Accurate Spectral Classification by Objective-Prism Techniques

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The objective-prism spectrograph or prismatic camera has been described by Newall (1910) as a truly remarkable optical instrument that utilizes a star for a slit and the Universe for a collimator. Obviously one must be rather circumspect in discussing the use and limitations of such an impressive piece of equipment!

It would appear that a great many astronomers think of the objective prism as a fine instrument for spectral surveys but are inclined to feel that results obtained through its use are of value largely, if not entirely, for "statistical purposes", whatever that rather vague term may mean. It is the purpose of this paper to encourage consideration of the objective-prism technique as one that permits the *accurate* classification of stellar spectra, by which I mean that information derived from its use can be accepted with considerable confidence without the necessity of further confirmation by slit-spectrographic observations.

The main reason for prevailing ideas of the rather low accuracy of objective-prism work lies, no doubt, in the extensive current use of very low dispersions; these, of course, permit the derivation of data concerning faint stars. Yet it was not always so. It is worth pointing out that the dispersion employed in the first comprehensive photographic survey of stellar spectra—the *Draper Catalogue* (Pickering, 1890)—was approximately 160 Å/mm, and that the early Harvard work on the brighter stars by Miss Maury (1897) and Miss Cannon (1901, 1908, 1911) utilized spectrograms ranging in dispersion from 11 to 50 Å/mm. In fact, all of the stars in the entire sky brighter than fifth magnitude, and about 3000 fainter stars as well, were classified at Harvard at dispersions no lower than 50 Å/mm rather more than 50 years ago! This is a remarkable fact which, I think, is not generally realized.

It is true that in the preparation of the *Henry Draper Catalogue*, and especially its *Extension*, and the Potsdam and Bergedorf work on faint Selected Area stars, preference was necessarily given to the use of lower dispersions. The objective-prism activities of most modern Schmidt telescopes are a continuation of this trend.

There have, however, been a few exceptions. Shapley, Mrs. Rieke (1935), Miss Hoffleit (1950), and others at Harvard, have made extensive use of objective-prism spectrograms of 45 Å/mm dispersion for absolute magintude investigations along the lines of the early Mount Wilson and Swedish work. I may add here that unfortunately this Harvard work has been to some extent ignored by many of the present workers in this field. Rimmer (1925, 1930) and Edwards (1930, 1932) did similar work in Australia and England, at even higher dispersion. But the work that has done the most to convince the writer that moderate-dispersion objective-prism work has very real merit was that done at Harvard some years ago by Miss Walther (1949) and Zirin (1951) on the spectra of the abnormal A-type stars. This work was done at dispersions of the order of 90 Å/mm at Hγ. The two authors together listed a total of 107 stars of the peculiar A and metallic-line types. Several years ago K. D. Abhyankar and I observed 95 of these objects with a slit spectrograph attached to the Lick 36-in. refractor. Comparison of our types with those given by Miss Walther and Zirin was most satisfactory; a brief summary is given in the accompanying table:

Walther	*Abhyankar and Bidelman*
Ap = 41 stars	40 Ap, 1 Am
Am = 4 stars	all 4 Am
Zirin	*Abhyankar and Bidelman*
Ap = 39 stars	26 Ap, 4 Am, 9 probably normal
Am = 11 stars	all 11 Am

The promise of this type of work is evident. It may be added parenthetically that Miss Walther's work was only part of an extensive and very careful investigation devoted to the application of the MKK system to objective-prism material; very unfortunately the bulk of her work was never published.

At present to my knowledge only three observatories are using moderately high-dispersion objective-prism equipment: Haute-Provence, the Vatican, and Michigan. Fehrenbach has used dispersions of the order of 80 and 110 Å/mm for spectral classification in conjunction with his radial-velocity work and extensive lists of classifications are now appearing in the *Haute-Provence Observatory Publications*. The Vatican Observatory work with their 12°-prism combination has just begun. Finally, there is the 24-in. Curtis Schmidt of the Observatory of the University of Michigan, which can be equipped with a 10°-prism combination affording a dispersion of 108 Å/mm at Hγ. The principal work done with the Michigan 10°-prism combination has been that by Yoss (1961) in which MK spectral types and CN-band strengths of 684 G8-K2 stars were determined. I do not wish here to discuss the accuracy of Yoss's work—I doubt whether sufficient slit spectrographic material presently exists for this purpose—but I am including in this paper a few illustrations that will serve to demonstrate the quality of the spectrograms obtainable with the Michigan instrument.

First, however, a few words concerning techniques. For spectral classification it is important that the spectra be well widened. Further, relatively fine-grained plates should be used and these must be developed with care. The best results with the Curtis Schmidt have been obtained through the use of Kodak IIa-O emulsion developed as suggested by W. W. Morgan. In another regard, the impression seems to be current that the seeing must be exceptionally good to permit good results to be obtained with objective-prism instruments. For the Curtis Schmidt, at least, this is not strictly true. The scale of this telescope is 97″/mm, so a 2″ stellar seeing disk extends over a distance of only approximately 20μ at the focus, and thus its size is comparable with the plate grain. Twenty microns corresponds to approximately 2 Å in the spectra. Hence only moderately good, and not exceptional, seeing is required. It must be admitted, of course, that the overall migration of the image is generally quite a bit larger than the seeing disk, due to a variety of causes, with the result that long exposures are almost inevitably somewhat poorer than short ones.

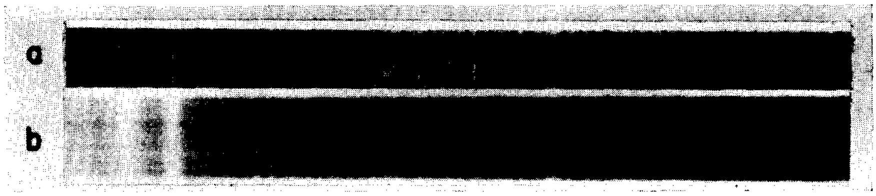

FIG. 1. Slit (a) and objective-prism (b) spectra of γ Comae, a $\lambda 4150$ star of type K1 III–IV. The dispersions are 150 and 108 Å/mm at Hγ, respectively.

FIG. 2. Slit (a) and objective-prism (b) spectra of the Sr-Cr star 21 Comae. The dispersions are 76 and 108 Å/mm at Hγ, respectively. The Sr II lines are indicated.

FIG. 3. Slit (a) and objective-prism (b) spectra of the metallic-line star HR 4751 = 17 Comae (B). The dispersions are 76 and 108 Å/mm at Hγ, respectively.

FIG. 4. Slit (a) and objective-prism (b) spectra of 12 Comae, a star showing a composite spectrum. The dispersions are 76 and 108 Å/mm at Hγ, respectively. The G band, characteristic of the spectrum of the later-type component, is indicated.

Figures 1 through 4 permit a direct comparison of spectrograms taken with objective-prism and slit equipment. Each contains two reproductions of the spectrum of the same star. The Curtis Schmidt spectra were all taken from the same plate, a 3-min exposure on IIa-O emulsion. The 150 Å/mm slit spectrogram of γ Comae (Fig. 1) was obtained with the Lick 36-in. refractor on a IIa-O plate, the 76 Å/mm slit spectrograms of the other three stars with the McDonald 82-in. reflector on 103a-O film. The very high quality spectra obtainable with the objective prism is evident from these illustrations, and it is clear that for purposes of spectral classification, at least as carried out by conventional visual inspection methods, the best Curtis Schmidt plates are only slightly inferior to slit spectrograms of the dispersion generally used for this type of work. This suggests that one should seriously consider using objective prisms rather than slit spectrographs for large-scale classification programs of moderately bright stars.

A few years ago a large number of excellent spectral plates were taken with the 10°-prism combination of the Curtis Schmidt by several observers working under the direction of Dr. Freeman D. Miller. It was originally planned to obtain complete coverage around the sky at four declinations: +57°, +53°, +27°, and +23°. Unfortunately the program was not carried to completion; the +57° zone is about 83 per cent complete, the +53° zone only 56 per cent complete, and the other two zones are only about 25 per cent complete. Altogether, good plates are available for a total of 105 circular fields, each about 5° in diameter. As there is considerable overlapping, the total area covered is probably about 1500 square degrees. For 65 fields both 10-min and 30-min exposures are available; the remainder have either one or the other. The useful limiting magnitude on the 30-min plates is near $m_{pg} = 9{\cdot}5$.

About a year ago the writer surveyed this material searching for peculiar A and metallic-line stars. The results of this search were as follows: a total of 62 peculiar A stars were found, of which 46 appear to be new discoveries. Three of these are brighter than magnitude 6·5, 14 are between magnitude 6·5 and 8·0, and 29 are fainter than magnitude 8·0. A total of 82 metallic-line stars were detected, of which 66 appear to be new discoveries. Seven of these are brighter than magnitude 6.5, 26 are between magnitude 6·5 and 8·0, and 33 are fainter than magnitude 8·0. More than half (26 stars) of the newly-discovered peculiar A stars belong to the silicon star group, while 15 of the metallic-line stars were designated as δ Delphini stars, in which the difference between the metallic-line type and the K-line type is rather small, the detection of these stars is rather difficult (even on slit spectrograms!) and hence a number of these attributions may be incorrect. The newly-recognized Ap and Am stars are listed in Tables 1 and 2, respectively. The photographic magnitudes are taken from the *AGK*2. In Table 2 a "δ" indicates probable membership in the δ Delphini class. Some of these stars may prove to be of considerable photometric interest.

For the most part no slit spectrograms are available for the stars listed in Tables 1 and 2, but it is hoped that the majority of the objects have been correctly classified. One of the stars found, HD 3473, appears to be of special interest; its spectrum is shown in Fig. 5. In addition to an extraordinarily strong blend due to Si II at $\lambda\lambda$ 4128–31, Mg II λ 4481 is also present in considerable strength. This is unusual for a silicon star, as Mg II is customarily rather weak in the spectra of these objects. Measurement suggests that a number of additional Mg II lines, notably λ 4740, are also present in surprising strength. If this star proves on further study to have

TABLE 1
NEW PECULIAR A STARS

Name	α (1900)	δ	m_{pg}	Type	Remarks
	h m				
HD 573	0 5·1	+24°59′	9·1	Cr–Eu	
2852	0 26·8	53 24	8·8	Sr–Eu	
2887	0 27·1	54 40	8·3	Sr–Cr	
3200	0 30·2	55 10	7·6	Si	
3473	0 32·6	50 55	8·8	Si–Mg	
7341	1 8·5	52 29	9·1	Si	
8892	1 22·6	51 22	8·5	Si	
10320	1 35·8	56 41	8·1	Si	
11140	1 44·5	53 34	8·4	Si	
18410	2 52·4	53 56	8·6	Si	ADS 2254
20662	3 14·5	52 21	7·8	Si	
22316	3 30·5	56 37	6·2	Cr:	HR 1094 (1)
25215	3 55·2	52 29	8·4	Si	
26792	4 9·2	56 56	6·5	Sr	
29371	4 32·5	57 41	7·3	Si	
29762	4 36·2	59 41	9·5	Si	
38129	5 38·4	56 53	6·8	Cr–Sr	
39658	5 48·9	54 44	8·6	Cr	
39724	5 49·3	55 39	7·4	Sr–Eu	(2)
40142	5 52·0	52 20	8·9	Sr–Eu	
52628	6 56·9	55 52	8·4	Cr–Eu	
+53°1183	7 39·1	53 54	(9·3)	Cr–Eu–Sr	
119213	13 36·8	57 42	6·2	Sr	HR 5153 (3)
169887	18 21·7	26 35	8·8	Si	
+26°3347	18 41·1	26 34	(9·3)	Sr	HD 336796
178308	19 3·0	27 36	8·5	Cr	
184383	19 29·1	28 19	8·7	Si	
193948	20 17·9	26 1	8·0	Si	
194132	20 18·8	52 47	8·5	Si	
194210	20 19·3	25 31	8·9	Si	
+25°4289	20 30·4	26 8	9·4	Sr–Cr–Eu	HD 340577
201834	21 7·1	53 9	5·7	Si	HR 8106 (1)
+27°4042	21 15·4	27 23	9·1	Sr–Eu	
203786	21 19·3	21 31	7·6	Si	
204117	21 21·4	52 57	8·5	Sr–Cr–Eu	
204905	21 26·6	52 30	7·6	Si	ADS 15035 (4)
205795	21 32·6	50 3	7·3	Cr–Eu	ADS 15135
205950	21 33·7	52 56	7·7	Si	
206028	21 34·2	23 57	7·8	Si	
208525	21 51·7	50 32	9·0	Sr	

TABLE 1—*Continued*

Name	α (1900)	δ	m_{pg}	Type	Remarks
	h m				
209059	21 55·5	26 18	7·7	Si	
+51°3356	22 19·0	51°26′	9·3	Si	(5)
216754	22 50·4	50 25	8·8	Si	
+59°2602	22 51·8	59 29	9·3	Si	HD 240121
220846	23 22·0	24 51	7·8	Sr–Eu	
222672	23 37·6	54 3	8·4	Si	ADS 16941

1. Spectral peculiarities noted by D. L. Edwards, *M.N.*, **92**, 389, 1932.
2. Spectral peculiarities noted in *Henry Draper Catalogue*.
3. Strong Sr II noted by W. E. Harper, *Pub. D.A.O.*, **7**, 55, 1937.
4. Probably optical.
5. Strong λ4128 noted by S. W. McCuskey, *Ap. J. Suppl.*, **2**, 120, 1955 (No. 15).

TABLE 2

New Metallic-Line Stars

Name	α (1900)	δ	m_{pg}	Type	Remarks
	h m				
HD 3448	0 32·3	+21°21′	9·3	δ	
3777	0 35·4	56 36	7·6		
7119	1 6·3	22 11	7·7		
16641	2 35·0	56 8	8·2		
16932	2 37·8	56 43	8·0		
18460	2 53·0	55 55	8·0	δ	
21769	3 25·5	58 26	6·3		HR 1068 ADS 2592
25021	3 53·4	55 45	7·2		
25305	3 56·2	51 37	8·7		
25515	3 58·1	50 30	8·6	δ	
28617	4 25·6	56 30	8·6		
30110	4 39·6	59 3	8·1	δ	ADS 3436
+57°911	5 38·9	57 45	9·2		HD 237421 ADS 4353
39390	5 47·3	59 1	8·3	δ	
42083	6 3·7	52 40	6·3		HR 2172
43508	6 11·5	56 56	8·7	δ	
45798	6 24·5	55 41	8·3		
47606	6 34·4	56 47	7·6		
50130	6 46·7	56 4	8·2		
53227	6 59·2	58 40	8·6		
62257	7 38·0	55 54	7·6		
66068–9	7 56·8	53 57	7·5		
66297	7 57·8	58 27	8·6		
67317	8 2·3	56 6	7·7		ADS 6620
69682	8 12·9	53 53	6·6	δ	HR 3258

TABLE 2—*Continued*

Name	α (1900)	δ	m_{pg}	Type	Remarks
	h m				
HD 72459	8 27·9	+50°44′	8·6		
72792	8 29·7	56 20	8·0	δ	
74502	8 39·3	53 26	9·1		
76310	8 50·2	22 4	8·5		(1)
76364	8 50·6	22 15	9·2		
78388	9 2·9	50 14	7·7	δ	
81772	9 22·6	58 34	8·3	δ	
82861	9 29·6	57 25	7·2		
97811	11 10·1	59 40	7·9		
99620	11 22·6	56 13	8·1		ADS 8173
99859	11 24·2	57 17	6·2		HR 4424
100992	11 32·3	59 21	9·4		
108346	12 21·8	55 43	7·5		
108844	12 25·3	58 57	5·6		74 UMa
109495	12 30·0	58 48	8·5		
172743	18 36·8	24 43	7·7	δ	ADS 11574
179461	19 7·6	26 5	7·8	δ	ADS 12153
185983	19 36·7	26 54	7·9		BDS 9522
+26°3658	19 40·7	26 59	9·1		HD 338782
192680	20 11·0	50 56	7·5		
192849	20 12·0	54 13	8·5		
192893	20 12·2	25 34	8·3		
193646	20 16·3	51 39	8·0		
195692–3	20 27·7	25 28	6·3		HR 7849, ADS 13964
195726	20 27·9	56 34	9·2		
196022	20 29·6	27 32	8·1		
200223	20 57·1	26 20	8·8		
204541	21 24·2	24 14	7·6		
207561	21 44·8	53 55	8·0		
212595	22 20·4	26 6	7·6		
213143	22 24·3	20 52	7·9	δ	
213634	22 27·8	22 53	8·4	δ	
218067	23 0·0	59 9	8·4		
218574	23 4·0	21 56	8·1		
220317	23 17·7	24 24	9·4		
222770	23 38·4	51 41	7·8		
223247	23 42·8	27 50	8·4	δ	
223461	23 44·6	28 17	6·0		79 Peg
223531	23 45·2	24 18	7·6		
224002	23 49·3	24 35	7·8		
224657	23 54·6	20 44	7·9		

(1). Possible Praesepe member.

in fact an abnormal abundance of Mg, it will be most interesting from the standpoint of stellar nucleosynthesis. Another peculiar object of special interest noted on the plates was the 6·5-magnitude star HD 205011, which is probably a new Ba II star. Its spectrum is shown in Fig. 6.

During the survey of the Curtis Schmidt plates a number of objects were noted whose spectra appeared to be characterized by a low metal abundance. A list of 17 stars of this type is given in Table 3. It is hoped that many of these objects will prove to be, in fact, low-metal stars, especially since stars of this type have not

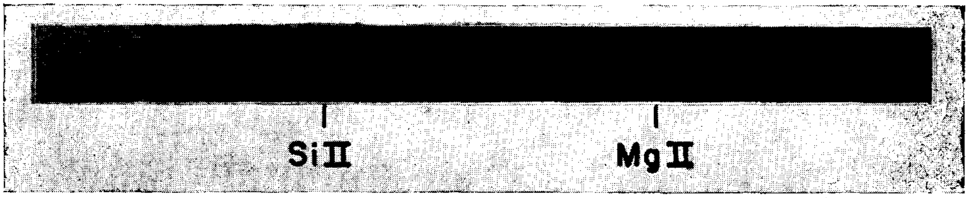

FIG. 5. Objective-prism spectrum of HD 3473, a new silicon star. $\lambda\lambda$4128–31 of Si II and λ4481 of Mg II are indicated.

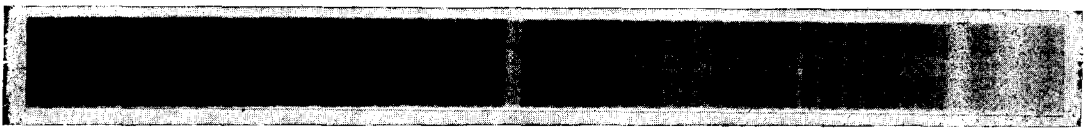

FIG. 6. Objective-prism spectrum of HD 205011, a probable Ba II star.

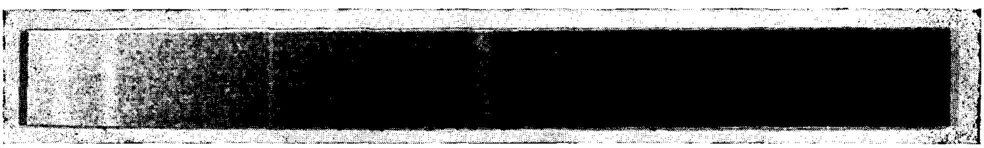

FIG. 7. Objective-prism spectrum of the high-velocity star HD 2665. Except for H and K of Ca II, the hydrogen lines, and features due to CH, little is visible in the spectrum.

generally been detected by objective-prism methods. One notable exception is HD 165195, found by W. W. Morgan; also a number of other weak-line stars have been noted by SLETTEBAK, BAHNER, and STOCK (1961) on low-dispersion Hamburg Schmidt plates of the north galactic pole region. The dispersion of the Hamburg plates is, however, certainly too low for definitive results in this regard, as comparison of objective-prism and slit classifications of the same stars indicates.

Perhaps the most interesting star in Table 3 is HD 2665, whose spectrum is shown in Fig. 7, taken from a 30-min Schmidt exposure. The star's weakness in metals is obvious. A slit spectrogram of this object has been obtained with the Michigan 37-in. reflector at a dispersion of 77 Å/mm at Hγ from which a radial velocity of -390 km/sec has been derived. The proper motion of the star is fairly small ($\mu = 0\overset{''}{.}077$/yr from *Yale Publ.*, Vol. 27, and from the *Second Greenwich Catalog* *of Stars for* 1925), and the luminosity is very uncertain; the writer is inclined to think that the star is a giant or at least a subgiant. If $M_v = 0$, the star's velocity in the direction of galactic rotation with respect to the local centroid is approximately -360 km/sec, and even if $M_v = +4$, this velocity is about -330 km/sec. The orbit is thus definitely retrograde unless the circular velocity is much higher than currently thought.

TABLE 3
Suspected Low-Metal Stars

Name	α (1900)	δ	m_{pg}	Type	Remarks
	h m				
HD 187	0 1·6	+22°56′	8·7	F	
2665	0 25·2	56 32	8·4	G	
6229	0 58·2	23 14	9·0	G	
10350	1 36·0	23 41	8·9	F	
46703	6 29·8	53 36	9·2	F	
67202	8 1·8	51 14	8·9	F	
73394	8 33·1	52 7	8·7	G	ADS 6906
79657	9 10·3	53 20	8·6	F0:	
+54°1323	9 35·5	53 56	9·7	G	HD 233666
95547	10 56·6	55 34	8·3	F	
+57°1331	11 30·6	57 23	9·2	G	HD 238020
109858	12 33·0	56 30	9·0	F	
113392	12 58·3	59 47	8·1	F	
210595	22 6·3	23 59	9·0	F	
+53°2883	22 22·7	54 8	9·2	G	HD 235845
221377	23 26·6	51 52	7·7	F	ADS 16810
223130	23 41·8	21 4	8·7	F	

It is hoped that the above discussion will lead to increased interest in extensive spectral classification surveys employing higher dispersions than those being generally used at the present time. Even such a large project as the reclassification of the stars of the *Henry Draper Catalogue* appears to be quite feasible and highly desirable in view of recent advances in both the theory and the practice of spectral classification.

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ZIRIN, H.	1951	*Harvard Bull.*, No. 920, p. 38.