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Ultraviolet Spectra of Stars

The ultraviolet spectra of stars are discussed from both theoretical and observational viewpoints.

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From the shape, strength, and wavelength of stellar absorption lines, one can deduce information about the composition, density, temperature, and state of motion of the gas forming a stellar atmosphere. If emission lines are observed, further particular conclusions can be drawn about the physical characteristics of the outer parts of the stellar atmosphere. Ground-based observations of stars, with spectrographs illuminated by light collected with large telescopes, permit one to study spectra from 3000 to 6800 Å and into the infrared in the parts of the spectrum that are not obscured by absorption bands originating in the earth's atmosphere. Extension of the observations into the infrared is done with recording devices sensitive to low levels of light for stars that are rather cool and so produce much radiation at long wavelengths. In practice, most stellar spectroscopy is done between the lower limit of wavelength, 3000 Å, imposed by the ozone absorption bands of the earth's atmosphere and about 6800 Å —the long limit of wavelength of most panchromatic photographic emulsions. The stellar spectra are usually recorded photographically; thus one may use most efficiently the limited amount of observing time that is available for high-resolution spectroscopy with large telescopes.

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Rockets and satellites provide means of transporting telescopes and spectrographs above the ozone of Earth's atmosphere. Once an instrument is above the ozone layers, one may expect to record stellar spectra from 3000 Å to the Lyman limit of hydrogen at 911.6 Å. Since interstellar space contains neutral hydrogen atoms, radiation emitted from stars more distant than the sun is absorbed strongly at wavelengths shorter than 911.6 Å. At extremely short wavelengths (soft x-rays), interstellar space becomes again fairly transparent, but normal stars are not expected to radiate a measurable amount of energy at such wavelengths. It is practical and convenient to define the ultraviolet spectrum of stars as lying between 911.6 and 3000 Å.

Two questions arise: (i) Which stars are expected to radiate in the ultraviolet spectral range at a detectable level? (ii) Is it reasonable to expect the spectral lines observed in the ultraviolet to contribute information not already available from the normally observed spectral region?

To answer these questions we must consider the theoretical models used to represent stellar atmospheres, and the validity of our theory of the formation of stellar spectra. One should remember that stellar atmospheres consist of gas (atoms, ions, and molecules) through which a stream of radiation is flowing. The atoms, ions, and molecules interact with the radiation to produce absorption or emission spectra. We know from laboratory studies the chief spectral lines produced by each species in the range of wavelengths from 911.6 to 6800 Å. Our predictions of the ultraviolet spectra of stars are based on the idea that any theory and model, representing well the part of the spectrum of a particular atom or ion observed in the spectral region 3000 to 6800 Å, should be also valid for prediction of the spectrum in the ultraviolet spectral region. No atom, ion, or molecule in a gas ever radiates only part of its spectrum, although we frequently observe only part of the spectrum because of the restrictions imposed by our observation techniques (untransparent windows, including the earth's atmosphere; insensitive recording devices at some wavelengths; and suchlike).

An important point is evaluation of the reliability of our theories of the formation of stellar spectra. Some weaknesses are well known, and deviations between predictions made with the imperfect theory, and observations can be interpreted qualitatively. One can gain new information about the stellar atmosphere by study of spectral lines when the deviations between observed and predicted line profiles and line strengths are largest. From our studies of stellar spectra with ground-based spectrographs we think we know what sort of spectral lines yield the most information. Naturally, surprises greet us in the ultraviolet spectral region, but they are a bonus that comes with a successful program of observation—they are not the primary reason for making the observations.

Before looking at the answers to the questions just posed and at the available observational material, we should remark that the light reaching the earth from the stars has passed through vast distances in interstellar space. The gas and dust lying between the earth and the stars absorb stellar light and form interstellar absorption lines in a stellar spectrum. These interstellar spectral features are expected to give much information about the physical conditions in interstellar space, but we shall not discuss them. Interstellar absorption lines can be distinguished from stellar absorption lines by the fact that, in a multiplet, only the component that arises from the ground state is observed. The dilute radiation and low particle density in interstellar space cannot excite atoms and ions even by 0.01 ev.

Models of Stellar Atmospheres

In the case of normal dwarf or main-sequence stars, the geometric extent of the layers through which the line spectrum is formed is small in comparison to the radius of the star. Consequently it is sufficient to consider that the stellar atmosphere consists of plane parallel layers of gas in hydrostatic equilibrium under the local acceleration of gravity. On the surface of a main-sequence star, gravity is about 10^4 centimeters per square second. The composition of the stellar atmosphere is constant throughout the relevant layers. The theoretical spectra to be presented have been computed for models having a fractional abundance, by weight, of hydrogen equal to 0.68; of helium, 0.32. The fractional abundance by weight of all other elements is small (1.41×10^{-4} for Fe, for instance), and it is usually neglected when a model is constructed. When the line spectrum is computed, a representative abundance, relative to hydrogen, for each element is adopted according to the results of abundance analyses of stellar spectra.

The condition that hydrostatic equilibrium should exist gives a relation between gas pressure and geometrical depth in the atmosphere. The relation between temperature and depth in the atmosphere is found by requiring that a constant flux of energy flow through the model. As the radiation field in all frequencies from 0 to ∞ passes through each layer of the model, no energy is lost or gained, but the energy is redistributed in frequency as a result of the interactions with the atoms and ions in the atmosphere. In principle this redistribution may be followed by solution of an equation of radiative transfer appropriate to the physical situation encountered. In practice these interactions between atoms, ions, and radiation are represented in a somewhat schematic manner that is complex enough to describe the major trends of the processes that occur but simple enough for expeditious handling by a large computer.

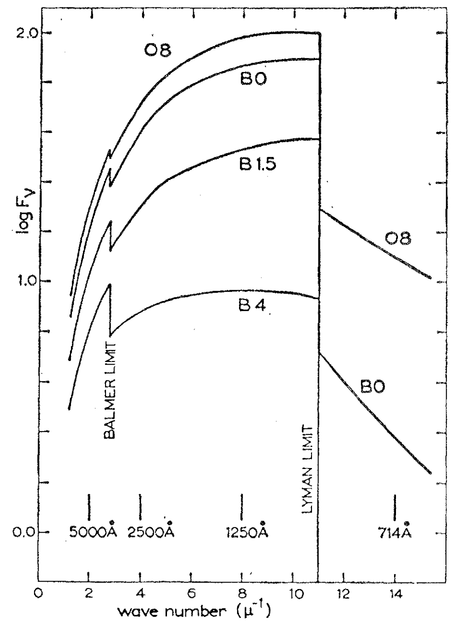


Fig. 1. The continuous spectrum of OB stars, predicted without attention to the blocking of radiation by the ultraviolet lines. The unit of flux is 10^{-4} erg per square centimeter per second per unit frequency interval.

Preliminary studies have indicated that only stars classified, according to empirically selected spectroscopic criteria, types O or B may be expected to produce an ultraviolet flux of energy comparable to that in the normally observed spectral region; they are among the hottest known. Consequently the results we present have been calculated with equations suitable for atmospheres in which the electron temperature varies between 8000° and 60,000°K.

In brief, the monochromatic flux emerging from the stellar surface has been calculated by use of the Milne-Eddington transfer equation. This equation represents the postulates that the radiation is removed from the beam by absorption in the continua of H, H^-, He I, and He II and in lines, and as a result of coherent isotropic scattering by electrons; and that energy is returned to the beam by reemission, as though the gas were in thermodynamic equilibrium at the local electron temperature, and as a result of coherent isotropic scattering by the electrons. The methods of constructing model stellar atmospheres and of computing the line and continuous spectrum have been described (*1*).

Theoretical Spectra from Models

When the first model atmospheres were constructed, the radiation-blocking effects of the strong stellar lines in the ultraviolet spectral region were ignored. These models, for stars of types O to B2, predicted a rather bright continuous spectrum in the ultraviolet spectral region (Fig. 1). Even so, it may be seen that only stars of spectral types O to B4 will produce a greater flux between 3000 and 911.6 Å than they produce in the spectral region observed with ground-based instruments (*2*). The predicted ultraviolet fluxes below 1500 Å will be reduced considerably when the absorption by the ultraviolet lines is taken into account; only O-type stars will produce a significant flux of energy at wavelengths shorter than the Lyman limit.

A few models have been constructed that take into account the line blanketing (*3*). An example of the resultant changes in the overall intensity distribution of the emergent spectrum appears in Fig. 2; both models shown may be classified type B1.5 according to the size of the Balmer jump. For main-sequence B-type stars a single-valued empirical relation exists between spectral type and the intensity jump at the Balmer limit of hydrogen; since this relation is rather insensitive to gravity and to the electron pressure in the atmosphere, it may be used to obtain a first approximation of the equivalent spectral type of a model atmosphere. In practice, spectral types are assigned to stars according to the relative intensity of a few empirically selected strong absorption lines.

Including the strong lines in the procedure for constructing the model is physically more correct than ignoring them. One result is that the effective temperature is reduced by about 10 percent from its value in an unblanketed model having the same Balmer jump and thus nominal spectral type. The temperature-pressure structure is not significantly changed in the deeper layers of a blanketed model from that in an unblanketed model of the same spectral type. However, in the extreme outer layers of a blanketed model, the temperature for a given value of the pressure is lowered from its value in an unblanketed model. This difference between models having the same nominal spectral type will be important only for interpretation of lines so strong that they are formed effectively in the outermost layers of the model. In this case however, one may be certain that the equation of transfer that has been adopted to represent line formation is no longer tenable; furthermore, that it is not appropriate to calculate degree of ionization and level of excitation by the equilibrium relations known as Saha's and Boltzmann's laws. In solving the problems of the monochromatic transfer of radiation through the outer parts of the stellar atmosphere one should take into account what are called "non-l.t.e. effects"—that is, departures from the equations representing local thermodynamic equilibrium.

In order to obtain a first prediction of the ultraviolet spectrum from OB stars, these important physical considerations have been ignored and the spectrum has been predicted by use of the existing thermal-equilibrium theory of line formation. When observed line profiles are compared with predicted line profiles, attention must be paid to isolation of discrepancies due to (i) departures from the adopted simple theory of line formation; (ii) departures of the state of motion, of the gas in the plane parallel layers, from the thermal motions appropriate to the local temperature, which are the only motions taken into account in the theory; and (iii) the fact that the stellar atmosphere may indeed be so extensive that it cannot be adequately represented by a plane parallel layer, but must be represented as a sphere or other geometric form.

An important concept for visualization of what occurs in the stellar atmosphere, and where it occurs, is the "depth of formation" of the spectrum at frequency ν. Whether this frequency lies in the continuous spectrum, or in a line, is immaterial; what is significant is that numerical work has shown that F_ν, the emergent flux in frequency ν, is approximately equal to B_ν, the value of the Planck function at this frequency, at the layer in the model in which the *monochromatic* optical depth t_ν is about equal to 0.4. In a very opaque spectral region the position at which t_ν equals 0.4 will occur in the outermost layers of the star; in a transparent spectral region t_ν will equal 0.4 at much greater depths. In the first case, the local temperature will be low; in the second it may be higher by 10,000° or 15,000°K. Clearly, in an opaque spectral region such as the centre of a strong line, one is observing a part of the star different from the one seen in a transparent spectral region, such as in the continuous spectrum or in weak lines. A large part of the ultraviolet brightness (Fig. 1), in comparison to the brightness at 4500 Å, is due to the fact that in these calculations the spectrum at 1300 Å comes from considerably deeper layers than does the spectrum at 4500 Å. Important in determination of the depth of an absorption-line profile at any spectral region is the factor of whether the selected frequency range lies on the steep side of the Planck function for the relevant temperatures or on the long-wavelength tail. In the latter case (at wavelengths greater than 3600 Å in B stars) even the stronger lines are not deep; at wavelengths shorter than 3000 Å, the strong lines become very deep, especially at very short wavelengths.

The foregoing qualitative explanation does not tell the full story (especially for resonance lines, where line-formation by scattering processes must be important), but it does demonstrate that the presence of strong lines in the ultraviolet spectral region causes greater reduction of the expected emergent flux, from the flux for the case of no lines, than would ever occur in the normally observed spectral region between 4000 and 5000 Å. The interplay of these various factors causes the two different spectral distributions shown in Fig. 2.

Expected Ultraviolet Absorption Lines

The ultraviolet spectrum of O and B stars divides into two regions. In the section 911.6 to 1900 Å there occur many resonance lines and strong lines from low-lying levels of the first, second, and third ions of the elements He to Ca; many of these lines are predicted to be exceedingly strong. The only important spectra not having resonance lines in this region are those of He I and II, O II and III, Ne I and II, and Mg II. Morton (*4*) has predicted the profiles of some of the stronger lines formed in an unblanketed model atmosphere of type about B1.5, using the simple theory of line formation sketched above. The results in the neighborhood of 1200 Å appear in Fig. 3; the great width and depth of the resonance lines are evident. The central parts of these lines are formed

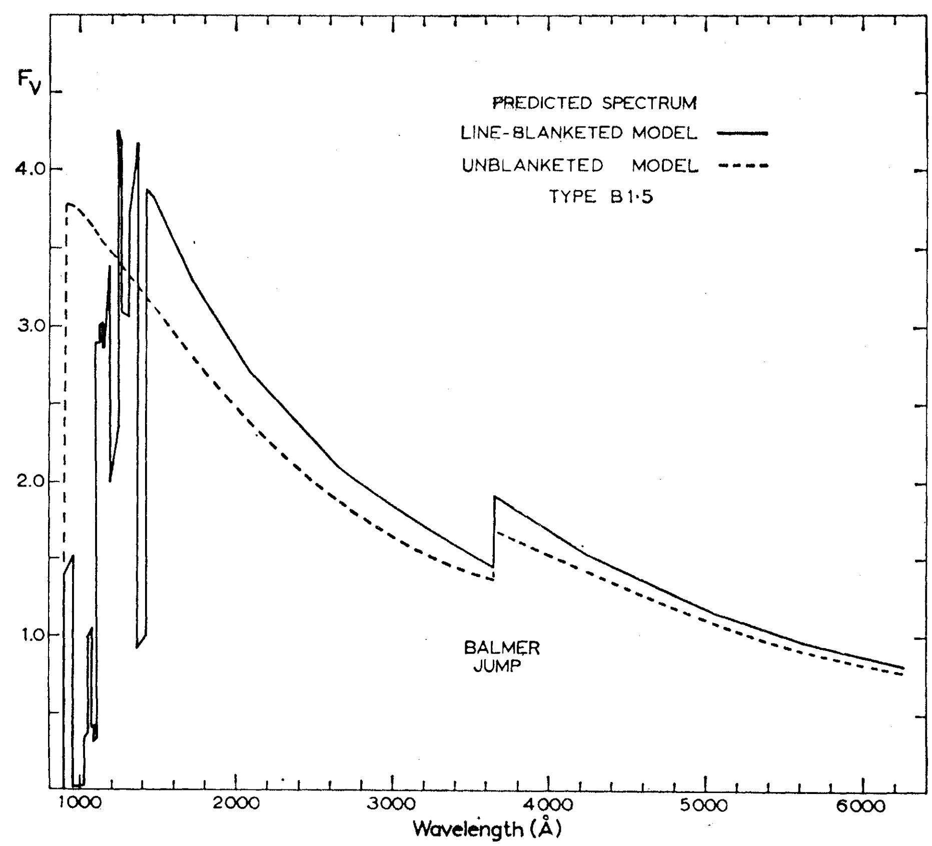


Fig. 2. The difference in spectral distribution between a line-blanketed model calculated by C. Guillaume and an unblanketed model calculated by one of us (A.B.U.). The unit of flux is 10^{-3} erg per square centimenter per second per unit frequency interval.

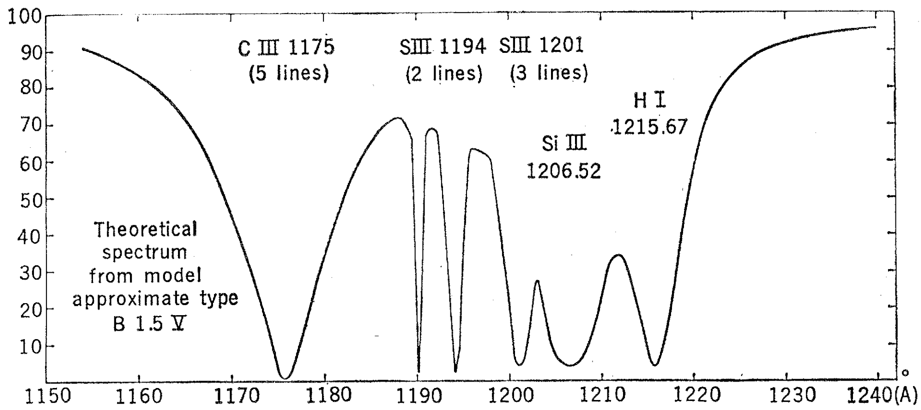


Fig. 3. Predicted strong stellar lines in the neighborhood of 1200 Å.

in the outermost layers of the models. Thus study of the observed profiles and displacements of the strong resonance lines should yield information about the electron temperature and pressure and the velocity field in the outermost parts of the stellar atmosphere, especially whene an improved theory of line-formation is used. Morton's calculations show that it is quite unreal to expect observation of a continuous spectrum from O and B stars (Fig. 1) at wavelengths between 911.6 and 1500 Å; rather the spectrum of main-sequence stars will be cut up by many deep absorption lines—some of which are shown schematically in Fig. 2.

The wavelength region between 1900 and 3000 Å has been studied at Utrecht. The only resonance lines expected are those of Mg II at 2800 Å. Calculations suggest that these lines will be quite strong in B-type spectra although less strong than the resonance lines of C IV and Si IV. This region contains a few strong lines of Si III and C III and very many lines of the second and third spectra of the metals. Estimates of the strength and profiles of the latter lines (*5*, *6*) have shown that the lines of the second spectra will be weak, but that the lines of the third spectra of the metals will be deep and as wide as 1 Å. The spectra of B stars between 1900 and 3000 Å are expected to look rather like spectra of F stars in the spectral region observed with ground-based instruments; many weak lines and a moderate number of moderately strong, deep lines will be present; typical line profiles appear in Fig. 4. The lines from the third spectra of the metals should be easily observed, with a spectral purity of the order of 0.5 to 1 Å.

The line profiles shown in Fig. 4 have been calculated with a so-called microturbulence equal to three times the thermal Doppler broadening. Observation has shown that the spectral lines of the standard "sharp line" stars are not really sharp, and that predicted profiles most easily can be made to fit the observed profiles by introduction of the arbitrary parameter microturbulence. The adopted motions are small, the root-mean-square velocity of an atom or ion being about 12 kilometers per second instead of 3 kilometers per second as is characteristic of heavier atoms at the temperatures in B1.5 atmospheres.

There are many ways in which such a velocity distribution could arise in a stellar atmosphere. Trial computations have shown that the adopted velocity field, which is used in description of the shape of the line-absorption coefficient, has far more influence on the shape and strength of lines predicted at wavelengths longer than 2000 Å than have differences in the temperature-pressure structure of the models due to the inclusion or omission of line blanketing in the process of construction of models.

Observation and interpretation of the line spectra of B stars in the wavelength region between 1900 and 3000 Å should lead to new and improved estimates of the abundances of the metals (Fe, Mn, Cr, Ti) in the atmospheres of B stars. These estimates should be quite reliable because the line spectrum in the region between 1900 and 3000 Å is formed through exactly the same parts of the atmosphere as is the part of the spectrum observed with ground-based instruments. (This statement appears obviously true from the relative value of the continuous-absorption coefficient in the region between 1900 and 6800 Å.) Thus good models for the relevant layers of the atmosphere can be established and controlled by normal ground-based observation.

The reason the abundances of the metals in B stars cannot be estimated easily from the parts of the spectrum that are observed by ground-based instruments is that too few lines of sufficient strength occur in the accessible spectral region to permit successful applications of the usual methods of spectrum analysis. It will be interesting to

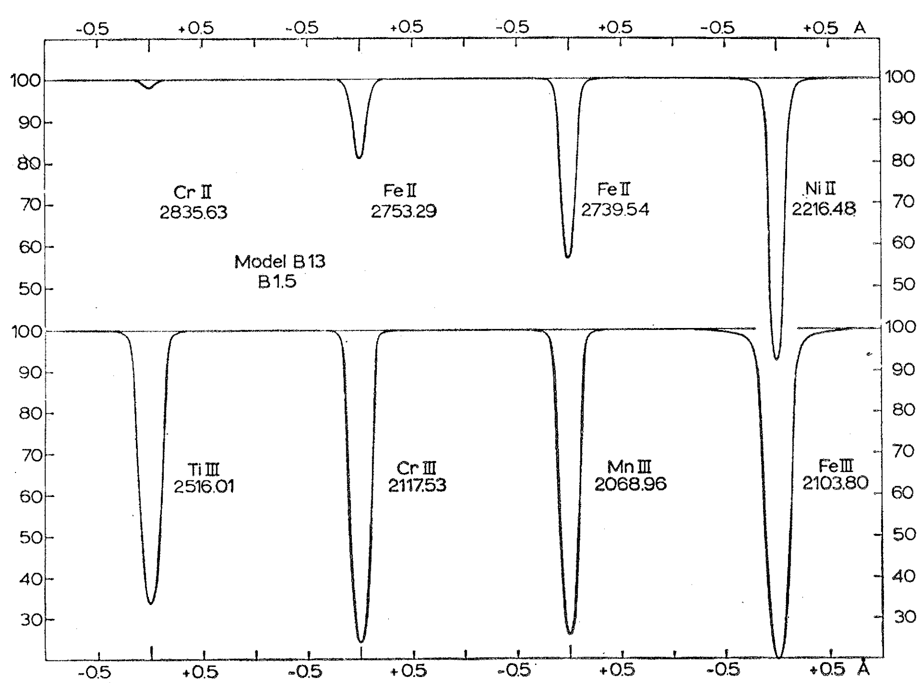


Fig. 4. Predicted lines from the second and third spectra of the metals in the spectral region 1900 to 3000 Å.

discover whether there are "strong line" and "weak line" B stars such as are known among the A, F, and G stars. The "strong line" or "weak line" characteristic is assigned chiefly according to the apparent strengths of the lines from the metals.

Should the ultraviolet spectra of stars be observed with photometers of narrow or wide band-pass, the effect of all the lines lying in the passband will reduce the measured intensity from what it would be if no lines were present. Elst (*6*) has estimated the line-blocking for each 100 Å between 1900 and 3000 Å in the spectrum of one model atmosphere; the results appear in Fig. 5, the blocking being expressed as a magnitude difference Δm. Clearly, to a narrow-band photometer, the ultraviolet spectrum of a B star will not appear smooth. In the spectral region below 1900 Å where the wide, deep resonance lines occur, the photometer response will vary even more irregularly with central wavelength and width of the passband, as a result of line blocking.

The Observations

Broad-band photoelectric observations of O and B stars in the ultraviolet have been made by several groups. Much interest was raised when it was reported that bright nebulosities in the direction of Spica and other hot stars had been detected by rocket-borne instruments recording in a wavelength band from 1225 to 1350 Å. However, subsequent flights found nothing unusual, so that the suspected nebulosity is now considered probably spurious (*7*).

Chubb *et al.* (*8*) have measured absolute fluxes from many hot stars in bands 60-, 70-, and 200-Å wide at 1115, 1314, and 1427 Å, respectively; relative to the fluxes at 5560 Å, determined from ground-based observations, the ultraviolet was fainter than expected, according to unblanketed models, by factors of 2 to 10. Morton (*4*) has shown that part of the discrepancy can be removed by inclusion of the strong absorption lines falling within the detector bandwidths in the calculation of the predicted fluxes. The differences are further reduced because the latest blanketed models predict lower fluxes in the relevant ultraviolet spectral regions and higher fluxes near 5560 Å than unblanketed models predict. The remaining discrepancies are no greater

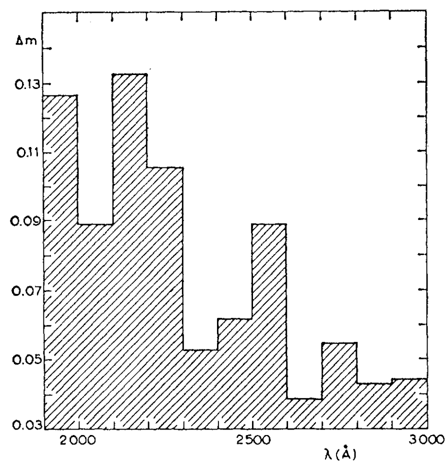


Fig. 5. Line blocking, in the region 1900 to 3000 Å, in the spectrum of a model atmosphere of type B1.5.

than may be expected from the possible systematic errors in the observations, the omission of weak lines in the models, and the effects of interstellar reddening.

It is certain that line blanketing plays an important role in establishing the emitted spectrum at wavelengths less than 1600 Å; this fact is borne out by the very recent results for 96 stars having spectral types from O7 to A2 obtained (*9*) with a satellite-borne photometer. After correction for interstellar reddening, the observed ratio of ultraviolet to visual fluxes is consistently below the prediction by unblanketed models, but in reasonable agreement with the Mihalas-Morton blanketed B1.5V model.

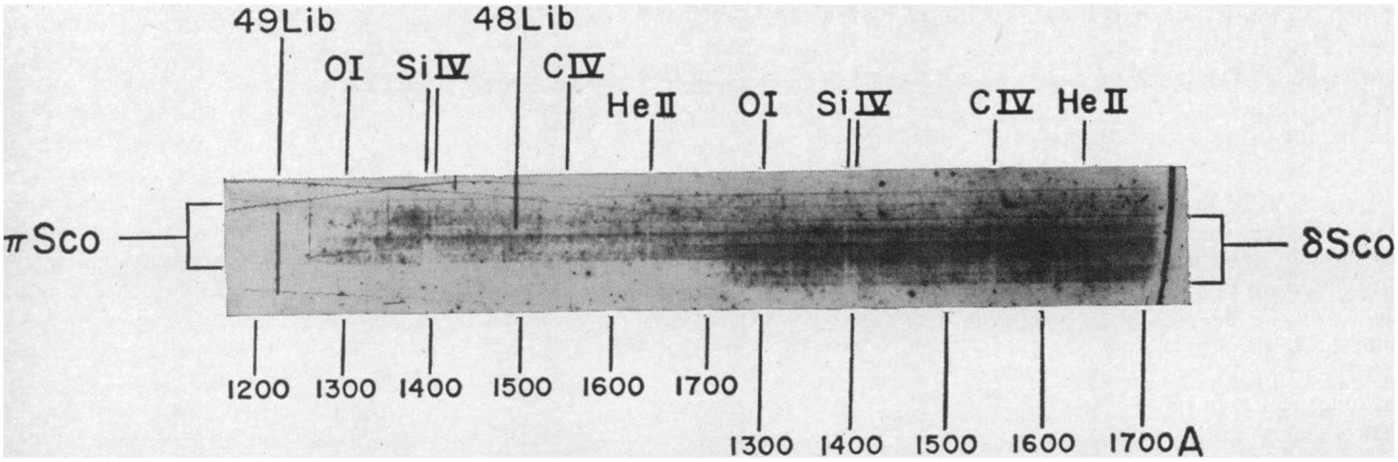
A rocket (*10*) scanned 22 early-type southern stars at 1900 Å with detectors of 400-Å half-width; the results indicated that the B stars were only 50 to 33 percent as bright at this wavelength as was expected from unblanketed models, but unfortunately there was no absolute calibration of the flight photomultipliers. Other (*11*) rocket-borne photometers have found fluxes at 2120 Å, in a passband with half-width of 188 Å, that were about 0.75 times those expected from models lacking lines. A few observations at 2200 and 2600 Å have been reported (*12*); no comparisons have been made with model atmospheres, but these data were used for estimation of the effects of interstellar reddening at these wavelengths. Fluxes from some 100 stars in bands of 400-Å half-width, centered at 2100, 2500, and 2800 Å, have been measured (*13*); when compared with the visual fluxes, these ultraviolet observations agree with the predictions by unblanketed models within 0.5 mag. Unfortunately, all published reports of the flights covering the range longward from 2000 Å are rather brief, so that it is difficult to judge the quality of the data; nevertheless it seems that the discrepancies can be resolved if we allow for the effects of interstellar reddening and the errors in the observations—if we make the comparison with the predictions from line-blanketed models.

Scans of seven stars between 1700 and 4000 Å were made with 50-Å resolution by use of a rocket-borne spectrometer (*14*). At wavelengths greater than 2600 Å the shapes of the observed spectra closely resembled those predicted from model stellar atmospheres, but at shorter wavelengths the fluxes decreased rapidly. This sudden decline does not accord with normal theories of stellar spectra. Later observations with the same type of spectrometer seem to give reasonable agreement with the models, suggesting that the earlier abrupt decline in flux may have been instrumental in origin.

The first ultraviolet line spectra of stars other than the sun were obtained (*15*) by use of Aerobee rockets; objective-grating spectrographs were used with *f*/2 Schmidt cameras having fields of view of 10 degrees. An active gyro system with gas jets oriented the rocket toward the desired target. The ± ¼-degree limit-cycle jitter in the dispersion direction was reduced to ± 16 seconds of arc by pivoting the spectrographs in the direction of the dispersion and by attaching to them a large gyro rotor gimbaled about a perpendicular axis. Torques in the dispersion direction resulted in precession of the gyro, with the end result that fine stabilization in one coordinate was achieved by a purely mechanical system.

On 2 June 1965 spectra of the main-sequence stars δ Scorpii, B0, and π Scorpii, B1, were photographed with a camera having a calcium fluoride corrector that transmitted wavelengths longer than 1265 Å (Fig. 6); wavelength resolution was about 1 Å. No fine stabilization was provided normal to the dispersion, so that the residual rocket motion widened the spectra, causing them to overlap in part; such widening increases confidence in the identification of features. The spectra of δ and π Scorpii are much as anticipated—continuous emission, with absorption lines.

The zero-order images of 48 and 49 Librae permit one to determine a wave-



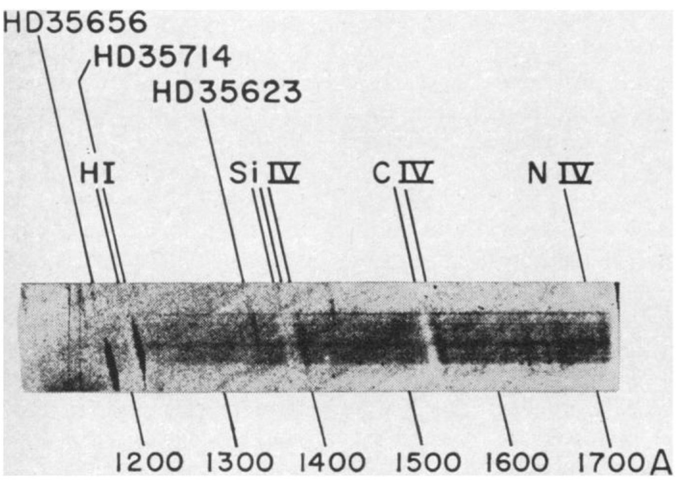


Fig. 6 (above). The ultraviolet spectra of π Scorpii (above) and of δ Scorpii (below).

Fig. 7 (left). The ultraviolet spectrum of ζ Orionis.

length scale to an accuracy of 1 Å, so that the spectral features can be identified. Both stars show the resonance lines of C IV and Si IV and an excited line of He II; also present are several excited multiplets of C III, which have yet to be studied in detail in the laboratory. Of particular interest in these stars are absorption lines of O I, C II, Si II, and Al II, which are all rather low states of ionization for such hot atmospheres; the lines, probably originating in the interstellar medium, give the first direct information on the abundances of these elements between the stars (*16*).

Spectra, longward from 1200 Å, of six OB stars in Orion were obtained on 13 October 1965 with a camera having a lithium fluoride corrector. The spectrum of the O9.5Ib supergiant ζ Orionis is reproduced in Fig. 7; the zero-order images at the left show that the pointing was not quite so good as on the first flight; the resolution is about 3 Å. Nevertheless several remarkable features are visible. The Lyman-α line due to interstellar absorption by hydrogen atoms may be seen beside one of the zero-order images; the position of this line confirms the wavelength scale determined from the zero-order images. The width of the Lyman-α line corresponds to only one-tenth the number of H atoms expected from the 21-cm radio emission in this direction.

The resonance-absorption doublet of Si IV and the unresolved doublet of C IV appear further to the right. Emission lines appear on the long-wavelength edges of these absorption lines; it is the wavelengths of the emission lines that agree with the laboratory values. The absorption lines are shifted to shorter wavelengths by some 9 Å; this shift corresponds to a velocity of 1900 kilometers per second toward the earth. These resonance lines must be formed in an expanding shell of gas around the star, the implication being that the star is losing mass, returning to it the interstellar medium from which the star once formed.

The other two supergiant stars, δ Orionis, O9.5 II, and ε Orionis, B0Ia, which with ζ Orionis form the belt of Orion, also show the displaced Si IV and C IV absorption lines. Consequently we suggest that this observed loss of mass was not by chance and that the loss is a continuous phenomenon typical of all hot supergiants. The presence of expanding atmospheres around the B0- and O-type supergiants had been suspected earlier (*17*) from several weak and very broad features observed in the part of the spectrum accessible to ground-based instruments. Nevertheless the ultraviolet observations are of tremendous value in confirming unmistakably the earlier inferences and permitting a quantitative estimate of the rate of mass ejection. The full implications of these ultraviolet spectra are yet to be worked out in terms of models for the outermost layers of O and B stars.

Within the past year additional ultraviolet stellar spectra have been obtained by several investigators using various techniques. During the flight of Gemini 11 on 14 September 1966 the astronauts photographed a number of stars longward of 2200 Å, with 15-Å resolution. According to Henize, Wackerling, and O'Callaghan (*18*) Canopus

(F0Ib) shows absorption lines of Mg I, Mg II, Si I, Fe I, and Fe II below the earth's atmospheric cutoff, while in Sirius (A1V) the main feature is the Mg II resonance doublet. On 20 September 1966 Jenkins and Morton (*19*) flew an all-reflective *f*/2 spectrograph on an Aerobee rocket, and obtained spectra of eight stars in Orion with about 1-Å resolution. These photographs confirmed the earlier results of the wavelength shifts in the C IV and Si IV absorption lines and the unexpectedly weak interstellar Lyman-α lines. The wavelength range was extended to 1130 Å and revealed absorption lines of N V, Si III, and C III also shifted to shorter wavelengths in δ, ϵ, and ζ Orionis. During four Aerobee flights Stecher (*20*) has scanned the spectra of at least ten hot stars with 5- and 10-Å resolution longward of 1100 Å. He also has found the C IV and Si IV resonance lines to be in emission with absorption components to shorter wavelengths in some of the stars. On an Aerobee launched on 16 March 1967 Carruthers (*21*) used a windowless image intensifier to photograph spectra of some 12 stars from 1030 to 1400 Å with 2- to 3-Å resolution. He confirmed the shifts of some of these lines in ζ Orionis and found the same phenomenon in ζ Puppis, γ Velae, and ι and κ Orionis. Both the spectral data and photon counters lead him to suggest that the photon flux decreases shortward of 1150 Å even in the hottest stars.

Summary

According to theories of model stellar atmospheres only stars of spectral types from O to about B3 may be expected to be bright in the ultraviolet-wavelength region. Observations of the strong resonance lines between 911.6 and 1900 Å will yield new information permitting construction of better models for the outermost layers of OB stars. However, an adequate theory of line-formation, including non-l.t.e. effects, should be used if an accurate physical representation is to result. Already it has been demonstrated beyond doubt that O and B0 supergiants are surrounded by expanding atmospheres.

The spectrum between 1900 and 3000 Å is formed chiefly in the same layers of the star as is the part of the spectrum observed with ground-based equipment; consequently, ground-based observations can be used to establish an adequate model. With such a model, observations of the absorption lines due to the first and second ions of the metals should permit new and reliable determinations of the abundances of Fe, Cr, Mn, and Ti in B stars.

The photometric and the spectral observations so far available of O and B stars do not generally conflict seriously with the predictions of theory, provided that we use line-blanketed models for the comparison and that we correct for the effects of interstellar reddening when necessary.

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Causality, Consciousness, and Cerebral Organization

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Psychology has been largely, if not exclusively, regarded as being in the domain of philosophy, and, until recently, reference to the brain as the substrate of psychological function was infrequent. It should be admitted that regional differences of approach exist; for example, in the United States psychological concepts are influenced more by the natural sciences than they are in tradition-bound Europe. The works of Herrick (*1*), Lashley (*2*), and Hebb (*3*), the publications of the experimentally oriented Canadian neurosurgeon Wilder Penfield (*4*), and more recent noteworthy works of Klüver (*5*), Ploog (*6*), Delgado (*7*), MacLean (*8*), and others are significant in this connection. On the other hand, it is surprising that the physiologists show some reluctance to teach psychological concepts. More than a minimum knowledge of the relationship between brain and psychological function is essential for students in biology and medicine, both because this function plays a role in the biology of men and the other higher mammals and because such knowledge is necessary for an understanding of mental illness. For all these reasons, an effort to survey psychological problems in biological perspective seems justified.

If a series of events relating to our past experience comes to our attention, we feel compelled to look for a causal

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