

HD 93521: A HIGH-LATITUDE SHELL STAR

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ABSTRACT

The evolutionary state of HD 93521 has been the subject of controversy. A review of the available evidence supports the conclusion that it is a main-sequence star. A principal argument for placing it in Population II rests on the erroneous application of the terminal velocity–escape velocity relation described by Abbot in 1978. H α observations of HD 93521 show it to be a shell star. With the known flux variations of shell stars, the use of this star as a UV flux standard should be reconsidered.

Subject headings: stars: circumstellar shells — stars: early-type — stars: emission-line — stars: individual (HD 93521)

I. INTRODUCTION

By virtue of its early type, comparative brightness, and rapid rotation (see Table 1) HD 93521 has been much used as a probe of the interstellar medium (e.g., Harris and Mas Hesse 1986; de Kool and de Jong 1985; Shull and Van Steenberg 1985; Harris and Bromage 1984; Hobbs and Albert 1984; Hobbs 1984; and Hobbs *et al.* 1982). In addition, its high Galactic latitude results in its being one of a fairly small number of stars used as probes of the interstellar medium in the Galactic halo (e.g., Lockman, Hobbs, and Shull 1986; Albert 1983). The high Galactic latitude and the implied great distance of the star from the Galactic plane, together with observed characteristics of the star, have stimulated a continuing controversy as to its nature. Is it a normal Population I main-sequence star or a low-mass evolved object?

HD 93521 was observed during the course of a search for bright new emission-line stars. It was selected as a candidate for the survey on the basis of its high $v \sin i$ and suspected variability as reported in the Supplement to the *Bright Star Catalogue* (Hoffleit, Saladyga, and Wlasuk 1983).

II. OBSERVATIONS

H α observations were made with MIRA's 91 cm telescope at the Oliver Observing Station. The spectrograph employed a 512 element Reticon detector. The initial indication of a peculiarity in HD 93521 was found in a 1987 April 20 observation using a dispersion of 2.6 Å per diode. The star was reobserved on 1987 April 27 and May 17 at a dispersion of 1.2 Å per diode. The latter observation is reproduced in Figure 1 corrected for Reticon fixed pattern noise and variable diode response to a flat lamp. For comparison ζ Oph is shown. This star has the same type (O9.5 Vn) and projected rotational velocity ($v \sin i = 379 \text{ km s}^{-1}$) (Hoffleit 1982) as HD 93521. The tracings show the profile of He I $\lambda 6678$ is very similar in the two stars, but H α is much narrower and deeper in HD 93521. A weak emission wing is seen on the red edge of H α in HD 93521. The reality of this emission feature is confirmed by the April 27 observation. The appearance of H α in HD 93521 indicates the existence of an optically thick shell around the star.

III. DISCUSSION

Hobbs *et al.* (1982) concluded HD 93521 is a normal Population I main-sequence star. Bisiacchi *et al.* (1978), Ramella,

Morossi, and Santin (1980), and Ebbets and Savage (1982) deduced it is a low-mass Population II star. Observations bearing on this question are discussed below.

a) Spectrum

From a reclassification of HD 93521 on the revised MK system, Hobbs *et al.* (1982) concluded the star is a normal O9.5 V star. The classification of Bisiacchi *et al.* (1978) is the only one that seriously disagrees with this type. Bisiacchi *et al.* classify the star as O9.5 Ib–II based, in part, on the equivalent width of H γ which implied a luminosity class of II and H α photometry by Mendoza (1976) which implied a luminosity class of I. The use of hydrogen line observations to determine luminosity for a shell star is clearly not reliable. In fact, the high luminosity deduced from the hydrogen line observations of Bisiacchi *et al.* and particularly Mendoza suggest that at the time of their observations the shell observed in 1987 was present. There is evidence that on at least one occasion shell characteristics were conspicuous in the blue part of the spectrum of HD 93521. Williams (1936) noted “H lines relatively much sharper than He.” Aside from that observation, the hydrogen line profiles in the blue have appeared normal. Plaskett and Pearce (1931) in describing plates taken in 1924 and 1925 remark on the exceptionally diffuse lines of hydrogen and helium, implying at that time the shell spectrum was absent. Morgan (1988) in reexamining plates taken in 1944 and 1981 noted that H δ and H γ were as broad as or broader than the strong helium lines.

The means of the absolute magnitude calibrations of Conti and Alschuler (1971), Walborn (1973), and Lesh (1979) for O9.5 V is $M_V = -4.13$. Using the bolometric correction appropriate for an O9.5 V star from Code *et al.* (1976) ($BC = -3.06$), the bolometric magnitude of HD 93521 is -7.2 .

b) Mass Loss and Luminosity

Snow (1979) found the mass-loss index $R_* v_\infty W_a$ is proportional to the bolometric luminosity, where R_* is the stellar radius, v_∞ is the terminal velocity of the stellar wind, and W_a is the absorption equivalent width. The latter two quantities are measured for the N v resonance doublet at $\lambda 1238.8$ and $\lambda 1243.1$. Abbott, Bohlin, and Savage (1982) measured the N v doublet in 53 early-type stars including HD 93521. Their mass-loss index for that star is consistent with the bolometric luminosity.

TABLE 1
CHARACTERISTICS OF HD 93521

Characteristic	Value	Source
MK type	O9.5 V ^a	1
	O9.5 Ib-II	2
	O9 Vp	3
Magnitude	$V = 7.04$	4
Color	$B - V = -0.28$	4
$v \sin i$ (km s ⁻¹)	380	5
	400	6
	350	7
Galactic latitude (degrees)	+62.1	1

^a Classified by Morgan.

REFERENCES.—(1) Hobbs *et al.* 1982; (2) Bisiacchi *et al.* 1978; (3) Morgan *et al.* 1955; (4) Guetter 1974; (5) Ramella *et al.* 1980; (6) Conti and Ebbets 1977; (7) Hack and Yilmaz 1977.

osity appropriate to the O9.5 V type. It should be noted, as will be discussed in the section below, that for the late O and early B dwarf stars the measured UV absorption edge velocities may not correspond to the terminal velocities of the stellar winds. This does not necessarily affect the validity of the mass-loss index–luminosity relation.

Prinja and Howarth (1986) determined the mass-loss rate for HD 93521 to be about $9 \times 10^{-8} M_{\odot} \text{ yr}^{-1}$. This value is consistent with those for the two other stars of similar type in their sample (10 Lac and ζ Oph). This mass-loss rate for an O9.5 V star is also consistent with the mass-loss rate–stellar luminosity relation for O-type stars derived by Garmany *et al.* (1981). The mass-loss rate for HD 93521 is one to three orders of magnitude higher than the mass-loss rates reported for hot subdwarfs (e.g., Hamann *et al.* 1981; Ebbets and Savage 1982).

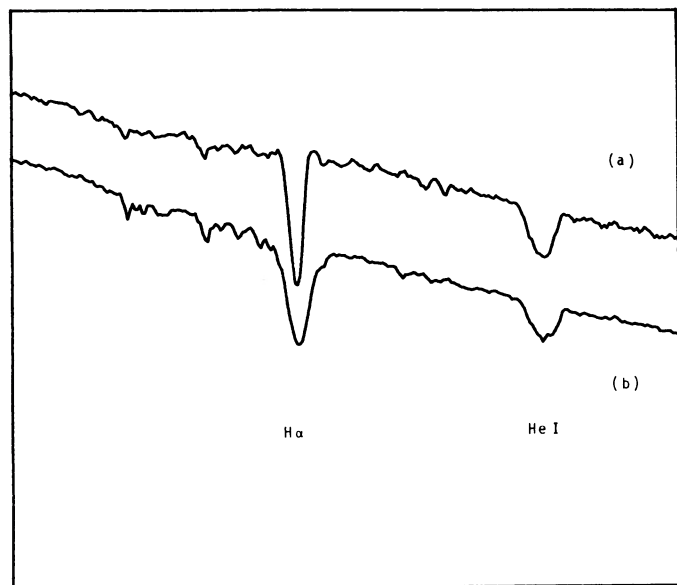


FIG. 1.—H α and He I $\lambda 6678$ in HD 93521 (a) and ζ Oph (b). The stars have the same MK type and $v \sin i$. The comparatively deep narrow H α absorption and red emission edge in HD 93521 indicate the presence of a shell. Both stars are plotted on the same intensity scale with an arbitrary zero point.

c) Escape Velocity

The principal argument that has been used to demonstrate that HD 93521 is a Population II object is based on the observed relation between terminal and escape velocity for stellar winds in early-type stars. From data for 34 early-type stars, Abbot (1978) found that the terminal velocities of stellar winds were related to escape velocities by $v_{\infty} = 3v_{\text{esc}}$. Ramella, Morrossi, and Santin (1980) and Ebbets and Savage (1982) used this relation and observed UV absorption edge velocities, assumed to represent terminal velocities, to determine an escape velocity for HD 93521. On the basis of a low escape velocity, both papers concluded HD 93521 is a low-mass evolved Population II star. The purpose of this section is to show that Abbot's relation is misapplied in the case of HD 93521.

Prinja and Howarth (1986) noted that for the three late O main-sequence stars in their study (including HD 93521) there were differences of more than 1000 km s^{-1} between the observed and calculated terminal velocities. With this in mind, I reexamined the Abbott (1978) data. Abbott discussed 65 stars in his paper. He deduced the relation between terminal and escape velocity from only those 34 stars where he was confident the measured UV absorption edge in fact represented the terminal velocity of the stellar wind. Abbott's data for all nine of his stars that are O9 or later and classified as main-sequence by one or more of his cited sources are shown in Table 2. The v_{edge} velocities in column (6) are enclosed in parentheses to indicate his uncertainty as to whether these velocities represent the terminal velocities of the stars. Accordingly, none of the stars in Table 2 were used in deriving his terminal velocity–escape velocity relation. The escape velocities in column (5) were computed from stellar parameters.

The last column of Table 2 shows the terminal velocities for three stars measured by Prinja and Howarth (1986). They stated that all the stars they analyzed had a sufficiently strong absorption profile, for at least one ion, that v_{∞} could be measured. Their v_{∞} velocities agree fairly well with Abbott's v_{edge} velocities.

From the Abbott data in Table 2, the relation between v_{edge} and v_{esc} for main-sequence stars O9 or later is $v_{\text{edge}} = 1.3v_{\text{esc}}$. If Abbott is correct, this relation differs from the terminal velocity–escape velocity relation he derived simply because edge velocity does not correspond to terminal velocity in these stars. If Prinja and Howarth are correct and we are in fact observing terminal velocities, then $v_{\infty} = 1.3v_{\text{esc}}$ applies to the O9 and later main-sequence, a relation distinctly different from that for hotter and/or more luminous stars.

In either case, it is clear from Table 2 that HD 93521 has an edge velocity similar to that of other main-sequence stars of similar type. Further, the relation $v_{\infty} = 3v_{\text{esc}}$ does not in practice apply to O9 or later main-sequence stars and cannot be used to calculate their escape velocities. Use of the relation to demonstrate a low escape velocity for HD 93521 and thus deduce it is a low-mass Population II star is invalid.

IV. CONCLUSIONS

The evidence discussed above is consistent with HD 93521 being a rotationally unstable O9.5 V star. However, based on the magnitude and color of Guetter (1974) (Table 1), the intrinsic color of Code *et al.* (1976) ($B - V = -0.30$), and $M_V = -4.13$, the star is at a distance of 1670 pc and is 1470 pc above the Galactic plane. The motion of the star with respect to the

TABLE 2
O9 AND LATER MAIN-SEQUENCE STARS WITH WINDS

NAME (1)	HD (2)	SPECTRAL TYPE		v_{esc} (km s ⁻¹) (5)	v_{edge} (km s ⁻¹) (6)	$v_{\text{edge}}/v_{\text{esc}}$ (km s ⁻¹) (7)	v_{∞} (km s ⁻¹) (8)
		Conti/Lesh (3)	Walborn (4)				
10 Lac	214680	O8 III	O9 V	1050	(1170)	1.1	1375
μ Col	38666	O9 V	O9.5 V	1080	(670)	0.6	...
	93521	...	O9 Vp	1000	(1210)	1.2	1075
θ^2 Ori A	37041	O9 V	O9.5 V	1010	(1650)	1.6	...
	57682	O9 V	O9 IV	950	(1700)	1.8	...
ζ Oph	149757	O9 V(e)	O9.5 V	910	(1580)	1.7	1640
τ Sco	149438	B0 V	...	1030	(2000)	1.9	...
θ Car	93030	B0.5 Vp	...	886	(930)	1.0	...
η Cen	127972	B1.5 V	...	820	(810)	1.0	...

NOTE.—Data are from Abbott 1978, except for col. (6), which are from Prinja and Howarth 1987.

Galactic plane is somewhat uncertain. Hobbs *et al.* (1982) determined it is moving toward the plane, while Bisiacchi *et al.* (1978) find it is moving away from the plane. It will be assumed here it is at a turning point. Using Oort's (1965) force law perpendicular to the Galactic plane, a star leaving the Galactic plane at about 80 km s⁻¹ will reach a turning point in the vicinity of 1500 pc above the plane in excess of 3 × 10⁷ yr. An O9.5 V star will have a mass of ≥ 16 M_⊙ and a hydrogen core burning lifetime of ≲ 10⁷ yr (Underhill and Doazan 1982). These facts are not compatible with HD 93521 having been formed in, and ejected from, the Galactic plane. Hobbs *et al.* (1982) suggest it is an example of a star recently formed in the halo by an undetermined mechanism.

Bohlin (1986) recommends basing all future UV calibrations, including the calibration of UV-sensitive instruments on the Hubble Space Telescope, on the five *IUE* standard stars (one of which is HD 93521). These UV standards have exhibited no evidence of UV flux variation since the *IUE* launch in 1977.

However, as a shell star HD 93521 is likely to eventually exhibit flux variability that is a common feature of Be and shell stars. Peters and Polidan (1987) report for three Be stars far-UV flux variations of 25%–30% on a time scale of months. For ζ Oph, Prinja and Howarth (1986) note significant UV spectrum changes coincident with a 1980 H α emission episode. The use of HD 93521 as a UV flux standard should be reconsidered.

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