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OPTICAL VARIABILITY IN THE UNUSUAL K5 V INFRARED-EXCESS STAR HD 98800

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ABSTRACT

The dusty infrared-excess star HD 98800 (K5 V) was observed for several weeks in the spring of 1993 by the Vanderbilt/Tennessee State 0.4 m automatic photoelectric telescope. It was found to be a variable star with an amplitude of 0.07 mag in V and a period of 14.7 days. We show, by comparison with other chromospherically active variable stars and constant stars with good observational histories, that the Rossby number for HD 98800, determined to be 0.30, places it well within the regime of stars whose convective envelopes and rotation rates combine to drive a magnetic dynamo strong enough to generate photometrically observable starspots. The light curve suggests at least two large spots at somewhat different longitudes on HD 98800, one of which could be as large as 16° in radius.

Subject headings: circumstellar matter — infrared: stars — stars: activity — stars: pre–main-sequence — stars: rotation — stars: variables: other (HD 98800)

1. INTRODUCTION

Several groups of observers have recently attempted to determine the nature of the unusual infrared source IRAS 11195−2430 (HD 98800 = ADS 8141) that appears in the *IRAS* Point Source Catalog (Version 2, 1988, hereafter PSC). García-Lario et al. (1990) included it in their survey of *IRAS* sources similar to planetary nebulae and suggested that one of the components of this close visual double star was undergoing strong mass loss in the asymptotic giant branch (AGB) of its evolution. Gregorio-Hetem et al. (1992) listed it as a new T Tauri star, possibly one of several newly discovered T Tauri stars loosely associated with TW Hya (the former prototype of an isolated T Tauri star). HD 98800 was listed, along with 30 other stars, by Walker & Wolstencroft (1988) as an object from the PSC with infrared colors similar to the main-sequence stars β Pic, Vega, α PsA, and ϵ Eri that have dust disks. Skinner, Barlow, & Justtanont (1992) modeled the *IRAS* data, along with a 10 micron spectrum obtained from Hawaii, as a circumstellar disk and found a dust grain size distribution covering at least the range from 0.01 micron to 100 microns. They noted, however, that the data were consistent with the existence of larger particles, i.e., planets. Zuckerman & Becklin (1993) confirmed the coincidence of the observed 10 micron radiation with HD 98800 and noted the uniqueness of HD 98800's infrared luminosity: the fractional luminosity of the dust emission compared to the luminosity of the primary component of HD 98800 is about 17%, far larger than for any other main-sequence star. Most recently, Fekel & Bopp (1993a) confirmed the K5 V spectral type of Upgren et al. (1972) and noted rotationally broadened photospheric lines, Hα emission, and strong Li I absorption, all of which suggested to them that HD 98800 is quite similar to the young, chromospherically active, single BY Dra star LQ Hya (=HD 82558; Fekel et al. 1986). They also reported a 1993 private communication from D. Latham in which he describes detection of a spectroscopic companion in a 265 day orbit around one of the visual components.

2. OBSERVATIONS

Because of the prediction of HD 98800's optical variability (Fekel & Bopp 1993b), we placed the star on the observing menu of the Vanderbilt/Tennessee State 0.4 m automatic photoelectric telescope (APT) located on Mount Hopkins (Henry & Hall 1994; Young et al. 1991). The APT obtained 24 observations in Johnson B and V between JD 2449094 and JD 2449121 with a new temperature-controlled precision photometer. The observations were made differentially with respect to the comparison star HD 98828 and were corrected for differential extinction and transformed to the Johnson system. HD 98346 was also observed each night as a check on the constancy of the comparison star. Despite the −25° declination and observations always obtained at an air mass of greater than 1.8, the standard deviation of the nightly differential magnitudes between HD 98346 and HD 98828 from their seasonal mean magnitude was only 0.005 mag. This represents the upper limit of the variability of the comparison and check stars and also serves as an estimate of the external precision of the nightly observations.

The light curve of HD 98800 in V is shown in Figure 1 and reveals it to be a new variable star with an amplitude of approximately 0.07 mag. Eggen (1986) gives $V = 6.69$ for our check star HD 98346 from Strömgren photometry. This, combined with our mean differential V magnitude of −1.136 for HD 98346 minus HD 98828, gives a V magnitude of 7.826 for our comparison star HD 98828. Thus, HD 98800 varied between a brightness maximum of $V = 8.91$ and a minimum of $V = 8.98$ at our epoch of observation. Periodogram analysis of our B and V differential magnitudes resulted in a period of 14.7 ± 0.2 days.

3. DISCUSSION

From their observed Li abundance, Fekel & Bopp (1993a) estimated the age of HD 98800 to be 10 Myr or less and therefore to be 1 mag or more above the ZAMS. The late

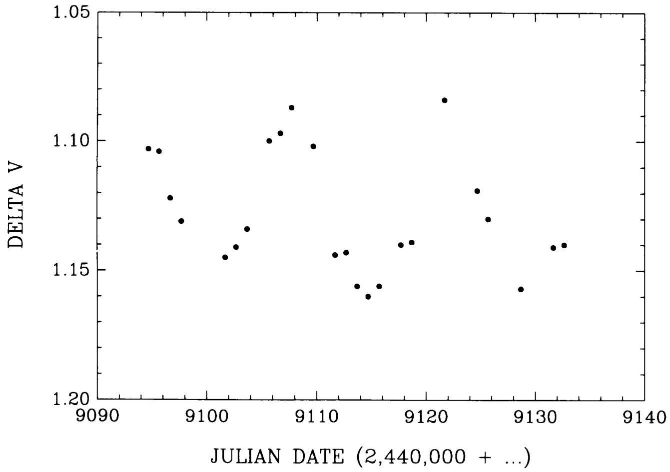

FIG. 1.—Light curve in V of HD 98800 obtained with the Vanderbilt/Tennessee State University 0.4 m APT. The star is revealed to be a new variable star with an amplitude of 0.07 mag and a period of 14.7 days.

spectral type, extreme youth, and presence of Hα emission observed by Gregorio-Hetem et al. (1992) and Fekel & Bopp (1993a) imply that the mechanism for light variability of HD 98800, like other chromospherically active stars, is probably rotational modulation by starspots, presumably on the primary component of the visual double. We see no detectable $B-V$ color change with rotation, in agreement with results on other low-amplitude chromospherically active stars. Thus the 14.7 day photometric period determined above represents the rotation period of the primary component of HD 98800. Further photometric observations will probably reveal brightness changes of varying amplitudes (as the spot distribution changes) and slightly differing periods (as spots appear at different latitudes on the differentially rotating star). The observed level of light variability (i.e., chromospheric activity) makes even more likely the possibility that HD 98800 might be a radio and X-ray source, as suggested earlier by Fekel & Bopp (1993a). Rucinski (1993) has already detected HD 98800 as a strong 0.8 mm source with a flux density of 102 ± 10 mJy.

Fekel & Bopp (1993a) observed substantial broadening in the absorption lines of HD 98800 and determined $v \sin i = 11 \pm 1$ km s^{-1}. However, our rotation period of 14.7 days, combined with a radius near the solar value, gives an equatorial rotation velocity v of only 3 km s^{-1}. This confirms the suspicion of Fekel & Bopp (1993a) that much of the observed line broadening might be due to velocity separation between the SB1 and the other, single visual component of HD 98800, both of which are included on the slit for spectroscopic observations.

The 3 km s^{-1} rotation velocity of HD 98800 places it somewhat below the minimal 5 km s^{-1} limit (Bopp & Fekel 1977) often assumed necessary for the onset of enhanced spot activity. The 14.7 day rotation period is also longer than nearly all known BY Dra variables (Bopp & Fekel 1977; Pettersen 1983; Torres, Busko, & Quast 1983; Strassmeier et al. 1988) and T Tauri variables (Bouvier et al. 1986; Vrba et al. 1986; Bouvier 1990; Attridge & Herbst 1992). It should not be too surprising that at least some young, low-mass stars rotate as slowly as HD 98800. Hartmann et al. (1986) report, for example, that 30% of their sample of 50 T Tauri stars in the Taurus-Auriga and Orion complexes have rotational velocities at or below their spectroscopic detection limit of 10 km s^{-1}. Bouvier et al. (1986), however, report a lack of *very* slow rotators ($v \sin i \leq 6$ km s^{-1}) in their sample of 28 T Tauri stars, and Attridge & Herbst (1992) find only two stars with periods 14 days or longer in their collected sample of all T Tauri stars with known rotation periods. To date, the number of young, lower-main-sequence stars with directly measured rotation periods longer than 2 weeks is certainly quite small and due, at least in part, to the observational difficulties involved.

How can such a slowly rotating star like HD 98800 drive a magnetic dynamo strong enough to generate photometrically observable starspots? Hall (1991, 1994) examined large samples of stars with good photometric histories including the RS CVn, BY Dra, FK Com, Algol, W UMa, and T Tau groups of spotted variables as well as normal lower–main-sequence stars. He used the convective turnover times of Gilliland (1985) to show that starspot activity sets in quite suddenly when the Rossy number Ro (the ratio of rotation period to convective turnover time) is less than 0.65. The K5 V spectral classification of HD 98800 implies an unreddened $B-V$ of 1.18 (Allen 1976) and a convective turnover time from Gilliland (1985) of 48 days. Therefore, Ro for HD 98800 is 0.30. Figure 2 plots spot amplitudes of the main-sequence stars from Hall (1994) against log (Ro) and shows that the Rossby number for HD 98800 is well within the range for which spot activity should be expected. There is some uncertainty about the actual convective turnover time for HD 98800 since Gilliland's calculations are for zero-age main-sequence stars and HD 98800 lies somewhat above the main sequence. However, Hall (1991) has shown that for stars of luminosity class IV the convective turnover times are longer by a factor of 2. Therefore, HD 98800 may, in fact, lie up to 0.3 units in the log further to the right in Figure 2. This would further strengthen the expectation of starspot activity; clearly, HD 98800 could have a rotation period of a month or longer and still display enhanced starspot activity with a photometric amplitude greater than a percent or so. Similarly, an M5 V star, with a deeper convective layer, could rotate as slowly as once in two months and still display this level of starspot activity, whereas a G5 V star would need a rotation period shorter than 18 days to do so. If such faint, young, low-mass, slowly rotating stars with periods of a month

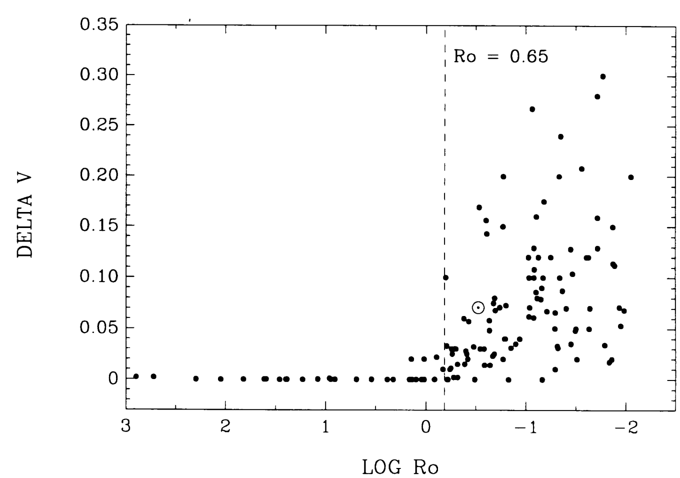

FIG. 2.—Photometric amplitudes of the main-sequence stars in the sample of Hall (1994) are plotted (*solid points*) against log of their Rossby numbers. We add HD 98800 (*circled point*) with an amplitude of 0.07 mag and a Rossby number of 0.30 to show that enhanced starspot activity is to be expected in this star.

or so do exist, perhaps in T Tauri complexes, their periods could be determined with modest telescopes and CCD photometric observations similar to those of Attridge & Herbst (1992); most such stars are below the magnitude limit of current APT's equipped with conventional photoelectric photometers.

Finally, we can estimate the size of the spots causing the light variability in HD 98800. If we assume that the spots occur on the primary component, then we must scale the observed amplitude of 0.07 mag up to 0.10 mag to account for light dilution by the visual companion star 0.4 mag fainter in V than the primary (Heintz 1990). We then convert this amplitude into a spot size by the method of Hall & Busby (1990) that assumes a circular spot of nominal temperature crossing the center of the star's disk. The result is a spot with an approximate radius of 16°. We note, however, that the asymmetric shape of our light curve plotted modulo the photometric period (Fig. 3) implies the existence of at least two separate spots at different longitudes, only one of which would be as large as 16°.

HD 98800 may well be providing us a glimpse of conditions in the formative stages of the solar system. The young age of HD 98800 may place it in the stage of its pre–main-sequence evolution prior to the spin up caused by gravitational contraction (Stauffer & Hartmann 1986). Nonetheless, it already supports a strong magnetic dynamo and so varies in brightness by several percent as it rotates. As Zuckerman & Becklin (1993) point out, the presence of a dusty disk in HD 98800 suggests that the formation of planetary systems in multiple star systems may be plausible.

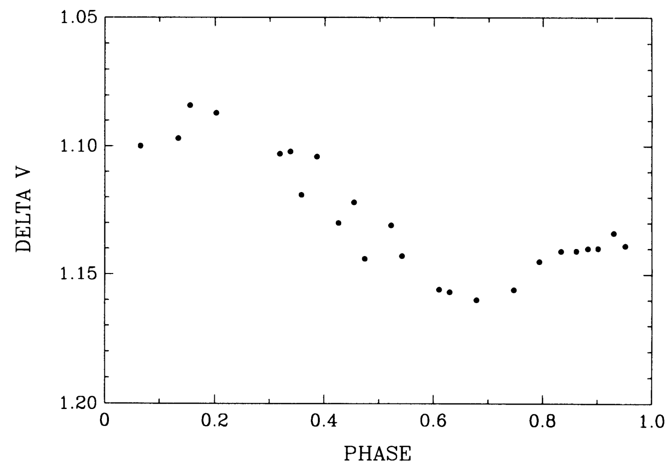

FIG. 3.—Light curve in V of HD 98800 plotted modulo the 14.7 day rotation period. The asymmetric shape of this phase curve reveals the presence of at least two starspots at different longitudes. The scatter in the observations between phases 0.3 and 0.5 demonstrates that some evolution of the spots has taken place over rotation timescales.

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