TWO-DIMENSIONAL CLASSIFICATION OF THE HD STARS

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Abstract. The major project of assigning spectral and luminosity classes to the Henry Draper stars south of $+30°$ is underway. The high-quality objective-prism plates have been taken with the Michigan Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory. The spectra, widened to .8 mm, have a dispersion of 108 Å mm^{-1} at Hγ. Plates exposed for 20^m and for $4^m + 1^m$ yield classifiable spectra between 4 and 10 m_{pg}.

Star identification is completely automatic, using a computer-generated plot to the Schmidt plate scale for each plate center. This plot, having the HD stars identified by number, is copied onto transparent material and placed under the Schmidt plate while the stars are visually classified.

Classification is being carried out by one person (N.H.) to maintain a uniform system. MK spectral standards of similar quality and density, also taken with the Schmidt, are continually referred to. Intercomparison of the new types with existing spectral types shows no systematic differences. However, the HD types themselves are systematically earlier in the range A to F.

Stars between the south celestial pole and $\delta = -55°$ are being classified first, with the first volume of results to be published late in 1973. It is expected that the catalogue of spectral types and remarks will be published in 6 volumes containing all HD stars south of $+30°$.

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During the past four years 10° objective prism plates covering the southern sky have been taken with the Curtis Schmidt telescope on loan at Cerro Tololo Inter-American Observatory. Most of the plates have already been scanned for peculiar spectra by Bidelman, MacConnell *et al.* The goal of the present Michigan spectral classification program is to assign two-dimensional spectral types to all stars in the Henry Draper Catalogue south of $+30°$ (the northern limit of the survey planned to be completed from Chile). It is hoped that this material will greatly add to our understanding of galactic structure, percentages of giants and dwarfs in the solar neighborhood, frequency and galactic distribution of both normal and peculiar stars to mention only a few applications. It will provide a moderately accurate spectral class for any individual HD star as well as being useful for statistical purposes.

The high quality plates have a dispersion of 108 Å mm^{-1} at Hγ with spectra widened to 0.8 mm. Because of the overlapping of plates about 25% of all stars appear on 2 or more plates. The 20-min exposures give classifiable images between 7 and 10 mag. $4^m + 1^m$ exposure plates are now also being taken to cover stars in the range 4–7 mag. Because of the excellent seeing in Chile the resolution of the spectrograms is comparable to that of the MK atlas. Multiple exposures of widely differing densities have been taken for the standard stars so that an unknown can be compared to a standard of similar density. 260 standard plates are presently available covering 145 MK types. Figure 1 illustrates some of the spectra so that the reader can get a visual impression of the high quality of the plate material.

An identification chart to the Schmidt scale marking the HD stars on each plate is generated by the Cal-Comp plotter and then copied on transparent Xerox material

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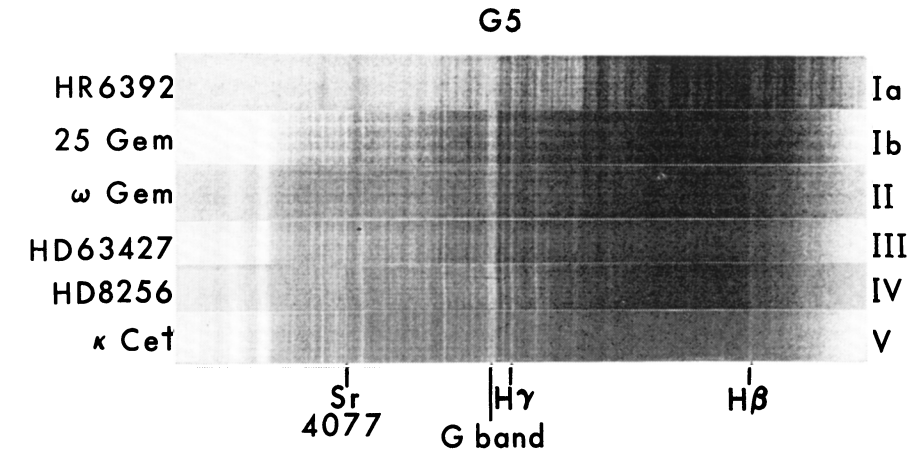

Fig. 1. Some G5 stars. The Sr II 4077/Fe I 4045 and 4063 ratios enable each of these luminosity classes to be differentiated. HR 6392 is a G5Ia standard, but on our plates it is a K0. It may have a somewhat variable spectrum.

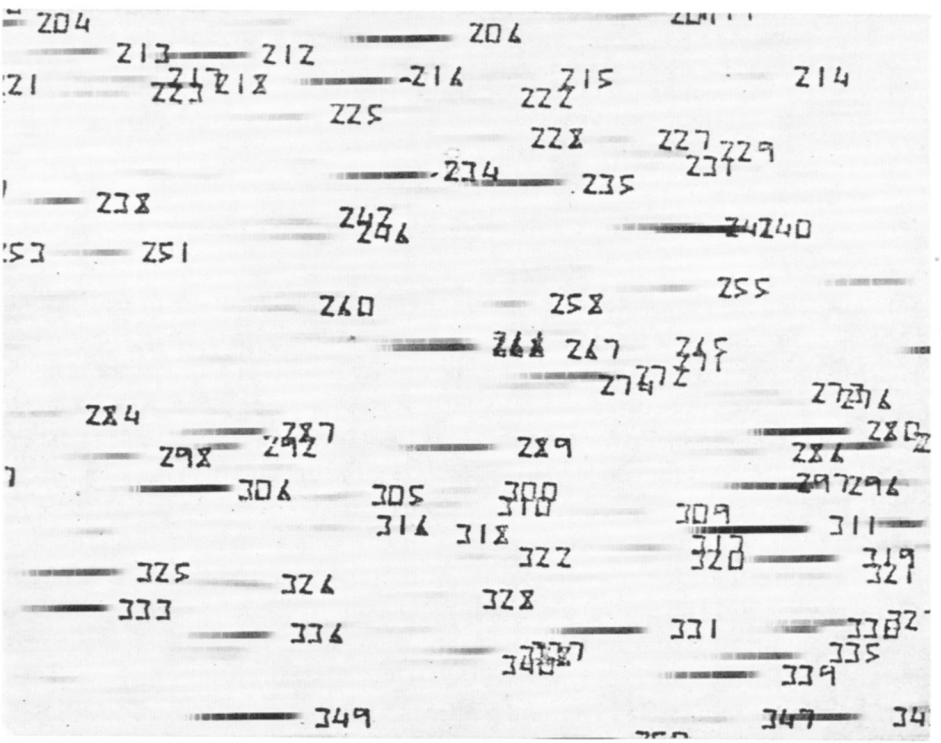

Fig. 2. Sample region $\sim 2° \times 2°$ showing spectra and superimposed identification chart. For each plate the computer generates both an overlay and an accompanying list giving the HD number, position, and magnitude corresponding to the identification number on the overlay.

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to form an overlay. An example of a stellar field with a superimposed identification plot is shown in Figure 2.

The classifications of all stars are now being made by one person (N. H.) to maintain a uniform system. A quality estimate ranging from 1 to 4 is assigned to each star. A description of each quality group is given in Table I. The table also lists the percentage of stars in each quality group for a representative sample. Although there are problems with overlapping spectra, especially in the galactic plane, this does not greatly affect the percentages of stars for which good types can be obtained. The main plate to plate variations arise because the limiting magnitude of the HD varies substantially from one region to another; on some plates there are many faint HD stars while on others almost none. In summary, good spectral and luminosity types should be obtained for 80% to 90% of the HD stars.

TABLE I

In plane (~500 stars)		Out of plane (~1000 stars)	
(1) 50 %	80 %	(1) 55 %	86 %
(2) 30		(2) 31	
(3) 17	20 %	(3) 11⁻	14 %
(4) 3		(4) 4⁻	

(1) Highest confidence; approximately equivalent to slit spectrum of similar dispersion and resolution.
(2) High quality but spectrum somewhat faint or overlapped; in many cases as accurate as group 1.
(3) Faint or overlapped to extent that spectral or luminosity type or both uncertain; range of possible types is often given.
(4) Poor type but better than nothing; usually no luminosity – 'early A', 'K', etc.

Several preliminary estimates of the internal and external accuracy of classification have been made. The first is from stars classified independently on overlapping plates by N.H. In all the comparisons only stars having quality ratings of 1 or 2 were included. Secondly a comparison between A.P.C. and N.H. on the same plates was made. Our agreement is good especially for spectral types (see Table II). This sample includes a large number of A stars for which luminosities are more difficult than for later spectral types. Finally, Morgan, Bidelman and Keenan have given us much valuable advice and stars which have been classified in common with them also show good agreement. Table II also shows comparison with HD types. The standard deviations are large, of course, and in some spectral regions are systematic. The types F2–G0 show relatively small scatter and no systematic differences. There is a large systematic difference between the Michigan types and the HD types for the A stars in the sense that the HD types are *earlier*. However, the scatter is such that no effective corrections to the HD types can be made (see Figure 3). A star classified as A2 in the HD is about equally likely to really be of type A2, A3, A5, A7 or F0. The difference is not magnitude dependent as is shown by Figure 4. There are also systematic differences in the B

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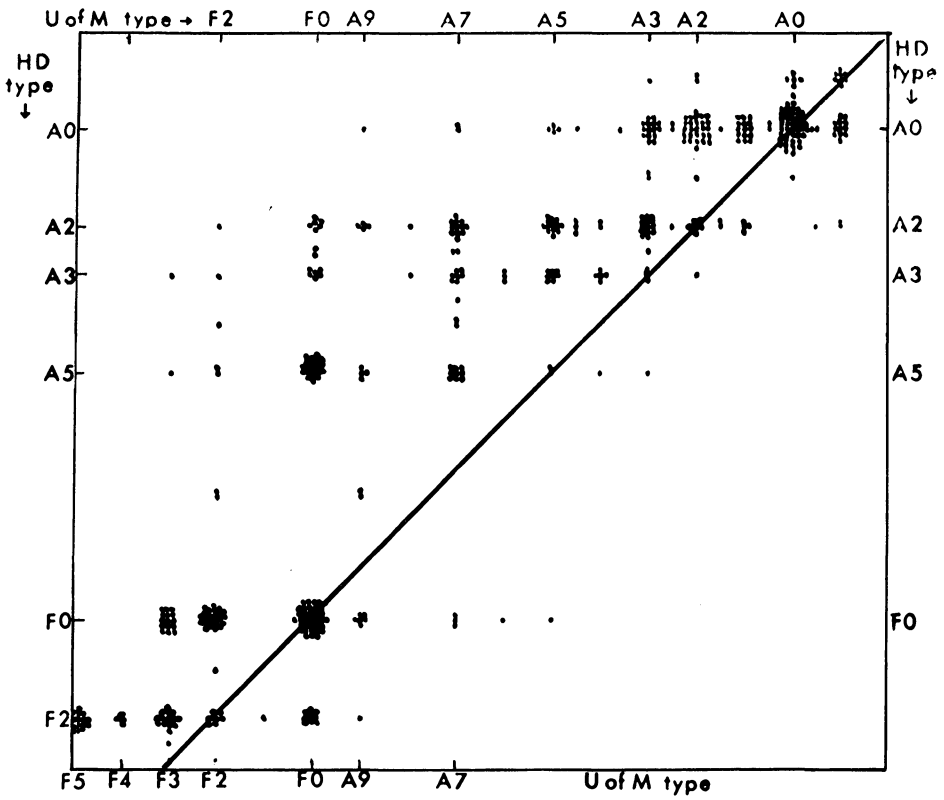

Fig. 3. Comparison of Michigan revised types with HD types for the A stars. Note the systematic difference in the middle A's such that the HD types are earlier.

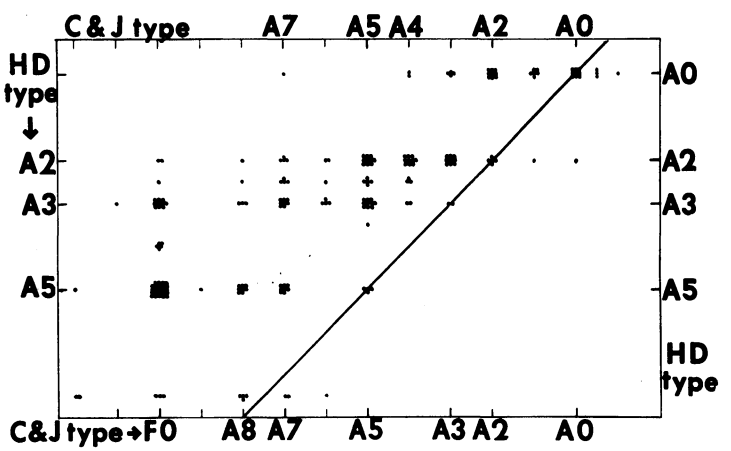

Fig. 4. Comparison of the types for the bright A stars as classified by Cowley *et al.* (1969) compared to HD types. Note the similarity of the systematic difference to that shown in Figure 2.

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stars when the Michigan revised types are compared to the HD types (see Figure 5). The G, K, and M stars show slight systematic differences (see Figure 6) with the HD types being earlier. However the scatter is large. It is of interest that over half of the M stars were classified as K stars in the HD catalogue.

N.H. has examined and classified some of the stars on Miss Cannon's original

TABLE II

$$\sigma = \sqrt{\frac{\Sigma^2}{N-1}}$$

	Spectral type	Luminosity type	N	
NH − NH	±0.13	±0.56	153	
NH − APC	0.10	0.90	93	
NH − HD	0.35 ≤ F0 ±0.38		261	1499
	0.35 F2–G0 ±0.29		493	1499
	0.35 G2–K0 ±0.37		373	1499
	0.35 > K0 ±0.36		372	1499

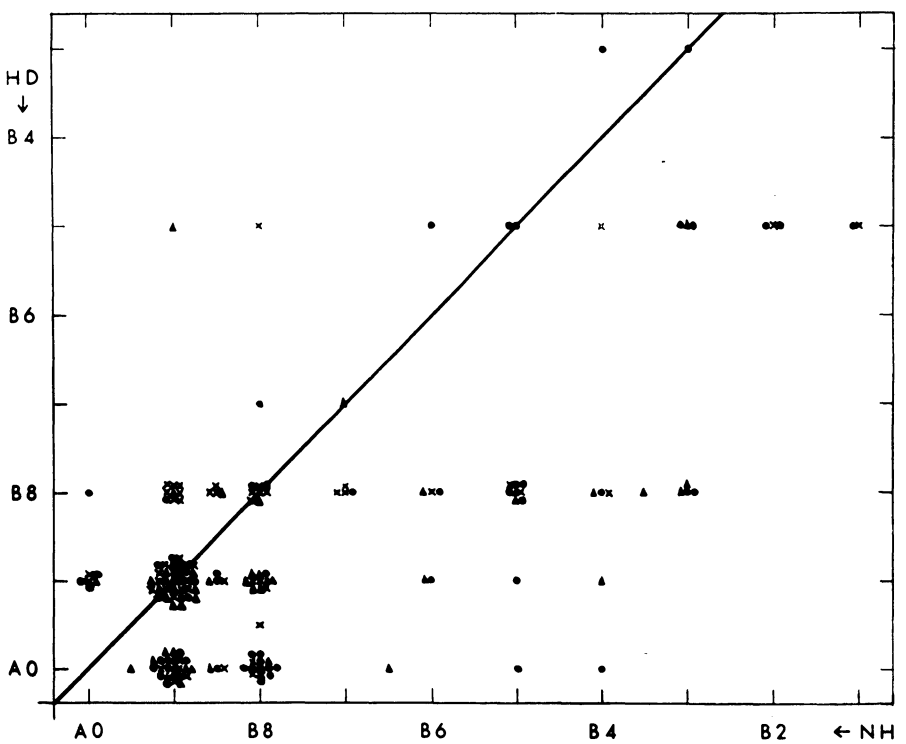

Fig. 5. Comparison of Michigan revised types with HD types for B stars. Note that the HD type B8, in particular, seems to be a catch-all for stars from B3–B9. The crosses are luminosity class III, triangles are IV, and filled circles are V.

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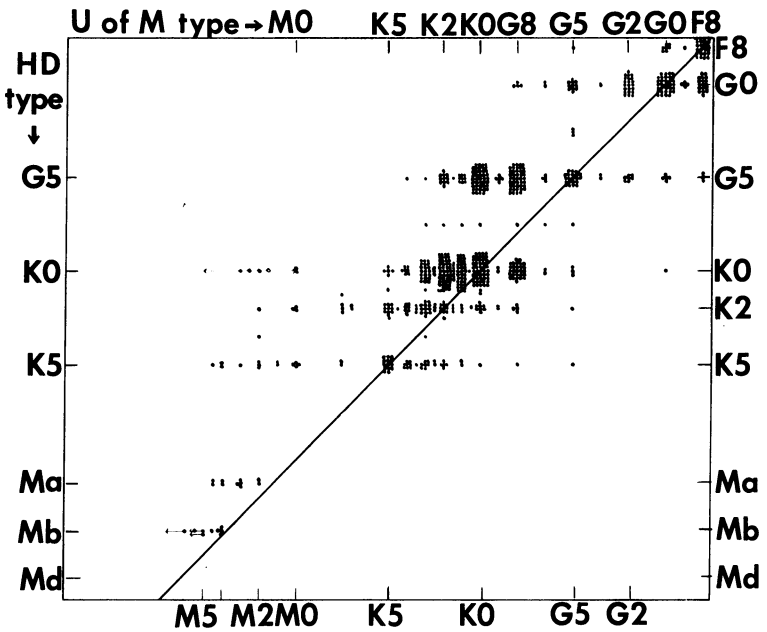

Fig. 6. Comparison of Michigan revised types with HD types for G, K, and M stars. Arrows indicate uncertainties in spectral type for 4 of the stars.

plates at Harvard. About 50 stars, mostly A's, were classified on 5 HD plates having a dispersion of approximately 400 Å mm^{-1}. For the stars which are of high quality on the HD plates the agreement with the types derived from Schmidt plates is good. However for the fainter images N.H.'s classifications from HD plates agree better with the HD types than with Michigan revised types. It is difficult to overstate the problems with focus on the HD plates. Only the central region of each plate is in good focus, and Miss Cannon classified many stars which were quite out of focus. On some no lines at all could be seen. Consequently the HD type may be uncertain even for some strongly exposed spectra.

By the end of September 1971 about 4200 HD stars had been classified from Michigan plates. All of these stars are South of $-55°$ and West of 12 h. According to present estimates all of the stars south of $-55°$ ($\sim$33000 stars) should be classified by mid 1973.

It is proposed that the new spectral data be published as it becomes available in broad declination zones. We anticipate that six volumes will be published containing all HD stars South of $+30°$. Some data, such as coordinates, magnitudes, etc. will be included in the catalogue in addition to the HD number, Michigan revised spectral types, quality estimates, and remarks about the spectrum.

We sincerely hope that it will be possible to extend the observational material to the North Celestial Pole so that the catalogue will be complete.

Acknowledgements

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