THE ASTROPHYSICAL JOURNAL, 257:656–671, 1982 June 15

VOYAGER ABSOLUTE FAR-ULTRAVIOLET SPECTROPHOTOMETRY OF HOT STARS

J. B. HOLBERG, W. T. FORRESTER, AND D. E. SHEMANSKY
Earth and Space Sciences Institute, University of Southern California, Tucson Laboratories

AND

DON C. BARRY
Department of Astronomy, University of Southern California
Received 1981 October 9; accepted 1981 December 22

ABSTRACT

Voyager observations in the 912–1200 Å spectral region are used to indirectly intercompare absolute stellar spectrophotometry from previous experiments. Measurements of hot stars obtained by the *Voyager 1* and *2* ultraviolet spectrometers show considerably higher 912–1200 Å continuum fluxes than the recent observations of Brune *et al.* and Carruthers *et al.* The intercomparisons show all observations in basic agreement near 1200 Å. The Carruthers *et al.* flux measurements are preferred down to 1050 Å at which point the *Voyager* and Brune *et al.* values are respectively ~60% higher and 60% lower. Below 1050 Å the disagreement among the observations becomes very large and the fluxes predicted by model atmospheres have been adopted. The pure hydrogen line-blanketed model atmosphere calculations of Wesemael *et al.* in comparison with *Voyager* observations of HZ 43 are used to adjust the *Voyager* calibration below 1050 Å. This adjusted *Voyager* calibration, which is in good agreement with current model atmosphere fluxes for both early-type stars and DA white dwarfs, will be used for *Voyager* astronomical observations. There is a clear need for further observations of absolute stellar fluxes, particularly at the shortest wavelengths.

Subject headings: spectrophotometry — stars: early type — ultraviolet: spectra

I. INTRODUCTION

The spectral band extending from the Lyman limit at 912 Å to 1200 Å is the last remaining portion of the astronomical far-ultraviolet spectrum where serious absolute calibration problems remain. Establishment of absolute fluxes for standard sources shortward of 1200 Å will provide important support for the next generation of far-ultraviolet instrumentation which is expected to have observational capabilities extending to wavelengths significantly below 1200 Å. This wavelength range includes a number of astrophysically important ground state transitions for ionized carbon, nitrogen, and oxygen as well as the Lyman and Werner band systems of molecular hydrogen, and the Lyman series of atomic hydrogen. This spectral region was first extensively explored by the *Copernicus* satellite at high spectral resolution. Because of problems with instrument stability and other factors, most *Copernicus* spectra lack a dependable absolute calibration basis. Progress in obtaining reliable measurements of absolute flux in this region has been slow, due principally to the different nature of the instrumentation required at the shortest wavelengths.

Recently, two independent sounding rocket experiments have been launched for the purpose of measuring absolute stellar fluxes in the 912–1200 Å region. Brune, Mount, and Feldman (1979, hereafter BMF) observed five bright southern hemisphere stars with a set of calibrated spectrometers, one of which yielded spectra from 890 to 1240 Å at 12 Å resolution. Carruthers, Heckathorn, and Opal (1981, hereafter CHO) flew an objective grating electrographic camera which obtained calibrated spectra of several stars in Orion down to 950 Å at 2 Å resolution. Earlier, Troy *et al.* (1975) reported broad band (912–1075 Å) photometric observations of the mean fluxes of eight stars at 950 Å. Detailed intercomparisons among these three sets of observations are hampered by the fact they contain no stars in common. We have used the *Voyager 1* and *2* ultraviolet spectrometers (UVS) to observe two or more stars in common with each of the above sets of observations. These *Voyager* observations are used to intercompare the results from these previous experiments.

The earlier authors have noted several significant disagreements between their results and model atmosphere flux predictions for wavelengths below 1200 Å. With respect to the solar composition models of Kurucz (1979), CHO find general agreement with model fluxes down to 1050 Å. However at shorter wavelengths their results fall factors of from 2 to 4 below the models. BMF find the model fluxes to be generally 30% to 60%

higher than their observations. On the other hand, the results reported by Troy *et al.* (1975) at 950 Å are significantly higher than the same model predictions. The *Voyager* results discussed here are also found to be higher than model atmosphere predictions by factors of 1.6–1.8.

In contrast, at wavelengths longer than 1200 Å the agreement among various observers and between observations of absolute flux and model atmosphere predictions is relatively good. Excluding the immediate vicinity of the H I Lyα line (1216 Å), there now seems to be sufficient experimental agreement longward of 1200 Å so that absolute flux measurements of standard stars can be relied upon to an accuracy of $\pm 10\%$ (Bohlin *et al.* 1980). In this long wavelength region, appropriate model atmosphere calculations have also been shown to be in very good agreement with observation (CHO; Bohlin *et al.* 1980; BMF).

Considering the success of the model atmosphere calculations in predicting absolute fluxes for hot stars longward of 1200 Å, the strong disagreement below 1200 Å is puzzling. BMF, whose observations fall below model predictions shortward of 1200 Å, have suggested it may be necessary for the models to include more line blanketing from ionized species in this wavelength region. CHO, whose observations agree with the models down to 1050 Å, have proposed the need for strong line blanketing effects in the models below 1050 Å. BMF have also suggested that hot stars may be inherently variable in the 912–1200 Å region, thus complicating the establishment of standard calibration stars at these wavelengths. The detailed consequences of these implied modifications to current model atmospheres have yet to be investigated.

Comparisons of observed short-wavelength fluxes with model predictions for early-type stars presently involve a number of uncertainties. Among these are the degree of line blanketing in model atmospheres of solar or near solar composition, potentially large corrections for the effects of interstellar reddening, and the unresolved issue of stellar variability at short wavelengths. These uncertainties can be largely avoided if it is possible to observe simpler, better understood stars such as nearby white dwarfs with pure or nearly pure hydrogen atmospheres. We have attempted to do this by comparing *Voyager* observations of the DA white dwarfs HZ 43 and G191 B2B with the line blanketed pure hydrogen model atmospheres of Wesemael *et al.* (1980).

II. INSTRUMENTATION

The *Voyager* ultraviolet spectrometers have been described by Broadfoot *et al.* (1977), and a summary of their inflight performance is given by Broadfoot *et al.* (1981). The *Voyager* instruments are nearly identical objective grating spectrometers which record the spectrum from 500 to 1700 Å on an array of 126 contiguous detectors. The detector, which operates in a photon counting mode, is a linear array of self-scanned anodes which collect the output charge of a microchannel plate. Development of these detectors is described by Broadfoot and Sandel (1977). The field of view (FOV), defined by a mechanical collimator, is 0°.1 full width at half-maximum (FWHM) in the dispersion direction by 0°.87 in the cross-dispersion direction. Spectral resolution for a point source is approximately 25 Å, and the channel separation is 9.26 Å.

a) *Calibration*

Two components control the wavelength sensitivity of the *Voyager* instruments. Shortward of 1250 Å, the quantum efficiency of the bare microchannel plate and the grating efficiency determine the overall sensitivity. Longward of 1250 Å, a semitransparent CuI photocathode deposited on a MgF_2 filter plate serves to enhance the falling long-wavelength response of the bare microchannel plates. The microchannel plates, supplied by Galileo Electro-Optics Corporation, were found to have quantum efficiencies similar to those described by Timothy and Bybee (1975). The platinum replica gratings, supplied by Hyperfine, Inc., were selected on the basis of uniformity of response and the high grating efficiency. Separate measurements of the detector and grating efficiencies were consistent with the final calibration of the assembled instrument. The sensitivity versus wavelength curve for the *Voyager 2* spectrometer is given in Figure 2 of Broadfoot *et al.* (1981).

Prior to launch, the spectrometers were extensively calibrated throughout their wavelength range during and after the spacecraft integration phase. The final calibrations, at 40 wavelengths, were performed 148 and 81 days prior to the launch of *Voyager 1* and *Voyager 2*, respectively. Calibrations were performed at the Kitt Peak vacuum-ultraviolet facility and consisted of illuminating the aperture of the instrument at various positions with an on-axis monochromater beam 1 cm in diamater and collimated to 0°.035. The off-axis response of the instruments was also measured with this beam. These calibrations were referred to two calibrated channel electron multiplier detectors which are traceable to NBS standard photodiodes. The transfer errors from the NBS standard photodiodes to the instruments was estimated to be $\pm 15\%$. The absolute calibration of the instruments in flight was estimated to be accurate to within $\pm 20\%$.

Prior to the final calibrations, a wavelength-dependent decline in counting efficiency was noted across the detector following each of several spacecraft thermal vacuum tests. For the *Voyager 2* instrument the total change, from initial instrument assembly to final calibration, expressed as a ratio of initial to final sensitivity was 1.05 at 584 Å, 1.24 at 1000 Å, 1.49 at 1164 Å, and 1.96 at 1265 Å. Over the portion of the detector covered by the photocathode this ratio averaged only 1.13. These changes were found to be stable and irreversible during subsequent vacuum testing and calibration at Kitt Peak.

Following launch, stellar observations revealed that the long-wavelength photocathode in each instrument has degraded. Repeated stellar observations have shown this loss of sensitivity to be stable with no evidence of further degradation or change. Due to this change in the long-wavelength response, it was decided to define the absolute calibration in the channels covered by the photocathode to be in agreement with the results of Bohlin *et al.* (1980). This was done for both instruments by establishing a calibration correction spectrum so that *Voyager 1* and *2* observations of η UMa were in agreement with the η UMa absolute fluxes adopted by Bohlin *et al.* for the calibration of *IUE* low-dispersion spectra. Shortward of 1250 Å, both instruments retain their original preflight calibrations.

It is also possible to relate the prelaunch calibration of the UVS instruments to independent absolute flux determinations of astronomical sources at 500 and 1200 Å. Holberg *et al.* (1980) have shown that the *Voyager 2* observations of the extreme-ultraviolet source HZ 43 at 520 Å are in agreement with the 500 Å fluxes of Bowyer (1979) to well within the joint calibration errors. At longer wavelengths, many comparisons are available near 1200 Å where *Voyager, OAO 2*, BMF, and CHO absolute flux determinations are in good agreement. This is also the case for *Voyager* H I Lyα disk observations of Jupiter when compared with *IUE* observations during similar time intervals.

b) *Stability*

The photometric stability of any instrument which has seen over 30,000 hours of nearly continuous operation and experienced the intense radiation environment of Jupiter is a major consideration. With the exception of a well documented decrease in the *Voyager 1* response due to the charged particle radiation environment at Jupiter, no discernible change has occurred in either instrument since launch.

Stellar observations performed early in the *Voyager* mission are available for evaluation of long-term instrument stability. For *Voyager 2* it is possible to compare stellar observations back to 1977 November 6, 78 days after launch, using observations of ε Per. These observations indicate that no change in instrument sensitivity has occurred since that time. *Voyager 2* spectra from the same area of the Cygnus Loop also show no evidence of change in instrumental sensitivity between 1977 November 18 and 1979 December 3. Finally, the UVS dark count rate on *Voyager 2* has remained constant to within 4% between 1978 and 1980. UVS dark counts are principally due to the detector response to radiation from the spacecraft radioisotope thermoelectric generators. This indicates the stability level of both the detectors and the dark count rate.

A well documented and predictable change occurred in the *Voyager 1* instrument sensitivity during the Jupiter encounter. When *Voyager 1* penetrated the inner Jovian magnetosphere, radiation-induced counting rates increased to over 10^5 times the normal interplanetary levels. The net effect of this excessive counting rate was to cause a permanent reduction of 30% in the overall response of the *Voyager 1* UVS. Analysis shows that the change took place in the microchannel plate gain, which through the pulse height distribution translates into a change in the effective counting thresholds of the anodes. The reduction in gain followed the degradation predicted from the microchannel plate life time tests of Sandel, Broadfoot, and Shemansky (1977). Understanding this change allows postencounter spectra to be restored to their preencounter character by applying a unique well-defined correction factor to the counting threshold of each of the detector channels, excluding the Lyα region. Application of the laboratory-determined threshold correction spectrum or "fixed-pattern noise" correction is the initial data reduction step applied to all UVS spectra. A representation of the *Voyager 2* "fixed pattern noise" is given in Broadfoot *et al.* (1981). For postencounter *Voyager 1* data the change to the "fixed pattern noise" correction was determined by comparing pre- and postencounter observations of the unilluminated calibration plate affixed to the spacecraft. In this mode, the calibration plate serves as a dark slide and the UVS registers principally dark counts. Spectra integrated during two $2^{\mathrm{d}}.6$ observations of the calibration plate made before and after encounter provided sufficient counting statistics to specify the radiation-induced change to the "fixed pattern noise" to within 3%. The resulting correction is essentially independent of wavelength, except for channels in the vicinity of Lyα. This method of determining the correction factors is not satisfactory for the Lyα channels due to the presence of a weak residual interplanetary Lyα flux reflected by the calibration plate. Since the interplanetary Lyα background is variable comparisons of calibration plate spectra separated by many months will not yield a true comparison of instrumental response near the Lyα line. It is important to note that this definition of the correction applied to post-Jupiter data is made without reference to stellar spectra and that the original preflight calibration curve shortward of 1250 Å has been retained. The principal effect of this postencounter reduction of instrumental response has been to increase the channel-to-channel statistical variations in the resulting spectra. Pre- and postencounter spectra of the same stars show no evidence of change above the 5% per channel level.

A similar reduction in the *Voyager 2* UVS response was prevented by reducing the microchannel plate high

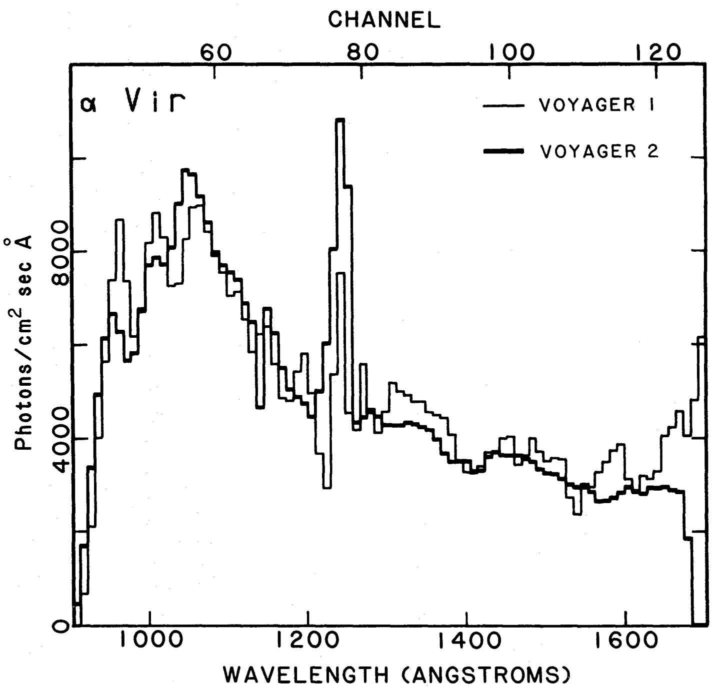

FIG. 1.—A comparison of *Voyager 1* (light line) and *2* (heavy line) observations of α Vir on an absolute scale. Longward of 1250 Å the absolute fluxes have been determined from the absolute calibration of η UMa given by Bohlin *et al.* (1980). Shortward of 1250 Å the original preflight calibrations have been used. The *Voyager 2* spectrum has been synthetically shifted to the left by 2.31 channels so that the wavelength scales and channel edges for both instruments are the same. The feature near 1240 Å in both spectra is an artifact of the edge of the filter-photocathode. These channels are deleted from the remainder of the *Voyager 2* spectra in this paper.

voltage during the critical period of the *Voyager 2* Jupiter encounter. Comparisons of pre- and postencounter calibration plate and stellar observations showed no change in the *Voyager 2* UVS gain following encounter.

An intensive study of the photometric stability of both instruments following the *Voyager 1* experience at Jupiter consisted of the repeated monitoring of several early-type stars at intervals of approximately 1 month. This study showed no drift in the sensitivity over a period of 500 days. The resulting upper limit to any monotonic change in a 185 Å band with an effective wavelength of 1070 Å and a 333.4 Å band with an effective wavelength of 1450 Å was less than 2% per year.

Finally both instruments, with the previously mentioned exception of wavelengths greater than 1250 Å, still maintain their original prelaunch calibration curves. In spite of quite different launch and flight histories, comparisons of the same star when observed by both spacecraft are in good agreement over most of the spectrum. A direct comparison of observation α Vir obtained with *Voyager 1* on 1980 March 25, and *Voyager 2* on 1980 March 5, is shown in Figure 1.

c) *Data Analysis*

The stellar observations reported here were obtained by slowly stepping the UVS FOV across the star in the dispersion direction with 0°.028 steps of the scan platform. The spacecraft data rate was increased so that complete spectra were read out of the UVS memory every 3.84 s. Using spacecraft pointing information, the spectra are placed in spatial bins of 0°.025 width in the dispersion direction. The spectrum from the bin containing the peak counting rate is then differenced with a sky background spectrum from bins well off (0°.5–0°.3) the star. UVS sky background spectra obtained in the outer solar system consist principally of H I Lyα (1216 Å), Lyβ (1026 Å) and He I (584 Å) emission from interplanetary H and He. For the bright stars reported here, the signal from these lines is less than 2% of the stellar signal except in the vicinity of Lyα. Following background subtraction, the spectra are multiplied by the "fixed pattern noise" correction spectrum which provides the equivalent of a flat field correction (Broadfoot *et al.* 1981). An inverse matrix operator is then applied to each spectrum which removes the effects of

TABLE 1

Voyager STELLAR OBSERVATIONS AND ADAPTED MODEL PARAMETERS

Star	BS	Epoch	*Voyager*	MK	$B-V$	m_{5500}	$E(B-V)$	Log g	$T_{\rm eff}$ (K)
ε Ori	1903	1981 Jan 15	2	B0 Ia	−0.18	1.684	0.06	3.0	25,000
σ Ori	1931	1981 Jan 15	2	O9.5 V	−0.24	3.80[b]	0.06	4.0	31,000
{ α Vir	5056	1980 Apr 1	2	B1 IV	−0.23	1.107	0.02	4.0	24,500
{ Companion[a]				B3 V	...	3.107	0.02	4.0	17,000
β Cen	5267	1980 Jan 24	2	B1 III	−0.22	0.59[b]	0.02	4.0	23,100
γ^2 Vel	3207	1980 Feb 7	1	WC8+O9 I[c]	−0.25	1.877	0.04	4.0	32,500
ζ Pup	3165	1980 Feb 7	1	O5f	−0.27	2.219	0.04	4.0	32,500
α Eri	472	1980 Jan 24	2	B3 Vp	−0.15	0.422	0.05	4.0	18,000
ε Per	1220	1980 Jan 30	2	B0.5 III	−0.18	2.84[b]	0.10	4.0	27,600

[a] Companion assumed to be $\Delta M = 2.0$ and B3 V in accordance with Herbison-Evans *et al.* 1971. Combined $m_{5500} = 0.947$.
[b] m_{5500} estimated from V magnitude of Johnson *et al.* 1966 and Hoffleit 1964 in order of preference.
[c] Conti and Smith 1972.

internal instrumental scattering. The use of this matrix operator is discussed by Sandel, Shemansky, and Broadfoot (1979) and Shemansky, Sandel, and Broadfoot (1979). The spectra are then normalized to counts per second and multiplied by the instrumental calibration curve, yielding a final spectrum in absolute units.

III. COMPARISONS WITH OTHER OBSERVATIONS

a) *Carruthers, Heckathorn, and Opal*

UVS observations of ε Ori and σ Ori (Table 1) were obtained with *Voyager 2* in order to directly compare our results with those of CHO. CHO reported the absolute fluxes shortward of 1200 Å for 10 stars in Orion. For ε and σ Ori, fluxes were measured down to 925 Å and 950 Å, respectively.

Most of Orion is normally obscured by the *Voyager* communications antenna. Therefore, a special effort was made to obtain *Voyager 2* observations of these two stars by rolling the spacecraft briefly to another navigation star. This navigation star was selected so that the resulting orientation of our FOV minimized the contribution of background star light from known faint stars. With respect to the plane of the sky, the long dimension of the UVS FOV was orientated nearly north to south and both ε and σ Ori were viewed by scanning the FOV from east to west across the star. The Orion region is relatively crowded with O and B stars and contains areas where diffuse nebulae are illuminated by hot stars. Careful consideration was given to these possible sources of background contamination in our ε and σ Ori spectra. Only one background star brighter than 8th magnitude was present in our FOV during the observations. The σ Ori spectrum is slightly blended with flux from HD 37479 which is located 41″ from σ Ori. Lesh (1968) gives $V = 6.66$ and spectral type B2 Vp for this star. From these data, we estimate that HD 37479 contributes less than 3% of the signal from σ Ori shortward of 1200 Å. No correction for the presence of HD 37479 was applied to our σ Ori data because it is also blended with the CHO data for this star. No other stars within the FOV are expected to contribute measurably to our observed fluxes from σ or ε Ori.

Possible contamination due to nebular emission must also be evaluated. The scans across ε and σ Ori are consistent with both stars being point sources with no evidence of an extended background. Signal levels 0°.15 on both sides of each star are below 3% of the peak signal. Finally, our absolute flux levels for σ Ori between 1250 and 1450 Å agree with those of CHO to within 5%. This argues against any significant effects from either stellar or diffuse background contamination in our data relative to CHO for this star.

The *Voyager 2* and CHO fluxes for ε Ori and σ Ori are shown in Figure 2. In order to facilitate a direct comparison between the two sets of observations, we obtained the CHO fluxes for both stars tabulated at 0.5 Å intervals (Heckathorn, private communication). To cover the wavelength range of interest it was necessary to obtain CHO fluxes from three different exposures. For σ Ori, the 100 s exposure provided the 950–964 Å fluxes while the 30 s exposure was used for the 978–1250 Å fluxes. Fluxes in the 964–978 Å gap were interpolated. For ε Ori we used the 100 s exposure between 925 Å and 955.4 Å, the 30 s exposure between 955.4 Å and 1020.3 Å, and the 10 s exposure between 1025.5 Å and 1250 Å. At 955.4 Å the calibrated spectra from the 100 s exposure were lower than the 30 s exposure fluxes by about 60%. The 100 s exposure data were used without an attempt to normalize them to the 30 s data. These fluxes were then placed in a *Voyager* spectral format in the following manner. An input CHO spectrum was first decalibrated into UVS counts and then multiplied by a scattering matrix which models internal instrumental scattering. This scattering matrix is the inverse of the scattering matrix routinely applied to UVS data for the removal of instrumental scattering.

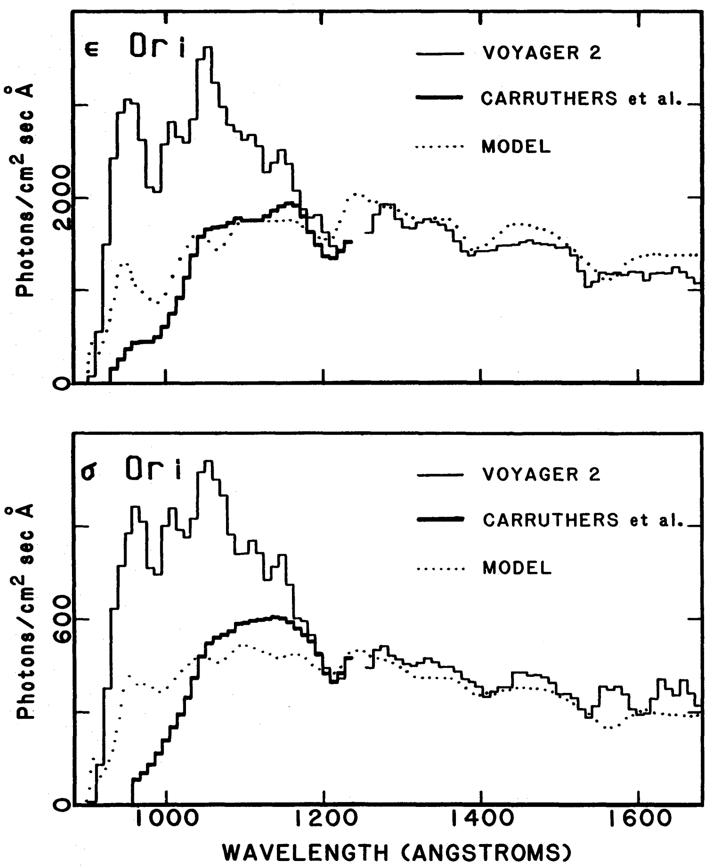

FIG. 2.—A comparison of *Voyager 2* and CHO observations of ε Ori (*above*) and σ Ori (*below*) with model atmosphere fluxes. The CHO fluxes have been placed into a *Voyager* spectral format by the procedure described in § IIIa. Only CHO fluxes obtained between 950 and 1250 Å and between 950 and 1250 Å for ε Ori and σ Ori, respectively, are shown here. Model atmosphere parameters are given in Table 1.

The absolute CHO spectra shown in Figure 2 were then obtained by analyzing the resulting count rate spectra in the same manner as UVS spectra from which a background has been subtracted—that is, by applying previously described operations (see § II*c*). The principal effect of this procedure is to produce a lower resolution version of the CHO spectra. A simple convolution which will produce a similar result is the convolution of two triangular response functions having FWHM of 14.91 and 25.09 Å. The CHO fluxes longward of 1250 Å have not been included in this analysis because there is no significant disagreement for this region between *Voyager*, CHO, and the model fluxes. Figure 2 shows that the *Voyager* fluxes are consistently above the CHO (and model) fluxes shortward of 1150 Å. At 1050 Å the CHO results begin to fall below the model predictions.

Figure 3 shows the results of forming ratio spectra for ε Ori and σ Ori. These ratio spectra were produced by dividing the observed *Voyager 2* count rate spectra by the synthetic CHO count rate spectra, where the synthetic CHO count rate spectra were formed in the manner discussed above. These ratio spectra graphically illustrate the differences between the *Voyager* and CHO results. In light of these differences it is noteworthy that the ratios for the two stars match quite well down to 985 Å, giving confidence in the self-consistency of both sets of data. The differences in the ratios for both stars below 985 Å are primarily due to our use of the fluxes from the ε Ori 100 s CHO exposure below 955 Å. We show later that the large ratio below 1000 Å cannot be due to an overestimation of the stellar flux by *Voyager*. The strong wavelength dependence of the ratio spectrum may in some manner be related to the large differences between the shapes of the sensitivity curves of the *Voyager* and CHO instruments. The *Voyager* sensitivity moderately increases toward the shorter wavelengths reaching a plateau at about 950 Å (Broadfoot *et al.* 1981) while, the CHO instrumental sensitivity peaks near 1050 Å and then begins a steep decline near 1010 Å.

b) *Brune, Mount, and Feldman*

All five of the hot stars (γ^2 Vel, ζ Pup, α Eri, β Cen and α Vir) observed by BMF have been observed by

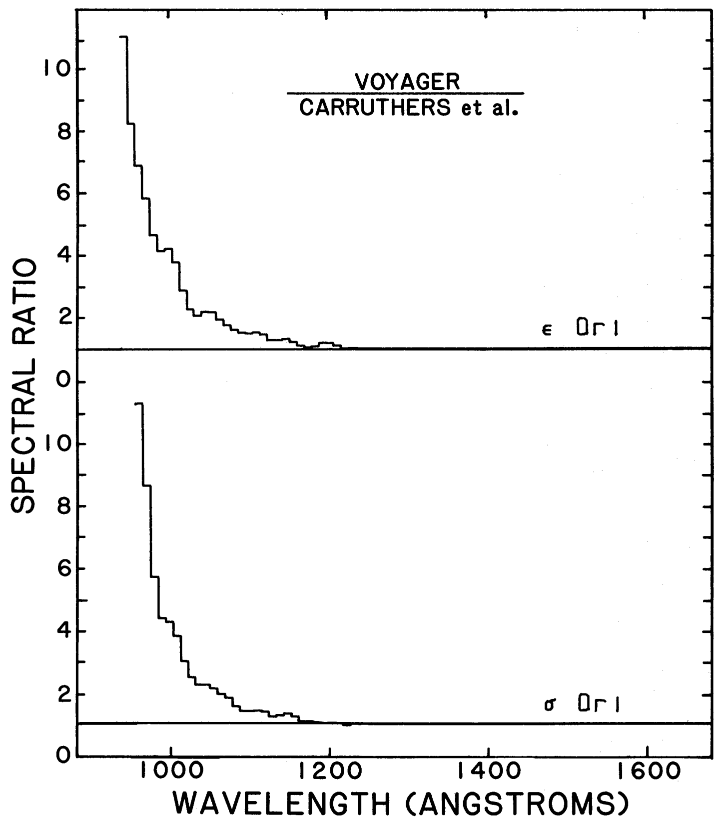

FIG. 3.—The ratio spectra of *Voyager* to CHO for ε Ori (*above*) and σ Ori (*below*). These ratio spectra represent a channel-by-channel division of the *Voyager 2* count rate spectra by the synthetic CHO count rate spectra for the respective stars. No ratio data were calculated longward of 1250 Å.

both *Voyager* instruments (Table 1). Multiple observations of the stars α Eri, β Cen and α Vir were made over a 16-month period. Because of obscuration, it was necessary to roll the spacecraft to view γ^2 Vel and ζ Pup; consequently only a single observation by each spacecraft was obtained for these stars. Figures 4, 5, and 6 show the results of a direct comparison of the absolute fluxes of BMF with those from *Voyager*. The absolute BMF fluxes shown in these three figures were formed by the same spectral synthesis procedure used with the CHO data. Here the input spectra were the 10 Å absolute fluxes tabulated by BMF. The resulting versions of the BMF spectra are at a somewhat lower spectral resolution than actual *Voyager* data, a consequence of using fluxes tabulated every 10 Å and the synthesis procedure. The BMF spectra shown in Figures 4, 5, and 6 are virtually identical to the smoothed versions of the original data published by BMF.

It is revealing to form ratio spectra of the *Voyager* and BMF data for each star shown in Figures 4, 5, and 6. Figure 7 shows ratio spectra for all five stars formed by dividing each *Voyager* spectrum by the corresponding BMF spectrum. This was done using count rate spectra in the same manner as with the CHO data. The large systematic variations among the spectral ratios of the stars in Figure 7 are far outside the bounds of those that can be expected in the *Voyager* data. Multiple observations of the same stars have established the reproducibility of *Voyager* spectra to be better than 15% in terms of channel-to-channel variations. In addition, variations tend to be isolated, showing no systematic trend with wavelength. The one exception to this statement might be the binary γ^2 Vel (O9 I+WC8) which exhibits previously observed variations in the far-ultraviolet (Willis and Wilson 1976). The orbital phases of the γ^2 Vel system at the time of the *Voyager* and BMF observations were 0.60 and 0.75, respectively.

Neither the character of the spectral ratios, nor the large variations among the spectral ratios of the five stars, can be explained in terms of the *Voyager* instruments or our data processing procedures. To explain the factor of 2 variation among the spectral ratios would seem to require a gross nonlinearity in the response of the UVS to different spectral distributions. Five years of accumulated experience with these instruments has revealed no such effect.

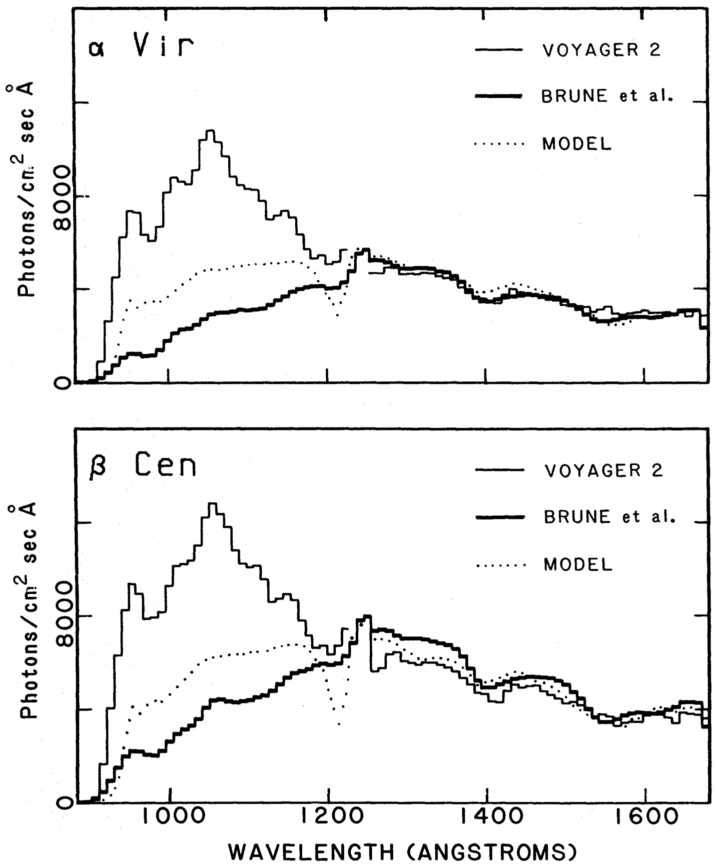

FIG. 4.—A comparison of *Voyager 2* and BMF observations of α Vir (*above*) and β Cen (*below*) with model atmosphere fluxes. The BMF fluxes have been placed into a *Voyager* spectral format as described in the text. Model parameters are given in Table 1.

The large differences in spectral ratios argue against the internal consistency of the BMF data. The spectral ratios for the stars in Figure 7 have been plotted in ascending order in the sequence in which they were observed during the BMF rocket flight. There is an apparent systematic trend toward increasing spectral ratio with increasing time into the flight. This, together with the fact that the BMF instrument was found on recovery to have essentially retained its preflight calibration, points in the direction of an environmental effect during the flight. Water vapor absorption, which was corrected for by BMF, may account for some of the discrepancies between the two sets of observations.

c) *Troy, Johnson, Young, and Holmes*

In light of the especially strong disagreement of the CHO and BMF observations with those of *Voyager*, below 1050 Å it is useful to determine how these experiments compare with the results of Troy *et al.* (1975) in this region. Troy *et al.* used two similar channel electron multiplier detectors with indium filters on a rocket flight to obtain absolute broad-band (912–1075 Å) fluxes for eight stars. *Voyager 1* and *2* have observed three of these eight stars (ε Per, γ Cas, and λ Ori). Troy *et al.* quote mean photon fluxes for these stars which are somewhat higher than model atmosphere fluxes but are in reasonable agreement with *Voyager* results. The relation of the *Voyager 2* spectrum, the Troy *et al.* flux, and a model atmosphere prediction is shown in Figure 8 for ε Per. A more quantitative comparison of the *Voyager* and Troy *et al.* results is achieved by convolving the observed *Voyager* fluxes and the published photometer sensitivity curve of Troy *et al.* When this is done, the effective wavelength of the photometer bandpass is found to be ~980 Å for each star rather than the 950 Å quoted by Troy *et al.* who implicitly assumed a flat spectrum. Identification of the photometer used to observe each star and the photometer sensitivity curve for each instrument were provided by Troy (private communication). From this information an estimate was made of the expected mean photon fluxes from the photometers based on the observed *Voyager* spectra for each star. These expected fluxes based on the *Voyager* preflight calibrations, are 15%, 24%, and 13% less than the published fluxes of Troy *et al.* for ε Per, γ Cas, and λ Ori,

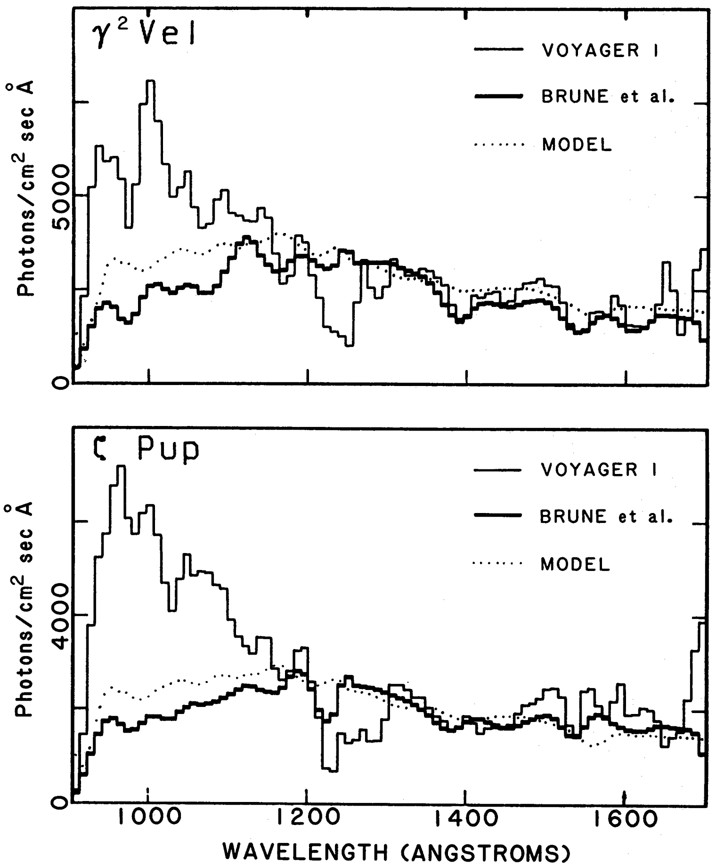

FIG. 5.—A comparison of *Voyager 1* and BMF observations for γ^2 Vel (*above*) and ζ Pup (*below*) with model atmosphere fluxes. The low *Voyager 1* fluxes between 1210 and 1300 Å result from the retention of the preflight "fixed pattern noise" correction for these channels and reflect the loss of sensitivity suffered by *Voyager 1* at Jupiter. Model parameters are given in Table 1.

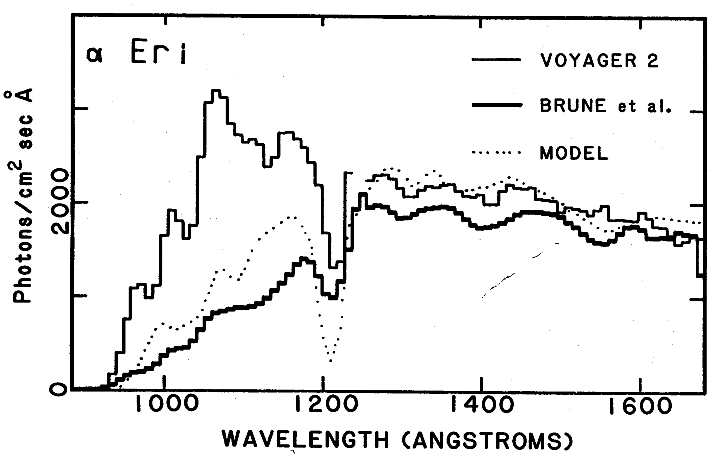

FIG. 6.—A comparison of *Voyager 2* and BMF observations of α Eri with model atmosphere fluxes. Model parameters are given in Table 1.

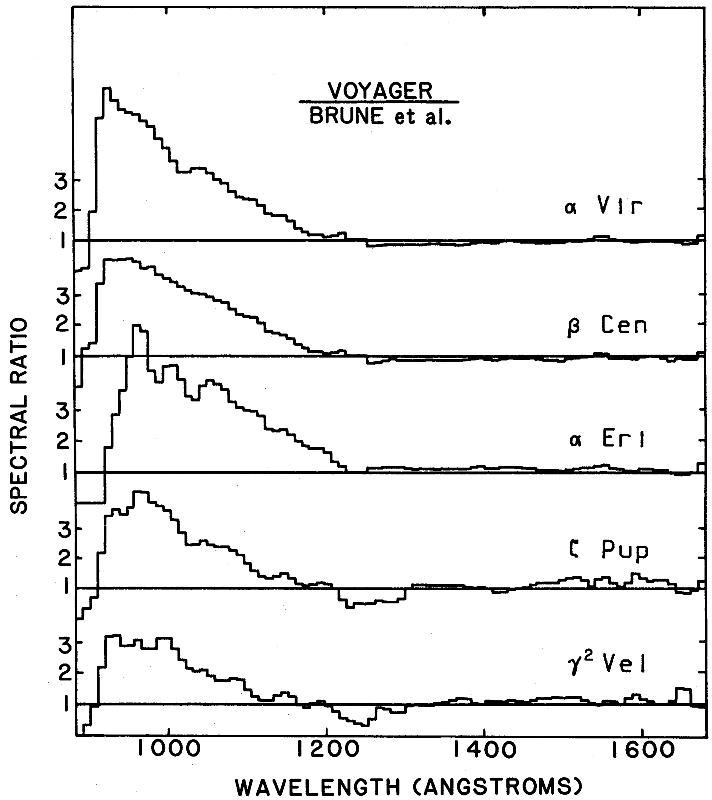

FIG. 7.—The ratio spectra of *Voyager* to BMF for all five of the BMF stars. The ratio spectra represent a channel-by-channel division of the *Voyager 1* and *2* count spectra by the BMF count rate spectra for each star. The ascending order of the stars shown here indicates the order of observation during the BMF rocket flight. The large differences among the stars, particularly shortward of 1100 Å, cannot be explained in terms of any known *Voyager* instrumental effect or data handling procedure.

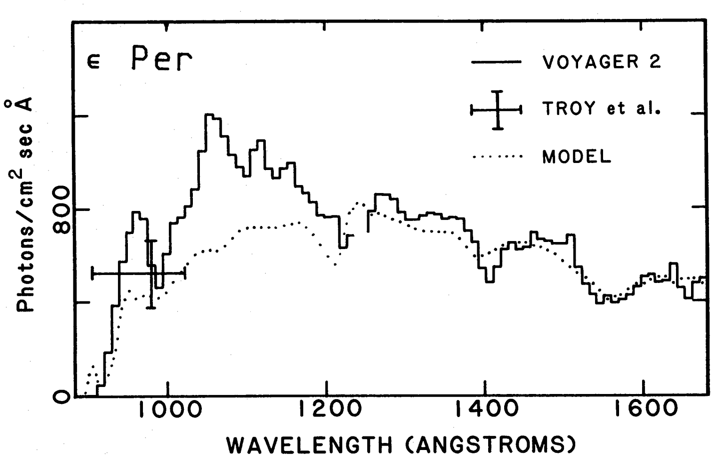

FIG. 8.—A comparison of *Voyager 2* and Troy *et al.* (1975) observations of ε Per with model atmosphere fluxes. The error bars represent the effective bandpass and quoted uncertainty of the Troy *et al.* results. Similar results were obtained in a comparison of *Voyager* and Troy *et al.* results for γ Cas and λ Ori. Model atmosphere parameters are given in Table 1.

respectively. The Troy *et al.* broad band fluxes thus represent effective 980 Å fluxes ~20% higher than the *Voyager* observations of the same stars based on our preflight calibration. In the case of λ Ori, it was necessary to correct the flux estimate for the contribution of ϕ^1 Ori which was blended with λ Ori in the Troy *et al.* data. The relative contribution from ϕ^1 Ori was estimated to be 24% of the signal using a model atmosphere.

IV. COMPARISONS WITH MODEL ATMOSPHERES

a) *Solar Composition Models*

The *Voyager*, CHO, and BMF observations have been compared with the LTE solar composition models of Kurucz (1979). The surface gravity used was $\log g = 4.0$ for all stars except ε Ori where $\log g = 3.0$ was used. The model fluxes for α Eri, ε Ori, α Vir, γ^2 Vel, and ζ Pup were normalized to the 5500 Å monochromatic magnitudes given in Code *et al.* (1976) using the absolute calibration of Tüg, White, and Lockwood (1977) for α Lyr. For the remaining stars, ε Per, β Cen, and σ Ori, 5500 Å monochromatic fluxes were estimated from their V magnitudes. The relevant observational data and model parameters used for each star are given in Table 1. The MK spectral types for Table 1 are taken from Lesh (1968) or Hiltner, Garrison, and Schild (1969) and the $B-V$ colors from Johnson *et al.* (1966) or Hoffleit (1964) in order of preference. In the case of α Vir we have accounted for the presence of the companion by modeling it at 17,000 K and 2 mag fainter in the visible in accordance with the results of Herbison-Evans *et al.* (1971).

The model atmosphere fluxes have been reddened using the average extinction curve of Savage and Mathis (1979). Below 1000 Å, values of extinction have been estimated by extrapolation from the Savage and Mathis curve such that at the Lyman limit (912 Å) we define $A_\lambda/E(B-V)$ to be 16.25.

The primary constraint on the effective temperatures of the models was agreement with observed fluxes longward of Lyα. The temperatures we obtain (Table 1) are thus not a great deal different from those found by BMF and CHO or by Code *et al.* (1976). Of the five BMF stars, only our α Eri long-wavelength fluxes ($\lambda >$ 1200 Å) show a significant difference with the BMF results. BMF noted that their α Eri fluxes in the 1200–1650 Å region were 12% lower than those of Henry *et al.* (1975) and suggested that variability might account for such a difference. We find our results in this region are in excellent agreement with those of Henry *et al.* We have examined 10 *Voyager 1* and *2* observations of α Eri in this wavelength region and find little evidence of any such variability over a six month period.

b) *Pure Hydrogen White Dwarf Models*

In spite of the fact that they are more than 10 mag fainter than commonly observed calibration stars, several characteristics of hot DA white dwarfs such as HZ 43 give them obvious potential as stellar standards in the far-ultraviolet. The most important property is their nearly pure hydrogen atmospheres. Except for H I Balmer and Lyman series lines, or (as in the case of HZ 43) the presence of a cooler companion (Margon *et al.* 1976), most of their spectrum is devoid of photospheric absorption lines. This relatively featureless continuum clearly diminishes the importance of such issues as instrumental spectral resolution, wavelength scale, and the definition of continuum levels in flux measurements. In addition, pure hydrogen atmospheres are also those which can be modeled with the most confidence. For the high temperatures and large surface gravities that characterize white dwarfs such as HZ 43, the model fluxes are nearly independent of surface gravity (Auer and Shipman 1977). Auer and Shipman have also used the absence of the He II λ4686 line to place an upper limit on the helium abundance in the atmosphere of HZ 43; they find $N_{\rm He}/N_{\rm H} < 10^{-3}$. The presence of such small amounts of helium or the introduction of a layered photosphere with higher helium abundances produces only small changes in far-ultraviolet continuum levels as can be seen in the results of Heise and Huizenga (1980). So far observations of hot white dwarfs have been used only as a check on the *IUE* calibration (Bohlin *et al.* 1980). The primary uncertainty is the temperature scale, which for high-temperature objects is poorly determined from ground-based observations alone.

Holberg *et al.* (1980) compared results from a pure hydrogen unblanketed 55,000 K model atmosphere to *Voyager 2*, *IUE*, and *ANS* far-ultraviolet observations of HZ 43. The model, which was not constrained by any of the far-ultraviolet data, was in excellent agreement with the *IUE* (Greenstein and Oke 1979) and *ANS* (Wesselius and Koester 1978) observations. The *Voyager 2* observations were significantly higher than the model, but a systematic comparison was not attempted since the model did not include the effects of line blanketing from the H I Lyman series. A comparison of these same *Voyager 2* observations with an analogous model including H I line blanketing is shown in Figure 9. The model used was interpolated with respect to temperature from the pure hydrogen, LTE, blanketed models of Wesemael *et al.* (1980). In these models, hydrogen line blanketing due to the Lyman series through Lyδ is taken into account. The model parameters used here are the same as those used by Holberg *et al.* (1980): $T_{\rm eff} = 55{,}000$ K, d (distance) = 62.5 pc, and r (radius) = 0.0146 $R_\odot$. Longward of Lyα, both blanketed and unblanketed models yield virtually identical results; therefore, agreement with *IUE* and *ANS* results remains excellent. In view of the

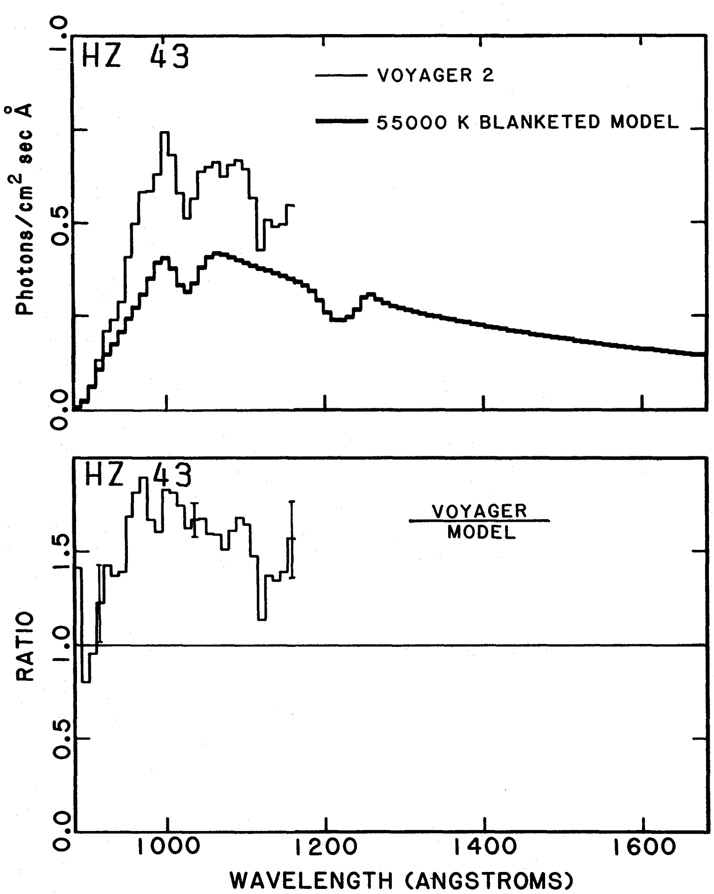

FIG. 9.—A comparison of *Voyager 2* observations (*above*) of the hot white dwarf HZ 43 (Holberg *et al.* 1980) with model atmosphere fluxes. A ratio spectrum formed by a division of the *Voyager 2* results by the model fluxes is shown below. The three error bars in the ratio spectrum represent the level of uncertainty due to counting statistics in the *Voyager 2* HZ 43 spectrum. The model used is a 55,000 K line blanketed pure hydrogen model of Wesemael *et al.* (1980). The temperature is based on the observed extreme ultraviolet fluxes of HZ 43 (Holberg *et al.* 1980). The model fluxes have been placed in a *Voyager* spectral format in a manner similar to the treatment of the CHO and BMF data. Due to low sensitivity no reliable *Voyager 2* fluxes exist for HZ 43 longward of 1160 Å. The spectral ratio is consistent with the CHO calibration between 1160 and 1050 Å.

extremely low interstellar hydrogen density along the line of sight to HZ 43, we have assumed no interstellar reddening.

The model shown in Figure 9 was placed in a *Voyager* spectral format in the manner discussed in § III*a*. The higher *Voyager* fluxes are evident, but the general shape of the spectrum is similar. The ratio spectrum formed by dividing the *Voyager 2* results by the model is also shown in Figure 9. This ratio spectrum is relatively flat at a value of 1.6 between 912 Å to 1160 Å. The slight dropoff at the lowest wavelengths is perhaps due to the fact that no line blanketing beyond Lyδ has been included in the model. Including blanketing beyond Lyδ would tend to decrease model fluxes and hence increase the ratio slightly to flatten it. We conclude that this ratio spectrum is significant and indicates that *Voyager* is overestimating the flux of HZ 43 by approximately 60%.

Observations longward of Lyα indicate that current models adequately predict continuum levels for HZ 43. This is in accordance with the view of Shipman (1979*b*) who finds no known problems with the physics of the pure hydrogen, high-temperature, high-gravity model atmospheres used for predicting continuum fluxes. Our conclusion, however, rests on the validity of these model fluxes in the 912–1200 Å region. Two considerations are important in this regard. The most important is the reliability of the continuum fluxes predicted by the blanketed models in the vicinity of the Lyman series lines. We are not in a position to evaluate this aspect of the models other than to point out the need for more detailed calculations which explore model sensitivity to the theoretical assumptions involved. Such calculations will without doubt provide valuable support for future far-ultraviolet instrumentation whose sensitivity will

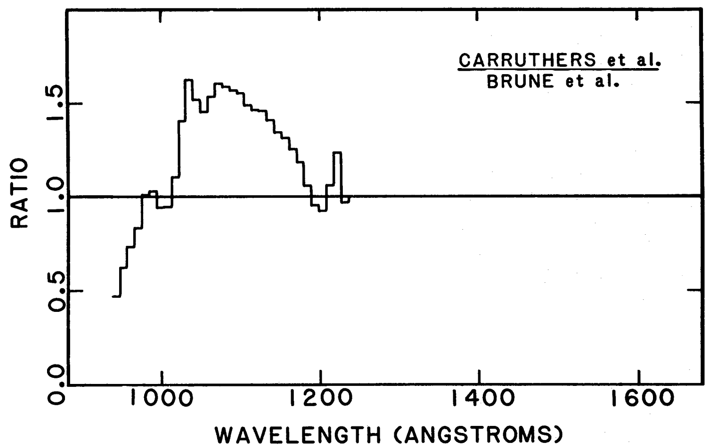

FIG. 10.—Ratio of the absolute CHO to BMF fluxes in the 925–1250 Å wavelength range. In this figure the *Voyager 2* to BMF ratio spectrum for α Vir (Fig. 7) has been divided by the *Voyager 2* to CHO ratio spectrum for ε Ori (Fig. 3). This result can be compared with the similar indirect determination, using *Copernicus* U2 observations, shown in Fig. 12 of CHO. Longward of 970 Å all features as well as the overall magnitude of the spectral ratio shown here are reproduced in the CHO determination. The comparison of the CHO to BMF results implied in this figure is valid only for the particular pair of stars used (ε Ori, and α Vir). As seen in Fig. 7, use of other BMF stars will produce different results.

make white dwarfs such as HZ 43 strong candidates for primary calibration standards. The other consideration which bears on our conclusions is the effective temperature of HZ 43. The value of 55,000 K used here is at the lower end of the 55,000–70,000 K range firmly established by the initial extreme-ultraviolet observations (Auer and Shipman 1977). The range 55,000–60,000 K is most likely based on subsequent extreme-ultraviolet observations (Holberg *et al.* 1980; Bowyer 1979). In this temperature range, the 912–1200 Å fluxes increase with increasing effective temperature at a rate of about 1.5% per 1000 K. Using the 55,000 K model, with its lower fluxes, thus yields an upper limit, with respect to model temperatures, on the amount by which *Voyager* fluxes may be overestimated.

There exists an additional DA white dwarf, G191 B2B, which we can use to strengthen the HZ 43 calibration adjustment. G191 B2B has been observed by both *Voyager* instruments (Holberg, Forrester, and Broadfoot 1981) and is approximately 1.2 mag brighter in the far-ultraviolet than HZ 43 and provides for better counting statistics. We find similar results for G191 B2B between 912 and 1160 Å, that is, a 60% higher flux than the model. Unfortunately the temperature of G191 B2B is not yet as well determined as that of HZ 43, and no other far-ultraviolet observations have been published. This introduces some uncertainty into the model fluxes. We can construct a simple model-based estimate of the difference in the temperatures of HZ 43 and G191 B2B by comparing the observed far-ultraviolet and visual color differences for both stars. Doing this, we find G191 B2B to be ~7000 K hotter than HZ 43. This is in very good agreement with the ground-based estimates of Shipman (1979*a*), which give 61,900 K for the effective temperature of G191 B2B.

V. DISCUSSION

An indirect comparison of the results of CHO with those of BMF is possible by using *Voyager* observations of stars common to both experiments. This was originally done by CHO through the use of *Copernicus* U2 observations of α Vir, ε Ori, and σ Ori. Figure 10 shows the result of dividing the ratio spectrum of α Vir (Fig. 7) by the ratio spectrum of ε Ori (Fig. 3). The ratio in Figure 10 is nearly identical to the results obtained by CHO, although two differences are apparent. Shortward of 970 Å we find the ratio of CHO to BMF to fall sharply below the value of 1.0 found by CHO. This decline is most likely due to the lower fluxes from the 100 s exposure of ε Ori in this region. We also find a wavelength shift of ~14 Å between our results (Fig. 10) and those of CHO, that is, in the same sense as the shift noted by CHO, between their results and those of *OAO 2*. Observationally we can only account for at most a half-channel (~5 Å) uncertainty in our wavelength scale for ε Ori. The agreement of our results (Fig. 10) with those of CHO for this ratio is confirmation that both comparison techniques do yield similar results over most of the wavelength region. The significance of the ratio spectrum which relates CHO to BMF is diminished by the fact that it is valid only for α Vir. Had any of the other BMF observations been used to make the comparison, different results would be found, as reference to Figure 7 shows.

The Troy *et al.* fluxes are found to be in relatively good agreement with the *Voyager* results and in sharp contrast to the much lower fluxes of CHO and BMF in the 912–1075 Å wavelength region. A comparison of the mean fluxes of Troy *et al.* at 980 Å with those of CHO, by means of *Voyager* observations, implies that the Troy *et al.* fluxes are a factor of 6^{+4}_{-1} higher than those of CHO. A similar result for BMF give Troy *et al.* a factor of $4.8^{+3.0}_{-0.8}$ higher than those of BMF.

A compelling argument against the validity of the low fluxes observed by CHO and BMF below 1000 Å is provided by the spectral ratios. In Figure 3 the *Voyager* to CHO ratios rapidly approach 10 or more at the shortest wavelengths. In Figure 7 the *Voyager* to BMF ratios, though not uniform from star to star, peak near a factor of 6 for several stars. The sense of these ratios is such that both *Voyager* instruments would have to be *more* sensitive than previously believed by the amounts of the ratios. It is relatively easy to imagine numerous circumstances which can reduce instrument sensitivity. Increases in sensitivity, however, are more difficult to explain. Gain changes caused by increased detector voltage are ruled out on several grounds. First, engineering data channels which monitor detector voltage have shown no change throughout the flight. Second, the nearly identical results from both instruments together with the strong spectral dependence of the ratios argue strongly against an explanation involving a simple change of gain. In order to explain the results implied by the ratios in Figures 3 and 7 as somehow due to higher than expected *Voyager* sensitivity, it would be necessary for the product of detector quantum efficiency and grating efficiency for both *Voyager* instruments to greatly exceed well established values for the both of these components. Therefore it is impossible to explain away the *Voyager* observations as being due to calibration errors or—even more unlikely—increasing instrumental sensitivity with age.

A similar argument regarding reasonable levels of instrument sensitivity can also be made with respect to the Troy *et al.* photometers. If the stellar fluxes below 1070 Å are as low as implied by the results of CHO and BMF, then both Troy *et al.* photometers would have had to be nearly an order of magnitude more sensitive than reported. Explanations of the larger fluxes of Troy *et al.* involving pinholes in the indium filters are unlikely on the grounds that no discrepancies were reported in observations of the same stars by both photometers. The integrity of the filters is further supported by the fact that Troy *et al.* found no response to stars of spectral type B3 and cooler.

The direct comparison of stellar observations made by *Voyager* with those of other observers can also be used to clarify the current status of absolute flux measurements in the 912–1200 Å region. In doing this, it is convenient to divide this wavelength region into three segments for separate discussion; these are 1150–1200 Å, 1050–1150 Å, and 912–1050 Å.

a) *1150 Å to 1200 Å*

The observational discrepancies are least in this region of the spectrum. At 1200 Å the observed stellar fluxes of *Voyager*, CHO and BMF (with the exception of α Eri) are in mutual agreement to within $\pm 10\%$. To this may be added the results of Henry *et al.* (1975) (α Vir and α Eri) and Bless, Code, and Fairchild (1976) (α Vir and η UMa). Comparison of these observed fluxes with model atmospheres at 1200 Å is also very good. Observational disagreement, however, grows toward shorter wavelengths. CHO find good agreement between their results and the model fluxes throughout this region. In contrast, *Voyager* fluxes become significantly higher than the models, reaching factors of from 1.4 to 1.5 at 1150 Å, while BMF find their fluxes 30% less than the models at 1150 Å. Shortward of 1200 Å we have also compared the results of *Voyager* to those of Bless, Code, and Fairchild (1976) for two stars, α Vir and η UMa. We find that at 1150 Å the *Voyager* fluxes are factors of 1.4 and 1.5 higher, respectively.

b) *1050 Å to 1150 Å*

In this spectral region the discrepancies between *Voyager*, CHO, and BMF are a continuation of the trends established at 1150 Å. The agreement which CHO finds with model predictions is still good. The BMF results are in general lower than the models in this region by 20%–60%. Ratios of *Voyager* and BMF data (Fig. 7) indicate a substantial amount of internal variation in the BMF data. The *Voyager* fluxes in this region are in general factors of 1.5 to 2 higher than the CHO results (Fig. 3) and consequently bear a similar relation to the models. It is also here that results of CHO and BMF diverge most clearly, with the CHO fluxes being a factor of 1.6 to 1.8 higher than those of BMF. Use of the *Voyager* spectra to indirectly compare the ε Ori fluxes of CHO to the α Vir fluxes of BMF (Fig. 10) confirm the findings of CHO with respect to the relative calibrations of both experiments. Finally, the *Voyager 2* observations of HZ 43, in this region, have nearly the same relation to the HZ 43 model as they do to the CHO fluxes. We believe, therefore, that the CHO fluxes in this region are presently the most reliable. To this can be added general agreement between CHO and the broad-band photometry of Carruthers (1969) at 1115 Å for several mutually observed stars. The tendency of the CHO fluxes to begin falling in the vicinity of 1050 Å is disturbing, however.

c) *912 Å to 1050 Å*

In this region the observations are in sharpest disagreement, among themselves and with models. Beginning near 1050 Å, the CHO fluxes become dramatically lower than the models. The BMF results also remain lower with respect to the models though not as much as CHO. *Voyager* fluxes, on the other hand, remain factors of 1.5 to 2.0 above the models. The *Voyager* to CHO (Fig. 3) and *Voyager* to BMF ratios (Fig. 7) indicate very large discrepancies in this wavelength region. If

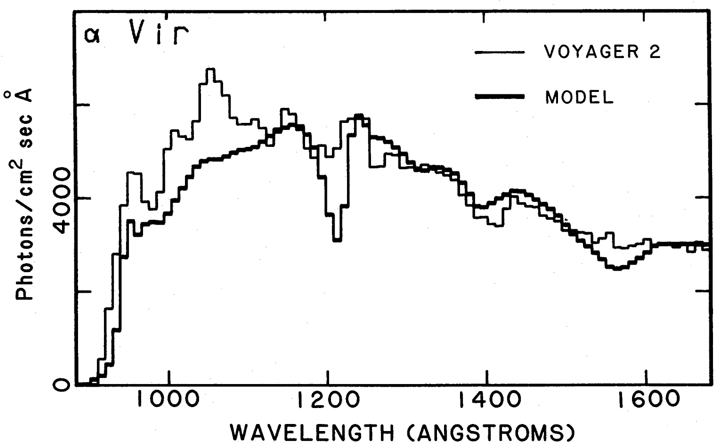

FIG. 11.—A comparison of the revised *Voyager 2* fluxes for α Vir (*light line*) with a model atmosphere for α Vir (*heavy line*) specified by the parameters given in Table 1. From 912 to 1050 Å we have reivsed the *Voyager* fluxes based on our HZ 43 observations. Fluxes in the 1050–1200 Å wavelength range have been revised based on CHO observations of ε Ori and σ Ori. Agreement of observation with the model is within the range expected on the basis of uncertainties in reddening for α Vir.

these ratios are assumed to represent actual *Voyager* overestimates of observed stellar flux, then they imply unrealistically large values of sensitivity for the *Voyager* instruments. For this reason we believe both CHO and BMF are underestimating stellar fluxes at these wavelengths. This is supported by the higher broad-band measurements of Troy *et al.* The *Voyager 2* observations of HZ 43 indicate that the flux is being overestimated by perhaps a factor of only 1.6 rather than the factors of 5 to 10 implied by BMF and CHO. In making their indirect comparison with the absolute fluxes of BMF through the use of the *Copernicus* U2 measurements, CHO found both experiments in agreement at 950 Å. Our analysis does not show this but rather shows the CHO results falling below BMF in this region by a factor of almost 2. The rough agreement between the two experiments near 990 Å is likely to be coincidental, the result of the rapidly falling CHO fluxes at the shortest wavelengths.

In summary, if the CHO fluxes are adopted between 1050 Å and 1200 Å and *Voyager* fluxes are revised downward by a factor of 1.6 between 912 Å and 1050 Å, the *Voyager* observations are in reasonably good agreement with both the model atmosphere predictions of Kurucz (1979) and Wesemael *et al.* (1980). An example of how such fluxes compare with *Voyager 2* observations is shown for α Vir in Figure 11.

The above revision in absolute *Voyager* fluxes shown in Figure 11 represents approximately three times the estimated error in our absolute calibration. We have reviewed the prelaunch calibrations of both spacecraft and find no justification for revising the calibrations of the *Voyager* instruments other than the stellar observations discussed here, nor do we find evidence for an increase in instrumental sensitivity having occurred during flight. The similarity of the results from the two instruments is a strong indication of an unrecognized systematic error. We can at present provide no explanation for such an error.

VI. CONCLUSIONS

Voyager UVS absolute spectrophotometry has been presented for eight early-type stars in the range 912–1200 Å. Using these observations, we have made indirect comparisons between the results of three previous experiments. We have directly compared our observations with the available absolute fluxes reported by the three other groups together with fits of stellar model atmospheres to the data. If the previously mentioned revisions and qualifications are applied to the *Voyager* and other observations discussed here, then we find that current stellar model atmospheres can be considered in reasonable agreement with observations. The present disagreement among existing measurements of absolute flux below 1200 Å is strong enough that a major revision of the models is not justified on the basis of observation alone.

We find, along with others, general agreement between observers at 1200 Å. Shortward of 1200 Å we find that the *Voyager* fluxes become significantly larger than those of CHO or BMF for the same stars. Comparisons of *Voyager* observations of the DA white dwarfs HZ 43 and G191 B2B with the line-blanketed pure hydrogen model atmospheres of Wesemael *et al.* (1980) are used to establish a downward revision in the *Voyager* fluxes. This revision provides good agreement between *Voyager* and CHO down to 1050 Å. We therefore adopt the CHO results at these wavelengths and note their good agreement in general with the model atmospheres of

Kurucz (1979). Our results also, in large part, confirm the nature of the discrepancy which CHO found between their results and those of BMF.

At the shortest wavelengths, 912–1050 Å, we are in strong disagreement with the results of both CHO and BMF, but in reasonably good agreement with the broad-band results of Troy *et al.* At these wavelengths, the dramatically lower fluxes reported by CHO and BMF would require physically improbable levels for the instrumental sensitivity of the *Voyager* UVS. The revised *Voyager* fluxes are therefore adopted in this wavelength region. Satisfactory agreement between models and the observations is found when this is done.

Until a few years ago model atmosphere calculations provided the best estimates of stellar fluxes for wavelengths shorter than 1200 Å. Model atmospheres still remain strong contenders for this role in spite of the recent attempts to measure the absolute flux distributions of some of the brighter hot stars at these wavelengths. All results to date, including the *Voyager* observations presented here, contain major unresolved difficulties. The conclusions concerning absolute fluxes reached here, in particular the acceptance of the CHO results down to 1050 Å and the downward revisions of the *Voyager* fluxes, are in need of independent confirmation. Future attempts at absolute flux measurement in this region of the spectrum are clearly called for. More attention needs to be paid to possible environmental effects associated with rocket flights, including perhaps reobservation of the same star during the flight. Mutual observation of some of the same stars by independent observing groups will make the task of direct comparison of results much easier. Consideration should also be given to extending absolute calibration efforts to include fainter unreddened sources such as some of the brighter pure hydrogen white dwarfs. Over most of the far-ultraviolet the continua of these objects are sufficiently uniform that relatively low spectral resolution should prove satisfactory.

The authors thank the *Voyager* project personnel, in particular R. Pomphrey, at JPL for their assistance in obtaining these observations. We also wish to thank H. Heckathorn and B. Troy for their valuable assistance with mutual flux comparisons. Finally, we wish to acknowledge the useful discussions and comments of B. Sandel. This work was supported by NASA grant NAGW-147 and by the JPL, California Institute of Technology, under NASA contract NAS 7-100.

REFERENCES

Auer, L. H., and Shipman, H. L. 1977, *Ap. J. (Letters)*, **211**, L103.
Bless, R. C., Code, A. D., and Fairchild, E. T. 1976, *Ap. J.*, **203**, 410.
Bohlin, R. C., Holm, A. V., Savage, B. D., Snijders, M. A. J., and Sparks, W. M. 1980, *Astr. Ap.*, **85**, 1.
Bowyer, S. 1979, in *IAU Colloquium 53, White Dwarfs and Variable Degenerate Stars*, ed. H. M. Van Horn and V. Weidemann (Rochester: University of Rochester), p. 66.
Broadfoot, A. L., and Sandel, B. R. 1977, *Appl. Opt.*, **16**, 1533.
Broadfoot, A. L., *et al.* 1977, *Space Sci. Rev.*, **21**, 183.
Broadfoot, A. L., *et al.* 1981, *J. Geophys. Res.*, **86**, 8259.
Brune, W. H., Mount, G. H., and Feldman, P. D. 1979, *Ap. J.*, **227**, 884 (BMF).
Carruthers, G. R. 1969, *Ap. Space Sci.*, **5**, 387.
Carruthers, G. R., Heckathorn, H. M., and Opal, C. B. 1981, *Ap. J.*, **243**, 855 (CHO).
Code, A. D., Davis, J., Bless, R. C., and Hanbury Brown, R. 1976, *Ap. J.*, **203**, 417.
Conti, P. S., and Smith, L. F. 1972, *Ap. J.*, **172**, 623.
Greenstein, J. L., and Oke, J. B. 1979, *Ap. J. (Letters)*, **229**, L141.
Heise, J., and Huizenga, H. 1980, *Astr. Ap.*, **84**, 280.
Henry, R. C., Weinstein, A., Feldman, P. D., Fastie, W. G., and Moos, H. W. 1975, *Ap. J.*, **201**, 613.
Herbison-Evans, D., Hanbury Brown, R., Davis, J., and Allen, L. R. 1971, *M.N.R.A.S.*, **151**, 161.
Hiltner, W. A., Garrison, R. F., and Schild, R. E. 1969, *Ap. J.*, **157**, 313.
Hoffleit, D. 1964, *Catalogue of Bright Stars* (3d ed.; New Haven: Yale University Observatory).
Holberg, J. B., Forrester, W. T., and Broadfoot, A. L. 1981, *Bull. AAS*, **12**, 872.
Holberg, J. B., Sandel, B. R., Forrester, W. T., Broadfoot, A. L., Shipman, H. L., and Barry, D. C. 1980, *Ap. J. (Letters)*, **242**, L119.
Johnson, H. L., Mitchell, R. I., Iriarte, B., and Wiśniewski, W. Z. 1966, *Comm. Lunar Planet. Lab.*, **4**, 99.
Kurucz, R. L. 1979, *Ap. J. Suppl.*, **40**, 1.
Lesh, J. L. 1968, *Ap. J. Suppl.*, **17**, 371.
Margon, B., Liebert, J., Gatewood, G., Lampton, M., Spinrad, H., and Bowyer, S. 1976, *Ap. J.*, **209**, 525.
Sandel, B. R., Broadfoot, A. L., and Shemansky, D. E. 1977, *Appl. Opt.*, **16**, 1435.
Sandel, B. R., Shemansky, D. E., and Broadfoot, A. L. 1979, *Ap. J.*, **227**, 808.
Savage, B. D., and Mathis, J. S., 1979, *Ann. Rev. Astr. Ap.*, **17**, 73.
Shemansky, D. E., Sandel, B. R., and Broadfoot, A. L. 1979, *J. Geophys. Res.*, **84**, 139.
Shipman, H. L. 1979*a*, *Ap. J.*, **228**, 240.
______. 1979*b*, in *IAU Colloquium 53, White Dwarfs and Variable Degenerate Stars*, ed. H. M. Van Horn and V. Weidemann (Rochester: University of Rochester), p. 86.
Timothy, J. G., and Bybee, R. L. 1975, *Appl. Opt.*, **14**, 1632.
Troy, B. E., Johnson, C. Y., Young, J. M., and Holmes, J. C. 1975, *Ap. J.*, **195**, 643.
Tüg, H., White, N. M., and Lockwood, G. W. 1977, *Astr. Ap.*, **61**, 679.
Wesemael, F., Auer, L. H., Van Horn, H. M., and Savedoff, M. P. 1980, *Ap. J. Suppl.*, **43**, 159.
Wesselius, P. R., and Koester, D. 1978, *Astr. Ap.*, **70**, 745.
Willis, A. J., and Wilson, R. 1976, *Astr. Ap.*, **47**, 429.

D. C. Barry: Department of Astronomy, University of Southern California, Los Angeles, CA 90007

W. T. Forrester, J. B. Holberg, and D. E. Shemansky: Earth and Space Sciences Institute, University of Southern California, Tucson Laboratories, 3625 East Ajo Way, Tucson, AZ 85713