THE ROLE OF SPACE OBSERVATIONS IN THE CALIBRATION OF FUNDAMENTAL STELLAR QUANTITIES

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ABSTRACT. This paper summarizes the current status of ultraviolet spectrophotometry with emphasis on the instrumental characteristics unique to space observations and on the application of existing data to the calibration of stellar properties. The currently available data bases will be briefly reviewed. When combined with ground based data, ultraviolet observations provide information on effective temperatures and bolometric corrections for early type stars and on the nature of the intervening interstellar medium. The ultraviolet measurements are sensitive to chemical composition differences and provide a powerful tool in discussion of stellar evolution in composite systems. This review concludes with a brief discussion of future directions in instrumentation and analysis.

1. INTRODUCTION

The traditional advantages of carrying out astronomical observations from space are associated with the absence of significant terrestrial atmospheric effects. Thus the sky is darker, the entire electromagnetic spectrum is observable and the "seeing" is always excellent. In particular the ability to extend observations to the X-ray, ultraviolet and the far infra-red have led to many new and exciting advances. The high energy region of the spectrum provides data on the final stages of stellar evolution and on the interaction of close binary systems, while infra-red observations enable astronomers to penetrate the dense clouds surrounding stellar systems in the process of forming. In this review, however, attention will be primarily directed to a discussion of stellar measurements of the ultraviolet flux. Ultraviolet spectrophotometry is simply an extension of classical stellar astronomy to shorter wavelengths. As such, the techniques and applications are in general similar to those of ground based observations. There are, however, certain characteristics of the instrumentation and of the data which are unique to this spectral region. In the following section we shall describe the current problems relating to photometric calibration.

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2. PHOTOMETRIC CALIBRATION

The bulk of the radiation from early-type stars is emitted at wavelengths shorter than 3300 Å in the vacuum ultraviolet, observable only from above the terrestrial atmosphere. The fraction of the flux radiated in the visual and ultraviolet regions of the spectrum of normal stars as a function of effective temperature is illustrated in Figure 1. For temperatures above 13000 °K most of the flux is radiated at wavelengths shortward of 3300 Å, while above about 42000 °K the major fraction of the flux is in the Lyman continuum shortward of 912 Å. Clearly any comprehensive discussion of the properties of stars of spectral types O8 through B8 must include data on the flux distribution in the vacuum ultraviolet. Main sequence and giant stars in this spectral interval represent the youngest population in a stellar system. The main sequence age is indicated by the dashed curve and the right hand scale on Figure 1. Any main sequence star with more than 50% of the flux in the ultraviolet has a life-time less than one galactic rotation. On the other hand many highly evolved stars such as sdO stars, WDA precursors, and planetary nuclei are characterized by temperatures in excess of 40000 °K. For these objects we cannot expect to measure the total flux distribution since the interstellar hydrogen is opaque near 912 Å for even the closest stars. We can, however, derive important information on their structure by extending the observation to the Lyman limit. Moreover, many of these objects are close enough and hot enough that observation in the extreme ultraviolet, (EUV), can be made. Observations of these high surface gravity hot stars have recently played a role in the calibration of ultraviolet fluxes.

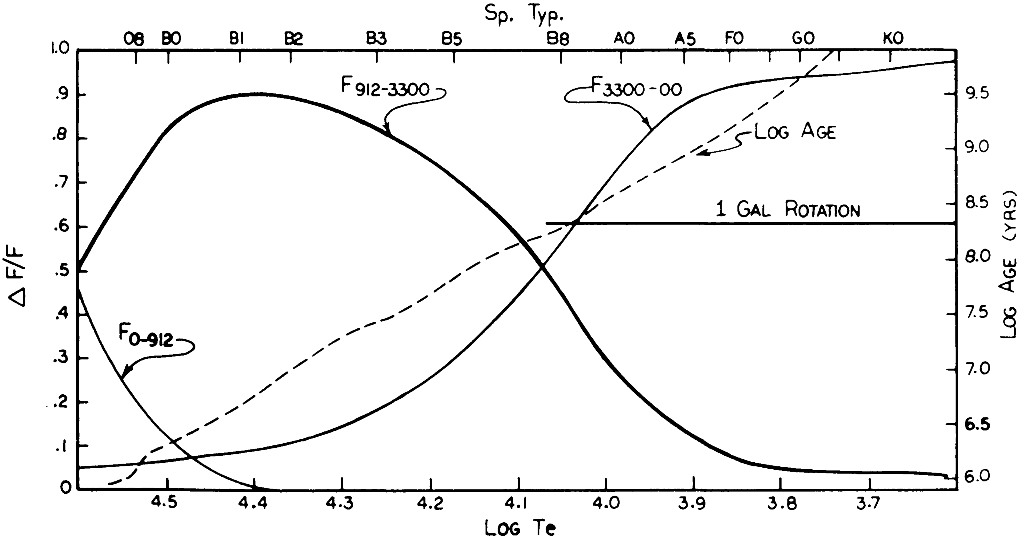

Fig. 1. Fractional flux vs effective temperature in the wavelength intervals 0-912 Å, 912-3300 Å and 3300-∞. Dashed curve and right hand scale is the logarithm of main sequence life-time.

The absolute energy calibration in the ultraviolet presents several unique problems. Most standard sources (and all thermal sources) have exceedingly little energy in the ultraviolet and a great deal at longer wavelengths, making scattered light a very difficult problem. Moreover all measurements must be carried out in a vacuum environment. This presents no problem in principle but is time consuming and complicates the procedures. Suitable transmission optics are limited and reflectivities are generally poorer in the ultraviolet. The fundamental absolute calibration efforts in the optical and infra-red have been based upon blackbody sources. For practical temperatures, thermal radiation is not suitable, however, in the UV. For example, a tungsten ribbon filament lamp operated at 2850 °K drops by 20 magnitudes between 5500 Å and 1500 Å.

In general calibration of flight instruments have been carried out using black receivers or calibrated detectors. Synchrotron radiation provides an ideal fundamental source for calibration of these secondary standards. Several synchrotron storage rings are now available as radiation sources. For calibration purposes, only a very small beam current is required to provide radiation of the desired intensity and spectral distribution. In calibrations carried out at the University of Wisconsin, it was found practical to operate at currents corresponding to approximately 100 electrons with energies of 240 Mev. The total number of electrons could then be counted. It is possible to measure the radiation from a single electron. Thus by allowing the beam to decay, it is possible to count the electrons one by one as they are "kicked" out of the beam. From these data and the theory of synchrotron

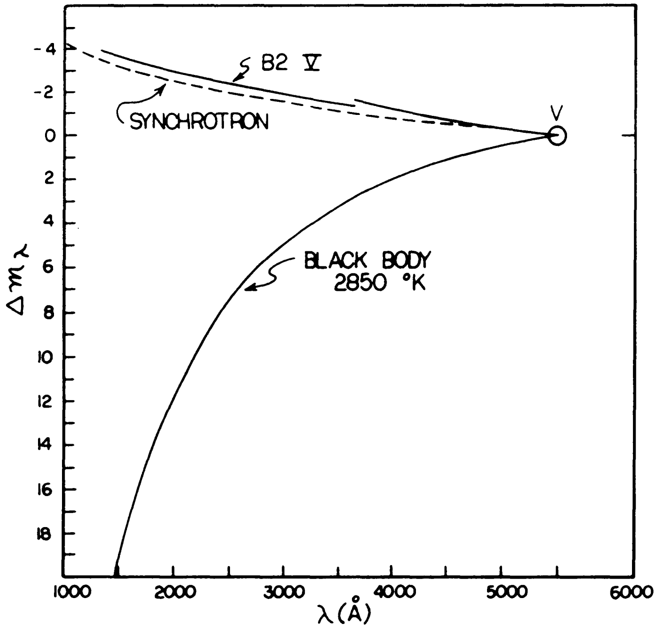

Fig. 2. Spectral distribution of a B2 V star, 240 Mev. synchrotron radiation and a 2850 °K black-body.

radiation the number of ergs per second per unit wavelength interval intercepted by the detector is easily determined. The synchrotron radiation from such storage rings has spectral distribution similar to a B5 star. Figure 2 shows the spectral distribution between 1000 Å and 5500 Å for a black body at 2850 °K, a 240 Mev synchrotron spectrum and the spectrum of a B2 V star. The flux is given in magnitudes per unit wavelength interval normalized to the V magnitude. The advantage of synchrotron radiation as a fundamental standard is obvious. Currently most calibration efforts are carried out by using photodiodes that are referenced to synchrotron calibrations carried out in the US by the National Bureau of Standards (Canfield, Johnston and Madden 1973). Despite the availability of these standard diodes the absolute energy calibration, particularly shortward of about 2000 Å, is a difficult process.

Most precision ultraviolet spectrophotometry has been obtained with the OAO-2, TD1, ANS, Copernicus and IUE satellite observatories. Of these only IUE is still providing data and the IUE calibration is generally adopted as the standard. Before discussing the current status of the IUE calibration, however, it is helpful to comment on the quality of data obtained by these earlier satellites. Koornneef et. al. (1980) have compared OAO-2, ANS and TD1 photometric data for some 531 stars. In general the absolute calibrations longward of 1800 Å agreed to within 10%. At 1550 Å the OAO-2 calibration was about 20% brighter than the other determinations. When these three independent sets of data were reduced to a common absolute energy calibration the agreement was generally better than 0.1 magnitudes. The photometric system adopted for these data expresses the absolute flux in magnitudes in accordance with the following definition.

$$m_\lambda = -2.5 \log F_\lambda - 21.10$$

The constant -21.10 was chosen so that a constant flux per unit wavelength interval would have a magnitude approximately equal to the visual magnitude of the star.

The basis for the absolute calibration of IUE is the observed flux for η UMa. The absolute flux chosen for η UMa is based on the results obtained by the above satellites, Apollo 17 and sounding rocket results. The procedure is described by Bohlin et al. (1980). Figure 3 shows the ratio of absolute fluxes for the several systems to the adopted IUE scale. The system is essentially the OAO-2 calibration longward of 2000 Å and the Johns Hopkins calibration shortward of 2000 Å. In order to reduce the random errors a number of standard stars observed by OAO and TD1 were used after correcting the data for the ratios indicated in the figure. With the exception of the high flux near 1500 Å shown by the OAO data the agreement between all these data is within about 10%. In addition comparison with a line blanketed LTE model atmosphere (T_{eff} = 17000 °K, log g = 4.0) shows agreement within the 10% level. This IUE calibration was revised in May 1980, however, the basis of the calibration remained the same. The new calibration utilized more data and incorporated some refined reduction algorithms. The current IUE calibration is described by Bohlin and Holm (1980). Since that time the sensitivity of the detectors has decreased and a redundant detector employed. In the final reduction of IUE data instrument signatures resulting from a variety of causes, temporal changes, temperature corrections, background non-linearities etc., will be more clearly defined and we can expect significant enhancement of the data.

The absolute calibration of IUE is based on standard stars and not any measurement of the instrument response function. Currently the flux of these standard stars is known to about 10%. For some applications this accuracy is insufficient and efforts to improve the flux calibration continue.

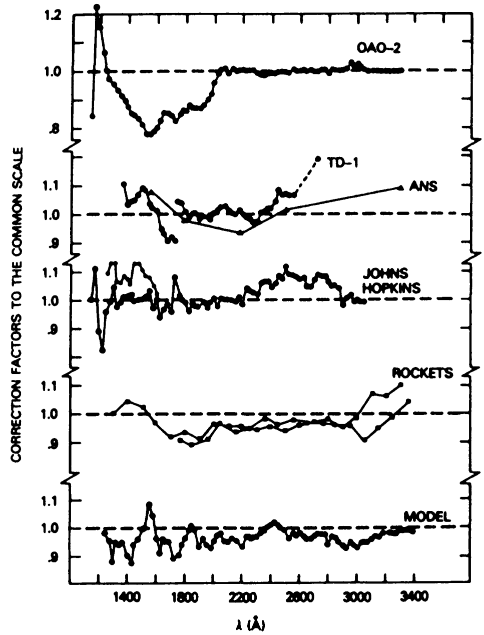

Fig. 3. Ratio of absolute fluxes on the IUE scale to those from different sources as given by Bohlin et al. (1980).

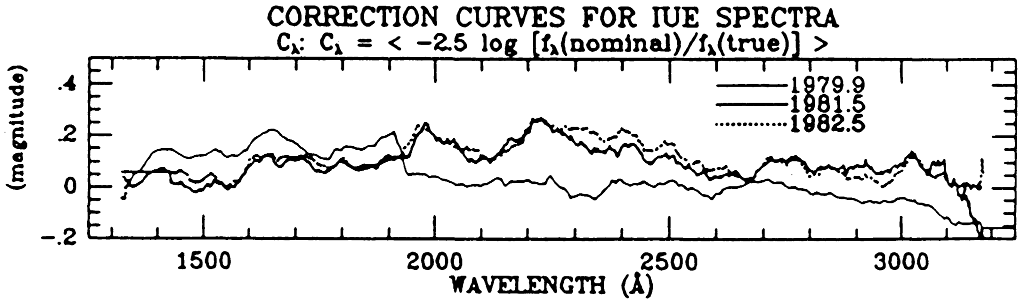

Fig. 4. Correction curves for IUE spectra based on fitting observations of DA white dwarfs to models (Finley et al. 1984).

One direction that calibration efforts has taken is to compare the measurements of hot subluminous stars to model atmospheres. Finley, Basri and Bowyer (1984) presented a self-consistent recalibration of IUE based on observations of hot DA white dwarfs. By averaging color differences between observed spectra of 13 objects and appropriate models they found the correction curves shown in Figure 4. The differences are large--amounting to as much as 0.2 magnitudes at 2200 Å. It was also found that the calibration corrections changed with time, although these time variations are somewhat different than those reported in the IUE Newsletters. Finley et al. believe that the model atmosphere fluxes are reliable to about 2%, that the physics employed is well understood and since these objects have very little interstellar reddening the DA white dwarfs provide the best available means of calibrating UV fluxes. Ultimately, however, the flux calibration must be based upon measurements and not consistency with models.

In the extension of the flux calibration from 1200 Å to 912 Å the hot subluminous stars have also recently been invoked. Ultraviolet observations of stars with the Voyager 1 and 2 UV spectrometers were reported by Holberg et al. (1982). The calibration of the flight instruments were based on reference to NBS photodiodes. They found that their fluxes from 1200 A down to about 1050 Å were in good agreement with the earlier calibrations of Carruthers et al. (1981) and the earlier Johns Hopkins calibration of Brune et al. (1979). Shortward of 1050 Å the Voyager fluxes were 60% higher and the Brune fluxes 60% lower than Carruthers. They then recalibrated the Voyager fluxes based on the high temperature, high surface gravity models of Wesemael et al. (1980) using the measured flux of HZ43. This recalibration showed good agreement with other star-model comparisons. Polidan and Holberg (1985) report in this volume on stellar fluxes between 912 Å and 1200 Å, based on the revised Voyager 1 calibration. They find that the spectra of the sdO star BD +28 4211 and central star of the planetary nebula NGC 246 fit a simple power law, $\lambda^{-3.78}$ from the visual to the Lyman limit. These results are interesting but a bit perplexing. The asymptotic limit as $T \rightarrow \infty$ is a slope of -4. To maintain a slope of -3.78 over this entire spectral range it is necessary that the opacity in the atmosphere vary in such a manner as to look to progressively higher temperatures towards the ultraviolet. Curiously a simple gray atmosphere temperature distribution with T_{eff} = 50000 °K and hydrogen opacity only does fit the relation, and indeed at high gravities electron scattering becomes unimportant. Unfortunately more sophisticated models such as the grid of Wesemael et al. (1980) do not behave this way. It would appear to require a temperature in excess of 100000 °K to approximate the power law although the red end of the spectrum is steeper. Figure 5 shows a plot of the magnitude differences between the infinite temperature -4 power law and a -3.78 power law and three representative model atmospheres. The differences are small for a 100000 °K model but the appropriateness of a power law spectrum is questionable. It may be that the modeling of DA white dwarfs is better understood than planetary nuclei but we return to the point that the ultimate calibration must involve absolute energy measurements. Both the NRL group and Johns Hopkins group have reported on new rocket measurements at the recent Seventh VUV Calibration Workshop.

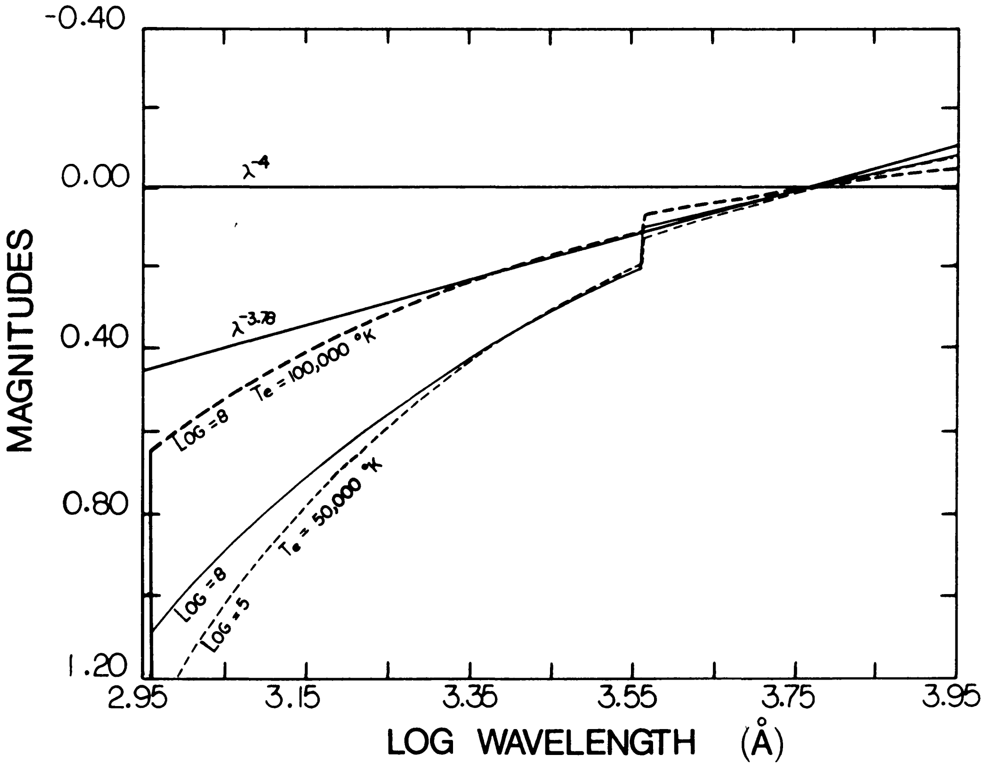

Fig. 5. Difference in magnitude between the flux from an infinite temperature black-body and (a) a power law of slope -3.78, and hydrogen model atmospheres for (b) upper dashed curve T_e = 100000 °K, log g = 8.0, (c) solid curve, T_e = 50000 °K log g = 8.0, (d) lower dashed curve T_e = 50000 °K, log g = 5.0.

Woods, Feldman and Bruner (1984) presented preliminary data agreeing with the revised Voyager calibration within ±20% Å in the 1600 Å to 1400 Å and the 1200 Å to 1000 Å region but falling below the Voyager results by nearly a factor of two shortward of 1000 Å. The possibility of stellar variability at these wavelengths must be kept open when comparing measurements at different epochs. This requires a larger data set than currently available. In any event recent calibration efforts appear to be converging. The discussion of hot subdwarfs is an interesting astrophysical problem in its own right and it is to the application of ultraviolet spectrophotometry that we turn our attention.

3. STELLAR OBSERVATIONS IN THE ULTRAVIOLET

The extension of stellar observations into the vacuum ultraviolet provides large photometric baselines which substantially increase the sensitivity to temperature, gravity and chemical composition variations.

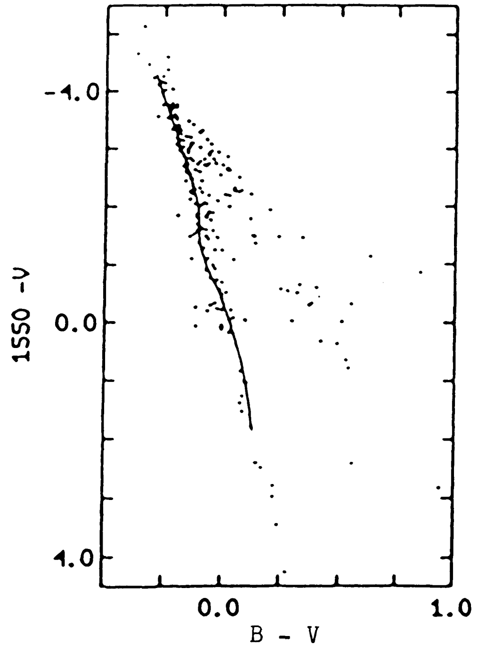

Fig. 6. A 1550-V color vs B-V color for 238 stars from OAO-2 photometry.

Figure 6 shows a typical color-color diagram in which the B-V color index is plotted against a color index between 1150 Å and the V band pass, m(1550)-V. For little redened early type main sequence stars the slope of this relation is $\nabla(1550\text{-}V)/\nabla(B\text{-}V) = 12.7$. As such the colors of comparable accuracy offer an order of magnitude greater discrimination between stellar types. For the data sets described above the photometric accuracy between systems is the order of 0.1 magnitudes while the internal accuracies are significantly higher, of the order of a few hundredths of a magnitude and thus comparable to ground-based photometry. In principal higher photometric accuracy should be attainable from space observations. The environment is benign, the instruments stable over long periods of time and there are no atmospheric extinction corrections or scintillation to contend with. This is particularly advantageous in the study of rapid time variations.

The ultraviolet is also more sensitive to interstellar extinction. The average interstellar extinction at 2400 Å is 5 times as great as the visual extinction and about 6 times the visual at 1200 Å. Fortunately the interstellar extinction curve is non-linear and displays a pronounced bump at 2200 Å corresponding to about 7 times the visual extinction. The measurement of the 2200 Å bump is frequently used to provide a determination of interstellar extinction. Unfortunately there is a significant variation from the average extinction for some objects (c.f. Meyer and Savage 1981). It is worth noting that in their discussion of the IUE calibration Finley et al. point out that their correction curve has a pronounced peak at 2200 Å that would lead one to assume that an unreddened star had a B-V color excess of 0.08 magnitudes.

There now exists a substantial set of data on the spectra of stars in the ultraviolet of both high and low spectral resolution. Thus from TD1, Copernicus and the IUE high resolution mode many studies have been carried out on interstellar and stellar lines of light elements previously unavailable from observations in the visual. From these investigations we have learned a great deal about the structure of the interstellar medium and have come to recognize the non-thermal nature of the upper atmosphere of B stars and the importance of mass loss. From these data and insight we have new tools to apply to the task of calibrating fundamental stellar quantities. Let me simply cite two examples in which the addition of ultraviolet data has played a role.

The theory of stellar structure provides us with an interpretation of the evolution and present structure of stars which traditionally is depicted in the form of an HR diagram. The connection between these theoretical HR diagrams and the stellar parameters of the observer has not always been direct. Appeal is often made to the concept of effective temperature and the bolometric correction. In the last decade we have been able to make empirical determinations of these parameters relatively independent of theory. The ability to observe most of the electromagnetic spectrum provides not only details on the spectral distribution but a reliable determination of the integrated flux. From the integrated flux we may determine bolometric corrections or alternatively, given a reliable parallax, the total stellar luminosity. Based on the definition of effective temperature the total integrated flux at the earth is

$$f = (\theta^2/4)\ T^4$$

where θ is the angular diameter subtended at the earth by the star. Significant progress has also been made in the measurement of angular diameters and with this information empirical effective temperatures can be found. This provides the framework within which other less direct methods may be compared and extended to a larger number of stars.

Due to the large number of atomic transitions occurring in the ultraviolet, this spectral region is sensitive to chemical composition. At high resolution, both weak lines and the resonance lines of abundant elements can be studied. At low resolution, line blends and line blanketing provide information on the metallicity. An example is shown in Figure 7 which compares the composite IUE spectra of a sample of Population I stars and field horizontal-branch stars with an average effective temperature of 8500 °K. The log of the flux is normalized to zero at 5500 Å. The lower spectrum is that of the Population I stars showing both stronger lines and a depressed ultraviolet continuum due to line blanketing. A color-color plot employing magnitude near 1500 Å provides a sensitive index of metallicity in the temperature range from about 7000 °K to 10000 °K. A comparison of HB stars with Population I standards has been described by Huenemoerder et al. (1984).

By combining measurements in the Balmer continuum (ultraviolet) and the Paschen continuum (visible) we should expect to be able to define photometric parameters whose principal components are sensitive to specific physical parameters such as temperature, reddening, gravity and

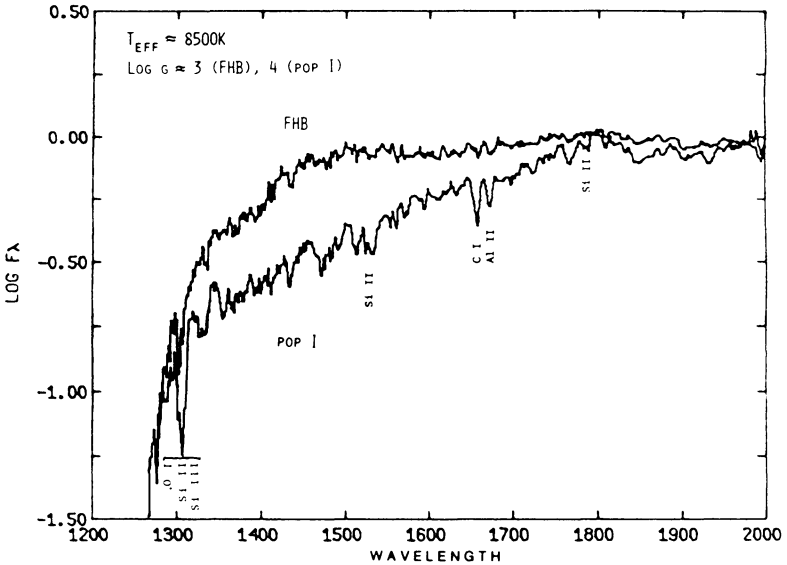

Fig. 7. Ultraviolet spectral distribution of average FHB star, upper curve and Population I star at T_e = 8500 °K. The curves are normalized at 5500 Å.

metallicity. The calibration of such indicators provides a useful tool in the study of composite systems such as globular clusters and galaxies

One valuable resource for reviewing the scope of current activity in ultraviolet astronomy are the conference reports of the several NASA and ESA IUE Conferences.

4. ULTRAVIOLET OBSERVATIONS OF COMPOSITE STELLAR SYSTEMS

The extension of the spectral range into the ultraviolet provides additional leverage in separating the components of multiple stellar systems. By way of a simple example Figure 8 shows the spectrum of Antares. It is of course primarily the spectrum of the companion (α Sco B), a B2.5 V star rather than the M1 Ib standard. There are a number of systems in which the difference is far less extreme for which UV data provides the decisive criteria. Among the composite stars contained in the ANS Ultraviolet Photometry catalog of point sources (Wesselius et al. 1982) the star 58 Per presents an interesting case. It has been variously classified as K4 III + A3 V, G5 Ib-II + A3 or simply G8 II. The ANS photometry contradicts these assignments. The 2200 Å channel suggest a color excess of about 0.2 magnitudes. Figure 9 shows the observed magnitudes in the five ANS channels along with the magnitudes at U, B and V. The upper solid curve is the result of applying the average galactic extinction law for a B-V color excess of 0.22 magnitudes. This envelope can be fit by two components with flux distributions similar to a G8 II star and a B 2.5 V star. On the basis

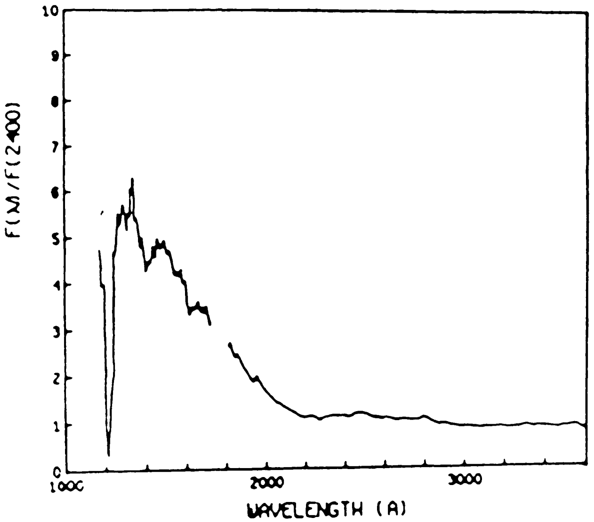

Fig. 8. Ultraviolet spectrum of Antares. The early type, B2.5 V, companion dominates.

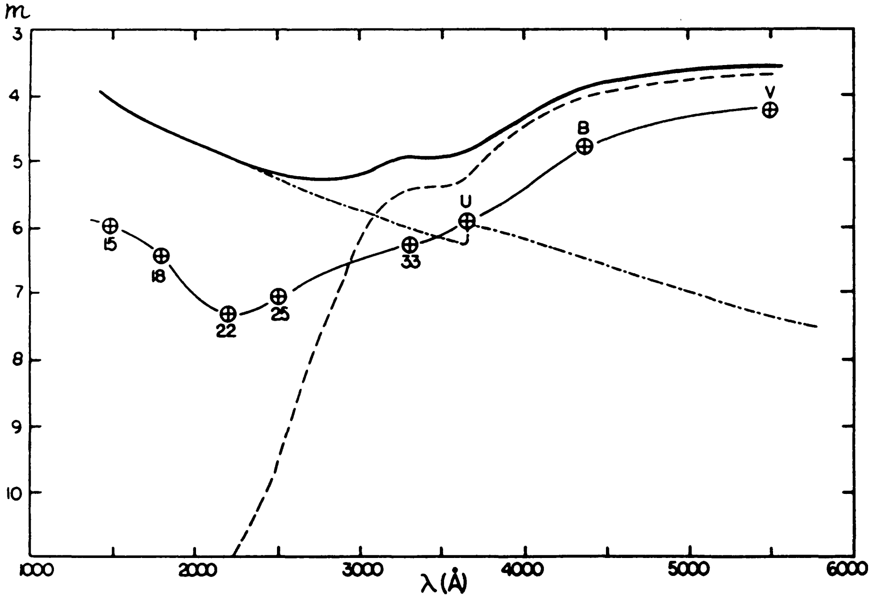

Fig. 9. Spectral distribution of possible components of the star 58 Per. Circled crosses are UBV and ANS observed magnitudes. Upper solid curve corresponds to observations corrected for E(B-V)=0.22 mag. reddening. Dashed curve is the flux for a G8 II star and the dash-dot curve that of a B2.5 V star. The two curves are normalized to yield the corrected total magnitudes.

of the ANS photometry one would conclude that either the G star is more luminous than a II or the B star is subluminous. Several IUE spectra have been obtained of 58 Per and Harmer et al. (1983) conclude that the components are G8 I and B5 V with a color excess of 0.3 magnitudes.

Another example of the leverage provided by extending observations into the ultraviolet comes from IUE observations of classical Cepheid variables. Apparently about one third of the Cepheids have blue companions such as S Mon whose spectrum in the UV is that of a B4 V star.

The extension of the study of composite systems to the integrated light from objects such as globular clusters and galaxies provides useful data for characterizing the population and evolution of these objects. In general, the ultraviolet spectra of these sources is dominated by the relatively few hot stars. In a typical globular cluster a single faint blue horizontal-branch star contributes as much light at 1500 Å as 1000 bright red giants. For the nearby systems observations of single members have been obtained in the ultraviolet as well as in the optical. On the basis of these investigations the integrated properties can be understood in terms of age and chemical composition. The integrated properties of globular clusters can then be extended to more distant clusters and to members of other galaxies. A review of some of the data on the ultraviolet spectra of globular clusters has been given by Code (1983).

Ultraviolet observations of galaxies have shown that many systems with similar spectra in the optical have distinctly different spectra in the UV. This reflects the difference in the number of hot stars and presumably the difference in the current rate of star formation. Galaxy evolution currently represents one of the more difficult problems facing the classical approaches to solving the cosmological problem. The extension of observations to the ultraviolet provides an important tool in studying the stellar and dynamical evolution of galaxies.

5. FUTURE DEVELOPMENTS IN ULTRAVIOLET ASTRONOMY

I shall conclude this review with some comments on future directions in satellite instrumentation. Many astronomers regard the forthcoming launch of Space Telescope a new milestone in astronomical research. This 2.4 meter telescope is the first stellar observatory designed to take full advantage of the spatial resolution achievable from above the earth's atmosphere. Optical, near infra-red and ultraviolet imagery with resolution consistently better than 0.1 seconds of arc open up a wide range of new investigations. The fabrication of optics and pointing systems capable of providing this precision have been a major challenge and this challenge appears to have been met. Space Telescope is different from past missions in a number of ways. It is to be launched by the shuttle and accessible to the shuttle for refurbishment and maintenance. Communication to and from the spacecraft will be through the new Tracking and Data Relay Satellite System (TDRSS). The quantity and diversity of data obtained require an extensive suite of dedicated hardware and software. The high resolution, in particular, provided by the Wide Field/Planetary camera and the Faint Object Camera present challenges in image processing that will have significant impact in all areas of astronomical data reduction. Perhaps most important to the astronomer is the fact that this unique space observatory is to be operated in a unique manner. The scientific responsibility for the operation of Space Telescope has been placed in the hands of the user community through the establishment of the Space Telescope Science Institute.

Space Telescope and other planned missions will, among other things, enrich our base of fundamental stellar quantities. We can anticipate an order of magnitude precision in parallaxes and proper motions and orbit determinations. Angular diameters from occultation measurements and from the space equivalent of speckle interferometry will add to our meager list. The gain to be expected from interferometric measurements in space is spectacular. The signal-to-noise ratio for such measurements varies linearly with the "coherency time", limited to less than 0.1 seconds due to seeing for ground-based observations; while in space times of the order of 1000 seconds are practical. The ability to observe stellar objects fainter than 26th magnitude will extend the luminosity function and explore the lower end of the main sequence in clusters in our own and other galaxies. Infra-red satellites will also make their contributions to fundamental astronomy and to a better determination of the birth rate function. Other instruments carried in the shuttle bay will provide data on the polarization of stars in the ultraviolet, and on the EUV spectrum of nearby stars. The shuttle may provide a means of carrying out absolute energy calibrations of high fidelity.

To exploit these opportunities, however, places a significant demand on current ground based telescopes. First the facilities in space for the near future will be limited and if an investigation can be done from the ground it will not have a very high priority in space. Secondly the preparation for carrying out space observations and the interpretation and exploitation of the results often requires ground based observing. Another related problem that I will conclude this review with is that of calibrating these advanced space flight instruments. The basis for photometric calibration of the scientific instruments on Space Telescope will be standard stars. For the most part current standards are too bright for some of the focal plane instruments. The instruments span a decade of the electromagnetic spectrum and yield imagery at flux levels unattainable from the ground. I believe the topic of calibration techniques for Space Telescope would be a suitable topic for discussion at this symposium and hope that there are some here that are prepared to contribute to that discussion.

In this review I have tried to indicate the scope of current stellar research in ultraviolet spectrophotometry. I have not strived for completeness, others here might well have chosen different topics to emphasize. The theme that runs throughout this text, however, is the unity of observations across the electromagnetic spectrum. Space observations eliminates the artifical boundary established by the atmospheric cut-off. Given facilities such as Space Telescope, ultraviolet astronomy, at least, disappears as a separate discipline.

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DISCUSSION

POLIDAN: I have two comments. First I agree with you completely that a definitive far-UV calibration does not yet exist. As stated in our paper (elsewhere in this volume) we feel that some of the differences between the existing calibrations are due to intrinsic variability in the reference stars observed. As discussed by many of the speakers at this symposium the proper choice of reference stars is critical to any fundamental system. Our observations of widespread flux variability in B stars at wavelengths less than 1150 Å would appear to make them unreliable as flux standards. It is primarily for this reason that we suggest that sub-luminous stars are more suitable as UV flux calibration standards. (See Polidan and Holberg in this volume for additional reasons.) Secondly, I will remark on a clarification of the techniques used to arrive at the revised Voyager calibration. The model atmosphere was used only to set the zero point of the flux calibration. The relative sensitivity function used was still the pre-launch value. While I agree with you that this is not a fundamental calibration, the situation in the far-UV was, as you have stated, confused. A working calibration had to be assumed. The fact that recent rocket flights have supported this assumed "calibration" have been quite encouraging.

BOHLIN: The Space Telescope project is the most expensive project ever undertaken by mankind for pure scientific research (except possibly the pyramids of Egypt). The ST calibration for the various photometric, geometric and polarimetric modes will be done using standard astronomical sources after launch. Therefore, the preparation of the data for the best standard targets must be completed during the remaining time before launch. There are considerable efforts currently being expended to define proper standards. We at the Space Telescope Science Institute invite the active participation of all calibration experts in defining the most appropriate ST standard sources.

GUSTAFSSON: I think the models we produce are quite up to date, but therefore necessarily very primitive descriptions of the quite complex systems that stars seem to be. Therefore, if somebody would rely on our models for calibrating the fundamental properties of his spectrophotometric system I am afraid I would stop calculating them, just because I would have difficulties sleeping at night.

ROUNTREE: I think it is time to lay to rest the ghost of Antares as a case of an MK standard that has a "different spectral type" in the ultraviolet. In fact, the M supergiant standard is Antares A, while the B star seen in the UV is Antares B. This is not a classification problem - we are seeing two different stars, not one star with two spectral types. There may be subtle problems that arise in using MK standards in the ultraviolet, but this is not one of them.

CODE: Yes, of course. I did not mean to imply a "different spectral type" but simply to illustrate what an actual composite spectrum of these type components would look like in the ultraviolet.

CAYREL: Have your hot subdwarfs all the same chemical composition? If not, how can you use them as standards?

CODE: I don't know the chemical composition of the hot subdwarfs. The spectra provide little information on chemical composition and there are various theoretical evolutionary scenarios for these stars. On the other hand, the flux is little affected by chemical composition and of course a standard star is simply a standard candle independent of chemical composition.