

SPECTRAL VARIATIONS OF THE HELIUM-RICH STAR HD 64740

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ABSTRACT

Ultraviolet observations of the spectral lines C II λ 1066, N II λ 1084, Si III λ 1108, 1109, 1113, and Si IV λ 1122, 1128 have been examined for evidence of variable strength with the period 1.33016 days established from the helium variations. Small amplitude variations are found for all the features, with minimum strength occurring at the phase of most negative magnetic field and the greatest helium strength. This result supports an oblique rotator model for the helium-rich stars. Searches for ultraviolet-light variations and radial-velocity variations of the spectral features used for this study both found the star to be constant. The upper limit to any velocity variations is about 10 km s^{-1} .

Subject headings: stars: individual — stars: peculiar A — stars: spectrum variables

I. INTRODUCTION

Several recent observational studies have shown that the helium-rich B stars are variable in a variety of ways. Walborn (1974) has found that σ Ori E, the prototype for this class of peculiar stars, has broad, variable emission at H α . His observations of two additional helium-rich stars, HD 37017 and HD 64740, indicated that they too probably have variable H α emission. Several observers have reported variations in the strengths of the helium lines of σ Ori E. Nissen (1974) found the variability in the course of a photometric study of He I λ 4026 among a large number of B stars, and Hunger (1974) detected significant variations upon a reexamination of coudé spectrograms. Thomsen (1974) attempted to determine a period for the variation using a photometric measure of He I λ 4471. Hesser, Moreno, and Ugarte (1977) have discussed an extensive set of *uvby* β photometry of σ Ori E, from which they found periodic variations, most pronounced in the *u*-band, that were stable over the three observing seasons of the program. Pedersen and Thomsen (1977) and Pedersen (1979) have used photometry to show that many of the helium-rich stars vary periodically in the strength of He I λ 4026. Most recently, Landstreet and Borra (1978) and Borra and Landstreet (1979) have found that the majority of the helium-rich stars they have observed exhibit strong magnetic fields which vary with the same period as the He I line.

The observational results cited above provide strong support for the suggestion of Osmer and Peterson (1974) that the helium-rich stars are an extension to higher effective temperatures of the Ap-star phenomenon. This seems to be true independent of the apparent rotational velocity of the helium-rich

stars, because Lester (1976) has found the same distribution of abundances in HD 64740 ($v \sin i = 150 \text{ km s}^{-1}$) as Osmer and Peterson found for sharp-lined stars. A major puzzle remains, however, because the helium-rich stars, unlike the Ap-stars, have constant radial velocities. Bolton (1974) has placed an upper limit of 4 km s^{-1} on the radial velocity variations of σ Ori E, and Groote, Kaufmann, and Hunger (1978) have reported an upper limit of 2 km s^{-1} for HD 64740. This behavior can be contrasted with the properties of HR 7129 (Wolff and Wolff 1976). With $T_{\text{eff}} \sim 20,000 \text{ K}$, this star is only slightly cooler than the helium-rich stars. It has been found to have a large and periodically varying magnetic field as well as periodic variations in the helium line strengths. However, it differs from the helium-rich stars in that it has regular velocity variations which are consistent with the oblique rotator model advanced for the Ap-stars. Therefore, the constant radial velocities represent a major difficulty in applying the standard oblique rotator model to the helium-rich peculiar stars.

In trying to gain a better understanding of the helium-rich stars, it is important to see if there are other points where the application of the oblique rotator model breaks down. One additional observational property of Ap-stars, and HR 7129 in particular, is that they are spectrum variables for elements besides helium. In HR 7129 (Wolff and Wolff 1976) carbon, silicon, and calcium vary roughly in antiphase with the helium lines. According to the conventional oblique rotator model, these variations are associated with areas of increased surface concentration of these elements. As such, the spectral variations, produced by the rotation of these enhanced patches in our line of sight, are closely connected with the velocity variations of these same lines. Therefore, the search for spectral variations of elements other than helium can provide another test of the oblique rotator model as it applies to the helium-rich stars.

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Because of observational difficulties, very little has been done to test this point. The helium-rich stars divide cleanly into a slowly rotating group, for which even helium variability has not been measured, and a rapidly rotating group, for which spectral features weaker than the helium lines are difficult to measure. On the basis of four coudé plates, Hunger (1974) has reported variations in Si III for σ Ori E which appear to be in antiphase with the helium variation. However, with only four data points from different epochs, the result needs confirmation. Hunger was unable to determine if C II or Mg II was variable.

To overcome these observational difficulties, we have used the *Copernicus* satellite to search for variations in the ultraviolet spectrum of the helium-rich star HD 64740. This star is the brightest of the helium-rich stars, and it is the only one which can be observed using *Copernicus*. The major advantage to using ultraviolet data is that the spectral lines present in stars of this type are intrinsically much stronger in the ultraviolet than in the visual. There is no difficulty in measuring the strength of these features even when the projected rotational velocity is substantially greater than 150 km s^{-1} . A second advantage is that B stars are bright in the ultraviolet, making the photometric accuracy of each individual measurement high while keeping the duration of each measurement short. These are significant advantages for a search for spectral variations.

II. OBSERVATIONS

We have used the scanning spectrometer of the Princeton experiment package aboard the *Copernicus* satellite to make repeated measurements of the features C II $\lambda 1066$, N II $\lambda 1084$, Si III $\lambda \lambda 1108, 1109, 1113$, and Si IV $\lambda \lambda 1122, 1128$. These features were chosen for several reasons. First, carbon and silicon are known to be variable in cooler stars for which the oblique rotator model seems to apply. Also, Hunger (1974) reported silicon variations in σ Ori E. Second, all of these lines are intrinsically strong. Although there is heavy line blanketing in the ultraviolet spectral region of B stars, these features are very prominent. Third, these lines fall in the region of maximum sensitivity of the *Copernicus* instrument. During the standard 14 s integration time each data point typically registered 2000 counts, corresponding to a noise from photon statistics of about 2% of the signal.

The data were obtained with the U2 photometer, providing a spectral resolution of 0.2 \AA . A single scan of each feature and its surrounding "continuum" typically took 13 minutes. In some cases the features were scanned twice in succession, so that the minimum time separation is also about 13 minutes. In all, each feature was scanned more than 20 times in a 5 day interval in May 1977. Also available to us were independent measurements made in 1974 May consisting of three or four scans of each feature. For all the spectral scans the high-resolution U1 photometer was held stationary and used as a monitor of the satellite guiding.

III. DATA ANALYSIS

Before searching for spectral variations, the data were corrected for the guiding stability of the satellite. For each scan, the high-resolution U1 counts were smoothed to reduce photon noise but not to remove trends. Then for each data point i of each scan of each feature, the quantity $U1_i / \langle U1 \rangle$ was formed as a measure of the satellite guiding. Each data point of the associated U2 scan was then divided by this quantity to get a value corrected to the mean throughput of the spectrometer.

After applying the guiding correction, a measure of the strength of each feature was constructed. A true equivalent width cannot be measured for these ultraviolet features because of the heavy line blanketing. However, it is possible to define a measure of the strength of each feature which can be derived in a consistent way for all the scans of that line. These strength measurements, in units of m\AA , are given in Table 1 together with the Julian Date of the midpoint of each scan. Table 1 contains both the 1974 and the 1977 data.

The photometric studies of Pedersen and Thomsen (1977) and Pedersen (1979) have shown that HD 64740 is variable in the strength of He I $\lambda 4026$ with a period of 1.33016 days. The observations in the first paper were made in 1976 January–February, while in the second paper the data were from 1976 October and December. Over this interval of nearly a year the period was found to be constant. The magnetic field observations of Borra and Landstreet (1979) were made in 1977 December through 1978 January. These authors found that the period established by Pedersen (1979) from his photometry yielded a good fit to the magnetic variations. The bulk of our observations were made in 1977 May, between the photometric and magnetic observations. Therefore, we have adopted the period of 1.33016 days in our search for spectral variations.

After phasing our data with the photometric period, we have performed a least-squares fit to the line strengths using an equation of the form

$$a_0 + \sum_{i=1}^2 (a_i \sin i\phi + b_i \cos i\phi).$$

This equation was adopted because it was used by Pedersen and Thomsen (1977) to fit their He I data. To do this fit we have used only the 1977 data because they were all taken within an interval of about 5 days, or three consecutive periods. The 1974 data lie outside the time interval during which the period is known to have been stable. These data can then be used to test either the value of the period or its stability. Our data have been plotted as a function of phase in Figure 1. Phase zero corresponds to the maximum He I strength (Pedersen 1979) and the most negative magnetic field strength (Borra and Landstreet 1979). Both the He I and the magnetic variations are shown in Figure 1 for comparison.

TABLE 1
 LINE STRENGTHS (mÅ)

JD (2442000+)	C II $\lambda 1066$	JD (2442000+)	N II $\lambda 1084$	JD (2442000+)	Si III			JD (2442000+)	Si IV	
					$\lambda 1108$	$\lambda 1109$	$\lambda 1113$		$\lambda 1122$	$\lambda 1128$
177.3272	376	177.5100	918	177.6184	359	401	371	177.7200	324	330
177.3967	351	177.5452	942	177.6741	367	407	367	177.7557	313	356
177.4331	372	177.5813	804	177.6851	348	437	392	177.7907	390	336
177.4695	400	1267.8763	801	1267.9080	296	371	364	1267.9389	289	333
1267.8633	423	1268.0124	755	1267.9793	358	392	365	1267.9484	244	325
1268.0469	341	1268.0893	751	1268.1559	348	361	357	1268.1952	292	309
1268.0791	372	1268.3537	724	1268.2986	323	357	351	1268.2513	270	312
1268.3919	326	1268.4814	752	1268.4984	351	419	375	1268.5506	309	380
1268.4268	346	1268.6005	795	1268.5702	335	349	414	1268.5600	311	351
1268.6300	423	1268.6890	916	1268.7010	396	447	--	1268.7130	344	289
1268.6394	406	1268.7807	848	1268.7683	314	379	368	1268.7582	358	301
1268.8273	356	1268.8469	849	1268.8987	361	400	414	1268.9088	332	309
1268.8368	436	1268.9824	860	1268.9700	403	426	350	1268.9183	339	285
1269.0152	390	1269.0559	883	1269.1215	373	390	341	1269.1601	361	357
1269.0458	333	1271.1276	733	1271.0636	316	339	348	1269.1980	319	330
1271.1655	348	1271.4539	737	1271.2951	377	442	357	1271.0543	303	331
1271.2027	361	1271.5009	763	1271.4022	386	420	382	1271.3410	358	386
1271.4641	380	1271.6122	813	1271.5303	367	408	378	1271.3848	375	349
1271.4735	310	1271.6774	924	1271.6002	327	368	374	1271.5442	334	392
1271.6407	326	1271.7998	794	1271.7069	357	397	348	1271.5729	338	324
1271.6672	380	1271.8475	835	1271.7554	366	400	362	1271.7357	336	347
1271.8100	377	1271.9592	715	1271.8773	339	375	362	1271.7452	344	375
1271.8194	432	1272.0619	716	1271.9461	326	346	337	1271.8886	315	253
1271.9927	293			1272.1002	348	367	366	1271.9170	318	382
1272.0255	348							1271.1704	299	319

IV. DISCUSSION

We conclude from Figure 1 that all of the spectral features which we have examined are variable with a period of 1.33016 days, and that each line varies in antiphase with the He I variations. Based on the amplitudes alone, this conclusion would not be very strong because of the rather small magnitude of the variations; the maximum departures from the mean values are only about 15%. However, the phasing provides much stronger support for the conclusion. For each feature, the least-squares curve has its minimum value near zero phase. The scans of C II, N II, Si III, and Si IV are each independent, and we have no reason to expect correlations between these quantities except for physical reasons imposed by the star. We know of no reason why the least-squares fitting procedure should seek a minimum at phase zero, and indeed our attempts to fit other quantities, such as the line depth, yielded extremes at phases other than zero. Therefore, we feel that the variations shown in Figure 1 are due to variations intrinsic to the star.

Examining the individual curves, we see that the C II variations resemble the He I variations in that the double-peaked behavior at phases 0.3 and 0.7 in C II corresponds to the double dips in He I. The Si IV $\lambda 1128$ line shows the same behavior, but the curve has been shifted by 0.1 to earlier phases.

Comparing the Si III and Si IV lines we find that they vary in phase, as would be expected if the variations are due to regions of enhanced silicon concentration on the stellar surface. An alternative explanation might be variations of the temperature from region to region

on the surface. At the present time the effective temperature of HD 64740 is rather uncertain. Using photometry, Lester (1976) found a value of 22,500 K, while Groote, Kaufmann, and Hunger (1978) cite a value of 28,500 K derived from the ionization equilibrium of silicon. Accepting this uncertainty, the effective temperature of the star still falls in the range 20,000–30,000 K, in which Kamp (1978) has shown that the strengths of Si IV $\lambda\lambda 1122, 1128$ increases with increasing effective temperature, whereas Si III $\lambda 1113$ decreases with increasing temperatures. To explain the variation of the two ionization stages of silicon in phase by a temperature variation would require either temperatures $> 30,000$ K or temperatures $< 20,000$ K. Both of these seem beyond the acceptable limits.

In Figure 1 we have also plotted the 1974 data, although they have not been used in the least-squares fits. We see that in general they do not phase well with the 1977 data. A shift of approximately $+0.2$ – 0.3 in phase produces a much better match between the data of the two epochs. This phase shift could be due to an error in the adopted period. Increasing the period by about 0.0004 days will bring the two epochs into much better agreement. This change is more than twice the stated uncertainty in the period for HD 64740 (Pedersen 1979), but we feel that the uncertainty might have been underestimated. The increase in the period would not change the relative phasing of the 1977 data or the comparison with the He I and the magnetic field data, both of which were taken within a year of our observations.

Our results, therefore, add yet another aspect in which the helium-rich stars and the hot Bp stars

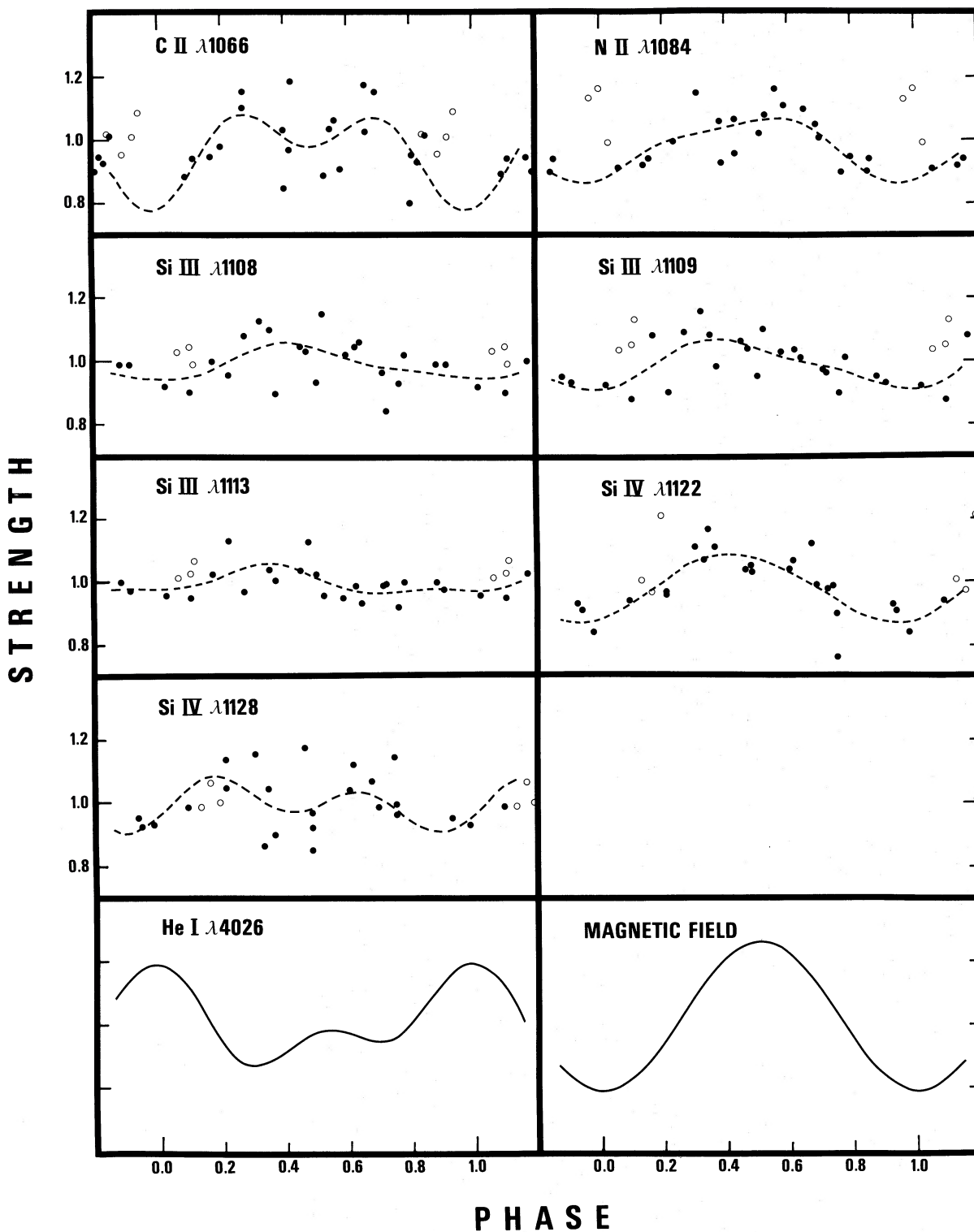


FIG. 1.—Strengths of the ultraviolet spectral features measured for HD 64740 as a function of phase, computed using the period 1.33016 days. For each spectral feature the value plotted is the individual measurement divided by the mean value. The 1977 data are shown as solid dots, and the 1974 data are shown as open circles. The dashed lines represent least-squares fits to the 1977 data. Also shown for comparison are the variations observed for He I $\lambda 4026$ (Pedersen 1979) and the magnetic field (Borra and Landstreet 1979).

have similar properties. Both types of stars have magnetic fields which vary periodically, variable helium strengths, and now variations in the strengths of the other elements which are in antiphase with the helium variations. For the case of silicon, two stages of ionization vary in phase. The major difference between the two types of stars is the constancy of the velocity for the helium-rich stars. A second difference is that some of the helium-rich stars, in particular HD 64740, have essentially constant photometric properties.

Elaborating on the photometric differences, Pedersen and Thomsen (1977) found that HD 64740 was constant in its light except for a marginal variation in the Strömgren c_1 index near the phase of magnetic minimum. By way of comparison, the Bp star HR 7129 (Wolff and Wolff 1976) varies in phase in all four Strömgren bands, with maximum light occurring at magnetic maximum. To gain an additional perspective on this difference between the two types of stars, we have examined our ultraviolet data for HD 64740 to see if there is any evidence for ultraviolet variations. Using the counts in the regions adopted as continuum for the line C II $\lambda 1066$, we have searched for variations with the characteristic period of the system. We find no systematic variations with phase, and the standard deviation about the mean value is only 0.88%. Therefore, the photometric constancy of this star holds in both the visual and the ultraviolet spectral regions.

Turning to the constancy of the radial velocity, there is the possibility that the previous attempts to find variations have failed because they have concentrated on the hydrogen and helium lines as the most measurable features available. As noted by Wolff and Wolff (1976), the velocity variations in HR 7129 are not found in the helium lines because of complications

introduced by the variable strengths. Therefore, we have searched our ultraviolet data for evidence of velocity variations in C II, N II, Si III, and Si IV. The results are ambiguous. There seems to be a tendency for the velocities in the interval between phases 0.8 and 0.3 to be negative for all the lines. However, the maximum amplitude is only 10 km s^{-1} . Recall that our spectral resolution is 0.2 \AA , which at these wavelengths corresponds to 55 km s^{-1} . Therefore, the variations, if they are present, are at the level of 20% of our resolution element. It is clear that there are no variations with an amplitude $\geq 25 \text{ km s}^{-1}$, but the detection of smaller amplitude variations will require higher-resolution observations.

V. CONCLUSIONS

We have searched for spectral variations in the helium-rich star HD 64740 using ultraviolet data from the *Copernicus* satellite. All of the spectral features we have examined appear to vary in phase with a small amplitude. The phasing is such that the minimum line strengths correspond to times of most negative magnetic field strength and maximum helium strength. This result increases the similarity between the helium-rich stars and the hot Bp stars, and it strengthens the case for an oblique rotator model. We have searched for photometric and radial-velocity variations, but HD 64740 is constant in these quantities to the accuracy of our data.

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