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HDE 233517: LITHIUM AND EXCESS INFRARED EMISSION IN GIANT STARS

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ABSTRACT

Recent studies have identified a small class of moderately rapidly rotating, chromospherically active, single giants, some of which are lithium rich. We present evidence suggesting the peculiar K-type star HDE 233517 is one such object. Previously, HDE 233517 has been suggested to be a young star, consistent with its large far-infrared excess and our log ϵ(Li) ~ 3.3. However, our high-resolution spectroscopic observations show it is likely a single, post–main-sequence K2 giant with $v \sin i = 15$ km s^{-1} and modest Ca II H and K emission. The giant status of HDE 233517 is determined directly from luminosity-sensitive line ratios and a lack of significant line wings, and is further supported by a large radial velocity (46.5 km s^{-1}), small proper motion, and the presence of interstellar absorption features. Interpretation of the data in the context of a recent mass outflow model for giant stars proposed by de la Reza and coworkers indicates that HDE 233517 has the largest mass-loss rate, $\sim 3 \times 10^{-7}$ $M_\odot$ yr^{-1}, of any known luminosity class III giant. We suggest that the processes causing rapid rotation, large lithium abundance, and infrared excess are triggered at the base of the giant branch when the convection zone reaches the rapidly rotating core of low-mass stars.

Subject headings: stars: individual (HDE 233517) — stars: late-type

1. INTRODUCTION

In the *IRAS* catalogs, a variety of stars have been identified as having excess far-infrared emission, providing a wealth of potentially interesting objects for follow-up observations. While the early-type stars Vega and β Pic have been extensively studied, several recent studies focused on two late-type stars. Skinner, Barlow, & Justtanont (1992) and Zuckerman & Becklin (1993) have emphasized the unusual nature of the K dwarf "Vega-excess" system HD 98800, which was first identified by Walker & Wolstencroft (1988). Recently, Skinner et al. (1995) obtained multiwavelength photometry, mid-infrared spectra, and a 10 μm image of another late-type infrared-excess star, HDE 233517 = SAO 26804. The 10 μm image indicated a resolved dust disk around HDE 233517. They argued that the star is a K2 dwarf and, by comparison with the optical results for HD 98800 (Fekel & Bopp 1993), suggested that the star is a young chromospherically active system. Although HDE 233517 does possess many of the characteristics of a young star, a closer inspection indicates instead that it is one of the most extreme examples of a group of rapidly rotating luminosity class III giants with large lithium abundance and far-infrared excess.

2. OBSERVATIONS

We obtained high-resolution optical spectra of HDE 233517 at two observatories. Our initial spectrum was obtained on 1994 April 1, at the Lick Observatory 3 m Shane telescope with the Hamilton Echelle Spectrometer (Vogt 1987) coupled to a TI 800 × 800 CCD. The resolution of the spectrograph is $\lambda/\Delta\lambda \sim 48{,}000$, resulting in a resolution of ~0.14 Å at Hα. This spectrum spanned roughly 5800–9400 Å and included orders containing the Na D lines, Hα, the lithium line (6707 Å), and the Ca II infrared triplet (at 8498, 8542, and 8662 Å). The exposure time of 10 minutes yielded a signal-to-noise ratio of about 50 over all orders.

From 1994 September to 1995 May, seven spectra were obtained during three observing runs at the Kitt Peak National Observatory (KPNO) with the coudé feed telescope, coudé spectrograph, and a TI CCD. Five are red-wavelength spectra, with three centered at 6430 Å and one each at Hα and the 6707 Å lithium line. All have a wavelength range of 80 Å, a resolution of 0.21 Å, and a signal-to-noise ratio of at least 100. The remaining two spectra, of the Ca II H and K region, have a wavelength range of 56 Å and a resolution of 0.21 Å. The better exposed spectrum has a signal-to-noise ratio of about 50.

3. SPECTROSCOPIC RESULTS

Upon inspection of our red-wavelength spectra, it was obvious that the lines of HDE 233517 are rotationally broadened. From the KPNO spectra obtained in the 6430 Å region, we determine $v \sin i = 15 \pm 2$ km s^{-1} via the method of Fekel, Moffett, & Henry (1986b). To determine whether the rapid rotation is the result of a close binary companion, we measured its radial velocity in eight spectra obtained over a temporal baseline of 13 months. Cross-correlation measurements with IAU standards from the list of Scarfe, Batten, & Fletcher (1990) yield a mean velocity of 46.5 ± 0.2 km s^{-1} and show no evidence for variability. The spacing of our observations and velocity constancy rule out periods of 5 days or less

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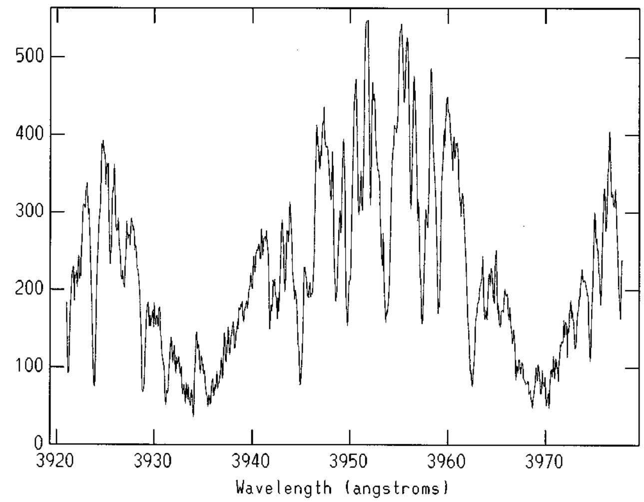

FIG. 1.—Spectrum of HDE 233517 in the Ca II H and K region obtained at KPNO. Modest strength but broad H and K emission is seen in the cores of the H and K absorption features at 3934.6 Å and 3969.6 Å, respectively. The *y*-axis is in counts and is not normalized.

and make periods of several weeks or months highly unlikely. We conclude that HDE 233517 is a single star.

The lithium line at 6707 Å is extremely strong in HD 233517, having an equivalent width (EW) of 580 mÅ. Table 2 of Soderblom et al. (1993), modified by the correction of Carlsson et al. (1994), yields a lithium abundance, log ϵ(Li) ~ 3.3, equal to that found in young Population I stars whose lithium has not been significantly destroyed or mixed.

The rapid rotation and extremely strong lithium line of HDE 233517 are consistent with the idea that the star is a very young, single K dwarf like HD 82558 (Fekel et al. 1986a) or HD 181943 (Strassmeier et al. 1990; Strassmeier 1991; Fekel, Henry, & Hall 1995). If HDE 233517 is young, then strong chromospheric emission should be seen as predicted by Skinner et al. (1995). Figure 1 shows our spectrum of the Ca II H and K lines. Although calcium emission is clearly visible at the center of both absorption features, unlike the above two young dwarfs, the emission comes nowhere near the level of the relative continuum. Rather, the emission EWs are modest, about 0.07 Å for Ca H and 0.14 Å for Ca K, and within the range of values found for active giants that rotate rapidly (e.g., Strassmeier et al. 1990).

Walter et al. (1988) found that naked T Tauri stars show a variety of Hα profiles from absorption to strong emission. However, the deepest Hα absorption line of the pre–main-sequence K star samples of Walter (1986) and Walter et al. (1988) has an EW of 0.6 Å, indicating that it is significantly filled with emission. The Hα absorption line in zero-age main sequence (ZAMS) K dwarfs also is significantly or completely filled with emission (e.g., Fekel et al. 1986a; Strassmeier 1991). Figure 2 shows a spectrum of the Hα region of HDE 233517 as well as the spectra of an inactive K3 dwarf and K2 giant, which have been overplotted for comparison. The Hα profile of HDE 233517 is clearly not significantly filled with emission. Instead, Hα is a strong absorption feature, having an EW = 1.3 Å, with its core blueshifted relative to the line center and with a blue wing rising slightly above the continuum. The line is also significantly wider than implied by rotational broadening. Additional profiles of K dwarfs and subgiants are shown in Pasquini & Pallavicini (1991) and

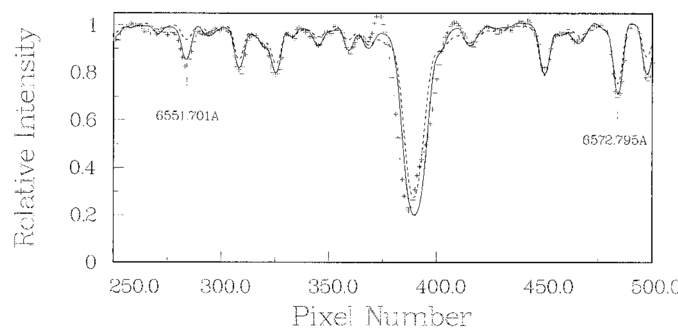

FIG. 2.—Spectrum of HDE 233517 (*crosses*) in the Hα region compared with appropriately broadened ($v \sin i = 15$ km s^{-1}) spectra of the K2 III α Ari (*solid line*) and the K3 V HR 8832 (*dashed line*). Note that the Hα line of HDE 233517 is a deep absorption feature with a blueshifted asymmetric core and modest blueshifted emission peak. The line is also significantly broader than the Hα line of either comparison star. All spectra were obtained at KPNO.

Strassmeier et al. (1990), while Eaton (1995) has compiled a catalog of Hα profiles for an extensive number of late-type giants, bright giants, and supergiants. The core and wings of the profile of HDE 233517 are not those of a normal dwarf or giant but appear most similar to those of ϵ Gem (Mallik 1993; Eaton 1995), which has a spectral type of G8 Ib (Keenan & McNeil 1989). Mallik (1993) has summarized previous work on supergiants, noting that the characteristics of the Hα profile are attributed to an expanding chromospheric wind, which results in mass outflows in the range 10^{-8} to 10^{-9} $M_\odot$ yr^{-1}. Although we conclude below that HDE 233517 is *not* a supergiant, the shape of the Hα profile can be interpreted reasonably in the context of mass loss from a luminosity class III giant (see § 5).

To determine the spectral type of HDE 233517, we use the spectrum-comparison technique of Strassmeier & Fekel (1990). They identified several luminosity-sensitive and temperature-sensitive line ratios in the 6430–6465 Å region and used them along with the general appearance of the spectrum as spectral-type criteria. In addition, for K dwarfs, the strength of the wings of saturated lines in this wavelength region is a very useful luminosity-classification criterion. Because of the conclusion of Skinner et al. (1995) that HDE 233517 is a K dwarf, its spectrum was first compared with appropriately broadened spectra of early K dwarfs. The strongest lines of the K dwarf spectra have significant line wings that are not seen in HDE 233517. Additionally, the luminosity-sensitive line ratios as well as the general pattern of line strengths are noticeably different. Thus, the spectra of K dwarfs proved to be poor fits in all respects. Comparison of our 6430 Å spectrum with that of θ Lyr (K0 II) and ϵ Gem (G8 Ib) showed that all lines of these two standards are significantly too strong relative to HDE 233517. Moreover, the two main luminosity-sensitive line ratios are also discrepant. Instead, α Ari, a K2 III with [Fe/H] = -0.26 ± 0.05 (Taylor 1991), provides the best fit to the spectrum of the 6430 Å region (Fig. 3) and also the photospheric lines of the 6560 Å region. The spectral class is well constrained with an uncertainty of about one subclass, while the luminosity class is uncertain by about one-half class.

4. DISTANCE AND KINEMATICS

HDE 233517 has a Galactic latitude of +34°.9. If it is a luminosity class III giant, then it is significantly above the Galactic plane. Photometric observations of Henry (1995) yield $V = 9.72$ mag and $B - V = 1.32$ mag. The spectral

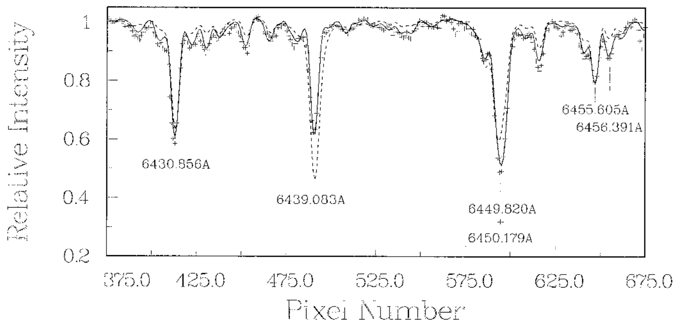

FIG. 3.—Spectrum of HDE 233517 (*crosses*) in the 6430 Å region compared with appropriately broadened spectra of the K2 III α Ari (*solid line*) and the K3 V HR 8832 (*dashed line*). Note the differences in the luminosity-sensitive line ratios 6455.6 Å/6456.4 Å and the blend of 6449.8 Å/6450.2 Å. All spectra were obtained at KPNO.

type–color relations of Johnson (1966) suggest that if HDE 233517 is a K2 V, then $E(B - V) = 0.40$ mag. Such a significant reddening is not expected for a nearby ZAMS K star and would have to be attributed to circumstellar dust grains. Additionally, HDE 233517 has a large radial velocity, 46.5 km s^{-1}, and a small proper motion (Röser & Bastian 1991), characteristics that are inconsistent with those of a young nearby star. On the other hand, the velocity, proper motion, and latitude above the Galactic plane are consistent with the expected properties of a K2 giant, which would have a modest color excess of $E(B - V) = 0.16$ or a reddening $A_v \sim 0.45$ mag. Table 1 presents the ***U***, ***V***, ***W*** space velocities in a right-handed coordinate system computed from our radial velocity, the proper motions of Röser & Bastian (1991), and a distance, corrected for reddening, derived for each of four assumed spectral types from the absolute magnitude calibration given by Corbally & Garrison (1984). These space velocities, even in the dwarf case, indicate that HDE 233517 is not associated with any young kinematic group or pre–main-sequence complex, and provide support for a post–main-sequence evolutionary state. From Table 1 and our classification uncertainties, a distance of 600 ± 200 pc is suggested if the star has the luminosity of a normal giant.

This large distance is further supported by the presence of narrow nonstellar Na D absorption features. These narrow absorption lines are separated in velocity by about 45 km s^{-1} from the stellar absorption features and closely correspond to the local standard of rest. We believe that these narrow lines are due to absorption in the interstellar medium. De-blending the stellar and interstellar absorption features yields EWs of 0.13 Å and 0.20 Å for the Na D1 and D2 interstellar components, respectively. However, the EW measurements are complicated by the superposition of sodium emission from San Jose street lights. These emission components at least slightly overlap our interstellar components, making our EW estimates more likely lower limits. It is well known that the strength of the Na D interstellar absorption roughly correlates with distance. Comparing our EW measurement with the study by Hobbs (1974) suggests HDE 233517 is at least a few hundred parsecs distant. We reject the possibility that these absorption features are due to circumstellar material because of their high velocity with respect to the star and their close match to the velocity of the local interstellar medium. Hence, despite the arguments of Skinner et al. (1995) that HDE 233517 is a K dwarf at a distance of ~25 pc, a variety of observations support its classification as a distant K giant.

TABLE 1

SPACE MOTIONS OF HDE 233517

Assumed Spectral Type	M_v (mag)	A_v (mag)	Distance (pc)	***U*** (km s^{-1})	***V*** (km s^{-1})	***W*** (km s^{-1})
K2 V...........	6.3	1.2	28	−36.0	10.9	27.4
K1 IV..........	3.2	1.0	125	−33.7	16.0	28.7
K2 IIIb	0.6	0.45	540	−24.0	38.0	34.3
K2 IIIab	0.1	0.45	680	−20.7	45.3	36.2

5. DISCUSSION AND CONCLUSIONS

If, as seems likely, HDE 233517 is a post–main-sequence luminosity class III giant, how might the combination of its large infrared excess and lithium abundance be explained? An important series of papers investigates the connection between infrared excess and large lithium abundance in luminosity class III giants (Gregorio-Hetem et al. 1992; Gregorio-Hetem, Castilho, & Barbuy 1993; Castilho, Barbuy, & Gregorio-Hetem 1995; de la Reza & da Silva 1995; da Silva, de la Reza, & Barbuy 1995; de la Reza, Drake, & da Silva 1996). The results of these investigations (see also Brown et al. 1989 and Zuckerman, Kim, & Liu 1995) are summarized by de la Reza et al. (1996). Giants with lithium richness and/or with far-infrared excess emission comprise $\lesssim 1\%$ of all luminosity class III stars. Like HDE 233517, there is no evidence that these stars are preferentially members of binary systems. Some giants, like HDE 233517, are lithium rich and have large infrared excesses (Fig. 2 in de la Reza et al. 1996), but others have excess lithium and no far-infrared excess and vice versa.

The evolutionary state of another lithium-rich star, HD 219025, has recently been considered by Whitelock et al. (1995). They prefer a pre–main-sequence interpretation based on the large lithium abundance and moderate infrared variability. We think it is more likely that HD 219025 is post–main sequence for the following reasons. Cutispoto (1995) derives a minimum radius of 6.7 $R_\odot$ from his optical variability measurements in conjunction with the $v \sin i$ measurements of Randich, Gratton, & Pallavicini (1993). Assuming an effective temperature of 4520 K, a minimum luminosity of 16.5 $L_\odot$ is implied for HD 219025. If it is a single pre–main-sequence star, its position on pre–main-sequence evolutionary tracks would indicate an extremely young star that is at or above the stellar birth line. Although the Hα line is filled (Bopp & Hearnshaw 1983), there are no strong indicators of extreme youth. In addition, HD 219025, like HDE 233517, is an isolated star at high Galactic latitude, far from any obvious region of star formation, and is not included in Figure 2 of de la Reza et al. (1996).

De la Reza et al. (1996) proposed a model in which every star with mass between 1 and 2.5 $M_\odot$ becomes lithium rich while a K giant, and the internal mechanism responsible for the enrichment initiates a prompt mass-loss event, which is responsible for the excess infrared emission. Even with an expansion velocity as small as 2 km s^{-1}, the lifetime of an expanding circumstellar shell as observed with the *IRAS* ($<10^5$ yr) is so short compared with the lifetime of a star as a red giant ($\sim 5 \times 10^7$ yr) that multiple ejection events may be required to explain the observed frequency of giants with infrared excesses (Zuckerman et al. 1995). If the photospheric lithium enhancement decreases in characteristic time greater than 10^5 yr, then lithium-rich stars with no infrared excess can be produced (Fig. 2 in de la Reza et al. 1996). However, since there exist stars with excess far-infrared emission but no lithium excess (e.g., HD 3627 and HD 153687; Brown et al. 1989; Zuckerman et al. 1995), a mechanism that ejects mass without lithium production or very rapid lithium destruction in some stars is also required to explain the data.

According to the model of de la Reza et al. (1996), the mass-loss rate ($\dot{M}$) at HDE 233517 is $\sim 3 \times 10^{-7}$ $M_\odot$ yr^{-1}, nearly an order of magnitude larger than that of any other star plotted in their Figure 3 and comparable to $\dot{M}$ for many Mira variables. The ejected shell would be $\sim$1000 yr old and, with an expansion velocity of 2 km s^{-1}, would subtend an angle of about a few arcseconds, consistent with the 10 μm measurements of Skinner et al. (1995). HD 219025, as discussed above, would have $\dot{M} \sim 5 \times 10^{-9}$ $M_\odot$ yr^{-1} and a shell age $\sim$1000 yr. Both HDE 233517 and HD 219025 occupy positions in the *IRAS* color-color diagram (Fig. 2 in de la Reza et al. 1996) well removed from any other lithium-rich giants.

It has been suggested (e.g., Brown et al. 1989) that lithium enhancement in red giants is due to engulfment of a planet in a close orbit about a star (e.g., 51 Peg B) when the star evolves into a red giant. However, such a model would not explain the size of the 10 μm emission region measured by Skinner et al. (1995).

If the model of de la Reza et al. (1996) is correct, we argue that infrared excess, high lithium abundance, and rapid rotation are mutually linked in luminosity class III giants. Although each of these phenomena occurs rarely and there is not a one-to-one correlation between them, they are triggered at a common evolutionary phase—when low-mass stars reach the base of the giant branch. It is at that point that the convection zone encounters the presumed rapidly rotating core. Fekel & Balachandran (1993) argued that rapid rotation and high lithium abundance are the result of the transport of angular momentum and material from the core. They noted, however, that particle and angular momentum transport would likely have different timescales. The timescales for rotational spin-down and dilution of surface lithium may also be different. Thus, it is not surprising that there is not a one-to-one correspondence between rapid rotation and high lithium abundance in giants.

Finally, 10 μm images of dusty disks around luminosity class III giants should be obtainable for stars other than HDE 233517. If the presence of the dusty disk is associated with extensive mass loss, then, as noted by de la Reza & da Silva (1995), K giants might be a significant source of lithium in the interstellar medium.

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