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CHROMOSPHERICALLY ACTIVE STARS. IX. HD 33798 = V390 AURIGAE: A LITHIUM-RICH RAPIDLY ROTATING SINGLE GIANT[1]

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ABSTRACT

HD 33798 is a chromospherically active, rapidly rotating, lithium-rich, late-type giant. Analysis of 40 radial velocities indicates no periodic velocity variations, suggesting that the star is single, so its rapid rotation ($v \sin i = 29$ km s^{-1}) is highly unusual. Such rotation is inconsistent with the rotational brake hypothesis of Gray [ApJ, 262, 682 (1982); 347, 1021 (1989)] and the results of Rutten & Pylyser [A&A, 191, 227 (1988)]. Although there are many similarities to the supposed pre-main-sequence star HDE 283572, the lithium abundance and space motion of HD 33798 appear to be inconsistent with such an evolutionary state. Instead HD 33798 appears to be in a post-main-sequence phase of evolution, but its previous evolutionary history is uncertain. Its space motion is similar to FK Com, suggesting that it is a coalesced binary in the process of spinning down. However, if that is so, its large lithium abundance needs to be explained. A scenario in which the star was a rapidly rotating late B or early A star that has recently crossed the H–R gap and become a convective late-type giant could explain the large lithium abundance but is inconsistent with the space velocity components. A third scenario in which material is transferred from a rapidly rotating core may be the most likely.

1. INTRODUCTION

HD 33798 [$\alpha = 05^{\rm h}\ 11^{\rm m}\ 30.8^{\rm s}, \delta = 47°\ 06'\ 56''$ (1950)] is a relatively bright, chromospherically active late-type giant that was first brought to our attention by Bidelman (1985), who identified it as a Ca II emission star of *G* or *K* spectral type with moderate emission. However, Gurzadyan (1975) had previously detected ultraviolet Mg II emission from this star in low-dispersion "Orion-2"" spectrograms obtained aboard the spaceship Soyuz-13.

HD 33798 is also the primary of the visual binary ADS 3812 whose secondary is 0.4" away but 3.3 mag fainter (Van Biesbroeck 1974). Stephenson & Sanwal (1969) classified the primary as K0 III-IV.

Because the star has Ca II *H* and *K* emission, Fekel & Hall (1985) suggested that the star should be checked for light variability. Following this suggestion, Spurr & Hoff (1987) found the star to be variable with a 9.8 day period and a *V* mag amplitude of 0.05. It was designated as V390 Aurigae by Kholopov *et al.* (1989) in the 69th name list of variable stars.

Strassmeier *et al.* (1990) obtained a high-dispersion spectrum of the Ca II *H* and *K* lines and determined a flux level for the *K* line of $\log F(K) = 6.3$. They found that the Hα line appears to be a normal absorption feature similar to that in chromospherically inactive stars and they determined a $v \sin i = 29 \pm 2$ km s^{-1}.

Since the properties of HD 33798 are reminiscent of those of the RS CVn binaries, we obtained spectroscopic observations to determine if this star is a short-period binary and to examine its evolutionary status.

2. OBSERVATIONS AND REDUCTIONS

From two sets of ground-based spectroscopic observations covering a 2 yr period we have obtained 27 radial velocities. The heliocentric Julian Dates and our radial velocities are listed in Table 1. Griffin (1990) has obtained an additional 13 velocities that also are listed in Table 1.

During a 2 month period in the autumn of 1987, 18 spectra of HD 33798 were obtained with the echelle spectrograph system of the Multiple Mirror Telescope (MMT) or the 61 in. Wyeth reflector of Oak Ridge Observatory. Those spectrographs, which are essentially identical, use intensified Reticon detectors to produce digitized spectra (2048 pixels long), covering in this case a region 45 Å wide centered at about 5187 Å. The spectral resolution was about 0.2 Å. Most of the spectra had photon counts of approximately 200 counts/pixel. Wavelength calibrations were provided by exposures of a Th–Ar lamp taken immediately before and immediately after each stellar spectrum.

The standard data reduction and radial-velocity measurement procedures of the Center for Astrophysics (CfA) (Latham 1985; Mathieu *et al.* 1986; Hartmann *et al.* 1986) were used. The digital spectra were cross correlated with a very high signal-to-noise template spectrum of the dusk or dawn sky. Radial velocities were derived by fitting the resulting correlation peaks with parabolas and determining the position of the central axis of each parabola.

From November 1985 through December 1987 nine observations were obtained at Kitt Peak National Observatory (KPNO) with the coudé feed telescope, coudé spectrograph, and a Texas Instruments charge-coupled device (CCD). Eight of the spectra covered an 80 Å region centered on 6430 Å and had a resolution of 0.2 Å. One spectrum was obtained of the lithium region. Most of the spectra had signal-to-noise ratios of 100:1 or better.

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[1] Some of the observations reported were obtained at the Multiple Mirror Telescope Observatory, a joint facility of the Smithsonian Institution and the University of Arizona.

[2] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

[3] Guest Observer with the *International Ultraviolet Explorer* satellite.

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TABLE 1. Radial-velocity observations of HD 33798.

HJD 2400000+	V (km s^{-1})	Standard Star	Observatory
46389.962	22.2	10 Tau	KPNO
46390.980	22.0	α Ari	KPNO
46392.965	22.5	10 Tau	KPNO
46721.002	20.9	β Gem	KPNO
46727.64	21.8		CO
46729.64	25.3		CO
46771.58	22.0		CO
46776.55	22.7		CO
46807.46	22.9		CO
46814.859	22.3	β Gem	KPNO
46825.91	22.0		CO
46856.49	24.0		OHP
46868.706	21.7	β Gem	KPNO
46869.710	20.4	β Gem	KPNO
47074.758	21.7		ORO
47079.032	26.0		MMT
47080.031	24.8		MMT
47081.838	21.6		ORO
47082.926	22.7		ORO
47083.915	23.1		ORO
47084.912	24.0		ORO
47086.68	23.8		OHP
47096.958	22.4	β Gem	KPNO
47100.923	21.7		ORO
47101.905	20.7		ORO
47104.744	22.5		ORO
47105.915	23.0		ORO
47106.813	22.6		ORO
47107.759	22.4		ORO
47114.698	20.3		ORO
47128.776	21.3		ORO
47132.813	21.9		ORO
47137.862	23.5		ORO
47139.804	21.2		ORO
47151.973	22.8	β Vir	KPNO
47184.85	21.6		DAO
47232.42	21.0		OHP
47233.38	21.8		OHP
47254.36	23.3		CO
47471.68	24.2		OHP

Notes to TABLE 1

KPNO = Kitt Peak National Observatory
MMT = Multiple Mirror Telescope
ORO = Oak Ridge Observatory
CO = Cambridge Observatory
OHP = Observatoire de Haute-Provence
DAO = Dominion Astrophysical Observatory

The KPNO velocities were determined relative to International Astronomical Union (IAU) radial-velocity standard stars (Pearce 1955). The IAU velocity system is currently undergoing revision. At present the most consistent and accurate velocities are those of Scarfe *et al.* (1990). From their work we assumed velocities of +27.9 for 10 Tau, −14.5 for α Ari, 3.2 for β Gem, and 4.4 km s^{-1} for β Vir. Details of the reduction procedure have been given by Fekel *et al.* (1978).

Griffin (1990) obtained 13 observations with various radial-velocity spectrometers. Seven observations were obtained with the Cambridge 0.9 m telescope (Griffin 1967), five were obtained with the CORAVEL instrument of Geneva Observatory at Haute-Provence (Baranne *et al.* 1979), and one observation was obtained with the 1.2 m telescope and velocity spectrometer at the Dominion Astrophysical Observatory (Fletcher *et al.* 1982). These velocities (Table 1) extend the time baseline to 3 yr.

Finally, one ultraviolet spectroscopic observation was obtained with the short-wavelength primary (SWP) camera of the *International Ultraviolet Explorer* (*IUE*) satellite on 8 November 1987. This 140 min exposure, SWP 32274, obtained through the large aperture, has a resolution of 6 Å and covers a wavelength region from 1100 to 2000 Å. The observation was absolutely calibrated with the standard computer software routines at the Regional Data Analysis Facility of the Goddard Space Flight Center.

3. VELOCITY VARIATIONS?

Because of possible zero point differences, the sets of velocities initially were analyzed separately for velocity variations. All 18 CfA spectra showed a single correlation peak, somewhat broadened by rotation. The mean heliocentric velocity derived from these spectra was 22.50 ± 0.35 km s^{-1}. No sign of a second correlation peak— indicative of a double-lined binary—was seen. Two methods were used to search for possible periodic velocity variations. First, the radial velocities were subjected to a power-spectrum analysis. Second, a program was used that fit orbits to the data for various trial periods from 1 to 35 days.

Fekel & Eitter (1989) used the data in Strassmeier *et al.* (1988) to examine the question of synchronization of the rotation period with the orbital period in chromospherically active binaries. They found that at least 90% are rotating synchronously or pseudosynchronously if their orbital periods are less than 30 days. For periods less than 10 days, 98% are synchronous. Since Spurr & Hoff (1987) found a photometric period of 9.8 days, particular attention was focused on periods near that value. Velocities plotted in a phase diagram with that period are shown in Fig. 1. No periodicity is evident.

We conclude from the CfA data that HD 33978 has no orbital period shorter than several months. It is true that the root-mean-square derivation (rms) of ± 1.40 km s^{-1} of the measured velocities around the mean is somewhat higher than is characteristic of constant-velocity, narrow-lined ($v \sin i < 10$ km/s), late-type stars observed with the CfA instrument. For such stars, one suspects a binary if the rms deviation in the measured velocities is greater than about 0.8 km s^{-1}. But in the case of HD 33798 rotational broadening has limited the precision of the radial-velocity determinations, and the higher rms deviation is typical of that from broad-lined spectra.

The nine Kitt Peak spectrograms cover a period of just over 2 yr and so can be used to look for longer periodicities. The average velocity from the nine KPNO observations is 21.9 ± 0.25 km s^{-1} and no long-term trends are evident. There is also no evidence of a 9.8 day period (Fig. 1). Likewise, a separate analysis of the 13 photoelectric radial veloc-

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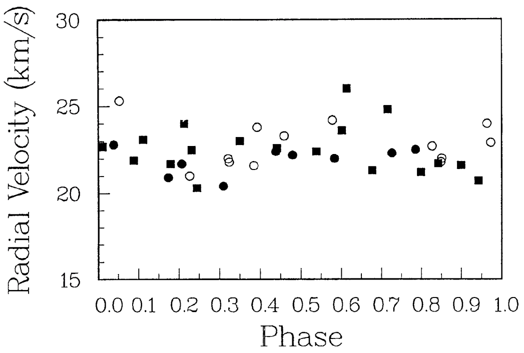

FIG. 1. A phase plot of the radial velocities with an assumed period of 9.825 days. Zero phase is the time of photometric minimum (Hooten & Hall 1990). Dots are the KPNO velocities, solid squares are the MMT/ORO velocities, and open circles represent Griffin's radial-velocity spectrometer data.

ities whose average velocity is 22.8 ± 0.3 km s^{-1} shows no long- or short-term periodicities. Finally combining all of the data also fails to show any periodic velocity variation. Thus, the star does not appear to be a single-lined spectroscopic binary. If the star were a double-lined spectroscopic binary in a low-inclination orbit so that the lines from the components were blended, we would expect variable linewidths and, if the stars had somewhat dissimilar line strengths, asymmetric, and variable line profiles. Since none of these possibilities has been detected, we conclude that HD 33798 is a single star with a velocity of 22.5 ± 0.2 km s^{-1}.

4. FUNDAMENTAL DATA

As noted in the introduction, Stephenson & Sanwal (1969) classified HD 33798 as K0 III-IV. We determined the spectral type using the spectrum synthesis technique of Strassmeier & Fekel (1990). The best fit to the spectrum of HD 33798 in the 6430 Å region is with κ Gem, a G8 III star (Fig. 2). When β Gem, a K0 III star, was used, many of its weak lines and all of its strong lines were too strong.

Dr. Lee Hartmann of the Harvard-Smithsonian Center for Astrophysics kindly derived rotational velocities from four of the spectra taken at Oak Ridge Observatory (on JD 2447074, 2447101, 2447104, and 2447106). The spectra were selected for high signal-to-noise correlation peaks, as measured by the value of R produced by the CfA reduction programs (Tonry & Davis 1979), and all had R values of 20 or higher.

The rotational velocities are derived from the width of the observed correlation peak, calibrated against similar peaks produced by synthetically broadened spectra. (For a full description see Hartmann *et al.* 1986.) For HD 33798, the average $V \sin i$ is 29 ± 1 km s^{-1}. The error given is just the rms deviation of the four derived values, but it is consistent with the expected errors from Hartmann's analysis for correlations with R values of 20. Strassmeier *et al.* (1990) determined a value of 29 ± 2 km s^{-1} from several of our Kitt Peak spectra in excellent agreement with the new determination.

Spurr & Hoff (1987) determined a photometric period, assumed to be the rotation period of the star, of 9.8 days. With additional photometry Hooten & Hall (1990) have refined the period to 9.825 days. This period and $V \sin i = 29$ km s^{-1} result in a *minimum* radius, $R \sin i$, of 5.6 ± 0.4 $R_{\odot}$, confirming that the star is a giant.

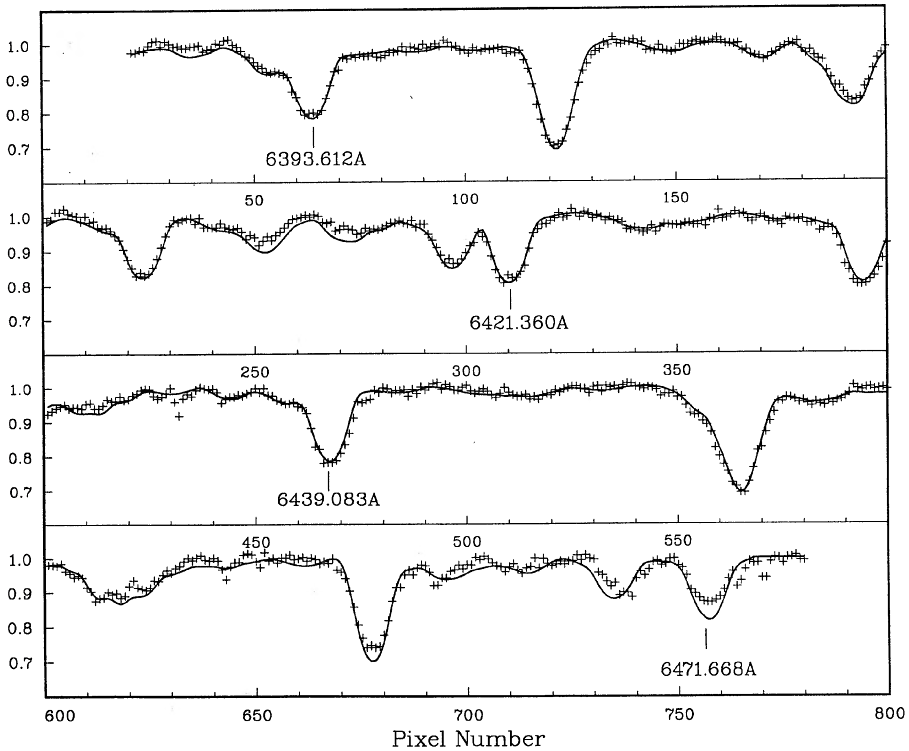

FIG. 2. A red wavelength spectrum of HD 33798 (pluses) covering a wavelength range of 80 Å centered on 6430 Å. The solid line is the spectrum of the G8 III star κ Gem rotationally broadened to 29 km s^{-1}. The wavelengths of several lines are indicated.

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Apparently, no modern photoelectric magnitudes have been determined for HD 33798. The *Henry Draper Catalogue* (Cannon & Pickering 1918) gives $m_{\rm ptm} = 6.97$ and $m_{\rm pg} = 7.75$. Assuming an apparent visual magnitude of 7.0 and an absolute magnitude range of 0.8–0.2 (Corbally & Garrison 1984) for a typical giant results in a parallax range of 0.004″-0.006″, corresponding to distances of 250–167 pc. A somewhat similar but perhaps more accurate distance is estimated in Sec. 8.

5. ACTIVE-CHROMOSPHERE CHARACTERISTICS

From objective-prism plates of moderate dispersion Bidelman (1985) detected moderate strength emission lines of Ca II *H* and *K*. Strassmeier *et al.* (1990) obtained a high-resolution spectrogram of the *H* and *K* lines and determined emission-line surface fluxes. They reported that the Hα line, which is filled in by emission in many chromospherically active stars (Smith & Bopp 1982), appears to be a normal absorption feature similar in strength to that in the inactive K0 III star β Gem.

The spectrum (Fig. 3) obtained with the *IUE* satellite shows ultraviolet emission lines typical of chromospherically active stars. Table 2 gives the emission-line identifications and the measured observed fluxes. The procedure of Linsky *et al.* (1979), has been used to convert the observed fluxes into surface fluxes. We have used the surface-brightness-(*B-V*) color relation of Barnes *et al.* (1978) and assumed $(B-V) = 0.95$ from the spectral-type–color relation of Johnson (1966).

Simon & Fekel (1987) examined the dependence of ultraviolet chromospheric emission upon rotation among late-type stars. For HD 33798 the C IV surface flux of 12×10^4 ergs cm^{-2} s^{-1} is consistent with the range of fluxes found for the active chromosphere stars with rotation periods near 10 days (Fig. 3 of Simon & Fekel 1987).

6. ROTATION

Gray (1982) measured the projected rotational velocities of 23 giants ranging in spectral type from G2 to K2. Combining his results with $v \sin i$'s from the literature for a number of additional stars, Gray concluded that a rotational discontinuity occurred at a spectral type of G5 III. He suggested that a dynamo brake is the most likely explanation and concluded that all giants leave the braking stage with a rotational rate of 5 km s^{-1}. Gray (1989) increased his sample size to 86 stars and found that the rotational discontinuity occurred closer to G0 III than G5 III.

Rutten & Pylyser (1988) modeled the rotational velocity during the evolution of cool giants with masses between 2.0 and 3.0 $\mathscr{M}_\odot$. They took into account the change in the moment of inertia and assumed rigid-body rotation and conservation of angular momentum. In addition they also took the spread of rotational velocities of B and A main-sequence stars into account in their evolutionary calculations. Contrary to Gray (1982) they conclude that changes in the moment of inertia and in the stellar radius during evolution are sufficient to explain the low rotational velocities of K giants and that loss of angular momentum from magnetic braking is of minor importance. They predict that the maximum $v \sin i$ value for a K0 III star is 10 km s^{-1}. If HD 33798, with $v \sin i = 29$ km s^{-1}, has evolved from the main sequence as a single star, its rotational velocity is inconsistent with both the rotational discontinuity of Gray (1982, 1989) and the predictions of Rutten & Pylyser (1988). HD 33798 is not a unique example. Fekel (1988) lists seven other moderately rapidly rotating ($v \sin i = 8$–46 km s^{-1}) single K giants and Balona (1987) lists other possible candidates. Fekel *et al.* (1986) suggested that these stars have evolved from single rapidly rotating early type stars.

TABLE 2. Ultraviolet emission line fluxes (ergs cm^{-2} s^{-1}).

Ion	Wavelength (A)	Observed flux ($\times 10^{-14}$)	Surface flux ($\times 10^{4}$)
N V	1240	6.5	3.6
O I	1305	16.2	8.9
C II	1335	12.1	6.6
SI IV	1400	-	-
C IV	1550	21.8	11.9
He II	1640	8.4	4.6
C I	1657	12.0	6.6
Si II	1808, 1817	14.4	7.9
Si III	1893	2.6	1.4

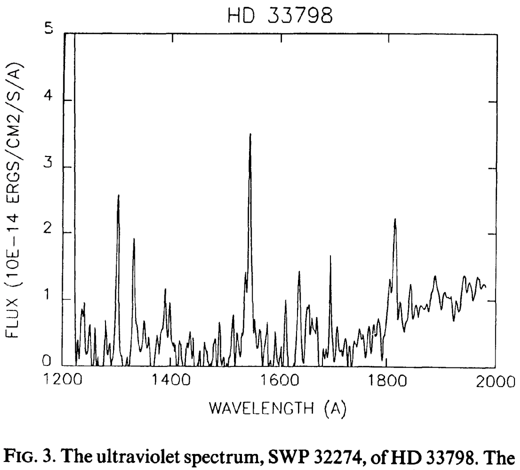

FIG. 3. The ultraviolet spectrum, SWP 32274, of HD 33798. The strongest emission feature is the C IV line at 1550 Å.

7. LITHIUM

Over the past few years new lithium abundance analyses of Spite & Spite (1982) and Boesgaard & Tripicco (1986a) have forced us to readjust our relatively straightforward ideas about how lithium is depleted in the outer atmospheres of late-type dwarf stars. Likewise our understanding of the lithium abundances of giants is undergoing revision. A red giant theoretically is expected to have little lithium, $\log \epsilon({\rm Li}) < 1.5$ (Iben 1967a,b), as a result of convective dilution compared to an initial value of $\log \epsilon({\rm Li}) \cong 3.0$–3.2 found for young early F stars that are on the main sequence (Boesgaard & Tripicco 1986b; Balachandran *et al.* 1988). Since the discovery of the lithium-rich K giant HD 112127 (Wallerstein & Sneden 1982), several other lithium-rich giants have been identified. Brown *et al.* (1989) observed 644 stars to assess the frequency of apparently normal G–K giants with anomalously large lithium abundances. They found a fairly well-defined cutoff for the stars in their sample at an abundance of $\log \epsilon(\mathrm{Li}) = 1.4$, in agreement with theoretical expectations. However, 12 stars or about 2% of their sample had abundances greater than $\log \epsilon(\mathrm{Li}) = 1.5$.

Fekel (1988) and Pallavicini *et al.* (1990) have detected substantial abundances of lithium in a number of chromospherically active giant and subgiant stars. Fekel (1988) suggested that these stars evolved from rapidly rotating A- or early F-type stars which have recently become giants with convective atmospheres. If that were the case, the stars might still be rapidly rotating as giants. Their lithium would not have been depleted while they were on the main sequence because the outer atmospheres of such A and early F stars are not convective. Thus, such chromospherically active late-type giants might have substantial lithium abundances. HD 33798 does indeed have a lithium line of moderate strength. Balachandran (1990), using a spectrum-synthesis analysis, has determined a lithium abundance of $\log \epsilon(\mathrm{Li}) = 1.8$, making the star lithium rich. The large lithium abundance suggests that HD 33798 may indeed have evolved recently from an A or early F star.

As discussed in Sec. 9, such a conclusion may or may not be correct. Brown *et al.* (1989) found that HR 454 = HD 9746, a giant with a nearly primordial lithium abundance, has a C^{12}/C^{13} ratio of 28 ± 4. This ratio is normal for convectively mixed G–K giant stars before helium ignition. But the evolutionary state indicated by the C^{12}/C^{13} ratio is at odds with the very large lithium abundance. Under standard scenarios one expects a convectively mixed star to have very little lithium in its outer atmosphere. Unfortunately, the $v \sin i$ value of 29 km s^{-1} for HD 33798 makes it nearly impossible to detect lines of the C^{13} isotope to test whether it is convectively mixed.

8. SPACE VELOCITIES

Another possible way to examine the evolutionary state of HD 33798 is to look at its space motion. If the star has evolved from an early type star and is not a relatively young giant, the U, V, W velocity vectors of the star relative to the Sun and a total space motion S should not be very large. To compute those velocities, we assume our average radial velocity and the proper motions from the AGK3 catalog (Dieckvoss 1975), $\mu = 0.081''$ and $\mu = -0.109''$ (note that the values in the SAO Catalogue are 10%–20% larger) and use a right-handed coordinate system (Johnson & Soderblom 1987). The resultant space velocity S then depends on the assumed distance. Table 3 summarizes the velocity components and total space motion for various distances ranging from 75 to 200 pc. Also included is the resulting absolute visual magnitude, which can be compared with the giant luminosity classification. The velocity components and space velocity of FK Comae (Guinan & Robinson 1986) are also listed.

The assumed absolute visual magnitude can be constrained by computing the minimum luminosity of the star from its minimum radius ($i = 90°$) and an effective temperature of 4970 K (Bell & Gustafsson 1989), assumed from our spectral type. From this calculation the absolute visual magnitude must be brighter than 2.0 which in turn results in a distance of at least 100 pc. A rotational inclination of 30° increases the star's radius to 11.3 $R_\odot$ and results in $M_v = 0.5$ and a distance of 200 pc. This distance estimate is probably more accurate than that determined in Sec. 4. Assuming the distance to HD 33798 is 150 ± 50 pc, its space velocity components are quite similar to FK Com.

TABLE 3. Space motions.

Star	Distance (pc)	M_V	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})	S (km s^{-1})
HD 33798	200	0.5	-61	-116	6	131
	150	1.1	-51	-85	5	99
	100	2.0	-41	-54	4	68
	75	2.6	-36	-39	4	53
FK Com	250		-46	-67	-11	82

9. EVOLUTIONARY STATE

Although we have assumed that HD 33798 is a post-main-sequence star, might it be a pre-main-sequence star? A comparison with HDE 283572 is instructive. Walter *et al.* (1987) investigated the properties of HDE 283572, many of which are similar to those of HD 33798, and concluded that HDE 283572 is a $2\mathscr{M}_\odot$ naked T Tauri, although its properties are much less extreme than those of most pre-main-sequence stars. The star is chromospherically active having emission lines of Ca II H and K as well as the usual ultraviolet emission features. Walter *et al.* estimated a spectral type of G5 IV and noted that the lines were rotationally broadened with $v \sin i$ estimated to be between 95 and 130 km s^{-1}. They found photometric variations having a period of 1.548 days. Combined with their $v \sin i$ range, that period results in a minimum radius of 3–4$R_\odot$. They determined a lithium abundance of $\log \epsilon(\mathrm{Li}) \cong 3.3$, indicating lithium has not been significantly depleted. They found $H\alpha$ to be an absorption feature and noted that a residual spectrum (HDE 283572–HD 199178) revealed no residual emission. It should be noted however that HD 199178 is a chromospherically active star whose Hα absorption feature is filled in by emission (Huenemoerder 1986). Thus, the Hα line of HDE 283572 may also be partially filled by emission. Finally, they noted its close spatial proximity to the Tau-Aur star-formation complex and that its proper motion and radial velocity are consistent with a physical association with the Taurus Cloud. They based their pre-main-sequence identification primarily on the large lithium abundance and similar space motion and close proximity to a star forming region. Although a low lithium abundance does imply that a star is a post-main-sequence star rather than a pre-main-sequence star, a logarithmic lithium abundance close to the cosmic value of 3–3.2 by itself may not necessarily indicate that a star is a pre-main-sequence star. Given the growing uncertainty about how lithium is depleted in at least some evolved giants, only the space motion of HDE 283572 and its proximity to the Taurus cloud firmly support the pre-main-sequence conclusion.

Compared to HDE 283572, HD 33798 has similar observed emission-line fluxes and a similar spectral class and minimum radius. Its rotation is 3–4 times slower but still substantial and there appears to be no Hα emission. The

1991AJ....102.1439F

major differences are that the lithium abundance of HD 33798, although larger than predicted by theory, is substantially less than the assumed primordial value. Its space motions are those of an old disk-population star. Finally, although a few isolated *T* Tauri stars have been detected (e.g., de la Raza *et al.* 1989), such pre-main-sequence stars are normally found associated with dark clouds. Although in the constellation of Auriga, HD 33798 is not particularly close to the Tau-Aur star-formation complex (Fig. 1 of Walter *et al.* 1988).

Because of the many similarities between HDE 283572 and HD 33798 and the increasing number of lithium-rich giants that are being found, we caution that great care is warranted in attempting to identify chromospherically active stars as pre- or post-main-sequence objects. From its moderate lithium abundance and space-velocity components we conclude that HD 33798 is a post rather than a pre-main-sequence star.

The observations of Gray (1982,1989) and the theoretical work of Endal & Sofia (1979), Gray & Endal (1982) and Rutten & Pylyser (1988) indicate that late-type single giants should have $v \sin i < 10$ km s^{-1}. Thus, a star such as HD 33798 with $v \sin i = 29$ km s^{-1} is exceptional.

Two scenarios have been suggested to produce rapidly rotating single late-type giants. Bopp & Rucinski (1981) suggested that coalescence of a W UMa system would result in a rapidly rotating single giant similar to FK Com. That star has extremely rapid rotation, $v \sin i = 160$ km s^{-1}, (Rucinski 1990) and extreme chromospheric activity (Bopp & Stencel 1981). Since few FK Com type stars have been identified, presumably such a star would be spun down rapidly decreasing its chromospheric activity as well. The observed emission-line fluxes of HD 33798 are a factor of 5–10 times less than the line fluxes of FK Com (Bopp & Stencel 1981) despite FK Com being somewhat farther away.

Guinan & Robinson (1986) concluded that the space-velocity components of FK Com were consistent with those of W UMa binaries and assigned FK Com to the old disk population. HD 33798 has space-velocity components that are strikingly similar to those of FK Com (Table 3).

Thus, the emission-line fluxes, rotation, and space motions are consistent with HD 33798 being a spun down FK Com star. However, the large lithium abundance in such a star remains a problem. Spite & Spite (1982) have listed several old disk slightly metal-poor late-G dwarfs and subgiants with substantial lithium abundances. Whether W UMa stars and a resulting coalesced object could have similar lithium abundances remains to be determined.

Fekel *et al.* (1986) suggested that the rapidly rotating single late-type giants that they identified might have evolved from rapidly rotating early type stars that have recently crossed the H–R gap. If that were correct, we might expect such stars to have a reduced but still substantial lithium abundance since depletion by convection would have begun only recently. Such a lithium abundance is seen in HD 33798.

Figure 4 compares the position of HD 33798 with the theoretical evolutionary tracks given by Maeder & Meynet (1988) for a solar composition model with some convective overshoot. Andersen *et al.* (1990) have shown that such overshoot models are appropriate for stars more massive than 1.5$\mathcal{M}_\odot$. Of the two plotted points, the lower luminosity one is for $i = 90°$, resulting in the minimum radius while the point with the greater luminosity has a radius computed

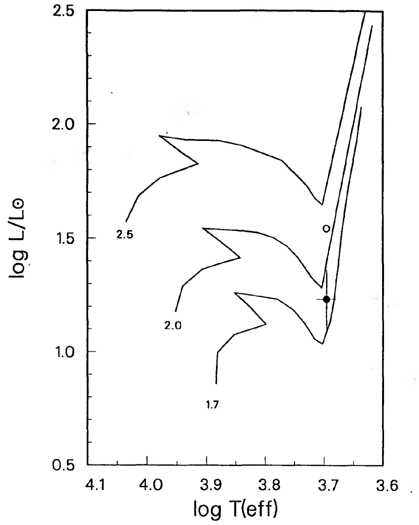

FIG. 4. The evolutionary tracks given by Maeder & Meynet (1988) for stars of masses 1.7, 2, and 2.5 $\mathcal{M}_\odot$. The dot indicates the position of HD 33798 with its minimum radius ($i = 90°$) and estimated uncertainties while the open circle assumes $i = 45°$.

with $i = 45°$. These positions are consistent with masses in the range 1.8–2.3 $\mathcal{M}_\odot$. HD 33798 appears to be massive enough to have evolved from a late-B or early A main-sequence star.

The space-velocity components of such a star would be expected to be similar to those of A and early F main-sequence stars. Instead, the space velocity components are those of an old disk star. The close visual companion makes it unlikely that HD 33798 is a runaway star. Thus, although the lithium abundance and position in the H–R diagram are consistent with a first crossing giant star, the space-velocity components are not.

To summarize, at present there appear to be problems with both scenarios. If HD 33798 is a spun-down FK Com star, its lithium abundance appears to be substantially greater than expected. If on the other hand, the star is just beginning its ascent of the red giant branch, it has the wrong space velocity. Given that there are some lithium-rich giants, the possibility that HD 33798 is a spun-down FK Com star cannot be ruled out.

Speculation continues on mechanisms that could inhibit lithium depletion. For example, Pallivicini *et al.* (1990) claim that the large lithium abundances they find in evolved rapidly rotating chromospherically active stars suggest that rotation inhibits lithium depletion. However, the lithium-rich giants of Brown *et al.* (1989) are slowly rotating, appearing to contradict this conclusion. Understanding why some giants are lithium rich may be a key to deciding whether either of the above two scenarios is correct or if a new scenario for the evolutionary history is needed.

Note added in proof. A third and perhaps the most likely evolutionary scenario for HD 33798 and all chromospherically active stars is suggested by the work of Pinsonneault *et al.* (1989). Their evolutionary models of the rotating Sun

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predict that the Sun has a rapidly rotating core. As such a star evolves off the main sequence and becomes a subgiant and then ascends the red giant branch, its surface convection zone deepens until it dredges up high angular-momentum material, CNO processed material, and ^{3}He from the core. Gratton & D'Antona (1989) note that lithium may be produced and burnt through the chain $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}(e,\nu)^7\mathrm{Li}(p,\alpha)^4\mathrm{He}$. Thus, if on its way to the surface, some ^{3}He were converted into lithium and this lithium was rapidly transported to the outer layers where it could no longer be destroyed, the star's outer layers might go through a stage where the layers were lithium rich. Such a stage, perhaps quite brief, in a star's evolution would show chromospheric activity, rapid rotation, an intermediate or possibly a low value of the $^{12}\mathrm{C}/^{13}\mathrm{C}$ ratio, and an enhanced lithium abundance.

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