THE STATUS OF THE ABSOLUTE CALIBRATION OF STELLAR FLUXES BETWEEN 912 AND 1200 Å

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ABSTRACT. Recent results have shed new light on the status of the calibration of absolute stellar fluxes between 912 and 1200 Å. Observations of hot white dwarfs, subdwarfs and planetary nebula nuclei with the *Voyager* ultraviolet spectrometers provide evidence that the current calibration agrees very well with extrapolations of IUE energy distributions shortwards of 1200 Å. *Voyager* observations of main sequence B-stars used as flux calibration sources have revealed that many are variable in brightness in the 912 - 1200 Å region. We conclude there is no current observational motivation for any revision of the 912 to 1200 Å calibration described by Holberg *et al*. (1982).

1. INTRODUCTION

The calibration used to determine absolute fluxes for the *Voyager 1* and *2* ultraviolet spectrometers (UVS) have been discussed by Holberg *et al*. (1982). At that time the status of absolute stellar fluxes in the spectral region between 912 and 1200 Å was in some doubt. The discrepancies were clear. The *Voyager* results were in overall disagreement with those of Brune, Mount, and Feldman (1979) and in partial disagreement with those of Carruthers, Heckathorn, and Opal (1981) (CHO). The latter two experiments, although in mutual disagreement, both indicated that the fluxes predicted by model atmospheres were substantially in excess of observation. A major conclusion of Holberg et al. was that model predictions appeared to adequately represent observations and were not in need of substantial revision. Recently, two new developments have occurred which clarify the situation regarding absolute fluxes in the 912 and 1050 Å region. Two new calibration flight results have been reported and an analysis of a much wider range of *Voyager* stellar observations has revealed wide spread photometric variability in B-stars in the far UV.

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2. NEW CALIBRATION RESULTS

Carruthers and Heckathorn (1982) have reported preliminary results from a reflight of the CHO instrumentation, employing osmium coated optics. They find the observed flux distributions of early type stars to be in closer agreement with the Kurucz (1979) model atmospheres than the results from the initial flight which employed LiF coated optics. Until actual calibrated fluxes are available for the new Carruthers and Heckathorn observations, the precise relation of these results to the Voyager observations remains unclear. But it would appear that the major discrepancy between Voyager and CHO in the 912 - 1050 Å region may have abated. In an independent experiment Opal and Weller (1984) report agreement between Voyager 2 and their extreme-ultraviolet photometer on board the STP 72-1 satellite. This single channel photometer measures stellar flux in an effective band pass covering the 912 - 1050 Å region. These authors report that absolute Voyager 2 fluxes from three isolated bright stars (α Vir, η UMa and ε Per) when convolved with the preflight (absolute) response curve of the photometer yield excellent agreement with the observed count rate signal from these stars.

3. B-STAR VARIABILITY

Since the publication of Holberg et al. (1982) the Voyager data base has been greatly expanded. One aspect of this program has been to make repeated high signal-to-noise observations of standard B-stars in order to refine the far-UV flux calibration. Analysis of these data has indicated that, in general, the observed 912 - 1200 Å flux distributions are in good agreement with predictions from model atmospheres (see Peters and Polidan 1985). However, the majority of these "standard" stars were found to be variable in their FUV flux level and distribution.

The largest variations have been observed in the B0.5 III star ε Per. Seven observations of ε Per obtained over three years show a 40% change in flux. Analysis of the FUV flux distribution also indicates a change in the shape of the distribution during this time. Comparison with Kurucz (1979) model atmospheres implies a change in T_{eff} of 1500 ± 500 K from maximum to minimum flux. Thus, the observed variability may be associated with changes in the effective temperature of the star. The majority of B-stars observed with Voyager exhibit similar variability, though with lower amplitude (typically ~10 - 20%). A few stars, notably α Vir, are observed to be effectively constant (Δflux $\lesssim$ 5%).

The source of this variability in B-stars appears to be 53 Persei type non-radial pulsations. In a joint program with Dr. M. Smith of the National Solar Observatory we are monitoring a sample of B-stars for FUV photometric variability and visual photospheric line profile changes. Preliminary results indicate that all the stars for which we find UV-flux variability do show non-radial pulsations. These stars are, in general, not known to be light variables in the visual region. This can be reconciled with the observed FUV variability through the realization that small changes in effective temperature will produce larger changes in the FUV, where most of the stellar flux is emitted, than in the visual region. A better understanding of the nature of B-star variability in the FUV waits further data. We can clearly state, however, the B-stars are unsuitable as photometric calibration sources in the FUV.

4. SUB-LUMINOUS STARS

The expanded Voyager stellar program has also included observations of sub-luminous stars: white dwarfs, subdwarfs, and planetary nebula nuclei. These objects offer numerous advantages over B-stars as FUV calibration sources. First, from our limited set of observations, they are constant in brightness. Second, their flux distributions, in general, have less line blocking and are frequently simpler (e.g. power law) than those of B-stars. They also offer an important third advantage. Some are known to be EUV sources (e.g. HZ 43) and, hence, will allow accurate calibration of stellar sources at wavelengths shorter than 912 Å.

Examples of these objects can be found in Figures 1 through 3. The hot (T_{eff} ~80,000 K) sdO star BD+28°4211 is presented in Figure 1. It exhibits a power law spectrum from 950 to 8000 Å. The nucleus of the planetary nebula NGC 246 (T_{eff} ~100,000 K) (Figure 2) also exhibits a power law spectrum. The nearby DA white dwarf CoD-38° 10980 (T_{eff}= 24,750 ± 250 K) is compared with pure hydrogen models of Wesemael et al. (1980) in Figure 3. In this case the flux distribution is not a power law but can be adequately fit with the pure hydrogen model atmosphere.

It is apparent from Figures 1 and 2 that Voyager fluxes shortward of 1200 Å fall along the same power laws which characterize the energy distributions longward of 1200 Å. To the extent that it is reasonable to extrapolate such power laws down to the Lyman limit, Voyager results can be considered to be in satisfactory agreement with accepted absolute calibrations. It is important to note that this conclusion is independent of any reliance on model atmosphere predictions. It is also stressed that various independent data sets in Figures 1 and 2 have not been forced into agreement or corrected in any non-standard manner. For example, no reddening corrections are applied to either BD+28°4211 or NGC 246, since estimates of the extinction for both objects are generally very low.

5. CONCLUSIONS

Our principal conclusion is that the results of Holberg et al. (1982) adequately represent the existing data and no change in the FUV calibration is warranted at this time. We propose that future experiments abandon B-stars as their principal calibration sources because of their observed FUV flux variability and adopt sub-luminous stars (white dwarfs, subdwarfs, and planetary nebula nuclei). These latter stars offer numerous advantages over B-stars, particularly in their constancy of flux, simple energy distributions, and chance for observable EUV emission.

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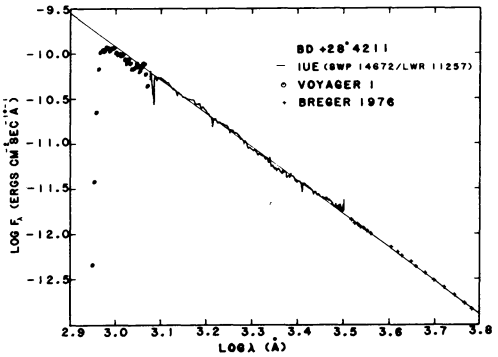

Fig. 1. The unadjusted absolute fluxes observed for the hot O subdwarf BD +28°4211. The straight line represents a least squares fit to the IUE and ground based data (excluding Voyager).

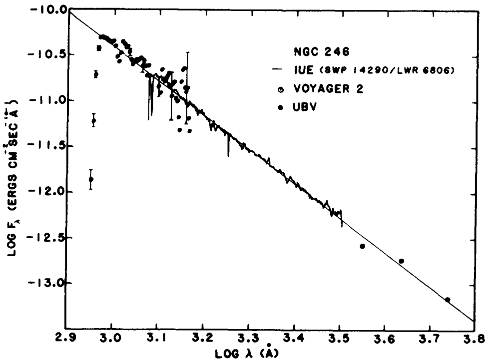

Fig. 2. The unadjusted absolute fluxes observed for the central star of the planetary nebula NGC 246. The error bars associated with the Voyager data are representative of counting statistics at various wavelengths. The straight line was computed in Fig. 1.

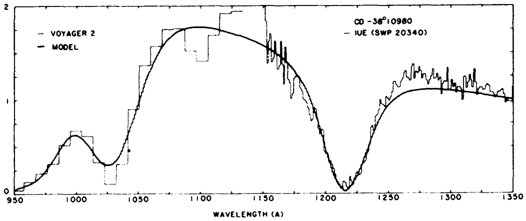

Fig. 3. The observed Voyager 2 and IUE fluxes for the nearby white dwarf CoD -38°10980. The model shown here employs an effective temperature of 24,500 K and a surface gravity of log g = 8.0.

DISCUSSION

JASCHEK: Is a 5% variation in UV flux not a little bit large for non-radial pulsation?

POLIDAN: Remember that we are observing near the maximum of the flux distribution of these stars. Small changes in visual flux translate to large changes in the far UV. As an example, consider the radial pulsator BW Vul. It has an observed change in V mag. of 0.15 mag. while at 1000 Å the amplitude of the variation is 1.2 mag. (Barry et al. 1984 Astrophys. J., in press). The limit of <5% variation for Alpha Vir implies a temperature variation of less than 500 K.