SPECTRAL CLASSIFICATION FROM COPERNICUS DATA

William P. Bidelman*
Warner & Swasey Observatory-CASE WESTERN RESERVE UNIV.
Cleveland, Ohio, U.S.A.

ABSTRACT. The suitability of Copernicus U2 spectrometer scans (resolution 0.2 Å, spectral range roughly 1000-1450 Å) for purposes of spectral classification is discussed. The main conclusion is that while many features in the spectra complicate the situation (numerous interstellar features and those related to the phenomenon of mass loss), the general behavior of the lines in the spectra of most of the 22 stars studied is entirely consistent with the presently accepted classifications of these objects. Whether a significant increase in the accuracy of determination of all of the relevant classification parameters can be obtained from this material is not yet certain. It is emphasized that study of the high-resolution Copernicus scans should be of great value for forthcoming classification programs necessarily utilizing spectral data of considerably lower resolution.

You have just seen what Copernicus spectra in the range λλ 1000-1450 look like, and have heard how these simulated photographic spectra were obtained. As has already been said, the homogeneity of the data is best in this spectral region, so when I started to think about the spectral classification problem a year or so ago it was precisely a portion of the material that you have heard described that I started to utilize. It is however true that I had, up to a few weeks ago, access only to the spectral scans and not to the simulated spectra. The spectra are certainly easier to intercompare than the scans, and more thought-provoking, as well. For a comparative qualitative study of the Copernicus spectra, I was fortunate enough to obtain from the Princeton investigators and others involved in the project spectral scans of twenty-two presumably normal stars, all of which had supposedly good spectral types. The stars involved ranged from 9 Sgr to α Cyg, and there was a good representation of both the most luminous supergiants and dwarfs. For the intermediate-luminosity stars the situation was not so favorable, as nothing was available between σ Sco at B1 and ζ Dra at B6; so while I have worked on the giants somewhat I do not propose to discuss them at this time.

*Guest Investigator with the Princeton University Telescope on the Copernicus satellite, which is sponsored and operated by the National Aeronautics and Space Administration.

Edith A. Müller (ed.), Highlights of Astronomy, Vol. 4, Part II, 355-359. *All Rights Reserved.*

Useful work in spectral classification necessitates, as is well known, comparable material covering a wide range of wave-lengths. I do have fairly comparable material, though there are substantial differences in the count rates among the various stars, which, of course, affect the appearance of the scans. The most serious deficiency, however, is the limited spectral range. Since most conventional classification work on the early type stars draws heavily on the lines of hydrogen and helium, it is unfortunate indeed that these lines are essentially unavailable in the material that I have used. The central portions of both Ly α and Ly β are of course completely dominated by interstellar absorption, and only the profiles of the far wings can occasionally give any useful information. No neutral helium lines are present at all, and the only available He II line, at λ1085, is hopelessly blended with N II.

When you ask a spectral classifier to classify one of your spectrograms, he is quite apt to excuse himself from giving a definite answer on the grounds that he "is not used to that dispersion". And further, if the spectral region is not just the one that he has specialized in, he will probably refuse to even hazard a guess. In discussing the Copernicus data both of these excuses come in handy! The resolution of the material is comparable to that of earth-based coudé spectrograms, and the spectral region is certainly novel. Since it is unlikely that we will be obtaining similar high-resolution scans for many fainter or previously unclassified stars, at least in the foreseeable future, I have not attempted to set up a classification scheme as such, in the way that Miss Maury and Miss Cannon did at the turn of the century, E.G. Williams did in the 30's, and Morgan, Kopylov, Conti, and Walborn have done more recently. What I have rather attempted to do up to now is to simply inquire whether the Copernicus spectra are qualitatively consistent with the spectral types presently assigned. Even this has not been as trivial a question as one might have thought.

When I started this work only one of the stars that I had scans of had been identified, namely the B5 supergiant η CMa (Underhill, 1974). There are by now several other line-lists available, but most of my effort still necessarily has had to go into identifying the spectra. This is nothing new: if you read the old Harvard work you will find that along with their attempts at spectral classification they also measured and attempted identifications of the spectral features that they were using. Miss Maury (1897) writes: "It was necessary to conduct the investigation systematically, by successively comparing each typical star with those most nearly resembling it in the nature of their spectra, in order to avoid errors in the identification of the lines."

Now for a word about the general nature of the spectra. First, they are predominently absorption, rather than emission, spectra, in this spectral range. And second, at least in the earliest types there is a reasonably well-defined continuous spectrum. However, there is a dramatic change in the middle B's, when the lines become so numerous and strong that the continuum disappears and you are left with an excessively choppy spectrum that makes quantitative analysis difficult if not impossible. This phenomenon happens earlier and is much more prominent in the more luminous stars, and generally resembles the situation in the conventional spectral region when one goes from A-type stars toward those of

https://doi.org/10.1017/S1539299600003579 Published online by Cambridge University Press

later types. The amount of line-blocking in the λλ1000-1500 spectral region is surprising, though anticipated (see Gaustad and Spitzer, 1961).

Now for some details. When one takes a casual glance at those simulated spectra one is struck by a considerably greater-than-expected diversity in their appearance. For this diversity differences in atmosperic temperature and pressure are only partly to blame: there are two additional factors that one does not have to contend with in the usual spectral range that are extremely important in the ultraviolet: (1) interstellar features, and (2) spectral features associated with mass loss. Since others are working on both of these things, I hesitate to say much about them, but in view of the important role that they play in the appearance of the spectra I feel bound to say something.

As previous work by the Princeton investigators has shown, there are a very large number of interstellar atomic and molecular hydrogen features in this spectral range and they can be of very substantial strength. In the earliest stars the majority of the most noticeable features in the spectra are apt to be interstellar. Shortward of λ1100 the H_2 absorption can drastically change the whole character of the spectrum. Once recognized it can be allowed for, but it is an unfortunate and important nuisance nevertheless. And the interstellar atomic lines are even worse, as they occur over the entire spectral range and are in many cases exactly the same lines that can be strong in a star as well. For example, carbon, nitrogen or silicon lines can be of interstellar origin in the earlier types and stellar in the later B's. In very broad-lined stars the interstellar features can be distinguished by their sharpness, but in the stars that I have been studying this doesn't work as most of my objects are fairly sharplined. Thus, one must rely on the fact that only the lowest-level lines will show up in interstellar space, as well as on good judgment as to what the physical conditions in the star are. The three N II lines near λ1085 are very helpful in this connection as their intensities reverse between interstellar and stellar conditions. I would warn anyone using these spectra that even little-reddened but moderately distant stars like 10 Lac, 15 Mon, or λ Ori can exhibit very prominent interstellar lines. A further cautionary word is that there is little correlation between the strenghts of the atomic and moelcular interstellar features. Luckily, in nearby dwarfs like γ Peg the interstellar lines appear to be essentially absent, except, of course, for hydrogen. I should add that in my material I have seen no evidence for sharp circumstellar--as distinct from interstellar--features.

The second thing that strongly affects the appearance of the spectra is the occurrence of broad longwarded-displaced emission and shortward-displaced absorption that is associated with very strong, mainly low-level, lines in the earlier and more luminous stars. This phenomenon is very marked in the supergiants, and can be seen nicely in S IV at λ1070, C III at λ1175, N V at λ1240, and Si IV at λ1400 in α Cam. However, it exists for other ions and in stars of somewhat lower luminosity as well. I will say nothing further about this, except to stress that one must be on the lookout for features of this sort. The strenghts of these emissions and displaced absorptions can, I think, be considered a luminosity criterion to the same extent as the somewhat similar phenomenon observed at Hα in the more luminous early type stars, i.e. as suggestive but not absolutely conclusive evidence of high luminosity.

Let me now turn to the problem of identifying the stellar lines. Happily, the resolution of the Copernicus U2 spectrometer is sufficiently high that blending is not a severe problem except in the later B stars; the wavelenghts can be read off the scans with an accuracy of .2 A or better, permitting line identifications to be done with fair ease. One finds quickly, however, that one needs all of the atomic data presently available, and then some. After plausibly identifying as many of the lines as one can, one still finds that perhaps 10% or so of the stronger lines are still unidentified. One can usually, of course, find a line in Kelly and Palumbo at the right wavelength, but it probably isn't the right line. I was at first very excited to find, for example, that the strongest line of Li II in this region, at λ1198, seemed to be in several of the hotter stars, but this line, which is the analogue of the well-known λ3889 line of neutral helium, arises from 59 e.v. and one may suspect that the identification is, to say the least, doubtful. In general I would say that the identifications, at least in the stars that I have studied, can be done with some conficence without the necessity of going to any exotic elements. The higher stages of ionization of elements like C and Si, N and P, and O and S account for many strong lines. Si III is much in evidence in the somewhat cooler stars. In the O-type stars we find many strong lines of Fe V and some of Ni IV (Fe IV is apparently inadequately studied in the laboratory). The great complication of the spectra of the middle and later B's is primarily due to the appearance of strong lines of Cr III and Fe III, along with a few of Mn III and Ti III. I have not attempted identifications as late as B8 but it may be safely assumed that the singly-ionized metals would account also for many lines there.

Finally, at last, to the problem of spectral classification. As yet I have studied carefully only spectra in the range O9-B5. I have carefully intercompared the supergiant sequence, the dwarf sequence, and the stars of differing luminosity with each other. My over-all conclusion is that the general behavior of the lines in most of the stars is entirely consistent with the presently accepted classifications of the stars. P V, C IV, Si IV, C III and N III weaken as one goes to later types, C II, N II, Si II, C I and N I strengthen. Si III goes through a maximum as one would expect. The lines of the metals behave just as anticipated. As far as luminosity is concerned, the wings of Ly α are much wider in the stars of low luminosity, at least in the later types. There is a general tendency for most of the lines to be substantially stronger in the supergiants than in the dwarfs, the same phenomenon that we see in the usual spectral region but at later spectral types than here. But at the same spectral type the level of ionization is evidently somewhat higher in the supergiants, as the lines of lower ionization potential tend to be stronger in the lower-luminosity stars.

The question of abnormal abundances in the CNO group is a matter of considerable current interest, and the ultraviolet spectra might be expected to shed some light on this matter. According to Walborn (1976) ρ Leo is somewhat nitrogen-enhanced and ε Ori somewhat nitrogen-deficient. Neither of these things is entirely obvious in my material, though such effects could easily be masked by slight differences in temperature and pressure among the stars being compared. As E. G. Williams (1934) well said: "There seems to be no line in type B suitable for classification purposes which is independent of luminosity." More marked elemental abnormalities should be more noticeable. This is not to say that everything is entirely clear. There are a few features in the spectra that defy easy explanation. I do not really understand the rather marked differences in the appearance of Ly α seen in some of the simulated photographic spectra. From a preliminary inspection the spectrum of ζ Dra seems rather peculiar, as the neutral C and N lines seem too strong for its spectral type. Originally noted as peculiar in the Yerkes Spectral Atlas, this star has been recently classified B6 III. ρ Leo may also be a bit odd in some ways. But I prefer to emphasize the normalities in the data rather than the abnormalities.

I would like to close with a word about work at lower resolutions. It is evident that the very-high-resolution data that I have been discussing will be mainly utilized for studies of the individual stars involved, and it seems very likely that substantial programs of spectral classification in the ultraviolet will in fact be done with data of considerably lower resolution. Consequently the chief application of the present work to that problem may well be in the assistance that the Copernicus data can give in determining the spectral features involved in the necessarily badly-blended spectra observed at lower resolution. We must thus, whether stellar astrophysicisists or workers in spectral classification, be enormously grateful for the splendid spectroscopic material that all those involved with Copernicus have made available to today's and tomorrow's astronomers.

Acknowledgements

The writer is happy to acknowledge that this investigation was suggested, encouraged, and greatly assisted by Drs. Donald G. York and Theodore P. Snow, Jr. of the Princeton Copernicus project. He is further indebted to the University of British Columbia's Department of Geophysics and Astronomy, where part ot the work was carried out, and to Barbara Lysakowski, in Vancouver, and Nancy Smith, in Cleveland, for substantial help in the analysis of the data.

References

Gaustad, J. E. and Spitzer, L.: 1961, Astrophys. J. 134, 771.
Maury, A. C.: 1897, Harvard Ann. 28, 3.
Underhill, A. B.: 1974, Astrophys. J. Suppl. 27, 359 (No. 249).
Walborn, N. R.: 1976, Astrophys. J. 205, 419.
Williams, E. G.: 1934, Publ. Astron. Soc. Pacific 46, 292.