the figures. Because of their very large projected rotational velocities, no clean metal features were available to measure $v \sin i$ for HD 54759, 102982, 123732, and 175897; upper limits were estimated from Hα.

We obtained several spectra for most of our targets so that we could detect short-term changes in the radial velocity. Stars with periods less than about 10 days show enhanced CE, and such systems have large radial velocity amplitudes and usually exhibit obvious changes from one night to the next. Relative radial velocities from our several spectra were computed, accounting for both instrumental shifts and heliocentric corrections. The former were measured by cross-correlating the telluric B-band region using the FXCOR routine in the IRAF RV suite. Radial velocities were measured by cross-correlating the spectra, usually in the 6440–6520 Å region, which contains numerous moderately strong lines. Because many of these objects are multiple systems, explanatory notes are needed for the rotational and radial velocities; these are provided in § 3.

3. COMMENTS ON INDIVIDUAL STARS

We will first discuss each of the VA objects separately before considering them in context. In most cases, our observations are the first high-resolution spectra published for these objects. Many spectra are composite, so the strengths of features are diluted by the flux of a companion. In other cases the features are extremely broad, because of rapid rotation. Our primary goal is to distinguish single young stars from close multiples that show the same high activity levels.

We compare these stars with the Pleiades, because many high-quality data are available for that ZAMS cluster. Figure 1 shows the normalized Hα emission flux, $R_{\mathrm{H}\alpha} \equiv F_{\mathrm{H}\alpha}/F_{\mathrm{bol}}$, versus $B-V$ for Pleiades stars (SSHJ), shown as dots. Stars referred to in this paper are shown as open circles, with the identifying letters given in Table 2. Figure 2 shows log N(Li) versus T_{eff} for Pleiades stars (Soderblom et al. 1993a) and the present sample, with the same symbols. In some cases we also compare the Li and Ca I λ6717 features qualitatively, because the strength of the Li feature generally only exceeds that of the Ca line in very young stars.

HD 37572A (*star P*).—This object is both a *ROSAT* and an *Extreme Ultraviolet Explorer* (*EUVE*) source (Pounds et al. 1993; Bowyer et al. 1994). The Hα profile (Fig. 3) confirms the VA nature of this object inferred from the Ca H and K lines in Paper I. We did not observe an inactive star

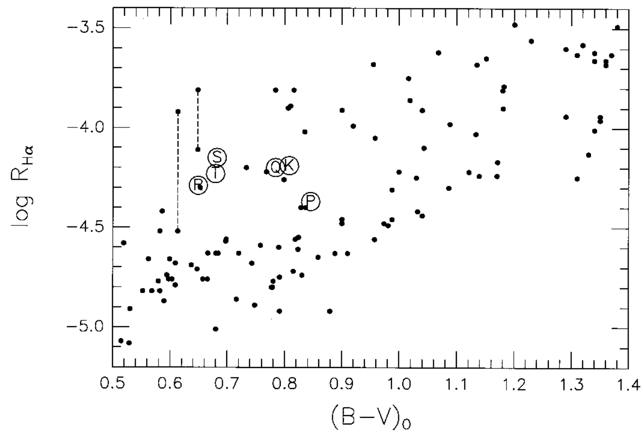

FIG. 1.—Normalized Hα emission flux, $R_{\mathrm{H}\alpha}$, vs. $B-V$, for the Pleiades (*dots*; from SSHJ) and the present sample (*open circles*). The letters inside the circles identify the stars; see Table 2. (The two vertical dashed lines indicate the range of possible $R_{\mathrm{H}\alpha}$ values in two Pleiades stars; see SSHJ.)

of exactly the same color as HD 37572A, but HD 38392 and HD 115617 bracket it in color. In the top panel of Figure 3, the similarly smoothed spectrum of HD 38392 is plotted as the dotted line; it can be seen that the HD 37572A Hα profile is filled in, compared with the cooler HD 38392. The resulting difference spectrum is shown as the dashed line in the top panel of Figure 3. The residual emission was measured by differencing with both standards HD 38392 and HD 115617; the mean equivalent width is listed in Table 2. The $R_{\mathrm{H}\alpha}$ values, computed with no color adjustment from the two inactive standards (which differ in $B-V$ by a sizable 0.23 mag), differ by about 0.3 dex; thus, errors in interpolating $R_{\mathrm{H}\alpha}$ at the VA star's intermediate color should be small ($\lesssim$0.1 dex). Comparison with the Pleiades indicates that $R_{\mathrm{H}\alpha}$ lies within the distribution of Pleiades stars of similar color.

The bottom panel of Figure 3 displays the co-added three individual spectra of the Li 6708 Å region; the Li feature is significantly stronger than the Ca I 6717 Å line. Our Li abundance of log N(Li) = 2.78 means that HD 37572A lies near the upper envelope of Pleiades abundances at similar T_{eff} (Fig. 2), suggesting that HD 37572A is ZAMS or younger.

We checked whether this component of a wide pair (∼18″ separation) might also be a part of a short-period system. The two spectra from the first night have identical radial velocities, and both of these deviate by only 0.6 km s^{-1} from the spectrum obtained on the last night. We do not consider the difference significant. We find no evidence that the star's activity is a result of membership in a close binary system.

An absolute radial velocity was measured using the sky spectrum obtained on a different night. Instrumental shifts were estimated from the telluric B-band regions, and radial velocities with respect to the sky were measured from cross-correlation of the 6500 Å region. Comparison of the measured wavelengths of numerous metallic features in the sky spectrum with accurate laboratory values indicated the need for a 2.7 km s^{-1} zero-point adjustment. Applying the zero-point, instrumental, and heliocentric corrections led to a final mean radial velocity of +29 km s^{-1}, with an uncertainty of 1 km s^{-1}.

In sum, our observations suggest that HD 37572A is a good candidate for a nearby very young star whose activity

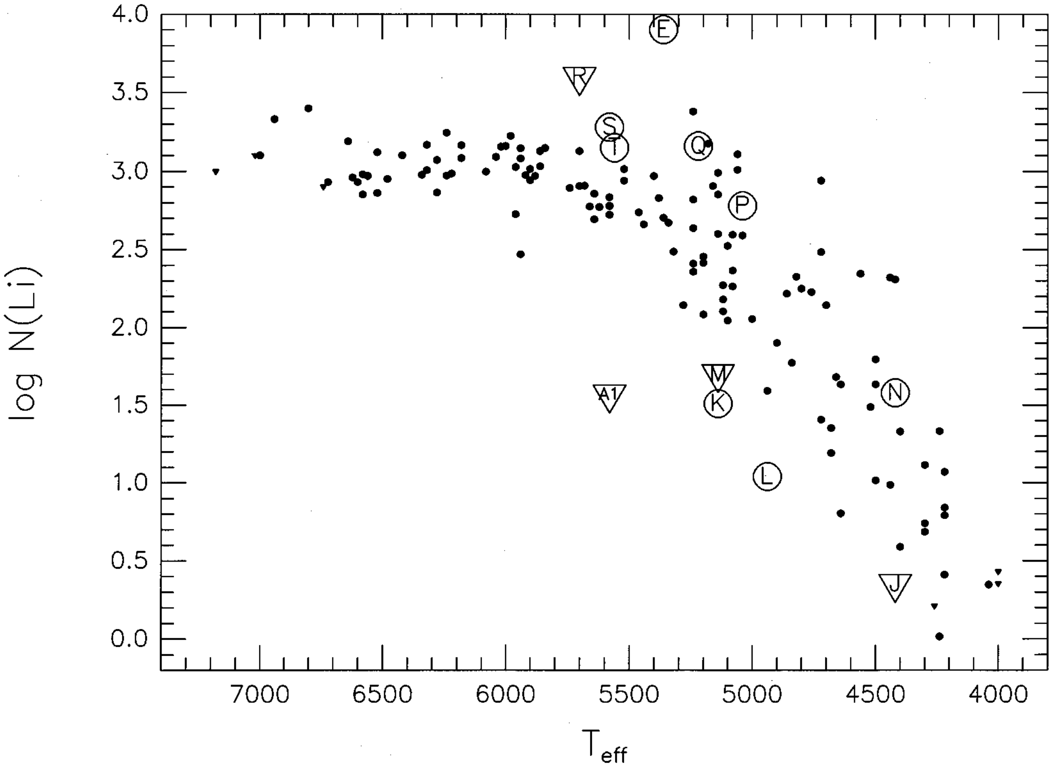

FIG. 2.—Lithium abundance [log N(Li), on a scale where log N(H) = 12] vs. $T_{\rm eff}$ for the Pleiades (*dots*, from Soderblom et al. 1993a) and the present sample (*open circles and triangles*). The letters inside the symbols identify the stars; see Table 2. Triangles indicate upper limits.

and large Li abundance are both associated with youth rather than membership in a close short-period binary system.

HD 41824AB (*star A*).—This long-period (>400 yr) binary system is both a *ROSAT* and an *EUVE* source (Pounds et al. 1993; Bowyer et al. 1994). Pounds et al. (1993) suggest that the B component may be an RS CVn system. Two CORAVEL measures, separated by nearly a year, indicate significant radial velocity variability for the A component, but not the B component (Andersen et al. 1985).

Hipparcos resolved this system into two stars separated by 2".5, but we did not resolve them, making the spectra appear double-lined. Figure 4 shows two spectra of the Li region acquired on succeeding nights. Two components are

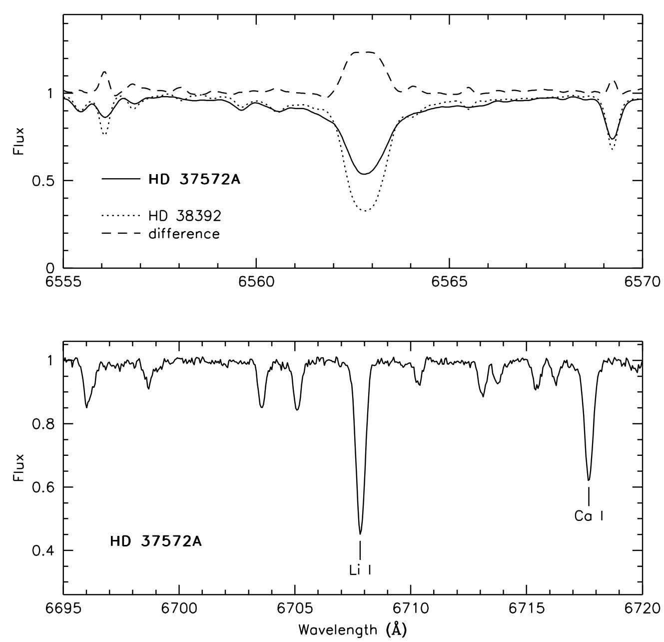

FIG. 3.—*Top*: Hα region spectra of HD 37572A (*solid line*) and H and K standard HD 38392 (*dotted line*). The residual difference spectrum renormalized to continuum level is shown as the dashed line. *Bottom*: Co-added spectrum of HD 37572A in the 6707.8 Å Li region.

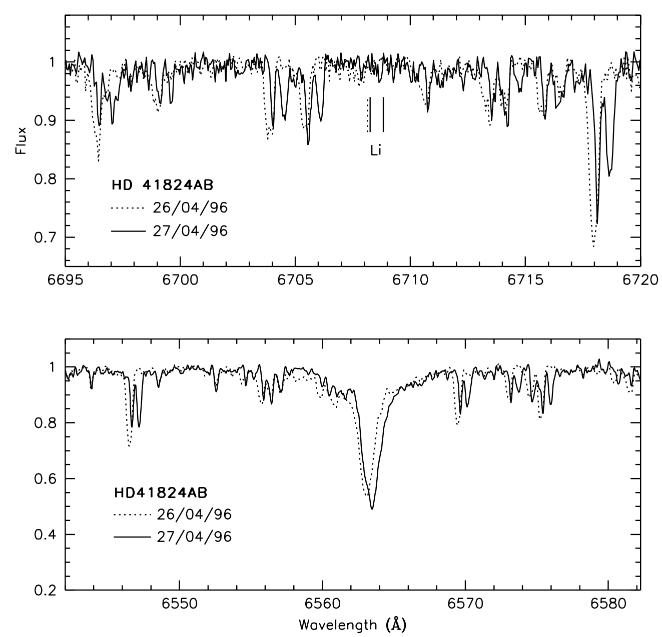

FIG. 4.—Spectra of HD 41824AB acquired on consecutive nights. Evidently, at least one of the components is a radial velocity variable. The bluer component in the second night's spectrum has sharper lines. There is no clear Li feature at the expected positions (*vertical lines*).

plainly evident on the first night but not the second. These spectra have not been adjusted to a rest velocity, because of their double-lined nature and velocity variability. However, the second night's spectrum was placed on the velocity scale of the first night by accounting for a small instrumental ($\sim$0.9 km s^{-1}) shift measured from cross-correlating the telluric B-band regions. Figure 4 indicates that at least one of the components is a radial velocity variable on short timescales. Radial velocity stability of one of the components like that suggested by the CORAVEL observations (Andersen et al. 1985) is the simplest explanation for the observations in Figure 4, though there is ambiguity in identifying the specific components in our spectra because of blending. From the second night's spectrum we determined $\Delta v_{\rm rad} = 23.8 \pm 0.4$ km s^{-1}. The systemic velocity on the first night appears to be $+2.7 \pm 3$ km s^{-1}.

All this suggests that, in fact, this is a triple system, because two stars 30 pc away that are 2$''$.5 apart will not change their velocities significantly in 1 day. We will call the two components we see "A" and "B," with A being the blueward spectrum in the April 27 spectrum, but the nomenclature is confused. The relative line strengths we see are consistent with the relative magnitudes listed in the Tycho Catalogue (7.180 for A and 7.546 for B), and so for the present we will assume that the Tycho photometry applies to these two spectra and we will label the stars in the diagrams "A1" and "A2."

The second night's spectrum indicates that the rotational velocities of the two components are not the same, because the bluer component has sharper lines. We estimate $v \sin i = 4$ and 7 km s^{-1}, but with large systematic errors of 2 km s^{-1}.

The vertical bars in Figure 4 mark the predicted positions of the Li features. No Li is evident in either component. We place a measured upper limit of 16 mÅ on any real feature in the second night's spectrum: this includes an estimated flux dilution correction of a factor of 2. With the $T_{\rm eff}$ values and abundance methodology as above, we find log N(Li) $\lesssim$ 1.45. Comparison with the Pleiades (Figs. 1 and 2) indicates that HD 41824 is not especially young and its activity is probably because one of the components is a short-period binary. In addition, the low-resolution spectroscopic H and K activity proxy measure from Paper I might be overestimated, because of effects of flux dilution.

HD 54579 (*star B*).—The H and K spectra displayed in Figure 2 of Paper I showed that this star is broad-lined, and this is confirmed by the Hα data. The Hα and Na D lines are the only features clearly seen in our spectra, and the latter only barely. The top panel of Figure 5 shows the first night's co-added Hα profile of HD 54579 compared with HD 81809; the broad-lined nature of the former is readily apparent. Present in all three of the individual HD 54579 spectra may be an *apparent* central reversal, marked by the vertical line. However, this peak does not appear to be in the center of the Hα profile, though the red half of the red wing also appears to be asymmetric. We estimated $v \sin i \leq 140$ km s^{-1} from the Hα profile obtained on the last night. We could not determine a useful $v_{\rm rad}$.

The bottom panel of Figure 5 shows the individual spectra from the first night and the single spectrum from the second night. No radial velocity shifts have been applied, but the alignment of marked telluric features indicates no significant instrumental shifts. It can be seen that as the central peak increases in amplitude during the first night,

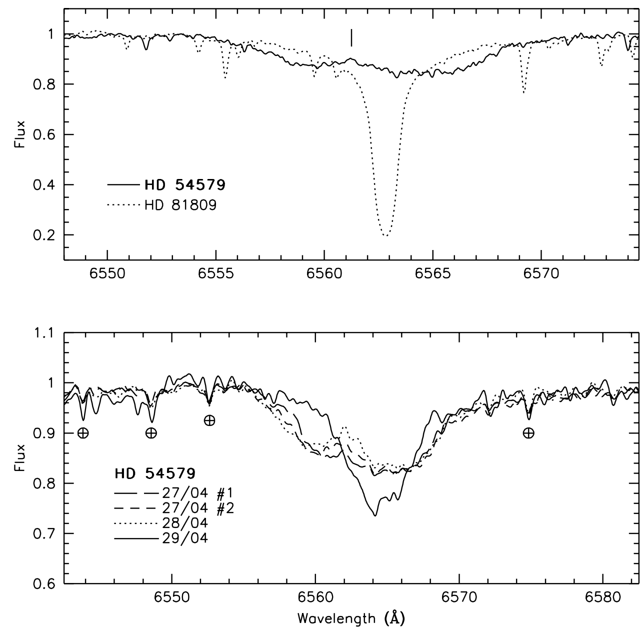

FIG. 5.—*Top*: Summed Hα profile of the VA star HD 54579 (*solid line*) and the similar $B-V$ color standard HD 81809 (*dotted line*). Both spectra have been mildly smoothed by convolution with a Gaussian kernel having $\sigma = 1$ pixel. The broad-lined nature of the VA star is apparent. The vertical line marks a possible central reversal. *Bottom*: Individual Hα profiles of HD 54579 that have been more heavily smoothed ($\sigma = 3$ pixels) to reduce clutter. Telluric features are marked with circled plus signs. A progression in the extent of the blue wing and the candidate central reversal amplitude in the first three spectra is apparent. The second night's spectrum is markedly different.

the width of the blue wing also increases. It is possible that the varying blue wing *width* is in fact caused by *depth* variations arising from errors in the continuum normalization of very broad features in a high-dispersion spectral order of limited wavelength range; however, the contrary behavior of the central peak amplitude (depth) and lack of any variations in the red wing are arguments against this. The second night's spectrum is narrower, though still very broad. Also conspicuous is an absorption "shelf" in the far red Hα wing. The centroids of the complex line profiles are, evidently, also different. While it is difficult to rule out complex emission variability, the simplest interpretation of the spectra is that there is short-period radial velocity variability caused by a companion (also broad-lined), and that the "reversal" noted above is where the two line profiles overlap.

Although our spectra in the D-line region are of lower S/N, and have an even greater uncertainty in continuum rectification as a result of their lying near the order edge, the D lines confirm the behavior seen at Hα. In particular, an extra blueward component is present in the first night's spectrum, and the blue wing does move outward in step with the Hα wing. The second night's spectrum is clearly different, having only a single component (for each D line) and the profiles having different centroids from those of the first night. This provides corroborating evidence that HD 54579 is a short-period SB2. As such, its relatively weak H and K and Hα absorption could also be affected by flux dilution in addition to activity-related emission. We note that there are no published *ROSAT*, *Einstein*, or *EUVE* detections for HD 54579.

HD 102982 (*star C*).—Recently, Lampton et al. (1997) have found this star to be both a *ROSAT* and an *EUVE* source. Our spectrum of HD 102982 indicates the star is broad-lined, with Hα and the D lines being the only clear features. We estimated $v \sin i \leq 100$ km s^{-1} from Hα and could not determine a useful $v_{\rm rad}$. In addition to the Tycho $B-V$ value, one can be estimated using $b-y$ from Olsen (1993, 1994). $T_{\rm eff} = 5630$ K was inferred from the mean $b-y$ using the calibration of Saxner & Hammarbäck (1985) and assuming [Fe/H] = 0. This $T_{\rm eff}$ agrees well with what we inferred from the Tycho photometry.

The top panel of Figure 6 compares HD 102982 with HD 76151, which has a similar $B-V$. The Hα line is asymmetric, in that the slope of the red wing appears shallower than that of the blue wing. This is confirmed by the D lines, which are shown in the bottom panel of Figure 6. This behavior is most simply explained if the star is an SB2, which could also contribute to the relative weakness of the H and K and Hα features. A contact or eclipsing system might explain the 0.09 mag discrepancy in the V magnitude measured by Olsen (1993, 1994) and any genuine emission (as opposed to flux dilution) inferred from the H and K and Balmer lines. Unfortunately, only one spectrum was secured, so we cannot address radial velocity variations. This star needs further spectroscopic study to draw firm conclusions; at present, we exclude it from our final young candidate sample.

HD 106506 (*star D*).—The Tycho $B-V$ value in Table 2 agrees well with the 0.58 value we used in Paper I. However, we estimate $B-V \approx 0.65$ from the $b-y$ photometry of Olsen (1993, 1994) and the color-$T_{\rm eff}$ relation of Saxner & Hammarbäck (1985), as above.

The top panel of Figure 7 plots the Hα spectra obtained on consecutive nights; they differ markedly. The bottom panel indicates that Li is present: moreover, it appears to be strong compared with Ca I λ6717. The second night's spectrum seems to have two distinct components. The strong Ca I λ6122.2 feature seems to show distinct components on

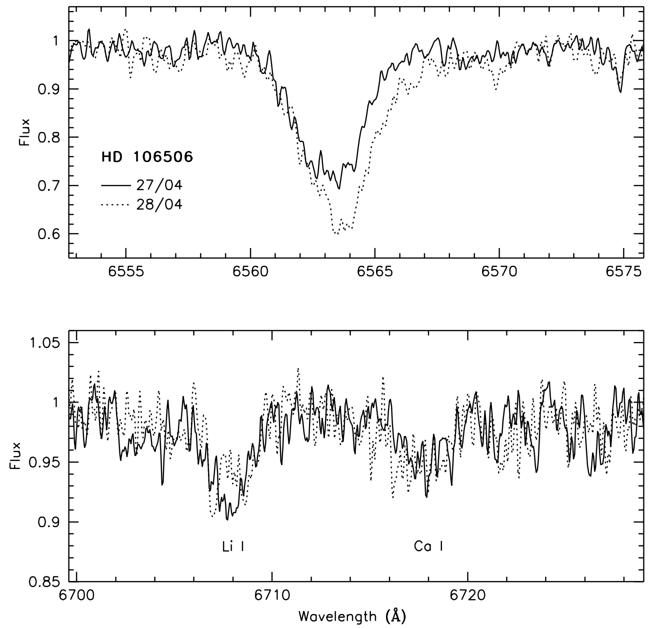

FIG. 7.—*Top*: Hα profiles of the VA star HD 106506. The spectra have been smoothed as above. No absolute or velocity shifts have been applied; any relative instrumental and heliocentric shifts are negligible. *Bottom*: Li I λ6707.8 and Ca I λ6717 regions.

both nights (Fig. 8). The profile on the second night appears to include a red asymmetry like the Hα feature. The solid line in the bottom panel of Figure 8 shows the central region of the cross-correlation function (CCF) resulting from convolution of this spectrum with our sky spectrum in the 6122 Å region. The dotted line is the Gaussian fit to the central peak. The observed CCF is clearly asymmetric with respect to the Gaussian, or any other symmetric fitting function one might choose to employ. Until higher quality data

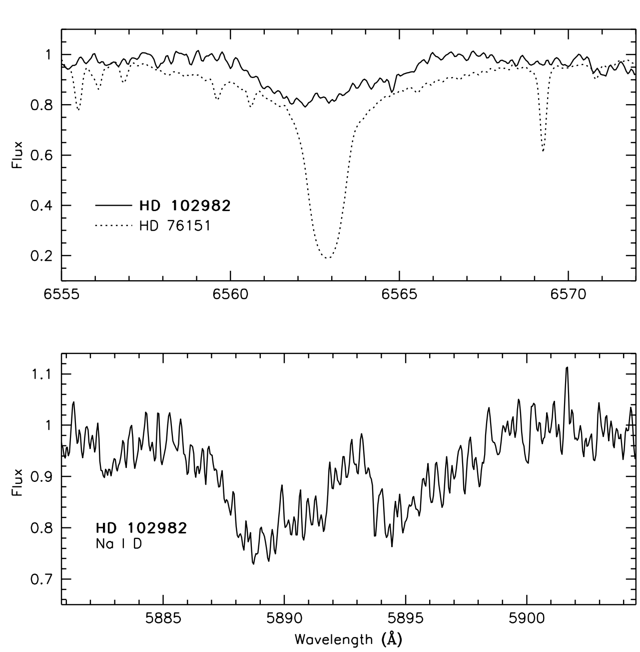

FIG. 6.—*Top*: Hα profiles of the VA star HD 102982 (*solid line*) and the similar $B-V$ color standard HD 76151 (*dotted line*). Spectra have been lightly smoothed with a $\sigma = 1$ pixel Gaussian. *Bottom*: Smoothed Na D features in HD 102982. Both the D lines and Balmer line show a red wing shallower than the blue wing.

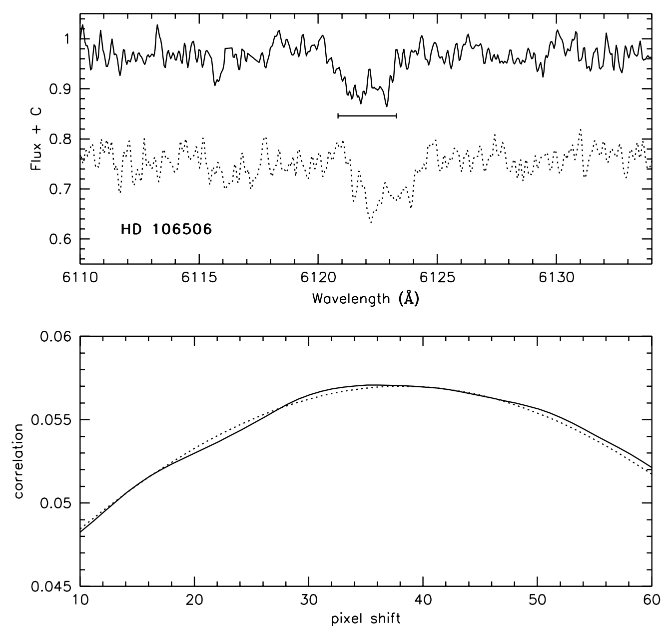

FIG. 8.—*Top*: Lightly smoothed Ca I λ6122 profiles of HD 106506. *Bottom*: Central region of the cross-correlation function (*solid line*) resulting from convolution with the sky spectrum in the 6122 Å region. The dotted line is a Gaussian fit to the peak of the CCF. The horizontal bar in the top panel corresponds to the same range of velocity encompassed by the cross-correlation in the bottom panel.

can be obtained, we classify the star as only a possible SB2. The D lines may contain a circumstellar or interstellar component, providing further justification for higher S/N observations. While the large Li content of the star may be consistent with youth, we do not include the star in our final sample of bona fide young candidates, since the inferred H and K emission could be affected by flux dilution or activity related to a close companion. We also note the lack of *ROSAT* or *EUVE* detections.

HD 119022 (*star E*).—This star was detected as an X-ray source in the *Einstein* Slew Survey (Elvis et al. 1992). Schachter et al. (1996), however, suggest that a nearby M star with weak Hα emission is more likely to be the source. In any case, the H and K measurements from Paper I and those alluded to in Schachter et al. (1996) suggest significant chromospheric emission for HD 119022. The top panel of Figure 9 contains the second night's Hα profile of HD 119022 and the inactive star HD 115617. The broad-lined nature of HD 119022 is readily apparent. The bottom panel compares the individual HD 119022 profiles acquired on three different nights. The strength of Hα varies, but its width does not, suggesting that HD 119022 is single. However, *Hipparcos* has resolved HD 119022 into two separate objects with a separation of $0''.202 \pm 0''.006$ and $\Delta m = 0.10 \pm 0.19$ mag: There are two objects of equal brightness contributing to the spectrum. The radial velocity in Table 2 was determined from Hα.

The *Hipparcos* Input Catalogue (INCA)–based color of $B-V = 0.78$ listed in Paper I seems too red for the G2 spectral type, but it agrees well with the Tycho value listed in Table 2. We made an independent $B-V$ estimate as before, using the Strömgren $b-y$ photometry from Twarog (1980). While this involves a nonnegligible excursion outside the color range of the Saxner & Hammarbäck (1985) relations, a cool $T_{\rm eff}$ or red $B-V$ is clearly indicated; we find $B-V = 0.77$, in excellent agreement with the INCA and Tycho values.

Figure 10 indicates that the broad stellar D lines include sharper features. While there are numerous telluric lines in the region, we do not believe these account for the deep sharp features. In particular, expected telluric features of comparable or greater strength than those near the position of the deep sharp features are not visible. If the lines are of circumstellar or interstellar origin, their presence could mean that HD 119022 is significantly reddened. Higher quality observations would be of interest to establish the nature of these features, and their implications for reddening.

The nature of HD 119022 is unclear. We see no evidence for radial velocity variations, but the breadth of the lines prevents us from imposing a stringent limit. We also cannot confirm any residual Hα chromospheric emission from the second night's spectrum. Measurements of the HD 119022 Hα (absorption) equivalent width are *larger* than the values measured in several of the inactive comparison stars that bracket HD 119022 in color. We do not believe that this circumstance is due to continuum uncertainties or the presence of telluric features. On the other hand, we do not have any reason to doubt the chromospheric emission inferred from the H and K lines in Paper I and Schachter et al. (1996). A possible explanation of the strong Balmer absorption, the color–spectral type discrepancy, and the narrow features in the D-line profiles may be that HD 119022 suffers from unappreciated and significant reddening.

All three spectra of HD 119022 demonstrate the presence of Li, and it is stronger than the Ca I λ6717 feature. The presence of strong Li (we estimate a strength of ≈350 mÅ), the H and K emission, and the broad-lined nature of this star are all consistent with youth, but it is too luminous to be merely young in the sense used here (on or barely before the ZAMS) and must instead be a T Tauri–like star (which the absence of Hα emission argues against), or an evolved object. In any case, we have not included it in our final sample of the best young candidates.

HD 123732 (*V759 Cen*, *star F*).—Bond (1970) noted the diffuse and SB2 nature of this star's spectrum from objective-prism plates. His follow-up photometry revealed this star to be a W UMa type binary. As expected, our high-resolution spectra indicate that the star is both broad- and double-lined, and that it undergoes significant $v_{\rm rad}$ variations on short timescales (Fig. 11). Our $v \sin i$ value (Table 2) was determined from Hα. We exclude this star from our final sample of objects whose activity arises from youth.

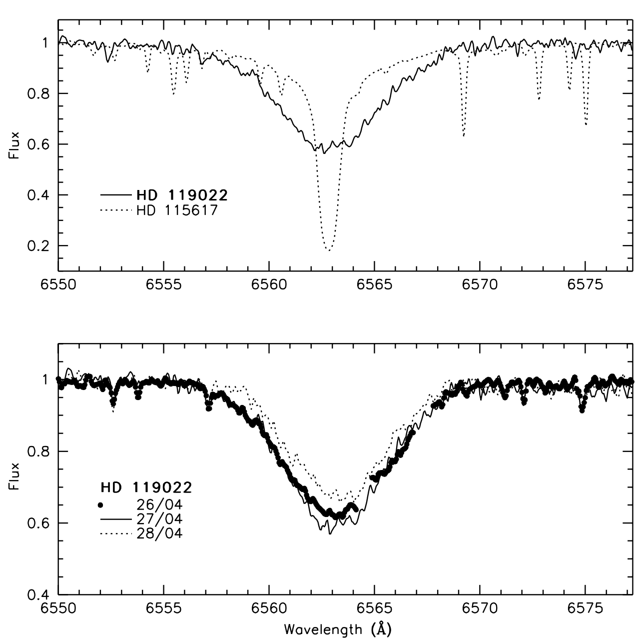

FIG. 9.—*Top*: Comparison of the smoothed second night Hα profiles of the VA star HD 119022 and the standard HD 115617, illustrating the broad-lined nature of the former. *Bottom*: Comparison of the smoothed HD 119022 profiles from the individual nights. Two regions severely afflicted by particle events have been excised from the first night's spectrum.

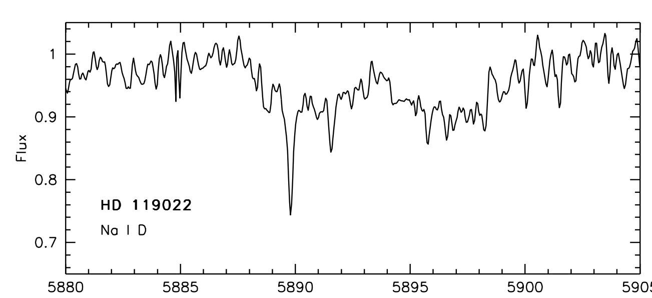

FIG. 10.—Lightly smoothed second night's spectrum of the Na D region in HD 119022.

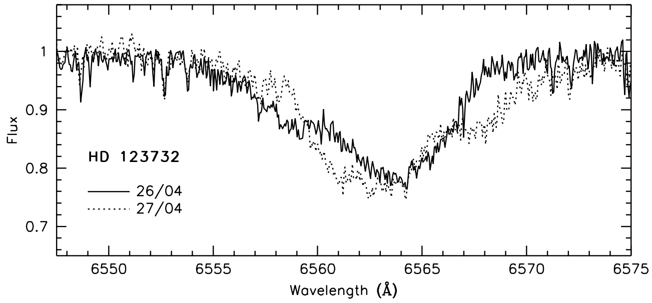

FIG. 11.—Unsmoothed spectra of the Hα region of HD 123732 acquired on consecutive nights, showing the broad- and double-lined nature of this W Ursae Majoris system.

HD 151770 (*star G*).—The top panel of Figure 12 shows the Li region for this star. Multiple components are present, and we classify the star as a spectroscopic triple, and possibly a quadruple. This is confirmed from the cross-correlation analysis. The CCF derived from convolution with our sky spectrum in the 6480 Å region is shown in the bottom panel of Figure 12; three peaks can be seen. There are intra- and internight shifts in the line positions and profile morphology, implicating some of the components as short-period systems. Lithium is present in moderate strength, but it is much too weak to correspond to a pre–main-sequence (PMS) star. HD 151770 lies above the main sequence (see Fig. 25 below), probably because it is an evolved system.

HD 155555AB (*V824 Ara*, *star H*).—This well-studied active field star is known to be a spectroscopic binary (Bennett, Evans, & Laing 1967), and is a *ROSAT* and *EUVE* source (Pounds et al. 1993; Bowyer et al. 1994). For consistency with other studies, we have departed from the nomenclature of Paper I; we consider the two spectroscopic components as A and B, reserving the C designation for the visual component some 30″ distant. Historically, HD 155555AB has been considered an RS CVn system, and is still considered such in some studies. Pasquini et al. (1991), however, suggest that the two spectroscopic components may be rare examples of post–T Tauri stars. This was motivated by the very large Li abundances, which are confirmed by our observations. Given its multiplicity and the persistent uncertainty in this system's evolutionary status, we do not include it in our final best list of young candidates, however.

Nonetheless, two novel results come from our spectroscopy of this star. First, as demonstrated in Figure 13, our single spectrum shows Hα to be in overt emission, which is different from the high-resolution spectrum in Figure 2*b* of Pasquini et al. (1991). Therefore, Hα appears to be variable over and above any profile changes casued by orbital motion alone. Second, we find evidence that additional components may be present in our spectrum. The bottom panel of Figure 13 shows the central region of the CCF of the convolution of the HD 155555AB spectrum with our sky spectrum in the 6480 Å region. Two distinct central peaks are evident. A broad peak displaced to the red is also seen. The CCF thus indicates that at least three components (but not necessarily individual stars) are producing the HD 155555AB spectrum. This is readily apparent from inspection of the spectrum itself. As seen in Figure 14, there is consistent line-to-line evidence of more than two components. Whether the additional components are previously unrecognized companions or the manifestation of cool

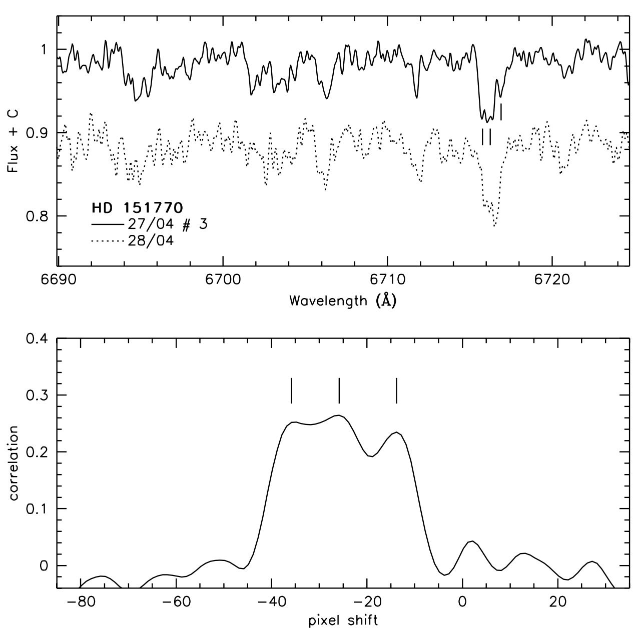

FIG. 12.—*Top*: Mildly smoothed spectra of HD 151770 in the Li region from the first and second nights of observation; the spectra are offset in flux by an additive constant. Multiple peaks are seen in the Ca I λ6717, Li, and Fe I λλ6703, 6705 features, all of which are blueshifted by ∼1.5 Å from rest wavelength. The different components are best seen in the Ca I λ6717 feature. *Bottom*: Same three peaks in the cross-correlation function of HD 151770 with a sky spectrum in the 6480 Å region. The three vertical bars in both panels are located at the same relative velocities, to show how the cross-correlation confirms the line structure seen in the 6717 Å feature.

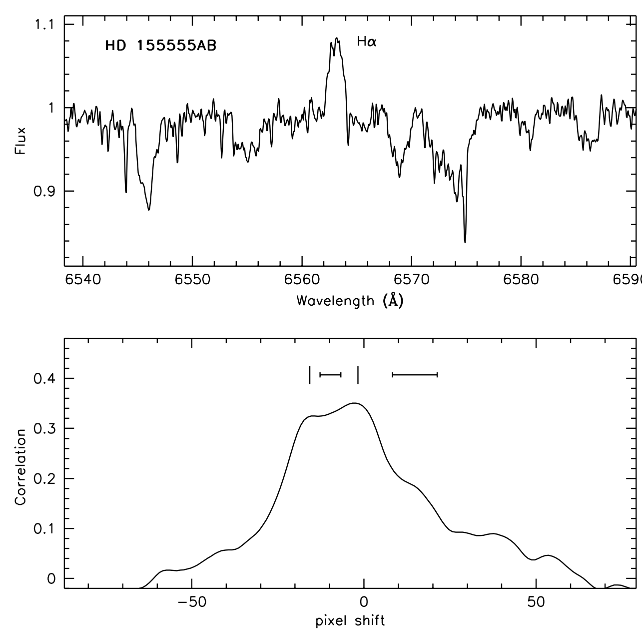

FIG. 13.—*Top*: Mildly smoothed Hα spectrum of HD 155555AB, which shows a Balmer line in overt emission. *Bottom*: Central region of the cross-correlation function from convolution with the solar spectrum in the 6480 Å region. Two distinct central peaks are seen in addition to a broad one to the red; this behavior can be seen in the spectra themselves (Fig. 14). The vertical and horizontal bars in the lower panel correspond in velocity to the same markings in Fig. 14.

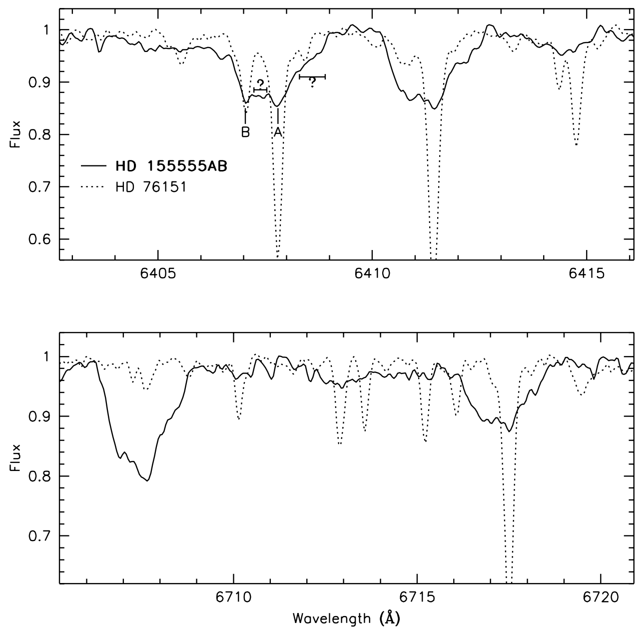

FIG. 14.—Mildly smoothed spectra of HD 155555AB in the Fe I λλ6408.0, 6411.7 (*top*) and Li (*bottom*) regions. The A and B components are marked in the top panel. The pronounced red shoulder, consistent from line to line, is marked with a question mark. Another possible component between the A and C components is also marked with a question mark. The comparison star is HD 76151.

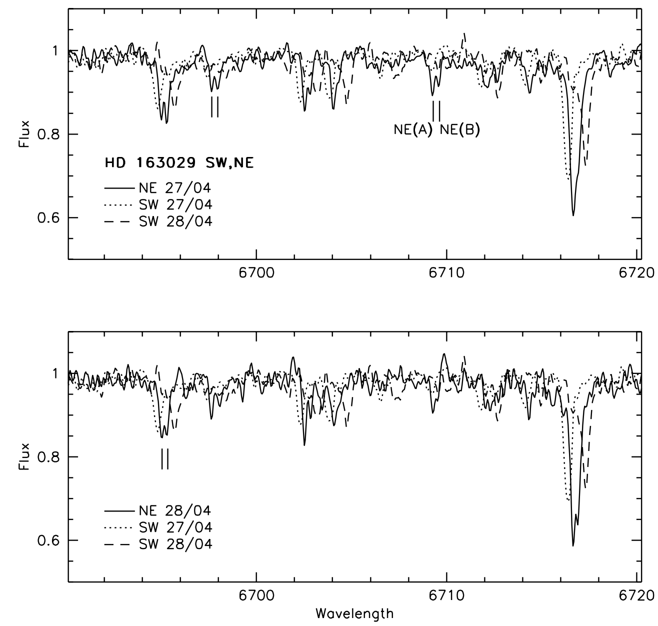

FIG. 15.—*Top*: Mildly smoothed spectrum of HD 163029 NE (*solid line*) from the second night plotted with spectra of HD 163029 SW (*dotted and dashed lines*) from the second and third nights. *Bottom*: Spectrum of HD 163029 NE from the third night plotted against the same southwest-component spectra. The vertical lines mark the two components of HD 163029 NE.

spots on the surface of the two established components is unclear. If the profiles' extended red shoulder—a consistent line-to-line characteristic—is due to cool spots, then the material must have a significant radial velocity relative to the local photosphere(s). This is unlikely, and we believe this is a triple system.

We determined upper limits to $v \sin i$ for both A and B of 20 km s^{-1} by fitting the peaks of the CCF. The $v_{\rm rad}$ separation between A and B is 35.5 km s^{-1}, and between A and the red hump in the profiles it is 38 km s^{-1}.

HD 163029 NE/SW (*stars J and K*).—These stars form a visual double with a separation of 2″.9 (*Hipparcos*), and we were able to obtain separate spectra for each component. They are considered VA stars in Paper I, based on a composite spectrum. No high-energy satellite detections of these stars have been reported. The accurate CCD-based $B-V$ values of Nakos, Sinachopoulos, & van Dessel (1997) for each component represent a substantial improvement over the uncertain composite color tabulated in Paper I. However, the true colors of these stars are uncertain. The Tycho Catalogue lists $B-V = 0.693$ and 0.822 for the southwest and northeast components, respectively, while Nakos et al. give 0.808 and 1.082 for these two stars. The V magnitudes from the two sources also differ. The wings of Hα, however (as shown in Fig. 16 below), suggest that the Nakos photometry fits these stars better, and so we use it here.

In Figure 15, the spectra of HD 163029 NE from the second (*top*) and third (*bottom*) nights are plotted against the HD 163029 SW spectra from both the second and third nights. Note that component NE is clearly double-lined, and both components are easily visible in the figure. That one set of these lines does not arise from the nearby southwest component is indicated by the overplotted spectra of the southwest component, which (on both nights) are of clearly different velocity from either of the northeast components; we note that this does not arise from instrumental shifts. Thus HD 163029 NE is an SB2.

Figure 15 reveals no absolute or differential radial velocity variations of the northeast SB2 system. This is verified by quantitative cross-correlation analysis that includes our two spectra from the first night also. The maximum radial velocity shifts seen between any two of our northeast spectra are limited to ≤ 0.3 km s^{-1}, which is indistinguishable from zero within the uncertainties.

Figure 15 also indicates that the southwest component undergoes radial velocity variations on a short (at least day-to-day) timescale. The velocities on the second and third nights differ by ~ 40 km s^{-1}; no significant velocity variation (≤ 0.3 km s^{-1}) is seen between the two spectra acquired on the first night. While not readily apparent from Figure 15, the lines in our spectrum from the third night consistently show shallow absorption shoulders in the blue wings; these show up most clearly as a notable mild asymmetry in the cross-correlation peak associated with this exposure. The velocity of this component is similar to that of the northeast component, so contamination may be the cause. However, the possibility remains that the southwest component is also an SB2.

Using the Hα profile of HD 163029 NE to try to detect residual emission is difficult because of the double-lined nature of the spectrum, as well as the fact that we do not have a standard as red as the northeast component (though the Hα profile strength does not change so rapidly at these cool $T_{\rm eff}$ values). Thus we rely on the hotter, single-lined component, HD 163029 SW. The top panel of Figure 16 shows the first night's co-added Hα region spectrum of HD 163029 SW compared with three stars of different color. The weakness of the HD 163029 SW profile is apparent, and its residual emission relative to HD 38392 is shown as

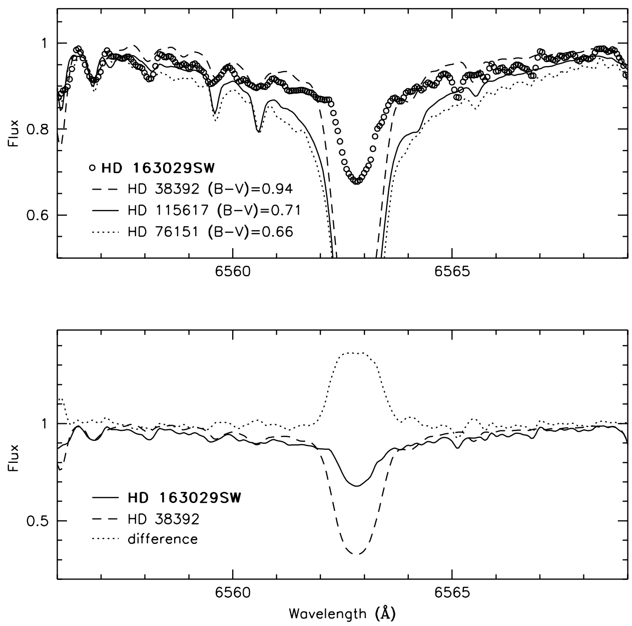

FIG. 16.—Mildly smoothed Hα profile of HD 163029 SW from the first night (*solid line*), plotted with the VA star HD 37572 (*dashed line*), itself inferred to have weak Hα. The residual emission of HD 163029 SW is shown as the dotted line.

the dotted line in the bottom panel. The resulting Hα flux is just below the upper envelope of Pleiades values at similar $B-V$, implying that it is similar to the more active Pleiades stars.

The spectra of the northeast component reveal no detectable Li feature. The Li abundance level can be reasonably and conservatively gauged by measuring a limit to any possible absorption and combining this with a conservative factor of 2 correction for flux dilution. Our upper limit of log N(Li) $\lesssim +0.35$ at $T_{\rm eff} = 4412$ K is considerably lower than nearly all the Pleiades stars of similar color or $T_{\rm eff}$. Also, we estimate upper limits to $v \sin i$ for the blue and red components of 3 and 4 km s^{-1}, respectively. We therefore exclude this object from the young candidate sample.

All our spectra of the southwest component show a weak Li feature. However, the equivalent width is not well determined. Our best spectrum gives a value near 26 mÅ, but the other spectra give values from 40 to 55 mÅ, yielding a mean value of 41 ± 15 mÅ. The color-based $T_{\rm eff}$ and this equivalent width lead to log N(Li) = 1.51. This value, too, is significantly below Pleiades values at similar color. However, it is significantly larger than Hyades stars of similar color. This suggests that HD 163029 is an intermediate-age system, but not especially young.

In sum, we have conflicting information. The composite nature of the northeast component (and possibly the southwest component, too), and the composite (SW plus NE) nature of the spectrum from Paper I have certainly influenced the estimated strong H and K emission level reported there. Also, the uncertain color used in Paper I may have led to an incorrect estimate of the H and K emission strength. On the other hand, we find that the southwest component does seem to have weak Hα, indicating moderate activity. However, the Li abundances in these stars are much lower than those seen in the Pleiades and other young cluster and field stars of similar age, which could suggest an intermediate age. While the Li constraints are not stringent and might be disregarded (though remaining interesting), the southwest component is a spectroscopic binary; thus, this might conceivably contribute to the origin of its chromospheric emission rather than youth. Because of this conflicting information, we exclude the system from our list of young candidates.

Because radial velocities are lacking for the HD 163029 stars, we derived values from cross-correlation of the 6440–6520 Å region using our sky spectrum. Instrumental shifts and zero-point corrections were made as described for HD 37572. We find a heliocentric radial velocity of −28.0 km s^{-1} for HD 163029 NE. The uncertainty, given the double-lined nature of the spectrum and the irregularly shaped correlation peak, is perhaps 3 km s^{-1}. Given the marked variations and the small number of spectra, a systemic measure for the southwest component will also be uncertain. The mean night 1 velocity, which is the median heliocentric systemic estimate, is −26.2 km s^{-1}. This agrees well with the northeast component; however, there are no individual proper motions to confirm a physical association.

HD 174429 (*PZ Tel, star Q*).—This is a well-studied VA star from Paper I known to demonstrate H and K emission since the work of Bidelman & MacConnell (1973). HD 174429 is a *ROSAT* XUV source (Kreysing, Brunner, & Staubert 1995) and a stellar radio source (see, e.g., Lim & White 1995). The Hα profile is known to be filled in (Innis, Coates, & Thompson 1988). No spectroscopic evidence of duplicity has ever been noted, and most recent studies consider this object to be single, with a rotational period of 0.94 days (Innis et al. 1988). Innis, Thompson, & Coates (1986) suggested that the star was a member of the local Pleiades group from its kinematics, its very strong Li feature, and its significant rotation (rapidly rotating cool Pleiades stars also demonstrate very large Li abundances). Combining $v \sin i$ and rotational period measures, Randich, Gratton, & Pallavicini (1993) note that the implied radius is too large for a main-sequence star, but indicative of PMS status. With respect to the PMS versus RS CVn classification, HD 174429 is similar to HD 155555AB. Perhaps additional PMS field candidates could be found by rigorous reinvestigation of systems classified as RS CVn.

Our Hα profile confirms the Balmer line weakness. The top panel of Figure 17 contains the Hα region of HD 174429 and the cooler inactive standard HD 38392; the weakness of the former's Balmer line is clear. Values of the Hα emission flux, listed in Table 2 and computed using the standards HD 38392 and HD 115617, place the emission in the upper portion of the Pleiades distribution at similar color. As previous spectroscopy has shown, the Li line is very strong—exceeding the strength of Ca I λ6717 (Fig. 17, *bottom*). Our measured equivalent width, corrected for the Fe I λ6707.4 contribution as before, is smaller than that measured by Pallavicini, Randich, & Giampapa (1992), but is within the uncertainties. The $B-V$ photometry from Cutispoto & Leto (1997) is in good agreement with the Tycho value used here. Our LTE abundance of log N(Li) = 3.11 is some 0.8 dex lower than the Pallavicini et al. value of 3.9; the difference seems larger than can be accounted for by small or modest $T_{\rm eff}$ and line-strength differences, but differences in other aspects of the analyses (e.g., model atmospheres, damping) may be nonnegligible. Comparison with the Pleiades shows that the HD 174429 Li abundance is equivalent to that demonstrated by the young cluster's rapid rotators of similar color.

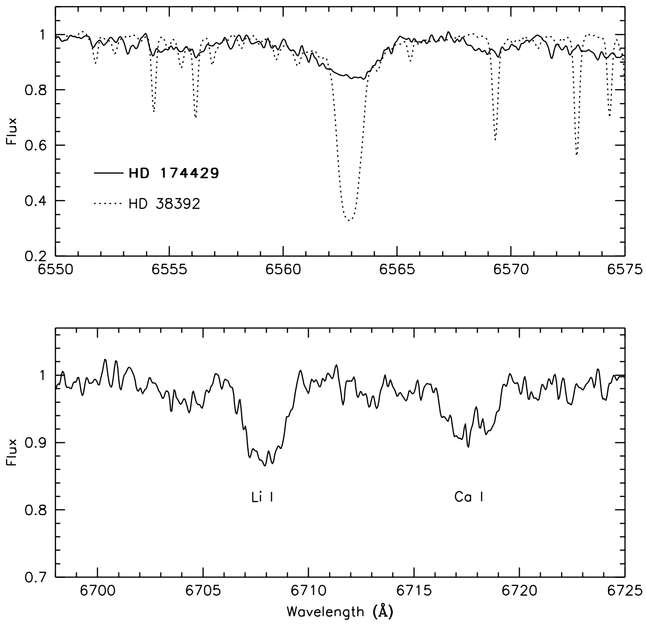

FIG. 17.—*Top*: Mildly smoothed Hα profiles of HD 174429 (*solid line*) and the cooler inactive standard HD 38392 (*dashed line*). *Bottom*: Smoothed Li I λ6707.8 and Ca I λ6717 profiles of HD 174429.

A radial velocity determination was made by cross-correlation of three different orders with our sky spectrum. Combining the instrumental shift and zero-point correction yields a heliocentric velocity of -13.5 km s^{-1}. Possible systematic errors may be as large as 2.5 km s^{-1}, and total uncertainties are near 3 km s^{-1}. Our velocity is significantly smaller than the $+4.4 \pm 6.2$ km s^{-1} estimate of Balona (1987), and the -3.2 ± 3.7 km s^{-1} estimate of Innis et al. (1988). Nevertheless, the V-velocity indicates that HD 174429 is *not* a member of the Eggen (1975) local association (Pleiades group), which has a well-defined value of $V = -25$ km s^{-1}.

Given the H and K and Hα emission, the large Li abundance, and the lack of any convincing evidence for duplicity, we include HD 174429 as a young candidate.

HD 175897 (*star R*).—This star is a far-UV point source (Bowyer et al. 1995). The Hα profile from the third night's spectrum is plotted with the profile of the similar color standard HD 76151 in Figure 18. The broad-lined nature of the VA star is clear. Hα, the D lines, and the Fe I λλ6136.6, 6137.7, and 6141.7 blend are the only obvious stellar features. There may be marginal evidence for small changes in the Hα emission strength, the possible appearance of a small central emission reversal on the first two nights, and a possible asymmetry in the blue wing relative to the first two nights.

Our measurements of Hα seem to confirm the VA classification, but given the uncertain $B-V$ color from Paper I, we first derived another estimate from the $b-y$ photometry of Olsen (1994), as described above. We find $B-V = 0.68$, somewhat redder than the Paper I value of 0.61, the Tycho value of 0.65, or the spectral type of G0. The Hα equivalent width was measured for HD 175897 and the similar color standards HD 76151 and HD 81809. Interpolating among the small color differences, we find the residual emission and Hα fluxes listed in Table 2. The Hα emission is in the middle of the Pleiades distribution.

Radial velocities were derived from cross-correlation of the Hα region. While not ideal, this is the only feature with enough statistical power to derive relatively secure results. We find no evidence for night-to-night variations larger than the apparent uncertainties. There may be asymmetries in the cross-correlation peak that result from the oddities noted above, but the significance is difficult to assess. Our heliocentric velocity estimate is $+20.7$ km s^{-1}, with an estimated uncertainty of 4.5 km s^{-1}, but it is possible that the Hα-based velocity does not precisely correspond to the systemic stellar velocity.

Given the VA nature of the star as determined from Paper I, our confirmation of this from Hα, and the lack of any evidence of duplicity, we have included HD 175897 as a young candidate. Additional monitoring and higher S/N spectra would be welcomed to investigate the possible spectral oddities noted above, as well as to derive a more secure limit on or value of the Li abundance.

HD 177996 (*star L*).—This object has no high-energy satellite detections. Spectra in the Hα and Li regions are shown in Figure 19; the star is clearly an SB2. While there are only small (a few km s^{-1}) radial velocity variations in the A component, large and significant shifts are present for the secondary; the period must be short (i.e., a few days or less). On the first night, the spectral lines of the two components coincided at a v_{rad} of -38.4 ± 1.5 km s^{-1}. Relative v_{rad} values on the other nights are noted in Table 2.

While both objects are not far from being sharp-lined (as defined by our instrumental resolution), the secondary appears to have broader lines than the primary. Li is present in the primary and the secondary also. Simple comparison relative to the 6717 Å Ca I line indicates Li is much lower than (unevolved) stars of similar color in young clusters. A rough estimate of the flux-corrected Li equivalent width of the primary is ~25 mÅ, which we believe accurate to 5–10 mÅ. Although we adopt the color and T_{eff} of the (now known to be) composite system, which is presumably systematically redder and cooler than the A component alone, this is not a dangerous assumption, because the abundance sensitivity to adopted T_{eff} is not expected to be any steeper than the observed log N(Li)–T_{eff} morphology of young and intermediate-age cluster stars at the approximate T_{eff}. We derive log N(Li) ~ 1.10, which is significantly less than the value for single stars or short-period binaries of similar color in the Pleiades. However, it is significantly larger than that of single Hyades stars, and comparable to cooler short-period Hyades binaries.

Given the SB2 nature of the star (which may have diluted the H and K absorption), the moderately low Li abundance,

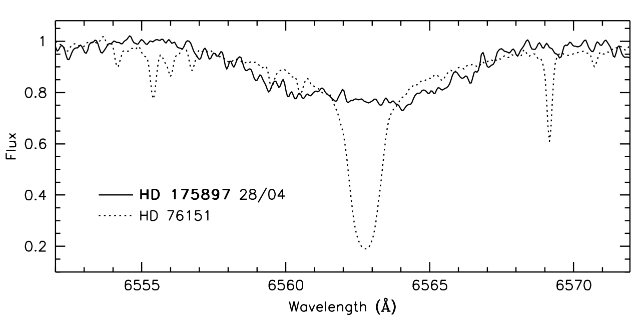

FIG. 18.—Mildly smoothed Hα profile of HD 175897 from the third night (*solid line*), plotted with the Hα profile of the similar color standard HD 76151 (*dotted line*). The very broad-lined nature of the VA star is clear.

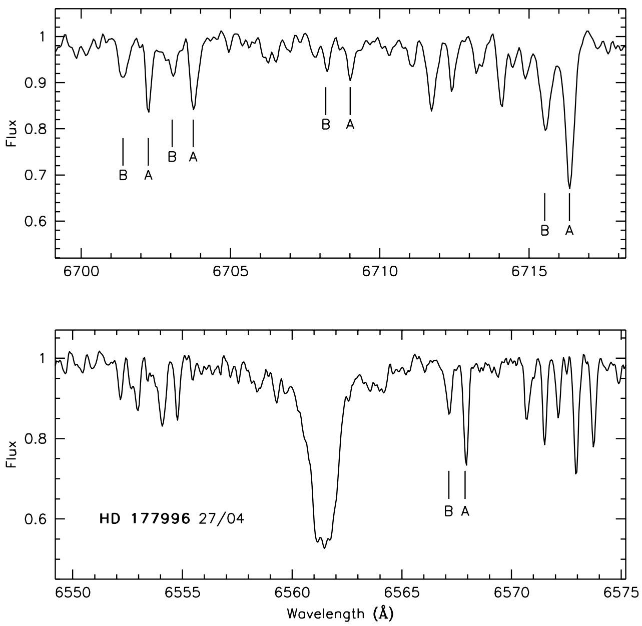

FIG. 19.—Mildly smoothed spectrum of HD 177996 from the second night of observations; no radial velocity corrections have been applied. The top panel contains the Li region. The two components of the (rest wavelength) Fe I $\lambda\lambda$6703.6, 6705.1, 6710.3, and Ca I λ6717 features are marked. The bottom panel shows the Hα region where, again, two sets of lines are evident.

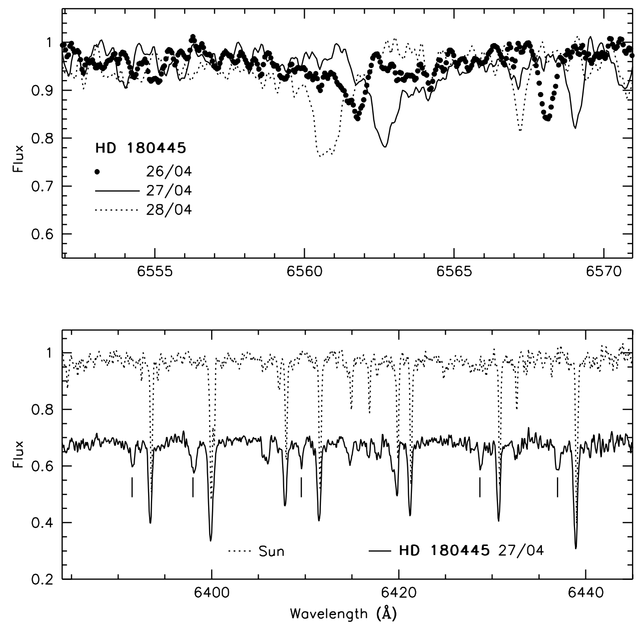

FIG. 20.—*Top*: Mildly smoothed Hα profiles of HD 180445 from all three nights. There are clear variations in radial velocity and the very weak Balmer absorption. *Bottom*: Spectra of the daytime sky (*dotted line*) and HD 180445 (*solid line*) in the 6410 Å region. A second set of lines, also seen in the other orders, is evident in the stellar spectrum.

and lack of X-ray or EUV detections, we do not consider the star as a young candidate.

HD 180445 (*star M*).—Our spectra are some of the few observations of any sort for this poorly studied VA star; it has no satellite detections. The Hα spectra confirm the H and K–based VA designation. The Balmer line is very weak—nearly filled in on the first night of observations—and variable in strength. This weakness is not due to dilution from a companion, though the second and third nights' data have a weak second set of lines.

The top panel of Figure 20 contains the Hα spectra from all three nights. Nightly velocity shifts, significantly larger than the tiny instrumental and heliocentric shifts, are evident. The period of this SB must be short (days or less). The bottom panel compares the 6410 Å regions of the Sun (*dotted line*) and the second night's spectrum of HD 180445 (*solid line*). A weak second set of lines appears in the stellar spectrum and is visible in other orders, too. The second set is less apparent on the first night, and not identifiable on the third night. Part of these changes could be related to lower S/N in some of the spectra from the second and third nights.

The $v_{\rm rad}$ of the A component on the first night is -26.2 ± 0.6 km s^{-1}, but the systematic error may be as large as 15 km s^{-1} because of effects of the secondary. The second night's spectrum yields a $v_{\rm rad}$ difference of -105 ± 7 km s^{-1} (A$-$B), and on the third night this difference is $+85 \pm 5$.

No consistent feature ascribed to Li can be seen in our three spectra. We are able to place a conservative limit (including any flux dilution) of 50 mÅ on the equivalent width of any Li line. This is about a factor of 2 less than the line strengths of Pleiades stars of similar color. While the resulting abundance upper limit is significantly larger than Hyades or Praesepe stars of similar color, the low Li abundance upper limit is considerably smaller than that seen in very young stars of any metallicity (Fig. 2). Given the binary nature and the low Li abundance, we do not include HD 180445 in our young candidate sample. Its Hα does appear to be genuinely filled in with emission, however, and this is probably caused by rapid rotation induced by a close, tidally locked secondary.

HD 202917 (*star S*).—This VA star, otherwise not well studied, has recently been classified as a *ROSAT* and an *EUVE* source (Lampton et al. 1997). The top panel of Figure 21 plots the Hα profile of HD 202917 with that of the slightly cooler standard HD 115617. The VA classification of Paper I is confirmed by the weakness of the Balmer line. We measured the residual Hα emission as before, using the standards HD 115617 and HD 76151, which bracket HD 202917 in color. The measurements, listed in Table 2, indicate that the Hα flux of HD 202917 lies near the upper envelope of the Pleiades distribution for its color (Fig. 1).

The bottom panel of Figure 21 shows the first night's co-added spectra in the Li region. The Li line is very strong, surpassing the Ca I λ6717 feature in strength—again, a rare occurrence generally limited to young stars. The measured Li line strength was corrected for Fe I λ6707.4 contamination, and the resulting equivalent width and (LTE) abundance are listed in Table 2. The abundance is a few tenths of a dex larger than that in Pleiades stars of similar color (Fig. 2), despite the fact that HD 202917 does not appear to be a rapid rotator; we estimate $v \sin i \approx$ 10–15 km s^{-1}.

The radial velocities from the first night's two spectra are indistinguishable. We find no radial velocity difference between the first and second nights larger than 0.35 km s^{-1}, which is within the errors. Eggen (1986) lists the star as having a variable radial velocity, based on a private communication of unpublished work. Without more detail, it is impossible to say whether our (quite limited) data conflict with such an assessment. We initially wondered whether the first night's spectra might contain asymmetric profiles indic-

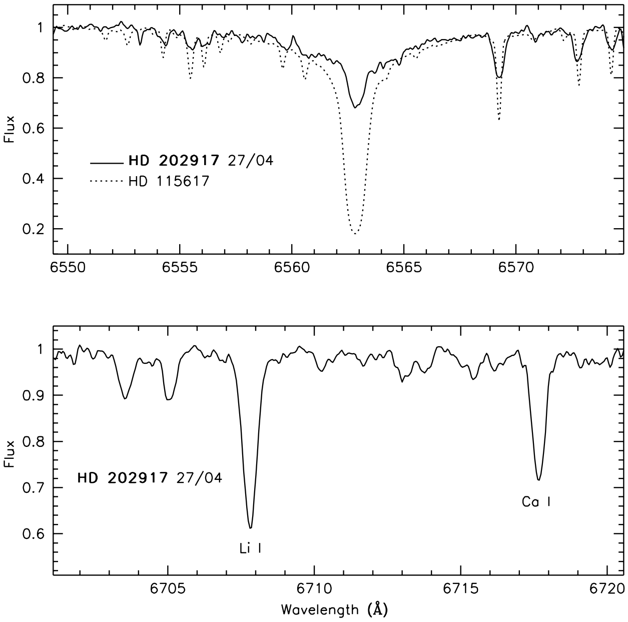

FIG. 21.—*Top*: First night's co-added and mildly smoothed Hα spectrum of HD 202917 (*solid line*), compared with the slightly redder and cooler standard HD 115617 (*dotted line*). The mild macroscopic broadening and weakened Hα for the VA star is apparent. *Bottom*: Co-added and mildly smoothed spectrum of the Li region in HD 202917.

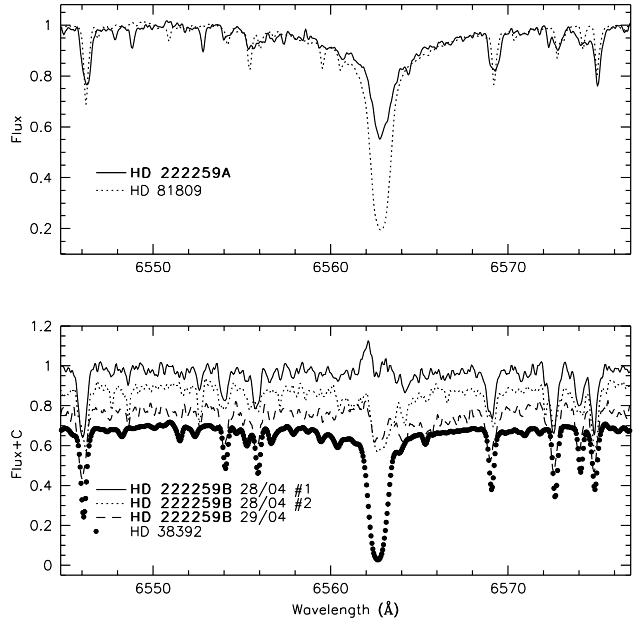

FIG. 22.—*Top*: Co-added and mildly smoothed Hα profile of HD 222259A (*solid line*) compared with the profile of the standard HD 81809, which is of nearly identical color; the modest macroscopic broadening and a significantly weakened Balmer line of the VA star are evident. *Bottom*: Hα profiles of HD 222259B from the individual spectra (*solid*, *dashed*, *and dotted lines*) compared with the slightly hotter standard HD 38392 (*circles*). The spectra have been offset vertically for clarity. Overt Hα emission is seen in the first VA spectrum, but absorption is seen in the spectra acquired 16 minutes later and on the next night. No velocity corrections have been applied to the VA spectra in order to preserve the relative velocities, but the HD 38392 spectrum was shifted to roughly align it with HD 222259B.

ative of an SB2 classification. Given the modest S/N, we co-added the spectra and cross-correlated the data with our sky spectrum in the 6480 Å region. The cross-correlation function appears symmetric, a conclusion that holds whether utilizing filtering or not. We measured a radial velocity from our spectra, with a zero-point and instrumental correction estimated as before. Our heliocentric value of -5.3 km s^{-1} is in good agreement with the -7 km s^{-1} value from Eggen (1986); the uncertainty in our velocity is near 1 km s^{-1}.

Given the significant H and K and Hα emission, large Li abundance, and X-ray and EUV detections, we include HD 202917 as a young candidate lacking convincing evidence for duplicity.

HD 222259AB (*stars T and N*).—This VA system from Paper I is both a *ROSAT* and an *EUVE* source (Bowyer et al. 1994). We observed the components of this 5″ visual double individually. Before proceeding with analysis of our spectra, we remedy the prior lack of individual $B-V$ colors or an accurate composite color for these stars by adopting the photometry of the *Hipparcos* double- and multiple-component solutions. These new values are listed in Table 2; the uncertainties are a few hundredths of a magnitude.

The bottom panel of Figure 22 shows the individual Hα profiles of the B component compared with the slightly warmer standard HD 38392. The overt Hα emission in the first spectrum confirms the VA nature of this star, despite any flux dilution from a companion (or companions). The Hα absorption seen in the spectrum acquired only 16 minutes later, as well as in that from the next night, suggests significant Hα variability on short timescales. Small but significant radial velocity shifts between the spectra are observed. Moreover, the line profiles also change, becoming significantly narrower in our second spectrum. The radial velocity variations indicate an SB designation; while no clear second set of lines is identifiable, the profile morphology changes indicate an SB2 designation. Apparently, this is a close system, with a period of $\lesssim 2$ days.

The Li features in all the spectra of both the A and B components are comparable in strength to the Ca I λ6717 feature (Fig. 23), indicating relatively high Li abundances. Estimates for both the A and B components were derived as before. For the binary's B component, the mean measured line strength (abundance) from the three individual spectra might be overestimated by a factor perhaps as large as 2 (0.5 dex) because of blending, though this is likely quite a generous bound. An underestimate on account of flux dilution is also possible but would only strengthen the conclusion of a large Li abundance. The raw equivalent widths were corrected for Fe I λ6707.4 contamination, and the derived LTE abundances are listed in Table 2. The value for A is large—comparable to or a couple tenths of a dex greater than the

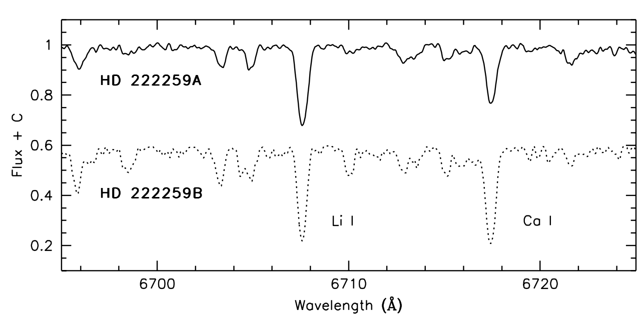

FIG. 23.—The first night's lightly smoothed first spectrum of the Li region of HD 222259A (*top*) and, offset vertically by an additive constant, the spectrum of HD 222259B (*bottom*). The Li line is of strength comparable to or larger than the Ca I λ6717 feature.

majority of Pleiades values at similar color and projected rotational velocity (Fig. 2). The B-component abundance is also large, and appears to fall on or perhaps slightly above the upper envelope of Pleiades abundances, which show significant scatter.

The H and K emission from Paper I, the Balmer line emission measured here, the extant X-ray and EUV satellite detections, the lack of convincing evidence for duplicity, and the very large Li abundance all make HD 222259A a promising young candidate system. This also means that HD 222259B should be a promising young candidate system too, but given our close-binary criterion, we have not labeled it as such in Table 2. The B component, then, is a specific example of a binary system that is most likely a young object, but which is rejected by our exclusive criteria. As mentioned before, there may be other young binaries we have similarly excluded.

Absolute radial velocities for the A and B components were measured from cross-correlation analysis of the 6440–6520 Å region as before. For the variable B component, the first spectrum (having the median velocity) was taken to be the best statistical estimate of the systemic velocity. The resulting heliocentric values are reported in Table 3 (see below). The uncertainties are estimated to be near or slightly below ~ 1 km s^{-1}; systematic errors could be significantly greater for the B component, of course, but there is good agreement between the A and B values. During the analysis we noticed the cross-correlation functions of the A component were slightly asymmetric, more so than the B-component functions despite the lack of evidence for double lines. The asymmetries (an extended blue tail) result in increased sensitivity of our derived radial velocities to the fitting function, and such uncertainties are the dominant item in our error budget. The asymmetries are not present in the cross-correlation function of the telluric B-band features, suggesting that the result is not instrumental. That the cross-correlation tail is preferentially extended in the same direction for both A and B indicates that the cause is not contamination of the given component's spectrum by the other component. Additional observations of higher S/N and resolution would be of interest to determine if the cause is an additional heavily blended set of weak lines in the A component.

4. DISCUSSION

Of the 18 stars in 16 VA systems from Paper I that we have observed at high resolution, 13 show evidence of being close binaries on the basis of either their line profiles or variable radial velocity. It is also possible, of course, that some of our young candidates are members of close binary systems that we did not recognize. While this close-binary fraction, nearly 75%, is high, it is not surprising given that our sample was composed of stars with strong chromospheric emission. In Figure 24, we reproduce Figure 7*a* of Paper I, showing the distribution of chromospheric emission strengths of the 600-plus stars observed there. We have updated the upper portion to reflect what we now know about duplicity in these systems. We have indicated known or probable doubles with crosses. In this updated figure we have added the three targets from the secondary sample of Paper I and have adjusted log $R'_{\rm HK}$ values using the newer $B-V$ values of Table 2.

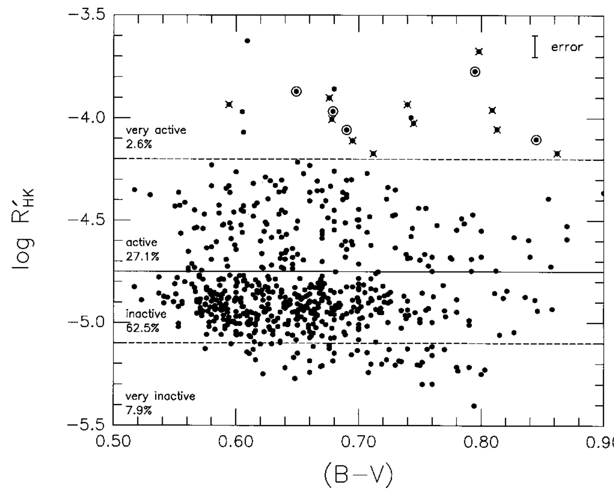

FIG. 24.—Normalized index of Ca H and K emission, log $R'_{\rm HK}$, vs. $B-V$ color for the 624 stars observed in Paper I. Here we have updated our knowledge of multiplicity among the VA stars. Multiple systems are indicated by crosses, and stars that are probably single are circled.

Five of our 18 VA stars are probably young stars (six if HD 222259B is included). The Hα emission levels and lithium abundances of these stars (see Fig. 2) confirm their youth. This number may be an underestimate, since we may have excluded some young stars because they were in close binaries. In particular, we note that HD 106506 may be a young SB2 and that HD 155555AB has been suggested to be a post–T Tauri star by others. Also, HD 119022 could be a young, heavily reddened star. In this respect, although excluded from our final young candidate list, HD 119022 could be one of the more interesting objects in our sample because of its high luminosity. Clearly, these possible young stars merit further study.

For the five apparently single young candidates, our Hα measurements confirm the VA assignment made in Paper I. Indeed, three of the five stars are at or above the upper

TABLE 3

KINEMATICS OF VERY YOUNG STARS

Object	$v_{\rm rad}$ (km s^{-1})	μ_α (mas yr^{-1})	μ_δ (mas yr^{-1})	π (mas)	Space Motion (km s^{-1}) U	V	W
HD 37572A	+28.9 ± 0.8	+30.1 ± 3.8	−6 ± 3.8	41.90 ± 1.74	−6.0 ± 0.5	−25.6 ± 0.7	−12.5 ± 0.6
HD 174429........	−13.5 ± 3.0	+16.3 ± 3.1	−88 ± 3.2	20.14 ± 1.18	−20.1 ± 2.8	−14.1 ± 1.4	−4.6 ± 1.4
HD 175897........	+20.7 ± 4.5	+5.4 ± 2.6	−44 ± 2.7	9.44 ± 1.26	+6.5 ± 4.1	−25.4 ± 3.2	−15.4 ± 2.4
HD 202917........	−5.3 ± 1.0	+30.7 ± 3.3	−93 ± 3.5	21.81 ± 1.17	−10.9 ± 0.9	−18.9 ± 1.3	+2.1 ± 0.9
HD 222259A......	+5.2 ± 1.0	+77.3 ± 2.5	−53 ± 2.9	21.64 ± 1.32	−10.7 ± 1.0	−18.3 ± 1.2	−1.1 ± 0.9
HD 222259B......	+3.5 ± 0.8	+77.3 ± 2.5	−53 ± 2.9	21.64 ± 1.32	−11.5 ± 1.0	−17.4 ± 1.2	+0.1 ± 0.7
HD 98800.........	+12.8 ± 0.1	−89 ± 3.1	−23 ± 2.9	21.43 ± 2.86	−13.2 ± 2.1	−19.7 ± 1.3	−3.5 ± 1.5
Pleiades					+7	−25	−15

bound of the Pleiades $R_{H\alpha}$-$(B-V)$ distribution for stars of their color. With the obvious exception of HD 119022, the apparent weakness of Hα absorption in the remaining VA objects—including the overt Hα emission for HD 155555AB and HD 222259B—is fully consistent with the weak Ca II absorption identified in Paper I. In this sense, the results of the low-resolution Ca II spectra in Paper I are reliable. The present work, however, indicates that in a significant number of cases the determination of whether those spectra reliably measure the effects of chromospheric emission (due either to youth or to a close companion) or the effects of flux dilution from a companion (or some combination) may require follow-up monitoring with high-resolution spectroscopy. Also, some of the $B-V$ colors used in Paper I were very uncertain, leading to possibly spurious identifications as VA systems, but that appears to have been rare.

Figure 25 shows a color-magnitude diagram (CMD) for 18 stars in our sample for which *Hipparcos* parallaxes (ESA 1997) are available (none was available for HD 102982). Three of the probable single stars (*circles*) appear to be PMS objects, with ages of about 10 to 15 Myr, putting them in the post–T Tauri class of stars. The other three have positions in the CMD consistent either with ZAMS or PMS evolutionary status. The multiple systems (Fig. 25, *squares*) are most likely RS CVn systems that lie above the main sequence because they are evolved.

In Table 3, we present the kinematics of our most likely young stars, using the radial velocities derived here. The proper motions are from the PPM Catalogue (Bastian & Roeser 1993), and the parallaxes are from *Hipparcos*. The space motions were calculated with an updated version of the prescription from Johnson & Soderblom (1987).

There are several noteworthy kinematic properties of our final young candidates. First, the space velocities of HD 175897 are in excellent agreement with those of the Pleiades

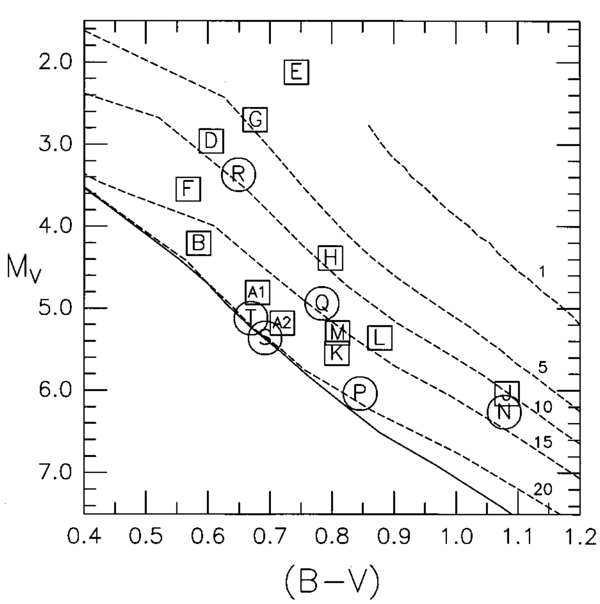

FIG. 25.—Color-magnitude diagram for stars with *Hipparcos* parallaxes. Stars are identified by the letters in Table 2. The squares represent stars that are probable or possible binaries, while the circles represent stars that are probably single. The dashed lines are isochrones from Siess, Forestini, & Dougados (1997) corresponding to ages, from top to bottom, of 1, 5, 10, 15, and 20 Myr. The solid line at the bottom is the ZAMS. Some points have been offset slightly to avoid overlap.

cluster (Eggen 1983). This is not conclusive evidence that these stars in fact have their origin in the Pleiades, because that part of velocity space is near the local standard of rest, where young stars are likely to be found in any case. If these stars indeed form a Pleiades halo, then the volume of space we have surveyed, compared with the distance to the Pleiades, suggests that that halo may contain a hundred or more stars, especially since their density is likely to be higher in the immediate vicinity of the cluster itself. HD 37572A may be another star associated with the Pleiades.

We previously noted that our assessment of the kinematics of HD 174429 does not place it in the Pleiades group, as had been suggested by Innis et al. (1986). Our radial velocity disagrees with theirs. Also, the *Hipparcos*-based distance is some 25% smaller than their assumed value. The origin of this VA young candidate star, which has a very high Li abundance, is unclear.

We note that the U- and V-velocities of HD 202917 and HD 222259A agree well with each other. Furthermore, these velocities also agree with the values for HD 98800, which Soderblom et al. (1998) argue is a rare example of a post–T Tauri star. The small differences in the U-velocities (2–3 km s^{-1}) between HD 98800 and the other two stars are consistent with their spatial separations (about 60 pc), given their ages ($\sim$10–20 Myr). The two VA young candidates and HD 98800 also share the property that their Li abundances are comparable to or larger than the Pleiades stars of similar color and projected rotational velocity. Thus we suggest that HD 202917 and HD 222259 may be two more examples of post–T Tauri stars. The ages for these stars from Figure 25 are about 20 Myr or more, older than the $\sim$10 Myr age of the HD 98800 system (Soderblom et al. 1998), but perhaps consistent to within the uncertainties. Furthermore, these three systems may provide evidence of a small group of very young stars sharing a common origin, supporting the suggestion of Kastner et al. (1997) that HD 98800 is accompanied by several other PMS objects. If this interpretation is correct, then HD 222259 would be another example of a multiple post–T Tauri system that could provide constraints on the origin of post–T Tauri stars in the field (Soderblom et al. 1998).

An occurrence of five very young stars means that $\sim$1% of the total sample of Paper I is younger than the Pleiades. Since the Pleiades is 100 Myr old and these stars have lifetimes of $\sim$10 Gyr, this fraction seems reasonable. However, 1% is, in fact, high. First, very old stars are missing from the solar neighborhood because of disk heating (meaning that five stars correspond to $\sim$1.5% once this effect is compensated for), but this is unimportant given the numbers of stars involved. More seriously, we expect few, if any, stars to have found their way from star-forming regions into the immediate solar vicinity in such a short time. The Pleiades itself could supply some of these stars, because a star need only move at $\sim$1 km s^{-1} relative to the cluster to cross the $\sim$100 pc from there to here in 100 Myr. But these very young stars appear to be much younger than the Pleiades and do not have the kinematics of that cluster. Getting a star from, say, Taurus-Auriga to the solar neighborhood in 10 Myr requires a peculiar velocity of 15 km s^{-1} or more, which is substantial.

5. Li ABUNDANCES IN THE Hα STANDARDS

Since they may be of interest, we have derived Li abundances for our inactive Hα standard stars. We expect these stars to be old and to have low Li abundances. Our results, given in Table 2, confirm this. Detailed spectrum synthesis could probably provide tighter constraints on the abundances, but we have chosen, as a reliable expedient, to simply measure equivalent widths in the spirit of our cursory examination of these stars' abundances. The results may provide a starting point for studies of very low Li abundances in older solar-type stars.

Peripheral notes about two stars may be of interest. First, Li is detected in HD 76151; despite being of solar $T_{\rm eff}$ or slightly cooler, the Li abundance is some 4 times higher than the Sun's (we also detect Li in HD 38393 and HD 45067, but this is not unusual at their relatively early spectral types). Second, because we lack precise multiband photometry for both components, we have assumed HD 158614 N and S to be identical, although orbital determinations and older photometry indicate a slight difference. Our spectrum of each component is contaminated by the other. There is some indication in our spectra that Li may be present in HD 158614 N. Extremely high (spatial and spectral) resolution and S/N spectra and precision resolved photometry would be worthwhile, since a difference in the components' Li abundances might be of interest.

6. CONCLUSIONS

We have presented high-resolution echelle spectroscopy of 18 "very active" (VA) southern solar-type stars identified in the Ca II H and K survey of Henry et al. (1996). We find evidence from line doubling or radial velocity variations that 13 of these are members of short-period, close binary systems. Activity in these stars may thus be due to the presence of a close companion, rather than youth; however, it is entirely possible that some of the objects (HD 106506, 119022, 155555AB, and 222259B) are young close binaries. Just a few exposures of high resolution but very modest S/N seem to be a highly effective and efficient means of identifying active close binary systems.

Based on our Hα observations, we confirm that the remaining five of the 18 stars are also VA, and we find no evidence that such activity is the result of membership in a close binary system. Four of these stars also have significant Li abundances, comparable to or larger than Pleiades stars of similar color. We consider these five stars to be young candidates, i.e., stars whose chromospheric activity seems associated solely with youth.

We note that two of the young candidates (HD 202917 and HD 222259) appear to have the same (U, V)-velocities as HD 98800, a rare example of a post–T Tauri star in the field, according to Soderblom et al. (1998). While the formation site of these stars is unclear, the three stellar systems may be part of a small group of very young stars sharing a common history and origin. The space velocities of HD 175897 are in excellent agreement with those of the Pleiades.

Two other interesting objects are HD 106506 and HD 119022, which were noted above as possible young objects that were excluded from our final best young candidate list because of their duplicity. Both of these objects demonstrate sharp features in the broader Na D lines and stronger features of other metals. We do not observe any radial velocity shifts of these sharp features. This would suggest an interstellar or circumstellar origin for the sharp D-line features. These two objects are among the most distant in our sample: the *Hipparcos*-based distances are ~ 125 pc, but this seems too near for an interstellar origin. There is thus the intriguing possibility that these features arise from circumstellar material, perhaps not unlike that surrounding β Pictoris or early-type shell stars similarly inferred from the presence of sharp features in a broader stellar absorption line. Comparison of the spectral type and photometry for HD 119022 suggests a moderate-sized reddening of perhaps 0.1 to 0.15 mag in $E(B-V)$. Higher quality spectra and high-resolution imaging of these objects would be of great interest.

Finally, Li abundances or upper limits were derived for the sharp-lined inactive Hα standards employed in our program. We report detectable Li for the solar-$T_{\rm eff}$ star HD 76151 and for the late F stars HD 38393 and HD 45067. There may be an Li abundance difference in the two similar wide components of HD 158614; better knowledge of their fundamental parameters from spatially resolved photometry and spectroscopy is needed.

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