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AGES OF LATE SPECTRAL TYPE VEGA-LIKE STARS

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ABSTRACT

We have estimated the ages of eight late-type Vega-like stars by using standard age-dating methods for single late-type stars, e.g., location on the color-magnitude diagram, Li λ6708 absorption, Ca II H and K emission, X-ray luminosity, and stellar kinematic population. With the exception of the very unusual pre–main-sequence star system HD 98800, all the late-type Vega-like stars are the same age as the Hyades cluster (600–800 Myr) or older.

Subject headings: planetary systems — stars: activity — stars: late-type

1. INTRODUCTION

Vega-like stars are stars with IR excess emission due to optically thin dust disks with little or no gas (Backman & Paresce 1993; Lagrange, Backman, & Artymowicz 2000). It is important to know the ages of Vega-like stars because they may provide crucial information about extrasolar planetary systems. Given the existence of a complete, flux-limited IR survey and a 100% success rate for identifying stars with IR excesses due to circumstellar disks, then if all identified Vega-like stars were young, one could conclude that the timescale for the disks to "go away" is short. Furthermore, if the ratio of the number of Vega-like stars to the total number of stars (N_V/N_T) is similar to the ratio of the average ages of Vega-like stars to the average ages of Milky Way disk stars (τ_V/τ_{MW}), then one could also conclude that most stars are born with such disks. Hence, if such Vega disks are signposts of planet formation, then one could infer that most stars have planetary systems. On the other hand, if Vega-like stars have a wide range of ages and $N_V/N_T \ll \tau_V/\tau_{MW}$, then one could plausibly conclude that disk formation—and hence possibly planet formation—is not a common process, at least at the level of sensitivity of the IR survey used to identify the Vega-like stars.

There have been many efforts to determine the ages of Vega-like stars. Backman & Paresce (1993) estimated the age of β Pictoris as 100 Myr, whereas Jura et al. (1993) claimed that β Pic is extremely young, ~2–3 Myr. They interpreted the same data in opposite ways, the latter group claiming that β Pic is approaching the zero-age main sequence (ZAMS) and the former group believing that β Pic is an old main-sequence (MS) star. More recent studies of β Pic support its young age (Jura et al. 1998; Barrado y Navascués et al. 1999). Another conspicuous Vega-like star, HR 4796A, is believed to be even younger than β Pic (Jura et al. 1993; Stauffer et al. 1995), while Fomalhaut and Vega are estimated to be much older, ~200 Myr (Backman & Paresce 1993; Barrado y Navascués et al. 1997; Barrado y Navascués 1998).

In order to increase the number of age estimates of Vega-like stars, we have compiled a list of 361 Vega-like stars from the literature and have searched for late-type binary companions in order to follow the techniques of Stauffer et al. (1995), who determined the age of HR 4796A by using the properties of its late-type companion star HR 4796B. The complete results of our survey can be found in Song (2000). However, there are eight late-type Vega-like stars in our list for which we can estimate ages directly by using standard age-dating methods for single late-type stars, methods such as their location on the color-magnitude diagram (CMD), Li λ6708 absorption, X-ray luminosity, rotation, and Ca II H and K emission.

In § 2, we present the late-type Vega-like stars and their age-related data. The age determinations are discussed in § 3, and a conclusion is provided in § 4.

2. DATA

In Table 1, we list the eight late-type ($B-V > 0.65$) Vega-like stars along with the data to be used for age estimations. All spectral types are taken from SIMBAD, and X-ray luminosities are from the *ROSAT* All-Sky Survey data (Hünsch, Schmitt, & Voges 1998; Hünsch et al. 1999). The fractional IR luminosity f (in the sixth column of Table 1) is defined as $f \equiv L_{IR}/L_*$. *IRAS* PSC2/FSC fluxes were used to calculate the f values. The values of the logarithm of the ratio between Ca II H and K fluxes and stellar bolometric luminosity log R'(HK) are from Henry et al. (1996), and the sources of the other parameters are indicated in the footnotes to Table 1.

HD 98800 is a quadruple system consisting of two spectroscopic binaries (Torres et al. 1995). Since the L_X flux includes the emission from all four components, we divided the published value by 4 to take the multiplicity into account. The Li abundance for this system is high [log N(Li) = 3.1, 2.3, and 3

TABLE 1
LATE-TYPE VEGA-LIKE STARS AND THEIR AGE-RELATED DATA

HD Number	Other Name	Spectral Type	M_v	$(B-V)$	$f(L_{IR}/L_*)$ $(\times 10^3)$	log L_X (ergs s^{-1})	log R'(HK)	log N(Li)
22049	ϵ Eri	K2 V	6.18 ± 0.11	0.88	0.08	28.32	−4.47	0.25[a]
53143	GL 260	K1 V	5.49 ± 0.14	0.81	0.18	28.69	−4.52	...
67199	...	K1 V	5.99 ± 0.06	1.0	0.24	27.87	−4.72	...
69830	GL 302	K0 V	5.45 ± 0.05	0.76	0.61	27.48	...	...
73752	HR 3430	G3/5 V	3.55 ± 0.11	0.73	0.03	27.98	...	1.3[b]
98800Aa	GL 2084	K5 V	6.06	1.17	...	30.17	...	3.1[c]
Ba	...	K7 V	6.36	1.37	230	30.17	...	2.3[c]
Bb	...	M1 V	8.1:	1.41	...	30.17	...	3:[c]
128400	...	G5 V	5.19 ± 0.07	0.67	3.2	28.59	−4.56	...
221354	GL 895.4	K2 V	5.63 ± 0.15	0.84	1.0	...	...	0.158[d]

[a] From Mallik 1998.
[b] From Lèbre et al. 1999.
[c] From Soderblom et al. 1993; and see § 2.
[d] From Fisher 1998.

for components Aa, Ba, and Bb, respectively; Soderblom et al. 1998], and the values for each component were used instead of the value from the whole system when possible. M_v values for each component were taken from Soderblom et al. (1998), and, according to Gehrz et al. (1999), component B emits most of the IR excess emission.

3. AGE ESTIMATIONS

3.1. *Color-Magnitude Diagram Location*

The eight late-type Vega-like stars are plotted in Figure 1 with theoretical solar abundance pre–main-sequence (PMS) evolutionary tracks from D'Antona & Mazzitelli (1997). We have used a "tuned" temperature scale to convert $T_{\rm eff}$ to $(V-I)_c$ (Stauffer, Hartmann, & Barrado Y Navascues 1995), which locates the 100 Myr isochrone onto the locus of Pleiades stars. Except for the HD 98800 system, we used *Hipparcos* $(V-I)_c$ colors to plot the CMD. With the exception of only HD 73752 and HD 98800, all the Vega-like stars are located on or close to the ZAMS, which makes it difficult to get an age estimation with precision smaller than the MS lifetime of the late-type stars. A star whose position in the CMD is above the ZAMS can either be in the PMS stage or in the post-ZAMS evolutionary stage. We need additional information to determine the actual ages of these stars. As argued below, HD 73752 is probably in the post-MS evolutionary stage, whereas HD 98800 is almost certainly a PMS star. Except for HD 73752 and HD 98800, we are only able to conclude that the stars in our sample are older than ∼30 Myr based solely in their locations in the CMD.

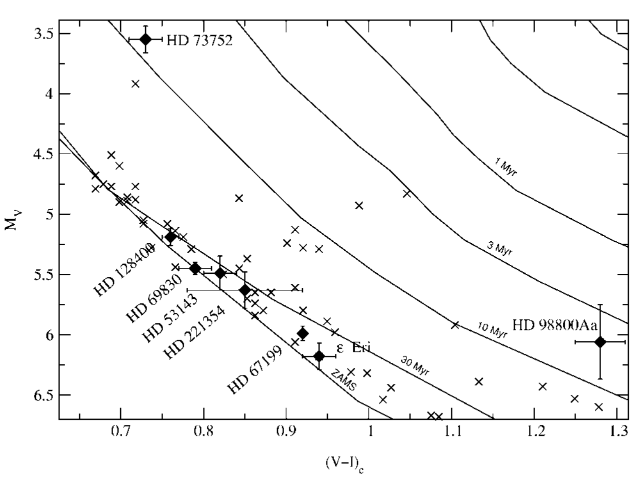

FIG. 1.—CMD of late-type Vega-like stars (*diamonds*) and the Pleiades stars (*crosses*). Isochrones are from D'Antona & Mazzitelli (1997).

3.2. *Lithium Abundance*

Four stars (ϵ Eri, HD 73752, HD 98800, and HD 221354) have had their Li λ6708 absorption strengths measured. Those values and the Li data for the Pleiades, the Hyades, and the M34 cluster members are plotted in Figure 2. It appears that HD 98800 is younger than the Pleiades cluster and that HD 73752, ϵ Eri, and HD 221352 are about the same age as the Hyades cluster (600–800 Myr).

3.3. *X-Ray Emission*

HD 98800 is again located above the Pleiades cluster in a plot of L_X versus $(B-V)$ (Fig. 3). HD 73752, HD 67199, and HD 69830 have X-ray luminosities much lower than those of Hyades stars with similar $(B-V)$ colors, so we assign older ages to those stars. However, ϵ Eri, HD 53143, and HD 128400 show about the same X-ray activity as Hyades stars, so their ages are probably similar.

3.4. Ca II H *and* K

By using the chromospheric activity-age relation of Donahue

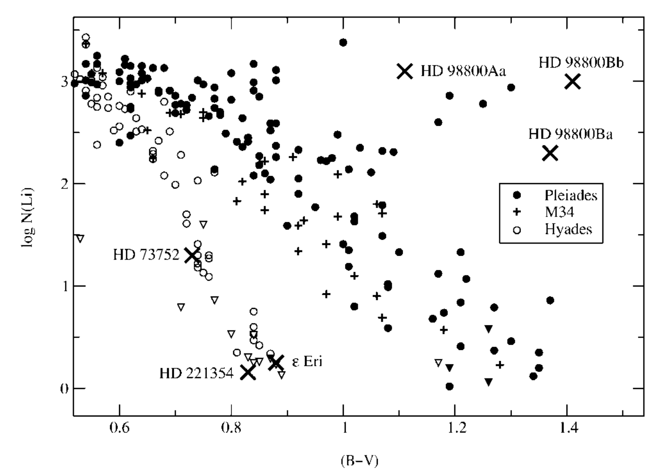

FIG. 2.—Li abundances of late-type Vega-like stars (*large crosses*) as well as members of the Pleiades cluster (*filled circles*; 125 Myr), M34 (*plus signs*; 250 Myr), and the Hyades (*open circles*; 600–800 Myr). Downward-pointing triangles indicate upper limits.

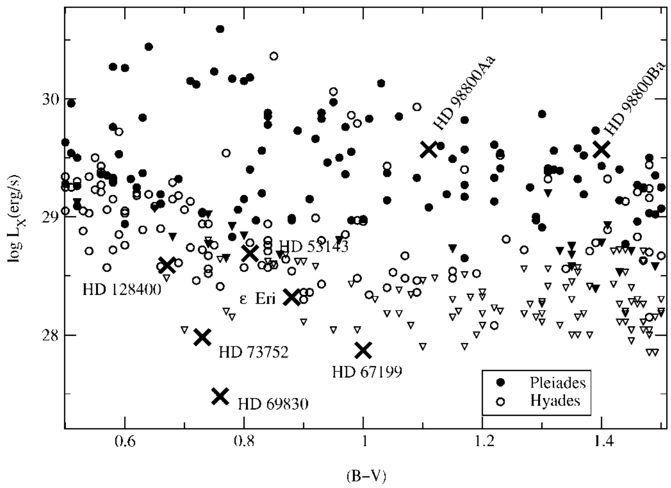

FIG. 3.—X-ray luminosities of late-type Vega-like stars, as well as those in the Pleiades and the Hyades. All symbols have the same meaning as in Fig. 2.

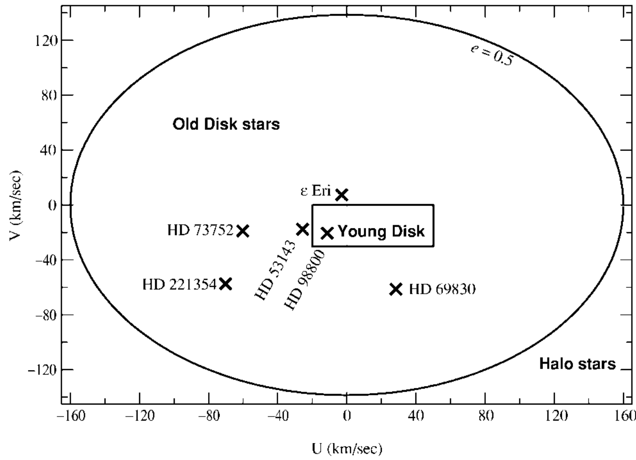

FIG. 4.—Kinematic population of late-type Vega-like stars

(1993),

$$\log t = 10.725 - 1.334R_5 + 0.4085R_5^2 - 0.0522R_5^3,$$

where t is the age in years and R_5 is defined as $R'_{\rm HK} \times 10^5$, we can obtain another estimate of the ages of ϵ Eri, HD 53143, HD 67199, and HD 128400. These ages agree with the age estimations from the previous sections. The age uncertainty can be obtained from the measurement error of $\log R'(\rm HK)$, $\Delta \log R'(\rm HK) = \pm 0.052$ ($\Delta\tau \sim 200$ Myr) (Henry et al. 1996). We adopted these ages as the final age estimations for the stars with Ca II H and K measurements because this method is the only one that provides a quantitative estimate. Age estimation from the CMD can also be fairly accurate, but only when a star is in its pre- or post-MS phase. Note that the calibration of this age formula is presumably tied to an age scale on which the Pleiades is 75 Myr and α Persei is 50 Myr old. If the new lithium depletion ages for these clusters (125 and 85 Myr, respectively; Stauffer et al. 1998, 1999) are correct, then the Ca II H and K ages should be increased by ~50%.

3.5. *Kinematics*

All eight stars appear in the *Hipparcos* catalog, but only six stars have radial velocity measurements (from Duflot, Figon, & Meyssonnier 1995 and references therein). We have used these radial velocities and parallaxes, along with B1950 coordinates and proper motions, to calculate (U, V, W) Galactic velocity components following Johnson & Soderblom (1987). The kinematic population of the Vega-like stars is determined by using the population criteria from Leggett (1992)—young disk stars are those with $-20 < U < 50$ and $-30 < V < 0$, while old disk stars have an eccentricity less than 0.5 in the (U, V)-plane but lie outside the young disk ellipsoid. Of the six Vega-like stars with (U, V, W)-velocities, only HD 98800 is located inside of the young disk star regime (Fig. 4).

3.6. *Other Criteria*

Since all Vega-like stars with $v \sin i$ measurements in this study are slow rotators, we can not assign any meaningful ages from this method. Metallicities of the Vega-like stars with [Fe/H] measurements are very close to the solar value. Thus, the metallicity data cannot constrain ages of these stars, either.

3.7. *Final Estimated Ages*

All age estimations are summarized in Table 2. Based on its X-ray luminosity, Li abundance, kinematics, and location on the CMD, we are confident that HD 98800 is a PMS star with a probable age of ~7 Myr, and it almost certainly lies between 2 and 12 Myr old, which is in good agreement with Soderblom et al.'s (1998) estimate of 10^{+10}_{-5} Myr. Based on a similar set of evidence, HD 73752, on the other hand, is almost certainly a post-MS star whose IR excess emission mechanism may be different from that of the younger Vega-like stars. The six other stars in our study lie close to the ZAMS in the CMD and seem to have ages ~1 Gyr. For HD 69830 and HD 73752, we assigned maximum ages of 2 Gyr because they have about the same X-ray activity as HD 67199, which has an age determination from Ca II H and K. However, the ages for these stars could be as small as the age of the Hyades cluster (but not smaller than that). Therefore, we assign ages in the range of

TABLE 2
AGE ESTIMATIONS FOR THE LATE-TYPE VEGA-LIKE STARS

Name	Age-dating Method					Final Age
	L_X	Ca II H and K	Li	Kinematics	CMD	(Myr)
ϵ Eri	~Hyades	730	~Hyades	Old disk population	MS	730 ± 200
HD 53143	~Hyades	965	...	Old disk population	MS	965 ± 200
HD 67199	>Hyades	2000	...	...	>MS	2000 ± 200
HD 69830	>Hyades	...	...	Old disk population	MS	600–2000
HD 73752	>Hyades	...	~Hyades	Old disk population	>MS	600–2000
HD 98800	<Pleiades	...	<Pleiades	Young disk population	7 ± 5	7 ± 5
HD 128400	~Hyades	1100	...	...	MS	1100 ± 600
HD 221354	...	...	≥Hyades	Old disk population	MS	1500 ± 1000

600–2000 Myr for these two stars. HD 221354 does not have a good age estimation, but from the fact that it is on the MS and that it belongs kinematically to the old disk population stars, we assign an age of 1.0 ± 0.5 Gyr.

Habing et al. (1999) performed a study very similar to ours but mainly of early-type stars. They found that most Vega disks disappear very sharply around an age of 400 Myr. I. Song, J.-P. Caillault, D. Barrado y Navascués, & J. Stauffer (2000, in preparation) have also found that early-type Vega-like stars are systematically young (<400 Myr) by using Strömgren *uvbyβ* photometry.

3.8. K *Stars with an Upper Limit in f*

As seen from Table 2, there are no Vega-like stars with ages in the range between a few tens and a few hundreds of megayears in the spectral type range in which we are interested. To have more data in that age range, we constructed a list of young K stars based on their strong Li absorption or strong X-ray emission (Fisher 1998; Jeffries, Bertram, & Spurgeon 1995). We collected age-related data for these stars from which we estimated their ages (see Song 2000). Some of these stars were detected with *IRAS*. Upper limits to *f* for these stars were calculated by assuming that each system has a dust disk with temperature of 100 K and that the system was barely undetected at 60 μm. These stars are plotted as downward-pointing triangles in Figure 5, a plot of *f* versus age for early- and late-type Vega-like stars with good age estimates. Two stars in the list of young K stars (Gl 150 and HD 68586) lie above the ZAMS in a CMD, but, based on the other data available for these stars, we find that they must be post-MS stars; as a result, they are not plotted in Figure 5.

We find Figure 5 both illuminating and puzzling. For the early-type stars, the correlation of age and IR excess plus the generally young ages for these prototypical objects suggest that many A stars form with disks and the disk excesses decrease with age because of some evolutionary process (Barrado y Navascués et al. 1999). For the late-type Vega-like stars, the much older derived ages at least suggest that the timescale for disk evolution is longer.

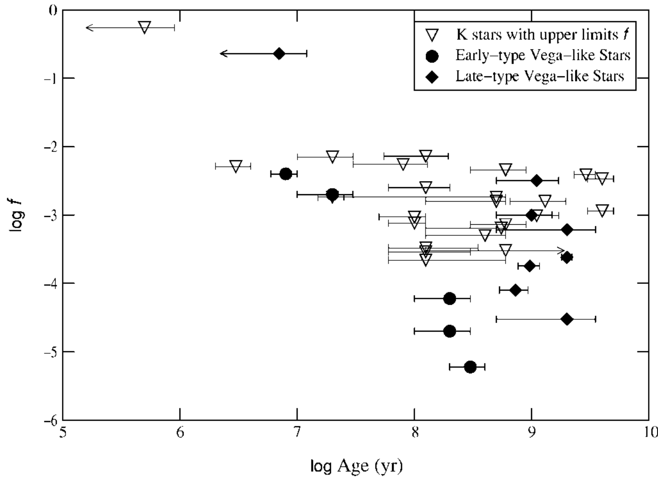

FIG. 5.—Fractional infrared luminosity vs. age. Early-type Vega-like stars are plotted as circles, and late-type Vega-like stars are plotted as diamonds. Field K stars with IR excess upper limits are represented with downward-pointing triangles.

4. CONCLUSION

We have estimated ages of eight late-type Vega-like stars by using standard age-dating methods for a late-type star. Except for the PMS star HD 98800, all Vega-like stars in this study are the same age as the Hyades cluster or older.

Because we have only one late-type Vega-like star with an age less than ~500 Myr, we cannot draw any strong conclusions about the evolutionary timescale for disk evolution for K dwarfs. It would be very useful to obtain mid-IR data (with the very sensitive *Space Infrared Telescope Facility* [*SIRTF*], for example) for the stars in the list of young K stars. It would also be useful to obtain more complete age indicator data for this sample in order to make the age estimation more precise.

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