FUTURE OBJECTIVE-PRISM SPECTRAL CLASSIFICATION AT MK DISPERSION

Nancy Houk

University of Michigan

ABSTRACT

A brief review and summary of results from Volumes 1 (-90° to -53°) and 2 (-53° to -40°) of the University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars is given. Plans for the classification of the remaining southern HD stars are outlined. Future plans for observation and classification of northern stars are discussed, including the problem of whether to limit such classification to the HD stars. More general remarks about spectral classification in the future, especially for fainter stars, conclude the paper.

At Michigan the Henry Draper stars are being systematically reclassified on the MK system, using objective-prism plates (IIaO) of excellent quality taken with the Michigan Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory. The 10°-prism combination yields a dispersion of 108 Å mm^{-1} and a resolution of 2 A, a close match to the original MK resolution, and spectra are widened to .8 mm. Stars from δ = -90° to -53° were published in Volume 1 of the Michigan Spectral Catalogue (Houk and Cowley 1975), which contains 36,400 HD stars. Volume 2 (Houk 1978), δ = -53° to -40° , contains 30,400 stars. Both are available on magnetic tape from Goddard Space Flight Center (Code 601). More details about the project may be found in the preface to Volumes 1 and 2.

For greater consistency the spectra are classified visually by a single classifier. About half of the spectra, including most of those of types B and A, are compared directly with MK standard spectra. Internal errors for Volumes 1 and 2, derived from stars classified independently on two or more plates are given in the upper part of Table I. Note that they are very consistent; I may not be

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TABLE I

INTERNAL AND EXTERNAL ERRORS

A. Internal Errors, Upper Numbers: Volume 1, Lower Numbers: Volume 2

Temperature			Luminosity		
Quality	No. of Classif.	σ	Quality	No. of Classif.	σ
1 + 2	5053 4039	±.41 .41	1 + 2	5039 4037	±.28 .27
3 + 4	550 644	.62 .59	3 + 4	385 490	.33 .33
all	5603 4683	.43 .44	all	5424 4527	.28 .28

B. External Errors

Comparison with R. F. Garrison

N = 75 stars

$\sigma_{temp.} = \pm.63$

$\sigma_{lum.} = \pm.45$

improving but at least I am not getting sloppy! The external errors derived by comparing 75 stars in Volume 1 which both Garrison and I had classified are given in the lower half of Table I. Garrison has done a much larger and much more complete comparison of Volume 1 results for early type stars and arrived at almost exactly the same figures. Both the external and internal errors are similar to those obtained doing careful classification of slit spectra.

Before turning to the future I would like to present some preliminary results from Volume 2, including comparisons with Volume 1.

The distribution by temperature and luminosity types of the normal stars in Volume 1 (upper numbers) and Volume 2 (lower numbers) is presented in Table II. Eighty-seven percent of the stars in Volume 1 and 88% of those in Volume 2 are included here. Nine percent of the other stars are peculiar or have no luminosity types, the remainder being unclassifiable on Michigan plates.

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TABLE II

THE DISTRIBUTION BY TEMPERATURE AND LUMINOSITY TYPES OF NORMAL STARS

Upper Numbers: Volume 1
Lower Numbers: Volume 2

	05-B4	B5-B9.5	A	F	G	K	M	A11
I	115	98	29	62	56	14	28	402
	94	89	20	12	15	5	5	240
II	136	554	101	106	105	170	32	1204
	106	308	115	31	82	86	21	749
III	345	1125	810	384	1923	6130	902	11619
	175	554	672	178	2000	5519	727	9825
IV	98	890	1709	1325	715	166	0	4903
	100	500	1313	698	585	142	3	3341
V	237	1905	4529	4799	1708	250	5	13433
	137	1291	3936	5308	1880	243	12	12807
A11	931	4572	7178	6676	4507	6730	967	31561
	612	2742	6056	6227	4562	5995	768	26962

One of the most conspicuous patterns is the tremendous drop, in Volume 2, in the number of supergiants of types F through M. In this case Volume 2 is probably reflecting more 'normal' percentages while Volume 1 contains unusually large numbers. Another striking difference is that the number of O and B stars is down sharply from Volume 1, especially the giants and lower luminosities. This drop is also reflected in the number of emission stars (from 150 in Vol. 1 to 70 in Vol. 2) and the broad-lined stars (from 300 to 100).

Note that the numbers of supergiants in Table II include my type I/II, half being put into I; thus the I totals are somewhat inflated. The actual numbers of definite I's are 281 for Volume 1 and 161 for Volume 2. As was indicated in an earlier publication (Houk, Hartoog and A. P. Cowley 1976) many of our supergiants are newly discovered, or at least not in major compilations of spectral types. In Volume 1, 44% of the supergiants were new. In Volume 2 about 30% are new, even though the same plates were earlier searched for supergiants (Bidelman and MacConnell 1976). For those of type FO and later about 60% are new, the same percentage as in Vol. 1, though the numbers involved are much smaller.

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The numbers of peculiar stars and a comparison between Volumes 1 and 2 will be given in a future paper. Just one comment before moving on to discuss the future. There are many tens of thousands of spectra involved in this project, but obviously it is vital to just consider each star on its own and to stay alert and ready for any surprises it has to offer. Even in the case of the ubiquitous K giants and late G giants one must not take them for granted. In Volumes 1 and 2 combined there are about 15,500 of them, comprising nearly one quarter of the stars classified, and more than 5% have something peculiar about them.

Although the title of this paper is "Future Objective-Prism Spectral Classification at MK Dispersion", I will here be restricting the discussion to my own plans and hopes. Because of the topic of this colloquium I have attempted, in Table II, to project more than a quarter of the HD stars have been classified, and this represents more like half of the work and time. More than 10% of the stars for Vol. 3 have already been classified and I think that the 1980 completion date is fairly firm. Vol. 4 will be the largest of all, so I have assumed three years for it. When it is finished between 2/3 and 3/4 of the HD stars will have been classified.

As shown in Table III each northern declination zone contains less than one half of the stars in the corresponding southern zone. The last three projected volumes, from $\delta = -10°$ to $\delta = +90°$, should take a total of 5 or 6 years at most. Of course, by then we may have made some different decisions about how to handle the northern sky. Several people are pressing to have us include fainter stars than those in the HD, which we could do with the plates that would be available. I am currently inclined to finish off the HD stars first, especially since we are set up to do this, with computer output and overlays for HD star identifications all the way to the north pole. After that if eyesight allows and if there is felt to be a real need for classifying the fainter stars to get a limiting magnitude consistent with the southern HD, that could be done.

Plans are nearly complete now for moving the Warner and Swasey Observatory Burrell Schmidt telescope of Case Western Reserve University from Ohio to Kitt Peak, Arizona. This telescope is a twin to the Michigan Curtis Schmidt. For the northern survey the same prisms would be used, brought up from Cerro Tololo, so hopefully the plates obtained would be very similar. It may be possible to use the same very extensive collection of MK standard stars of many exposures. Of course, careful sample test classifications would be done, and if necessary most of the standards could be reobserved from Kitt Peak with the Warner and Swasey Schmidt. Regions up to $\delta = +35°$ are being taken from Cerro Tololo and a substantial strip will be retaken from the north to provide sufficient data for intercomparisons. Since the move to Kitt Peak should occur within a year

TABLE III

PLANNED RECLASSIFICATION OF HD STARS

Declination 10° zones	No. HD stars	Cumul. Sum HD	Catalogue Zones	Approx. Stars/Vol	Vol. No.	Completed
-90° to -80°	1519	1519				
-80° to -70°	6195	7714				
-70° to -60°	13772	21486	-90° to -53°	36,400	1	1975
-60° to -50°	21400	42886				
-50° to -40°	23600	66486	-53° to -40°	30,400	2	1978
-40° to -30°	21016	87502	-40° to -26°	31,000	3	1980
-30° to -20°	23036	110538				
-20° to -10°	23780	134318	-26° to -10°	38,000	4	(1983)
-10° to 0°	18699	153017	-10° to +5°	29,000	5	
0° to +10°	15671	168688				
+10° to +20°	11416	180104				
+20° to +30°	9187	189291	+5° to +35°	31,000	6	
+30° to +40°	8836	198214				
+40° to +50°	9803	207930	+35° to +90°	27,000	7	
+50° to +60°	7246	215176				
+60° to +70°	5105	220281				
+70° to +80°	3037	223318				
+80° to +90°	836	224154				

or so there will be plenty of time for such studies. Dr. Bidelman will become reinvolved in the project and my Cleveland contact in forwarding these plans.

Even if the HD reclassification project is never completed as envisioned here, I think that what we have done will be of help in moving to studies of fainter stars in the future. Certainly such fainter surveys will have to be, to a considerable extent, automated and of lower-than-MK dispersion. However, I hope that the principles outlined by Morgan and Keenan will continue to be followed and that a trained and experienced eye -- and brain -- will be around and ready to take a look.

Many people are involved in a project of this scope, and I wish to thank all those who helped prepare the data for this paper. We are grateful to the National Science Foundation for its continuing support. Thanks also to the Vatican for paying expenses, including travel, of my attendance at this colloquium.

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DISCUSSION

Walborn: I think the relatively smaller numbers of O, WR, and supergiant stars in Volume 2 as compared to Volume 1 can be readily understood in terms of the characteristics of the Southern Milky Way. On the low right ascension side the second zone includes the inter-arm region between Puppis-Vela and Carina while on the high right ascension side it includes the relatively poor section of the Milky Way between Crux-Centaurus and the galactic center region.

Houk: Would you then predict a more interesting Volume 3 (-40°0 to -26°0)?

Walborn: Yes, the galactic center region should be very interesting.

Kharadze: The value of the work being realized at Michigan is beyond doubt.

But nevertheless it is a pity that the magnitude limit is only 10. From the point of view of pure stellar astronomy interests, the shift of the limit even by only one or two magnitudes will be a great gain.

We understand, of course, that this may be realized only by decreasing the dispersion and consequently losing accuracy in the classificiation, but when we are dealing with the determinations of parameters for a multitude of stars, statistical problems should be considered in the first place. And in that case the penetration problem stands in competition with the accuracy problem.

In addition there are problems with overlapping spectra, so that one should discuss and decide what might be the optimal dispersion to get the maximum efficiency of classification. My opinion is that the problem remains open.

Houk: It would add a great many more stars to go down another magnitude or two.

Garrison: First, I want to say this this work is, in my opinion, an outstanding contribution to twentieth century astronomy and the amount of work you have put in is very impressive.

Secondly, you mentioned that I also plotted your types against mine to get external errors. The result for about 600 OB stars from the southern survey (Garrison, Hiltner and Schild, 1977, Ap. J. Supplement) is almost exactly the one you quote, less than one subclass. There is an interesting systematic error, which would be good to point out as an illustration. I believe that, as a result of my warning to you, this has been corrected in the final version of Volume 1 or in the corrections, so this remark in no way detracts from the catalog. The effect is that the late O stars which have faint HeII lines and are distant enough to show a K line were misclassified in the HD catalogue as late B or early A giants. The effect is obviously distance dependent. The same effect to a much smaller degree was present in the current catalogue, but I understand that it has been removed. I hope those who classify at low resolution will note this.

Houk: In my case overlapping spectra turned out to be a villain in that too, obscuring the He II 4200 Å line.

Fehrenbach: It seems impossible to increase the limiting magnitude by 2, because the number of spectra to be classified would become too large. It will be necessary to select areas rather than decrease the dispersion. The time spent in classifying is actually the important consideration and not the exposure times.

Houk: I think it partly depends on what you are looking for. I can envision a lower-dispersion automated survey and after that a look at the interesting things with higher dispersion; but then you don't get statistics.

Fehrenbach: You are then looking for stars which are not normal stars?

Houk: Well, how many more normal K giants and G8 III's do you want? There will be 60,000 by the time all the HD stars are classified.

Nandy: From the analysis of S2/68 spectra I found very few B supergiants relative to main sequence stars. Is this true for your sample?

Houk: Yes.

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Nandy: I would like to point out that the spectral classifications which I derived from ultraviolet colors agree well with your MK classifications.

McCarthy: What is the planned overlap of fields to be taken with the Curtis Schmidt in CTIO and the Burrell Schmidt to be erected at KPNO?

Houk: We will take overlapping fields in order to do careful testing to be sure the systems are compatible, and to retake standard plates if necessary, but the results will probably not be mixed in one volume of the catalogue. Curtis Schmidt plates will probably be used up to +35° because of the better seeing at CTIO.

Jaschek: Now that a very large number of homogeneously classified stars has become available through the extremely valuable work of the speaker, I would suggest that the photometrists use this material to test the accuracy of their "photometric classifications."

Blanco: It is well to remark in connection with the planned extension of this beautiful survey to the Northern Hemisphere that the Burrell telescope has had its optical components refurbished recently. Its resolution will be just as good as that of the Curtis telescope; the only difference between the quality of the Southern and that of the Northern survey should therefore be that produced by the difference in average seeing at CTIO and KPNO.

It is also well to mention that an overlap between the Northern and Southern surveys, as supported by McCarthy, will be worthwhile because the Curtis telescope has a plate glass correcting plate while the Burrell telescope will have an ultraviolet transmitting correcting plate. This may result in systematic differences in the spectra of the two surveys.

Houk: We certainly have plans to do extensive studies with overlapping fields before undertaking the northern portion of the survey.